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Review of Nuclear Physics Experiments for Space Radiation

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Abstract

Human space flight requires protecting astronauts from the harmful effects of space radiation. The availability of measured nuclear cross section data needed for these studies is reviewed in the present paper. The energy range of interest for radiation protection is approximately 100 MeV/n to 10 GeV/n. The majority of data are for projectile fragmentation partial and total cross sections, including both charge changing and isotopic cross sections. The cross section data are organized into categories which include charge changing, elemental, isotopic for total, single and double differential with respect to momentum, energy and angle. Gaps in the data relevant to space radiation protection are discussed and recommendations for future experiments are made.

1 Introduction

The space radiation environment is comprised of energetic particles produced from three sources. Firstly, solar particle events (SPE) consist primarily of protons emitted from the Sun during coronal mass ejections (CME) and solar flares. Very large SPEs are rare, but can potentially inflict a lethal radiation dose to astronauts. SPEs can also affect the stability of electronic devices. Energies can reach up to the GeV region. Secondly, galactic cosmic rays (GCR) consist of protons and heavier nuclei emitted from supernovae within the Milky Way Galaxy and are accelerated to the vicinity of the Solar system and elsewhere. GCR particles have energies from 10 A MeV to the ZeV region (Zetta eV = 10^{21} eV). The peak of the spectrum is in the hundreds of MeV to GeV range, which is most important region for space radiation. Thirdly, the geomagnetically trapped particles consist of protons and electrons confined by the magnetic field of Earth. There are two regions called the inner and outer Van Allen radiation belts. Protons and electrons are found in both belts, with the most important being inner belt protons with energies up to a few 100 MeV and beyond, and outer belt electrons with energies up to a few 100 keV and beyond.

It is important to have an accurate knowledge of the particle spectrum at various places in the Solar system where a particular mission will take place. The spectrum is modified when particles impinge on a medium. For instance, the spectrum of particles is modified after traversal through a spacecraft wall, due to the atomic and nuclear reactions that take place. Knowledge of the spectrum on the other side of the medium enables one to determine the accumulated radiation dose that an astronaut receives. Transport codes are used in studies of cosmic rays propagating through various media. If the cosmic ray spectrum incident on top of the Earth's atmosphere is known, then the cosmic ray spectrum observed on the ground can be deduced by transporting through the atmosphere. Similarly, knowing the cosmic ray spectrum incident on a spacecraft allows one to deduce the radiation environment inside the vehicle [Wilson91]. Essential ingredients to transport

codes are the atomic, nuclear and particle interaction cross sections. For space radiation purposes, the nuclear cross sections, which describe nuclear interactions and break up are increasingly important as the primary radiation is slowed or stopped in the medium.

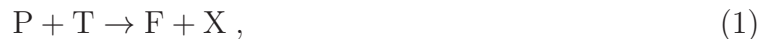
The purpose of this paper is to review the data available for nuclear cross sections, with the aim of identifying gaps in the data and recommending future measurements. The focus is on data needed for space radiation, although this report can be useful for other areas such as heavy ion beam therapy. Neutrons projectiles and fragments are not specifically considered in the present work, in order to keep the paper to a reasonable length. However, some neutron projectiles, represented by $Z_P = 0$, occur in the database and on the plots displayed herein. A detailed discussion of neutrons can be found in the book by Nakamura and Heilbronn [Nakamura07]. In the present work, a database has been constructed which compiles the results of all published nuclear physics experiments relevant to space radiation. It consists of about 50,000 entries. Information regarding the types of cross sections measured, journal references, projectile energy, mass numbers, and projectile, target and fragment charge, is included in the database.

1.1 Reactions and cross sections

Table 1 contains a list of symbols used throughout this document. Reaction and cross section notation is summarized in Tables 2 and 3.

1.1.1 Inclusive cross section

The inclusive cross section results when only specified particles are measured. An inclusive reaction is typically denoted as



where the projectile P and the target T make up the initial state. The final state consists of the measured projectile fragment F and the outgoing particles X , which may or may not be measured. The isotopic notation for an inclusive nuclear reaction is given by



where Z refers to the nuclear charge or element. The total nucleon number is defined as $A \equiv Z + N$, where N is the neutron number.

In contrast, an exclusive cross section results when all outgoing particles are assumed to have been detected. An inclusive cross section is the sum of all exclusive cross sections. Theorists typically calculate and sum exclusive processes to obtain the inclusive cross section. However, experimentally it is difficult to measure every exclusive process. It is easier to measure a particular fragment F , which is the inclusive process. Thus, in a simplified way of speaking, exclusive cross sections are easier for theorists to calculate,

but more difficult for experimentalists to measure. In contrast, inclusive cross sections are more difficult for theorists to calculate, but easier for experimentalists to measure. More stringent tests of theoretical models can be achieved by comparing theory and experiment for exclusive reactions. Comparing theoretical models to inclusive cross section measurements results in less precise tests of theoretical models.

1.1.2 Charge changing cross section

The charge changing cross section [Westfall79, Webber90a], denoted by $\sigma_{\Delta Z \geq 1}$, is often defined to be the cross section for removing at least one charge from the projectile. The mass changing cross section, $\sigma_{\Delta A \geq 1}$, is defined [Westfall79, Webber90a] to be the cross section for removing at least one nucleon from the projectile. The charge changing cross section is for production of a fragment with a charge different from the projectile. This can refer to a specific fragment or to the total charge changing cross section, which is the cross section for a reaction where the projectile nucleus is not observed in the reaction products. For example, if the projectile nucleus is a ^{12}C projectile, then ^{12}C nuclei are not observed in the reaction products. The terms “total charge changing” and “charge changing” are often used interchangeably. See Table 3 for explanations of cross section notation. In the present work, charge changing cross sections are represented by figures with a light blue background, as shown in Figure 1. In terms of testing theoretical models, the fragment production cross section, which refers to production of a specific element, is a more stringent test than the charge changing cross section.

One way to calculate charge changing cross sections is the following. The total absorption cross section, σ_{abs} , is first calculated for a given projectile and target combination. Next, the cross section for single neutron removal, two neutron removal, three neutron removal, etc. are calculated for the projectile-target system of interest until all neutrons are removed. The charge changing cross section, σ_{cc} , is then computed by subtracting the sum of the neutron removal cross sections from σ_{abs} . More explicitly,

$$\sigma_{cc} = \sigma_{abs} - \sigma_{1n} - \sigma_{2n} - \sigma_{3n} \dots - \sigma_{Nn} = \sigma_{abs} - \sum_{j=1}^N \sigma_{jn}, \quad (3)$$

where σ_{jn} is the cross section for removing j neutrons from the projectile and N is the number of neutrons in the projectile.

1.1.3 Fragment production (elemental) cross section

Fragment production (or fragmentation or partial charge changing or elemental) cross sections quantify the probability for production of fragments with a given charge. Charge changing cross sections are more easily measured than fragment production (elemental) cross sections. A theorist might first calculate the fragment production cross sections and then sum them to obtain the charge changing cross section. For intermediate to heavy

projectiles, most measurements are of fragments in excess of one third of the projectile charge. For heavier projectiles, it is difficult for an experimentalist to accurately identify individual light fragments against the background produced by multiple charged fragments from intermediate to heavy reacting nuclei. The projectile fragment production cross section is for production of a fragment with a given charge. An example is the reaction



where the cross section is for production of a fragment Z_{F} , with charge 3. A projectile fragment production cross section is also referred to as a partial fragmentation, partial charge changing, fragmentation, or elemental cross section. The elemental fragmentation cross section, which is listed as $\sigma(Z_{\text{F}})$ in Table 3, is the cross section for the production of a specific element. In the present work, elemental cross sections are represented by figures shaded in yellow background, as in Figure 2.

Data points comprise many separate, and sometimes overlapping measurements. In a few cases, such as the experimental measurements of Gutbrod et al. [Gutbrod76], light fragments were measured but not heavy fragments. Typically, experiments can be optimized to measure either low Z or high Z fragments, but not both. Most experimental measurements are of fragment production near the beam axis, which is where kinematics dictate that most fragments will be emitted. Therefore, experimental cross section data require correction factors. In addition to corrections for secondary interactions and multiple scattering in the target and detectors, corrections for fragments emitted outside of the detector acceptance rely on assumptions about fragment transverse momentum distributions. Correction methods are specific to each experimental setup and these details should be taken into account when comparing models to data.

In many on-axis experiments, only small corrections are needed to obtain the charge-changing cross sections and fragment cross sections for $Z_{\text{F}} > Z_{\text{beam}}/2$. This is an important point; in many experiments, total corrections for these cross sections are on the order of 10%, and are not a significant issue. This is the point of doing the experiments on-axis; they are relatively simple and accurate.

1.1.4 Isotopic cross section

The isotopic cross section describes the production of a fragment with a given charge and mass. An example is the reaction



Compared to fragment production (elemental) or charge changing cross sections, isotopic cross sections provide the most stringent test of theoretical models. Isotopic cross sections are more difficult to measure experimentally, because one must identify each separate isotope. In the present work, isotopic cross sections are represented by figures shaded in

pink background, as in Figures 3 - 5. Measured isotopic cross sections include inclusive, exclusive, total and differential cross sections with respect to both momentum and angle. The data were measured primarily for investigations of basic nuclear physics or cosmic ray propagation. These aims dictated the choice of energies, collision systems and observables.

1.1.5 Differential cross section

The previous discussions have been concerned with total cross sections, which are related to the total number of particles detected. Angular or energy information has not yet been considered. Differential cross sections are measured as a function of one or more variables, such as fragment energy E , momentum p , or emission angle θ . For example, the single differential cross section, $\frac{d\sigma}{dp}$, is a cross section measured as a function of the single variable p . A double differential cross section, such as $\frac{d\sigma}{dE d\theta}$, is with respect to two variables. Instead of momentum (or energy) and angle, other variables for the double differential cross section are equivalent. Common choices are the longitudinal (z) and transverse (\perp) components of momentum,

$$p_z \equiv p \cos \theta \quad (6)$$

$$p_\perp \equiv p \sin \theta. \quad (7)$$

Another commonly used kinematic pair is rapidity and transverse momentum, where rapidity is defined as

$$y \equiv \frac{1}{2} \ln \left(\frac{E + p_z}{E - p_z} \right), \quad (8)$$

with

$$E = m_\perp \cosh y \quad (9)$$

$$p_z = m_\perp \sinh y. \quad (10)$$

The transverse mass is defined as

$$m_\perp^2 \equiv m^2 + p_\perp^2 = E^2 - p_z^2, \quad (11)$$

where m is the mass of the fragment.

In summary, the following pairs of kinematic variables are equivalent, (p, θ) , (p_z, p_\perp) and (y, p_\perp) . Also, use of p is equivalent to E or T , where T is the fragment kinetic energy. The solid angle Ω is equivalent to θ . Kinematic variables are summarized in Table 4. Note that many authors use the symbol E for kinetic energy. In this paper, E describes total energy and T represents kinetic energy. For differential cross sections (usually plotted on a vertical axis), the distinction does not matter because $dE = dT$. However, the

horizontal axis on a differential cross section plot is usually the kinetic energy T where the distinction does matter, because $E \neq T$.

A theorist would first calculate a double differential cross section, and then integrate over energy or angle to get a single differential cross section. To obtain a total cross section, the double differential cross section is integrated twice. It is easier for an experimentalist to measure total cross sections. Measurements involving energy or angle are more complicated. For example, it is difficult to measure a double differential cross section because count rates must be obtained for a range of energy at a variety of angles. Furthermore, such experiments must, by definition, be capable of resolving different fragment energies, which implies a more complicated detection scheme than is used in most on-axis experiments. The most stringent test of a theory is comparing a double differential cross section calculation to experiment, and the least stringent test is comparing a total cross section calculation to experiment.

Single differential cross sections are measured with respect to a single observable as the dependent variable. Most measurements were undertaken to elucidate basic nuclear physics issues such as whether bulk nuclear matter exhibits thermodynamic or hydrodynamic behavior. However, angular and momentum distribution data can also be used to differentiate between models and to estimate two and three dimensional dose distributions at depths in materials. The fact that there is only one dependent variable in single differential cross sections does not imply that the data was integrated over all other observables. Consequently, it is important to consider details presented in the literature for each data set. For example, a differential cross section with respect to laboratory angle, $\frac{d\sigma}{d\theta}$ or $\frac{d\sigma}{d\Omega}$, may have a specific acceptance in fragment momentum or energy, as opposed to including all fragment momenta or energies. Differential cross sections with respect to momentum, $\frac{d\sigma}{dp}$, are generally quoted at one or more specific angles or angular acceptances. Acceptances in many cases depend sensitively on model dependent momentum distributions.

Angular distribution cross sections are generally quoted as a function of solid angle Ω , in units of mb/sr. Although, in some cases [Kidd88], acceptance corrections are applied and the tabulated result is quoted as a differential cross section (in mb) at a specific angle. When comparing to models, experimental details must be taken into account. Most angular distributions are published as cross sections with respect to momentum, or as double differential cross sections, as discussed below.

Transverse, $\frac{d\sigma}{dp_{\perp}}$, and longitudinal, $\frac{d\sigma}{dp_z}$, momentum distributions yield information on the detailed dynamics of nucleus-nucleus collisions, including both initial and final state interactions. Momentum distribution widths are a sensitive test of models and an essential tool for extrapolating from limited angular data. Double differential cross sections measured as a function of both fragment energy (or momentum) and angle are also a stringent test of models. In addition, they provide more detailed information on dose distributions than simple angular distributions integrated over all fragment energies or energy spectra taken at a single angle. However, as seen later, the data are limited.

1.2 Light ion reactions

An important subset of reactions are the light ion reactions represented by

$$A_P + A_T \rightarrow L_F + X, \quad (12)$$

where L_F is defined to be a charged fragment with $Z_F \leq 2$. Thus, a light ion reaction has a light fragment present in the final state, whether in combination with a heavy fragment or not. Inclusive data for light fragments produced by heavy projectiles are very limited, due to the difficulty of separating light fragments from the background generated by multifragmentation. Almost all of the heavy projectile data include only measured fragments with a minimum charge, which is approximately one half that of the projectile. Now consider the different types of cross sections.

1.2.1 Light ion total cross sections

The data [Lindstrom75] for protons emitted near the beam axis are primarily for 1.05 and 2.1 GeV/n ^{12}C , and 2.1 GeV/n ^{16}O . Lindstrom et al. [Lindstrom75] measured $^{1,2,3}\text{H}$ and $^{3,4,6}\text{He}$ in a 12.5 sr cone around 0° . Note that these are actually differential cross section measurements at 0° and not total cross sections, as is often assumed. Nevertheless, as the authors state, the forward cross section accounts for 70% - 100% of the total cross section, except for light ions. Measurements of $^{3,4,6}\text{He}$ production have also been made by Kobayashi et al. [Kobayashi88] and Korejwo et al. [Korejwo00, Korejwo02]. Projectile energies are between 790 and 2100 MeV/n, except for data taken by Korejwo et al. [Korejwo00, Korejwo02] for He isotope production from the reaction $^{12}\text{C} + ^1\text{H}$ at 2.69 and 3.66 GeV/n.

1.2.2 Light ion angular differential cross sections

Cross sections for elastic and quasielastic alpha particle scattering at $\theta_{\text{lab}} = 17^\circ, 26^\circ$ and 45° were reported in reference [Gooding61]. Reference [Poskanzer75] contains plotted angular distributions for ^3He and ^4He at $\theta_{\text{lab}} = 20^\circ - 120^\circ$ from 1.05 GeV/n ^4He and ^{16}O ions. The most extensive data set is reference [Nagamiya81]. It includes data for $^{1,2,3}\text{H}$ and $^{3,4}\text{He}$ (as well as π^+ and π^-) produced at $\theta_{\text{lab}} = 10^\circ - 145^\circ$ for 800 and 2100 MeV/n ^{12}C , ^{20}Ne and ^{40}Ar beams. Total inclusive cross sections as a function of angle, as well as double and triple differential cross sections, are tabulated.

1.2.3 Light ion momentum distributions, $\frac{d\sigma}{dp_z}$, $\frac{d\sigma}{dp_\perp}$

The momentum distribution centers and widths for p, d, t and $^{3,4,6}\text{He}$ produced in 1.05 and 2.1 GeV/n ^{12}C and 2.1 GeV/n ^{16}O are tabulated in reference [Greiner75]. Nagamiya [Nagamiya81] has detailed contour plots of proton (and pion) production cross sections in the momentum rapidity plane for 800 MeV/n $^{40}\text{Ar} + \text{KCl}$ and Pb.

1.2.4 Light ion double differential cross sections

Most of the double differential cross section data are for light fragments. Heavy fragment double differential cross sections measurements are rare. There may be a need for some limited sets of angular measurements to verify the assumption [Wilson91] that all of the projectile fragments heavier than He travel in the incident beam direction with essentially no angular spread.

2 Survey of measurements for space radiation

The experimental data that are available for space radiation studies will now be analyzed. Projectile nuclei from H to Ni are the most important with energies up to about 10 GeV/n, although data up to 100 GeV/n would be useful in calibrating theoretical models. Also, heavier nuclei, up to U, can be useful for studies of space electronics. Thus, the broadest region of interest includes the entire periodic table up to 100 GeV/n.

The majority of data referenced in this paper are for projectile fragmentation total cross sections. In addition, charge changing, mass changing, elemental and isotopic cross sections are included. In this report, a fragment is defined as a charged nuclear fragment with a mass and charge that is different from the primary beam particle. In certain special cases (for example, ^{12}C break up into three α particles), an exclusive total fragment production cross section, in which all fragments of a given charge are accounted for, requires a detector arrangement covering 4π steradian in solid angle. No such exclusive measurements have been made in the target, projectile or energy regimes relevant to space radiation studies, although there have been measurements at several different angles. The most extensive and detailed fragment production total cross section data of this type are from survey measurements for astrophysics and space radiation protection applications. For example, see references [Webber90, Webber90a, Webber90b, Webber90c, Webber98, Webber98b], [Cummings90], [Chen94], [Knott96], [Knott97], and also [Zeitlin97], [Zeitlin01], [Zeitlin07], [Zeitlin07a], [Zeitlin08]. In many cases, experimental data includes isotopic cross sections, which will be discussed in the next section. In order to elucidate the knowledge gaps, the data are grouped into several different categories. Note that there is some overlap and some data points appear in more than one grouping.

The energy range of greatest interest for GCR studies is approximately 100 MeV/n to 10 GeV/n. For particle energies less than about 100 MeV/n, energy deposition is dominated by atomic interactions with the target, and nuclear reactions are less important. (Note however, that secondary neutrons produced from these fragments can penetrate through the spacecraft or habitat.) For lunar surface sorties, they can be an issue. Lower energy ions are also of interest for heavy ion therapy. The small number of GCR ions, substantially more energetic than 10 GeV/n, contribute relatively little to radiation dose.

Figures 1 - 68 identify all the cross section measurements relevant to space radiation. Each symbol on each plot represents on or more cross section measurement. Actual cross section values are not provided, because the intent is to identify gaps in the available cross section data relevant for space exploration. The kinetic energy (T) regions are typically broken down into four regions, namely below the pion threshold at 280 MeV/n, then up to 3 GeV/n, then up to 15 GeV/n and finally above 15 GeV/n. The cut-offs at 3 GeV/n and 15 GeV/n were chosen to overlap experiments performed at the Berkeley Bevalac and the Brookhaven Alternating Gradient Synchrotron (AGS) with typical beam energies of 2.1 GeV/n and 14.6 GeV/n, respectively. Henceforth, these energy regions will be defined as follows:

Below the pion threshold: $T < 280$ MeV/n

Low energy: $280 \text{ MeV/n} \leq T < 3$ GeV/n

Medium energy: $3 \text{ GeV/n} \leq T < 15$ GeV/n

High energy: $T \geq 15$ GeV/n

The projectiles of most interest for space radiation are those from H to Ni. Henceforth, projectiles, targets and fragments will be defined in terms of charge Z as follows:

Light: $Z = 1, 2$ (H, He isotopes)

Medium-Light: $Z = 3 - 9$ (Li - F)

Medium: $Z = 10 - 19$ (Ne - K)

Heavy: $Z = 20 - 30$ (Ca - Zn)

Very Heavy: $Z > 30$ (heavier than Zn)

Light to heavy projectiles are of most interest for space radiation. Light projectiles are very abundant and highly penetrating. Light fragments are also highly penetrating. Figures 1 - 62 plot the experimental measurements as a function of projectile charge and target charge. The database contains information on projectile charges ranging across the entire periodic table, however Figures 1 - 62 only show projectile charges up to 30. This cut-off was selected since it is the range of interest for space radiation, and makes it easier to read the projectile charge on the plots.

The galactic cosmic ray spectrum shows local peaks in abundance [Simpson83], relative to their near neighbors, for the following six nuclei: ${}^1\text{H}$, ${}^2\text{He}$, ${}^6\text{C}$, ${}^8\text{O}$, ${}^{14}\text{Si}$, ${}^{26}\text{Fe}$, where charge numbers are indicated as lower case. This is not to say, for example, that ${}^{26}\text{Fe}$ has a higher abundance than ${}^{10}\text{Ne}$ for instance. Rather, these six nuclei are most important in terms of contribution to dose in unshielded deep space [Wilson91]. (Note that Mg is just as important as Si. Given that they are close in mass number and have similar shell structure, only Si is emphasized. Even though C and O are similar in mass number, O is doubly magic and C is not. Therefore, both C and O are considered because they have quite different shell structure.)

While it is important to understand the physical interactions of all nuclei up to Ni, it is important to always have these six nuclei represented in any set of projectile measurements. The recommendations presented herein will focus on these six nuclei. Recall that the nuclear magic numbers are 2, 8, 20, 28, 50, 82 and 126, which correspond to fully

closed nucleon shells. This is analagous to electron closed shells for inert gases. Nuclei with magic proton numbers are ${}^2\text{He}$, ${}^8\text{O}$, ${}^{20}\text{Ca}$, ${}^{28}\text{Ni}$, ${}^{50}\text{Sn}$ and ${}^{82}\text{Pb}$. Note that the naturally occuring isotopes, ${}^4\text{He}$, ${}^{16}\text{O}$, ${}^{40}\text{Ca}$, ${}^{208}\text{Pb}$, are doubly magic (magic numbers of both protons and neutrons). The naturally occurring isotopes of Ni and Sn are ${}^{59}\text{Ni}$ and ${}^{119}\text{Sn}$, whereas the doubly magic isotopes are ${}^{56}\text{Ni}$ and ${}^{100}\text{Sn}$. Even though C and O possess similar proton numbers, it is important to have both represented in the experimental data, because one is (doubly) magic and the other is not.

2.1 Targets

Alloys made up primarily of aluminum ($Z=13$) are the typical material used for spacecraft structures. However, low Z materials have been shown to provide better space radiation protection [Wilson91]. Therefore, targets with $Z \leq 13$ are of special interest for space radiation. Experimentally, it is rather simple to use a variety of targets. Such data are useful for testing theoretical models. ***In all of the recommendations for future experiments presented below, a range of targets across the periodic table is recommended, unless otherwise noted.*** Note that emulsion targets, which include AgBr [Hyde71], are represented in the database with an average target charge of 41.

Hydrogen targets are of particular interest to cosmic ray transport and space radiation shielding, since hydrogenous materials have highly favorable properties for shielding against charged nuclei [Wilson91]. Figures 1 - 62 show plots of projectile charge versus target charge. As mentioned earlier, the database contains projectile charges across the entire periodic table. However, only projectile charges up to 30 are shown in the plots, for ease in identifying projectiles. The entire range of target charges up to 100 will always be shown. Each symbol on the plots is centered on the projectile charge / target charge value it represents. For example, the symbols that just touch the horizontal axis in Figure 1 represent measurements using H targets with a target charge of 1. Thus, H targets are easily read from the plots. Note that H target cross sections can be obtained in principle using inverse collisions of protons onto heavy targets. However, extracting elemental and isotopic cross sections can be especially challenging. Therefore, it is preferred that hydrogen targets be used for these cross section measurements.

2.2 Charge changing measurements

Charge changing total cross section measurements are shown in Figure 1. Of course, no charge changing measurements exist for H projectiles, because they do not break up into smaller nuclear fragments. Differential cross sections also do not exist, because charge changing involves many fragments. There are obvious gaps below the pion threshold and above 3 GeV/n. The principal gaps are at low and high energies for heavy projectiles ($Z = 20 - 30$). In particular, there are no data for Fe projectiles at the lowest and highest energies. In addition, there are only a few measurements for light projectiles.

H targets are well represented for low energy, but are poorly represented at all other energies. Exceptions occur for C and Si projectiles below the pion threshold and for O and Si projectiles at medium and high energy. At high energy, there are measurements for S projectiles, but Si is not represented,

Charge changing measurement recommendations are summarized in Table 5. Of course, H projectiles are not considered for charge changing measurements. He projectiles will not be considered either, because the only fragment is H, and this will be considered separately in the H fragments discussion. Although charge changing cross sections have been useful in providing the first tests of theoretical models, further charge changing experiments augment the extensive comparisons between theoretical models and measurements that have been performed to date [Zeitlin11].

2.3 Hydrogen fragment measurements

Hydrogen fragment measurements are shown in Figures 2 - 19. Recommendations are summarized in Table 6 and are discussed in detail below. Elemental energy differential and momentum differential cross section data are not plotted because no data are currently available.

2.3.1 Total cross sections

Total cross sections for elemental H fragments are shown in Figure 2. Total cross sections for isotopic H fragments are shown in Figures 3, 4 and 5. For elemental fragments at low energy, there are a series of measurements for C, Ne and Fe projectiles on a variety of targets. The most serious lack of data is for He and Si projectiles. At low energy, there are measurements for Ne projectiles. These cannot take the place of new O measurements because O is doubly magic, as explained previously. C and O projectile data are also available. However, Si and Fe projectiles are not represented.

Isotopic data can be summed to obtain elemental data. ***Filling in the gaps for isotopic data would supersede the need for filling in gaps in elemental data. Isotopic data provide tests of coalescence models that are used for light ion production modeling.*** At medium energy, there is only one elemental measurement, but there are more isotopic measurements, especially for He projectiles. Heavier projectiles are missing. Recommendations for future measurements are summarized in Table 6.

2.3.2 Differential cross sections

Available differential cross sections for elemental and isotopic H fragments are shown in Figures 6 - 19. It can be seen that dE and $d\Omega$ data are very sparse, with most of the available data being for H projectiles. At low energy, for ${}^{1,2,3}\text{H}$ fragments there are parallel momentum data for C and O projectiles on a variety of targets. However, with

only parallel momentum measurements, an angular distribution must be assumed in order to extract dE information. For light fragments, the angular information is important. Assumptions cannot be made about the angular distribution because light fragments are scattered over a larger range of angles. Therefore, these parallel momentum distributions, by themselves, are of limited usefulness.

The most complete set of data are double differential cross sections for H isotopes. H projectiles are well represented, except for medium energy deuteron and triton production and at high energy. ***He projectile data are available at low energy, but not at medium energy.*** Given that most measurements are double differential, it is worthwhile to continue them to complement existing data sets, since double differential cross sections are the most precise test of theoretical models. Consequently, additional single differential cross section measurements are not recommended. At low energy, He projectiles on several targets are represented, as well as heavier projectiles. At low energy, O measurements on H and a few other light targets would be useful. Fe projectiles are missing. At medium energy there are no data except for H projectiles. Therefore, ***a full set of medium energy measurements are recommended.*** Recommendations are summarized in Table 6.

2.4 Helium fragment measurements

Helium fragment measurements are shown in Figures 20 - 38. Recommendations are discussed in detail below and are summarized in Table 7. Elemental momentum differential cross section data are not plotted because no data are currently available.

2.4.1 Total cross sections

Total cross sections for elemental He fragments are shown in Figure 20. Total cross sections for isotopic He fragments are shown in Figures 21, 22 and 23. For elemental fragments at low energy, there are a series of measurements for C, Ne and Fe projectiles on a variety of targets. The most serious lack of data is for He and Si projectiles. For $^{3,4,6}\text{He}$ isotopic fragments at low energy, there are some He projectile measurements on low Z targets. C and O projectile data are also available. However, Si and Fe projectiles are not represented. Filling in the gaps for isotopic data would supersede the need for filling in gaps in elemental data. At medium energy, there are only a couple of elemental measurements, but there are some isotopic measurements. Heavier projectiles are missing. Recommendations for total cross section measurements are summarized in Table 7.

2.4.2 Differential cross sections

Available differential cross sections for elemental and isotopic He fragments are shown in Figures 24 - 38. For He, the situation is similar to that previously found for H fragments;

the data are very sparse. Most of the available data are for H projectiles, with an exception at low energy. For $^{3,4,6}\text{He}$ fragments, there are parallel momentum data for C and O projectiles on a variety of targets. At medium energy, there are transverse momentum distributions for Si projectiles producing ^6He fragments. As with H fragments, these parallel momentum distributions, by themselves, are of limited usefulness. Again, as with H fragments, the most complete set of data are for double differential cross sections. For the reasons quoted previously for H fragments, *it is recommended that double differential cross section measurements be pursued instead of single differential measurements*. These recommendations are summarized in Table 7.

2.5 Medium-light ($Z_F = 3 - 9$) fragment measurements

Medium-light fragment measurements are shown in Figures 39 - 48. Recommendations are discussed in detail below and are summarized in Table 8. H and He projectiles are not considered herein because projectile fragmentation will not produce medium-light fragments.

2.5.1 Total cross sections

Total cross sections for elemental and isotopic medium-light fragments are shown in Figures 39 and 40. At low energy, elemental cross sections are well represented and there is a reasonable representation of isotopic measurements. The data seems sufficient, so no new measurements are recommended. At medium energy, there is a lack of elemental and isotopic cross section data for C and Fe projectiles and isotopic data for O projectiles. At high energy, the elemental S measurements will suffice, instead of new elemental Si measurements. Recommendations are summarized in Table 8.

2.5.2 Differential cross sections

For non-light fragments there remain discrepancies in the codes when compared to large and small acceptance zero degree data, owing circumstantially to incorrect transverse momentum assumptions in the code. Therefore, a range of double differential cross section measurements for medium-light fragments is being made for C, O, Si and Fe. (He projectiles will not produce medium-light fragments except in pick-up reactions.) A full range of measurements is recommended, as shown in Table 8.

2.6 Medium ($Z_F = 10 - 19$) fragment measurements

Medium fragment measurements are shown in Figures 49 - 57. Recommendations are discussed in detail below and are summarized in Table 9. Projectiles with $Z \leq 10$ are not considered herein, because projectile fragmentation will not produce medium fragments.

Elemental momentum differential cross section data are not plotted because of the lack of available data.

2.6.1 Total cross sections

Total cross sections for elemental and isotopic medium fragments are shown in Figures 49 and 50. Low energy elemental cross sections are well represented and there is a reasonable representation of isotopic measurements. The data seems sufficient, therefore no new measurements are recommended. At medium energy, there is a lack of elemental and isotopic cross sections for Fe projectiles. At medium energy, medium fragment total cross sections should be measured for Fe projectiles. At high energy, the elemental S measurements will suffice, instead of new elemental Si data. Recommendations are summarized in Table 9.

2.6.2 Differential cross sections

Figures 51 - 57 show that existing differential cross section measurements for medium fragments are even more sparse than for medium-light fragments. A range of double differential cross section measurements for medium fragments is being recommended for Si and Fe projectiles. (He, C and O projectiles will not produce medium fragments except in pick-up reactions.) Recommendations are shown in Table 9.

2.7 Heavy ($Z_F = 20 - 30$) fragment measurements

Heavy fragment measurements are shown in Figures 58 - 62. Recommendations are discussed in detail below and are summarized in Table 10. Projectiles with $Z \leq 20$ are not considered, because projectile fragmentation will not produce heavy fragments. Elemental energy differential, isotopic energy differential, elemental angular differential, elemental momentum differential cross sections and isotopic momentum differential cross sections are not plotted because of the lack of available data.

2.7.1 Total cross sections

Total cross sections for elemental and isotopic heavy fragments are shown in Figures 58 and 59. Low energy elemental cross sections are well represented and there is a reasonable representation of isotopic measurements. The data seems sufficient, so no new measurements are recommended. At medium energy, there is a lack of elemental and isotopic cross sections for Fe projectiles. At medium energy, heavy fragment total cross sections should be measured for Fe projectiles. Recommendations are summarized in Table 10.

2.7.2 Differential cross sections

Figures 60 - 62 show that existing measurements for heavy projectiles are extremely sparse. $Z_F = 20 - 30$ fragments produced by Fe projectiles are expected to continue with approximately the same trajectory as the projectile. Nevertheless, this should be checked. These fragments will be produced from H, He, C, O and Si projectiles only for pick-up, but not fragmentation reactions. Fe projectiles will produce heavy fragments in fragmentation reactions. Therefore, a range of experiments is being recommended for Fe projectiles.

2.8 Hydrogen targets

Figure 63 shows all cross sections plotted as a function of projectile charge and energy for H targets, which shows that *there are significant gaps for most projectiles below the pion threshold and at medium and high energy. It is recommended that an extensive set of measurements on H targets be performed.*

2.9 Isotopic data for ^4He , ^{12}C , ^{16}O , ^{28}Si , ^{56}Fe projectiles

The information being presented in the elemental cross section figures, such as Figures 2 and 20, represents points in a multi-dimensional space. Each individual plot in Figure 2, for example, consists of the 2-dimensional space of (Z_P, Z_T) . With the four plots of Figure 20 each representing different kinetic energy T regions, the space is 3-dimensional, namely (Z_P, Z_T, T) . Figures 2 and 20 contain this 3-dimensional information for particular elemental fragments Z_F , expanding the space to the 4-dimensions of (Z_P, Z_T, T, Z_F) . The space is further expanded when considering isotopic fragments, such as Figures 3, 4 and 5, with the 5-dimensional space being (Z_P, Z_T, T, Z_F, A_F) . Finally, the different cross section types, such as σ , $\frac{d\sigma}{dE}$, $\frac{d\sigma}{d\Omega}$, etc., expand to a 6-dimensional space consisting of $(Z_P, Z_T, T, Z_F, A_F, \Sigma_i)$, where Σ_i denotes the different types of cross sections. The entire collection of plots in this paper represent a single plot in this 6-dimensional space, and judicious choices have been made in presenting the 2-dimensional slices of this 6-dimensional space. In Figures 1 - 62, the 2-dimensional slices have been (Z_P, Z_T) , with other dimensions represented as separate plots. Figure 63 presents a (Z_P, T) slice for H ($Z_T = 1$) targets.

A 2-dimensional slice of interest is the plane (Z_F, A_F) for each of the six important GCR nuclei ^1H , ^4He , ^{12}C , ^{16}O , ^{28}Si and ^{56}Fe shown in Figures 64 - 68. The question is: Are all important isotopic fragments measured for the six important GCR nuclei? (^1H projectiles are not of interest, because they do not fragment (apart from charge changing into neutrons), although they can undergo pick-up reactions.)

Consider Figure 64, which shows (Z_F, A_F) total cross sections for ^4He projectiles at a variety of energies. One clearly sees the isotopic fragments $^{1,2,3}\text{H}$ and ^3He , which are precisely the important fragments for which one wants cross section data. (^4He fragments do

not represent a fragmentation reaction and ${}^6\text{He}$ fragments involve a two neutron pickup with a low cross section. Therefore, these two fragments are of considerably less importance for ${}^4\text{He}$ projectiles.) However, this information for ${}^{1,2,3}\text{H}$ and ${}^3\text{He}$ fragments is already contained in Figures 3, 4, 5 and 21, which actually convey more information because the target charge Z_T is also represented. Therefore, Figure 64 is redundant, but is included in order to clarify the discussion. The other isotopic fragment cross sections of Figures 65 - 68 are not redundant, and are of interest because the information has not been captured in previous figures which only cover a range of fragment charges, such as $Z_F = 3 - 9$, $Z_F = 10 - 19$ or $Z_F = 20 - 30$. Clearly, the information referring to ${}^{1,2,3}\text{H}$ or ${}^{3,4,6}\text{He}$ fragments in Figures 64 - 68 is redundant since it has been displayed previously. *Careful examination of Figures 3 - 5 and Figures 21 - 23 will reveal consistency with ${}^{1,2,3}\text{H}$ and ${}^{3,4,6}\text{He}$ isotope information displayed in Figures 64 - 68. Equivalently, the recommendations for ${}^{1,2,3}\text{H}$ and ${}^{3,4,6}\text{He}$ isotope measurements in Tables 6 and 7 are consistent with all the Figures 3 - 5, 21 - 23 and 64 - 68. In checking these consistencies, the target information needs to be carefully considered.*

Therefore, focus has been placed on only non-light fragments in Figures 65 - 68. Consider the ${}^{12}\text{C}$ projectile data in Figure 65. Fragment data are well represented in all energy regimes, except high energy. Consider the ${}^{16}\text{O}$ projectile data in Figure 66. Data are well represented at low energy, but there are major gaps below the pion threshold and at intermediate and high energy. Consider the ${}^{28}\text{Si}$ projectile data in Figure 67. There are major gaps at all energies. Consider the ${}^{56}\text{Fe}$ projectile data in Figure 68. The low energy region is well represented with major gaps at all other energies. The corresponding new measurement recommendations are summarized in Table 11.

Appendices 1 and 2 describe inverse kinematics and relations between cross sections. Table 12 summarizes all the measurements.

3 Conclusions

A database has been created which contains information on all nuclear physics experiments, relevant to space radiation protection, that have been performed to date. However, neutrons are not considered. This paper has focused on the nuclei prominent in the galactic cosmic ray spectrum, namely H, He, C, O, Si and Fe. Recommendations have been made for charge changing, elemental and isotopic measurements. These recommendations have been summarized in Tables 5 - 10. Isotopic cross sections are the most difficult to measure, but provide the best test of theoretical models and are the preferred measurement type. Overall, there are a surprisingly large number of gaps in the experimental data concerning the important galactic cosmic ray nuclei mentioned above. This represents a significant gap in validating theoretical models.

Finally, a prioritized list of experimental measurements is now presented. The experiments are summarized in the Tables, which are listed in priority order below. Within the

tables themselves, double differential cross sections are a higher priority than total cross sections.

1. Finish analysis of existing data
2. Complete the set of measurements listed in Table 7
3. Complete the set of measurements listed in Table 6
4. Complete the set of measurements listed in Table 11
5. Complete the set of measurements listed in Table 8
6. Complete the set of measurements listed in Table 9
7. Complete the set of measurements listed in Table 10
8. Complete the set of measurements listed in Table 5

The reasoning for this priority order has already been discussed in the text, but some of the reasons are worth repeating here. The light ions of H and He are especially important due to their high penetrating power and their large angular spread from the beam. Therefore, double differential cross sections for light ions are especially important, which is why the experiments listed in Tables 7 and 6 are of high priority. As previously discussed, the projectiles of H, He, C, O, Si, Fe are particularly prominent and it is important to have an accurate knowledge of all the fragments produced from these projectiles. This is why Table 11 is next on the priority list. The measurements listed in Tables 8, 9, 10 are in that order because lighter fragments undergo more deflection than heavier fragments, making measurements of double differential cross sections more important for light fragments than for heavier ones. Finally, completion of the experiments listed in Table 5 would provide a nearly complete set (from a space radiation perspective) of charge changing cross section measurements.

4 Appendix 1: Inverse kinematics

If one has, for example, cross section data for the reaction ${}^4\text{He} + {}^{12}\text{C}$, then this same data will, of course, suffice for the reaction ${}^{12}\text{C} + {}^4\text{He}$. However, the projectile energies will be different in each case. The use of such inverse kinematics greatly reduces the need to perform separate experiments. A brief review of inverse kinematics is presented here.

The notation is as follows. Subscripts will refer to the projectile or target nuclei, and sub-subscripts will refer to the projectile or target reference frame. For example, the quantity E_{TP} refers to the total energy of the target as measured in the projectile frame. The quantity T_{PT} refers to the kinetic energy of the projectile as measured in the target frame. The symbol x_{PP} refers the quantity x of the projectile as measured in the projectile frame. Mass m always refers to rest mass and so is independent of the frame. Thus, m_{P} and m_{T} refer to the projectile and target rest mass (as measured in any frame). Finally, the notation $(x)_{\text{P}}$ or $(x)_{\text{T}}$ denotes the quantity in parenthesis as measured in the projectile or target frames, respectively.

The square of the projectile and target 4-momenta as measured in the projectile frame is equal to the square of the projectile and target 4-momenta as measured in the target frame,

$$\begin{aligned} (\tilde{p}_{\text{P}} + \tilde{p}_{\text{T}})_{\text{P}}^2 &= (\tilde{p}_{\text{P}} + \tilde{p}_{\text{T}})_{\text{T}}^2 \\ m_{\text{P}}^2 + m_{\text{T}}^2 + (2\tilde{p}_{\text{P}} \cdot \tilde{p}_{\text{T}})_{\text{P}} &= m_{\text{P}}^2 + m_{\text{T}}^2 + (2\tilde{p}_{\text{P}} \cdot \tilde{p}_{\text{T}})_{\text{T}}. \end{aligned} \quad (13)$$

The 4-vector scalar product (also invariant) is

$$\tilde{p}_1 \cdot \tilde{p}_1 \equiv E_1 E_2 - \mathbf{p}_1 \cdot \mathbf{p}_2. \quad (14)$$

Note also that

$$\begin{aligned} \mathbf{p}_{\text{PP}} &\equiv 0 &\Rightarrow E_{\text{PP}} &= m_{\text{P}} \\ \mathbf{p}_{\text{TT}} &\equiv 0 &\Rightarrow E_{\text{TT}} &= m_{\text{T}}. \end{aligned} \quad (15)$$

Equation (13) reduces to

$$m_{\text{P}} E_{\text{TP}} = m_{\text{T}} E_{\text{PT}} \quad (16)$$

or

$$E_{\text{TP}} = \frac{m_{\text{T}}}{m_{\text{P}}} E_{\text{PT}}. \quad (17)$$

This formula shows how to convert from the energy of the projectile as measured in the target frame to the energy of the target as measured in the projectile frame. It is easily shown that a similar formula holds for the kinetic energies,

$$T_{\text{TP}} = \frac{m_{\text{T}}}{m_{\text{P}}} T_{\text{PT}}. \quad (18)$$

Consider the reaction $p + {}^{12}\text{C}$. Assuming that the mass of ${}^{12}\text{C}$ is roughly 12 times the mass of the proton, gives

$$T_{pC} = \frac{1}{12}T_{Cp}, \quad (19)$$

which says that the kinetic energy of the proton in the C frame is $\frac{1}{12}$ times the kinetic energy of the C in the proton frame. That is, the kinetic energy of the projectile in the reaction $p + {}^{12}\text{C}$ is $\frac{1}{12}$ times the kinetic energy of the projectile in the ${}^{12}\text{C} + p$ reaction. Here, the kinetic energy is measured in MeV and not MeV/n. Note that for the special case of a nucleon-nucleus reaction, if the kinetic energy is measured in MeV/n then there is no mass conversion factor. That is, for example, if the kinetic energy of the nucleus is 1000 MeV/n in a nucleus-nucleon reaction then the inverse kinematic kinetic energy of the nucleon in the nucleon-nucleus reaction will also be 1000 MeV/n (which for the case of a nucleon is 1000 MeV). Thus, for nucleon-nucleus reactions, inverse kinematics is trivial when measuring in units of MeV/n. Finally, one can easily show that equation (18) implies that the speed of the projectile in the target frame is the same as the speed of the target in the projectile frame, as it should be. Each observer sees the other one moving at the same speed,

$$\beta_{Tp} = \beta_{pT}. \quad (20)$$

5 Appendix 2: Relations between cross sections

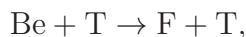
It is important to note that the charge changing cross section is *not* simply the sum of the elemental cross sections, i.e.

$$\sigma(\text{cc}) \neq \sum_{Z_F} \sigma(Z_F).$$

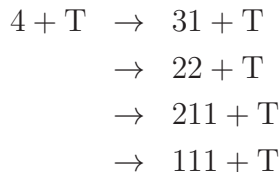
Similarly, the elemental cross section is *not* simply the sum of the isotopic cross sections, i.e.

$$\sigma(Z_F) \neq \sum_{A_F} \sigma(A_F).$$

To see this, consider the following reaction.



where T represents the target and F represents the fragments. Rewrite this reaction in terms of nuclear charge denoted by numbers, i.e.



where, for example, the notation $4 + \text{T} \rightarrow 31 + \text{T}$ means $4 + \text{T} \rightarrow 3 + 1 + \text{T}$ which is the reaction $\text{Be} + \text{T} \rightarrow \text{Li} + \text{H} + \text{T}$.

The cross section for producing $Z_F = 1, 2, 3$ (H,He,Li) contains the following terms,

$$\begin{aligned} \sigma(3) &\sim |\langle 31|t|i\rangle|^2 \\ \sigma(2) &\sim |\langle 22|t|i\rangle + \langle 211|t|i\rangle|^2 \\ \sigma(1) &\sim |\langle 31|t|i\rangle + \langle 211|t|i\rangle + \langle 111|t|i\rangle|^2, \end{aligned}$$

where transition operator t matrix elements are denoted as $\langle f|t|i\rangle$. The initial state is $|i\rangle \equiv |4 + \text{T}\rangle$ and the T state is suppressed (not written explicitly) in the final states $\langle f|$. Statistical weighting factors due to different possible arrangements of the final states are not written explicitly. For example, there would be a factor of $3!$ outside the $\langle 111|t|i\rangle$ term.

The charge changing cross section contains the following terms

$$\sigma(\text{cc}) \sim |\langle 31|t|i\rangle + \langle 22|t|i\rangle + \langle 211|t|i\rangle + \langle 111|t|i\rangle|^2.$$

Even if one ignores all the cross terms resulting from expanding the modulus squared $|x|^2$, such as $\langle 31|t|i\rangle\langle 22|t|i\rangle$, it is evident that

$$\sum_{Z_F} \sigma(Z_F) > \sigma(cc),$$

where $\sum_{Z_F} \sigma(Z_F) = \sigma(3) + \sigma(2) + \sigma(1)$. This is because

$$\begin{aligned} & |\langle 31|t|i\rangle|^2 + |\langle 22|t|i\rangle + \langle 211|t|i\rangle|^2 + |\langle 31|t|i\rangle + \langle 211|t|i\rangle + \langle 111|t|i\rangle|^2 \\ & > |\langle 31|t|i\rangle + \langle 22|t|i\rangle + \langle 211|t|i\rangle + \langle 111|t|i\rangle|^2, \end{aligned}$$

assuming that minus signs don't occur in cross terms such that significant cancellations occur. A similar argument also shows that

$$\sum_{A_F} \sigma(A_F) > \sigma(Z_F).$$

Table 1: Symbols

Symbol	Meaning
n	Neutron
p	Proton
d	Deuteron
t	Triton
h	Helion
α	Alpha particle
Z	Proton number
N	Neutron number
A	Nucleon number ($A \equiv Z+N$)
A_P	Nucleon number of projectile
A_T	Nucleon number of target
A_F	Nucleon number of fragment
H	Heavy ion ($A > 4$)
L	Light ion ($A \leq 4$)
P	Projectile
T	Target
F	Fragments (Defined as projectile nuclei that have lost one or more nucleons. However, a projectile nucleus in the final state is not classified as a fragment.)
X	Unspecified reaction product
H_P	Heavy ion projectile
H_T	Heavy ion target
H_F	Heavy ion fragment
L_P	Light ion projectile
L_T	Light ion target
L_F	Light ion fragment
AZ	Isotope
${}^{A_P}Z_P$	Projectile isotope
${}^{A_T}Z_T$	Target isotope
${}^{A_F}Z_F$	Fragment isotope
MeV/n	Kinetic energy in units of MeV per nucleon e.g. 100 MeV/n for ${}^{12}\text{C}$ implies a nuclear kinetic energy of 1200 MeV
GeV/n	Kinetic energy in units of GeV per nucleon

Table 2: Reaction notation.

Symbol	Explanation
$P + T \rightarrow F + X$	Notation for an inclusive nuclear reaction. The projectile appears first on the left hand side, and the target appears second. The projectile fragment F appears first on the right hand side.
${}^A_P Z_P + {}^A_T Z_T \rightarrow {}^A_F Z_F + X$	Isotopic notation for an inclusive nuclear reaction.

Table 3: Cross section definitions. Several names are listed for $\sigma(Z_F)$, in accordance with literature conventions.

Symbol	Names	Explanations
Z_F	Fragment proton number	
σ	Total cross section	
$\sigma_{\Delta Z \geq 1}$	<i>Total</i> charge changing cross section Charge changing cross section	Cross section for a reaction where the projectile nucleus is not observed in the reaction products.
$\sigma(Z_F)$	<i>Partial</i> charge changing cross section Projectile fragmentation cross section Fragmentation cross section Fragment production cross section Partial fragmentation cross section Elemental fragmentation cross section	
$\sigma(^{A_F}Z_F)$	Isotopic cross section	

Table 4: Kinematic variables (with $c \equiv 1$).

Variable	Meaning
T	Kinetic energy
E	Total energy, $E = T + m$
$p \equiv \mathbf{p} $	Magnitude of 3-momentum, as in $E^2 = \mathbf{p}^2 + m^2$
θ	Angle
Ω	Solid angle
p_z	Longitudinal 3-momentum
p_\perp	Transverse (perpendicular) 3-momentum
y	Rapidity
\tilde{p}	4-momentum, $\tilde{p}^2 = E^2 - \mathbf{p}^2 = m^2$

Table 5: ***Charge changing total cross section measurement recommendations.*** A range of targets is needed. The notation (T) indicates that only a few additional targets are required. The notation, “ $< \pi$ threshold” signifies projectile energies below the pion threshold. As explained in the text, H and He projectiles are not considered for charge changing measurements.

Cross section	$< \pi$ threshold projectile	Low energy projectile	Medium energy projectile	High energy projectile
σ	O,Fe	—	C,Fe(T)	C,Fe

Table 6: ***H elemental and ^{1,2,3}H isotopic fragment measurement recommendations.*** “All” projectiles signifies He, C, O, Si, Fe. Projectiles needed for *only* H targets are listed with (H). Projectiles needed for a range of targets, *except* H, are listed with (\cancel{H}). No parentheses indicates that a range of targets, including H, is needed. The notation (T) means that only a few additional targets are required. H projectiles are not considered.

Cross section	Frag-ment	Below π threshold projectile	Low energy projectile	Medium energy projectile	High energy projectile
σ	H	All	He,O,Si,Fe(T)	All	All
	^{1,2,3} H	He(T),C,O(H),Si,Fe	He(\cancel{H}),O(T),Si,Fe	He(H),C(\cancel{H}),O,Si,Fe	All
dEd Ω	H	All	All	All	All
	^{1,2,3} H	He(H),C,O(H),Si,Fe	O,Si,Fe	All	All

Table 7: ***He elemental and ^{3,4,6}He isotopic fragment measurement recommendations.*** “All” projectiles signifies He, C, O, Si, Fe. Projectiles needed for *only* H targets are listed with (H). Projectiles needed for a range of targets, *except* H are listed with (\cancel{H}). No parentheses indicates that a range of targets, including H, is needed. The notation (T) indicates that only a few additional targets are required.

Cross section	Frag-ment	Below π threshold projectile	Low energy projectile	Medium energy projectile	High energy projectile
σ	He	All	He,O,Si,Fe(T)	All	All
	³ He	He(T),C,O(H),Si,Fe	He(\cancel{H}),O(T),Si,Fe	He(H),C(\cancel{H}),O,Si,Fe	All
	⁴ He	He(T),C,O(H),Si(\cancel{H}),Fe	He,Si(\cancel{H}),Fe	He,C(\cancel{H}),O,Si,Fe	All
	⁶ He	All	He,O(T),Si,Fe	He,C(\cancel{H}),O,Si(H),Fe	All
dEd Ω	He	All	All	All	All
	³ He	He(H),C,O(H),Si,Fe	O,Si,Fe	All	All
	⁴ He	He(H),C,O(H),Si,Fe	O,Si,Fe	All	All
	⁶ He	All	He,O,Si,Fe	All	All

Table 8: *Medium-light ($Z_F=3 - 9$) elemental and isotopic fragment measurement recommendations.* A complete measurement set for C, O, Si and Fe projectiles would be required to fill this gap. Projectiles needed for *only* H targets are listed with (H). Projectiles needed for a range of targets, *except* H, are listed with (\cancel{H}). No parentheses indicates that a range of targets, including H, is needed. H and He projectiles are not considered, because projectile fragmentation will not produce medium-light fragments.

Cross section	Fragment	Below π threshold projectile	Low energy projectile	Medium energy projectile	High energy projectile
σ	Elemental	C(T),O,Fe	–	C(\cancel{H}),O(H),Fe	C,Fe
	Isotopic	C(H),O,Si,Fe	Fe(\cancel{H})	C(\cancel{H}),O,Si(H),Fe	C,O,Si,Fe
dEd Ω	Elemental	C,O,Si,Fe	C,O,Si,Fe	C,O,Si,Fe	C,O,Si,Fe
	Isotopic	C,O,Si,Fe	C,O,Si,Fe	C,O,Si,Fe	C,O,Si,Fe

Table 9: *Medium ($Z_F=10 - 19$) elemental and isotopic fragment measurement recommendations.* Projectiles needed for *only* H targets are listed with (H). Projectiles needed for a range of targets, *except* H, are listed with (\cancel{H}). No parentheses indicates that a range of targets, including H, is needed. Projectiles with $Z \leq 10$ are not considered, because projectile fragmentation will not produce medium fragments.

Cross section	Fragment	Below π threshold projectile	Low energy projectile	Medium energy projectile	High energy projectile
σ	Elemental	Fe	–	Fe	Fe
	Isotopic	Si(\cancel{H}),Fe	–	Fe	Fe(\cancel{H})
dEd Ω	Elemental	Si,Fe	Si,Fe	Si,Fe	Si,Fe
	Isotopic	Si,Fe	Si,Fe	Si,Fe	Si,Fe

Table 10: **Heavy ($Z_F=20 - 30$) elemental and isotopic fragment measurement recommendations.** Projectiles needed for *only* H targets are listed with (H). Projectiles needed for a range of targets, *except*, H are listed with (\cancel{H}). No parentheses indicates that a range of targets, including H, is needed. Projectiles with $Z \leq 20$ are not considered, because projectile fragmentation will not produce heavy fragments.

Cross section	Fragment	Below π threshold projectile	Low energy projectile	Medium energy projectile	High energy projectile
σ	Elemental	Fe	–	Fe	Fe
	Isotopic	Fe	–	Fe	Fe(\cancel{H})
dEd Ω	Elemental	Fe	Fe	Fe	Fe
	Isotopic	Fe	Fe	Fe	Fe

Table 11: **Non-light ($Z_F \geq 3$) isotopic fragment total cross section measurement recommendations for ^{12}C , ^{16}O , ^{28}Si , ^{56}Fe projectiles.** Fragment recommendations are listed in terms of fragment charge Z_F . Measurements should be made for as many fragment masses A_F as possible, on a variety of targets.

Projectile	Below π threshold projectile	Low energy projectile	Medium energy projectile	High energy projectile
^{12}C	–	–	–	$Z_F = 1 - 6$
^{16}O	$Z_F = 3 - 8$	–	$Z_F = 3 - 8$	$Z_F = 3 - 8$
^{28}Si	$Z_F = 3 - 14$	$Z_F = 3 - 7$	$Z_F = 3 - 14$	$Z_F = 3 - 14$
^{56}Fe	$Z_F = 3 - 26$	–	$Z_F = 3 - 26$	$Z_F = 3 - 17, 19, 20, 22, 25, 26$

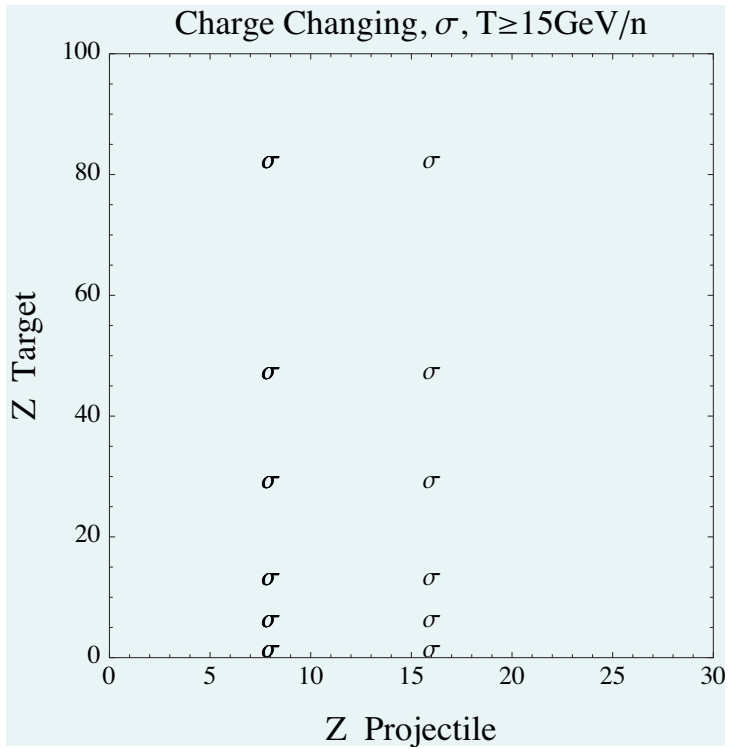
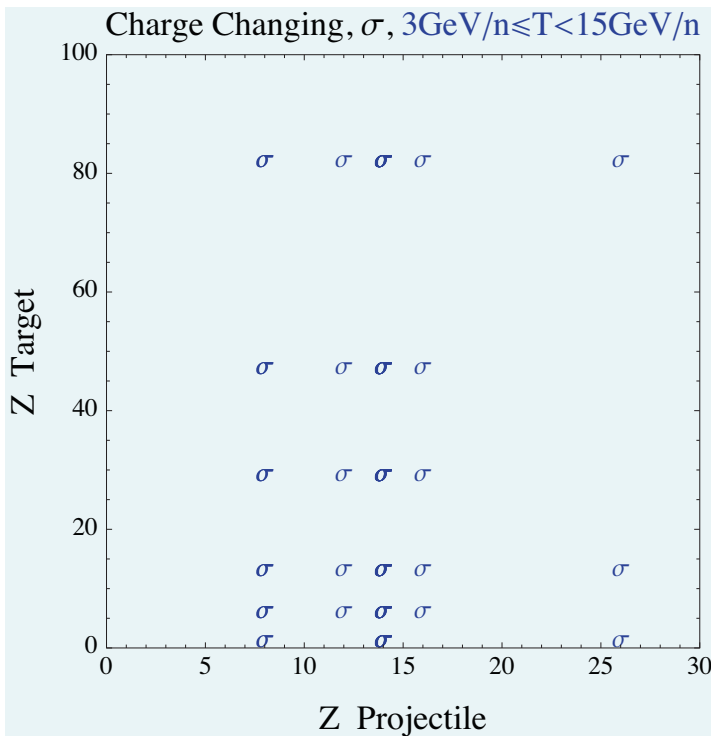
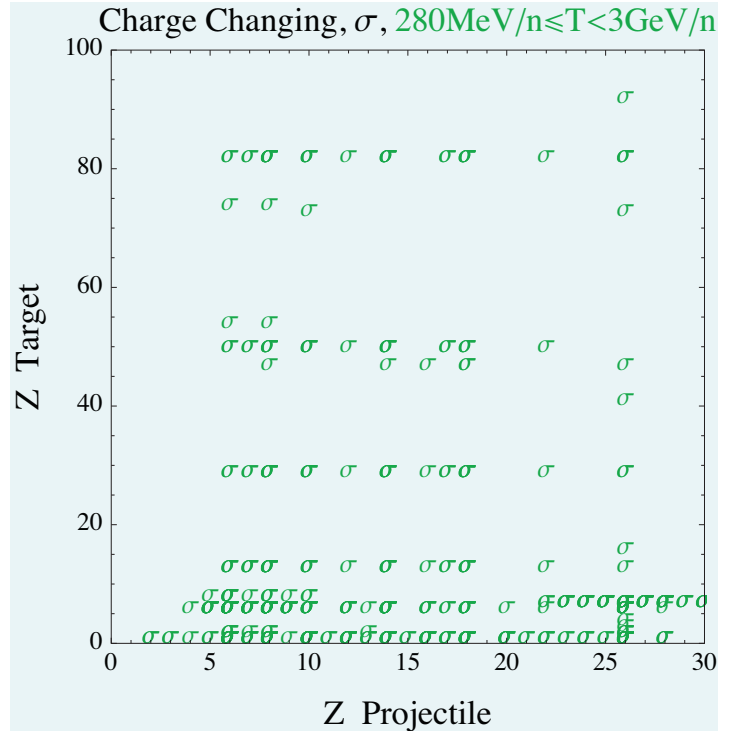
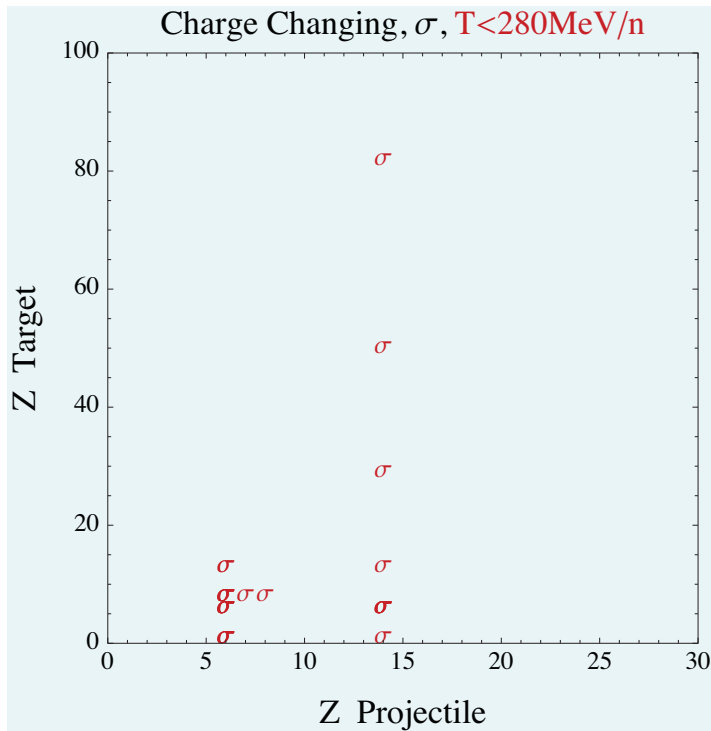


Figure 1: Charge changing total cross sections.

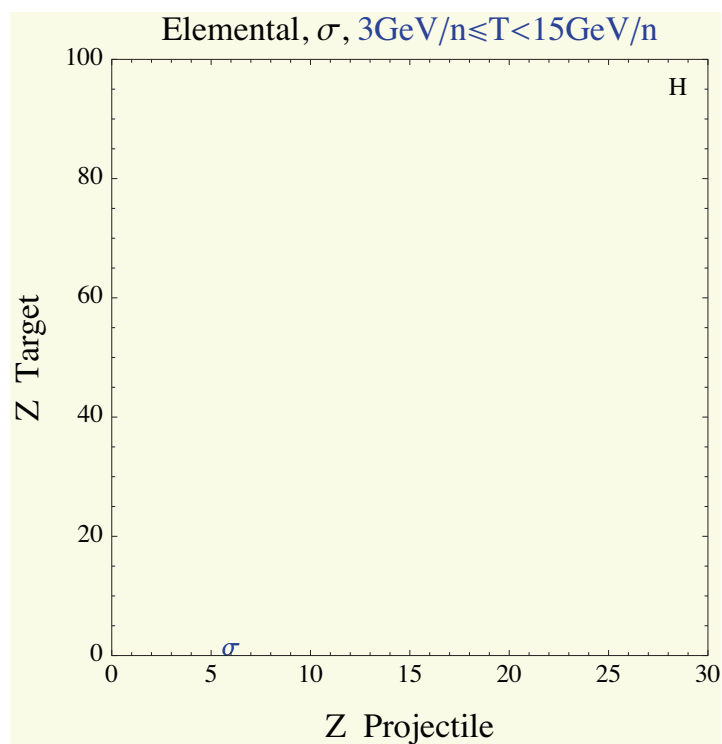
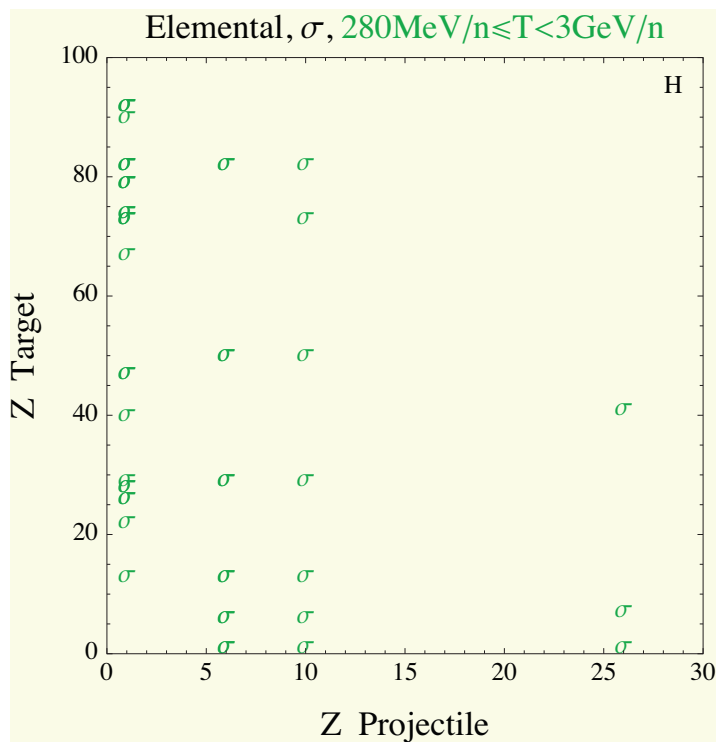


Figure 2: Elemental total cross sections for H fragments.

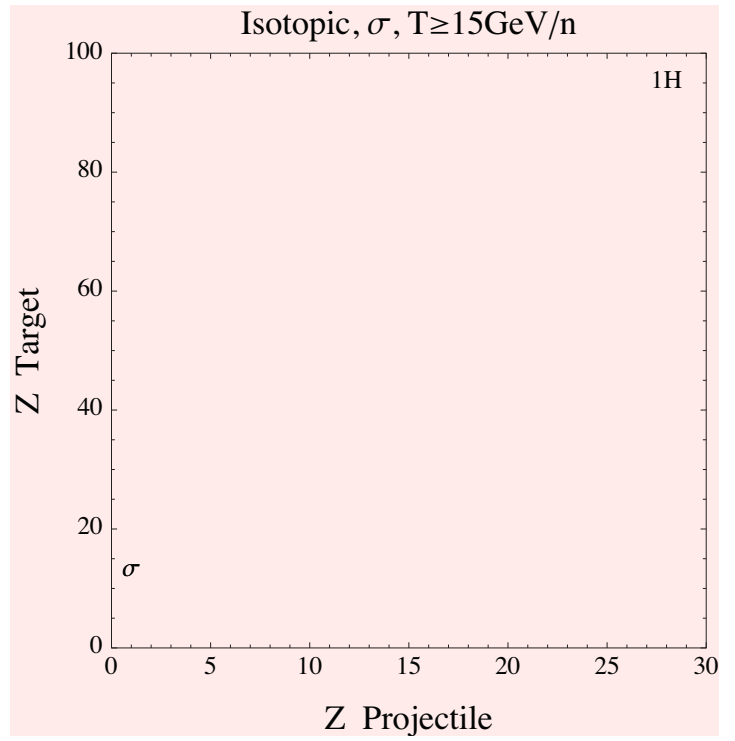
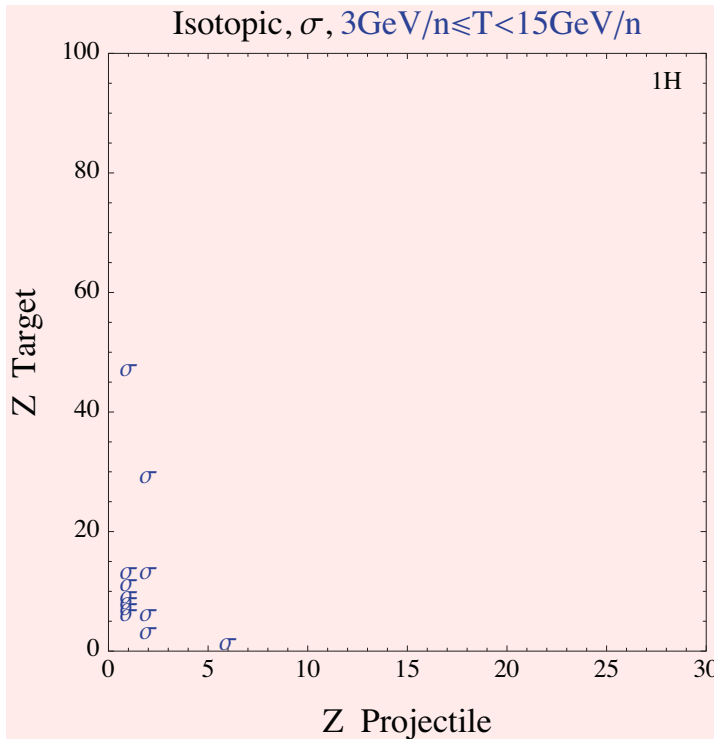
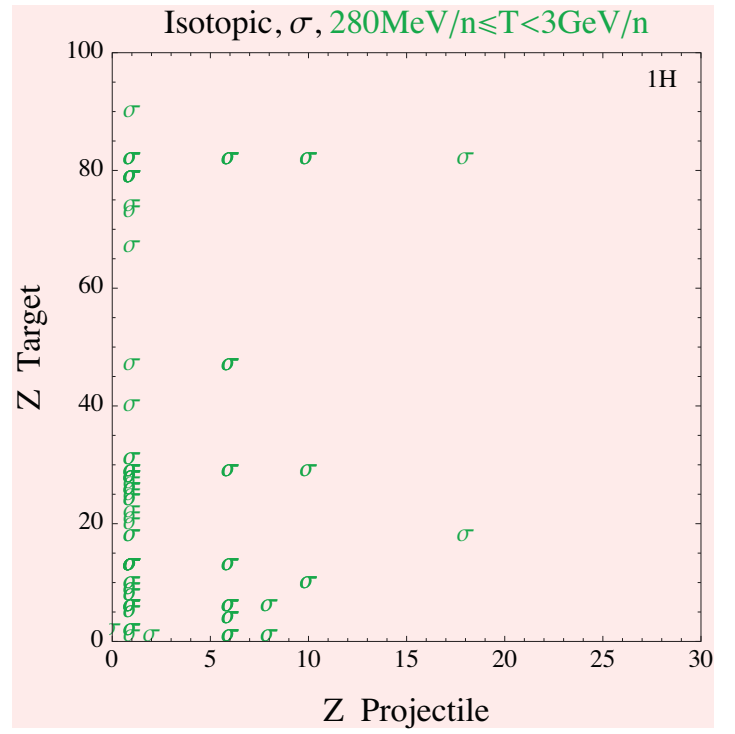
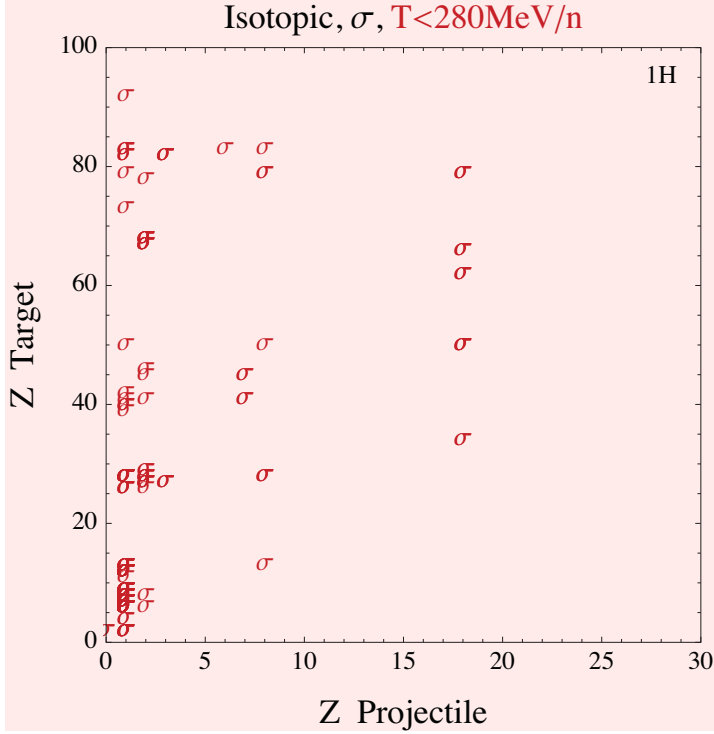


Figure 3: Isotopic total cross sections for ^1H fragments.

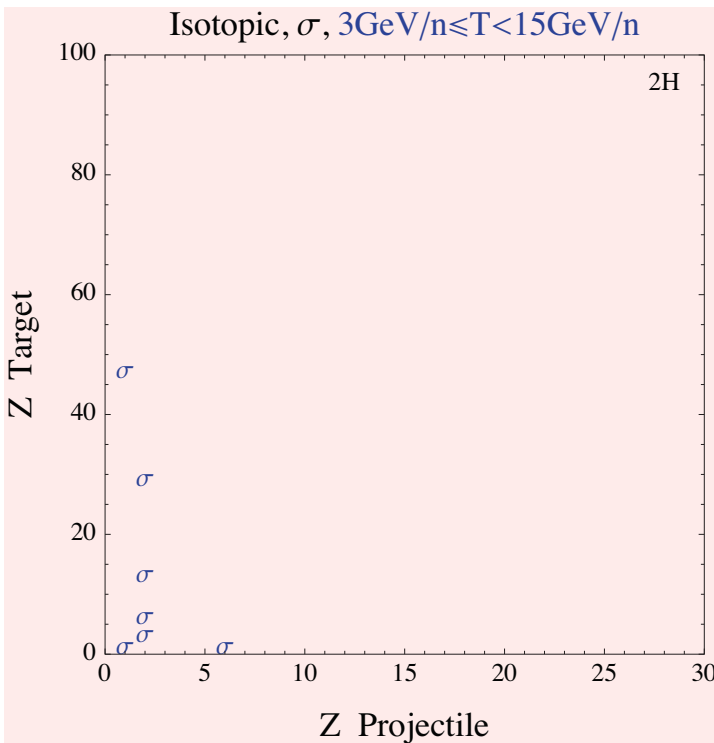
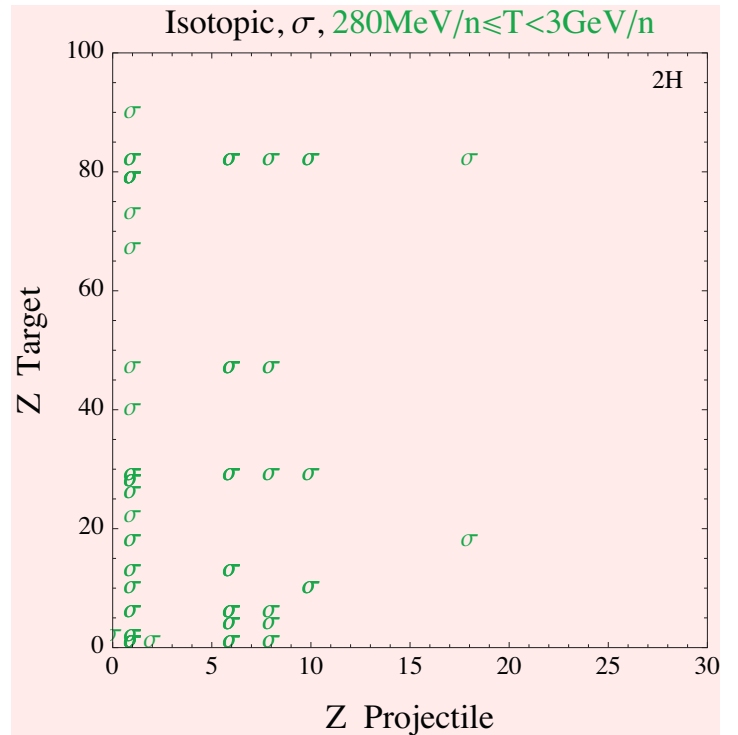
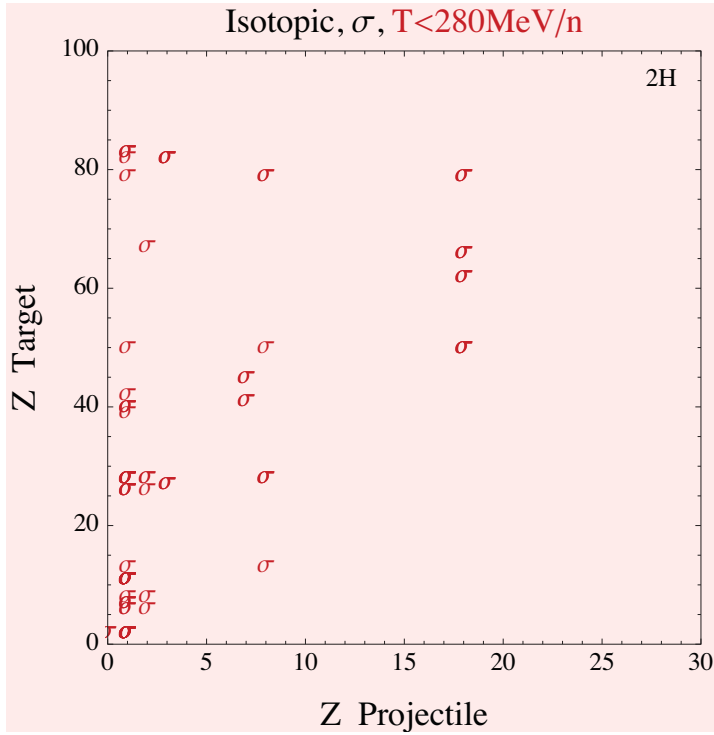


Figure 4: Isotopic total cross sections for ^2H fragments.

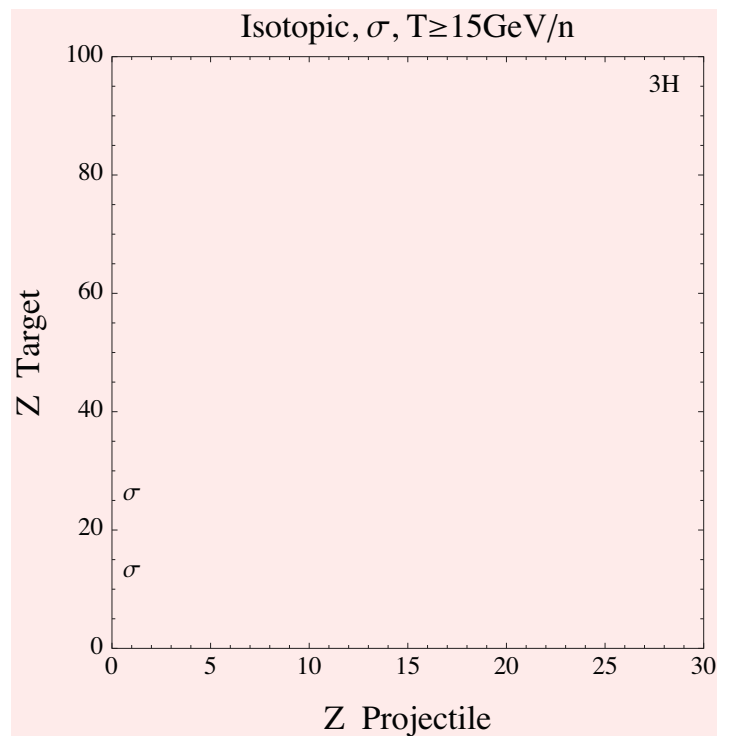
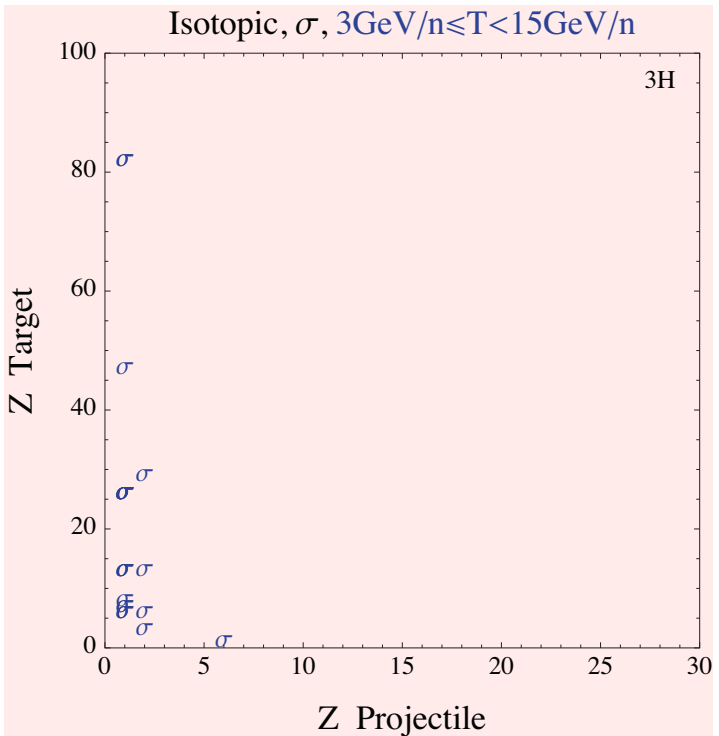
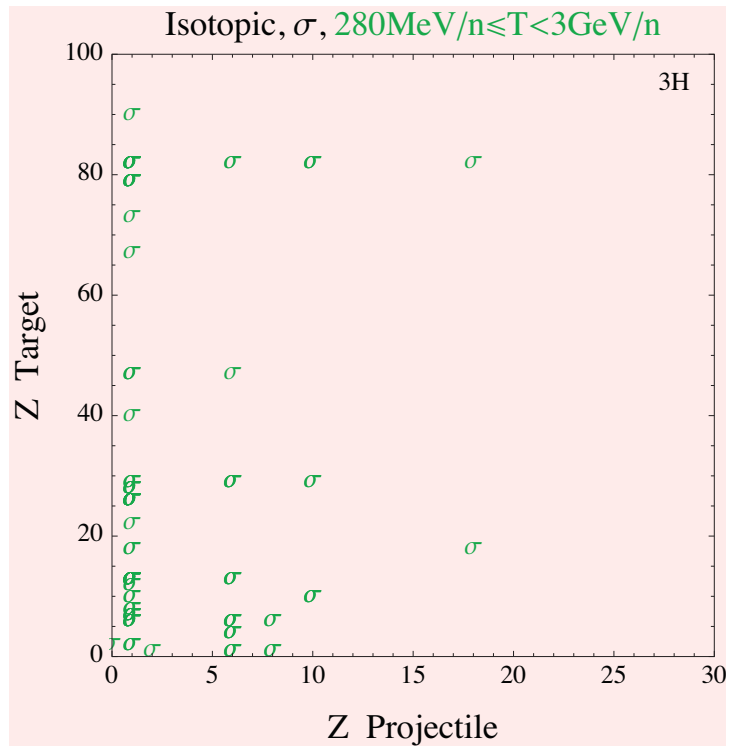
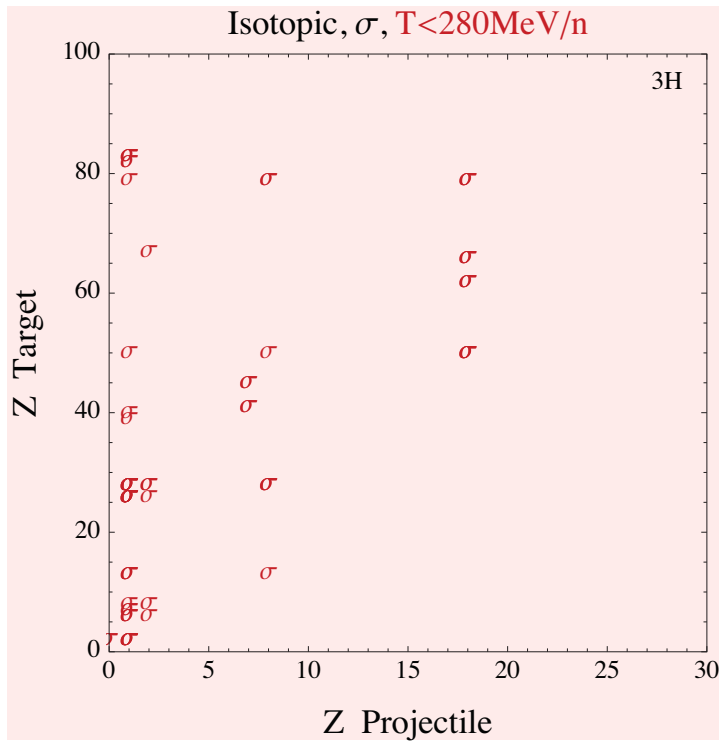


Figure 5: Isotopic total cross sections for ^3H fragments.

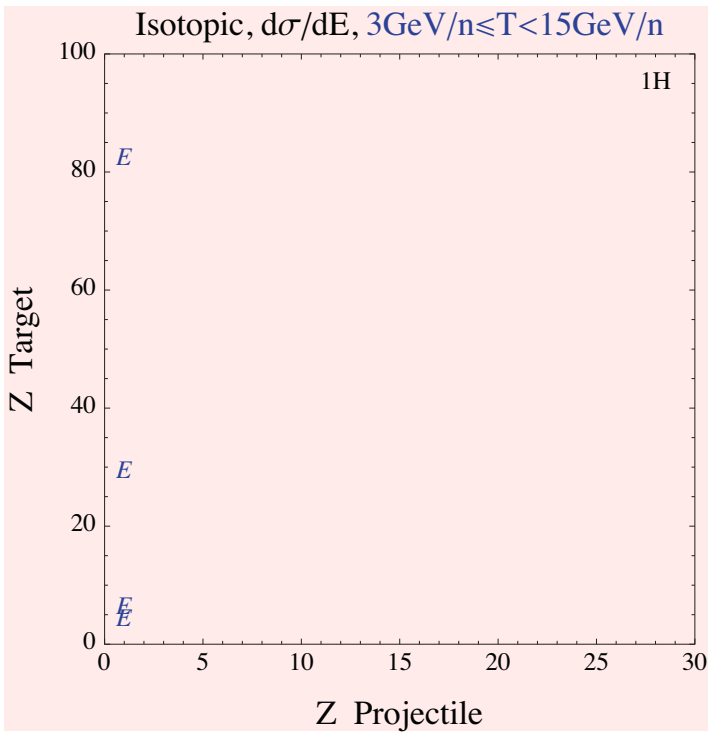
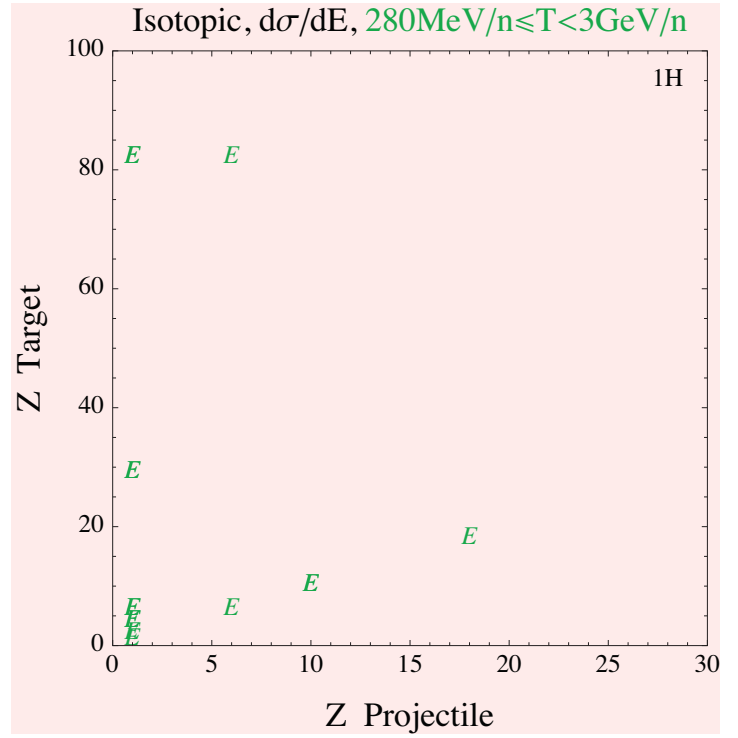
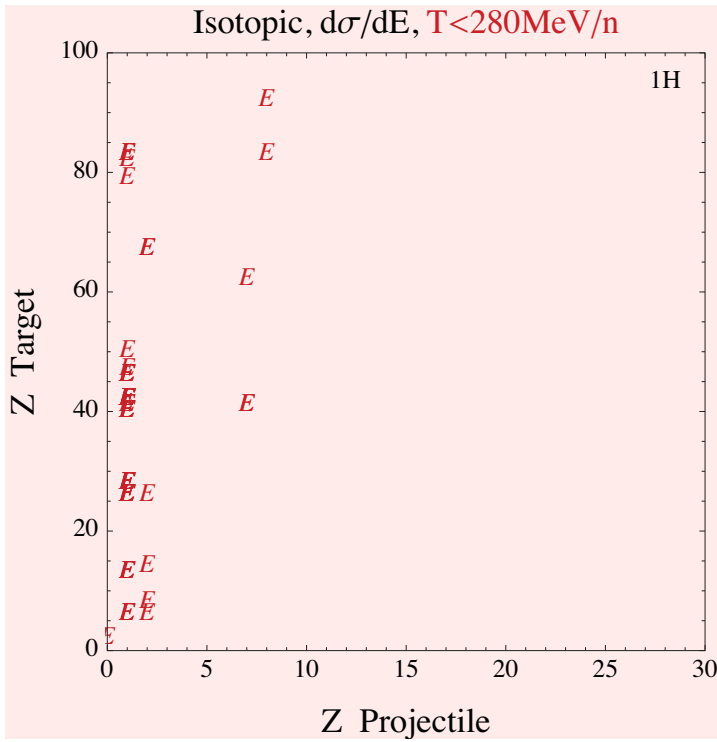


Figure 6: Isotopic energy differential cross sections for ^1H fragments.

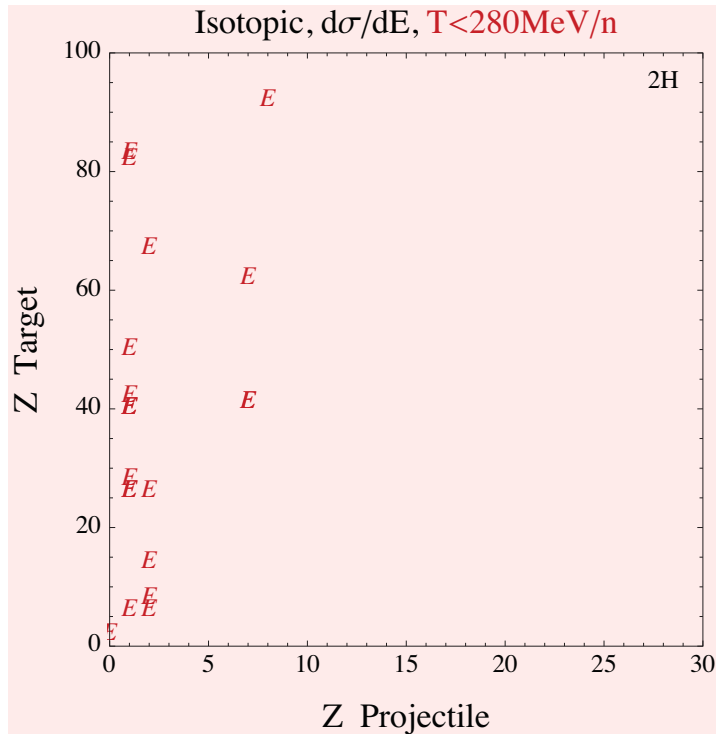


Figure 7: Isotopic energy differential cross sections for ^2H fragments.

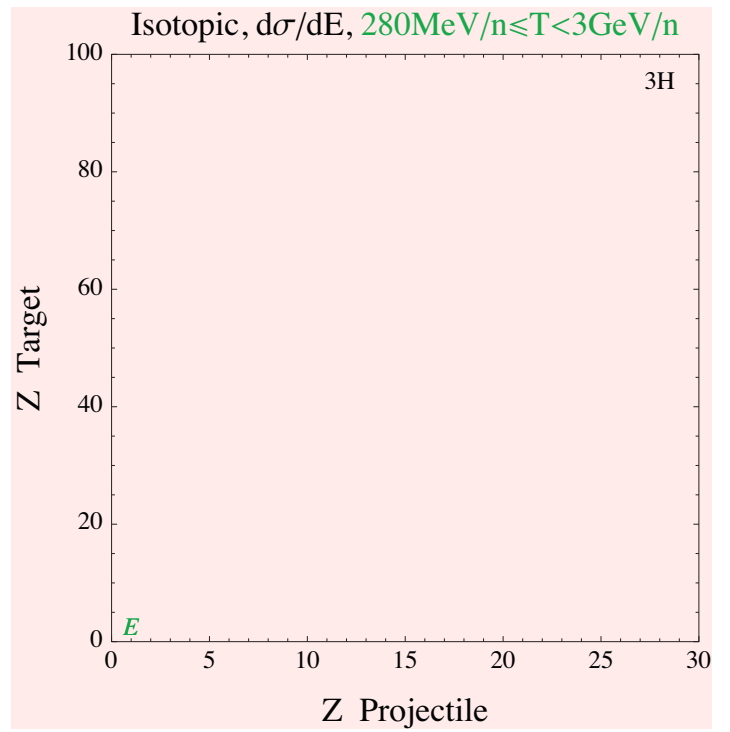
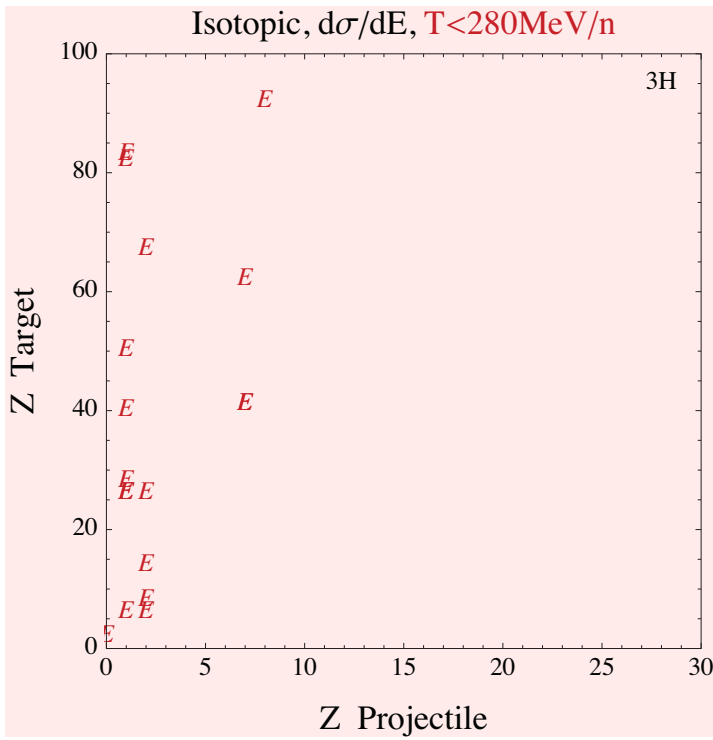


Figure 8: Isotopic energy differential cross sections for ${}^3\text{H}$ fragments.

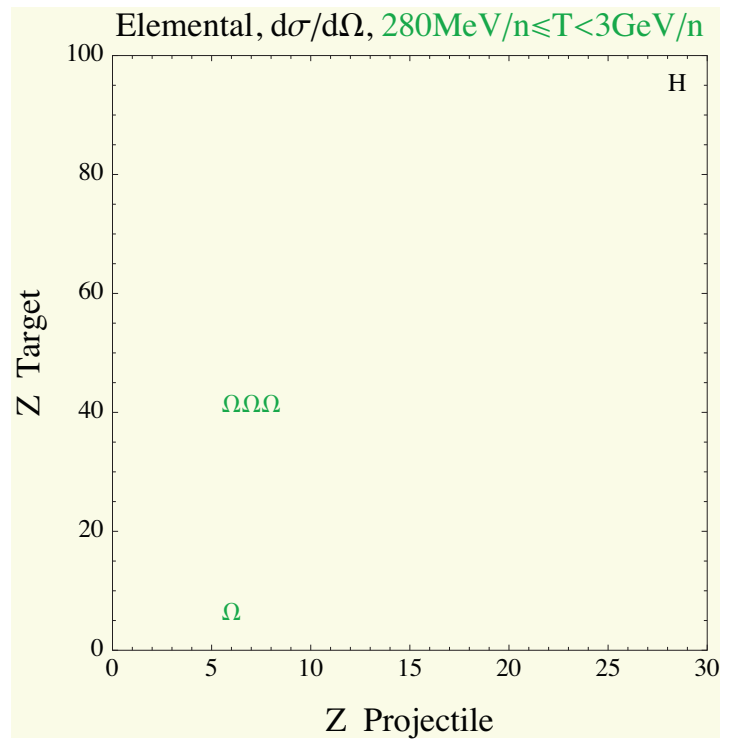
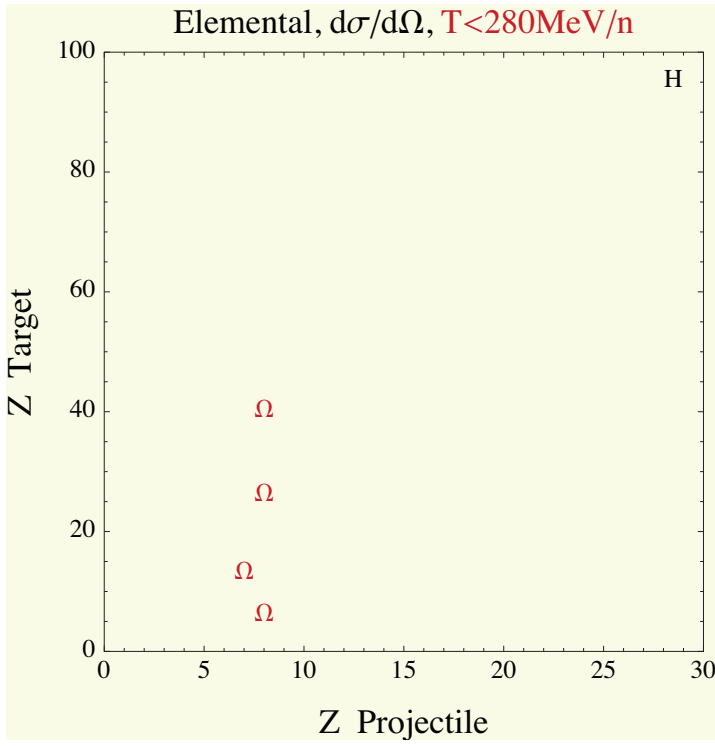


Figure 9: Elemental angular differential cross sections for H fragments.

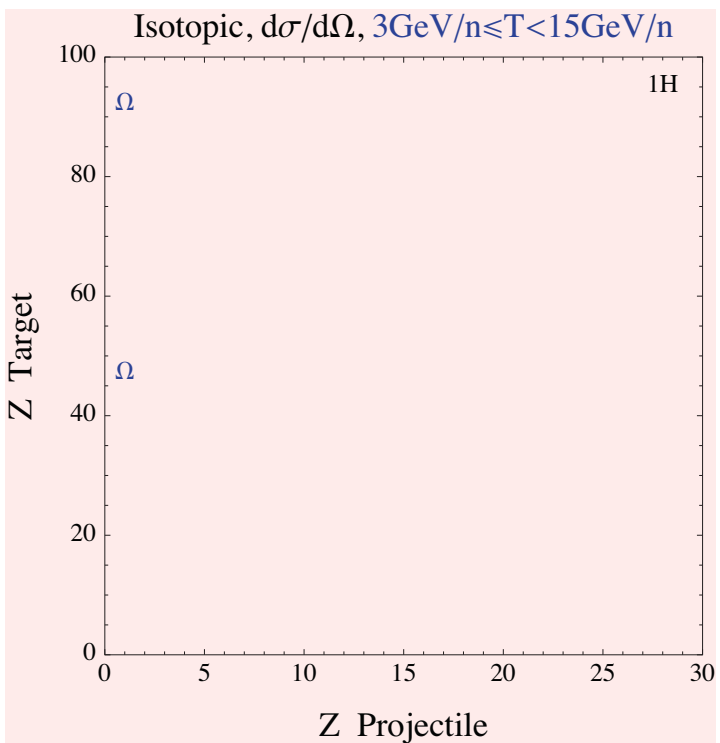
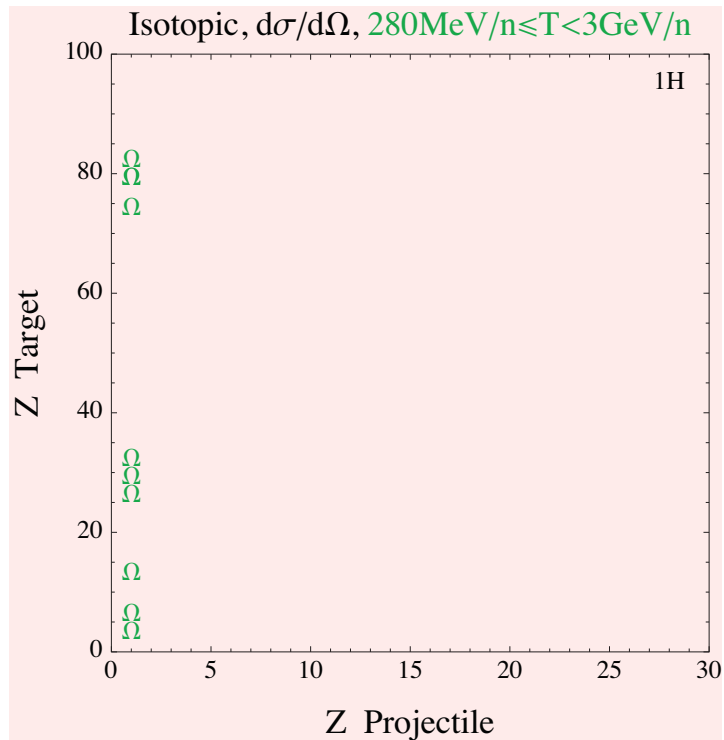
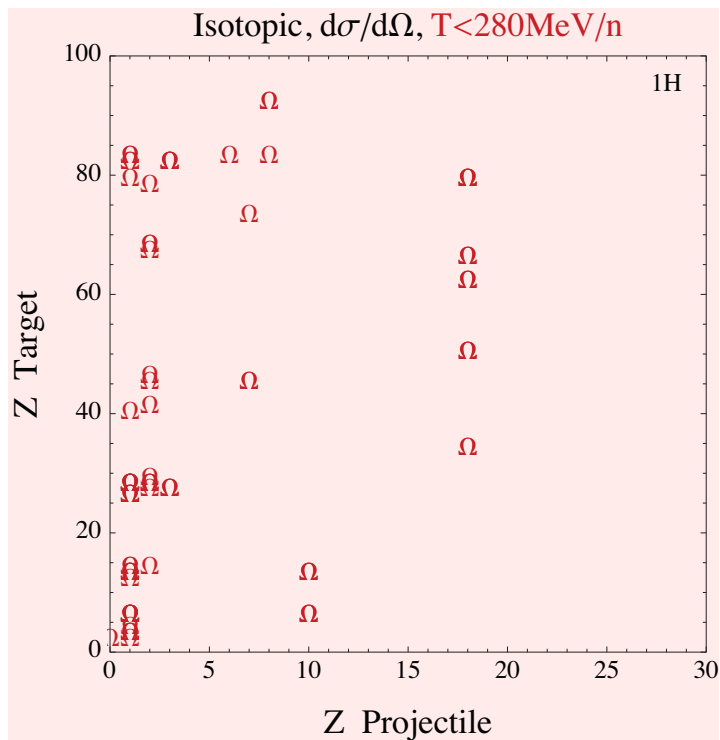


Figure 10: Isotopic angular differential cross sections for ^1H fragments.

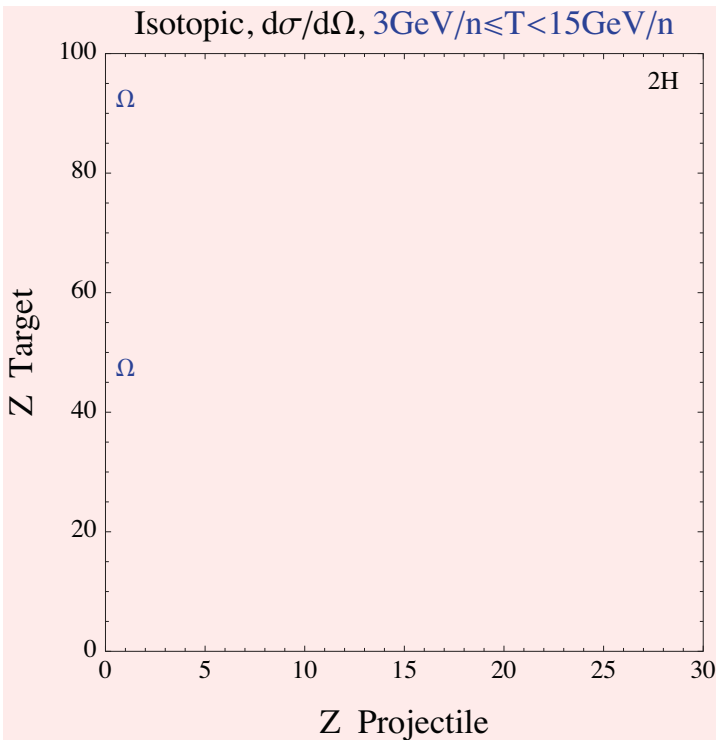
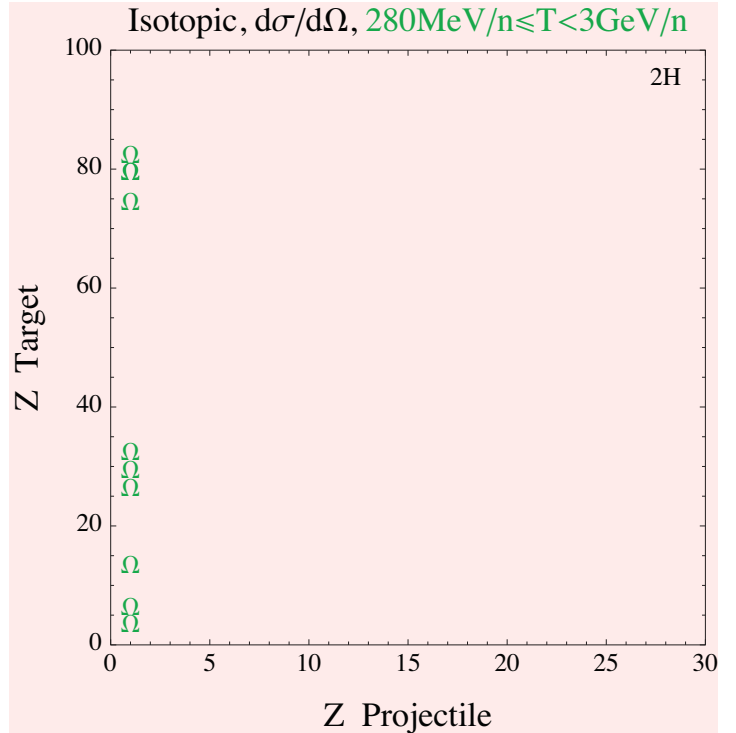
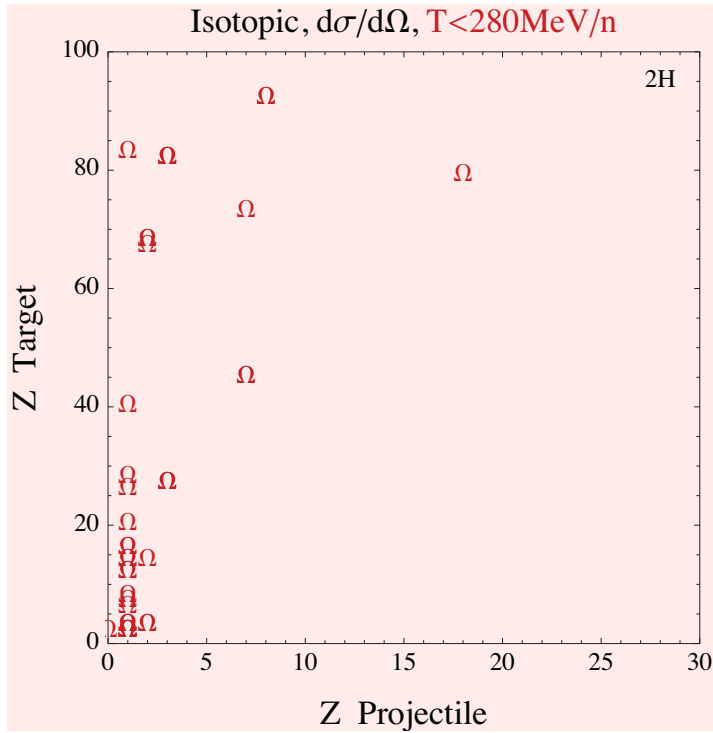


Figure 11: Isotopic angular differential cross sections for ${}^2\text{H}$ fragments.

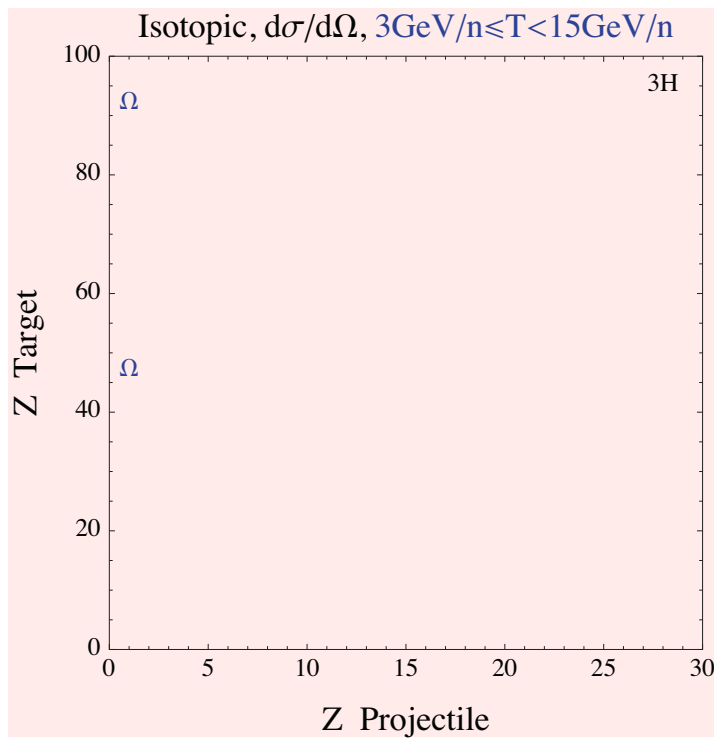
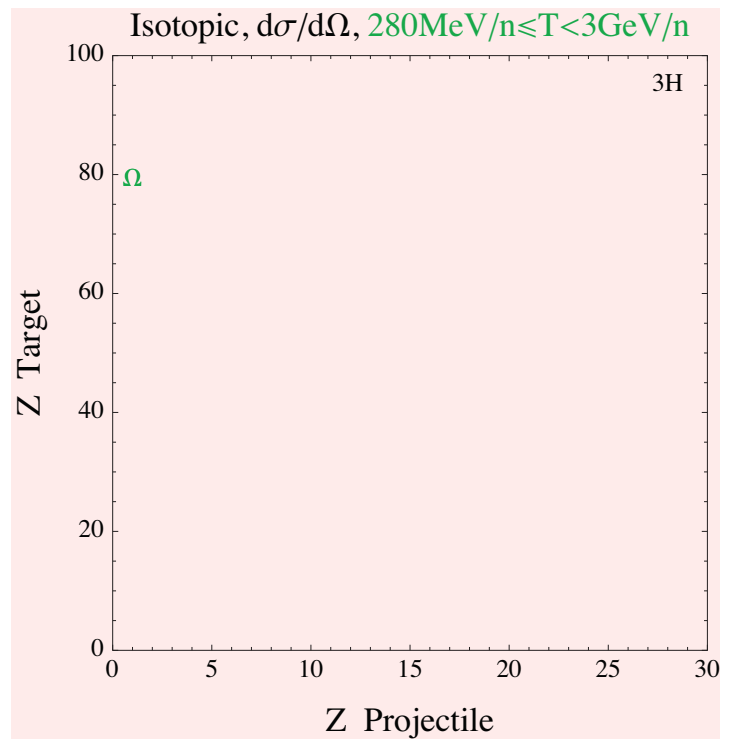
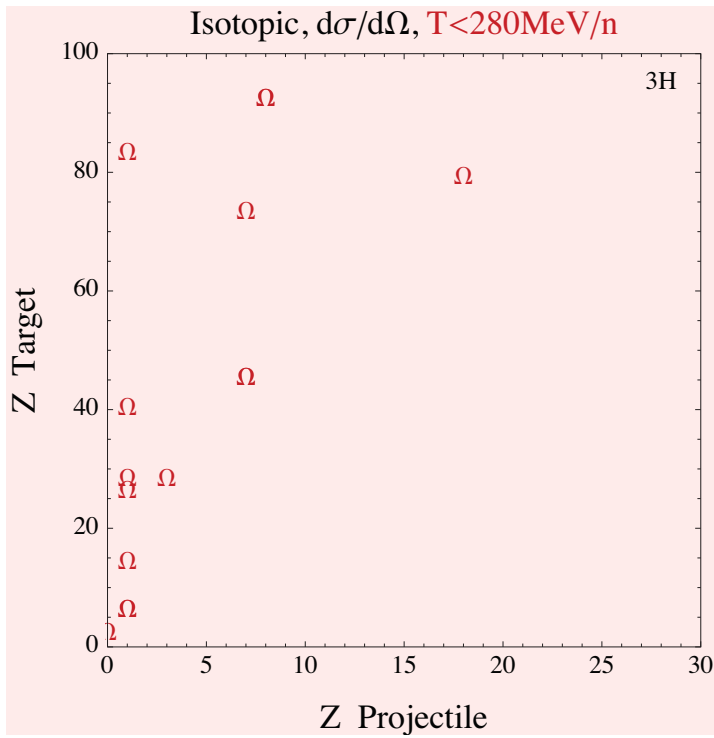


Figure 12: Isotopic angular differential cross sections for ${}^3\text{H}$ fragments.

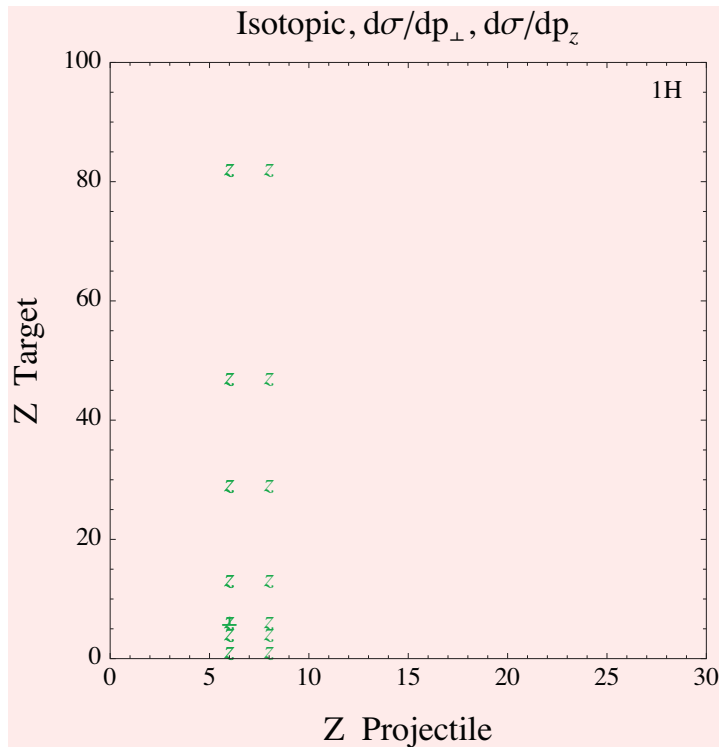


Figure 13: Isotopic momentum differential cross sections for ^1H fragments covering all energies.

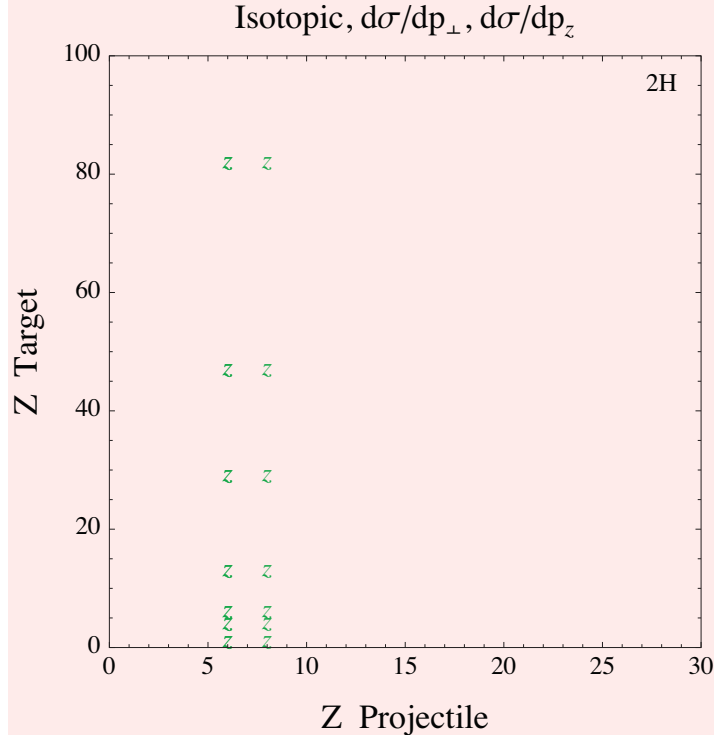


Figure 14: Isotopic momentum differential cross sections for ^2H fragments covering all energies.

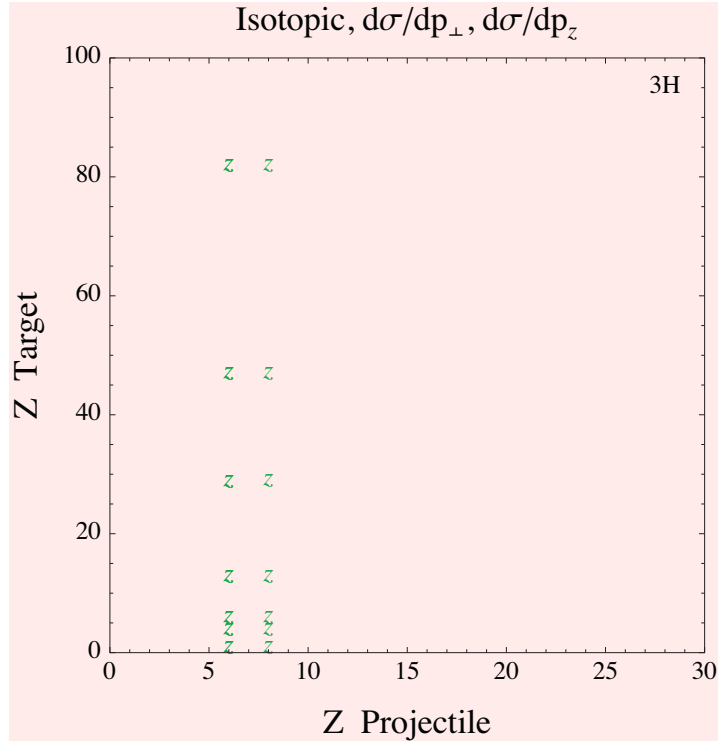


Figure 15: Isotopic momentum differential cross sections for ${}^3\text{H}$ fragments covering all energies.

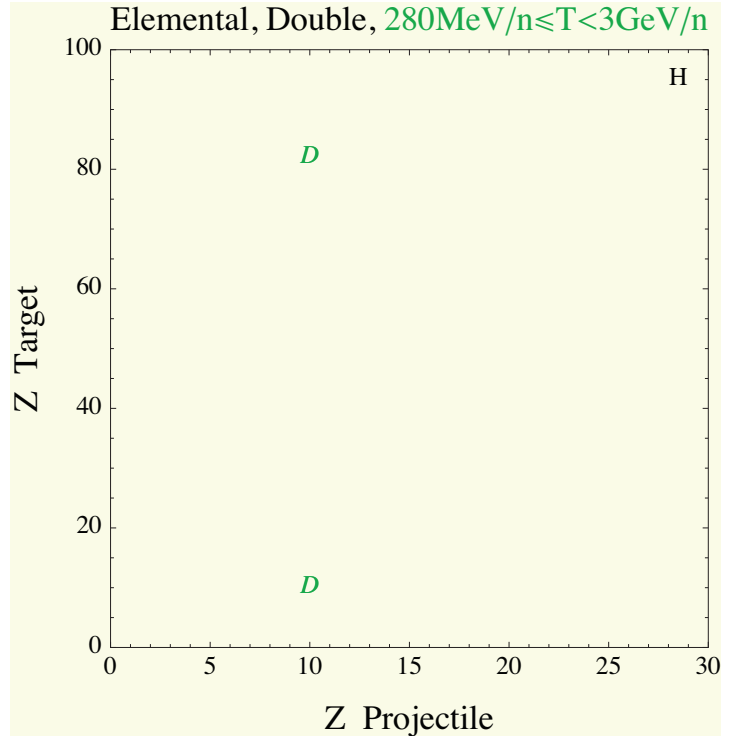
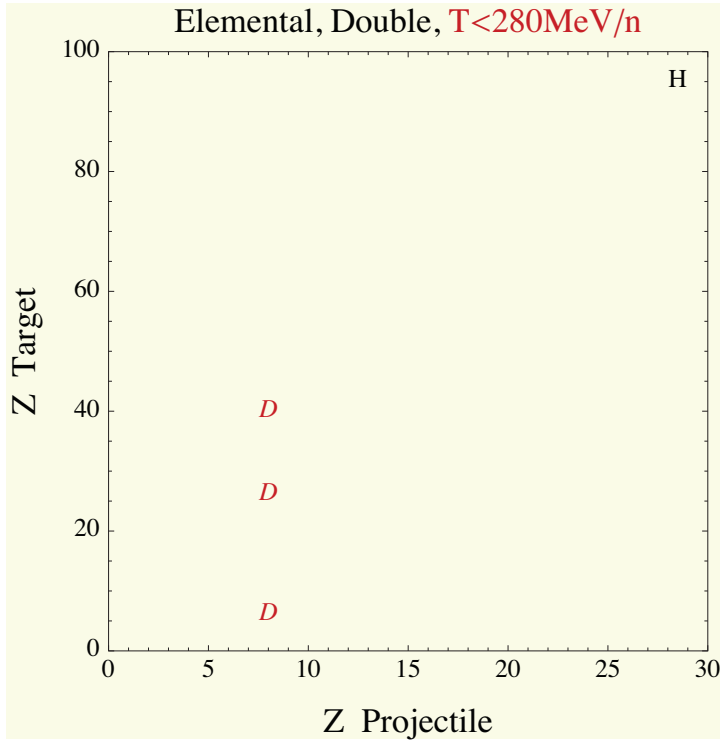


Figure 16: Elemental double differential cross sections for H fragments.

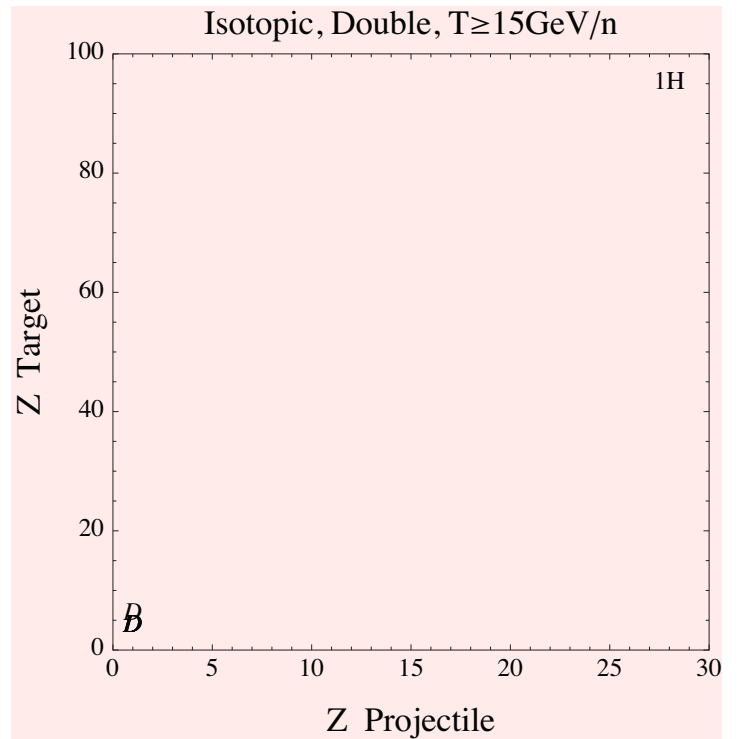
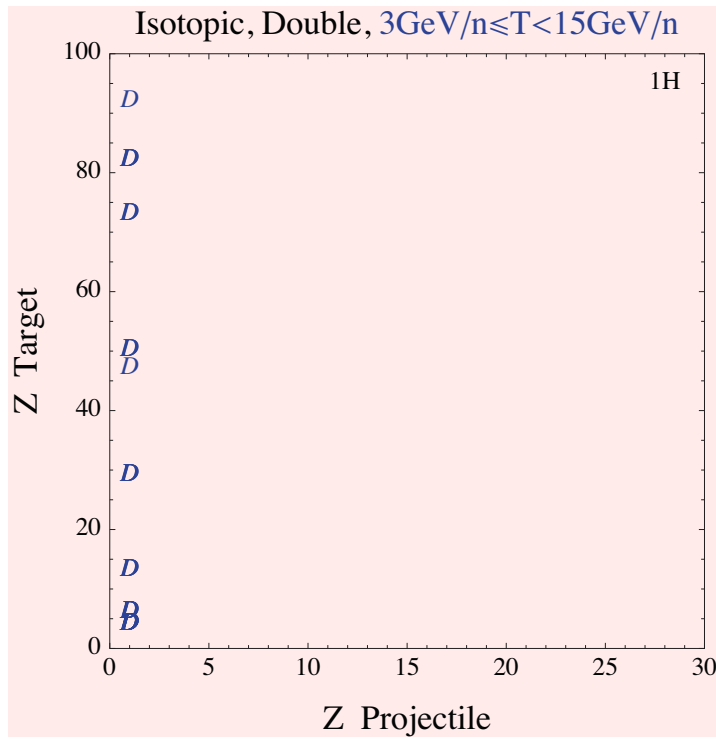
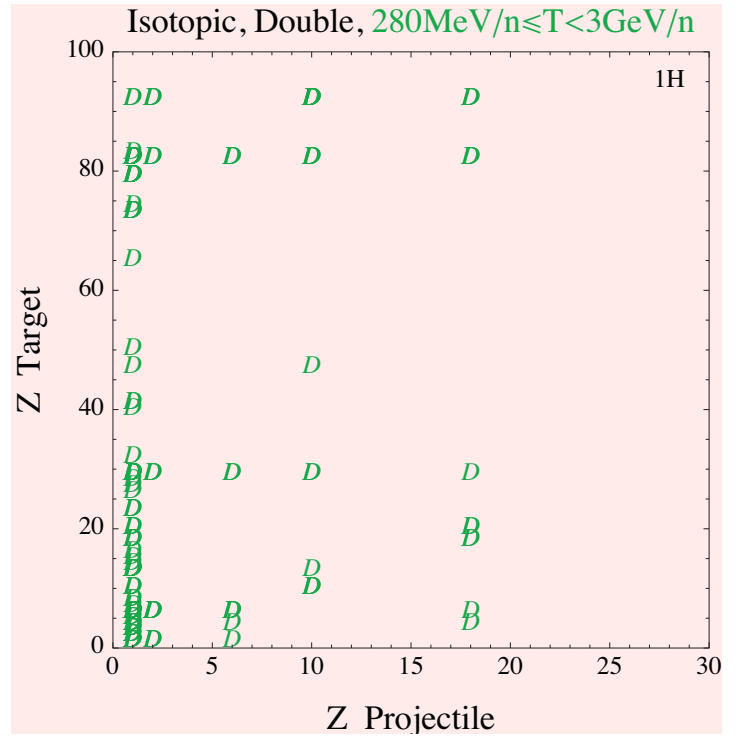
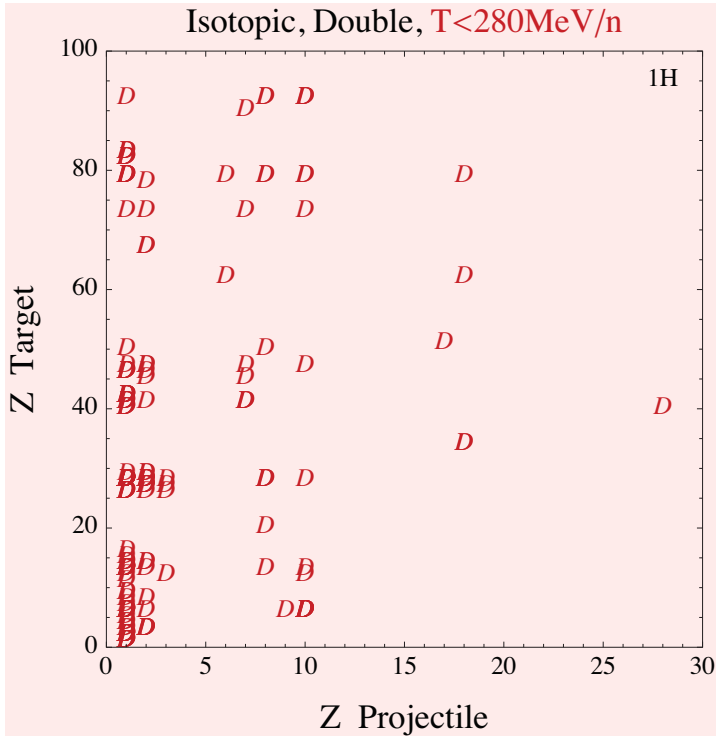


Figure 17: Isotopic double differential cross sections for ^1H fragments.

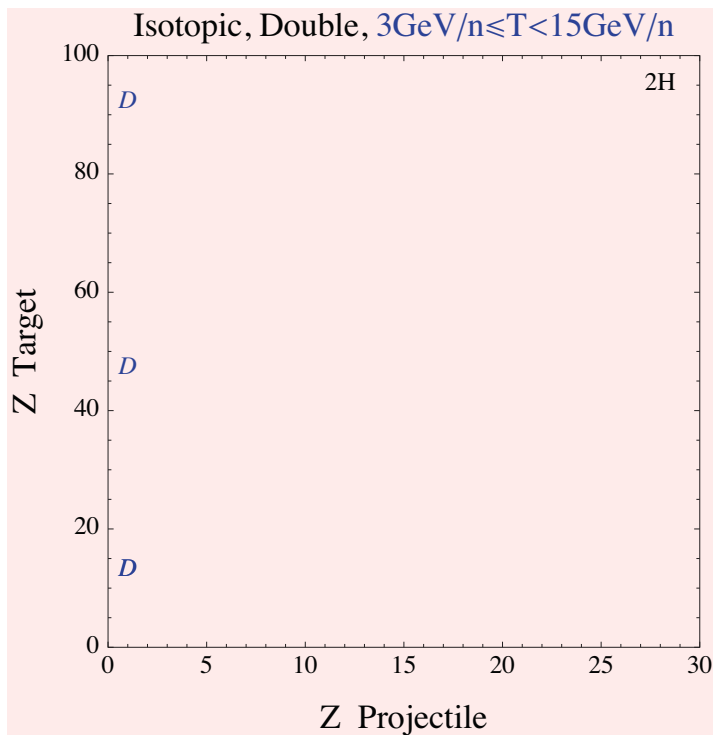
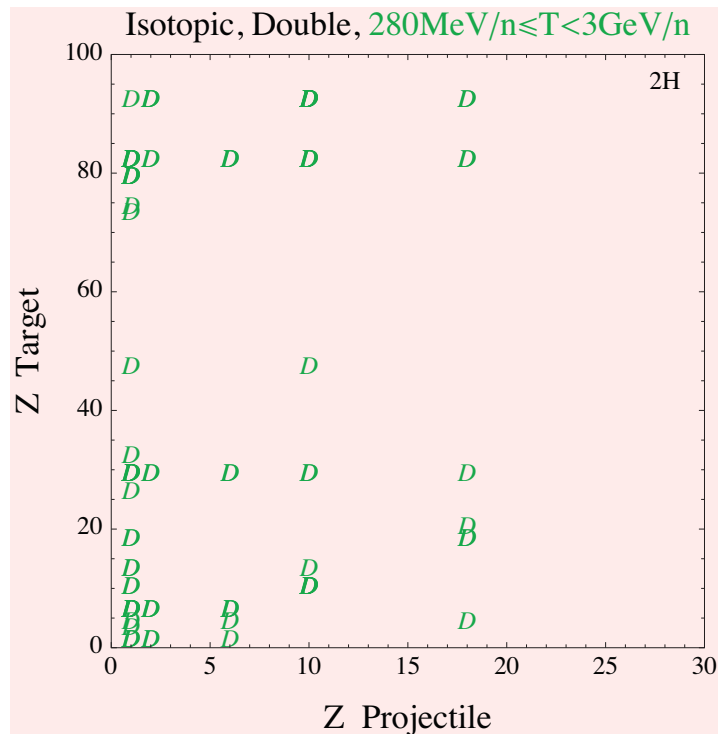
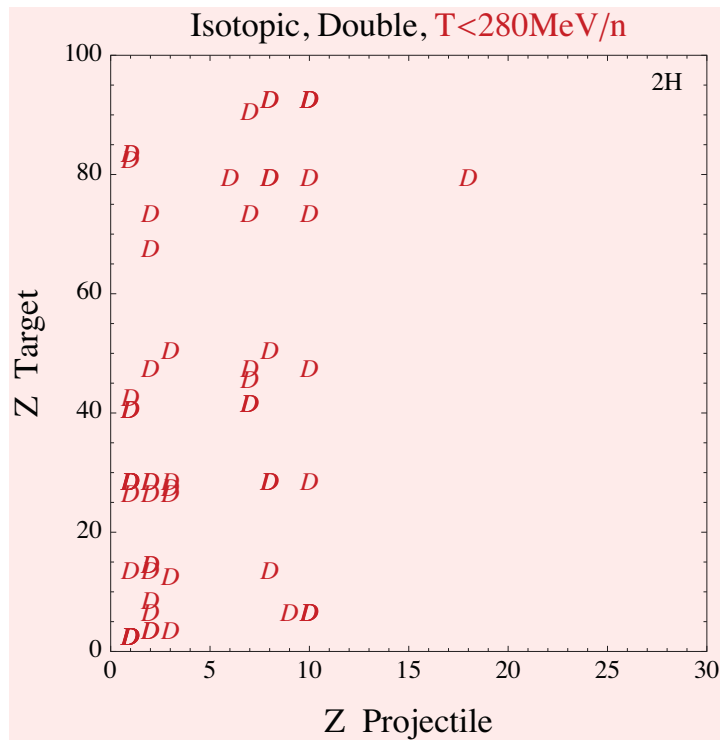


Figure 18: Isotopic double differential cross sections for ^2H fragments.

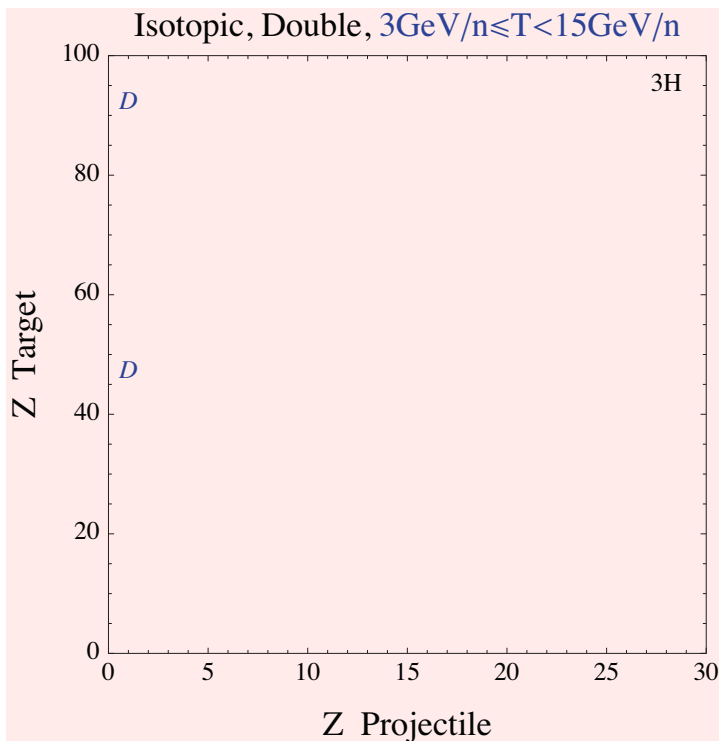
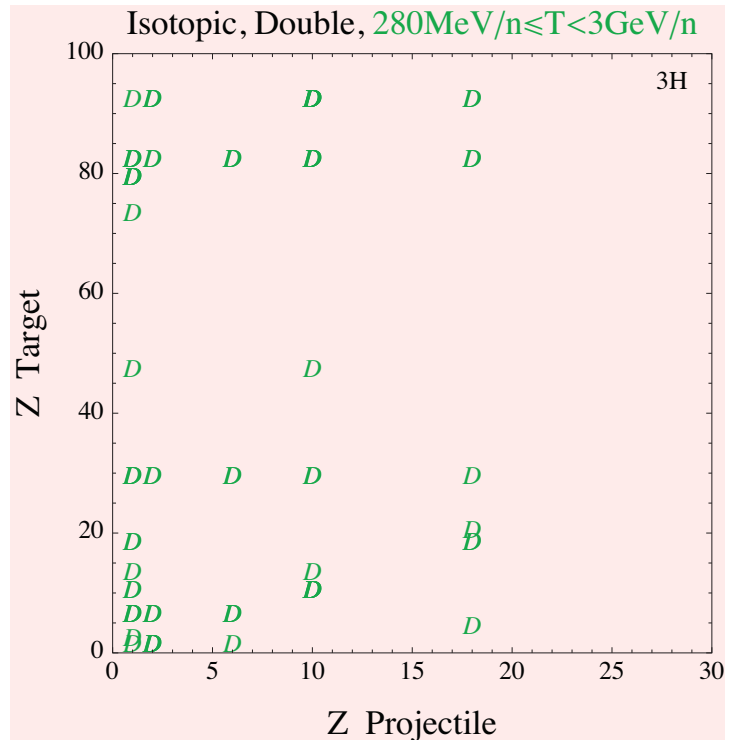
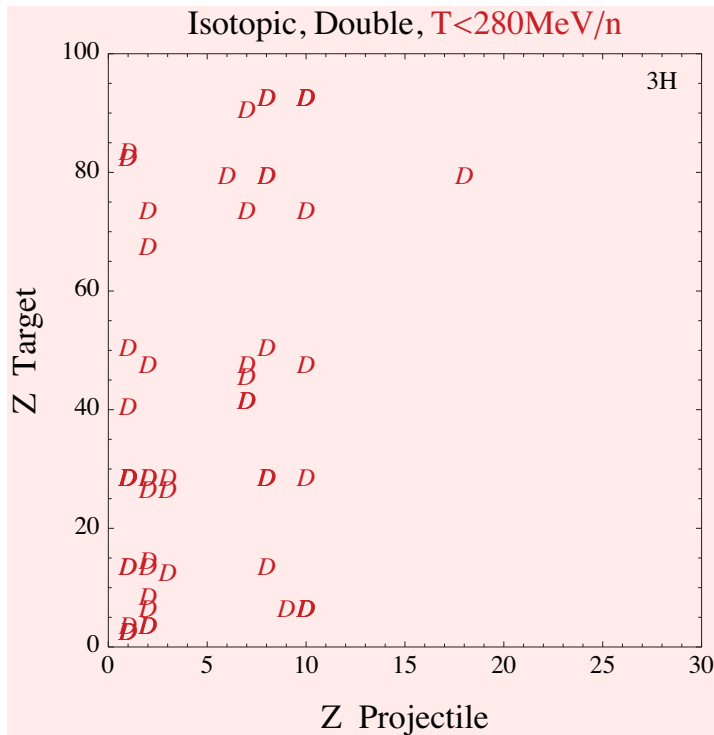


Figure 19: Isotopic double differential cross sections for ^3H fragments.

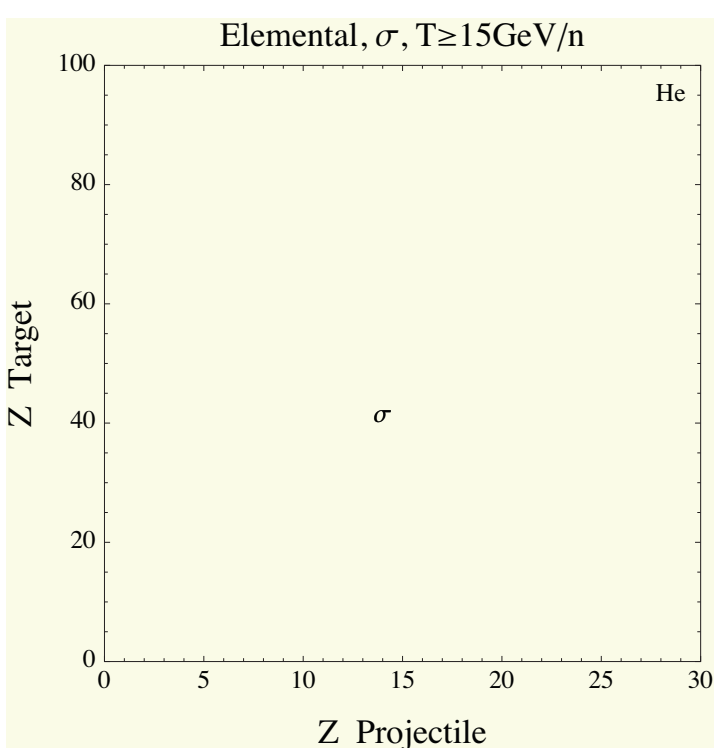
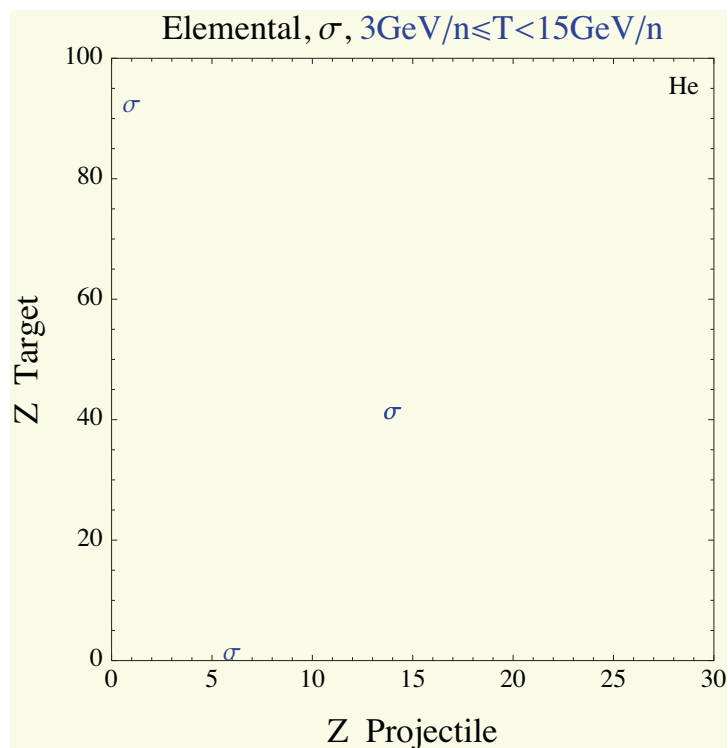
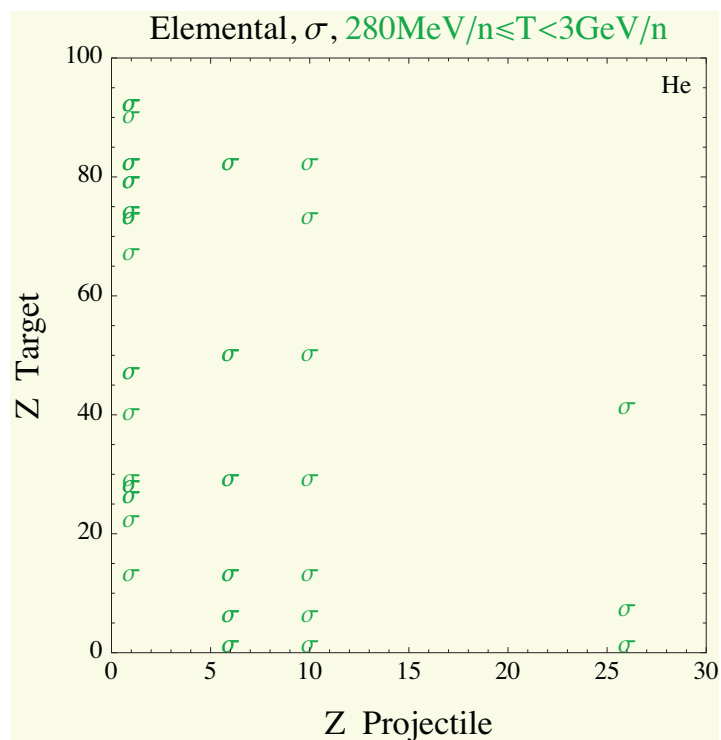
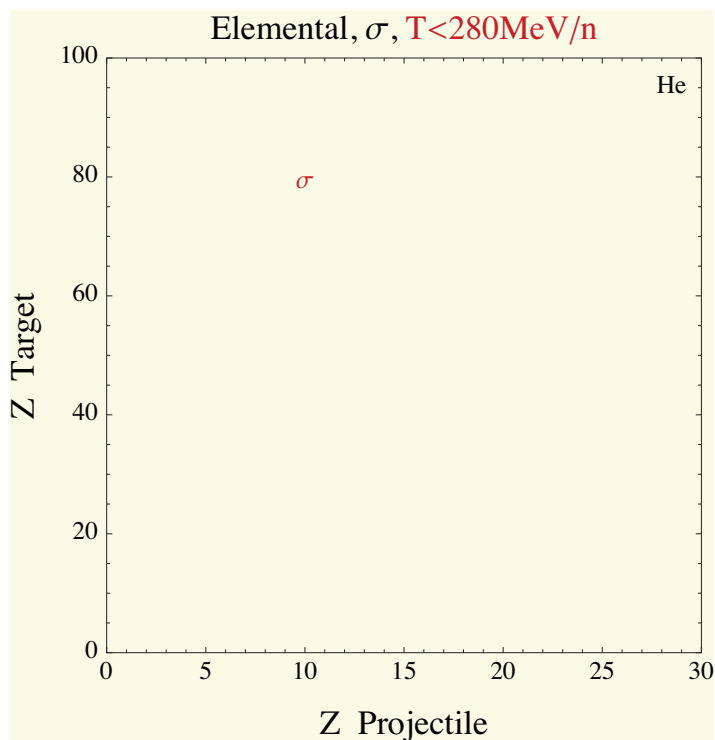


Figure 20: Elemental total cross sections for He fragments.

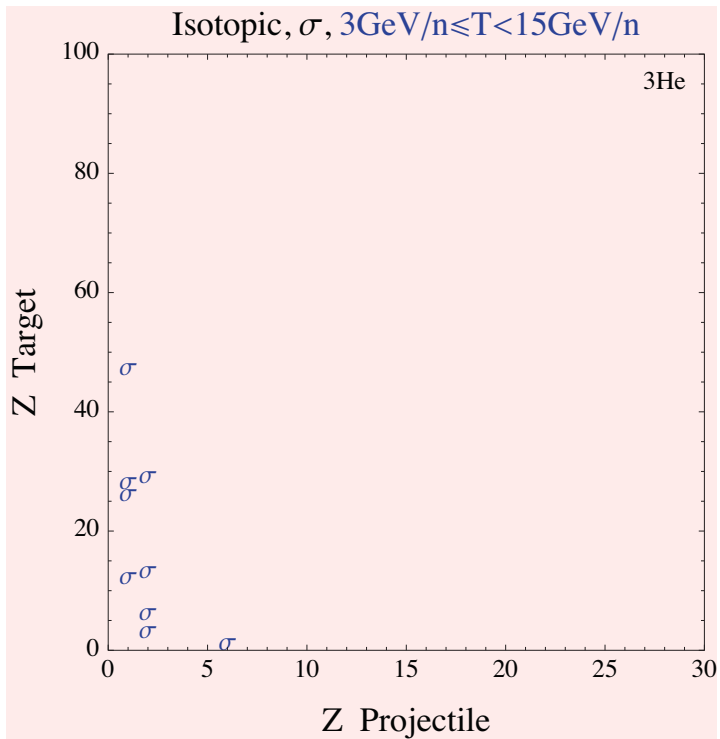
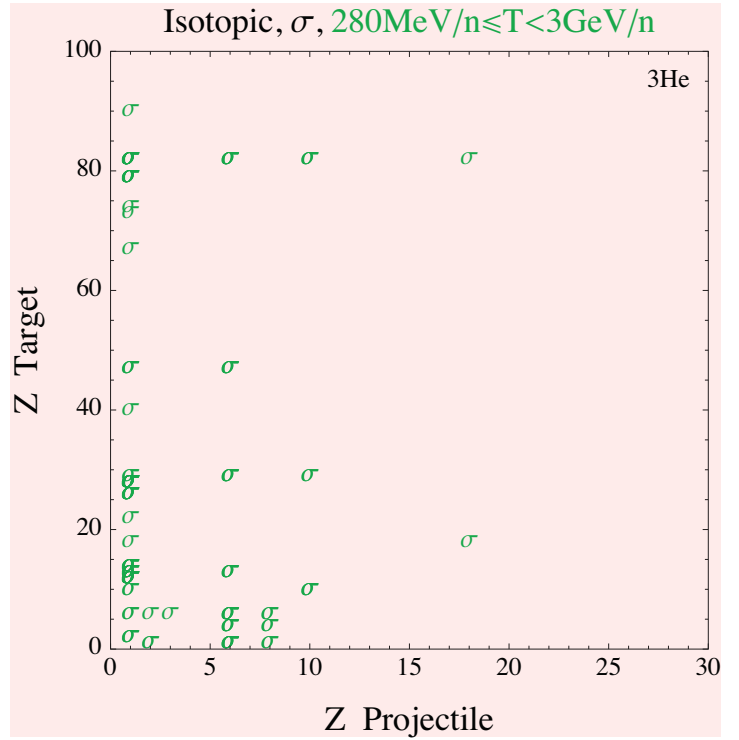
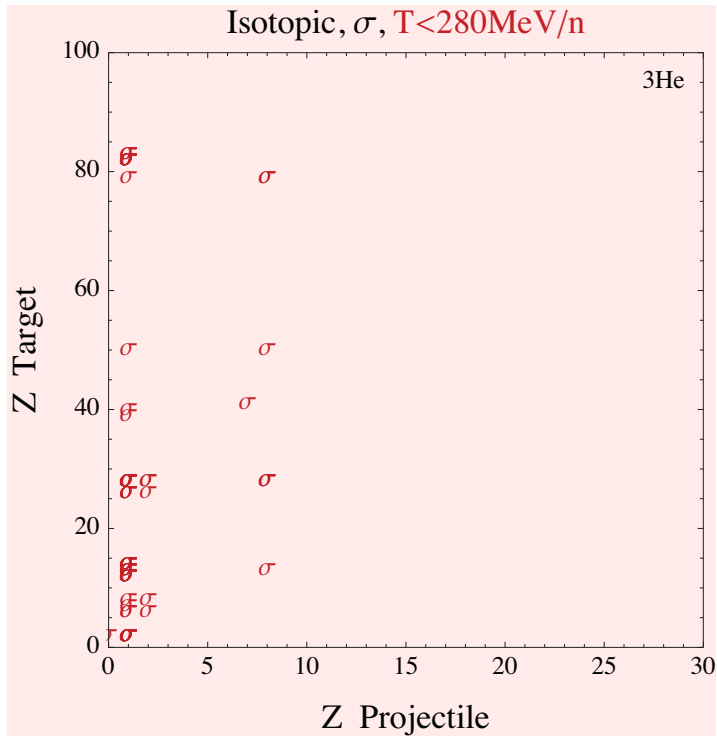


Figure 21: Isotopic total cross sections for ^3He fragments.

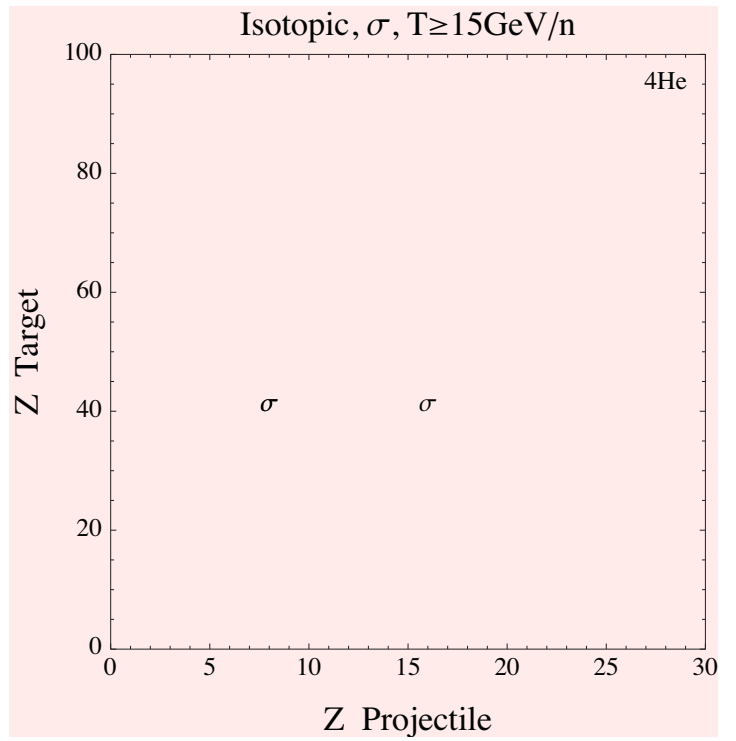
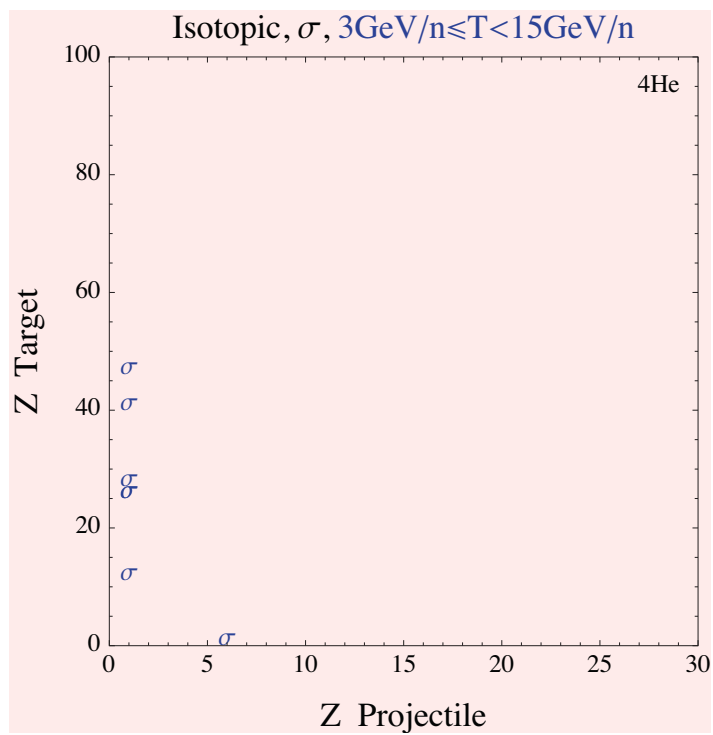
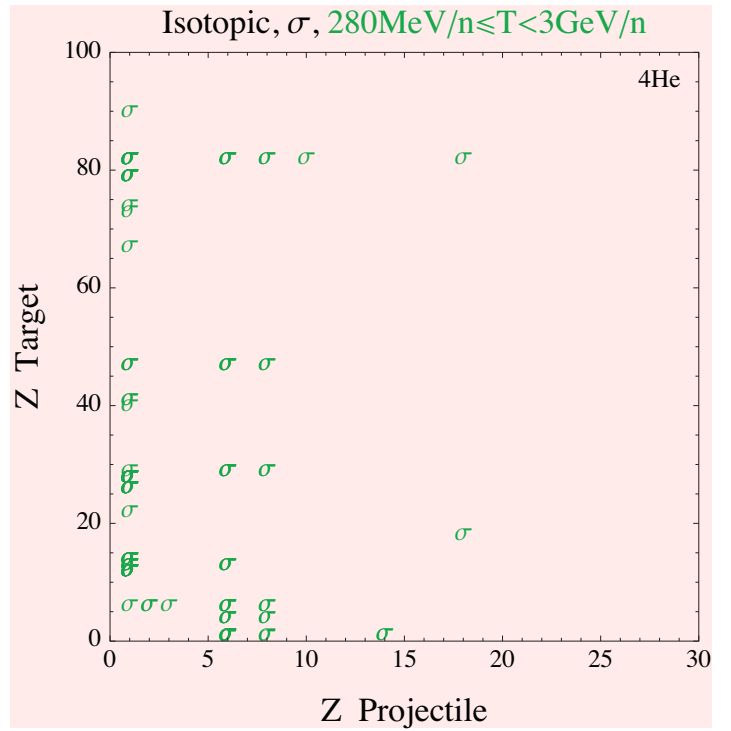
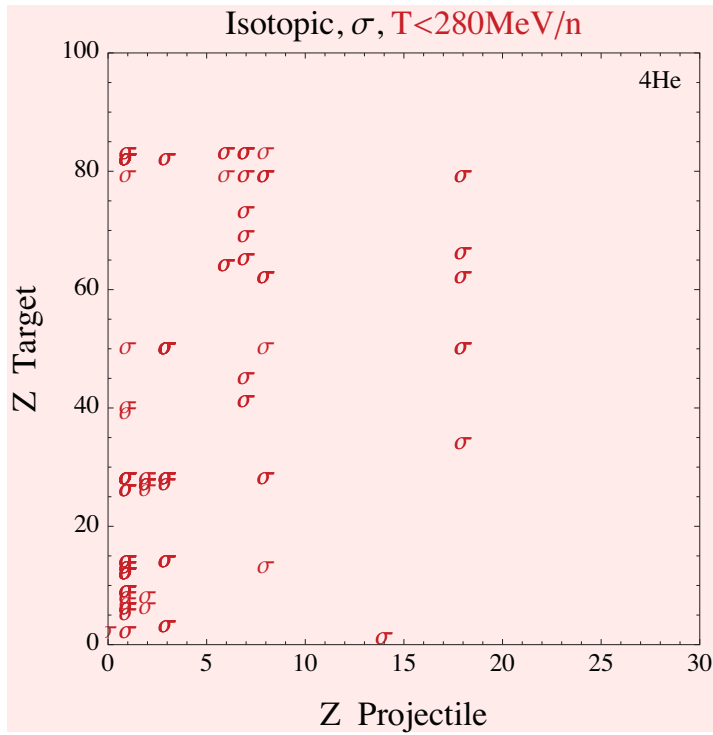


Figure 22: Isotopic total cross sections for ^4He fragments.

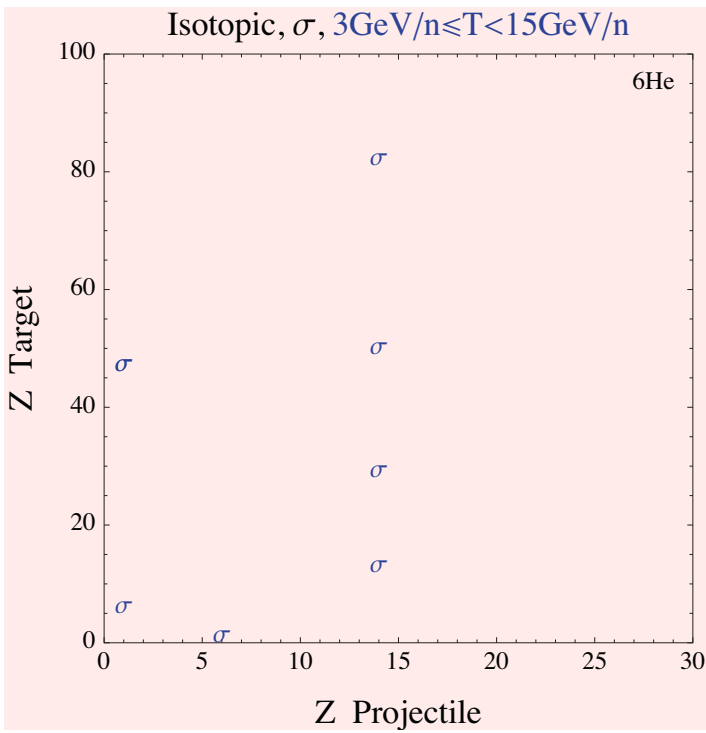
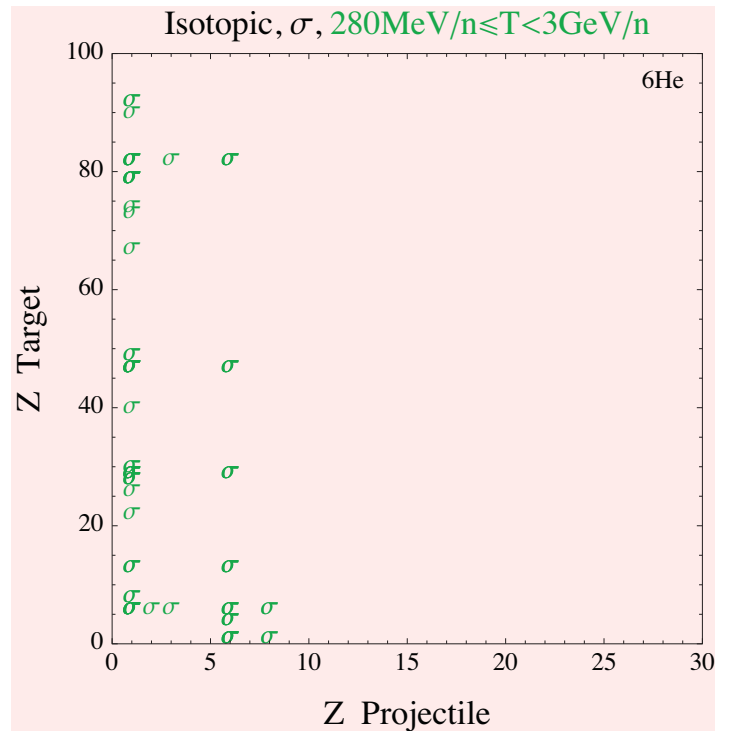
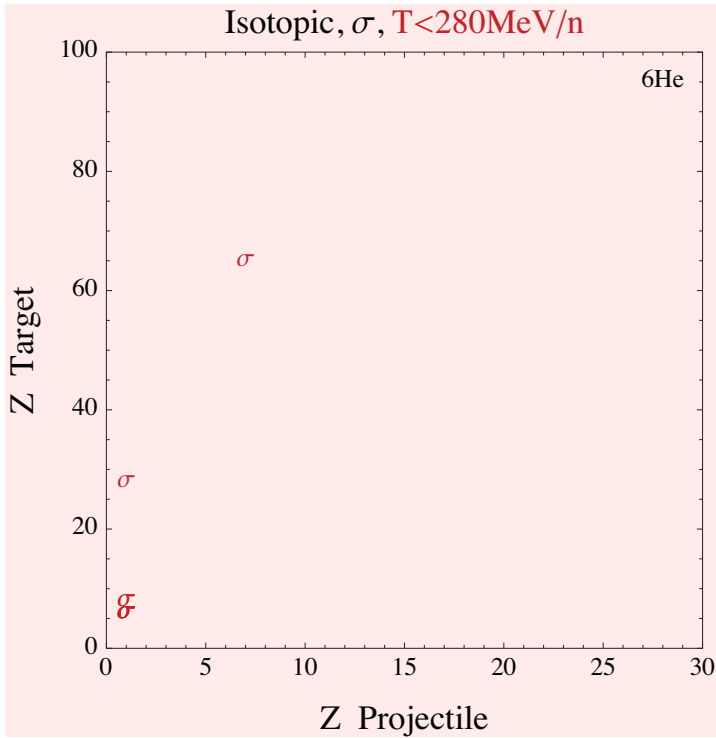


Figure 23: Isotopic total cross sections for ${}^6\text{He}$ fragments.

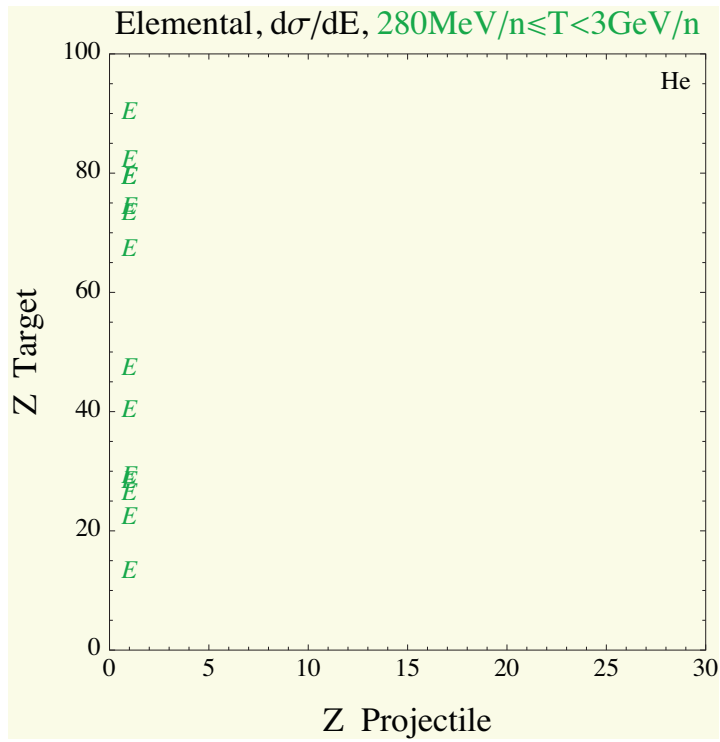


Figure 24: Elemental energy differential cross sections for He fragments.

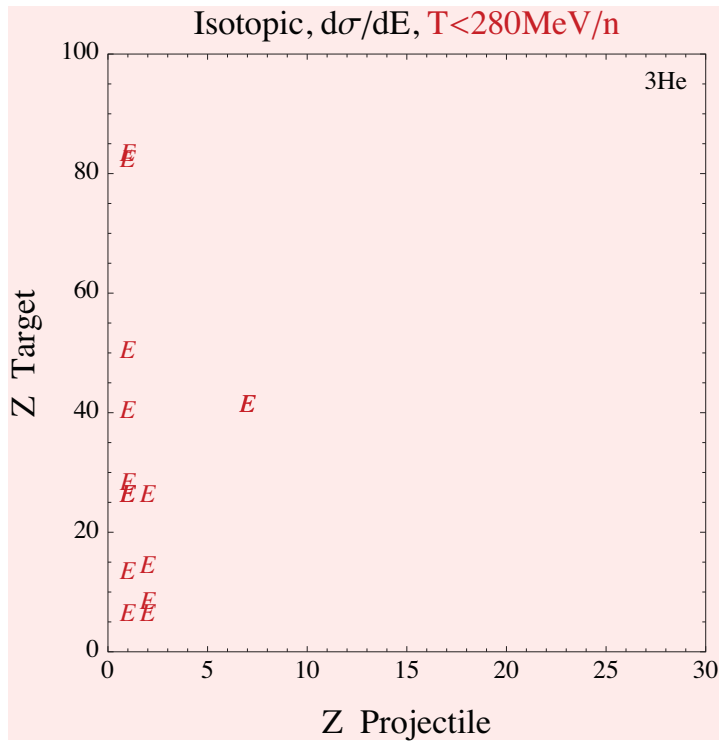


Figure 25: Isotopic energy differential cross sections for ${}^3\text{He}$ fragments.

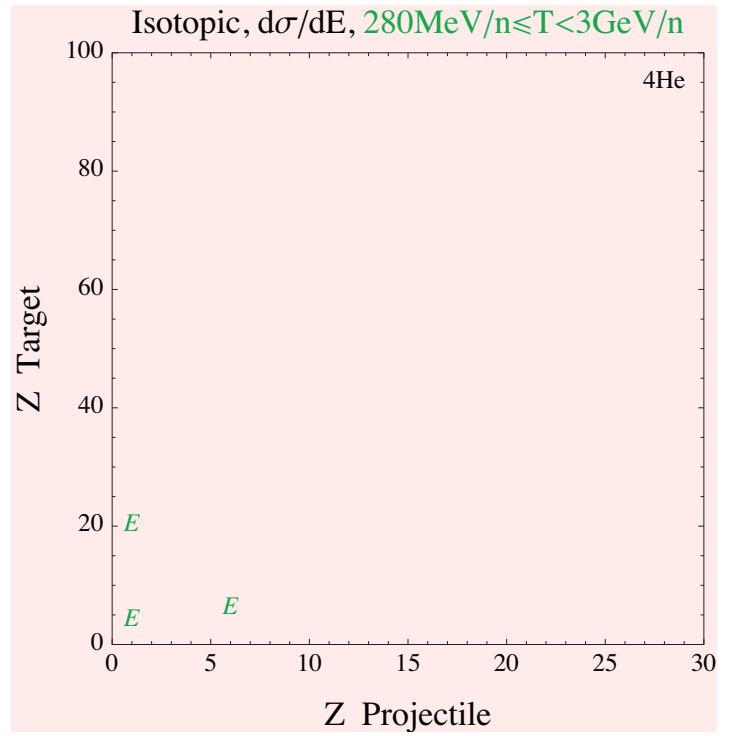
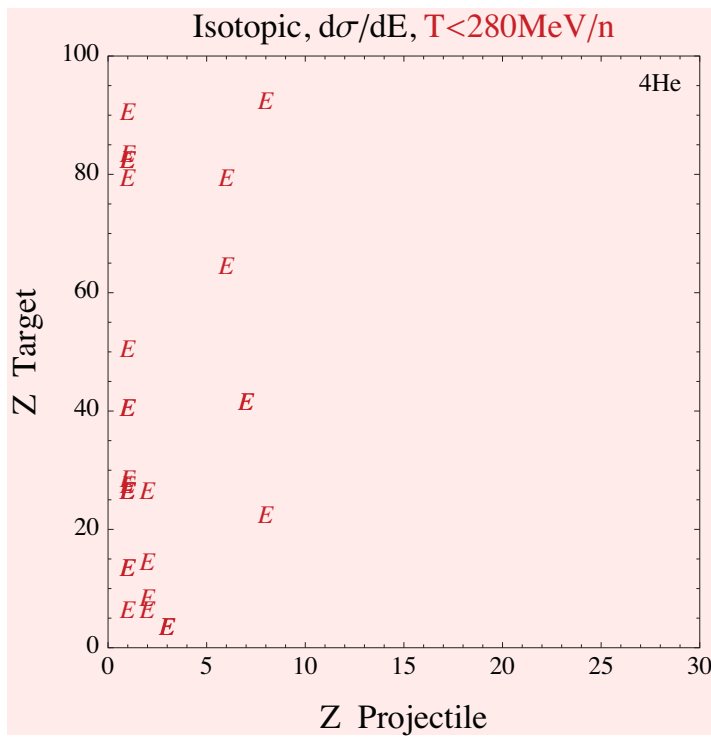


Figure 26: Isotopic energy differential cross sections for ${}^4\text{He}$ fragments.

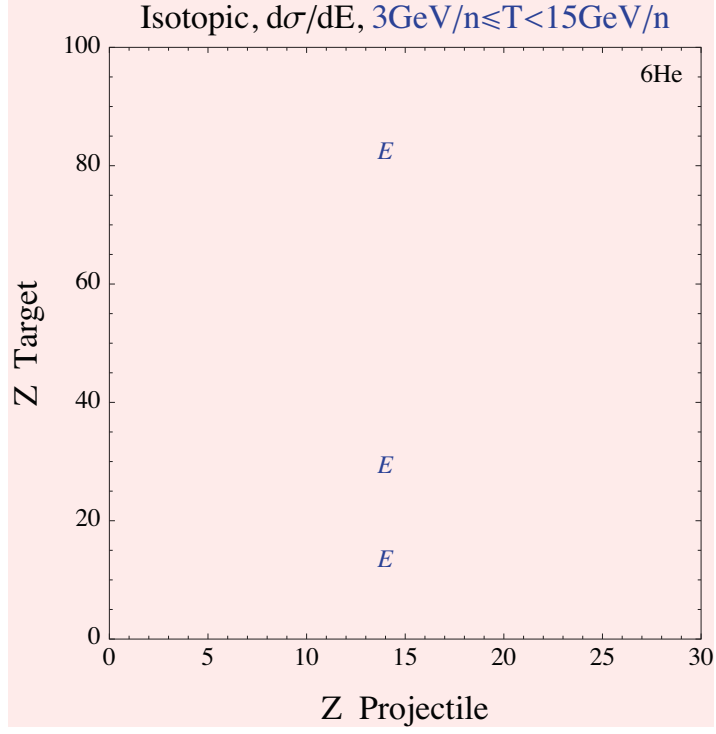


Figure 27: Isotopic energy differential cross sections for ${}^6\text{He}$ fragments.

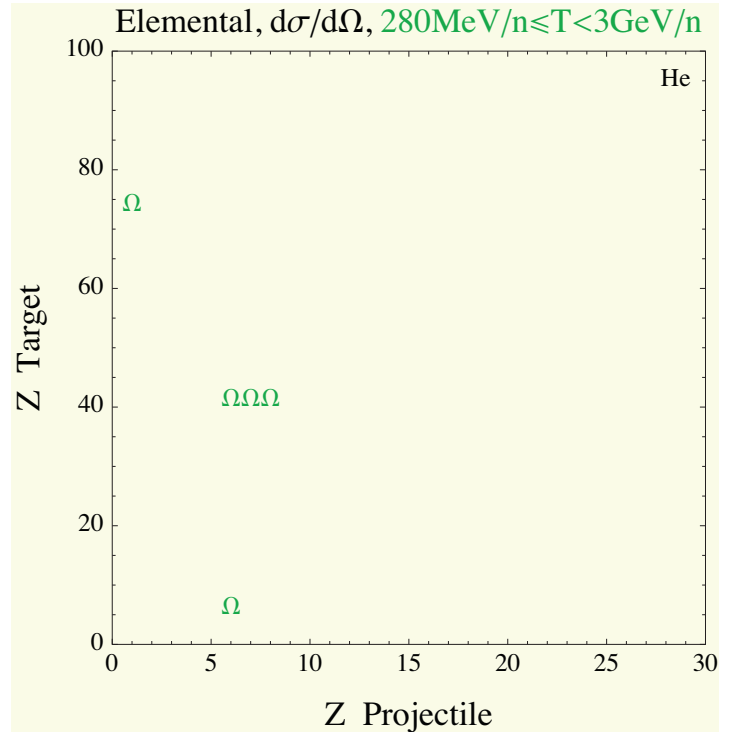
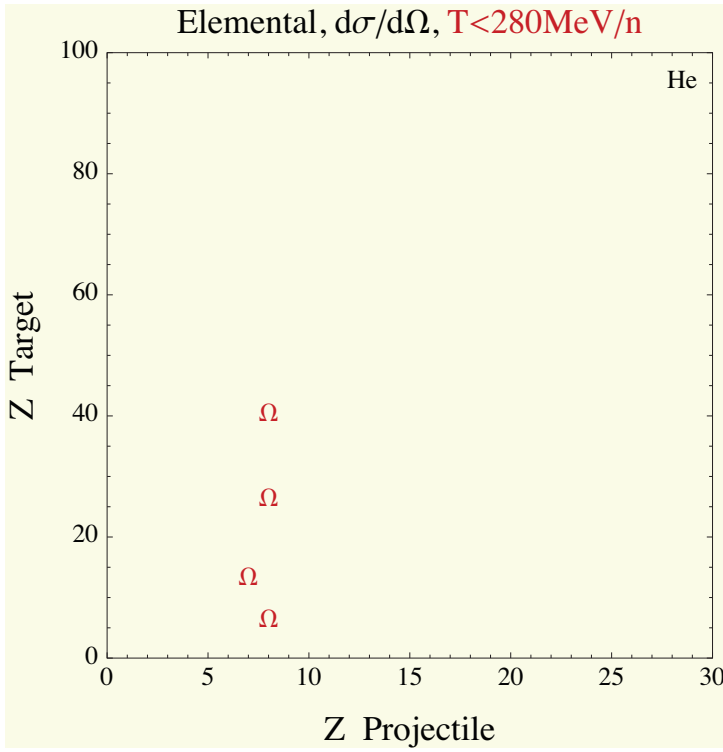


Figure 28: Elemental angular differential cross sections for He fragments.

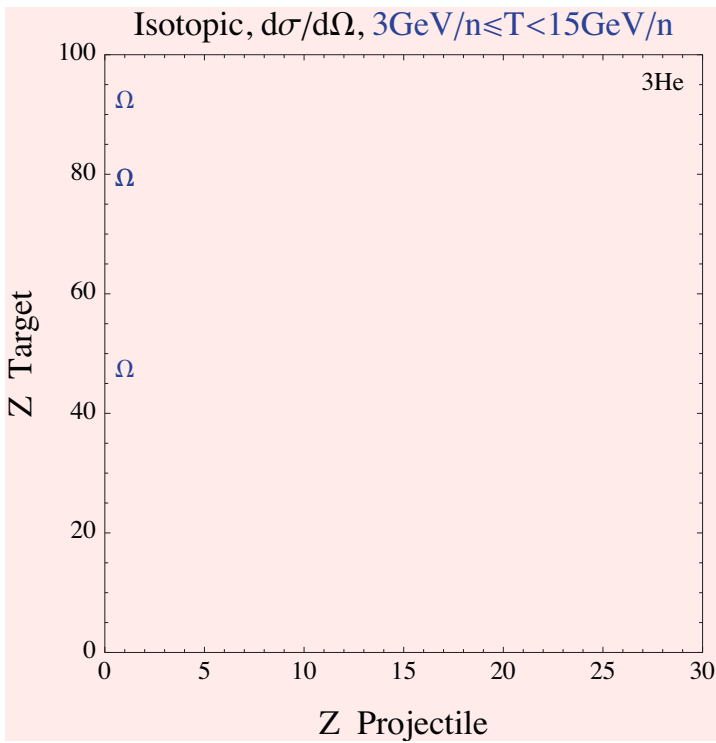
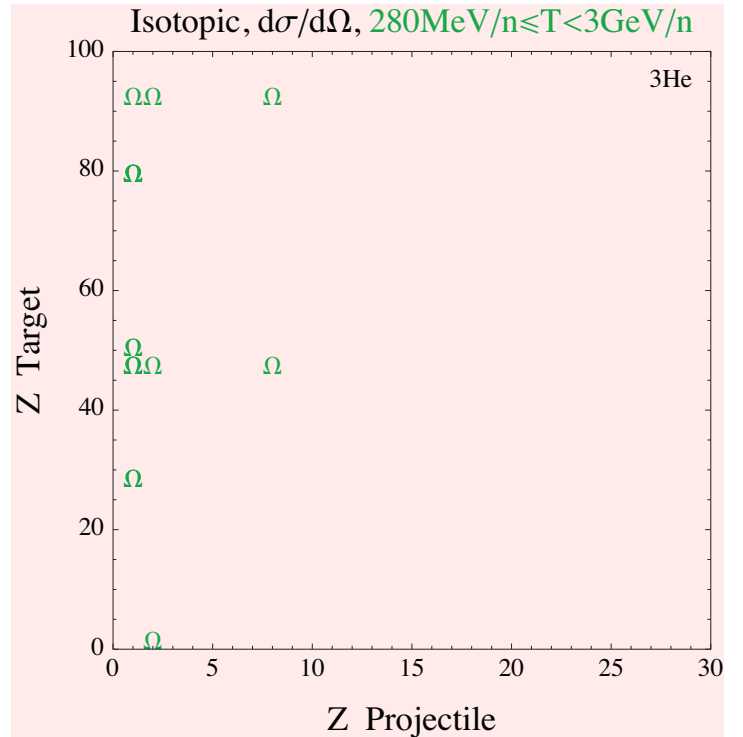
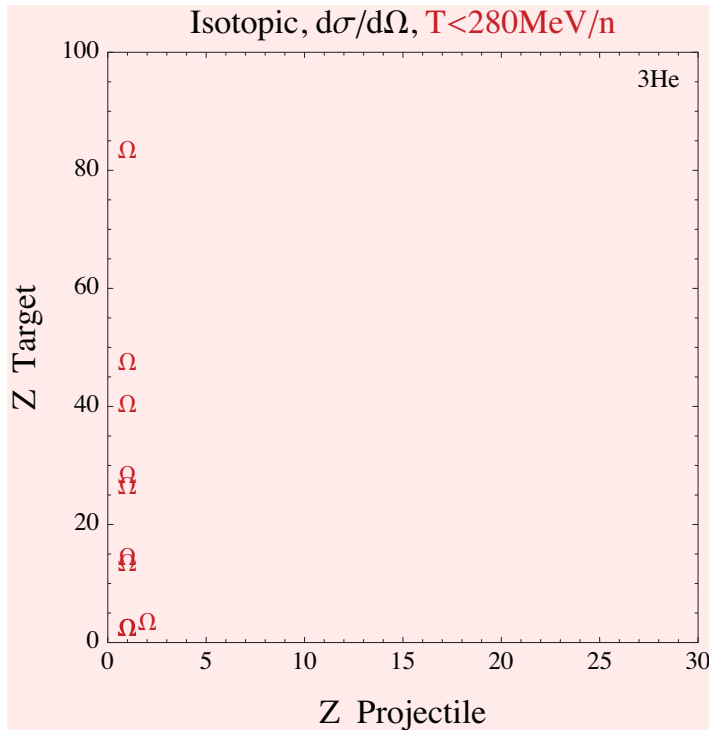


Figure 29: Isotopic angular differential cross sections for ^3He fragments.

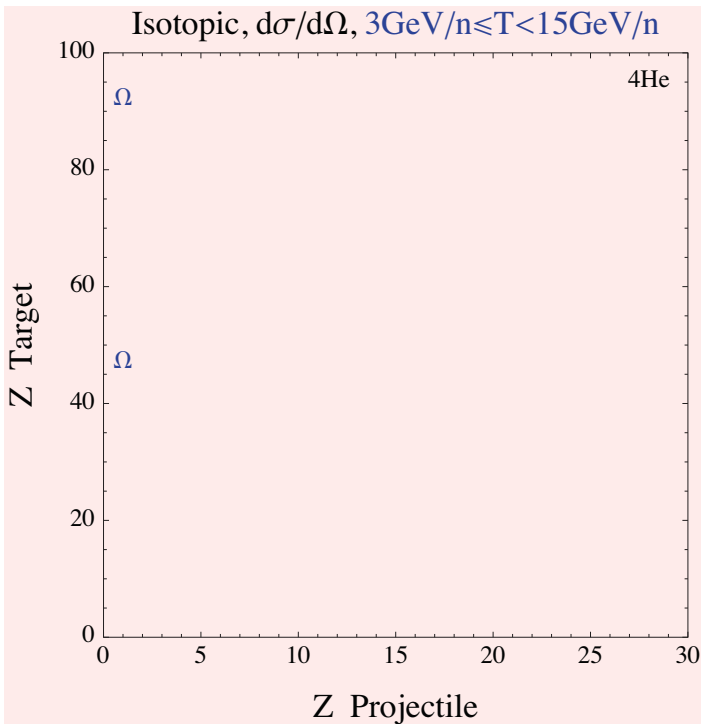
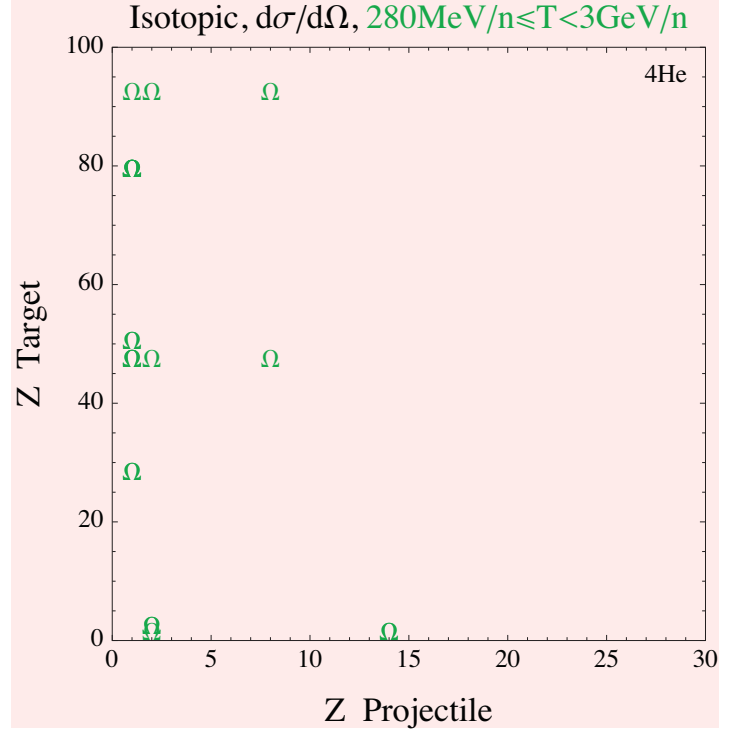
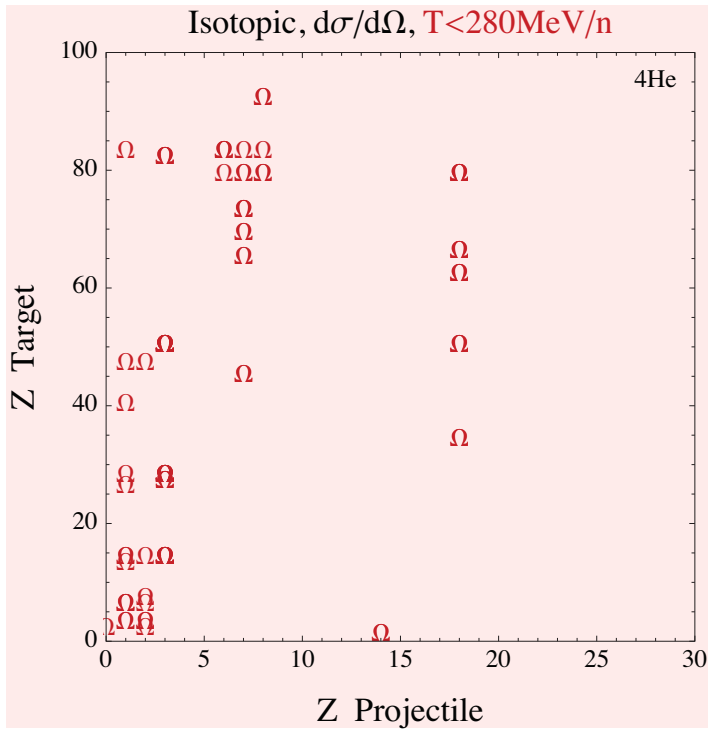


Figure 30: Isotopic angular differential cross sections for ^4He fragments.

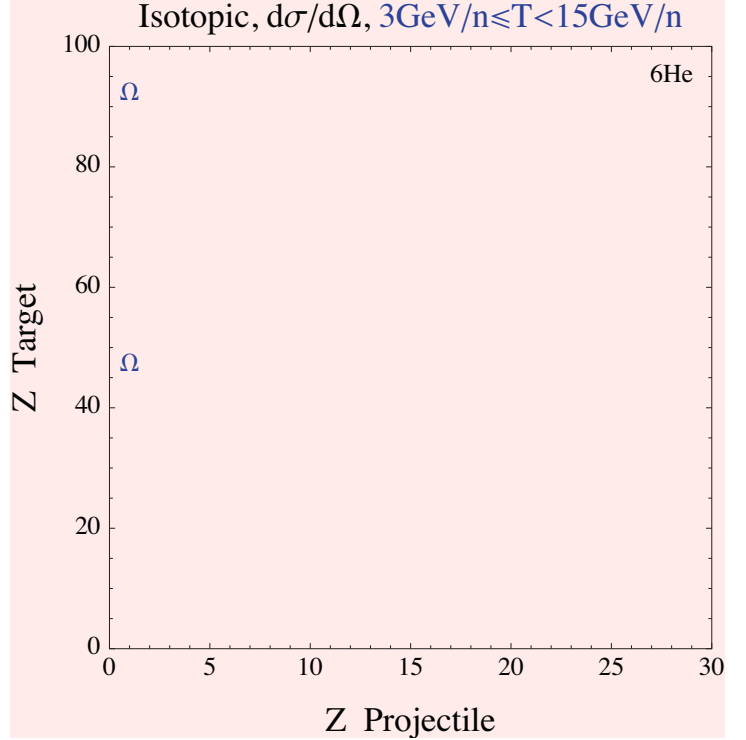
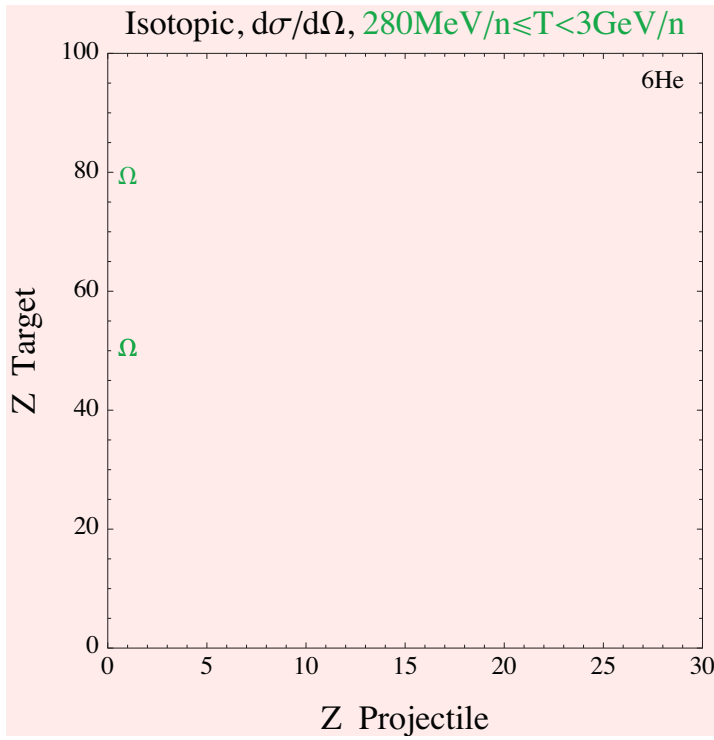


Figure 31: Isotopic angular differential cross sections for ${}^6\text{He}$ fragments.

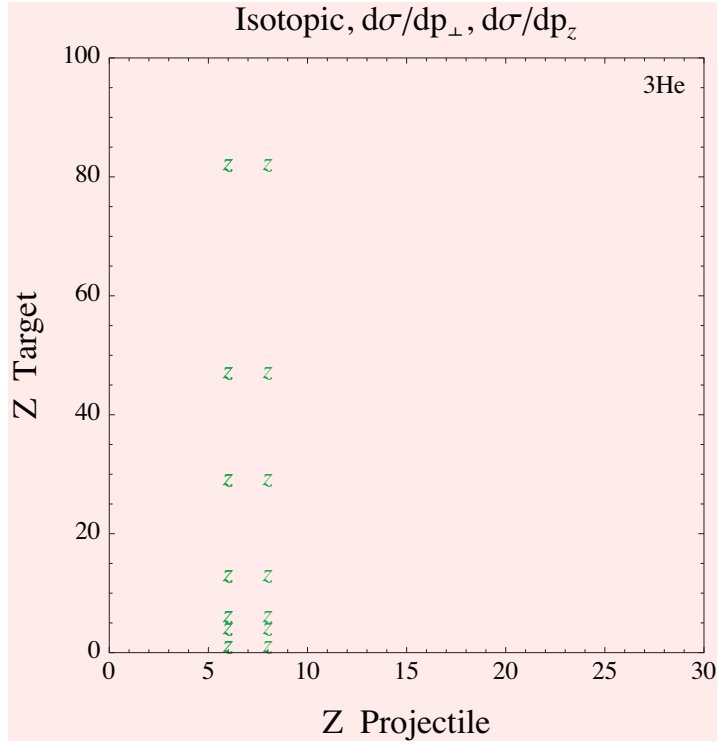


Figure 32: Isotopic momentum differential cross sections for ^3He fragments covering all energies.

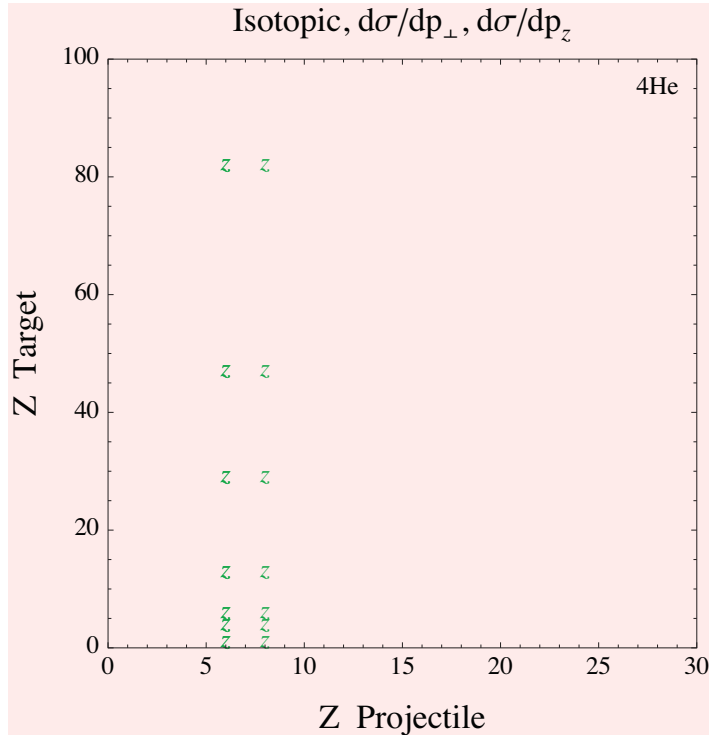


Figure 33: Isotopic momentum differential cross sections for ^4He fragments covering all energies.

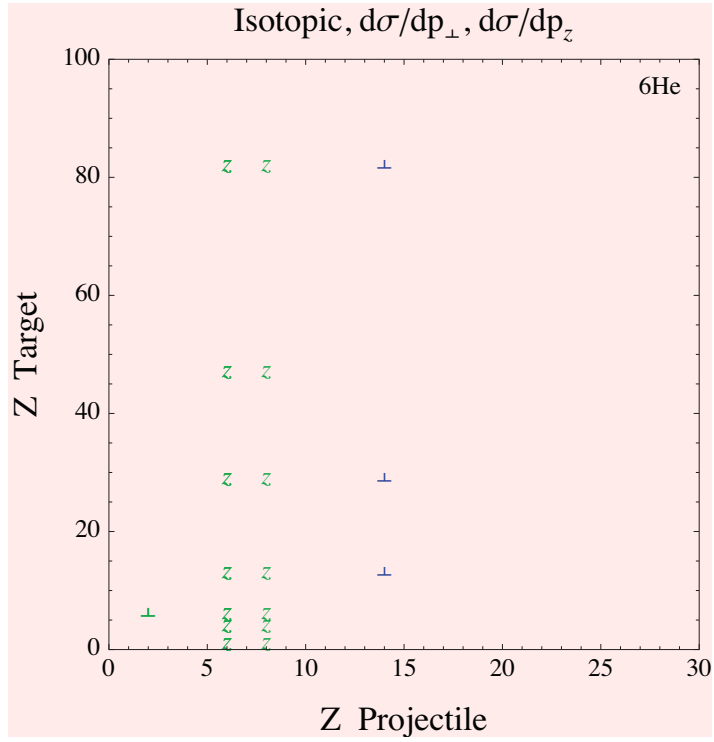


Figure 34: Isotopic momentum differential cross sections for ${}^6\text{He}$ fragments covering all energies.

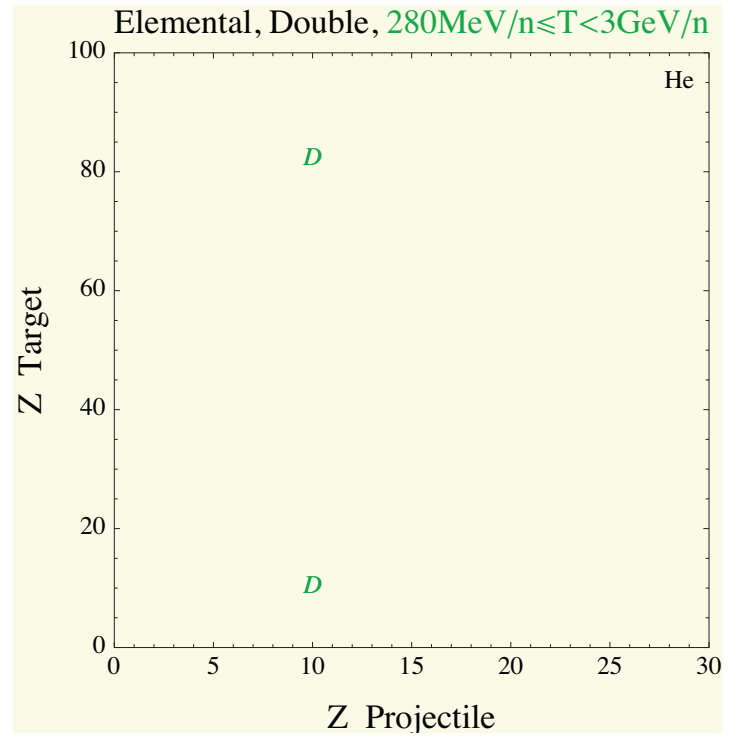
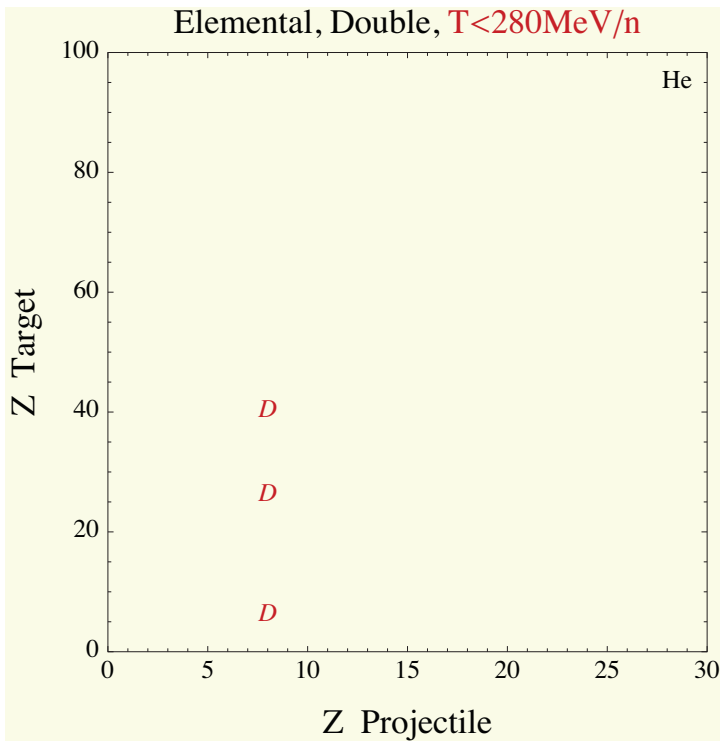


Figure 35: Elemental double differential cross sections for He fragments.

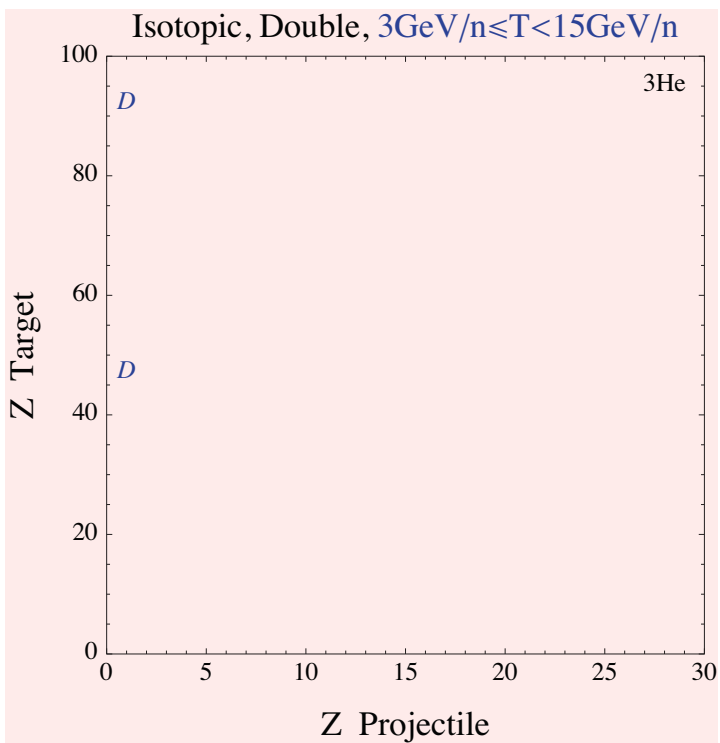
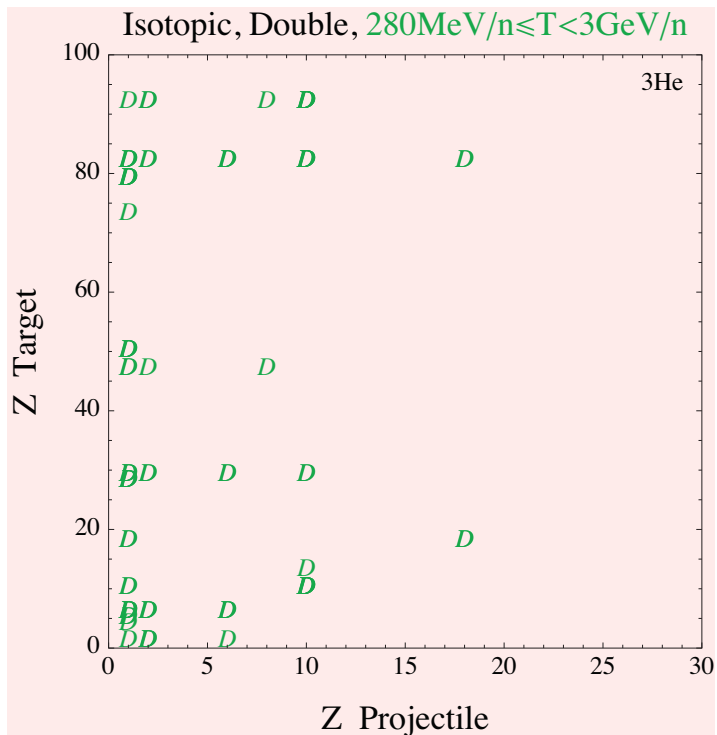
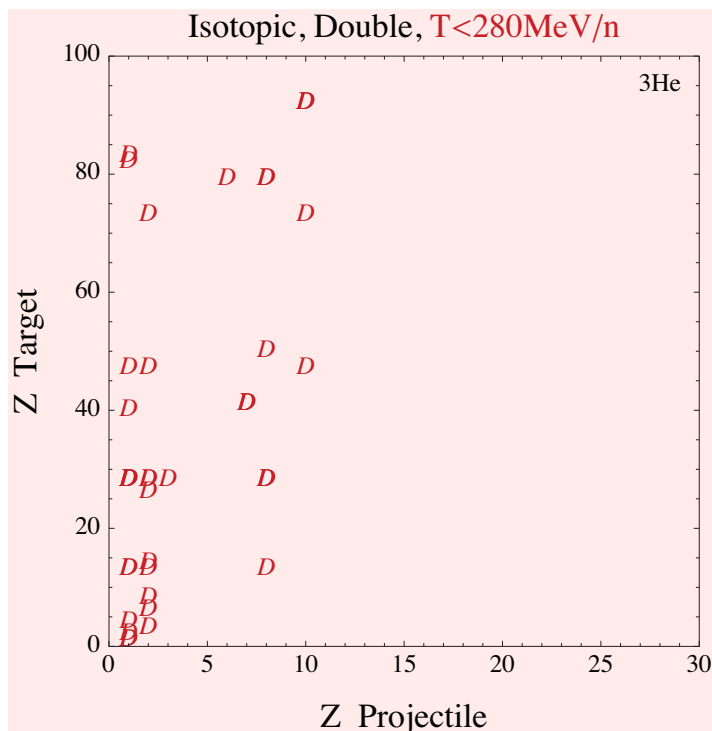


Figure 36: Isotopic double differential cross sections for ^3He fragments.

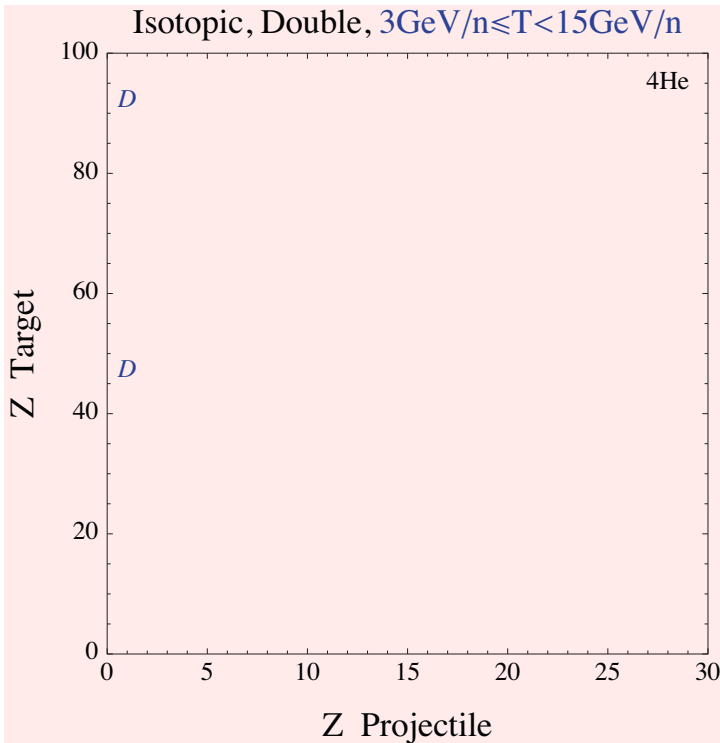
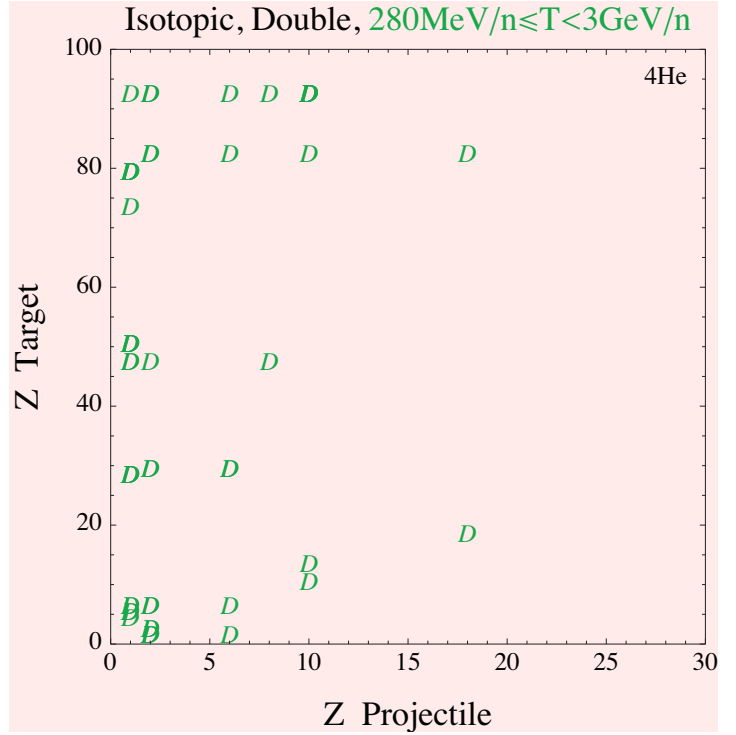
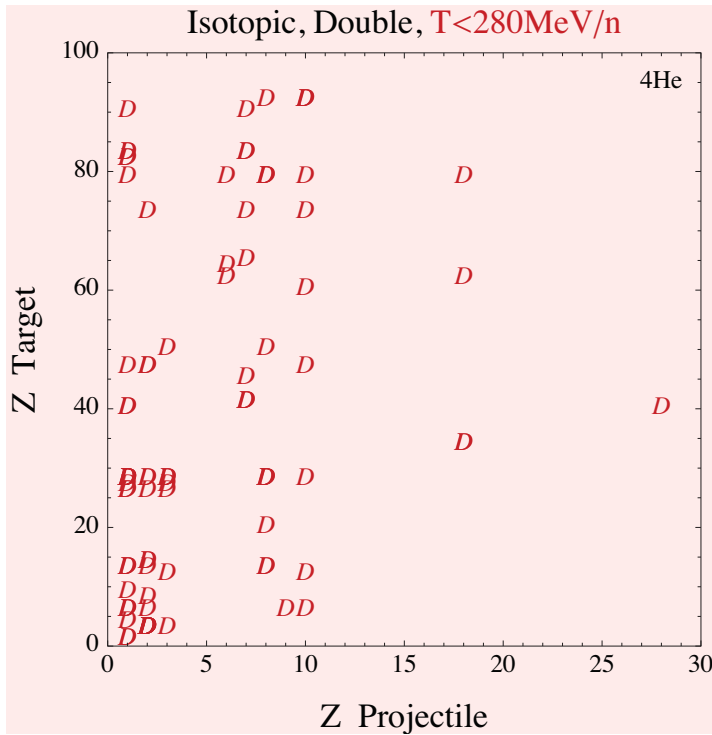


Figure 37: Isotopic double differential cross sections for ${}^4\text{He}$ fragments.

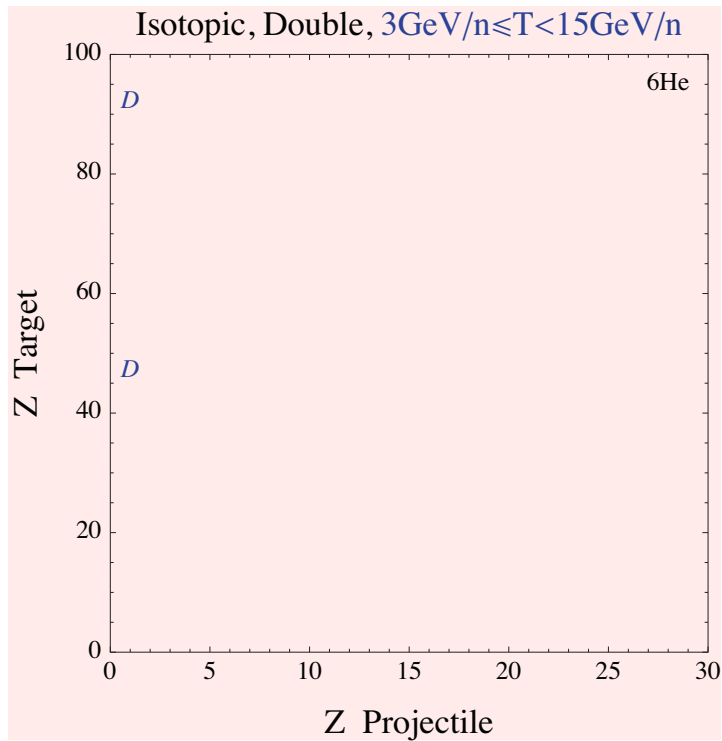
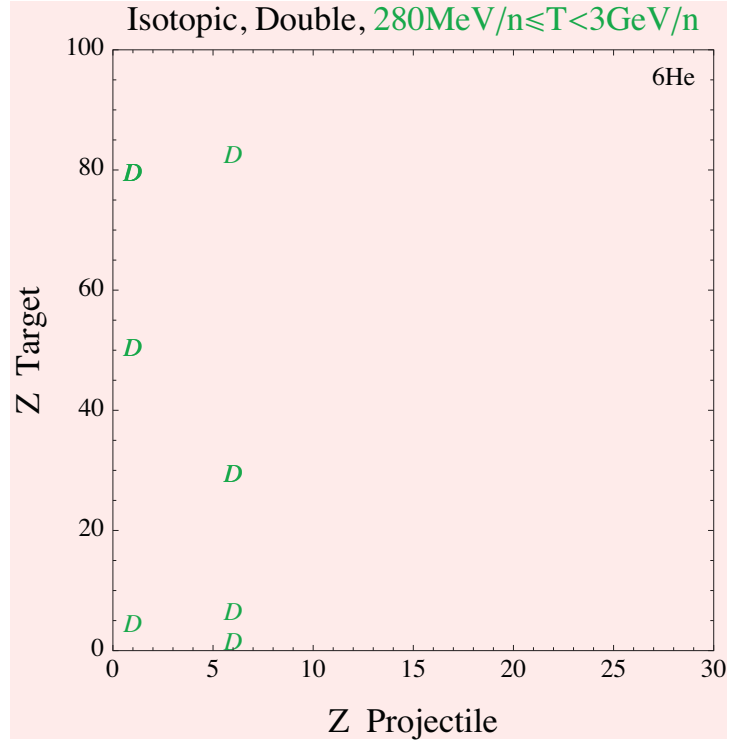
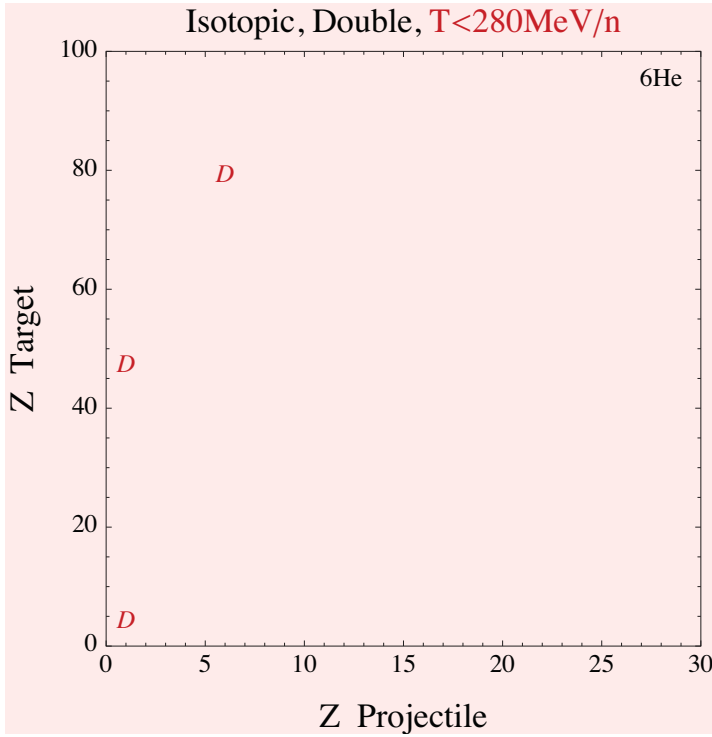


Figure 38: Isotopic double differential cross sections for ${}^6\text{He}$ fragments.

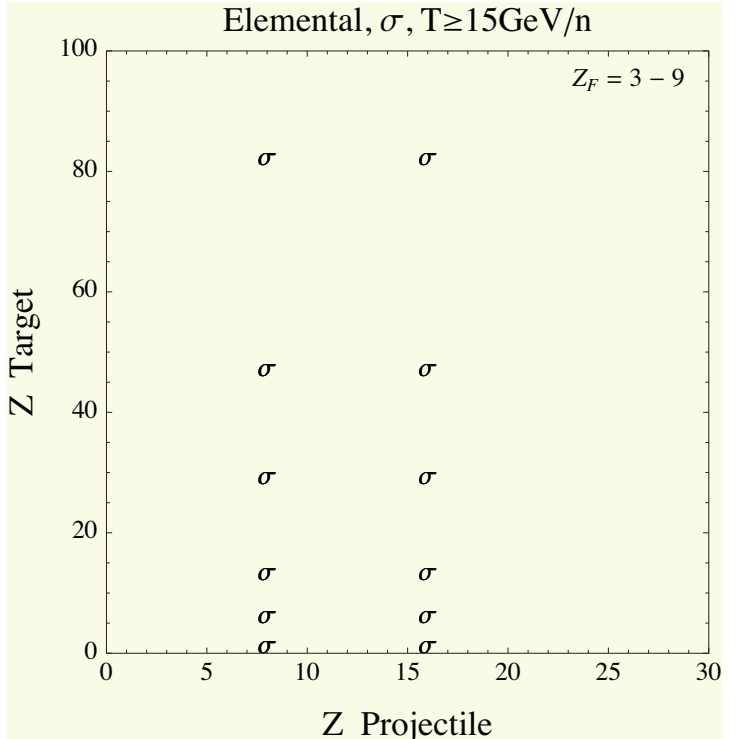
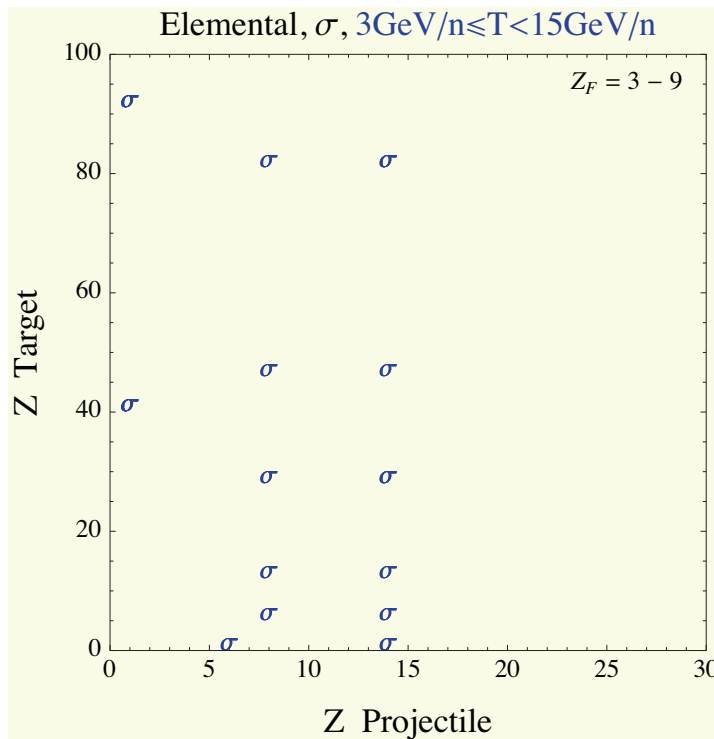
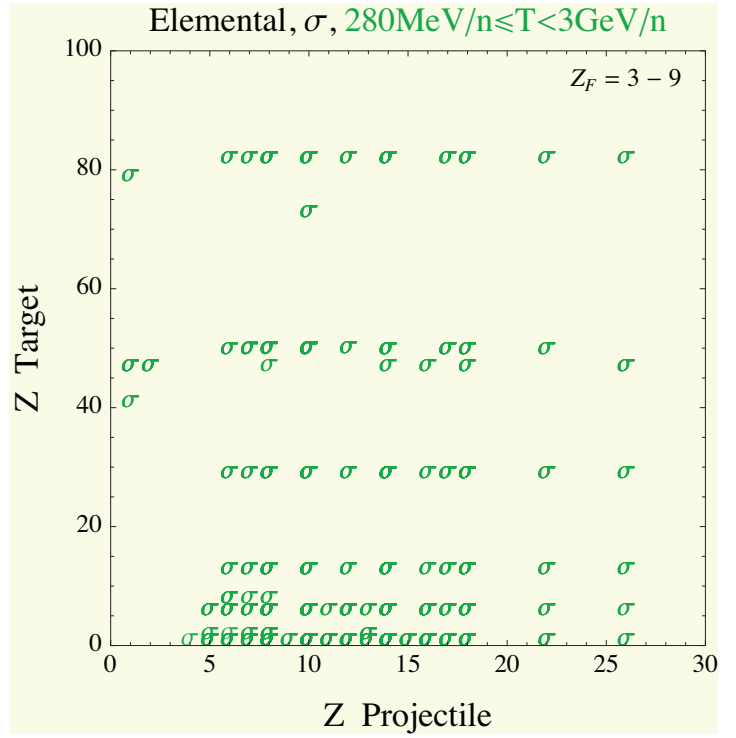
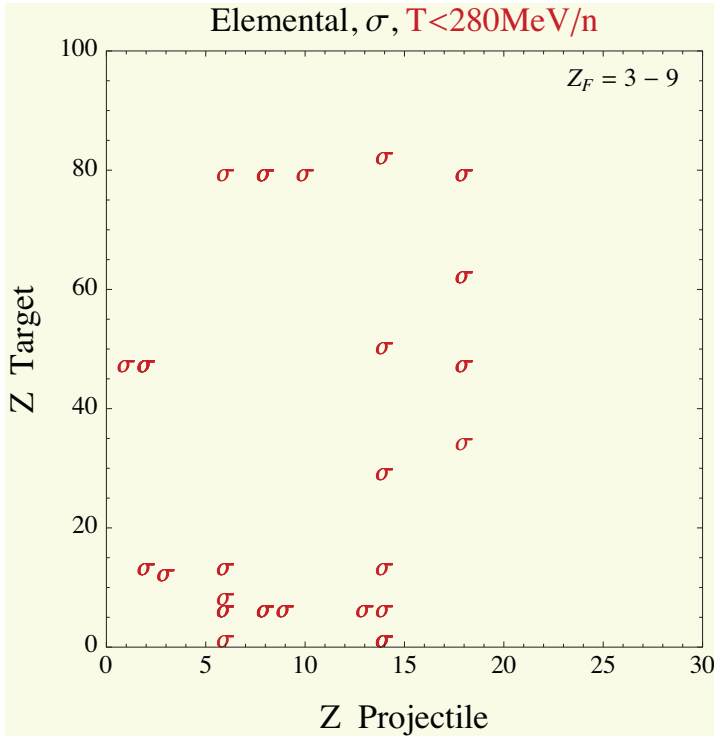


Figure 39: Elemental total cross sections for $Z = 3 - 9$ fragments.

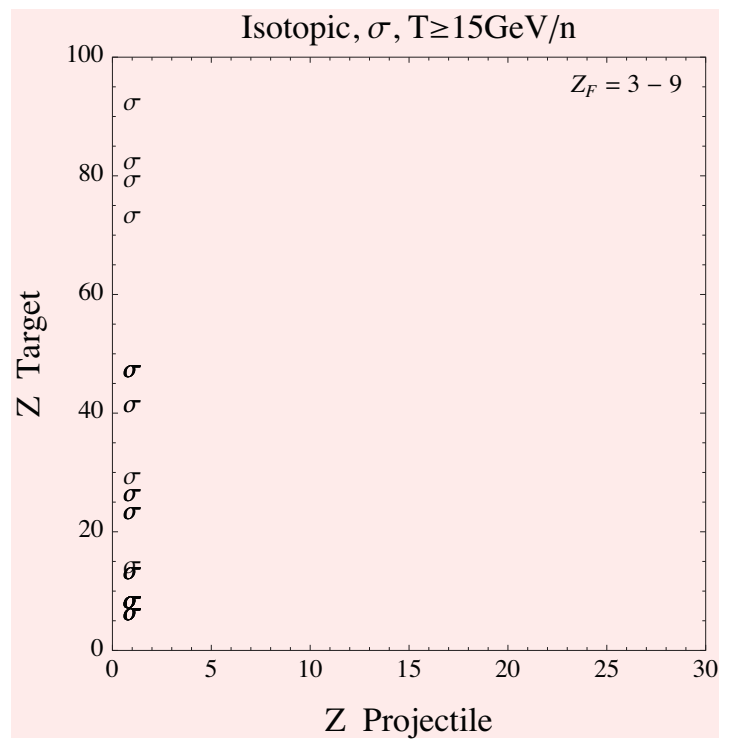
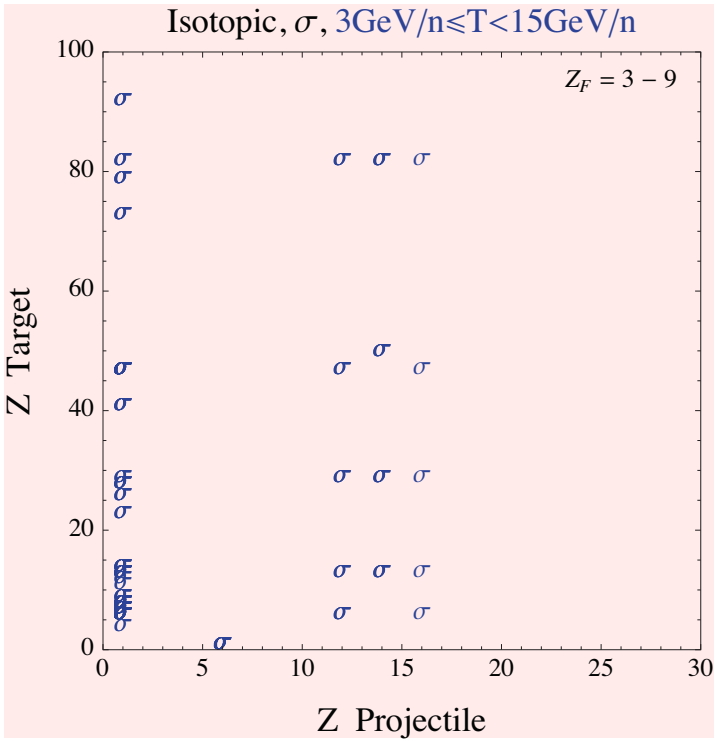
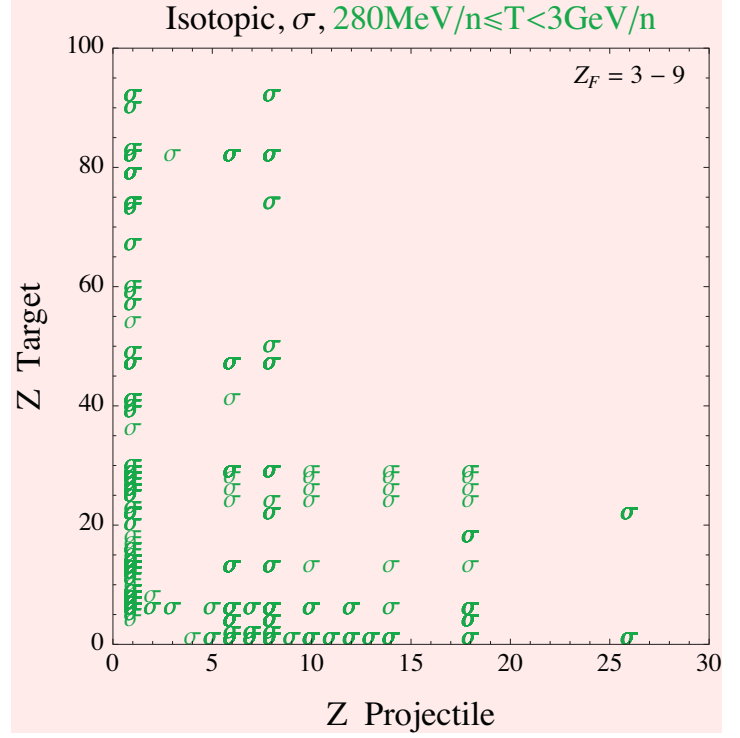
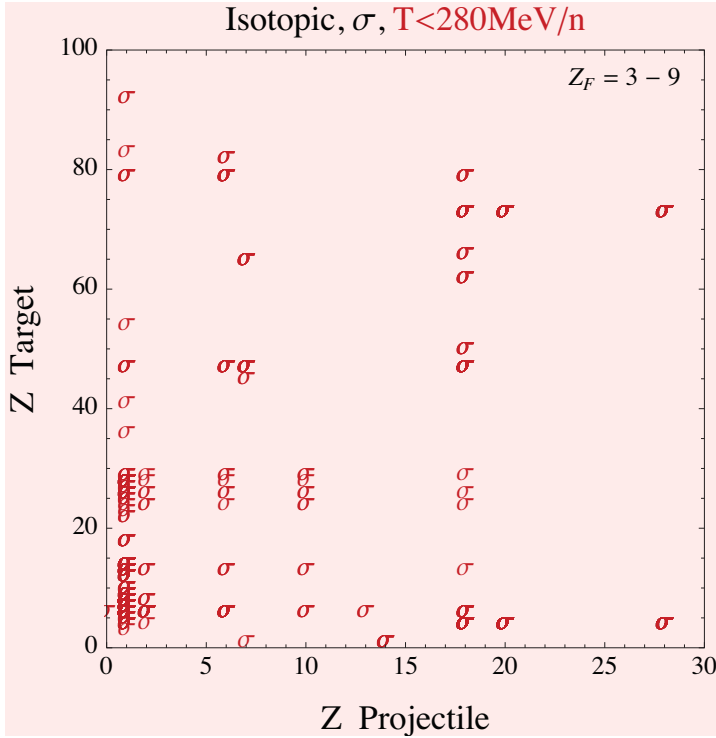


Figure 40: Isotopic total cross sections for $Z = 3 - 9$ fragments.

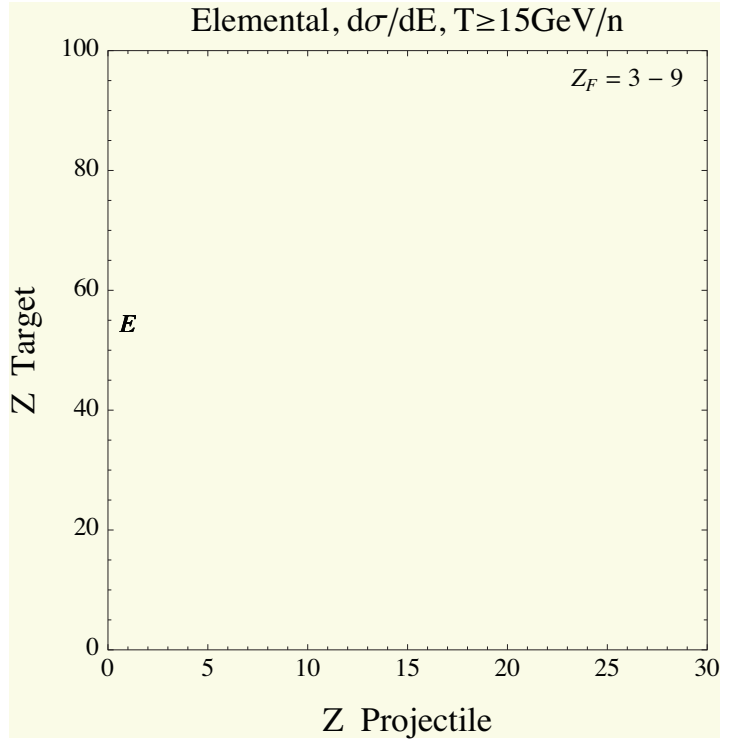
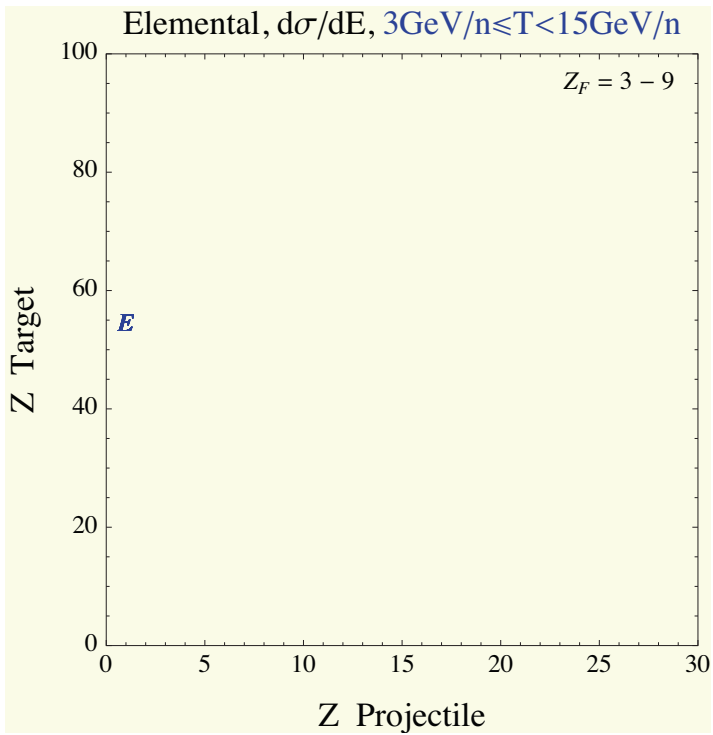
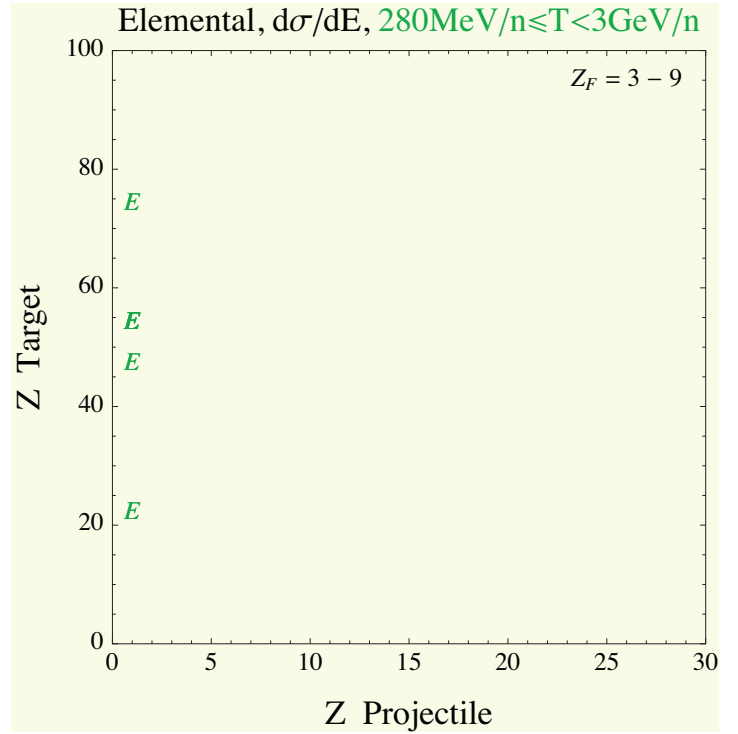
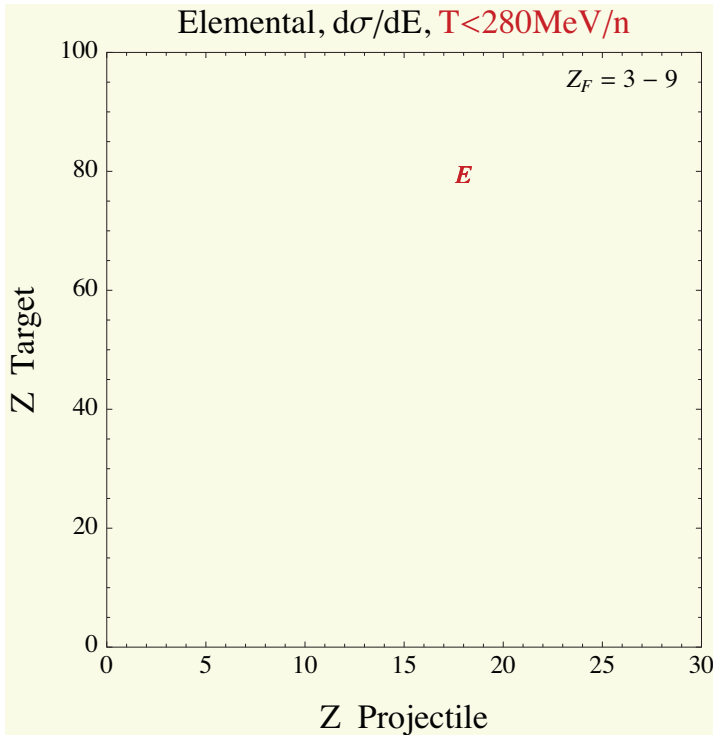


Figure 41: Elemental energy differential cross sections for $Z = 3 - 9$ fragments.

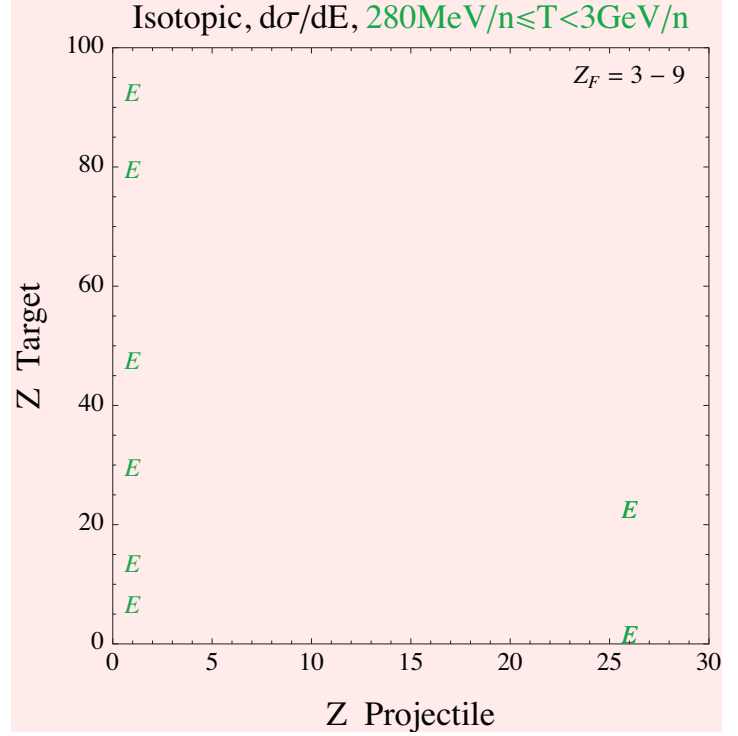
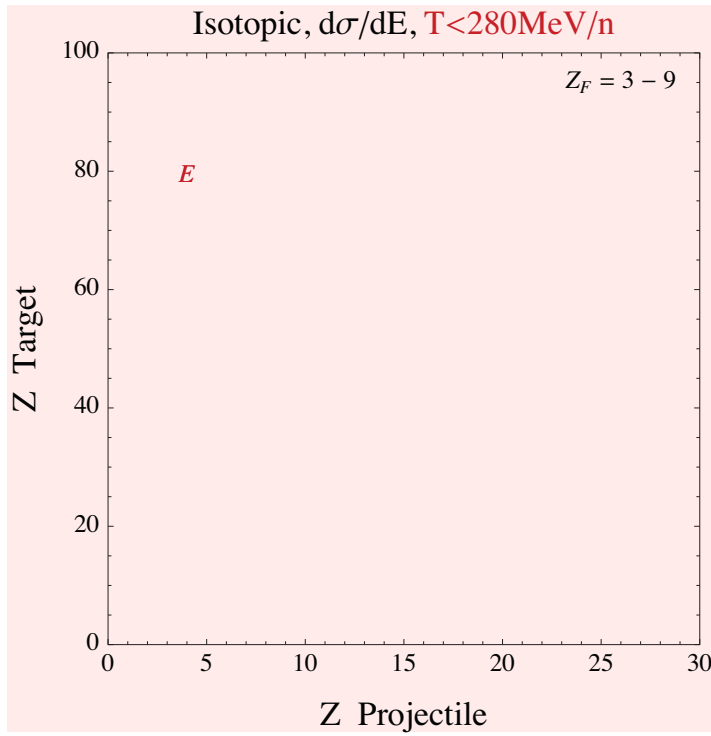


Figure 42: Isotopic energy differential cross sections for $Z = 3 - 9$ fragments.

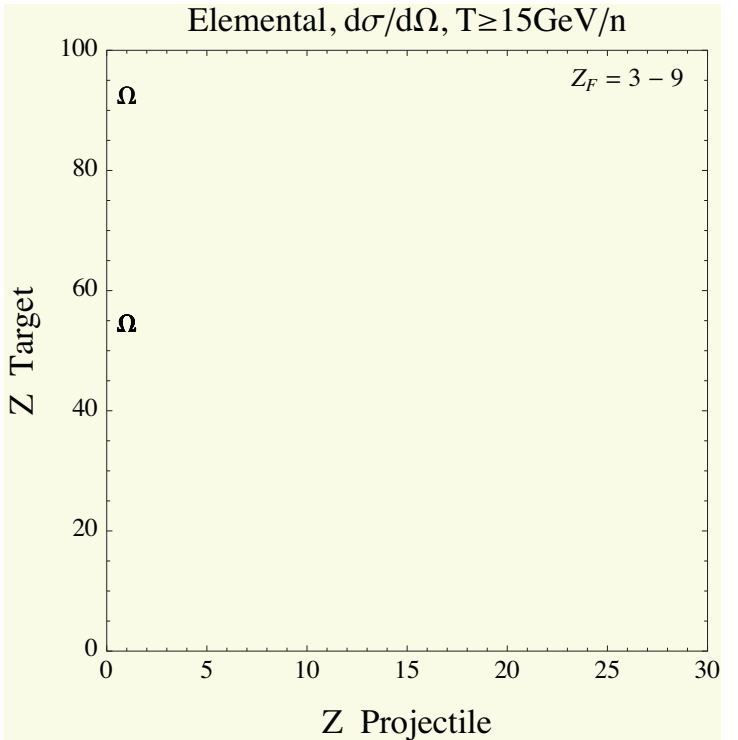
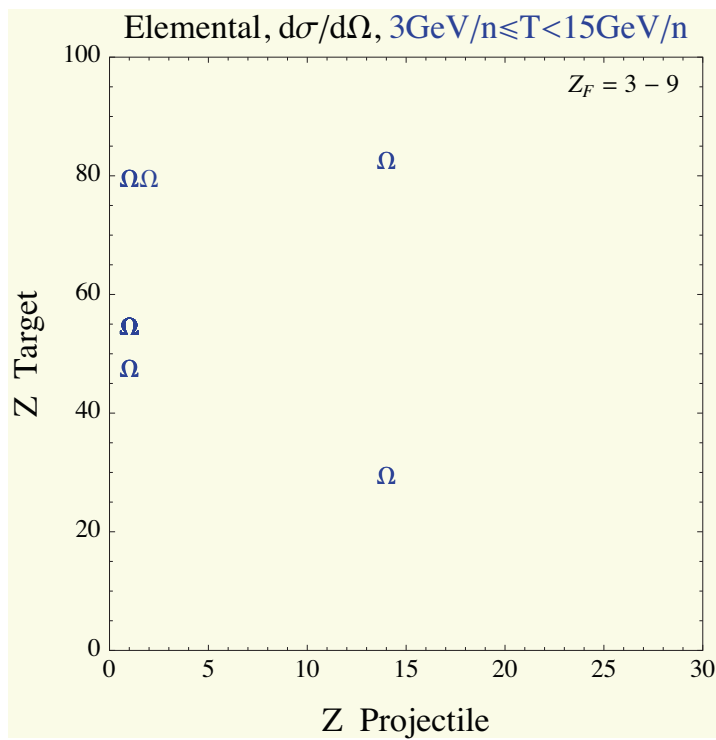
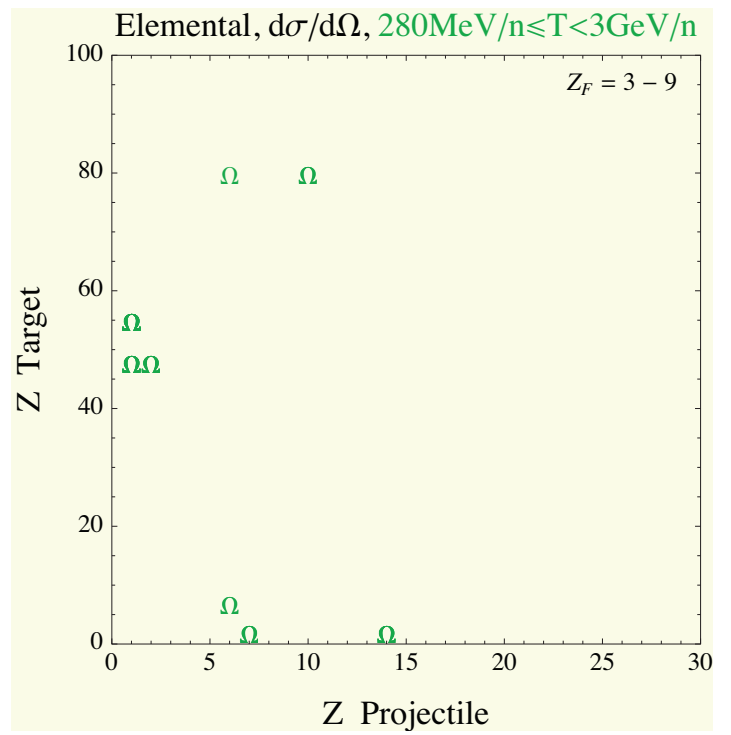
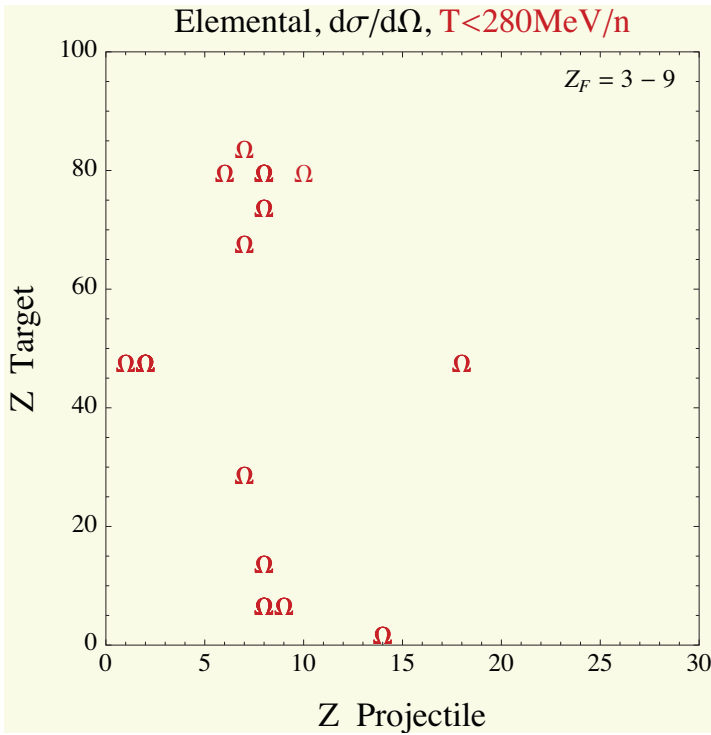


Figure 43: Elemental angular differential cross sections for $Z = 3 - 9$ fragments.

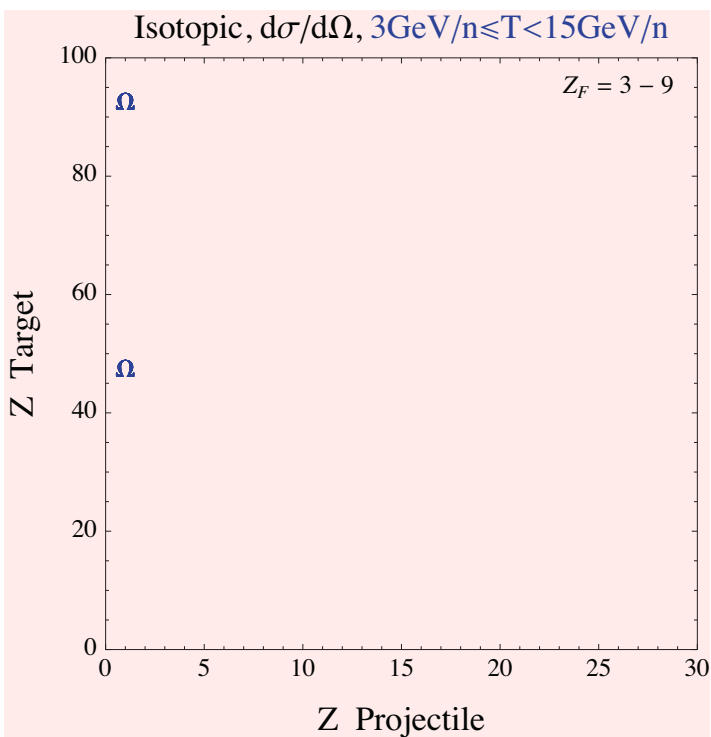
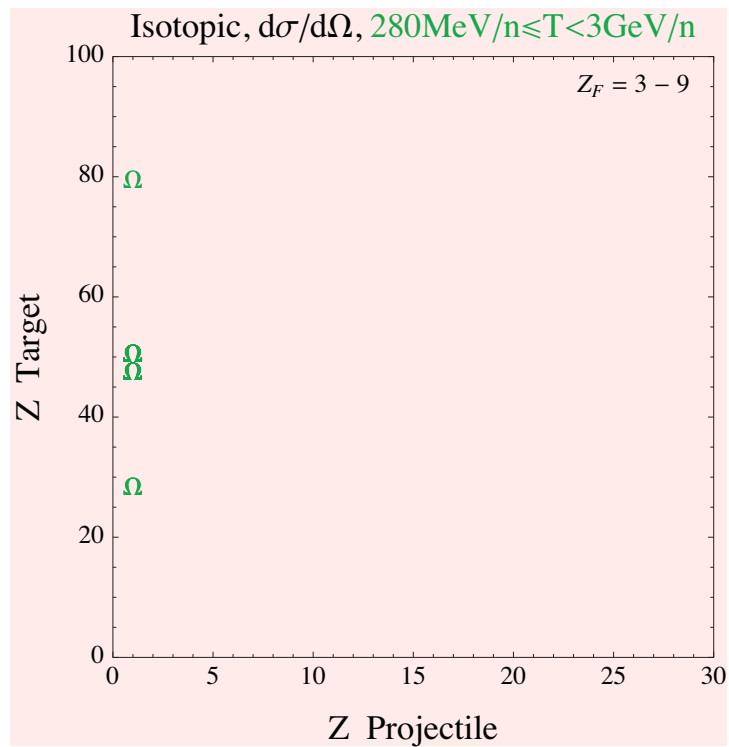
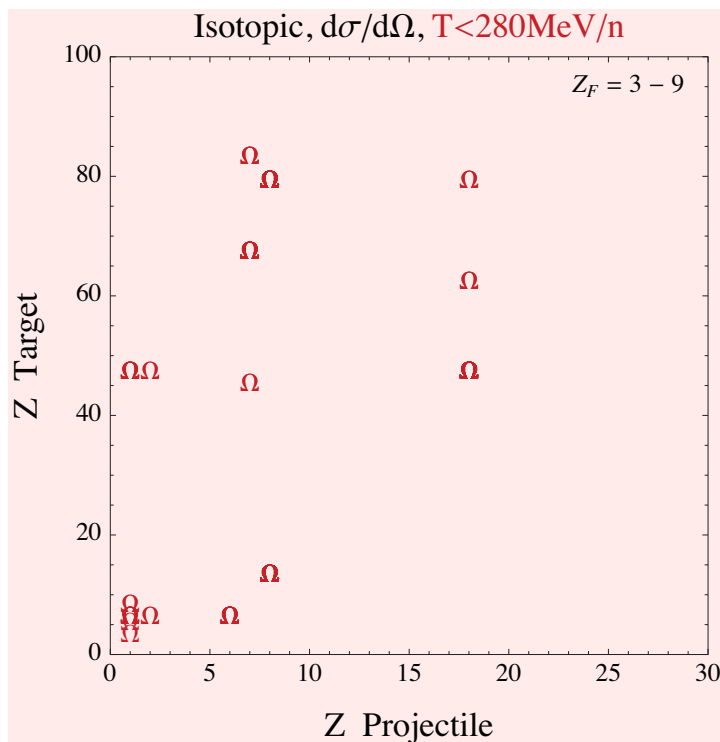


Figure 44: Isotopic angular differential cross sections for $Z = 3 - 9$ fragments.

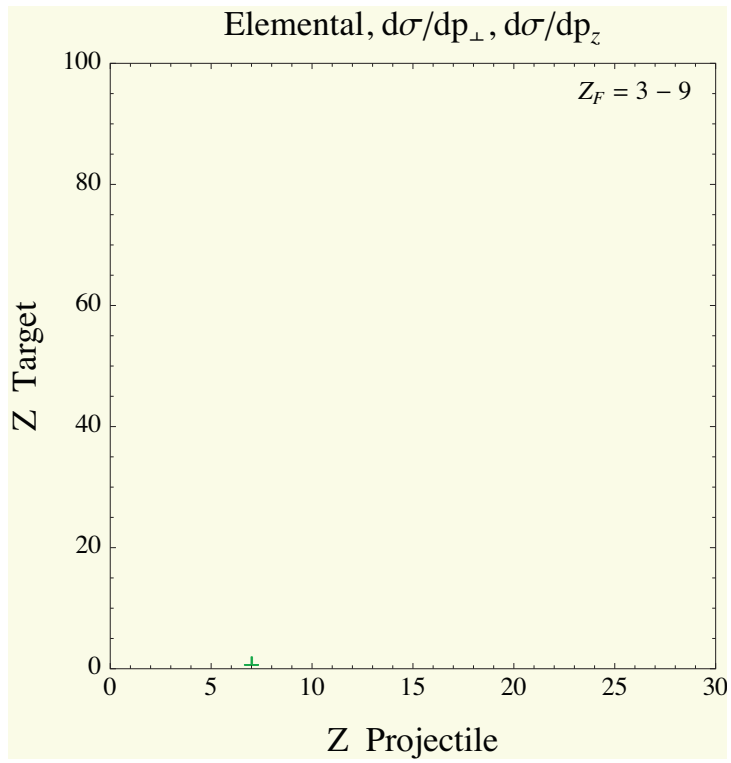


Figure 45: Elemental momentum differential cross sections for $Z = 3 - 9$ fragments covering all energies.

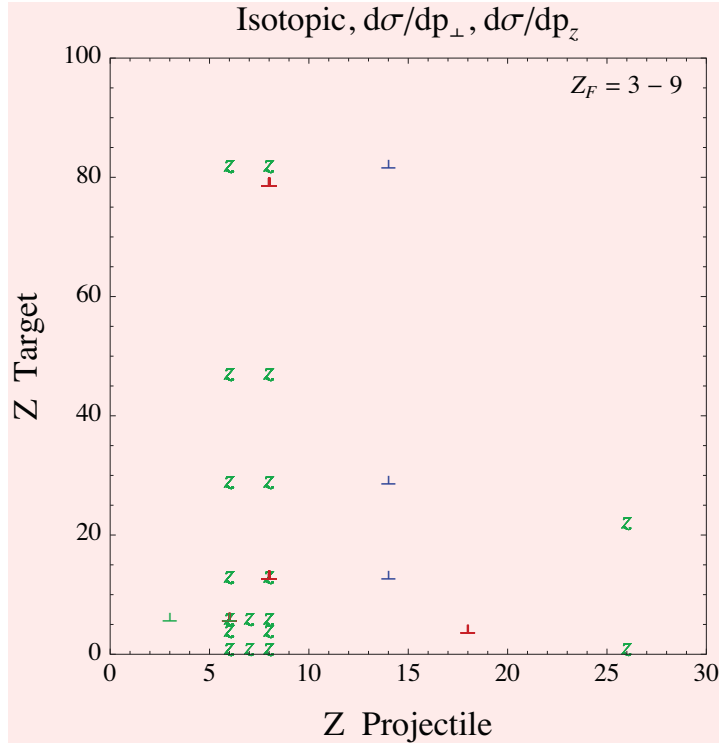


Figure 46: Isotopic momentum differential cross sections for $Z = 3 - 9$ fragments covering all energies.

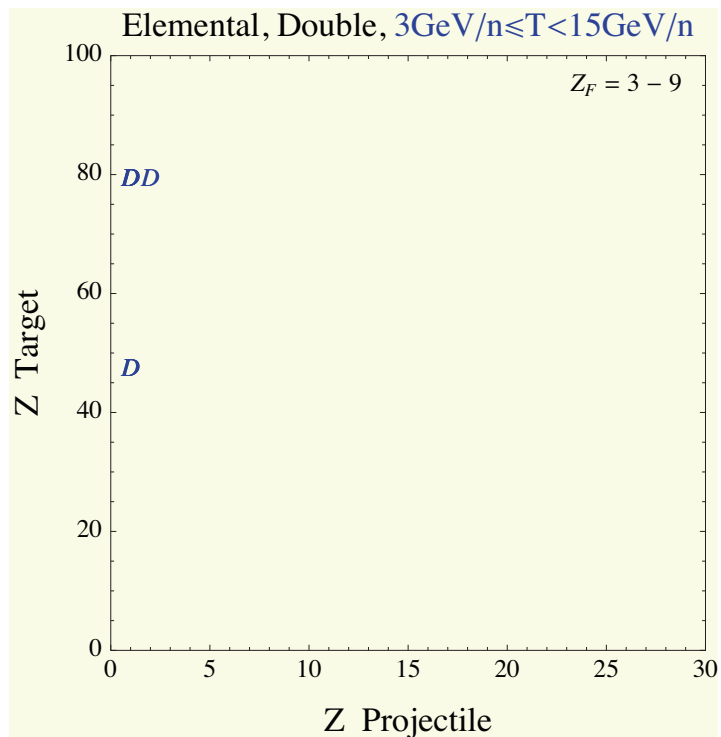
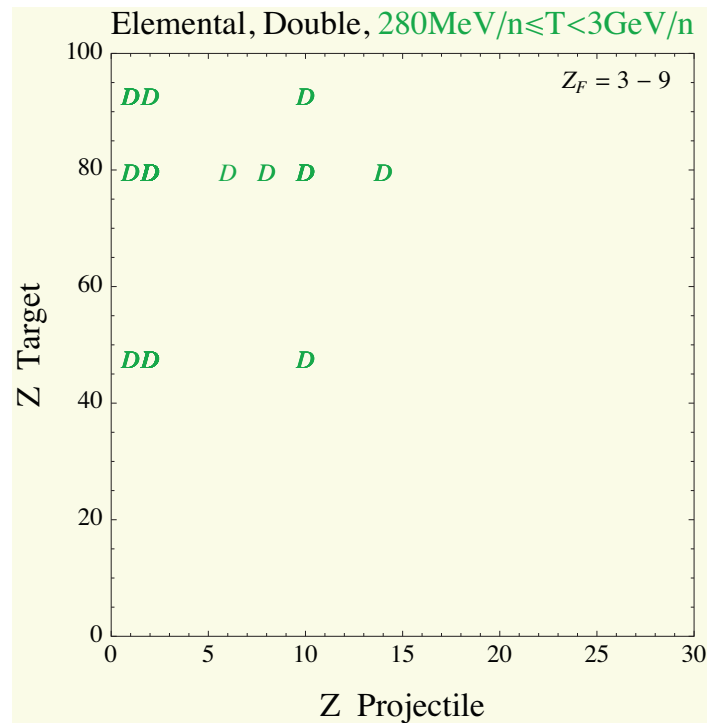
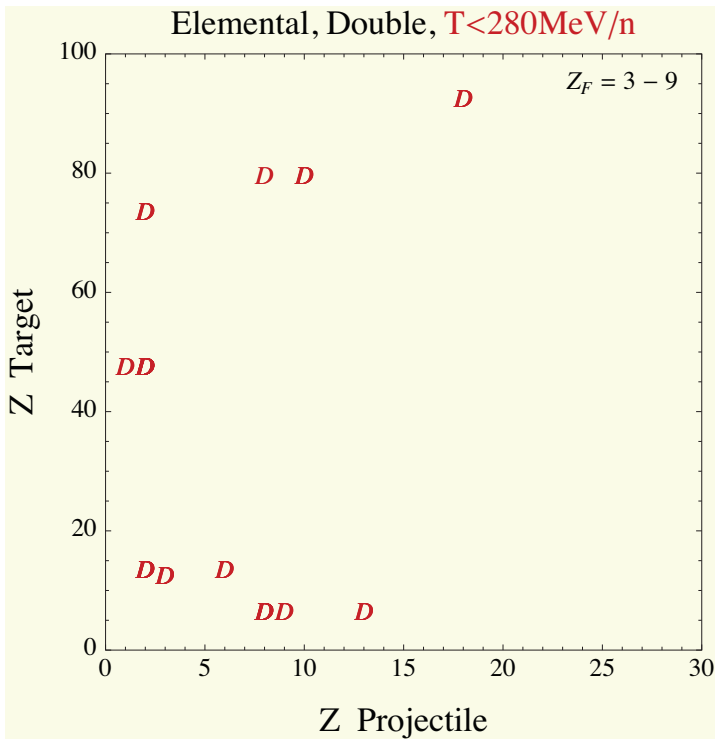


Figure 47: Elemental double differential cross sections for $Z = 3 - 9$ fragments.

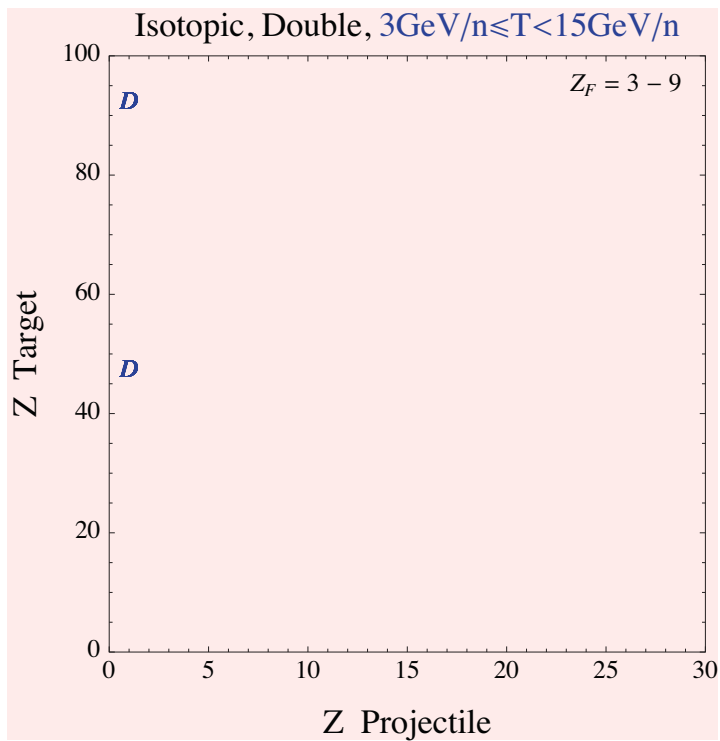
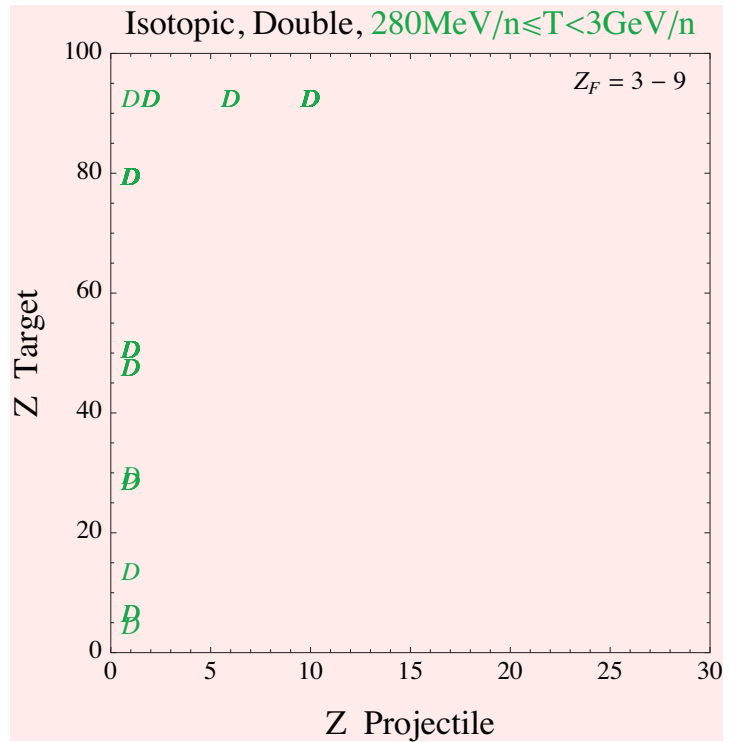
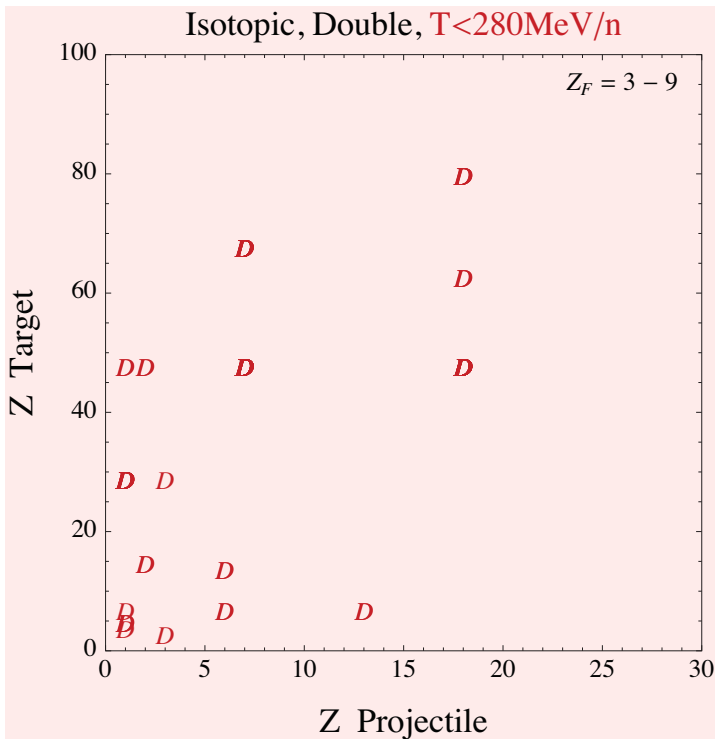


Figure 48: Isotopic double differential cross sections for $Z = 3 - 9$ fragments.

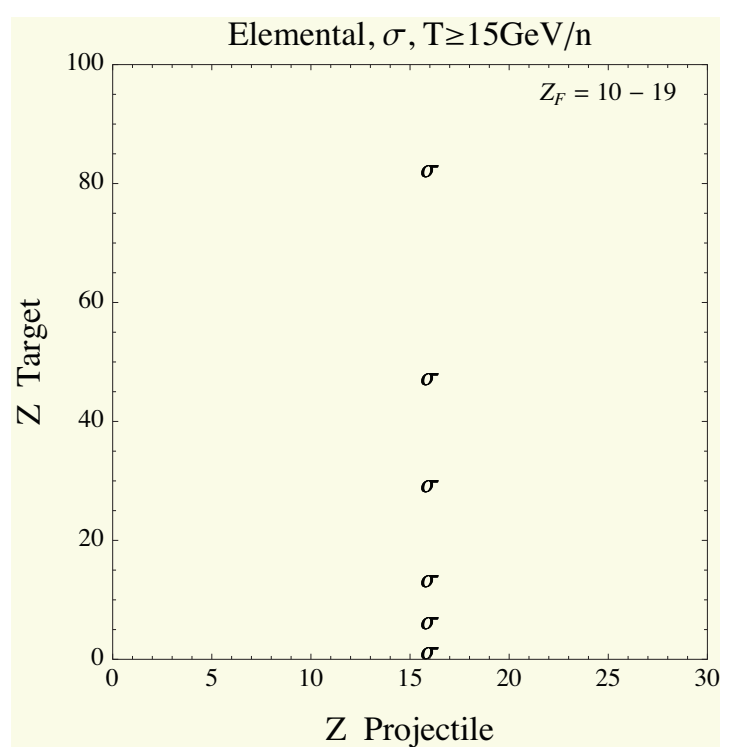
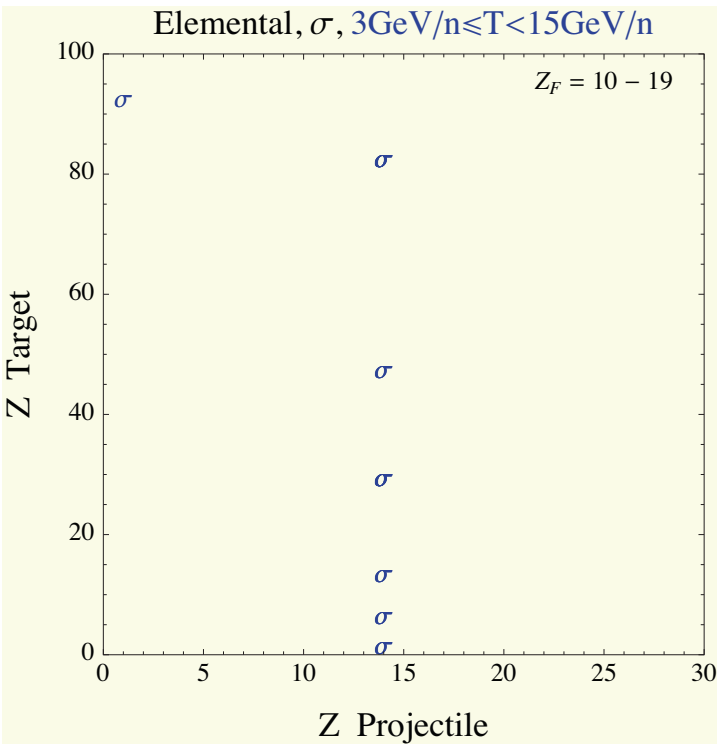
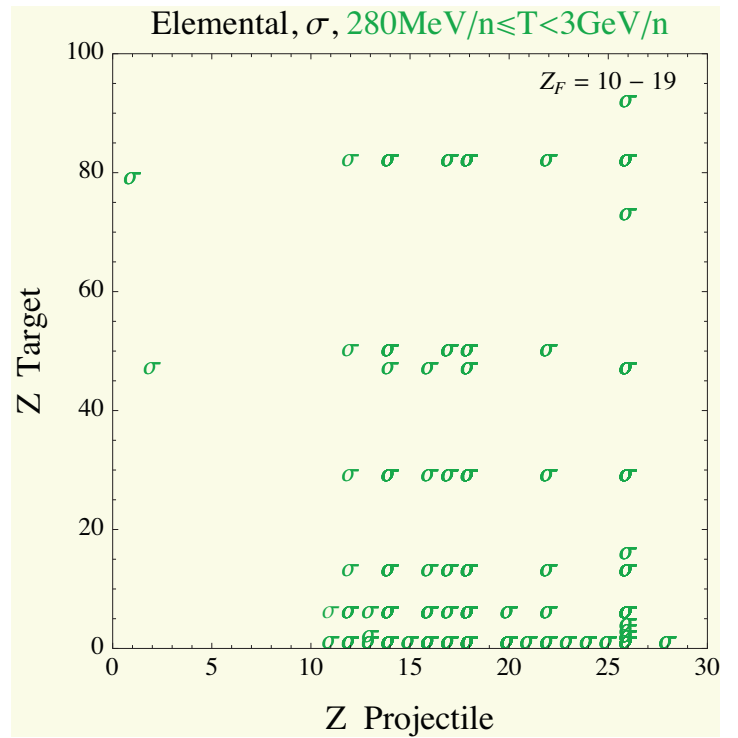
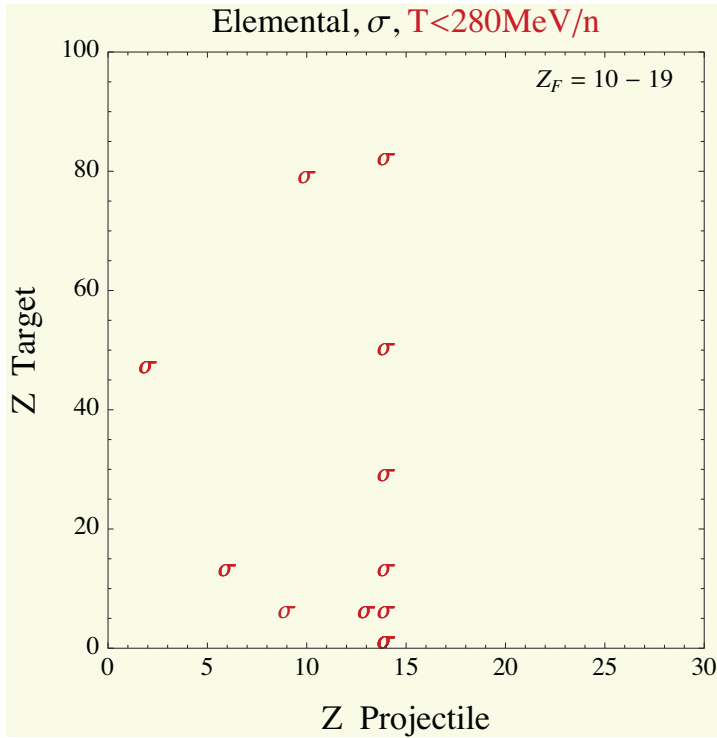


Figure 49: Elemental total cross sections for $Z = 10 - 19$ fragments.

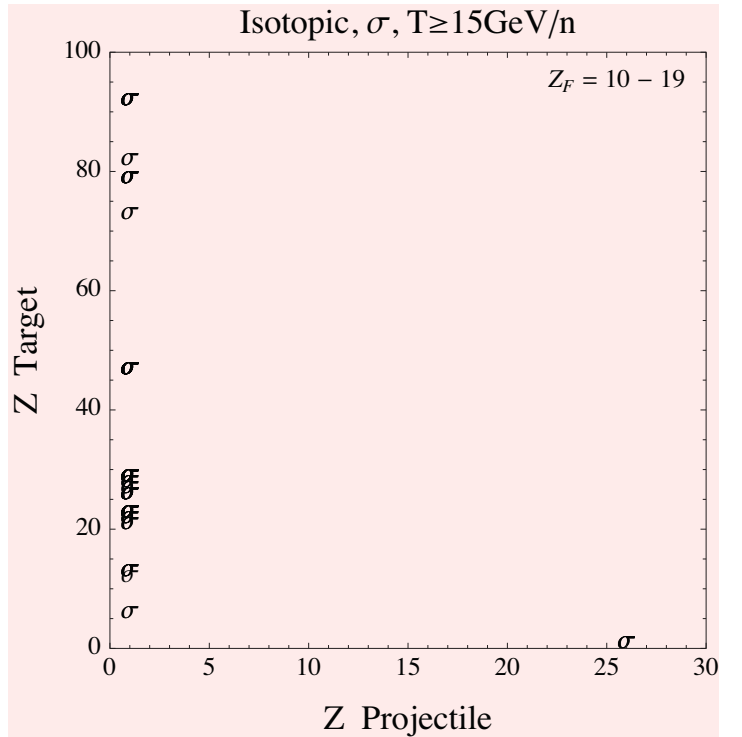
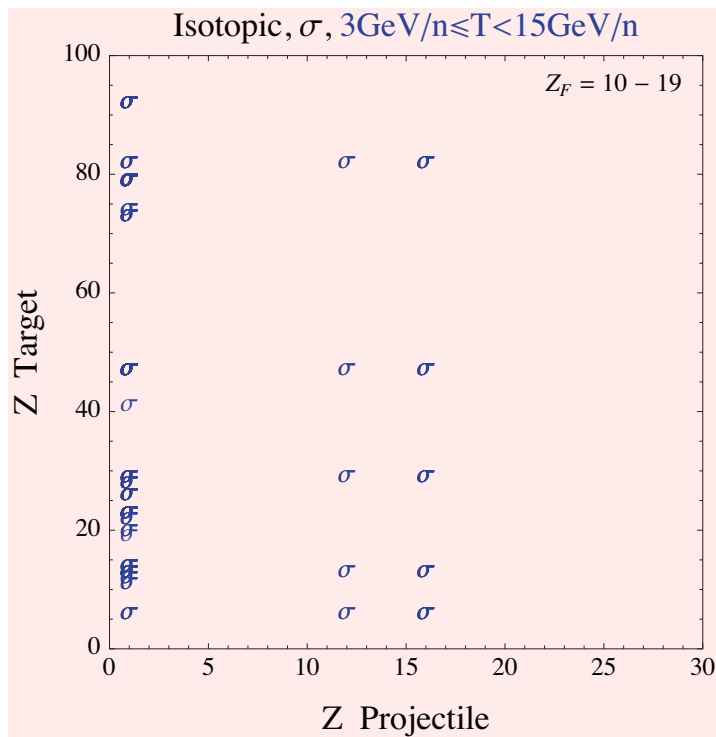
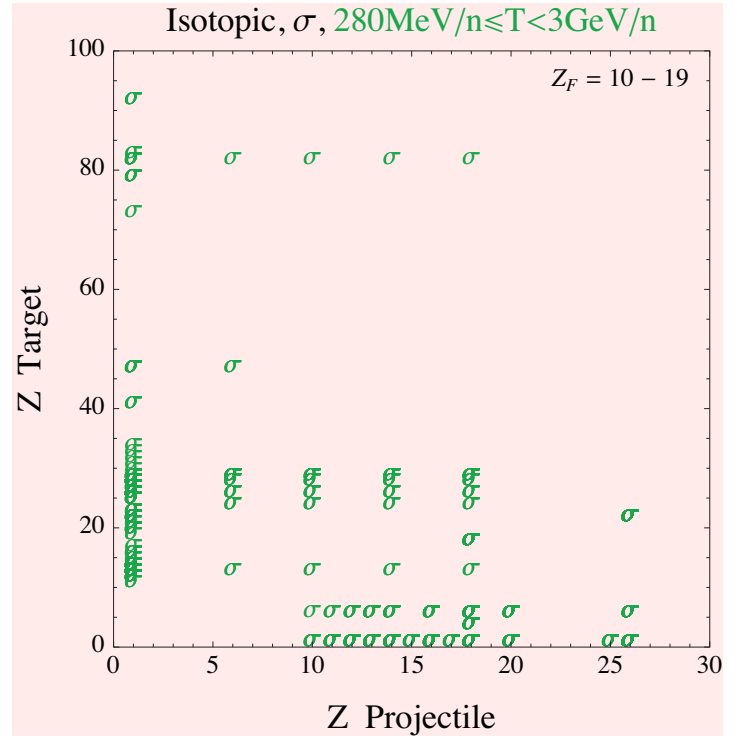
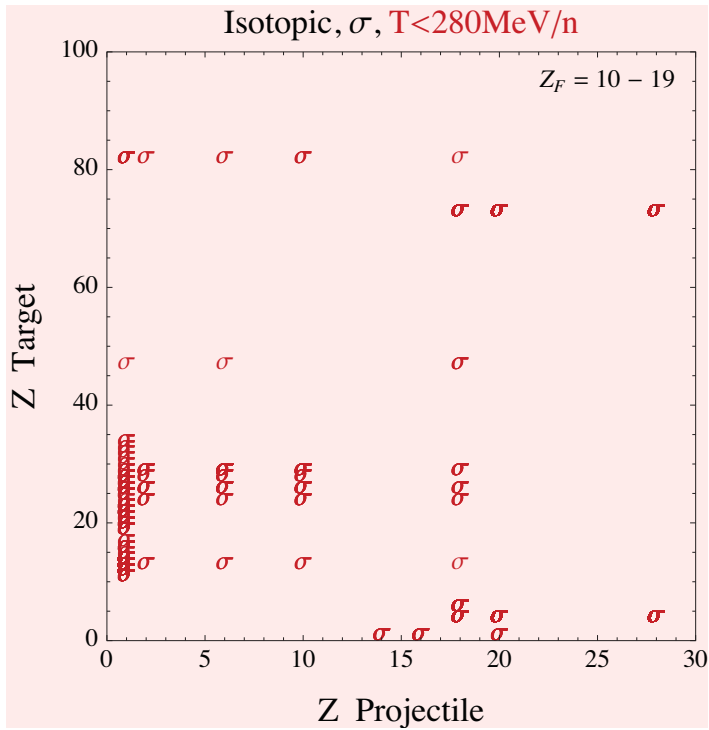


Figure 50: Isotopic total cross sections for $Z = 10 - 19$ fragments.

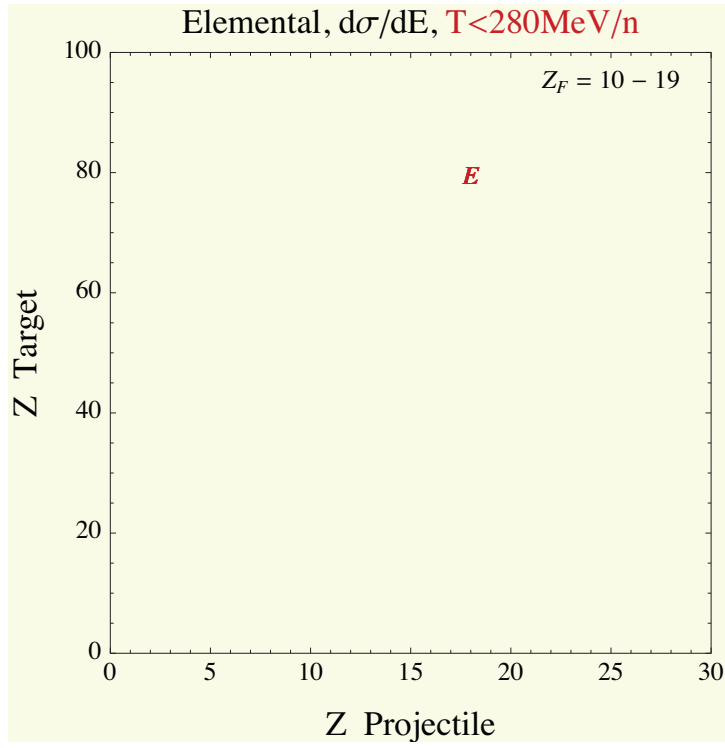


Figure 51: Elemental energy differential cross sections for $Z = 10 - 19$ fragments.

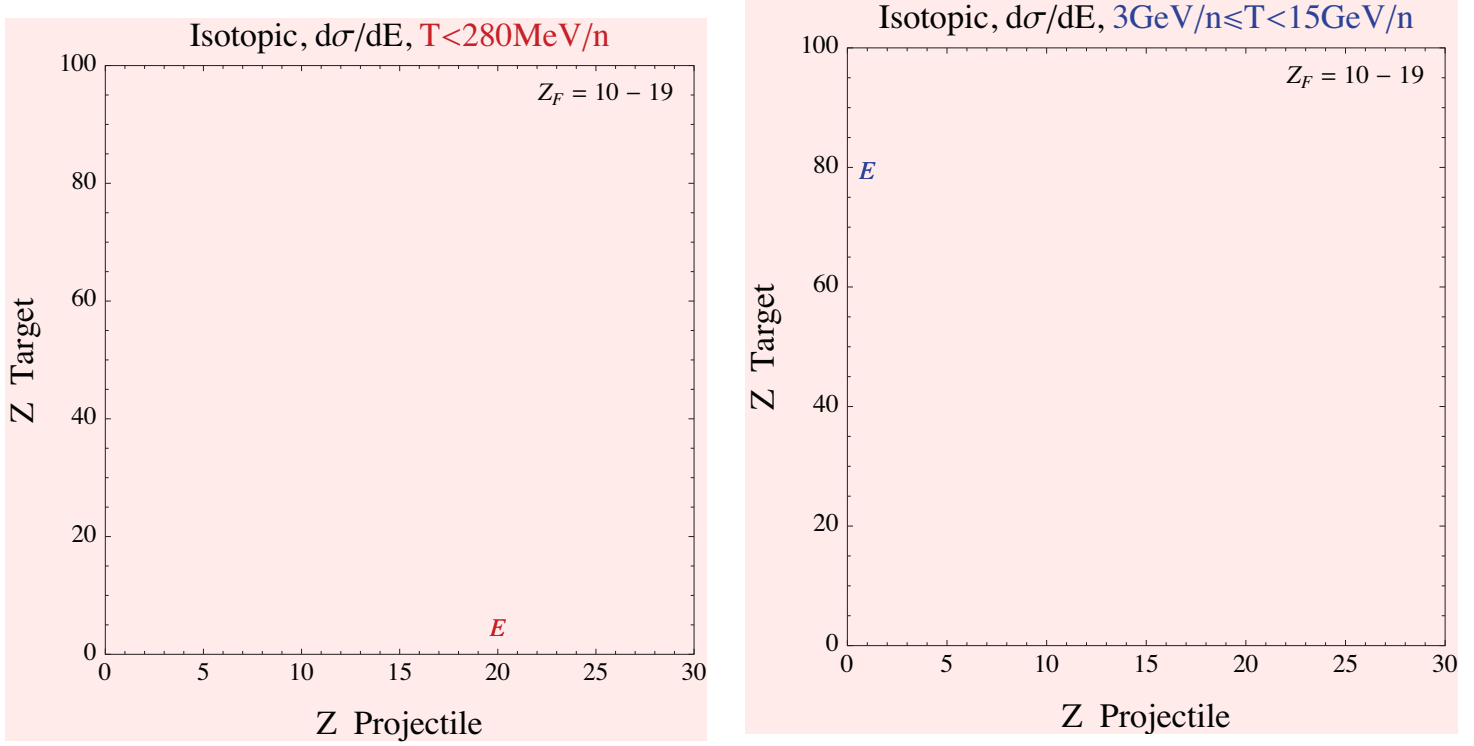


Figure 52: Isotopic energy differential cross sections for $Z = 10 - 19$ fragments.

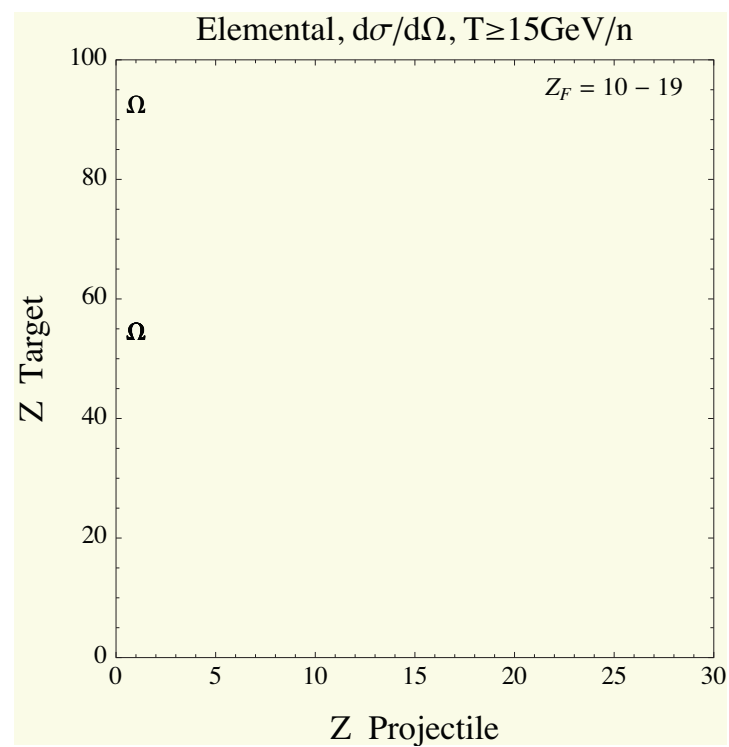
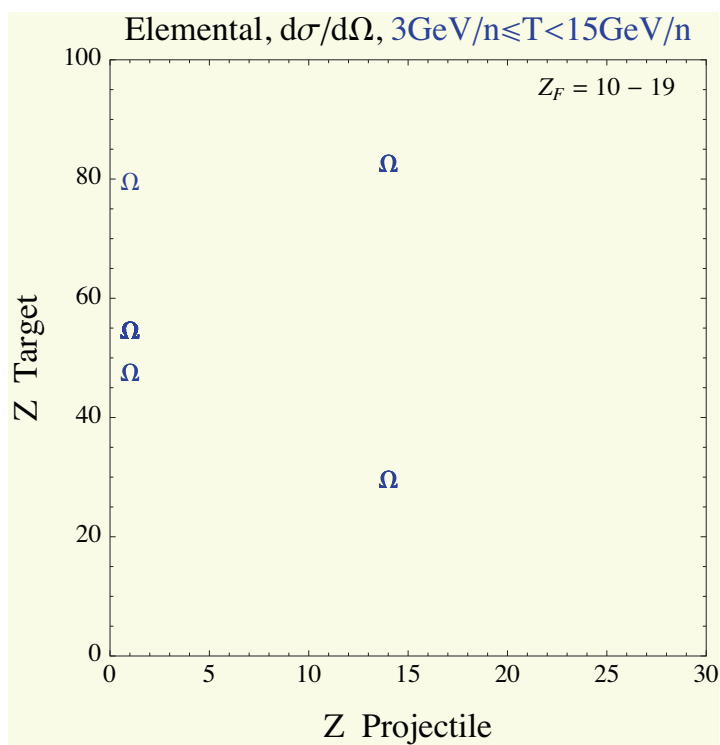
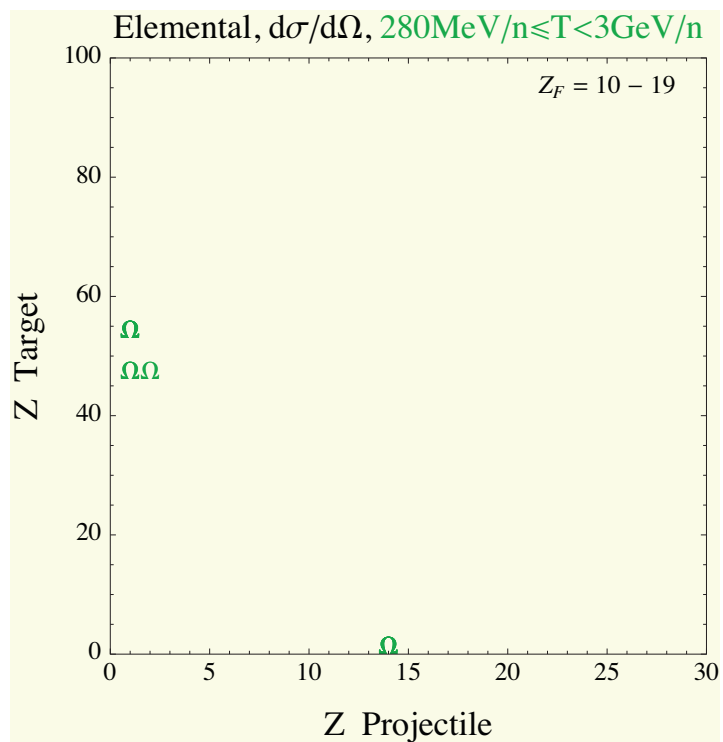
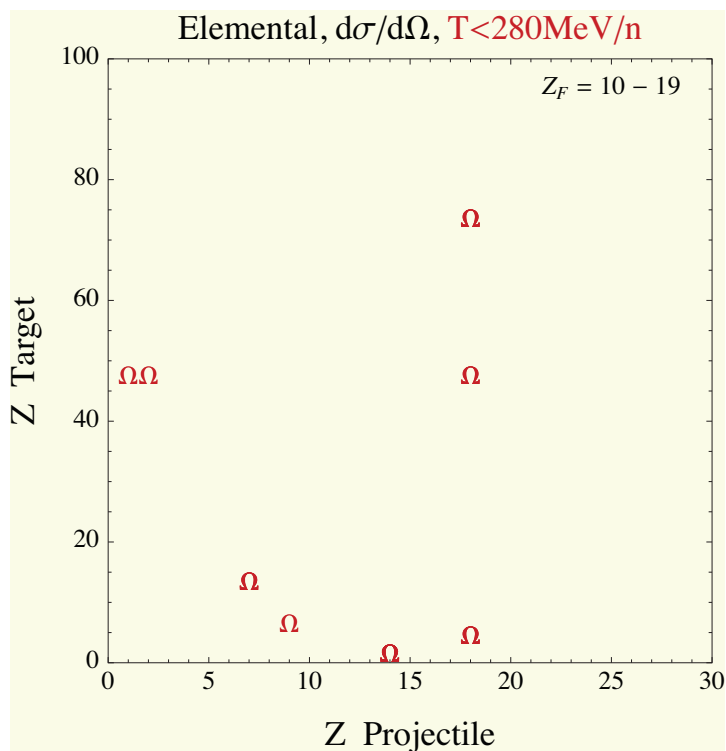


Figure 53: Elemental angular differential cross sections for $Z = 10 - 19$ fragments.

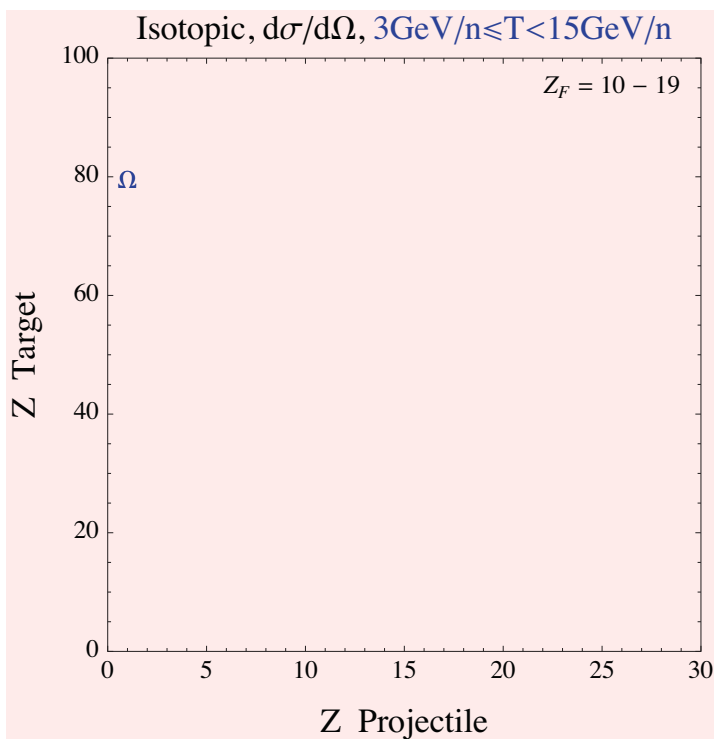
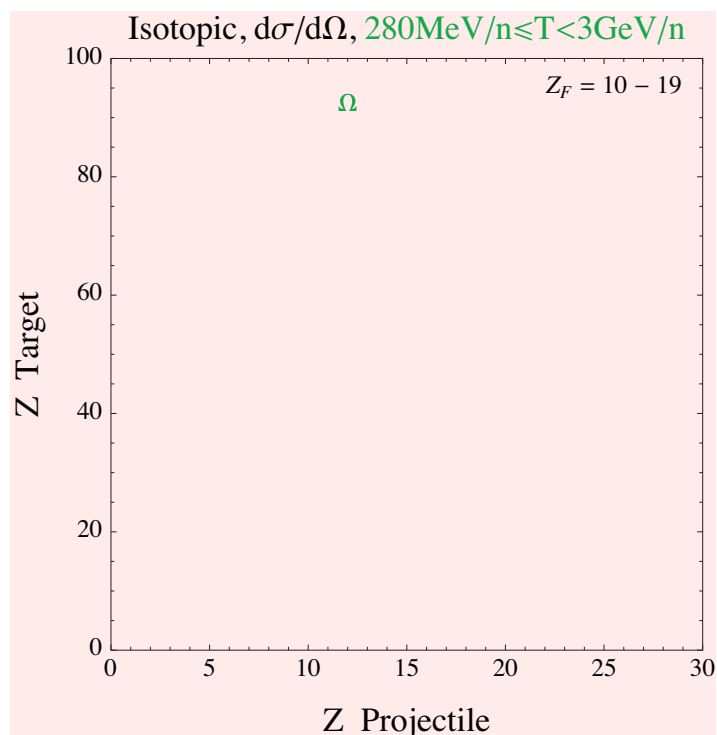
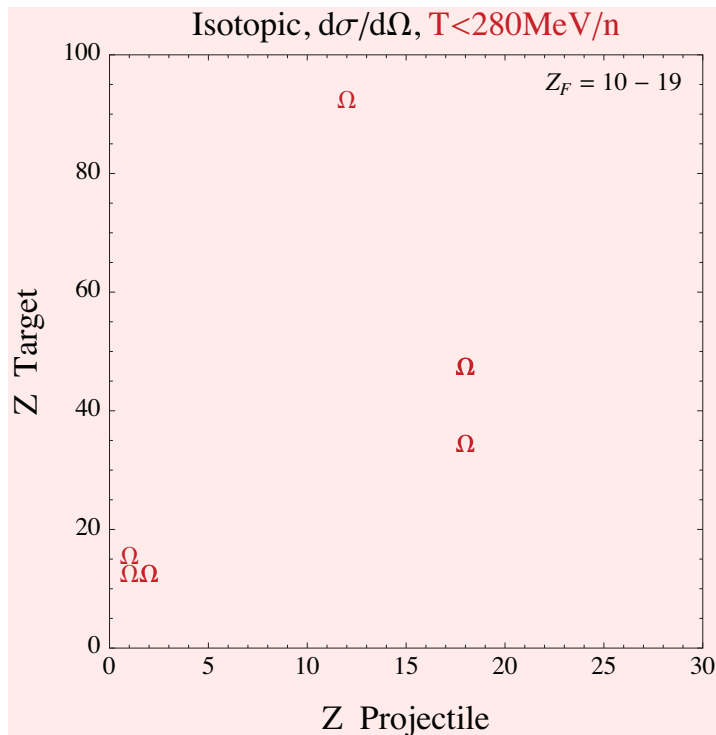


Figure 54: Isotopic angular differential cross sections for $Z = 10 - 19$ fragments.

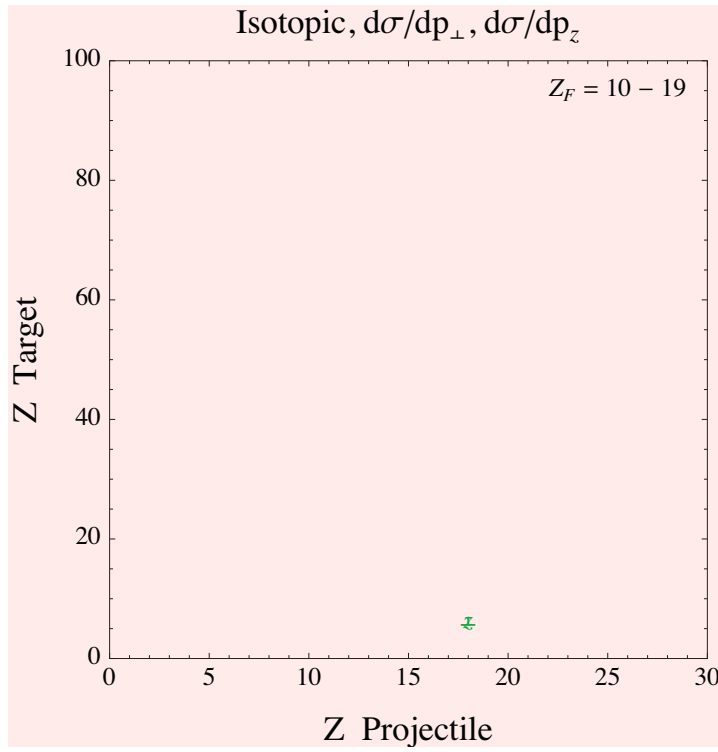


Figure 55: Isotopic momentum differential cross sections for $Z = 10 - 19$ fragments covering all energies.

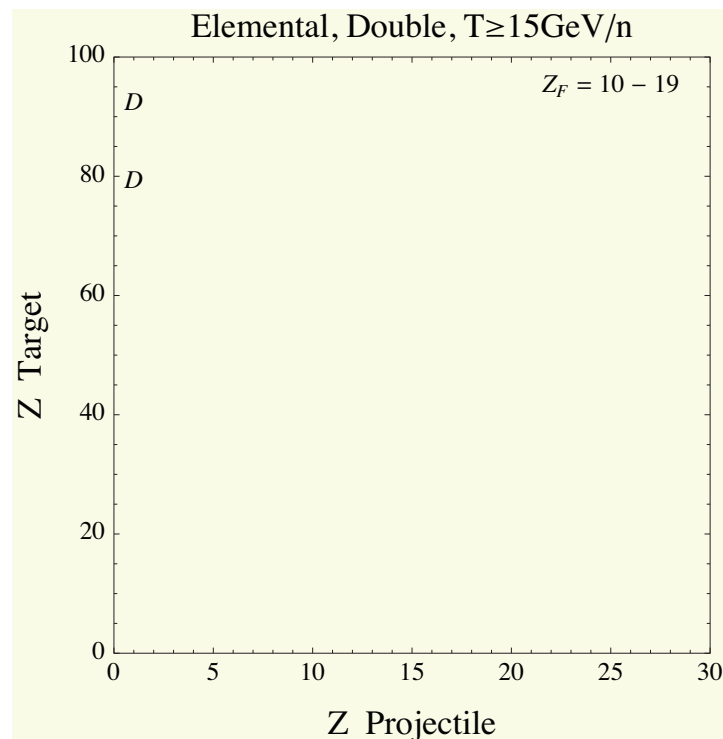
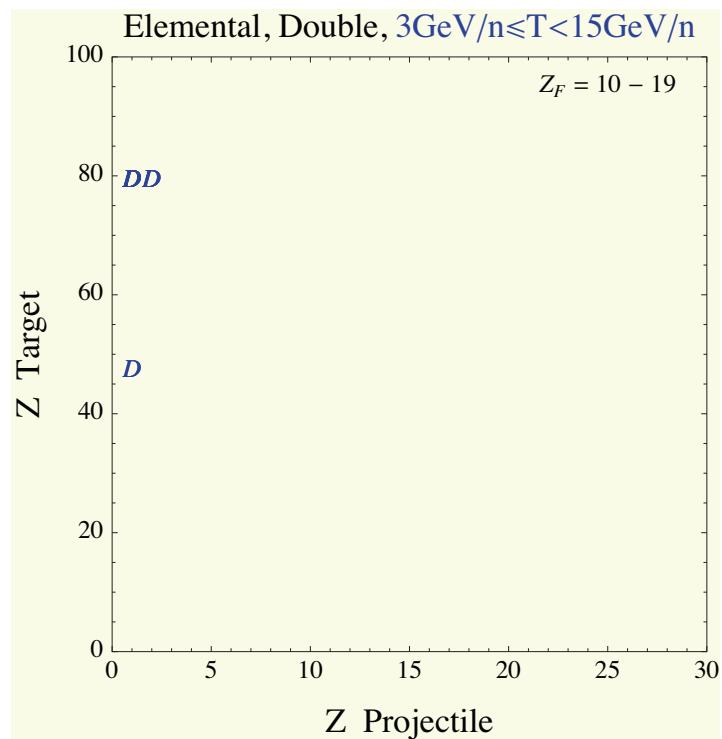
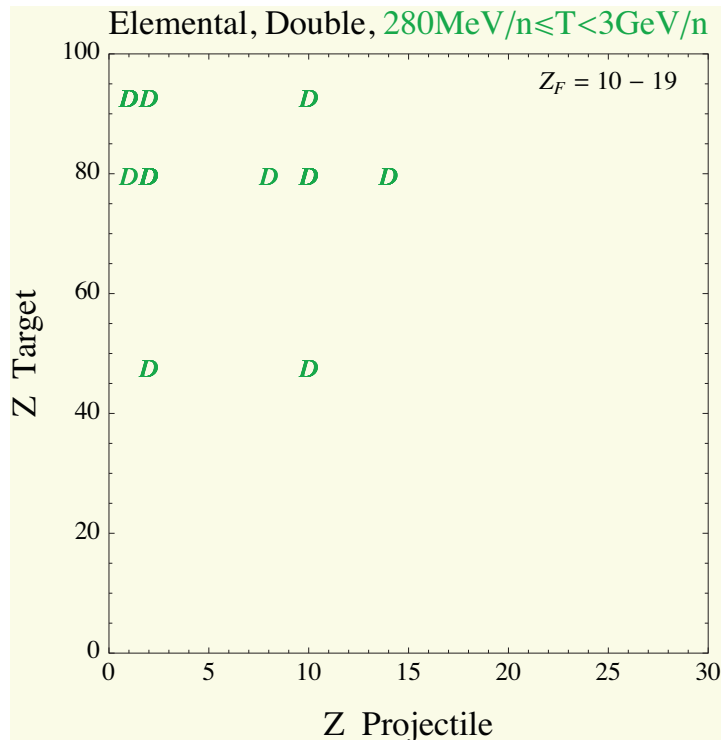
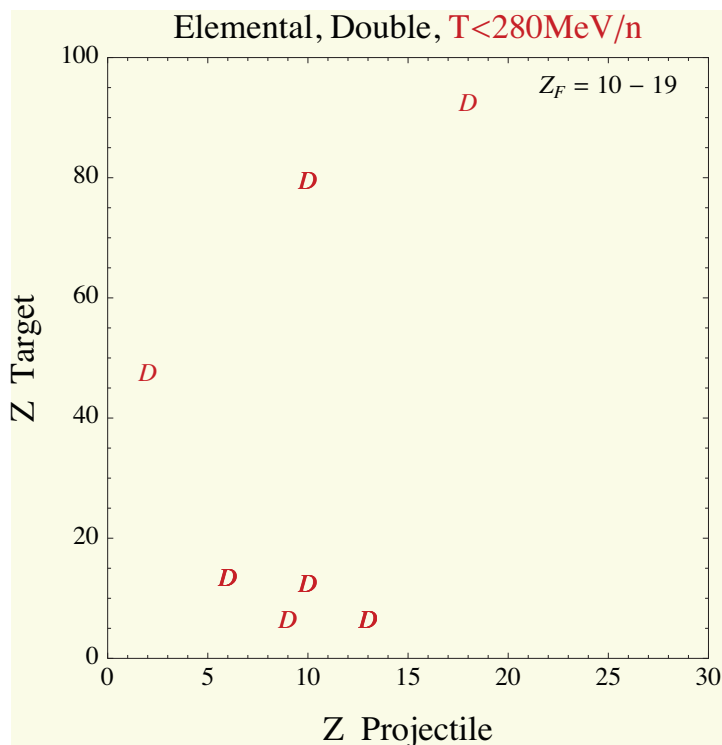


Figure 56: Elemental double differential cross sections for $Z = 10 - 19$ fragments.

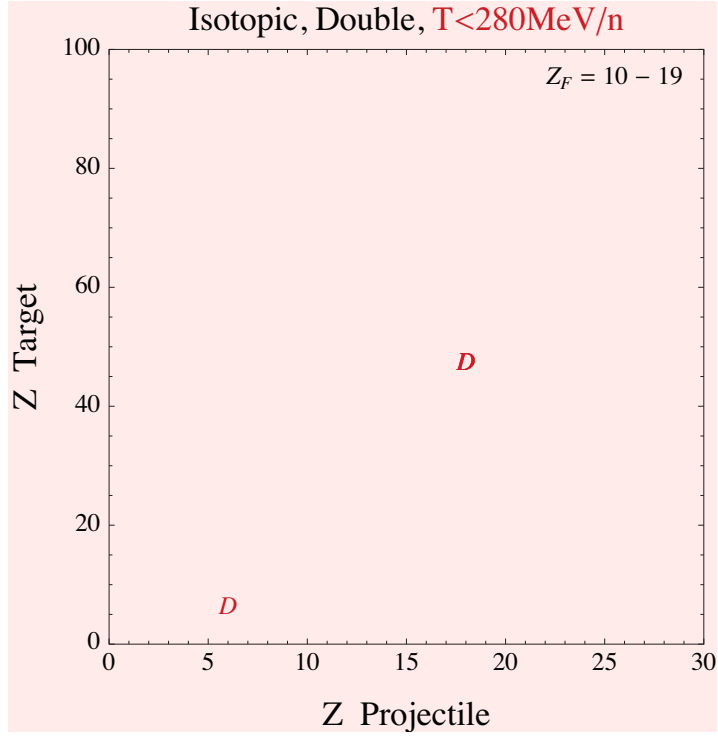


Figure 57: Isotopic double differential cross sections for $Z = 10 - 19$ fragments.

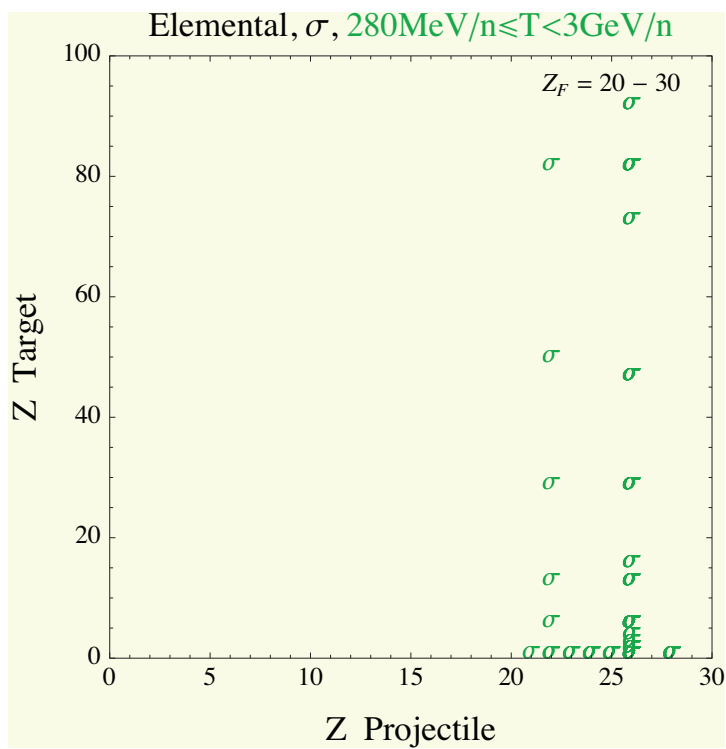


Figure 58: Elemental total cross sections for $Z = 20 - 30$ fragments.

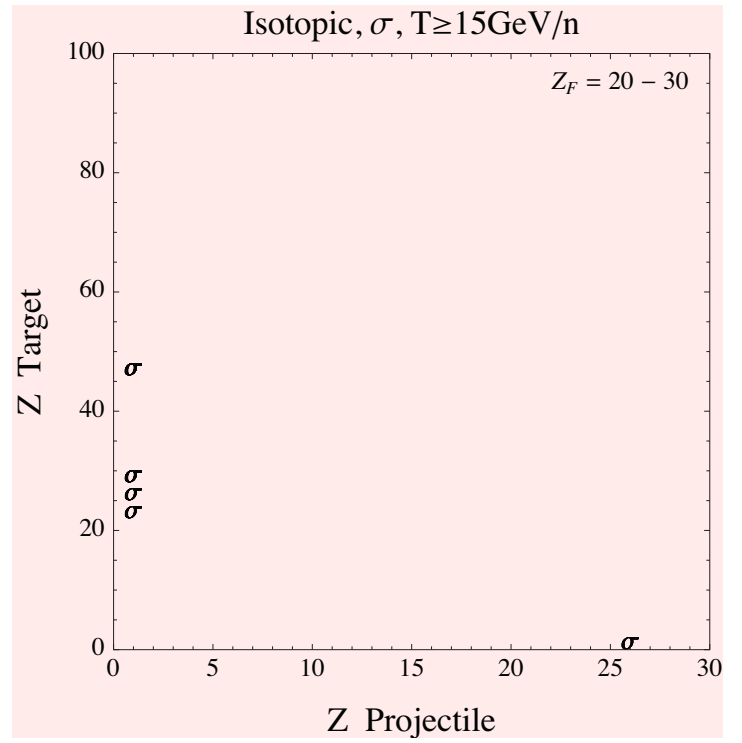
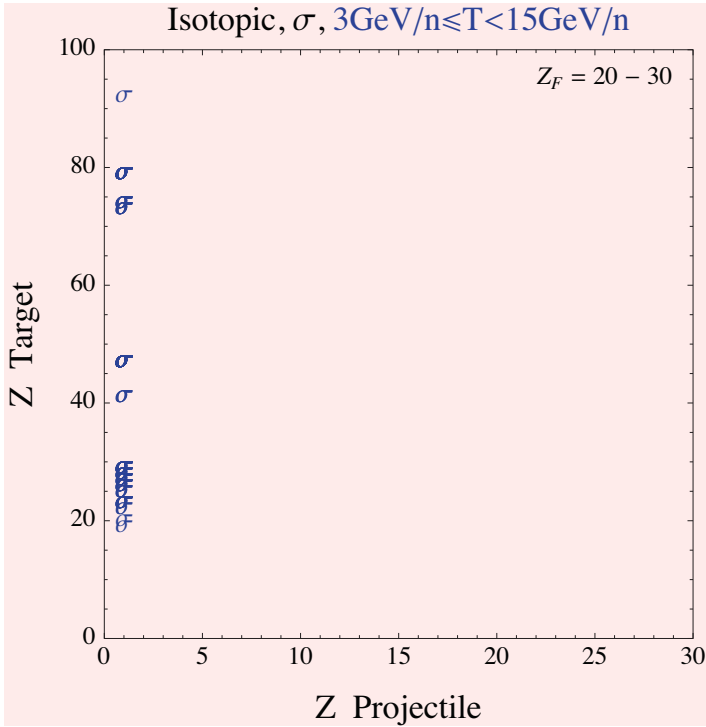
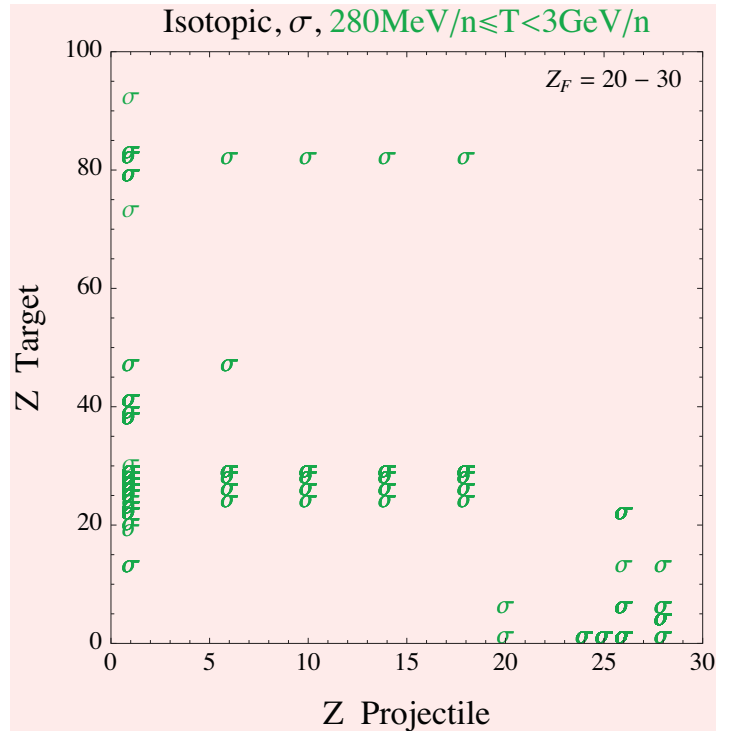
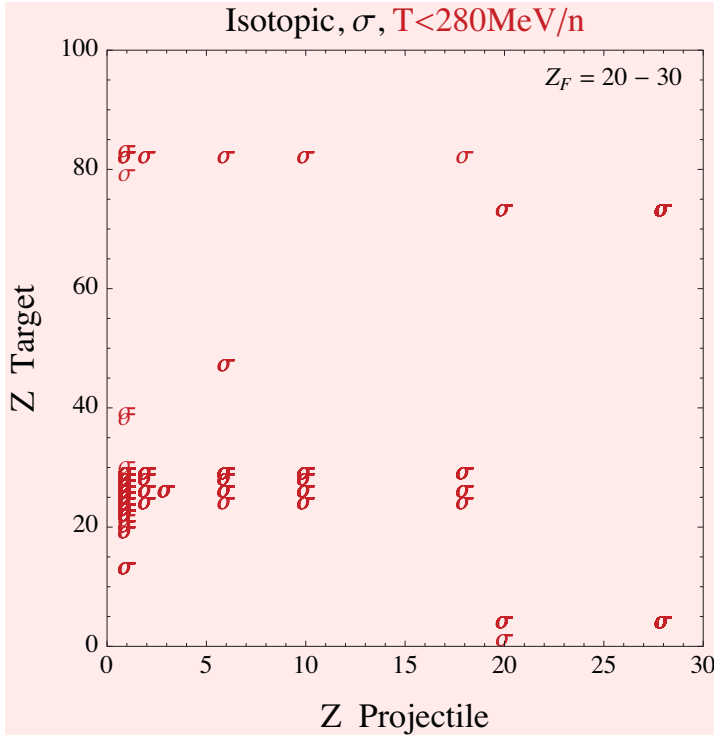


Figure 59: Isotopic total cross sections for $Z = 20 - 30$ fragments.

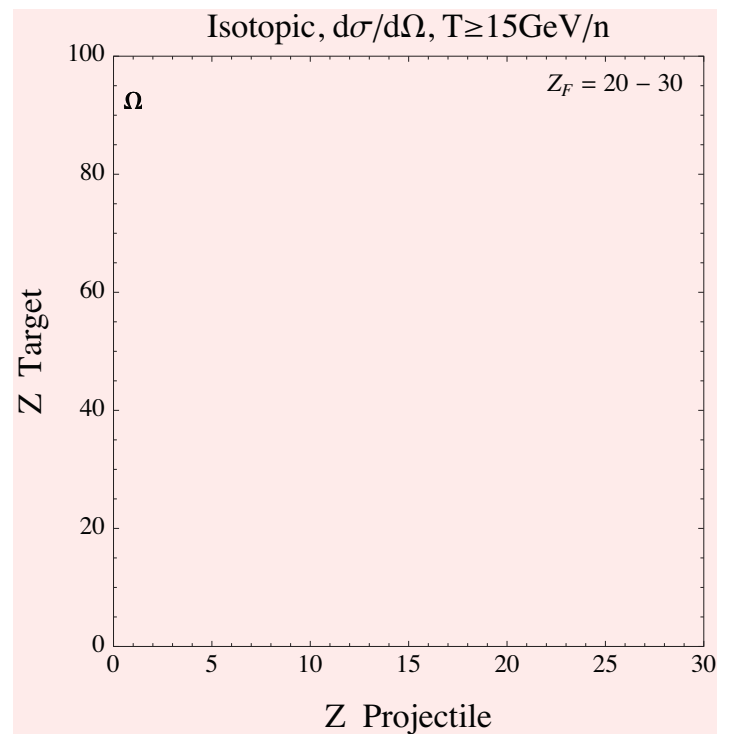
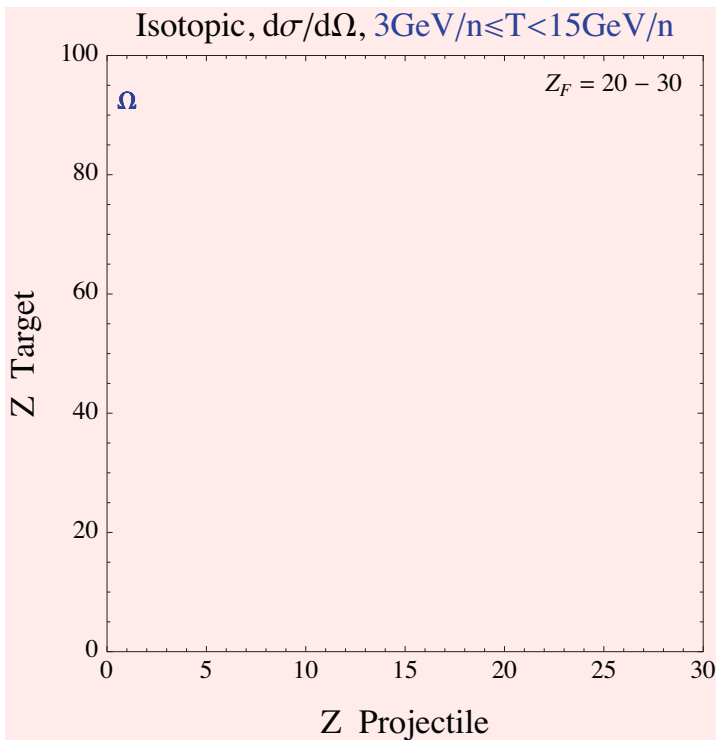
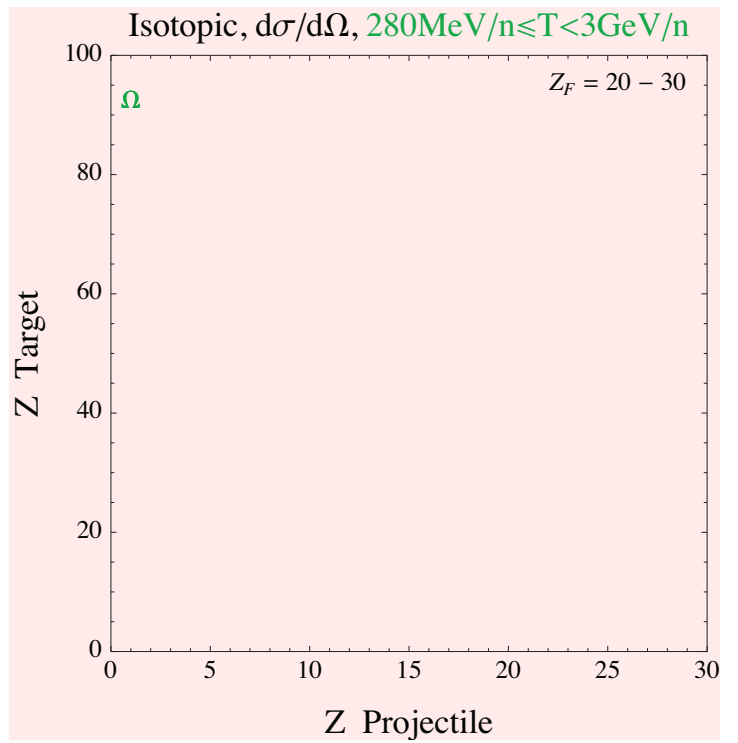


Figure 60: Isotopic angular differential cross sections for $Z = 20 - 30$ fragments.

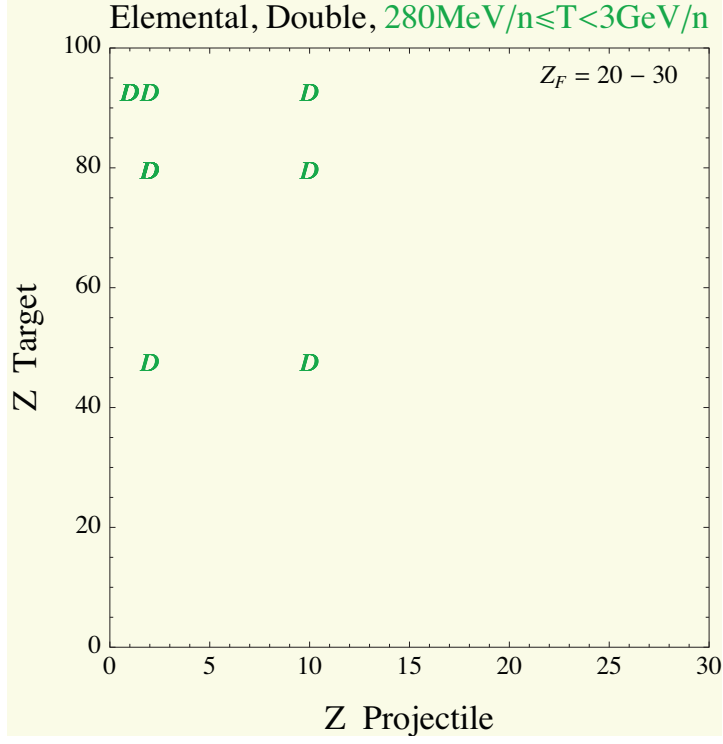


Figure 61: Elemental double differential cross sections for $Z = 20 - 30$ fragments.

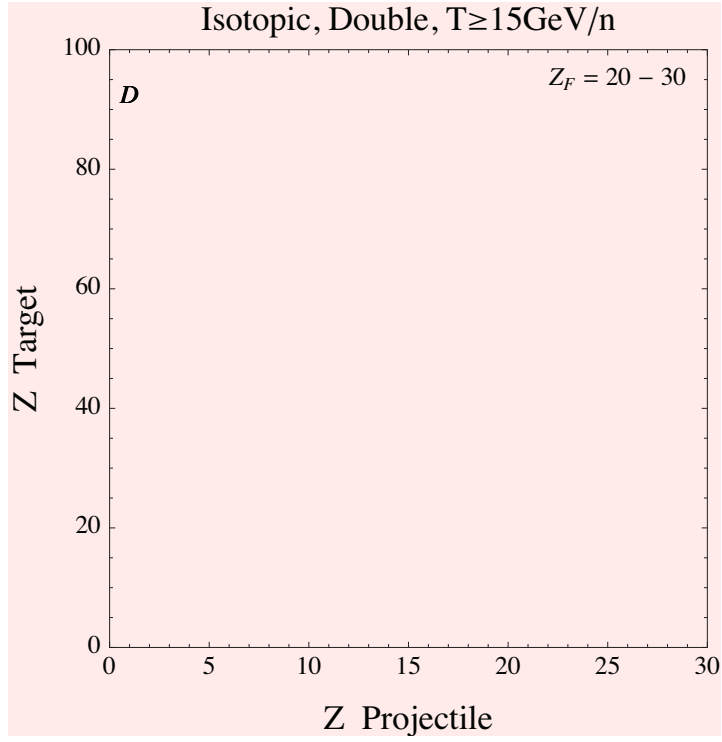


Figure 62: Isotopic double differential cross sections for $Z = 20 - 30$ fragments.

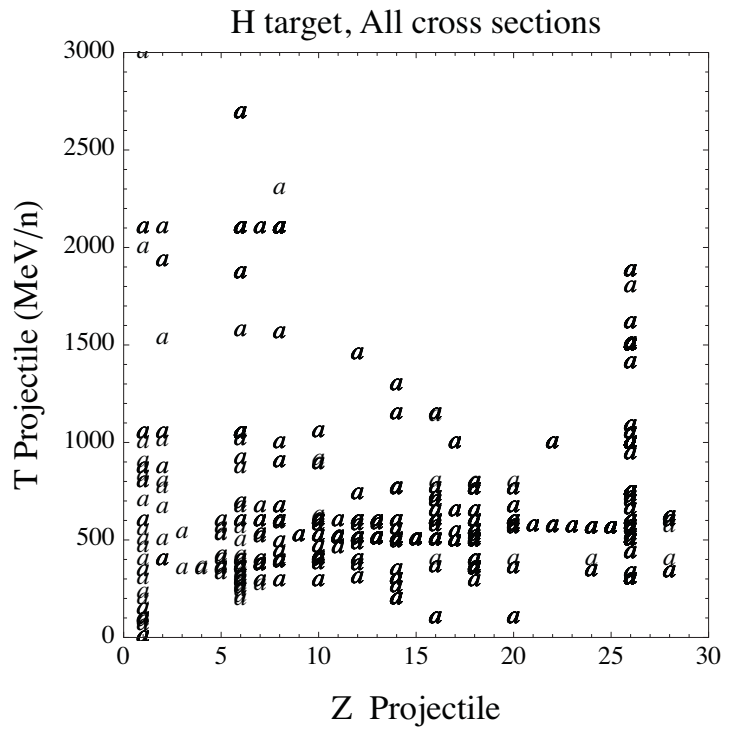
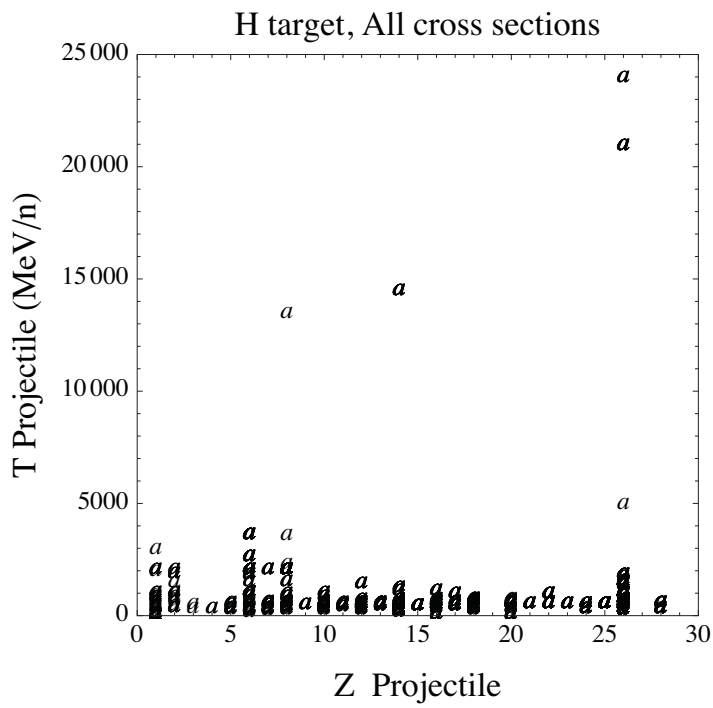


Figure 63: All cross sections for H targets. The right hand panel is the same as the left panel, except zooming in to energies less than 3 GeV/n.

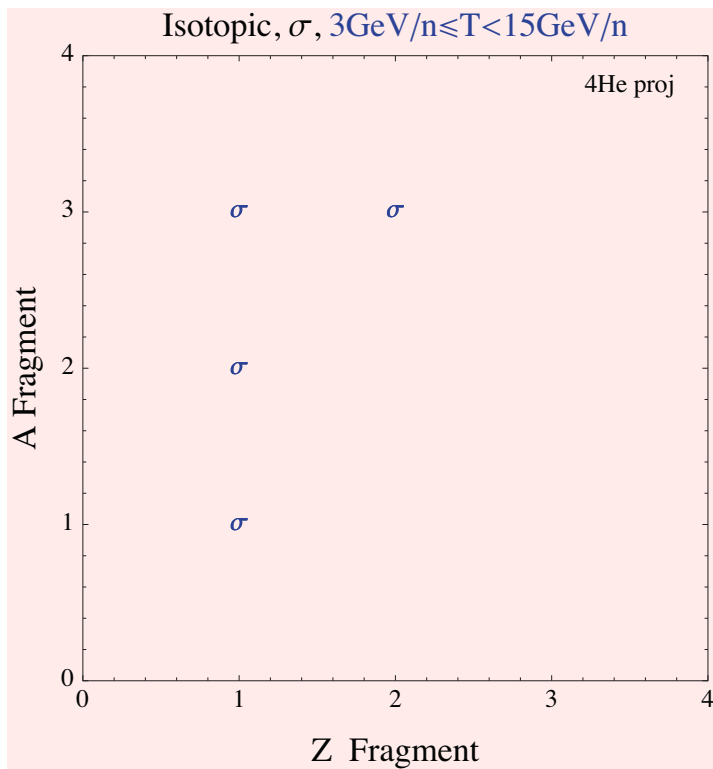
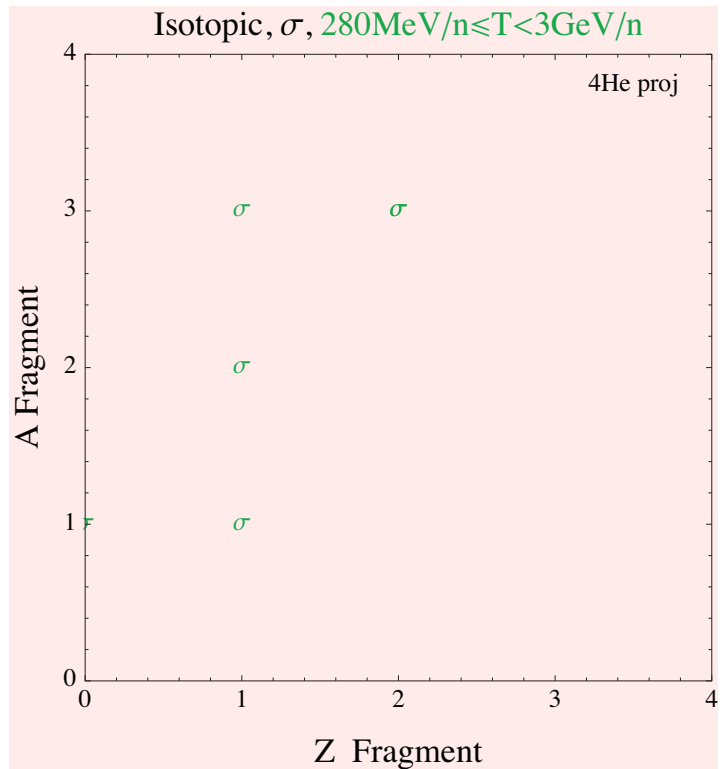
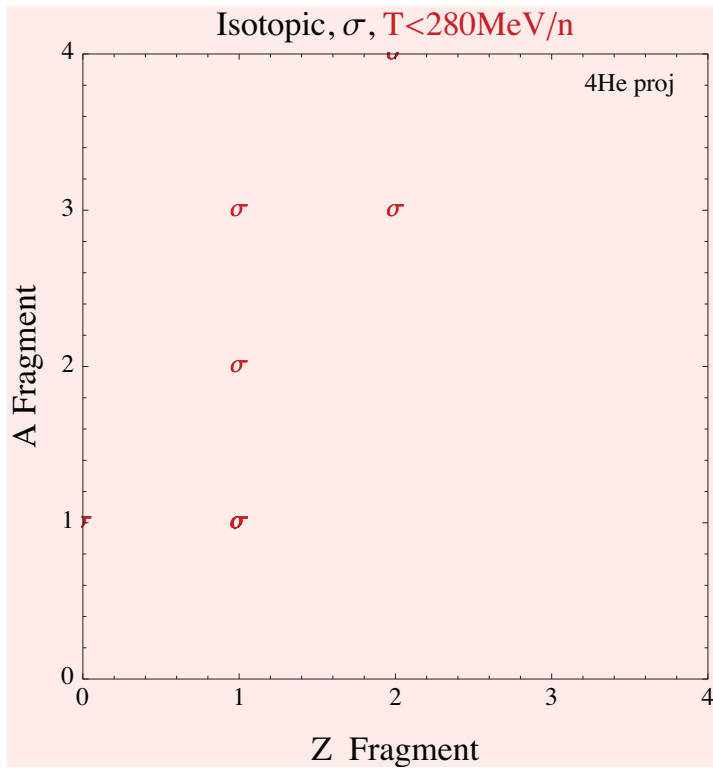


Figure 64: Isotopic total cross sections for ^4He projectiles.

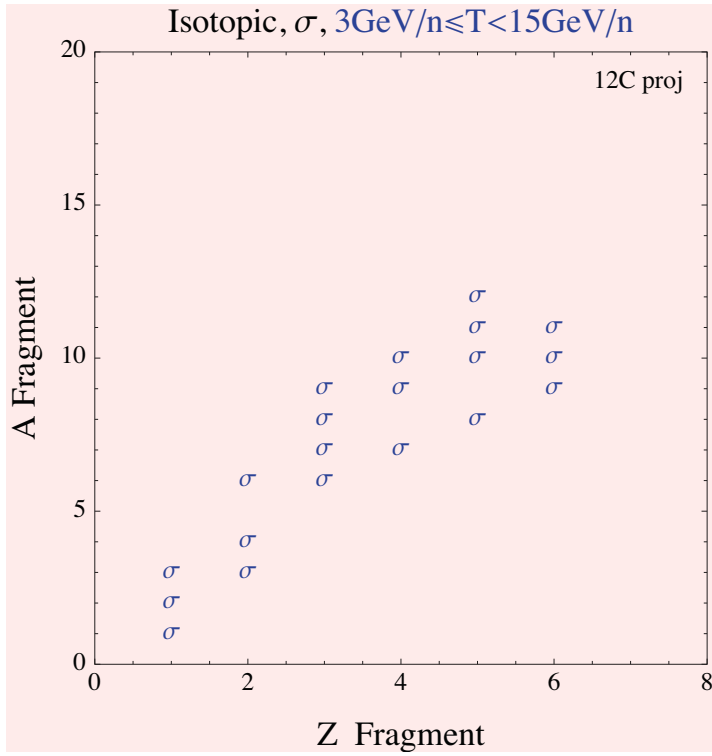
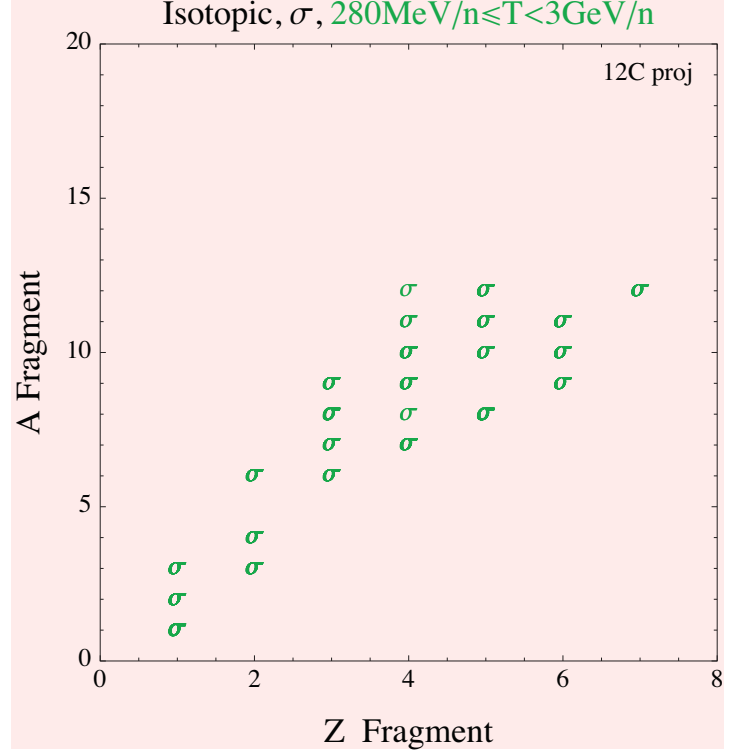
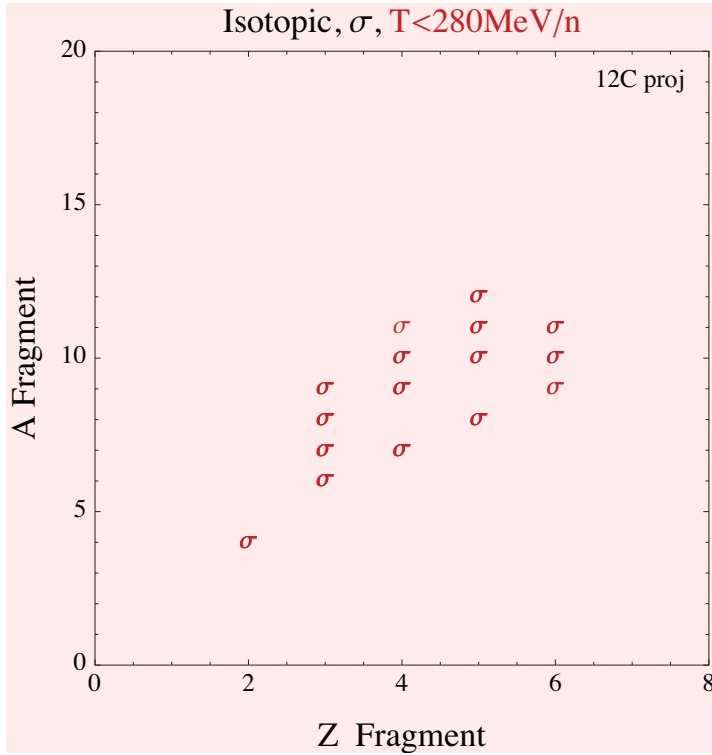


Figure 65: Isotopic total cross sections for ^{12}C projectiles.

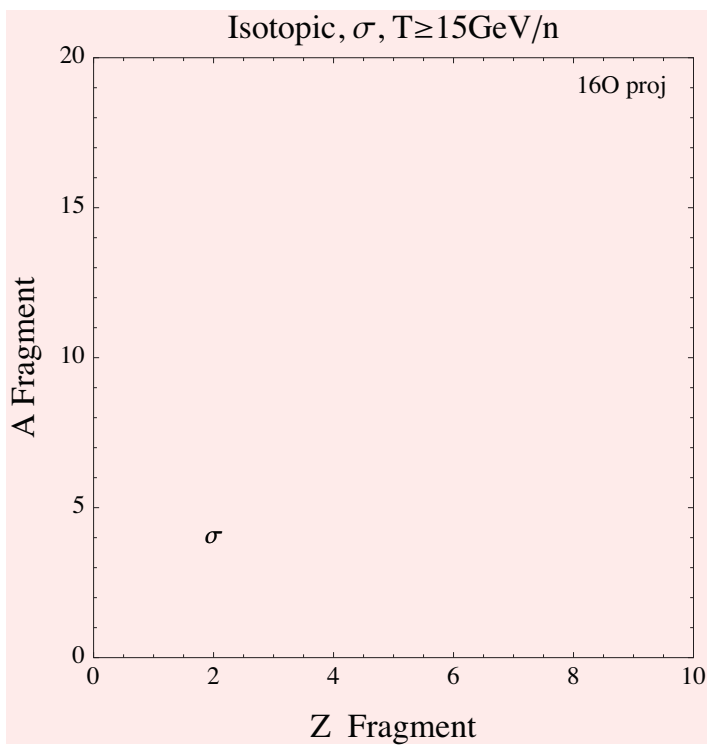
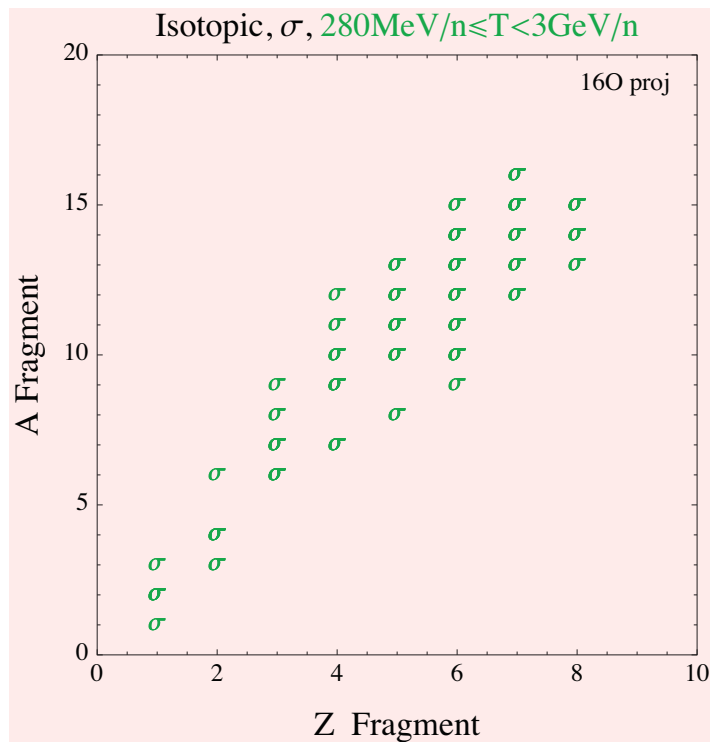
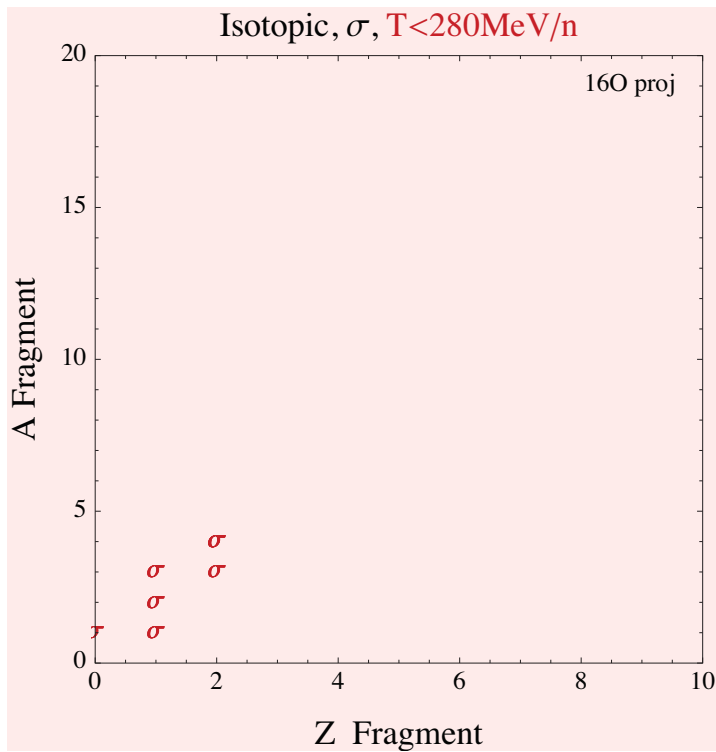


Figure 66: Isotopic total cross sections for ^{16}O projectiles.

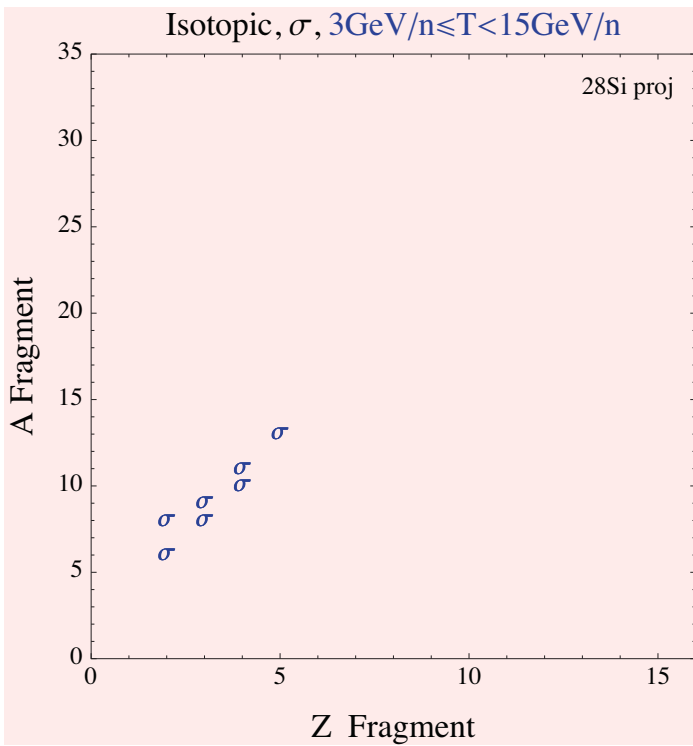
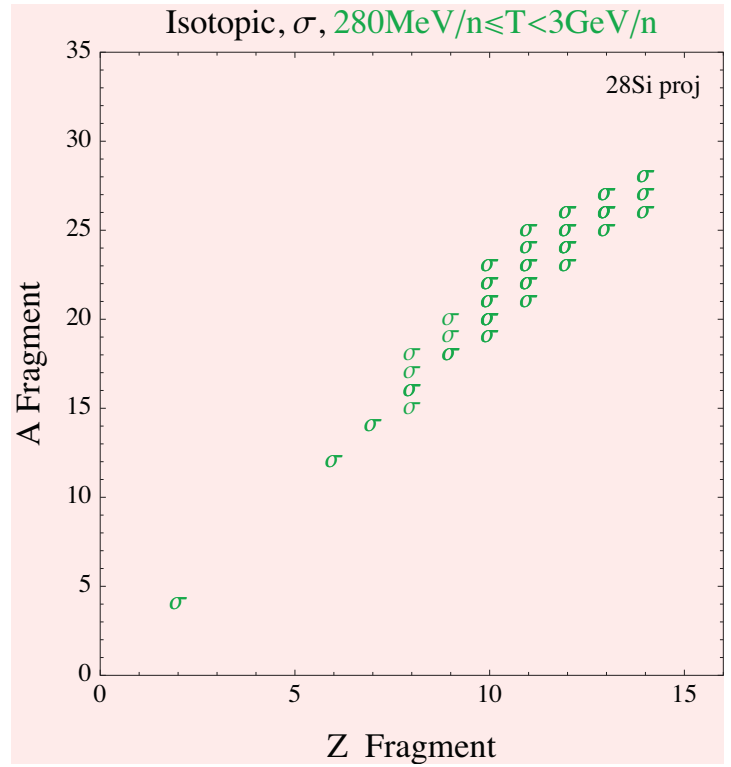
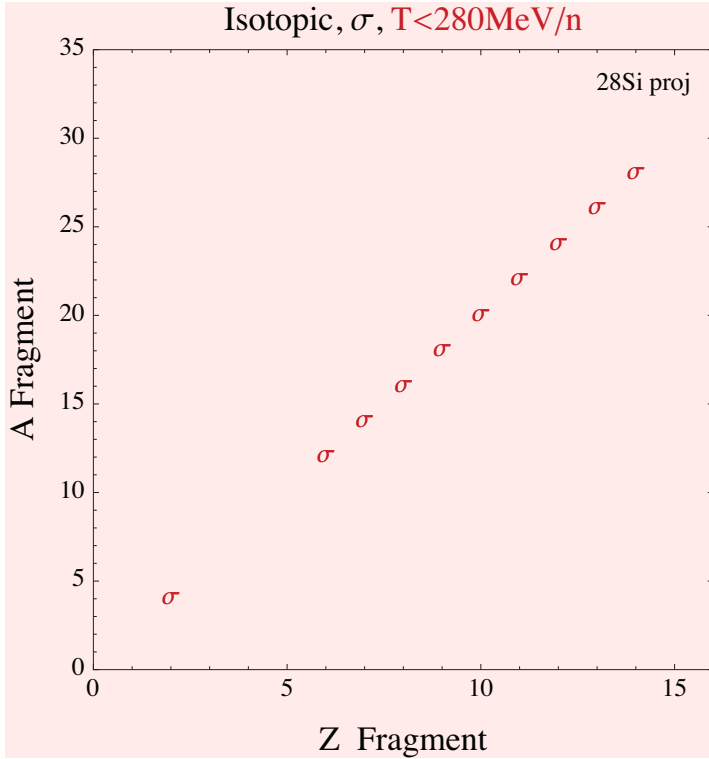


Figure 67: Isotopic total cross sections for ^{28}Si projectiles.

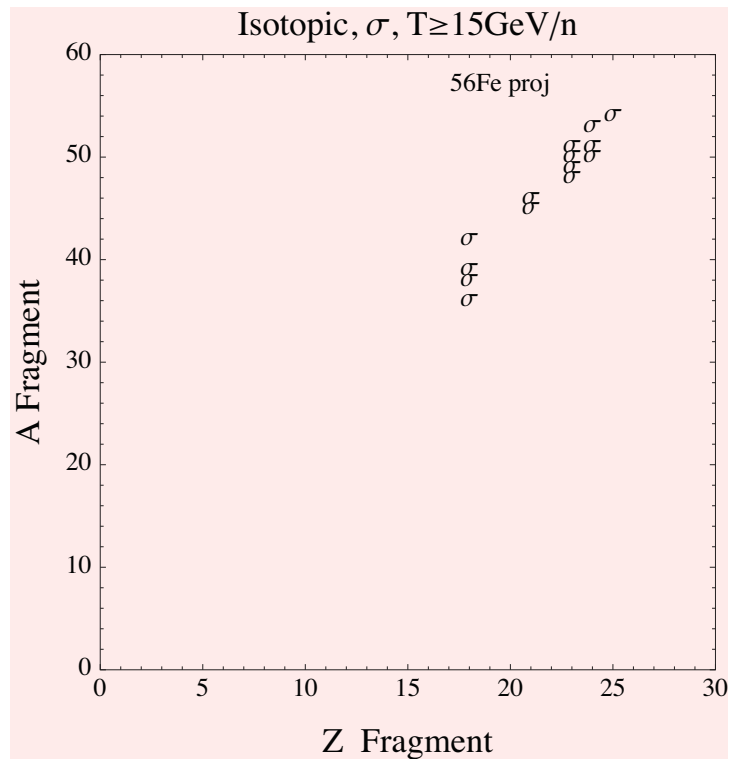
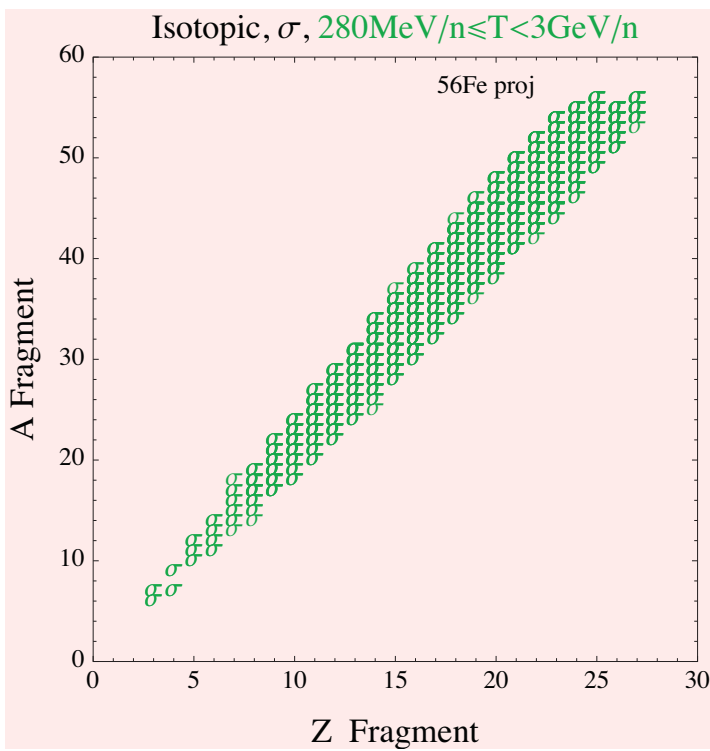


Figure 68: Isotopic total cross sections for ^{56}Fe projectiles.

Table 12: Data Reference. Assume reactions are inclusive unless stated as exclusive (excl) under the Type column. Kinetic energy numbers with or without a decimal point are in units of GeV/n or MeV/n respectively. Abbreviations are as follows: cc = charge changing, elem = elemental, iso = isotopic, inel = inelastic, mult = multiplicity, ex = exclusive, emd = electromagnetic dissociation, inv kin = inverse kinematics, corr = correlations, fss = fission, pol = polarization, imf = intermediate mass fragments, triple = triple differential cross section, quad = quadruple differential cross section. Also rev = review and means that data from other sources are reviewed in the reference. This table is continued in the following pages.

Reference	Projectile	Kinetic Energy	Target	Fragment	Type	Cross Section	Other
[Abdurakhimov81]	^4He	4.5	Li, C, Al, Cu	$1-^3\text{H}, ^3\text{He}$	iso	σ	
[Abe87]	^3He	9, 15	^{12}C	$\text{n}, ^{14}\text{O}$	iso	$\text{d}\Omega$	ex
[Abe87a]	^3He	8, 15	^{26}Mg	$\text{n}, ^{28}\text{Si}$	iso	$\text{d}\Omega$	ex
[Abramov10]	^{12}C	300	Be	$1, ^2\text{H}$	iso	$\text{E}_{\text{d}^3\text{p}}^{\text{d}^3\sigma}$	
[Aksinenko80]	$^4\text{He}, ^{12}\text{C}$	3.66	Li, C, Ne, Al Cu, Zn, Pb		inel	σ	mult
[Aladashvili81]	^4He	1.93	^1H	$\text{n}, ^1-^3\text{H}, ^3\text{He}, \pi$	iso	σ	ex
[Alard75]	^1H	600	C, Al, Fe, Au $^9\text{Be}, ^{40}\text{Ca}$	$1-^3\text{H}, ^3, ^4\text{He}$	iso	$\sigma, \text{dE}, \text{dEd}\Omega$	
[Alexakhin00]	^{14}N	52	Ag	$1-^3\text{H}$	iso	$\text{dEd}\Omega$	mult
[Alexander63]	^1H	0.5 – 6.2	^{238}U	$^{67}\text{Cu}, ^{90,93,99}\text{Mo}, ^{111}\text{Ag}$ $^{121,123-125,130,132,133-135}\text{I}$	iso	σ	
[Alvarez10]	^{238}U	1.0	Be	$^{112}\text{Pd}, ^{132,134}\text{Te}$	iso	σ	
[Anderson83]	$^1, ^2\text{H}, ^4\text{He}, ^{12}\text{C}$	400, 1.05, 2.1	H, C, Cu, Pb	$^{\text{A}}\text{Pt} - ^{\text{A}}\text{Fr}$	iso	σ	
[Anikina83]	^{20}Ne	3.3	C, Al, Cu, Pb	$1, ^2, ^3\text{H}, ^3, ^4, ^6, ^8\text{He}$	iso	$\text{dpd}\Omega$	
[Apollonio10]	^1H	2.2, 4.1, 7.1 8.0, 11.1	Be, C, Al, Cu Sn, Ta, Pb	^1H	inel	σ	
[Armbruster04]	^{238}U	1.0	^1H	$^{\text{A}}\text{N} - ^{\text{A}}\text{U}$	iso	σ	
[Asano85]	^1H	500	Ta, W, Au	$^{\text{A}}\text{Co} - ^{\text{A}}\text{Hg}$	iso	σ	
[Asano88]	^1H	12.0	Ta, W, Au	$^{\text{A}}\text{Na} - ^{\text{A}}\text{Pt}$	iso	σ	
[Auble83]	^{16}O	52, 100, 147	Al, Ni, Sn, Au	$1, ^2, ^3\text{H}, ^3, ^4\text{He}$	iso	$\sigma, \text{dEd}\Omega$	
[Audouin06]	^{208}Pb	500	^1H	$^{\text{A}}\text{Tm} - ^{\text{A}}\text{Bi}$	iso	σ	
[Austin62]	$\text{n}, ^1\text{H}$	120, 153	^{12}C	$^{11}\text{B}, ^{11}\text{C}$	iso	σ	ex

Reference	Projectile	Kinetic Energy	Target	Fragment	Type	Cross Section	Other
[Avan84]	^1H	200	$^6\text{Li}, ^{27}\text{Al}, ^{58}\text{Ni}, ^{197}\text{Au}$	^1H	iso	dEd Ω	
[Avdeyev02]	$^4\text{He}, ^{12}\text{C}$	3.65, 1.87	Au	C	elem	d Ω , dEd Ω	mult
[Awes79]	^{16}O	20	^{238}U	$1-^3\text{H}, ^4\text{He}$	iso	dE, d Ω	
[Awes80]	^{16}O	20	^{238}U	$1-^3\text{H}$	iso	dEd Ω	
[Awes81]	^{16}O	20	^{238}U	$1-^3\text{H}, ^4\text{He}$	iso	dE, d Ω , dEd Ω	
[Badala93]	^{16}O	94	Al, Ni, Au	^4He	iso		
[Badran01]	^7Li	1 – 13	^{56}Fe	$1-^3\text{H}, ^4\text{He}, ^{52,54}\text{Mn}$ $^{56-58,60}\text{Co}, ^{60,61}\text{Cu}$	iso	σ , dEd Ω	
[Baker58]	^1H	1.0 – 3.0	C, Al, Cu, Ag, Au	^7Be	iso	σ	
[Banaigs87]	^4He	1.53	$^2\text{H}, ^{3,4}\text{He}$	^4He	iso	d Ω , dpd Ω	
[Bandyopadhyay02]	$^7\text{Li}, ^{19}\text{F}$	7, 5	$^{12}\text{C}, ^{24}\text{Mg}$	$1-^3\text{H}, ^4\text{He}$	iso	dEd Ω	
[Barrette95]	^{28}Si	13.7	Al, Cu, Sn, Pb	$6, ^8\text{He}, ^8, ^9\text{Li}, ^{10, 11}\text{Be}, ^{13}\text{B}$	iso	σ , dE, dp $_{\perp}$	w(p $_{\perp}$)
[Barrette00]	^{197}Au	10.6	^{197}Au	$2, ^3\text{H}, ^3, ^4\text{He}$	iso	dpdy	mult
[Bastid90]	^{20}Ne	400, 800	NaF, Pb	H, He	elem	dpd Ω	
[Basu07]	^{16}O	5	^{40}Ca	$^1\text{H}, ^4\text{He}$	iso	dEd Ω	
[Batzel54]	^1H	10 – 33	Mg, Al	^{22}Na	iso	σ	
[Bazin90]	^{86}Kr	44	$^{27}\text{Al}, ^{103}\text{Rh}$	$^{12}\text{C}, ^{16}\text{O}, ^{23}\text{Na}, ^{19-25}\text{Ne}$	iso	dp, yield	
[Beck76]	^1H	558	^{197}Au	$^{40-47}\text{Ca}, ^A\text{Zn} - ^A\text{Sr}$	iso		
[Beene81]	^{16}O	7 – 11	Be, C, Al, Fe	$1, ^2\text{H}$	iso	d Ω , dEd Ω	
[Benenson67]	^1H	43, 52	Cu, Ge, W, Pb	n, ^4He	iso	σ	mult, ex
[Benioff60]	^1H	5.7	^{154}Sm	$^1\text{H}, ^{10}\text{C}$	iso	d Ω	ex
	^1H		Be, C, N, O	$^3\text{H}, ^7\text{Be}, ^{11}\text{C}, ^{13}\text{N},$ $^{14, 15}\text{O}, ^{18}\text{F}, ^{24}\text{Ne}, ^{22}\text{Na}, ^{27}\text{Mg}$	iso	σ	ex
			F, Na, Al				

Reference	Projectile	Kinetic Energy	Target	Fragment	Type	Cross Section	Other
[Benlliure98]	^{238}U	750	^{208}Pb	62–71Zn, $^{66-73}\text{Ga}$, $^{67-76}\text{Ge}$, $^{69-77}\text{As}$ 71–79Se, $^{75-81}\text{Br}$, $^{75-84}\text{Kr}$, $^{77-86}\text{Rb}$ 80–90Sr, $^{82-93}\text{Y}$, $^{84-93}\text{Zr}$, $^{87-97}\text{Nb}$ 89–100Mo, $^{91-102}\text{Tc}$, $^{91-105}\text{Ru}$, $^{95-107}\text{Rh}$ 97–107Pd, $^{100-111}\text{Ag}$, $^{102-114}\text{Cd}$, $^{104-116}\text{In}$ $^{107-118}\text{Sn}$, $^{109-121}\text{Sb}$, $^{111-124}\text{Te}$, $^{114-126}\text{I}$ $^{192-195}\text{Ir}$, $^{190-194}\text{Os}$, $^{189-194}\text{Re}$, $^{187-192}\text{W}$, $^{185-189}\text{Ta}$, $^{184-188}\text{Hf}$ $^{38-42}\text{Ar}$, $^{40-44}\text{K}$, $^{42-47}\text{Ca}$, $^{44-49}\text{Sc}$, $^{46-52}\text{Ti}$, $^{48-54}\text{V}$ $^{50-57}\text{Cr}$, $^{52-59}\text{Mn}$, $^{54-61}\text{Fe}$, $^{57-64}\text{Co}$, $^{59-66}\text{Ni}$, $^{61-68}\text{Cu}$ $^{63-71}\text{Zn}$, $^{65-75}\text{Ga}$, $^{68-77}\text{Ge}$, $^{70-80}\text{As}$, $^{72-82}\text{Se}$, $^{74-84}\text{Br}$ $^{77-87}\text{Kr}$, $^{79-89}\text{Rb}$, $^{81-91}\text{Sr}$, $^{84-94}\text{Y}$, $^{87-96}\text{Zr}$, $^{89-99}\text{Nb}$ $^{91-101}\text{Mo}$, $^{93-104}\text{Tc}$, $^{96-106}\text{Ru}$, $^{98-108}\text{Rh}$, $^{100-110}\text{Pd}$ $^{102-112}\text{Ag}$, $^{105-114}\text{Cd}$, $^{107-116}\text{In}$, $^{109-119}\text{Sn}$, $^{111-121}\text{Sb}$ $^{114-123}\text{Te}$, $^{118-125}\text{I}$, $^{120-127}\text{Xe}$, $^{125-130}\text{Cs}$	iso	σ	
[Benlliure99]	^{197}Au	950	Be	Ca – Xe	iso	σ	
[Benlliure01]	^{197}Au	800	H	$^{42-47}\text{Ca}$, $^{46-52}\text{Ti}$, $^{53-59}\text{Mn}$, $^{57-64}\text{Co}$ $^{61-67}\text{Cu}$, $^{65-75}\text{Ga}$, $^{70-80}\text{As}$, $^{74-83}\text{Br}$ $^{78-89}\text{Rb}$, $^{84-94}\text{Y}$, $^{89-99}\text{Nb}$, $^{93-104}\text{Tc}$ $^{98-108}\text{Rh}$, $^{105-112}\text{Ag}$, $^{107-116}\text{In}$, $^{111-121}\text{Sb}$ $^{156-177}\text{Lu}$, $^{159-178}\text{Hf}$, $^{160-182}\text{Ta}$, $^{163-185}\text{W}$ $^{164-186}\text{Re}$, $^{169-191}\text{Os}$, $^{168-193}\text{Ir}$, $^{173-196}\text{Pt}$ $^{174-196}\text{Au}$ AYb – AFr	elem iso	σ σ	
[Benlliure10]	^{208}Pb , ^{238}U	1.0	Be		iso	σ	

Reference	Projectile	Kinetic Energy	Target	Fragment	Type	Cross Section	Other
[Bernas65]	^1H	44 – 25.0	$^{12}\text{C}, ^{16}\text{O}$	$^6\text{He}, ^6,7\text{Li}, ^7\text{Be}$	iso	σ	rev
[Bernas67]	^1H	20 – 10.0	^{12}C	$6-9\text{Li}, ^7,^{10}\text{Be}, ^{10}\text{B}, ^{10,11}$	iso	σ	
	^1H	1 – 10.0	^{14}N	$6,8,9\text{Li}, ^7,^{11}\text{Be}, ^{10,11}\text{B},$ $^{10-12}\text{C}, ^{13}\text{N}, ^{14,15}\text{O}$			
	^1H	10 – 10.0	^{16}O	$6,7,9\text{Li}, ^7\text{Be}, ^{10}\text{B}$ $^{10,11,14}\text{C}, ^{13}\text{N}, ^{15}\text{O}$			
	^1H	20 – 5.7	$^{12}\text{C}, ^{16}\text{O}, ^{14}\text{N}$ $^{19}\text{F}, ^{23}\text{Na}$	$n, ^1\text{H}, ^{11}\text{C}, ^{13}\text{N}, ^{15}\text{O}, ^{22}\text{Na}$			(p,pn), ex
	^1H	150	^{12}C	$n, ^{1,3}\text{H}, ^4\text{He}, ^{6-9}\text{Li}, ^7,8,^{10}\text{Be}$ $^{10,11}\text{B}, ^{10-12}\text{C}$			ex
	^1H	150	^{14}N	$n, ^1\text{H}, ^4\text{He}, ^{6,8,9}\text{Li}, ^7,^{10}\text{Be}$ $^{10}\text{B}, ^{10-12}\text{C}, ^{13}\text{N}, ^{13,14}\text{O}$			ex
	^1H	150	^{16}O	$n, ^1\text{H}, ^4\text{He}, ^{6,7,9}\text{Li}, ^7,9,^{12}\text{Be}$ $^{13}\text{N}, ^{14,15}\text{O}$			ex
	^1H	150	$^7\text{Li}, ^9\text{Be}, ^{10,11}\text{B}, ^{13}\text{C}$ $^{18}\text{O}, ^{19,20}\text{F}$	$n, ^1\text{H}, ^4\text{He}, ^8\text{Li}, ^7\text{Be}, ^{13,17}\text{N}$ $^{14,15}\text{O}, ^{17,18}\text{F}, ^{19}\text{Ne}$			ex
[Bernas97]	^{238}U	750	Be	A Ca – APd	iso	σ	
[Bernas03]	^{238}U	1.0	^1H	A Ni – A Eu	elem, iso	σ	
[Bernas06]	^{238}U	1.0	^1H	A Gd – A Re	iso	σ	
[Bertrand73]	^1H	30 – 60	$^{12}\text{C}, ^{27}\text{Al}, ^{54,56}\text{Fe}$ $^{120}\text{Sn}, ^{197}\text{Au}, ^{209}\text{Bi}$	$1-3\text{H}, ^{3,4}\text{He}$	iso	dE, d Ω , dEd Ω , σ	
[Bertrand74]	^4He	15	$^{12}\text{C}, ^{16}\text{O}, ^{54}\text{Fe}$	$1-3\text{H}, ^{3,4}\text{He}$	iso	σ , dE, dEd Ω	
[Bhattacharya91]	^4He	15	Al	Li – O	elem	σ , dEd Ω	
[Bhattacharya95]	^7Li	5	Mg	Be – F	elem	σ , dEd Ω	
[Bhattacharya96]	^{19}F	5	^{12}C	Li – Na	elem	σ , d Ω , d θ , dEd Ω	
[Billerey81]	^{14}N	7	^{27}Al	H, He, Mg, Al, Si, P, S, Cl	elem	d Ω_1 , d Ω_2	ex
[Binns87]	$^{56}\text{Fe}, ^{84}\text{Kr}$ $^{132}\text{Xe}, ^{165}\text{Ho}$ ^{197}Au	1.0 – 1.7	H, C, CH ₂ , Al	Sn – Pt	cc, elem	σ	
[Bizard77]	^4He	1.01	^1H	^3He	iso	σ , d Ω , dpd Ω	
[Blank94]	^{58}Ni	585	Be	$^{40-44}\text{Sc}, ^{40-46}\text{Ti}, ^{43-48}\text{V}$ $^{43-49}\text{Cr}, ^{47-52}\text{Mn}, ^{46-54}\text{Fe}$ $^{50-56}\text{Co}, ^{50-57}\text{Ni}$	iso	σ	

Reference	Projectile	Kinetic Energy	Target	Fragment	Type	Cross Section	Other
[Bloch88]	^{14}N	20,35	Ag	$n, {}^6\text{--}8\text{Li}, {}^7\text{--}^{10}\text{Be}, {}^{10,11}\text{B}$	iso	$\sigma, \text{dEd}\Omega$	mult, ex
[Bobchenko79]	^1H	4.2 – 8.1	Be, B, C, F, Mg, Al S, Ca, Ti, V, Fe, Cu Nb, Cd, Sn, Ta, Pb, U ${}^{10,11}\text{B}, {}^{58,64}\text{Ni}, {}^{112,124}\text{Sn}$		total inel	σ	
[Bogatin76]	^1H	660	Al, Fe, Pb	${}^{3,4}\text{He}$	iso	dEd Ω	
[Boger94]	^1H	200 – 20.0	${}^{63}\text{Cu}$	${}^3\text{H}, {}^7\text{Be}$	iso	σ	rev
	${}^{86}\text{Kr}$	6 – 9		H – Cr	elem	$\sigma, \text{d}\Omega, \text{dEd}\Omega$	ex
[Bolshakova09]	^1H	7.1, 8.0	Be	${}^4\text{He}$	iso	dEd Ω	
[Bolshakova09a]	^1H	2.2 – 14.1	Be	${}^1\text{H}$	iso	dPd Ω	
[Bolshakova09b]	^1H	2.2 – 14.1	Ta	${}^1\text{H}$	iso	dPd Ω	
[Bolshakova10]	^1H	2.2 – 14.1	Cu	${}^{1,2}\text{H}$	iso	dPd Ω	
[Bolshakova10a]	^1H	2.2 – 14.1	Pb	${}^{1,2}\text{H}$	iso	dPd Ω	
[Brechtmann86]	${}^{56}\text{Fe}$	1.7	Ag	O – Mn	elem	σ	
[Brechtmann88]	${}^{32}\text{S}$	720	H, C	C – P	cc, elem	σ	
[Brechtmann88a]	${}^{32}\text{S}$	700, 1.2, 200.0	H, C, Al,	O – Mn	cc, elem	σ	emd
[Brechtmann88b]	${}^{16}\text{O}$	60.0, 200.0	Cu, Ag, Pb	C, N	cc, elem	σ	emd
[Brechtmann89]	${}^{28}\text{Si}$	14.5	H, C, Al	C – Al	cc, elem	σ	emd
			Cu, Ag, Pb				
[Britt61]	C, O	7, 9, 11	H, C, Al	C – Al	cc, elem	$\sigma, \text{dE}, \text{d}\Omega$	
[Brohm95]	${}^{46,47}\text{Ti}, {}^{48\text{--}51}\text{V}$ ${}^{49\text{--}53}\text{Cr}, {}^{50\text{--}56}\text{Mn}$ ${}^{51\text{--}58}\text{Fe}$ ${}^{54\text{--}55, 57\text{--}60}\text{Co}$ ${}^{56, 59\text{--}63}\text{Ni}$ ${}^{61, 62, 65}\text{Cu}$ ${}^{63, 64, 67, 68}\text{Zn}$ ${}^{69, 70}\text{Ga}$ ${}^{72, 73}\text{Ge}, {}^{74, 75}\text{As}$ ${}^{76, 77}\text{Se}$	500 – 750	Cu, Ag, Pb Au, Bi CH ₂	${}^1\text{H}, {}^4\text{He}$	iso cc	σ	

Reference	Projectile	Kinetic Energy	Target	Fragment	Type	Cross Section	Other
[Bubak07]	^1H	2.5	Au	C – Al $1-^3\text{H}, ^{3,4,6}\text{He}, ^{6-9}\text{Li}$ $^{7,9,10}\text{Be}, ^{10-12}\text{B}$	elem iso	$\sigma, \text{dEd}\Omega$ $\sigma, \text{dEd}\Omega$	
[Budzanowski08]	^1H	1.2, 1.9, 2.5	Au	$1-^3\text{H}, ^{3,4,6}\text{He}, ^{6-9}\text{Li}$ $^{7,9,10}\text{Be}, ^{10-12}\text{B}$	iso	$\text{dEd}\Omega, \sigma$	
[Budzanowski09]	^1H	175	Ni	$1-^3\text{H}, ^{3,4}\text{He}, ^{6,7}\text{Li}$ $^{7,9}\text{Be}, ^{10,11}\text{B}$	iso	$\text{dEd}\Omega, \sigma$	
[Budzanowski09a]	^1H	10 – 3.0	Ni	$1-^3\text{H}, ^{3-6}\text{He}, ^{6-8}\text{Li}, ^{7-10}\text{Be}$ $^{10,11}\text{B}, ^{12}\text{C}, ^{14}\text{N}, ^{21,22}\text{Ne}, ^{26}\text{Al}$ $^{36}\text{Cl}, ^{36,38}\text{Ar}, ^{44,46}\text{Sc}, ^{44}\text{Ti}$ $^{48}\text{V}, ^{48,51}\text{Cr}, ^{52,54}\text{Mn}, ^{55-57}\text{Co}$ $^{56,57}\text{Ni}$	iso	σ	rev
[Budzanowski10]	^1H	1.2, 1.9, 2.5	Ni, Au	$1-^3\text{H}, ^{3,4}\text{He}, ^{6-8}\text{Li}, ^{7,9,10}\text{Be}, ^{11}\text{B}$ $^{12,13}\text{N}, ^{13-16}\text{O}, ^{17,18}\text{F}$	iso	$\text{dEd}\Omega, \sigma$	w(p_z)
[Caamano04]	^{36}Ar	1.05	^9Be	$^{17-20}\text{Ne}, ^{20-22}\text{Na}, ^{20-23}\text{Mg}$ $^{22-25}\text{Al}, ^{24-27}\text{Si}, ^{27-29}\text{P}$ $^{29-31}\text{S}, ^{31-33}\text{Cl}, ^{33,34}\text{Ar}$ $^{24}\text{Na}, ^{18}\text{F}$	iso	σ	
[Caretto58]	^1H	1.0 – 6.0	Cu, Ag, Ta Au, Pb, U		iso	σ	
[Casarejos06]	^{238}U	1.0	^2H	A Ce – ANp	iso	σ	
[Caskey88]	^{14}N	35	^{165}Ho	$^{6-9}\text{Li}, ^{7,9,10}\text{Be}$ $^{10-13}\text{B}, ^{10-15}\text{C}$	iso	$\text{d}\Omega, \text{dEd}\Omega$ dpd Ω	w(p)
[Charvet87]	^{84}Kr	35	^{93}Nb	H, He	elem	dE	
[Chen94]	$^4\text{He}, ^{22}\text{Ne}, ^{26}\text{Mg}, ^{32}\text{S}$ $^{40}\text{Ca}, ^{52}\text{Cr}, ^{58}\text{Ni}$	400 – 900	H		cc	σ	
[Chen94a]	^{12}C	20	Ag	$^{43}\text{K}, ^{48}\text{Sc}, ^{48}\text{V}, ^{52}\text{Mn}, ^{52}\text{Fe}, ^{55}\text{Co}$ $^{57}\text{Ni}, ^{62}\text{Zn}, ^{67}\text{Ga}, ^{71}\text{As}, ^{87}\text{Y}, ^{89}\text{Zr},$ $^{93}\text{Mo}, ^{95}\text{Tc}, ^{97}\text{Ru}, ^{99}\text{Rh}, ^{100,101}\text{Pd}$ $^{105,106}\text{Ag}, ^{107}\text{Cd}, ^{109,111}\text{In}, ^{113}\text{Sn}$	iso	σ	

Reference	Projectile	Kinetic Energy	Target	Fragment	Type	Cross Section	Other
[Cheshire74]	$^{12}\text{C}, ^{16}\text{O}$	2.1	CsI, W		cc	σ	
[Chiba91]	^1H	831	H, C	n	iso	dEd Ω	ex
[Chrien80]	^1H	800	Li, ^6Li , ^{12}C , ^{27}Al ^{40}Ca , ^{51}V , ^{90}Zr , Pb	^1H	iso	dEd Ω	
[Christie93]	^{139}La	1.2	H, C	Fe – Ba	cc,elem	σ	w(p_{\perp})
[Chulkov00]	^{14}Be , $^{10-19}\text{B}$, $^{12-20}\text{C}$ $^{14-23}\text{N}$, $^{16-24}\text{O}$, $^{18-27}\text{F}$	930	Pb		cc	σ	
[Clerc95]	^{208}Pb	1.0	C		cc	σ	n removal
[Cline76]	^{238}U	950	Cu	$^{199-207}\text{Pb}$, $^{196-207}\text{Tl}$	iso	σ	
	^1H	590	Al, Fe, Ni, Cu	$^{230-237}\text{U}$, $^{227-237}\text{Pa}$	iso	σ	
	^1H	8.0 – 24.0	Be	$^{\text{A}}\text{Be}$, $^{\text{A}}\text{O}$, $^{\text{A}}\text{F}$, $^{\text{A}}\text{Na}$	iso	σ	
[Cocconi61]	^1H	600	^{27}Al , ^{181}Ta	$^{\text{A}}\text{Al}$, $^{\text{A}}\text{Cl}$ – $^{\text{A}}\text{K}$, $^{\text{A}}\text{Sc}$	iso	dpd Ω	
[Corde181]	^1H	10 – 340	C, N, Ne	$^{\text{A}}\text{V}$ – $^{\text{A}}\text{Zn}$	iso	dEd Ω	
mn[Courtenay-Wright50]	$^{1,2}\text{H}$	100	Ar, Kr, Xe	^1H	iso	σ	
[Cowley80]	^1H	392	^{58}Ni	^1H	iso	dEd Ω	ex
[Cowley98]	^1H	392	^{40}Ca	^1H	iso	dEd Ω	ex
[Cowley00]	^1H	392	^{40}Ca	^1H	iso	dEd Ω	ex
[Crandall56]	$^{1,2}\text{H}$, $^{2,3}\text{He}$	43 – 350	^{12}C , ^{27}Al	^3He , ^{11}C , ^{24}Na	iso	σ	ex

Reference	Projectile	Kinetic Energy	Target	Fragment	Type	Cross Section	Other
[Cumming58]	^1H	350 – 4.0	^{12}C	^{11}C	iso	σ	ex
[Cumming62]	^1H	28.0	C, Al	$^A\text{Be} - ^A\text{Mg}$	iso	σ	ex
[Cumming62a]	^1H	2.0 – 28.0	^{12}C	^{11}C	iso	σ	ex
[Cumming63]	^1H	30 – 28.0	C, Al	$^7\text{Be}, ^{11}\text{C}, ^{24}\text{Na}, ^{18}\text{F}$	iso	σ	rev
[Cumming76]	^1H	28.0	Cu	$^7\text{Be}, ^{22,24}\text{Na}, ^{28}\text{Mg}, ^{38}\text{S}, ^{34,38,39}\text{Cl}, ^{37,39,41,42}\text{Ar}, ^{42,43}\text{K}, ^{47}\text{Ca}, ^{43,44,47,48}\text{Sc}, ^{48}\text{V}, ^{48,49,51}\text{Cr}, ^{52,54,46}\text{Mn}, ^{52,59}\text{Fe}, ^{55,56,58,60,61}\text{Co}, ^{56,57,65}\text{Ni}, ^{60,61,64}\text{Cu}, ^{62,63,65}\text{Zn}, ^{66,67}\text{Ga}$	iso	σ	
[Cumming78]	^{40}Ar	2.0	Cu	$^7\text{Be}, ^{22,24}\text{Na}, ^{28}\text{Mg}, ^{37,39}\text{Ar}$	iso	σ	
[Cummings90]	$^{56}\text{Fe}, ^{139}\text{La}$	500 – 1.6	H, C, CH_2	$^{42,43}\text{K}, ^{43,44,46-48}\text{Sc}, ^{48}\text{V}, ^{48,51}\text{Cr}, ^{52,54,46}\text{Mn}, ^{52,59}\text{Fe}, ^{55-58,60}\text{Co}, ^{56,57}\text{Ni}, ^{61,64}\text{Cu}, ^{62,65}\text{Zn}, ^{66,67}\text{Ga}$	elem	σ	$\Delta Z = +1$
[Currie56]	$^{165}\text{Ho}, ^{197}\text{Au}$	450, 2.05	C, Al, Cu, Pb	Ne – Mn, Co	iso	σ	
[Currie59]	^1H	120 – 6.2	C, N, O, Mg, Al	Tc – Pt, Hg	iso	σ	
[D'Auria68]	^4He	2 – 6	C, N, O, Mg, Al, Fe, Ni, Ag, Pb	^3H	iso	σ	
[Deak90]	^{14}N	35	Ag	^3H	iso	σ	
[de Jong98]	^{208}Pb	1.0	Cu	$^3\text{H}, ^4\text{He}$	iso	σ	rev
[De Lellis11]	^{12}C	313	emulsion	$^6,7\text{Li}, ^{7-10}\text{Be}, ^{10-12}\text{B}, ^{11-13}\text{C}, ^{14,15}\text{N}$	iso	$\sigma, \text{dEd}\Omega$	rev, reac
[Devins69]	^1H	30	^7Li	$^A\text{Pr} - ^A\text{Bi}$	iso	dEd Ω	ex
[Dey09]	^{20}Ne	8, 9, 10	$^{12}\text{C}, ^{27}\text{Al}$	$^8\text{Be}, ^{1-3}\text{H}, ^{4,5}\text{He}, ^{5,6}\text{Li}$	iso	d $\Omega, \text{dEd}\Omega$	ex
[Dittrich90]	^1H	50 – 20.0	O, Mg, Al, Si, Mn, Fe, Ni	$^{10}\text{Be}, ^{26}\text{Al}, ^{1,2,3}\text{H}, ^{3,4}\text{He}$	iso	d $\Omega, \text{dEd}\Omega$	ex
[Doering78]	^4He	180	Al, Ag, Ta		iso	σ	rev

Reference	Projectile	Kinetic Energy	Target	Fragment	Type	Cross Section	Other
[Dostrovsky61]	^1H	940,1.84,2.9	Cu,Zn,Ag,In,Au,Pb,U	$^6\text{He}, ^8\text{Li}, ^7\text{Be}, ^{13}\text{N}$	iso	σ	ex
[Dostrovsky65]	^1H	1.0,2.8	B - F, Na - Si, S Ca, Ti, Ni, Cu Nb, Ag, La, Pr Nd, Ta, W, Pb, U	$^1\text{H}, ^9\text{Li}, ^{16}\text{C}, ^{17}\text{N}$	iso	σ	
[Dudkin90]	^{56}Fe	1.8	H, CNO, AgBr	H, He	elem, cc	σ	mult
[Dufauquez06]	^1H	27,63	Al, Si	$1-^3\text{H}, ^3, ^4\text{He}$	iso	d Ω , dEd Ω	
[Duisebayev03]	^4He	6,11,15	Si	$n, ^1-^3\text{H}, ^3, ^4\text{He}, ^6\text{Li}, ^7\text{Be}$	iso	d Ω , dEd Ω	ex, mult
[Duisebayev05]	^1H	30	$^{90,92}\text{Zr}, ^{92}\text{Mo}$	$1, ^2\text{H}$	iso	σ , dE, dEd Ω	
[Edge69]	^1H	30	^{56}Fe	$^1\text{H}, ^4\text{He}$	iso	σ , dE	
[Ellegaard85]	^1H	1.0,2.0,3.0	Be, C, Cu, Pb	^1H	iso	dE, dEd Ω	
[El Nadi64]	^3He	500,667,767	^1H	^3H	iso	dEd Ω	ex Δ^{++}
[El Nadi02]	$^1\text{H}, ^3\text{He}$	2,19	^{14}N	$^2\text{H}, ^4\text{He}$	iso	d Ω	
[Engelage86]	^{28}Si	3.7,14.6,200.0	Emulsion	He	elem	σ	rev, mult
[English73]	^{12}C	2.1	^{12}C	$3 \times ^4\text{He}$	iso, ex	dE	w(p_z) w(p_\perp)
[English74]	^1H	11.5,300.0	Ag	$^7\text{Be}, ^{24}\text{Na}, ^{28}\text{Mg}, ^{44,47,48}\text{Sc}$ $^{48}\text{V}, ^{52}\text{Mn}, ^{67}\text{Ga}, ^{69}\text{Ge}$ $^{74}\text{As}, ^{73}\text{Se}, ^{76,77}\text{Br}, ^{83,84}\text{Rb}$ $^{87}\text{Y}, ^{86,89}\text{Zr}, ^{90}\text{Nb}, ^{95,96}\text{Tc}$ $^{97}\text{Ru}, ^{101,103}\text{Rh}, ^{106}\text{Ag}$	iso	σ	
[English74a]	^1H	11.5	Ag	$^7\text{Be}, ^{22,24}\text{Na}, ^{28}\text{Mg}, ^{38}\text{Cl}$ $^{41}\text{Ar}, ^A\text{Sc} - ^A\text{Ag}$ $^7\text{Be}, ^{22,24}\text{Na}, ^{38}\text{Cl}, ^{41}\text{Ar}$ $^{44,46-48}\text{Sc}, ^{48}\text{V}, ^A\text{Mn} - ^A\text{Co}$ $^A\text{Cu} - ^A\text{Ga}, ^A\text{As} - ^A\text{Br}$ $^A\text{Rb} - ^A\text{Nb}, ^A\text{Tc} - ^A\text{Ag}$ $n, ^2-^3\text{H}, ^3, ^4\text{He}$	iso	σ	
[Enke99]	^1H	1.2,1.8	Fe, Ni, Ag, Ta W, Au, Pb, U		elem, iso	d Ω , dE, σ	mult

Reference	Projectile	Kinetic Energy	Target	Fragment	Type	Cross Section	Other
[Enqvist99]	^{238}U	1.0	Pb	$^A\text{H} - ^A\text{Bi}$	iso	σ	
[Enqvist01]	^{208}Pb	1.0	^1H	$^A\text{Ti} - ^A\text{Te}, ^A\text{Pm} - ^A\text{Pb}$	iso	σ	
[Enqvist02]	^{208}Pb	1.0	^2H	$^A\text{Ti} - ^A\text{Pb}$	iso	σ	
[Erb76]	^{12}C		^{12}C	$^4\text{He}, ^{20}\text{Ne}$	iso	dEd Ω	ex
[Eyal73]	^{16}O	8,10	^{197}Au	C	elem	dEd Ω	
	$^{12}\text{C}, ^{16}\text{O}$	8,10	^{197}Au	Li, Be, B, C, N	elem	$\sigma, \text{d}\Omega$	
	$^{12}\text{C}, ^{16}\text{O}$	8,10	^{197}Au	$^{202-205}\text{Po}, ^{198-203}\text{Bi}, ^{196-203}\text{Pb}$ $^{195-201}\text{Tl}, ^{195,197}\text{Hg}, ^{192-199}\text{Au}$	iso	σ	
[Fernandez05]	^{208}Pb	500	^1H	$^A\text{V} - ^A\text{Ba}$	iso	σ	
[Fink87]	^1H	41 – 600	Ti, Fe, Ni	^{41}Ca	iso	σ	
[Fink90]	^1H	40 – 200	Ti	$^{42,43}\text{K}, ^{44,46-48}\text{Sc}, ^{48}\text{V}, ^{41}\text{Ca}$	iso	σ	
[Fink00]	^1H	20 – 3.0	K, Ca, Ti, Fe	^{36}Cl	iso	σ	
[Fireman55]	^1H	2.2	N, O	n, ^3H	iso	σ	
[Flesch99]	^{56}Fe	700	H, C, Al, Cu, Ag, Pb	C – Cr	elem	σ	
[Flesch01]	^{28}Si	490	$\text{CH}_2, \text{C}, \text{Al}$	C – Al	cc, elem	σ	
[Fohr11]	^{112}Sn	1.0	Cu, Ag, Pb	$^A\text{Ne} - ^A\text{Sn}$	iso	σ	
	^{124}Sn	1.0	^{112}Sn	$^A\text{Ne} - ^A\text{Sn}$	iso	σ	
[Fontes71]	^1H	150, 600	^{124}Sn	6, $^7\text{Li}, ^{7,9,10}\text{Be}$	iso	σ	
	^4He	100 – 137	^{12}C	6, $^7\text{Li}, ^{7,9,10}\text{Be}$	iso	σ	
[Fontes77]	^1H	41, 49, 150, 600, 25.0	^{12}C	$^7\text{Be}, ^{10,11}\text{B}$	iso	σ	
	^4He	100 – 160	^{12}C	$^7\text{Be}, ^{10,11}\text{B}$	iso	σ	
[Fortney80]	^1H	800, 3.0, 11.5, 400.0	^{238}U	44, 46 – 48 Sc	iso	d Ω	
[Fortney80a]	^1H	400.0	^{238}U	44, 46 – 48 Sc	iso	dEd Ω	
[Fortsch88]	^1H	90, 200	^{12}C	^1H	iso	dEd Ω	
[Fortsch91]	^1H	100 – 200	^{58}Ni	^1H	iso	dEd $\Omega, \text{dE}, \sigma$	
[Fortsch07]	$^{12}\text{C}, ^{27}\text{Al}$	13	$^{12}\text{C}, ^{27}\text{Al}$	$^7, ^9\text{Be}$	iso	dEd Ω	
[Frankel81]	^{40}Ar	100	U	B – Si	elem	dEd Ω	
[Frascaria75]	^1H	156	^4He	B – Ne $^{1,2,3}\text{H}$	elem	dEd Ω	ex

Reference	Projectile	Kinetic Energy	Target	Fragment	Type	Cross Section	Other
[Friedlander54]	^1H	2.2	Cu	$^A\text{Be} - ^A\text{Zn}$	iso	σ	
[Friedlander55]	^1H	400 – 3.0	Al	$n, ^1\text{H}, ^7\text{Be}, ^{11}\text{C}$ $^{13}\text{N}, ^{15}\text{O}, ^{18}\text{F}, ^{22}\text{Na}$	iso	σ	ex
[Friese93]	^{136}Xe	760	Al	$^{116}\text{Rh}, ^{119}\text{Pd}, ^{122}\text{Ag}, ^{124}\text{Cd}$ $^{127}\text{In}, ^{129}, ^{130}, ^{132}\text{Sn}$ $^{132}, ^{133}\text{Sb}, ^{134}, ^{135}\text{Te}, ^{136}\text{I}$	iso	σ	
[Fukuda84]	^{14}N	9, 11, 15	^{93}Nb	$1-^3\text{H}, ^{3,4}\text{He}$	iso	$\sigma, \text{dEd}\Omega$	
[Fukuda84a]	^{14}N	15	^{232}Th	$1-^3\text{H}, ^4\text{He}$	iso	$\text{dEd}\Omega$	
[Fulmer81]	^{16}O	13	$^{12}\text{C}, ^{56}\text{Fe}, ^{91}\text{Zr}$	He, He	elem	$\text{d}\Omega, \text{dEd}\Omega$	
[Furukawa71]	^1H	5 – 50	Si, Al, Mg	$^{22}\text{Na}, ^{26}\text{Al}$	iso	σ	
[Galini74]	^{40}Ar	4, 5	Se	$^1\text{H}, ^4\text{He}, \text{Li}$	iso, elem	$\sigma, \text{d}\Omega, \text{dEd}\Omega$	
[Galini74a]	^{14}N	6, 9	^{103}Rh	$1-^3\text{H}, ^4\text{He}$	iso	$\sigma, \text{d}\Omega, \text{dEd}\Omega$	
[Gazzaly78]	^{40}Ar	1.8	Be, Cu	$1-^3\text{H}$	iso	$\text{dpd}\Omega$	
[Geaga80]	$^1\text{H}, ^{12}\text{C}, ^{40}\text{Ar}$	1.05, 2.1, 4.89, 7.71, 400.0	C, Al	^1H	iso	$\text{dpd}\Omega$	
[Geer95]	^{197}Au	10.6	H, C, CH_2 , Al Cu, Sn, Pb	Sn – Pt, Hg	cc, elem	σ	emd
[Goldhaber78]	^{12}C	2.1	Be	^{10}Be	iso	dp_z	$w(p_z)$
[Golovchenko01]	$^4\text{He}, ^{20}\text{Ne}$	250, 400, 1.05, 2.1	C, U	$1-^3\text{H}, ^{3,4}\text{He}$	type	$\text{dpd}\Omega$	
[Golovchenko02]	^{12}C	32 - 102	CH_2	B	cc, elem	σ	
[Gonthier80]	^{12}C	112 - 254	C, CH_2 , H_2O	Be, B	cc, elem	σ	
[Gooding60]	^{16}O	19	Ti	^4He	iso	dE	
[Gooding61]	^1H	153	^{12}C	^{11}B	iso	σ	ex
[Gosset77]	^4He	229	He, C	$2 \times ^4\text{He}$	iso, ex	d Ω	
[Gradsztajn65]	$^4\text{He}, ^{12}\text{C}, ^{20}\text{Ne}$	250, 400, 2.1	Al, U	$1-^3\text{H}, ^{3,4}\text{He}, ^7\text{Li}, ^{7,9,10}\text{Be}$ $^{10}\text{B}, ^{12}\text{C}, ^{14}\text{N}, ^{16}\text{O}$	iso	dEd Ω	mult
[Graulich00]	^1H	156	^{12}C	$^6\text{He}, ^{6-9}\text{Li}, ^{9,10}\text{Be}$ $^{10,11}\text{B}, ^{10,11}\text{C}$	iso	σ	
[Green80]	^1H	1	^{18}F	$^1\text{H}, ^4\text{He}, ^{15}\text{O}$	iso	dEd Ω	
[Green87]	^1H	100 – 100.0	Ag	$^{3,4}\text{He}, ^6, ^7\text{Li}, ^{7-10}\text{Be}, \text{B}, \text{C}, \text{N}$ $\text{O}, \text{F}, \text{Ne}, \text{Na}, ^{11}\text{C}, ^{24}\text{Na}, ^{32}\text{P}$	elem, iso	$\sigma, \text{d}\Omega, \text{dEd}\Omega$	rev
	^1H	190, 300	Be, Ag	$1-^3\text{H}, ^{3,4,6}\text{He}, ^6, ^7\text{Li}, ^7\text{Be}$	iso	dEd Ω	

Reference	Projectile	Kinetic Energy	Target	Fragment	Type	Cross Section	Other
[Greiner75]	$^{12}\text{C}, ^{16}\text{O}$	1.05, 2.1	Be, CH_2 , C, Al Cu, Ag, Pb	$1-^3\text{H}, ^3-^6\text{He}, ^6-^9\text{Li}$ $7-^{11}\text{Be}, ^8-^{13}\text{B}, ^9-^{15}\text{C}$ $12-^{16}\text{N}, ^{13-15}\text{O}$	iso	dp_z	$w(p_z)$
[Griffiths69]	^1H	30, 50	$^3, ^4\text{He}$	$n, ^1, ^2\text{H}, ^3\text{He}$	iso	$\sigma, d\Omega, d\text{Ed}\Omega$	ex
[Guertin05]	^1H	63	^{208}Pb	$n, ^1-^3\text{H}, ^3, ^4\text{He}$	iso	$\sigma, d\text{E}, d\text{Ed}\Omega$	
[Gupta99]	^7Li	6	^{58}Ni	$1-^3\text{H}, ^3, ^4\text{He}, ^7\text{Li}$	iso	$d\Omega, d\text{Ed}\Omega$	$\frac{d^3\sigma}{dE_\alpha d\Omega_\alpha d\Omega_t}$
[Gutbrod76]	$^4\text{He}, ^{20}\text{Ne}$	250, 400, 2.1	U	$1, ^2, ^3\text{H}, ^3, ^4\text{He}$	iso	$d\text{Ed}\Omega$	
[Harada99]	^1H	14, 18, 26	^{12}C	$^1\text{H}, ^4\text{He}, ^8\text{Be}$	iso	$d\text{Ed}\Omega$	ex
[Hautala02]	^1H	197	C, Ca, Pb	n	iso	$d\text{Ed}\Omega$	pol
[He94]	^{197}Au	2250.0	C, Al, Fe, Cu, Sn, Pb	Yb - Pt	cc, elem	σ	
[Heckman72]	^{14}N	2.1	H, C	$6, ^7\text{Li}, ^7, ^9\text{Be}, ^8, ^{10-12}\text{B}$ $9-^{13}\text{C}, ^{12, 13}\text{N}$	iso	$d\Omega (0^\circ)$	
[Heckman78]	$^{12}\text{C}, ^{14}\text{N}, ^{16}\text{O}$	2.1	Emulsion	H, He	elem	$d\Omega$	
[Heilbronm91]	$^{12}\text{C}, ^{14}\text{N}, ^{16}\text{O}$	2.1	Emulsion	$1-^3\text{H}, ^3, ^4\text{He}$	iso		$w(p)$, mult
[Henzlova08]	^{14}N	35	Ag	$6, ^7\text{Li}, ^9, ^{10}\text{Be}, ^{11, 12}\text{B}, ^{12-14}\text{C}$	iso	$d\text{Ed}\Omega$	
[Herbach06]	$^{124, 136}\text{Xe}$	1.0	Pb	A Ne - A Ba	iso	σ	
	^1H	1.2	Al, Ti, Fe, Ni, Cu, Zr, Ag	$1-^3\text{H}, ^3-^6\text{He}, ^6-^9\text{Li}$	elem, iso	$\sigma, d\text{E}$	mult
[Heydegger76]	^1H	82 - 800	Ho, Ta, W, Au, Pb, Th, U	$7, ^9, ^{10}\text{Be}$	iso		
[Hicks56]	^1H	32 - 350	Mg, Al, SiO_2	$^7\text{Be}, ^{22}\text{Na}, ^{28}\text{Mg}$	iso	σ	
[Hintz52]	^1H	10 - 150	^{27}Al $^{12}\text{C}, ^{27}\text{Al}, ^{11}\text{B}, ^{34}\text{S}$	^{24}Na $n, ^1\text{H}, ^{18}\text{F}, ^{22, 24}\text{Na}$ $^{11}\text{C}, ^{34}\text{Cl}$	iso	σ	ex
[Hirzebruch92]	^{16}O	900, 2.3 3.6, 13.5	H, C, Al, Cu Ag, Pb, CH_2 CR-39(CHO7)	C, N	cc, elem	σ	emd
[Hirzebruch95]	^{197}Au	10.0	H, C, Al, Cu, Ag, Pb	Os, Ir, Pt, Hg	cc, elem	σ	emd
[Honda60]	^1H	300 - 800	C, Fe	$^7\text{Be}, ^{22}\text{Na}, ^{26}\text{Al}, ^{34, 36, 38}\text{Cl}$ $^{42, 43}\text{K}, ^{52, 54}\text{Mn}$	iso	σ	
[Honda64]	^1H	730	Fe	$^7, ^{10}\text{Be}, ^{22}\text{Na}, ^{26}\text{Al}, ^{32}\text{Si}$ $^{34, 36, 38, 39}\text{Cl}, ^{42}\text{Ar}$ $^{40, 42, 43}\text{K}, ^{45}\text{Ca}, ^{46}\text{Sc}$ $^{44}\text{Ti}, ^{52, 54}\text{Mn}$	iso	σ	

Reference	Projectile	Kinetic Energy	Target	Fragment	Type	Cross Section	Other
[Horvath94]	^{36}Ar	35	Ag	$9-^{11}\text{Be}, ^{8,11-13}\text{B}, ^{11-15}\text{C}, ^{12-16}\text{N}$ $^{15-19}\text{O}, ^{17-21}\text{F}, ^{19-22}\text{Ne}$	iso	$\sigma, \text{dE}, \text{dEd}\Omega$	
[Horwitz60]	^1H	2.0 – 6.0	^{12}C	^{11}C	iso	σ	ex
[Hsi99]	^1H	831 – 13.7	^{197}Au	$\text{C}, ^{3,4}\text{He}$	elem, iso	$\text{dE}, \text{dEd}\Omega$	
[Hudis68]	^1H	3.0 – 30.0	$\text{C}, \text{Ag}, \text{Ta}, \text{Au}, \text{Pb}, \text{U}$	$^7\text{Be}, ^{22,24}\text{Na}$	iso	σ	
[Hudis68a]	^1H	1.0, 2.0, 3.0	$\text{Cu}, \text{Ag}, \text{Au}, \text{U}$	$^{24}\text{Ne}, ^{24}\text{Na}$	iso	σ	
[Hudis70]	^1H	3.0, 29.0	$\text{Cu}, \text{Ag}, \text{Au}, \text{U}$	$^{20-22}\text{Ne}, ^{36-39,42}\text{Ar}$ $^{76-86}\text{Kr}, ^{122-136}\text{Xe}$	iso	σ	
[Husain73]	^1H	3.0, 29.0	V	$^{\text{A}}\text{Be} - ^{\text{A}}\text{Cr}$	iso	σ	
[Hyde71]	^1H	1.0 – 30.0	Ag, Emulsion	$1-^3\text{H}, ^{3,4,6}\text{He}, ^{6-9}\text{Li},$ $7-^{10}\text{Be}, ^{9-13}\text{B}$	iso	$\sigma, \text{dEd}\Omega, \text{d}\Omega$	rev
[Iancu05]	$^{36,40}\text{Ar}$	318 – 361	H, C, Al	$^{11-14}\text{C}, ^{14,15}\text{N}, ^{18}\text{F},$ $^{20-22,24}\text{Ne}, ^{22,24}\text{Na}$	cc, elem	σ	
[Ieiri89]	^2H	33	$\text{Cu}, \text{Ag}, \text{Pb}$	N – Cl	iso	$\text{dEd}\Omega$	pol
[Inamura79]	^{14}N	7	^{58}Ni	^1H	iso	$\text{dEd}\Omega$	
[Iwamoto10]	^1H	300, 392	^{159}Tb	n, ^4He	iso	$\text{dEd}\Omega$	
[Jacak83]	^{40}Ar	Au	$^{16}\text{O}, ^{51}\text{V}, ^{159}\text{Tb}, ^{181}\text{Ta}$ $^{197}\text{Au}, ^{208}\text{Pb}, ^{209}\text{Bi}$	^1H	iso	$\text{dEd}\Omega$	
[Jaderstrom08]	^{28}Si	200, 300	42, 92, 137	^{10}Be	iso	$\text{dEd}\Omega$	
[Jaros78]	$^1, ^2\text{H}, ^4\text{He}, ^{12}\text{C}$	870, 2.1	$^1, ^2\text{H}, \text{He}, \text{C}$	$\text{A} = 1 - 14$	elem, iso	$\sigma, \text{dp}, \text{d}\Omega$	
[Jilany04]	^{24}Mg	Emulsion	3.7	$^4\text{He}, ^{12}\text{C}, ^{14}\text{N}, ^{16}\text{O}, ^{18}\text{F}$ $^{20}\text{Ne}, ^{22}\text{Na}, ^{26}\text{Al}, ^{28}\text{Si}$	tot, inel	σ	mult
[Jungthans98]	$^{208}\text{Pb}, ^{238}\text{U}$	1.0, 950	Cu	AW – AU	iso	σ	

Reference	Projectile	Kinetic Energy	Target	Fragment	Type	Cross Section	Other
[Kadkin98]	^3He	32	$^{58,64}\text{Ni}$	$1-^3\text{H}, ^3,4\text{He}$	iso	$\sigma, \text{dEd}\Omega$	
[Karnaikhov03]	$^1\text{H}, ^4\text{He}, ^{12}\text{C}$	4.0, 8.1, 14.6, 22.4	Au	He - Mg	elem	yield	
[Katcoff59]	^1H	2.2	C, Al, Cu, Ag, Au, U	^8Li	iso	dE, dEd Ω	
[Katcoff68]	^1H	3.0, 29.0	Ag	$^A\text{He} - ^A\text{Ag}$	iso	σ	
[Kaufman80]	^1H	200 - 20.0	^{197}Au	$^A\text{Na} - ^A\text{Au}$	iso	σ	
[Kavaloski63]	^1H	40	$^{12}\text{C}, ^{16}\text{O}, ^{24,25}\text{Mg}$	^2H	iso	d Ω	
[Kiang89]	^1H	35	^{24}Mg	n, ^{24}Al	iso	d Ω	ex
[Kidd88]	^{12}C	250	C	$6-^8\text{Li}, ^{7,9-11}\text{Be}$	iso	$\sigma, \text{d}\theta, \text{dp}_\perp$	w(p_z) w(p_\perp)
[Kim94]	^{12}C	135	Cu	$8,10-^{12}\text{B}, ^{10,11}\text{C}$	iso	σ	
[Kim02]	^1H	10 - 1.0	C, O	$^{22,24}\text{Na}, ^{27,28}\text{Mg}, ^{29}\text{Al}$	iso		
[Kin05]	^1H	300, 392	$^{12}\text{C}, ^{27}\text{Al}, ^{93}\text{Nb}$	$^{34,38,39}\text{Cl}, ^{41}\text{Ar}, ^{42-44}\text{K}$	iso		
[Knott96]	$^{22}\text{Ne}, ^{26}\text{Mg}, ^{32}\text{S}$	338 - 894	H	$^{47}\text{Ca}, ^{43,44,46-48}\text{Sc}$	elem		
[Knott97]	$^{36,40}\text{Ar}, ^{40}\text{Ca}$	352 - 765	H	$^{48}\text{V}, ^{48,49,51}\text{Cr}$	iso	σ	
	$^{52}\text{Cr}, ^{58}\text{Ni}$			$^{52,54,56}\text{Mn}, ^{52,53,59}\text{Fe}$	iso	dEd Ω	
	$^{36,40}\text{Ar}$			$^{55-58,60-62}\text{Co}, ^{57}\text{Ni}$	iso	σ	
				$^{60,61,64}\text{Cu}, ^{62,63,65}\text{Zn}$	elem		
				$^{10}\text{Be}, ^{14}\text{C}$	iso		
				^1H	iso		
				B - Co	elem		
				$^{17-21}\text{F}, ^{19-23}\text{Ne}$	iso		
				$^{21-25}\text{Na}, ^{22-28}\text{Mg}$	iso		
				$^{25-30}\text{Al}, ^{26-32}\text{Si}$	iso		
				$^{29-35}\text{P}, ^{31-37}\text{S}$	iso		
				$^{33-39}\text{Cl}$	iso		
				$^{3,4,6,8}\text{He}, ^{6-9}\text{Li}$	iso	σ, dp_\perp	w(p_\perp) emd
[Kobayashi88]	$^6,^8\text{He}, ^{11}\text{Li}$	790	C, Pb		iso		

Reference	Projectile	Kinetic Energy	Target	Fragment	Type	Cross Section	Other
[Korejwo00]	^{12}C	3.66	H	H, He, Li, Be, B, C $1-^3\text{H}$, $^{3,4,6}\text{He}$, ^{6-9}Li $^{7,9,10}\text{Be}$, $^{8,10-12}\text{B}$, ^{9-11}C	elem iso	σ	
[Korejwo02]	^{12}C	1.87, 2.69	H	$^{3,4,6}\text{He}$, ^{6-9}Li $^{7,9,10}\text{Be}$, $^{8,10-12}\text{B}$, ^{9-11}C $^{22,24}\text{Na}$	iso	σ	
[Korteling70]	^1H	100, 200, 300	Na – Se	^{23}Na , $^{24-26}\text{Mg}$, ^{27}Al	iso	σ	
[Korteling70a]	^1H	300, 400	$^{28-30}\text{Si}$, ^{31}P , $^{32-34}\text{S}$	^{12}C , ^{27}Al , ^{40}Ca	iso	σ	
[Kox87]	^{12}C , ^{16}O , ^{20}Ne	9 – 300	$^{54,56,57}\text{Fe}$, ^{89}Y $^{64,66,68}\text{Zn}$, Ag	^{18}F , $^{22,24}\text{Na}$	reac	σ	
[Kreutz93]	^{197}Au	600	C, Al, Cu, Pb	He – Pt	cc, elem	σ	
[Kundu08]	^{16}O	15, 16, 18, 20	^{12}C	Li, Be, B	type	σ	
[Kwiatkowski86]	^3He	66	Ag	Li – Al	elem	σ , $d\Omega$, $d\text{Ed}\Omega$	
[Lafleur66]	^1H	30 – 4.0	O, Al	^7Be	elem	$d\text{Ed}\Omega$, σ	
	^1H	30 – 85	O, Al, Ti – Cu	^7Be	iso	σ	rev
[La Tessa07]	^{40}Ar	400	Ag, Au, Pb	Ne – Ar	elem	σ	
[Lee Aamodt52]	^1H	18 – 340	H, C, Al, Cu, Sn, Pb	^{11}C	iso	σ	ex
[Leistenschneider02]	$^{17-21}\text{O}$	557-635	^{12}C	$^{11-16}\text{C}$, $^{13-19}\text{N}$, $^{16-20}\text{O}$	iso	σ	
[Lemaire79]	^{12}C , ^{20}Ne , ^{40}Ar	400, 800, 2.1	C, KCl, NaF, Pb	$^{2,3}\text{H}$, ^3He , $^{7,9,10}\text{Be}$	reac	σ	
[Lestringuez71]	^1H , ^4He	600, 220	C	$^{2,3}\text{H}$, ^3He , $^{7,9,10}\text{Be}$	iso	$d\text{pd}\Omega$	
[Letourneau02]	^1H	2.5	Au	^{1-3}H , $^{3,4,6}\text{He}$, $^{6,7}\text{Li}$	iso	σ	mult
[Lewandowski80]	^1H	72	^{27}Al , ^{59}Co , ^{90}Zr ^{197}Au , ^{208}Pb , ^{232}Th	^4He	iso	$d\text{Ed}\Omega$, $d\Omega$, σ $d\text{E}$, $d\text{Ed}\Omega$	
[Leya98]	^1H	13 – 1.6	Mg, Al, Si	$^{3,4}\text{He}$, $^{20-22}\text{Ne}$	iso	σ	
[Leya05]	^1H	44 – 2.6	Pb	$^{3,4}\text{He}$, $^{21,22}\text{Ne}$, $^{36,38}\text{Ar}$ $^{78,80-86}\text{Kr}$, $^{124,126,128-134}\text{Xe}$	iso	σ	

Reference	Projectile	Kinetic Energy	Target	Fragment	Type	Cross Section	Other
[Liang97]	$^{12}\text{C}, ^{35}\text{Cl}, ^{60}\text{Ni}$,	6, 12	$^{144}\text{Sm}, ^{121}\text{Sb}, ^{96}\text{Zr}$,	$^1\text{H}, ^4\text{He}$	iso	$\sigma, \text{dEd}\Omega$	mult
[Lindner56]	^1H	100 – 340	$^{238}\text{U}, ^{232}\text{Th}$	ABi – ANp	iso	σ	
[Lindsay62]	^1H	27 – 32	Mg, ^{27}Al	^7Be	iso	σ	
[Lindstrom75]	$^{12}\text{C}, ^{16}\text{O}$	1.05, 2.1	H, Be, CH_2 , C Al, Cu, Ag, Pb	$1-^3\text{H}, ^{3,4,6}\text{He}, ^{6-9}\text{Li}$ $7-^{12}\text{Be}, ^{8,10-13}\text{B}, ^{9-15}\text{C}$ $^{12-16}\text{N}, ^{13-15}\text{O}$	iso	σ	
[Logan80]	^{40}Ar	9	^{197}Au	$1-^3\text{H}, ^4\text{He}$	iso	$\text{d}\Omega, \text{dEd}\Omega$	fission, ex
[Logan80a]	^{40}Ar	5, 7, 9	$^{116}\text{Sn}, ^{154}\text{Sm}, ^{164}\text{Dy}, ^{197}\text{Au}$	$^1\text{H}, ^4\text{He}$	iso	$\sigma, \text{d}\Omega, \text{dEd}\Omega$	
[Loveland77]	^{12}C	2.1	U	$A = 22 - 210$	mass	σ	
[Loveland77a]	^{12}C	2.1	Au, Pb	$A = 22 - 210$	mass	σ	
[Lukyanov09]	^{72}Zn	95	Be	$^{47}\text{Ca}, ^{54}\text{V}, ^{62}\text{Co}$	iso	dp	
	$^{64,68}\text{Ni}, ^{69}\text{Cu}$	95	Be	$^{35-40}\text{Cl}, ^{36-42}\text{Ar}, ^{39-45}\text{K}$ $^{41-48}\text{Ca}, ^{46-51}\text{Sc}, ^{45-54}\text{Ti}$ $^{48-56}\text{V}, ^{50-58}\text{Cr}, ^{52-60}\text{Mn}$ $^{55-62}\text{Fe}, ^{57-64}\text{Co}, ^{59-65}\text{Ni}$ $^{64-68}\text{Cu}, ^{67-69}\text{Zn}$	iso	σ	
[Machner84]	^1H	62, 200, 558	^{27}Al	^1H	iso	$\text{dEd}\Omega$	
[Marcinkowski98]	$^1\text{H}, \text{n}$	18, 20, 26, 27	^{93}Nb	$^1\text{H}, \text{n}$	iso	$\text{dE}, \text{dEd}\Omega$	
[Marquez51]	^1H	335	Be, C, Al, Cu, Ag, Au	$^7\text{Be}, ^{11}\text{C}, ^{18}\text{F}, ^{22,24}\text{Na}$	iso	σ	
[Marquez52]	^1H	335, 420	O, F, Al, Cl, Cu, Ag, Au	$^7\text{Be}, ^{11}\text{C}, ^{13}\text{N}, ^{22,24}\text{Na}, ^{18}\text{F}$	iso	σ	
[Matsuoka83]	^2H	28	$^{58}\text{Ni}, ^{90}\text{Zr}$	^1H	iso	$\text{dEd}\Omega$	
[Meadows51]	^1H	4 – 95	$^{24-26}\text{Mg}$	$\text{n}, ^1\text{H}, ^{22}\text{Na}$	iso	σ	ex
[Merchel00]	^1H	17 – 2.6	Fe, Ni	$^{53}\text{Mn}, ^{60}\text{Fe}$	iso	σ	
[Meyer72]	$\text{n}, ^1\text{H}$	30 – 300	^4He	$\text{n}, ^{1-3}\text{H}, ^3\text{He}$	iso	σ	ex
[Meyer80]	$^1\text{H}, ^4\text{He}, ^{20}\text{Ne}$	400, 1.05, 2.1	Ag, Au, U	He – Fe	elem	$\text{dEd}\Omega$	mult, corr
	$^4\text{He}, ^{20}\text{Ne}$	400, 1.05, 2.1	U			σ	fiss
[McGill84]	^1H	800	$^{1,2}\text{H}, ^{12}\text{C}, ^{40}\text{Ca}, ^{208}\text{Pb}$	^1H	iso	$\sigma, \text{dpd}\Omega$	

Reference	Projectile	Kinetic Energy	Target	Fragment	Type	Cross Section	Other
[Michel79]	^1H	12 – 45	V, Fe, Co	$^A\text{Sc}, ^A\text{V}, ^A\text{Cr}, ^A\text{Mn}$ $^A\text{Fe}, ^A\text{Co}, ^A\text{Ni}$	iso	σ	
[Michel85]	^1H	10 – 200	Al, V, Mn, Co	$^{22,24}\text{Na}, ^{43}\text{K}, ^{47}\text{Ca}, ^{44,46-48}\text{Sc}$ $^{48}\text{V}, ^{48,51}\text{Cr}, ^{52,54}\text{Mn}, ^{55-58}\text{Co}$	iso	σ	rev
[Michel95]	^1H	800 – 2.6	C – Si, Ca – Co	$^A\text{He} - ^A\text{Zn}$	iso	σ	
[Michel96]	^1H	20 – 5.0	Mg, Al, Si, V, Mn, Fe, Ni, Cu	$^A\text{He}, ^A\text{Be}, ^A\text{Ne}, ^A\text{Na}, ^A\text{Sc}$ $^A\text{V}, ^A\text{Cr}, ^A\text{Co}$	iso	σ	rev
[Michel97]	^1H	20 – 3.0	O, Si, Al, Fe	$^{10}\text{Be}, ^{26}\text{Al}$	iso	σ	
[Mills92]	^1H	10 – 3.0	Al, Fe, Co, Sr, Y, Zr, Nb, Au	$^7\text{Be}, ^{22,24}\text{Na}, ^A\text{Sc}$ $^A\text{Mn} - ^A\text{Co}, ^A\text{Zn}$ $^A\text{Ge} - ^A\text{Ru}, ^A\text{Lu}$ $^A\text{Hf}, ^A\text{Re} - ^A\text{Hg}$ $^{46,48}\text{Sc}, ^{48}\text{V}, ^{48,49,51}\text{Cr}$ $^{52,54,56}\text{Mn}, ^{52,59}\text{Fe}$ $^{55-58,60}\text{Co}, ^{56,57}\text{Ni}$ $^{60,61,64}\text{Cu}, ^{62,63,65}\text{Zn}$	iso	σ	rev
[Miura87]	^2H	12.5	^{31}P	$^n, ^{32}\text{S}$	iso	$d\Omega$	ex
[Mocko06]	$^{40,48}\text{Ca}, ^{58,64}\text{Ni}$	140	$^9\text{Be}, ^{181}\text{Ta}$	$^A\text{B} - ^A\text{Cu}$	iso	σ, dp	
[Mocko07]	^{86}Kr	64	$^9\text{Be}, ^{181}\text{Ta}$	$^A\text{Mn} - ^A\text{Kr}$	iso	σ, dp	
[Momota02]	^{40}Ar	90	^9Be	$^{6,8-11}\text{Be}, ^{10-15}\text{B}, ^{11-18}\text{C}$ $^{13-21}\text{N}, ^{15-24}\text{O}, ^{18-26}\text{F}$ $^{19-29}\text{Ne}, ^{21-31}\text{Na}, ^{23-34}\text{Mg}$ $^{25-36}\text{Al}, ^{27-38}\text{Si}, ^{29-39}\text{P}$	iso	σ	w(p $_{\perp}$)
[Morita82]	^{16}O	290	^{12}C	$^7\text{Li}, ^{7,9-11}\text{Be}, ^{8,11-13}\text{B}$ $^{9-11,13}\text{C}, ^{12,13,15}\text{N}, ^{13-15}\text{O}$	iso	σ	
	^{12}C	250, 1.0	$^{197}\text{Au}, ^{238}\text{U}$	$^{43}\text{K}, ^{72}\text{As}, ^{89,97}\text{Zr}, ^{90}\text{Nb},$ $^{99}\text{Mo}, ^{97}\text{Ru}, ^{123,133}\text{I}, ^{145}\text{Eu},$ $^{149}\text{Gd}, ^{152}\text{Tb}, ^{155}\text{Dy}$	iso	$d\theta$	

Reference	Projectile	Kinetic Energy	Target	Fragment	Type	Cross Section	Other
[Motobayashi84]	^3He	33	^{165}Ho , $^{166,167}\text{Er}$	n , $^1\text{-}^3\text{H}$	iso	σ , dE, d Ω , dEd Ω	ex
[Mougey81]	^3He ^{12}C	30 – 100 86	^{165}Ho , $^{166,167}\text{Er}$ C, Ag, Au	n , ^1H $6\text{-}^9\text{Li}$, $^7,9,10\text{Be}$ $8,10\text{-}^{12}\text{B}$, $^9\text{-}^{11}\text{C}$ O – Si	iso iso dEd Ω (^7Be , ^{10}B) elem	σ σ dEd Ω	
[Murakami03]	^1H , ^4He , ^{16}O ^{20}Ne , ^{28}Si	290 – 12.0	Au	O – Si	iso	dE	w(p)
[Murphy83]	^9Be	27	Au	$6,7\text{Li}$	iso	dE	
[Mustapha99]	^{197}Au	800	H	$^{135\text{-}145}\text{Pm}$, $^{135\text{-}147}\text{Sm}$ $^{143\text{-}148}\text{Eu}$, $^{144\text{-}152}\text{Gd}$ $^{145\text{-}154}\text{Tb}$, $^{146\text{-}157}\text{Dy}$ $^{149\text{-}160}\text{Ho}$, $^{150\text{-}167}\text{Er}$ $^{152\text{-}166}\text{Tm}$, $^{155\text{-}170}\text{Yb}$ $^{152\text{-}173}\text{Lu}$, $^{160\text{-}191}\text{Hf}$ $^{162\text{-}180}\text{Ta}$, $^{165\text{-}183}\text{W}$ $^{167\text{-}191}\text{Re}$, $^{169\text{-}200}\text{Os}$ $^{173\text{-}193}\text{Ir}$, $^{170\text{-}196}\text{Pt}$ $^{178\text{-}196}\text{Au}$, $^{182\text{-}196}\text{Hg}$	iso iso	σ	
[Nagamiya79]	^{12}C , ^{20}Ne , ^{40}Ar	800	C, NaF, KCl, Pb	^1H	iso	dpd Ω	corr
[Nagamiya80]	^{40}Ar	800	Pb	^1H	iso	dpd Ω	mult
[Nagamiya81]	^1H , ^{12}C , ^{20}Ne , ^{40}Ar	400, 800, 2.1	C, NaF, KCl Cu, Pb	$1,2,3\text{H}$, $^3,4\text{He}$	iso	σ , dpd Ω	
[Nakayama07]	^7Li	51	^4He	^7Be	iso	dEd Ω	
[Napolitani04]	^{56}Fe	1.0	H, Ti	^ALi – ^ACo	iso	σ , dE, dp $_z$	
[Napolitani07]	^{136}Xe	1.0	^1H	^ALi – ^ABa	iso	σ	
[Natowitz81]	^{20}Ne	43	Ni, Ag, Ta	$1\text{-}^3\text{H}$, $^3,4\text{He}$	iso	dEd Ω	w(p)
[Newton62]	^1H	150	^7Li	^1H	iso	d Ω	
[Nicholls72]	^1H	141	^4He	n , $1\text{-}^3\text{H}$, $^3,4\text{He}$	iso, inel, elas	σ , dE, dEd Ω	ex
[Nilsen95]	^{84}Kr , ^{109}Ag	444 – 1.47	H, Li, C, CH $_2$ Al, Cu, Sn, Pb	Cr – Ag	cc, elem	σ	

Reference	Projectile	Kinetic Energy	Target	Fragment	Type	Cross Section	Other
[Nomura78] [Notani07]	^{14}N ^{40}Ar	6,7 100	^{209}Bi Be, Ta	n, ^4He ^{30}Mg , ^{36}Al $A = 6 - 39$ $6-8\text{Li}$, $9-11\text{Be}$, $10-14\text{B}$ $12-17\text{C}$, $13-20\text{N}$, $15-24\text{O}$, $17-26\text{F}$, $19-28\text{Ne}$, $21-31\text{Na}$ $23-33\text{Mg}$, $24-35\text{Al}$, $26-36\text{Si}$ $29-37\text{P}$, $30-37\text{S}$, $33-36\text{Cl}$ $35-38\text{Ar}$, $37-41\text{K}$	iso iso mass iso	σ dpd Ω σ	w(p)
[Ogilvie91] [Ohnuma86] [Ohnuma87] [Okihana97] [Okumusoglu74] [Olson81]	^{197}Au ^1H ^1H ^4He ^2H ^{18}O	600 35 35,40 30 6 1.7	C, Al, Cu ^{13}C ^{12}C , ^{16}O ^6Li ^1H Be, C, Al, Ti, Cu Sn, W, Pb, U	Li - P n, ^{13}N n, ^{12}N , ^{16}F ^2H , ^3-5He n, ^1H $^6,7\text{Li}$, ^{10}Be , $^{10,12}\text{B}$ $^{12-15}\text{C}$, $^{14-17}\text{N}$ $^{16,17}\text{O}$, ^{18}F	elem iso iso iso iso iso	σ d Ω d Ω d Ω , dEd Ω dEd Ω σ	mult ex ex ex ex emd
[Olson83]	^{12}C , ^{16}O	1.05, 2.1	H, Be, C, Al Cu, Ag, Pb	$1-3\text{H}$, $^{3,4,6}\text{He}$, ^{6-9}Li $^{7,9-11}\text{Be}$, $^{8,10-13}\text{B}$ $9-15\text{C}$, $^{12-16}\text{N}$ $^{13-15}\text{O}$	iso	σ	emd
[Ozawa00] [Pakou03] [Pakou05] [Parikh60] [Parikh60a] [Pate61] [Perdrisat69] [Pereira07] [Perron76]	^{40}Ar ^6Li ^7Li ^1H ^1H ^1H ^1H ^1H ^{238}U ^1H	1.0 1,2 1,2 50 - 950 100 - 1.0 680 - 1.8 600 1.0 600, 21.0	Be ^{28}Si ^{28}Si ^{12}C ^{27}Al , ^{12}C $^{235,238}\text{U}$, ^{232}Th ^2H , ^4He ^2H Fe	$^{11-19}\text{B}$, $^{13-22}\text{C}$, $^{14-23}\text{N}$, $^{16-24}\text{O}$, $^{18-29}\text{F}$ ^4He ^4He ^{11}C ^7Be , ^{11}C , ^{18}F , ^{24}Na AAc - ANp n, $^{1,3}\text{H}$ AV - ATm ^{7-10}Be , ^{22}Na , $^{45,46}\text{Sc}$, $^{48-51}\text{V}$ $^{50-54}\text{Cr}$, $^{53-55}\text{Mn}$, ^{56}Co	iso iso iso iso iso iso iso iso iso	σ σ , d Ω σ , d Ω σ σ σ dE, dEd Ω σ σ	ex ex

Reference	Projectile	Kinetic Energy	Target	Fragment	Type	Cross Section	Other
[Pfaff95]	^{86}Kr	70	Al	$^{68-76}\text{As}$, $^{69-78}\text{Se}$, $^{76-80}\text{Br}$, $^{73-82}\text{Kr}$ $^{75-85}\text{Rb}$, $^{79-85}\text{Sr}$, $^{81-85}\text{Y}$	iso	σ	w(p_z)
[Pfaff96]	^{78}Kr	75	^{58}Ni	$^{61-67}\text{Zn}$, $^{62-70}\text{Ga}$, $^{64-71}\text{Ge}$ $^{66-73}\text{As}$, $^{68-74}\text{Se}$, $^{70-75}\text{Br}$, $^{72-76}\text{Kr}$, $^{74-79}\text{Rb}$, $^{77-80}\text{Sr}$	iso	σ	
[Pfeiffer73]	$^{6,7}\text{Li}$	2,3,4	^{58}Ni , ^{118}Sn	^2H , ^4He	iso	σ , $d\Omega$	
[Pfutznner95]	$^{56,58}\text{Ni}$, ^{52}Fe	470 – 635	Be, Al	$^{54-57}\text{Ni}$, $^{50-52}\text{Fe}$	iso, emd	σ	
[Poppe63]	^2H	2 – 6	$^{1,3}\text{H}$	n	iso	dEd Ω	
[Porile64]	^1H	29.0	Cu, Fe, Ti	$^{22,24}\text{Na}$, $^{42,43}\text{K}$	iso	σ	
[Porile89]	^1H	1.6 – 18.1	Xe	Be, C, O, N, F	elem	dE	
[Poskanzer71]	^1H	5.5	U	Li – Si	elem	d Ω	
[Poskanzer75]	^1H , ^4He , ^{16}O	1.05, 2.7	Ag, U	^{1-3}H , $^{3,4,6}\text{He}$, ^{6-9}Li , $^{7,9,10}\text{Be}$ $^{10-13}\text{B}$, $^{11-15}\text{C}$, $^{14-17}\text{N}$	elem, iso	dEd Ω , d Ω , σ	
[Price91]	^{28}Si	14.5	Cu, Pb	$^{3,4}\text{He}$	iso	dEd Ω , d θ	
[Prout02]	^1H	197	^2H , $^{3,4}\text{He}$	O – Si	cc, elem, emd	σ , d Ω	
[Pugh73]	^1H	65, 85, 100	^2H , $^{3,4}\text{He}$	n, $^{1,2}\text{H}$	iso	d Ω , dEd Ω	pol ex
[Radin74]	^4He	230	^9Be , ^{12}C , ^{16}O , ^{27}Al	^7Be , ^{11}C , ^{13}N , ^{15}O , ^{18}F	iso	dEd Ω	
[Raisbeck72]	^1H , ^4He	150, 220, 600	^{12}C	$^{6,7}\text{Li}$	iso	σ	
[Raisbeck74]	^1H	150, 600	N, Mg, Si	$^{7,10}\text{Be}$	iso	σ	
[Raisbeck75]	^4He	700	C, O	$^{7,9,10}\text{Be}$	iso	σ	
[Raisbeck75a]	^1H	1, 2, 3, 23	Si, Mg, Fe, Ni	^7Be , ^{22}Na	iso	σ	
[Ramaty69]	^1H	20 – 9.0	H, He, C, N, O	n, ^{1-3}H , $^{3,4}\text{He}$, π	iso	σ , d Ω	rev
[Rayudu63]	^1H	130 – 400	Fe, Ni	^7Be , ^{32}P , ^{48}V , ^{51}Cr $^{52,54}\text{Mn}$, ^{56}Co	iso	σ	
[Reeder65]	^1H	2.2	$^{14,15}\text{N}$, $^{16,18}\text{O}$	^9Li , ^7Be	iso	σ	
[Reedy87]	^1H	20 – 10.0	Al, Si	^{26}Al	iso	σ	
[Reedy07]	^1H	5 – 10.0	C, O, Mg, Al, Si Fe, Ni, K, Ca, Ti, Cr	^{10}Be , ^{14}C , ^{26}Al ^{36}Cl , ^{41}Ca , ^{53}Mn	iso	σ	rev

Reference	Projectile	Kinetic Energy	Target	Fragment	Type	Cross Section	Other
[Regnier79] [Reinhold98]	^1H ^{129}Xe	80 – 24.0 790	Sc, Ti, V, Fe, Co, Ni, Cu Al	$^{36,38,39,42}\text{Ar}$ $^{85-93}\text{Zr}$, $^{86-96}\text{Nb}$, $^{88-98}\text{Mo}$, $^{90-100}\text{Tc}$, $^{92-103}\text{Ru}$, $^{94-112}\text{Rh}$ $^{96-114}\text{Pd}$, $^{101-117}\text{Ag}$, $^{100-119}\text{Cd}$ $^{102-122}\text{In}$, $^{102-124}\text{Sn}$, $^{108-127}\text{Sb}$ $^{110-128}\text{Te}$, $^{113-124}\text{I}$, $^{115-126}\text{Xe}$ $^{118-129}\text{Cs}$ $1-3\text{H}$, $^{3,4}\text{He}$	iso iso	σ σ	w(p_z)
[Reisdorf10]	^{40}Ca , ^{96}Ru ^{197}Au , ^{58}Ni ^{96}Zr , ^{129}Xe ^{197}Au	400 – 1.9	^{40}Ca , ^{96}Ru ^{197}Au , ^{58}Ni ^{96}Zr , ^{129}Xe ^1H	$^{131-142}\text{Nd}$, $^{133-144}\text{Pm}$, $^{134-147}\text{Sm}$ $^{139-148}\text{Eu}$, $^{141-152}\text{Gd}$, $^{144-153}\text{Tb}$ $^{147-157}\text{Dy}$, $^{148-159}\text{Ho}$, $^{150-166}\text{Er}$ $^{153-169}\text{Tm}$, $^{155-171}\text{Yb}$, $^{156-174}\text{Lu}$ $^{159-176}\text{Hf}$, $^{162-182}\text{Ta}$, $^{164-186}\text{W}$ $^{166-186}\text{Re}$, $^{169-191}\text{Os}$, $^{171-193}\text{Ir}$ $^{175-196}\text{Pt}$, $^{174-196}\text{Au}$, $^{178-196}\text{Hg}$	iso	dy	mult
[Rejmund01]	^{14}N	800	Ni, Ho	n Li, Be, B, C n, ^1H , $^{51,52}\text{Mn}$, ^{49}Cr $^{55-57}\text{Co}$, $^{65,66,68}\text{Ga}$ C, N, O, F, Ne, Na, Mg	iso	σ , dEd Ω	ex, mult ex
[Remington86]	^1H	35	Ni, Ho	n Li, Be, B, C n, ^1H , $^{51,52}\text{Mn}$, ^{49}Cr $^{55-57}\text{Co}$, $^{65,66,68}\text{Ga}$ C, N, O, F, Ne, Na, Mg	iso	σ , dEd Ω	ex, mult ex
[Remsberg63]	^1H	370	^{45}Sc , $^{50,52}\text{Cr}$, ^{55}Mn , ^{56}Fe ^{58}Ni , ^{59}Co , ^{65}Cu , $^{69,71}\text{Ga}$ Au, U	n Li, Be, B, C n, ^1H , $^{51,52}\text{Mn}$, ^{49}Cr $^{55-57}\text{Co}$, $^{65,66,68}\text{Ga}$ C, N, O, F, Ne, Na, Mg	elem iso	d Ω σ	ex, mult ex
[Remsberg75] [Renberg71]	^1H ^1H	28.0 220 – 570	Au, U H, Be, B, C, O, Na, Al, Fe I, Cu, Ge, Sn, Pb	C, N, O, F, Ne, Na, Mg	elem reac	d Ω , dEd Ω σ	

Reference	Projectile	Kinetic Energy	Target	Fragment	Type	Cross Section	Other
[Ricciardi06]	^{238}U	1.0	H	15-17N, 16-19O, 19-21F 20-24Ne, 23-26Na, 24-30Mg 27-31Al, 28-32Si, 31-35P 33-38S, 35-40Cl, 37-42Ar 39-46K, 41-48Ca, 46-54Sc 46-54Ti, 48-54V, 48-58Cr 52-61Mn, 53-63Fe, 56-66Co 58-73Ni, 60-76Cu, 62-77Zn 64-81Ga, 67-84Ge, 69-85As 71-88Se, 73-94Br, 75-95Kr 78-98Rb	iso	σ	
[Richter92]	^1H	100, 120, 150, 200	^{58}Ni , ^{100}Mo , ^{197}Au	^1H	iso	dEd Ω	
[Ridikas00]	^2H	50	^9Be , ^{12}C , ^{13}Al , ^{58}Ni , ^{93}Nb ^{181}Ta , ^{208}Pb , ^{238}U	^1H	iso	σ , d Ω dEd Ω	mult
[Roeder06]	^{48}Ca , $^{40,42}\text{S}$	100	^2H	31-33Al, 33-36Si, 36-39P, 38-41S 39,40,42Cl, 42,44,45Ar, 44-48K 46,47Ca, 48Sc	iso	σ	
[Rosenfeld56]	^1H	50 - 900	^{12}C	^{11}C	iso	σ	ex
[Rowland58]	^1H	1.0, 1.9, 2.85	C, Al, Cu, Ag, Pb	^6He	iso	σ	
[Roy81]	^1H	500	^4He , Ni, Ta	^1H	iso	dEd Ω	
[Rudy75]	^{12}C , ^1H	2.1, 300.0	Ag	^7Be , ^{24}Na , ^{28}Mg $^{42,43}\text{K}$, $^{44,46-48}\text{Sc}$, ^{48}V ^{52}Mn , ^{66}Ga , ^{69}Ge ^{74}As , $^{73,75}\text{Se}$, $^{76,77}\text{Br}$ ^{79}Kr	iso	σ	
[Samanta92]	^4He	13	^6Li	^2H , ^4He	iso	d Ω , dEd Ω	
[Sampsonidis95]	^{16}O , ^{24}Mg ^{32}S	3.65	C, Al, Cu, Ag, Pb	C, N, O, F, Ne Na, Mg, Al, Si, P $^1\text{-}^3\text{H}$	cc, iso	σ	
[Sandoval80]	^1H , ^4He ^{20}Ne , ^{18}Ar	241 - 2.1	Al, Ca, Ag, U		iso	dEd Ω	mult

Reference	Projectile	Kinetic Energy	Target	Fragment	Type	Cross Section	Other
[Scampoli05]	^{56}Fe	1.0, 5.0	$\text{CH}_2, \text{C}, \text{Al}, \text{Pb}$	$^3\text{H}, ^3,4\text{He}, ^{21}\text{Ne}, ^{36-39}\text{Ar}$	cc	σ	
[Schaeffer59]	^1H	160 – 6.0	Fe	B, C, N	iso	σ	
[Schall96]	$^{19,20}\text{Ne}, ^{18}\text{F}$ $^{15,16}\text{O}$	200 – 670	$\text{H}_2\text{O}, \text{CH}_2, \text{O}_2\text{C}_5\text{H}_8$ $\text{Al}, \text{C}, ^{14}\text{N}, ^{12}\text{C}, ^{10}\text{B}$	^{36}Cl	cc,elem	σ	
[Schiekell96]	^1H	50 – 3.0	Ca, Ti, Fe, Ni, $^{55}\text{Mn}, ^{59}\text{Co}$	$^{7,10}\text{Be}, ^{22,24}\text{Na}, ^{28}\text{Mg}$	iso	σ	rev
[Schiekell96a]	^1H	200 – 2.0	C, N, O, Mg, $^{27}\text{Al}, \text{Si}, \text{Ca}$ Ti, Mn, Fe, Co, Ni, Cu	$^{26}\text{Al}, ^{36}\text{Cl}, ^{44-48}\text{Sc}$ $^{48}\text{V}, ^{48,51}\text{Cr}, ^{47}\text{Ca}$ $^{43}\text{K}, ^{52,54}\text{Mn}, ^{59}\text{Fe}$ $^{56-58}\text{Co}, ^{56,57}\text{Ni}, ^{65}\text{Zn}$	iso	σ	rev
[Schnabel04]	^1H	98 – 1.6	Ni	^{41}Ca	iso	σ	
[Schweizer79]	^4He	180	Al, Ag, Ta	Li, Be, B, C, N, O	elem	dEd Ω	
[Segel82]	^1H	100, 164	$^{27}\text{Al}, ^{58,62}\text{Ni}, ^{208}\text{Pb}$	$^{1-3}\text{H}, ^{3,4}\text{He}$	iso	$\sigma, \text{d}\Omega, \text{dEd}\Omega$	
[Sengupta89]	$^{16}\text{O}, ^{32}\text{S}$	60.0, 200.0	Emulsion	^4He	iso	σ	mult
[Shibata85]	^4He	27	^{165}Ho	$^1\text{H}, \text{n}$	iso	$\sigma, \text{dE}, \text{dEd}\Omega$	ex, mult
[Shyam99]	^1H		^7Be	^8B	iso,emd	σ	
[Signorini03]	^6Li	5, 6, 7	^{208}Pb	$^{1,2}\text{H}, ^4\text{He}$	iso	$\sigma, \text{d}\Omega$	ex
[Singh90]	^{32}S	200.0	Emulsion	He	elem		mult
[Singh91]	^{28}Si	14.5	Emulsion	He	elem		mult
[Singh94]	$^{1,2}\text{H}, ^4\text{He}, ^{12}\text{C}$ $^{16}\text{O}, ^{22}\text{Ne}$	4.5	Emulsion		iso	σ	mult
[Singh96]	$^{24}\text{Mg}, ^{28}\text{Si}$						
[Singh10]	^{208}Pb ^{84}Kr	10.6, 160.0 950	Emulsion H, CNO, AgBr	H, He ^4He	elem iso	σ	mult mult
[Singh10a]	^{84}Kr	500 – 1.7	Emulsion	^4He	iso	w(p_{\perp})	mult
[Sisterson97]	^1H	30 – 5000	Emulsion	$^{7,10}\text{Be}, ^{22}\text{Na}, ^{26}\text{Al}, ^{7,10}\text{Be}$	iso	σ	rev
[Siwek-Wilcznska79]	^{12}C	8 – 17	O, Si ^{160}Gd	^4He	iso	σ	
[Skoski73]	^{14}N	270	H	^{11}C	iso	σ	

Reference	Projectile	Kinetic Energy	Target	Fragment	Type	Cross Section	Other
[Sobotka83]	^3He	30	Ag	$^4\text{He}, \text{Li}, ^7\text{Be}, \text{B}, \text{C}, \text{N}, \text{O}, \text{F}$	elem, iso	d Ω , dEd Ω	
[Souliotis94]	$^{18}\text{O}, ^{40}\text{Ar}$	80	$^9\text{Be}, ^{27}\text{Al}, ^{181}\text{Ta}$	Li - Ar	elem	d Ω	
[Sourkes76]	^1H	18 - 48	$^3, ^4\text{He}$		reac	σ	
[Souza09]	^6Li	3, 4, 5	^{59}Co	$^1, ^2\text{H}, ^4\text{He}$	iso	$\sigma, \text{d}\Omega, \text{dEd}\Omega$	
[Stapleton71]	^1H	7.0	O	^7Be	iso	σ	
[Steckmeyer89]	^{40}Ar	60	Ag, Au	Li - Cl	elem	dE, d Ω	mult
[Stephan91]	Kr	200	Ar	$^{\text{A}}\text{Na} - ^{\text{A}}\text{Rb}$	iso	d Ω	
[Stevenson81]	^{48}Ca	213	Be	$^{20}\text{C}, ^{27}\text{F}$	iso	σ	
[Stock80]	$^1\text{H}, ^{20}\text{Ne}, ^{49}\text{Ar}$	393, 1.04, 2.1	Ca, U	^1H	iso	dEd Ω	mult
[Stolz02]	^{112}Sn	1.015	Be, Cu	$^{75-77}\text{Sr}, ^{76-79}\text{Y}, ^{78-81}\text{Zr}$ $^{82, 83}\text{Nb}, ^{83-85}\text{Mo}, ^{86, 87}\text{Tc}$ $^{87-90}\text{Ru}, ^{90-92}\text{Rh}, ^{91-94}\text{Pd}$ $^{94-97}\text{Ag}, ^{96-99}\text{Cd}, ^{98-107}\text{In}$ $^{100-109}\text{Sn}, ^{106-109}\text{Sb}, ^{108-111}\text{Te}$	iso	σ	
[Stovall64]	^1H	40	C, $^{24}\text{Mg}, ^{54, 56}\text{Fe}$ $^{58, 56}\text{Ni}, ^{208}\text{Pb}$	^1H	iso	d $\Omega, \text{dEd}\Omega$	
[Strauch56]	^1H	96	Li - F, Na - S Cu, Ag, Pb, Bi	^1H	iso	dEd Ω	
[Streibel97]	^{197}Au	10.0	C, CH $_2$, Al Cu, Ag, Pb		cc	σ	emd
[Sugitate82]	^{93}Nb	1	^{14}N	^1H	iso	dEd Ω	pol
[Symons79]	$^1\text{H}, ^{40}\text{Ar}$	24.0, 205	$^{238}\text{U}, ^{12}\text{C}$	$^{26-30}\text{Na}$	iso	σ	
[Taieb03]	^{238}U	1.0	^1H	AW - $^{\text{A}}\text{U}$	iso	σ	inv kin
[Tanaka95]	^1H	12.0	Au	Na	elem	d $\Omega, \text{dEd}\Omega$	
[Tanihata80]	$^{12}\text{C}, ^{20}\text{Ne}, ^{40}\text{Ar}$	400, 800	C, NaF, KCl, Pb	^1H	iso	dp	mult
[Tanihata81]	^1H	800	C, NaF, KCl, Cu, Pb	^1H	iso	dpd Ω	
[Tannenwald53]	n	90	^4He	n, $^{1-3}\text{H}, ^{3, 4}\text{He}$	iso	$\sigma, \text{dE}, \text{d}\Omega$	ex
[Titarenko98]	^1H	10 - 3.0	^{209}Bi	$^{\text{A}}\text{Co} - ^{\text{A}}\text{Bi}$	iso	σ	rev
[Titarenko02]	^1H	1.0	^{208}Pb	$^{\text{A}}\text{Sc} - ^{\text{A}}\text{Bi}$	iso	σ	rev
[Titarenko06]	^1H	40 - 2.6	$^{208, \text{nat}}\text{Pb}, ^{209}\text{Bi}$	$^7\text{Be}, ^{24}\text{Na}, ^{59}\text{Fe}, ^{86}\text{Rb}$ $^{101}\text{Rh}, ^{173}\text{Lu}, ^{190, 192}\text{Ir}$ $^{196}\text{Au}, ^{199, 200}\text{Tl}, ^{203}\text{Pb}$	iso	σ	rev

Reference	Projectile	Kinetic Energy	Target	Fragment	Type	Cross Section	Other
[Titarenko08]	^1H	25 – 3.0	^{27}Al	^{22}Na	iso	σ	rev
[Tokushukoku90]	^1H	300 – 2.6	^{56}Fe	A Be – A Co	iso	σ	rev
[Toshito07]	^1h	3.2	Al	$^1,^2\text{H}$	iso	dpd Ω	
[Trockel88]	^{12}C	200 – 400	$\text{H}_2\text{O}, \text{CHO}_3$	Li, Be, B	cc,elem	σ	
[Tull90]	^{12}C	30,48,84	^{197}Au	$3 \leq Z \leq 16$	imf	σ	mult
	^{40}Ar	1.65	C, KCl	$8-^{13}\text{B}, ^{10-16}\text{C}, ^{13-18}\text{N}$	iso	$\sigma, \text{dp}_z, \text{dp}_\perp$	w(p_z) w(p_\perp)
				$^{14-20}\text{O}, ^{17-22}\text{F}, ^{19-25}\text{Ne}$	elem		
[Tyren57]	^1H	185	C	$^{21-27}\text{Na}, ^{23-30}\text{Mg}, ^{25-32}\text{Al}$	iso	d $\Omega, \text{dEd}\Omega$	(p,2p)
[Tyren66]	^1H	460	$^4\text{He}, ^6,^7\text{Li}, ^9\text{Be}, ^{10,11}\text{B}$	$^{27-34}\text{Si}, ^{29-36}\text{P}, ^{31-38}\text{S}$	iso	dEd Ω	
			$^{12}\text{C}, ^{14}\text{N}, ^{16}\text{O}, ^{27}\text{Al}$	$^{34-40}\text{Cl}$	iso		
			$^{28}\text{Si}, ^{31}\text{P}, ^{32}\text{S}, ^{40}\text{Ar}$	^1H	iso		
			$^{40}\text{Ca}, ^{51}\text{V}, ^{59}\text{Co}$	^1H	iso		
[Uozumi07]	^1H	392	^{12}C	^1H	iso	dEd Ω	
[Urbon80]	^1H	11.5	^{197}Au	^1H	iso	dE, d Ω	
[Utsunomiya80]	^{14}N	6,7,8	$^{159}\text{Tb}, ^{169}\text{Tm}, ^{181}\text{Ta}, ^{197}\text{Au}, ^{209}\text{Bi}$	$^3,^4\text{He}, ^6,^7\text{Li}$	iso	dEd Ω	
[Utsunomiya81]	^{14}N	8	^{209}Bi	$^1-^3\text{H}, ^4\text{He}$	iso	$\sigma, \text{d}\Omega, \text{dEd}\Omega$	
[Valentin65]	^1H	50 – 5.7	$^7\text{Li}, ^{10,11}\text{B}, ^{13}\text{C}, ^{14}\text{N}, ^{19}\text{F}, ^{23}\text{Na}, ^{48}\text{Ti}, ^{51}\text{V}, ^{52}\text{Cr}$	^4He	iso	d $\Omega, \text{dEd}\Omega$	
[Van Bibber79]	^{16}O	90,120	Al, Au	n, $^1\text{H}, ^{15}\text{O}, ^{13}\text{N}, ^{11}\text{C}$	iso	$\sigma, \text{d}\Omega$	
[Vaz83]	^{40}Ar	8	Ag, Sm, Au	$^6-^8\text{Li}, ^{7,9,10}\text{Be}, ^{8,10-12}\text{B}$	iso	d Ω, dp_\perp	
[Villagrasa07]	^{56}Fe	300,500 750,1.0,1.5	H	$^{10-14}\text{C}, ^{13-15}\text{N}, ^{15}\text{O}$	iso	σ	
				Be, B, C, N, O, F	elem	σ	
				$^7\text{Li}, ^{12}\text{C}, ^{16}\text{O}, ^1\text{H}, ^4\text{He}$	iso	$\sigma, \text{d}\Omega, \text{dEd}\Omega$	
				$^{16-19}\text{O}, ^{17-22}\text{F}, ^{18-24}\text{Ne}$	iso	σ	
				$^{20-27}\text{Na}, ^{22-29}\text{Mg}, ^{24-31}\text{Al}$	iso		
				$^{26-34}\text{Si}, ^{28-37}\text{P}, ^{30-39}\text{S}$	iso		
				$^{32-41}\text{Cl}, ^{34-44}\text{Ar}, ^{37-46}\text{K}$	iso		
				$^{38-48}\text{Ca}, ^{41-50}\text{Sc}, ^{42-52}\text{Ti}$	iso		
				$^{44-54}\text{V}, ^{46-55}\text{Cr}, ^{49-56}\text{Mn}$	iso		
				$^{51-55}\text{Fe}, ^{51-55}\text{Co}$	iso		

Reference	Projectile	Kinetic Energy	Target	Fragment	Type	Cross Section	Other
[Viyogi79]	^{40}Ar	213	C	$^{13-20}\text{O}$, $^{17-23}\text{F}$, $^{18-25}\text{Ne}$ $^{20-27}\text{Na}$, $^{22-30}\text{Mg}$ $^{24-32}\text{Al}$, $^{26-34}\text{Si}$ $^{29-34}\text{P}$, $^{31-38}\text{S}$	iso	σ	
[Volnin75]	^1H	1.0	$^{112,124}\text{Sn}$, $^{58,64}\text{Ni}$	$^{3,4,6}\text{He}$, ^{6-9}Li , $^{7,9}\text{Be}$ $^{10,11}\text{B}$, ^{12}C	iso	dEd Ω , d Ω	
[Waddington93]	^{197}Au	910, 10.6	A=1, 5, 12, 30, 60, 120, 200	Pr - Pt	cc, pickup	σ	
[Waddington00]	^{197}Au	910, 10.6	H, C, Cu, Pb	La - Tl	elem	σ	
		920 - 10.6	H, CH ₂ , C, Al, Cu, Sn, Pb		cc, elem	σ	
[Warner80]	^6Li	6 - 8	^6Li	^4He	iso	pickup	ex
[Warner83]	^6Li	16	^6Li	^2H , ^4He	iso	dE, σ dEd Ω	triple quad
[Warner92]	^4He	11 - 17	^7Li	^3H , ^4He	iso	dEd Ω	ex
[Warner92a]	^4He	12 - 20	^6Li	n, ^1H , ^4He	iso	dEd Ω	ex
[Warwick83]	^1H , ^4He ^{20}Ne	250 - 4.9	Au	A = 12 - 140 C - Mg	mass, elem	dEd Ω	mult
[Watanabe87]	^1H	18	^{90}Zr , ^{93}Nb , $^{92,94,96,98,100}\text{Mo}$ ^{106}Pd , Ag	^1H	iso	dE, dEd Ω	
[Watanabe90]	^1H	12, 14, 16, 18 29, 39	^{56}Fe , ^{60}Ni , ^{98}Mo , ^{106}Pd	^1H	iso	dE, dEd Ω	
[Watanabe95]	^1H , n	14, 18, 21, 26	^{93}Nb , ^{98}Mo , ^{106}Pd	^1H , n	iso	dE, dEd Ω	
[Webb87]	^{12}C	2.1	C	^{11}B + p	exc	dp $_{\perp}$	
[Webber90]	^{23}Na , $^{24-26}\text{Mg}$, ^{27}Al ^{28}Si , ^{32}S , ^{40}Ca , ^{56}Fe	600	H	$^{21,22}\text{Ne}$, ^{23}Na , $^{25,26}\text{Mg}$ $^{26,27}\text{Al}$, $^{29,30}\text{Si}$, ^{31}P	iso	σ	

Reference	Projectile	Kinetic Energy	Target	Fragment	Type	Cross Section	Other
[Webber90a]	^{12}C , ^{14}N , ^{16}O , ^{20}Ne ^{24}Mg , ^{27}Al , ^{28}Si , ^{32}S ^{40}Ar , ^{40}Ca , ^{56}Fe , ^{58}Ni	300 – 1.6	H, He, C		cc, mc	σ	
[Webber90b]	^{11}B , ^{12}C , ^{14}N , ^{16}O , ^{20}Ne ^{23}Na , ^{24}Mg , ^{27}Al , ^{28}Si ^{32}S , ^{40}Ar , ^{40}Ca , ^{56}Fe	300 – 1.6	H, He, C	Li – Mn	elem	σ	
[Webber90c]	^{11}B , ^{12}C , ^{14}N , ^{16}O , ^{20}Ne ^{23}Na , ^{24}Mg , ^{27}Al , ^{28}Si ^{32}S , ^{40}Ar , ^{40}Ca , ^{56}Fe	600	H, He, C	$^{7,9,10}\text{Be}$, $^{10-12}\text{B}$, $^{10-14}\text{C}$, $^{12-16}\text{N}$ $^{14-18}\text{O}$, $^{16-21}\text{F}$, $^{18-24}\text{Ne}$, $^{21-25}\text{Na}$ $^{22-27}\text{Mg}$, $^{24-30}\text{Al}$, $^{26-32}\text{Si}$, $^{28-35}\text{P}$ $^{30-38}\text{S}$, $^{33-39}\text{Cl}$, $^{35-41}\text{Ar}$, $^{36-44}\text{K}$ $^{38-45}\text{Ca}$, $^{43-48}\text{Sc}$, $^{44-50}\text{Ti}$, $^{47-52}\text{V}$ $^{49-54}\text{Cr}$, $^{51-55}\text{Mn}$, $^{53-56}\text{Fe}$ $^{55-57}\text{Co}$, $^{56,57}\text{Ni}$	iso	σ	
[Webber98]	^7Li , ^9Be , ^{11}B , ^{12}C , $^{14,15}\text{N}$ ^{16}O , $^{20,22}\text{Ne}$, ^{56}Fe , ^{58}Ni	353 – 620	H	Li – F, Si – Co	cc, elem	σ	
[Webber98a]	^9Be , ^{11}B , ^{12}C , $^{14,15}\text{N}$ ^{16}O , $^{20,22}\text{Ne}$, ^{56}Fe , ^{58}Ni	365 – 620	H	$^{7,9,10}\text{Be}$, $^{10,11}\text{B}$, $^{10-14}\text{C}$, $^{13-16}\text{N}$ $^{14-20}\text{O}$, $^{17-21}\text{F}$, $^{18-21}\text{Ne}$, $^{32-36}\text{S}$ $^{34-38}\text{Cl}$, $^{36-40}\text{Ar}$, $^{39-43}\text{K}$, $^{40-45}\text{Ca}$ $^{43-47}\text{Sc}$, $^{44-50}\text{Ti}$, $^{47-51}\text{V}$, $^{49-54}\text{Cr}$ $^{51-55}\text{Mn}$, $^{53-55}\text{Fe}$, $^{55-57}\text{Co}$,	iso	σ	
[Webber98b]	^6Li , ^{10}B , ^{19}F , ^{21}Ne , $^{22,23}\text{Na}$ $^{24,25}\text{Mg}$, $^{26,27}\text{Al}$, $^{28,29}\text{Si}$, $^{30,31}\text{P}$ $^{32,33}\text{S}$, $^{34,37}\text{Cl}$, $^{36,38}\text{Ar}$, $^{42,44}\text{Ca}$ $^{44,46}\text{Sc}$, $^{46,48}\text{Ti}$, $^{48,50}\text{V}$, $^{50,52}\text{Cr}$ $^{52,55}\text{Mn}$, $^{54,56}\text{Fe}$ ($Z_p = 3, 5, 9 - 18, 20 - 26$)	500-600	H	Li – Mn $^{15-18}\text{O}$, $^{17-20}\text{F}$, $^{19-23}\text{Ne}$ $^{21-25}\text{Na}$, $^{23-27}\text{Mg}$, $^{25-29}\text{Al}$ $^{27-31}\text{Si}$, $^{29-33}\text{P}$, $^{31-36}\text{S}$ $^{33-38}\text{Cl}$, $^{36-41}\text{Ar}$, $^{39-43}\text{K}$ $^{40-46}\text{Ca}$, $^{43-48}\text{Sc}$, $^{45-50}\text{Ti}$ $^{47-52}\text{V}$, $^{49-54}\text{Cr}$, $^{51-54}\text{Mn}$ $^{52-53}\text{Fe}$	cc, elem iso	σ σ	

Reference	Projectile	Kinetic Energy	Target	Fragment	Type	Cross Section	Other
[Weber92]	^{86}Kr	500	Be	$^{53-55}\text{Sc}$, $^{56-58}\text{Ti}$, $^{60,61}\text{V}$ $^{61-64}\text{Cr}$, $^{64-66}\text{Mn}$, $^{66-69}\text{Fe}$ $^{69-72}\text{Co}$, $^{72-75}\text{Ni}$	iso	σ	
[Weber94]	^{86}Kr	500	Be	^{41}K , $^{59-67,70}\text{Cu}$, $^{61-70,75-77}\text{Zn}$ $^{64-72,76-78}\text{Ga}$, $^{65-74,79-82}\text{Ge}$ $^{68-77,80,81,83}\text{As}$, $^{70-79,83,84}\text{Se}$ $^{72-81}\text{Br}$, $^{74-84}\text{Kr}$	iso	σ , dp_z	w(p_z)
[Wefel79]	^{14}N	530	H	Li, Be, B, C	elem	σ , $\text{d}\Omega$, dp_\perp	w(p)
[Wesick85]	^1H	100, 150	^2H , $^3,^4\text{He}$	$^1,^2\text{H}$	iso	$\text{dEd}\Omega$	ex
[West66]	^4He	10	^{59}Co , $^{58,60,62}\text{Ni}$, $^{63,65}\text{Cu}$	^1H	iso	σ , $\text{d}\Omega$, $\text{dEd}\Omega$	
[Westerberg78]	^{12}C , ^{20}Ne	13, 9	Nb, Rh, Pd, Pt	n , ^4He	iso	dE , $\text{dEd}\Omega$	mult
[Westfall79]	^{56}Fe	600, 1.05, 1.88	^{158}Gd , ^{150}Nd	Al - Mn	cc,mc,elem	σ	emd
[Westfall79a]	^{48}Ca	21.0, 24.0	H, Li, Be, B C, S, Cu, Ag Ta, Pb, U	$^{36,38,39,42}\text{Ar}$, $^{45,46}\text{Sc}$, $^{48-51}\text{V}$, $^{50,51,53}\text{Cr}$, ^{54}Mn $^{14-18}\text{C}$, $^{17-22}\text{N}$, $^{20-23}\text{O}$ $^{21-26}\text{F}$, $^{24-28}\text{Ne}$, $^{27-31}\text{Na}$ $^{29-34}\text{Mg}$, $^{32-36}\text{Al}$, $^{35-39}\text{Si}$ $^{37-42}\text{P}$, $^{39-44}\text{S}$, $^{41-45}\text{Cl}$	iso	σ	rev
[Westfall82]	^{20}Ne	100, 156	Au	$^1,^2\text{H}$, ^4He	iso	$\text{dEd}\Omega$	
[Westfall84]	^{12}C	35	Au	$^1-^3\text{H}$, $^3,^4,^6\text{He}$	iso	$\text{dEd}\Omega$	
[Wickersham57]	^1H	28	^4He	n , $^1-^3\text{H}$, $^3,^4\text{He}$	iso	σ , $\text{d}\Omega$	ex
[Wilczynski80]	^{14}N	10	^{159}Tb	$^4,^6\text{He}$, $^6,^7\text{Li}$, $^7-^{10}\text{Be}$ $^{10-12}\text{B}$, $^{11-13}\text{C}$	iso	σ	
[Whitfield93]	^{12}C	90	Cu	$^{22,24}\text{Na}$, ^{28}Mg , $^{34,39}\text{Cl}$, ^{41}Ar , $^{42,43}\text{K}$, $^{43,44,46-48}\text{Sc}$ ^{48}V , $^{48,49,51}\text{Cr}$, $^{52,54,56}\text{Mn}$ $^{52,59}\text{Fe}$, $^{55-58,60}\text{Co}$ $^{56,57,65}\text{Ni}$, $^{60,61,64}\text{Cu}$ $^{62,63,65}\text{Zn}$	iso	σ	

Reference	Projectile	Kinetic Energy	Target	Fragment	Type	Cross Section	Other
[Wlazlo00]	^{208}Pb	1.0	H	$^{134-145}\text{Pm}$, $^{136-147}\text{Sm}$, $^{138-151}\text{Eu}$ $^{140-154}\text{Gd}$, $^{142-157}\text{Tb}$, $^{145-160}\text{Dy}$ $^{147-163}\text{Ho}$, $^{149-166}\text{Er}$, $^{152-169}\text{Tm}$ $^{154-172}\text{Yb}$, $^{156-175}\text{Lu}$, $^{159-178}\text{Hf}$ $^{161-182}\text{Ta}$, $^{163-185}\text{W}$, $^{166-188}\text{Re}$ $^{168-190}\text{Os}$, $^{171-199}\text{Ir}$, $^{174-201}\text{Pt}$ $^{177-205}\text{Au}$, $^{180-201}\text{Hg}$, $^{184-207}\text{Tl}$ $^{188-208}\text{Pb}$	iso	σ	
[Wu79]	^1H	90,100	^{27}Al , ^{58}Ni ^{90}Zr , ^{209}Bi	$1-^3\text{H}$, $^{3,4}\text{He}$	iso	σ , dEd Ω , d Ω , dE	
[Yamada79]	^{14}N	12	^{154}Sm	$1-^3\text{H}$	iso	dE	
[Yamaguchi06]	^{80}Kr	1.05	Be	$^{64-68}\text{Ge}$, $^{66-70}\text{As}$, $^{68-72}\text{Se}$ $^{70-74}\text{Br}$, $^{72-76}\text{Kr}$, $^{74,76,78}\text{Rb}$	iso	σ	
[Yamaguchi10]	^{28}Si	90 – 550	C	^{11}C , ^7Be , $^{22,24}\text{Na}$, $^{27,28}\text{Mg}$, ^{29}Al , $^{24,38,39}\text{Cl}$, ^{41}Ar , $^{42,43}\text{K}$ $^{44,46-48}\text{Sc}$, $^{48,49,51}\text{Cr}$, $^{54,56}\text{Mn}$ $^{52,59}\text{Fe}$, $^{55-58,60-62}\text{Co}$, $^{57,65}\text{Ni}$ $^{60,61,64}\text{Cu}$, $^{62,63,65}\text{Zn}$	cc	σ	
[Yashima03]	^1H , He , C , Ne , Ar	100,230	C, Al, Cu		iso	σ	
[Yashima04]	^1H , He , Ne , C , Ar , Si	100,230,400,800	Al, Cr, Fe Ni, Cu, Pb	^7Be , ^{11}C , $^{22,24}\text{Na}$, $^{27,28}\text{Mg}$ ^{29}Al , $^{34,38,39}\text{Cl}$, ^{41}Ar $^{42,43}\text{K}$, $^{43,44,46-48}\text{Sc}$, $^{48,49,51}\text{Cr}$ $^{54,56}\text{Mn}$, $^{52,59}\text{Fe}$ $^{55-58,60-62}\text{Co}$, $^{57,65}\text{Ni}$ $^{60,61,64}\text{Cu}$, $^{62,63,65}\text{Zn}$ ^{202}Tl , ^{201}Pb , $^{204,205}\text{Bi}$	iso	σ	
[Yennello91]	^3He	300,1.2	Ag	C	elem	dEd Ω	mult
[Yennello93]	^3He	160 – 1.2	Ag, ^{197}Au	Li – Na	elem	σ , d Ω , dEd Ω	mult

Reference	Projectile	Kinetic Energy	Target	Fragment	Type	Cross Section	Other
[Yiou68]	^1H	135 – 19.0	O,Al	$^1\text{H}, ^6,7\text{Li}, ^7-^{10}\text{Be}$ $^{10,11}\text{B}, ^{22}\text{Na}$	iso	σ	
[Yiou69]	^1H	135,600,19.0	O	$^6,7\text{Li}, ^7,9\text{Be}, ^{10}\text{B}$	iso	σ	
[Yokoyama01]	C	180,290	Nb,Pr,Au	A = 60 – 200	iso	σ	rev
[Yule60]	^1H	80 – 500	$^{12}\text{C}, ^{14}\text{N}, ^{19}\text{F},$ $^{23}\text{Na}, ^{27}\text{Al}, ^{45}\text{Sc}$ $^{54}\text{Fe}, ^{59}\text{Co}, ^{58}\text{Ni}$ $^{63,65}\text{Cu}, ^{64}\text{Zn}, ^{69}\text{Ga}$ $^{75}\text{As}, ^{81}\text{Br}, ^{89}\text{Y}$ $^{100}\text{Ru}, ^{100}\text{Mo}$ $^{107}\text{Ag}, ^{127}\text{I}, ^{133}\text{Cs}$ $^{142}\text{Ce}, ^{181}\text{Ta}$ $^{197}\text{Au}, ^{232}\text{Th}, ^{238}\text{U}$	A- ^1T Target	iso	σ	rev
[Zamani10]	^2H	250 – 2.5	Pb	Be – Na	inel	σ	rev
[Zeitlin97]	^{56}Fe	1.05	H,C,Al,Cu,Pb	Mg – Mn	cc,elem	σ	
[Zeitlin01]	^{20}Ne	600	H,C,Al,Cu,Sn,Ta,Pb	H – F	cc,elem	σ	
[Zeitlin07]	^{12}C	290,400	H,C,Al,Cu,Sn,Pb	H – B	cc,elem	$\sigma, \text{d}\Omega$	
[Zeitlin07a]	^{28}Si	263 – 1.16	H,C,Al,Cu,Sn,Pb	C – Al	cc,elem	σ	
[Zeitlin08]	$^{35}\text{Cl}, ^{40}\text{Ar}$ ^{48}Ti	290,400,650,1.0	H,C,Al,Cu,Sn,Pb	B – Sc	cc,elem	σ	
[Zeitlin11]	$^{14}\text{N}, ^{16}\text{O}$ $^{20}\text{Ne}, ^{24}\text{Mg}$	290 – 1.0	H,C,Al,Cu,Sn,Pb	Be – Na	cc,elem	σ	
[Zhou10]	n	37	^{209}Bi	n	iso	d Ω	
[Zhu91]	^3He	67	Ag	^1H	iso	dEd Ω	

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14. ABSTRACT Human space flight requires protecting astronauts from the harmful effects of space radiation. The availability of measured nuclear cross section data needed for these studies is reviewed in the present paper. The energy range of interest for radiation protection is approximately 100 MeV/n to 10 GeV/n. The majority of data are for projectile fragmentation partial and total cross sections, including both charge changing and isotopic cross sections. The cross section data are organized into categories which include charge changing, elemental, isotopic for total, single and double differential with respect to momentum, energy and angle. Gaps in the data relevant to space radiation protection are discussed and recommendations for future experiments are made.					
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