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Λ_C PHOTOPRODUCTION AND LIFETIME MEASUREMENT

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ABSTRACT

A measurement of the lifetime of the Λ_c baryon photoproduced coherently off a Germanium-Silicon target is presented. A signal of $\Lambda_c \rightarrow \Delta K^* \rightarrow pK\pi\pi^0$ has been observed and the two different decay diagrams for this process are compared. A sample of 9 Λ_c decays gives a lifetime of $1.1^{+0.8}_{-0.4}\ 10^{13}$ s.

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1. Introduction

The knowledge of charmed baryon lifetimes and decay modes is still rather poor. In particular the short lifetime of the Λ_c makes the measurement of its lifetime difficult.

In the NA1 experiment we use a technique based on the direct measurement of the decay path of the particle by means of a Germanium-Silicon active target taking full advantage of the large Lorentz factor available in high energy photoproduction.

In this paper we present for the first time a signal in Λ_c decaying into $pk\pi\pi^0$ and we measure its lifetime.

2. Apparatus

The NA1 apparatus, consisting of a tagged photon beam, an active target and a forward spectrometer for charged and neutral particles with two threshold Cerenkov counters, is described elsewhere [1]. The target samples the ionization of crossing charged particles with a granularity of 100 μm and identifies the locations of the primary and secondary vertices due to particle production and decay by means of steps in ionization. This detector allows a very precise definition of decay lengths : the efficiency for the detection of proper time larger than 0.02 ps is greater than 85% due to the average gamma factor of 50. An example of a Λ_c event as seen in the target is shown in Fig.1.

Data were taken at the CERN SPS using a 225 GeV electron beam striking a lead radiator. The tagging system selected bremsstrahlung photons in the energy range 70-220 Gev; tight trigger conditions were used to reject the large electromagnetic background.

The total sample amounts to 5 10^6 triggers. For charmed particle identification we have considered only events with at least four charged tracks, with no electrons within 5 mr of the forward direction, and with at most one track not in the forward spectrometer acceptance. This selection reduces the data to about 1.5 10^5 purely hadronic events that have been used for a Λ_c search.

3. Evidence for Λ_c photoproduction

We started our search for Λ_c and $\bar{\Lambda}_c$ by selecting events with a proton identified by the Cerenkov counters. In this way we limited the proton momentum in the range 17 to 43 GeV. We looked for a signal in $pK^-\pi^+$, $pK^-\pi^+\pi^0$ and the charge conjugated channels. Since the combinatorial background was overwhelming we added the requirement of Λ_0 tagging, defined as a single track with impact parameter greater than 2.5 cm at the center of the target. Selecting the events in which one of the Λ_c decays into Λ^0 we enhanced the $\Lambda_c\bar{\Lambda}_c$ production since the branching ratio $\Lambda_c \rightarrow \Lambda^0$+X is high [2]. Fig 2 shows the invariant mass plot of the $pK^-\pi^+\pi^0$ and charged conjugated channel for the events selected in this way (solid line) : a clear signal at the Λ_c mass is seen. The dashed line in the plot represents the background evaluated by computing the mass combinations for the wrong sign (Cabibbo suppressed) mode $pK^+\pi^-\pi^0$ and its charge conjugated channel. This background is mostly due to combinations of the same events that appear in the peak with different mass assignments. We do not see any signal in $pK^-\pi^+$ and its charge conjugated channel due to the large combinatorial background.

Among the 13 combinations in the peak we found 7 combinations with the $K\pi$ system compatible with the K^* mass and 6 combinations with the $p\pi$ system compatible with the Δ mass. We then replaced the Λ^0 tagging requirement by the condition that either a K^* or a Δ be present in the combination. Fig. 3 (solid line) shows the invariant mass plot for $pK^-\pi^+\pi^0$ and charged conjugated channel when a $K\pi$ invariant mass is compatible with a K^* while Fig. 4 shows the Δ case. In both figures the dashed line shows the wrong sign combinations.

Following the observation that in many of these events Δ and K^* are present in the same combination we have added the requirement of having both present and we have removed the condition of proton identification that reduces our momentum acceptance. Fig. 5 shows the invariant mass plot for the right sign (solid line) and wrong sign (dashed line) combinations satisfying these conditions.

The average number of combinations per event in the plot of Figs. 2-5 is 1.2 in the interval 2250 to 2330 MeV. Due to overlap between the different samples some events are present in more than one plot. Altogether we have identified 31 events of $\Lambda_c \to pK^-\pi^+\pi^0$ and 23 of the charge conjugated mode with a background of 6 and 4 events respectively. These numbers have been evaluated also taking into account the wrong combinations of the Λ_c events contributing to the background. The statistically equivalent number of Λ_c and $\bar{\Lambda}_c$ is in agreement with diffractive photoproduction as selected by the trigger of the experiment.

4. Exchange diagram

The decay $\Lambda_c \to \Delta^+\bar{K}^{*0}$ can go via a W exchange diagram or via a "spectator" single quark decay. The decay $\Lambda_c \to \Delta^{++}K^{*-}$ can go only through the exchange diagram as shown in Fig. 6. A prediction on the relative importance of diagram A and B of Fig. 6 is obtained with the Clebsch-Gordan coefficients in the hypothesis of a $\Delta I=1$ transition : the decay via diagram A occurs with a rate three times that of diagram B.

The probability of detecting the two channels $\Delta^{++}K^{*-}$ and $\Delta^+\bar{K}^{*0}$ is different since the analysis is restricted to the final state $pK^-\pi^+\pi^0$.

```
Δ++  K*-                          Δ+  K̄*0
|    |                            |   |
|    |-→ K-π0  33%                |   |--→ K-π+  67 %
|-----→ pπ+    100%               |------→ pπ0   67%
```

We found 27 $\Delta^{++}K^{*-}$ and 18 $\Delta^+\bar{K}^{*0}$ events with an evaluated background of 5 and 3 respectively. Hence, taking into account the quoted braching ratios, we conclude that the ratio $|A|^2/|B+C|^2$ is 2±.7 . The interference between the diagram B and C in the decay $\Lambda_c \to \Delta^+\bar{K}^{*0}$ prevents us making a quantitative conclusion on the ratio $|B|^2/|C|^2$, however this result shows that the exchange diagram plays a significant role in Λ_c decay.

5. Measurement of the lifetime

The 54 final Λ_c have been carefully scanned and the target information has been analysed. Although a large fraction of the events present the typical pattern of a non coherent interaction with nuclear breakup, we found 9 events with a single charge multiplicity change of 2 that we interpreted as Λ_c decays. In addition we found 3 events with 2 multiplicity changes of 2.

For the measurement of the lifetime we use only the sample with a single charged multiplicity change of 2 because the presence of two multiplicity steps of 2 makes the association with the reconstructed Λ_c ambiguous. This selection does not reduce the decay sample significantly because the other Λ_c, possibly associated to the reconstructed one, decays for a large fraction (60% [3]) with a charge multiplicity change other than 2.

Small corrections have been applied for the inhomogeneity of the target and the range of detectable decay times. The corrected distribution of the events versus the decay time is shown in Fig. 7. It has been fitted to an exponential decay function using the maximum likelihood method, providing a lifetime of

$$\tau_{\Lambda_c} = 1.1^{+0.8}_{-0.4} \quad 10^{-13}\ \mathrm{s}$$

The line superimposed on the data in Fig. 7 shows the fitted exponential.

The 54 Λ_c candidates contain a background of 10 events. In order to evaluate the systematic effect on the lifetime we have studied the occurrence of events with a single multiplicity change of 2 in the phase space background. Among 194 background events we found 13 events with the requested pattern in the target, corresponding to a contamination of 0.7 events in the sample used for the lifetime measurement. The quoted lifetime value does not change appreciably when one random event is excluded from the sample.

Among the 9 events one was also compatible with the D_s mass when the mass of the proton was replaced with mass of the kaon in calculating the invariant mass of the Λ_c. The other 8 events had no ambiguity. Excluding this event from the data sample did not change the lifetime value appreciably.

Another possible source of systematic error is the multiplicity change in the target being produced by the associated Λ_c instead of the one we detected in the spectrometer. With the request of a single secondary vertex detected in the target this effect, evaluated with a Montecarlo program, is of the order of 2%. The importance of this error increases if we consider the possible contamination of associated D production in our sample. We believe that this production mechanism is not significant in our experimental conditions for the following reasons :

1) We searched for associated charmed particles in the 9 event lifetime sample by taking all particles not used in making our Λ_c's and we did not find a single associated D while 2 fully reconstructed $\Lambda_c\bar{\Lambda}_c$ events were present.

2) Since in diffractive coherent photoproduction the final state has baryon number 0, $\Lambda_c\bar{\Lambda}_c$ production is energetically more economic. A simple calculation in terms of masses and the Germanium form factor shows that this production mechanism is favoured by a factor 2. A Monte Carlo simulation shows that a D meson contamination at this level would increase the fitted lifetime value by 18%.

3) The selection procedure for the decay multiplicity steps in the target pattern strongly reduces the possible contamination by D decays. The probability of detecting the Λ_c decay in the target is very high (> 80%) and therefore the single multiplicity step of 2 observed is most likely the one associated with the reconstruced Λ_c.

Two groups have recently presented measurements for the Λ_c lifetime [4-5] :

$$1.2^{+0.5}_{-0.3}\ 10^{-13}\ \mathrm{s} \quad \text{and} \quad 1.4^{+0.5}_{-0.3}\ 10^{-13}\ \mathrm{s}$$

These results are in agreement with our measurement. All three results are consistently lower than the present world average [2] :

$$2.3^{+0.8}_{-0.5}\ 10^{-13}\ \mathrm{s}$$

We emphasize that our measurement technique gives a direct observation of the production and decay points and is particularly sensitive to lifetimes around 10^{-13} s.

Our results indicate also that W-exchange makes a significant contribution to Λ_c decay.

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Figure Captions

1) The pulse height for each Ge strip/Si layer in equivalent minimum ionizing particles for a typical Λ_c decay (multiplicity 0-4-6).

2) Invariant mass plot of $pK^-\pi^+\pi^0$ and charge conjugated channel (solid line) in the events with a Λ^0 tagging. The dashed line represent the background.

3) Invariant mass plot of $pK^-\pi^+\pi^0$ and charge conjugated channel (solid line) in the events with a K^* tagging. The dashed line represent the background.

4) Invariant mass plot of $pK^-\pi^+\pi^0$ and charge conjugated channel (solid line) in the events with a Δ tagging. The dashed line represent the background.

5) Invariant mass plot of $pK^-\pi^+\pi^0$ and charge conjugated channel (solid line) in the events with a Δ and K^* tagging. The dashed line represent the background.

6) Diagrams contributing to the decay $\Lambda_c \to \Delta K^*$.

7) Distribution of number of events versus decay time for the 9 selected events.

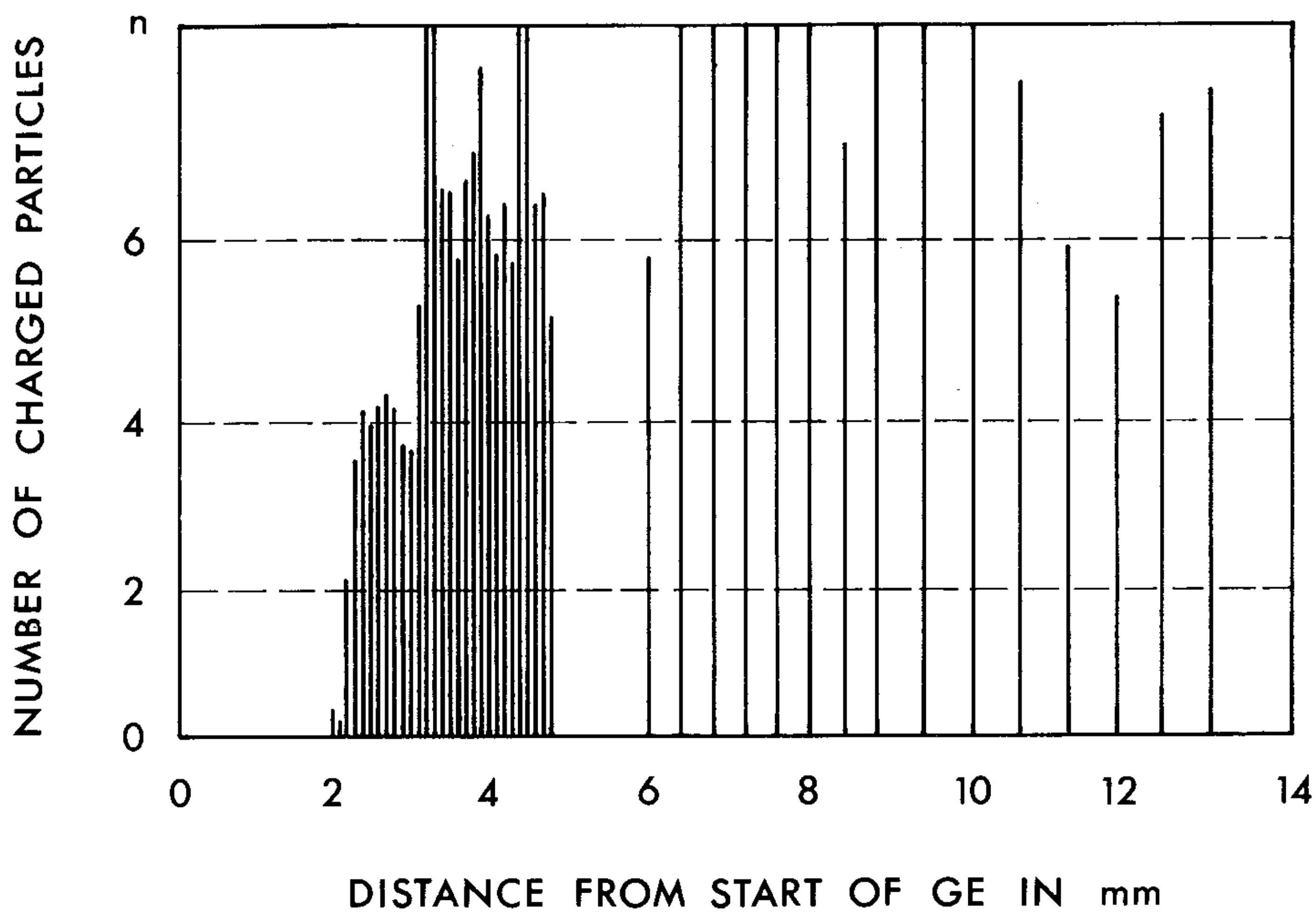

n
6
4
2
0
0
2
4
6
8
10
12
14
NUMBER OF CHARGED PARTICLES
DISTANCE FROM START OF GE IN mm

Fig. 1

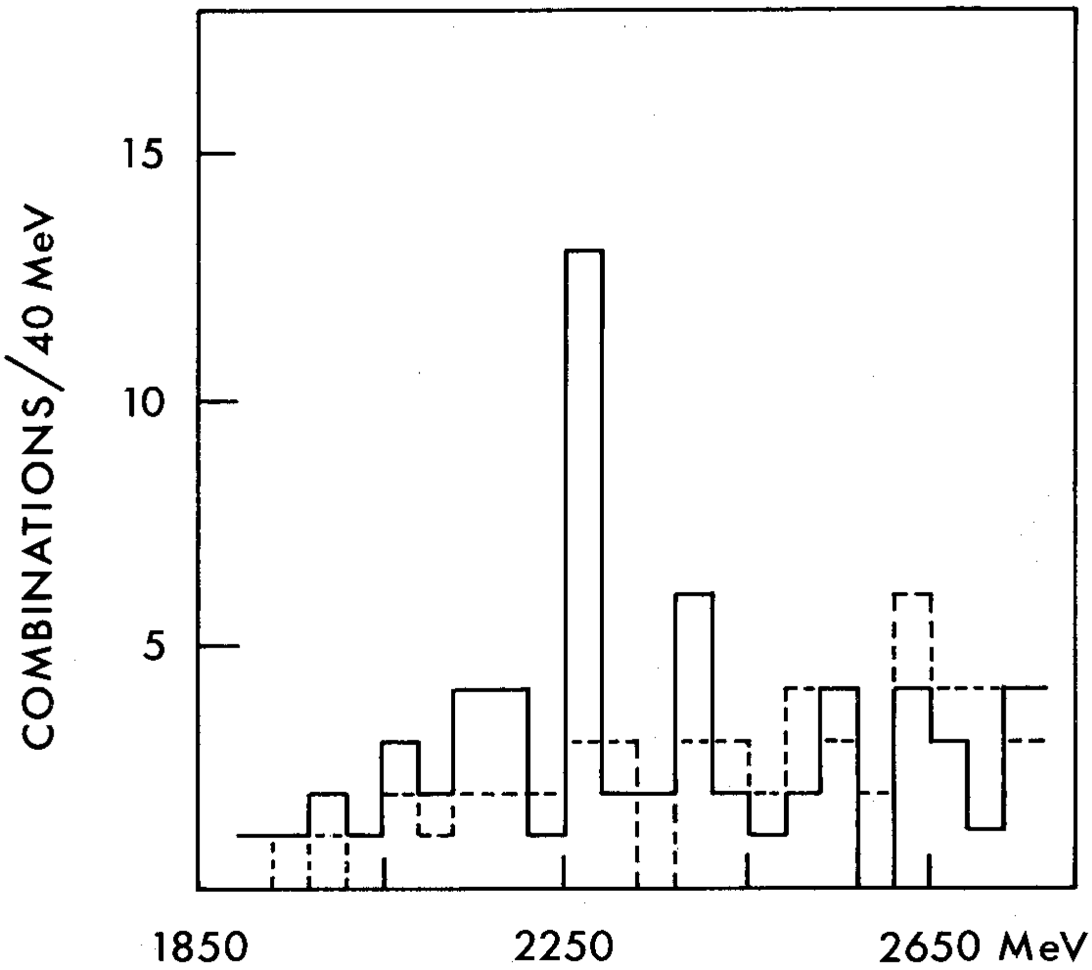


Fig. 2

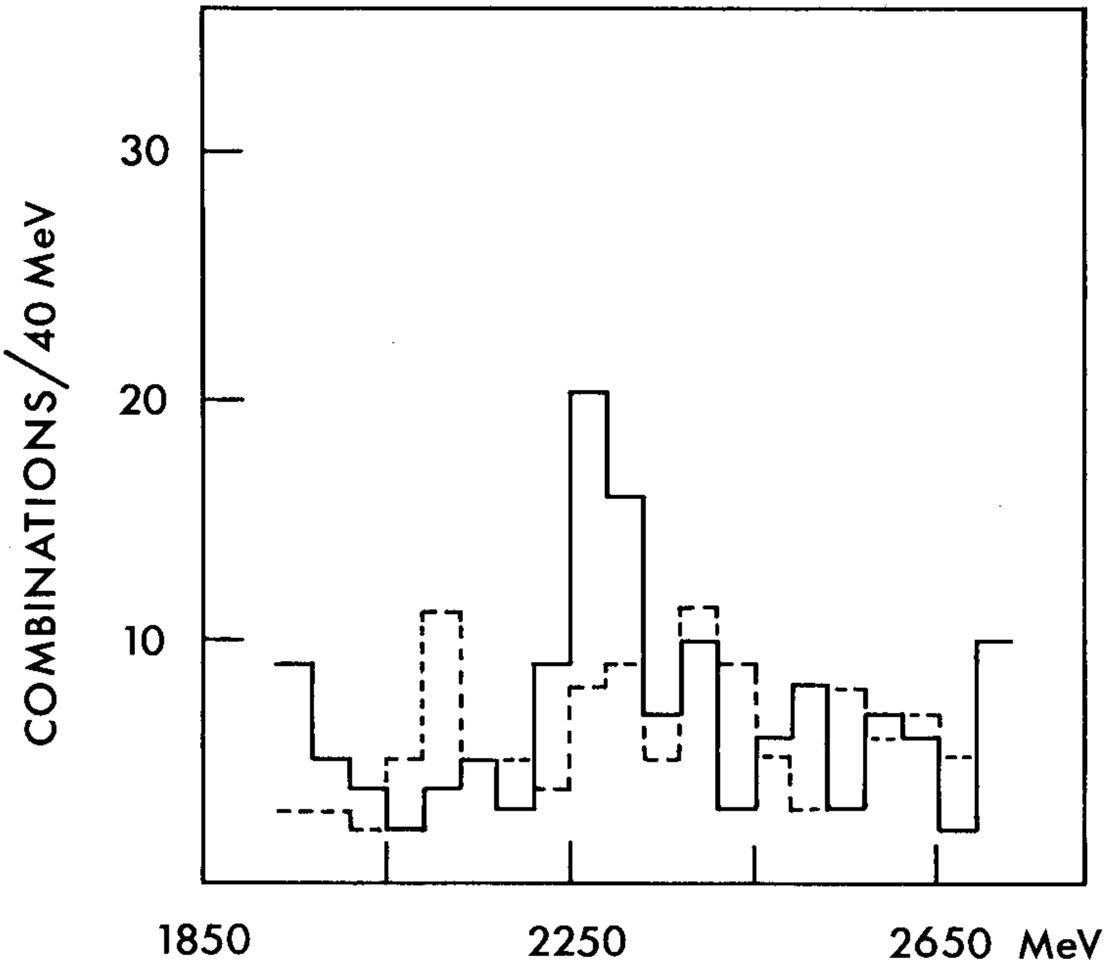


Fig. 3

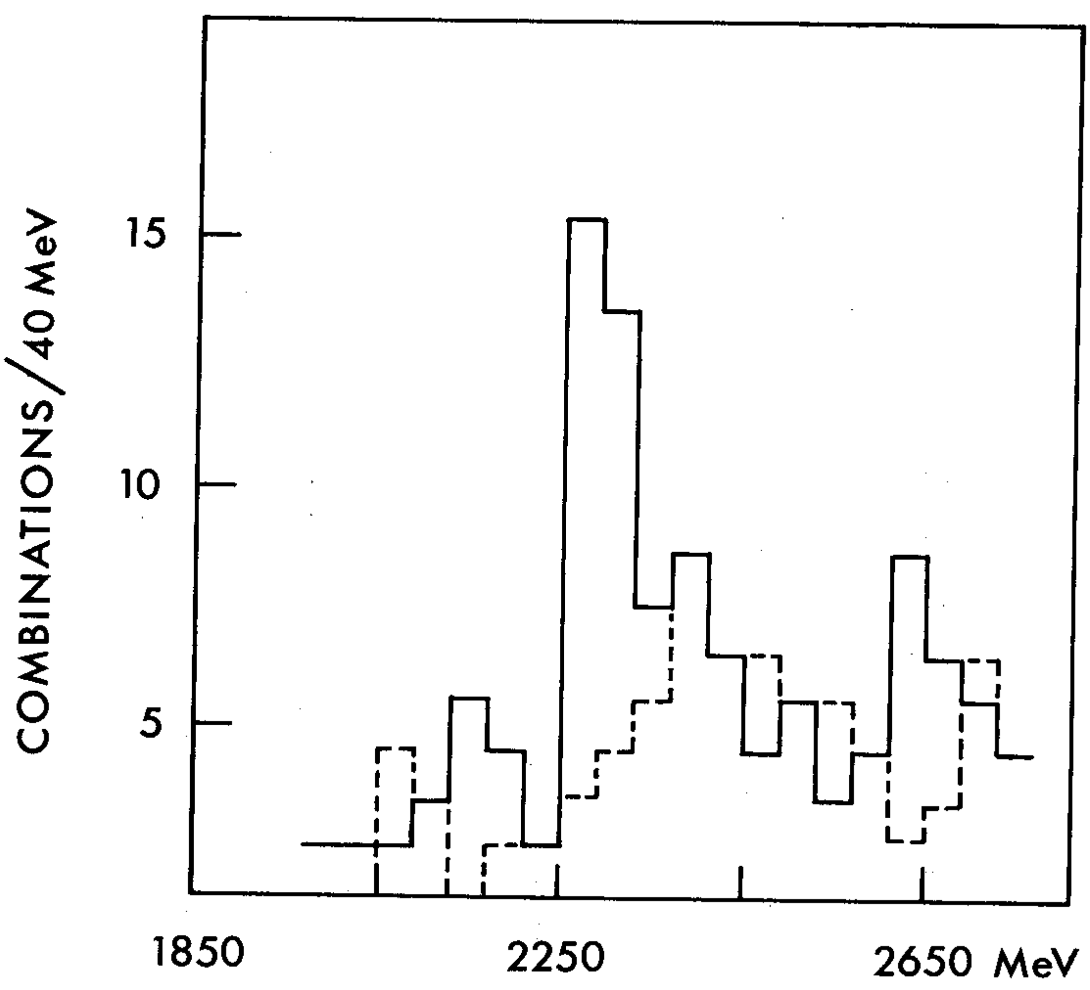


Fig. 4

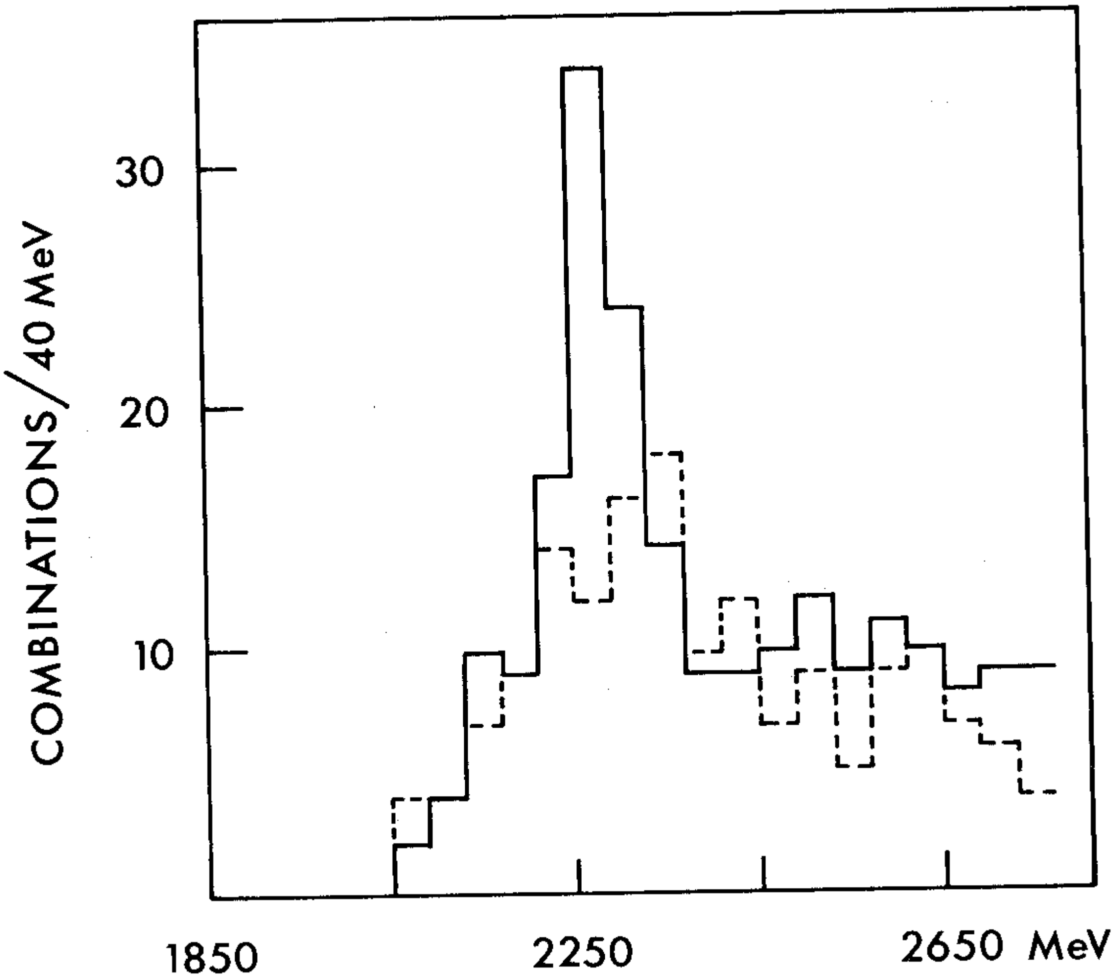


Fig. 5

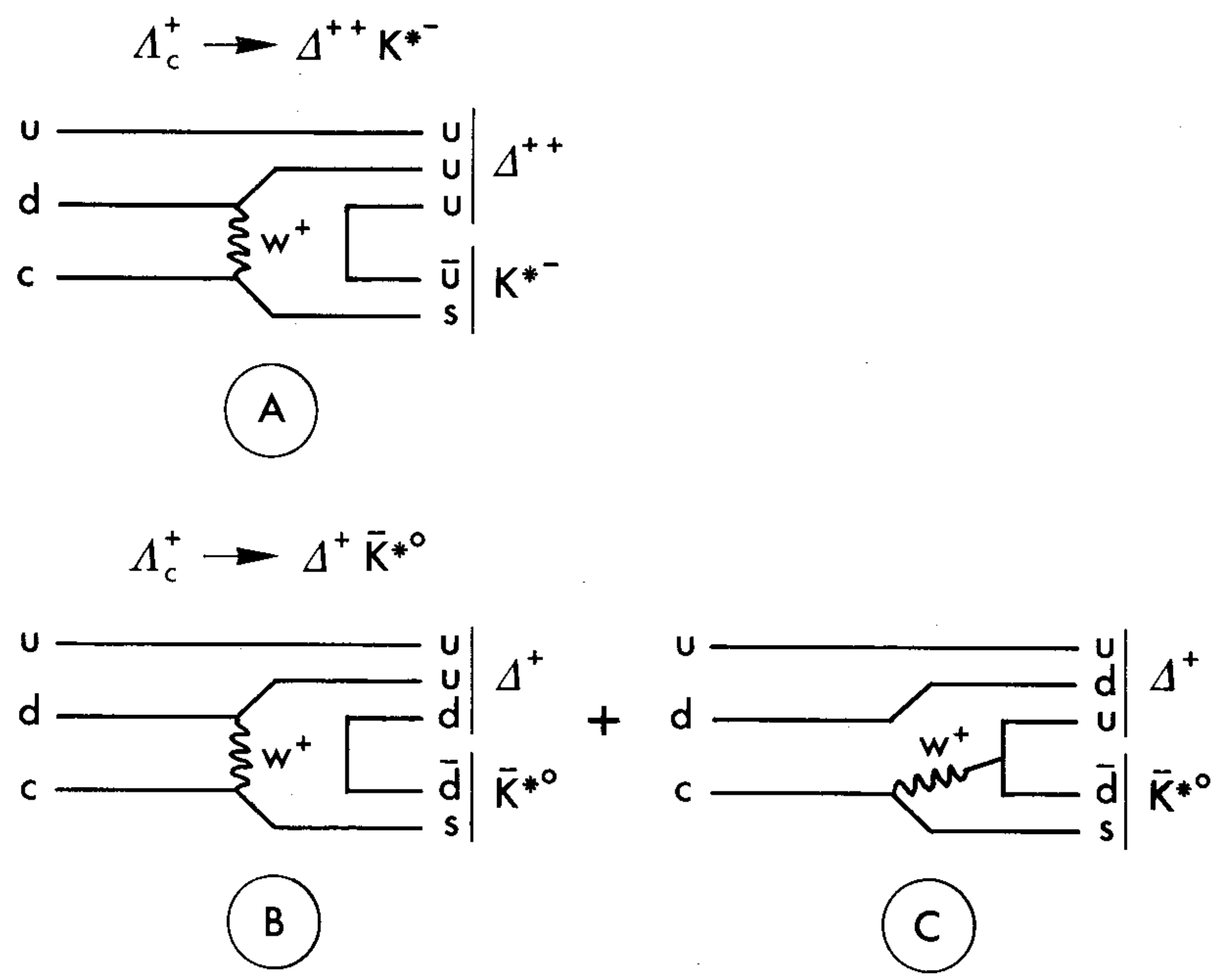
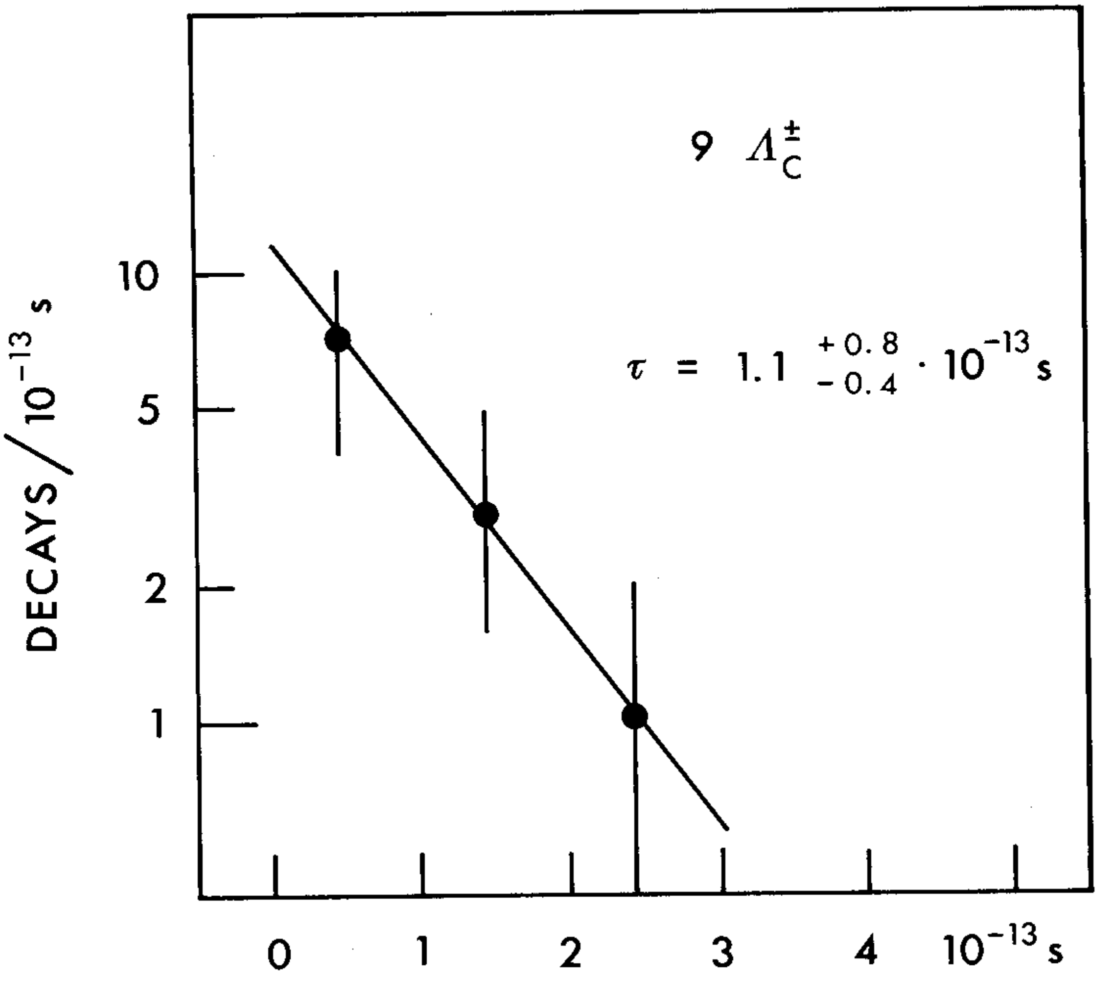


Fig. 6



9 $\Lambda_c^{\pm}$
$\tau = 1.1\,^{+0.8}_{-0.4} \cdot 10^{-13}$ s
DECAYS / 10^{-13} s
10
5
2
1
0
1
2
3
4
10^{-13} s

Fig. 7