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EMU01 - collaboration

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Abstract: Pseudo-rapidity distributions of relativistic, singly charged particles in oxygen induced emulsion interactions at 14.6, 60 and 200 A GeV are studied. Limiting fragmentation behaviour is observed in both the target and projectile fragmentation regions for a central as well as for a minimum bias sample. Comparisons with the Fritiof model reveal that the picture of fragmenting strings successfully describes the observed data.

The efforts at CERN (60 and 200 A GeV) and at BNL (14.6 A GeV) to accelerate heavy ions to ultrarelativistic energies, in order to obtain the necessary requirements for the creation of a quark-gluon plasma state, have resulted in a lot of experimental data on various projectile-target combinations [1,2]. The emulsion technique allows studies of produced charged particles and their distributions in space with higher accuracy and a larger acceptance than most of the current counter experiments, although with rather limited statistics. A great advantage with emulsions is that the same projectile-target system can be studied at the three available energies with identical detectors and with identical analysis criteria. In this letter we will focus on pseudo-rapidity ($\eta = -\ln \tan \Theta/2$) distributions of charged particles emerging from interactions between oxygen and emulsion nuclei.

In the EMU01 experiments two complementary exposure techniques were used, each having its own advantages. The technique utilizing vertically exposed emulsion chambers has been described elswhere [2]. In this letter we report on results obtained using conventional emulsion stacks exposed horizontally. These stacks consist of 30 BR-2 type pellicles, each of size 20x10x0.06 or 10x10x0.06 cm^3. The sensivity varies between 20 and 30 grains per 100 microns for minimum ionizing particles. The density of the beam was about $5x10^3$ $nuclei/cm^2$.

Interactions were found by along-the-track scanning, which is the optimal method for obtaining a minimum bias sample. Each projectile was followed up to a distance of 6 to 7 cm from the point of incidence, and the minimum bias samples were obtained from completely measured events found at a distance 2-5 cm from the front edge. At larger distances from the front edge measurements were prevented due to the background of secondary particles emerging from upstream interactions. Measurements of small-angle tracks ($\Theta \leq 10-15°$) were done relative to non-interacting beam tracks selected in the vicinity, enabling an accuracy of about $\Delta\Theta = 0.1$ mrad for angles $\Theta \leq 1$ mrad. For each event the multiplicity of shower particles, n_s, and of target associated particles, N_h, was determined. The shower particles are singly charged particles with $\beta > 0.7$ and the target associated particles are mainly knock-out protons and evaporation fragments from the target. Projectile fragments with $Z \geq 2$ were charge determined by the δ-electron or gap density counting methods. The spectator fragments with $Z = 1$ were assumed to be among the shower particles having $\Theta \leq \Theta_c = 0.2/p_{beam}$. All singly charged particles within this cone were excluded from the number n_s. The value of Θ_c has been chosen so that the probability of including produced particles among the fragments is minimized. Events produced by electromagnetic dissociation and elastic scattering were removed from the final samples by the requirement $n_s \geq 1$. In all such events, all of the 8 projectile charges were found inside the cone.

Besides the three data samples two samples of ≈10000 events from the Lund model Fritiof (version 1.7) [3] were generated, one at 60 A GeV and one at 200 A GeV. The Fritiof samples were subjects to the same restrictions as the real data. The fraction of events from the different target nuclei in emulsion was simulated using known data on the chemical composition of the emulsion. No Fritiof sample was produced for 14.6 A GeV, since the foundations of the model prohibits its usage at too low energies. The fraction of events in the Fritiof samples rejected due to the requirement $n_s \geq 1$ is less than 0.5%, and gives an estimate of the systematic errors in the real data, introduced by this requirement. Table 1 summarizes some of the features of the different event samples.

In fig 1 a and b the pseudo-rapidity distributions for the minimum bias samples at the three different energies are compared. In fig 1 a the comparison is made in the target rest-frame and in 1 b in the projectile rest-frame. The projectile rest-frame is obtained by using the approximation

$$\eta \simeq y = 1/2 \ln (E + p_L)/(E - p_L)$$

and the wellknown boost invariance of rapidity. η_p is given by

$$\eta_p \simeq - \ln ((\langle p_T{}^{\pi}\rangle * m_p)/(2 * \langle m_T{}^{\pi}\rangle * p_{inc})) \simeq y_p + 0.08$$

where $\langle m_T{}^{\pi}\rangle$ is the average transverse mass of a pion with average transverse momentum $\langle p_T{}^{\pi}\rangle = 0.34$ GeV/c. m_p is the proton mass and p_{inc} its incident momentum. η_p thus corresponds to the average pseudo-rapidity of a pion emerging from the projectile system. For the three energies η_p is 3.58, 4.95 and 6.14, respectively. In fig 1 a we clearly see evidence for limiting fragmentation in the target fragmentation region, where the distributions from the three energies fall on top of each other below $\eta \simeq 1$. We also see that for the two higher energies the distributions coincide up to $\eta \simeq 2$, showing that the extension of the region of limiting fragmentation is dependent of the incident energy. A similar feature is seen in fig 1 b where the three energies show limiting fragmentation also in the projectile region for $\eta - \eta_p \geq -1$. Again an energy dependence of the size of the region is seen. It is interesting to observe that at 14.6 A GeV the shape of the distribution is quite dominated by the large-η tail, but still this tail is identical to the tails observed at higher energies. It is important to note that the exclusion of interactions due to electromagnetic dissociation and elastic scattering is essential for obtaining these results.

In fig 1 c and d the pseudo-rapidity distributions from 200 A GeV and 60 A GeV are compared to the corresponding distributions from the Fritiof samples. It is essential to point out that no normalization is involved in this figure, i e the average multiplicities obtained by Fritiof is in excellent agreement with the data as can be seen in Table 1. The comparison of the distributions reveals a very nice agreement except for the region $\eta \geq \eta_p$, where the fragmentation of the spectator parts of the projectiles becomes important. The fragmentation products from these parts are, however, not included in the distributions from the Fritiof model.

In order to obtain a sample of central events, the N_h information is normally used in emulsion experiments. It has been observed in hadron induced interactions that the N_h-distribution is energy independent over a large range of energies. Furthermore N_h was found to be strongly correlated to the centrality of the event [4]. The same has been conjectured to be true also when heavy ions are used as projectiles. When comparing data with models like Fritiof, N_h-cuts are however not a good criterion for centrality, since the target break-up is, up to the present date, not included in these models. We therefore introduce the forward charge-flow, Q_{ZD}, defined as

$$Q_{ZD} = \Sigma Z_{frag} + n(\eta \geq \eta_{ZD})$$

where Z_{frag} is the charge of an observed projectile fragment with $Z \geq 2$, and $n(\eta \geq \eta_{ZD})$ is the number of shower particles with $\eta \geq \eta_{ZD}$, given by $\eta_{ZD} = \eta_p + 0.36$. Due to the limiting fragmentation seen in fig 1, Q_{ZD} is expected to be an energy independent quantity in the studied energy range. The value of η_{ZD}, is chosen as a compromise between not having too many produced pions inside the cone and not having too many spectator protons outside. Thus Q_{ZD} is analogus to the forward energy-flow, E_{ZD}, used by some of the current counter experiments [1]. The corresponding angles, Θ_{ZD}, are 39, 10 and 3 mrad for 14.6, 60 and 200 A GeV, respectively.

In fig 2 we compare two different central samples from 200 A GeV, both consisting of about 11 % of the minimum bias sample, one with $N_h \geq 23$ and one with $Q_{ZD} \leq 2$. We observe a similarity between the two samples and conclude that the two cuts are comparable as criteria for centrality. It is interesting to observe that the information obtained either from the projectile or from the target fragmentation regions, can be used to deduce the particle density in the central region. We obseve however a small indication that Q_{ZD} might be somewhat more efficient, since the density of observed particles is 10-20% higher in the region $2 \leq \eta \leq 4$ using that quantity.

For the Fritiof model, Q_{ZD} can be calculated as the sum of the number of projectile spectator-protons and the number of particles observed in the cone $\Theta \leq \Theta_{ZD}$, and in fig 3 we compare how the 200 A GeV events fall in the Q_{ZD}-n_s space, for the data and for the Fritiof model, respectively. The two plots show great similarities, with the bulk of the distributions with Q_{ZD} around 7 and 8. The width of the n_s-distribution for a given Q_{ZD}-value is well described by the model.

For the data samples we now introduce the cut $Q_{ZD} \leq 2$ combined with $N_h \geq 10$, the last cut being implemented in order to get rid of the small fraction of central interactions from the light component (C N O) in the emulsions, leaving a clean sample of central events having interacted with Ag or Br. The same restrictions were implemented on the Fritiof events by requiering $Q_{ZD} \leq 2$ and an interaction with Bromine or a heavier target. The percentage of the events from the different samples fulfilling the centrality criterion is given in Table 1. As can be seen in the table, the event fractions seem to increase with increasing energy, which can be interpreted as a sign of a decreasing transparancy with increasing energy, for the most central events. This effect is hardly statistically significant, but is, however, also present in the model. Furthermore, the fractions are larger in the data than in the model, indicating a larger stopping power, than predicted by the picture of independently fragmenting strings. In fig 4 we show the pseudo-rapidity distributions obtained for the central samples in the same kind of representation as in fig 1. We observe a similar limiting fragmentation behaviour as before for the minimum bias sample, although the shapes of the individual spectra have changed. In the comparisons with Fritiof we see that the model somewhat overestimates the average multiplicities in the region $2 \leq \eta \leq 4$, and the peak value at 60 A GeV seems to be shifted to a larger value of η. The overall behaviour is however in quite good agreement with the data.

To conclude we note that limiting fragmentation concerning heavy-ion collisions is fulfilled in the energy range 14.6 to 200 A GeV for both the target and the projectile fragmentation regions, independent of the centrality of the interactions. The forward charge-flow seems to be a convenient measure of centrality, well suited for model comparisons.

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Figure captions

Figure 1. Pseudo-rapidity distributions of charged particles in oxygen induced interactions with emulsion at 14.6, 60 and 200 A GeV for the minimum bias samples. a) In the target rest-frame. b) In the projectile rest-frame. c) Comparison between data and the Fritiof-model at 200 A GeV. d) Comparison between data and the Fritiof-model at 60 A GeV.

Figure 2. Pseudo-rapidity distributions of charged particles in oxygen induced interactions with emulsion 200 A GeV for two different central samples.

Figure 3. The event distribution in Q_{ZD}-n_s space for a) the 200 A GeV data and b) the corresponding Fritiof sample.

Figure 4. As for fig 1, but for central ^{16}O+Ag(Br) samples with $Q_{ZD} \leq 2$.

Table 1: Characteristics of the used samples.

	Data			Fritiof	
E_{inc} (A GeV)	14.6	60	200	60	200
No of Events	385	372	503	9848	9788
σ_{inel} (mb)$^{*)}$	1050±20	1060±40	1090±30	1000	1000
$\langle n_s \rangle$	21.2±1.1	40.6±2.2	58.1±2.8	39.4±0.4	58.0±0.6
Central sample	7.5%	8.6%	10.1%	5.5%	7.9%

$^{*)}$ calculated as $\sigma = 1/(\rho * \lambda)$, where ρ is the atom density in nuclear emulsion, and λ is the observed mean free path measured for inelastic interactions

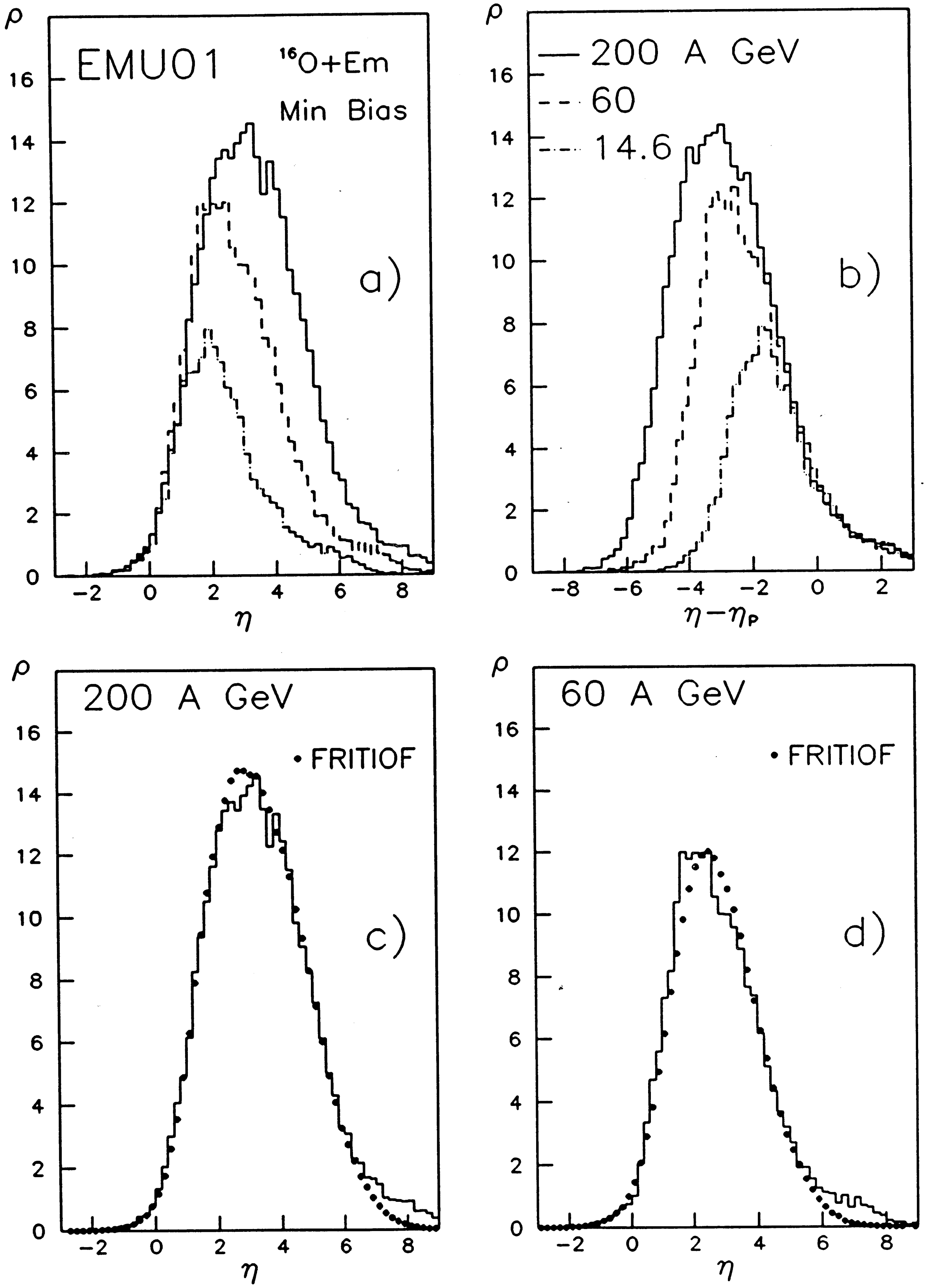
ρ
EMU01
^{16}O+Em
Min Bias
a)
16
14
12
10
8
6
4
2
0
−2
0
2
4
6
8
η
ρ
— 200 A GeV
- - 60
-·- 14.6
b)
−8
−6
−4
−2
0
2
η−η$_P$
ρ
200 A GeV
• FRITIOF
c)
η
ρ
60 A GeV
• FRITIOF
d)
η

FIG 1

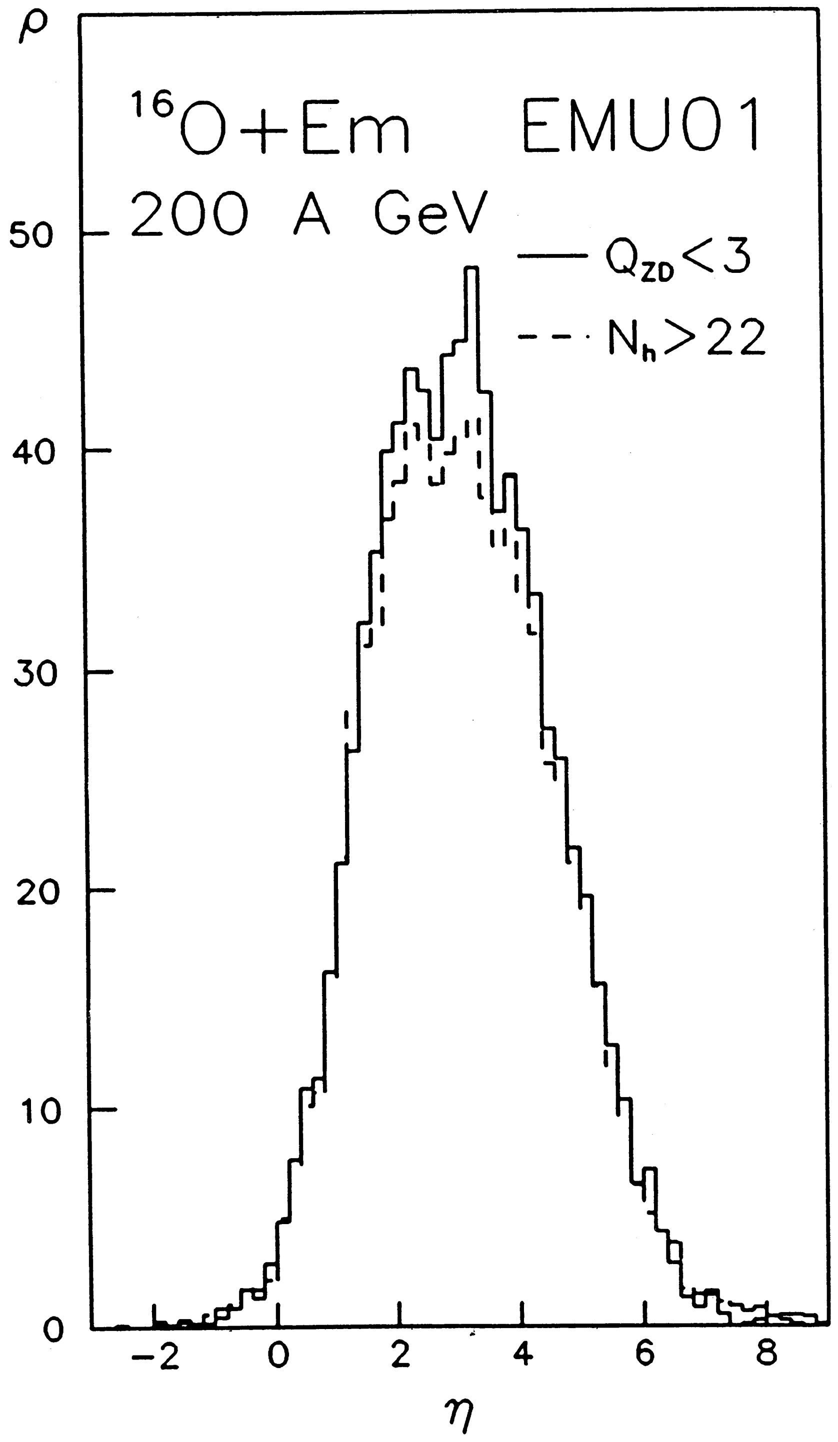

FIG 2

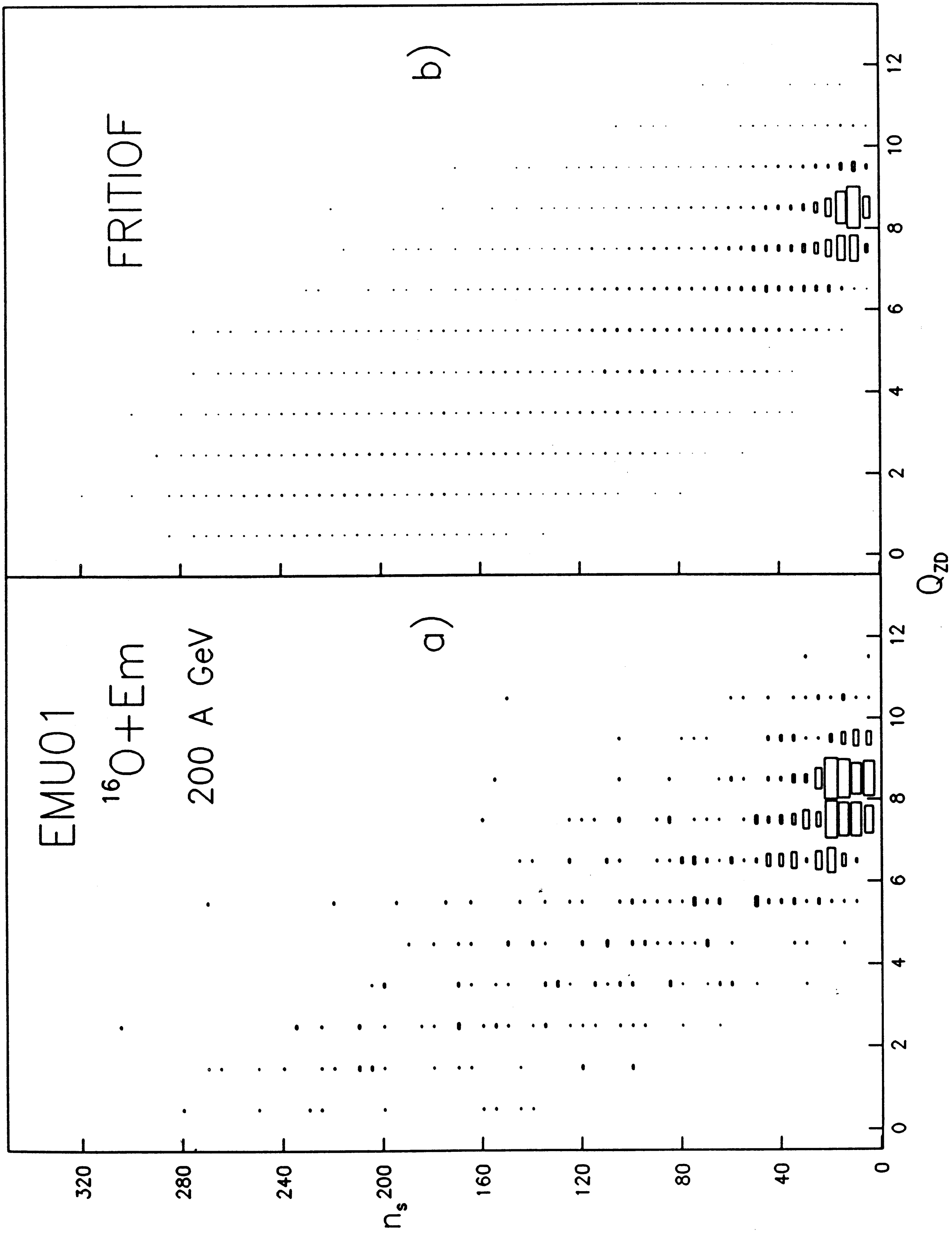
EMU01
^{16}O+Em
200 A GeV
a)
FRITIOF
b)
n_s
Q_{ZD}
0
40
80
120
160
200
240
280
320
0
2
4
6
8
10
12

FIG 3

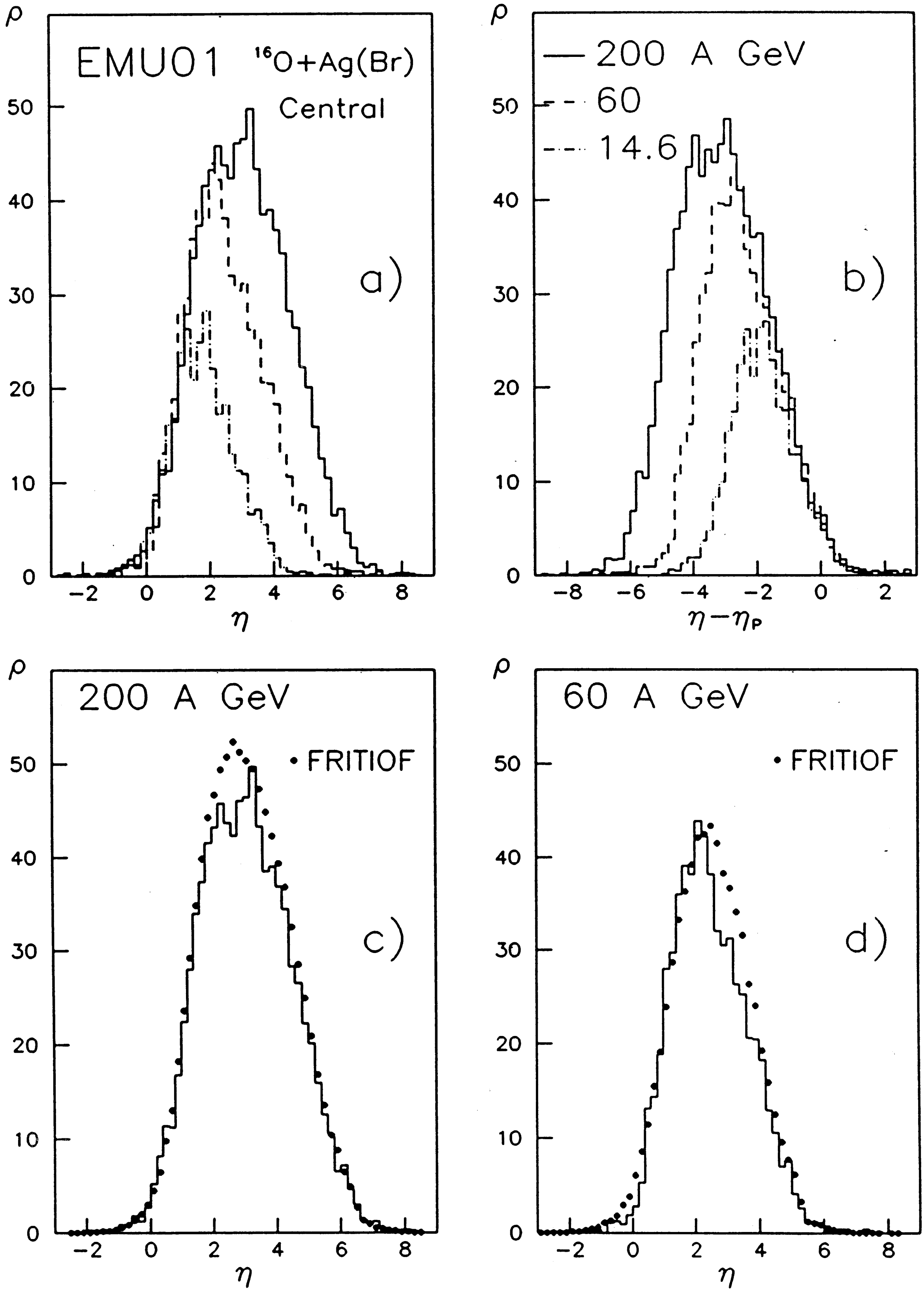
ρ
EMU01 ^{16}O+Ag(Br)
Central
a)
50
40
30
20
10
0
−2
0
2
4
6
8
η
ρ
— 200 A GeV
- - 60
-·- 14.6
b)
50
40
30
20
10
0
−8
−6
−4
−2
0
2
η−η$_P$
ρ
200 A GeV
• FRITIOF
c)
50
40
30
20
10
0
−2
0
2
4
6
8
η
ρ
60 A GeV
• FRITIOF
d)
50
40
30
20
10
0
−2
0
2
4
6
8
η

FIG 4