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EMU01 - collaboration

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Scaling Properties of Charged Particle Multiplicity Distributions in Oxygen Induced Emulsion Interactions at 14.6, 60 and 200 A GeV.

EMU01 - collaboration

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Abstract: The multiplicity distributions of shower particles (n_s) are measured in inclusive inelastic oxygen emulsion interactions. Scaling is observed in the normalized variable $n_s/\langle n_s\rangle$ for 14.6, 60 and 200 A GeV. The dependence of $\langle n_s\rangle$ on the charge flow in the forward direction (Q_{ZD}) and the distribution of the number of participating projectile protons is examined. The normalized multiplicities as a function of Q_{ZD} seem also to be independent of incident energies. A comparison with the Lund Model Fritiof yields satisfactory agreement.

The search for the quark-gluon plasma state, which initiated the SPS fixed target heavy-ion program at CERN and BNL, has resulted in a profusion of data on particle production [1-7]. In counter experiments it is generally not possible to obtain minimum bias distributions, due to restriction in coverage and coarse granularity of the detectors. In contrast, the emulsion technique with its superior spatial resolution is very well suited for this purpose. In the EMU01 experiment at CERN two exposure techniques were used, horizontal and vertical. The latter technique, utilizing emulsion chambers, has been described elsewhere [7,8]. Both of these detection techniques have their own advantage and are complementary. Here we report on the horizontally exposed emulsion stacks. These 16 stacks contain emulsion of BR-2 type and consist of 30 plates, each of size 20 x 10 x 0.06 cm^3 (10 stacks) or 10 x 10 x 0.06 cm^3 (6 stacks). The emulsion has a sensitivity of 20-30 grains per 100 microns for a minimum ionizing particle. The stacks were exposed to the ^{16}O beams at CERN (60 and 200 A GeV) and BNL (14.6 A GeV). The density of the beam was about $5*10^3$ nuclei/cm^2.

Interactions were found by along-the-track scanning which, because of its high detection efficiency, produces a reliable minimum bias sample. Each track was followed from the entry point up to a distance of 6-7 cm. For events found at a distance of 2-5 cm from the edge of the plate the angles of all particles were measured. Measurements at distances more than 5 cm from the front edge are difficult due to the background of secondary particles. All measurements of angles $\Theta \leq 10-15°$ were done relative to non-interacting beam tracks selected in the vicinity of the interaction point. This procedure results in an accuracy of about $\Delta\Theta \simeq 0.1$ mrad for angles $\Theta \leq 1$ mrad. In the measured events the angles of all particles were recorded as well as the multiplicities n_s (shower particles), N_g (grey particles) and N_b (black particles). For the definition of these quantities and how the particles are categorized see, for instance, ref [9]. For the projectile fragments the charge Z was determined by δ-electron or gap density counting. The projectile fragments with Z = 1 were picked up among the relativistic particles according to the criterion $\Theta_{fp} \leq \Theta_c = 0.2/p_{beam}$ ($\Theta_c \simeq 1$, 3.3 and 13 mrad at 200, 60 and 14.6 A GeV). The value of Θ_c was chosen to minimize the probability of including produced particles among the fragments. All singly charged particles having $\Theta \leq \Theta_c$ were excluded from n_s. However not all of the events were measured since the conditions were not always suitable to do so. After removal of the events from electromagnetic dissociation and elastic scattering subject to the condition that at least one shower particle should appear outside the fragmentation cone, the final event samples were obtained. The total number of scanned and the number of so far completely measured events are given in Table 1. The data allow for determination of the cross section for the ^{16}O projectile to interact inelastically with an average emulsion nucleus ($\sigma = 1/(\rho*\lambda)$ [10]), see Table 1.

Besides the three data samples two samples of ≃10000 events from the Lund model Fritiof (version 1.7) [11] were used for comparisons. These samples were treated in the same way as the real data as described in [12]. No comparison is made at 14.6 A GeV since inherent restrictions of the model makes it doubtful at lower energies.

In Fig. 1 a, b and c we show the multiplicity distributions of shower particles for 200, 60 and 14.6 A GeV, respectively. As can be seen in the figure the observed tails of the distributions extend up to 320, 180 and 100 shower particles for the three incident energies. As can be seen the model can explain the multiplicity distributions over three orders of magnitude. The average number of shower particles $\langle n_s \rangle$ is shown in Table 1. The corresponding values for the Fritiof samples are 39.4±0.4 and 58.0±0.6, for 60 and 200 A GeV, respectively.

In Fig. 2 we show the behaviour of the "normalized" quantity $n_s/\langle n_s \rangle$ for the three incident energies. The first striking observation is that for all three energies the data fall on the same universal curve. This scaling is a consequence of the nuclear geometry, which is energy independent, and reflects the distribution of the number of participating nucleons from the two nuclei. The measured distributions reveal the participant distributions, rather than the multiplicity distribution emerging from a single binary nucleon-nucleon collision, and the observed scaling is thus not related to whether KNO-scaling [13,14] in hadron-hadron collisions is fulfilled or not. Even at a fixed impact parameter the fluctuation in the number of participants is large and to a certain extent washes out effects from the binary collisions.

In order to examine the geometrical aspects of the collision we define a quantity, Q_{ZD}, which measures the charge flow in the forward direction, analogous to the quantity E_{ZD}, which measures the energy flow in the forward direction, used in the counter experiments [15,4], as:

$$Q_{ZD} = \Sigma Z_i + n(\eta \leq \eta_{ZD})$$

Here Z_i is the the charge of the i^{th} observed fragment, and η is the pseudorapidity ($\eta = -\ln \tan \Theta/2$) measured with respect to the beam direction. It is obvious that peripheral collisions have large values of Q_{ZD}, whereas central ones produce small values. The chosen cut is defined by $\eta_{ZD} \simeq \eta_p + 0.36$ [12], where

$$\eta_p \simeq -\ln((\langle p_T{}^{\pi}\rangle * m_p)/(\langle m_T{}^{\pi}\rangle * p * 2))$$

Here $\langle p_T{}^{\pi}\rangle \simeq 0.34$ GeV/c and $\langle m_T{}^{\pi}\rangle \simeq 0.37$ GeV/c for a pion, and p and m_p are the incident momentum and rest mass of a proton in the projectile, respectively. For the three cases η_p is equal to 6.14, 4.95 and 3.58, corresponding to an angle Θ_{ZD} of 3, 10 and 39 mrad at 200, 60 and 14.6 A GeV, respectively. The judicious choice of the cut is to ensure that practically none of the proton spectator will occur outside the defined cone, and that not too many produced particles should fall inside. This definition allows for a precise comparison with the Lund Model where the fate of the spectator protons (but not their number) is unknown. In Fig. 3 a the distributions of Q_{ZD} for the three incident energies are shown. As can be seen the distributions seem to be independent of incident energy and exhibit the underlying geometry of the collisions. To examine the sensitivity of the cuts and for completeness we also define the number of participating beam protons W as:

$$W = Z_{beam} - \Sigma Z_i - n(\Theta \leq \Theta_c)$$

where Z_{beam} is the charge of the incident nucleus. The values of Θ_c are given above. This definition gives rather low probability to find shower particles inside the fragmentation cone and for the few occurrences of negative values, W is set to zero. In Fig 3 b we show the distributions of W for the three incident energies. As can be seen, close concurrence of the distributions is obtained, again reflecting the independence of the incident energy. In Fig 3 c and d the Q_{ZD} distributions at 200 and 60 A GeV are compared with those obtained by the Lund Model Fritiof subject to the same cuts. As can be seen an agreement in shape is obtained for both cases, showing that the concept of the model with independently fragmenting strings, describes the general features seen in the data. Note, however, that it seems that the data sample shows a small shift to smaller Q_{ZD} values, which might signal a somewhat larger stopping power, i e it is harder for particles to penatrate the target nucleus than predicted by the model. This is also indicated in the percentage of events having $Q_{ZD} \leq 2$ as discussed in ref [12].

In Fig. 4 a we show the "normalized" quantity $\langle n_s\rangle_{QZD}/\langle n_s\rangle$ as a function of Q_{ZD}. A rise in this quantity with decreasing Q_{ZD} is expected, but more important, the data for the three incident energies seem to fall on a universal curve. In Fig. 4 b we show a comparison of $\langle n_s\rangle_{QZD}$ with Fritiof for 60 and 200 A GeV. The model gives the general shape of the spectra, but some deviations are seen, which are related to the difference in the Q_{ZD}-spectra discussed in connection with fig 3. The events with $Q_{ZD} > 8$ are among the most peripheral ones, with a typical diffractive behaviour, thus having a large fraction of the observed particles inside the Θ_{ZD}-cone. Consequently a positive correlation between Q_{ZD} and n_s is expected in this region, as observed in both the data and the model.

To conclude, our interaction mean free paths agree well with that of ref [5], where 12.0±0.3 cm, corresponding to a total inelastic cross section of 1.05±0.03 barn, was reported. However, the value for the interaction mean free path of 10.9±0.8 cm reported by ref [6] using Ilford G-5 emulsion is somewhat low. The maximum observed multiplicities agree well at the three incident enegies with ref [5]. We have assigned a variable Q_{ZD} useful for selection of centrality and shown the close resemblance between our data and those obtained from the Lund Model Fritiof concerning multiplicity distributions and event distributions. Scaling with respect to incident energies in terms of normalized variables $n_s/\langle n_s\rangle$ and $\langle n_s\rangle_{QZD}/\langle n_s\rangle$ seem to be present. A small but significant shift to smaller Q_{ZD} in our data, as compared to the Fritiof calculations, suggest a somewhat larger stopping power in ultrarelativistic heavy-ion interactions than expected in the model.

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Figure Captions

Figure 1

The differential cross section for shower particle production $d\sigma/dn_s$ as a function of n_s for a) 200 A GeV, b) 60 A GeV and c) 14.6 A GeV incident oxygen energy. In a) and b) a comparison with spectra obtained from the Lund Model Fritiof is shown.

Figure 2

The distribution of normalized shower particle multiplicity $n_s/\langle n_s\rangle$ for 200, 60 and 14.6 A GeV incident oxygen energy.

Figure 3

The distribution of a) events with a given value of Q_{ZD} for 200 , 60 and 14.6 A GeV and b) events with a given number of participating protons W. Comparisons between the Q_{ZD} distribution at c) 200 A GeV and d) 60 A GeV obtained in the experiment and those obtained from Fritiof. Also shown are the Q_{ZD} distribution obtained from Fritiof for Ag(Br) interactions and for Ag(Br) and CNO interactions combined.

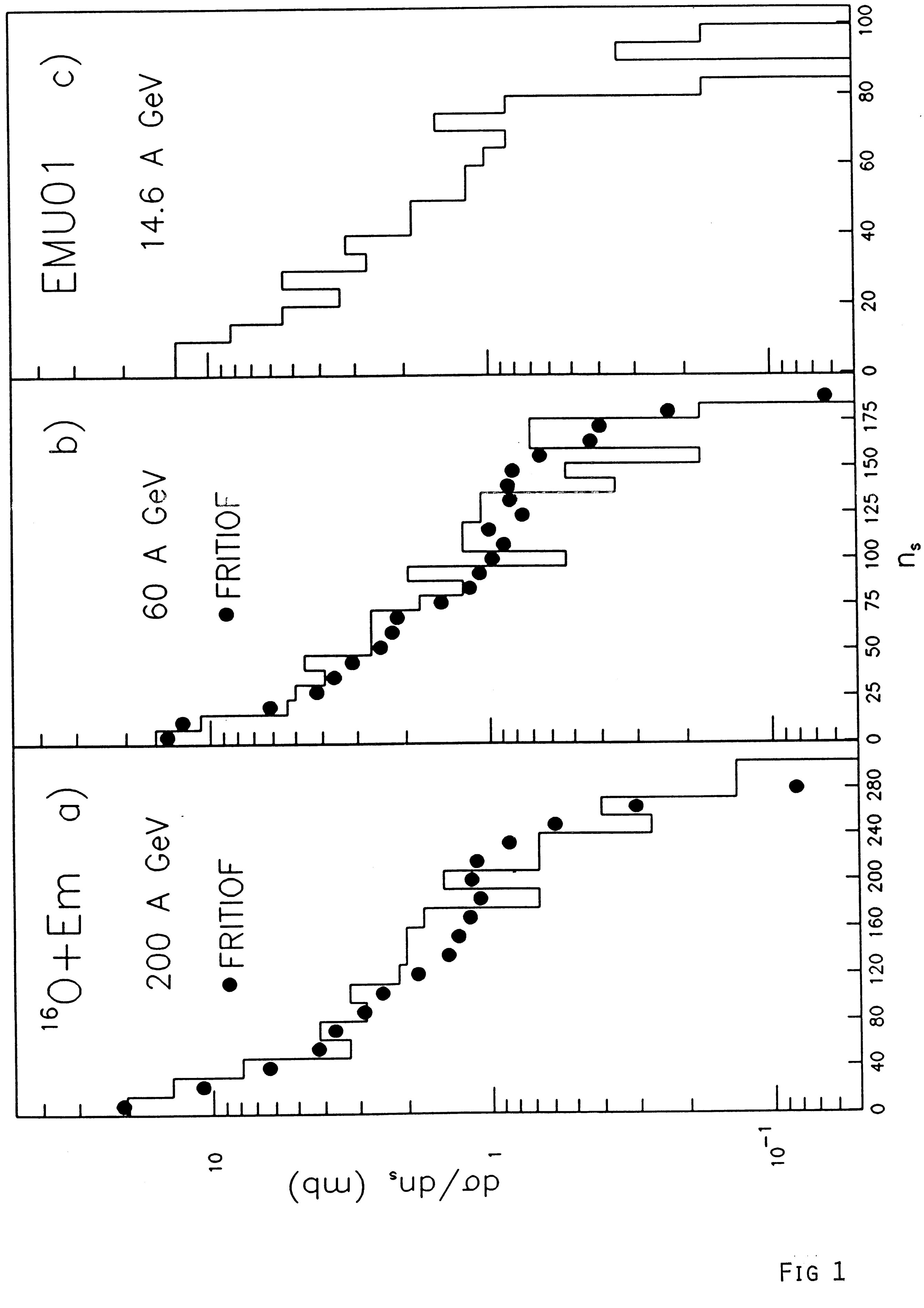
Figure 4

a) The normalized average multiplicity $\langle n_s\rangle_{QZD}/\langle n_s\rangle$ as a function of Q_{ZD}. b) The average multiplicity $\langle n_s\rangle_{QZD}$ as a function of Q_{ZD}. The result from the Fritiof model is also shown.

Table 1

E_{inc} (A GeV)	14.6	60	200
No of Scanned Events	2107	691	1586
λ_{inel} (cm)	12.1±0.2	11.9±0.4	11.6±0.3
σ_{inel} (mb)*)	1050±20	1060±40	1090±30
No of Measured Events	385	372	503
$\langle n_s \rangle$	21.2±1.1	40.6±2.2	58.1±2.8

*) 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.



^{16}O+Em a)
200 A GeV
● FRITIOF
60 A GeV
● FRITIOF
b)
EMU01 c)
14.6 A GeV
dσ/dn$_s$ (mb)
10
1
10^{-1}
n$_s$
0
40
80
120
160
200
240
280
0
25
50
75
100
125
150
175
0
20
40
60
80
100

FIG 1

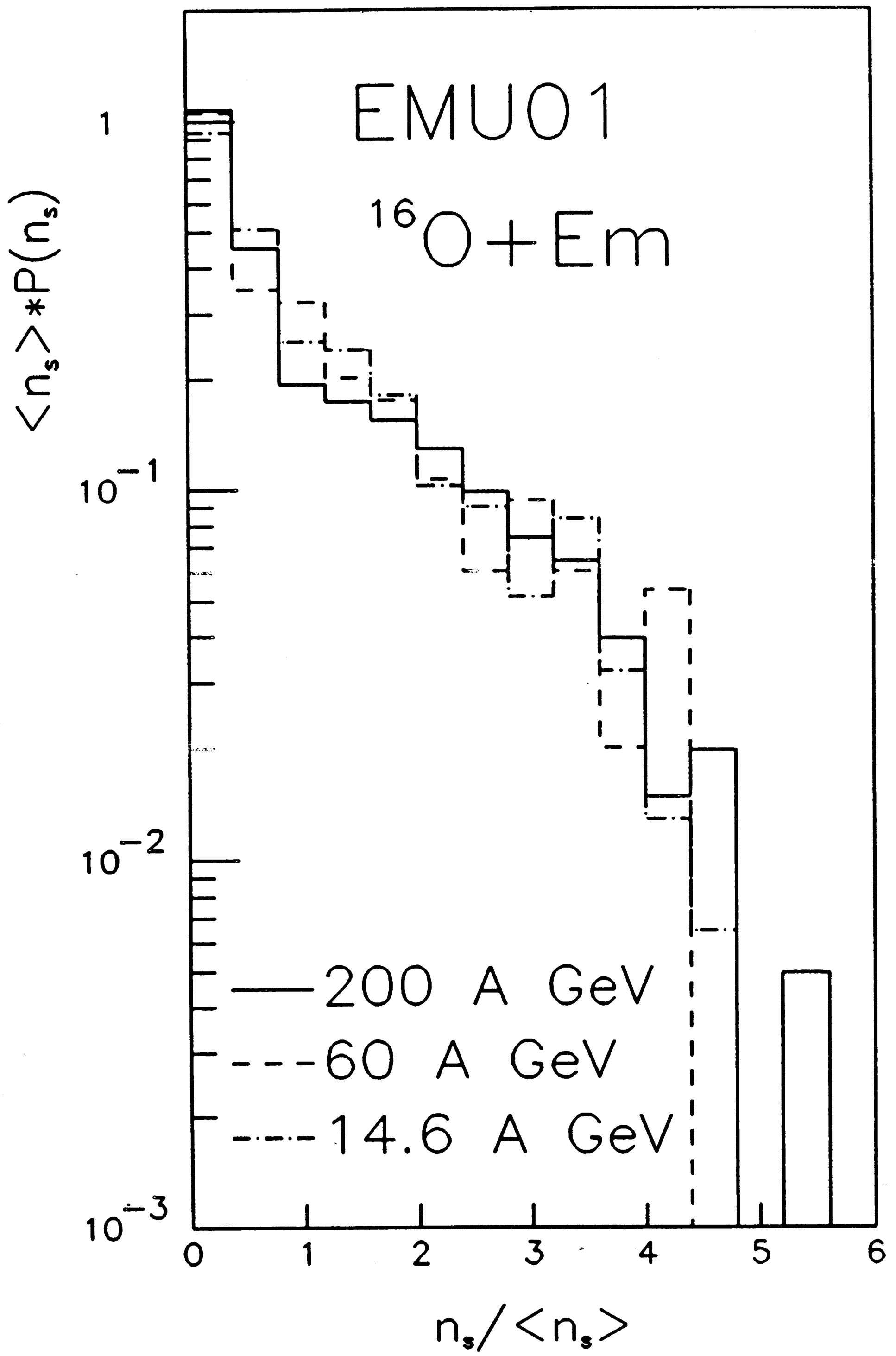
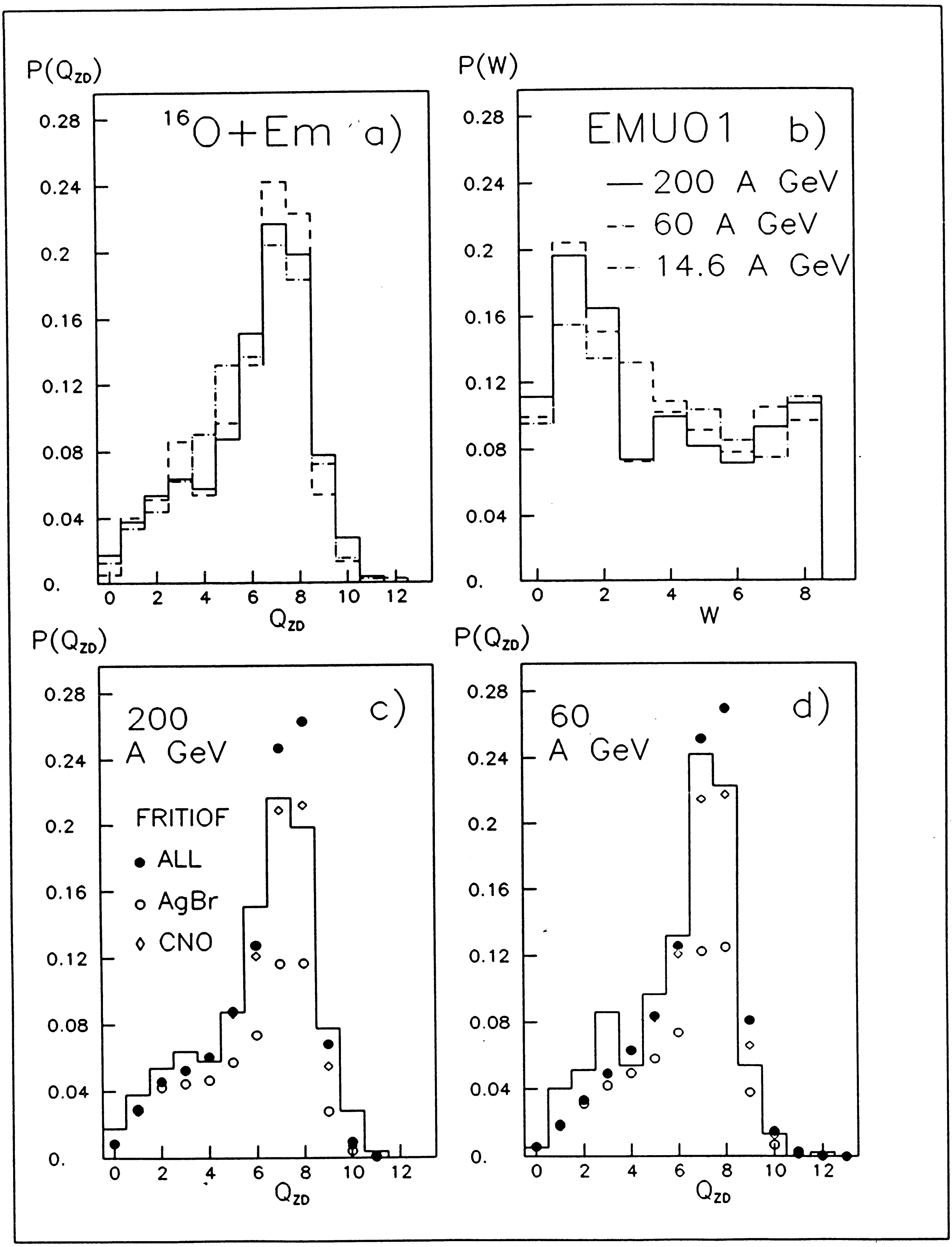

EMU01
$^{16}O+Em$
$\langle n_s \rangle * P(n_s)$
1
10^{-1}
10^{-2}
10^{-3}
200 A GeV
60 A GeV
14.6 A GeV
0
1
2
3
4
5
6
$n_s/\langle n_s \rangle$

FIG 2



P(Q_ZD)
16O+Em a)
Q_ZD
P(W)
EMU01 b)
200 A GeV
60 A GeV
14.6 A GeV
W
P(Q_ZD)
200
A GeV
c)
FRITIOF
ALL
AgBr
CNO
Q_ZD
P(Q_ZD)
60
A GeV
d)
Q_ZD

FIG 3

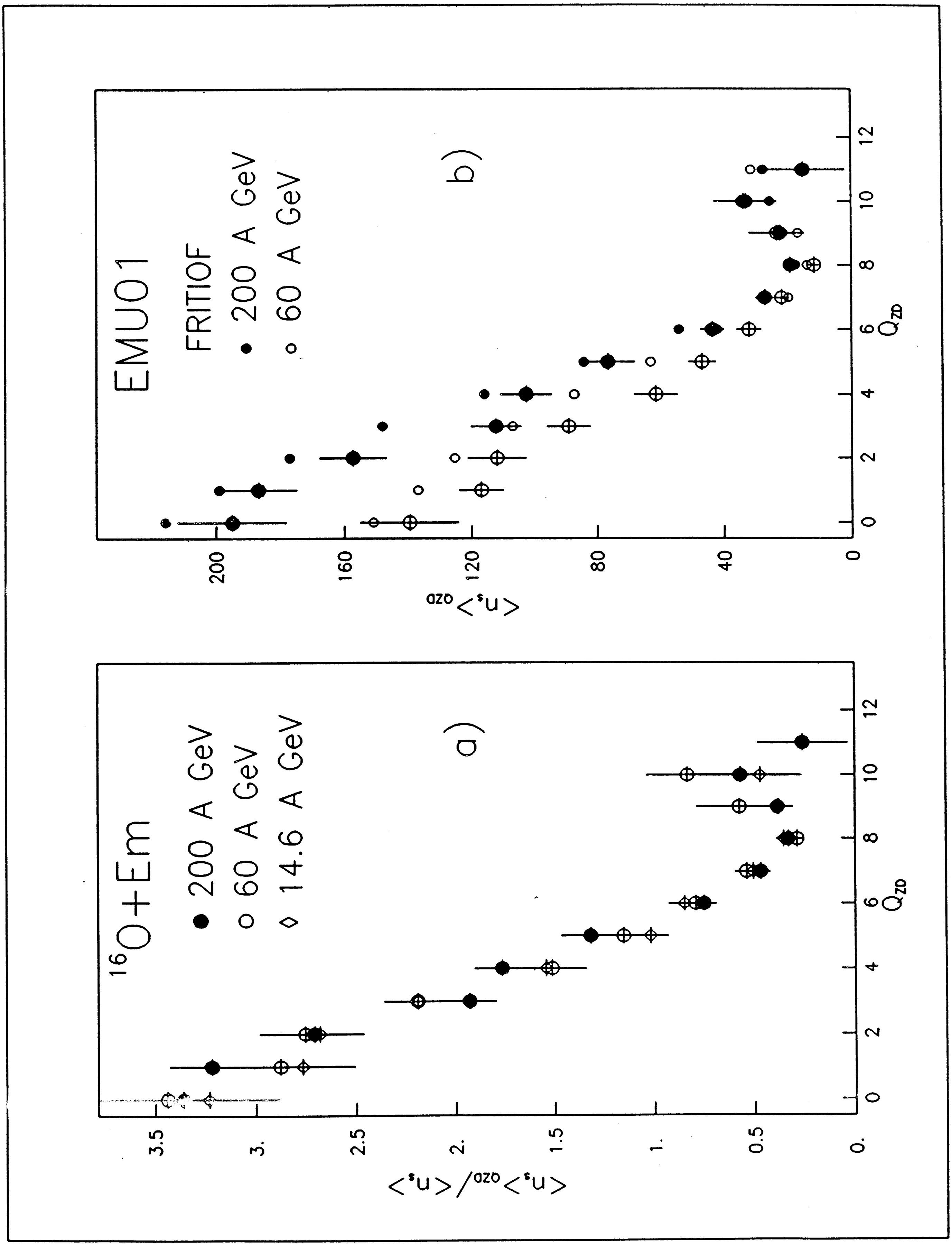

EMU01
FRITIOF
• 200 A GeV
∘ 60 A GeV
b)
$\langle n_s \rangle_{Q_{ZD}}$
Q_{ZD}
^{16}O+Em
● 200 A GeV
○ 60 A GeV
◊ 14.6 A GeV
a)
$\langle n_s \rangle_{Q_{ZD}} / \langle n_s \rangle$
Q_{ZD}

FIG 4