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CHARGED PARTICLE SPECTRA IN OXYGEN-INDUCED REACTIONS AT 14.6 AND 60 GeV/NUCLEON

EMU01 - collaboration

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ABSTRACT Multiplicity distributions and pseudo-rapidity distributions of charged particles from oxygen- induced nuclear reactions at 14.6 and 60 GeV/nucleon are presented. The data were taken from the EMU-01 emulsion stacks and compared to simulations from the Lund Monte Carlo Model (FRITIOF).

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In the last few years the great interest in ultra-relativistic heavy-ion collision experiments has been growing. The main physical goal for the study of these programs is to investigate the existence and properties of a new state of matter—a quark-gluon plasma (QGP), which is predicted by the theory of Quantum Chromodynamics (QCD) [1]. The hope is that such a state, which must have occurred during the first few quivering moments of the universe and perhaps exists in some dense stellar objects, can also be recreated for a short time and in a volume of nuclear size by heavy-ion collisions at sufficiently high energy in the accelerator laboratory. Although it is widely believed that the normal nuclear matter (NM), which are composed of well-separated colourless hadrons, will coalesce into a plasma of quarks and gluons which are free to roam, the nature of the deconfinement phase transition from the NM to the QGP is still uncertain as yet. Even more uncertain is whether the conditions necessary for the phase transition, sufficiently high temperature and/or density, can be reached in ultra-relativistic heavy-ion collisions and how to search for the expected signals of deconfinement phenomena if it has occurred. For these reasons we need a thorough understanding of the hadronization in high energy nucleus-nucleus interactions.

The successful acceleration of beams of heavy-ions at energies up to 200 GeV/nucleon allows these questions to be addressed experimentally. In the present paper, we report our results on charged particle spectra in 14.6 and 60 GeV/nucleon oxygen-induced reactions with emulsion nuclei (Em). As far as we know, nuclear emulsion has the highest spatial resolution among all the particle detectors.

In this experiment, stacks of emulsion pellicles with dimensions 10 cm $\times$ 10 cm $\times$ 600 μm were exposed horizontally at the Brookhaven National Laboratory (BNL) to 14.6 and at CERN to 60 GeV/nucleon oxygen beam. At BNL [2] the link between the Tandem Van de Graff and the AGS (Alternating Gradient Synchrotron) was emploied and at CERN [3] the acceleration complex consists of ECR (Electron Cyclotron Resonance source), RFQ (Radio-Frequency Quadrupol), Linac I, PSB, PS and SPS (Super Proton Synchrotron). The emulsions were developed and then scanned by along-the-track method with optical microscopes. The following attentions have been paid in the process of scanning: Only primary tracks with ionization corresponding to the usual ionization of oxygen nuclei in a given stacks were selected visually for scanning. Any primary track with doubt was not followed.

So far, 417 events of 14.6 GeV/nucleon and 592 events of 60 GeV/nucleon have been measured under a 100$\times$ oil objective. Secondary charged particles to each event are identified as shower, heavy and forward particles respectively in following ways:

i) Shower particles (denoted by n_s) are defined as singly charged relativistic ones with grain density $g < 1.4g_0$, which are mainly pions with energies above 70 MeV and protons with energies above 400 MeV. g_0 corresponds to the minimum ionization.

ii) Heavy prongs as target fragments are divided into two groups: grey tracks and black tracks (expressed by $N_h = n_g + n_b$). Grey particles are defined as heavily ionizing ones ($1.4 < g/g_0 < 8$) and most of them are recoiled protons from target nuclei. Black particles are the evaporated fragments out of target nuclei difined as heavily ionizing ones ($g/g_0 > 8$).

iii) Forward particles (denoted N_f) are projectile fragments, which are defined as relativistic ones with emission angles $\theta < 14$ mrad at 14.6 GeV/nucleon and $\theta < 3$ mrad at 60 GeV/nucleon. Ionization of these particles does not change considerably within the range of $L < 2$ cm. They are also classified into several types according to their charge Z:

alpha particles (n_α) with $1.4 < g/g_0 < 4$ for $Z = 2$, lightly-ionizing fragments (n_l) and medium-ionizing fragments (n_m) for $Z > 3$.

Table 1 gives the mean value $\langle n \rangle$, the dispersion $D = (\langle n^2 \rangle - \langle n \rangle^2)^{1/2}$, and the characteristic parameter $D/\langle n \rangle$ of multiplicity distributions for shower, grey and black particles at each energy. The normalized multiplicity distributions of grey and black particles at 14.6 and 60 GeV/nucleon are plotted in Fig. 1a and 1b. Also indicated in Fig. 1a is the distribution for grey particle obtained from the Lund Monte Carlo Model (FRITIOF) [4] for high energy nucleus-nucleus interactions. Fragmentation of target-nucleus might be still independent of the energy in present experiment. In Fig. 2 is shown the approximate scaling of the multiplicity distributions of shower particles in term of the variable $z = n_s/\langle n_s \rangle$ for nucleus-nucleus collisions in the present energy region. Data are in good agreement with the geometry of FRITIOF [4], as shown in Fig. 2.

The normalized pseudo-rapidity ($\eta = -\ln\tan\theta/2$) distributions in the rest frame of projectile-nucleon for shower paticles produced in ^{16}O - Em interaction at 14.6 and 60 GeV/nucleon are shown in Fig. 3. There is an obvious scaling property in projectile fragmentation region. The limiting fragmentation behaviour [5] is also observed in heavy-ion collisions in present energy range.

During a high energy collision the target nucleus is left in a highly excited state, which subsequently break up as heavy fragments N_h . We selected events with the number of the heavy prong $N_h > 8$, which are taken for induced interactions with AgBr, the heavy elements of emulsion. The scaled multiplicity distributions for shower particles measured from these events at 14.6 and 60 GeV/nucleon are shown in Fig. 4. We also observed the property of approximate scaling. Pseudo-rapidity distributions in the rest frame of projectile-nucleon at 14.6 and 60 GeV/nucleon display that the shape of curves in the projectile fragmentation region are independent of beam energy, as seen in Fig. 5.

In conclusion, we feel that data on the multiplicity distributions and pseudo-rapidity distributions of charged particles presented in this paper in oxygen-induced nuclear reaction with emulsion at 14.6 and 60 GeV/nucleon explored many features, so to say scaling properties, on the high energy heavy-ion collisions. But, whether the conditions for the formation of QGP at the present energy region is still an open question because of the lack of reliable quantitative predications for the experimental observables.

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Table 1 Mean values $\langle n \rangle$, dispersions D and $D/\langle n \rangle$ values of multiplicity distributions for shower, grey and black particles at 14.6 and 60 GeV/nucleon.

energy (A GeV)		type of particles: shower	grey	black
14.6	$\langle n \rangle$	20.89±1.02	4.52±0.22	4.43±0.22
	D	20.35±1.47	5.54±0.29	4.32±0.31
	$D/\langle n \rangle$	0.97±0.09	1.23±0.06	0.98±0.09
60	$\langle n \rangle$	37.77±1.55	4.47±0.18	4.32±0.18
	D	39.60±2.15	6.14±0.23	4.49±0.25
	$D/\langle n \rangle$	1.05±0.06	1.37±0.04	1.03±0.07

Figure Captions

Fig.1a Normalized multiplicity distributions of grey particles at 14.6 and 60 GeV/nucleon. The cross points are calculated from the Lund Monte Carlo Model (FRITIOF).

Fig.1b Normalized multiplicity distributions of black particles at 14.6 and 60 GeV/nucleon.

Fig.2 Scaled multiplicity distributions of shower particles at 14.6 and 60 GeV/nucleon. The curve is calculated from the Lund Monte Carlo Mode (FRITIOF).

Fig.3 Pseudo-rapidity distributions in the rest frame of the projectile-nucleon for shower particles at 14.6 and 60 GeV/nucleon.

Fig.4 Scaled multiplicity distributions of shower particles for events with $N_h > 8$ at 14.6 and 60 GeV/nucleon.

Fig.5 Pseudo-rapidity distributions of shower particles in the rest frame of the projectile-nucleon for events with $N_h > 8$ at 14.6 and 60 GeV/nucleon.

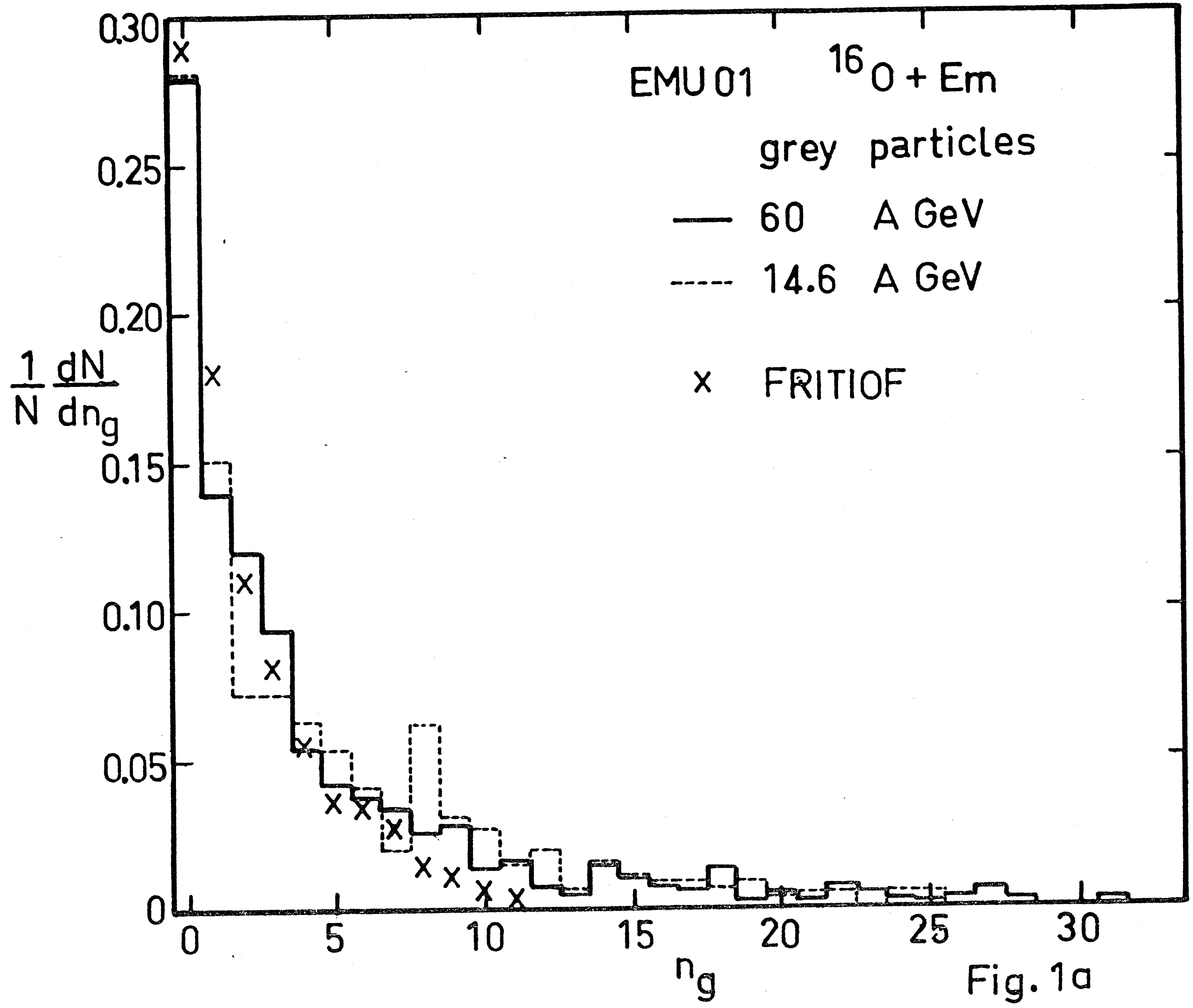

EMU 01
16O + Em
grey particles
60 A GeV
14.6 A GeV
x FRITIOF
0.30
0.25
0.20
0.15
0.10
0.05
0
1/N dN/dng
0
5
10
15
20
25
30
ng

Fig. 1a

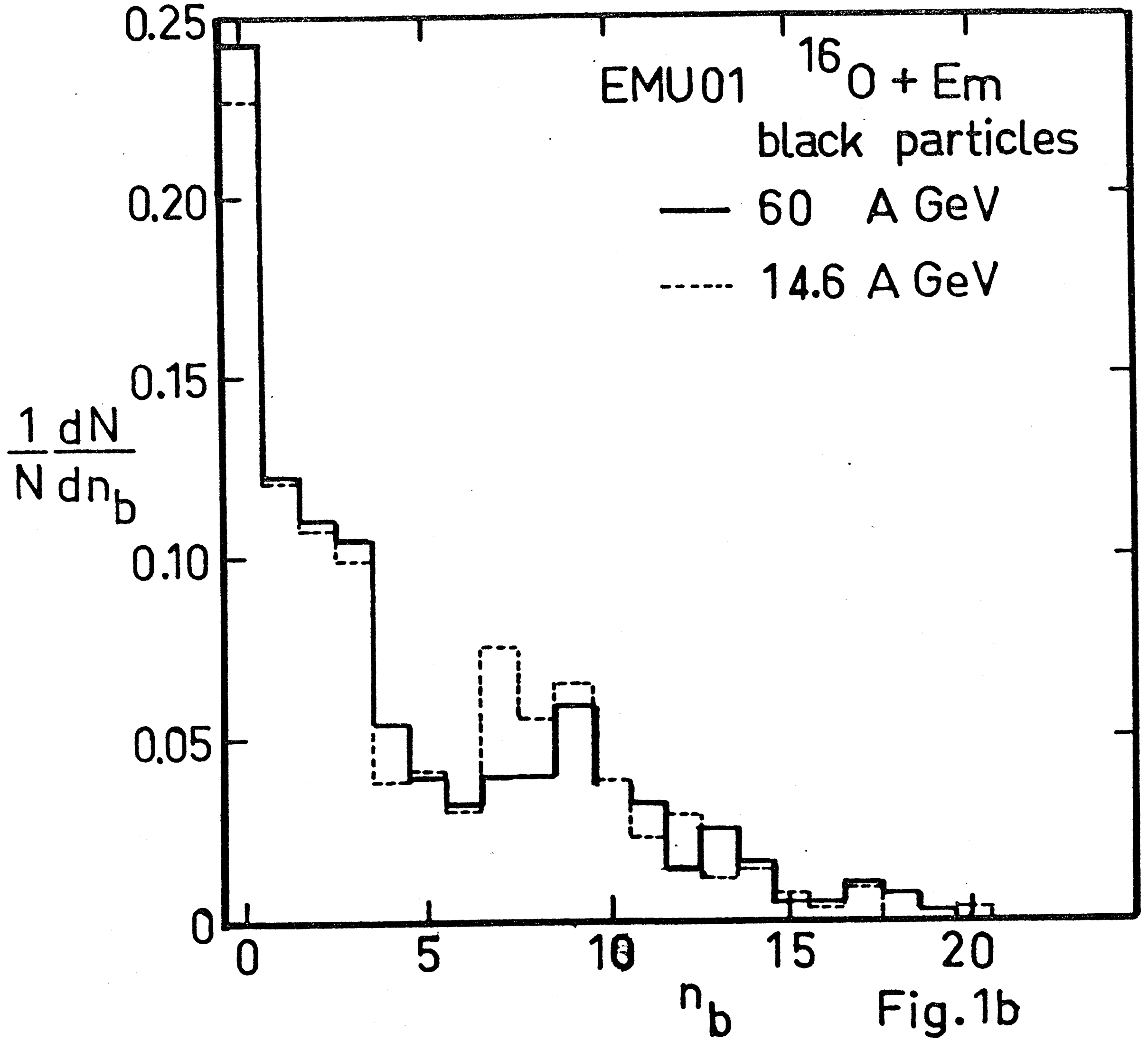

EMU01 16O + Em
black particles
60 A GeV
14.6 A GeV
1 dN / N dn_b
0.25
0.20
0.15
0.10
0.05
0
5
10
15
20
n_b

Fig.1b

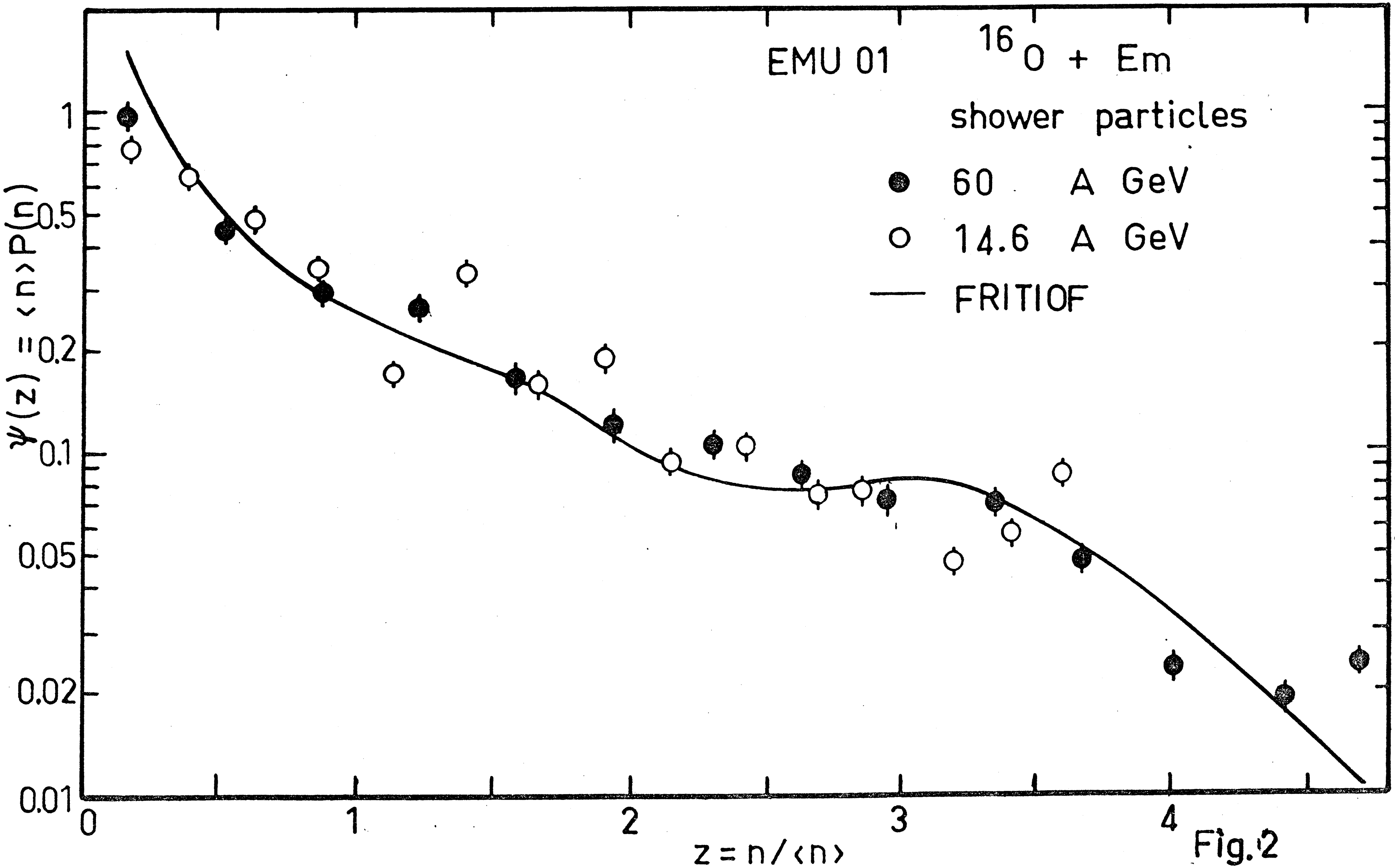

EMU 01
16O + Em
shower particles
60 A GeV
14.6 A GeV
FRITIOF
ψ(z) = ‹n› P(n)
1
0.5
0.2
0.1
0.05
0.02
0.01
0
1
2
3
4
z = n/‹n›

Fig. 2

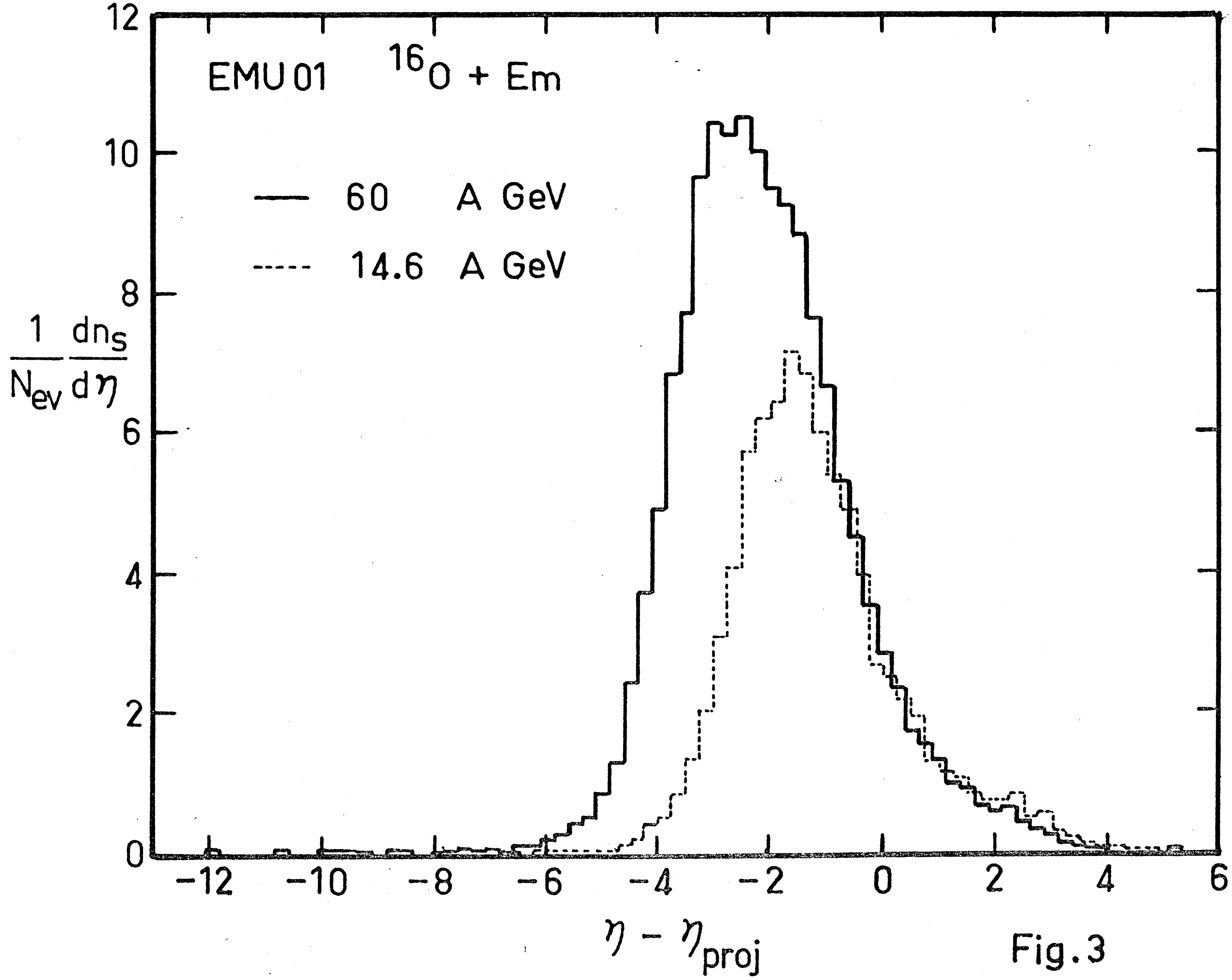

EMU 01 16O + Em
60 A GeV
14.6 A GeV
1/Nev dns/dη
η - ηproj
12
10
8
6
4
2
0
-12
-10
-8
-6
-4
-2
0
2
4
6

Fig.3

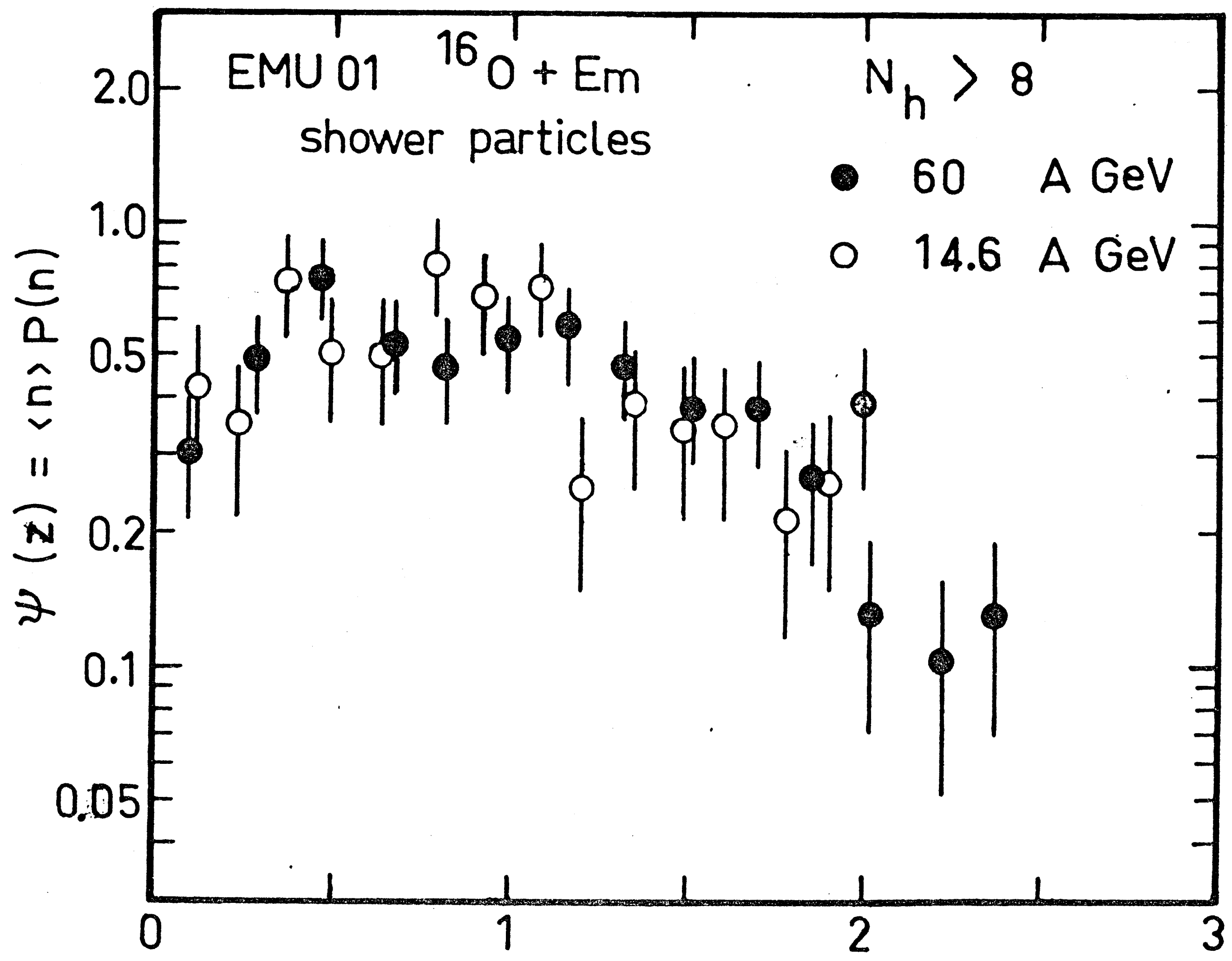
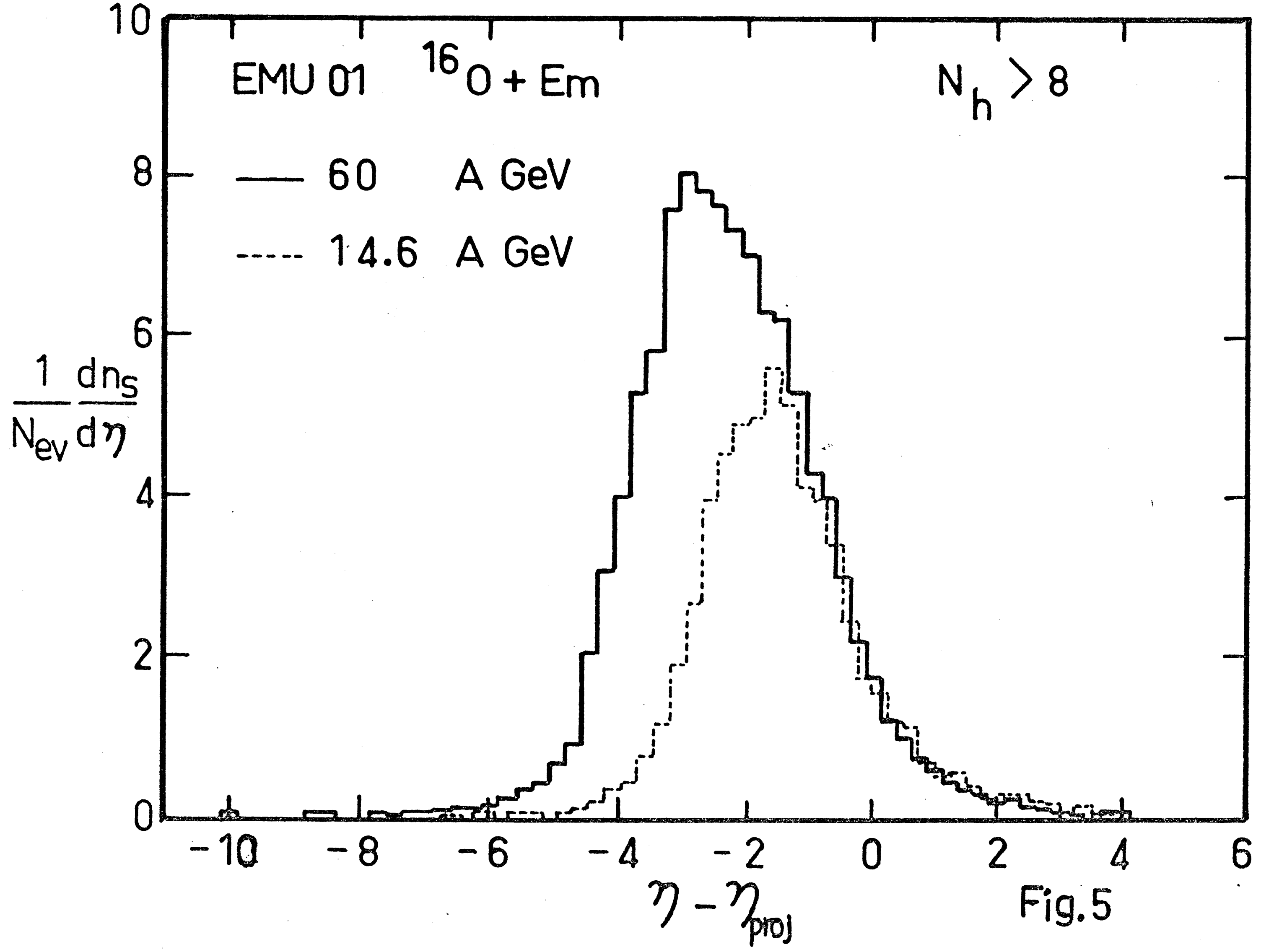

EMU 01 16O + Em
shower particles
N_h > 8
60 A GeV
14.6 A GeV
2.0
1.0
0.5
0.2
0.1
0.05
0
1
2
3
ψ (z) = ‹n› P(n)
z = n / ‹n›

Fig. 4



EMU 01
$^{16}O + Em$
$N_h > 8$
60 A GeV
14.6 A GeV
$\frac{1}{N_{ev}} \frac{dn_s}{d\eta}$
10
8
6
4
2
0
-10
-8
-6
-4
-2
0
2
4
6
$\eta - \eta_{proj}$

Fig.5