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EMU01 - collaboration

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Abstract: An investigation of the energy dependence of grey prong producing particles in ^{16}O+Emulsion interactions at energies from 2.1 to 200 A GeV is reported. Many of the features of these particles, known from hadron-induced interactions, are shown to be of importance also in heavy-ion interactions, i e multiplicity and angular distributions as well as the impact parameter dependence are energy independent. Furthermore the angular distribution seems to be independent of the projectile and target masses as well as centrality of the interactions. Both the Fritiof and Ranft models fail to reproduce this general angular shape.

A lot of results from the fixed target heavy-ion experiments at CERN (60 and 200 A GeV) and Brookhaven (14.6 A GeV) have recently been communicated[1]. The main emphasis have been put on the particle production in the forward and central regions of pseudo-rapidity but the target region is still comparably unexplored. To achieve a complete understanding of the underlying reaction mechanismes in nucleus-nucleus collisions at ultra-relativistic energies also the target region has to be investigated.

In an earlier paper by the EMU01 collaboration[2], the target associated particles have been studied and compared with the multichain model by Ranft[3,4] and the Lund model Fritiof[5]. The model by Ranft is the only one, so far, that at least partially includes an intra-nuclear cascade inside the target. In this model there is a free parameter, τ_0, related to the formation time of hadronic matter which has to be determine by experiments. The formation time is an important quantity since it is closely related to the energy densities and thereby to the creation of a quark-gluon plasma. A good determination of this quantity is one of the most desirable things for the time being.

The conclusions in the earlier paper[2] were that the Ranft model with τ_0 = 5 fm/c can reasonable well explain the multiplicity spectra of grey prong producing particles (N_g) in ^{16}O+emulsion interactions at 200 A GeV whereas a complete cascade together with an evaporation process are necessary to explain the multiplicity spectra of black prong producing particles (N_b). Furthermore it was found that the Ranft model with τ_0 = 10 fm/c, i e a less developed cascade, and Fritiof show a great similarity conserning the multiplicities of grey prong producing particles. The definitions of the different types of tracks can be found in reference [2]. In this paper we continue our studies of the grey prong producing particles, by investigating their angular distributions and energy dependence. Data will, furthermore, be confronted with predictions from the Fritiof and Ranft models.

The events used for this investigation are found in the 16 emulsion stacks, horizontally exposed with Oxygen ions at CERN (60 and 200 A GeV) and Brookhaven (14.6 A GeV). Each stack consists of 30 plates of BR-2 emulsion, each of size 20·10·0.06 cm^3 (10 stacks) or 10·10·0.06 cm^3 (6 stacks). The sensitivity of this emulsion is almost 30 grains per 100 μm for a minimum ionizing particle. The interactions were found by along-the-track scanning which has a high detection efficiency. The selection of central events used in this investigation is based on the charge flow in the forward direction, Q_{zd}, defined in ref [6]. More detailes about the measurement procedure can be found elsewhere[6,7]. Grey prong producing particles (N_g), the focus of this investigation, are particles with a range greater than 3 mm in emulsion and a velocity less than 0.7·c. Based on the knowledge from hadron-induced interactions, grey prongs are believed to mainly be knock-out protons from the target with a kinetic energy of 26.2-375 MeV with some admixture of produced kaons and pions with a kinetic energy of 19.8-198 MeV and 11.6-55.6 MeV, respectively. In Table 1 the experimental data are summarized, together with data from another experiment at 2.1 A GeV[8]. Apart from the data samples in Table 1 one sample from the Fritiof model (version 1.7)[5], and one sample from the Ranft model (τ_0 = 5 fm/c)[3,4], both at 200 A GeV, were generated for comparisons. Due to inherent problems of the cascade the Ranft model could only generate interactions with the heavy component (Ag,Br) of nuclear emulsion. The Fritiof model has no such restrictions and in the generated sample the contributions from the different components in nuclear emusion are weighed together according to their abundance. Fritiof does not include any target cascading but has successfully described the particle production in the central and projectile fragmentation regions [6,7,9]. Both model samples contain of the order 10000 events.

In fig 1 we show the multiplicity distributions of grey prongs at four different energies. The three highest energies are from the present study, whereas the 2.1 A GeV data are from ref [8]. The multiplicity distribution of grey prongs seems to be independent of the projectile energy which is a well-known feature in hadron-induced interactions.

Fig 2 deals with the angular distribution of grey prongs. In fig 2a the results from 200 A GeV is plotted together with the predictions from the Fritiof and Ranft models. Both models generate spectra which are more forward peaked than the experimental one. The Ranft model, with a first order cascade approximation, seems to lie in between the data and the Fritiof model. Note that since most grey prongs are produced in interactions with the heavy component in nuclear emulsion, the exclusion of the lighter target components in the Ranft model should not influence the spectrum significantly.

In ref [10] it was found that the angular distribution in proton-induced interactions up to incident energies of 400 GeV is described by $e^{0.96\cdot\cos\Theta}$. A fit to 800 GeV proton data[11] gives the same exponent. In fig 2b the angular distributions for 14.6, 60 and 200 A GeV are plotted together with the line from ref [10]. As can be seen the data and the line show quite a good agreement. Data from all three energies follows the exponential shape and the slopes are very close to the ones obtained in proton-induced experiments. In fig 2c the data samples are divided into one central sample with $Q_{ZD} \leq 3$ (corresponding to 17% of the events) and a peripheral sample with $Q_{ZD} \geq 6$ (66% of the events). In this figure we have combined the results from all the three energies. There seems to be no dependence on the centrality of the events, a result also obtained for 800 GeV proton data[11]. Figure 2 shows that the angular distribution of grey prongs is independent of the projectile size, projectile energy and the centrality of the events. This is predicted in a simple superposition picture where each participant nucleon in the target on the average gives the same contribution of grey prongs independent of each other. A simulation along these lines gives the same slope as the experimentally observed one[12].

To get an energy independent measure of the centrality of an interaction the quantity $m/\langle m\rangle$ is defined. Here m is the number of singly charged particles with a velocity greater than $0.7 \cdot c$ corrected for the number of singly charged particles from the projectile spectator break-up. For ^{16}O+emulsion interactions m is equal to

$$m = n_s - (8 - \sum_{Z \geq 2} Z)$$

where the sum is the total charge of all identified, multiple-charged projectile fragments. In figures 3 and 4 we plot $\langle N_g\rangle$ versus $m/\langle m\rangle$. These figures show a measure of the number of target participants, i e N_g, on the abscissa and a measure of the total number of participants on the ordinate. In fig 3 the 200 A GeV data are compared with the Fritiof and the Ranft models. Since for the Ranft model a minimum bias value of $\langle m\rangle$ was not possible to obtain, we used the same value as for Fritiof, i e 55.3 (± 0.6), which is in good agreement with the experimental value of 54 ± 3. Both models show a similar trend with a linear behaviour for $m < 2 \cdot \langle m\rangle$, a kink at about $2 \cdot \langle m\rangle$ followed by a new linear behaviour. This can be understood in a simple geometric picture, since a change in impact parameter for peripheral interactions influences both the number of projectile and target participants whereas a similar change for central interactions mainly influences the number of target participants. Thus $2 \cdot \langle m\rangle$ seems to correspond roughly to the impact parameter $R_{targ} - R_{proj}$. The exclusion of interactions with the lighter components in the Ranft sample again only marginally effects the plot, since these events only would have lowered the points for small values of $m/\langle m\rangle$. Lead by the simple geometrical picture, straight lines for all three samples in the region $0 < m/\langle m\rangle < 2$ are fitted and we find that also the experimental data points have a tendency to lie above the line for $m/\langle m\rangle > 2$. We note that although the average value of $\langle N_g\rangle$ from the Ranft model can, with a suitable choise of τ_0, be brought to agreement with the data, the dependence of $\langle N_g\rangle$ on the centrality is larger than in the data. In the simple superposition picture mentioned above, $\langle N_g\rangle/P_{targ}$ (where P_{targ} are the number of participating nucleons from the target) will be a constant independent of the value of $m/\langle m\rangle$. For Fritiof, where $\langle N_g\rangle$ is essentially determined by the number of participating target protons it is observed that an overall factor of about 2.8 from a cascade would raise the points to agreement with the data.

In fig 4 the experimental data from 60, 14.6 and 2.1[8] A GeV are shown together with the line from the 200 A GeV experimental sample in fig 3. For all energies we find a nice agreement between the line and the data points for values $m < 2\cdot\langle m\rangle$. For larger values the data from the different energies behave somewhat irregular but on the average the points lie above the line.

We conclude that many of the features of the grey prong producing particles, already observed in hadron-induced interactions, are of importance also in heavy-ion interactions. Multiplicity and angular distributions as well as the impact parameter dependence are shown to be energy independent. Furthermore the angular distribution is independent of the projectile and target masses as well as centrality of the interactions and are nicely described by $e^{0.96\cdot\cos\Theta}$. Both the Fritiof and Ranft models fail to reproduce this general angular shape but reproduce the general impact parameter dependence rather well.

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Figure Captions

Figure 1

The multiplicity distribution of grey prongs in ^{16}O+emulsion interactions at 200, 60, 14.6 and 2.1 A GeV.

Figure 2

The angular distribution of grey prongs in ^{16}O+emulsion interactions. a) a comparison between the experimental results, Fritiof and the Ranft model with τ_0 = 5 fm/c at 200 A GeV. b) compares the experimental samples at 200, 60 and 14.6 A GeV with the line from ref [10]. c) a comparison between central and peripheral events. In this case the three energies, 200, 60 and 14.6 A GeV, are summed up to increase the statistics.

Figure 3

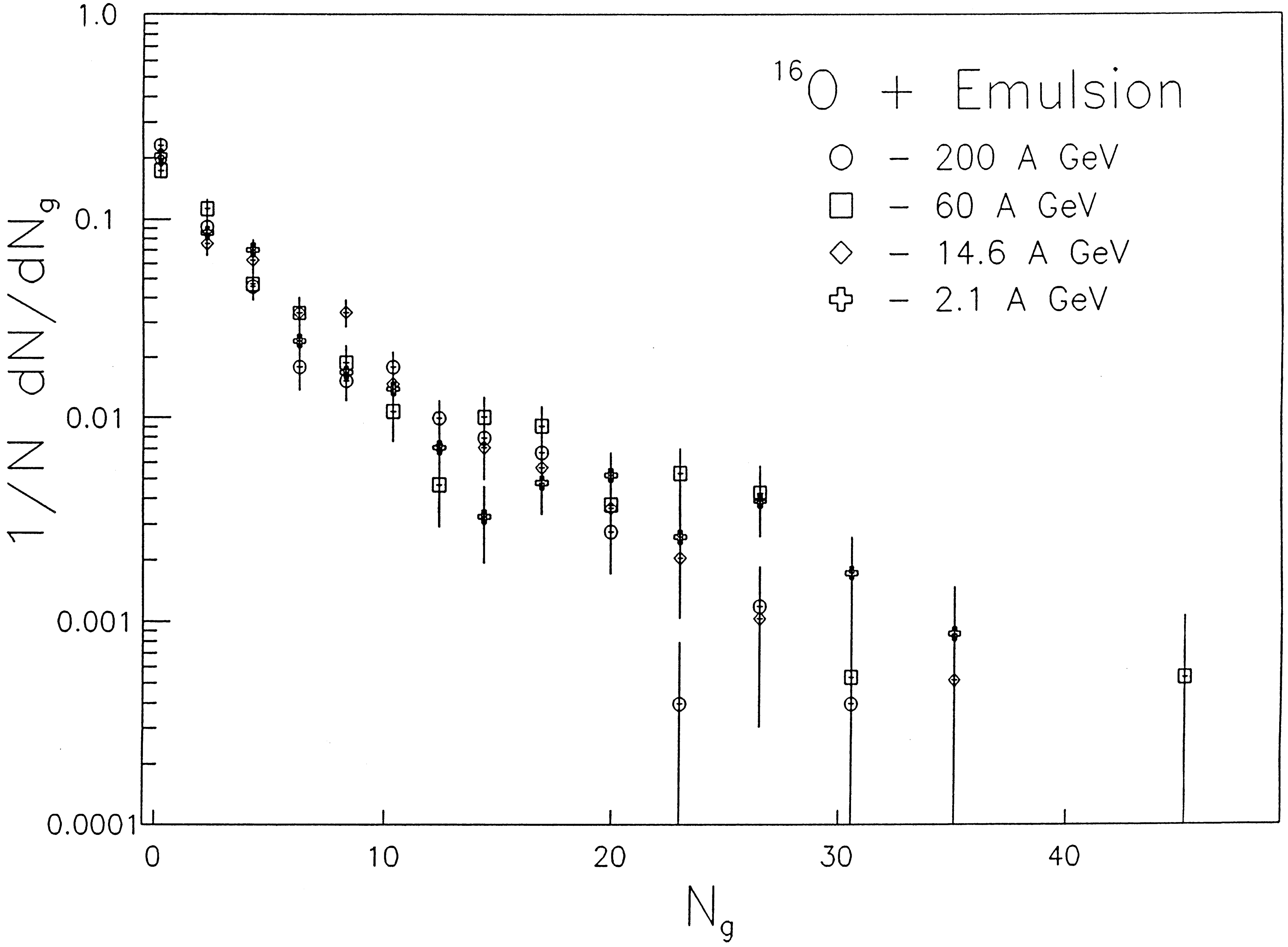
The average number of grey prongs versus m/<m> (defined in the text) at 200 A GeV compared with Fritiof and the Ranft model with τ_0 = 5 fm/c. In all cases a straight line is fitted in the interval $0 \leq m/\langle m\rangle < 2.0$ and continued through the whole region.

Figure 4

The average number of grey prongs versus m/<m> (defined in the text) at 60, 14.6 and 2.1 A GeV. The fitted line from the 200 A GeV experimental sample in fig 3 is also shown as a comparison.

Table 1

	Data			
E_{inc} (A GeV)	200	60	14.6	2.1
no of events	503	372	385	456
$\langle m \rangle$	54 ± 3	37 ± 2	17.6 ± 0.9	3.1 ± 0.3
$\langle N_g \rangle$	4.3 ± 0.2	5.7 ± 0.4	4.9 ± 0.3	5.1 ± 0.3



^{16}O + Emulsion
○ – 200 A GeV
□ – 60 A GeV
◇ – 14.6 A GeV
✚ – 2.1 A GeV
$1/N \; dN/dN_g$
1.0
0.1
0.01
0.001
0.0001
0
10
20
30
40
N_g

Fig 1

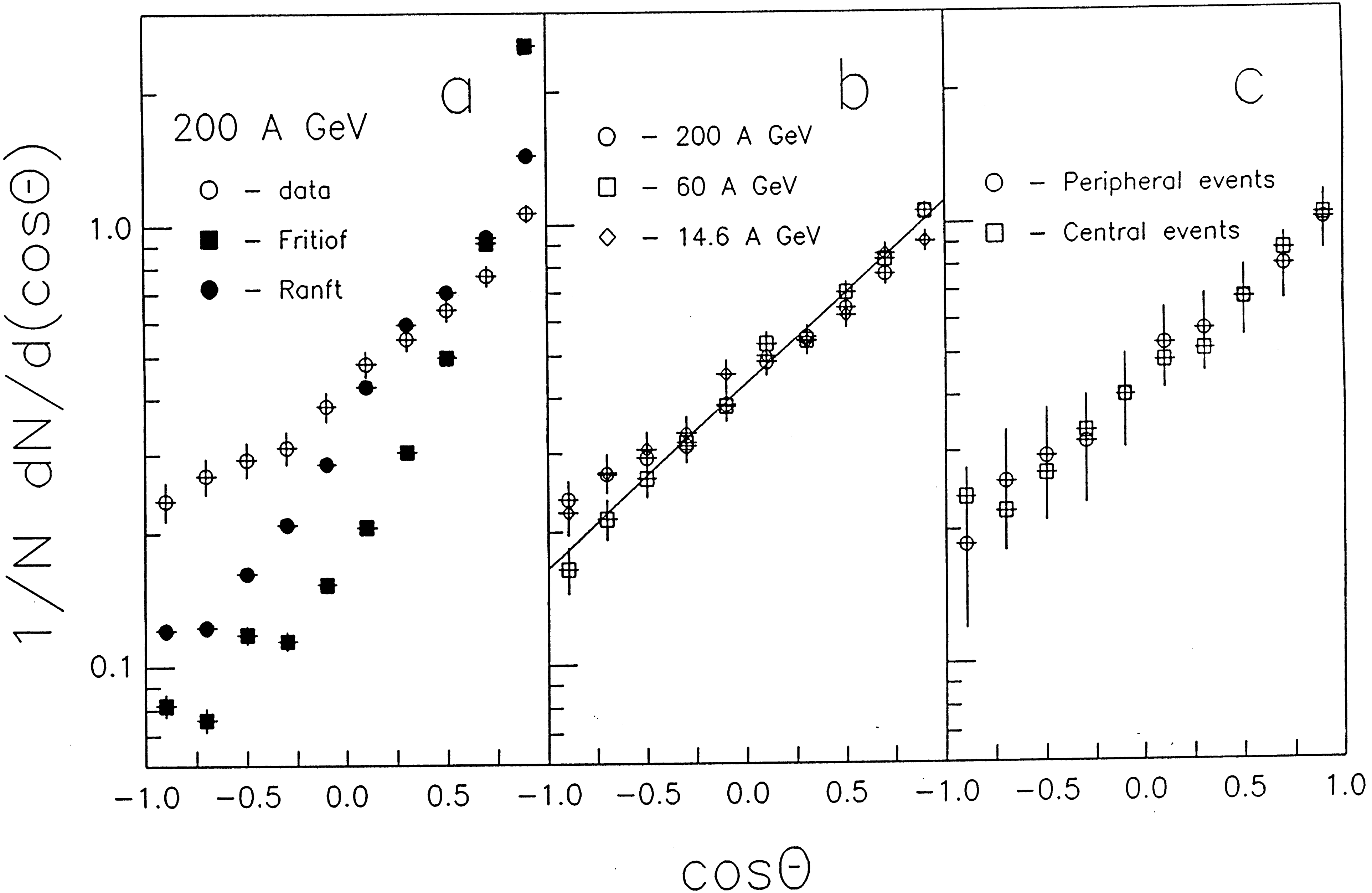

a
200 A GeV
○ – data
■ – Fritiof
● – Ranft
b
○ – 200 A GeV
□ – 60 A GeV
◇ – 14.6 A GeV
C
○ – Peripheral events
□ – Central events
1/N dN/d(cosΘ)
1.0
0.1
−1.0
−0.5
0.0
0.5
1.0
cosΘ

Fig 2

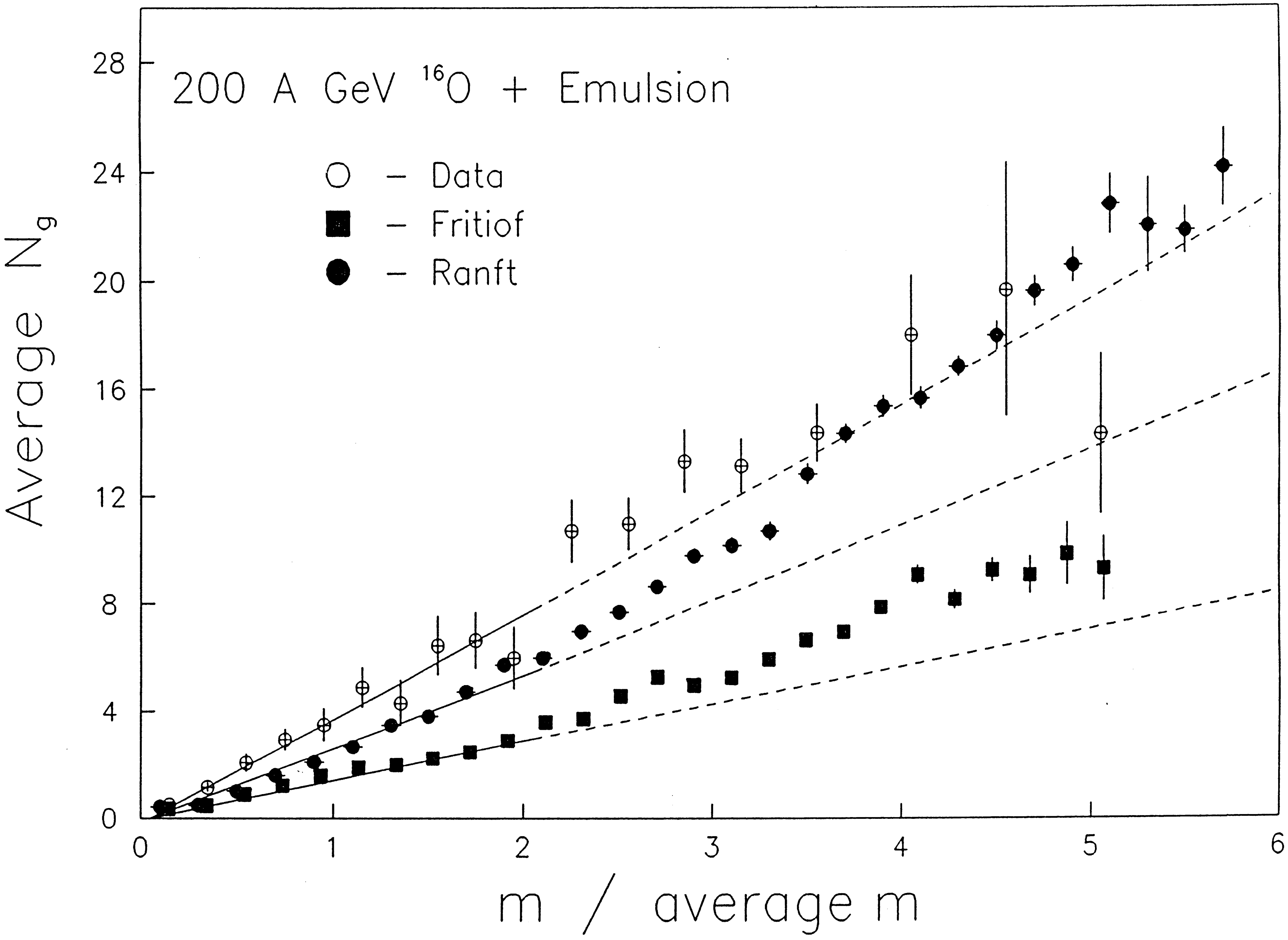

200 A GeV ^{16}O + Emulsion
○ – Data
■ – Fritiof
● – Ranft
Average N_g
0
4
8
12
16
20
24
28
0
1
2
3
4
5
6
m / average m

Fig 3

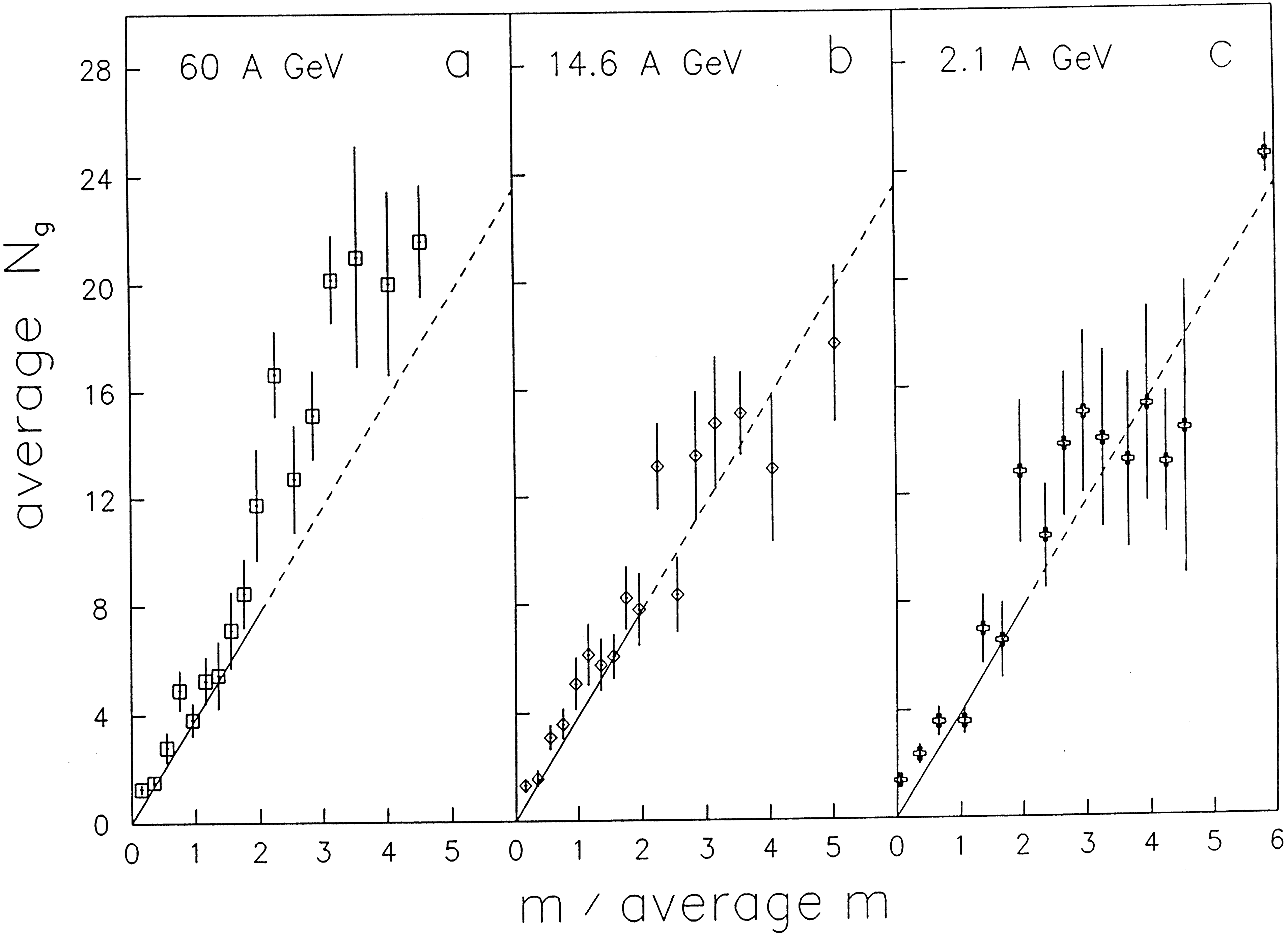

60 A GeV
a
14.6 A GeV
b
2.1 A GeV
C
average N_g
0
4
8
12
16
20
24
28
m / average m
0
1
2
3
4
5
6

Fig 4