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Abstract: The multiplicity distributions of low-energetic target-associated particles from 200 A GeV Oxygen-induced interactions with emulsion nuclei are presented. The experimental distributions are compared with distributions obtained using the Ranft and Fritiof simulation codes. It is found that the intranuclear cascade plays an important role for the target break-up in ion-induced interactions, similar to what is the case for hadron-induced interactions.

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The first generation of relativistic heavy-ion experiments have produced a variety of data. The bulk of the data is well reproduced by current models, at least in a qualitative sense, and very few surprises have emerged from the analysis so far. The models have taught us that the nuclear geometry may be the dominating ingredient and most of the experimental inclusive spectra have characteristic shapes, largely influenced by the variations in the amount of participating nuclear matter. The hope of finding a strong unmistakable signal, establishing the presence of the quark gluon plasma (QGP), is by now abandoned and more refined techniques are employed in the chase of the QGP.

An early observation was that the achieved energy densities were reaching the values necessary for the creation of the QGP, advocated by most theoretical investigators, although no unquestionable way to experimentally estimate the energy density exists. One uncertainty is related to the formation time of hadronic matter which influences such an estimate.

Most of the models on the market make the assumption that the formation time is long enough, so that effects of rescattering of secondaries can be neglected. This is obviously a simplification but nevertheless the gross features of the data are reproduced as long as the target fragmentation region is excluded from the comparison. One of the models based on the dual fragmentation scheme, here referred to as the Ranft-code1-3), at least partly takes into account the rescattering of secondaries and the subsequent cascading inside the target nucleus. In this model the formation time is treated as a free parameter and a comparison with experimental data on target related particles may reveal the magnitude of this parameter.

In this letter the multiplicity distributions of recoiling protons and spectator particles obtained in Oxygen-induced interactions with emulsion nuclei at 200 A GeV are investigated and compared with calculations from the Ranft- and Fritiof4)-codes. We will check our observations by a comparison also for proton-induced interactions where the production mechanism for the target associated particles are fairly well known5).

The experimental data used in this investigation is collected in emulsion stacks exposed horizontally at the CERN SPS. Each stack consisted of 30 BR-2 emulsion plates with a sensitivity for a minimum ionizing particle of almost 30 grains per 100 μm. The interactions were found by along-the-track scanning which has a very high detection efficiency. Further details on the experimental procedures can be found in references 6 and 7. In each event the emission angle of all emerging charged particles were determined together with the multiplicities of shower particles (n_s), grey (N_g) and black (N_b) prong producing particles and the projectile fragments. The experimental definitions of the different particle categories are:

Shower particles	-	singly charged particles with a velocity $\geq 0.7 \cdot c$.
Grey particles	-	charged particles producing tracks with a range ≥ 3 mm and having a velocity $< 0.7 \cdot c$.
Black particles	-	charged particles producing tracks with a range < 3 mm.

A proton with a range of 3 mm in emulsion has a kinetic energy of 26.2 MeV and the corresponding values for pions and kaons are 11.6 and 19.8 MeV, respectively. The corresponding limits between grey particles and shower particles are 375, 198 and 55.6 MeV for protons, kaons and pions, respectively. In hadron-induced interactions grey particles are mainly knock-out protons with a small admixture of charged pions and kaons whereas the black prongs are evaporation products, both singly and multiply charged, from the remnant of the target nucleus. The average charge for a black particle is found to be ~ 1.2 - 1.3⁸⁾. In ion-induced interactions these categories are believed to have a similar origin although this has to be confirmed.

In the experimental sample, events which are due to electromagnetic dissociation and elastic scattering are excluded, by the criterion that at least one shower particle should appear outside the fragmentation cone (1 mrad for heavy-ion interactions at 200 A GeV). After the subtraction of these events, 503 ^{16}O-emulsion events remain out of a total sample of 530 events. The average numbers of grey and black prongs are for the remaining sample 4.3 ± 0.2 and 4.0 ± 0.2, respectively.

Besides the data three samples have been generated using the Ranft- and Fritiof-codes. Details of these samples can be found in Table 1.

The Ranft model is based on the dual multichain fragmentation model with the inclusion of a leading order secondary cascade correction¹˒²⁾. A phenomenological parameter, τ_0, which is related to the formation zone, τ_s, in the rest frame of the secondary particle by

$$\tau_s = \tau_0 \frac{m_s^2}{m_s^2 + p_{ts}^2} ,$$

is introduced to describe the timelapse necessary for a secondary hadron to reinteract hadronically. Here m_s and p_{ts} are the mass and the transverse momentum of a secondary, respectively. Note that τ_0 used in ref 1 differs from the τ used in ref 2.

The Fritiof-code is based on the Lund fragmentation scheme[4)] where the particpating nucleons are excited longitudinally into stringlike objects, decaying independently. The main difference between the models is that in Fritiof a string can reinteract and gradually increase its mass, whereas in the Ranft-code additional strings consisting of seaquarks are produced in the repeated collisions. There is also a difference in the treatement of the nuclear geometry leading to differences in the number of participant nucleons, the number of binary collisions, etc. Both models are quite successful in describing the general trends of the particle production in both hadron-nucleus and nucleus-nucleus reactions. In Fritiof the target cascade is totally neglected. Whereas the main contribution to the grey particles in the Ranft-code comes from the cascade, i e from the inital spectator part of the nucleus, the only contribution in Fritiof is the low-energetic particles emerging from the fragmentation of the strings.

In fig 1 the N_g-distributions from the four samples are compared. The data are compared with the Fritiof sample in a) and with the two Ranft samples in b). In c) the two models are compared with each other. The distributions from the data and the complete Fritiof sample are both normalized to unity, whereas the AgBr distributions from both models are normalized to the fraction of AgBr events, i e 56% of the total inelastic cross section. It should be noted that the tail of the distributions consist entirely of events from the heavy components in the emulsion.

It is found that the Fritiof-code underestimates the production of grey prongs, as expected. Furthermore, it is observed that out of the two Ranft samples the one with τ_0 = 5 fm is in good agreement with the data, whereas the sample with τ_0 = 10 fm closely resembles the Fritiof sample. If τ_0 is increased the N_g-production in the Ranft-code decreases even further and the number of grey prongs becomes smaller than the corresponding number in Fritiof. For very small values of τ_0 the number of grey prongs in the Ranft-code increases drastically but this seems to be at the expense of the conservation of baryon number as well as charge.

The composition of the grey prongs are similar in the three generated samples. The baryon number per grey prong is 0.69 for the Fritiof sample (the same for both the total and the AgBr samples) and 0.71 (τ_0 = 5 fm) and 0.52 (τ_0 = 10 fm) for the two Ranft samples, respectively. From the Ranft-code we learn that a more prominent cascade mainly produces more grey protons, whereas the mesonic content is only weakly dependent on τ_0.

In a recent investigation of shower particle densities$^{6)}$ it was shown that the Fritiof-model is in good agreement with data also when the target fragmentation region is concerned. This means that the meson production in the target fragmentation region hardly is influenced at all by the cascade. The observation from the Ranft-code, that τ_0 only effects the baryon production in this region, show that an intra-nuclear cascade can give a reasonable result without contradicting the observed data concerning the limiting fragmentation behaviour.

In fig 2 the N_b distributions are compared. The normalization is the same as in the previous figure. It is observed that not even the Ranft sample with τ_0 = 5 fm can fully reach the experimental tail. This can be interpreted as a signal for an additional mechanism, i e evaporation which is important in the case of hadron-induced interactions, but could also be due to the incomplete cascade approach adapted in the code. The two other generated samples, which looked similar when the grey prong production was considered, now are quite different.

Before we conclude calculations from the Ranft-code are compared with N_g- and N_b-distributions obtained from proton-emulsion interactions. For this purpose two p + AgBr samples at 200 GeV with the same values of τ_0 as before have been generated. Both samples consist of 7200 events each. In proton-induced interactions the AgBr-component is 72% and the model distributions are normalized correspondingly. The experimental data are taken from ref 5 where emulsion data with incident energies between 200 and 400 GeV was compiled. The distributions showed no energy dependence within this energy range why such a compilation is justified.

Fig 3 shows the results of the comparison for both N_g, a) and N_b, b). As can be seen the model has severe difficulties to explain the observed experimental data. It is presumably possible to decrease τ_0 in order to find an agreement for the N_g case but for N_b the difference is too large to be bridged by any reasonable value of τ_0.

When the data and the Ranft-samples are compared we find that it is possible, within the framework of the model, to understand the production of grey prongs. The black prong production cannot, however, be explained by the cascade and it seems plausible that an evaporation from the remnant of the target nucleus has to be included if the aim is to completely describe the data. If also the findings from the proton-induced interactions are to be included, it is impossible to describe both sets of data with the same value of the time parameter, τ_0, indicating that a deeper understanding of the cascade is needed. In the proton case it is furthermore evident that the evaporation process is essential for the low energy component.

Comparing the results from Fritiof and the Ranft-code with a moderate cascade (τ_0 = 10 fm) indicates that the two models give similar results although the amount of black prongs is larger in the Ranft-code. This similarity is also seen for the shower particles, somewhat obscured by the differences in the treatment of the nuclear geometry, i e with the same geometry the two models essentially coincide. These comparisons are, however, outside the scope of this letter.

We conclude that the intra-nuclear cascade is important for the production of the target associated particles in ion-induced interactions. However, we have the feeling that the treatment of the cascade, in the Ranft-code, is too simplified to give quantitative answers to the question of the formation time. It is also our opinion that questions like this eventually will be answered by this type of analyses, provided that the models incorporate the cascade and possibly also the evaporation process in a more consistant manner.

We like to express our thanks to the CERN staff of the PS and SPS for their outstanding performance in producing the ^{16}O beam for the experiment, with special thanks to G Vanderhaeghe, K Ratz, N Doble, P Grafström, M Reinharz, H. Sletten and J Wotschack. We are also extremely thankful for the contributions given by the scanning/measuring staffs within the collaboration. We thank H R Schmidt and the WA80-collaboration for valuable help regarding the Ranft-code. The financial support from the Swedish NFR, the German Federal Minister of

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References

1) J Ranft, Phys Rev D37(1988)1842
2) J Ranft, Preprint CERN-TIS/Rp 219/PP (1988), submitted to Z Phys C
3) H R Schmidt, private communication
4) B Nilsson-Almqvist and E Stenlund, Comp Phys Comm 43(1987)387
5) E Stenlund and I Otterlund, Nucl Phys B198(1982)407
6) M I Adamovich et al, Phys Rev Lett 62(1989)2801
7) M I Adamovich et al, Phys Lett B123(1989)262
8) C F Powell, P H Fowler and D H Perkins, "The Study of Elementary Particles by the Photographic Method", chapter 5, Pergamon Press 1959

Figure Captions

Figure 1

Multiplicity distributions of grey prong producing particles in Oxygen-induced interactions with emulsion nuclei from this experiment compared with the same distributions from the Fritiof- and Ranft-models.

Figure 2

Multiplicity distributions of black prong producing particles in Oxygen-induced interactions with emulsion nuclei from this experiment compared with the same distributions from the Fritiof- and Ranft-models.

Figure 3

Multiplicity distributions of grey and black prong producing particles in proton-induced interactions with emulsion nuclei from ref 5 compared with the same distributions from the Ranft-model.

Table 1: Generated samples

	Code	τ(fm)	Total	AgBr	Total $\langle N_g \rangle$	Total $\langle N_b \rangle$	AgBr $\langle N_g \rangle$	AgBr $\langle N_b \rangle$
1	Fritiof (vers 1.7)	-	9788	5540	1.80	0.14	2.64	0.20
2	Ranft (Sept 88)	5	-	5600	-	-	6.13	2.83
3	Ranft (Sept 88)	10	-	5600	-	-	3.15	1.19

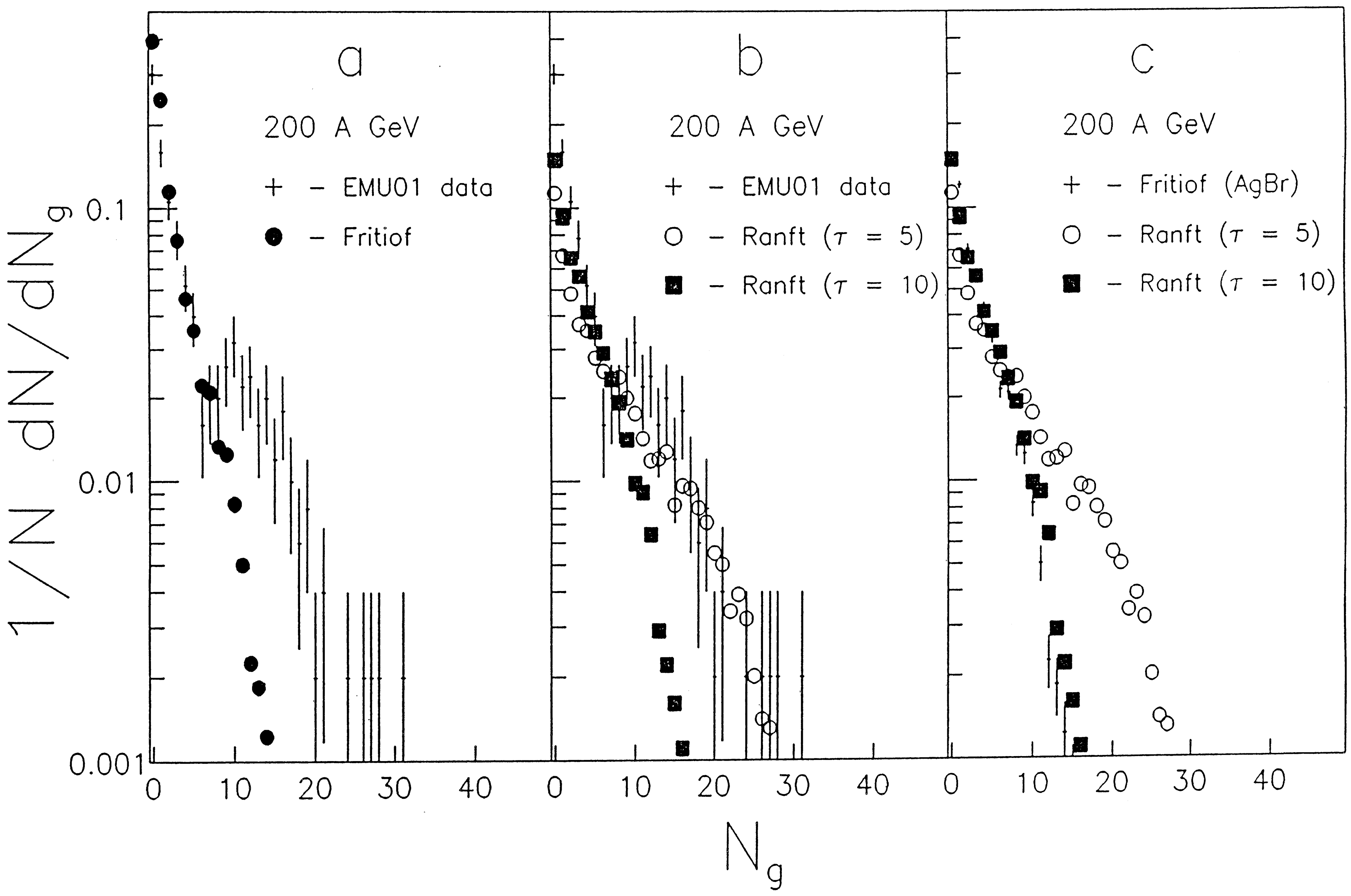
a
200 A GeV
+ – EMU01 data
● – Fritiof
b
200 A GeV
+ – EMU01 data
○ – Ranft (τ = 5)
■ – Ranft (τ = 10)
C
200 A GeV
+ – Fritiof (AgBr)
○ – Ranft (τ = 5)
■ – Ranft (τ = 10)
1/N dN/dN_g
0.1
0.01
0.001
0
10
20
30
40
N_g

Fig 1

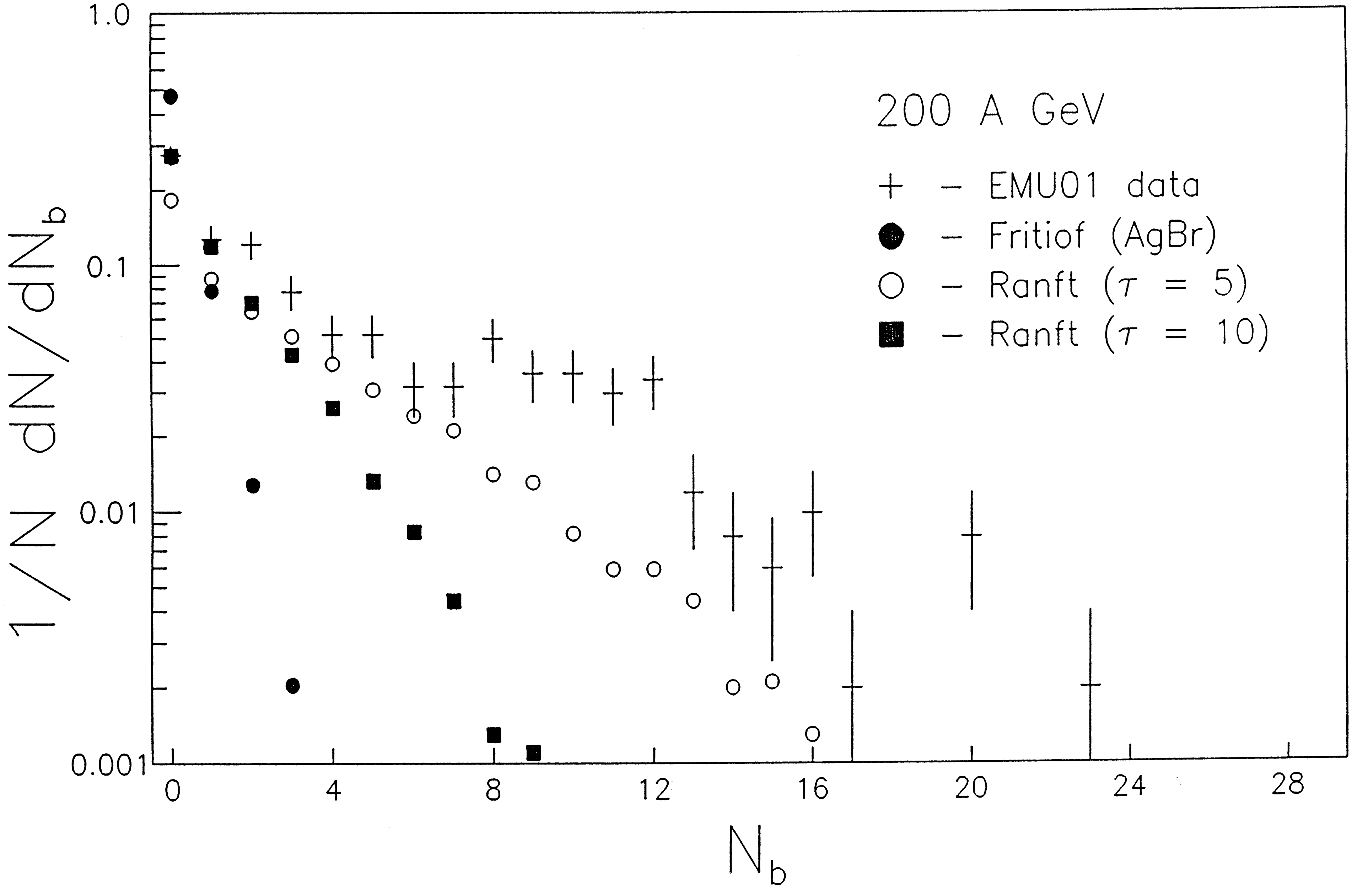
200 A GeV
+ – EMU01 data
● – Fritiof (AgBr)
○ – Ranft (τ = 5)
■ – Ranft (τ = 10)
1/N dN/dN$_b$
1.0
0.1
0.01
0.001
0
4
8
12
16
20
24
28
N$_b$

Fig 2

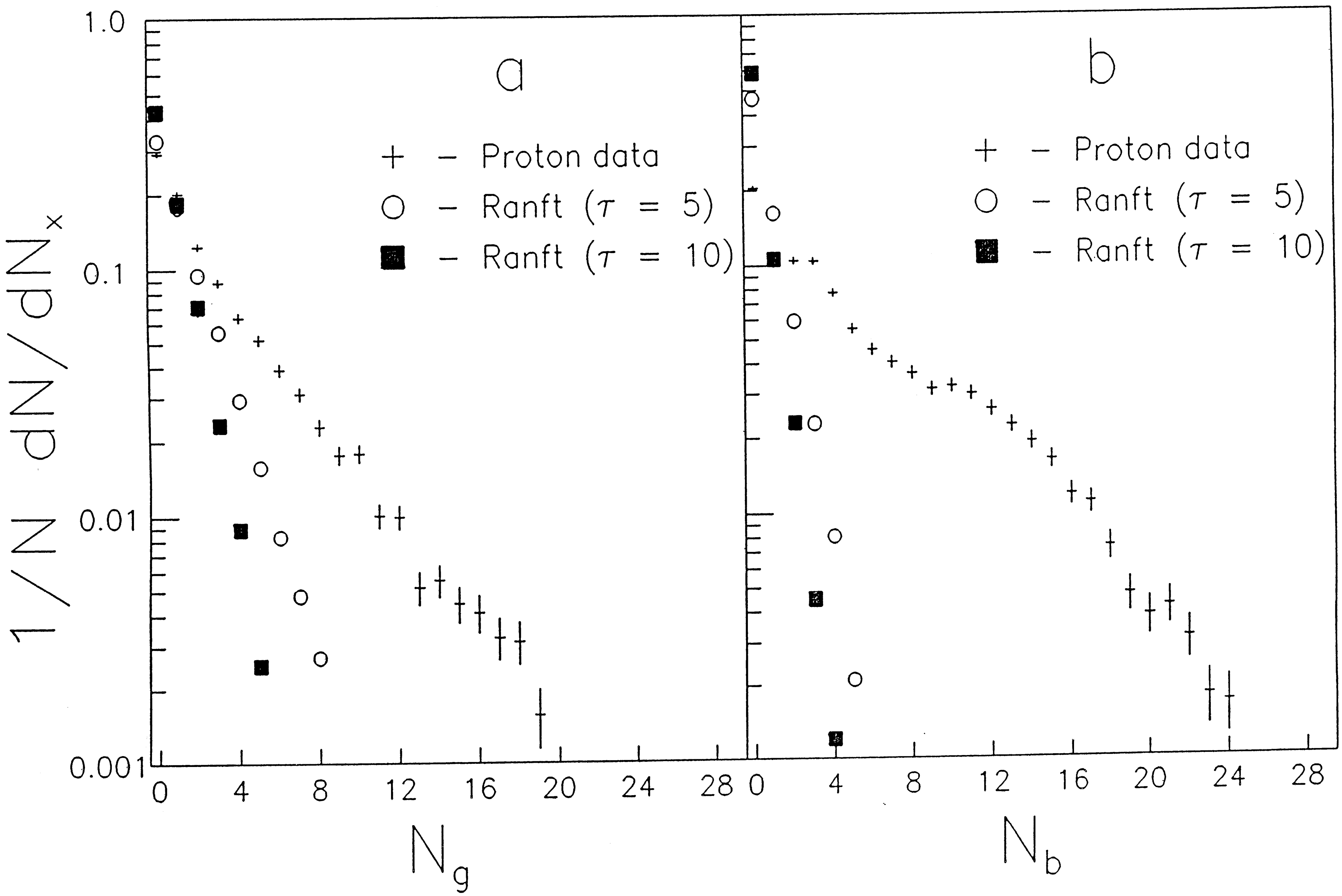
a
b
+ – Proton data
○ – Ranft (τ = 5)
■ – Ranft (τ = 10)
1/N dN/dN_x
1.0
0.1
0.01
0.001
0
4
8
12
16
20
24
28
N_g
N_b

Fig 3