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ARTICLE PRODUCTION IN RELATIVISTIC HEAVY-ION INTERACTIONS

EMU01 - collaboration

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Substructual Dependence of the Multiparticle Production in Relativistic Heavy-Ion Interactions

EMU01 - collaboration

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Abstract: The average multiplicities of singly charged relativistic particles in oxygen-induced interactions with a nuclear emulsion target are studied over the energy range 2.1 - 200 A GeV. A similar energy dependence as for proton-induced interactions is observed. Both the number of participating nucleons and the number of binary collisions are shown to be of importance for the particle production.

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Ten years ago the average multiplicities of singly charged relativistic particles, $\langle n_s \rangle$, in proton-induced nuclear interactions were shown to depend linearly on the charged particle multiplicity in proton-proton interactions at the corresponding energy[1]. The fact that the line did not pass through the origin, explained why the multiplicity ratios showed an energy dependence and only asymptotically seemed to level off. For proton-Emulsion interactions the linear relation could be written

$$\langle n_s \rangle_{pEm} = 2.34 \cdot \langle n_{ch} \rangle_{pp} - 4.12 \qquad (1)$$

and was shown to be valid in the energy range 1 - 400 GeV. Extrapolation to 800 GeV, using $\langle n_{ch} \rangle_{pp} = 10.40$, reveals a value of 20.2, which is in a good agreement with the recently measured value 19.8 ± 0.3[2]. An obvious advantage of dividing the multiplicity into two terms is that the entire energy dependence will be embraced in $\langle n_{ch} \rangle_{pp}$. Furthermore, the dynamic properties of the production mechanism will be separated from the energy independent contributions. Also differences in the conventions in pp studies on one hand and p-nucleus and nucleus-nucleus studies on the other, are to a large extent absorbed by the second term. Thus it is not important to make any corrections to $\langle n_s \rangle$ from heavy-ion interactions due to, for instance, the inclusion of a few spectator protons in the very forward region of phase space, as long as their contribution is the same at all energies[3].

In this note we explore the possibility to apply the same phenomenological technique on heavy-ion interactions. The venture at CERN and Brookhaven to accelerate oxygen-ions, together with data from earlier beams at Dubna and Berkeley, allows the possibility to collect data at five different energies with the same projectile nucleus, where almost identical detectors, i e nuclear emulsion, have been emploied. The five data sets used in this note are summarized in Table 1.

In fig 1 $\langle n_s \rangle_{OEm}$ is plotted versus $\langle n_{ch} \rangle_{pp}$ and a linear fit to the five data points is indicated by the solid line. We observe that the line

$$\langle n_s \rangle_{OEm} = 10.1 \cdot \langle n_{ch} \rangle_{pp} - 16.6 \qquad (2)$$

reasonably well reproduces the data. We thus conclude that the energy dependence of the average multiplicites in heavy-ion induced interactions is similar to the one observed for proton-induced interactions. The slope is of course larger, reflecting the increased amount of nuclear matter involved in the interaction. The result may be compared to that of a similar study utilizing a selection of central interactions at CERN and Brookhaven energies[8,9].

There are two alternative approaches used to describe the global particle production in nuclear interactions, one based on the number of participating or "wounded" nucleons and the other on the number of binary collisions between nucleons from the two nuclei. These numbers are strongly depending on the impact parameter and for a given impact parameter large fluctuations in the numbers may occur due to density variations in the two nuclei.

Table 2 summarizes a model independent method of calculating the two numbers averaged over impact parameter and over the different target constituents in nuclear emulsion. The reaction percentages are calculated using the relative abundance of the different target constituents in "standard nuclear emulsion"[10] and the inelastic cross sections, parametrized as

$$\sigma_{pp} = 32.3, \ \sigma_{pA} = 38.17 \cdot A^{.719}, \text{ and } \sigma_{A_1A_2} = 109.2 \cdot (A_1^{.29} + A_2^{.29} - 1.39)^2,$$

given in mb. Simple geometrical considerations give the following expressions for the number of projectile participants, P_{proj}, target participants, P_{targ}, and binary collisions, BC:

$$\text{Projectile participants} = \frac{A_{proj} \cdot \sigma_{pA_{targ}}}{\sigma_{A_{proj}A_{targ}}} .$$

$$\text{Target participants} = \frac{A_{targ} \cdot \sigma_{pA_{proj}}}{\sigma_{A_{proj}A_{targ}}} .$$

$$\text{Binary collisions} = \frac{A_{proj} \cdot A_{targ} \cdot \sigma_{pp}}{\sigma_{A_{proj}A_{targ}}} .$$

We thus find that we have on the average 13.46 participants and 14.67 binary collisions in an average ^{16}O+Emulsion interaction, to be compared with the corresponding values for proton-induced interactions which are 3.66 and 2.66, respectively. The two ratios describing the increase of the amount of nuclear matter will thus be 3.68 for the case of participating nucleons and 5.52 for binary collisions. Multiplying the multiplicities given by eq (1) by these two ratios give

$$\langle n_s\rangle_{OEm} = 8.61\cdot\langle n_{ch}\rangle_{pp} - 15.16 \qquad (3)$$

for the participant approach and

$$\langle n_s\rangle_{OEm} = 12.92\cdot\langle n_{ch}\rangle_{pp} - 22.74 \qquad (4)$$

for the binary collision approach. These two lines are included in fig 1. It should be noted that when multiplicities in local regions of phase space are considered, the two approaces have to be modified, since, for instance, participants from the target may contribute differently than those from the projectile.

Several of the current models for relativistic heavy-ion collisions can be seen as developements of the two alternative approaches. In, for instance, the Fritiof model[11] all participant nucleons will be longitudinally excited and become strings, which later on fragment independently. Thus Fritiof can be seen as a participant nucleon model, however modified in the direction of binary collisions, since the excitation of a string gradually increases as it collides further on. Average multiplicities calculated by the Fritiof model, based on approximately 10000 events, are included in Table 1. An other group of models are the ones based on the dual topological scheeme[12]. Here chains are created in each binary collision and these chains later on fragment, similar to the strings in Fritiof. Those models can thus be viewed as binary collision models. In this case, however, those chains carrying the original quantum numbers of the participating nucleons, will produce more particles than the ones consisting entirely of sea-quarks. Some of the models within the latter category have also been shown to successfully predict different experimental observations. The "average predictions" from a generalized model might thus be parametrized as $\alpha\cdot$participants + $(1 - \alpha)\cdot$binary collisions. The two different approaches can here be regarded as the two limiting cases. Based on the slopes of equations (2), (3) and (4), we estimate α to be roughly 2/3 for oxygen-Emulsion interactions. This parameter might be quite dependent on both the projectile and target nuclei.

We conclude by estimating $\langle n_s\rangle_{SEm}$ for sulphur-induced interactions at 200 A GeV from the calculations summarized in Table 2, and find for the participant approach 68.5 and for the binary collision approach 114.6. Using the α-value found for oxygen-Emulsion interactions we obtain the prediction 83.9. Within the EMU01-collaboration we have so far measured 73 minimum bias interactions of this kind, excluding events due to electromagnetic dissociation. A preliminary result from those events gives $\langle n_s \rangle_{SEm} = 84 \pm 10$.

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Figure Caption

Figure 1. The average number of singly charged relativistic particles in ^{16}O+Em interactions at various energies, plotted versus the corresponding multiplicity in pp interactions. The best linear fit is shown by the solid line, whereas the dashed lines correspond to the two limiting cases described in the text.

Table 1

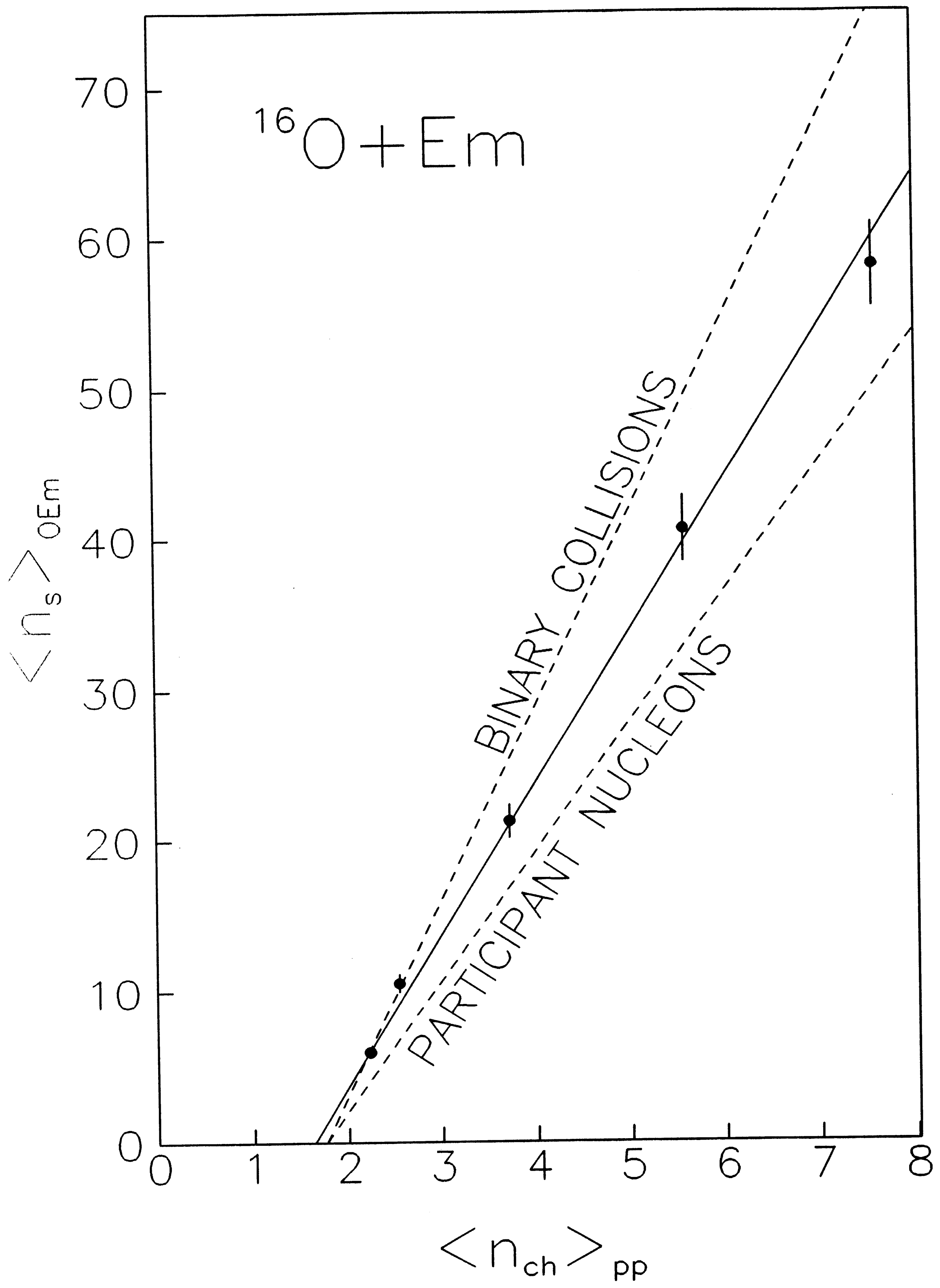
Summary of the data sets used in this note.

E_{inc} (A GeV)	$\langle n_{ch} \rangle_{pp}$	$\langle n_s \rangle_{OEm}$	Ref	Fritiof
200	7.61	58.1 ± 2.8	4,5	58.0 ± 0.6
60	5.60	40.6 ± 2.2	4,5	39.4 ± 0.4
14.6	3.75	21.2 ± 1.1	4,5	
3.6	2.57	10.5 ± 0.6	6	
2.1	2.26	5.9 ± 0.3	7	

Table 2

Estimates of the amount of nucler matter involved in various interactions with a nuclear emulsion target, averaged over impact parameter.

Target	A	% of reactions	σ_{inel} (mb)	P_{proj}	P_{targ}	BC
			p – Em			
Hydrogen	1.0	3.8	32.3	1.00	1.00	1.00
Carbon	12.0	11.3	228	1.00	1.70	1.70
Nitrogen	14.0	2.9	255	1.00	1.78	1.78
Oxygen	16.0	9.5	280	1.00	1.84	1.84
Sulphur	32.1	0.2	462	1.00	2.24	2.24
Bromine	79.9	32.0	891	1.00	2.90	2.90
Silver	107.9	40.0	1105	1.00	3.15	3.15
Iodine	126.9	0.3	1242	1.00	3.30	3.30
Emulsion				1.00	2.66	2.66
			^{16}O – Em			
Hydrogen	1.0	11.2	280	1.84	1.00	1.84
Carbon	12.0	15.7	919	3.97	3.66	6.75
Nitrogen	14.0	3.8	979	4.16	4.01	7.39
Oxygen	16.0	12.1	1035	4.33	4.33	7.99
Sulphur	32.1	0.2	1399	5.29	6.43	11.86
Bromine	79.9	26.3	2120	6.72	10.56	19.47
Silver	107.9	30.5	2444	7.23	12.37	22.81
Iodine	126.9	0.2	2641	7.52	13.46	24.83
Emulsion				5.51	7.95	14.67
			^{32}S – Em			
Hydrogen	1.0	14.0	462	2.24	1.00	2.24
Carbon	12.0	16.3	1263	5.79	4.39	9.85
Nitrogen	14.0	4.0	1333	6.13	4.85	10.89
Oxygen	16.0	12.4	1399	6.43	5.29	11.86
Sulphur	32.1	0.2	1817	8.17	8.17	18.32
Bromine	79.9	24.7	2629	10.87	14.05	31.51
Silver	107.9	28.2	2988	11.87	16.69	37.44
Iodine	126.9	0.2	3206	12.84	18.30	41.04
Emulsion				8.38	9.94	22.28


$^{16}O+Em$
BINARY COLLISIONS
PARTICIPANT NUCLEONS
$\langle n_s \rangle_{OEm}$
$\langle n_{ch} \rangle_{pp}$
0
10
20
30
40
50
60
70
0
1
2
3
4
5
6
7
8