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Full Length Research Paper

Multiplicity distributions in ^{24}Mg-emulsion collisions at 4.5 A GeV/c.

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The experimental results of target multiplicity distributions in ^{24}Mg emulsion collisions at 4.5 A GeV/c are reported. The multiplicity distributions of target fragments, the correlations between the multiplicity distributions and the projectile fragments, as well as the correlations between the black and gray fragments are given. A comparison between theory and experiment among ^{24}Mg and ^{16}O at various energies is reported too.

Key words: Multiplicity, angular distribution and correlation measurements, projectile and target fragmentation, multifragment emission and correlation.

INTRODUCTION

According to the "participant-spectator model" (Glauber, 1959) the nuclear interacting system in high energy nucleus-nucleus collisions can be divided into three parts: a target, a participant and a projectile spectator. The overlapping part of the two colliding nuclei is called the participant and the other parts are called the target and the projectile spectator, respectively. There are relations between the participant and the spectator. It is expected that a quark-gluon plasma (quark matter) (Odyniec, 2002) will be formed in the participant at very high incident energies and a liquid-gas phase transition (Ma and Lett, 1999) will occur in the spectator. Both the participant and the spectator are relevant for studying the nuclear reaction mechanism.

The Dubna energy (a few A GeV) is a special energy, at which the nuclear limiting fragmentation applies initially. For ^{24}Mg the limiting fragmentation may set in at or below the Dubna energy. The study nuclear reaction, e.g., ^{24}Mg induced nuclear reaction at the Dubna energy, is of great importance.

The aim of this work is to perform an investigation of particle multiplicities in ^{24}Mg-emulsion collisions at 4.5 A GeV/c. The multiplicity distributions of the target black and gray fragments and shower particles, as well as, the correlations between the target fragment multiplicities are obtained. The saturation effect of the target black fragment multiplicity is observed in the collision.

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EXPERIMENTAL DETAILS

Stacks of the BR-2 nuclear emulsion exposed to 4.5 A GeV/c ^{24}Mg beam at the Dubna Synchrohastron (JINR) were used to collect the data. The stacks have the dimensions of 20 cm x 10 cm x 600 µm (undeveloped emulsion). The intensity of irradiation was 10^4 particles/cm^2, and the beam diameter was about 1 cm. Along the track, a scanning method was adopted to pick up the interactions. In the final sample, we included the interaction events due the beam tracks making an angle of less than 3° with the beam direction and lying in the emulsion at depth greater than 20 µm from either surface of the pellicles. According to the range "L" in the emulsion and the relative ionization $I^*=I/I_0$ (where I is the particle track ionization and I_0 is the ionization of the relativistic shower tracks in the narrow forward cone of opening angle θ less than 3°) all the charged secondary particles in the observed interactions were classified into the following groups:

i) Black track producing particles (b-particles) having a range L<3 mm in emulsion, which corresponds to a proton kinetic energy of less than 26 MeV.
ii) Gray track producing particles (g-particles) having relative ionization I^* >1.4 and range L>3 mm, which corresponds to a proton kinetic energy of 26-400 MeV. The b- and g-particle tracks are called heavy ionizing particle tracks (h), that is, h = b+g.
iii) Shower track producing particles (s-particles) having a relative ionization I^*<1.4, such tracks, having an emission angle θ<3° have been further subjected multiple scattering measurements for momentum determination in order to separate the produced pions from the single charged projectile fragments (protons, deuterons and tritons).

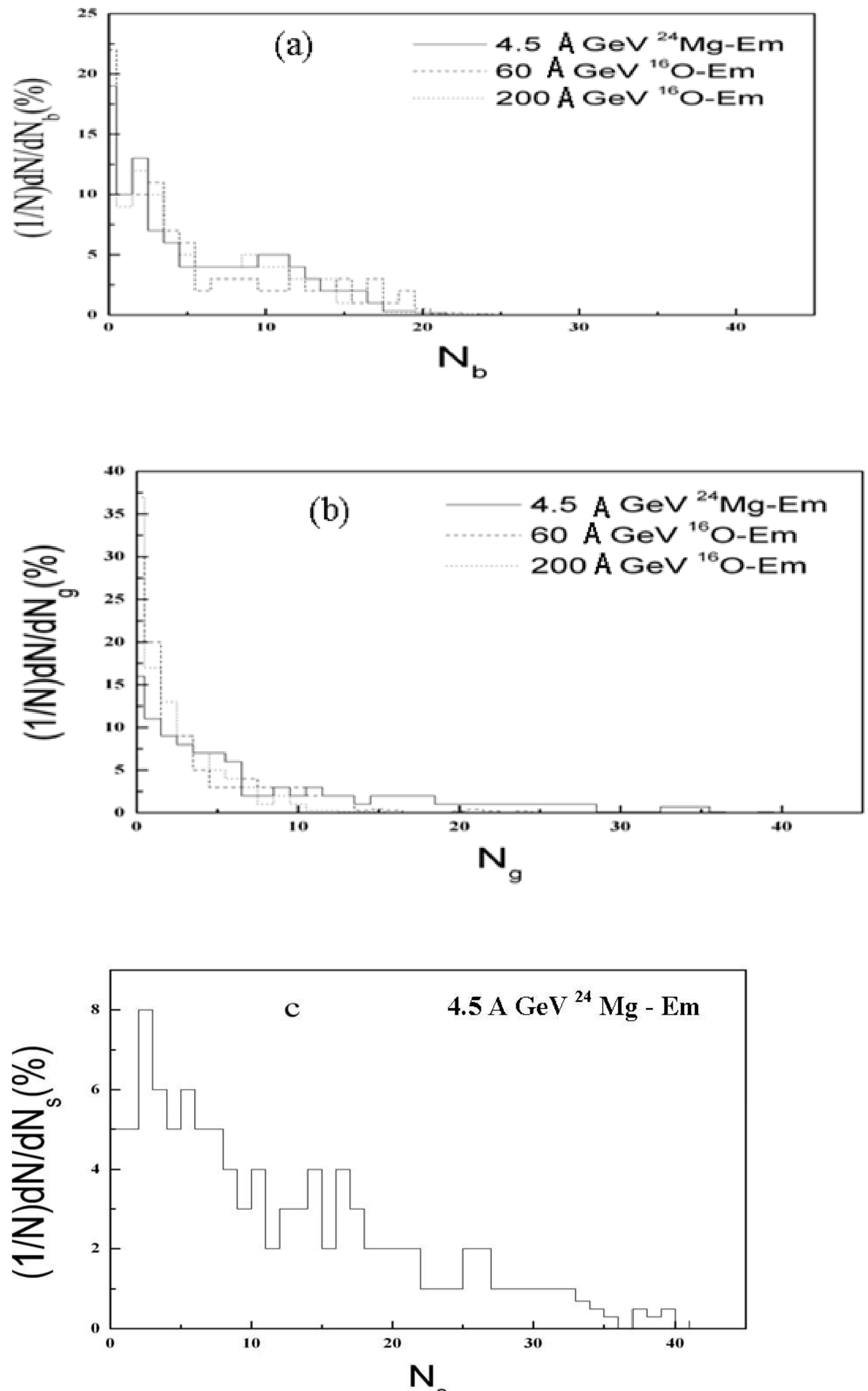

Figure 1. Multiplicity distributions of (a) target black fragments, (b) target gray fragments, and (c) shower particles produced in heavy ion induced interaction in nuclear emulsion at high energies.

Multiplicity distribution of target fragments

Figure (1) presents the multiplicity distributions of target black fragments (a), target gray fragments (b), and show er particles (c) produced in ^{24}Mg with emulsions at 4.5 A GeV/c (solid histogram). The average multiplicities $\langle N_b \rangle$,$\langle N_g \rangle$ and $\langle N_s \rangle$ are 5.1 ± 0.2, 7.9 ± 0.4 and 11.0 ± 0.4, respectively. In order to give a comparison, the multiplicity distributions of target black and gray fragments produced in oxygen with emulsion collisions at 60 A GeV and 200 A GeV are given in the figure by the dashed and dotted histograms, respectively. The experimental data

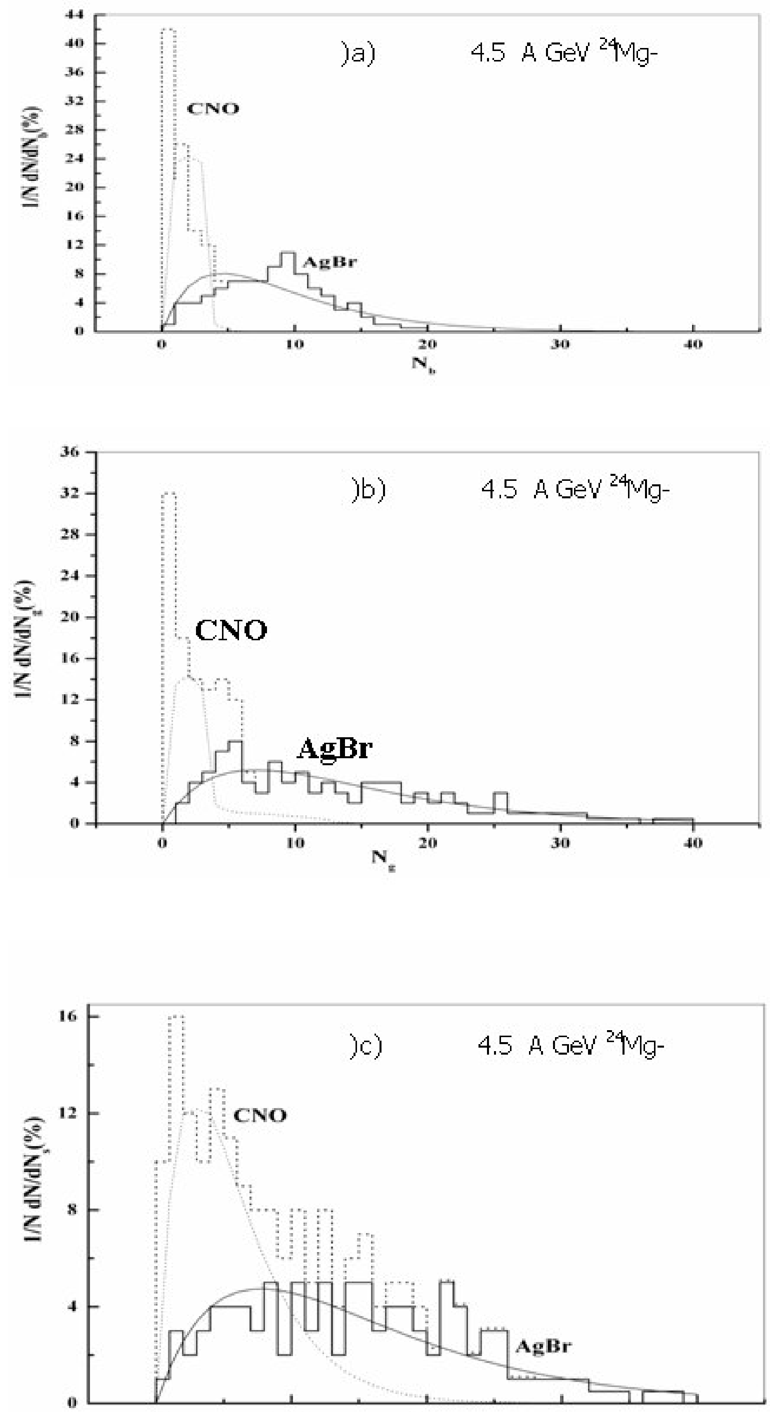

Figure 2. Multiplicity distributions of (a) target black fragments, (b) target gray fragments, and (c) shower particles produced in ^{24}Mg–CNO and AgBr interaction in nuclear emulsion at 4.5 A GeV/c.

for oxygen at 60 A GeV and 200 A GeV are taken from the High Energy Laboratory at Cairo University. From Figure (1) we see that the target fragment multiplicity distribution from 200 A GeV oxygen – emulsion collisions is clearly higher at N_b,N_g=0, and the other multiplicity distributions of target fragments are approximately similar

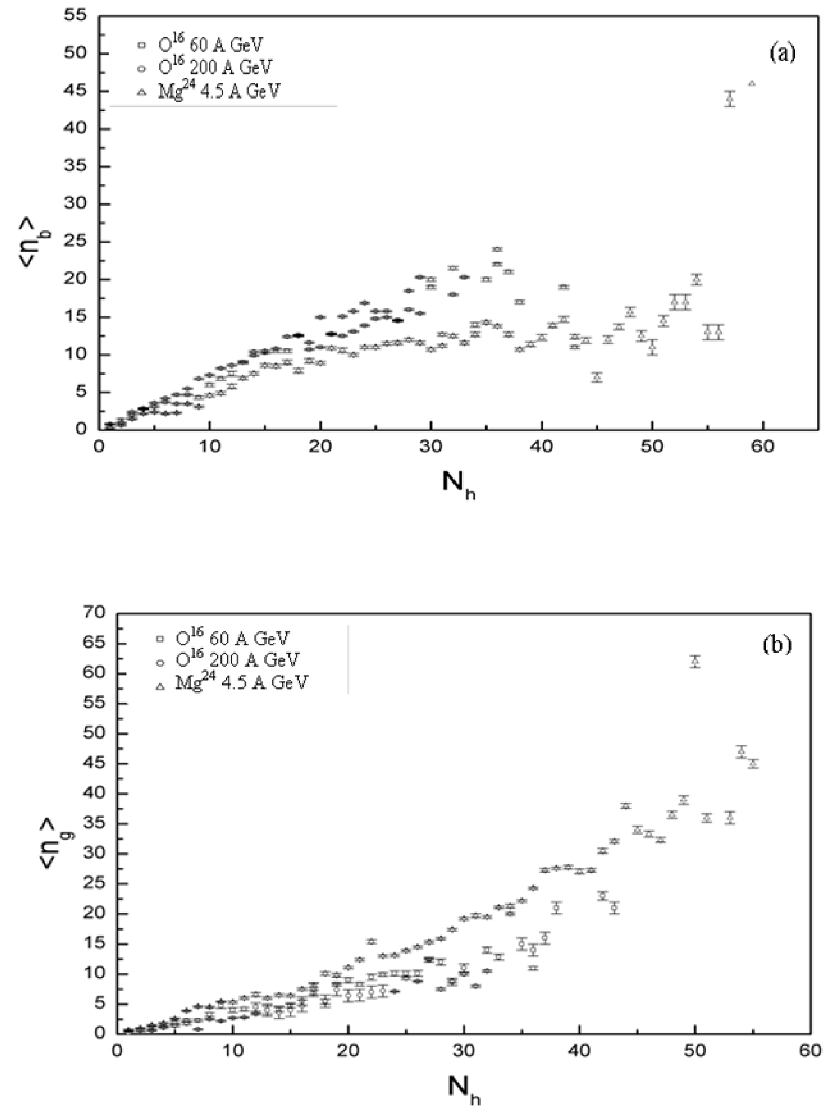

Figure 3. Correlations between $<N_b>$ and N_h (a), as well as $<N_g>$ and N_h (b), in heavy ion induced interactions in nuclear emulsion at high energies.

for the three kinds of interactions.

Figure (2) presents a comparison between the multiplicity distributions and the calculated results of (a) target black fragments, (b) target gray fragments, and (c) shower particles produced in ^{24}Mg-CNO (dotted) and ^{24}Mg-AgBr (solid) collisions at 4.5 A GeV/c. The presented histograms display the experimental measurements, while the calculated results are given by the curves. The latter are calculated by (Liu and Panebratsev, 1998; Liu, 2000).

$$f(N_i)=4N_i/< N_i>^2 \exp(-2N_i/< N_i>) \qquad (1)$$

Where i=b, g or s. N_i and $< N_i>$ are the multiplicity and the average multiplicity, respectively.

From Figure (2) we see that the target black fragment and shower particles multiplicity distributions shapes in ^{24}Mg-AgBr collisions at 4.5 A GeV/c cannot be described by Eq. (l). The other four distribution shapes are approximately in agreement with the result calculated by Equation (1). In the calculation, the average multiplicities for ^{24}Mg-CNO collisions are $<N_b> = 1.1$, $<N_g> = 1.8$, and $<N_s> = 5.9$. The average multiplicities for ^{24}Mg-AgBr collisions are $<N_b>= 9.6$, $<N_g> = 11.3$, and $<N_s> = 15.5$.

Correlations between the multiplicities of target fragments

Figure (3) displays the correlations between $<N_b>$ and N_h (a), as well as $<N_g>$ and N_h (b), for ^{24}Mg- emulsion collisions at 4.5 A GeV/c (triangle). In order to give a

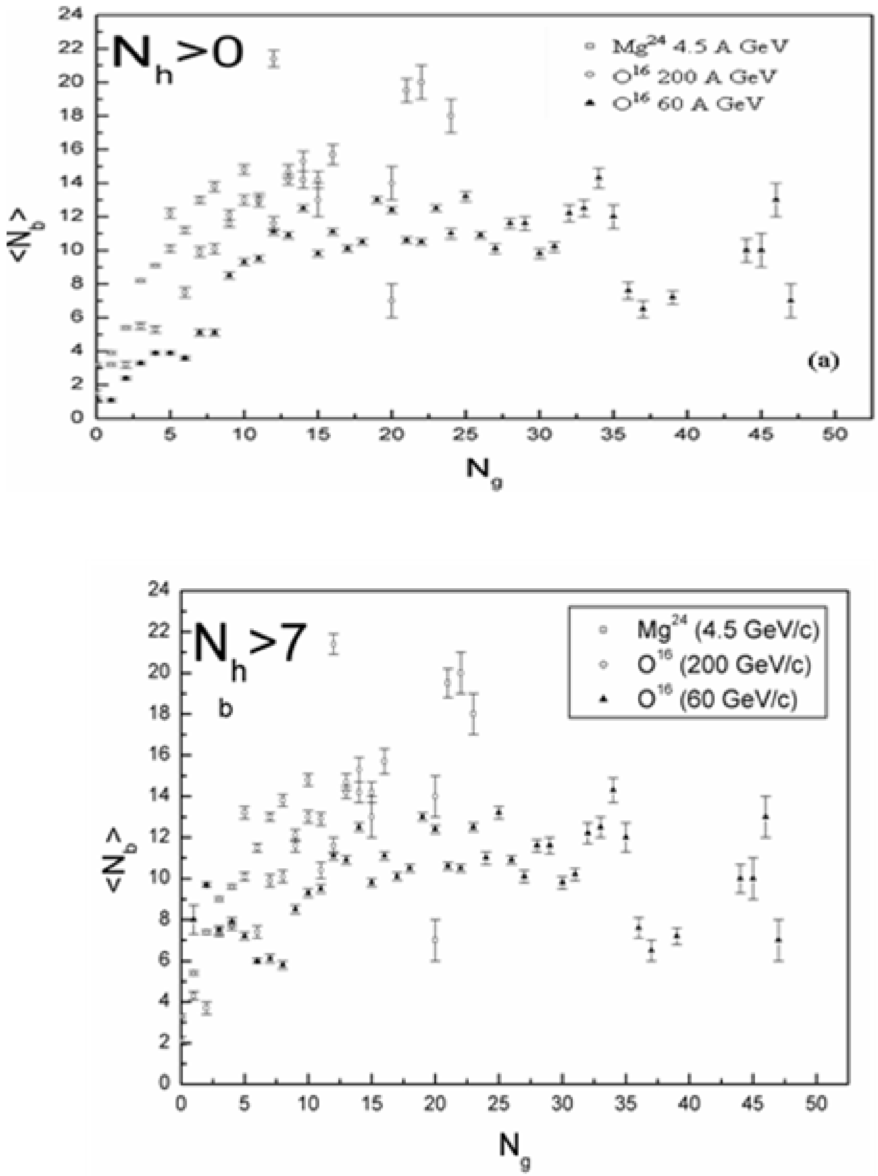

Figure 4. Correlations between <N_b> and N_g for events with N_h>0 (a) and N_h>7 (b) in heavy ion induced interactions in nuclear emulsion at high energies.

comparison, the corresponding results for ^{16}O-emulsion collisions at 60 A GeV (open circles) and 200 A GeV (closed circles) are given in the figure, too. We see that the values of <N_g> and <N_b> increase with increasing N_h. In the region of N_h < 30, the correlations for the three interactions are almost the same. In the region of N_h >30, we cannot draw a solid statement due to rather large statistic errors in the ^{24}Mg-emulsion data.

Figure (4) presents the dependence of <N_b> on N_g for ^{24}Mg-emulsion collisions at 4.5 A GeV/c (open squares), ^{16}O-emulsion collisions at 60 A GeV (triangles) and ^{16}O-emulsion collisions at 200 A GeV (open circles) at N_h > 0 (diagram (a)) and N_h > 7 (diagram (b)). One sees that the value of <N_b> increases with increasing N_g in the region of N_g < 7, and the saturation effect appears in the region of N_g > 7. This saturation effect was previously observed in proton-emulsion collision at high energy (Abduzhamilov et al., 1988). Recently, in ^{16}O-emulsion collisions at the Dubna and SPS energies, the saturation effect was observed (Liu, 2002) too. In the present work, we show also that the saturation effect is observed in ^{24}Mg- emulsion collisions at the Dubna energy.

In addition, one can see that the experimental data in diagram (b) of Figure (4) are the same as those in diagram (a) for the events with N_h>7. This renders that the saturation effect is a characteristic of heavy target

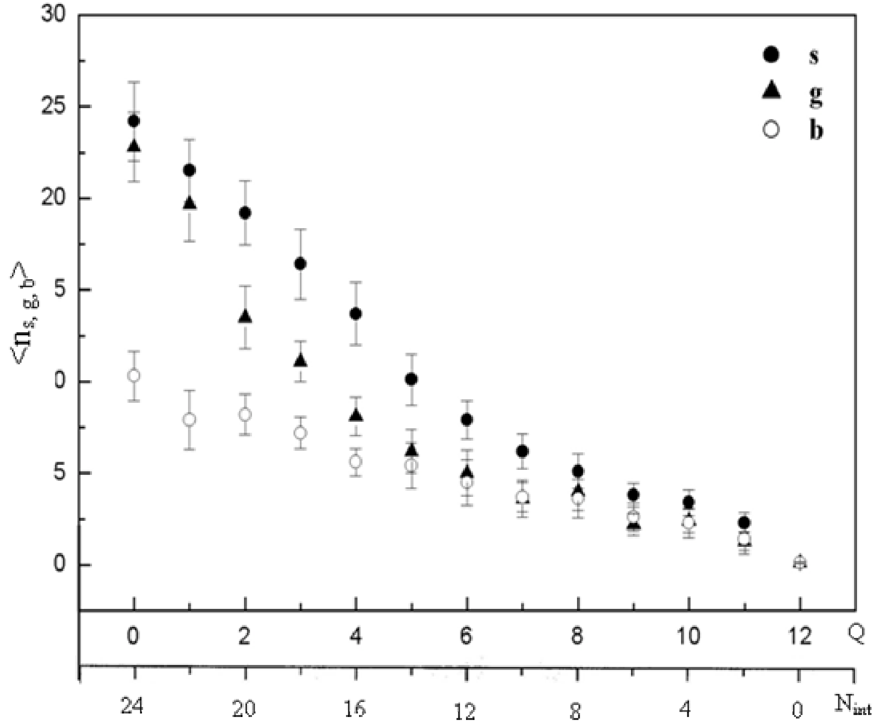

Figure 5. The average multiplicity values of secondary <ni> versus Nint and Q.

fragmentation in non-peripheral collisions. The target black fragments have the saturation affect, and the gray fragments do not have the reason is that the black fragments are the results of the target spectators evaporation and the gray fragments are the results of cascading collisions in the target spectator and participant.

It is also interesting to study the dependence of the multiplicity of secondary particles on the number of nucleons, in the projectile–nucleons, interacting with the target. It is possible to estimate roughly this number knowing the total change of non-interaction particles (fragments) in the magnesium nucleus: $Q=\Sigma N_iZ_i$, where N_i denotes the number of projectile fragments with charge Z_i and make a summation over all such fragment, the number of interacting nucleons of the projectile nucleus, on the average, equal to $N_{int}=12–2Q$.

Figure (5) shows the dependence of the mean multiplicities of secondary particle on N_{int} (and Q). One can see that they increase (abruptly) with increasing N_{int} (with decreasing Q). The increasing of $<n_i>$ (where i denotes s, g and b) with N_{int} is nearly linear one. In this case $< n_i >/N_{int}$=constant, which shows evidence for an approximate validity of the assumption that nuclear interactions at energy equal to a few GeV/nucleon can be to a first rough approximation, considered as a superposition of nucleon–nucleons collisions.

It is evidence that, despite the roughness of the definition N_{int} (or Q) is a convenient experimental character to classify nuclear–nuclear interactions and degrees of their peripheries interactions with small Q (large N_{int}) are naturally considered to be "central" collisions, and events with large Q (small N_{int}) to be "peripheral" nuclear collisions, with large impact parameter.

Conclusion

From the investigation of particles emitted from ^{24}Mg with emulsion collisions, we can make the following conclusions:

i. The average multiplicities $<N_b>$, $<N_g>$ and $<N_s>$ are 5.1±0.2, 7.9±0.4 and 11.0±0.4, respectively.

ii. Note, that the mean multiplicities for ^{24}Mg–CNO collisions are $<N_b>$=1.1, $<N_g>$=1.8 and $<N_s>$=5.9. The mean multiplicities for ^{24}Mg–AgBr collisions are $<N_b>$=9.6, $<N_g>$=11.3 and $<N_s>$=15.5.

iii. We found that the values of $<N_b>$ and $<N_g>$ increase with increasing N_h.

iv. The target black fragments have the saturation effect and the gray fragments do not have. The reason is that the black fragments are the results of the target spectators' evaporation, and the gray fragments are the results of cascading collisions in the target spectator and participant.

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