Study of Gold Nuclei Fragmentation due to Nuclear Interactions at 10.6 GeV/nucleon

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Abstract

Fragmentation of 10.6 GeV/nucleon gold nuclei interacting in nuclear emulsion was studied. Emission angles of all interaction products were measured, including fragments of the colliding nuclei. Charges of heavy fragments of the projectile were determined using a semi-automatic system based on photometric analysis of tracks in emulsion. Correlations of fragmentation modes with parameters characterizing the interaction were studied.

1 Introduction

The complex collision of two heavy nuclei can be viewed as superposition of many individual nucleon-nucleon interactions. Usually, not all nucleons of both colliding nuclei participate in the collision - the number of participant nucleons depends on the impact parameter of the collision. The nucleons which are in the part of the nucleus not directly hit, are called the spectator part of the nucleus. This part gets highly excited due to breakup of the parent nucleus and later disintegrates with characteristic nuclear decay time (Hufner 1985, Moretto 1993).

The spectator fragments of the projectile nucleus have momentum per nucleon almost equal to that of the parent nucleus, so they are deflected very little from the direction of flight of the projectile, and remain relativistic. Hence, unlike the fragments of the target nucleus, the heavy fragments of the projectile nucleus are very easily and reliably distinguished from all other particles emitted from the collision vertex. In the following, we will deal with fragments of the *projectile* only.

The impact parameter of the collision cannot be directly measured and must be inferred from observables measured in the interaction events. One of such observables, related to violence of the collision is Z_{bound}, the total charge of the spectator nucleons remaining bound in multicharged nuclear fragments (Ogilivie 1991). Other measures were also used, such as $\sum Z_f$, sum of charges of heavy ($Z \geq 3$) fragments, or Q, the total spectator charge within a cone around the forward direction, consisting of Z_{bound} plus number of single spectator protons, N_{sp}. The number of the spectator protons can be approximated by a number of the relativistic particles within a forward cone of $\theta < 48$ mrad (Cherry 1996).

In this paper, we examine fragmentation modes of 10.6 GeV/nucleon gold nuclei in interactions with nuclei of nuclear emulsion. The experiment was done by the Krakow-Louisiana-Minnesota (KLM) Collaboration (Cherry 1994, 1995, 1996, 1998). In each interaction event emission angles of all secondary particles were measured as well as charges of the heavy fragments of the projectile nucleus. The gold nuclei fragmentation was studied by the KLM Collaboration, with fragment charges determined by delta ray counting method. For this study, we have used a new, more accurate method of charge measurements, described below, based on photometric analysis of tracks in emulsion. Preliminary results on fragment charges from a subset of 870 minimum bias interaction events are presented.

2 Method of charge measurement

A method of heavy ion charge determination in emulsion was recently developed (Wilczyński 1997, Kudzia 1998), using CCD camera images of tracks in emulsion. The photometric profiles of tracks, acquired from a number of fields of view under a microscope need to be averaged in order to minimize the fluctuations. The shape of a track profile depends on illumination of the field of view and depth of the track in emulsion. These dependencies were parameterized and necessary corrections were applied. After these corrections, both profile height and width can be used as a measure of the particle charge over the full charge range up to $Z = 79$.

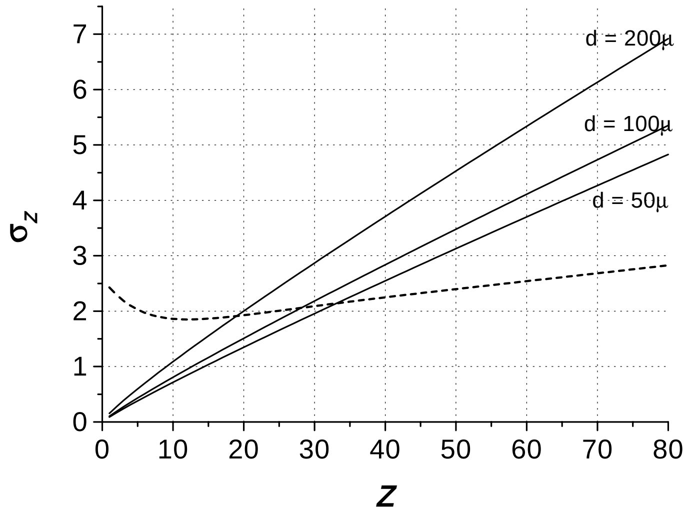

Figure 1: Standard deviation of charge measurements, σ_Z, for measurements of charge Z, based on the height and width of the track profile. The solid line shows the accuracy of the profile height method for tracks at different depths d in emulsion, and the dashed line shows the accuracy of profile width measurements.

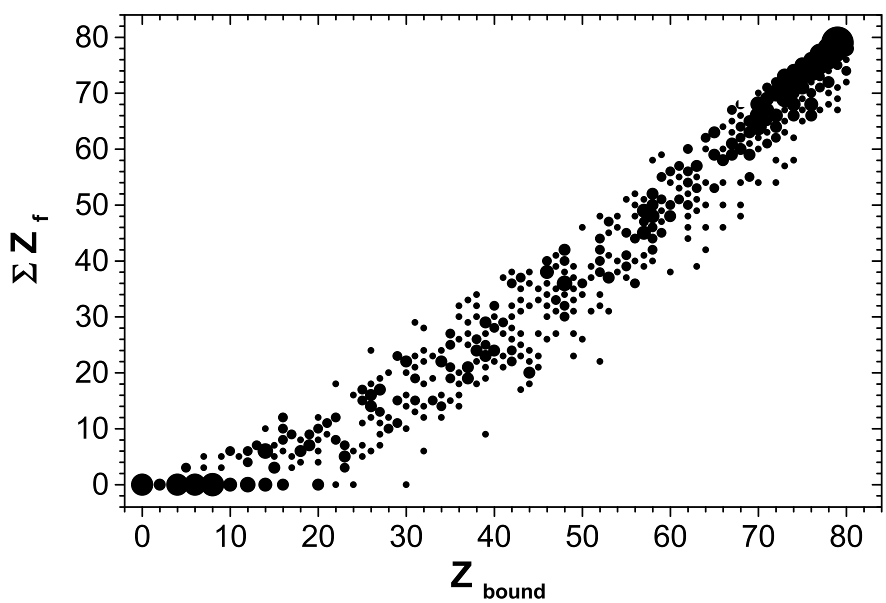

Figure 2: Scatter plot of $\sum Z_F$ versus Z_{bound} for 870 Au-Em interactions. The area of a circle is proportional to the number of events in a given bin.

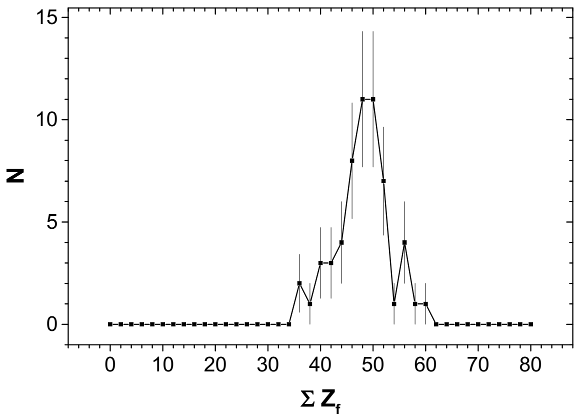

Figure 3: Distribution of $\sum Z_f$ in events with $55 < Z_{bound} < 61$.

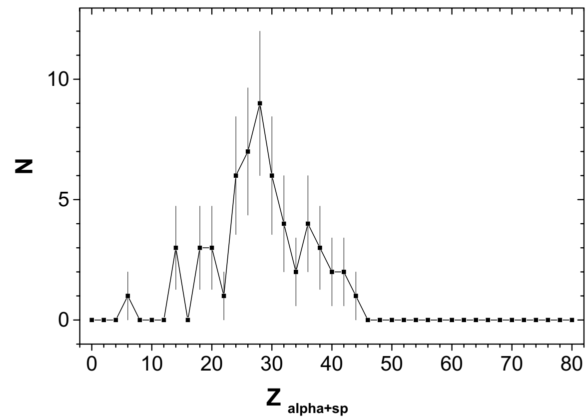

Figure 4: Distribution of total charge of light fragments (alphas and spectator protons) in events with $55 < Z_{bound} < 61$.

The regions of best sensitivity of charge measurements based on height and on width of the profile are complementary to each other. The profile height is better for measuring small charges, while the measurements based on profile width are more accurate for large charges. The two methods combined provide a way for reliable charge determination of nuclear fragments from protons to gold nuclei. The accuracy of the charge measurements is shown in Figure 1. Using the photometric method, the charges can be measured quicker and more reliably than by delta ray counting, especially when only a short track is available for measurements.

3 Fragmentation of projectile nuclei

Figure 2 shows the $\sum Z_f$ versus Z_{bound} scatter plot of available remeasured data on Au-Em interactions. The distribution is not uniform; some clusters of events can be easily discerned at Z_{bound} near 60, 50, 40 etc. The Z_{bound} and $\sum Z_f$ are of course strongly correlated: $Z_{bound} = \sum Z_f + \sum Z_{alpha}$. Nevertheless, the fact that there are clusters in Figure 2 indicates that the distribution of alpha fragments for a given $\sum Z_f$ must be rather narrow, so that the clustering is not washed out in the Z_{bound} variable.

A possible explanation of the observed clusters in $Z_{bound} - Z_f$ scatter plot may be a correlation of the nuclear fragmentation modes with magic numbers, as conjectured in (Wilczyńska 1997). The nuclear magic numbers are 2, 8, 20, 28, 50, 82, 126. Nuclei containing a magic number of protons or neutrons are bound considerably stronger than other nuclei. This fact is well explained by the shell model of the nucleus: the magic numbers correspond to closed shells of proton or neutron states in a nucleus, in analogy to closed electron shells in atoms of noble gases. In the nuclei, also subshells are observed at 6, 16, 40, 58 protons or neutrons.

Let's look closer at a prominent cluster at $Z_{bound} \approx 60$ in Figure 2, in order to better see if it correlates with magic numbers. The distribution of $\sum Z_f$ in events with $55 < Z_{bound} < 61$ (around the sub-magic number 58) is shown in Figure 3 and charge of light fragments $Z_L = \sum Z_{alpha} + N_{sp}$ (i.e. the charge of alpha particles and spectator protons) is shown in Figure 4. Although the statistics is small, one can clearly see a narrow peak over a broad Z_L distribution. To select the cluster in question more precisely, let's also restrict the range of $\sum Z_f$ to $45 < \sum Z_f < 53$ (around the magic number 50) . The distributions of N_{sp} and Z_L for the restricted cluster are shown in Figures 5 and 6. Both these distributions are single, rather narrow peaks. Similar distributions can be plotted for other clusters seen in Figure 2.

The fact that the peaks near magic numbers in Z_{bound}, $\sum Z_f$, Z_L correlate with each other may suggest that fragmentation of the residual nucleus left after the nucleus-nucleus collision proceeds in a sequential way rather than via multifragmentation. In multifragmentation, all observed fragments are supposed to be emitted in a single fragmentation act. It may be interesting to note that the positions of the peaks shown in Figures 3–6

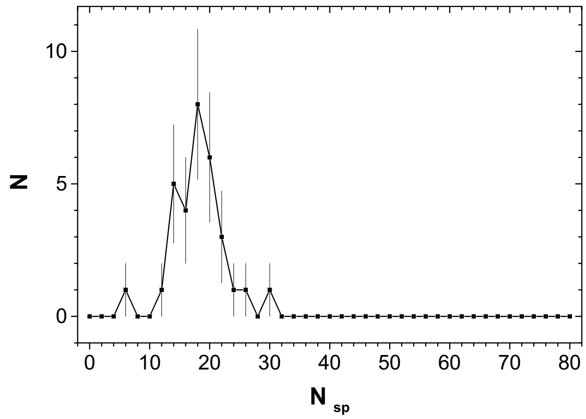

Figure 5: Distribution of the number of spectator protons in events with $55 < Z_{bound} < 61$ and $45 < \sum Z_f < 53$.

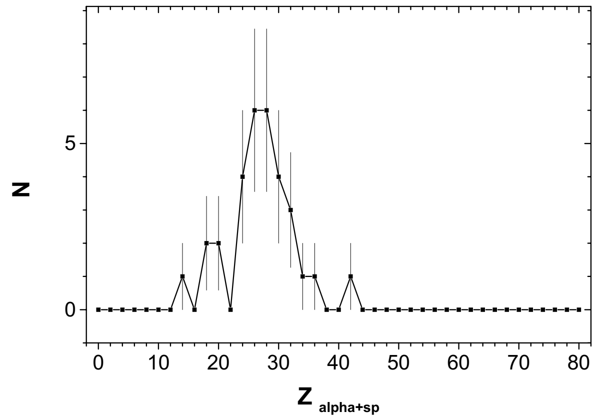

Figure 6: Distribution of total charge of light fragments (alphas and spectator protons) in events with $55 < Z_{bound} < 61$ and $45 < \sum Z_f < 53$.

approximately coincide with magic numbers. Although this may be circumstantial, the significance of this effect should be checked carefully. The detailed analysis will be performed when the charge remeasurements using the new method are complete.

4 Conclusion

Preliminary results on charge distribution of gold nuclei fragments, remeasured with the new photometric method, are presented. The charges of various classes of fragments tend to correlate with each other. The sums of charges of fragments in some classes (like Z_f, Z_{bound}, Q, etc.) seem to peak near nuclear magic numbers. This may suggest the influence of nuclear structure effects on fragmentation process of the spectator part of the projectile nucleus. Further data acquisition and analysis are in progress.

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References

Cherry M.L. et al, 1994, Z. Phys. C62, 25

Cherry M.L. et al, 1994, Z. Phys. C63, 549

Cherry M.L. et al, 1995, Phys. Rev. C52, 2652

Cherry M.L. et al, 1995, Phys. Rev. C53, 1532

Cherry M.L. et al, 1998, Europ. Phys. J. C5, 641

Hufner J, 1985, Phys. Rep. 125, 129

Kudzia D. et al., 1998, INP report No. 1802/PH, Kraków, Nucl. Instr. Meth. A, in print

Moretto L.G., Wozniak G.J., 1993, Ann. Rev. Nucl. Part. Phys. 43, 374

Ogilivie C.A. et al., 1991, Phys. Rev. Lett. 67, 1214

Wilczyńska B. et al., 1997, Proc. 25th ICRC, Durban, 6, 13

Wilczyński H. et al., 1997, Proc. 25th ICRC, Durban, 7, 285