# Target Nuclei Excitation after Interactions of 10.6 Gev/Nucleon Gold Nuclei in Emulsion

**W. Wolter[1], M.L. Cherry[2], A. Dąbrowska[1], P. Deines-Jones[2*], R. Hołyński[1], B.S. Nilsen[2**], A. Olszewski[1], M.Szarska[1], A. Trzupek[1], C.J. Waddington[3], J.P. Wefel[2], B. Wilczyńska[1], H. Wilczyński[1], B. Wosiek[1], and K. Woźniak[1]**

[1] *Institute of Nuclear Physics, Kawiory 26A, 30-055 Kraków, Poland*
[2] *Department of Physics and Astronomy, Louisiana State University, Baton Rouge, LA 70803, USA*
[3] *School of Physics and Astronomy, University of Minnesota, Minneapolis, MN 55455, USA*
**presently at NASA Goddard Space Flight Center, Greenbolt, MD,USA*
***presently at the Department of Physics, Ohio State University, Columbus, OH 43210, USA*

**Abstract**

The excitation of nuclei in emulsion target due to nuclear interactions of gold nuclei at 10.6 GeV/nucleon has been investigated. The results were compared with interactions of oxygen and sulfur projectiles in emulsion at 200 GeV/nucleon. Assuming that the number of low energy particles emitted from the struck target nucleus can be interpreted as a measure of the temperature of the residual target nucleus, it has been shown that for heavy Ag/Br nuclei of emulsion the critical temperature in collisions with gold projectiles is the same as in collisions with oxygen and sulfur projectiles of comparable total energy.

## 1 Experiment:

Several emulsion stacks were exposed to the 10.6 GeV/nucleon gold beams at BNL. The details of exposure, emulsion scanning and measurements can be found in [1,2,3,4]. Our minimum bias sample consists of 1089 Au inelastic interactions in emulsion. In each event we measured the emission angles of relativistic singly and multiply charged particles. Their numbers are denoted by $N_s$ and $N_f$ respectively. The last are multiply charged projectile fragments. Their charges were measured by $\delta$ ray counting [4]. The number of produced charged particles $N_\pi=N_s-(Z_p-\Sigma Z_f)$ where $Z_p$ is the charge of the projectile. Slow $\beta<0.7$, heavily ionizing $I>1.4\ I_0$ particles ($I_0$ is the minimum ionization produced by relativistic singly charged particle) emitted from the target nucleus were separated into: - black tracks which are slow singly and multiply charged target fragments and - grey tracks being mostly recoil protons or pions from the development of the low energy intranuclear cascade. Their numbers are denoted by $N_b$ and $N_g$ respectively. The separation between black and grey tracks corresponds to the ionization of 30 MeV proton.

Interactions of gold projectiles in emulsion were separated into interactions with hydrogen, light C/N/O and heavy Ag/Br nuclei of emulsion. For the method of separation of interactions see [4]. The subject of this paper is the analysis of fragmentation of emulsion nuclei bombarded by Au projectiles. The results are compared with those obtained from the analysis of interactions of oxygen and sulfur projectiles in emulsion [5].

## 2 The Number of Target Fragments and the Mass of the Projectile:

It was observed [5] that the average number $\langle N_b\rangle_{Em}$ of target fragments in collisions of proton, oxygen and sulfur at 200 GeV/nucleon in emulsion does not depend on the mass of the projectile when it changes from A=1 to A=32. For Au projectiles $\langle N_b\rangle_{Em}$ is smaller than for the rest of projectiles (see Table 1). However, one has to remember that nuclear emulsion is a composite target. It consists of hydrogen, light C/N/O and heavy Ag/Br nuclei and the yields of interactions with different constituents (given in Table 1) depend on the mass of the projectile. The yields were calculated using the composition [6] of nuclear emulsion and the charge changing cross sections [7]. Taking into account that for a given target the yield of interactions depends on the projectile mass while the number of target fragments $N_b$ does not, we can use

**Table** 1

| Projectile | A | $<N_b>_{Em}$ | H | C/N/O | Ag/Br |
|---|---|---|---|---|---|
| proton | 1 | 5.0 ±0.1 | 3 % | 26 % | 71 % |
| oxygen | 16 | 4.7 ±0.2 | 7 % | 33 % | 60 % |
| sulfur | 32 | 4.9 ±0.2 | 10 % | 34 % | 56 % |
| gold | 197 | 3.9 ±0.1 | 19 % | 36 % | 45 % |

the $N_b$ values from Au interactions i.e. $<N_b>_H=0$, $<N_b>_{C/N/O}=1.53\pm0.07$ and $<N_b>_{Ag/Br}=8.0\pm0.2$ [4] and calculate the $<N_b>_{Em}$ for interactions with different projectiles. The comparison between the calculated and experimentally found values of $<N_b>_{Em}$ is given in Table 2.

The agreement for gold and sulfur projectiles is very good. Even for oxygen projectile it is satisfactory. Only for proton projectiles the difference is significant.

In conclusion we can say that in nucleus-nucleus collision, for a given target nucleus, the mass of the projectile nucleus has no, or negligible influence on the mean number of target fragments. In other words one can say that assuming the number of target fragments $N_b$ as a measure of the temperature [5] of the residual target nucleus, this temperature is limited to a given value no matter how heavy is the projectile nucleus. It is astonishing that this is true for both light projectile nuclei and as heavy as gold projectile nucleus. Even more surprising is this observation in view of nucleus-nucleus interaction treated as a superposition of a number of elementary intranuclear nucleon-nucleon collisions. This number grows rapidly with the mass of the projectile (see Table. 2).

**Table** 2

| Projectile | $[<N_b>_{Em}]_{exp.}$ | $[<N_b>_{Em}]_{calc}$ | $[<N_{coll}>]_{calc}$ |
|---|---|---|---|
| Proton | 5.0 ± 0.1 | 6.1 ± 0.1 | 2.5±0.1 |
| Oxygen | 4.7 ± 0.2 | 5.3 ± 0.1 | 13.5±0.3 |
| Sulfur | 4.9 ± 0.2 | 5.0 ± 0.1 | 20.5±0.4 |
| Gold | 3.9 ± 0.1 | 4.1 ± 0.1 | 57.0±1.3 |

## 3 The Number of Target Fragments as a Function of the Degree of Centrality of Collision:

Till now our conclusions were based on the $<N_b>_{Em}$ of target fragments in inclusive interactions of projectiles with different mass. It seems interesting to look at the dependence of $<N_b>_{Em}$ on the degree of centrality of collision as a function of projectile mass. One of the available experimental parameter that can be used to organize interactions according to the degree of centrality of collision is the multiplicity of particles produced in collision. It follows from interaction models (see e.g. [8,9,10]) that there is a nearly linear dependence between the multiplicity of produced particles and the number of intranuclear nucleon-nucleon collisions. Fig.1 shows the dependence of $<N_b>_{Em}$ on the normalized multiplicity of produced charged particles $N_\pi/<N_\pi>$ for different projectiles. $<N_b>_{Em}$ values for all particles have a maximum except for protons. For still higher normalized multiplicities (more central collisions) the $<N_b>_{Em}$ is reduced. The falling of $<N_b>_{Em}$ was already observed [1] but for smaller statistics. It is spectacular for Au projectile but even for light projectiles it is well visible. However, due to the composite target (nuclear emulsion) the position and the height of the maximum of $<N_b>_{Em}$ depend on the mass of the projectile. Only for large values of relative multiplicities the target is well defined and represents Ag/Br nuclei of emulsion. More information about the behavior of the number of target fragments with the increasing centrality of

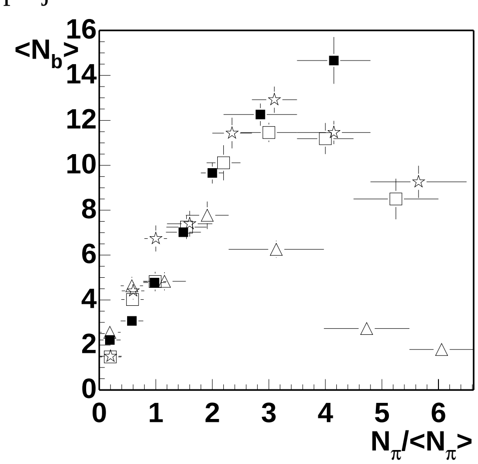


**Figure 1:** The number $<N_b>$ of target fragments in collisions of p(■), O(□), S(☆), and Au(Δ) with emulsion vs. normalized multiplicity of produced particles $N_\pi/<N_\pi>_{Em}$.

collision can be obtained from the analysis of Au interactions separately with light C/N/O and heavy Ag/Br nuclei of emulsion.

The relation between $<N_b>$ and $N_\pi/<N_\pi>$ for interactions of Au projectiles with heavy Ag/Br and light C/N/O nuclei of emulsion is depicted in Fig.2 and Fig.3. For Ag/Br target nuclei (Fig.2) and very peripheral collisions the number of target fragments first increases with the increasing centrality and then decreases for more central collisions. For light C/N/O nuclei (Fig.3), only the decrease of the number of target fragments with increasing centrality is observed. It is worth while to stress that the maximum value of $<N_b>$ for Ag/ Br target is about 11 and is the same [5] as that observed for oxygen and sulfur projectiles interacting with Ag/Br target.

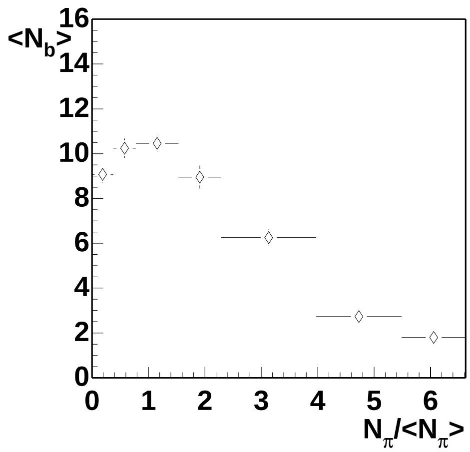


**Figure 2:** The number $<N_b>$ of target fragments in collisions of Au with Ag/Br vs. $N_\pi/<N_\pi>_{Em}$.

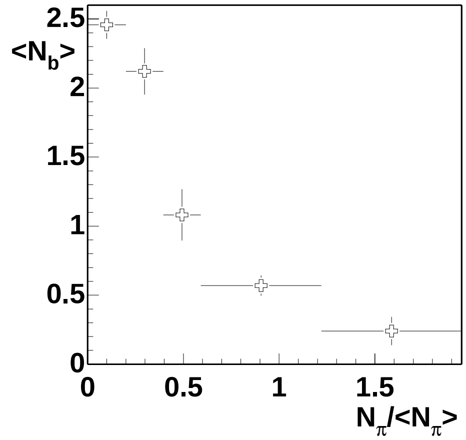


**Figure 3:** The number $<N_b>$ of target fragments in collisions of Au with C/N/O vs. $N_\pi/<N_\pi>_{Em}$.

One of possible explanations of the observed decrease of the number of target fragments with the increasing centrality of collision is the diminishing of the residual target nucleus.

## 4 The Dependence of the Number of Recoil Protons on the Degree of Centrality of Collision:

The other observable that can throw some light on the mechanism of nucleus-nucleus collision is the number $N_g$ of grey tracks emitted from the struck target nucleus. For proton interactions in emulsion the number of $N_g$ tracks continuously increases with increasing centrality of collision (see Fig.4); for interactions of heavier projectiles like oxygen and sulfur it has a tendency to saturate; for Au projectiles central collisions the $<N_g>$ falls down.

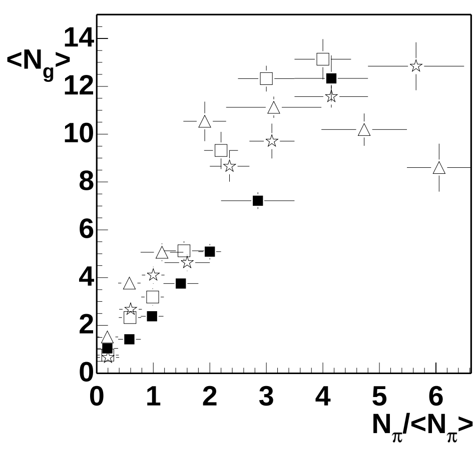


**Figure 4:** The number $<N_g>$ of recoil target protons in collisions of p(■), O(☐), S(✰), and Au(Δ) with emulsion vs. normalized multiplicity of produced particles $N_\pi/<N_\pi>_{Em}$.

After separating Au interactions in emulsion into those with light C/N/O and heavy Ag/Br nuclei and analyzing the dependence of $N_g$ tracks as a function of centrality of collision we observe similar behavior as for $N_b$ tracks. For Ag/Br target nuclei an increase of $<N_g>$ for peripheral collisions and a decrease for more central collisions is observed (Fig.5). For Au interactions with light C/N/O/ nuclei an increase of $<N_g>$ for very peripheral collisions is meaningless and for the rest of interactions only the decrease of $<N_g>$ with increasing centrality of collision is observed (Fig.6). This is in agreement with the observed suppression of nuclear cascading with the increasing mass of the projectile [5]. In other words when the mass of the projectile increases and the interaction becomes more central there are less and less target nucleons available to participate in nuclear cascade.

The decrease of $\langle N_g \rangle$ with increasing centrality of collision can be explained by a high momentum transfer into the target nucleons that became relativistic and appear in emulsion as $N_s$ tracks. For proton projectiles the $\langle N_g \rangle$ in emulsion continuously grows with the increasing centrality of collision (Fig.4) and therefore this observable is a good measure (widely used for many years [11,12]) of the number of intranuclear nucleon-nucleon collisions.

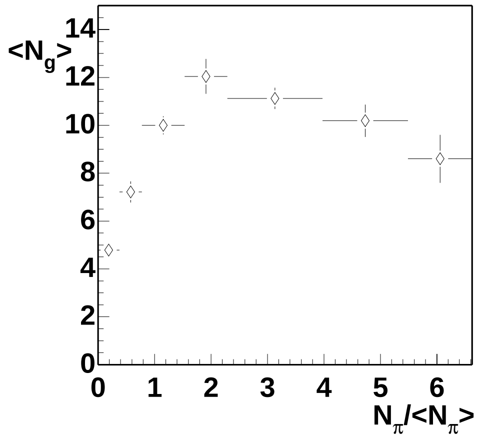


**Figure 5:** The number $\langle N_g \rangle$ of recoil target protons in collisions of Au with Ag/Br vs. $N_\pi/\langle N_\pi \rangle_{Em}$.

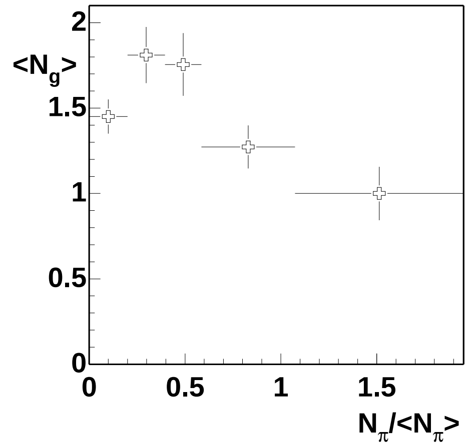


**Figure 6:** The number $\langle N_g \rangle$ of recoil target protons in collisions of Au with CNO vs. $N_\pi/\langle N_\pi \rangle_{Em}$.

## 5 Conclusions:

We have shown that for the Au projectile colliding with Ag/Br nucleus, the mean number of target fragments ($N_b$ tracks) never exceeds about 11. The same maximum number of $\langle N_b \rangle$ was observed in interactions of oxygen and sulfur projectiles with Ag/Br nuclei [5]. Thus, we have confirmed that within the projectile mass interval A=8 to A=197 the mean temperature of the residual target nucleus after interactions with Ag/Br nuclei never exceeds a value corresponding to $\langle N_b \rangle \approx 11$.

For more central collisions of Au with Ag/Br nuclei the number of target fragments decreases rapidly indicating that the residual target nucleus becomes smaller. For light C/N/O target nuclei the number of target fragments is the largest in peripheral collisions. With increasing centrality of collision only a decrease of the number of target fragments is observed.

With increasing centrality of collision we observe a decrease of both the number of target fragments and recoil protons. This indicates that the collision becomes so violent that the participating target protons receive enough momentum to leave the interaction volume as relativistic particles unresolved from the produced ones.

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