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Multiplicity distributions of slow singly charged target fragments from ^{16}O induced reactions on C, Cu, Ag and Au are studied at 60 and 200 A GeV. The distributions from the two energies are essentially the same. Energy and angular distributions for slow protons are revealing the important role of cascading and rescattering in the spectator matter. The target dependence of the multiplicity of slow fragments exceeds $A_T^{2/3}$ for the heaviest targets.

Most of the results from the CERN/SPS fixed target heavy ion experiments have focused on the multiparticle production in the central region of rapidity. Current models generally gives a fair description of the pionisation in the central region, but do have problems describing the particle emission in the fragmentation regions where rescattering and break-up of the nuclei are important. The experimental studies of the phenomena related to the fragmentation regions are relatively few [1,2] but have so far revealed evidence for limiting fragmentation [3], i.e. particle yields independent of the incident energy. Furthermore distributions of emission angles of target related particles are found to be nicely represented by the form $C\exp[\kappa\cos(\theta)]$ with similar values of κ for different incident energies, both for hadron induced and for oxygen induced interactions [2,4]. The WA80 experiment is unique in the sense of having a good coverage in the target region, achieved by the Plastic Ball spectrometer [5].

Results obtained with hadronic and nuclear beams for baryon spectra in the target region have been published earlier [6,7], and in this letter a study of low energy ($30\,A$ MeV $< E < 400\,A$ MeV) singly charged target fragments, emitted in oxygen induced interactions on various targets, is presented.

The data presented here were taken by WA80 [8] during the 1986 run at the CERN/SPS. The slow singly charged fragments, i.e. predominantly protons with an admixture of deuterons and tritons, were measured and identified with the Plastic Ball detector through ΔE–E measurements [5]. In the upper part of the energy range ($E > 350$ MeV) there might be a small contamination of misidentified pions. This contamination is less than one percent of the full slow fragment sample. The detector covers angles from 30°

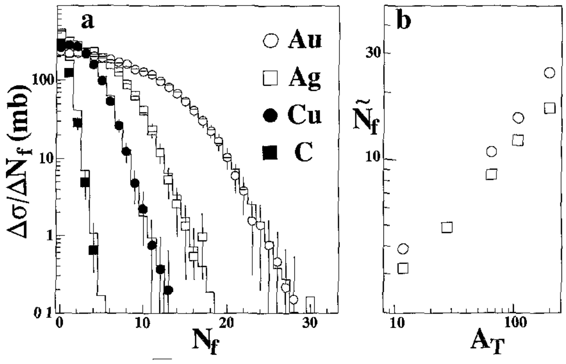

Fig. 1. (a) Multiplicity distributions of slow fragments, N_f, in 200 and 60 A GeV ^{16}O induced reactions on C, Cu, Ag and Au. The symbols represent the 200 A GeV data and the histograms correspond to the 60 A GeV data. (b) The values of N_f at which the cross section of the N_f-distribution has fallen to 1 mb as a function of target mass for 200 A GeV O–A data (open circles) and 200 GeV/c p–A data (open squares).

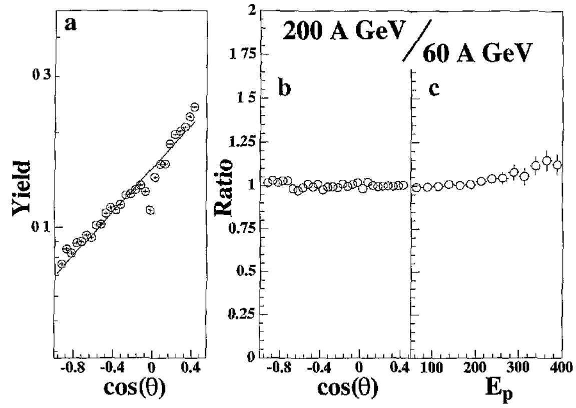

Fig. 2. (a) The angular distribution of slow protons for 200 A GeV ^{16}O induced reactions on Au. The line represents a fit to an exponential function, $C\exp[\kappa\cos(\theta)]$. (b) The angular distribution for 200 A GeV ^{16}O–Au collisions divided by the same distribution at 60 A GeV. (c) The energy distribution for 200 A GeV ^{16}O–Au collisions divided by the same distribution at 60 A GeV.

to 160°, but due to the high particle density in the most forward part the analysis was restricted to particles emitted with angles larger than 60° ($\eta \leqslant 0.55$). The data were taken with a minimum bias trigger requiring (a) a valid beam particle, (b) at least one accepted charged particle in the pseudorapidity region $1.3 < \eta < 4.2$ covered by the streamer tube multiplicity arrays [9] and (c) the energy measured in the Zero Degree Calorimeter [10], ZDC, to be less than 88% of the beam energy. The ZDC measures the forward energy flow inside a cone with an opening angle of 0.3°. This invokes a trigger condition which depends on the incident energy. The differences between 60 and 200 A GeV are however small and only affects the most peripheral events. The total observed cross sections are roughly 300 mb larger at 60 A GeV than at 200 A GeV.

Multiplicity distributions of slow singly charged fragments, N_f, from interactions with C, Cu, Ag and Au targets are shown in fig. 1a, for 60 and 200 A GeV ^{16}O induced reactions. The measured yields are very similar for the two energies except for low N_f values where the 60 A GeV data have slightly higher cross sections. This is due to the difference in minimum bias conditions for the two energies as discussed above. The similarities at the two energies strongly supports the idea that the emission of slow fragments is dictated by the nuclear geometry. N_f-values, extracted at a given level of cross section, exhibit the same target dependence independent of the choice of level, as long as we are on the tail of the distributions. Values, $\tilde{N}_f$, obtained for $\Delta\sigma/\Delta N_f = 1$ mb, are shown in fig. 1b for both oxygen and proton induced reactions. The proton data are taken from an earlier work [7] where a slightly different angular range was used ($30° < \theta < 60°$), this has however been corrected, taking into account the effect of fluctuations as described in one of our earlier works [11]. An overall target dependence of roughly $A_T^{2/3}$ ($A_T^{0.64\pm0.02}$) is observed for both projectiles, but the dependence seem to increase with increasing target mass (if the carbon point is excluded one finds a dependence of $A_T^{0.74\pm0.06}$). An $A_T^{2/3}$ dependence can be interpreted in the following way: The number of participating target nucleons are essentially given by $A_P^{2/3}A_T^{1/3}$. Each participant then has a path through nuclear matter which is roughly proportional to $A_T^{1/3}$. If slow fragments are produced mainly in the spectator matter along the trajectories of the participants, the net effect will thus be an $A_T^{2/3}$ dependence. The data thus indicates a stronger cascade for the larger target nuclei.

To further examine the emission of slow protons, i.e. protons in the same energy interval as the slow fragments, their emission angles and energies were studied. The angular distribution is shown in fig. 2a for the ^{16}O–Au at 200 A GeV case. The dip at

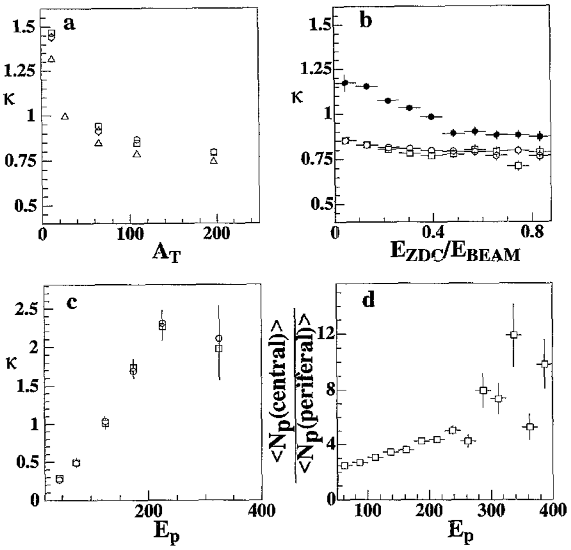

Fig. 3. κ dependences on (a) target mass for ^{16}O–A and p–A collisions, (b) centrality of the collisions for ^{16}O–Au (open symbols) and ^{16}O–Cu (filled symbols) collisions, (c) energy of the emitted protons for ^{16}O–Au collisions. The squares correspond to the 200 A GeV ^{16}O–A data, the circles to the 60 A GeV ^{16}O–A data and the triangles represent the 200 GeV/c p–A data. (d) The ratio of the energy spectra for central and peripheral events, as defined in the text.

$\cos(\theta)=0$ is due to the limited experimental acceptance in this region. The form of the distribution is found to be well described by the parametrization $C\exp[\kappa\cos(\theta)]$. The angular distributions are very similar at the two energies as can be seen in fig. 2b, where the ratio between the 200 A GeV and 60 A GeV data is shown. A similar plot for the energy distributions is given in fig. 2c. The figures show that both energies have essentially the same shapes of the distributions. For the largest proton energies a rise of the ratio is however observed. This rise, which is found to appear mainly for particles emitted at angles less than 90°, could be an indication of a small divergence from a complete limiting fragmentation scenario. It should however be noted that in this part of the detector the occupancy in the modules is large, ≈18% at 60°, and the systematic errors are large enough not to exclude a constant ratio.

The slopes of the angular distribution, extracted from exponential fits, $C\exp[\kappa\cos(\theta)]$, provide information about the cascading and rescattering processes within the target. Large values of κ correspond

Table 1
The values of κ extracted from exponential fits $C\exp[\kappa\cos(\theta)]$ to the angular distribution for oxygen and proton induced reactions.

Target	^{16}O–A 200 A GeV	^{16}O–A 60 A GeV	p–A 200 GeV/c
Au	0.79 ± 0.01	0.80 ± 0.01	0.75 ± 0.01
Ag	0.85 ± 0.02	0.87 ± 0.01	0.79 ± 0.01
Cu	0 94 ± 0.01	0.91 ± 0.03	0.85 ± 0.01
Al	–	–	1.00 ± 0.01
C	1.47 ± 0.02	1.44 ± 0.02	1.32 ± 0.01

to a small amount of rescattering, whereas smaller values are related to a larger cascade. In fig. 3a the target dependence of κ is shown. As can be seen in the figure κ decreases with increasing target mass, indicating a cascade which grows with increasing amount of surrounding matter. Points from proton induced interactions are included in the figure and show that the target dependence is similar in this case although the κ values are somewhat smaller. Numerical values of κ are summarised in table 1. From emulsion studies of grey particles, values of κ between 0 92 and 0.96 are reported for hadron and heavy ion induced reactions with AgBr [2,4], which are larger than the corresponding values obtained in this experiment. The grey particles in emulsion experiments do however cover a slightly different energy window and contain a minor fraction of mesons, which may account for the differences.

In fig. 3b extracted values of κ are plotted as a function of centrality, as characterised by the fraction of total beam energy seen by the ZDC. Central events are characterised by a small fraction and are thus found to the left in the figure. The copper data show a marked rise for events with less than half of the beam energy at zero degrees, clearly indicating a reduced spectator. In central interactions the spectator is essentially vanishing, whereas in peripheral interactions a large part of the target is left as a spectator. Not all participants will traverse the spectator. Those that do will however be multiplied and give rise to particles with large emission angles.

The trend is different for the gold data. A much weaker centrality dependence is observed here, clearly indicating that the spectator part of the gold nucleus is sizable, even for small impact parameters. Furthermore no difference is observed as the incident energy is changed. These observations agree with earlier findings [1–3].

The above results clearly indicates the important role played by the spectator part of the target nucleus. Here the main cascading and rescattering takes place and thus these effects are, for smaller targets, predominantly seen in peripheral interactions. To test these ideas further the κ values are extracted for emitted protons within different energy ranges as shown in fig. 3c. First of all the same independence of incident energy as observed in previous plots are seen once more. Secondly a clear rise in κ is observed as the energy of the emitted proton increases. In fig. 3d the ratio between the number of emitted protons in central and peripheral interactions for 200 A GeV ^{16}O–Au data is plotted as a function of the energy of the emitted protons. The central sample has less than 20% of the beam energy seen by the ZDC, while the peripheral sample has between 50% and 88%. From this figure it is evident that in central interactions the emitted protons are faster than in peripheral interactions.

In fig. 3a it was observed that in proton induced interactions the κ values were reduced as compared to the corresponding values for oxygen induced interactions. This is qualitatively what should be expected due to the larger spectators left over from a target struck by a proton.

In summary we have found that in most respects the emission of slow target related fragments is identical at 60 and 200 A GeV, strongly supporting the hypothesis of limiting fragmentation. A target dependence exceeding $A_T^{2/3}$ is extracted from the multiplicities of slow singly charged fragments. Angular and energy distributions of slow protons can only be understood if major cascading and rescattering takes place in the spectator matter.

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