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# He production in 158 A GeV/c Pb on Pb interactions

EMU01 Collaboration

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## Abstract

Angular distributions of projectile-associated He fragments from Pb induced reactions on stationary Pb target at 158 A GeV/c incident momentum are reported. The precision of the angular measurements was about ±0.01 mrad. Two emission components are appearing in the projected angular spectra of the He particles, one representing fragmentation at Fermi momentum scale, while the other one exhibits large transverse momentum transfer. By scaling with the incident momentum the angular spectra of He particles are compared with earlier reported measurements of Au on Au interactions at 11.6 A GeV/c. The $p_T$ spectrum of the He particles appears the same for the two cases.

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Angular and multiplicity measurements of fragments produced in heavy ion reactions at high energies are interesting for tracing the underlying reaction mechanisms. At these relativistic energies, the relative velocities of the colliding nuclei far exceed the Fermi velocities of the nucleons in the target and projectile. So, there is a separation of projectile and target fragmentation regions. Equilibration of nuclear matter is therefore expected to occur mainly in the so-called participant region (the region of mutual geometrical overlap). The measurements of the $p_T$ distributions of the fragments can reveal possible deviations from Fermi motion break-up [1]. Furthermore by comparing relative azimuthal angles in a pair of fragments one can establish whether the emission is correlated or not. The projectile fragmentation can be advantageously studied with emulsion technique utilizing vertically exposed emulsion plates in chambers due to a very good polar angular precision of about ±0.01 mrad [2,3].

The data presented here has been recorded with a $^{208}$Pb beam with 158 A GeV/c incident momentum from CERN, SPS on a stationary thin Pb foil ($\approx 250\mu$ thick) placed in front of series of plastic sheets each coated on both sides by nuclear emulsion (FUJI ET-7B) acting as the detector. The foil and the sheets were placed in light-tight chambers.

The exposure was controlled by measuring heavily ionizing particles with a scintillator and discriminator with high threshold setting. The counter was placed behind the chamber which were in the beam during one 5 second spill. In this way the number of beam particles could be counted. A CAEN N145 preset scaler and driver electronics formed a pulse sent to a SPS "kicker" magnet which removed the beam when a preset number 3000 beam particles were collected per spot. The spot size was about 6 cm$^2$ which gives a density of the beam of about $5 \cdot 10^2$ nuclei/cm$^2$. The expected number of collisions in the target foil is:

$$N^* = N \cdot d/\lambda \tag{1}$$

Here $N = 3000$, $d = 0.025$ cm and $\lambda_{\mathrm{PbPb}} = 4.3$ cm is the mean free path for a Pb nucleus in a Pb target. Based on parametrization of nucleus-nucleus inelastic cross-sections we obtain $\sigma_{\mathrm{PbPb}} = 7.01$ barn [4]. We find $N^* \approx 17$ per exposure. For a total of 4 exposures, each centred on one of the 4 quadrants of the chambers, we expect a total of about 68 interactions. By actually counting the number of beam tracks, $N_{\mathrm{Pb}}$, and the number of interactions, $N^*_{\mathrm{obs}}$, in the chamber

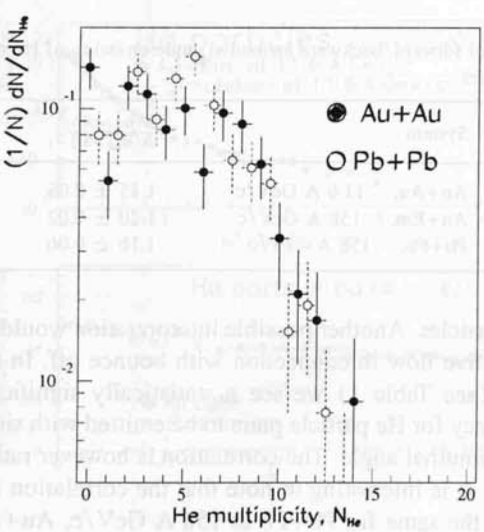

**Fig. 1. The multiplicity of He fragments for Au+Au and Pb+Pb interactions at 11.6 and 158 A GeV/c, respectively**

the scanning efficiency, $\varepsilon$ can be measured as:

$$\varepsilon = N^*_{\mathrm{obs}}/(N_{\mathrm{Pb}} \cdot d/\lambda_{\mathrm{PbPb}}) \qquad (2)$$

We found $\varepsilon = 0.75\ (\pm\ 0.05)$. This rather low scanning efficiency can be attributed to peripheral collisions where the shower particles are hidden by the thick projectile fragment tracks. With the same technique utilizing Au+Au collisions at BNL at about 11.1 and 11.6 A GeV/c incoming momentum scanning efficiencies close to unity were obtained. At this lower momentum the polar angle is about 18 mrad in the fragmentation cone, enough to separate the shower particles as compared to polar angle 1.3 mrad for Pb+Pb interactions.

In Fig. 1 we show the multiplicity distribution of He particles for Au+Au and Pb+Pb at 11.6 and 158 A GeV/c, respectively. Due to what has been said above the Pb+Pb multiplicity distribution might have a slight bias. Note the close similarity of the data for the two different incoming momenta indicating that limiting fragmentation is reached already at 12 A GeV/c.

In Fig. 2a we show the distribution of squared transverse momenta for He fragments in Au+Au and Pb+Pb collisions at 11.6 and 158 A GeV/c, respectively. The transverse momenta of the He fragments was calculated under the assumption that the fragments move with the beam velocity. The $P_T^2$ distributions are rather similar again indicating limiting fragmentation. These distributions appear to have two different slopes: one steep at low $P_T^2$, and one slowly descending for larger $P_T^2$, for both the samples. At low $P_T^2$ the steep slope could be fitted to an exponential shape: $\approx \exp(-P_T^2/(2\sigma^2))$. For 1173 measured He fragments, the Pb+Pb data gives $\sigma = 283 \pm 9$ MeV/c. As a comparison we have the value $\sigma = 322 \pm 3$ and $\sigma = 290 \pm 6$ MeV/c for Au+Em and Au+Au interactions [6]. In that paper we examined the angular spectra of fast He particles (projectile-associated) emerging in Au+Au collisions and Au+Em interactions at 10.7 A GeV. We found two components in the spectra: one soft at small angles and a hard component at larger angle. The soft contribution could be tentatively understood as a sudden Goldhaber fragmentation with additional Coulomb scattering, whereas the understanding of the hard component remained incomplete.

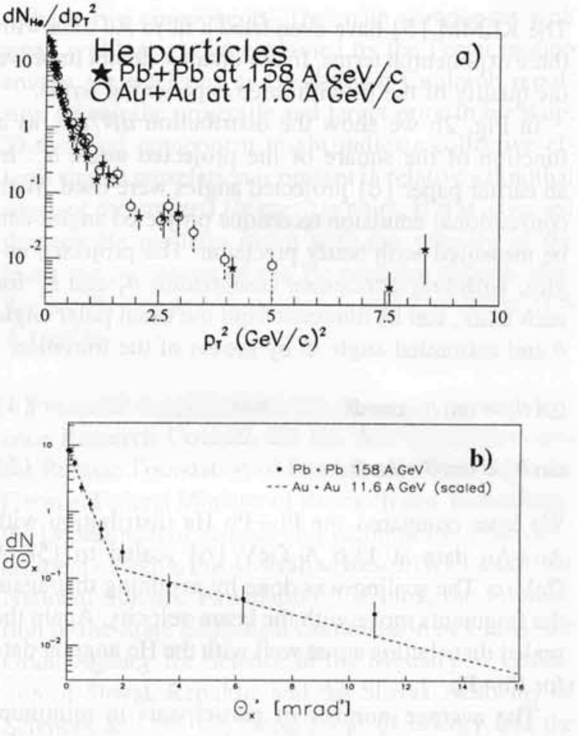

Fig. 2. a) $dN_{\mathrm{He}}/dP_T^2$ as a function of $P_T^2$ (GeV/c)$^2$ for Pb+Pb and Au+Au interactions at 158 A or 11.6 A GeV/c, respectively. b) $dN/d\theta_x$ as a function of $\theta_x^2$ (mrad$^2$) for Pb+Pb interactions at 158 A GeV/c.

We can thus parametrize the distribution as:

$$dN_{\mathrm{He}}/dP_T^2 = A \cdot \exp(\alpha \cdot P_T^2) + B \cdot \exp(\beta \cdot P_T^2) \qquad (3)$$

The KLMM [5] have even tried a fit to Au data with three exponential terms. In our data we do not improve the quality of the fit with three exponential terms.

In Fig. 2b we show the distribution $dN/d\theta_x$ as a function of the square of the projected angle $\theta_x^2$. In an earlier paper [6] projected angles were used. With conventional emulsion technique projected angles can be measured with better precision. The projected angles, with two orthogonal components $\theta_x$ and $\theta_y$ for each track, can be obtained from the usual polar angle $\theta$ and azimuthal angle $\Phi$ by means of the formulas:

$$\tan\theta_x = \tan\theta \cdot \cos\Phi \tag{4}$$

$$\tan\theta_y = \tan\theta \cdot \sin\Phi \tag{5}$$

We have compared the Pb+Pb He distribution with Au+Au data at 11.6 A GeV [6] scaled to 158 A GeV/c. The scaling was done by assuming that again the fragments move with the beam velocity. Again the scaled distribution agree well with the He angular data for Pb+Pb.

The average number of participants in minimum bias Pb+Pb events is estimated from geometry to be 53 in both projectile and target, whereas about 200 binary collisions are expected in minimum bias events. This means that on average a nucleon collides with about 4 nucleons from the other nuclei. For O+O the corresponding number is about 2. Therefore it might be interesting to examine the degree of azimuthal correlation among the fragments to observe possible collective phenomena in Pb+Pb.

Let us consider pair of emitted He particles with azimuthal angles $\Phi_1$ and $\Phi_2$, respectively. To search for correlation in relative azimuthal angle we define $\Phi_{\rm rel}^{\rm pair}$ as:

$$\Phi_{\rm rel}^{\rm pair} = |\Phi_1 - \Phi_2|, \quad |\Phi_1 - \Phi_2| < 180^\circ \tag{6}$$

$$\Phi_{\rm rel}^{\rm pair} = 360^\circ - |\Phi_1 - \Phi_2|, \quad |\Phi_1 - \Phi_2| > 180^\circ \tag{7}$$

If correlations in relative azimuthal angle are absent this distribution is uniform. If He particles tend to be emitted in the same direction the distribution will be forward peaked, whereas a "back-to-back" correlation gives a peak at 180°.

A correlation in azimuthal angle could result from a medium mass prefragment, with transverse motion with respect to the beam direction, which emits a few He particles. Another possible interpretation would be collective flow in connection with bounce off. In the data (see Table 1) we see a statistically significant tendency for He particle pairs to be emitted with similar azimuthal angle. The correlation is however rather weak. It is interesting to note that the correlation appears the same for Pb+Pb at 158 A GeV/c, Au+Au and Au+Em at 11.6 A GeV/c. If He production occur due to scattering of preexisting He clusters in the projectile with target constituents one would not expect azimuthal pair correlations. Thus some collective effect seems to be present.

Table 1
Ratios of forward/backward azimuthal angle emission of He particle pairs

| System | $\frac{N(\Phi_{\rm rel}<90)}{N(\Phi_{\rm rel}>90)}$ |
|---|---|
| Au+Au, 11.6 A GeV/c | $1.15 \pm 0.06$ |
| Au+Em, 158 A GeV/c | $1.20 \pm 0.02$ |
| Pb+Pb, 158 A GeV/c | $1.16 \pm 0.06$ |

We have made a simple simulation in order to understand both the relative azimuthal angle correlation as well as the tail of the $p_T$ distribution for He fragments. We assume that He particles are emitted from a source where a collective momentum transfer, $P_T^{\rm kick}$, is given to a part of the spectator which then emits the He particles. In the rest frame of the source the He particles are assumed to have gaussian momentum distributions with $\sigma = 0.322$ GeV/c [6].

In other words the correlated He pairs have momenta like:

$$p_{1x} = g_{1x} \cdot \sigma + g_3 \cdot \sigma^{\rm kick}$$

$$p_{1y} = g_{1y} \cdot \sigma + g_4 \cdot \sigma^{\rm kick}$$

$$p_{2x} = g_{2x} \cdot \sigma + g_3 \cdot \sigma^{\rm kick}$$

$$p_{2y} = g_{2y} \cdot \sigma + g_4 \cdot \sigma^{\rm kick}$$

$g_{1x}, g_{2x}, g_{1y}, g_{2y}, g_3$ and $g_4$ are standard gaussian distributed, $N(\mu = 0, \sigma^2 = 1)$, random numbers. With a gaussian distribution for $P_T^{\rm kick}$ we obtain:

$$P_T^{\rm kick} = \langle P_T \rangle = \sigma^{\rm kick} \cdot \sqrt{(\pi/2)}$$

As can be seen in Fig. 3 a rather good agreement with our data can be obtained for $P_T^{\rm kick} = 1.2$ GeV/c and

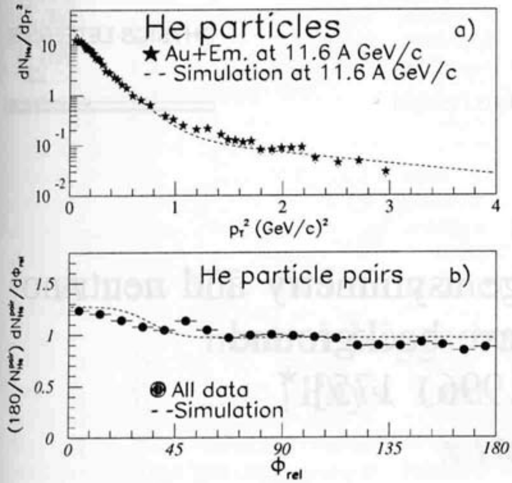

Fig. 3. a) $dN_{\mathrm{He}}/dP_T^2$ as a function of $P_T^2$ (GeV/c)$^2$ for Au+Em interactions at 11.6 A GeV/c. b) $(180°/N_{\mathrm{He}}^{\mathrm{pair}})\ dN_{\mathrm{He}}^{\mathrm{pair}}/d\Phi_{\mathrm{rel}}$ as a function of $\Phi_{\mathrm{rel}}$ degree for all data.

10% fraction of the helium particles being correlated. The angular correlation can of course be explained by a much smaller $p_T^{\mathrm{kick}}$, if a larger fraction of the He particles are correlated.

Then the high $p_T$-tail has to be due to a different mechanism, e.g. pre-existing He clusters in the nuclei, or alternatively, coalescence of multiple scattered nucleons into He particles. However, in an ongoing analysis of bounce-off effects in Au- induced interactions it is found that also those fragments with the largest $p_T$ are strongly correlated to the direction of the rest of the fragments [7], which would not be the case for smaller momentum transfers. It should be noted that fluctuations in $p_L$ ($p_T = p_L \cdot \tan\theta$) are neglected in this approach. They are a few percent for $\alpha$'s from $^{28}$Si+Pb at the AGS [8] and might be somewhat larger for Pb+Pb at the SPS. Such fluctuations are not likely to affect our conclusions.

In conclusion the angular spectra of He particles emitted in Pb+Pb collisions at 158 A GeV/c appear to have two components. The main component with small width might be explained by the Fermi motion among the nucleons and additional Coulomb repulsion among the projectile and target prior to breakup. The second component might indicate collective effects since a correlation is present in relative azimuthal angle of the emitted He particle pairs. If it is assumed that the He particles move with the velocity of the beam the $p_T$ spectra of the He particles appears similar for Pb+Pb at 158 A GeV/c and Au+Au at 11.6 A GeV/c.

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