сообщения
объединенного
института
ядерных
исследований
дубна

E1-87-362

K.Miller, T.Pawlak*, W.Peryt*, J.Pluta,
Z.Strugalski*

LOSSES AND DISSIPATION OF PION ENERGY IN π^--XENON COLLISIONS AT 3.5 GeV/c

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* Institute of Physics, Warsaw Technical University, Koszykowa 75, 00-662 Warsaw, Poland

1987

1. INTRODUCTION

Investigations of pion production characteristics in hadron-nucleus collisions, depending on the nuclear matter layer thickness involved in the interaction process, provide information on projectile energy dissipation in its passage through the target nucleus[1]. Nuclear matter excitation and particle ejection take place as a result of incident particle energy deposition. To investigate the properties of the excited objects, which are the sources of secondary particles, a suitable reference frame should be used. The rest frame of particle sources would be the best one if such a frame generally exists. This problem is clearly seen when evaluating the space-time characteristics of the emission process by means of the two-particle correlation method[2,3]. The dependence of the size of the pion emission volume on the reference frame velocity was observed experimentally[4]. A strong dependence of inclusive pion distributions on their emission angles in the laboratory system can be taken as another example[5]. The influence of the particle source velocity seems to be involved here as well[6].

The elimination of the dependence of secondary particle characteristics on the source velocity could, on the one hand, yield information on the local nuclear matter excitation and, on the other, allow one to evaluate the stopping power of the target nucleus. Looking for the dependence of the secondary particle characteristics on the involved nuclear matter layer thickness seems to be a suitable method for this purpose.

In the present paper we investigate the process of incident particle energy dissipation inside the target nucleus by analysing neutral pion distributions as a function of the number of fast protons emitted. This number is commonly used as a characteristic of impact parameter and is related to the involved nuclear matter layer thickness[7].

The method of data analysis used here is similar to the approach proposed by T.Siemiarczuk twenty years ago[8] for π^--Xe collisions at 9 GeV/c and by J.Bartke et al. for nucleus-nucleus reactions at 4.2 GeV/c per nucleon[9].

2. EXPERIMENT

The collisions of 3.5 GeV/c negatively charged pions with xenon nuclei ($Z = 54$, $\langle A \rangle = 131.3$) were investigated on photographs from the 180 litre xenon bubble chamber irradiated at ITEP, Moscow. The dimensions of the chamber were 103x44x x40 cm^3. The interactions of beam particles were recorded in a central region of 40x10x10 cm^3. The chamber operated without a magnetic field. The events of primary pion collisions with the xenon nuclei were selected independently of the number of secondary charged particles and negaton-positron pairs produced by gamma-quanta outgoing from the interaction point.

The tracks of lengths larger than about 5 mm are detectable in the chamber with an approximately constant efficiency of nearly 100%. A kinetic energy of 22 MeV for protons and about 10 MeV for charged pions corresponds to this track length. The positive pions stopping within the chamber are identified by the characteristic track sequence left by the charged secondaries emerging in the decay process. All the tracks left by the particles stopping inside the chamber without visible interaction or decay are accepted to be proton tracks. The fraction of negative pion tracks in such a sample is estimated to be no more than 2%. The protons of momenta between 200 and 600 MeV/c are recorded with a full efficiency while some of faster protons leave the chamber without stopping. The corresponding loss should not exceed 4% as indicated by the extrapolation of the proton momentum spectrum.

Secondary neutral pions of any kinetic energy, including zero, are recorded and identified by the tracks of negaton-positron conversion pairs and electron-photon showers created by gamma quanta. (The dimensions of the chamber in radiation length units are 26x11x10). The gamma quantum energies are determined from the total track length of conversion negatons ans positrons. The mean accuracies in determining gamma quantum energy and emission angle are 17% and 1.2 degrees, respectively. The detection efficiency of gamma quanta is higher than 90%, and it does not depend essentially on the energies and multiplicities of gammas.

It has been found that neutral pions are the main source of the observed gammas: the decays $\eta^\circ \to 2\gamma$ and others are only a few per cent. In the sample of events with $N_\gamma > 2$, individual π° and η° mesons were identified by searching for such a combination of gamma quantum pairs, in each event separately, for which the effective masses are the nearest to the masses of π° and η° mesons. For the identified π° mesons the energy correction of corresponding gamma quanta was made on condition that the effective mass $m_{\gamma\gamma}$ coincides with the mass of π° meson. The mean accuracies in determining π° energy

and angle (after gamma quantum energy correction) are 9.3% and 1.9 degrees, respectively.

3. RAPIDITY AND ANGULAR DISTRIBUTIONS OF NEUTRAL PIONS

Later on we use the number of identified protons, N_p, as a measure of nuclear matter involvement in the interaction process.

Figure 1 presents the π° rapidity distributions in the laboratory system for various classes of proton multiplicities. All the distributions are normalized to one. The vertical dotted lines denoted by arrows (y_{lab} , y_{cms}) show the positions of the values of y for the laboratory system and for the frame of incident pion-target nucleon, respectively. All the distributions are approximately similar and symmetrical in form, but their location on the y axis shifts to smaller values with increasing N_p. The dispersion of the y distributions decreases as well.

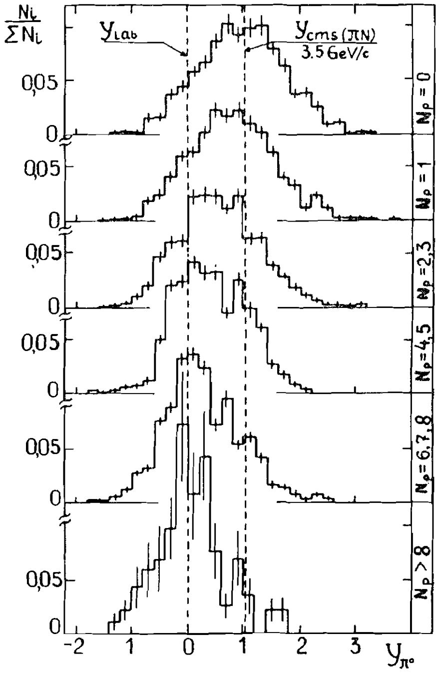


Fig. 1. Rapidity distributions of neutral pions for different numbers of emitted protons N_p.

Figure 2 shows a quantitative picture of these dependences. The empty circles and bars in Fig.2a denote the mean and median values of y, respectively. Both values are generally the same for the same numbers N_p what corresponds to symmetrical distribution shapes. The values of y for the smallest and greatest N_p are close to the above defined values of y_{cms} and y_{lab}, respectively. The first case is related to quasi-elementary reactions with peripheral nucleons; the second one corresponds to central collisions with nearly isotropic pion emission in the laboratory system. The events having intermediate velocities of emitting systems lie between them. Apart from the first point for N_p=0, the change of <y> with increasing N_p has a linear character.

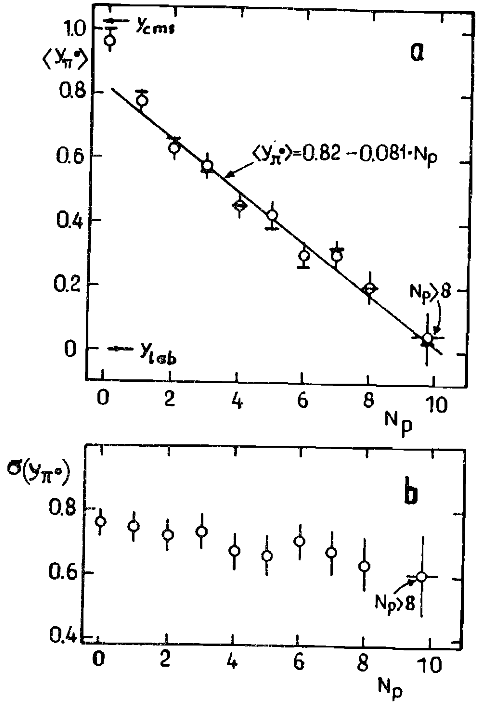


Fig. 2. Dependence of the neutral pion distribution parameters on the number of protons emitted. $\langle y_{\pi^0}\rangle$ - mean value. $\sigma(y_{\pi^0})$ - dispersion of the rapidity distribution. The bars in Fig.2a show the positions of median rapidity values.

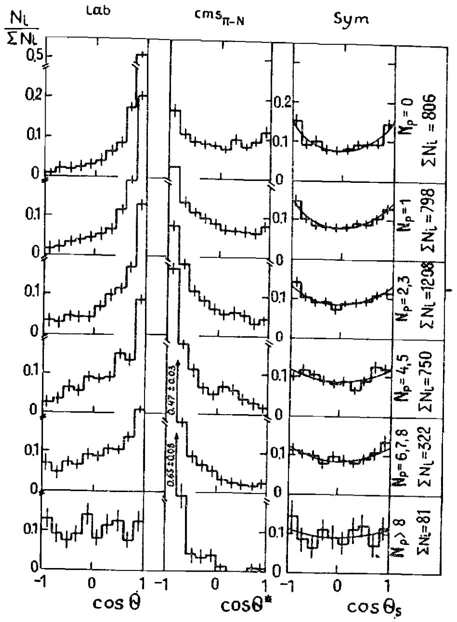


Fig. 3. Angular distributions of neutral pions for different classes of proton multiplicities. lab - laboratory systems, cms - π^--N cms, sym - system of symmetrical pion emission.

The slope coefficient

$$\Delta y/\Delta N_p = -0.081 \pm 0.003$$

can be used as a measure of xenon nucleus stopping power. The dispersion $\sigma(y_{\pi^0})$ decreases slightly with increasing N_p as shown in Fig.2b.

The changes of angular distributions with the increase of N_p are shown in Fig.3. The first column presents the π^0 angular distributions in the laboratory system. For small proton multiplicities a sharp peak is seen in the forward direction; for $N_p > 8$ the distribution becomes flat. The second column shows the distributions of the same pions but in the π^--N_{cms}. For $N_p = 0$ the distribution is nearly isotropic (Note that we cannot take invisible neutrons into account and a small part of protons remains unidentified).A sharp peak in the backward direction is seen for the greatest N_p numbers. The third column presents the angular distributions in the frames moving in the laboratory system with velocities depending on the number of emitted protons. These distributions will be discussed in the next section.

4. SYSTEM OF SYMMETRIC PION EMISSION

The observed regularities in the π^0 characteristics are consistent with the assumption of pion emission from the systems moving in the laboratory with velocities depending on the number of emitted protons or, in other words, on the involved nuclear matter layer thickness. Taking this assumption as a working hypothesis, the energies and longitudinal components of pion momenta were transformed to the systems (sym) moving in the laboratory with velocities depending on N_p and defined as /9/:

$$\beta_s(N_p) = \tanh[y_M(N_p)],$$

where $y_M(N_p)$ is a median value of y as a function of N_p.

The results of transformation are presented in the third column of Fig.3 and in the following figures.

Equal pion numbers in the forward and backward directions seen in Fig.3 (column marked "sym") are the result of imposed transformation conditions. Both the degree of symmetry and isotropy reflect physical properties of the pion emission process. All the distributions were approximated by a symmetrical function of the form:

$$dN/d\cos\theta = c*(1 + a*\cos^2\theta).$$

The results of approximation are shown in Fig.3 by the continuous lines. All fits give reasonable values of χ^2 what reflects a satisfactory degree of symmetry. The anisotropy coefficient a reaches its greatest values for the distributions of the smalest numbers N_p, i.e. for quasi-elementary reactions. For the greatest numbers N_p, i.e. for central collisions, the angular distribution corresponds to nearly isotropic pion emission. The values of the coefficient a for the smallest and greatest numbers N_p are

$a(N_p = 0, 1) = 0.68 \pm 0.12$ and $a(N_p \geqslant 7) = 0.30 \pm 0.22$.

Fig.4 illustrates a symmetry test of the rapidity distribution in the (sym) system. Two parts of the forward and backward y distributions are superimposed on this figure for comparison. Both parts have practically the same shape.

A test for incident pion momentum dissapation into parallel and perpendicular components of neutral pion momenta is presented in Fig.5. The mean longitudinal π^0 momenta in the (sym) system and the transversal ones as a function of proton number are presented in this figure. Both components decrease with increasing N_p, but the absolute values of $P_{\parallel}$ are distinctly greater than $P_{\perp}$ for small numbers of emitted protons. The difference disappears for the highest numbers N_p showing that in the case of central collisions the momenta of secondary pions are approximately uniformly distributed.

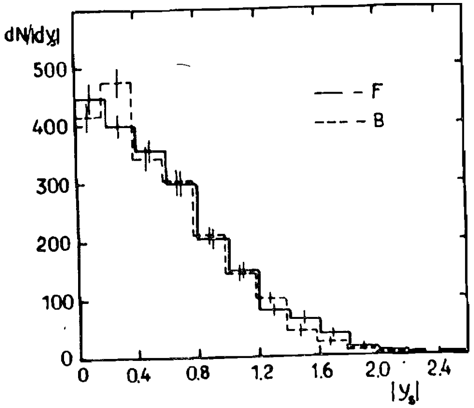
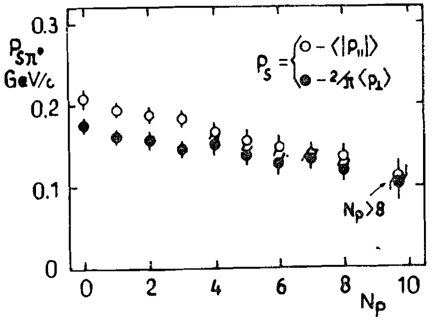


Fig.4. Distribution of the absolute values of neutral pion rapidity in the symmetrical system. F - forward, B - backward hemisphere.

Fig.5. Mean transversal and transformed longitudinal momenta of neutral pions depending on proton multiplicity.



5. CONCLUSIONS

In the performed data analysis the system (sym) was used in which neutral pion distributions have similar properties independently of the target nucleus involvement in the interaction process. It seems to us that this approach can be used to separate the local source parameters from the global characteristics of secondary particles.

For small proton numbers we have observed the characteristic properties of elementary reactions in the angular pion distributions. The pion energy degradation, seen through the dependence of mean rapidity values on N_p, is followed by increasing the degree of isotropy observed in the angular and momentum distributions. The characteristic features of pion emission from the system resting in the laboratory have been observed in the case of central pion-nucleus collisions. Therefore, the xenon nucleus appears to be able to completely stop the incident pion at 3.5 GeV/c. The events, where the incident pion was absorbed in the xenon nucleus without pion production, were identified in our earlier paper /10/. The mean number of emitted protons in such events is more than two times greater than in other inelastic collisions.

Finally, we would like to note that the method of data analysis applied here is of a general nature and is not related to some particular reaction mechanism. So, the observed tendencies can be explained in the frame of the approach /8/, where "π^0-mesons are produced in a single act of interaction of an incident pion with an aggregate of nucleons". It is possible, however, that a more complex process leads to the same final experimental results /11,12/. It has been shown /9/ that the symmetry effect of the π^--meson rapidity distributions in nucleus-nucleus collisions, similar to those observed here, can be naturally explained in the frame of the additive quark model /13/ .

Thus, the mass of an "aggregate of nucleons" or the "number of interacting nucleons" related to the "number of wounded quarks" can be found from the symmetry properties of pions in a given reference frame. The mass of the effective target involved in the formation of pion sources, M_t, can be evaluated from the relation /14/:

$$\beta = P_{inc}/(E_{inc}+M_t),$$

where E_{inc} and P_{inc} are the energy and momentum of the incident pion and β is the velocity of the symmetrical system.

The values of M_t obtained from this relation as a function of emitted proton numbers are given in the Table. The corresponding values of mean rapidity $\langle y\rangle$ and velocity β are also given here. The kind of dependence of these values on the number of emitted protons shows that the process of energy loss and dissipation has a monotonous character and is directly related to the nuclear matter layer thickness involved in the interaction. The system of symmetric pion emission seems to be suitable as a reference frame for hadron-nucleus and nucleus-nucleus data analysis.

The authors are grateful to V.G.Grishin, L.M.Shcheglova and A.N.Solomin for useful discussions and comments.

Table

Values of mean π^0 rapidity $\langle y\rangle$, velocity β and effective target mass M_t as a function of proton number N_p

Np	⟨y⟩	β	M_t, GeV
0	0.95 ± 0.02	0.74 ± 0.01	1.2 ± 0.1
1	0.78 ± 0.02	0.65 ± 0.02	1.9 ± 0.1
2	0.62 ± 0.03	0.55 ± 0.02	2.8 ± 0.2
3	0.58 ± 0.03	0.52 ± 0.02	3.2 ± 0.3
4	0.45 ± 0.03	0.42 ± 0.03	4.8 ± 0.5
5	0.43 ± 0.03	0.40 ± 0.03	5.1 (+0.6, -0.5)
6	0.30 ± 0.04	0.29 ± 0.04	8.6 (+2.4, -1.4)
7	0.30 ± 0.05	0.29 ± 0.05	8.6 (+2.4, -1.4)
8	0.20 ± 0.06	0.20 ± 0.06	13.8 (+7.7, -3.6)
>8	0.05 ± 0.06	0.05 ± 0.06	66. (+65., -40.)
≥ 0	0.62 ± 0.01	0.55 ± 0.01	2.8 ± 0.1

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Received by Publishing Department
on May 25, 1987.

Миллер К. и др. E1-87-362
Потери и рассеяние энергии пионов
в столкновениях π^--мезонов с ядрами ксенона
при 3,5 ГэВ/с

Изучалась зависимость характеристик нейтральных пионов от числа испущенных протонов в столкновениях π^--Xe при 3,5 ГэВ/с. Для анализа данных использовалась система отсчета, в которой эмиссия пионов обладает симметрией вперед-назад. Потери энергии пионов имеют монотонный характер и прямо связаны с толщиной ядерной материи участвующей во взаимодействии. В случае центральных столкновений угловые и импульсные распределения π^0-мезонов близки к сферически-симметричным.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна 1987

Miller K. et al. E1-87-362
Losses and Dissipation of Pion Energy
in π^--Xenon Collisions at 3.5 GeV/c

The dependence of neutral pion characteristics on the number of emitted protons has been investigated in π^--xenon collisions at 3.5 GeV/c. A reference frame of symmetrical pion emission was used for data analysis. The process of pion energy dissipation has a monotonous character and is directly related to the involved nuclear matter layer thickness. In the case of central collisions the angles and momenta of secondary pions seem to be uniformly distributed.

The investigation has been performed at the Laboratory of High Energies, JINR.

Communication of the Joint Institute for Nuclear Research. Dubna 1987