Vol. 33 (2002) ACTA PHYSICA POLONICA B No 3

PION REABSORPTION IN THE NUCLEAR MATTER A SIMPLE MODEL*

K. Tymińska, T. Matulewicz and K. Piasecki

Institute of Experimental Physics, Warsaw University
Hoża 69, 00-681 Warsaw, Poland

(Received February 7, 2002)

The paper raises the problem of reabsorption of neutral pions in nuclear matter. Sophisticated transport models are unable to reconstruct the energy spectra and angular distributions of subthreshold particles. In order to reproduce angular distributions of subthreshold pions we have developed a simple, geometrical model and have tried to compare its predictions to the wealth of experimental data. Although the assumptions of the model are very simple, the agreement between data and the model results is generally very good. The angular distribution of primordial pions was described by the formula $1 + A_2P_2(\cos\vartheta)$. For each data set the A_2 parameter was determined from the comparison to experimental distribution. No apparent trend is observed and we concluded that the angular distribution of primordial pions has a universal value of A_2 parameter.

PACS numbers: 25.70.–z

1. Introduction

The anisotropy in angular distributions of neutral pions produced in heavy-ion collisions at subthreshold energies was interpreted as reabsorption effects already in pioneering experiments by Grosse and coworkers [1, 2]. The development of dedicated electromagnetic calorimeters (like the TAPS photon spectrometer [3]) improved the quality of measurements of neutral pions. The experiments extended the knowledge of the reaction mechanism, confirming that the subthreshold pion production is dominated by the first-chance collisions [4, 5] and that the Δ-resonance is important both to the production [6] and absorption [7] processes. The present work reports an analysis of the available experimental data on subthreshold pion production in the framework of a simple production and absorption model, aiming at

* Presented at the VI TAPS Workshop, Krzyże, Poland, September 9–13, 2001.

the determination of global characteristics of the primordial pions angular distribution. The determination of any regularity would be essential for an attempt to create the systematics of production cross section of primordial pions.

2. Assumptions

The model used in our calculations assumes, that the pions are produced in the maximum overlap zone between two spherical nuclei (Fig. 1). The production probability for collisions at different impact parameters is proportional to the volume of the overlap zone (constant for $b < |R_1 - R_2|$ and decreasing for larger impact parameters). The production vertex is randomly selected within that volume. The energy of the neutral pion is random according to the thermal distribution with the 'temperature' parameter reproducing the experimental data. At beam energies below 100 $A\,$MeV, where our analysis is mostly applied, this parameter does not show any energy dependence [8]. The pion emission angle ϑ is selected randomly from the distribution $1 + A_2 P_2(\cos\vartheta)$, where P_2 is the second-order Legendre polynomial $P_2(x) = (3x^2 - 1)/2$. The A_2 parameter was later varied in order to reproduce the experimental angular distributions. The geometrical configuration of two colliding nuclei is treated as frozen and the path L from the creation point to the point where the pion leaves the nuclear system is calculated. The probability that the pion leaves the nuclear medium is taken

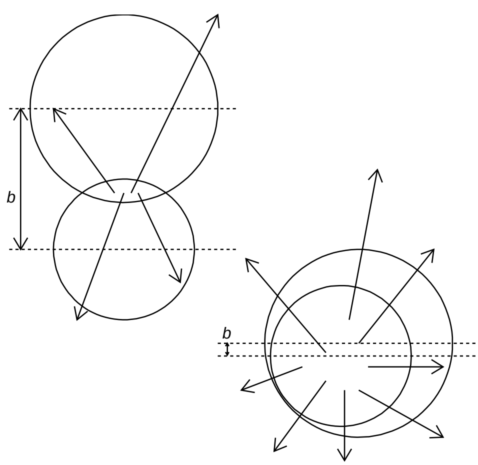

Fig. 1. Schematic description of the pion creation and absorption model. The impact parameter b determines the size of the production zone. The production probability depends on the volume of the overlap zone, and this is illustrated by the different number of arrows depicting produced pions.

as $\exp(-L/\lambda)$, where the absorption length λ is energy-dependent and was parametrized according to [9]. This parametrization accounts for the large cross section for the pion absorption around the energy corresponding to the excitation of the Δ resonance. The model accounts for neither the dynamical evolution of nuclear matter in course of the collision, nor for the increased nuclear matter density along the pion flight path. It might be argued, that the first approximation is validated by the fact that pions as light particles are, on the average, moving faster compared to the speed of evolution of the nuclear collision. It corresponds to the model assumption, that the amount of nuclear matter the pion has to travel through is predetermined at the beginning of the collision. The pion absorption on nuclei has little dependence on the nuclear density [10], so we can neglect the effects of increased density. The model does not account for the secondary pion emission following pionic decays of Δ-resonances excited by already produced pions. At beam energies per nucleon below the pion production threshold only the low-energy tail of the Δ-resonance is effectively populated, so the pionic decay channel is suppressed in favour of nucleon–hole excitations [11].

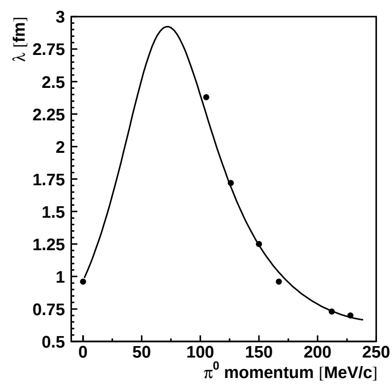

Fig. 2. The dependence of absorption length on the pion momentum. Full circles denote the values calculated within the optical model in Ref. [9].

3. Comparison of the model to the experimental angular distributions

We have compared the predictions of our model with the available experimental data obtained in a wide range of energies and masses of colliding nuclei (Table I). For each case the A_2 parameter was adjusted to reproduce the experimental angular distributions. Some results of the calculations and corresponding experimental data are shown in figure 3. Generally, the agreement is very good. The only problem appeared in the case of the reaction carbon on lithium, where the experimental cross section continues to fall down with the increasing emission angle, while the model predicts a rise. The observed discrepancy is particularly astonishing in view of the very good description of Mg + α reaction, where one of the collision partners is even smaller than lithium.

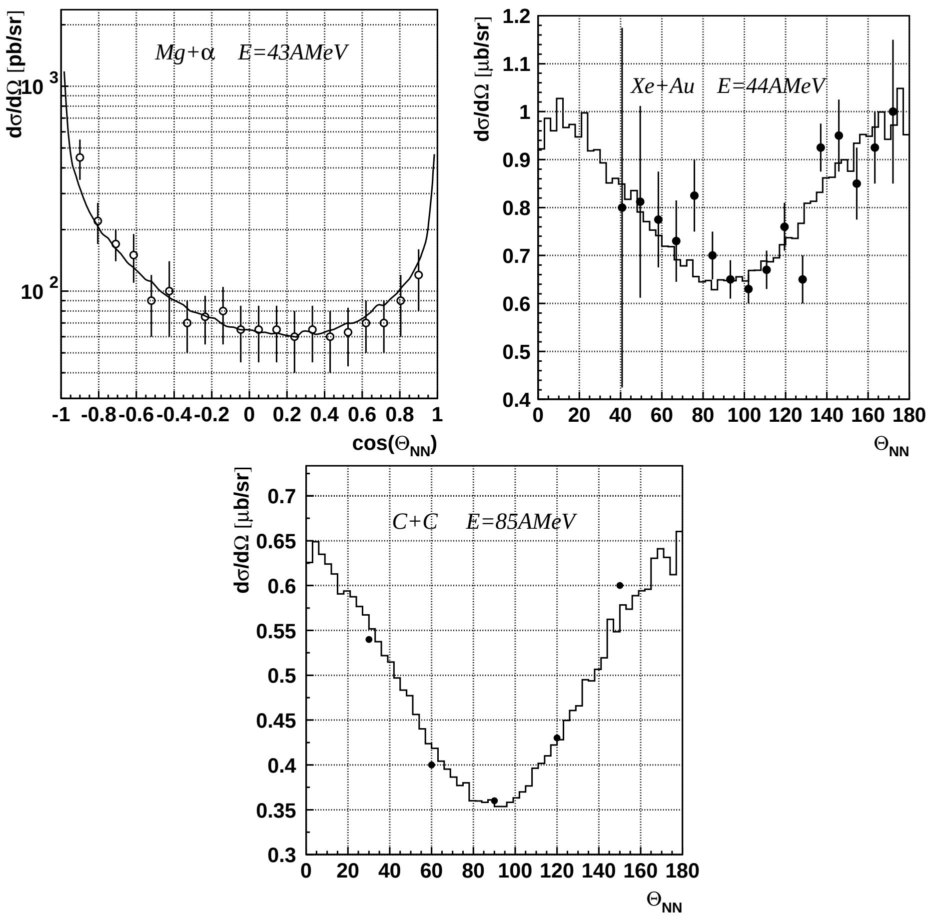

Fig. 3. Comparison of some of the experimental angular distributions (circles) and the model calculations.

The parameter A_2 of the primordial pion angular distributions was obtained from the best fit to experimental data. The values of this parameter are plotted as a function of the total mass of colliding nuclei (Fig. 4). No apparent trend can be observed. We then conclude, that the angular distribution of primordial pions is constant, with parameter $A_2 = 0.40 \pm 0.08$.

TABLE I

List of the systems of colliding nuclei, for which the angular distribution was calculated within the presented model.

Projectile	Target	Beam energy [AMeV]	Ref.
He	Mg	43	[12]
Xe	Au	44	[4]
C	Li	85	[13]
C	C	85	[13]
C	Pb	85	[13]
Ar	C	95	[5]
Ar	Au	95	[5]
Au	Au	1000	[14]

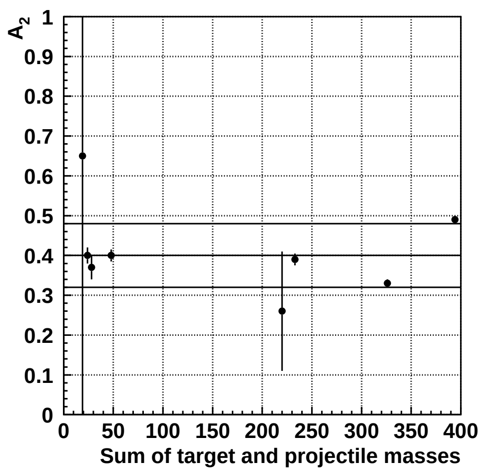

Fig. 4. The A_2 coefficient obtained from the fit to the experimental angular distributions, plotted as a function of the sum of mass of colliding nuclei. The lines indicate the average value and error limits.

4. Conclusions

The angular distribution of neutral pions are generally well described in a simple model asumming the $1 + A_2P_2(\cos\vartheta)$ angular distribution of primordial pions and the absorption process treated in a simple geometrical way. The A_2 parameter of the primordial angular distribution seems to be independent of the size of the collision system and of the beam energy. The average value of A_2 equals 0.40 ± 0.08. The model presented here may be used for a quite precise estimation of the contribution of photons originating from π^0 decay to the hard photon spectrum of heavy ion collision.

This work was supported in part by the Polish State Committee for Scientific Research (KBN) Grant no 2P03B 013 14.

REFERENCES

[1] E. Grosse, *International School of Physics* Enrico Fermi, edited by P. Kienle, R.A. Ricci, and A. Rubbiano, North Holland, Amsterdam 1987.

[2] P. Grimm, PhD thesis, Univ. Heidelberg 1987 (GSI Report 87-2).

[3] H. Ströher, *Nucl. Phys. News* **6**, 7 (1996).

[4] R.S. Mayer *et al.*, *Phys. Rev. Lett.* **70**, 904 (1993).

[5] A. Schubert *et al.*, *Phys. Lett.* **B328**, 10 (1994).

[6] T. Matulewicz *et al.*, *Eur. Phys. J.* **A9**, 69 (2000).

[7] R. Holzmann *et al.*, *Phys. Lett.* **B366**, 63 (1996).

[8] V. Metag, *Nucl. Phys.* **A553**, 283c (1993).

[9] R. Mehrem *et al.*, *Phys. Rev.* **C30**, 301 (1984).

[10] C.H.Q. Ingram, *Nucl. Phys.* **A553**, 573c (1993).

[11] J. Helgesson, J. Randrup, *Ann. Phys.* **244**, 12 (1995).

[12] M. Waters *et al.*, *Nucl. Phys.* **A564**, 595 (1993).

[13] V. Bernard *et al.*, *Nucl. Phys.* **A423**, 511 (1984).

[14] S.A. Bass *et al.*, *Phys. Rev.* **C51**, 3345 (1995).