π^0 MESON PRODUCTION IN Ta+Au COLLISIONS AT 40A MeV*

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(Received December 15, 2009)

Angular and transverse momentum distributions have been measured for the Ta+Au collisions at $40A$ MeV using the TAPS photon spectrometer installed at GANIL, Caen. The data sample of $528\,\pi^0$ mesons is superior compared to the previous measurement at the beam energy being only 14% of the free nucleon–nucleon threshold. The angular distribution has been found to be almost symmetric and can be described well within a parametrisation using a second-order Legendre polynomial. The correction of data by the simple reabsorption model based on static geometrical considerations indicates, that the angular distribution of primordial neutral mesons might be almost isotropic, in contrast to many of the results obtained from the reanalysis of published data. The transverse momentum spectrum cannot be reasonably described within the thermal model, even when the spectrum is corrected for the reabsorption effects.

PACS numbers: 25.70.–z

Neutral pions are the favourite probes of the initial phase of nucleus – nucleus collisions at (deep) subthreshold energies, *i.e.* beam energies per nucleon well below the neutral pion production threshold of about 280 MeV in nucleon–nucleon (NN) interaction. The dominant (99% [1]) two-photon decay channel of π^0 mesons makes their detection feasible down to null kinetic energy. This is particularly interesting as their production already absorbs a lot of energy available in an individual NN collision, when the beam energy is of the order of few tens MeV per nucleon. Extensive studies of π^0 production have been done ([2,3] and references therein) in the past two decades with the use of high-energy photon spectrometers TAPS [4] and MEDEA [5]. Their large angular coverage and good energy and position resolution for photon detection made possible the detection of neutral pions in a wide angular and energy range.

* Presented at the XXXI Mazurian Lakes Conference on Physics, Piaski, Poland, August 30–September 6, 2009.

An important property of neutral pions as probes of the nuclear medium is their short and momentum-dependent mean free path. Both angular and energy distributions are subject to distortions caused by nuclear matter surrounding the production zone. A clear example is the strong forward –backward asymmetry of the angular distribution of π^0 mesons observed in mass-asymmetric nucleus–nucleus collisions (see *e.g.* [6–8]). This asymmetry might be attributed to the stronger reabsorption of pions occurring on the side of heavier collision partner.

Continuing our systematical study of angular distributions of neutral pions [3, 9], this paper presents the analysis yielding insights into the reabsorption effects concerning neutral pions produced in Ta+Au collisions at $40A$ MeV. The experiment was performed by the TAPS Collaboration using ^{181}Ta beam delivered by the GANIL accelerator complex. The method of the identification of energetic photons [10] in this experiment has been described in [11]. Neutral pions have been identified through the invariant mass analysis of photon pairs, supplemented by the kinematical fit procedure [12]. The mass resolution of the π^0 peak was about 11%, in agreement with the predictions of GEANT3 simulation package. With negligible background in the invariant mass spectrum, 528 photon pairs were assigned to π^0 decays. It is worth to mention that this data sample has been obtained at the beam energy per nucleon equal to only 14% of the threshold energy in a free NN interaction.

The angular distribution of neutral pions (Fig. 1) shows that π^0 mesons are emitted with reduced intensity at sideward directions. The forward and backward emission are found to be equally intensive within experimental errors, what can be attributed to the close symmetry in the mass number of colliding nuclei. The shape of the distribution can be described by

$$\frac{d\sigma}{d\Omega} = K\left(1 + A_2 P_2(\cos\vartheta)\right) , \tag{1}$$

where $P_2(x) = (3x^2 - 1)/2$ is the second order Legendre polynomial and K is the normalisation constant. From the fit to the data we obtain $A_2 = 0.31 \pm 0.09$. Anisotropy of the angular distribution is often described in terms of anisotropy factor $A_{\rm f}$ defined as [13]

$$A_{\rm f} = \int\limits_{-1}^{1} \frac{f(x)dx}{2a_0} , \tag{2}$$

where $f(x) = a_0 + a_2x^2 + a_4x^4$ describes the shape of the angular distribution. In our case, where $a_4 = 0$, the following relation between A_2 and $A_{\rm f}$ holds:

$$A_{\rm f} = \frac{2}{2 - A_2} . \tag{3}$$

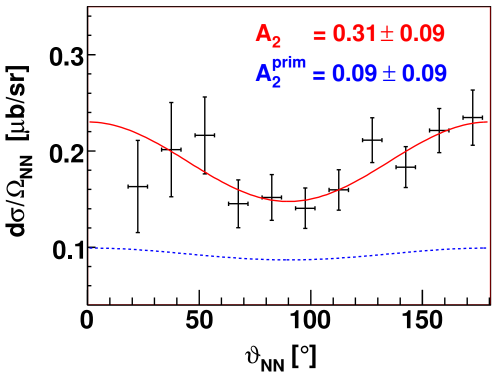

Fig. 1. Angular distribution of neutral pions obtained experimentally (full symbols) from Ta+Au collisions at $40A$ MeV with $1 + A_2P_2(\cos\vartheta)$ function fitted to the data (solid line). The dashed line shows (in arbitrary scale) the angular distribution of primordial pions, that after the reabsorption process in nuclear matter produces the experimentally observed shape. The reabsorption process is treated within the model described in Ref. [3].

The A_2 coefficient obtained for Ta+Au collisions at $40A$ MeV corresponds to $A_{\mathrm{f}} = 1.18{\pm}0.06$. Similar values were reported in Au+Au collisions at the SIS energy range, particularly for most central collisions [13] (the measured data at $40A$ MeV does not allow to study centrality dependence).

In an attempt to obtain the primary angular distribution of neutral pions, the effects of reabsorption in nuclear matter surrounding the production zone can be phenomenologically estimated within a geometrical model [3]. In this static model, the pion path is evaluated from the production point, generated randomly within the overlap zone, to the surface. The pion energy is randomly sampled from the thermal distribution. For this energy, the mean free path of pion is taken from the parametrisation of the results obtained within the optical model [14]. After application of the above mentioned model, it has been found that the angular distribution of primordial π^0 mesons should be characterised by $A_2^{\mathrm{prim}} = 0.09{\pm}0.09$ in order to reproduce the measured angular distribution at freeze-out. This value suggests that the primordial distribution is close to the isotropic one. The result obtained for Ta+Au system at $40A$ MeV can be compared to the A_2^{prim} parameters resulting from the analysis of the angular distributions available in the literature (Fig. 2, based on [3]). The actual result is well below the average trend observed in [3]. It means, that the predictive power of the systematics as a function of the total mass number is rather low and another dependence should be searched for, or the static geometrical model does not properly describe the effects of pion reabsorption.

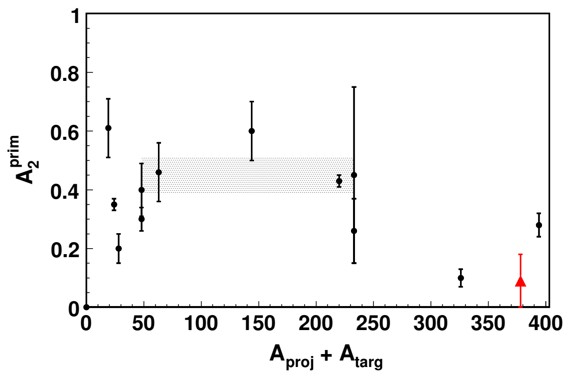

Fig. 2. The systematics of the A_2 coefficient of the angular distributions of primordial neutral pions, obtained from the fit of $1 + A_2 P_2(\cos\vartheta)$ function to the experimental data, incorporating the reabsorption process described within the model [3]. The values are plotted as a function of the sum of mass numbers of colliding nuclei. The result of the present analysis is indicated with a triangle.

The transverse momentum distribution of neutral pions measured at $95A$ MeV Ar-induced reactions [9] were not properly described within the thermal approach. Correcting the above mentioned spectra by momentum-dependent absorption effects, evaluated within the model [3], surprisingly resulted in spectra that were nicely described by the thermal model. However, the same procedure applied to the spectra obtained in the current experiment (Fig. 3) does not result in the distributions that can be reasonably described within the Boltzmann profile. Fitting the high-momentum tail (above 67 MeV/c) yields temperature parameter 11.6 ± 1.9 MeV for the experimental spectrum and 14.7 ± 3.1 MeV for the spectrum corrected for the absorption. The low-momentum part is clearly overestimated by this parametrisation.

Concluding, the high statistics measurement of neutral pion production from Ta+Au collisions at $40A$ MeV allowed to study in some details the angular and transverse momentum distributions of π^0 mesons. The angular distribution is almost symmetric and can be described well within a parametrisation using the second-order Legendre polynomial. The transverse momentum spectrum cannot be reasonably described within the thermal model. The correction of the data by the simple reabsorption model based on static geometrical considerations indicates, that the angular distribution of primordial neutral mesons might be almost isotropic. The A_2 coefficient obtained from this measurement is one of the smallest at this energy range. The transverse momentum spectrum of primordial neutral pions, corrected for the reabsorption effects, does not show the thermal behaviour.

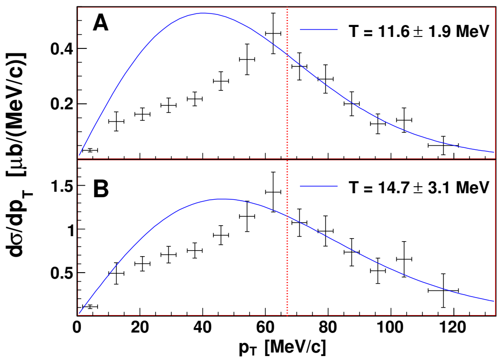

Fig. 3. Transverse momentum spectrum of neutral pions from Ta+Au collisions at 40*A* MeV without (upper panel) and with (lower panel) the correction due to the reabsorption in nuclear matter, evaluated according to the model of pion reabsorption [3]. The lines show the thermal model fit to the data above 67 MeV/c pion momentum.

The experiment was carried out at GANIL, Caen, by the TAPS Collaboration (L. Aphecetche, H. Delagrange, J. Díaz, D.G. d'Enterria, F. Fernández, H. Löhner, A. Kugler, G. Martínez, T. Matulewicz, R.W. Ostendorf, Y. Schutz, R. Turrisi, V. Wagner, H.W. Wilschut, N. Yahlali).

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