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SEARCH FOR η MESON PRODUCTION IN HEAVY ION COLLISIONS AT 100 MeV/NUCLEON

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Abstract

A search for the production of η mesons in nucleus-nucleus collisions at energies around 100 MeV/nucleon has been carried out. A 4π detector array has been used to look for the electromagnetic showers originating from the different decay modes of the η. A few events which are compatible with the $\eta \to \gamma\gamma$ decay were found. The cross section of the process has been estimated and compared with recent systematics on deep subthreshold processes.

The study of energetic products, such as high energy photons, pions and other light mesons in heavy-ion collisions provides detailed information on the dynamics of such collisions, on the underlying production mechanisms, and on the influence of the residual nuclear matter on the emitted particles. At deep subthreshold energies these particles cannot be originated by simple nucleon-nucleon collisions even if the Fermi motion of the nucleons inside the nucleus is taken into account, and the intervention of multiple collisions in the hot and compressed matter or some cooperative process must be invoked to explain the measured cross section. At present no satisfactory complete model seems to be able to reproduce the available data in a consistent way starting from energies as low as 20 MeV/nucleon up to the GeV/nucleon regime. Pion production has been extensively studied in recent years by inclusive and exclusive experiments, and a detailed systematics is now available, even though several questions still need to be clarified. For the other light mesons, there is however a lack of experimental data, due to the very low cross sections and to the difficulties inherent to the detection of the decay products. Recent data have been reported for the deep subthreshold K^+ production at 92 MeV/nucleon [1,2] and the cross section for this process has been extracted for several targets. For the η mesons, the data obtained so far from the TAPS collaboration are basically in the 1-2 GeV/nucleon region [3] , so that it would be extremely important to probe the relevance of such a process also at lower energies. An upper limit of 30 nb for the total cross section in the Ar+Au collision was set from an experiment carried out with the TAPS detector at 95 MeV/nucleon [4]. Due to the dramatically low expected cross section for η production, a high detection efficiency is then needed to search for this process.

In this paper we report on the search for η production in heavy-ion collisions at 95 MeV/nucleon by the use of a large array of BaF_2 detectors. Some evidence was found for a few events which could be assigned to the decay of η mesons. Such measurement allows to estimate the production cross section, which turned out to be in the order of 10 nb.

The data were extracted in the course of an experiment performed at GANIL by an ^{36}Ar beam at 95 MeV/nucleon on the targets ^{27}Al, ^{58}Ni, ^{112}Sn and ^{197}Au. The MEDEA detector [5] was used, together with a forward hodoscope of plastic scintillators. The overall polar angle coverage was from 2.5° to 138°. This set-up was used for inclusive and exclusive experiments on π° production with a trigger given by the two-fold multiplicity in the BaF_2 modules of the MEDEA array, with a 17 MeV γ-equivalent energy. Further details on the experimental technique may be found in Ref. [6,7]. Preselection of the events resulted in a set with at least two recognized electromagnetic (e.m.) showers, which formed the basis for the previously reported investigation on π° production. An additional analysis of this set of events has been done to search for signatures of the η meson decay products. Extensive simulations by the code GEANT3 were carried out to understand the response of the experimental set-up to the decay of η mesons. This allowed to evaluate the efficiency of the detector array for each of the decay modes and to predict the shape of the invariant mass spectrum.

The analysis was carried out firstly on the events with two e.m. showers, for which an invariant mass may be extracted from the usual relationships. From such analysis all the events identified as π° events were disregarded. The identification of neutral pions has been previously discussed [6,7]. Due to the expected cross section, data from all targets were summed together. By this method, the invariant mass spectrum shown in fig. 1 was obtained. The combinatorial background from uncorrelated showers was obtained from event mixing and is reported in fig. 1 as a solid histogram. Two events were found above m_{inv}=450 MeV, where the combinatorial background is negligible, with a gap between 370 and 450 MeV, where no events were observed. A detailed analysis of these events was made by looking at the spatial topology of the involved showers and the associated information on the charged particles measured in coincidence. In a previous work we have shown that contamination from cosmics for this detector is basically destroyed by imposing the detection of at least a charged particle in the event [8]. The expected overall trigger rate due to cosmics, after imposing this condition, is around $3 \times 10^{-4}/s$, which is negligible in our data, which come from a total running time of about $2 \times 10^5 s$. Actually all the events reported in fig. 1 have at least one charged particles detected in coincidence. An additional event, for which no charged particle was detected in coincidence, was found at m_{inv} around 460 MeV but it is not reported in fig. 1.

Table I shows the efficiency ϵ of the MEDEA array for the detection of two e.m. showers originating from the different decay modes of η. To evaluate the efficiency a realistic energy and angular distribution of η mesons was assumed, similar to that which was measured for π° in the same experiment. Since the η's are expected to be produced with kinetic energies much lower than the rest mass, the efficiency is however very close to the geometrical one. The last column in Table I shows the corrected efficiency $\epsilon \times$B.R., given by the product of the detection efficiency ϵ and the branching ratio for that decay mode. It is seen that the $\gamma\gamma$ decay mode is the dominant one, but some contribution may be also expected from the $3\pi^\circ$ decay mode. The $\pi^+\pi^-\pi^\circ$ channel gives two e.m. showers, but this decay mode cannot be of course used due to the background induced by the π°'s directly produced in the collision.

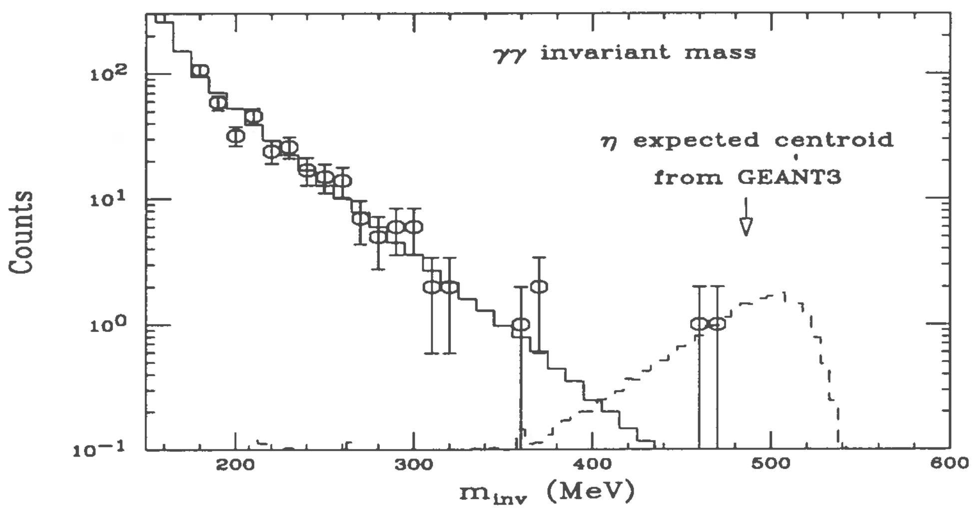

FIG. 1. $\gamma\gamma$ invariant mass spectrum obtained from ^{36}Ar+X (X=Al, Ni, Sn, Au) interaction at 95 MeV/nucleon. The data from different targets were summed together. The solid histogram is the combinatorial background, obtained with the event mixing procedure. The dashed histogram, arbitrarily normalized to the counts above 450 MeV, is the result of a GEANT3 simulation incorporating all the decay modes of the η which produce two photons, and the effect of the experimental set-up.

TABLE I. Efficiency ϵ of the MEDEA array to the different decay modes of η mesons resulting in two e.m. showers being detected.

Decay mode	ϵ(%)	B.R. (%)	$\epsilon\times$ B.R. (%)
$\gamma\gamma$	55.8	38.9	21.7
$3\pi^{\circ}$	10.8	31.9	3.4
$\pi^{+}\pi^{-}\pi^{\circ}$	45.4	23.6	10.7
$\pi^{+}\pi^{-}\gamma$		4.9	
$e^{+}e^{-}\gamma$		0.5	

The invariant mass which results from the two e.m. showers for these last decay modes is moreover much smaller than for the main decay mode, making it difficult to observe such a contribution. By taking into account all possible decay modes which can give two e.m. showers being detected, the expected invariant mass spectrum was reported in fig. 1 as a dashed histogram, arbitrarily normalized to the counts above 450 MeV. The centroid of the expected distribution is around m_{inv}=486 MeV, thus confirming the location of the observed events.

A search was also done on the events with more than two e.m. showers. Due to the large solid angle of the MEDEA detector, the efficiency for multishowers events is relatively high. In case of π°, it was possible to reconstruct the Dalitz decay mode $\pi^{\circ} \rightarrow e^{+}e^{-}\gamma$ from an invariant mass analysis and to evaluate the branching ratio of this mode with respect to the main one without the intervention of systematic errors [9]. In case of η decay, the probability to correctly reconstruct n showers from the $3\pi^{\circ}$ decay (which produce 6 γ's in 96 % of the cases) is reported in Table II as a function of n. As it is seen, the probability to reconstruct 3 or 4 of the 6 e.m. showers is comparable to that for the detection of two photons from the main decay mode. A GEANT3 simulation was also carried out for this situation, and one event from experimental data was found in the expected region of invariant mass.

TABLE II. Efficiency of the MEDEA detector to the $\eta \to 3\pi^\circ$ decay from the reconstruction of n e.m. showers, as a function of n

No. of showers n	0	1	2	3	4	5	6
$\epsilon(\%)$	0.1	2	10.8	31.5	36.8	16.0	2.6
$\epsilon \times (B.R. = 31.9\%)$	0.03	0.6	3.4	10.0	11.7	5.1	0.8

Limiting the analysis to the events with two e.m. showers which can be originated from the main decay mode of η, an average cross section (over the lightest targets) around 20 nb could be deduced. Due to the integrated beam flux, target thickness, and acquisition dead time in this experiment, the sensitivity was such that one event would correspond to 14 nb for Al, 60 nb for Ni, 40 nb for Sn and 130 nb for Au.

Data concerning the yield of light mesons produced in heavy-ion collisions have been usually reported in a systematics showing the probability per participant nucleon as a function of the bombarding energy per nucleon (corrected for the Coulomb barrier) normalized to the respective meson production threshold in the NN system [10]. A simple energy scaling law was observed for π, K^+, η in a large energy range. These data'are summarized in fig. 2, together with the value which can be deduced from the present experiment. Also reported are the values which were extracted for the total π° cross section for the Al, Ni, Sn and Au targets in the same experiment. It is seen that the cross section for η production at energies as low as 95 MeV/nucleon falls approximately on the same universal behaviour. It should be observed that for most of these experiments total cross sections have been obtained by an extrapolation of the differential spectra by assuming realistic angular distributions, so that only a roughly general trend must be inferred from such a systematics. The ratio $\sigma_\eta/\sigma_{\pi^\circ}$ for the Ar+Al at 95 MeV/nucleon turned out to be in the order of 10^{-4}. Recently, an approach was described [11], based on the log-normal statistical distribution as a parametrization of the energy fluctuations leading to the subthreshold production of particles in nuclear collisions. This approach gave a good fit to the available data for π°, but still needs to be tested for heavier mésons such as η and K^+, where more data are required. For the experiments discussed here, where $(E/A)_\eta/E_{thresh}$ is 0.075, a ratio $\sigma_\eta/\sigma_{\pi^0}$ around 10^{-5} is predicted by such analysis, whereas a somewhat larger value (10^{-4}) seems to be pointed out by our result.

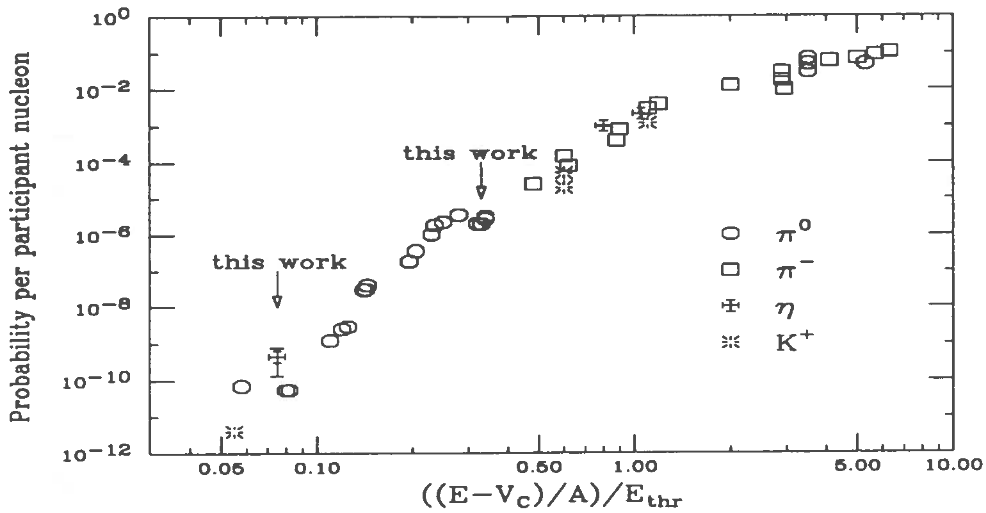

FIG. 2. Probability per participant nucleon of different subthreshold meson production processes in heavy-ion collisions, reported as a function of the bombarding energy per nucleon (corrected by the Coulomb barrier) and normalized to the energy threshold for that process. The arrows show the values obtained in the present experiment for the π^0 and η production at 95 MeV/nucleon.

In conclusion, despite the extremely low statistics, it has been possible for the first time to get some evidence for the production of η mesons in heavy-ion collisions at energies as low as 95 MeV/nucleon. The data are compatible with a cross section in the order of 10 nb, and in agreement with a systematics on other deep subthreshold processes. More data are clearly needed to confirm this result and to evaluate more precise values of the involved cross sections.

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