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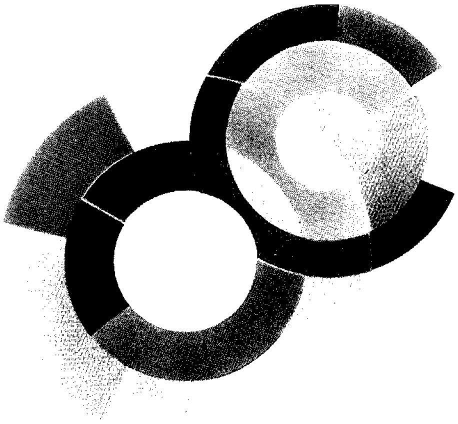

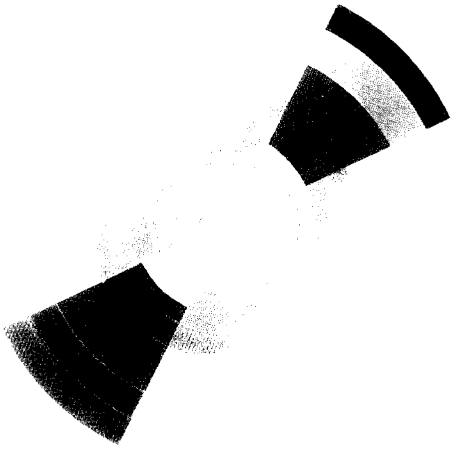

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Kaon production in nucleus - nucleus collisions at 92 MeV per nucleon *

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The cross sections for K^+ meson production in collisions of ^{36}Ar on ^{12}C, ^{nat}Ti and ^{181}Ta at an incident energy of 92 MeV per nucleon have been measured. A description of the set-up and of the method is given ; it is based on measurement of the muon decay of the positive kaon. At such a low incident energy the K^+ production seems to be more sensitive to the available energy in the center of mass of the nucleus-nucleus system than to the coulomb corrected incident energy normalized to the production threshold in a free nucleon-nucleon process.

1. INTRODUCTION

One of the first aim of the heavy ions collisions study is to get information on the macroscopic properties of the nuclear matter out of equilibrium. During the first stage of the collisions, when the projectile kinetic energy is damped, the nuclear matter is compressed, deformed and heated and we have to find observables from the final products whose characteristics are reminiscent of this first stage. Among the possible observables and besides collective variables such as matter flow, the study of energetic particle production (Λ, π, μ, K, ... high energy proton, ...) can provide such an information. Kaons are particularly suitable since, due to the strangeness conservation, they have extremely low absorption and small scattering cross section with nucleons especially for K^+. Once the kaons are created even in a compressed zone, they may escape without reinteractions. Moreover, their production requires the associate production of a pair of quarks which are not constituants of the nuclear matter and are to be created or to be pulled out of the quark sea around the valence quarks. The simplest elementary way to create a kaon is the

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*Experiment performed at GANIL, Caen

associate production $N + N \rightarrow K^+ + \Lambda + N$ which requires an energy $E_0 = 671.0$ MeV, that is to say an incident energy of 1.59 GeV on a fixed target. This threshold value is far below the beam energy (92 MeV/nucleon) and even if we take into account the Fermi motion inside the nuclei, the kaon cannot be produced by a first chance nucleon-nucleon collision. Nucleons have to undergo several collisions in the hot and compressed zone to by chance gain enough energy to make possible the kaon production or in a cooperative model several nucleons succeed in sharing their energy to produce the particles. Both processes are density and temperature dependent and may give some pieces of information on the macroscopic properties of nuclear matter. Two different calculations for kaon production far below the nucleon-nucleon threshold have been performed. The first one assumes an incoherent production mechanism and introduces fluctuations using the Boltzmann-Langevin equation with a soft equation of state [1]. The second one calculates K^+ production cross sections in the framework of a cooperative model which has been already applied to subthreshold pion production [2]. These two different approaches can reproduce the order of magnitude of our first measurement at 92 MeV/nucleon [3], so more data are clearly needed.

2. THE EXPERIMENTS

We have performed two experiments at GANIL to measure the kaon production cross section in heavy ions collisions ; the first one, already published [3] was a test of feasibility and the second one, using the same methods with an entirely different set-up, measures the kaon production induced by a 92 MeV/u argon beam on three targets ^{12}C, ^{nat}Ti and ^{181}Ta. The maximum available energies are respectively 828 MeV very closed to the absolute threshold, 1893 MeV and 2763 MeV and we were expecting to observe a clear variation in the cross section production with the various targets.

2.1. Kaon measurement

The kaon is identified owing to its decay properties. The main decay channel is $K^+ \rightarrow \mu\nu$ (64 %) which gives a monoenergetic muon of 153 MeV when the kaon is at rest and a mean lifetime of 12.4 ns. The delayed muon is identified and measured out of the beam time microstructure ; this technique has been used in a proton induced subthreshold production experiment [4] and in our first measurement. We take advantage of two very interesting characteristics of the GANIL beam : the high intensity needed because of the low cross section and a good time structure (1 ns beam every 70 ns) which allows the measurement out of the beam spill. A beam intensity of about 200 nAe and target thicknesses ranging from 79 mg/cm^2 to 100 mg/cm^2 have been used.

2.2. Experimental set-up

It is sketched on the Figure 1. A copper plate stopping kaons up to 40 MeV for normal trajectories was located close to the target covering polar angles from 45 ° to 135 °.

Doing that, we measure only energy and angle integrated cross sections but the major part of the muons are emitted at rest and can be well identified. That is done with a range telescope. The range of 153 MeV muons is 70 g/cm^2 and is measured by using passive and active absorbers. In front of the first detection plane, we have studied the best arrangement of copper and carbon absorbers giving a reasonnable length for the range

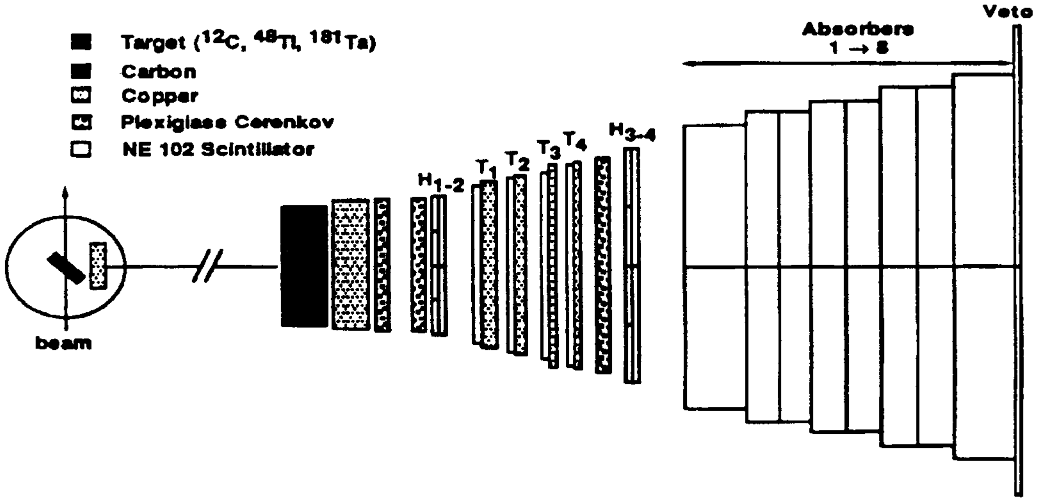

Figure 1. sketch of the experimental set up.

telescope and an acceptable counting rate in the first detection planes. Copper absorbers were placed also between several planes to adjust the stopping point of the muons in the detector. The range telescope consisted of three parts (figure 1):

- The trigger where a coincidence between the detection planes is required, a time measurement with respect to the beam time structure (accelerator r.f.) is performed, and the trajectories may be checked in two hodoscopes (H1-2, H3-4).
- Just behind, the muons are stopped in the absorbers, allowing the measurement of the range, the specific energy loss and the residual energy.
- The last detection plane is used as a veto to reject energetic cosmic muons crossing the whole telescope.

The whole detector has been checked and energy calibrated using cosmic muons and has been simulated using the GEANT simulation program from CERN.

3. ANALYSIS

The following conditions were used in the off-line analysis:

- A narrow coincidence is required between all the planes to reject random events.
- Only delayed particles with time arrival into the T3 counters larger than at least 4 ns are considered to reject prompt events.

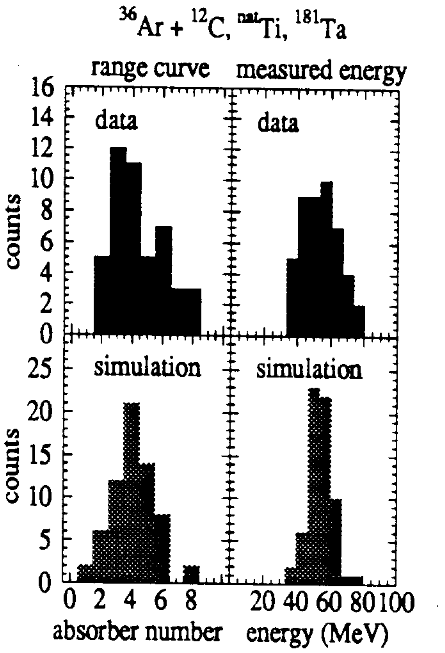

Figure 2. Range and measured energy.

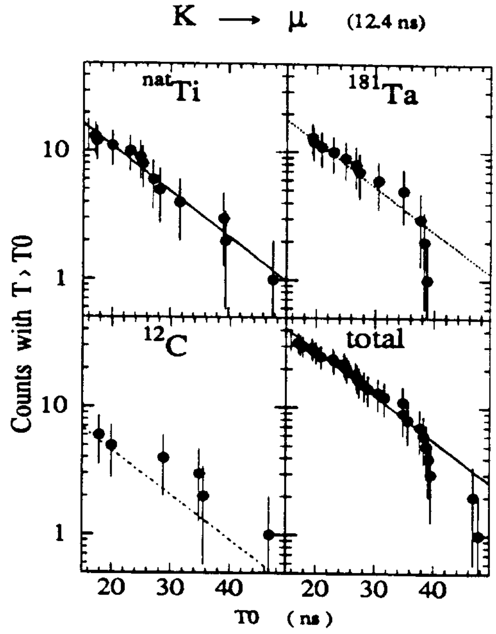

Figure 3. decay time spectra.

- The measured energy loss in each counter are inside an energy window defined on the lower part by the cosmic muon at the minimum of ionization and on the higher part, by the values calculated for protons.

- The triggering conditions are still satisfied when requiring only one hit per detection plane.

4. RESULTS

Using the above selections, figure 2 shows the measured range in the aborber part of the telescope and the measured energy in the detector summed for the three targets (bottom panels) compared to a GEANT simulation for 35 MeV kaons with similar statistics (top panels). Although the experimental distributions are wider than predicted by the simulation, it is clear that monoenergetic muons from kaon decays have been observed. A confirmation can be obtained from the time decay spectra. Because of the high prompt counting rate and of the electronic dead time, a loss of counting has been observed for times less than 15 ns. On figure 3, the time decay spectra for the ^{12}C, ^{rmnat}Ti and ^{181}Ta targets and for the summed events of the three targets are displayed for times larger than 15 ns. All these spectra are compatible with the decay of the kaons with a mean life of 12.4 ns as shown by the lines.

Assuming an isotropic emission of the kaons in the laboratory rest frame, total cross sections for kaon production have been estimated by extrapolating the kaon decay curves. An overall detection efficiency of 0.8 % has been calculated with GEANT for the emission of 35 MeV K^+. The estimated cross sections vary from 75 pb ± 60 pb for ^{12}C up to

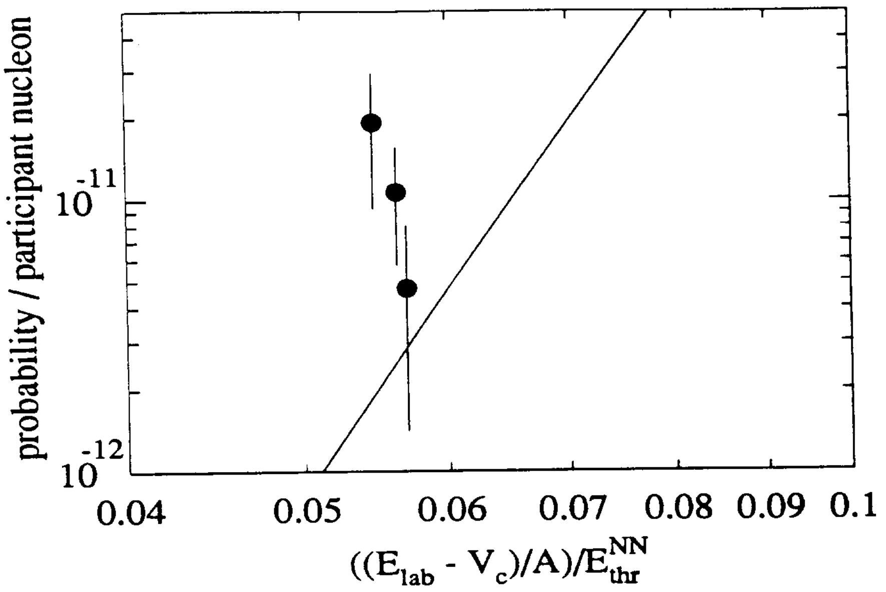

Figure 4. Probability of kaon production per participant nucleon as a function of the coulomb corrected incident energy per nucleon normalized to the free nucleon-nucleon threshold.The solid line is the universal curve from ref [5].

2900 pb ± 1600 pb for ^{181}Ta, the estimated cross section for ^{nat}Ti is found about twice as large as in the first experiment [3] at 525 pb ± 300 pb.

This variation of the cross section with the different systems is not proportional to the number of participant nucleons. But it has been shown in Ref [5] that the data probability for meson production (π, K, η, ρ) per participant nucleon as a function of the coulomb corrected incident energy per nucleon normalized to the free nucleon nucleon threshold are falling on a single universal curve. This seems to be the case for incident energies below and above the free nucleon-nucleon threshold.

The probability of kaon production per participant nucleon for the three systems studied in this experiment as a function of the coulomb corrected incident energy per nucleon normalized to the free nucleon-nucleon threshold, is plotted on figure 4. The solid line represents the universal curve [5] deduced from higher energy data. Although the universal curve gives the right order of magnitude, the data show a systematic departure from the universal curve at such a low incident energy.

On the other hand, the same probabilities for kaon production are shown on figure 5 as a function of the total available energy in the center of mass. The solid line shows the variation of the 2-body phase space volume. Starting from the absolute threshold (671 MeV) where full collectivity is needed, the kaon production follows the variation of the 2-body phase space and this trend seems to extend to more than 1 GeV above the absolute threshold.

Very close to the absolute threshold, the kaon production in heavy ion collisions is more dependent on the total available energy in the center of mass than on the coulomb

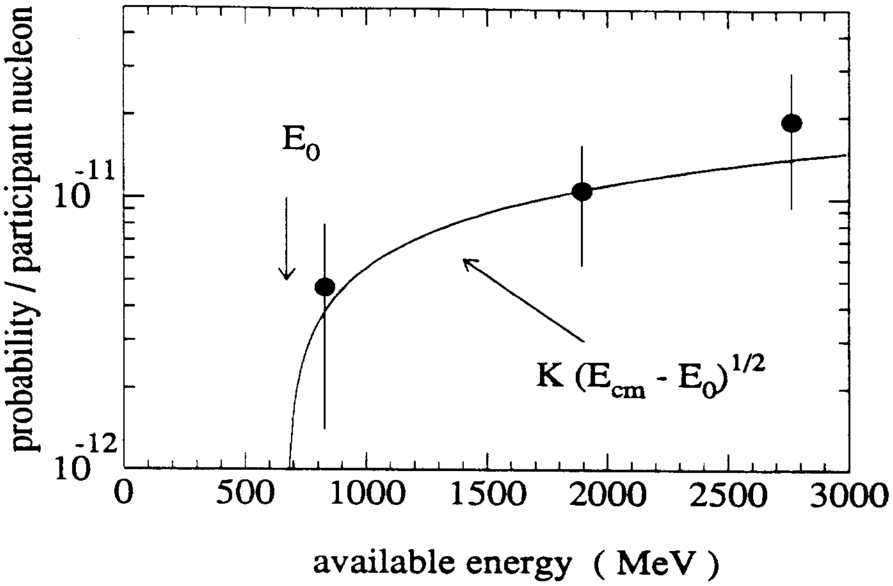

Figure 5. Probability of kaon production per participant nucleon as a function of the total available energy in the center of mass. The solid line shows the variation of the 2-body phase space. E_0 is the minimum energy necessary to produce a kaon (671 MeV).

corrected incident energy per nucleon normalized to the free nucleon-nucleon threshold.

5. CONCLUSION

Kaon decays have been observed in the reactions of 92 MeV/nucleon ^{36}Ar with ^{12}C, ^{nat}Ti and ^{181}Ta targets and estimates of the total kaon production cross sections have been derived. At such a low incident energy and close to the absolute threshold, kaon production seems to be sensitive to the characteristics of the participant interaction zone. These data on the target dependence of K^+ production in heavy ions collisions far below the nucleon-nucleon threshold will put more constraints on new theoretical calculations.

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