PION PRODUCTION IN NUCLEAR REACTIONS EXPERIMENTS WITH SLOWLY RAMPED BEAMS AT STORAGE RINGS*

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(Received October 9, 1996)

The utilization of the slow ramping mode at the CELSIUS storage ring to perform excitation function experiments is discussed. New results on pion production from the international CHIC collaboration are presented.

PACS numbers: 25.40. Qa

With the storage rings, that have started to operate in the last decade, one deals with qualitatively different facilities as compared to conventional accelerators. CELSIUS [1] (an acronym for Cooling with ELectrons and Storing of Ions in the Uppsala Syncrocyclotron) is an ion storage ring operating since 1989 at the "The Svedberg Laboratory" (TSL) in Uppsala (Sweden). The four straight sections of the CELSIUS lattice are used for injection of ions from the TSL cyclotron, cooling, acceleration and experiments with internal targets. A long life-time of the beam is ensured by very thin gas-jet targets and ultra-high-vacuum environment (10^{-11} mbar inside the ring, 10^{-8} mbar inside the scattering chamber). An electron cooler in CELSIUS is used to shrink the beam in all six dimensions of phase space and compensate beam heating due to beam-target interactions. This gives an opportunity to perform very precise measurements with well defined beam energy. Another important feature of CELSIUS is the possibility to work in the so-called slowly ramped mode, when the beam energy slowly increases during a cycle of up to several minutes.

Cooler rings are well suited to study threshold production phenomena, since the very high energy resolution and the possibility to vary the energy permits one to explore the detailed physics very close to the threshold,

* Presented at the "Meson 96" Workshop, Cracow, Poland, May 10–14, 1996

with reasonable count rates in spite of the vanishing phase space at exact treshold. Meson and pion production is particularly interesting at threshold and subthreshold [2]. Details on the collision energy dependence of the pion production below and slightly above the free nucleon-nucleon threshold ($\approx$ 290A MeV) are badly known both in p-nucleus and nucleus-nucleus collisions. The reason for this is partly the traditional way of measuring the cross section with one beam energy per experiment.

The CHIC collaboration is perfoming a series of experiments where plastic range telescopes are used to study charged pion production from proton-induced and heavy-ion reactions on gas-jet targets. The CELSIUS storage ring in slow ramping mode, has been utilized to measure the yield of π^+ and π^- as *a function of beam energy* in proton and ^{20}Ne induced reactions in gas-jet targets of N, Ar, Kr and Xe (with thicknesses $10^{13} - 10^{14}$ atoms/cm^2). 10-element plastic range telescopes (covering 14.4 msr solid angle each), were used to identify decaying π^+ from the t=26 ns delayed muon and π^- indirectly via ΔE-ΔE correlations [3]. These telescopes, that can register pions with energies between 16 and 75 MeV, were placed outside the gas-jet chamber at polar angles 55°, 75°, 97° (or 90°) and 120° (limitations in the angular position exist in the forward direction due to the high flux of fast protons). The time-in-cycle signal (that can be translated to beam energy) was registered for each event trigger along with the normal scaler, ADC and TDC information during 2 or 5 min proton cycles and 2 or 3 min Ne cyles with ramping linear momentum (590–760 MeV/c and 730–1090 MeV/c for protons and 309A–498A MeV/c and 448A–52A MeV/c for Ne) giving proton beam energies of 170–500 MeV and Ne beam energies of 50–400A MeV. The total (non rejected) yield of protons was measured from a monitor telescope at 90° for absolute normalization through existing data and model calculations. The main problem of the data analysis in experiments with slowly ramped beams is in fact the absolute normalization, which arises from different variations of the beam luminosity during one accelerator cycle. To avoid this problem one can use different experimental ratios, for example pions/protons or low energy/high energy pions, to cancel any beam luminosity variations. Furthermore in our analysis we employed the BUU model [4] to calculate the proton yield from reactions of our type. Since BUU is able to predict the differential proton cross section well enough for different initial beam energies, different targets and emission angles, we used this model together with available empirical data to get the normalized pion cross section from the π/p experimental ratio. Our normalization also includes corrections for pion decay in flight, reactions in the scintillator material and muon detection efficiency. Using this normalization procedure, *preliminary* differential cross sections for π^+ have been extracted. Fig. 1 shows π^+ excitation functions from p+^{40}Ar data at four different emission angles. The substantial yield of pions below the free nucleon-nucleon threshold and also below the (ground state) Fermi boosted threshold is obvious.

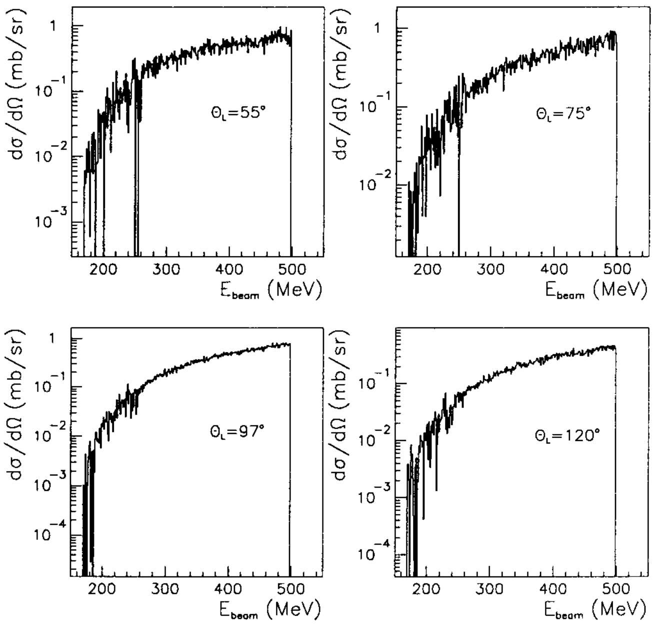

Fig. 1. Differential cross sections of π^+ ($E\pi^+$=16–75 MeV) emitted at 55°, 75°, 97° and 120° from $p+^{40}Ar$ reactions at beam energies 170–500 MeV (1 MeV binning is used).

The 97° differential cross section is compared to theoretical calculations in Fig. 2. The collisions were simulated with the BUU microscopic transport model [4], using 1000 test particles per nucleon and integrating over the impact parameter. The BUU stop time was chosen long enough for all pions produced and not reabsorbed in the collision to be free. When the target nucleon internal momenta are not taken into account (calculation a), the BUU cross section largely underestimates the data. The intial momentum of each test particle has then been included and chosen: randomly inside a sphere of radius $P_{\rm Fermi}$ (calculation b) or according to a gaussian probability distribution (calculation c). Taking into account the two-body collision dynamics and the influence of the mean field leads to a rather good description of the data. The agreement with the data is remarcably good also close to the threshold when internal momentum components are included.

Important information about collectivity in the production mechanism and about in-medium details of the delta resonance are expected particu-

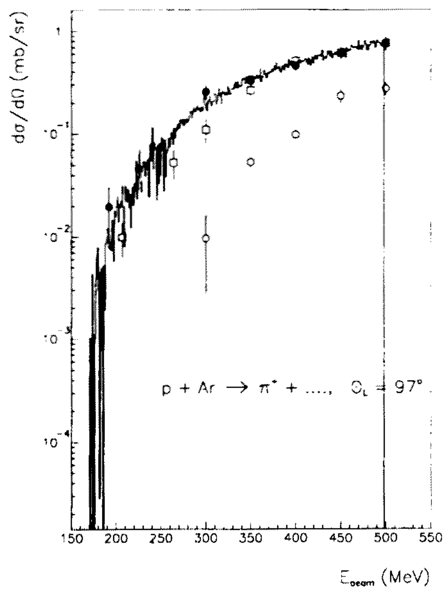

Fig. 2. BUU calculations (symbols) compared to experimental differential π^+ cross section ($\theta = 97°$) from p+^{40}Ar reactions (histogram). Open circles: calculation a. Open squares: calculation b. Solid circles: calculation c. See text for details.

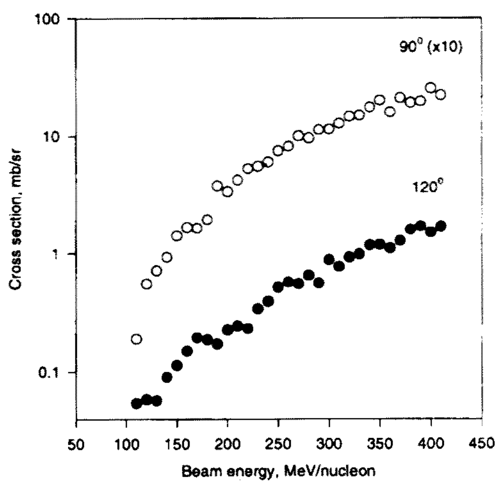

Fig. 3. Differential cross sections of π^+ ($E\pi^+$=16–75 MeV) emitted at 90° and 120° from ^{20}Ne+^{40}Ar reactions at beam energies 100–400A MeV (5 MeV binning is used).

larly from nucleus-nucleus data. Even though the experimental data taking was limited by a low beam luminosity, preliminary results from ^{20}Ne+^{40}Ar collisions are shown in Fig. 3. No indications of dibaryon resonance [5] or Cooper pair formation [6] have been observed in the data yet. This data will be improved in a new, already scheduled experiment.

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