PION PRODUCTION

CE21: TOTAL CROSS SECTION FOR pd → pdπ^0 CLOSE TO THRESHOLD*

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Recent investigations of NN → NNπ processes close to threshold have produced data of unprecedented precision.[1-3] This makes it worthwhile to study pion production in the three-nucleon system, as it is the simplest system for tests of models which explain pion production on nuclei in terms of the NN → NNπ amplitudes. As yet, pion production data in the three-nucleon system close to threshold have been sparse; only one measurement of the reaction pd→^{3}Heπ^0 has been reported.[4]

Experiment CE-21 is a study of the reaction pd → pdπ^0 at proton energies E_p from 208.1 to 234.3 MeV (corresponding to $\eta = p^{max}_{\pi,c.m.}/m_\pi c^2 = 0.08-0.50$) close to the threshold at 207.4 MeV. It was performed in a similar experimental environment as experiment CE-01, an investigation of the reaction pp → ppπ^0. (See Refs. 1 and 3.)

An internal D_2 gas-jet, mounted in a general purpose target chamber in the straight G-section of the Cooler Ring, served as the target for the cooled, stored proton beam. Close to threshold, the protons and deuterons are confined to a narrow forward cone in the laboratory system. Thus, a detector positioned behind a thin exit-window downstream of the target box covers most of the phase space. Two paired wire chambers and a scintillator hodoscope, consisting of a thin ΔE counter (F), a thick counter (E), and a Veto (V) (for a detailed description, see Ref. 3) measured angle, energy and time-of-flight (TOF) of the charged particles. Protons and deuterons are distinguished by their TOF as a function of the deposited energy (see Fig. 1). Events for the pd → pdπ^0 reaction are then identified by the reconstructed missing mass.

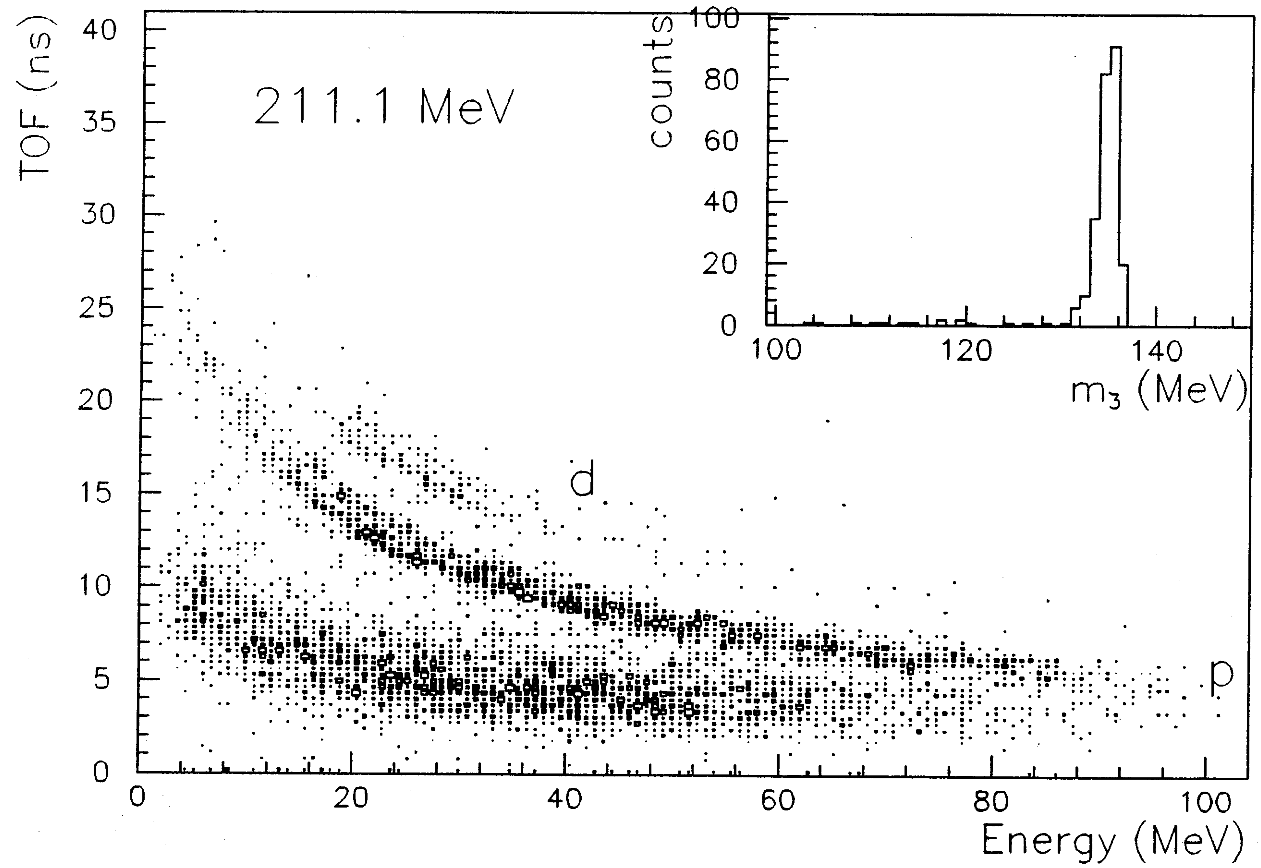

Figure 1. Scatter plot of TOF distribution as a function of the energy deposited in the E-detector. The proton and deuteron loci can be clearly distinguished. The events with small TOF originate from high-energy protons which do not deposit their full energy. The missing mass distribution for a coincidence of a proton and a neutron is peaked at the π^0-mass with a resolution of 2 MeV close to threshold; see insert.

In preparation for the experiment, a Monte-Carlo (MC) simulation which modeled the detector geometry and response was used to study the feasibility of the experiment and to estimate the phase space accessible as a function of E_p.

It was found that a sizable fraction of the protons cannot be completely detected in the detector array, since they are stopped before reaching the thick E-detector. In order to minimize the stopping power in the first detector layers, the thickness of the F-detector was reduced from 1.5 mm to 0.5 mm of plastic scintillator. This corresponds to a lowering of the threshold for proton detection from 20 MeV to 17 MeV, reducing these losses to at most 10%.

The four quadrants of the new F-detector were manufactured in Hamburg and tested in a 3 GeV electron beam at DESY for time resolution and spatial homogeneity. The time resolution of 500 ps necessary for the proton-deuteron separation was reached and the light guide design chosen ensured sufficient light collection from the full active detector area.

CE-21 had two production runs of 13 shifts each. They differed in the target position and the detector geometry. With the target mounted in the central position of the target chamber (angular acceptance: $2° \leq \theta_{lab} \leq 11°$), data taking focused on the region very close to threshold (208–212 MeV) where more than 50% of phase space could be covered. In a second run with the target mounted in the downstream position (angular acceptance: $4° \leq \theta_{lab} \leq 19°$), higher energies (212–234 MeV) were investigated. In addition, the yields for pd $\rightarrow$ pdπ^0 at six higher energies up to 294.1 MeV were measured to explore this reaction for π^0-production purposes; see also Ref. 5.

The luminosity was obtained by a simultaneous measurement of pd elastic scattering. Four position-sensitive silicon detectors (PSD) detected recoil deuterons in coincidence with the forward protons. Two detectors were placed on either side of the jet, with their acceptances being sensitive to contributions from the jet and the uniform gas density in the first pumping stage, respectively. This technique allows us to reconstruct the gas density distribution along the beam axis and to extrapolate the contributions of the diffuse gas background from regions outside the PSD acceptance.

Only a few measurements of pd elastic scattering in the energy region covered by this experiment have been reported for small angles. We therefore made a separate measurement of the pd differential cross section, running with an HD gas-jet target, to normalize to the well- known pp elastic scattering rate. In contrast to the use of any mixture of H_2 and D_2, the use of the HD gas ensures that the p/d ratio in the jet is not altered by flow restrictions and differential pumping. By mass spectrometry, carried out in the IU geology department, the purity of the HD gas was determined to be 97%, where H_2 and D_2 account for the remaining 3%. The recoiling particle was identified by its energy deposited in the PSD as a function of the forward scattering angle. Contributions from d(p,pn)p could be corrected for by measurements with a pure D_2 target. Data were taken at six energies between 200 MeV and 294 MeV. Differential cross sections at three selected energies are shown in Fig. 2, where an overall normalization error of about 5% (due to an uncertainty in the pp cross section) is not included. One finds only a moderate energy dependence.

With beam currents of 100-300 μA and a D_2 target thickness in the order of 10^{15} atoms/cm^2, we reached luminosities of $4 - 9 \times 10^{29}$ s^{-1}cm^{-2} averaged over the Cooler cycle. In approximately 70 h of net data taking time per production run, we accumulated a total luminosity of 150 nb^{-1} each.

The analysis of the pd $\rightarrow$ pdπ^0 reaction data is currently in progress. For the calculation of total cross sections, corrections must be made for losses from particles escaping through the central hole in the detector setup (necessary in order to allow the passage of the beam). In addition, losses on the outer edge of the detector occur, too, as the maximum proton angle increases much faster with the energy above threshold than the deuteron angle.

The remaining detector acceptance can be calculated by a MC simulation, but assumptions about the population of the accessible phase space have to be made. Close to threshold, where s-wave pion production should dominate, the events are expected to be distributed uniformly in phase-space. Figure 3 shows angular distributions of protons and deuterons gated on the missing mass peak (as shown in Fig. 1) for two energies. A MC-simulation based on a pure phase-space distribution reproduces the experimental data

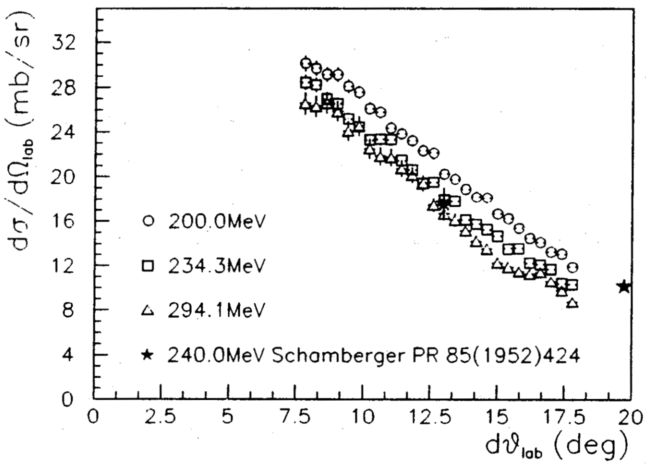

Figure 2. Differential cross section for d(p,p)d at three selected projectile energies. Errors do not include an overall normalization uncertainty of ≈5% . The only published data in this energy region are shown for a comparison.

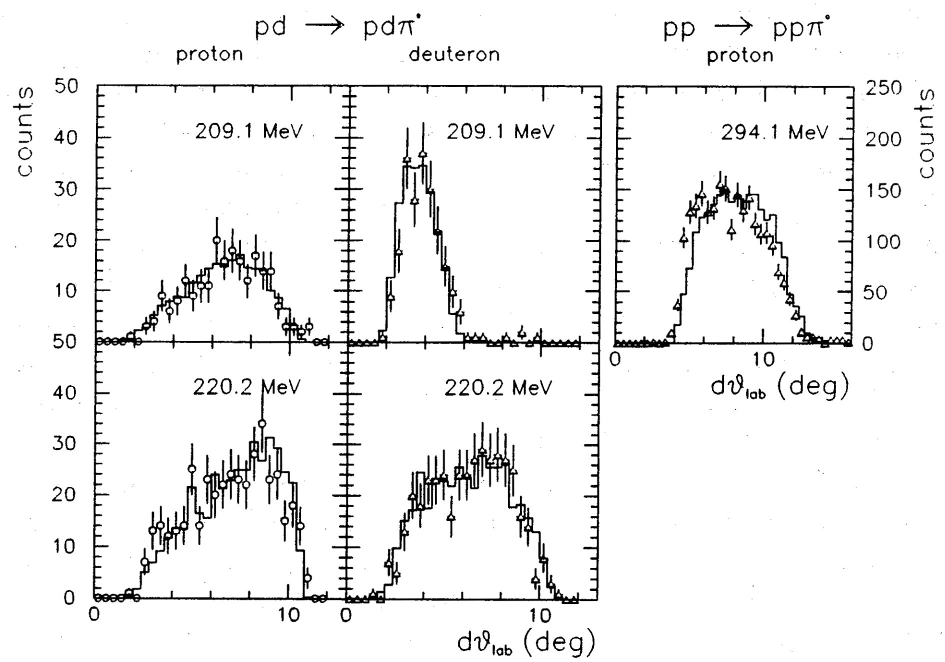

Figure 3. Left: Angular distributions for protons and deuterons from pd → pdπ^0 at two projectile energies, 1.7 and 12.8 MeV above threshold, respectively. The symbols with the error bars represent our measurements; the histograms show a Monte-Carlo simulation assuming a phase-space distribution. Right: The same for protons from pp → ppπ^0, 14.4 MeV above threshold.

within the error bars. Thus, at energies close to threshold ($T_p \leq 220$ MeV) we find no evidence for large deviations from phase space, e.g., due to final-state interaction (FSI).

For comparison, we show in Fig. 3 data for the pp → ppπ^0reaction taken at 294.1 MeV with an H_2-jet. Here the effect of the attractive FSI of the two protons in the relative $^1S_0$-state can be seen clearly. Including the FSI in the MC-calculation already applied in Ref. 1 and 3 modifies the detector acceptance by ≈20%.

Therefore our current MC estimate of the acceptance for pd → pdπ^0 close to threshold should be fairly reliable. The resulting total cross sections are smaller than for the two-body exit channel pd→^{3}Heπ^0 by factors as much as 60 to 10 in the region of 0.5 to 3.0 MeV excitation energy in the c.m.-system ($\eta = 0.1 \ldots 0.2$). The rise of the excitation function with energy is much steeper as expected for a three-body final state. Final results are expected to become available during 1992.

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