THREE-PARTICLE FINAL STATES MEASURED AT THE PION THRESHOLD WITH THE COSY–TOF SPECTROMETER*

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The production of pions in pp collisions at beam energies of ≤ 300 MeV has been studied with the COSY-TOF spectrometer, which was recently extended to flight paths of ≈ 3 m for charged particles through the addition of a barrel section. Together with the bremsstrahlung channel, which was investigated in an earlier experiment, pion production exhausts the inelastic pp cross section at these energies. TOF allows the simultaneous study of all channels, the measurement of $pn\pi^+$ being facilitated by the neutron detector COSYnus. In this contribution, preliminary results on the pionic three-body final states are discussed.

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1. Introduction

Recently, the elementary pion production reactions $pp \to d\pi^+$, $pp\pi^0$, $pn\pi^+$ have gained renewed interest since exclusive measurements of the small cross sections near threshold have become feasible. While at high energies, the pp reaction is obviously dominated by resonant production via the Δ, the reaction mechanism near threshold may involve heavy meson exchange, intermediate Δ contributions and other effects.

Only one data set is available for the mixed isospin channel $pn\pi^+$ [1]. Recently, a measurement of the $pp \to pp\pi^0$ and $pn\pi^+$ reactions was performed at COSY using a proton beam impinging on a liquid hydrogen target and an extended version of the TOF including the large solid angle barrel and a large area neutron detector.

The standard experimental equipment at the COSY-TOF spectrometer includes a liquid hydrogen target, a start detector for ToF measurements and the central hodoscope, which have been described in Ref. [2]. Figure 1 shows a sketch of the setup including the new components, namely the barrel and neutron detector which was constructed following concepts developed in Ref. [3]. The barrel hodoscope is equipped with 96 scintillator bars, which

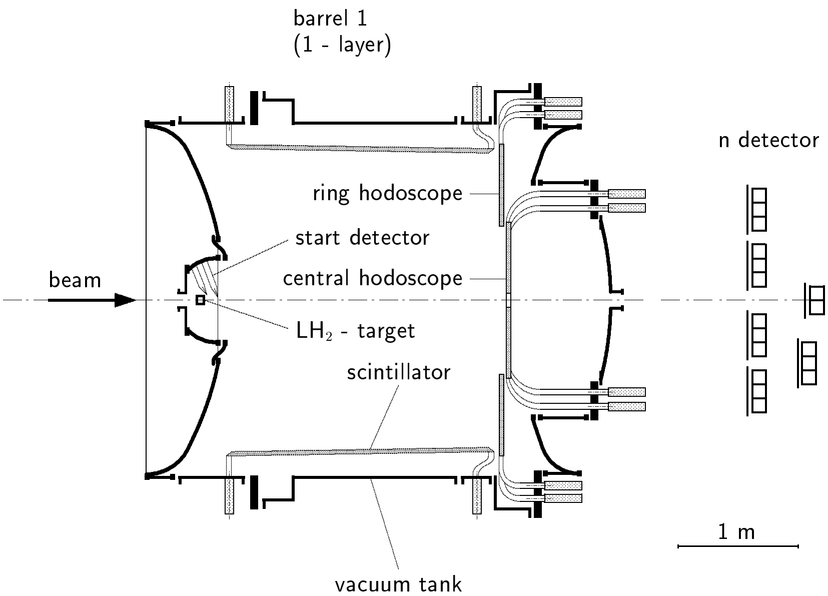

Fig. 1. Schematic setup of the TOF spectrometer for the measurement of near-threshold pion production at beam energies around 300 MeV, including the barrel detector. The segmented neutron detector, which is used in the channel $pp \to pn\pi^+$, and the veto counters in front of each module are also shown.

are 285 cm long, 10 cm wide and 15 mm thick. Each of these bars is read out with photomultipliers at both ends through bent light guides. ToF and position of impact of a particle are reconstructed from the times of arrival measured at both ends with respect to the overall start.

2. Experimental results

In the present experiment, proton beams with momenta of 805 MeV/c and 797 MeV/c were extracted from COSY. The barrel enlarges the accessible angular range appreciably. Firstly, it was used to detect coincidences of pp elastic scattering. The resulting angular distribution covering proton angles between 25° and 60° compared to the results from the phase shift analysis SAID [4] provides a direct measure of the integrated luminosity. Secondly, the barrel yields the momenta of charged pions (or their decay muons) in coincidence with the associated deuteron in the forward hodoscope to a high level of accuracy, allowing the reconstruction of the momentum parallel and perpendicular to the beam direction. The resulting kinematic locus is used to determine the beam momentum to about ±0.5 MeV/c. A precise knowledge of the momentum is crucial for the subsequent analysis of three-particle final states and the reliability of the results on the excess energy scale. The three-particle final states are identified through velocity correlations between the two nucleons of the specific reaction channel. Figure 2 shows this for an incident beam momentum of 805 MeV/c. The symmetric structure in the left frame at $\beta_1 = \beta_2 \approx 0.35$ for two charged particles is due to protons from $pp\pi^0$, while the neutral-charged coincidences shown in the right frame exhibit an enhancement due to $pn\pi^+$. With the

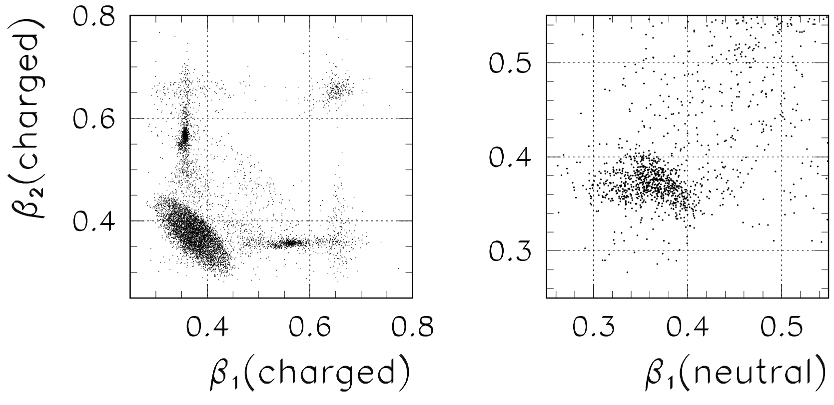

Fig. 2. Velocity correlation of two charged particles (left frame) and a neutral with a charged particle (right frame) measured at 805 MeV/c beam momentum.

identification of the respective reaction channel, masses can be assigned, so that the unobserved third particle can be reconstructed. A cut on the resulting missing mass spectrum unambigiously identifies the reaction channel under study. Then, projections on the various observables of interest can be performed, as shown exemplary in figure 3 for the invariant mass between the two protons from the $pp\pi^0$ channel at 805 MeV/c. The comparison with the acceptance-corrected spectrum calculated assuming a pure phase space distribution exhibits a large enhancement at small pp relative energies which is due to S-wave final state interaction of the nucleons. This enhancement was not observed in the recent $pp\gamma$ experiment at TOF [5].

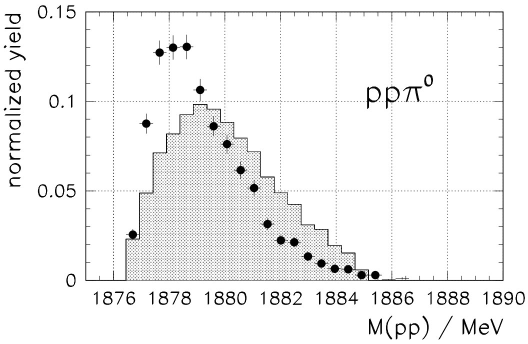

Fig. 3. Invariant mass spectrum of two protons from $pp \rightarrow pp\pi^0$ measured at 805 MeV/c beam momentum (points) compared to a phase space simulation including detector acceptance (grey area).

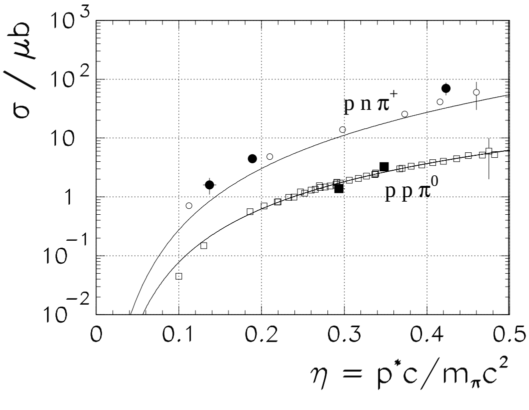

Fig. 4. Measured cross sections for $pp\pi^0$ and $pn\pi^+$ (full points and squares) compared to available experimental data (open points and squares) and a calculation from Ref. [6]. The two data points for $pn\pi^+$ above and below the one at $\eta = 0.189$ are from an earlier measurement [7].

Applying Monte Carlo acceptance corrections, absolute cross sections can be determined. The preliminary results of this analysis (with an estimated overall scale uncertainty of perhaps 20%) are shown in Figure 4. They agree nicely with the available experimental data [1,8] and the overall trend of the calculation by Fäldt and Wilkin [6] for $pn\pi^+$.

3. Conclusions

While the above quoted results for pion production are still preliminary and taken from ongoing analyses, they already demonstrate the TOF spectrometer to be an excellent tool for the simultaneous study of various exit channels in proton–proton collisions. The feasibility of neutron measurements with COSYnus operating in conjunction with COSY–TOF was demonstrated by the measurement of $pp \to pn\pi^+$. Our results agree nicely with available data.

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