

KINEMATICALLY COMPLETE MEASUREMENTS
OF $pp \rightarrow pn\pi^+$ NEAR THRESHOLD

W.W. Daehnick, S.A. Dytman, W.K. Brooks, J.G. Hardie, and R.W. Flammang
University of Pittsburgh, Pittsburgh, PA 15260

L. Bland, W. Jacobs, and T. Rinckel
Indiana University Cyclotron Facility, Bloomington, IN 47408

P. Pancella
Western Michigan University, Kalamazoo, MI 49008

J.D. Brown and E. Jacobsen
Princeton University, Princeton, NJ 08544

The purpose of CE03, the present experiment, is to investigate the $pp \rightarrow pn\pi^+$ branch of the fundamental $NN \rightarrow NN\pi$ reaction very close to threshold. Such measurements are particularly interesting because only a few channels contribute, and the pion vertex and the off-shell character of the reaction can be studied in a controlled way. The PCAC simplifies the theoretical analysis, whereas the soft pion theorem may (or may not) be applicable, a question of current interest in itself.

Any Δ contribution will manifest itself through the anisotropy of the center-of-mass ejectile distribution and through different analyzing powers. The expectation that the Δ terms are present, but small, is supported by predictions of Lee and Matsuyama,¹ who have calculated total $pp \rightarrow pn\pi^+$ and $pp \rightarrow pp\pi^0$ cross-sections near threshold. The calculated cross-sections due to the Δ term alone are about one order of magnitude smaller near threshold than those from the non-resonant Born term. Measurements at several energies, supplemented by analyzing powers, should suffice to distinguish the Δ contribution, i.e., the resonant P-wave part, from the S-wave Born term. The predicted Δ contribution becomes increasingly more important as the beam energy is raised to 400 MeV. It becomes 30% at 400 MeV; but it may be as small as 7% at 293 MeV, 0.7 MeV above threshold.¹

The $pn\pi^+$ cross-section near threshold is expected to increase approximately linearly with a slope of $1.4 \mu\text{barn}/\text{MeV}$. Cross-sections of $10 \mu\text{barn}$ should be visible easily. We hope to make measurements as low as 0.7 MeV above the pion creation threshold. The other experimental concern is angular resolution as the cone formed by the neutron and proton ejectiles is very narrow. At 0.7 MeV above threshold the cone half angle is only 2.6° . Near threshold pions are too soft to be detected reliably or with high efficiency. Most pions decay before reaching the detectors. The alternative, chosen in experiment CE03, is the detection of the proton and the neutron. This approach must deal with the familiar difficulties of neutron measurements, particularly when cross sections are very small. In the year 1990/1991 major progress has been made in completing and testing the apparatus under actual running conditions. The 1991 runs of the experiment have yielded some useful data and have confirmed that the relatively small background at the Indiana Cooler permits measurements of such small cross sections.

For the $pp \rightarrow pn\pi^+$ experiment we take advantage of the 6° bend at the T-site in the Cooler. With the target positioned just before the bending magnet, all neutrons in

the forward cone are separated from the circulating beam and detected by a neutron hodoscope, even for ejectile angles of 0° . The reaction protons are approximately 4 times lower in energy than the circulating beam and are deflected toward the inside of the ring. At threshold, the magnetic rigidity of the proton ejectiles is half that of the circulating beam and their typical deflection is 12° compared to the 6° deflection of the beam. Therefore, a separation of all ejectiles, even those emanating at 0° , is possible.

Figure 1 gives a scale drawing of the T-site detector that we have constructed and are using. The neutron hodoscope is shown in its closest position where neutrons to the left of the 0° line are not blocked by beam quadrupole magnets and can still be observed. Typically the neutron detector is placed 4.5 m away from the target to permit improved time-of-flight resolution for the measurement of neutron velocities.

The neutron hodoscope consists of 14 plastic scintillator bars 15 cm thick, 5 cm high, and 120 cm long, and has a detection efficiency of about 20% for neutrons from $pp \rightarrow pn\pi^+$ near threshold. For each neutron event detected we measure the vertical and the horizontal position of the trajectory intercept to an accuracy of 2.5 and 5 cm respectively. Using ray tracing from the proton arm, or assuming that the neutrons come from the gas jet, this measurement determines the neutron lab angles θ and ϕ to an accuracy of 0.3° and 0.6° , respectively, when the detector is at a distance of 5 m from the gas jet.

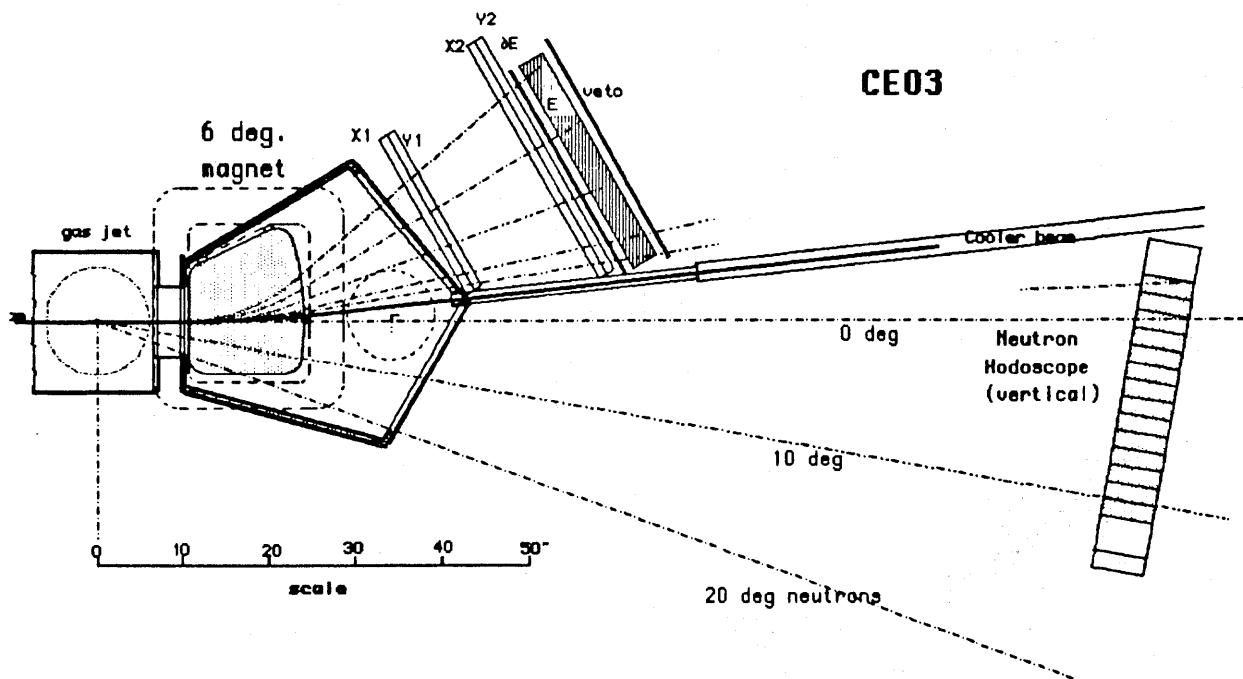


Figure 1. Layout of the T-site detector for experiment CE03.

The correlated charged particle is detected in the proton arm that consists of 4 multi-wire drift chambers, a ΔE detector, a segmented E detector and a veto detector. Angular resolution for the proton ejectiles is limited by the thickness of the vacuum exit foil (made of two Kapton and two Kevlar layers of total thickness 15 mg/cm^2) and by multiple scattering in the air and wire chamber gas, which together limit angular resolution to about 0.12° . The total angular resolution for the protons including wire chamber resolution is about $\pm 0.15^\circ$.

For a typical n-p coincidence event, we measure six parameters: the post-magnet direction of the proton, i.e. its angles ϕ'_p and θ'_p , the proton energy, the neutron time of flight, and the neutron scattering angles ϕ_n and θ_n . The accuracy of the measured ejectile angles is, of course, a function of the accuracy of the ray-tracing. Therefore, the magnetic field of the 6° magnet was carefully mapped at IUCF. The comparison between our (TOSCA) design calculation and the field mapping of the assembled magnet showed good agreement. For an exit channel with three known particles, one has to measure a minimum of 5 degrees of freedom. A measurement of six degrees of freedom will verify that the undetected particle is a pion. In addition to the detectors shown in Figure 1 we use a position sensitive recoil detector near the gas jet in coincidence with the proton arm that serves as a luminosity monitor using elastic (p+p) scattering.

The useful gap opening of the 6° magnet is 12.5 cm. For the gas target in the position shown in Fig. 1, this gives a vertical angular acceptance of $\pm 6^\circ$ and a horizontal acceptance of $\pm 20^\circ$, adequate for the measurements anticipated.

The gas jet has been monitored with a position-sensitive recoil detector of about 200 micrometer thickness. Figure 2 shows the scattering angle of the primary proton against the energy deposit of the recoil proton in the Si position detector. For small scattering angles of the primary proton, i.e., for values of $y \leq 1700$ in the graph, the recoil particles are of low enough energy to stop in the detector. For larger scattering angles of the primary

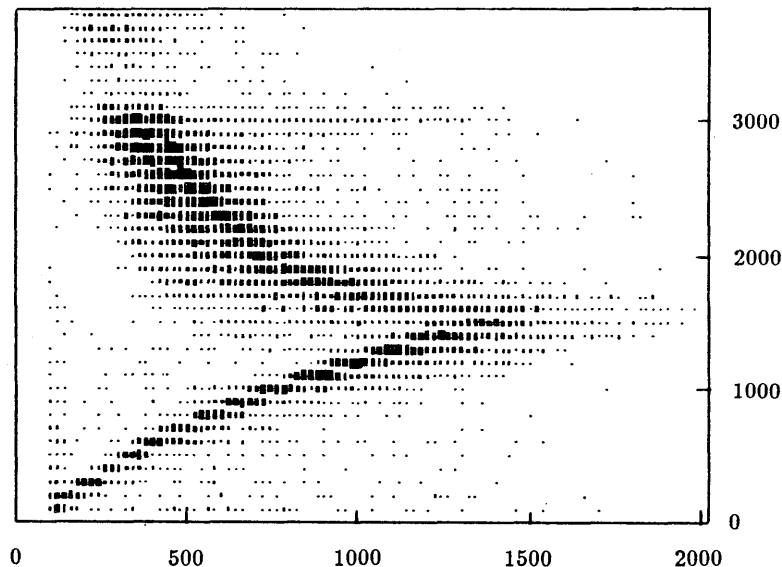


Figure 2. Proton forward scattering angle vs. E or ΔE deposited in the PSD by the recoil proton.

proton, the recoil particles "punch through" and deposit energies characteristic of a ΔE spectrum. The data of Fig. 2 can be used to construct a profile of the illuminated portion of the jet. The spectrum shown in Fig. 3 shows a typical gas jet profile.

At this stage of the experiment, preliminary data have been taken at 320, 300 and 275 MeV and rough cross-sections calculated, which suggest that the luminosity and particle discrimination achieved should be adequate for useful measurements. Some secondary problems remain to be solved before reliable results can be presented. Figure 4 presents missing mass distributions for beam energies above (i.e., at 320 MeV) and below (at 275 MeV) the pion threshold. Angular distributions are currently being measured at 295, 300 and 320 MeV.

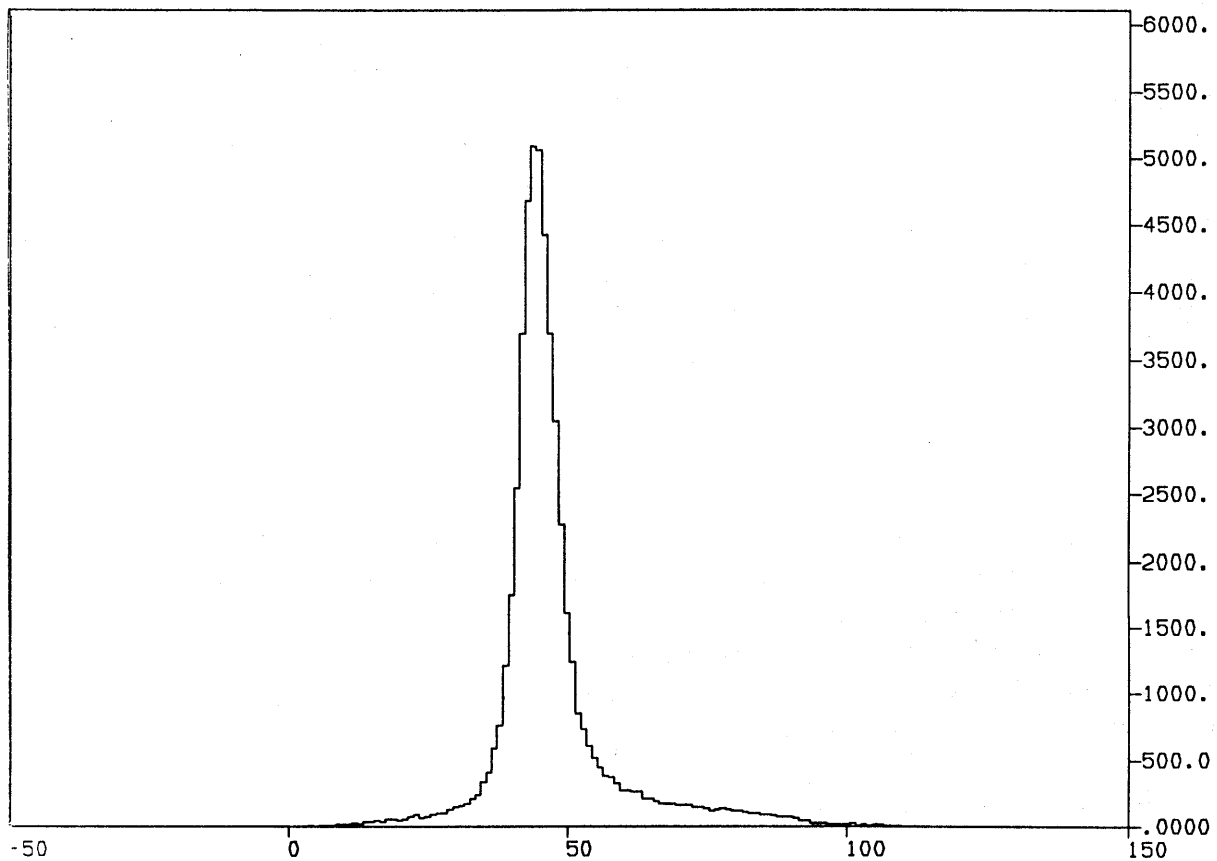


Figure 3. Approximate gas jet profile after optimizing beam position. The horizontal scale is 0.75 mm per channel.

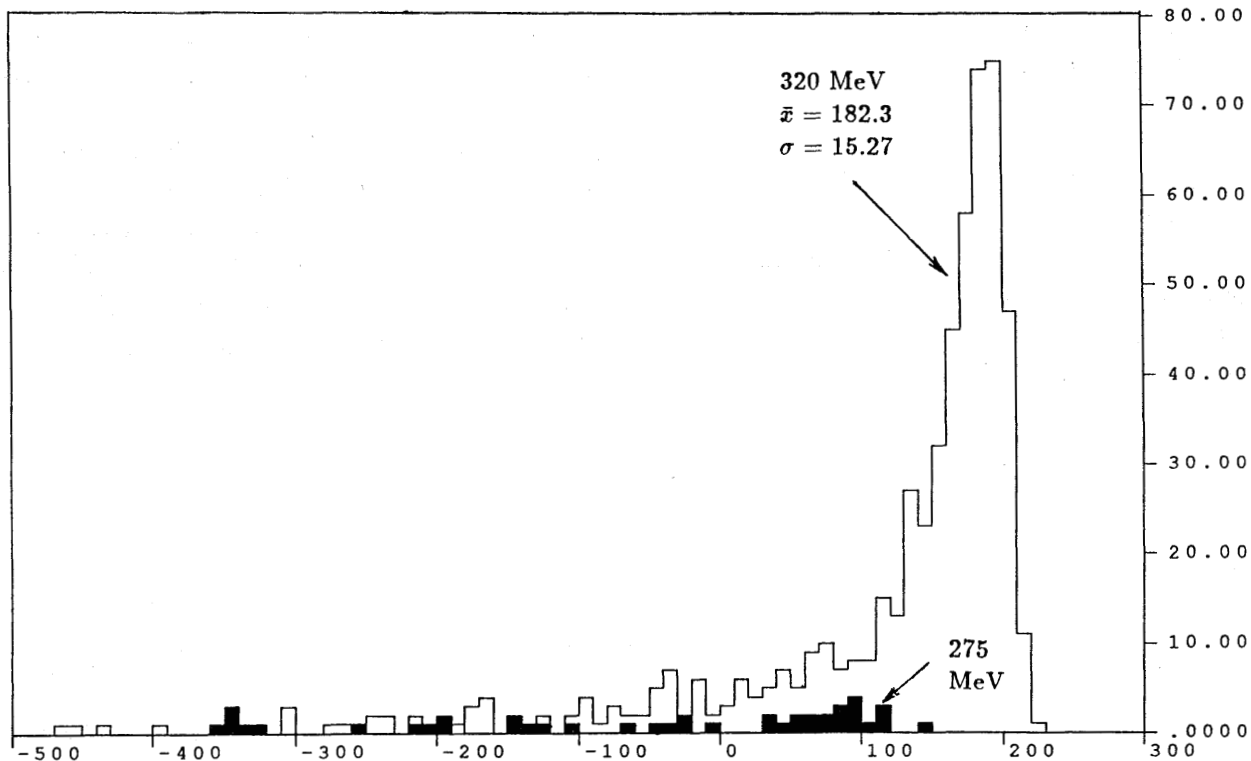


Figure 4. Missing mass squared (divided by 100) spectra for pions from n-p coincidence events. The darker histogram is taken from a shorter run at 275 MeV. The lighter histogram represents 320 MeV data for which the typical missing mass deduced is about 135 MeV.

Experiment CE03 has run at the Indiana Cooler ring for three 5-9 day periods with unpolarized protons. The 6° magnet and all detectors have exceeded design specifications, although some of our commercial electronics and the wires chamber have required repairs. We plan to complete the measurements with unpolarized beam during 1991 and hope to follow up with analyzing power measurements when a polarized beam of sufficient luminosity and low enough background is available.

1. Lee and Matsuyama, private communication, 1990.