Title

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Authors

Peterson, Vincent Z.
Cence, Robert J.
Stenger, Victor J.
et al.

Publication Date

1964-07-01

UCRL-11576

University of California

Ernest O. Lawrence Radiation Laboratory

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Berkeley, California

Paper submitted to the
International Conference on High
Energy Physics, Dubna, U.S.S.R.
August 5-15, 1964.

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AEC Contract No. W-7405-eng-48

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Vincent Z. Peterson, Robert J. Cence, and Victor J. Stenger, University of Hawaii; Charles B. Chiu, Richard D. Eandi, Robert W. Kenney, Burton J. Moyer, John A. Poirier, and W. Bruce Richards, Lawrence Radiation Laboratory, University of California, Berkeley. (Paper to be presented by Vincent Z. Peterson at the International Conference on Physics of High Energy Particles, Dubna, U.S.S.R., August 5-15, 1964.)

We have measured the total cross-sections and angular distributions for several neutral final states produced in negative pion-proton collisions for incident pion energies from 531 MeV to 1308 MeV. The primary objective of the experiment was to obtain differential cross sections for charge exchange scattering of negative pions, $\pi^-p \rightarrow \pi^on$; this will be reported in the adjoining paper by Professor Moyer. Analysis of about 15% of the data so far has shown substantial production of eta mesons, $\pi^-p \rightarrow \eta^on$, above the threshold of 560 MeV and we have been able to separate the decay $\eta^o \rightarrow 2\gamma$ from $\pi^o \rightarrow 2\gamma$ by decay kinematics. This paper will summarize the information obtained on eta production and the total cross sections for single and multiple π^o production in π^-p collisions.

Preliminary reports of this work have been given at two meetings of the American Physical Society.[1]

The experimental arrangement, shown in Fig. 1, will be described briefly. A 4π spark chamber array consisted of six steel-plate chambers surrounding a cubical enclosure 1 meter on a side. Neutral final states were selected by an anti-counter nearly surrounding the hdyrogen target; the ratio of neutral triggers to incident pions was measured electronically. The distribution of neutral event types was determined by observing the spark chambers (90-deg stereo, 12 views); events containing up to 8 showers were observed. Each spark chamber contained 4 thin aluminum plates and 35 1/8-in.-thick steel plates (6.3 radiation lengths). Charged particles made tracks in the front aluminum gaps, whereas most photons were converted in the first 12 steel plates. The calculated efficiency for detecting 100 MeV photons is 98%. The requirement of ≥ 3 gaps/shower imposes a minimum photon energy cutoff of about 80 MeV. The probability for seeing at least one shower from single $\pi^0 \to 2\gamma$ at our lowest incident pion energy (531 MeV) is essentially 100%, and when only one shower is seen it is close to the π^0 direction. Decays $\eta^0 \to 2\gamma$ always give energetic photons and the problem of converting the low energy photon does not exist. The small number of "0-shower" events, the energy spectrum of 1-shower events, and the high ratio of 2-shower/1-shower events, lead us to believe that essentially all of the 1- and 2-shower events correspond to single π^0 and η^0 production; 3- and 4-shower events are almost certainly due to $\pi^- p \to 2\pi^0 n$, and the events with 5 or more showers correspond to ≥ 3 π^0 produced.

Measurements were made at pion kinetic energies of 502, 534, 582, 652, 699, 873, 989, 1100, and 1308 MeV with about 50,000 frames at each energy. The contamination of the incident pion beam by muons and electrons was measured with a gas Cerenkov counter; 10% to 30% corrections to the monitor were required. The net (Full-Empty) electronic triggering rate for "neutral events" is shown as the top solid line in Fig. 2. The spark chamber pictures show some charged particles due to the expected inefficiency (.03%) of the beam anti-counter and a few back-scattered pions; however, the (Full-Empty) target subtractions eliminate essentially all charged events. Hence the top curve may be regarded as "total neutrals" cross section, $\sigma(\pi^- p \to \text{neut.})$. Until final corrections are made we consider the absolute scale to be uncertain to ± 15%; our neutrals cross section is about 6% below the Saclay curve[2] but has very nearly the same shape.

Separation of the various neutral final states depends upon the number of showers observed and the opening-angle distribution for 2-shower events.

One-shower events were about half of the 2-shower events at low pion energies and considerably less at the higher pion energies (where both photons from $\pi^0 \to 2\gamma$ have > 80 MeV). Three- and 4-shower events occur 20 to 80% as often as the 2-shower events, whereas ≥ 5-shower events were quite rare. In Fig. 2 the 3- and 4-shower events are used to derive the $\pi^- p \to 2\pi^0 n$ total cross section, while the ≥ 5-shower events are lumped together to give the total cross section for $\pi^- p \to \geq 3\pi^0 n$. The reaction $\pi^- p \to \Lambda^0 K^0$ is negligible in this experiment.

The 2-shower events appear to be almost completely due to the reactions $\pi^- p \to \pi^0 n$ and $\pi^- p \to \eta^0 n$, since very few multiple π^0's fail to give fewer than 3 showers in our chambers. (Analysis of our data with the top and bottom chambers removed show that 31% of the 3- and 4-shower events would appear as 1- or 2-shower events.) The 2-photon opening angle distribution ($\pi^- p$ c.m. system) at 699 MeV is shown in Fig. 3. (Empty subtraction of 19% of the total events has not been made.) The solid lines are expected opening angle distributions for $\pi^0 \to 2\gamma$ (θ_{min} = 30.6 deg) and $\eta^0 \to 2\gamma$ (θ_{min} = 131.6 deg) with an experimental resolution of ± 3 deg folded in. The residual background is assumed to be due to $2\pi^0$ events in which only one photon/π^0 converts; if we assume each π^0 to be distributed isotropically in the $\pi^- p$ center-of-mass system we get a contribution of 12% of the 2-shower events which fits the opening angle distribution within statistics.

The fraction of 2-shower events which are $\eta^0 \to 2\gamma$ is 18% at 652 MeV, and is already 8% at 581 MeV (only 21 MeV above threshold). The variation of the $\pi^- p \to \eta^0 n$ cross section with π^- kinetic energy is shown in Fig. 2. The sudden rise above threshold to a peak of about 2.5 mb. near 650 MeV is closely proportional to the c.m. momentum of the η^0 (solid line) as expected for pure S-wave production near threshold. This new inelastac channel may be expected to produce some effects in $\pi^- p \rightarrow \pi^- p$ elastic scattering.

The angular distributions of the η^0 (c.m. system) at several pion energies are shown in Fig. 4. The principal conclusion is that the distributions are consistent with isotropy near threshold, but begin to peak forward at higher energies. The statistics are not yet adequate for more detailed conclusions.

Close to threshold the low c.m. eta velocity and large Q-value in $\eta^0 \rightarrow 2\gamma$ produce wide opening angles. Resolution of the quadratic ambiguity in η^0 direction then becomes difficult, even using shower length as a measure of photon energy. At 699 MeV half of the "good" η^0's are ambiguous in eta-direction. If we plot the direction closest to the bisector, we obtain the black squares (Fig. 4). These events do not alter the angular distribution significantly.

At higher energies the fraction of ambiguous events decreases (20% at 1308 MeV). As statistics improve we expect to be able to compare the angular distributions of η^0 and π^0 which are closely associated in various octet models.

We wish to thank Milton Cha, Jack Semura, and Narender Sehgal for assistance in data analysis, Mr. Richard Hansen for taking a leading part in the construction of the spark chambers, and our scanning and measuring staffs for their hard work. This work was supported by the U. S. Atomic Energy Commission.

[1] Bull. Amer. Phys. Soc. <u>8</u>, 603 (Dec. 1963); <u>9</u>, 409 (April 1964).

[2] Rene Turley, CEA 2136, p. 35 (1962).

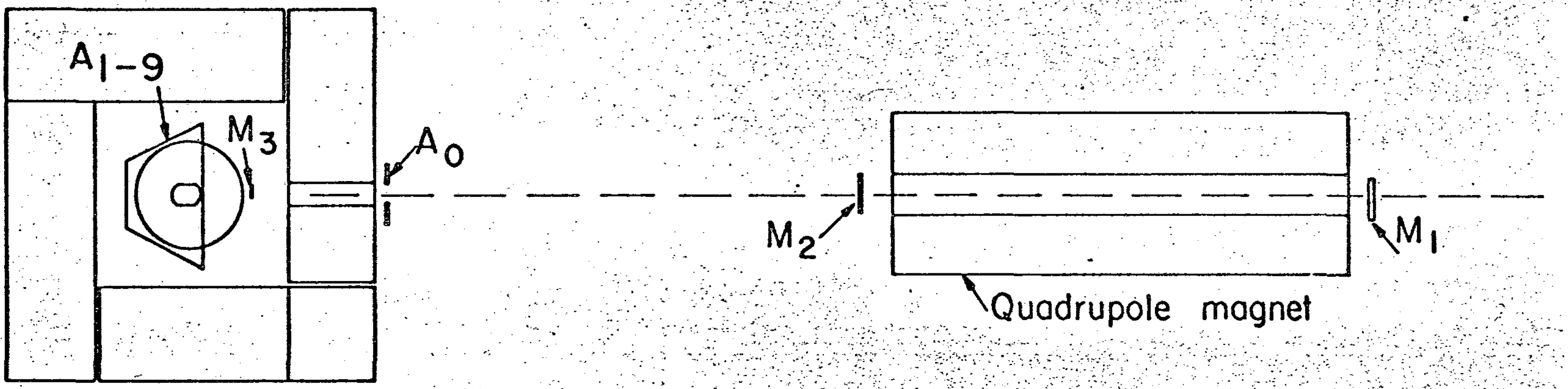

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Figure 1. Experimental arrangement. Six spark chambers form the walls of a cubical box. A_{1-9} are anti counters. M_1, M_2, M_3 are π^- monitor counters.

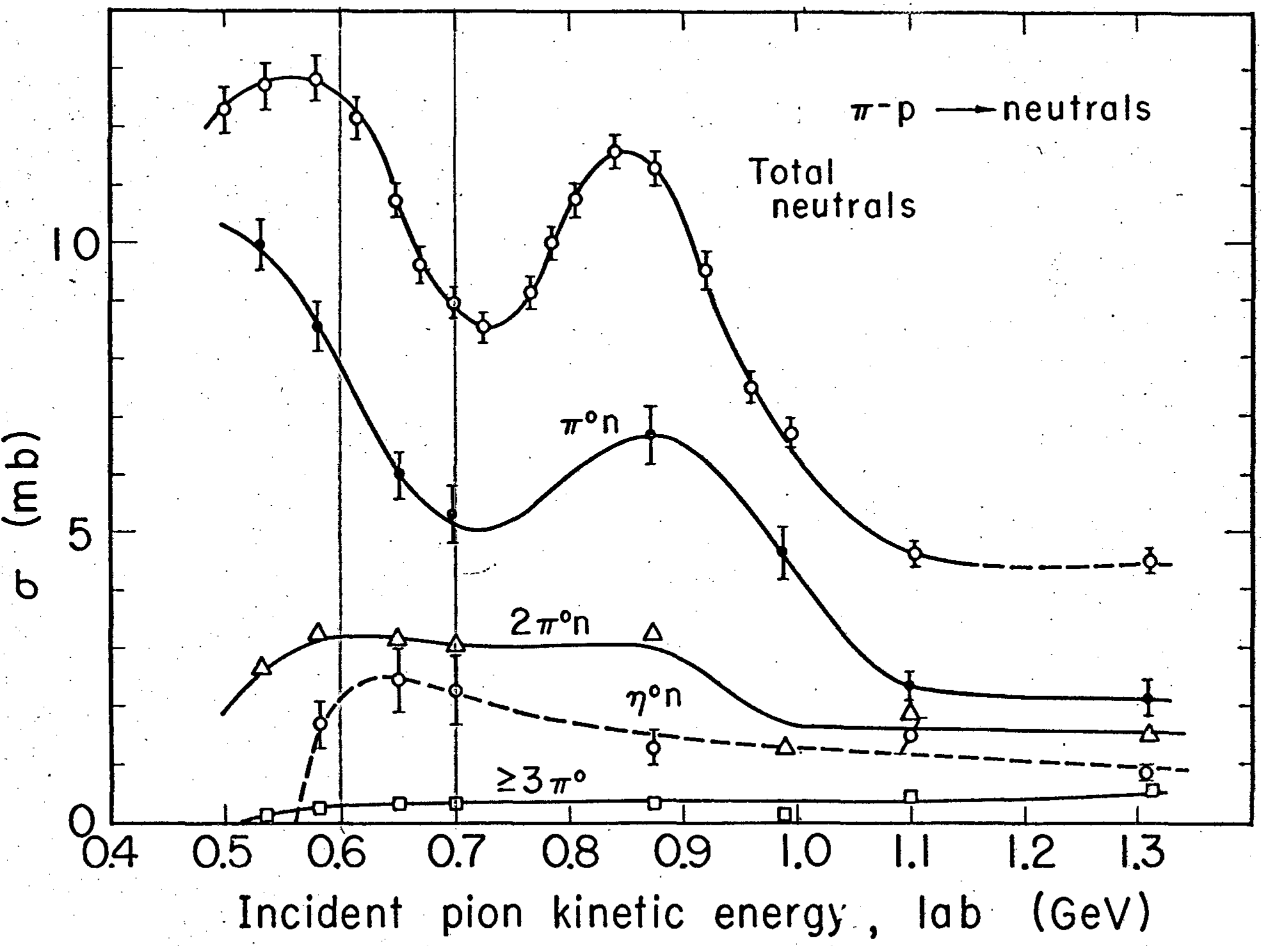

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Figure 2. Total cross sections for neutral final states in $\pi^- p$ collisions.

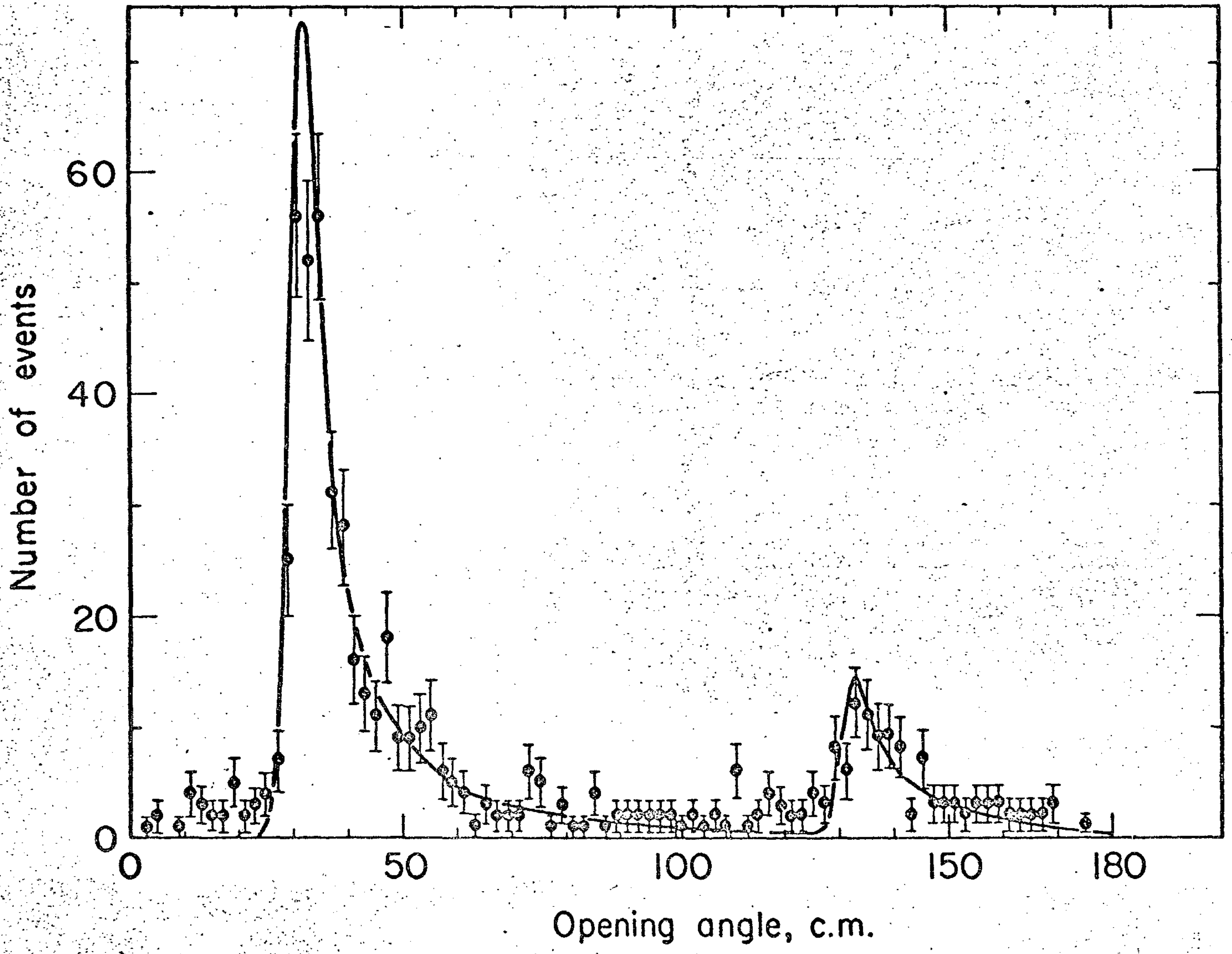

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Figure 3. Opening angle distribution ($\pi^- p$ c.m. system) for 2-shower events at 690 MeV. Target full (empty subtraction not yet made).

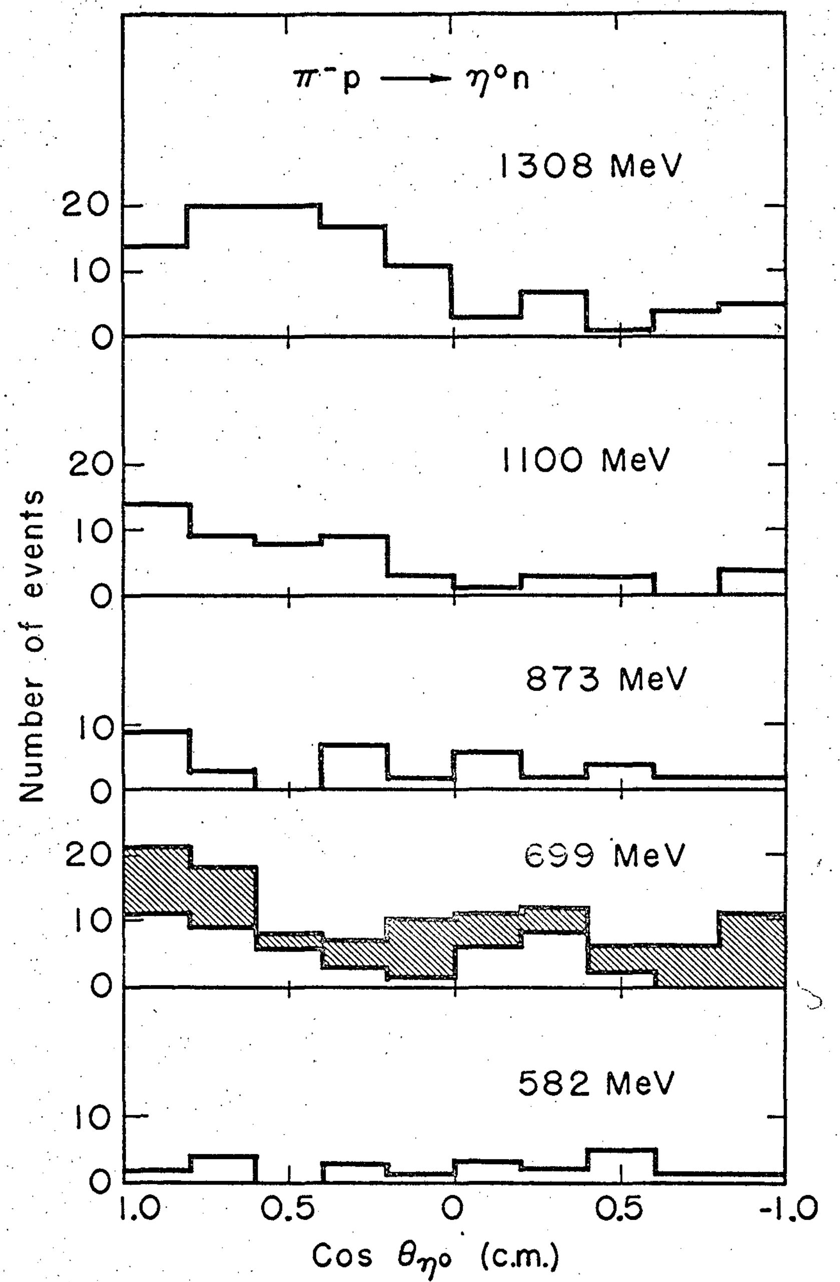

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Figure 4. Angular distributions of eta meson in reaction $\pi^- p \rightarrow \eta^0 n$ at various π^- energies.