REACTION $\pi^- p \to \pi^0 n$ NEAR 180° AT HIGH ENERGIES

J. Schneider* and V. Lepeltier
Institut de Physique Nucléaire, Orsay, France

and

P. Bonamy, P. Borgeaud, O. Guisan, and P. Sonderegger
Département de Physique des Particules Elémentaires,
Centre d'Etudes Nucléaires de Saclay, Gif-Sur-Yvette, France
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Differential cross sections for the reaction $\pi^- p \to \pi^0 n$ near 180° at 4, 6, 8, and 11 GeV/c have been measured. Data analysis and results are presented.

We have measured the differential cross sections for the reaction $\pi^- p \to \pi^0 n$ at 4, 6, 8, and 11 GeV/c (π^- lab momentum) in the range of u-momentum transfer

$$u_{\max} \geq u \geq u_{\max} - 0.27\ (\mathrm{GeV}/c)^2.$$

A total of 742 events have been retained in the analysis. We describe here the experimental setup, explain how the analysis was carried out, and present the results. Preliminary results from this experiment have been given at the 1968 Vienna Conference.[1]

Experimental method.—We have carried out a spark-chamber experiment at the CERN proton synchrotron aiming at the study of the backward $\pi^- p$ charge-exchange reaction, by means of a simple layout. The pion beam was focused on a 5.2-cm-long liquid-hydrogen target. The two backward-emitted γ rays were converted in a spark chamber of dimensions $50 \times 50 \times 50$ cm^3 which had 27 lead plates and a total of 11 radiation lengths. The nearest plate was 12 cm from the target. The π^- beam passed through a central hole in these plates. The target was surrounded by five lead-and-scintillator sandwich counters (total lead thickness 14-20 mm) which worked in anticoincidence to prevent the chamber from firing when outgoing charged particles or additional γ rays were present. The selectivity of the trigger was never better than one good event per 130 pictures. Approximately half of the trigger rate was due to reactions in the heavy material surrounding the incoming beam.

For each event, the conversion points of two γ rays were measured and the total number of sparks (n_1 and n_2) in their showers recorded.

Analysis.—In the energy and u ranges considered, the π^0 momentum is around 400 MeV/c. The energy E_γ of one of the two γ's from the π^0 decay is between 10 and 400 MeV, corresponding to a number N of sparks in the developed shower varying from 1 to ~40. In these conditions, the following relation connecting N to E_γ is used:

$$N = \alpha E_\gamma \cos\theta (1-f)(1+\delta).$$

An average value of 1 spark/11 MeV is taken for α (α was allowed to vary from film to film to take into account small fluctuations, the variations in α not exceeding $\pm 10\%$); θ is the angle between the shower direction and a line perpendicular to the spark-chamber plates. When part of the shower escapes the chamber, the factor f, which depends primarily on geometrical conditions and varies slowly with the energy E_γ, takes into account the resulting loss of sparks. This linear relation is found not to hold for low values of N. An additional factor

$$\delta = \{[16 - \alpha E_\gamma \cos\theta (1-f)]/15\}^3$$

has to be introduced for $N \leq 16$. The corresponding error for N is found to be $\Delta N = 1.4\sqrt{N}$.

Showers with less than three sparks were not taken into account. A detection efficiency $\epsilon = N/6$ was estimated for the showers, with $3 \leq N \leq 6$.

All these parameters have been determined by fitting unambiguous events and by the extrapolation of results obtained at higher γ energies in previous experiments.

Using this $N(E_\gamma)$ relation with its error, we carried out the analysis in the following way: The interaction point was varied along the beam (z) axis in steps of 1 mm; the allowed range of z covered the physical length of the H_2 target and the position of the last beam counter. For a given z, the kinematics of the reaction $\pi^- p \to \pi^0 (\to 2\gamma) n$ lead either to no solution or to two solutions for the γ-ray energies $E_\gamma(z)$. From these solutions we determined two sets of values for $N_i(E_{\gamma i})$ ($i = 1, 2$). For each solution a χ^2 value was calculated:

$$\chi^2(z) = \sum_{i=1}^{2} \left(\frac{N_i(E_{\gamma i}) - n_i}{N_i} \right)^2 + \left(\frac{z}{4} \right)^{2.5}.$$

The last term was introduced to decrease artifi-

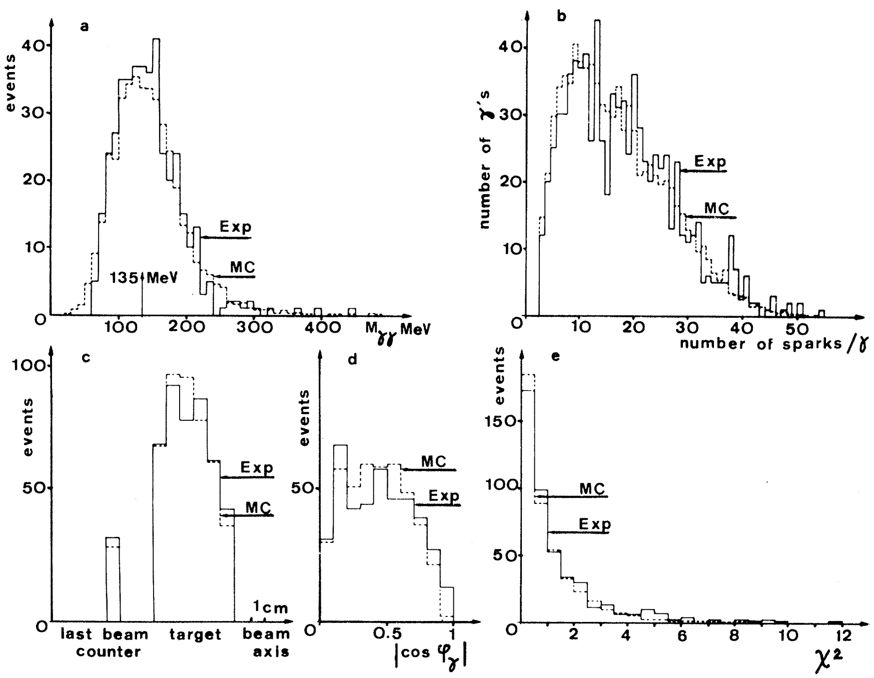

FIG. 1. Observed distributions (Exp) for 419 $\pi^- p \rightarrow \pi^0 n$ events at 6 GeV/c with $\chi^2 < 4$. Dashed-line distributions correspond to Monte Carlo calculations (MC). (a) Reconstructed mass of the two γ's (see text). (b) Number of sparks per γ distribution. (c) Distribution of the reconstructed $\pi^- p \rightarrow \pi^0 n$ vertex along the beam axis. (d) Angular distribution for the two γ's decaying in the π^0 c.m. system. (e) χ^2 distribution of the fitted events (41 events have $\chi^2 > 4$).

cially an accumulation of events at both ends of the target ($z = 0$ corresponds to the center of the target). The solution with the smallest χ^2 was retained. Events with a reconstructed interaction point falling in the last beam counter were rejected.

This procedure was checked with Monte Carlo calculations. Figure 1 shows a comparison of distributions obtained from observed events and from Monte Carlo events. The invariant mass of the two γ's, $M_{\gamma\gamma}$, plotted in Fig. 1(a), was computed using the following relation (in the lab system):

$$M_{\gamma\gamma}{}^2 = 2E_{\gamma 1}E_{\gamma 2}(1 - \cos\Phi_{\gamma\gamma}),$$

where $\Phi_{\gamma\gamma}$ is the angle between the γ's seen from the center of the target and $E_{\gamma 1}$ and $E_{\gamma 2}$ are deduced from the observed numbers of sparks (n_1, n_2). No assumption is made about the production of the two γ's. The peak at 135 MeV ensures us that we are dealing with π^0's. The other distributions, such as the number of sparks per γ [Fig. 1(b)], the reconstructed interaction point [Fig. 1(c)], the decay angle φ_γ of one of the two γ's in the π^0 c.m. system [Fig. 1(d)], or the χ^2 [Fig. 1(e)] are satisfactorily reproduced by the Monte Carlo calculations and ensure the reliability of the analysis.

The applied cuts are $\chi^2 < 4$ and the interaction point is required to be in the H_2 target.

From the Monte Carlo calculations we find the following: (1) The resolution corresponding to the reconstruction of the interaction point is $\Delta z = \pm 0.8$ cm (target length is 5.2 cm). (2) The resolution Δu is given in $(\mathrm{GeV}/c)^2$ by

$$\Delta u = 0.003 + 0.22|u - u_{\mathrm{max}}| \text{ for } |u - u_{\mathrm{max}}| < 0.16,$$
$$= 0.040 \text{ for } |u - u_{\mathrm{max}}| > 0.16.$$

(It corresponds roughly to half the size of the u bins used in Table I and Fig. 2.) (3) The global detection efficiency for the two γ's depends slowly on the energy and varies typically from 50% at $u = u_{\mathrm{max}}$ down to 5% at $u = u_{\mathrm{max}} - 0.27$.

The background coming from counters or target walls was separately determined by "target empty" measurements and subtracted out (~5%). A large correction is the 18% probability that the neutron be detected in the anticoincidence counters. The overall factor, including these two corrections and other small ones, is 1.32 on the average.

Contamination. – The slight overdetermination

Table I. Cross sections obtained for the reaction $\pi^- p \to \pi^0 n$ near 180°. u is expressed in $(\mathrm{GeV}/c)^2$, $d\sigma/du$ in $\mu\mathrm{b}/(\mathrm{GeV}/c)^2$. See text for further comments. Values carrying an asterisk correspond to 0^{+1}_{-0} observed event.

Beam momentum (GeV/c)	4		6		8		11	
	u	dσ/du	u	dσ/du	u	dσ/du	u	dσ/du
dσ/du (u)	0.083	57 ± 20	0.056	14 ± 2	0.042	5.6 ± 1.0	0.030	1.9 ± 0.7
	0.073	37 ± 16	0.046	11.3 ± 1.8	0.032	4.5 ± 0.9	0.020	1.4 ± 0.7
	0.058	27 ± 10	0.031	8.8 ± 1.2	0.017	3.2 ± 0.6	0.005	1.9 ± 0.5
	0.033	15 ± 7	0.006	6.9 ± 0.8	-0.008	2.8 ± 0.4	-0.020	1.9 ± 0.5
	-0.002	11 ± 5	-0.029	4.5 ± 0.5	-0.043	2.0 ± 0.3	-0.055	1.0 ± 0.3
	-0.042	0^{+3}_{-0} *)	-0.069	2.5 ± 0.4	-0.083	1.5 ± 0.3	-0.095	0.70 ± 0.18
	-0.102	0^{+3}_{-0} *)	-0.129	1.06 ± 0.28	-0.143	0.53 ± 0.17	-0.155	0.34 ± 0.16
	-0.152	0^{+5}_{-0} *)	-0.179	0.50 ± 0.40	-0.193	0.44 ± 0.25	-0.205	0^{+1}_{-0} *)
u_{max}	0.008		0.061		0.047		0.0345	
σ_I	2.4 ± 0.5		1.08 ± 0.10		0.49 ± 0.06		0.24 ± 0.04	
σ_{II}	0.64 ± 0.27		0.52 ± 0.06		0.24 ± 0.03		0.15 ± 0.03	
Slope B	21 ± 3		14 ± 2		11 ± 2		10 ± 2	
No. of events	30		419		212		81	
π^0/picture	1/133		1/144		1/240		1/350	
1γ/picture	1/200		1/100		1/90		1/70	

of the events ensures that the observed γ pairs are really π^0's with the energy expected for the reaction $\pi^- p \to \pi^0 n$. Since the reaction studied is characterized by very small cross sections, there is the possibility that the sample of observed events was contaminated by π^0's with about the expected energy but coming from reactions other than $\pi^- p \to \pi^0 n$, all other particles involved escaping detection.

At 4 GeV/c we took additional data with one lead-scintillator sandwich counter disconnected. The apparent cross section we measured was increased by a factor of 2, without any observable change in the different distributions of Fig. 1. But we found that the corresponding contamination was characterized by a flat u distribution (in the u range considered). Owing to the high rejection power of the anticoincidence counters against charged particles and additional γ rays, we estimate that the contamination does not exceed 20% of the measured cross section at 4 GeV/c, and 40% at 11 GeV/c. This possible bias is not taken into account in the presented results. If there is such a contamination, it should be rather isotropic and would decrease the values of the observed cross sections, in particular at the more negative u values.

Results. - The results are presented in Table I. For $d\sigma/du$, the errors are only statistical. σ_I and σ_{II} are defined by

$$\sigma_I = \int_{u=u_{max}-0.27}^{u_{max}} \frac{d\sigma}{du} du, \quad \sigma_{II} = \int_{-0.07}^{0.03} \frac{d\sigma}{du} du,$$

the corresponding errors including statistics and normalization errors. The energy dependence of σ_I and σ_{II} can be fitted by $\sigma_I = \sigma_{I0} p^{-2.3}$ and $\sigma_{II} = \sigma_{II0} p^{-1.7}$ (where p is the lab beam momentum). The slope B is defined by

$$\frac{d\sigma}{du} = \left.\frac{d\sigma}{du}\right|_{u=u_{max}} e^{-Bu},$$

the corresponding errors including u resolution effects. "No. of events" is the number remaining after cuts. For completeness we give the ratio (π^0/picture) of this number of events to the total corresponding number of pictures and also the

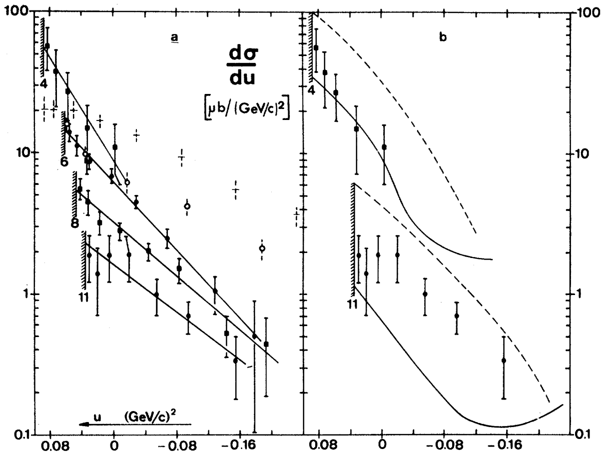

FIG. 2. (a) Differential cross sections $d\sigma/du$ for the reaction $\pi^- p \rightarrow \pi^0 n$ at 4, 6, 8, 11 GeV/c (π^- lab momentum). An exponential fit to the results is shown and the u_{max} limit is represented. Dashed-line results are those of R. C. Chase et al., Phys. Rev. Letters 22, 1137 (1969), at 4 and 6 GeV/c. (b) $d\sigma/du$ at 4 and 11 GeV/c as compared with the predictions of V. Barger and D. Cline, Phys. Letters 27B, 312 (1968), and 19, 1504 (1967). Solid and dashed curves correspond to the two possible choices of the relative sign of the N and Δ residues.

number (1γ/picture) of 1-γ events observed in the same pictures.

Figure 2(a) shows our results. Results of Chase et al.[2] at 4 and 6 GeV/c are also shown. These results agree roughly for the normalization but exhibit a discrepancy for the observed slope of the differential cross sections.

In Fig. 2(b), the 4-GeV/c results are in agreement with the preferred prediction of Barger and Cline.[3] At higher momenta a deviation appears which seems difficult to explain by contamination effects.

At 180° the charge-exchange cross section is slightly above the lower limit imposed by isospin conservation.

More refined results are desirable for a better understanding.

Our most enthusiastic thanks go the the Pisa-Orsay Group for having allowed us to use their beam and γ detector and to photograph our events on their film, simultaneously with their own $\pi^- p \rightarrow K^0\Lambda^0$ experiment. We are grateful to Dr. P. Roubeau and Mr. Der Nigohossian who designed, built, and installed the elegant and reliable hydrogen target.

*The experiment presented here will be the object of a doctorate thesis which will be submitted by J. Schneider at the Faculté des Sciences de Paris in 1970.

[1]J. Schneider, V. Lepeltier, P. Bonamy, P. Borgeaud, O. Guisan, and P. Sonderegger, communication to the Fourteenth International Conference on High Energy Physics, Vienna, Austria, September, 1968 (unpublished).

[2]R. C. Chase, E. Coleman, H. W. J. Courant, E. Marquit, E. W. Petraske, H. Romer, and K. Ruddick, Phys. Rev. Letters 22, 1137 (1969).

[3]V. Barger and D. Cline, Phys. Letters 27B, 312 (1968), and 19, 1504 (1967).

UNSPLIT K^*'S

Philip J. Davis, Stephen E. Derenzo, Stanley M. Flatté, Margaret A. Garnjost, Gerald R. Lynch, and Frank T. Solmitz
Lawrence Radiation Laboratory, University of California, Berkeley, California 94720
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It is shown that the $K_N(1420)$ and the $K^*(890)$ in our 12-GeV/c K^+p experiment fit poorly to the double-pole structure reported for the A_2 meson. The probability that our data agree with the double-pole hypothesis is less than 1% for the $K_N(1420)$ and completely negligible for the $K^*(890)$, although both resonances are fitted well by a Breit-Wigner shape. Our mass resolution is ±7 MeV at the $K_N(1420)$ and ±5 MeV at the $K^*(890)$.

The reported splitting[1,2] of the A_2 meson has stimulated a large amount of speculation about possible similar structure in other mesons. The source of the excitement seems to be the suggestion that, if the splitting exists, it may not arise from mundane interference between two resonances (this possibility fits the A_2 data), but rather it may be that the A_2 itself is a new kind of particle: a double pole.[3]

If the A_2 is a double pole, it quite naturally becomes of extreme interest to examine the other members of the SU(3) multiplet to which the A_2 has been assigned; i.e., the $K_N(1420)$ and the f_0.

We present here an analysis of the $K_N(1420)$ and the $K^*(890)$. We have studied $K^*(890)$ because it seems useful to examine all possible