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5 February 1985FIRST MEASUREMENT OF THE REACTION $\pi^-e \rightarrow \pi^-\pi^0e$

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ABSTRACT

The first observation of neutral pion production in πe inelastic scattering is presented. The cross-section at 300 GeV for $|t| > 10^{-3}$ (GeV/c)² is 2.11 ± 0.47 nb, in good agreement with the theory of PCAC anomalies with 3 quark colours.

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In 1981-82 an experiment (NA7) was performed at the CERN SPS to measure the pion charge radius to a high degree of accuracy [1] and to study the pion form factor up to 0.26 (GeV/c)^2 . In this experiment about 2.5 million triggers were collected using a 300 GeV/c pion beam and a liquid hydrogen target. Here we report the results of a search for events in which a neutral pion was produced in the inelastic scattering of pions by electrons in the target. The importance of the process $\pi e \rightarrow \pi\pi^0 e$ has been stressed repeatedly in the past and recently [2], because it provides a direct test of the Adler et al. [3] and Terent'ev [4] low energy theorem relating this reaction to π^0 decay. It is also a useful source of information on the $\rho\pi\gamma$ vertex [5]. The fact that the process has never previously been observed is due to the problem of measuring a low cross section, of the order of a few nanobarn, in the presence of a large competing background.

From general invariance principles the matrix element for the process is

$$M = eF^{3\pi}(t, s_1, t_1) \frac{1}{t} \bar{u}(P_5) \gamma^\mu u(P_4) \epsilon_{\mu\sigma\nu\rho} P_1^\sigma P_2^\nu P_3^\rho$$

where $F^{3\pi}$ is the inelastic pion form factor. Fig. 1a gives the definitions of incoming and outgoing particle momenta and the relativistic invariants. In the theory of PCAC anomalies the $\gamma\pi\pi\pi$ vertex is given by a "box" diagram (Fig. 1b) which is related to the "triangle" diagram of π^0 decay (Fig. 1c) through

$$eF^{3\pi} = F^\pi f_\pi^{-2}$$

where f_π is the usual pion decay constant and F^π corresponds to the Adler, Bell and Jackiw anomaly [6,7]. In the quark model $F^{3\pi}$ and F^π are proportional to the number of colours. The theorem is only strictly applicable when all the invariants are zero but it is possible to extend its validity, with some model dependent assumptions, to the physical region [8,9]. The modified cross section for $\pi e \rightarrow \pi\pi^0 e$ is then approximately proportional to the square of the number of colours, provided one is not too far from threshold. This theorem is particularly interesting

now, since it appears in recent attempts to construct a low energy effective lagrangian for QCD [10]. A measurement of the cross-section for this process provides a test of the low energy theorem and a determination of the number of colours.

The experimental apparatus consisted of the FRAMM forward spectrometer plus a vertex detector (Fig. 2). FRAMM was a multiparticle spectrometer designed to measure charged particle momenta and photon energies using four successive groups of magnets, drift chambers and shower detectors. The shower detectors were divided into front and back parts in order to discriminate between electromagnetic and hadronic showers. The vertex detector, consisting of groups of MWPC and scintillation counters, provided a high precision measurement of charged particle directions before and after the target. The main trigger requirements were at least one electromagnetic shower signal plus a configuration consistent with two outgoing charged particles in the vertex detector. For an extensive description of the NA7 experimental setup and of the trigger conditions, see Refs [1,11].

The expected number of events was of the order of 30 in our sample of 2.5 million triggers. The bulk of the events, consisting of π -proton hadronic interactions that passed the trigger plus πe elastic scattering, was removed by applying the following criteria :

- 1) A well-reconstructed vertex inside the target, with two downstream tracks, was required.
- 2) Events having a positive track and events with a track of less than 1 GeV/c or of more than 250 GeV/c were rejected.
- 3) Well identified πe elastic events were also removed.
- 4) We required a signal of either two or more showers of at least 2 GeV or just one of at least 20 GeV.

A Monte Carlo calculation confirmed that the sample surviving the selection, 6% of the total, contained all $\pi e \rightarrow \pi\pi^0 e$ events within our acceptance.

In Fig. 3a the missing mass to the π^-e system for events with two photons is shown and a clear signal at the π^0 mass is seen. Here the π^- and e are distinguished on the basis of shower detector information. Events clearly identified as elastic π^-e with electron bremsstrahlung are not included in this plot. The latter are defined as having the pion momentum consistent with elastic π^-e kinematics and two showers compatible with electron bremsstrahlung in the target or in the spectrometer. Fig. 3a also shows the missing mass distribution for events without photons. Fig. 3b shows the invariant mass of the $\gamma\gamma$ system for events with a missing mass between 100 and 180 MeV/c², with the requirement that both photons are well away from the inner edges of the shower detectors to avoid edge effects. The large number of π^-e elastic events recorded contributes a background in which the photons are due to electron bremsstrahlung and the pion falls slightly outside the elastic kinematic cuts. In order to reduce this background we rejected those events which had one photon consistent with electron bremsstrahlung and the invariant mass of the 2γ system outside the range 90 to 180 MeV/c². A further analysis of special configurations, for example events with the electron close to the edge of the shower detector, generated a few more events. The missing mass distribution of the final sample is shown in Fig. 3c.

This distribution was fitted to a gaussian (with standard deviation given by the experimental resolution) plus a linear function, and the result is shown on Fig. 3c. This simple fit has a χ^2 of 13 for 16 degrees of freedom. The estimated number of $\pi\pi^0e$ events is 36 ± 8 .

To obtain the total cross section for $t > .001$ (GeV/c)² (the lowest limit of electron energy measured in the spectrometer is 1 GeV) the number of detected events has been corrected for the following effects :

- 1) The acceptance of the spectrometer, which is defined by the Front Shower (FS) detector and by several veto counters (see Fig. 2), causes a loss of events. The correction factor has been evaluated to be 1.57.

- 2) Off-line analysis losses, e.g. events with the two photons so close to each other that the two showers are not resolved. The correction factor for such losses is 1.24.
- 3) Pion absorption introduces a correction factor 1.05.

These correction factors have been evaluated by Monte Carlo programmes and are insensitive to the model used to describe the production mechanism.

The resulting value for the $\pi e \rightarrow \pi\pi^0 e$ cross-section for $t > 0.001 \text{ (GeV/c}^2\text{)}$ is $2.11 \pm 0.47 \text{ nb}$

As mentioned earlier, the current algebra matrix element needs to be supplemented by a phenomenological extrapolation away from zero four-momenta. We have compared our result with two such models [8,9], by inserting the corresponding matrix elements in the Monte Carlo programme. The comparison is summarised in Fig. 4.

The extrapolation formula of Terent'ev [9] is

$$F^{3\pi} = F^{3\pi}(0) \left(1 + e^{i\varphi} \Delta_\rho \left\{ \sum_{i>j=1}^3 \frac{s_{ij}}{m_\rho^2 - s_{ij}} \right\} + e^{i\varphi'} \Delta_\omega \frac{Q^2}{m_\omega^2 - Q^2} \right)$$

where Q is the virtual photon 4-momentum and s_{ij} are the appropriate invariants for the three pairs of pions. Δ_ρ and Δ_ω are determined by ρ and ω couplings and are numerically about 0.35 and 3.2 respectively. The unknown phases φ and φ' reduce the predictive power of this formula considerably, but still permit a clear distinction between one and three quark colours. In Fig. 4 we also show the effect of taking only the ρ terms in the Terent'ev formula.

The model of Rudaz [8], based on an effective lagrangian incorporating vector meson dominance, provides the formula (normalized to PCAC at zero energy)

$$F^{3\pi} = F^{3\pi}(0) \left(\frac{m_\omega^2}{m_\omega^2 - Q^2} \right) \frac{m_\rho^2}{3} \left(\frac{1}{m_\rho^2 - s_{12}} + \frac{1}{m_\rho^2 - s_{13}} + \frac{1}{m_\rho^2 - s_{23}} \right)$$

in which there are no unknown phases.

From Fig. 4 it is clear that our data are in good agreement with both these models. It is equally clear that the data firmly dictate the necessity of three quark colours.

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REFERENCES

- [1] S.R. Amendolia et al., Phys. Lett. 146B (1984) 116.
- [2] S. Rudaz, Phys. Lett. 145B (1984) 281.
- [3] S. Adler et al., Phys. Rev. D4 (1971) 3497.
- [4] M.V. Terent'ev Zh. Eksp. i Teor. Fiz. Pis'ma 14 (1971) 140.
- [5] W. Gajewski and A. Jurewicz, Phys. Rev. D17 (1978) 755.
- [6] S. Adler, Phys. Rev. 177 (1969) 2426.
- [7] J. Bell and R. Jackiw, Nuovo Cimento 60 (1969) 47.
- [8] S. Rudaz, Phys. Rev. D10 (1974) 3857.
- [9] M.V. Terent'ev, Phys. Lett. 38B (1972) 419.
- [10] N.K. Pak and P. Rossi, Phys. Lett. 148B (1984) 343.
- [11] S.R. Amendolia et al., Phys. Lett. 138B (1984) 454.

FIGURE CAPTIONS

Fig.1a) The reaction $\pi^- e \rightarrow \pi^- \pi^0 e$: definition of the kinematic variables.

b) $\gamma \pi \pi \pi$ vertex.

c) π^0 decay.

Fig. 2) The experimental apparatus (see ref. [1]).

Fig. 3a) Missing mass to the $\pi^- e$ system for events with 2 photons. The dashed histogram is for events without photons, in arbitrary units.

3b) Invariant mass of the 2 photons, for events with missing mass between 100 and 180 MeV.

3c) Missing mass to the $\pi^- e$ system for the final sample. The fit to the data is shown.

Fig. 4) Comparison between theoretical predictions and our result.

(1,2,3) PCAC prediction for 1,2 and 3 colours.

(4) PCAC (3 colours) corrected according to ref. [9] with phases set to zero showing the effects of ρ and ω terms.

(5) as (4), with ρ terms only.

(6,7) as (4) and (5), generalized to arbitrary phases, showing the allowed ranges.

(8) The range covered by the same model (ρ and ω) for 1 colour.

(9) The prediction of ref. [8].

a)

$$t_1 = |p_2 - p_1|^2$$

$$t = |p_5 - p_4|^2$$

$$S_1 = |p_2 + p_3|^2$$

FIG. 1

FIG. 2

FIG. 3

FIG. 4