Coherent Production of Neutral Pions off Al^{27} by Neutral Currents

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The angular distribution of "naked" π^0's, produced by ν_μ's (and $\bar{\nu}_\mu$'s) in the Aachen-Padova Al sparkchamber, shows a peak in forward direction, not explicable by resonance production, and not present in a contrôle sample which shows a proton recoil. The peak is more pronounced at higher energies, and its size and shape are consistent with being due to coherent π^0 production off the Al^{27} nucleus as a whole. The mere existence of this process shows that the axial vector piece of the weak neutral current is isovector - as predicted by the standard model.

The study of neutral and charged current induced single π^0 production was one of the first objectives of the Aachen-Padova sparkchamber experiments[1-3]. This was indicated, since a π^0, with one decay gamma missing, could be mistaken as an electron, and thus jeopardize the $\overset{(-)}{\nu}_\mu e$ scattering, and μe production studies of the group. Besides, neutrino produced single π^0's are of interest in their own right, and may yield insight into the structure of weak neutral currents (NC), as well as into the mechanism of resonance excitation[4].

In contrast to other groups, the Aachen-Padova collaboration insisted in accepting complete and reconstructed neutral pions only, that is two visible e.m. showers without obvious losses, and with an invariant mass $m_{\gamma\gamma}$ compatible with m_{π^0} = 139 MeV. As a matter of fact, it took the group several years, and detailed calibration runs, to understand the energy measurement of gamma rays from spark counting completely: low energy electron pairs suffer particularly heavily from spark losses, around 1 GeV the losses become less severe, but start growing again if $E_\gamma >> 1$ GeV. Precise knowledge of this bizarre calibration curve is mandatory, not only for finding the π^0 energy and mass, but also for determining its direction.

The early studies of NC $\nu_\mu(\bar{\nu}_\mu)$ produced π^0's concentrated on their ratio R_o ($\bar{R}_o$) to the well-known charged current reactions off the nucleon ($\mathcal{N}$):

$$R_o = \frac{\sigma(\nu_\mu \mathcal{N} \rightarrow \pi^0 \nu_\mu \mathcal{N})}{2\sigma(\nu_\mu n \rightarrow \pi^0 \mu^- p)} \quad , \qquad (1)$$

$$\bar{R}_o = \frac{\sigma(\bar{\nu}_\mu \mathcal{N} \rightarrow \pi^0 \bar{\nu}_\mu \mathcal{N})}{2\sigma(\bar{\nu}_\mu p \rightarrow \pi^0 \mu^+ n)} \qquad (\bar{1})$$

These numbers are very sensitive to the Glashow-Salam-Weinberg mixing angle Θ_W[5]. But all the early measurements were made with complex nuclei, where a modified R_o' ($\bar{R}_o'$) is measured. As was correctly remarked by Evelyn Monsay[6], the mutual agreement was not very good. And strong doubts were cast on the high values of R_o' and $\bar{R}_o'$ ($\approx 1/2$), obtained by the Aachen-Padova group[1,2].

A breakthrough was achieved by Krenz et al.[7] who used GARGAMELLE (GGM), filled with propane, and could study single π production sans souci, as it were, off free protons. Unbiased $\mathcal{N}\pi$ invariant mass distributions showed clearly that Δ production dominates in both, NC and CC reactions, and that higher resonances which showed up in NC, were absent in the $p\pi^+$-channel of CC reactions, due to isospin selection rules. All this information together with a wealth of data from electro-pion production was condensed by Rein and Sehgal in a quark-resonance-model along the lines of Feynman, Kislinger, and Ravndal[8]. The fit to the data is impressive, and the Aachen-Padova values, corrected for nuclear effects[9]:

$$R_o = 0.47 \pm 0.06 \ , \quad \bar{R}_o = 0.62 \pm 0.08$$

fit neatly with the theoretical predictions[4] of 0.45 and 0.56, respectively, as well as with the GGM result[7] of 0.45 ± 0.08 and $0.57^{+0.11}_{-0.10}$.

All that has to be borne in mind, in order to appreciate the oddity of the π^o angular distribution, derived by Helmut de Witt[9] from a sample of about 800 π^o's, registered without any accompanying track or recoil (i.e. "naked") in the AC-PD sparkchamber (Fig. 1): There is a marked peak

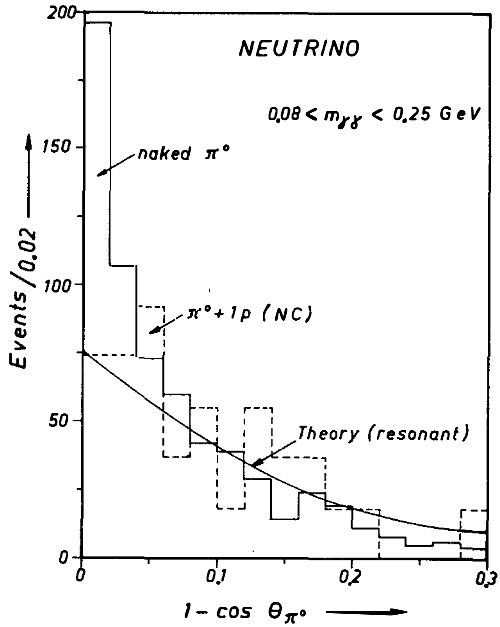

Fig. 1: Angular distribution of ν_μ produced, muon- and hadron-less π^o's: solid histogram = experiment[9], smooth line = theory of resonance production[4], dashed histogram = incoherent contrôle sample with visible recoil proton.

in the forward direction! Clearly, the resonance production theory of Rein and Sehgal[4)] (smooth line) is incapable to describe it - even though the ν spectrum, and the experimental acceptance have properly been folded in.

Fortunately, we have been warned in advance by Otto Nachtmann[10)] that such a peak might show up and signalize the coherent production of neutral pions by a neutral current off the nucleus as a whole. The relevant diagram is given in Fig. 2:

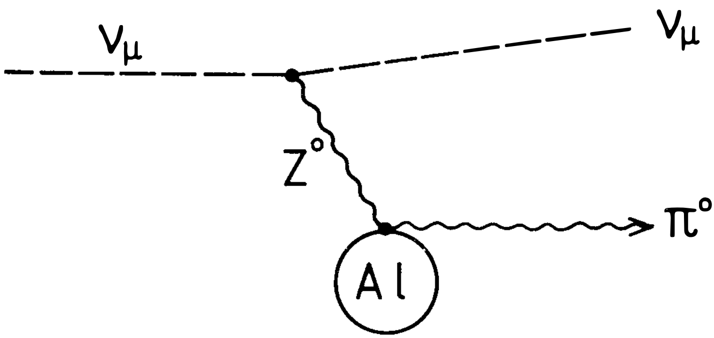

Fig. 2: Coherent π^o production by the neutral weak current (= the Z^o) off a nucleus.

An incoming neutrino "radiates" the quantum of the weak neutral force Z^o, and this converts[*)] into a π^o, with the nucleus, as a spectator, taking up some excess momentum q. The nucleus stays together, provided $|q| \lesssim R_{Al}^{-1} = 53$ MeV, and no quantum numbers $\neq 0$ are exchanged. Under these conditions the contributions from all the nucleons in the nucleus add up coherently; the cross section goes with A^2 (or nearly so[11)], as it is known from coherent pion photo-production). And most important: In the forward direction only the divergence of the neutral current is active. But the vector part of it vanishes, because of CVC. Thus coherent meson production tests the axial vector part of the neutral weak current by itself! Its mere existence shows there is an axialvector part - and that the pion is produced

*) Beginners in quantum mechanics have difficulties with an axialvector particle transforming into a pseudoscalar. But the detailed analysis shows, that the Z^o, under these very special kinematical conditions, reduces to an effective pseudoscalar.

(but not the eta) demonstrates that this piece is isovector - indeed a very specific ingredient of the standard model of electro-weak interactions[5].

In view of the importance of the matter, we tried to get an experimental proof that coherent production has been seen: we collected a (small) contrôle sample of NC produced π^o's, where a proton recoil at the production vertex signalizes that the process had happened at a single nucleon. As may be seen from the dashed histogram in Fig. 1, these incoherent events do not show the peak in question. Moreover, they follow the theoretical resonance production curve quite well.

As it is expected from the detailed theory of Lackner's[11], the coherent production is more pronounced at higher energies, and we have checked this by suitable cuts. Its absolute cross section can be got from PCAC, and we are in agreement with that within a factor of 2. Antineutrinos are expected to have the same cross section (of course!), and our (small) antineutrino sample does show a peak.

Summing up we may say that Aachen-Padova have, for the first time, seen coherent π^o production by neutral currents off a complex nucleus. This shows that an axialvector piece is involved, and that it is isovector, as demanded by the standard model. Following Lackner the analysis can be extended as to exclude also more remote possibilities as tensor or scalar interactions.

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References

1) Milla Baldo-Ceolin, Proc. Neutrino '75, Balaton (1975), Vol. I p. 166
H. Faissner, ibid. Vol. I p. 116

2) H. Faissner et al., pres. Traudl Hansl, Proc. Neutrino '76, Aachen (1977), p. 278

3) H. Faissner et al., Phys. Lett. 68B (1978) 377

4) D. Rein and L.M. Sehgal, Annals of Physics (N.Y.) 133 (1981) 79

5) S.L. Glashow, Rev. Mod. Phys. 52 (1980) 539
A. Salam, ibid, p. 525
S. Weinberg, ibid, p. 515
and ref. quoted there.

6) E. Monsay, Phys. Rev. D18 (1978) 2277; Phys. Rev. Lett. 41 (1978) 728

7) W. Krenz et al., Nucl. Phys. B135 (1978) 45
O. Erriques et al., Phys. Lett. B73 (1978) 350

8) R.P. Feynman, M. Kislinger, and F. Ravndal, Phys. Rev. D3 (1971) 2706

9) H. de Witt, Doctoral Thesis, Aachen Tech (1981), and Talk at Neutrino '80 (Erice), unpublished

10) O. Nachtmann, private communication at the occasion of the Hamburg 1977 Lepton Conference. The theory of coherent NC meson production was worked out by his student Lackner[11,12]

11) K.S. Lackner, Nucl. Phys. B153 (1979) 526

12) K.S. Lackner, Nucl. Phys. B153 (1979) 505