Later we were joined by Ron Martin and Guarang Yodh. The experiments measured the transmission of the hydrogen; the effective cross section for the reaction in question being simply the negative logarithm of the transmission divided by the number of atoms per square centimeter in the hydrogen target.

The results showed the cross sections for negative pions rising about linearly with the energy up to 100 MeV or so and then appearing to level off at about 60 millibarns, the expected "geometrical" value, i.e., π times the pion Compton wavelength squared. This type of energy dependence was expected by the theoretical calculations then in vogue, which used expansions in terms of the pion-nucleon coupling constant ("weak coupling" theory) and assumed the coupling favored P-states (pseudo vector coupling). The positive pion cross sections for a more limited range of energies seemed to be rising in a similar way but at the energies then available had not "leveled off."

Charge Independence and the Resonance

At first it puzzled us all: why did the positive pion reactions proceed more strongly than the negative pion reactions, considering that the only channel open for positive pions at low energy was the elastic one,

$$\pi^+ + P \rightarrow \pi^+ + P \quad ,$$

whereas for negative pions the three reactions,

$$\pi^- + P \rightarrow \pi^- + p \quad \text{(elastic scattering)} \ ,$$

$$\pi^- + P \rightarrow \pi^0 + N \quad \text{(charge exchange), and}$$

$$\pi^- + P \rightarrow \gamma + N \quad \text{(radiative capture),}$$

all can proceed.

Anderson gives, in a review article,* an account of how Fermi reacted to a paper by Keith Brueckner, which came, and purported to explain the relative strengths of these several reactions and their energy dependence, and notably predicted a peak in the cross sections (other than the radiative one) at about 180 MeV, how quickly Fermi appreciated what Brueckner had to say, and how we regained the initiative.

In his paper Brueckner introduced a phenomenology based on earlier ideas of strong coupling meson theory and the charge independence of nuclear forces, ideas which had had a long prior history. Forgive me for reminding you of them.

Charge symmetry of the nuclear force:

$$\text{N N force} = \text{P P force and}$$

$$\pi^- \text{N force} = \pi^+ \text{P force} \quad .$$

Charge independence:

$\left.\begin{matrix}N\\P\end{matrix}\right\}$ form a doublet, the *nucleon*, whose interactions with other nucleons (or pions) is independent of the charge state. The three pions form a triplet, the *pion*,

$$\pi : \quad \left.\begin{matrix}\pi^+\\ \pi^0\\ \pi^-\end{matrix}\right\} .$$

In analogy with an ordinary spin (J) multiplet, the multiplicity is connected with the *isospin*; for example, the nucleon isospin is one-half and the corresponding multiplicity is

$$(2 \times \tfrac{1}{2} + 1) = 2 \quad ,$$

and evidently the pion isospin must be unity since the pion forms the triplet $I_\pi = 1$. The quantum mechanical rules for combining I-spin states are identical to those for ordinary angular momentum.

The further assumption that there is a *resonance* in the cross section between pion and nucleon, at about 180-MeV pion energy in the $I = 3/2$, $J = 3/2$ state, led Brueckner to the prediction that near 180 MeV the intensity ratios for the reactions

$$\pi^+ + P \rightarrow \pi^+ + P \quad ,$$

$$\pi^- + P \rightarrow \pi^0 + N \quad \text{, and}$$

$$\pi^- + P \rightarrow \pi^- + P$$

would have the relative strength 9 : 2 : 1. Some mighty strong indications of this seemed to be in the data although the ratios were not exactly 9 : 2 : 1.

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*H. L. Anderson, *Journal De Physique*, Supp. au No. 12, Tome 43 (December 1982), pp. c8-101.