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DETERMINATION OF AN UPPER LIMIT FOR THE PARTIAL WIDTH $\Gamma(\rho\pi\gamma)$ G. Fidecaro^{*†}), M. Fidecaro^{*}), P. Schiavon[†])

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1. The width of the $\rho \rightarrow \pi\gamma$ decay has been the subject of extensive experimental and theoretical investigations.

The existing theoretical predictions follow three main lines:

- a) the pole approximation, in which the decay is represented as

$$\rho \rightarrow \pi + \omega^{1,2,3,4,5})$$

$\searrow \gamma$
- b) SU_3 or SU_6 unitary symmetry schemes, which allow to predict the ratio between the decay probability of various bosons of the same multiplet^{6,7,8)}
- c) quark models, which allow to calculate the absolute value of the decay width^{9,10)}, from the magnetic moment of the quarks.

The conservation law of Bronzan and Low¹¹⁾, which forbids the $\rho \rightarrow \pi\gamma$ decay, could be considered as a fourth line of approach.

The predictions for the width of the $\rho \rightarrow \pi\gamma$ decay mentioned above, range from zero to a few MeV, so that a comparison with experiments is necessary. It would be particularly interesting to check the predictions of b) and c). These give for the width $\Gamma(\rho\pi\gamma)$ values of the order of a tenth of MeV.

The present experimental information has been summarized in Table I, where P indicates momentum and M mass.

Only one of the experiments reported in Table I is based on an attempt to detect directly the $\rho \rightarrow \pi\gamma$ decays¹¹⁾. The other results

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have all been indirectly derived from phenomena in which the $\rho\pi\gamma$ coupling constant does not play the main role. These results are therefore all affected by uncertainties of model.

One should also mention the attempts of getting the $\gamma\pi\rho$ coupling constant from photo-production experiments of pions near threshold¹⁹⁾ from radiative scattering of low energy pions²⁰⁾, and from deuteron electromagnetic interaction²¹⁾.

2. The experiment described here was aimed at a search of the $\rho \rightarrow \pi\gamma$, through a study of events of the type $\pi^- p \rightarrow p\pi^- \gamma$.

The spark chamber set up is shown in Fig. 1. The two 140 cm diameter, 10 metre focal length lucite lenses, used to converge the light rays into the two cameras, are also indicated. The spark chambers, except the proton range chamber, were all made of thin aluminium plates, each 0.025 mm thick.

A total of $4.4 \cdot 10^9$ pions, having a momentum of 2.45 ± 0.9 % GeV/c, traversed the 20 cm long, 3 cm diameter liquid hydrogen target, after passing through counter 1a (not shown in the figure), counter 1b and through the holes of the anticoincidence counters $\bar{2}$ and $\bar{3}$.

The proton telescope, defined by counters 4, 5 and $\bar{6}$, was set at the maximum angle allowed by the kinematics of the reaction $\pi^- p \rightarrow X^- p$ for $m_X = 750$ MeV, and accepted protons in the momentum interval 330 - 600 MeV/c, corresponding to a momentum transfer of $3.6 \leq \Delta^2/\mu^2 \leq 18.2$. The momentum of the proton was determined with an uncertainty of 12 MeV/c by means of a measurement of its range. This accuracy was sufficient for a good determination of the mass m_X , because of the particular kinematical configuration chosen for the production reaction. The pion background was eliminated from the proton telescope by means of a correlation between the pulse height of counter 5 and the range of the particle. Counter 4, placed inside the vacuum jacket, determined the effective length of the target, which was 6 cm, and eliminated events produced in the mylar walls of the target.

The approximate direction of the ρ^- , at about 9° with the beam axis, is also indicated in Fig. 1. The decay of the ρ^- was observed in the system of spark chambers located behind the hydrogen target. The γ -rays were converted in the 3 mm thick lead plates. Counter 7 was used to ensure that one, and not more than one, charged particle had been produced in the forward direction, and counter 9 to ensure that at least two charged particles had reached the end plate of the decay spark chamber. However, part of the pictures were taken without these requirements.

The apparatus was mounted on a sturdy support in order to guarantee a long-term general stability for the geometrical reconstruction, of the order of a tenth of a millimetre. The alignment of lenses, mirrors and reference points was done with the highest precision allowed by good optical survey instruments.

3. A total of about 350,000 pictures, taken under various trigger conditions, were first scanned in order to select events with a recoil proton track in the proton chambers, and a charged particle accompanied by one or two gamma rays in the decay chambers.

The selected events were measured by aligning the ruler of a polar co-ordinatometer along the reprojected track of each particle. The polar co-ordinates of the corresponding straight lines were automatically punched on a 5-hole paper tape. The conversion point of the gamma rays were also recorded in the same co-ordinates.

The events were then analysed by means of Fortran programmes on the various CERN computers. The "one gamma" events were treated separately.

The computer performed the following operations:

- a) reconstruction in space of the trajectory of the various particles, taking into account also the spherical aberrations of the lucite lenses
- b) a geometrical fit
- c) a kinematical fit.

An accurate study of the input errors for the computer programmes was also made. Because of the small angle that the particles made with the electric field of the spark chambers, it was assumed²²⁾ that the main source of errors was in the evaluation of the pictures. A number of events representing a sample of the various possible geometrical configurations were therefore measured up to fifty times. The resulting distributions of projected angles and projected displacements enabled the attribution of specific errors to the various particles. Typical errors for the incoming and outgoing pions were of the order 2-3 mrad. In the case of the proton, an important contribution to the error came from the multiple scattering in the liquid hydrogen and in the other material near the target.

An attempt was made to improve further the accuracy of measurement by using a more refined measuring instrument. However, this line was abandoned as soon as it was realized that no important improvement could be easily obtained.

Figure 2 shows the distribution of the standard error for the mass of the ρ^- after the geometrical fit had been performed. As an over-all mass resolution, the value corresponding to the peak of the histogram can be taken. It corresponds to a mass resolution of ± 10 MeV.

4. The "two gamma" events were reconstructed as events of the type $\pi^- p \rightarrow p \pi^- \pi^0$ by means of a programme in which the direction of one of the two observed gamma rays was compared with the direction calculated from all the other particles observed. The χ^2 distribution of the "two gamma" events with the ρ^- mass in the interval $650 \leq m \leq 850$ is shown in Fig. 3. It is slightly wider in comparison with the distribution expected for a two constraint fit as if the errors had been underestimated by a factor 1.2. However, further work showed that the wider distribution is more likely to be connected with the fact that a kinematical fit of the events was not made.

It was therefore assumed that the events with $\chi^2 < 15$ were all decays of the type $\rho^- \rightarrow \pi^- \pi^0$. Further tests were made on these events to calibrate and check the apparatus.

First the combination of a Breit and Wigner curve²³), having an assigned width of 125 MeV, plus a phase space background, was fitted to the experimental distribution of the mass m_ρ , corrected for experimental efficiency by means of a Monte Carlo calculation. Figure 4 shows the experimental mass spectrum and the calculated one. From these calculations one derives:

- a) for the mass of the ρ^- , a value $m_{\rho^-} = 772 \pm 19$ MeV
- b) that in the course of the experiment $(4.6 \pm 0.2)10^5$ ρ 's were produced in the whole solid angle. This result is in agreement with the cross-sections of the Orsay, Saclay, Bari, Bologna collaboration²⁴), within the uncertainties of the present experiment
- c) that out of the 2600 two gamma events mentioned above 1820 ± 74 were ρ 's.

Secondly, the $\rho^- \rightarrow \pi^- \pi^0$ events were used to check the efficiency of the gamma ray spark chamber system, as a function of energy. Figure 5 shows a comparison between the energy spectrum of the γ -rays coming from the observed $\rho^- \rightarrow \pi^- \pi^0$ events and the energy spectrum of a number of γ -rays from π^0 decay computed by means of a Monte Carlo calculation. The artificial π^0 's had the same energy and spacial distribution as the real events. The gamma rays were selected according to the geometry of the apparatus. Within the statistics the result is compatible with an over-all efficiency of 100%.

5. The "single gamma" events were analysed as $\pi^- p \rightarrow p \pi^- \gamma$ events. Because of the smallness of the $\rho^- \rightarrow \pi^- \gamma$ / $\rho^- \rightarrow \pi^- \pi^0$ branching ratio, the majority of the "single gamma" events were expected to be $\rho^- \rightarrow \pi^- \pi^0$ decays in which one of the gamma rays was missing, either for geometrical reasons or for detection inefficiency.

In order to improve the observed ratio of $\rho^- \rightarrow \pi^- \gamma$ decays over the background of $\rho^- \rightarrow \pi^- \pi^0$ decays a selection of the events was first made on the basis of the following criteria:

- a) the mass of the missing particle m_ρ should be between 650 and 850 MeV

- b) the angle ϑ^* between the incident and the outgoing pion in the rest system of the missing particle should be such that $-0.5 \leq \cos \vartheta^* \leq +0.5$. This selection was made because one expected that if the $\rho^- \rightarrow \pi^- \pi^0$ decays showed a $\cos^2 \vartheta^*$ angular distribution, the $\rho^- \rightarrow \pi^- \gamma$ decays should show a $\sin^2 \vartheta^*$ ~~distrib-~~ distribution.

The χ^2 distribution of the "single gamma" type events, reconstructed with the same method already explained for the case of the two gamma events, was compared, in the region of the small χ^2 , with the expected χ^2 distribution of "single gamma" $\rho^- \rightarrow \pi^- \pi^0$ events, in order to subtract from the observed effect the background of $\rho^- \rightarrow \pi^- \pi^0$ events simulating $\rho^- \rightarrow \pi^- \gamma$.

The expected χ^2 distribution of "single gamma" $\rho^- \rightarrow \pi^- \pi^0$ events was computed in the following way. Each observed "single gamma" event was interpreted as $\rho^- \rightarrow \pi^- \pi^0$ event and the reconstructed π^0 was made to decay several times by means of a Monte Carlo calculation. Only those artificial events having a single gamma ray within the geometrical limits of the apparatus were retained for the computation of the theoretical χ^2 distribution. The normalization was obtained by comparison of the Monte Carlo produced "two gamma" events with the observed "two gamma" events.

The subtraction gave as a result zero, thus showing no evidence for $\rho^- \rightarrow \pi^- \gamma$ decay.

It should be noted that for large χ^2 the experimental χ^2 distribution was somewhat higher than the theoretical one. This fact was interpreted as due to the presence of multiple neutral pion production events among the observed "single gamma" events. A rough estimate, from the known cross-sections for multiple pion production, made this interpretation plausible.

In order to set an upper limit for the branching ratio $\rho^- \rightarrow \pi^- \gamma / \rho^- \rightarrow \pi^- \pi^0$ the events in the region of the small χ^2 were analysed with a new reconstruction programme which was based on a complete geometrical and kinematical fit of the events.

The obtained χ^2 distribution is shown in Fig. 6. Having verified, through tests made on the various parts of the reconstruction programme, that with the assigned errors the expected χ^2 distribution of the true $\rho^- \rightarrow \pi^- \gamma$ events had to be in agreement with the theoretical χ^2 distribution for a two constraint fit, all the events having $\chi^2 > 5$ were rejected. Assuming still applicable the result previously mentioned, i.e. that no real effect was present, a number equal to twice the standard deviation of the number of events with $\chi^2 < 5$ was taken as upper limit for the number of $\rho^- \rightarrow \pi^- \gamma$ events.

This corresponds to a branching ratio

$$\frac{\rho^- \rightarrow \pi^- \gamma}{\rho^- \rightarrow \pi^- \pi^0} < 0.5\% .$$

The upper limit for the width of the $\rho^- \rightarrow \pi^- \gamma$ is thus 0.6 MeV, with a statistical confidence level of 97%. However, if one takes into account the various uncertainties encountered in the evaluation of the experiment, the above-quoted upper limit should be considered as having an uncertainty of the order of 20%.

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T A B L E I

Ref.	Exp. Techn.	Reaction	Primary particle P (GeV/c)	Rho M (MeV)	Rho I (MeV)	$\Gamma(\pi\pi)$ (MeV)	Model used	Statistics
12	counters	$\gamma+p \rightarrow p+\pi^++\pi^-$	0.9-1.2	720	90	0.5	OPE	-----
13	counters and spark chambers	"	1.3	750	100	~ 0	OPE	$\sim 3.31 \cdot 10^4$
14	counters	"	5.5	750 ± 10	150 ± 10	1.5 ± 1.5	OPE + diff.mod.	$2.5 \cdot 10^4$
15a	H B C	"	0.5-2.0	725	150	$1.65^{+0.40}_{-0.60}$	OPE	145
15b				728 ± 8	175	< 1	OPE + diff.mod.	~ 330
16	H B C		0.3-5.5	729 ± 5	?	0.1	"	~ 280
17	propane B.C.	$\pi^- + Z \rightarrow \rho^- + Z$	15			< 0.7	---	12
18	H B C	$\pi^+ p \rightarrow p \rho^+ \pi^+ \gamma$	1.6			< 2	---	252

Figure Captions

Fig. 1. Experimental set up. The side view of the proton spark chambers is photographed through the mirror shown in the front view. The dimensions of the scintillation counters are collected in the following table:

Scintillator	Size	
1a	$60 \times 7 \times 4$	mm ³
1b	$\emptyset 40 \times 1.5$	"
$\bar{2}$	18×10	"} dimension of hole
$\bar{3}$	20×10	
4	$60 \times 36 \times 1.5$	"
5	$160 \times 150 \times 20$	"
$\bar{6}$	$310 \times 310 \times 15$	"
7	$240 \times 240 \times 10$	"
$\bar{8}$	$50 \times 60 \times 10$	"
9	$1000 \times 1000 \times 20$	"

Fig. 2. Distribution of the standard errors of the mass of the missing particles. The peak corresponds to a mass resolution of ± 10 MeV.

Fig. 3. χ^2 distribution of reconstructed "two gamma" events.

Fig. 4. Observed mass distribution non-corrected for experimental efficiency. The higher curve is the superposition of a Breit and Wigner curve and the phase space background also shown in the figure.

Fig. 5. Energy spectrum of the γ rays from the "two gamma" events. The dotted line has been computed by means of a Monte Carlo calculation. The two spectra are practically identical so that one can assume that the efficiency of the gamma spark chambers was close to 100%.

Fig. 6. χ^2 distribution of "single gamma" events. A complete kinematical fit programme was used. True $\rho^- \rightarrow \pi^- \gamma$ events should cluster below an exponential decaying with a mean $\chi^2 = 2$.

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Fig.1

Fig. 2

Fig. 3

Fig. 6

χ^2 - distribution of $(p\pi\gamma)$ events
fitted as $\pi^-p \rightarrow \pi^-p\gamma$
 $.650 \leq m_\gamma \leq .850 \text{ MeV}$
 $-.5 \leq \cos \theta_{\pi\pi}^* \leq .5$