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**A Measurement of the $\bar{p}p \rightarrow \pi^+ \pi^-$ Reaction
for $158 \leq p(\bar{p}) \leq 275$ MeV/c**

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Abstract

A measurement of the total cross-section for the reaction $\bar{p}p \rightarrow \pi^+ \pi^-$ has been performed for 7 values of the incident momentum between 158 and 275 MeV/c. The values obtained, if compared with previous results at higher momenta, agree with a $1/\beta$ dependence. The differential cross-section summed over the whole incident momentum range has also been measured and the result of a fit by Legendre polynomials is given.

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The understanding of low energy $\bar{p} p$ annihilation is still an open question. Annihilations into two mesons, because of their kinematic simplicity are of particular interest ⁽¹⁾. Amongst the various processes of this type, the experimental knowledge of the reaction:

$$\bar{p} p \rightarrow \pi^+ \pi^- \quad (1)$$

below 300 MeV/c is either poor ⁽²⁾ or indirect ⁽³⁾. The LEAR PS170 experiment at CERN has been designed primarily in order to study the electromagnetic form factor of the proton via the reaction:

$$\bar{p} p \rightarrow e^+ e^- \quad (2)$$

However a fraction (10^{-3}) of the two charged hadrons (K^+K^- or $\pi^+\pi^-$) annihilation has also been recorded for monitoring purpose. We present here results concerning reaction (1) for 7 bins of incident momentum between 158 and 275 MeV/c. The whole $\bar{p}$ momentum spectrum is obtained in one exposure by energy loss in our liquid hydrogen target. The highest value is the beam momentum at the target entrance whereas the lowest momentum corresponds to a cut in the data necessary to avoid any contamination from annihilations at rest in the in-flight events. This measurement has been made possible by the quality of the beam ($\Delta p/p = 10^{-3}$) and by the resolution of our detector. The results presented here correspond to a total flux of 2.02×10^{10} $\bar{p}$ impinging on the target, the effective flux for reaction (1) being 2.02×10^7 $\bar{p}$.

The apparatus, fig. 1, is described in detail elsewhere ⁽⁴⁾. We recall here its main features. A 30 cm long, 6 cm diameter liquid hydrogen target and a central detector (CD) consisting of 4 layers of multiwire proportional chambers with cathode strips analog read-out are placed inside a 1 Tesla C-magnet with a gap of 40 cm and polar faces 1 m in diameter. The resolution of the chambers, in the horizontal deflecting plane, varies between 120 and 320 μm , depending on the impact angle of the track on the chamber. The resolution in the vertical direction is 1.2 mm. Right outside the central detector there is a ring of gas Cerenkov counters for the selection of reaction (2), followed by a second position detector of drift tubes (DTR) with a 300 μm resolution to improve the momentum measurement. The $\Delta p/p$ thus obtained is 2% for the pions of 928 MeV/c outgoing from $\bar{p} p$ annihilations at rest and of comparable value in the range 870 + 1060 MeV/c of our in-flight events. Behind the drift tubes follows a first hodoscope of trigger scintillation counters (H1). A second hodoscope (H2) is placed after the first two layers of a (lead + streamer tubes) shower detector contributing to the selection of electrons in reaction (2).

The beam flux is recorded by counting in fast scalers the number of gated coincidences between two counters H0 and B0. The B0 counter, not shown in fig. 1, is 37 m upstream. H0 is a hodoscope of 6

counters 1 mm thick and 1 cm wide, at the target entrance. The trigger of reaction (1) requires 2 and only 2 hits in the H1×H2 hodoscopes in coincidence and no hit in the anticoincidence counters covering the dead solid angle of the magnet (poles and yoke). The 2 hits in H1×H2 have to satisfy a fast correlation matrix programmed according to the pattern of two-body kinematics computed by a Monte-Carlo calculation and properly widened to avoid any bias.

A pattern recognition in CD and DTR for two charged tracks pointing to the hit H1×H2 counters was followed by an iterative momentum and direction reconstruction and by a fit to the two-body kinematics. Fig. 2 shows the squared mass spectrum of the outgoing particles for the two-body in-flight events. The pion and kaon peaks stand clearly out and are well separated. The background below the pion signal negligible. Because of the smaller cross section and the higher background level the kaon signal requires the analysis of a larger set of data (in progress) to provide significant results.

A residual range (RR) is defined as the difference between the nominal full range at 275 MeV/c (8.7 cm) and the track length of the incident antiproton measured between the target entrance and the interaction vertex. Fig. 3 gives a scatter plot of RR vs the opening angle (Θ) of the two outgoing particles for events satisfying loose cuts around the kinematics of the two pion annihilations, including annihilations at rest. The signal of in-flight $\pi^+\pi^-$ events stands clearly out for $163^\circ < \Theta < 176^\circ$ and $1.0 < \text{RR} < 8.7$ cm i.e. for antiproton momenta between 158 and 275 MeV/c.

The GEANT ⁽⁵⁾ Monte-Carlo program has been implemented with a detailed description of our apparatus, efficiencies included and an interface to our reconstruction program has been written. This allows the determination of both the total and the differential acceptance×efficiency factors, including the reconstruction efficiency. A satisfactory understanding of the differential acceptance, essential for both reaction (1) and (2), has been obtained ⁽⁴⁾.

By subdividing the events in bins of 1 cm in RR, as allowed by the resolution, we obtain the cross section values as a function of the incident momentum summarized in table I and shown in fig. 4. The results include a correction (1%/cm) of the beam flux for the attenuation due to the total cross section of 240 mb ⁽⁶⁾. The efficiency for each bin was computed by Monte-Carlo events generated according to the experimental differential cross-section discussed below. This obviously required an iteration. A slight fall of the efficiency for the shortest RR is due the Θ cut which had to be applied in order to exclude the annihilations at rest.

A K/β (lab.) fit can be drawn through our cross sections and those in ref. (7)-(10), as it is shown in fig. 4, with K a constant determined by the fit as $(.241 \pm .006)$ mb. The results from ref. (11) and (12), that could only be read from figures, are not reported in fig. 4. However ref. (11) follows the general trend while ref. (12) would indicate a different pattern.

Due to the very small spread in $\sqrt{s}$ (13 MeV) in this sample, we have used the whole statistics of 349 events for the differential cross section shown in fig. 5 and reported in table II; the

average momentum is 220 MeV/c. A fit by Legendre polynomials is also reported in fig. 5. The number of polynomials used has been determined by the leveling off of the χ^2 probability. The coefficients of the fit are reported in table III.

The coefficients of the polynomials of order 1,2 and 3 are not compatible with zero, indicating a large contribution of p and possibly d-waves even at these low energies. Their values follow the trend of previous results at higher energies (9), (10).

Our results concerning both the total and the differential cross section supply further checks and constraints to models such as that recently published by M. Kohno and W. Weise ⁽¹⁾, ⁽¹³⁾ for energies above 300 MeV/c and based on quark rearrangement and quark-antiquark annihilation, with which they are in qualitative agreement.

TABLE ICross section for $\bar{p} p \rightarrow \pi^+ \pi^-$.

$p_{Ave} (MeV/c)$	Events	$\sigma (mb)$
173	56	1.53(.20)
198	44	1.06(.16)
216	50	1.13(.16)
231	53	1.17(.16)
243	43	0.94(.14)
254	39	0.84(.14)
266	64	0.80(.10)

TABLE II

Differential cross section for the whole sample of events.

The average incident momentum is 220 MeV/c.

$\cos(\theta (\pi^-)_{(CM)})$	Events	$d\sigma/d\Omega (\mu b/sr)$
-.65	2	11.0 (7.8)
-.55	1	3.8 (3.8)
-.45	2	5.8 (4.1)
-.35	4	9.8 (4.9)
-.25	3	7.2 (4.1)
-.15	5	13.3 (6.0)
-.05	5	14.8 (6.6)
+.05	13	40.1(11.1)
+.15	13	40.1(11.1)
+.25	11	29.3 (8.8)
+.35	36	76.6(12.8)
+.45	41	75.5(11.8)
+.55	65	116.6(14.5)
+.65	84	177.0(19.3)
+.75	61	223.0(28.6)

TABLE III

Coefficients of Legendre polynomials

$$4\pi a_0 = (1.07 \pm .13) \text{ mb}$$

i	1	2	3	4
a_i/a_0	1.73(.29)	1.92(.50)	0.71(.23)	0.54(.31)

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Figure captions

- Fig. 1 - Apparatus.
- Fig. 2 - Squared mass distribution of the outgoing particles for in-flight 2-body events.
- Fig. 3 - Scatter plot of residual range (RR) vs $\pi^+\pi^-$ opening angle (Θ). The annihilation-in-flight signal is clear for range above 1 cm and angle between 163 and 176 degrees.
- Fig. 4 - Cross section for $\bar{p} p \rightarrow \pi^+ \pi^-$ as a function of $\bar{p}$ laboratory momentum. Errors are purely statistical, MC included. The curve represents a const/β fit.
- Fig. 5 - $\bar{p} p \rightarrow \pi^+ \pi^-$ differential cross section $d\sigma/d\Omega$. Errors are purely statistical, MC included.

Fig. 1

fig. 2

fig. 3

fig. 4

fig. 5