EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

OBSERVATION OF A NARROW RESONANCE NEAR THE $\bar{p}p$ THRESHOLD

W. Brückner*), B. Granz, D. Ingham**), K. Kilian, U. Lynen***), J. Niewisch,
B. Pietrzyk, B. Povh, H.G. Ritter and H. Schröder
Max-Planck-Institut für Kernphysik, Heidelberg, Germany
Physikalisches Institut der Universität Heidelberg, Germany
CERN, Geneva, Switzerland

ABSTRACT

Annihilation and elastic cross-sections of $\bar{p}p$ have been measured between 400 and 850 MeV/c. In both cross-sections a resonance is observed at a mass of 1939 ± 3 MeV. For its natural width an upper limit of $\Gamma \lesssim 4$ MeV is obtained.

Geneva - 22 December 1976
(Submitted to Physics Letters B)

---

*) Now at LBL, University of California, Berkeley, Calif., USA.

**) Now at University of Minnesota, Minneapolis, Minn., USA.

***) Now at Gesellschaft für Schwerionenforschung Darmstadt, Federal Republic of Germany.

The discovery of the J/ψ particle has largely removed the prejudice according to which narrow resonances should not be seen at energies of few GeV. It stimulated, in particular, the re-investigation of the $\bar{p}p$ system at low momentum with regard to possible narrow structures in this system. There are some experimental indications of resonances in the $\bar{p}p$ system close to the threshold, but their existence has not been proved beyond doubt[1,2].

The origin of narrow resonances, however, is believed to be very different from that of the J/ψ particles. One speculates that, close to the $\bar{p}p$ threshold, proton and antiproton may form long-living nuclear states[3,4]. In analogy to the positronium one calls this system baryonium. The baryonium is bound to a nuclear force and its typical dimension is that of a light nucleus, i.e. about 2 fm. A similar way of looking at these states has been put forward by Chew and Rosenzweig[5], who treat the baryonium as an exotic meson composed of di-quark and di-antiquark. Only high angular states of baryonium should be observable, since only in these states is the annihilation suppressed because of the relatively small overlap between the proton and antiproton wave function. A quantitative estimation of the annihilation probability in these states is completely uncertain[6]. Therefore it is very interesting to find out whether baryonium states are observable or not. The investigation of these states would provide direct information on the nuclear force. The best experimental evidence is offered by a narrow state in the $\bar{p}p$ system at a mass of about 1935 MeV. Carroll et al.[7] report on a resonance at $E_{cm} = 1932 \pm 2$ MeV in the total absorption cross-section with a width of 9^{+4}_{-3} MeV. In a recent bubble-chamber experiment[8] a resonance at 1936 ± 1 MeV and a width of $8.8^{+4.3}_{-3.2}$ MeV has been seen in the total elastic cross-section and, with lower confidence level, in the inelastic cross-section.

Bearing in mind the obvious experimental discrepancies, which have been governing for a long time the so-called "s-meson" region just above the $\bar{p}p$ threshold, the aim of our experiment was to study the energy dependence of some topological $\bar{p}p$ cross-sections with high resolution ($\Delta E < 4$ MeV in E_{cm}) and good statistics in a counter experiment.

Our experimental set-up is shown in Fig. 1. It consisted of a symmetric magnetic spectrometer (described in detail in Ref. 9), which focused the $\bar{p}$ beam on a LH_2 target. The nominal momentum of the beam was varied from 406 to 841 MeV/c. This corresponded to a c.m. energy range from 1915 to 2031 MeV, including the energy losses in the target. The momentum acceptance of the spectrometer was ±1.2%, thus ensuring a reasonable $\bar{p}$ rate also at a very low momentum. The $\bar{p}$ were identified by the time of flight between the entrance of the spectrometer and the target, as well as by a lucite Č-counter to veto the other particles. The momentum of each $\bar{p}$ was individually determined by measuring the trajectory via the drift chambers W1, W2, and W3. In this way a momentum resolution of ±1 MeV/c [9] was obtained. LH_2 targets 3.5 cm and 8 cm thick were used. The thickness of 8 cm limited our experimental resolution to 4 MeV at $p_{\bar{p}} \approx 500$ MeV/c.

The following counter arrangement enabled us to study the $\bar{p}p$ annihilation and scattering: The LH_2 target was used as a Čerenkov counter (LH_2) for charged particles with $\beta > 0.9$. The target was surrounded by a scintillator hodoscope (SH), which covered 50% of the solid angle. Above and below the target we had four arrays of four lead-glass counters (LG). In the forward direction another scintillator hodoscope (FH) was placed 1 m behind the target to distinguish fast charged particles from scattered $\bar{p}$ by time of flight and pulse height. The coordinates of the scattered $\bar{p}$ were measured with the drift chamber W4. The signatures for different particles were given for charged annihilation products by $LH_2 \vee SH \vee FH(\pi\text{-TOF})$ for scattered $\bar{p}$ by $FH(\bar{p}\text{-TOF})$ and for neutral annihilation products by $LG \wedge \overline{SH} \wedge \overline{BH}$.

In this way, we were able to measure the energy dependence of three topological cross-sections: (i) the total charged cross-section, (ii) the elastic cross-section up to a scattering angle of $\theta_{cm} \sim 60°$, and (iii) the neutral cross-section. In principle, also other cross-sections -- as for different multiplicities or backward scattering -- can be studied. However, the statistics collected in the experiment for these special channels are too bad to be presented.

The excitation function for the $\bar{p}p$ annihilation into charged particles is plotted in Fig. 2. The measurement with empty target, which gives a 14% contribution to the 8 cm thick LH_2 target, is already subtracted. In the spectrum we observe with 4 standard deviations a resonance structure at 505 ± 15 MeV/c, corresponding to a c.m. energy $E_{cm} = 1939 \pm 3$ MeV. The experimental width is 25 ± 5 MeV/c. Comparing this data with the experimental resolution of 18 MeV/c, we get an upper limit of $\Gamma \leq 4$ MeV for the natural width of this resonance. The integrated charged annihilation cross-section for the resonance amounts to 26 ± 6 mb MeV. In the elastic cross-section from which we can detect roughly 50 to 60% of the total one, we observe -- despite the poor statistics -- also a line at 505 MeV/c with an integrated cross-section of 20 ± 10 mb MeV. .

Compared with the two previous experiments[7,8] the general energy dependence and the absolute values of the charged annihilation and elastic cross-sections agree rather well. In addition, in all three experiments a structure is observed at a c.m. energy of about 1935 MeV. But the results concerning this resonance can hardly be claimed to be consistent with one another. In the experiment of Caroll et al.[7], which was performed with much poorer resolution, the resonance that showed up in the total absorption cross-section had an integrated cross-section of ∿ 160 mb MeV, i.e. almost more than three times larger than our corresponding value. In the bubble-chamber experiment[8] the resonance has been mainly recorded in the elastic cross-section. Despite the comparable resolution, Chaloupka et al. observe a $8.8^{+4.3}_{-3.4}$ MeV broad peak with an integrated cross-section of ∿ 60 mb MeV, what one has to compare with our value for the elastic cross-section of 20 ± 10 mb MeV. The structure of the annihilation cross-section observed in Ref. 8 is less reliable and does not allow the determination of the resonance parameters independent of the elastic scattering. The integrated cross-section agrees approximately with ours.

We feel that the observation of a narrow resonance in the charged annihilation cross-section in the present experiment is a sufficient argument in favour of the existence of such a resonance in the $\bar{p}p$ system at 1939 ± 3 MeV. The discrepancies from the previous measurements are probably due to systematic errors which are not rare in an s-channel type of experiment. Nevertheless, the bubble-chamber data[8] seem to be consistent with ours within the experimental errors, but the results of

Caroll et al.[7] give a much too large total integrated cross-section to be in agreement. The short allocation of beam time for the present experiment did not allow for a significant identification of the resonance in the elastic channel. Only with the two contributions, annihilation and elastic, a more restrictive interpretation of the character of the resonance can be given. Nevertheless, already the existence of such a narrow resonance close to the $\bar{p}p$ threshold is of great importance. The only theoretical picture proposed for such resonances is the baryonium one. The uncertainty as to their observability by experiment was only due to the lack of knowledge of the lifetimes of these states. Despite the badly known character of the resonance, we nevertheless conclude that its existence very likely indicates that the baryonium states live long enough to be observable. Due to the fundamental interest in the baryonium properties, the result of the present experiment justifies a further intensified search for baryonium states.

We would like to thank Professor H.H. Thies for his assistance during the run. The continuous support of the CERN MPS group was essential for the success of the experiment. This work was supported by the Bundesministerium für Bildung und Wissenschaft, Bonn, Germany.

REFERENCES

1) A. Astbury, Proc. Symposium on Antinucleon-Nucleon Interactions, Liblice, 25-28 June 1974, CERN 74-18, p. 46.

2) T.E. Kalogeropoulos and G.S. Tzanakos, Phys. Rev. Letters 34 (1975) 1047.

3) L.N. Bogdanova et al., Ann. Phys. (N.Y.) 84 (1974) 261.

4) C. Dover, Proc. 4th Internat. Symposium on $\bar{N}N$ Interactions, Syracuse, N.Y., 2-4 May 1975 (Syracuse University, N.Y., 1975), Vol. 2, p. VIII 37-91.

5) G.F. Chew, States of baryonium within the hadron family, preprint LBL-5391, submitted to Phys. Letters B.
C. Rosenzweig, Phys. Rev. Letters 36 (1976) 679.

6) F. Myhrer and A. Gersten, Preprint CERN TH.2170 (1976).

7) A.S. Carroll et al., Phys. Rev. Letters 32 (1974) 247.

8) V. Chaloupka et al., Phys. Letters 61B (1976) 487.

9) W. Brückner et al., Phys. Letters 55B (1975) 107.

Figure captions

Fig. 1 : $\bar{p}$ beam and detection system: plastic scintillators (P), multiwire drift chambers (W), lucite Čerenkov counter (C), LH_2 target (LH_2), scintillator hodoscopes (SH and FH), lead-glass counters (LG).

Fig. 2 : Measured $\bar{p}p$ cross-sections: inelastic (two or more prongs), elastic and neutral cross-sections. The solid curves are the results of a fit to a smooth background and a Breit-Wigner resonance.

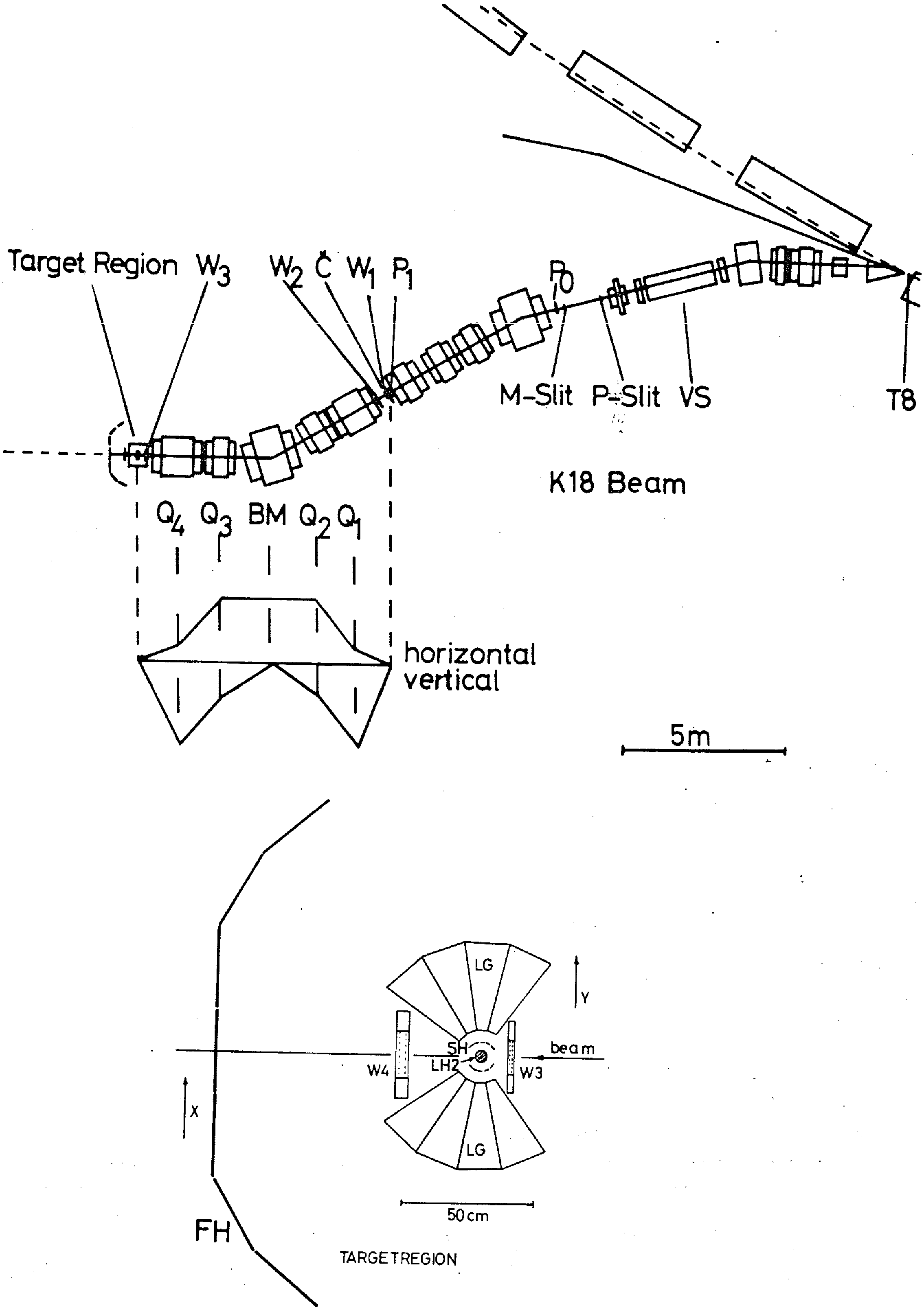
Target Region
W3
W2
C
W1
P1
P0
M-Slit
P-Slit
VS
T8
K18 Beam
Q4
Q3
BM
Q2
Q1
horizontal
vertical
5m
LG
Y
SH
beam
LH2
W4
W3
X
LG
50cm
FH
TARGETREGION

Fig. 1

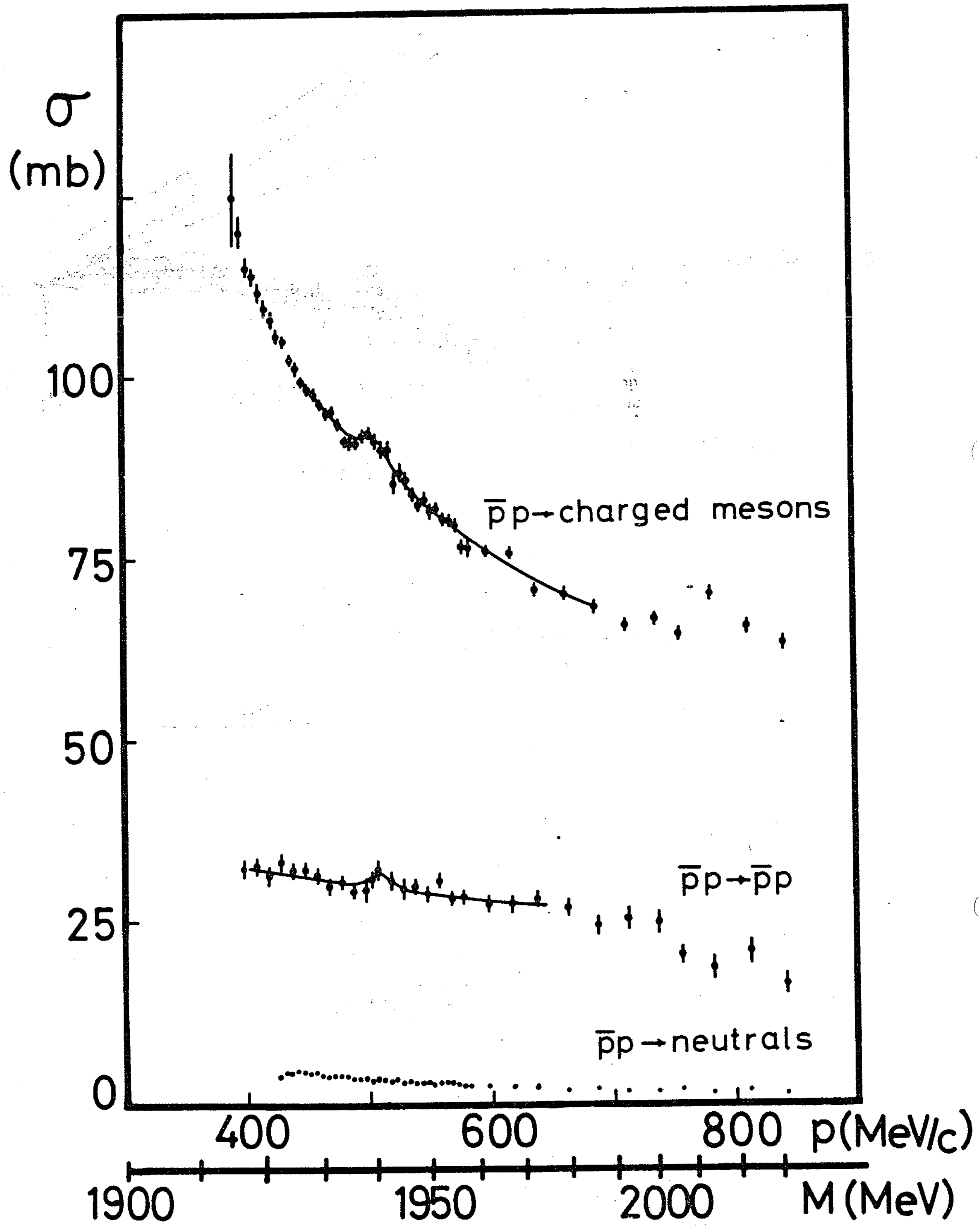
σ
(mb)
100
75
50
25
0
p̄p→charged mesons
p̄p→p̄p
p̄p→neutrals
400
600
800
p(MeV/c)
1900
1950
2000
M(MeV)

Fig. 2