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EVIDENCE FOR THE PRODUCTION OF HEAVY VECTOR MESONS IN ANTIPROTON-PROTON ANNIHILATION AT REST

G. Bassompierre*), G. Binder, P. Dalpiaz, P.F. Dalpiaz,
G. Gissinger, S. Jacquey, C. Peroni, A. Ruzza,
M.A. Schneegans and L. Tecchio

Institut des Sciences exactes et appliquées, Mulhouse, France
Centre national de la recherche scientifique, Strasbourg, France
Istituto di Fisica Superiore dell'Università e
Istituto Nazionale di Fisica Nucleare, Torino, Italy

ABSTRACT

Stopping antiprotons in a hydrogen target, 26 electron pairs have been found, which can be attributed to the reaction $\bar{p}p \to V^0(e^+e^-) + \pi^0$. The analysis of the data supports the existence of the $\rho''(1600)$ and the $\rho'(1250)$ mesons.

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*) Present address: L.A.P.P., Annecy-le-Vieux, France.

The existence of vector mesons with mass above that of the well-established ρ, ω, and ϕ has been predicted long ago on the basis of various theoretical approaches[1,2].

In the last years, much effort was spent on the search for the $\rho'(1250$ MeV) and $\rho''(1600$ MeV), first and second daughters of the $\rho(760)$ in the Veneziano recurrence theory. The resonant structure near 1600 MeV, appearing in e^+e^- annihilation experiments[3,4] and also observed in photoproduction experiments[5,6] can be interpreted as the $\rho''(1600)$ meson. In the 1250 MeV mass region, only an $\omega\pi^{\pm}$ enhancement, known as the B(1235) meson, is observed but the absence of a similar structure in 2π or 2K effective mass distributions seems to indicate that no vector meson is present in this mass region. However, various independent experimental indications of the possible existence of the $\rho'(1250)$ have been published in the last years. Although none of them seems conclusive, it is worth while to summarize here the experimental situation. In a bubble chamber experiment, Frenkiel et al.[7] have shown that a fit to their $\bar{p}p \to \omega\pi^+\pi^-$ angular distributions requires the presence of two structures around 1250 MeV: an $\omega\pi$ resonance with $J^P = 1^+$, but also a new vector meson state with mass and width compatible with the $\rho'(1250)$ and decaying into $\omega\pi$. Photoproduction experiments[8,9] are not conclusive on whether the observed effects are due to the B meson, Deck mechanism, or $\rho'(1250)$. Data from Novosibirsk[10] and more recently two independent results from Frascati[4,11,12], together with Orsay[13] data give some indirect hints at the existence of the $\rho'(1250)$ meson produced via e^+e^- annihilation into hadrons.

To establish the existence of vector mesons in this region, reactions where the resonance is produced without contamination from other channels, should be studied. In particular, the production of electron pairs plus neutrals in antiproton-proton annihilation seems very promising.

In this paper we present the analysis of our data on the reaction

$$\bar{p}p \to e^+e^- + \text{neutrals} \ , \qquad (1)$$

studied with antiprotons at rest.

Our data have been collected in an experiment still in progress at the CERN Proton Synchrotron (PS), where a beam of antiprotons is brought to rest in a liquid-hydrogen target, surrounded by four equal electron detectors composed of optical spark chambers, absorbers, and scintillators. A more detailed description of our set-up has already been published[14,15]. Note that our apparatus rejects hadronic processes to the level of 2.5×10^{-7} while detecting electron pairs with 52% efficiency.

Scanning a sample of 220,000 pictures, to select the events with two electrons in opposite blocks, we have found 60 pairs of electrons with energy above 700 MeV. Figure 1a shows the opening angle $\theta_{\bar{e}e}$ distribution of the whole sample of electron pairs. The narrow peak at 180° is due to collinear electron pairs produced in reaction

$$\bar{p}p \to e^+e^- \qquad (2)$$

at rest. Reaction (2) has been extensively studied elsewhere[14].

The contribution of reaction (2), produced in flight or at rest, is easily removed, selecting the electron pairs acoplanar with the beam direction, or/and showing a γ-ray on the picture. Applying these conditions, we are left with 26 events, distributed in $\theta_{\bar{e}e}$ as shown in Fig. 1b.

Two types of background, i.e. simulation of electron pairs, could contribute to this spectrum:

i) Uncorrelated electrons. One electron can be simulated by several processes:
   - a charged pion giving an interaction or a charge exchange;
   - a superposition of a pion and a γ-ray from the same annihilation;
   - a converted γ-ray;
   - one electron of a Dalitz pair.

ii) Two correlated electrons. The only processes to take into consideration are K^+K^- pair production where both kaons decay via $K^{\pm}_{e3}$, or a large-angle Dalitz pair produced by one π^0.

Each of the sources of uncorrelated background was studied separately by Monte Carlo calculations and by measurements on our data or on our calibrations. None of them contributes to our sample of 26 events by more than one event. Moreover, we have a very reliable over-all estimate of this type of background by counting the number of single "electrons" in our photographs. By single "electron", we mean an event where the particle in one detector has all the characteristics of an electron and the particle in the opposite detector is clearly a pion or a converted γ-ray. In 1000 photographs, we find an average of 3.0 single "electrons", corresponding to a simulation of approximately two electron pairs in our sample of 2.2×10^5 pictures.

The sources of background of the second type, where the two electrons have some correlation, were estimated by Monte Carlo calculation and found to contribute by less than 1‰ to the 26 pairs for electrons of energy above 700 MeV with opening angle larger than 120°.

The 26 "acoplanar" electron pairs observed in our experiment seem therefore mainly produced in interactions of the type

$$\bar{p}p \to V^0 + \pi^0 \quad , \qquad (3)$$
$$\qquad\quad \hookrightarrow e^+e^-$$

Processes involving more than one π^0 or higher mass neutrals are strongly depressed by phase space, and by the electron energy cut at 700 MeV. The ρ, ω, and ϕ vector mesons do not contribute to our sample, since they are practically out of our acceptance.

To determine the mass and the width of the objects produced in reaction (3), we have fitted the $\theta_{\bar{e}e}$ spectrum (Fig. 1b) with opening angle distributions calculated assuming Breit-Wigner mass distributions and isotropic production and decay. Assuming that only one vector meson, with mass $M \sim 1600$ MeV and width $\Gamma \sim 300$ MeV, is produced, the best fit yields a probability of 12%. Introducing a second vector meson with $M \sim 1250$ MeV and $\Gamma \sim 150$ MeV, we obtain a probability of 80%. The best fits, represented by continuous lines on Fig. 1b, give the following masses and widths:

$$M_{\rho'(1250)} = (1250 \pm 50) \text{ MeV}, \quad \Gamma_{\rho'(1250)} \sim 150 \text{ MeV}$$

$$M_{\rho''(1600)} = (1600 \pm 50) \text{ MeV}, \quad \Gamma_{\rho''(1600)} \sim 300 \text{ MeV} .$$

The production of the $\rho''(1600)$ meson seems thus established in $\bar{p}p$ annihilations, and its decay mode into e^+e^- is observed for the first time. The existence of the $\rho'(1250)$ is supported by our results, but a clear-cut statement requires larger statistics.

We have evaluated the branching ratio:

$$B_{\rho''} = \frac{\Gamma(\bar{p}p \to \rho'' + \pi^0)}{\Gamma(\bar{p}p \to \text{total})}$$

assuming $\Gamma[\rho''(1600) \to e^+e^-] = \Gamma[\rho(760) \to e^+e^-]$. Comparing this to the branching ratio for $\bar{p}p \to e^+e^-$ at rest[14], we obtain:

$$B_{\rho''} = (0.5 - 1)\% \ .$$

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Figure captions

Fig. 1a : Opening angle distribution of the 60 reconstructed electron pairs.

Fig. 1b : Opening angle distribution of the acoplanar electron pairs. The solid curves represent fits to the data assuming the production of two vector mesons of mass 1600 MeV (Γ = 300 MeV) and 1250 MeV (Γ = 150 MeV).

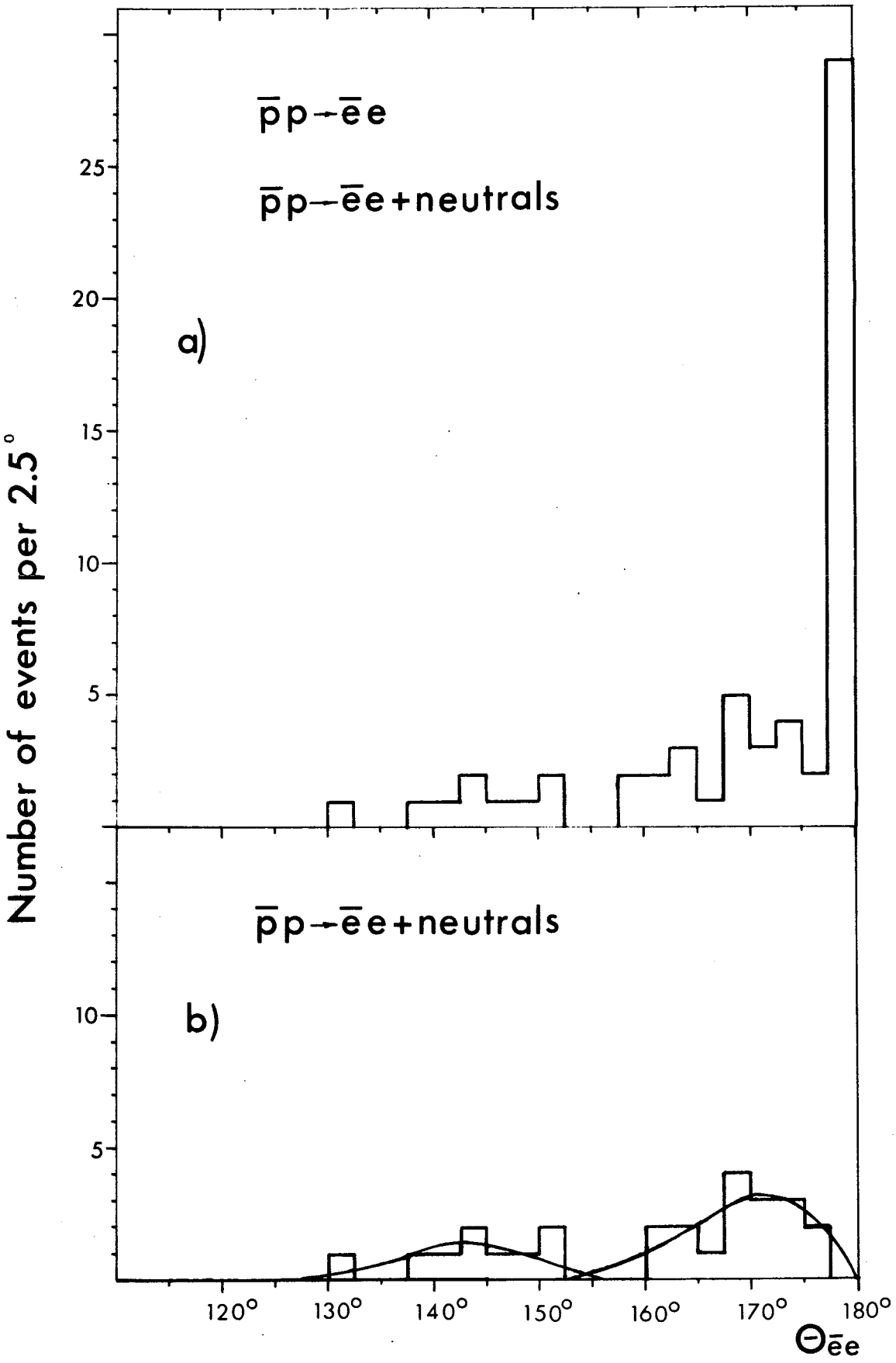
$\bar{p}p \to \bar{e}e$
$\bar{p}p \to \bar{e}e$+neutrals
a)
$\bar{p}p \to \bar{e}e$+neutrals
b)
Number of events per 2.5°
25
20
15
10
5
10
5
120°
130°
140°
150°
160°
170°
180°
$\Theta_{\bar{e}e}$

Fig. 1