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MEASUREMENT OF THE BRANCHING RATIO $\Gamma(\bar{p}p \rightarrow e^+e^-)/\Gamma(\bar{p}p \rightarrow \text{total})$
IN ANTIPROTON-PROTON ANNIHILATION AT REST

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ABSTRACT

Analysing a sample of 220,000 events from an experiment still in progress at the CERN Proton Synchrotron (PS), 60 pairs of electrons with an energy above 700 MeV have been observed. The electrons, produced by annihilation of anti-protons stopped in a liquid-hydrogen target, are detected with optical spark chambers and scintillation counters. Twenty-nine out of these 60 pairs have been found to be collinear; normalizing with respect to the hadronic two-body channels $\pi^+\pi^-$ and K^+K^- , a branching ratio

$$B_{ee} = \frac{\Gamma(\bar{p}p \rightarrow e^+e^-)}{\Gamma(\bar{p}p \rightarrow \text{total})} = (3.2 \pm 0.9) \times 10^{-7}$$

has been obtained.

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The experimental information on the proton electromagnetic form factors in the time-like region is very poor, in spite of the great interest of such a study.

In fact, only upper limits for reaction

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

at $q^2 = -6.8, -6.1, \text{ and } -5.1 \text{ (GeV/c)}^2$ have been obtained in two experiments at CERN¹⁾, and BNL²⁾.

The inverse process

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

has been studied at ADONE³⁾, and DORIS⁴⁾. The ADONE experiment gave the first positive result at $q^2 = -4.3 \text{ (GeV/c)}^2$, on the basis of 25 events. Fourteen events have been observed in the DORIS experiment, at $q^2 = -9.61 \text{ (GeV/c)}^2$, corresponding to the J/ψ (3100) mass.

The evaluation of the electromagnetic form factor is of particular interest at the threshold of the "time-like" region, i.e. $q^2 = -3.5 \text{ (GeV/c)}^2$, where $G_E = G_M$. Moreover, the colliding beam experiments cannot reach such low q^2 values.

In this letter we intend to give the result of the measurement of the branching ratio

$$B_{ee} = \frac{\Gamma(\bar{p}p \rightarrow e^+e^-)}{\Gamma(\bar{p}p \rightarrow \text{total})} \quad (3)$$

at the threshold of the "time-like" region; that is, for reaction (1) at rest. This is a necessary step towards the determination of the proton electromagnetic form factor at this value of q^2 ⁵⁾.

Our data have been collected in an experiment still in progress at the CERN Proton Synchrotron (PS), where the antiproton beam m_{14} is moderated and brought to rest in a 50 cm long hydrogen target, surrounded by four electron detectors as shown in Fig. 1. The m_{14} is a low-momentum beam, produced in a PS internal target and enriched by electrostatic separation. At 900 MeV/c, with $\Delta p/p = \pm 1.8\%$, the \bar{p} flux obtained is $\sim 6000 \bar{p} / 6 \times 10^{11} p$ on the PS target, the π^-/\bar{p} ratio is ~ 11 , and the image size at the final focus is $8 \times 3 \text{ cm}^2$.

The beam telescope used to monitor the incoming antiproton beam and the stopping of the antiprotons is shown in Fig. 1. A stopping antiproton is defined by the electronic coincidence $1*2*3*4*\bar{A}*\bar{Q}$. More details of the m_{14} beam performance and the \bar{p} stopping techniques are given elsewhere⁶⁾.

The charged particles emerging from the target and missing \bar{A} and \bar{Q} enter the four blocks of detectors. In each block, the thin-foil optical spark chambers (K) allow us to determine the particle direction within $\pm 1^\circ$. Counter M ensures that only one charged particle enters the region of the optical spark chambers, scintillators and absorbers, where the shower develops. The shower starts in chambers MC, which have thick plates corresponding to a total of 2.2 radiation lengths. Particles not initiating a shower in the MC chambers are eliminated by discrimination on the pulse height in counter F. In this way, we accept $\sim 90\%$ of the electrons and 15% of the pions. The pion contamination is further reduced by discrimination on the total pulse height of the counters in the S detectors; in this way we can obtain an electronic efficiency of 80% for electrons and 4% for pions. The efficiencies were measured with electrons or pions of a direct beam of 900 MeV/c. The chosen discrimination levels allow an efficient electron detection down to 600 MeV. The measured energy resolution of our detectors is about $\pm 20\%$ for electrons of 900 MeV.

An optical system of mirrors and lenses allows us to concentrate two views of each block of detectors on film. Inspecting the pictures, we obtain a further rejection of pions, eliminating all events in which the shower is not sufficiently developed or not aligned with the track direction in the K chambers. This well-known method of discriminating pions and electrons is described elsewhere⁷⁾. We obtain an over-all efficiency for 900 MeV/c electrons of 72%, corresponding to a pion contamination lower than 5×10^{-4} . We have periodically tested the π/e rejection of our apparatus, displacing each block of detectors in a direct beam of pions or electrons.

In eight weeks of data-taking at the CERN PS, we have collected $\sim 220,000$ pictures; scanning this sample, we have selected the photographs showing two electrons in opposite blocks, rejecting pion contamination as explained above. Sixty electron pairs with electron energies above 700 MeV have been reconstructed in space; Fig. 2a shows the opening angle (θ_{ee}) distribution of the electron pairs.

An upper limit of the over-all background which can simulate electron pairs has been evaluated, scanning for events in which one particle is clearly a pion or a converted gamma-ray, while the other shows all the electron characteristics. An average of three such single "electrons" were found in 1000 pictures, corresponding to approximately two random "electron" pairs in 2.2×10^5 photographs. Since the opening angles between single "electrons" and corresponding pions or gamma-rays show a flat distribution between 130° and 180° , two events mean 0.4% contamination of the collinear sample and less than 7% for the remaining 31 pairs.

This background evaluation takes into account all possible sources of contamination, excluding electrons produced by K^+K^- both decaying by K_{e3}^+ and the case of a single neutral pion producing a large opening angle Dalitz pair. The probability for these processes has been evaluated by Monte Carlo calculation, and found to be less than $1/_{00}$ for electrons of energy above 700 MeV and with opening angle larger than 120° .

Figure 2b shows the θ_{ee} distribution for electron pairs coplanar with the beam direction within $\pm 6.5^\circ$ and with no visible gamma-ray on the picture. At 180° are accumulated the 29 collinear electrons coming from $\bar{p}p$ annihilation at rest. The other five events, distributed between 155° and 180° , are likely to be produced in $\bar{p}p$ annihilation in flight. The continuous line shows in fact the expected opening angle distribution for pairs produced in flight, following the calculation of Bogdanova et al.⁸⁾, and using the measured momentum spectrum of \bar{p} entering the target. This distribution is verified with high statistics in the data taken for the process $\bar{p}p \rightarrow \pi^+\pi^-$ at rest (see Ref. 6).

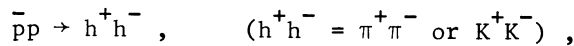
Concluding, we observe in an unambiguous way the process $\bar{p}p \rightarrow e^+e^-$ at rest, since the contamination by the annihilations in flight is negligible.

The 26 acoplanar events are probably produced by high-mass vector mesons from processes of the type



Results on these reactions are presented elsewhere⁹⁾.

We have evaluated the branching ratio B_{ee} on the basis of the 29 collinear electron pairs, normalizing to 240 events of the reaction at rest:



detected with our apparatus. With this method we eliminate important instrumental uncertainties such as the fraction of stopping \bar{p} , solid angle and M counter efficiency.

We obtain

$$\frac{\Gamma(\bar{p}p \rightarrow e^+e^-)}{\Gamma(\bar{p}p \rightarrow h^+h^-)} = (0.74 \pm 0.2) \times 10^{-4}$$

and, using the known branching ratios into $\pi^+\pi^-$ and K^+K^- *)¹⁰⁾, we derive

$$B_{ee} = \frac{\Gamma(\bar{p}p \rightarrow e^+e^-)}{\Gamma(\bar{p}p \rightarrow \text{total})} = (3.2 \pm 0.9) \times 10^{-7}.$$

*) $BR_{\pi^+\pi^-} = (3.2 \pm 0.3) \times 10^{-3}$

$BR_{K^+K^-} = (1.1 \pm 0.1) \times 10^{-3}.$

Note¹¹⁾ that the observation of a non-zero B_{ee} at rest makes the "scaling law" $G_E = G_M/\mu$, valid in the space-like region up to $q^2 \approx 5 \text{ (GeV/c)}^2$, incompatible with the constraint at $q^2 = -4M^2$: $G_E = G_M$.

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Figure captions

Fig. 1 : Scheme of the four electron detectors surrounding the liquid hydrogen target. The counters of the antiproton beam telescope are also represented.

Fig. 2a : Opening angle distribution of the 60 electron pairs found until now.

2b : Opening angle distribution of the coplanar electron pairs. The curve represents the distribution expected for e^+e^- pairs produced by antiprotons in flight.

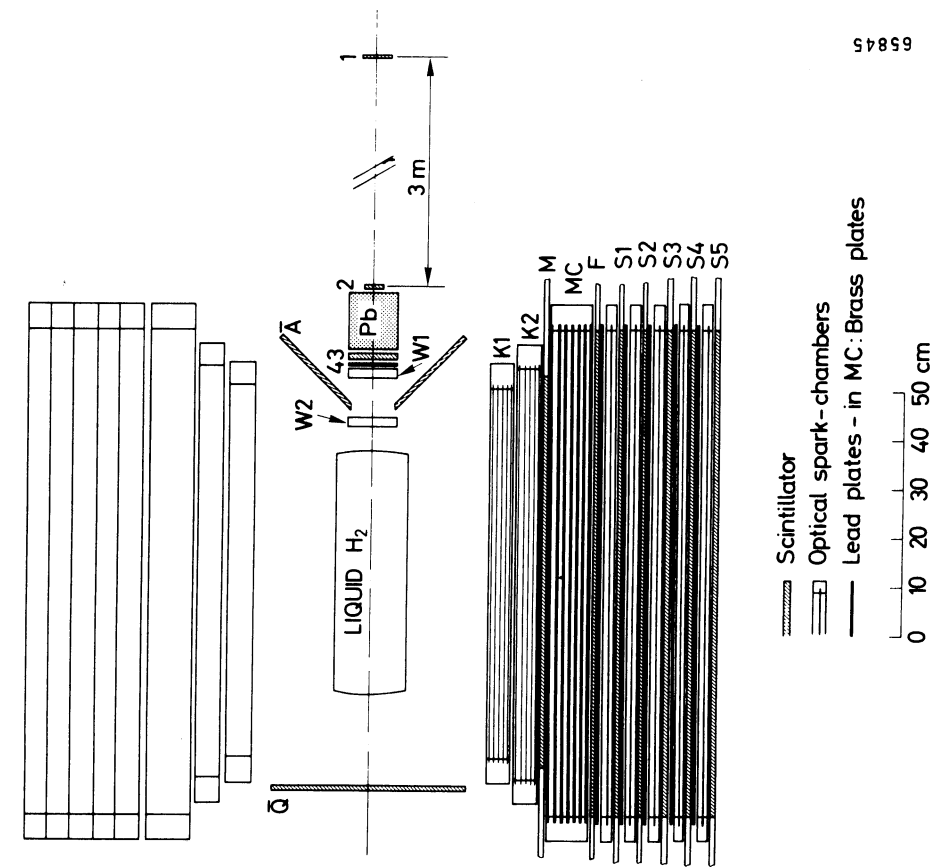


Fig. 1

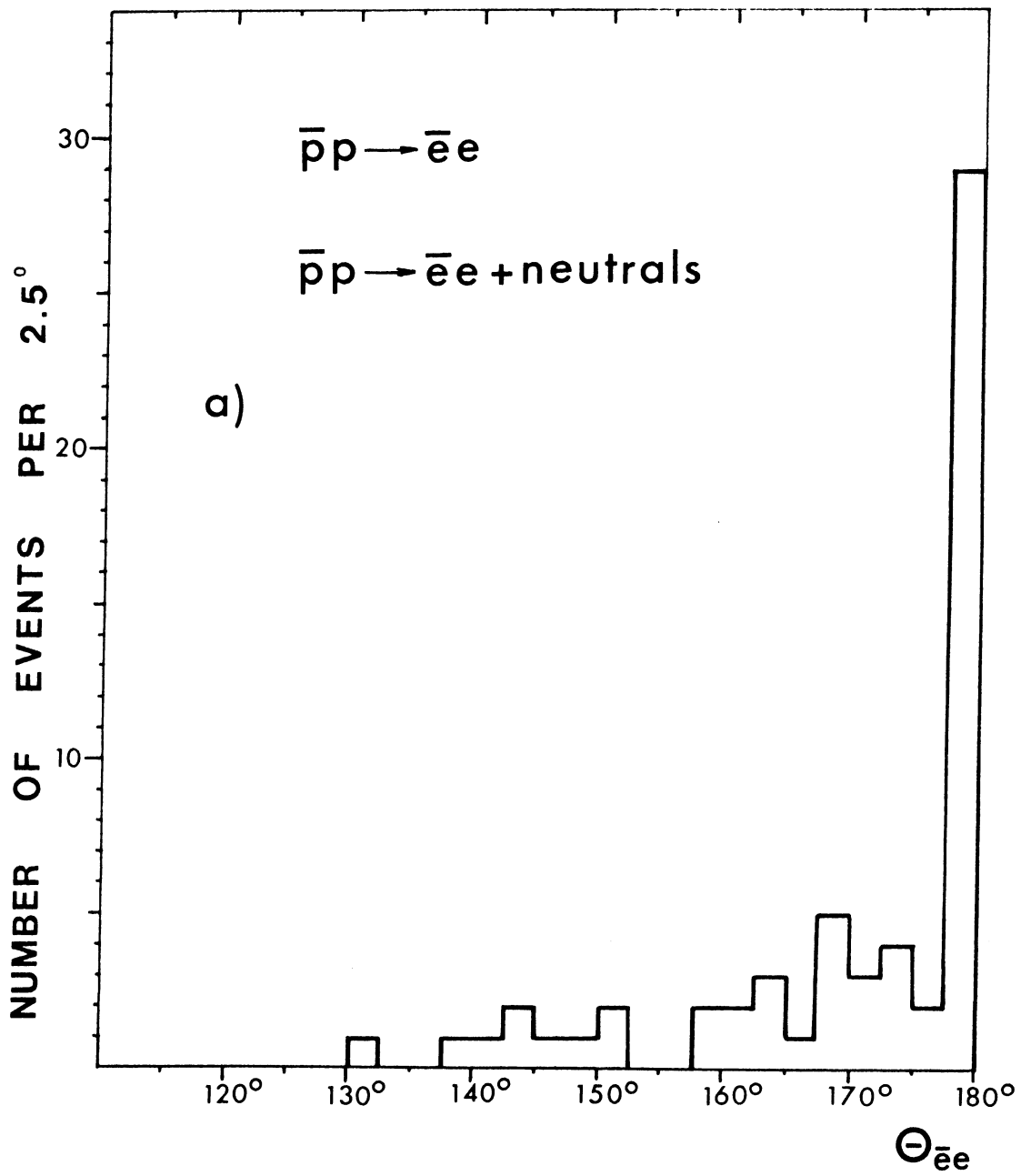


Fig. 2a)

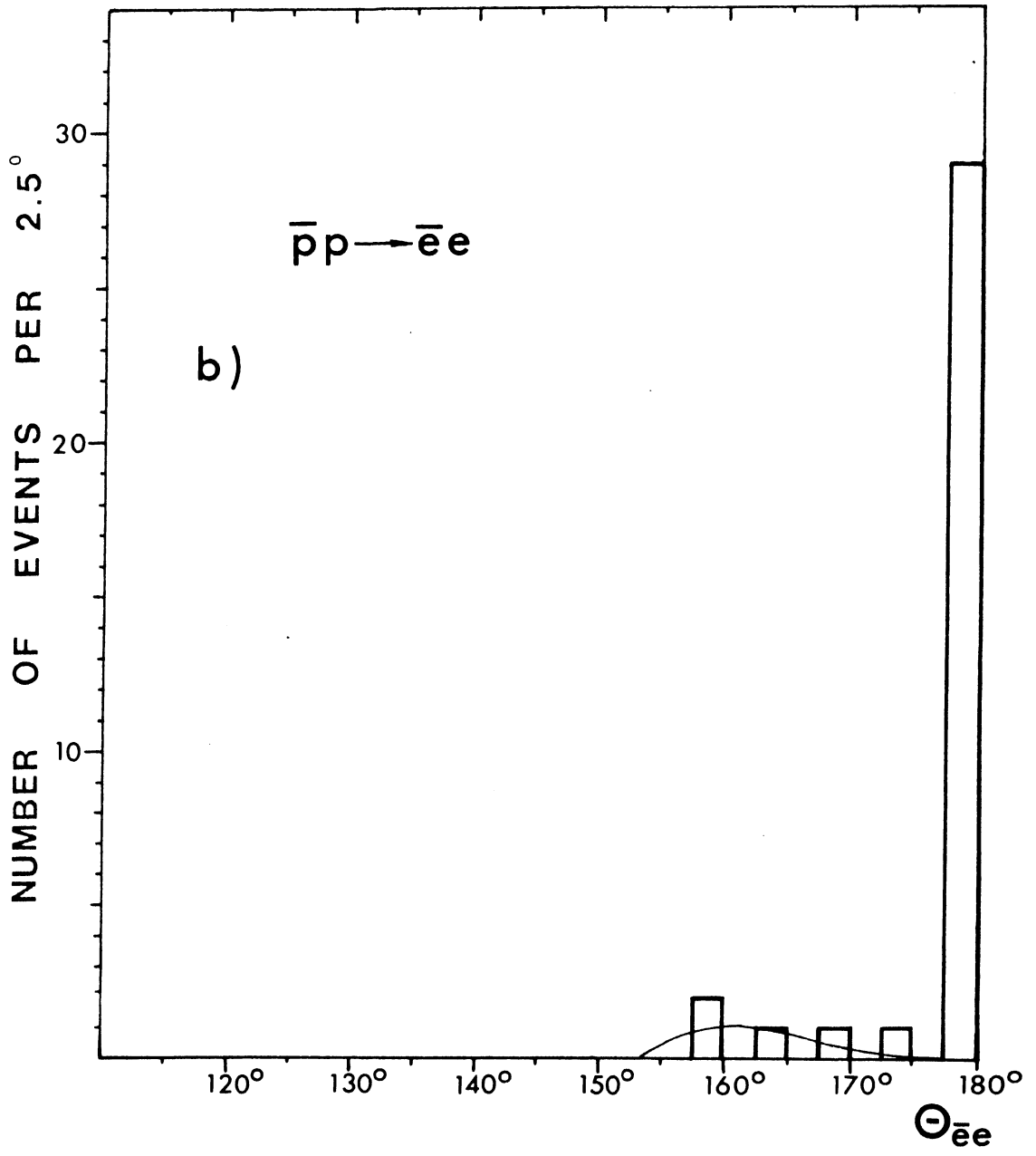


Fig. 2b)