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FIRST DETERMINATION OF THE PROTON ELECTROMAGNETIC FORM FACTORS AT THE THRESHOLD OF THE TIME-LIKE REGION

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ABSTRACT

From the measurement of

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

obtained in an experiment at CERN with antiprotons at rest, a value of the proton electromagnetic form factors at the threshold of the time-like region is derived:

$$G_E = G_M = 0.51 \pm 0.08 \text{ at } q^2 = -3.52 \ (\text{GeV/c})^2 .$$

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The knowledge of the proton electromagnetic form factors $F_{1,2}(q^2)$ is fundamental to the understanding of the structure of this particle. Several models [1] attempted to fit the numerous data in the space-like region, without any constraint in the time-like region, where the existing measurements were extremely poor. However, data in the latter region are most essential to determine the analytic function $F(q^2)$ in the whole complex plane [2].

Attempts to measure the proton form factors in the time-like region started about 15 years ago, just after precise measurements [3] were obtained in the space-like region. Experiments at CERN [4] and BNL [5] gave only upper limits at $q^2 = -6.8$, -6.6 and -5.1 $(GeV/c)^2$. The first positive result was obtained in 1972 from an e^+e^- colliding beam experiment in Frascati [6]. On the basis of 27 events, the authors evaluated $G = 0.27 \pm 0.04$ at $q^2 = -4.3$ $(GeV/c)^2$ with the hypothesis $|G_E| = |G_M| = G$.

We give here the first evaluation of the proton electromagnetic form factors at the threshold of the time-like region, at $q^2 = -3.52$ $(GeV/c)^2$, and at a near value: $q^2 = -3.61$ $(GeV/c)^2$. These results were obtained from the analysis of our data on the process:

$$\bar{p}p \to e^+e^- \tag{1}$$

with $\bar{p}$ brought to rest. The reasons for studying process (1) at rest are twofold:

i) at $q^2 = -4M_p^2$, we have strictly $G_E = G_M = G$ with G real, thus allowing an unambiguous determination of G;

ii) furthermore, such an experiment is complementary to any e^+e^- colliding beam experiment which could not attempt measurements below $|q^2| \sim 4$ $(GeV/c)^2$.

To allow the determination of G, the branching ratio:

$$B_{e^+e^-} = \frac{\Gamma(\bar{p}p \to e^+e^-)}{\Gamma(\bar{p}p \to \text{total})}$$

is needed. It was measured by our group in an experiment where antiprotons were stopped in a liquid hydrogen target surrounded by electron detectors [7]. These detectors, consisting essentially of scintillation counters and optical spark chambers, allow the detection of electrons in a high hadronic background and the measurement of their direction and energy. Twenty-nine collinear pairs were found which can be attributed to reaction (1), yielding

$$B_{e^+e^-} = (3.2 \pm 0.9) \times 10^{-7} .$$

Contamination by accidental background was evaluated and found to be negligible.

Five more events can be attributed to reaction (1) in flight, where the antiproton momentum lies between 150 and 500 MeV/c with an average value of (300 ± 20) MeV/c. Normalizing to the rate of the reaction:

$$\bar{p}p \to h^+h^- , \qquad \text{where} \quad h^+h^- = \pi^+\pi^- \text{ or } K^+K^- ,$$

observed [8] in the same apparatus and in the same momentum interval, we obtain

$$\frac{\Gamma(\bar{p}p \to e^+e^-)}{\Gamma(\bar{p}p \to h^+h^-)} = \left(0.40 \begin{array}{l} +0.25 \\ -0.16 \end{array}\right) \times 10^{-4} ,$$

on the hypothesis of equal angular distributions of the two electrons and of the two hadrons from $\bar{p}p$ annihilations at this energy.

Using the cross-section $\sigma(\bar{p}p \to h^+h^-)$ at 300 MeV/c also measured in our apparatus [9]:

$$\sigma_{h^+h^-}(300 \text{ MeV/c}) = 1.25 \pm 0.2 \text{ mb} ,$$

we derive

$$\sigma_{e^+e^-} = \left(50 \begin{array}{l} +32 \\ -20 \end{array}\right) \text{nb} .$$

At 300 MeV/c, G can be readily obtained if we assume $|G_E| = |G_M| = G$. In fact, we have

$$G = \frac{1}{\alpha} \sqrt{\frac{m \times p_{\bar{p}} \times \sigma_{e^+e^-}}{\pi}}$$

$$G = 0.46 \begin{array}{l} +0.15 \\ -0.09 \end{array} .$$

At rest, we have to use a different method to evaluate G. We can determine $\sigma_{tot} \times p_{\bar{p}}$ at rest by extrapolation of the known measurements of σ_{tot} between 0.3 and 1 GeV/c. Figure 1 shows these data together with the best linear fit ($X^2/n_D \approx 1.6$). If we assume that the behaviour of $\sigma_{tot} \times p_{\bar{p}}$ remains linear when the antiproton momentum goes to zero, we obtain:

$$\lim_{p_{\bar{p}} \to 0} (\sigma_{tot} \times p_{\bar{p}}) = (56 \pm 2)\text{mb} \times \text{GeV/c} .$$

Using our measurement of $B_{e^+e^-}$ [7], we derive $\sigma_{e^+e^-} \times p_{\bar{p}}$. Thus

$$G_E = G_M = G = 0.51 \pm 0.08 .$$

Our values of G near and at threshold are shown in Fig. 2, together with the e^+e^- colliding beam measurement [6], the CERN [4] and BNL [5] limits and the data in the space-like region [3]. The continuous line represents a tentative fit to the experimental points in the space-like and in the time-like regions. We used the formalism of Blatnik and Zovko [1] based on the VDM model with three isoscalar (ω,ω',ϕ) poles, three isovector $(\rho,\rho'_{1250},\rho''_{1600})$ poles and asymptotic constraints on G. More details on this fit and its significance can be found in another paper [10].

Attempts to fit all the data without heavy vector mesons did not succeed. In particular, a dipole fit (dashed line in the time-like region) with

$$G_D(q^2) = (1 + q^2/m^2)^{-2}, \qquad m^2 = 0.71\ \text{GeV}^2$$

is away from the data by an order of magnitude in the time-like region.

REFERENCES

1) For instance: T. Massam and A. Zichichi, Nuovo Cimento Letters 1 (1969) 387, and S. Blatnik and N. Zovko, Acta Phys. Austriaca 39 (1974) 62.

2) For instance: M. Gourdin, Physics Reports 11 (1974) 29-98.

3) See, for example: D.J. Drickey and L. Hand, Phys. Rev. Letters 9 (1962) 521.
D. Frerejacque, D. Benaksas and D. Drickey, Phys. Rev. Letters 148, 1327 (1966).
T. Janssens, T. Hofstadter, E.B. Hughes and M.R. Yearian, Phys. Rev. 142 (1966) 922.
K.W. Chen, J.R. Dunning, Jr., A.A. Cone, N.F. Ramsey, J.K. Walker and R. Wilson, Phys. Rev. 141 (1966) 1267.
W. Bartel, B. Dudelzak, H. Krehbiel, J.M. McElroy, U. Meyer-Berhout, R.J. Morrison, H. Nguyen-Ngoc, W. Schmidt and G. Weber, Phys. Rev. Letters 17, (1966) 608.
W. Albrecht, H.J. Behrend, F.W. Brasse, W. Flauger, H. Hultschig and K.G. Steffen, Phys. Rev. Letters 17 (1966) 1192.
M. Goiten, R.J. Budnitz, L. Carroll, J. Chen, J.R. Dunning, Jr., K. Hanson, D. Imrie, C. Mistrette, J.K. Walker, R. Wilson, G.F. Dell, M. Fotino, J.M. Paterson and H. Winick, Phys. Rev. Letters 18 (1967) 1017.
D.H. Coward, H. Destaebler, R.A. Early, J. Litt, A. Minten, L.W. Mo, W.K. Panofsky, R.E. Taylor, M. Breidenbach, J.I. Friedman, H.W. Kendall, P.N. Kirk, B.C. Barish, J. Mar and J. Pine, Phys. Rev. Letters 20 (1968) 292.
H. Behrend, F. Brasse, J. Engler, H. Hultschig, S. Galster, G. Hartwig, H. Schopper and E. Ganssauge, Nuovo Cimento 48A (1967) 140.
W. Albrecht, H.J. Behrend, H. Dorner, W. Flauger and H. Hultschig, Phys. Rev. Letters 18 (1967) 1014.
D. Yount and J. Pine, Phys. Rev. 128 (1962) 1842.

4) M. Conversi, T. Massam, Th. Muller and A. Zichichi, Nuovo Cimento 40 (1965) 690.

5) D.L. Mertill, B.C. Barish, D.G. Fong, R. Gomez, J. Pine and A.V. Tollestrup, Phys. Rev. 184 (1969) 1415.

6) M. Castellano, G. Di Giugno, J.W. Humphrey, E. Sassi Palmieri, G. Troise, U. Troya and S. Vitale, Nuovo Cimento 14 (1973) 1.

7) G. Bassompierre, G. Binder, P. Dalpiaz, P.F. Dalpiaz, G. Gissinger, S. Jacquey, C. Peroni, M.A. Schneegans and L. Tecchio, Phys. Letters 64B (1976) 475.

8) G. Bassompierre, G. Binder, P. Dalpiaz, P.F. Dalpiaz, M. Ferro-Luzzi, G. Gissinger, S. Jacquey, C. Peroni, F.M. Schmitt, M.A. Schneegans and L. Tecchio, Nuclear Instrum. Methods 140 (1977) 251.

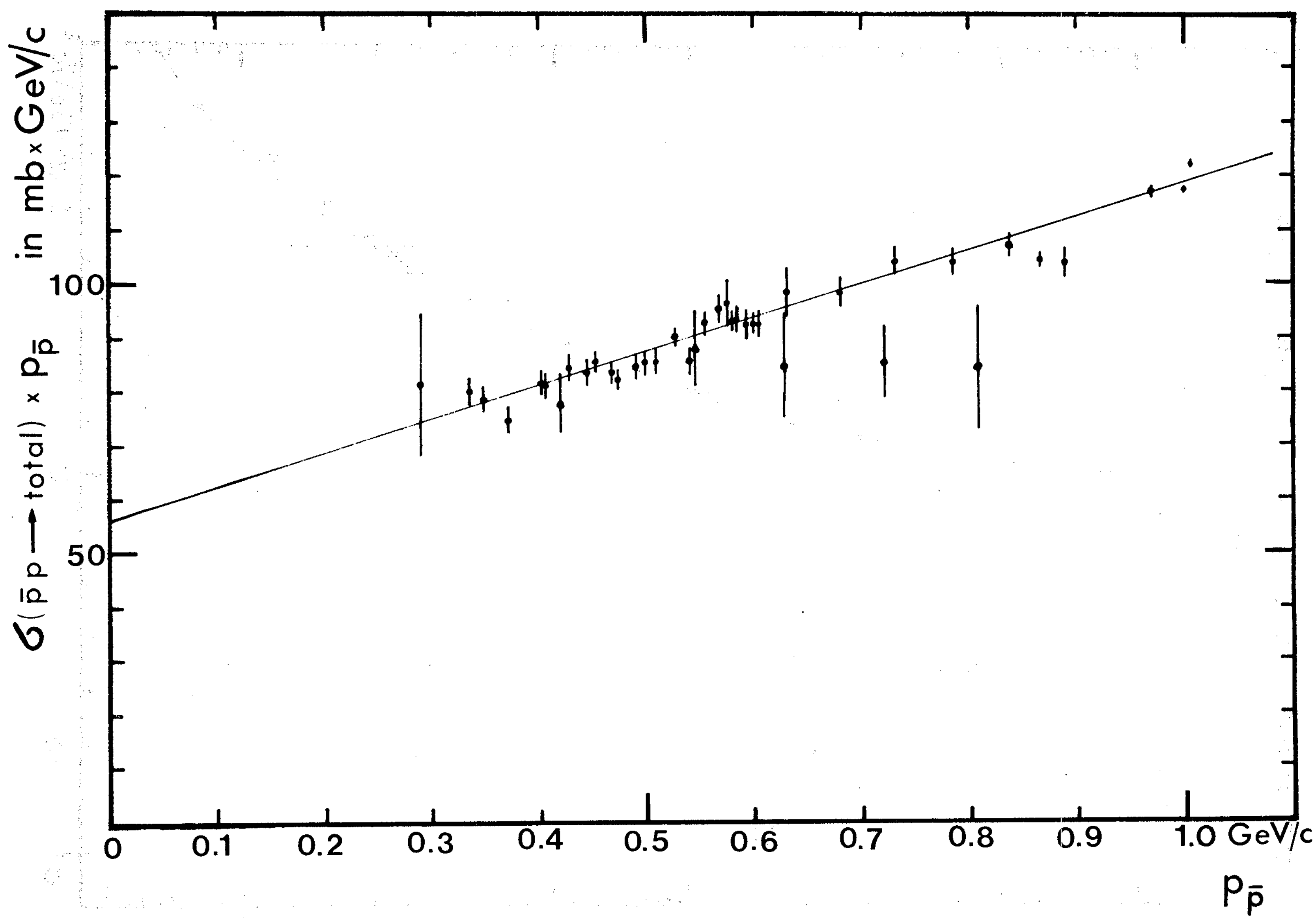
9) G. Bassompierre, G. Binder, P. Dalpiaz, P.F. Dalpiaz, G. Gissinger, S. Jacquey, C. Peroni, M.A. Schneegans and L. Tecchio, Measurement of the antiproton-proton annihilation cross-section into ($\pi^+\pi^-$ or K^+K^-) at 300 MeV/c, submitted to Nuovo Cimento Letters.

10) S. Jacquey, Détermination des facteurs de forme électromagnétiques du proton au seuil de la région temps, Thesis to be published at the University of Mulhouse, France.

Figure captions

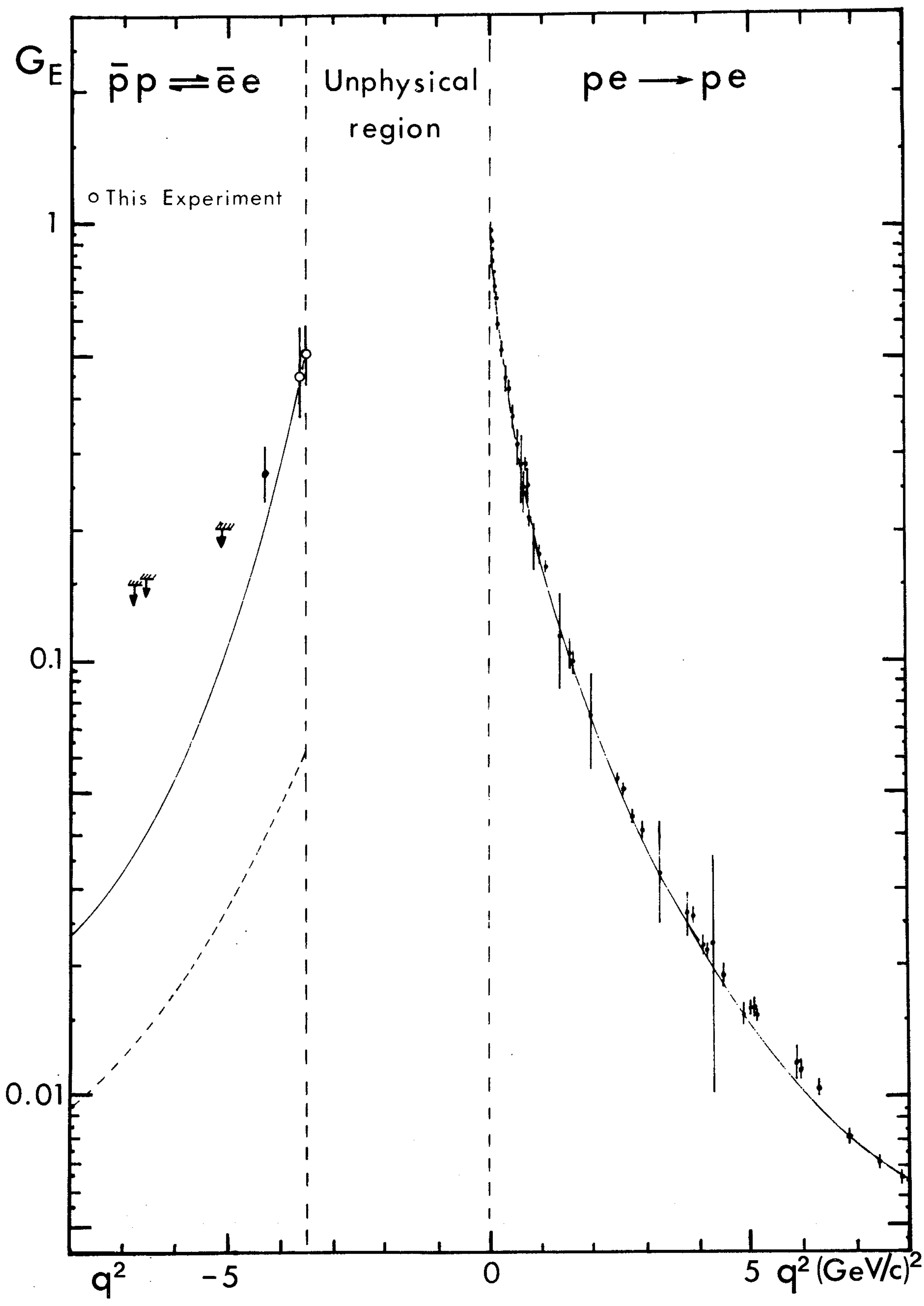
Fig. 1 : Linear extrapolation to $p_{\bar{p}} = 0$ of the known data in $\sigma(\bar{p}p \to \text{total}) \times p_{\bar{p}}$.

Fig. 2 : Present situation of the data on G_E for $-8(\text{GeV/c})^2 < q^2 < 8(\text{GeV/c})^2$. The solid line represents a fit to the existing data, based on the VDM model with the contribution of $\omega, \omega', \phi, \rho, \rho'_{1250}, \rho''_{1600}$ mesons. An increased statistical weight was given to the time-like data. A dipole fit (dashed line) with $G_D(q^2) = [1 + q^2/m^2]^{-2}$, $m^2 = 0.71$ GeV^2, is also shown. For $q^2 > 0$, it is superposed on the solid curve.



$\sigma(\bar{p}p \longrightarrow total) \times p_{\bar{p}}$ in mb x GeV/c
100
50
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0 GeV/c
$p_{\bar{p}}$

Fig. 1



G_E
$\bar{p}p \rightleftharpoons \bar{e}e$
Unphysical region
pe → pe
o This Experiment
1
0.1
0.01
q^2
-5
0
5
q^2 (GeV/c)^2

Fig. 2