EXPERIMENTAL STATUS REPORT ON TIME-LIKE BARYON FORM FACTORS

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Workshop on e^+e^- Physics

at Intermediate Energies

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OUTLINE

- Introduction

- Proton time-like form factors:
  - ➡ near threshold PS170 (CERN)
  - ➡ large q^2 E835 (FNAL)

- Neutron time-like form factors
  FENICE (FRASCATI)

- Narrow structure in $e^+e^- \rightarrow$ hadrons near $\overline{N}N$ threshold

- Other baryon time-like form factors

- Conclusions

THE PHYSICS OF E.M. FORM FACTORS

- Small Q^2
  - ➡ charge distribution
    magnetization current

- High Q^2
  - ➡ valence quark distribution

Test of QCD from
non perturbative regime (near threshold)
to perturbative regime (large Q^2)

SPACE-LIKE REGION

- Study of the reaction

$$e^- p \rightarrow e^- p$$

$$q^2 = -4EE' \sin^2(\theta/2) < 0 \Rightarrow \quad \text{space-like}$$

- Reduced Rosenbluth cross section:

$$\left(\frac{d\sigma}{d\Omega}\right)_{rid} = \frac{\varepsilon(q^2,\theta)}{\tau(q^2)} G_E^2 + G_M^2 \qquad 0 \le \varepsilon \le 1$$

- Dipolar behavior and scaling for $Q^2 < 10 (GeV/c)^2$

$$(Q^2 = -q^2)$$

$$G_E = G_M / \mu_p = \left(1 + \frac{Q^2}{\Lambda^2}\right)^{-2}$$

$$\Lambda^2 = 0.71 (GeV/c)^2$$

TIME-LIKE REGION

- Study of the reactions

$$e^+e^- \Leftrightarrow \overline{N}\ N \qquad (Q^2 = s > 0)$$

- Differential cross section $\left(e^+e^- \rightarrow \overline{p}\ p\right)$

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2 \beta C}{4s}\left[\left|G_M(Q^2)\right|^2 (1+\cos^2\theta^*) + \frac{4m_p^2}{s}\left|G_E(Q^2)\right|^2 \sin^2\theta^*\right]$$

➡ at threshold $G_E = G_M$

➡ uniform angular distribution

➡ At $Q^2 >> 4m_p^2$

➡ G_E contribution negligible

TIME-LIKE REGION

➡ QCD asymptotic behaviour

$$\frac{|G_M|}{\mu_p} = \frac{C}{Q^4 \ln\left(Q^2/\Lambda^2\right)^2}$$

C and Λ
free parameters

➡ at large Q^2 (QCD, analyticity)

$$G(Q^2) = G(-Q^2)$$

➡ ratio of neutron to proton form factor $\left|\frac{G_M^n}{G_M^p}\right|^2$

→ QCD, analyticity ~ 0.25

→ Vector Meson Dominance models ~ 1÷10

→ Soliton models ~ 1

PROTON FORM FACTOR (LOW Q^2)

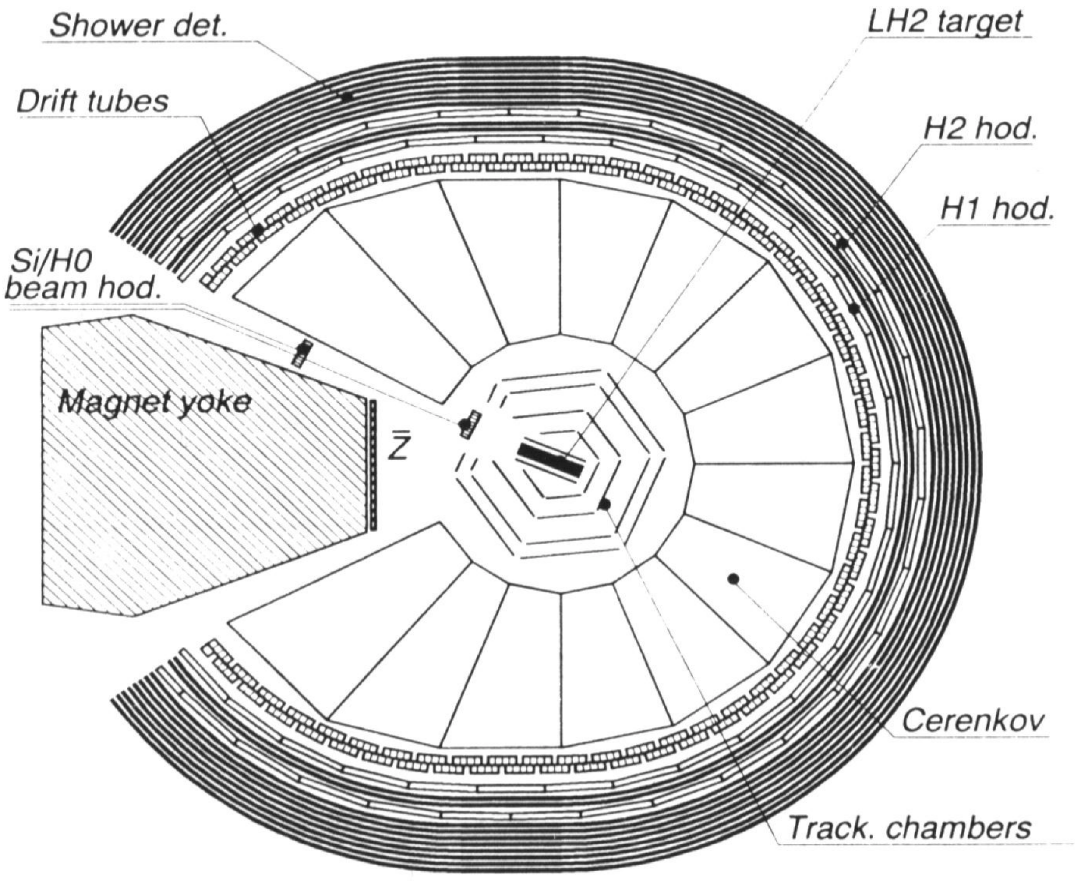
PS170 exp. (CERN)
Nucl.Phys.B 411 (1994), 3

- $\bar{p}p \to e^+e^-$ from threshold to $E_{CM} \cong 2$ GeV at LEAR-CERN

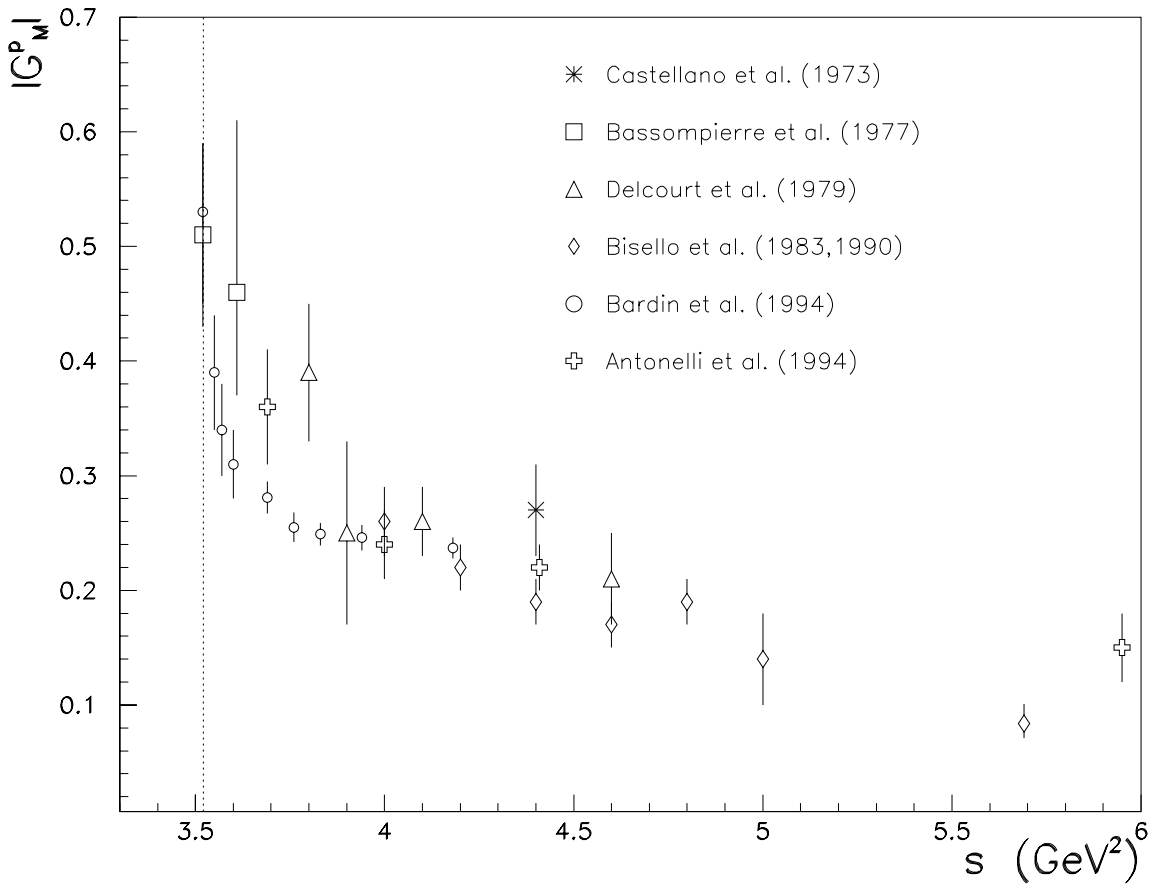
- Selection of e^+e^- pairs in high hadronic background
  - ➡ threshold Cerenkov counter + shower detector
- Two body reconstruction
  - ➡ tracking system (MWPC, drift tubes)

- About 2000 e^+e^- events above threshold

PS170 DETECTOR

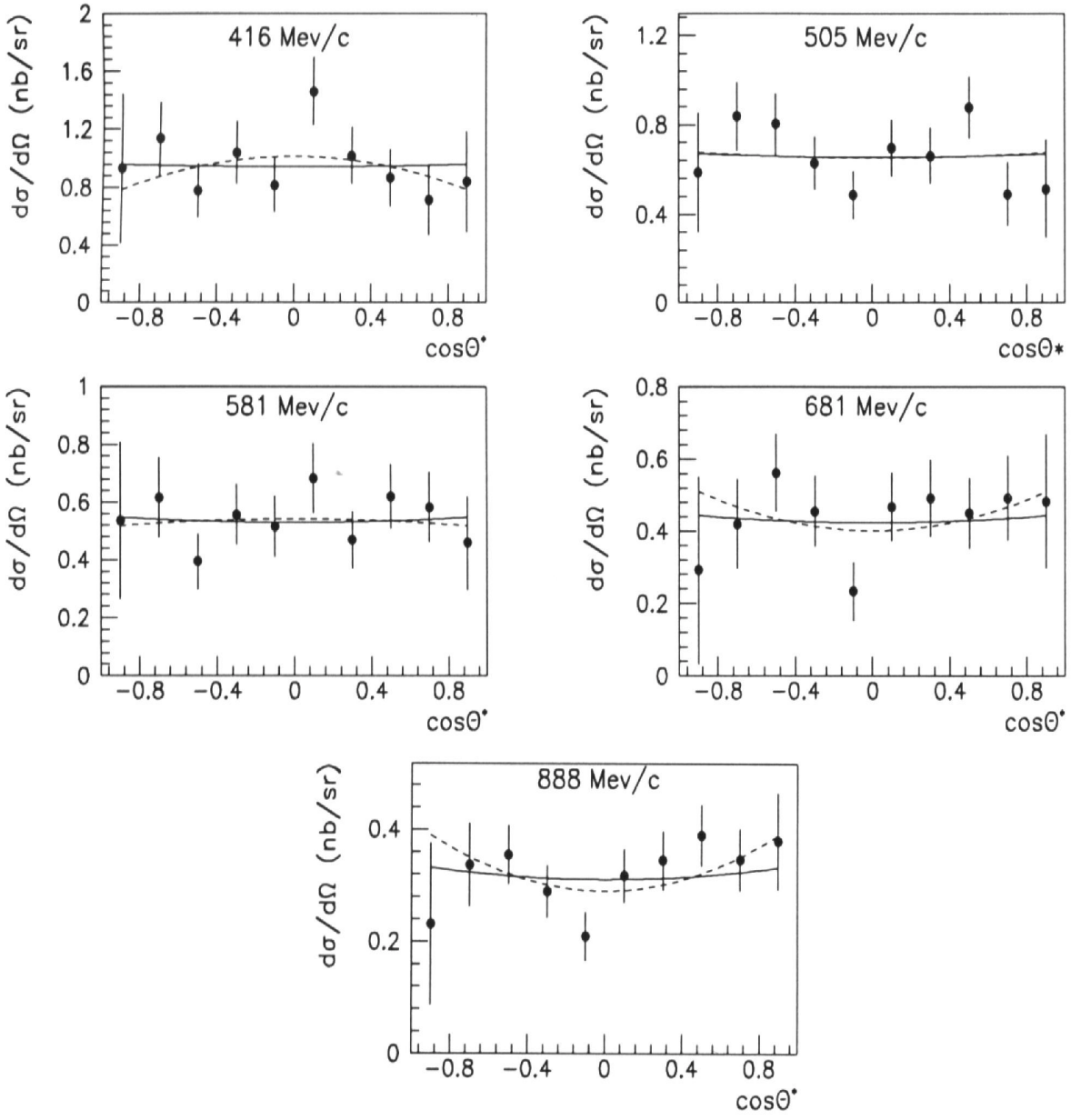


PROTON FORM FACTOR (LOW Q^2)



Steep threshold behavior

ANGULAR DISTRIBUTIONS



Indication of $\frac{|G_E{}^p|}{|G_M{}^p|}$ decrease with energy

PROTON FORM FACTOR (HIGH Q^2)

E835 exp. (FNAL)
Phys. Rev. D60 (1999), 032002

- E835 study the charmonium spectroscopy in $\bar{p}p$ annihilations into electromagnetic final states:

$$\bar{p}p \to J/\psi(\to e^+e^-) + X$$
$$\bar{p}p \to \gamma\gamma$$

- Resonance are scanned by decelerating the antiproton beam.

- Data collected in the energy range $2.9 < \sqrt{s} < 4.4 GeV$
  1996/97 run (143 pb^{-1})
  2000 run (113 pb^{-1})

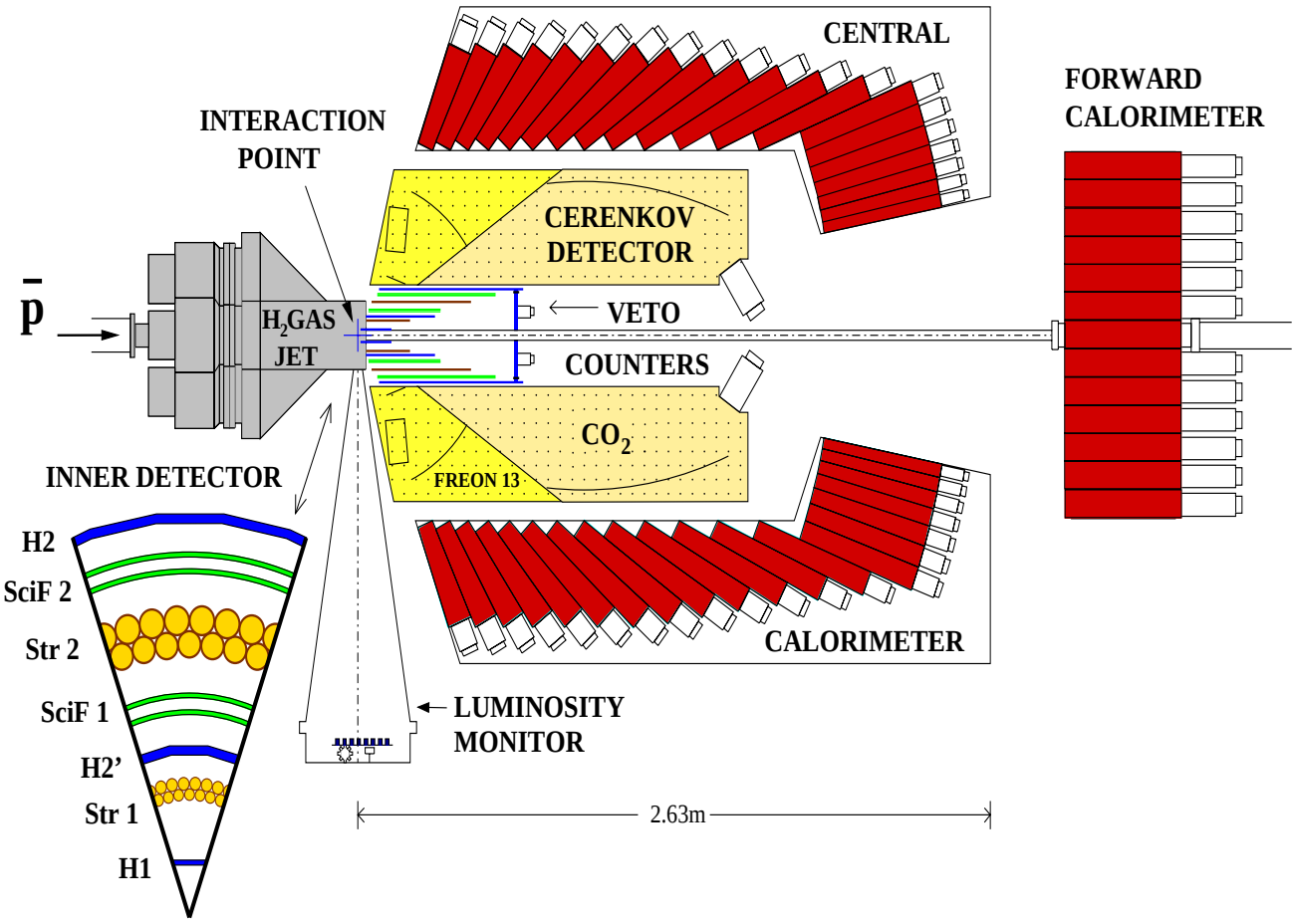
E835 experiment at Fermilab

- Ideal for study of form factors as well, through the reaction

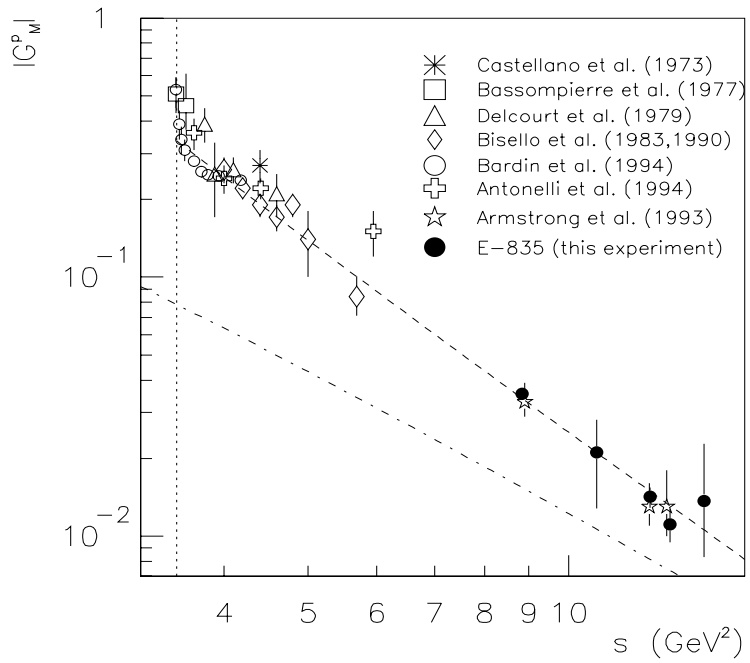
$$\bar{p}p \rightarrow e^{+}e^{-}$$

  - ➨ High Q^2, but cross section still detectable
  - ➨ High luminosity
  - ➨ Efficient reconstruction of e^+e^- pairs with high invariant mass
  - ➨ Low background level

E835 DETECTOR



PROTON FORM FACTOR (HIGH Q^2)



The dashed line is the QCD fit.

The dot-dashed line represents the dipole behavior of the form factor in the space-like region for the same values of $|Q|^2$.

NEUTRON FORM FACTOR

FENICE exp. (Frascati)
Nucl.Phys.B 517 (1998), 3

- $e^+e^- \rightarrow \bar{n}\,n$ from threshold to $E_{CM} \cong 2.5$ GeV at ADONE (Frascati)

- Antineutron annihilation in nuclei:
  many prong event ("star topology")
  ➡ iron converters + limited streamer tubes (tracking)
- Low antineutron velocity
  ➡ hodoscopes for TOF measurement

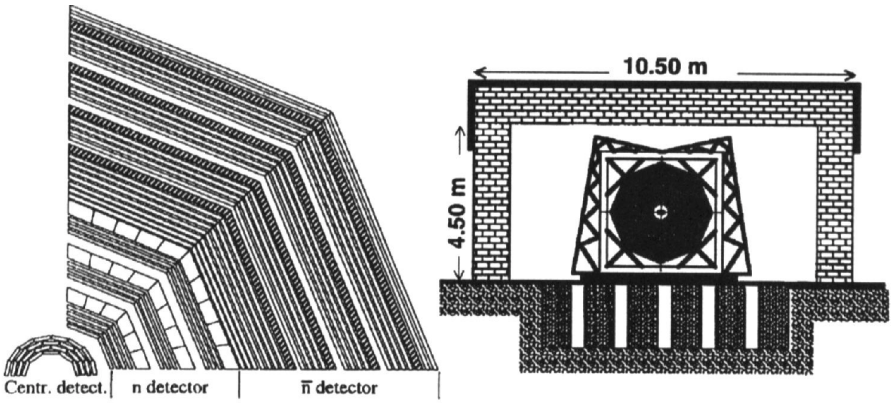
- Low luminosity
  ➡ shield against cosmic ray background

$$e^+e^- \rightarrow \bar{n}n$$

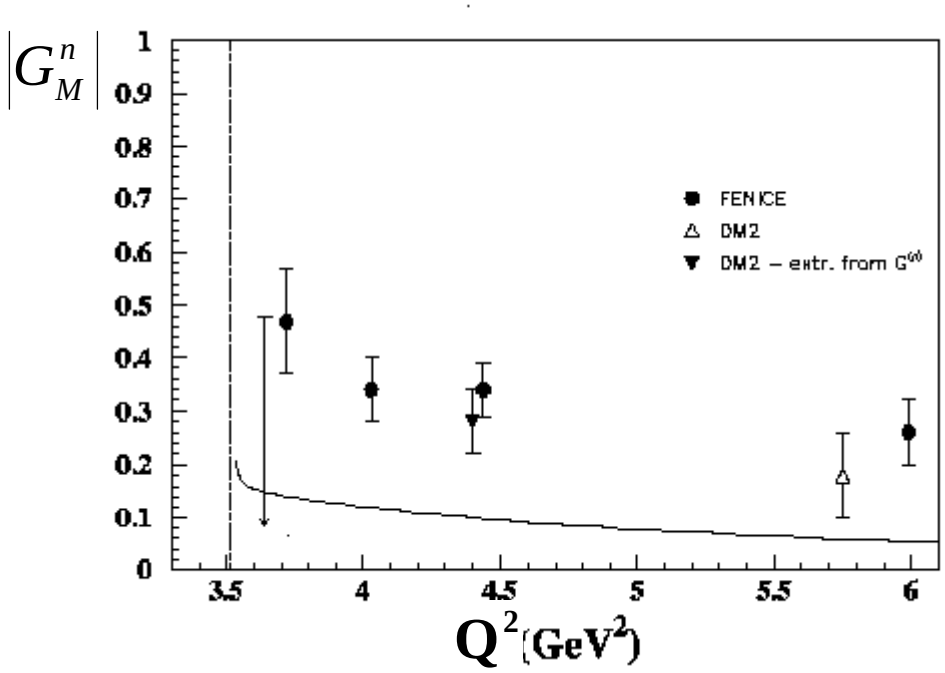
- $\bar{n}$ identification ➡ isolated annihilation star + $\beta_{\bar{n}}$ measurement
- n detection efficiency ≈ 10% at 2 GeV

➡ no signal from neutron required

FENICE DETECTOR



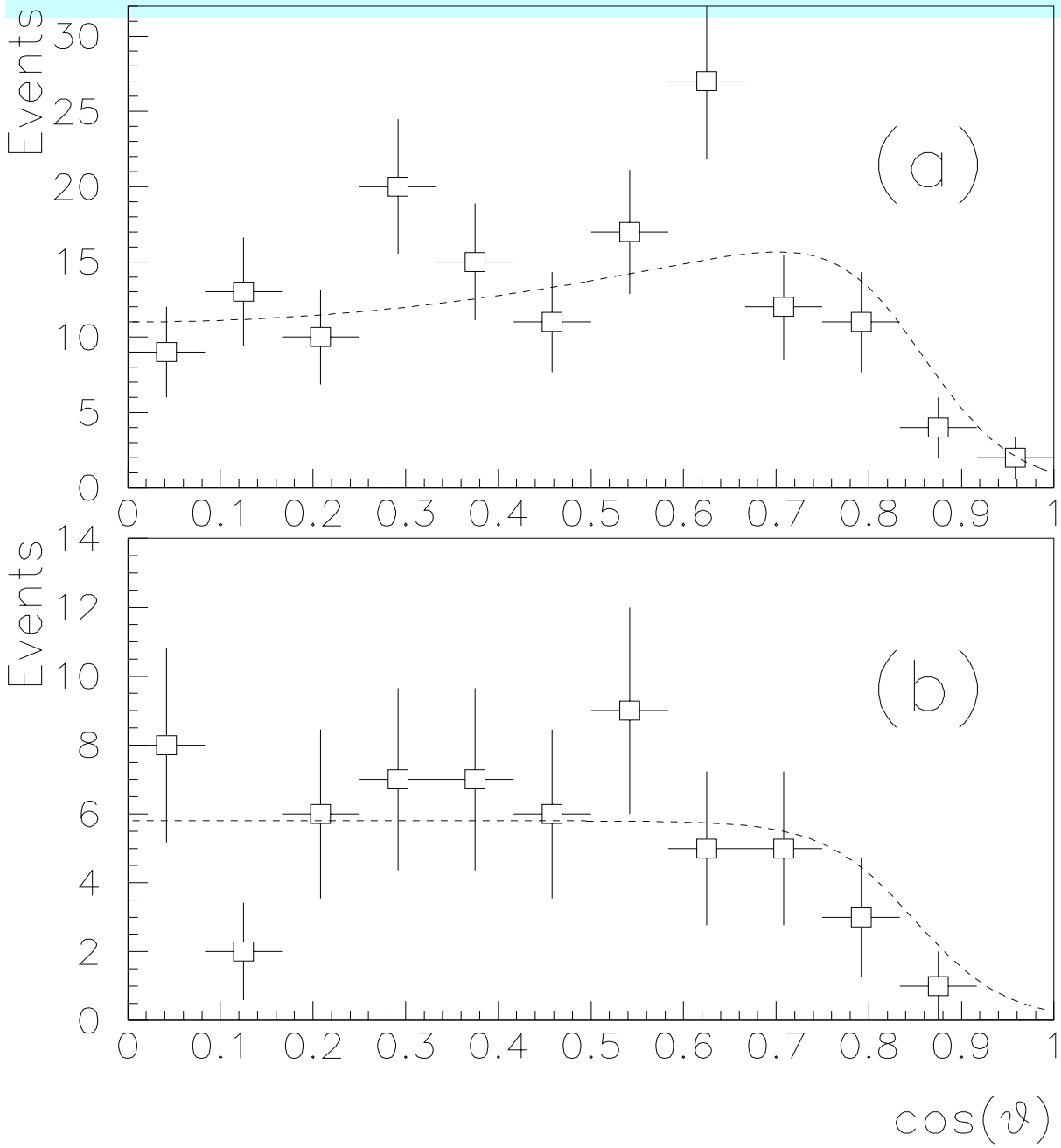
NEUTRON FORM FACTOR



$\int L dt \approx 0.4 pb^{-1}$ 74 events

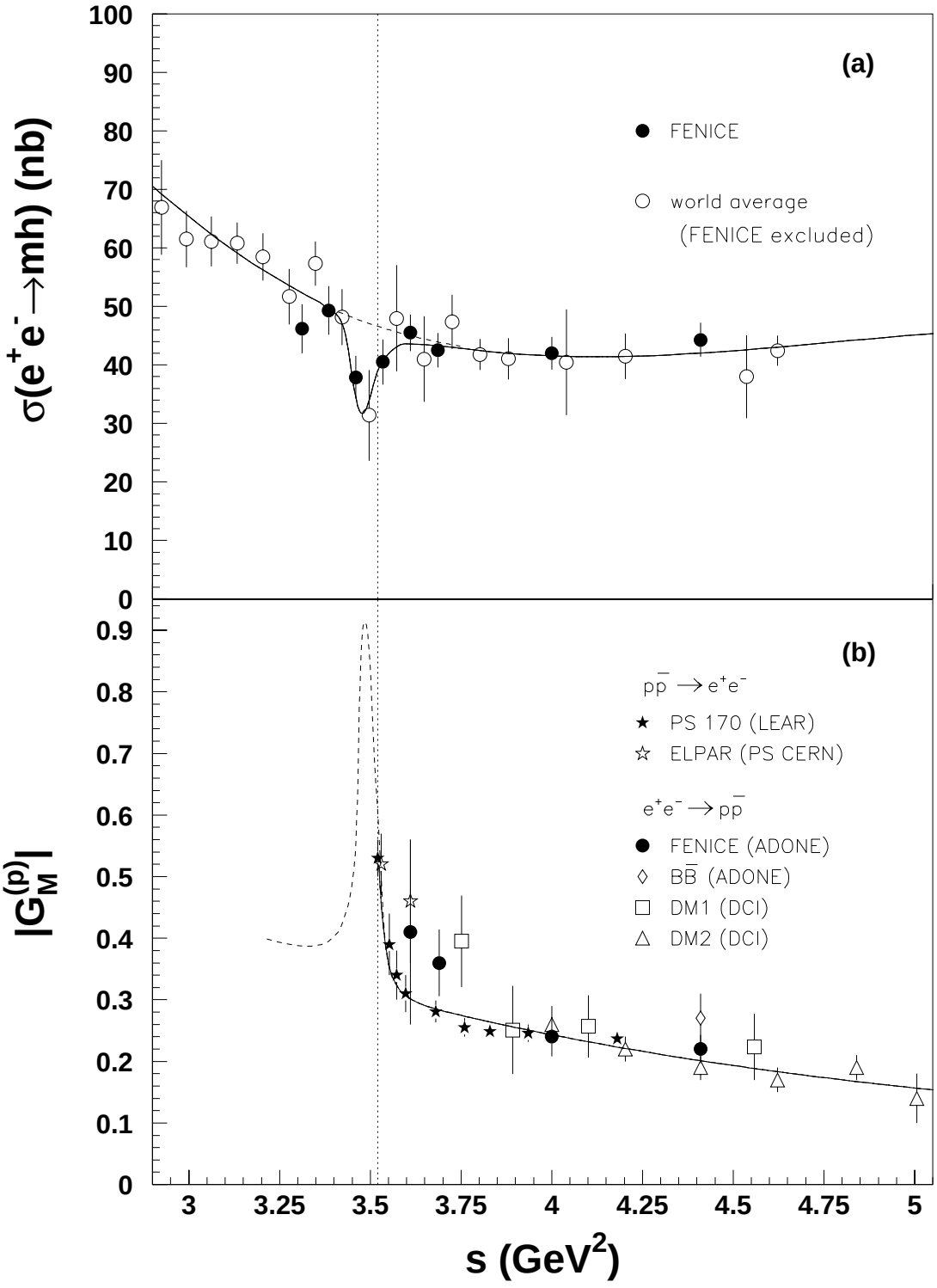
The neutron form factor is bigger than that of the proton.

NEUTRON ANGULAR DISTRIBUTION



From the fit of the angular distribution $\left|G_E^{\,n}\right| << \left|G_M^{\,n}\right|$

PROTON FORM FACTOR AND TOTAL HADRONIC CROSS SECTION



OTHER BARYON FORM FACTOR MEASUREMENTS

- Δ, Λ, Σ

  Δ-N, Σ^0-Λ transition form factors

- No data exists

  (only Λ form factor with poor statistical accuracy)

- Flavor symmetry relates the hyperon form factors to those of the nucleons

  ➡ accurate prediction of flavor- simmetry breaking as test of QCD

CONCLUSIONS

- Open issues
  - $G_{\text{time-like}} \approx 2\, G_{\text{space-like}}$
  - $\left|G_M^{\,n}\right| > \left|G_M^{\,p}\right|$
  - $\left|G_E^{\,n}\right| << \left|G_M^{\,n}\right|$?
  - Steep threshold behavior (related to narrow structure in $e^+e^- \rightarrow$ hadrons cross section ?)
- New high statistics measurements in order to highlight in this field ➡ P.Bosted talk