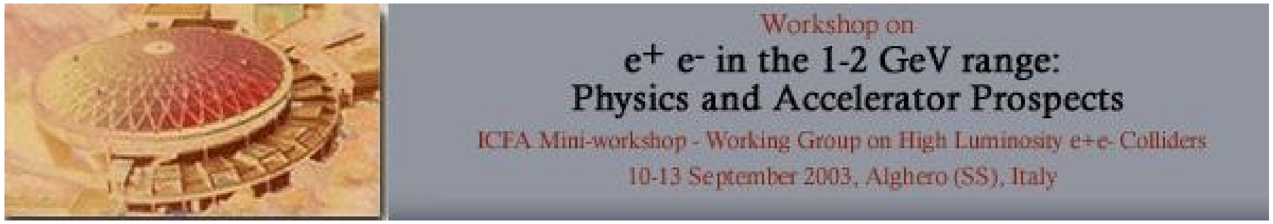


Short status report of the nucleon time like form factors measurements

Alessandro De Falco
Dipartimento di Fisica and I.N.F.N.
Cagliari, Italy

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 and related measurements

  FENICE
  BES
  BELLE

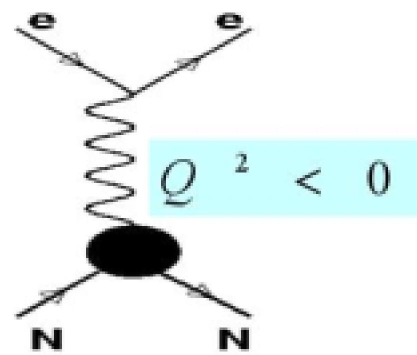
Nucleon E.M. Form Factors

- Low Q^2
  - charge distribution
    magnetization current

- High Q^2
  - valence quark distribution

- Crucial test of QCD from the non perturbative regime (near threshold) to perturbative regime (large Q^2)

SPACE-LIKE REGION



- Study of the reaction $e^-p \rightarrow e^-p$
- Rosenbluth cross section:

$$\left(\frac{d\sigma}{d\Omega}\right)_R = \left(\frac{d\sigma}{d\Omega}\right)_{Mott} \left[\frac{G_E^2 + \tau G_M^2}{1+\tau} + 2\tau G_M^2 \tan\left(\frac{\theta}{2}\right)\right]$$

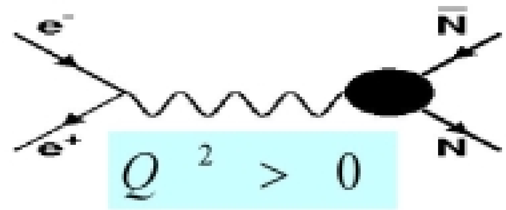
$$\tau = -q^2 / 4m_p^2$$

$$G_E = F_1 + \frac{q^2}{4m^2} F_2 \qquad G_M = F_1 + F_2$$

- The FF in the space-like region are real
- Dipolar behaviour and scaling at low Q^2 (<10 GeV^2) **??**

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

TIME-LIKE REGION



- Study of the reactions $e^+ e^- \leftrightarrow N \bar{N}$
- Differential cross section

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

  - at threshold **$G_E = G_M$** (uniform angular distribution)
  - At $Q^2 >> 4m_p^2$, G_E contribution negligible
- Complex form factors
  - Relative phase can be determined measuring the polarization of the outgoing p
- at large Q^2 (QCD, analyticity) **$G(Q^2) = G(-Q^2)$**
- According to pQCD simplest expectations:

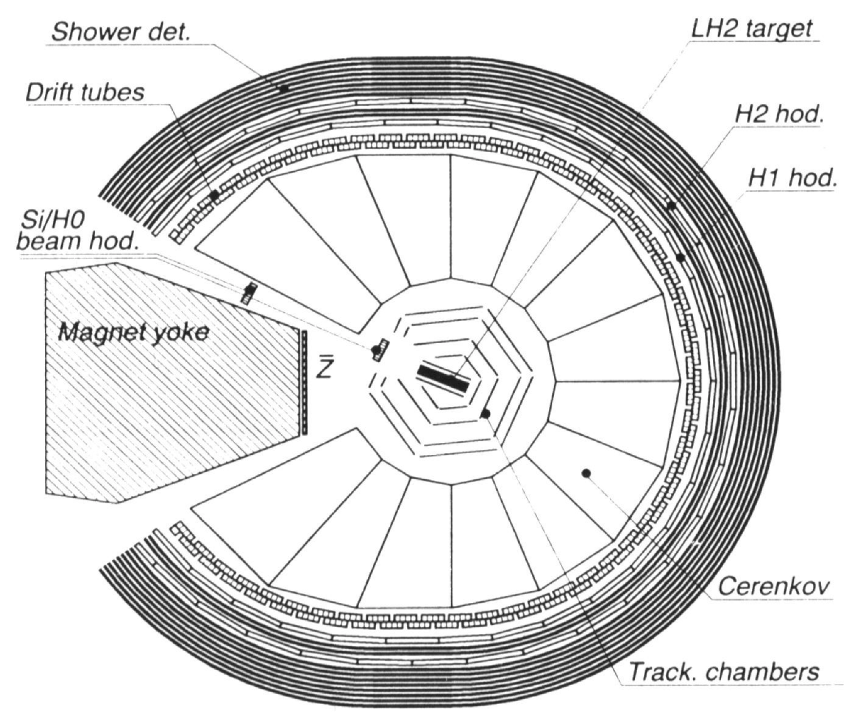
$$\left|\frac{G_M^n}{G_M^p}\right|^2 \approx \left(\frac{q_d}{q_u}\right)^2 = 0.25$$

- Any prediction where the nucleon is mostly represented in terms of valence quarks should *hardly foresee* **$G_M^n > G_M^p$**

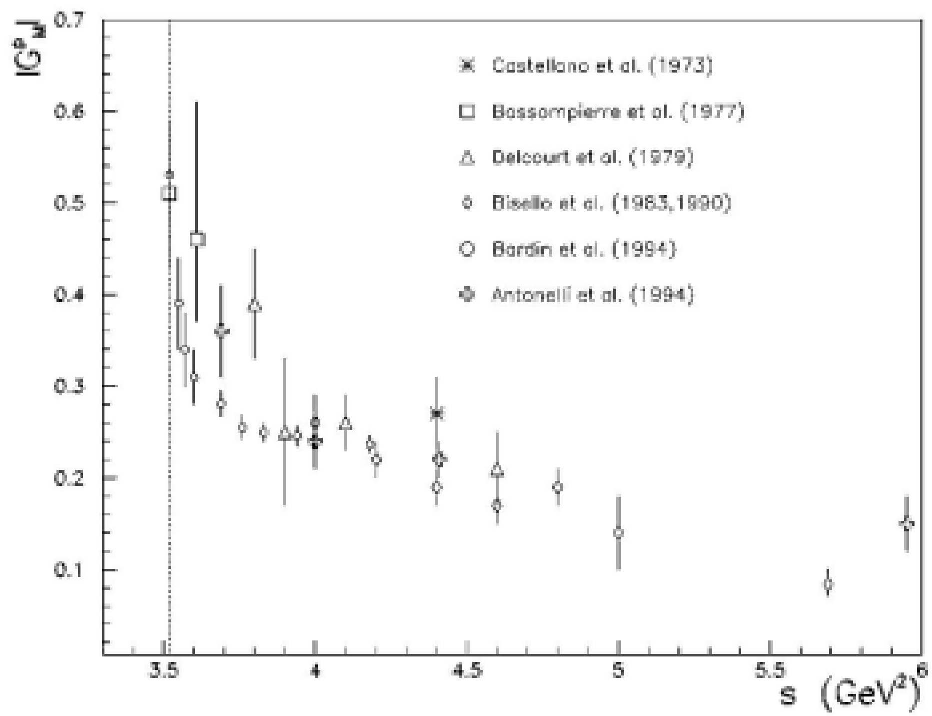
PROTON FORM FACTOR (LOW Q^2)

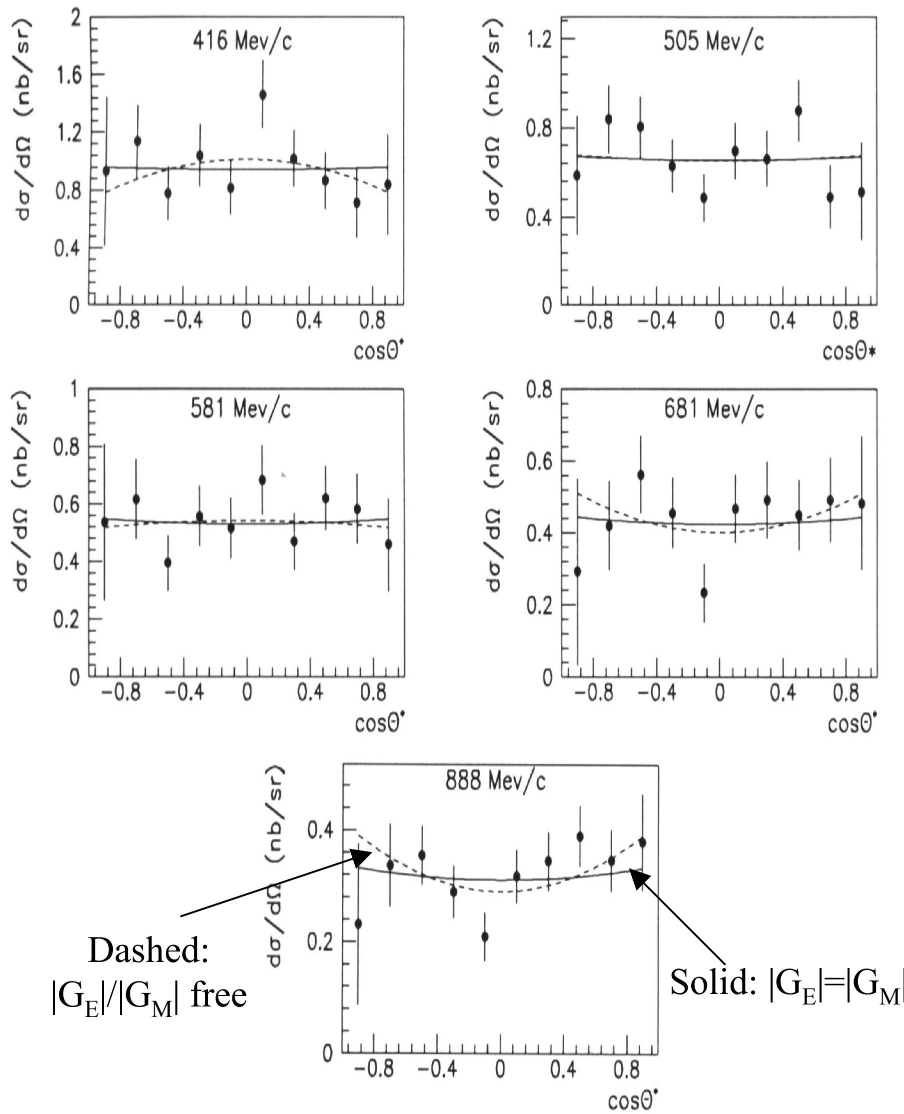
PS170 exp. (CERN) Nucl.Phys.B 411 (1994), 3

- **$\bar{p}p \rightarrow e^+e^-$** from threshold to $E_{CM} \cong 2$ GeV at LEAR
- Selection of e^+e^- pairs in high hadronic background
  - threshold Čerenkov counter + shower detector
- Two body reconstruction
  - tracking system (MWPC, drift tubes)
- About 2000 e^+e^- events above threshold



PROTON FORM FACTOR (LOW Q^2)





Rapid fall just above threshold

Hint for a decrease with energy of the ratio $\frac{|G_E{}^p|}{|G_M{}^p|}$?

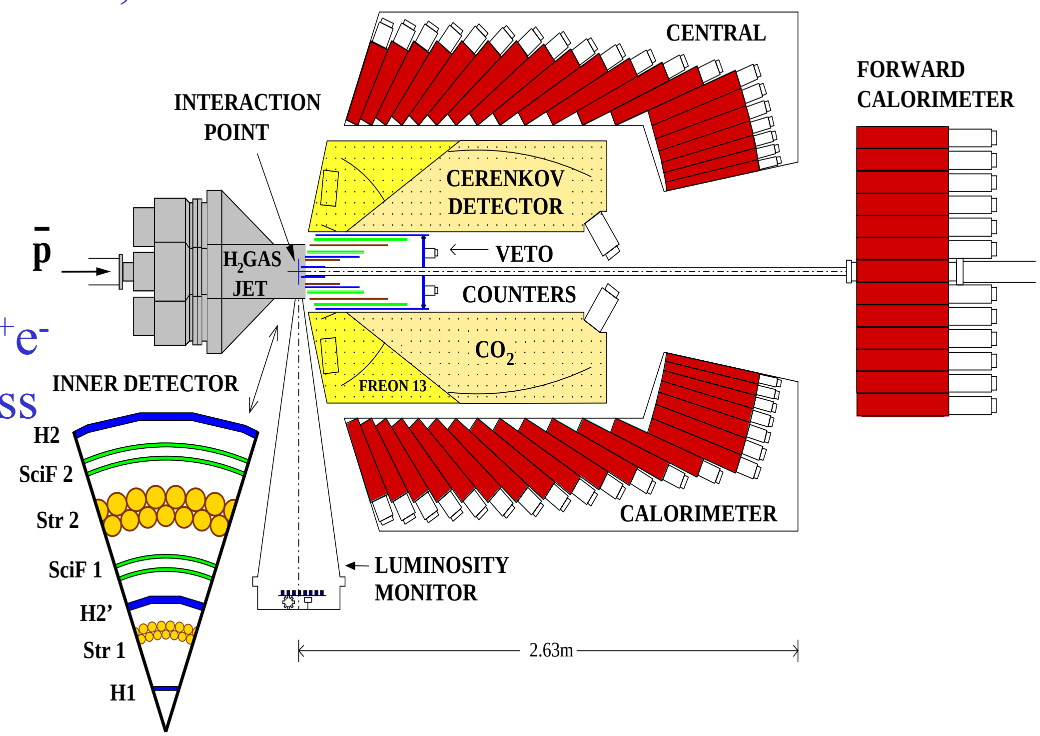
PROTON FORM FACTOR (HIGH Q^2)

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

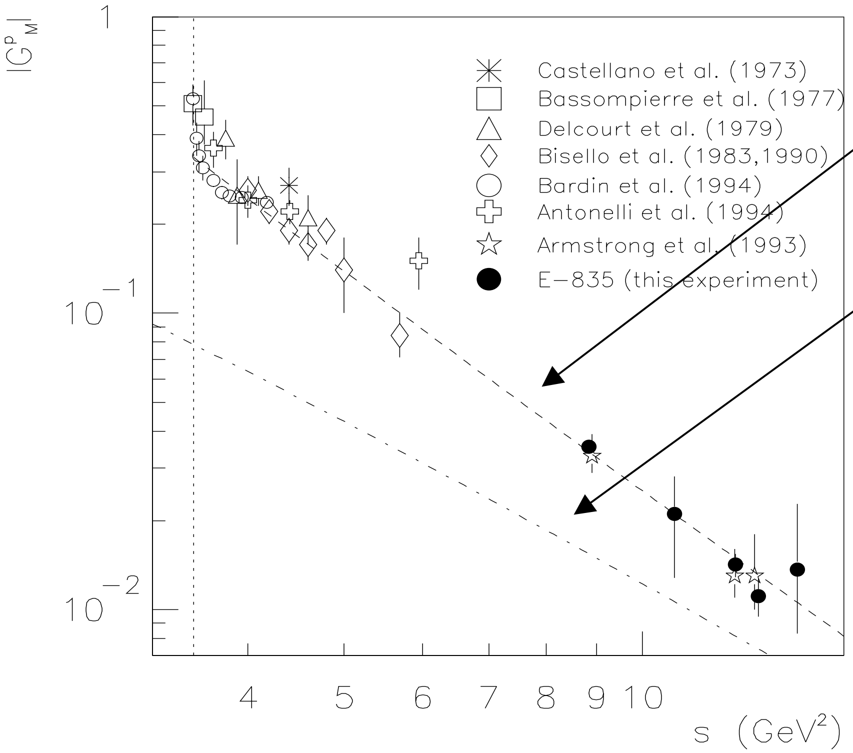
- E835 study the charmonium spectroscopy in $\bar{p}p$ annihilations into electromagnetic final states:

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

- Ideal for study of form factors as well, through the reaction $\bar{p}p \to e^+e^-$
  - High Q^2, but cross section still detectable
  - High luminosity
  - Efficient reconstruction of e^+e^- pairs with high invariant mass
  - Low background level



PROTON FORM FACTOR (HIGH Q^2)



The dashed line is the pQCD fit.

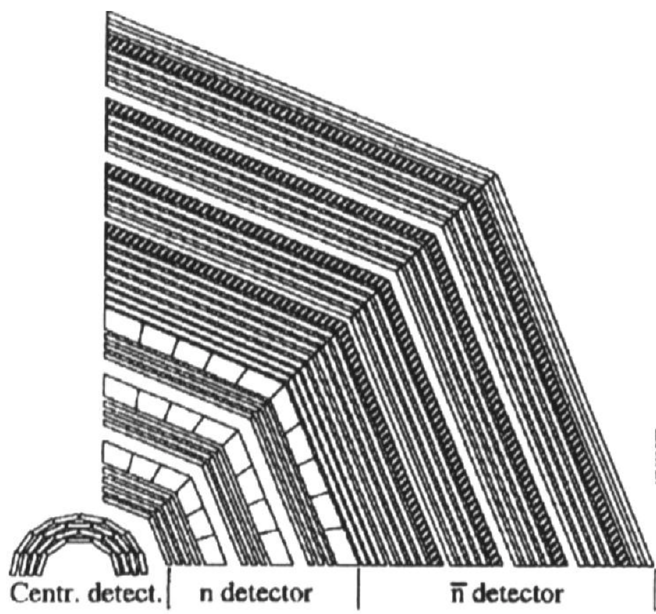
The dot-dashed line represents the dipole behavior of the form factor in the space-like region for the same values of $|Q|^2$.

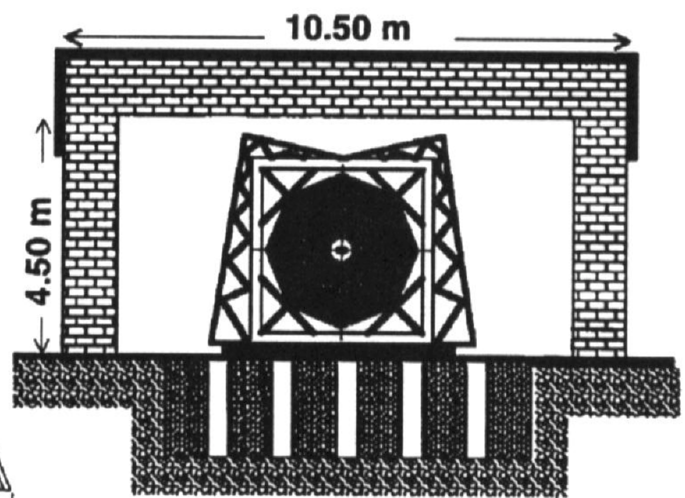
The expected $|Q|^2$ behaviour is reached quite early, however there is a factor of 2 between timelike and spacelike data measured at the same $|Q|^2$.

NEUTRON FORM FACTOR

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

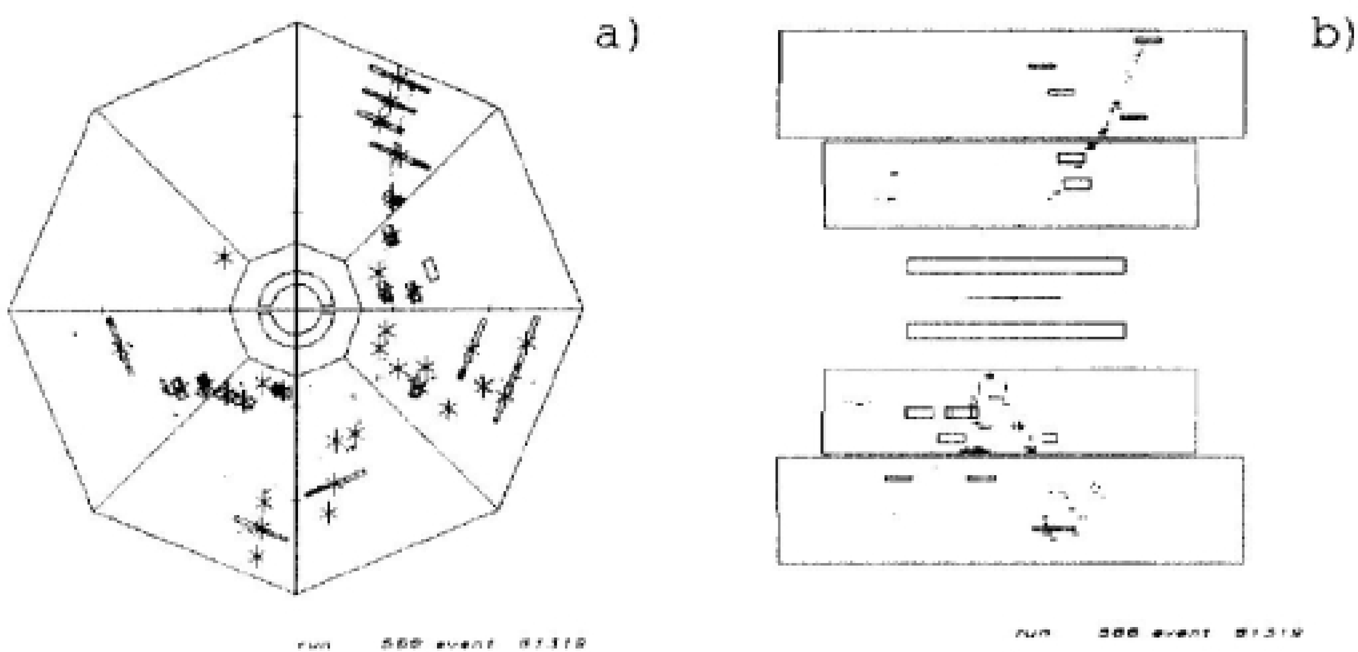
- $e^+e^- \rightarrow n\,\bar{n}$ from threshold to $E_{CM} \cong 2.5$ GeV at ADONE (Frascati)
- Antineutron annihilation in nuclei: many prong event ("star topology")
  - ➢ iron converters + limited streamer tubes (tracking)
- Low antineutron velocity → hodoscopes for TOF measurement
- Low luminosity → shield against cosmic ray background



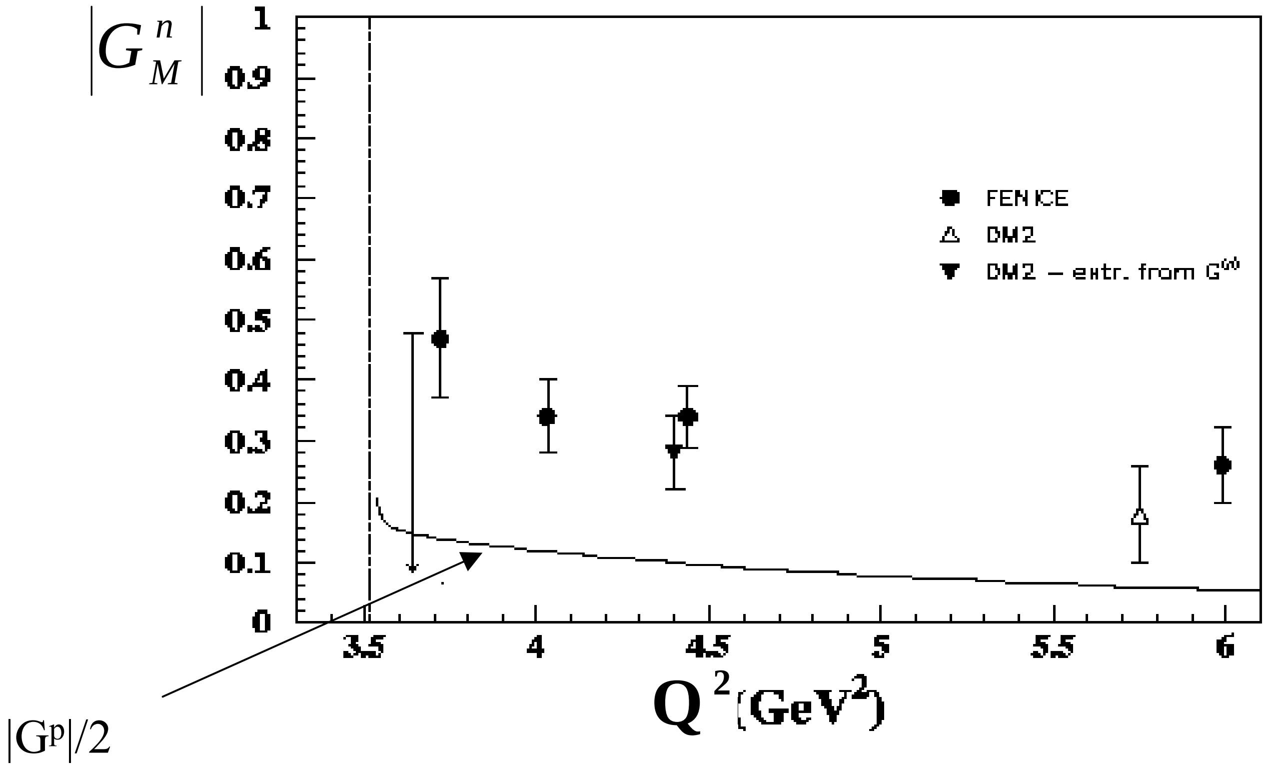


•Antineutron identification → isolated annihilation star + β measurement

•Neutron detection efficiency ~10% at 2 GeV → no signal from neutron required



NEUTRON FORM FACTOR



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

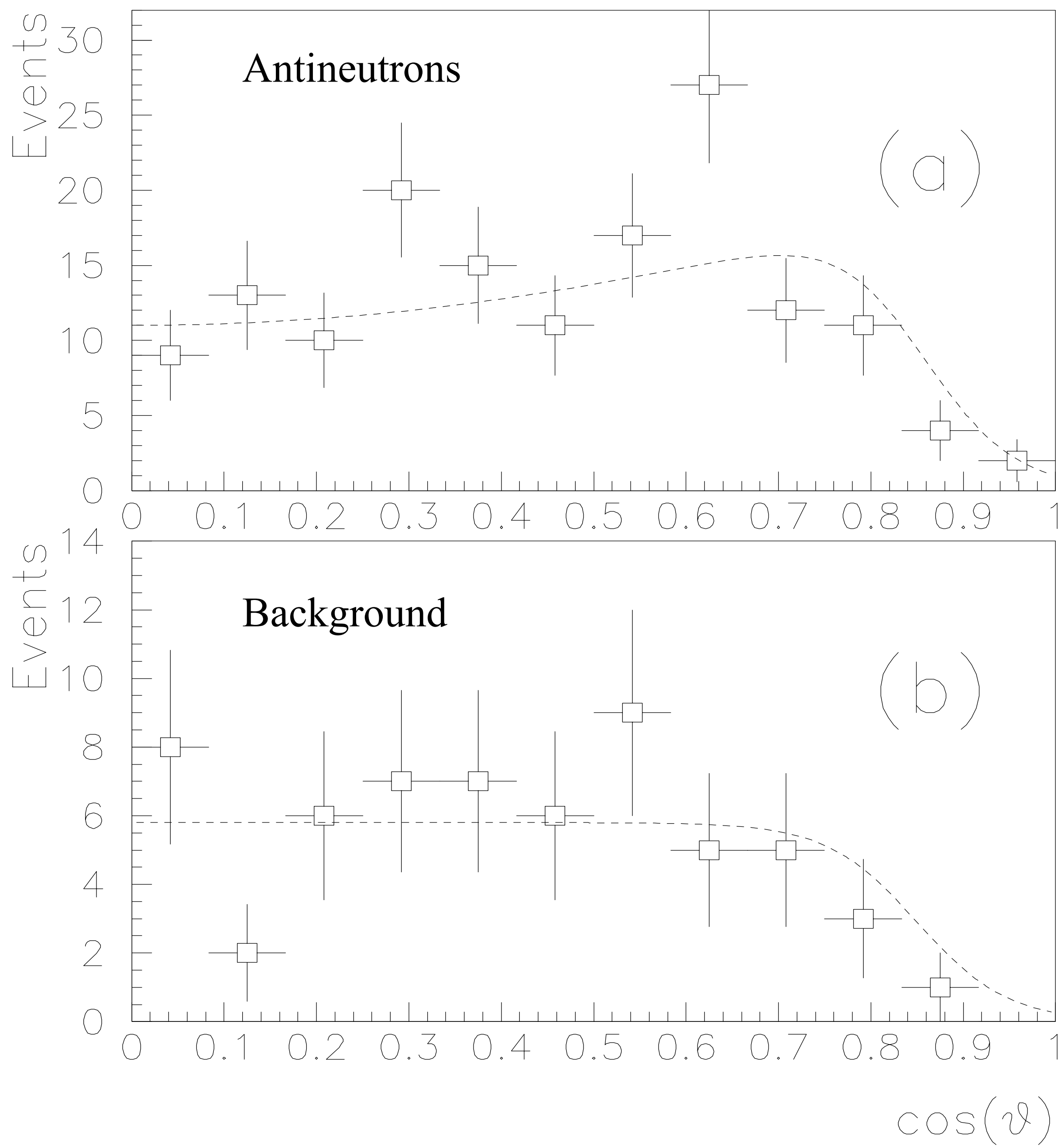
74 events

$$|G_M^n| > |G_M^p|$$

NEUTRON ANGULAR DISTRIBUTION

From the fit of the angular distribution with the function $A(1+\cos^2\theta) + B\sin^2\theta$ hint for

$$|G_E^{\,n}| \ll |G_M^{\,n}|$$



OTHER BARYONS FORM FACTORS

- Only one measurement for the Λ with poor statistics (4 events)

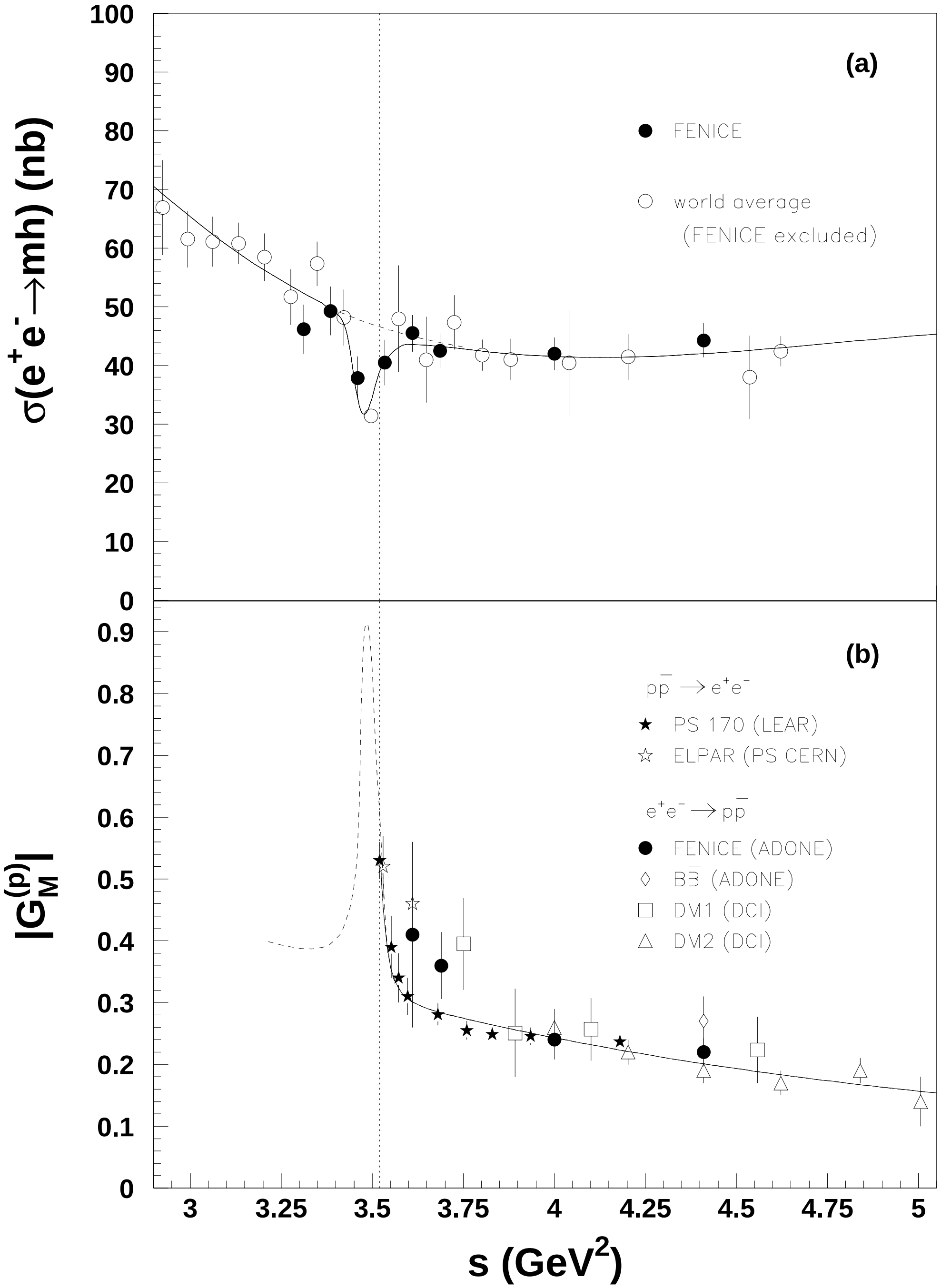
- No measurement for other baryons

PROTON FORM FACTOR AND TOTAL HADRONIC CROSS SECTION

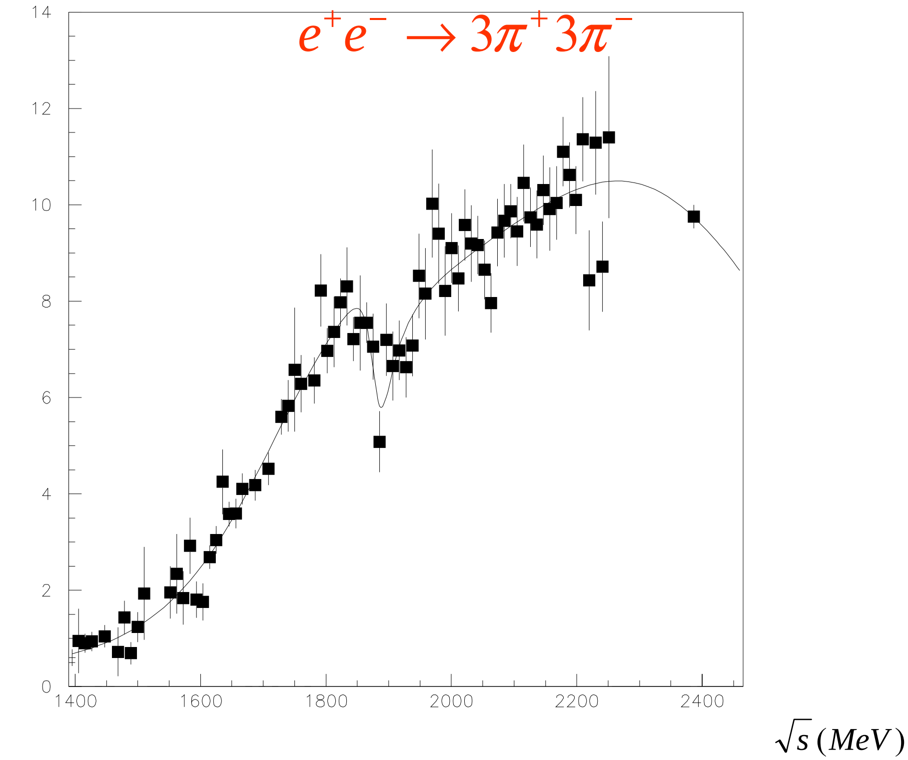
Narrow vector resonance interfering with the background given by broad resonances can generate the dip in $e^+e^- \to$hadrons

$M = (1.87 \pm 0.01)$ GeV

$\Gamma = (10 \pm 5)$ MeV

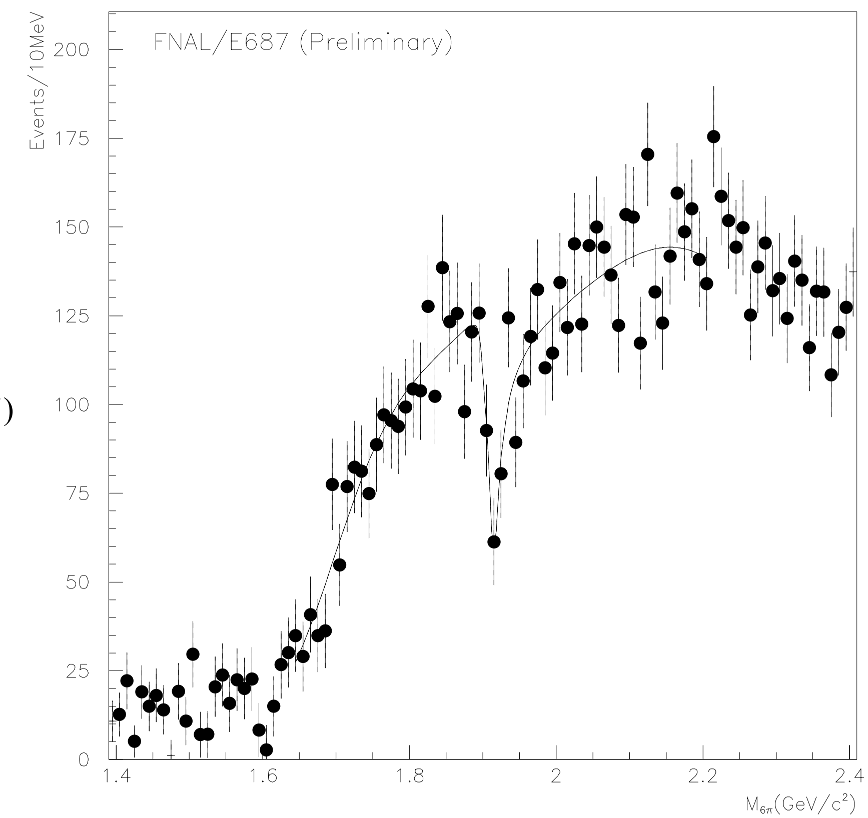


DM2 data



FNAL E687

$3\pi^+3\pi^-$ from high energy diffractive photoproduction

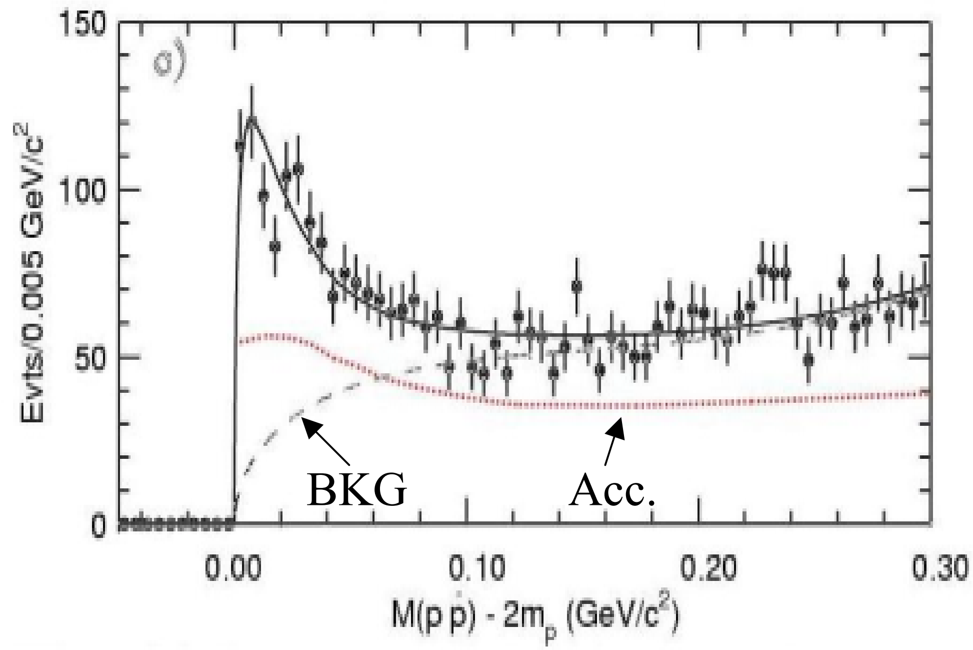


BES results

(Phys. Rev. Lett. 91 022001 (2003))

Study of the $J/\Psi \rightarrow \bar{p}p\gamma$ decay at theBejing e^+e^- collider with a large solid angle magnetic spectrometer

Events with a high energy γ and 2 opposite sign tracks selected



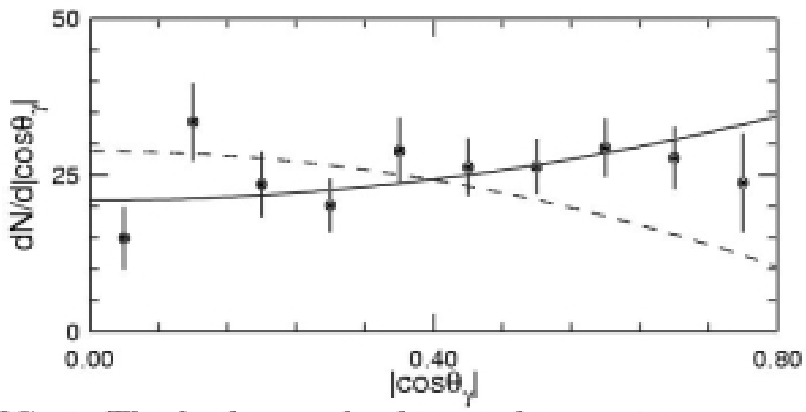


FIG. 4. The background-subtracted, acceptance-corrected $|\cos\theta_\gamma|$ distribution for $J/\psi \rightarrow \gamma p\bar{p}$-enriched events with $M_{p\bar{p}} \leq 1.9$ GeV$/c^2$. The solid curve is a fit to a $1 + \cos^2\theta_\gamma$ shape for the region $|\cos\theta_\gamma| \leq 0.8$; the dashed curve is the result of a fit to $\sin^2\theta_\gamma$.

The mass distribution is fitted with a f_{BKG} + a Breit Wigner with

M = 1876.4 ± 0.9 MeV

Γ = 4.6 ± 1.8 MeV

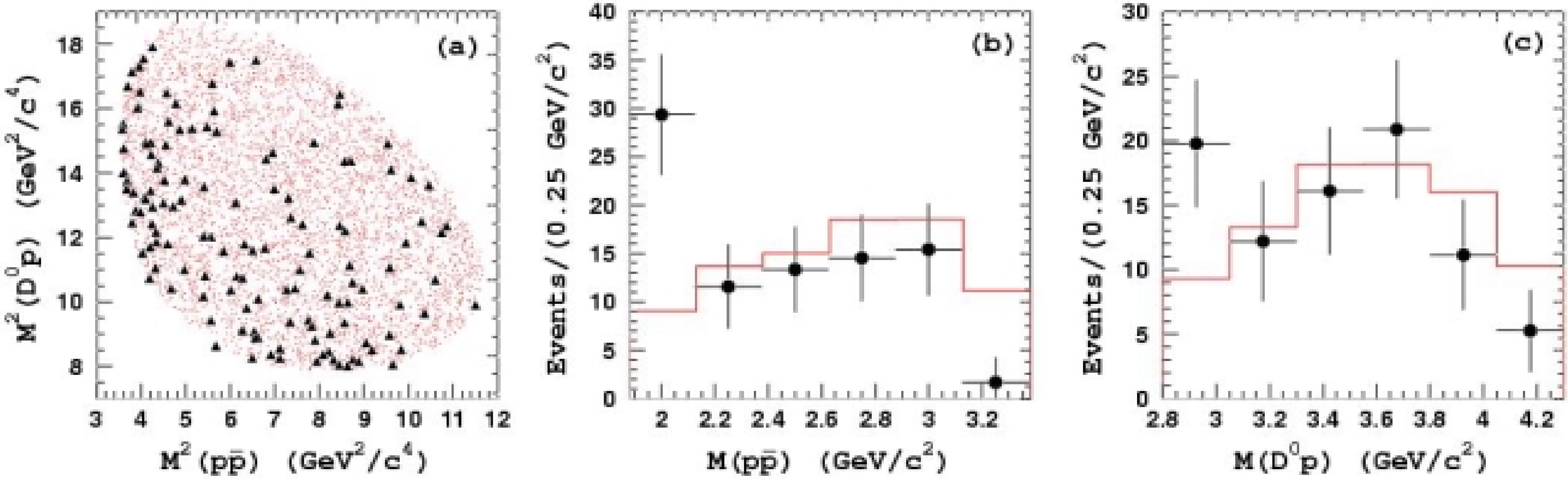
Angular distribution consistent with that expected for a resonance with $J^{PC}=0^{-+}$ or $J^{PC}=0^{++}$

Results from Belle

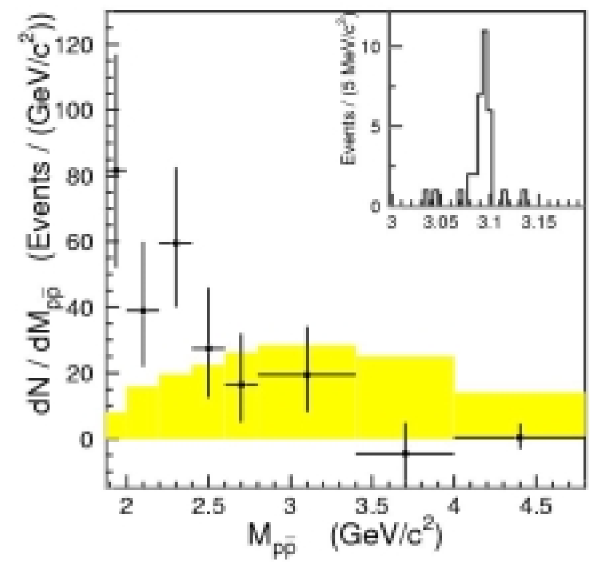
Phys. Rev. Lett. 88(181803) 2002

Phys. Rev. Lett. 89(151802) 2002

$$\overline{B}^0 \to D^{(*)0} p\overline{p}$$



$$B^{\pm} \to p\overline{p}K^{\pm}$$



CONCLUSIONS AND OPEN ISSUES

- **$|G_M^n| > |G_M^p|$**
- **$|G_E^n| << |G_M^n|$?**
- Steep threshold behaviour
- Resonant structures
- High Q^2 predictions
- Present/future measurements at BaBar:
  - $p\,\bar{p}$: Data collected (statistics ~ 10 ev/10 MeV bin)
    - ✓ Separation between G_E and G_M?
    - ✓ No measurement of relative phase possible
  - $n\,\bar{n}$: measurement not possible (trigger/background rejection)
  - $\Lambda\,\bar{\Lambda}$: measurement not possible (small cross section and trigger) ?

High statistics samples with a good measurement of the polar angle distributions are needed to disentangle the contributions of G_E^p, G_M^p, G_E^n, G_M^n