Time-like proton form factors measurement with PANDA

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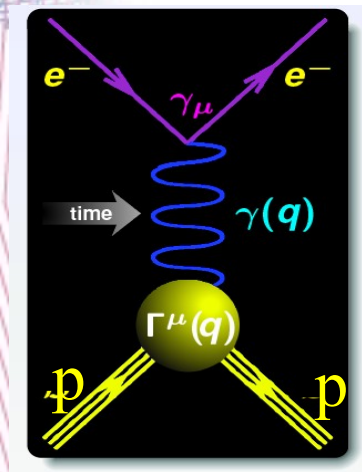
Proton form factors

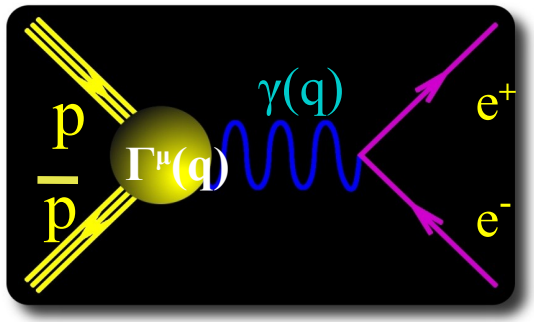
Space Like (SL)



FFs real

Unphysical region
$\bar{p}\,p \rightarrow e^+ e^- \pi^0$

Time Like (TL)



FFs complex

q^2

Nucleon current operator (Dirac and Pauli FFs)

$$\Gamma^{\mu}(q^2) = \gamma^{\mu} F_1(q^2) + \frac{i}{2M_N}\sigma^{\mu\nu} q_{\nu} F_2(q^2)$$

non-spin flip — spin flip

Electric and Magnetic Sachs FFs

$$G_E(q^2) = F_1(q^2) + \tau F_2(q^2)$$

$$G_M(q^2) = F_1(q^2) + F_2(q^2)$$

$$\tau = \frac{q^2}{4M_N^2}$$

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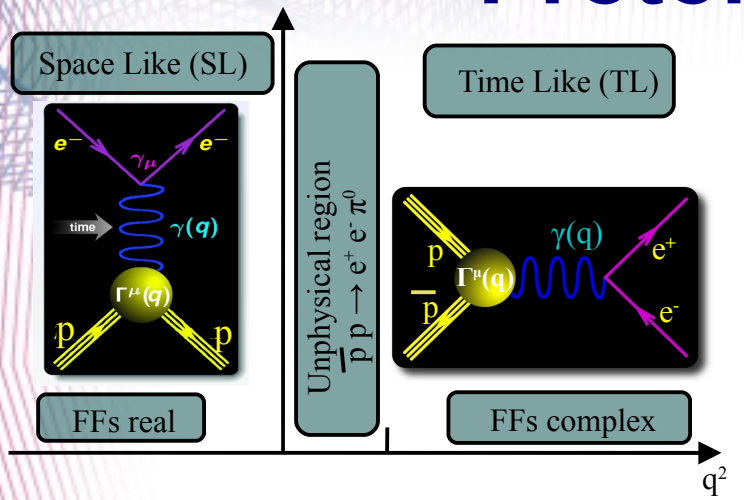
Proton form factors



pQCD asymptotic behavior of nucleon FFs

$$G_M(q^2) \sim F_1(q^2) \sim \frac{\alpha_s^2}{q^4}$$

$$G_E(q^2) \sim \frac{\alpha_s^2}{q^4}$$

$$at \quad q^2 \sim \infty$$

$$\frac{G_E(q^2)}{G_M(q^2)} \sim constant$$

Electric and Magnetic Sachs FFs

$$G_E(q^2) = F_1(q^2) + \tau F_2(q^2)$$

$$G_M(q^2) = F_1(q^2) + F_2(q^2)$$

$$\tau = \frac{q^2}{4M_N^2}$$

Phragmen Lindeloef theorem:

$$\underbrace{\lim_{q^2 \to -\infty} G_{E,M}(q^2)}_{\text{Space like}} = \underbrace{\lim_{q^2 \to +\infty} G_{E,M}(q^2)}_{\text{Time like}}$$

Vanishing of the phase of time like FFs

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Present situation of the proton form factors in space like and time like regions

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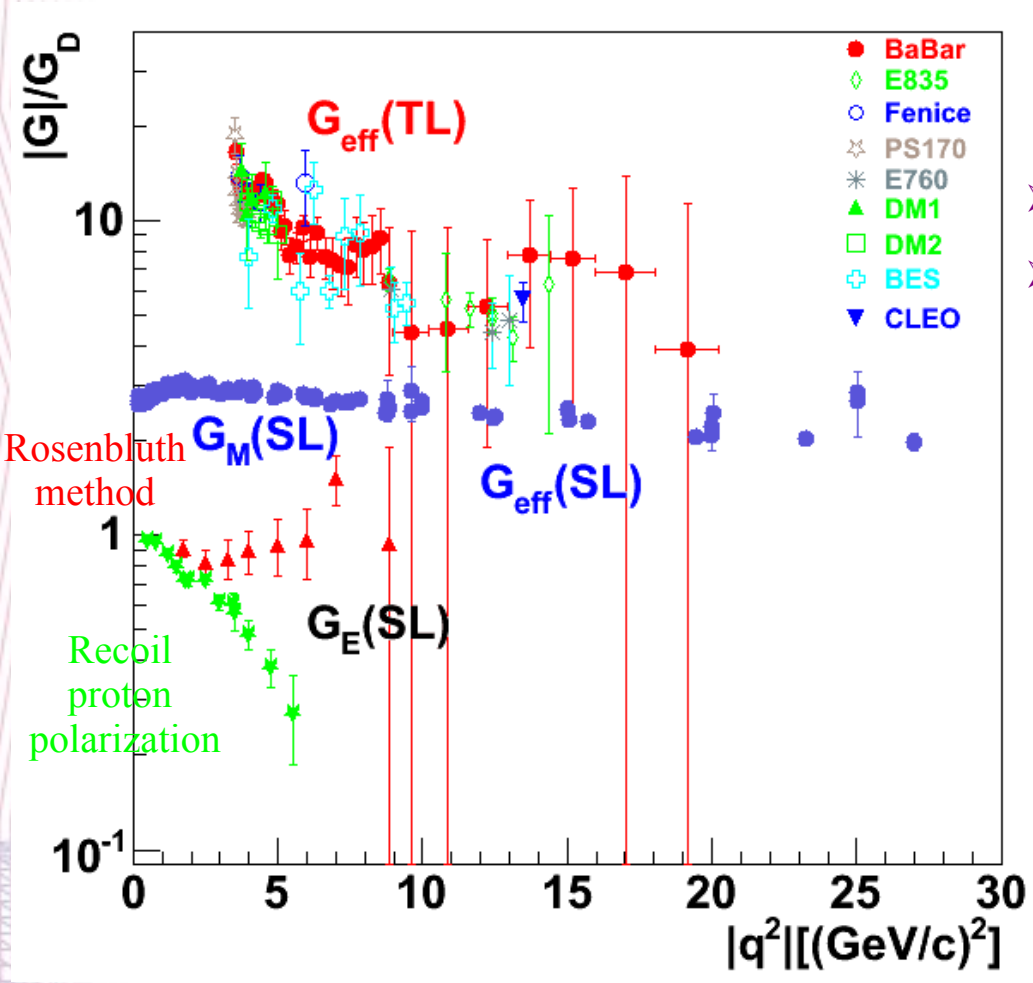


Space like

- Separation between G_E and G_M
- Contradictory results from the Rosenbluth and recoil proton polarization methods

Time like

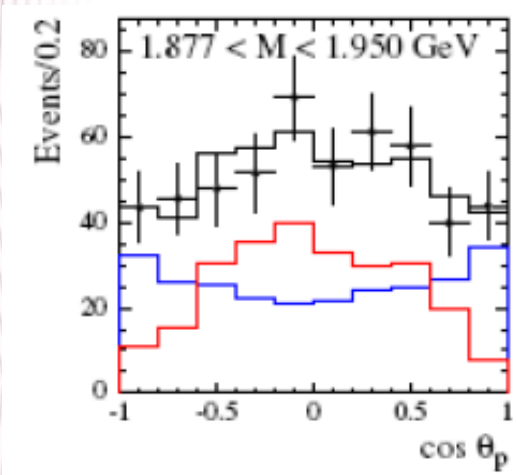
- No individual determination G_E and G_M
- Assume $G_E = G_M$
- Few data available at high q^2

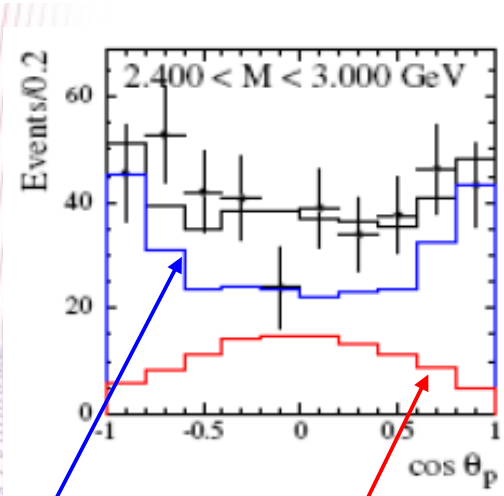
Experimental situation in time like region

angular distributions from BaBar

$$e^+ e^- \rightarrow \bar{p}\, p\, \gamma_{ISR}$$

$$\frac{d\sigma}{d\cos\theta_{CM}} = \pi \frac{\alpha^2}{8M_p^2\sqrt{\tau(\tau-1)}}\left[|G_M|^2(1+\cos^2\theta_{CM}) + \frac{|G_E|^2}{\tau}\sin^2\theta_{CM}\right]$$

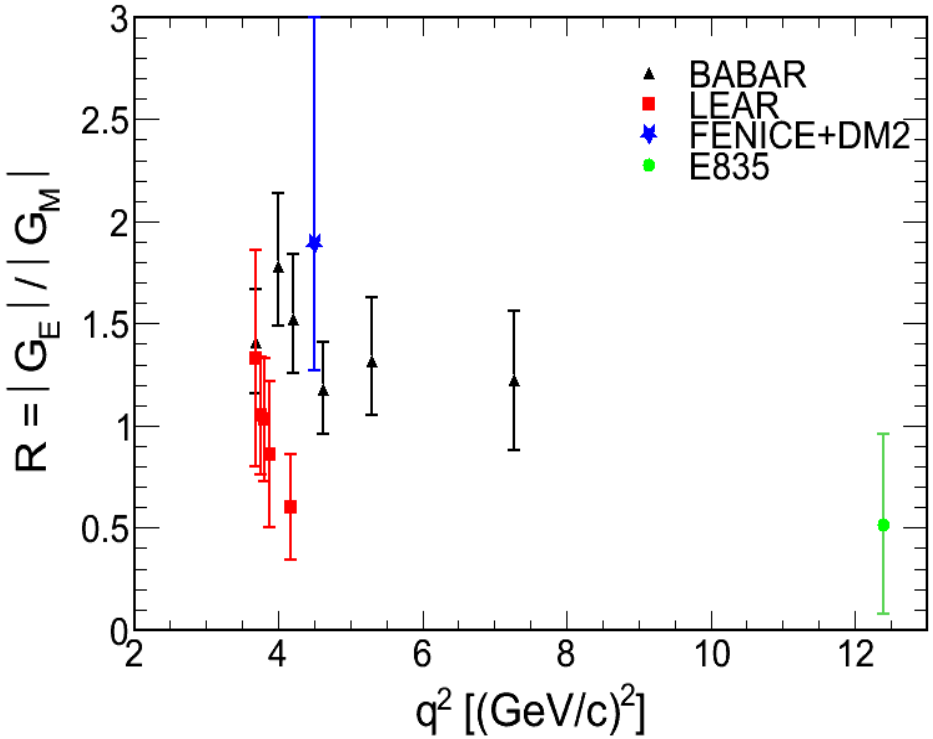




G_M factor

G_E factor

Only 4 experiment in TL region provided ratio of electric and magnetic form factors



Need for more precise data !!

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FAIR, Facility for Antiproton and Ion Research at Darmstadt, Germany

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GSI, Darmstadt

- heavy ion physics
- nuclear structure
- atomic and plasma physics

FAIR: New facility

- heavy ion physics & nuclear structure
- atomic, plasma and applied physics
- higher intensities & energies
- **antiproton physics**

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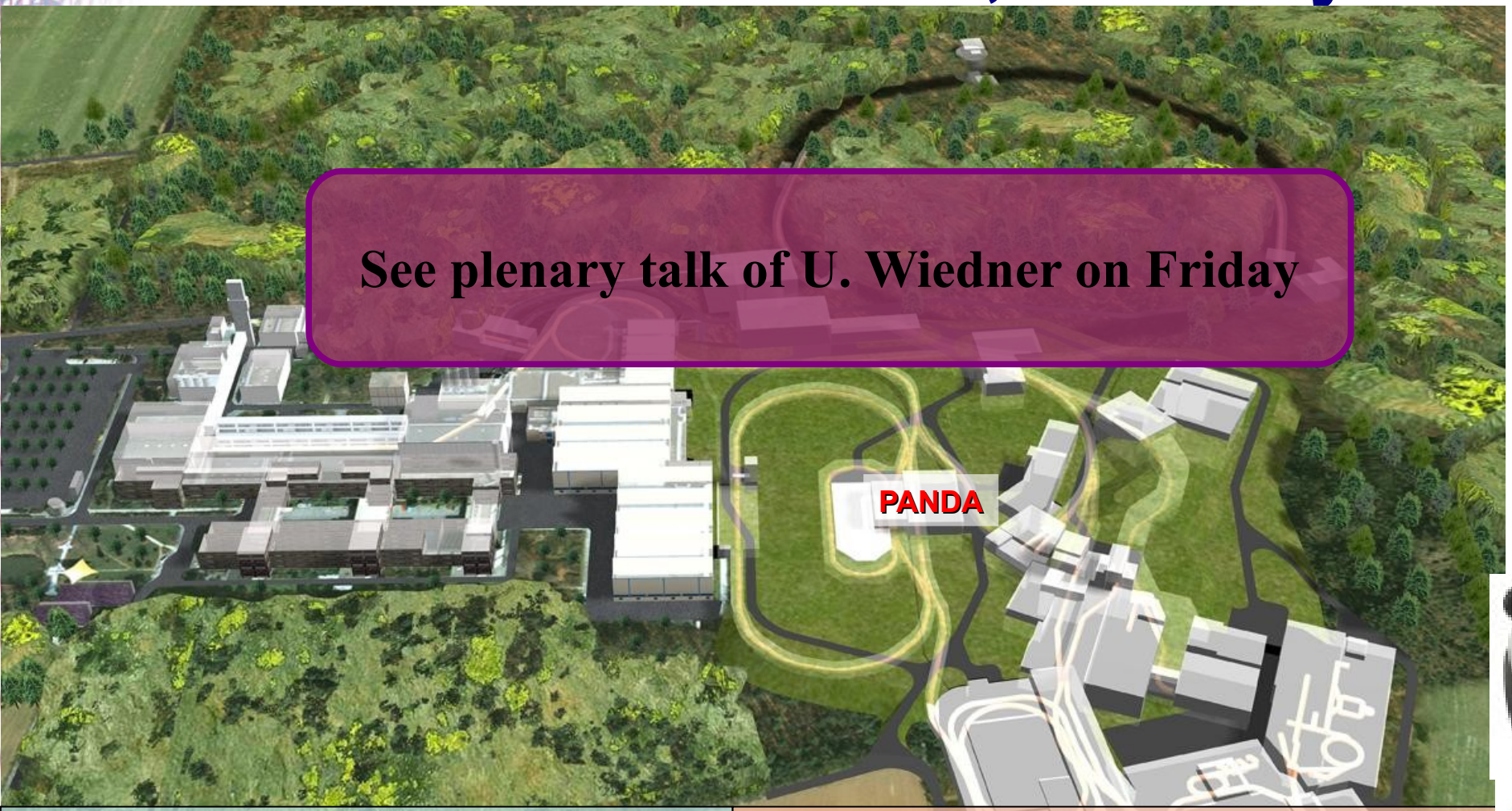


See plenary talk of U. Wiedner on Friday

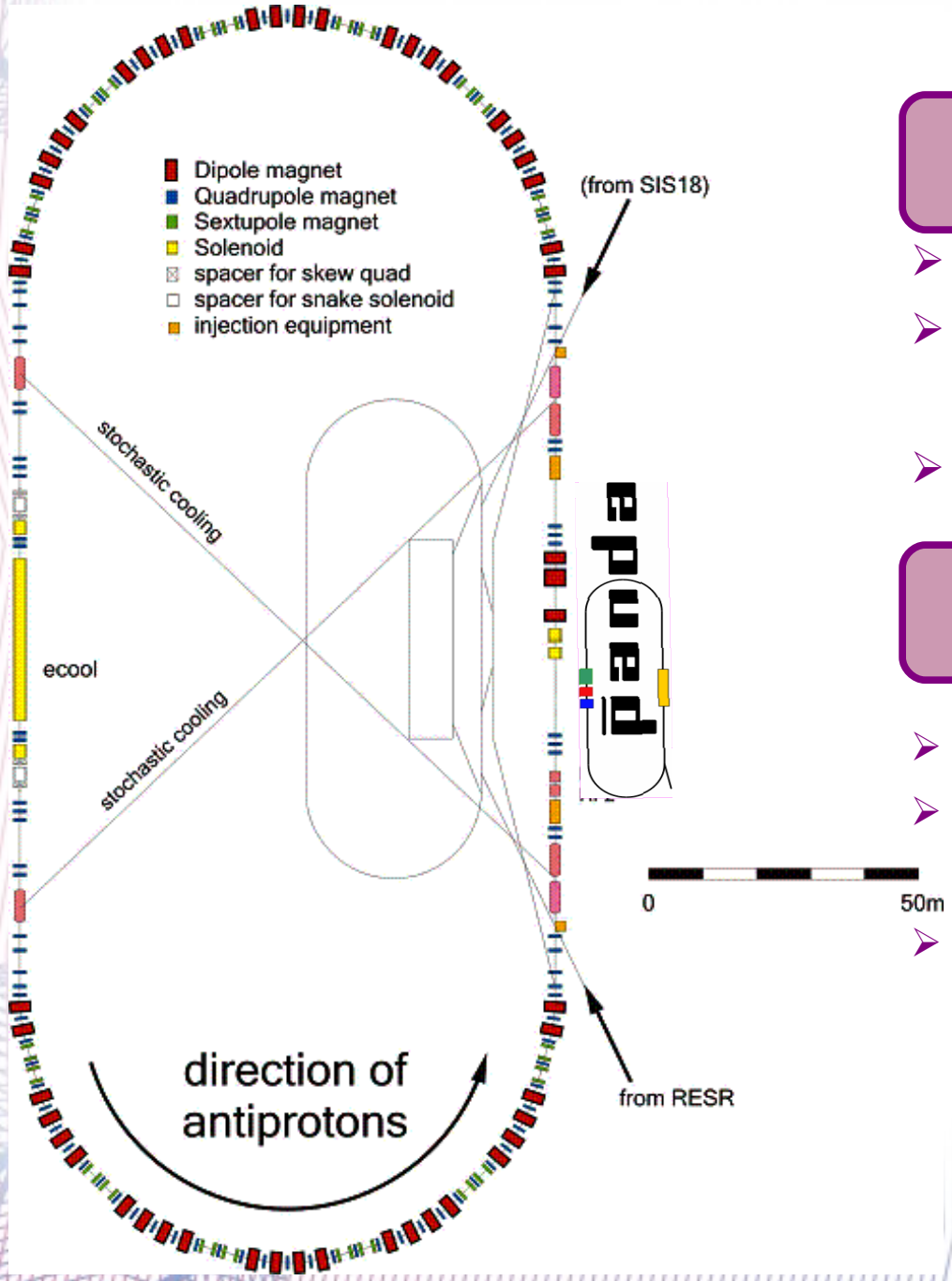
GSI, Darmstadt

- heavy ion physics
- nuclear structure
- atomic and plasma physics

FAIR: New facility

- heavy ion physics & nuclear structure
- atomic, plasma and applied physics
- higher intensities & energies
- **antiproton physics**

HESR, High Energy Storage Ring



High luminosity mode

- Momentum range: 1.5 – 15 GeV/c
- $L = 2x10^{32}\ cm^{-2}\ s^{-1}$ for 10^{11} stored anti-protons
- $\sigma_p/p = 10^{-4}$

High resolution mode

- Momentum range: 1.5 – 9 GeV/c
- $L = 2x10^{31}\ cm^{-2}\ s^{-1}$ for 10^{10} stored anti-protons
- $\sigma_p/p = 2x10^{-5}$

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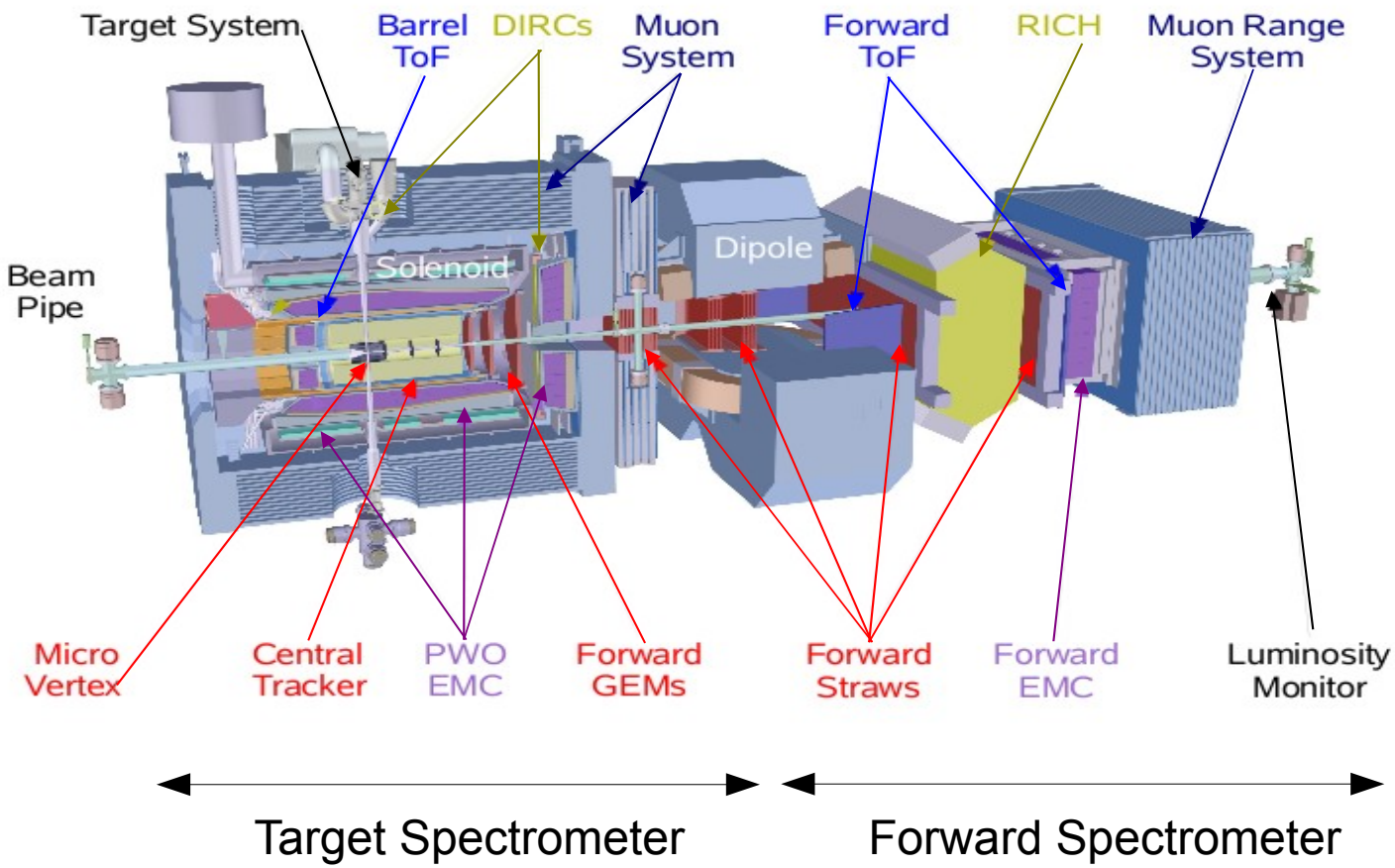
PANDA detector



Detector requirements:

- *nearly 4π solid angle for PWA;*
- *high rate capability: $2x10^7$ interactions/s;*
- *efficient event selection;*
- *good momentum resolution $\Delta p/p \approx 1\%$;*
- *vertex resolution < 100 μm for K^0, Σ, Λ, ($D^{\pm}$,$c\tau \approx 317$ μm);*
- *good PID (γ, e, μ, π, K, p);*
- *γ detection, few MeV < E_γ < 10 GeV*

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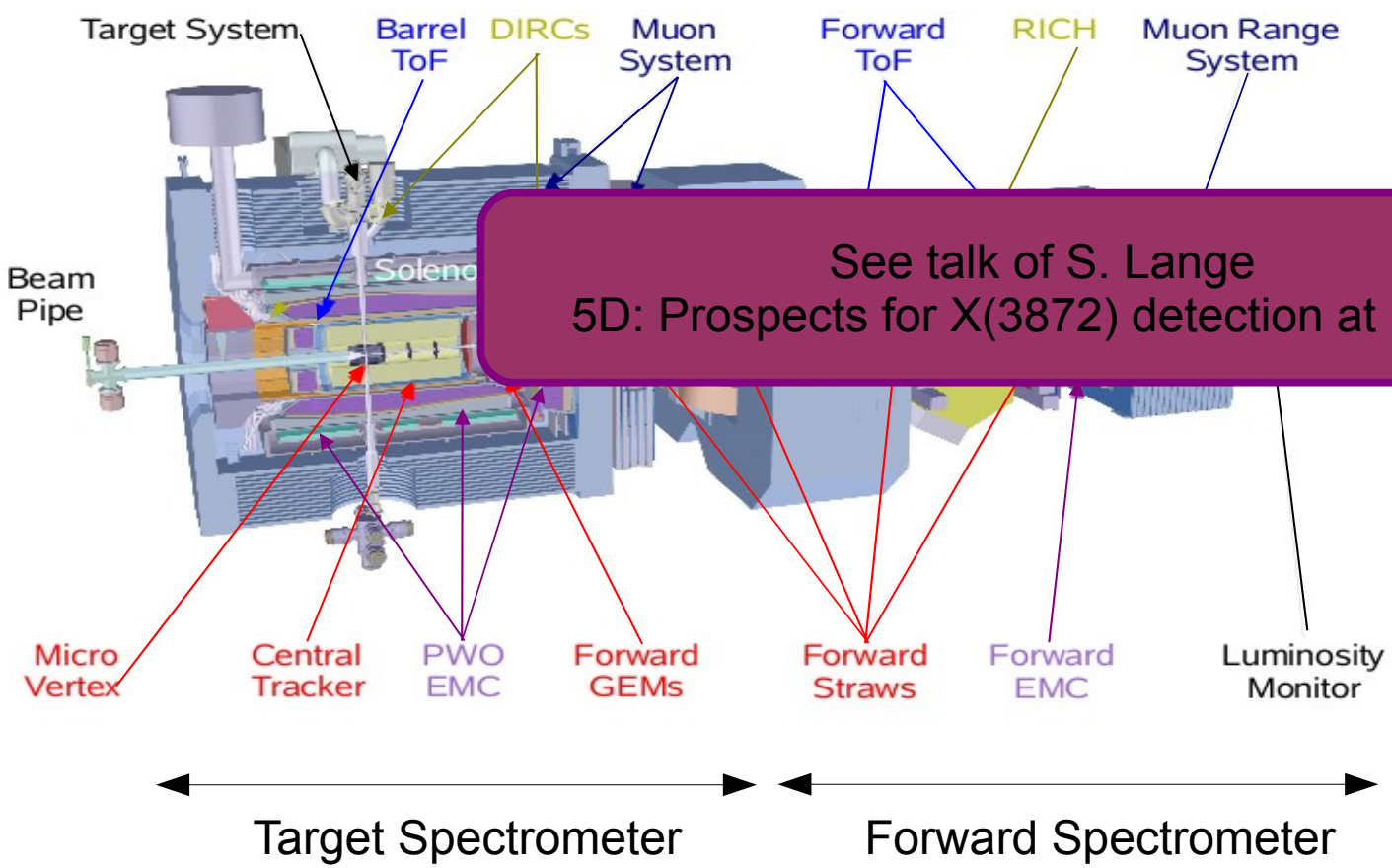
PANDA detector



See talk of S. Lange
5D: Prospects for X(3872) detection at Panda

Detector requirements:

- *nearly 4π solid angle for PWA;*
- *high rate capability: $2x10^7$ interactions/s;*
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What PANDA will bring ?

- Knowledge of proton form factors up to large q^2
- Transition to QCD: asymptotic
- Reaction mechanism (1 or 2 photon exchange)

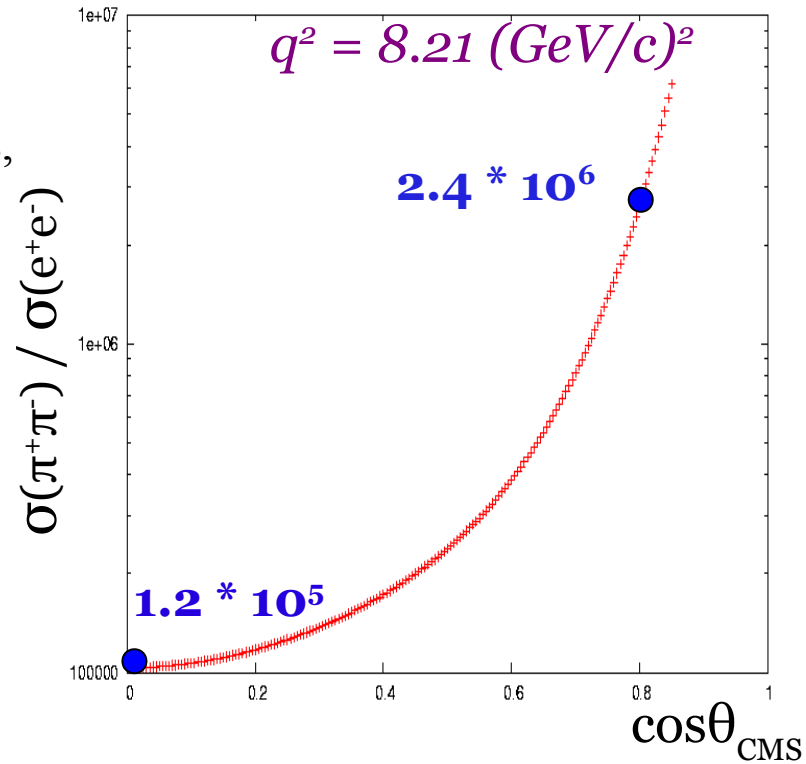
Experimental challenges

Background reactions

- 3 body reactions
  - Tracking in magnet, θ and φ correlations,
  - Missing or invariant mass cuts, PID

- 2 charged body reactions

  (e.g. π+π-,μ+μ-,K+K-)
  - Most important background is π+π- ,
  - Kinematical correlation p=f(θ),
  - PID very important,



Need of rejection against $\pi^+\pi^- \sim 10^9$

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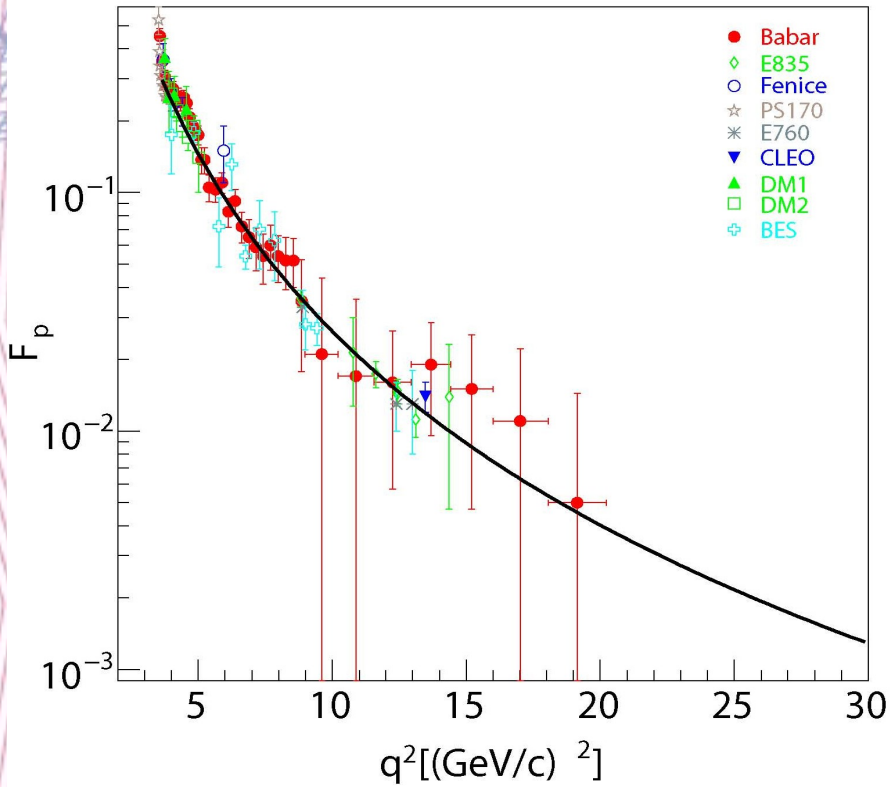
Counting rates and G_E/G_M separation

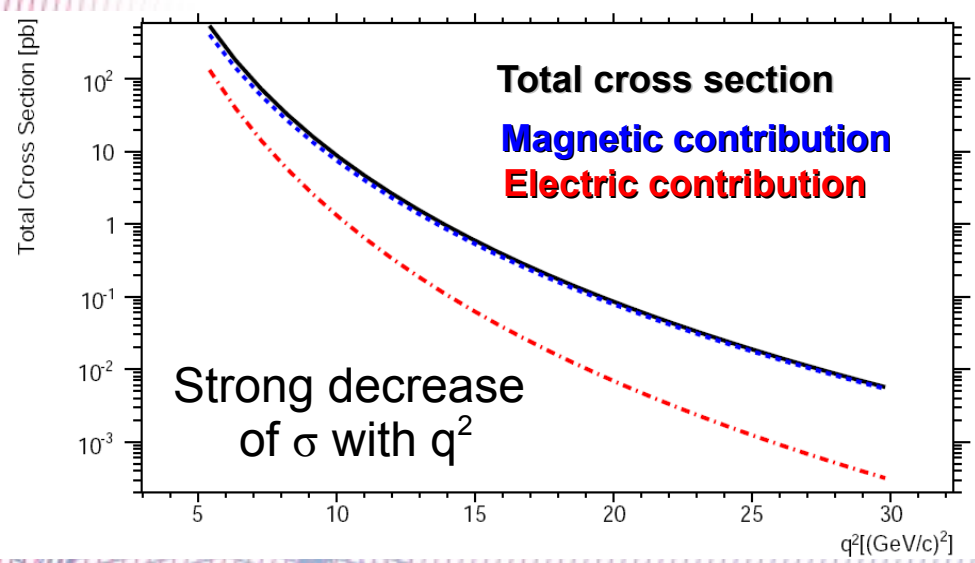


Estimates for the total cross section

$$|G_{E,M}| = \frac{22.5}{\left(1+\frac{q^2}{0.71}\right)^2} \cdot \frac{1}{\left(1+\frac{q^2}{3.6}\right)}$$

fit to the TL data

~120 days; L = 2 fb^{-1}



q^2 [(GeV/c)²]	# evt
5.4	1100000
7.4	140000
8.2	64200
11.0	9100
12.9	3200
13.8	2000
16.7	580
22.3	81
27	22

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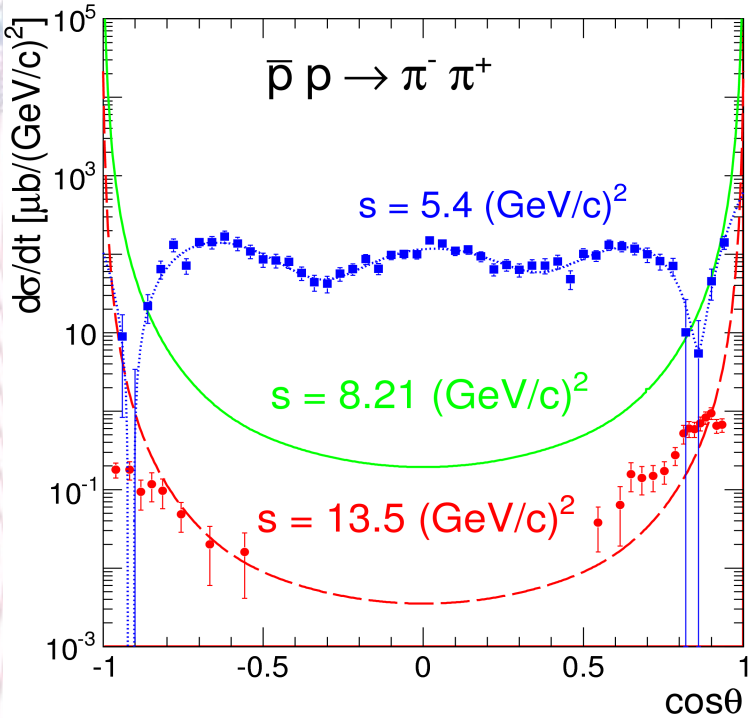
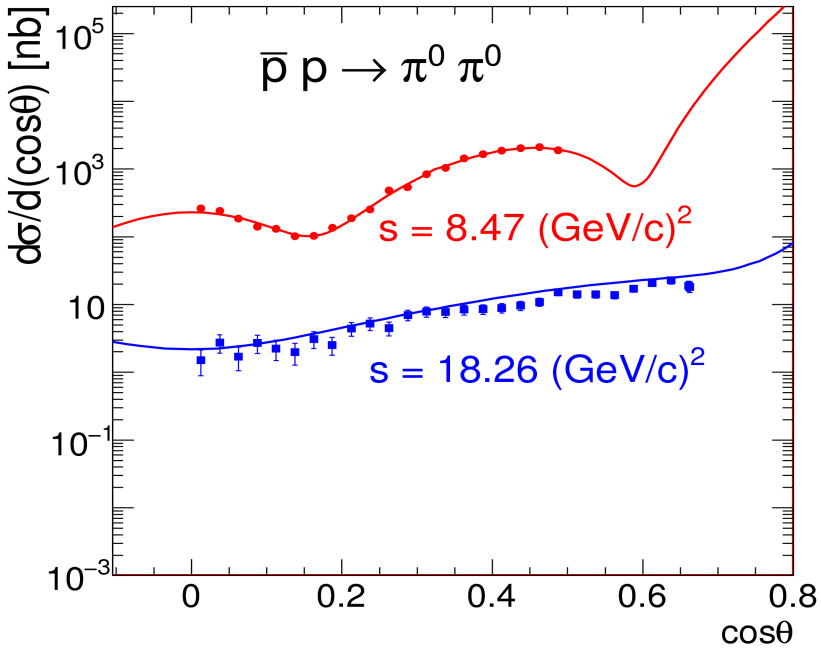
Background simulation and rejection



Angular cross section

- s < 6 (GeV/c)^2 fitted by Legendre polynomials to the data
- s > 6 (GeV/c)^2 counting rules



Using information out of EMC, STT, MVD detectors and kinematic constraints the suppression of the background channels is better than a few 10^9.

background from $\pi^+\pi^-$ < 1 ‰

< 1% on the total cross section

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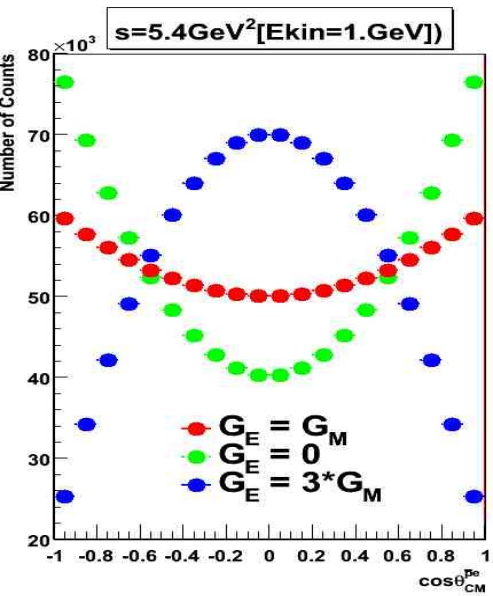
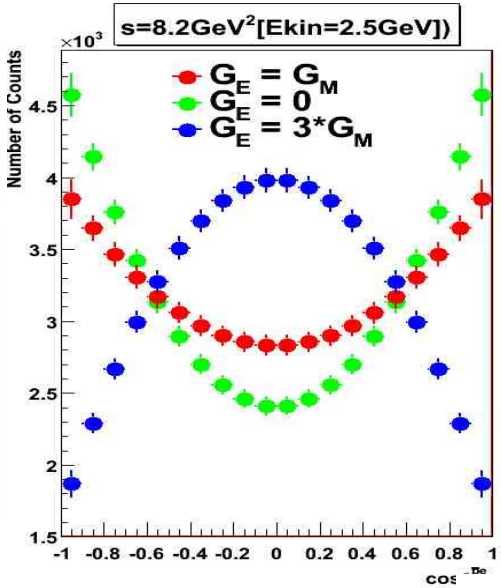
Signal simulation

Monte Carlo distributions

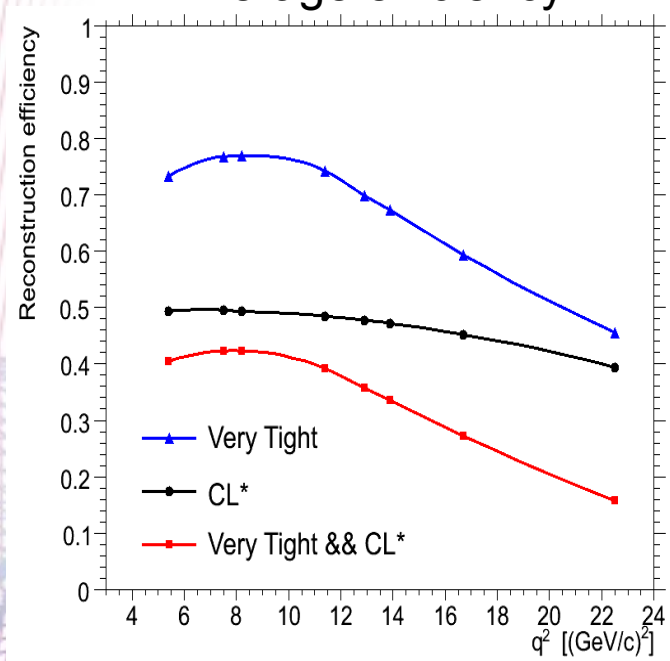


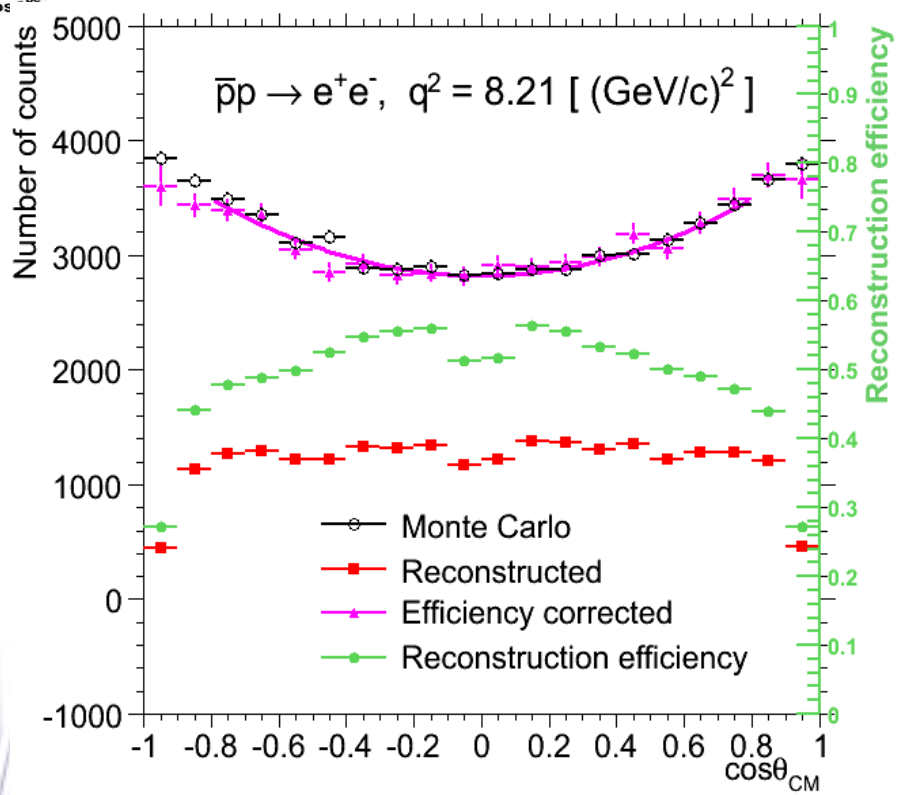


The same analysis code chain and cuts have been applied for signal and background channels.

Efficiency correction determined from isotropic distributions with high statistics.

Average efficiency





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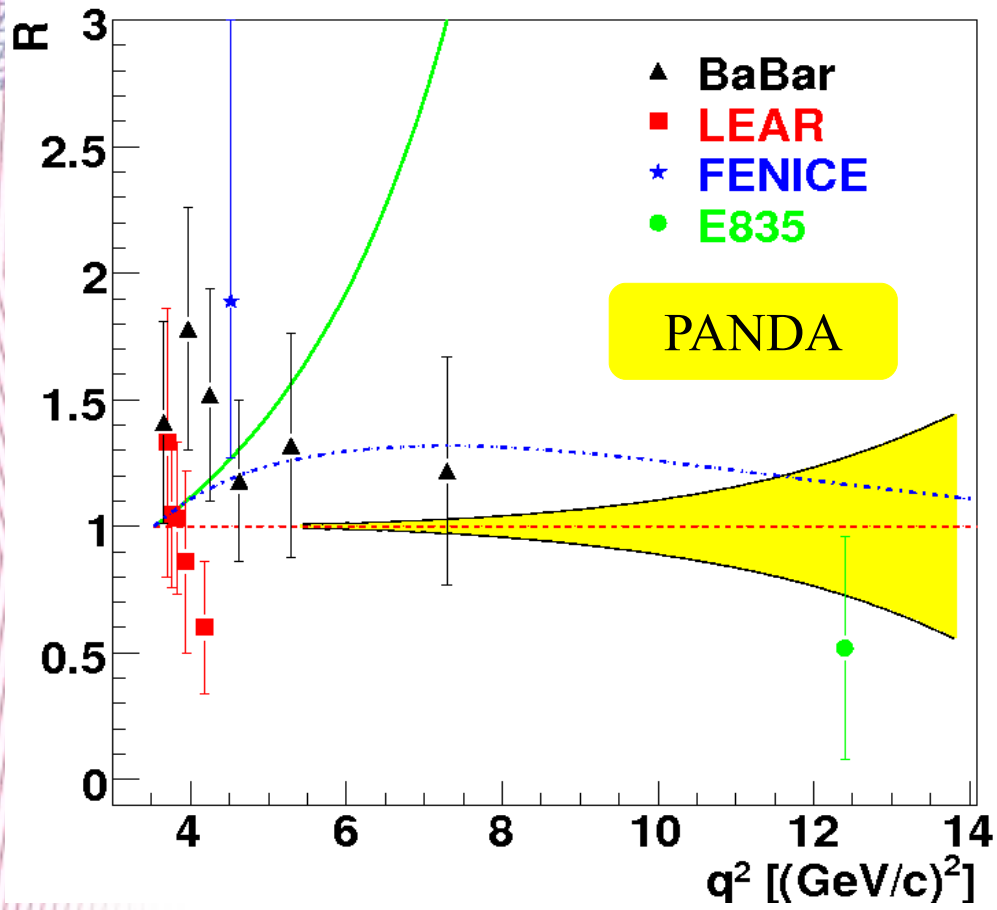
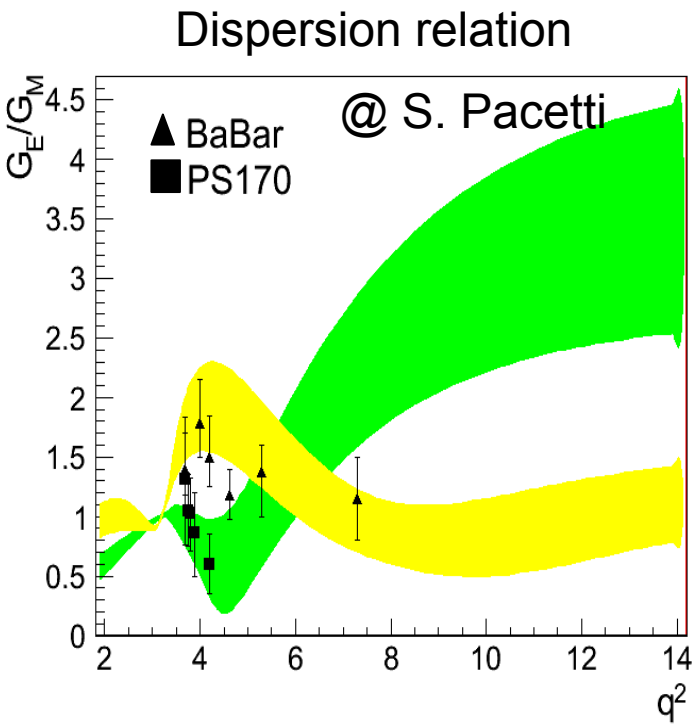
PANDA vs. exp data and theory



VMD: F. Iachello et al., PLB43, 171 (1973)

Extended VMD, PRC66, 045501 (2002)

QCD inspired >> $|G_E|=|G_M|$



Many models have been constructed in order to fit space like data. Analytic continuation of the models to time-like region needed !

PANDA will provide good quality data which can distinguish models.

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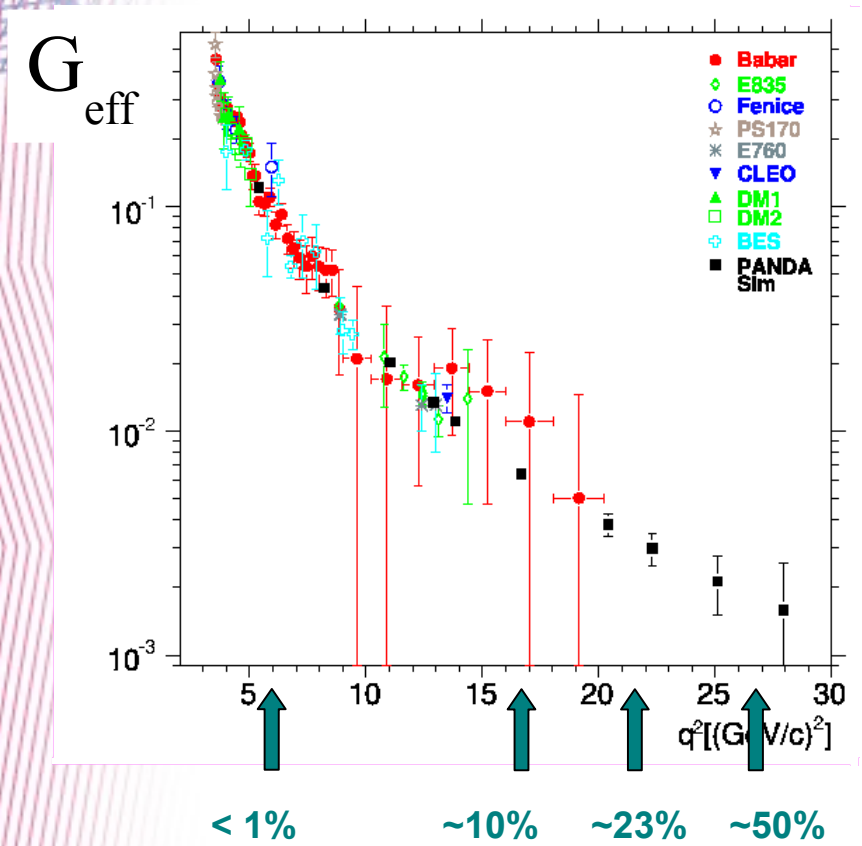
Effective proton form factor: world data



Effective proton form factor (G_{eff}) extracted from time like data.

$$G_{eff} \Rightarrow G_E = G_M$$

With a precise luminosity measurement, one can also determine

- differential cross section up to 22 $(GeV/c)^2$
- the total cross section up to the maximum available q^2 (q^2 = 30$(GeV/c)^2$).

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Conclusion

- PANDA will enhanced knowledge on the proton time like FFs by providing information on
  - ratio of electric to magnetic FFs up to 14 $(GeV/c)^2$
  - total cross-section up to 28 $(GeV/c)^2$

- Unphysical region can be accessed via e.g.: $\bar{p}\,p \rightarrow e^+ e^- \pi^0$

- Possible to study reaction mechanism (1 or 2 photon exchange)
  - sensitivity to odd cosθ contribution (>5%)

- PANDA will provide a new set of data that can be compared to the SL data in the region where asymptotic behavior of FFs might show up

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