Time like proton form factor measurements at PANDA

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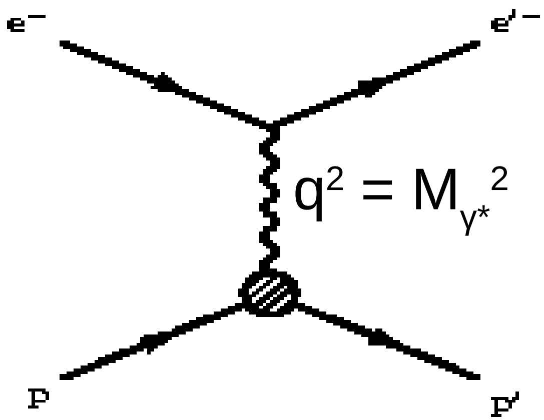
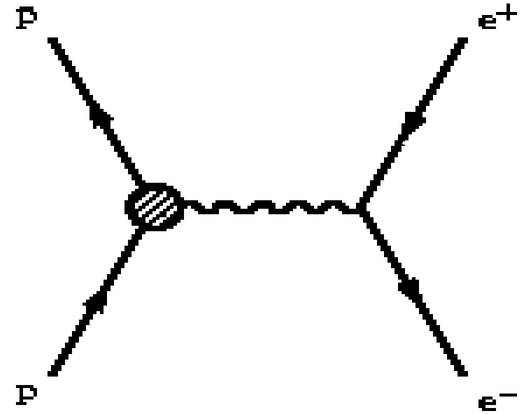
Outline of the talk

- Introduction
  - Time like proton form factors
  - Experimental overview of the existing data
- Panda experiment
  - FAIR/HESR
  - Detector description
  - Feasibility of the time like proton form factors measurements with PANDA
- Comparison of the estimates for PANDA with BaBar and LEAR
- Summary and outlook

How to access nucleon electromagnetic form factors ?



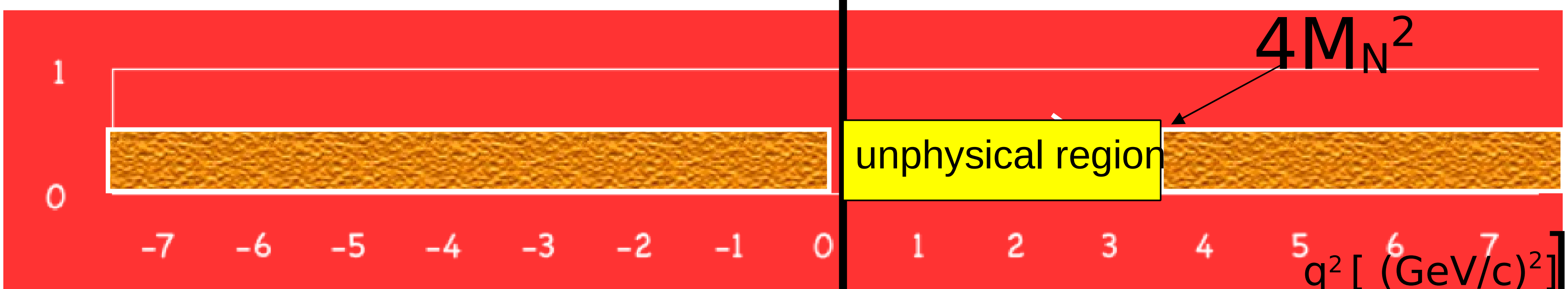


electron scattering

$q^2 < 0$: **S**pace **L**ike

annihilation

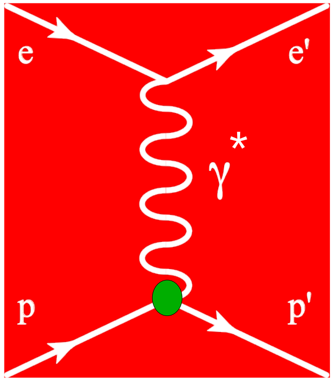
$q^2 > 0$: **T**ime **L**ike



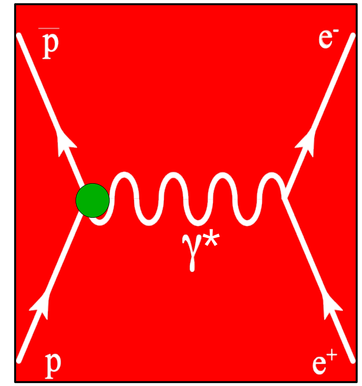
Real Form Factors

Complex Form Factors

Form factors: definitions



Vertex of the proton is parameterized in terms of Pauli and Dirac FFs



$$\langle N(p')|\bar{q}\gamma_\mu q|N(p)\rangle \rightarrow F_1(q^2)\gamma_\mu + i(k/2\mathrm{M})F_2(q^2)\sigma_{\mu\nu}q^\nu$$

➔ Sachs Form Factors

$$G_E = F_1 + \tau F_2$$
$$G_M = F_1 + F_2$$

$$,\ where\ \tau = \frac{q^2}{4\mathrm{M}_N^2}$$

➔ At threshold in TL, when $\tau = 1$ $\rightarrow G_E^{TL} = G_M^{TL}$

➔ Asymptotic properties

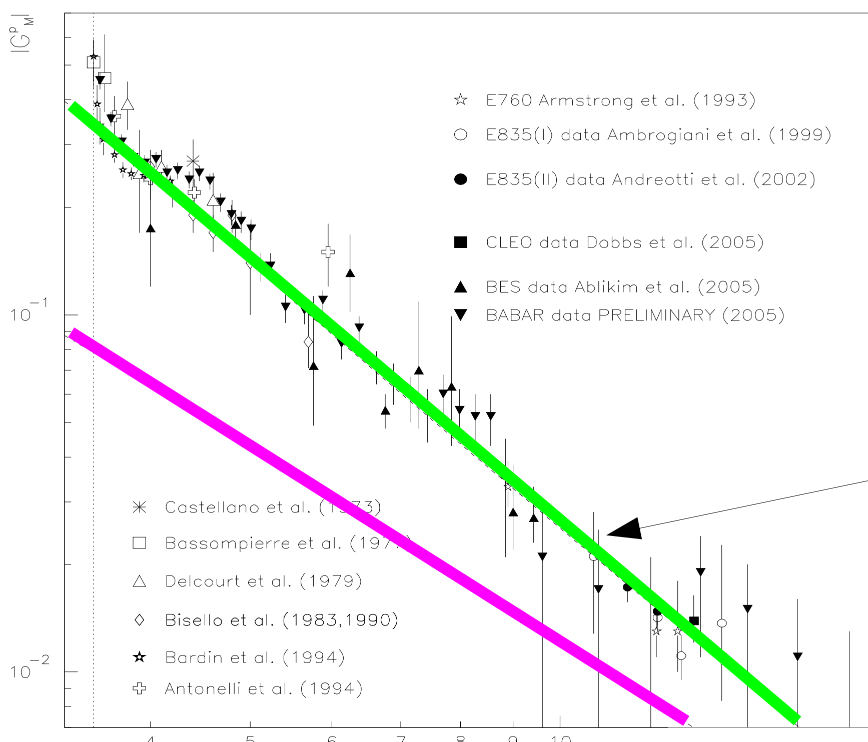
$$\lim_{q^2 \rightarrow +\infty} \left. \begin{array}{l} G_E(q^2)^{TL} = G_E(-q^2)^{SL} \\ G_M(q^2)^{TL} = G_M(-q^2)^{SL} \end{array} \right\} \text{phase vanished}$$

Proton time like form factors

The FF of the proton in the TL region can be extracted from the differential cross section of the reactions: $\bar{p}\,p \rightarrow$ e$^+$e$^-$ or e$^+$e$^-$ $\rightarrow \bar{p}\,p$

The center of mass (CM) differential cross section, in the one photon approximation can directly give access to the moduli $|G_E|$ and $|G_M|$.

$$\frac{d\sigma}{d\cos\theta_{CM}} = \pi \frac{\alpha^2}{8M_p^2\sqrt{\tau(\tau-1)}} * \left[|G_M|^2(1+\cos^2\theta_{CM}) + \frac{|G_E|^2}{\tau}\sin^2\theta_{CM}\right] \qquad \tau = \frac{q^2}{4M_p^2}$$



q^2 [GeV/c^2]

All data: The absolute cross section was obtained under assumption $|G_E| = |G_M|$.

pQCD predicts asymptotic behaviour of G_M

$$\lim_{q^2\rightarrow\infty} G_M(q^2) \propto \frac{1}{q^4}$$

Data OK with pQCD behaviour, but experimental data gives

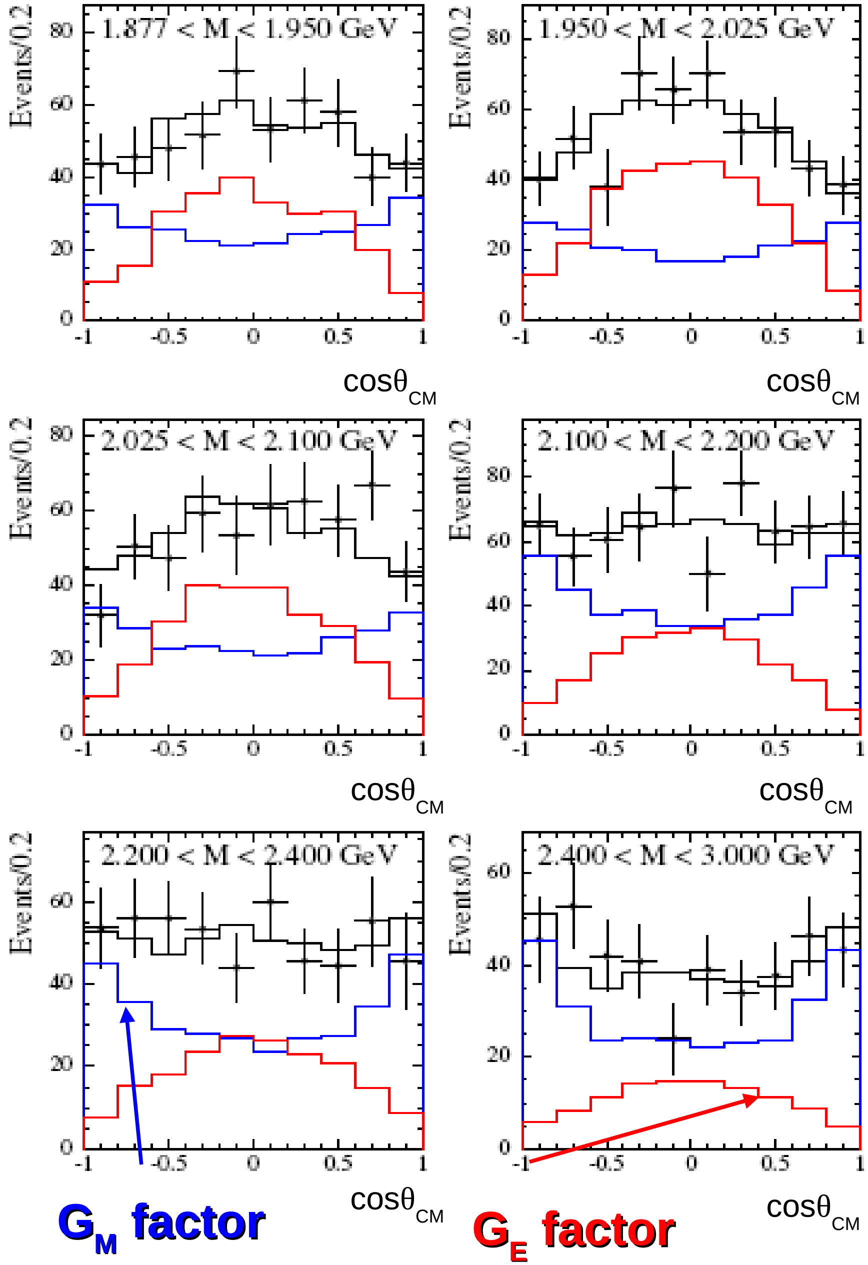
$$|G_M|^{TL} \approx 2\,|G_M|^{SL}$$

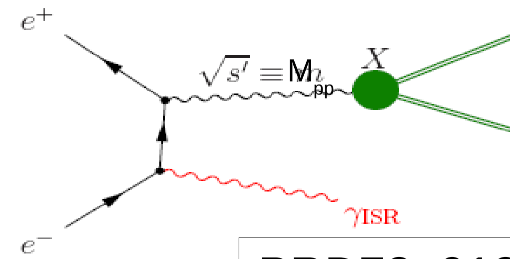
Perturbative regime not reached !!!

'pQCD like' fit to Time Like FF

'pQCD like' fit to Space Like FF

Angular distributions from the BaBar





PRD73, 012005

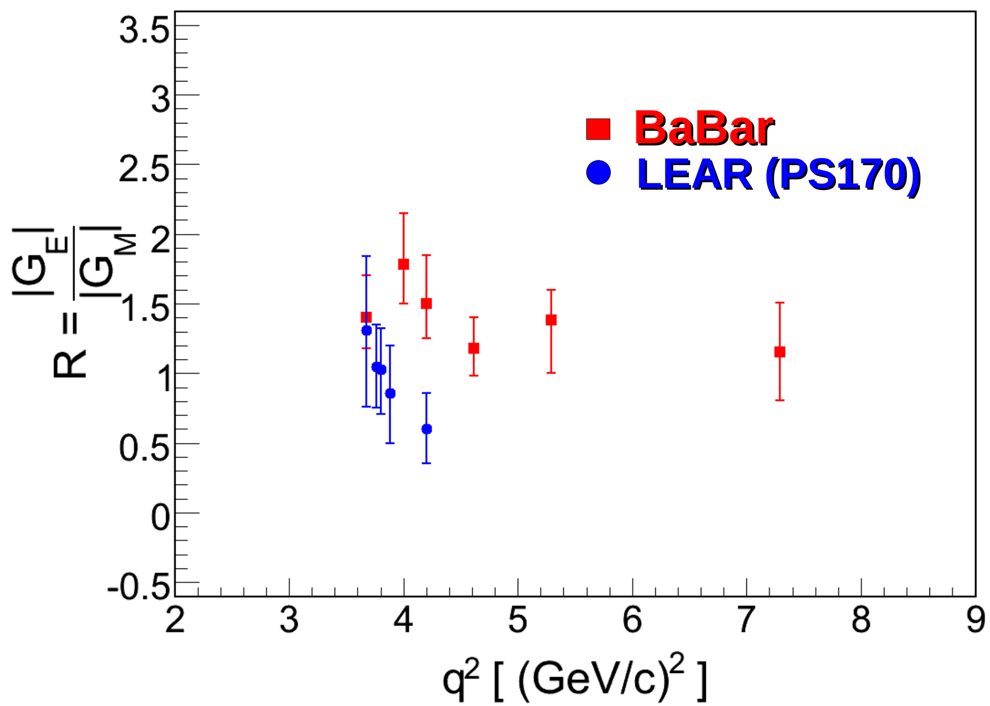
- Proton angular distributions are fitted in 6 bins of M_{pp} from threshold up to 3GeV,

$$\frac{d\sigma}{d\cos\theta_{CM}} = A\left(H_M(\cos\theta_{CM}, M_{pp}) + \left|\frac{G_E}{G_M}\right|^2 H_E(\cos\theta_{CM}, M_{pp})\right)$$

- $H_M(\cos\theta_{CM}, M_{pp}), H_E(\cos\theta_{CM}, M_{pp})$ are determined using MC, do not strongly differs from functions $1+\cos^2(\theta_{CM})$ and $\sin^2(\theta_{CM})$

- Monte Carlo histograms show separate contribution from G_M and G_E

BaBar and LEAR ratio for the $|G_E|/|G_M|$



Observations:

Inconsistency of the 2 data sets:

- BaBar, $|G_E| > |G_M|$ at low q^2,
- BaBar, results become consistent with assumption of R=1 at large q^2.

Summary on the present measurements:

The several unexpected features in the existing FF data deserve further experimental investigations which could be explored with PANDA experiment:

- Threshold q^2 dependence of R,
- High q^2 predictions (test the transition to pQCD regime),
- More precise data needed.

FAIR, Facility for Antiproton and Ion Research
Darmstadt, Germany

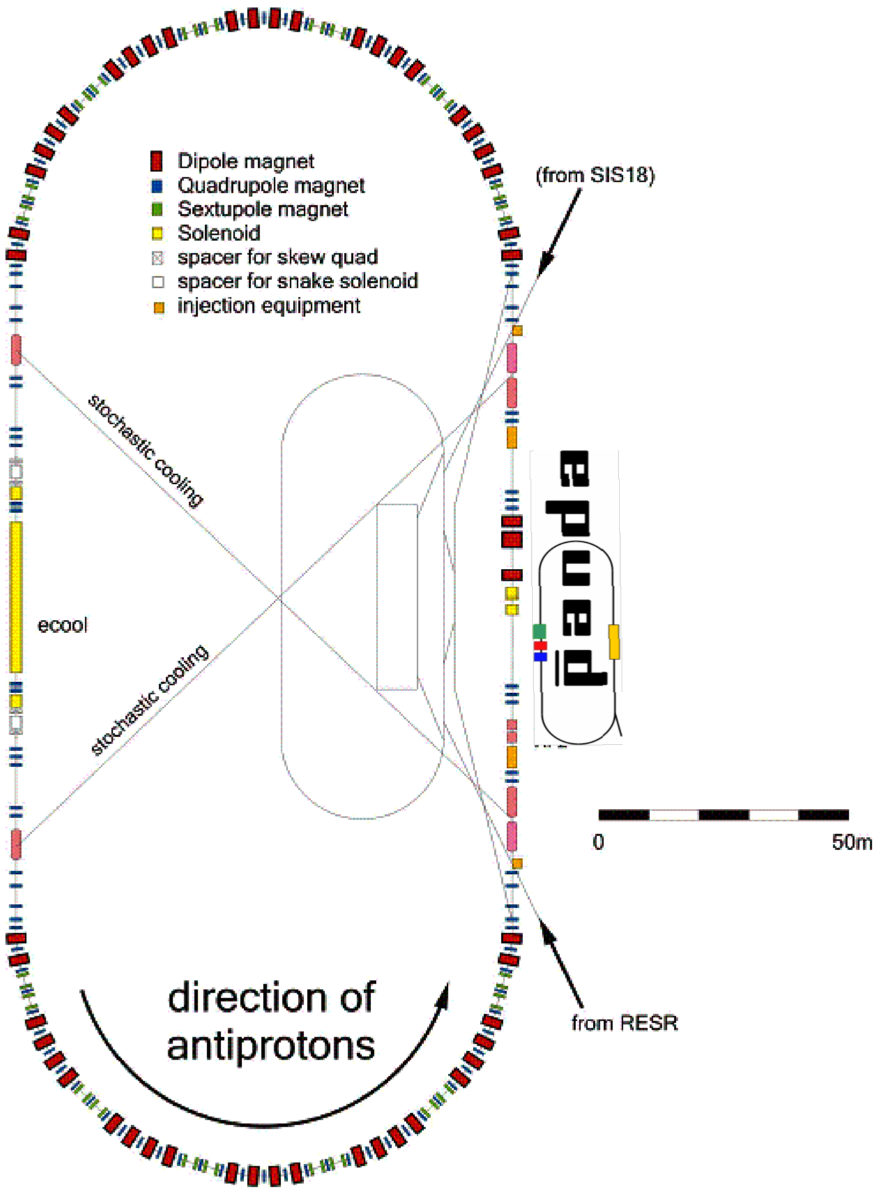
GSI, Darmstadt

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

FAIR: New facility

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

HESR, High Energy Storage Ring



Experimental requirements

- pbar energy range 3 to 14 GeV
- maximum luminosity 10^{32} cm^{-2} s^{-1}
- momentum spread in beam $\delta p/p \approx 10^{-5}$
- fixed proton target H2 cluster jet $\geq 10^{14}$ molec./cm^2

High Luminosity mode:

Momentum range: 1.5 – 15 GeV/c

L = $2x10^{32}$ cm^{-2} s^{-1} for 10^{11} stored anti-protons

$\sigma_p/p = 10^{-4}$

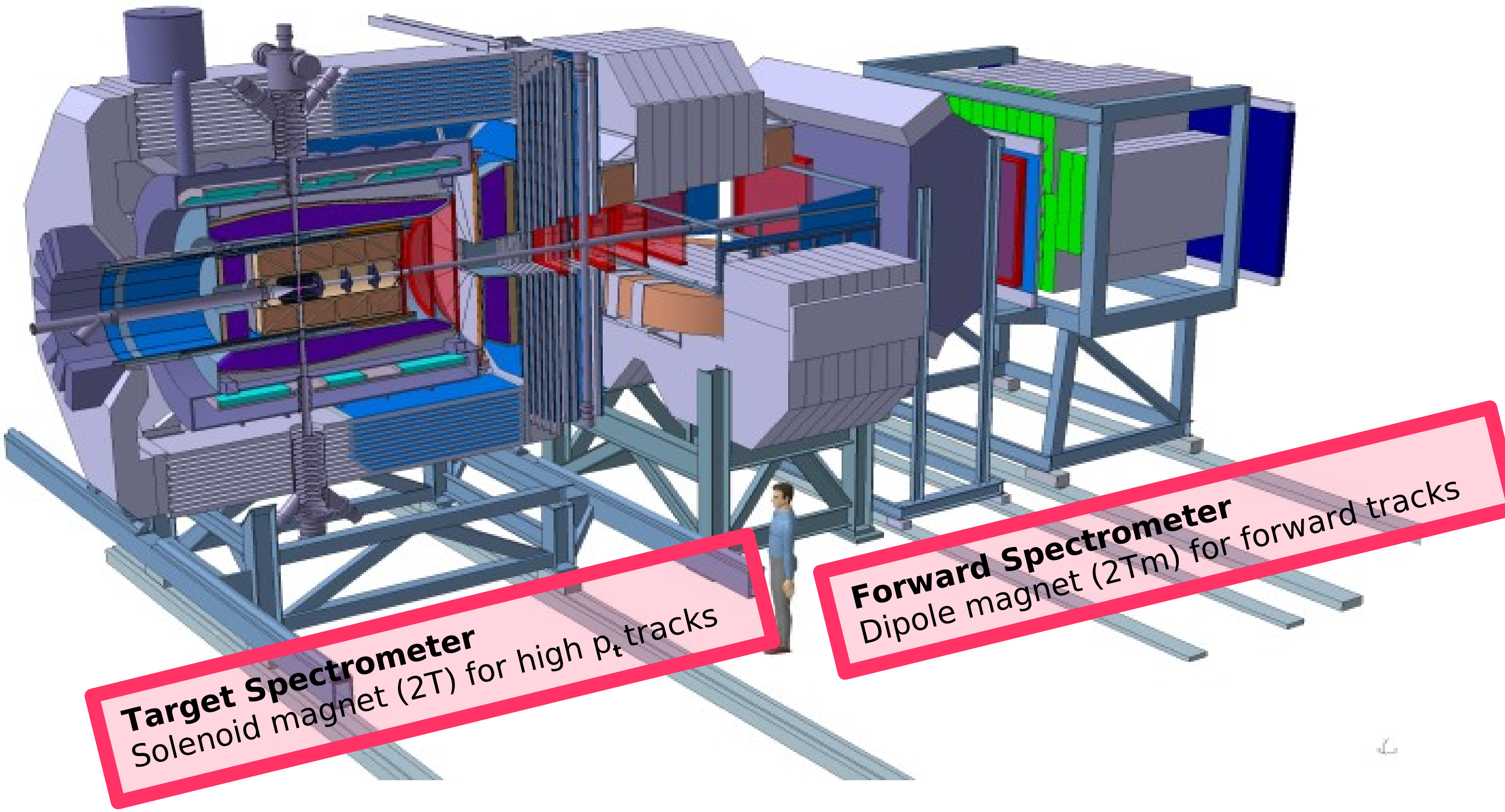
High Resolution mode:

Momentum range: 1.5 – 9 GeV/c

L = $2x10^{31}$ cm^{-2} s^{-1} for 10^{10} stored anti-protons

$\sigma_p/p = 2x10^{-5}$

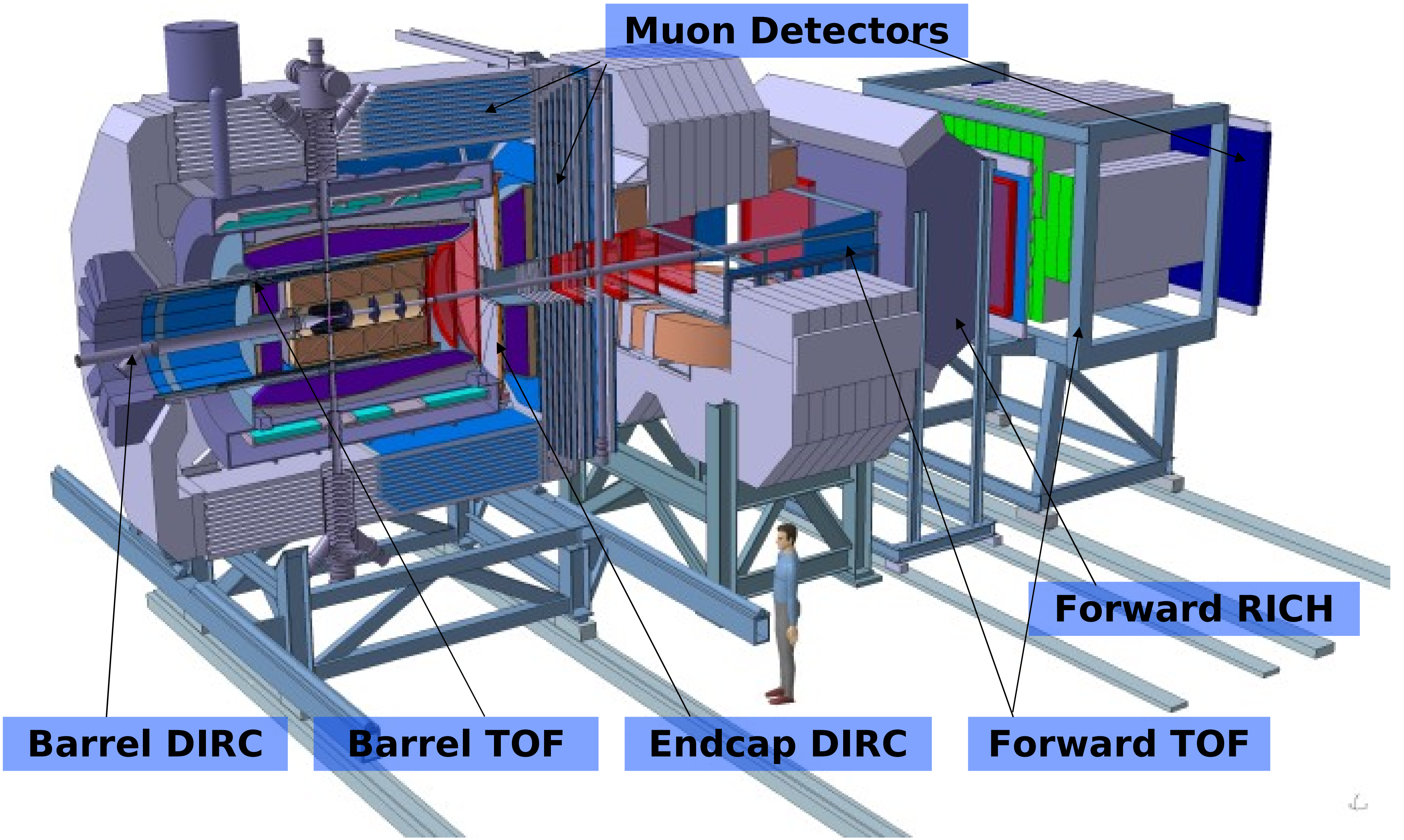
PANDA detector



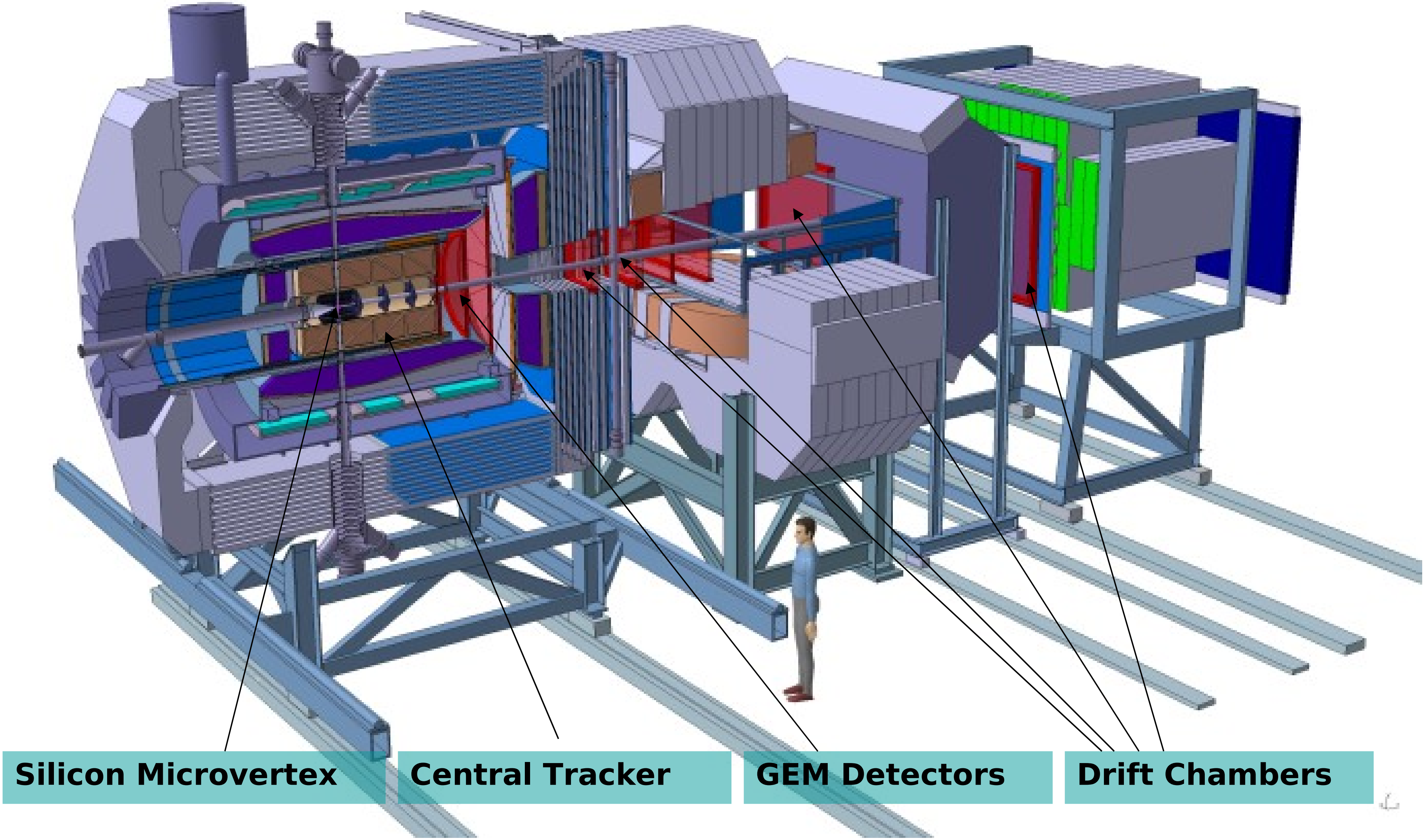
Detector requirements:

- 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, ($D^{\pm}$,cτ ≈ 317 μm);
- good PID (γ, e, μ, π, K, p);
- γ detection ->few MeV < E_γ < 10 GeV.

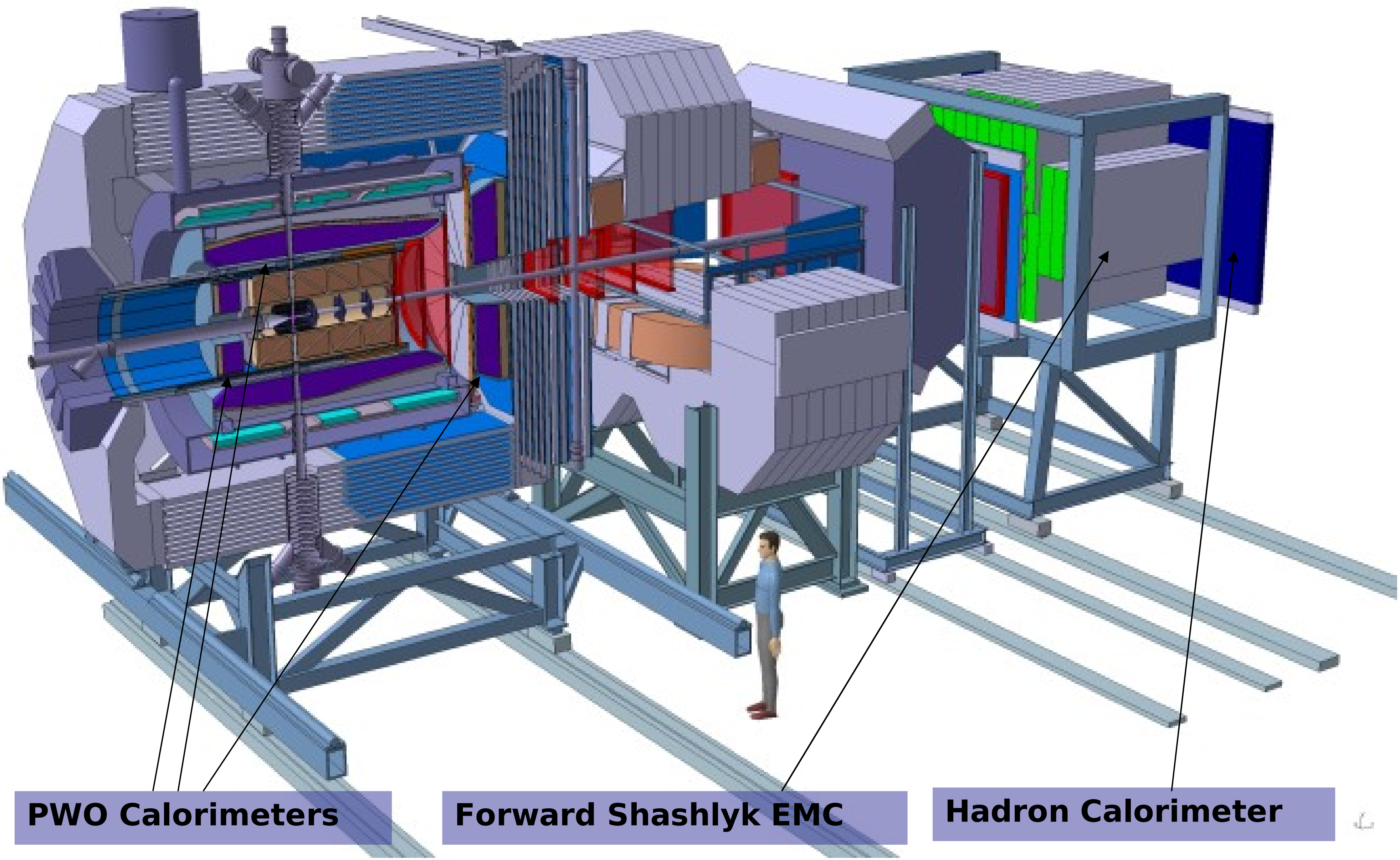
Detectors for charged particle identification



Tracking detectors



PANDA calorimeters (γ and PID)



PANDA Physics Program

Charm spectroscopy

- charmonium: Positronium of QCD
- charm hybrids
- c-states narrow, understood
- mass 4–4.5 GeV
  - $c\bar{c}g$ narrow
  - little interference between $c\bar{c}g$ and $c\bar{c}$-states
- charm meson spectroscopy

Charm in the Medium

- mesons in nuclear matter
- masses change in nuclei
- D-mass lower
- enhanced charmonium states due to lower $D\bar{D}$ threshold
- J/ψ absorption in nuclei

Hypernuclei

- 3rd dimension in nuclear chart
- study interactions of hyperons in the nuclear potential
- PANDA: Double Hypernuclei
  - production via Ξ^- capture
- $\Lambda\Lambda$ interaction in nucleus

Electromagnetic form factors

- Measure $\bar{p}p \rightarrow e^+e^-$
  - $|G_E|$ & $|G_M|$ not measured before
  - Asymptotic behaviour at high q^2

Generalized Parton Distributions

- wide angle Compton scattering
- hard exclusive meson production

Transverse nucleon spin

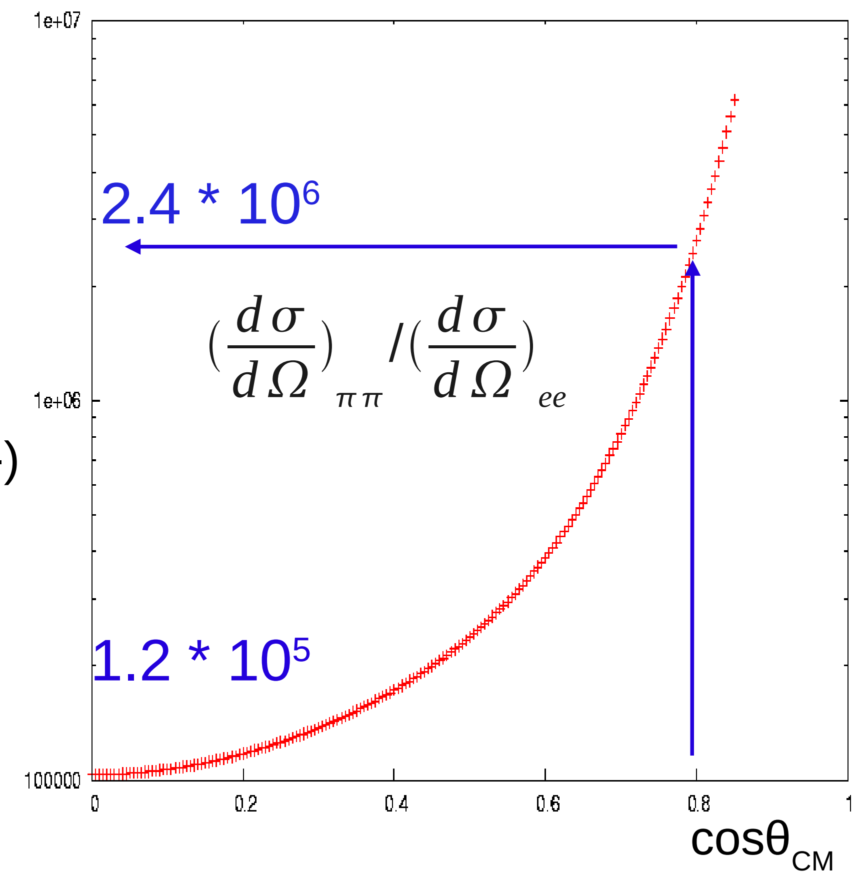
- Drell Yan Process
- *(full PWA or polarized beam/target)*

General information about simulation

We have studied two aspects concerning the determination of the 2 proton form factors:

- Background contamination
- Sensitivity to G_E and G_M

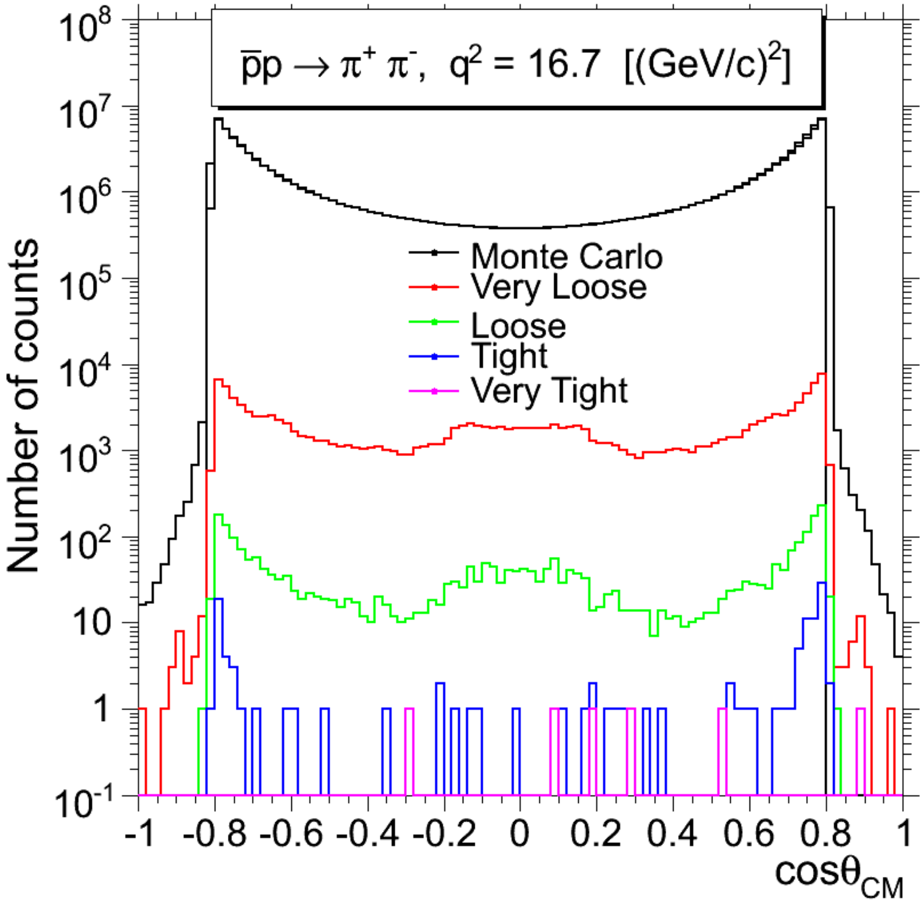
$q^2 = 8.21\ (GeV/c)^2$



Background reactions

- 3 body reactions ('easy' to eliminate)
  - 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,

Hadronic background channels suppression



Definition of the PID cuts

Very Loose : 19.9%
Loose : 85%
Tight : 99%
Very Tight : 99.8 %

PID from 5 detectors:
EMC, STT, DIRC, MVD and MUO

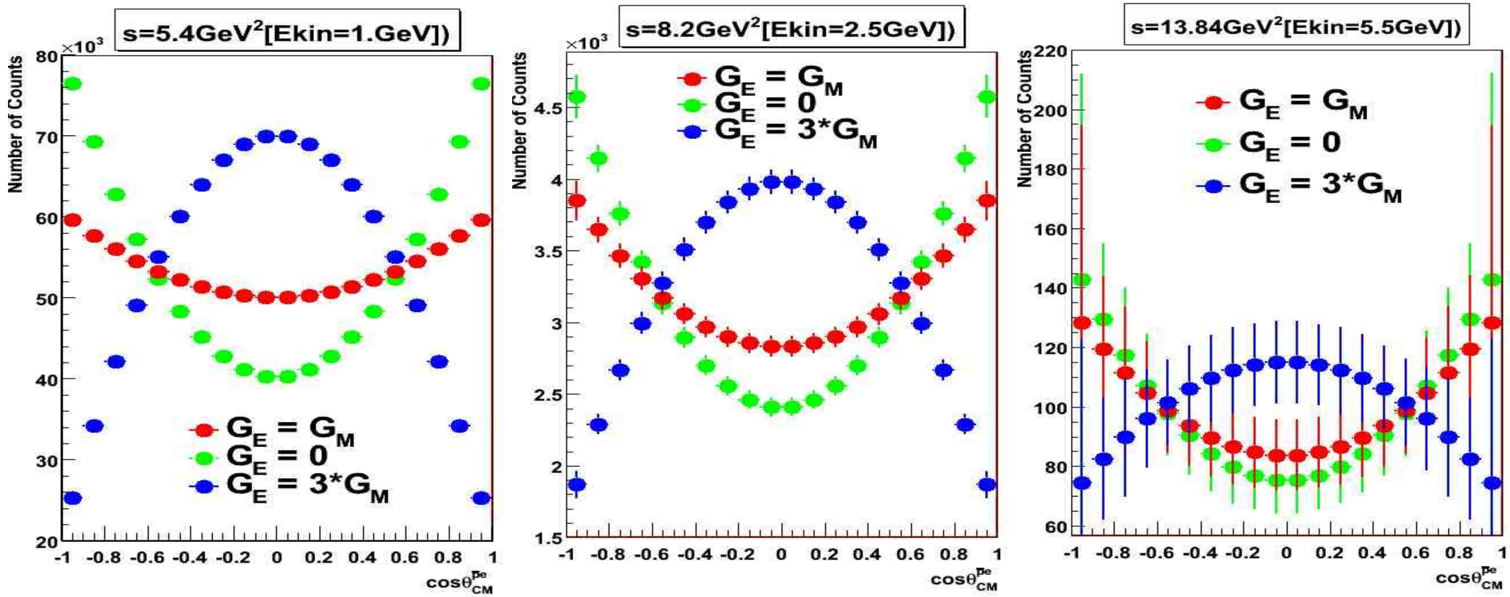
Background suppresion after
Very Tight PID cuts:

- 8.2 (GeV/c)^2 : 1/10^8
- 12.9 (GeV/c)^2 : 3/10^8
- 16.7 (GeV/c)^2 : 5/10^8

Additional factor ~ 100 applying the kinematic fit

Background suppression factor is at least of the order of 10^{-9} taking into account PID & kinematic fit !!

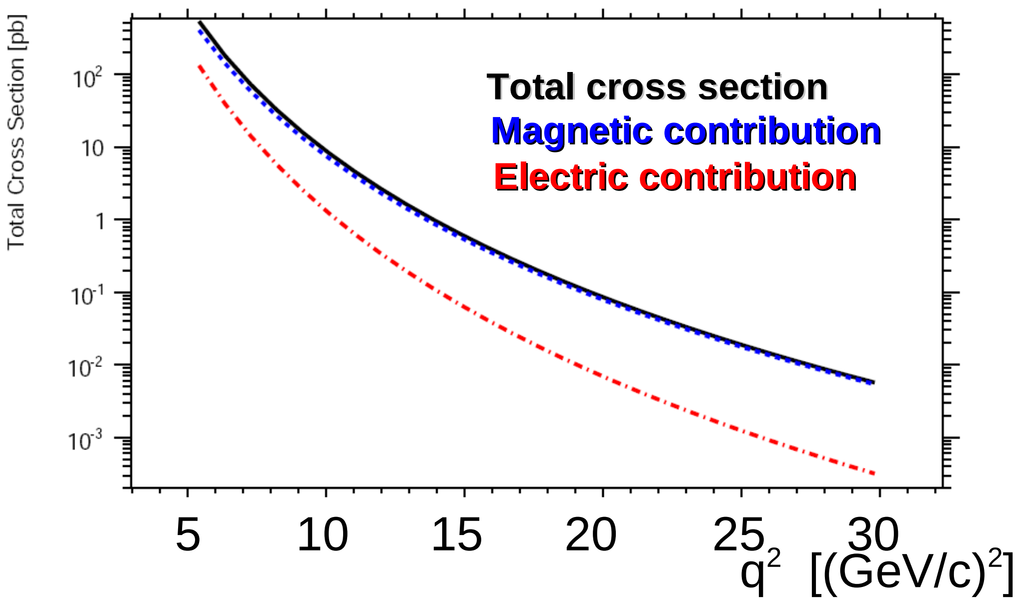
Physics: Counting rates and $|G_E|/|G_M|$ separation



~120 days
L = 2. 10^{32} $cm^{-2}s^{-1}$
(2 fb^{-1})

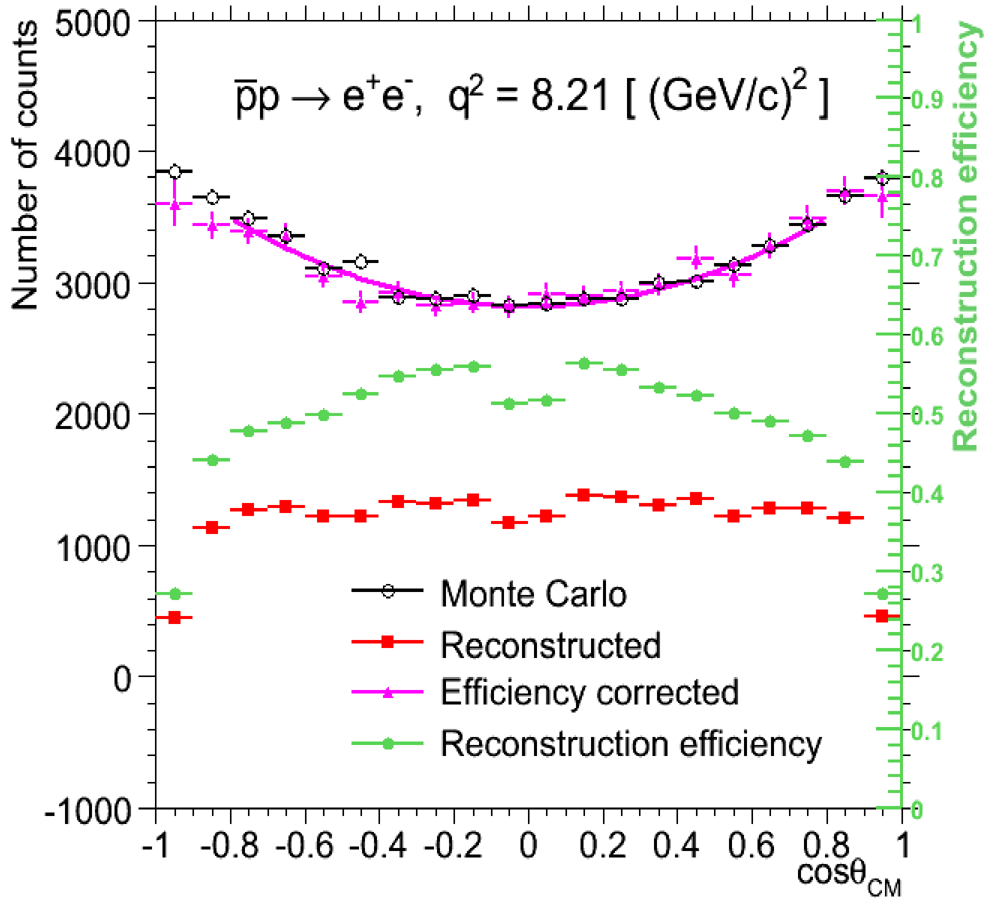
Expected number of events (no eff)

q^2 [(GeV/c)^2]	# evt.
5.4	1071489
7.4	124000
8.2	64200
11.0	9080
12.9	3200
13.8	2000
16.7	577
22.3	81

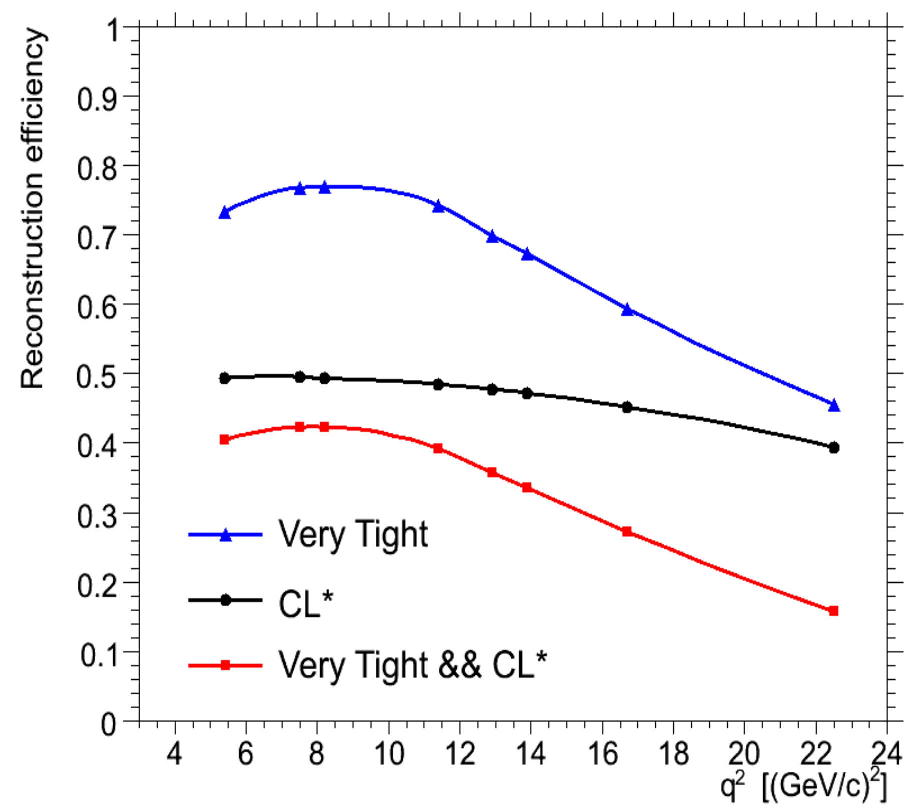


Decreasing sensitivity to G_E form factor with increasing q^2.

Monte Carlo, reconstructed, efficiency corrected spectra

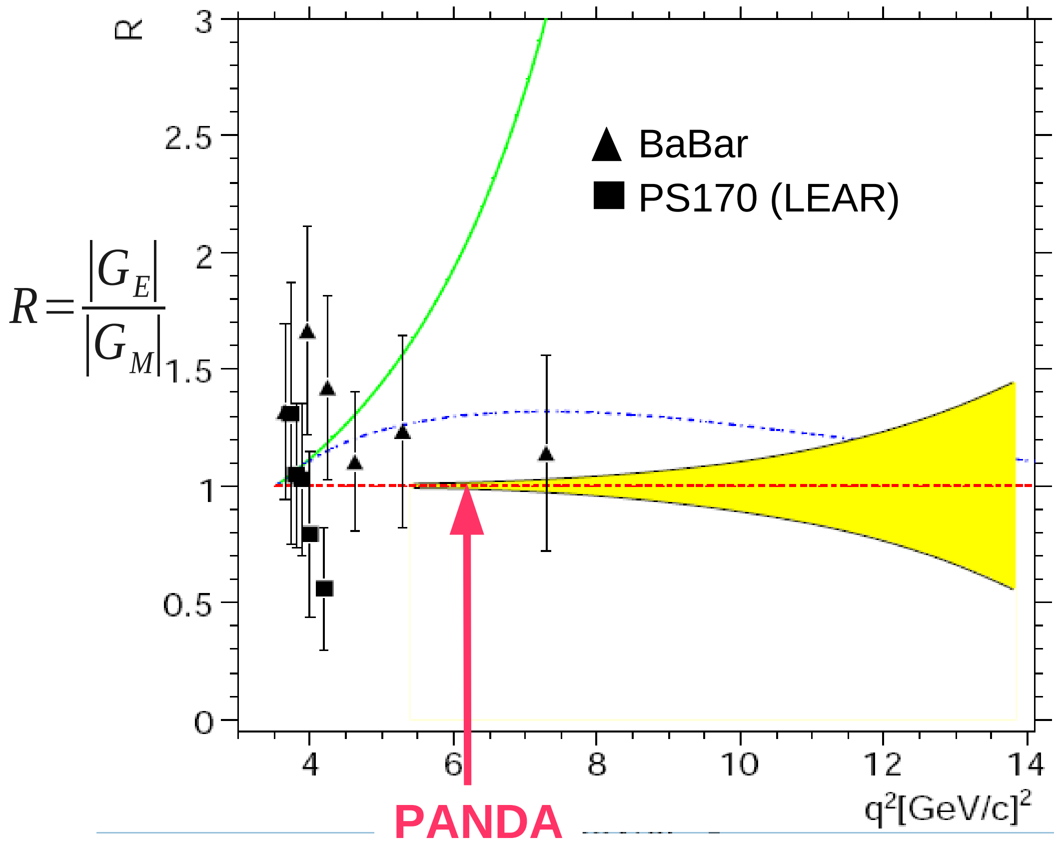


For the efficiency correction determined from the isotropic distributions with the high statistics have been used.



Distributions include all PID cuts as well as kinematic conditions.

Comparison with the BaBar and LEAR results



Yellow band represents the errors from the fits to the efficiency corrected data. It represents only the case $|G_E| = |G_M|$.

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

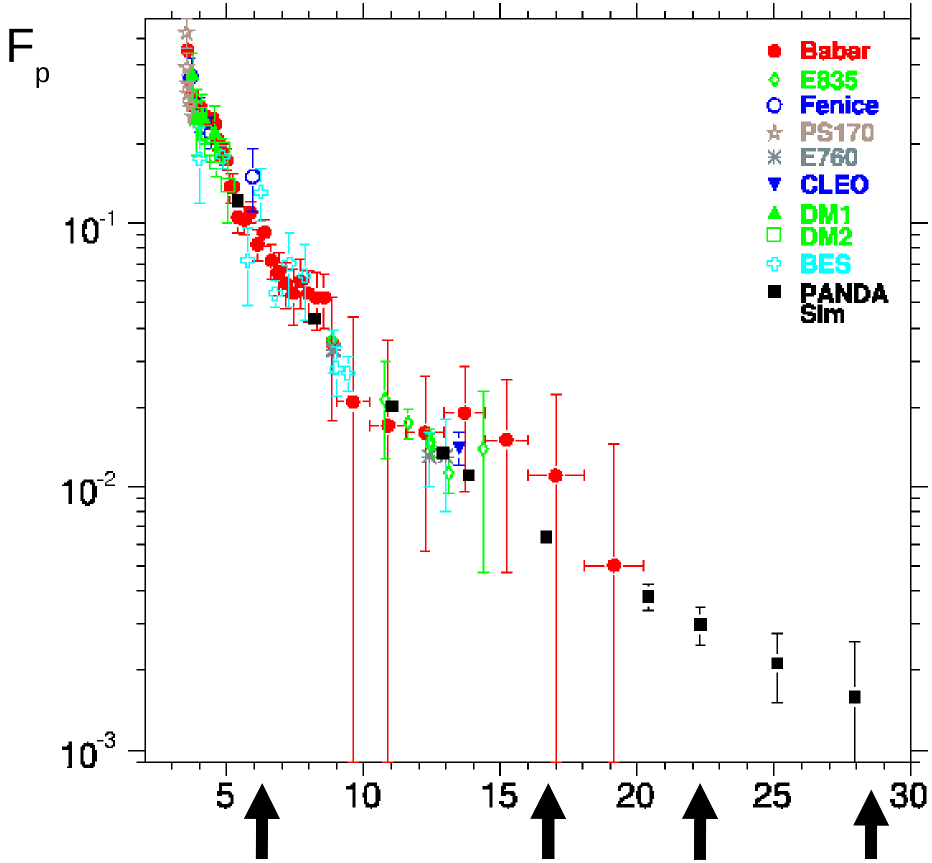
Extended VMD, PRC66, 045501 (2002)

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

With PANDA the measurement of the $|G_E|/|G_M|$ ratio can be done with much better precision than it was possible with BaBar or at LEAR.

At the low q^2 values PANDA will improve the error bars on R by an order of magnitude in comparison to the most recent BaBar data last 2 points, but also measure $|G_E|/|G_M|$ up to 14 $(GeV/c)^2$.

Effective proton form factor : world data



< 1% ~10% ~23% ~ 50%

Effective proton form factor extracted from different experiments using:

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

In all cases, the hypothesis of $|G_E|=|G_M|$ has been used to analyze the data.

$$F_p = \sqrt{(\sigma_{pp}/\sigma_n)}$$

σ_{pp} - measured pp → e+e- under assumption $|G_E|=|G_M|$

σ_n - calculated under assumption $|G_M|=|G_E| = 1$

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 ($q^2 = 30\ (GeV/c)^2$).

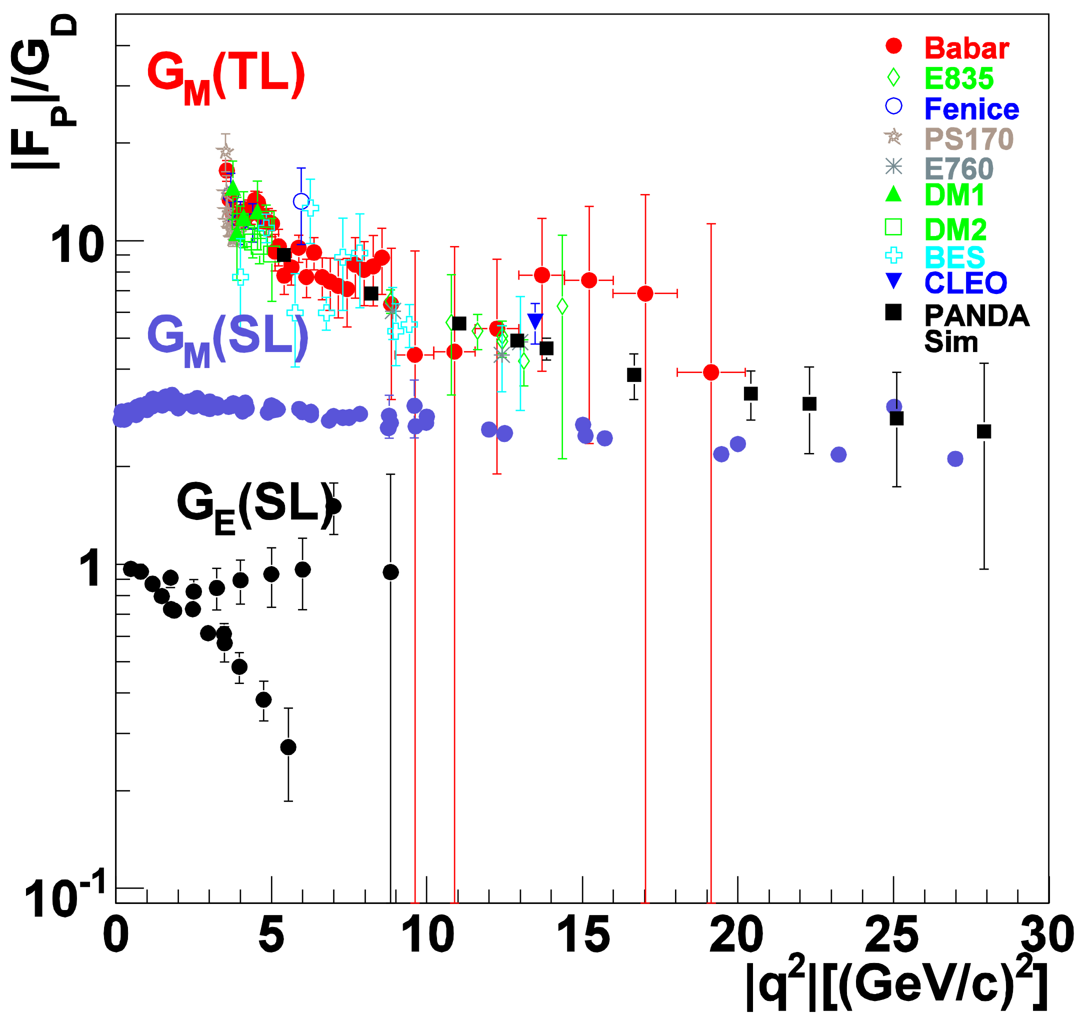
Conclusions & outlook

- Feasibility of the Time Like proton Form Factors measurement with PANDA in the reaction

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

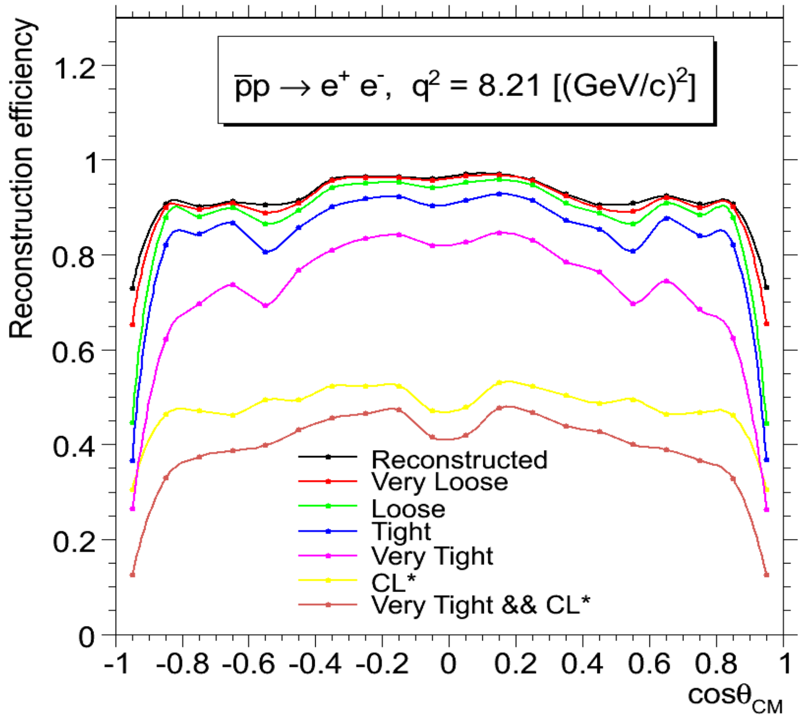
- Full scale (GEANT and detector digitalization) analysis have been performed,
- PANDA will provide data on:
  - magnetic AND electric form factors up to $q^2 = 14\ (GeV/c)^2$,
  - Cross sections up to $q^2 = 30\ (GeV/c)^2$

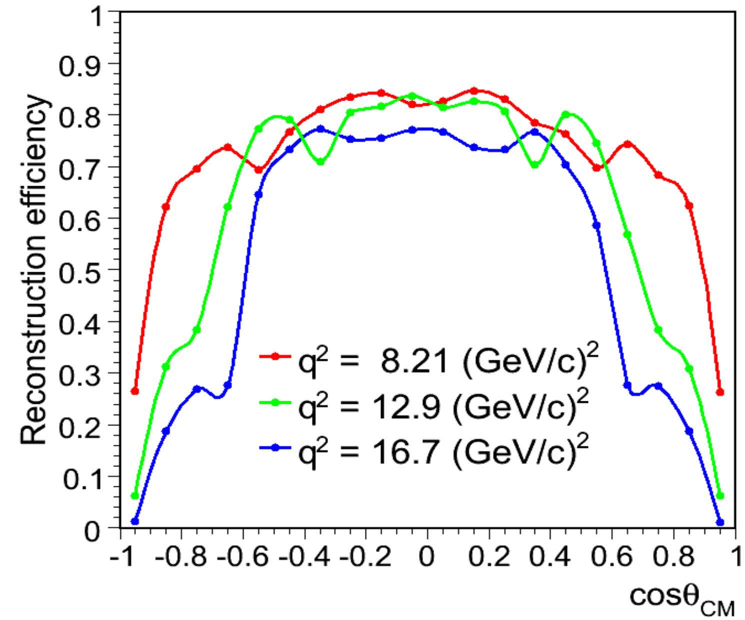
- Future plans for the analysis:
  - Checking feasibility for the measurement of the form factors via $\bar{p}\,p \rightarrow \mu+\mu-,$
  - Study of the other channels $\bar{p}\,p \rightarrow e+e-\pi^0(\gamma)$ access to subthreshold time like form factors
  - TDA (Transition Distribution Amplitude)
  - Pbar + A



G_M(TL)
G_M(SL)
G_E(SL)
Babar
E835
Fenice
PS170
E760
DM1
DM2
BES
CLEO
PANDA Sim
$|F_p|/G_D$
$|q^2|[(GeV/c)^2]$

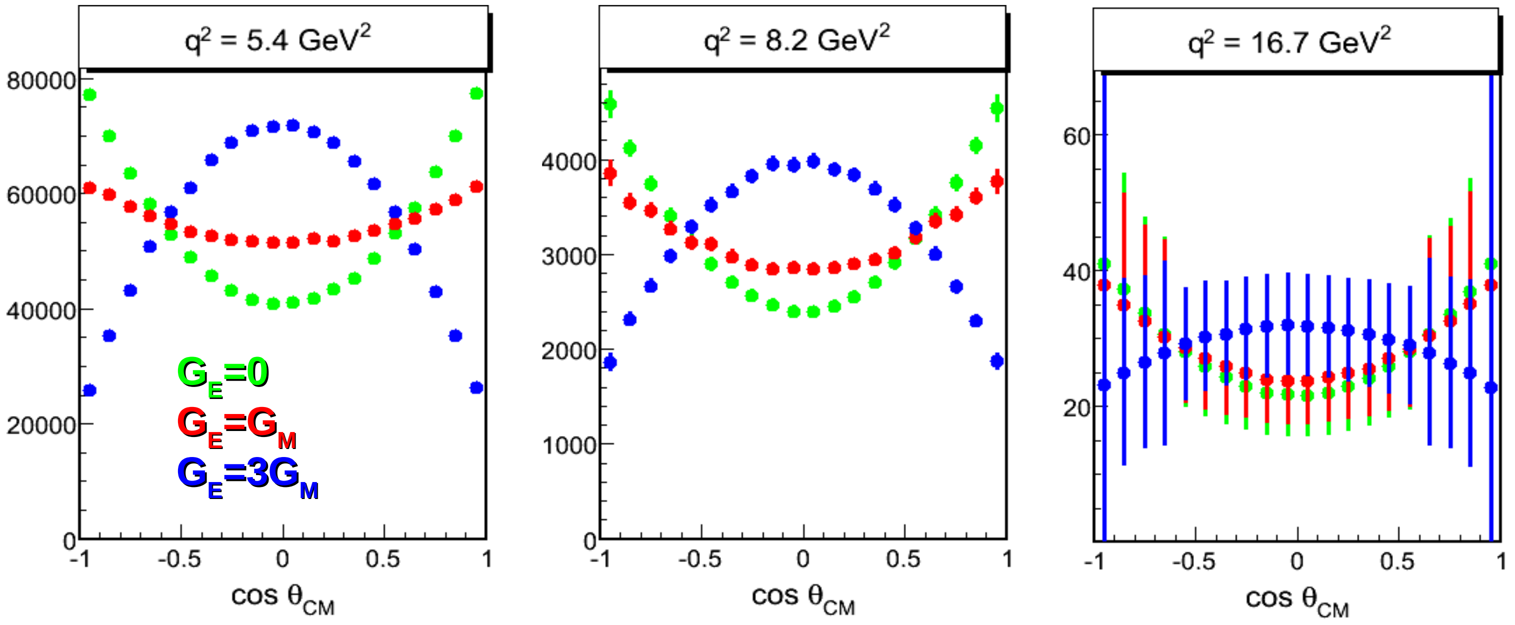
Electron efficiency reconstruction as a function of $\cos\theta_{CM}$





e+e- signal

- efficiency about 35 % at $\cos\theta_{CM}=0$ after all cuts (PID and CL*)
- decrease at forward/backward angles (combined PID with acceptance)
  - more pronounced for the high q^2
- still on average a factor 2 higher than BABAR experiment (ε ~ 18 %)



q² = 5.4 GeV²
q² = 8.2 GeV²
q² = 16.7 GeV²
G_E=0
G_E=G_M
G_E=3G_M
cos θ_CM
cos θ_CM
cos θ_CM