Proton Time-Like form factor measurements with P̄ANDA

B. Ramstein, IPN Orsay, France

on behalf of the PANDA collaboration

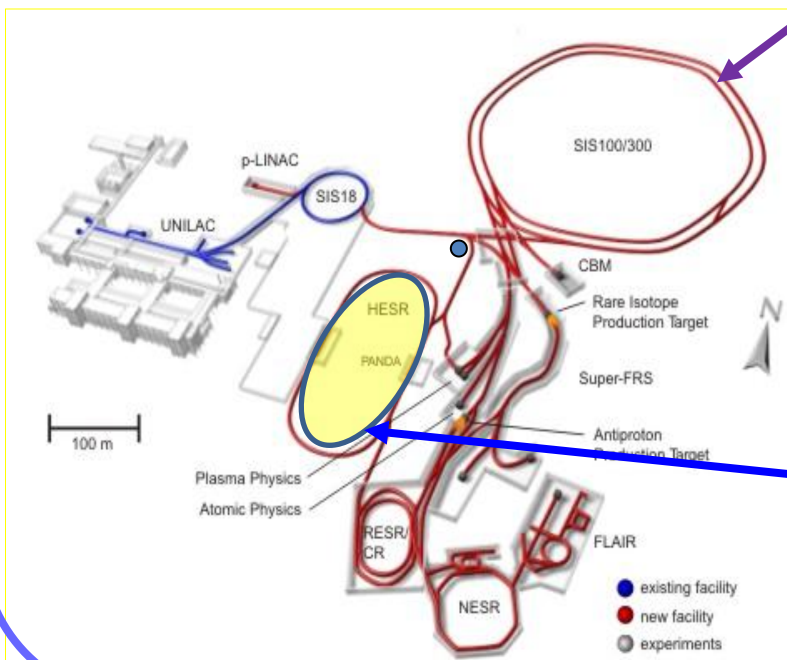
Olympus workshop, Gatchina, July, 9th ,2012

Outline

- The PANDA@FAIR project
- Electromagnetic channels with PANDA
  - $\bar{p}p \to e^+e^-$ at PANDA: proton time-like electromagnetic form factors
  - $\bar{p}p \to \pi^\circ e^+e^-$ reaction: time-like electromagnetic form factors in the unphysical region
  - Transition Distribution Amplitudes and other measurements
- Conclusion and outlook

The FAIR facility (1)

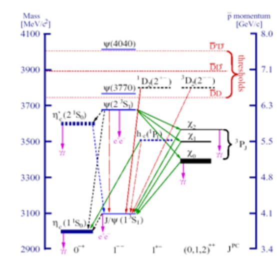
FAIR at Darmstadt/Germany

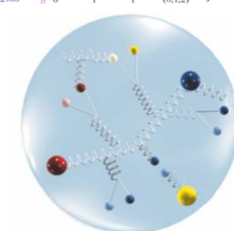


Facility for Antiproton and Ion Research

- Hadron Structure and Dynamics
- Nuclear and quark matter
- Super-heavy elements
- Nuclear Structure and Astrophysics
- Atomic, Plasma and Material Physics
- Radiobiology

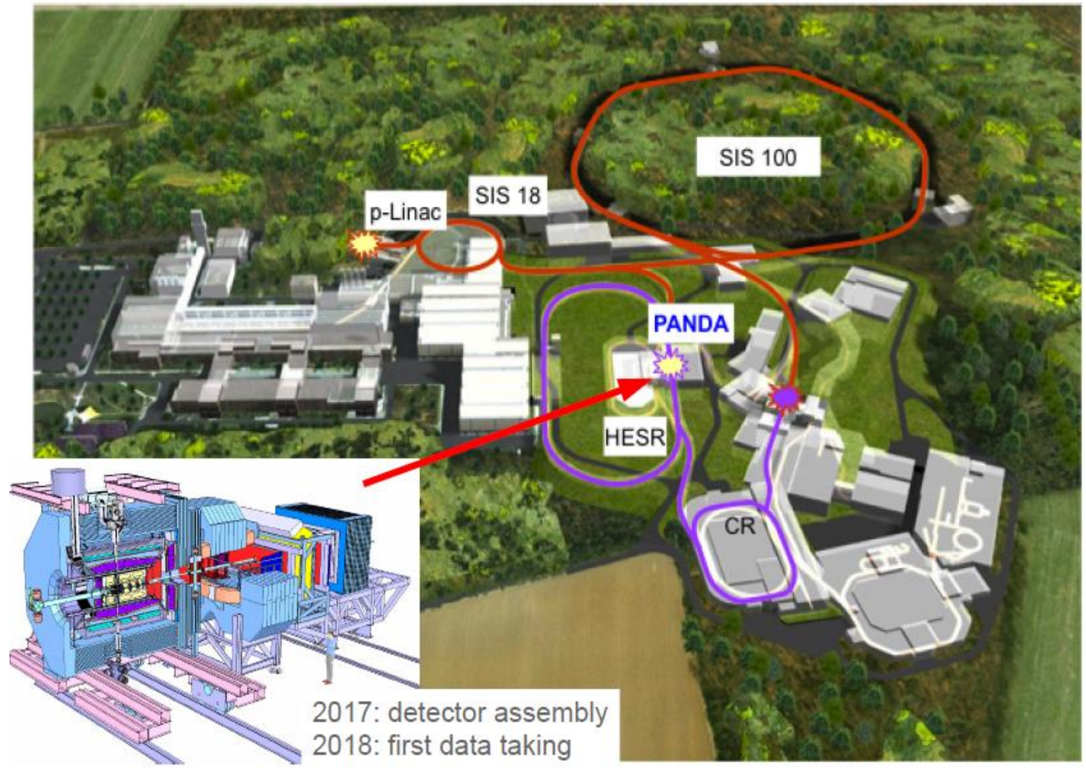
Antiproton ring
High Energy Storage Ring 1.5 – 15 GeV/c
L = 2 x 10^{32} cm^{-2} s^{-1}
$\sigma_p/p = 10^{-4}$
$2x10^7$ int.s^{-1}





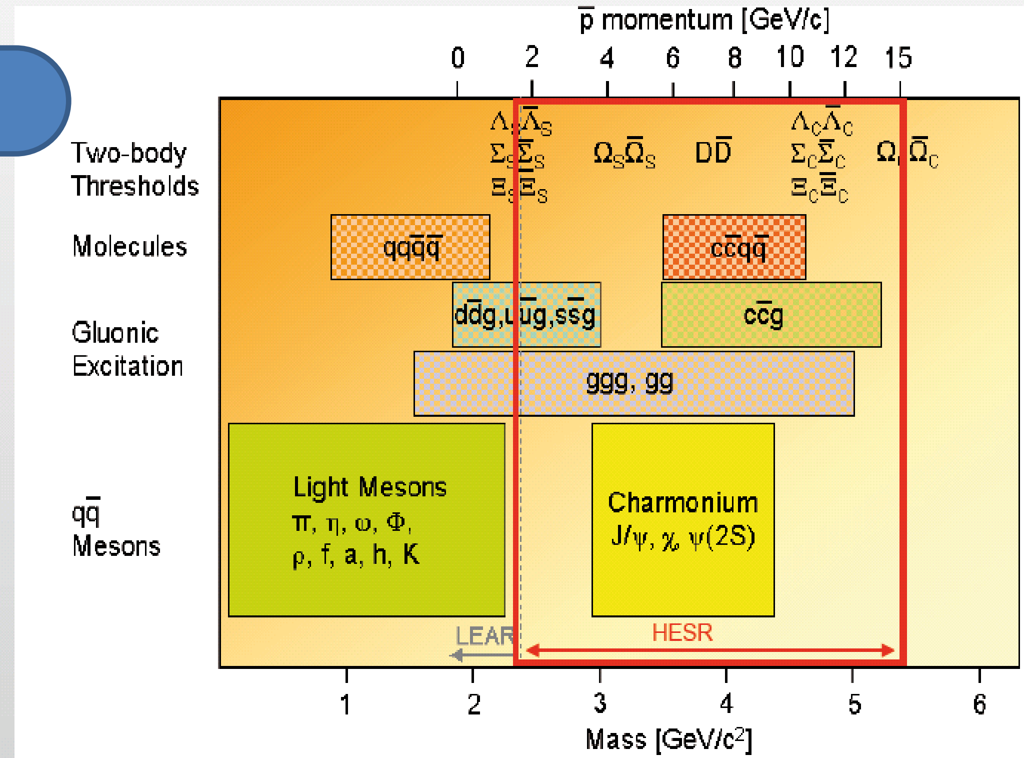
The FAIR facility (2)

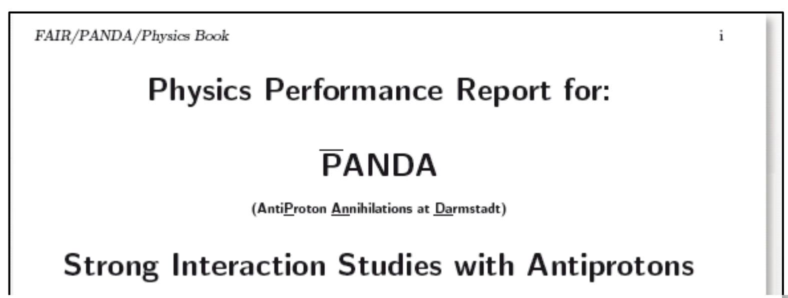
Foundation of FAIR, Oct. 4 2010



PANDA physics program

- ✓ Meson spectroscopy
  - •D mesons
  - •Charmonium
  - •Glueballs, hybrids, tetraquarks, molecules,…
- ✓ Charmed and multi-strange baryon spectroscopy
- ✓ Single and double hypernuclei
- ✓ Hadrons in nuclear matter
- ✓ Proton structure



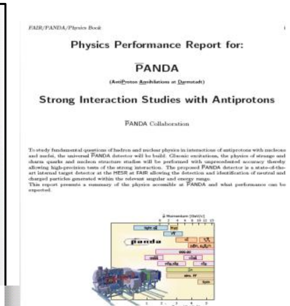

FAIR/PANDA/Physics Book i

Physics Performance Report for:

PANDA

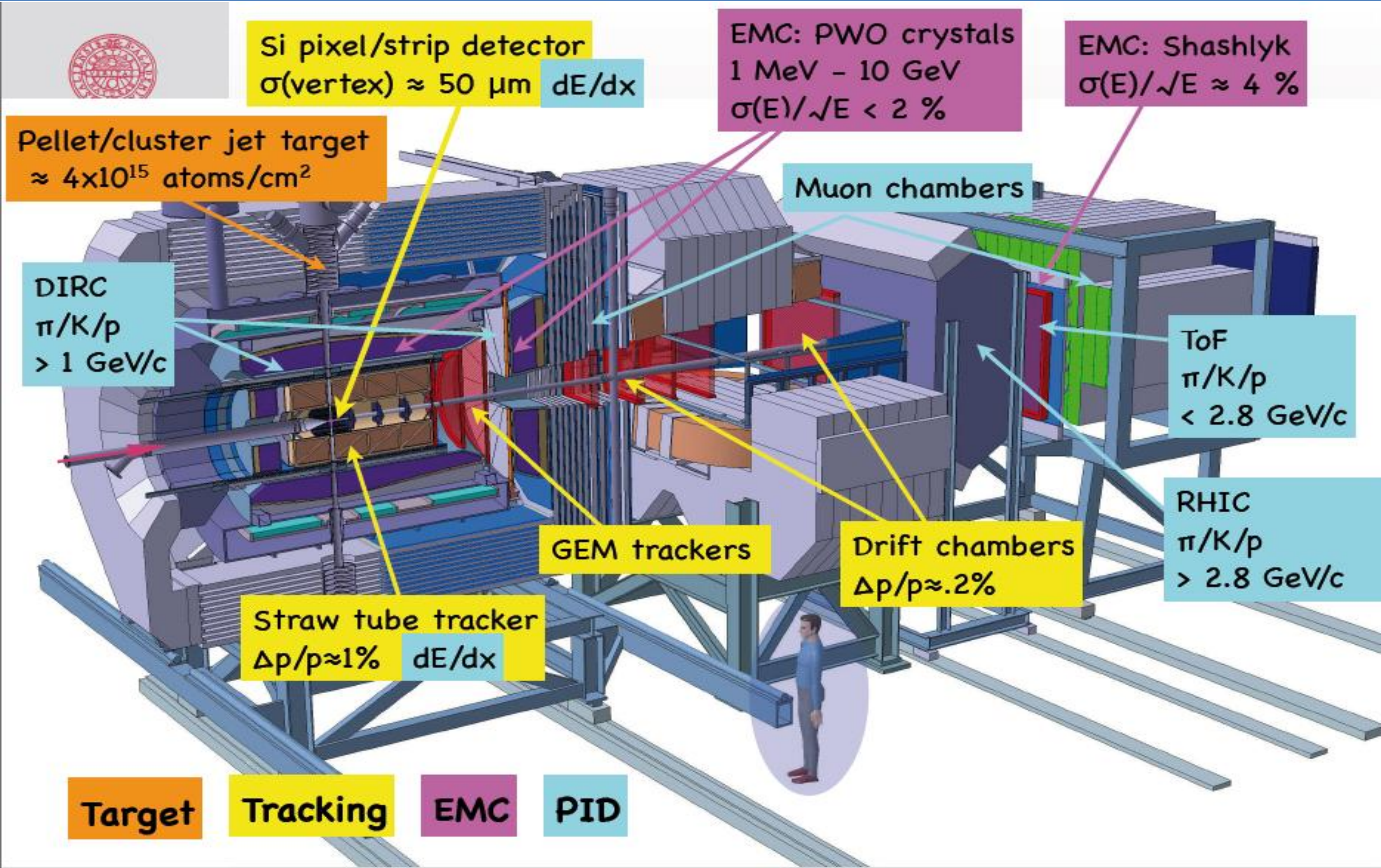
(AntiProton Annihilations at Darmstadt)

Strong Interaction Studies with Antiprotons



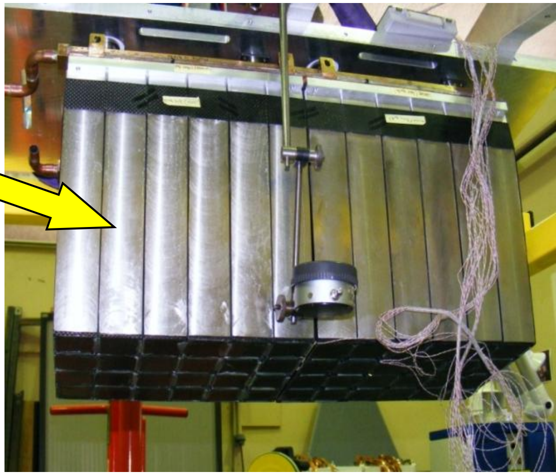
arXiv:0903.3905v1

The PANDA experimental set-up

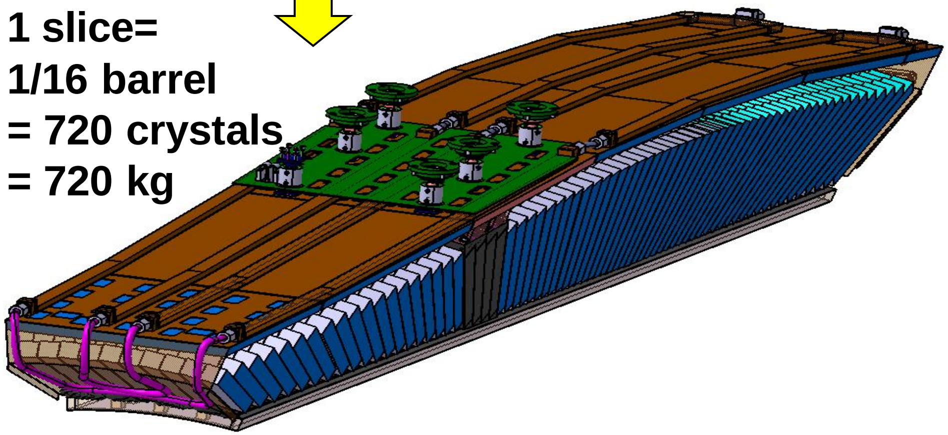


PANDA Barrel EMC

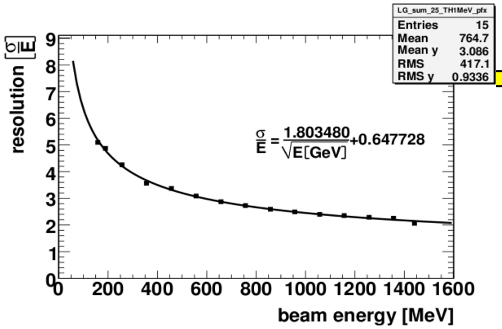
- Barrel calorimeter: 11000 PbWO4 crystals
- Mechanical structure: carbon alveoles + Al inserts

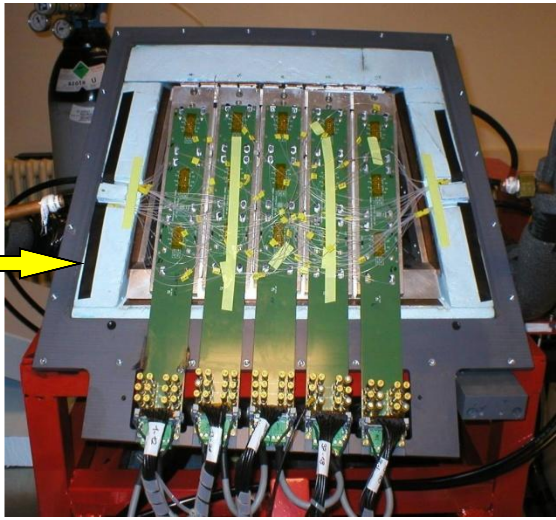


1 slice=
1/16 barrel
= 720 crystals
= 720 kg



- Proto60
  - 60 crystals cooled to -25°
  - tests with Bremsstrahlung photons at MAMI





$\sigma_E/E = 1.8\% / \sqrt{E} + 0.65\%$

The PANDA Collaboration

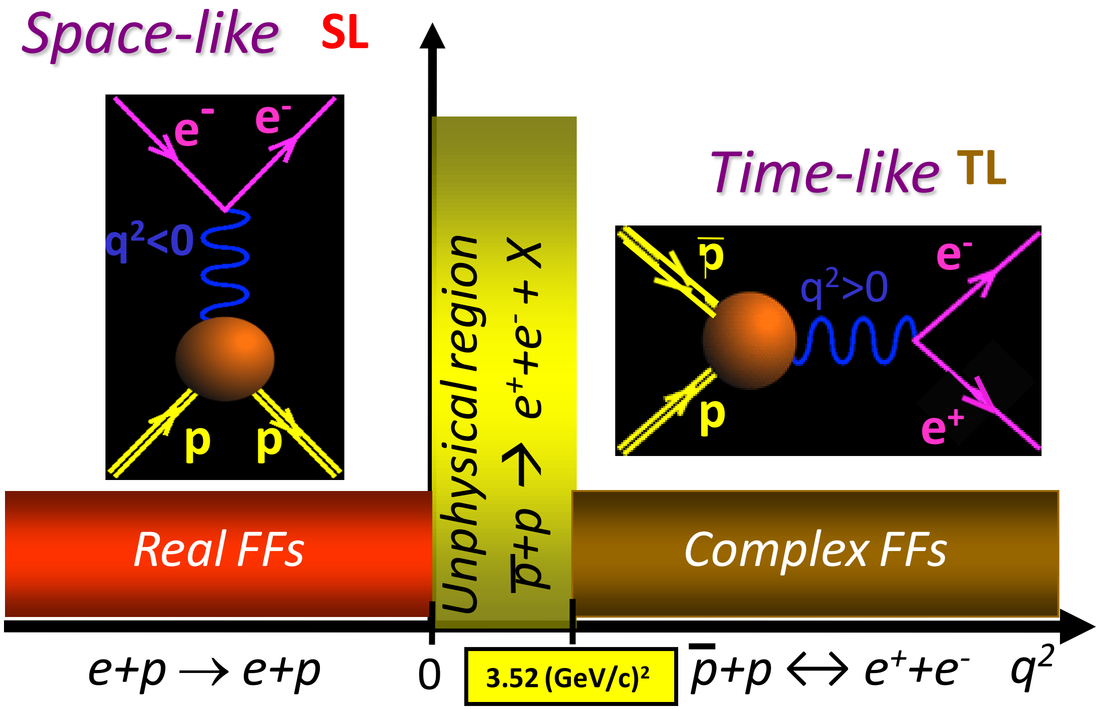
At present a group of **500 physicists**
from 53 institutions of 16 countries

Austria – Belaruz - China - France - Germany –India - Italy – Netherlands
Poland – Romania - Russia – Spain - Sweden – Switzerland - U.K. – U.S.A..

Basel, Beijing, Bochum, IIT Bombay, Bonn, Brescia,
IFIN Bucharest, Catania, Chicago, Cracow,
IFJ PAN Cracow, Cracow UT, Dresden, Edinburg, Erlangen,
Ferrara, Frankfurt, Genova, Giessen, Glasgow, GSI,
FZ Jülich, JINR Dubna, Katowice, KVI Groningen, Lanzhou,
LNF, Lund, Mainz, Minsk, ITEP Moscow, MPEI Moscow,
TU München, Münster, Northwestern, BINP Novosibirsk,
IPN Orsay, Pavia, Piemonte_Orientale, IHEP Protvino,
PNPI St. Petersburg, KTH Stockholm, Stockholm, U Torino,
INFN Torino, Torino Politecnico, Trieste, TSL Uppsala,
Tübingen, Uppsala, Valencia, SINS Warsaw, TU Warsaw,
SMI Wien

http://www.gsi.de/panda

Time-Like and Space-Like electromagnetic form factors (1)



Constraints:

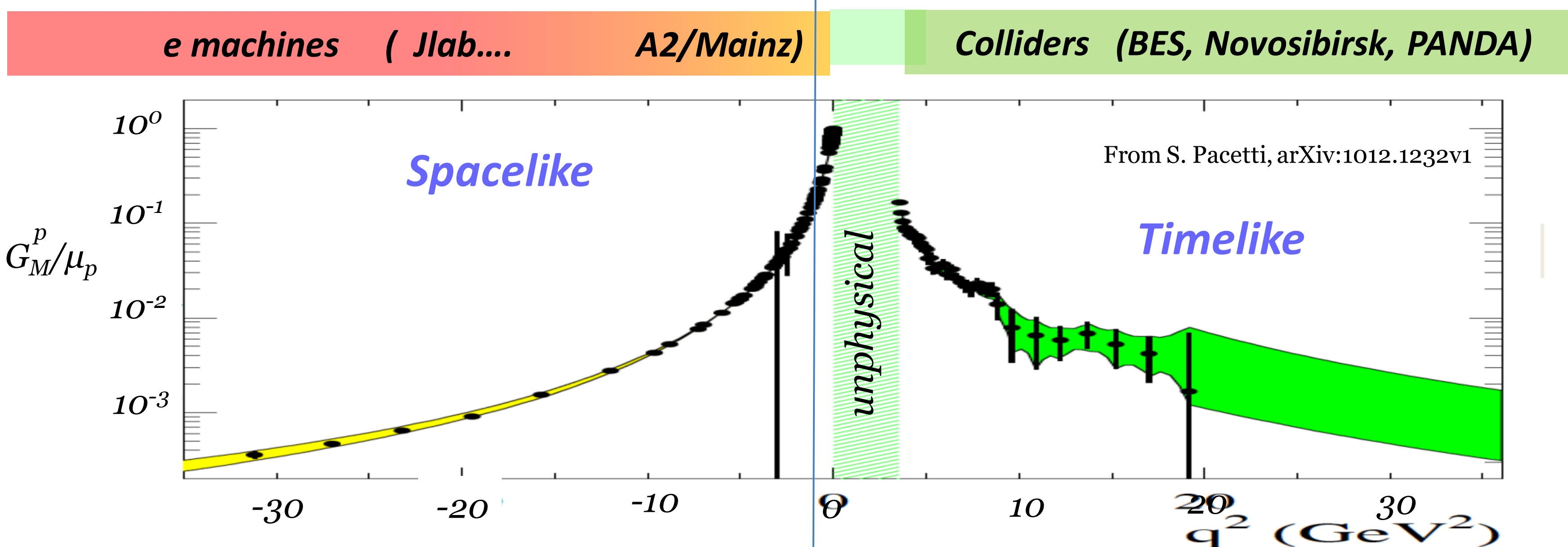
- $G_E^p(0)=1$
- $G_M^p(0)=\mu_p$
- $G_E^p(4m_p^2)= G_M^p(4m_p^2)$

Asymptotics

- $|G_{E,M}(q^2)| \sim (q^2)^{-2}$

- $\lim_{q^2\to -\infty} G_{E,M}^{SL}(q^2) = \lim_{q^2\to +\infty} G_{E,M}^{TL}(q^2)$ (Phragmén-Lindelhöf theorem)
- Imaginary part of Time-Like form factors vanishes for $q^2 \to +\infty$

Time-Like and Space-Like electromagnetic form factors (2)



Dispersion relations:

$q^2 < 0$

$$G(q^2) = \frac{1}{\pi}\left[\int_{4m_\pi^2}^{4m_p^2} \frac{\text{Im } G(s)\,ds}{s-q^2} + \int_{4m_p^2}^{\infty} \frac{\text{Im } G(s)\,ds}{s-q^2}\right]$$

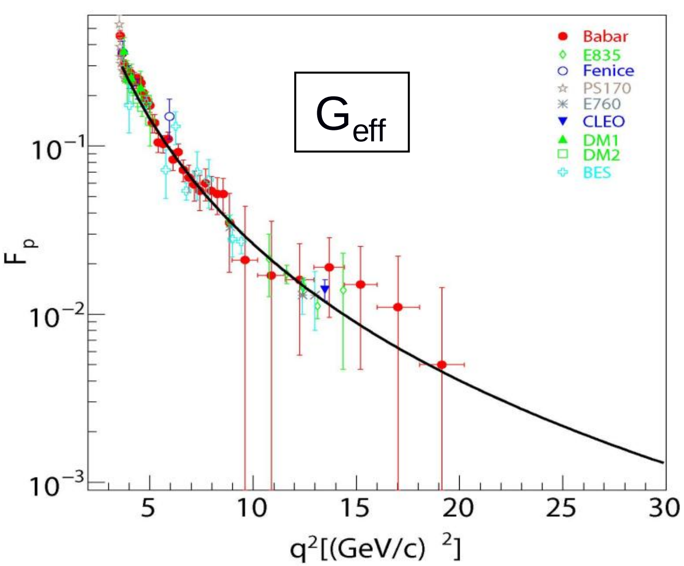
proton electromagnetic form factors in Time-Like region

Cross-sections: $\bar{p}p \rightarrow e^+e^-$

$$\sigma_{tot} \sim \left| G_{eff} \right|^2 \qquad \tau = \frac{q^2}{4M_p^2}$$

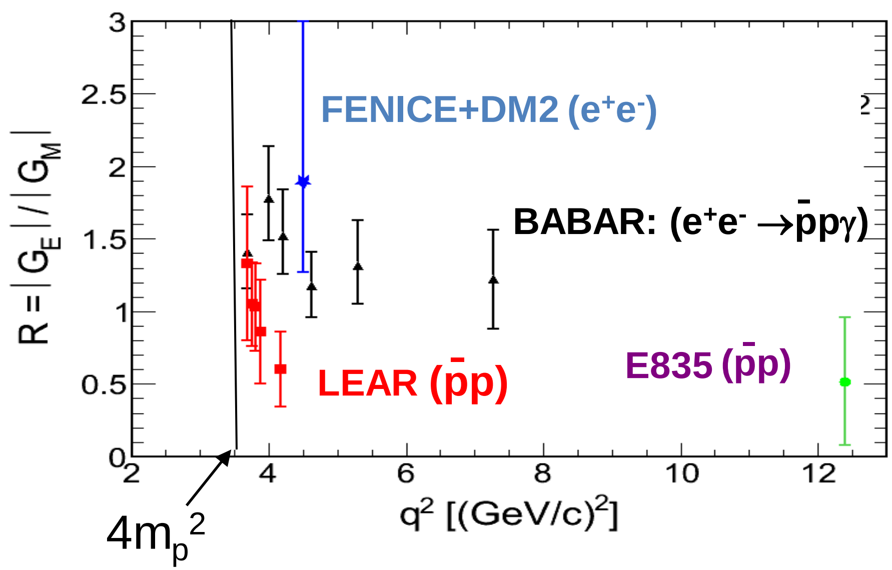
$$G_{eff} = \left|G_M\right| \quad if \quad \left|G_E\right| = \left|G_M\right| \quad or \quad \tau >> 1$$

$$\left|G_{eff}\right|^2 = \frac{2\tau\left|G_M\right|^2 + \left|G_E\right|^2}{2\tau + 1}$$



angular distributions: $\bar{p}p \rightarrow e^+e^-$

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



- ✓ G_{eff} : large error bars above 13 (GeV/c)^2
- ✓ $|G_E/G_M|$:
  - Inconsistent data above threshold
  - Lack of precise data above 5 (GeV/c)^2

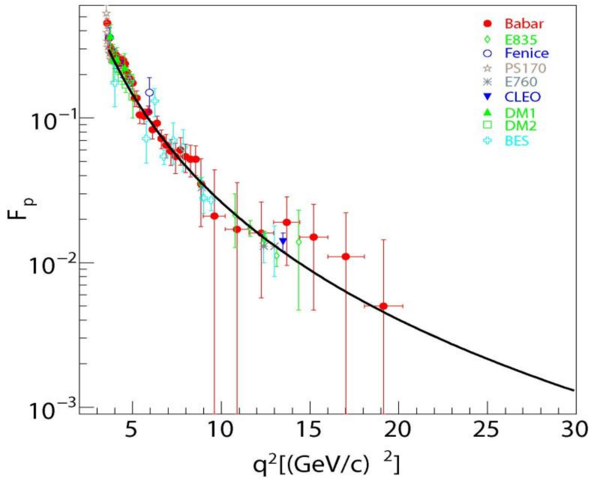
Goal of PANDA measurements

Extract Time-Like $|G_E|$ and $|G_M|$ for proton up to 14 $(GeV/c)^2$ from lepton angular distributions in $\bar{p}p \rightarrow e^+e^-$ reaction and measure G_{eff} up to 30 $(GeV/c)^2$

Two major challenges:

- ✓ Decrease of sensitivity to G_E with increasing q^2
- ✓ Huge hadronic background $\sigma(\bar{p}p \rightarrow \pi^+\pi^-) / \sigma(\bar{p}p \rightarrow e^+e^-) \sim 10^6$

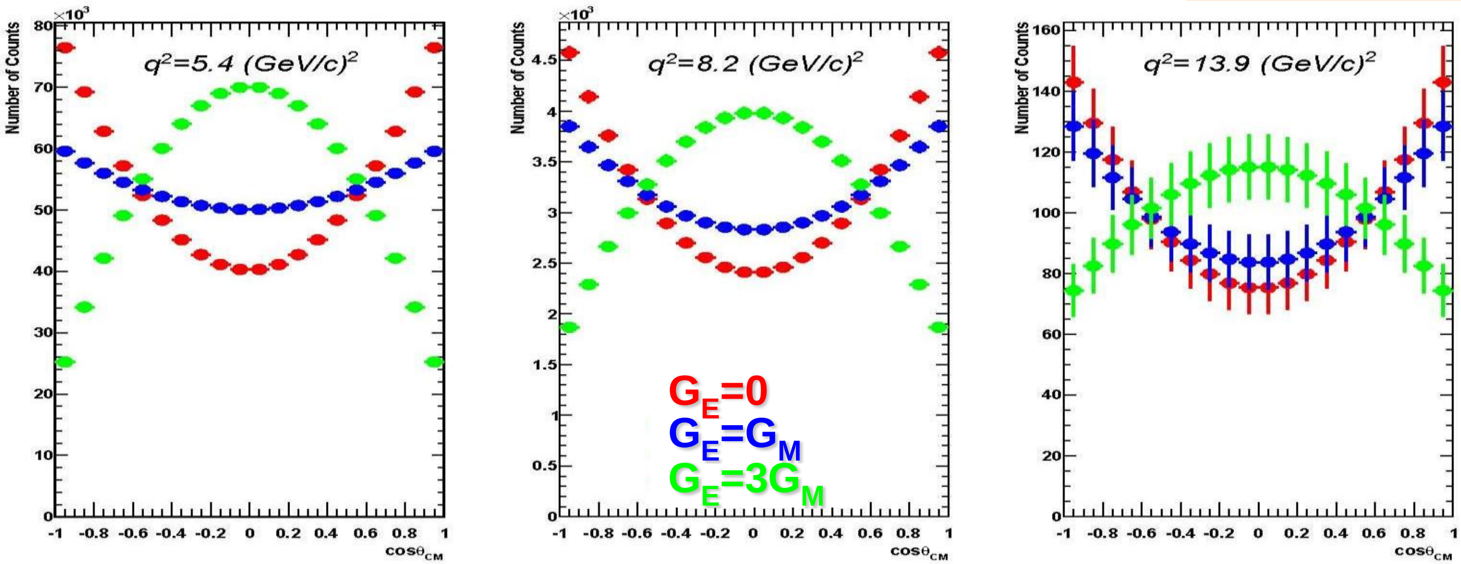
Counting rate and sensitivity to $|G_E|$



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

~120 days, $\mathcal{L}$ = 2. 10^{32} $cm^{-2}s^{-1}$ = 2 fb^{-1}

Statistical errors only

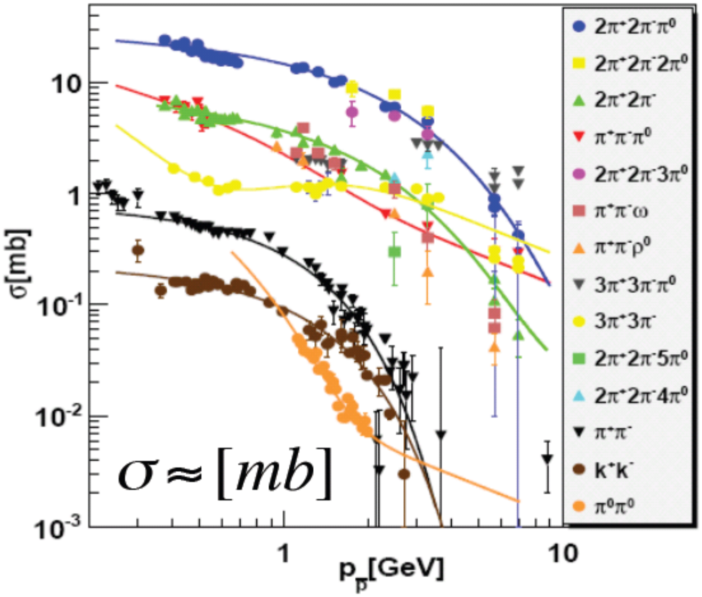


N_{tot}=1.1 10^6 **N_{tot}=64000** **N_{tot}=2000**

M. Sudol et al. EPJA 44 (2010) 373

Hadronic background rejection for $\bar{p}p \to e^+e^-$

pion production



A. Dbeyssi PhD, Orsay

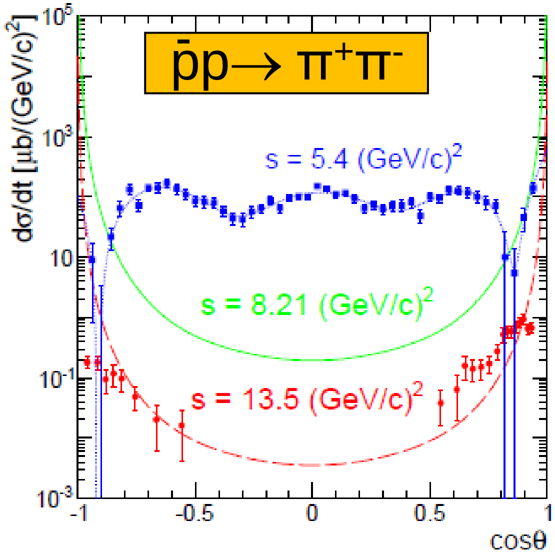
Background rejection takes advantage of :

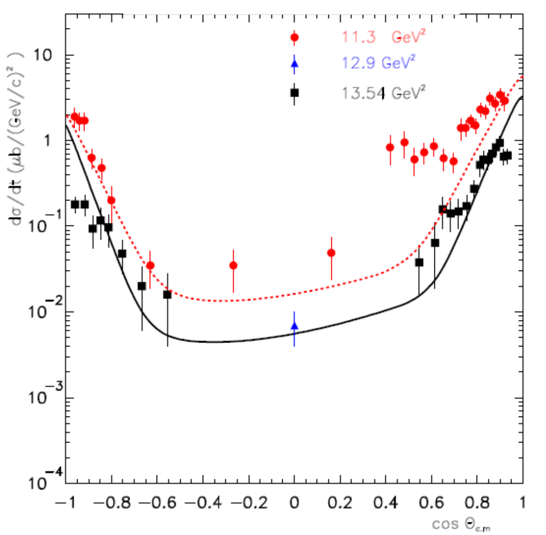
- **Hermiticity of the detector**
- **Particle Identification**
- **Kinematical constraints**

Most problematic background is $\bar{p}p \to \pi^+\pi^-$

Full scale GEANT simulations for $\bar{p}p \to e^+e^-$ and $\bar{p}p \to \pi^+\pi^-$ background

$\bar{p}p \to \pi^+\pi^-$





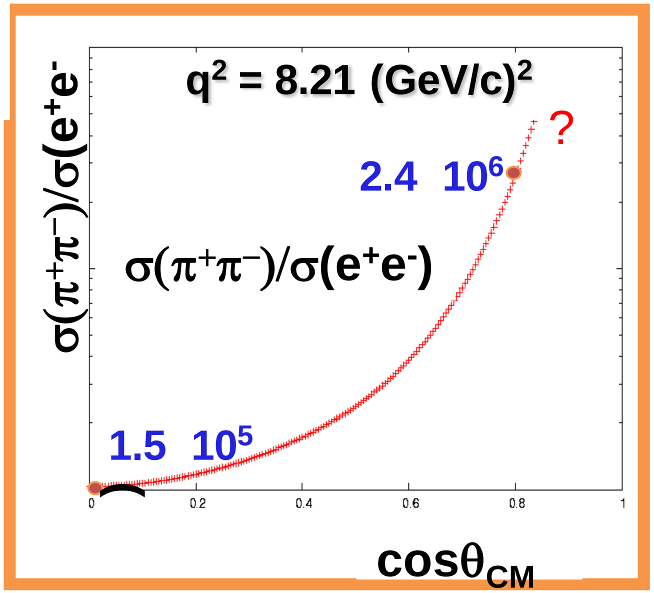
parametrization of CERN data for $\bar{p}$ p → $\pi^+\pi^-$

s < 6 (GeV/c)² : Legendre polynomial fits

s > 6 (GeV/c)² :

counting rules (*Ong et Van de Wiele, IPNO-DR-08-01*)

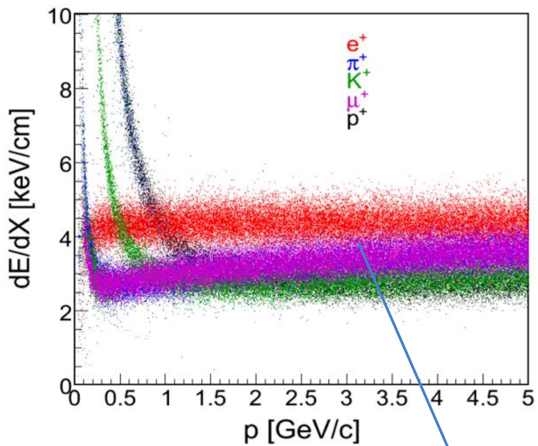
or Regge trajectories (*idem, EPJA46 (2010) 291*).



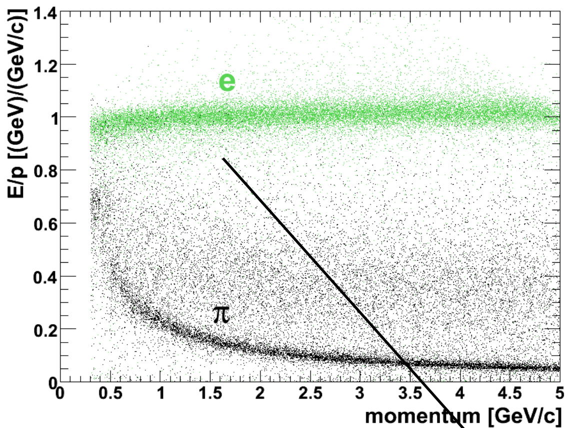
New measurements of $\bar{p}$ p → $\pi^+\pi^-$ will be provided by PANDA (also important for pQCD mechanism studies)

Rejection of $\bar{p}p \rightarrow \pi^+\pi^-$

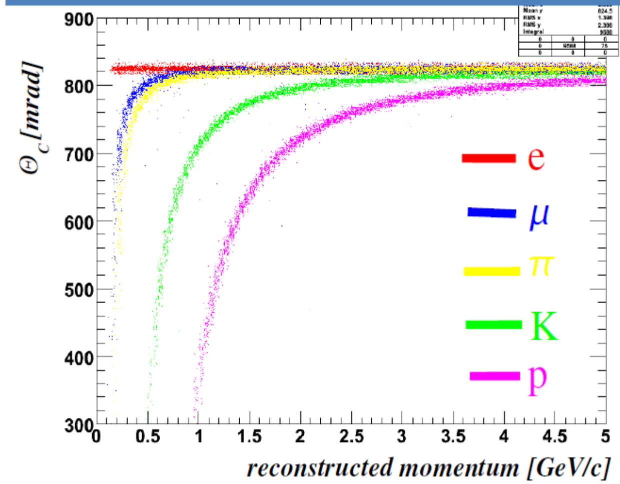
Straw Tube Tracker



ElectroMagneticCalorimeter



DIRC(Cerenkov)

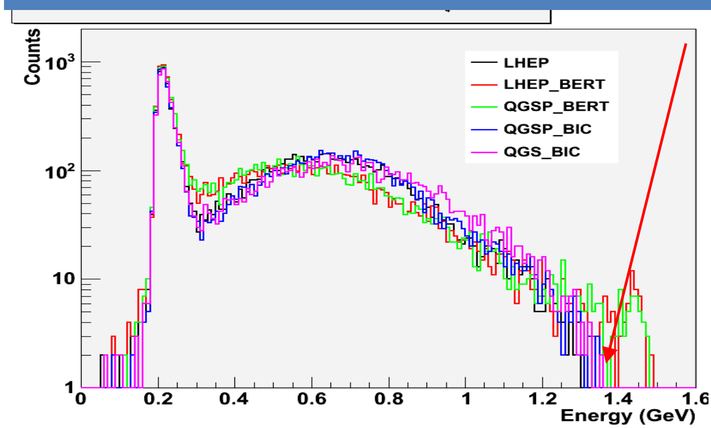


Non-gaussian tails of truncated dE/dx distribution

(π^-, π°), $\pi^\circ \rightarrow 2\gamma$

$E_{dep}/p \sim 1$

EMC response to π^- p=1.5 GeV/c



1) Use complementarity of e/π discrimination capability of the different detectors

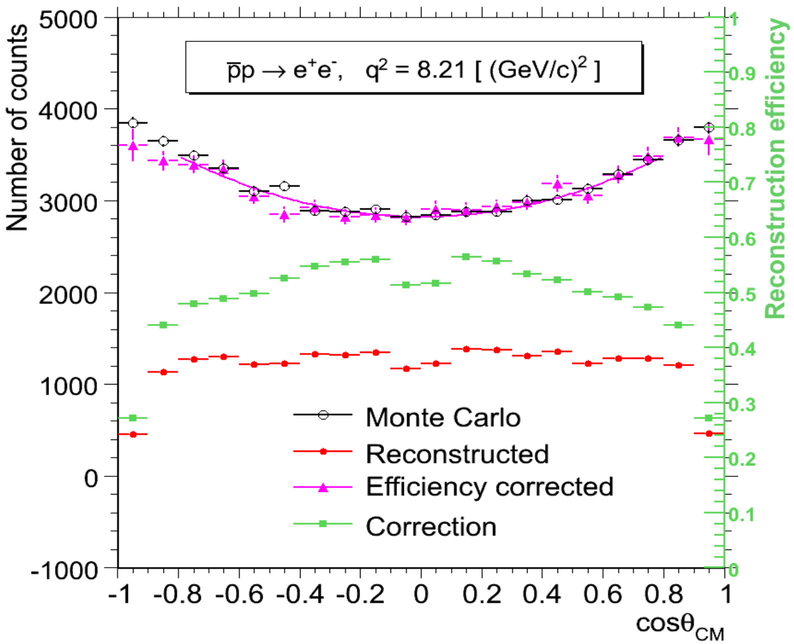
2) Use the different kinematical constraints of $\bar{p}p \rightarrow e^+e^-$ and $\bar{p}p \rightarrow \pi^+\pi^-$ reactions

Electron momentum resolution (bremstrahlung)

T.Zerguerras, IPN Orsay

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

Sudol et al. EPJA 44 (2010) 373



q^2 $[GeV/c]^2$	$\pi^+\pi^-$ contamination
8.2	0.004 %
12.9	0.017 %
16.7	0.061 %

→ contamination **< 0.1 %**

- Background suppression factor is at least of the order of 10^9
- Taking into account PID & kinematic fit contamination <<1%

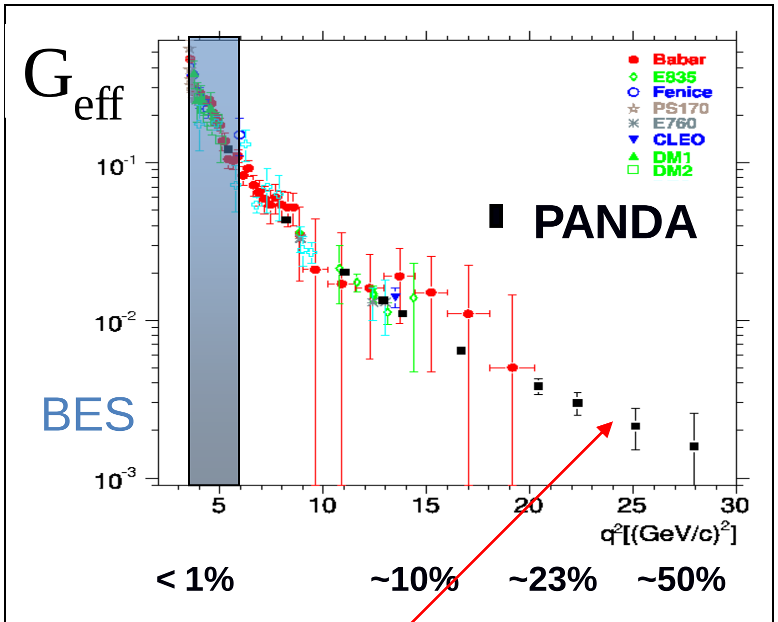
Time-Like Form Factor measurement with PANDA : precision estimates

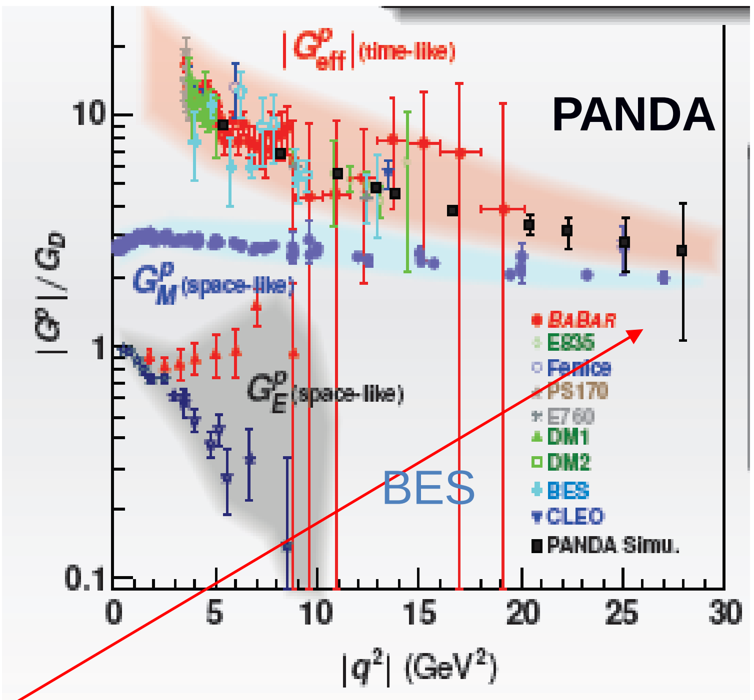
L=2 fb^{-1}

Sudol et al. EPJA 44 (2010) 373

Courtesy of S. Pacetti

E. Tomasi-Gustafsson and M.P. Rekalo, PLB504,291
E. Tomasi-Gustafsson, arXIv:0907.4442





pQCD ?

Phragmèn-Lindelöf theorem ?

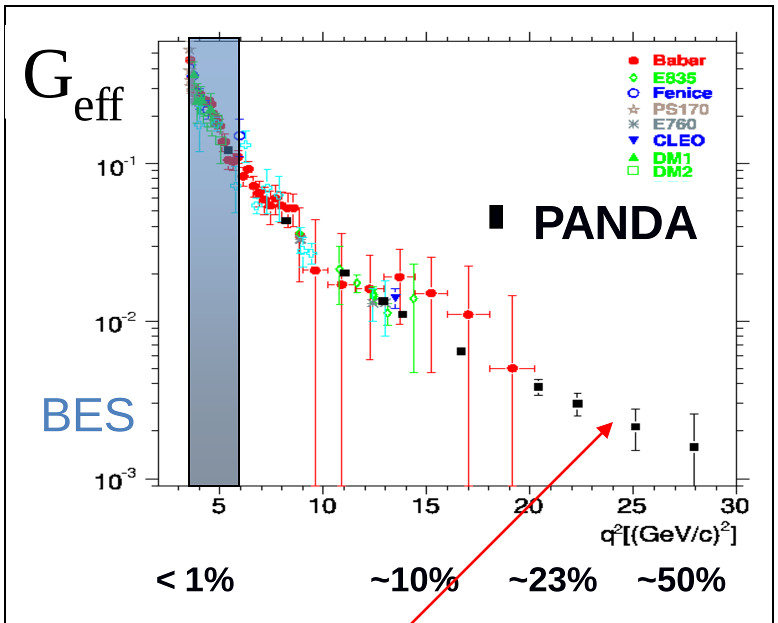
$$\lim_{q^2 \to -\infty} G^{SL}(q^2) = \lim_{q^2 \to +\infty} G^{TL}(q^2)$$

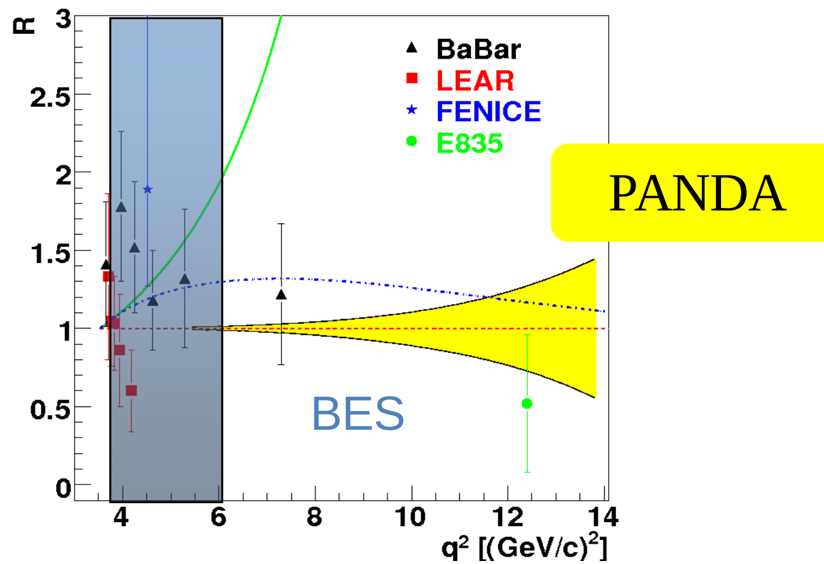
Time-Like Form Factor measurement with PANDA : precision estimates

L=2 fb^{-1}

Sudol et al. EPJA 44 (2010) 373

-VDM: F. Iachello et al., PLB43, 171 (1973)
…extended VDM, PRC66, 045501 (2002)
Egle Tomasi-Gustafsson et al., EPJA24 (2005) 419

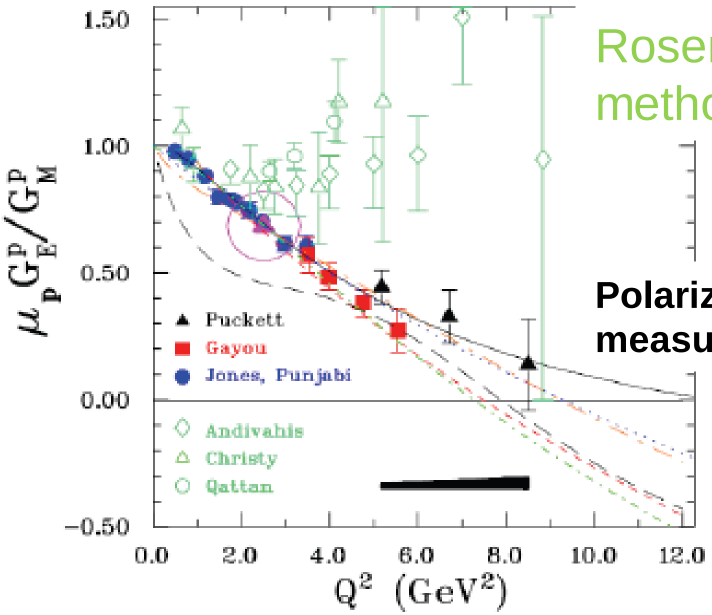




pQCD ?

PANDA will bring
Precise determination of $|G_E|$ and $|G_M|$ up to 14 (GeV/c)^2
G_{eff} up to 30 (GeV/c)^2 : transition towards perturbative QCD

2γ contributions and radiative corrections



Rosenbluth method

Polarization measurements

Important role of 2γ exchange and radiative corrections

$$\mathcal{S} = \frac{1}{2}\left(\frac{d\sigma}{d\Omega_{e^+}} + \frac{d\sigma}{d\Omega_{e^-}}\right)$$

No C-odd terms contribution

$$\mathcal{A} = \left(\frac{d\sigma}{d\Omega_{e^+}} - \frac{d\sigma}{d\Omega_{e^-}}\right) \Big/ \left(\frac{d\sigma}{d\Omega_{e^+}} + \frac{d\sigma}{d\Omega_{e^-}}\right)$$

C-odd terms contribution

- Advantage of annihilation reactions $\bar{p}p \leftrightarrow e^+e^-$

The e^+ and e^- angular distributions are measured in the same experiment

- PANDA measurements are sensitive to *odd cos* θ terms

$d\sigma/d\cos\theta_e \sim A\,(1 + b \cos\theta_e \sin^2\theta_e + c \cos^2\theta_e + ..)$ with b=5% or more

(M. Sudol et al EPJA 44(2010) 373).

2γ contributions in $\bar{p}p \rightarrow e^+e^-$

- ***Model independent properties on cross sections and polarization observables :*** *G. Gakh and E. Tomasi-Gustafsson NPA761(2005)120.*

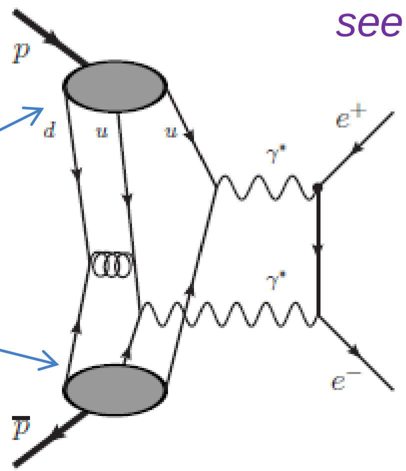
  see E. Tomasi-Gustafsson's talk

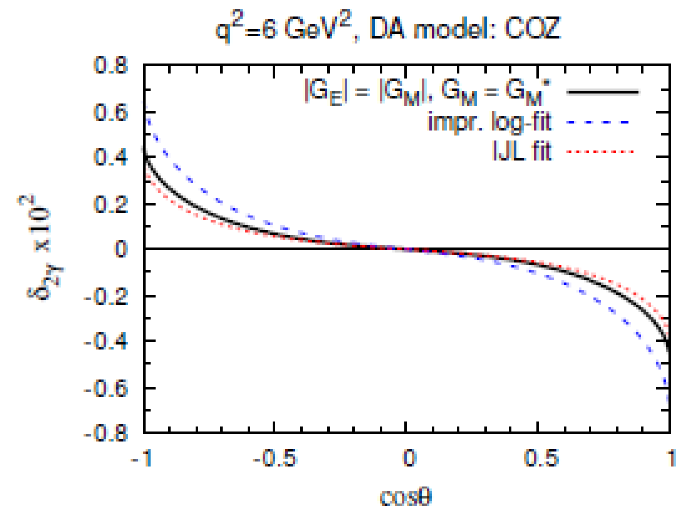
- 2γ contributions at large q^2 in **a factorization approach**

  J. Guttmann, N. Kivel, M, Vanderhaeghen PRD83 (2011) 094021

see N. Kivel's talk

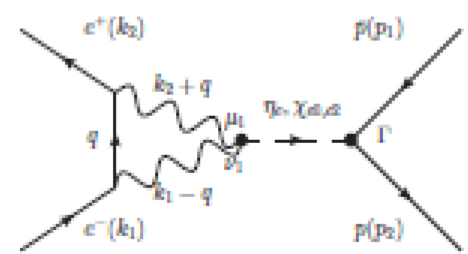
Distribution Amplitudes





- **resonant contribution:**

  H.-Q . Zhou and B.S. Zou .arXiv:1112.4615v2

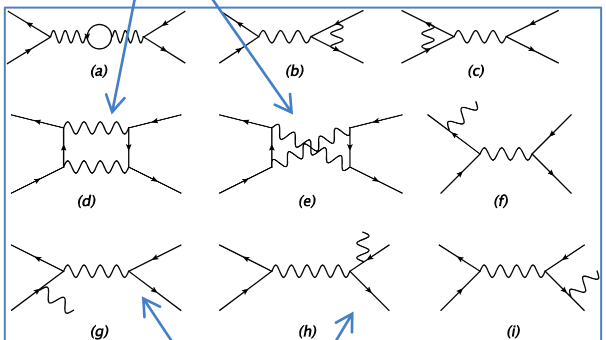


radiative corrections for $\bar{p}p \rightarrow e^+e^-$

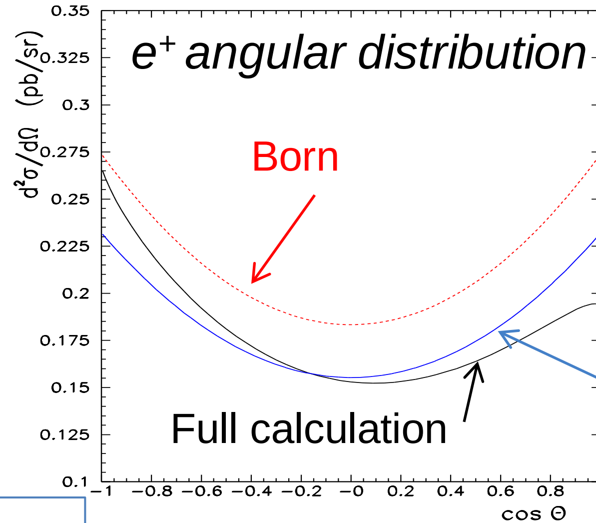
IPN Orsay et al. contributions: *A. Ahmadov et al., Phys.Rev.D82:094016,2010*

J. Van de Wiele and S. Ong, arXiv:1202.1114v1 [nucl-th]

Small contribution of box terms



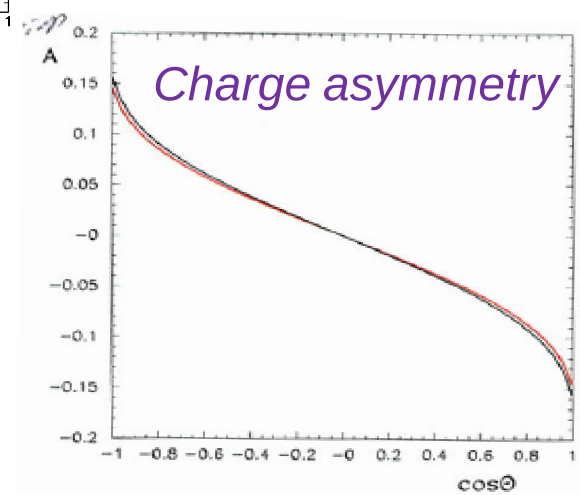
Important effect of interference between proton and lepton radiation



δ~-15% for $E_{\gamma\ cut}$=100 MeV

angle dependent effect

Final state radiation only



$$\mathcal{A} = \left(\frac{d\sigma}{d\Omega_{e+}} - \frac{d\sigma}{d\Omega_{e-}}\right) \Big/ \left(\frac{d\sigma}{d\Omega_{e+}} + \frac{d\sigma}{d\Omega_{e-}}\right)$$

J. Van de Wiele ans S. Ong, arXiv:1202.1114v1 [nucl-th]

Event generators with photon emission for PANDA experiments

Time-Like form factors in the unphysical region (1)

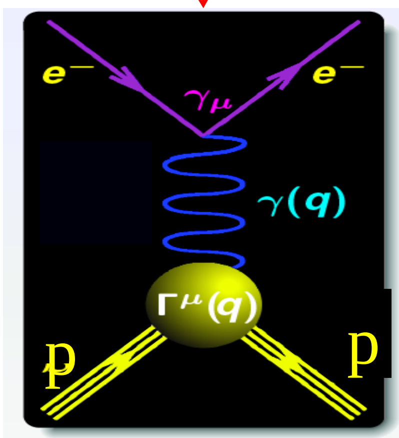
Dispersion relations

$$G(q^2) = \frac{1}{\pi}\left[\int_{4m_\pi^2}^{4m_p^2} \frac{\mathrm{Im}\, G(s)\,ds}{s-q^2} + \int_{4m_p^2}^{\infty} \frac{\mathrm{Im}\, G(s)\,ds}{s-q^2}\right]$$

$q^2 < 0$

Space Like (SL)

$q^2 < 0$



FFs real

Unphysical region

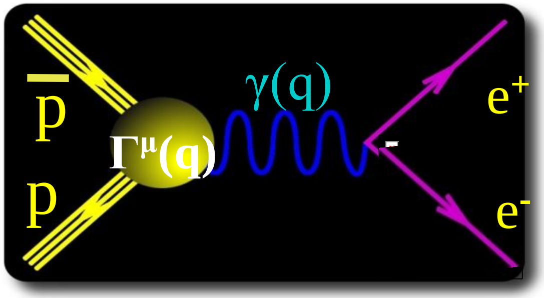
$\bar{p}\,p \rightarrow e^+ e^- \pi^0$

$\bar{p}p \leftrightarrow e^+e^-$ annihilation

Time Like (TL)

$q^2 = s$

$q^2 > 4m_p^2$



FFs complex

$4m_p^2$ $\quad q^2$

Vector meson poles: $q^2 = m^2_\rho, m^2_\omega, m^2_\phi$

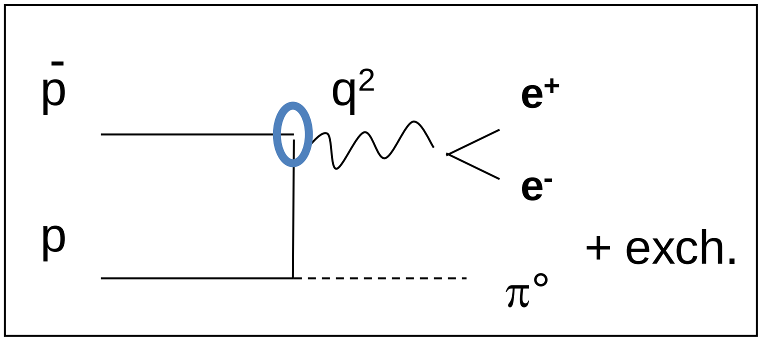
$\rightarrow$ Vector Meson Dominance (VMD)

form factor models can be tested

Form factors in the unphysical region (2)

Basic idea: **reach $q^2 < 4\, m_p^2$ by giving 4-momentum to another particle (e.g. π^0)**

M. P. Rekalo, Sov. J. Nucl. Phys., vol1, 760 (1965)

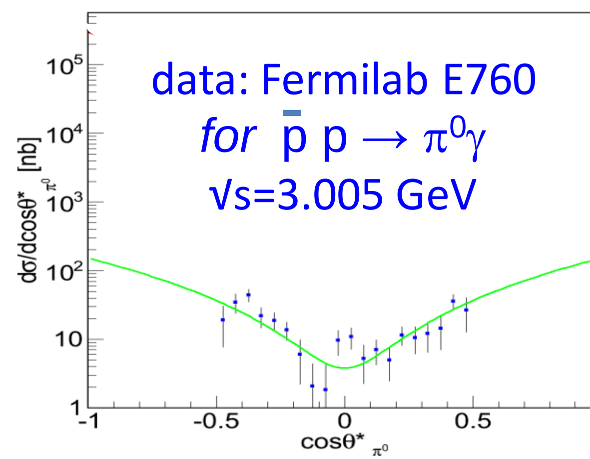


$$d^5\sigma \propto |M|^2 \propto L^{\mu\nu} H_{\mu\nu}\left(\theta_{\pi^0}, \phi_{\pi^0}, q^2, G_E(q^2), G_M(q^2), \theta_e, \varphi_e\right)$$

- ❑ 1st calculation of $d\sigma/dq^2$ for $\bar{p}\, p \rightarrow e^+ e^- \pi^0$
  A. Dubnickova et al,. Z.Phys. C70 (1996) 473-482
  C. Adamuščín et al., Phys. Rev. C 75, 045205, 2007

- ❑ New investigations by J. Van de Wiele and J. Boucher in IPN Orsay to build an event generator for simulation studies

  ✓ $d^5\sigma / dq^2 d\theta_{\pi 0} d\varphi_{\pi 0}\, d\theta_e d\varphi_e$
  ✓ *constrained on existing data*
  Armstrong et al.,PRD56,(1997)2509



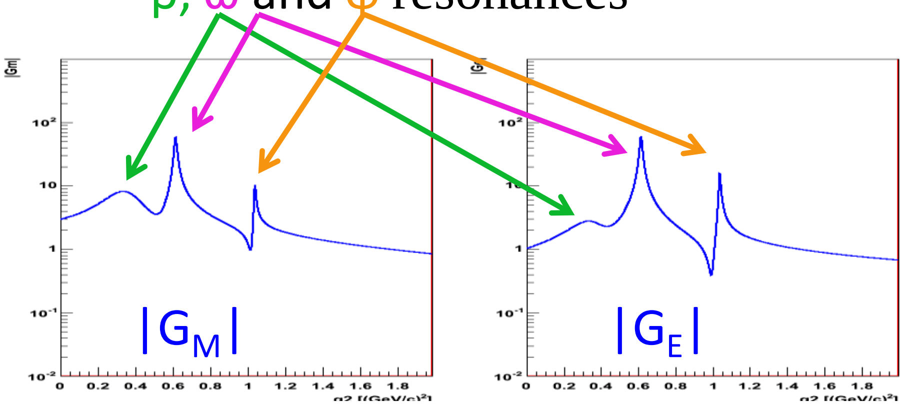
- ❑ *Recent calculation of* $d^5\sigma / dq^2 d\theta_{\pi 0} d\varphi_{\pi 0}\, d\theta_e d\varphi_e$ *and polarization observables*
  G.I. Gakh et al. arXiv:1206.0929

Count rate predictions for $\bar{p}p \rightarrow \pi^0 e^+ e^-$

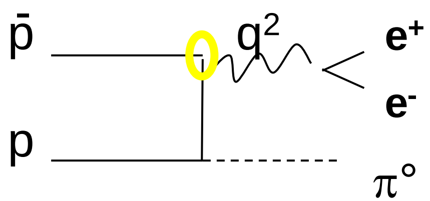
Iachello VMD form factor model

Phys. Rev. C69, 055204, 2004

ρ, ω and ϕ resonances



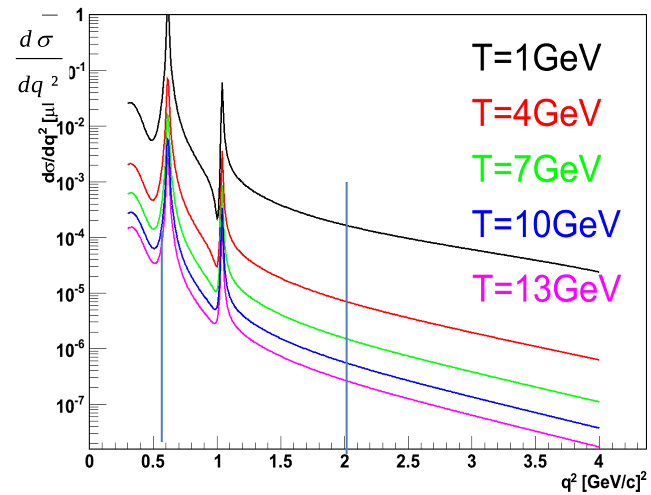
q^2 (GeV/c2)　　q^2 (GeV/c2)



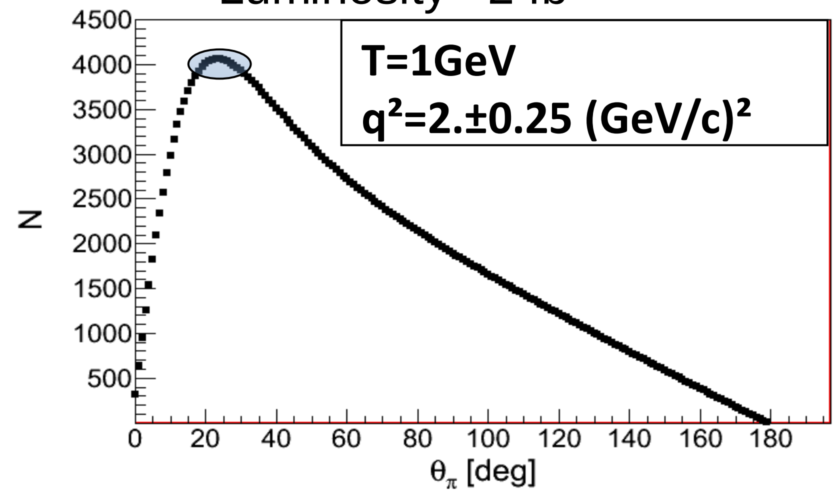
at T=1 GeV , q^2=2 $(GeV/c)^2$
172000 events for Δq^2=0.5 $(GeV/c)^2$,
4000 events for $\Delta\theta_\pi$=1° (θ_π=20°)

J. Boucher PhD Orsay dec.2011

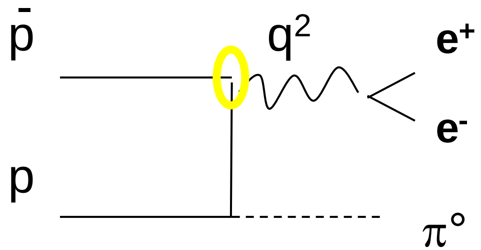
Incident energy dependence



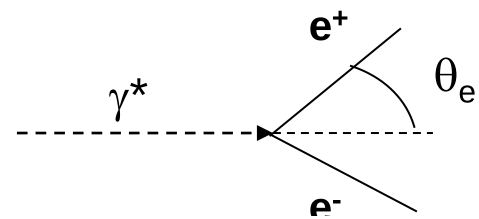
Luminosity =2 fb^{-1}



From hadronic tensors to form factors

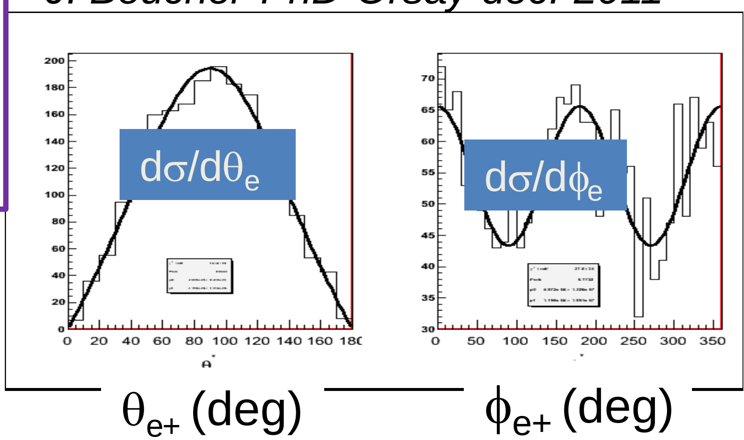


+ exch.



$$d^5\sigma \propto |M|^2 \propto L^{\mu\nu} H_{\mu\nu} = 4e^2 \frac{q^2}{2}\left(H_{11} + H_{22} + H_{33}\right)$$
$$- 8e^2 p_e^2 \left(H_{11} \sin^2\theta_e \cos^2\varphi_e + 2 H_{13} \sin\theta_e \cos\theta_e \cos\varphi_e\right.$$
$$\left. + H_{22} \sin^2\theta_e \sin^2\varphi_e + H_{33} \cos^2\theta_e\right)$$

J. Boucher PhD Orsay dec. 2011



In the one nucleon exchange model :

$$H_{\mu\nu} = \alpha_{\mu\nu} |G_E|^2 + \beta_{\mu\nu} |G_M|^2 + \gamma_{\mu\nu} |G_E||G_M| \cos(\varphi_E - \varphi_M)$$

For fixed $\theta_{\pi 0}$ and q^2,
Fit of lepton angular distributions in γ^* frame
$\rightarrow R=|G_E/G_M|$ and $\cos(\varphi_E-\varphi_M)$

General result: the angular distribution in θ_e^* and φ_e^* in γ^* frame gives access to 4 $H_{\mu\nu}$ at fixed $\theta_{\pi 0}$ and q^2

Background for $\bar{p}p \to \pi^0 e^+ e^-$

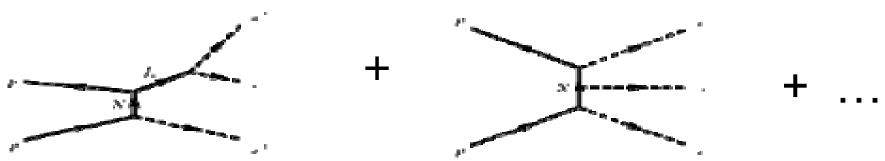
Background rejection takes advantage of :
- **Hermiticity of the detector**
- **Particle Identification**
- **Kinematical constraints**

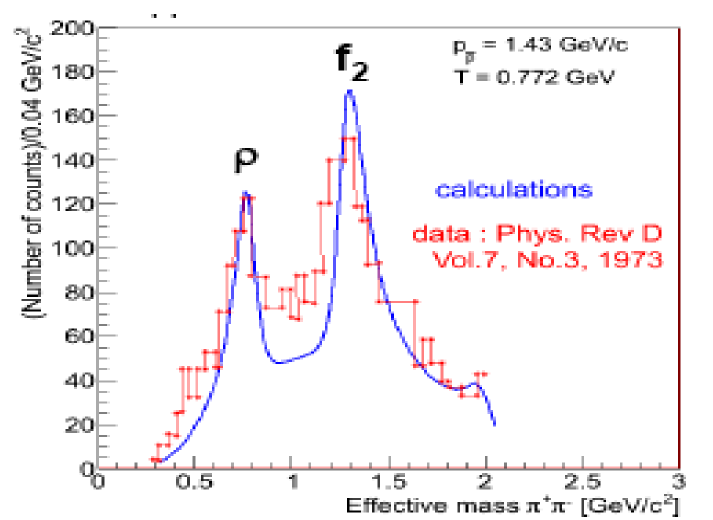
Most problematic background is $\bar{p}p \to \pi^+\pi^-\pi^0$

❑ $\bar{p}p \to \pi^+\pi^- \pi^0$

Calculation for T=1 GeV
J. Van de Wiele, IPN Orsay

Effective lagrangians: 9 graphs in total





at T=1 GeV , q^2=0.6 (GeV/c)^2 σ_B/σ_S=3-5.10^3
q^2=2 (GeV/c)^2 σ_B/σ_S=3.10^6-3.10^7 → input for simulations

N.B. PANDA will provide new measurements of $\bar{p}p \to \pi^+\pi^-\pi^0$

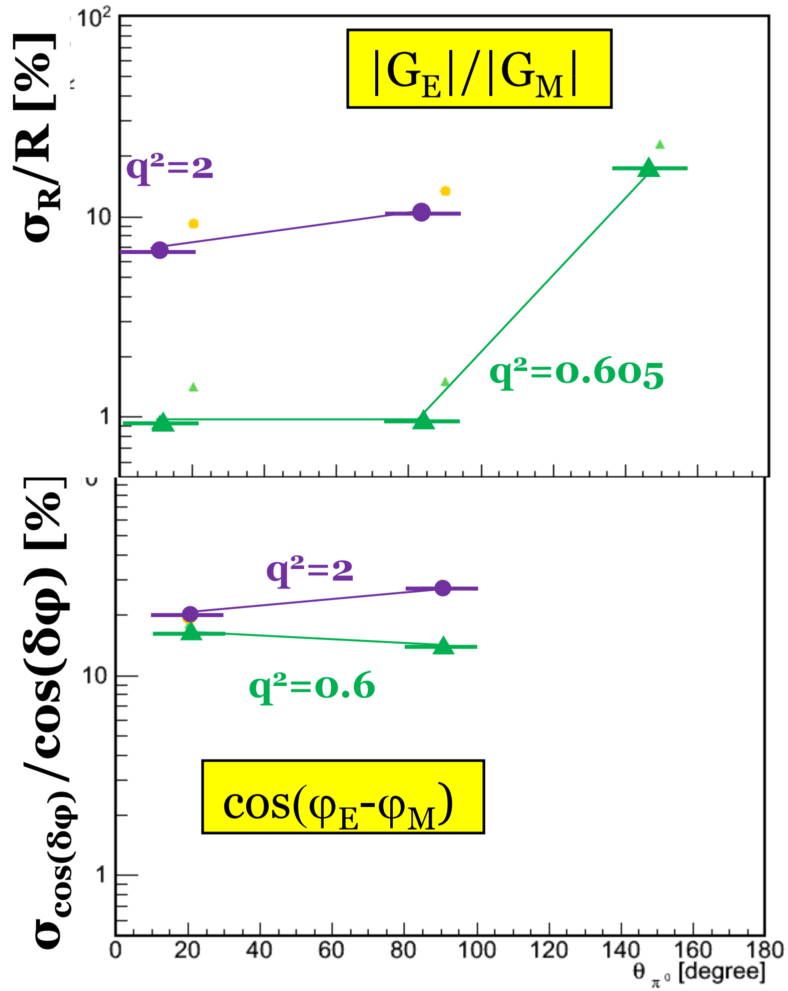
Expected precision on $|G_E|/|G_M|$ and the phase difference

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

$q^2 = 0.605 \pm 0.005\ (GeV/c^2)^2$

$q^2 = 2.0 \pm 0.125\ (GeV/c^2)^2$

$L_{int} = 2\ fb^{-1}$



Signal contamination <1 % at $q^2=0.6$
< 10% at $q^2=2.0$

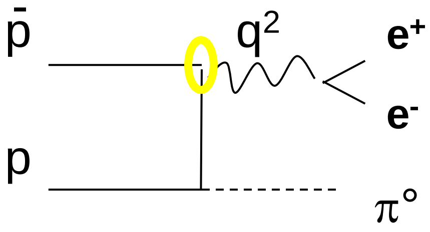
~ 1% precision close to the ω resonance
~ 10% precision at $q^2 = 2\ (GeV/c^2)^2$
~ 20% precision at $q^2 = 4M_p^2 = 3.52\ (GeV/c^2)^2$

For the first time $cos(\phi_E-\phi_M)$ can be extracted with 10-30% precision

T. Hennino, J. Boucher, IPN Orsay

Form factor measurement in the unphysical region: outlook

- ***The measurement of electromagnetic form factors moduli and phase difference below $4m_p^2$ threshold in $\bar{p}p \to \pi^0 e^+ e^-$, following the one nucleon exchange model is feasible***



- **However: there are open questions:**
  - ✓ **off-shell effects on form factor**
  - ✓ **Validity of the nucleon exchange model ,**
    - **role of Δ exchange**
    - **importance of s-channel terms**

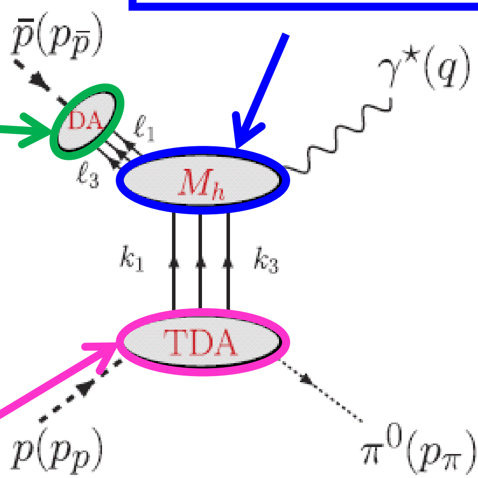
    E.A. Kuraev et al. arXiv:1012.5720v2 [hep-ph]

    → **can be checked with $\bar{p}p \to \pi^0\gamma$ measurement at PANDA**

Another approach for the $\bar{p}p \rightarrow e^+e^-\pi^0$ reaction : Transition Distribution Amplitudes

Distribution Amplitude = 3-quark operator matrix element
<0|uud|p>

Hard sub-process :



Transition Distribution Amplitude = 3-quark operator matrix element
<π|uud|p>

Signature: Angular distribution of the e^+/e^- in the γ^* frame
~ $(1+\cos^2\theta)$

$q^2 >> 1$

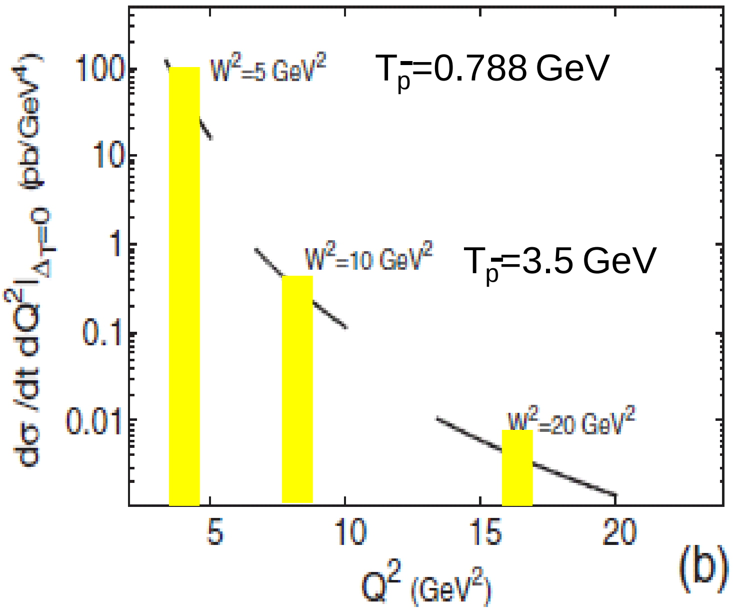
$\theta_\pi = 0^o$ or $\theta_\pi = 180^o$
'π' at rest in p or pbar rest frame
$\Delta_t = (p_{\bar{p}/p} - p_\pi)_t = 0 \rightarrow 3$ TDA

J.P. Lansberg et al, PRC76,111502(2007)

New window on the sea quarks in proton wave function complementary to corresponding quantities from CLAS/JLAB

Transition Distribution Amplitudes in $\bar{p}p \to e^+e^-\pi^0$ reaction : estimates for PANDA

J.P. Lansberg et al, PRC76,111502(2007)



Estimates for PANDA: (*Mainz/Orsay collaboration M.C. Mora Espi, B. Ma)* **including acceptance and efficiency**
L= 2 fb^{-1} , $\Delta Q^2 < 1$ GeV^2
→ Feasible at s=W^2=5 (GeV/c)^2, but probably not at W^2=10 (GeV/c)^2

also to be studied

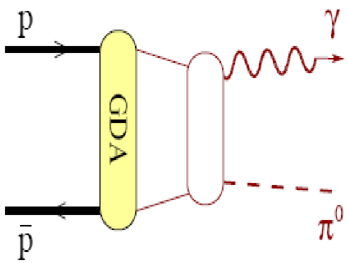
- **pp→J/Ψ π^0 (same TDA's)**
- **Possible generalization to η and ρ (more TDAs)**

Nucleon structure and pQCD with PANDA

Panda Physics Performance ***arXiv:0903.3905 [hep-ex]***

- **More about electromagnetic Time-Like proton form factors**
  - $\bar{p}p \to \mu^+\mu^-$ (collaboration with Torino)
  - $\bar{p}d \to n\, e^+e^-$ *H. Fonvieille and V. Karmanov, EPJA42 (2009)287*
  - Polarization in $\bar{p}p \to e^+e^-$ → relative phase of G_E and G_M

- **Other electromagnetic processes:**
  - $\bar{p}p \to \gamma\gamma$, $\bar{p}p \to \gamma\pi^\circ$ (GDA, Giessen)
  - $\bar{p}p \to e^+e^-\pi^\circ$ (Transition Distribution Amplitude $p\to\pi$)
  - $\bar{p}p \to \mu^+\mu^- X$ (Drell-Yan, Torino/Ferrara)



Conclusion and outlook

The PANDA detector at FAIR will allow for a variety of QCD studies, from 2018

- **Electromagnetic channel measurements** :
  - $\bar{p}p \rightarrow e^+e^-$ Proton Time-like Form factors :
  G_E and G_M up to q^2=14 $(GeV/c)^2$,, Geff up to 30 $(GeV/c)^2$
  and $\bar{p}p \rightarrow \pi^0 e^+e^-$: access to form factors in the unphysical region

  - $\bar{p}p \rightarrow e^+e^-\pi^0$, $\bar{p}p \rightarrow J/\Psi\ \pi^0$,$\bar{p}p \rightarrow e^+e^-\rho$, $\bar{p}p \rightarrow e^+e^-\eta$ (TDA)
  - $\bar{p}p \rightarrow \gamma\pi^0, \gamma\ \gamma$ General Distribution Amplitudes
  complementary to JLAB/CLAS
  - $\bar{p}p \rightarrow \mu^+\mu^- X$ Drell-Yann

- Simultaneous measurement of **hadronic channels:** $(\pi^+\pi^-, \pi^+\pi^-\pi^0, \ldots.)$
  - background for electromagnetic channels
  - Interest for pQCD mechanisms

Thanks

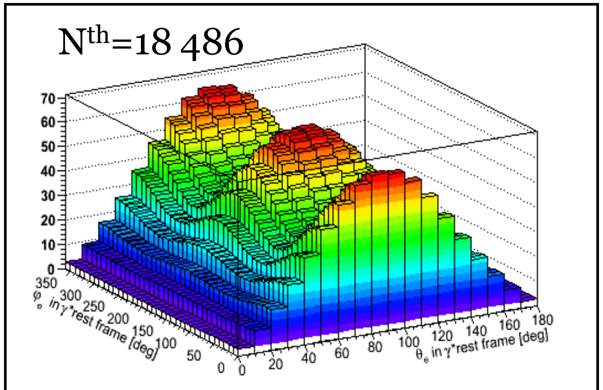
PANDA/IPN Orsay team: J. Boucher, A. Dbeyssi, M. Gumberidze, T. Hennino, R. Kunne, T. Liu, B. Ma, D. Marchand, S. Ong, E. Tomasi-Gustafsson, J. Van de Wiele

in collaboration with Mainz/GSI

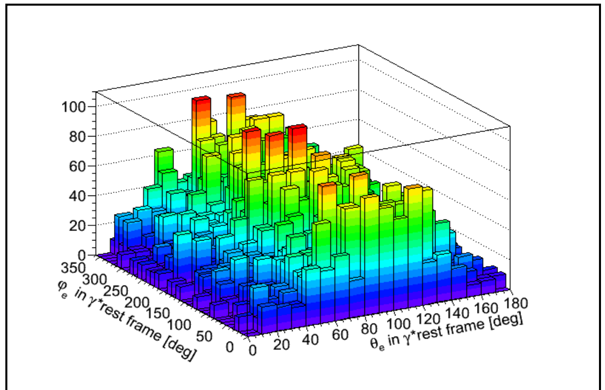
Thank you for your attention !

From experimental to physical information

$T_{\bar{p}}$=1 GeV ; $q^2=2.0 \pm 0.125\ (\mathrm{GeV}/c^2)^2$; $10° < \theta_{\pi^0} < 30°$; $L_{int} = 2\ fb^{-1}$



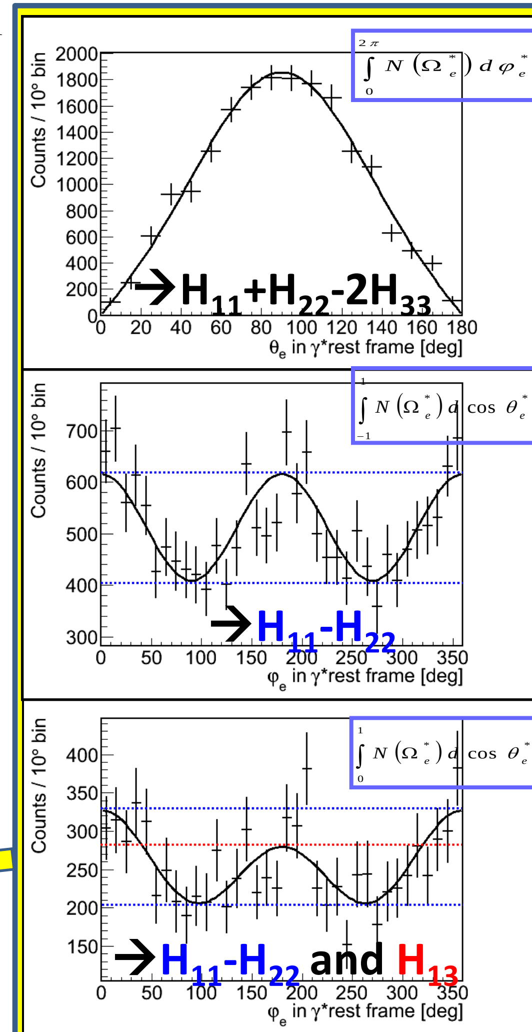
Predicted e^+ distribution in γ*



Corrected experimental distribution

Full simulation chain

Projection and fit



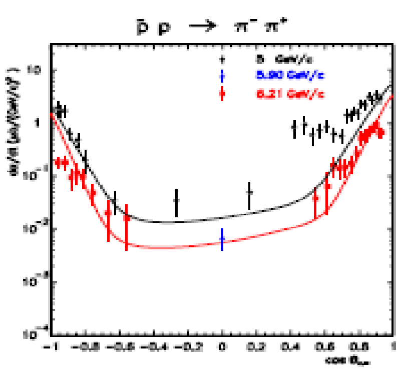
Determination of
$R=|G_E|/|G_M|$ and $\cos(\varphi_E-\varphi_M)$
from the shapes only

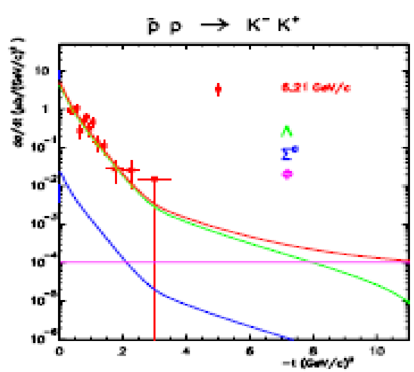
Hadronic channels

understand the reaction mechanism and the transition towards pQCD

$$\bar{p}p \to \pi^+\pi^-, \; p\bar{p} \to K^+K^-, \; \bar{p}p \to \pi^+\pi^-\pi^0$$

- only low quality data exist from CERN
- High statistics expected at PANDA, easy to measure
- $\bar{p}p \to \pi^+\pi^-$, $\bar{p}p \to \pi^+\pi^-\pi^0$ needed anyway to control the background for proton form factor measurements in $\bar{p}p \to e^+e^-$ and $\bar{p}p \to e^+e^-\pi^0$ reactions
- theoretical work: J. Van de Wiele and S. Ong EPJA46 (2010) 291: models checked on existing data to be used as generators for simulations



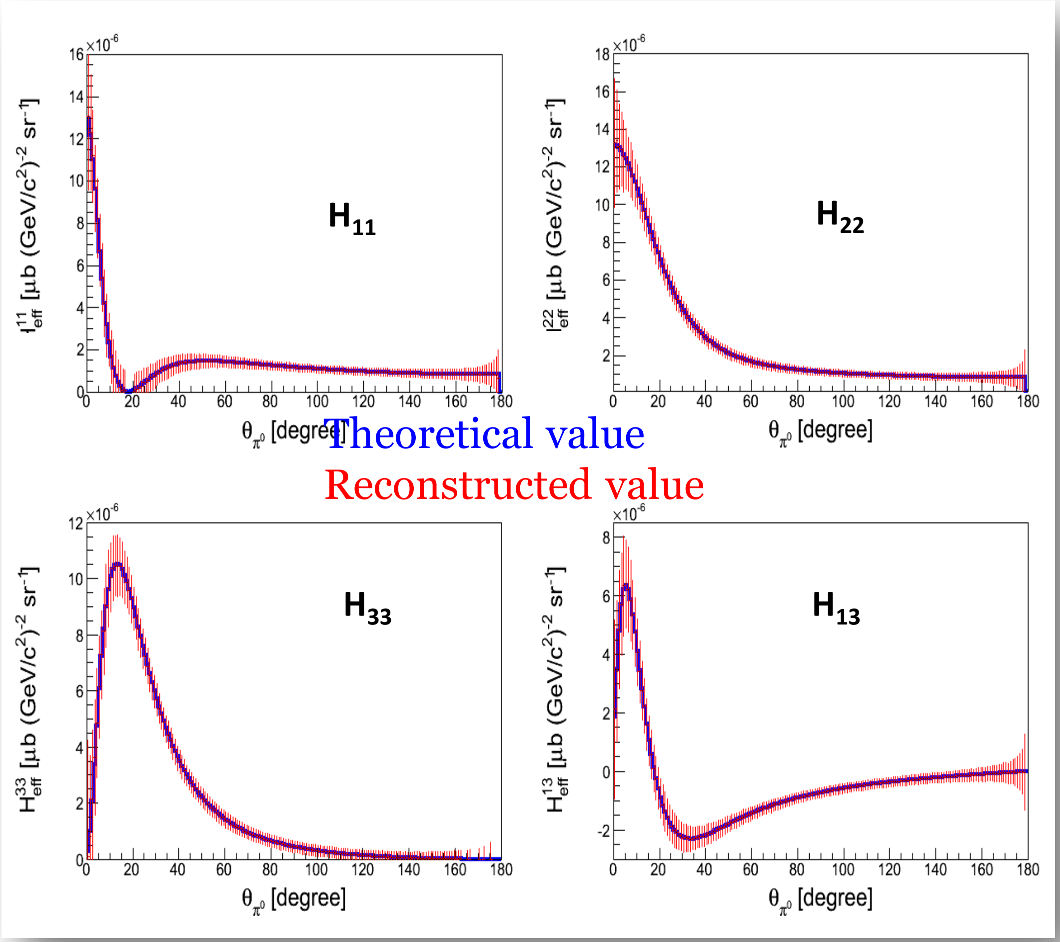


Possibility to explore up to $-t=30$ (GeV/c)^2 With PANDA

Hadronic tensor extraction: proof of principle

- $T_{\bar{p}}$=1GeV
- q^2=2.0 ± 0.125 $(GeV/c^2)^2$
- L_{int} = 2 fb^{-1}

- $d^2\sigma/d\Omega_e^*$ generated in the γ^* rest frame (θ_e^*, φ_e^* in10°/bin)
- Reconstructed value from the fit of $d^2\sigma/d\Omega_e^*$ in each θ_{π^0} interval ($\Delta\theta_{\pi^0}$=1°)



Direct access to $H_{\mu\nu}$ via the angular distribution valid whatever the model is

Only statistical errors without acceptance nor efficiency