Feasibility studies of proton time-like electromagnetic form factors with the $\bar{\text{P}}$ANDA detector

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HK 1.5
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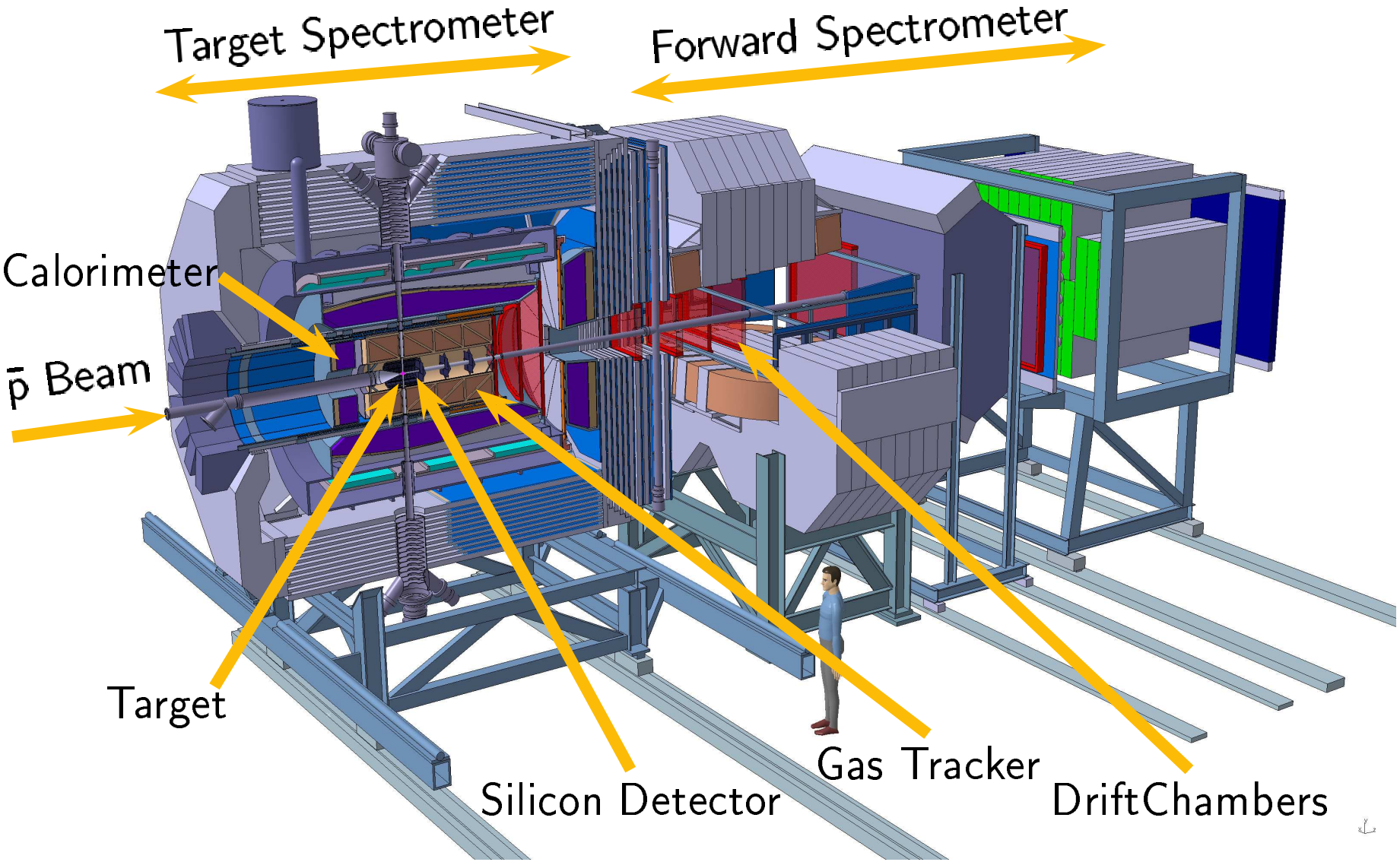
Outline

P̄ANDA detector



P̄ANDA physics program

- Charmonium spectroscopy
- Nuclear structure
- Hypernuclear physics

Nucleon structure: form factors measurement

e p scattering

$\bar{p}$ p annihilation

"unphysical region"

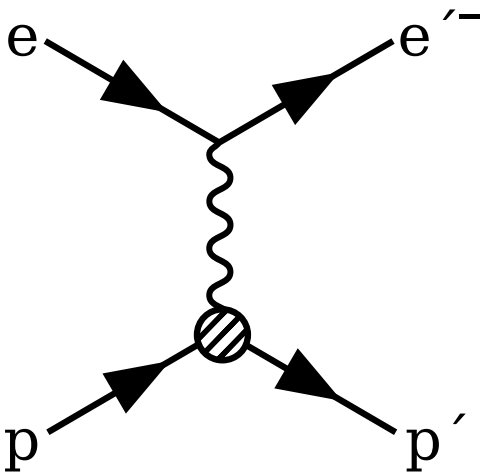
SPACELIKE
real FF

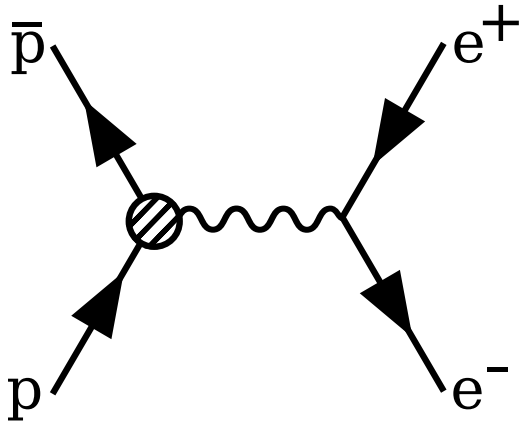
TIMELIKE
complex FF

0

$4M^2$

q^2





Nucleon structure: time-like form factors measurement

- Form Factors (FF) parametrize structure of the nucleon
- Functions of the 4-momentum transfer q^2
- In $\bar{p}p$ CM frame, $\bar{p}p \to e^+e^-$ cross section is given by

$$\boxed{\frac{d\sigma}{d\cos\theta} = C[|G_M|^2(1+cos^2\theta) + \frac{|G_E|^2}{\tau}(1-cos^2\theta)]}$$

where $C = \frac{\pi\alpha^2(\hbar c)^2}{8m_p^2\sqrt{\tau(\tau-1)}}$, $\tau = q^2/4m_p^2$ and
$\theta = angle(e^-\bar{p})$ in $\bar{p}p$ CM frame

our goal:

make measurements of proton electromagnetic time-like form factors with the $\bar{P}$ANDA detector

Challenge: background

Background channel: $\bar{p}p \to \pi^+\pi^-$

- Main background source to e^+e^- production

$$\boxed{\frac{\sigma(\bar{p}p \to \pi^+\pi^-)}{\sigma(\bar{p}p \to e^+e^-)} \sim 10^6} \Rightarrow \text{need suppression factor} \sim 10^8$$

- No unique cross section parametrization valid in the full kinematic range
  - low energy range: $1 < p_{beam} < 2.5\,GeV$ data
    Eisenhandler et. al., Nucl. Phy. B96 (1975) 109
  - high energy range: $2.5 < p_{beam} < 12\,GeV$ Regge model
    J. Van de Wiele and S. Ong: Eur. Phy. J. A46(2010) 291
  - See talk of Manuel Zambrana (HK 54.7)

PandaRoot

PandaRoot simulation chain

- Simulation
- Digitization
- Reconstruction
- Particle identification

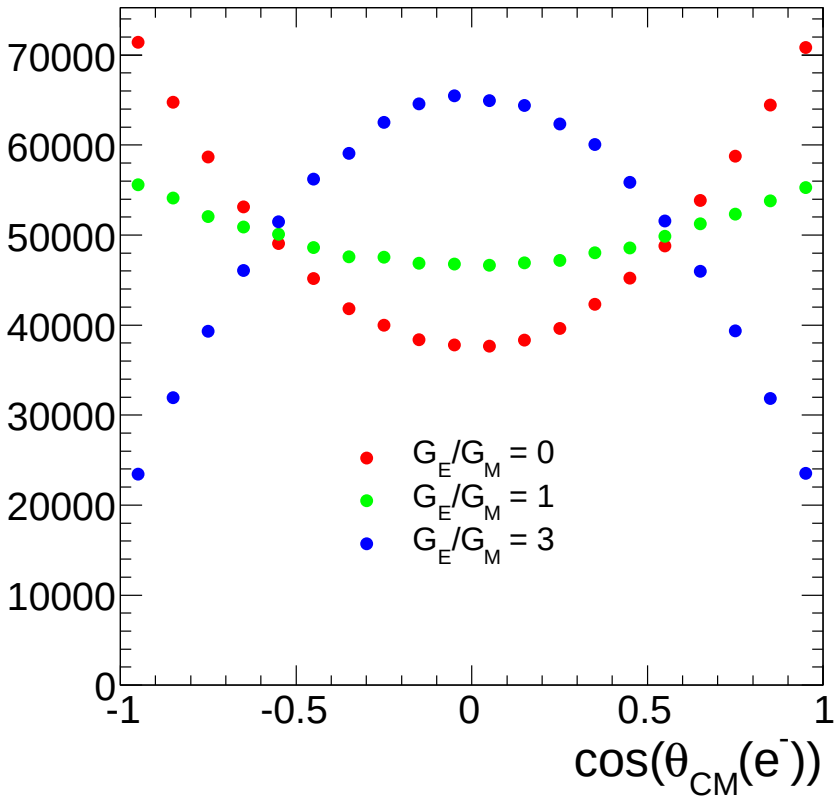
Simulations

	$\bar{p}p \to e^+e^-$	$\bar{p}p \to e^+e^-$	$\bar{p}p \to \pi^+\pi^-$
	simulation	realistic sim	background
G_E/G_M	0, 1, 3	0, 1, 3	-
$p_{beam} = 1.7\ [GeV/c]$	$5 * 10^6$	$1.1 * 10^6$	$1.1 * 10^8$
$p_{beam} = 3.3\ [GeV/c]$	10^6	$6.4 * 10^4$	$1.1 * 10^8$
$p_{beam} = 6.4\ [GeV/c]$	10^6	$2.0 * 10^3$	-

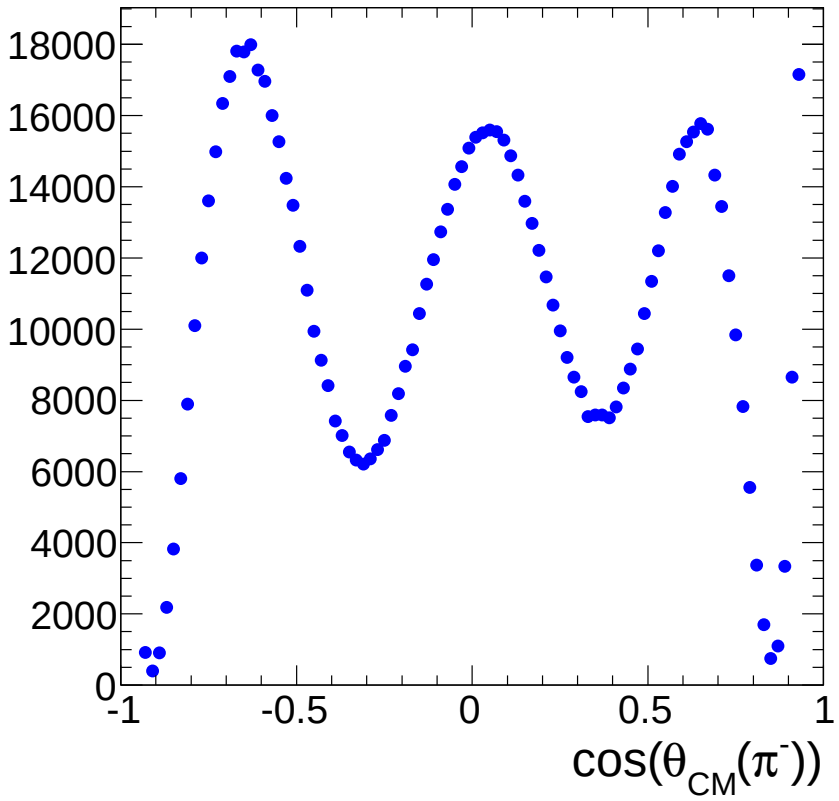
Expected luminosity $L = 2fb^{-1}$
Simulation was performed **@HIMSTER** cluster of
Helmholtz-Institut Mainz

Monte-Carlo $cos(\theta_{CM})$ distribution $p_{beam} = 1.7 GeV/c$

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



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

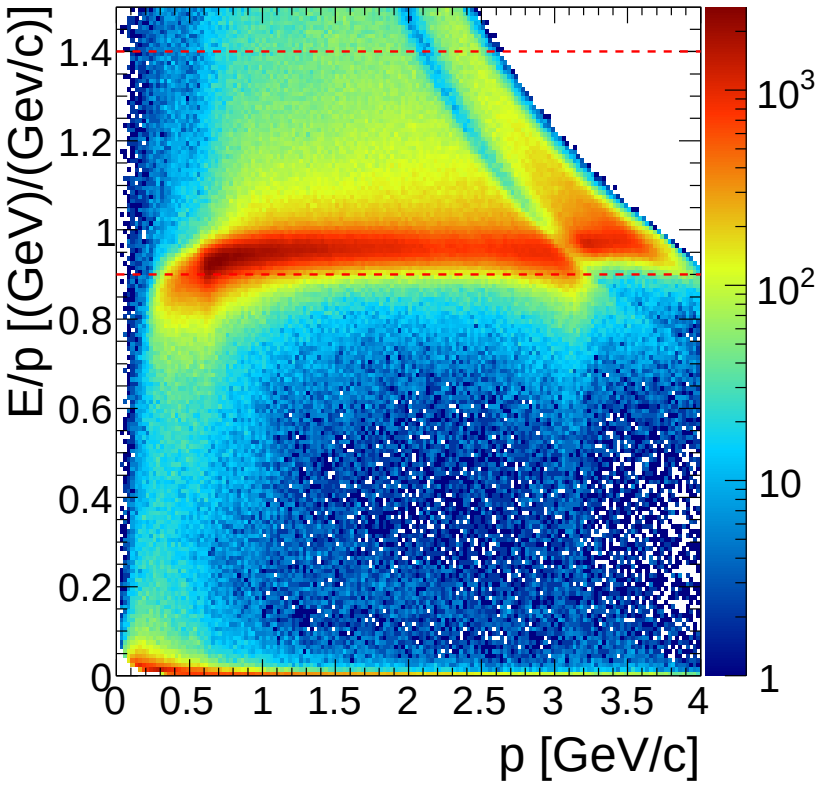


Selection criteria for e^+e^-

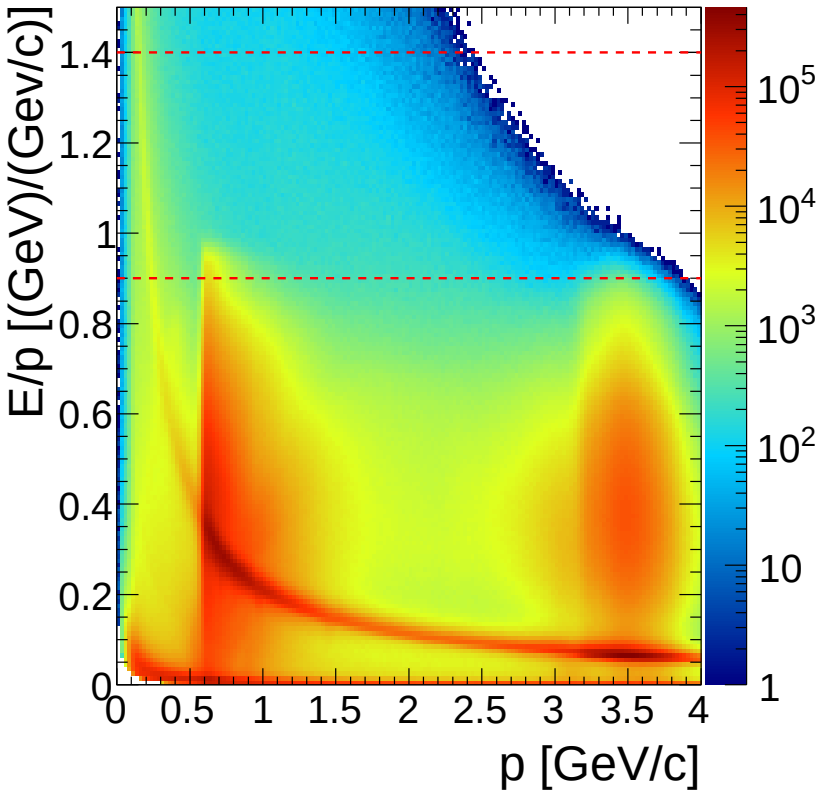
- Exactly 1 positive and 1 negative track
- Energy and momentum conservation within resolution of 20%
- Ratio of deposited energy vs momentum (E/p)
- Energy deposited in central tracker
- Minimum cluster size in EMC

E/p vs p

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

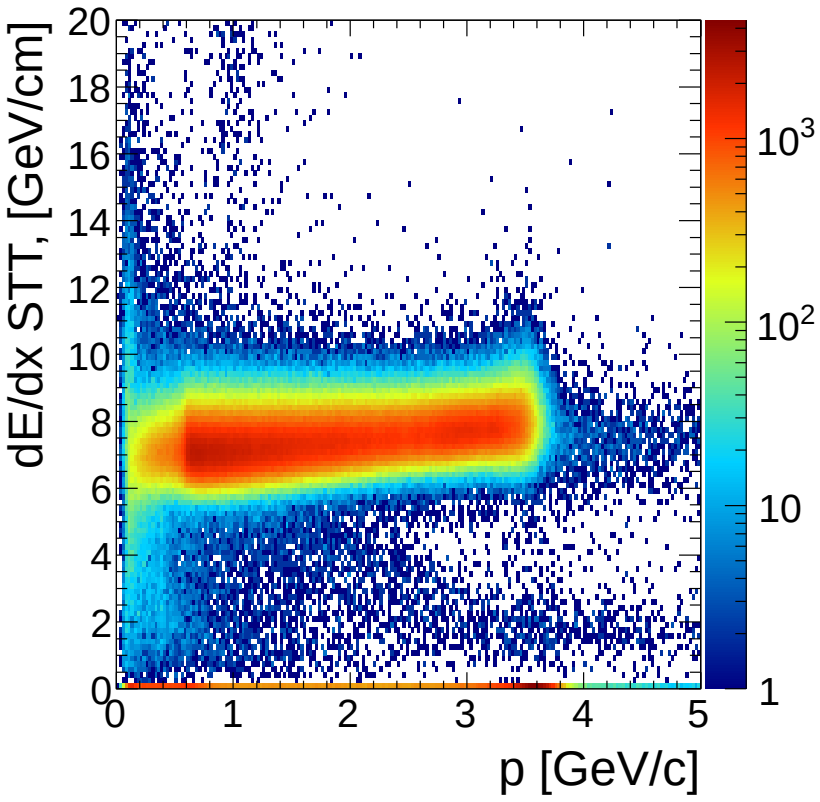


$\bar{p}p \to \pi^+\pi^-$

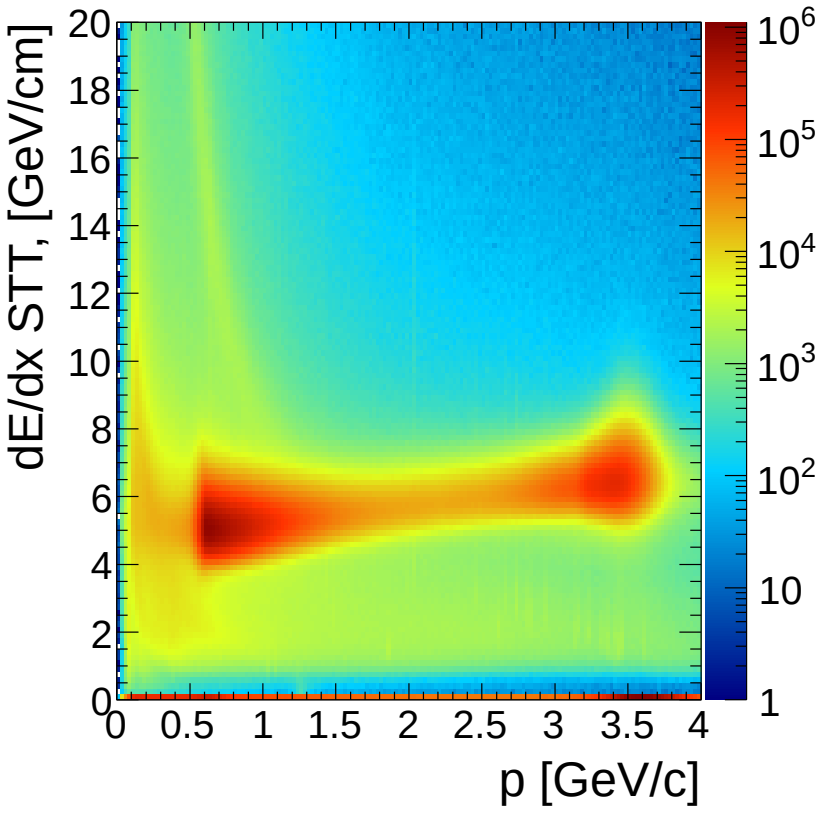


Energy loss in STT

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



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

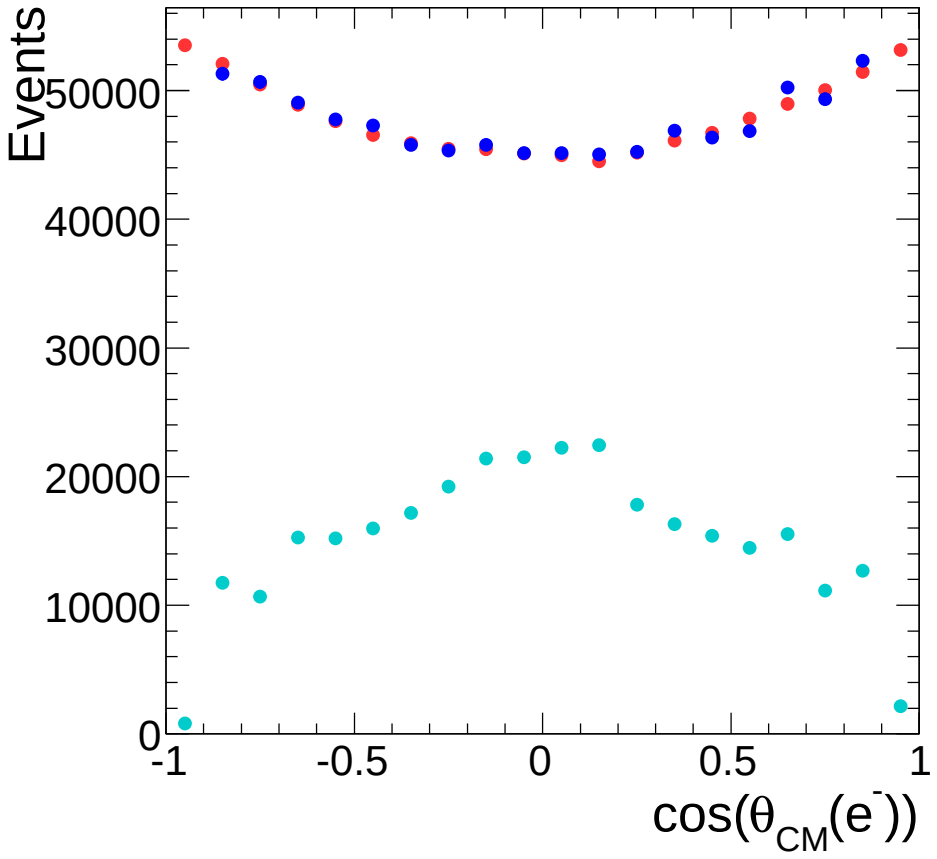


Reconstruction efficiency of e^+e^- and $\pi^+\pi^-$ pairs

	$\bar{p}p \to e^+e^-$			$\bar{p}p \to \pi^+\pi^-$
G_E/G_M	0	1	3	-
$p_{beam} = 1.7\ [GeV/c]$	46%	48%	52%	0.000009%
$p_{beam} = 3.3\ [GeV/c]$	41%	42%	46%	0.000007%
$p_{beam} = 6.4\ [GeV/c]$	30%	32%	37%	-

Efficiency correction
[statistical errors only]

$$p_{beam} = 1.7 GeV/c, G_E/G_M = 1$$



preliminary

- Monte-Carlo
- Reconstructed
- Corrected

Zichichi cross section

$$\frac{d\sigma}{d\cos\theta} = C[|G_M|^2(1+cos^2\theta) + \frac{|G_E|^2}{\tau}(1-cos^2\theta)]$$

$$\frac{d\sigma}{d\cos\theta} = C|G_M|^2[(1+cos^2\theta) + \frac{|R|^2}{\tau}(1-cos^2\theta)]$$

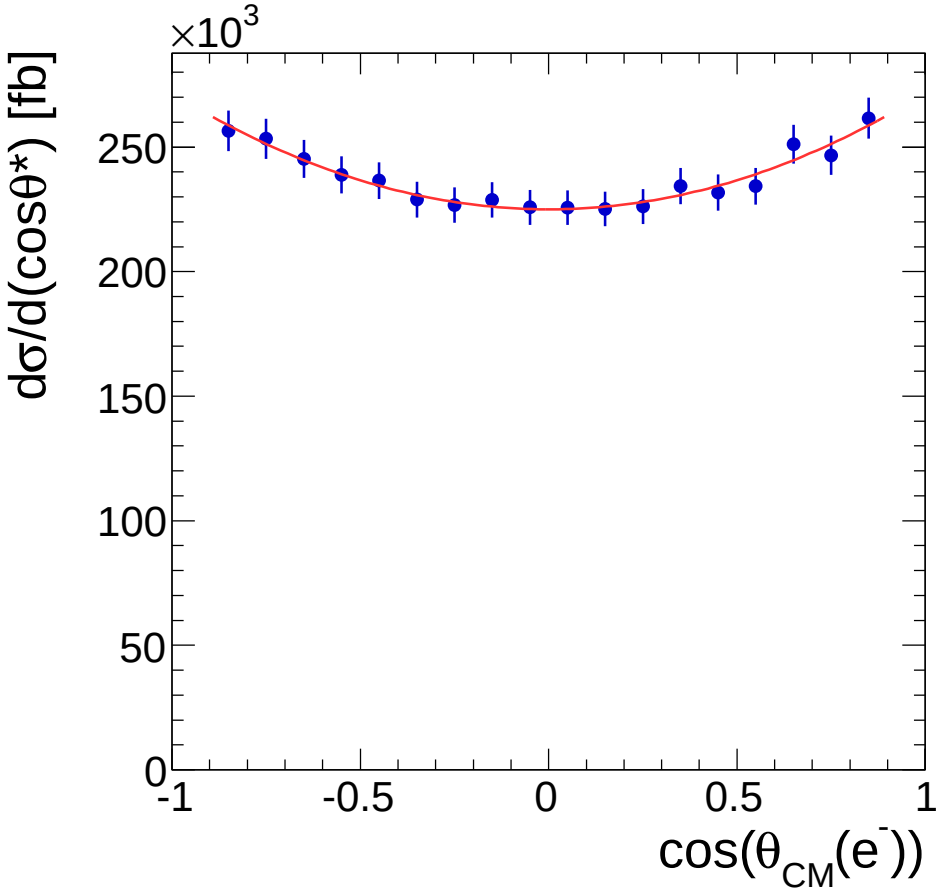
A. Zichichi et. al., Nuovo Cimento XXIV, 170 (1962)

$$|G_M| = \frac{22.5}{(1+q^2/0.71)^2(1+q^2/3.6)}$$

E. Tomasi-Gustafsson and M. P. Rekalo, Phys. Lett. B 504, (2001) 291.

Accuracy of form factors extraction [statistical errors only]

$$p_{beam} = 1.7 GeV/c, G_E/G_M = 1$$



preliminary

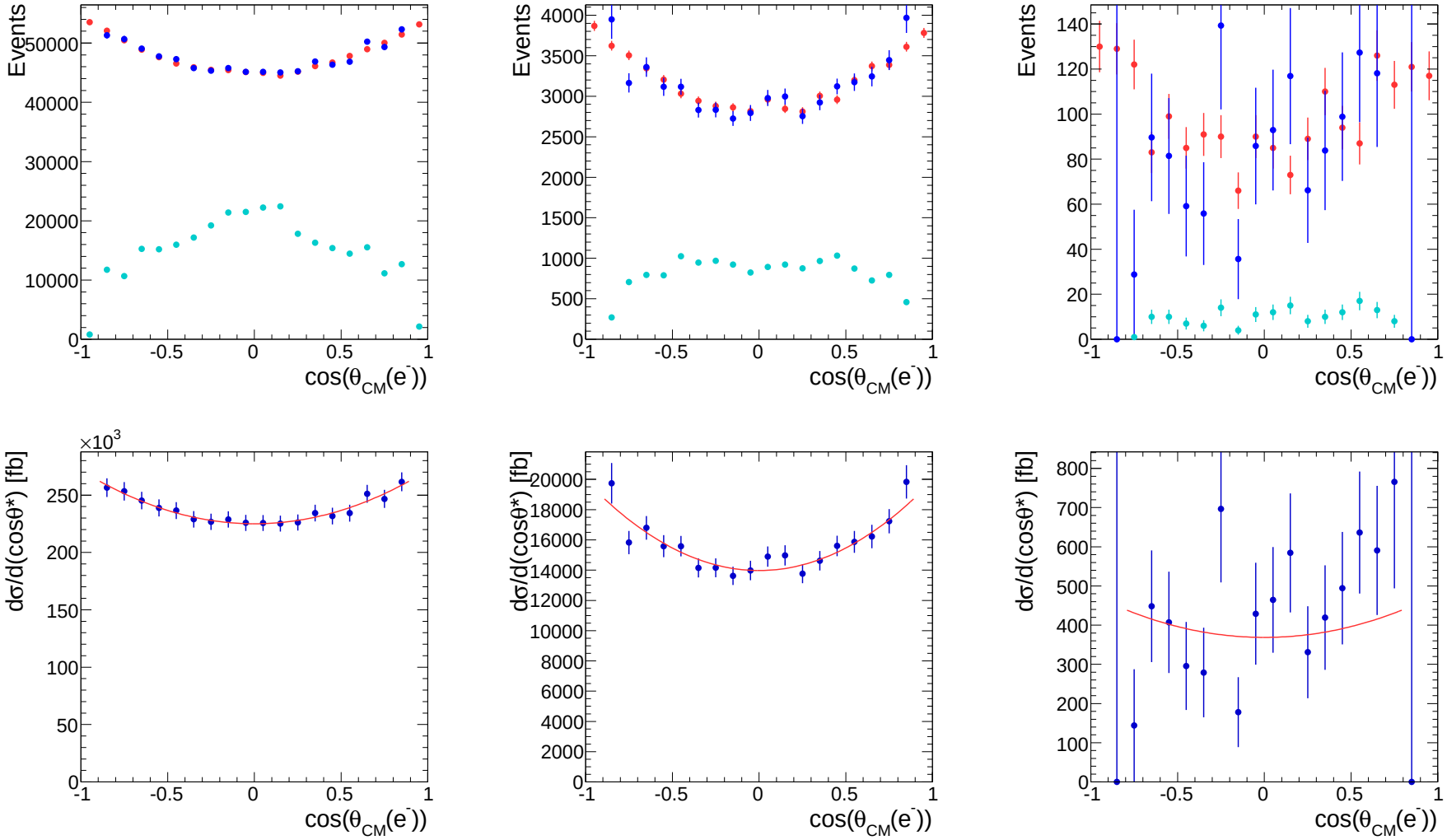
- Calculated cross section
- Fit

$G_E = 0.116 \pm 0.003$

$G_M = 0.115 \pm 0.001$

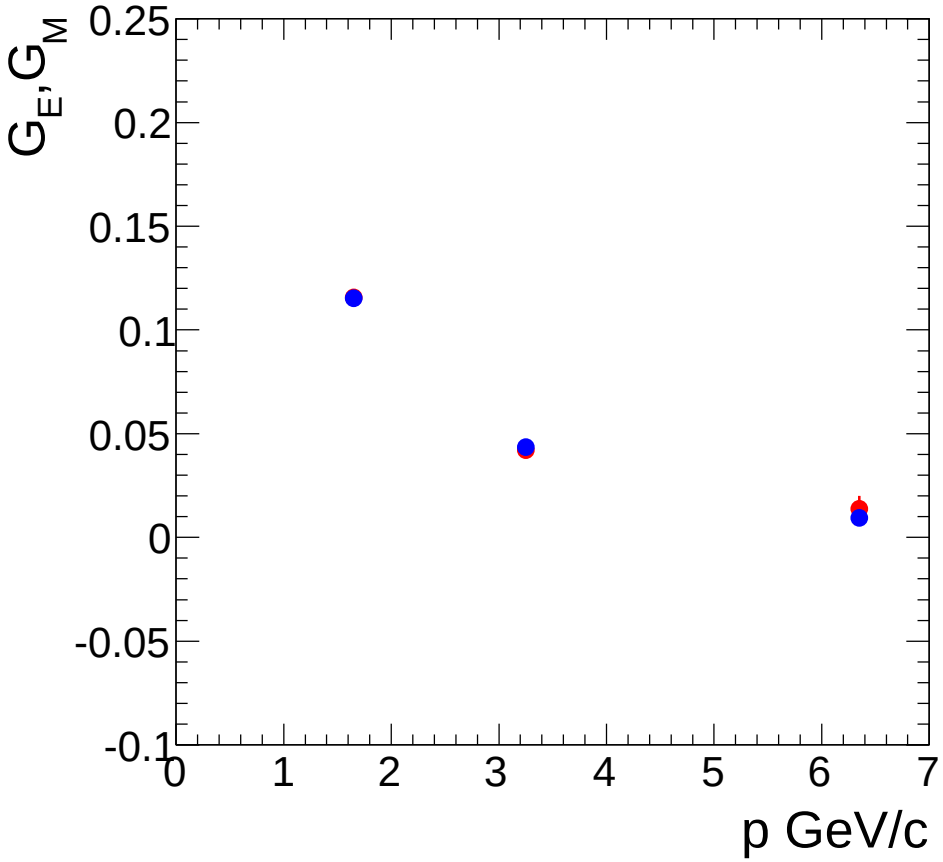
$cos(\theta_{CM})$ distribution for $G_E/G_M = 1$ [statistical errors only]

$p_{beam} = 1.7\,GeV/c$ $p_{beam} = 3.3\,GeV/c$ $p_{beam} = 6.4\,GeV/c$



Individual G_E and G_M extracted from the fit [statistical errors only]

$$G_E/G_M = 1$$

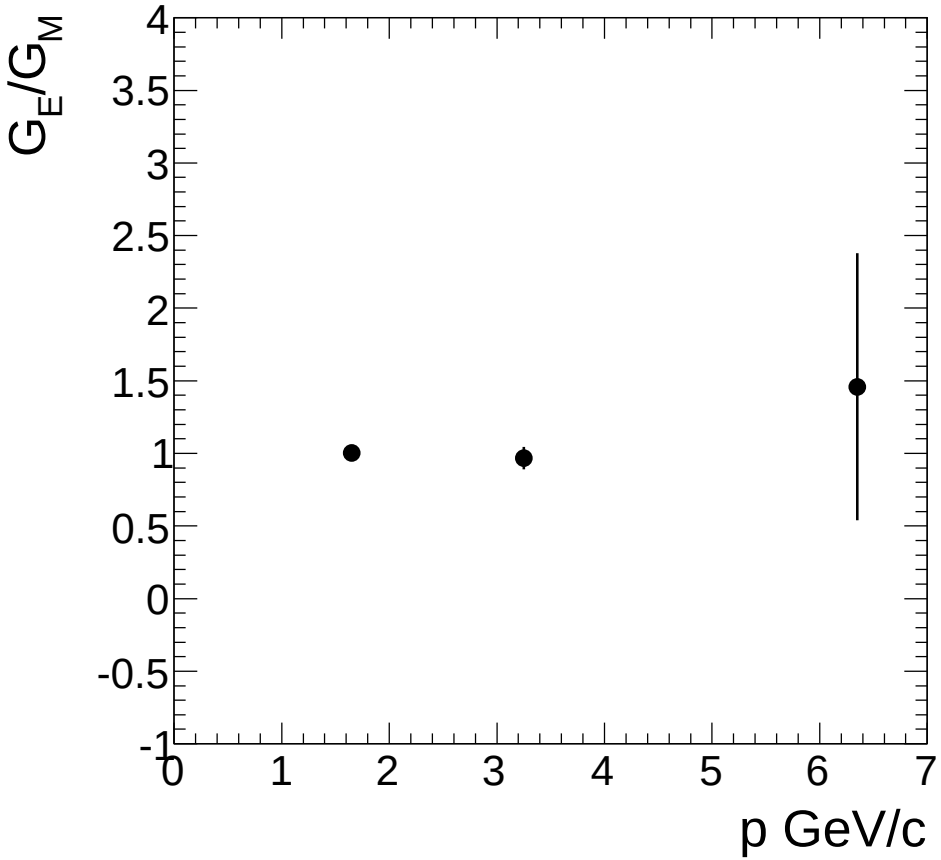


preliminary

- G_E
- G_M

G_E/G_M ratio extracted from the fit [statistical errors only]

$$G_E/G_M = 1$$

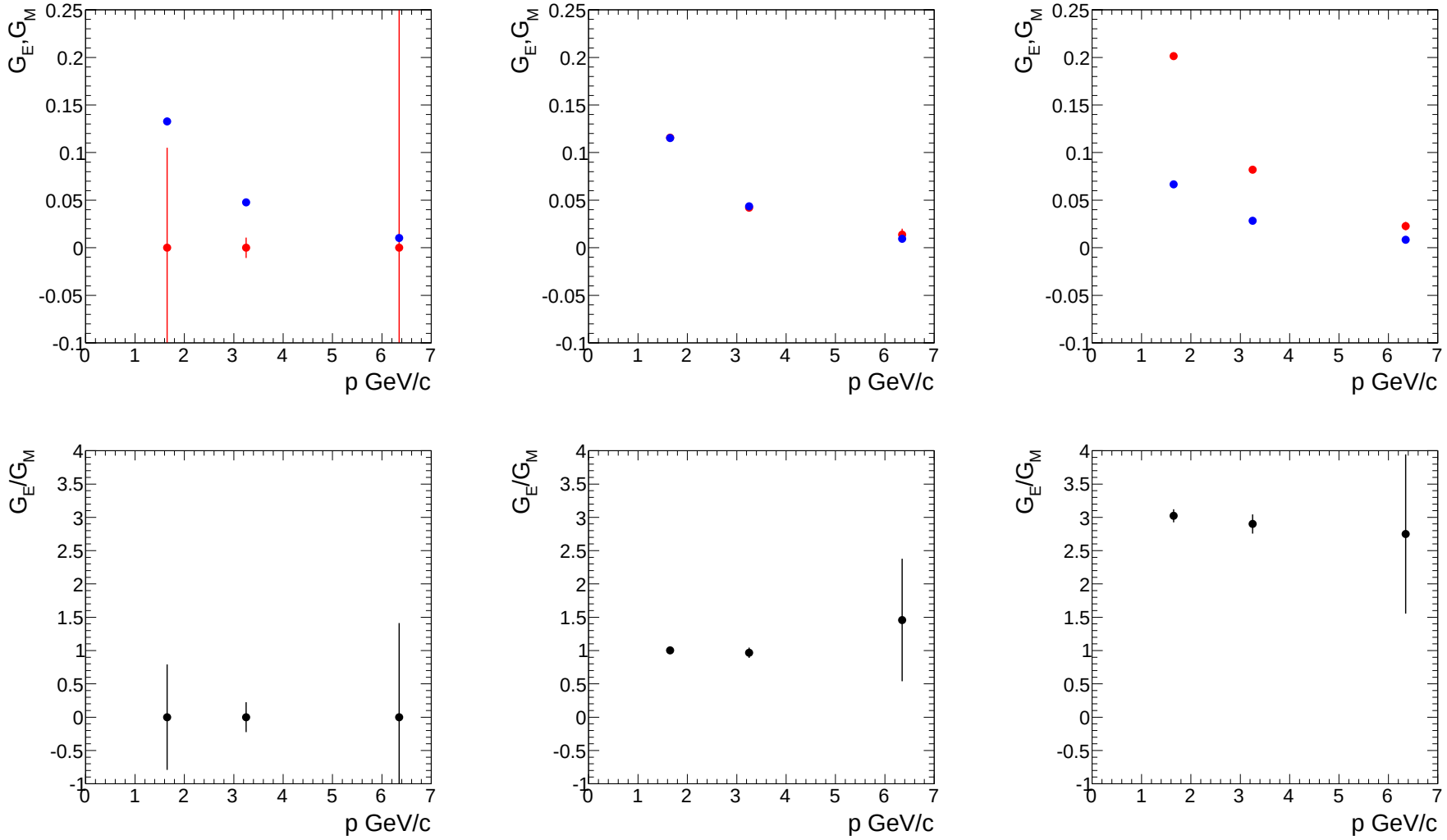


preliminary

- G_E/G_M

Extracted values of G_E, G_M and G_E/G_M [statistical errors only]

$G_E/G_M = 0$ $G_E/G_M = 1$ $G_E/G_M = 3$



Conclusions

- Very promising preliminary results for G_E and G_M
- Smaller errors in comparison to other experiments
- Signal efficiency about $30 - 52\%$
- Background rejection factor about 10^7

$\bar{\text{P}}$ANDA related talks and posters

- Cristina Morales (HK 1.2)
- Yue Ma, Frank Maas (HK 8.7)
- Bertalan Feher (HK 8.8)
- Maria Carmen Mora Espi (HK 8.9)
- Zimmermann Iris (HK 45.3)
- Manuel ZambranaHK (HK 54.7)