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

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Trento
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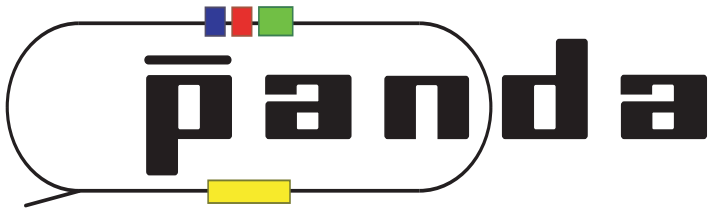
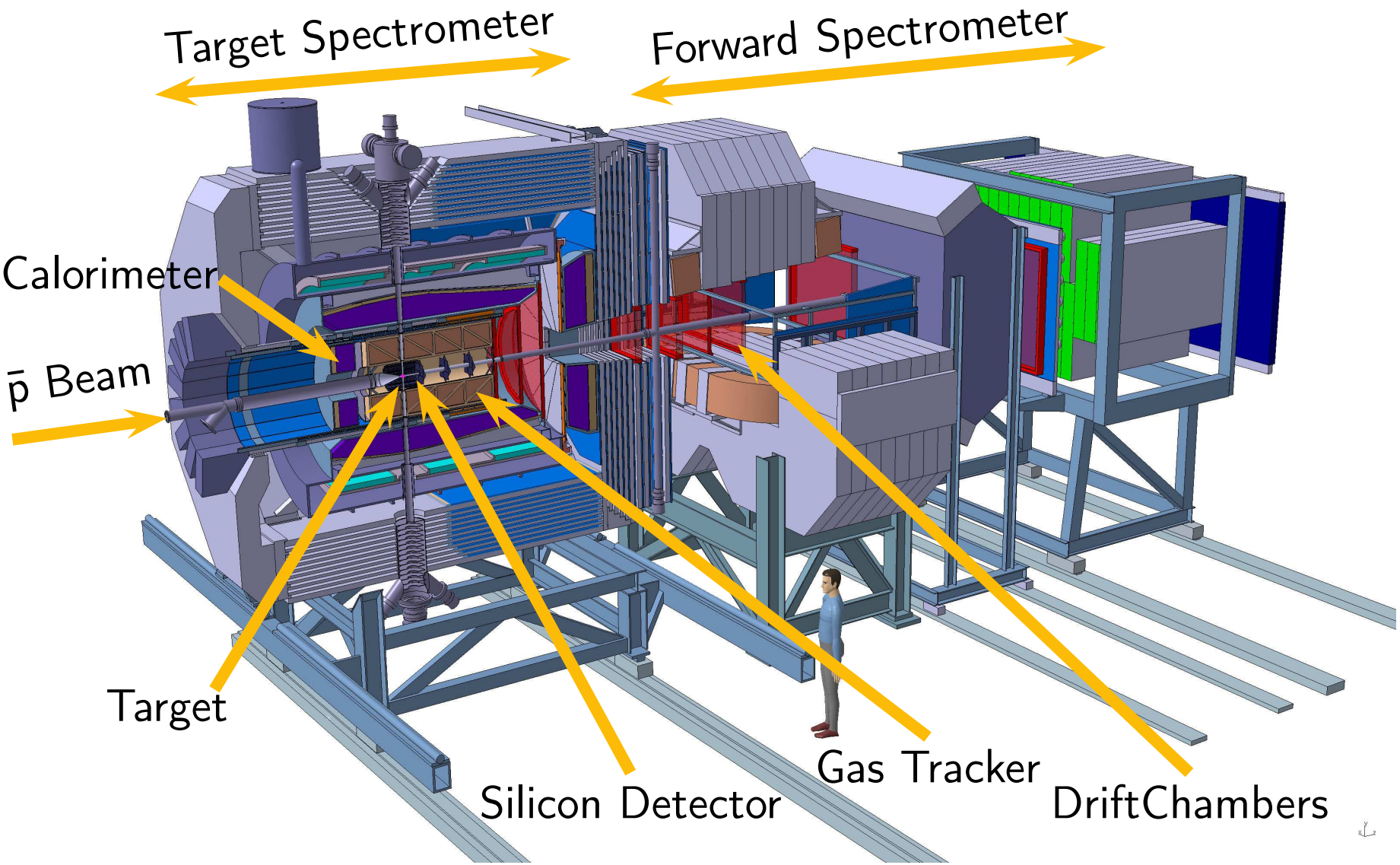


JOHANNES GUTENBERG
UNIVERSITÄT MAINZ

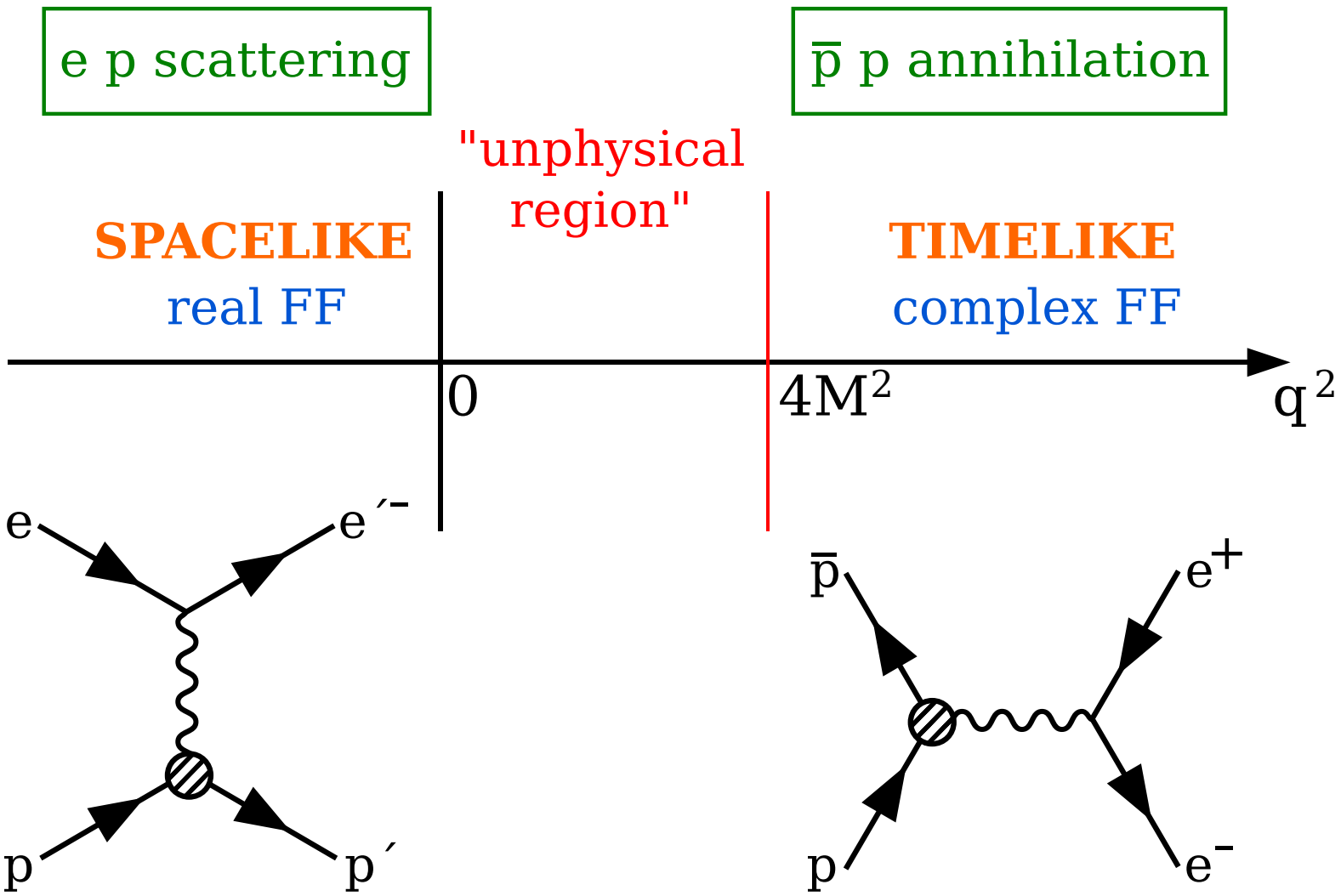
Helmholtz-Institut Mainz

Outline

P̄ANDA detector



Nucleon structure: form factors measurement



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
  - data in the low energy range
    Eisenhandler et. al., Nucl. Phy. B96 (1975) 109
  - data in the high energy range
    J. Van de Wiele and S. Ong: Eur. Phy. J. A46(2010) 291

Expected number of events for $\bar{p}p \to e^+e^-$

$p_{beam}[GeV/c]$	$s[GeV/c]^2$	N
1.7	5.4	$1.1 \cdot 10^6$
2.78	7.27	$1.4 \cdot 10^5$
3.3	8.21	$6.4 \cdot 10^4$
4.9	11.0	$9.1 \cdot 10^3$
5.9	12.9	$3.2 \cdot 10^3$
6.4	13.8	$2 \cdot 10^3$
7.9	16.7	580
10.9	22.3	81
13.4	27.9	18

Integrated luminosity $L = 2fb^{-1}$

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

Efficiency and suppresion studies with $\bar{\text{P}}$ANDAroot

	$\bar{p}p \to e^+e^-$	$\bar{p}p \to \pi^+\pi^-$
$p_{beam}[GeV/c]$	$G_E/G_M = 0, 1, 3$	
1.7	10^6	10^8
2.78	10^6	-
3.3	10^6	10^8
4.9	10^6	-
5.9	10^6	-
6.4	10^6	-
7.9	10^6	-
10.9	10^6	-
13.4	10^6	-

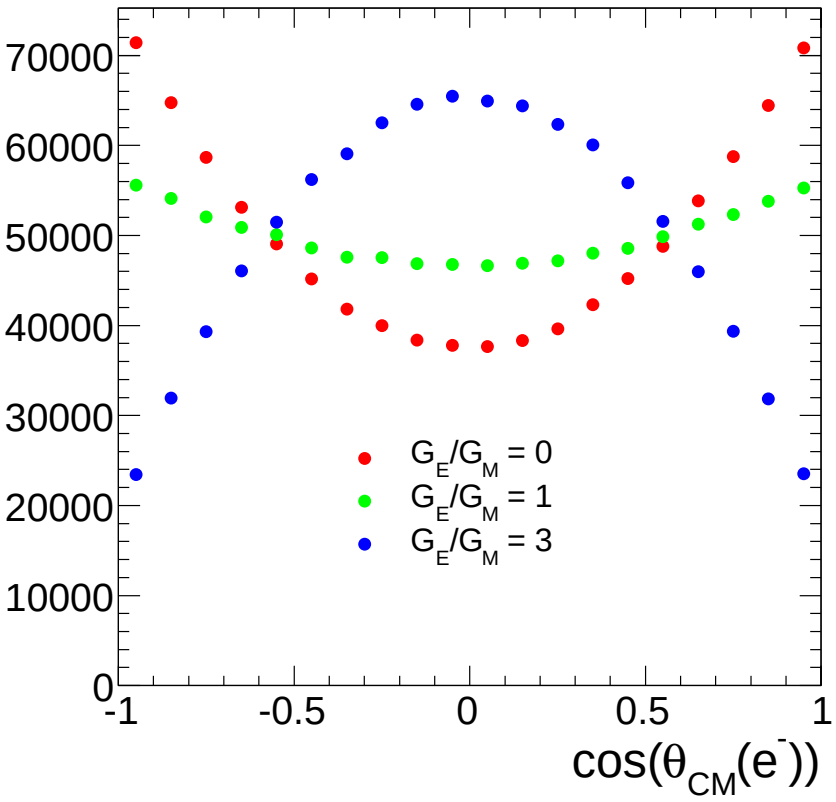
Simulation was performed **@HIMSTER (2000 CPUs)** cluster of **Helmholtz-Institut Mainz**

$\bar{\text{P}}$ANDAroot

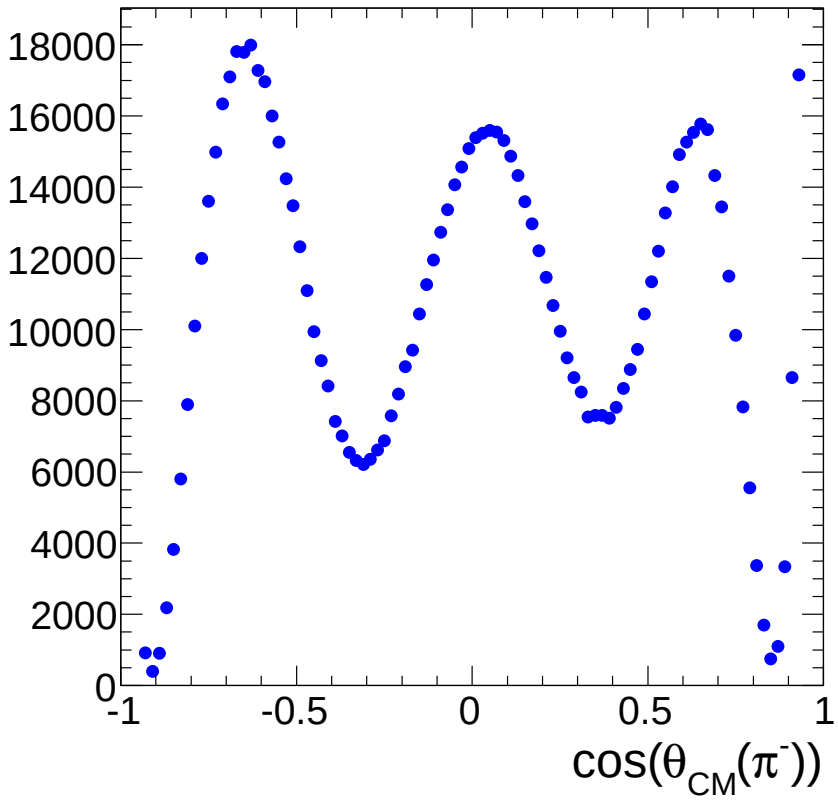
- Official $\bar{\text{P}}$ANDA software framework
- Improved detector geometry including dead material
- Realistic reconstruction and tracking
- Includes PHOTOS for radiative corrections

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

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



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

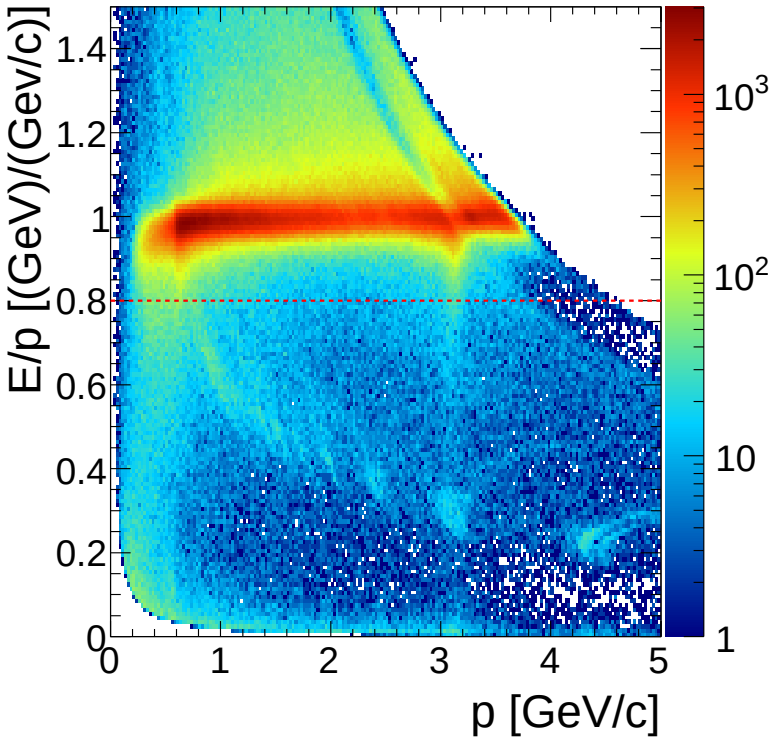


Selection criteria

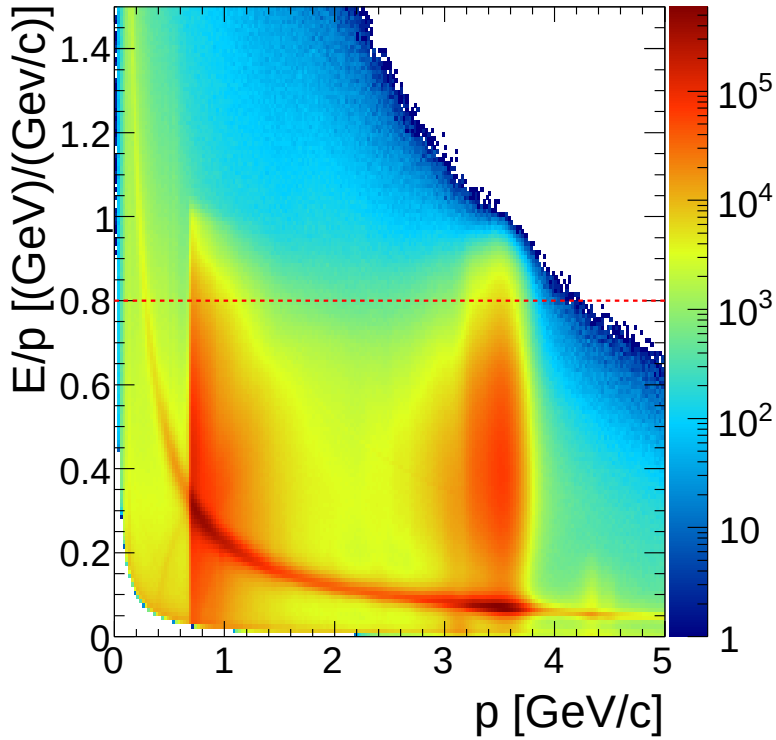
- Particle identification probabilities
- The event must have exactly one positive and one negative particle
- No muon detector
- E/p
- dE/dx_{STT}
- Common vertex
- Energy and momentum conservation
- EMC cluster size
- θ and ϕ in CMS

E/p vs p for $p_{beam} = 3.3[GeV/c]$

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

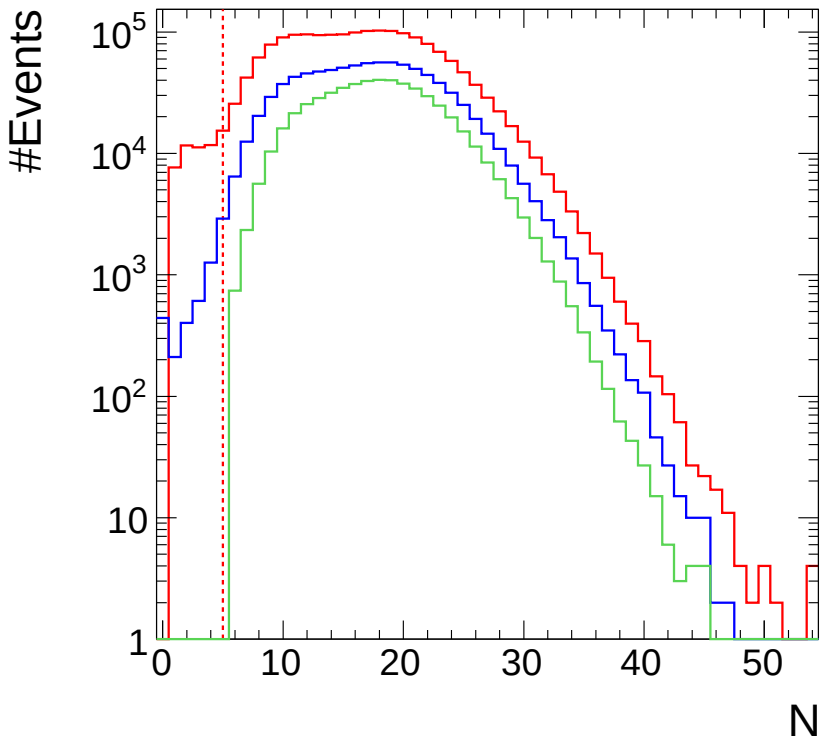


$\bar{p}p \to \pi^+\pi^-$

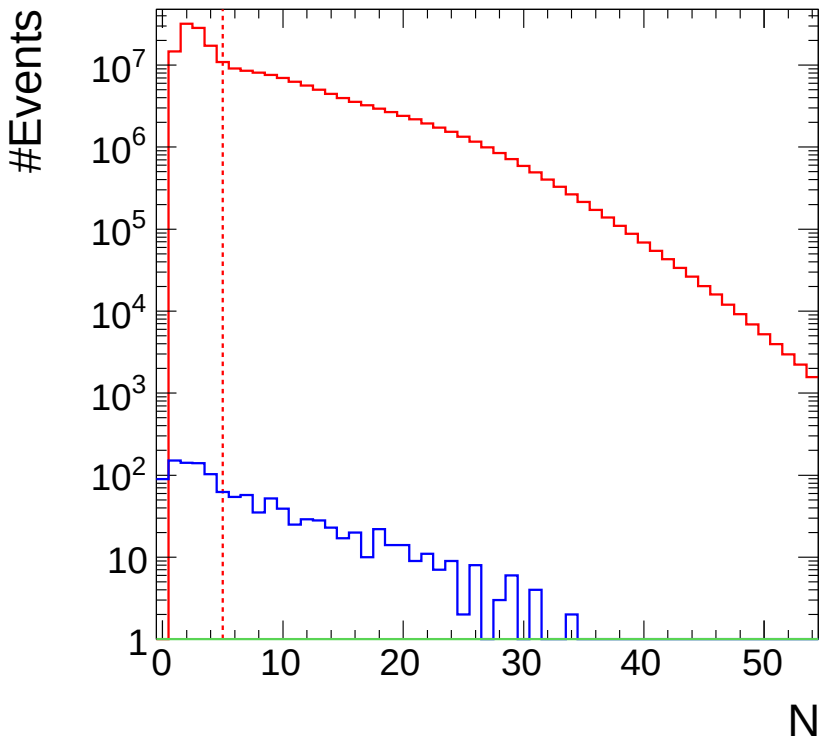


EMC cluster size for $p_{beam} = 3.3[GeV/c]$

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



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



Red all events **Blue** intermediate stage **Green** after all cuts

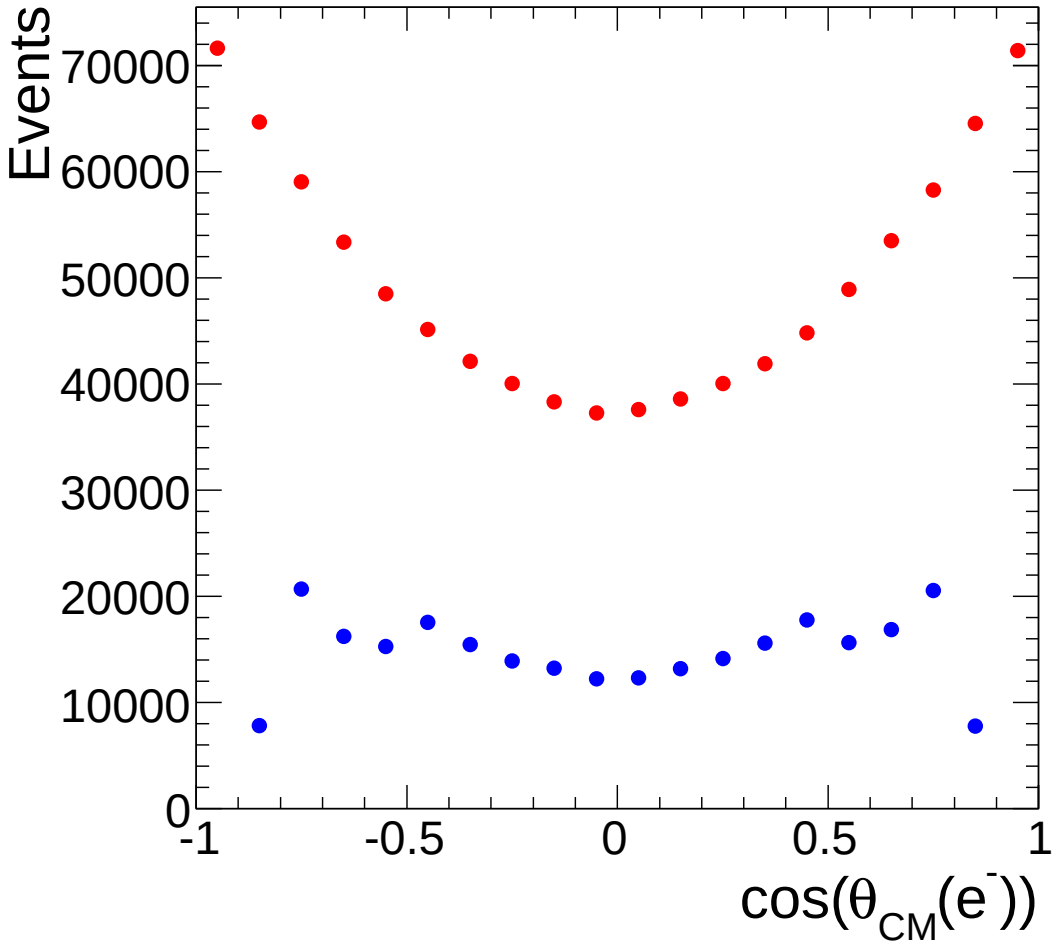
Efficiency for e^+e^- and suppresion of $\pi^+\pi^-$

	$e^+e^-(10^6)$			$\pi^+\pi^-(10^8)$
$p_{beam}[GeV/c]$	$G_E/G_M = 0, 1, 3$			–
1.7	32.1%	33.6%	37.0%	0.0%
2.78	28.4%	26.8	31.8	–
3.3	26.6%	28.8%	31.1%	0.0%
4.9	21.55%	21.9	25.4	–
5.9	18.5%	–	–	–
6.4	17.1%	17.8%	21.0%	–
7.9	12.7%	–	–	–
10.9	7.4%	–	–	–
13.4	4.8%	–	–	–

Angular distribution for e^+e^-

$p_{beam} = 3.3[GeV/c]$, $G_E/G_M = 0$

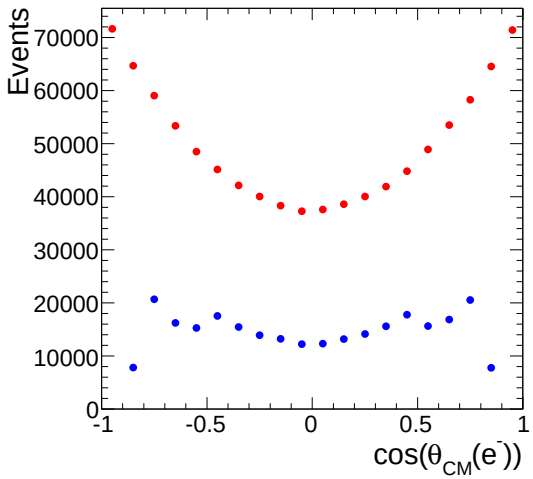
● Monte-Carlo ● Reconstructed



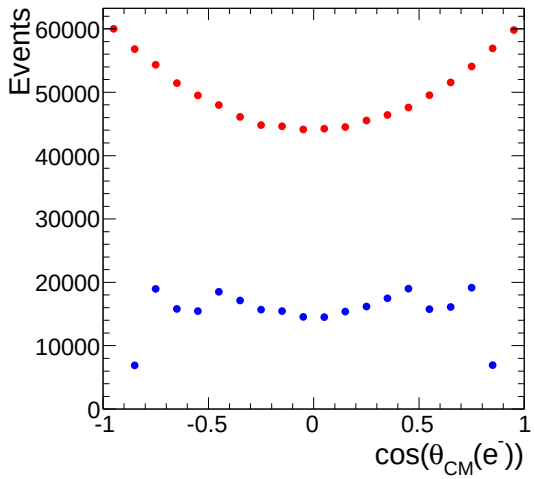
Angular distribution for e^+e^-

$p_{beam} = 3.3[GeV/c]$

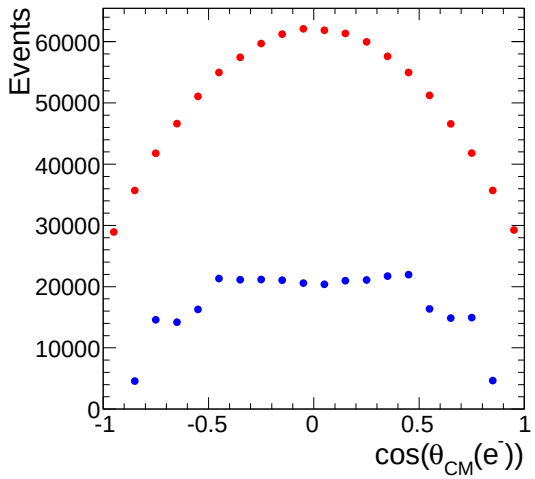
$G_E/G_M = 0$



$G_E/G_M = 1$



$G_E/G_M = 3$



● Monte-Carlo ● Reconstructed

G_E and G_M extraction

1. Efficiency correction
   - Sample with expected number of events
   - Independent sample for the efficiency correction
2. Angular distribution fit
3. Extraction of G_E and G_M from the fit function

Zichichi cross section

Fit function for G_E and G_M extraction

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

A. Zichichi et. al., Nuovo Cimento XXIV, 170 (1962)
Input into the fit tunction:

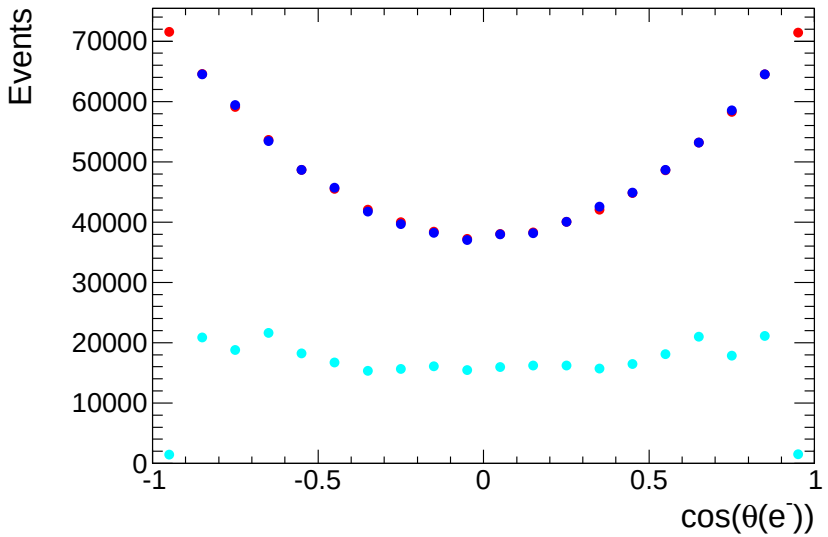
$$|G_M| = \frac{22.5}{(1+q^2/0.71)^2(1+q^2/3.6)}$$

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

G_E, G_M extraction for $G_E/G_M = 0$

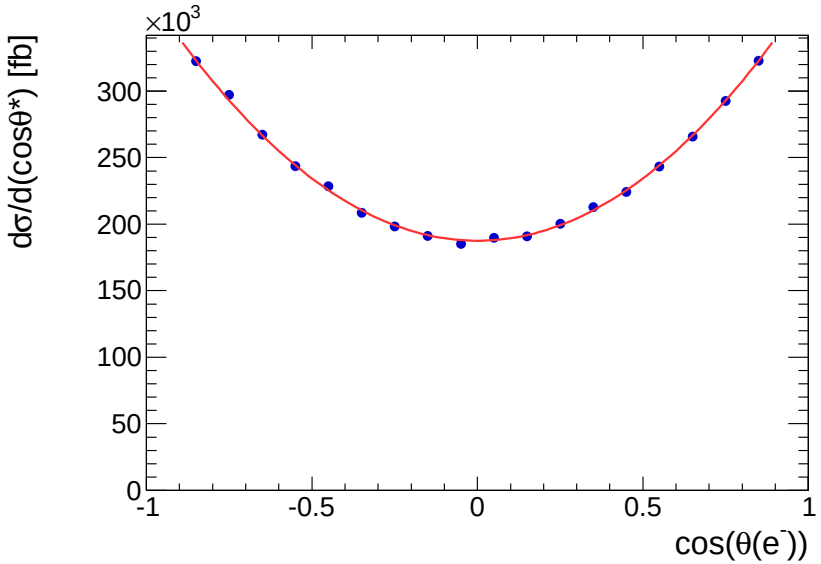
$$p_{beam} = 1.7[GeV/c],\ N = 1.1 \cdot 10^6$$

Efficiency correction



- Monte-carlo
- Reconstructed
- Corrected

Form-factors extraction



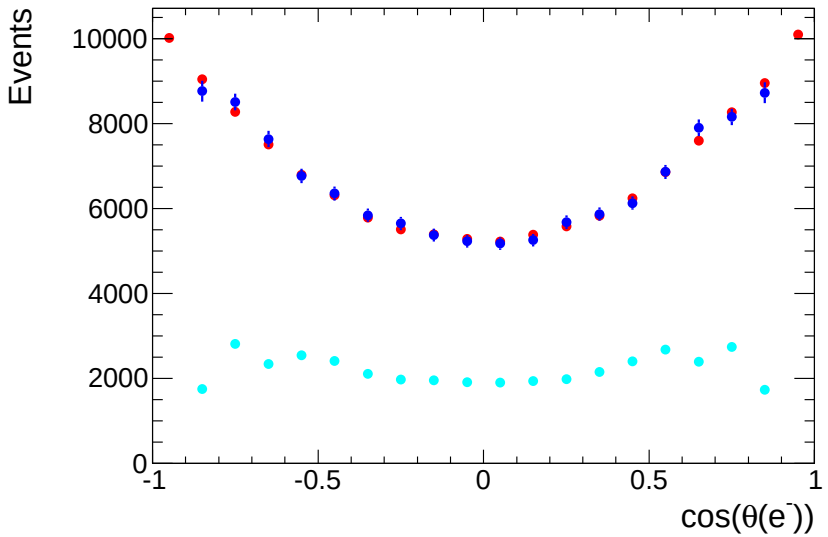
- Cross-section
- Fit

Efficiency determind from independent simulation sample

G_E, G_M extraction for $G_E/G_M = 0$

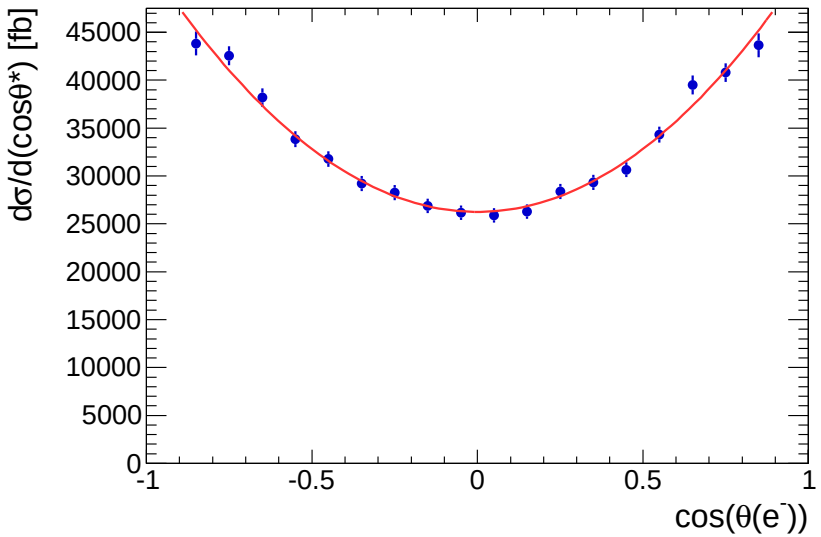
$$p_{beam} = 2.78[GeV/c],\ N = 1.4 \cdot 10^5$$

Efficiency correction



- Monte-carlo
- Reconstructed
- Corrected

Form-factors extraction



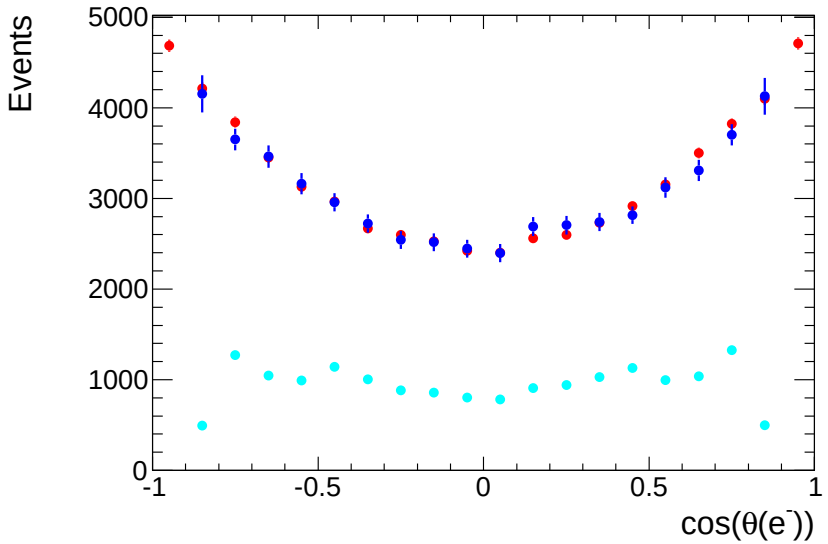
- Cross-section
- Fit

Efficiency determind from independent simulation sample

G_E, G_M extraction for $G_E/G_M = 0$

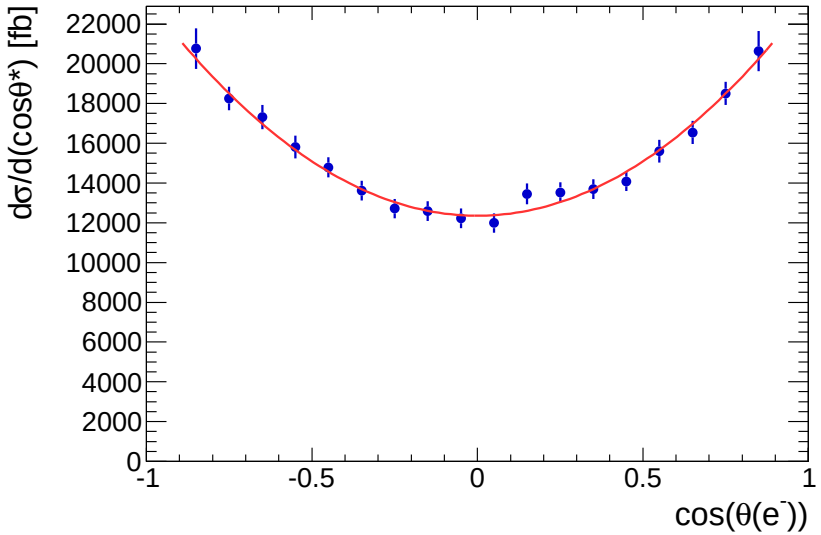
$$p_{beam} = 3.3[GeV/c],\ N = 6.4 \cdot 10^4$$

Efficiency correction



- Monte-carlo
- Reconstructed
- Corrected

Form-factors extraction



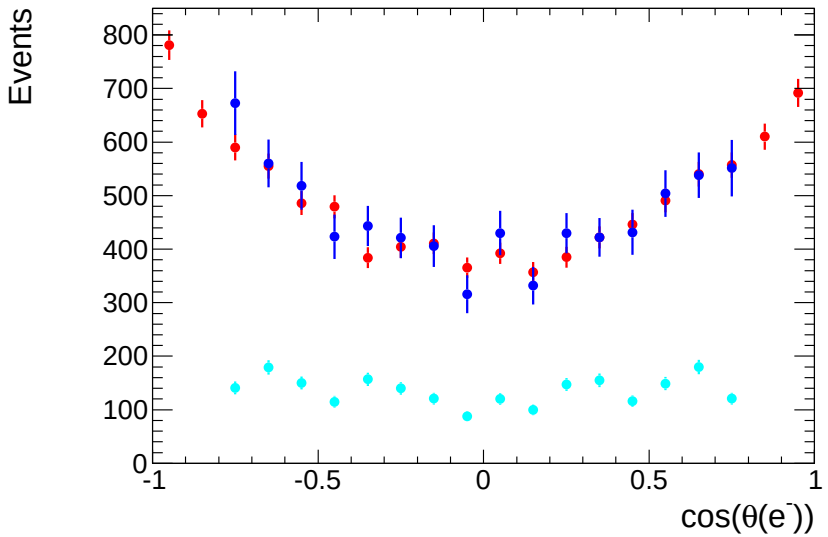
- Cross-section
- Fit

Efficiency determind from independent simulation sample

G_E, G_M extraction for $G_E/G_M = 0$

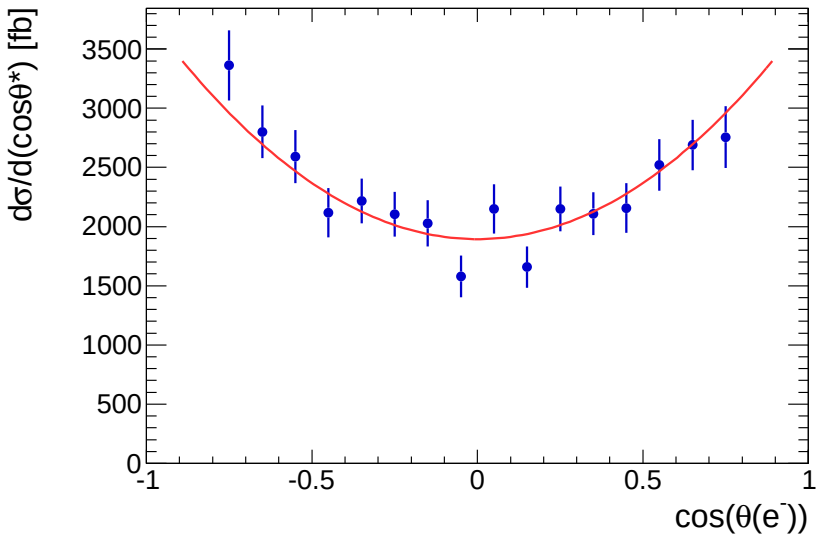
$$p_{beam} = 4.9[GeV/c],\ N = 9.1 \cdot 10^3$$

Efficiency correction



- Monte-carlo
- Reconstructed
- Corrected

Form-factors extraction



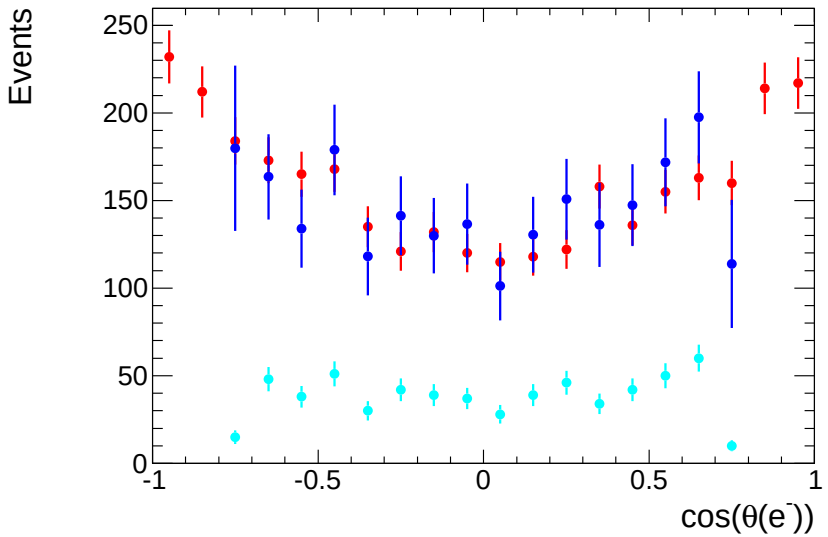
- Cross-section
- Fit

Efficiency determind from independent simulation sample

G_E, G_M extraction for $G_E/G_M = 0$

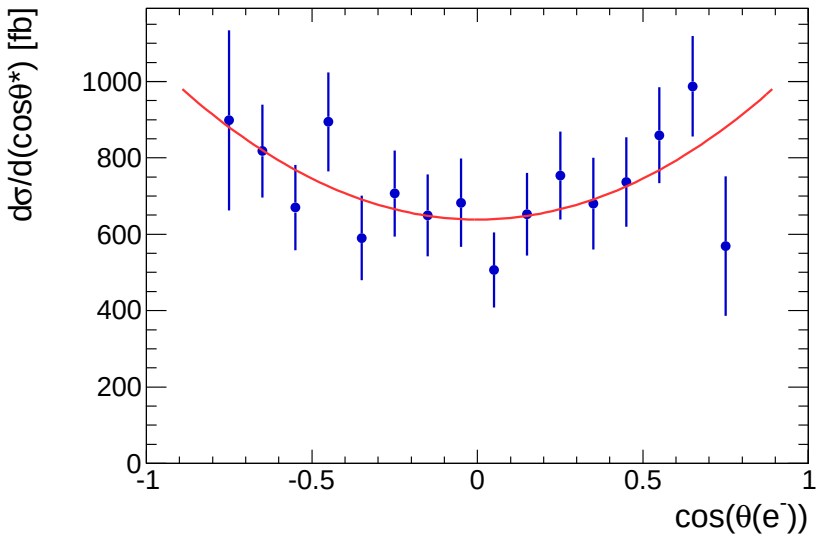
$$p_{beam} = 5.9[GeV/c],\ N = 3.2 \cdot 10^3$$

Efficiency correction



- Monte-carlo
- Reconstructed
- Corrected

Form-factors extraction



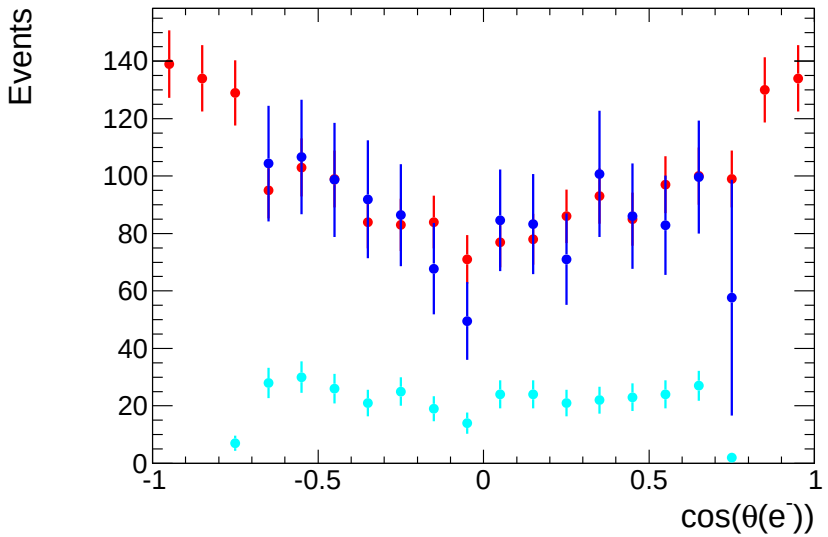
- Cross-section
- Fit

Efficiency determind from independent simulation sample

G_E, G_M extraction for $G_E/G_M = 0$

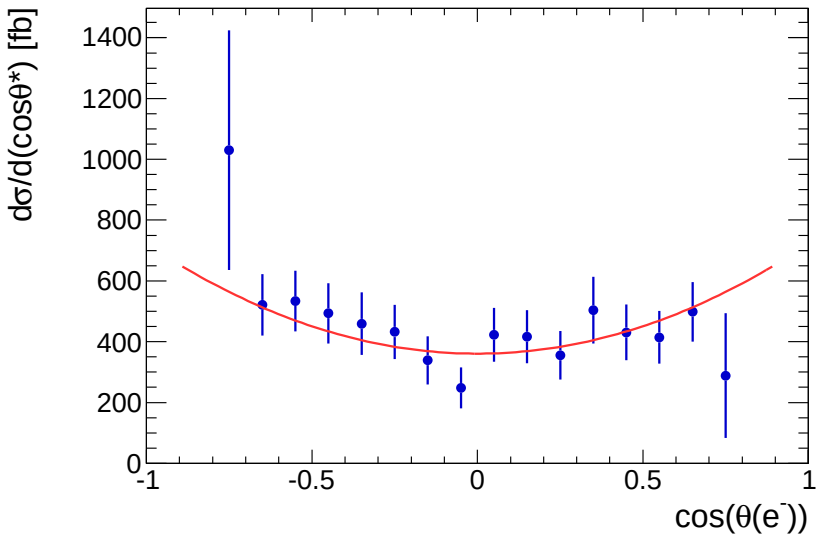
$$p_{beam} = 6.4[GeV/c],\ N = 2 \cdot 10^3$$

Efficiency correction



- Monte-carlo
- Reconstructed
- Corrected

Form-factors extraction



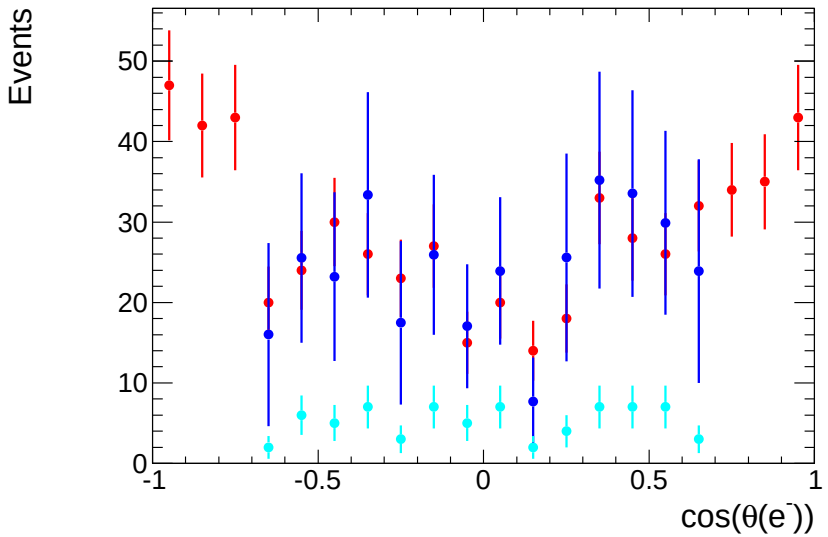
- Cross-section
- Fit

Efficiency determind from independent simulation sample

G_E, G_M extraction for $G_E/G_M = 0$

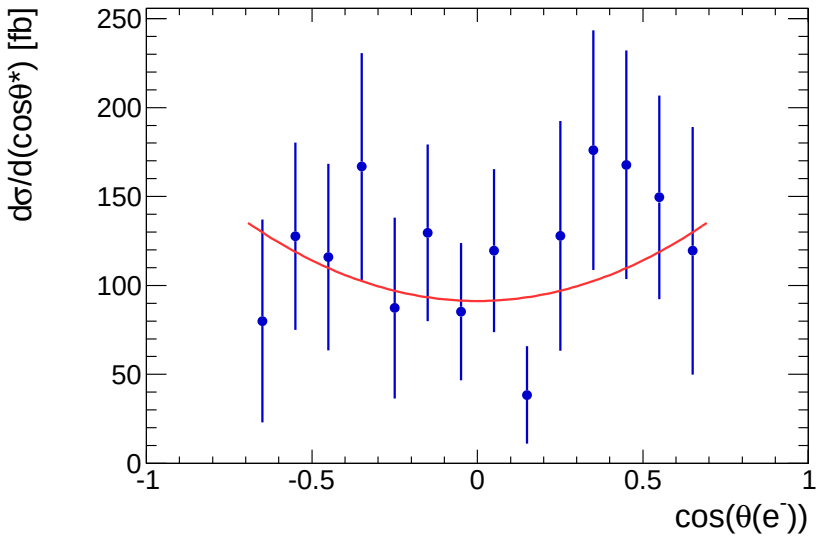
$$p_{beam} = 7.9[GeV/c],\ N = 580$$

Efficiency correction



- Monte-carlo
- Reconstructed
- Corrected

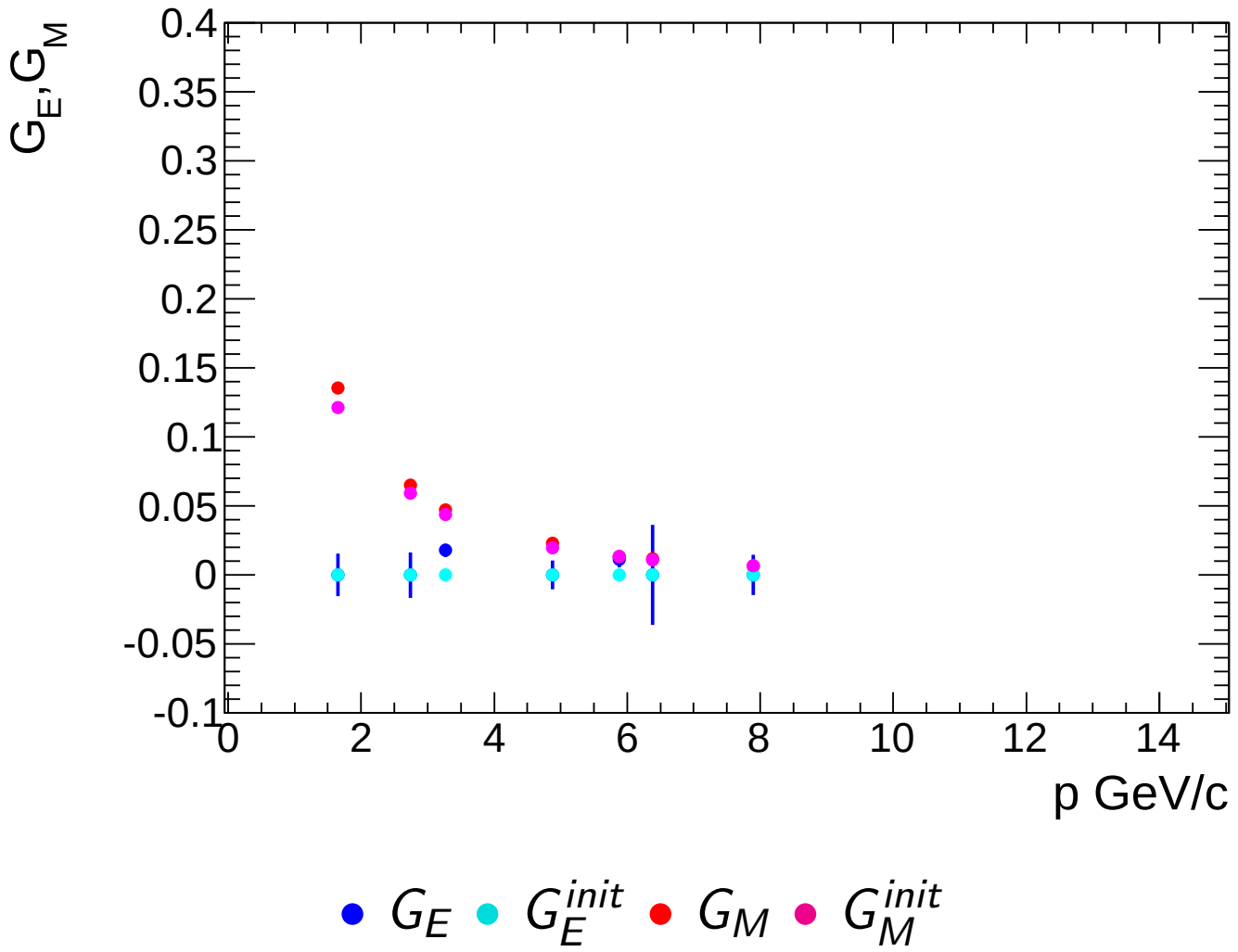
Form-factors extraction



- Cross-section
- Fit

Efficiency determind from independent simulation sample

G_E, G_M extraction for $G_E/G_M = 0$

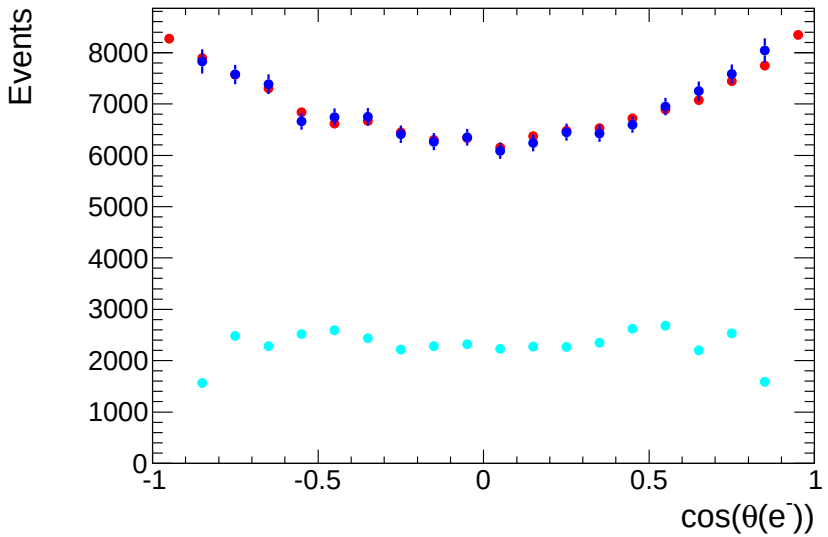


errors not physical yet; $|G_E|^2 > 0$

G_E, G_M extraction for $G_E/G_M = 1$

$$p_{beam} = 2.78[GeV/c],\ N = 1.4 \cdot 10^5$$

Efficiency correction



- Monte-carlo
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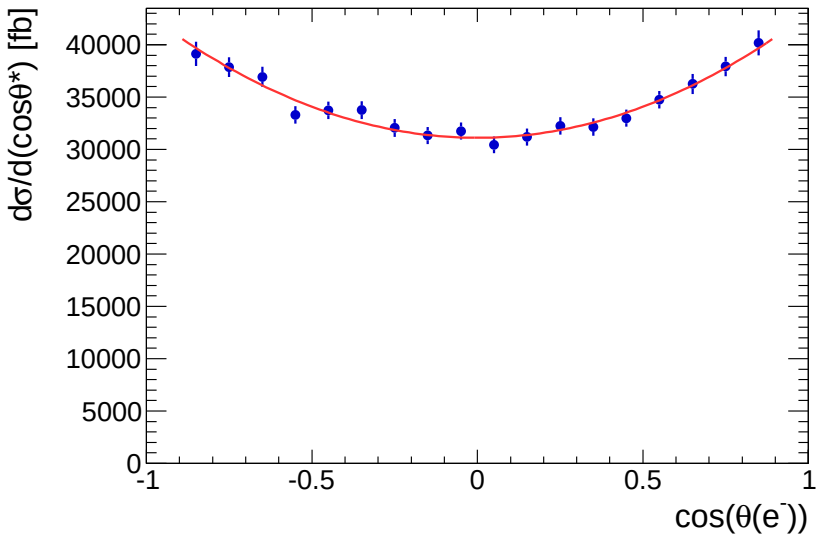
- Corrected

Form-factors extraction



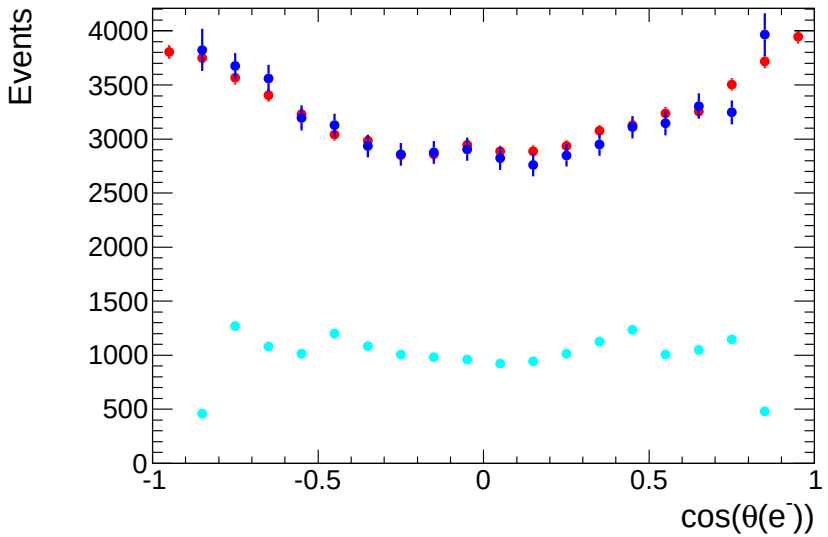
- Cross-section
- Fit

Efficiency determind from independent simulation sample

G_E, G_M extraction for $G_E/G_M = 1$

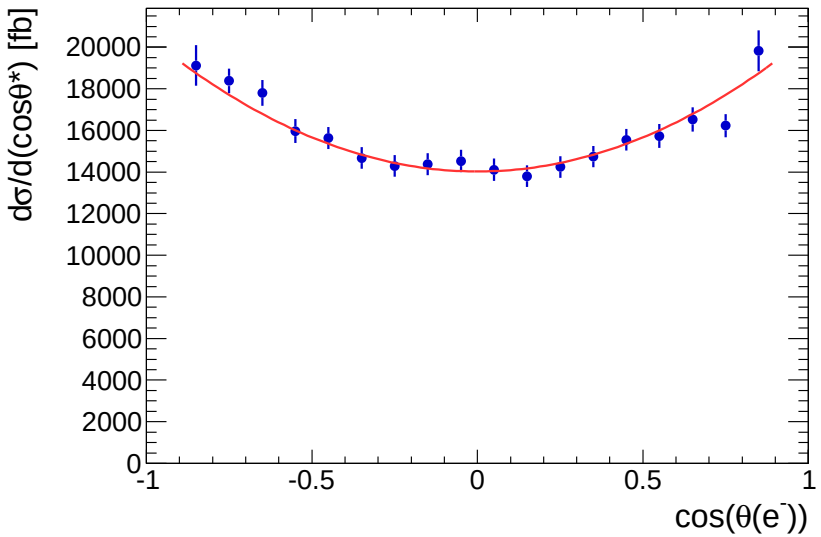
$$p_{beam} = 3.3[GeV/c],\ N = 6.4 \cdot 10^4$$

Efficiency correction



- Monte-carlo
- Reconstructed
- Corrected

Form-factors extraction



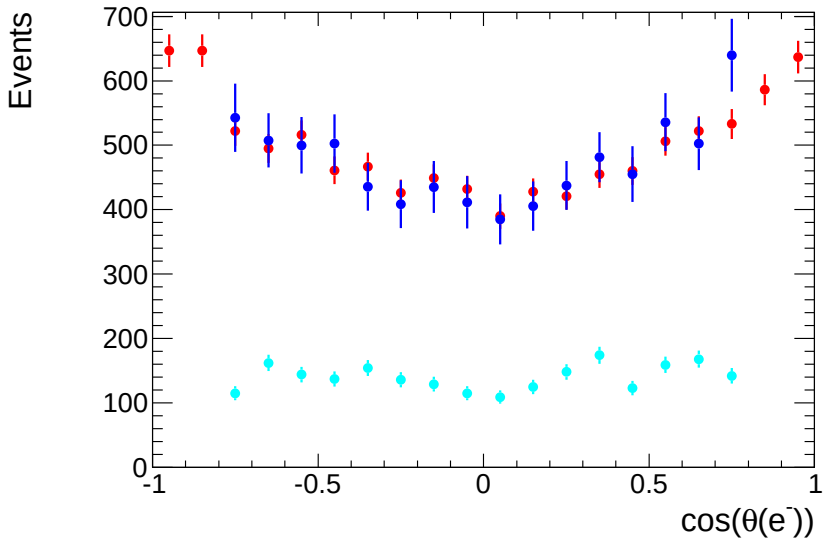
- Cross-section
- Fit

Efficiency determind from independent simulation sample

G_E, G_M extraction for $G_E/G_M = 1$

$$p_{beam} = 4.9[GeV/c],\ N = 9.1 \cdot 10^3$$

Efficiency correction



- Monte-carlo
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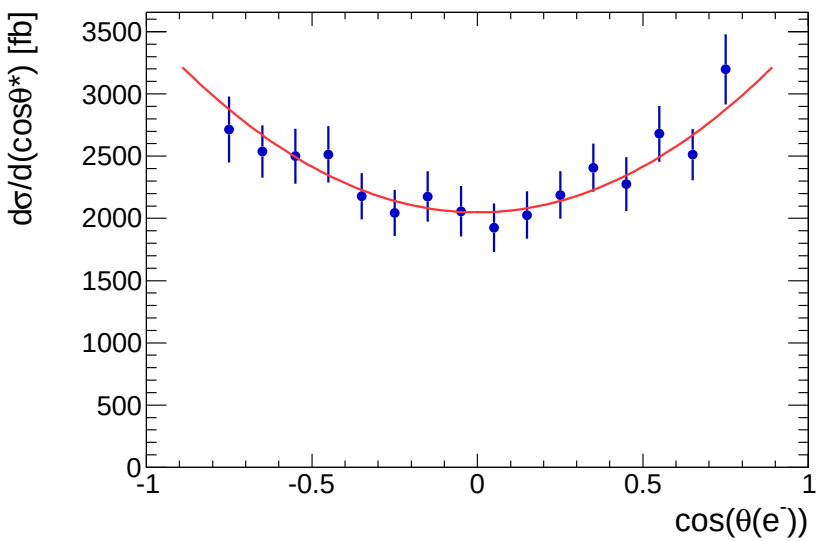
- Corrected

Form-factors extraction



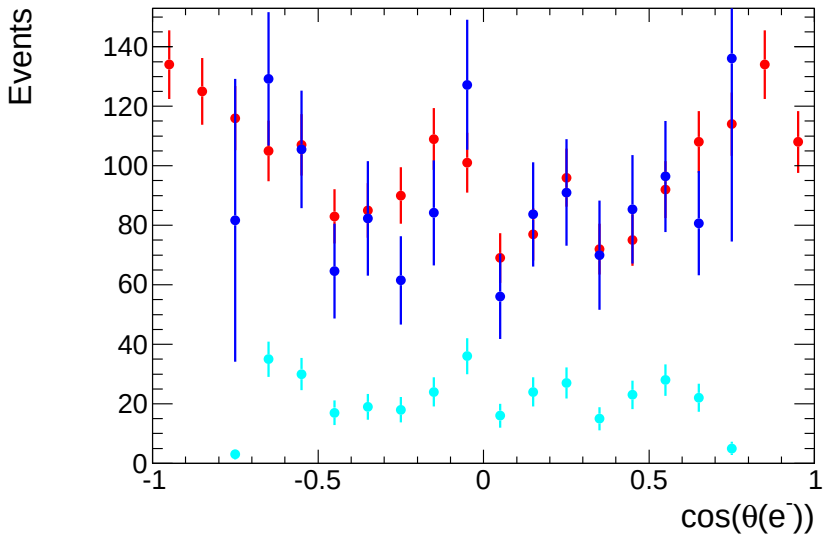
- Cross-section
- Fit

Efficiency determind from independent simulation sample

G_E, G_M extraction for $G_E/G_M = 1$

$$p_{beam} = 6.4[GeV/c],\ N = 2 \cdot 10^3$$

Efficiency correction



- Monte-carlo
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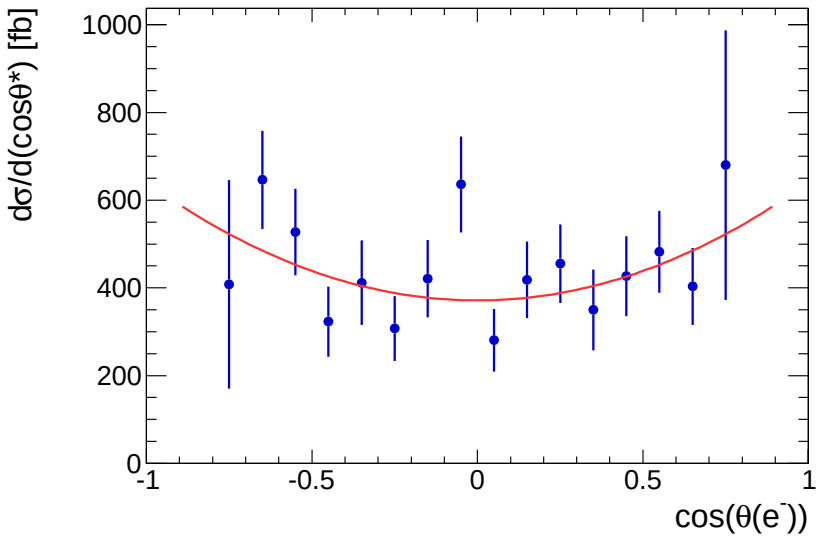
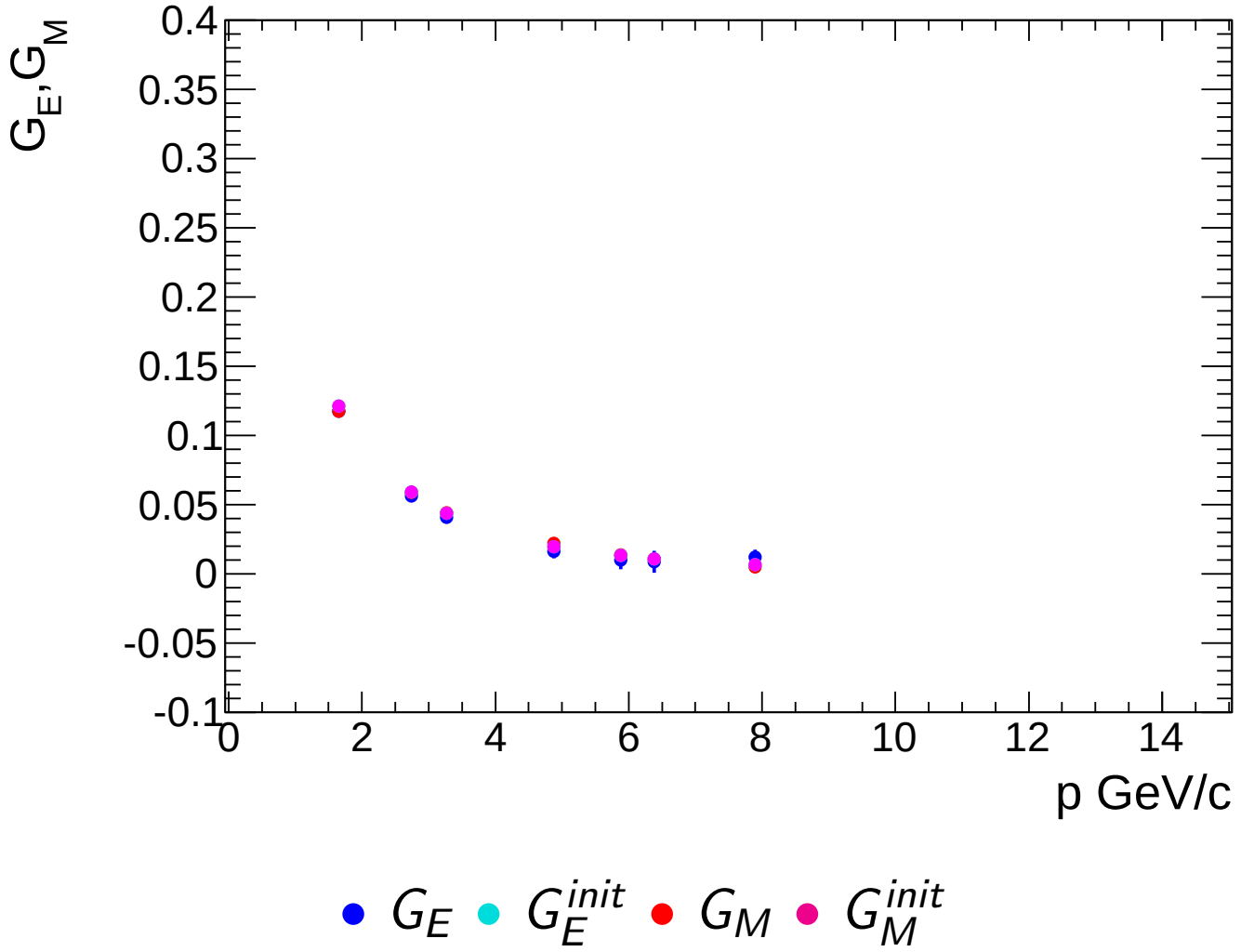
Form-factors extraction



- Cross-section
- Fit

Efficiency determind from independent simulation sample

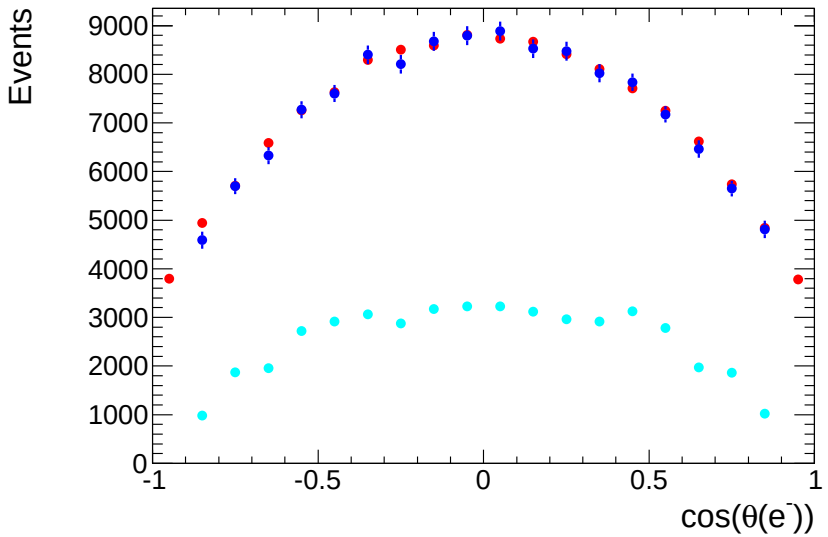
G_E, G_M extraction for $G_E/G_M = 1$



G_E, G_M extraction for $G_E/G_M = 1$

$$p_{beam} = 2.78[GeV/c],\ N = 1.4 \cdot 10^5$$

Efficiency correction



- Monte-carlo
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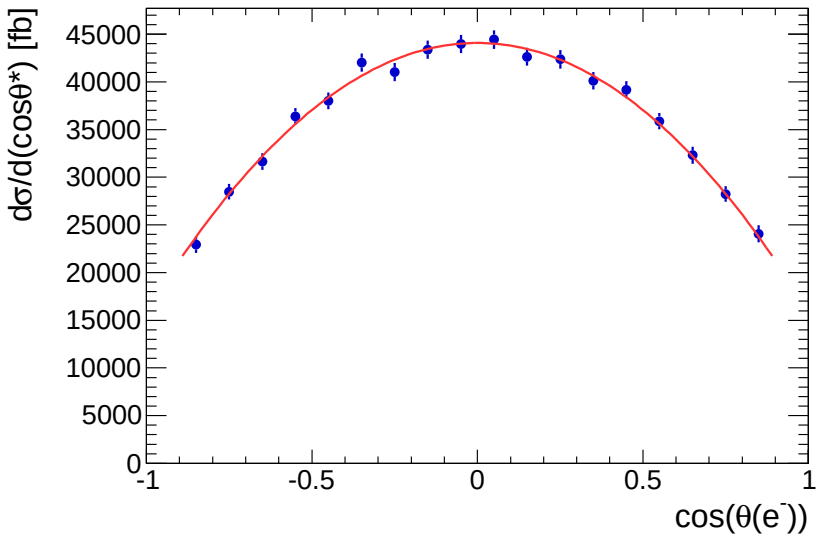
- Corrected

Form-factors extraction



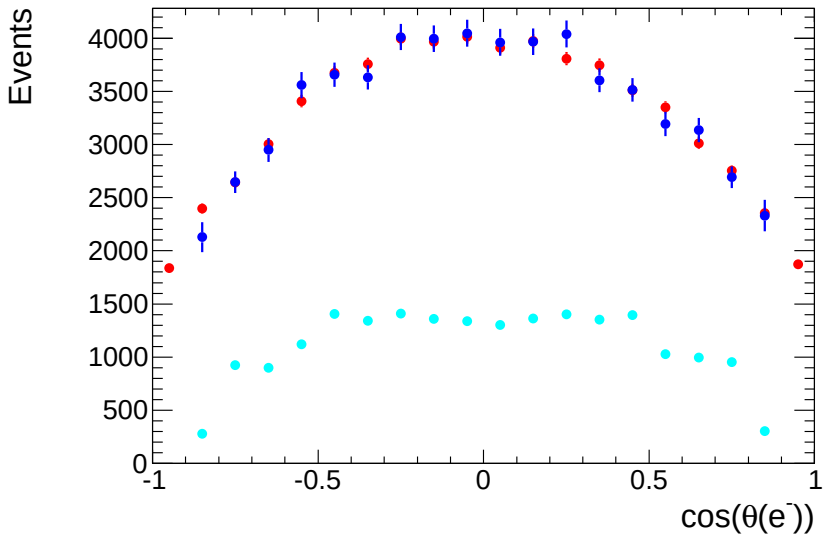
- Cross-section
- Fit

Efficiency determind from independent simulation sample

G_E, G_M extraction for $G_E/G_M = 3$

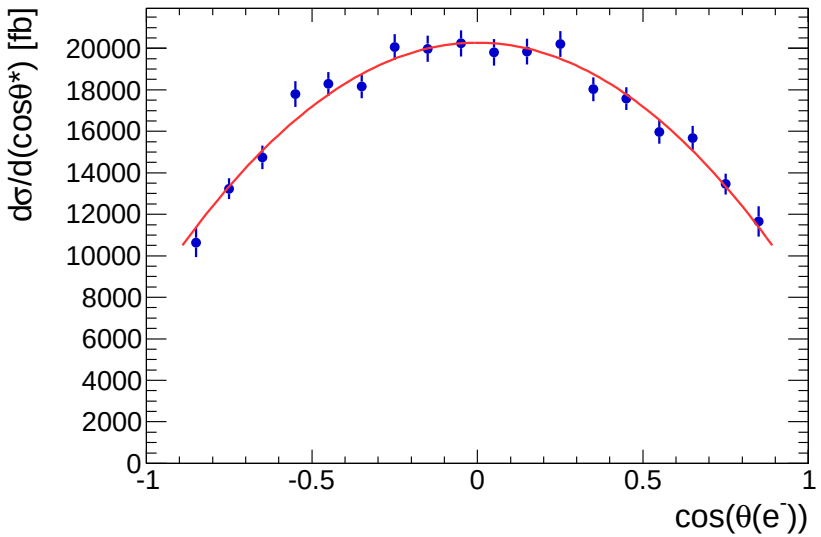
$$p_{beam} = 3.3[GeV/c],\ N = 6.4 \cdot 10^4$$

Efficiency correction



- Monte-carlo
- Reconstructed
- Corrected

Form-factors extraction



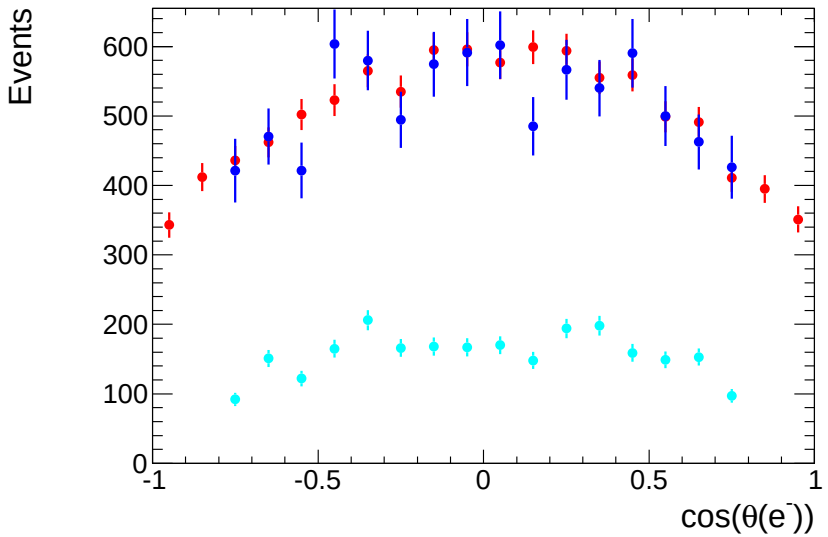
- Cross-section
- Fit

Efficiency determind from independent simulation sample

G_E, G_M extraction for $G_E/G_M = 3$

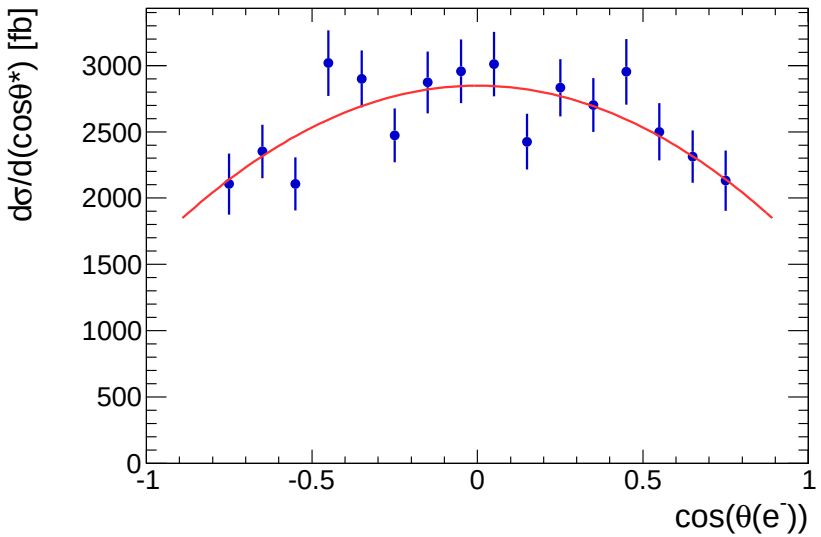
$$p_{beam} = 4.9[GeV/c],\ N = 9.1 \cdot 10^3$$

Efficiency correction



- Monte-carlo
- Reconstructed
- Corrected

Form-factors extraction



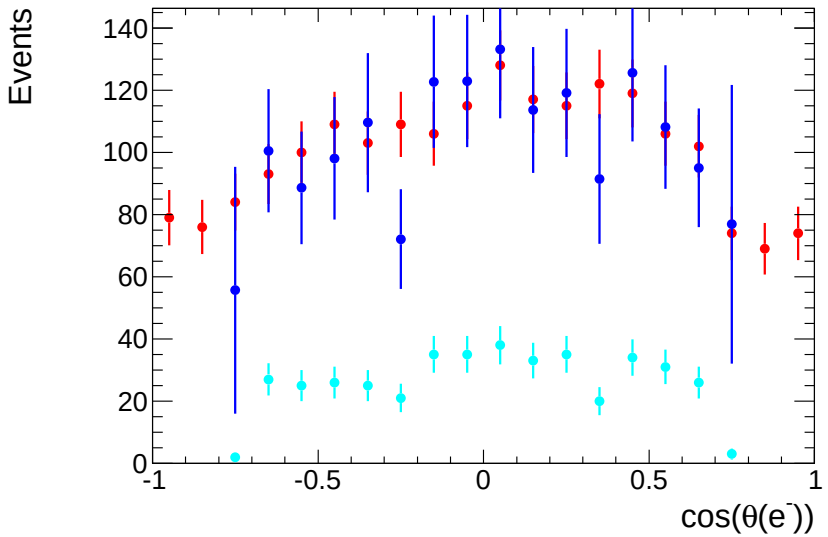
- Cross-section
- Fit

Efficiency determind from independent simulation sample

G_E, G_M extraction for $G_E/G_M = 3$

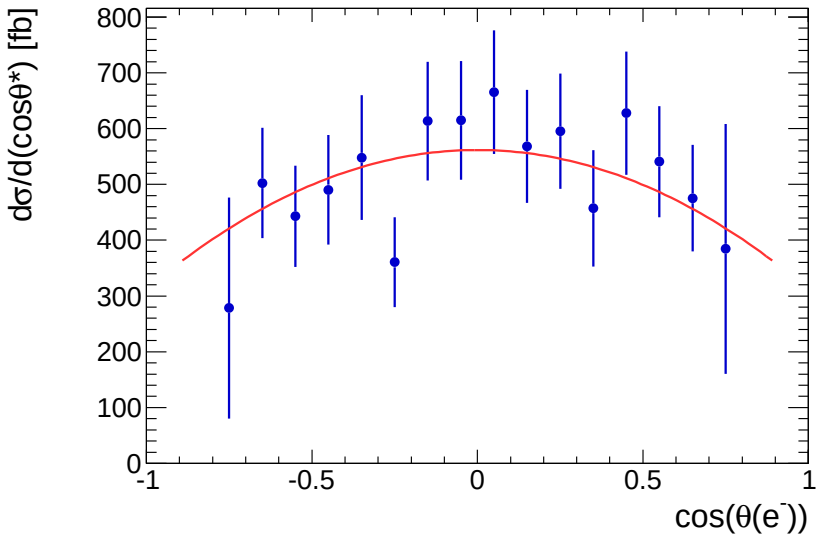
$$p_{beam} = 6.4[GeV/c],\ N = 2 \cdot 10^3$$

Efficiency correction



- Monte-carlo
- Reconstructed
- Corrected

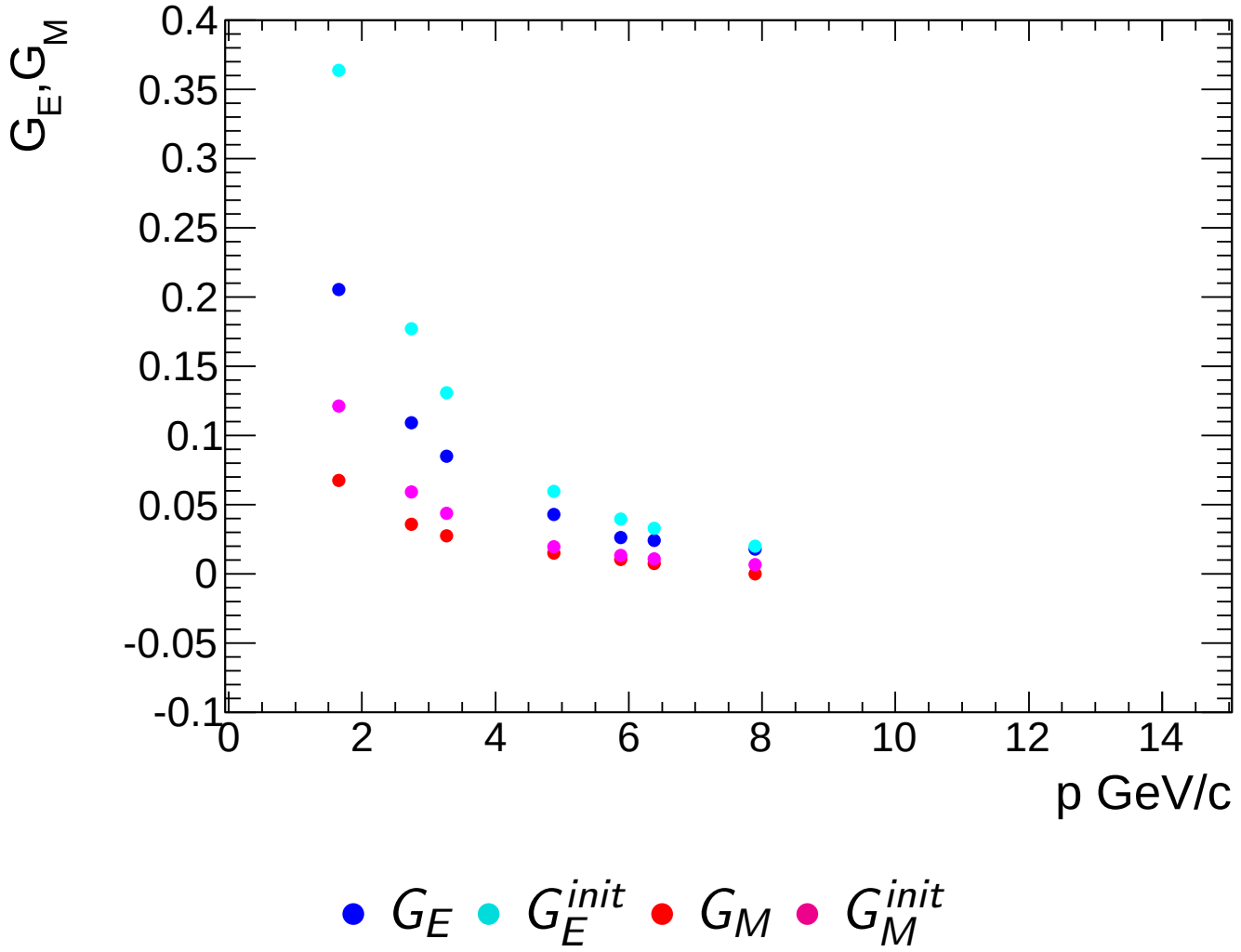
Form-factors extraction



- Cross-section
- Fit

Efficiency determind from independent simulation sample

G_E, G_M extraction for $G_E/G_M = 3$



G_E extraction

p_{beam}	G_E for $G_E/G_M = 0, 1, 3$		
1.7	$6.8E-11 \pm 0.015$	–	–
2.78	$8.2E-11 \pm 0.016$	$5.7E-2 \pm 0.002$	$1.1E-1 \pm 0.001$
3.3	$1.8E-2 \pm 0.005$	$4.0E-2 \pm 0.004$	$8.5E-2 \pm 0.001$
4.9	$6.4-11 \pm 0.011$	$1.6E-2 \pm 0.005$	$4.3E-2 \pm 0.002$
5.9	$1.2E-2 \pm 0.006$	–	–
6.4	$2.8E-10 \pm 0.036$	$8.6E-3 \pm 0.008$	$2.4E-2 \pm 0.003$
7.9	0 ± 0.015	–	–
10.9	–	–	–
13.4	–	–	–

G_M extraction

p_{beam}	G_M for $G_E/G_M = 0, 1, 3$		
1.7	0.1355 ± 0.0002	–	–
2.78	0.0648 ± 0.0002	0.0587 ± 0.0005	0.0357 ± 0.0007
3.3	0.0470 ± 0.0005	0.0442 ± 0.0006	0.0275 ± 0.0008
4.9	0.0231 ± 0.0002	0.0223 ± 0.0008	0.0139 ± 0.0011
5.9	0.0135 ± 0.0009	–	–
6.4	0.0112 ± 0.0003	0.0109 ± 0.0012	0.0076 ± 0.0016
7.9	0.0064 ± 0.0004	–	–
10.9	–	–	–
13.4	–	–	–

Conclusions

- Statistical errors are expected to be smaller in comparison to other experiments
- Signal efficiency sufficient for the extraction of G_E and G_M
- Background rejection of 10^8 factor achieved
- Measurement of proton time-like electromagnetic form factors with $\bar{\mathrm{P}}$ANDA precision data up to at least $p_{beam} = 13.4$