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Monte Carlo event generators for PANDA

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OUTLINE

- **Introduction**

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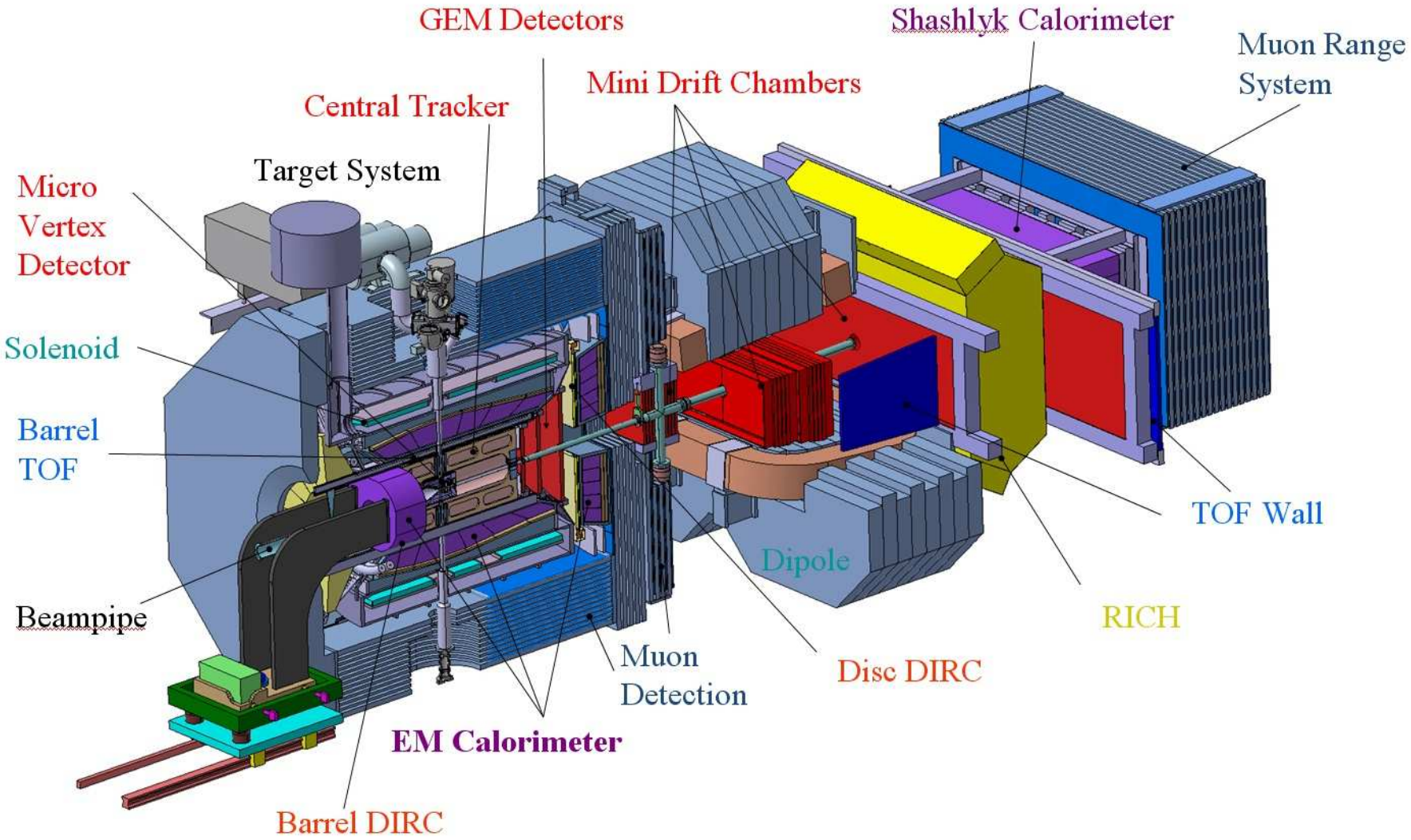
  $\rightarrow$ **the electromagnetic proton form factors**
  $\rightarrow$ **goals**

- **Generating distributions**

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

- **Summary and Conclusions**

The PANDA Experiment



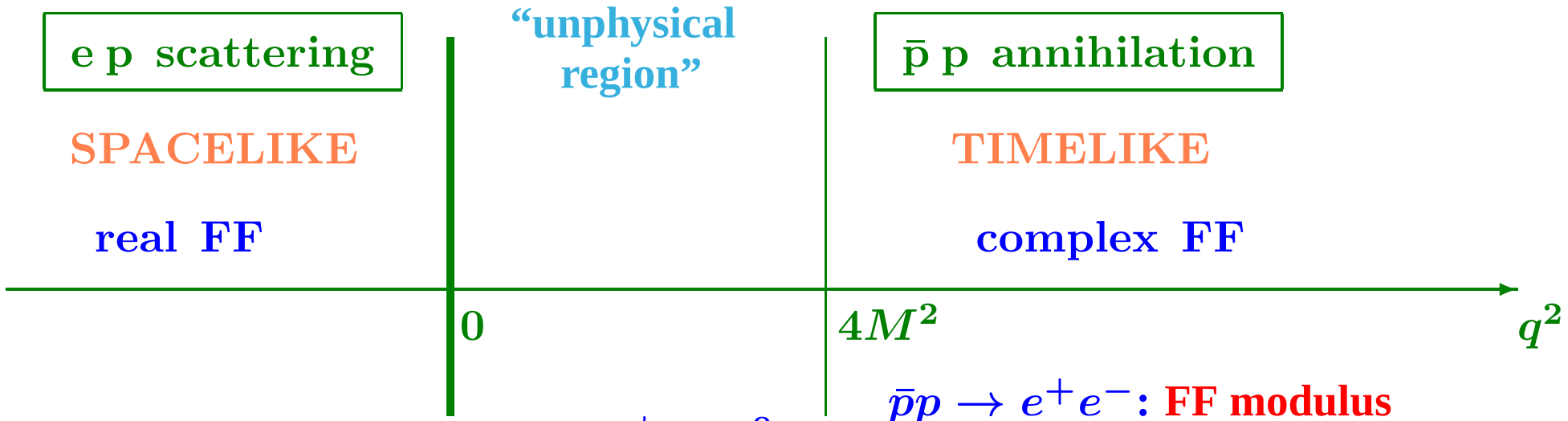
- $\bar{p}p$ **fixed target experiment at the FAIR facility (GSI, Darmstadt)**
  $1.5 < \mathrm{p}(\bar{\mathrm{p}}) < 15$ **GeV, data taking programmed for 2018**
- **high performance: high luminosity** $\mathrm{L} = 2 \cdot 10^{32}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$**, good tracking/PID**
- **wide physics program: hadron spectroscopy (up to c-sector, exotics), hadron structure (time-like form factors, TPD), non-perturbative dynamics (TDA, spin), hypernuclei, etc.**

The Electromagnetic Proton Form Factors

- **parametrisation of the nucleon structure:** G_E, G_M, (Sachs) / F_1, F_2 (Pauli-Dirac)

  → **functions of the four-momentum transfer** q^2

  → **related by** $G_M = F_1 + F_2$ **and** $G_E = F_1 + \tau F_2$, **with** $\tau = \dfrac{q^2}{4M}$



our goal:

measure the timelike electromagnetic proton form factors with PANDA

feasibility studies ⇒ **Monte Carlo development, detector simulation and data analysis**

Generating distributions

The problem: generate distribution following $f(X)$, $X \in R \subset \mathbb{R}^n$

The simplest algorithm:

- find upper bound C to f in R, i.e. $f(X) < C \quad \forall X \in R$
- uniform sampling (X, h) in $R \times [0, C]$:
  - $\rightarrow$ if $h < f(X)$, accept event (and fill histogram)
  - $\rightarrow$ if $h > f(X)$, reject event
- iterate previous step until the desired statistics is reached

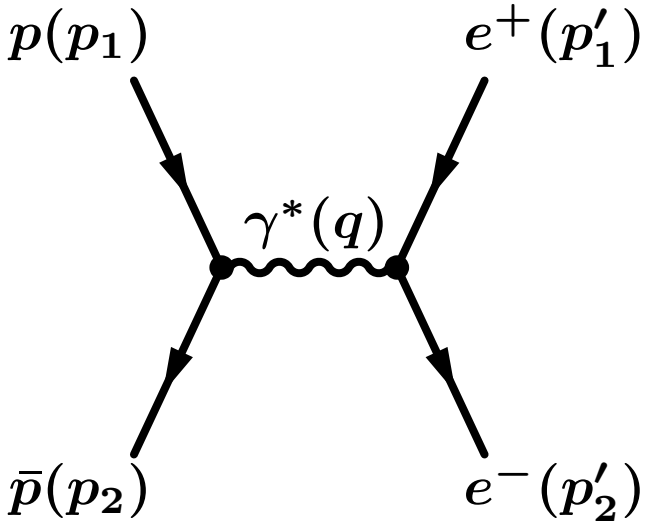
$\Rightarrow$ always work, but cumbersome in high dimension
improvements: importance sampling, etc.

In our case:

- worked well for $n = 1$ and $n = 2$, with reasonable rejection rates
- random number generator: RANLUX$^{(*)}$
  - $\rightarrow$ widely used in lattice QCD Monte Carlo simulations
  - $\rightarrow$ huge periods $\sim 10^{171}$, even at the lowest "luxury level"

(*) M. Luescher, Comp. Phys. Comm. 79 (1994) 100

$\bar{p}p \to e^+e^-$: Cross Section and Event Generator



- **LO calculation (one-photon exchange approximation)**
  A.Zichichi et al., Nuovo Cimento XXIV, 170 (1962)
- **in $\bar{p}p$ CM frame, cross section given by**

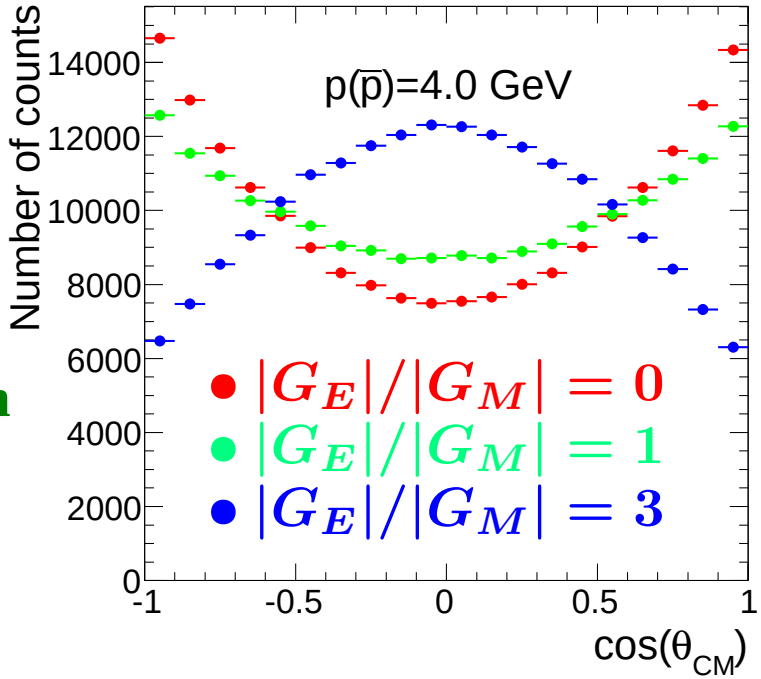
$$\frac{d\sigma}{d\cos\theta^*} \sim |G_M|^2(1+\cos^2\theta^*) + \frac{1}{\tau}|G_E|^2(1-\cos^2\theta^*)$$

$$\theta^* = \text{angle}(e^-, \bar{p}) \qquad \tau = \frac{q^2}{4M^2}$$

→ **sensitive to $|G_E|$ and $|G_M|$ (with absolute normalization)**
→ $q = p_1 + p_2 \Rightarrow$ **kinematic threshold $q^2 > 4M^2$**

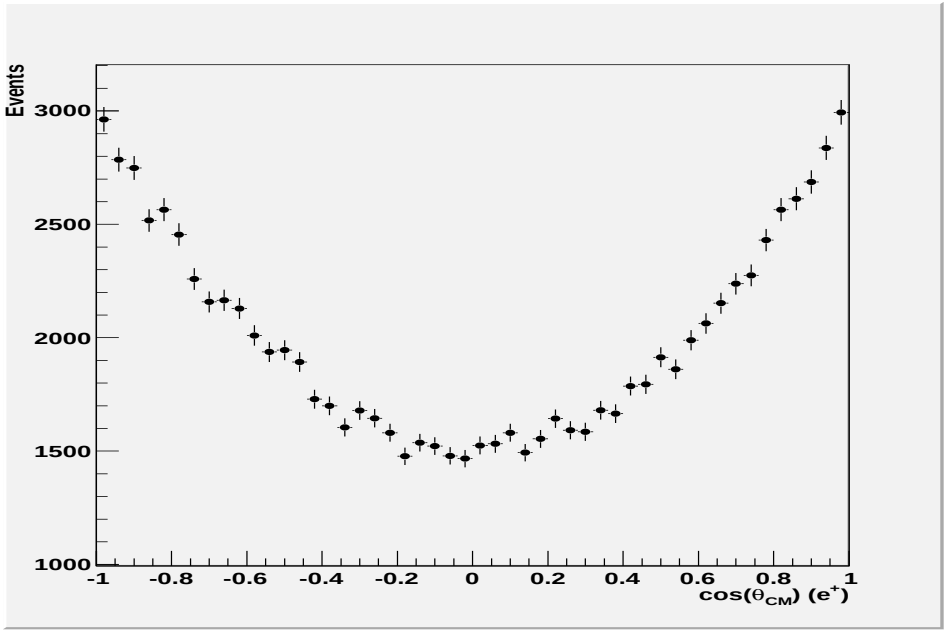
Event Generator :

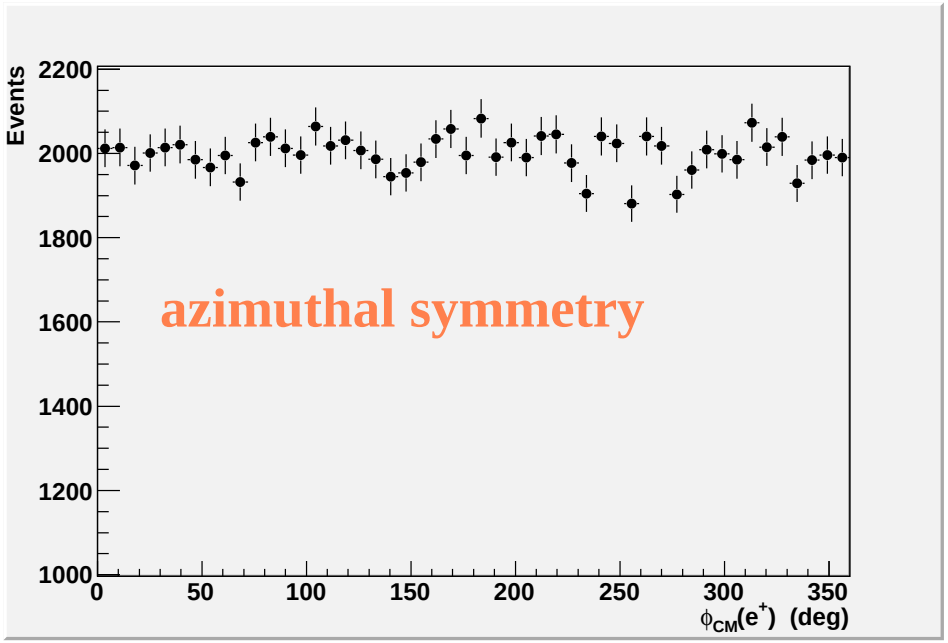
- **in CM frame:**
  - → $E(e^+) = E(e^-) = \sqrt{s}/2$
  - → e^+ **and** e^- **in "back to back" configuration**
  - → $\cos\theta^*$ **distributed according to cross section**
    (naive accept/reject algorithm,
    random number generator: RANLUX)
  - → **azymuthal symmetry, i.e. ϕ^* uniform**
- **boost event to LAB frame**

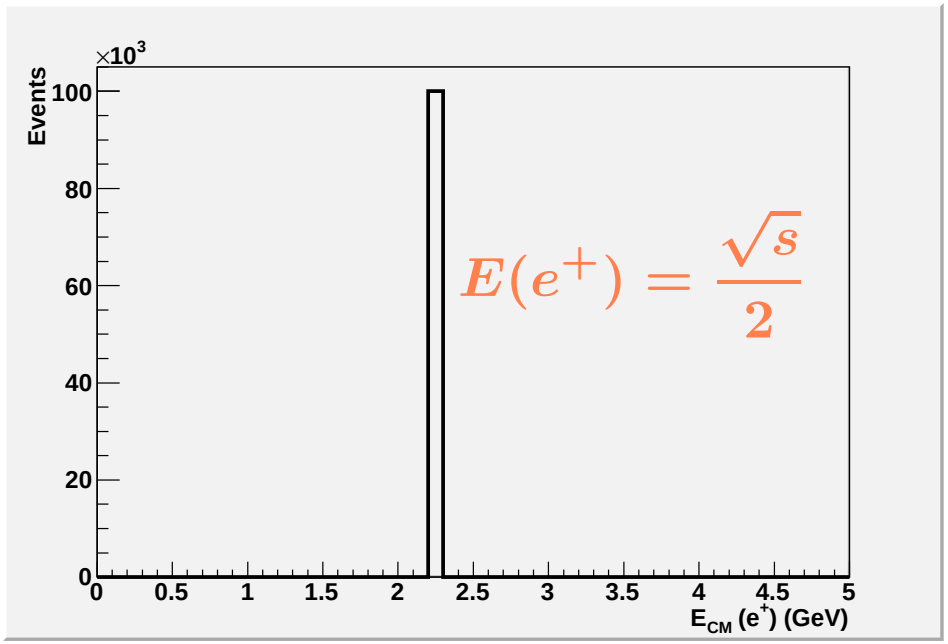


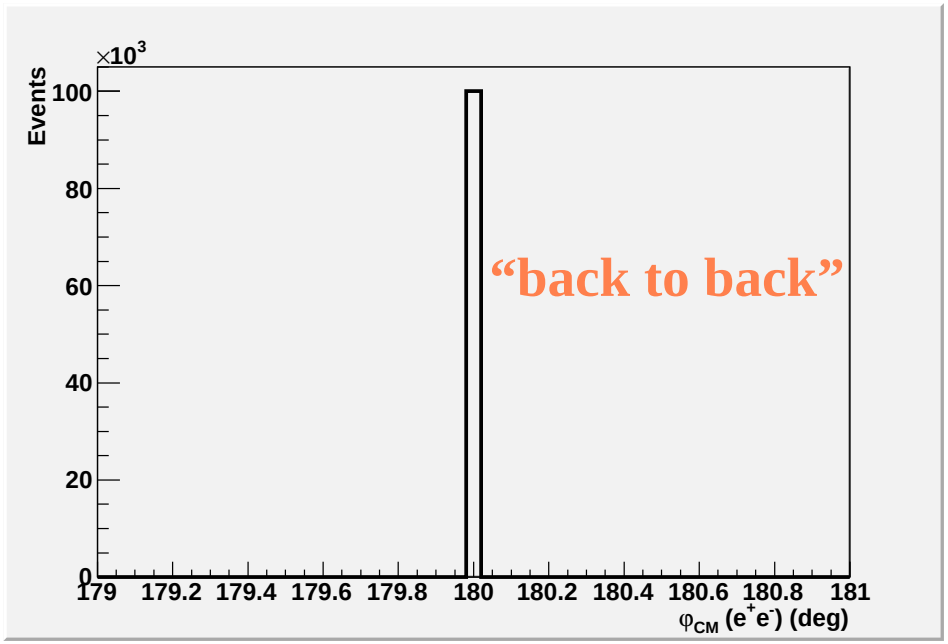
$\bar{p}p \to e^+e^-$: distributions in CM frame

P = 4.0 GeV $|G_E|/|G_M| = 0$ **N = 10^5 events**



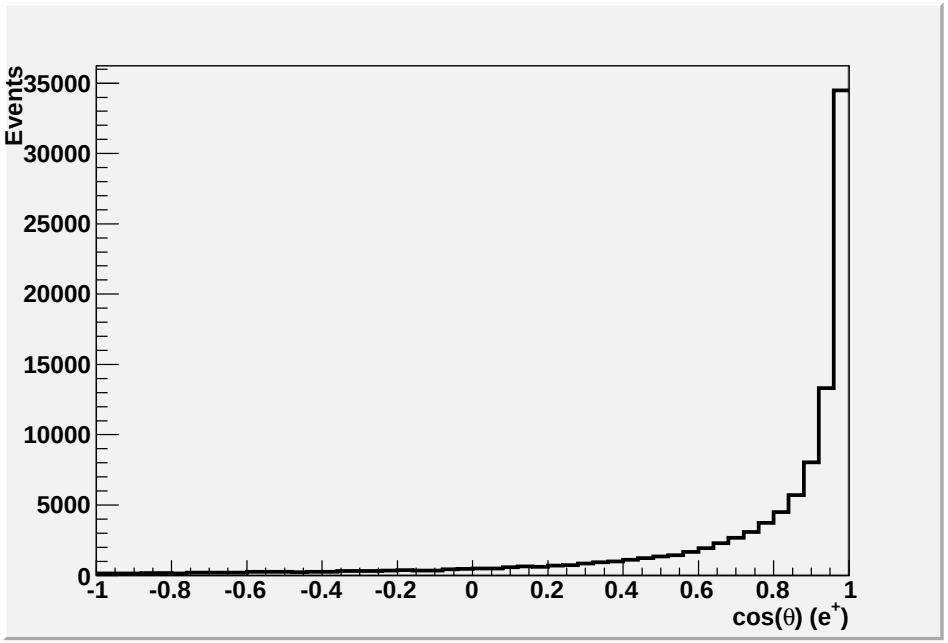


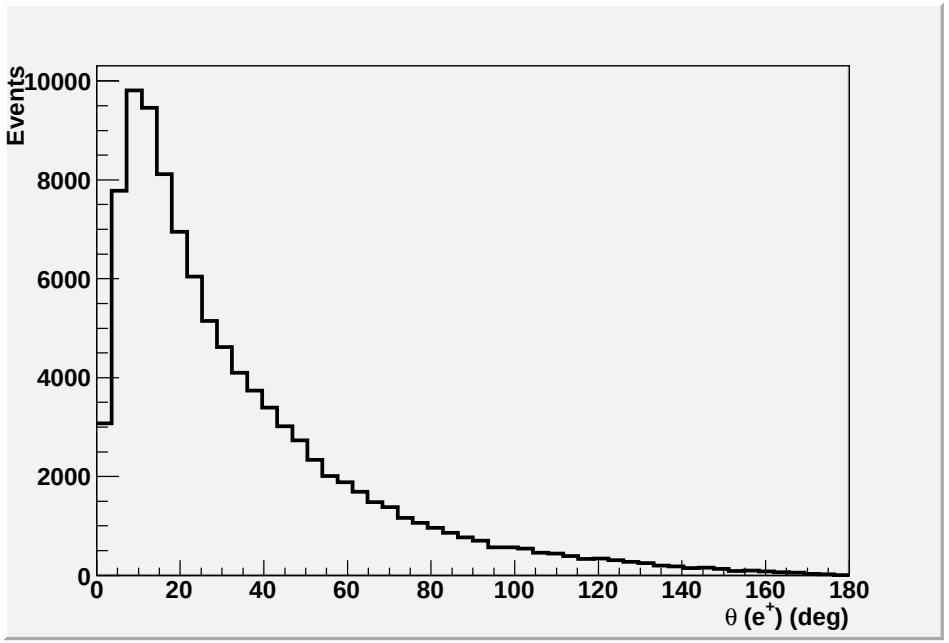


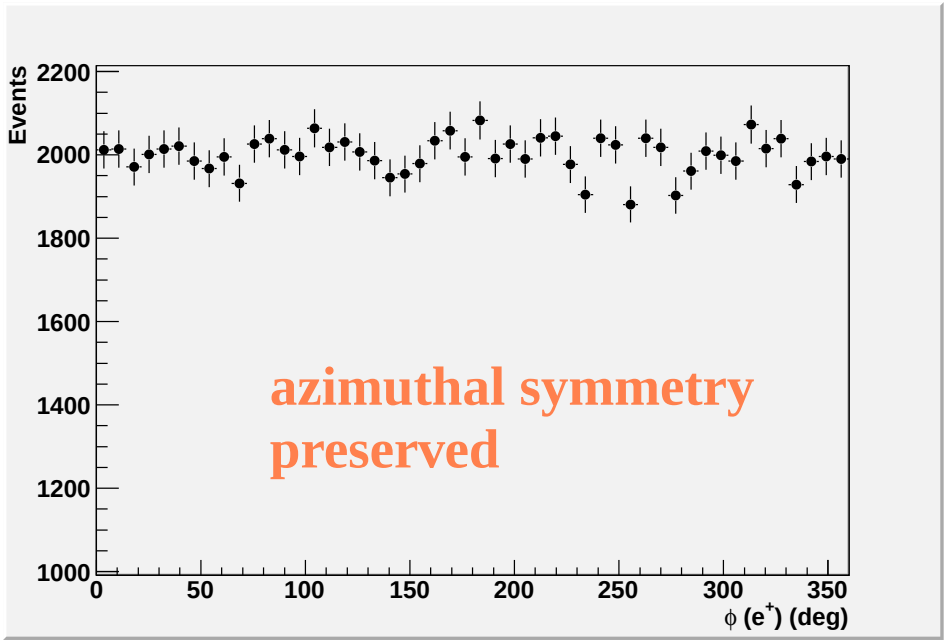


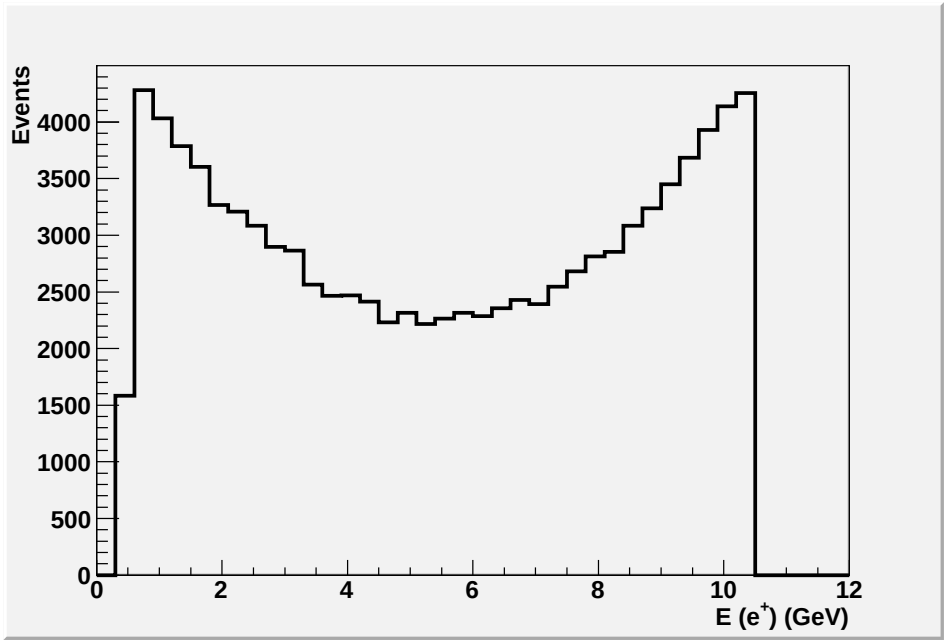
$\bar{p}p \to e^+e^-$: distributions in LAB frame

event boosted in the forward direction









$\bar{p}p \to \pi^+\pi^-$: Cross Section and Event Generator

low energy | transition region | high energy

$\sim 6,7$ | 9 | $s(GeV^2)$

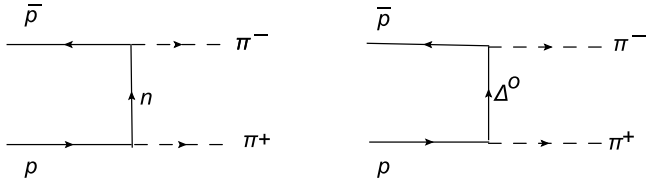
data : yes (ps) | no | yes (ps, ags)

model : **polynomial fit** ← interpolation → **Regge description**

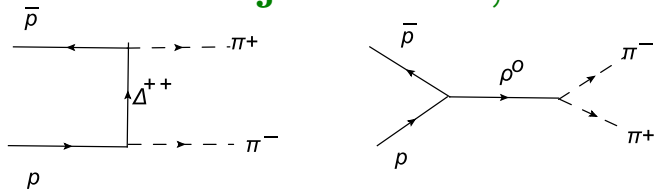
Eisenhandler et al.
Nucl. Phys. B96 (1975) 109

J. Van de Wiele and S. Ong
Eur. Phys. J. A46, 291 (2010)

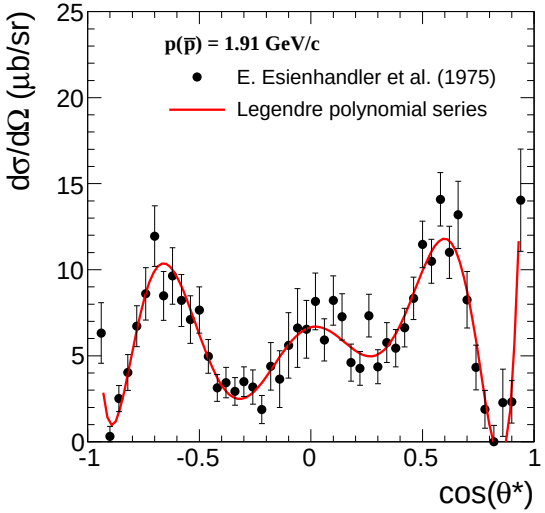
$$\frac{d\sigma}{d\Omega} = \sum_{i=0}^{10} a_i P_i(\cos\theta^*)$$

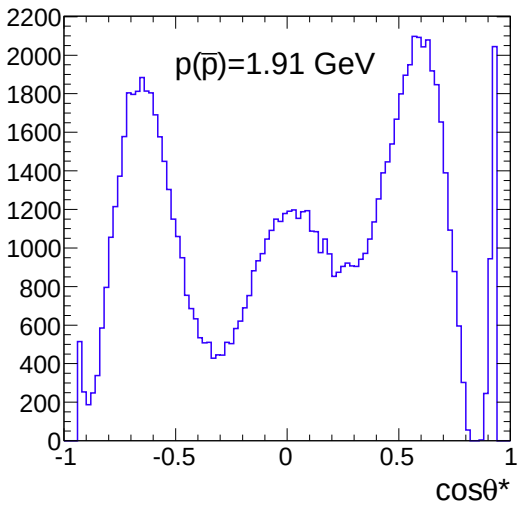


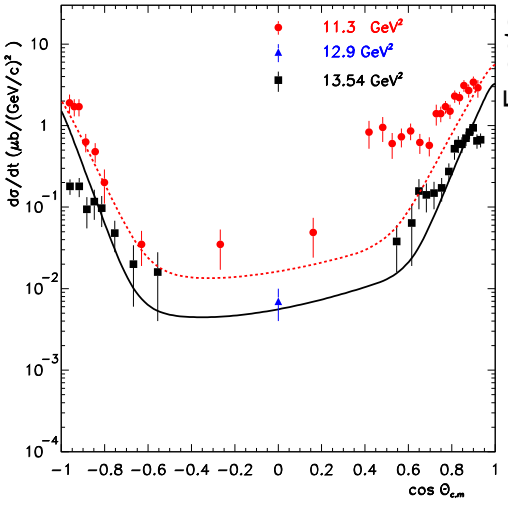
amplitudes ~ trajectories t, u channels

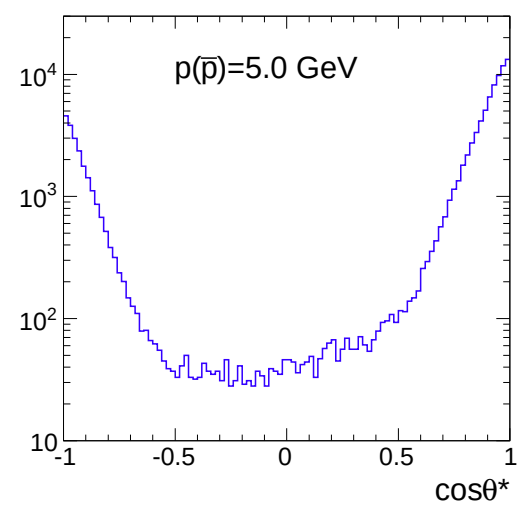


kinematics : as in $\bar{p}p \to e^+e^-$, $m_e \to m_\pi$









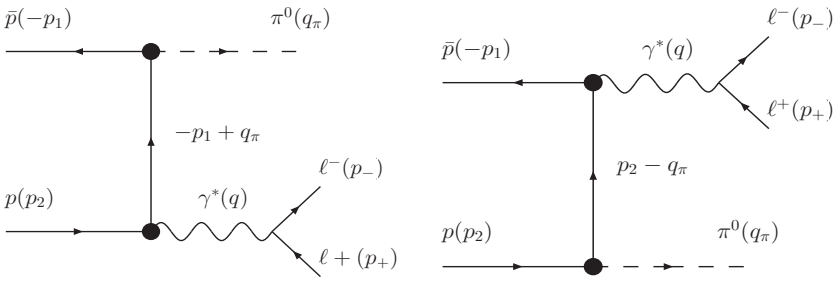
$d\sigma(\pi^+\pi^-)/d\sigma(e^+e^-) \sim 10^6 \Rightarrow$ **rejection factor 10^8 for 1% pion contamination**

$\bar{p}p \to e^+e^-\pi^0$: Form Factors below Threshold

- **model: phenomenological approach based on Compton-like Feynman amplitudes**

  C. Adamuscin et al., Phys. Rev. C 75, 04205 (2007)

- **sequence of two 2-body decays:**
  $\bar{p}p \to \gamma^*\pi^0, \gamma^* \to e^+e^-$



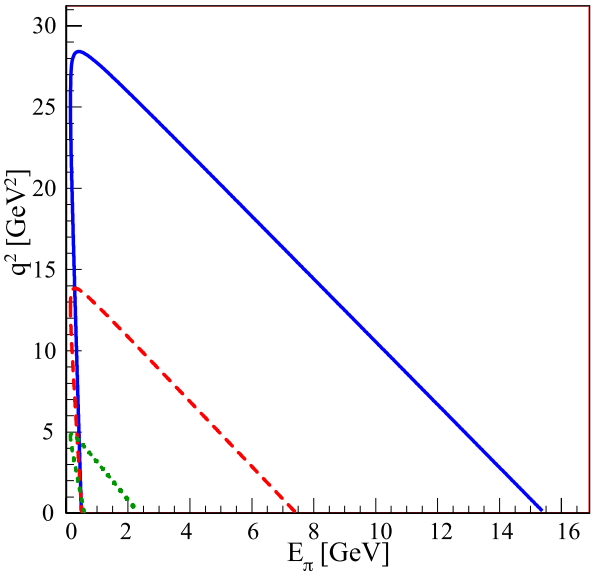
(a) (b)

kinematics :

part of the total initial four-momentum transferred to π^0

$$\Rightarrow 4m_e^2 < q^2 < q^2_{max};\ \ q^2_{max} = (\sqrt{s} - m_\pi)^2$$

$$\Rightarrow \text{ region } 4m_e^2 < q^2 < 4M^2 \text{ becomes accesible}$$



form factor parametrisation : **(off-shell effects neglected)**

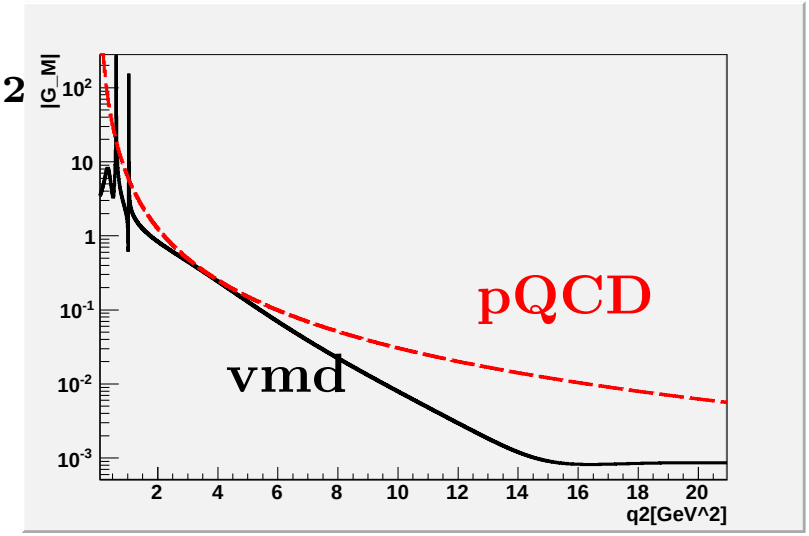
(1) "perturbative QCD inspired" (pQCD)

$$|G_E| = |G_M| \sim \frac{1}{q^4\left(\ln\left(\frac{q^2}{\Lambda^2}\right) + \pi^2\right)},\ \ q^2 > \Lambda^2$$

(2) "vector meson dominance" (vmd)

F. Iachello et al., Phys. Rev. C69, 055204 (2004)

→ **spacelike, analytically continued to timelike**
→ **contributions from (ρ, ω, ϕ) resonances, regularization**

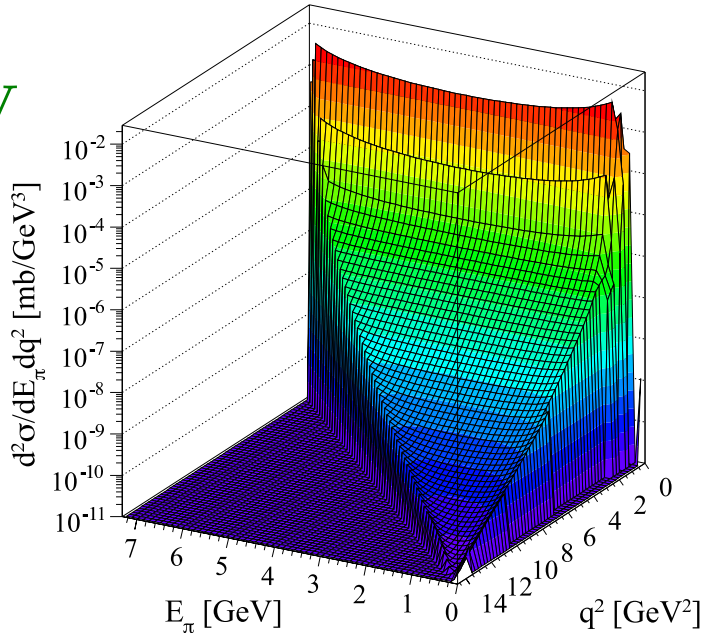


$\bar{p}p \to e^+e^-\pi^0$: Form Factors below Threshold

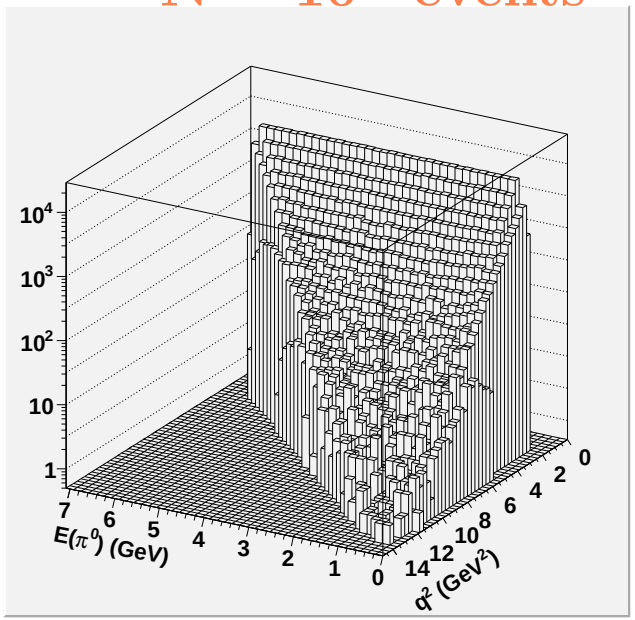
- **cross section: integrated in leptonic phase space, preliminary MC generator developed**

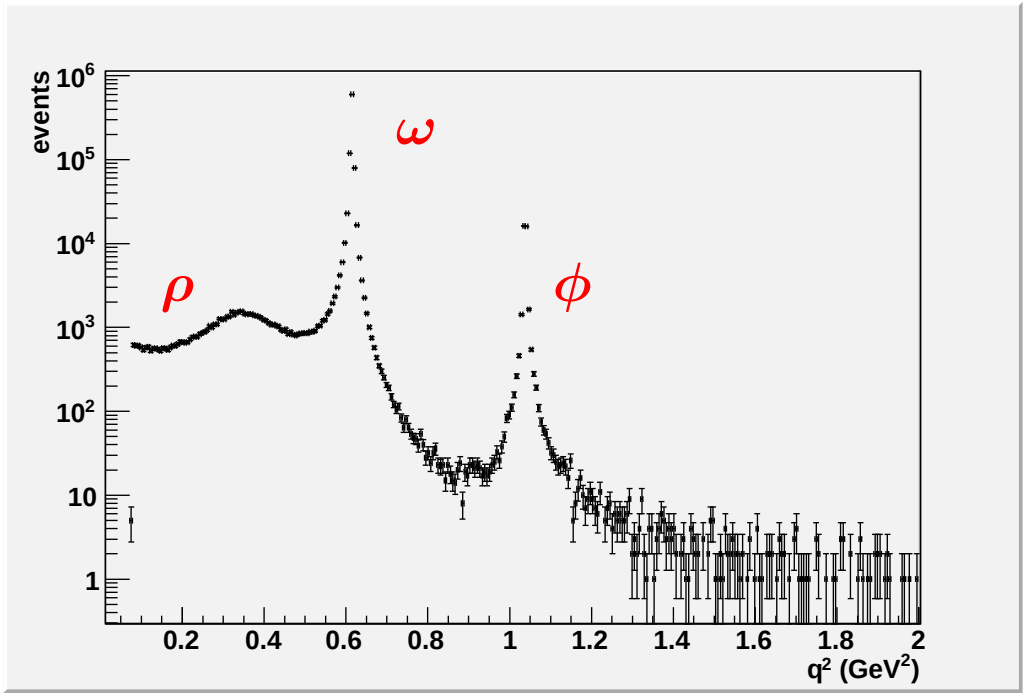
E = 7 GeV

vmd FF



N = 10^6 events





ongoing work:

calculation of full phase-space (5-dim) cross section

$\Rightarrow$ possibility of accessing FF relative phase without polarization

C. Adamuscin and J. Guttmann (in preparation)

Summary and Conclusions

- **event generators developed for**
  - $i)$ $\bar{p}p \to e^+e^-$
  - $ii)$ $\bar{p}p \to \pi^+\pi^-$
  - $iii)$ $\bar{p}p \to e^+e^-\pi^0$ **(preliminary)**

- **interfaced to PandaRoot**

  → **code public and ready for simulations, documentation available**

ongoing work . . .

→ simulation and data analysis (see Dmitry Khaneft's talk)

→ calculation full differential cross section for $\bar{p}p \to e^+e^-\pi^0$ (J. Guttmann, C. Adamuscin)

→ more channels : $\bar{p}p \to e^+e^-\pi^0$ (TDA), $\bar{p}p \to \pi^+\pi^-\pi^0$, etc.

related talks :

D. Khaneft, HK 1.5
M.C. Mora Espí, HK 8.9
Y. Ma, HK 8.7
B. Feher, HK 8.8
I. Zimmermann, HK 45.3