Feasibility study of time like form factor measurement in Pbar+p -> e+ e-

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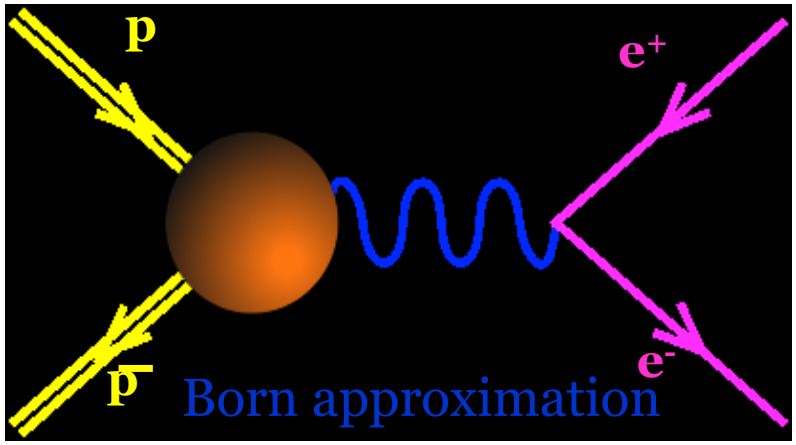
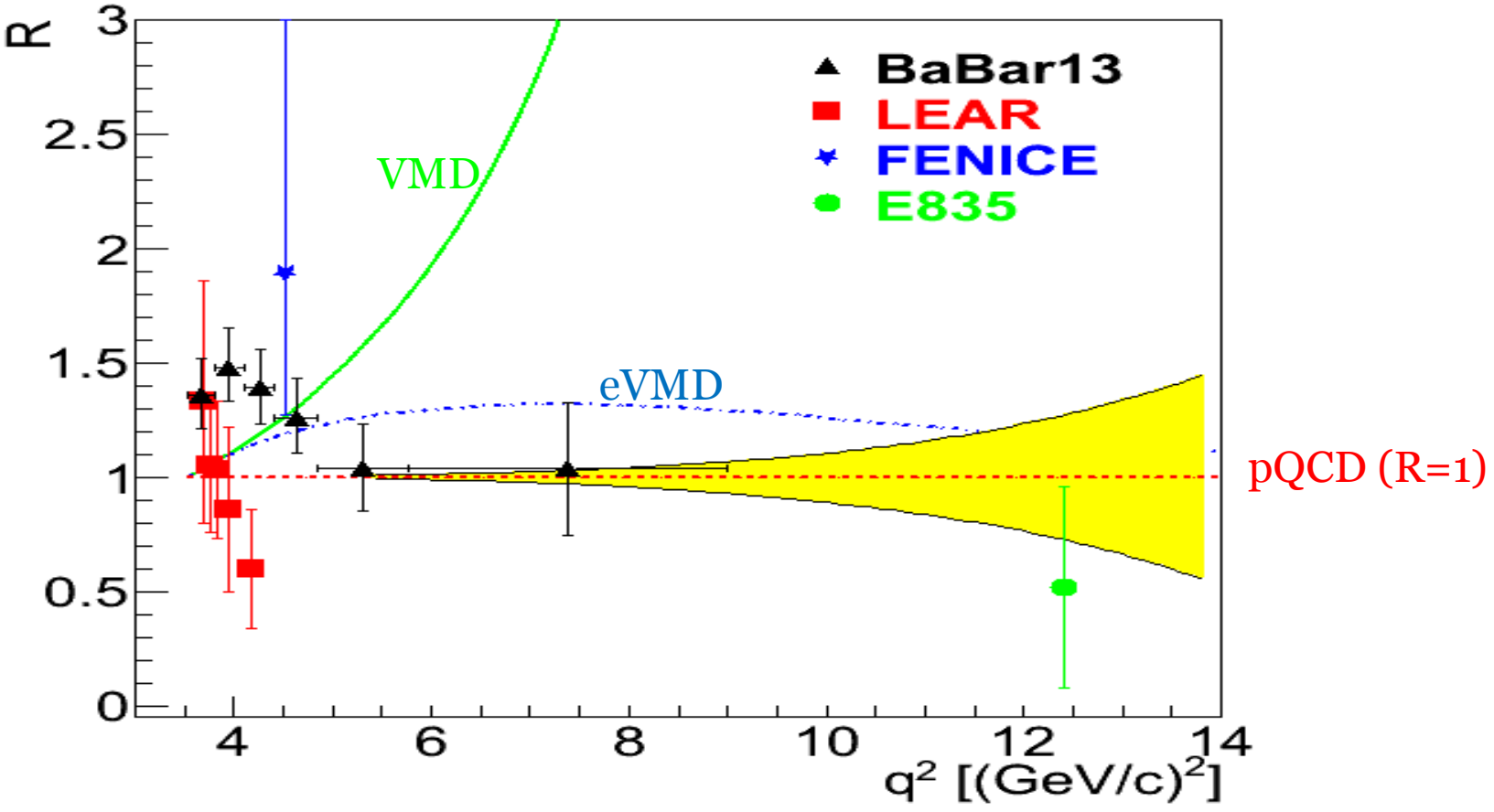
Electromagnetic channels : Time-like proton form factor measurements



Hadronic vertex is parametrized in terms of two electromagnetic FFs: GE and GM

- Total cross section -> effective form factor
- Angular distribution of the electron -> R= |GE|/|GM|
- Angular distribution + normalization -> |GE| and |GM|
- Polarization observables -> relative phase between GE and GM.

Data on TL proton FF ratio



Yellow band :Expected statistical precision of PANDA using the BaBar framework for R=1.

[M. Sudol *et al.* EPJ **A44**, 373 (2010)]

Form factor measurements at PANDA: Challenges

- **Huge hadronic background:**

Signal: $\bar{p} + p \rightarrow e^+ + e^-$,
Main Background : $\bar{p} + p \rightarrow \pi^+ + \pi^-$

Total cross sections: $\frac{\sigma(\pi^+\pi^-)}{\sigma(e^+e^-)} \sim 10^6$

At least a rejection factor of 10^{-8} is needed

M. Sudol *et al.* EPJ **A44**, 373 (2010)

- **Radiative corrections to $\bar{p} + p \rightarrow e^+ + e^-$:**
  PHOTOS @ PANDA: Final state radiations

Outline

1) $\pi^+\pi^-$ background suppression

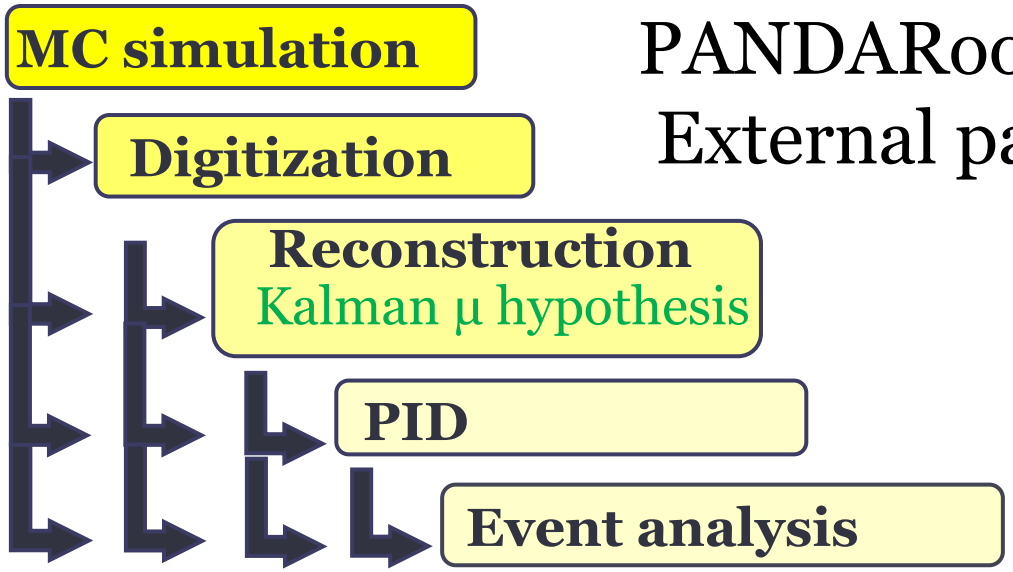
vs.

e+ e- signal efficiency

2) Extraction of the error on the proton FF ratio

Based on MC simulations using PANDARoot framework

Standard chain of reconstruction



PANDARoot version: nov12
External packages: sep12

Simulation done on the PANDA grid and GSI batch farm (Paul Buehler)

3×10^8 events for the background reaction are generated and reconstructed

Monte Carlo parameters:

- $\bar{p}$ + p -> $e^+ + e^-$ (PHSP).
  $\bar{p}$ + p -> $\pi^+ + \pi^-$ (PHSP).

Full range in θ and ϕ angles.

- **PHOTOS for FSR radiative corrections.**

$p_{\bar{p}}$ [GeV/c]	3.3	6.4
s $[GeV/c]^2$	8.2	13.9
N(e+e-) [events]	10^6	10^6
N($\pi^+\pi^-$) [events]	10^8	10^8

Principal points of analysis :

Selected events 1: Reconstructed events which satisfy the conditions:

- One positive and one negative particle per event.
- Best back to back pair in the center of mass system was selected in the multi (positive or negative) particle events.

Selected Events 2:

- After Cuts on the PID probabilities and kinematics.

Kinematical and PID Cuts

$p_{\bar{p}}$ [GeV/c]	3.3	6.4
Total PID	>99%	>99.9%
PID_i	>5%	>6%
Nb. of fired crystals in the EMC	>5	>5
$(\theta^+ + \theta^-)[CM]$	[178°-182°]	[175°-185°]
$\lvert\boldsymbol{\phi}^+ - \boldsymbol{\phi}^-\rvert$	[178°-182°]	[175°-185°]
Invariant mass $\sqrt{s}$	>2.14	>2.5

PID: probability for the detected particle to be identified as electron.
Information from EMC, STT, DIRC and MVD.

Signal efficiency vs. background rejection power

$p_{\bar{p}}$ [GeV/c]	3.3	6.4
Pions [events]	0	0
Electron efficiency integrated in the range of cosθ=[-1,1]	44 %	35 %

The efficiency is defined as:

$$\varepsilon = \frac{Number\ of\ reconstructed\ events\ after\ the\ cuts}{Number\ of\ the\ Monte\ Carlo\ events}$$

Extraction of the error on the proton FF ratio:

- Differential cross section of pbar p->e+e- (OPE):

$$\frac{d\sigma}{d(c)} = \sigma_0 \left[1 + \mathcal{A}c^2\right] \text{, c=cos}\theta\text{, } \sigma_0 = \frac{d\sigma}{dc}\left(\theta = \frac{\pi}{2}\right).$$

- The angular asymmetry :

$$\mathcal{A} = \frac{\tau|G_M|^2 - |G_E|^2}{\tau|G_M|^2 + |G_E|^2} = \frac{\tau - \mathcal{R}^2}{\tau + \mathcal{R}^2}. \qquad \mathcal{R} = |G_E|/|G_M|$$

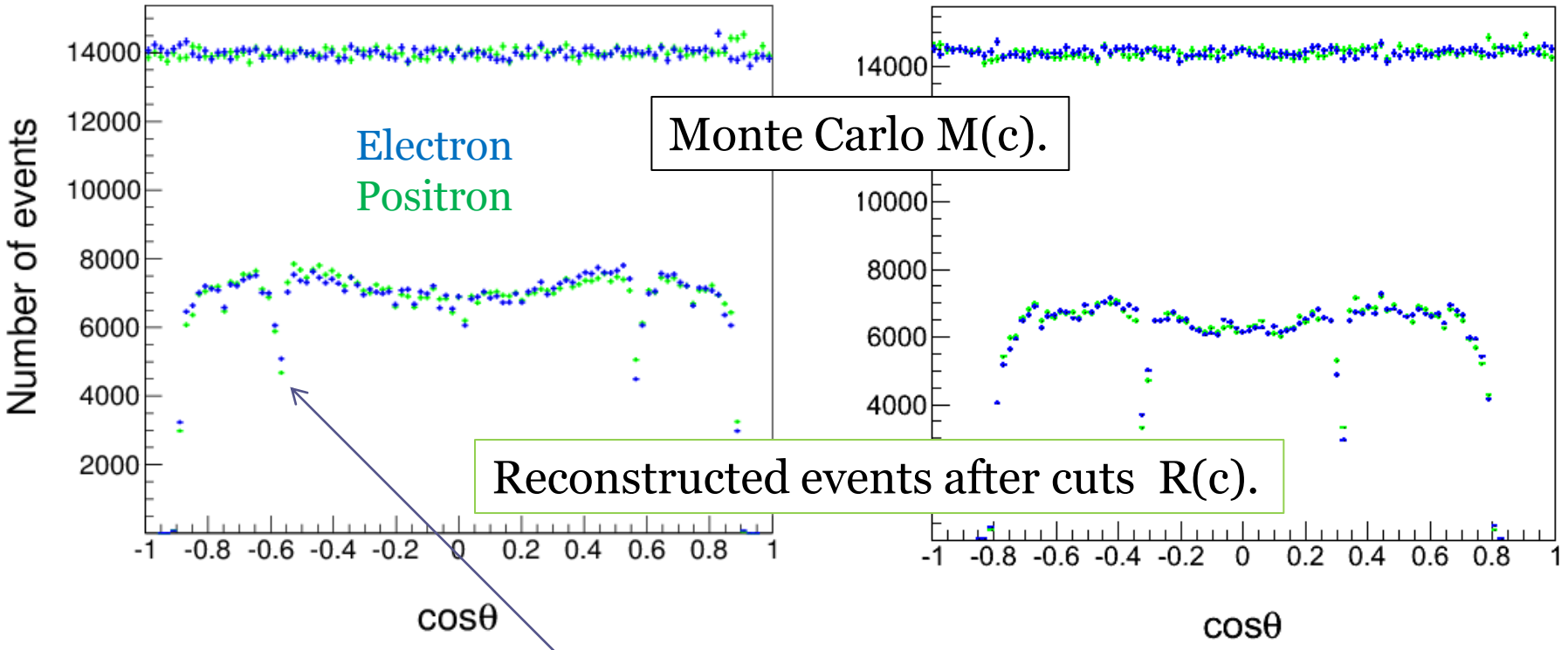
$\tau = s/4M_p$ and θ is the CM angle of the electron

Electron angular distribution:

PHSP

P=3.3 GeV/c

P=6.4 GeV/c

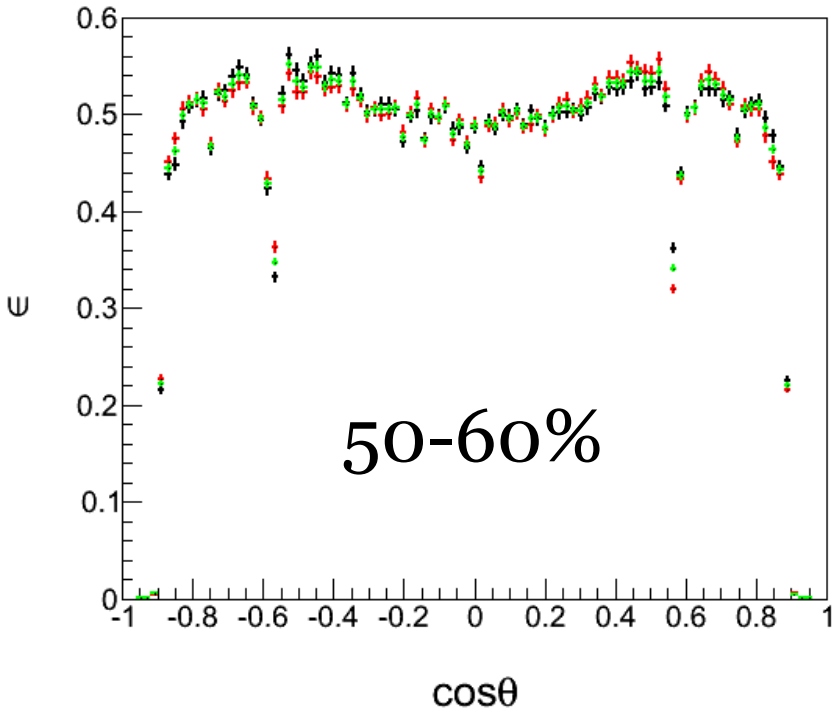


$\mathbf{Cos\theta_{CM}=0.57}$

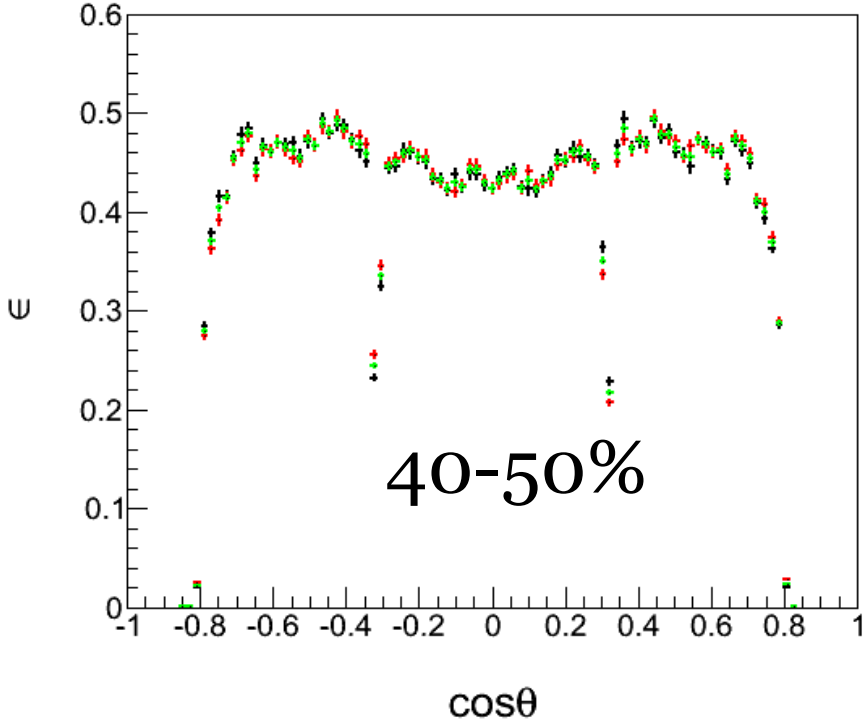
$\mathbf{\theta_{Lab}:22^{\circ}}$

Signal efficiency:

P=3.3 GeV/c

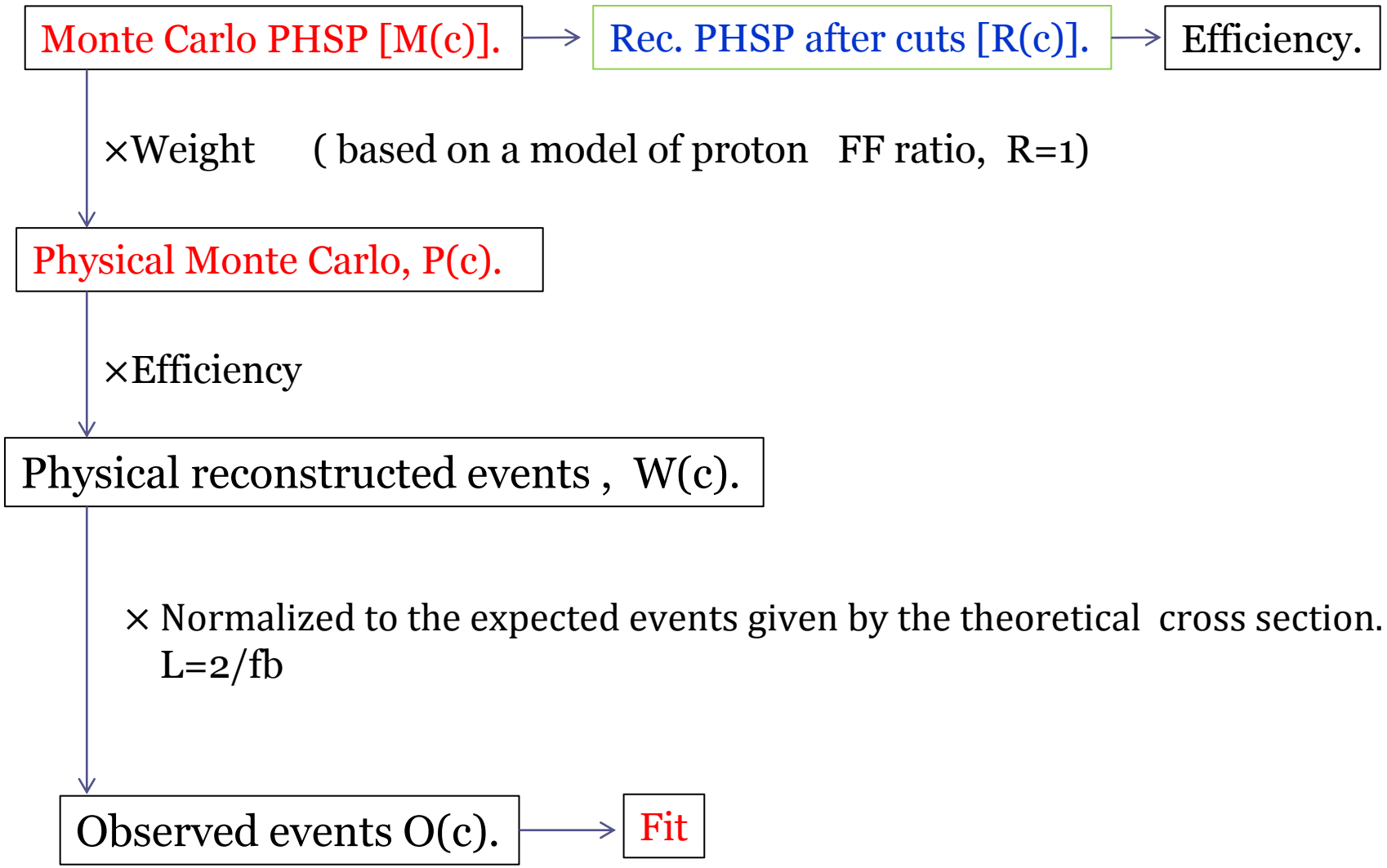


P=6.4 GeV/c

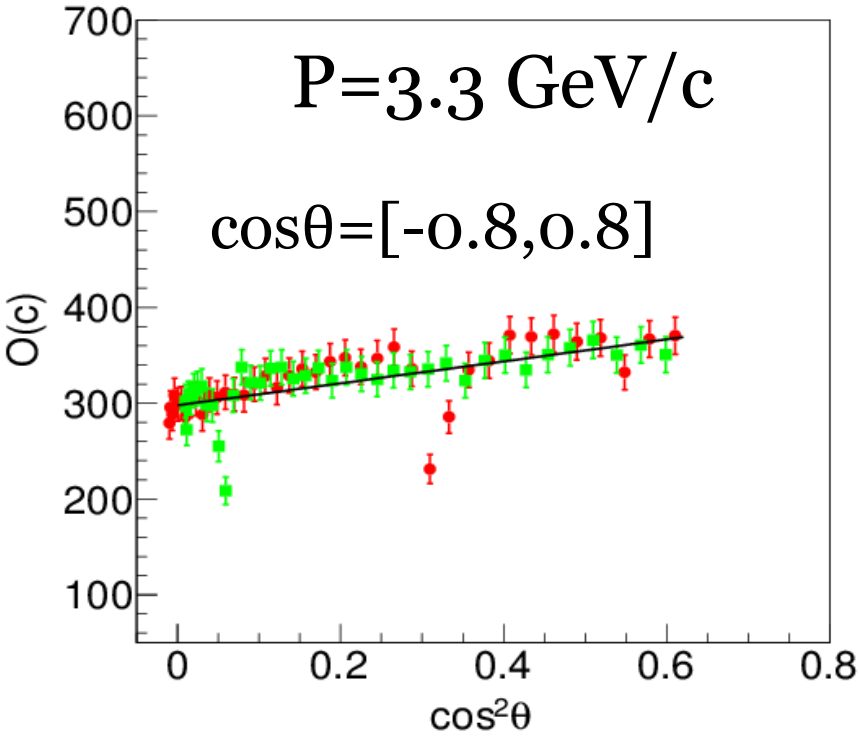


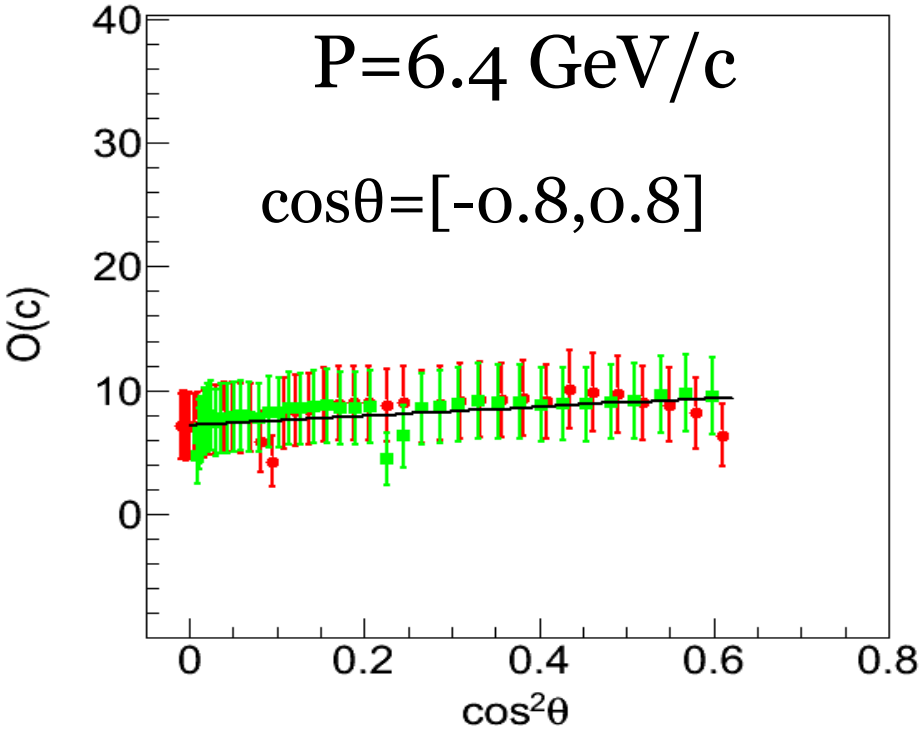
Angular cut: $\cos\theta=[-0.8,0.8]$

Strategy:


Monte Carlo PHSP [M(c)].
Rec. PHSP after cuts [R(c)].
Efficiency.
×Weight (based on a model of proton FF ratio, R=1)
Physical Monte Carlo, P(c).
×Efficiency
Physical reconstructed events , W(c).
× Normalized to the expected events given by the theoretical cross section.
L=2/fb
Observed events O(c).
Fit

Linear Fit of the observed events:



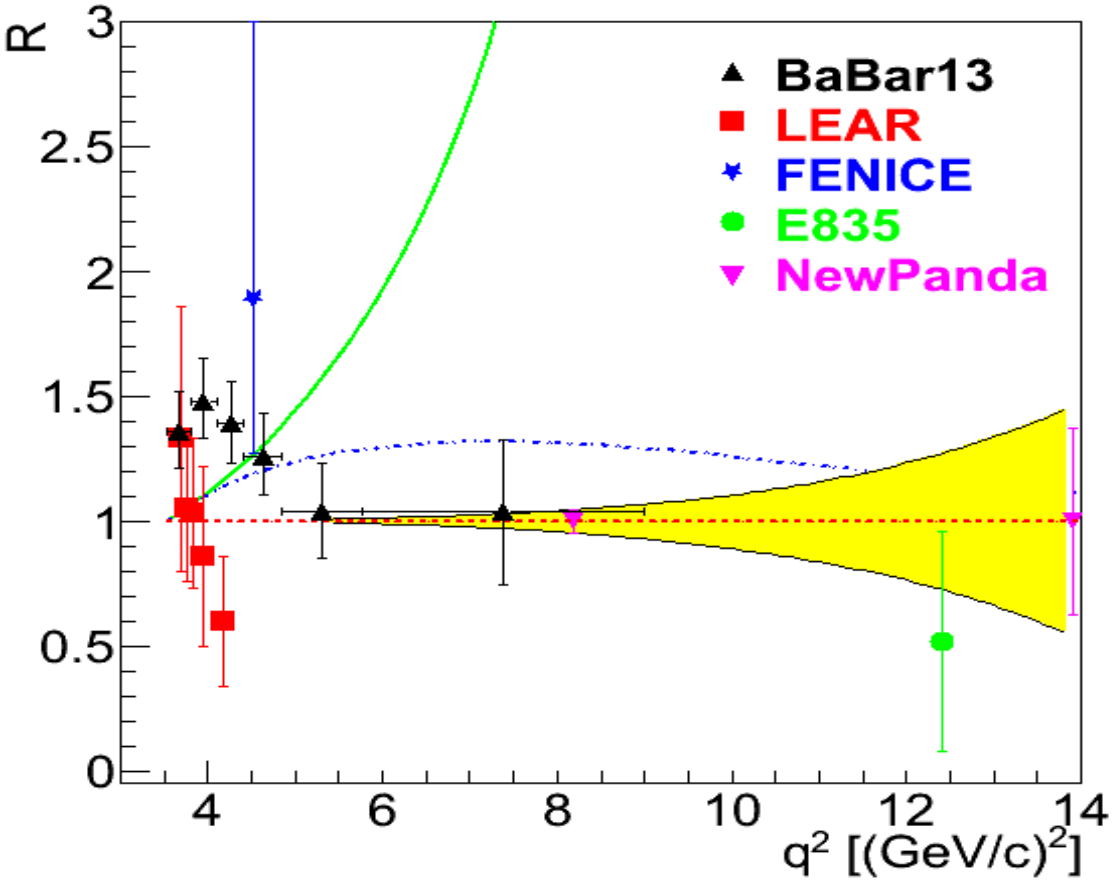


Fit function:

$$y = a_0 + a_1 x \text{ with } x = c^2,\ a_0 \equiv \sigma_0,\ a_1 \equiv \sigma_0 \mathcal{A}$$

Results:

s $[GeV/c]^2$	8.2	13.9
ΔA	0.038	0.245
ΔR	0.045	0.375



Effect of the angular cut

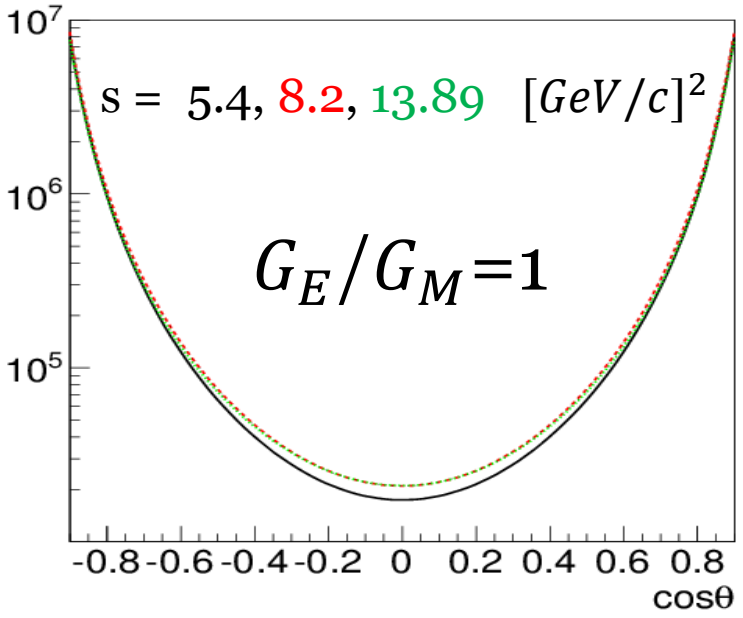
Rejection power should be effective in each bin of the angular distribution

$$\frac{\sigma(\pi^+\pi^-)}{\sigma(e^+e^-)} \sim 10^6$$

$$\cos\theta = \pm 0.8$$

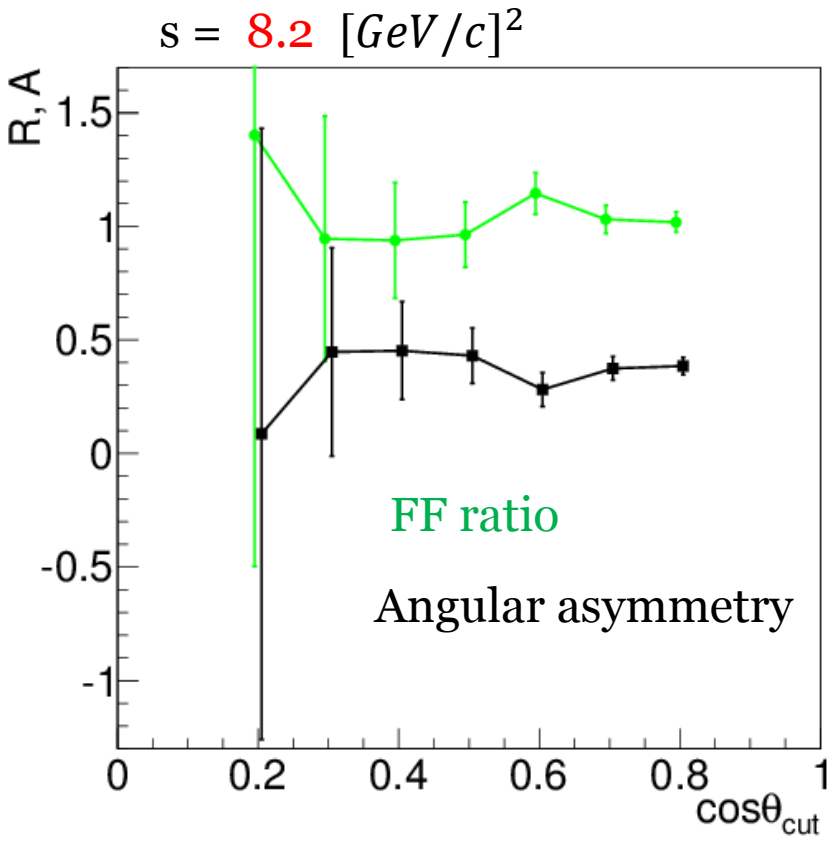
$$\frac{d\sigma(\pi^+\pi^-)}{d\sigma(e^+e^-)} \sim 10^6$$

$$d\sigma(\pi^+\pi^-)/d\sigma(e^+e^-)$$



Differential cross section for the pions
J. Van de Wiele *et al.*, EPJ A46 (2010) 291

Effect of the angular cut



Experimental data on **R** have been extracted in the region of $|\cos\theta|<0.8$:

Small effect of the angular cut

M. Ambrogiani et al., PRD 60 (1999)
Bardin NPB 411 (1994)

$\cos\theta_{cut}$	0.8	0.6
ΔR	0.045	0.092

Conclusions

In this work we studied the feasibility of the measurement of proton FF ratio at PANDA :

- Two values of momentum transfer squared are considered: s=8.2 and 13.9 $[GeV/c]^2$.
- Suppression of the main background with a rejection factor of 10^{-8} was achieved.
- Small errors are obtained on the proton FF ratio.

The simulation of the low energy point (s=5.4 $[GeV/c]^2$) is finished and will be analyzed soon.

Thank you for your attention

This work was done in collaboration with

Gosia Gumberidze and PANDA Orsay team.

Backup slides

Observed Events O (c):

- Generated Monte Carlo events P= $\int_{-0.8}^{0.8} P(c)$.
- Expected events with L=2/fb:

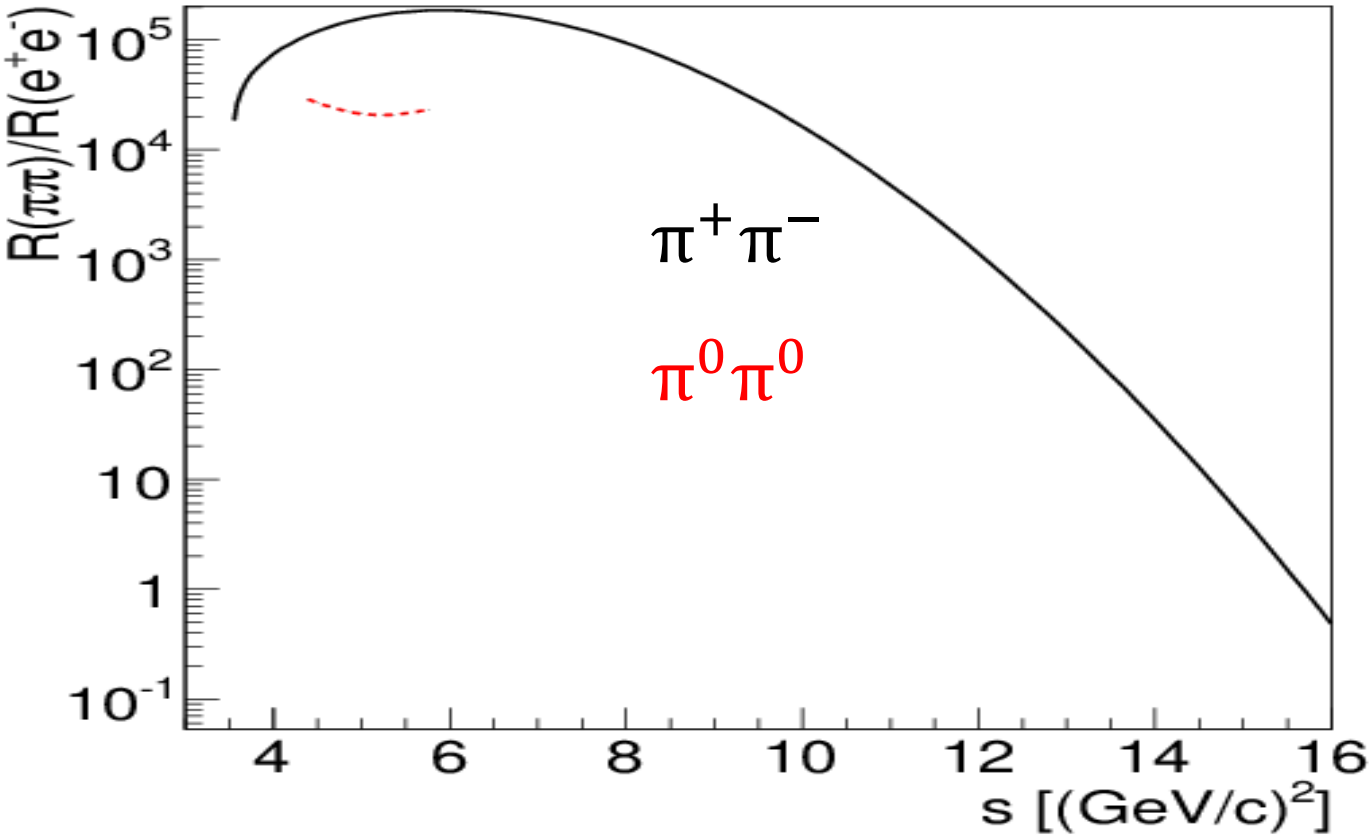
s $[GeV/c]^2$	8.2	13.9
E[-0.8,0.8]	4.9×10^4	1.4×10^3

- The observed events are:

$$O(c)=W(c).\ E/P$$

W(c) are the electron reconstructed events for R=1

Total cross section ratio



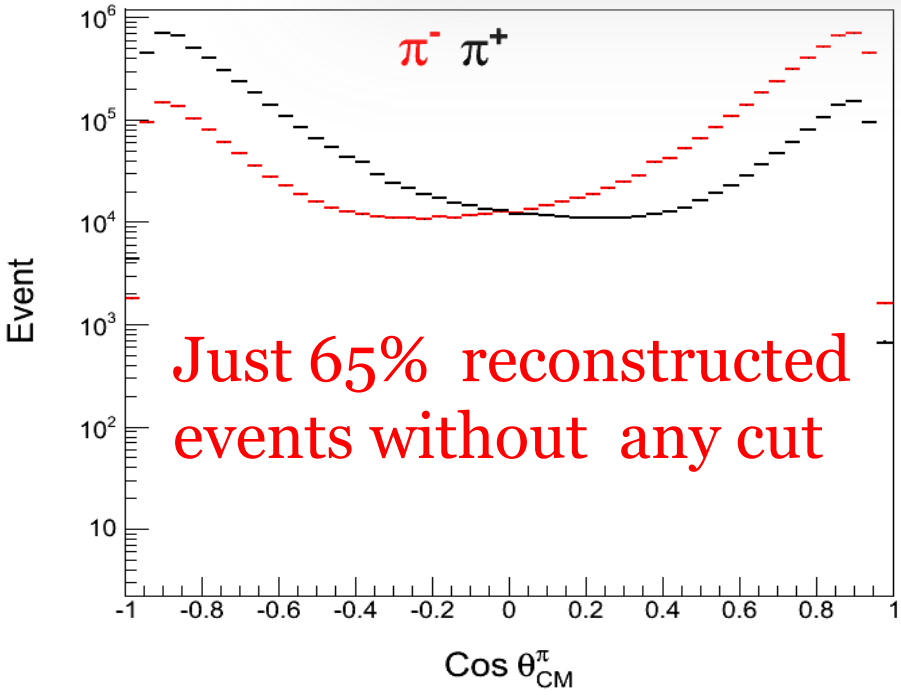
Why PHSP ?

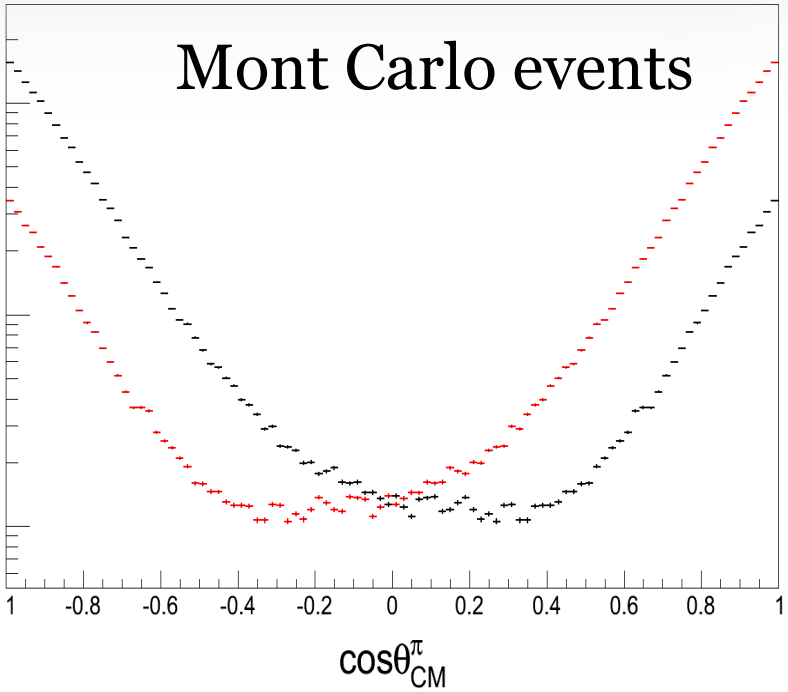
PIONS: PANDARoot Event Generator (Mainz PANDA group)

2.43<p<5.0 GeV: No data are available.

Extrapolation of Regge theory approach from high energy limit.

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





Distribution of pi-/pi+ is very peaked forward/backward :

loosing statistics

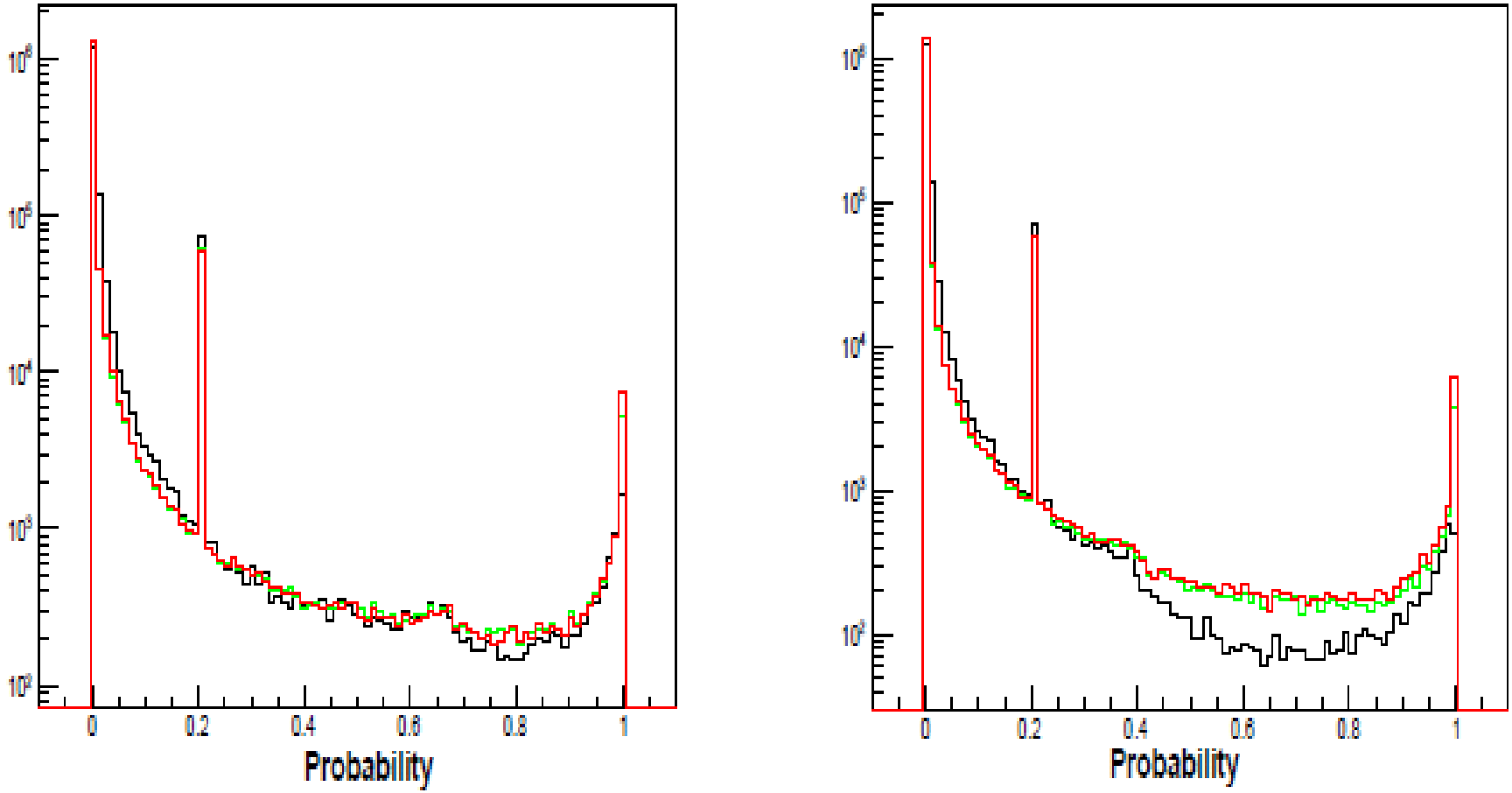


Figure 1.9: Distribution of the PID probability for the detected particles to be identified as positron or electron, in the case of positive pions (left) and negative pions (right).

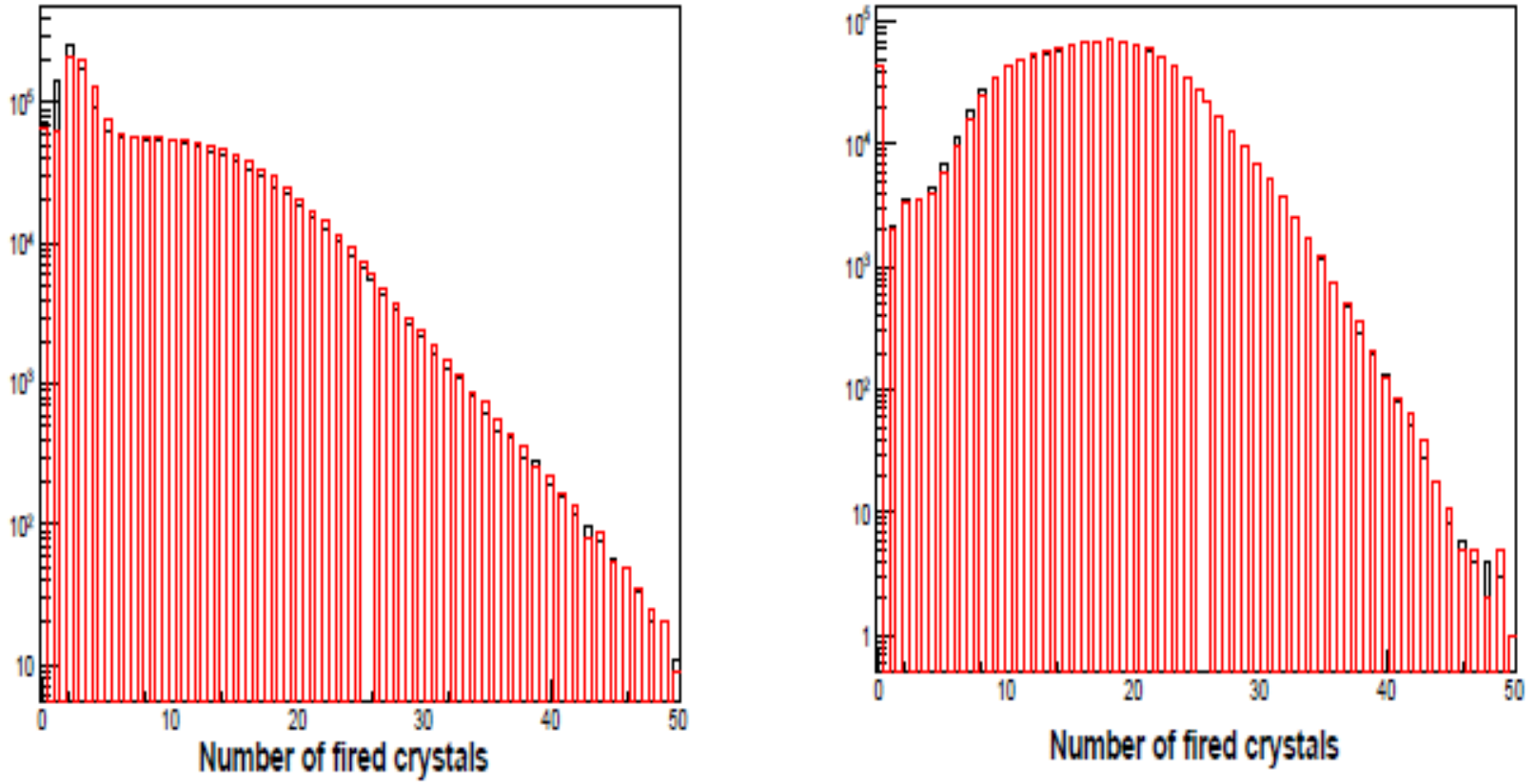


Figure 1.12: Number of the fired crystals in the EMC, for positive (black) and negative (red) particles, for pions (left) and electron (right).

Cut	pions [events]	electron efficiency
$PID^{tot} > 0.99$, $PID_i > 0.05$	693	61%
$Nb_c > 5$	268	60%
Kinematical cuts (θ, ϕ)	9	51%
$\sqrt{s} > 2.$	3, [-0.8,0.8]=1	46%, $[-0.8, 0.8] = 52\%$
$\sqrt{s} > 2.135$	0	44%, $[-0.8, 0.8] = 50\%$

Tab. 1.2: Effects of the PID and kinematical cuts on the electron and pion events.