A Monte Carlo event generator for $\bar{p}p \rightarrow \pi^+\pi^-$

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OUTLINE

- **introduction**

- **kinematic regimes**

- **the cross section in all kinematic regimes**

- **event generation: generalities and examples in all kinematic regimes**

- **interface to PANDA ROOT**

- **summary and conclusions**

Introduction

- $\bar{p}p \to e^+e^-$ **used to extract the (modulus) proton form factors** $|G_E|$ **and** $|G_M|$
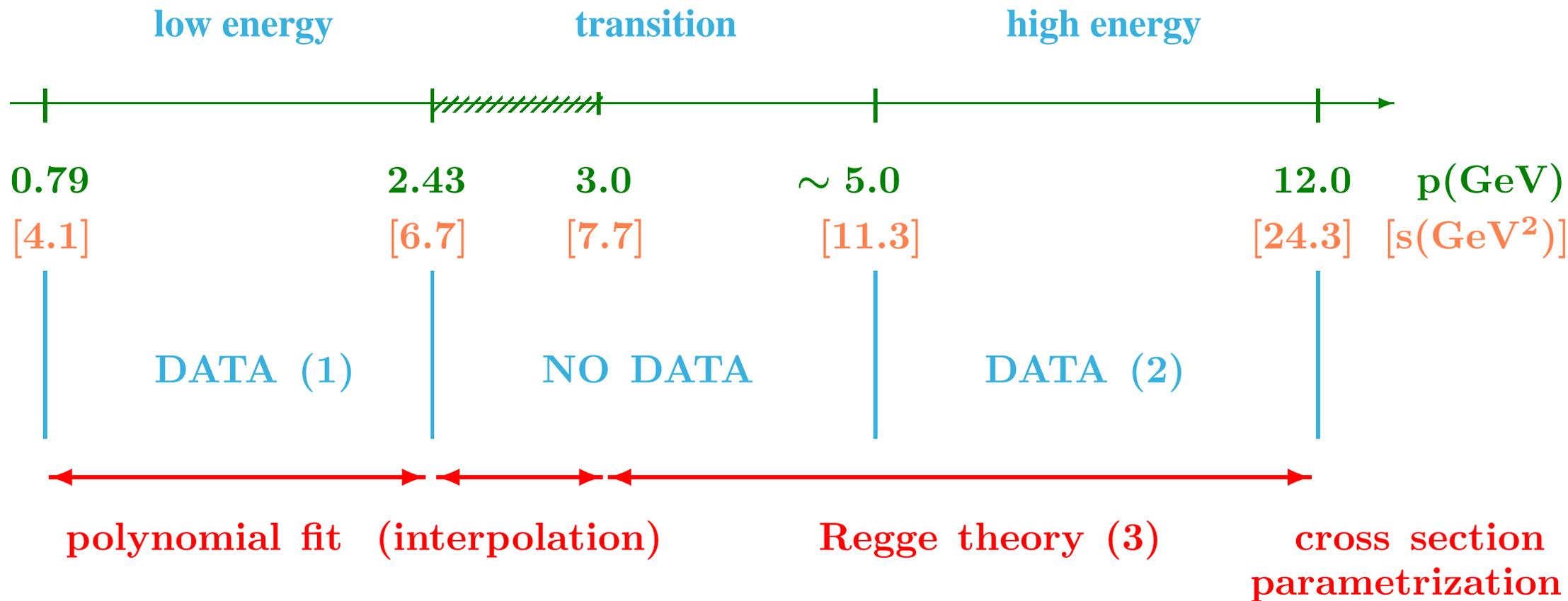- $\bar{p}p \to \pi^+\pi^-$ **production main background source to** e^+e^- **signal**

our goal:

make feasibility studies of proton form factors measurements

using the PANDA detector

$\Rightarrow$ **need realistic models of the cross sections (signal and background)**
implemented in event generators (Monte Carlo true-level):

study supression factors, expected number of events, etc.

In this talk we discuss a "realistic" event generator for $\bar{p}p \to \pi^+\pi^-$

Kinematic regimes

low energy **transition** **high energy**

0.79   2.43   3.0 ~ 5.0 12.0   p(GeV)

[4.1]   [6.7]   [7.7]   [11.3]   [24.3] [s(GeV^2)]

DATA (1)   NO DATA   DATA (2)

polynomial fit   (interpolation)   Regge theory (3)   cross section parametrization

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

(2) ref [6], [8] and [26] in (3)

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

The cross section in the low energy regime

● **data:** $\dfrac{d\sigma}{d\Omega}$ **at a** $(\mathrm{p}, \cos\theta^*)$ **grid with** (20×48) **lattice sites**

[Eisenhandler et al., Nucl. Phys. B96 (1975) 109]

p = antiproton momentum in lab frame, $\qquad$ $\mathrm{p} = 0.79, \ldots, 2.43$ GeV

θ^* = angle $(\pi^-, \bar{\mathrm{p}})$ in $\bar{\mathrm{p}}\mathrm{p}$ CMS frame, $\qquad$ $\cos\theta^* = -0.94, \ldots, 0.94$

● **at each momentum value, cross section fitted using a** Legendre polynomial series:

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

$\rightarrow$ **fit function follows data**

$\rightarrow \chi^2/\mathrm{dof} \sim 1$

$\rightarrow$ MINUIT output : $\qquad$ status = "CONVERGED"

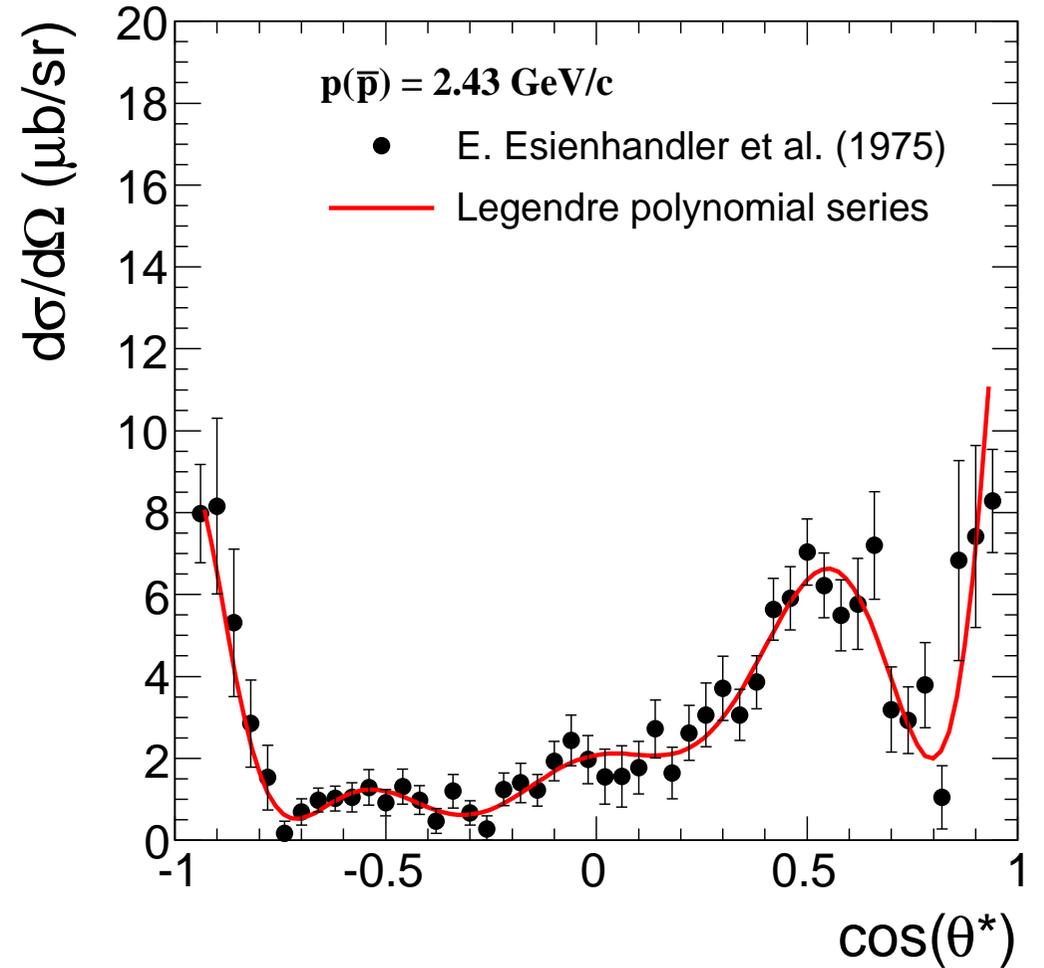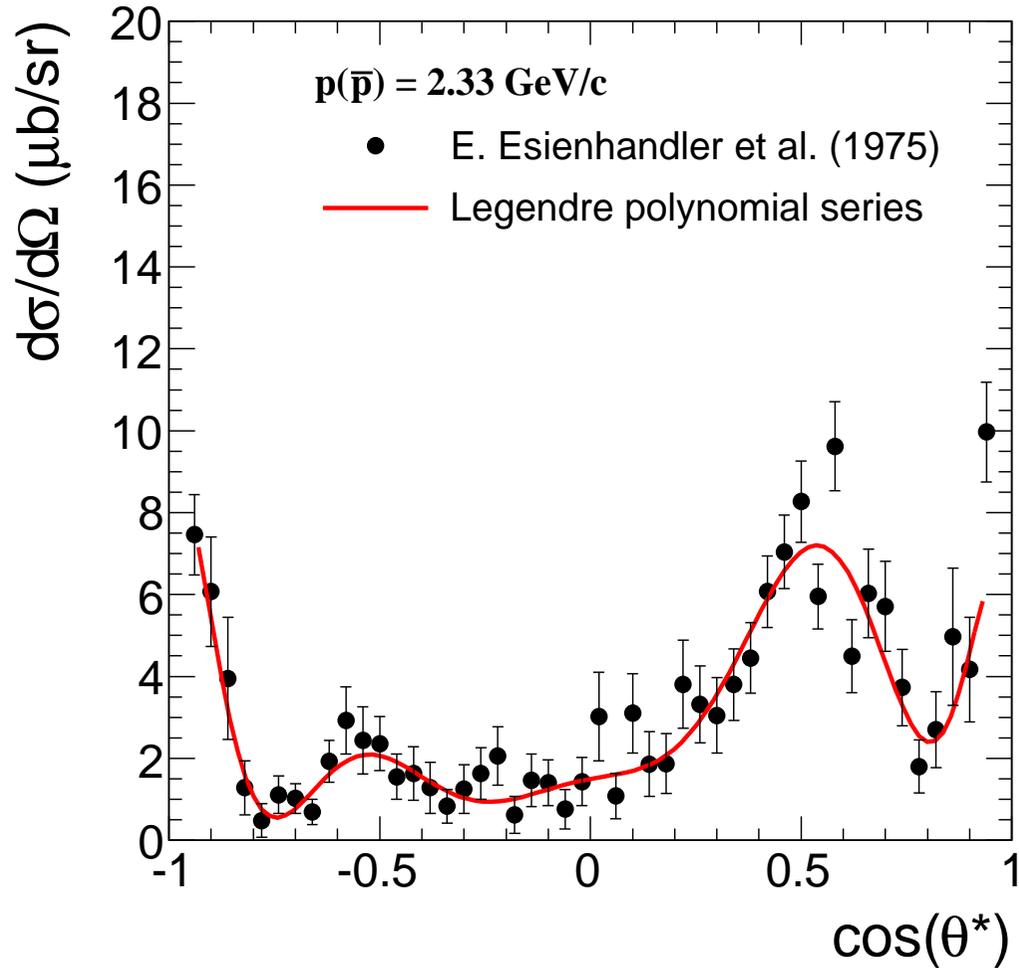$\qquad\qquad\qquad\qquad\qquad$ error matrix = "ACCURATE"

The cross section in the low energy regime
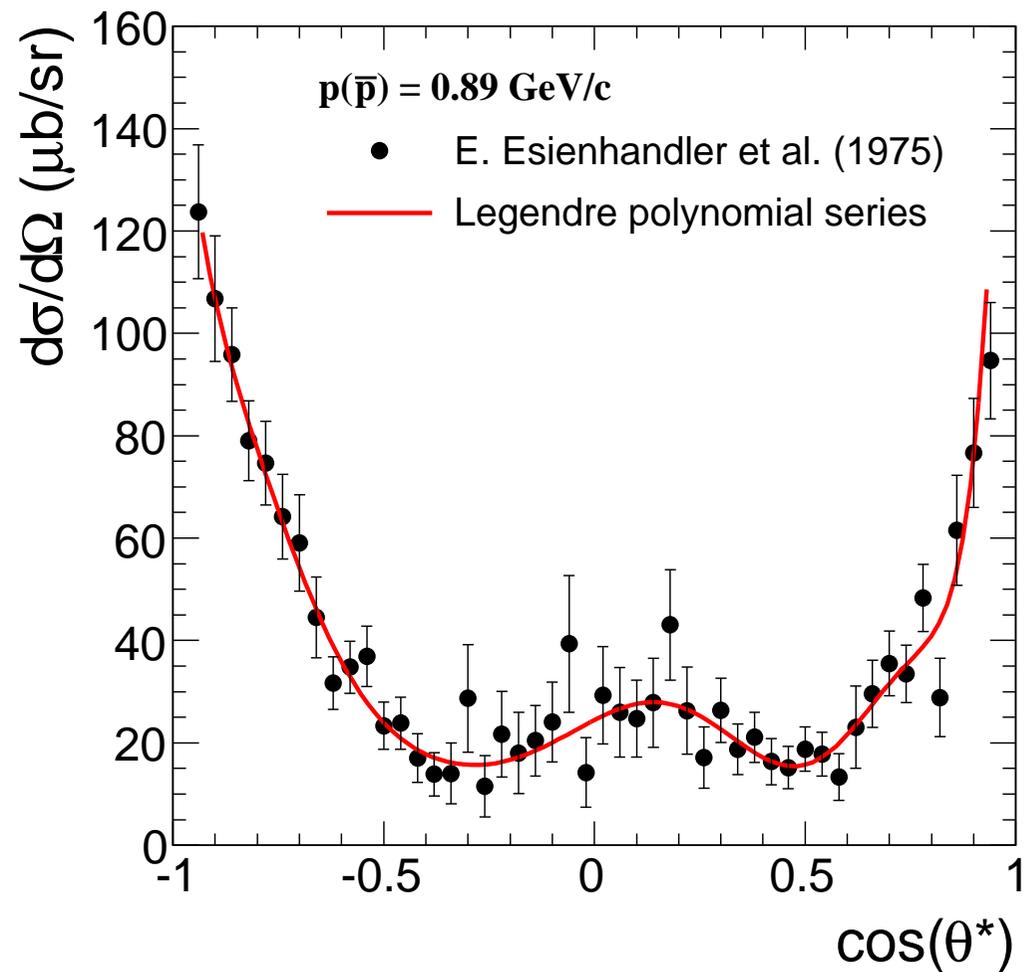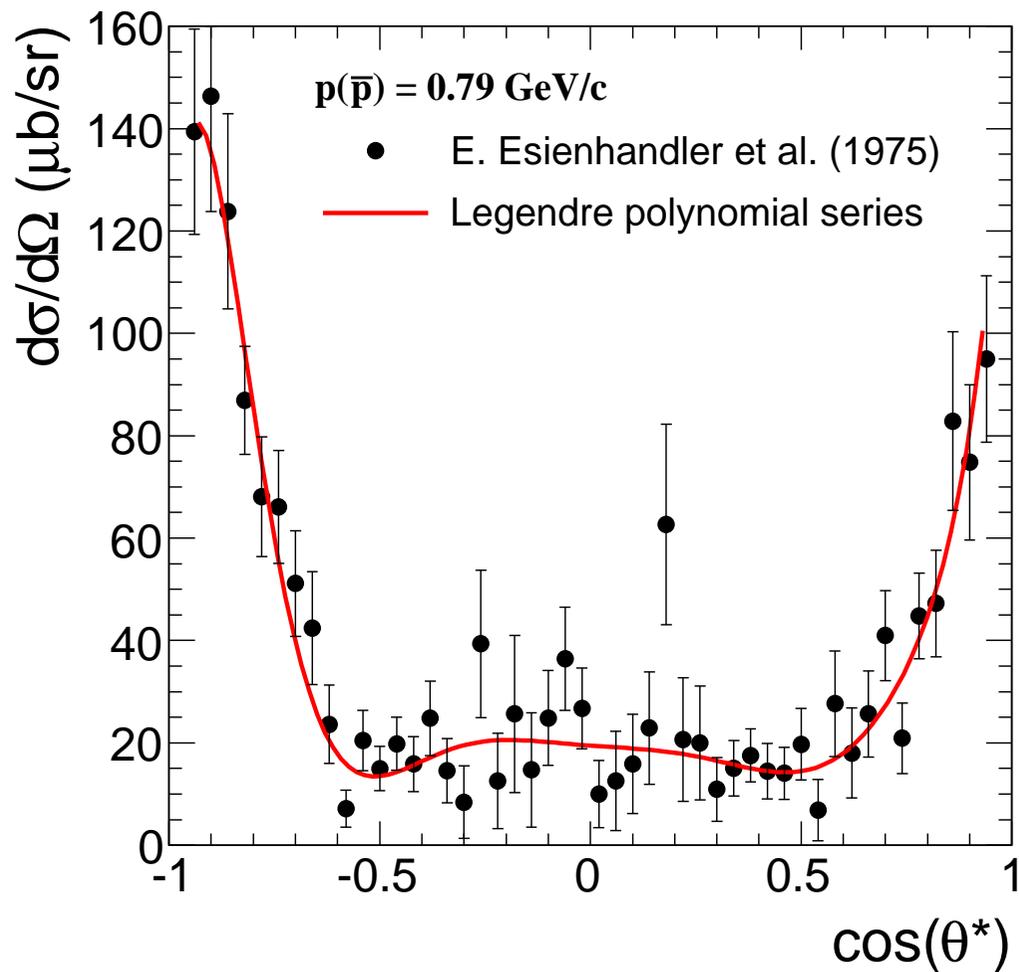
The cross section in the low energy regime
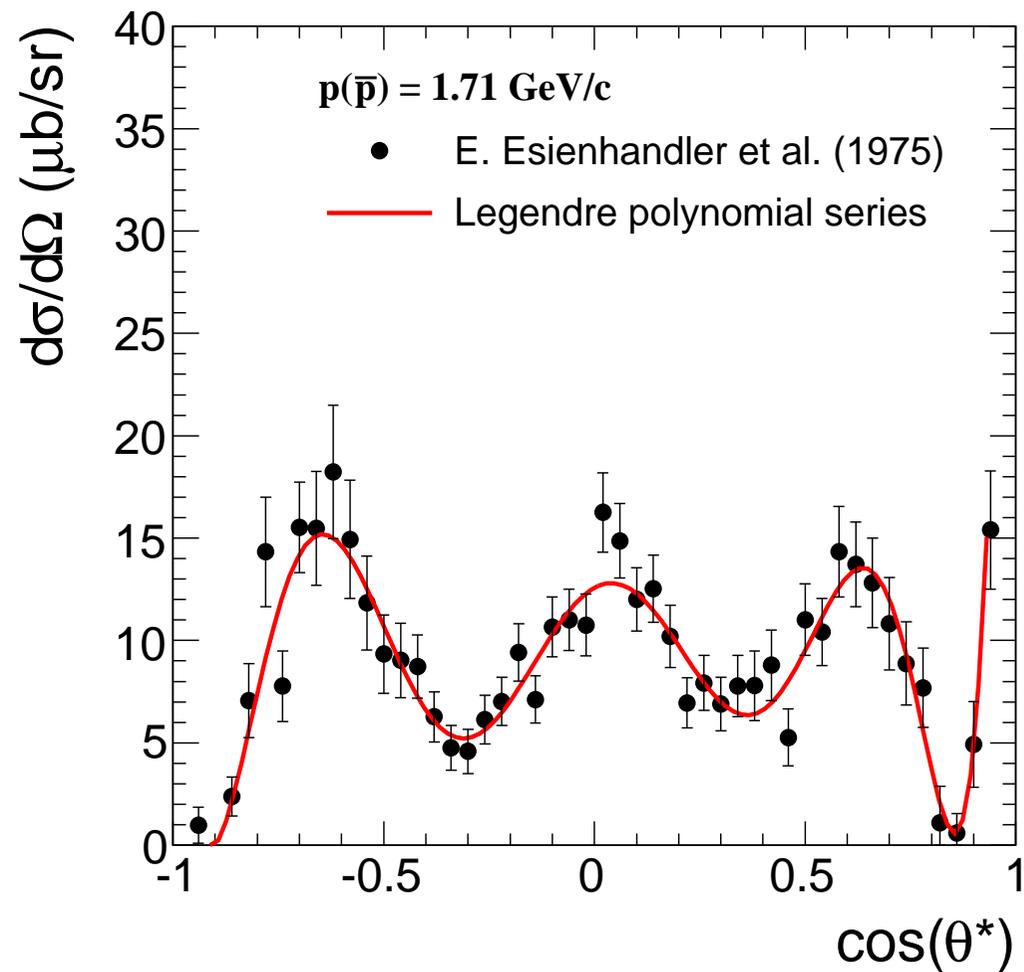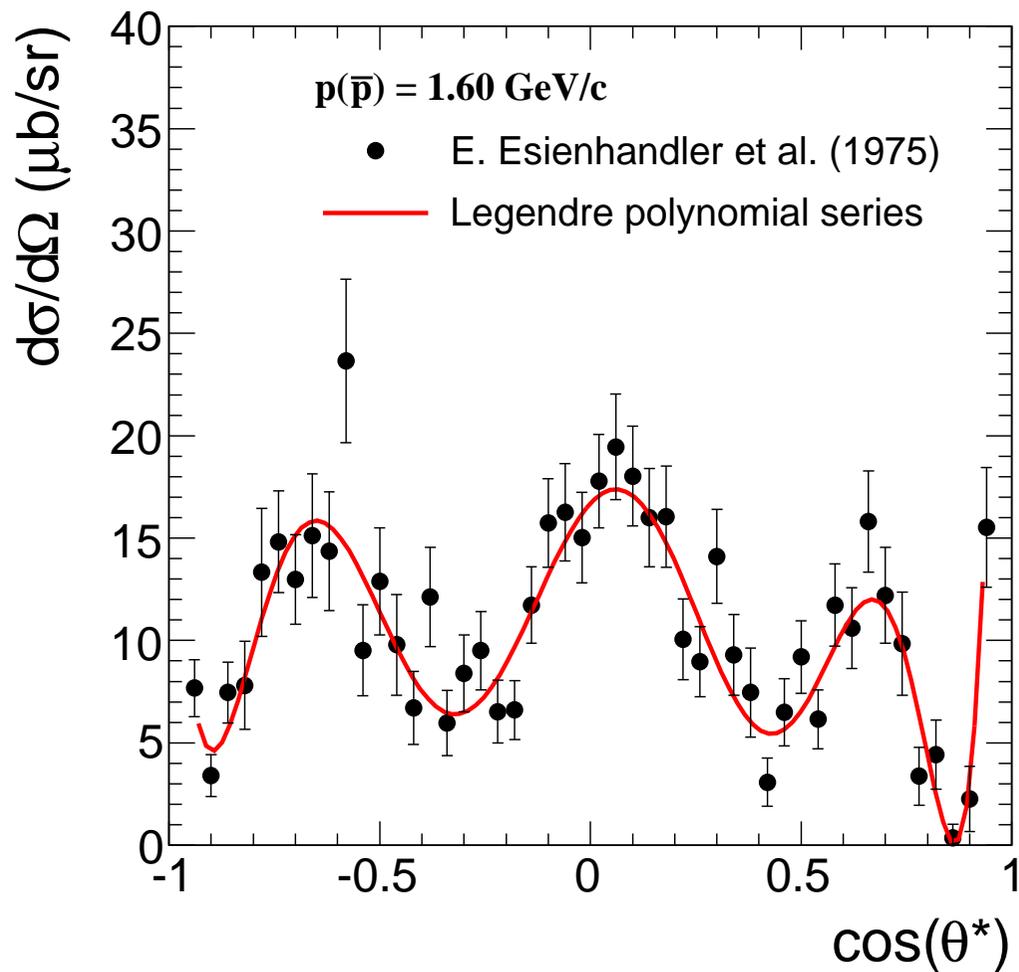
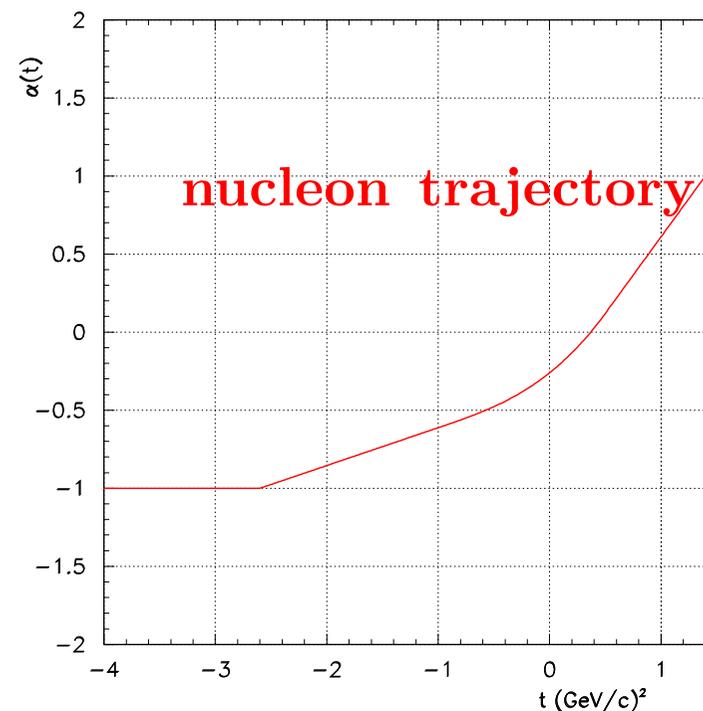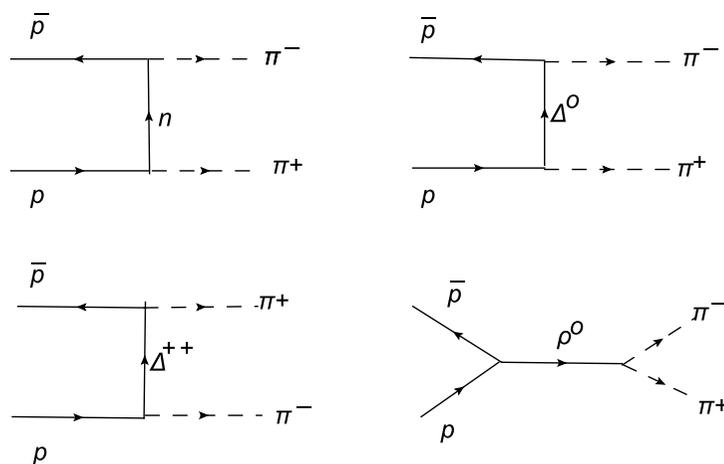# The cross section in the low energy regime

The cross section in the high energy regime

- **Regge Theory** approach to cross section calculation

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

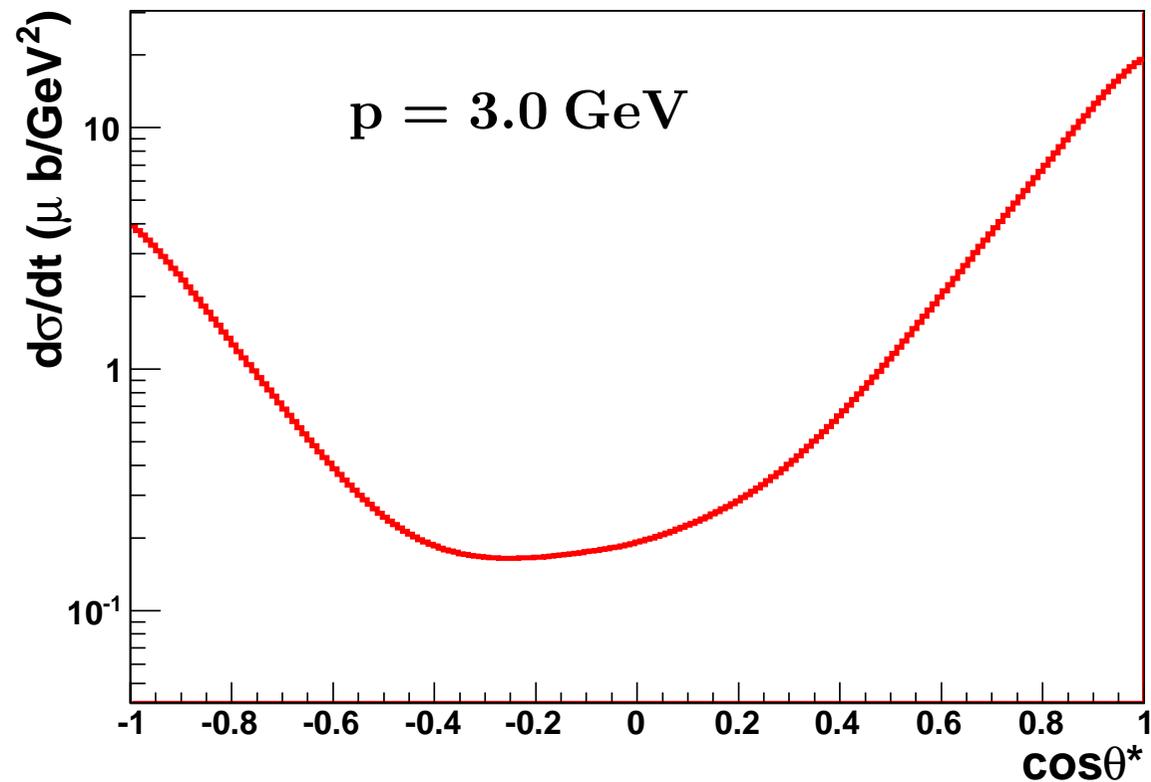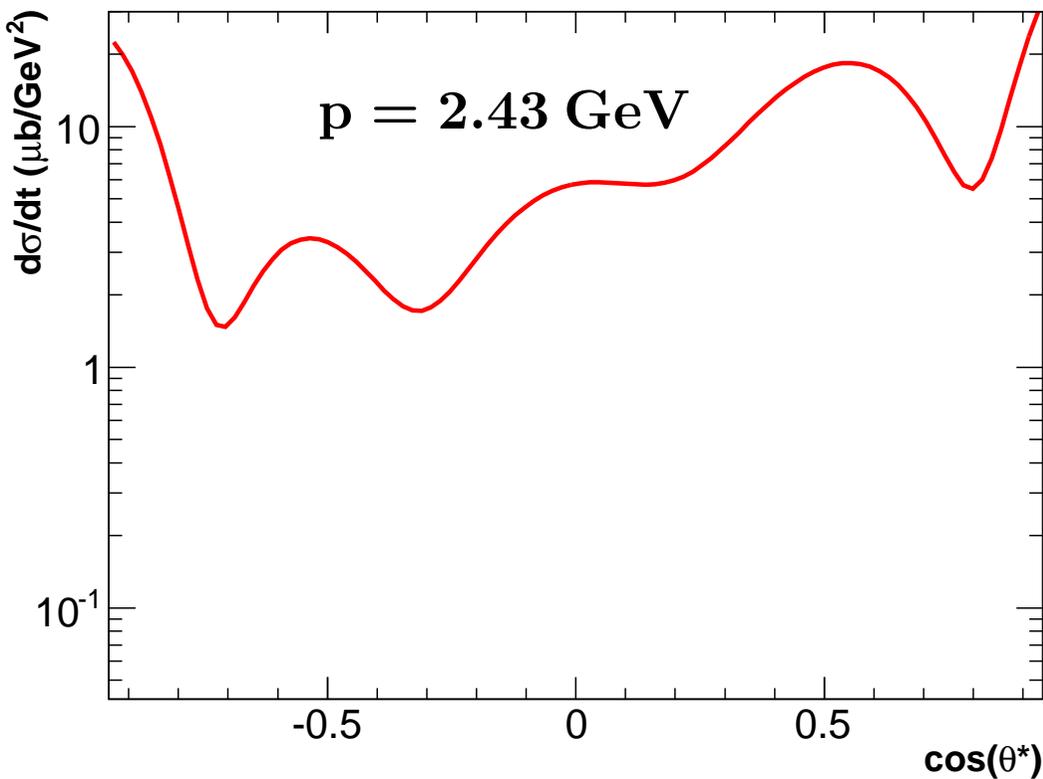 $\Rightarrow$ **parametrization of scattering amplitudes in terms of "Regge trajectories" exchanged in the t and u channels**

$\Rightarrow \dfrac{d\sigma}{dt}$ **at a** $(\mathrm{p}, \cos\theta^*)$ **grid of** (19×201) **lattice sites**

$\mathrm{p} = 3.0, \ldots, 5.0, \ldots, 12.0$ **GeV** $\Rightarrow$ **high+transition-extrapolated energy regime**
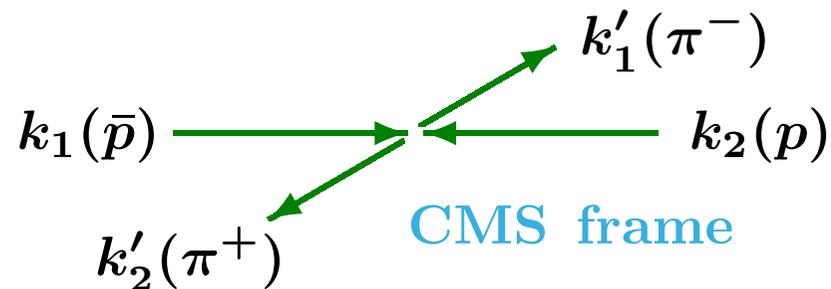
$\cos\theta^* = -1.0, \ldots, 1.0$

The cross section in the transition energy regime

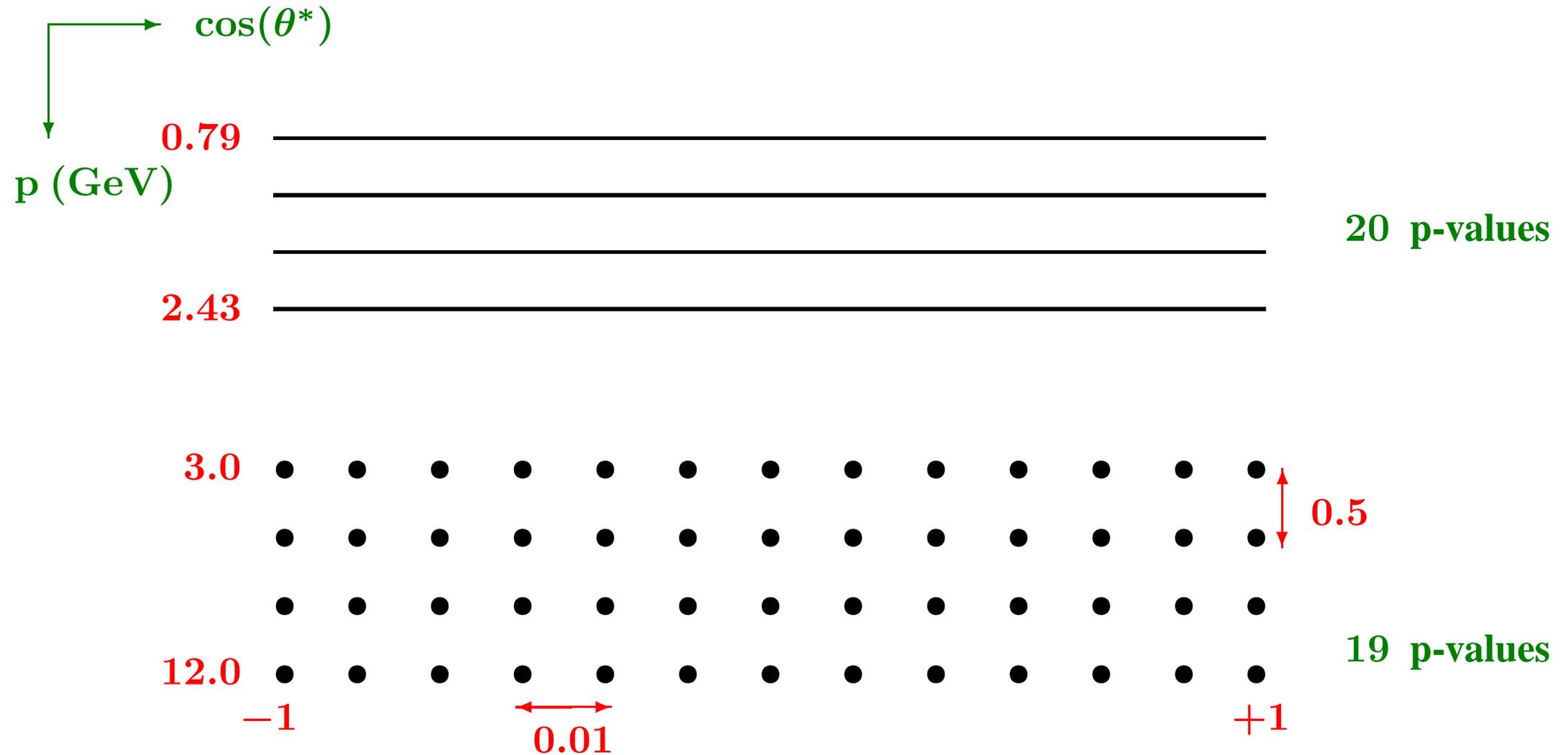$$\frac{d\sigma}{d\Omega} \rightarrow \frac{d\sigma}{dt}$$

$$t = -(k_1' - k_1)^2$$

$$\Rightarrow dt = 2|k_1||k_1'|d(\cos\theta^*)$$

The cross section : general overview

cos(θ^*)

p (GeV)

0.79 _____

_____

_____ 20 p-values

2.43 _____

3.0 • • • • • • • • • • • • • ↕ 0.5

• • • • • • • • • • • • •

• • • • • • • • • • • • •

12.0 • • • • • • • • • • • • • 19 p-values

−1

←→ 0.01

+1

σ at (p, cosθ^*) point NOT sitting at line or dot:

$\Rightarrow$ linear interpolation from nearest neirboughs $\longrightarrow$ 8 different cases

Event generation : generalities

- naive **accept/reject algorithm** (no importance sampling)
- particle momenta build in $\bar{p}p$ **CMS frame:**

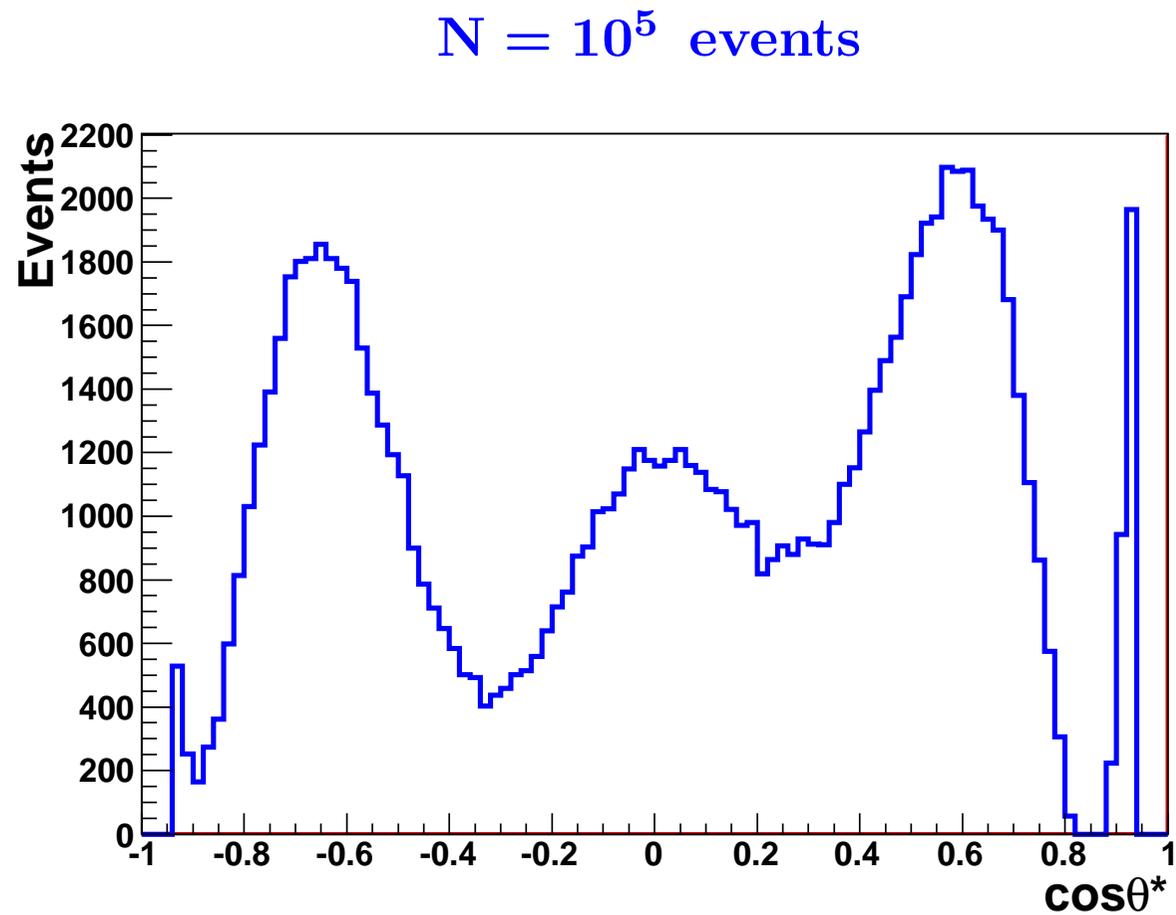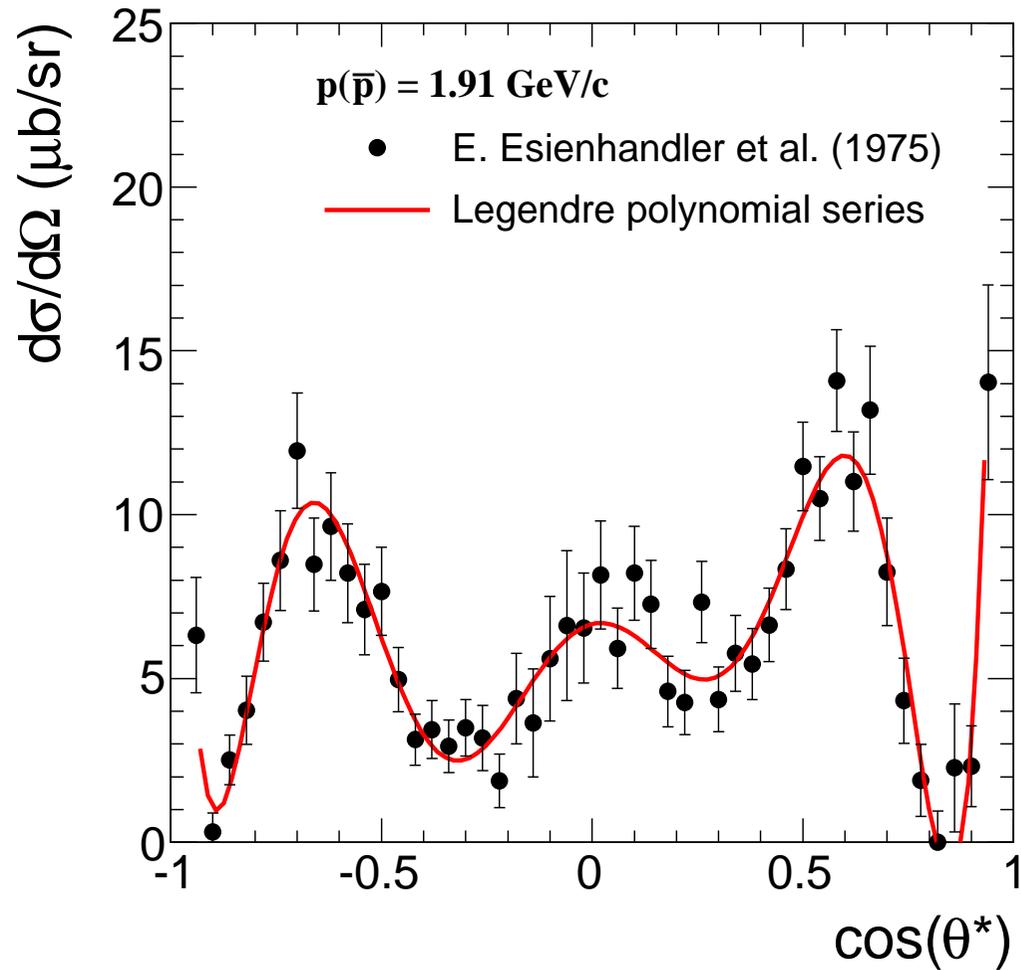$$E_{\pi+} = E_{\pi-} = \frac{\sqrt{s}}{2}, \qquad \varphi_{\pi+\pi-} = 180 \ \text{deg}$$

$$\text{prob}(\cos\theta^*) \sim \frac{d\sigma}{d\cos\theta^*}, \quad \phi^* \ \text{flat distribution}$$

- boosting to LAB frame

- random number generator: $\text{RANLUX}^{(*)}$
  - $\rightarrow$ widely used in lattice QCD monte carlo simulations
  - $\rightarrow$ huge periods $\sim 10^{171}$, even at the lowest "luxury level"

$\Rightarrow$ **T** $\sim$ **30** μ sec /event
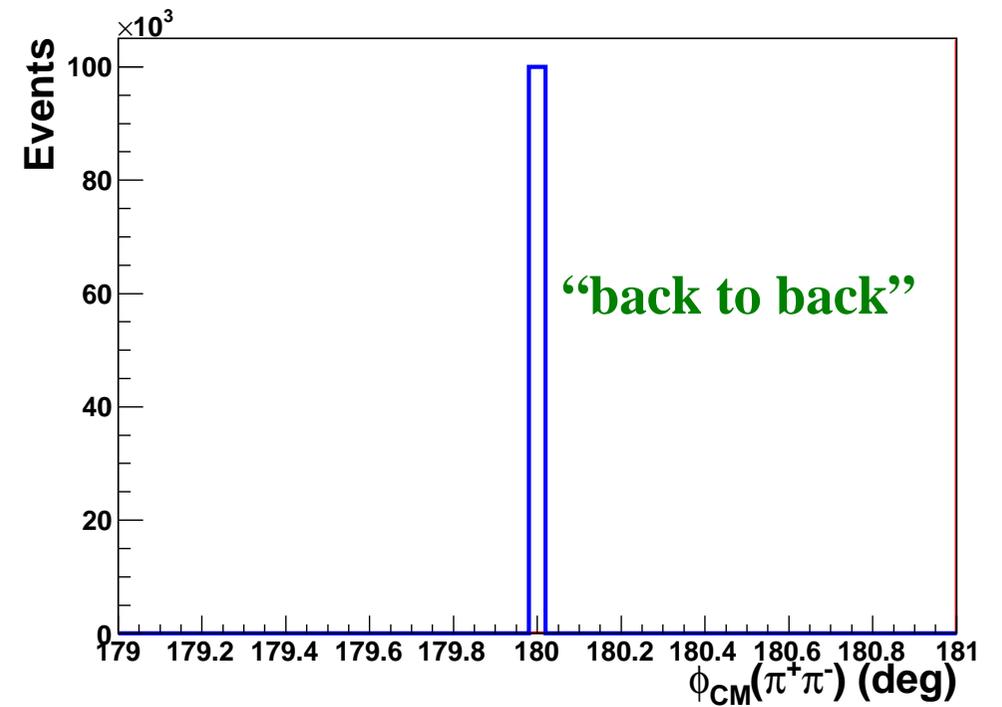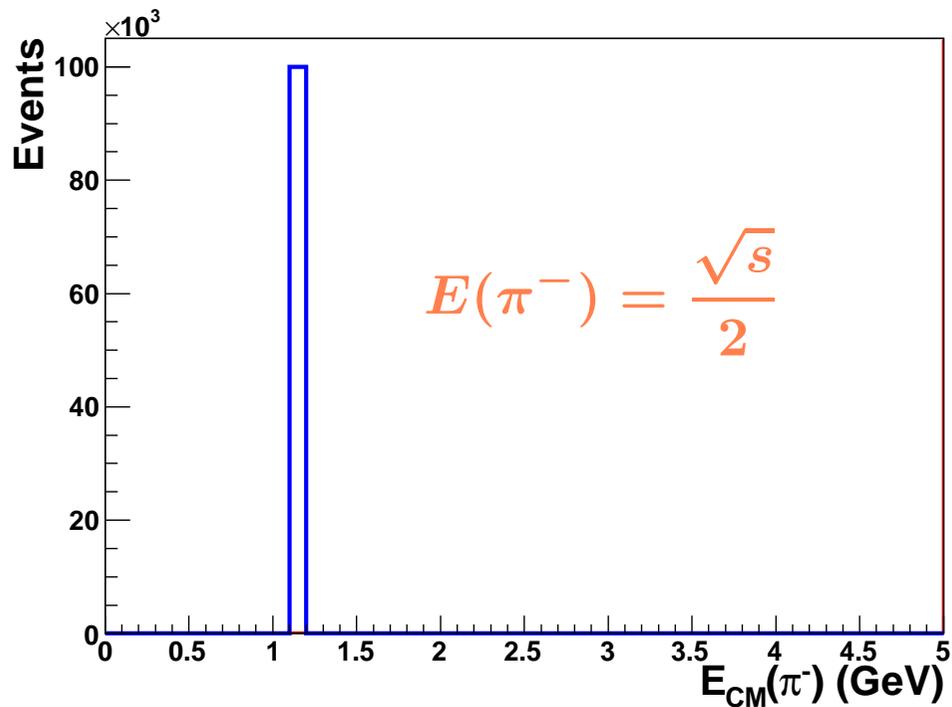
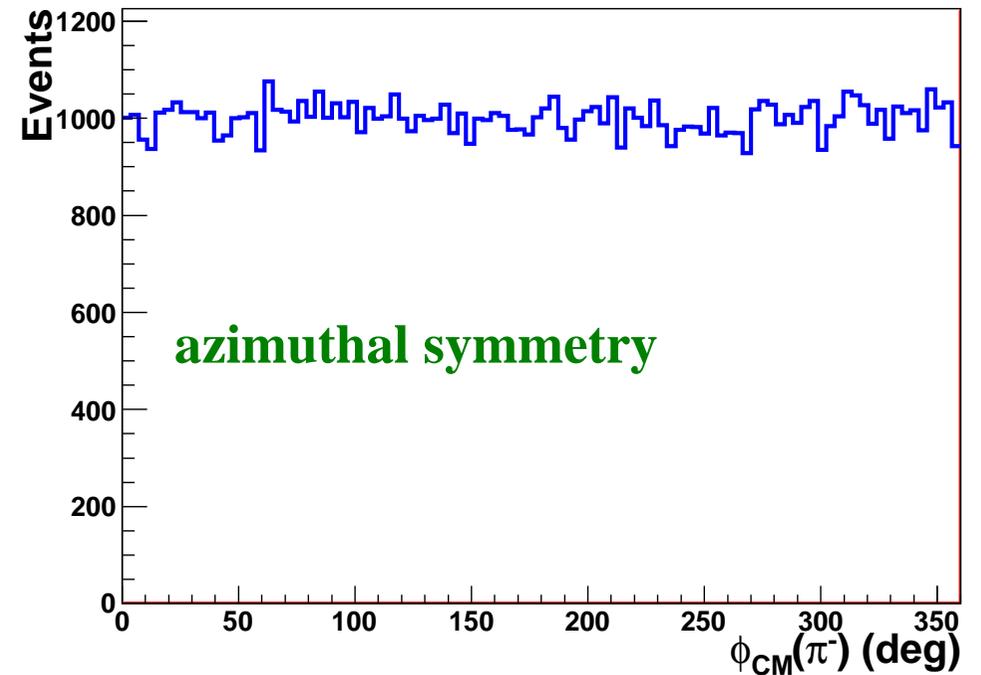(*) M. Luescher, Comp. Phys. Comm. 79 (1994) 100

Event generation : example in the low energy regime
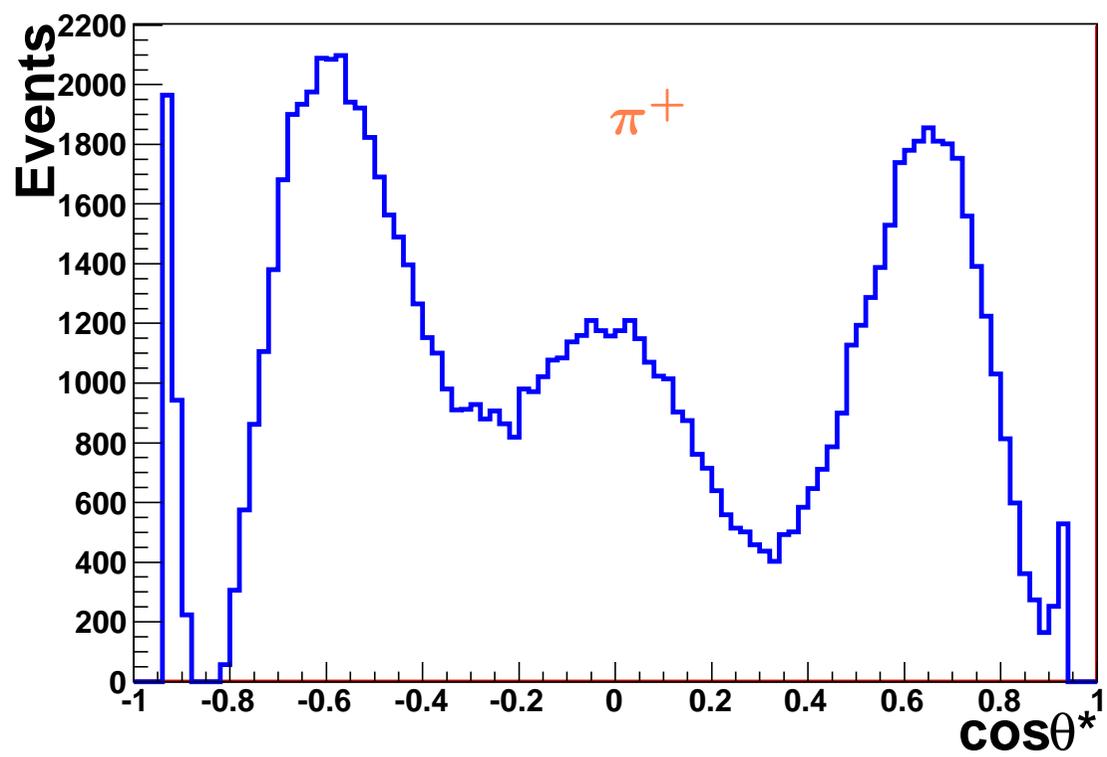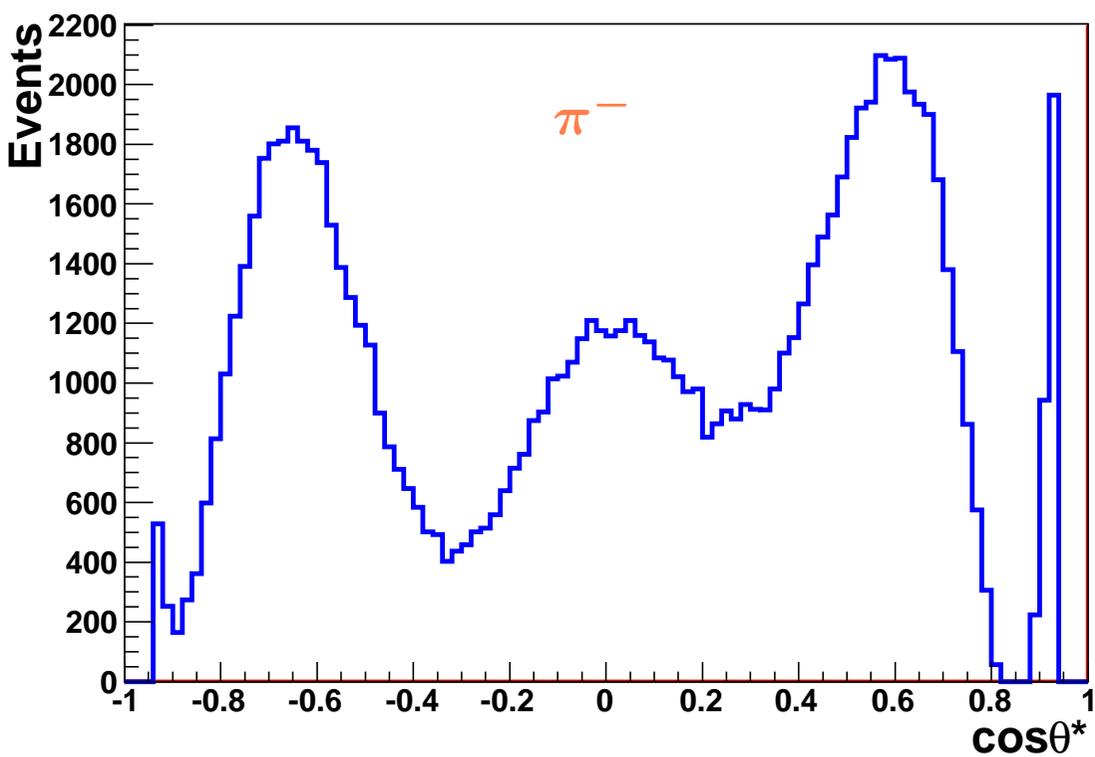
$\cdots$ some distributions in CMS frame

$$p = 1.91 \text{ GeV}$$

$$\Rightarrow \sqrt{s} = 2.4 \text{ GeV}$$

azimuthal symmetry

$\phi_{CM}(\pi^-)$ (deg)

$$E(\pi^-) = \frac{\sqrt{s}}{2}$$

$E_{CM}(\pi^-)$ (GeV)
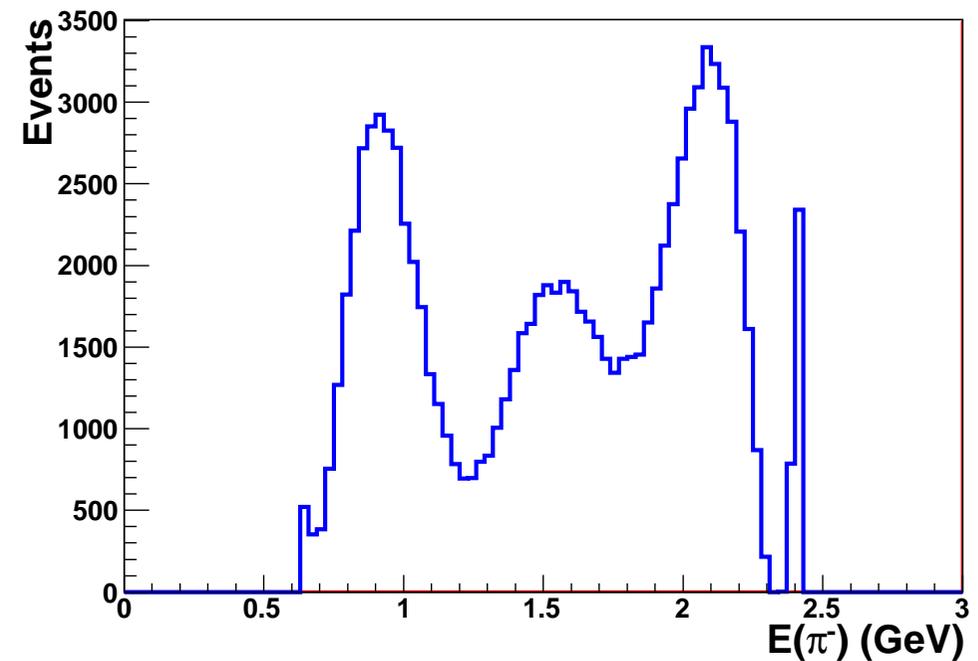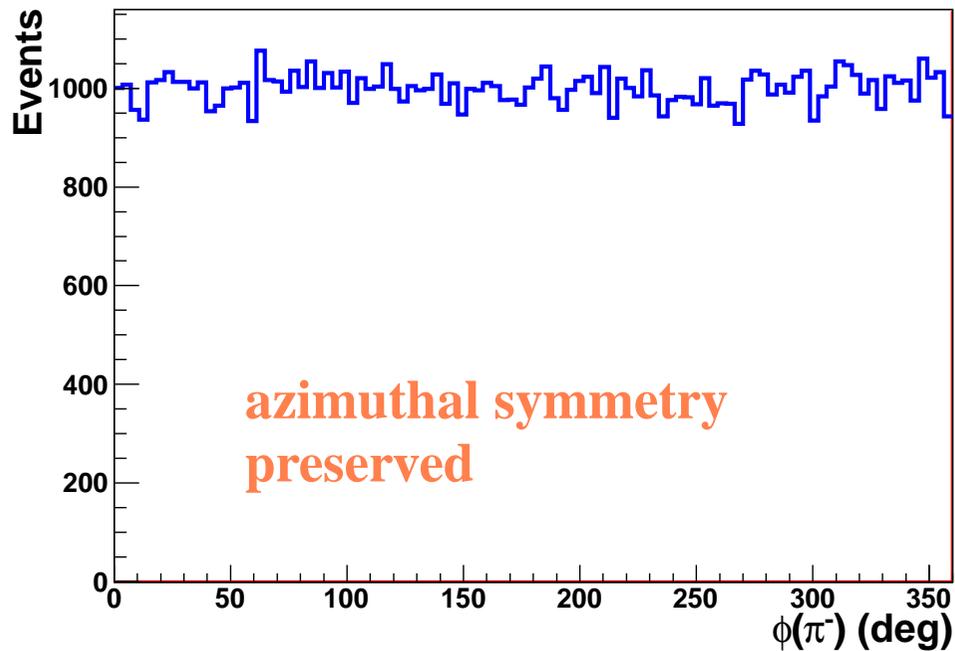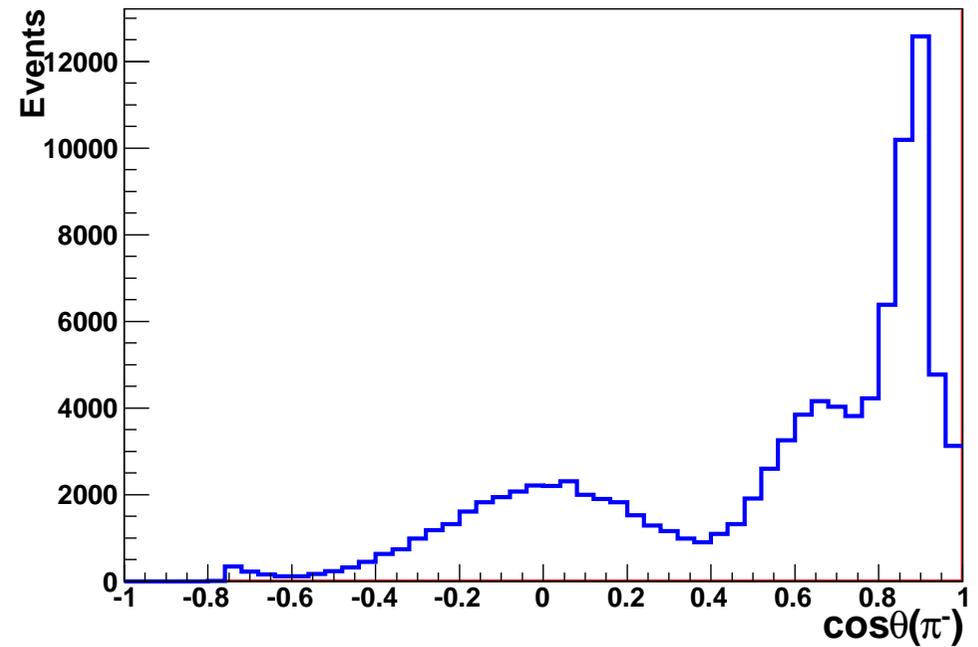

"back to back"

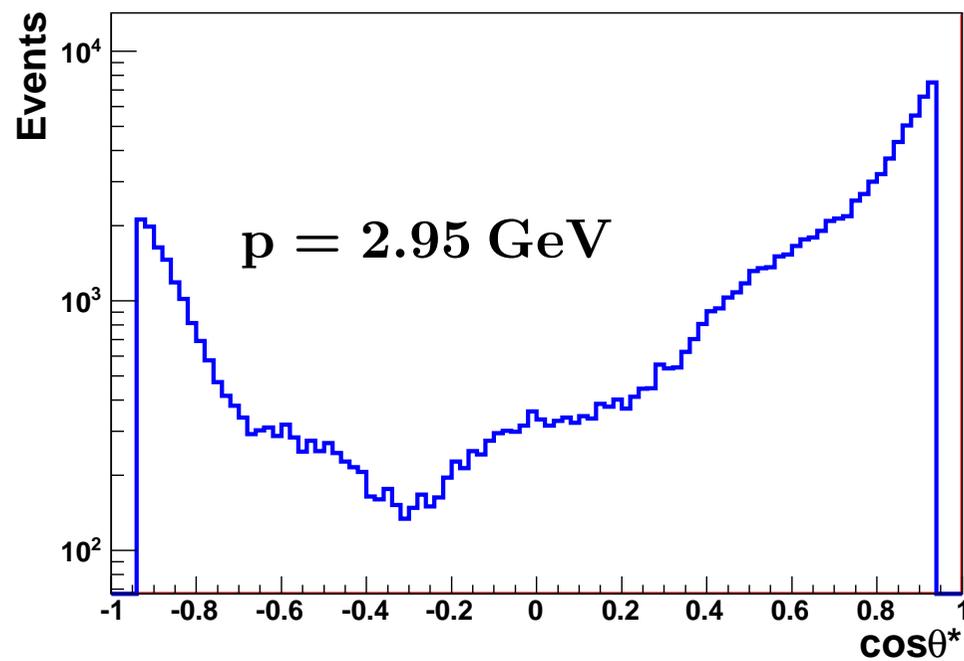$\phi_{CM}(\pi^+\pi^-)$ (deg)

⋯ some distributions in CMS frame

mirror symmetry around $\cos\theta^* = 0$
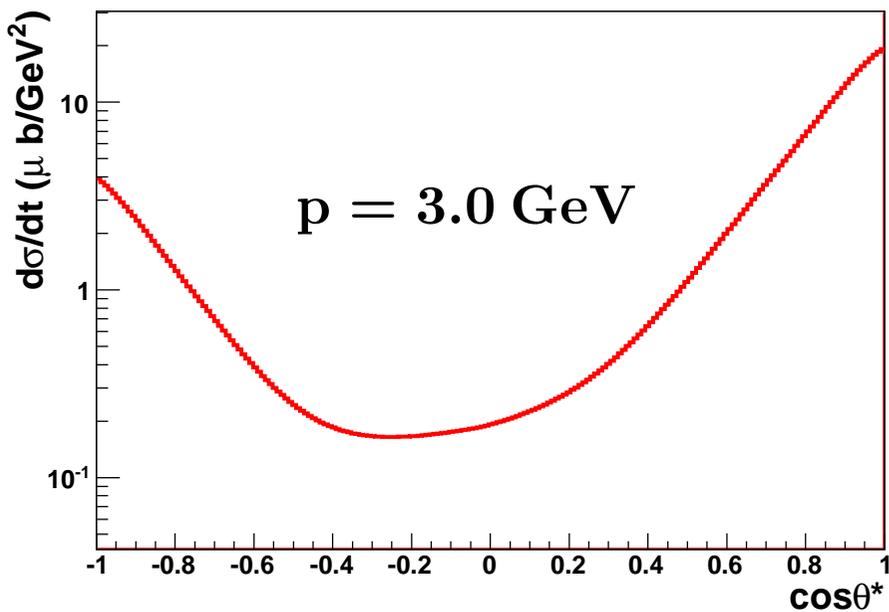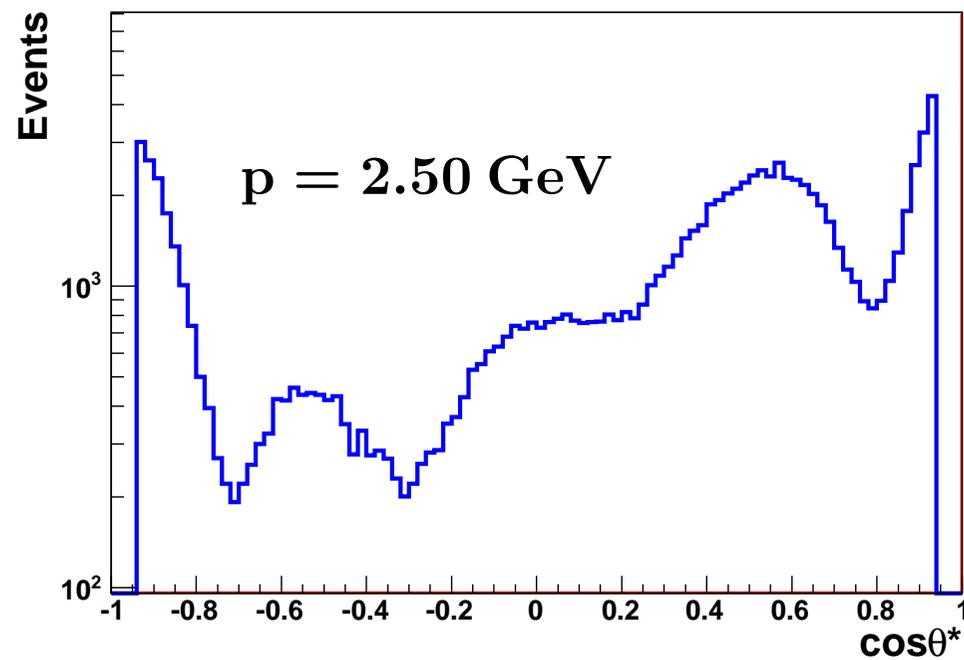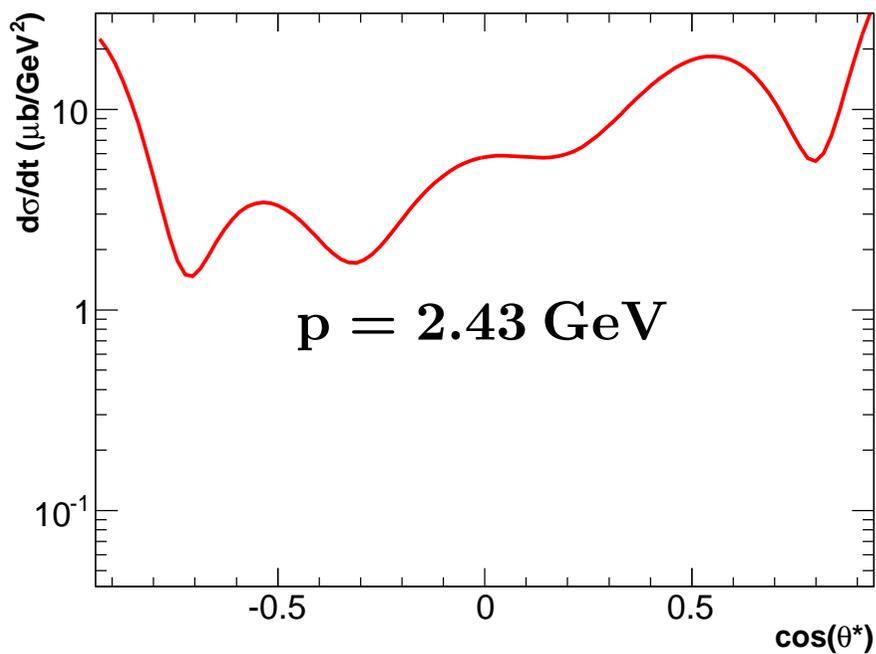
··· some distributions in LAB frame

boosting in the forward direction...

azimuthal symmetry
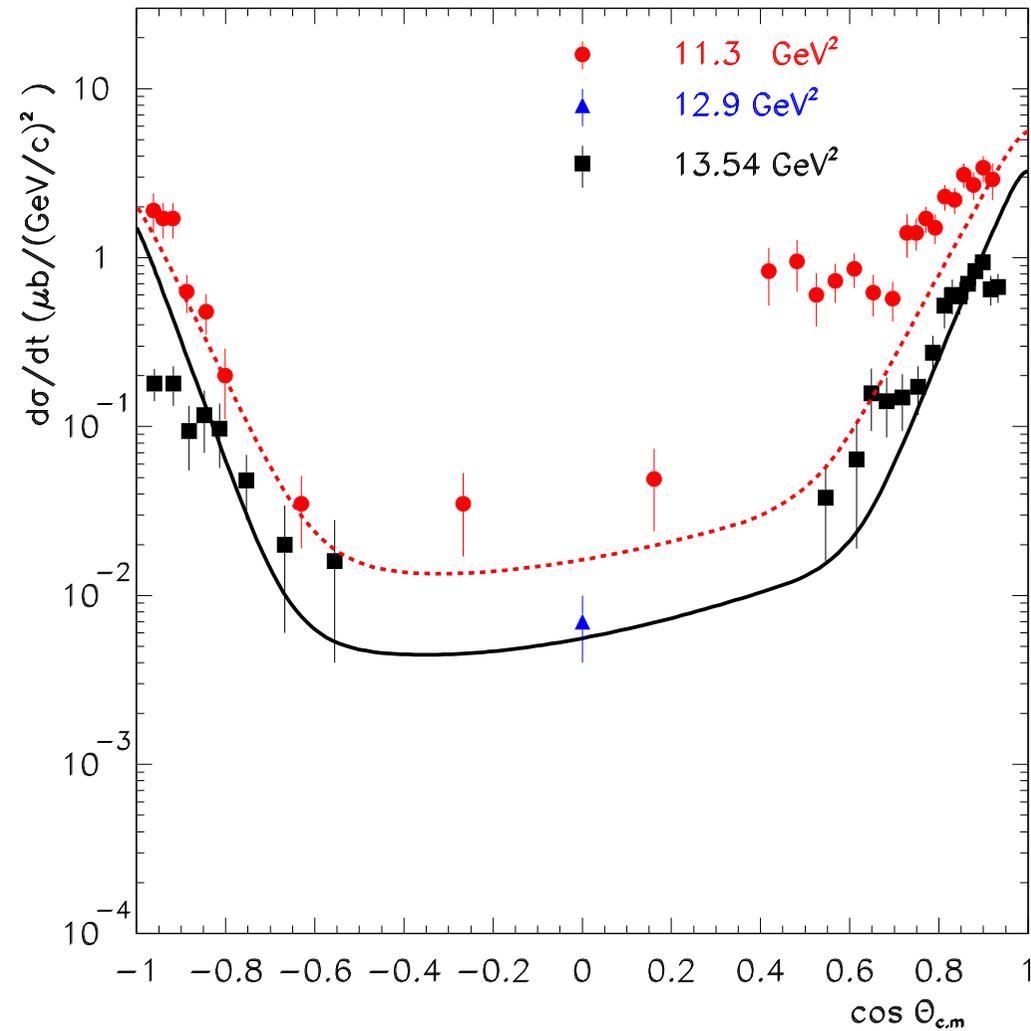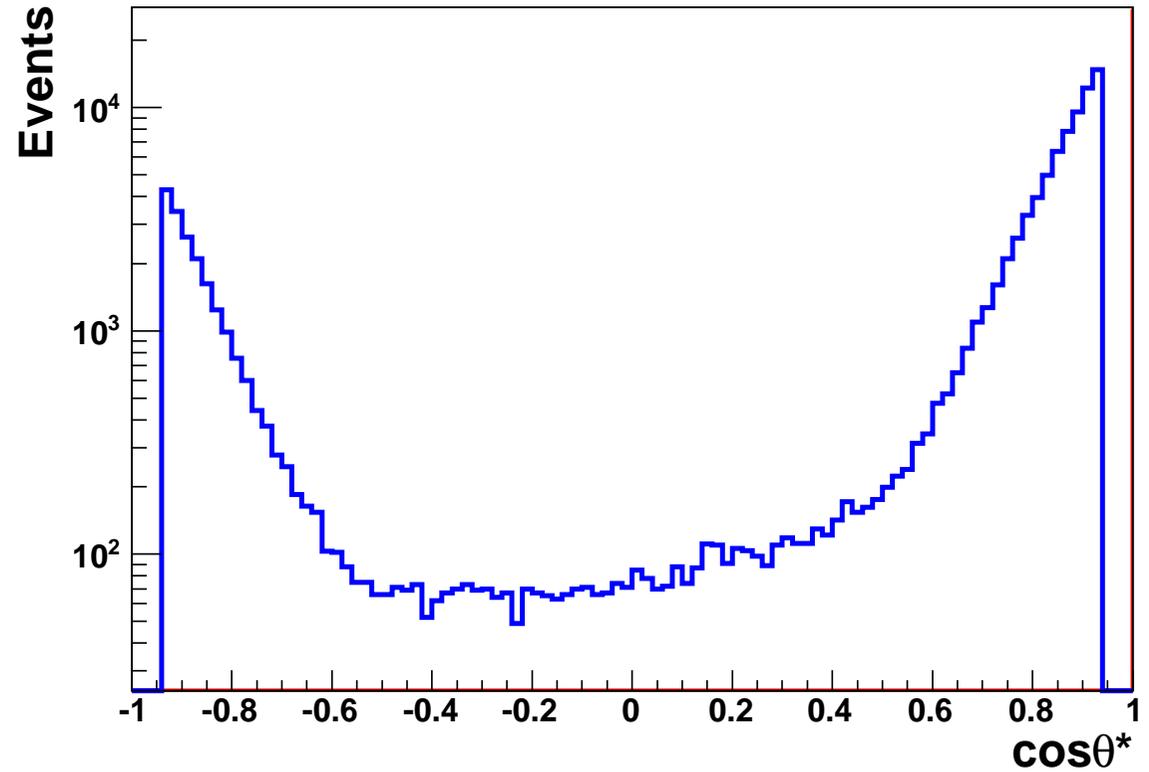preserved

Event generation : example in the transition energy regime

Event generation : example in the high energy regime

$p = 5.0 \text{ GeV} \Rightarrow s = 11.3 \text{ GeV}^2$

J. Van de Wiele and S. Ong

Interface to PandaRoot

- **generator successfully interfaced to PandaRoot (simulation framework)**

  $\rightarrow$ **output (i.e. particle momenta) directly streamed to simulation framework during execution time (no ASCII files or trees needed)**

- **generator made public to the PANDA Collaboration and available for simulations in current "trunk" PandaRoot version**

- **complete documentation already available:**

```
http://panda-wiki.gsi.de/
cgi-bin/view/PANDAMainz/EventGenerators
```

Summary and conclusions

- full $\bar{\text{p}}\text{p} \to \pi^+\pi^-$ event generator in the $\bar{\text{p}}$ momentum range $0.79 < \text{p} < 12.0\ \text{GeV}$

- generator interfaced to PandaRoot

- full documentation available

ongoing work . . .

$\to$ simulation and analysis (see Dmitry Khaneft's talk)
$\to$ working on more channels : $\bar{\text{p}}\text{p} \to \text{e}^+\text{e}^-\pi^0$, etc.

hope that you will also use the generator!