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

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OUTLINE

- **introduction**
- **kinematic regimes**
- **the cross section in all kinematic regimes**
- **event generation: generalities and examples in all kinematic regimes**
- **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:

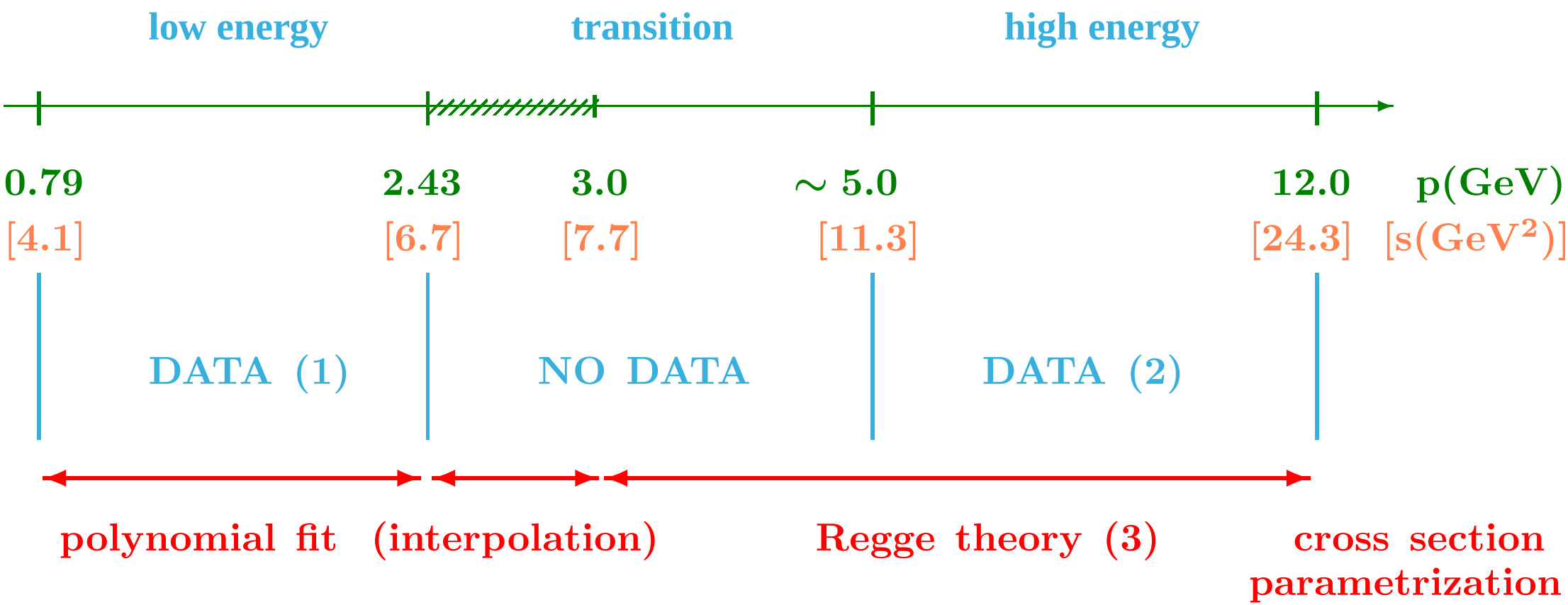
make feasibility studies of proton form factors measurements using the PANDA detector

$\Rightarrow$ **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



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

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

  $\mathrm{p} = \text{antiproton momentum in lab frame}, \qquad \mathrm{p} = 0.79, \ldots, 2.43 \text{ GeV}$
  $\theta^* = \text{angle}\,(\pi^-, \bar{\mathrm{p}}) \text{ in } \bar{\mathrm{p}}\mathrm{p} \text{ CMS frame}, \qquad \cos\theta^* = -0.94, \ldots, 0.94$

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

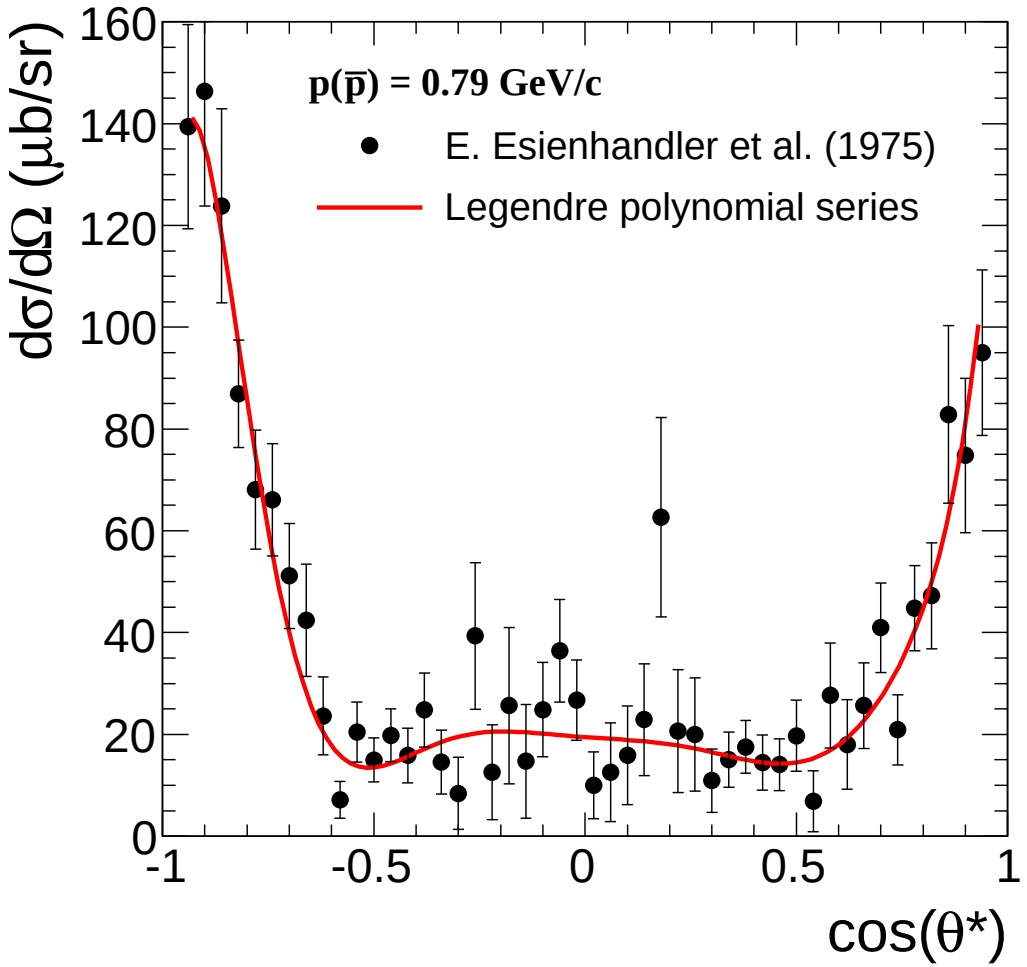
$$\frac{d\sigma}{d\Omega} = \sum_{i=0}^{10} a_i P_i(\cos\theta^*)$$

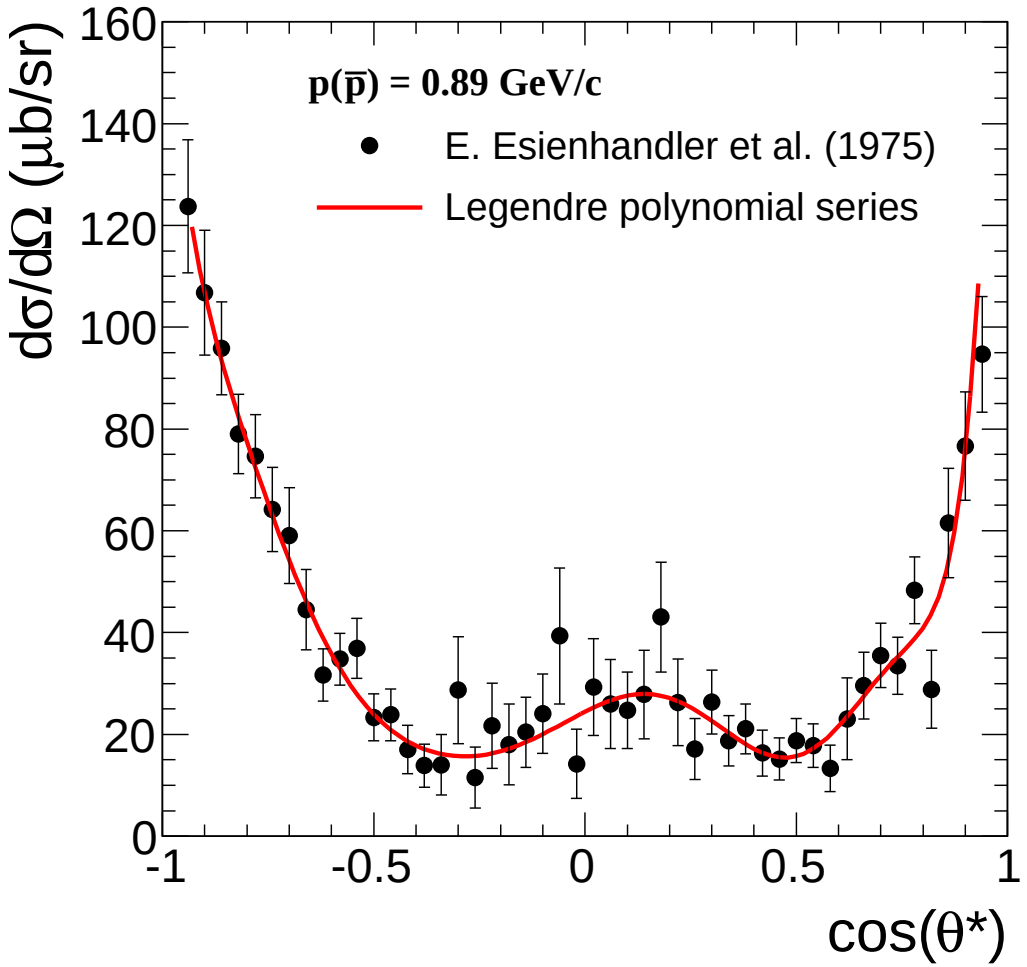
  $\rightarrow$ **fit function follows data**

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

  $\rightarrow \text{MINUIT output}: \qquad \text{status} = \text{“CONVERGED”}$
  $\text{error matrix} = \text{“ACCURATE”}$

The cross section in the low energy regime





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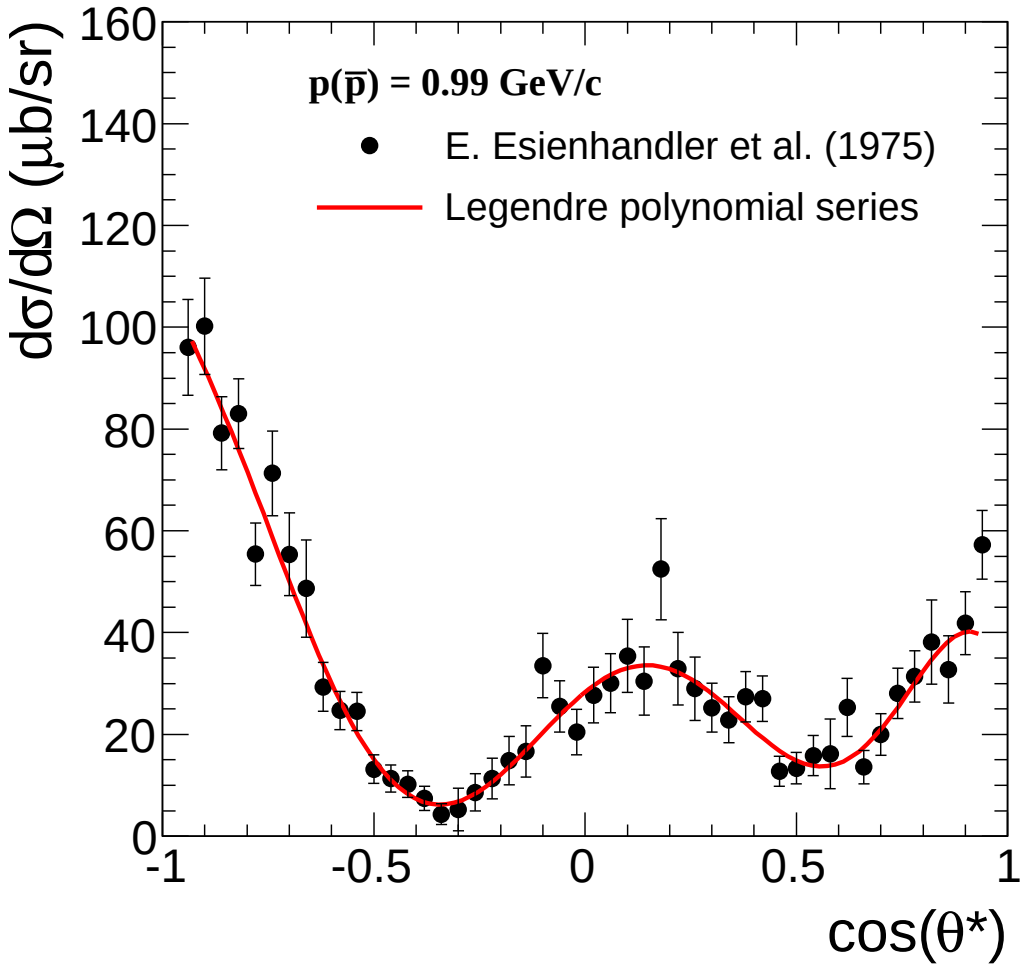

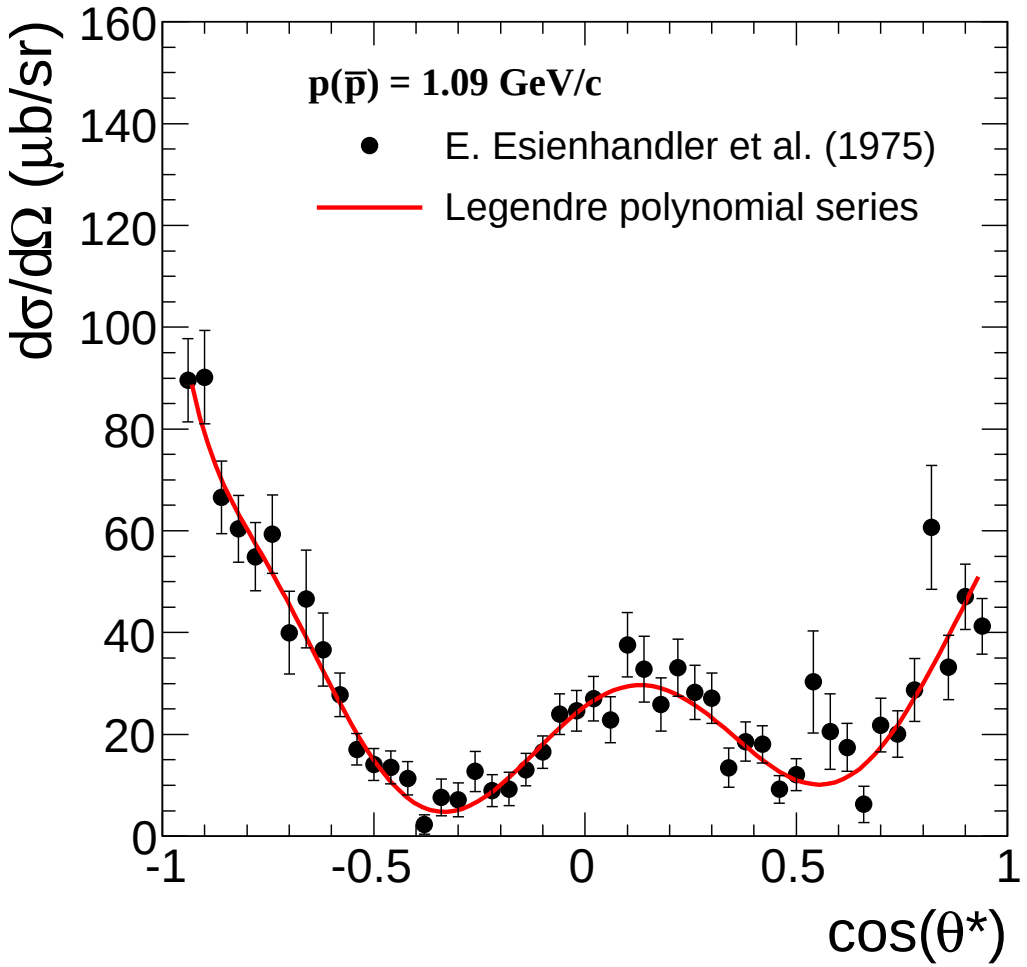

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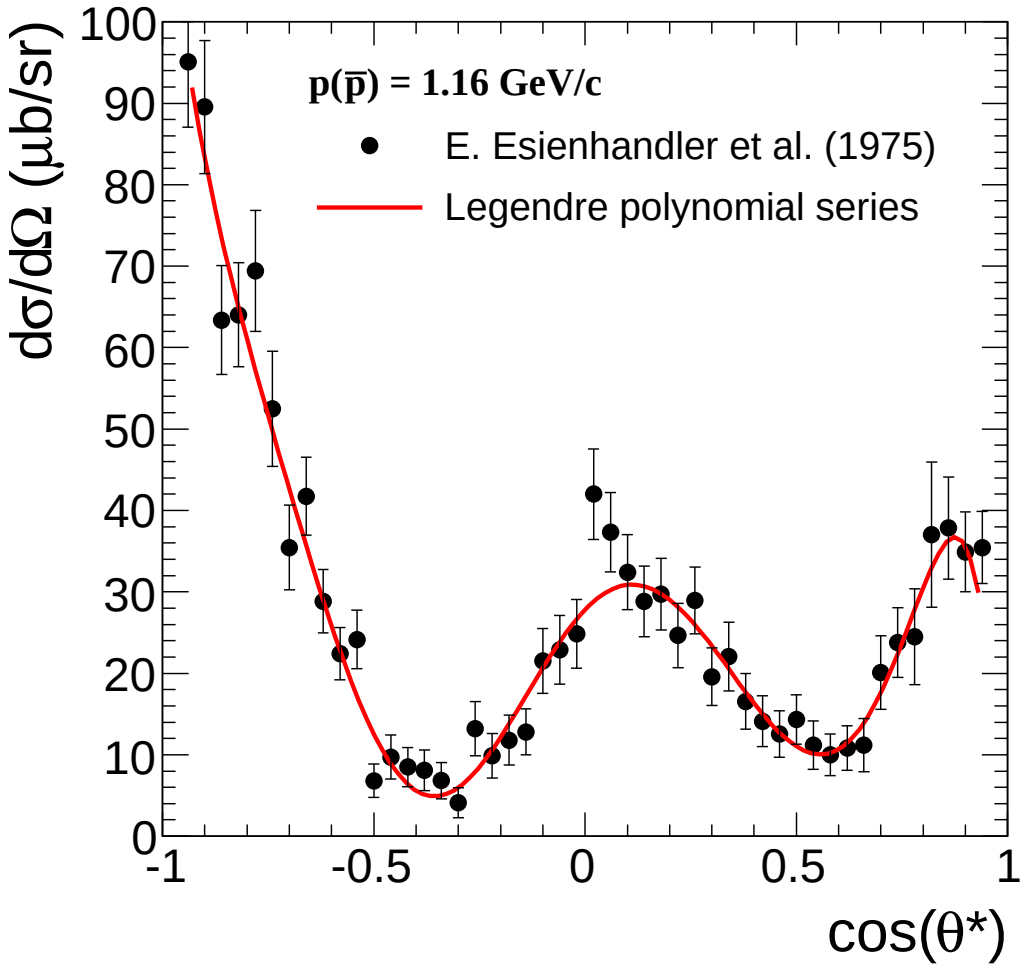

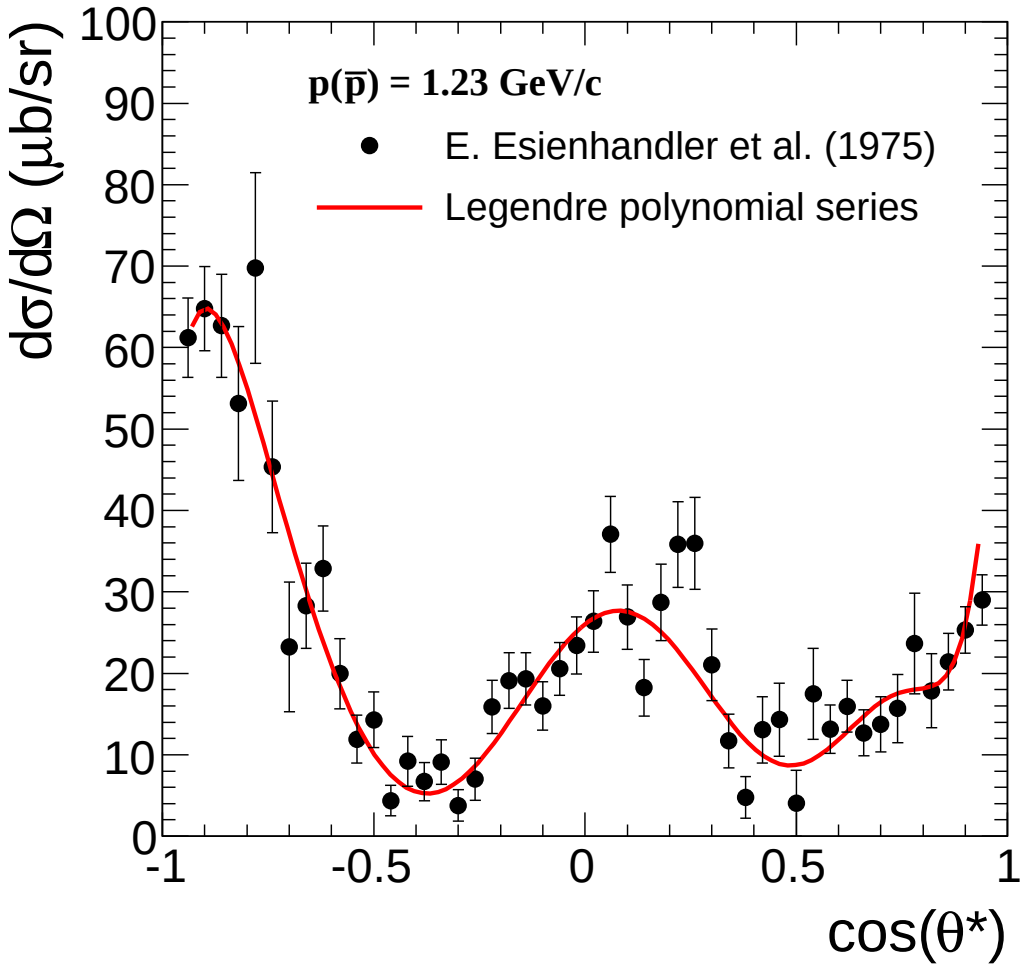

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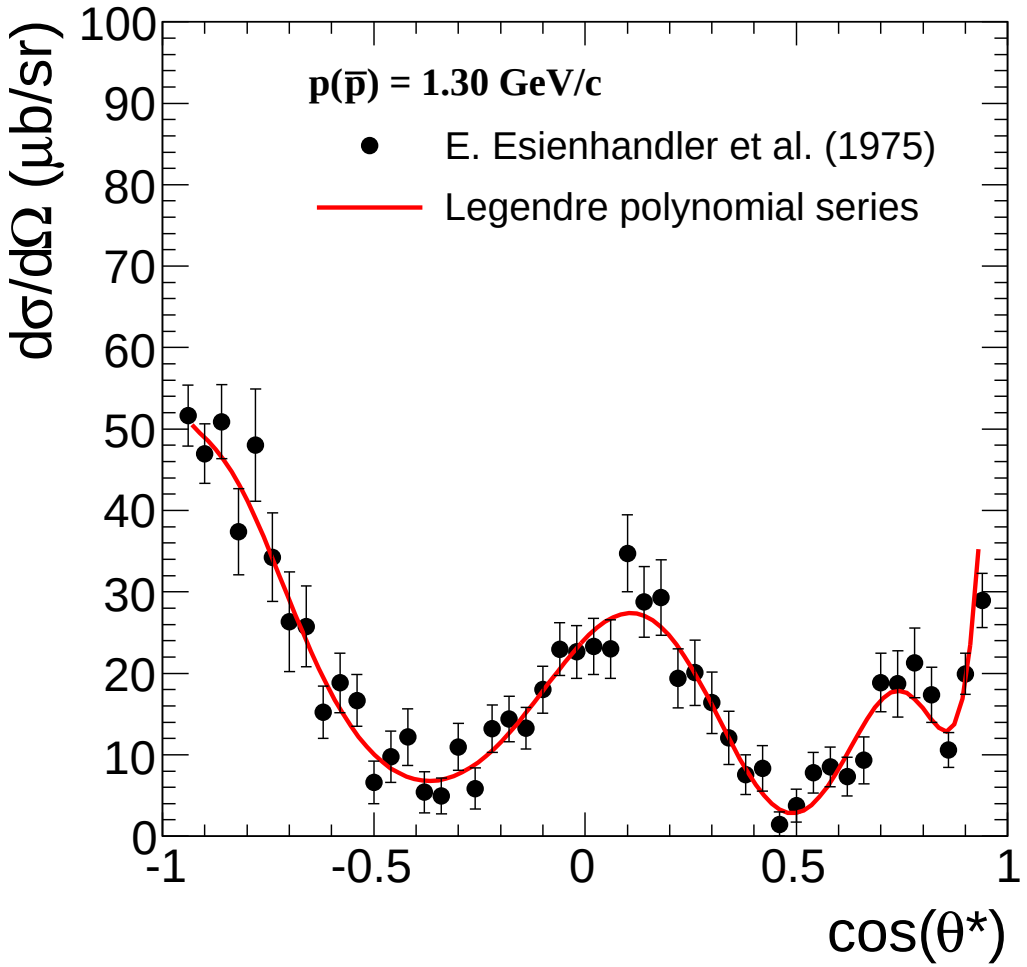
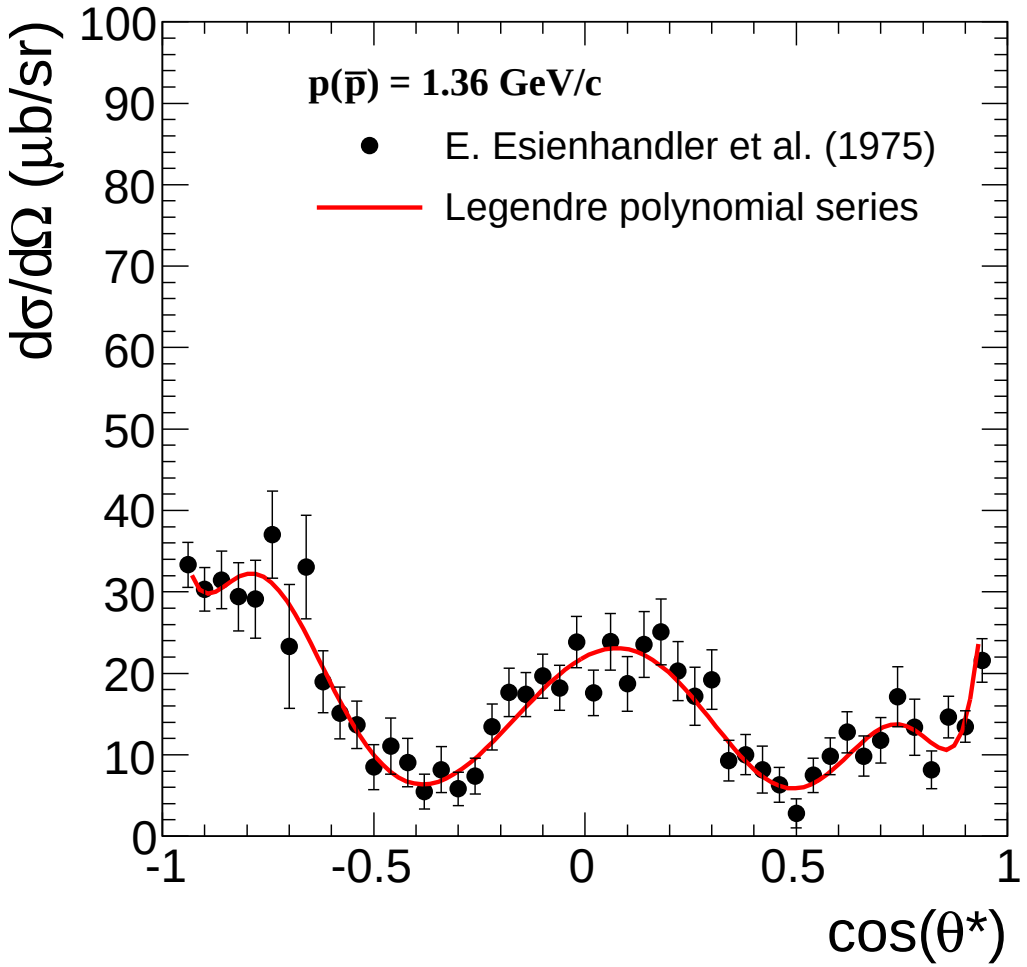
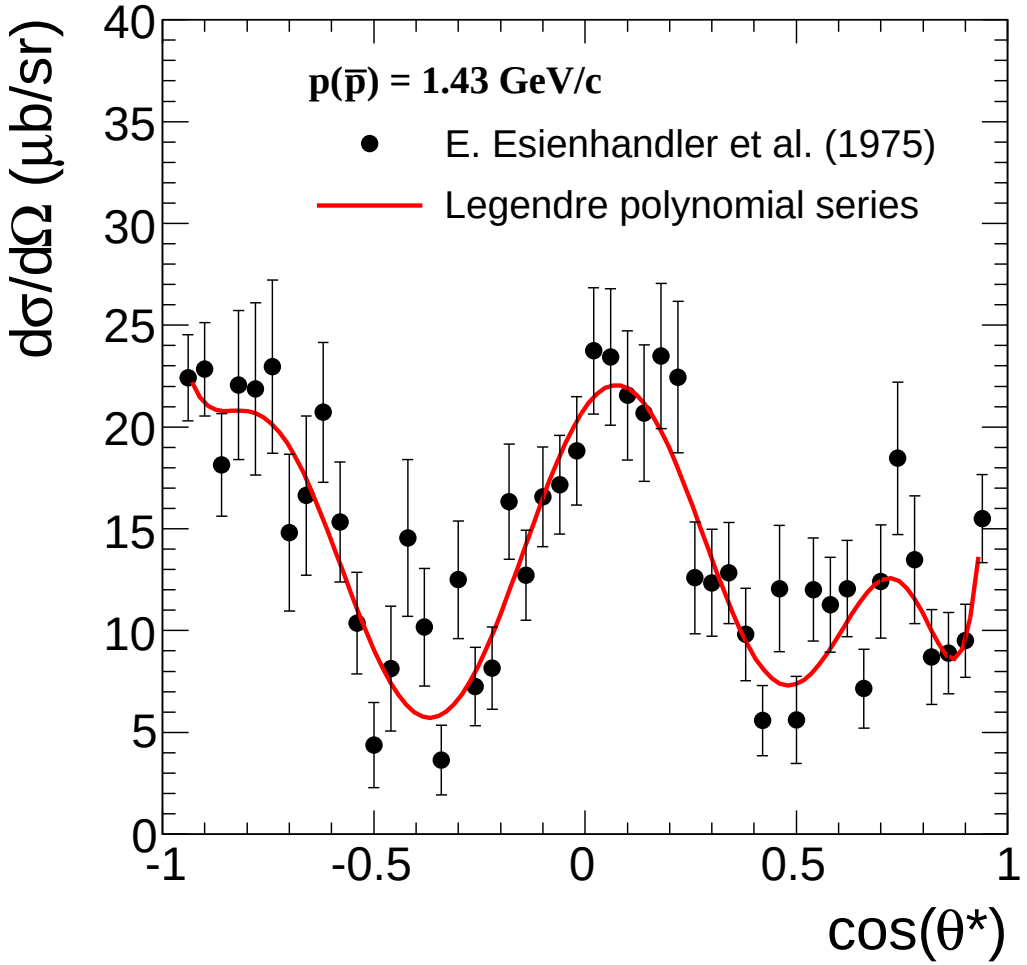
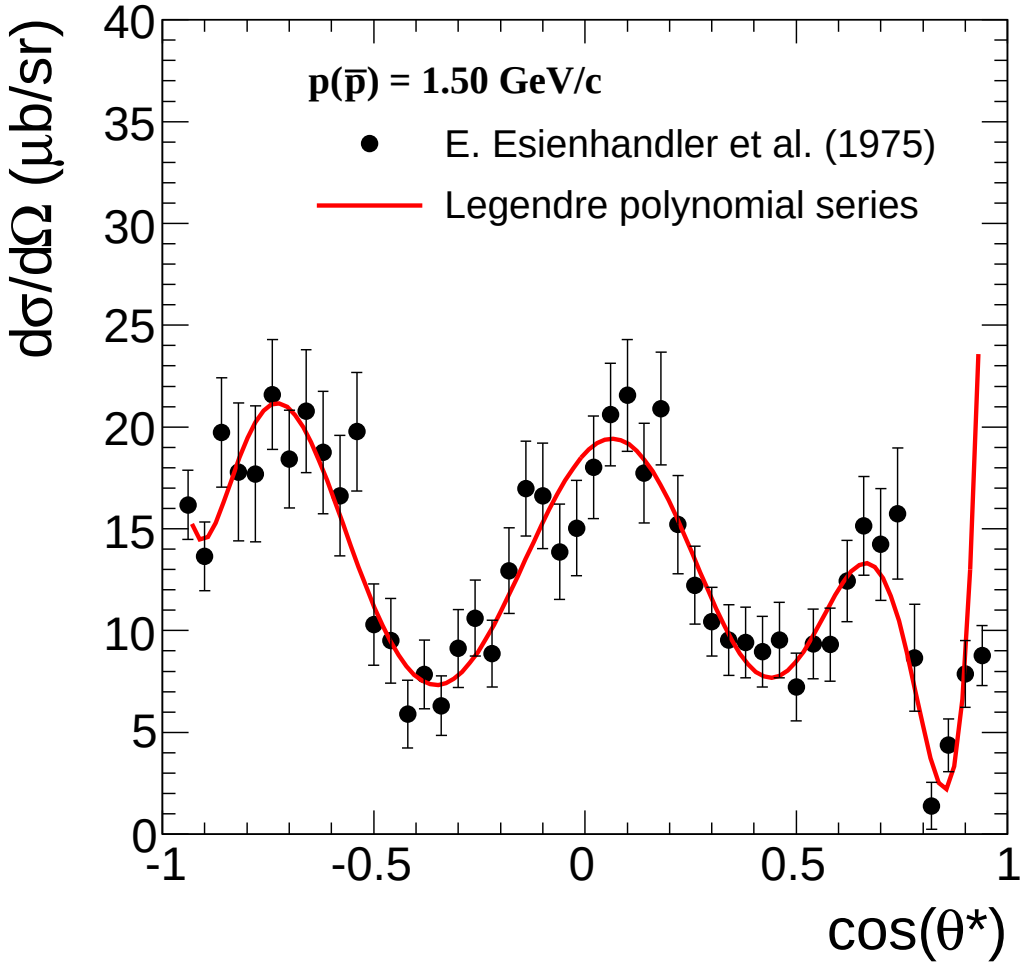


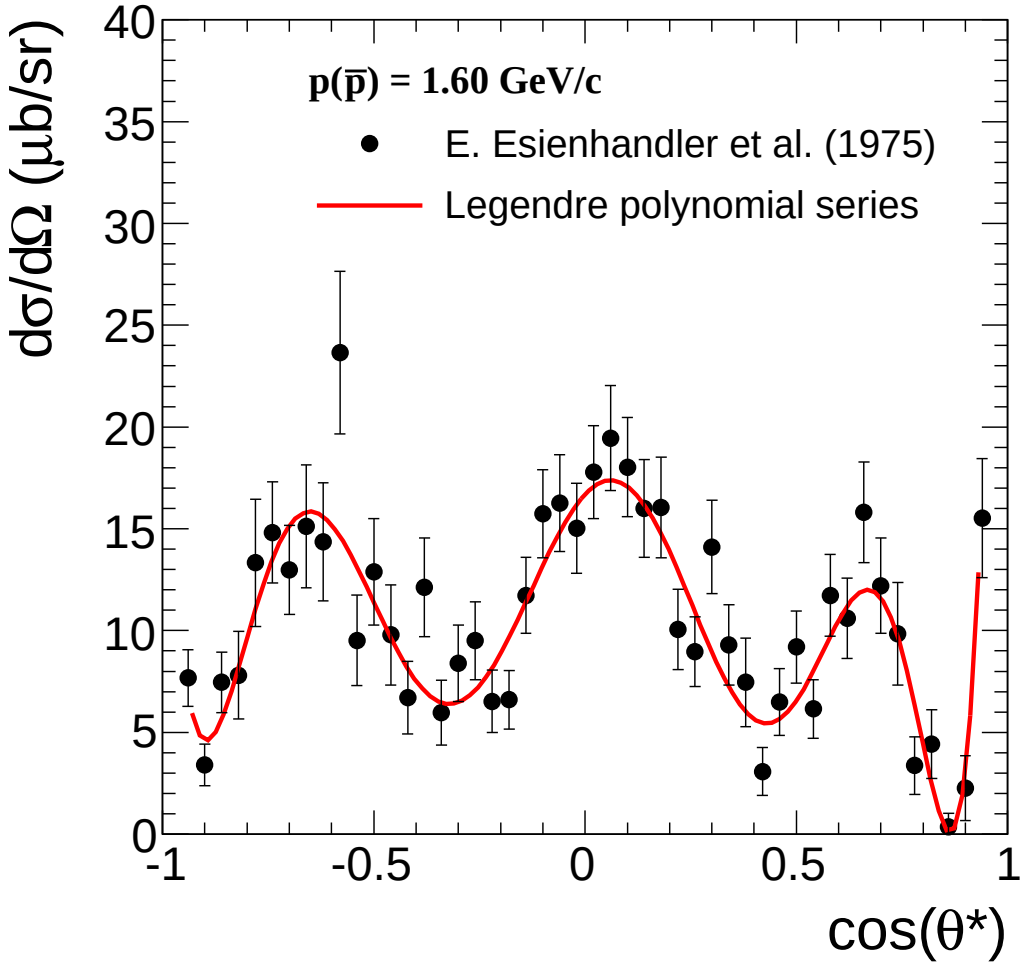


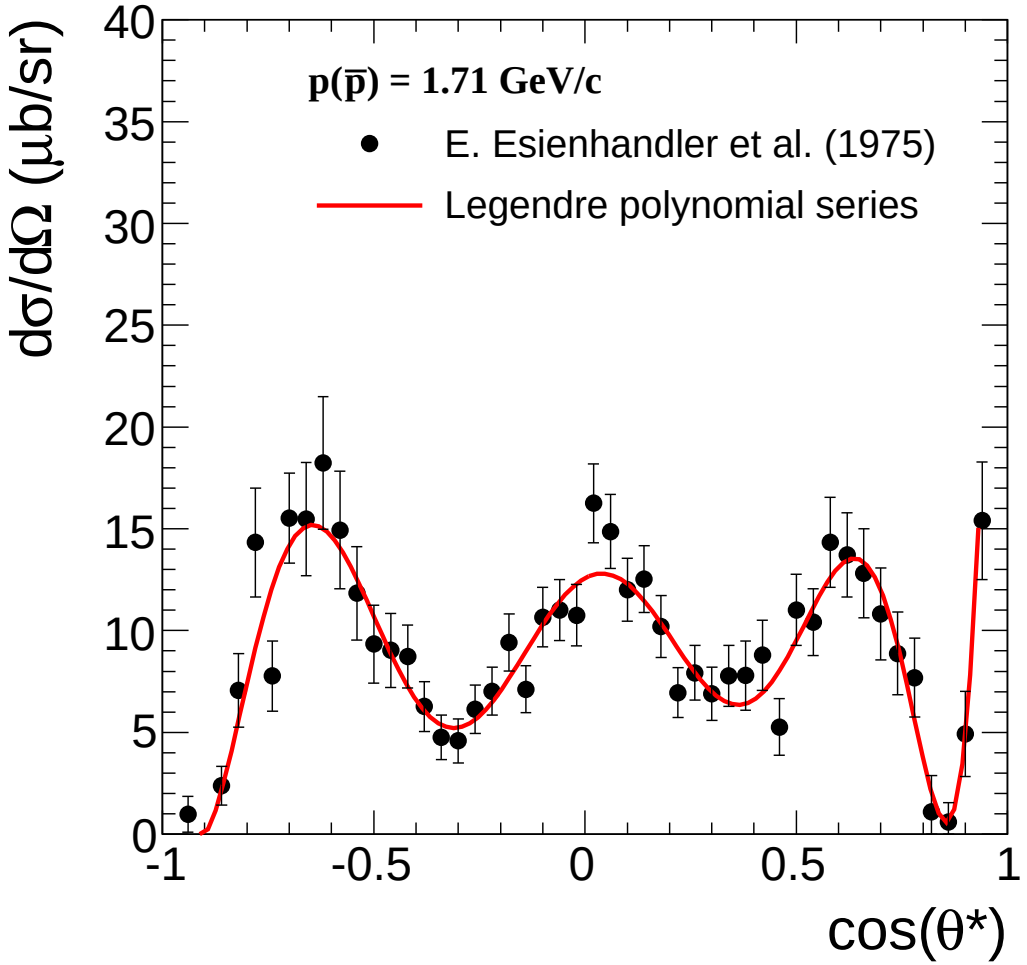
The cross section in the low energy regime



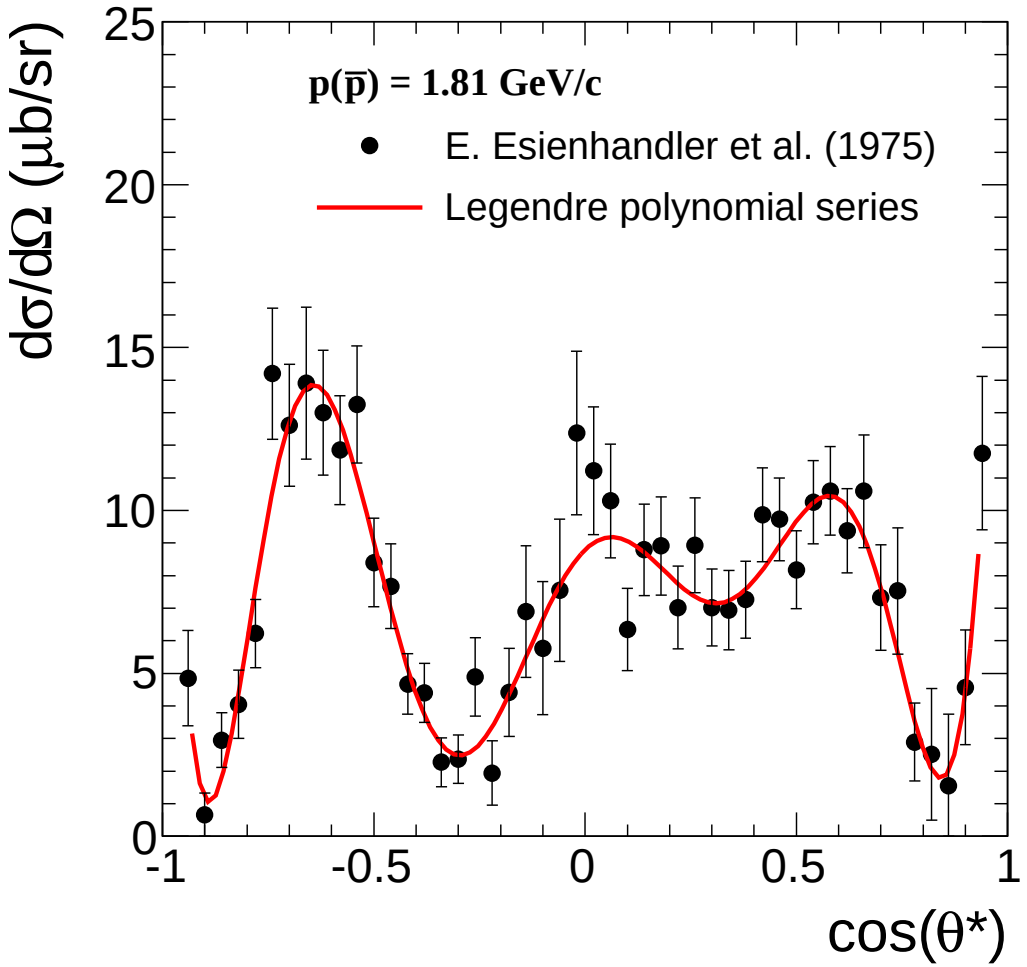


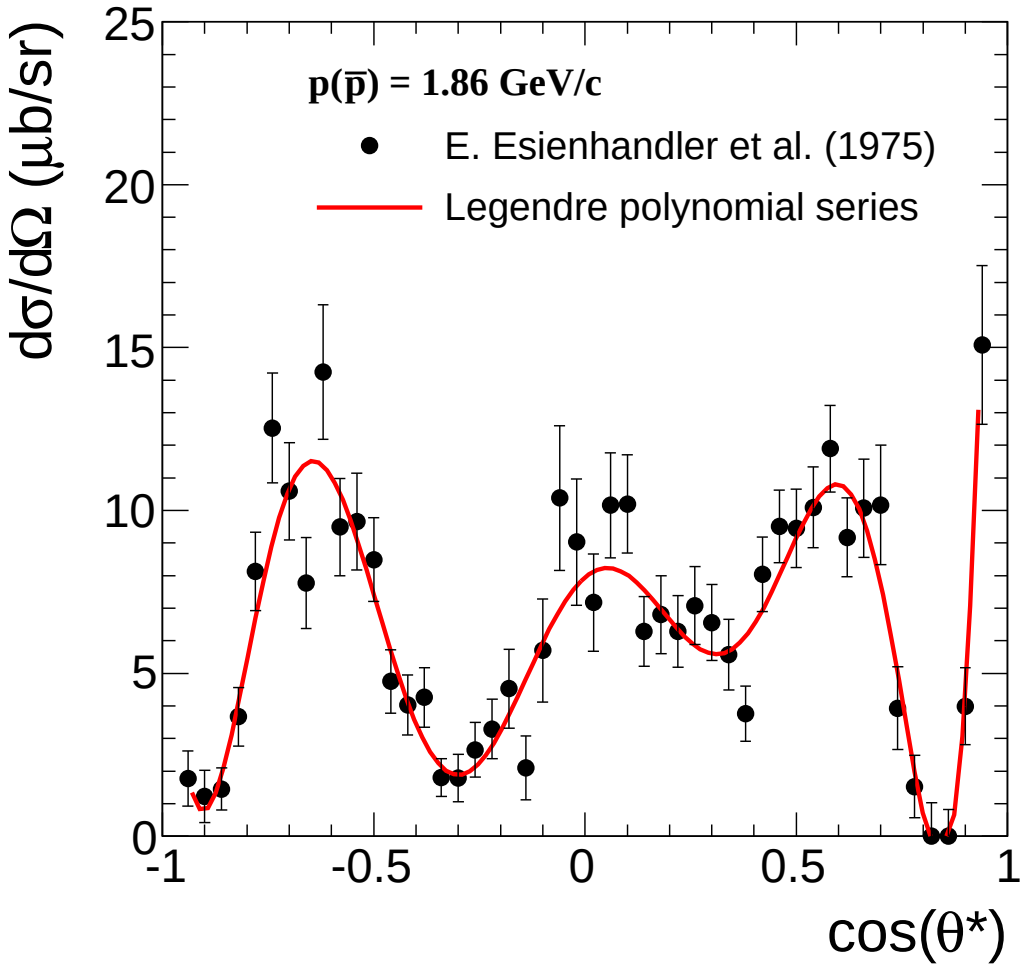
The cross section in the low energy regime





The cross section in the low energy regime





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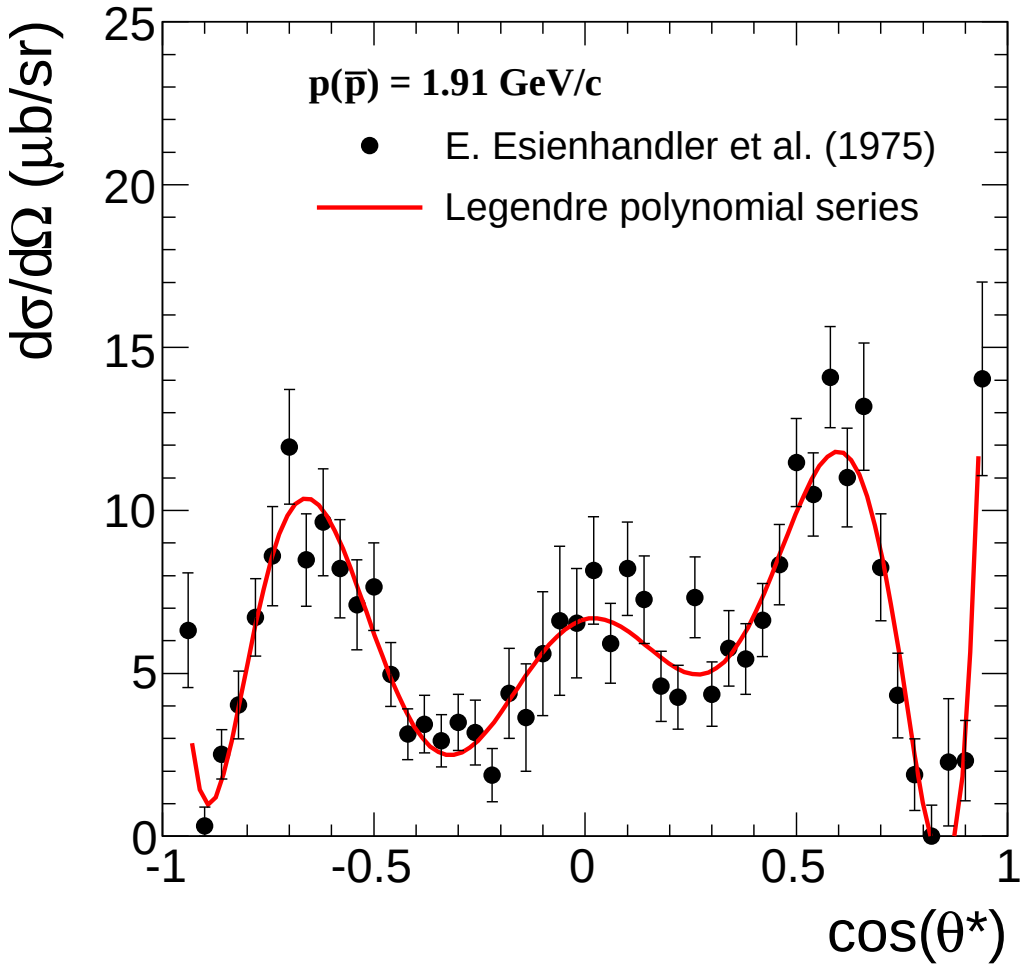
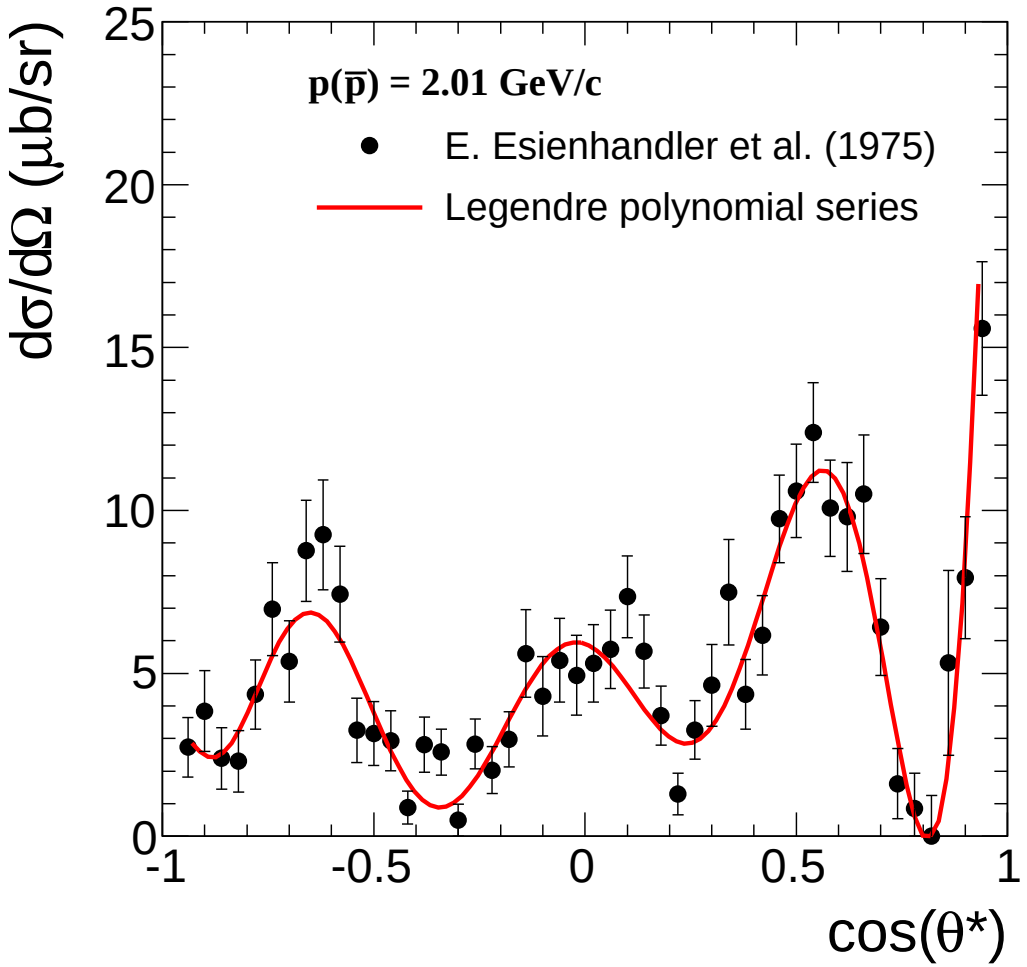
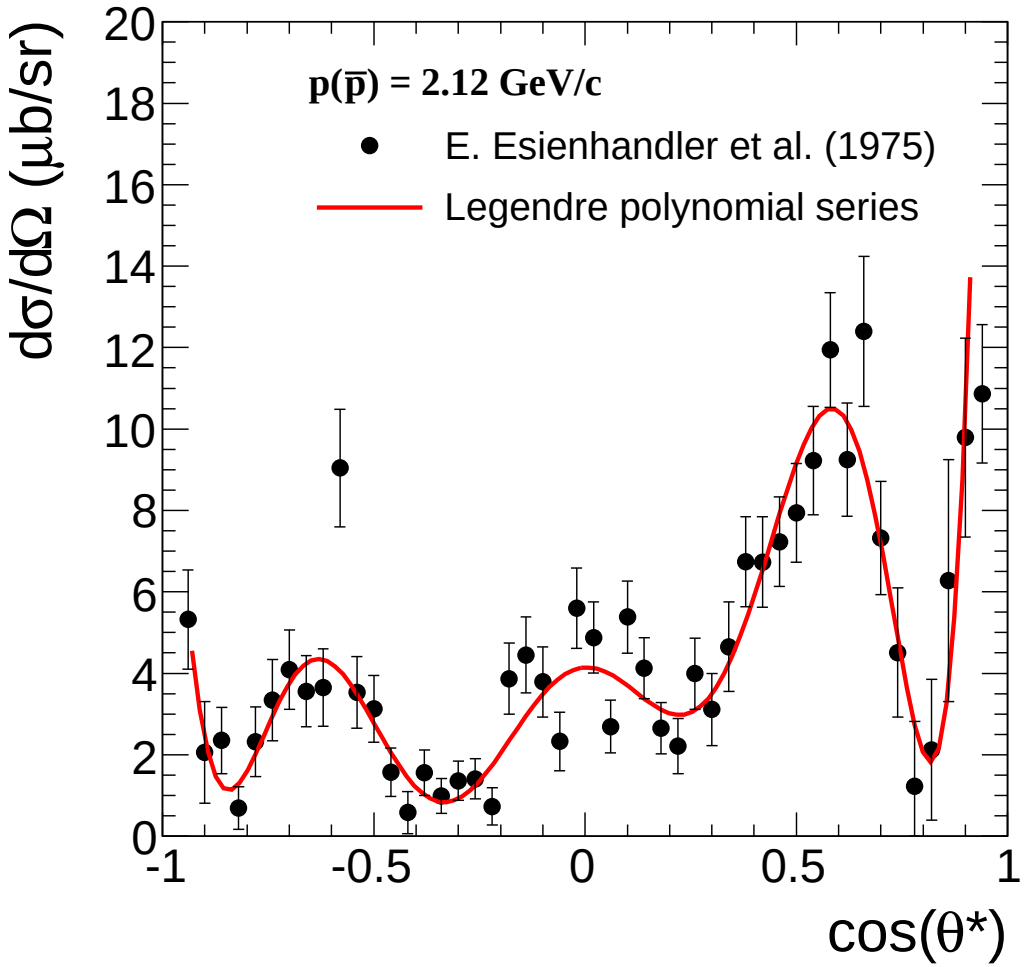
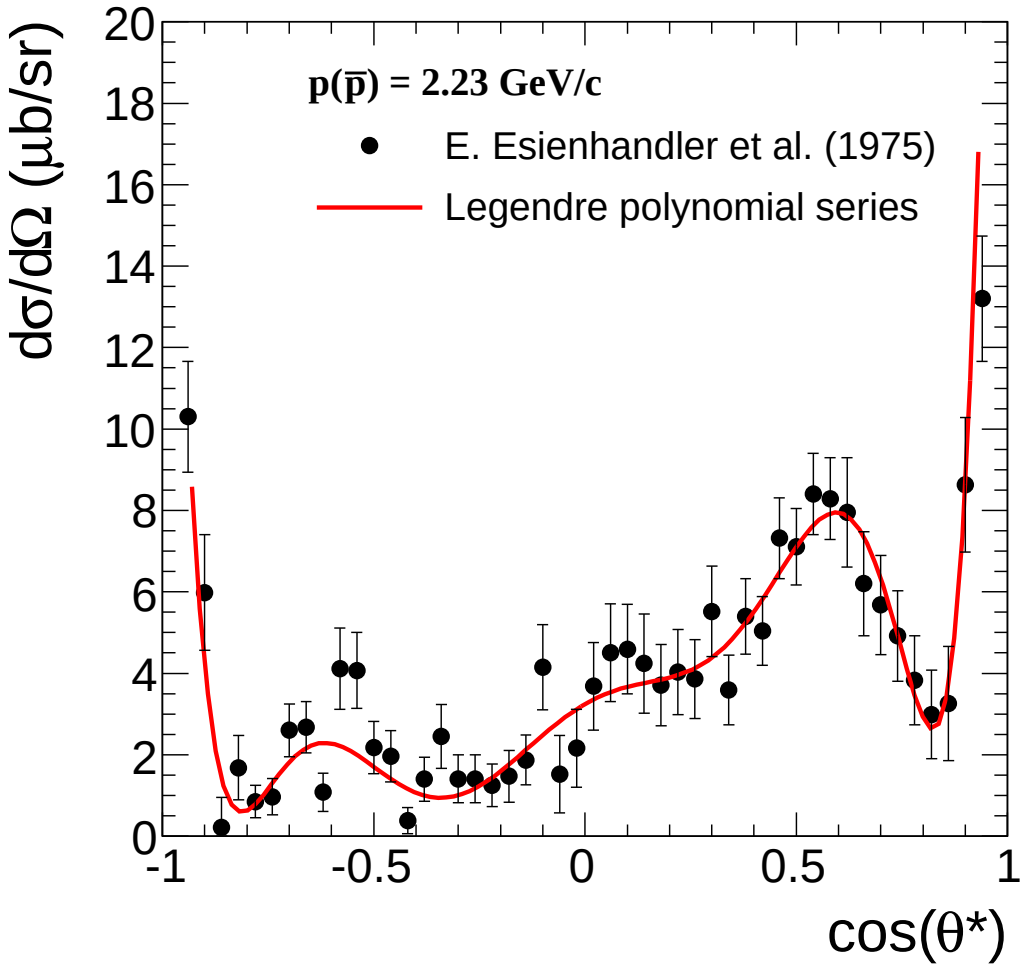


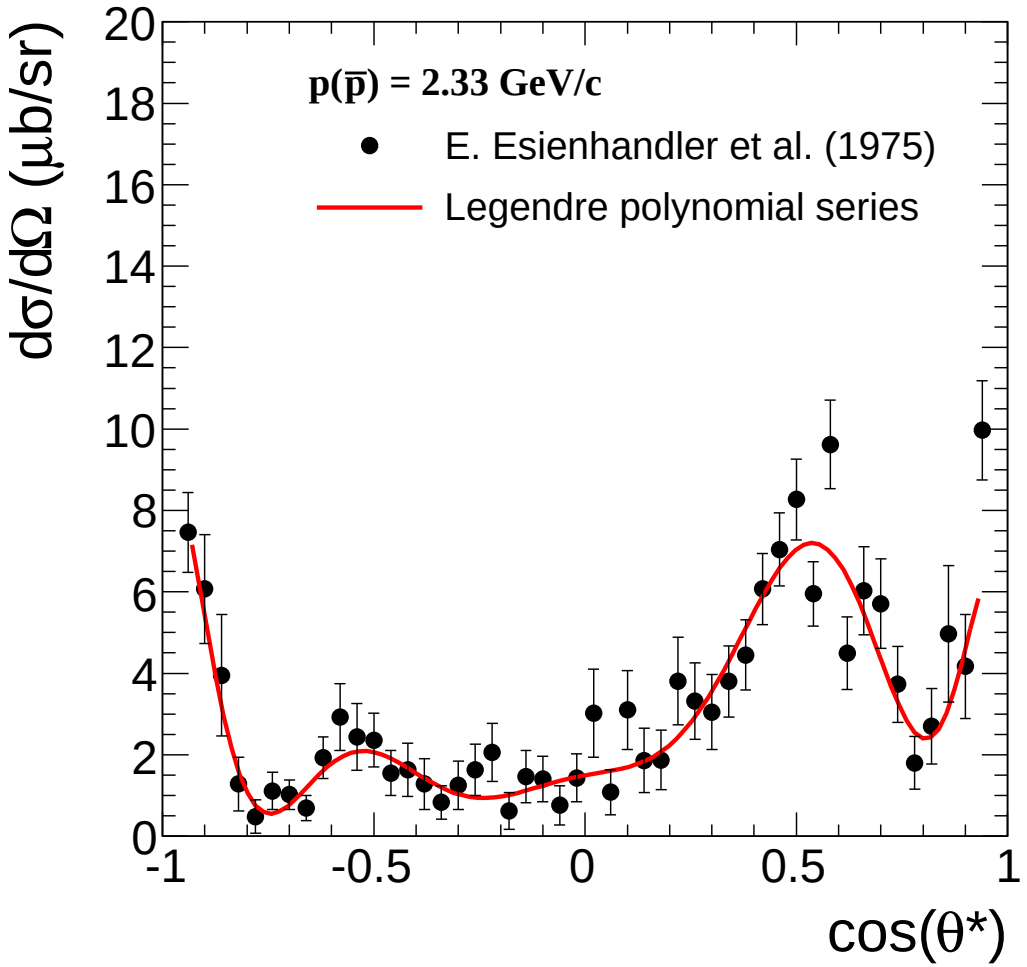


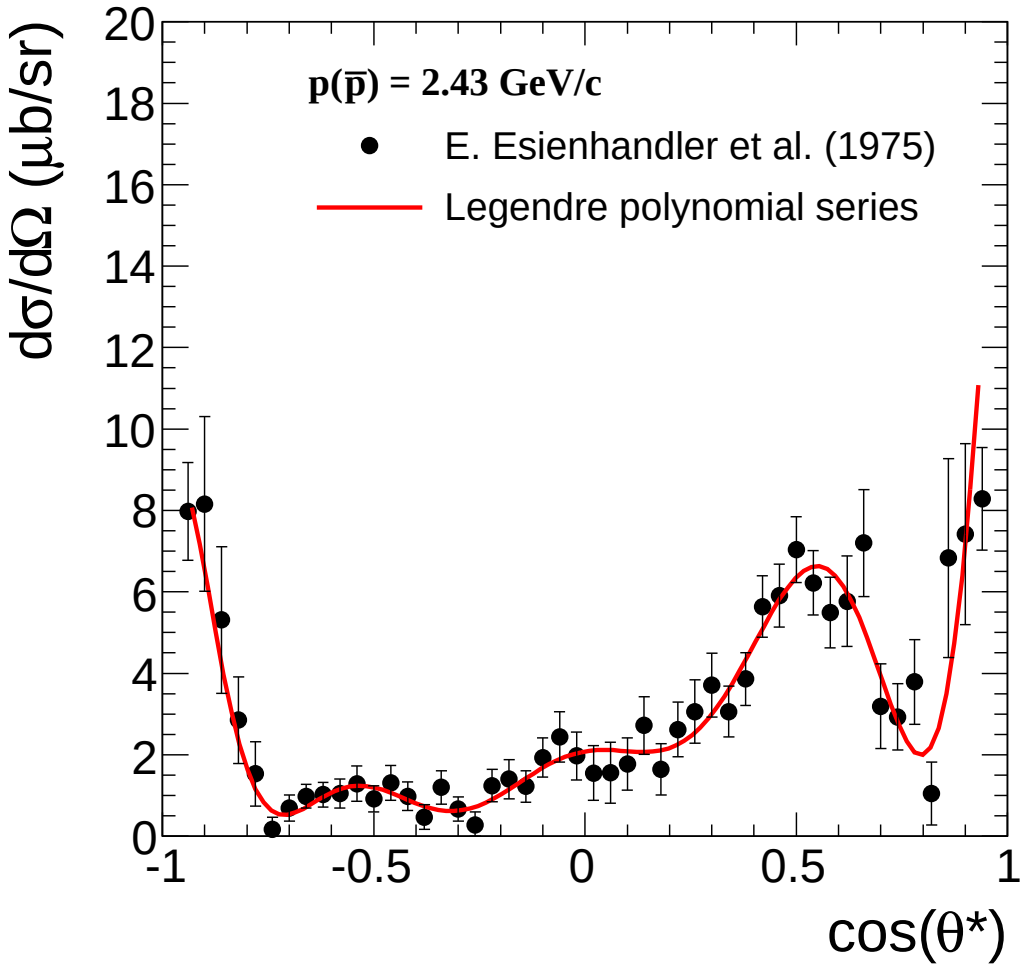
The cross section in the low energy regime





The cross section in the low energy regime



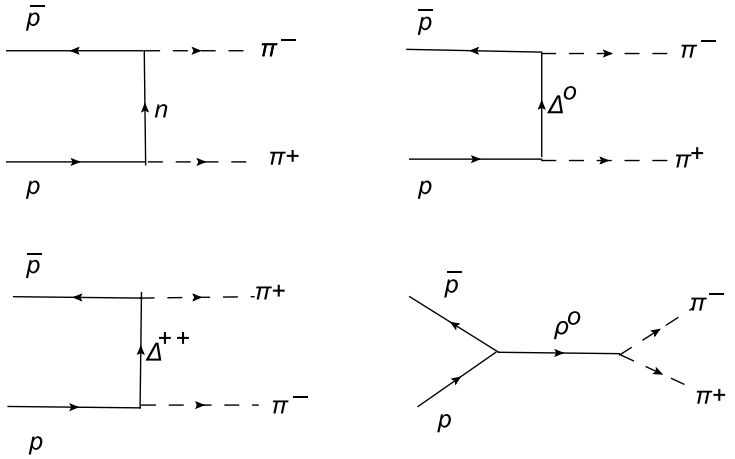


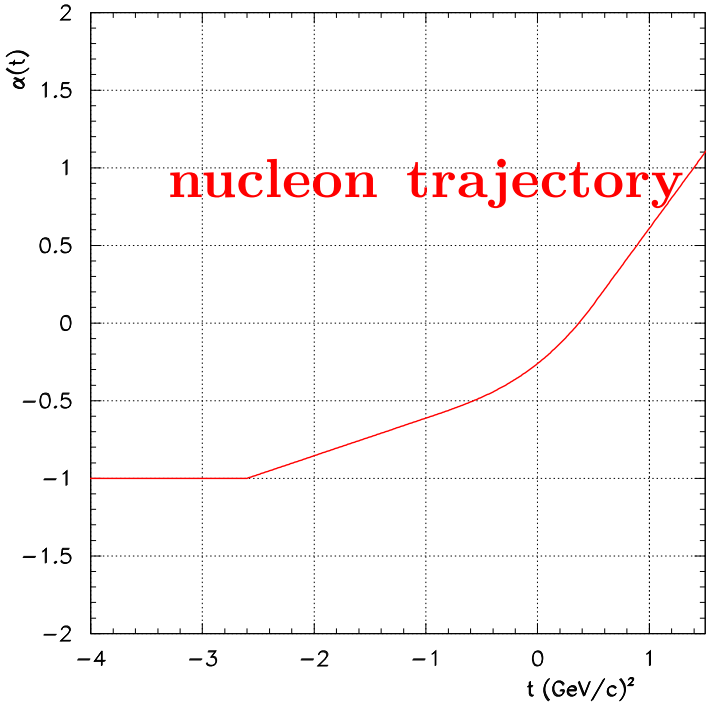
The cross section in the high energy regime

- **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





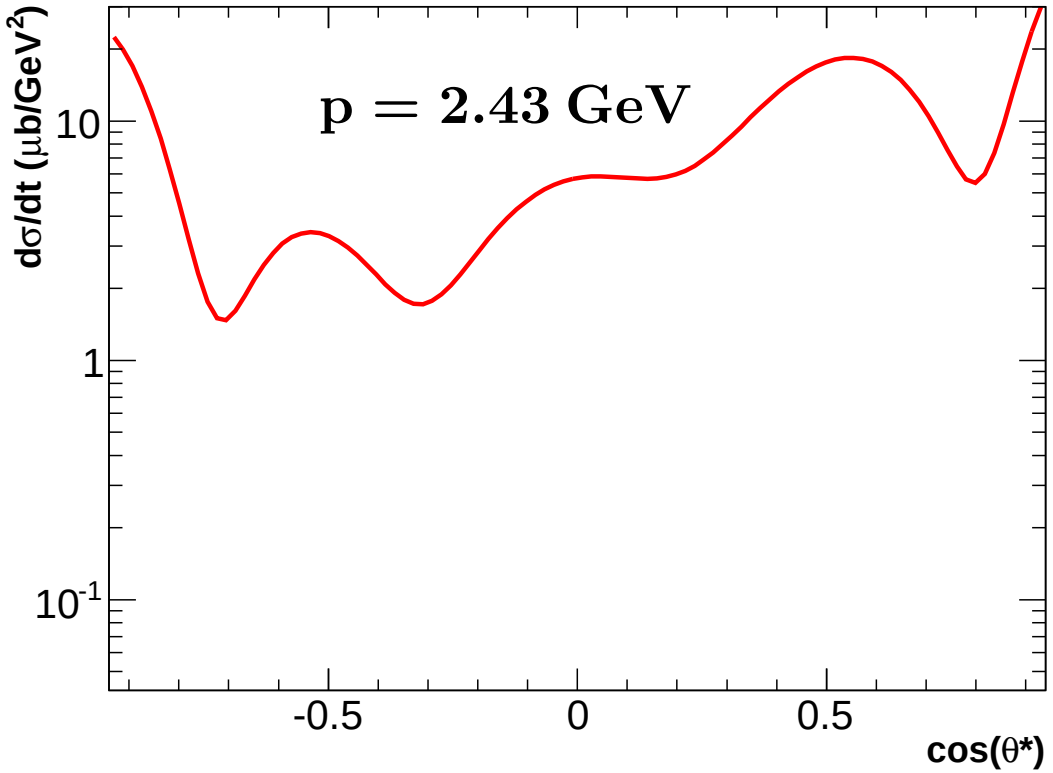
$\Rightarrow \dfrac{d\sigma}{dt}$ at a $(\mathrm{p}, \cos\theta^*)$ grid of (19×201) lattice sites

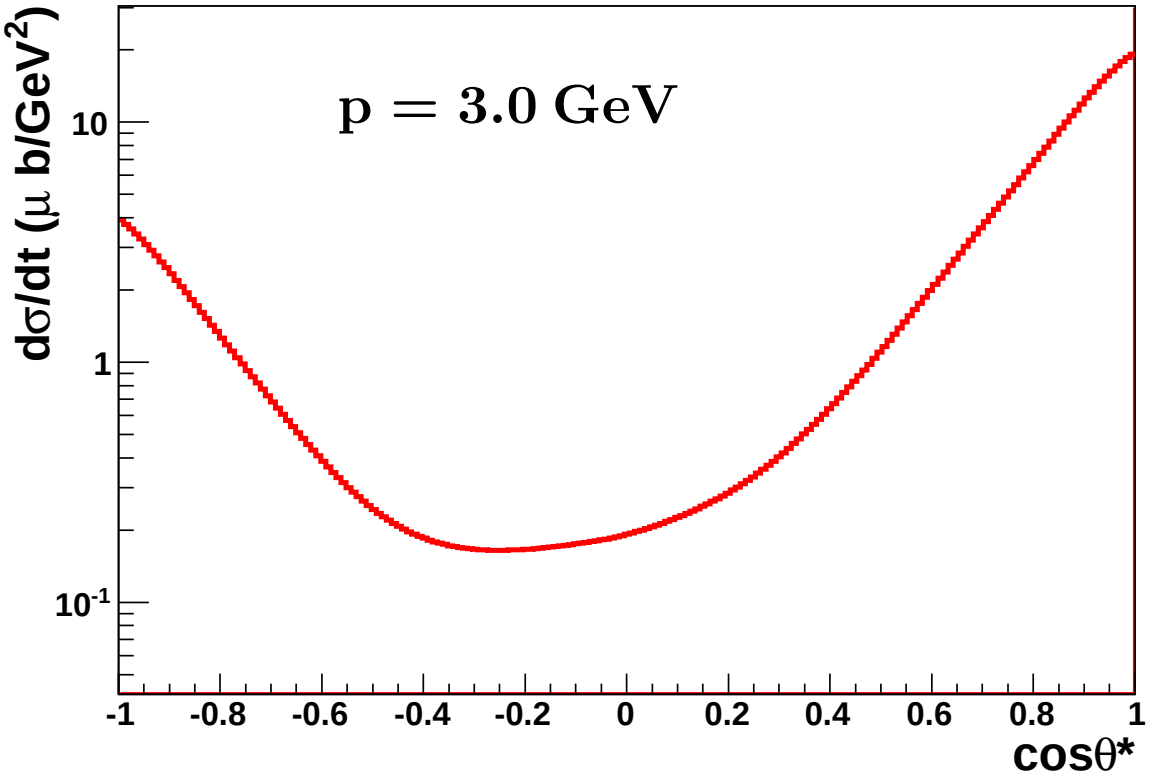
$\mathrm{p} = 3.0, \ldots, 5.0, \ldots, 12.0$ GeV $\Rightarrow$ **high+transition-extrapolated energy regime**

$\cos\theta^* = -1.0, \ldots, 1.0$

The cross section in the transition energy regime

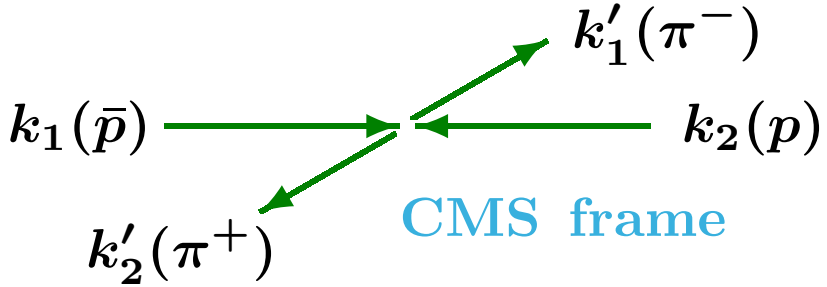
$$\frac{d\sigma}{d\Omega} \rightarrow \frac{d\sigma}{dt}$$



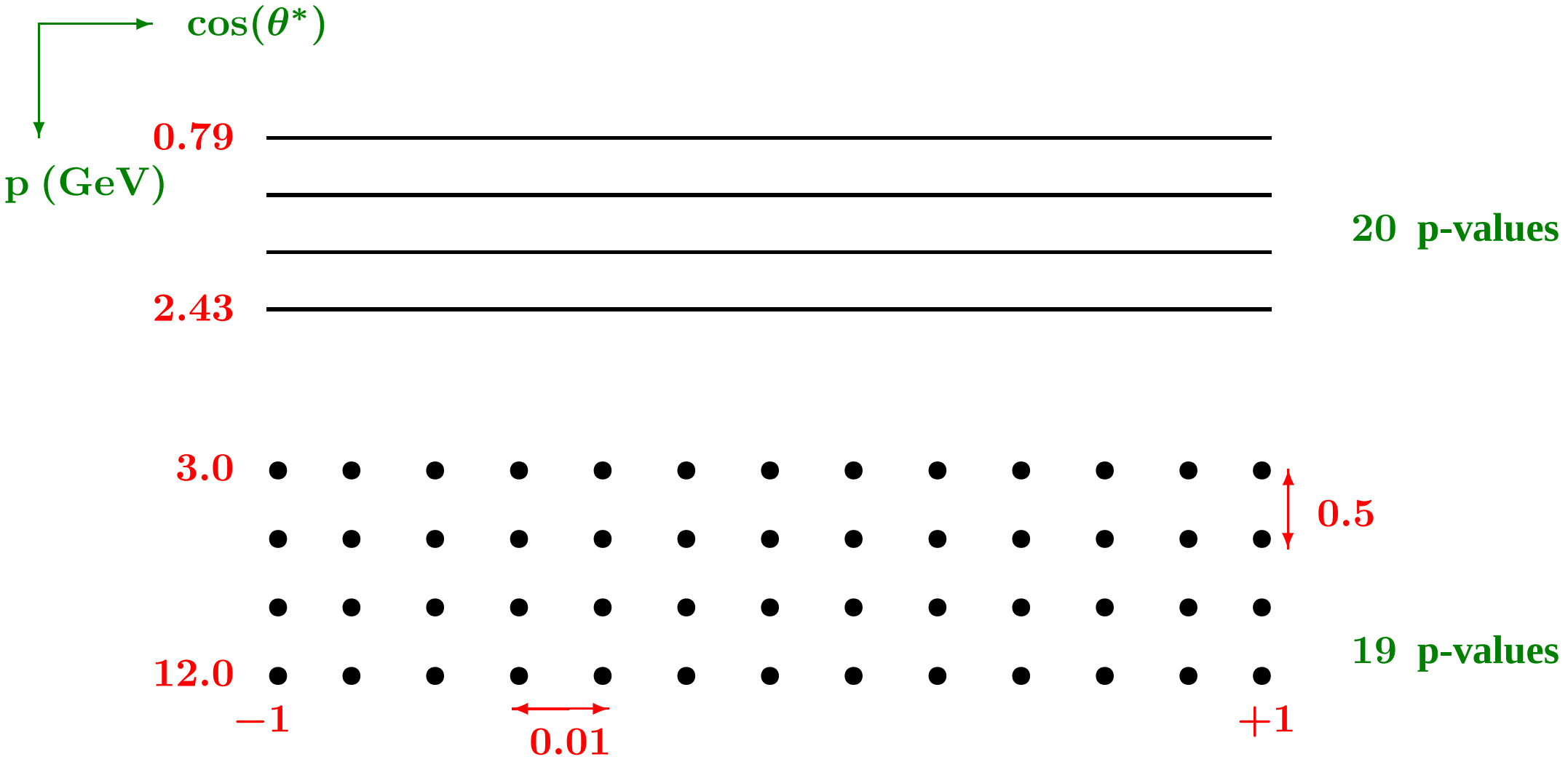


$$t = -(k_1' - k_1)^2$$

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



The cross section : general overview



σ at $(\mathrm{p}, \cos\theta^*)$ point NOT sitting at line or dot:

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

Event generation : generalities

generate $\cos\theta^*$ events with $\quad \mathrm{prob}(\cos\theta^*) \sim \dfrac{\mathrm{d}\sigma}{\mathrm{d}\cos\theta^*}$

- **naive accept/reject algorithm (no importance sampling)**
- **particle momenta build in CMS frame:**

$$\mathrm{E}_{\pi^+} = \mathrm{E}_{\pi^-} = \frac{\sqrt{\mathrm{s}}}{2}, \qquad \varphi_{\pi^+\pi^-} = 180 \ \mathrm{deg}$$

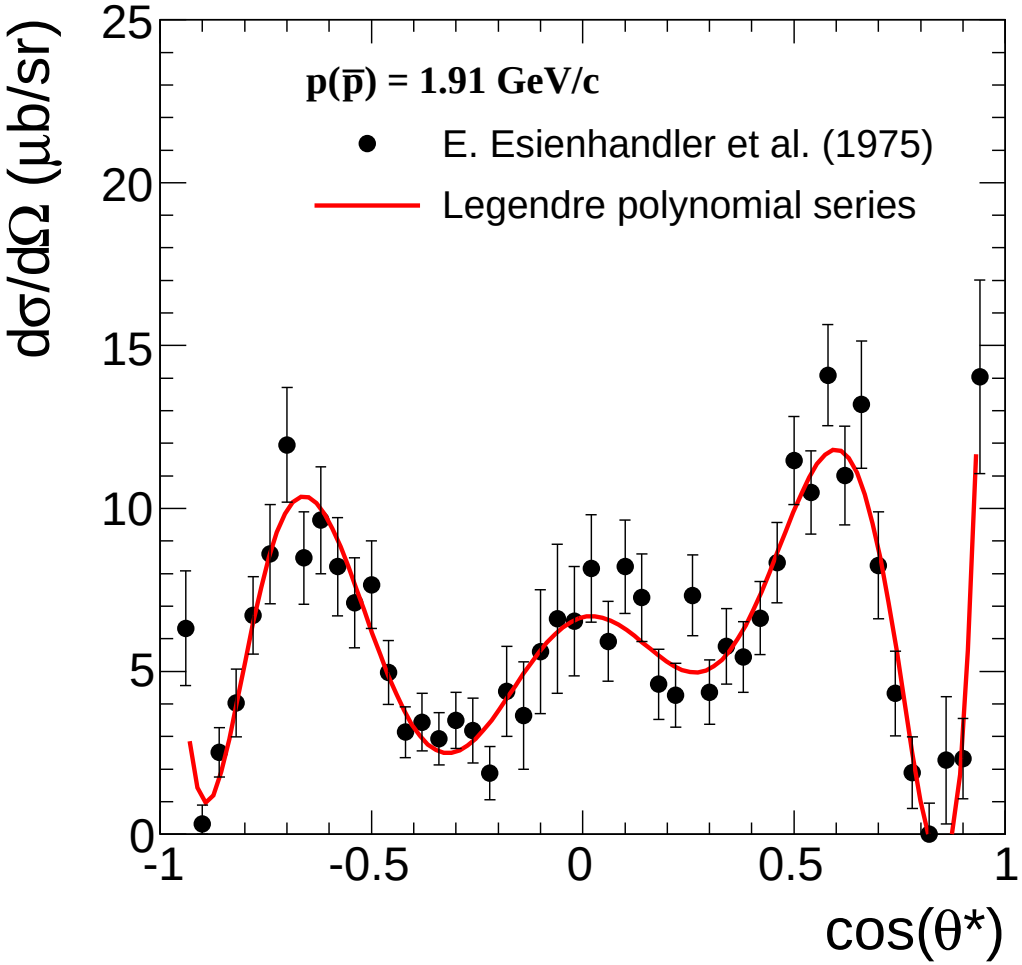
- **boosting to LAB frame**

- **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"**

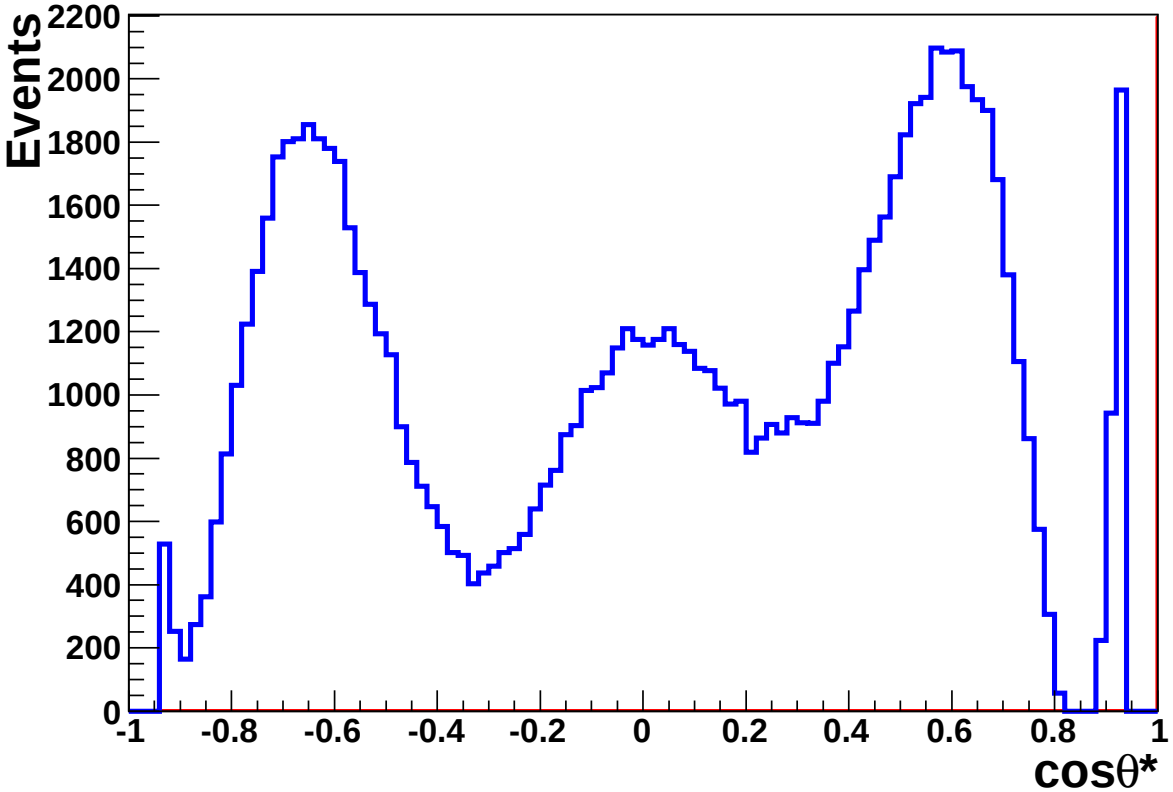
$\Rightarrow \mathrm{T} \sim 30 \ \mu\,\mathrm{sec}\,/\mathrm{event}$

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

Event generation : example in the low energy regime



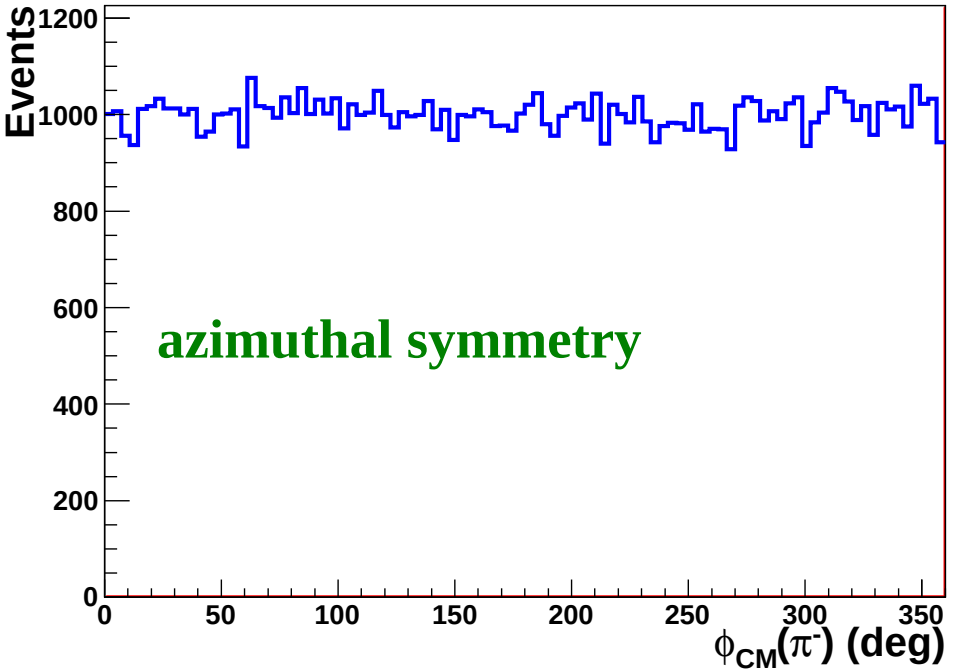
$N = 10^5$ events

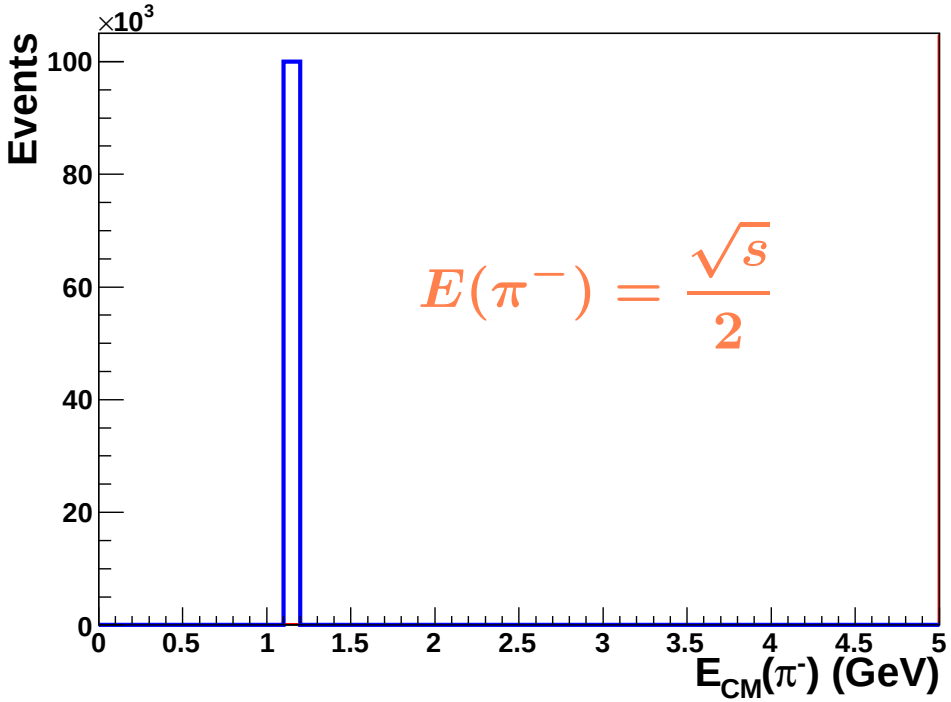


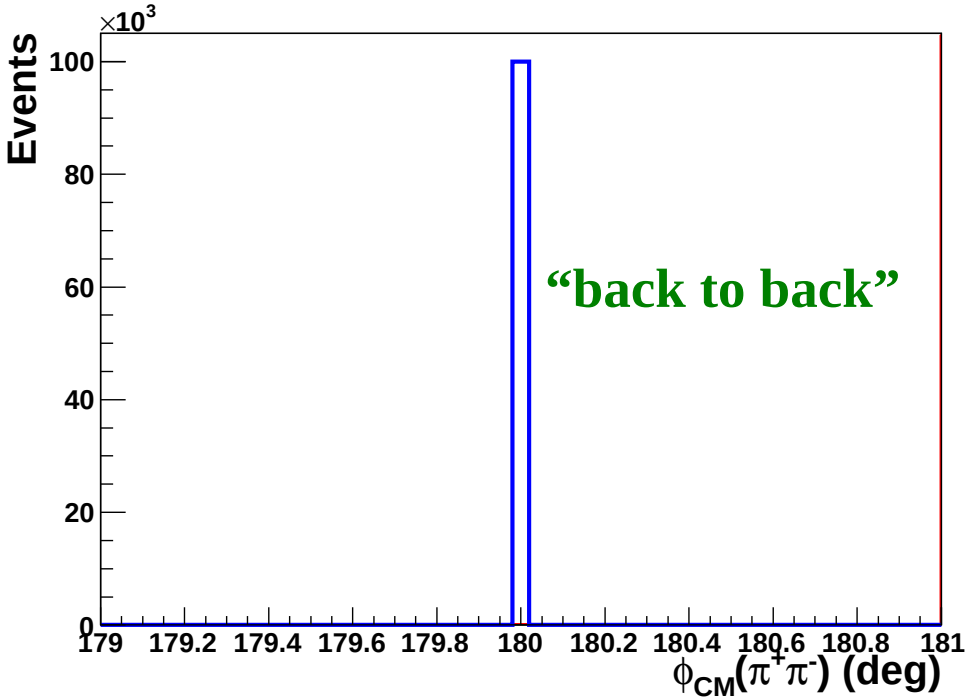
··· some distributions in CMS frame

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

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

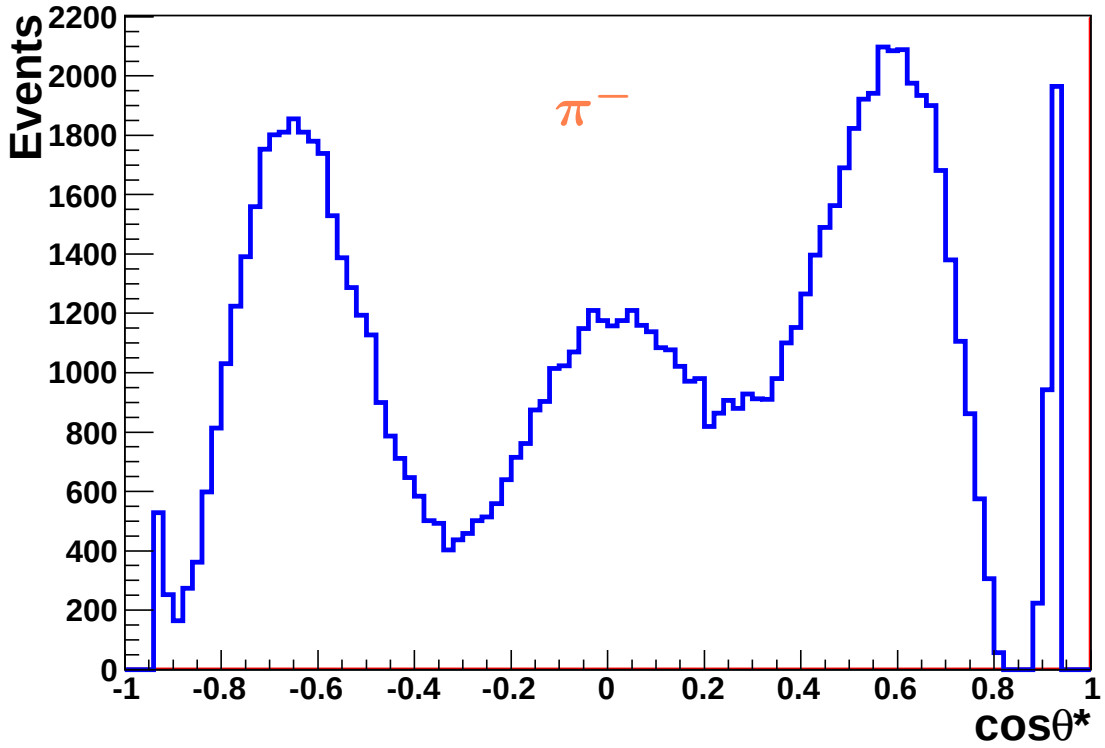


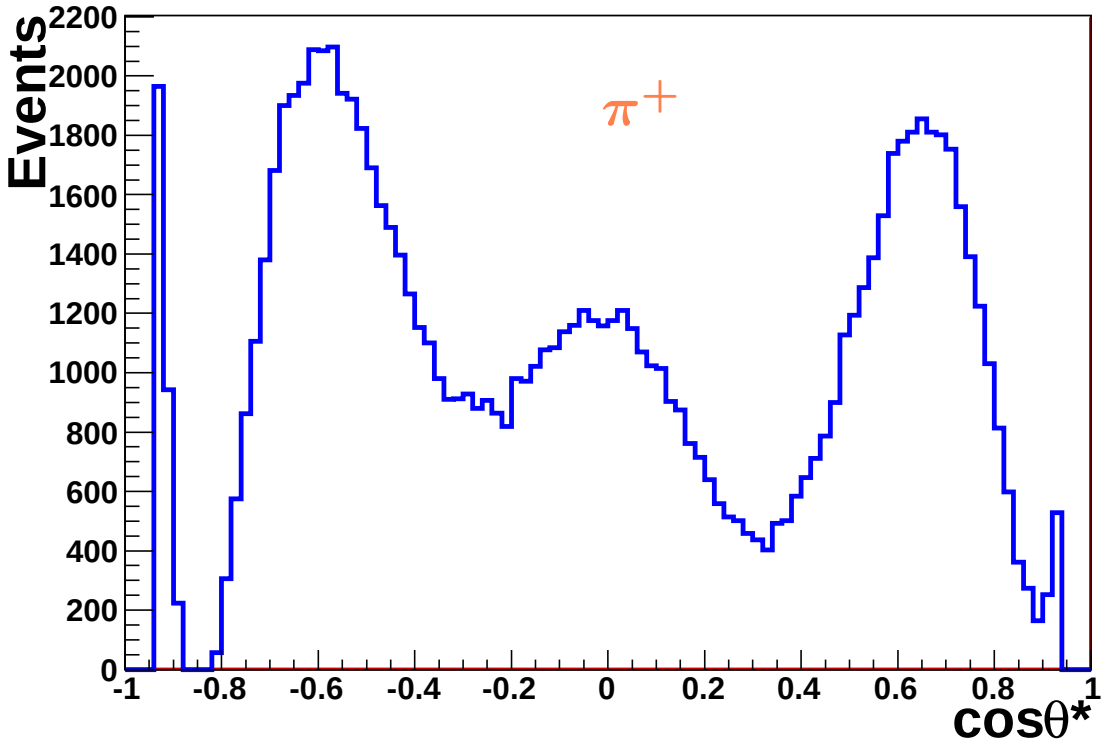




··· some distributions in CMS frame

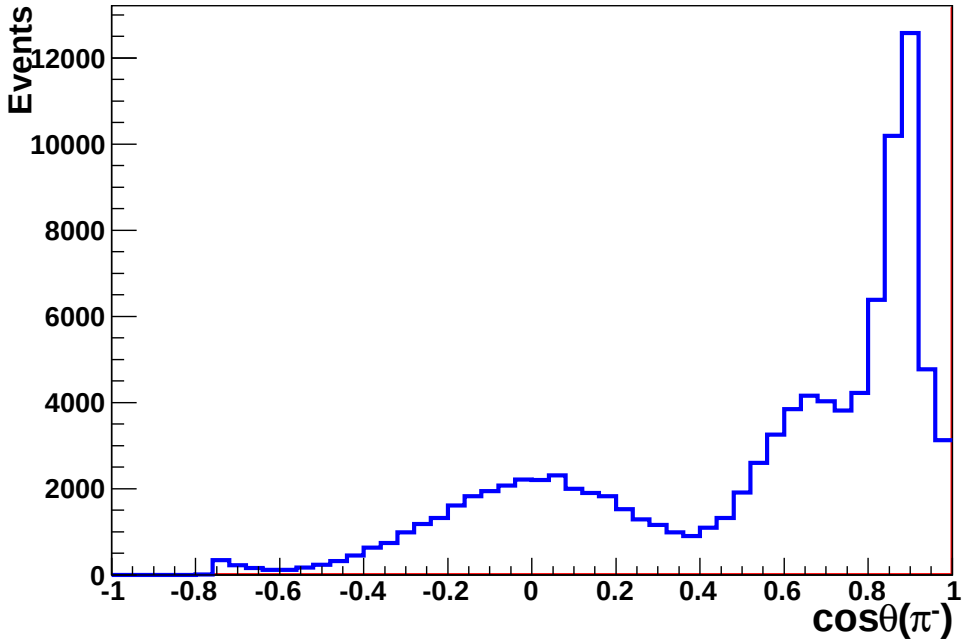
mirror symmetry around $\cos\theta^* = 0$

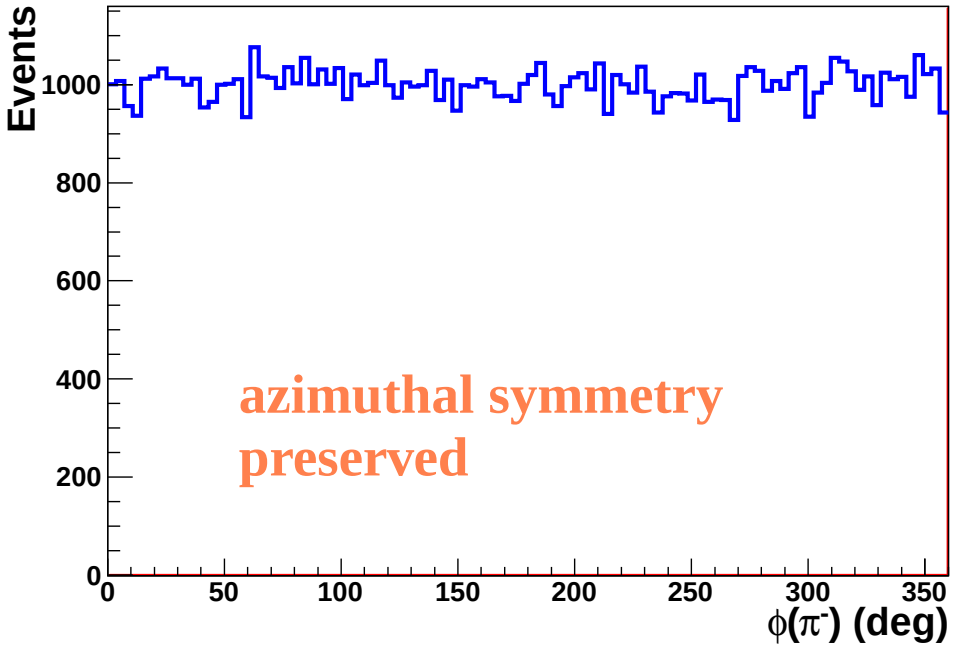


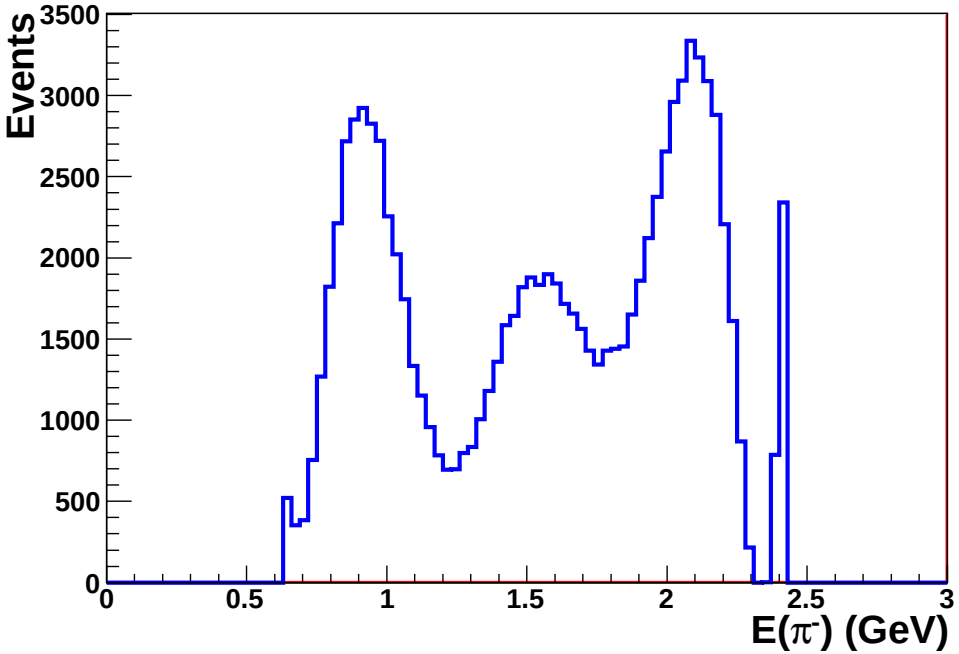


··· some distributions in LAB frame

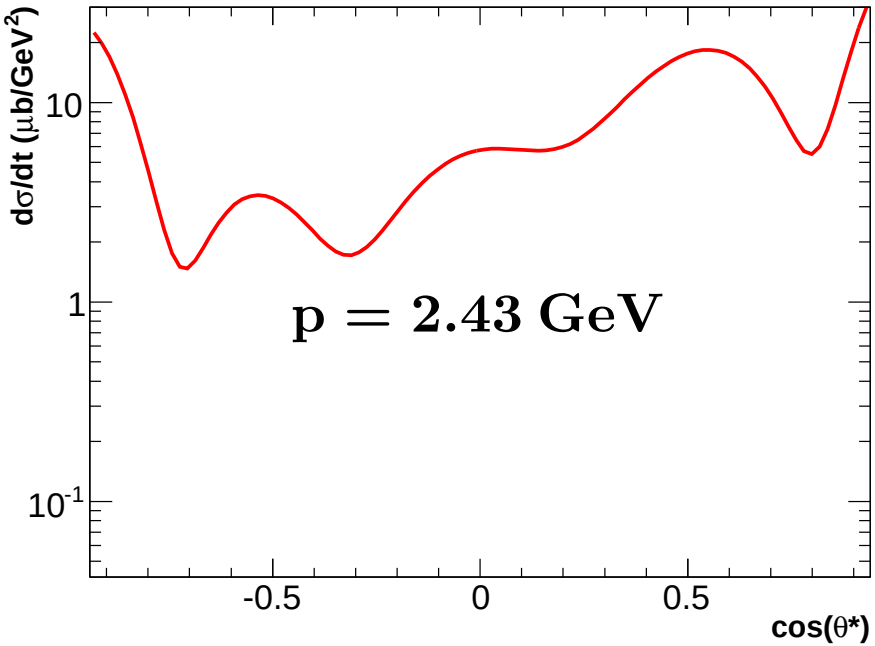
boosting in the forward direction ...

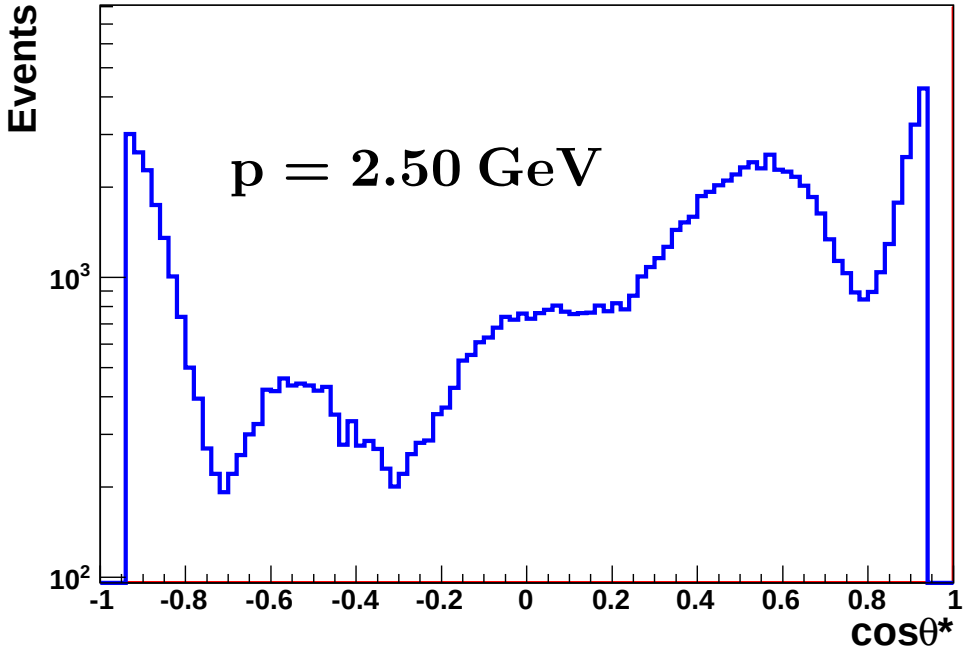


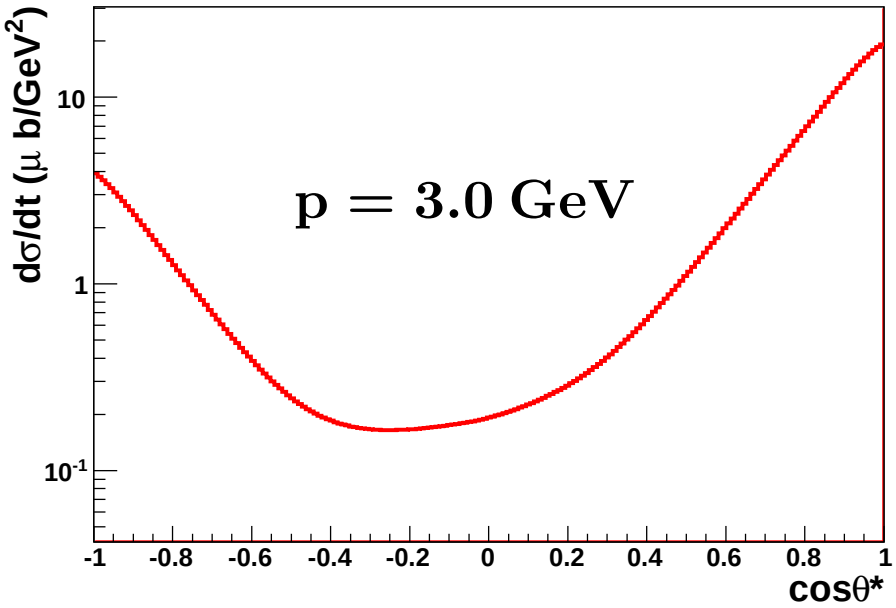


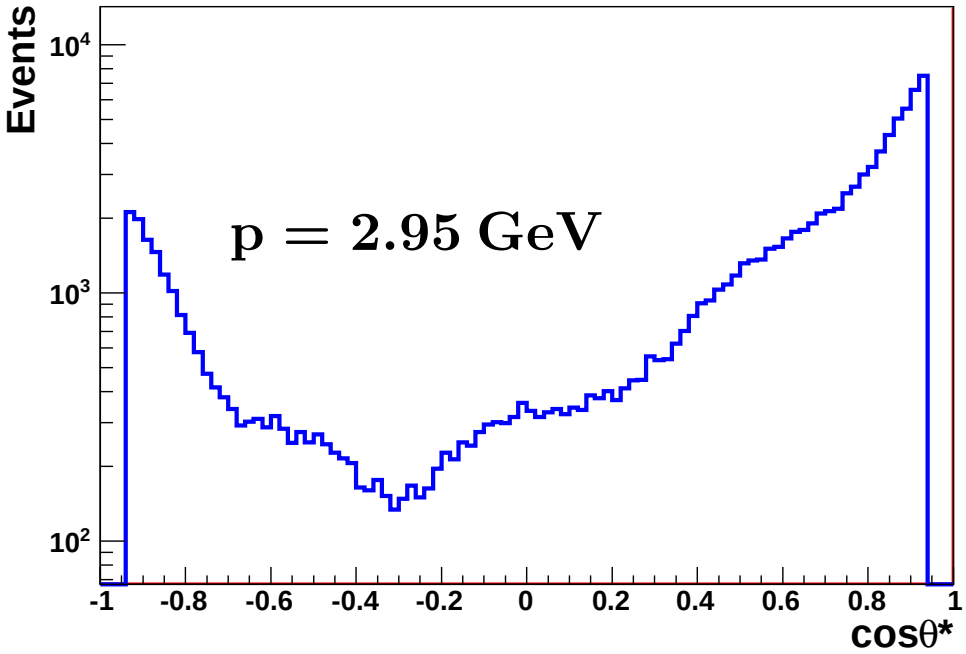


Event generation : example in the transition energy regime

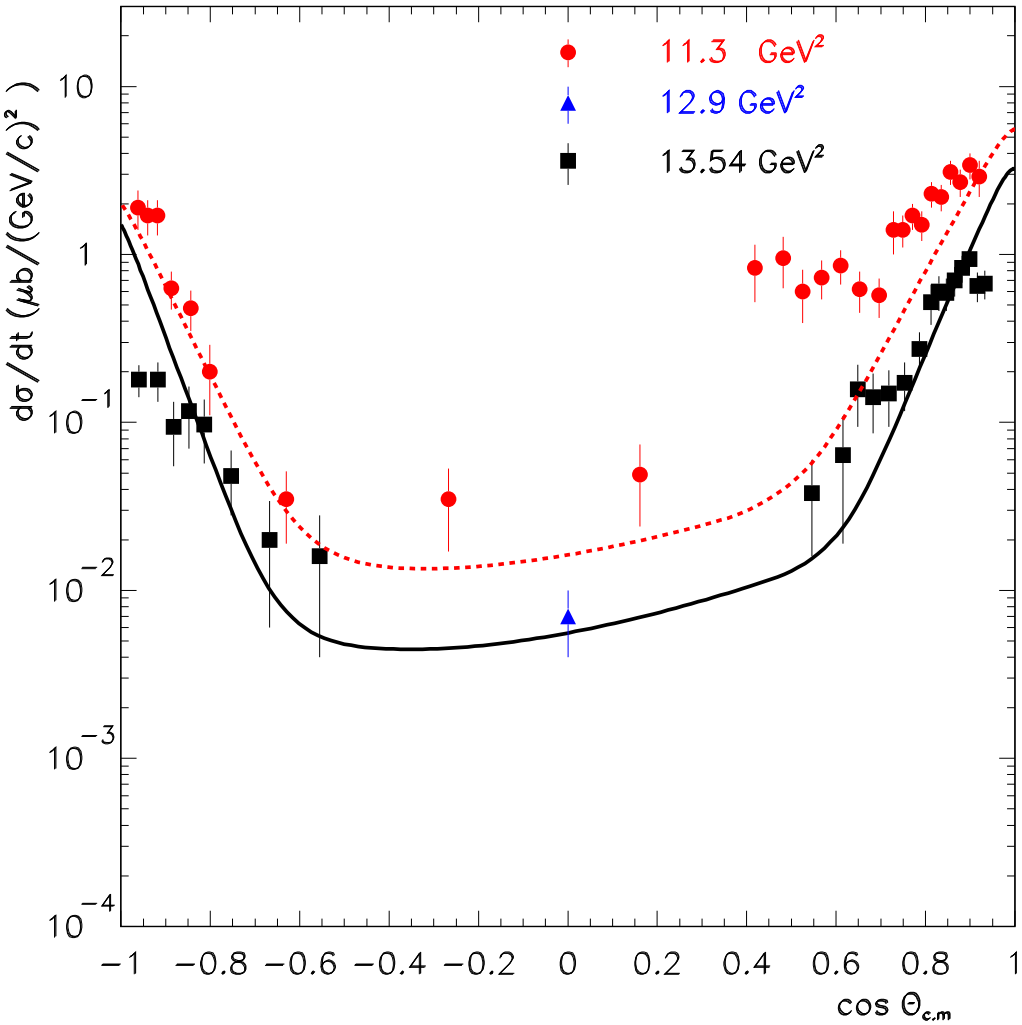








Event generation : example in the high energy regime



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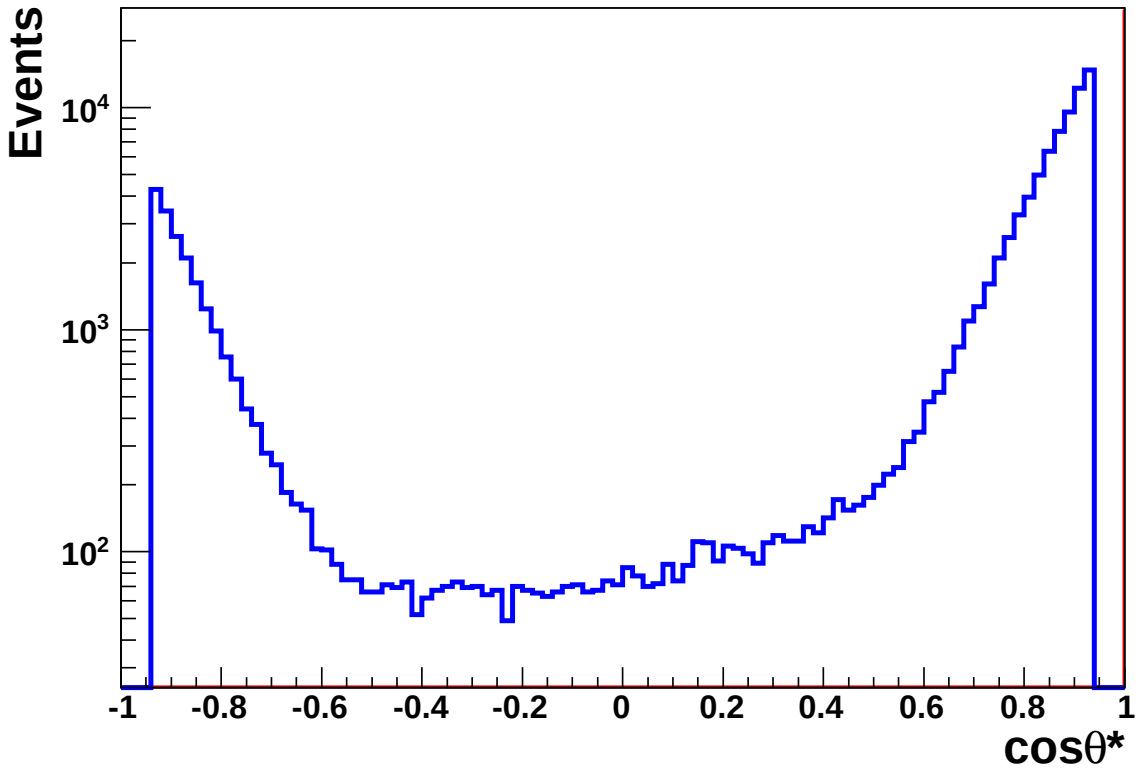
$p = 5.0\ \mathrm{GeV} \Rightarrow s = 11.3\ \mathrm{GeV}^2$



Summary and conclusions

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

next steps . . .

$\to$ write user documentation

$\to$ full integration in PANDA ROOT + analysis

$\to$ submission in next release