PANDA collaboration meeting
CNRS, Paris

September $10th$ 2012

The $\bar{p}p \rightarrow l^+l^-$ and $\bar{p}p \rightarrow \pi^+\pi^-$ cross section

Manuel Zambrana

Institut für Kernphysik, University of Mainz / Helmholtz Institute Mainz

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

HELMHOLTZ GEMEINSCHAFT

Helmholtz-Institut Mainz

OUTLINE

- **introduction**
- **the $\bar{p}p \to l^+l^-$ cross section**
  - $\to$ **differential**
  - $\to$ **models for the electromagnetic form factors**
  - $\to$ **integrated**
- **the $\bar{p}p \to \pi^+\pi^-$ cross section**
  - $\to$ **differential**
  - $\to$ **integrated**
- **numerical implementation**
- **summary and conclusions**

Introduction

we are doing

feasibility studies of proton form factors measurements via electromagnetic processes with the PANDA detector

$\Rightarrow$ **need realistic models for both signal and background channels cross section**

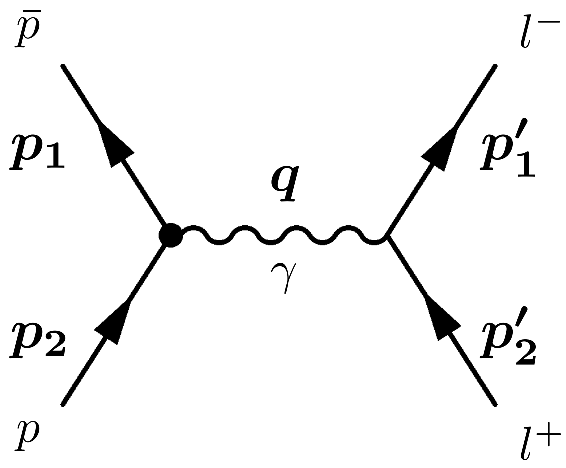
- $i)$ **study suppression factors**
- $ii)$ **estimate number of expected events for a given luminosity**
  - $\longrightarrow$ **integrated cross sections**

in this talk, we discuss

$\rightarrow \sigma(\bar{p}p \rightarrow l^+ l^-) \quad l = e, \mu, \tau \quad$ (signal)

$\rightarrow \sigma(\bar{p}p \rightarrow \pi^+ \pi^-) \quad$ (background)

The $\bar{\text{p}}\text{p} \to \text{l}^+\text{l}^-$ differential cross section



- **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**

$$\frac{d\sigma}{d\cos\theta^*} = \frac{\pi\alpha^2}{2s}\,\frac{\beta_l}{\beta_p}\,\left\{\left(2-\beta_l^2+\beta_l^2\cos^2\theta^*\right)|G_M|^2+\frac{1}{\tau}\left(1-\beta_l^2\cos^2\theta^*\right)|G_E|^2\right\}$$

$$\beta_l = \sqrt{1-4m_l^2/s} \qquad \beta_p = \sqrt{1-4M^2/s} \qquad \tau = \frac{q^2}{4M^2} \qquad \theta^* = \text{angle}(\text{e}^-,\bar{\text{p}})$$

$\to$ **sensitive to $|G_E|$ and $|G_M|$ (with absolute normalization)**

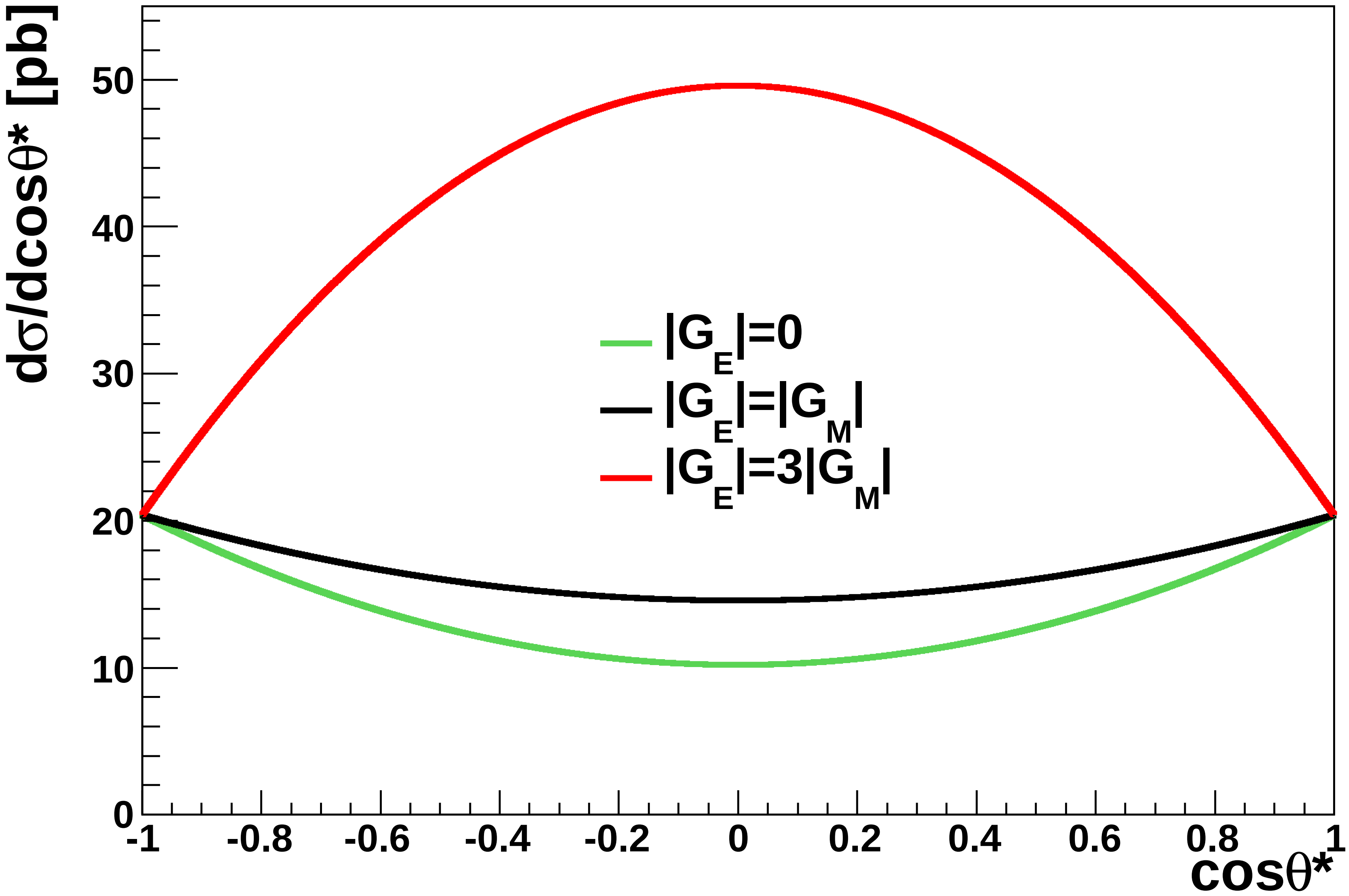
$\to q = p_1 + p_2 \Rightarrow$ **kinematic threshold $q^2 > 4M^2$**

massless final state lepton limit : $m_l \to 0 \;\Rightarrow\; \beta_l \to 1$

$$\frac{d\sigma}{d\cos\theta^*} = \frac{\pi\alpha^2}{2s}\,\frac{1}{\beta_p}\,\left\{\left(1+\cos^2\theta^*\right)|G_M|^2+\frac{1}{\tau}(1-\cos^2\theta^*)|G_E|^2\right\}$$

The $\bar{p}p \to l^+l^-$ differential cross section

$\bar{p}p \to e^+e^-$ $\quad p(\bar{p}) = 3.3$ GeV (s = 8.2 GeV^2) $\quad |G_M|$: pQCD



Models for the form factors

Dipole – modified (1)

- in space-like, data described by dipole model, up to $Q^2 < 31$ GeV^2

$$G_M(Q^2)/\mu = G_d(Q^2) \quad G_d(Q^2) = (1 + Q^2/m_d^2)^{-2} \quad \mu \sim 2.79 \quad m_d^2 \sim 0.71 \text{ GeV}^2$$

- in time-like, parametrize as

$$|G_M(q^2)| = a\,(1 + q^2/m_d^2)^{-2}\,(1 + q^2/m_{nd}^2)^{-1}, \quad a = 22.5 \quad m_{nd}^2 = 3.6 \text{ GeV}^2$$

Perturbative QCD – inspired (2)

- $|G_E|$ and $|G_M|$ from analytical continuation of the dipole form factor to time-like, with corrections to avoid "ghost" poles in α_s

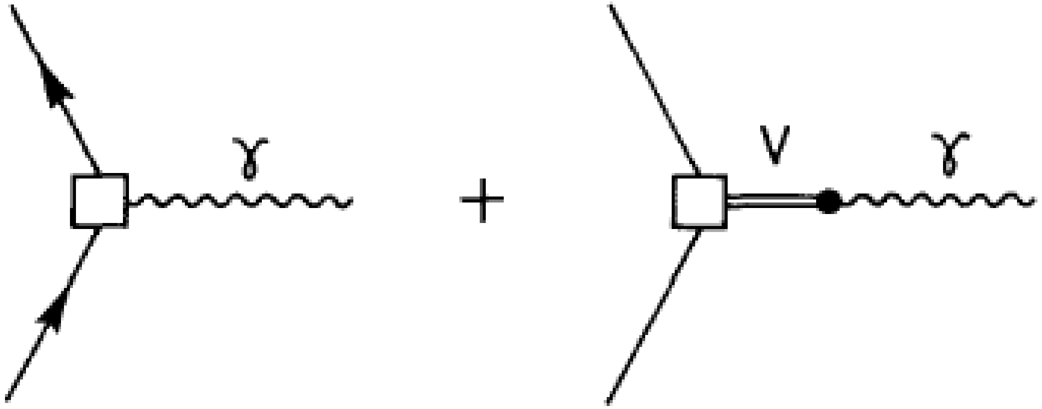
$$|G_E(q^2)| = |G_M(q^2)| = \frac{D}{q^4\left[\log^2(q^2/\Lambda^2) + \pi^2\right]}$$

$$D = 89.45 \text{ GeV}^2 \quad \Lambda = 0.3$$

(1) R.G. Arnold et al., Phys. Rev. Lett. 57, 174 (1986)
(2) D.V. Shirkov and I.L. Solovtsov, Phys. Rev. Lett. 79, 1209 (1997)

Models for the form factors

Vector meson dominance (3)



- **photon couples to both intrinsic structure $g(q^2)$ + meson cloud (ρ, ω, ϕ)**
- **parametrization in spacelike domain, analytically continued to timelike**

(3) F. Iachello, A.D. Jackson and A. Lande, Phys. Lett. B 43, 191 (173)
F. Iachello and Q. Wan, Phys. Rev. C 69, 055204 (2004)

Models for the form factors

$$F_1^S(q^2) = \frac{1}{2}g(q^2)\Big\{(1-\beta_\omega-\beta_\varphi)+\beta_\omega P_\omega(q^2)+\beta_\varphi P_\varphi(q^2)\Big\}$$

$$F_1^V(q^2) = \frac{1}{2}g(q^2)\Big\{(1-\beta_\rho)+\beta_\rho P_\rho(q^2)\Big\}$$

$$F_2^S(q^2) = \frac{1}{2}g(q^2)\Big\{(-0.120-\alpha_\varphi)P_\omega(q^2)+\alpha_\varphi P_\varphi(q^2)\Big\}$$

$$F_2^V(q^2) = \frac{1}{2}g(q^2)\Big\{3.706\, P_\rho(q^2)\Big\}$$

$\beta_\rho = 0.672$
$\beta_\omega = 1.102$
$\beta_\varphi = 0.112$
$\alpha_\varphi = -0.052$
$\gamma = 0.25\ \mathrm{GeV}^{-2}$
$\theta = 53\ \mathrm{deg}$

$$g(q^2) = \frac{1}{(1-\gamma\, e^{i\theta}\, q^2)} \qquad P_\omega(q^2) = \frac{m_\omega^2}{m_\omega^2-q^2} \qquad P_\varphi(q^2) = \frac{m_\varphi^2}{m_\varphi^2-q^2}$$

$$P_\rho(q^2) = \frac{m_\rho^2 + 8\Gamma_\rho m_\pi/\pi}{m_\rho^2 - q^2 + (4m_\pi^2 - q^2)\Gamma_\rho \alpha(q^2)/m_\pi + i\Gamma_\rho 4m_\pi \beta(q^2)}$$

$$\alpha(q^2) = \frac{2}{\pi}\left[\frac{q^2-4m_\pi^2}{q^2}\right]^{1/2} \ln\left(\frac{\sqrt{q^2-4m_\pi^2}+\sqrt{q^2}}{2m_\pi}\right)$$

$$\beta(q^2) = \sqrt{\left(\frac{q^2}{4m_\pi^2}-1\right)^3 \Big/ \left(\frac{q^2}{4m_\pi^2}\right)}$$

Models for the form factors

• in the model, narrow resonances ω and ϕ have $\Gamma_\omega = \Gamma_\phi = 0$ in propagators

$$P_\omega(q^2) = \frac{m_\omega^2}{m_\omega^2 - q^2} \qquad P_\varphi(q^2) = \frac{m_\varphi^2}{m_\varphi^2 - q^2}$$

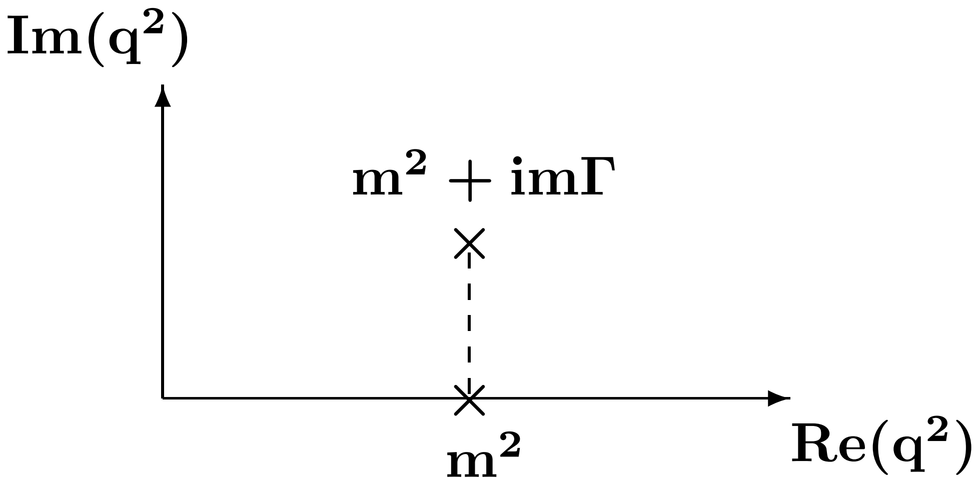
$\rightarrow$ singularities at $q^2 = m_\omega^2$ and $q^2 = m_\phi^2$ $\Rightarrow$ regularization

modified propagators with non-zero Γ_ω, Γ_ϕ:

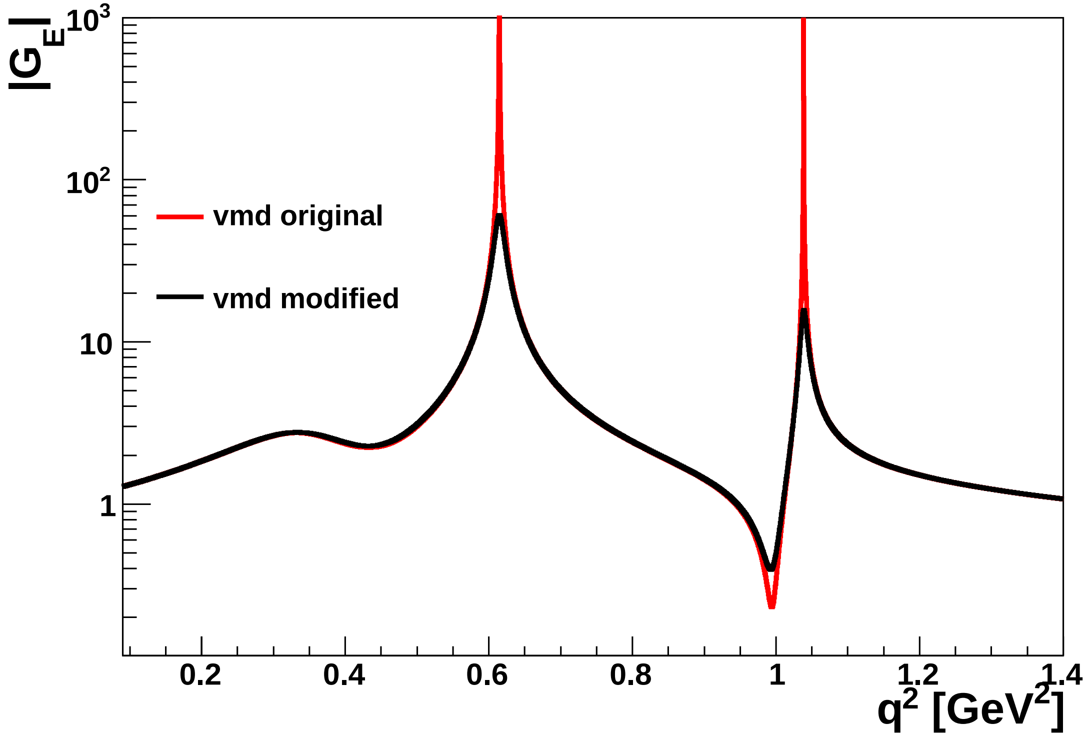
$$P_\omega(q^2) \rightarrow \frac{m_\omega^2}{m_\omega^2 - q^2 + i m_\omega \Gamma_\omega} \qquad P_\varphi(q^2) \rightarrow \frac{m_\varphi^2}{m_\varphi^2 - q^2 + i m_\phi \Gamma_\phi}$$

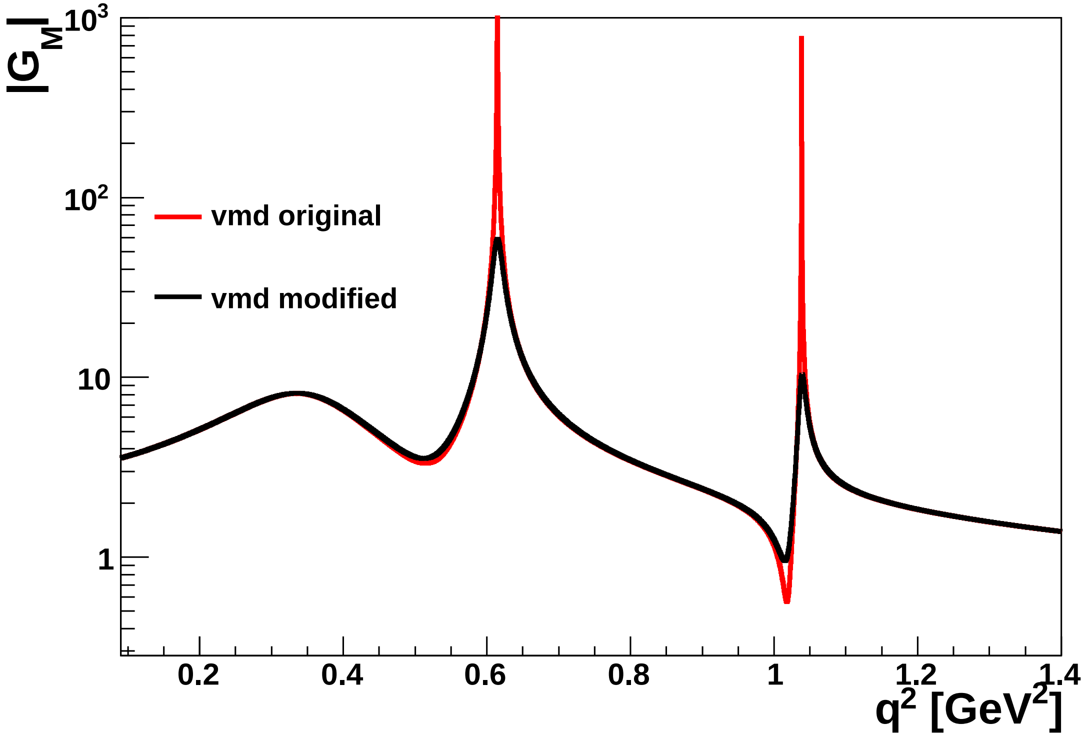
$\Rightarrow$ poles shifted to complex values

$$q^2 = m_\omega^2 + i m_\omega \Gamma_\omega$$
$$q^2 = m_\phi^2 + i m_\phi \Gamma_\phi$$



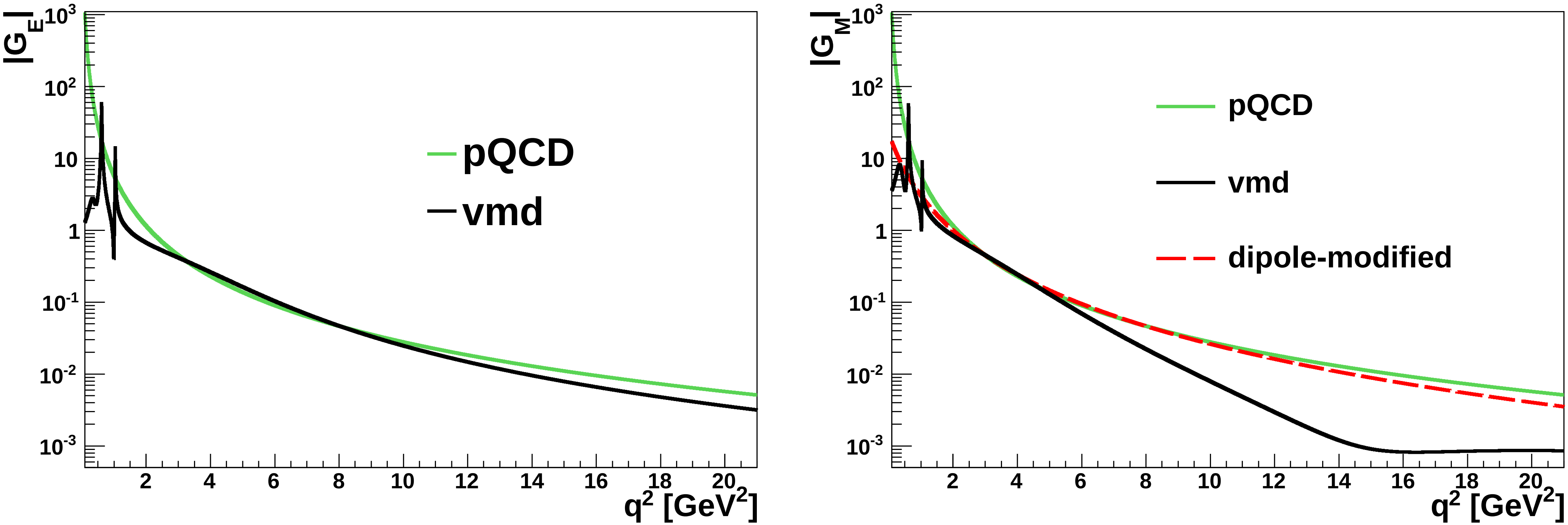
Models for the form factors





$\Rightarrow$ **we use regularized model in calculations**

Models for the form factors



The $\bar{\text{p}}\text{p} \to \text{l}^+\text{l}^-$ integrated cross section

- $\bar{p}p \to l^+l^-$ differential cross section can be written

$$\frac{d\sigma}{dx} = A_1\,(A_2 + A_3\,x^2) \qquad x \equiv \cos\theta^*$$

$$A_1 = \frac{\pi\alpha^2}{2}\,\frac{\beta_l}{s\beta_p}$$

$$A_2 = (2-\beta_l^2)|G_M|^2 + \frac{1}{\tau}|G_E|^2$$

$$A_3 = \beta_l^2\left(|G_M|^2 - \frac{1}{\tau}|G_E|^2\right)$$

$$\beta_l = \sqrt{1-4m_l^2/s}$$

$$\beta_p = \sqrt{1-4M^2/s}$$

$$\tau = \frac{q^2}{4M^2}$$

$\Rightarrow$ quadratic function in x, trivially integrated in $a < x < b$

$$\sigma = \int_a^b dx\,\frac{d\sigma}{dx} = A_1\left[A_2(b-a) + \frac{1}{3}A_3(b^3-a^3)\right]$$

full angular range $-1 < x < 1$

$$\sigma_T = 2A_1\left[A_2 + \frac{1}{3}A_3\right] \quad \sim \quad \frac{1}{s^2} \;\; \text{as} \;\; \text{s} \to \infty$$

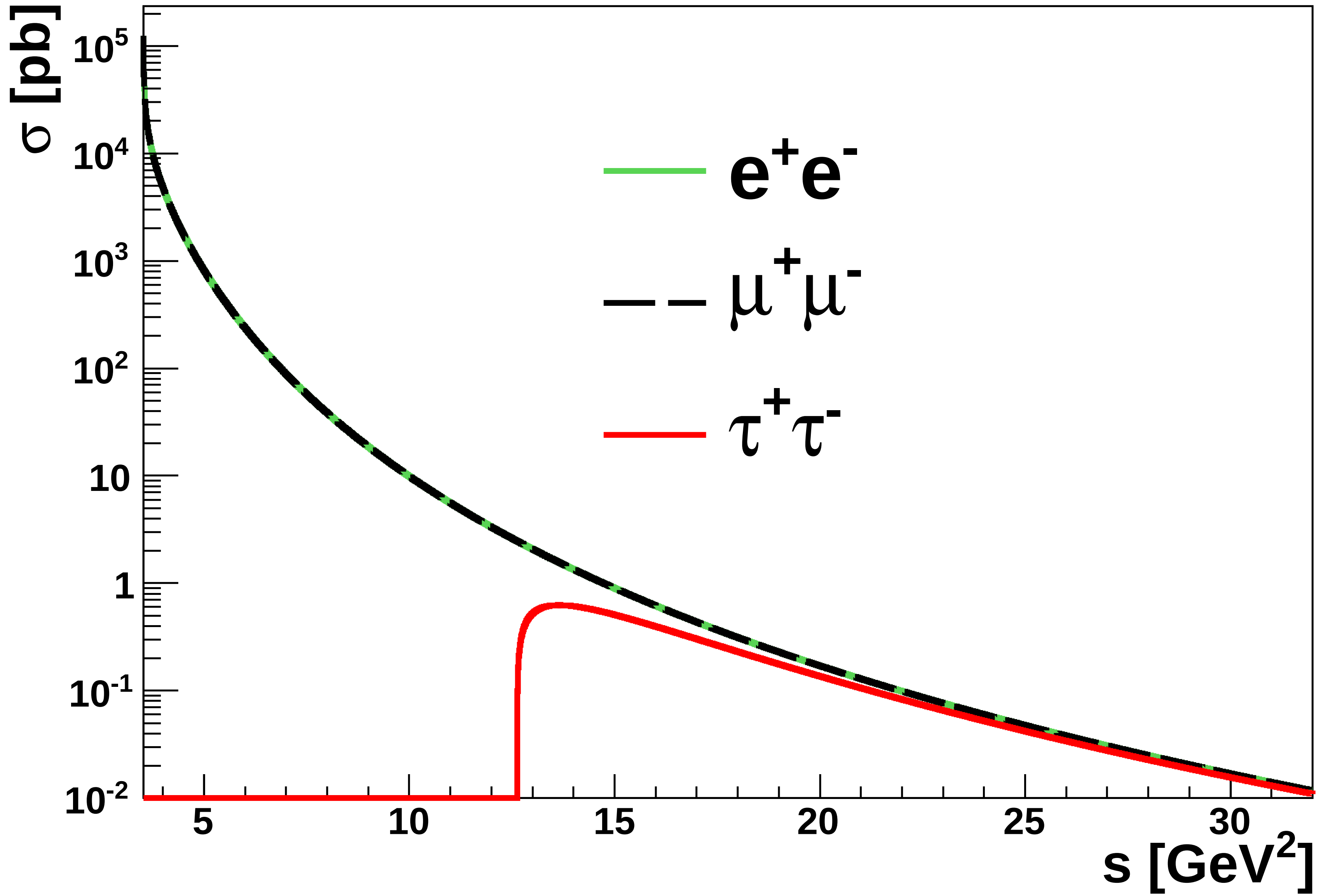
The $\bar{p}p \to l^+l^-$ integrated cross section

$-1 < \cos\theta^* < 1$ FFs: pQCD;

$s = 13.16\ \mathrm{GeV}^2 \Rightarrow \sigma(e^+e^-) = 1.94\ \mathrm{pb}$

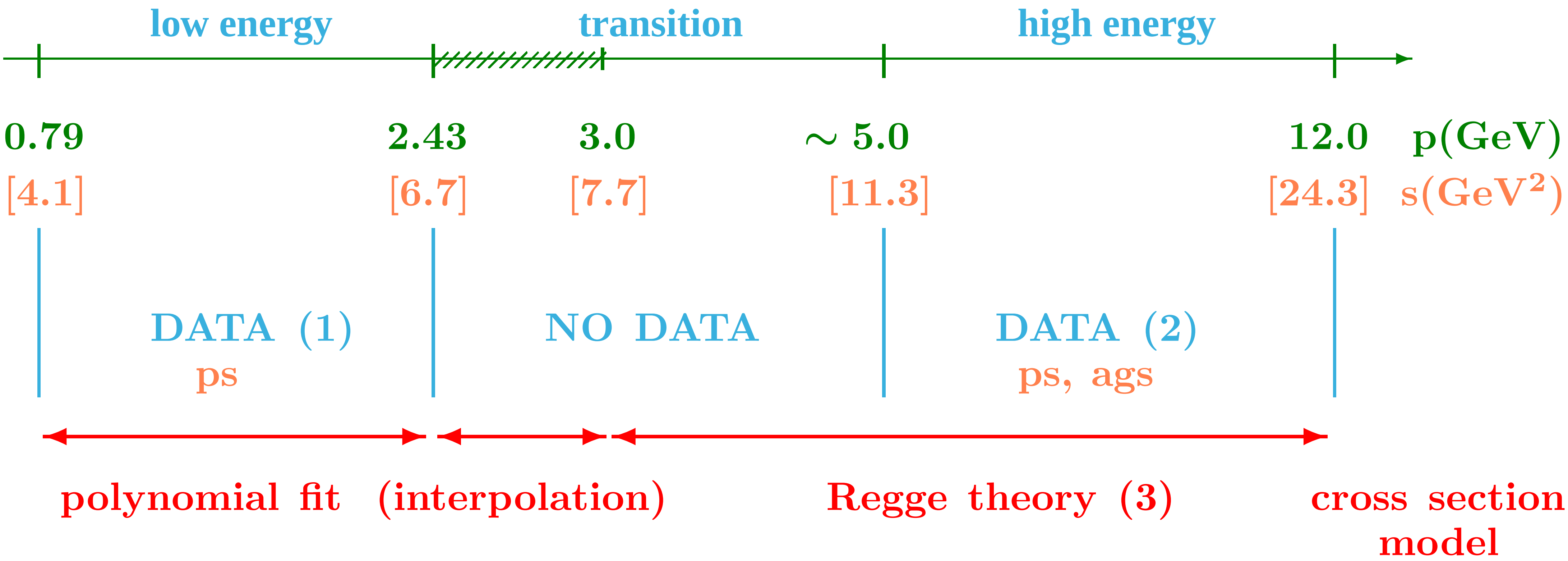
$\sigma(\mu^+\mu^-) = 1.94\ \mathrm{pb}$

$\sigma(\tau^+\tau^-) = 0.57\ \mathrm{pb}$



The $\bar{p}p \to \pi^+\pi^-$ differential cross section : kinematic regimes

- $\pi^+\pi^-$ **production is the main background channel to the** e^+e^- **signal,** $\frac{\sigma(\pi^+\pi^-)}{\sigma(e^+e^-)} \sim 10^6$



(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

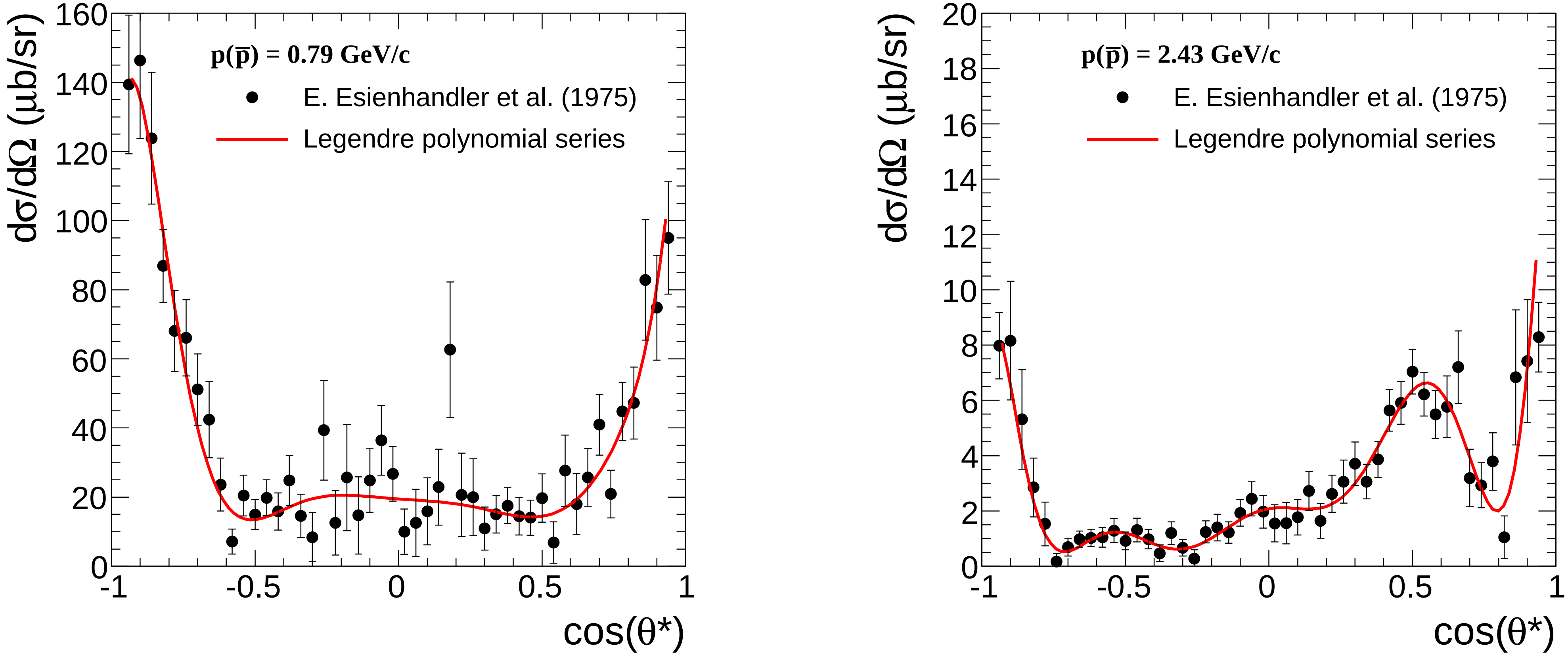
The $\bar{p}p \to \pi^+\pi^-$ differential cross section : low energy regime

- **data:** $\frac{d\sigma}{d\Omega}$ **at a (p, cos θ^*) grid with (20 $\times$ 48) lattice sites** **[Eisenhandler et al., 1975]**

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

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

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

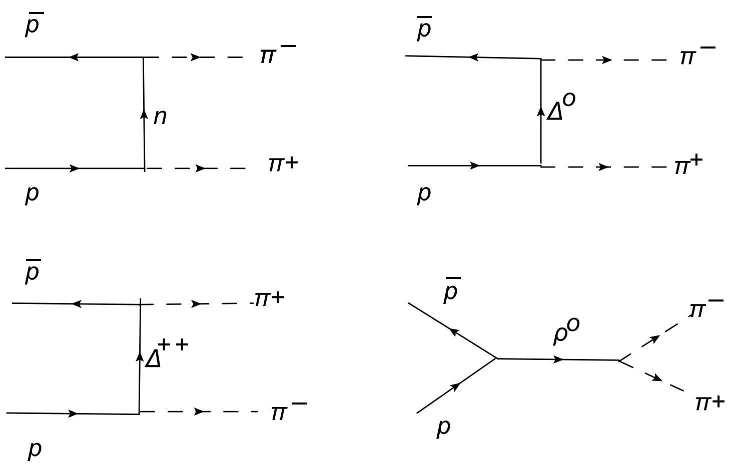


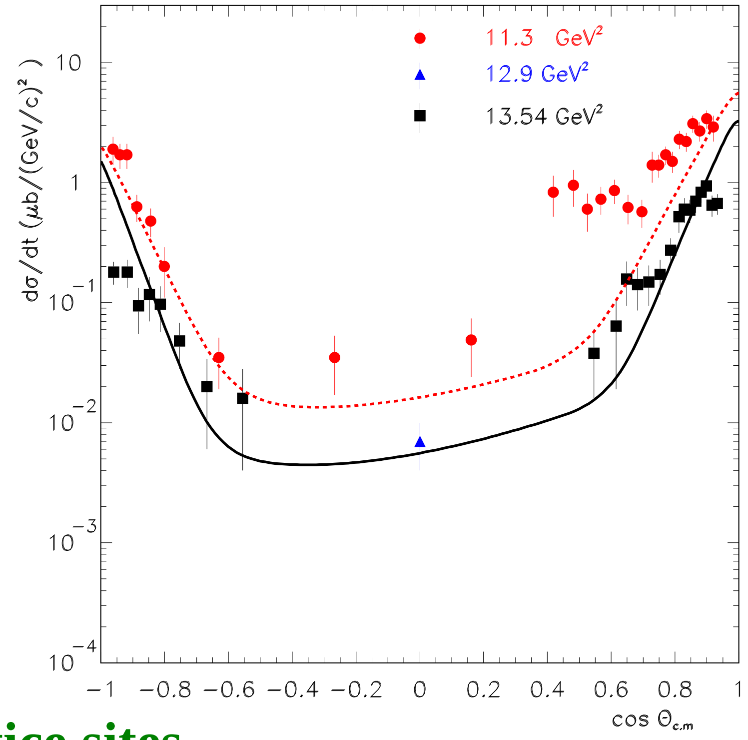
The $\bar{p}p \to \pi^+\pi^-$ differential cross section : high energy regime

- **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**



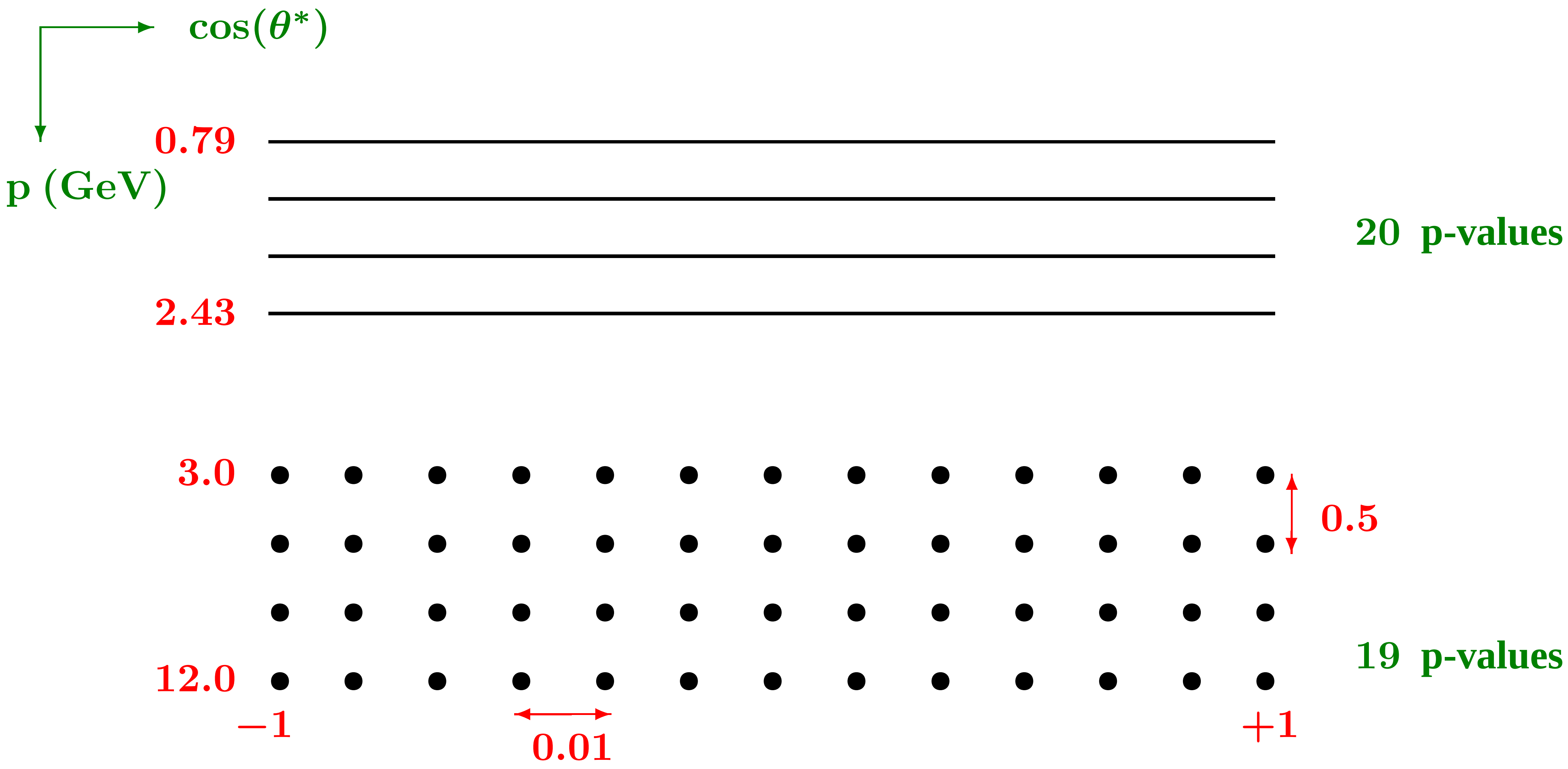


$\Rightarrow$ $\dfrac{d\sigma}{dt}$ **at a $(\mathrm{p}, \cos\theta^*)$ grid of (19×201) lattice sites**

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

$\mathbf{\cos\theta^* = -1.0, \ldots, 1.0}$

The $\bar{p}p \to \pi^+\pi^-$ differential cross section : $(p, \cos\theta^*)$ plane



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

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

The $\bar{p}p \to \pi^+\pi^-$ integrated cross section

- no analytical description, $d\sigma(\bar{p}p \to \pi^+\pi^-)/d\cos\theta^*$ numerically integrated

Monte Carlo integration :

$$\langle f \rangle = \frac{I}{L}\,, \qquad I = \int_a^b dx\, f(x), \qquad L = b - a \qquad \Rightarrow \qquad \boxed{I = L\,\langle f \rangle}$$

MC estimator of $\langle f \rangle$:

$$\langle f \rangle \sim \overline{f} = \frac{1}{N}\sum_{i=1}^{N} f(x_i), \qquad \text{sample } \{x_i\} : \text{ uniform}^{(*)} \text{ sampling x variable}$$

$$\Rightarrow \quad I \sim L \cdot \overline{f}$$

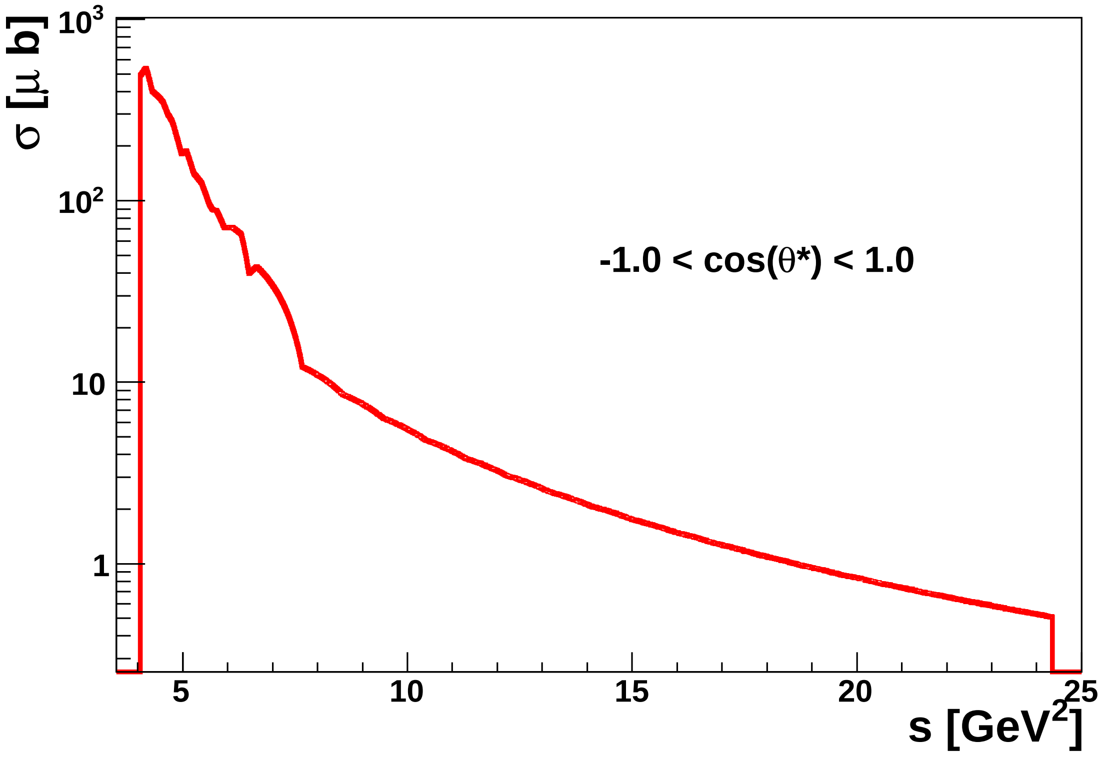
$$\Delta I \sim L\sqrt{\frac{1}{N-1}\left(\overline{f^2} - \overline{f}^2\right)}, \qquad \overline{f^2} = \frac{1}{N}\sum_{i=1}^{N} f(x_i)^2$$

$(*)$ **random number generator: RANLUX**

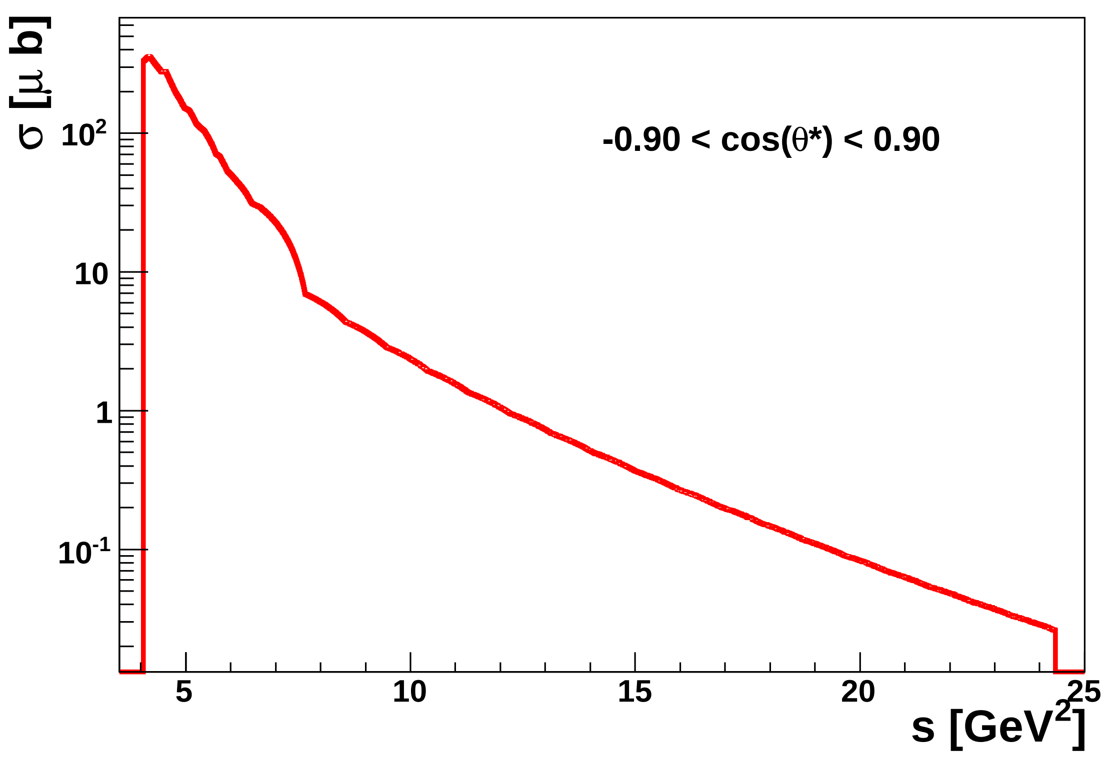
M. Luescher, Comp. Phys. Comm. 79 (1994) 100

The $\bar{p}p \to \pi^+\pi^-$ integrated cross section

$-1 < \cos\theta^* < 1$



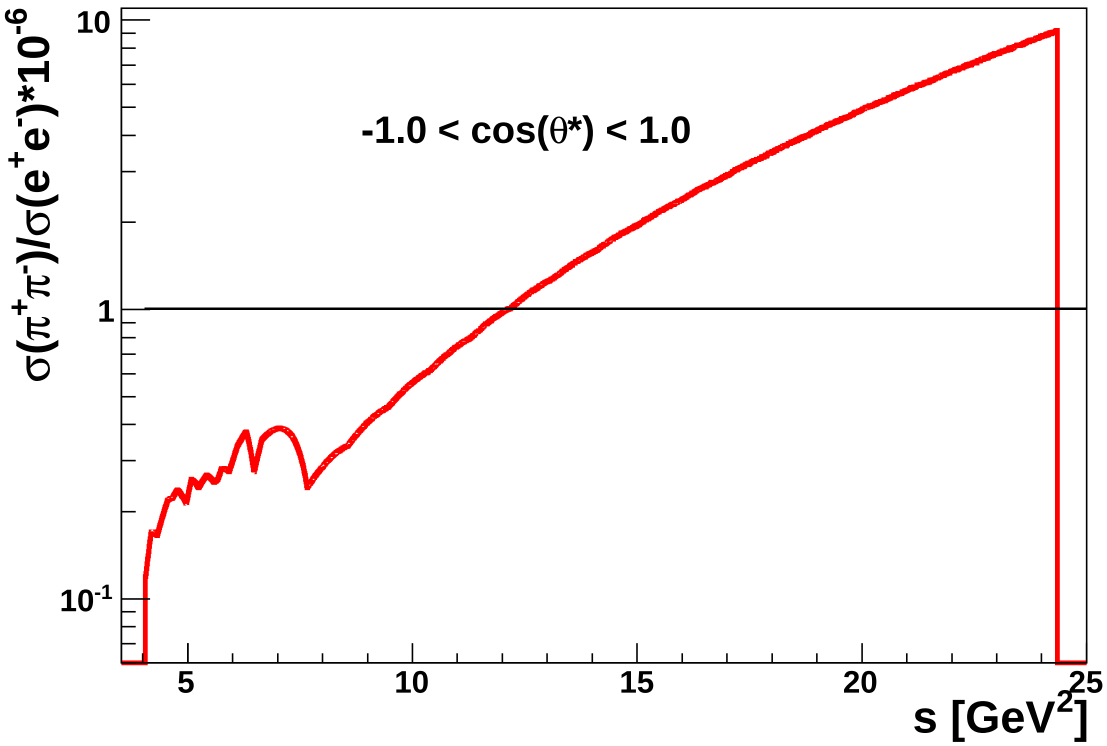
$-0.9 < \cos\theta^* < 0.9$



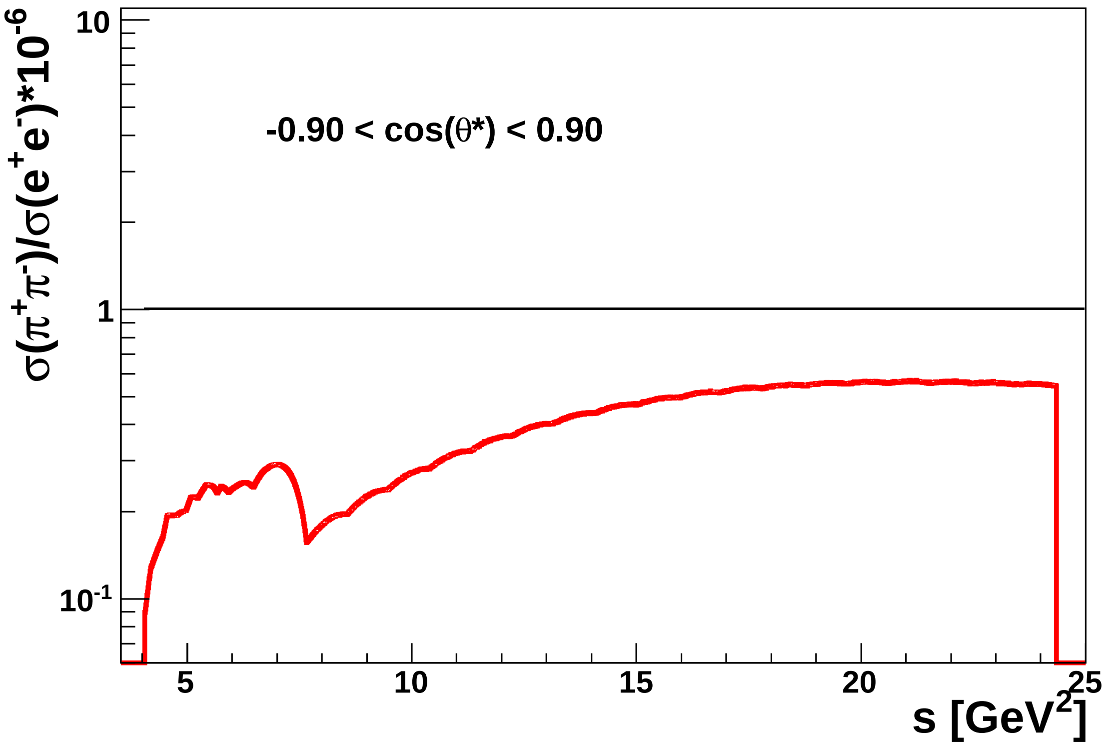
The ratio $\sigma(\pi^+\pi^-)/\sigma(e^+e^-)$

$\sigma(e^+e^-)$: FFs from pQCD

$-1 < \cos\theta^* < 1$



$-0.9 < \cos\theta^* < 0.9$



$\sigma(l^+l^-)$ and $\sigma(\pi^+\pi^-)$: numerical implementation

- **C++ code developed to compute differential and integrated cross sections and ratios**

  $\Rightarrow$ **source code and full documentation available in the PANDA-Mainz wiki:**

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

- **parameters are passed to the program through an infile:**

```
0           !   lepton, 0=electron, 1=muon, 2=tau
3.3         !   momentum pbar (GeV)
-1.0        !   cos(theta*) min
1.0         !   cos(theta*) max
10          !   #bins
0           !   FF model, 0=pQCD, 1=vmd, 2=dipole-modified
3.0         !   ratio GE/GM
2.0         !   luminosity (fb^-1)
1           !   RANLUX seed:  [1,2^31-1]
1000000     !   #MC integration points
../output   !   pathout
myhistos    !   outfile
```

$\sigma(l^+l^-)$ and $\sigma(\pi^+\pi^-)$: numerical implementation


```
------------------------------------
   Reading infile
------------------------------------

particle flag:                 0
momentum pbar:                 3.30 GeV
cos(theta*) min:               -1.00
cos(theta*) max:               1.00
number of bins:                10
FF flag:                       0
ratio GE/GM:                   3.00
luminosity:                    2.00 fb^-1
RANLUX seed:                   1
number of MC points:           1000000
pathout:                       ../output
outfile:                       mzhistos







PION PRODUCTION: Kinematic regime and cross section parametrization
-------------------------------------------------------------------

 3.00 < P <  5.00 GeV => transition energy regime
cross section parametrization: Regge description


P NOT at lattice site: interpolating cross section between momenta  3.00 and  3.50 GeV






Initial state kinematics
------------------------

=> CM energy square:        S =  8.20 GeV^2
   CM energy:         sqrt(S) =  2.86 GeV
```

$\sigma(l^+l^-)$ and $\sigma(\pi^+\pi^-)$: numerical implementation

Printed by Manuel Zambrana

Jun 12, 12 16:10 **output.log** Page 1/1

```
TOTAL CROSS SECTION
===================

-1.00 < cos(theta*) < 1.00
GE, GM from FF model
q2 = 8.20 GeV^2

GE = 0.0440
GM = 0.0440

 => GE/GM = 1.0000

sigma(e+e-)   =  33.02065592                            [pb]
sigma(pi+pi-) =  10.17569261  +/-   0.01857744 (0.18 %) [micro b]

N(e+e-)   =        66041
N(pi+pi-) =  20351385216

sigma(pi+pi-)/sigma(e+e-)*10^{-6}  =   0.30816143

BIN-INTEGRATED CROSS SECTION
============================

-1.00 < cos(theta*) < 1.00,    #bins = 10    =>   cos(theta*) bin width:  a = 0.20
GE, GM from FF model
```

cos(theta*) bin		sigma(e+e-) [pb]	sigma(pi+pi-) [micro b]	error [micro b]	error [%]	ratio*10^{-6}
-1.00	-0.80	3.86034351	1.25397467	0.00045853	0.03656586	0.32483500
-0.80	-0.60	3.48815823	0.32780510	0.00012320	0.03758293	0.09397656
-0.60	-0.40	3.20901927	0.10722799	0.00002415	0.02252184	0.03341457
-0.40	-0.20	3.02292663	0.07171337	0.00000196	0.00272879	0.02372316
-0.20	0.00	2.92988031	0.07513733	0.00000295	0.00393083	0.02564519
0.00	0.20	2.92988031	0.09468527	0.00000953	0.01006871	0.03231711
0.20	0.40	3.02292663	0.16523636	0.00003734	0.02259554	0.05466106
0.40	0.60	3.20901927	0.46320527	0.00015988	0.03451538	0.14434481
0.60	0.80	3.48815823	1.67221640	0.00062153	0.03716788	0.47939809
0.80	1.00	3.86034351	5.96525735	0.00200834	0.03366724	1.54526594

```
sum_{i} sigma(e+e-)[i]   =  33.02065592                            [pb]
sum_{i} sigma(pi+pi-)[i] =  10.19645912   +/-   0.00216166 (0.02 %) [micro b]
```

cos(theta*) bin		sigma(e+e-)/a [pb]	sigma(pi+pi-)/a [micro b]	error [micro b]	error [%]	ratio*10^{-6}
-1.00	-0.80	19.30171755	6.26987335	0.00229263	0.03656586	0.32483500
-0.80	-0.60	17.44079116	1.63902551	0.00061599	0.03758293	0.09397656
-0.60	-0.40	16.04509636	0.53613996	0.00012075	0.02252184	0.03341457
-0.40	-0.20	15.11463316	0.35856687	0.00000978	0.00272879	0.02372316
-0.20	0.00	14.64940156	0.37568666	0.00001477	0.00393083	0.02564519
0.00	0.20	14.64940156	0.47342636	0.00004767	0.01006871	0.03231711
0.20	0.40	15.11463316	0.82618181	0.00018668	0.02259554	0.05466106
0.40	0.60	16.04509636	2.31602634	0.00079939	0.03451538	0.14434481
0.60	0.80	17.44079116	8.36108201	0.00310764	0.03716788	0.47939809
0.80	1.00	19.30171755	29.82628674	0.01004169	0.03366724	1.54526594

$\sigma(l^+l^-)$ and $\sigma(\pi^+\pi^-)$: numerical implementation


```
TOTAL CROSS SECTION
===================

-1.00 < cos(theta*) < 1.00
GM from FF model, GE=R*GM, R user-defined ratio GE/GM
q2 = 8.20 GeV^2

GE = 0.1321
GM = 0.0440

 => GE/GM = 3.0000

sigma(e+e-)   =  79.72181058                            [pb]
sigma(pi+pi-) =  10.17569261  +/-   0.01857744 (0.18 %) [micro b]

N(e+e-)   =       159444
N(pi+pi-) =  20351385216

sigma(pi+pi-)/sigma(e+e-)*10^{-6}  =   0.12764001

BIN-INTEGRATED CROSS SECTION
============================

-1.00 < cos(theta*) < 1.00,    #bins = 10    =>   cos(theta*) bin width:  a = 0.20
GM from FF model, GE=R*GM, R  user-defined ratio GE/GM
```

cos(theta*) bin		sigma(e+e-) [pb]	sigma(pi+pi-) [micro b]	error [micro b]	error [%]	ratio*10^{-6}
-1.00	-0.80	5.16797648	1.25397467	0.00045853	0.03656586	0.24264326
-0.80	-0.60	7.03744620	0.32780510	0.00012320	0.03758293	0.04658012
-0.60	-0.40	8.43954849	0.10722799	0.00002415	0.02252184	0.01270542
-0.40	-0.20	9.37428334	0.07171337	0.00000196	0.00272879	0.00765001
-0.20	0.00	9.84165077	0.07513733	0.00000295	0.00393083	0.00763463
0.00	0.20	9.84165077	0.09468527	0.00000953	0.01006871	0.00962087
0.20	0.40	9.37428334	0.16523636	0.00003734	0.02259554	0.01762656
0.40	0.60	8.43954849	0.46320527	0.00015988	0.03451538	0.05488508
0.60	0.80	7.03744620	1.67221640	0.00062153	0.03716788	0.23761694
0.80	1.00	5.16797648	5.96525735	0.00200834	0.03366724	1.15427332

```
sum_{i} sigma(e+e-)[i]   =  79.72181058                            [pb]
sum_{i} sigma(pi+pi-)[i] =  10.19645912  +/-   0.00216166 (0.02 %) [micro b]
```

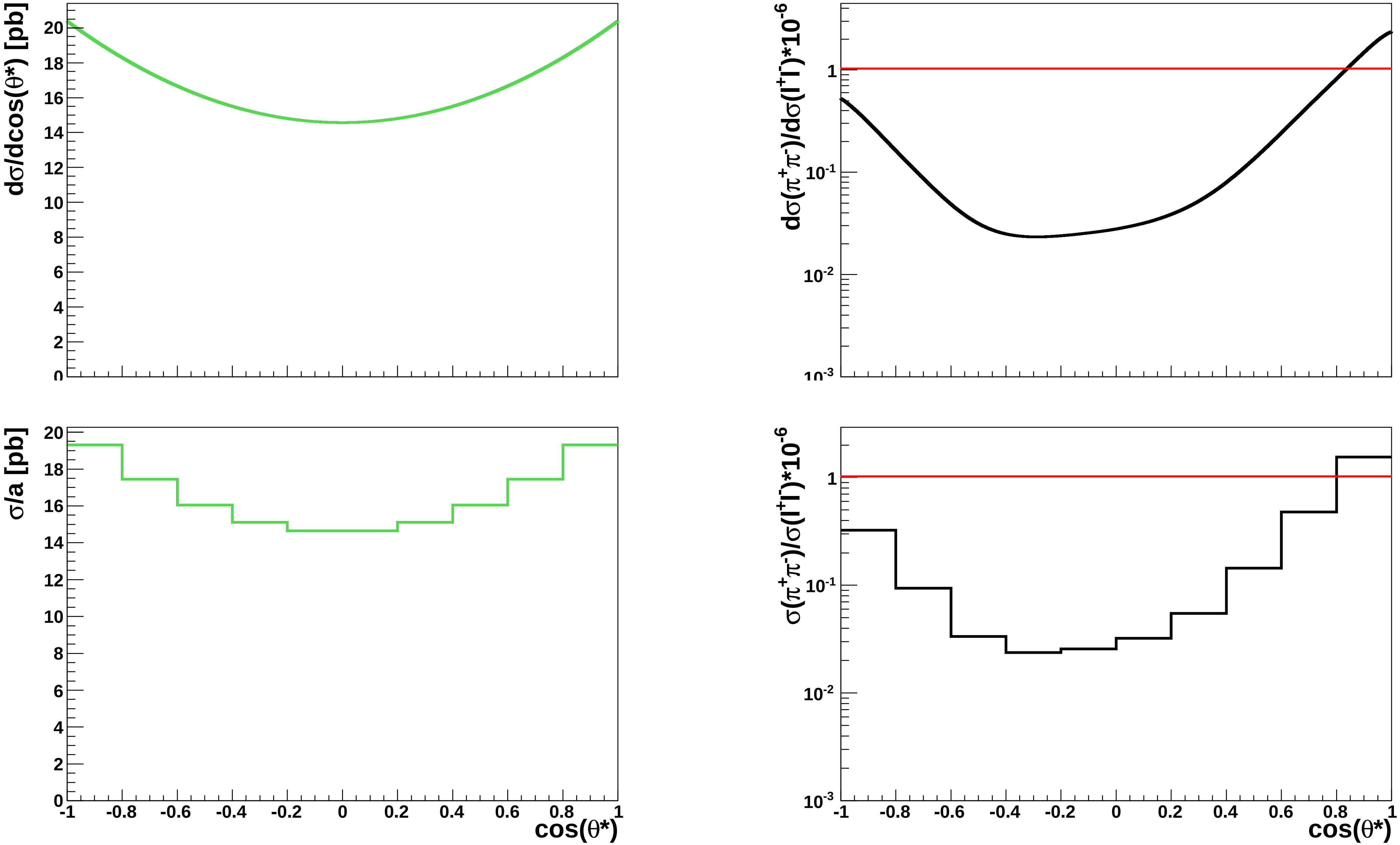
cos(theta*) bin		sigma(e+e-)/a [pb]	sigma(pi+pi-)/a [micro b]	error [micro b]	error [%]	ratio*10^{-6}
-1.00	-0.80	25.83988242	6.26987335	0.00229263	0.03656586	0.24264326
-0.80	-0.60	35.18723100	1.63902551	0.00061599	0.03758293	0.04658012
-0.60	-0.40	42.19774243	0.53613996	0.00012075	0.02252184	0.01270542
-0.40	-0.20	46.87141672	0.35856687	0.00000978	0.00272879	0.00765001
-0.20	0.00	49.20825387	0.37568666	0.00001477	0.00393083	0.00763463
0.00	0.20	49.20825387	0.47342636	0.00004767	0.01006871	0.00962087
0.20	0.40	46.87141672	0.82618181	0.00018668	0.02259554	0.01762656
0.40	0.60	42.19774243	2.31602634	0.00079939	0.03451538	0.05488508
0.60	0.80	35.18723100	8.36108201	0.00310764	0.03716788	0.23761694
0.80	1.00	25.83988242	29.82628674	0.01004169	0.03366724	1.15427332

$\sigma(l^+l^-)$ and $\sigma(\pi^+\pi^-)$: numerical implementation


```
<TCanvas::MakeDefCanvas>: created default TCanvas with name c1




Writing histos to file:
     ../output/mzhistos.root   (root file)



HISTOGRAM DESCRIPTION
=====================

h0  -> dsigma(e+e-)/dcos(theta*), GE and GM from FF model
h1  -> dsigma(pi+pi-)/dcos(theta*)
h2  -> dsigma(pi+pi-)/dsigma(e^+e^-)*10^{-6}, GE and GM from FF model

h10 -> sigma(e+e-)[i], GE and GM from FF model
h11 -> sigma(pi+pi-)[i]
h12 -> sigma(pi+pi-)[i]/sigma(e+e-)[i]*10^{-6}, GE and GM from FF model
h14 -> sigma(e+e-)[i]/a, a=bin width, GE and GM from FF model
h15 -> sigma(pi+pi-)[i]/a, a=bin width

h100  -> dsigma(e+e-)/dcos(theta*), GM from FF model, GE=R*GM, R user-defined ratio GE/GM
h102  -> dsigma(pi+pi-)/dsigma(e^+e^-)*10^{-6}, GM from FF model, GE=R*GM, R user-defined ratio GE/GM

h110 -> sigma(e+e-)[i], GM from FF model, GE=R*GM, R user-defined ratio GE/GM
h112 -> sigma(pi+pi-)[i]/sigma(e+e-)[i]*10^{-6}, GM from FF model, GE=R*GM, R user-defined ratio GE/GM
h114 -> sigma(e+e-)[i]/a, a=bin width, GM from FF model, GE=R*GM, R user-defined ratio GE/GM



Execution time... 8.97s
```

$\sigma(l^+l^-)$ and $\sigma(\pi^+\pi^-)$: numerical implementation

$P = 3.3$ GeV $\quad -1 < \cos\theta^* < 1 \quad$ FFs: pQCD



Summary and conclusions

- we have given a description of $\sigma(\bar{p}p \to l^+l^-)$ and $\sigma(\bar{p}p \to \pi^+\pi^-)$
- C++ code developed (public, documented) to calculate differential and integrated cross sections and ratios, available at

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

(+documentation for event generators developed in Mainz and part of current PandaRoot)

$\to$ useful to study suppresion factors, expected events, systematics

ongoing work . . .

$\to$ simulation and data analysis (Dmitry Khaneft, Iris Zimmermann)
$\to$ higher order effects (two photons, radiative corrections)
$\to$ other channels : $\sigma(\bar{\mathrm{p}}\mathrm{p} \to \mathrm{e}^+\mathrm{e}^-\pi^0)$, etc.