Exclusive electroproduction of $f_0(980)$ and $f_2(1270)$ with the CLAS detector

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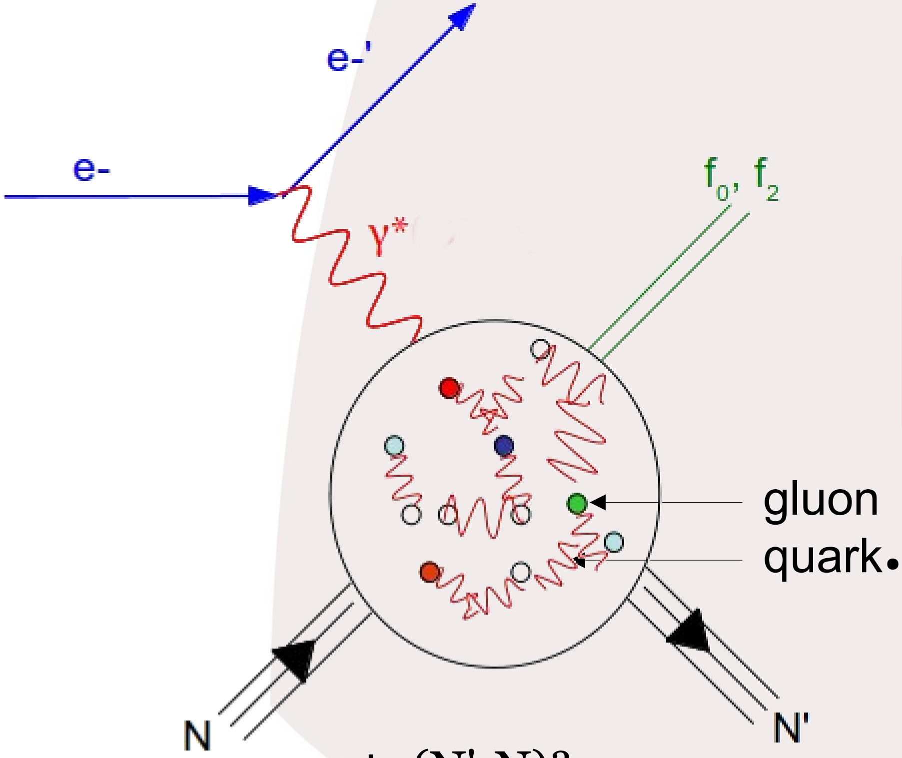
Electroproduction of the $f_0(980)$ and $f_2(1270)$ mesons

f_0 et f_2 are **light unflavoured mesons**



t=(N'-N)²

Meson electroproduction
(single-photon exchange)

f_0 (980+/-10) MeV
J^{PC}=0++ (Scalar)
Γ = From 40 to 100 MeV

ππ	**Dominant**
KK	Observed
γγ	Observed

f_2 (1270+/-1.2) MeV
J^{PC}=2++ (Tensor)
Γ = 185.1 MeV

ππ	**84.8 %**
$\pi\pi\pi^-2\pi^0$	7.1 %
KK	4.6 %

Cross sections for
exclusive ep → epf_0/f_2 → ep$\pi^+\pi^-$
have never been measured so far !

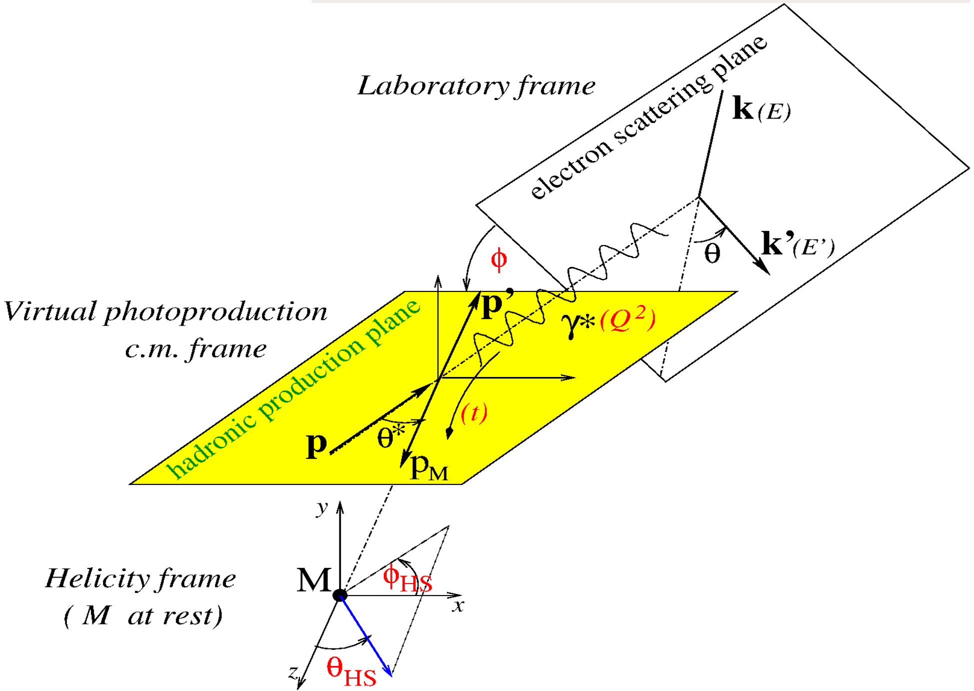
Physics motivations

- **Nature of f_0 and f_2 :** Q^2, t dependence of the differential cross sections may shed light on the nature of these mesons.
  → f_0: Standard meson ? $K\overline{K}$ molecule?
  → f_2 : Resonance produced in vector meson-vector meson interactions ?
- **Nucleon structure :** f_0 and some helicity states of f_2 might be sensitive to Generalized Parton Distributions.

The exclusive ep → ep$\pi^+\pi^-$ channel

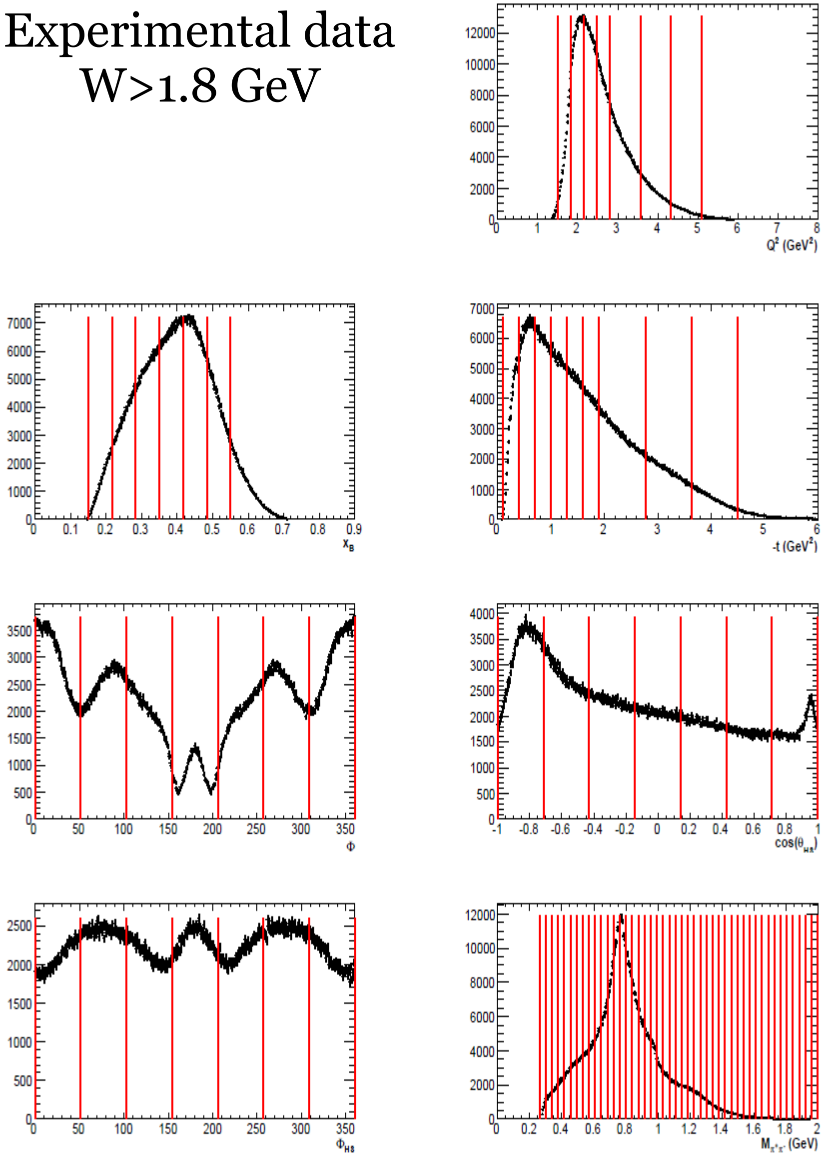
Unpolarized cross sections are described by 7 kinematic variables :

- **Q²** Virtual photon (γ*) squared mass.
- **x_B** Bjorken variable (x_B ~1/W , the (γ*,p) CM energy).
- **t** Momentum transfer to the nucleon
- **Φ** Azimuthal angle between leptonic (γ*,e') and hadronic (γ*,p') planes.
- **Cos($\theta_{\pi+}$) , $\Phi_{\pi+}$** Angles of the π^+ in the meson helicity rest frame : Z axis defined by meson 4- vector (γ*,p) in the center of mass frame.
- **$M_{\pi\pi}$** Invariant mass of $\pi^+\pi^-$



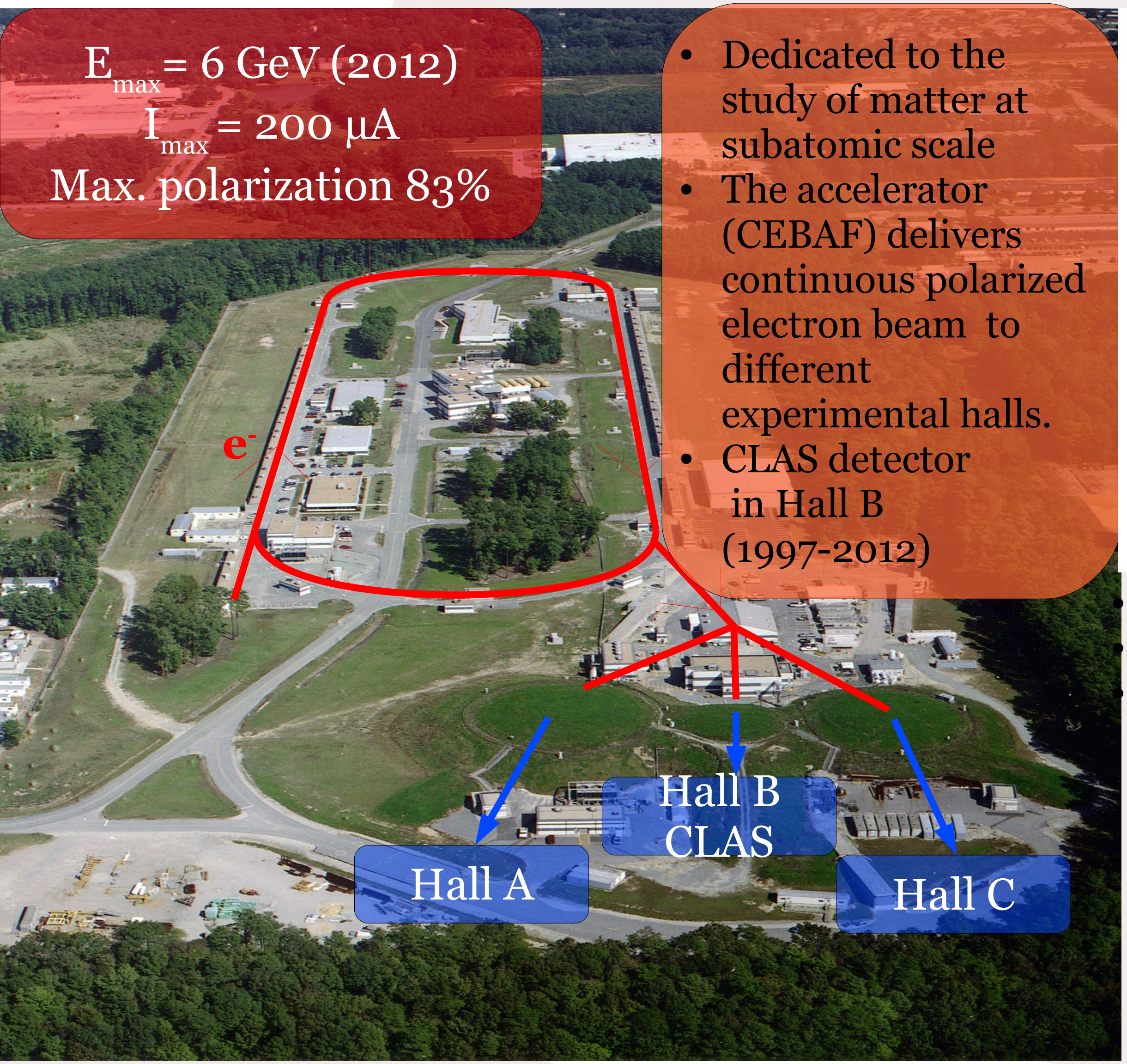
Phase space binning

Experimental data
W>1.8 GeV



JLAB and the CLAS detector

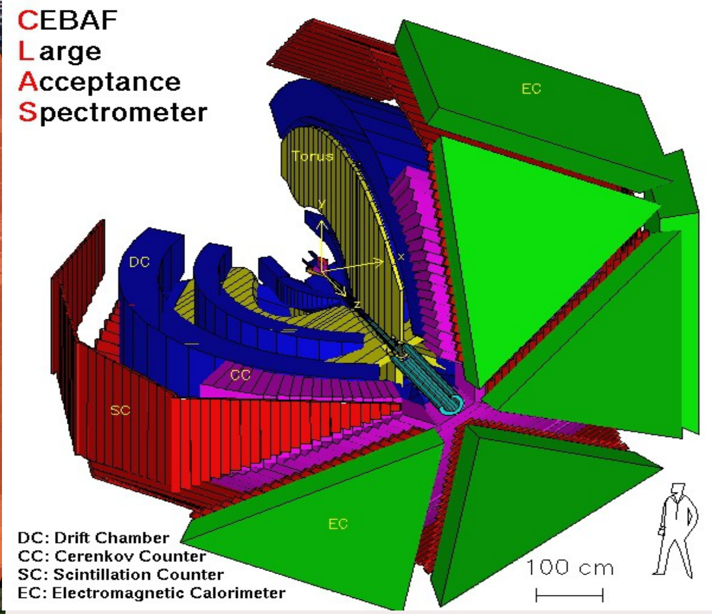
The Jefferson Laboratory (Newport-News,USA)



E_{max} = 6 GeV (2012)
I_{max} = 200 μA
Max. polarization 83%

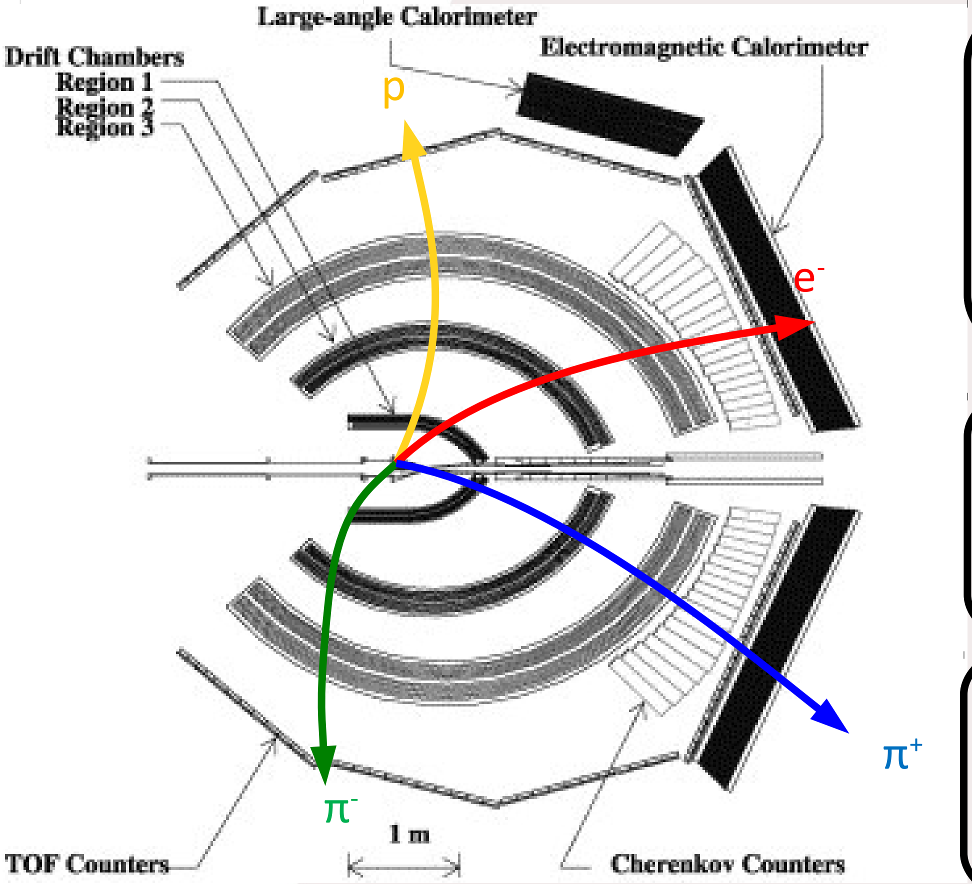
- Dedicated to the study of matter at subatomic scale
- The accelerator (CEBAF) delivers continuous polarized electron beam to different experimental halls.
- CLAS detector in Hall B (1997-2012)

The CEBAF Large Acceptance Spectrometer (CLAS)



- L=10^{35} $cm^{-2}s^{-1}$
- Wide angle coverage.
- Divided into 6 azimuthal sectors. Each sector includes :
  - Torus magnet
  - Drift Chambers (DC)
  - Cherenkov Counters (CC)
  - Electromagnetic Calorimeters (EC)
  - Time of Flight Counters (SC)

Channel Selection



e^- identification

- EC and DC fiducial cuts.
- Selection on vertex position along the direction of the beam.
- Cuts on the fraction of energy deposited in EC.
- Track matching between CC and SC.

p and π^+ identification

- DC fiducial cuts
- Identification by time of flight (SC)

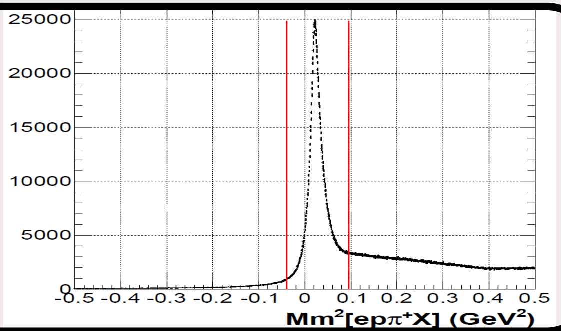
Energy loss correction

- Kinematics of the final state particles at the vertex are retrieved with the aid of MC simulations.

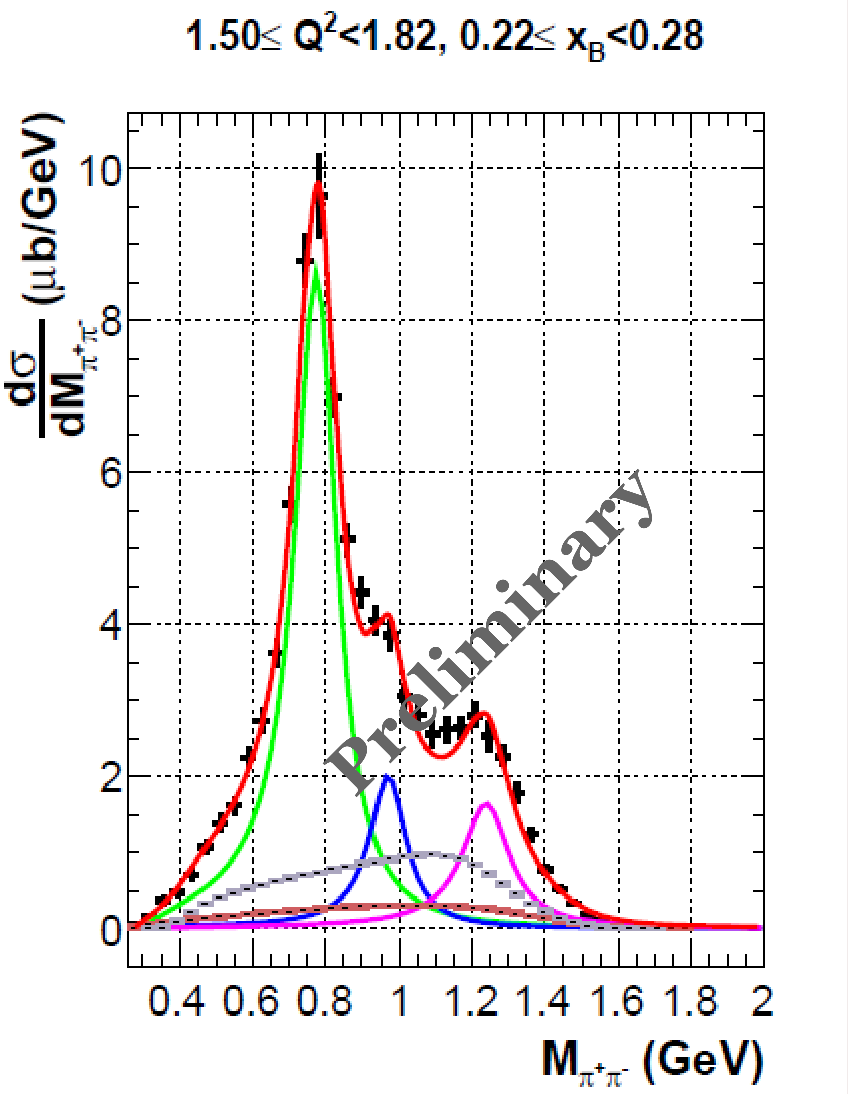
Exclusivity

- Additional vertex cuts.
- Selection on π^- peak in missing mass $Mm[ep\pi^+X]$ spectrum.

$$-0.05 < Mm^2[ep\pi^+X] < 0.08 \text{ GeV}^2$$



Background subtraction



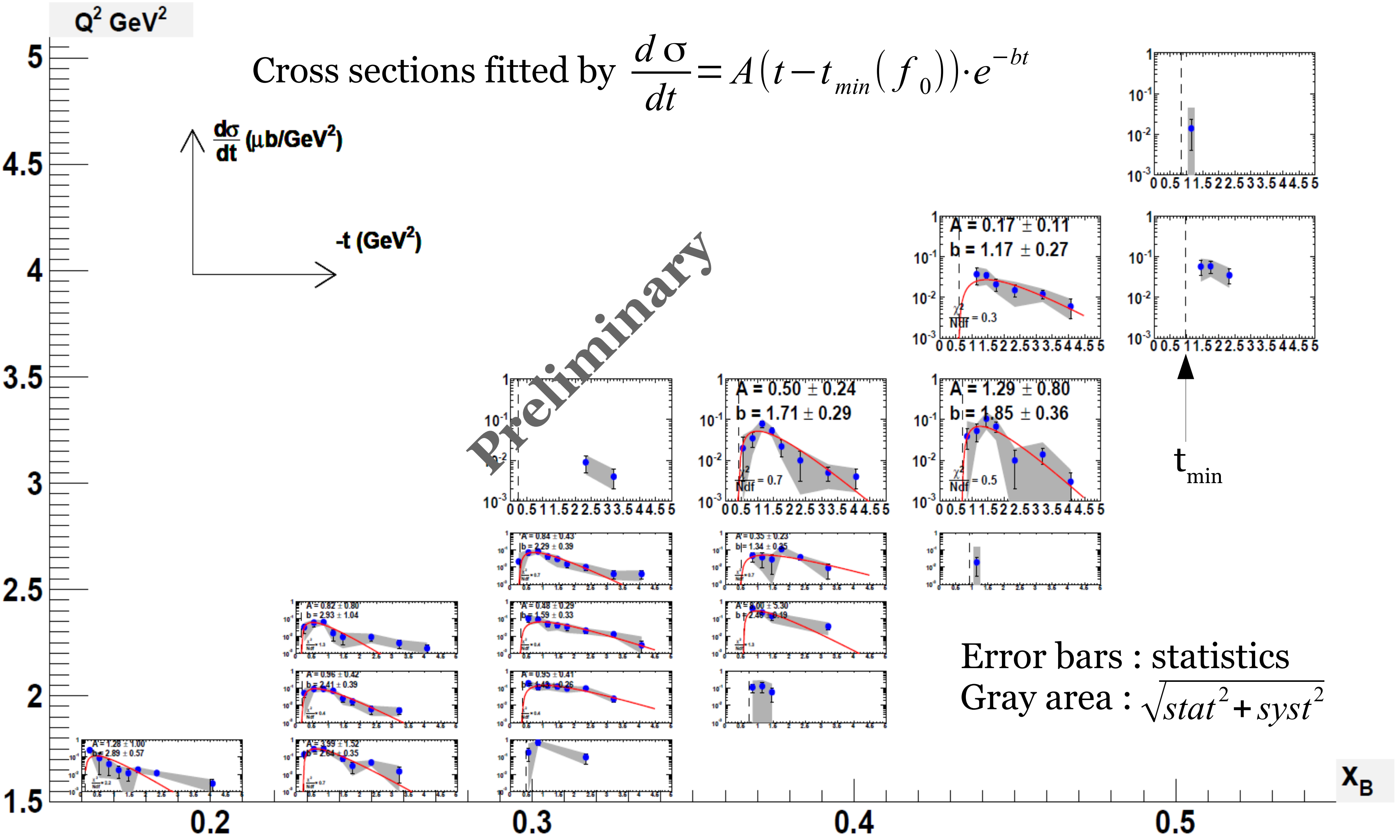
- Experimental data are corrected from **acceptance** and **radiative effect** thanks to **Monte Carlo simulations**, then normalized to a cross section.
- f_o and f_2 are extracted from **a fit of Born differential cross sections as a function of $M_{\pi+\pi-}$**, in a (Q^2, x_B, ν) bin.
  ν= t, Φ, cos θ_{HS} , φ_{HS} or nothing.
- Fit of $M_{\pi+\pi-}$ spectra with several incoherent contributions :
  - Skewed Breit Wigner (BW) for **ρ**, **f_o**, **f_2** (4 parameters each)
  - Scale parameters for background MC non radiative **non resonant ππ** and Δ^{++} .

Cross section for meson production

$$\sigma^{\gamma^* p \rightarrow p\,\mathrm{Meson}} = \frac{\int_0^2 BW_{skew}^{\mathrm{Meson}}(M_{\pi^+\pi^-})\, dM_{\pi^+\pi^-}}{BR^{\mathrm{Meson} \rightarrow \pi^+\pi^-}}$$

t-dependent cross sections (f_0)

Cross sections fitted by $\frac{d\sigma}{dt} = A(t - t_{min}(f_0)) \cdot e^{-bt}$

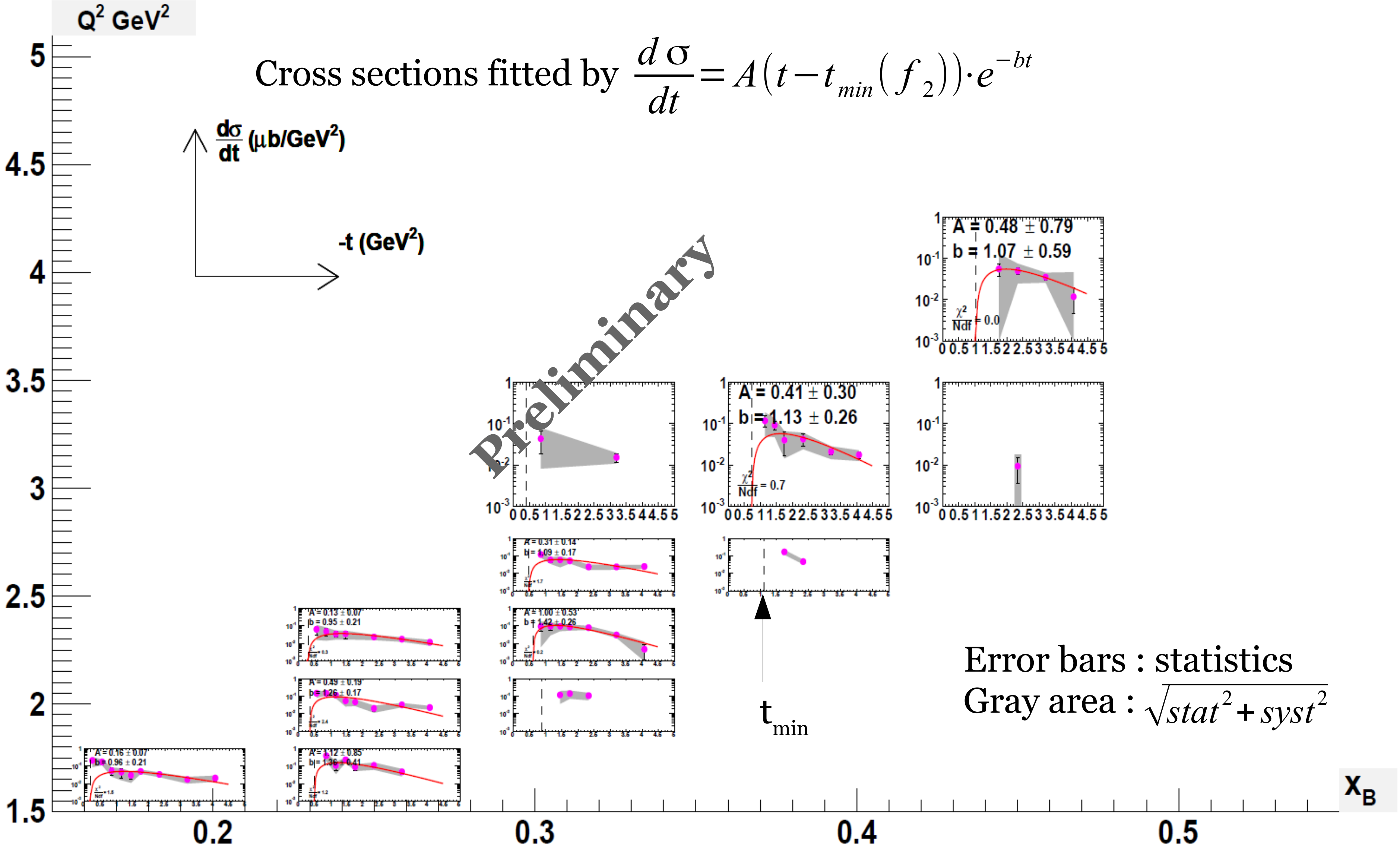


Error bars : statistics

Gray area : $\sqrt{stat^2 + syst^2}$

t-dependent cross sections (f_2)

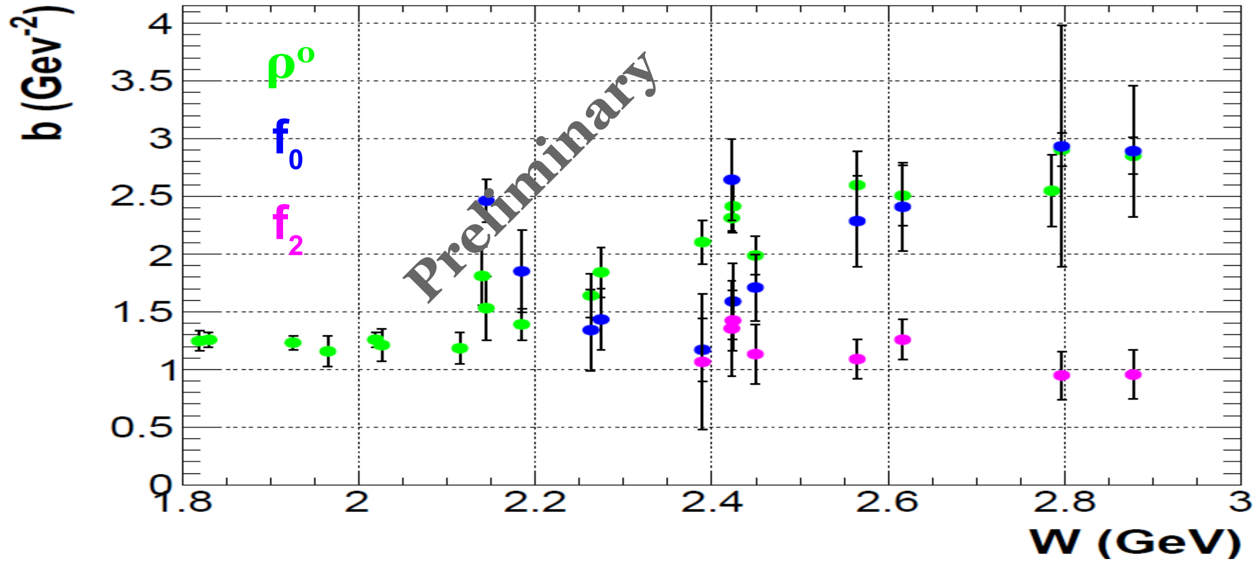
Cross sections fitted by $\frac{d\sigma}{dt} = A(t - t_{min}(f_2)) \cdot e^{-bt}$



Error bars : statistics

Gray area : $\sqrt{stat^2 + syst^2}$

b-slope

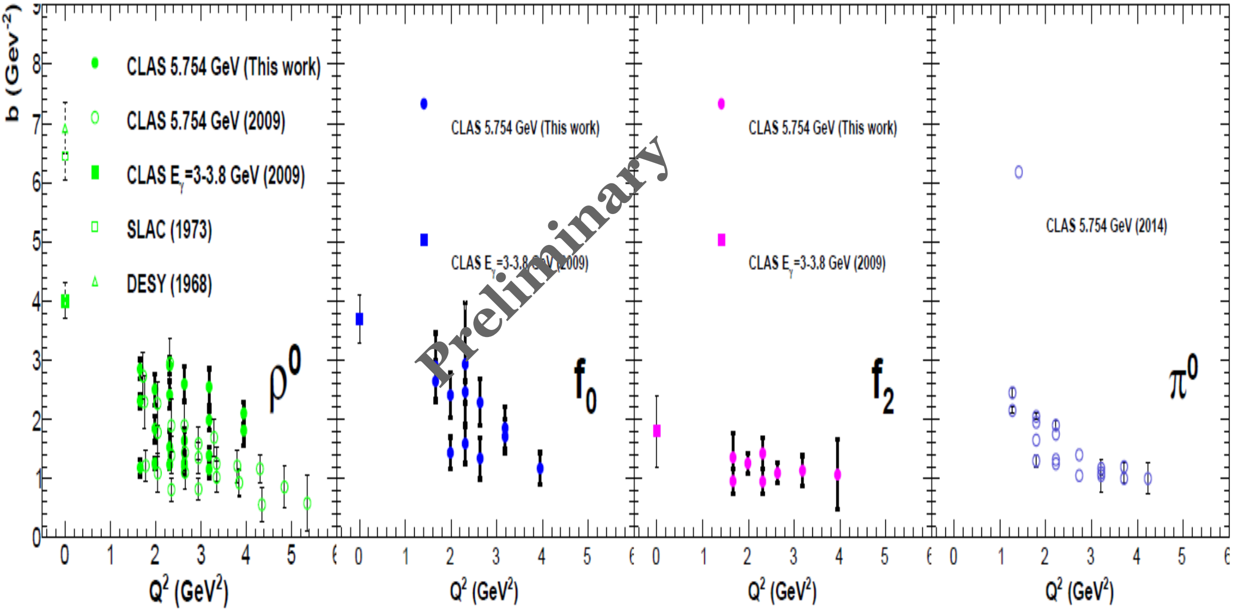


$$\frac{d\sigma}{dt} = A\left(t - t_{min}(\text{Meson})\right)\cdot e^{-bt}$$

b related to the transverse size of the γ*p system.

b vs W

- Same behaviour for f_o and ρ°.
- Constant b for f_2 in the available W range.



b vs Q²

- b slope decreases as Q² increases
  → γ*p interaction region is smaller with a finer resolution.
- Weaker decrease of b with Q² for f_2, the heaviest meson considered.
  → The mass of the meson acts as a resolution scale.

Extraction of moments : Method

In a 2-pion decay, the spin of the meson can be retrieved by analysing the angular distributions of the decay π^+ .

Moment of the angular distribution of π^+

$$< Y_{LM} > (Q^2, x_B, t, \Phi, M_{\pi^+\pi^-}) = \sqrt{4\pi} \int d\Omega_{\pi^+} \frac{d\sigma^{\gamma^* p \to p' \pi^+ \pi^-}}{dt d\Phi dM_{\pi^+\pi^-}} \Re(Y_{LM}(\Omega_{\pi^+}))$$

$<V_{LM}>$ Moment (0<=M<=L) **Y_{LM}** Spherical harmonics.

$\Omega_{\pi+}$ Decay solid angle of the π^+ in meson helicity frame.

Parametrization

$$I(\Theta,\Phi)=\sqrt{4\pi}\sum_{L=0}^{L_{max}}\sum_{M=0}^{L}<Y_{LM}>\Re\left(Y_{LM}(\Theta,\Phi)\right),\ L_{max}=4$$

Intensity : weight applied to each ep$\pi^+\pi^-$ event.

$<Y_{LM}>$ are free parameters to be fitted.

The intensity is fitted to the data by maximizing the likelihood L (AmpTools[1] software) :

$$\underbrace{-\ln L=-\left(\sum_{i}^{n}\ln\left(I\left(\tau_i,\vec{x}\right)\right)\right)}_{\textbf{Experimental data}}+\underbrace{\frac{1}{N^{GEN}}\sum_{k=1}^{NREC}I\left(\tau_i,\vec{x}\right)}_{\textbf{Acceptance term, calculated with MC phase space}}$$

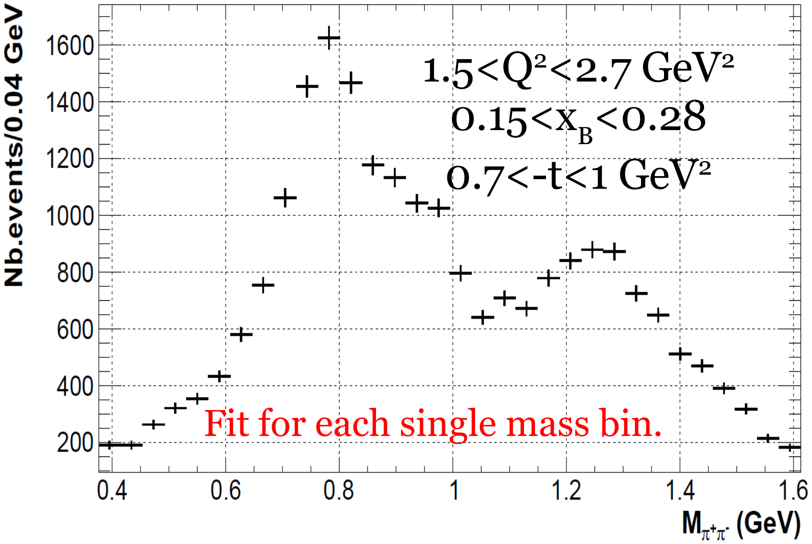
$\tau_i=(\theta,\Phi)$

$\vec{x}=<Y_{LM}>$

Reference : [1] http://amptools.sourceforge.net

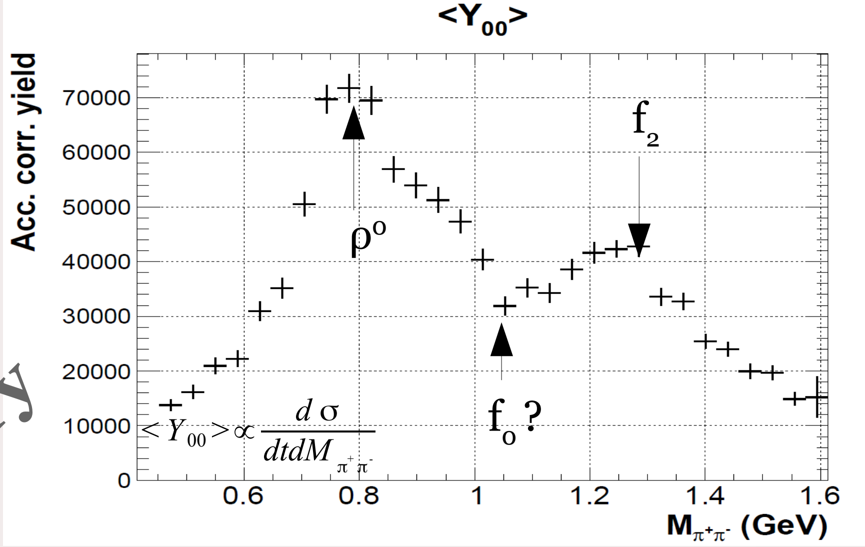
Extraction of moments : selected results

Moments are sensitive to **interferences between partial waves amplitudes.**



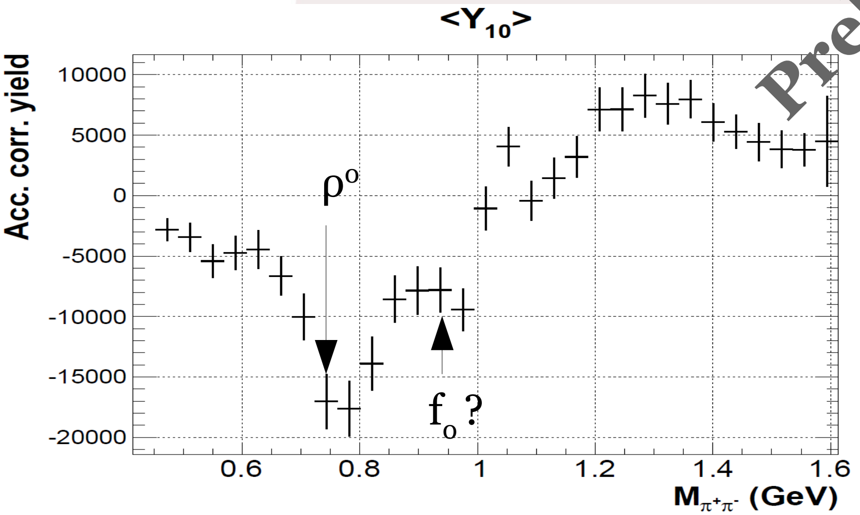
$1.5<Q^2<2.7$ GeV²
$0.15<x_B<0.28$
$0.7<-t<1$ GeV²

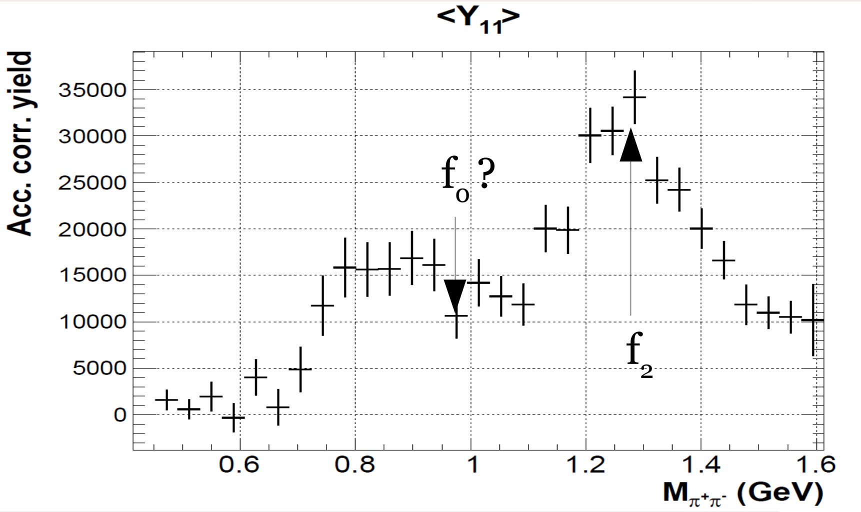
Fit for each single mass bin.



$<Y_{00}> \propto \frac{d\sigma}{dtdM_{\pi^+\pi^-}}$

Preliminary





Statistical errors only

Conclusions and perspectives

- First time measurement of cross sections for the electroproduction of the f_0 (980) and f_2 (1270).

- t, Φ, and cos θ_{HS} dependence of cross sections studied.

- The f_0 and f_2 lie on a large background region; subtracting the various backgrounds incoherently leads to large systematic errors.

- Alternative extraction of f_0 and f_2 through an analysis in terms of moments : f_2 clearly visible and presence of f_0 to be confirmed with better statistics.

- Quality of the analysis of moments is limited by the statistics of the data.
  → New experiments (CLAS12) may help to perform a more accurate analysis.

Thanks for your attention.

Backup slides

Born reduced cross section

The reduced cross section is computed for each (Q^2 , x_B, ν, $M_{\pi\pi}$) bin.
(*ν* **:** a kinematical variable among (-t , φ, cos θ_{hs}))

$$\frac{d^2\sigma^{\gamma^* p\to p\pi^+\pi^-}}{d\nu\, dM_{\pi\pi}}(Q^2, x_B, \nu, M_{\pi\pi}) = \frac{n_w}{L_{\text{int}} * \underbrace{\Delta Q^2 \Delta x_B \Delta\nu} * HF(Q^2, x_B, \nu, M_{\pi\pi})}$$

L_{int} = 30 fb^{-1} integrated luminosity.

$\Delta Q^2 \Delta x_B \Delta\nu \Delta M_{\pi\pi}$ Bin volume.

Hole factor :
Correction to the
acceptance in
(Q^2,x_B,ν,$M_{\pi\pi}$) bin.

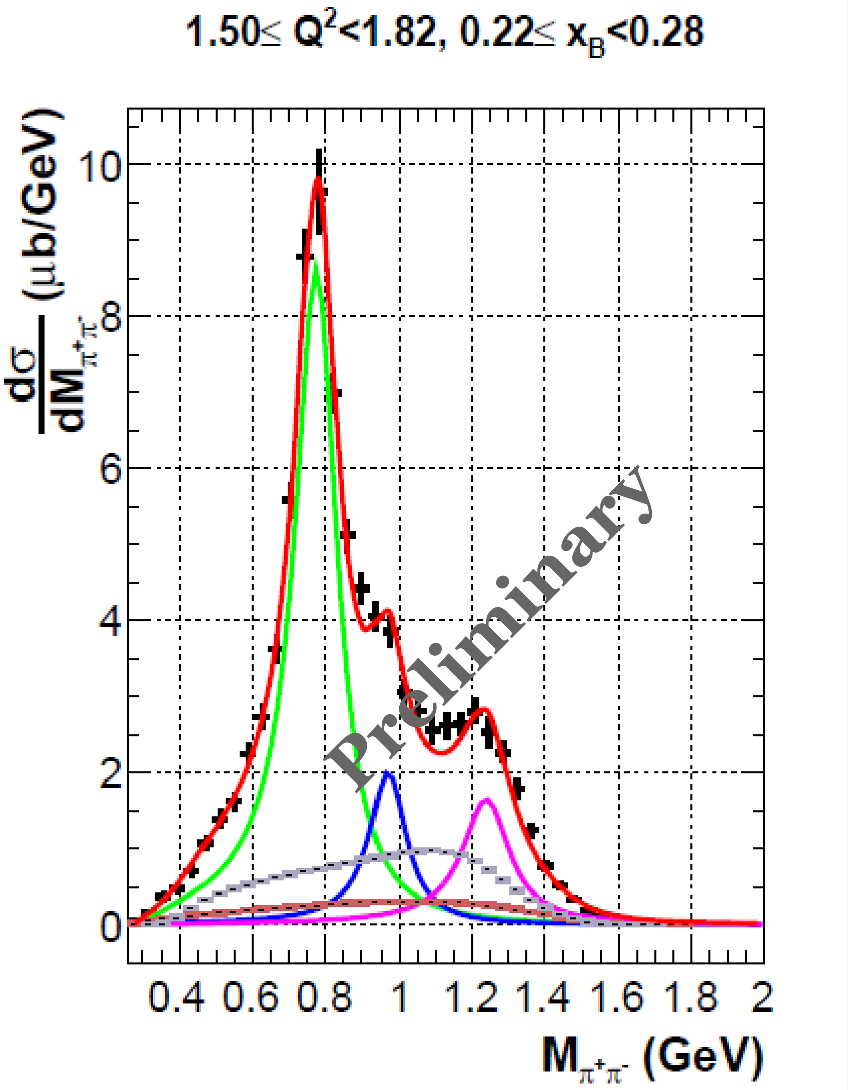
With

$$n_w = \sum_{\text{events}\in(Q^2, x_B, \nu, M_{\pi\pi})} \frac{1}{\Gamma_V * Acc_{\text{Corr RAD}}(Q^2, x_B, -t, \Phi, \cos\theta_{HS}, \varphi_{HS}, M_{\pi\pi}) * Eff_{CC}(p_{e-}, Q^2, x_B}$$

The number of weighed events in a (Q^2 , x_B, ν, $M_{\pi\pi}$) bin.

- **$Acc_{\text{Corr Rad}}$ (Q^2,x_B,t,Φ,cos θ_{HS} , φ_{HS} , $M_{\pi\pi}$):** CLAS acceptance, corrected for the radiative effects.
- **Eff_{CC}(p_{e-},Q^2,x_B) :** Efficiencies of electron-identification cuts.

Background subtraction


$1.50 \leq Q^2 < 1.82,\ 0.22 \leq x_B < 0.28$

- f_o and f_2 are **extracted from a fit of Born differential cross sections as a function of $M_{\pi\ \pi}$.**
- Fit of $M_{\pi+\pi-}$ spectra with several incoherent contributions :
  - Skewed Breit Wigner (BW) for **ρ**, **f_o**, **f_2** (4 parameters each)
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Cross section for meson production

$$\sigma^{\gamma^* p \to p\,\text{Meson}} = \frac{\int_0^2 BW^{\text{Meson}}_{skew}\left(M_{\pi^+\pi^-}\right) dM_{\pi^+\pi^-}}{BR^{\text{Meson}\to\pi^+\pi^-}}$$

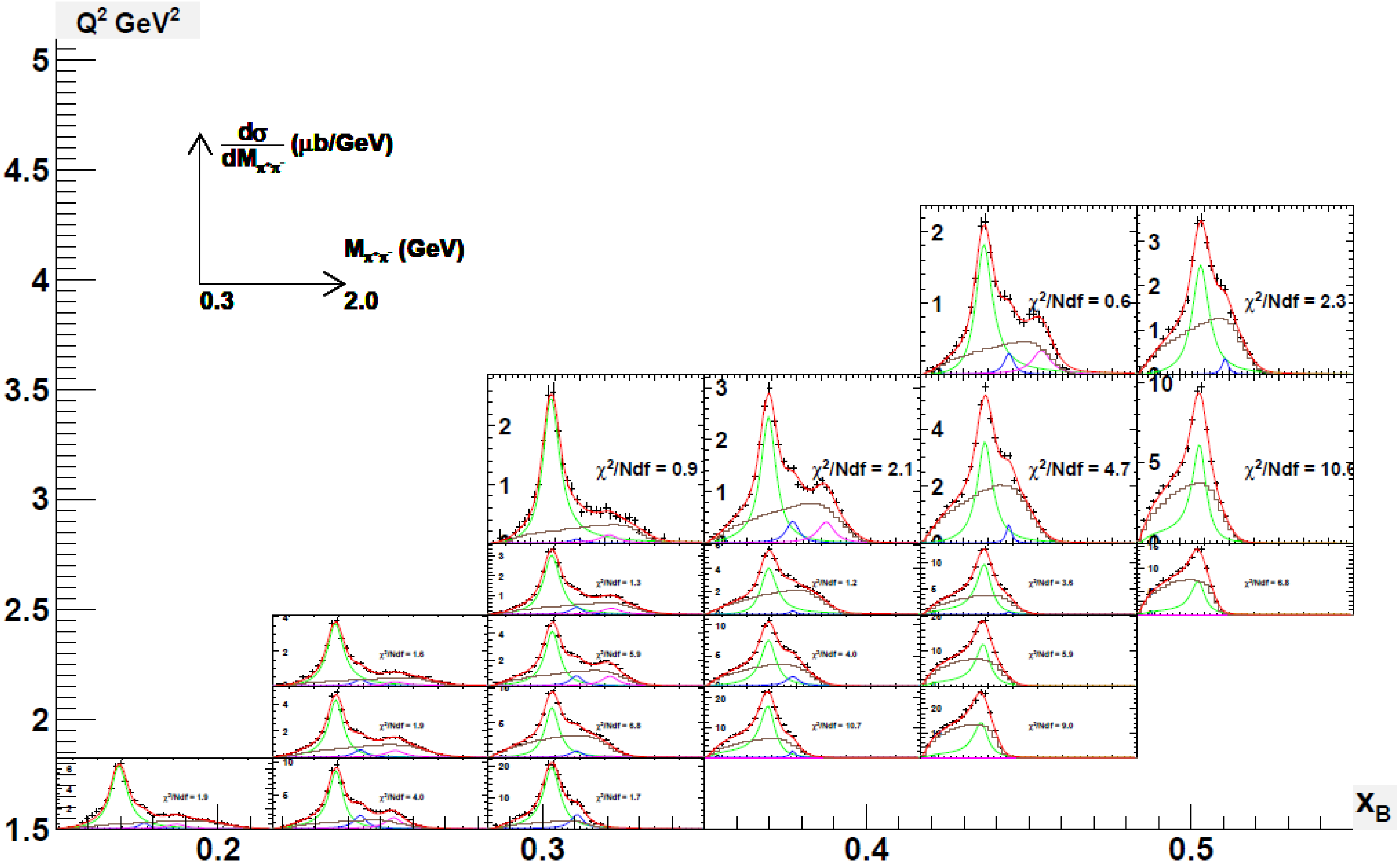
Total error on cross section

$$\frac{\Delta\sigma}{\sigma} = \sqrt{\underset{\substack{\downarrow \\ \text{Bin-by-bin}}}{\frac{\Delta\sigma_{\text{stat fit}}}{\sigma}}^{2} + \underset{\substack{\downarrow \\ 17\ \%}}{\frac{\Delta\sigma_{\text{syst norm}}}{\sigma}}^{2} + \underset{\substack{\downarrow \\ \text{Bin-by-bin}}}{\frac{\Delta\sigma_{\text{syst fit}}}{\sigma}}^{2}}$$

ρ^o : 17 to 22 % f_o: 28 to 150 % f_2 : 44 to 85 %

Cross section point with $\Delta\sigma/\sigma_{\text{stat}}$ > 90 % rejected.

Fit in (Q^2,x_B) bins



Systematic errors

$$\frac{\Delta\sigma}{\sigma} = \sqrt{\frac{\Delta\sigma_{\text{stat fit}}}{\sigma}^2 + \frac{\Delta\sigma_{\text{syst norm}}}{\sigma}^2 + \frac{\Delta\sigma_{\text{syst fit}}}{\sigma}^2}$$

Acceptance and Radiative Corrections	15 %
MC Model	5 %
Holes in DC	6 %
Electron ID : CC cuts efficiencies	1.5 %
Luminosity	3 %
Fit procedure	Bin by bin

$$\frac{\Delta\sigma_{syst\,norm}}{\sigma} = 17\,\%$$

Global normalization evaluated on cross section spectrum integrated over invariant mass

$$\Delta\sigma_{\text{syst fit}} = \sqrt{\frac{1}{4}\sum_{i=1}^{4}(\sigma - \sigma_i)^2}$$

4 systematic variations on fitting procedure :

1) Free background scale parameters
2)Non resonant background only
3)No skewness for f_0 and f_2
4)+/- 15 % variation of mass and width of f_2 and ρ^0.

Fit procedure is the main source of systematic errors :

+/- 15 % for ρ^0, 25 to over 100 % for f_0 and f_2 !!!

Cross section point with $\Delta\sigma/\sigma_{stat} > 90\,\%$ rejected.

Φ-dependent cross sections (f$_0$)

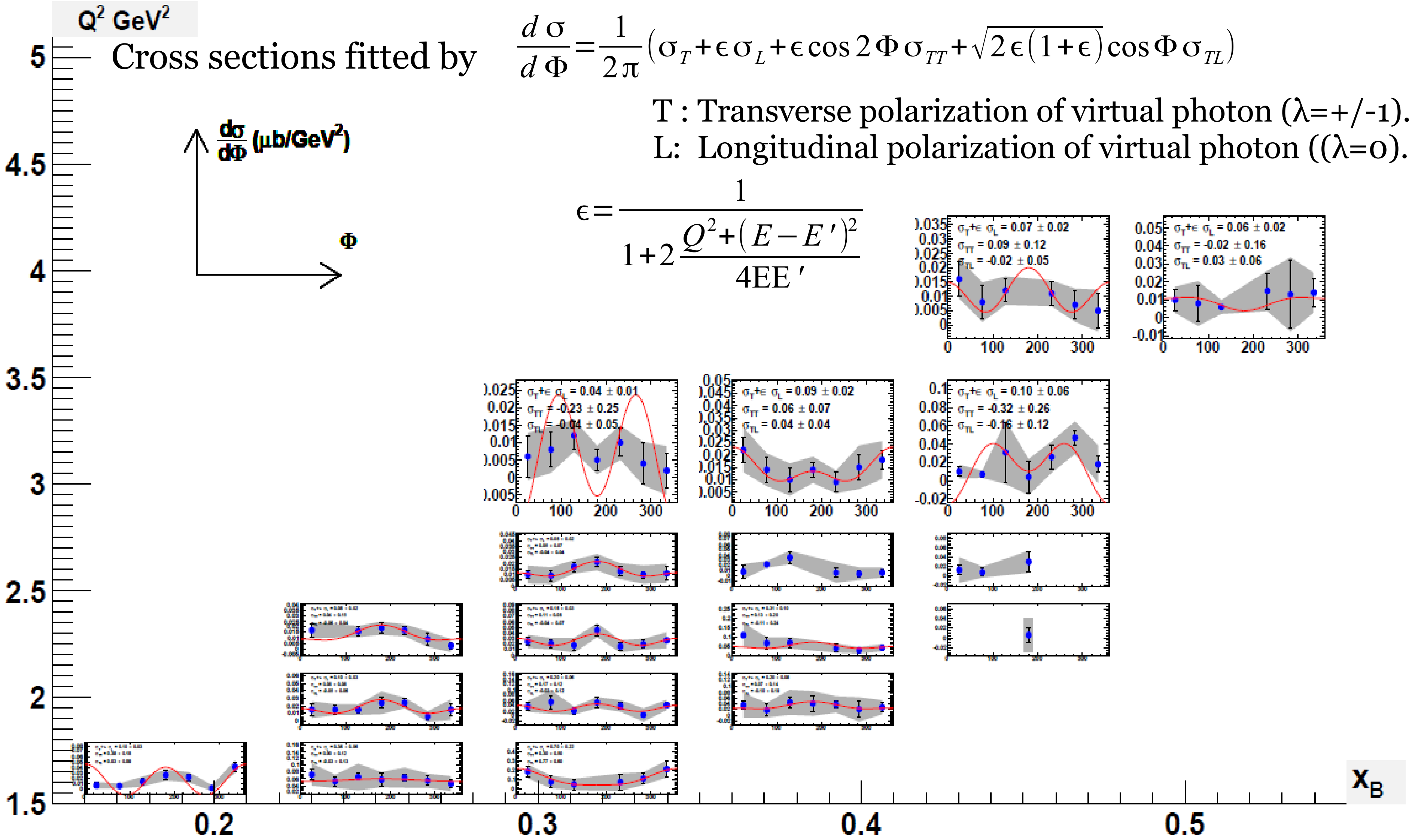
Cross sections fitted by

$$\frac{d\sigma}{d\Phi}=\frac{1}{2\pi}\left(\sigma_T+\epsilon\sigma_L+\epsilon\cos 2\Phi\,\sigma_{TT}+\sqrt{2\epsilon(1+\epsilon)}\cos\Phi\,\sigma_{TL}\right)$$

T : Transverse polarization of virtual photon (λ=+/-1).

L: Longitudinal polarization of virtual photon ((λ=0).

$$\epsilon=\frac{1}{1+2\dfrac{Q^2+(E-E')^2}{4EE'}}$$



Φ-dependent cross sections (f_2)

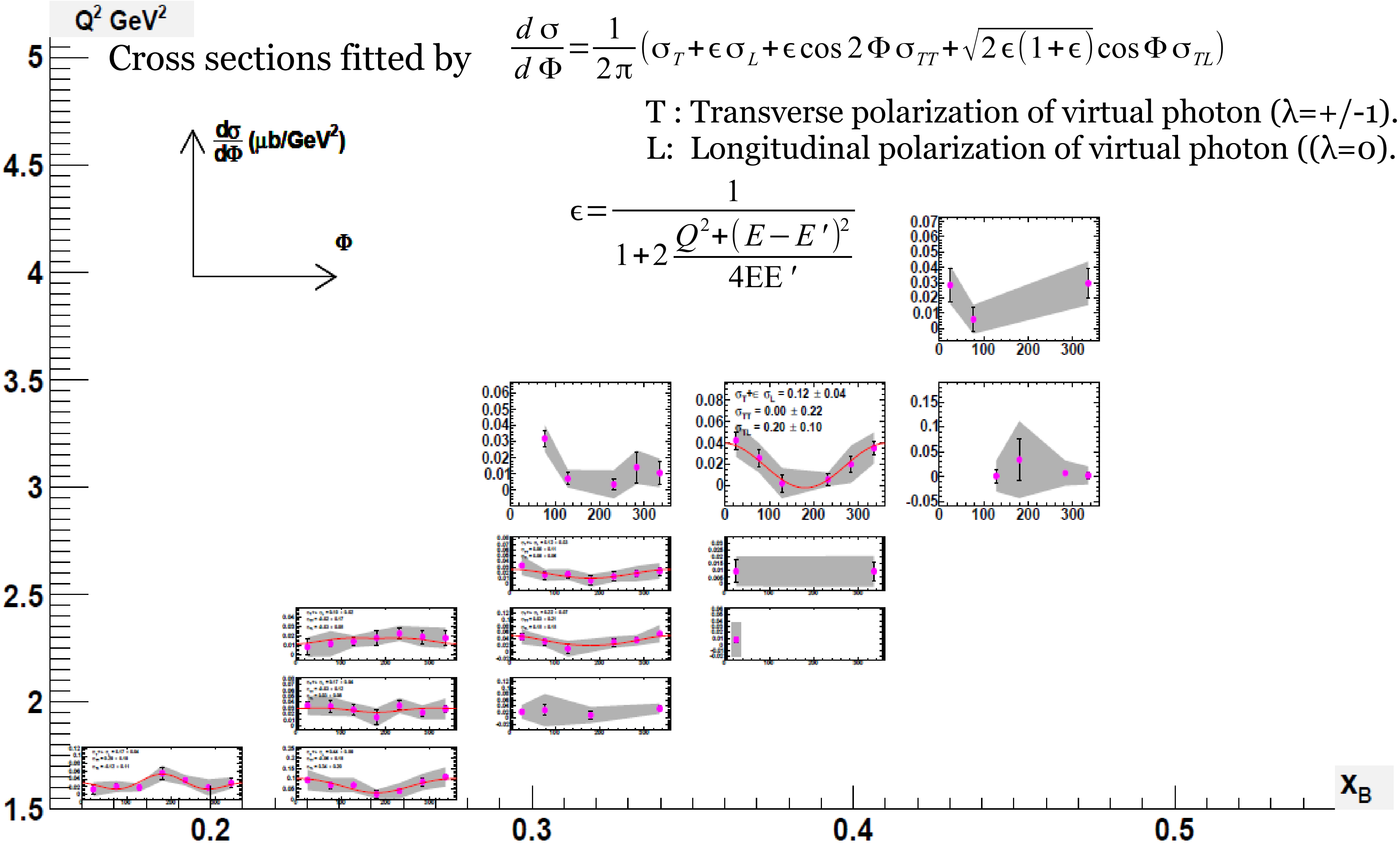
Cross sections fitted by

$$\frac{d\sigma}{d\Phi}=\frac{1}{2\pi}\left(\sigma_T+\epsilon\sigma_L+\epsilon\cos 2\Phi\,\sigma_{TT}+\sqrt{2\epsilon(1+\epsilon)}\cos\Phi\,\sigma_{TL}\right)$$

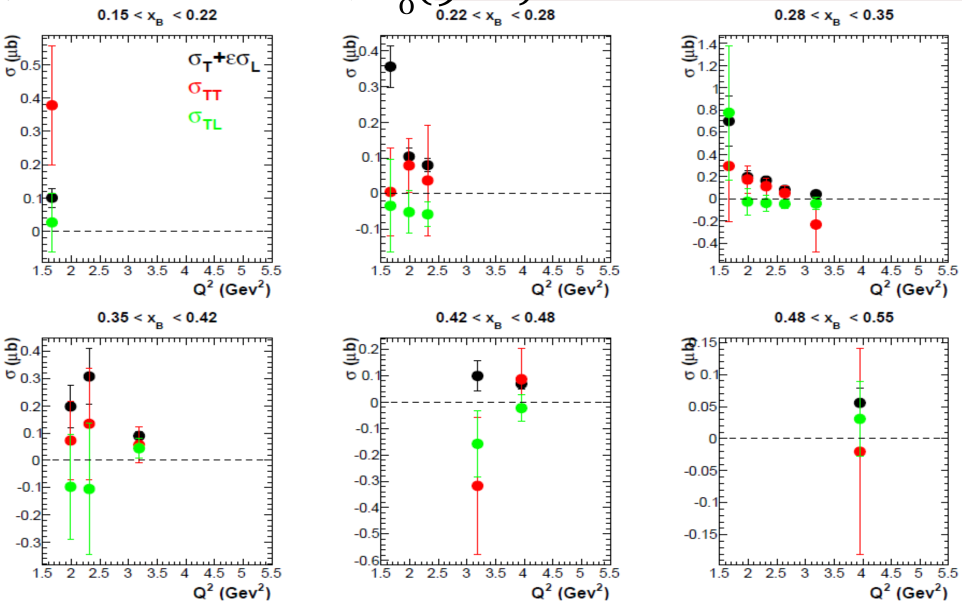
T : Transverse polarization of virtual photon (λ=+/-1).

L: Longitudinal polarization of virtual photon ((λ=0).

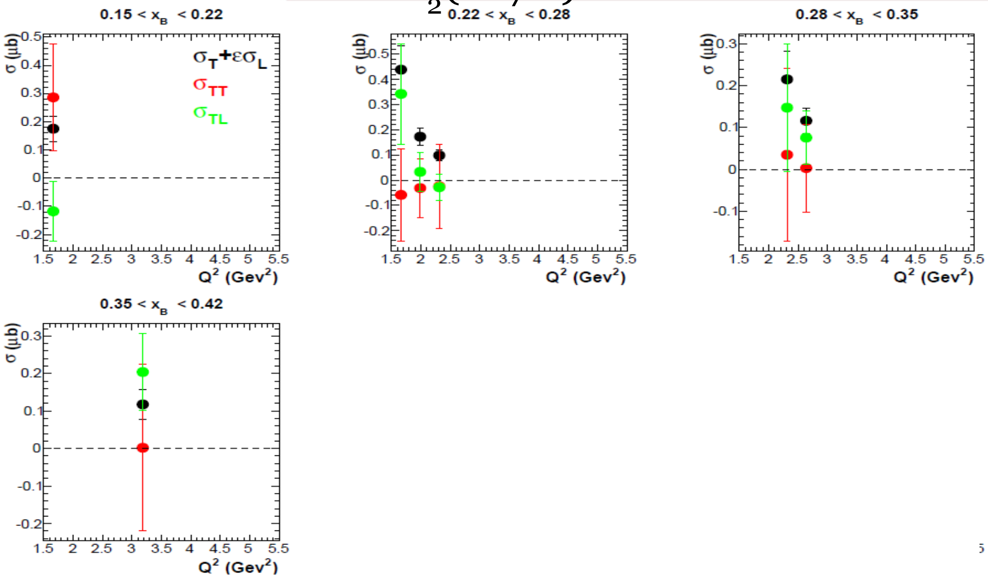
$$\epsilon=\frac{1}{1+2\frac{Q^2+(E-E')^2}{4EE'}}$$



$f_0(980)$



$f_2(1270)$

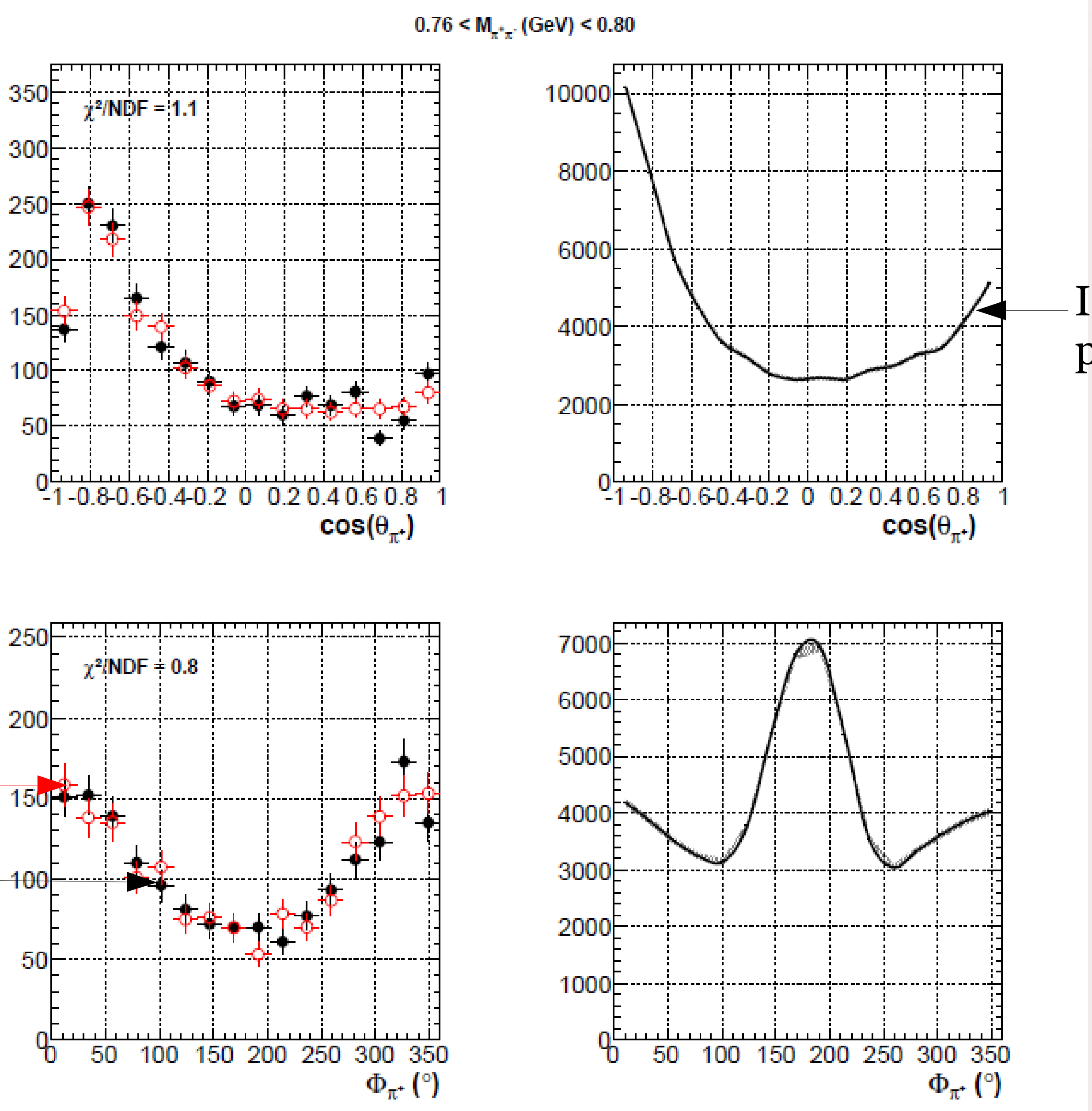


- Large contribution of TT interference for f_0.
- Large contribution of TL interference for f_2.
- Strong TT and TL interferences supported by analysis of Legendre moments[1].
- Rosenbluth separation needed for extraction of σ_L and σ_T.

[1] Airapetian et al. (HERMES Collaboration) Phys. Lett. B 599, 212 (2004)

Fit of the moment : example on a single mass bin

$1.5<Q^2<2.7$ GeV²
$0.15<x_B<0.28$
$0.7<-t<1$ GeV²



Intensity predicted

Intensity with CLAS acceptance

Data