



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**

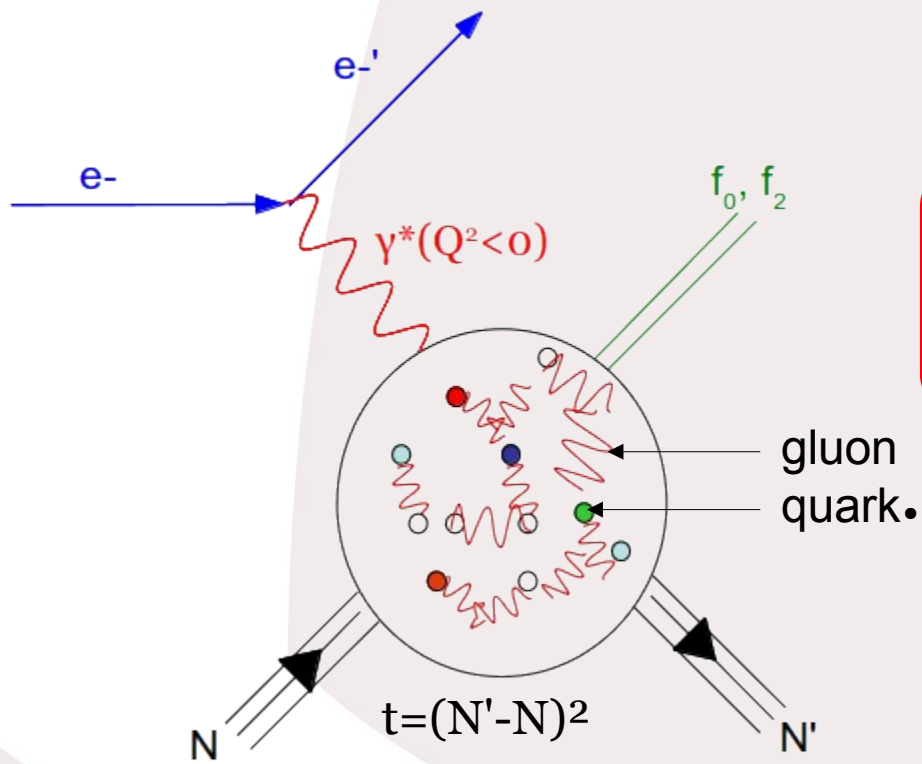
$f_0(980 \pm 10) \text{ MeV}$	
$J^{PC} = 0^{++}$ (Scalar)	
$\Gamma = \text{From } 40 \text{ to } 100 \text{ MeV}$	
$\pi\pi$	Dominant
KK	Observed
$\gamma\gamma$	Observed

$f_2(1270 \pm 1.2) \text{ MeV}$	
$J^{PC} = 2^{++}$ (Tensor)	
$\Gamma = 185.1 \text{ MeV}$	
$\pi\pi$	84.8 %
$\pi\pi\pi 2\pi^0$	7.1 %
KK	4.6 %

Cross sections for exclusive $ep \rightarrow ep f_0/f_2 \rightarrow ep \pi^+\pi^-$ 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 ? $K\bar{K}$ 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.



Meson electroproduction (single-photon exchange)

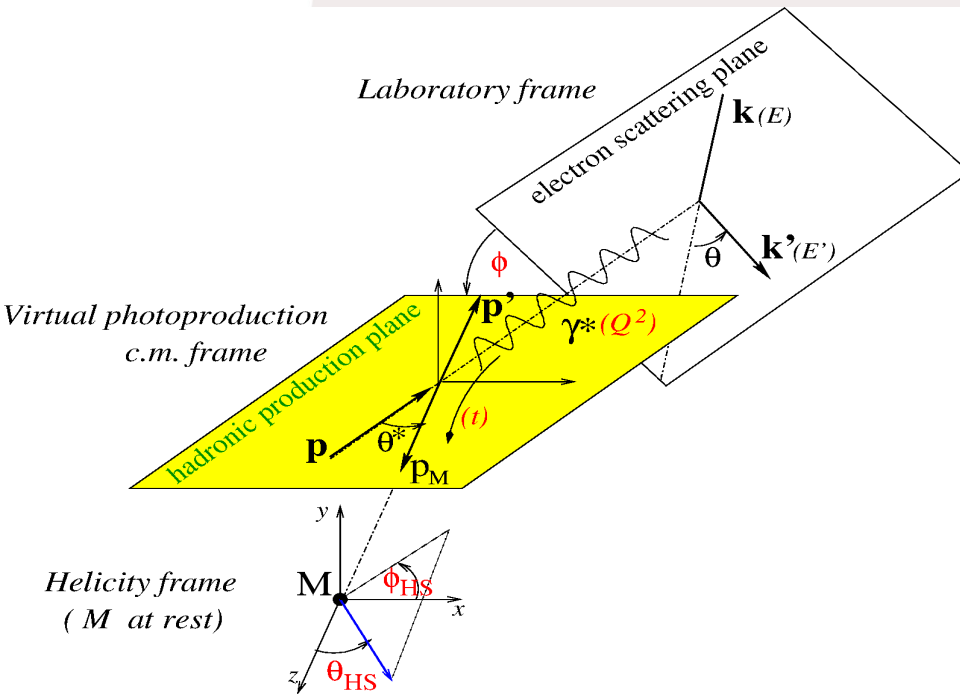
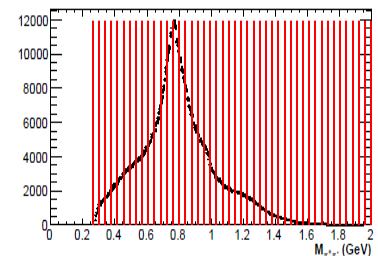
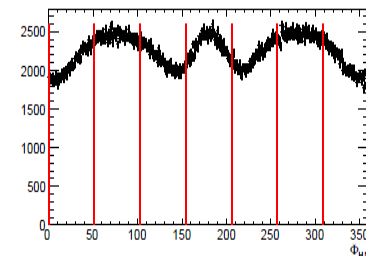
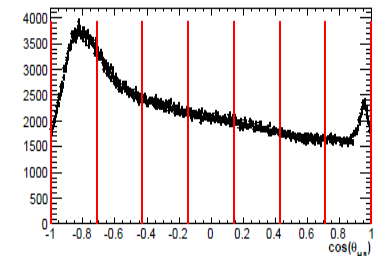
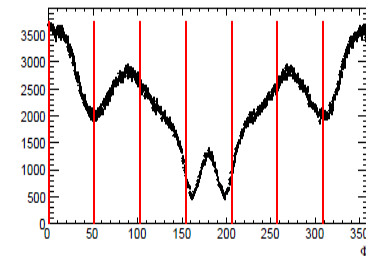
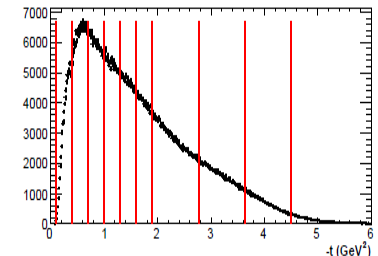
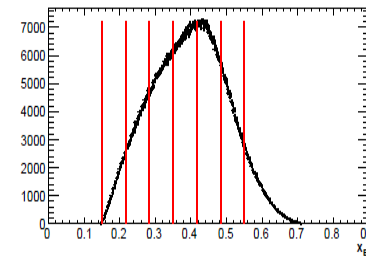
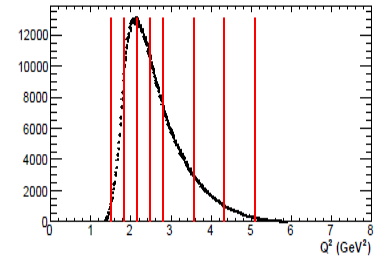
The exclusive $ep \rightarrow ep\pi^+\pi^-$ channel

Phase space binning

Unpolarized cross sections are described by 7 kinematic variables :

- Q^2 Virtual photon (γ^*) squared mass.
- x_B Bjorken variable ($x_B \sim 1/W$, the (γ^*, p) CM energy).
- t Momentum transfer to the nucleon
- Φ Azimuthal angle between leptonic (γ^*, e') and hadronic (γ^*, p') planes.
- $\text{Cos}(\theta_{\pi^+})$, Φ_{π^+} 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 $\pi^+\pi^-$

Experimental data
 $W > 1.8 \text{ GeV}$



JLAB and the CLAS detector

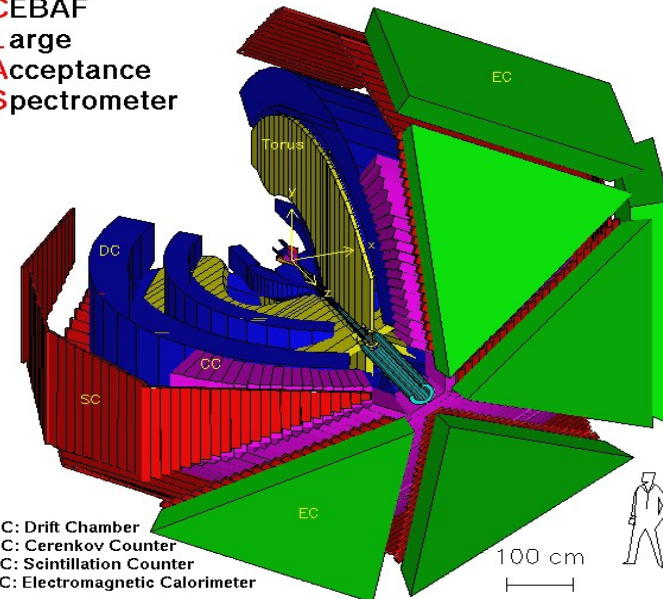
The Jefferson Laboratory (Newport-News, USA)

$E_{\max} = 6 \text{ GeV (2012)}$
 $I_{\max} = 200 \mu\text{A}$
 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)

CEBAF
Large
Acceptance
Spectrometer



DC: Drift Chamber
 CC: Cherenkov Counter
 SC: Scintillation Counter
 EC: Electromagnetic Calorimeter

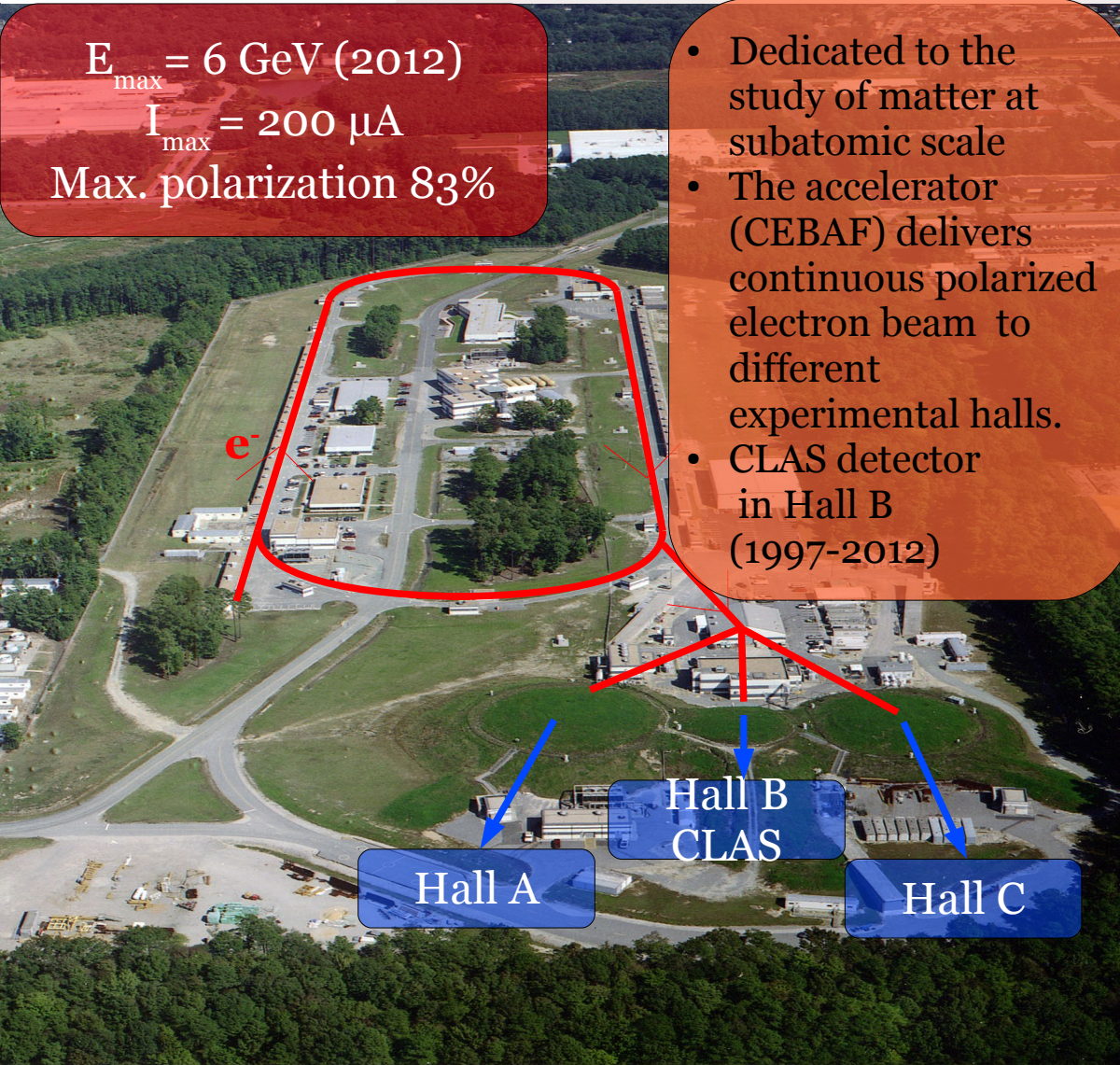
$$L = 10^{35} \text{ cm}^{-2}\text{s}^{-1}$$

Wide angle coverage.

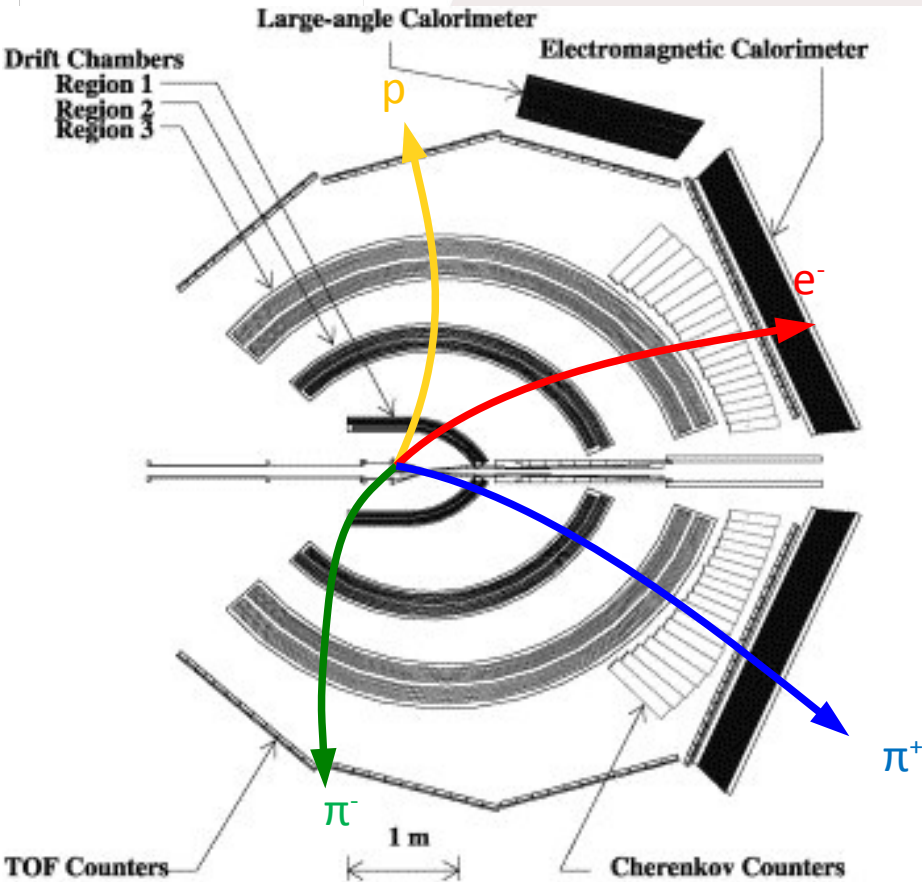
Divided into 6 azimuthal sectors.

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)

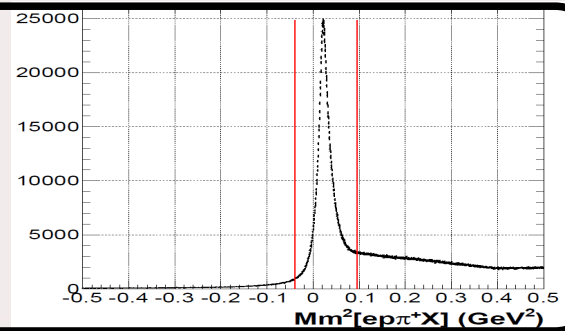
Energy loss correction

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

Exclusivity

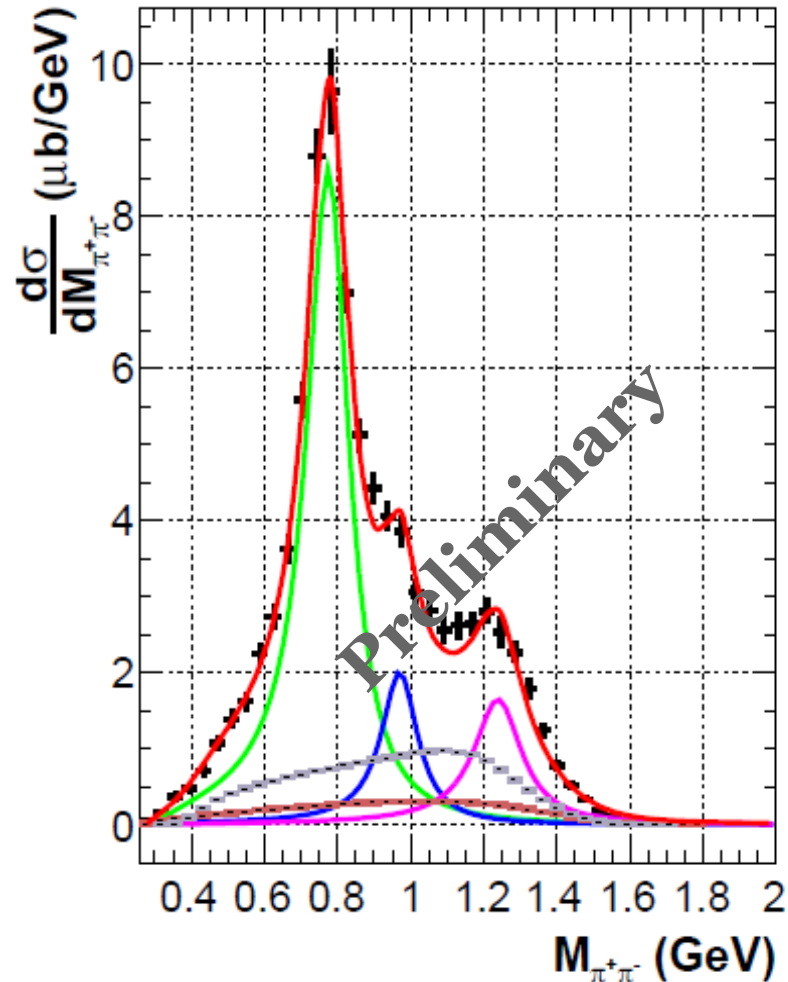
- Additional vertex cuts.
- Selection on π^- peak in missing mass $Mm[er\pi^+X]$ spectrum.

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



Background subtraction

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



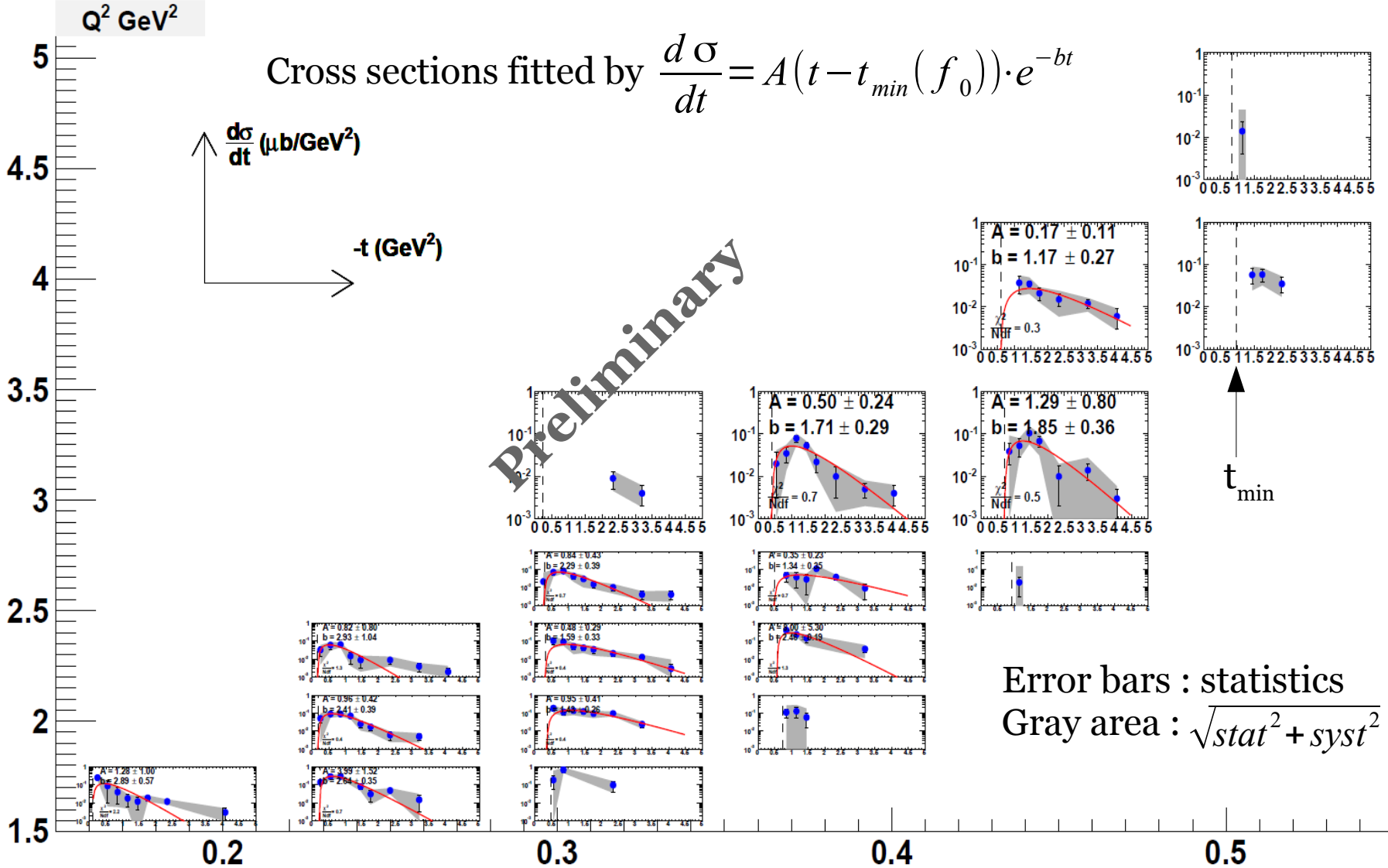
- Experimental data are corrected from **acceptance** and **radiative effect** thanks to **Monte Carlo simulations**, then normalized to a cross section.
- f_0 and f_2 are extracted from a **fit of Born differential cross sections** as a function of $M_{\pi^+\pi^-}$, in a (Q^2, x_B, ν) bin.
 $\nu = t, \varphi, \cos \theta_{hs}, \varphi_{hs}$ or nothing.
- Fit of $M_{\pi^+\pi^-}$ spectra with several incoherent contributions :
 - Skewed Breit Wigner (BW) for ρ, f_0, f_2 (4 parameters each)
 - Scale parameters for background MC non radiative **non resonant $\pi\pi$** and Δ^{++} .

Cross section for meson production

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

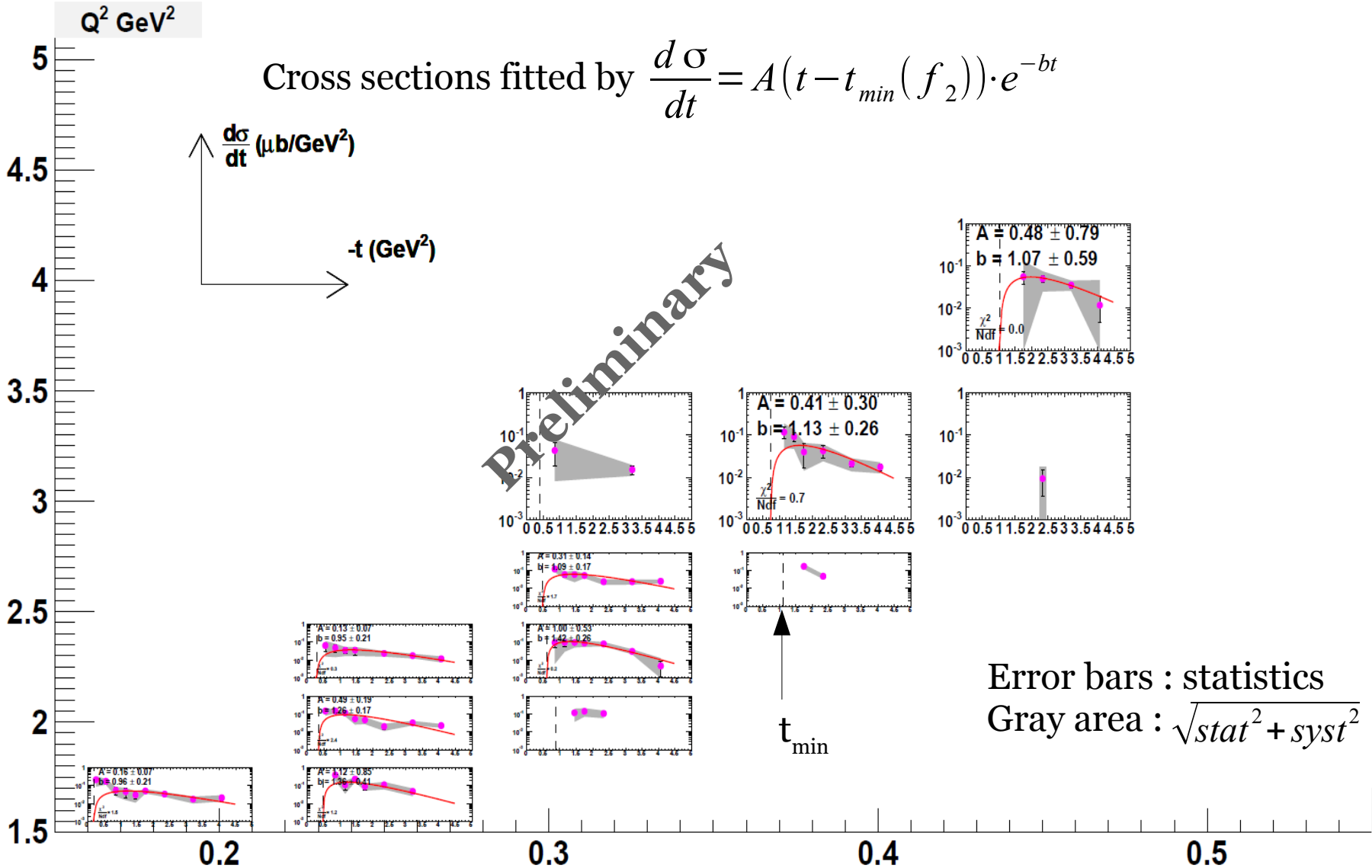
t-dependent cross sections (f_0)

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

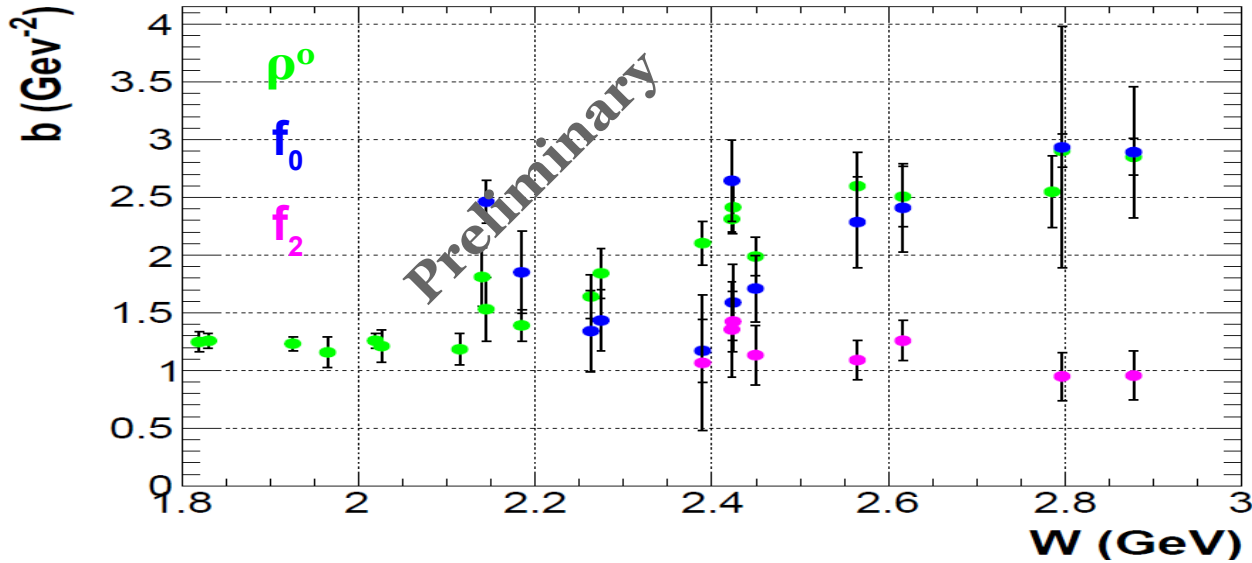


t-dependent cross sections (f_2)

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



b-slope



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

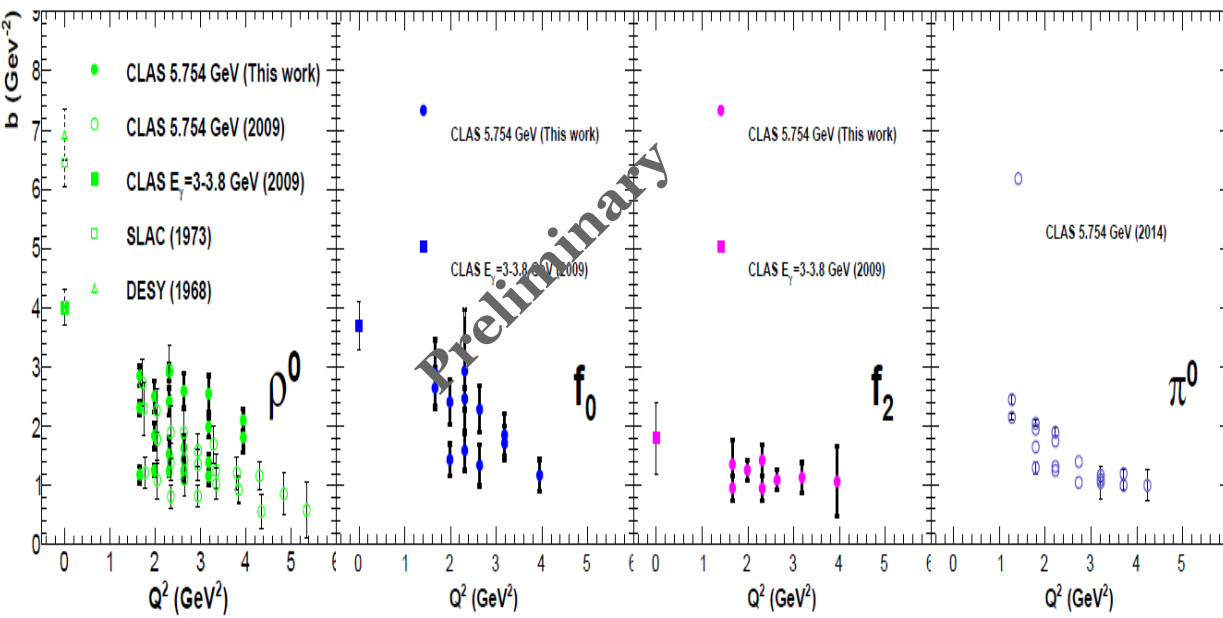
b related to the transverse size of the γ^*p system.

b vs W

- Same behaviour for f_0 and ρ^0 .
- 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^+

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

$\langle \mathbf{V}_{LM} \rangle$ Moment ($0 \leq M \leq L$) \mathbf{Y}_{LM} Spherical harmonics.

Ω_{π^+} Decay solid angle of the π^+ in meson helicity frame.

Parametrization

$$I(\Theta, \Phi) = \sqrt{4\pi} \sum_{L=0}^{L_{max}} \sum_{M=0}^L \langle Y_{LM} \rangle \Re(Y_{LM}(\Theta, \Phi)), \quad L_{max}=4$$

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

$\langle \mathbf{Y}_{LM} \rangle$ are free parameters to be fitted.

The intensity is fitted to the data by maximizing the likelihood L (AmpTools¹ software) :

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

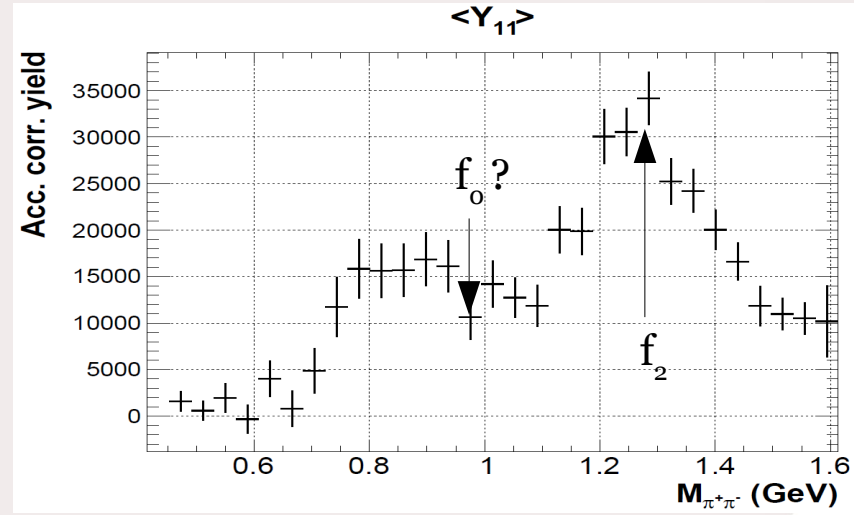
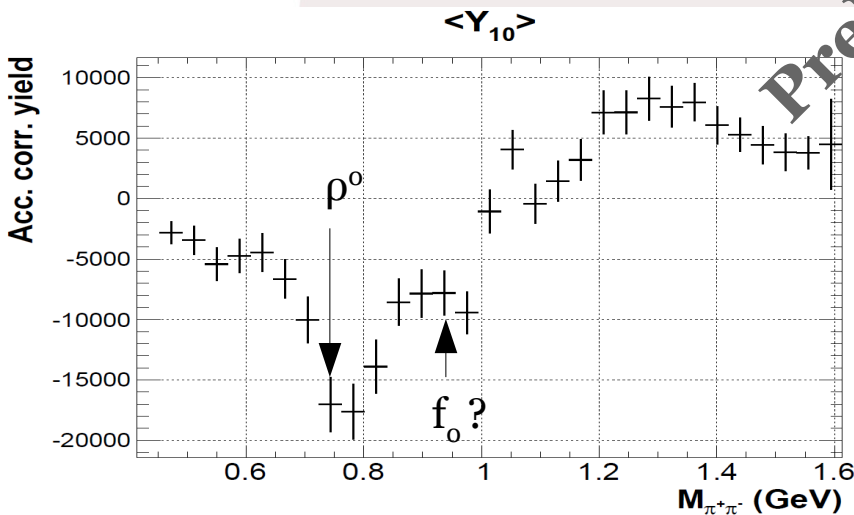
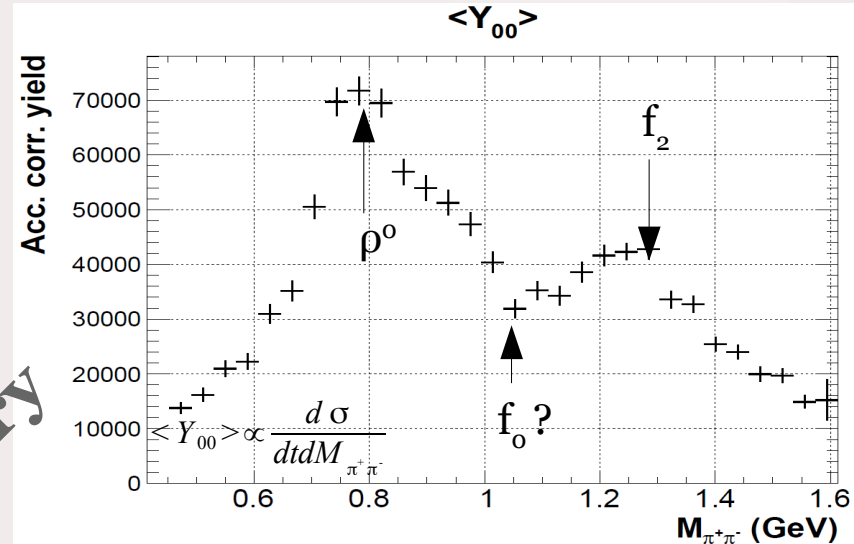
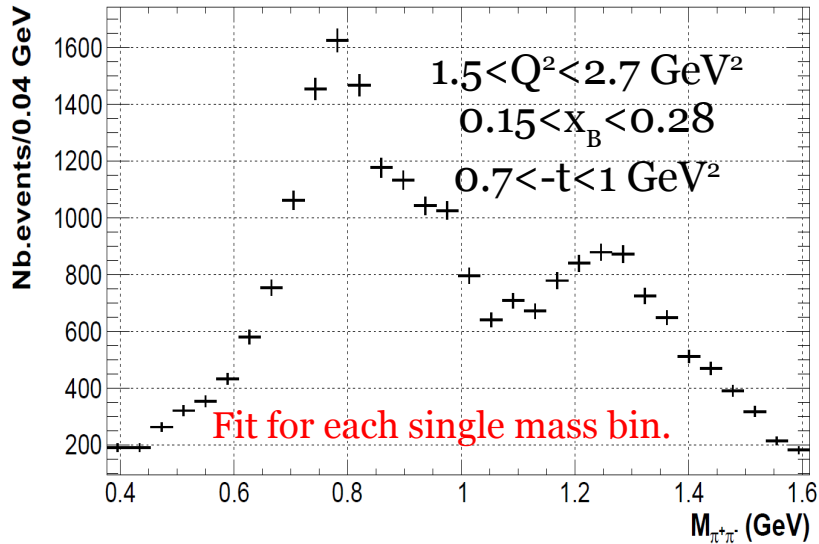
$\tau_i = (\theta, \Phi)$
 $\vec{x} = \langle Y_{LM} \rangle$

Experimental data

**Acceptance term,
calculated with MC phase space**

Extraction of moments : selected results

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



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 $\cos \theta_{HS}$ 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 $(Q^2, x_B, \nu, M_{\pi\pi})$ bin.
 (ν : a kinematical variable among $(-t, \Phi, \cos \theta_{hs})$)

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

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

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

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

With

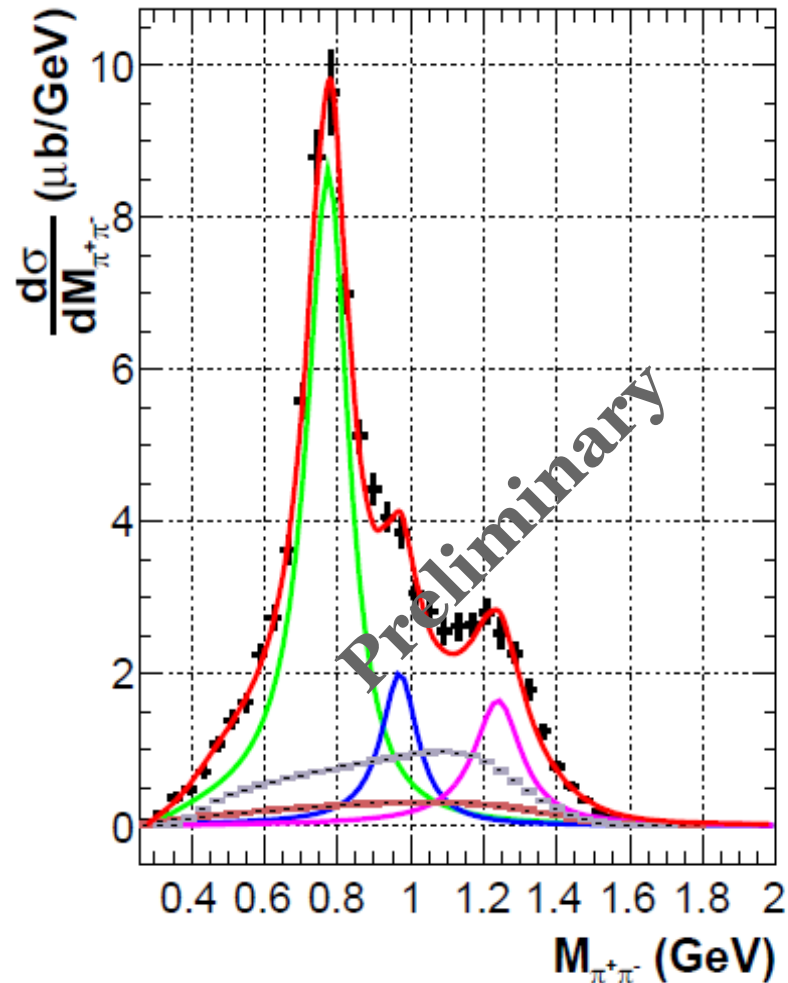
$$n_w = \sum_{\text{events} \in (Q^2, x_B, \nu, M_{\pi\pi})} \frac{1}{\Gamma_V * \text{Acc}_{\text{CORR RAD}}(Q^2, x_B, -t, \Phi, \cos \theta_{HS}, \varphi_{HS}, M_{\pi\pi}) * \text{Eff}_{\text{CC}}(p_{e^-}, Q^2, x_B)}$$

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

- $\text{Acc}_{\text{CORR RAD}}(Q^2, x_B, t, \Phi, \cos \theta_{HS}, \varphi_{HS}, M_{\pi\pi})$: CLAS acceptance, corrected for the radiative effects.
- $\text{Eff}_{\text{CC}}(p_{e^-}, Q^2, x_B)$: Efficiencies of electron-identification cuts.

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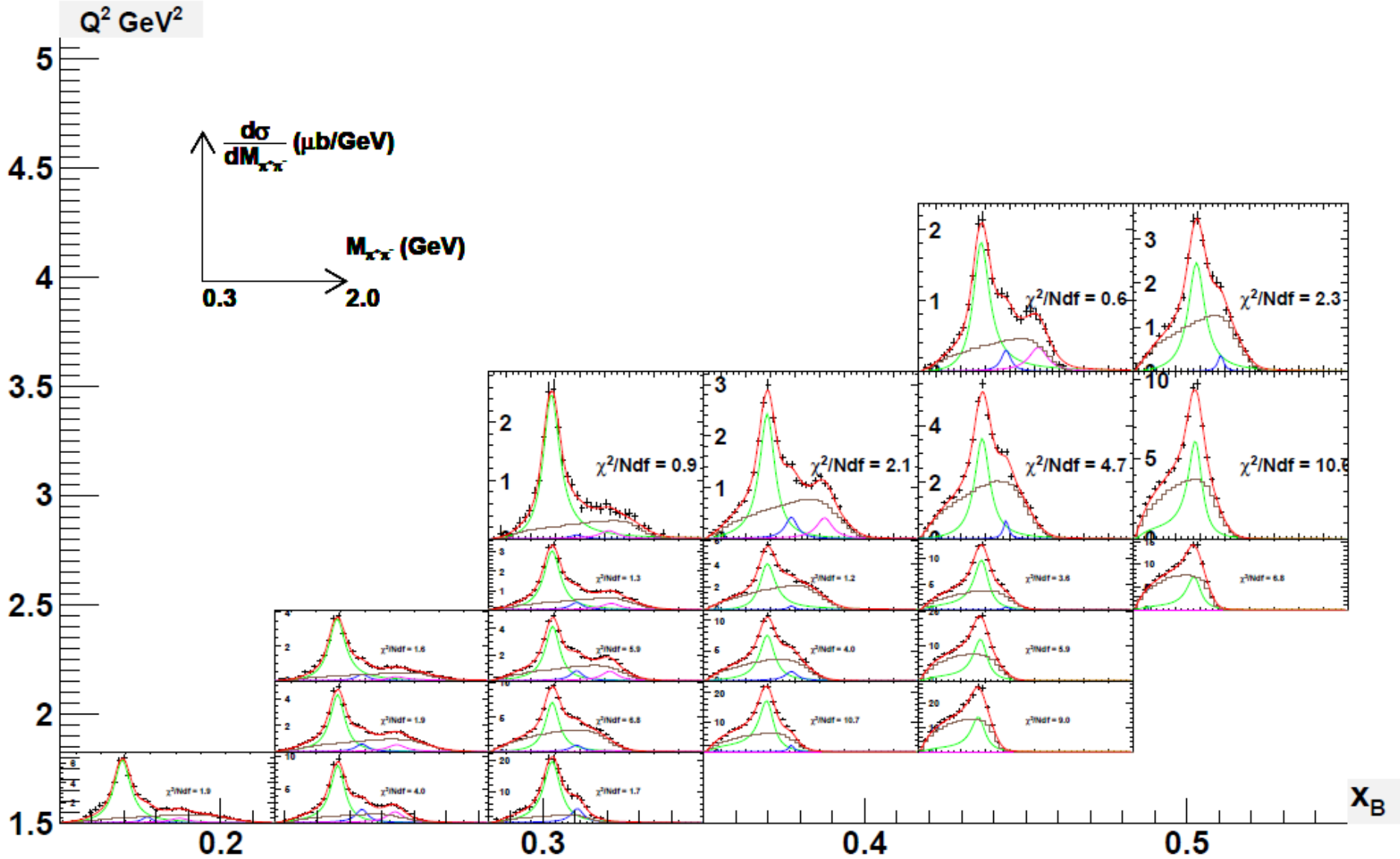
Total error on cross section

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

ρ^0 : 17 to 22 % f_0 : 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

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

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

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

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 $\Delta\sigma/\sigma_{\text{stat}} > 90$ % rejected.