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CEBAF Large Acceptance Spectrometer

UNIVERSITÉ PARIS SUD

Cross sections for $ep \rightarrow epf_0/f_2$

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3rd year PhD

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Newport-News VA

I. Data analysis and comparison with previous results

II. f_0/f_2 differential cross sections vs. t

III. Partial Waves Analysis on the data

Physics motivations

f_0 (980+/-10) MeV

JPC=0++

Γ = From 40 to 100 MeV

ππ	Dominant
KK	Observed
γγ	Observed

f_2 (1270+/-1.2) MeV

JPC=2++

Γ = 185.1 MeV

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

Particle Data Group (2010)

Cross sections for f_0 et f_2 electroproduction have never been measured so far

Spectroscopy

Q^2, t dependence of differential cross section may shed light on mesons' nature

- f_0 : Standard meson ? 4-quarks state ? $K\bar{K}$ molecule?
- f_2 : Resonance produced in vector meson-vector meson interactions?

Access to GPDs

f_0 and some helicity states of f_2 might be sensitive to the GPDs H and E.

The ep → epπ⁺π⁻ channel

The channel is described by 7 kinematic variables :

Q^2 Virtual photon (γ*) squared mass

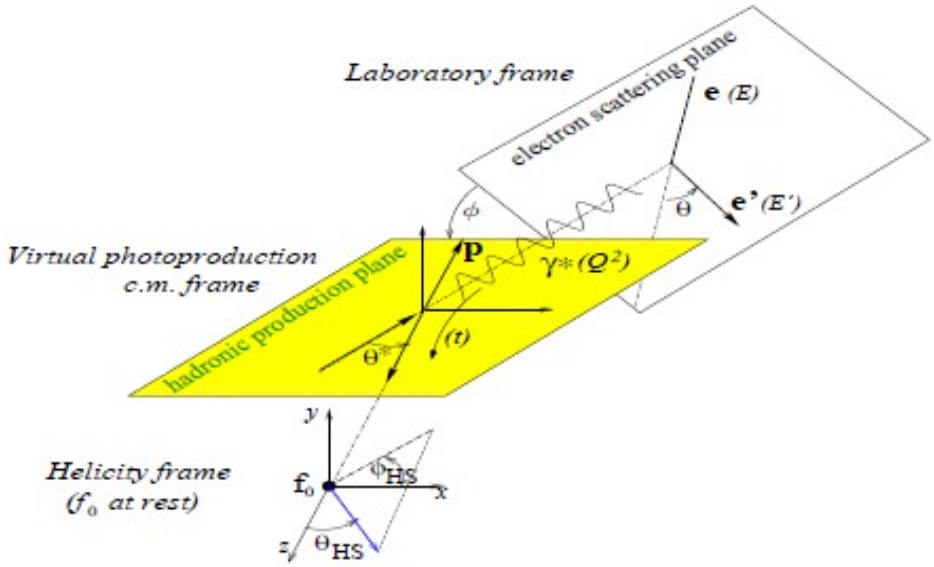
x_B

t Momentum transfer to the nucleon

Φ Azimuthal angle between leptonic (γ*,e') and hadronic plane (γ*,p')

$\mathrm{Cos}(\theta_{HS})$, Φ_{HS} Decay angles of $\pi^+\pi^-$

$M_{\pi\pi}$ Invariant mass of $\pi^+\pi^-$



N-fold differential Born reduced cros section (N<7)

$$\frac{d^N \sigma_{\gamma^* p \pi\pi}}{dV} = \frac{n_w}{L_{integrated} * \Delta V * HF(V)}$$

- $L_{integrated}$ Integrated Luminosity
- N dimensional ΔV Bin volume.
- HF(V) Hole Factor : Correction factor to 7D acceptance calculation.

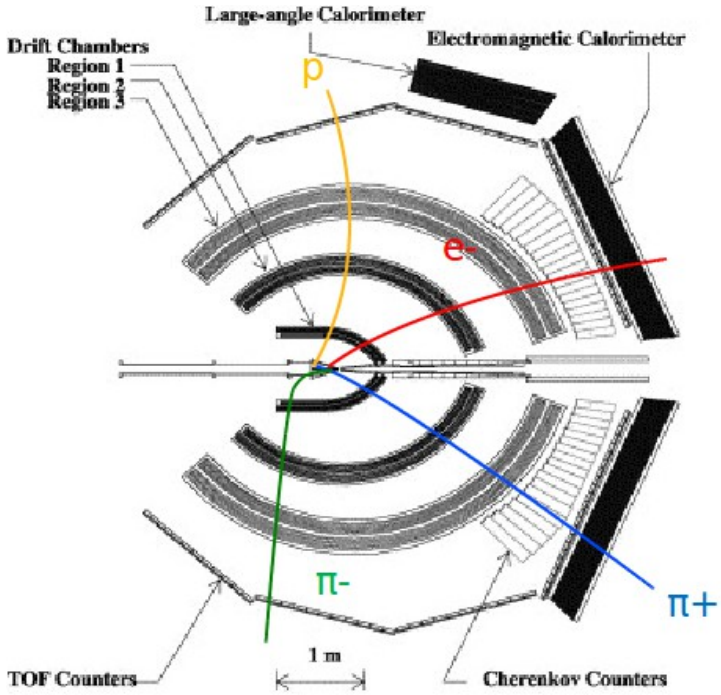
With

$$n_w = \frac{N_{measured}}{\Gamma_V * Acc_{RAD}(7D)}$$

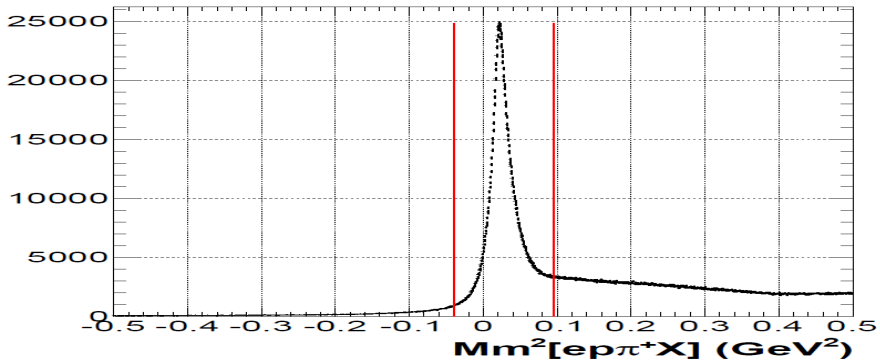
- Number of weighted events in **7D bin**.
- Γ_V virtual photon flux (Hand convention)
- Acc_{RAD} Acceptance with radiative corrections.

Channel selection

- Electron selection
  - Sector dependent Z Vertex cuts
  - CC and EC fiducial cuts
  - E_{tot}/p and E_{Inner}>60 MeV cuts
  - Track matching with CC data
- Proton/π^+ selection
  - DC Fiducial cuts
  - 2.5σ cut on Δβ
- $ep\pi^+\pi^-$
  - -0.05<Mm²[epπ+X]<0.08 GeV²
  - Additional CC cuts
  - $\Delta v^z_{e\text{-}p}$ and $\Delta v^z_{e\text{-}\pi+}$ 3σ cuts



CLAS detector
Data analysis of CLAS e1-6
e^- beam scattering off LH_2 @ 5.7GeV
Integrated luminosity ~30fb^{-1}

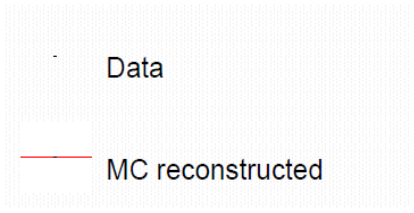


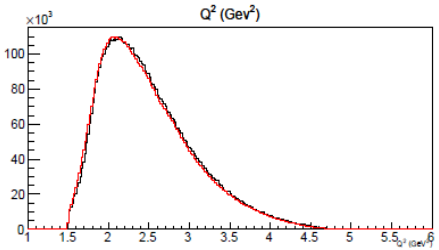
Acceptance and radiative corrections

$$\sigma_{\gamma p\pi^+\pi^-} = \frac{N_{\gamma p\pi^+\pi^-} * F_{RAD}}{L_{intg} * \Delta^7\Gamma * Acceptance * Eff_{cuts}} \rightarrow \frac{F_{RAD}}{Acc} = \frac{N_{GEN}^{No\ Rad}}{N_{REC}^{RAD-soft}}$$

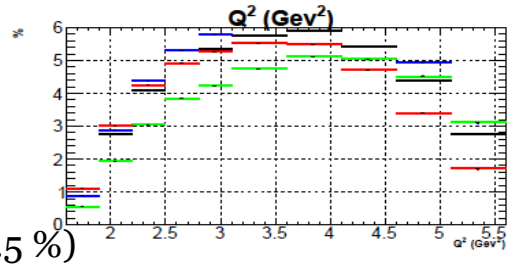
The radiative correction (Mo-Tsai) is embedded in the Monte Carlo simulation.

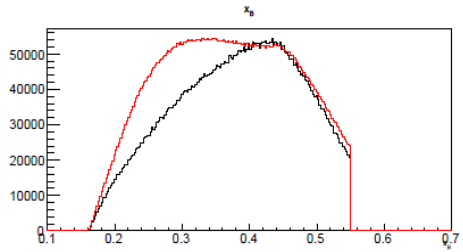
Cross section

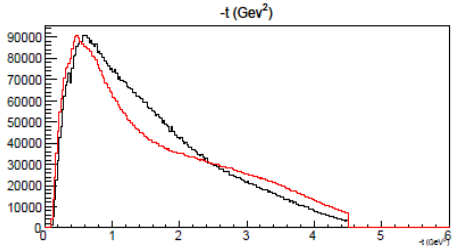


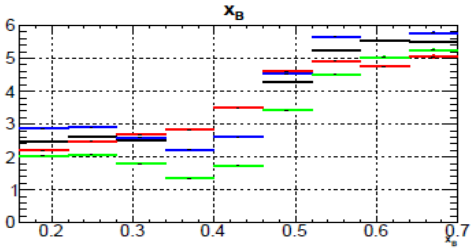


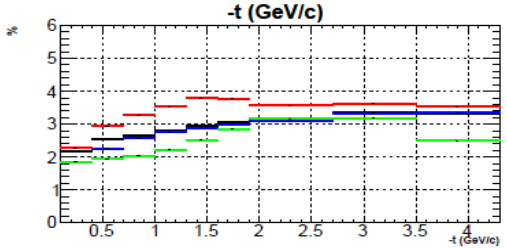
Integrated acceptances (Mean ~ 2.5 %)

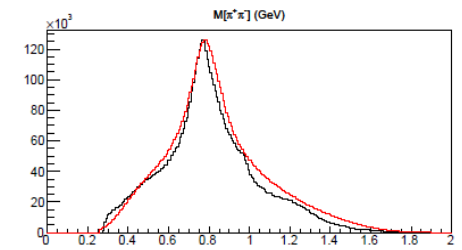


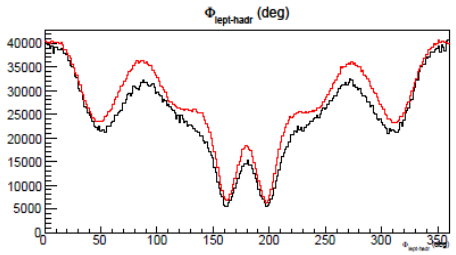


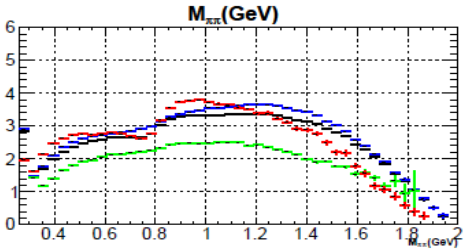


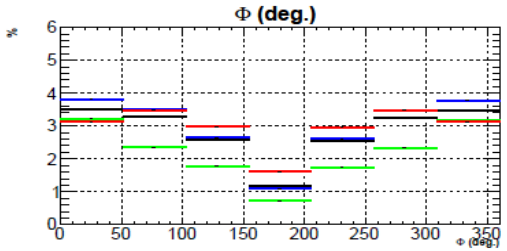


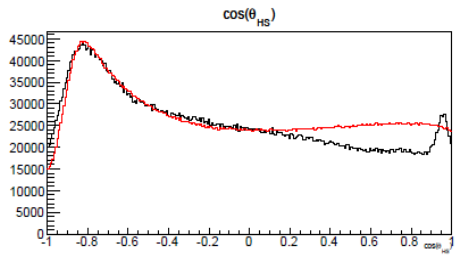


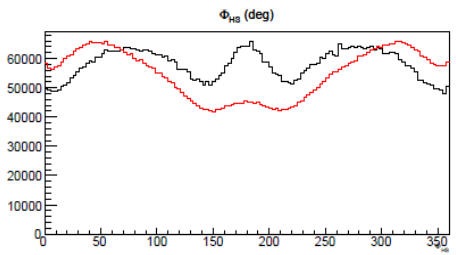


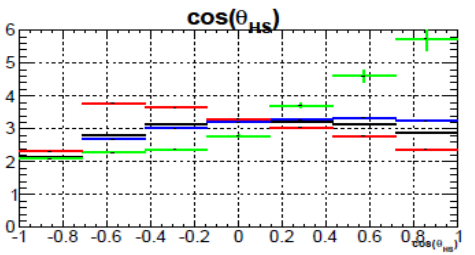


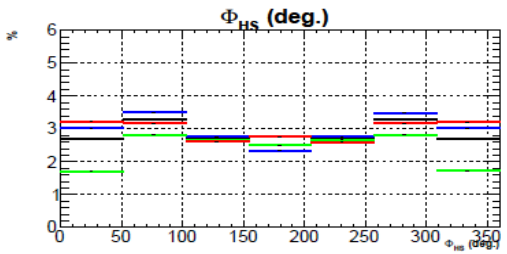




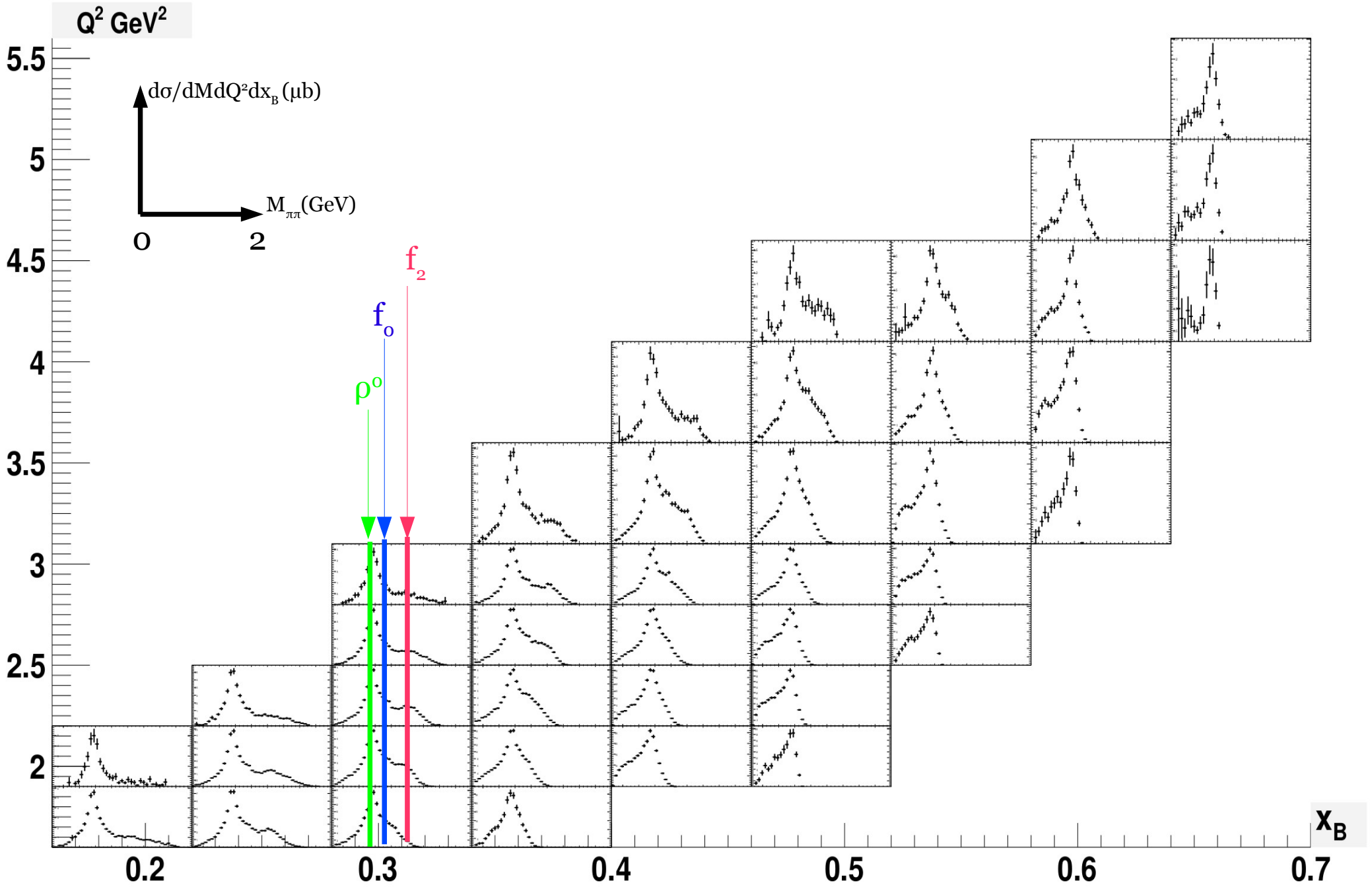




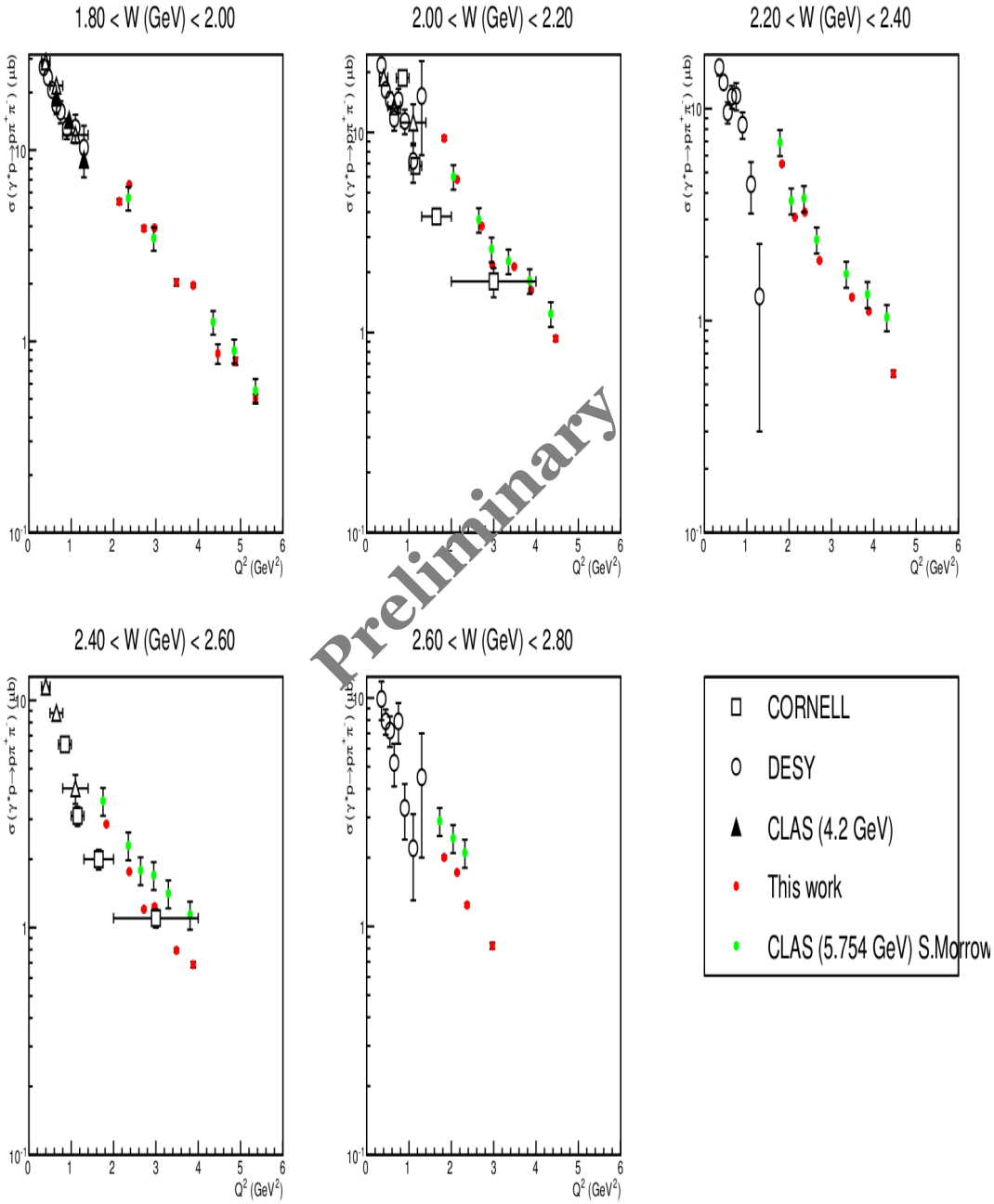




$\gamma^* p \rightarrow p\pi^+\pi^-$ spectra



$\gamma^* p \rightarrow p\pi^+\pi^-$ cross sections

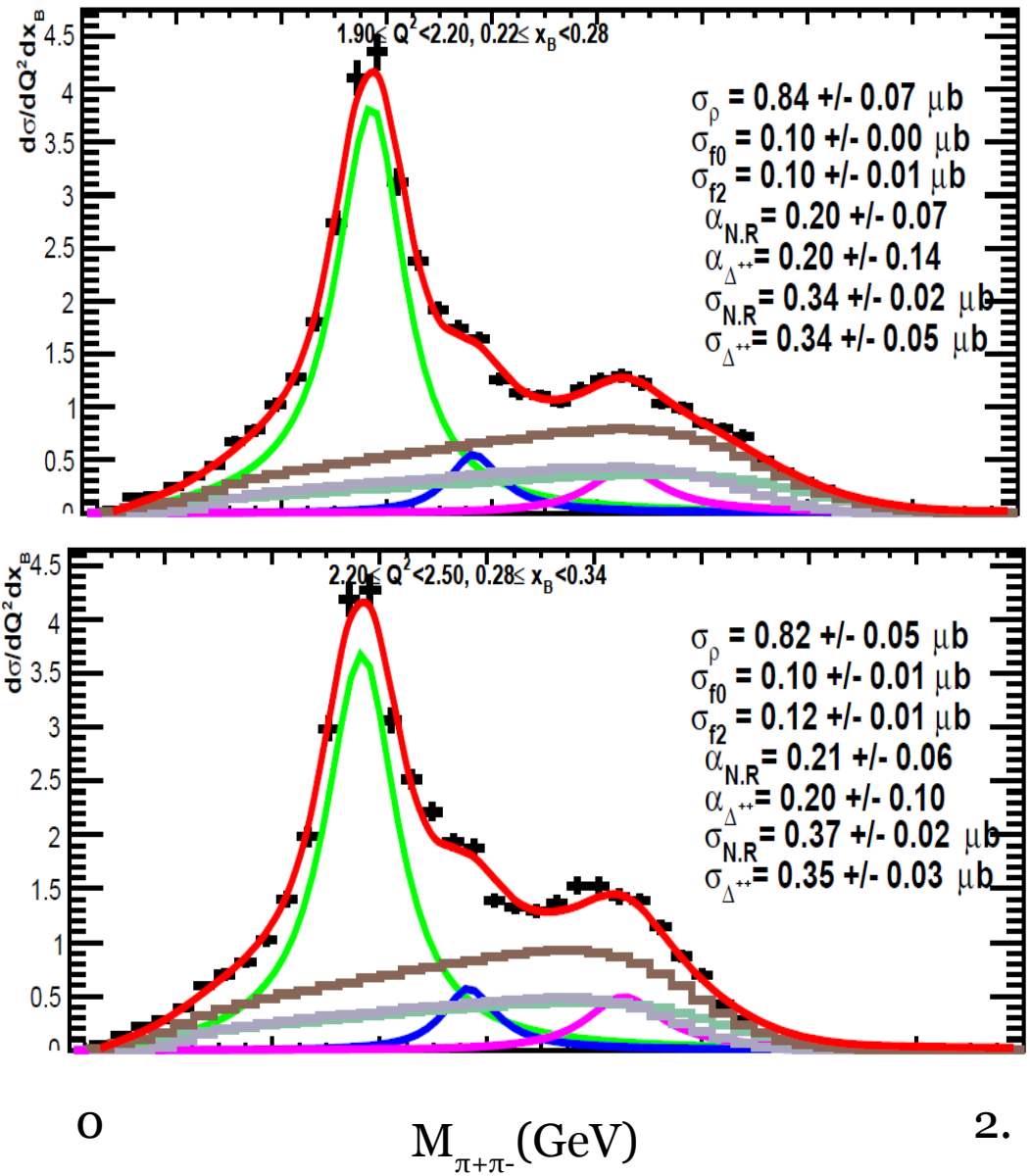


$\gamma^* p \rightarrow p\pi^+\pi^-$ cross sections = Integral of $\pi^+\pi^-$ spectrum in (Q^2, x_B) bins.

- W computed using (Q^2, x_B) bin centering from [1].
- For most W bins, agreement with previous results.
- Maximal discrepancy for high W (low x_B) ~50 %

[1] *Eur.Phys. Journal A Volume 39, pp 5-31* (S.Morrow et al. (2009) *)*

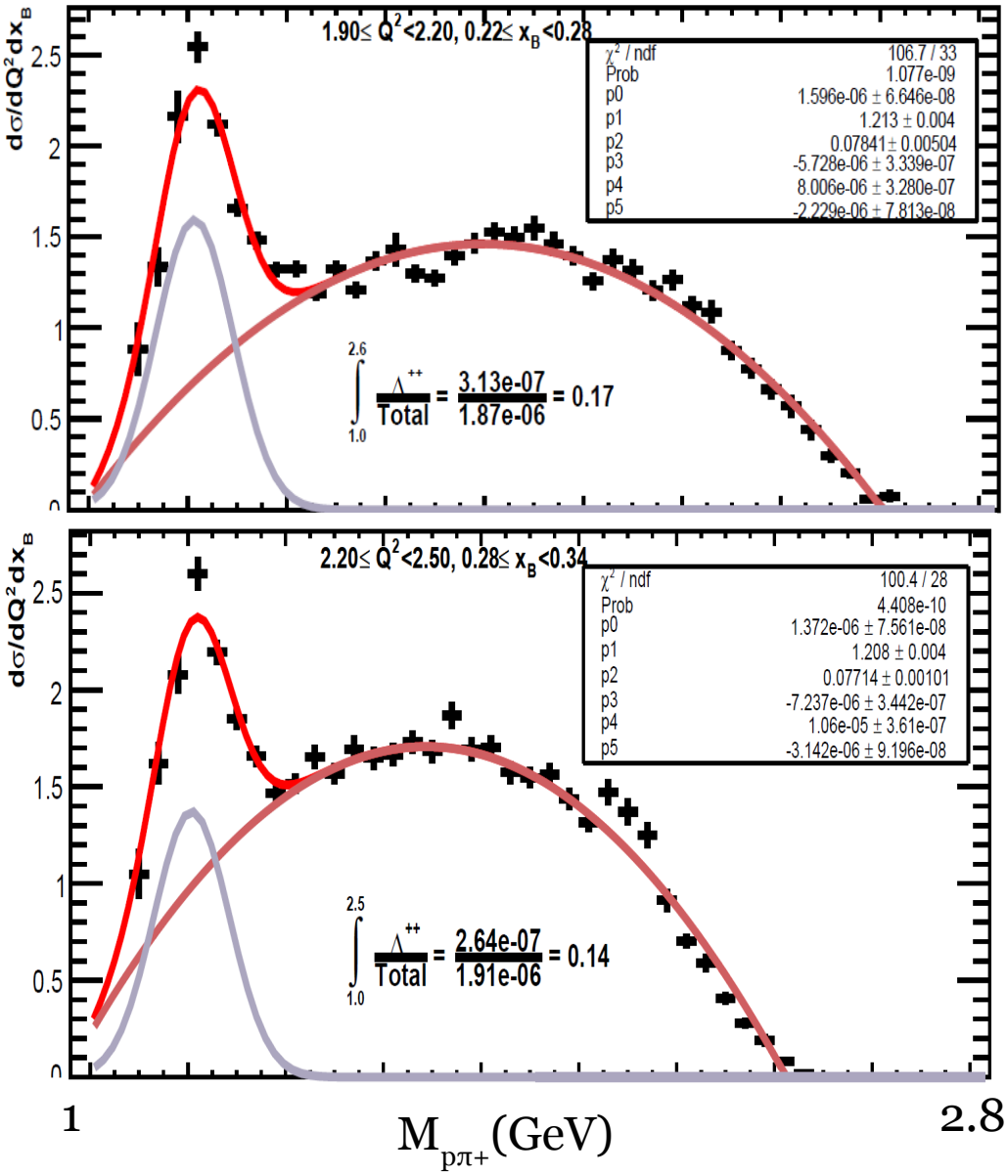
Fit results in (Q^2,x_B) bins



- Fit with several contributions :
  - Skewed BW for **ρ**,**f_0**,**f_2** (4 parameters each)
  - Scale parameters for Background MC non radiative **non resonant ππ** and **Δ^{++} channels** (Generated with Genev)

Background histograms normalized to data integrated cross section in the corresponding ππ spectrum.

Δ^{++} contribution in (Q^2, x_B) bin



- $p\pi^+$ cross section spectrum calculated from a $p\pi^+$ acceptance table .
- $p\pi^+$ fit : gaussian (Δ^{++} signal)+2nd order polynomials (background)
- Contribution of Δ^{++} to the $p\pi^+$ cross section : less than 20 % for $Q^2<4$ GeV^2
- Constraint on $\Delta^{++}(M_{\pi+\pi-})$ background :

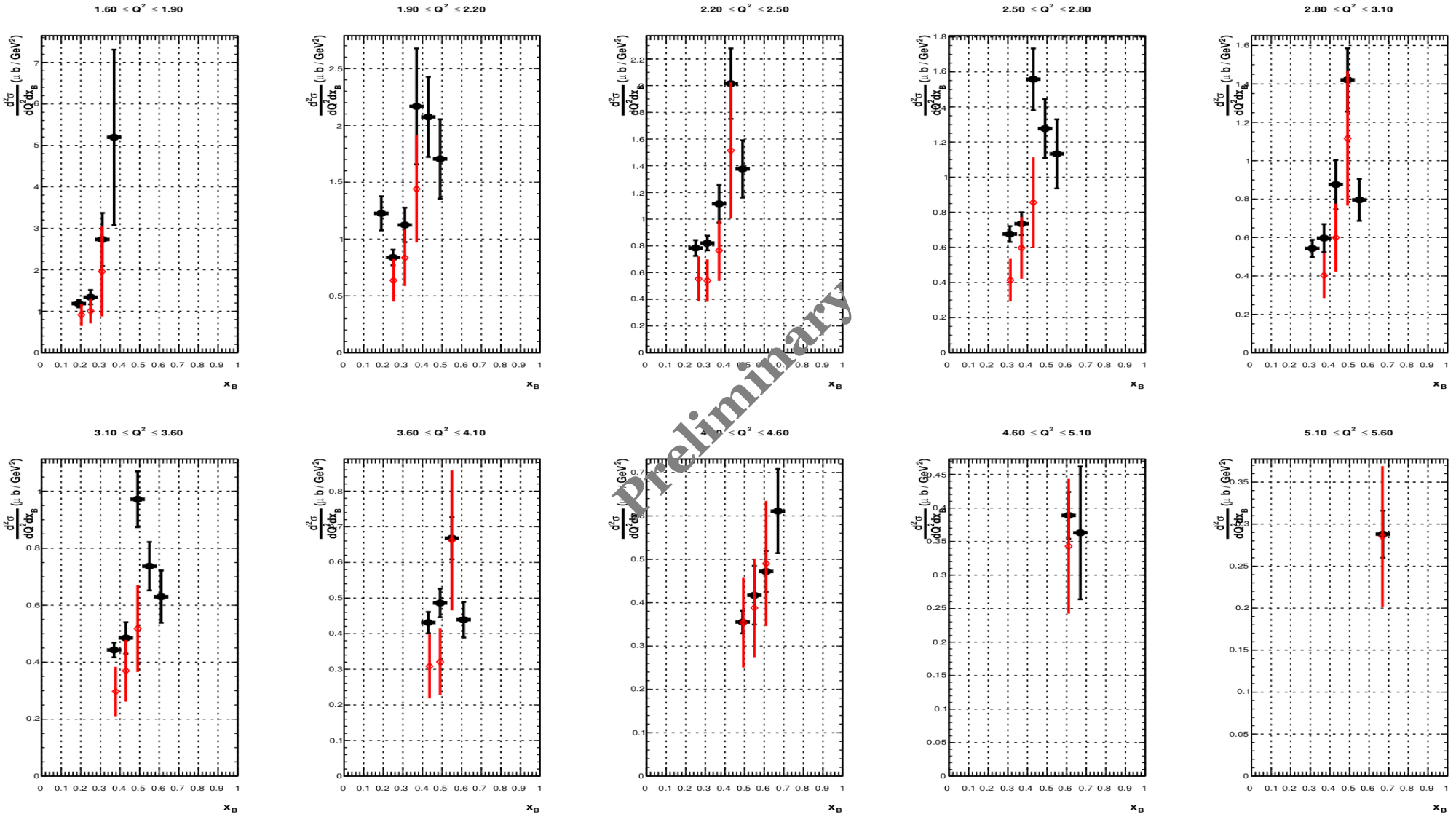
$$\alpha_{\Delta++} < 0.2$$

Side note : In a given (Q^2, x_B) bin,

$$\frac{d\sigma(M_{p\pi+})}{dx_B Q^2} = \frac{d\sigma(M_{\pi+\pi-})}{dx_B Q^2} \text{ +/- 5-10\%}$$

→ Systematic error on acceptance calculation.

γ*p → pρ⁰ cross sections



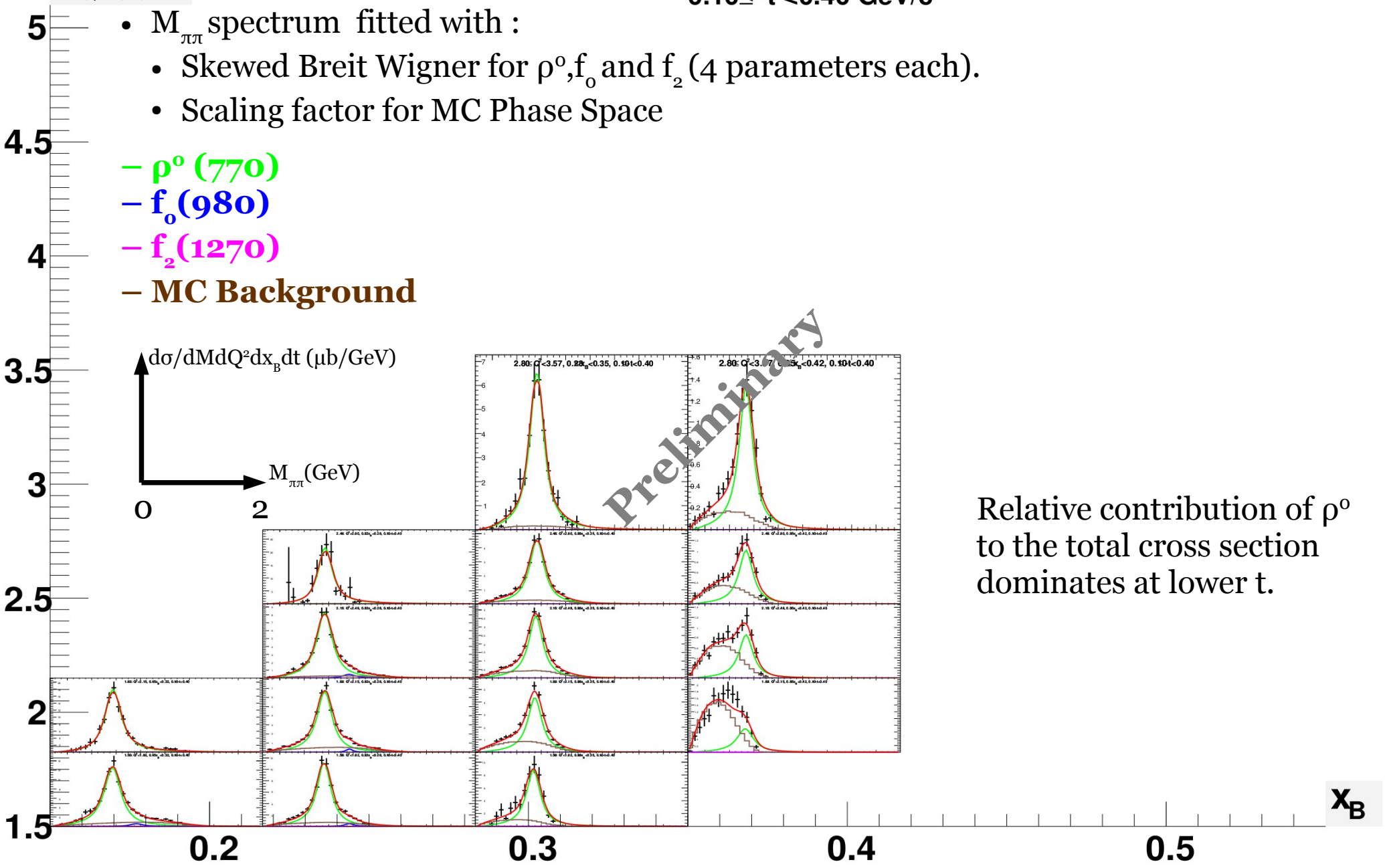
– **ρ⁰ CLAS paper (stat.²+syst.²)**
– **This work (stat. only)**

Most cross sections points are **within systematics** of the previous measurements.

(Q^2, x_B, t) fits

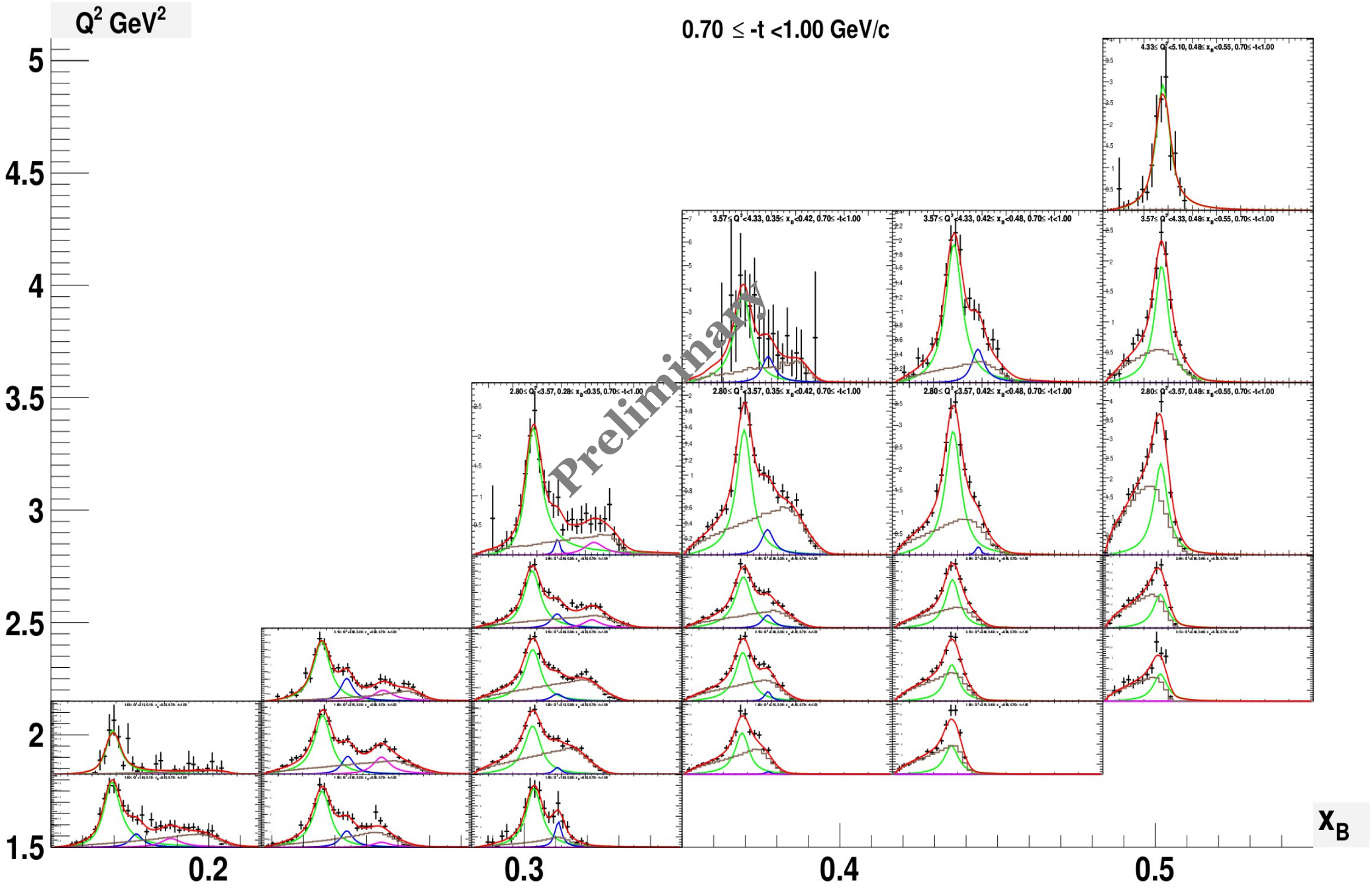
- $M_{\pi\pi}$ spectrum fitted with :
  - Skewed Breit Wigner for ρ^o, f_0 and f_2 (4 parameters each).
  - Scaling factor for MC Phase Space

– ρ^o (770)
– f_0(980)
– f_2(1270)
– **MC Background**

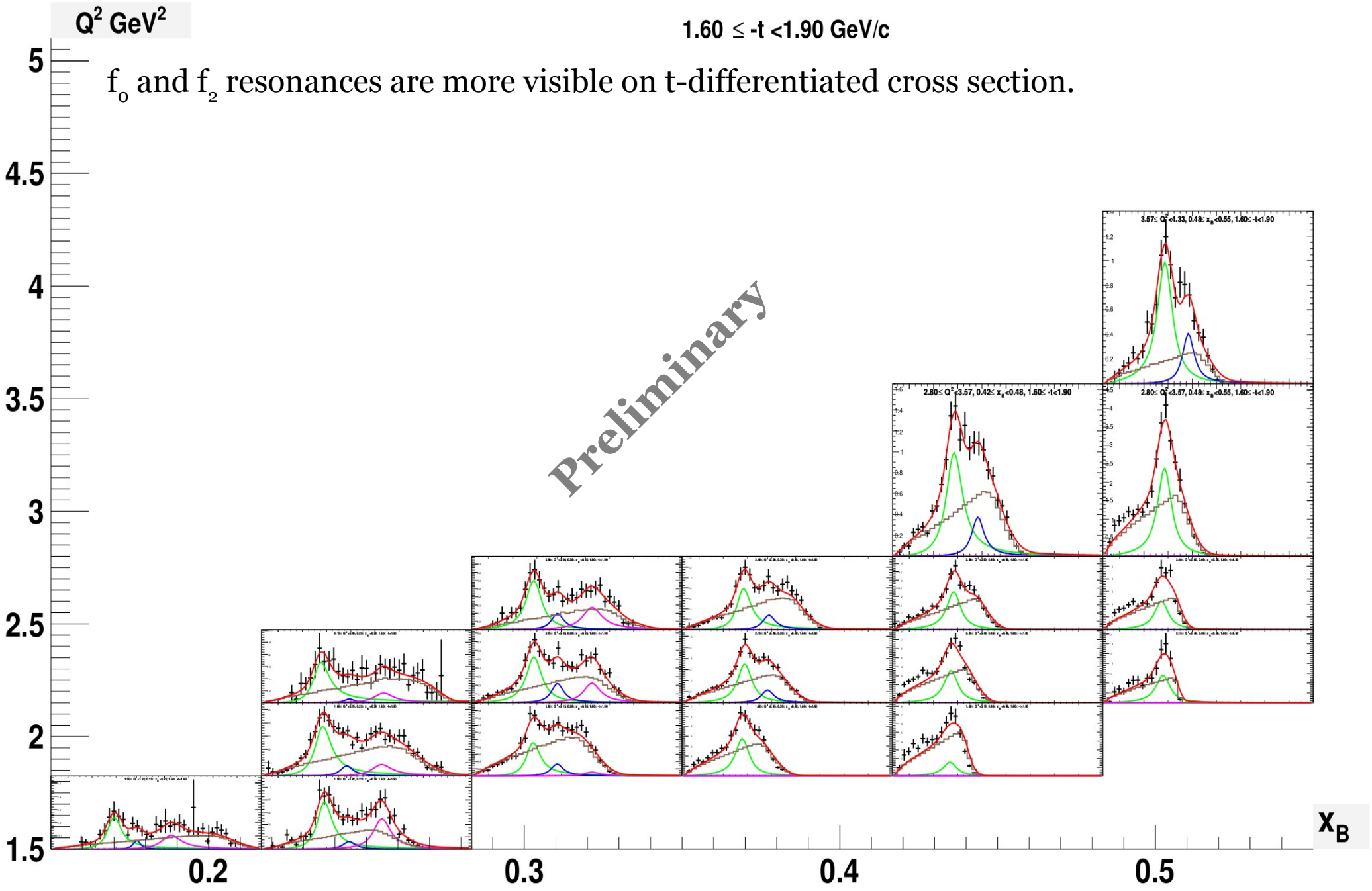


Relative contribution of ρ^o to the total cross section dominates at lower t.

(Q^2, x_B, t) fits

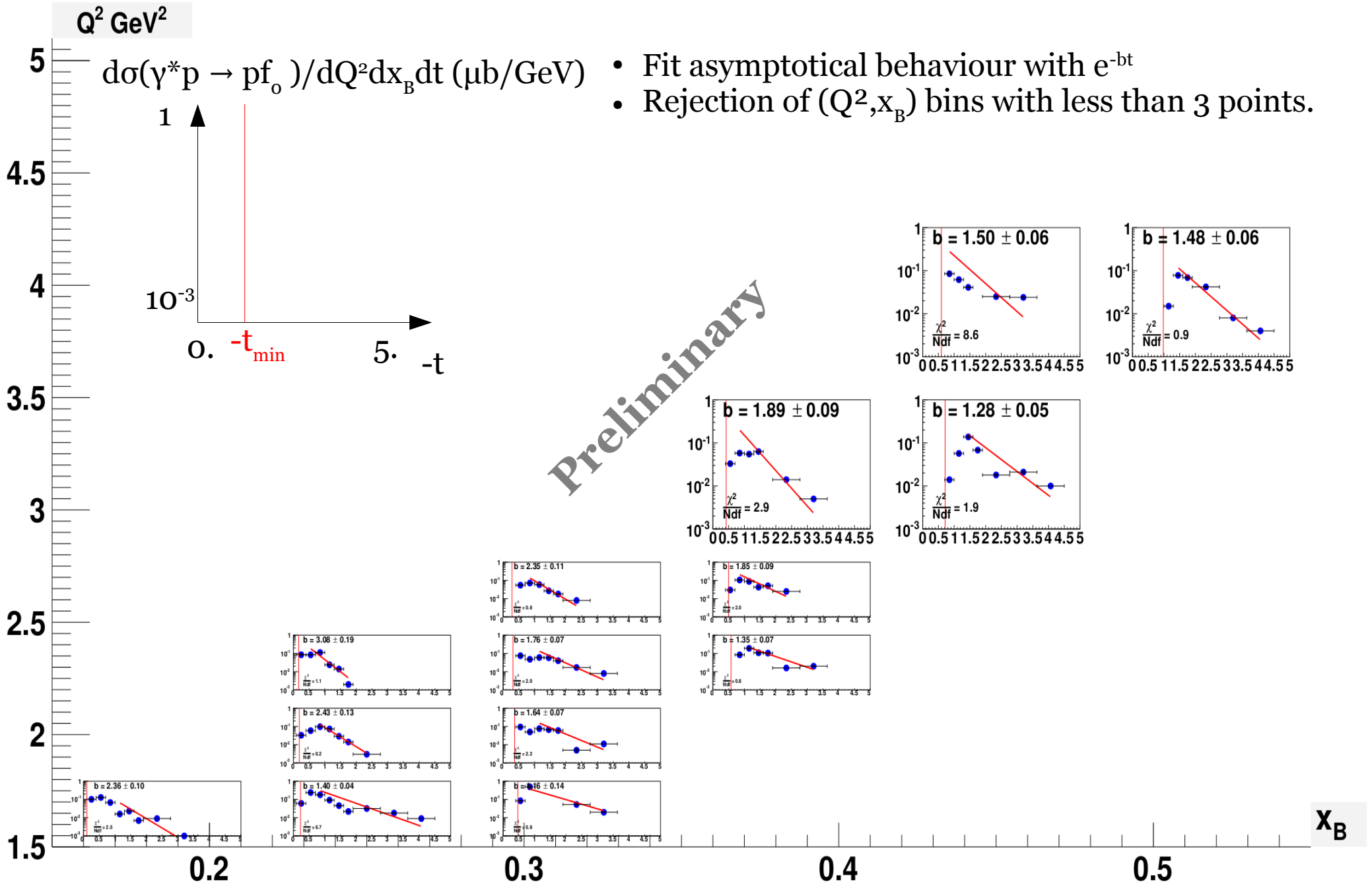

Q² GeV²
0.70 ≤ -t <1.00 GeV/c
Preliminary
x_B
5
4.5
4
3.5
3
2.5
2
1.5
0.2
0.3
0.4
0.5

(Q^2, x_B, t) fits



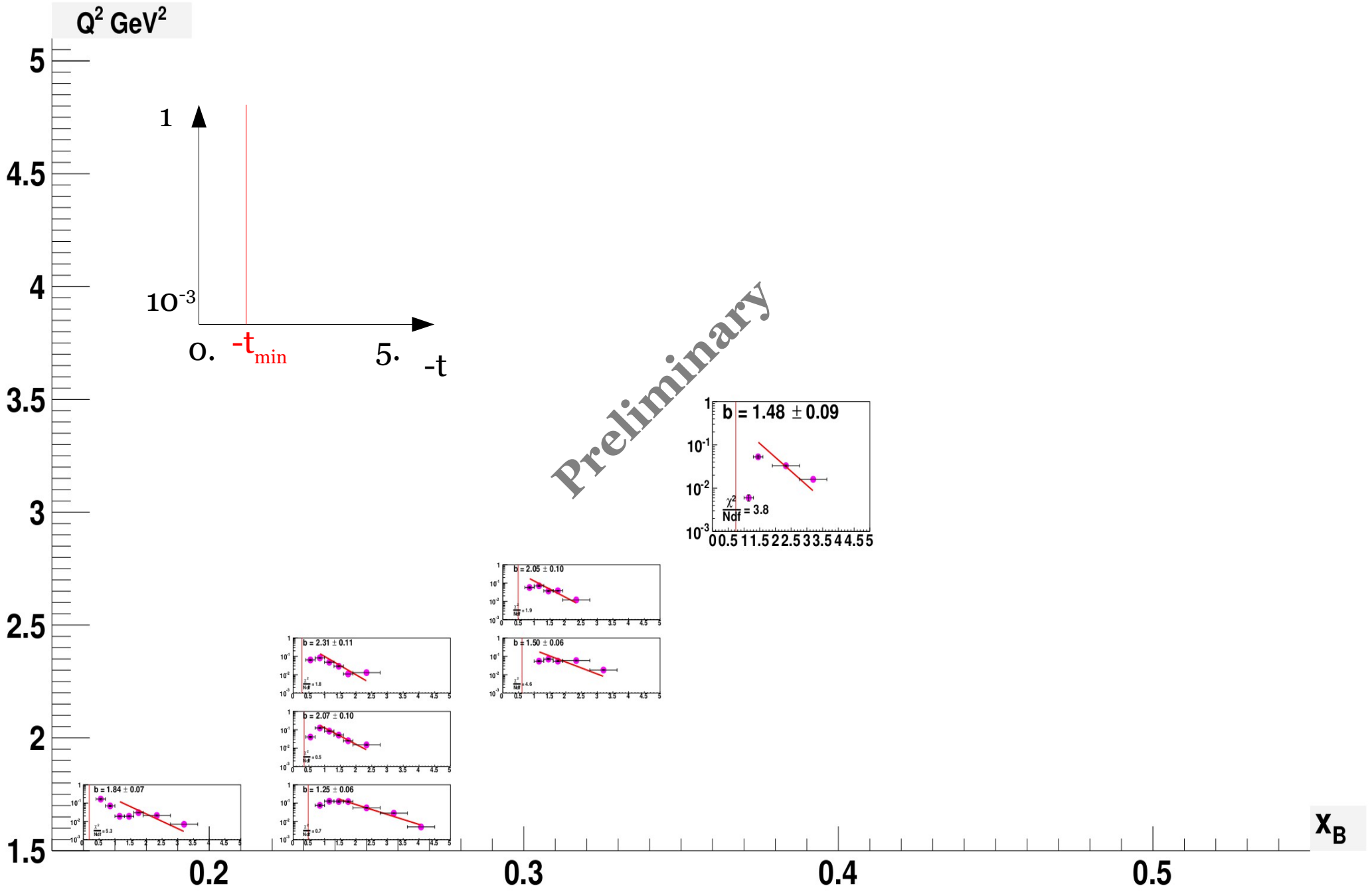
f_0 and f_2 resonances are more visible on t-differentiated cross section.

t-distributions in (Q^2, x_B) bins for f_0

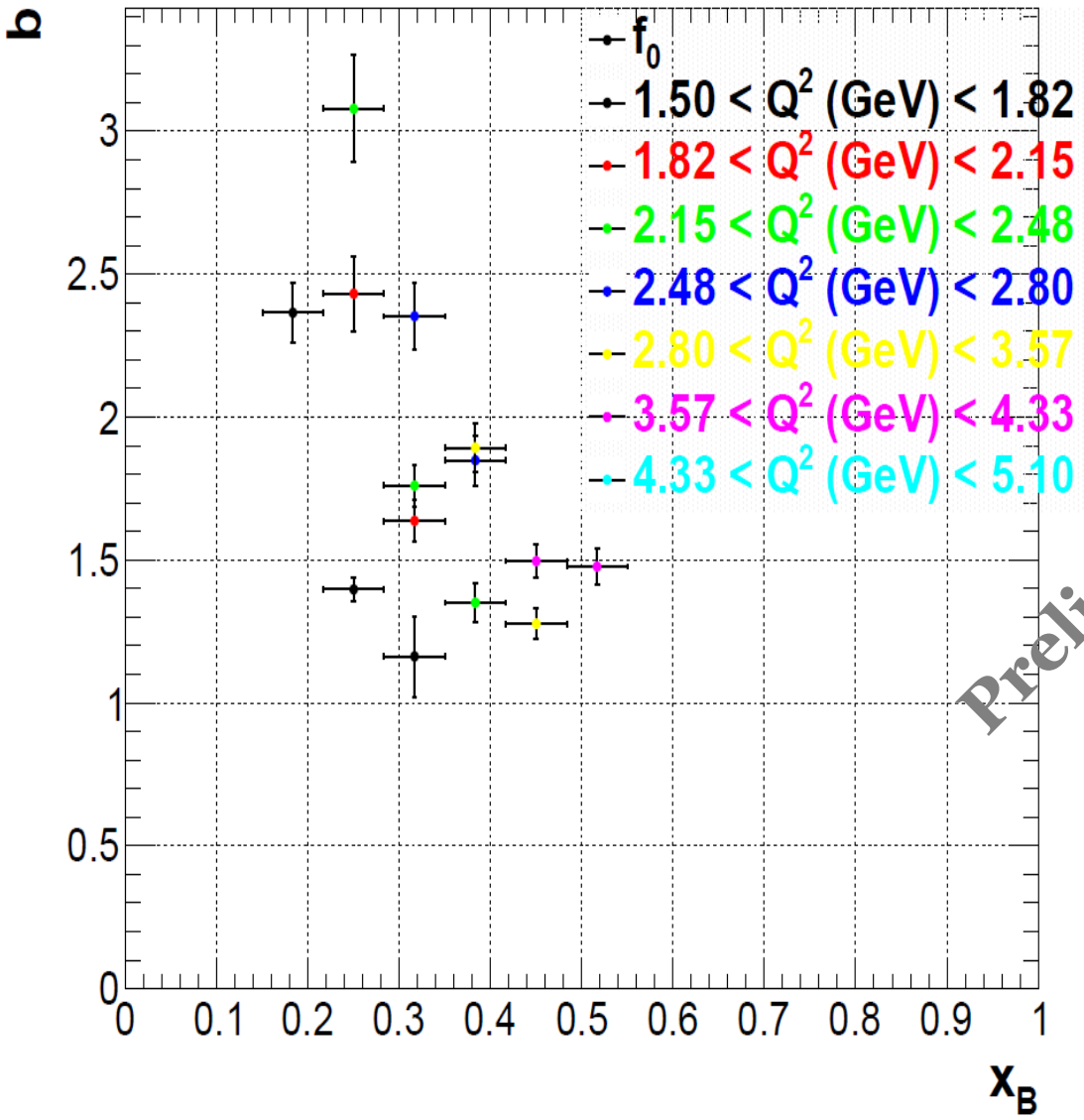


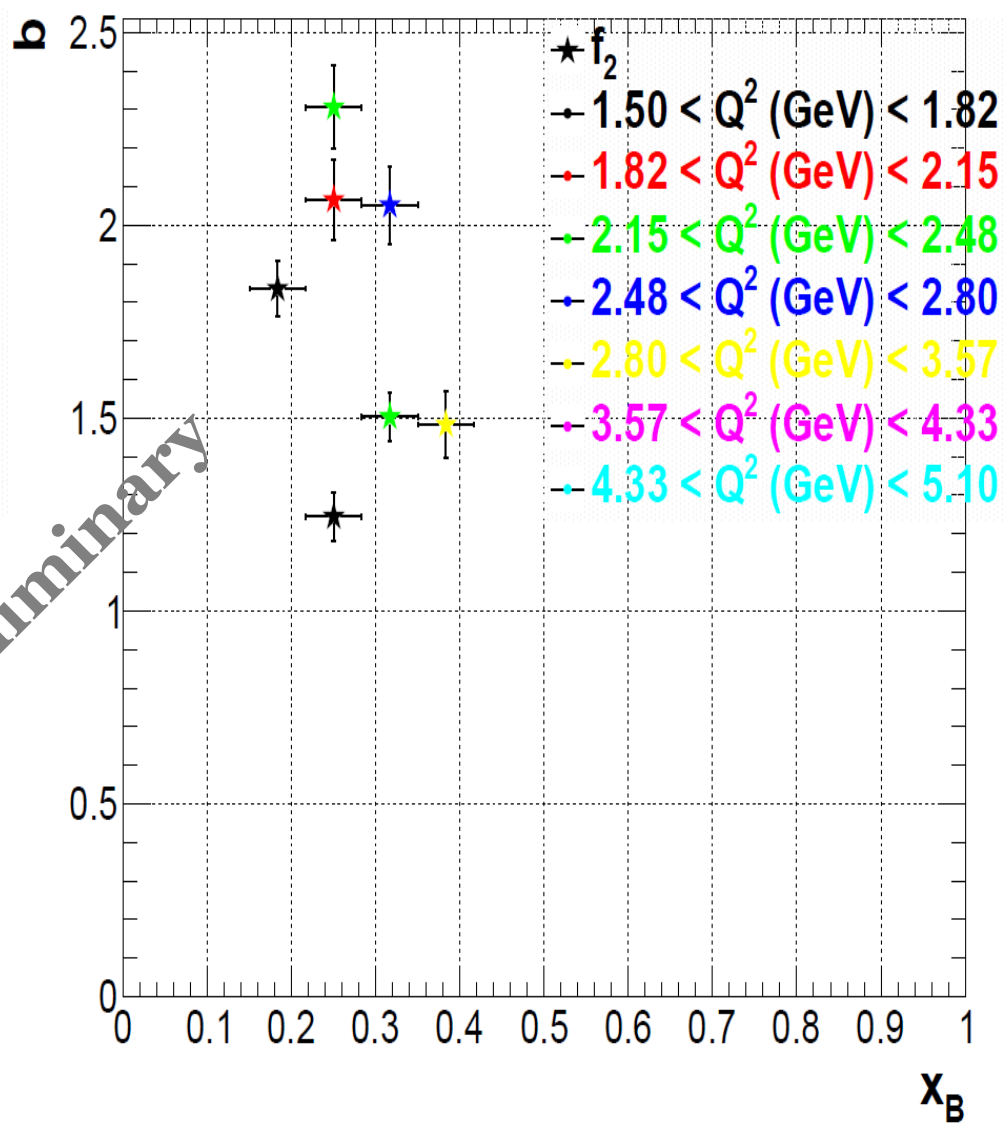
- Fit asymptotical behaviour with e^{-bt}
- Rejection of (Q^2, x_B) bins with less than 3 points.

t-distributions in (Q^2,x_B) bins for f_2



b slope in (Q^2,x_B) bins





Preliminary

b decreases as x_B increases at fixed Q^2 for f_0 and f_2.

Partial Waves Analysis : Principles

Step 1 : Fit the amplitude

Production amplitude are fitted to the data by maximizing a likelihood L :

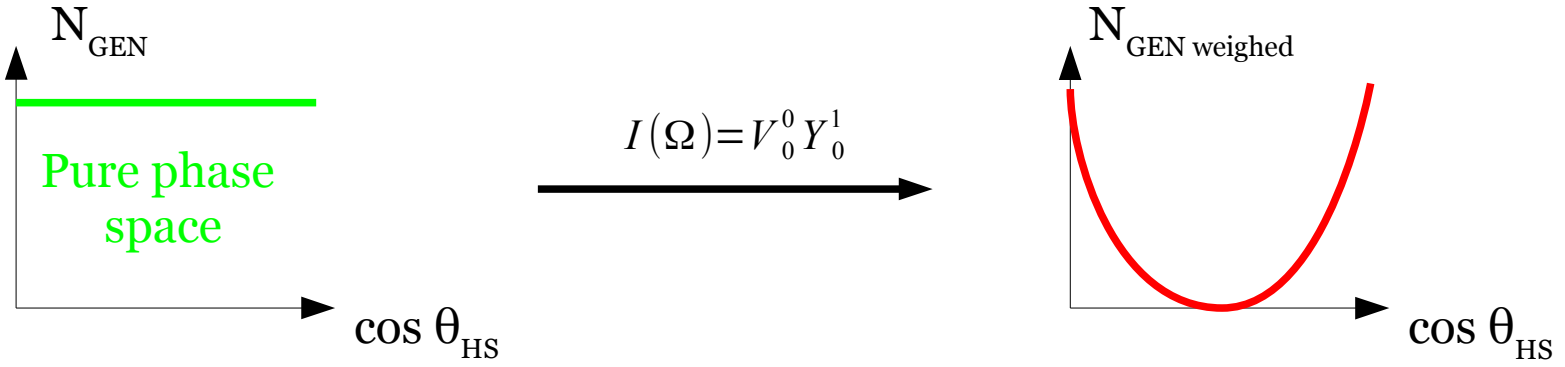
$$-\ln L = \underbrace{-\left(\sum_{i}^{n} \ln\left(I\left(\tau_i, \vec{x}\right)\right)\right)}_{\text{Experimental data}} + \underbrace{\frac{1}{N^{GEN}} \sum_{k=1}^{NREC} I\left(\tau_i\right)}_{\text{Acceptance term. Calculated with MC phase space}}$$

Step 2 : Extract the physical distribution predicted by the fitted amplitude

After the fit, the intensity is **fully determined** and its parameters V_i are such that :

$$\frac{1}{N^{GEN}} \sum_{k=1}^{NREC} I_{fitted}\left(\tau_i\right) = N_{acceptance\ corrected}$$

Each generated MC phase space event is weighed according to the fitted partial waves.



PWA on data

« S-Wave »

Intensity to fit :

$$I(\Theta,\Phi) = \left|V_0^0 Y_0^0\right|^2 + \left|V_{-1}^1 Y_{-1}^1 + V_0^1 Y_0^1 + V_1^1 Y_1^1\right|^2 + \left|V_{-1}^2 Y_{-1}^2 + V_0^2 Y_0^2 + V_1^2 Y_1^2\right|^2$$

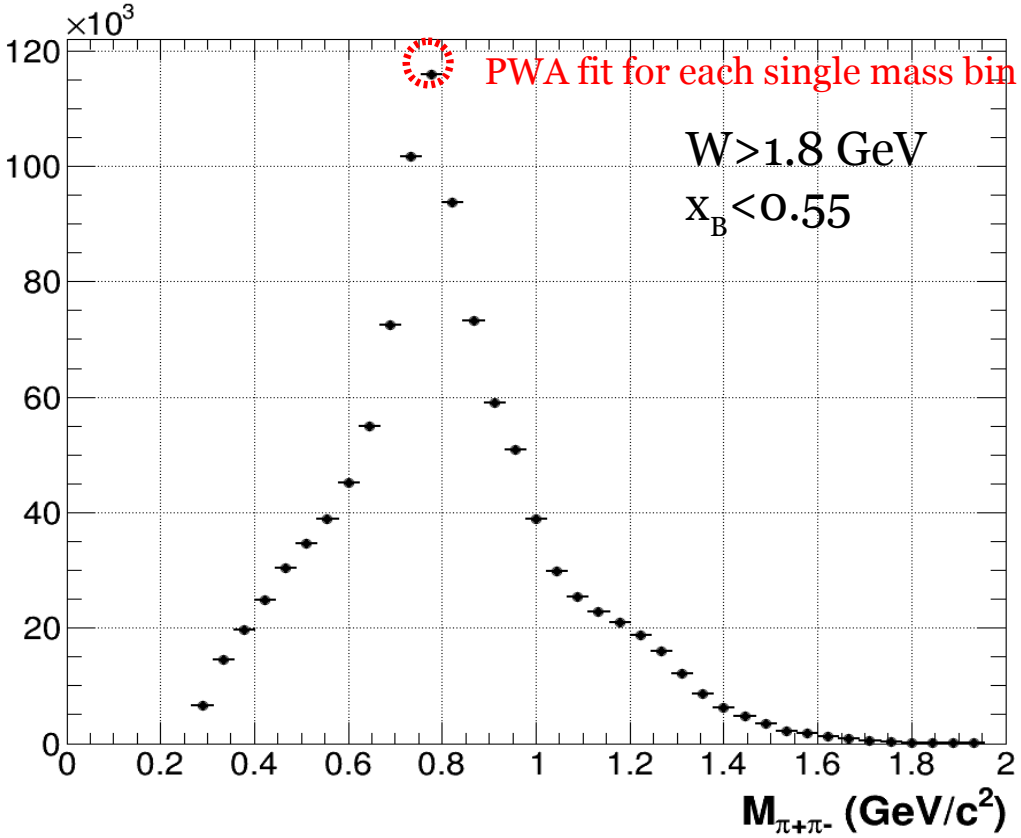
« P-Wave » « D-Wave »

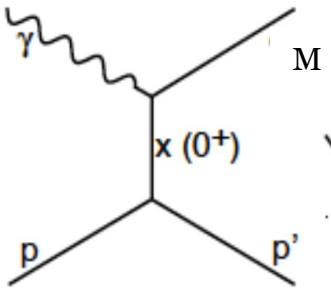
Y^J_M spherical harmonics. V^J_M production amplitude.

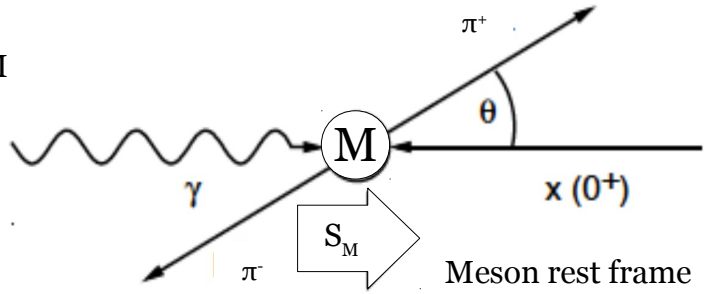
Θ,Φ : Decay angles of the π^+ in **Gottfried Jackson** frame

Incoherent sum on J of spherical harmonics :

J=0,1,2 (truncated to |M|<=1)

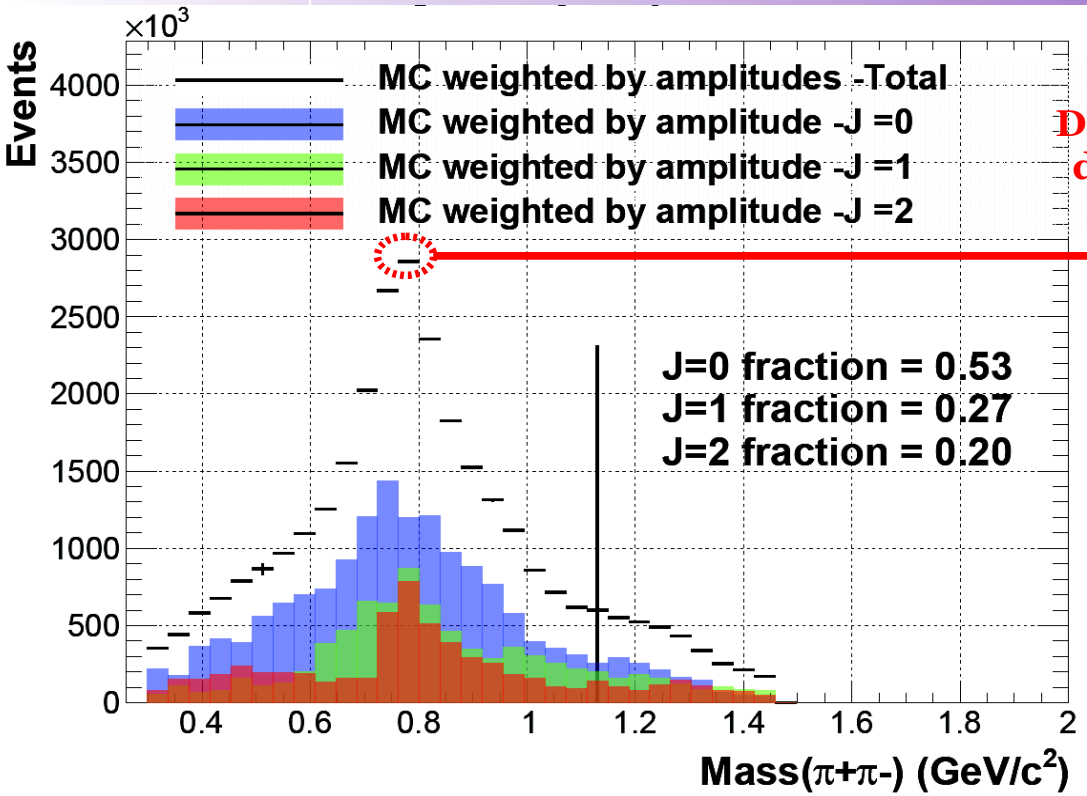




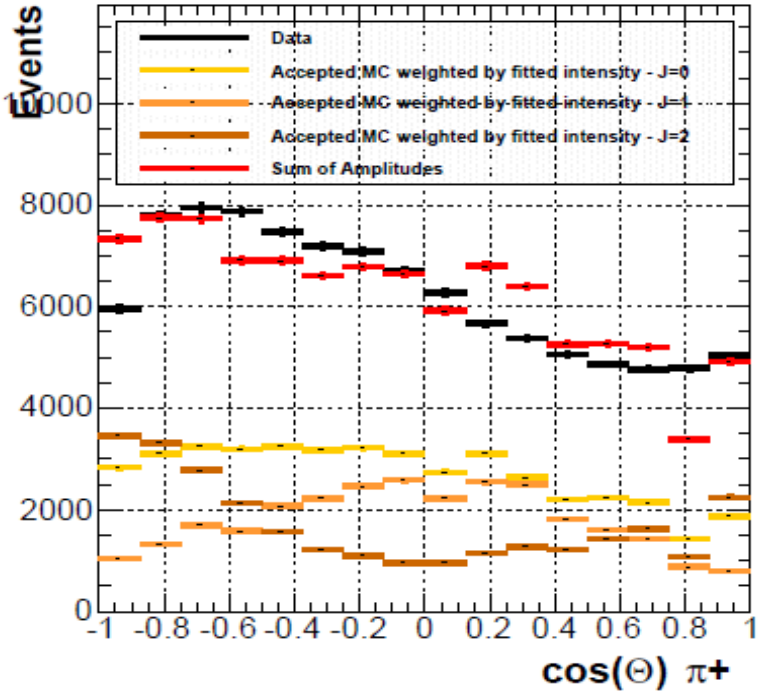


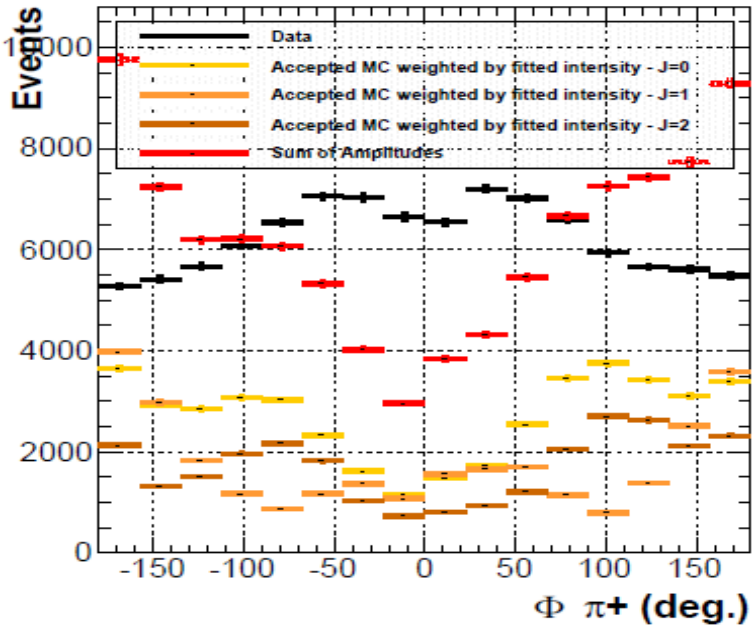
Fit for each single mass bin on integrated dataset at the moment.
(statistical limitation on MC)

Random fits



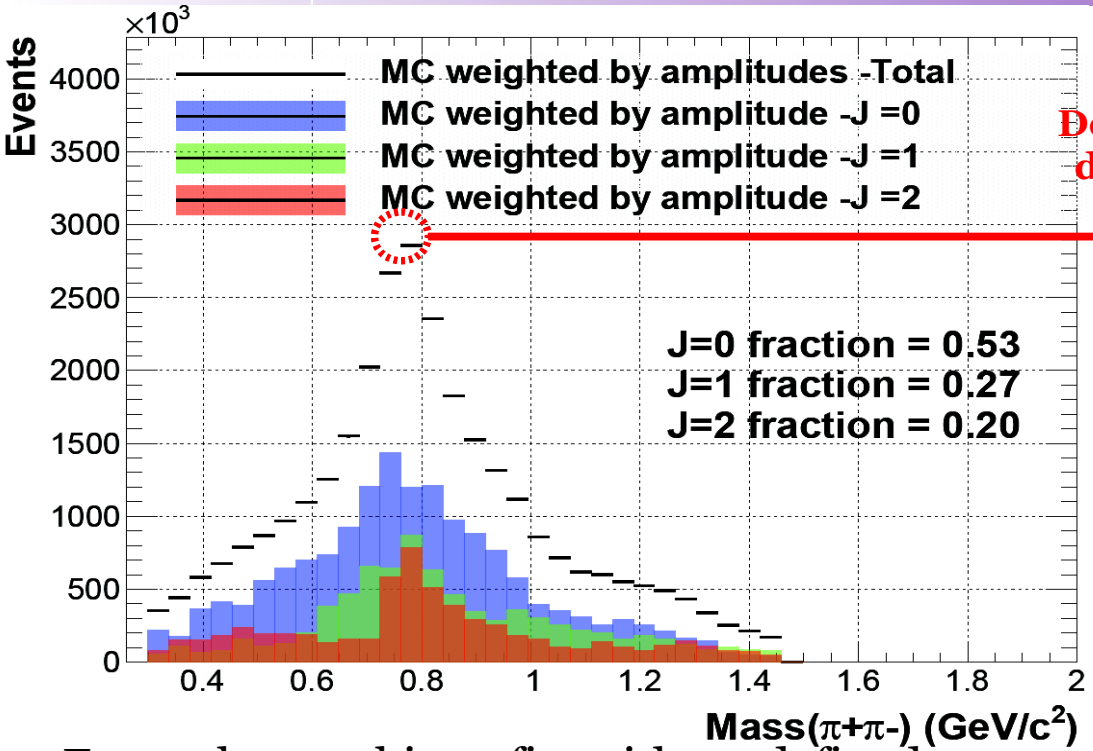
Decay angular distributions



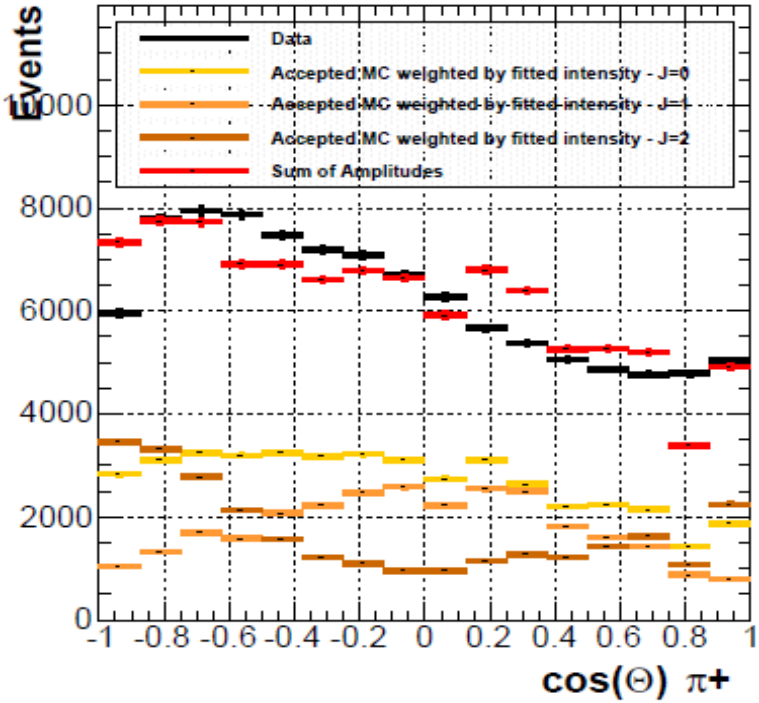


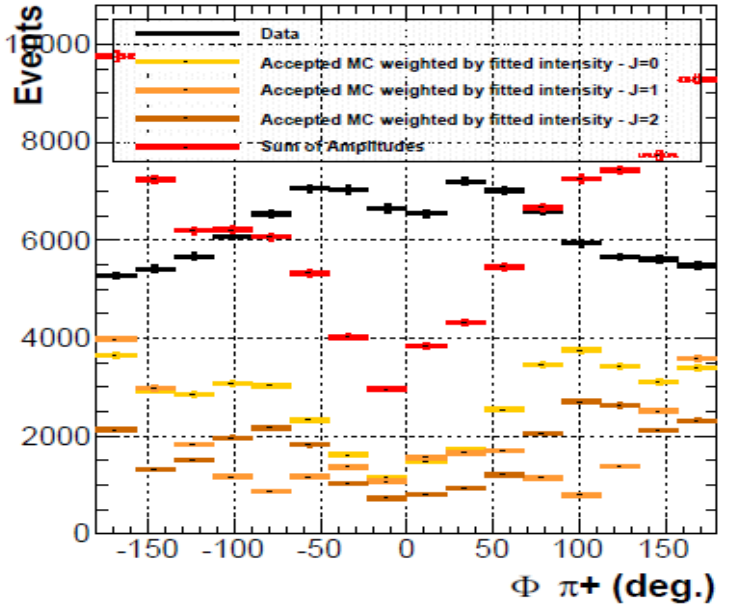
- For each mass bin, 5 fit tries with random parameters+1 fit wit all parameters to 0 then keep the fit with best likelihood.
- Same contribution for P and D-Wave in rho region.
  → Truncation to |m|<2 ?
- Phi angular distribution from data not well reproduced by accepted MC weighed by fitted partial waves.
  → Pure spherical harmonics partial waves inappropriate ?
  Looking into the wrong frame ?

Predefined fits



Decay angular distributions





- For each mass bin, 4 fits with predefined parameters values :
  - All parameters to 0
  - Parameters from one wave set to 1000, 0 otherwise.
- Best likelihood with this procedure = Best likelihood with random fitting
- Same wave contribution as in random fitting procedure
- BUT **fitted parameters for each Y^L_M are different in the two methods !**
- **No significant resonances with this partial wave decomposition.**

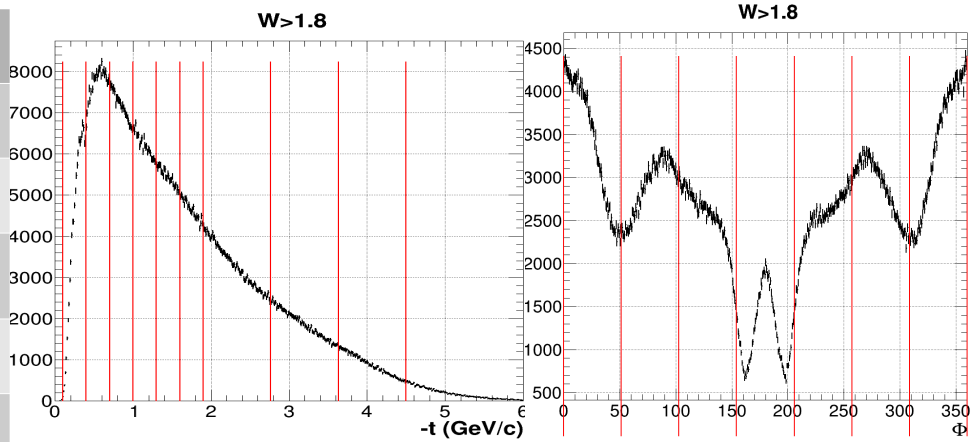
Conclusion

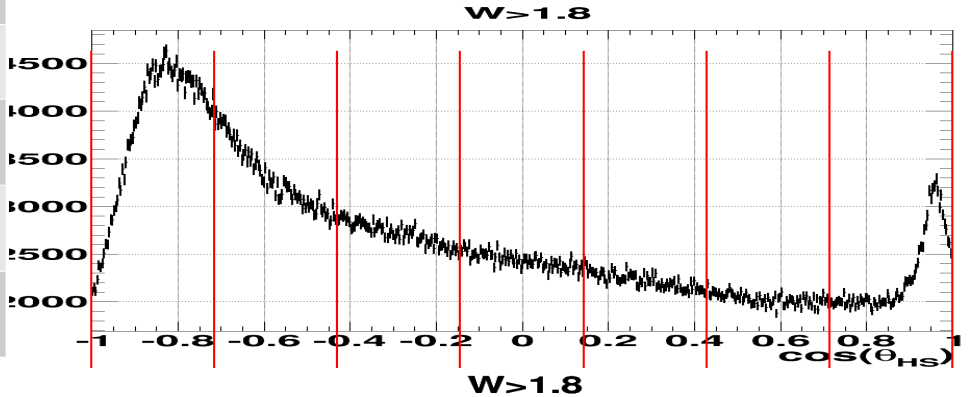
- First time extraction of cross sections for $ep \rightarrow e'p'f_0/f_2$
- Refinement of previous $ep \rightarrow ep\pi^+\pi^-$ CLAS analysis.
- $\pi^+\pi^-$ and ρ^0 cross sections : Good agreement with previous analysis.
- Expected b slope behaviour vs. x_B for f_0 and f_2
- No clear resonances in unbinned partial wave decomposition in GJ frame so far:
  - PWA fit in helicity frame ongoing.
  - Fully coherent amplitude basis ?
  - Different amplitude basis to match phi angular distribution ?
  - MC Phase Space : radiative effects ?

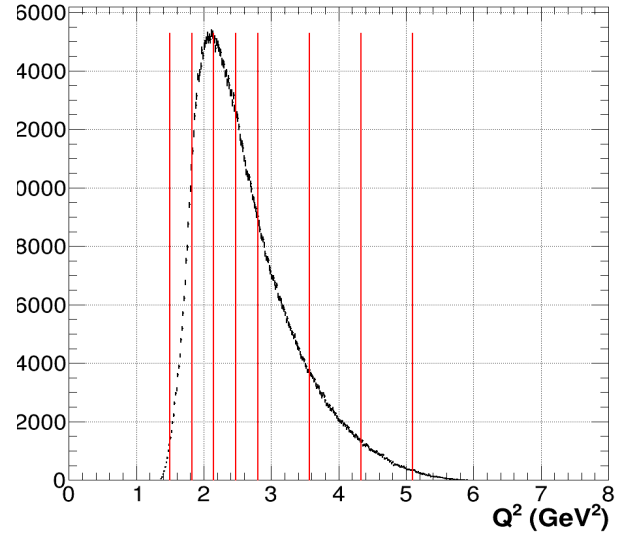
Thanks for your attention

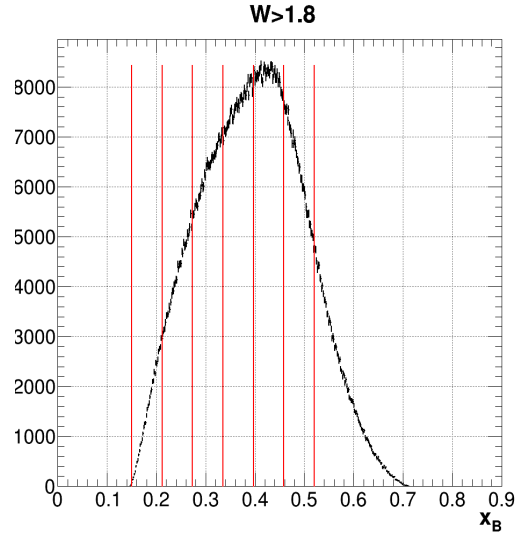
Binning for f_0/f_2 analysis

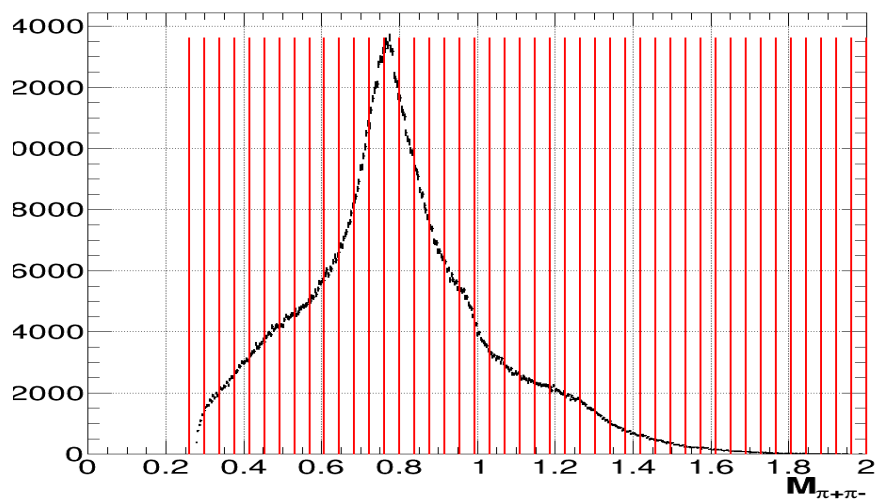
Variable	Number of bins	Range
Q^2	4	1.5-2.8
	3	2.8-5.1
x_B	6	0.15-0.55
-t	6	0.1-1.9
	3	4.5-1.9
Φ	7	0-360
Cos θ_{HS}	7	-1-1
Φ_{HS}	7	0-360
$M_{\pi\pi}$	45	0. 26-2.







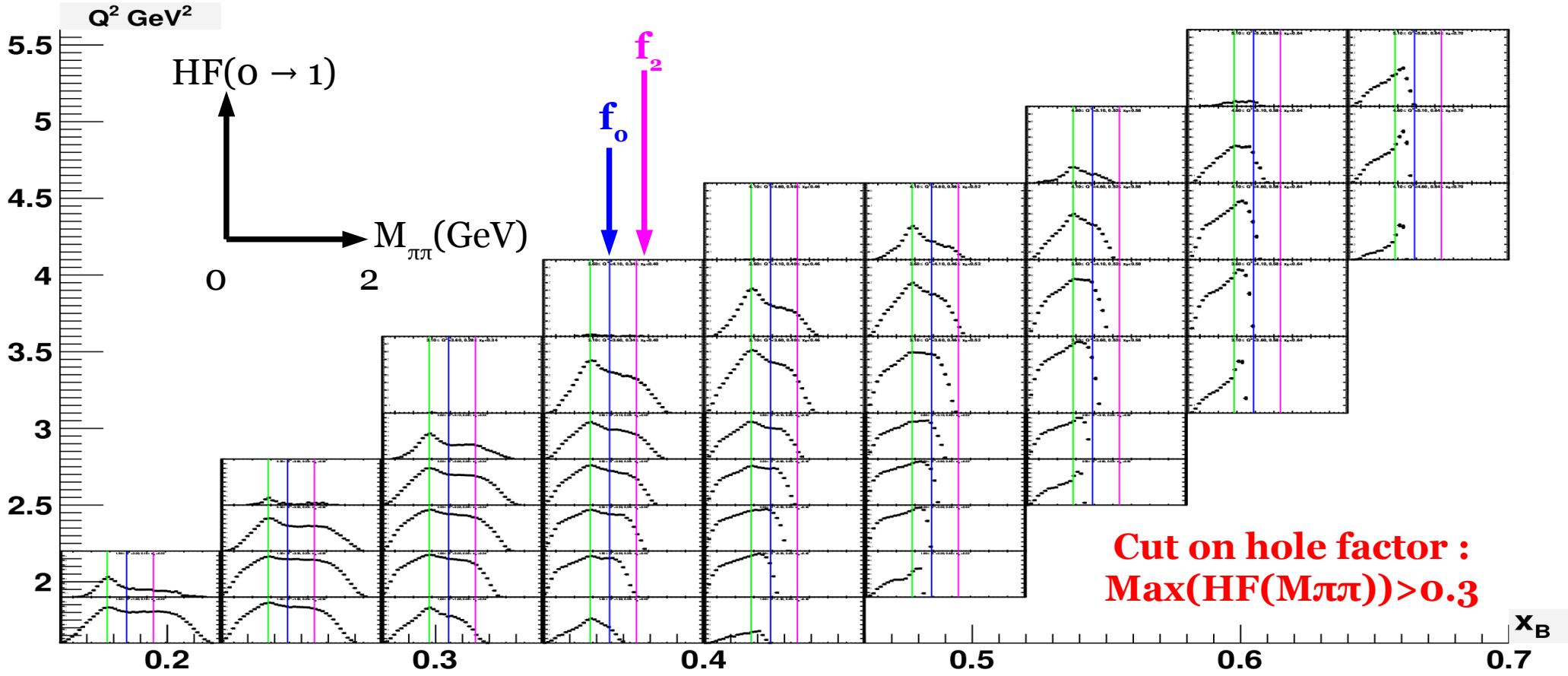




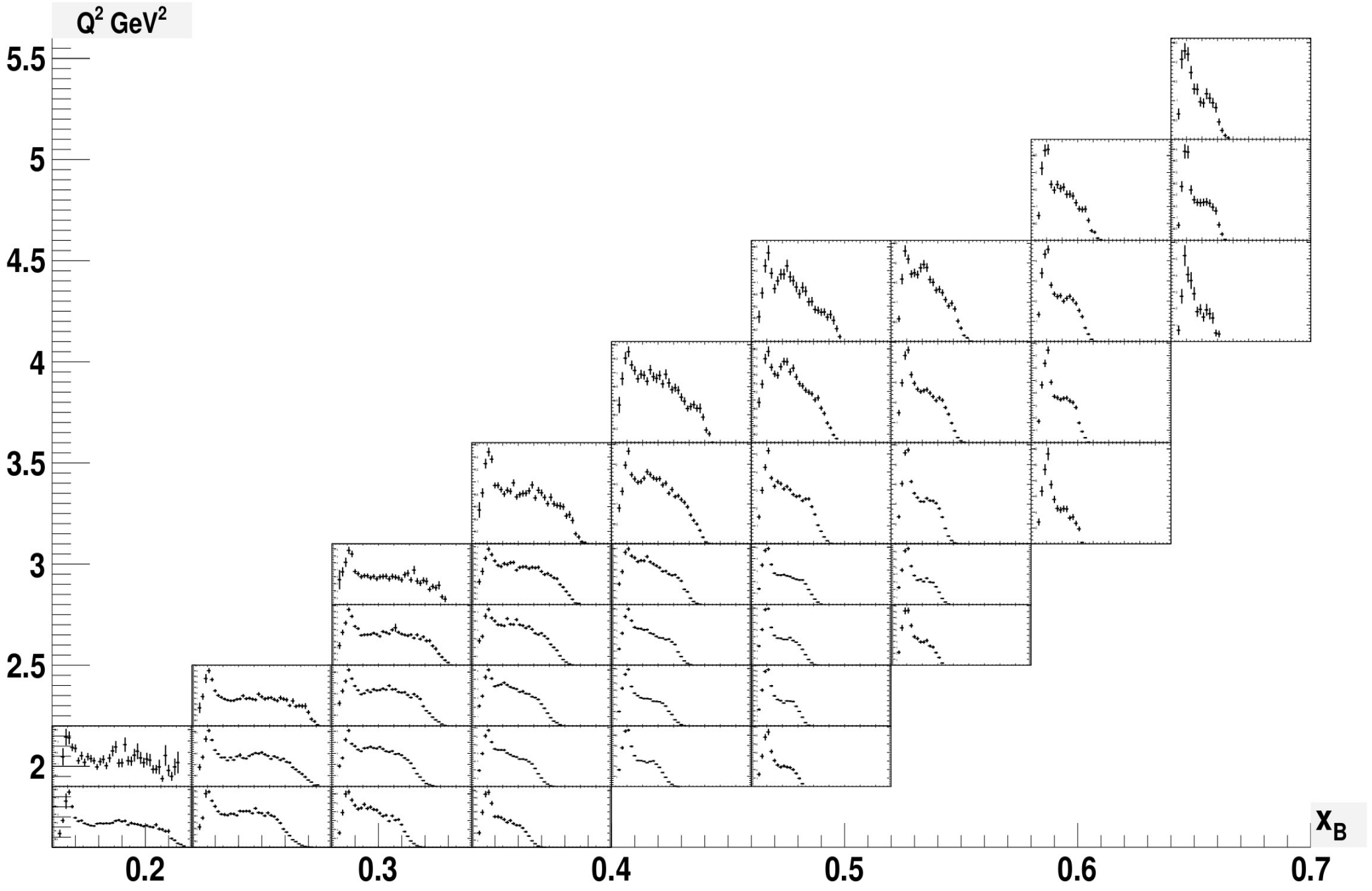
Hole Factor (Q^2,x_B,$M_{\pi\pi}$)

- Differential cross section studied on N<7 dimension.
- Due to statistical effect, some 7D bins are not filled and generated events are not fully recovered by acceptance correction on an integrated bin V (dimension N<7).
- A **model dependent** correction term called « **hole factor** » is used to retrieve generated events :

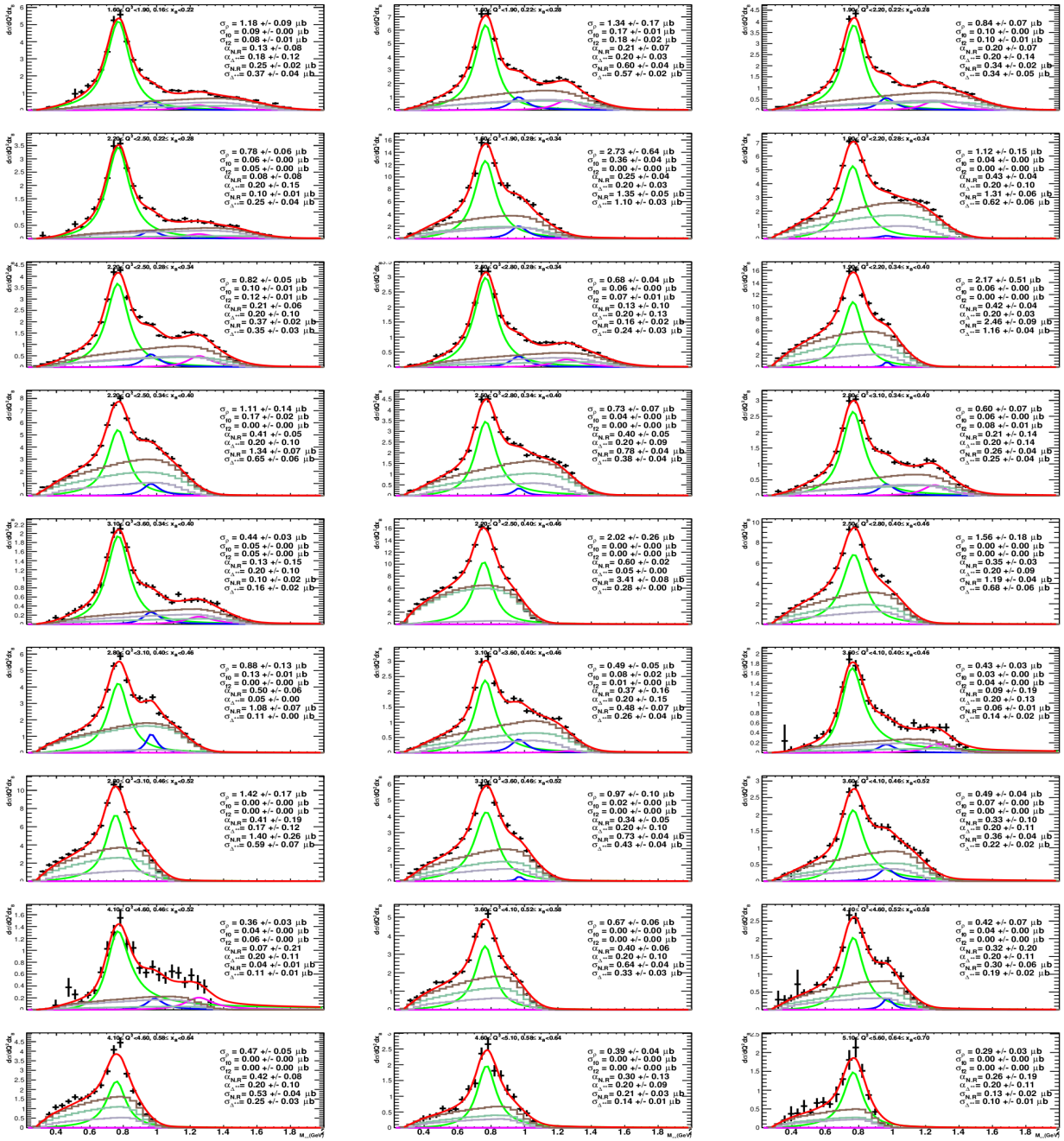
$$HF(V) = \frac{\int \frac{REC}{Acc}(V, x, y, z...) * dx * dy * dz * ...}{\int GEN(V, x, y, z...) * dx * dy * dz * ...}$$



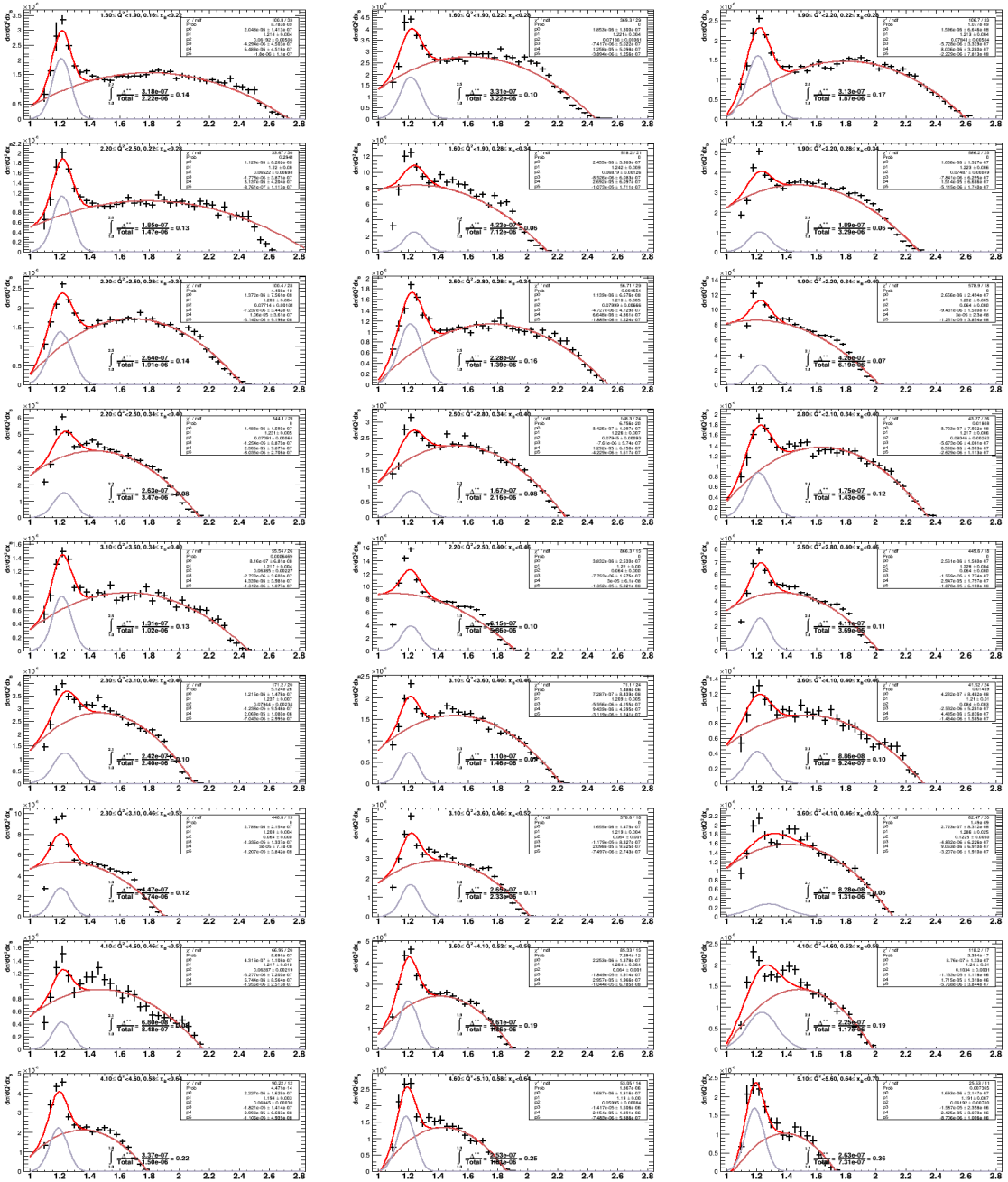
$\gamma^* p \rightarrow p\pi^+$ spectra



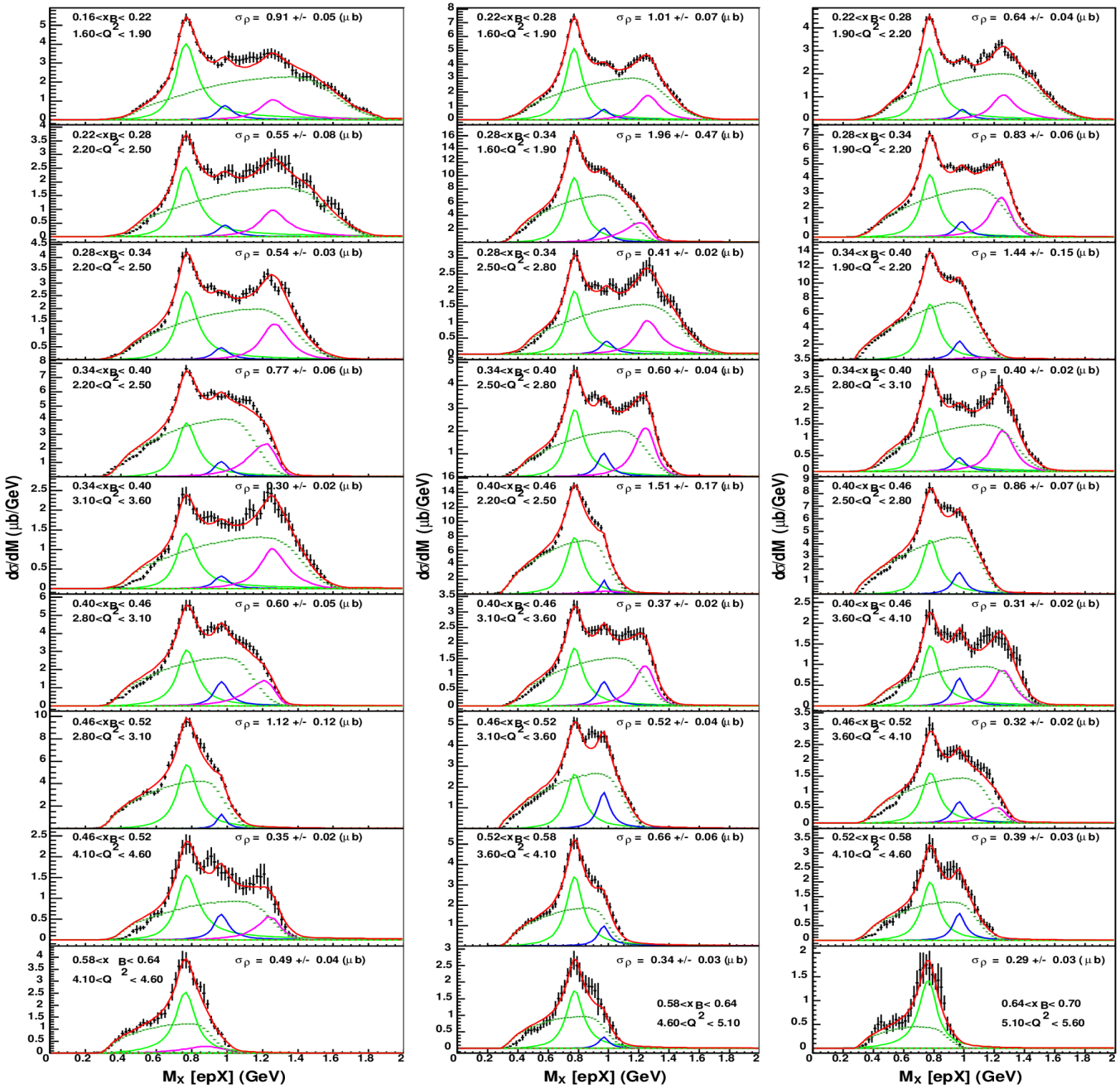
Fit results in (Q^2,x_B) bins



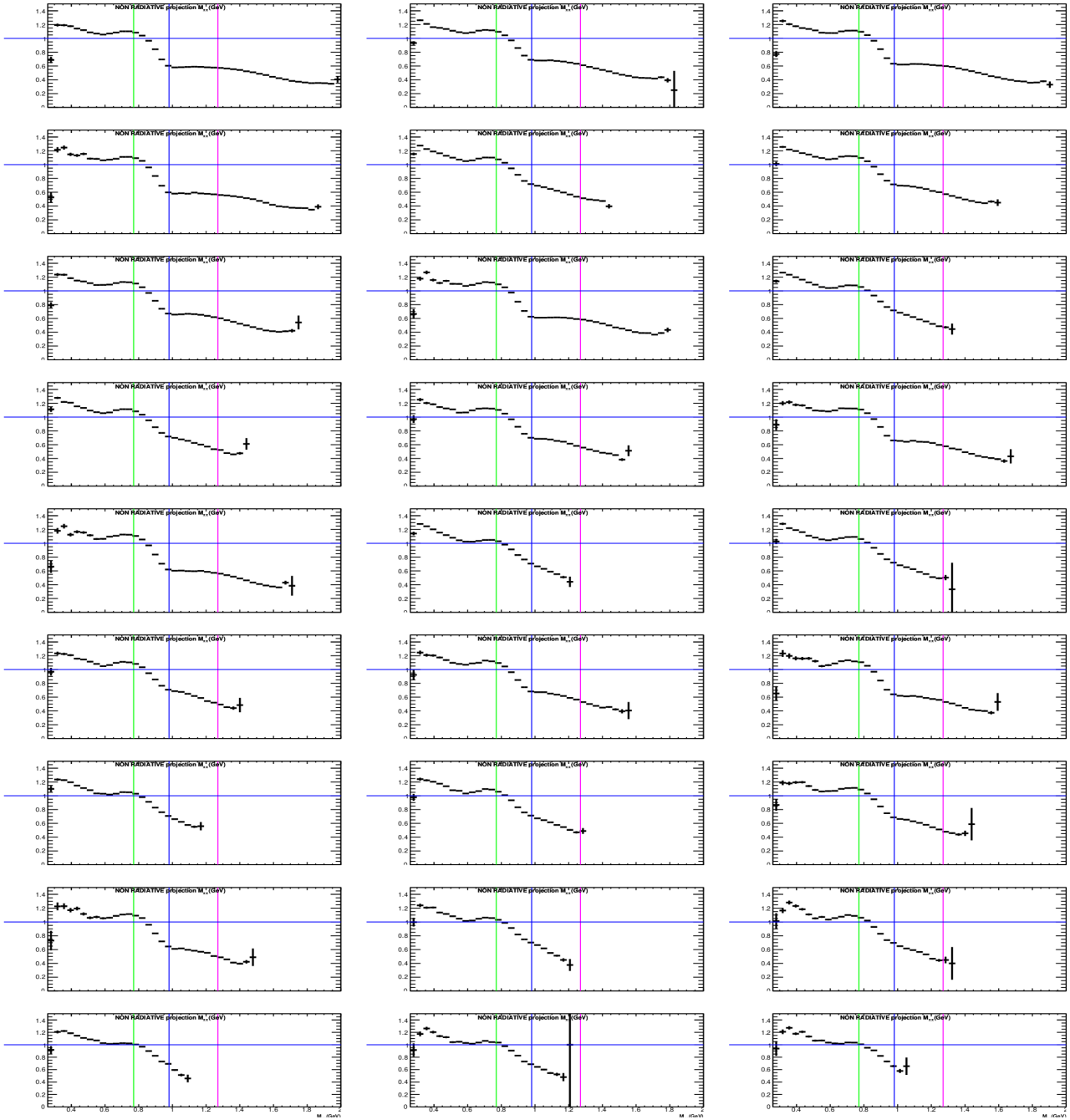
Δ^{++} contribution in (Q^2, x_B) bin



Fit results in (Q^2,x_B) (ρ^o analysis)

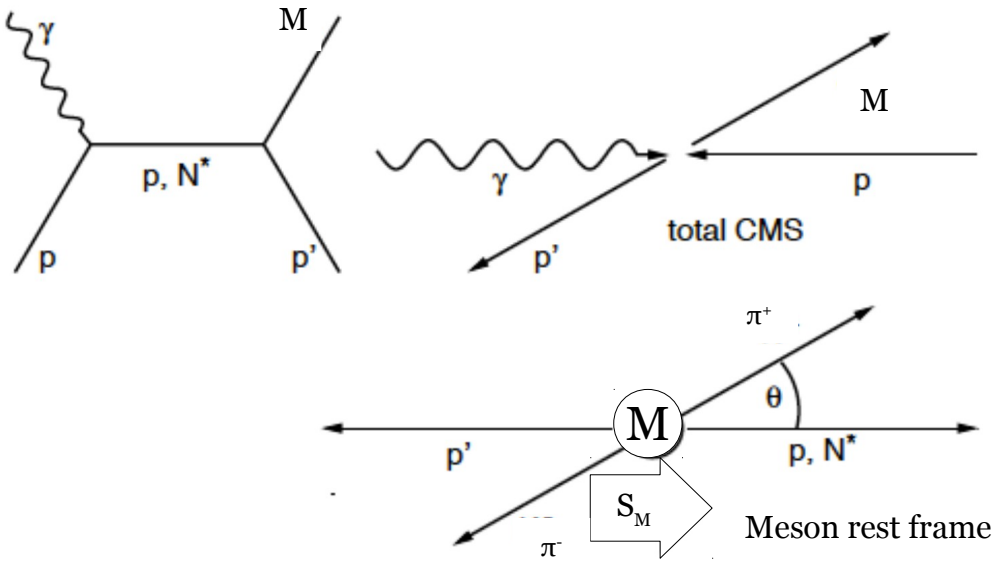


$F_{RAD}(M_{epX})$ in (Q^2, x_B) bins



Decay meson frames

Helicity frame



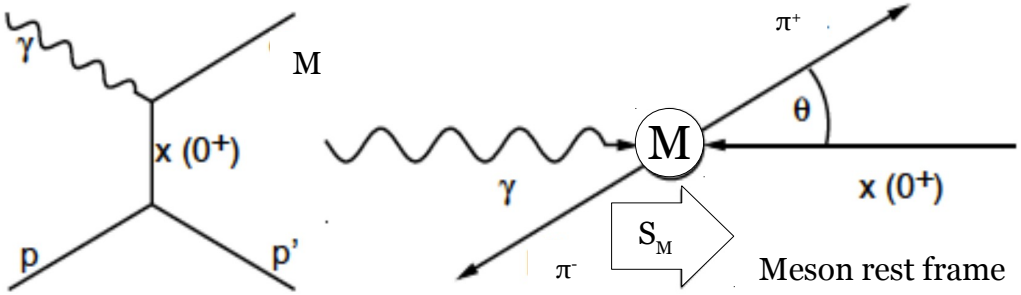
The quantization axis z points into the direction of the meson M in the (γ*,p) system.

2 Lorentz boost performed :

1/ Boost from laboratory to (γ*,p) CDM

2/Boost from CDM to meson rest frame

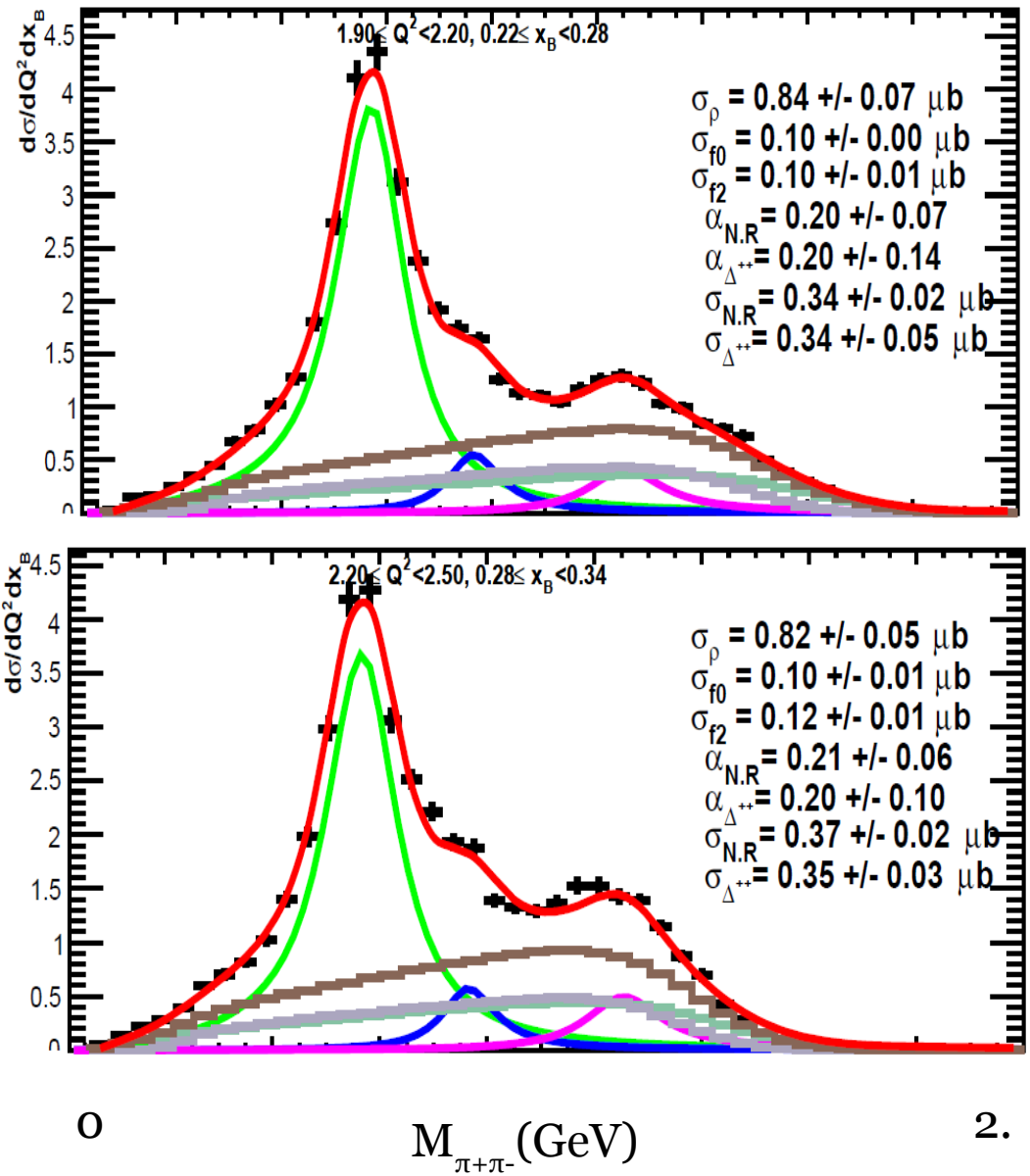
Gottfried Jackson frame



The quantization axis z points into the direction of the virtual photon in the meson M rest frame

Lorentz boost from laboratory to meson rest frame.

Fit results in (Q^2,x_B) bins



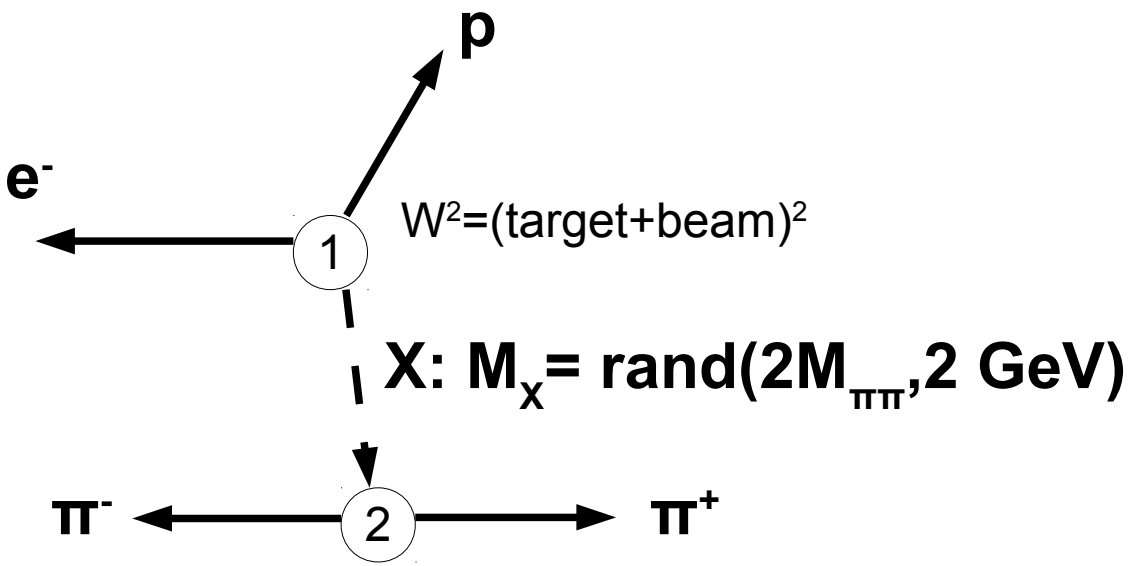
- Fit with several contributions :
  - Skewed BW for **ρ**,**f_0**,**f_2** (4 parameters each)
  - Scale parameters for Background MC non radiative **non resonant ππ** and **Δ^{++} channels** (Generated with Genev)

Background histograms normalized to data cross section in the corresponding ππ spectrum.
→ Scale parameters for background are defined such that :

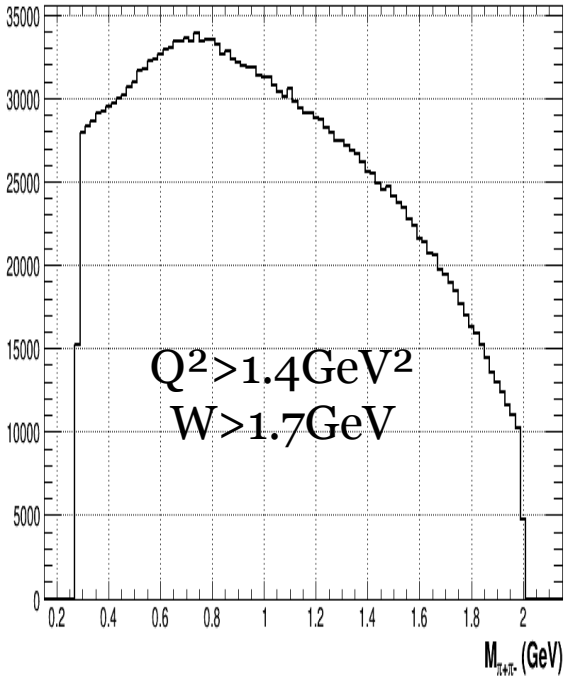
$$\alpha_{NR} = \frac{\int MC_{N.R}(M_{\pi+\pi-})\,dM_{\pi+\pi-}}{\int \frac{d\sigma}{dQ^2\,dx_B\,dM_{\pi+\pi-}}(M_{\pi+\pi-})\,dM_{\pi+\pi-}}$$

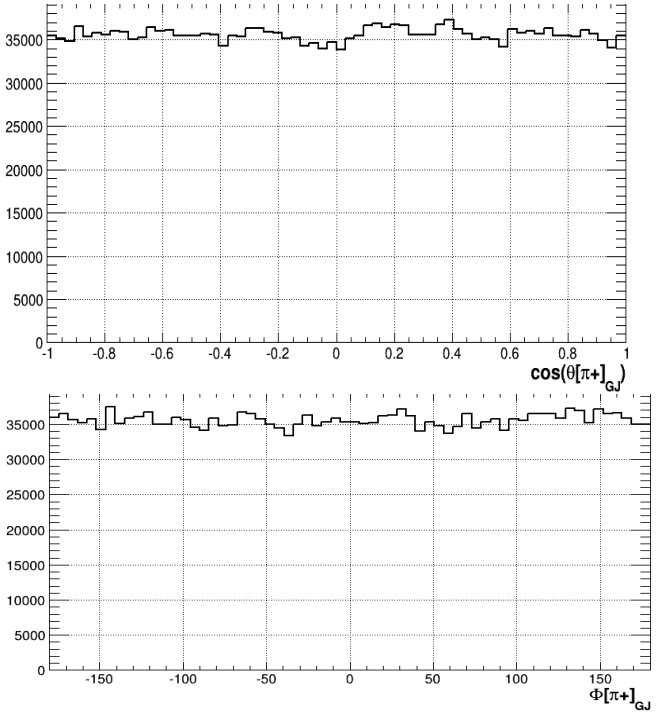
$$\alpha_{\Delta++} = \frac{\int MC_{\Delta++}(M_{\pi+\pi-})\,dM_{\pi+\pi-}}{\int \frac{d\sigma}{dQ^2\,dx_B\,dM_{\pi+\pi-}}(M_{\pi+\pi-})\,dM_{\pi+\pi-}}$$

Toy phase space MC



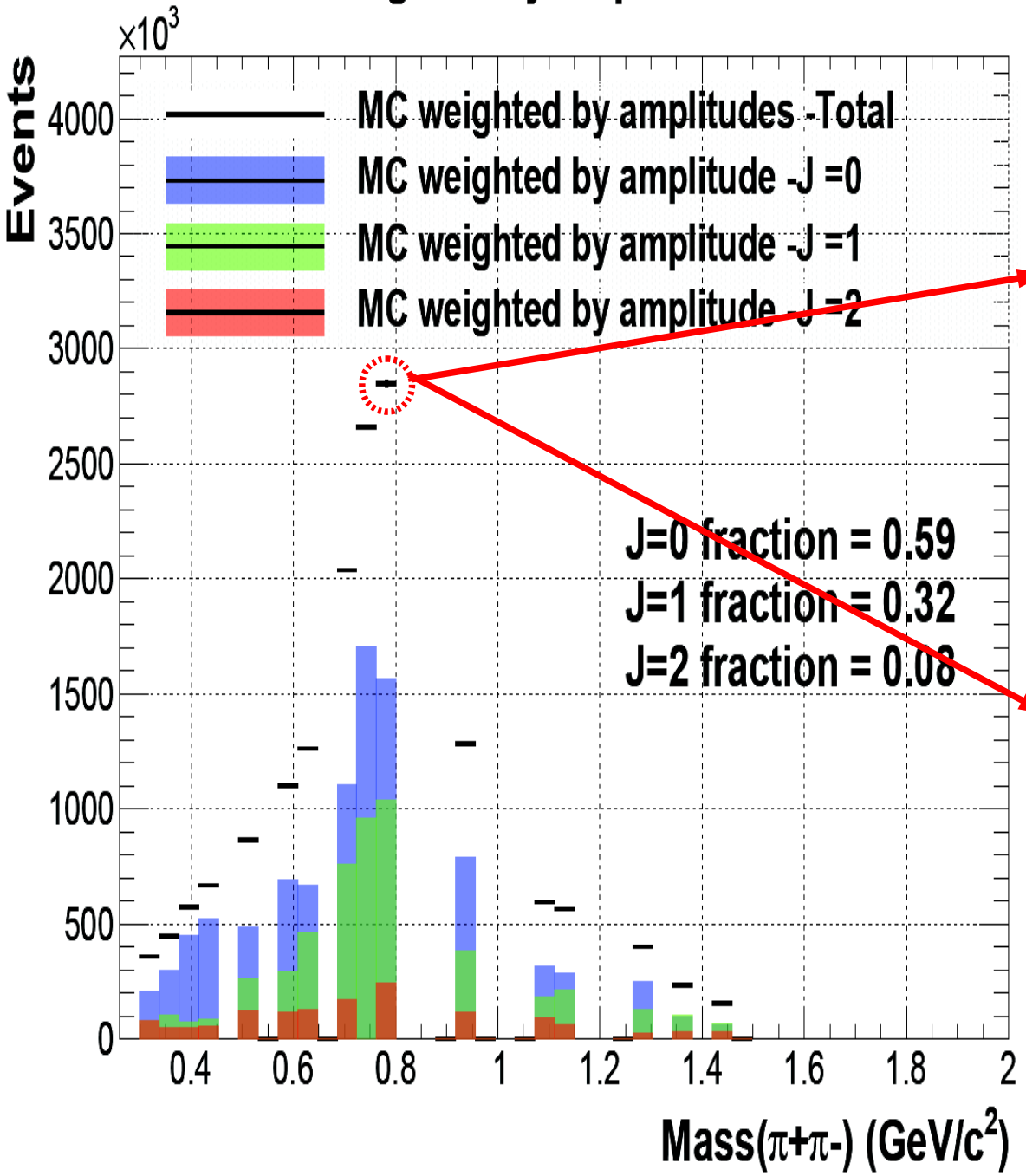
- 3 requirements :
  - Whole phase space covered
  - Uniform decay angular distribution for pion in dipion rest frame
  - Particles generated according to phase space only.

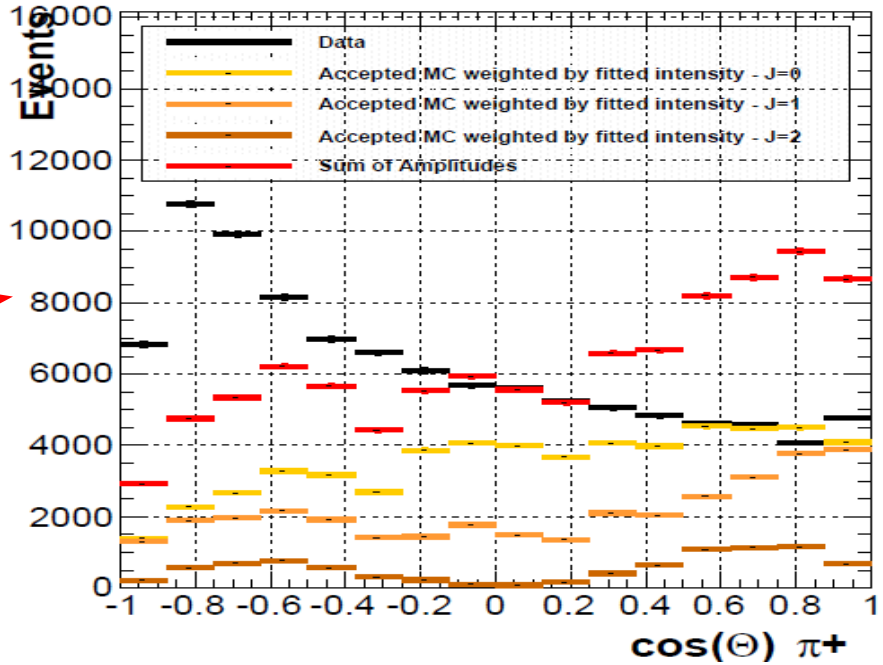


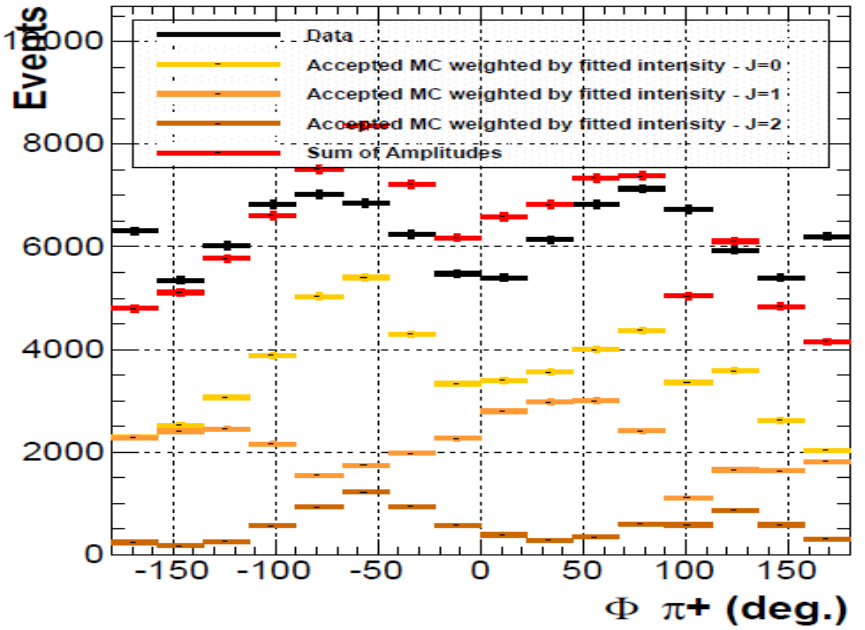


Note : No radiative effects are considered

Fit in helicity frame

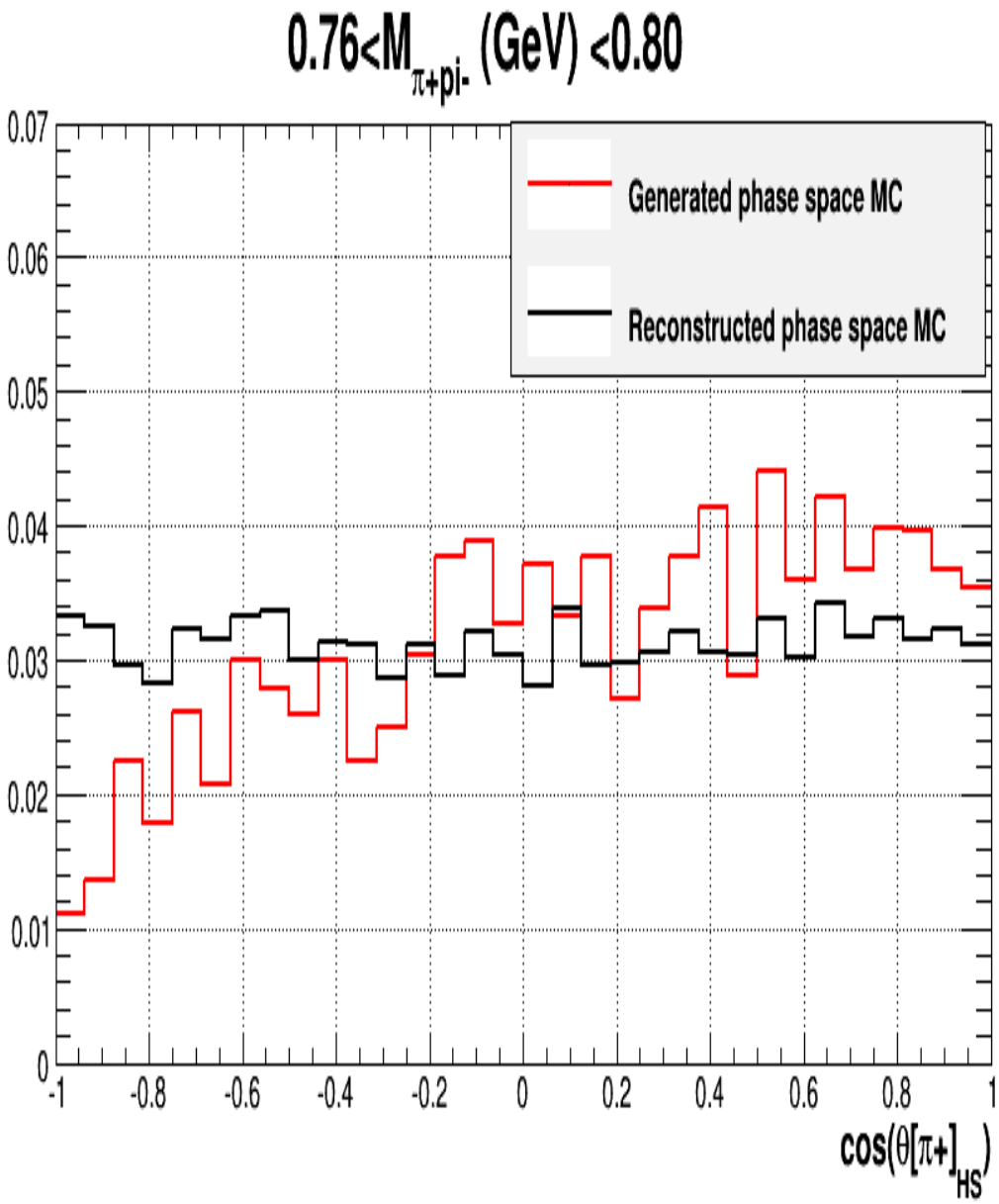






Acceptance for decay angles

Helicity frame



Gottfried-Jackson frame