Deep exclusive π^+ electroproduction off the proton at CLAS

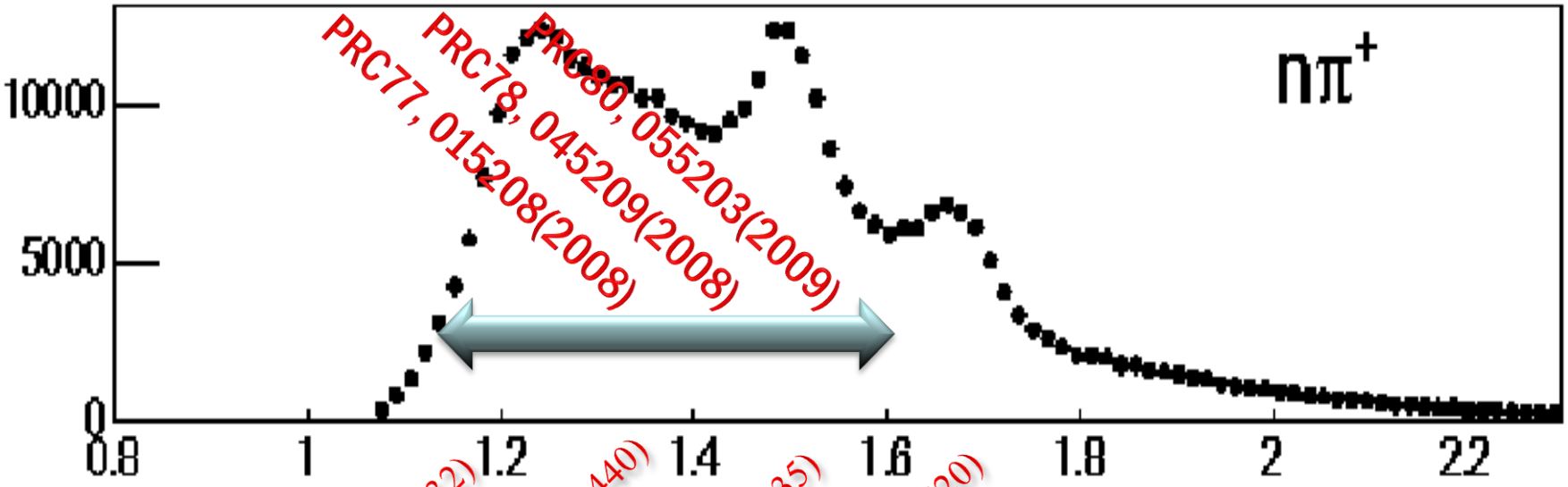
Aug. 13 - 15, 2012
γ*NN* Workshop at USC

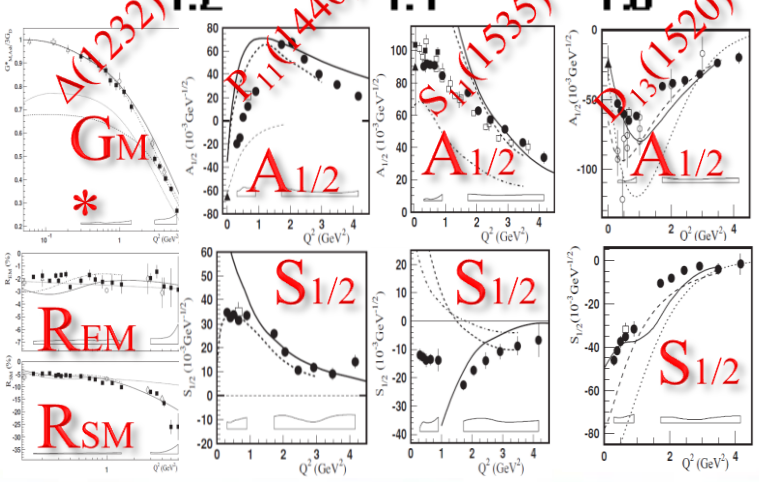
K. Park
Jefferson Lab
Thomas Jefferson National Accelerator Facility

Exclusive single positively charged pion electroproduction off the proton

$Q^2 < 5.0 GeV^2$

from CLAS

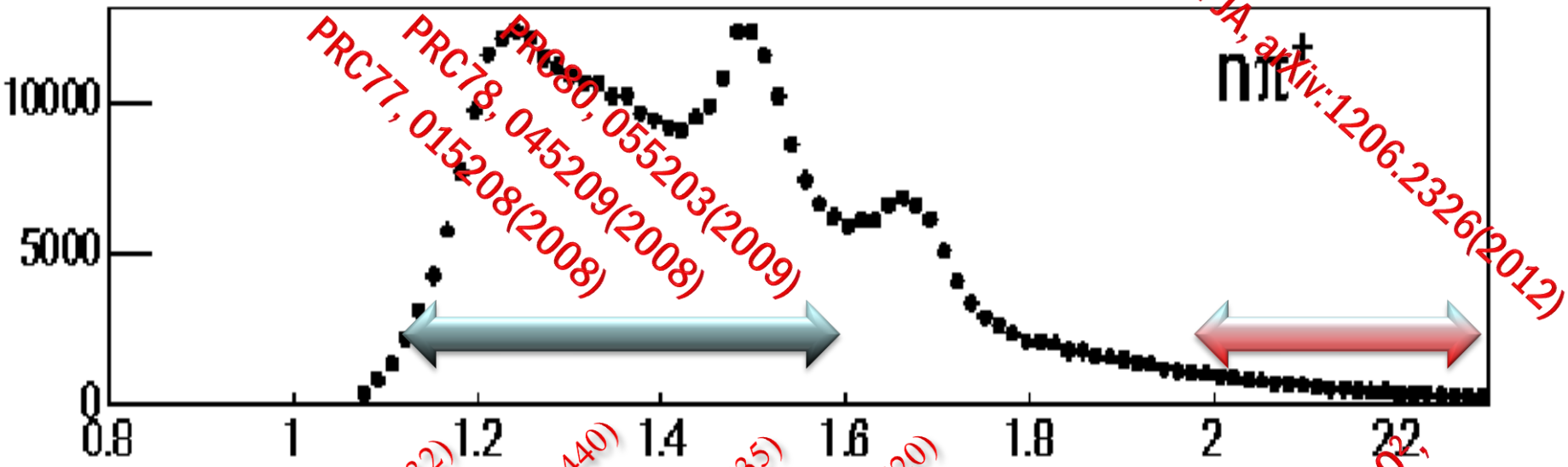


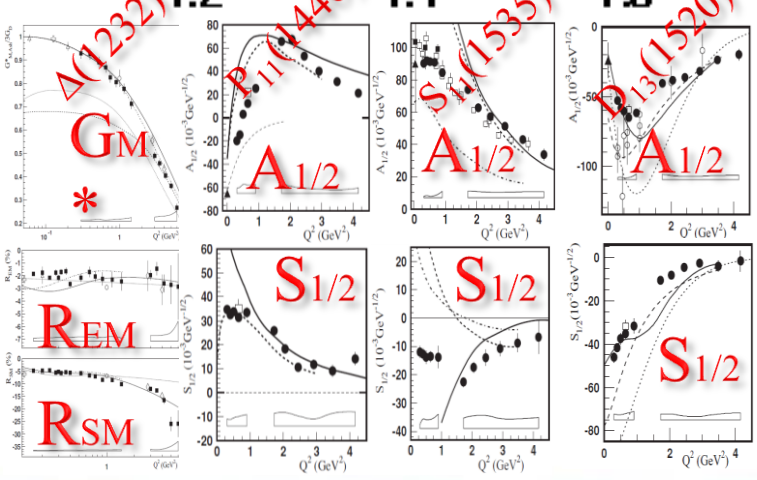


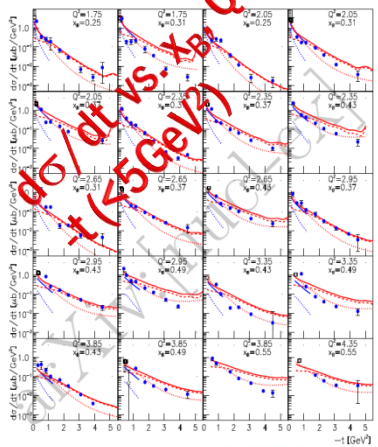
Exclusive single positively charged pion electroproduction off the proton

$Q^2 < 5.0 GeV^2$

from CLAS



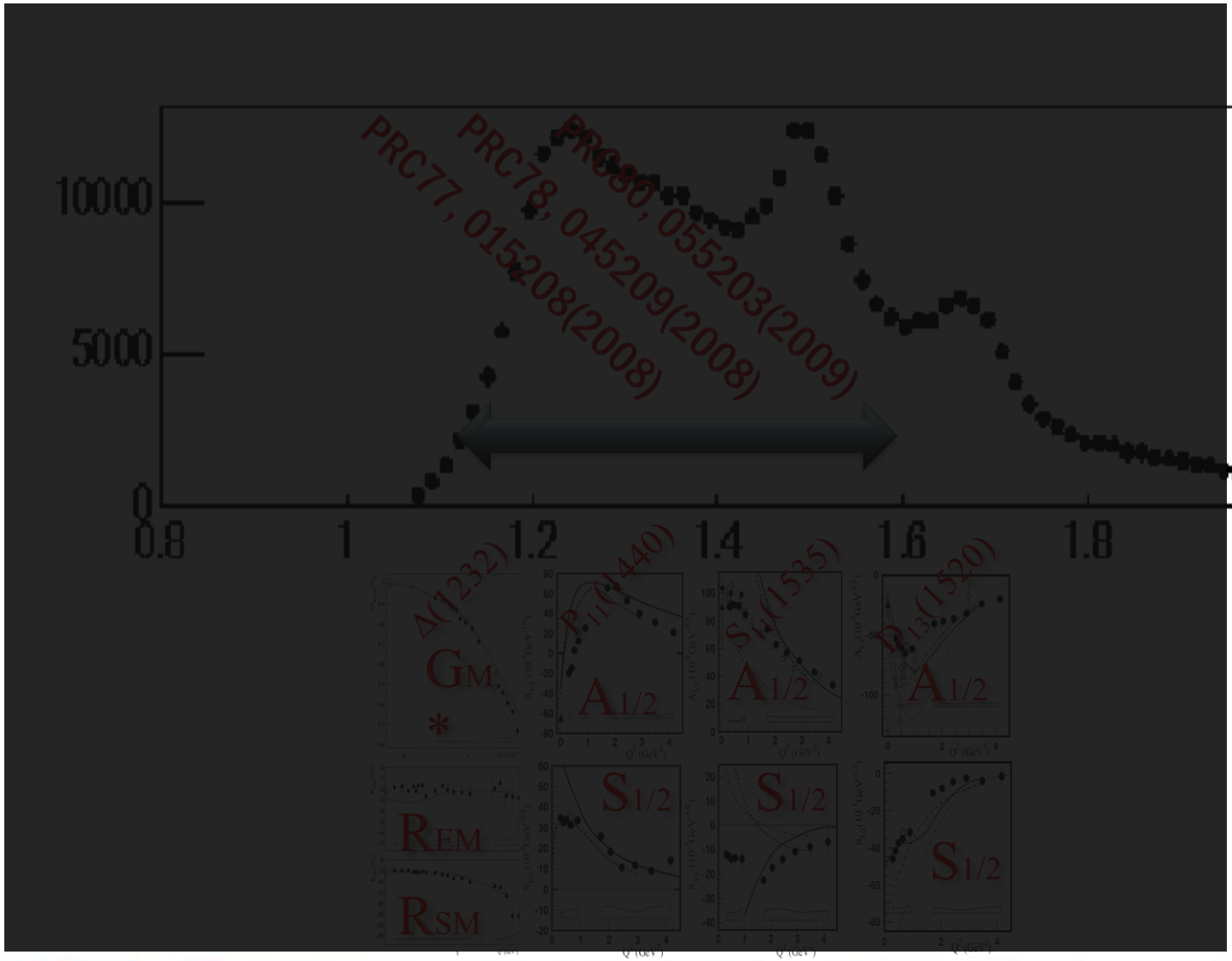


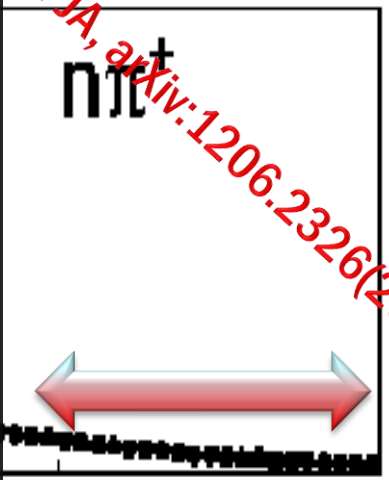


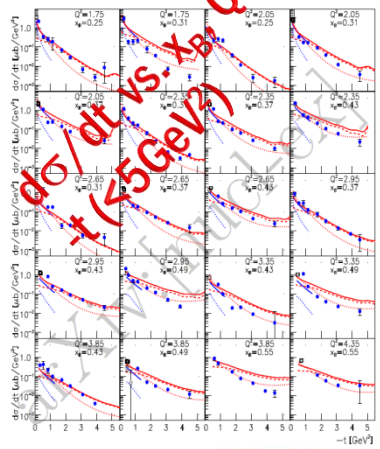
Exclusive single positively charged pion electroproduction off the proton

$Q^2 < 5.0 GeV^2$

from CLAS







Exclusive single positively charged pion electroproduction off the proton

$Q^2 < 5.0 GeV^2$

from CLAS

(1) Transition region

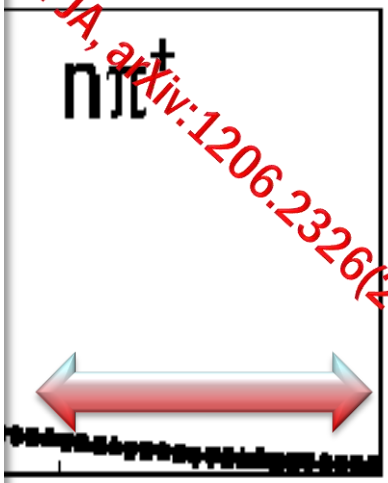
(2) Scaling (s-, Q^2,…)

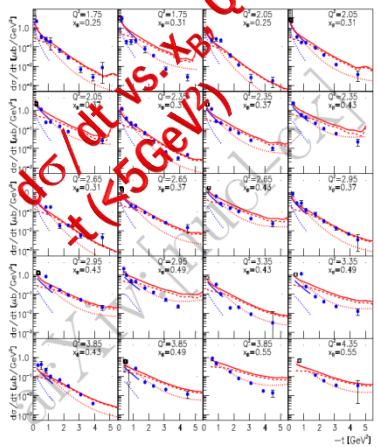
(3) Generalized Parton Distribution

(4) Transition Distribution Amplitude

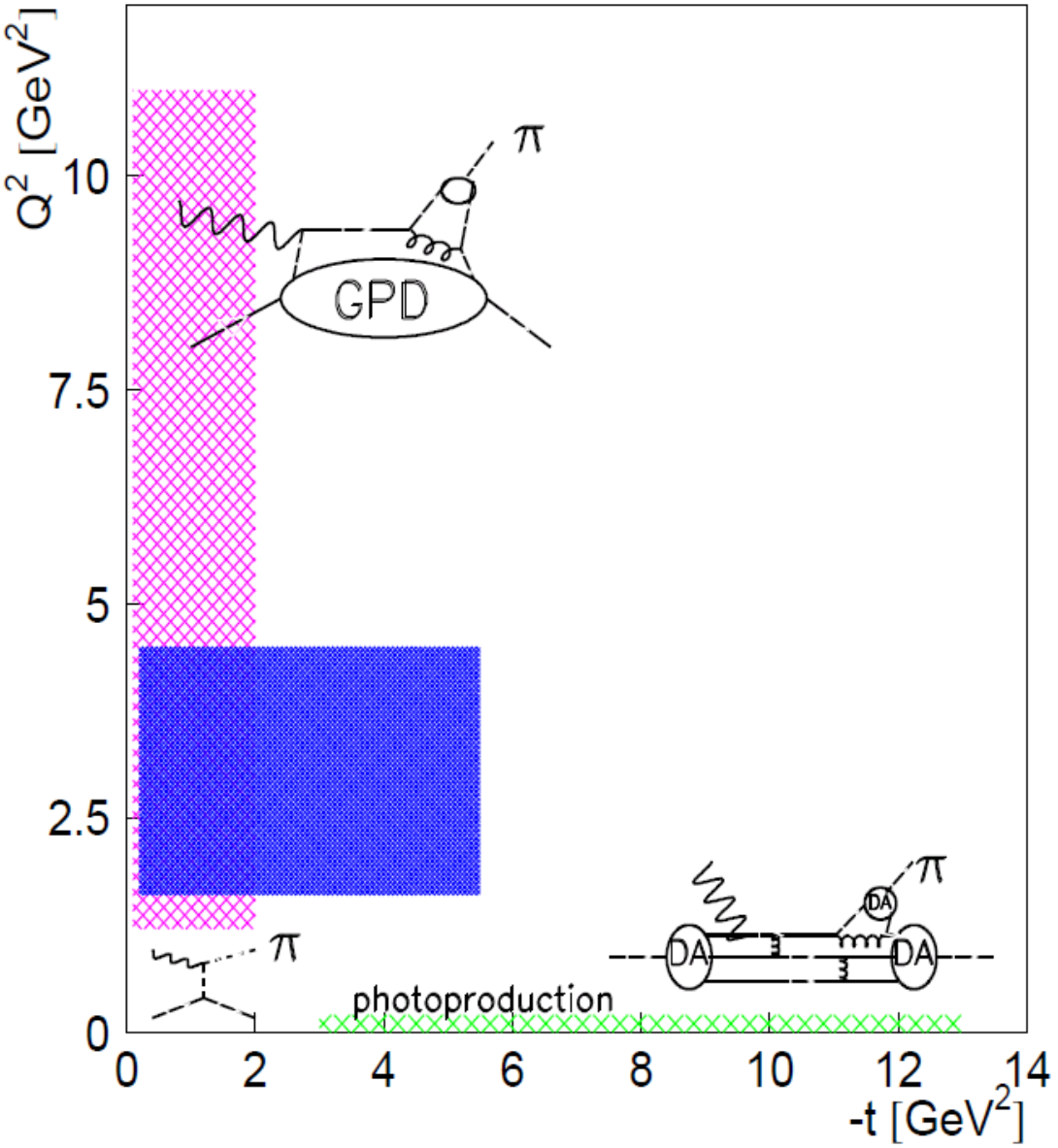
(5) …

EPJA, arXiv:1206.2326(2012)

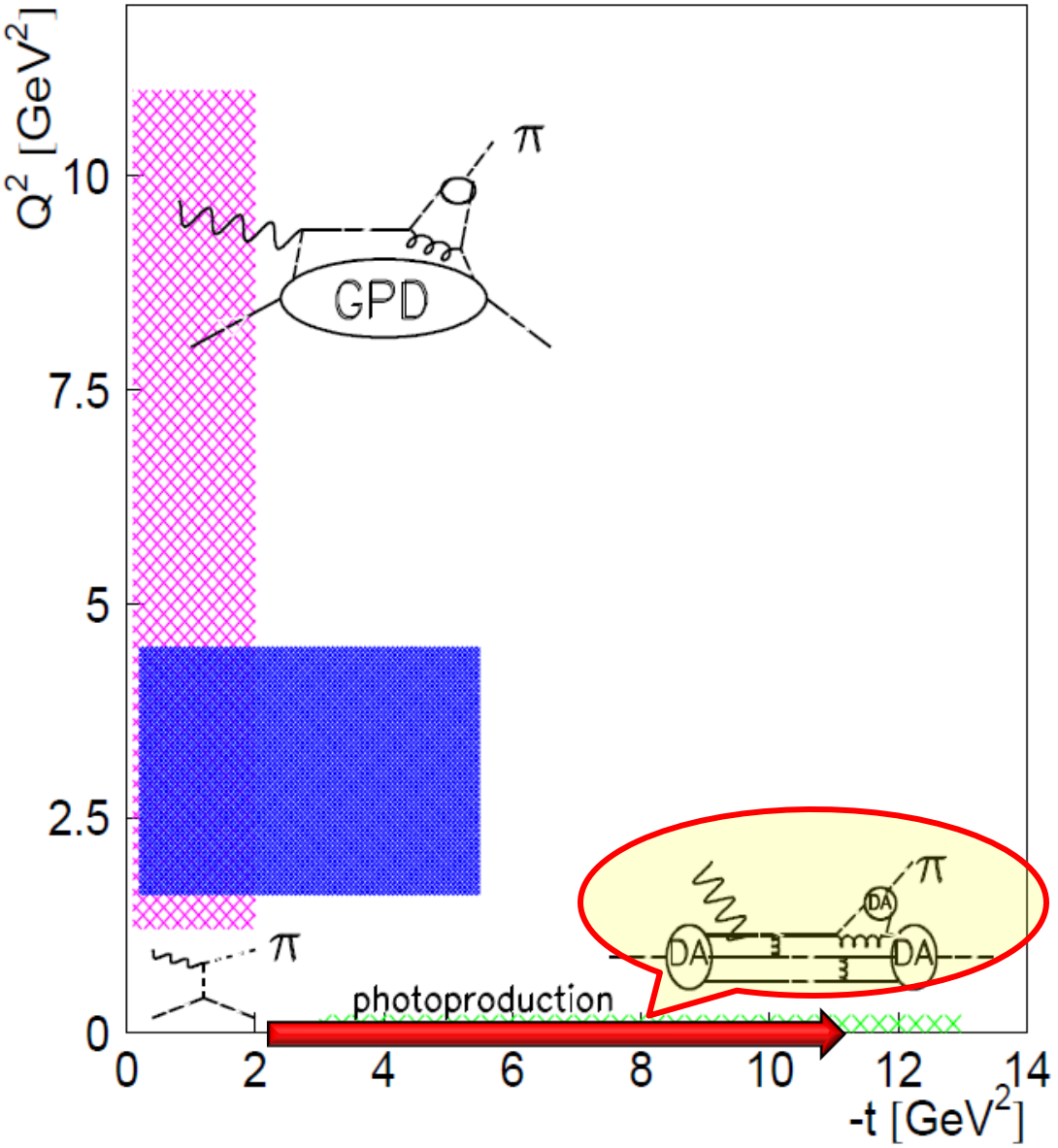




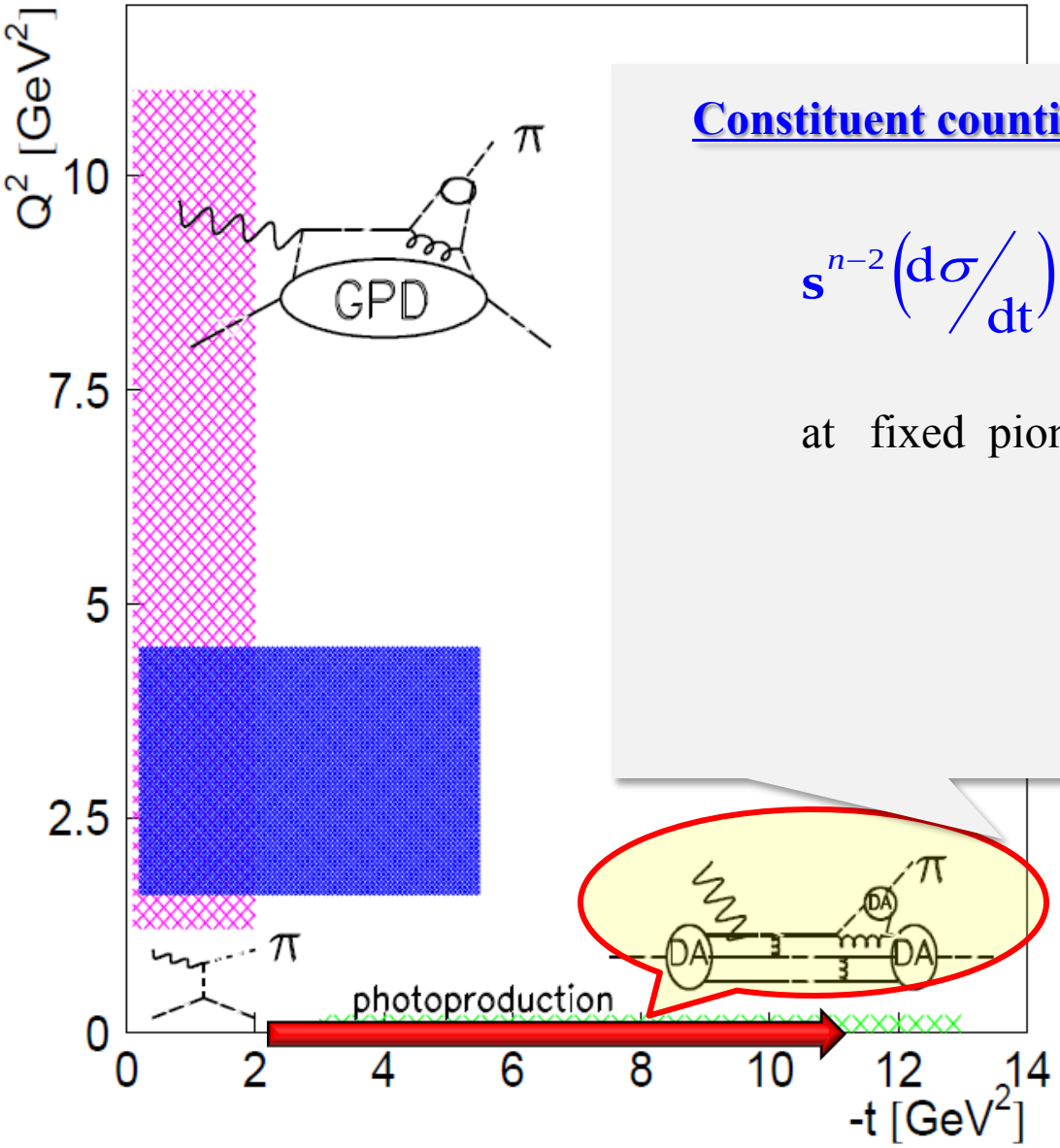
GPD currently…



GPD currently…



GPD currently…



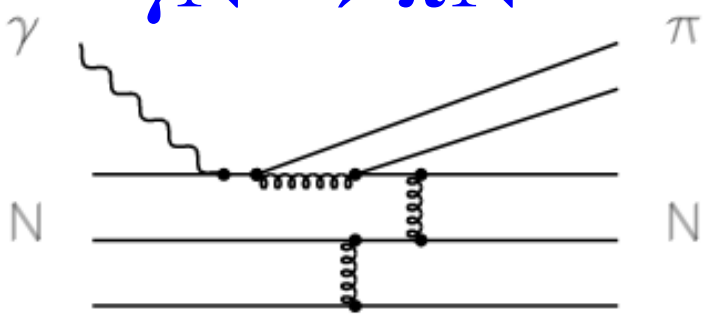
Constituent counting rule (CCR)

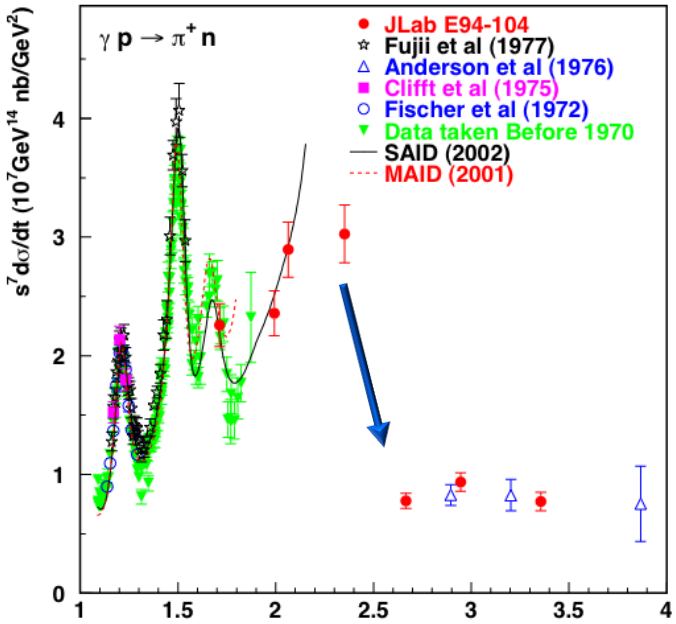
$$s^{n-2}\left(d\sigma/dt\right) \propto const.(s)$$

at fixed pion angle (cms)

Transition observed 90 deg ?

$$\gamma N \rightarrow \pi N$$

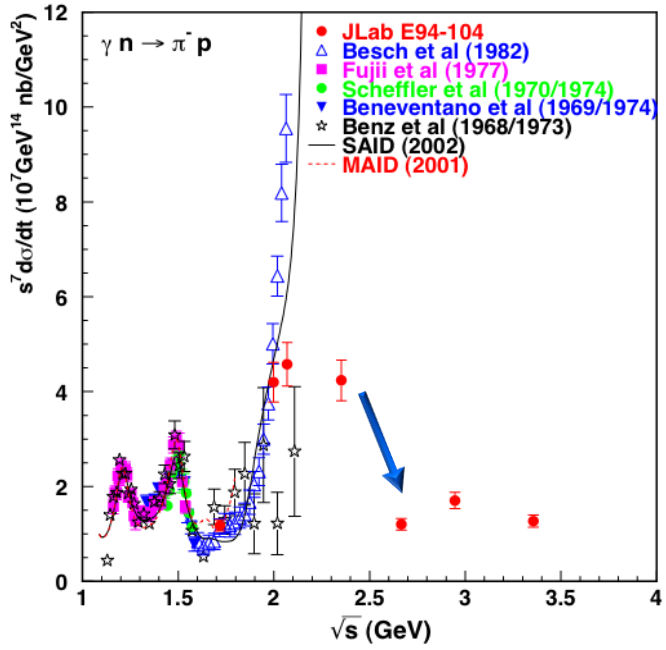




$$\frac{d\sigma}{dt} \propto s^{-2} M^2 \propto s^{-7}$$

$$M_{\text{hel.conserving}} \propto s^{-5/2}$$

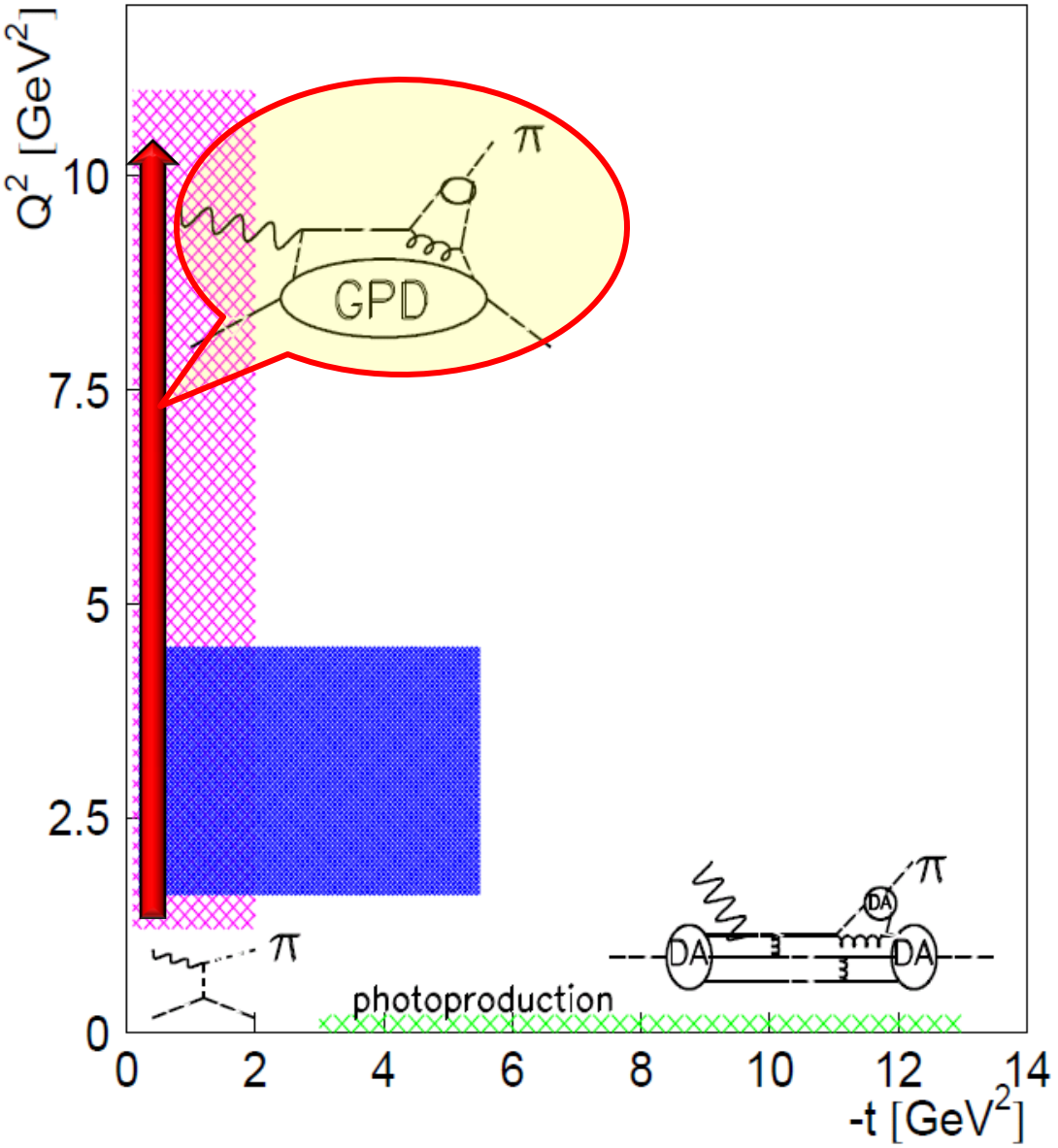
$$M_{\text{hel.flipping}} \propto s^{-3}$$



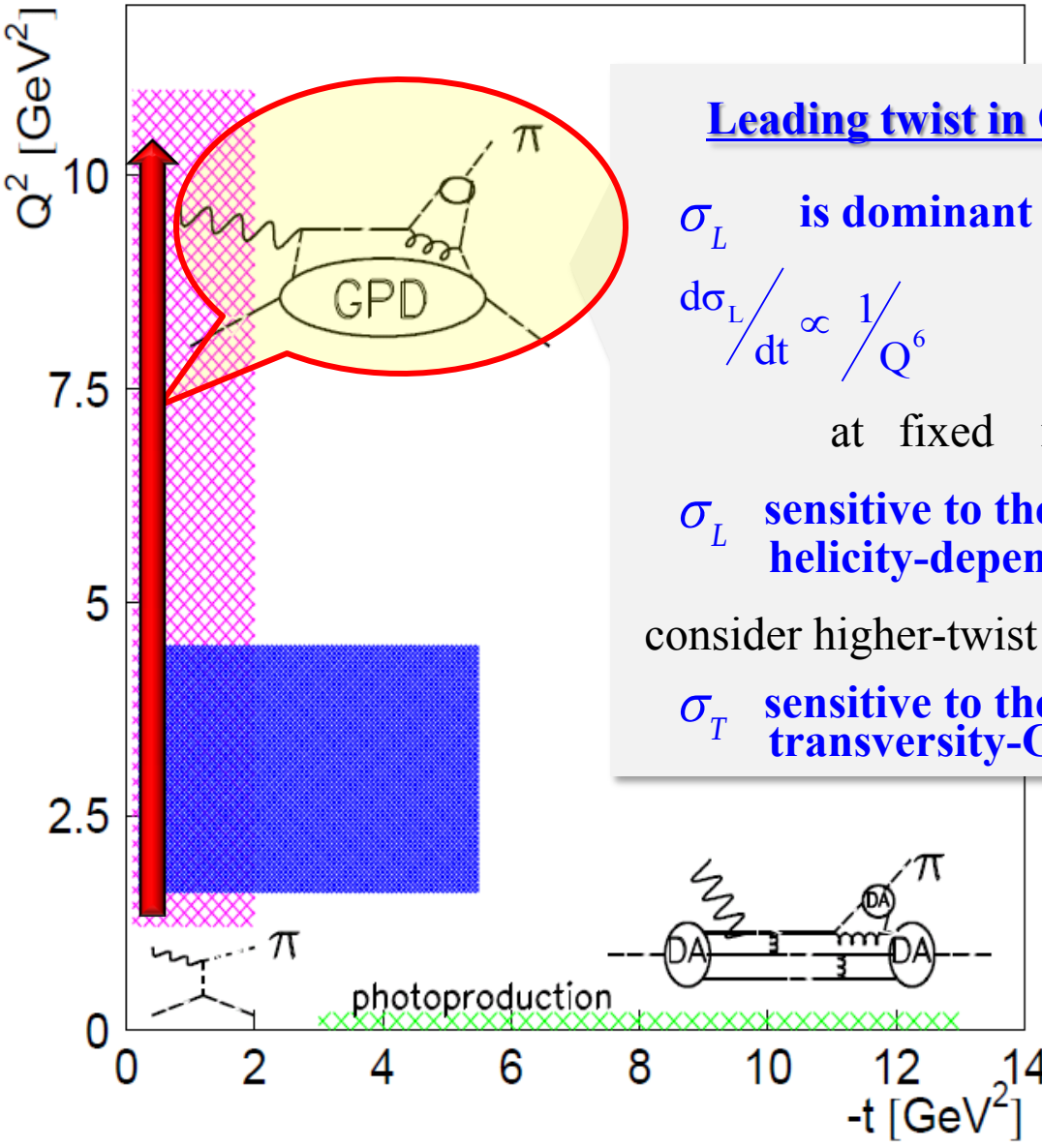
$\gamma N \rightarrow \pi N$; n-2=7

L.Y. Zhu, PRL 91, 022003 (2003)

GPD currently…



GPD currently…



Leading twist in QCD for π^+

σ_L **is dominant over** σ_T

$$d\sigma_L/dt \propto 1/Q^6 \qquad d\sigma_T/dt \propto 1/Q^8$$

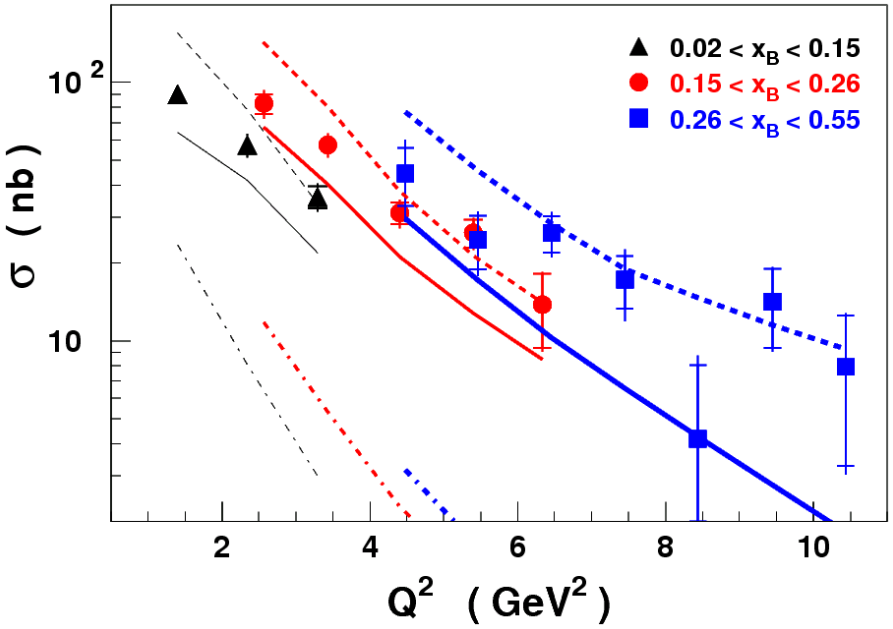
at fixed x_B and $|t|$

σ_L **sensitive to the helicity-dependent GPD** $\tilde{E}$ $\tilde{H}$

consider higher-twist effect

σ_T **sensitive to the transversity-GPD** $\bar{E}_T$ H_T

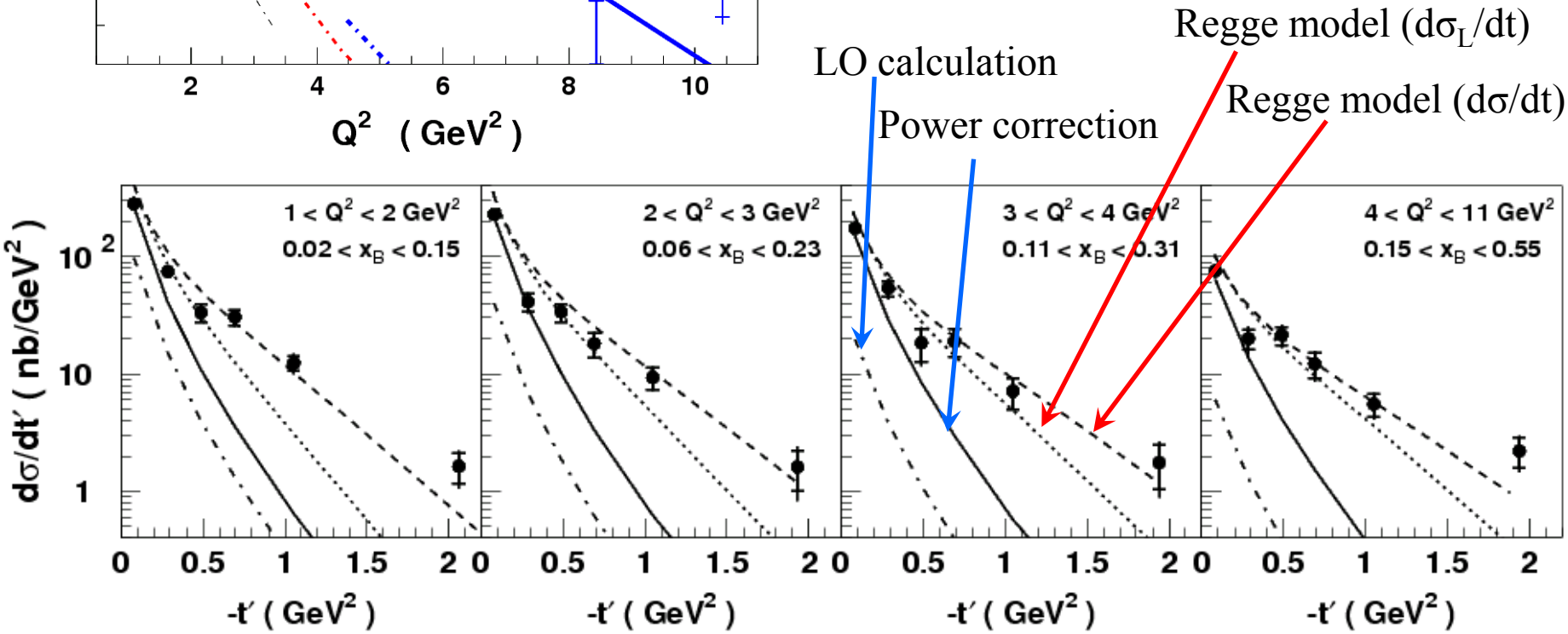
World Data …(HERMES)



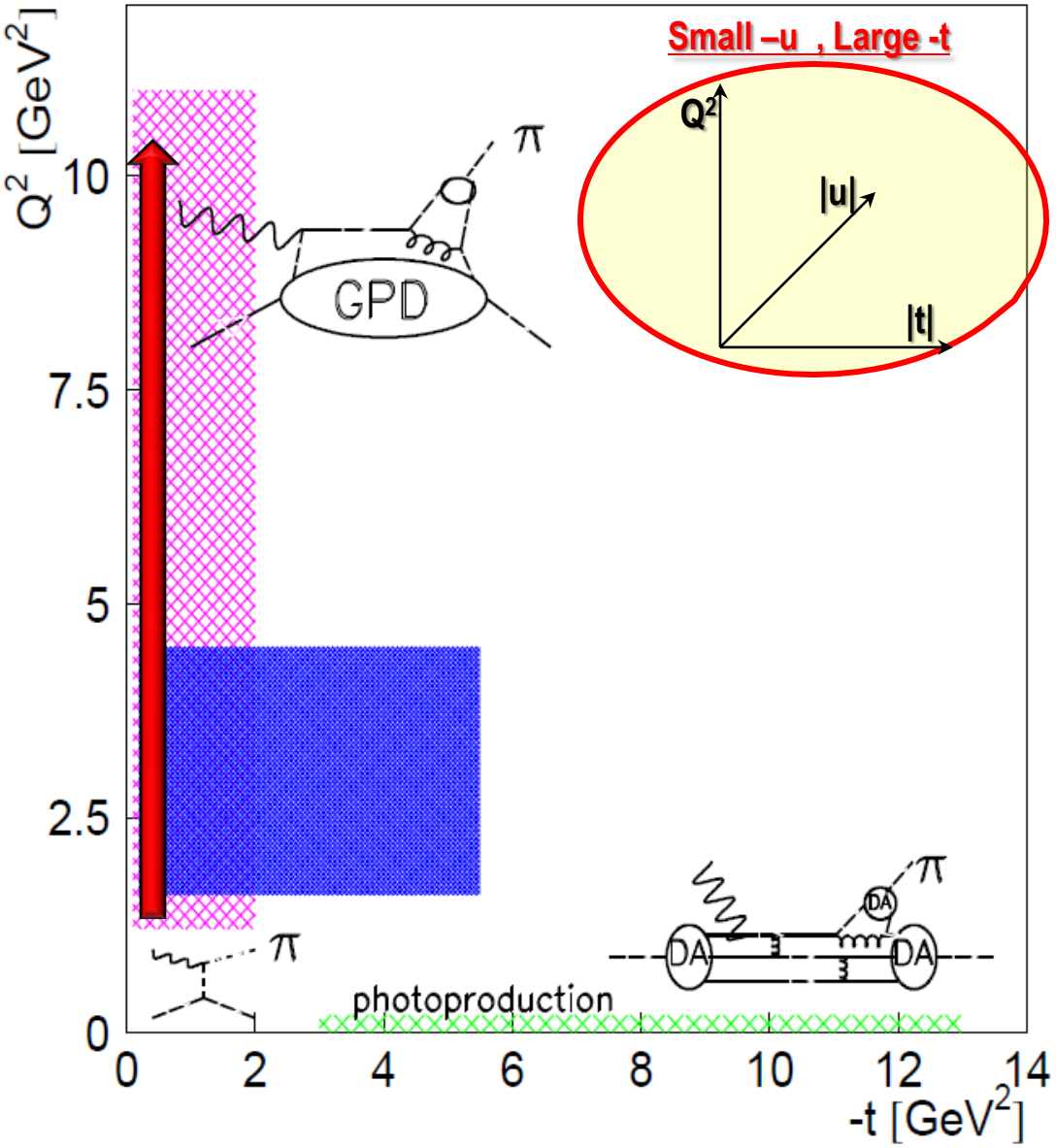
A. Airapetian *et al.*, HERMES collaboration
Phys.Lett.B 659, 486-492 (2008).
arXiv:0707.0222v1 (2007).

GPD Model

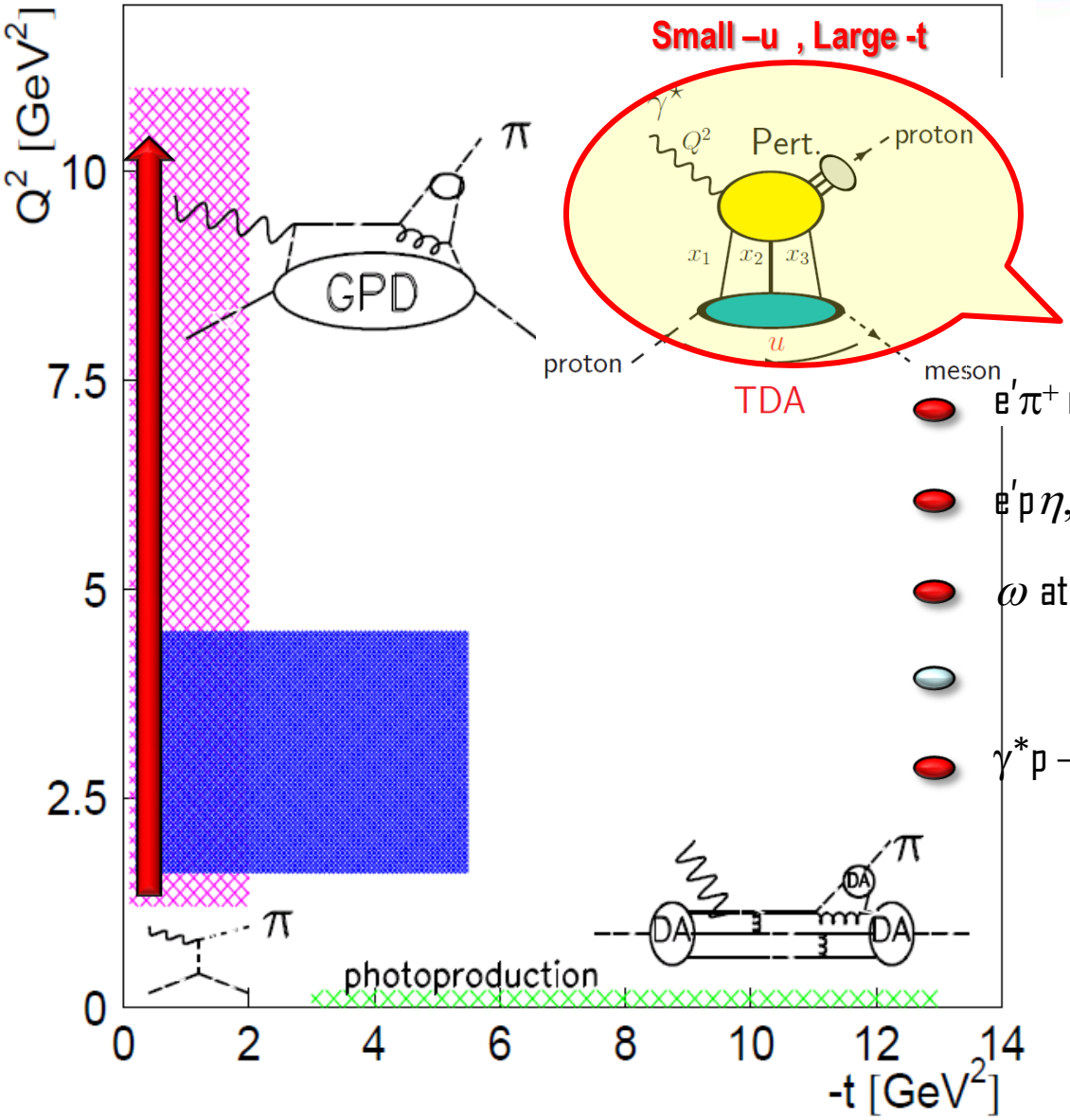
Vanderhaeghen, Guichon, Guidal (1999)



GPD currently…



GPD currently…



Baryonic TDA

- e′π⁺ n — u << , t >> @ CLAS
- e′p η, e′pπ⁰ — @ CLAS
- ω at 180° — @ Hall-C
- JLAB 12GeV
- γ*p → pJ/ψ — @ COMPASS

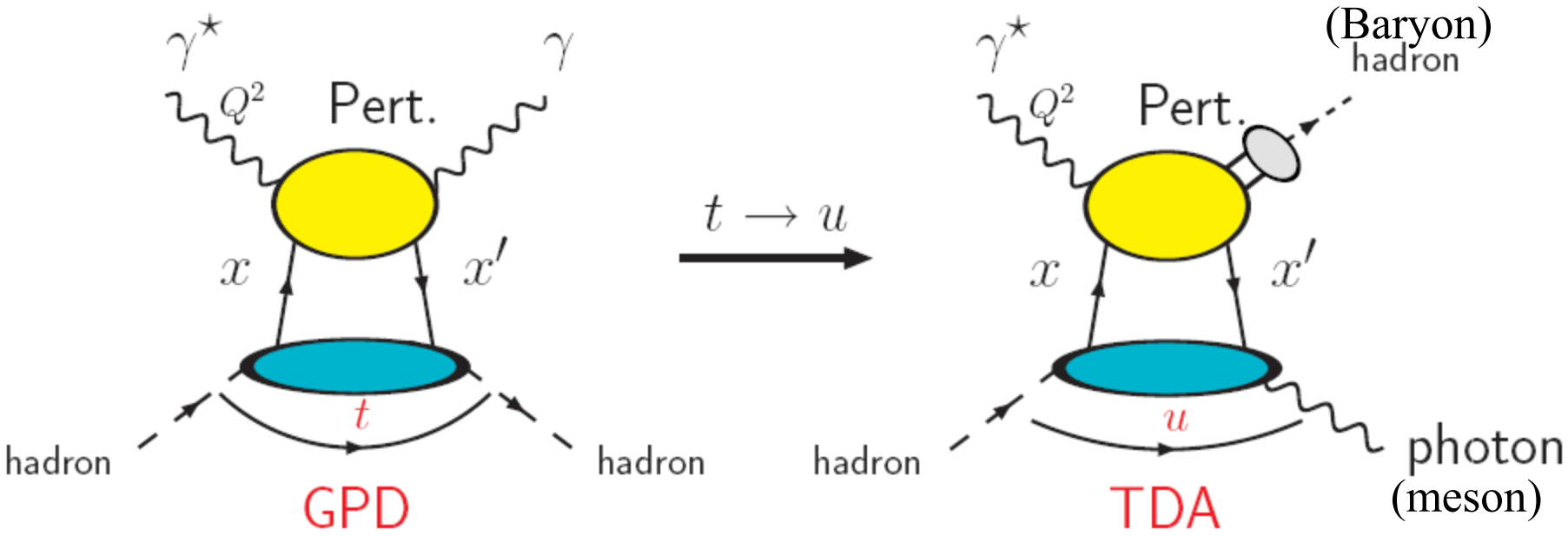
Transition Distribution Amplitude

At, small |u| << $\Delta_T^2 << Q^2$

Non-perturbative can not describe **H → H transition**

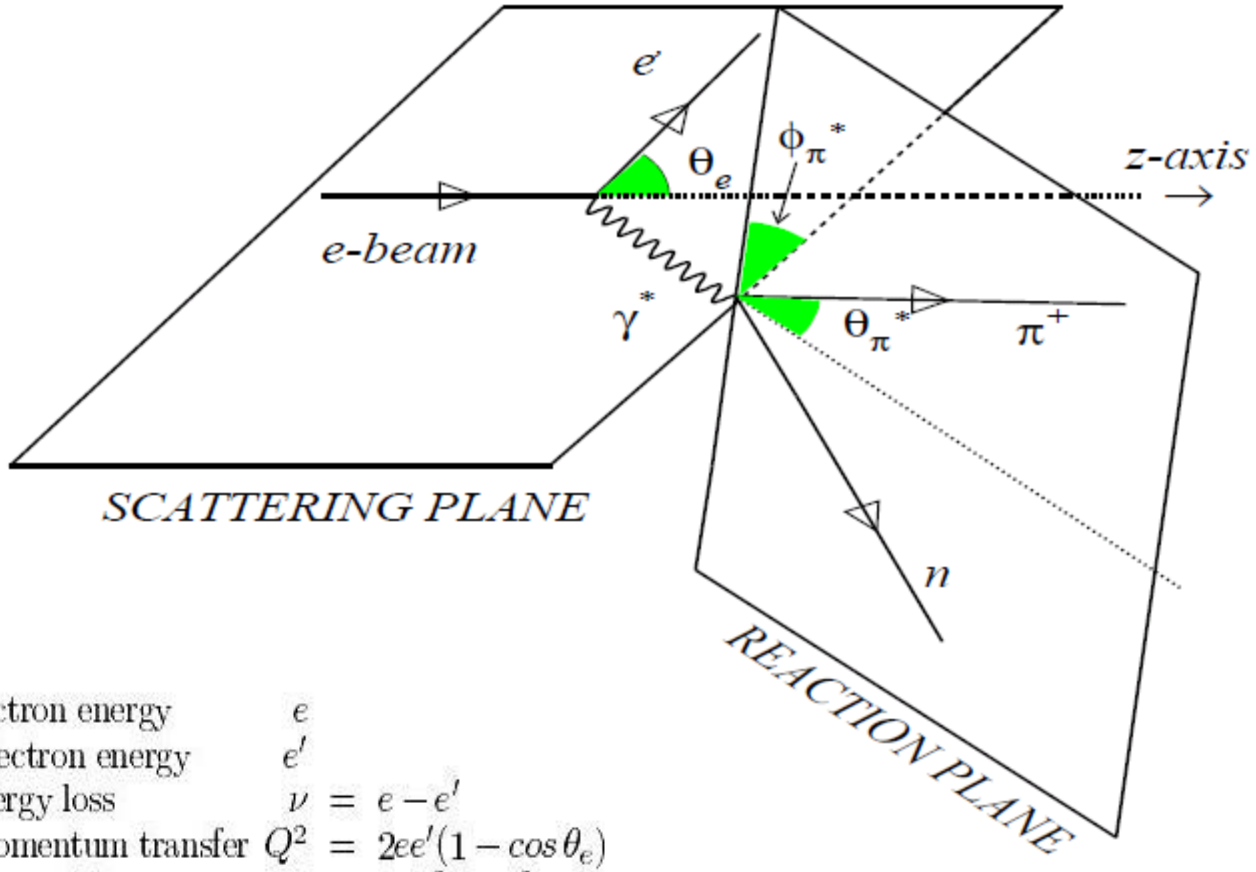
Baryon → γ transition

Baryon →π transition



B. Pire, K. Semenov-Tian-Shansky, L. Szymanowski, PRD 82, 094030 (2010).
J.P. Lansburg, B. Pire, L. Szymanowski, PRD 75, 074004 (2007).

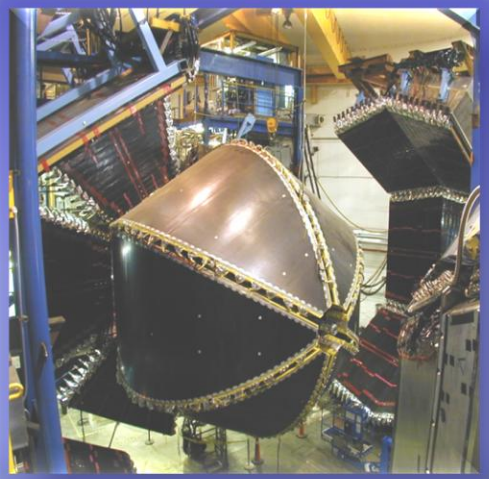
Reaction



Incident electron energy	e	
Scattered electron energy	e'	
Electron energy loss	ν	$= e - e'$
Invariant momentum transfer	Q^2	$= 2ee'(1 - \cos\theta_e)$
Invariant mass of final state	W	$= -Q^2 + m_p^2 + 2m_p\nu$
Virtual photon 3-momentum	$\lvert\vec{q}\rvert$	$= (Q^2 + \nu^2)^{1/2}$

Experimental data /kinematic bin (el-6)

- Oct.,2001 ~ Jan., 2002
- E0 =5.754GeV (pol. e), LH2 target
- target position = 4cm upstream
- Length = 5cm, Φ= 6mm
- I_B = 3375A
- Trigger = ECin x ECtot x CC

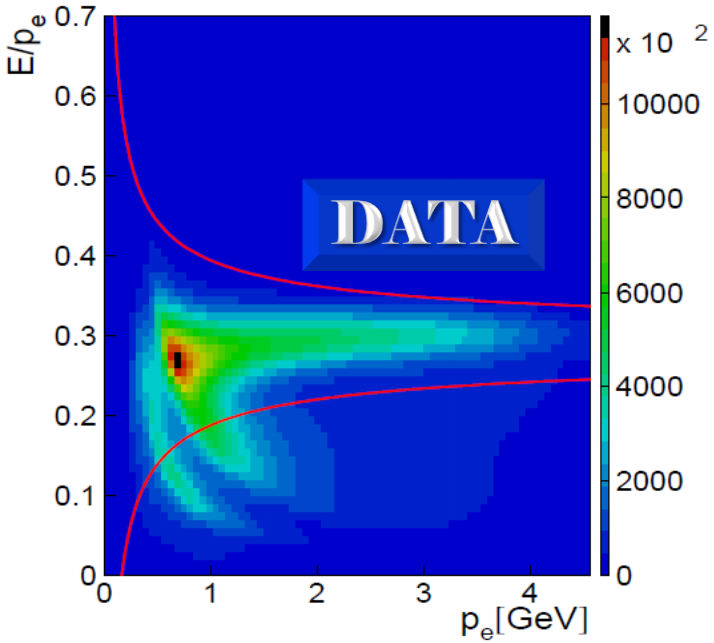


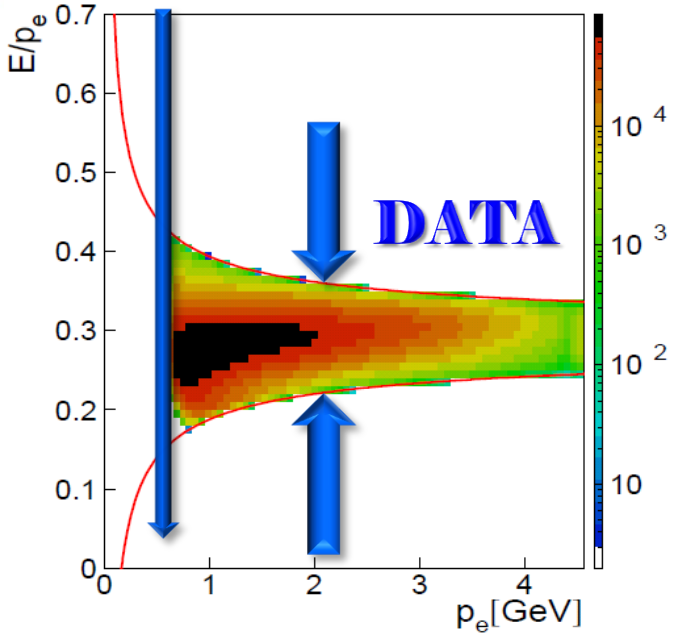
Variable	Number of bins	Range	Bin size
x_B	7	0.16 - 0.58	0.06
Q^2	5	1.6 - 3.1 GeV^2	0.3 GeV^2
	3	3.1 - 4.5 GeV^2	0.5 GeV^2
$-t$	6	0.1 - 1.9 GeV^2	0.3 GeV^2
	3	1.9 - 4.3 GeV^2	0.8 GeV^2
	1	4.3 - 5.3 GeV^2	1.0 GeV^2

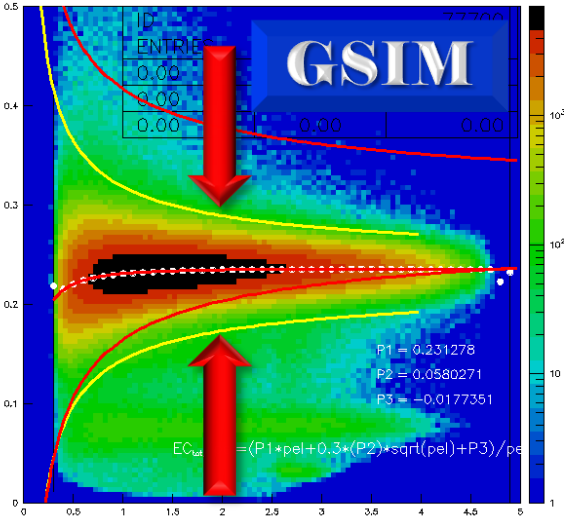
Analysis - PID electrons

PID (e)

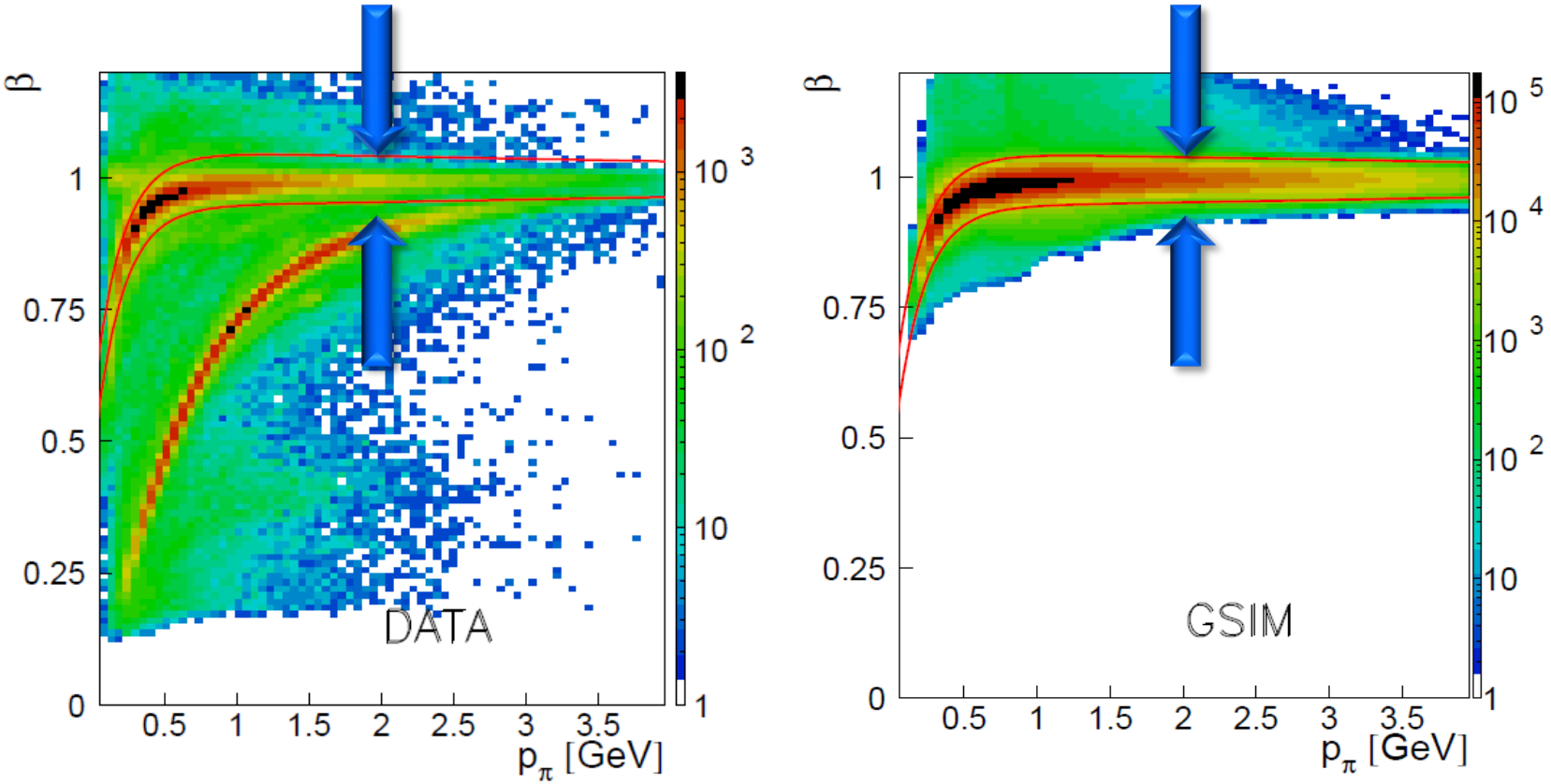
EC/CC cuts



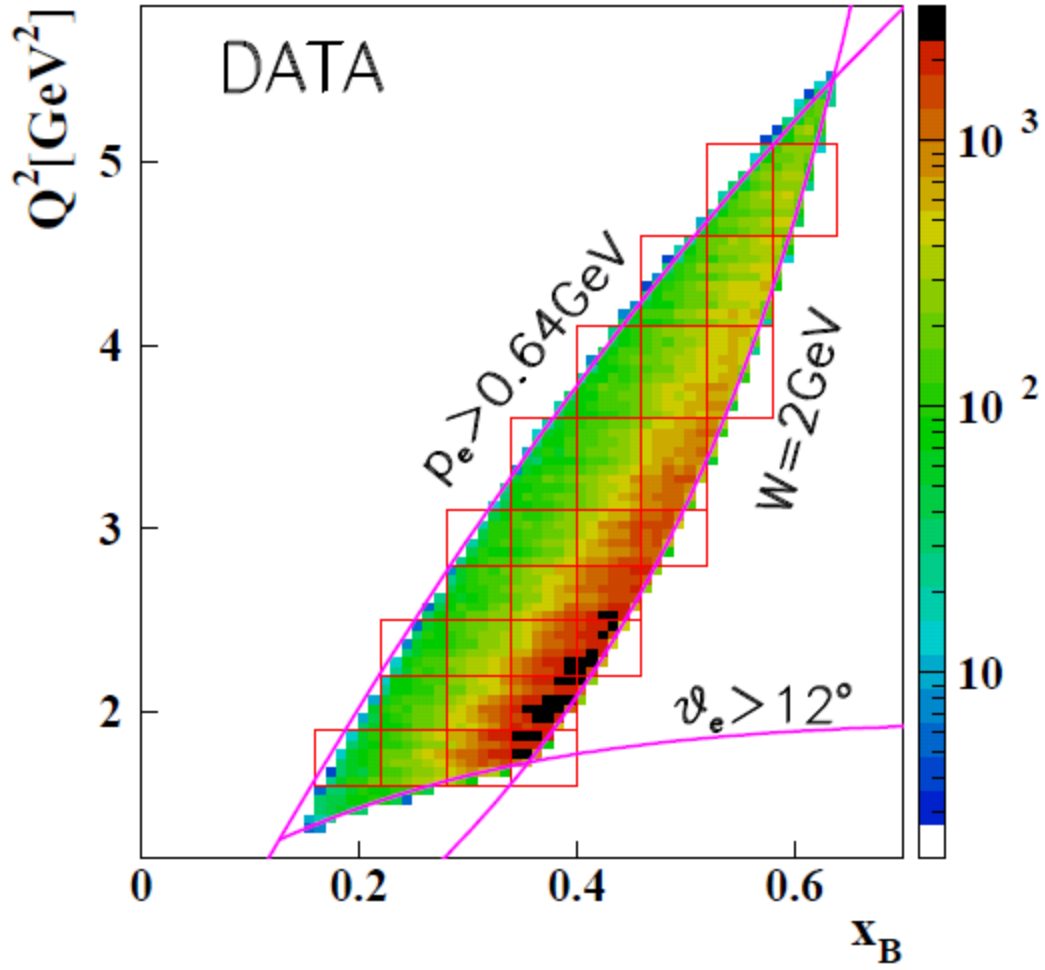


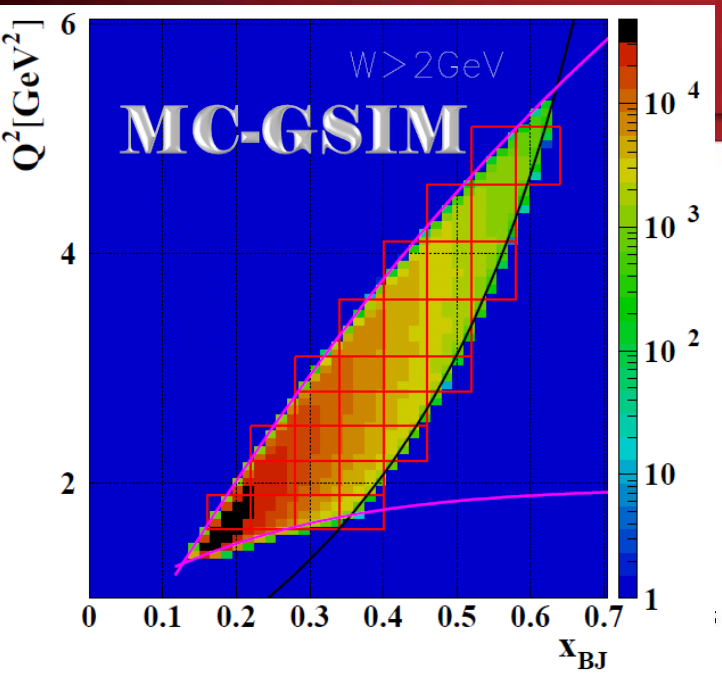


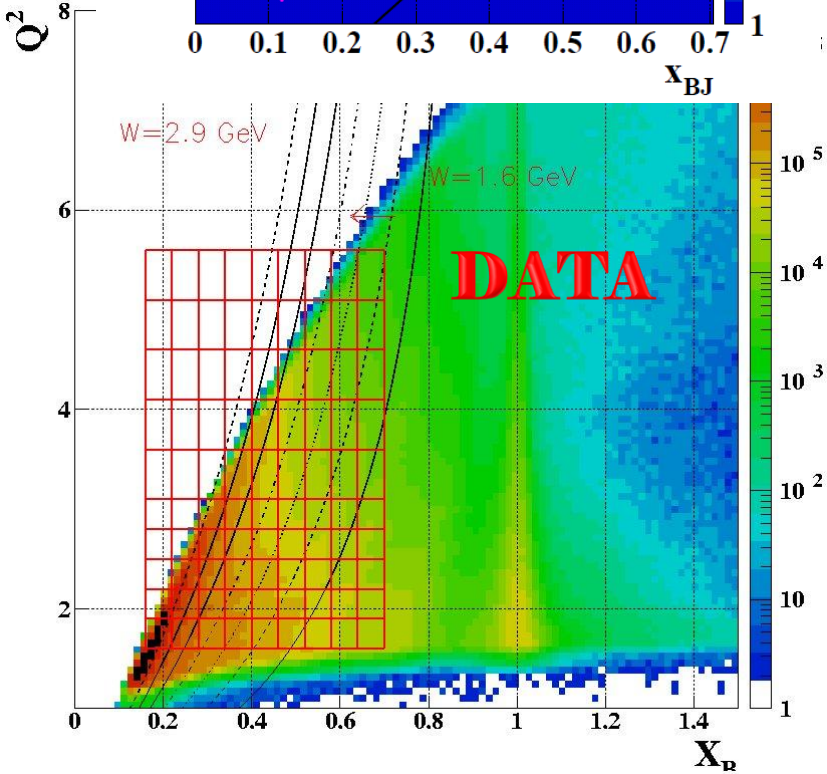
PID (π^+) – TOF/DC


β
1
0.75
0.5
0.25
0
0.5
1
1.5
2
2.5
3
3.5
p_π [GeV]
DATA
10^3
10^2
10
1
GSIM
10^5
10^4

Kinematic coverage

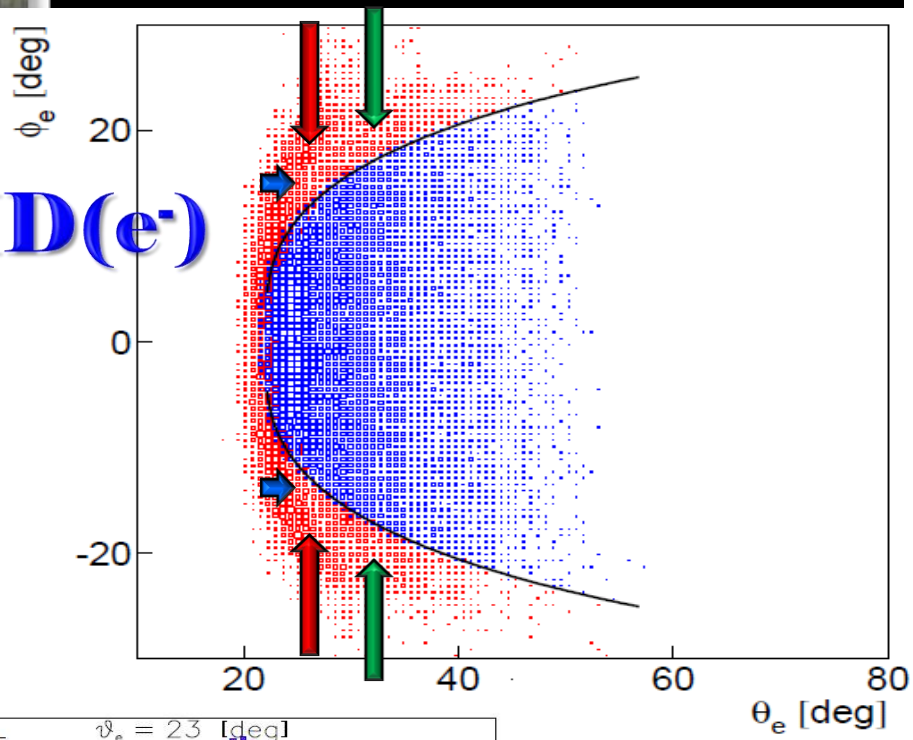


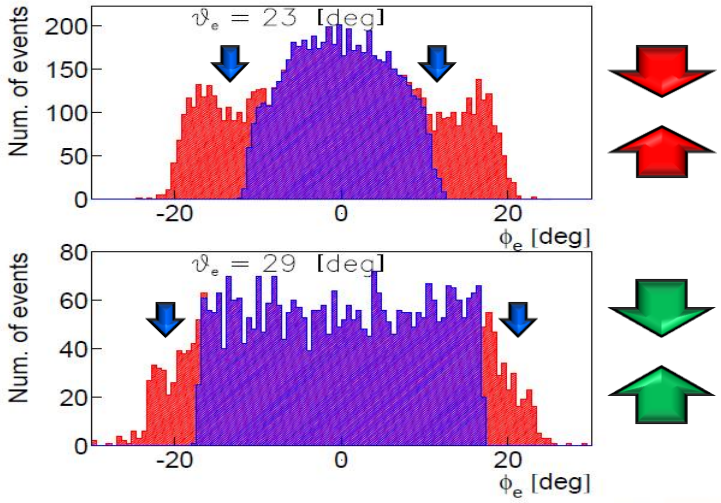




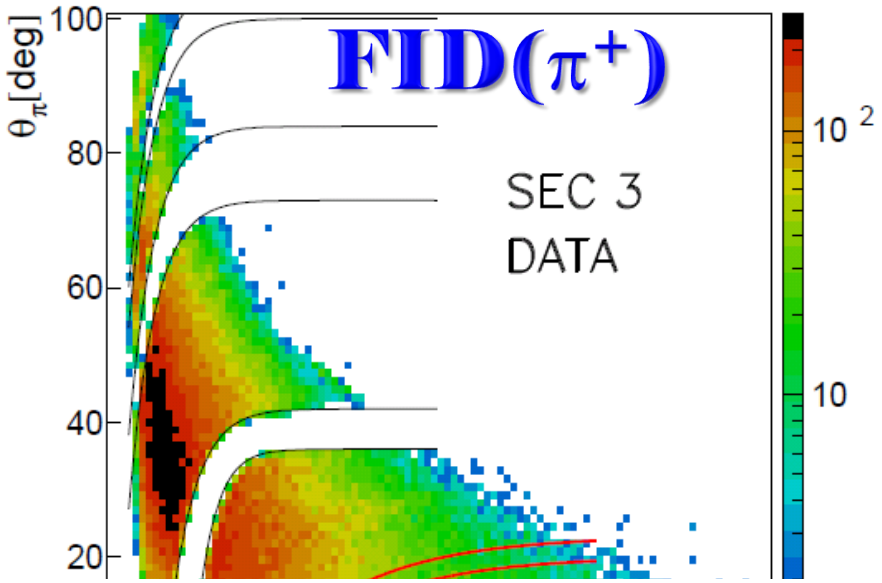
Analysis - fiducial cuts

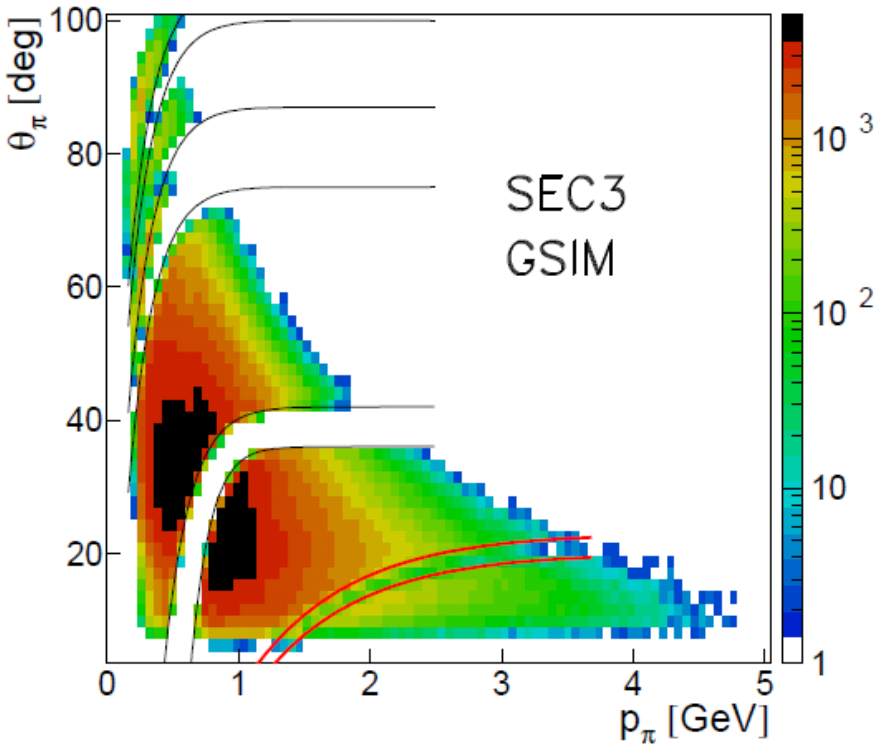
FID(e^-)





FID(π^+)





MC – GSIM (acceptances)

- **~850M event generated**
- **Reconstruction under same cuts as data**
- **calculate the Acc as function of Q^2, x_B, -t, and φ^***

1. Exclusive, Semi-inclusive channels have been compared
2. Missing mass cut applied : 3.5σ cut from mmx resolution (~20MeV)

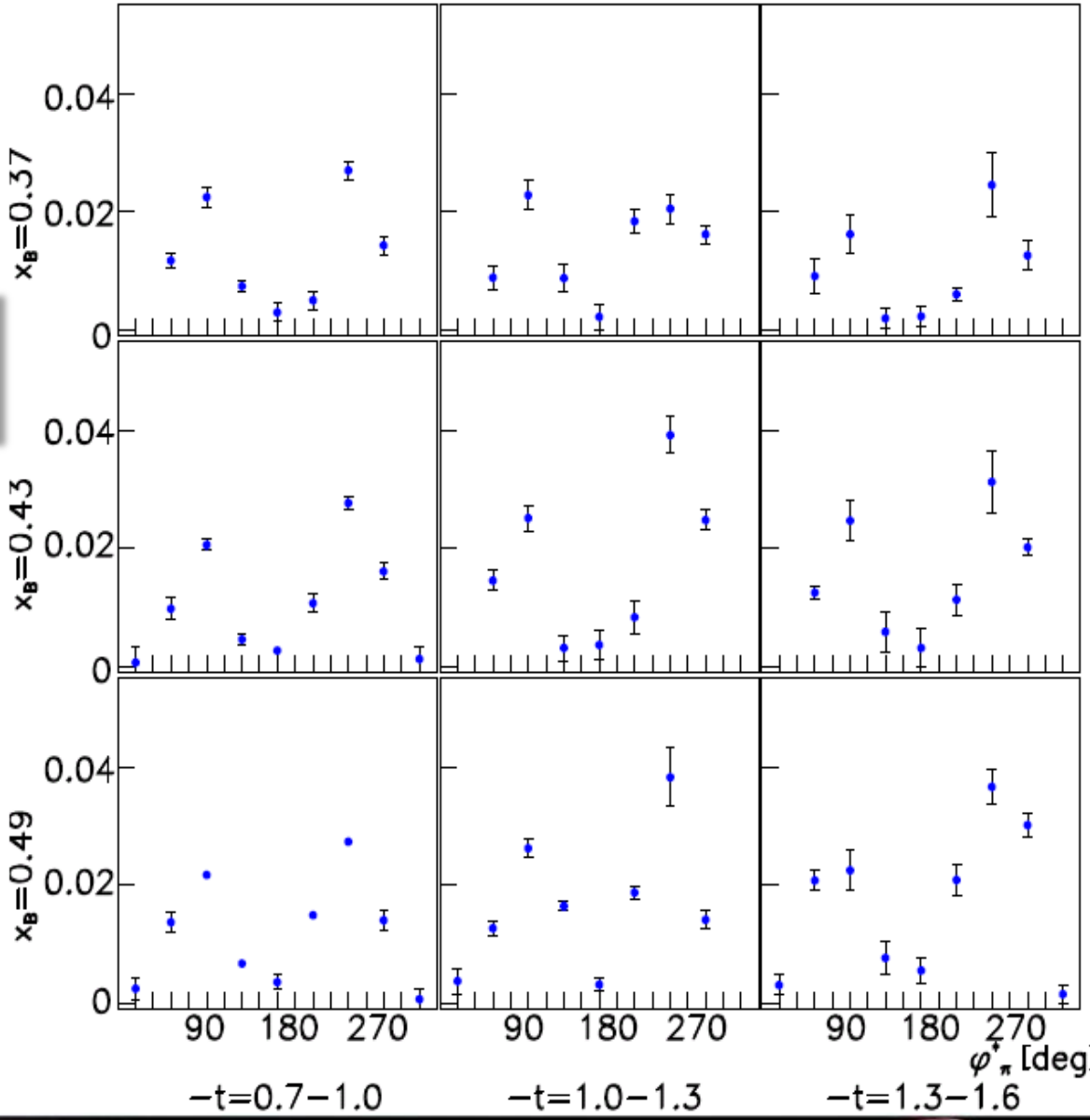
1. Exclusive : including reaction = $n\pi^+$
2. Semi-inclusive : including reactions = $n\pi^+$, $\Delta^{++}\pi^-$, $\Delta^+\pi^0$, $\Delta^0\pi^+$, $\rho^0 p$, $\rho^+ n$, $p\pi^+\pi^-$, $n\pi^0\pi^+$, ωp, $p\pi^+\pi^-\pi^0$, $n\pi^+\pi^+\pi^-$, φp, $p\pi^+\pi^+\pi^-\pi^-$, $p\pi^+\pi^+\pi^-\pi^-\pi^0$, $n\pi^+\pi^+\pi^+\pi^-\pi^-$

Acceptance corrections

$$Acc(x_B, Q^2, -t, \phi_\pi^*) = \frac{N^{REC}(x_B, Q^2, -t, \phi_\pi^*)}{N^{GEN}(x_B, Q^2, -t, \phi_\pi^*)}$$

N^{REC} the number of reconstructed particles

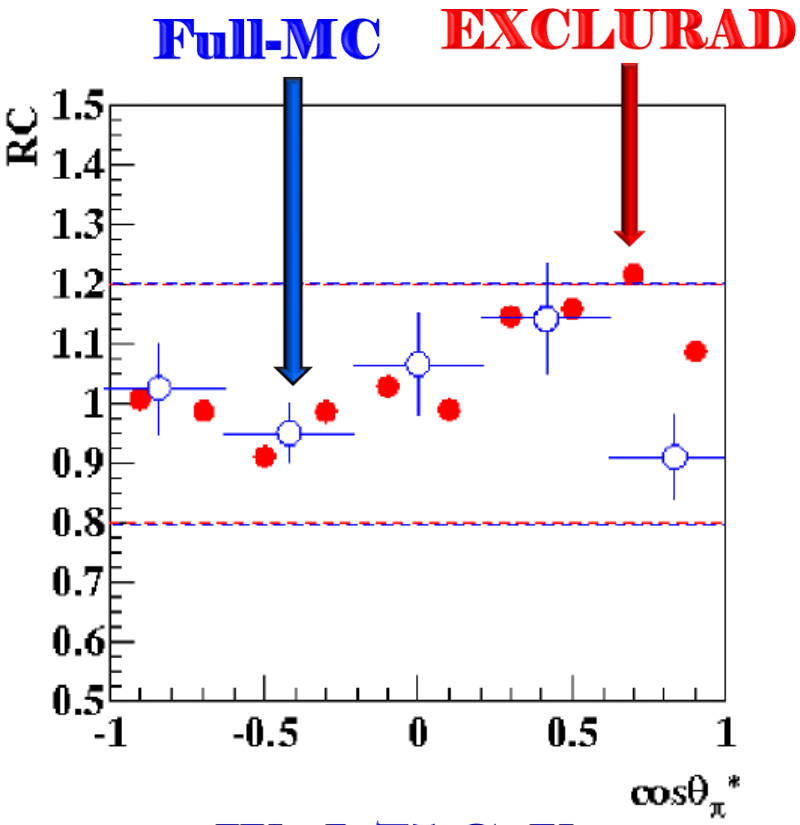
N^{GEN} the number of generated particles



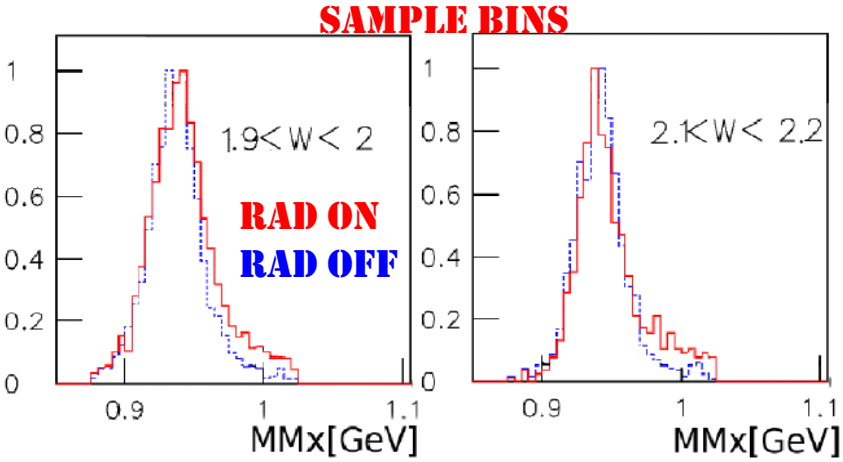
Fact(s)

(1) No model support to EXCLURAD for radiative correction (W<2GeV)

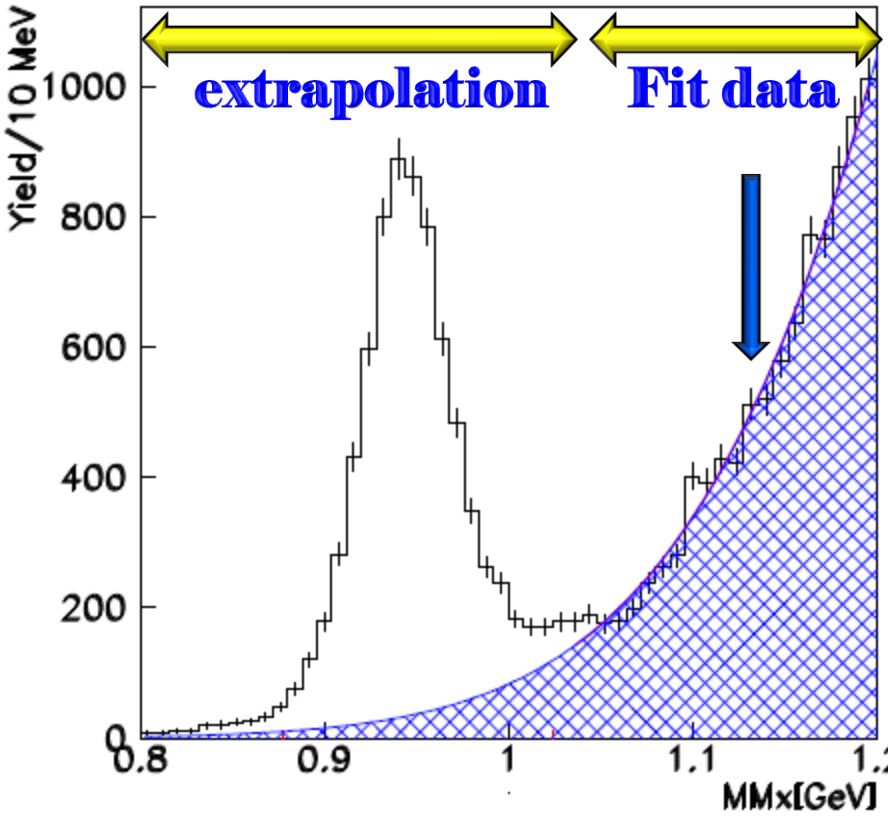
(2) GENEV full-simulation shows a reasonable good agreement with EXCLURAD's result in the valid kinematic region for both



W~1.75 GeV
Q^2~3 GeV^2
ϕ^*=80-120 deg

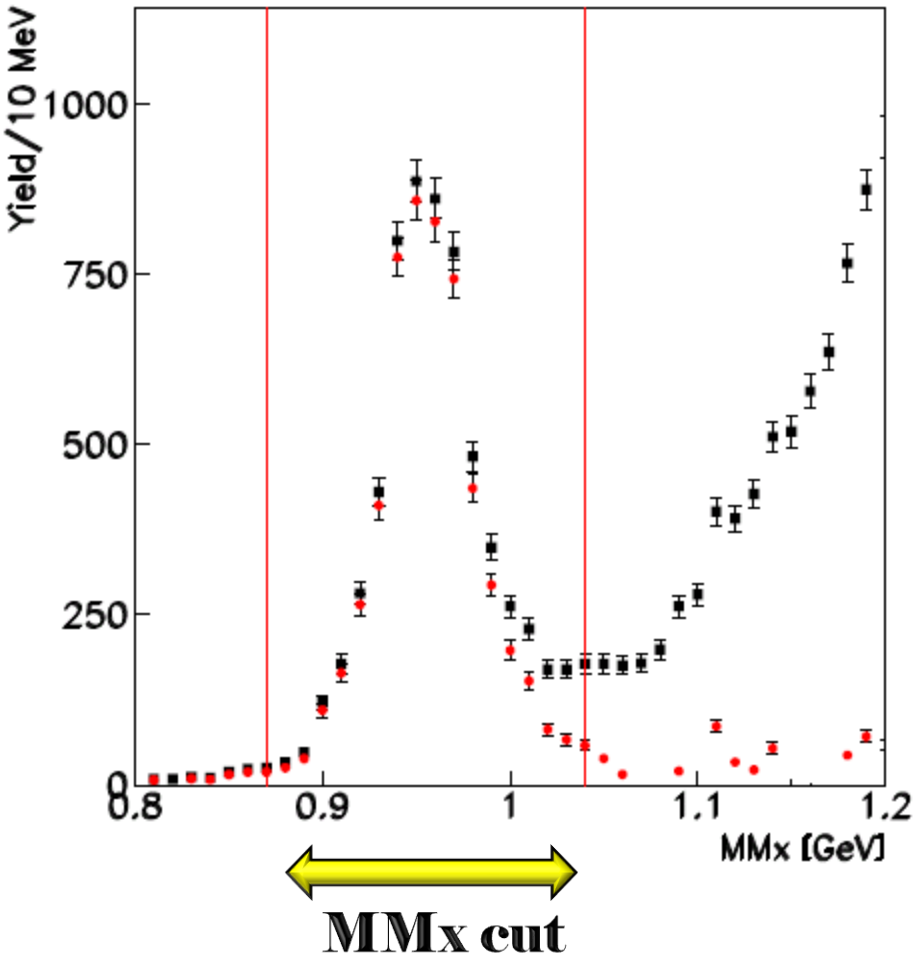


Background subtraction



Before subtraction

After subtraction

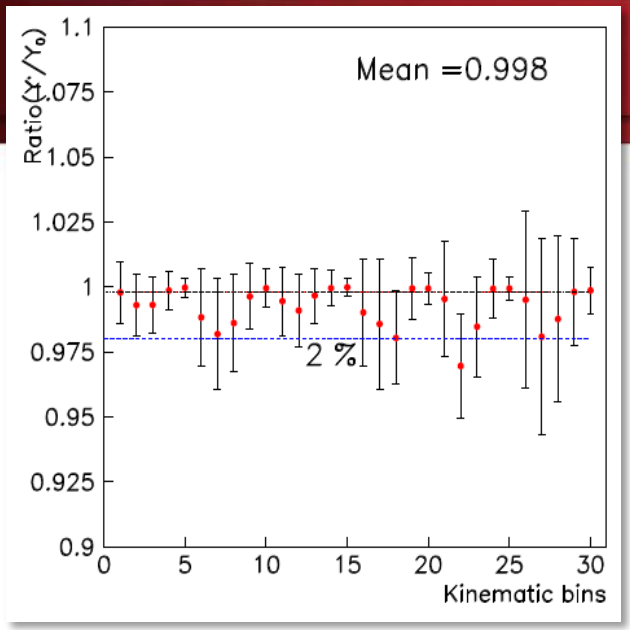


Background subtraction

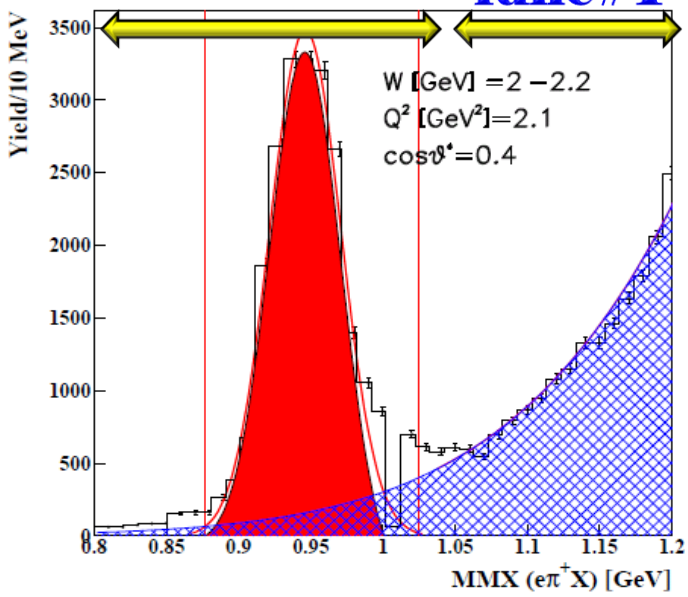
$$ratio = \frac{Y'(n\pi^+)}{Y_0(n\pi^+)}$$

Y_0 is the yield with nominal BG subtraction.

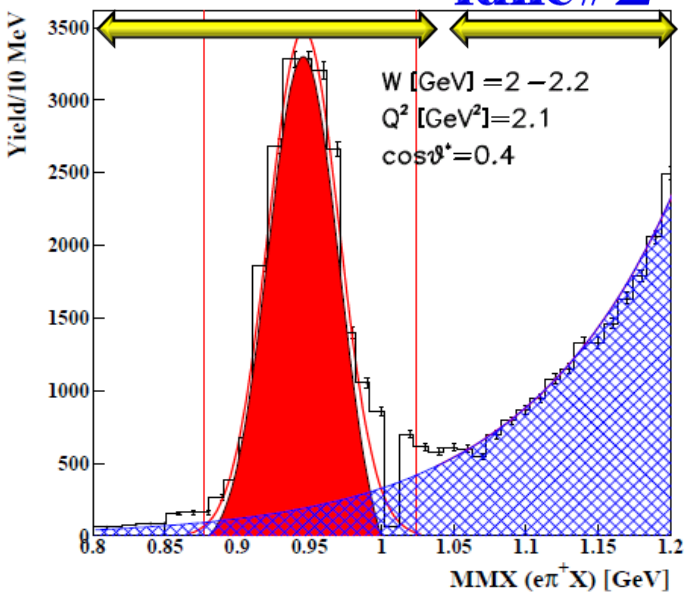
Y' is the yield with subtraction of the BG and the left tail of missing mass neutron



func#1



func#2



Same fit range
Different functions

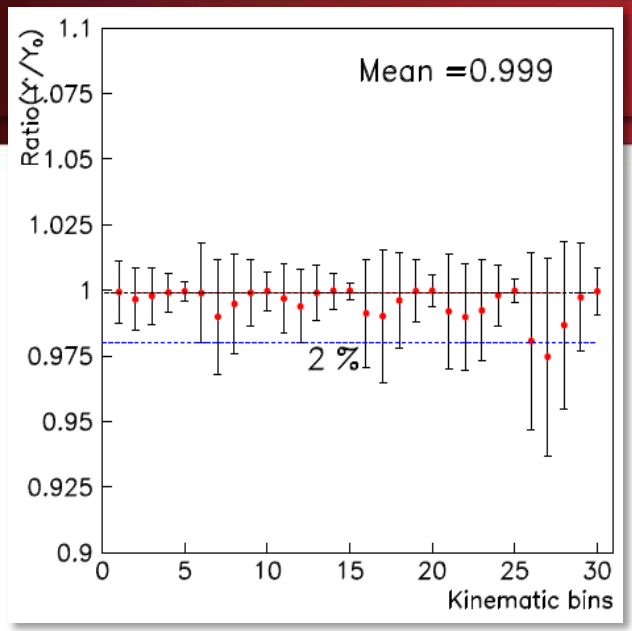
func#1 : G+pol3
func#2 : E+pol2

Background subtraction

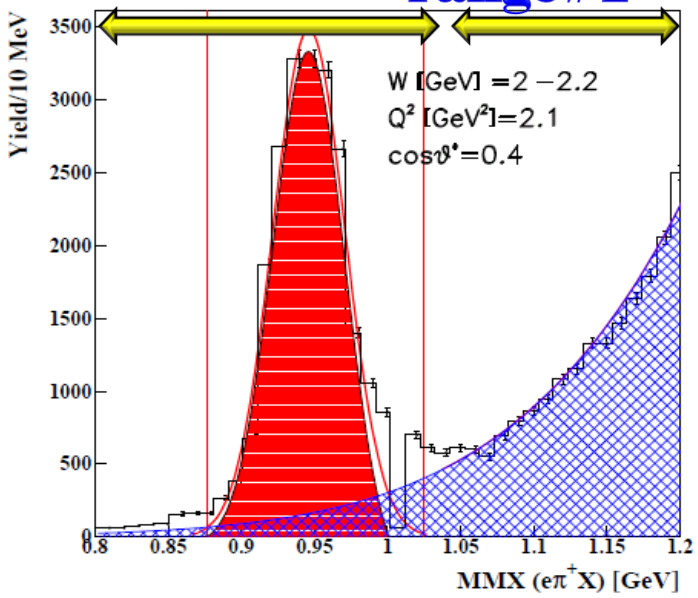
$$ratio = \frac{Y'(n\pi^+)}{Y_0(n\pi^+)}$$

Y_0 is the yield with nominal BG subtraction.

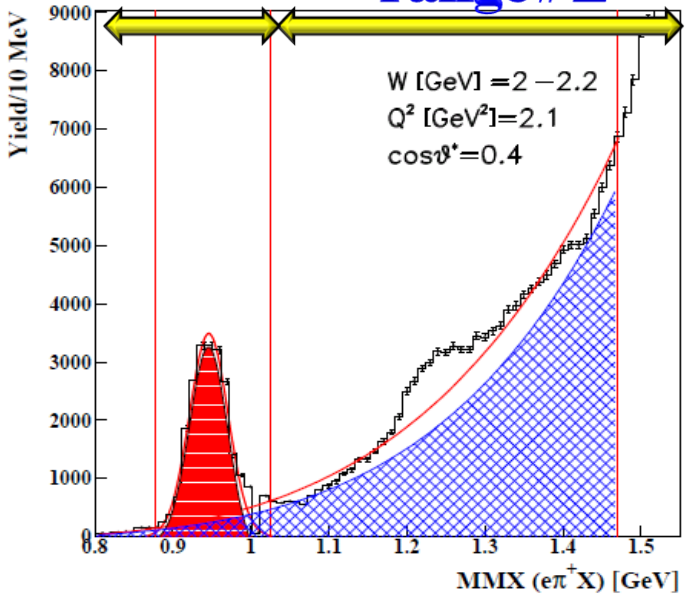
Y' is the yield with subtraction of the BG and the left tail of missing mass neutron



range#1



range#2



Same functio
Different fit ranges

range#1 : 0.8 - 1.2GeV

range#2 : 0.75 - 1.45GeV

** away from radiative tail

Cross-sections vs. -t

$$\frac{d\sigma}{dt} = \frac{1}{\Gamma}\frac{d^3\sigma}{dQ^2 dx_B dt}$$

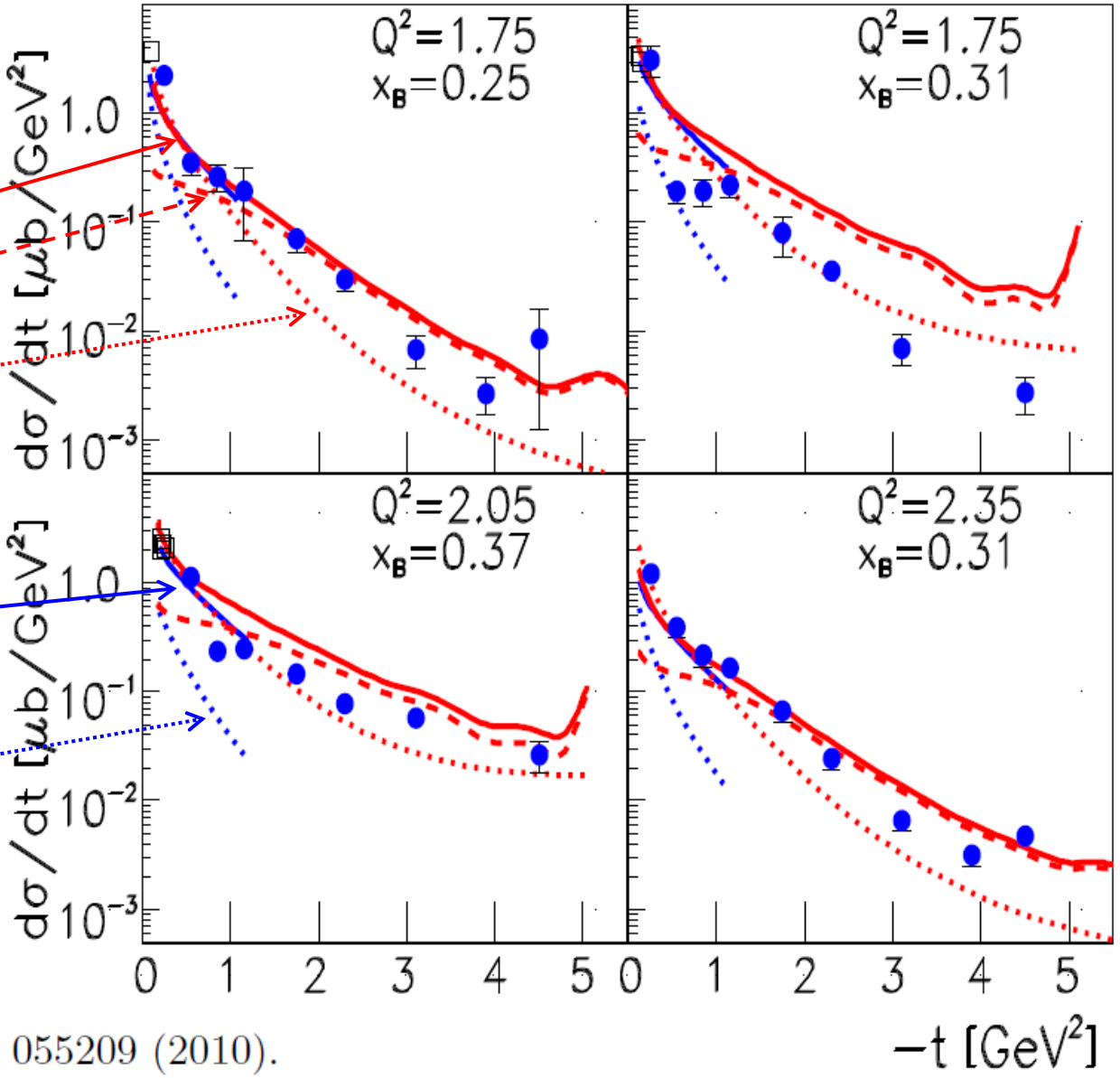
Laget $d\sigma/dt$

$d\sigma_T/dt$

$d\sigma_L/dt$

GK $d\sigma/dt$

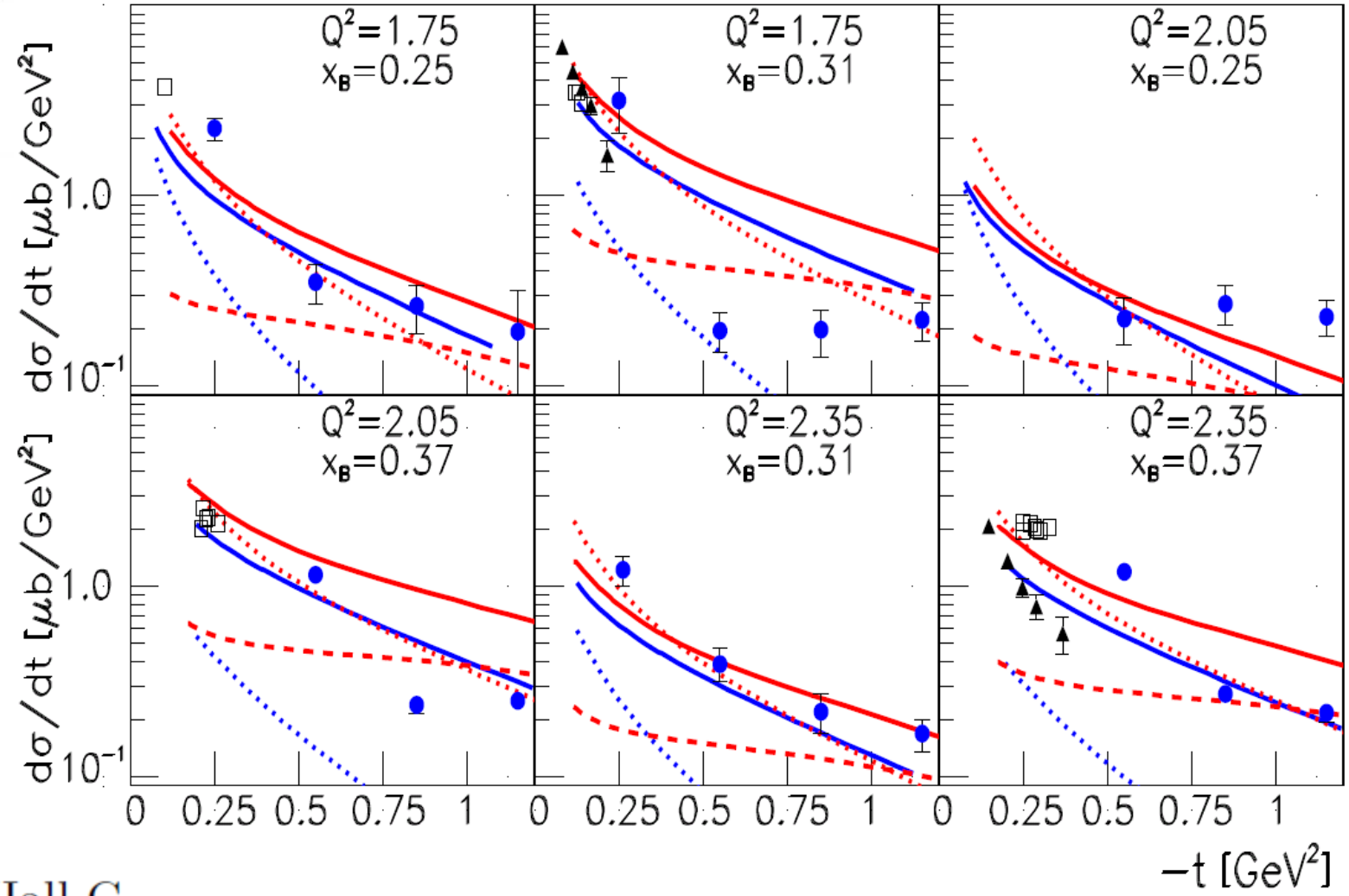
$d\sigma_L/dt$



JLab Hall C
black open squares $(d\sigma/dt)$

X. Qian *et al.*, Phys. Rev. C **81**, 055209 (2010).

Cross-sections

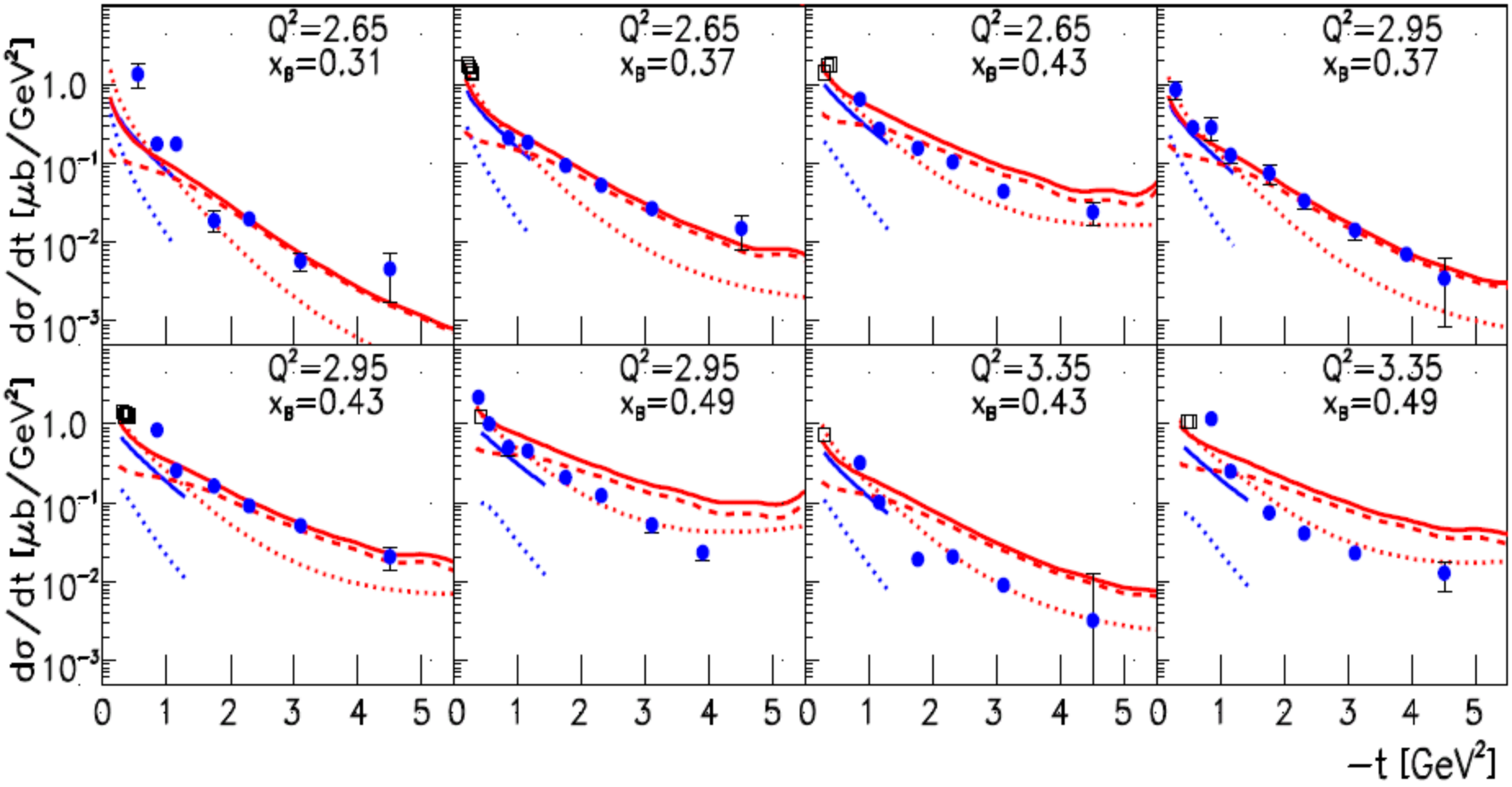


JLab Hall C

black solid triangles $d\sigma_L/dt$

H. P. Blok *et al.*, Phys. Rev. C **78**, 045202 (2008).

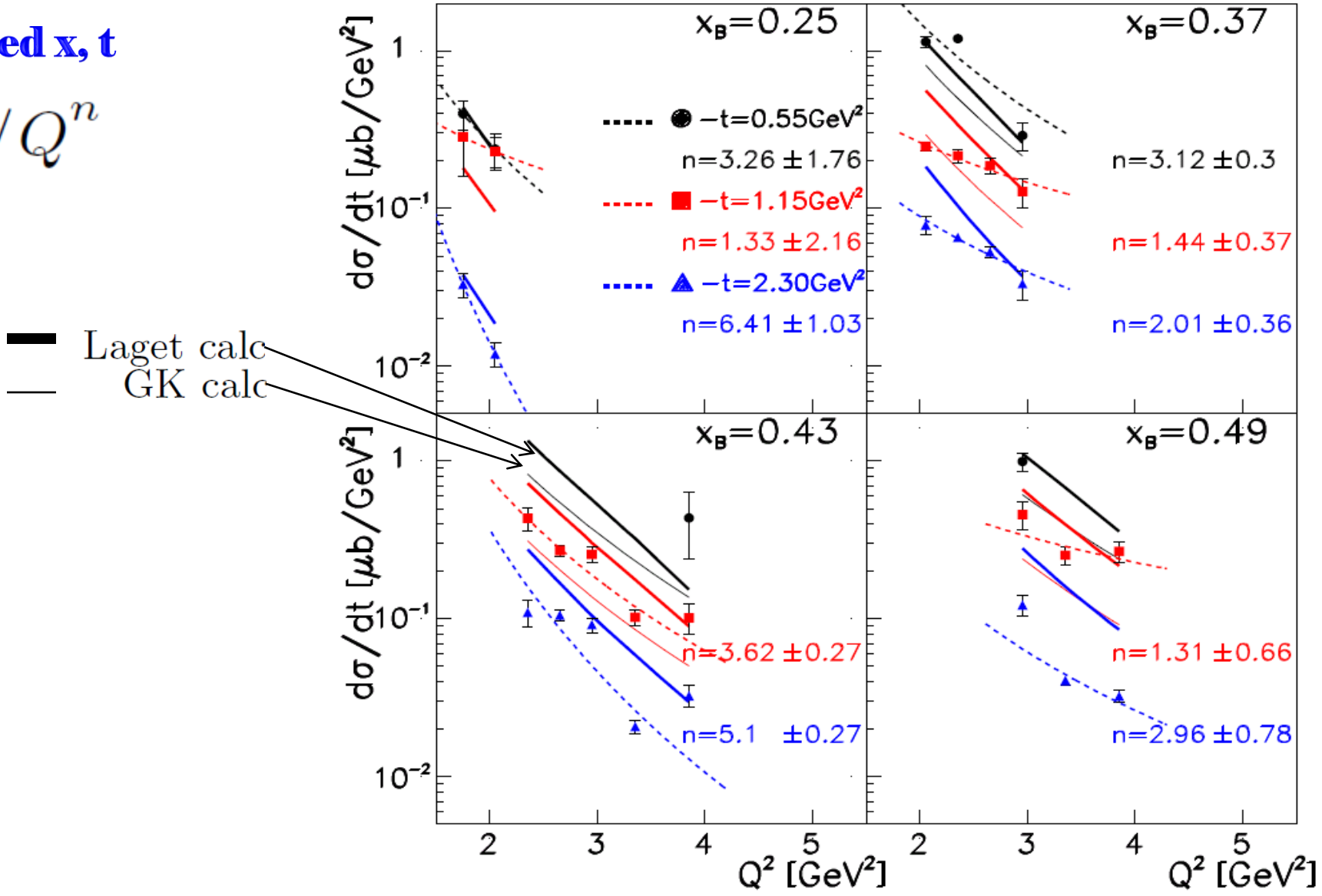
Cross-sections vs. -t



Q^2 - scaling cross-sections

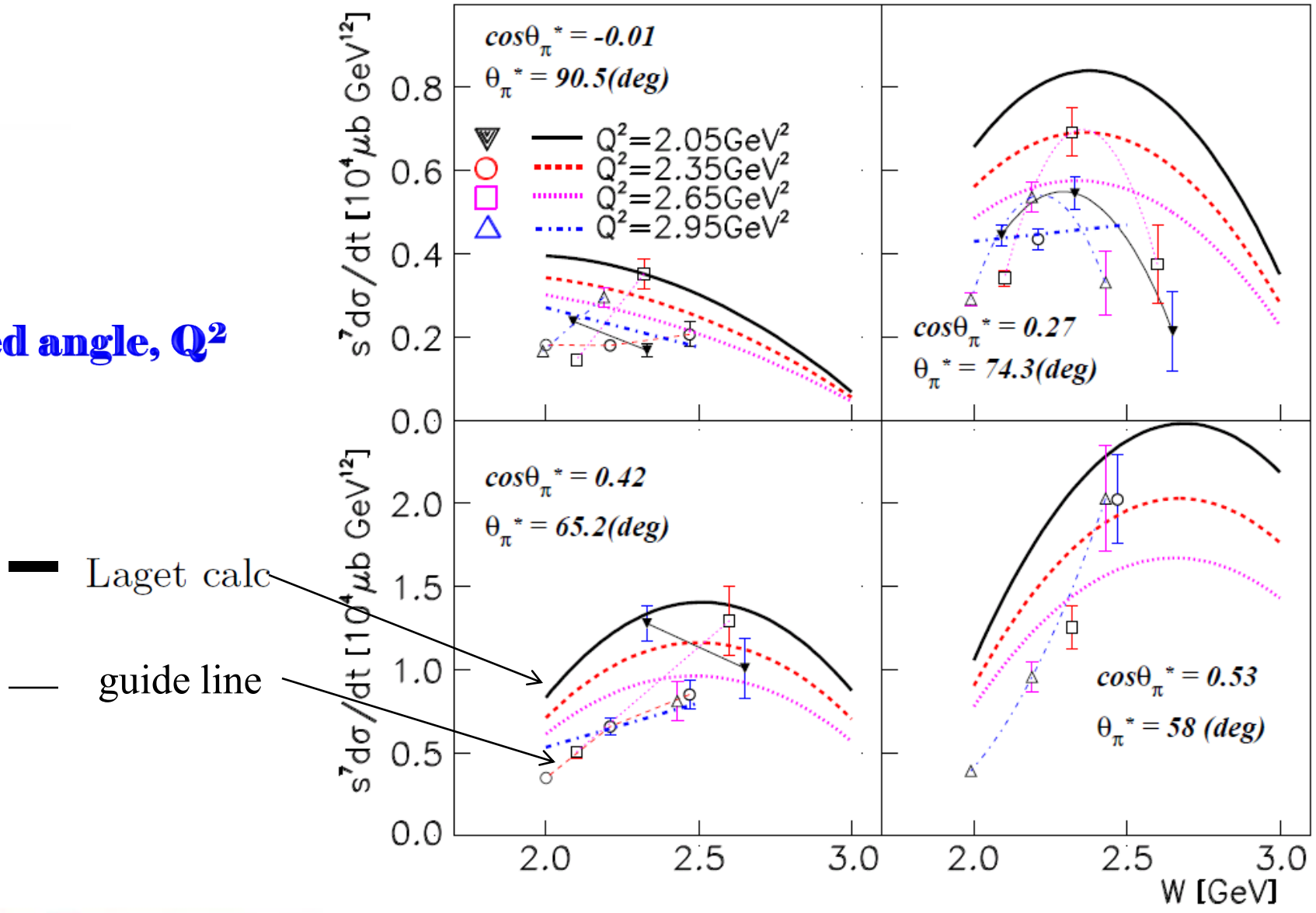
Fixed x, t

$$A/Q^n$$



S - scaled cross-sections

Fixed angle, Q^2



Summary

- We have measured the cross sections of $p(e,e'\pi^+)n$ as a function of

$$-t = 0.1 - 5.3\ \text{GeV}^2,\ x_B = 0.16 - 0.58,\ Q^2 = 1.6 - 4.5\ \text{GeV}^2.$$

- Compared our differential cross sections to two recent calculations:
  - ✓ Hadronic degrees of freedom (Laget Regge)
  - ✓ Partonic degrees of freedom (GK handbag).

- Two approaches differ in the relative contributions of the longitudinal and transverse parts of the cross section, in particular as x_B increases

- If the handbag approach is confirmed, the $p(e, e'\pi^+)n$ process offers the outstanding potential to access transversity -GPDs.

Than you for your attention~!

Cross-sections vs. -t

First time compare data with hadronic degree of freedom

Laget model : Reggeized ρ^+ and π^+ meson exchange in t-channel.

Laget model :

(1) Well-known (constraint) hadronic coupling constant
(2) Main free parameters = mass-scaled electromagnetic form factors @ γN vertex
(3) Use of the standard mono-pole form factor $\rightarrow$ steeper t-slope than data
(4) Agreement with data is achieved by recovering mass scaled form factors and depending on |t|.
(5) The form factor is shrinking in size of the nucleon system as |t| increases.

This size effect quantitatively same as ω-electroproduction

(6) Laget calculation already gives a good description of the photo-production data (SLAC and JLab) and HERMES electro-production data.
Note that this calculation has not been adjusted to fit our data.
(7) Calculation shows L-T crossing at –t ~ 1GeV2 overall kinematic regions.
(8) The dominance of σ_L at low |t| is a consequence of the t-channel π^+ -exchange (pion pole)
At large |t|, ρ^+ meson exchange which contributed by mostly to the transverse part of the cross-section begin to dominate.
(9) Laget model contains not only t-channel meson exchange but also u-channel baryon exchange. This can be shown in certain kinematic region such as large |t| and small |u|.

Cross-sections vs. -t

GK model : handbag GPD formalism

σ_L : mostly generated by the pion-pole (similar as Laget model)

*** Important difference : treatment of the pion-pole calculation

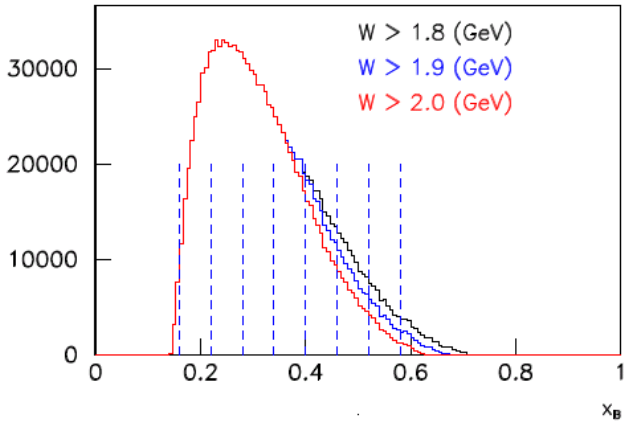
Laget model : t-channel propagator $\propto s^{\alpha(t)}$

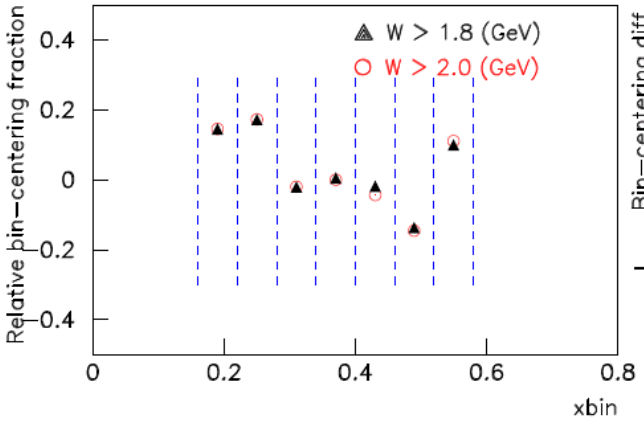
$\alpha(t)$ is the pion Regge trajectory
Q2, t-dependent electromagnetic form factor allows
to have s- x_B-, t- dependent of the pion-pole

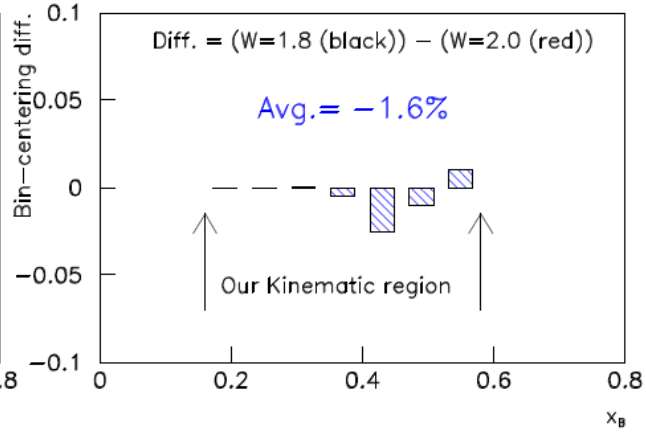
GK model : t-channel pion propagator $\propto 1/(t-m_\pi^2)$

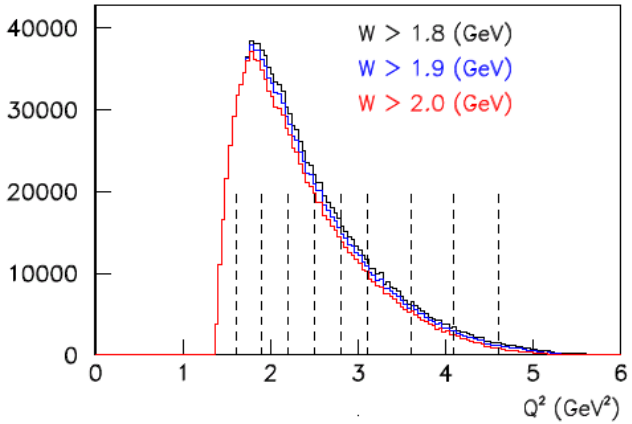
no s-dependence.
The hadronic for factor at πNN vertex is only t-dependence.

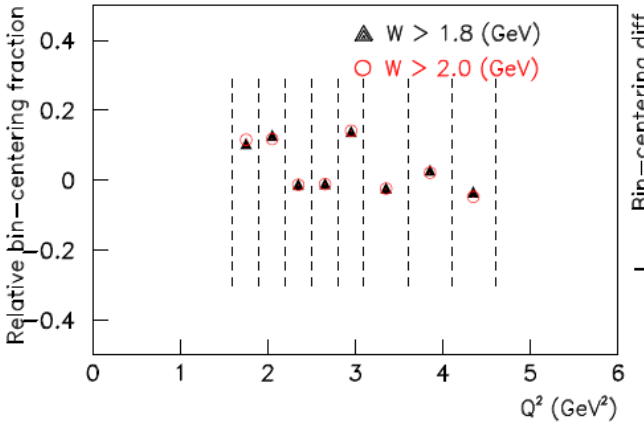
Systematic uncertainties for bin-centering by W cut

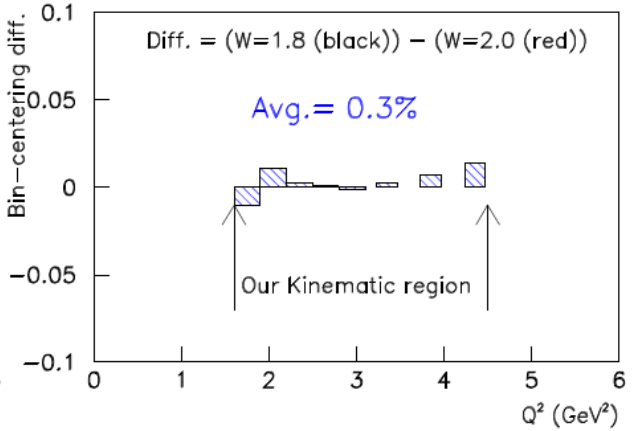




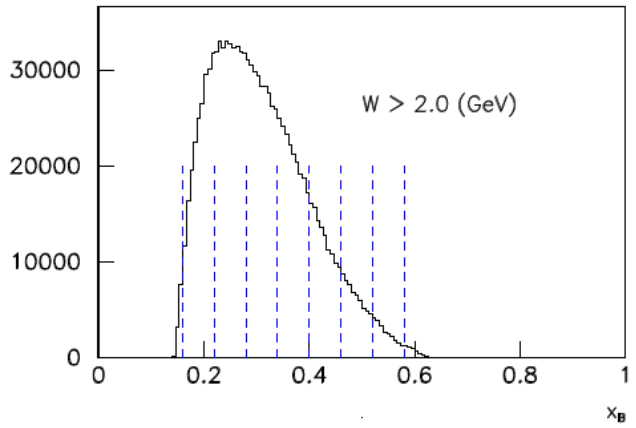


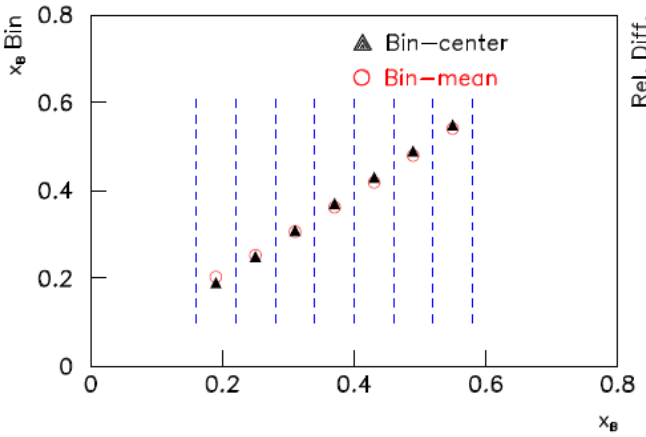


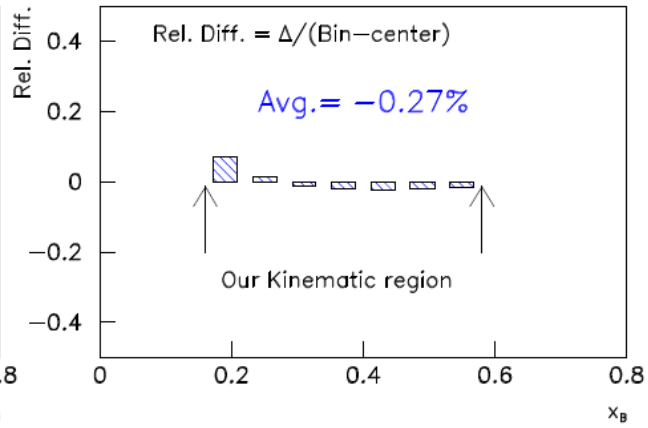


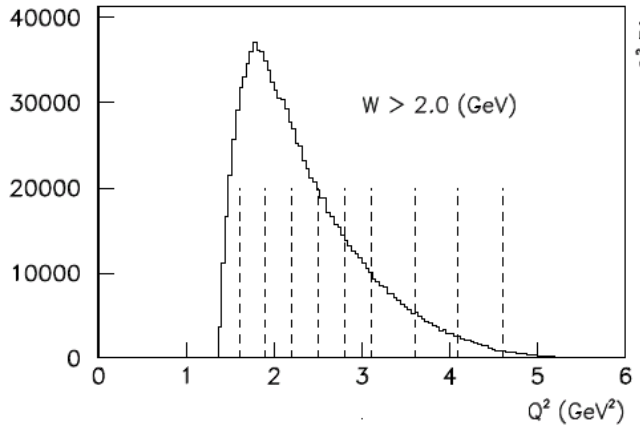


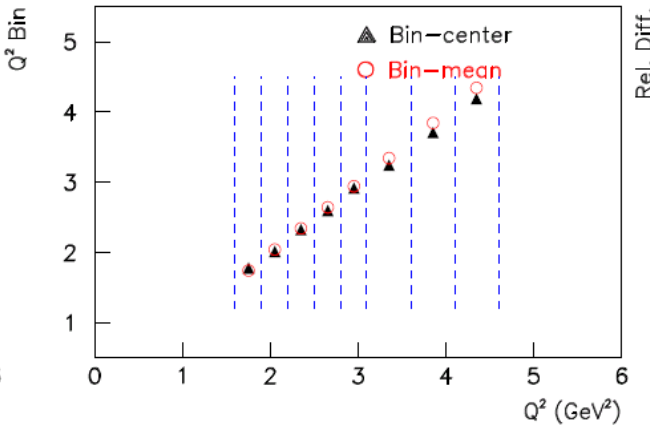
Difference between bin-mean vs. bin-center

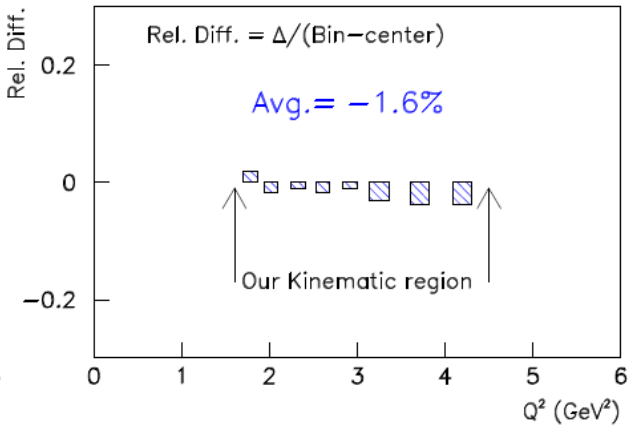




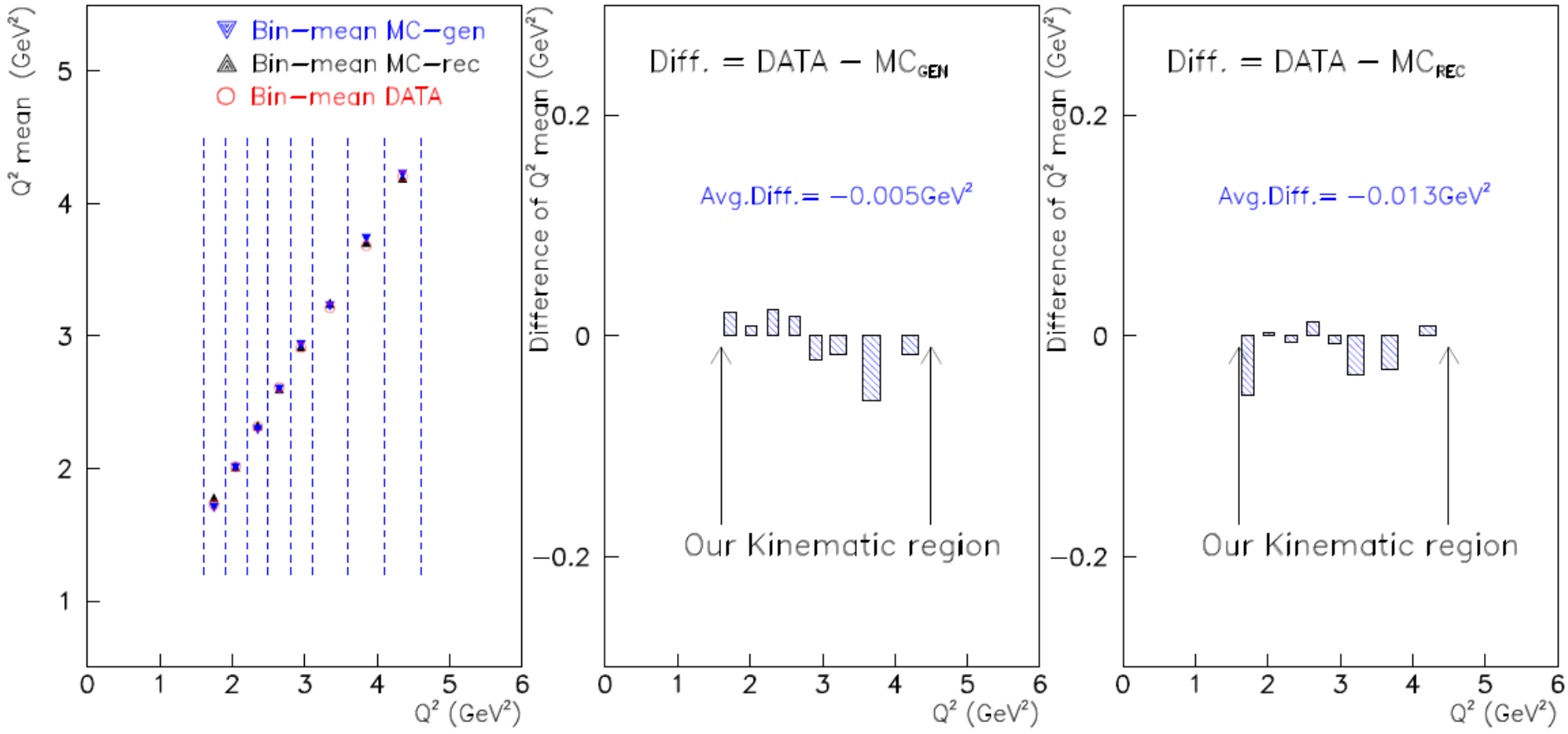




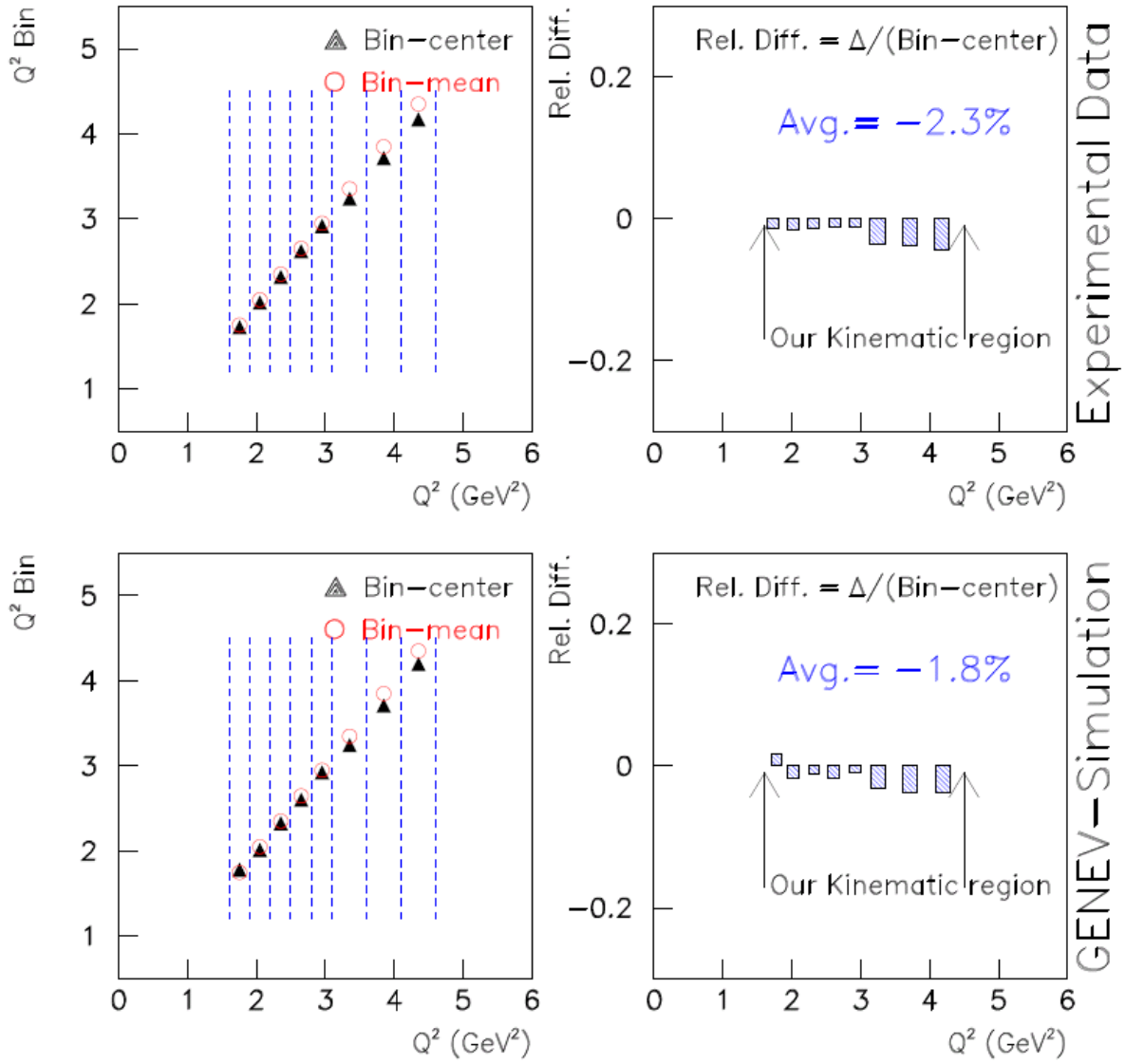




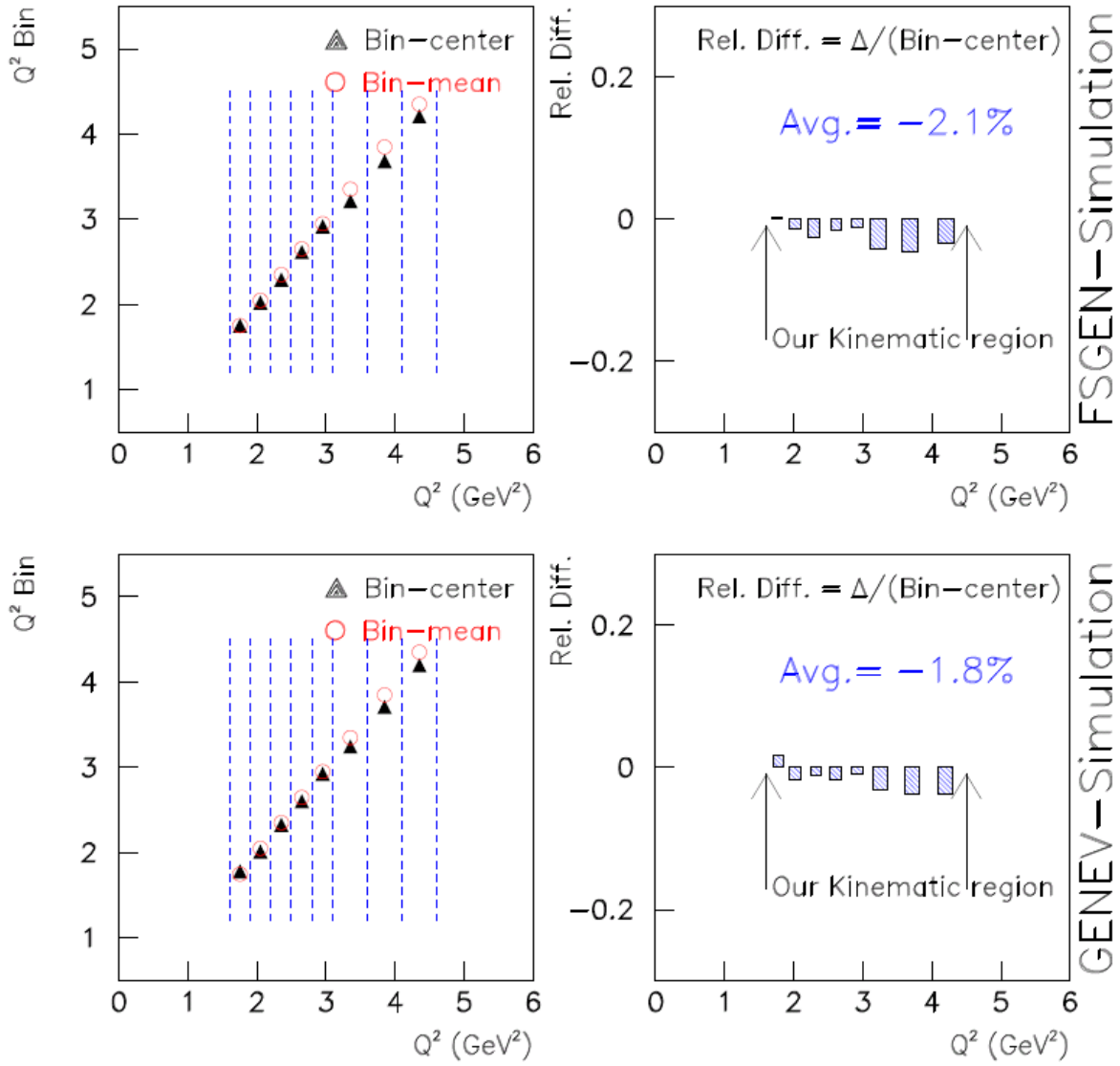
Difference of bin-mean from GEN/REC/DATA



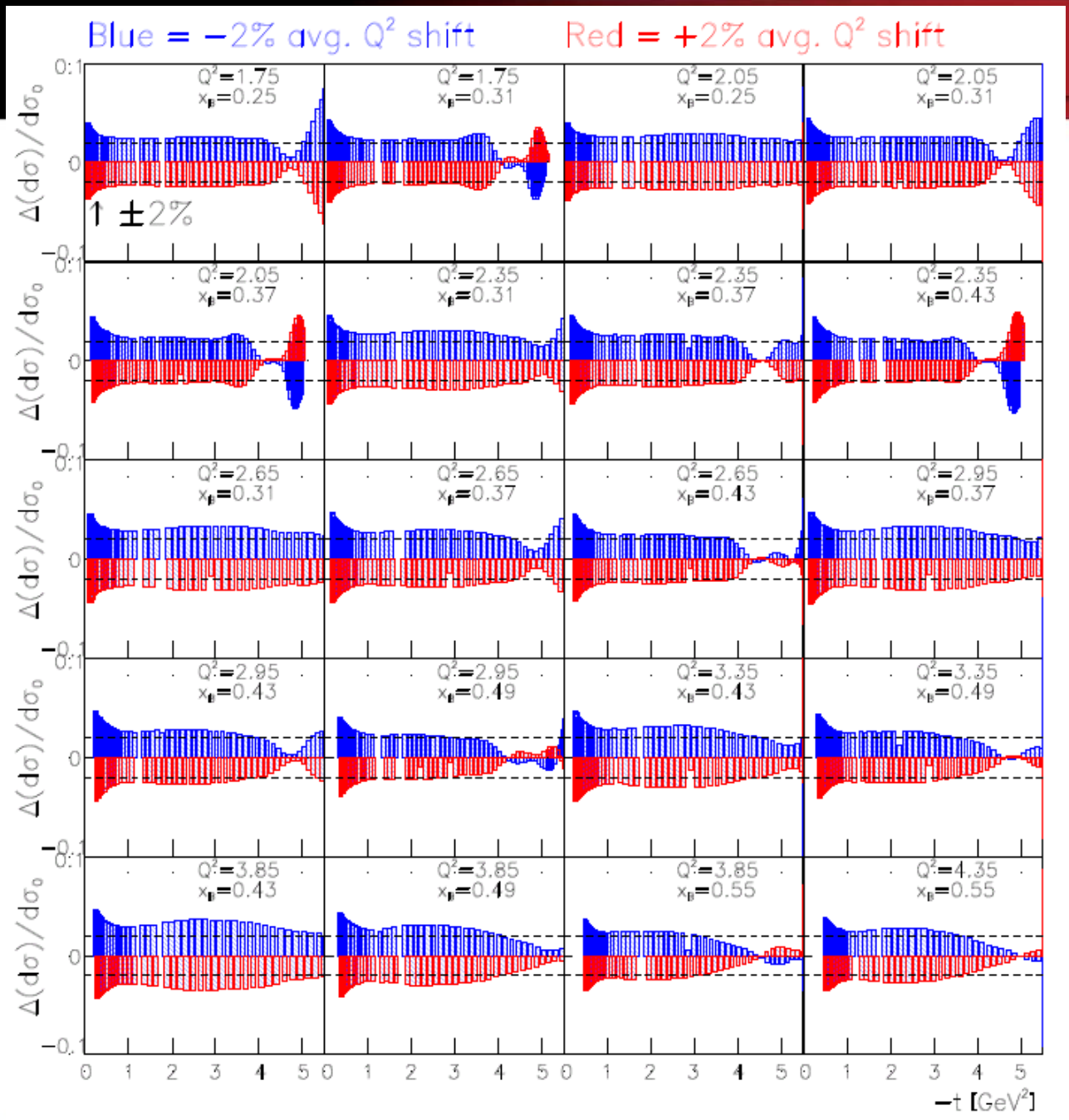
Difference between bin-mean vs. bin-center



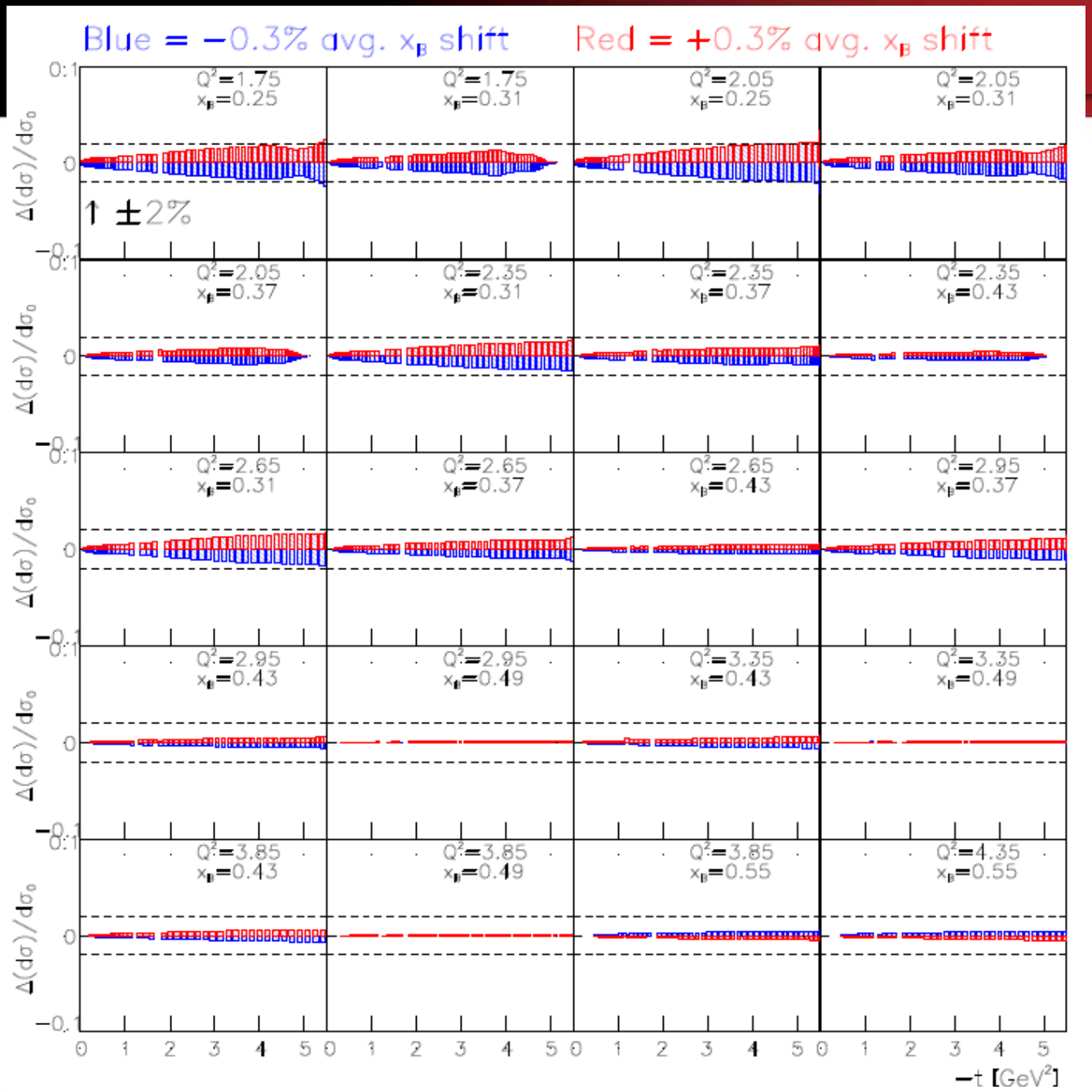
Difference between bin-mean vs. bin-center



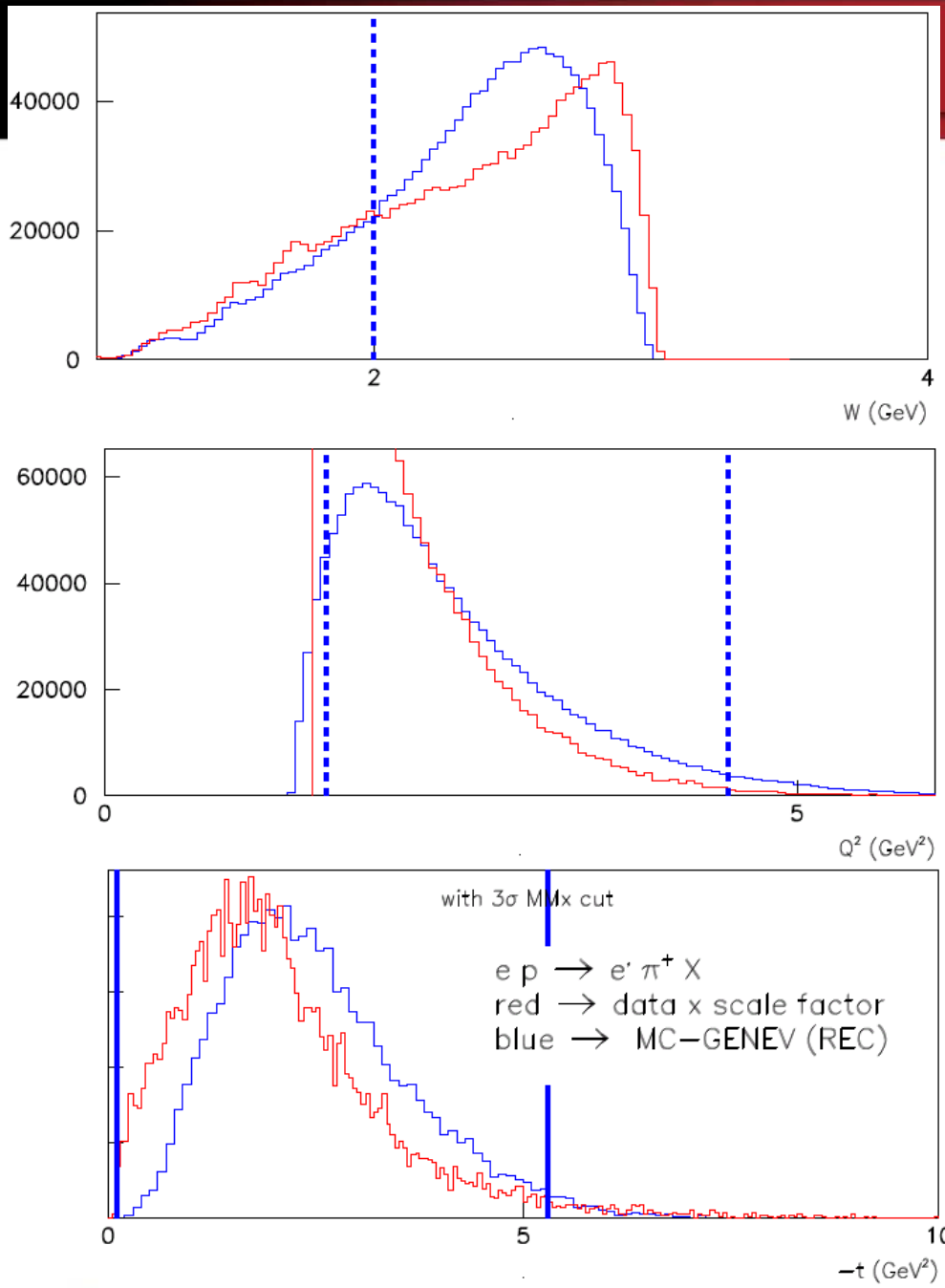
Bin-effect by model



Bin-effect by model



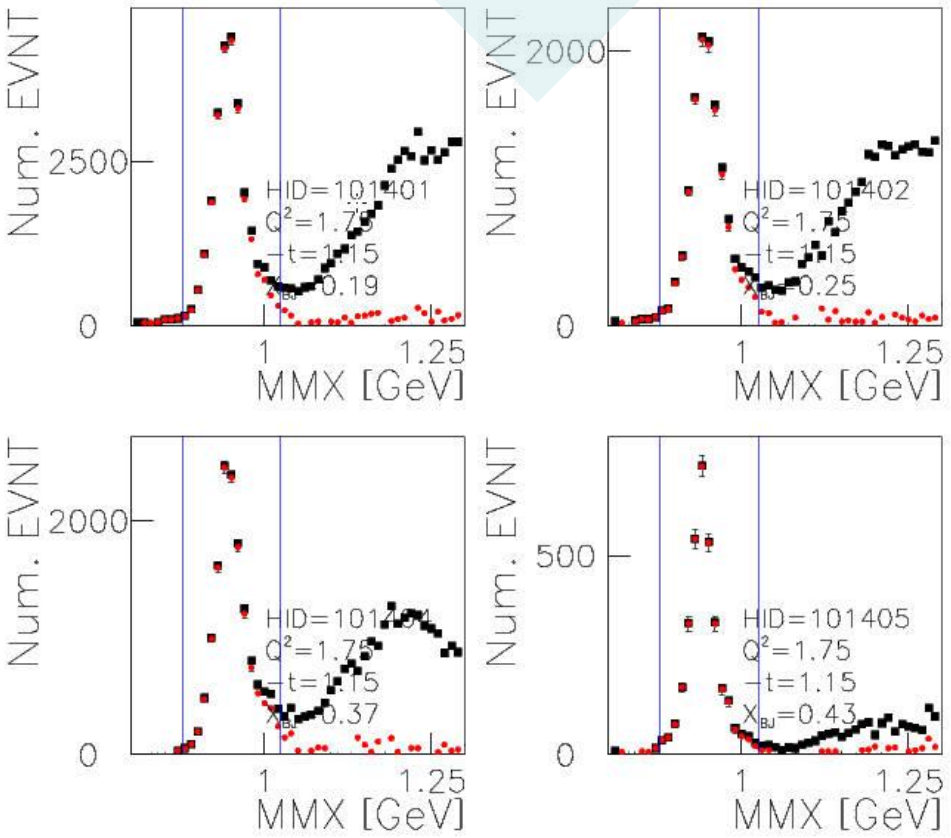
DATA vs. MC

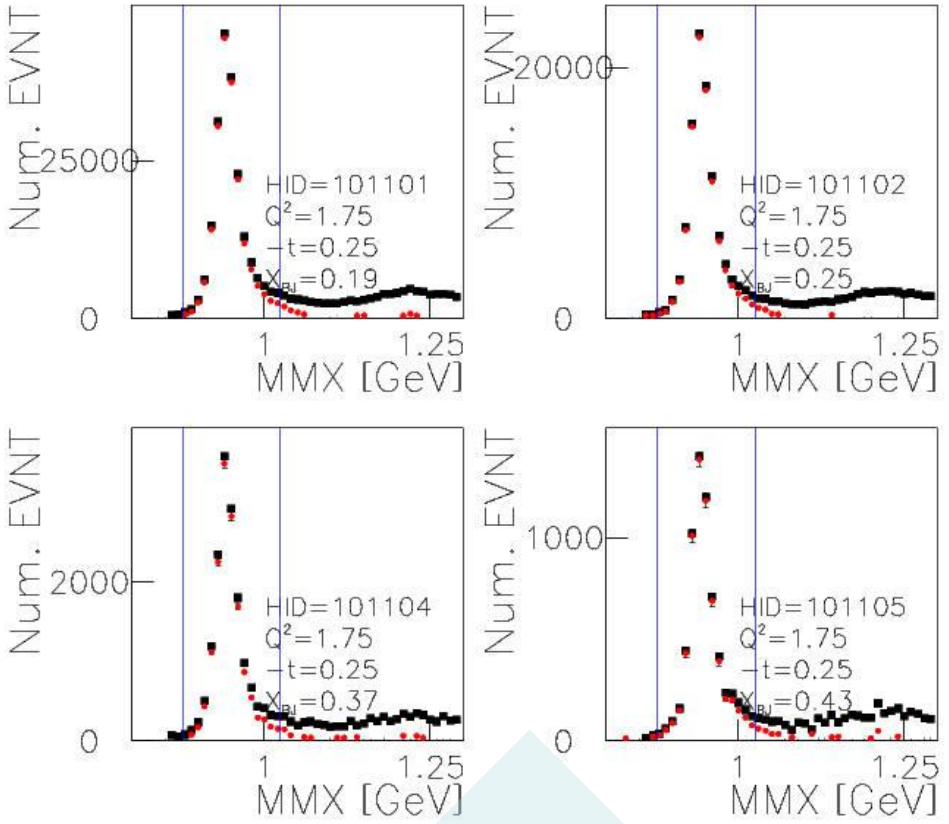

40000
20000
0
2
4
W (GeV)
60000
40000
20000
0
0
5
Q² (GeV²)
with 3σ MMx cut
e p → e' π⁺ X
red → data x scale factor
blue → MC−GENEV (REC)
0
5
10
−t (GeV²)

Background subtraction

$Q^2 = 1.75 GeV^2$

High –t range





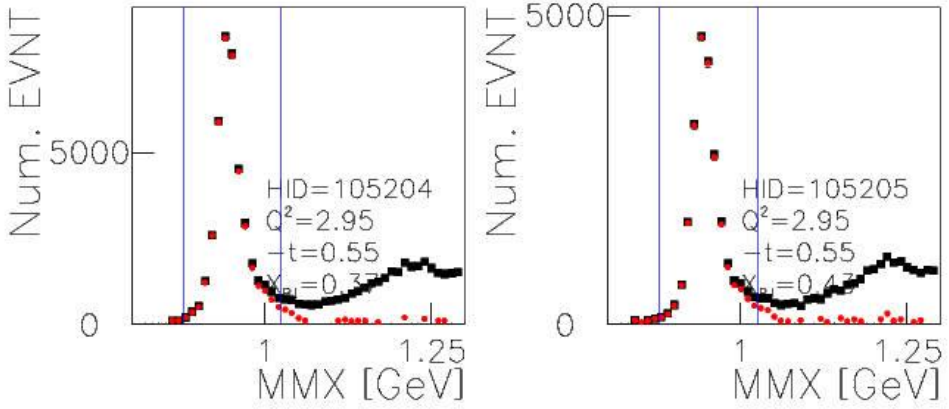
Low –t range

Background subtraction

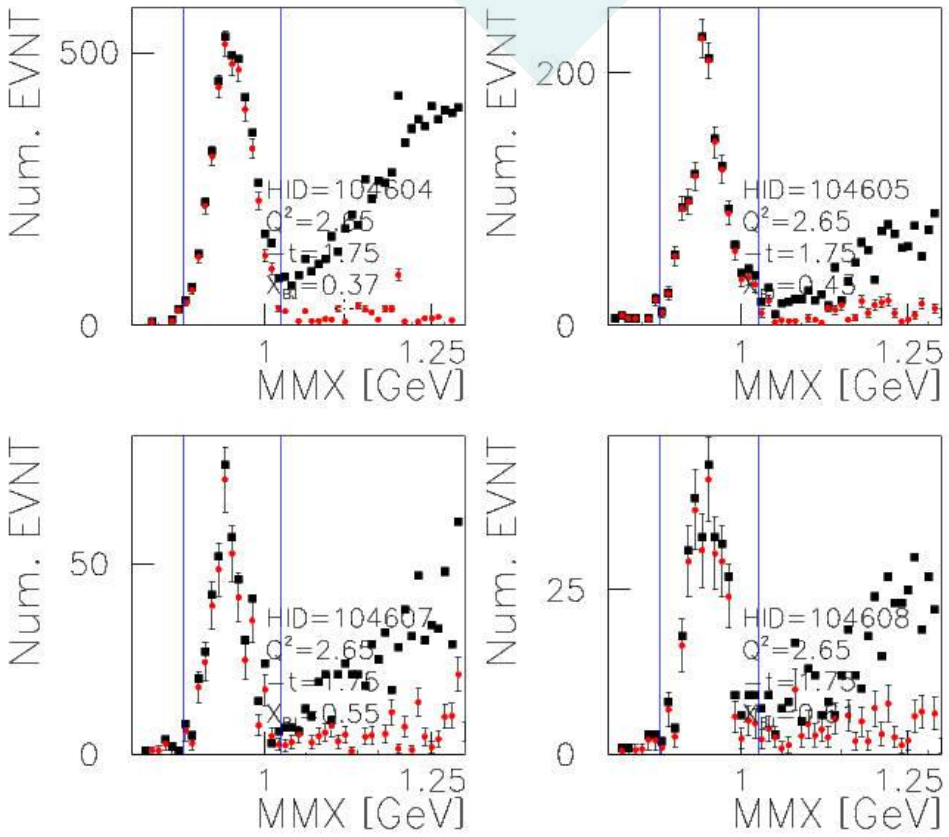
$Q^2 = 2.65 GeV^2$

$Q^2 = 2.95 GeV^2$

High –t range

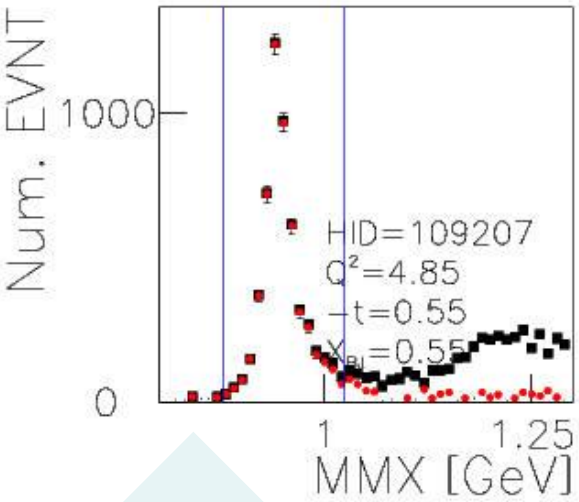


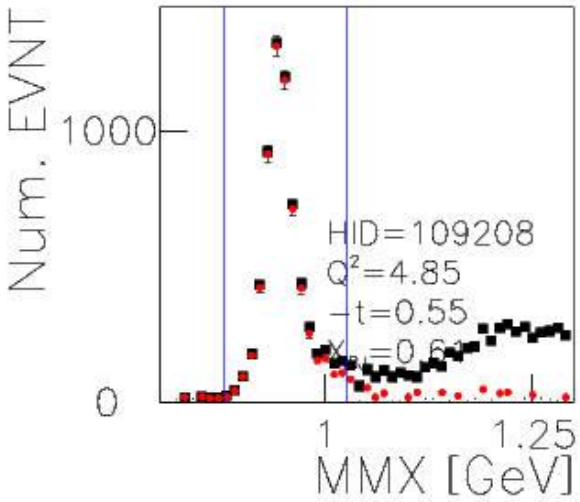
Low –t range



Background subtraction

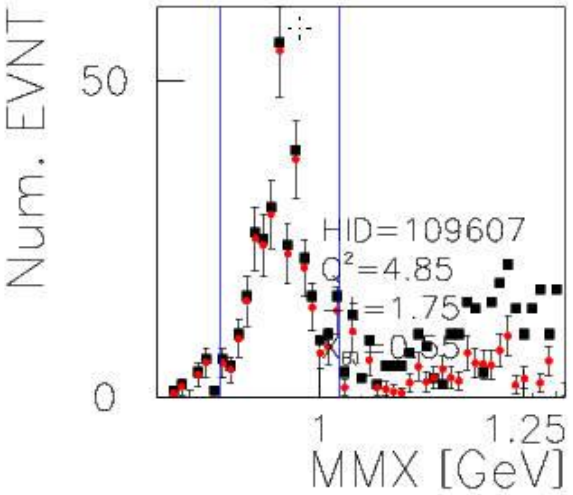
$Q^2 = 4.85 GeV^2$

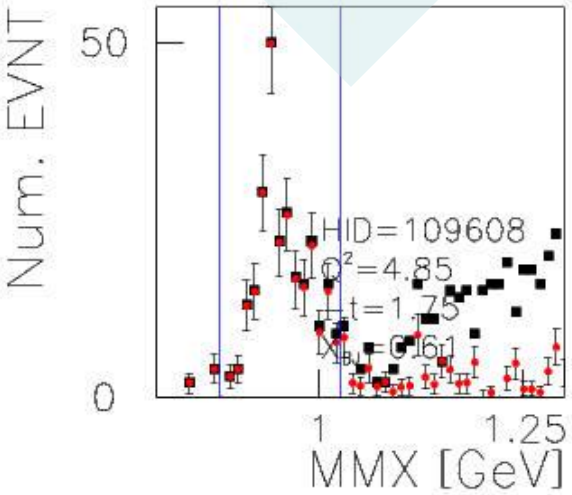




Low –t range

High –t range





Analysis - fiducial cuts

FID(π^+)

$$f = \begin{cases} P_0 & : \phi < P_2 - P_1 \\ \frac{P_6 - P_0}{P_1}(\phi - P_2 + P_1) + P_0 & : P_2 - P_1 \le \phi < P_2 \\ P_6 & : P_2 \le \phi < P_3 \\ \frac{P_6 - P_5}{P_4}(-\phi + P_3 + P_4) + P_5 & : P_3 \le \phi < P_3 + P_4 \\ P_5 & : P_3 + P_4 \le \phi \end{cases}$$