Rutgers EIC workshop

Exclusive vector meson electroproduction @ CLAS6, CLAS12 and EIC

M. Guidal, IPN Orsay

Overview of existing data (valence region)

- ρ^0, ω, ϕ & ρ^+ electroproduction on the proton @ CLAS6
- *GPDs or not GPDs ?*

Perspectives with CLAS12 & EIC

Overview of existing data (valence region)

- ρ^0, ω, ϕ & ρ^+ electroproduction on the proton @ CLAS6
- *GPDs or not GPDs ?*

Perspectives with CLAS12 & EIC

Exclusive ρ^0, ω, ϕ & ρ^+ electroproduc
on the proton @ CLAS6

K. Lukashin et al., Phys.Rev.C63:065205,2001 (ϕ @4.2 GeV)
C. Hadjidakis et al., Phys.Lett.B605:256-264,2005 (ρ^0@4.2 GeV)

e1-b (1999)

L. Morand et al., Eur.Phys.J.A24:445-458,2005 (ω @5.75GeV)
J. Santoro et al., Phys.Rev.C78:025210,2008 (ϕ @5.75GeV)
S. Morrow et al., Eur.Phys.J.A39:5-31,2009 (ρ^0@5.75GeV)

e1-6 (2001-2002)

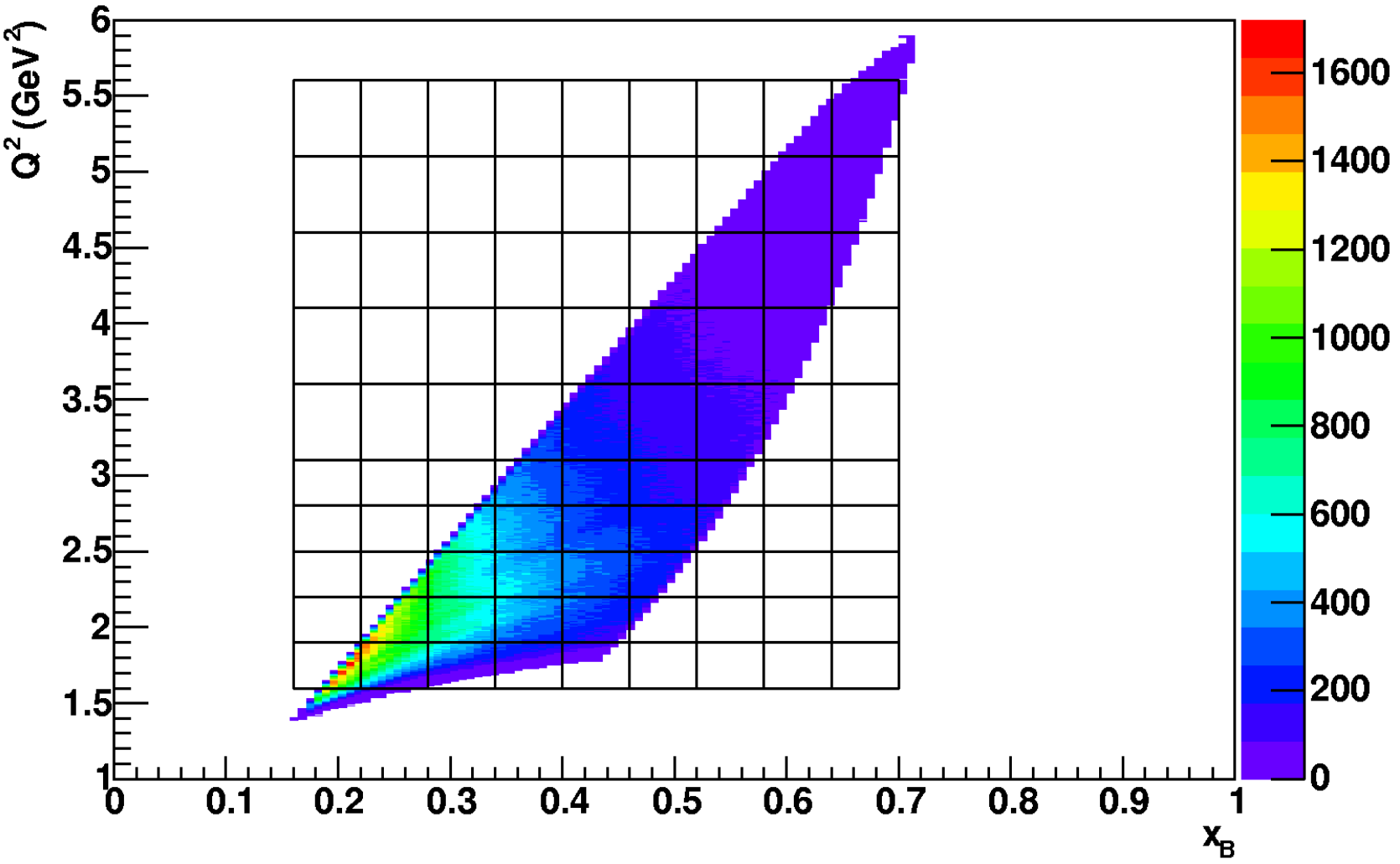
A. Fradi, Orsay Univ. PhD thesis (ρ^+@5.75 GeV)

e1-dvcs (2005)

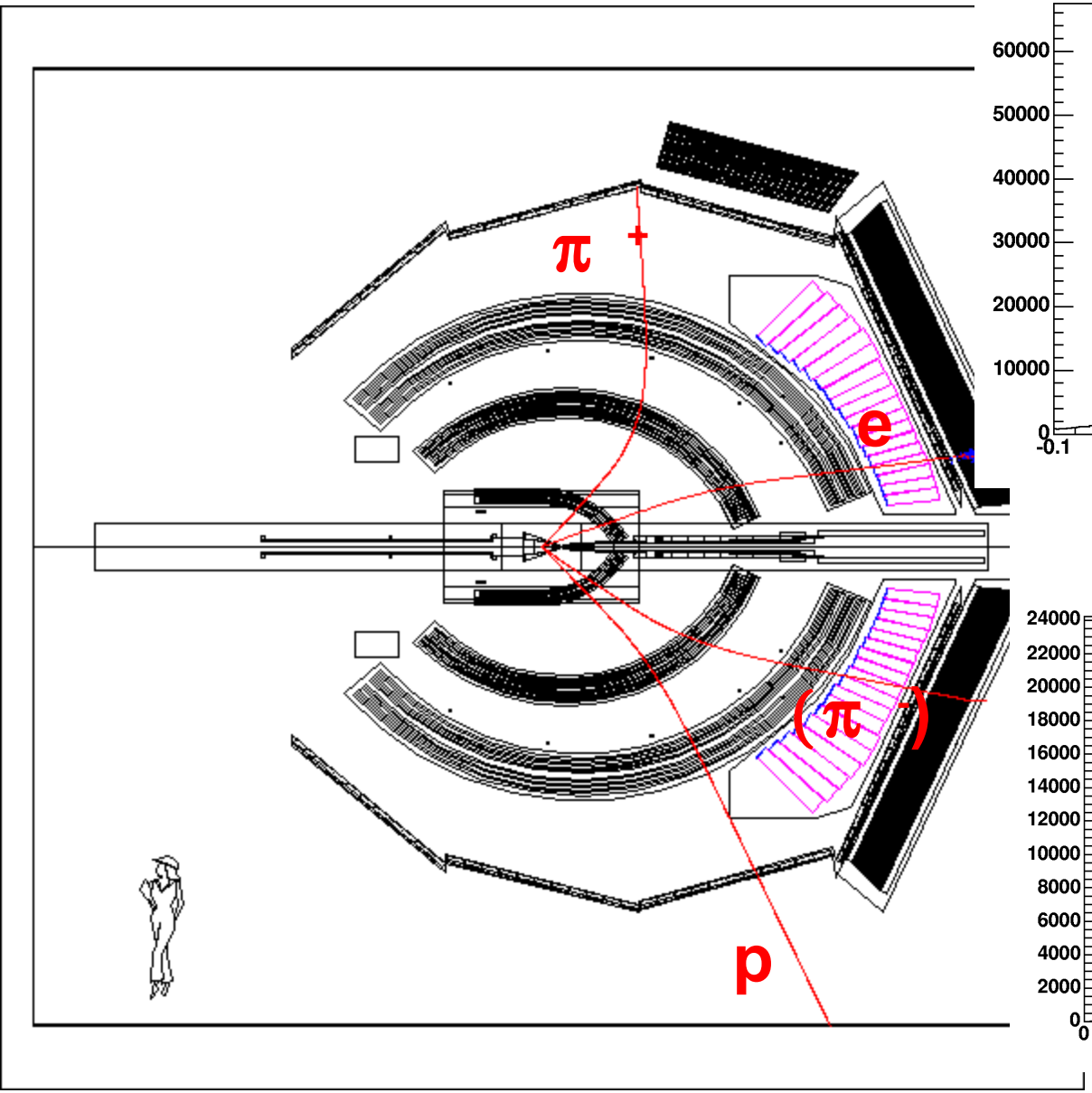
Exclusive ρ^0 electroproduction

e1-6 experiment (E_e =5.75 GeV)

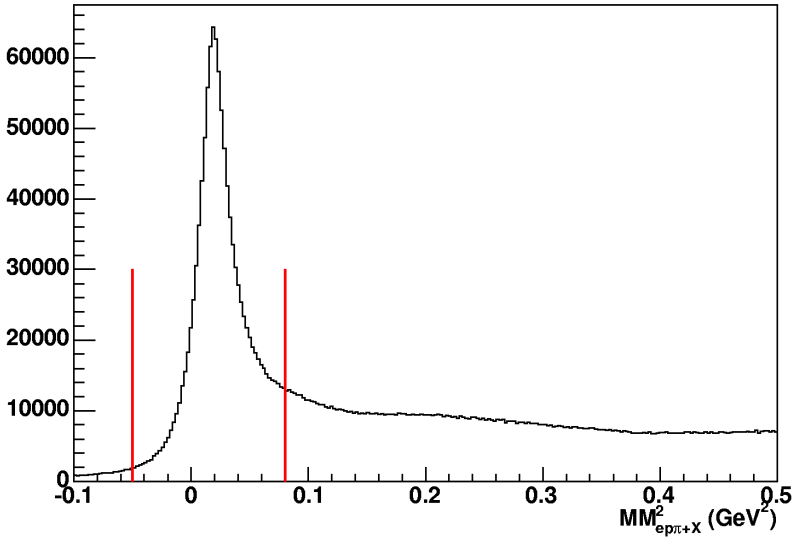
(October 2001 – January 2002)



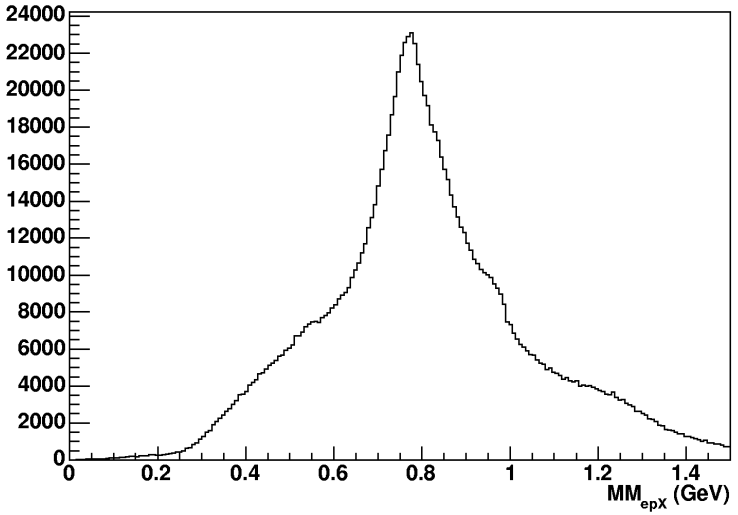
$ep \rightarrow ep\,\pi^{+}(\pi^{-})$



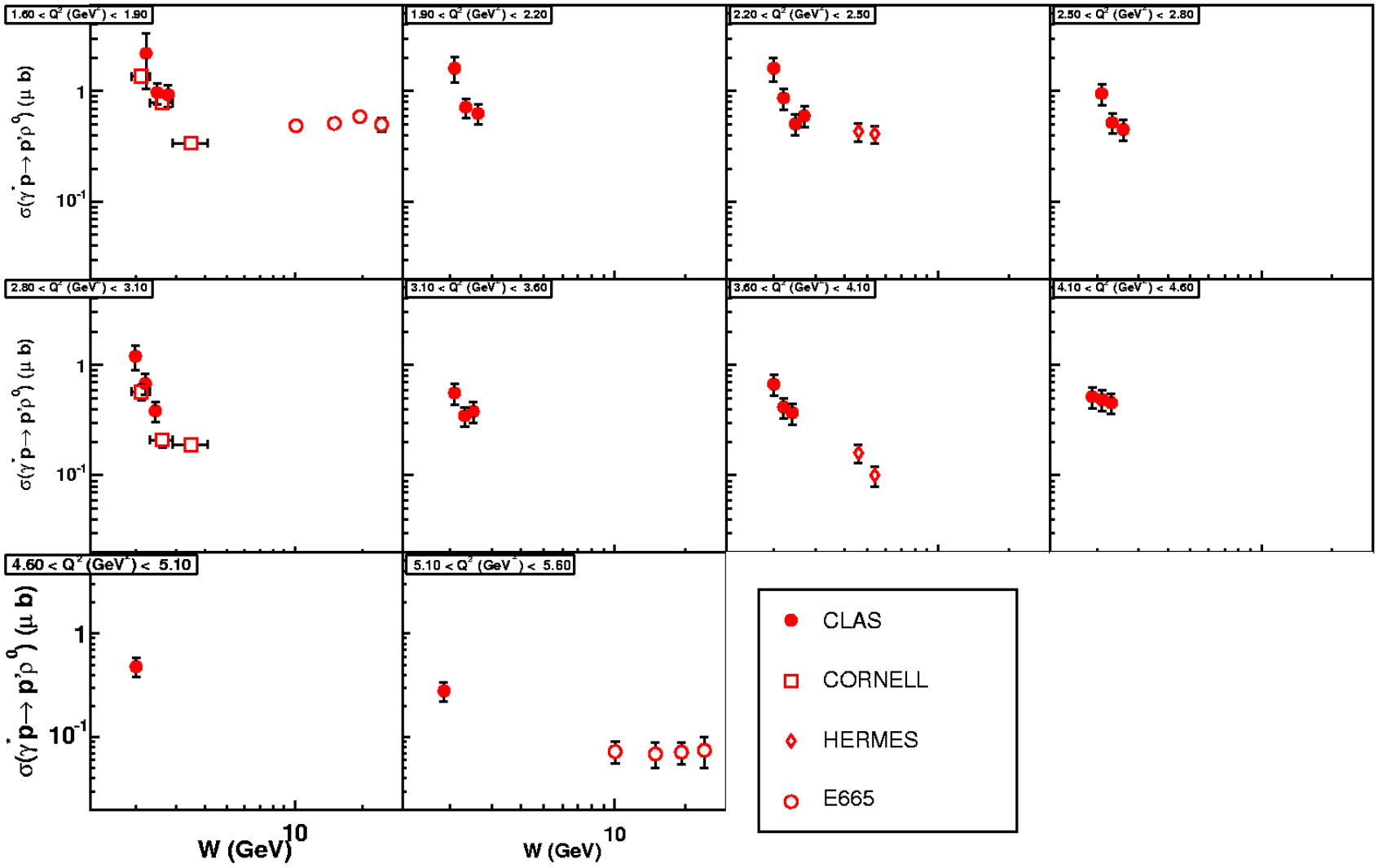
$Mm(ep\pi^{+}X)$



Mm(epX)



$\sigma_{\rho}\ (\gamma^{*}p \rightarrow p\rho^{0})$ vs W



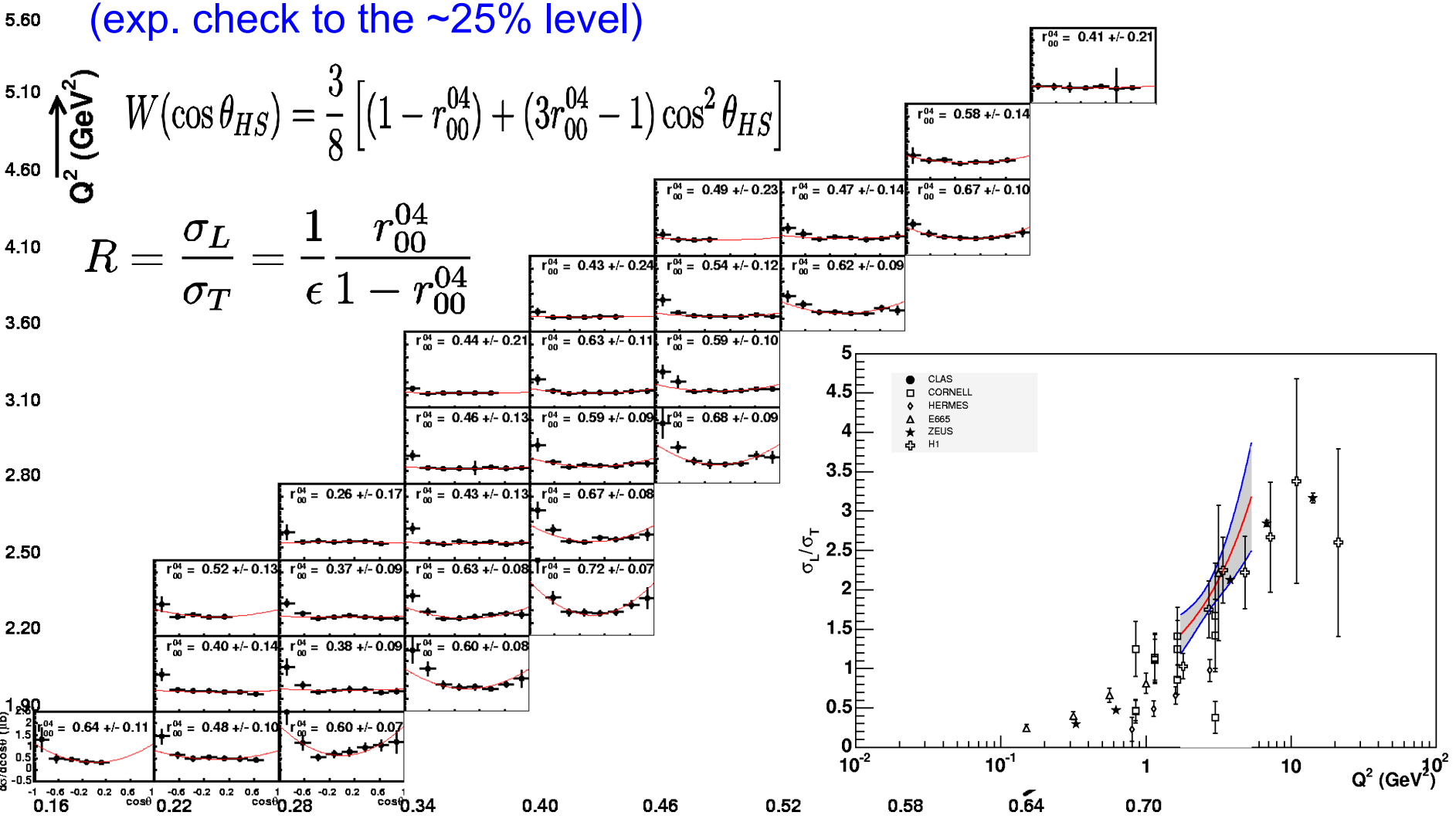
Angular distribution analysis, cos θ $_{cm}$

Relying on SCHC

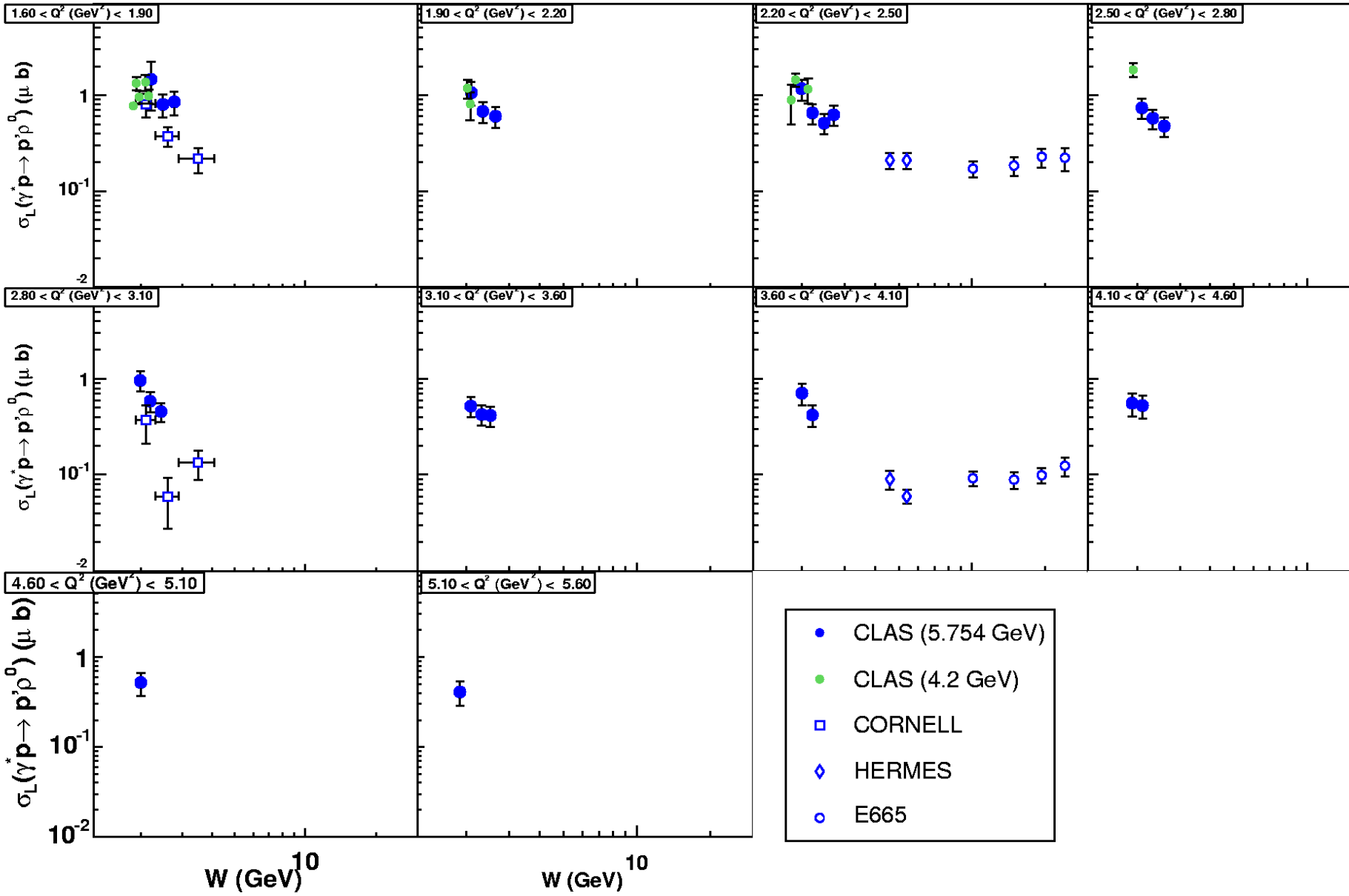
(exp. check to the ~25% level)

$$W(\cos\theta_{HS}) = \frac{3}{8}\left[(1 - r_{00}^{04}) + (3r_{00}^{04} - 1)\cos^2\theta_{HS}\right]$$

$$R = \frac{\sigma_L}{\sigma_T} = \frac{1}{\epsilon}\frac{r_{00}^{04}}{1 - r_{00}^{04}}$$



Longitudinal cross section $\sigma_L(\gamma^*_L p \to p\rho^0_L)$

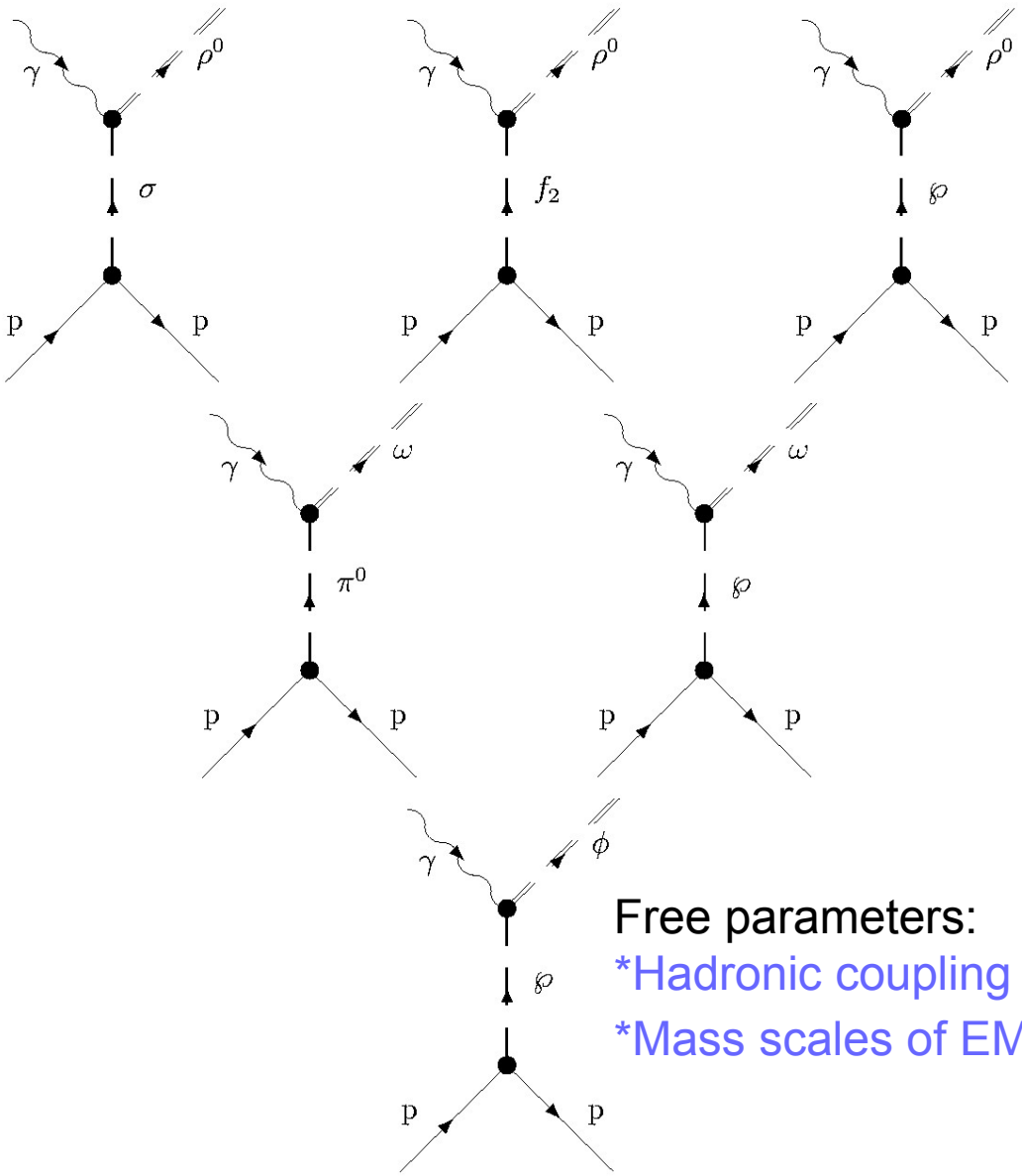


Interpretation "a la Regge" : Laget model

$\gamma^* p \to p\rho^0$

$\gamma^* p \to p\omega$

$\gamma^* p \to p\phi$

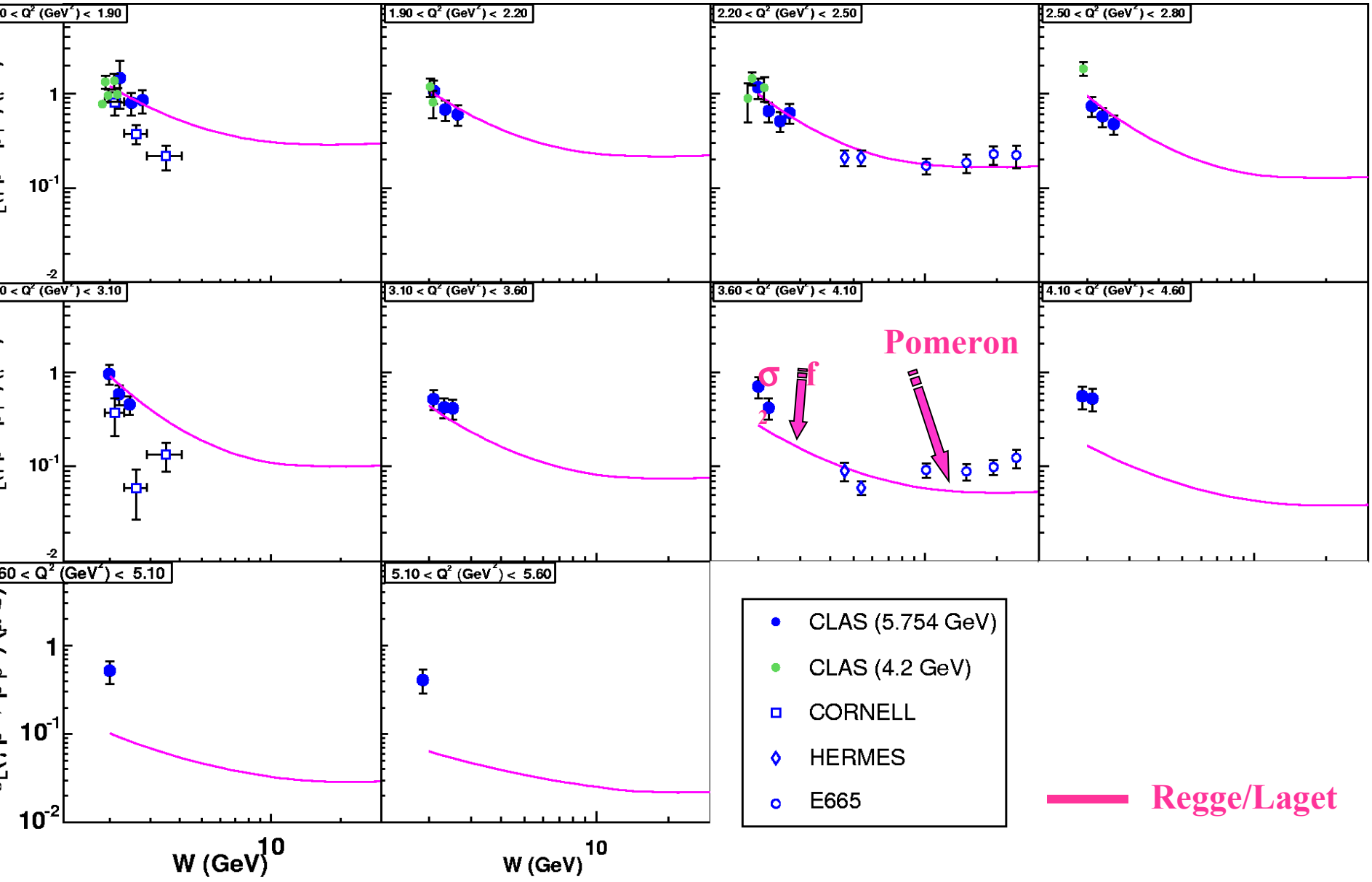


Free parameters:

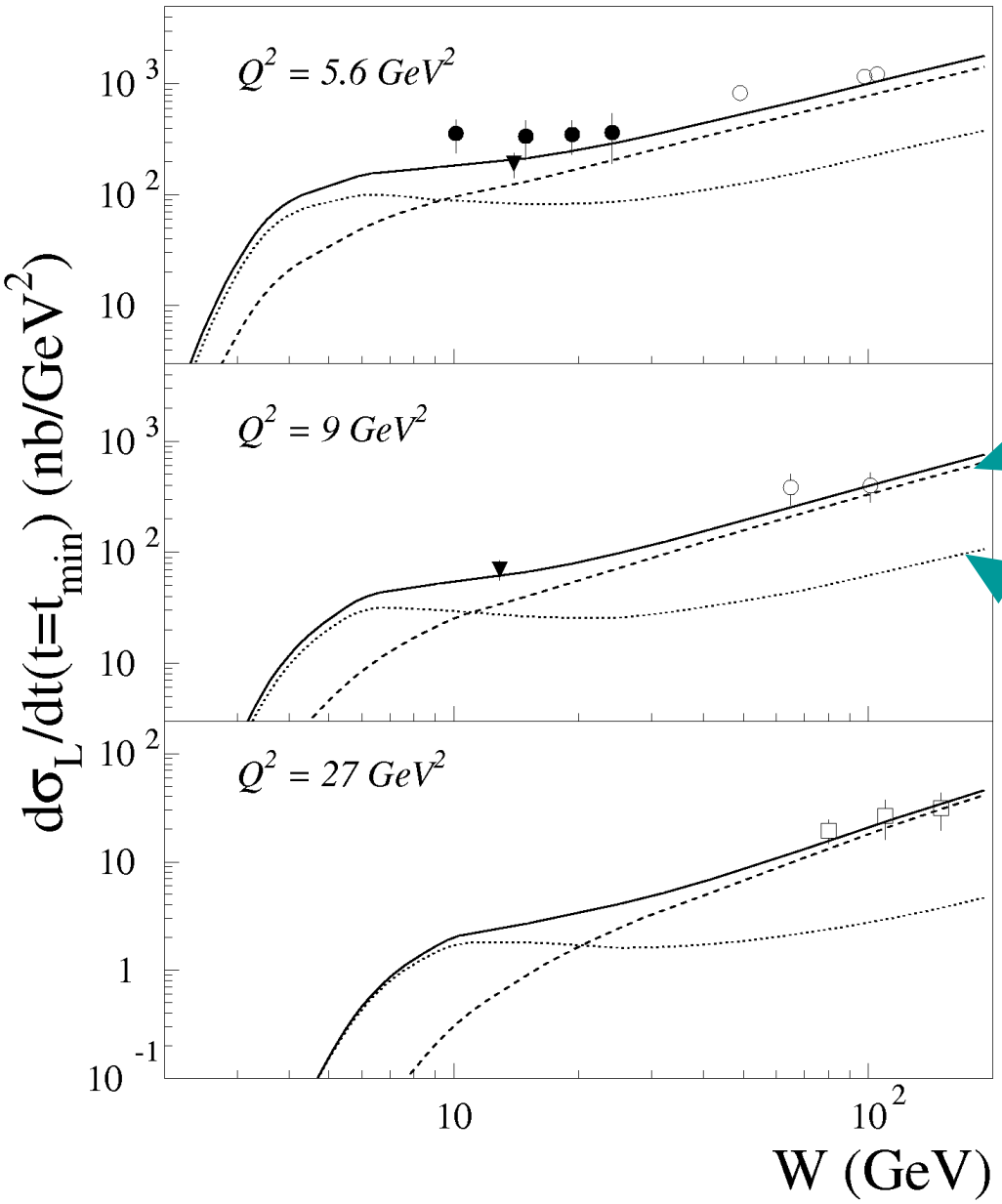
*Hadronic coupling constants: g_{MNN}

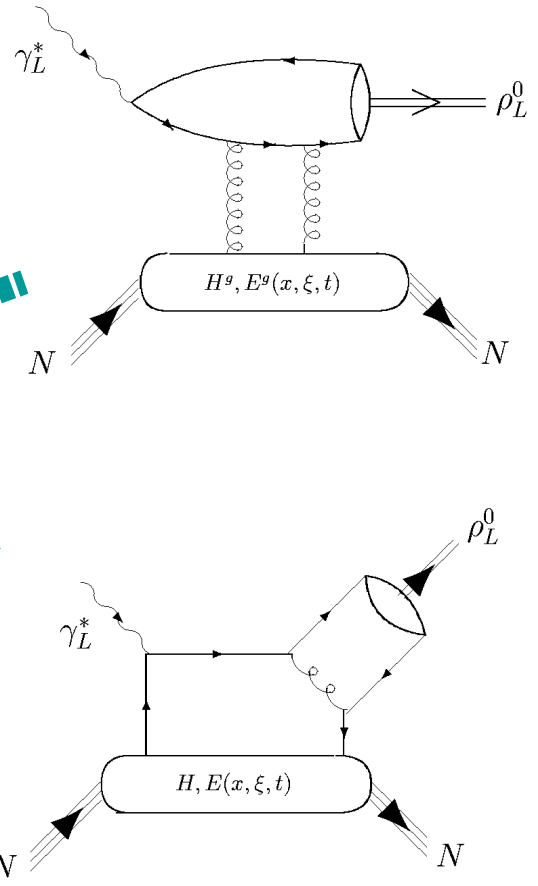
*Mass scales of EM FFs: $(1+Q^2/\Lambda^2)^{-2}$

$\sigma_L(\gamma^*_L p \to p\rho^0_L)$



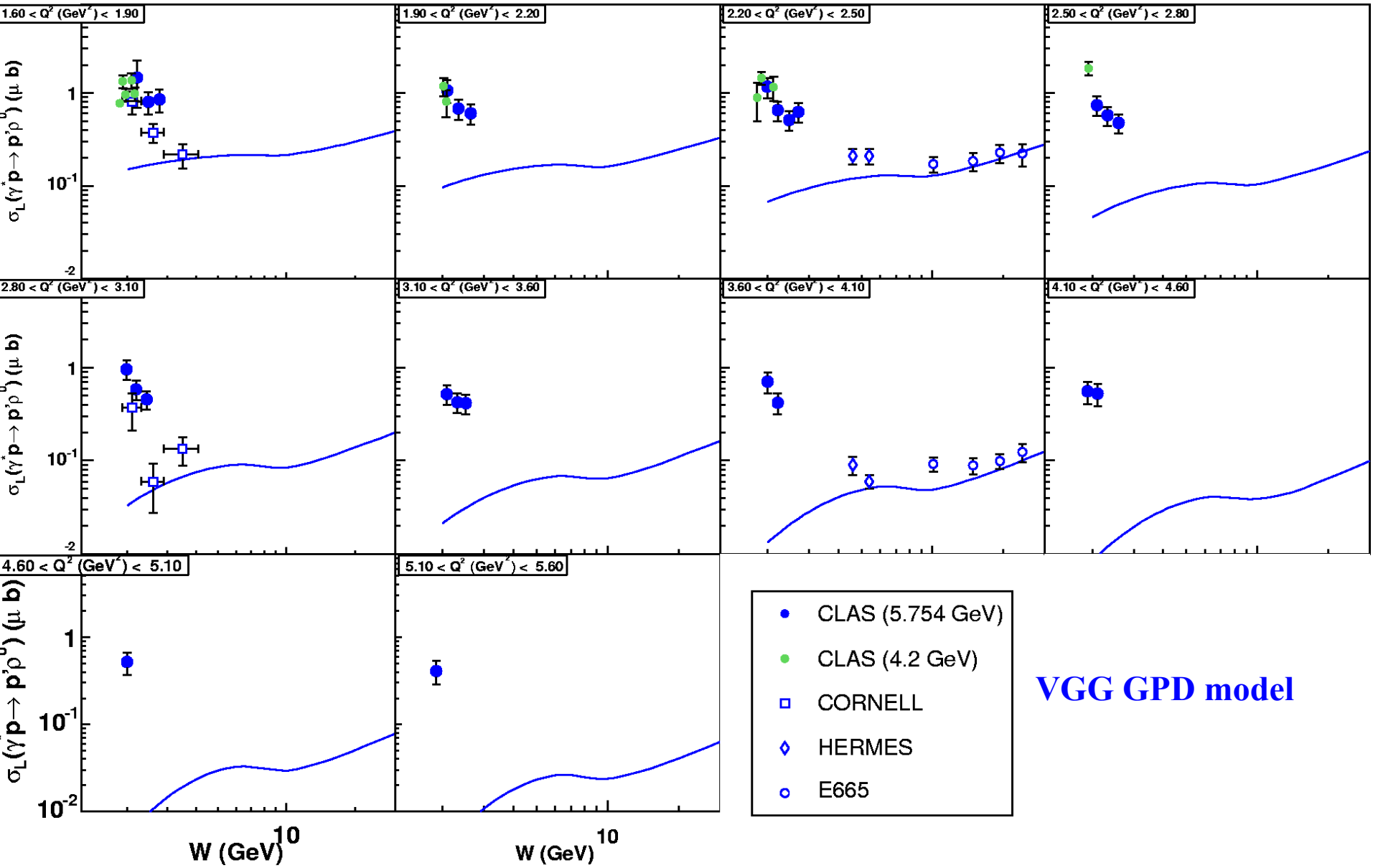
$\gamma^* + p \to \rho^0_L + p$

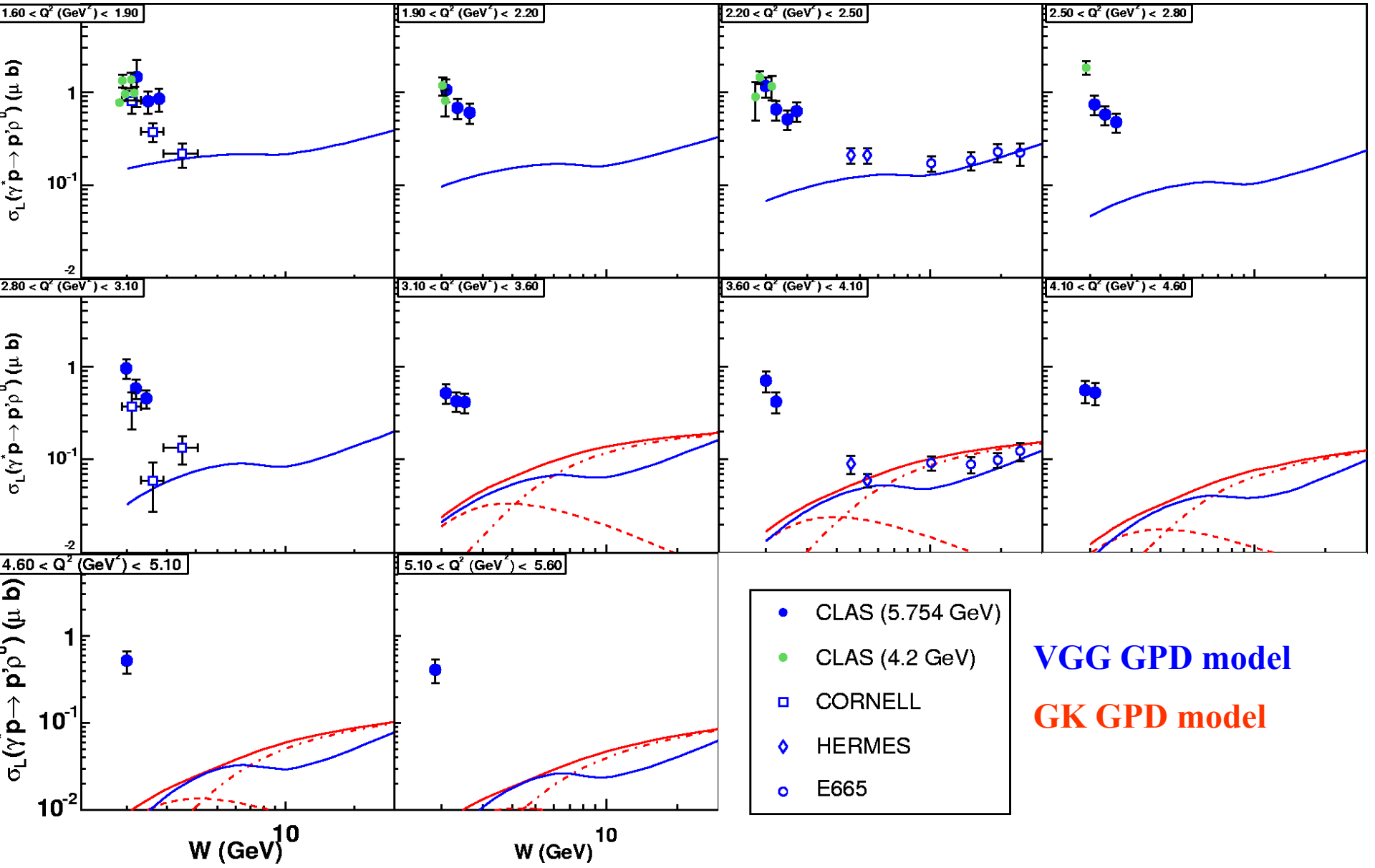




GPDs parametrization based on DDs (VGG/GK model)

Strong power corrections… but seems to work at large W…


1.60 < Q² (GeV²) < 1.90
1.90 < Q² (GeV²) < 2.20
2.20 < Q² (GeV²) < 2.50
2.50 < Q² (GeV²) < 2.80
2.80 < Q² (GeV²) < 3.10
3.10 < Q² (GeV²) < 3.60
3.60 < Q² (GeV²) < 4.10
4.10 < Q² (GeV²) < 4.60
4.60 < Q² (GeV²) < 5.10
5.10 < Q² (GeV²) < 5.60
σL(γ*p→p'ρ0) (μb)
W (GeV)
CLAS (5.754 GeV)
CLAS (4.2 GeV)
CORNELL
HERMES
E665
VGG GPD model


1.60 < Q² (GeV²) < 1.90
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σL(γ*p→p'ρ0) (μb)
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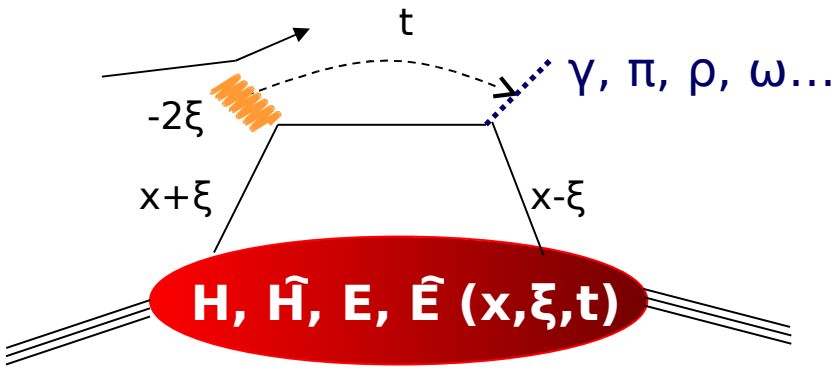
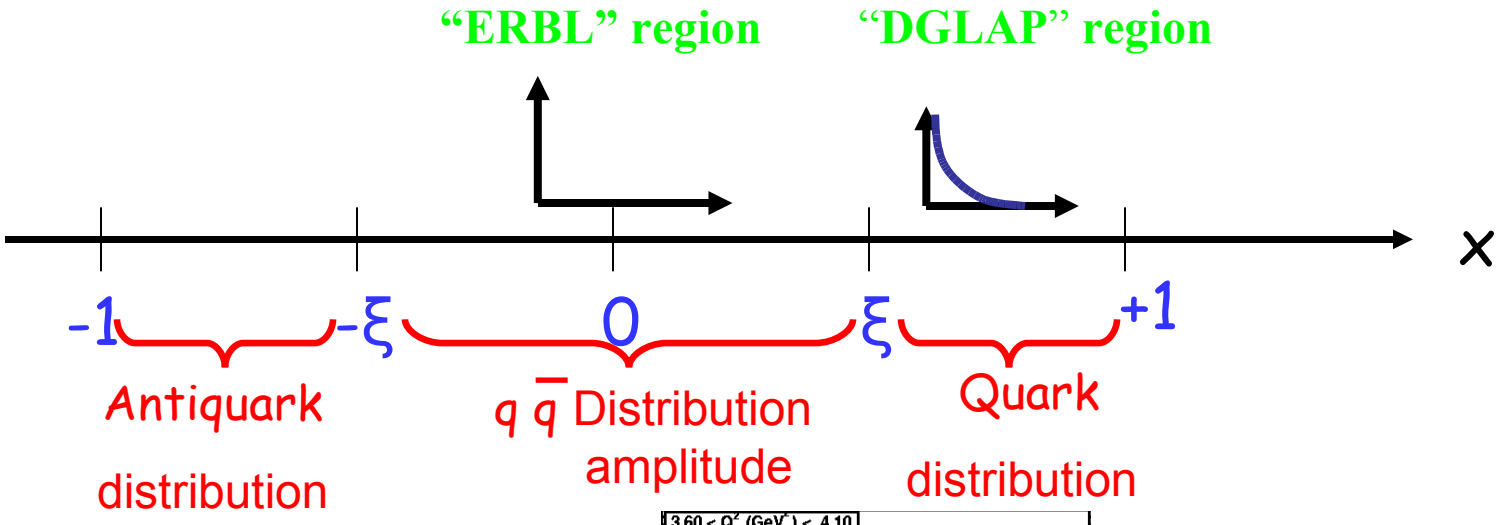
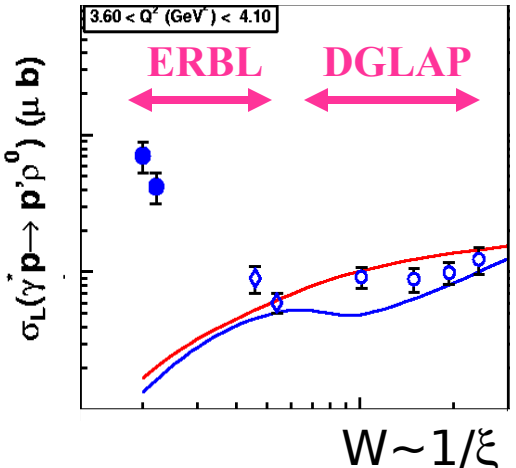
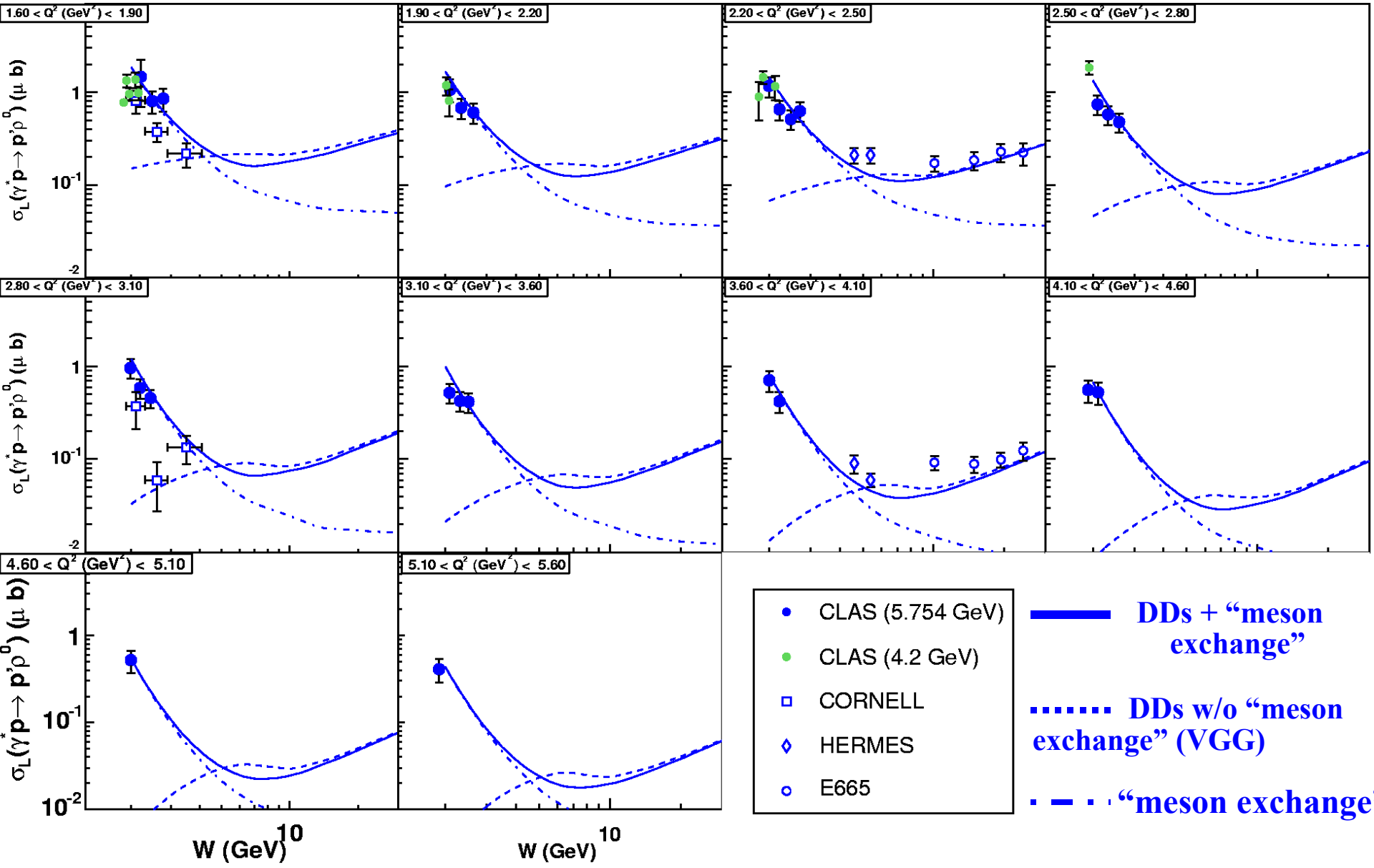

t
γ, π, ρ, ω…
-2ξ
x+ξ
x-ξ
H, H̃, E, Ẽ (x,ξ,t)


"ERBL" region
"DGLAP" region
x
-1
-ξ
0
ξ
+1
Antiquark distribution
q q̄ Distribution amplitude
Quark distribution


3.60 < Q² (GeV²) < 4.10
ERBL
DGLAP
W~1/ξ


1.60 < Q² (GeV²) < 1.90
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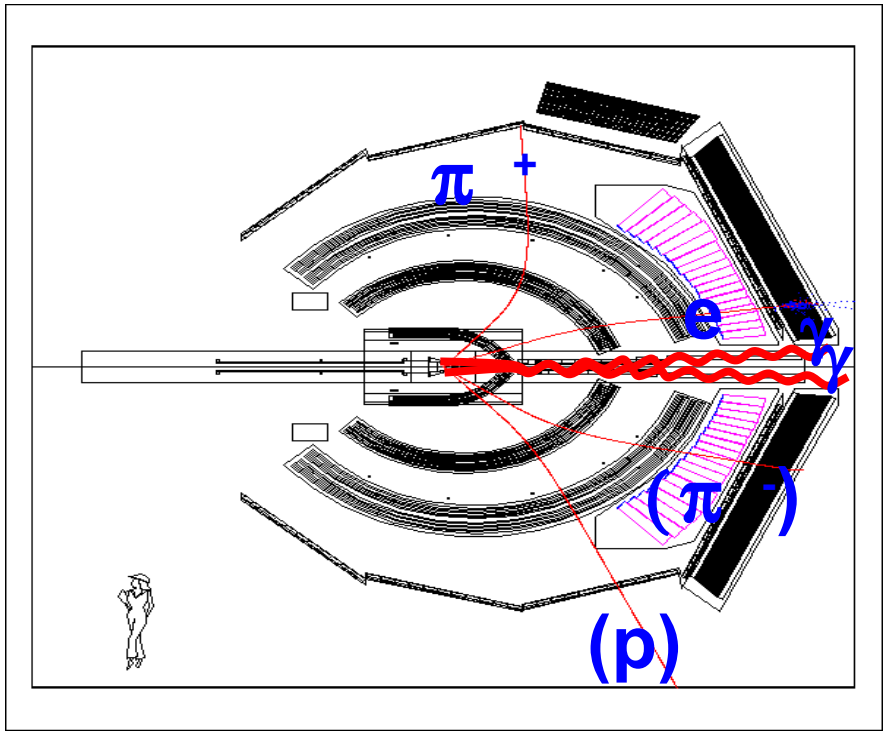
3.60 < Q² (GeV²) < 4.10
4.10 < Q² (GeV²) < 4.60
4.60 < Q² (GeV²) < 5.10
5.10 < Q² (GeV²) < 5.60
σL(γ*p→p'ρ0) (μb)
W (GeV)
CLAS (5.754 GeV)
CLAS (4.2 GeV)
CORNELL
HERMES
E665
DDs + "meson exchange"
DDs w/o "meson exchange" (VGG)
"meson exchange"

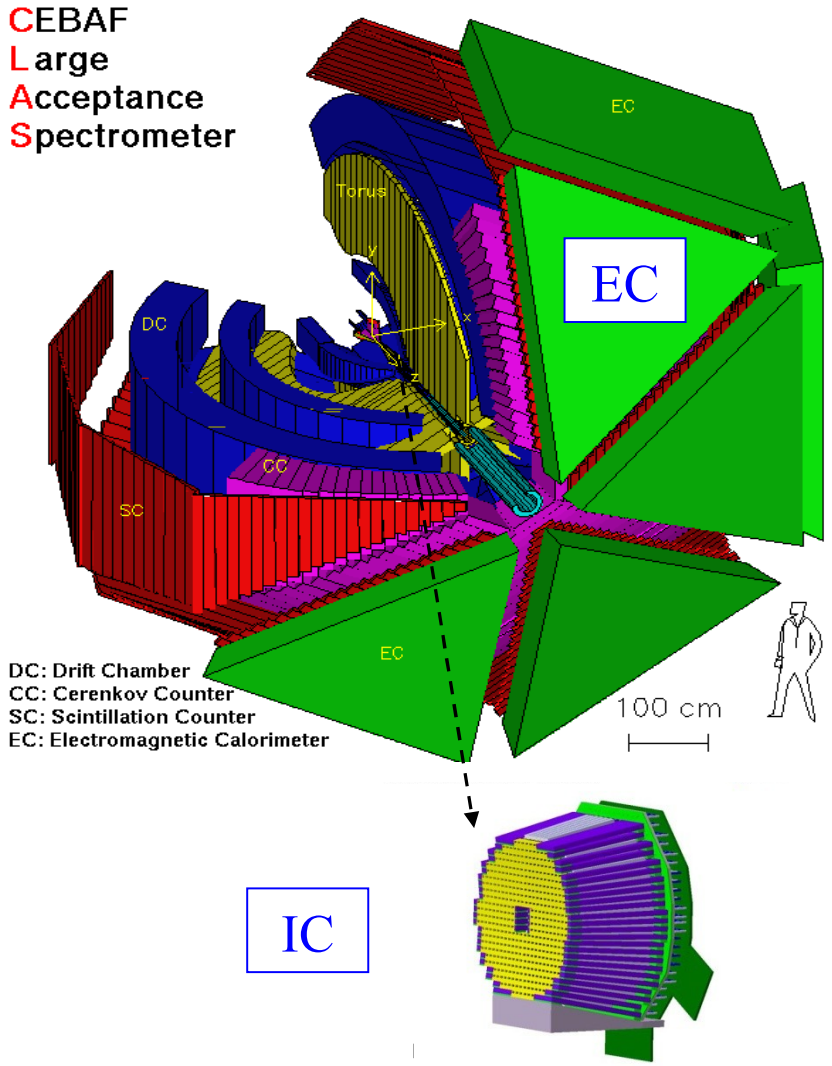
Exclusive ρ^+ electroproduction

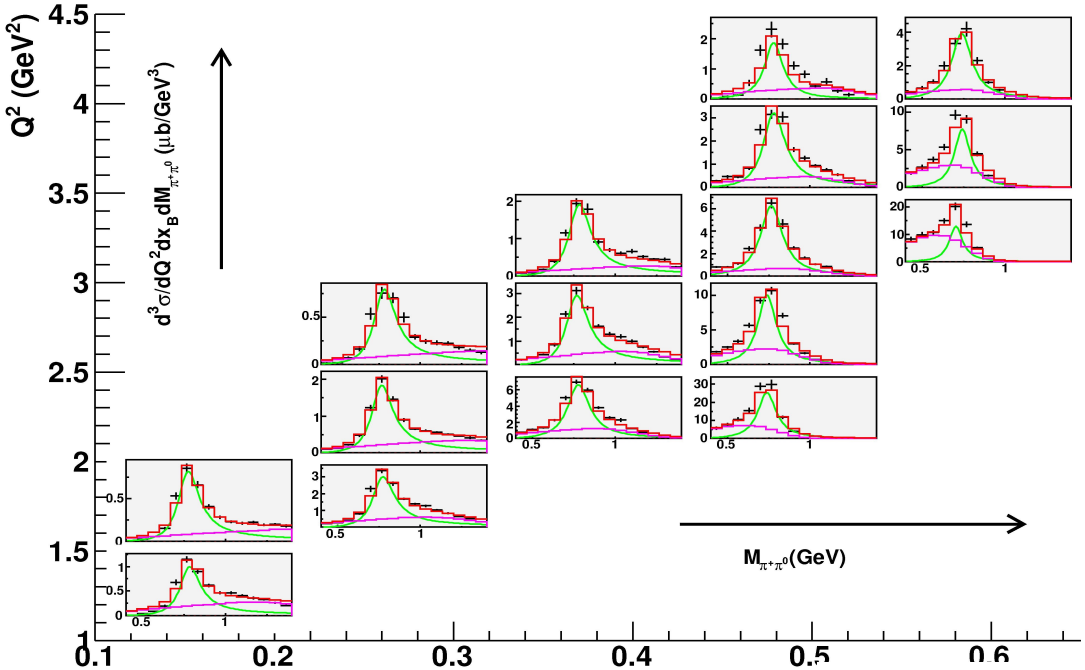
Channel selection

$p \rightarrow e' [n] \rho^{+} \rightarrow e' [n] \pi^{+} \pi^{0} \rightarrow e' [n] \pi^{+} \gamma \gamma$



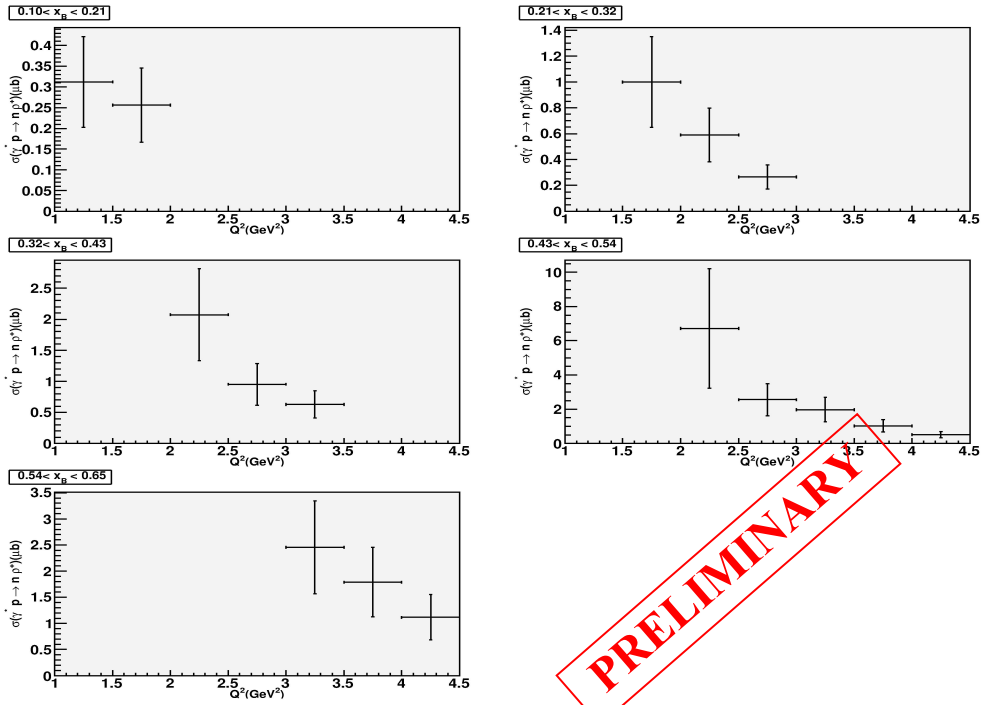
One event in CLAS



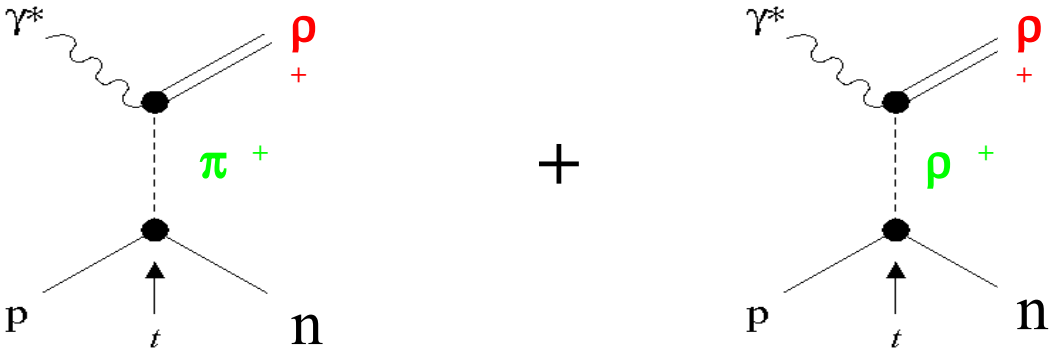


Invariant mass IM($\pi^+\pi^0$)

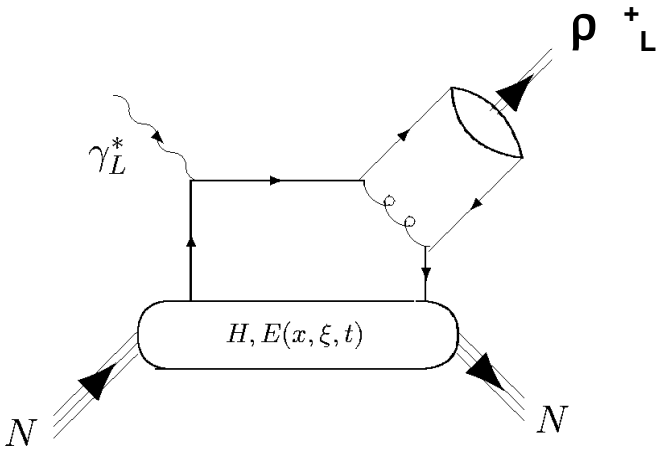
Total cross section σ (Q^2,x_B) ρ^+



Regge "hadronic" approach

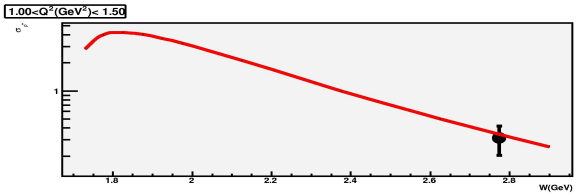


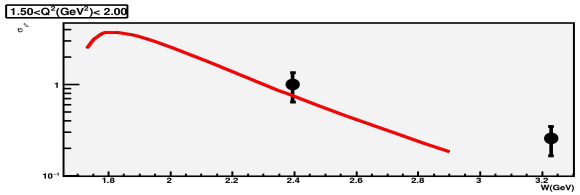
GPD "partonic" approach

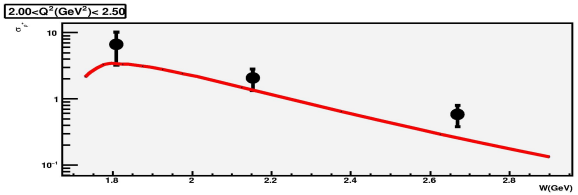


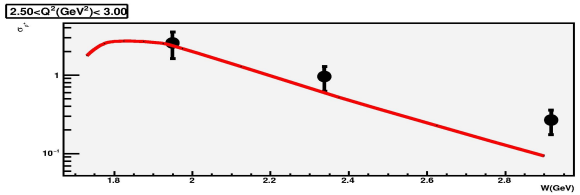
H , E

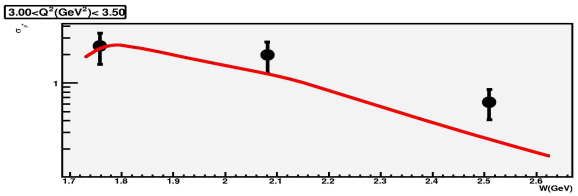
ρ^0	$e_u H^u - e_d H^d$ $e_u E^u - e_d E^d$
ω	$e_u H^u + e_d H^d$ $e_u E^u + e_d E^d$
ρ^+	$H^u - H^d$ $E^u - E^d$

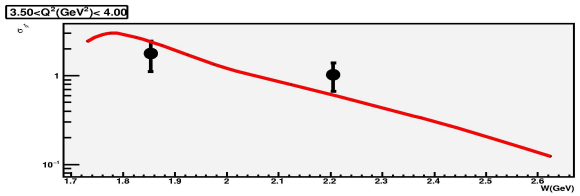


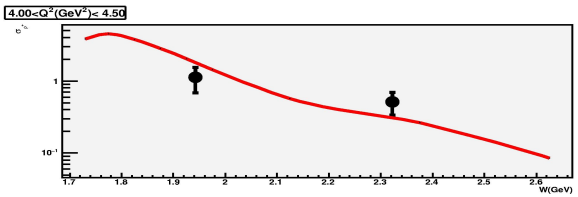








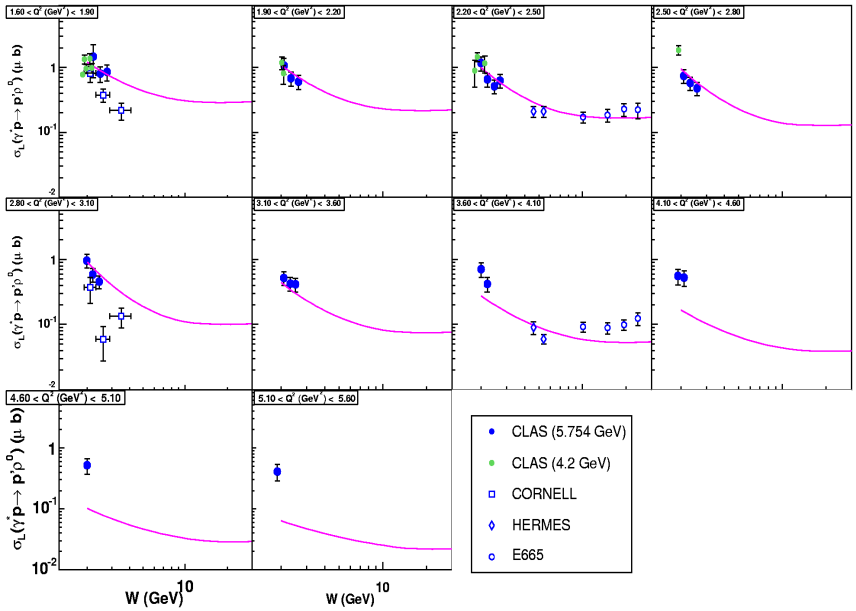




"Hadronic approach": Laget model

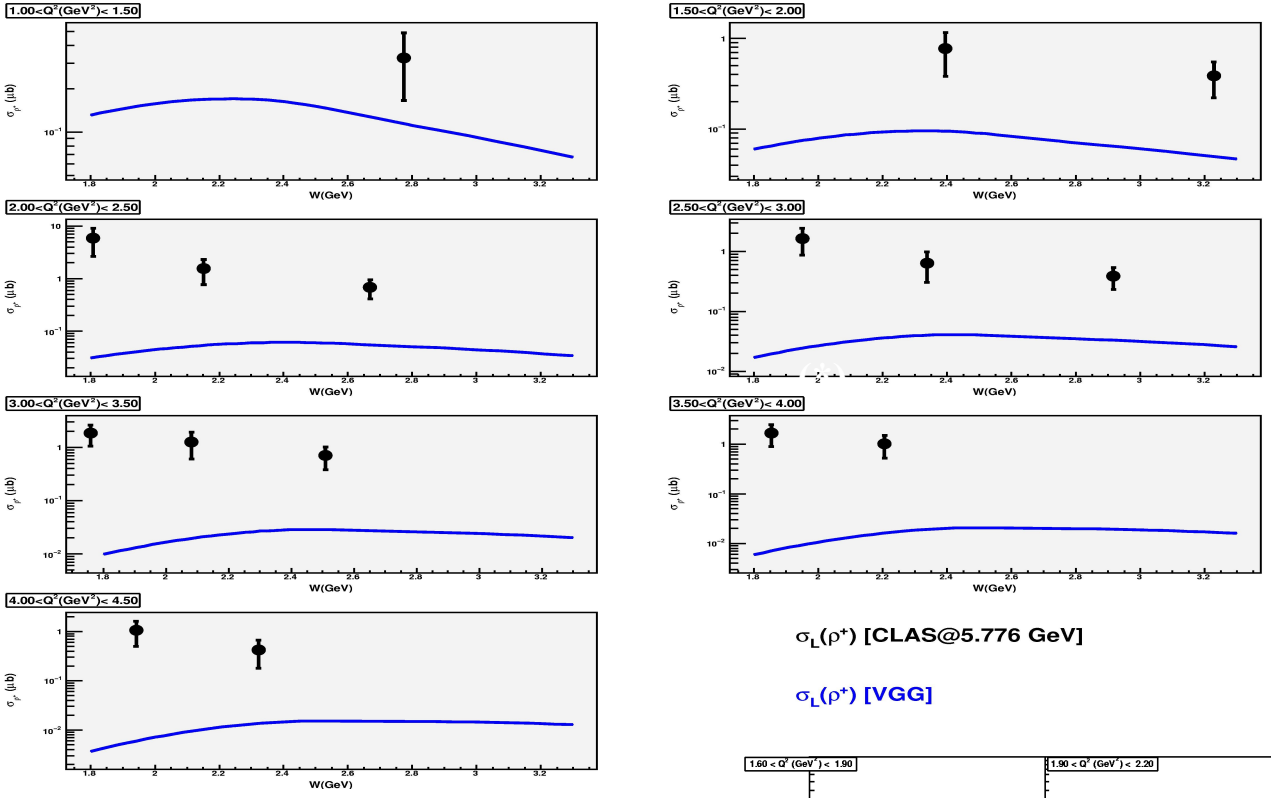
$\sigma(\rho^+)$ [CLAS@5.776 GeV]

$\sigma(\rho^+)$ [JML]



ρ^+

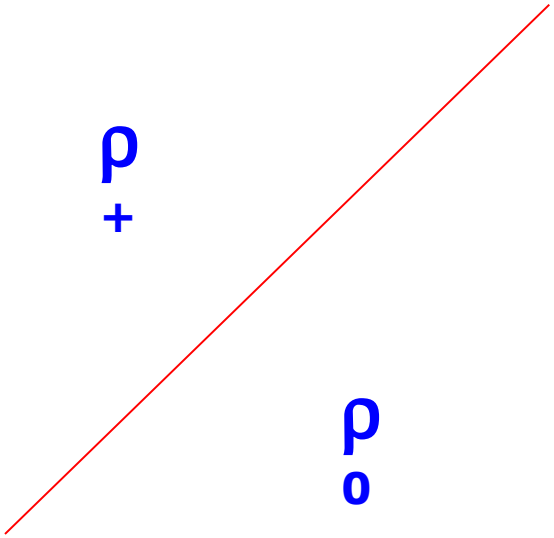
ρ^o

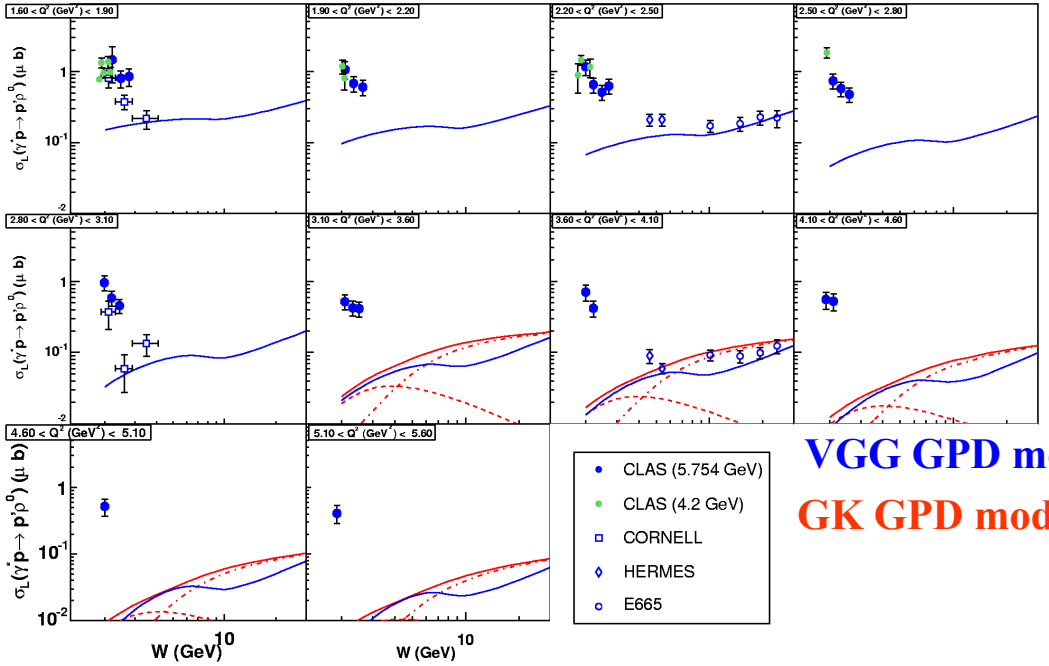


"Partonic approach": GPDs

$\sigma_L(\rho^+)$ [CLAS@5.776 GeV]

$\sigma_L(\rho^+)$ [VGG]





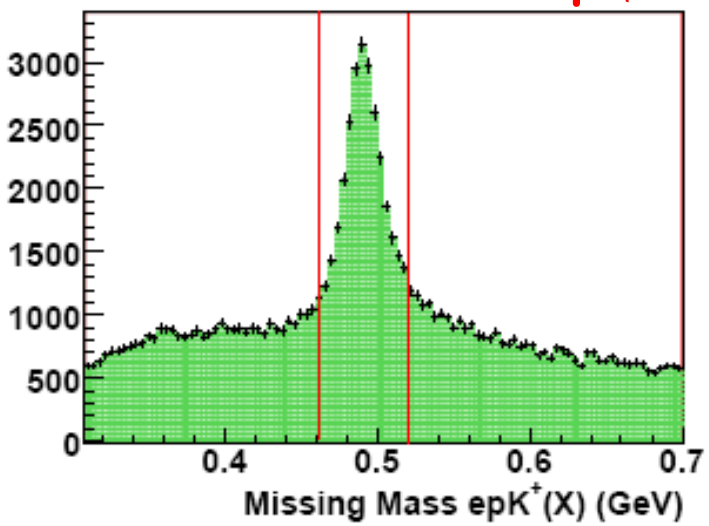
VGG GPD model

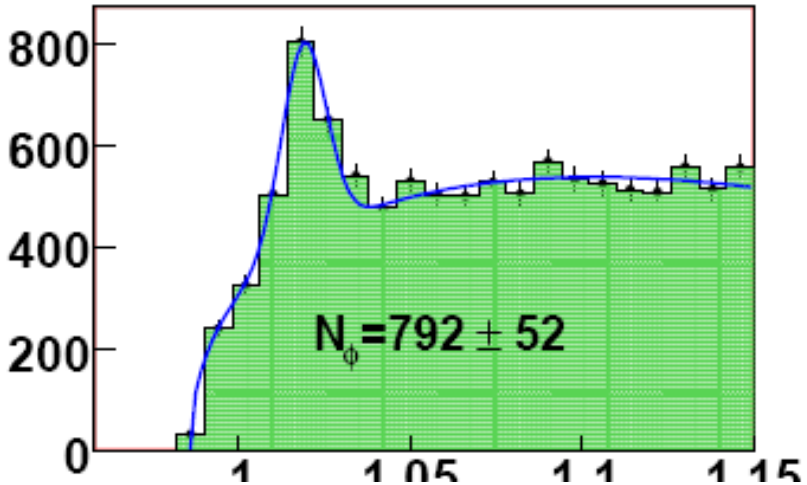
GK GPD model

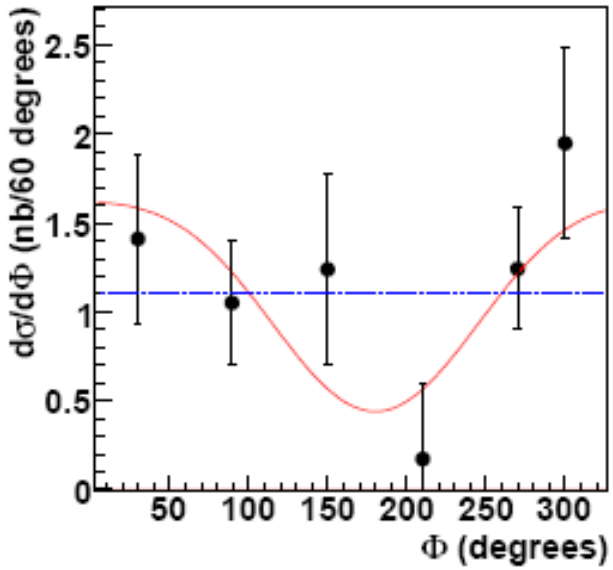
Exclusive ϕ electroproduction

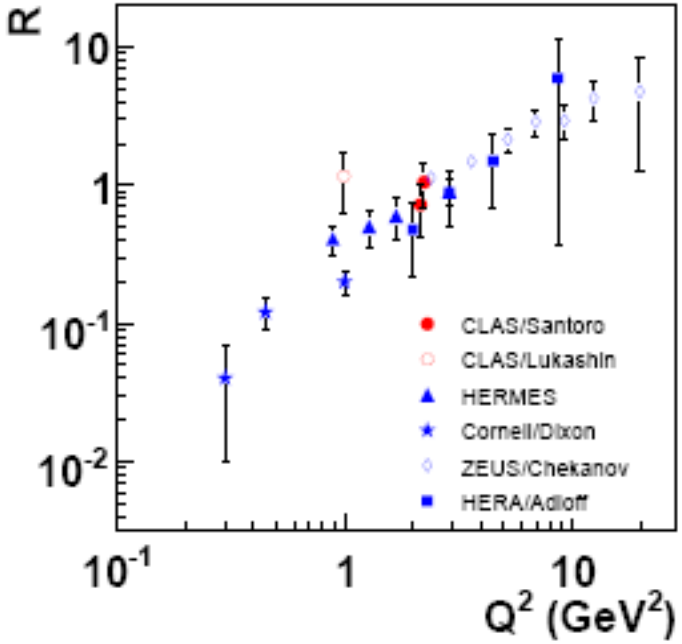
ep-

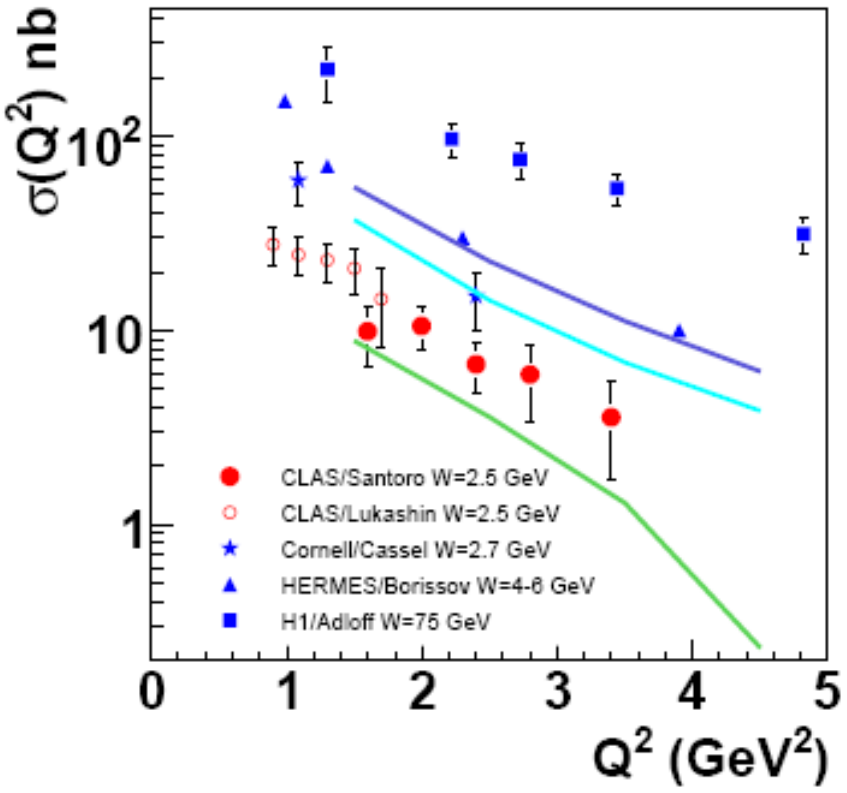
>epφ (


3000
2500
2000
1500
1000
500
0
0.4
0.5
0.6
0.7
Missing Mass epK+(X) (GeV)


800
600
400
200
0
Nφ=792 ± 52


dσ/dΦ (nb/60 degrees)
2.5
2
1.5
1
0.5
0
50
100
150
200
250
300
Φ (degrees)


R
10
1
10-1
10-2
10-1
1
10
Q2 (GeV2)
CLAS/Santoro
CLAS/Lukashin
HERMES
Cornell/Dixon
ZEUS/Chekanov
HERA/Adloff

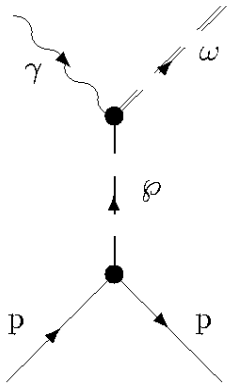


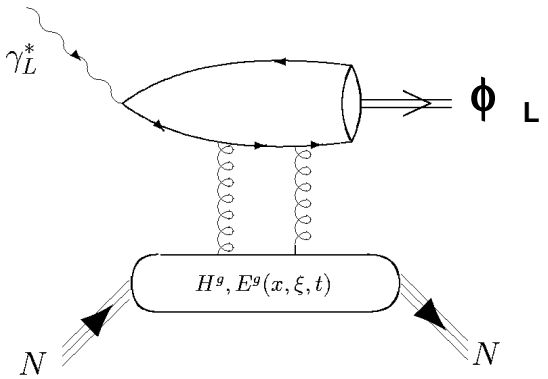
Laget $\sigma_T + \varepsilon\,\sigma_L$

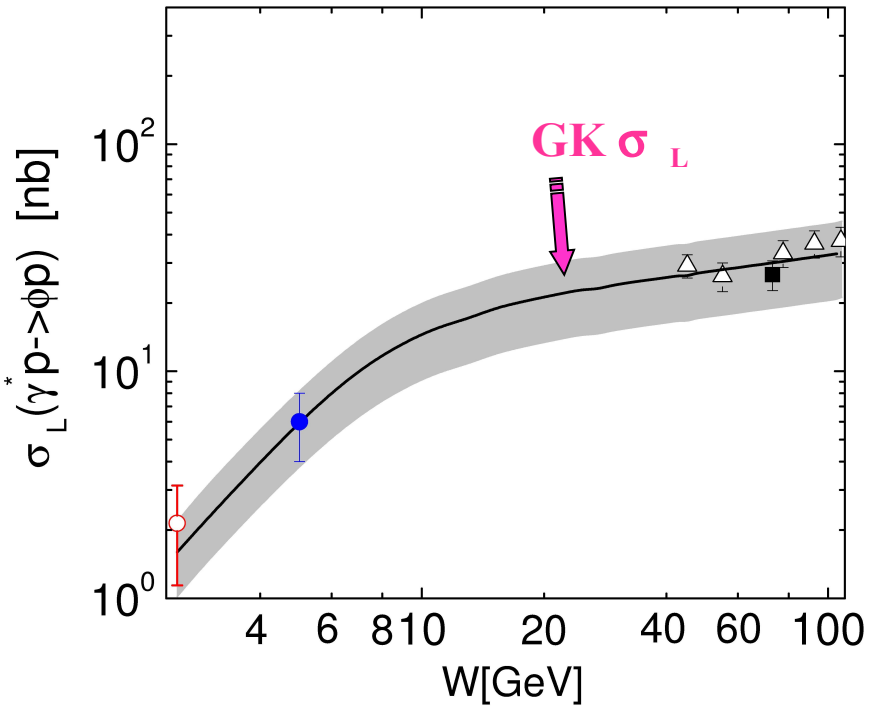
W=2.9 GeV

W=2.45 GeV

W=2.1 GeV





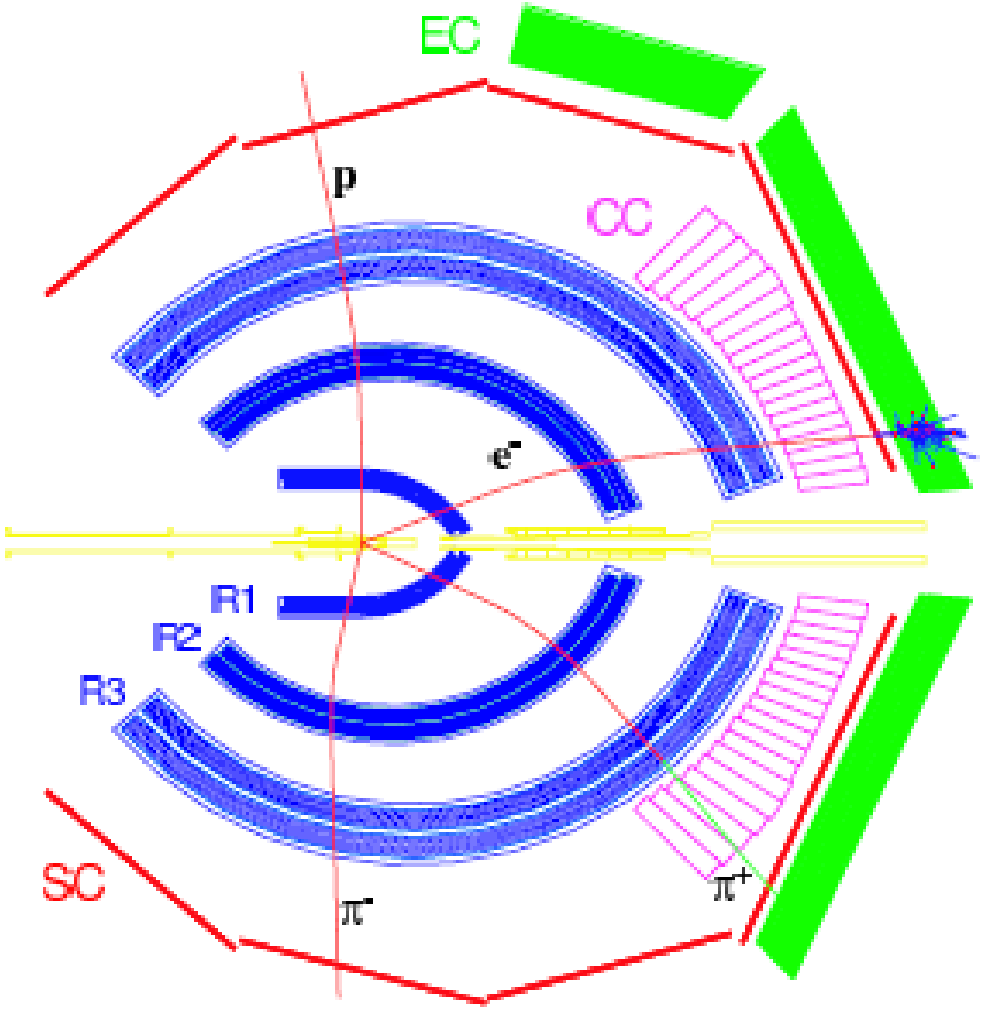


Exclusive ω electroproduction

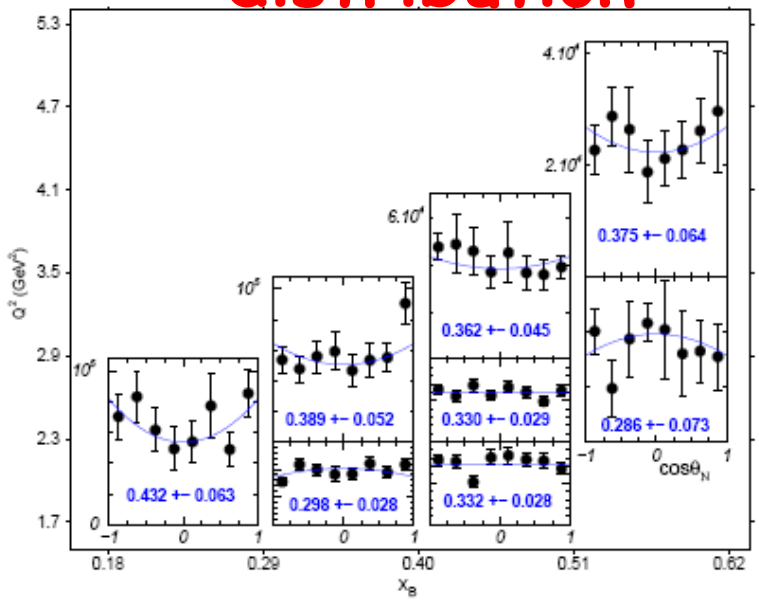
ep-

>epω (↳ π +π −[π

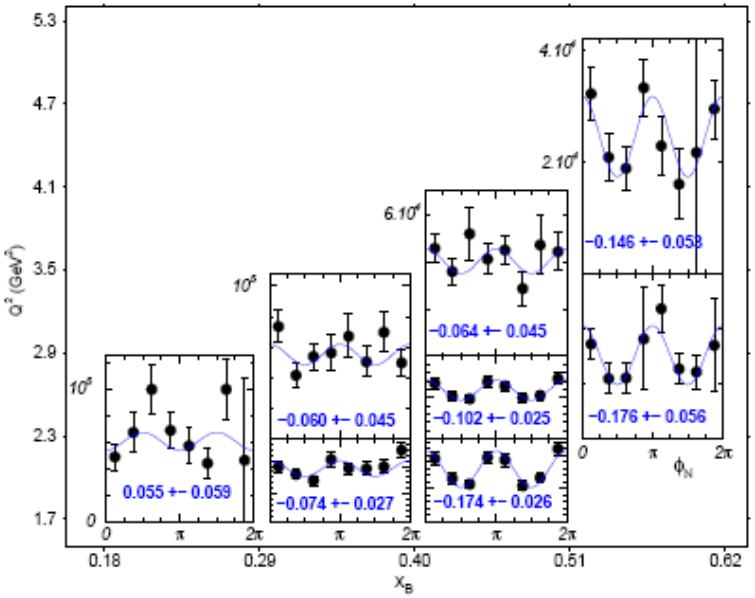
0])

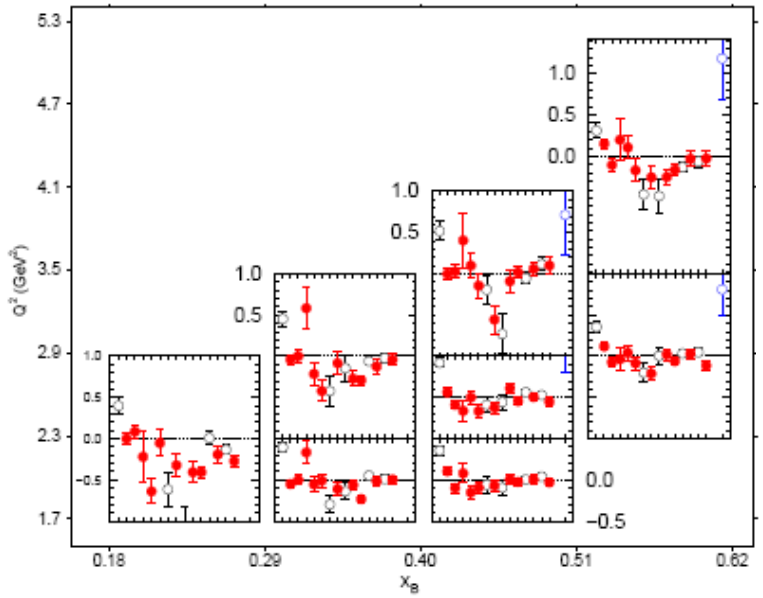


$\cos(\theta_{cm})$ distribution



ϕ_{cm} distribution



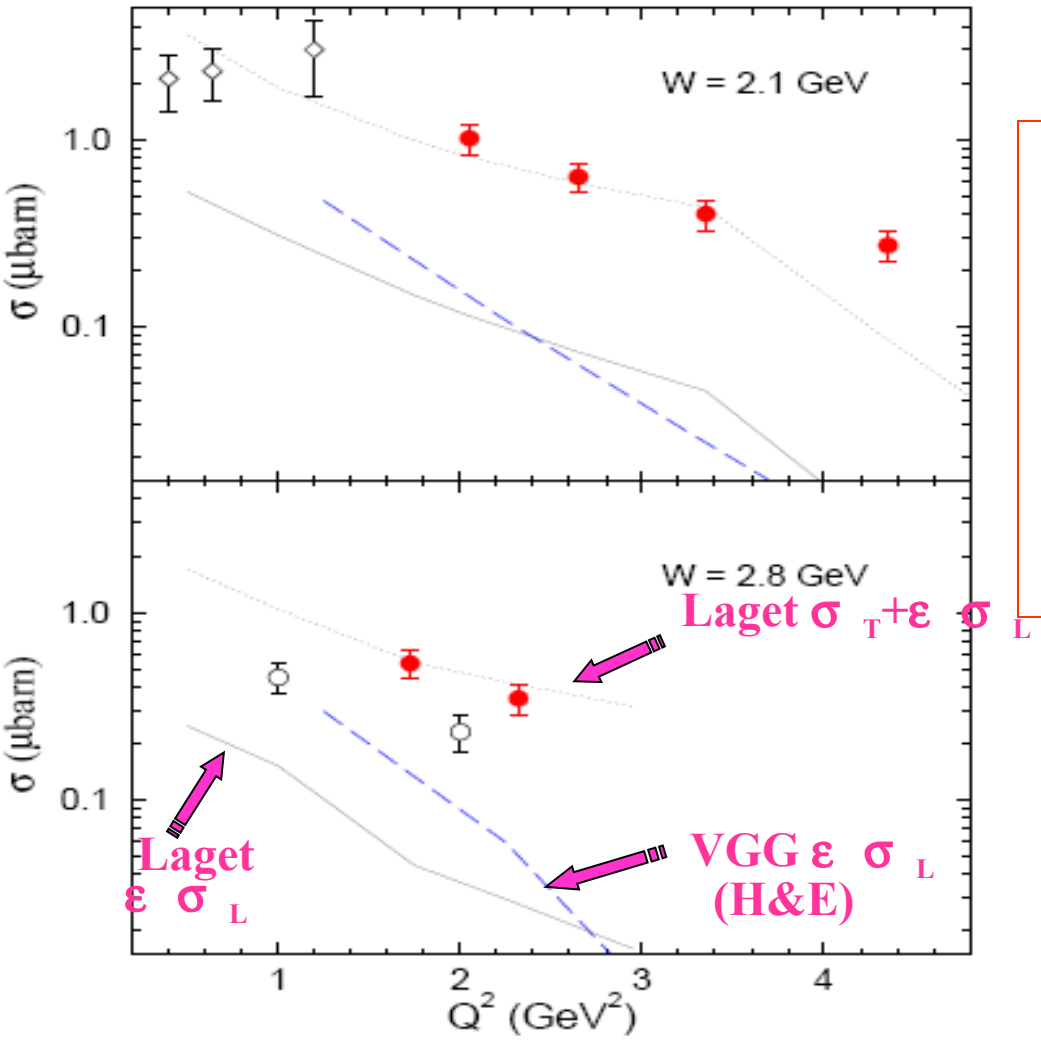


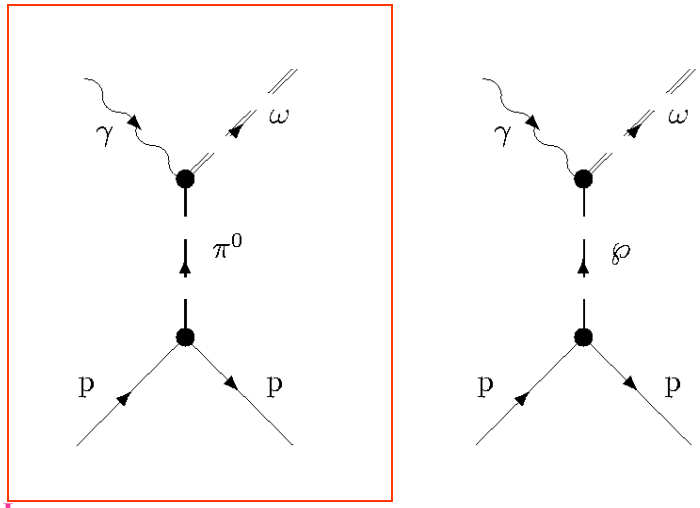
The abscissa on each graph corresponds to the following list of matrix elements: r^{04}_{00}, Re r^{04}_{10}, r^{04}_{1-1}, r^{1}_{00}, r^{1}_{11}, Re r^{1}_{10}, r^{1}_{1-1}, Im r^{2}_{10}, Im r^{2}_{1-1}, r^{5}_{00}, r^{5}_{11}, Re r^{5}_{10}, r^{5}_{1-1}, Im r^{6}_{10}, Im r^{6}_{1-1}. The red filled symbols indicate those matrix elements which are zero if SCHC applies.

Cross section $\sigma(\gamma^* p \to p\omega)$

Laget Regge model

for $\gamma^* p \to p\omega$





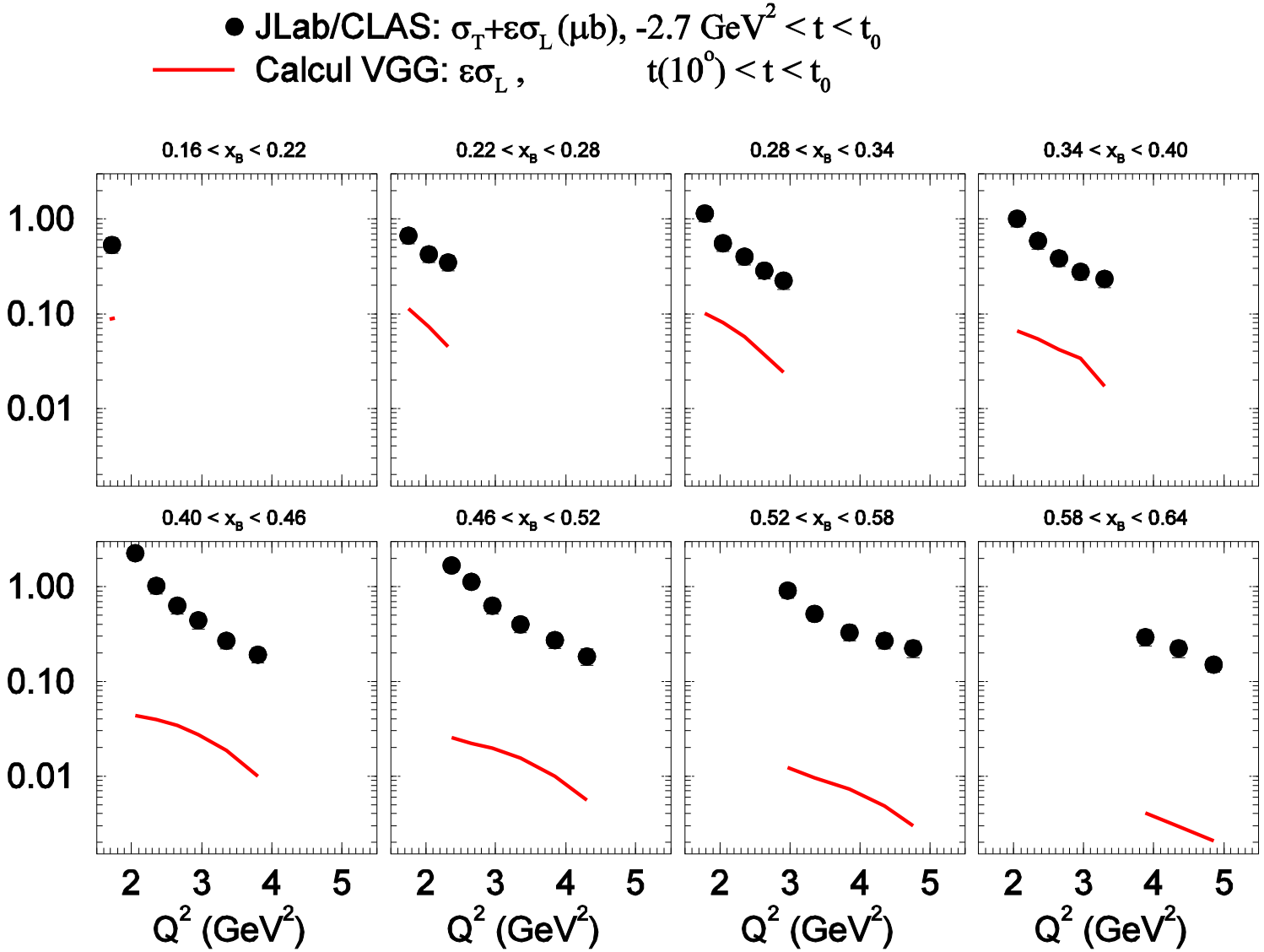
Issue with GPD approach if π^0 exchange dominant :

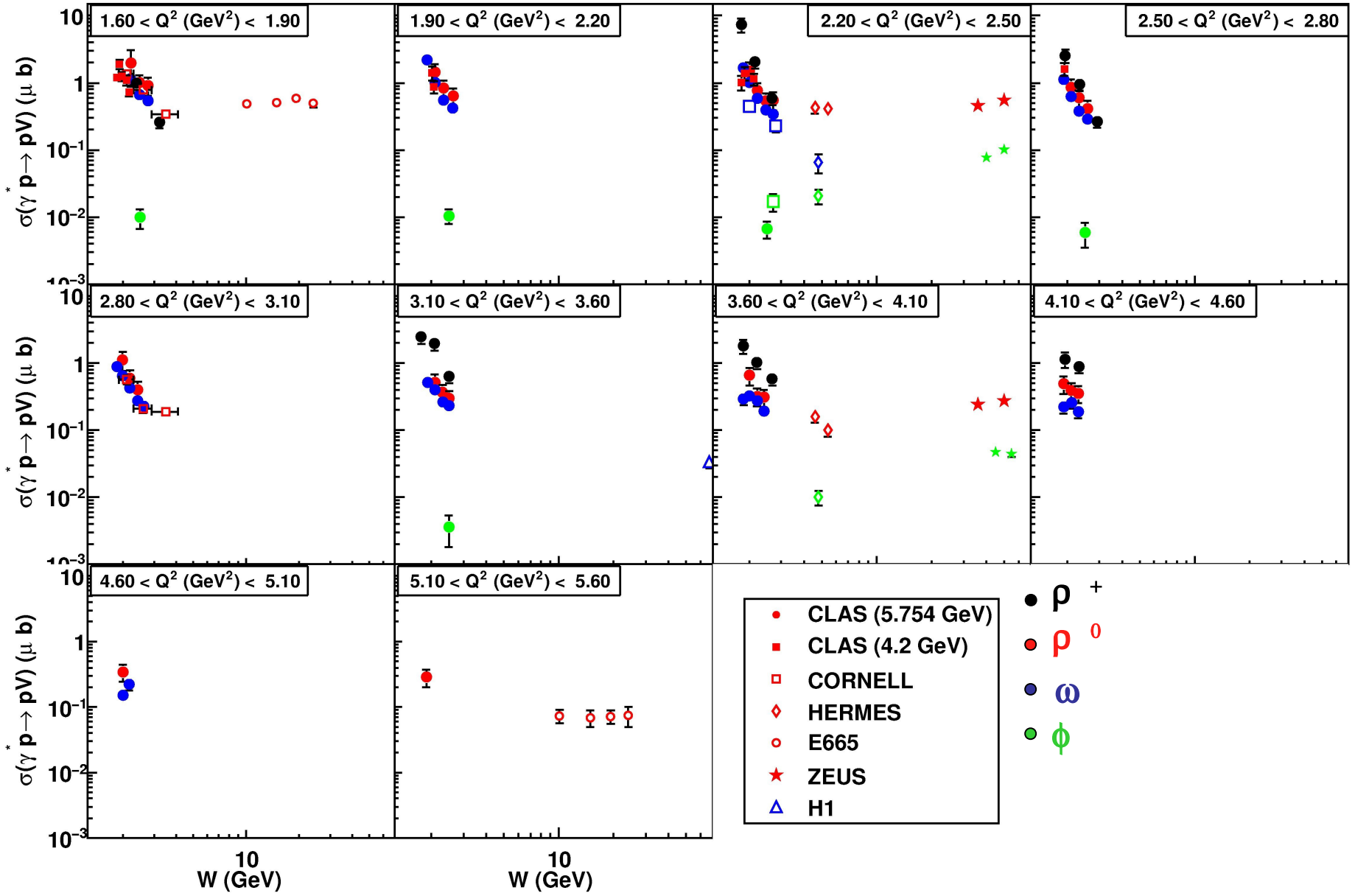
$\pi^0 \to \tilde{E}$

while

$\tilde{E}$ subleading in handbag for VM production

Cross section σ ($\gamma^* p \rightarrow p\omega$)
–Comparison with GPD calculation (VGG)-





C. Hadjidakis et al., Phys.Lett.B605:256-264,2005 (ρ ^{0}@4.2 GeV)

L. Morand et al., Eur.Phys.J.A24:445-458,2005 (ω @5.75GeV)

K. Lukashin, Phys.Rev.C63:065205,2001 (φ @4.2 GeV)

S. Morrow et al., Eur.Phys.J.A39:5-31,2009 (ρ ^{0}@5.75GeV)

J. Santoro et al., Phys.Rev.C78:025210,2008 (φ @5.75GeV)

A. Fradi, Orsay Univ. PhD thesis, 2009 (ρ $^+$@5.75GeV)

- Largest set ever of data for VM ($\rho^0, \omega, \phi, \rho^+$) production in the valence region ($\sigma_{L,T}$, $d\sigma/dt$,…)

- Laget Regge model describes well most of the features of ($\rho^0, \omega, \phi, \rho^+$) cross sections (total and diff., L and T) up to $Q^2 \sim 3.5\ GeV^2$.

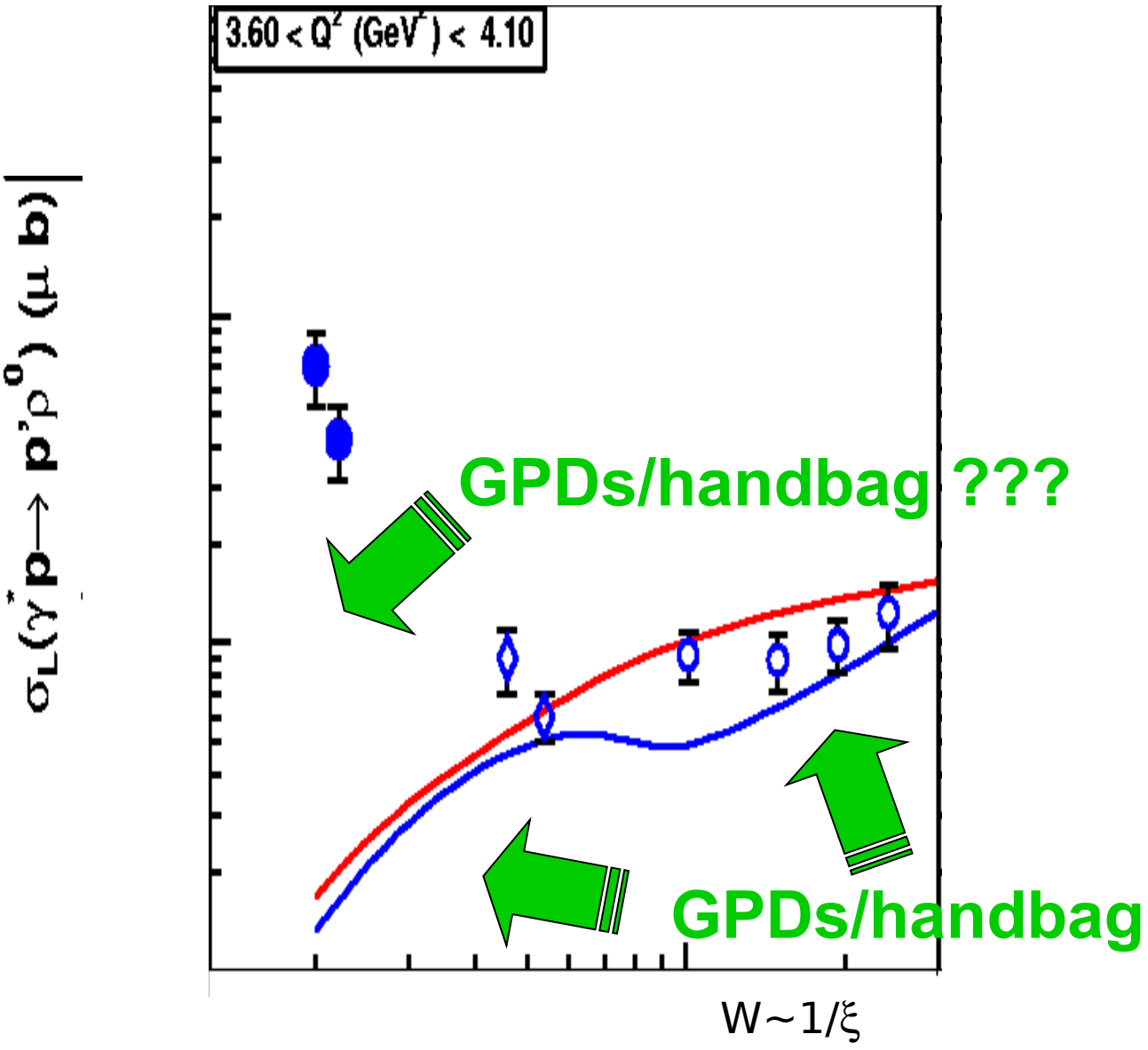
- GPD handbag approach, though with large corrections (k_{perp}), Describes well data for $W > \sim 5\ GeV$ for the (ρ^0, ω, ϕ) channels.

  For ϕ channel: continues to work for $W < \sim 5\ GeV$

  For ρ^0 channel: fails by large for $W < \sim 5\ GeV$ (can potentially be cured by adding new contribution to GPD DD parametrisation)

  For ω channel: fails by large for $W < \sim 5\ GeV$ (won't be cured by the same ansatz than the ρ^0; π^0 vs H&E VM GPD dominance)

  For ρ^+ channel: fails by large for $W < \sim 5\ GeV$ (won't be cured by the same ansatz than the ρ^0; π^+, ρ^+ exchanges are higher-twist)


3.60 < Q² (GeV²) < 4.10
σL(γ*p → p'ρ⁰) (μ b)
GPDs/handbag ???
GPDs/handbag
W~1/ξ

Motivation to go to higher Q^2 (but stay in valence region):

- ***Approach asymptotic regime and test validity of power corrections***

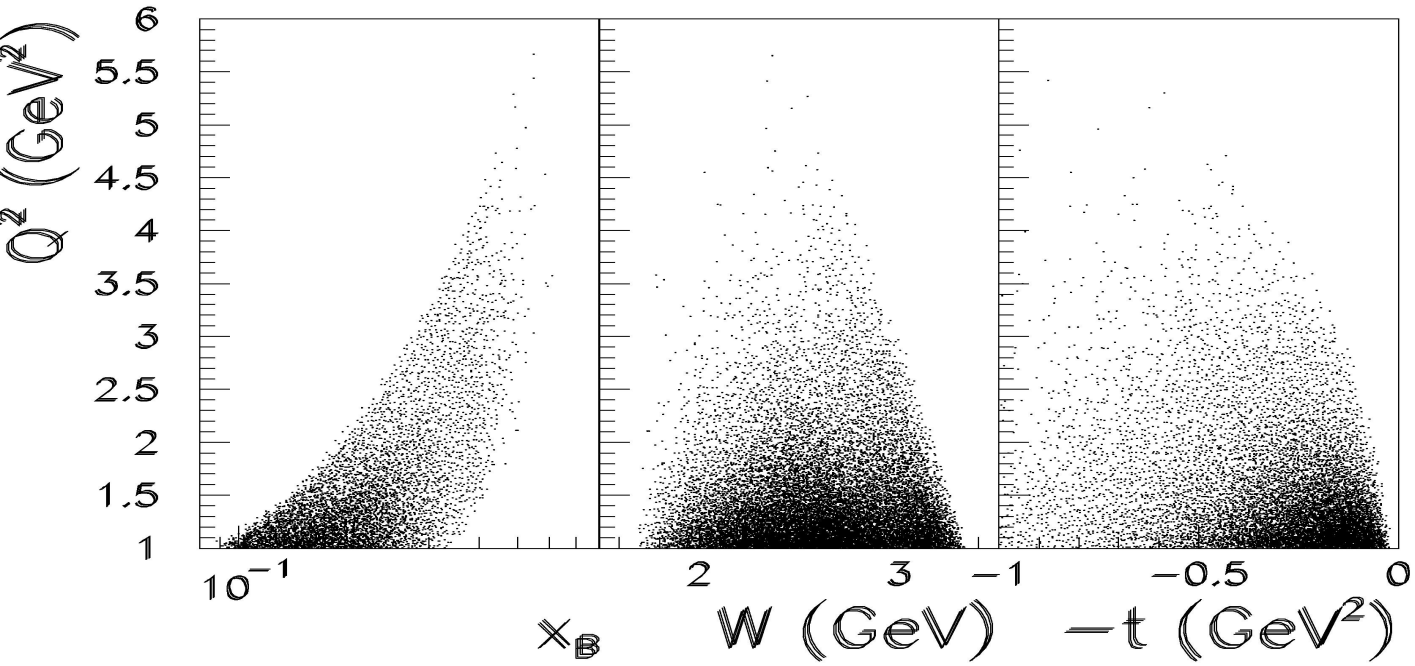
- ***If (power corrected) handbag diagram in valence region: same Q^2 dependence at low W than at large W:***
  ρ^0 and ϕ should be different from ω and ρ^+, these latter having higher-twist t-channel exchanges

- ***If higher twist contribution in valence region: cross section will drop faster as a function of Q^2 at low W than at large W:***

Overview of existing data (valence region)

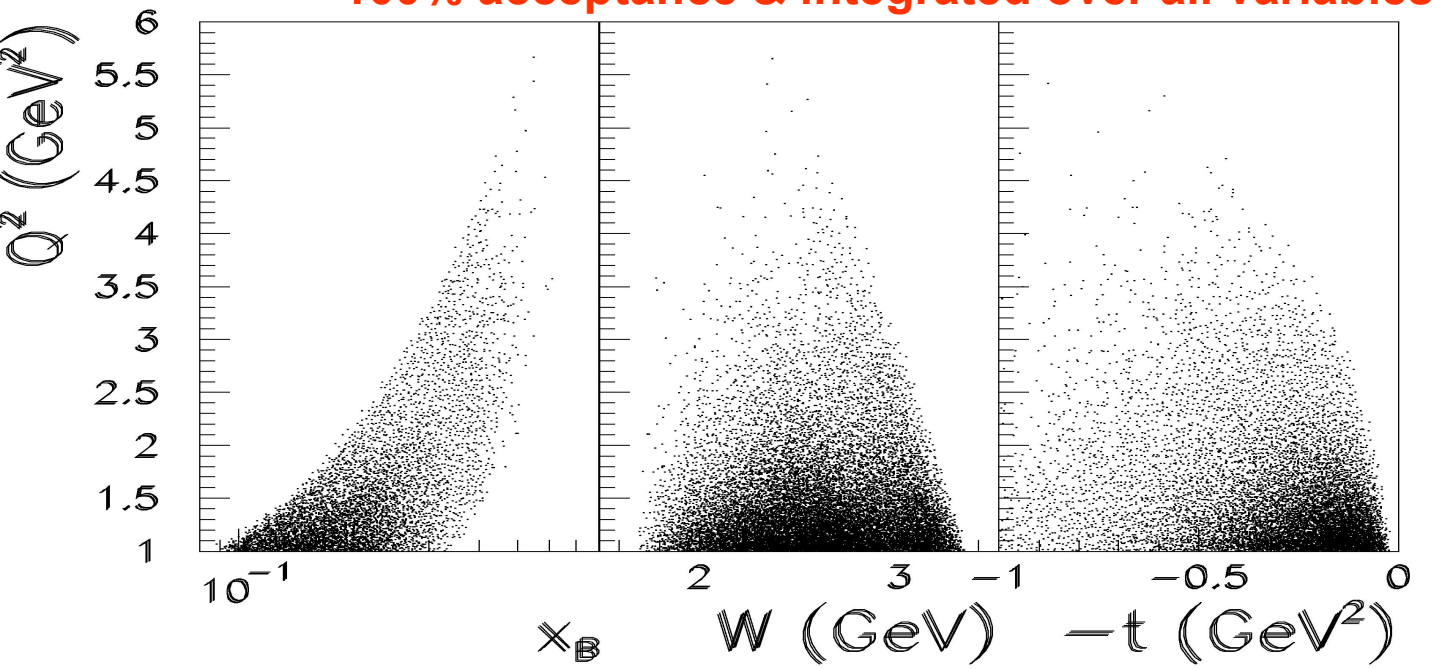
- ρ^0, ω, ϕ & ρ^+ electroproduction on the proton @ CLAS6
- *GPDs or not GPDs ?*

Perspectives with CLAS12 & EIC

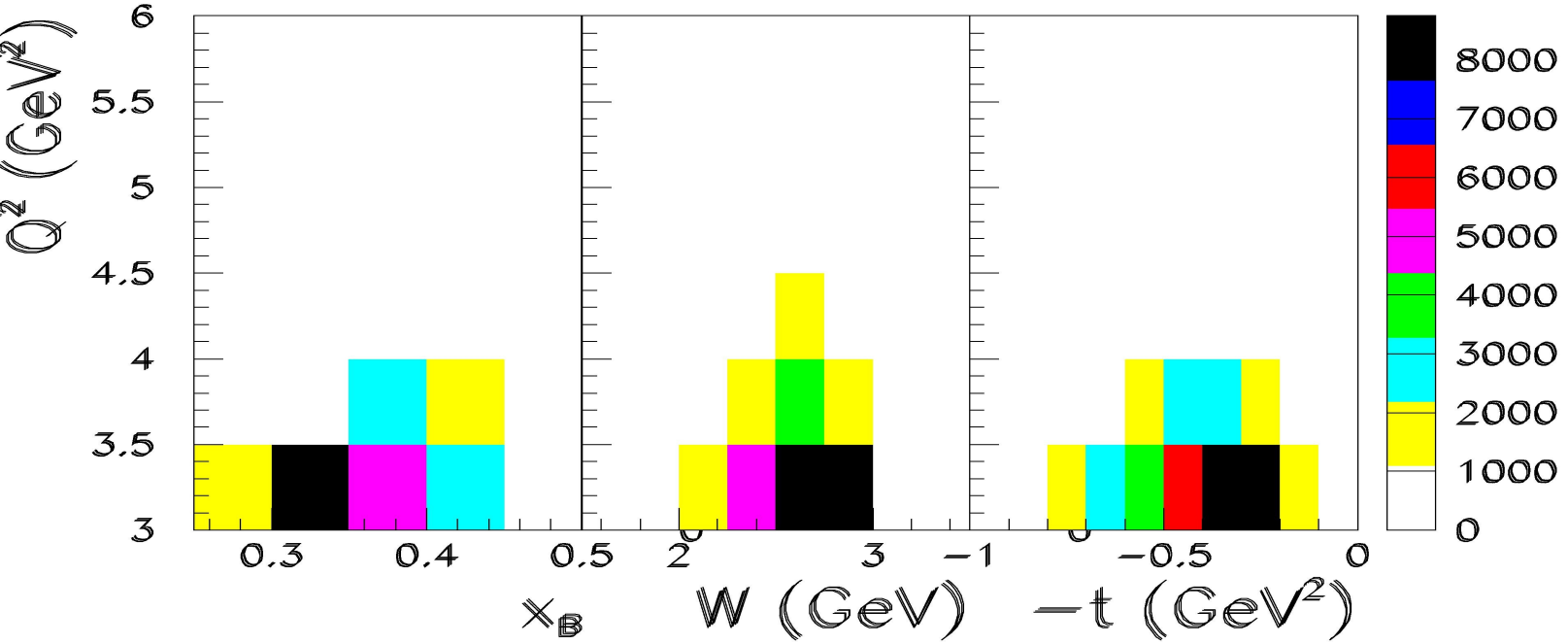


6 GeV e
fixed p target

100% acceptance & integrated over all variables but (x_B,Q^2)

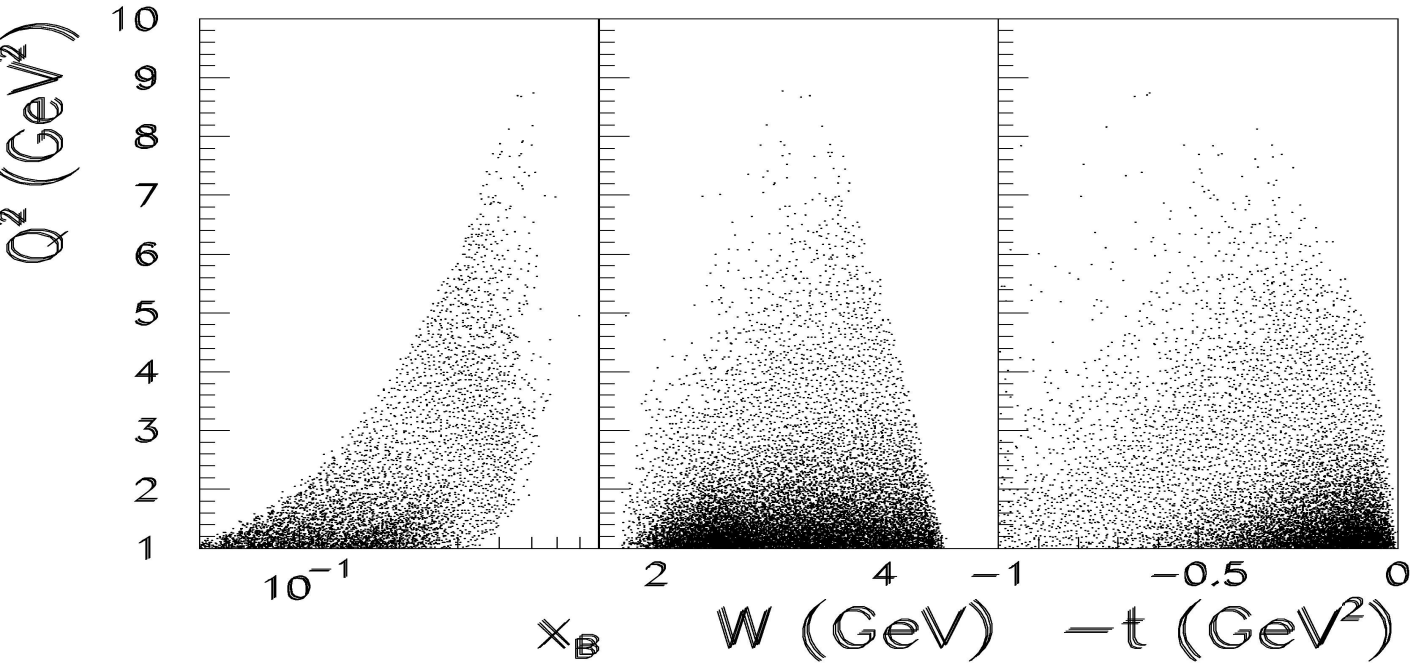


6 GeV e
fixed p target



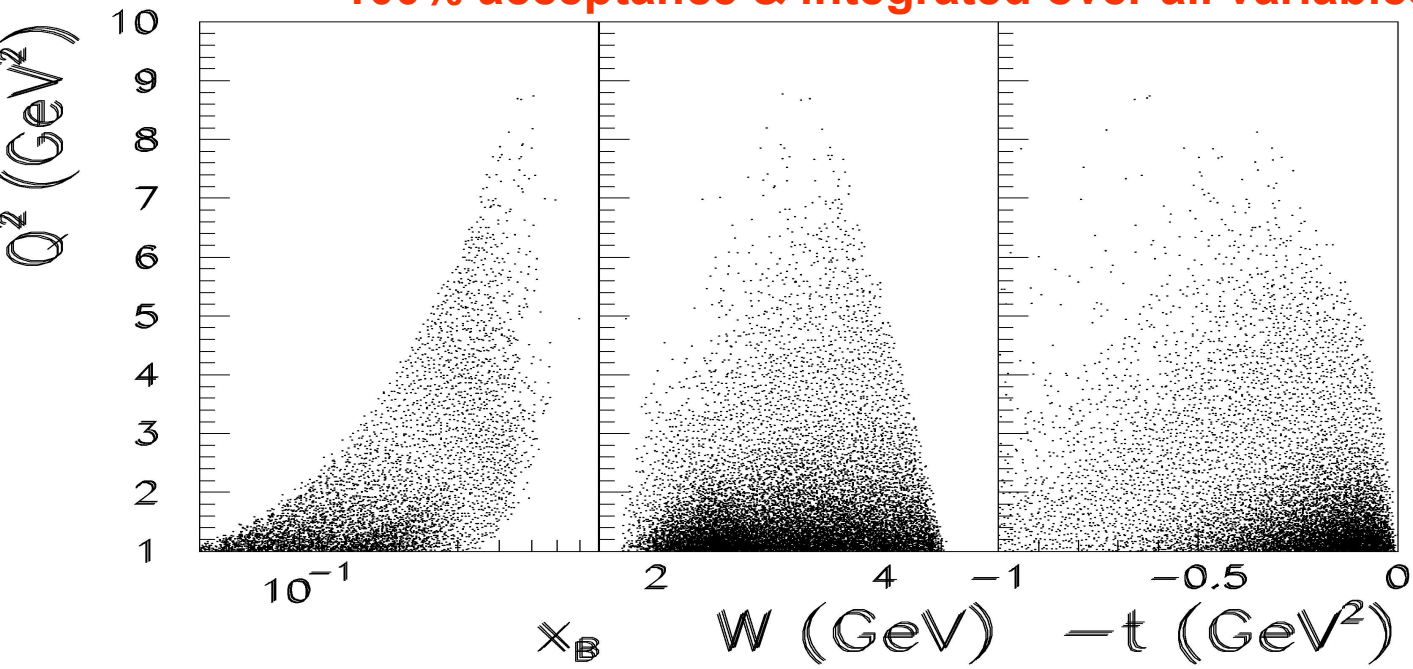
Counting ra
for 100 hou
at 10^{34} cm^{-2}s

Limitation co
from phase s

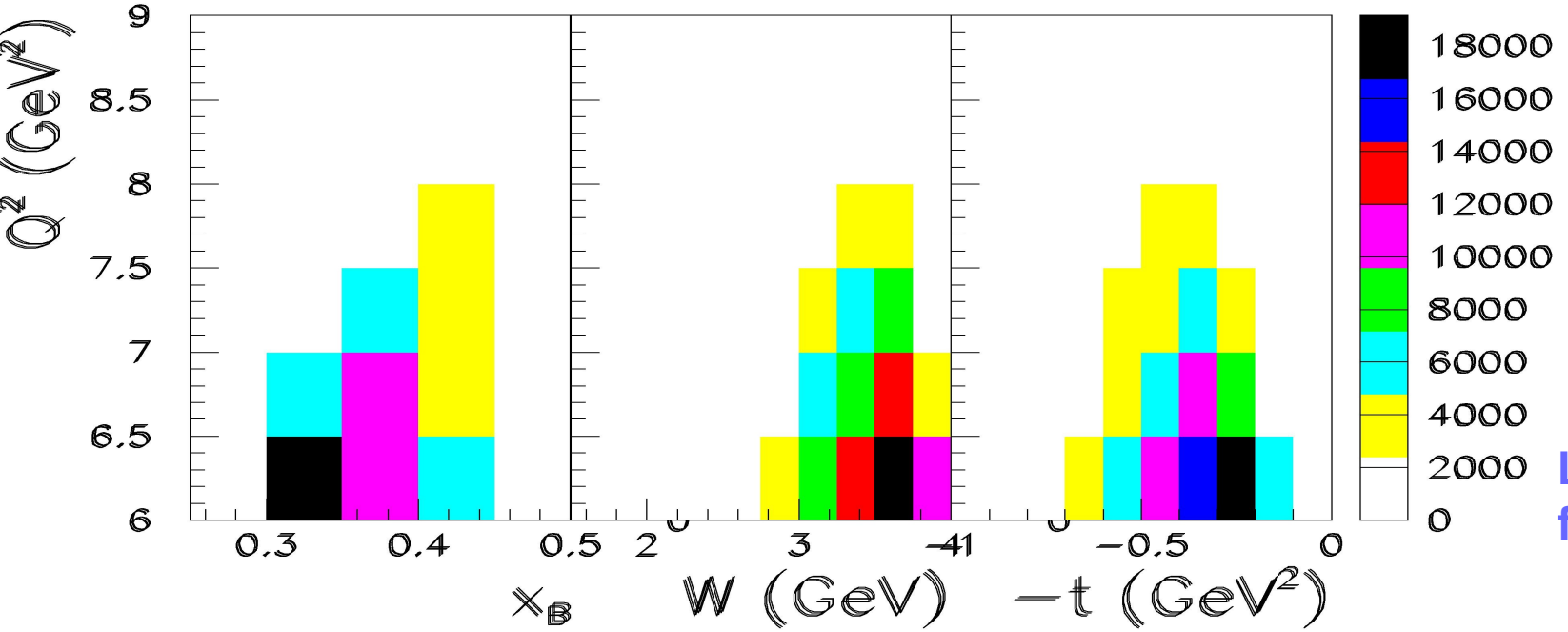


11 GeV e
fixed p target

100% acceptance & integrated over all variables but (x_B,Q^2)

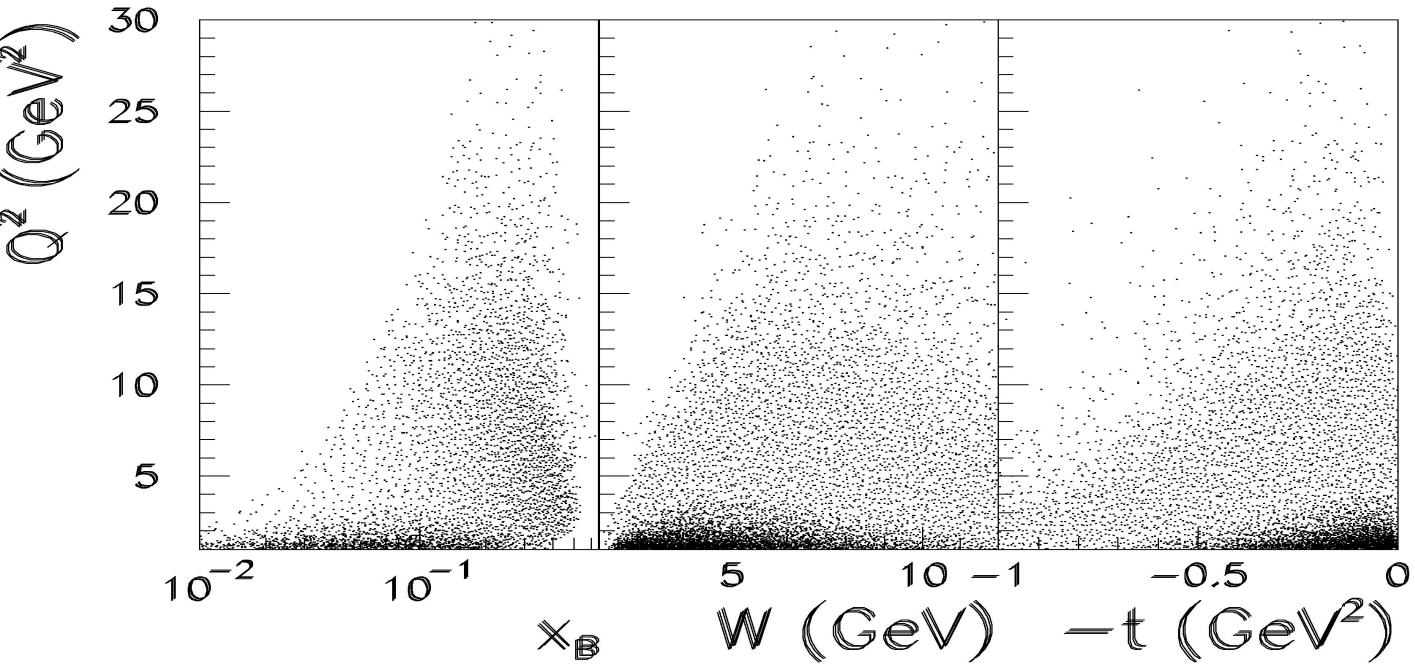


11 GeV e
fixed p target



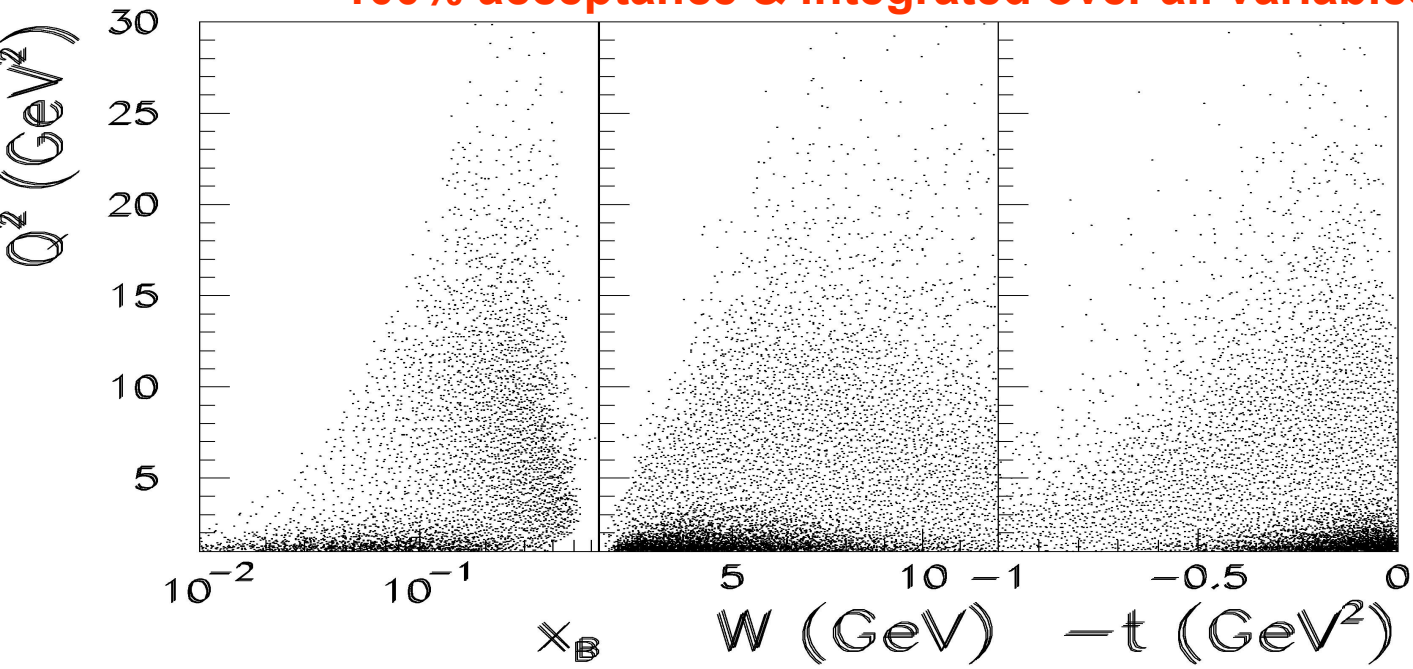
Counting ra
for 1000 hou
at 10^{35} cm^{-2}s

Limitation co
from phase s

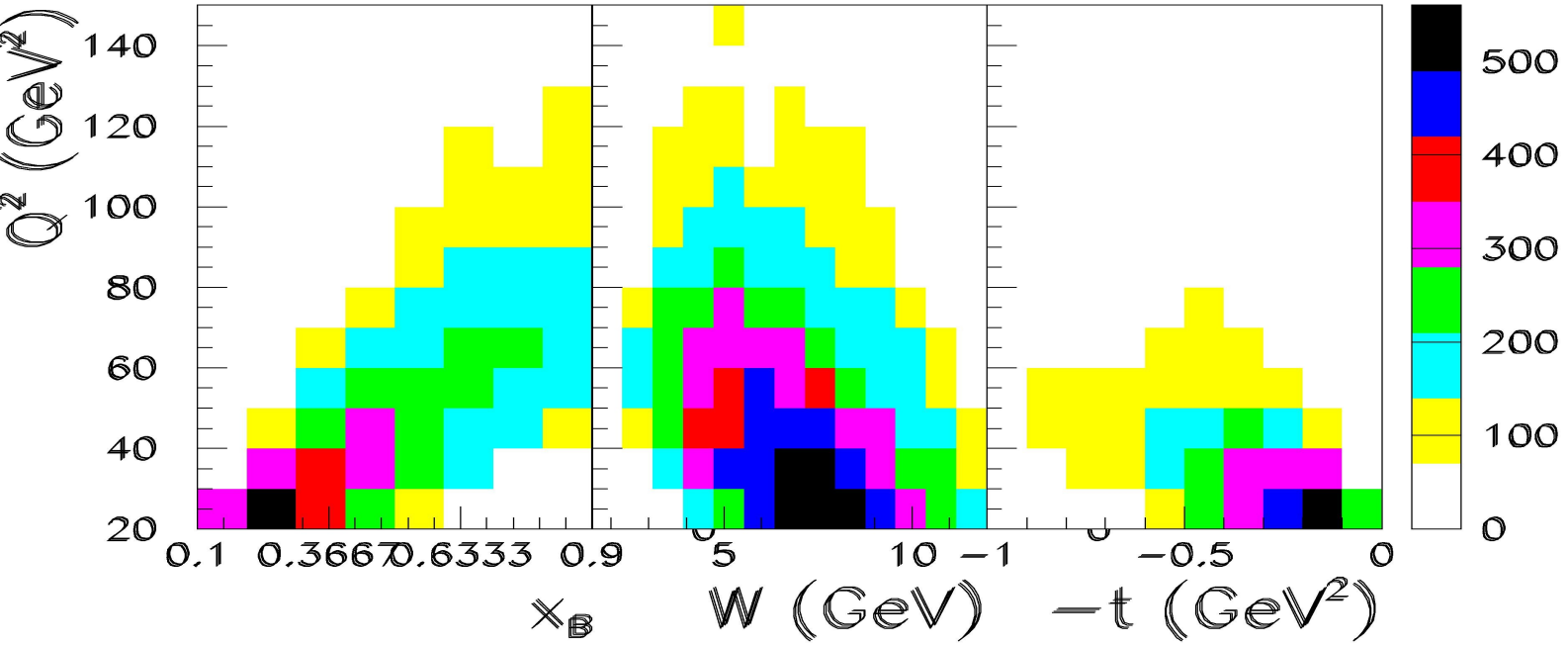


11 GeV e
60 GeV p

100% acceptance & integrated over all variables but (x_B,Q^2)

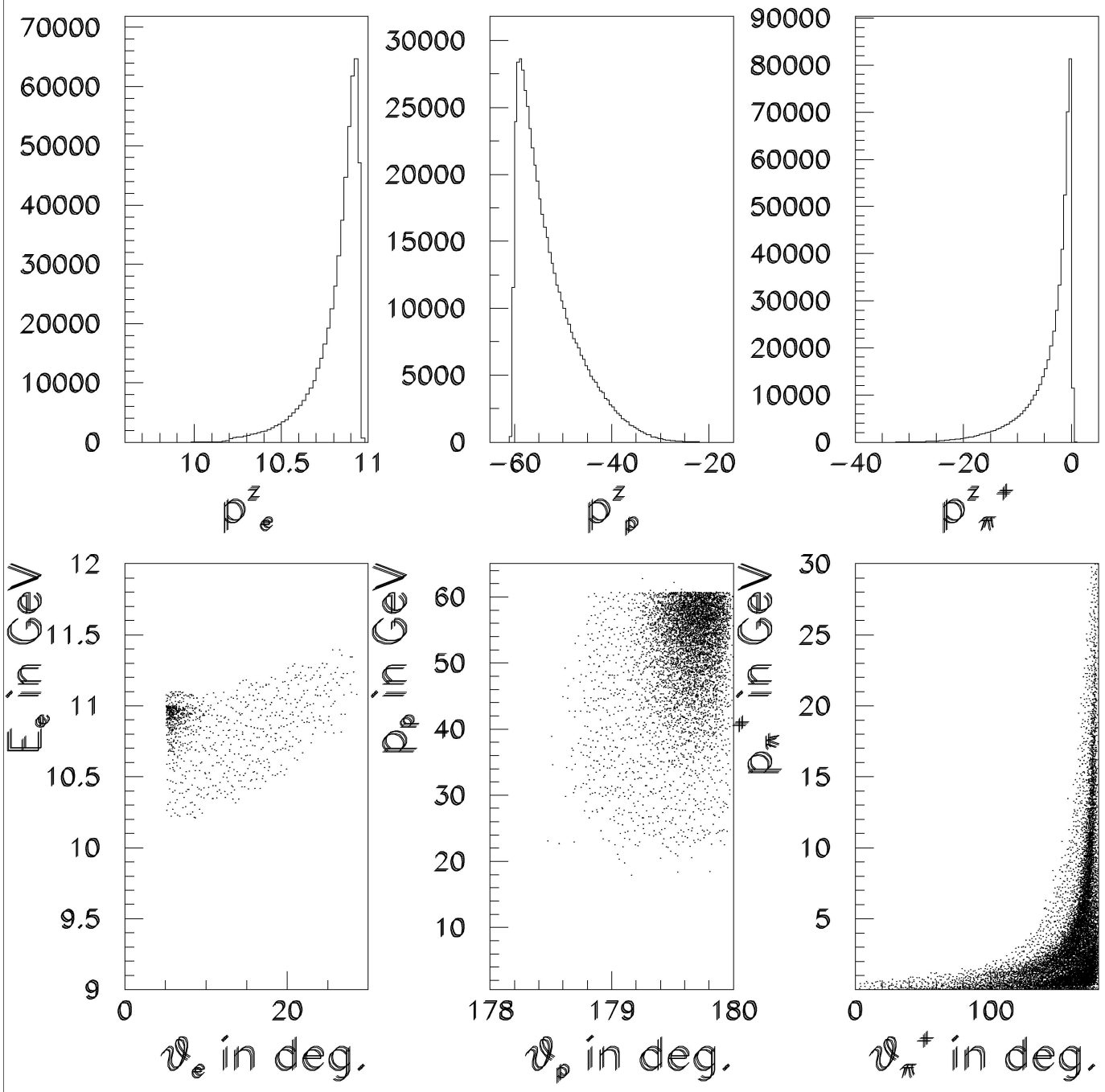


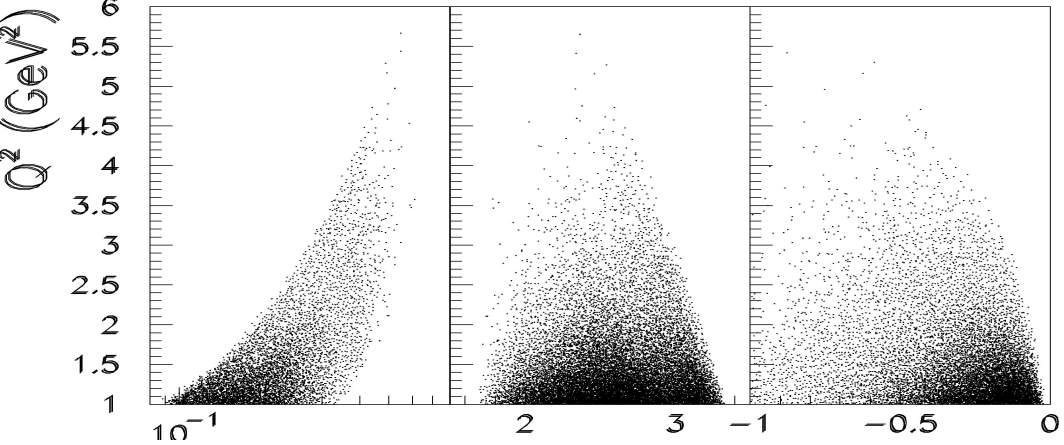
11 GeV e
60 GeV p



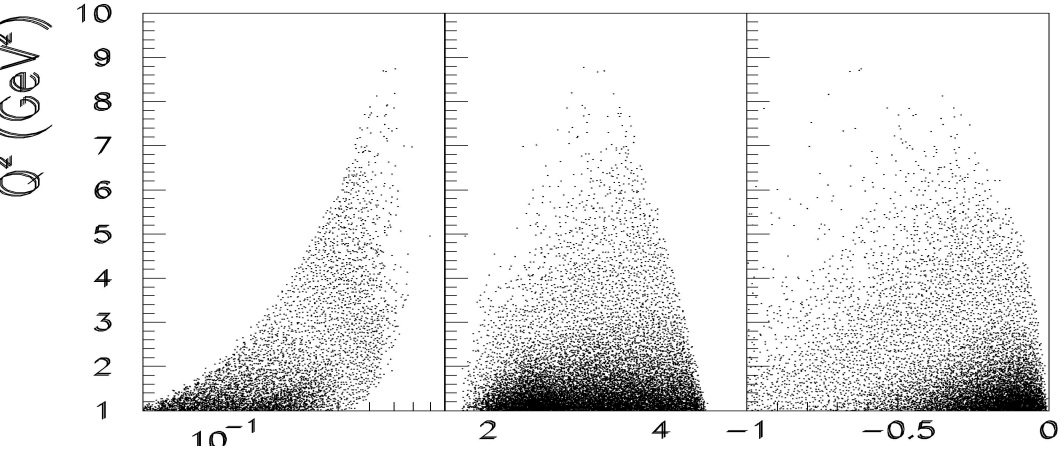
Counting ra
for 1000 hou
at 10^{34} $cm^{-2}s$

Limitation co
from luminos

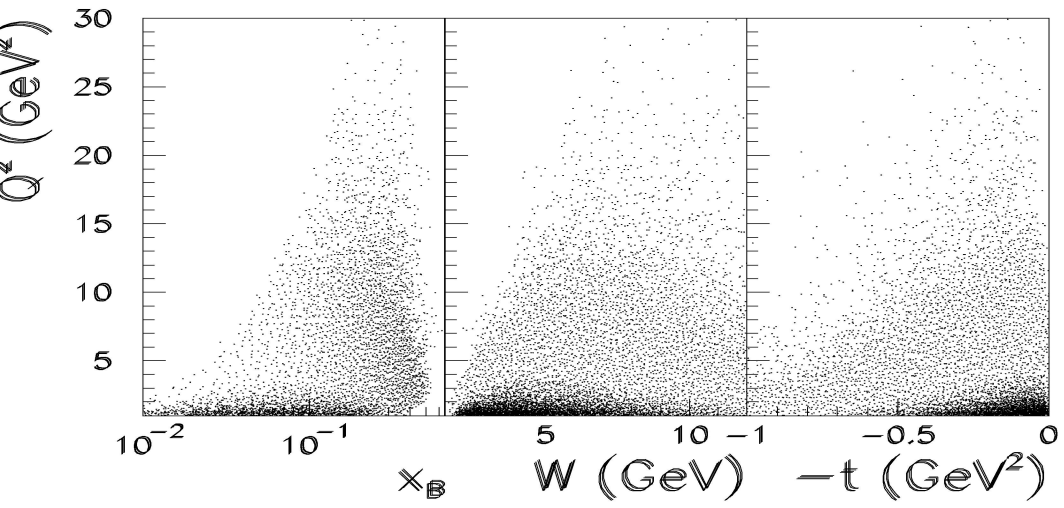

70000
60000
50000
40000
30000
20000
10000
0
10
10.5
11
p^z_e
30000
25000
20000
15000
10000
5000
0
−60
−40
−20
p^z_p
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
−40
−20
0
$p^z_{\pi^+}$
12
11.5
11
10.5
10
9.5
9
E_e in GeV
0
20
ϑ_e in deg.
60
50
40
30
20
10
p_p in GeV
178
179
180
ϑ_p in deg.
30
25
20
15
10
5
p_{π^+} in GeV
0
100
ϑ_{π^+} in deg.



6 GeV e
fixed p target

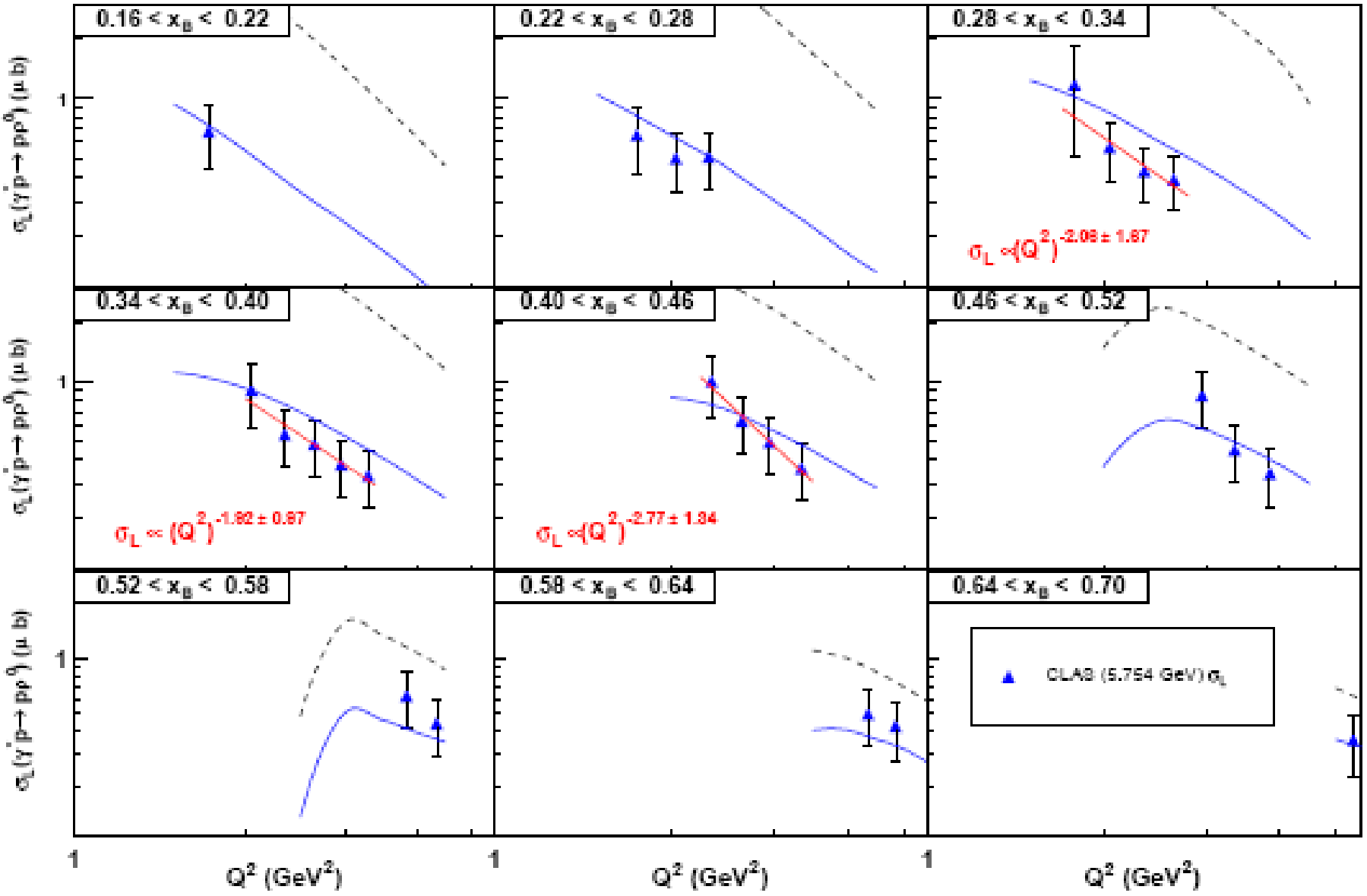


11 GeV e
fixed p target

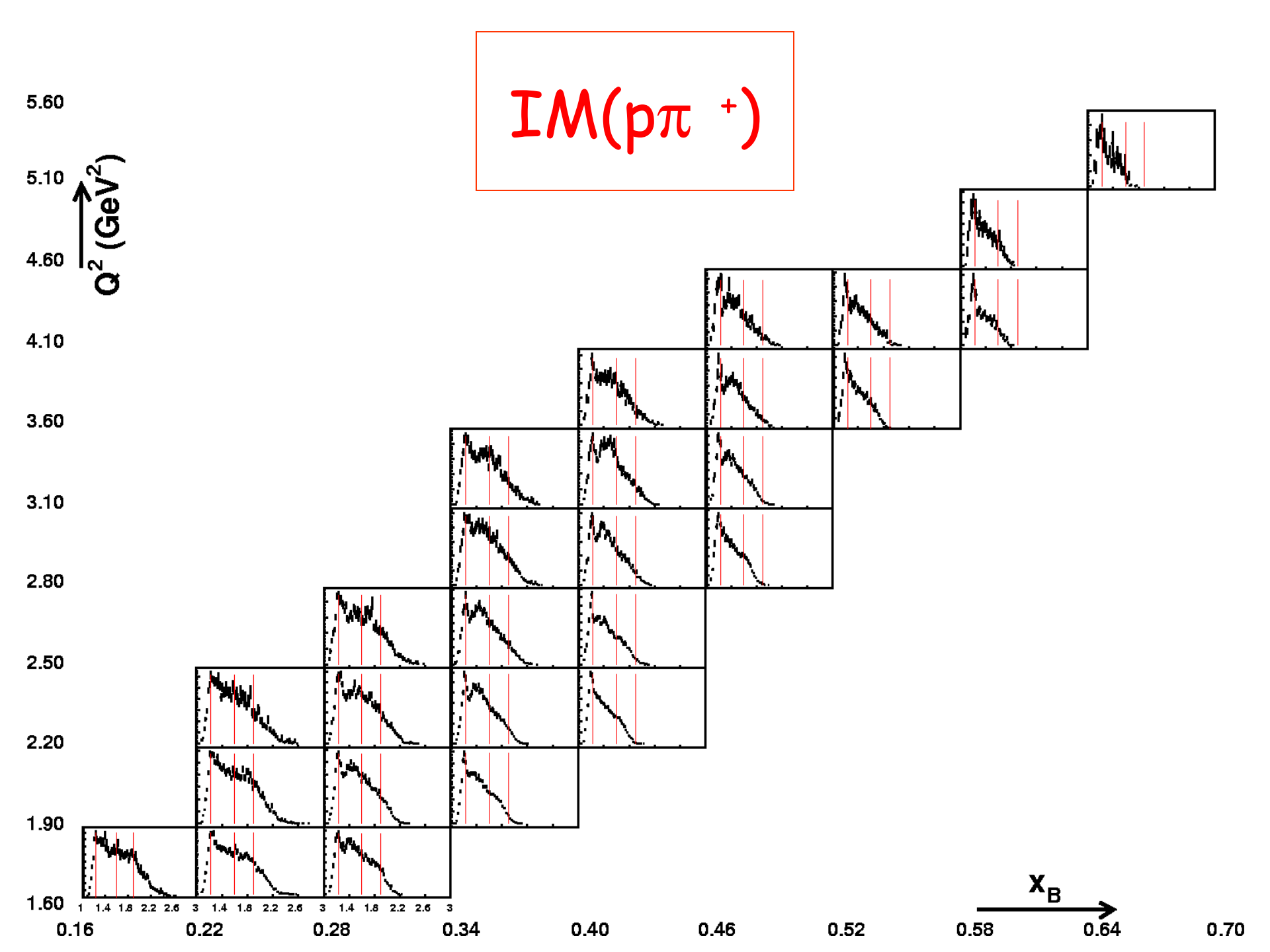


11 GeV e
60 GeV p

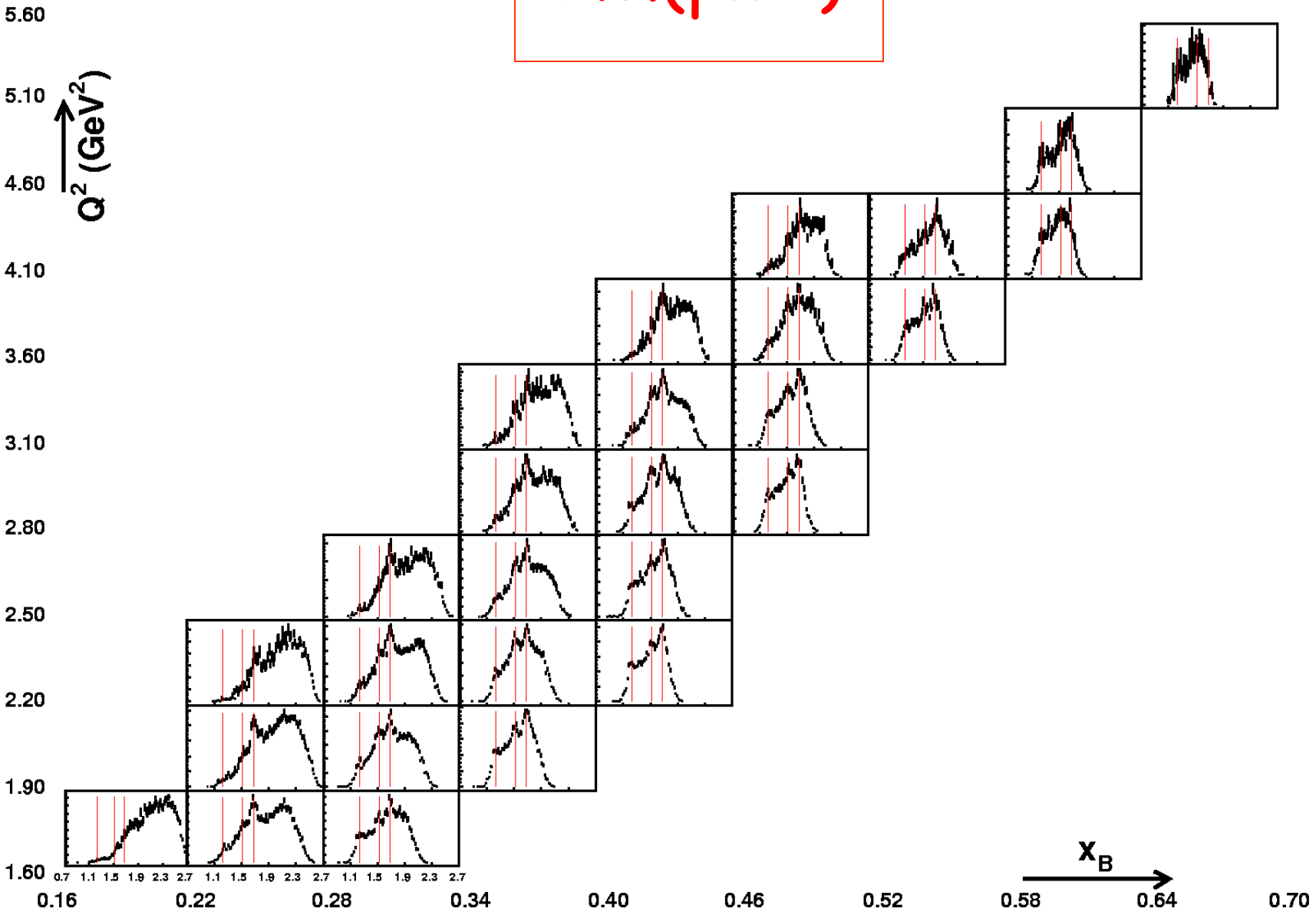
CLAS@6 GeV **S. Morrow et al., Eur.Phys.J.A39:5-31,2009 (ρ^0@5.75GeV)**



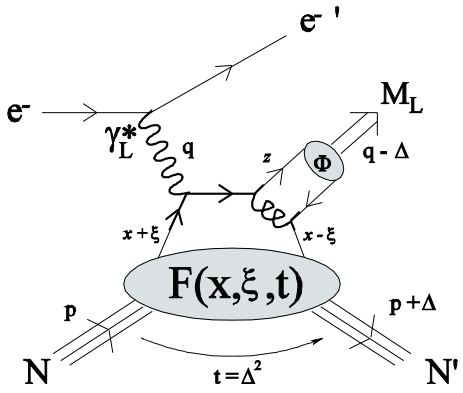
Back-up slides


IM(pπ +)
5.60
5.10
4.60
4.10
3.60
3.10
2.80
2.50
2.20
1.90
1.60
Q2 (GeV2)
1 1.4 1.8 2.2 2.6 3 1.4 1.8 2.2 2.6 3 1.4 1.8 2.2 2.6 3
0.16
0.22
0.28
0.34
0.40
0.46
0.52
0.58
0.64
0.70
xB

IM($p\pi^-$)

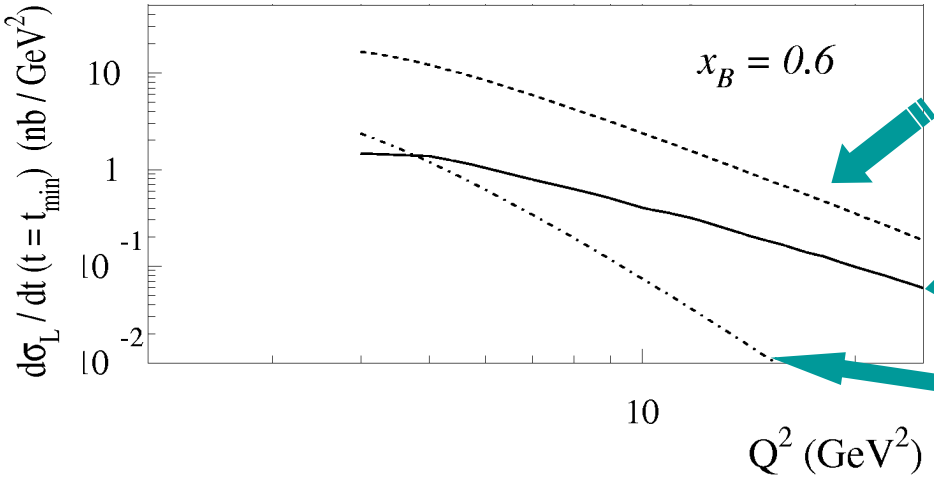

5.60
5.10
4.60
4.10
3.60
3.10
2.80
2.50
2.20
1.90
1.60
Q^2 (GeV^2)
0.7 1.1 1.5 1.9 2.3 2.7 1.1 1.5 1.9 2.3 2.7 1.1 1.5 1.9 2.3 2.7
0.16
0.22
0.28
0.34
0.40
0.46
0.52
0.58
0.64
0.70
x_B

Interpretation in terms of GPDs ?



$$\mathcal{A}_L = -\frac{2ie}{9}\left(\int_0^1 dz \frac{\Phi(z)}{z}\right)\frac{4\pi\alpha_S(Q^2)}{Q}\int_{-1}^{+1} dx \left\{\left[\frac{1}{x-\xi+i\epsilon}+\frac{1}{x+\xi-i\epsilon}\right]F(x,\xi,t)\right\}$$

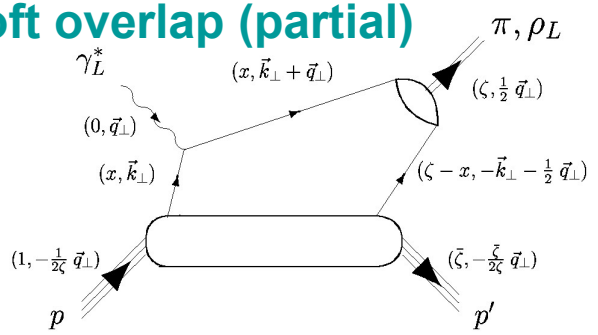
$$F(x,\xi,t) = H_M^N(x,\xi,t)\bar{N}(p')\gamma\cdot nN(p) + E_M^N(x,\xi,t)\bar{N}(p')i\sigma^{\kappa\lambda}\frac{n_\kappa\Delta_\lambda}{2m_N}N(p)$$



LO (w/o kperp effect)

LO (with kperp effect)

Soft overlap (partial)

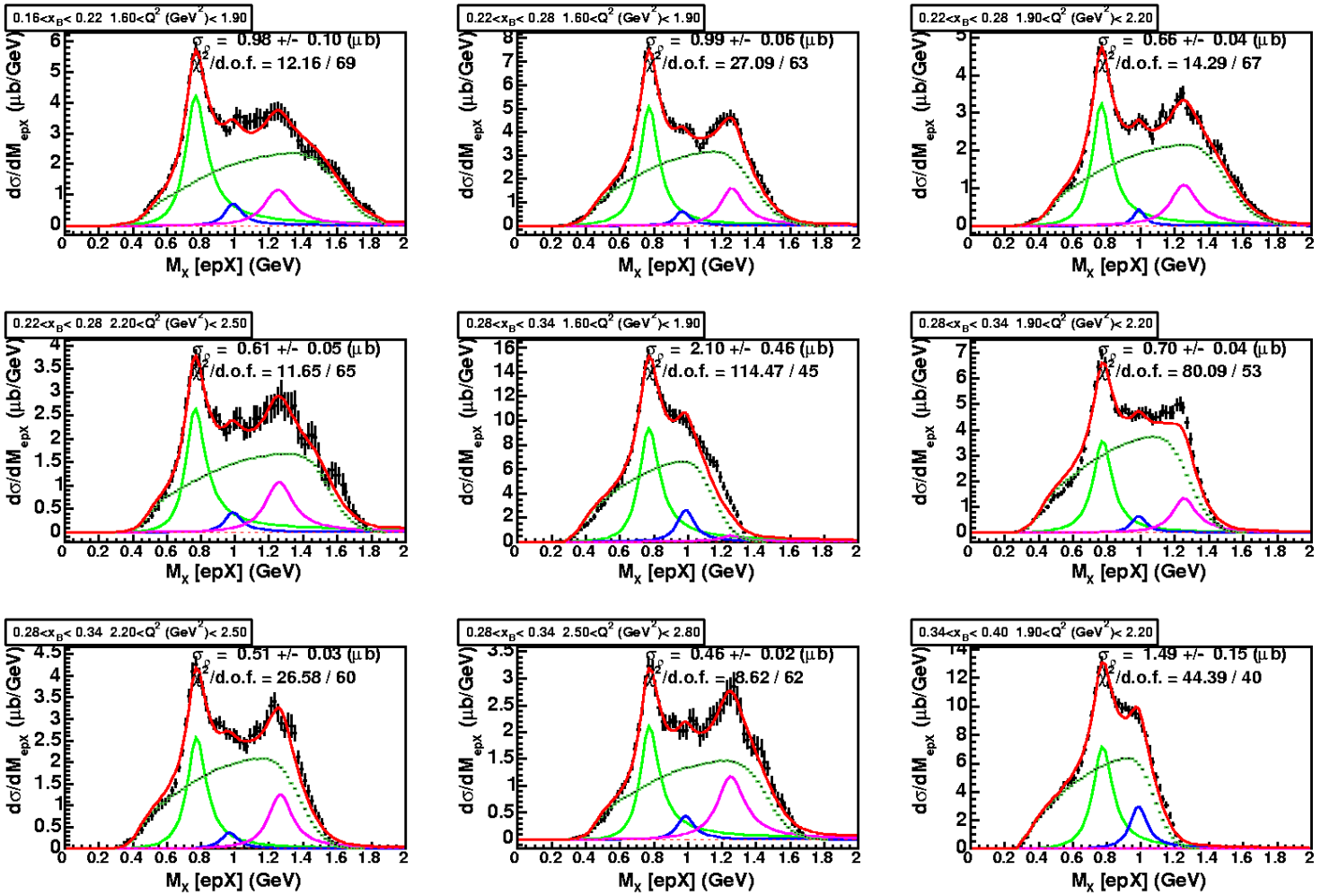


Handbag diagram calculation has k_{perp} effects to account for preasymptotic effects

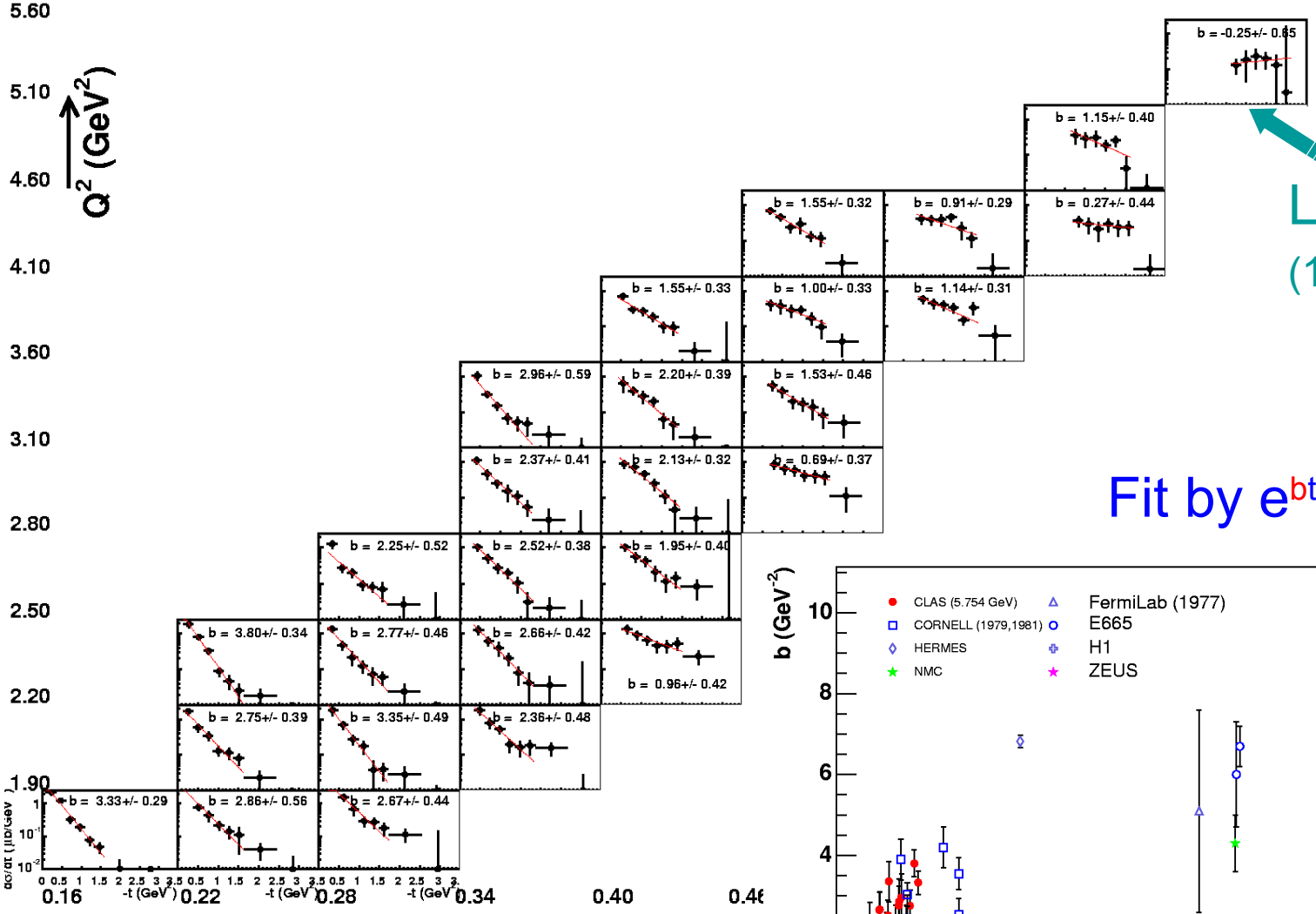
Background Subtraction (normalized spectra)

1) Ross-Stodolsky B-W for $\rho^0(770)$, $f_0(980)$ and $f_2(1270)$ with variable skewedness parameter,

2) $\Delta^{++}(1232)\,\pi^+\pi^-$ inv.mass spectrum and $\pi^+\pi^-$ phase space.

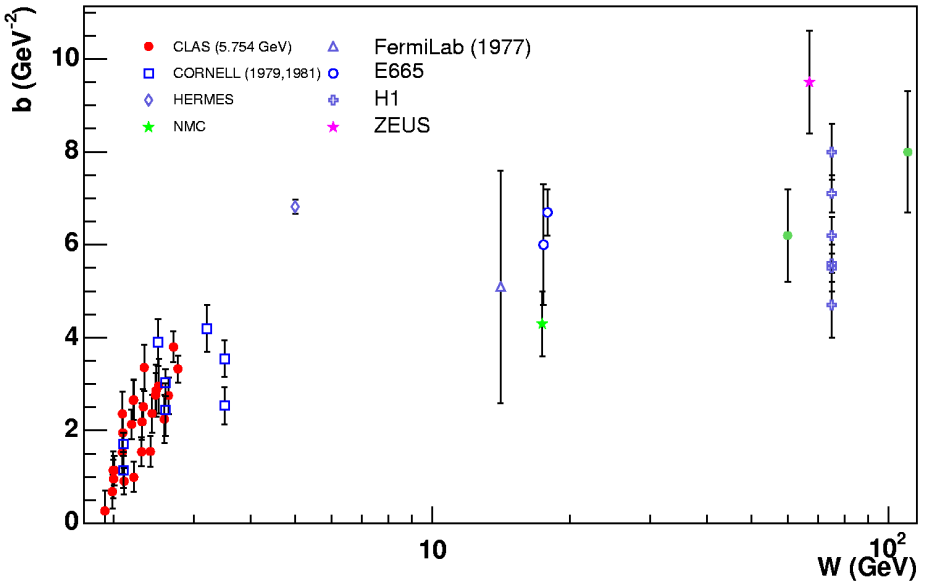


$d\sigma/dt\,(\gamma^{*}p \rightarrow p\rho^{0})$

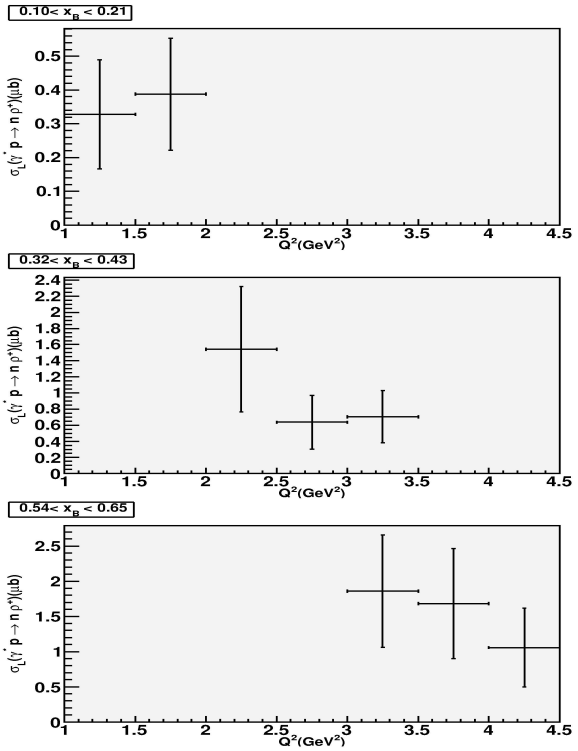


Large t_{min} !
(1.6 GeV²)

Fit by e^{bt}



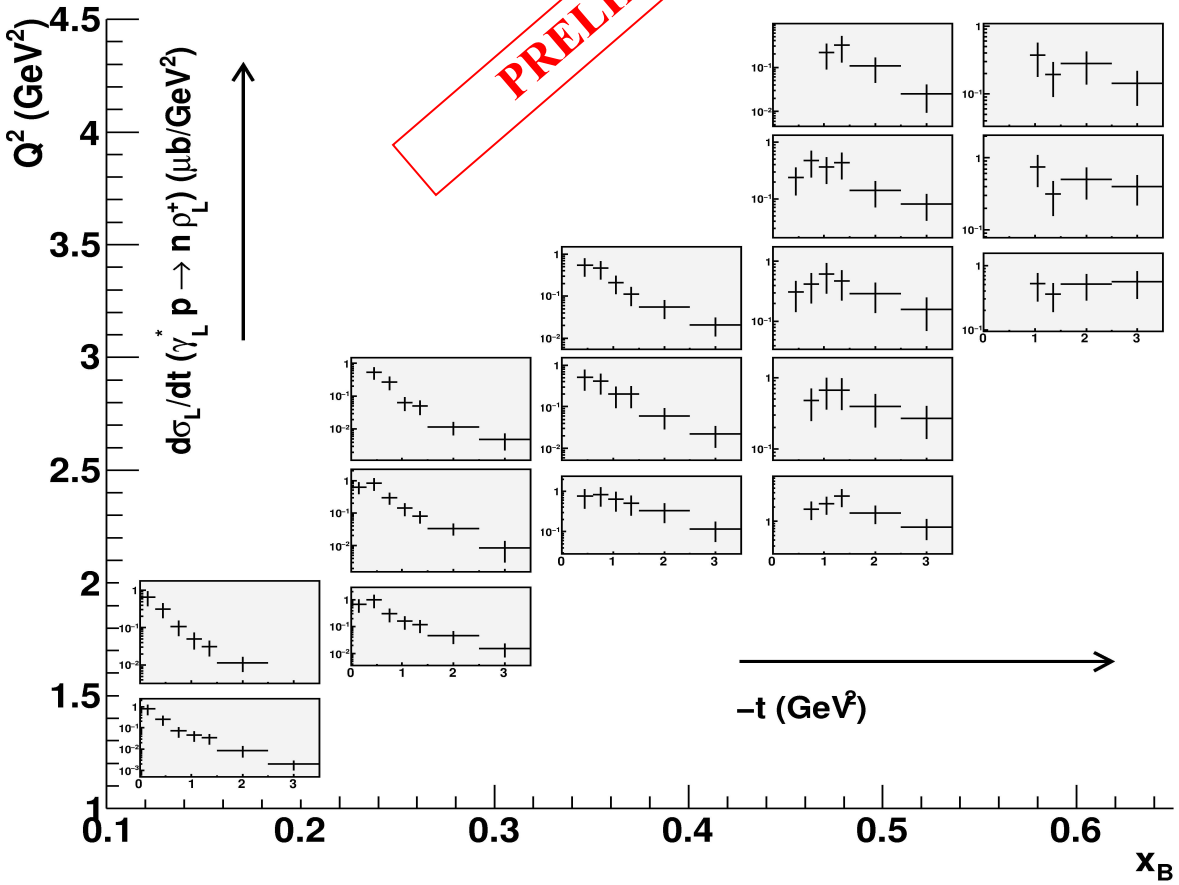
Longitudinal cross sections

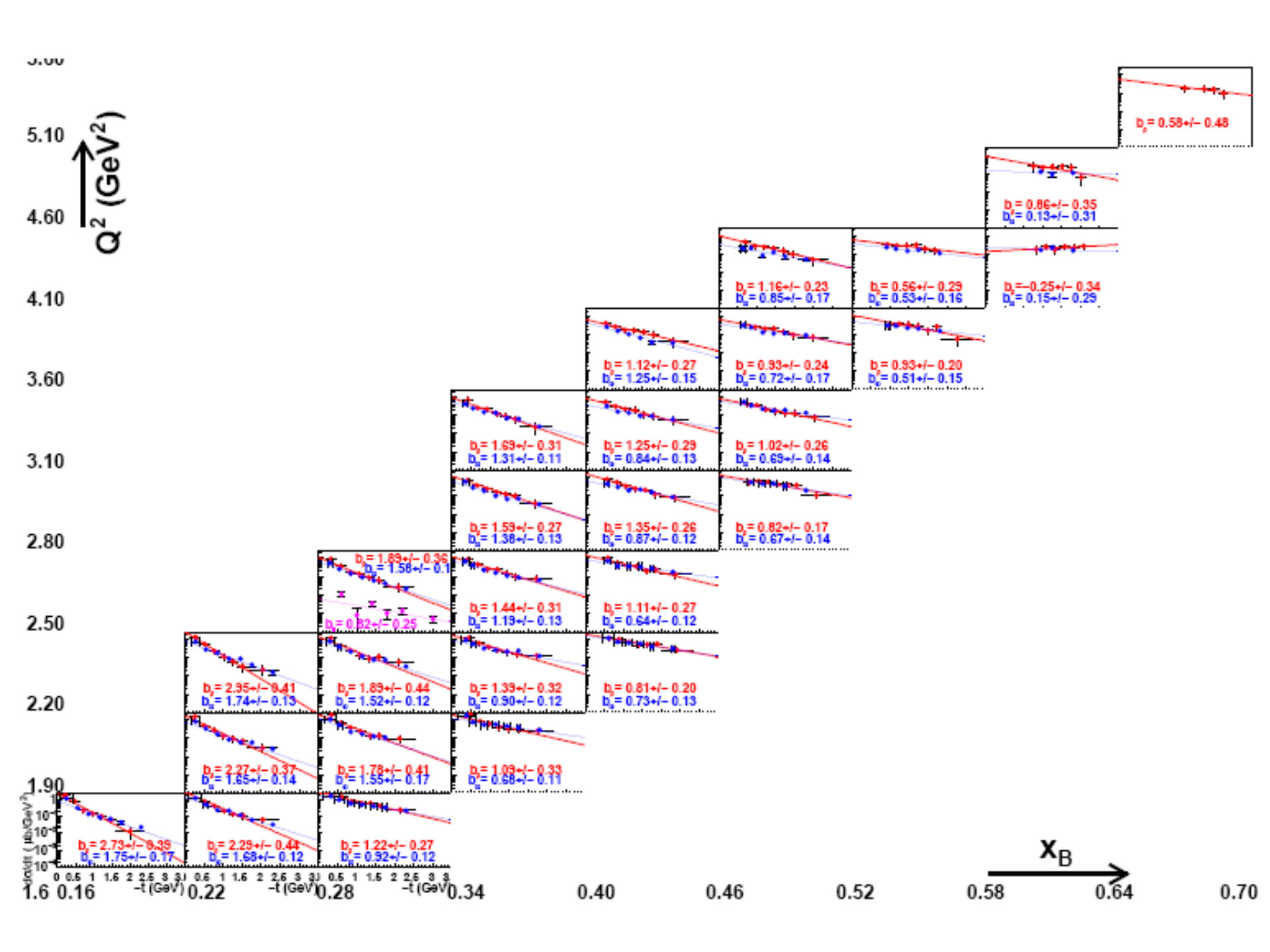


PRELIMINARY

$\sigma_L(\rho^+)[\mu b]$

$d\sigma_L/dt\,(\rho^+)[\mu b]$




Q² (GeV²)
5.10
4.60
4.10
3.60
3.10
2.80
2.50
2.20
1.90
1.6
0.16
0.22
0.28
0.34
0.40
0.46
0.52
0.58
0.64
0.70
x_B
−t (GeV)
b_p = 0.58+/− 0.48
b_p = 0.86+/− 0.35
b_π = 0.13+/− 0.31
b_p = 1.16+/− 0.23
b_π = 0.85+/− 0.17
b_p = 0.56+/− 0.29
b_π = 0.53+/− 0.16
b_p = −0.25+/− 0.34
b_π = 0.15+/− 0.29
b_p = 1.12+/− 0.27
b_π = 1.25+/− 0.15
b_p = 0.93+/− 0.24
b_π = 0.72+/− 0.17
b_p = 0.93+/− 0.20
b_π = 0.51+/− 0.15
b_p = 1.69+/− 0.31
b_π = 1.31+/− 0.11
b_p = 1.25+/− 0.29
b_π = 0.84+/− 0.13
b_p = 1.02+/− 0.26
b_π = 0.69+/− 0.14
b_p = 1.59+/− 0.27
b_π = 1.38+/− 0.13
b_p = 1.35+/− 0.26
b_π = 0.87+/− 0.12
b_p = 0.82+/− 0.17
b_π = 0.67+/− 0.14
b_p = 1.89+/− 0.36
b_π = 1.58+/− 0.1
b_p = 0.82+/− 0.25
b_p = 1.44+/− 0.31
b_π = 1.19+/− 0.13
b_p = 1.11+/− 0.27
b_π = 0.64+/− 0.12
b_p = 2.95+/− 0.41
b_π = 1.74+/− 0.13
b_p = 1.89+/− 0.44
b_π = 1.52+/− 0.12
b_p = 1.39+/− 0.32
b_π = 0.90+/− 0.12
b_p = 0.81+/− 0.20
b_π = 0.73+/− 0.13
b_p = 2.27+/− 0.37
b_π = 1.65+/− 0.14
b_p = 1.78+/− 0.41
b_π = 1.55+/− 0.17
b_p = 1.09+/− 0.33
b_π = 0.68+/− 0.11
b_p = 2.73+/− 0.39
b_π = 1.75+/− 0.17
b_p = 2.29+/− 0.44
b_π = 1.68+/− 0.12
b_p = 1.22+/− 0.27
b_π = 0.92+/− 0.12

Comparison with ρ^0, ω, ϕ