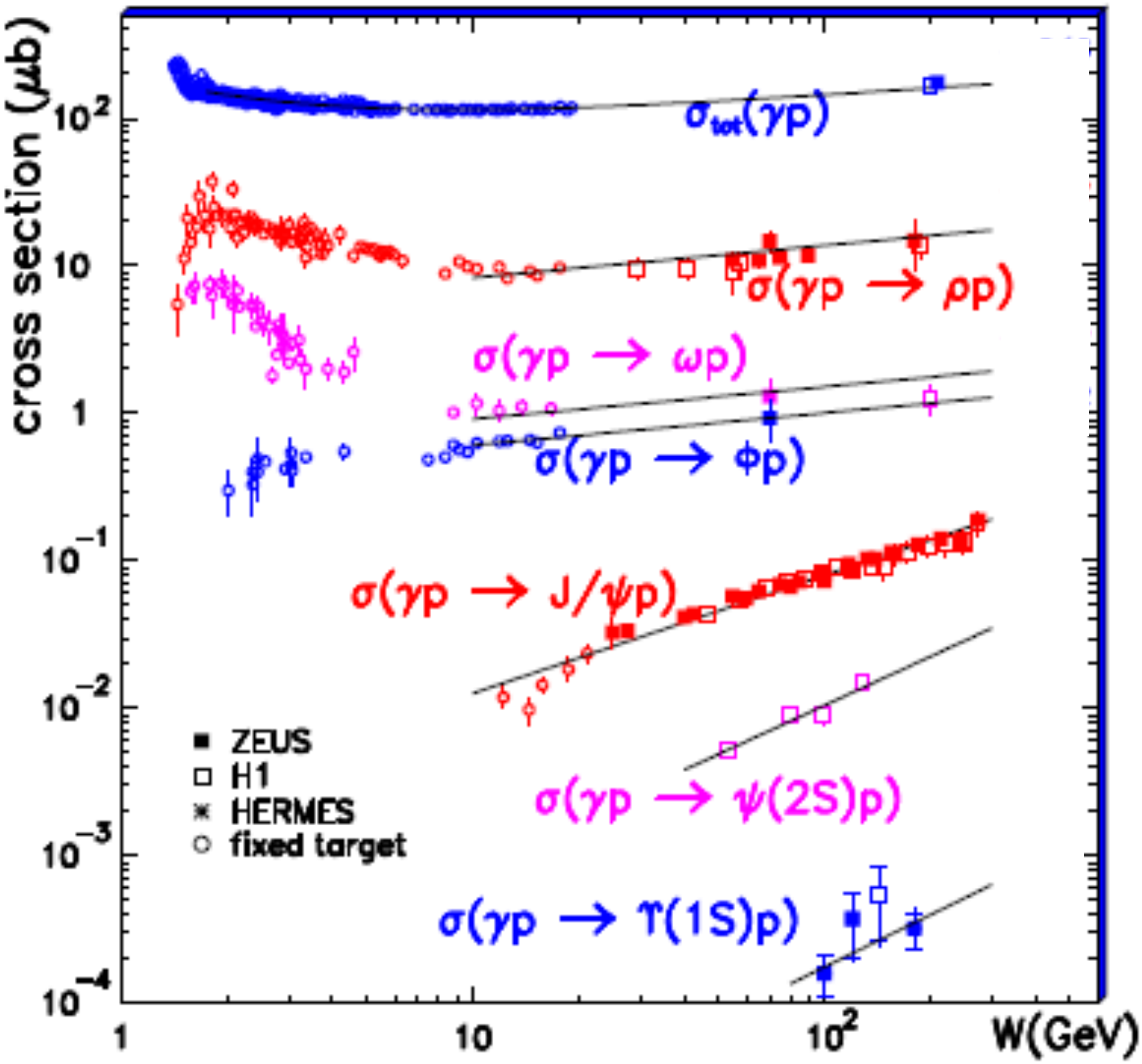
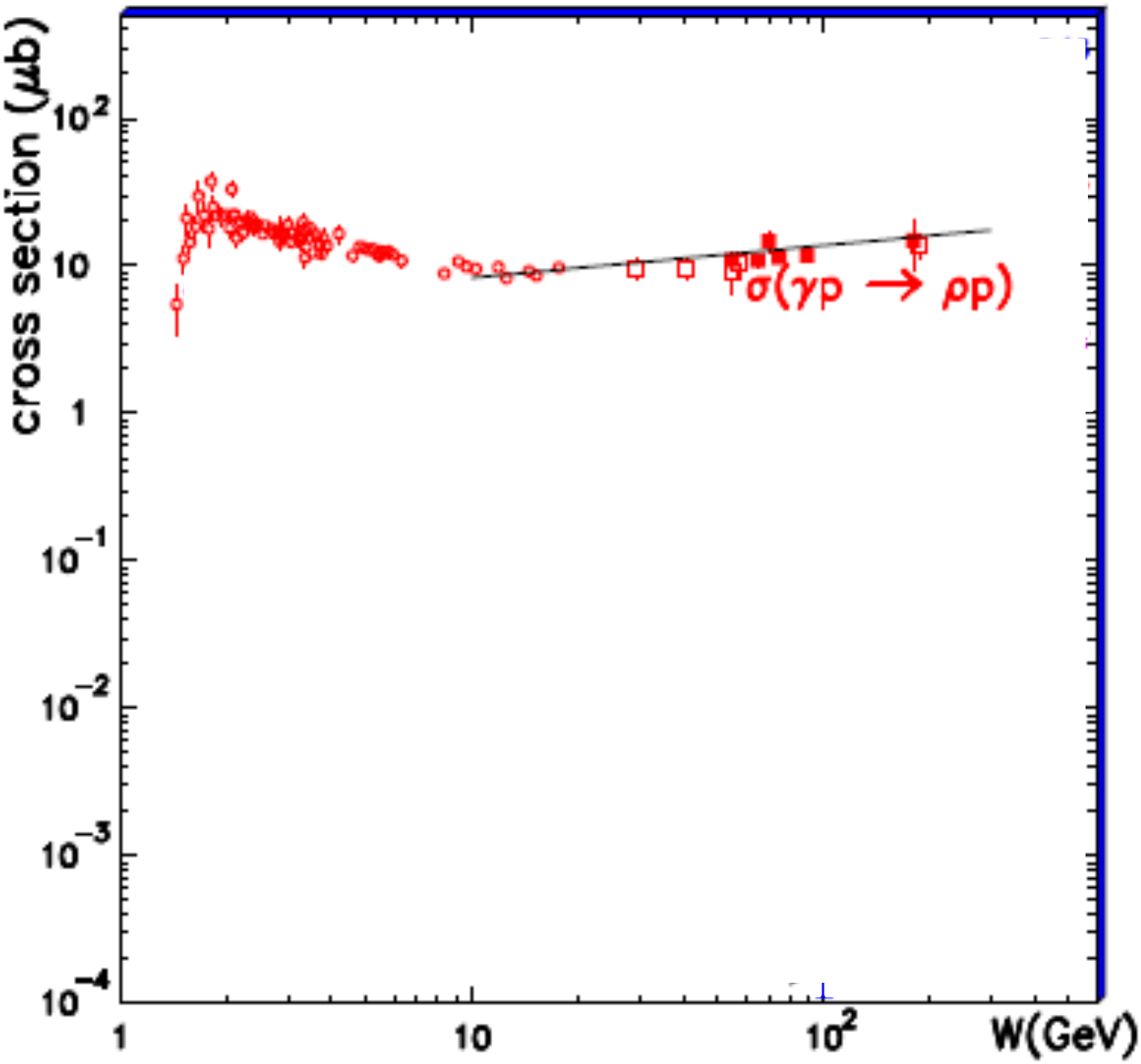
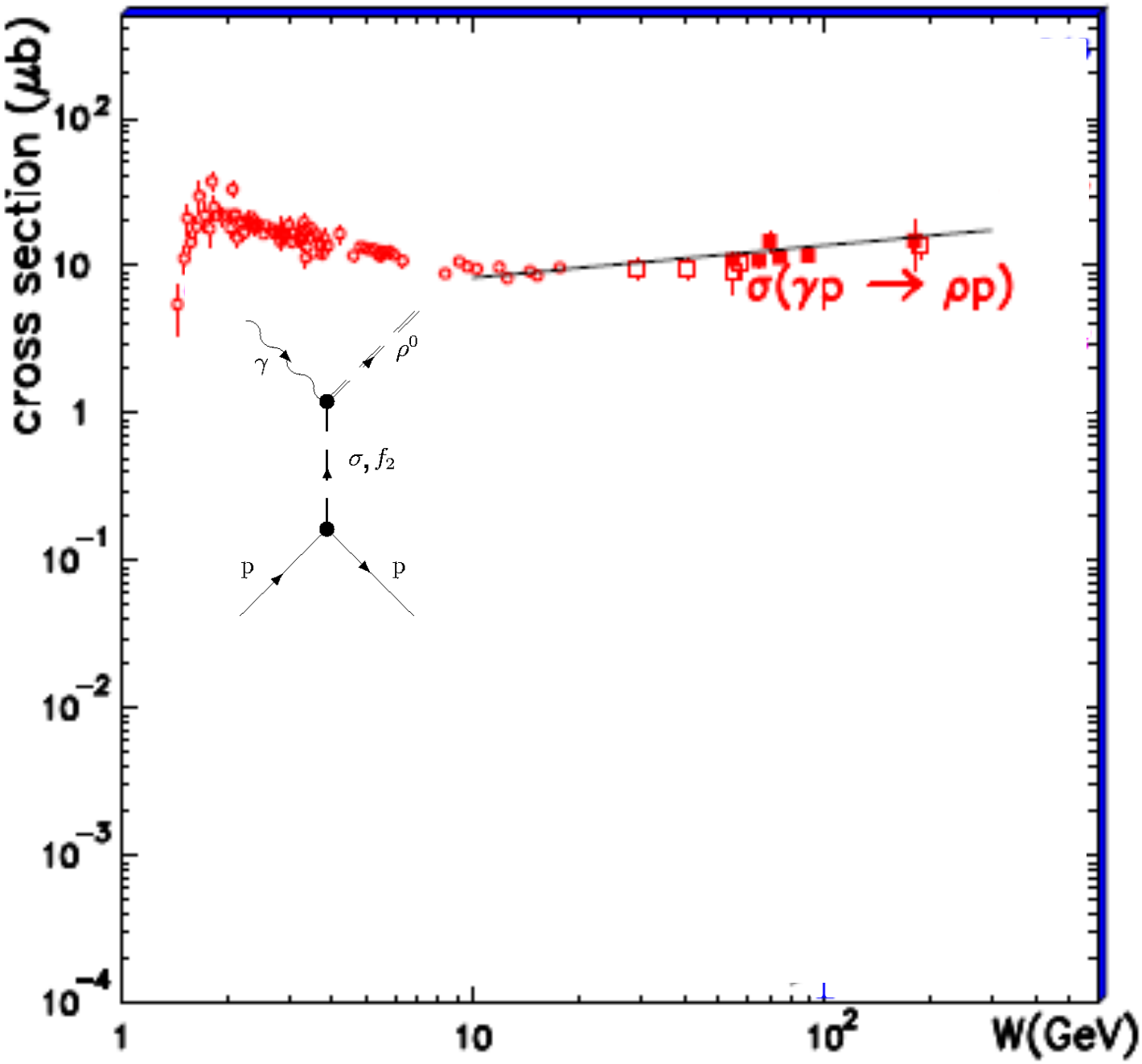
Deep exclusive meson electroproduction: review

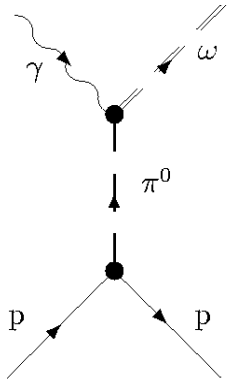
M. Guidal, IPN Orsay

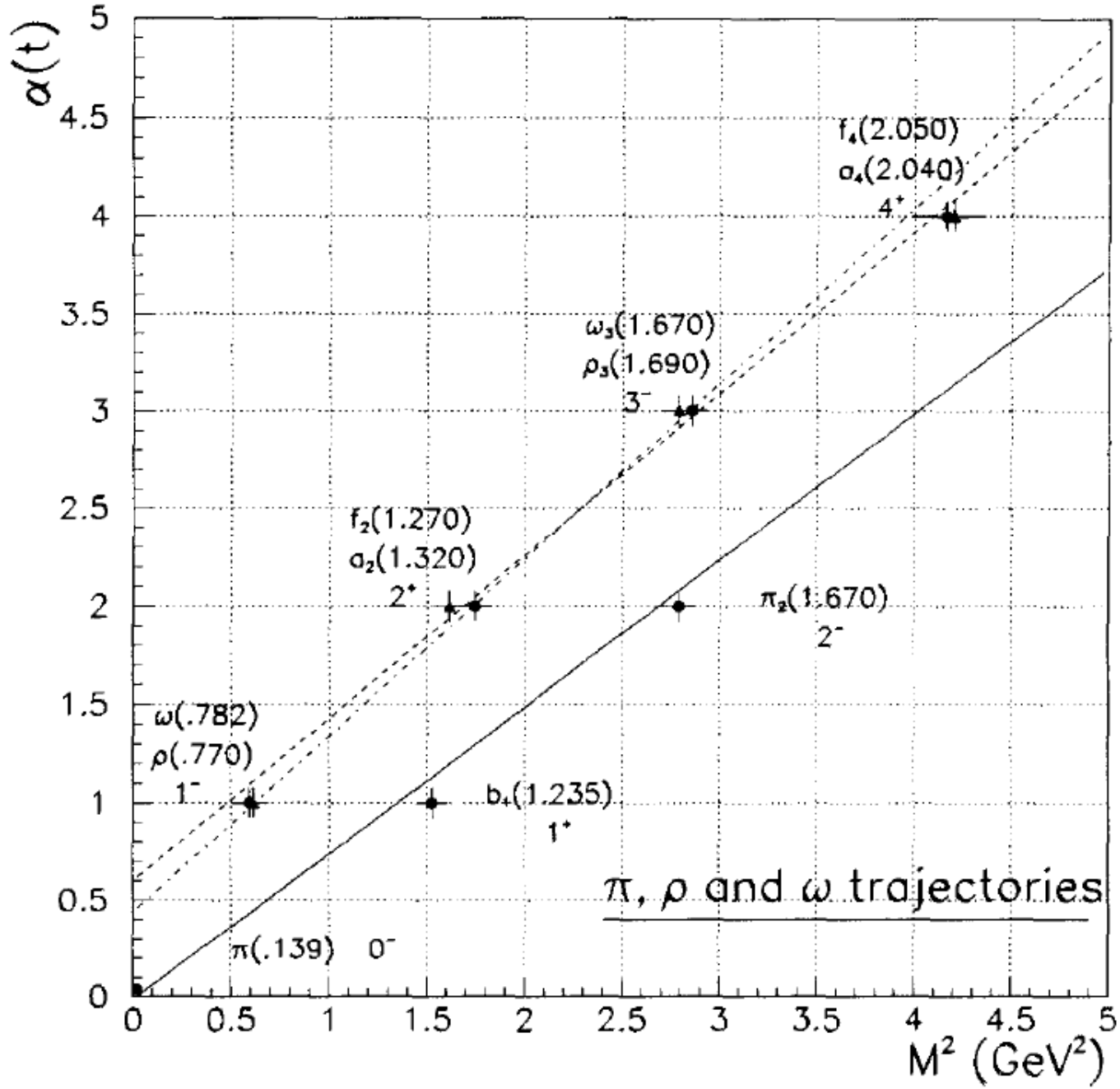

cross section (μb)
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
1
10
10^2
W(GeV)
$\sigma_{tot}(\gamma p)$
$\sigma(\gamma p \to \rho p)$
$\sigma(\gamma p \to \omega p)$
$\sigma(\gamma p \to \phi p)$
$\sigma(\gamma p \to J/\psi p)$
$\sigma(\gamma p \to \psi(2S)p)$
$\sigma(\gamma p \to \Upsilon(1S)p)$
ZEUS
H1
HERMES
fixed target


cross section (μb)
10^2
10
1
10^-1
10^-2
10^-3
10^-4
1
10
10^2
W(GeV)
σ(γp → ρp)

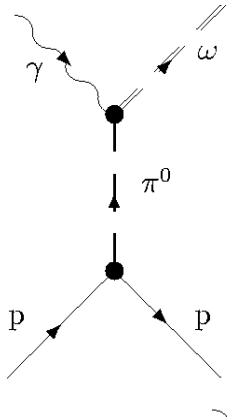

cross section (μb)
10^2
10
1
10^-1
10^-2
10^-3
10^-4
1
10
10^2
W(GeV)
σ(γp → ρp)
γ
ρ^0
σ, f_2
p
p

Regge theory: **Exchange of families of mesons in the t-channel**




α(t)
M² (GeV²)
f₄(2.050)
a₄(2.040)
4⁺
ω₃(1.670)
ρ₃(1.690)
3⁻
f₂(1.270)
a₂(1.320)
2⁺
π₂(1.670)
2⁻
ω(.782)
ρ(.770)
1⁻
b₁(1.235)
1⁺
π(.139) 0⁻
π, ρ and ω trajectories

Regge theory: Exchange of families of mesons in the t-channel



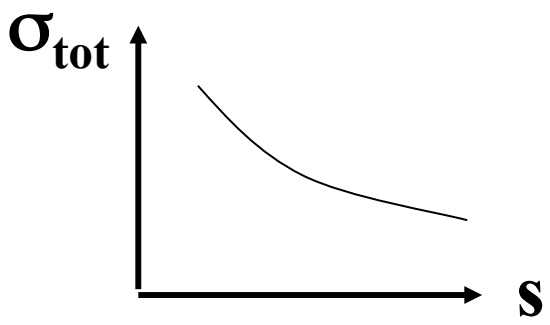
$$M(s,t) \sim s^{\alpha(t)}$$

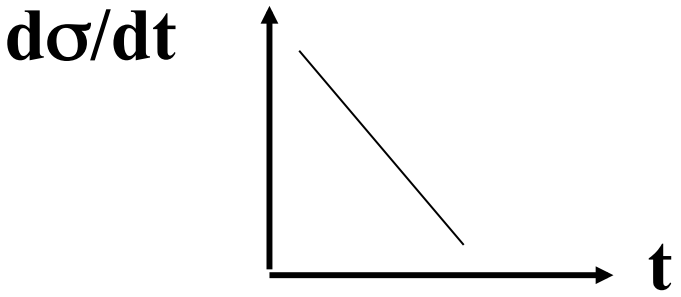
where $\alpha(t)$ (trajectory) is the relation between the spin and the (squared) mass of a family of particles

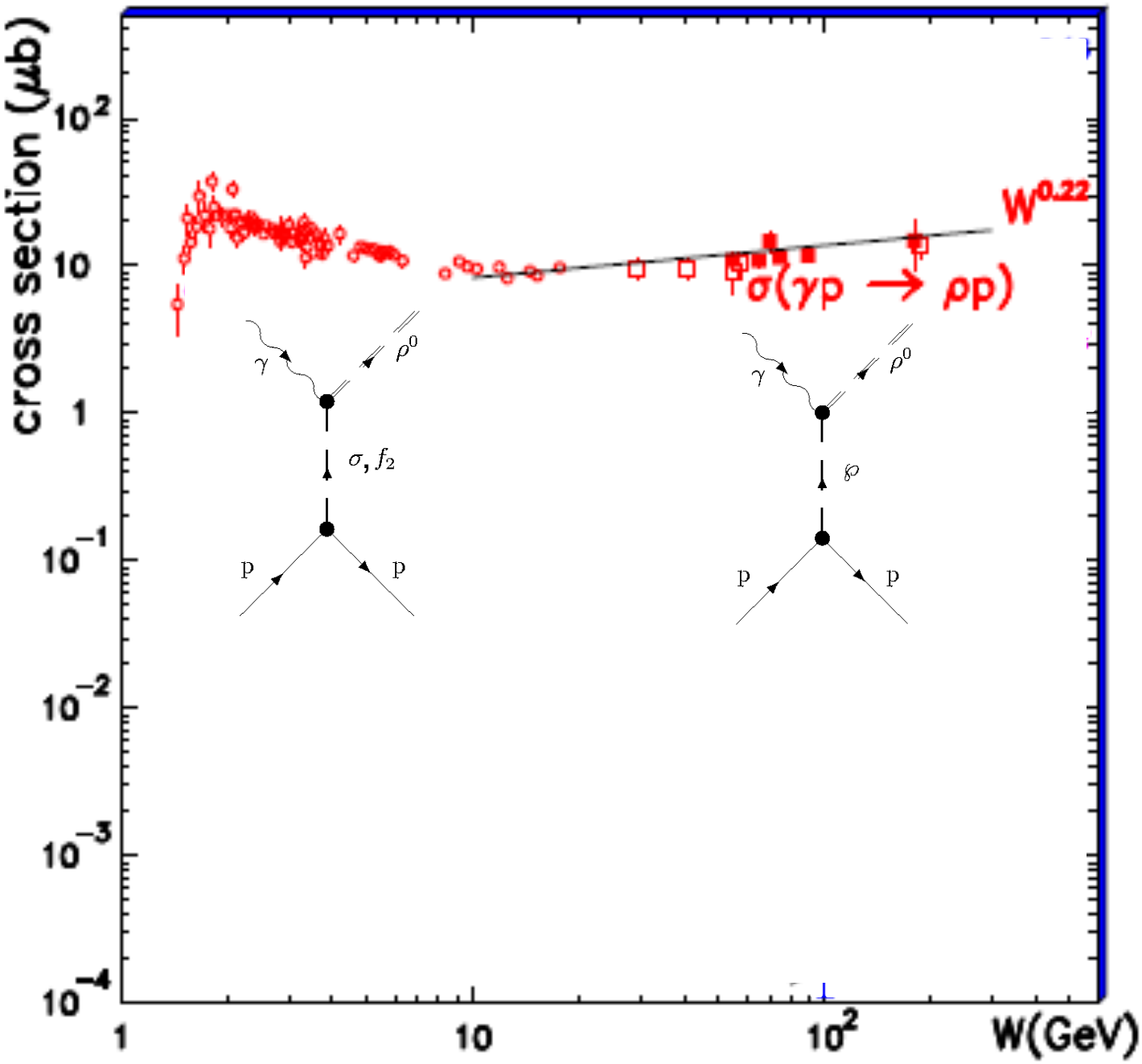
$M \to s^{\alpha(t)}$

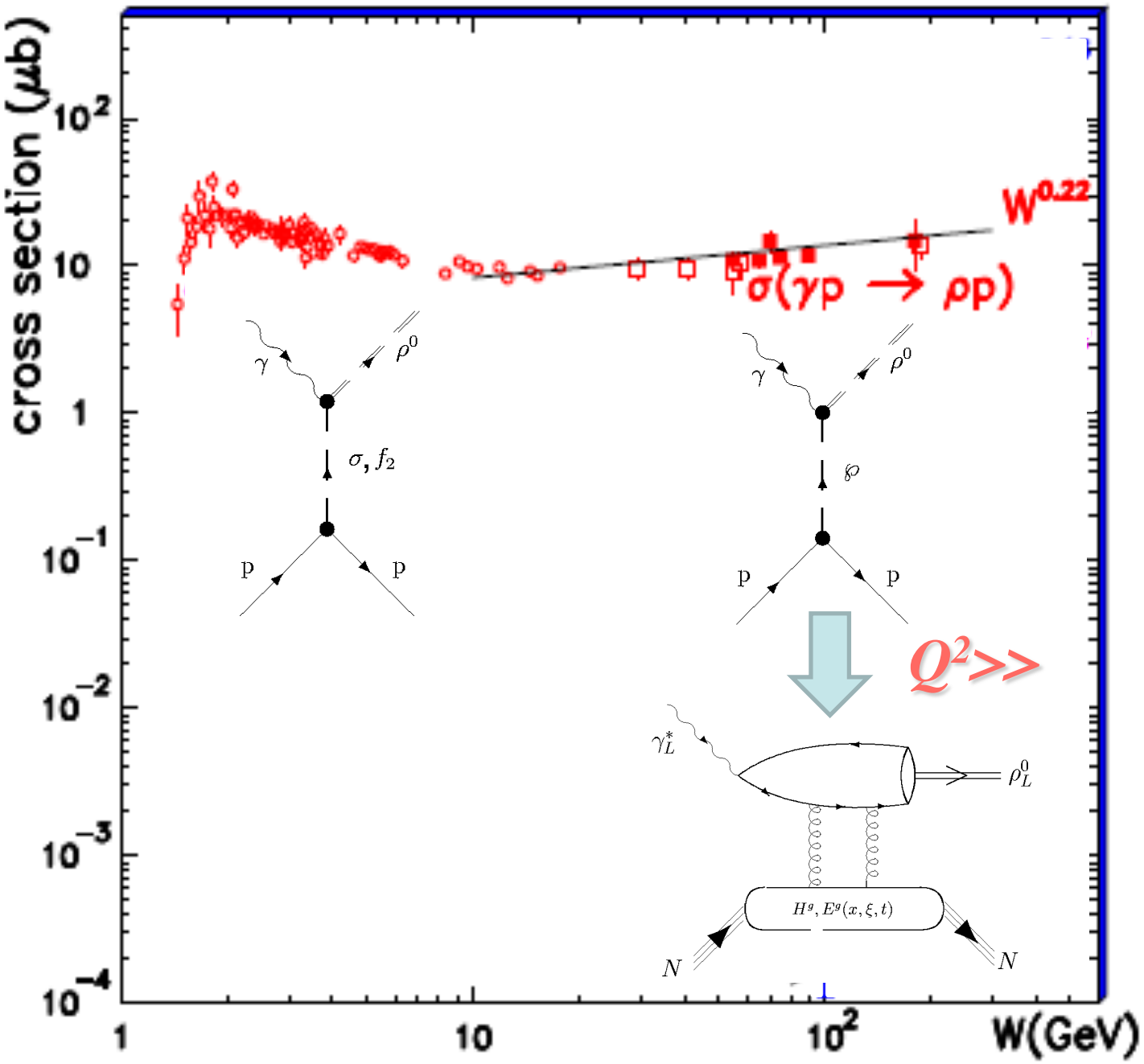
$\sigma_{tot} \sim 1/s \times Im(M(s,t=0)) \to s^{\alpha(0)-1}$ [optical theorem]

$d\sigma/dt \sim 1/s^2 \times |M(s,t)|^2 \to s^{2\alpha(t)-2}$ $\to [e^{\alpha(t) \ln s(s)}]$






cross section (μb)
10^2
10
1
10^-1
10^-2
10^-3
10^-4
1
10
10^2
W(GeV)
W^0.22
σ(γp → ρp)
γ
ρ^0
σ, f_2
p
p
γ
ρ^0
φ
p
p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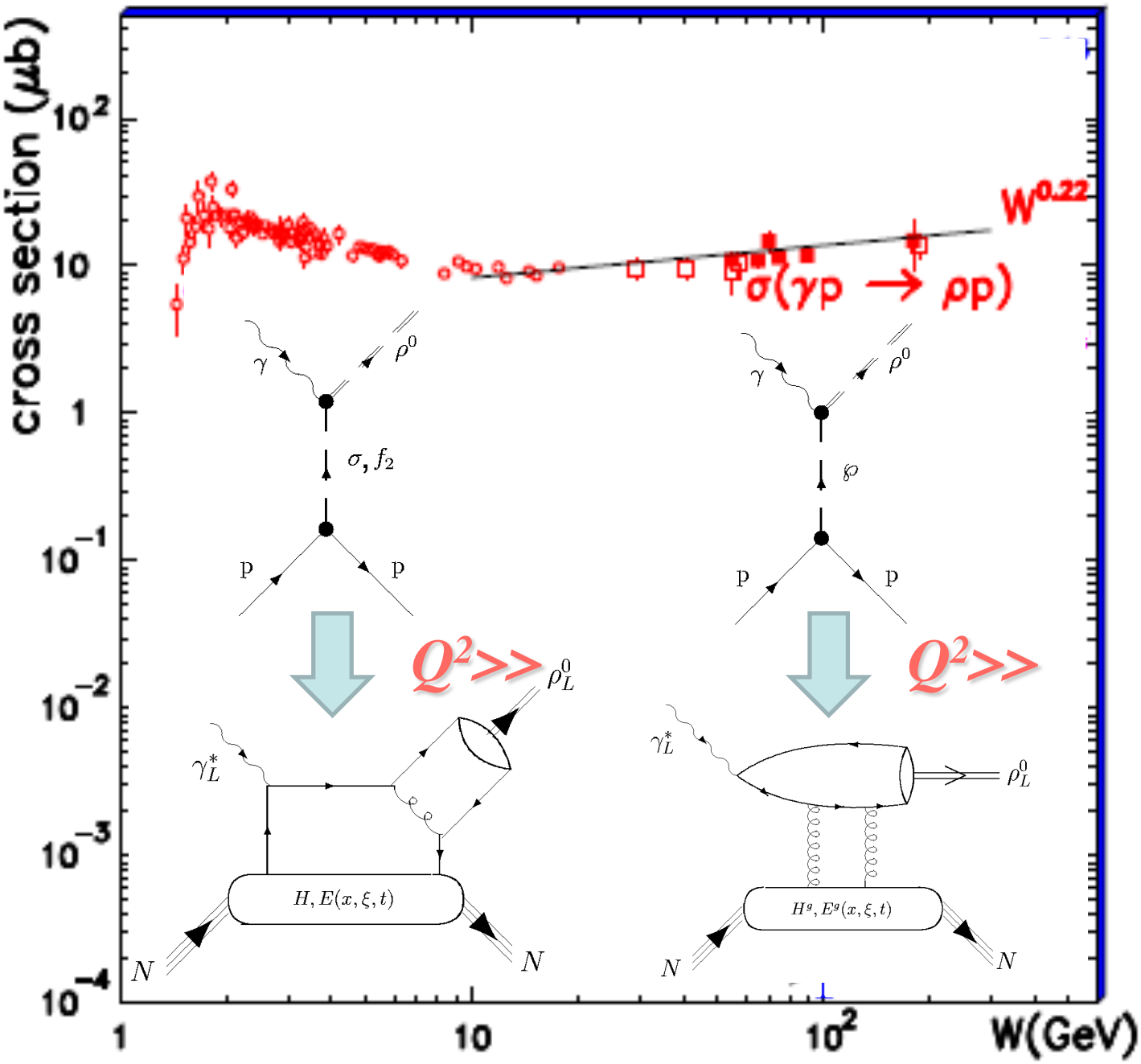
10^-3
10^-4
1
10
10^2
W(GeV)
W^0.22
σ(γp → ρp)
γ
ρ^0
σ, f_2
p
p
γ
ρ^0
℘
p
p
Q^2>>
γ*_L
ρ^0_L
H^g, E^g(x, ξ, t)
N
N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W^0.22
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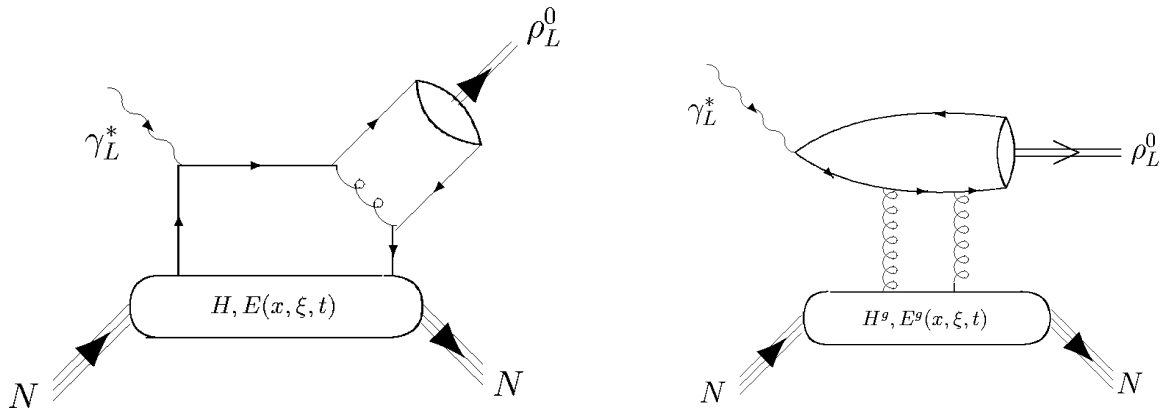
γ
ρ^0
σ, f_2
p
p
Q^2>>
ρ_L^0
γ*_L
H, E(x, ξ, t)
N
N
γ
ρ^0
℘
p
p
Q^2>>
γ*_L
ρ_L^0
H^g, E^g(x, ξ, t)
N
N

Some signatures of the (asymptotic) « hard » processes:



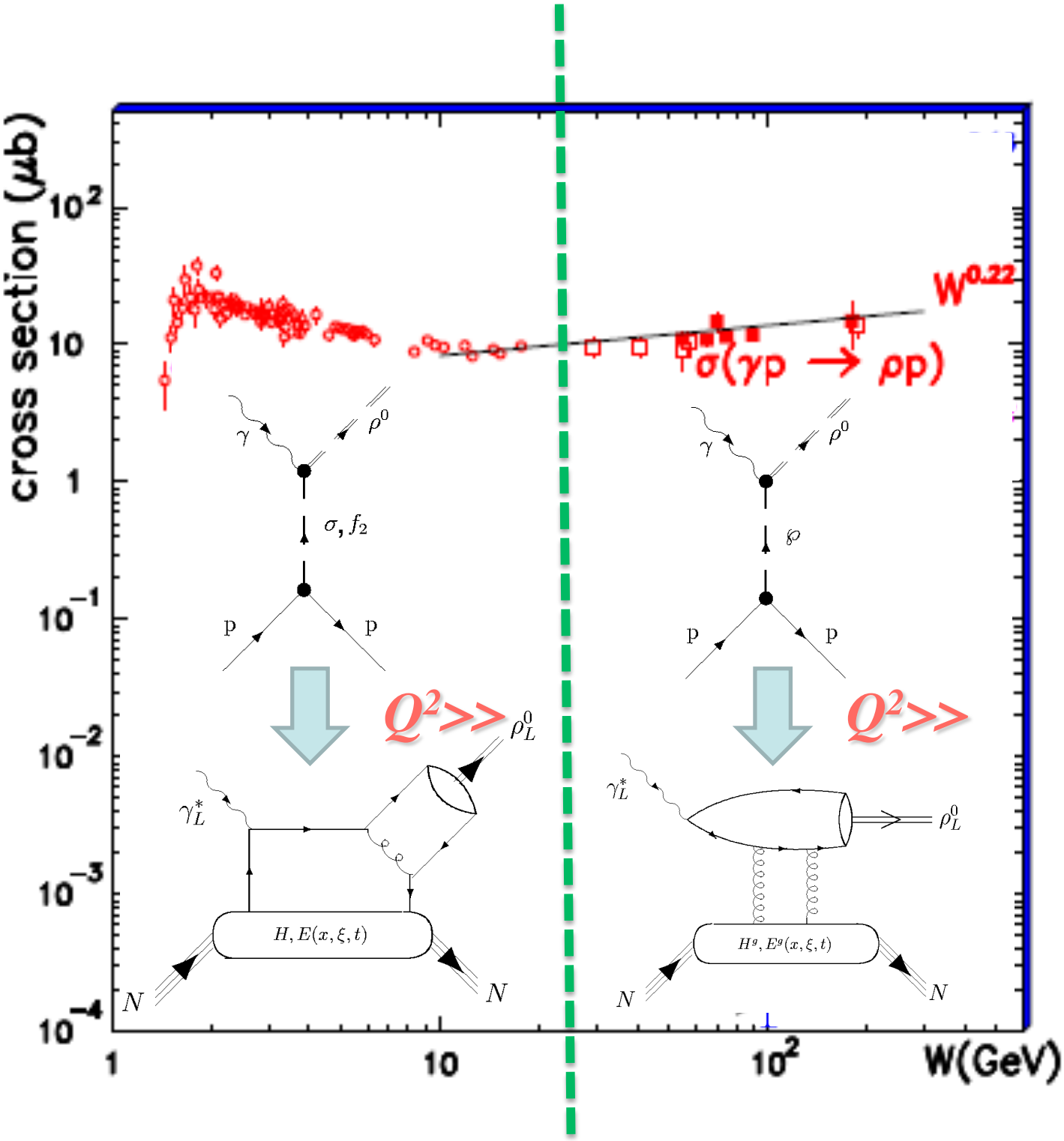
Q^2 dependence: $\sigma_L \sim 1/Q^6$ $\sigma_T \sim 1/Q^8$ $\sigma_L/\sigma_T \sim Q^2$

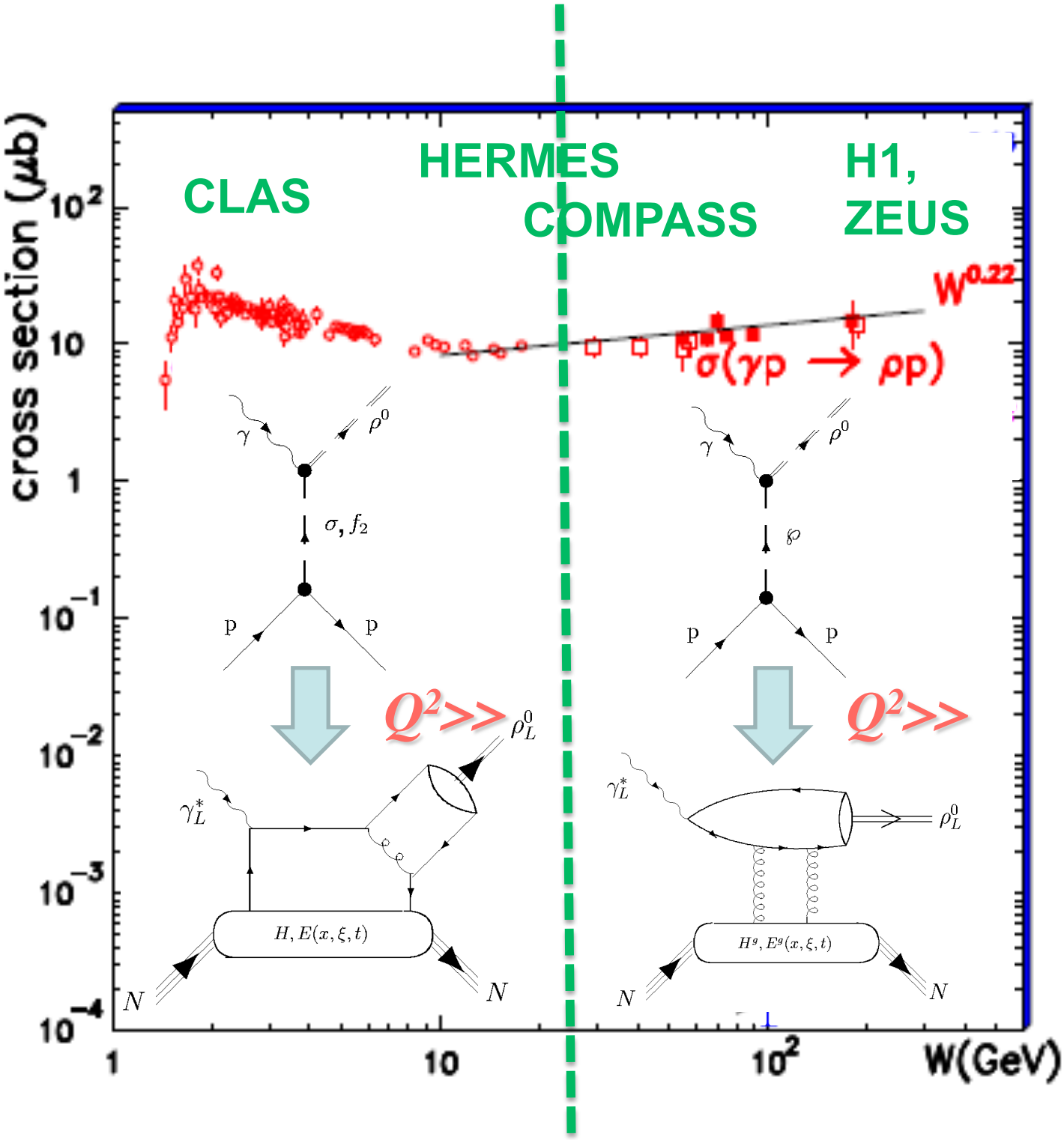
W (or x_B) dependence: $\sigma \sim |xG(x)|^2$ (for gluon handbag)

Ratio of yields: $\rho/\omega/\phi/(J/\Psi) \sim 9/1/2/8$ (for gluon handbag)

Saturation with hard scale of $\alpha_P(0)$, b, …

SCHC : checks with SDMEs


cross section (μb)
10²
10
1
10⁻¹
10⁻²
10⁻³
10⁻⁴
1
10
10²
W(GeV)
W^0.22
σ(γp → ρp)
γ
ρ⁰
σ, f₂
p
p
Q²>>
ρ⁰_L
γ*_L
H, E(x, ξ, t)
N
N
γ
ρ⁰
℘
p
p
Q²>>
γ*_L
ρ⁰_L
H^g, E^g(x, ξ, t)
N
N


CLAS
HERMES
COMPASS
H1,
ZEUS
cross section (μb)
10^2
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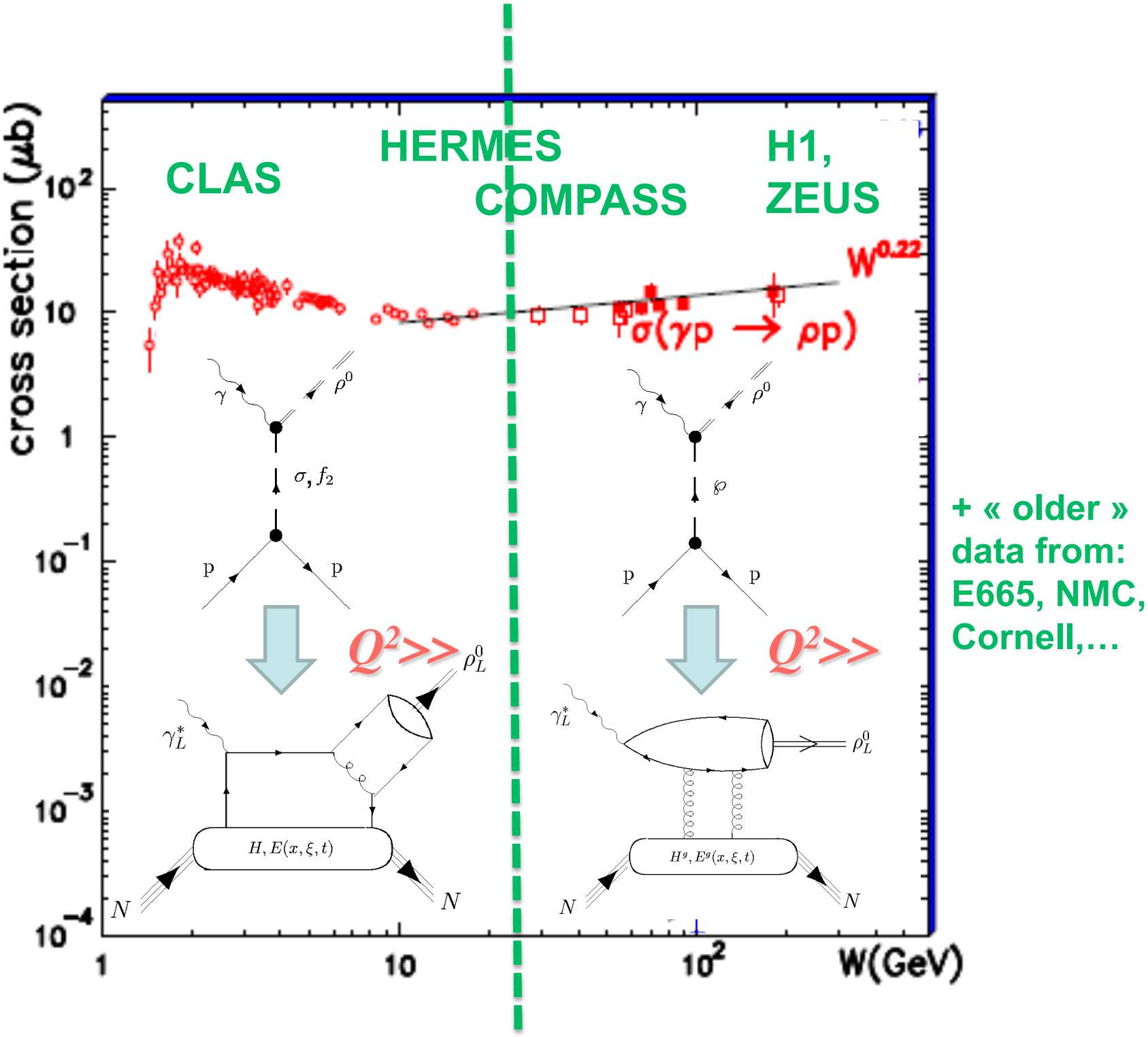
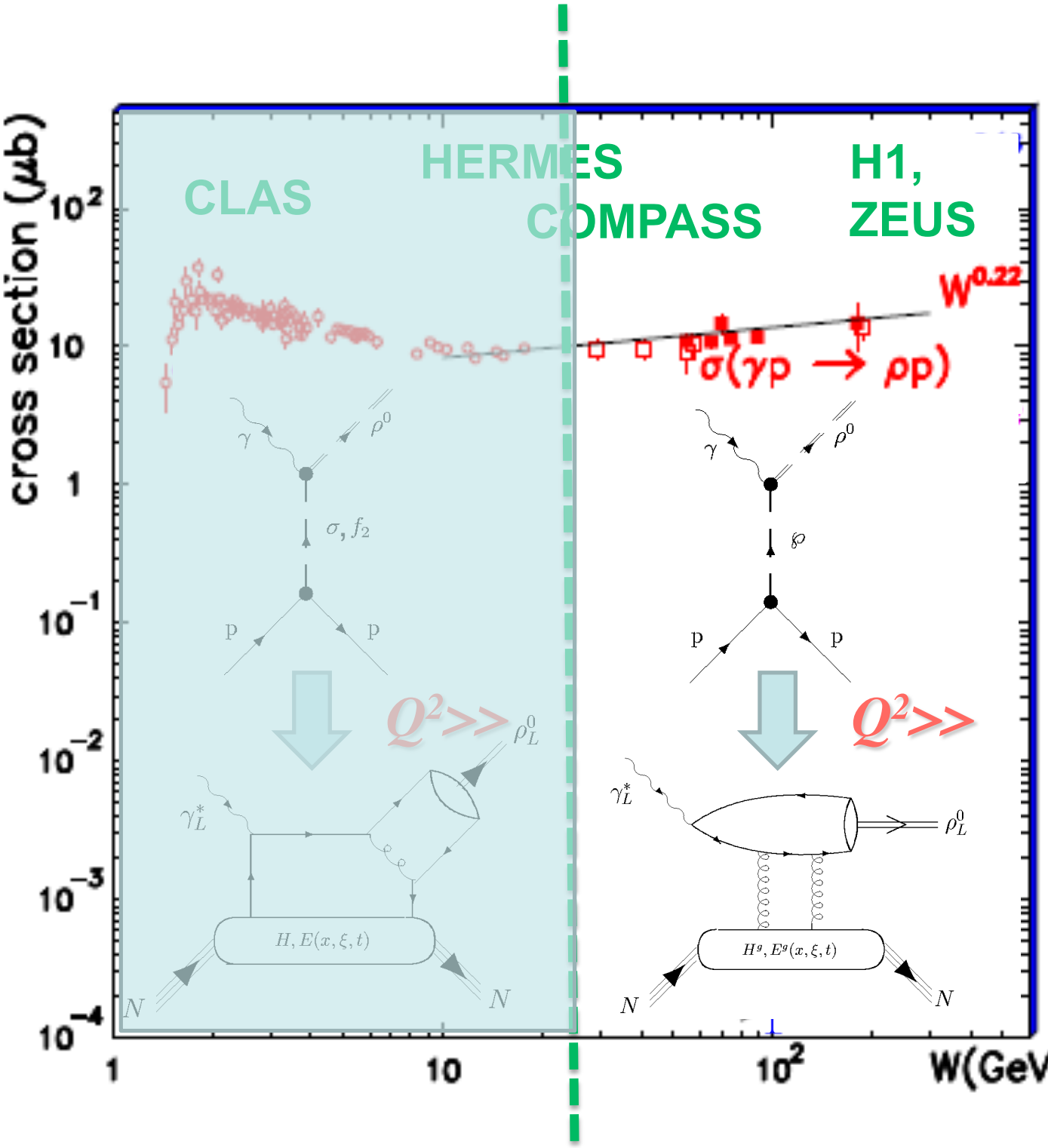
10^{-2}
10^{-3}
10^{-4}
1
10
10^2
W(GeV)
$W^{0.22}$
$\sigma(\gamma p \to \rho p)$
γ
ρ^0
σ, f_2
p
p
$Q^2>>$
ρ_L^0
γ_L^*
$H, E(x,\xi,t)$
N
N
$\wp$
$H^g, E^g(x,\xi,t)$



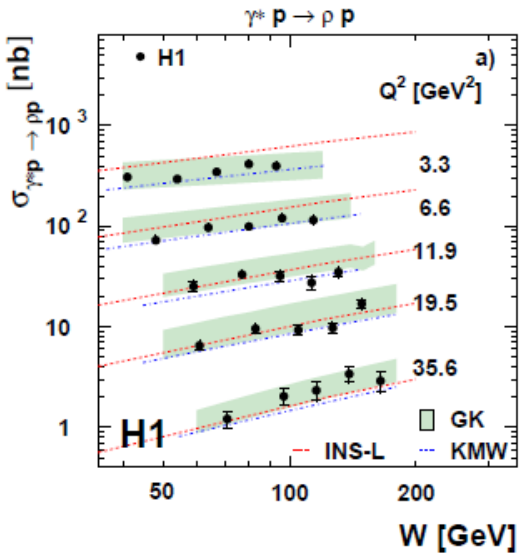
+ « older » data from: E665, NMC, Cornell,…

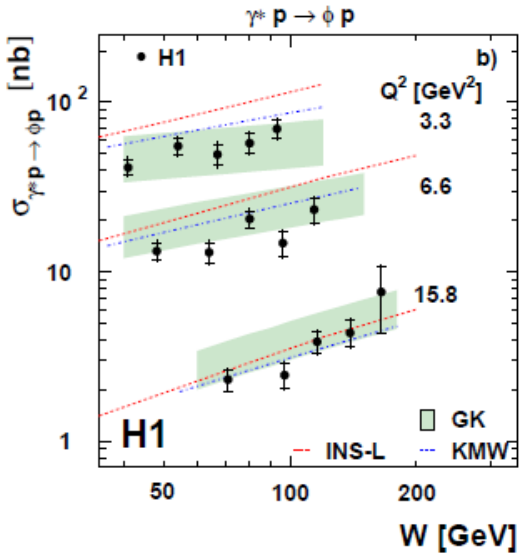


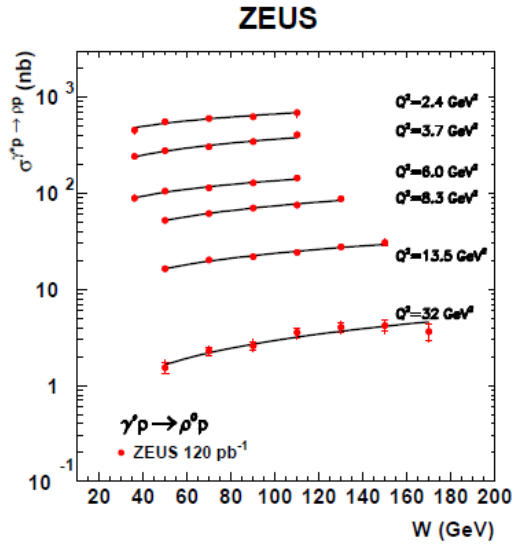
+ « older » data from: E665, NMC, Cornell,…

W dependence

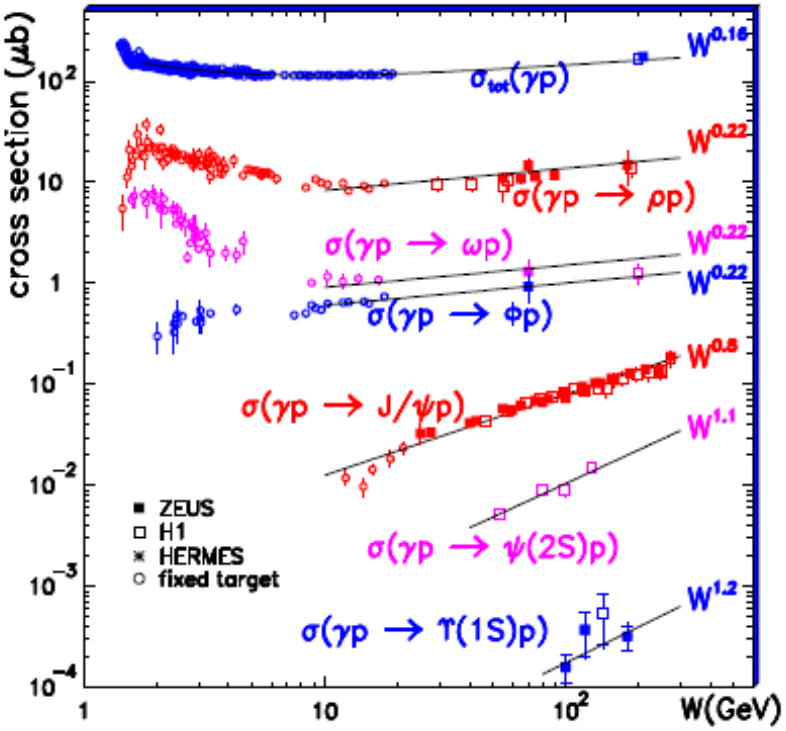
Steepening W slope as a function of Q^2 indicates « hard » regime
(reflects gluon distribution in the proton)





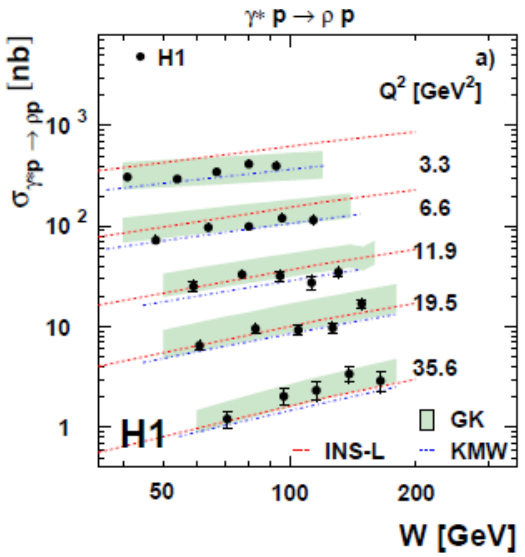


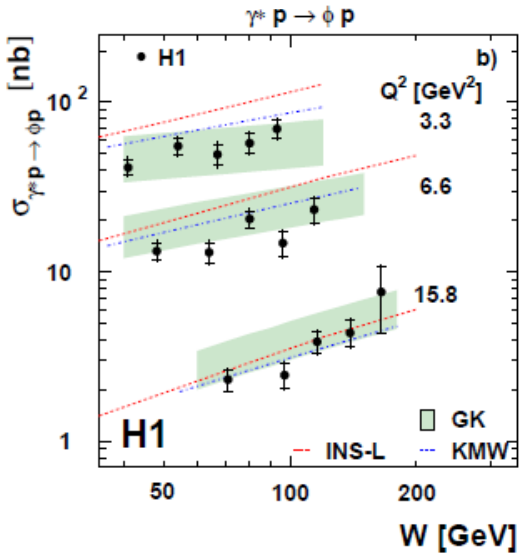
W dependence

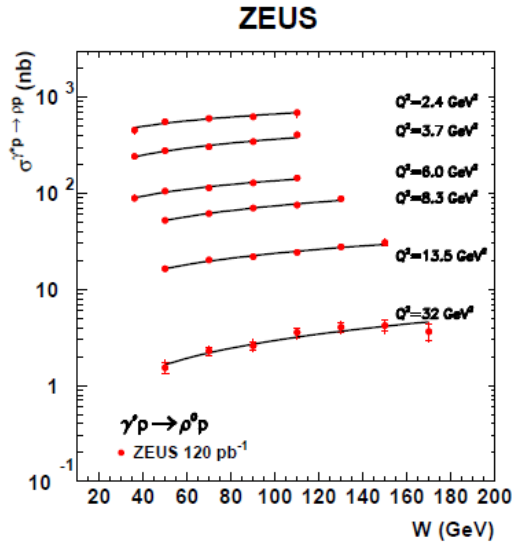


Steepening W slope as a function of Q^2 indicates « hard » regime
(reflects gluon distribution in the proton)

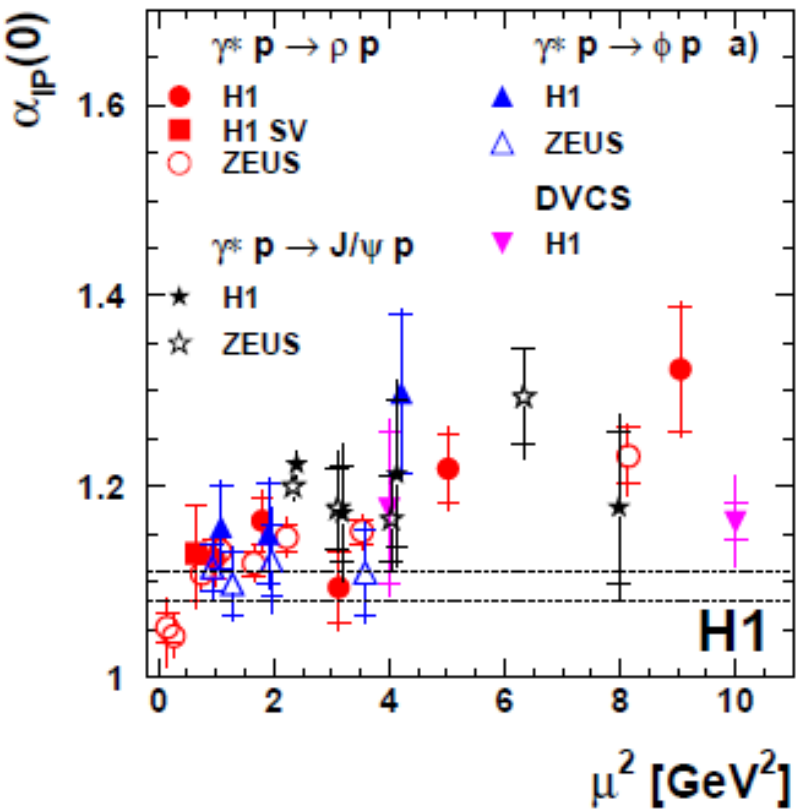
Two ways to set a « hard » scale:
***large Q^2**
***mass of produced VM**







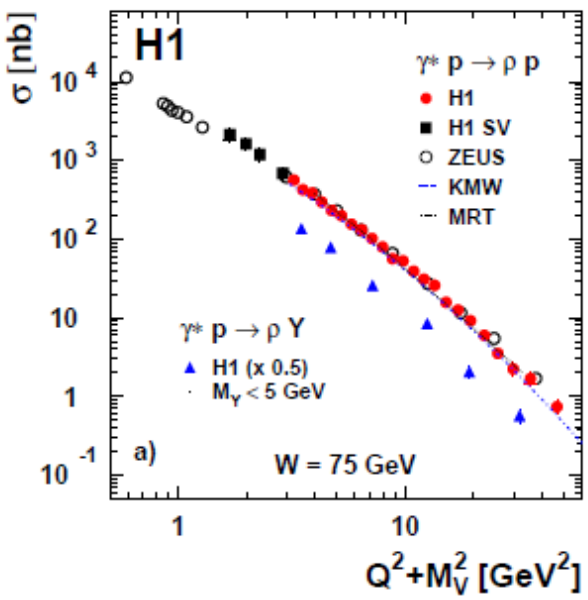
Universality : ρ, φ at large $Q^2+M_V^2$ similar to J/ψ

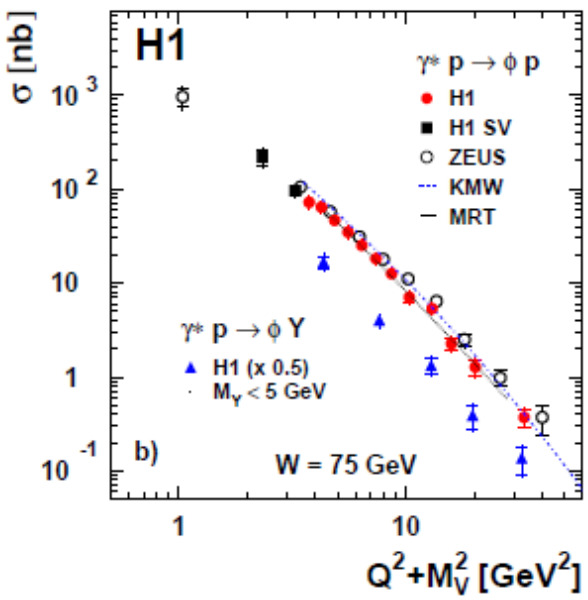


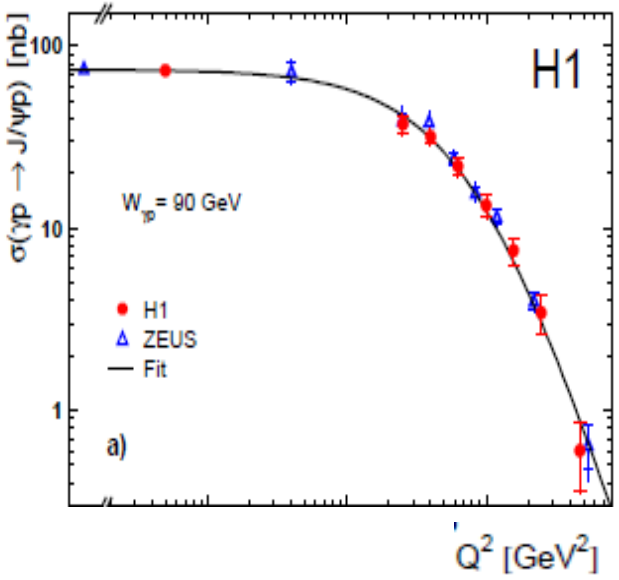
$\alpha_P(0)$ increases from "soft" (~1.1) to "hard" (~1.3) as a function of scale $\mu^2=(Q^2+M_V^2)/4$.

Hardening of W distributions with μ^2

Q^2 dependence







$\sigma_L \sim 1/Q^6$ => **Fit with** $\sigma \sim 1/(Q^2+M_V^2)^n$

ρ: $Q^2 > 0$ GeV² => n=2+/- 0.01
$Q^2 > 10$ GeV² => n=2.5+/- 0.02

(S. Kananov)

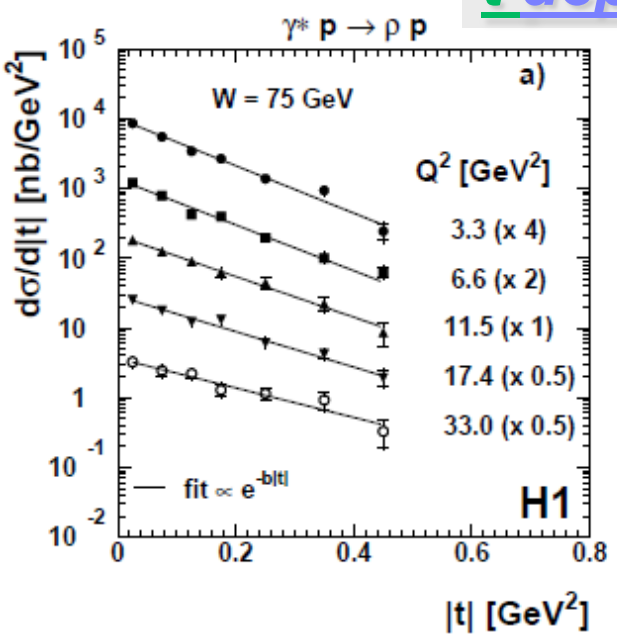
J/ψ: $Q^2 > 0$ GeV² => n=2.486 +/- 0.08 +/-0.068

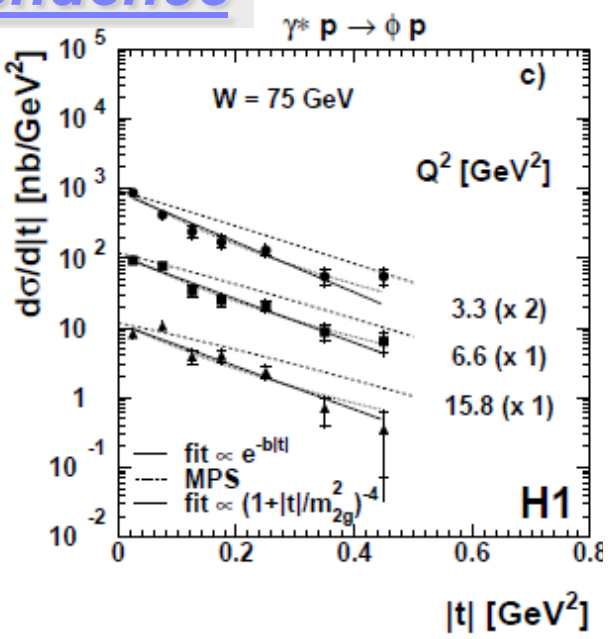
Q^2 dependence is damped at low Q^2 and steepens at large Q^2

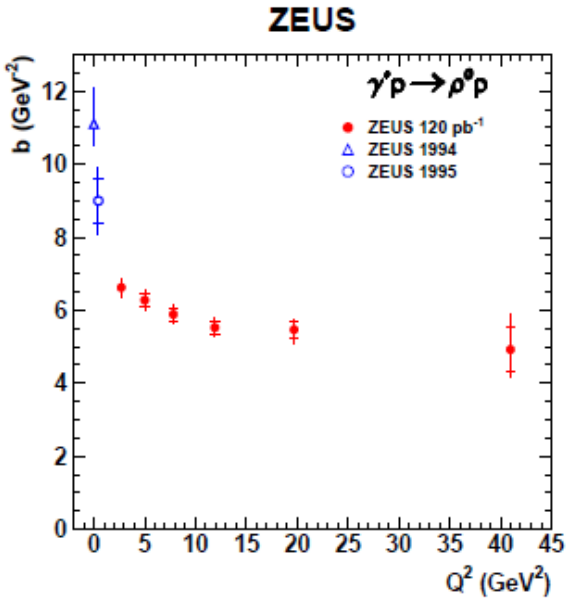
Approaching handbag prediction of n=6

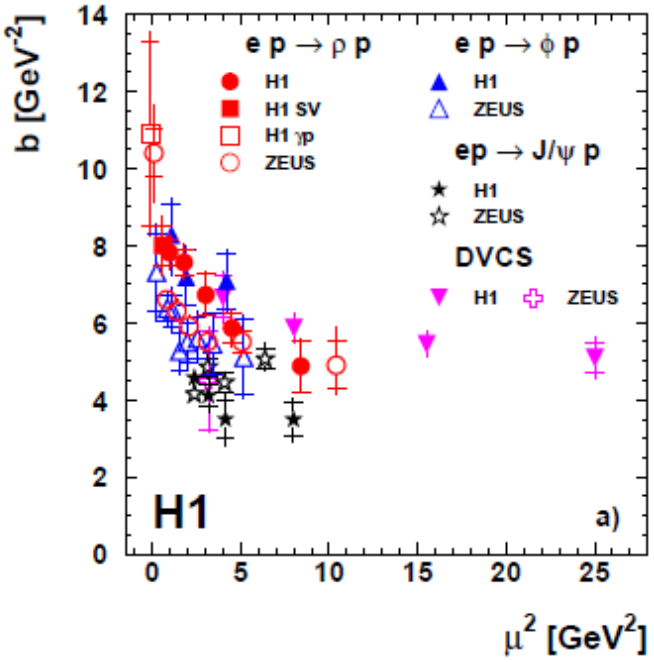
(Q^2 not asymptotic, fixed W vs fixed x_B, σ_{tot} vs σ_L, Q^2 evolution of G(x)…)

t dependence



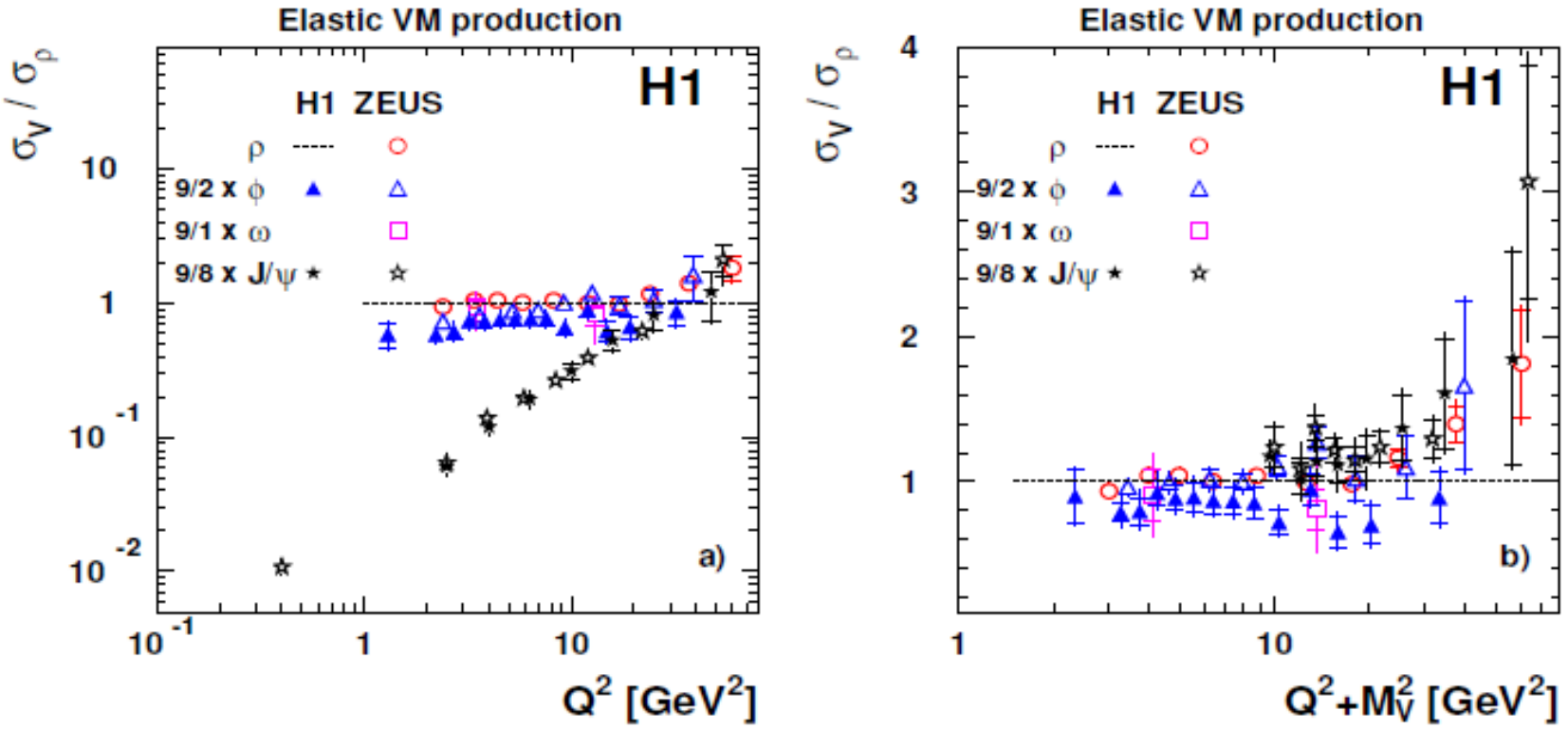






b decreases from "soft" (~10 GeV^{-2}) to "hard" (~4-5 GeV^{-2}) as a function of scale $\mu^2=(Q^2+M_V^2)/4$

Ratios



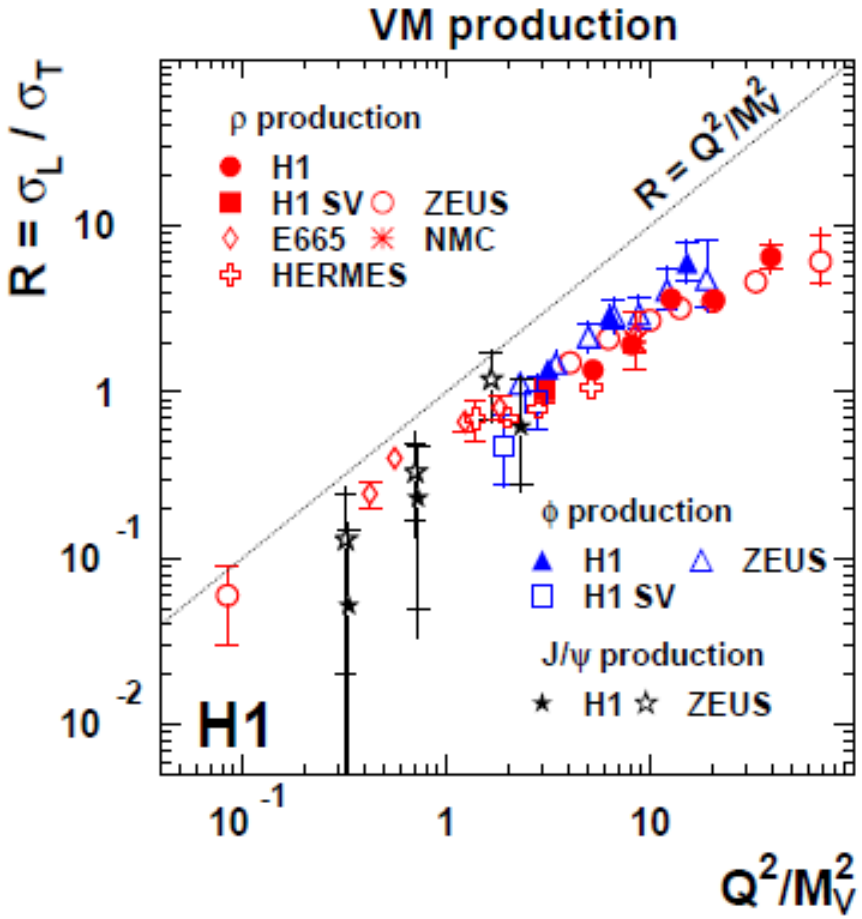
ρ/ω/ϕ/(J/Ψ) ~ 9/1/2/8

$|\rho^0\rangle = 1/\sqrt{2}\{|u\bar{u}\rangle - |d\bar{d}\rangle\}$

$|\omega\rangle = 1/\sqrt{2}\{|u\bar{u}\rangle + |d\bar{d}\rangle\}$

$\Rightarrow$ $\sim\{2/3-(-1/3)\}$ / $\sim\{2/3+(-1/3)\}$ $\Rightarrow$ Ratio ρ/ω=9

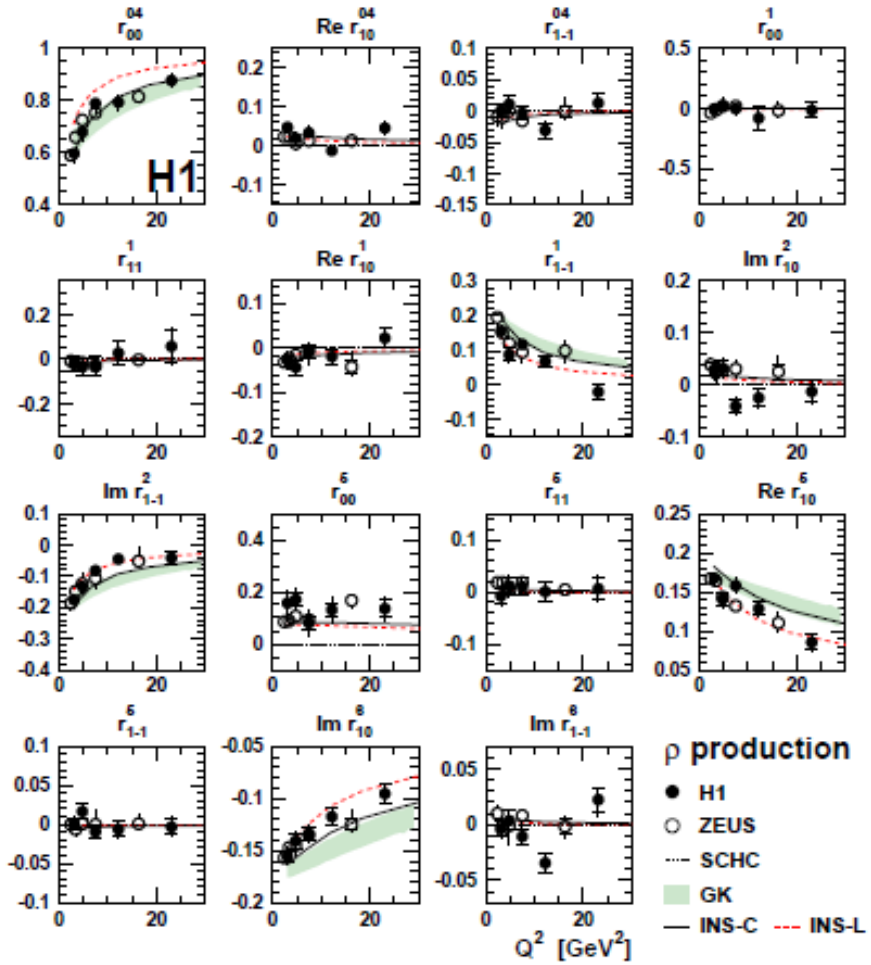
σ_L/σ_T



(almost) compatible with handbag prediction

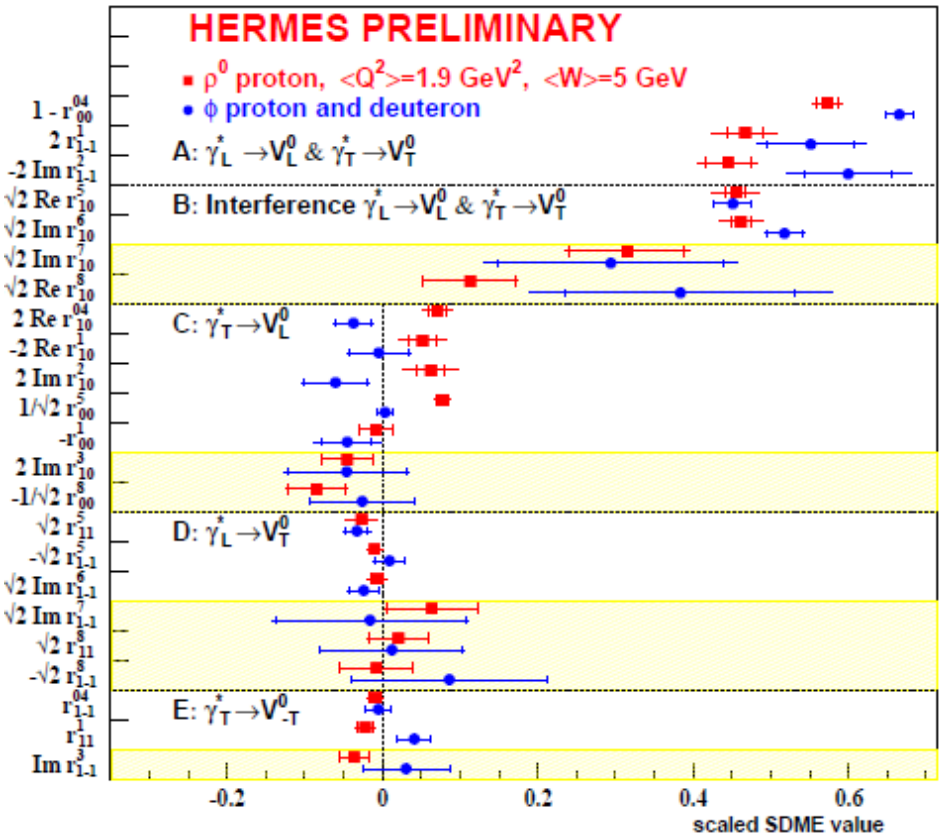
(damping at large Q^2)

SDMEs



H1

HERMES

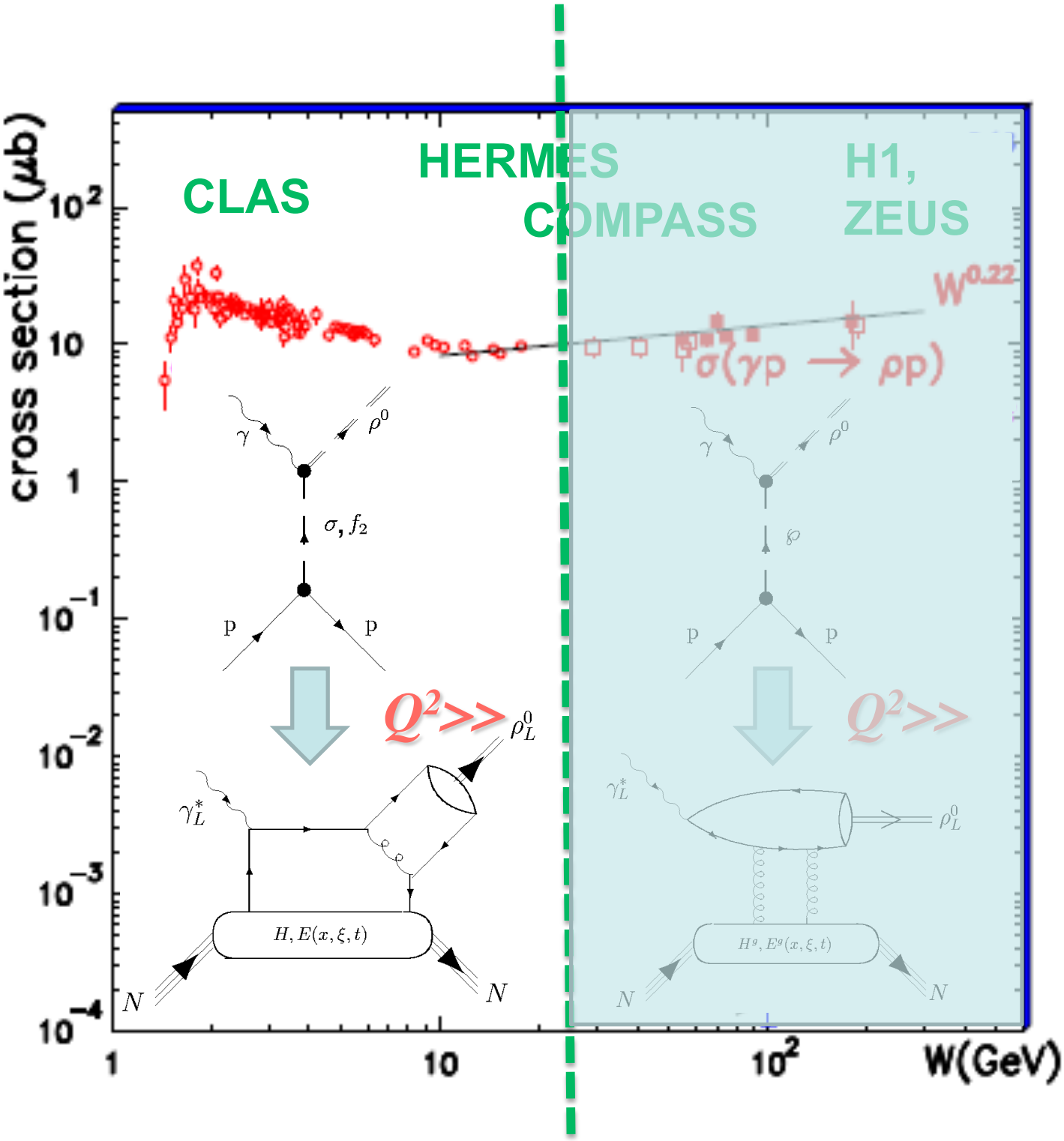


(almost) no SCHC violation

- ***At high energy (W>5 GeV), the general features of the kinematics dependences and of the SDMEs are relatively/qualitatively well understood***

- ***Good indications that the "hard"/pQCD regime is dominant for*** $\mu^2=(Q^2+M_V^2)/4 \sim 3\text{-}5\ \text{GeV}^2$.

- ***Data are relatively well described by GPD/handbag approaches***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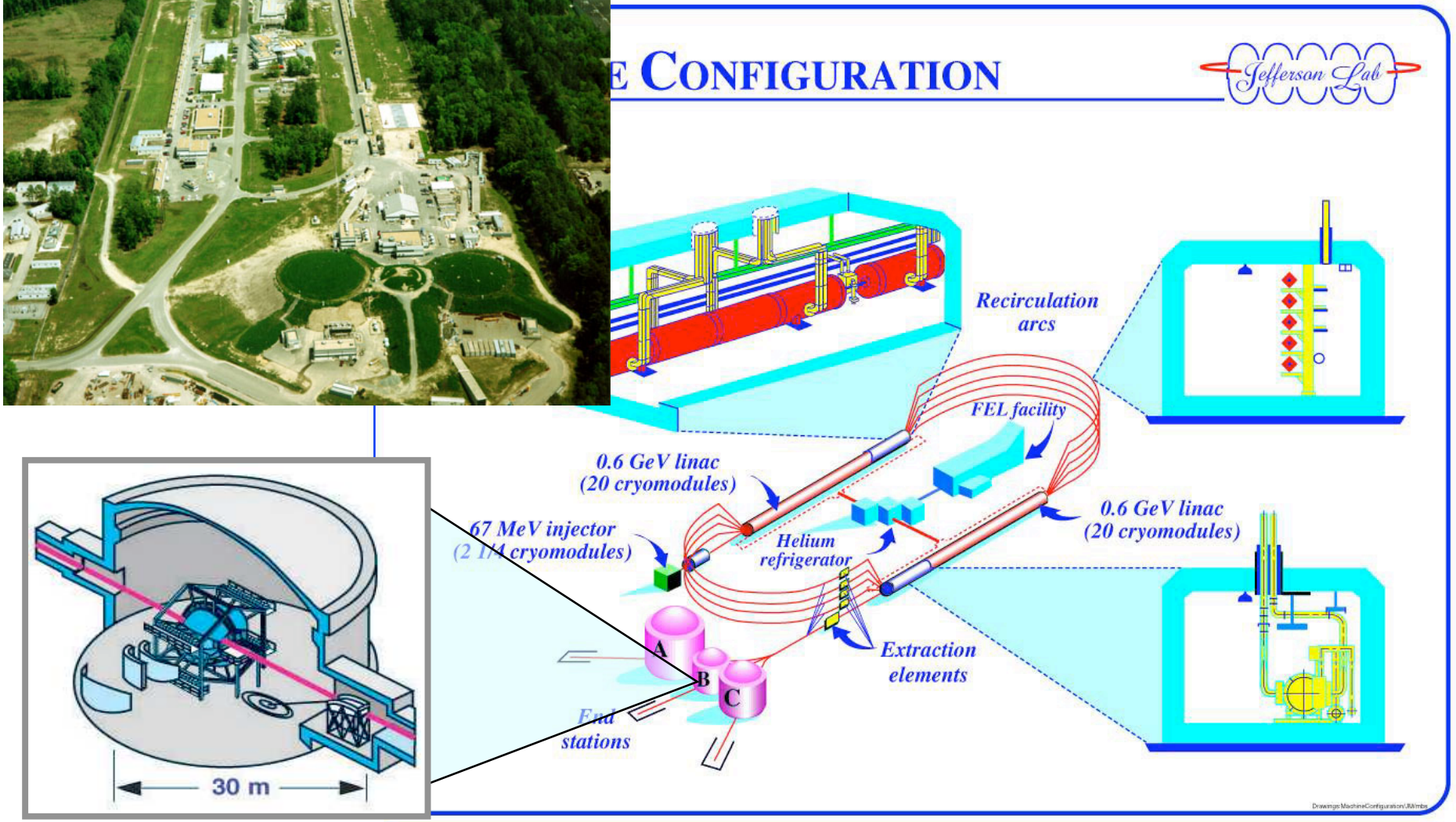
$H, E(x,\xi,t)$
N
N
$\wp$
$H^g, E^g(x,\xi,t)$

JLab & CLAS in Hall B

Duty cycle ~100% E_{max}~6 GeV



Exclusive ρ^0, ω, ϕ & ρ^+ electroproduction 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)

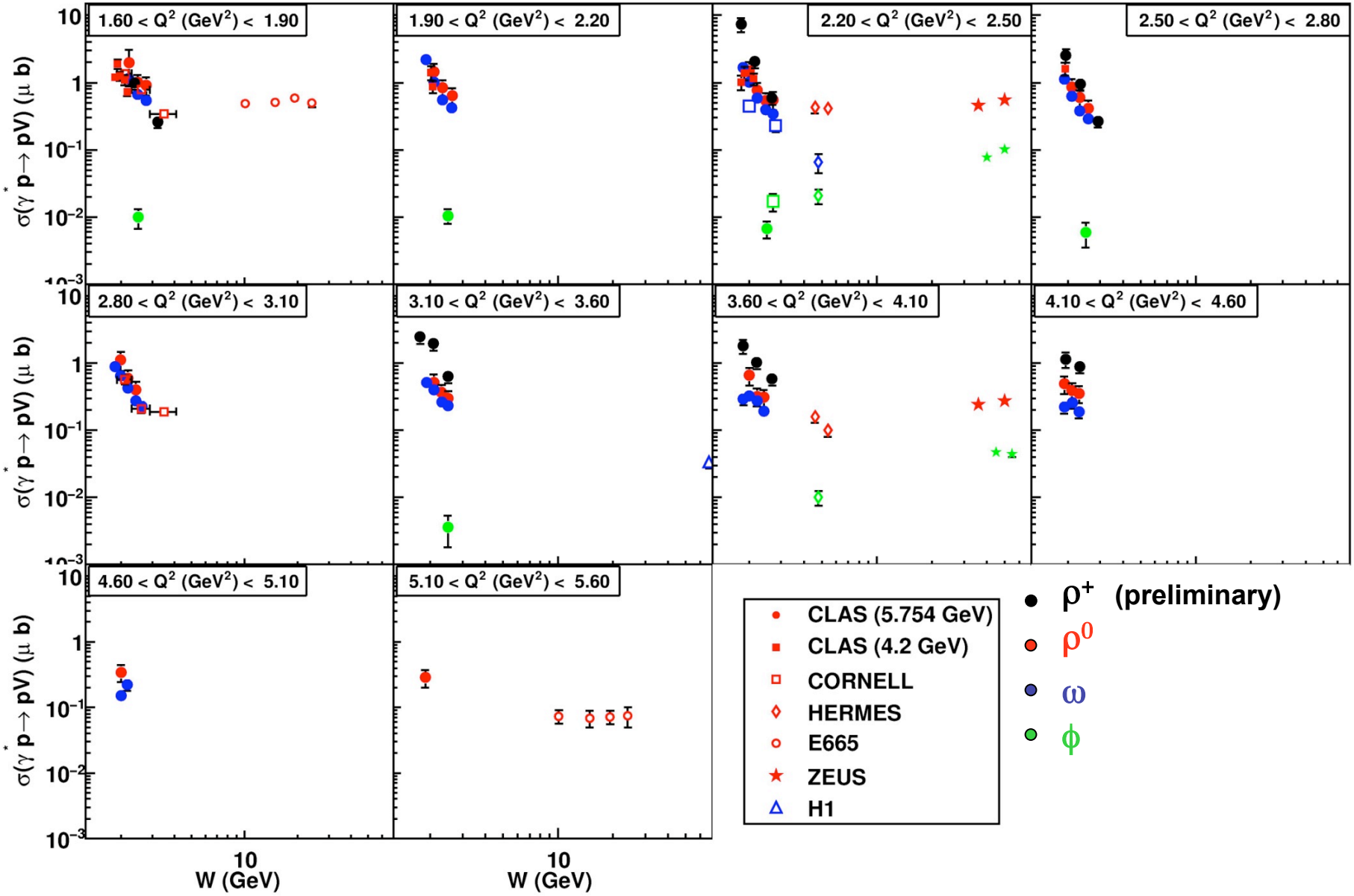
e1-b (1999)

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)



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)

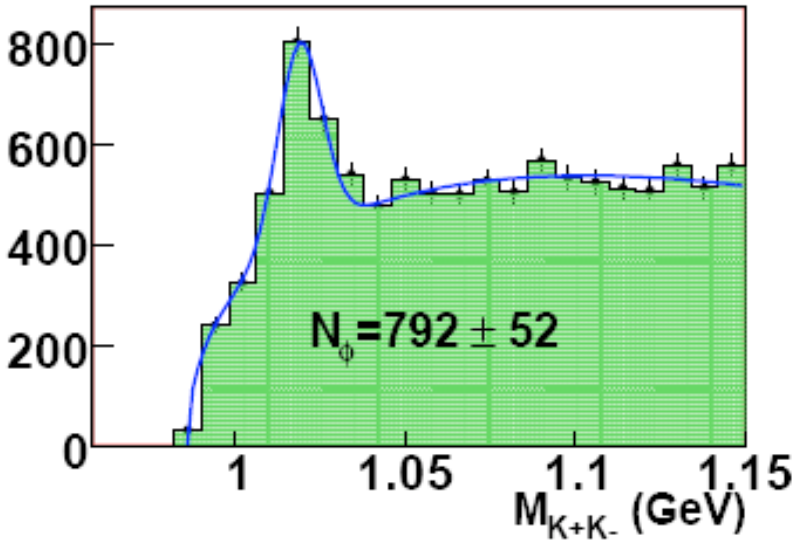
K. Lukashin, Phys.Rev.C63:065205,2001 (ϕ@4.2 GeV)

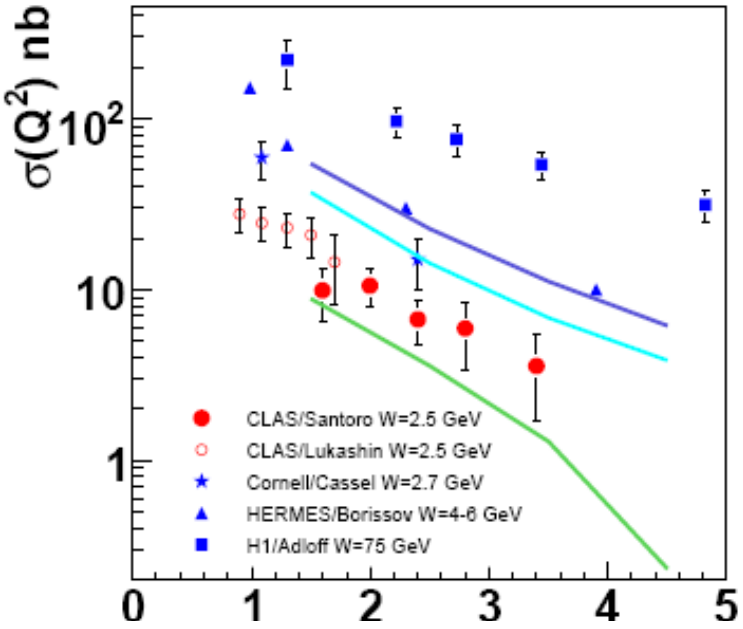
S. Morrow et al., Eur.Phys.J.A39:5-31,2009 (ρ^0@5.75GeV)

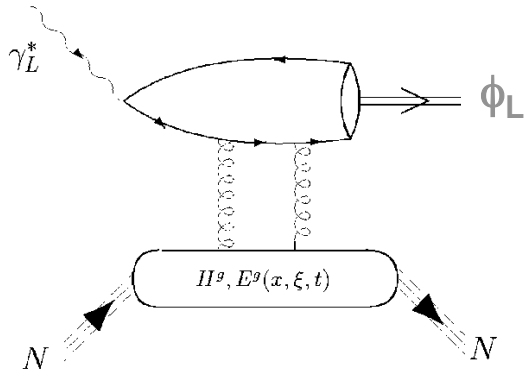
J. Santoro et al., Phys.Rev.C78:025210,2008 (ϕ@5.75GeV)

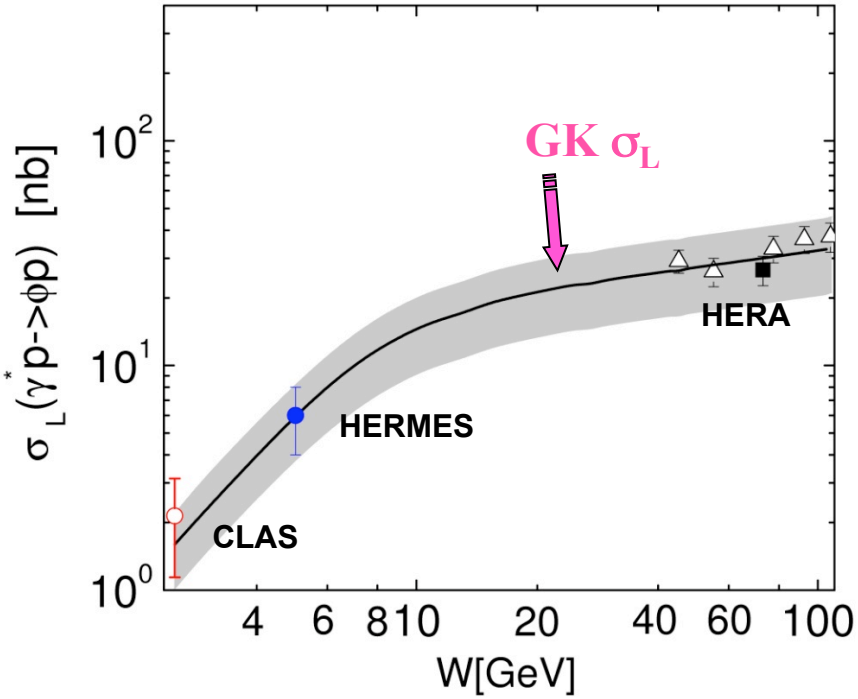
A. Fradi, Orsay Univ. PhD thesis, 2009 (ρ^+@5.75GeV)

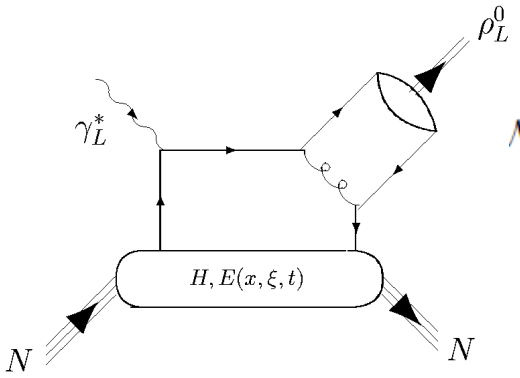
ep->epϕ (↳ $K^+[K^-]$)


800
600
400
200
0
1
1.05
1.1
1.15
$N_\phi = 792 \pm 52$
M_{K+K-} (GeV)

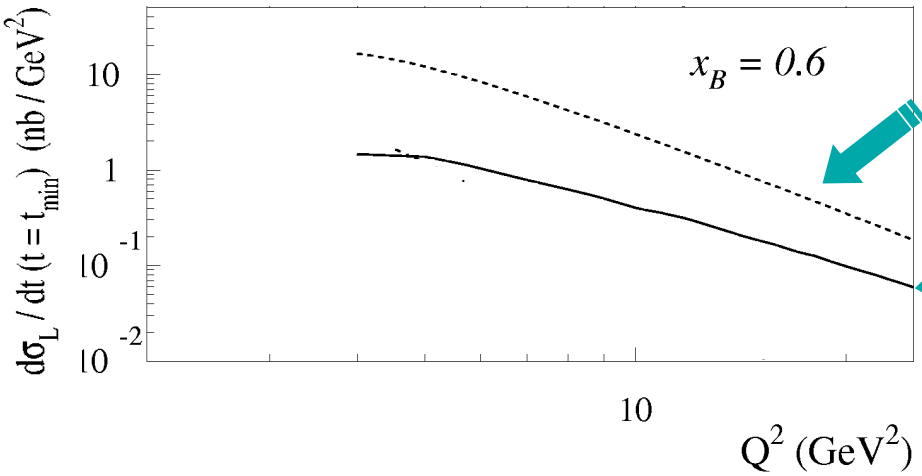

$\sigma(Q^2)$ nb
10^2
10
1
0
1
2
3
4
5
CLAS/Santoro W=2.5 GeV
CLAS/Lukashin W=2.5 GeV
Cornell/Cassel W=2.7 GeV
HERMES/Borissov W=4-6 GeV
H1/Adloff W=75 GeV


γ_L^*
ϕ_L
$I\!I^g, E^g(x,\xi,t)$
N
N


$\sigma_L(\gamma^* p \to \phi p)$ [nb]
10^2
10^1
10^0
GK σ_L
HERA
HERMES
CLAS
4
6
8
10
20
40
60
100
W[GeV]



$$\mathcal{M}^L_{\rho^0_L} = -ie\frac{4}{9}\frac{1}{Q}\left[\int_0^1 dz\frac{\Phi_\rho(z)}{z}\right]\frac{1}{2}\int_{-1}^{+1}dx\left[\frac{1}{x-\xi+i\epsilon}+\frac{1}{x+\xi-i\epsilon}\right]$$
$$\times(4\pi\alpha_s)\left\{H^p_{\rho^0_L}(x,\xi,t)\bar{N}(p')\gamma.nN(p)+E^p_{\rho^0_L}(x,\xi,t)\bar{N}(p')i\sigma^{\kappa\lambda}\frac{n_\kappa\Delta_\lambda}{2m_N}N(p)\right\}$$



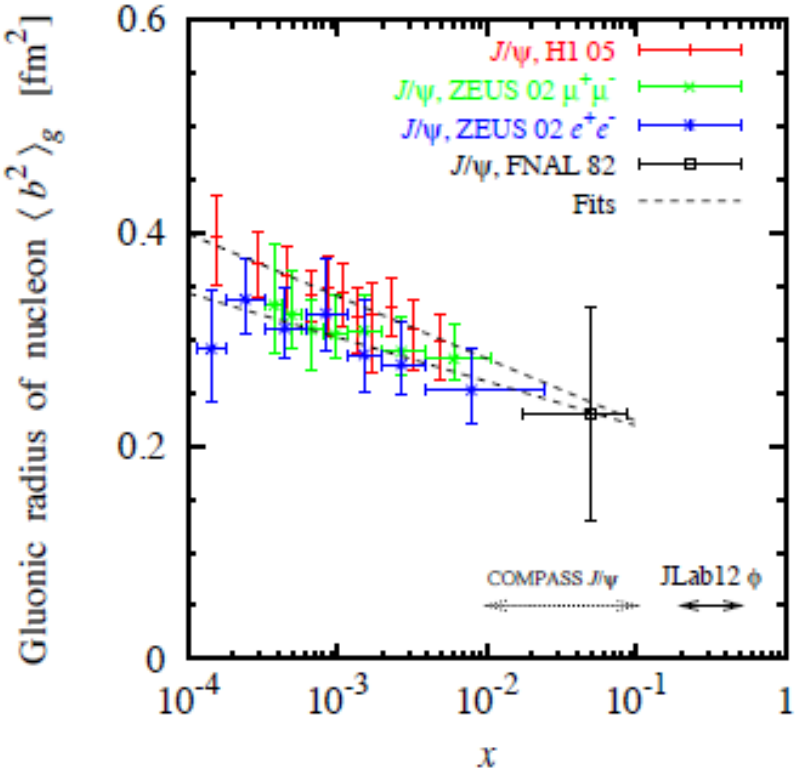
LO (w/o kperp effect)

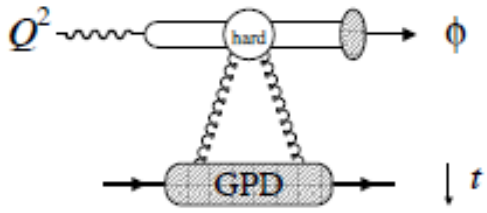
LO (with kperp effect)

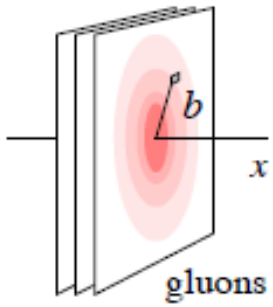
Handbag diagram calculation needs k_{perp} effects to account for preasymptotic effects

Same thing for 2-gluon exchange process

Exclusive ϕ electroproduction: gluon imaging of the proton





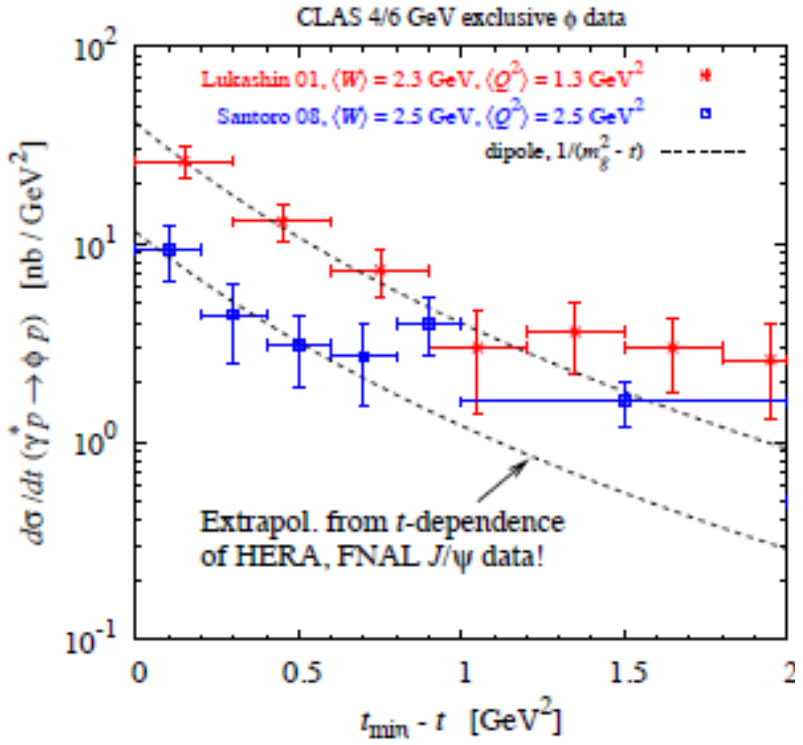


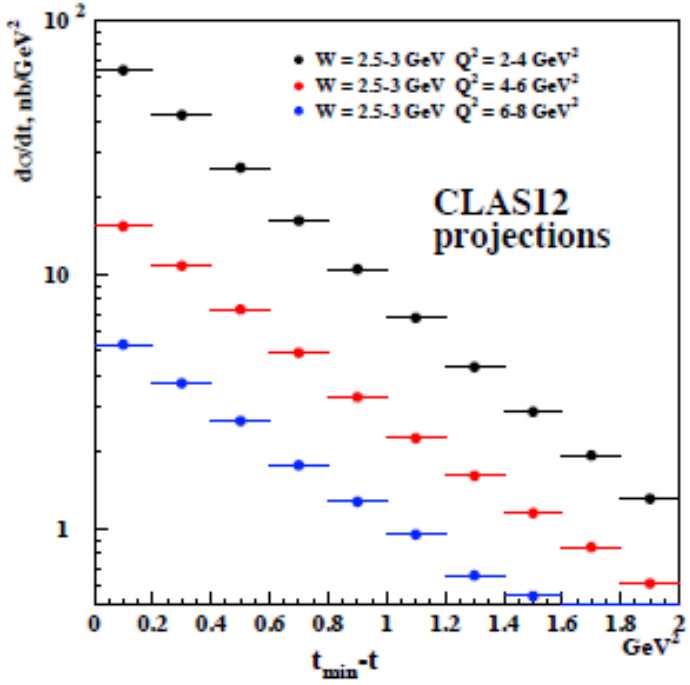
x<0.01: measured at H1/ZEUS

x>0.1: practically unknown: ϕ with CLAS12

(from JLab PAC38 PR12-11-103, C. Weiss/P. Stoler's slides)

Exclusive ϕ electroproduction: gluon imaging of the proton



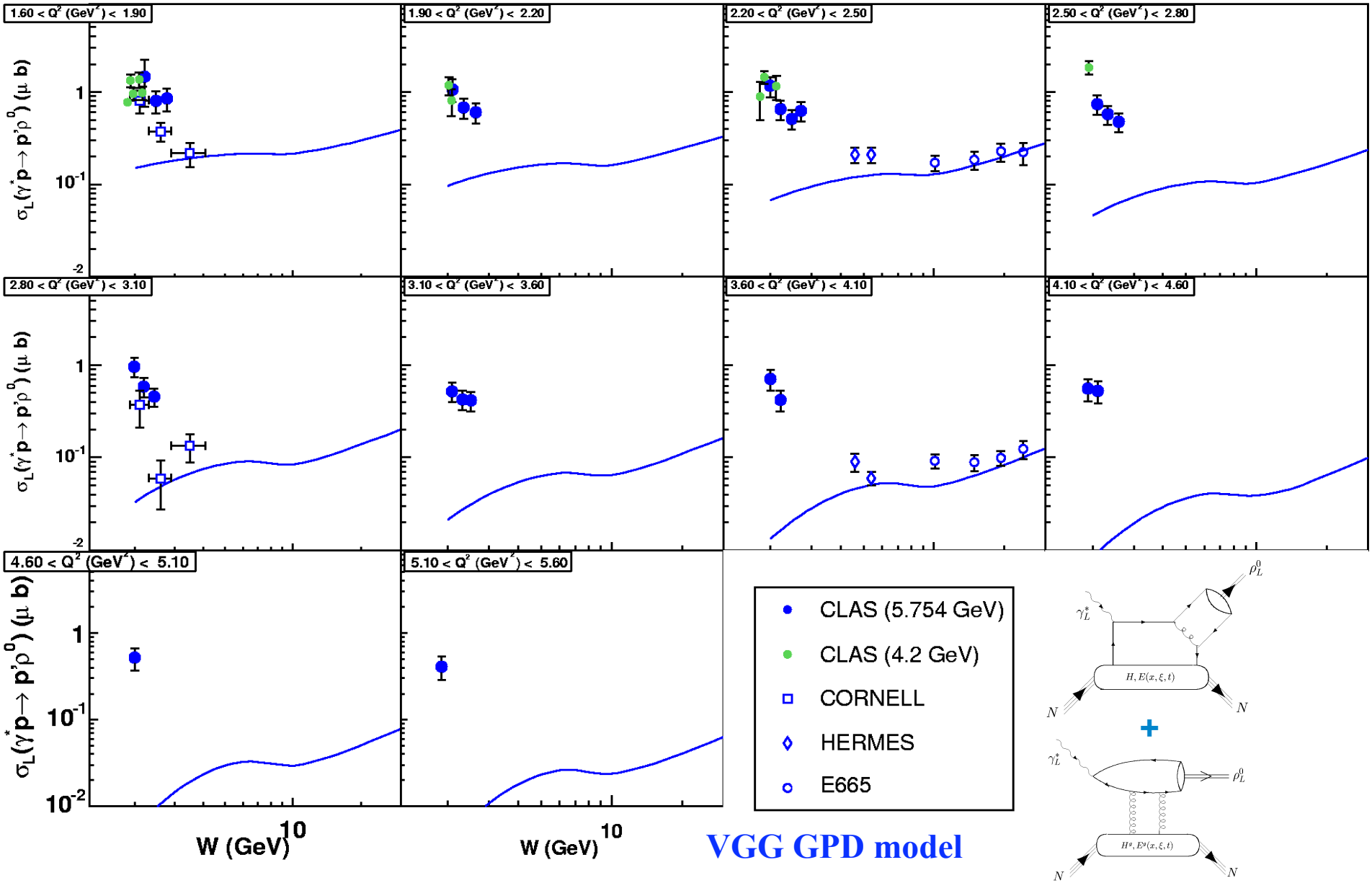


(A. Kubarovsky's simulations)

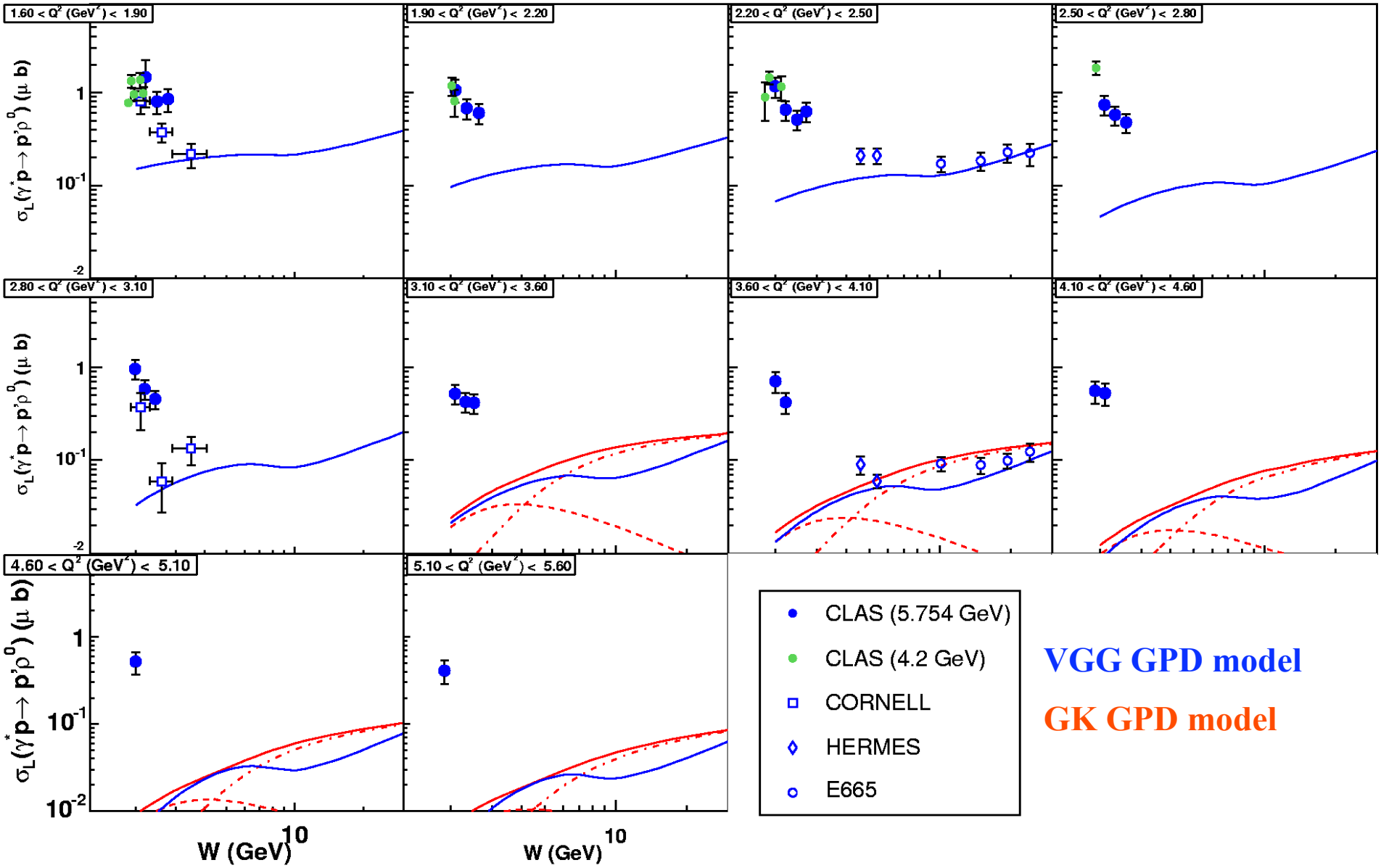
CLAS12 proposal PR12-11-103:

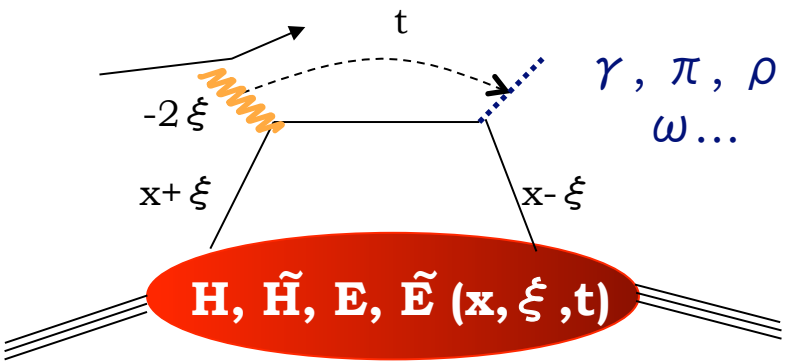
Extract t–slope of $d\sigma_L/dt$

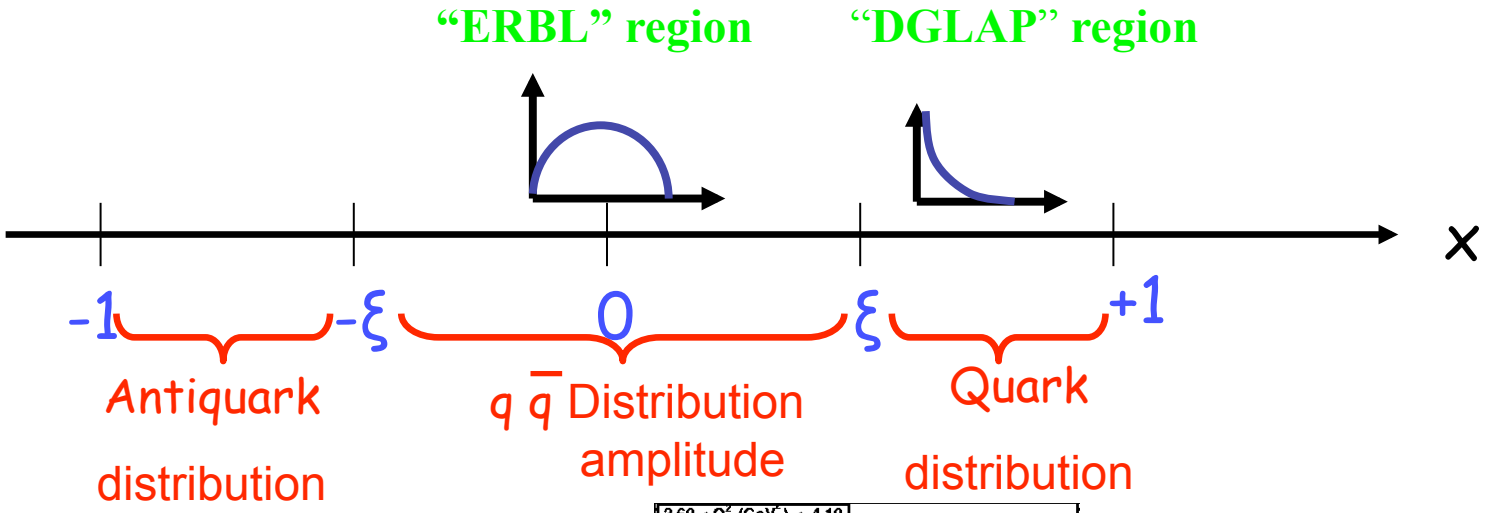
As a function of Q^2: check when Q^2-independence settles
As a function of x_B (or W): first 3D-gluon imaging at large x

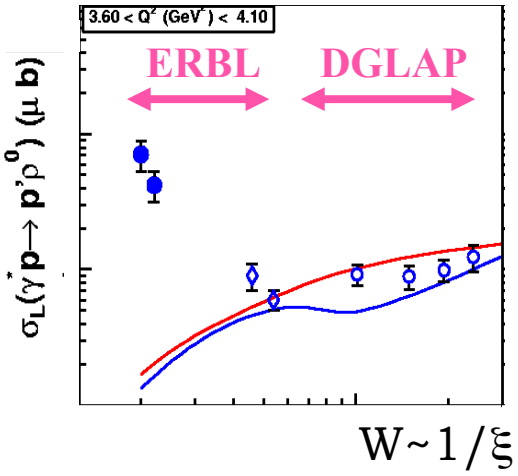


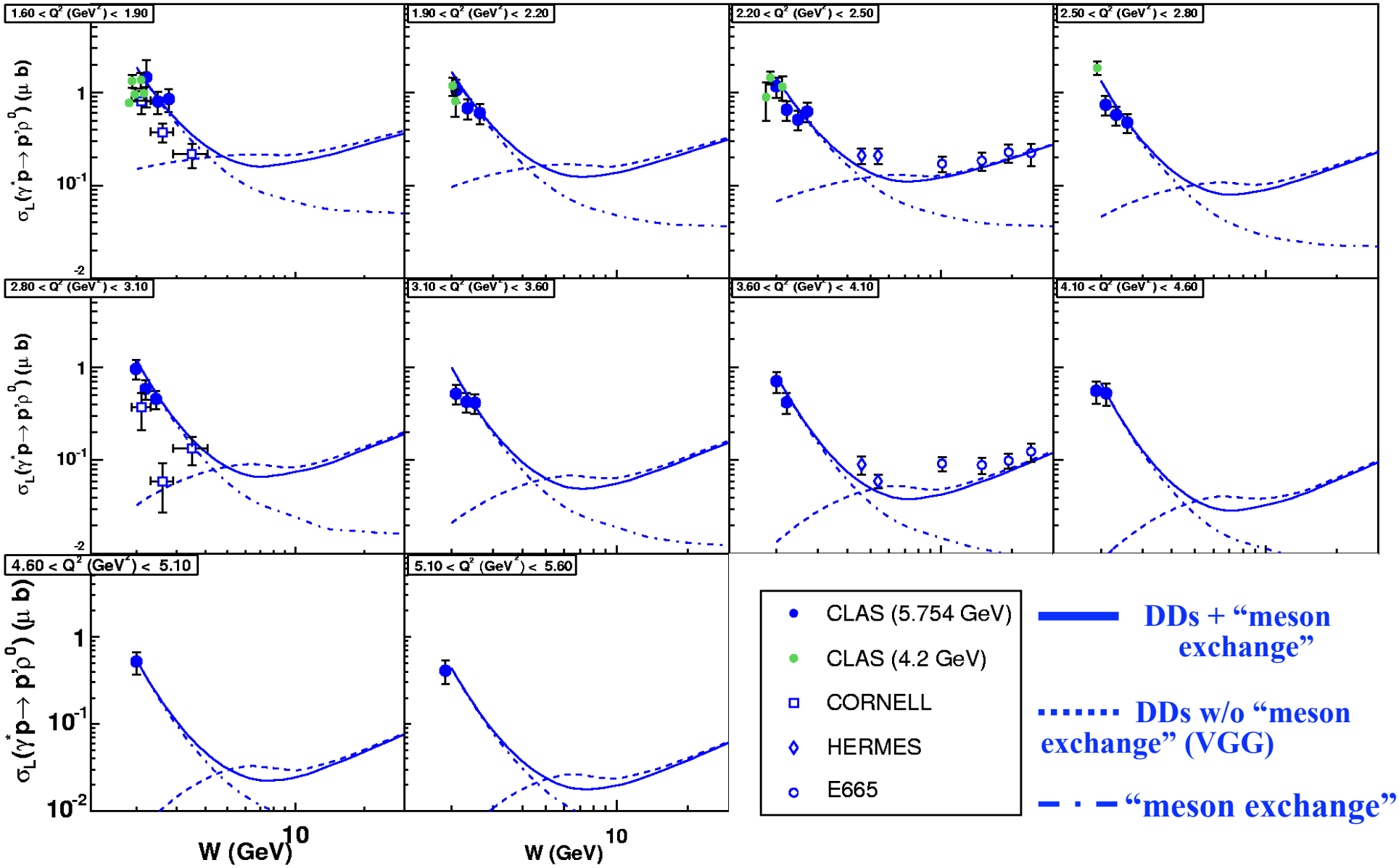
VGG GPD model


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
GK GPD model


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

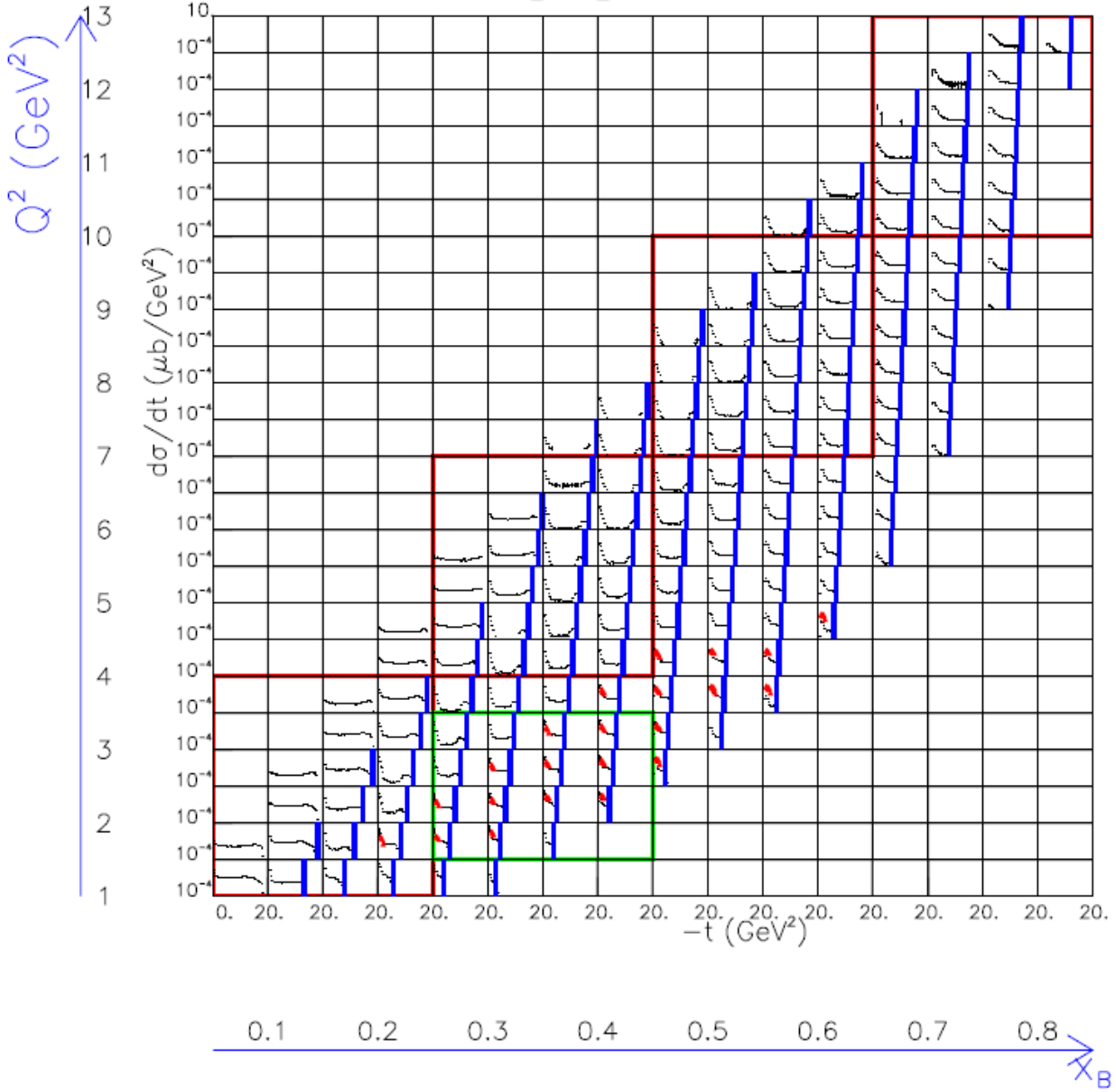

"ERBL" region
"DGLAP" region
x
-1
-ξ
0
ξ
+1
Antiquark distribution
q q̄ Distribution amplitude
Quark distribution

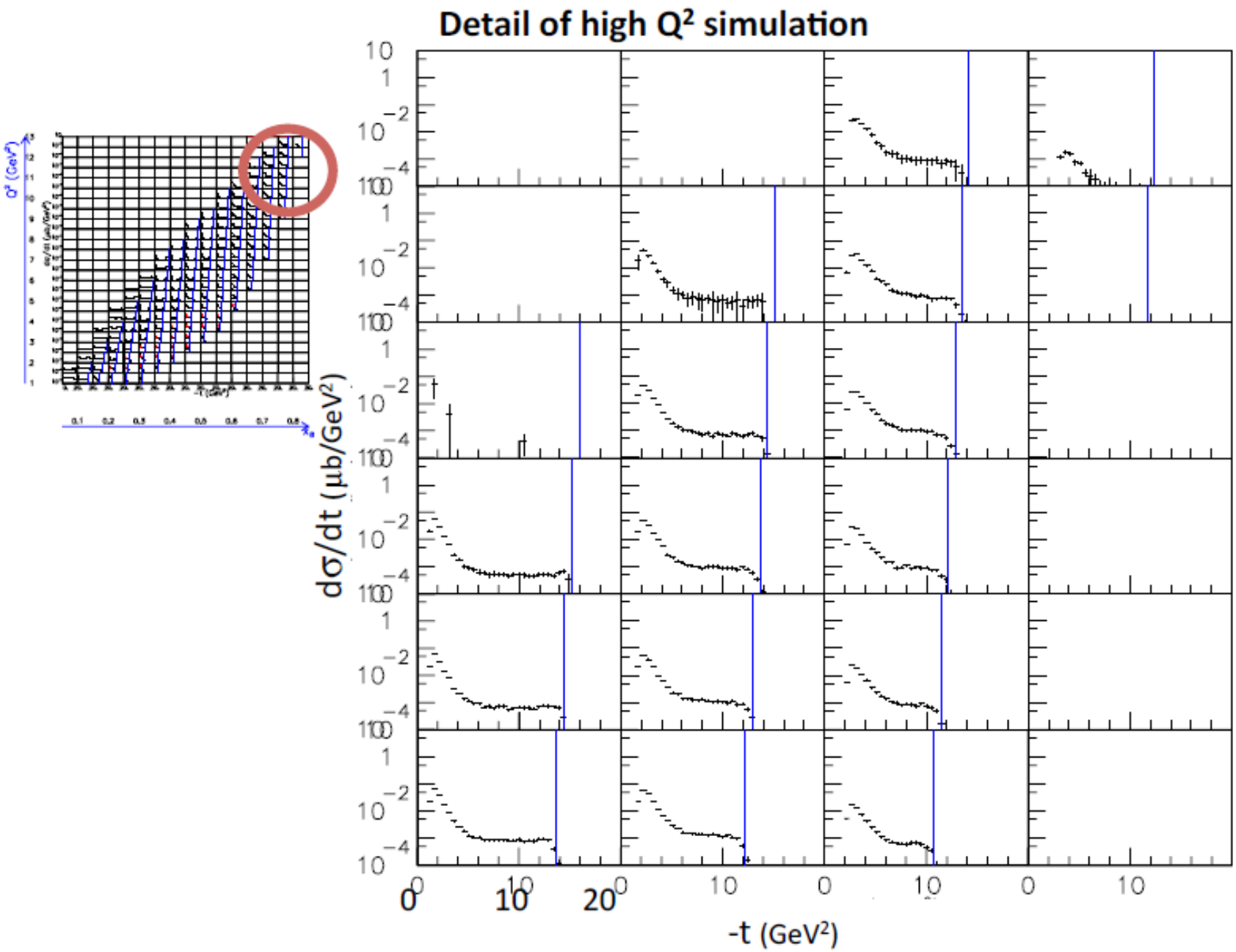

3.60 < Q² (GeV²) < 4.10
ERBL
DGLAP
W~1/ξ


1.60 < Q² (GeV²) < 1.90
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
DDs + "meson exchange"
DDs w/o "meson exchange" (VGG)
"meson exchange"

Exclusive ρ^0 electroproduction at CLAS12

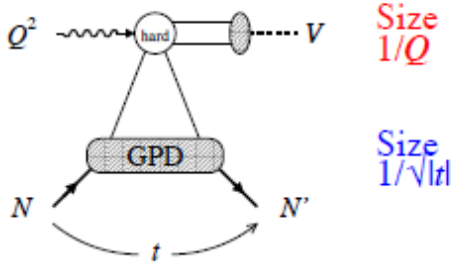
CLAS12 proposal PR12-11-103

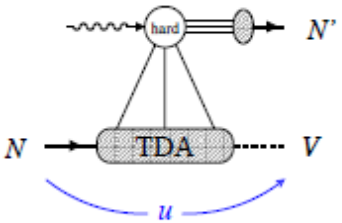


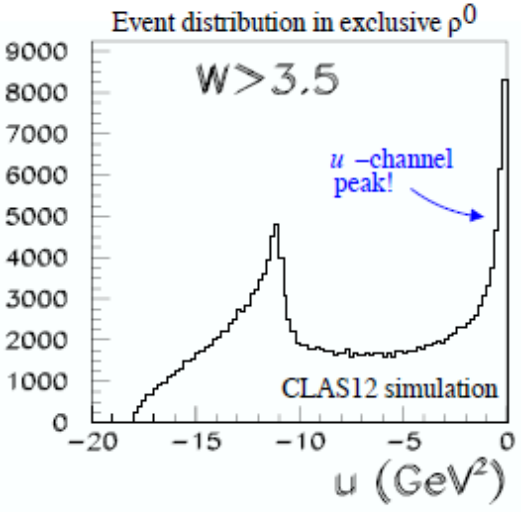

Detail of high Q² simulation
dσ/dt (μb/GeV²)
-t (GeV²)

High–t: Small–size qqq configurations

(from JLab PAC38 PR12-11-103, C. Weiss/P. Stoler's slides)







- Meson production at $|t| \gg 1\,\mathrm{GeV}^2$: Nucleon in small–size configuration

  Cf. high–t elastic nucleon form factors

  Progress with GPD description of high–t processes
  Kumano, Strikman, Sudoh 10

- Backward production: $|u| < 1\,\mathrm{GeV}^2$

  Knockout of small–size qqq configuration, mesonic system left behind

  Transition distribution amplitude $\langle V|qqq|N\rangle$
  New information on short–range nucleon structure
  Frankfurt et al. 02; Pire, Semenov–Tian–Shansky, Szymanowski 10/11
  Great interest! Cross section calculations available soon

- CLAS12: Explore high–$|t|$, high–Q^2 region for the first time

New QCD probe of nucleon's valence quark core!

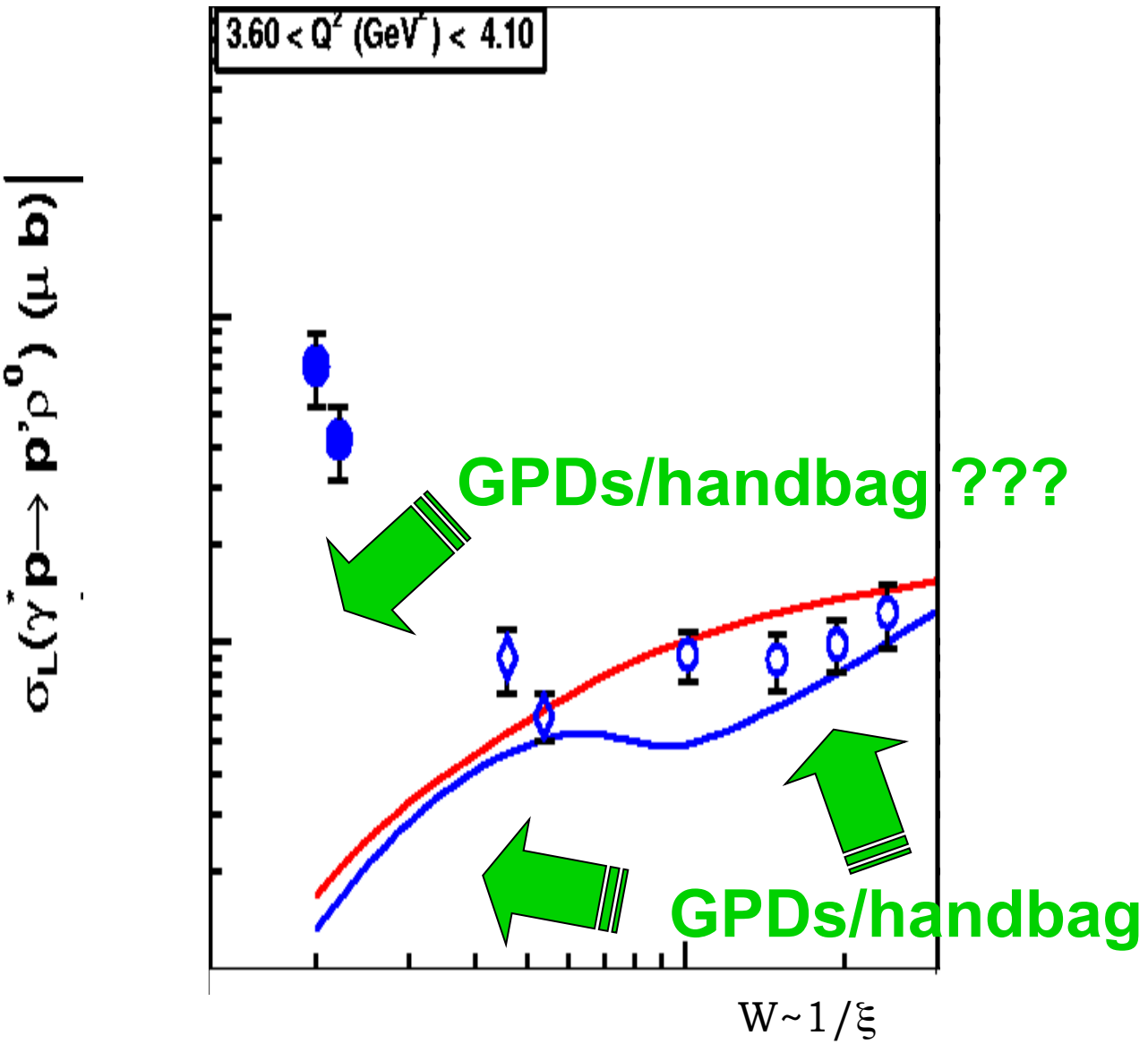
- *VMs (ρ^0,ω,ϕ) the only exclusive process [with DVCS] measured over a W range of 2 orders of magnitude ($\sigma_{L,T}$, $d\sigma/dt$, SDMEs,…)*

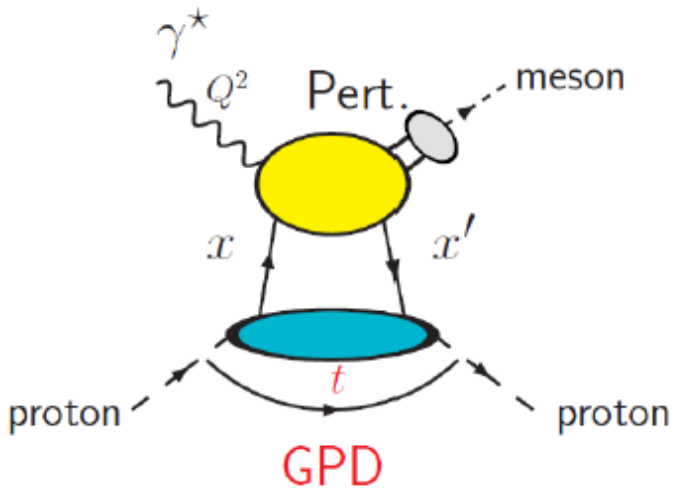
- *At high energy (W>5 GeV), transition from "soft" to "hard" (μ^2 scale) physics relatively well understood (further work needed for precision understanding/extractions)*

- *At low energy (W<5 GeV), success of "hard" approach for the ϕ channel (⇨ nucleon gluon imaging) but large failure for the ρ^0,ω, ρ^+ channels.*
  This is not understood. Why the GPD/handbag approach sould set at much larger Q^2 for valence quarks ?
  Are the widely used GPD parametrisations in the valence region completely wrong ?

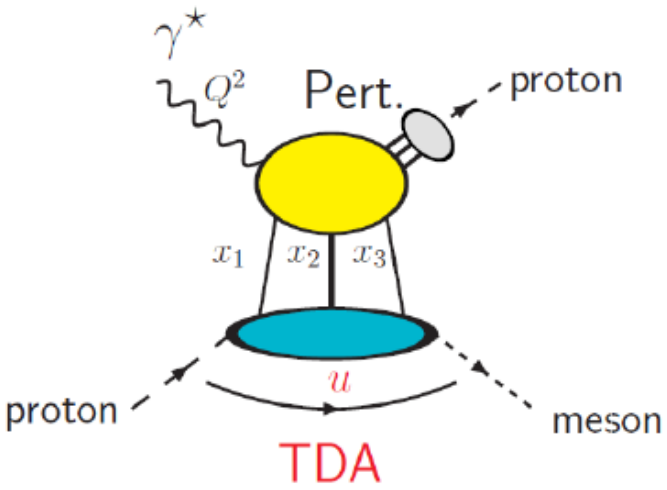
- *A lot of new data expected soon from JLab@11GeV, COMPASS (transv. target), HERA new analysis,…*

- *CLAS12 PR12-11-103 proposal: broader phase space, check when Q^2 independence settles for a variety of observables*


3.60 < Q² (GeV²) < 4.10
GPDs/handbag ???
GPDs/handbag
W~1/ξ
σL(γ*p→p'π0) (μb)

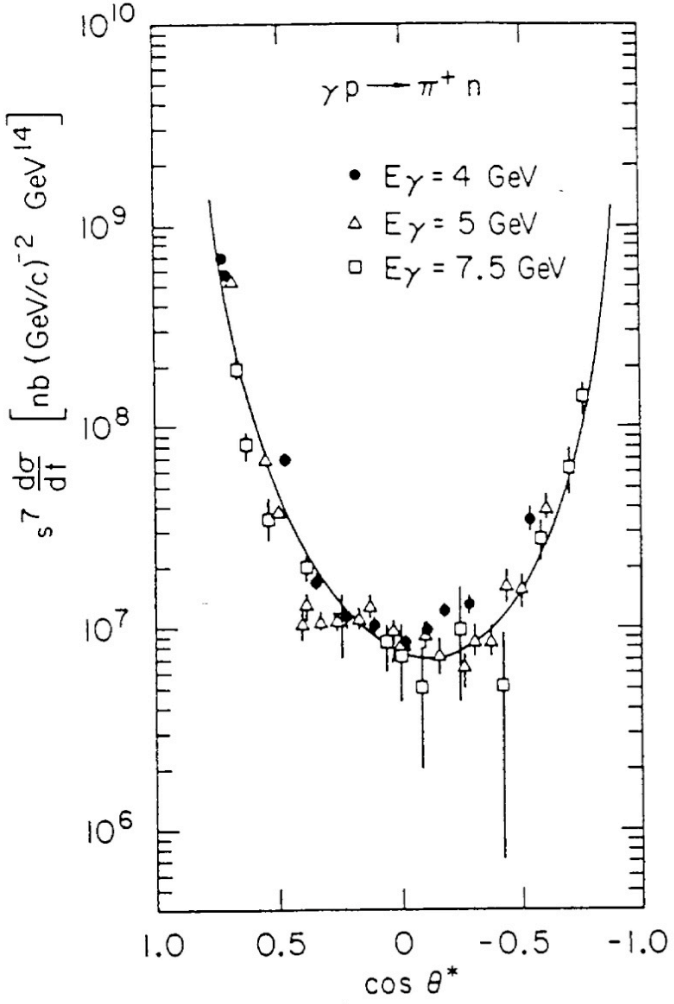

$\gamma^\star$
Q^2
Pert.
meson
x
x'
t
proton
proton

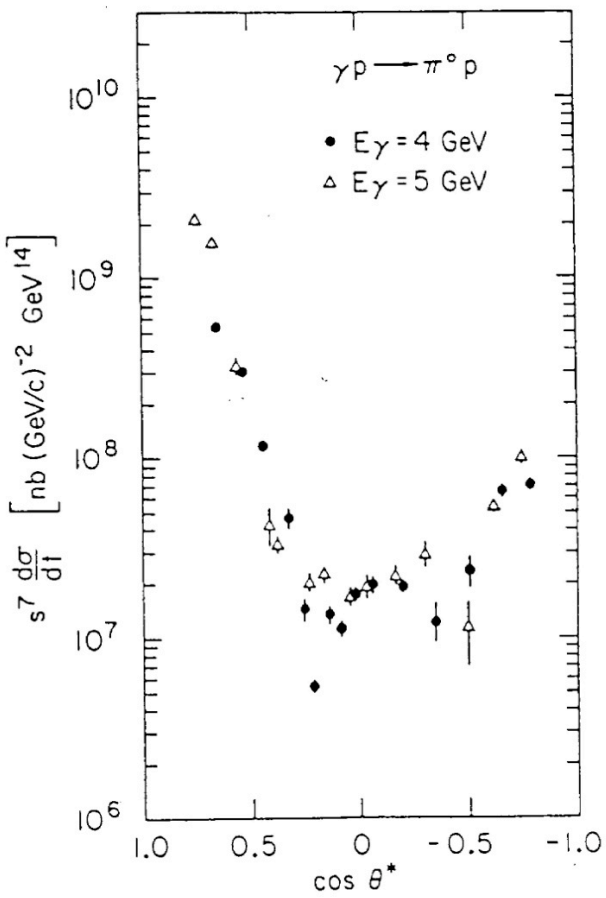
GPD


$\gamma^\star$
Q^2
Pert.
proton
x_1
x_2
x_3
u
proton
meson

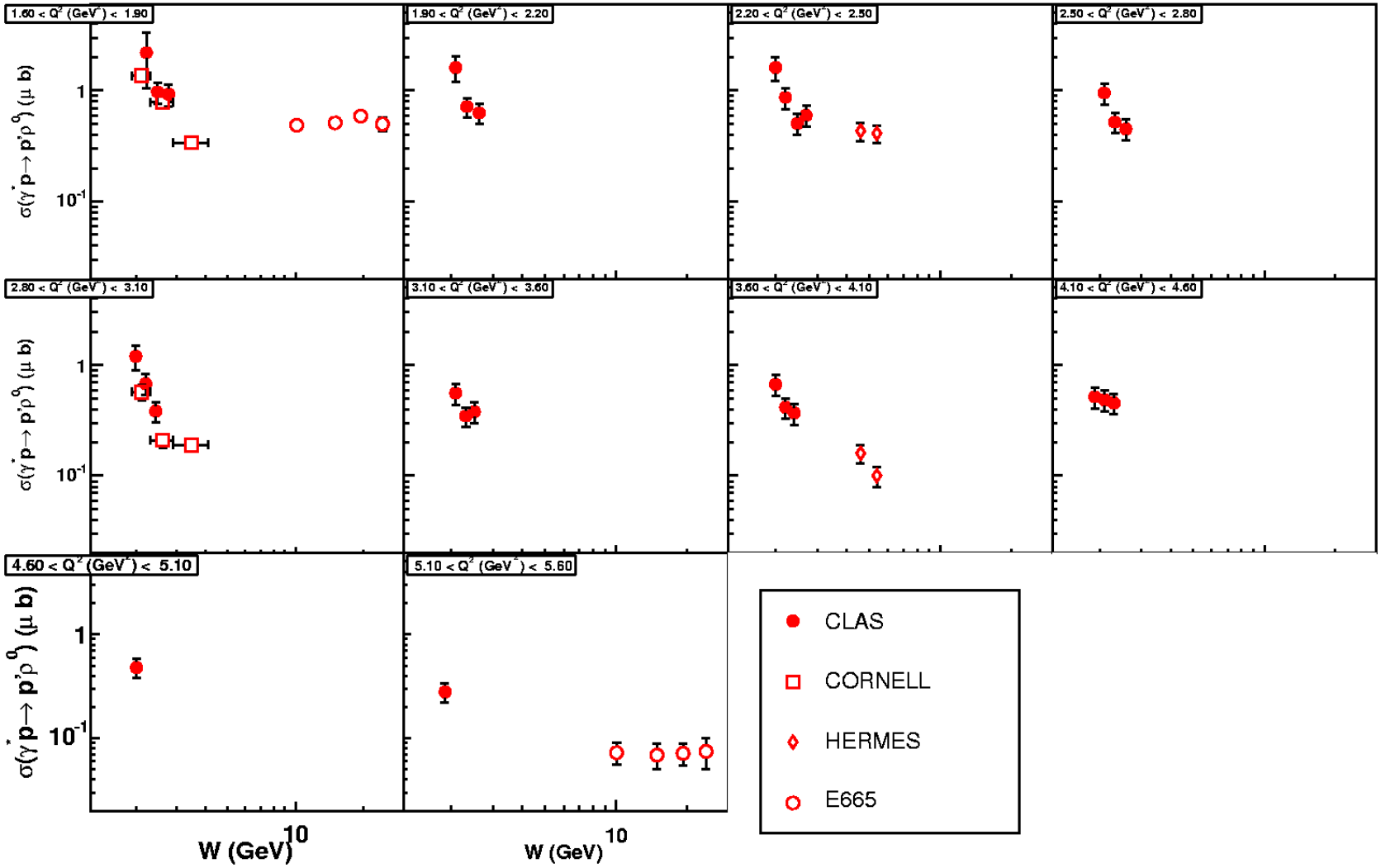
TDA

γN->Nπ


$\gamma p \rightarrow \pi^+ n$
$E_\gamma = 4$ GeV
$E_\gamma = 5$ GeV
$E_\gamma = 7.5$ GeV
$s^7 \frac{d\sigma}{dt}$ [nb (GeV/c)$^{-2}$ GeV^{14}]
10^{10}
10^9
10^8
10^7
10^6
1.0
0.5
0
-0.5
-1.0
cos θ*

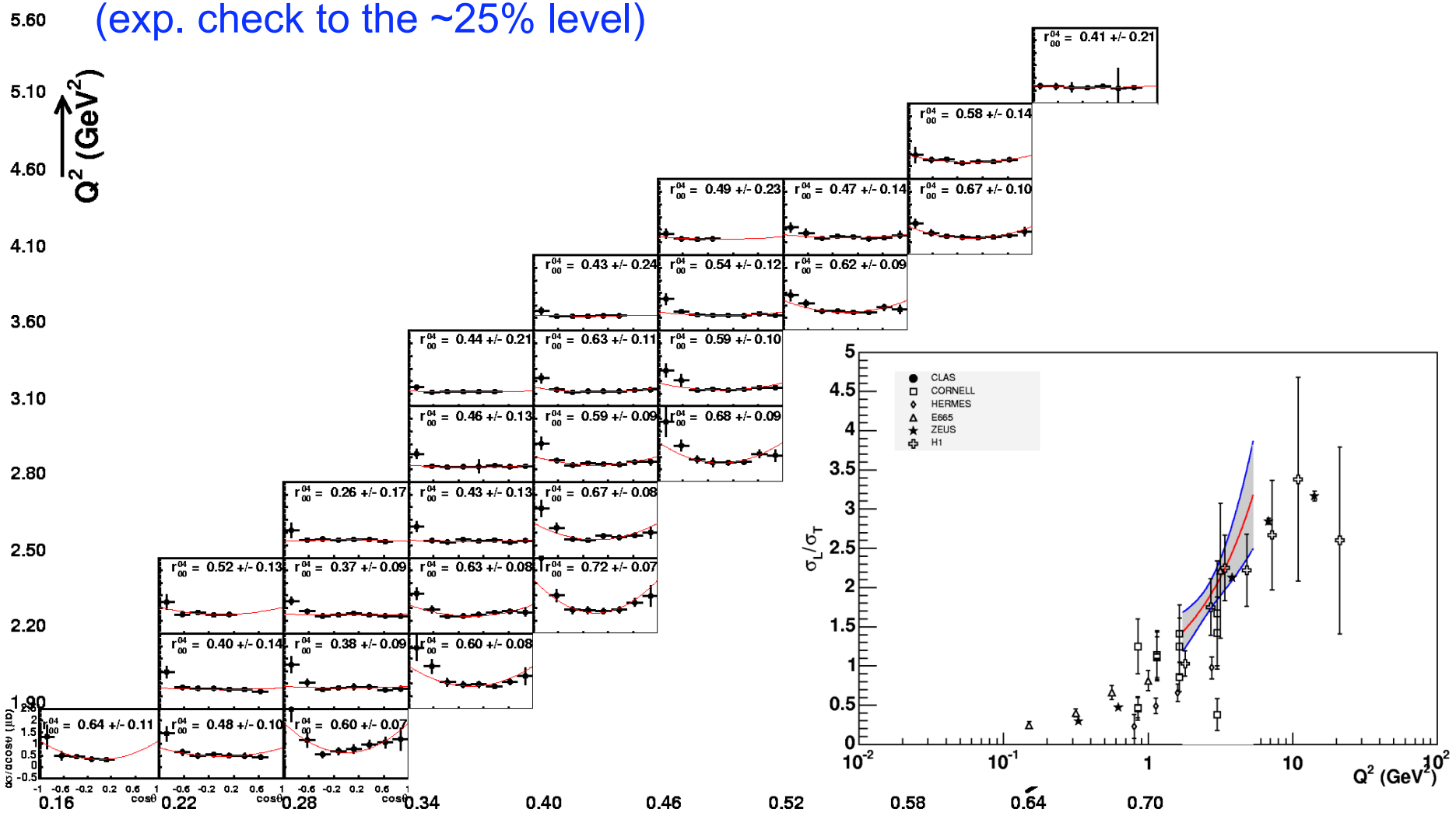

$\gamma p \rightarrow \pi^\circ p$
$E_\gamma = 4$ GeV
$E_\gamma = 5$ GeV
$s^7 \frac{d\sigma}{dt}$ [nb (GeV/c)$^{-2}$ GeV^{14}]
10^{10}
10^9
10^8
10^7
10^6
1.0
0.5
0
-0.5
-1.0
cos θ*

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

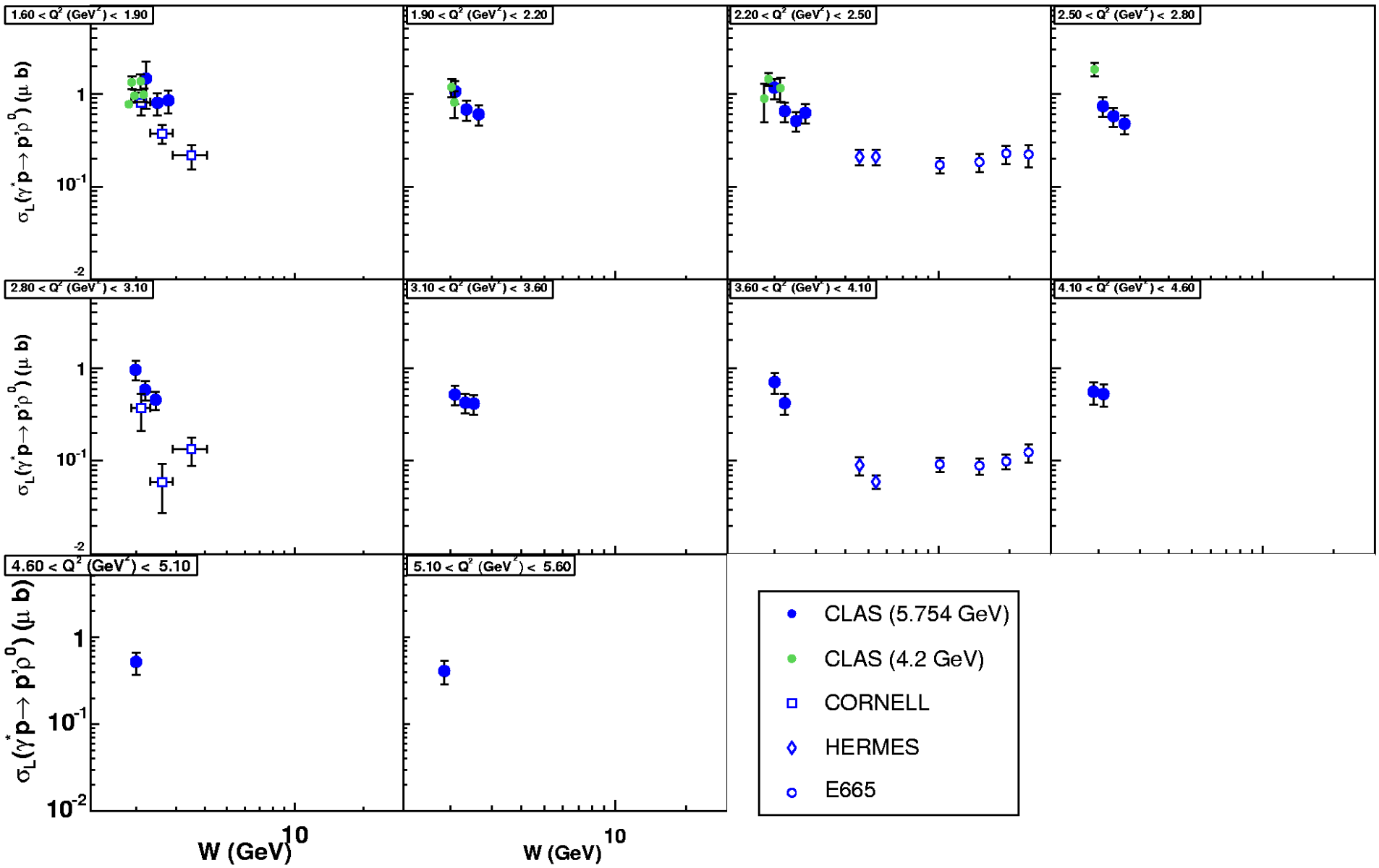


Angular distribution analysis, cos θ_{cm}

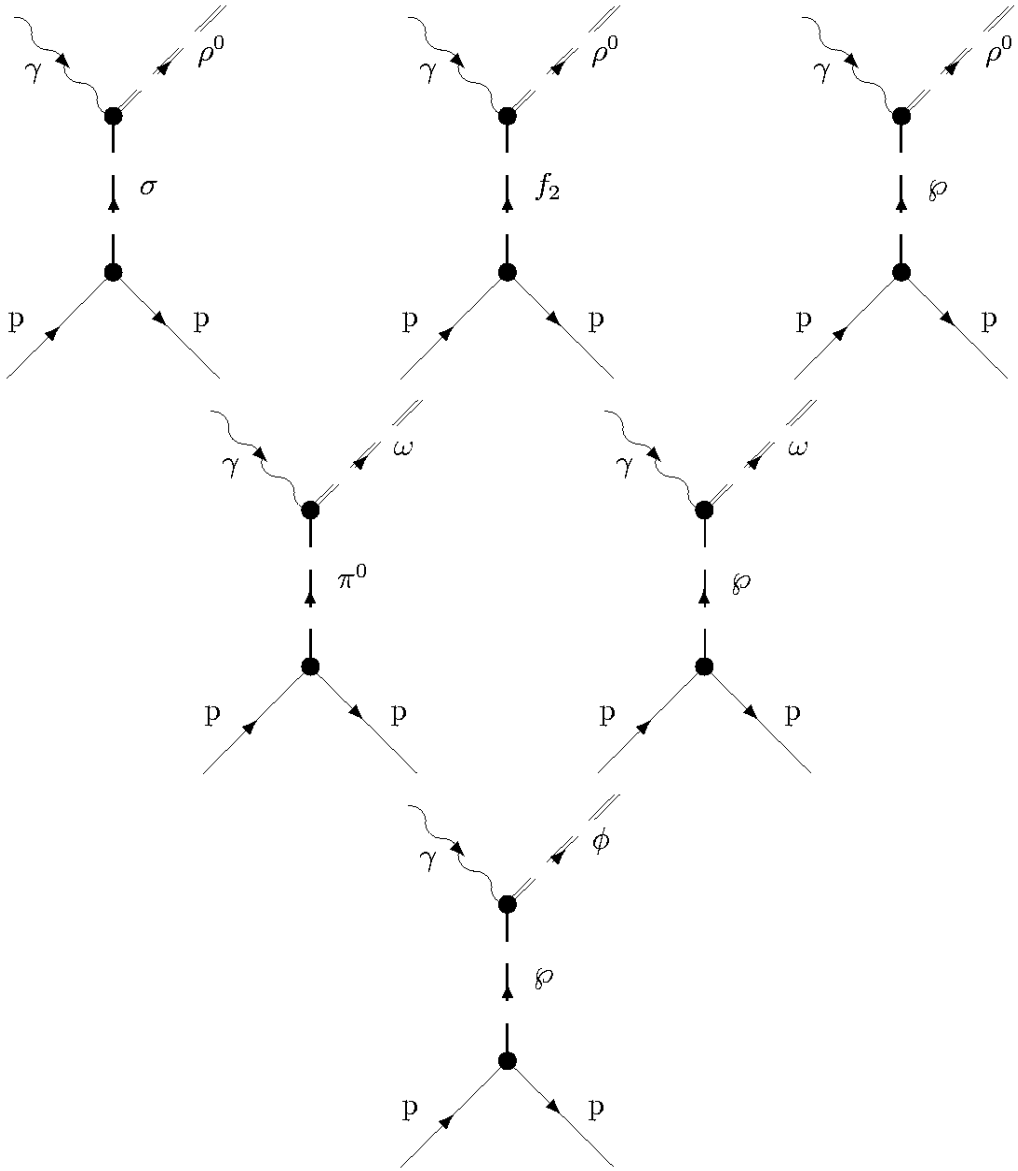
Relying on SCHC
(exp. check to the ~25% level)



Longitudinal cross section σ_L ($\gamma^*_L p \rightarrow p\rho^0_L$)



Interpretation "a la Regge" : Laget model

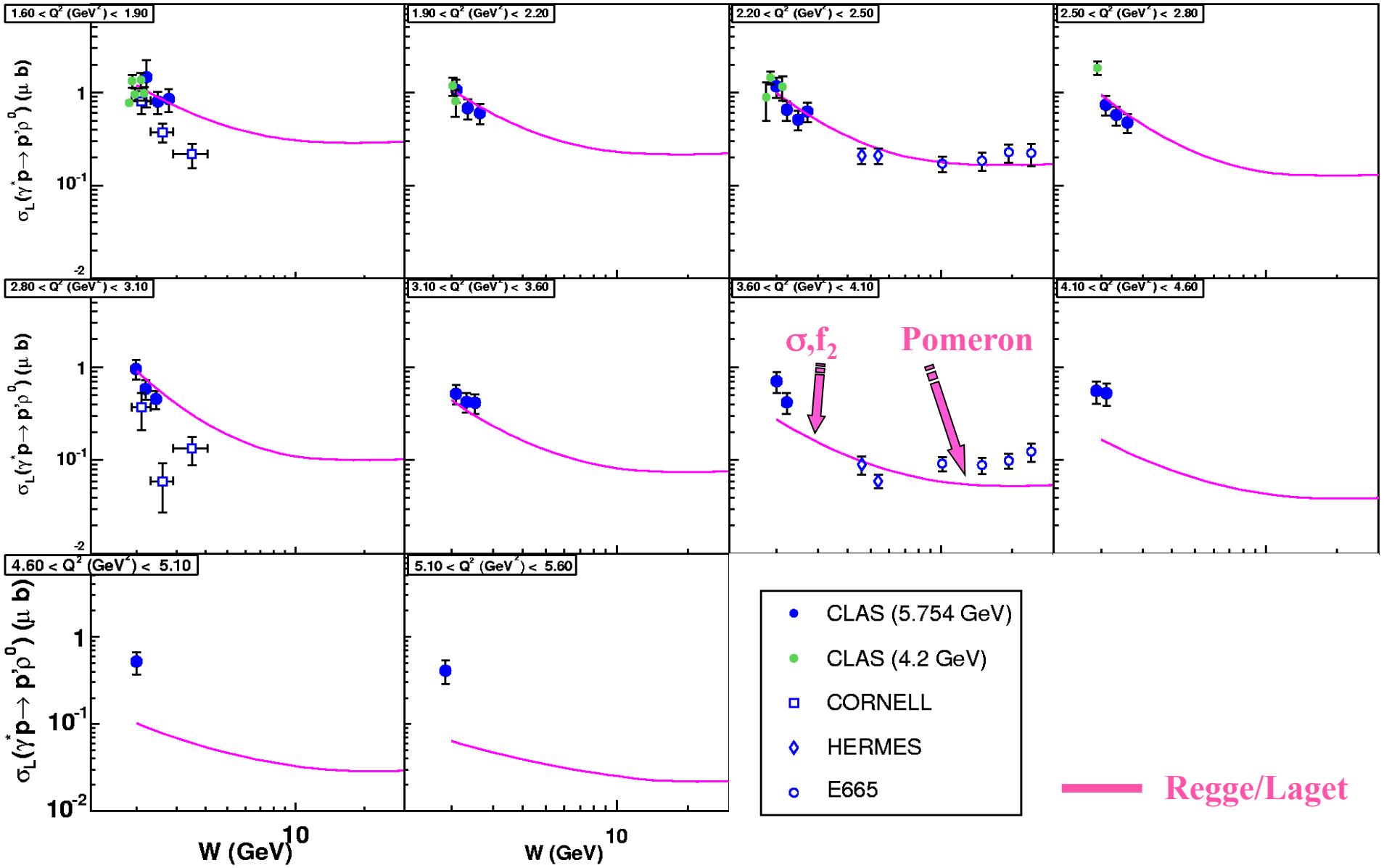


ers:

oling constants: g_{MNN}

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

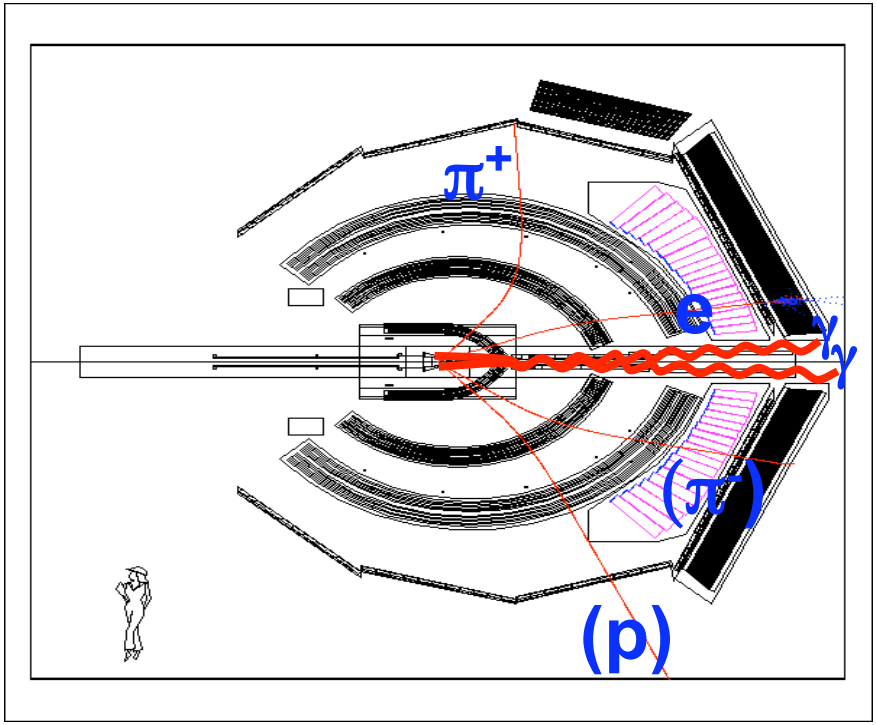
$\sigma_L\ (\gamma^*_L p \rightarrow p\rho_L^0)$



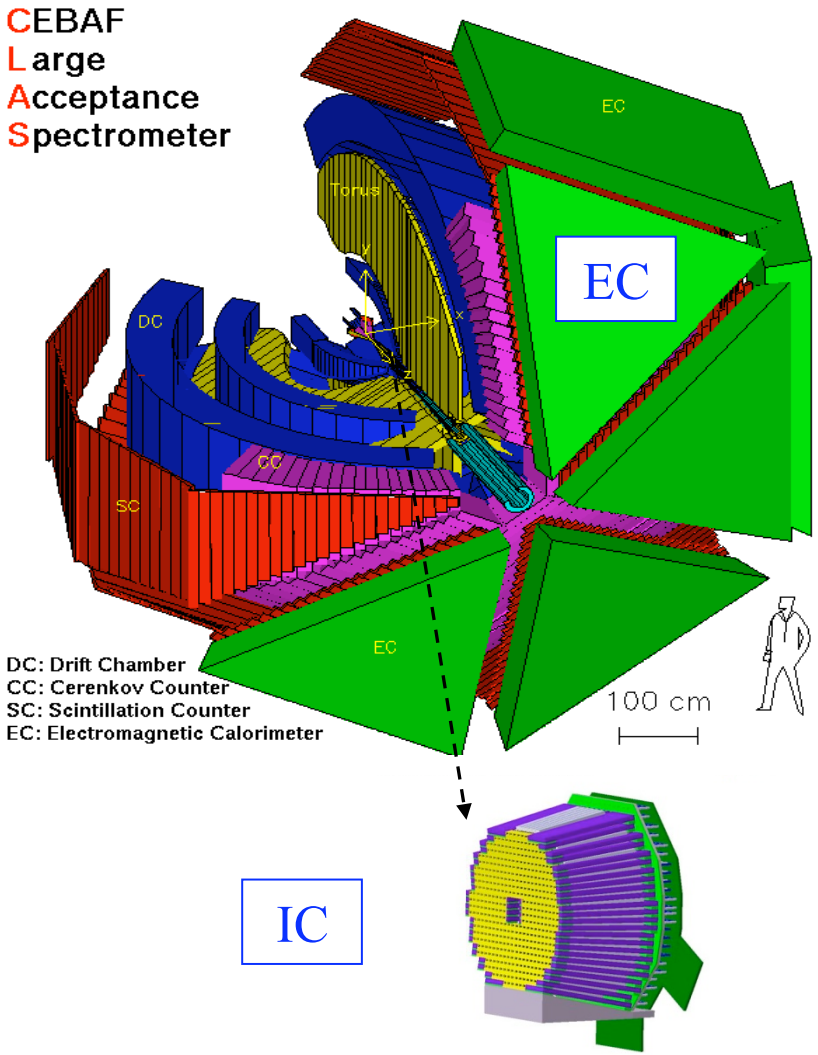
Exclusive ρ^+ electroproduction

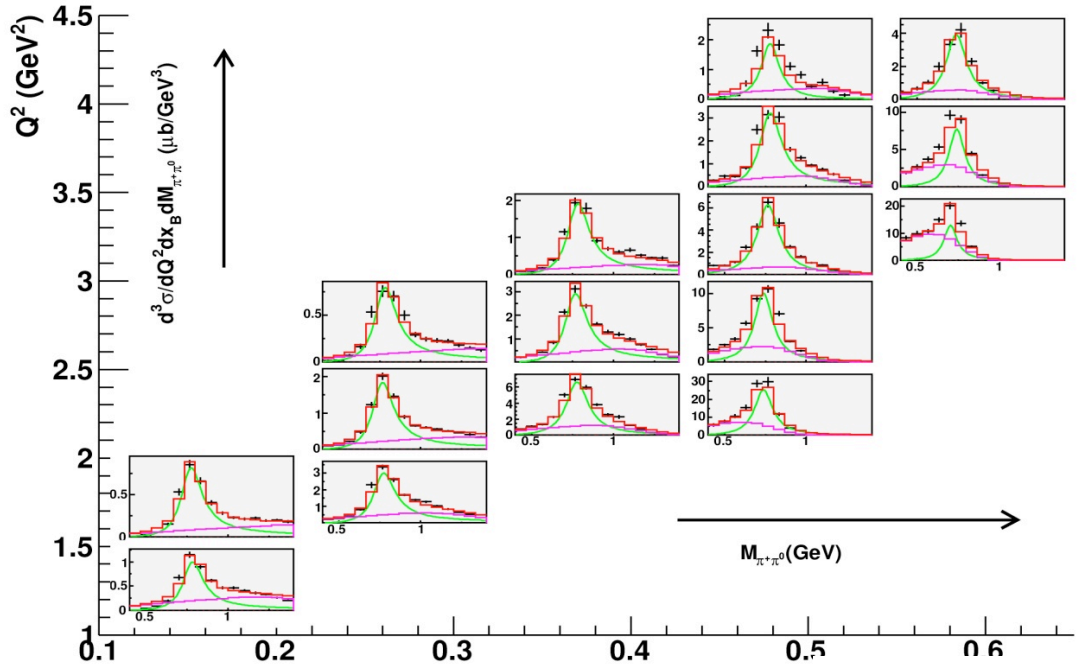
Channel selection

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



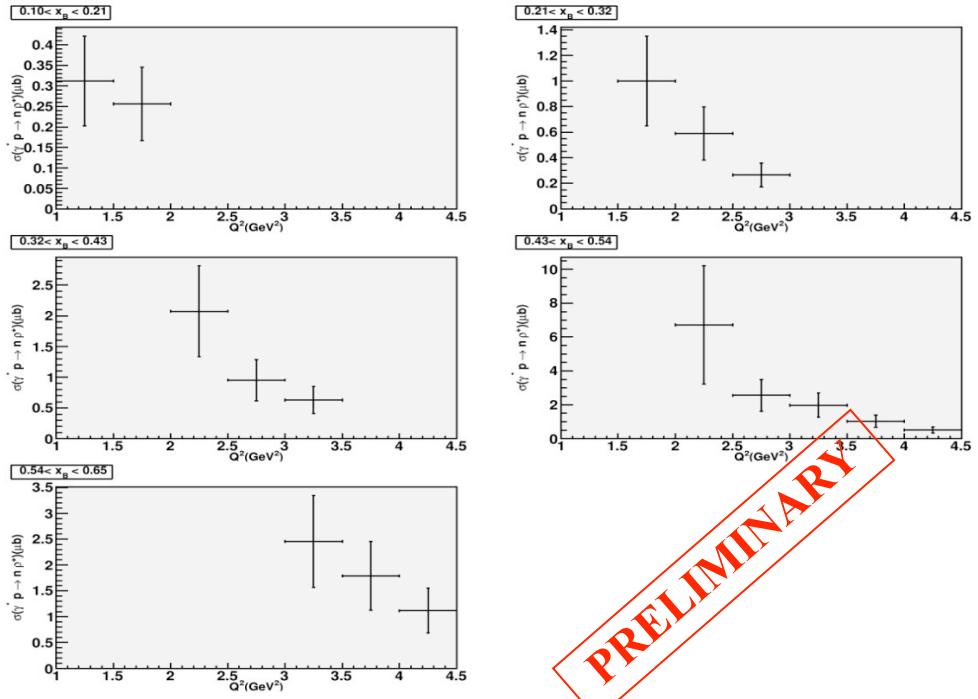
One event in CLAS





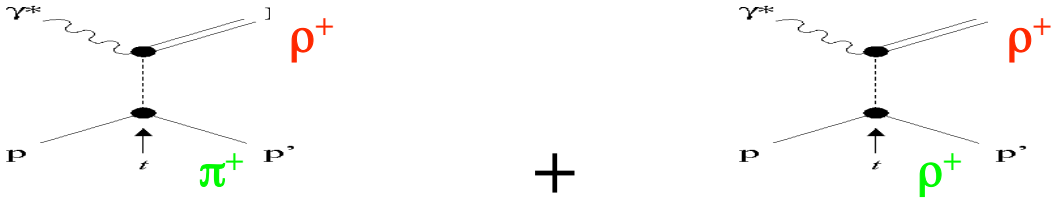
Invariant mass
$IM(\pi^+\pi^0)$

Total cross section
$\sigma\,(Q^2,x_B)$ ρ^+



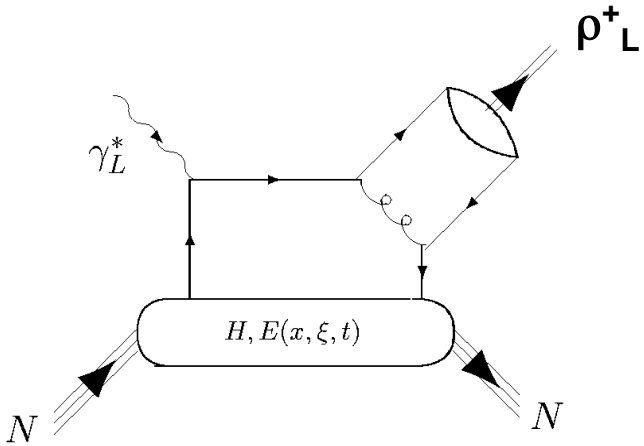
PRELIMINARY

Regge "hadronic" approach



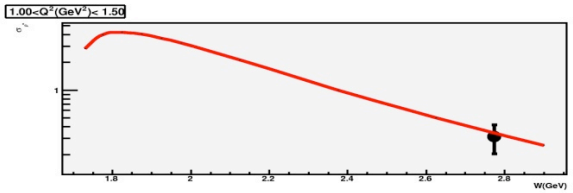
n n

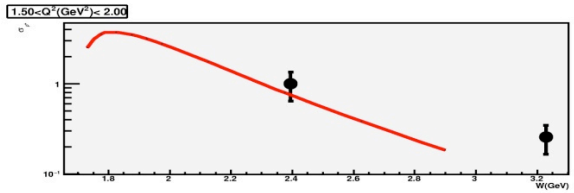
GPD "partonic" approach

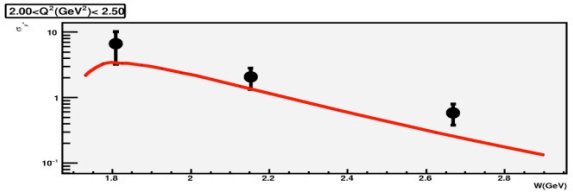


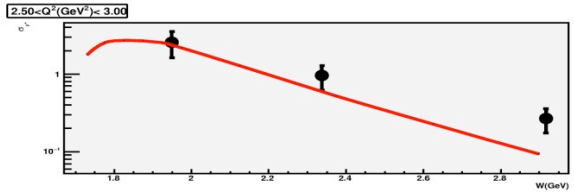
H , E

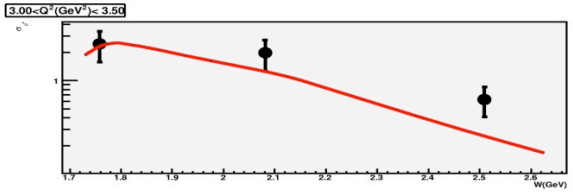
ρ^0	$e_u H^u - e_d H^d$ $e_u E^u - e_d E^d$
ω	$e_u H^u + e_d H^d$ $e_u E^u + e_d E^d$
ρ^+	$H^u - H^d$ $E^u - E^d$

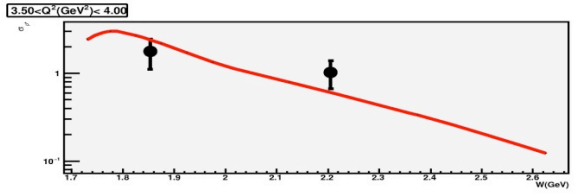


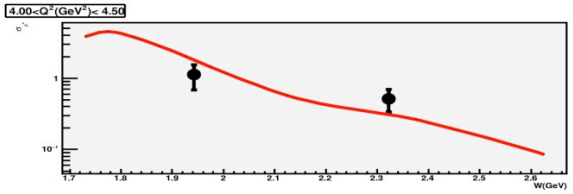








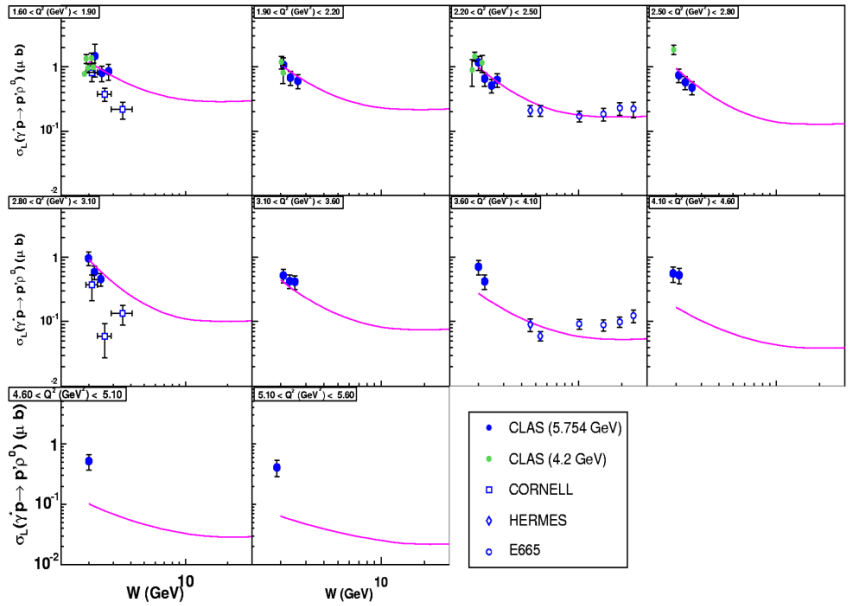




"Hadronic approach": Laget model

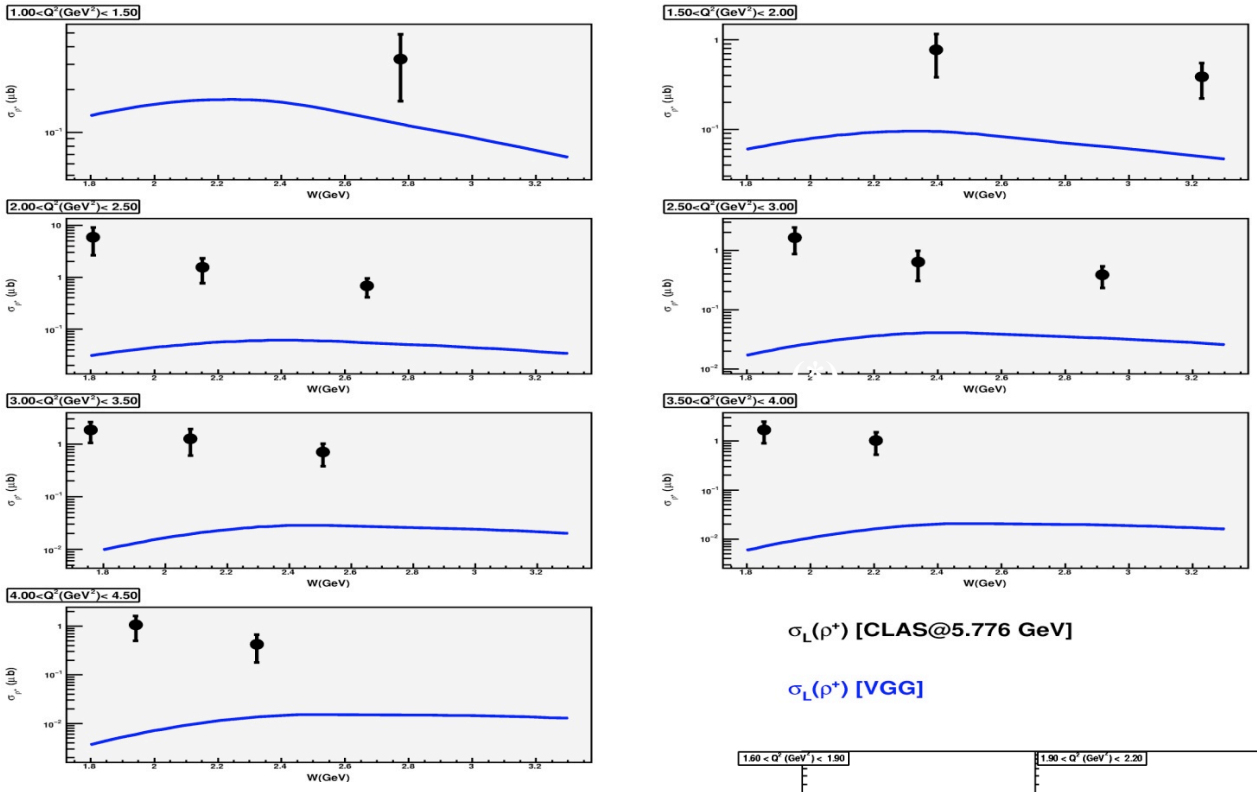
$\sigma(\rho^+)$ [CLAS@5.776 GeV]

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



ρ^+

ρ^o



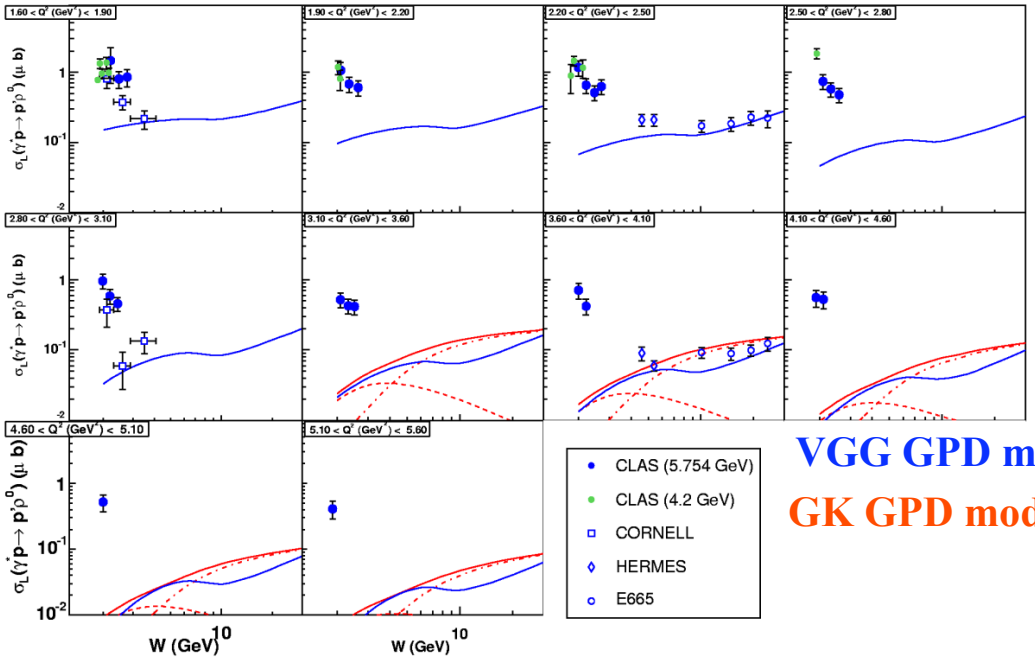
$\sigma_L(\rho^+)$ [CLAS@5.776 GeV]

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

"Partonic approach": GPDs

ρ^+

ρ^0

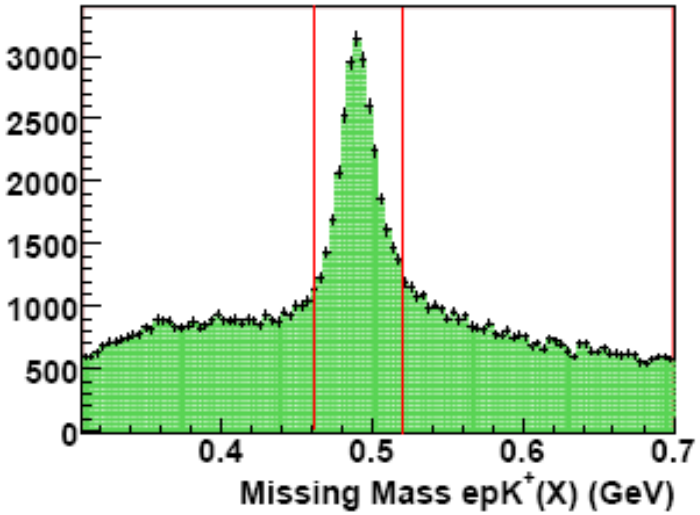


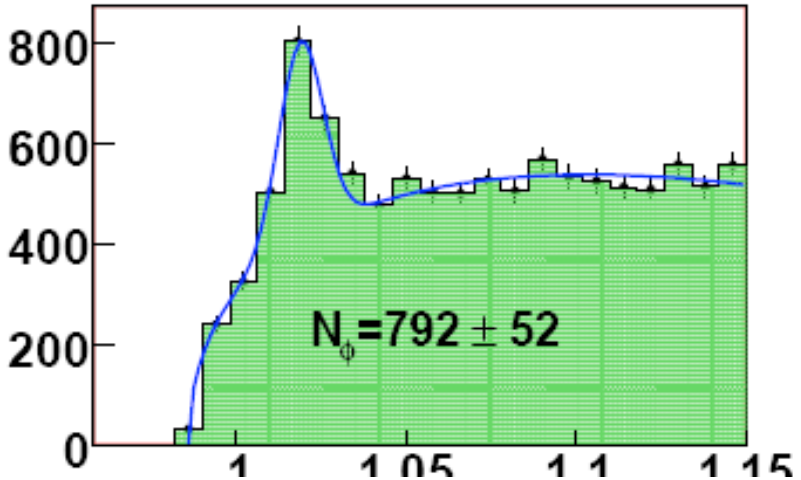
VGG GPD model

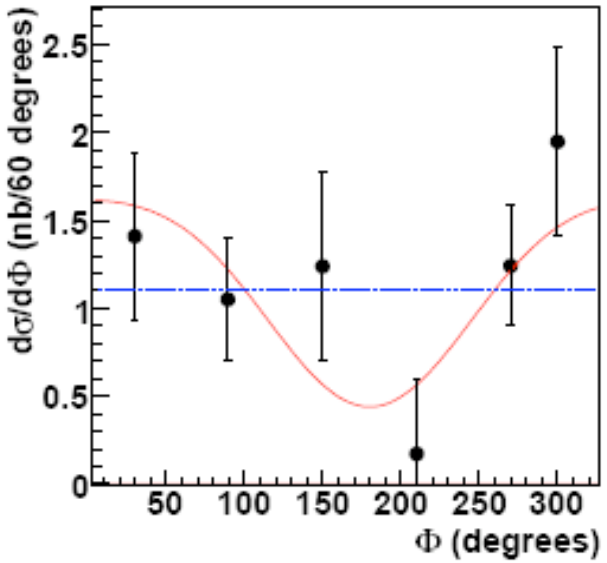
GK GPD model

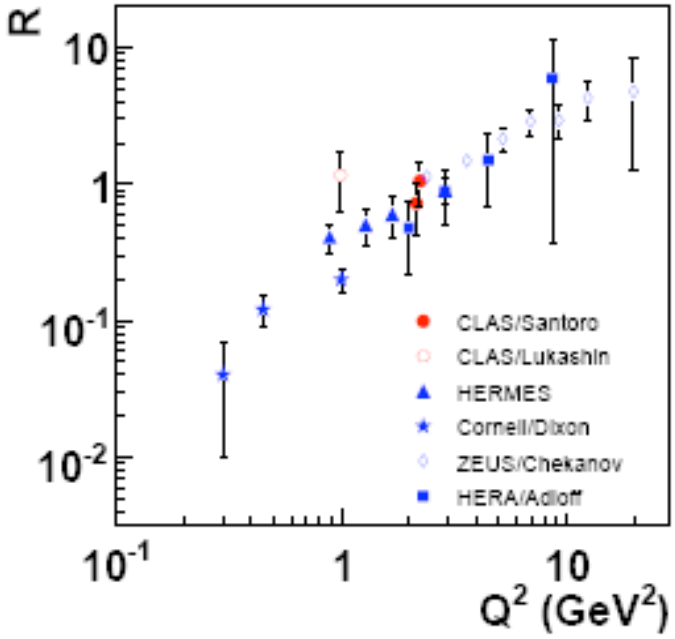
Exclusive ϕ electroproduction

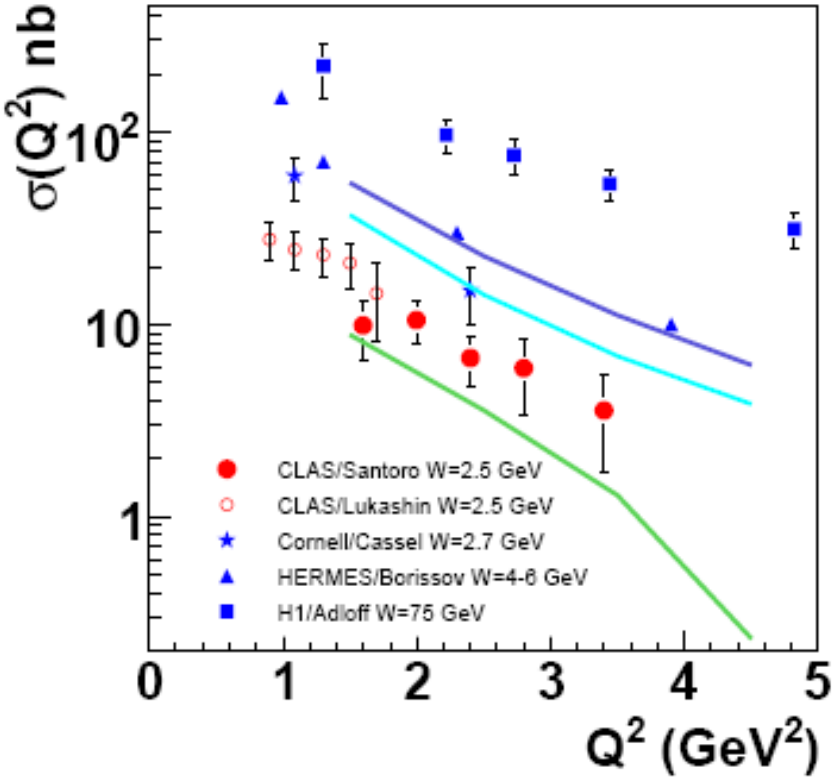
ep->epϕ (↳ $K^+[K^-]$)


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
N_ϕ=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
Q^2 (GeV^2)
CLAS/Santoro
CLAS/Lukashin
HERMES
Cornell/Dixon
ZEUS/Chekanov
HERA/Adloff

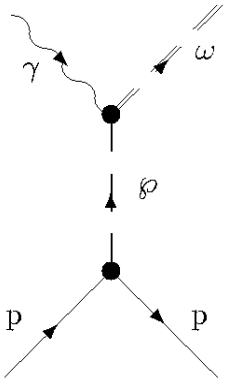


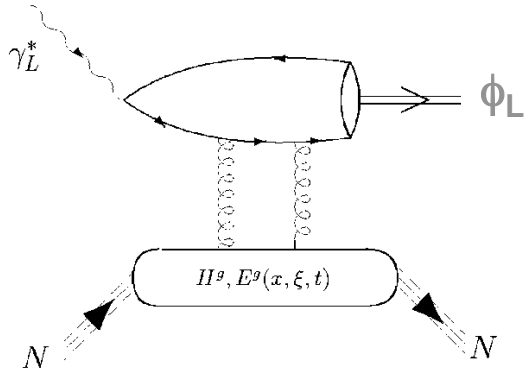
Laget $\sigma_T+\varepsilon\sigma_L$

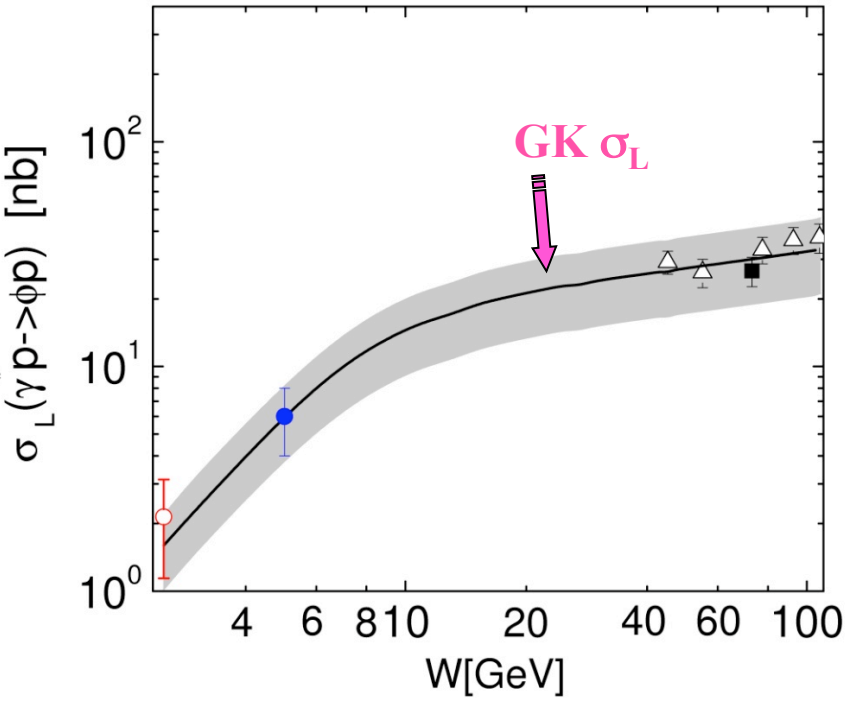
W=2.9 GeV

W=2.45 GeV

W=2.1 GeV

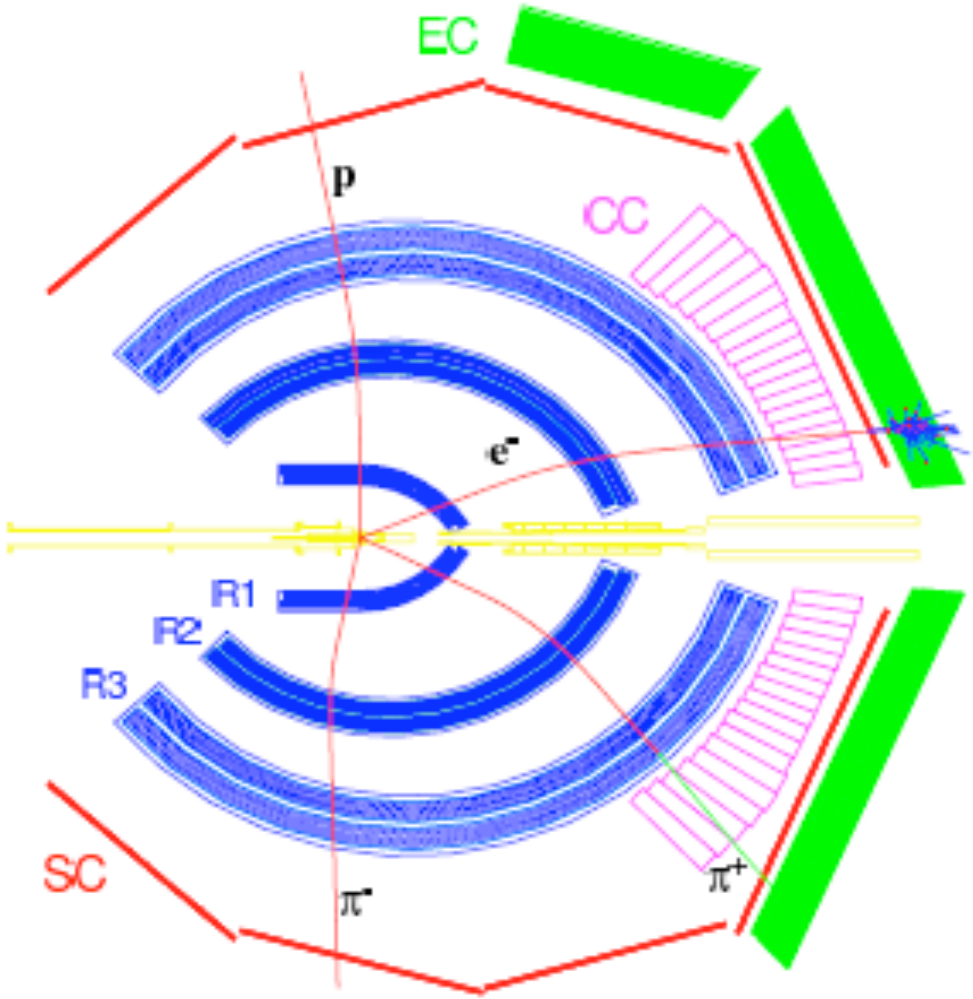




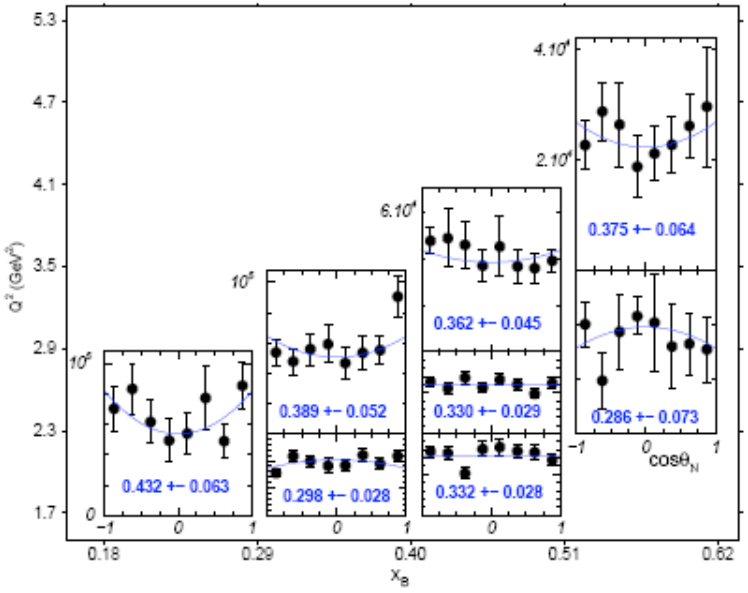


Exclusive ω electroproduction

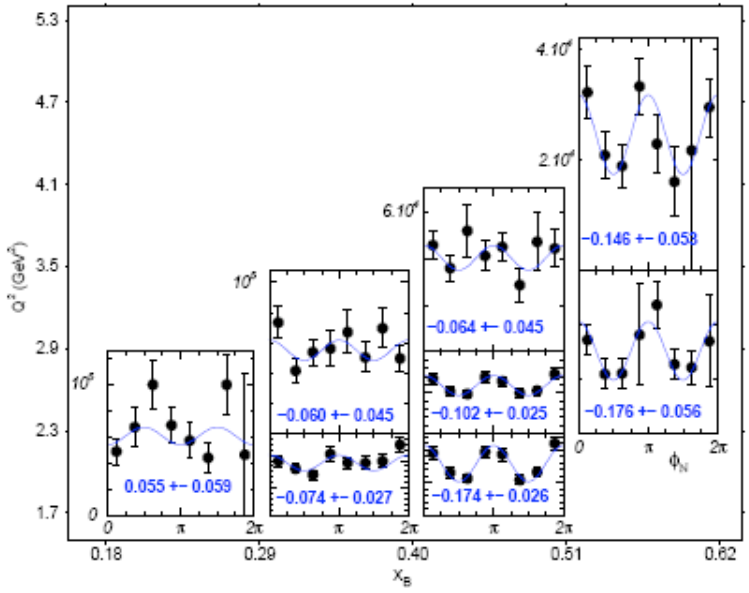
$ep \to ep\omega$ ($\hookrightarrow \pi^+\pi^-[\pi^0]$)

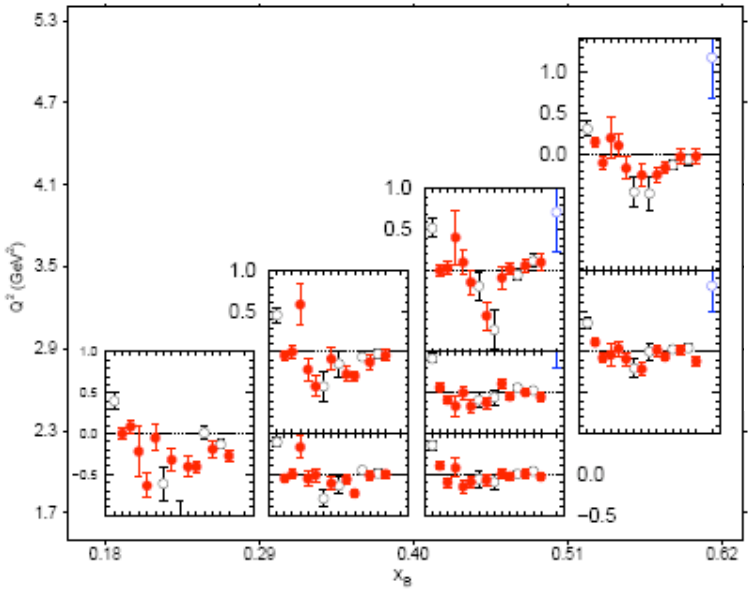


$\cos(\theta_{cm})$ distribution



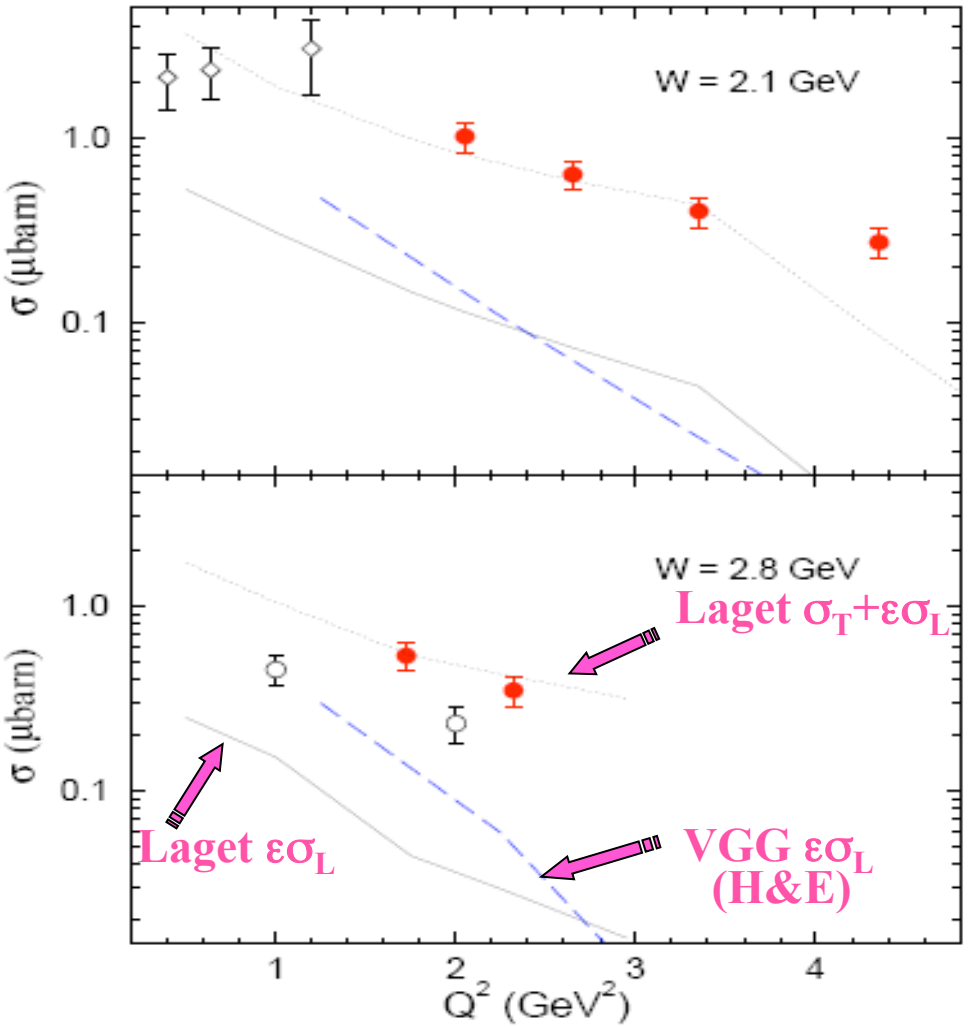
ϕ_{cm} distribution





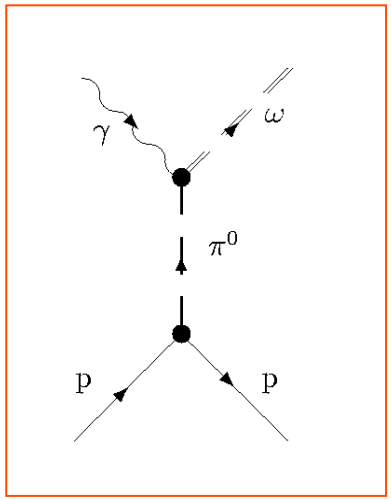
The abscissa on each graph corresponds to the following list of matrix elements: r^{04}_{00}, Re r^{04}_{10}, r^{04}_{1-1}, r^{1}_{00}, r^{1}_{11}, Re r^{1}_{10}, r^{1}_{1-1}, Im r^{2}_{10}, Im r^{2}_{1-1}, r^{5}_{00}, r^{5}_{11}, Re r^{5}_{10}, r^{5}_{1-1}, Im r^{6}_{10}, Im r^{6}_{1-1}. The red filled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

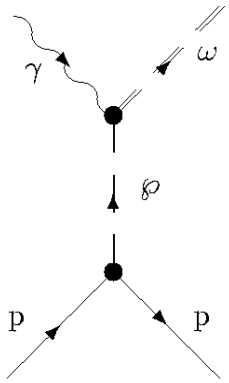
Cross section $\sigma(\gamma^* p \to p\omega)$



Laget Regge model

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





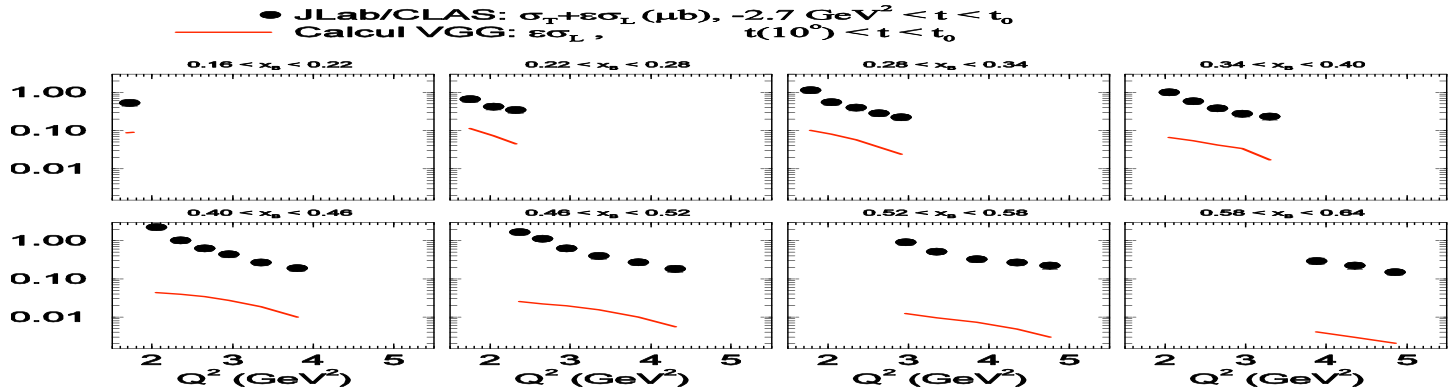
Issue with GPD approach if π^0 exchange dominant :

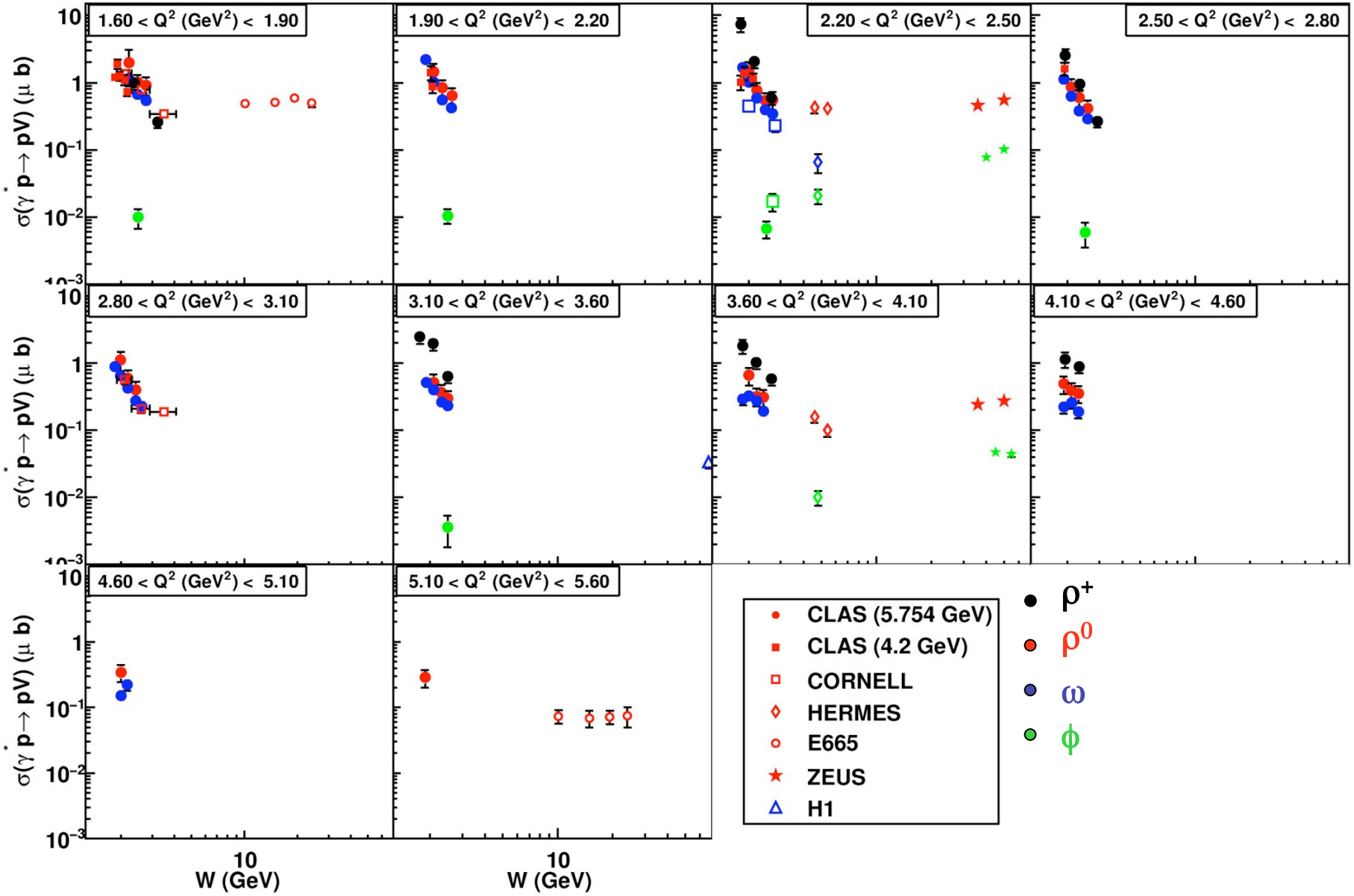
$\pi^0 \to \tilde{E}$

while

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

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





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

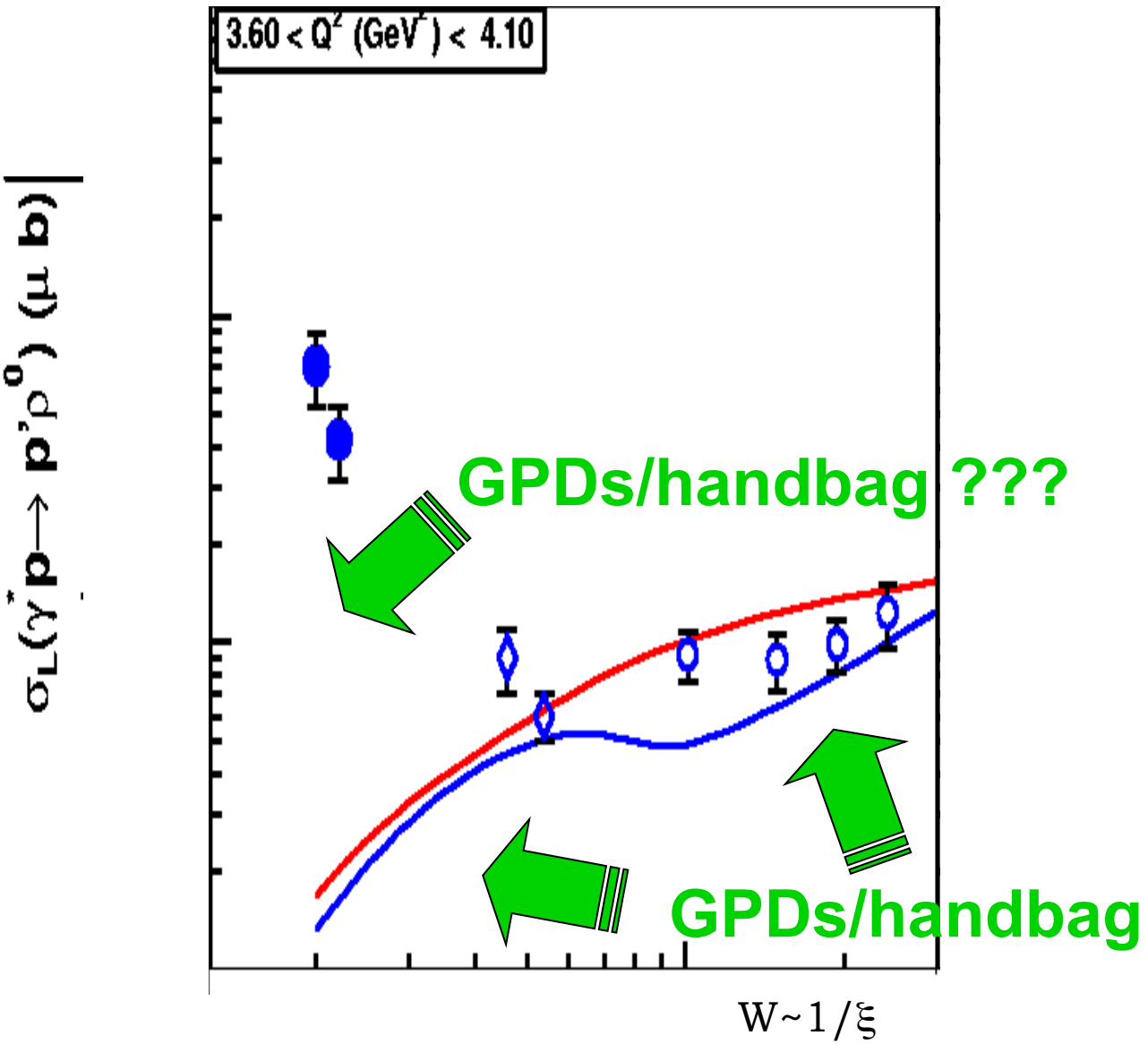
L. Morand et al., Eur.Phys.J.A24:445-458,2005 (ω@5.75GeV)

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)


3.60 < Q² (GeV²) < 4.10
GPDs/handbag ???
GPDs/handbag
W~1/ξ
σL(γ*p→p'π0) (μb)

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

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

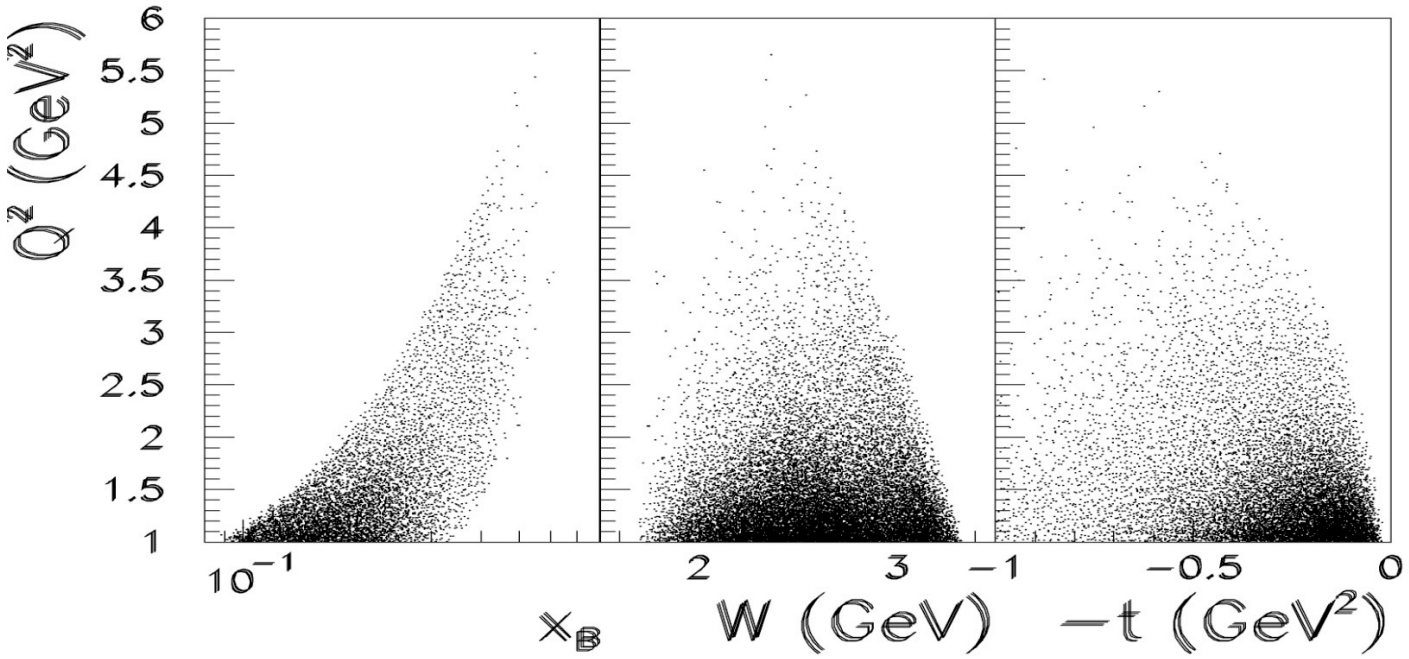
- ***If (power corrected) handbag diagram in valence region: same Q^2 dependence at low W than at large W:***
  ρ^0 and ϕ should be different from ω and ρ^+, these latter having higher-twist t-channel exchanges

- ***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)

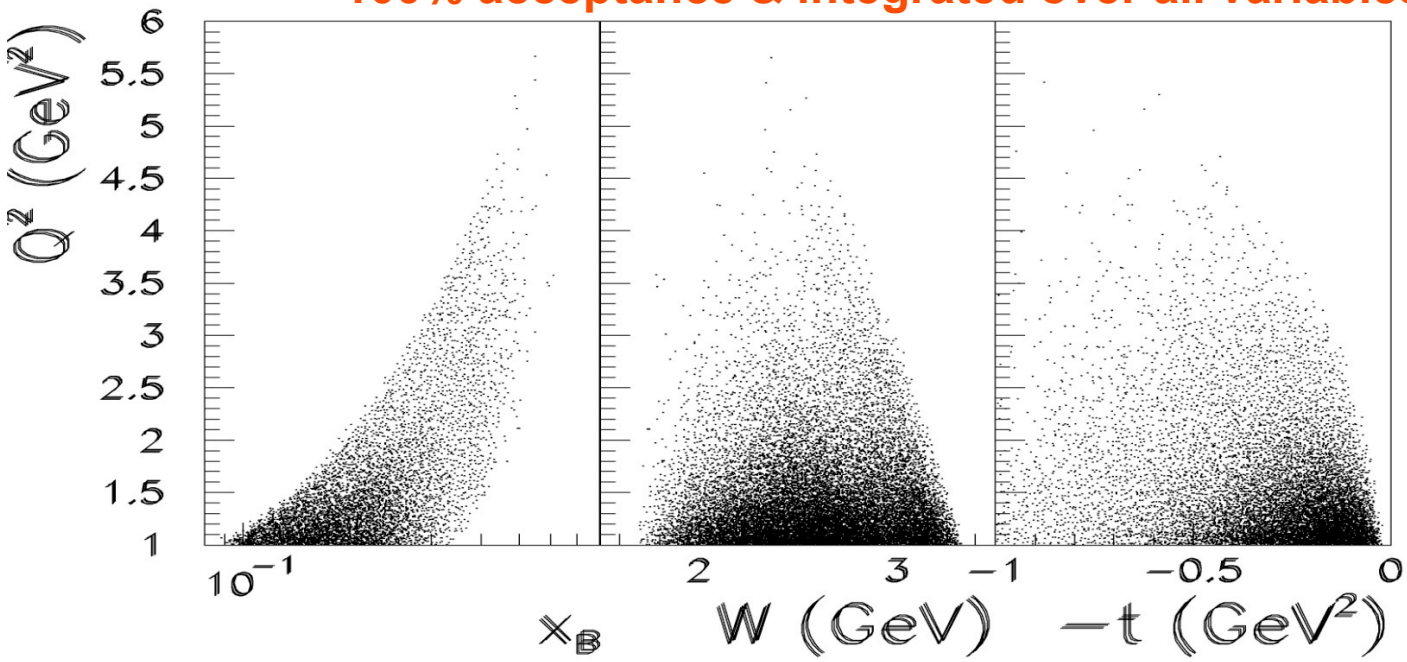
- ρ^0, ω, ϕ & ρ^+ **electroproduction on the proton @ CLAS6**
- ***GPDs or not GPDs ?***

Perspectives with CLAS12 & EIC

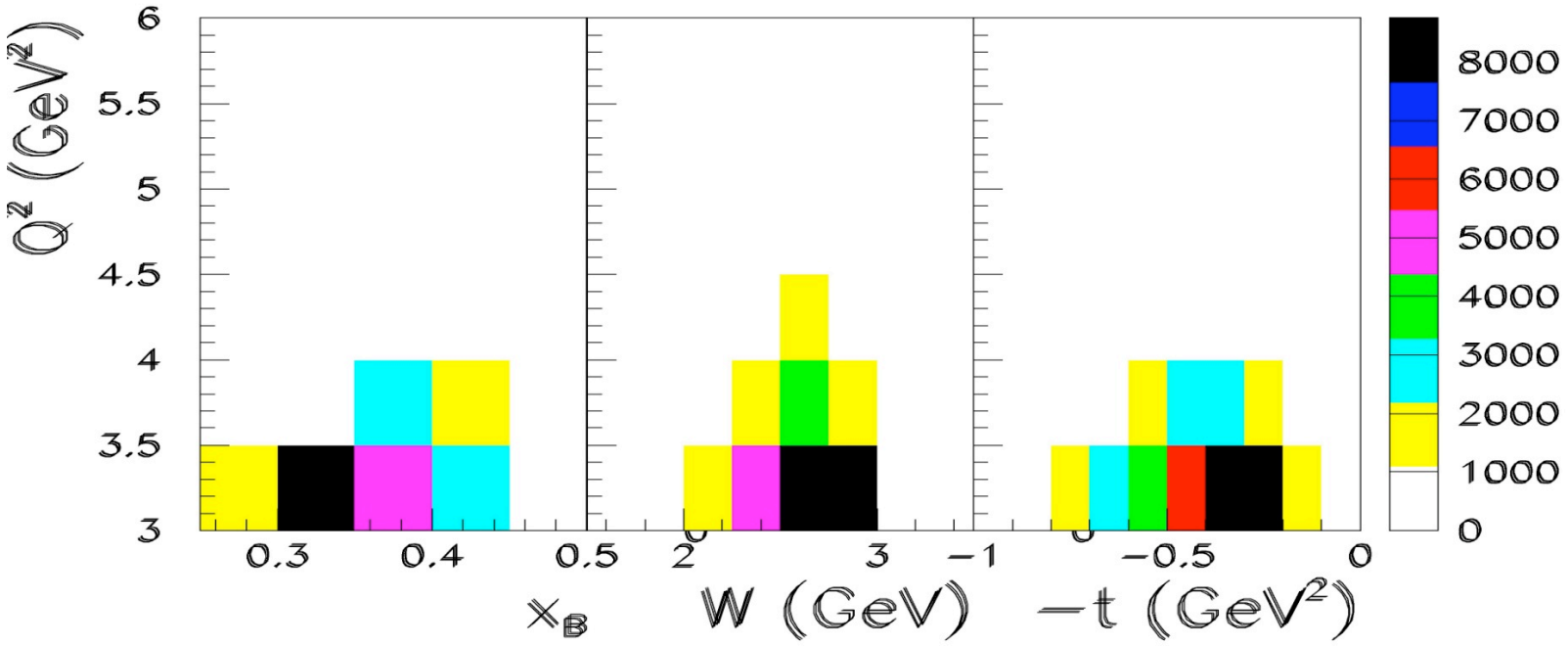


6 GeV e
fixed p target

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

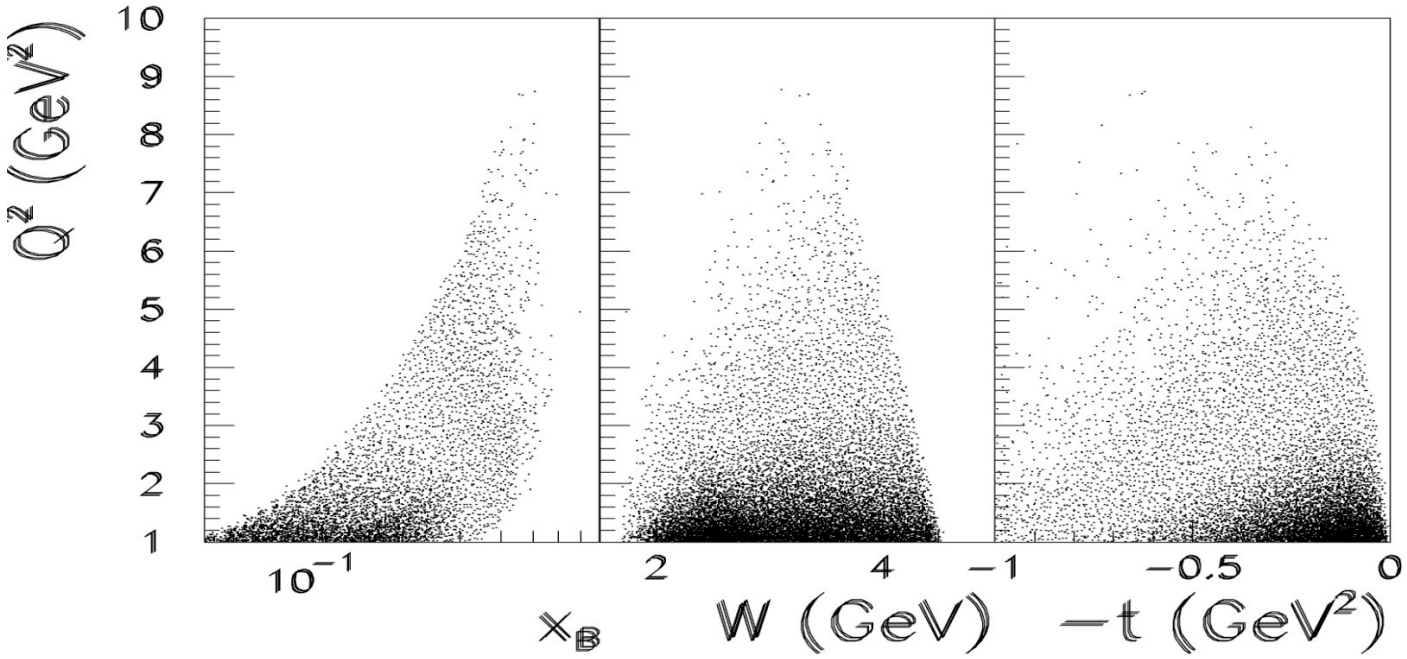


6 GeV e
fixed p target



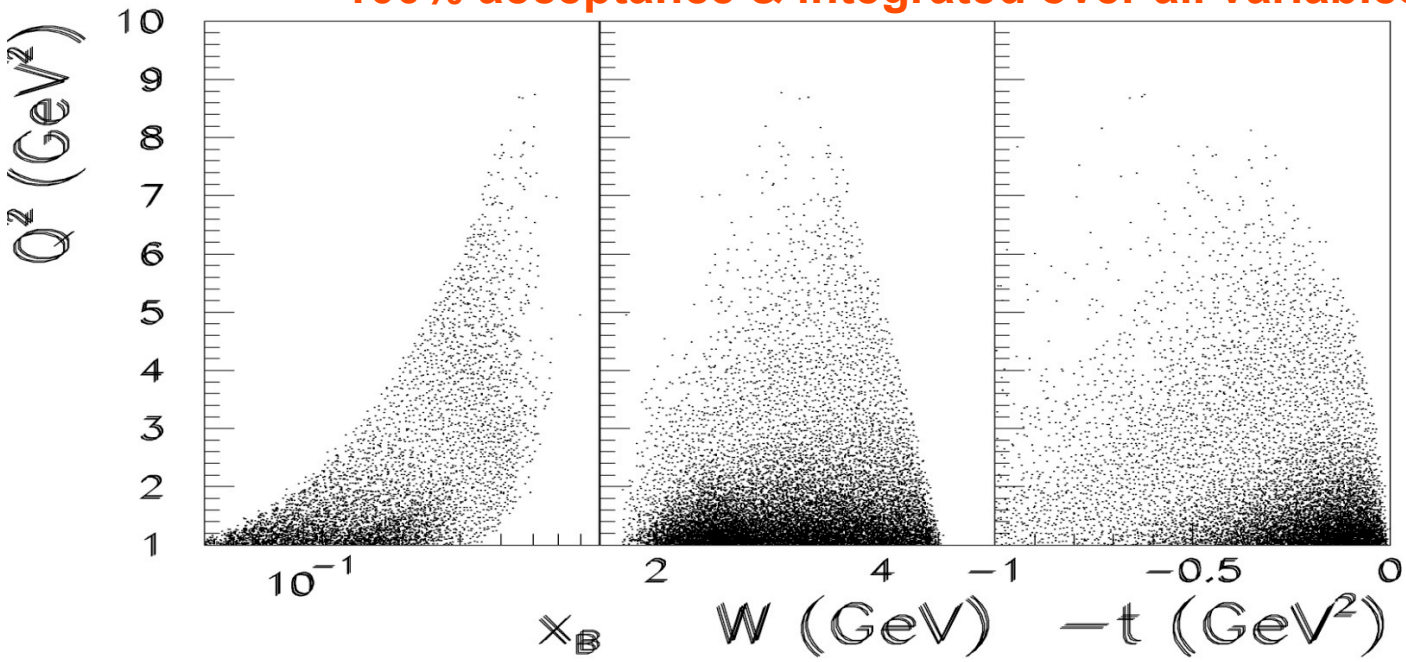
Counting rates
for 100 hours
at 10^{34} cm^{-2}s^{-1}

Limitation comes
from phase space

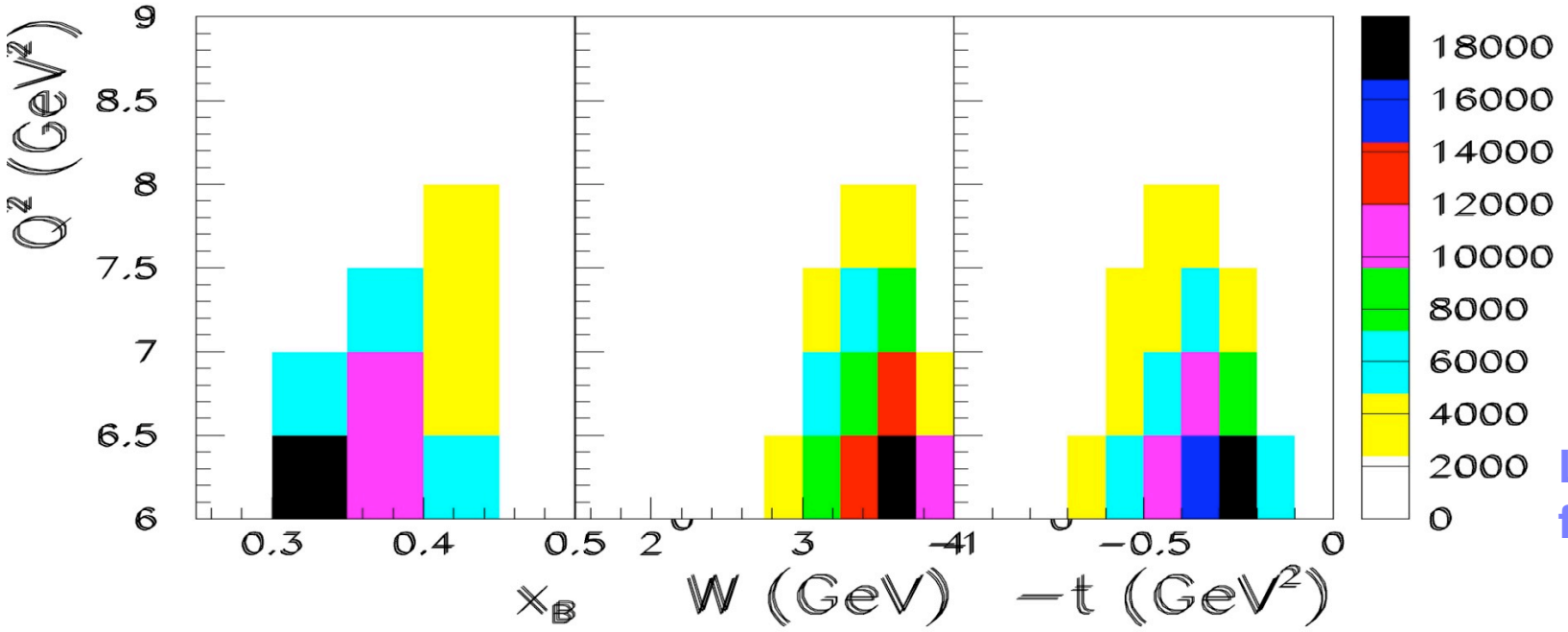


11 GeV e
fixed p target

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

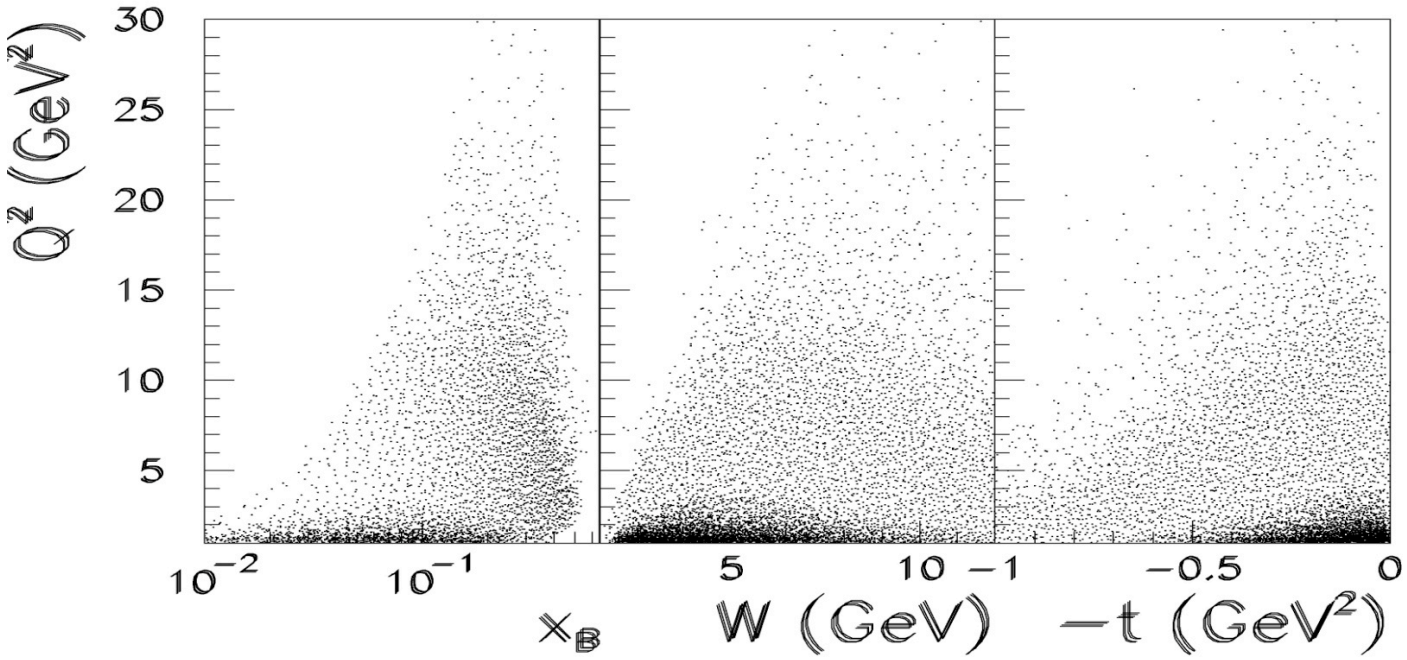


11 GeV e
fixed p target



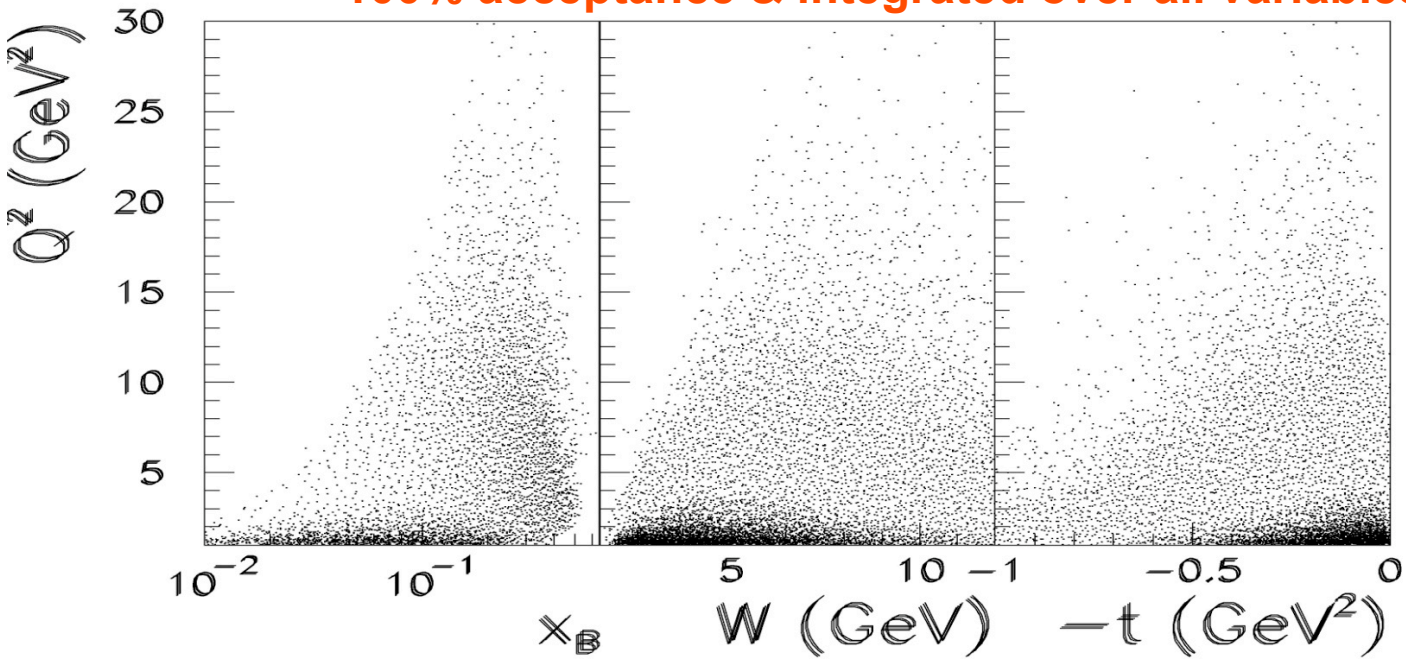
Counting rates
for 1000 hours
at 10^{35} $cm^{-2}s^{-1}$

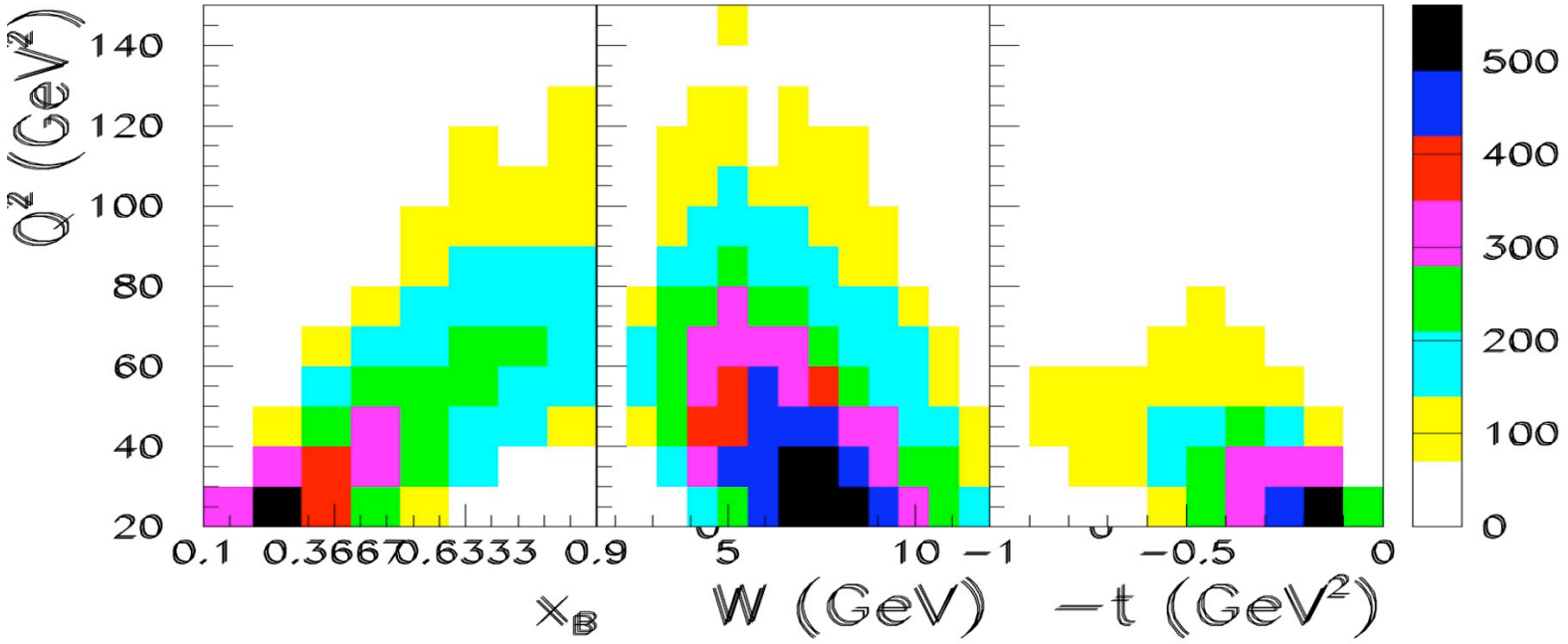
Limitation comes
from phase space



11 GeV e
60 GeV p

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

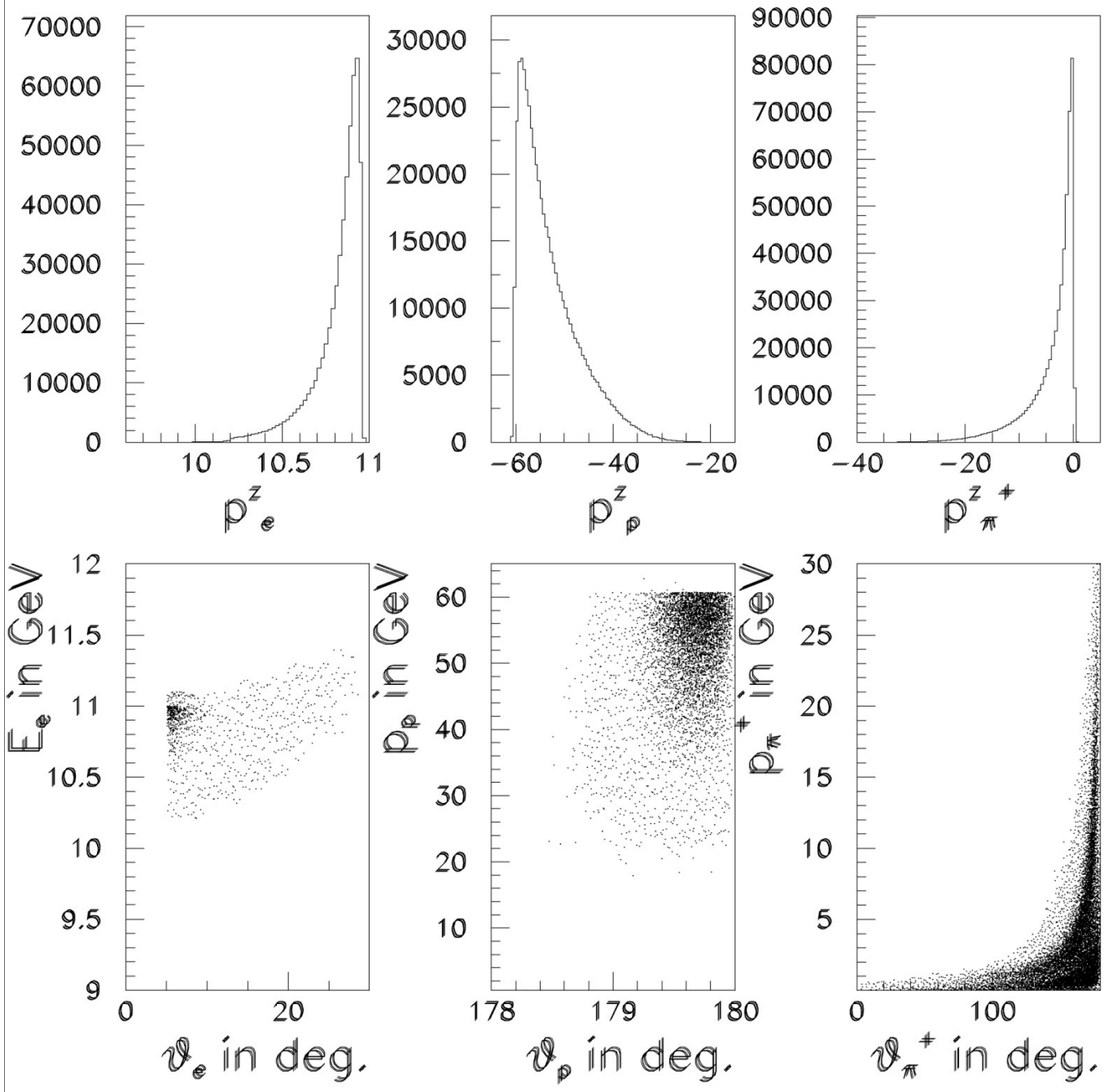


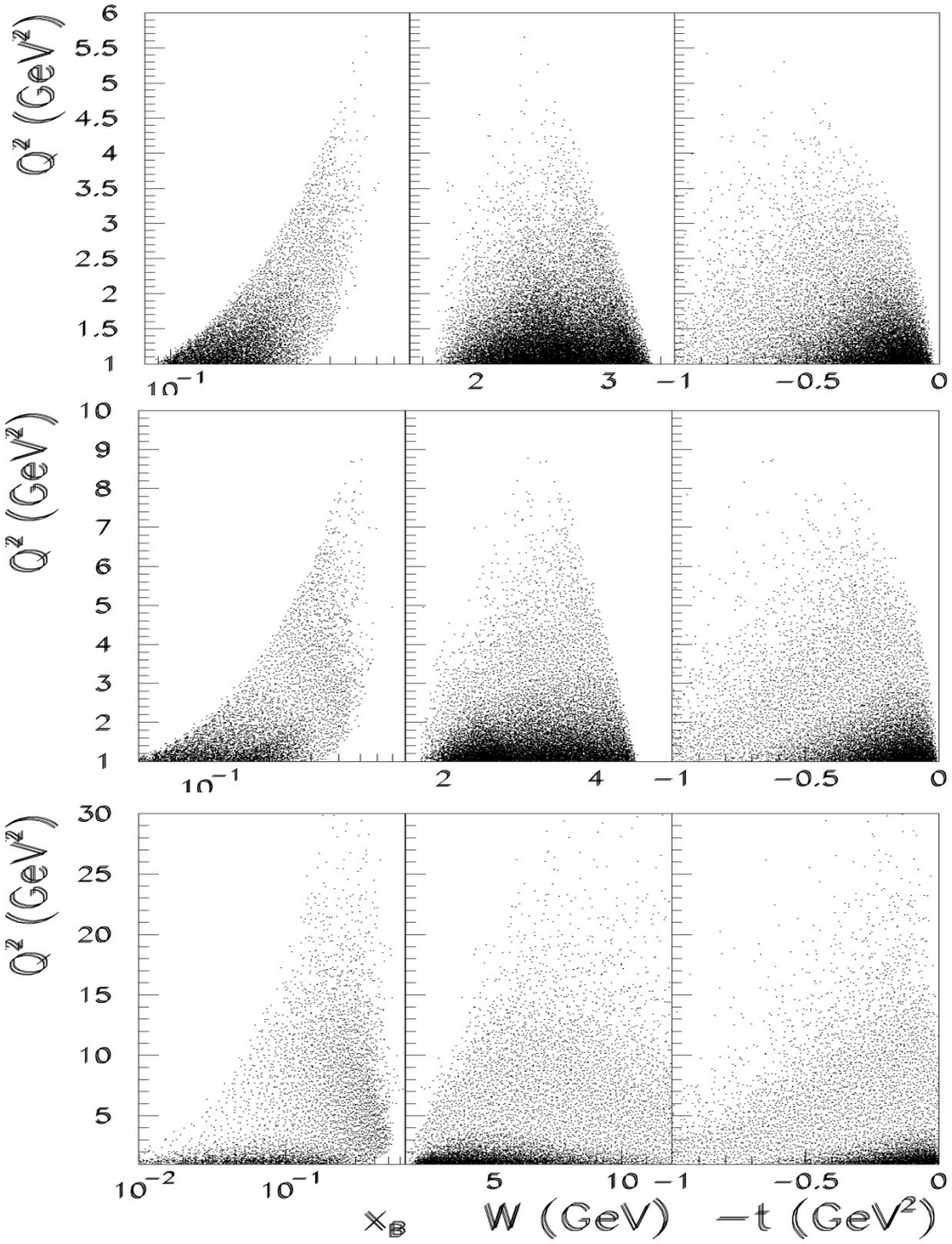


11 GeV e
60 GeV p

Counting rates for 1000 hours at 10^{34} $cm^{-2}s^{-1}$

Limitation comes from luminosity


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
$p^z_{\pi^+}$
E_e' in GeV
12
11.5
11
10.5
10
9.5
9
0
20
ϑ_e in deg.
p_p' in GeV
60
50
40
30
20
10
178
179
180
ϑ_p in deg.
p_{π^+}' in GeV
30
25
20
15
10
5
0
100
ϑ_{π^+} in deg.

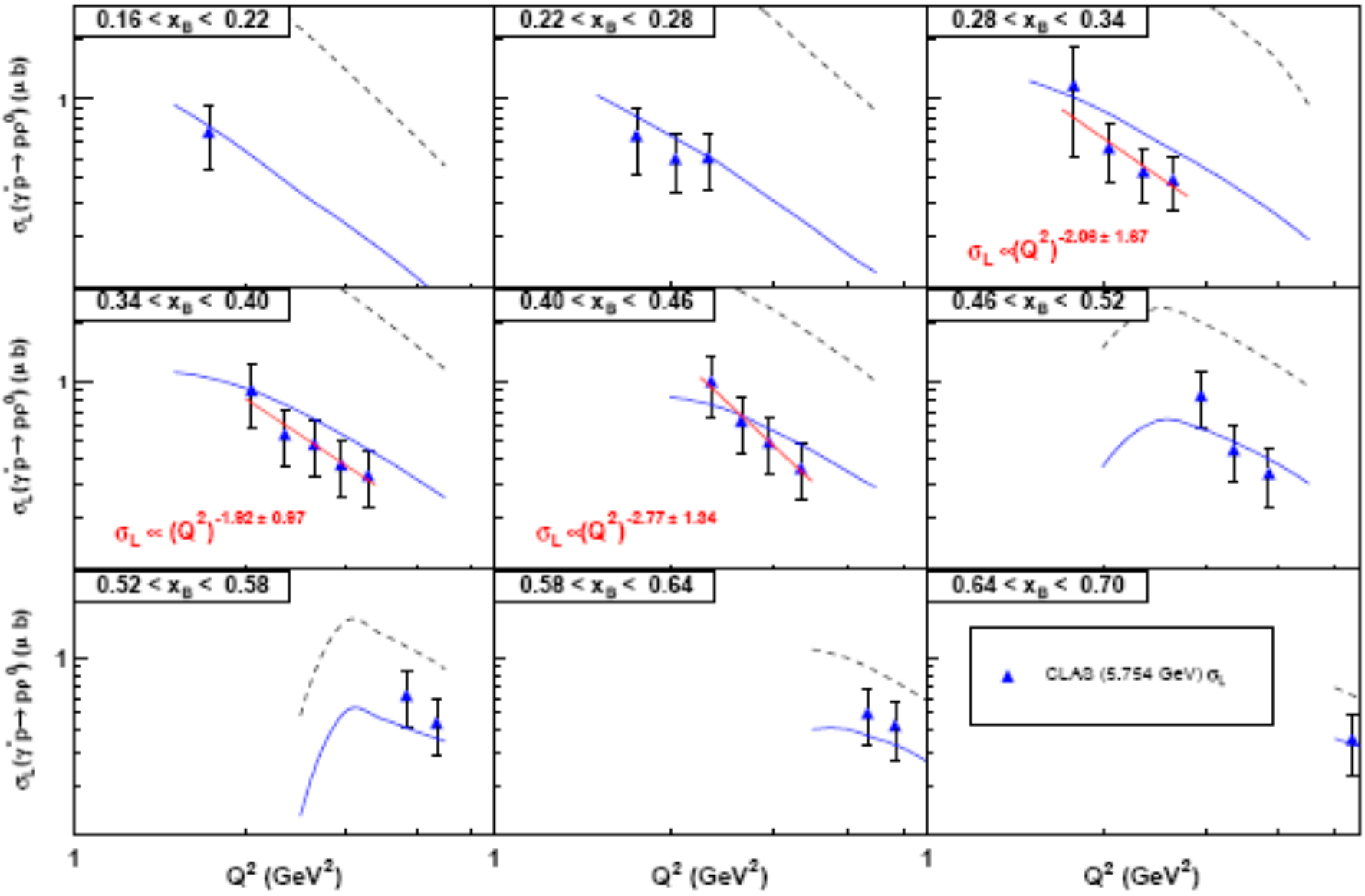


6 GeV e
fixed p target

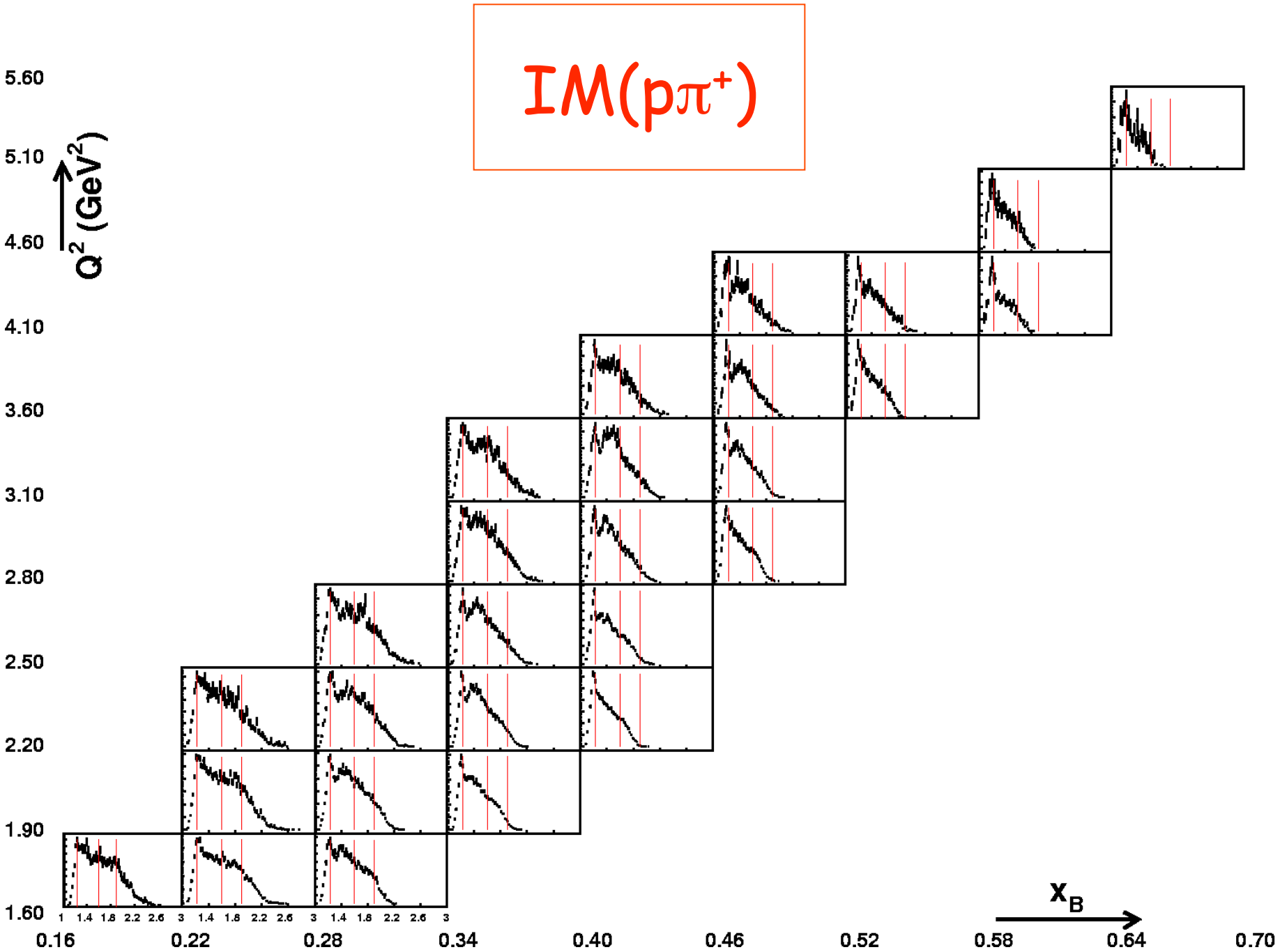
11 GeV e
fixed p target

11 GeV e
60 GeV p

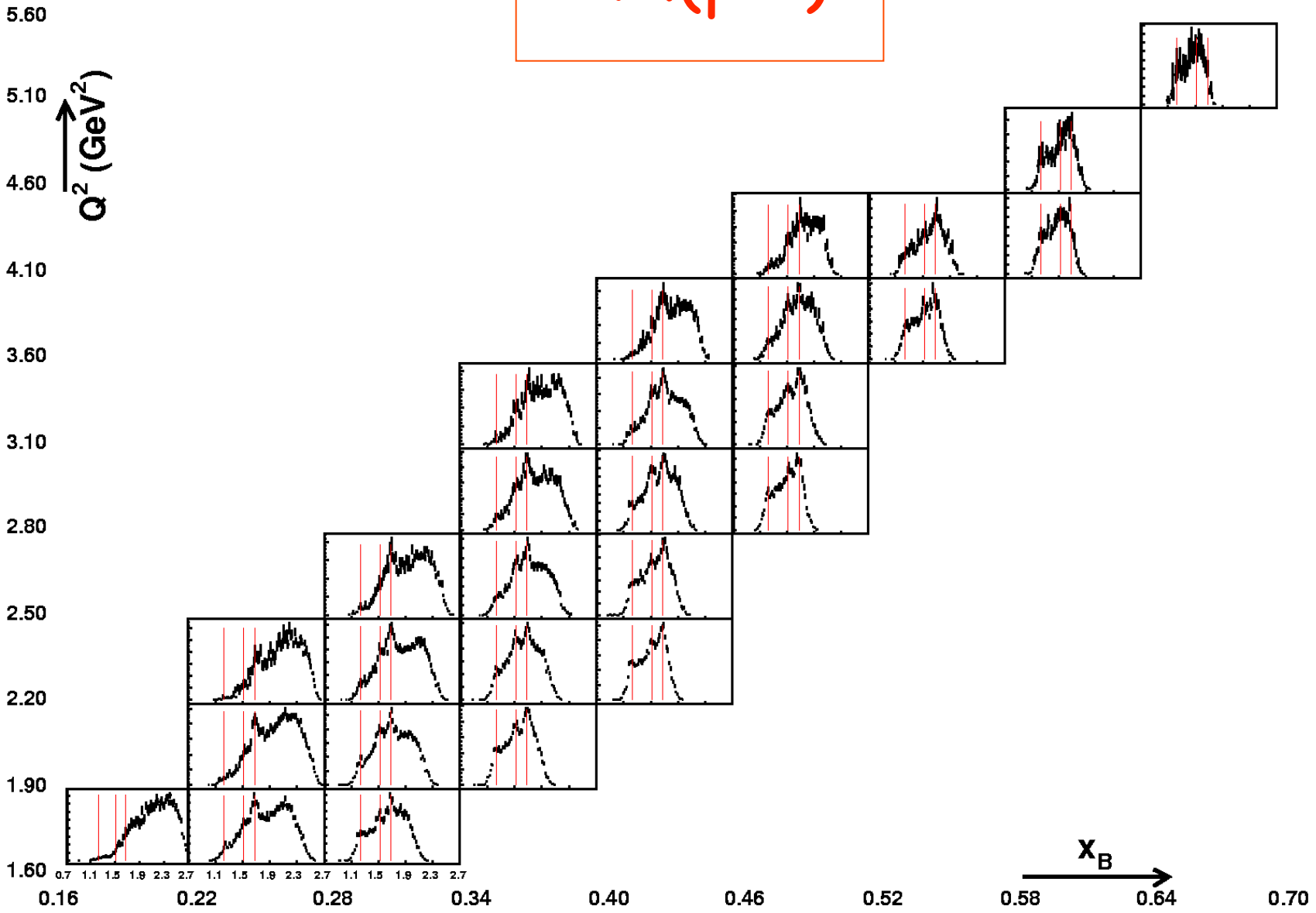
CLAS@6 GeV **S. Morrow et al., Eur.Phys.J.A39:5-31,2009 (ρ^0@5.75GeV)**



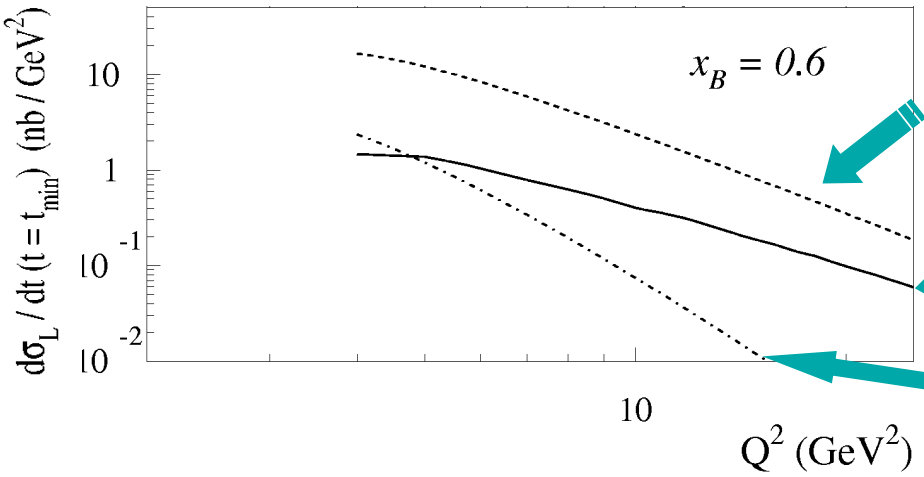
Back-up slides


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

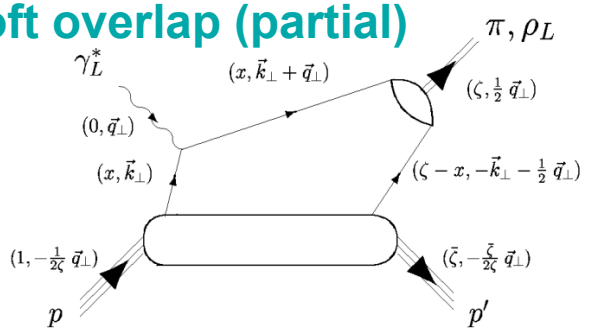
Interpretation in terms of GPDs ?



LO (w/o kperp effect)

LO (with kperp effect)

Soft overlap (partial)

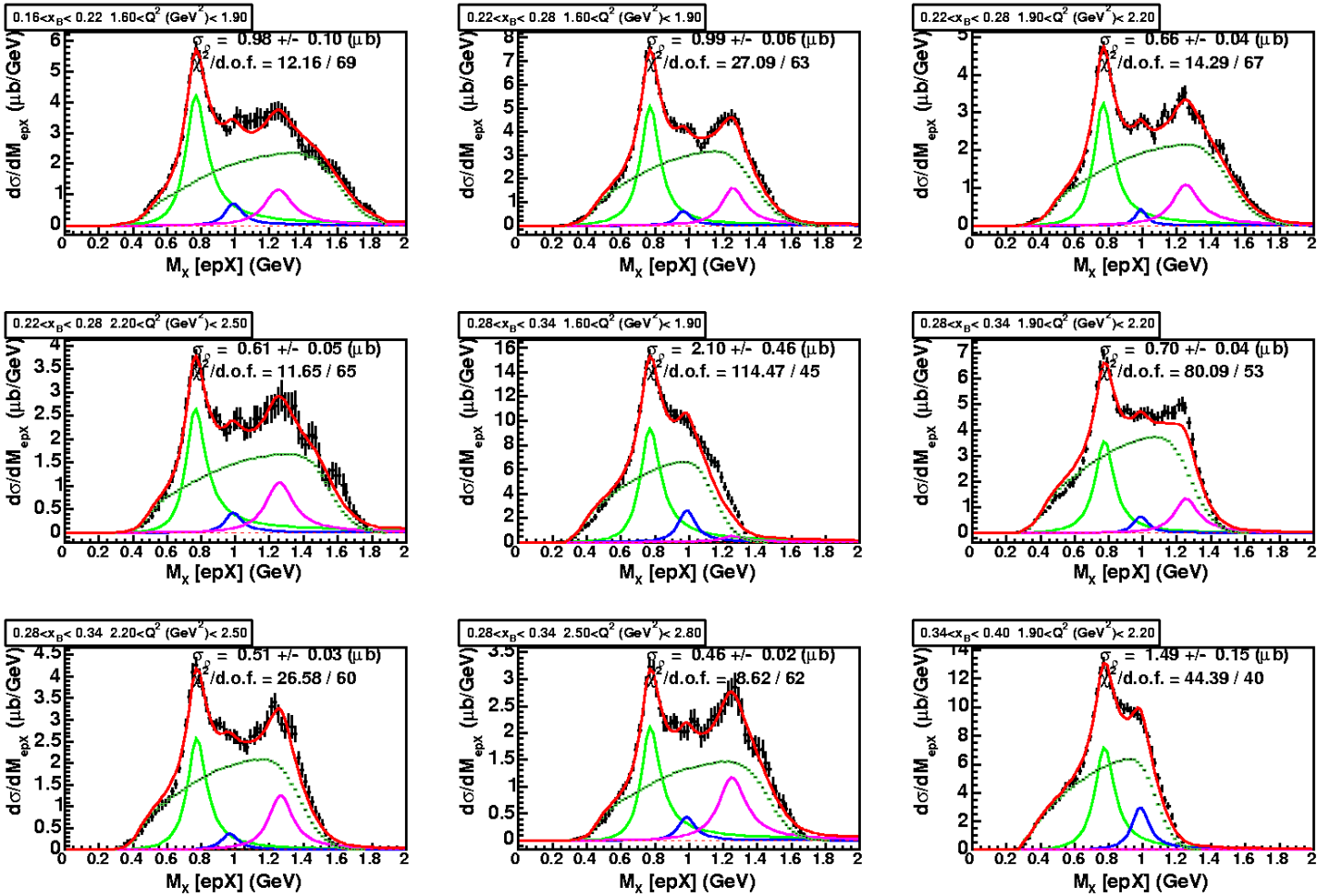


Handbag diagram calculation has k_{perp} effects to account for preasymptotic effects

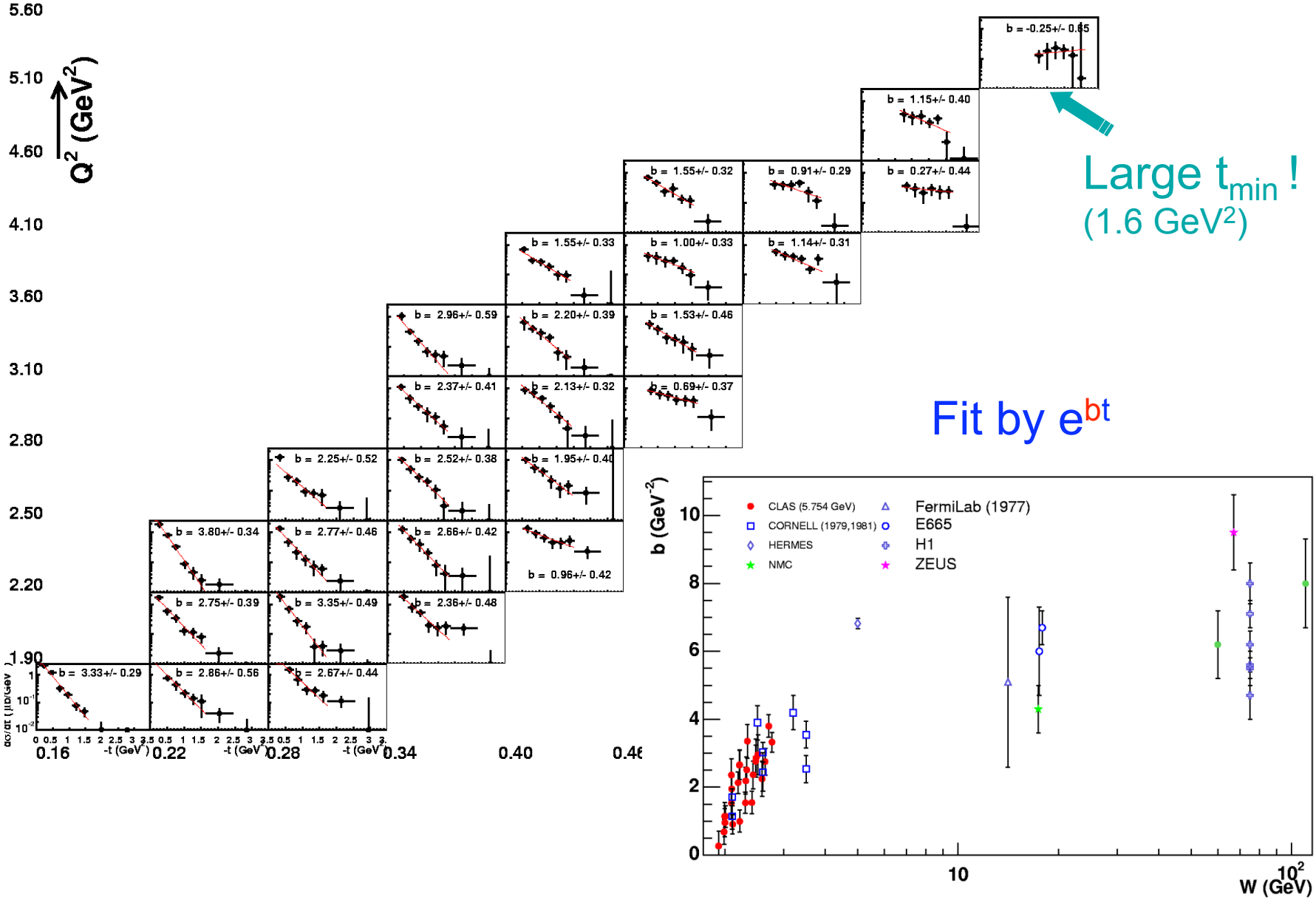
Background Subtraction (normalized spectra)

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.



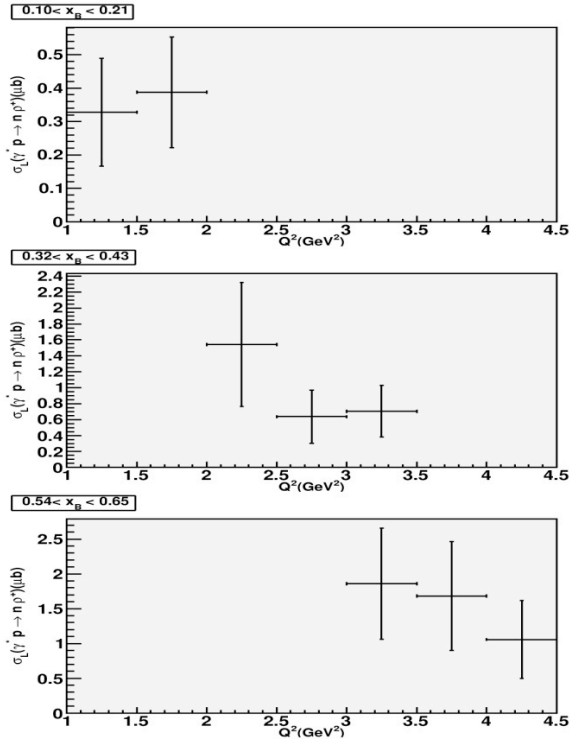
$d\sigma/dt\ (\gamma^* p \rightarrow p\rho^0)$



Large t_{min} !
(1.6 GeV²)

Fit by e^{bt}

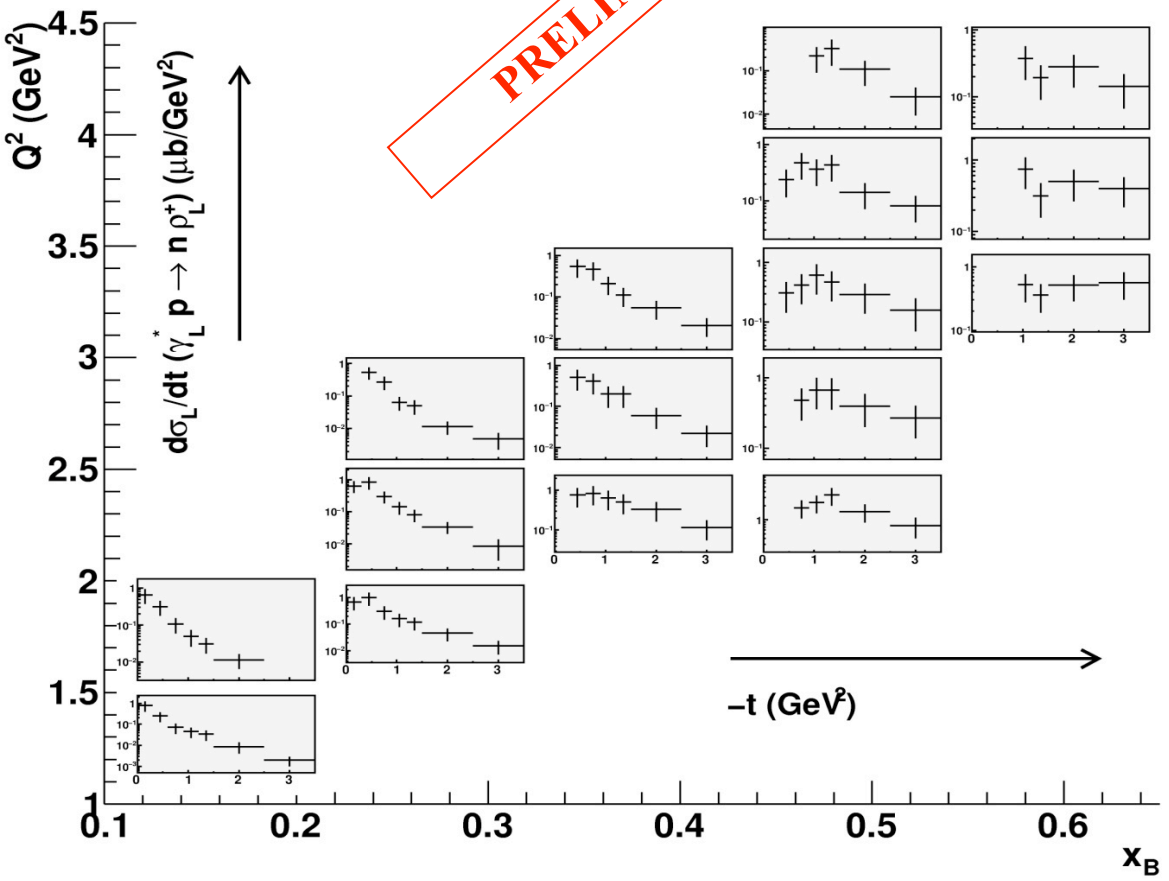
Longitudinal cross sections

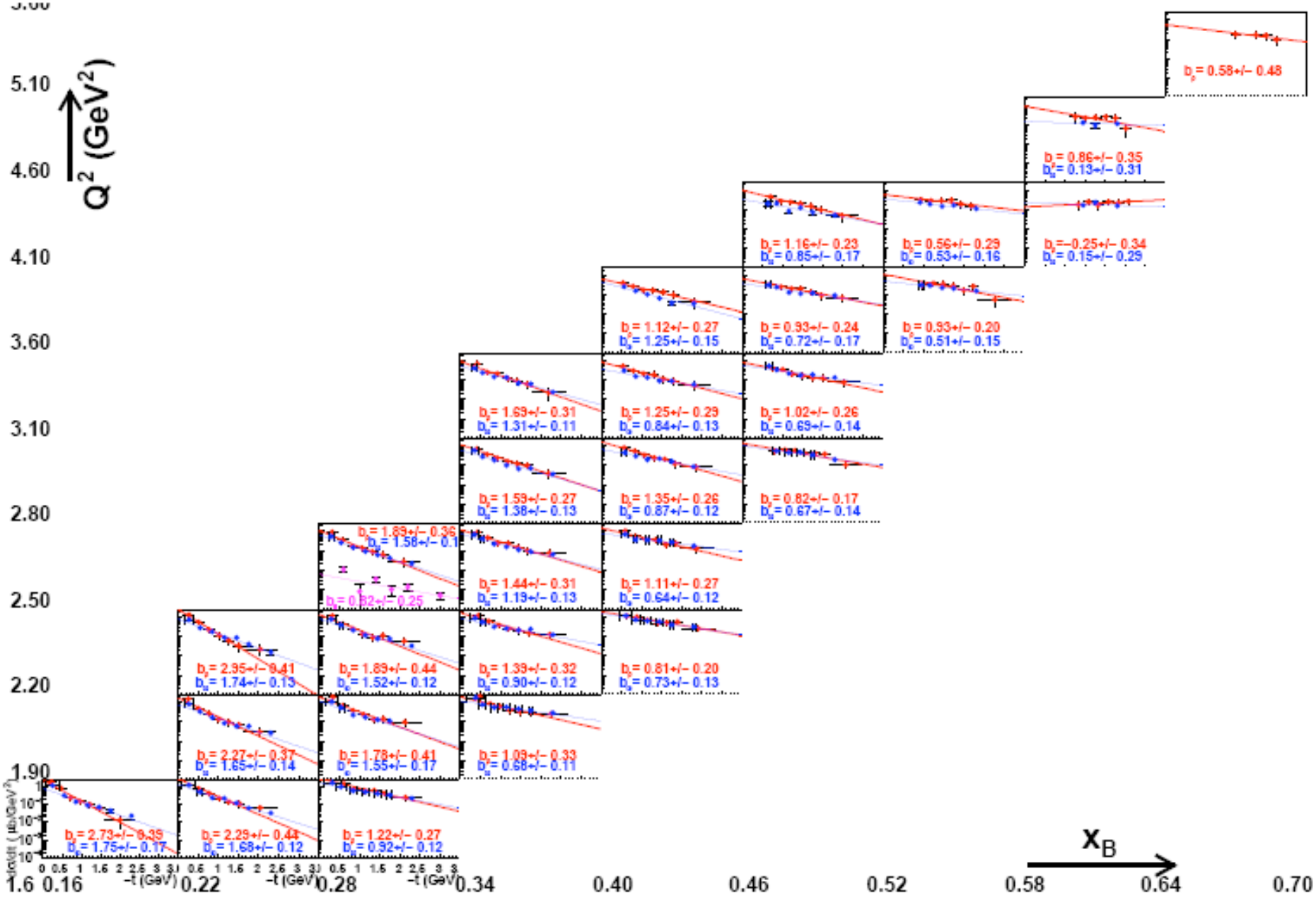


PRELIMINARY

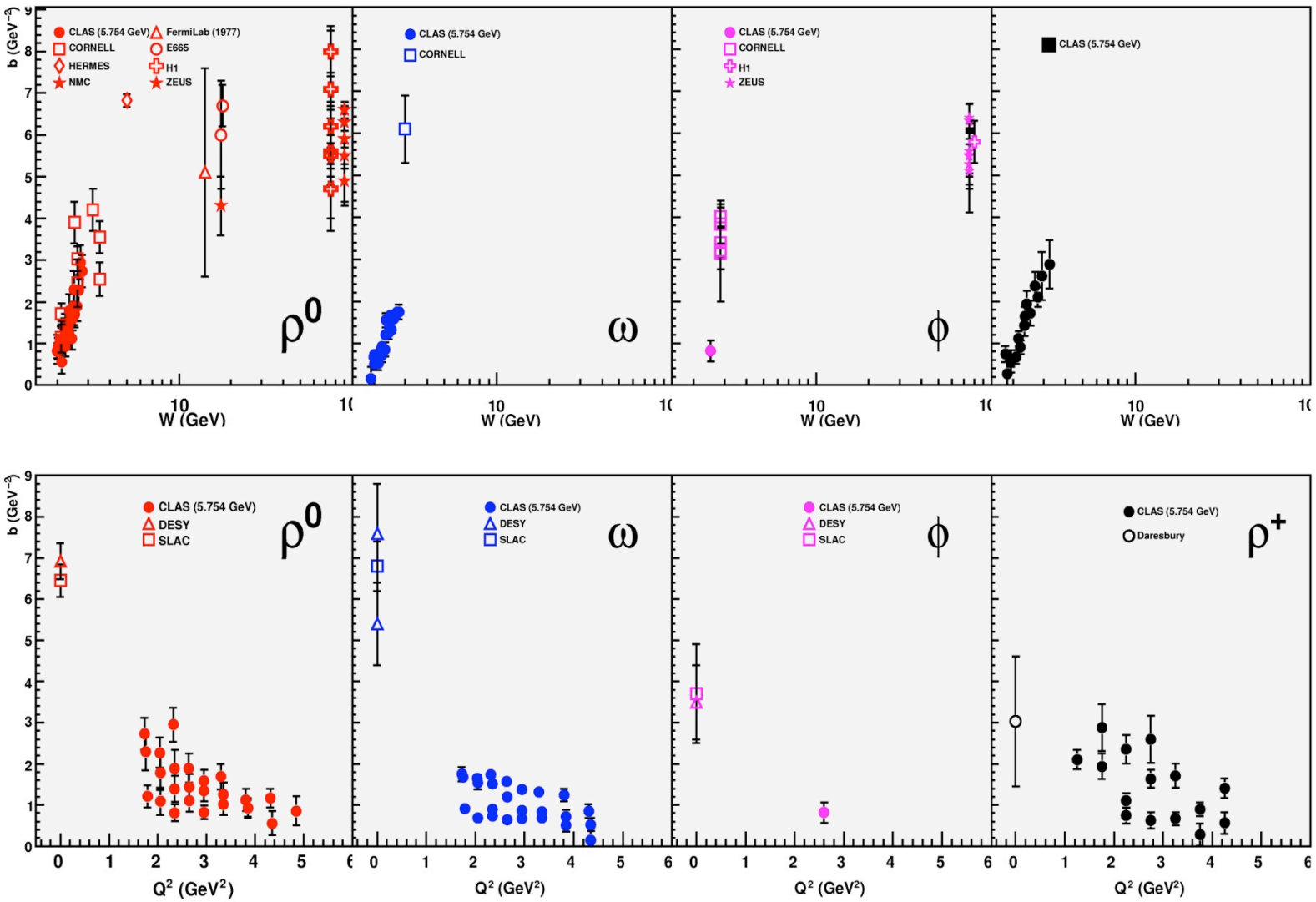
$\sigma_L(\rho^+)[\mu b]$

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

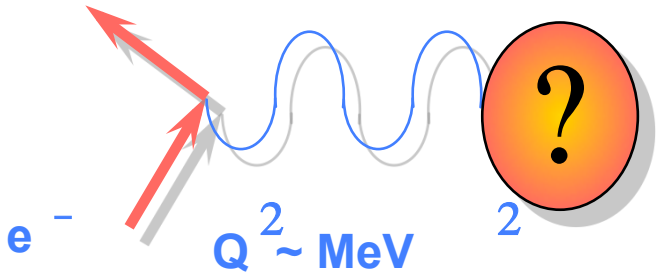


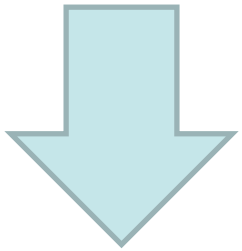

Q² (GeV²)
5.10
4.60
4.10
3.60
3.10
2.80
2.50
2.20
1.90
1.6
0.16
0.22
0.28
0.34
0.40
0.46
0.52
0.58
0.64
0.70
x_B
dσ/dt (μb/GeV²)
−t (GeV)
b_p = 0.58+/− 0.48
b_p = 0.86+/− 0.35
b_ρ = 0.13+/− 0.31
b_p = 1.16+/− 0.23
b_ρ = 0.85+/− 0.17
b_p = 0.56+/− 0.29
b_ρ = 0.53+/− 0.16
b_p = −0.25+/− 0.34
b_ρ = 0.15+/− 0.29
b_p = 1.12+/− 0.27
b_ρ = 1.25+/− 0.15
b_p = 0.93+/− 0.24
b_ρ = 0.72+/− 0.17
b_p = 0.93+/− 0.20
b_ρ = 0.51+/− 0.15
b_p = 1.69+/− 0.31
b_ρ = 1.31+/− 0.11
b_p = 1.25+/− 0.29
b_ρ = 0.84+/− 0.13
b_p = 1.02+/− 0.26
b_ρ = 0.69+/− 0.14
b_p = 1.59+/− 0.27
b_ρ = 1.38+/− 0.13
b_p = 1.35+/− 0.26
b_ρ = 0.87+/− 0.12
b_p = 0.82+/− 0.17
b_ρ = 0.67+/− 0.14
b_p = 1.69+/− 0.36
b_ρ = 1.58+/− 0.1
b_p = 0.82+/− 0.25
b_p = 1.44+/− 0.31
b_ρ = 1.13+/− 0.13
b_p = 1.11+/− 0.27
b_ρ = 0.64+/− 0.12
b_p = 2.35+/− 0.41
b_ρ = 1.74+/− 0.13
b_p = 1.69+/− 0.44
b_ρ = 1.52+/− 0.12
b_p = 1.39+/− 0.32
b_ρ = 0.90+/− 0.12
b_p = 0.81+/− 0.20
b_ρ = 0.73+/− 0.13
b_p = 2.27+/− 0.37
b_ρ = 1.65+/− 0.14
b_p = 1.78+/− 0.41
b_ρ = 1.55+/− 0.17
b_p = 1.09+/− 0.33
b_ρ = 0.68+/− 0.11
b_p = 2.73+/− 0.39
b_ρ = 1.75+/− 0.17
b_p = 2.29+/− 0.44
b_ρ = 1.68+/− 0.12
b_p = 1.22+/− 0.27
b_ρ = 0.92+/− 0.12

Comparison with ρ^0, ω, ϕ

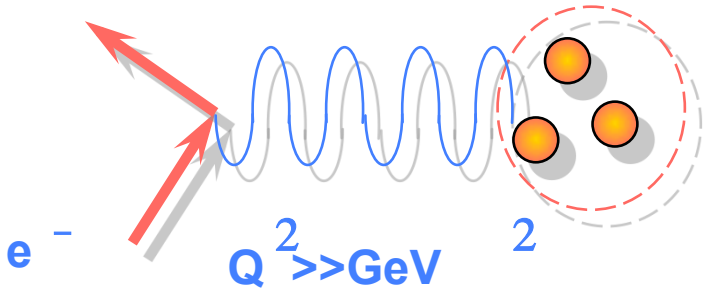


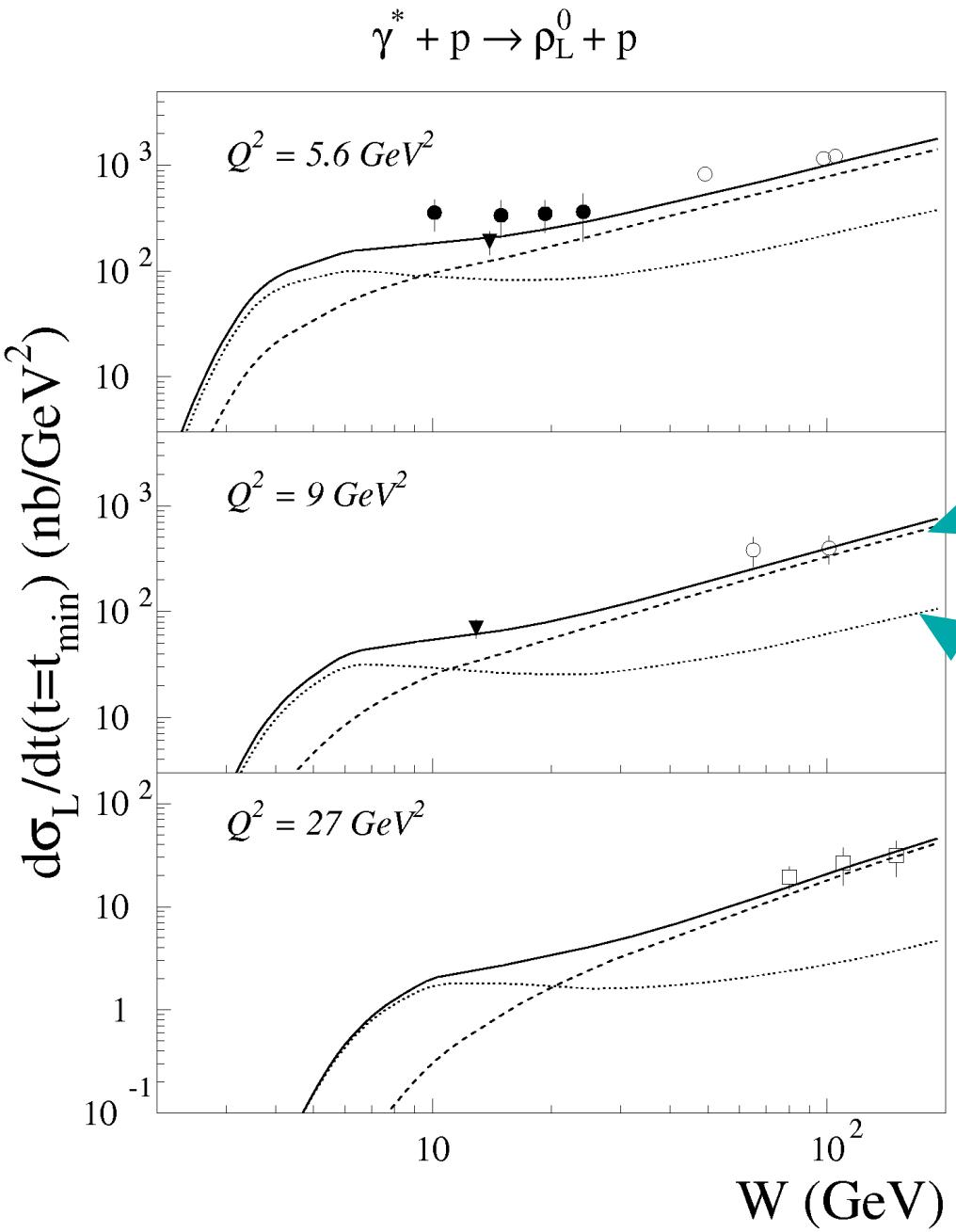
Increasing Q^2:

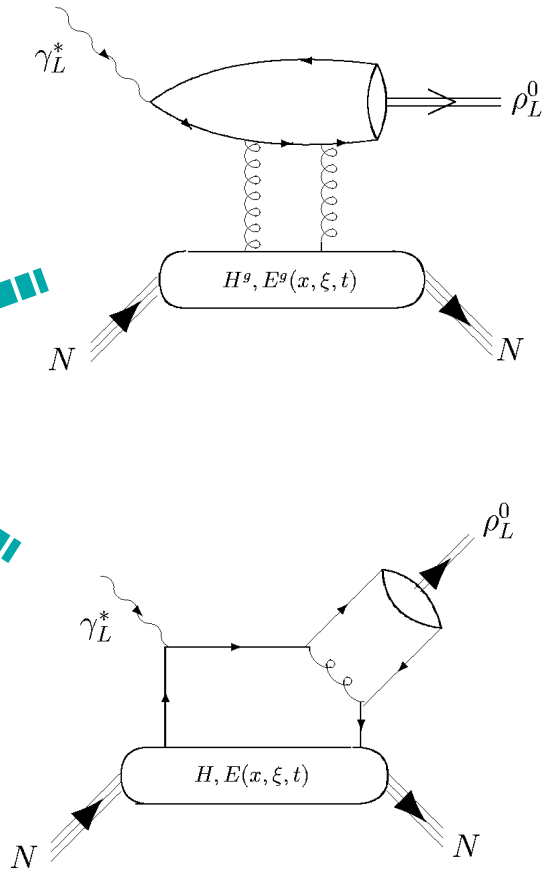




Q^2>>



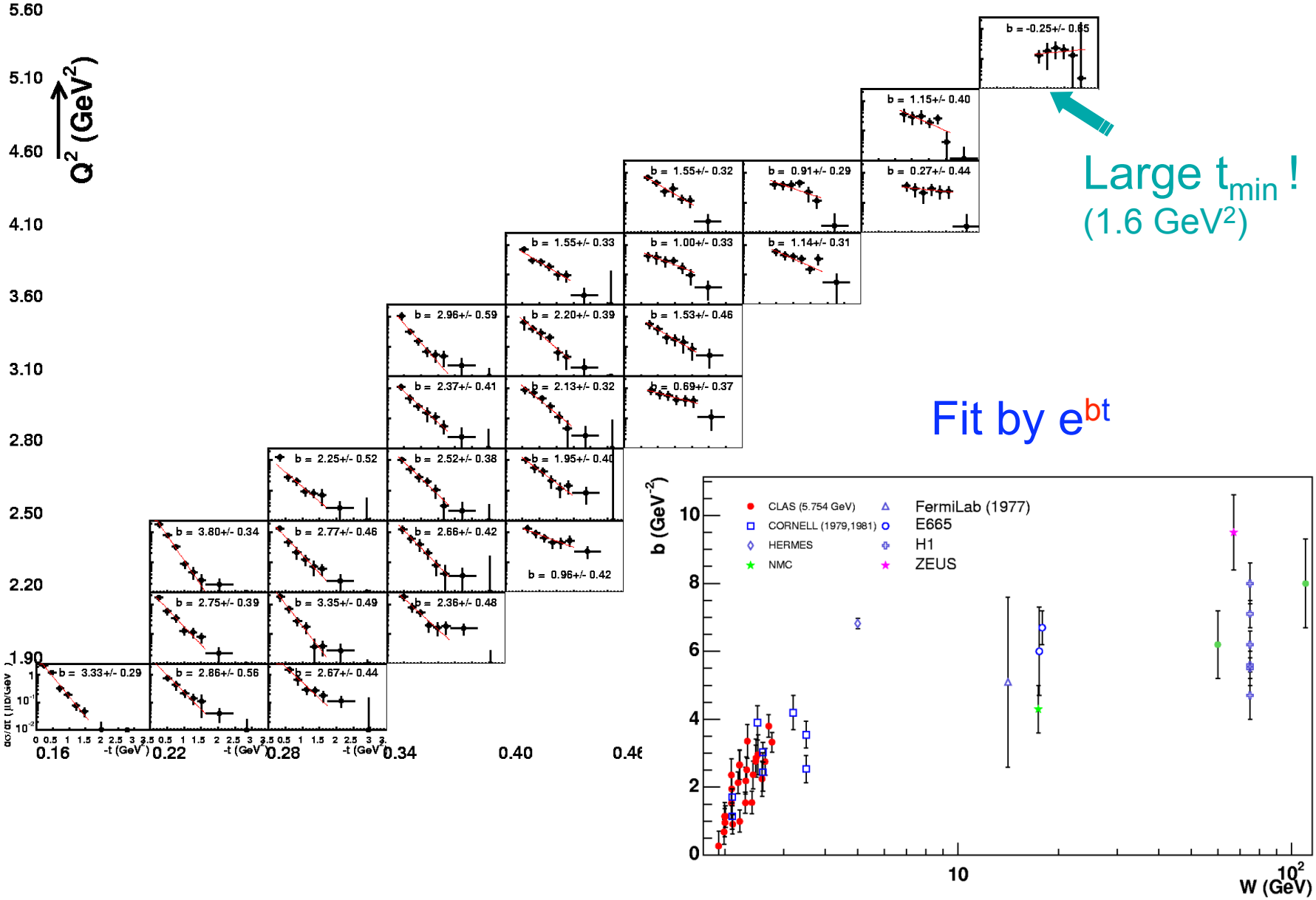




GPDs parametrization based on DDs (VGG/GK model)

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

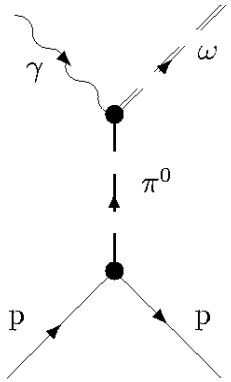
$d\sigma/dt\ (\gamma^* p \rightarrow p\rho^0)$

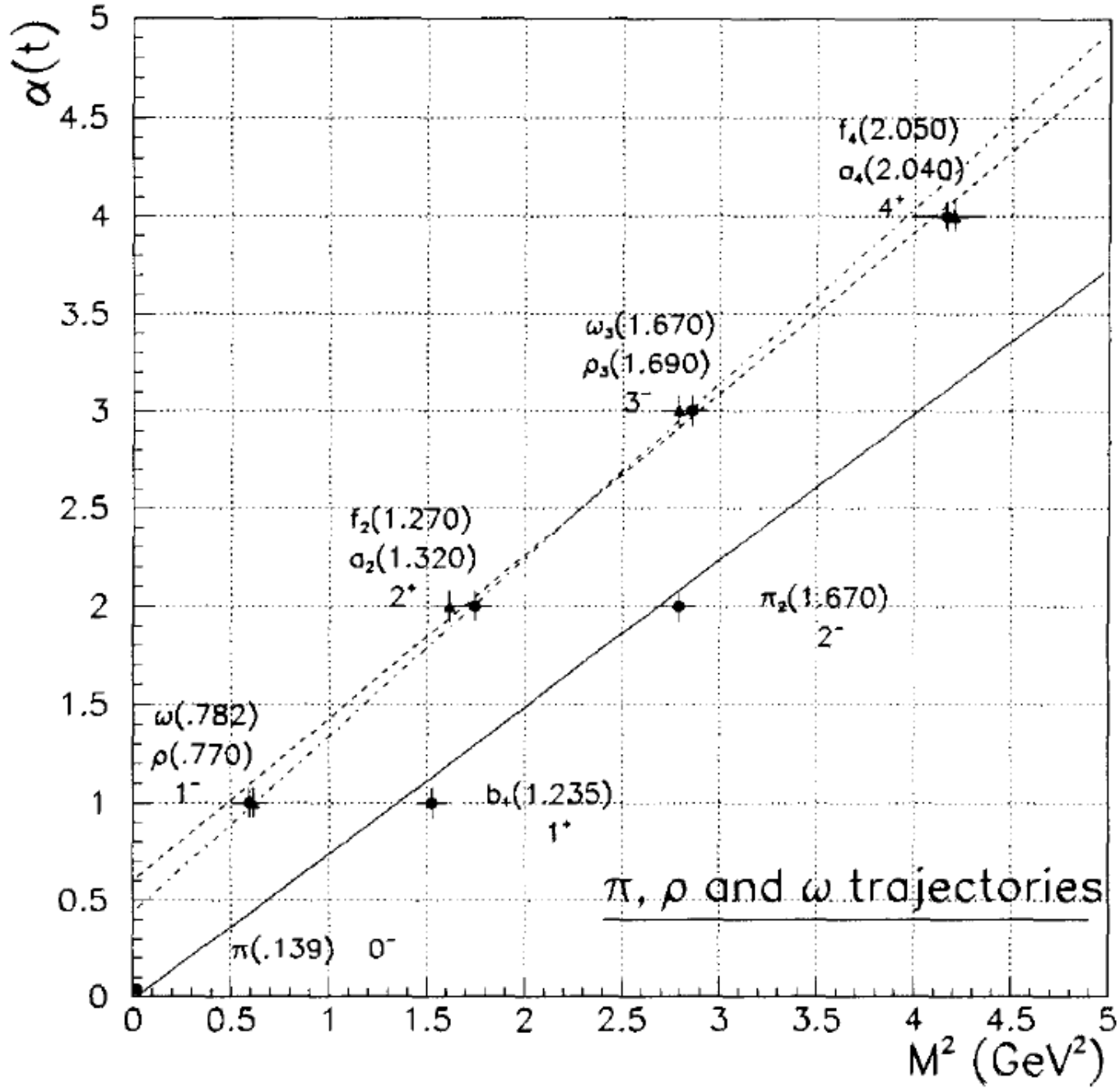


Large t_{min} !
(1.6 GeV²)

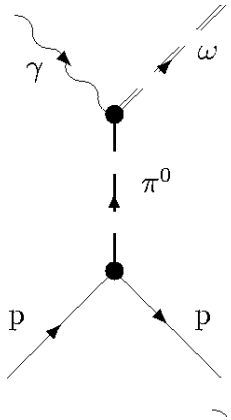
Fit by e^{bt}

Regge theory: **Exchange of families of mesons in the t-channel**




α(t)
M² (GeV²)
f₄(2.050)
a₄(2.040)
4⁺
ω₃(1.670)
ρ₃(1.690)
3⁻
f₂(1.270)
a₂(1.320)
2⁺
π₂(1.670)
2⁻
ω(.782)
ρ(.770)
1⁻
b₁(1.235)
1⁺
π(.139) 0⁻
π, ρ and ω trajectories

Regge theory: Exchange of families of mesons in the t-channel



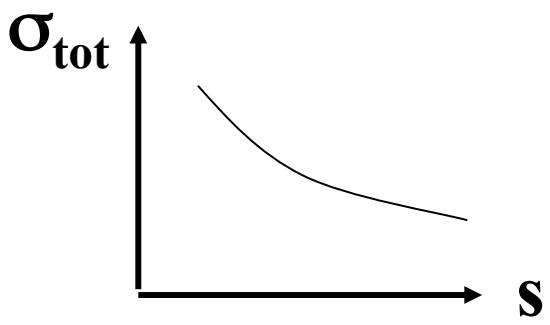
$$M(s,t) \sim s^{\alpha(t)}$$

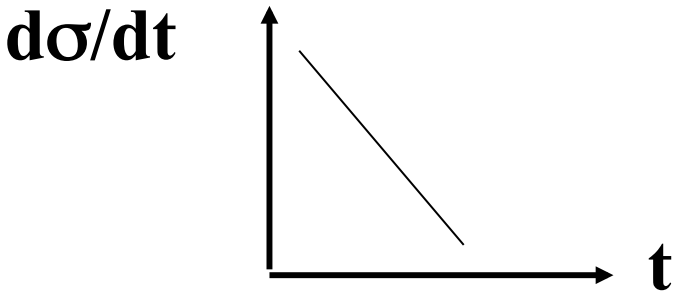
where $\alpha(t)$ (trajectory) is the relation between the spin and the (squared) mass of a family of particles

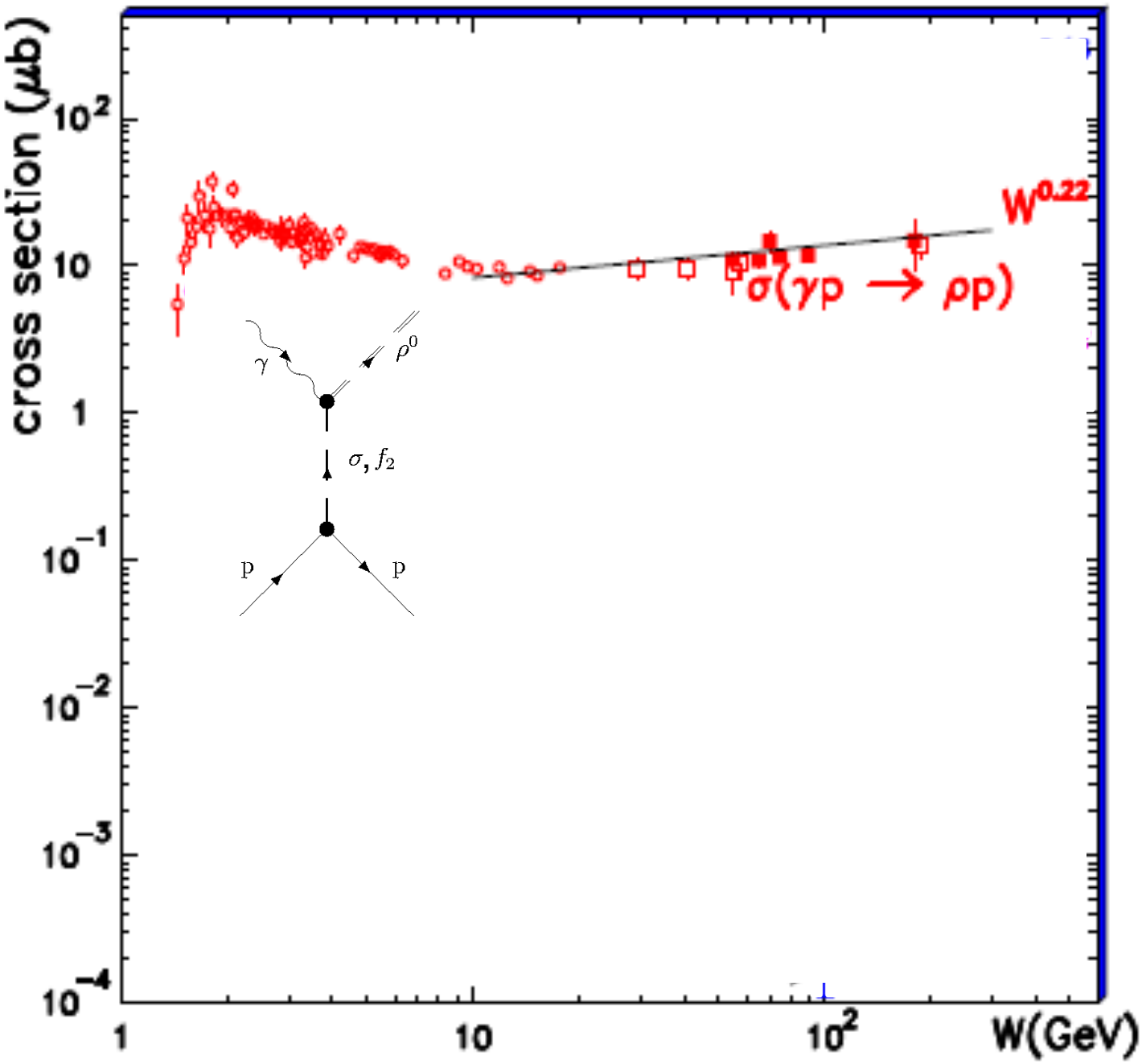
$M \to s^{\alpha(t)}$

$\sigma_{tot} \sim 1/s \times Im(M(s,t=0)) \to s^{\alpha(0)-1}$ [optical theorem]

$d\sigma/dt \sim 1/s^2 \times |M(s,t)|^2 \to s^{2\alpha(t)-2}$ $\to [e^{\alpha(t) \ln s(s)}]$

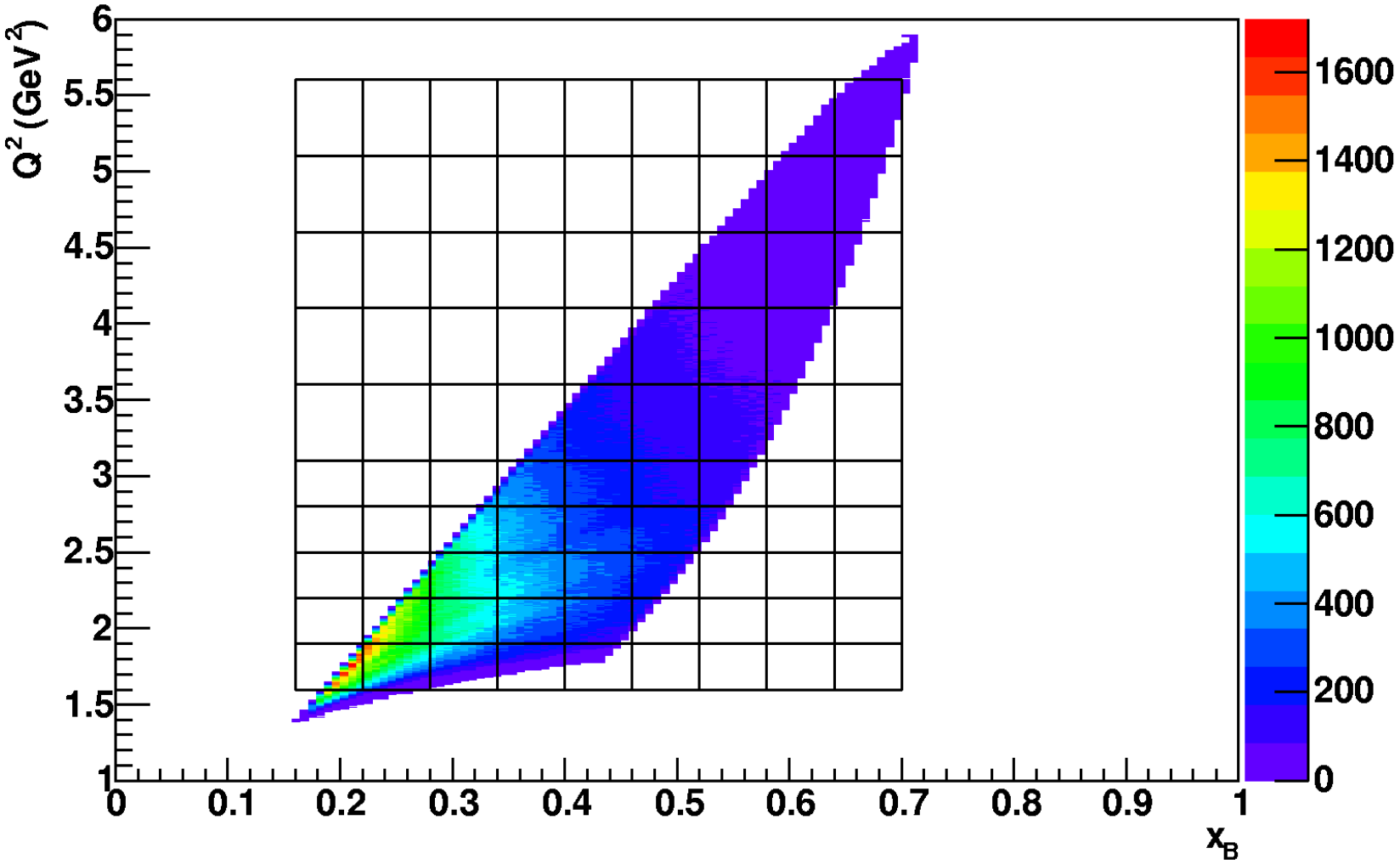





cross section (μb)
10^2
10
1
10^-1
10^-2
10^-3
10^-4
1
10
10^2
W(GeV)
W^0.22
σ(γp → ρp)
γ
ρ^0
σ, f_2
p
p

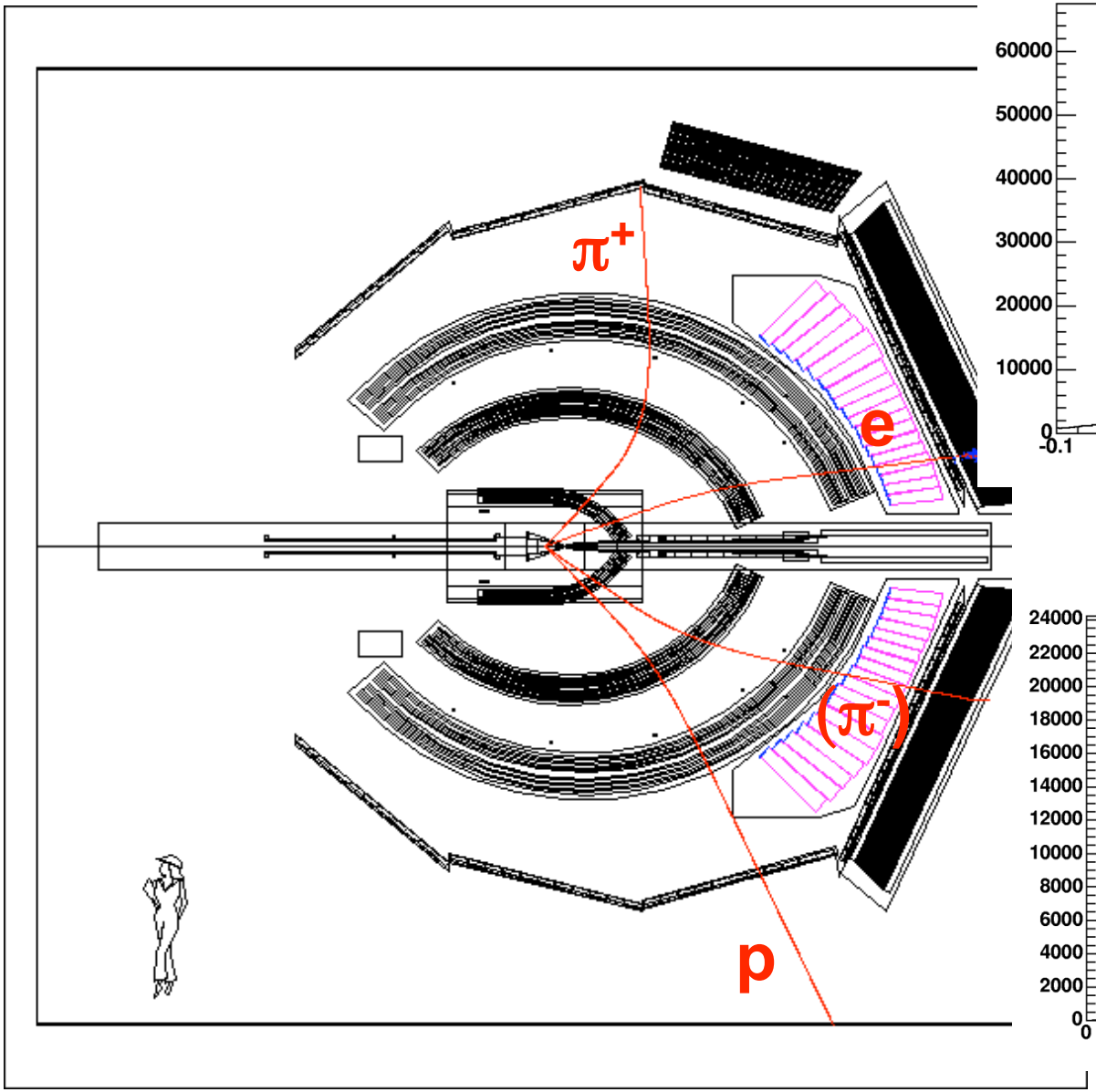
e1-6 experiment (E_e =5.75 GeV)

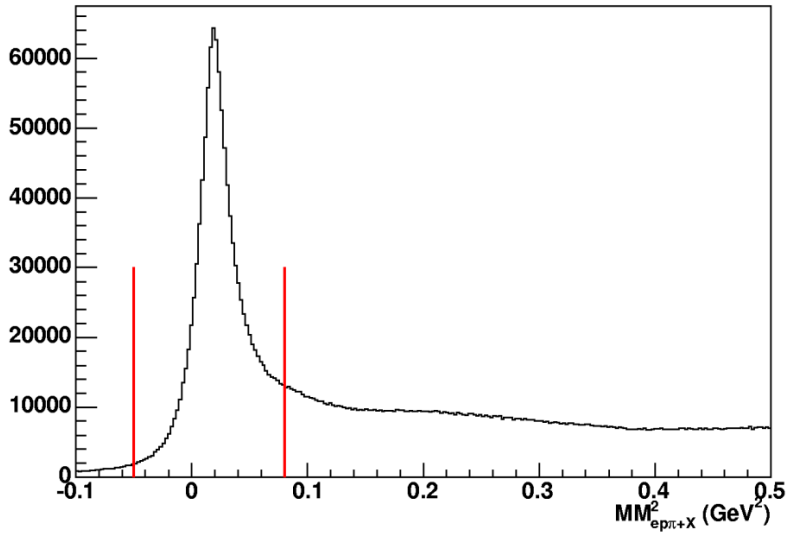
(October 2001 – January 2002)



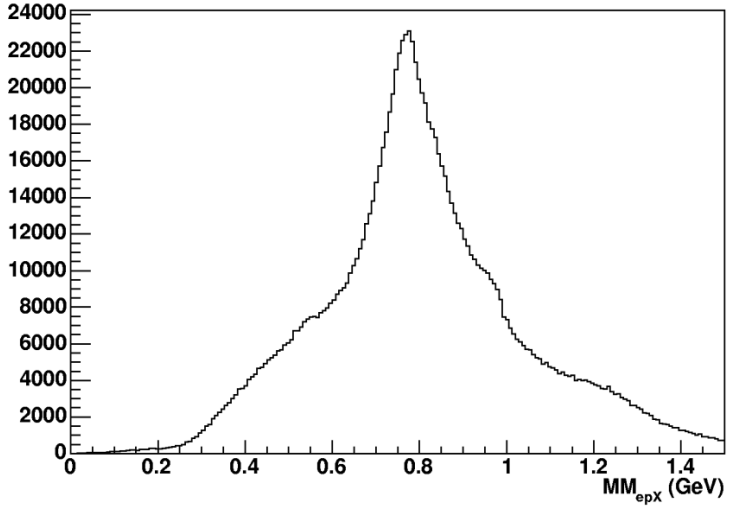
$ep \rightarrow ep\,\pi^+(\pi^-)$

$Mm(ep\pi^+ X)$

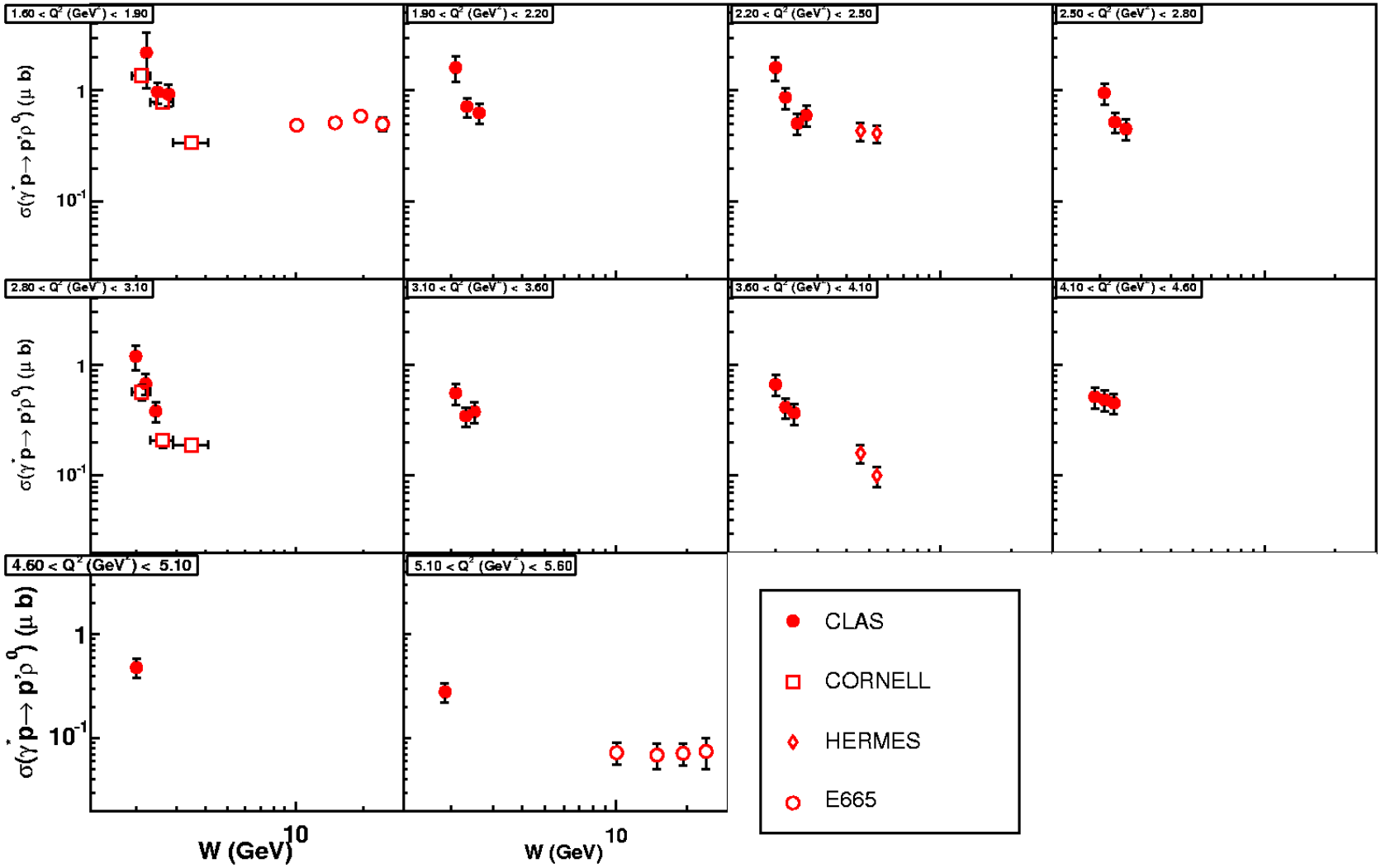
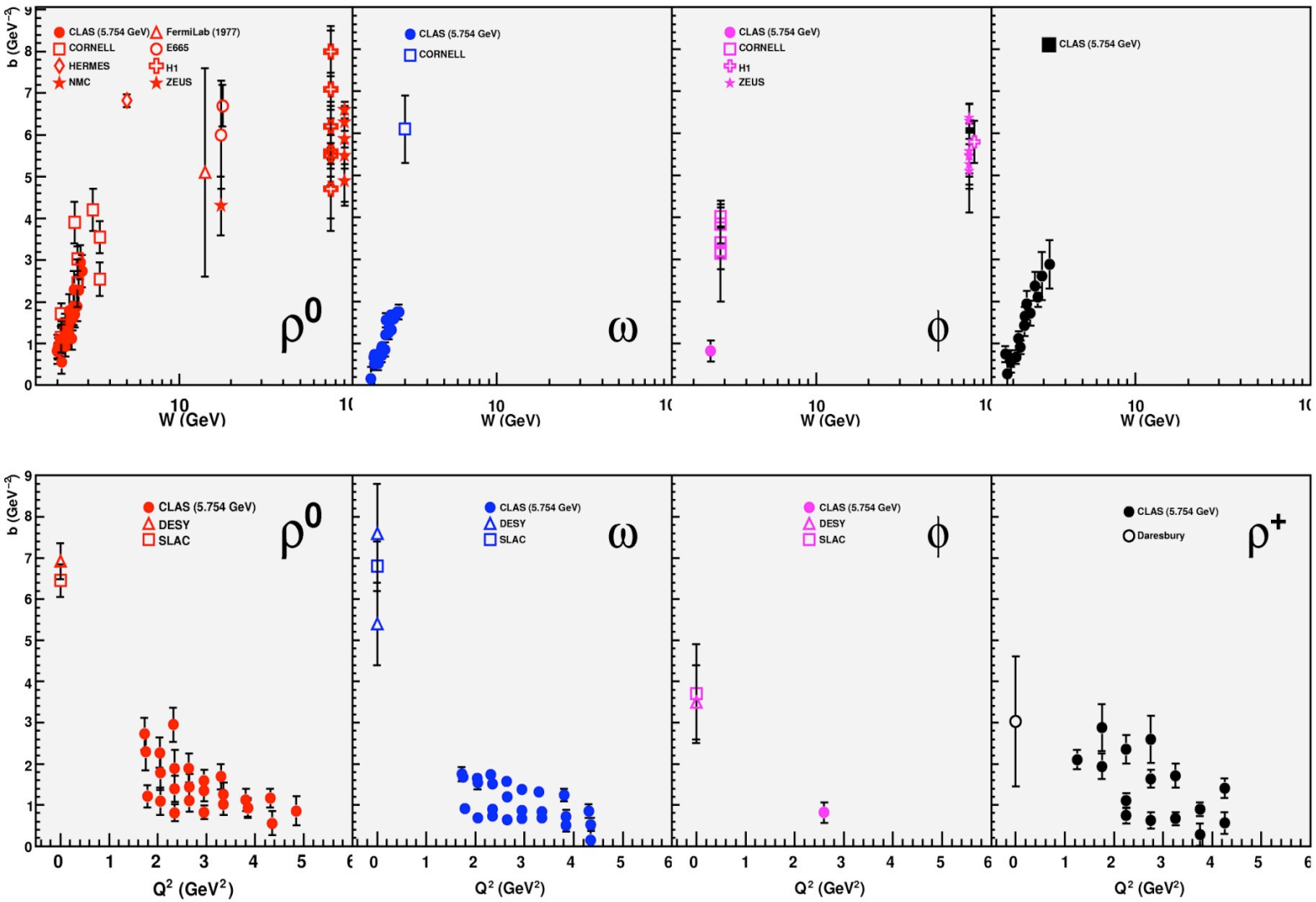




$Mm(epX)$



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



Comparison with ρ^0, ω, ϕ