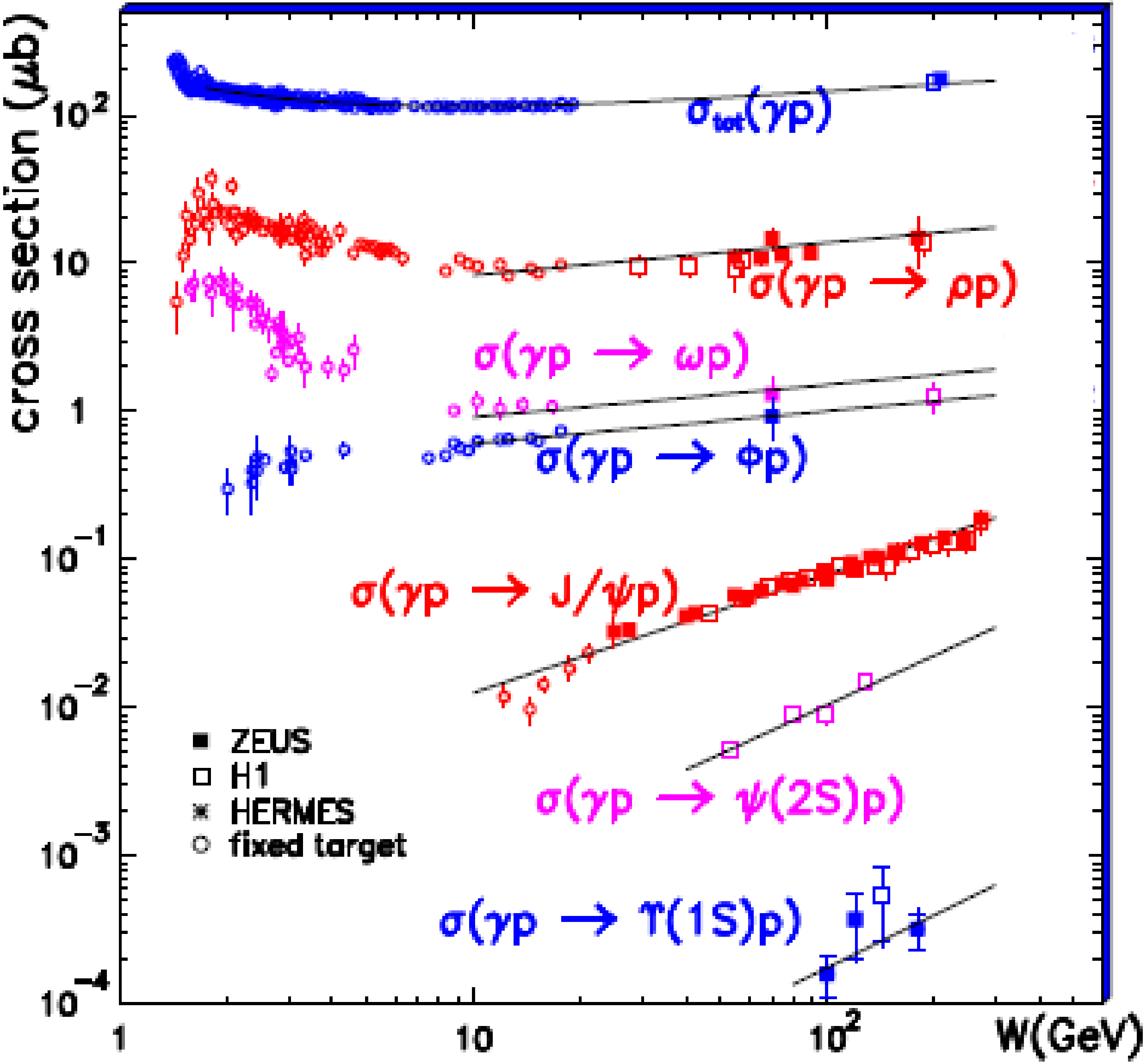
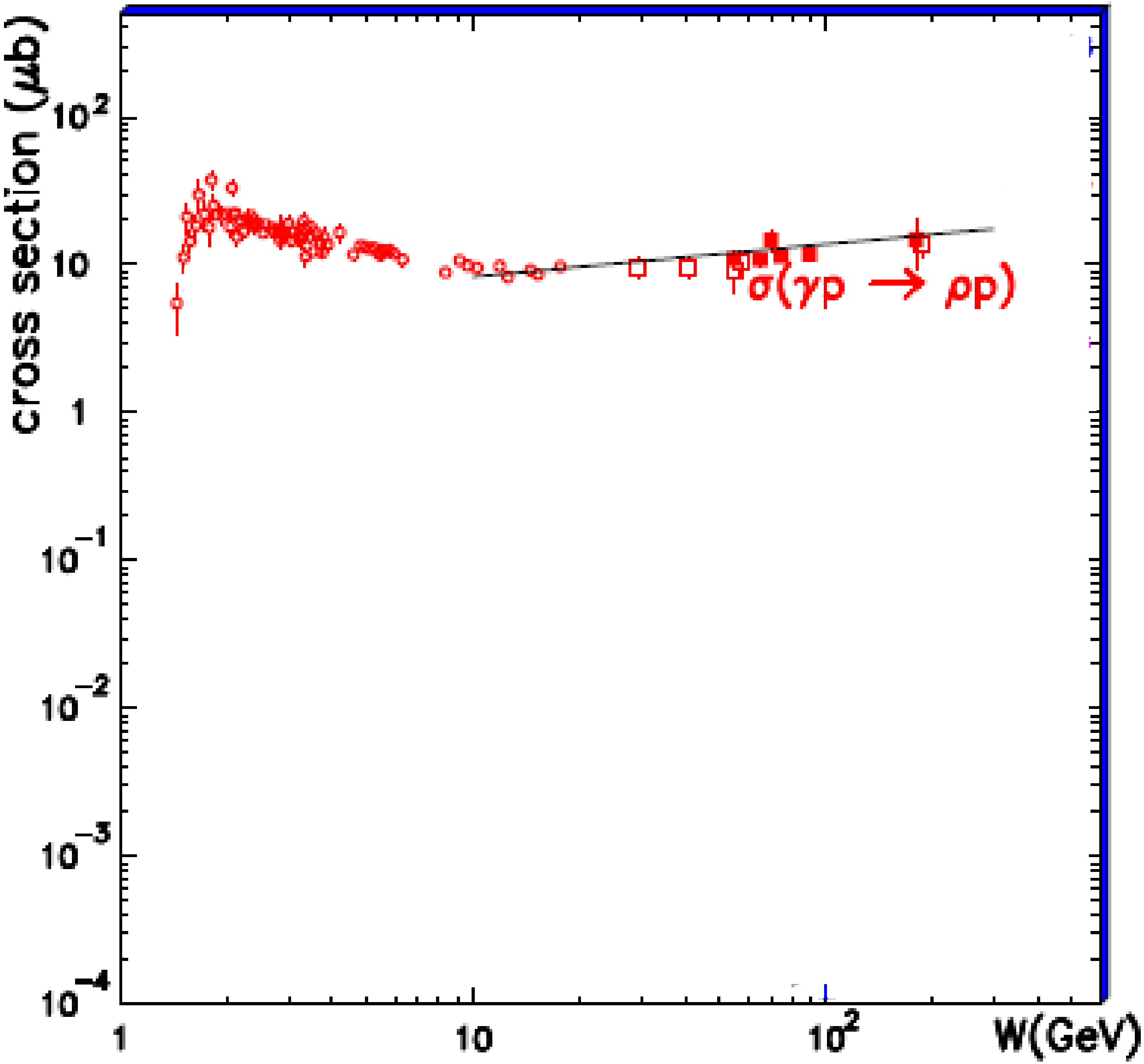
SEATTLE 2012

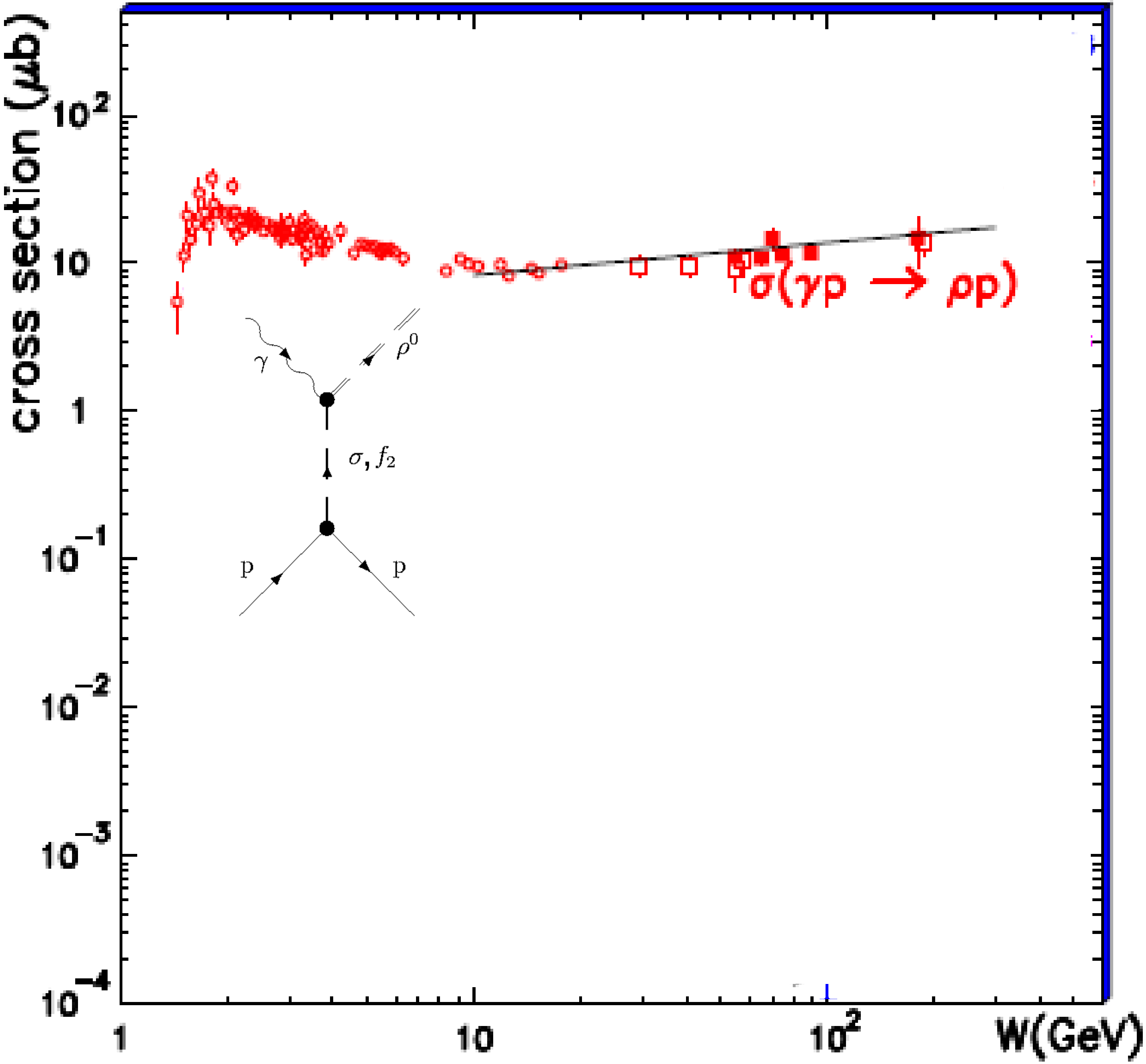
Exclusive vector meson with JLab 6 and 12 GeV

M. Guidal, IPN Orsay



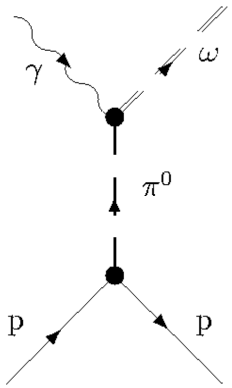
cross section (μb)
W(GeV)
σ_tot(γp)
σ(γp → ρp)
σ(γp → ωp)
σ(γp → φp)
σ(γp → J/ψp)
σ(γp → ψ(2S)p)
σ(γp → Υ(1S)p)
ZEUS
H1
HERMES
fixed target

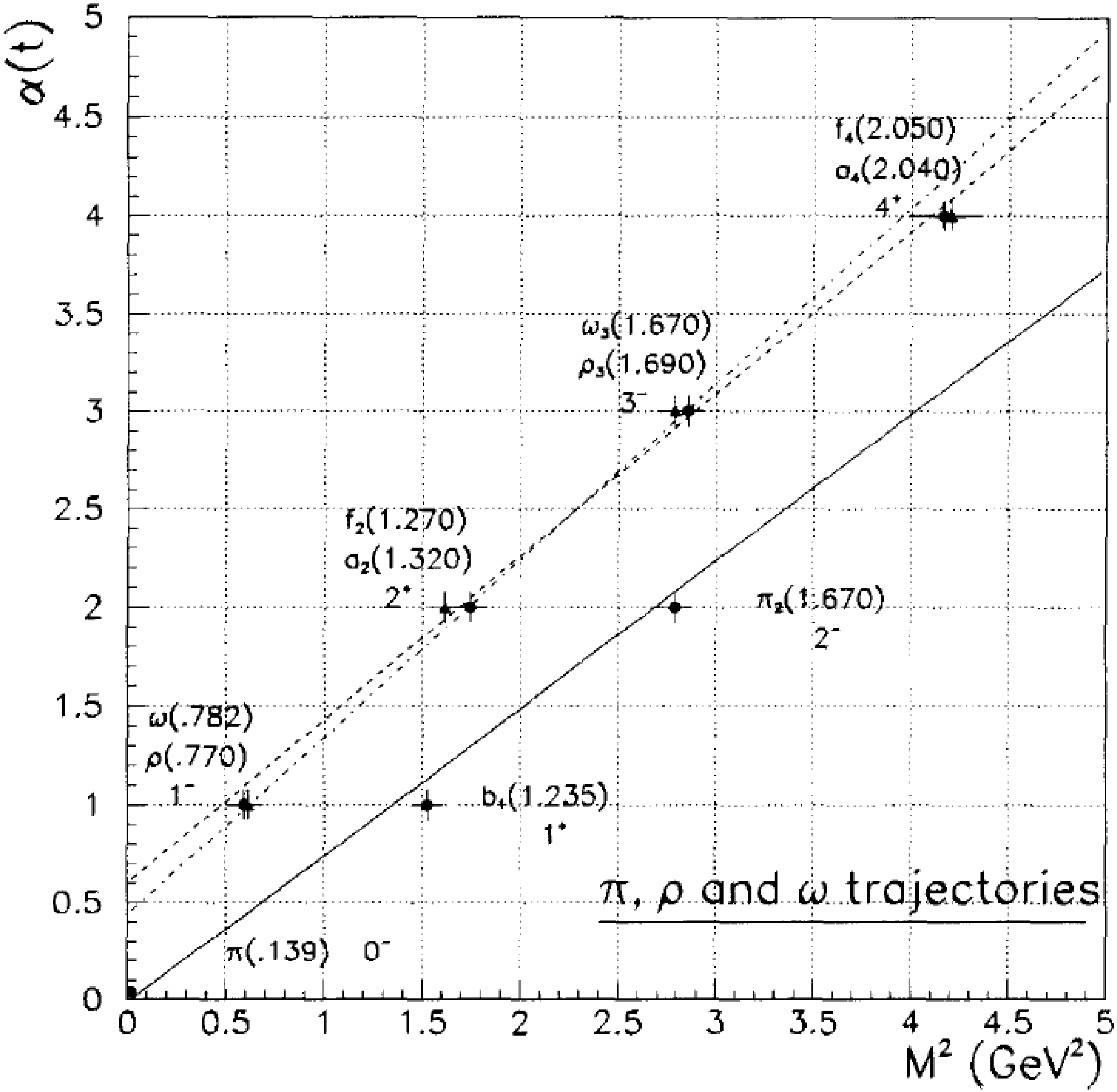

cross section (μb)
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
1
10
10^2
W(GeV)
$\sigma(\gamma p \rightarrow \rho p)$



cross section (μb)
10²
10
1
10⁻¹
10⁻²
10⁻³
10⁻⁴
1
10
10²
W(GeV)
σ(γp → ρp)
γ
ρ⁰
σ, f₂
p
p

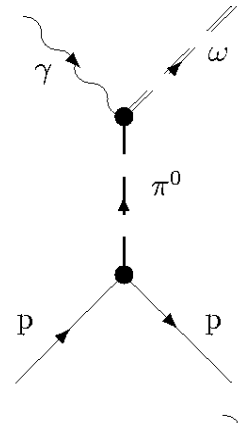
Regge theory: Exchange of families of mesons in the t-channel





α(t)
M² (GeV²)
π, ρ and ω trajectories
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⁻
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

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



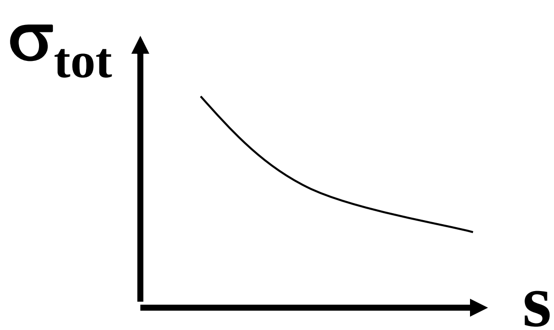
$$M(s,t) \sim s^{\alpha(t)}$$

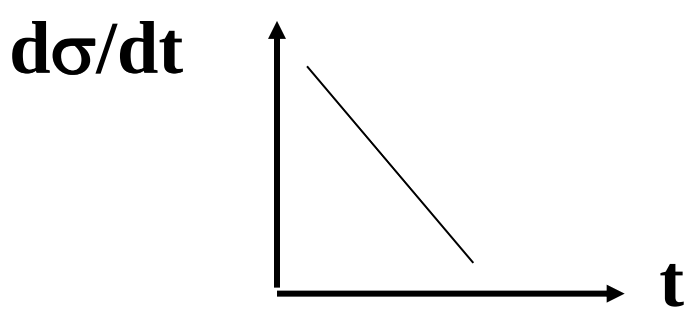
where $\alpha(t)$ (trajectory) is the relation between the spin and the (squared) mass of a family of particles

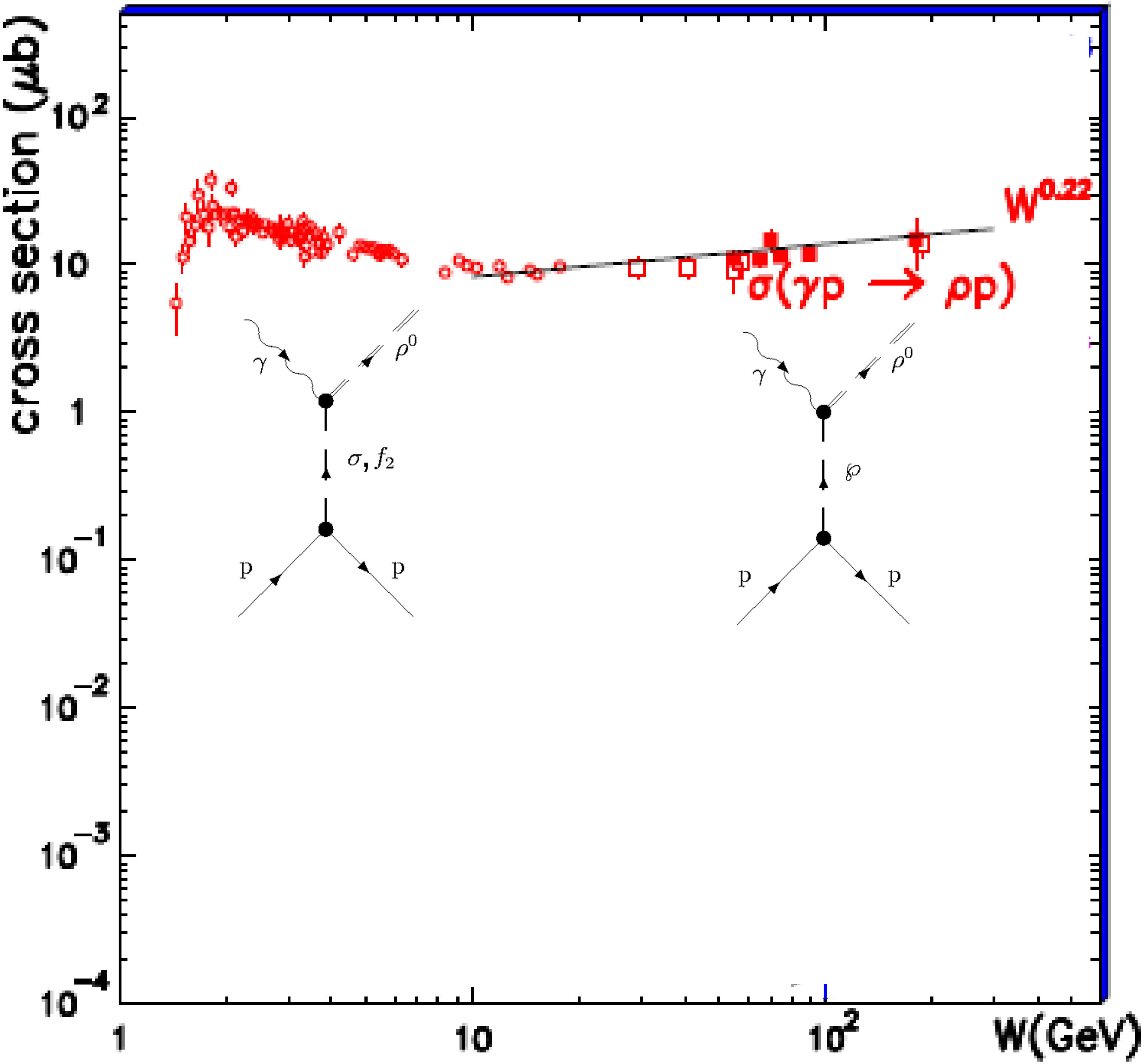
$M \rightarrow s^{\alpha(t)}$

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

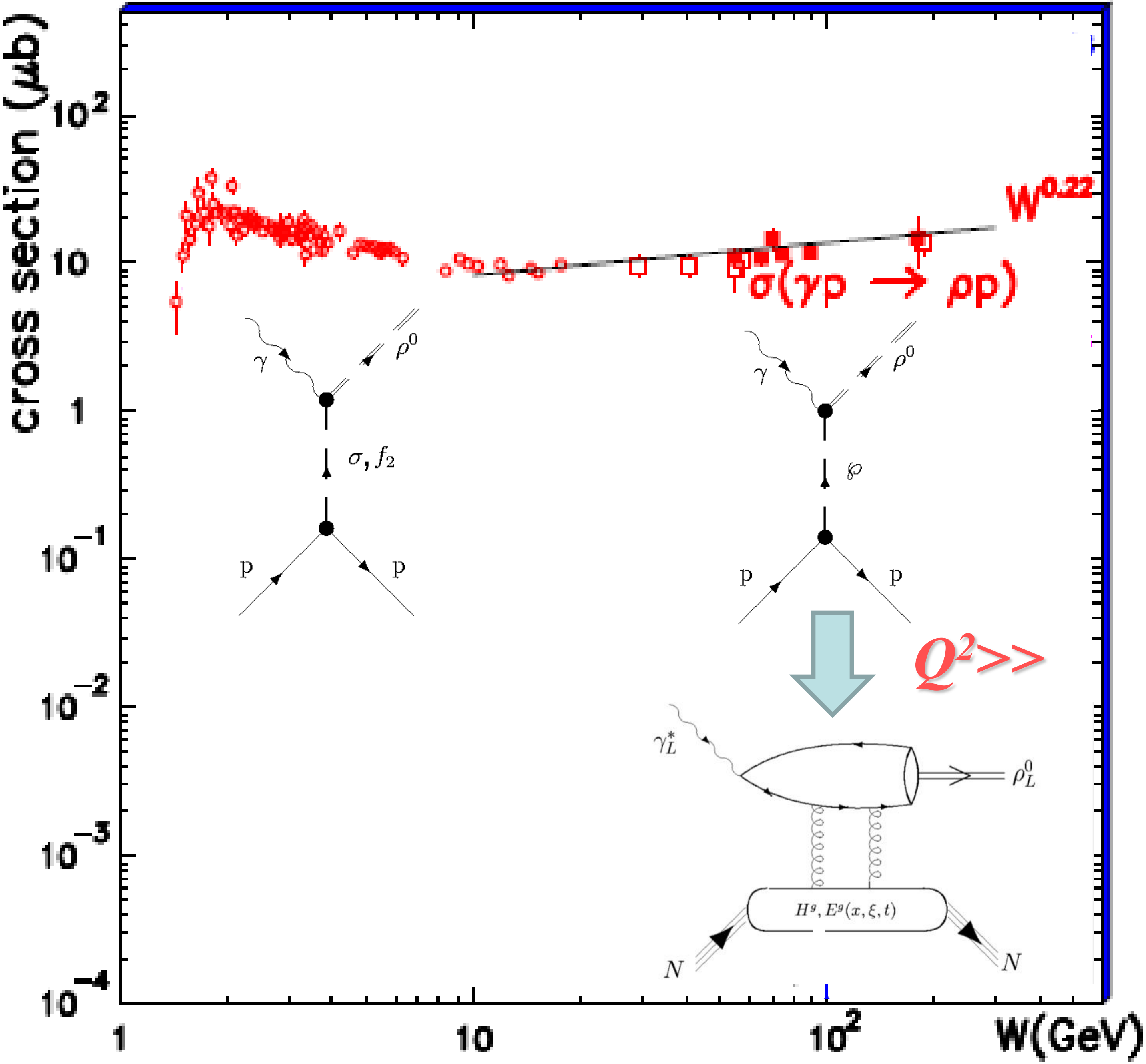
$d\sigma/dt \sim 1/s^2 \times |M(s,t)|^2 \rightarrow s^{2\alpha(t)-2}$ $\rightarrow [e^{\alpha(t)\ln s(s)}]$



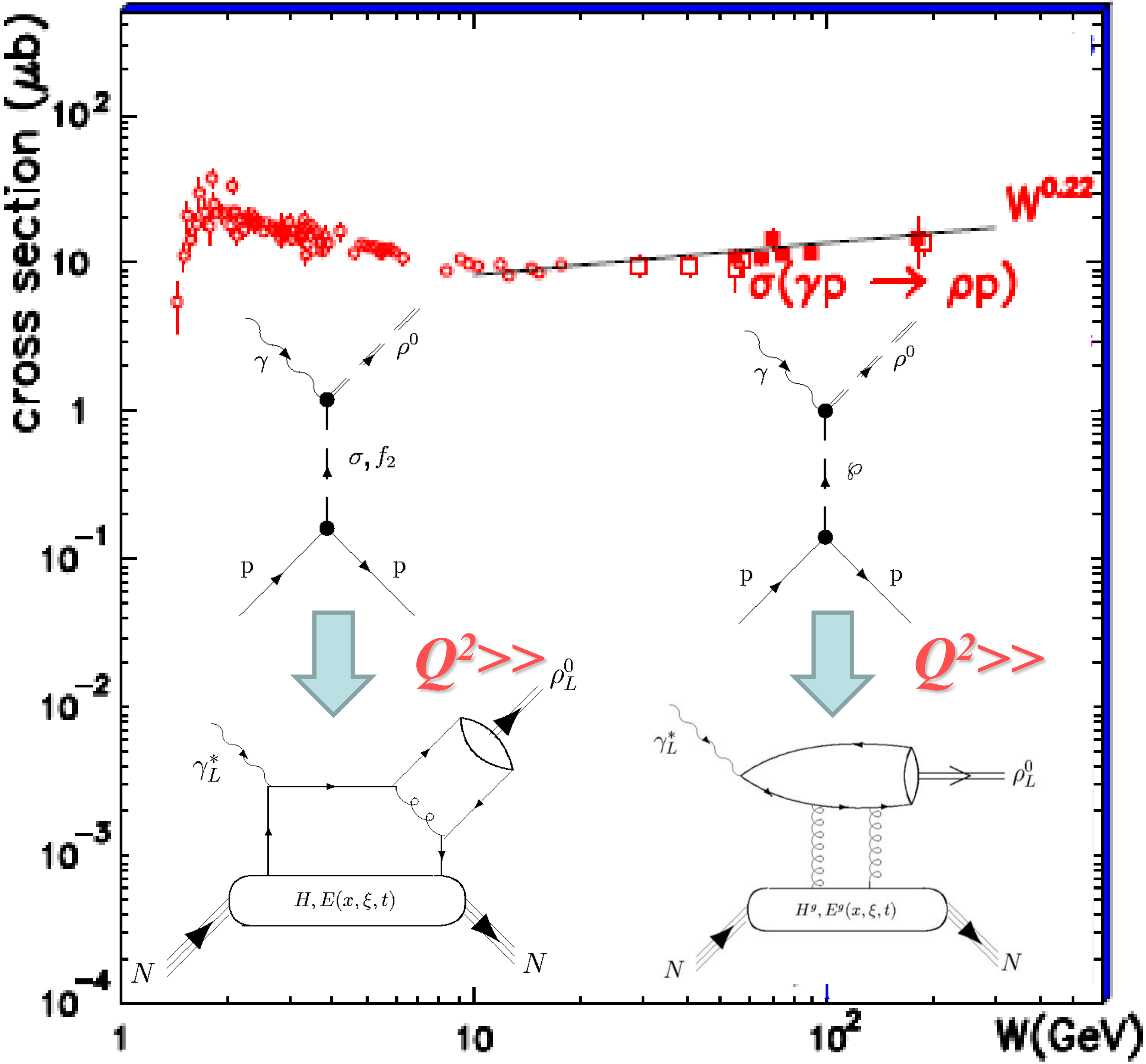




cross section (μb)
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
1
10
10^2
W(GeV)
$W^{0.22}$
$\sigma(\gamma p \rightarrow \rho p)$
γ
ρ^0
σ, f_2
p
p
γ
ρ^0
$\wp$
p
p

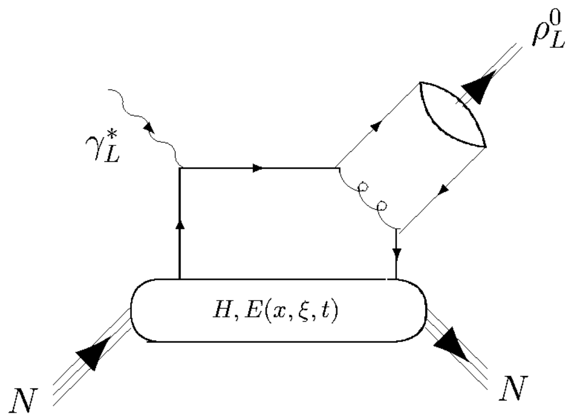


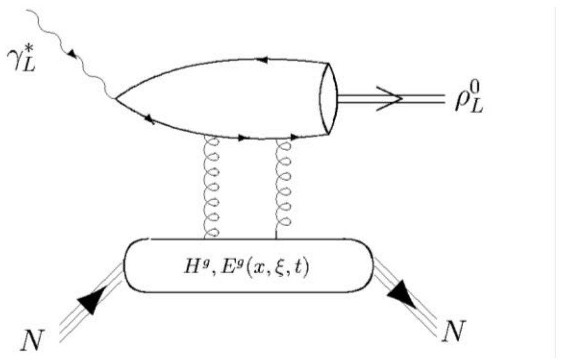
cross section (μb)
W(GeV)
$W^{0.22}$
$\sigma(\gamma p \rightarrow \rho p)$
γ
ρ^0
σ, f_2
p
p
$\wp$
Q^2>>
γ_L^*
ρ_L^0
$H^g, E^g(x, \xi, t)$
N
N



cross section (μb)
W(GeV)
$W^{0.22}$
$\sigma(\gamma p \to \rho p)$
σ, f_2
Q^2>>
Q^2>>
$H, E(x, \xi, t)$
$H^g, E^g(x, \xi, t)$

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





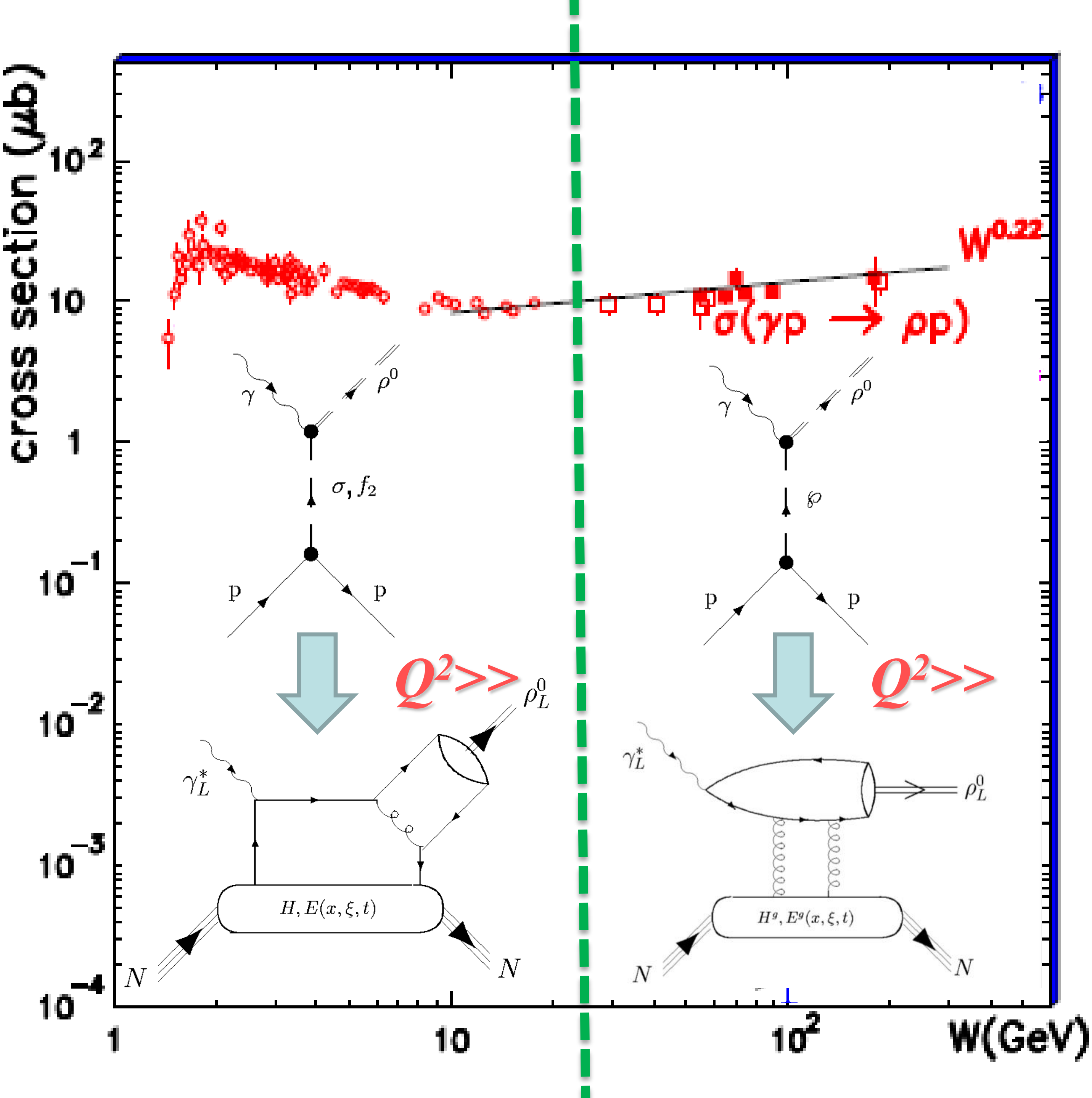
Q^2 dependence: $\sigma_L \sim 1/Q^6$ $\sigma_T \sim 1/Q^8$ $\sigma_L/\sigma_T \sim Q^2$

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

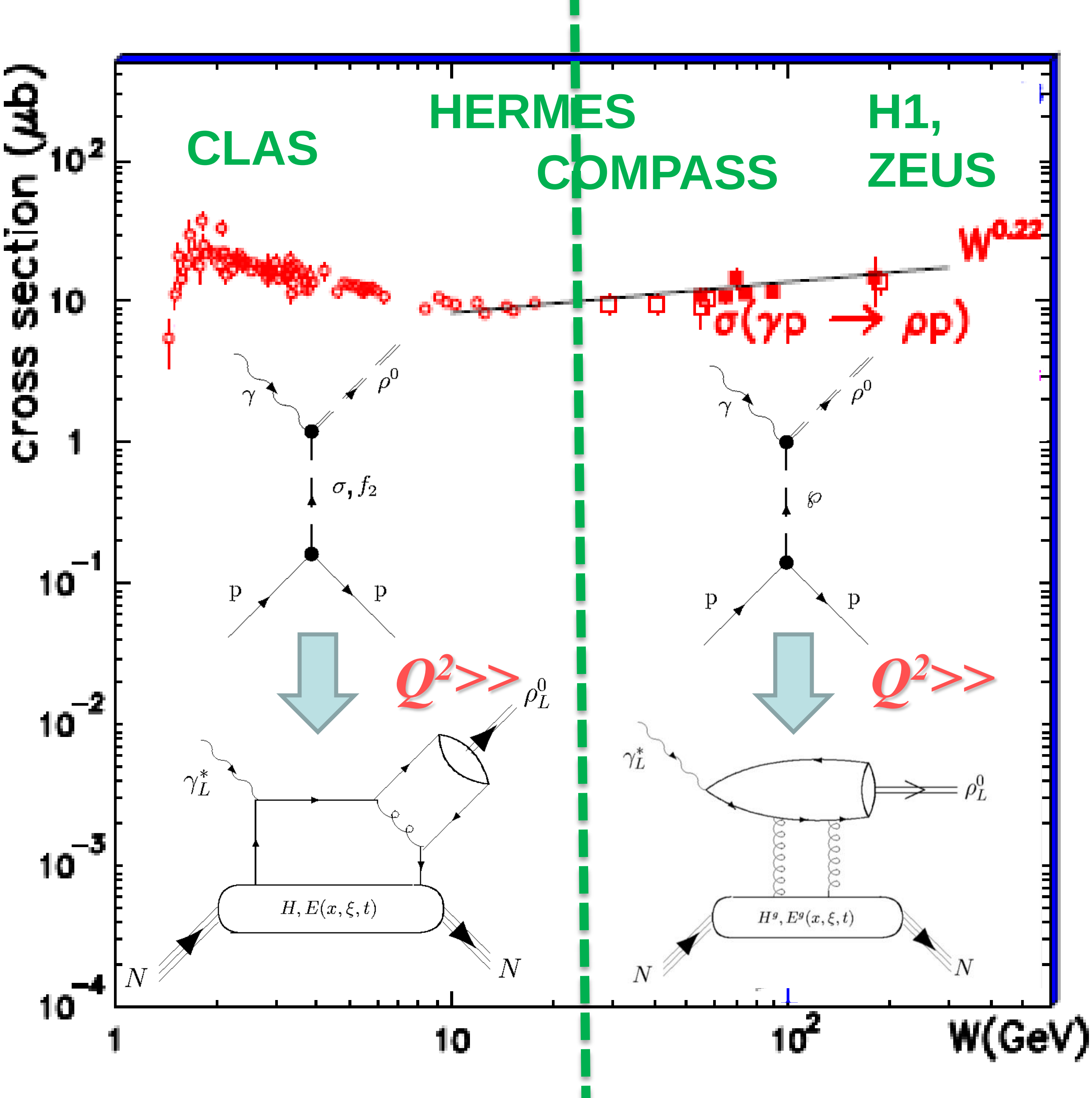
Ratio of yields: $\rho/\omega/\phi/(J/\Psi) \sim 9/1/2/8$ (for gluon handbag)

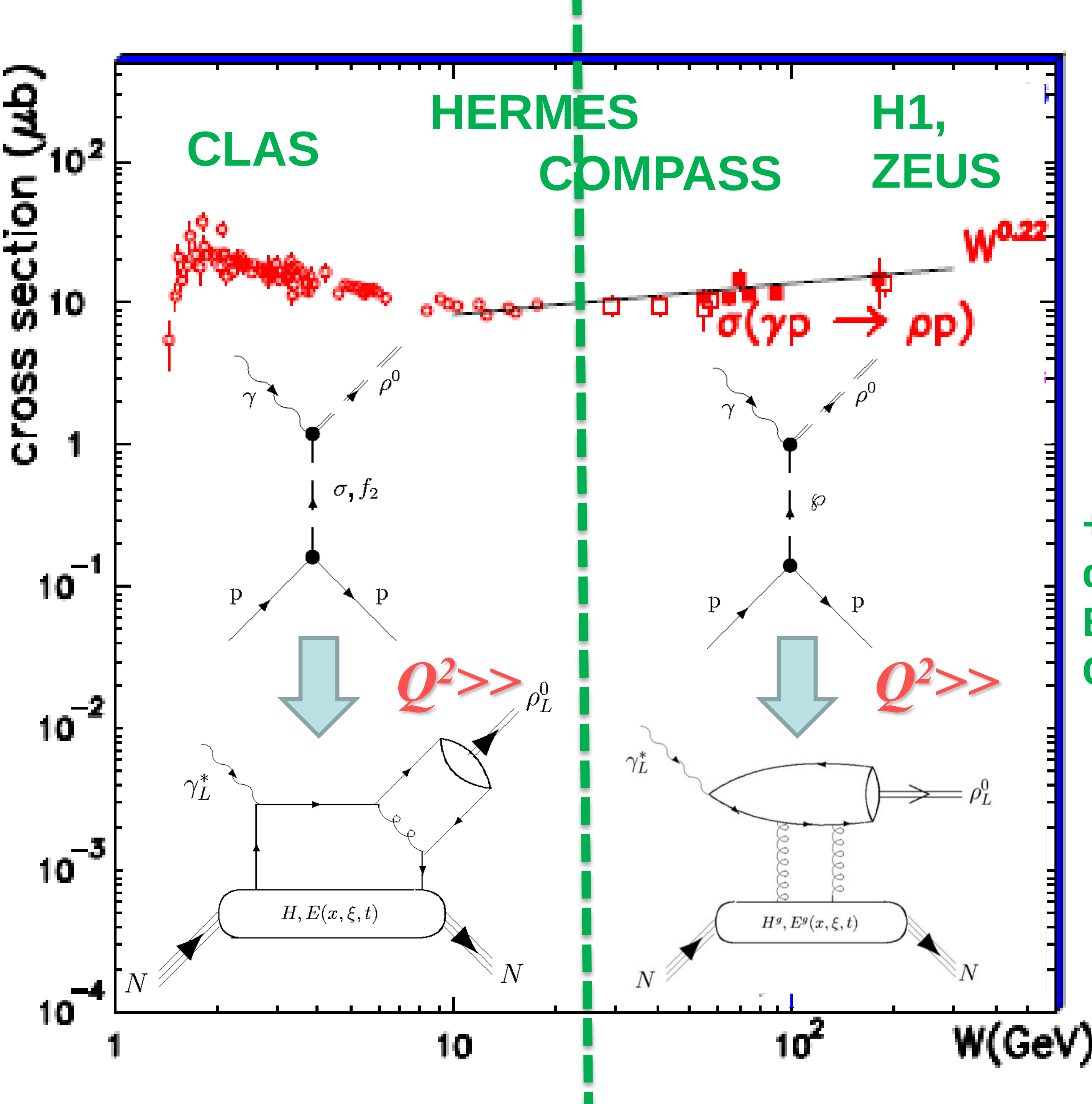
Saturation with hard scale of $\alpha_P(0)$, b, …

SCHC : checks with SDMEs

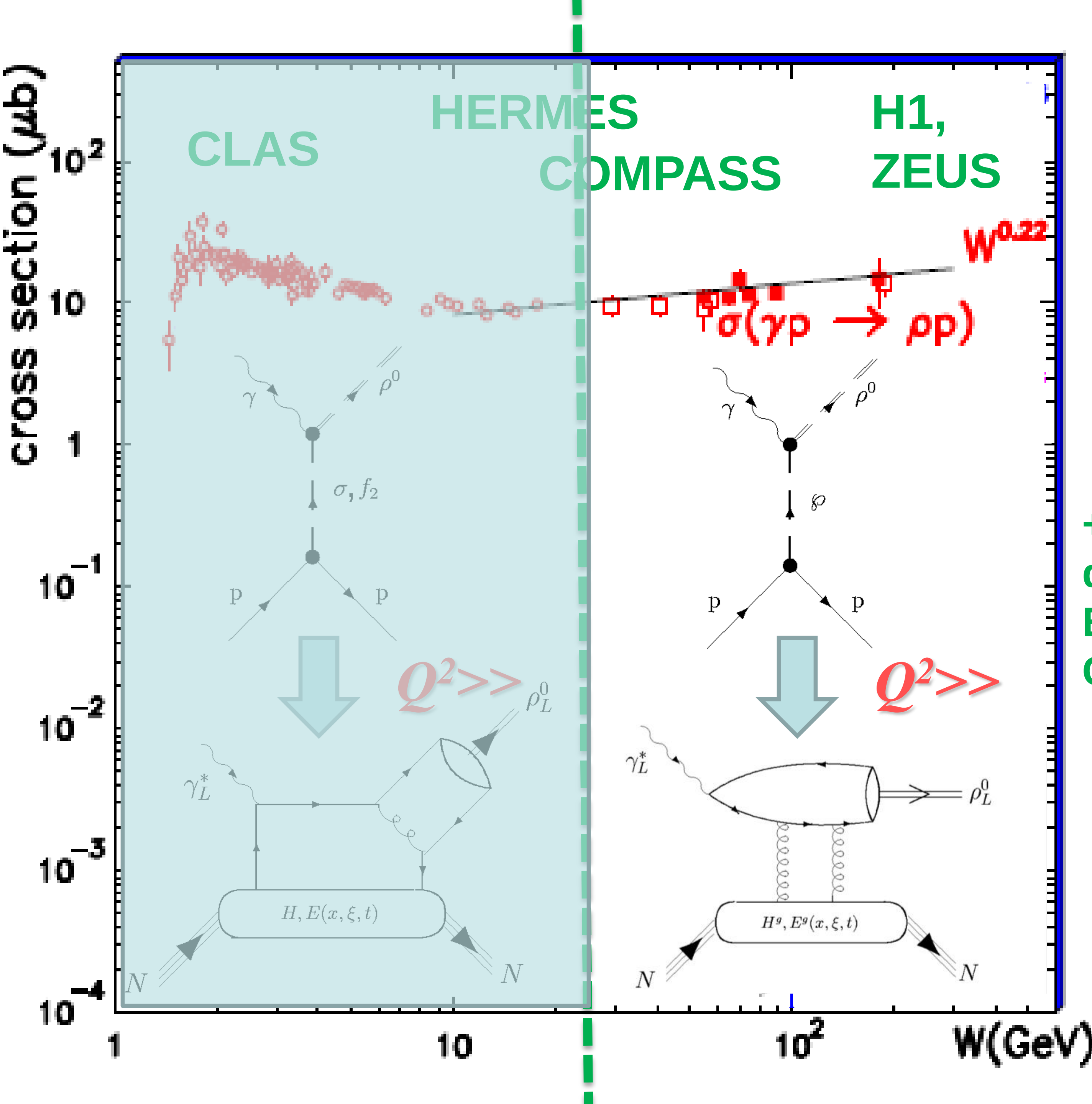


cross section (μb)
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
1
10
10^2
W(GeV)
$W^{0.22}$
$\sigma(\gamma p \to \rho p)$
γ
ρ^0
σ, f_2
p
p
$\wp$
Q^2>>
Q^2>>
ρ_L^0
γ_L^*
$H, E(x, \xi, t)$
$H^g, E^g(x, \xi, t)$
N
N
N
N


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



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

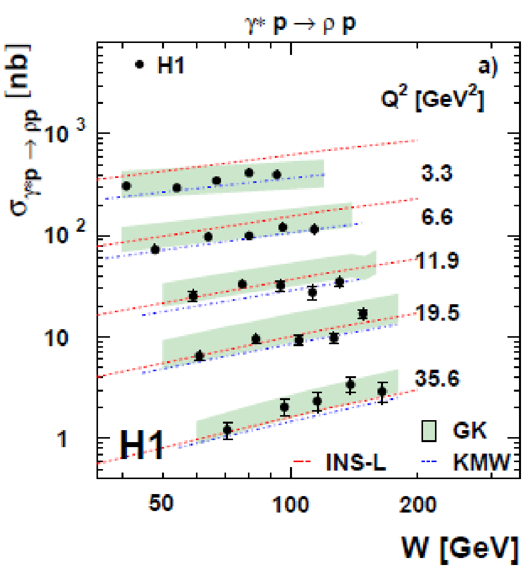


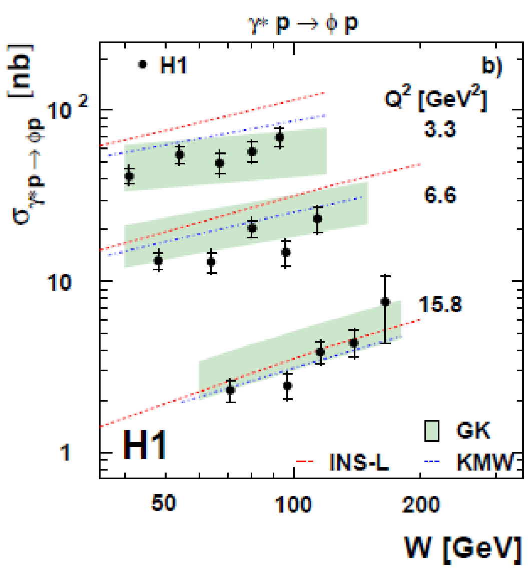
+ « older » data from: E665, NMC, Cornell,…

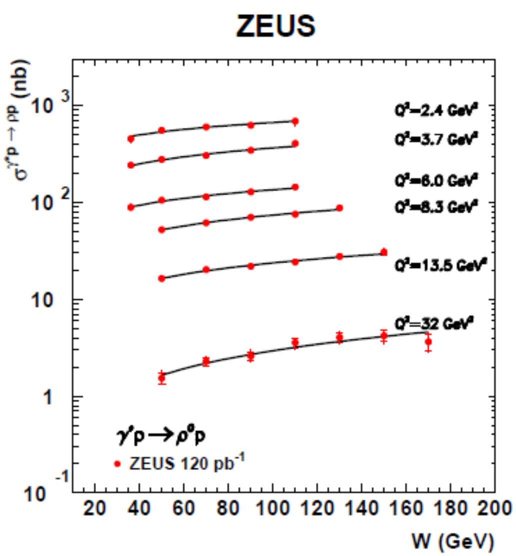
W dependence

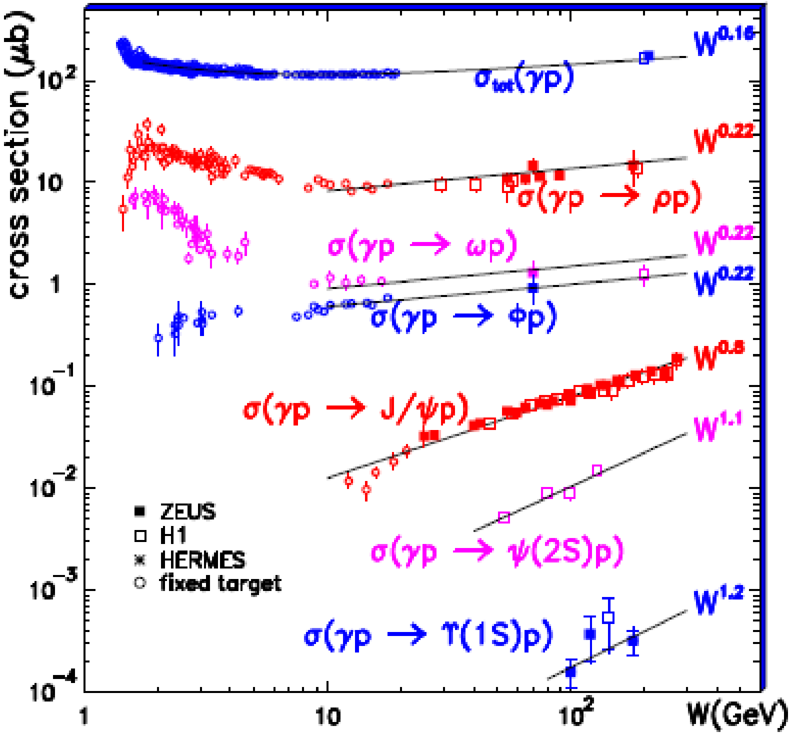
Steepening W slope as a function of Q^2 indicates « hard » regime

(reflects gluon distribution in the proton)





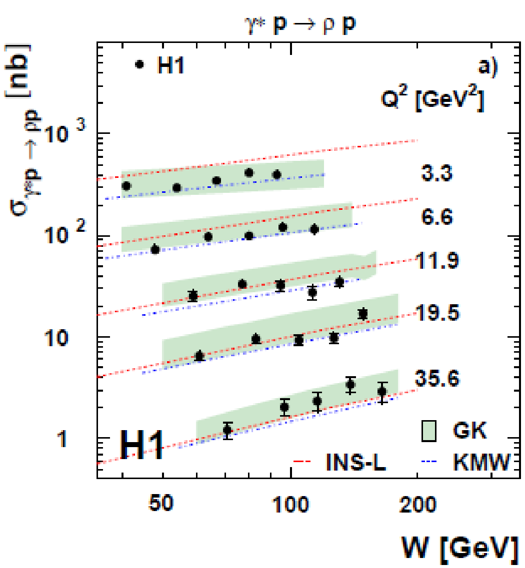


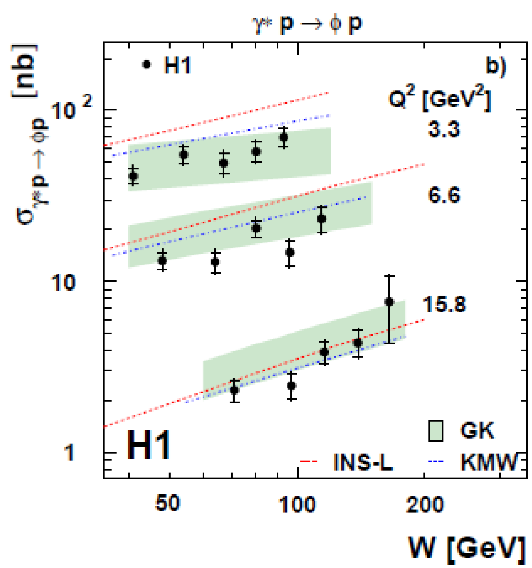


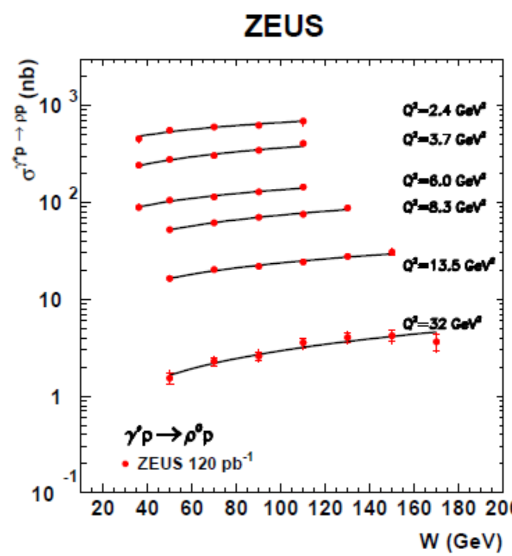
W dependence

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

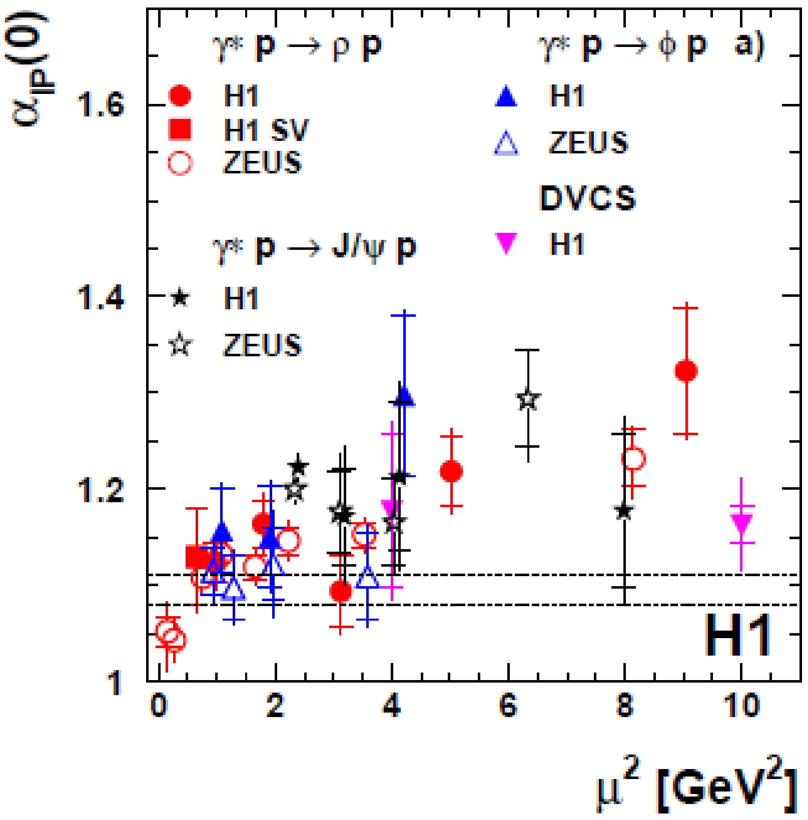
Two ways to set a « hard » scale:
*large Q^2
*mass of produced VM







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

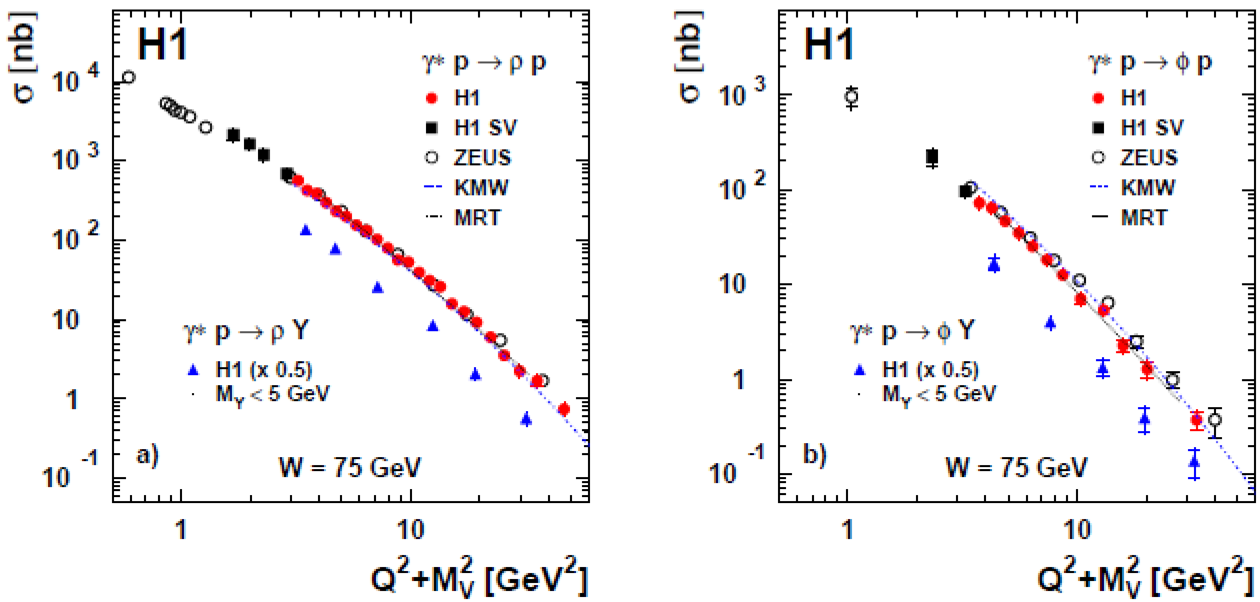


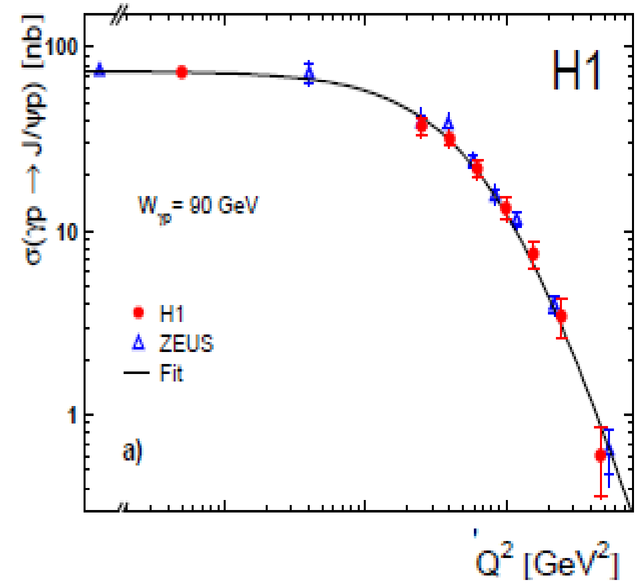
$\alpha_P(0)$ increases from "soft" (~1.1) to "hard" (~1.3)

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: $Q^2 > 0$ GeV^2 => $n = 2 \pm 0.01$

$Q^2 > 10$ GeV^2 => $n = 2.5 \pm 0.02$

(S. Kananov)

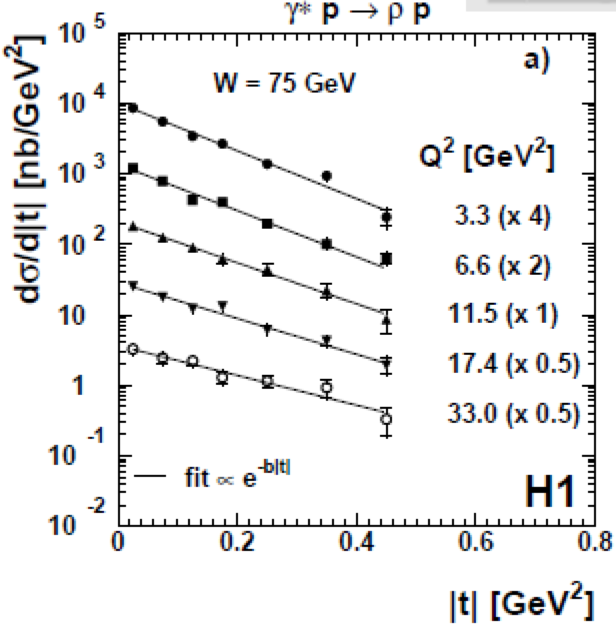
J/ψ: $Q^2 > 0$ GeV^2 => $n = 2.486 \pm 0.08 \pm 0.068$

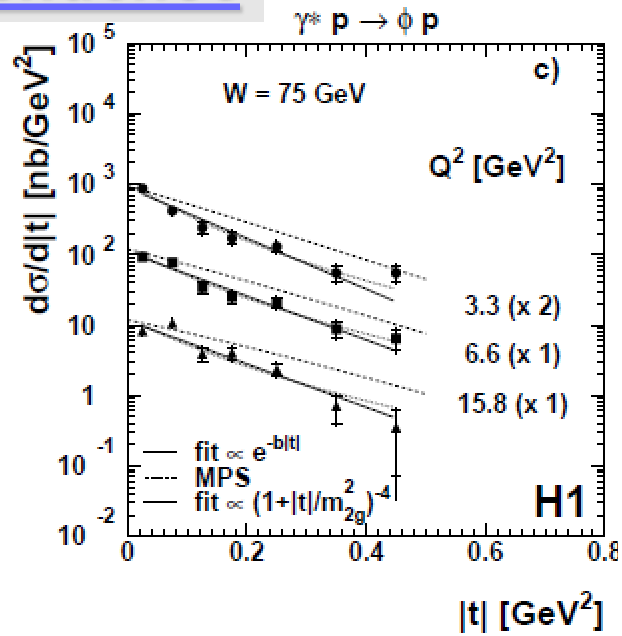
Q^2 dependence is damped at low Q^2 and steepens at large Q^2

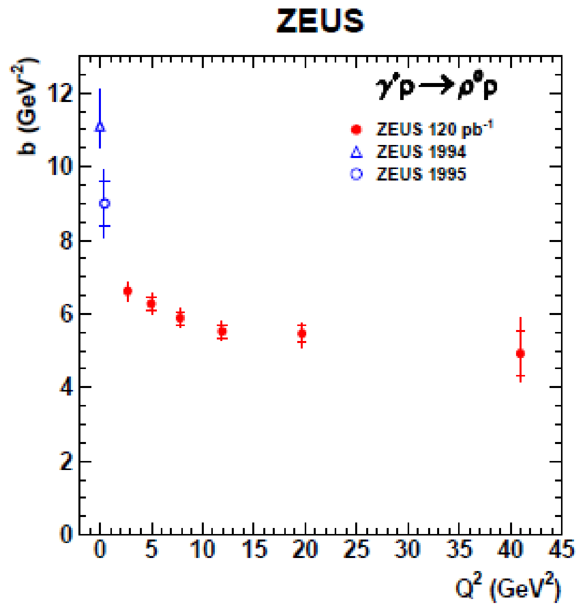
Approaching handbag prediction of $n=6$

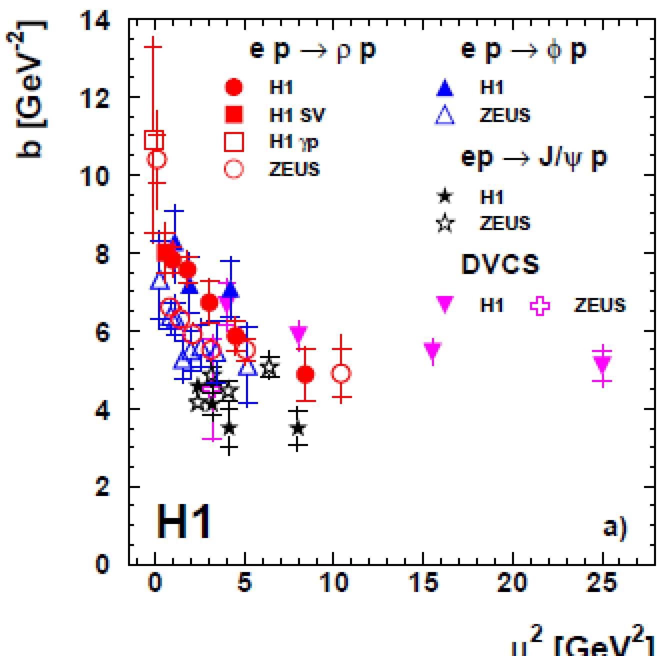
(Q^2 not asymptotic, fixed W vs fixed x_B, σ_{tot} vs σ_L, Q^2 evolution of G(x)…)

t dependence



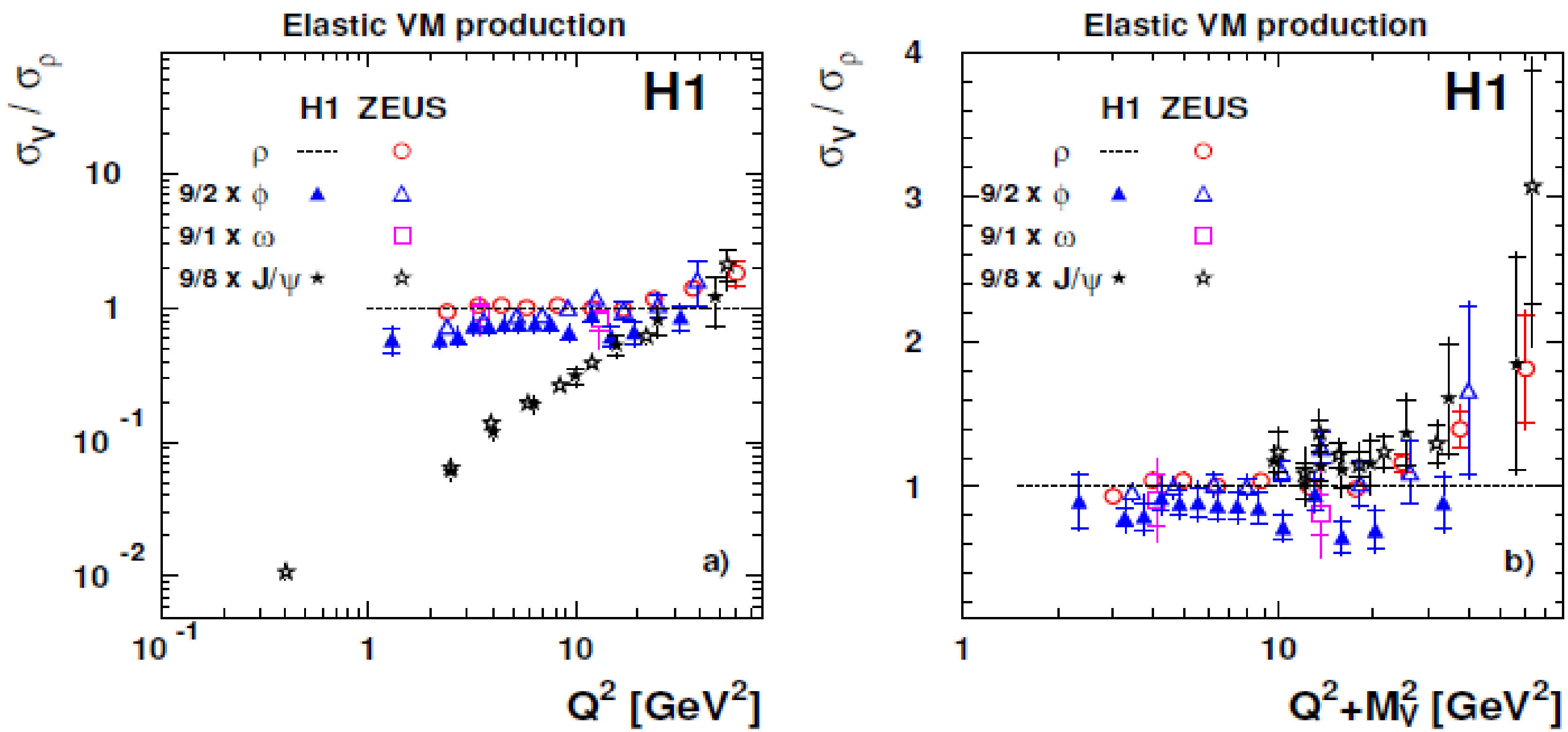






b decreases from "soft" (~10 GeV^{-2}) to "hard" (~4-5 GeV^{-2}) as a function of scale $\mu^2=(Q^2+M_V^2)/4$

Ratios



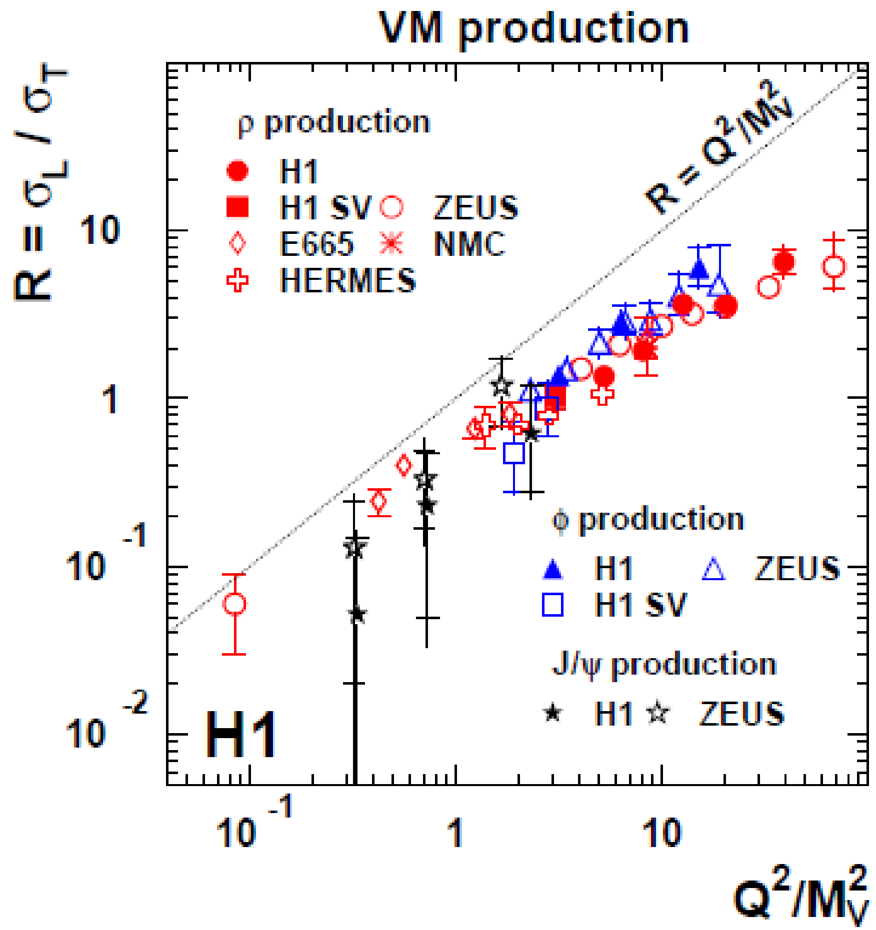
$\rho/\omega/\phi/(J/\Psi) \sim$ **9/1/2/8**

$|\rho^0\rangle = 1/\mathrm{sqrt}(2)\{|u\bar{u}\rangle - |d\bar{d}\rangle\}$ $\sim\{2/3-(-1/3)\}$

$|\omega\rangle = 1/\mathrm{sqrt}(2)\{|u\bar{u}\rangle + |d\bar{d}\rangle\}$ $\sim\{2/3+(-1/3)\}$

Ratio ρ/ω=9

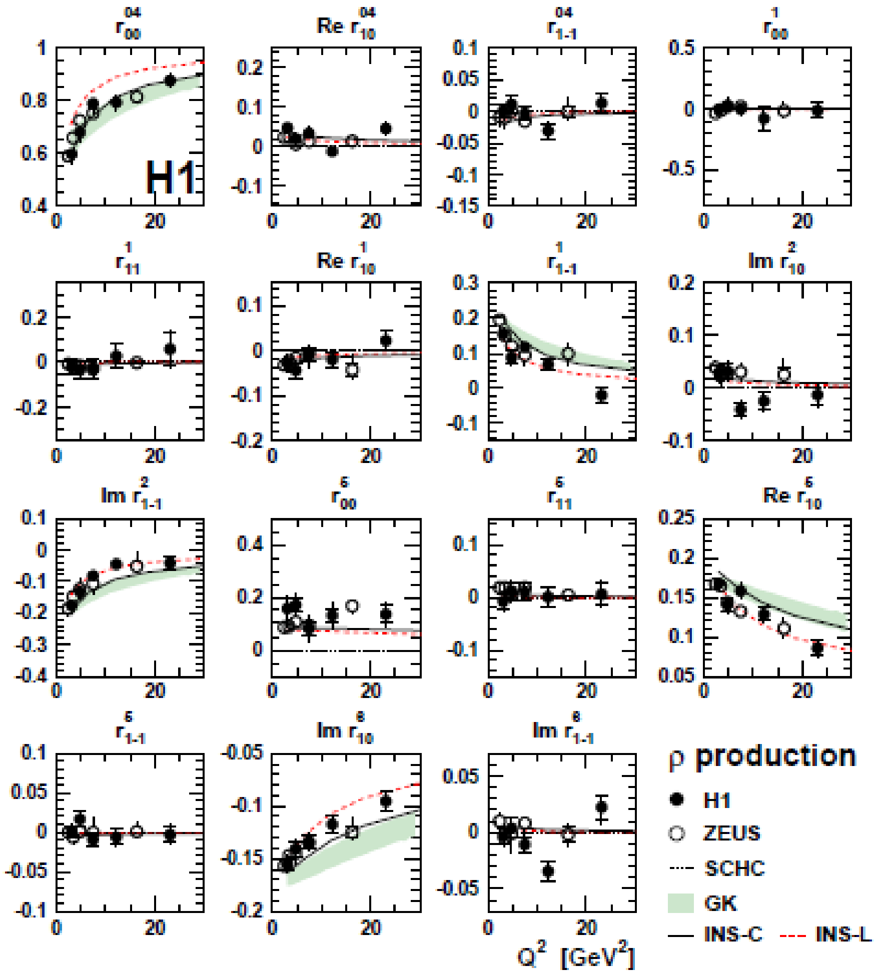
σ_L/σ_T



(almost) compatible with handbag prediction

(damping at large Q^2)

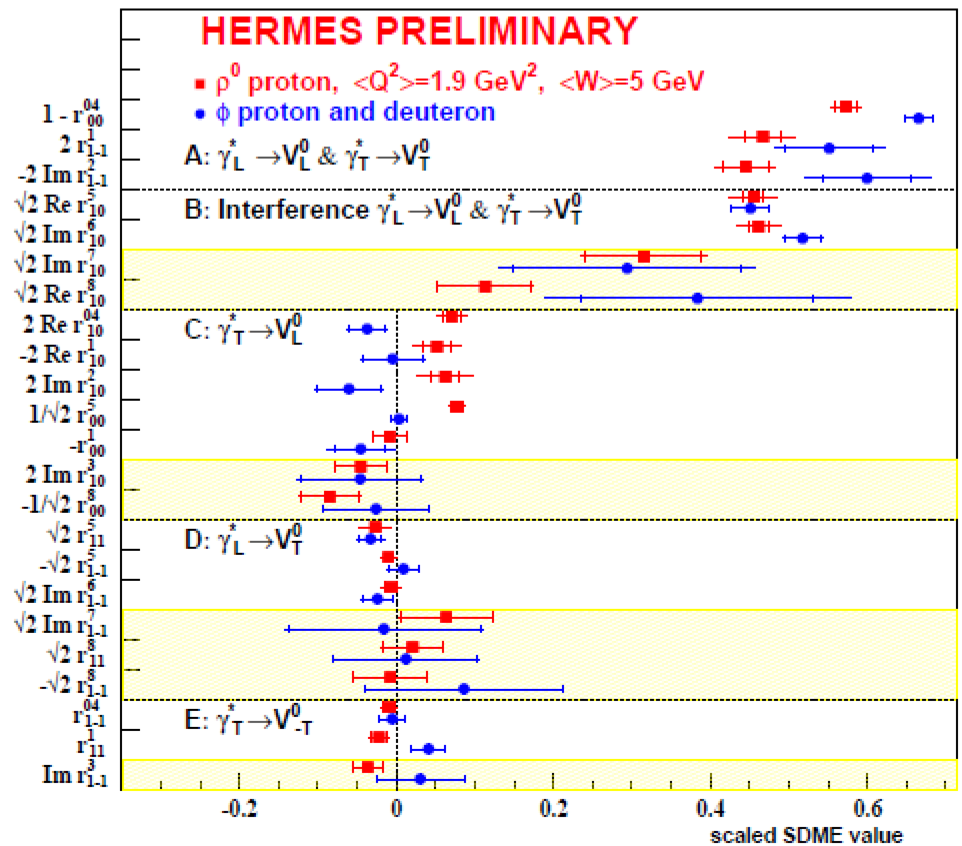
SDMEs



H1

(almost) no SCHC violation

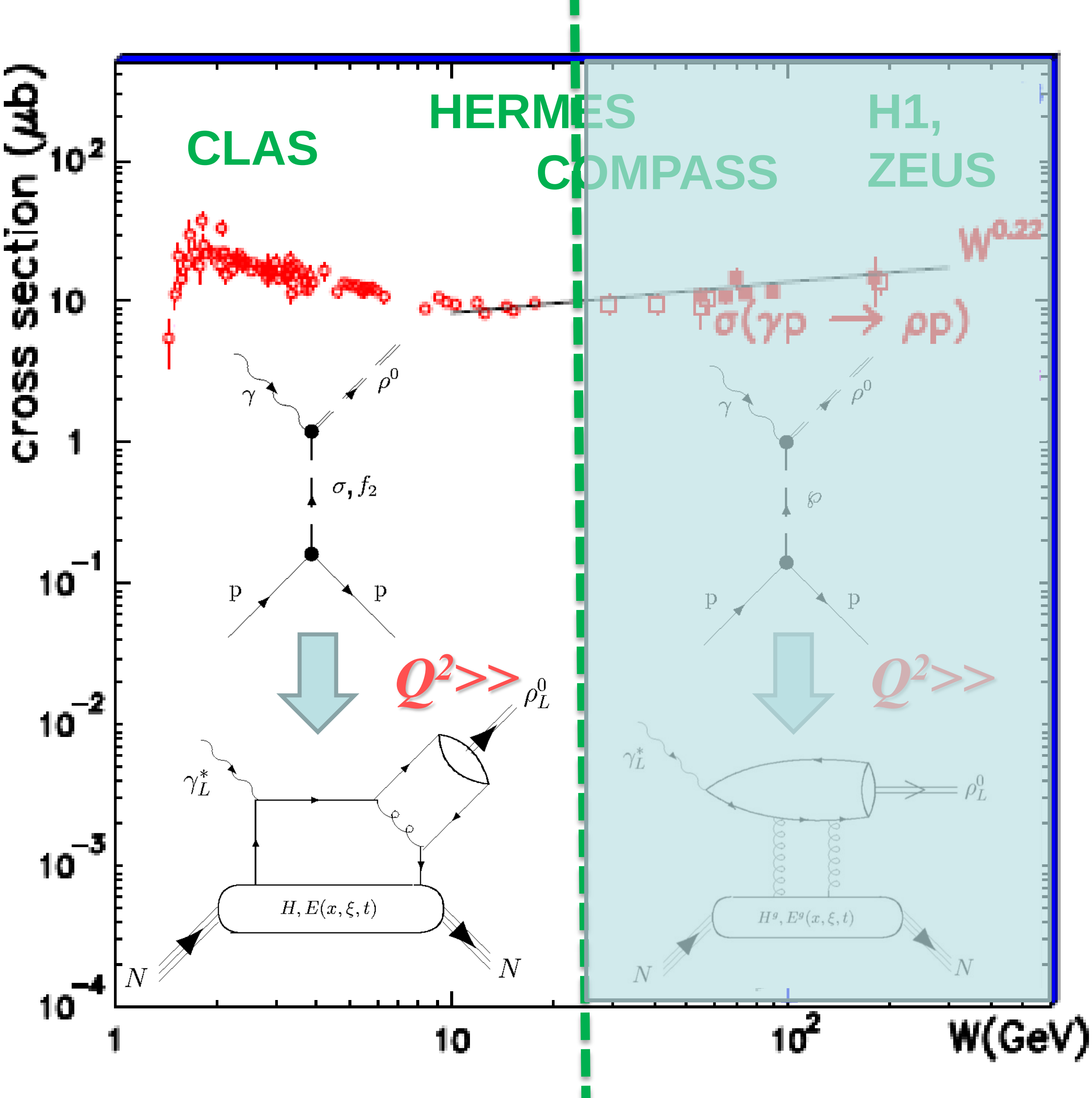
HERMES



- ***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*** $\mu^2=(Q^2+M_V^2)/4 \sim 3\text{-}5\ \mathrm{GeV}^2$.

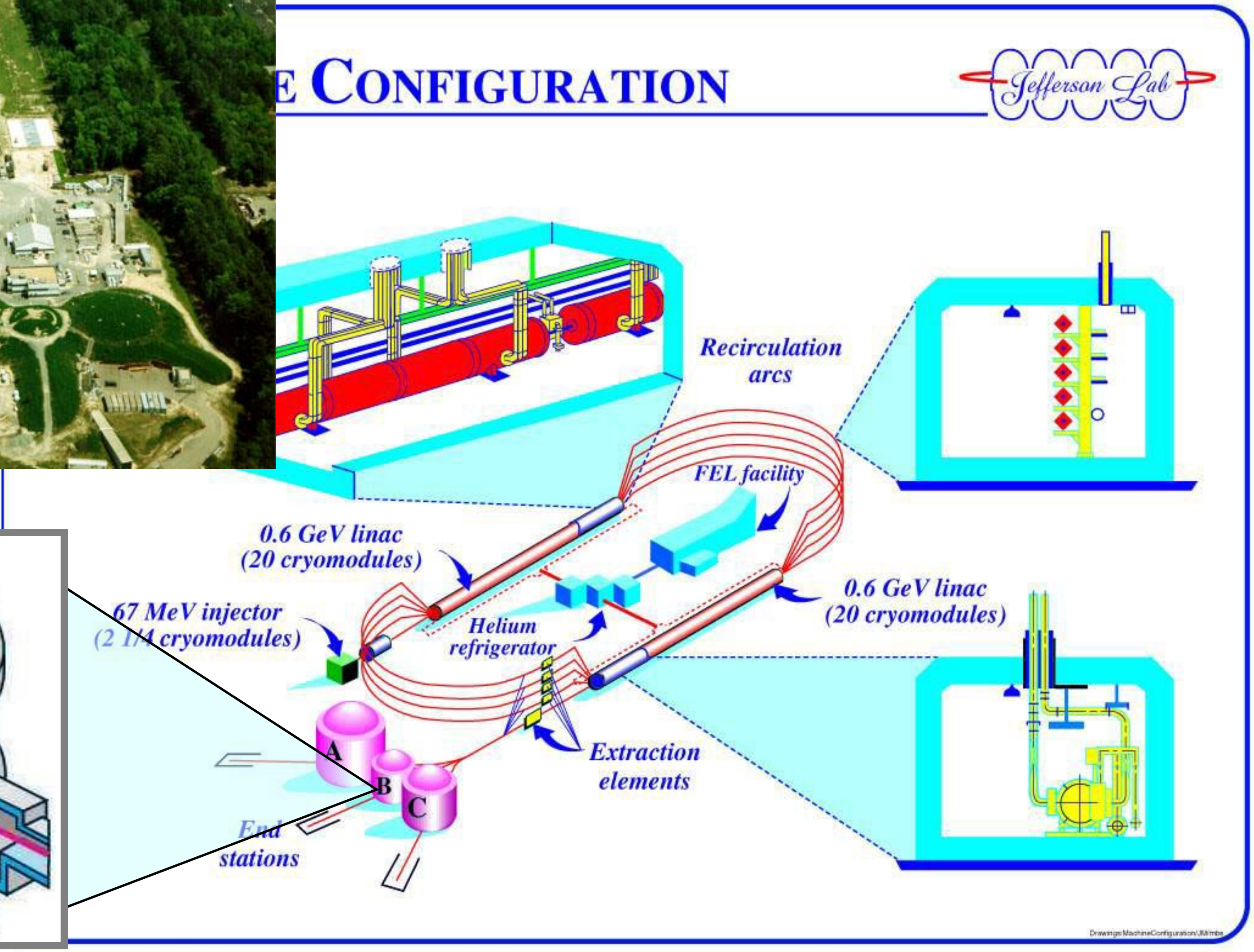
- ***Data are relatively well described by GPD/handbag approaches***

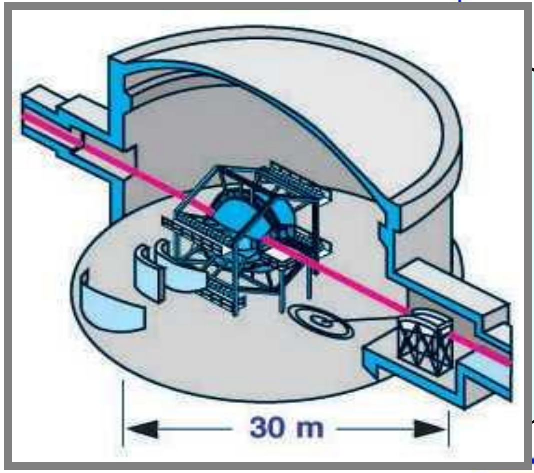


cross section (μb)
W(GeV)
CLAS
HERMES
COMPASS
H1,
ZEUS
$W^{0.22}$
$\sigma(\gamma p \to \rho p)$
γ
ρ^0
σ, f_2
p
p
Q^2>>
ρ^0_L
γ^*_L
$H, E(x, \xi, t)$
N
N
γ^*_L
ρ^0_L
$H^g, E^g(x, \xi, t)$
N
N

JLab & CLAS in Hall B

Duty cycle ~100%　　E_{max}~6 GeV



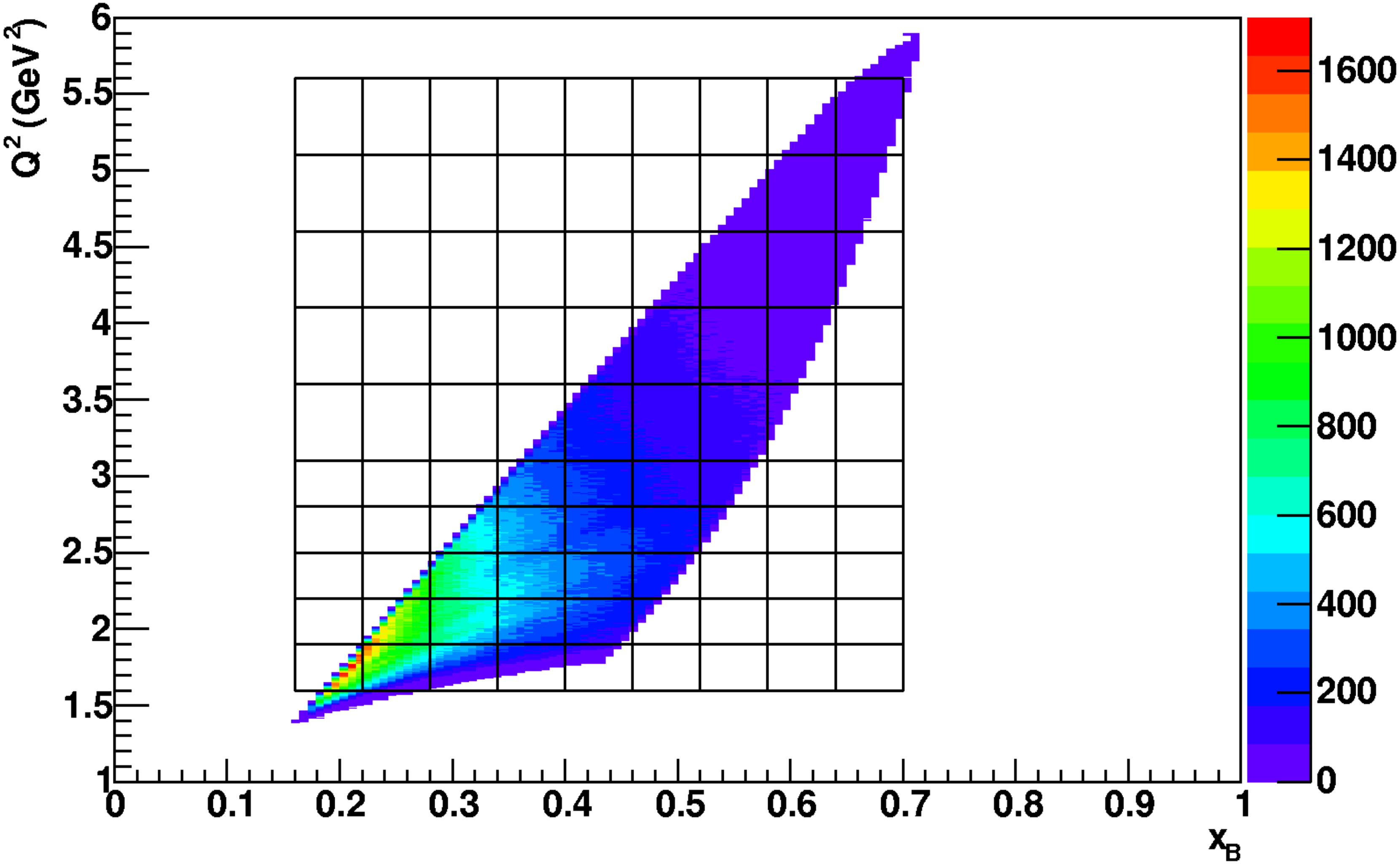


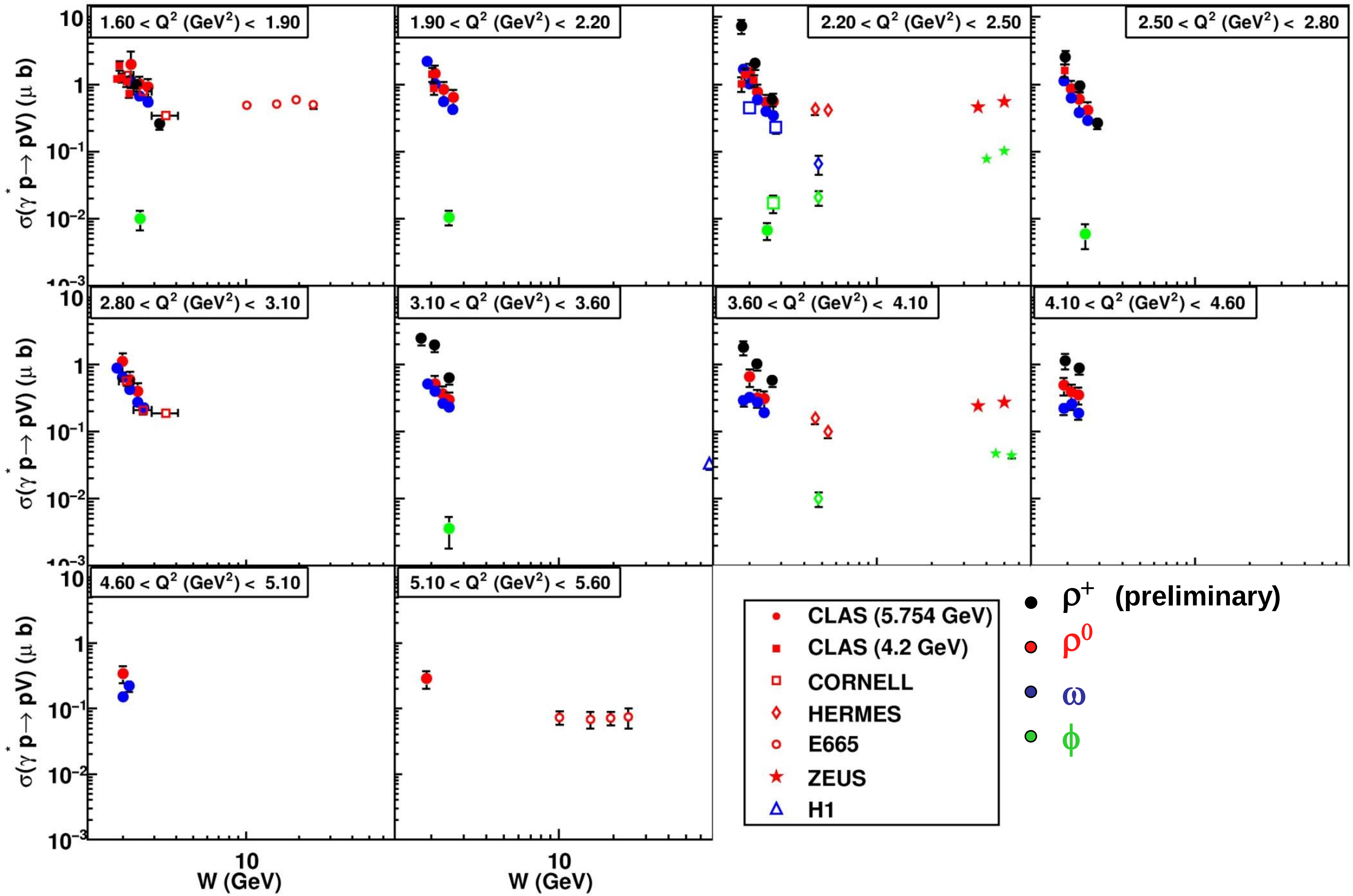
Exclusive ρ^0, ω, ϕ & ρ^+ electroproduction on the proton @ CLAS6

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)

e1-6 experiment (E_e =5.75 GeV)

(October 2001 – January 2002)





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

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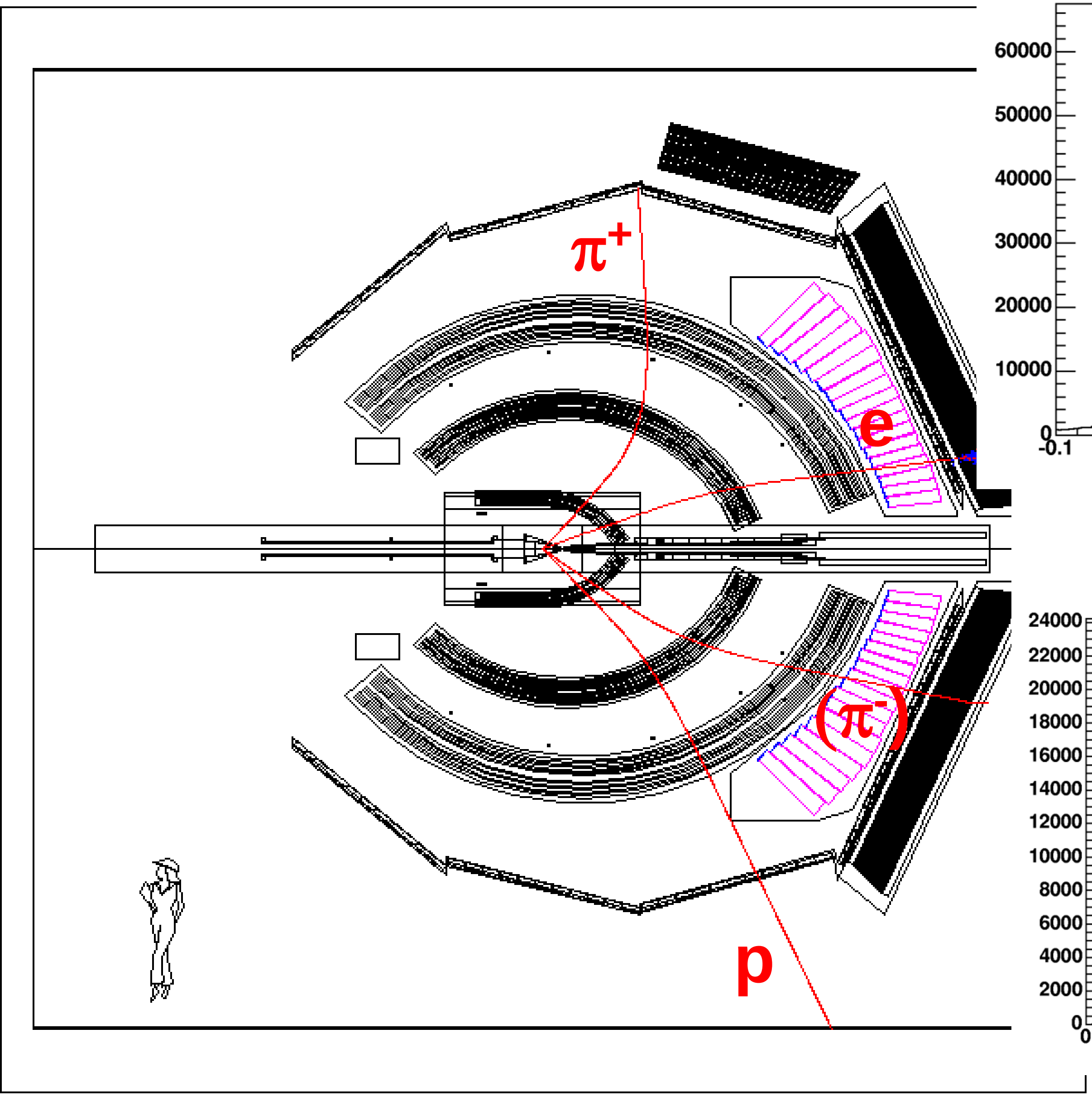
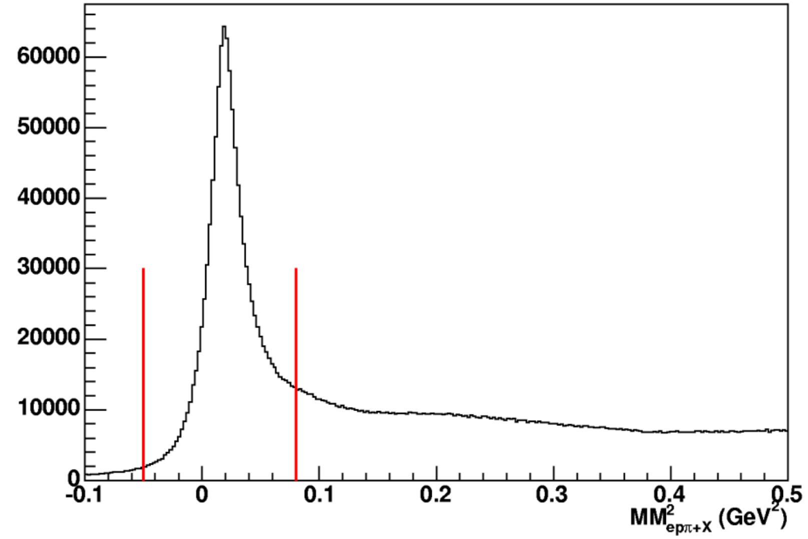
J. Santoro et al., Phys.Rev.C78:025210,2008 (ϕ@5.75GeV)

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

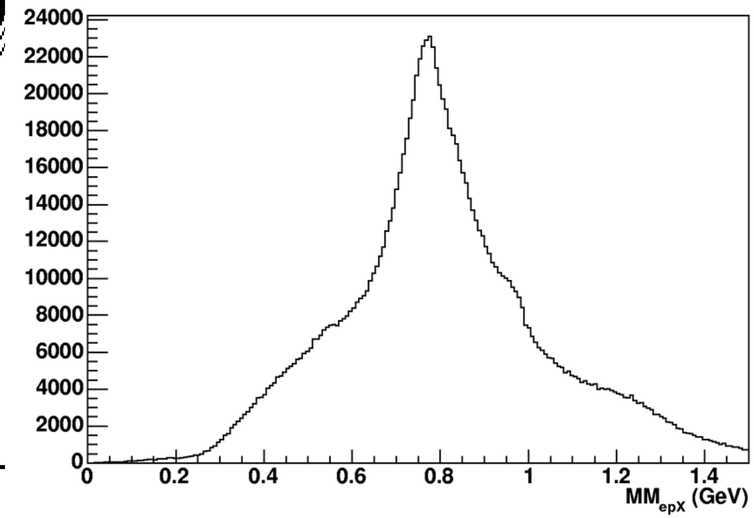
$ep \rightarrow ep\,\pi^+(\pi^-)$

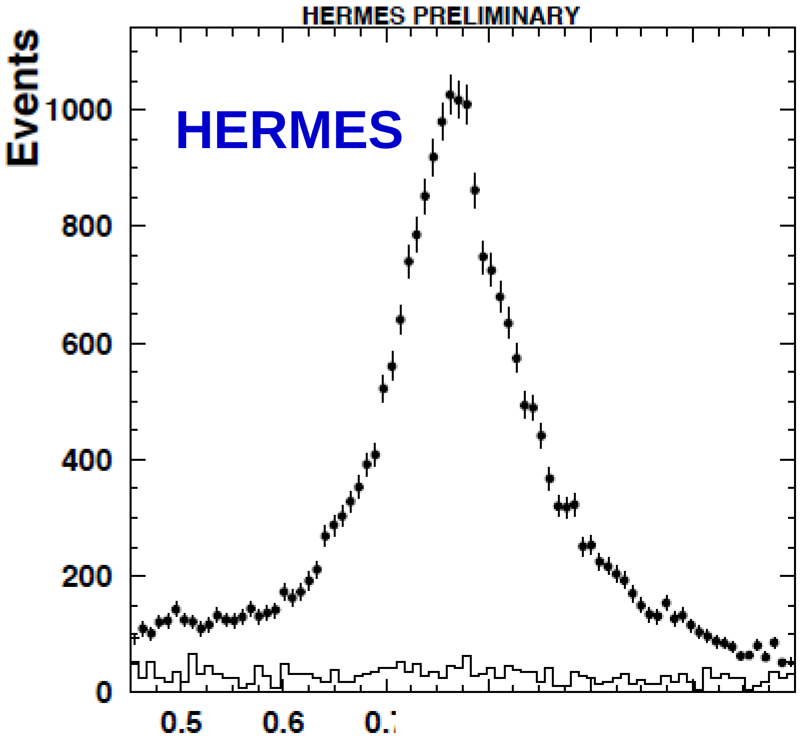


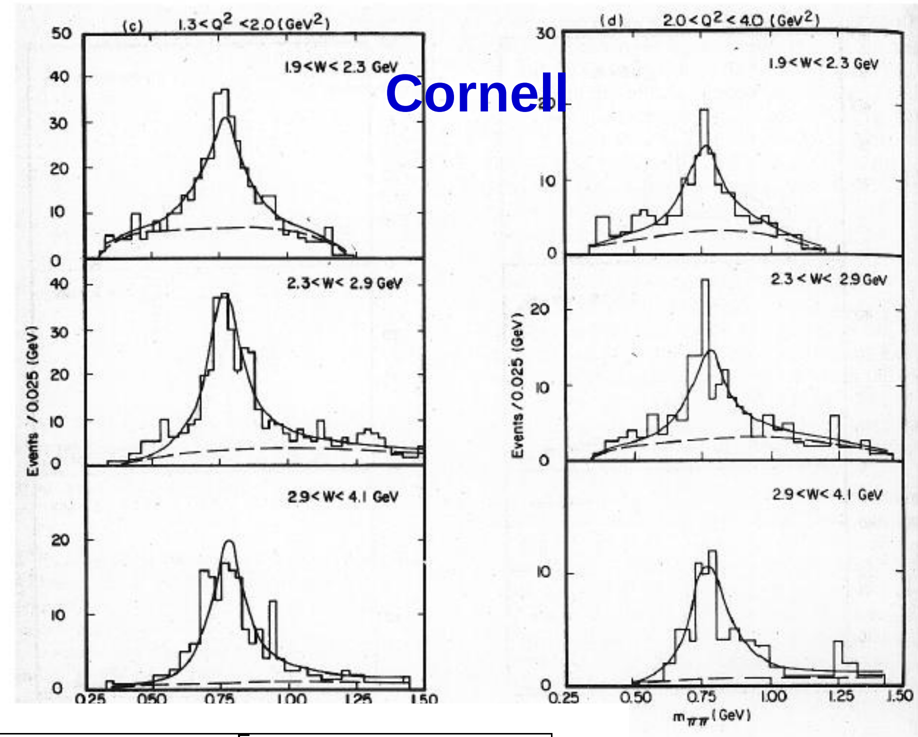
$Mm(ep\pi^+ X)$

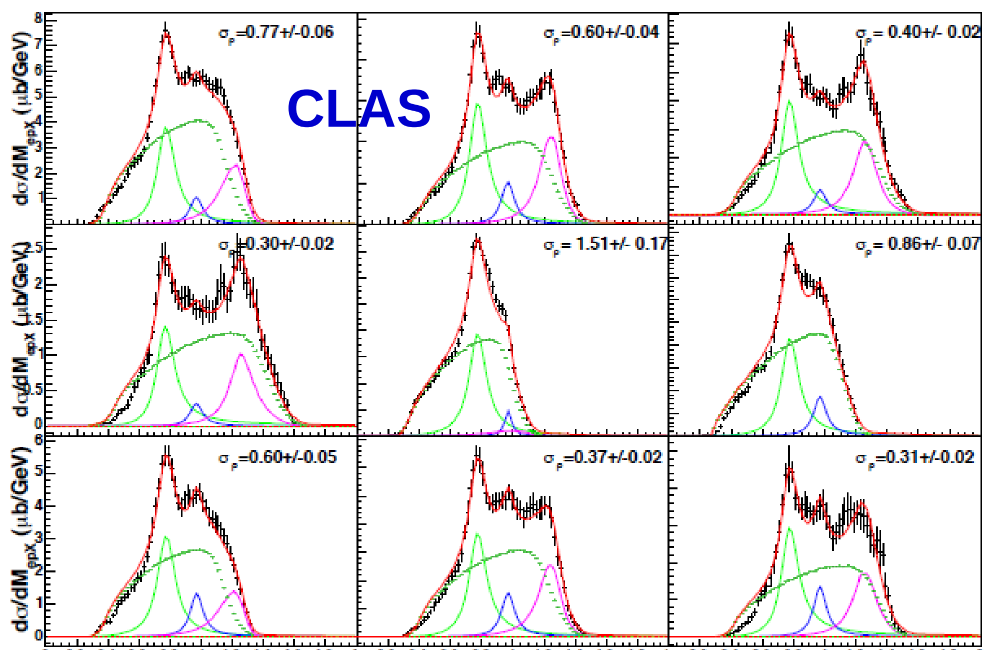


$Mm(epX)$




HERMES PRELIMINARY
HERMES
Events
1000
800
600
400
200
0
0.5
0.6

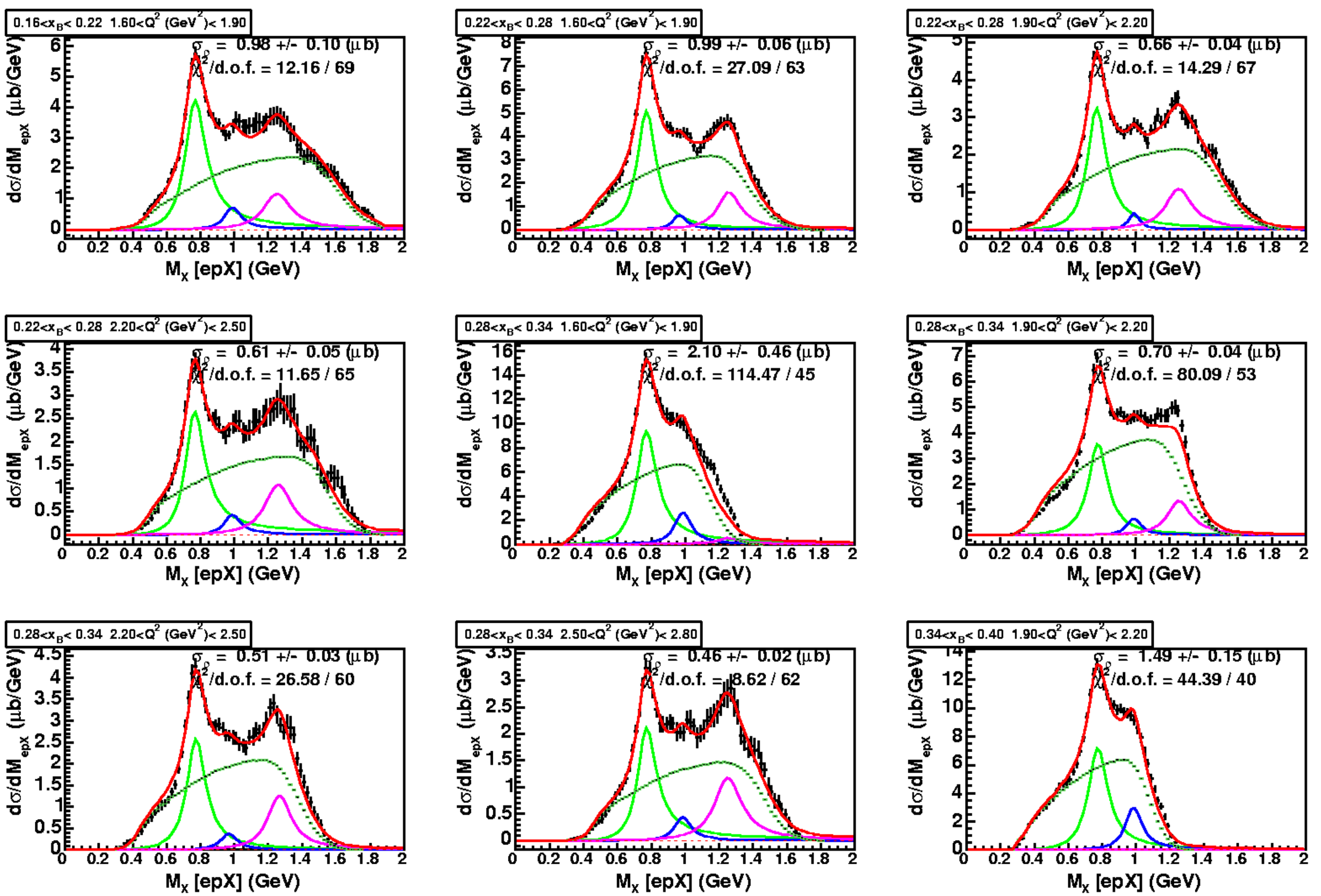

Cornell
(c) 1.3<Q2<2.0 (GeV2)
(d) 2.0<Q2<4.0 (GeV2)
1.9<W<2.3 GeV
2.3<W<2.9 GeV
2.9<W<4.1 GeV
Events / 0.025 (GeV)
mππ (GeV)

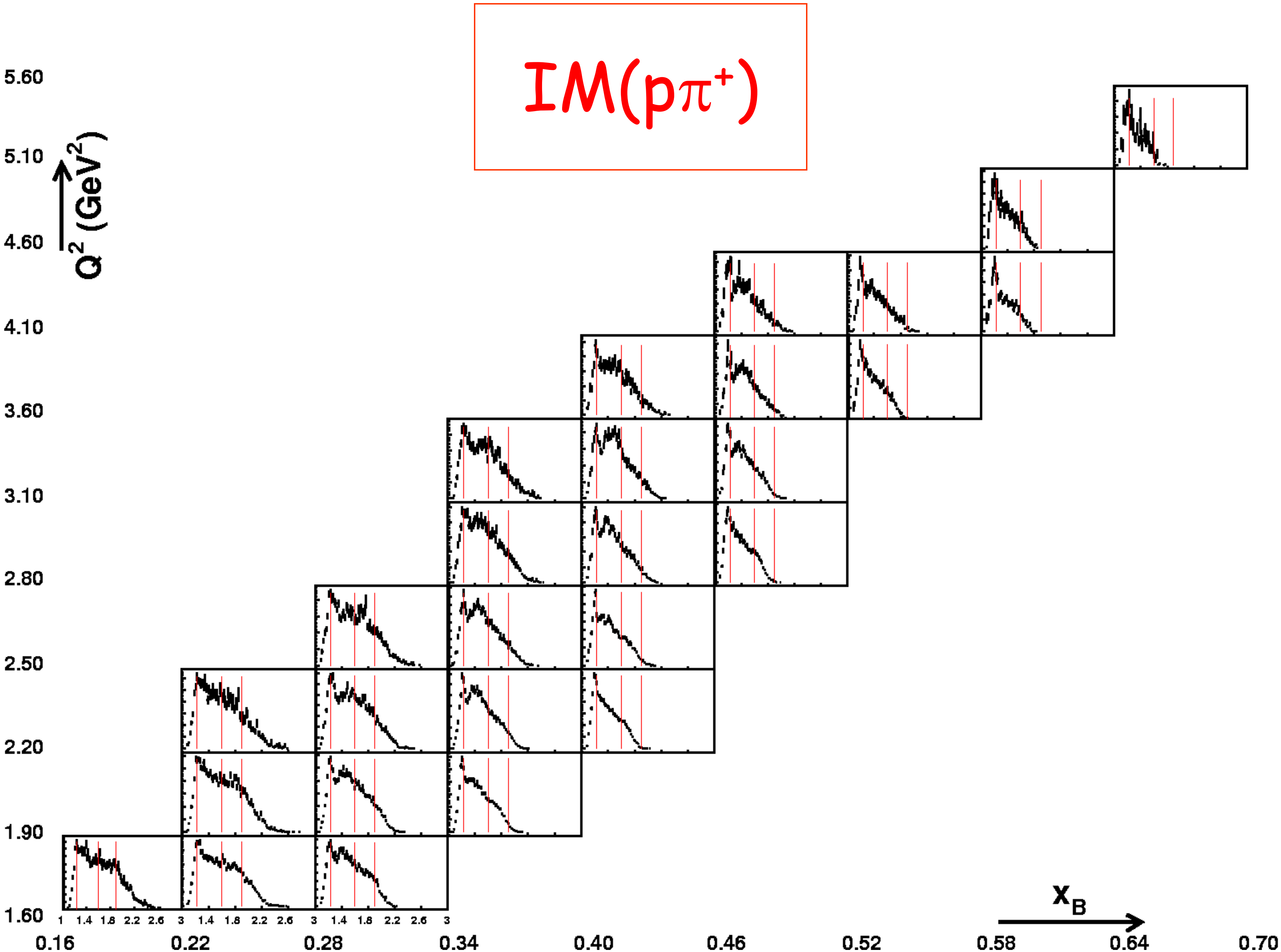

CLAS
σρ=0.77+/-0.06
σρ=0.60+/-0.04
σρ= 0.40+/- 0.02
σρ=0.30+/-0.02
σρ= 1.51+/- 0.17
σρ= 0.86+/- 0.07
σρ=0.60+/-0.05
σρ=0.37+/-0.02
σρ=0.31+/-0.02
dσ/dMρpX (μb/GeV)

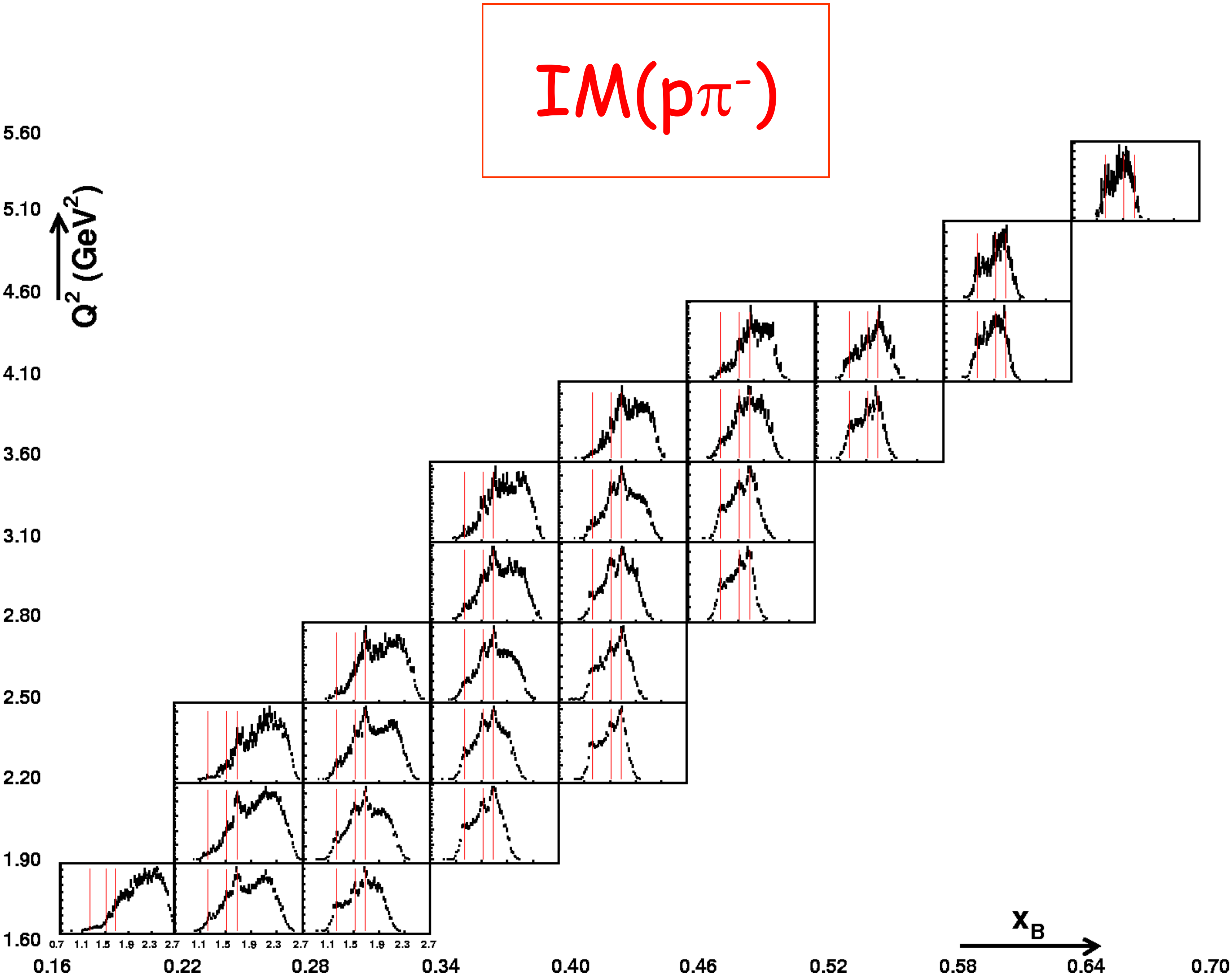
Background Subtraction

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.




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

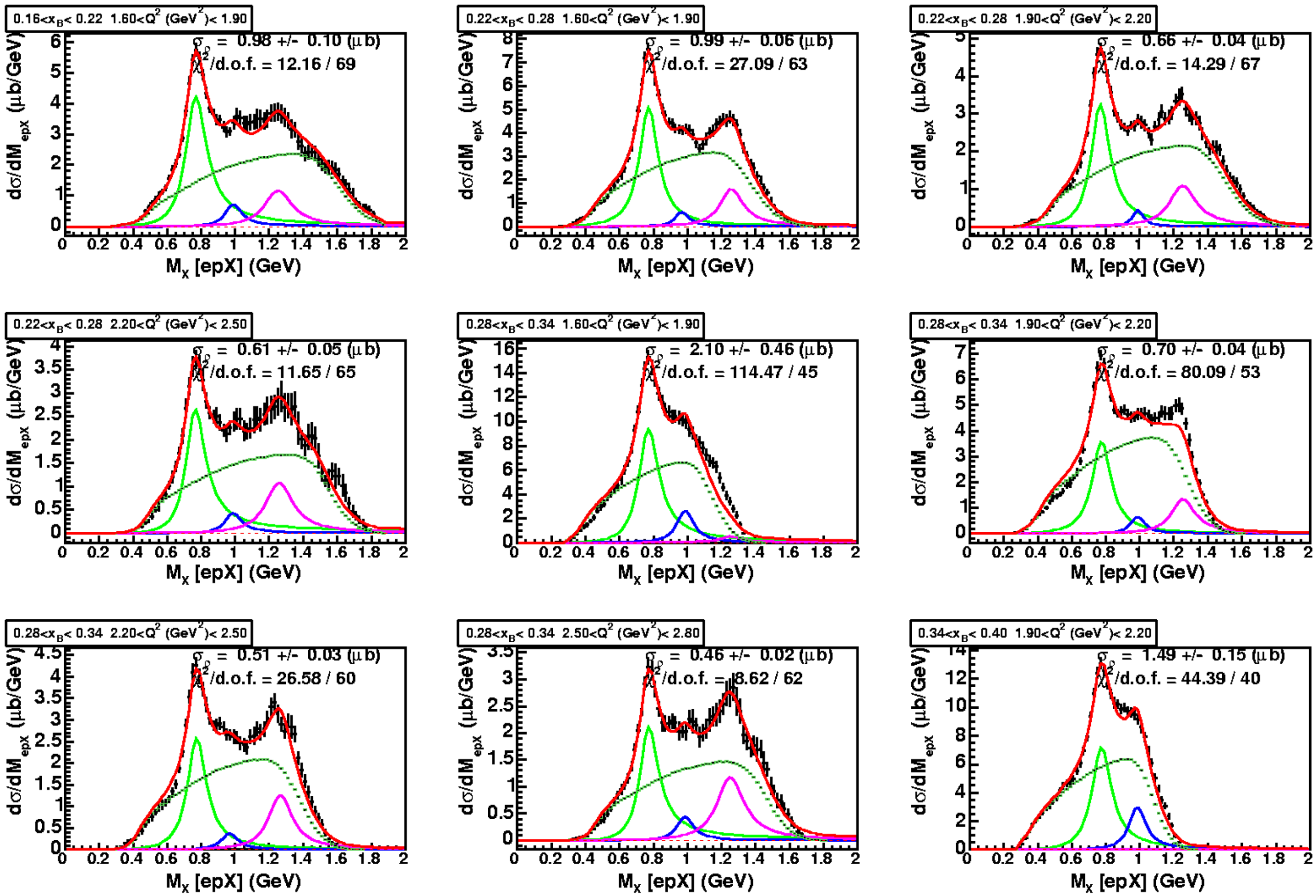


IM(pπ⁻)
Q² (GeV²)
5.60
5.10
4.60
4.10
3.60
3.10
2.80
2.50
2.20
1.90
1.60
0.7 1.1 1.5 1.9 2.3 2.7
1.1 1.5 1.9 2.3 2.7
1.1 1.5 1.9 2.3 2.7
x_B
0.16
0.22
0.28
0.34
0.40
0.46
0.52
0.58
0.64
0.70

Background Subtraction

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.



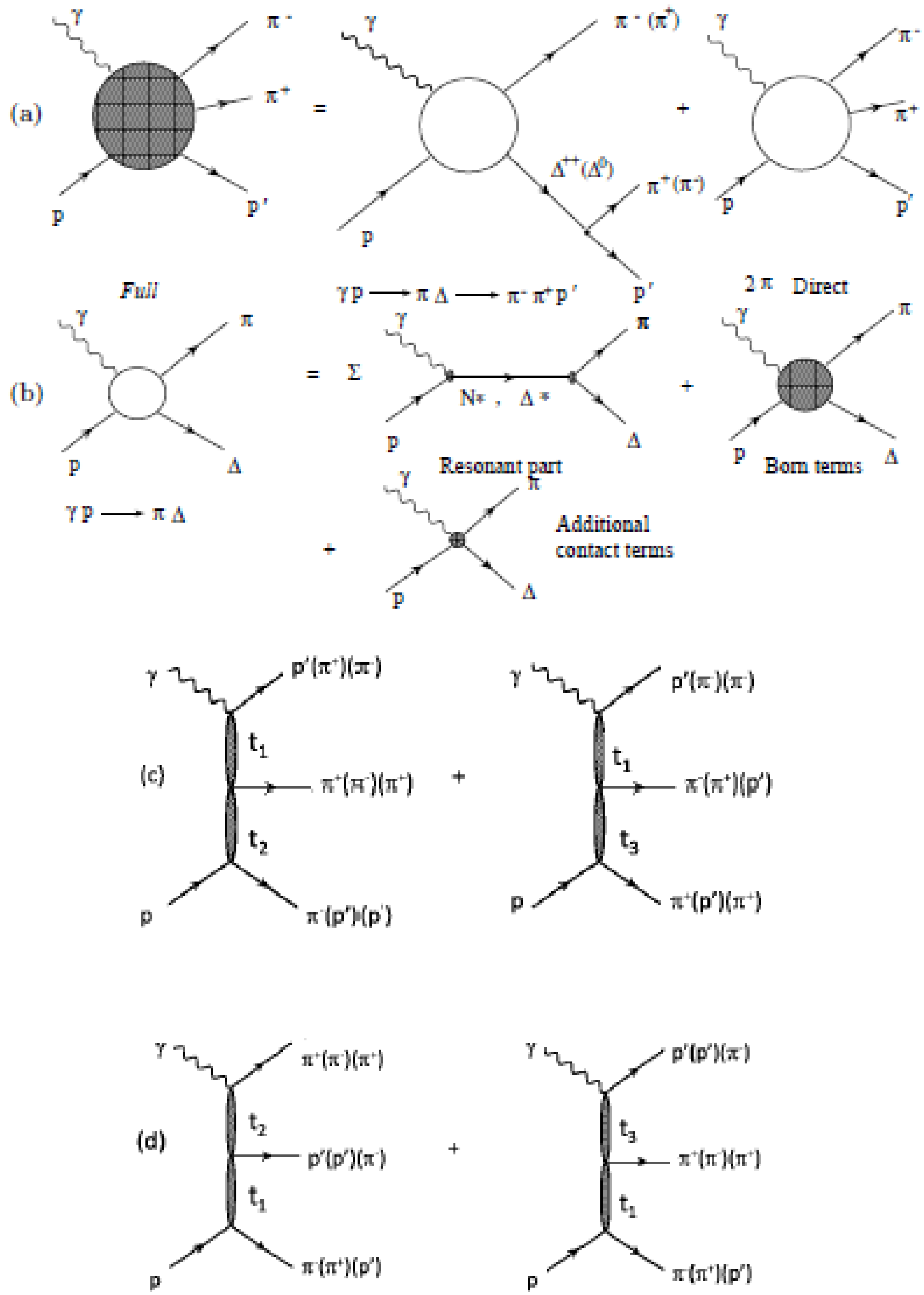
V. Mokeev

2π e-prod model

Working

up to W=1.6 GeV

up to Q^2~1 GeV^2



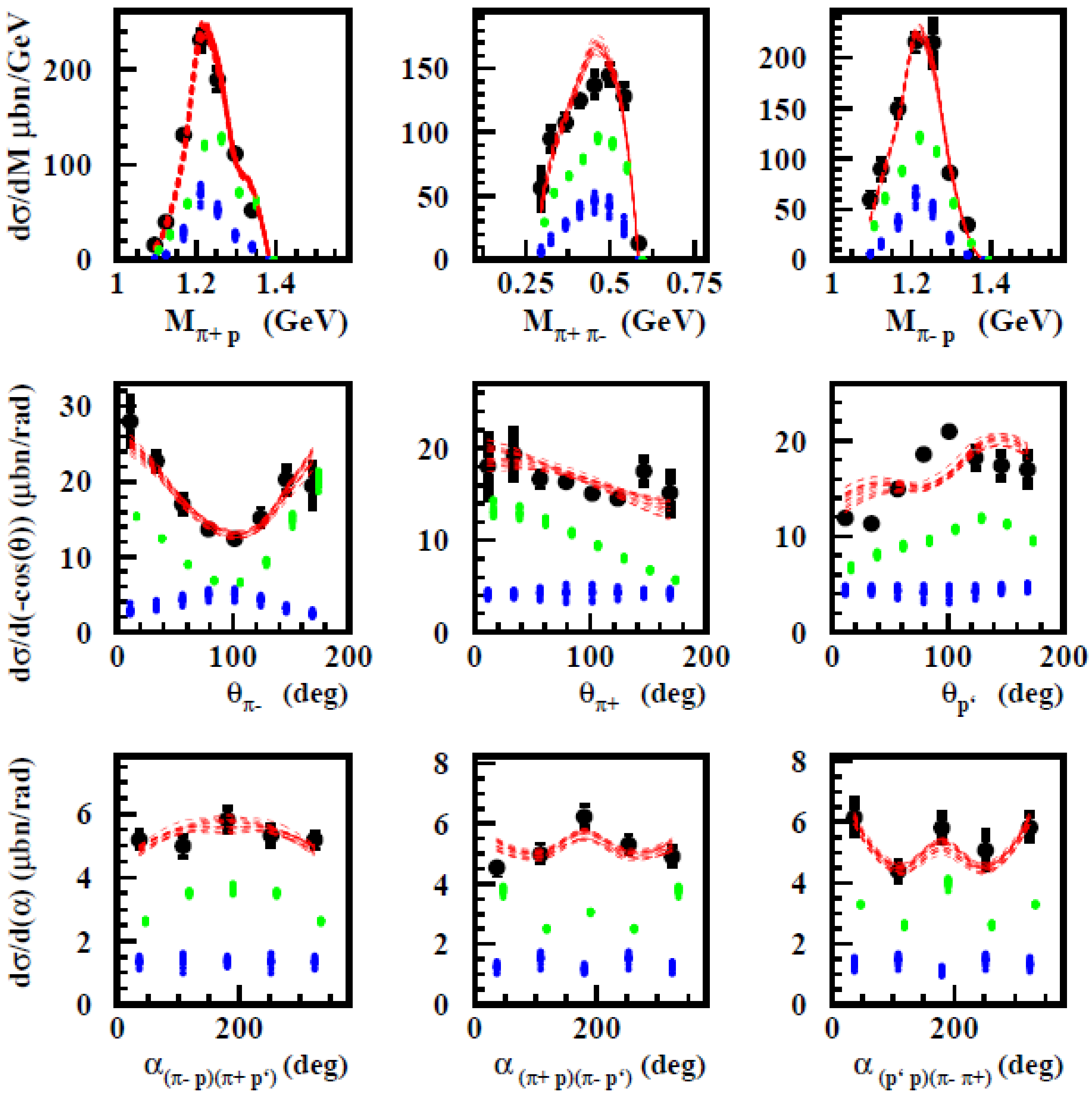
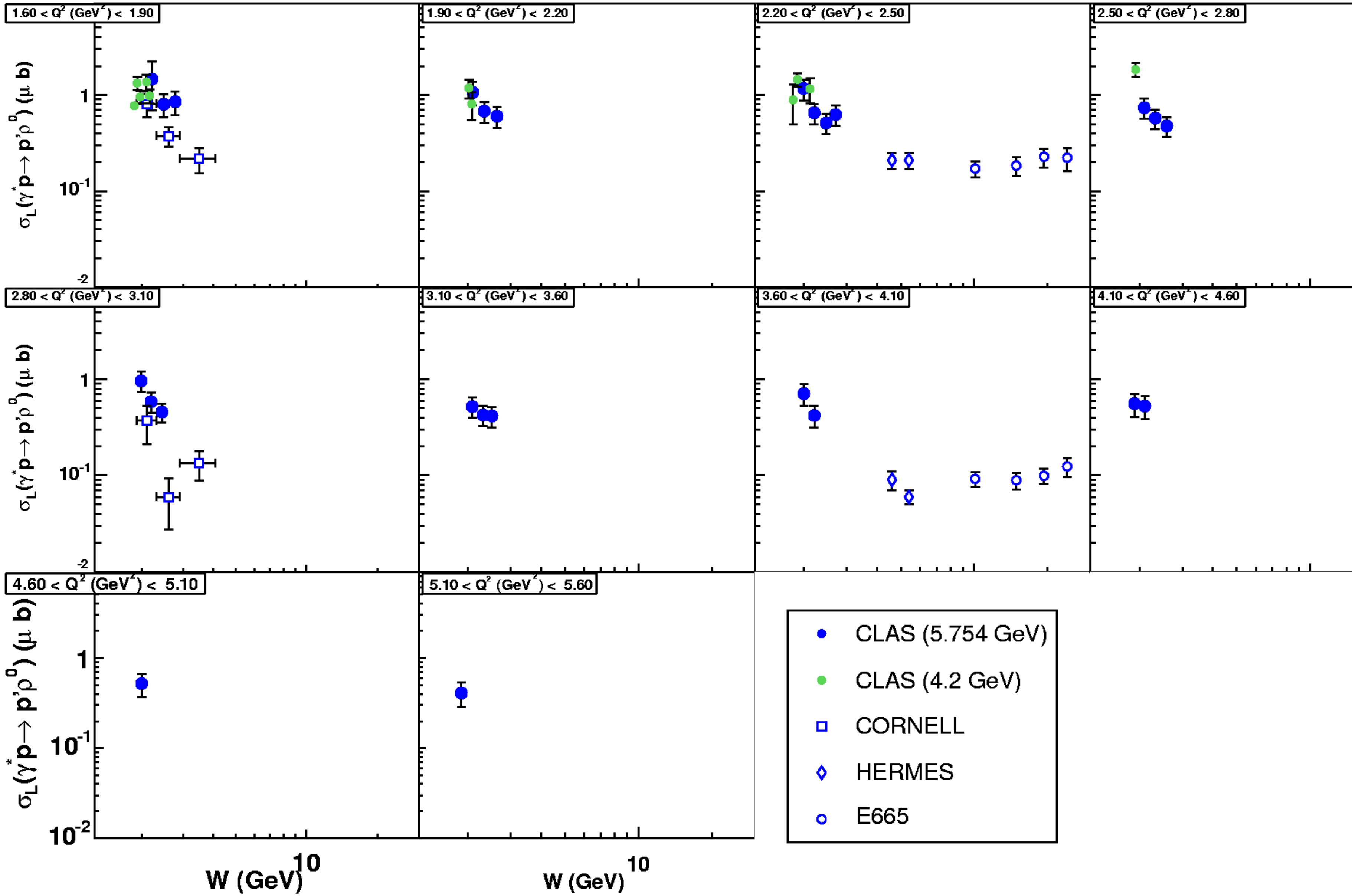
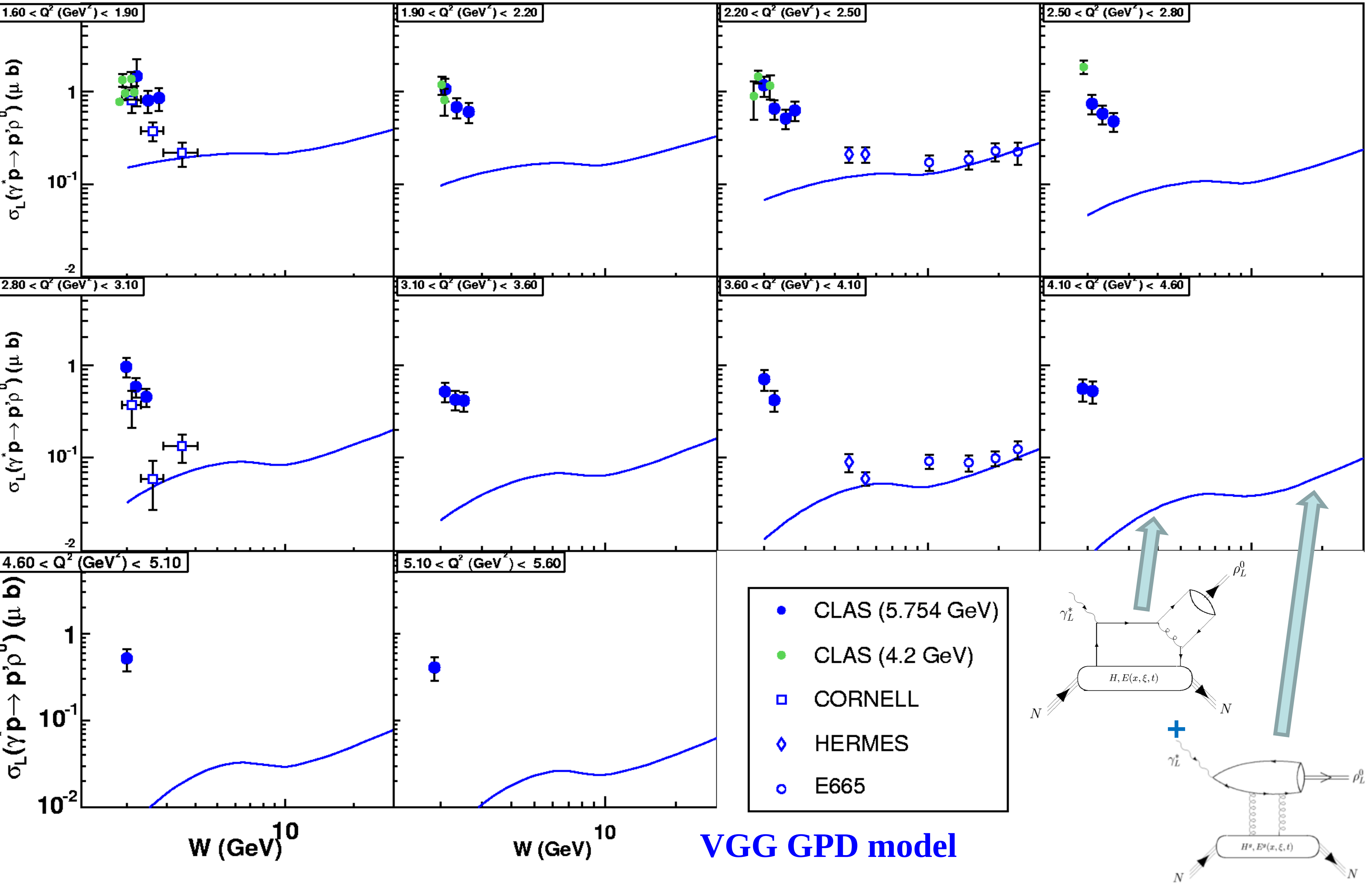


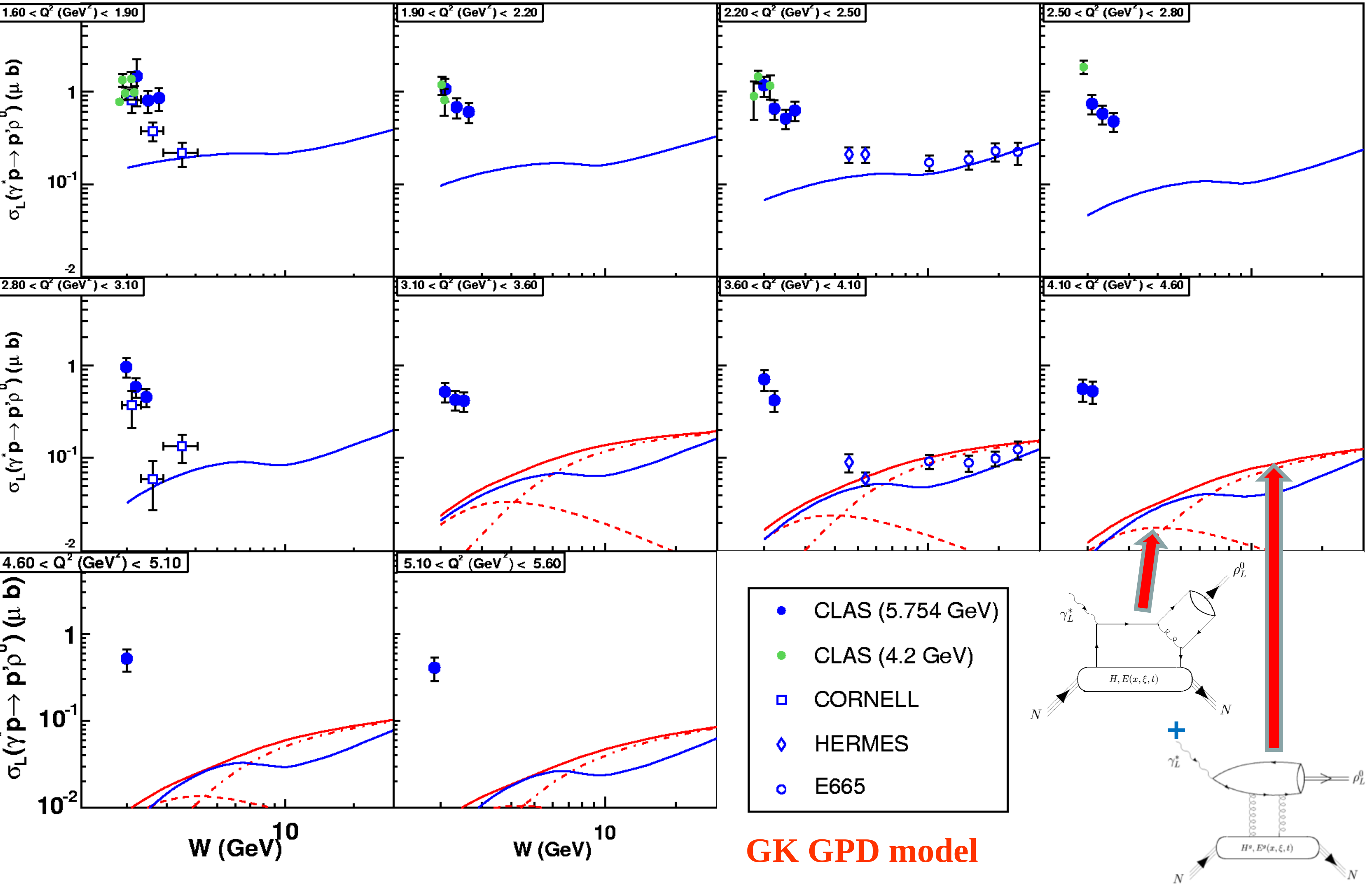
FIG. 4: (color online) Resonant (blue bars) and non-resonant (green bars) contributions to differential cross sections obtained from the CLAS data [7] fit within the framework of JM model at $W = 1.51$ GeV, Q^2=0.38 GeV^2. Dashed lines show the fit results.

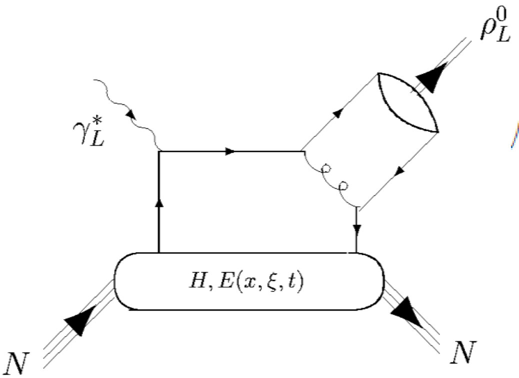
Longitudinal cross section $\sigma_L\ (\gamma^*_L p \rightarrow p\rho_L^0)$



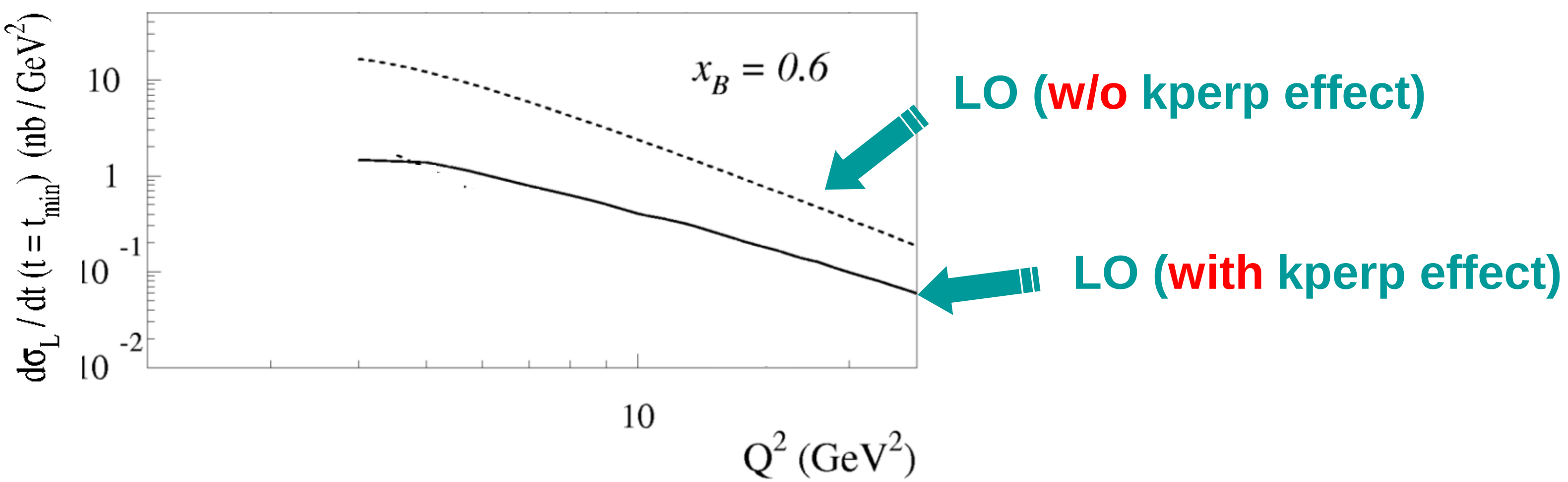


VGG GPD model


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
σ_L(γ*p → p'ρ⁰) (μ b)
W (GeV)
CLAS (5.754 GeV)
CLAS (4.2 GeV)
CORNELL
HERMES
E665
GK GPD model
$H, E(x,\xi,t)$
$H^g, E^g(x,\xi,t)$
γ_L^*
ρ_L^0
N



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



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

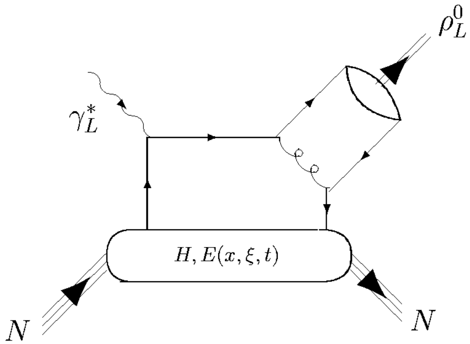
Same thing for 2-gluon exchange process

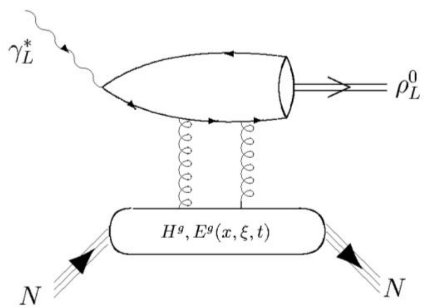
Comparison of cross sections is **model-dependent**:
k_{perp} dependence ansatz, model for GPDs,…

Some signatures available for gluon handbag are not relevant for quark handbag:

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

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



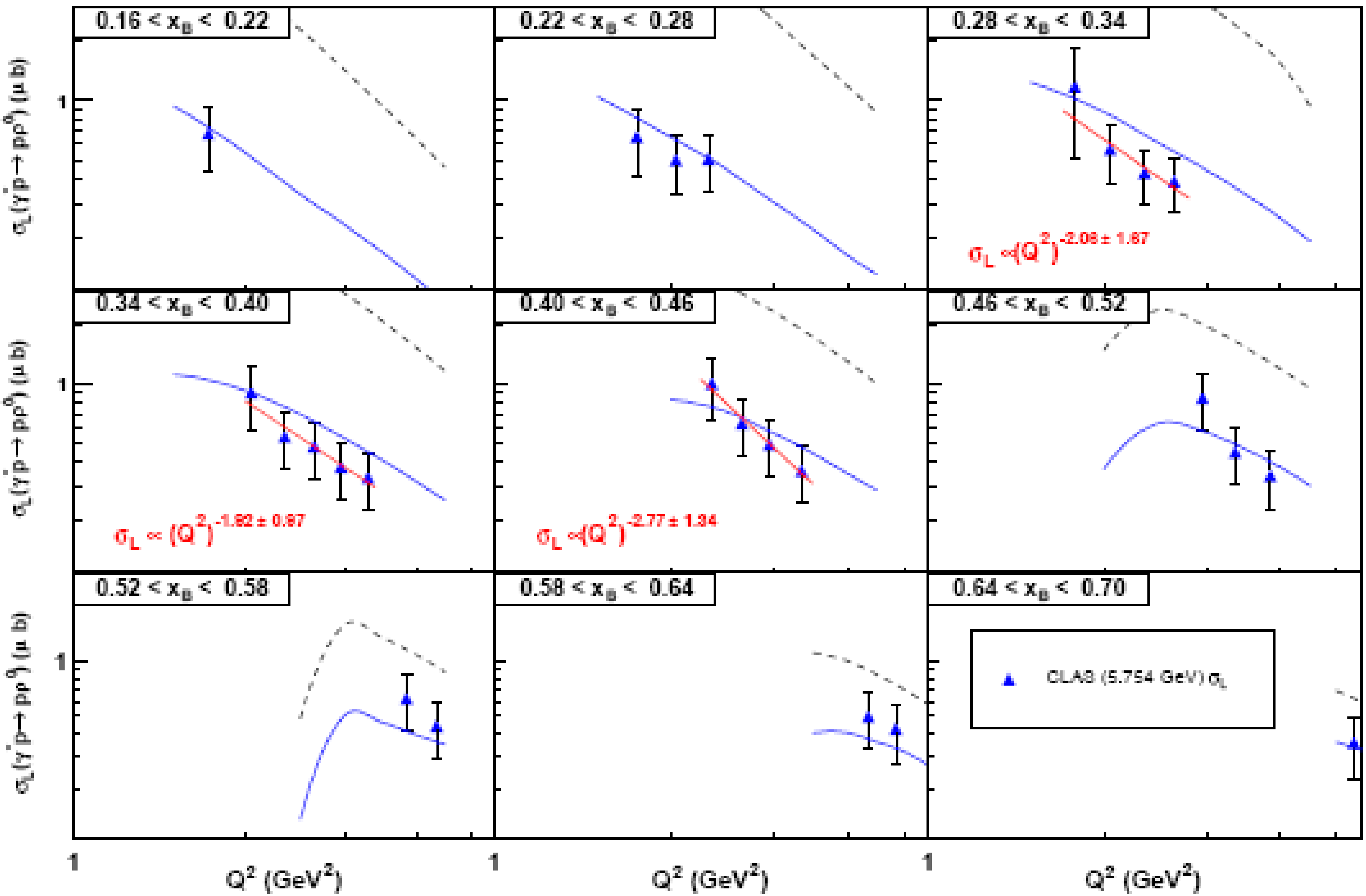


Model-independent features:

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

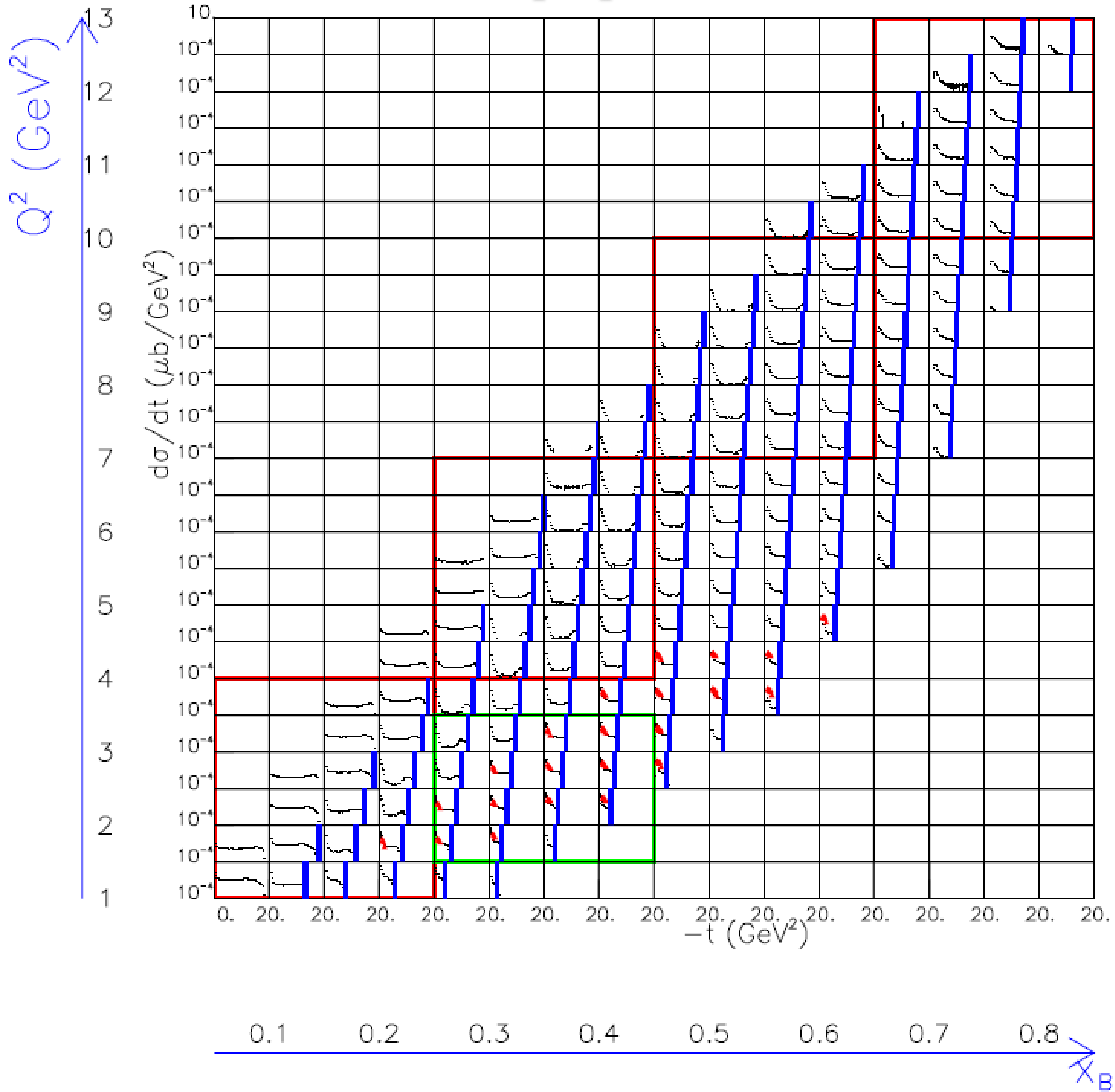
Saturation with hard scale of b **SCHC** : checks with SDMEs

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

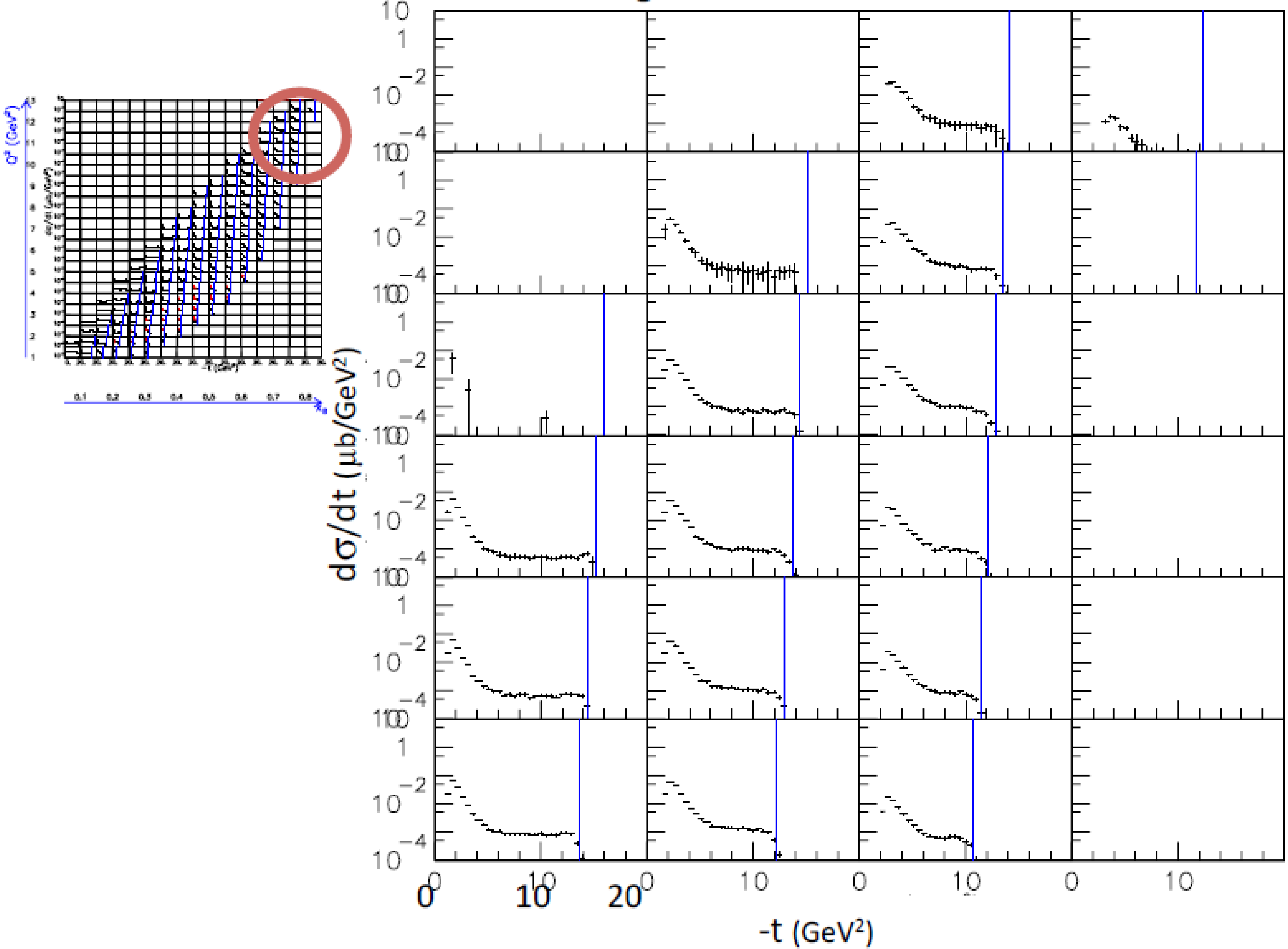


Exclusive ρ^0 electroproduction at CLAS12

CLAS12 proposal PR12-11-103

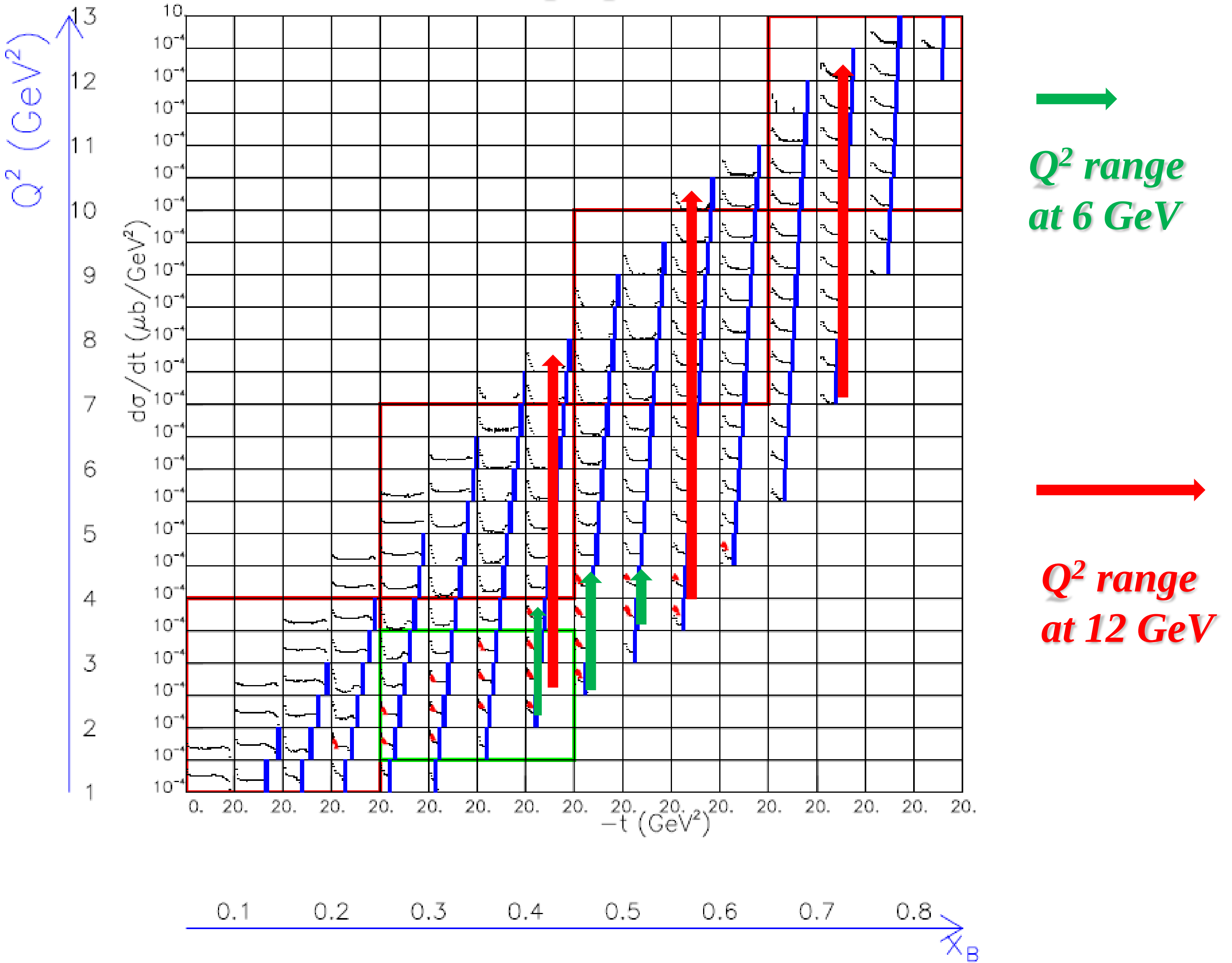


Detail of high Q^2 simulation

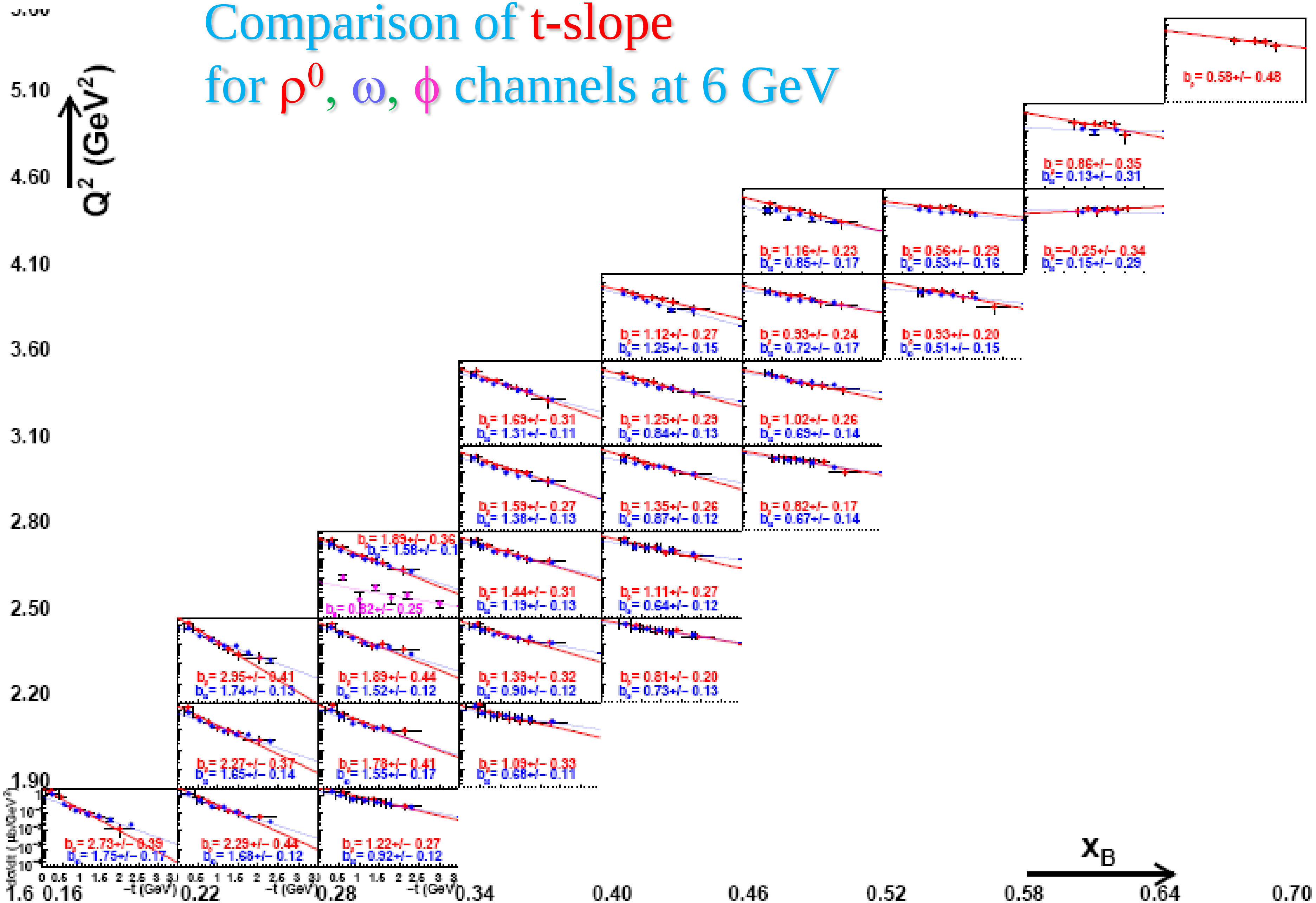


Exclusive ρ^0 electroproduction at CLAS12

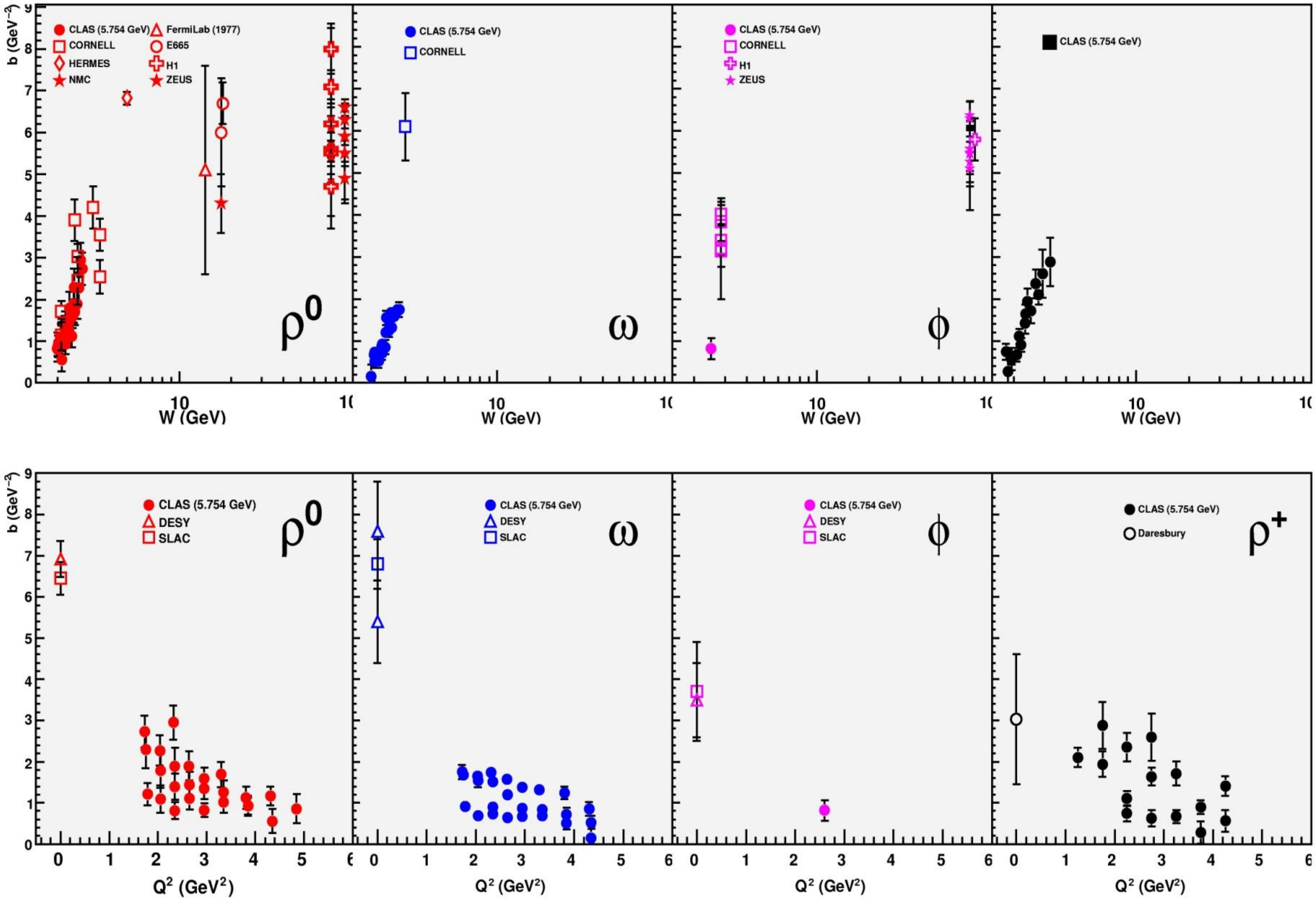
CLAS12 proposal PR12-11-103



Comparison of t-slope for ρ^0, ω, ϕ channels at 6 GeV

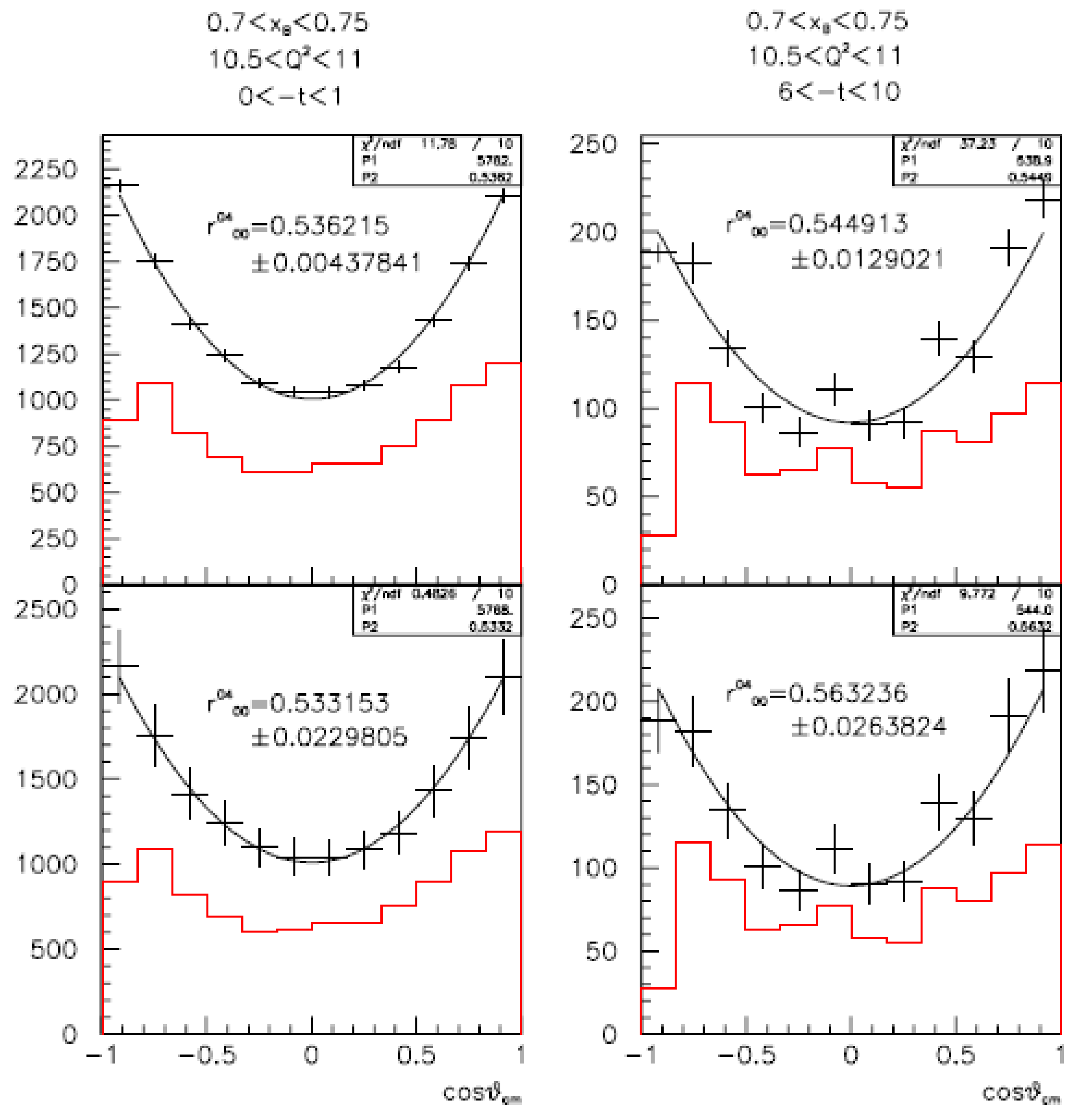


Comparison of b for ρ^0, ω, ϕ channels at 6 GeV



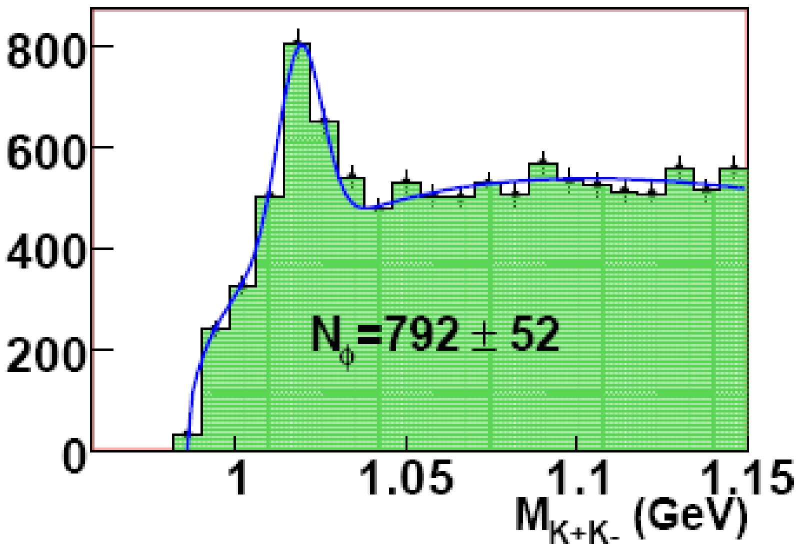
ρ^0 decay angular distribution (polar angle θ_{cm})

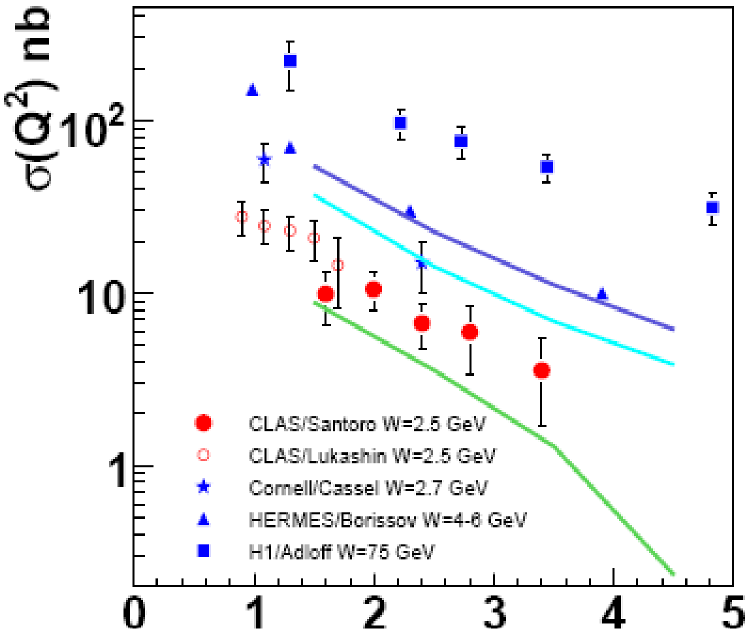
CLAS12 proposal PR12-11-103

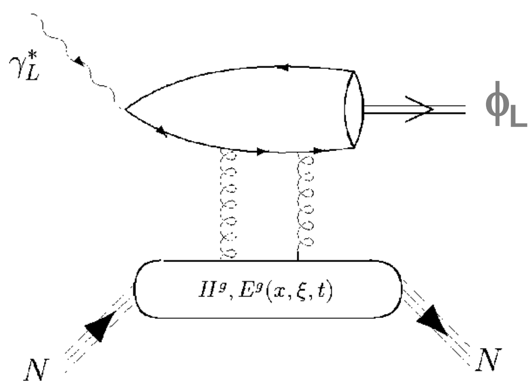


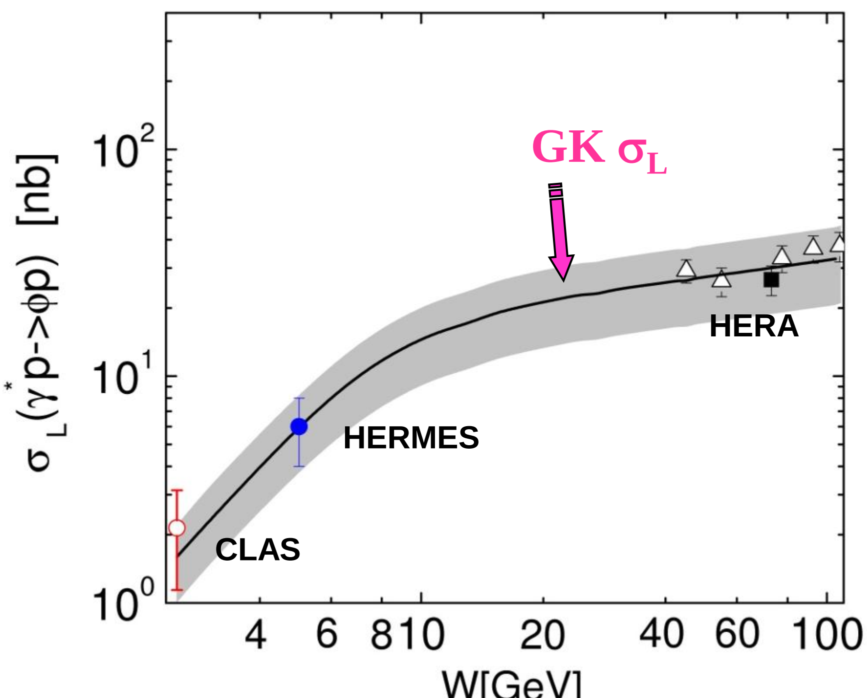
purely statistical error bars

statistical error bars +10% systematic ep->epϕ ($\hookrightarrow$ $K^+[K^-]$)

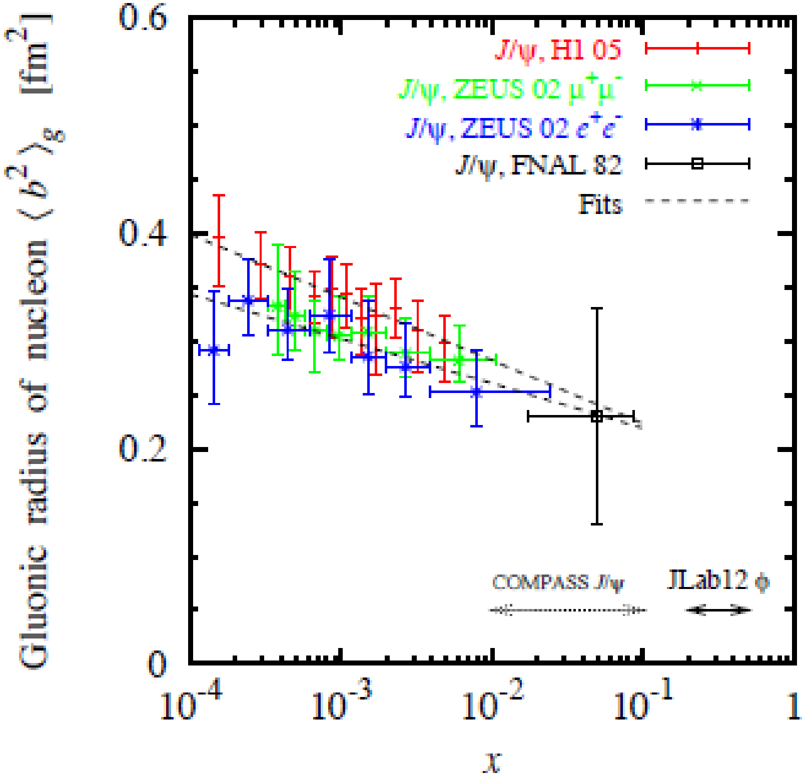


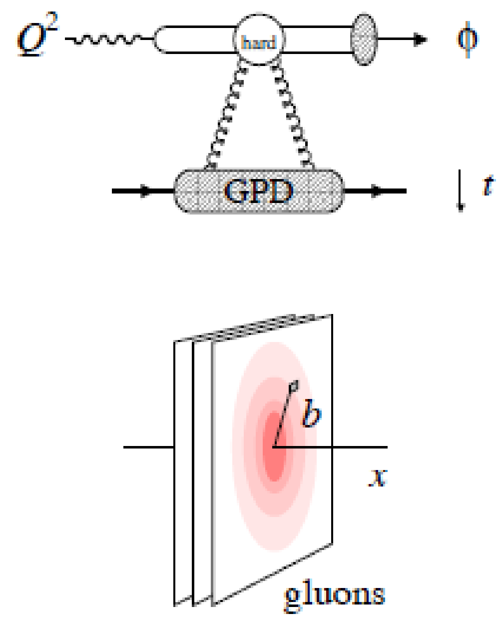






Exclusive ϕ electroproduction: gluon imaging of the proton

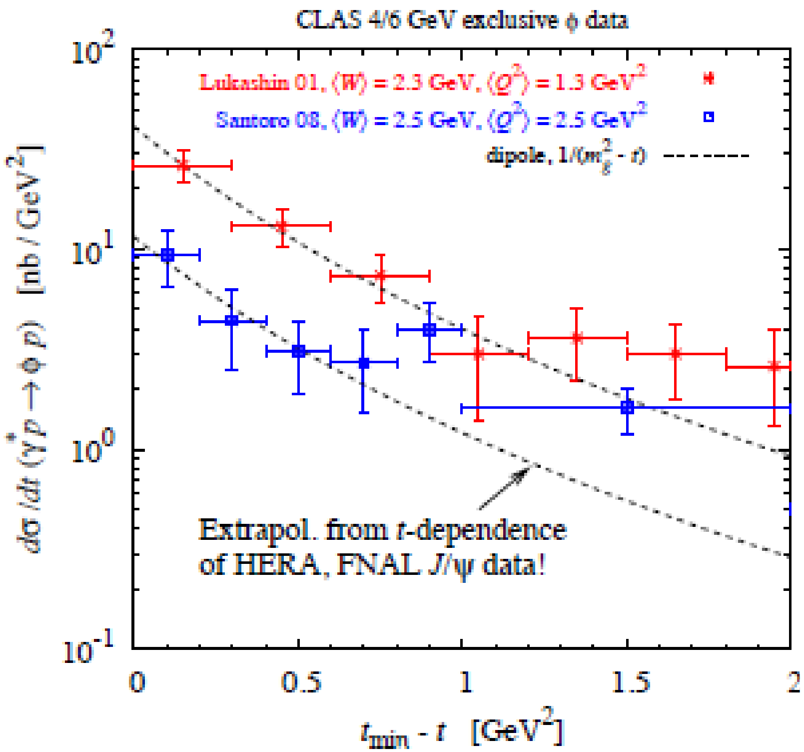


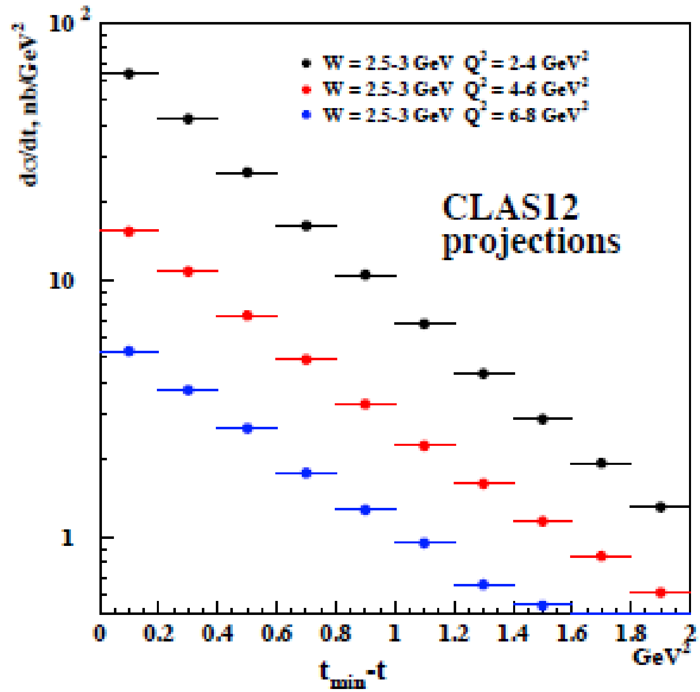


x<0.01: measured at H1/ZEUS

x>0.1: practically unknown: ϕ with CLAS12

Exclusive ϕ electroproduction: gluon imaging of the proton





(A. Kubarovsky's simulations)

CLAS12 proposal PR12-11-103:

Extract t–slope of $d\sigma_L/dt$ up to Q^2~7 GeV2

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

- *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*