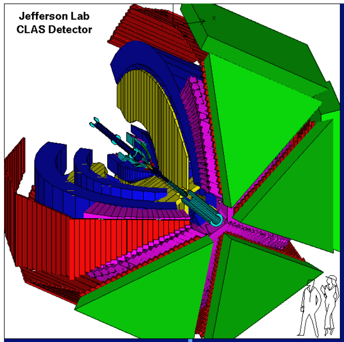
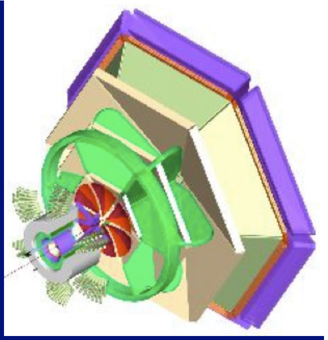




High-t meson electroproduction. Experimental status and prospects

Valery Kubarovsky
Jefferson Lab

Newport News
March 25 , 2011

Jefferson Lab
Thomas Jefferson National Accelerator Facility

Pseudoscalar mesons

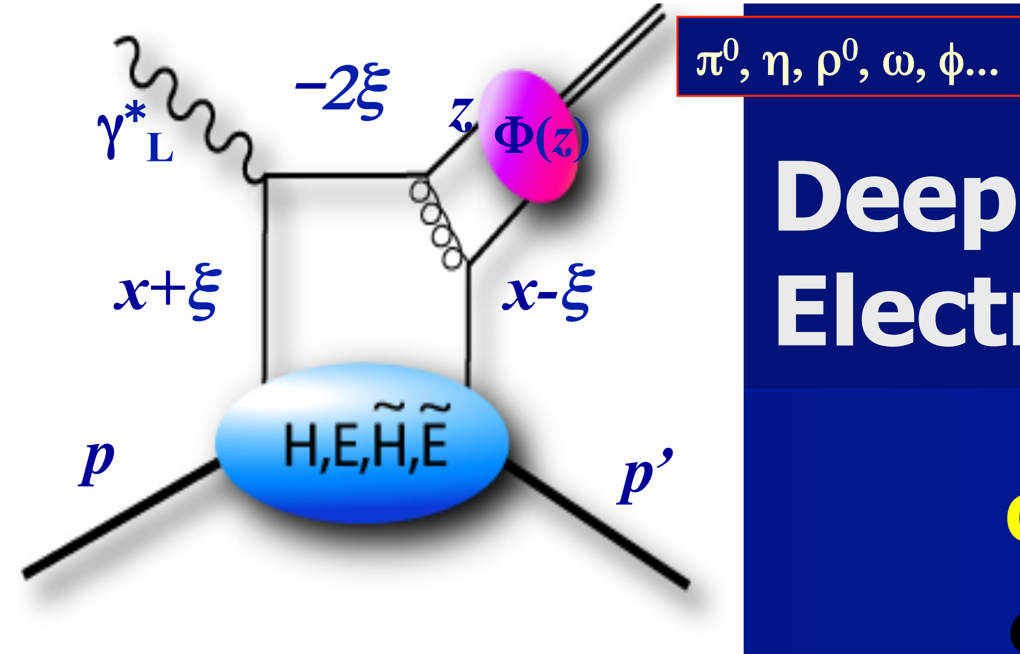
$$ep \to en\pi^+$$
$$ep \to ep\pi^0, \quad \pi^0 \to \gamma\gamma$$
$$ep \to ep\eta, \quad \eta \to \gamma\gamma$$

CLAS6: lots of data.
CLAS12: Exp. # E12-06-108

Vector mesons

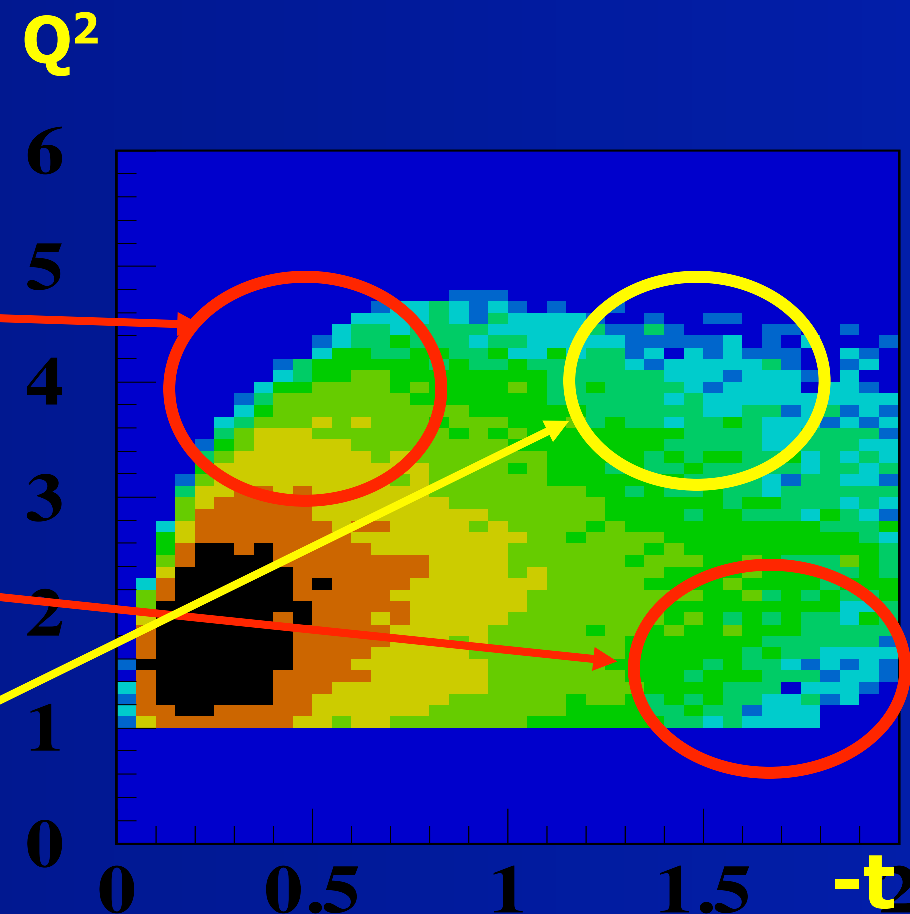
$$ep \to en\rho^+, \quad \rho^+ \to \pi^+\pi^0$$
$$ep \to ep\rho^0, \quad \rho^0 \to \pi^+\pi^-$$
$$ep \to ep\omega, \quad \omega \to \pi^+\pi^-\pi^0$$
$$ep \to ep\phi, \quad \phi \to K^+K^-$$

New proposal being prepared for PAC 38



Deeply Virtual Meson Electroproduction

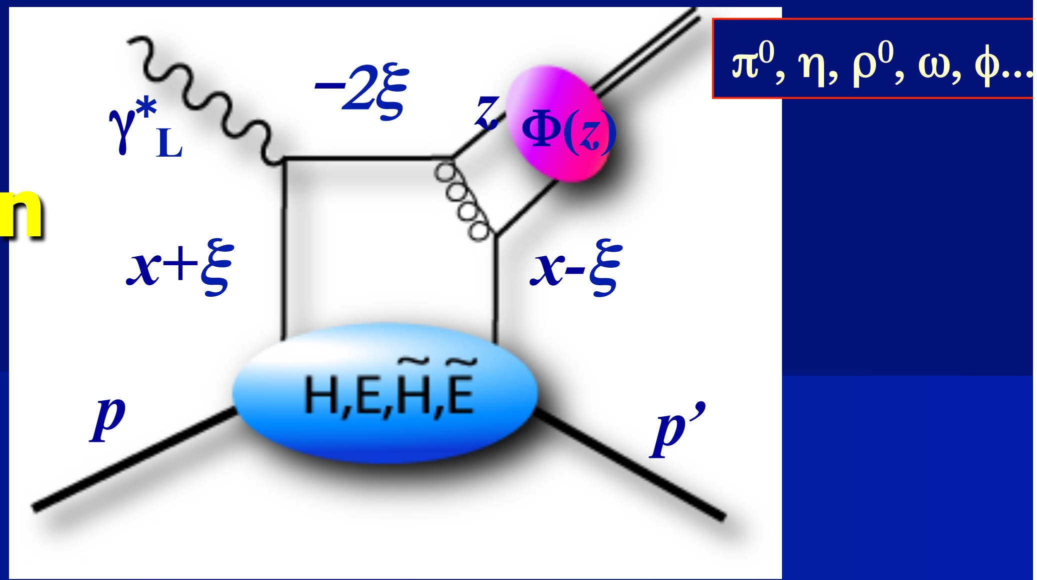
- High Q^2 - Low $-t$
  Complement DVCS experiment.
  Unique access to spin dependent GPDs
- Low Q^2 - High $-t$
  New form factors related to *1/x* moments of GPDs
- High Q^2 - High $-t$
  Region never accessed.



Kinematic regions in meson electroproduction

W>2 GeV High Q^2 Low -t	Complement ***DVCS*** experiment. Unique access to spin dependent ***GPD***s.
W>2 GeV Low Q^2 High -t	New form factors related to ***1/x*** moments of ***GPD***s
W>2 GeV High Q^2 High -t	Region never before accessed. Small initial configurations and small reaction size.
W<2 GeV High Q^2 - High -t	Resonance form factors. Subject of proposal PR12-06-116

High Q^2, Low t Region

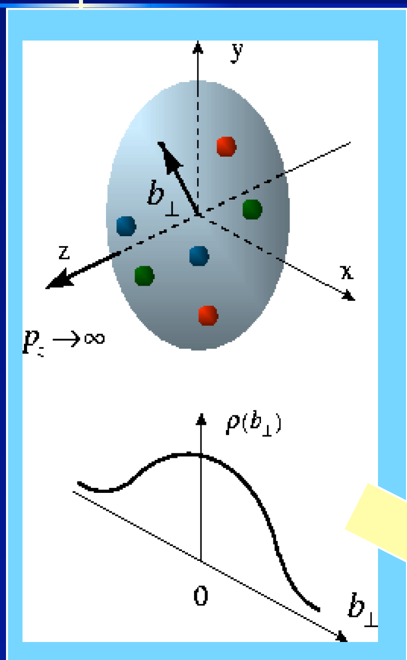


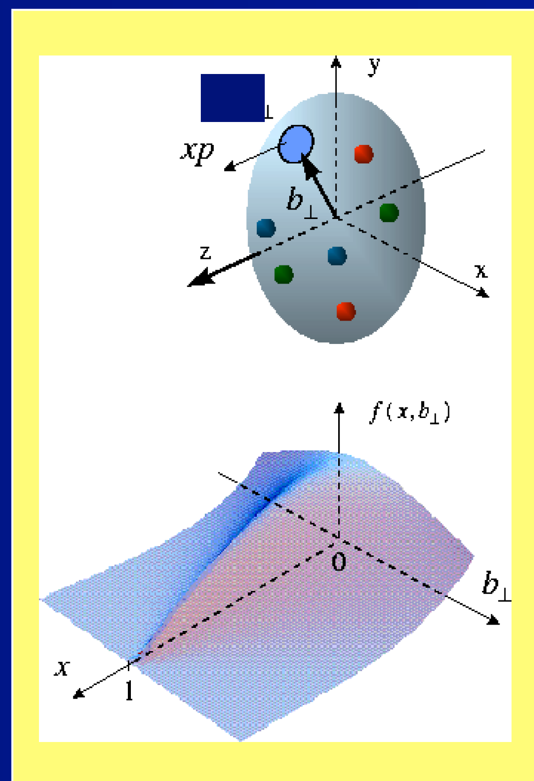
Collins,Frankfurt,Strikman -1997

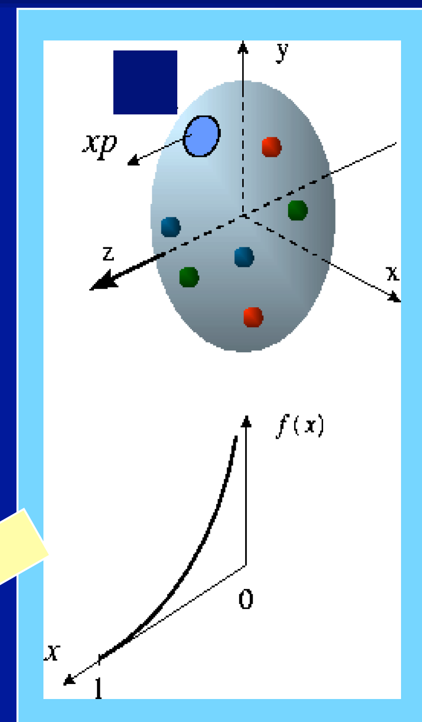
- Factorization theorem states that in the limit $Q^2 \rightarrow \infty$ exclusive electroproduction of mesons is described by hard rescattering amplitude, generalized parton distributions (GPDs), and the distribution amplitude $\Phi(z)$ of the outgoing meson.
- The prove applies only to the case when the virtual photon has longitudinal polarization
- $Q^2 \rightarrow \infty$ $\sigma_L \sim 1/Q^6$, $\sigma_T/\sigma_L \sim 1/Q^2$

How are the proton's charge densities related to its quark momentum distribution?

D. Mueller, X. Ji, A. Radyushkin, …1994 -1997
M. Burkardt, A. Belitsky… Interpretation in impact parameter space







Proton form factors, transverse charge & current densities

Correlated quark momentum and helicity distributions in transverse space - GPDs

Structure functions, quark longitudinal momentum & spin distributions

GPDs

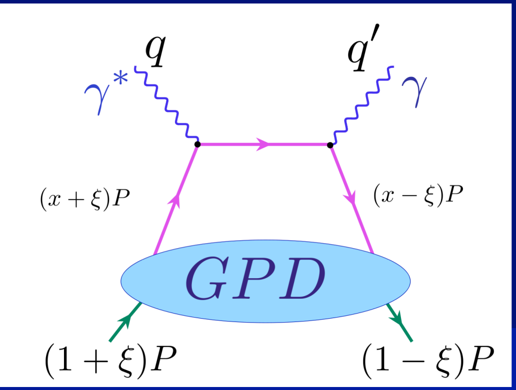
- GPD is Fourier Transform of matrix elements
- t-dependence of GPDs maps transverse position of quarks
- GPDs at zero skewedness ($\xi=0$) is the probability to find quark with momentum x and impact parameter b_x
- Generalize at $\xi\neq0 \rightarrow$ Quantum femtophotography
- DGLAP region ($x>\xi$) – quark femtophotography
- ERBL region ($x<\xi$) – quark-antiquark femtophotography pair of the size 1/Q

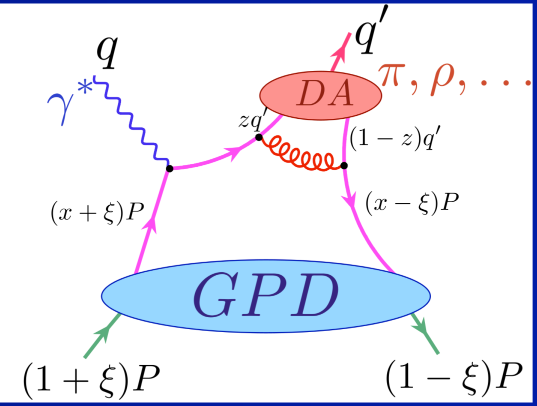
Deeply Virtual Meson production

$$ep \to ep\pi^0, \quad \pi^0 \to \gamma\gamma$$

$$ep \to ep\eta, \quad \eta \to \gamma\gamma$$

$$ep \to en\rho^+, \quad \rho^+ \to \pi^+\pi^0$$





Meson	GPD flavor composition
π^+	$\Delta u - \Delta d$
π^0	$2\Delta u + \Delta d$
η	$2\Delta u - \Delta d$
ρ^0	$2u + d$
ρ^+	$u - d$
ω	$2u - d$

$$\widetilde{H}, \widetilde{E}$$

$$H, E$$

- DVCS is the cleanest way of accessing GPDs. However, it is difficult to perform a flavor separation.
- Vector and pseudoscalar meson production allows one to separate flavor and isolate the helicity-dependent GPDs.

π^0 electroproduction Handbag predictions

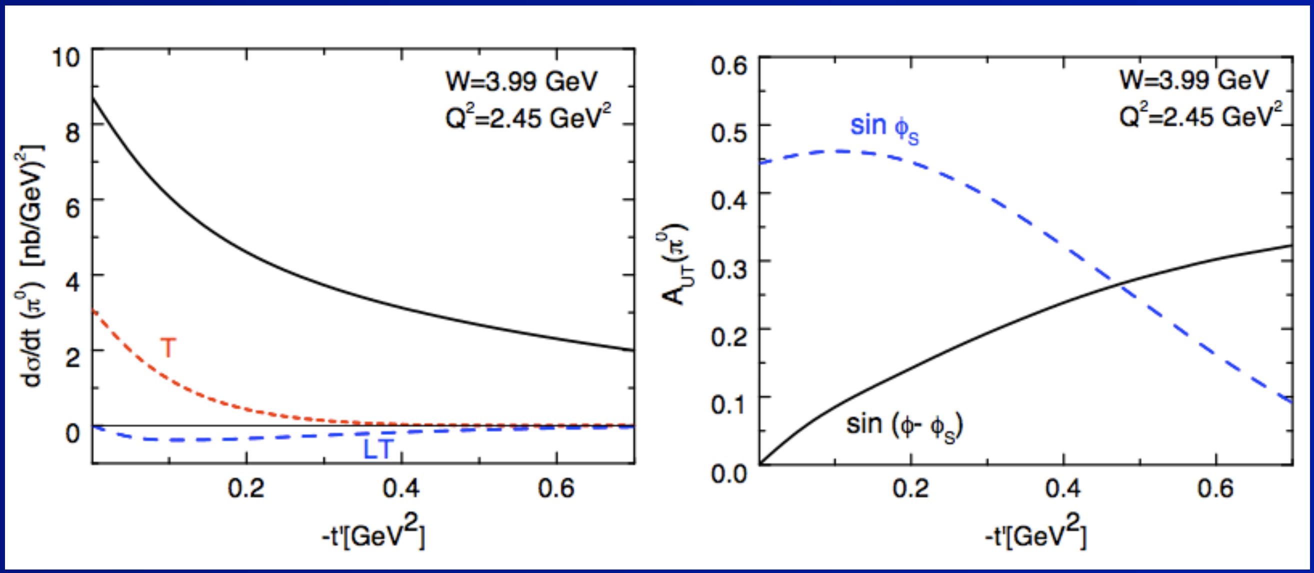
$\gamma^* p \to p\pi^0$

Kroll, Goloskokov, 2009.

$\sigma_T + \varepsilon\sigma_L$

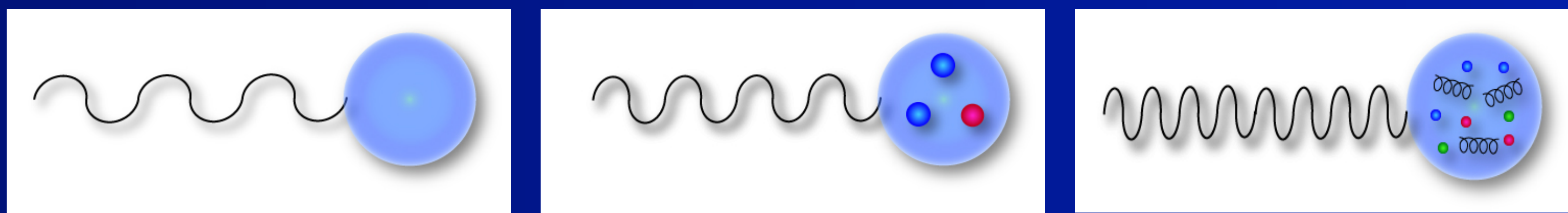
σ_T

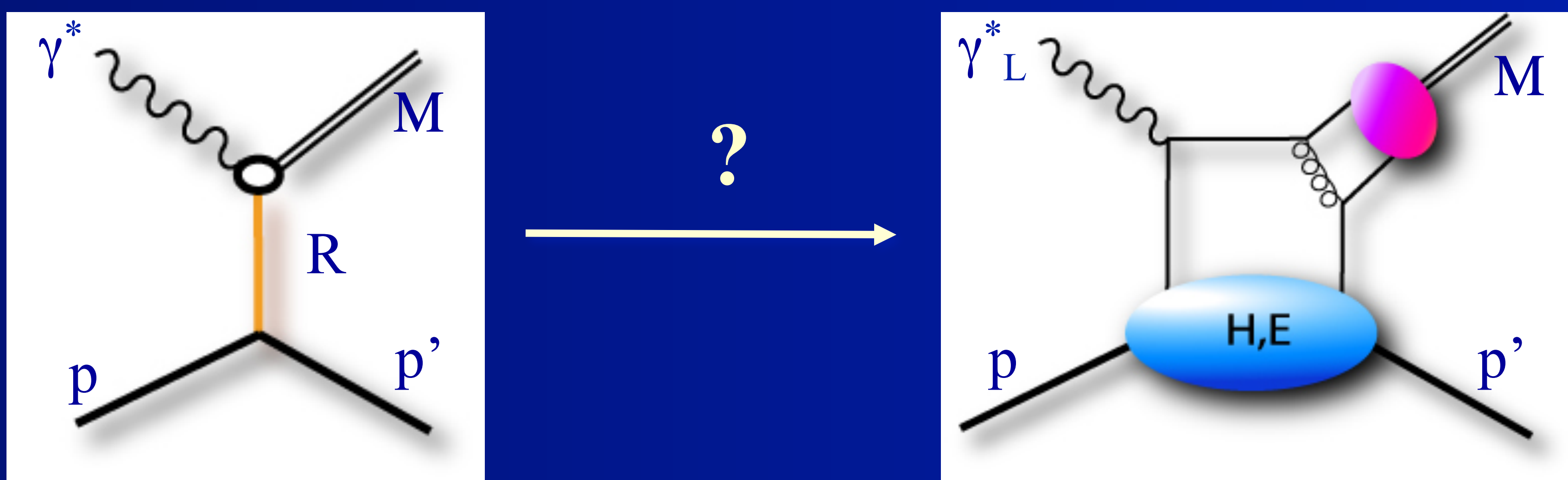
σ_{LT}



Predictions for the cross section (left) and A_{UT} (right) for the π^0 electroproduction versus –t. The unseparated(σ_L,σ_T) cross section was calculated as well as σ_T and σ_{LT}. At W=2.2 GeV the cross section will be a factor of 10 larger. We can check it at Jlab.

Transition from "hadronic" to the partonic degrees of freedom

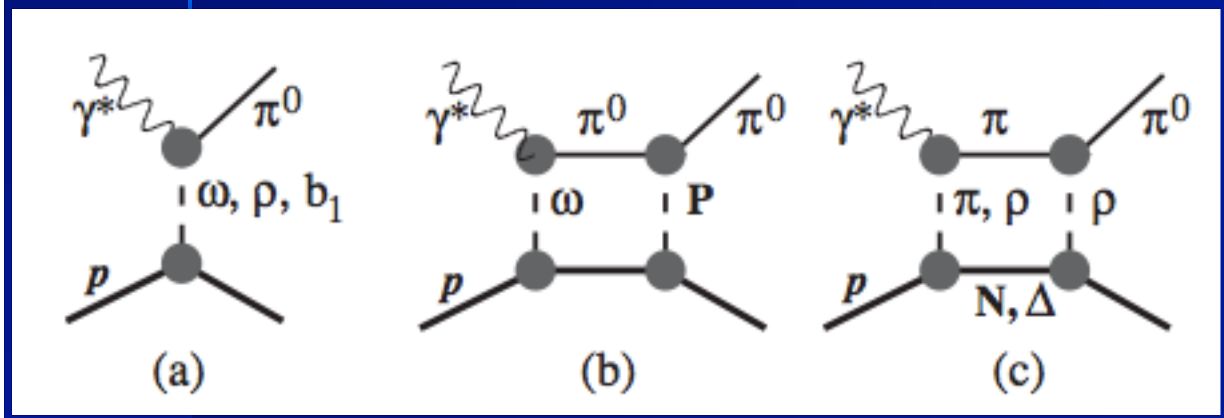


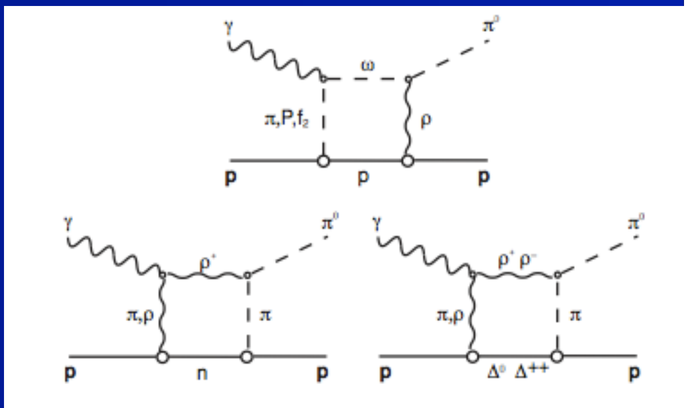


$$\gamma^* p \rightarrow p\pi^0$$

Regge Model

J.M. Laget 2010





(a) Regge poles (vector and axial vector mesons)
(b) and (c) pion cuts

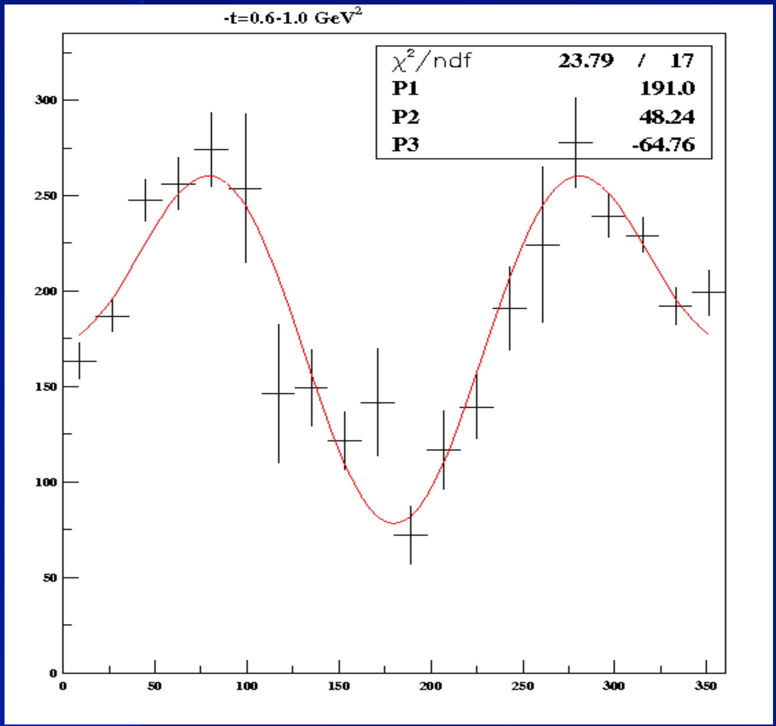
Vector meson cuts

Structure Functions

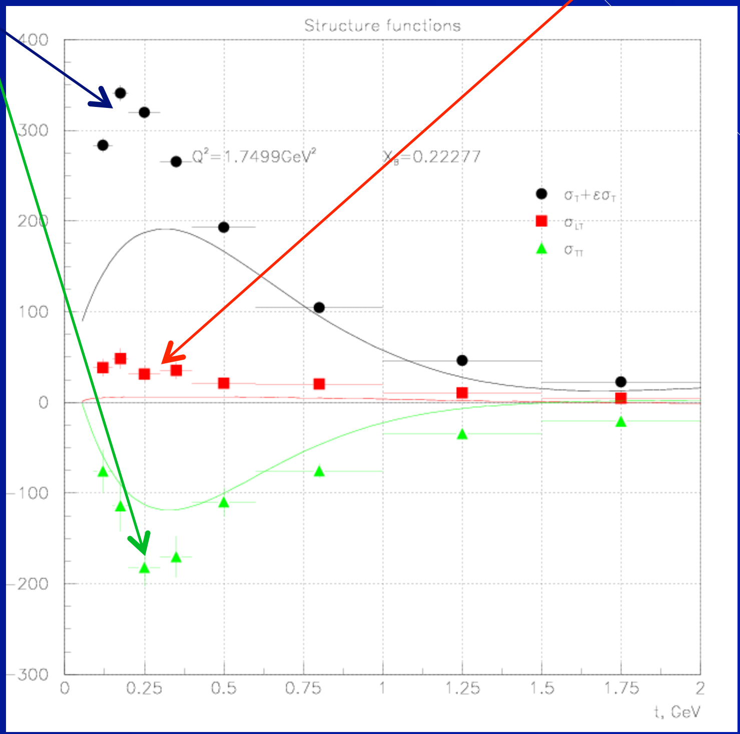
$\gamma^* p \rightarrow p\pi^0$

$\sigma_T + \varepsilon\sigma_L \quad \sigma_{TT} \quad \sigma_{LT}$

$$\frac{d\sigma}{dt\,d\phi}(Q^2,x,t,\phi) = \frac{1}{2\pi}\left(\frac{d\sigma_T}{dt} + \varepsilon\frac{d\sigma_L}{dt} + \varepsilon\frac{d\sigma_{TT}}{dt}\cos 2\phi + \sqrt{2\varepsilon(\varepsilon+1)}\frac{d\sigma_{LT}}{dt}\cos\phi\right)$$



φ distribution



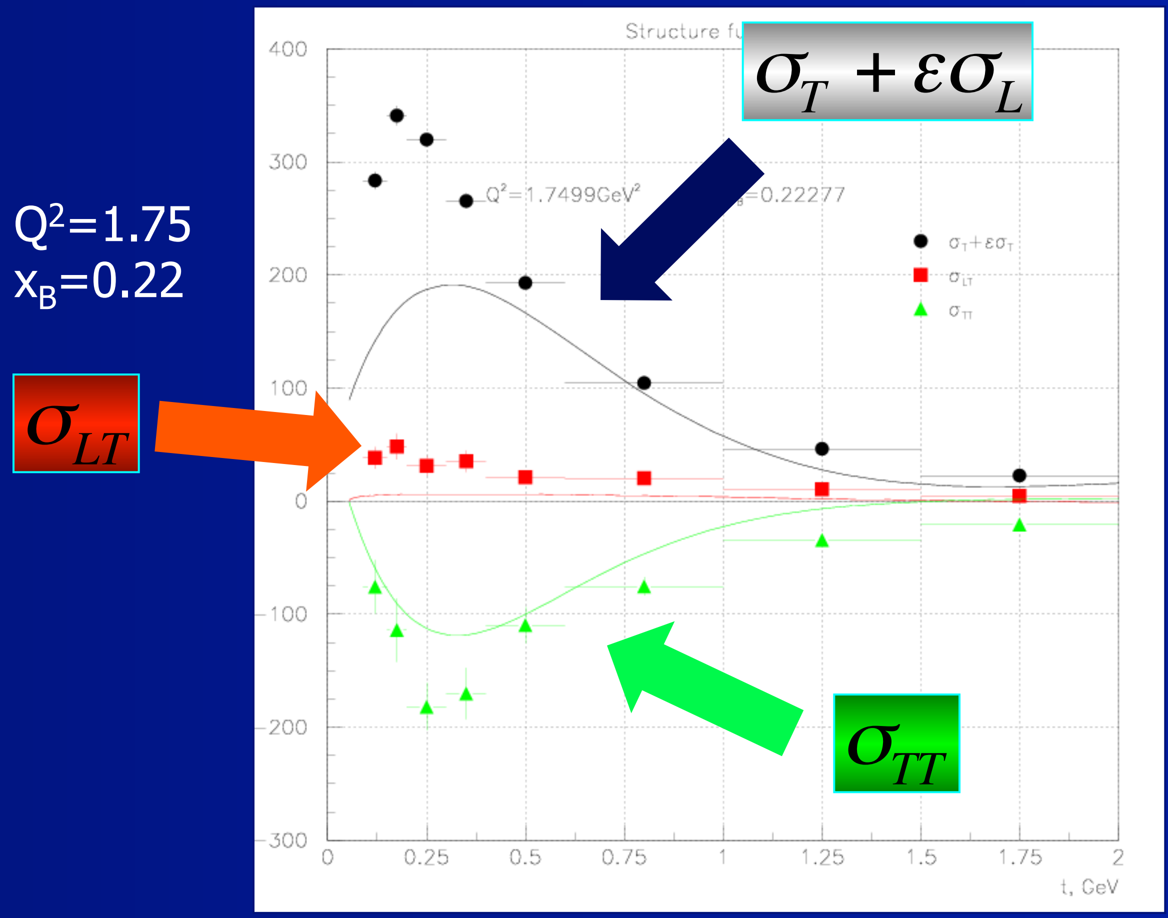
-t

GM Laget Regge model

$\gamma^* p \rightarrow p\pi^0$

JML Regge predictions

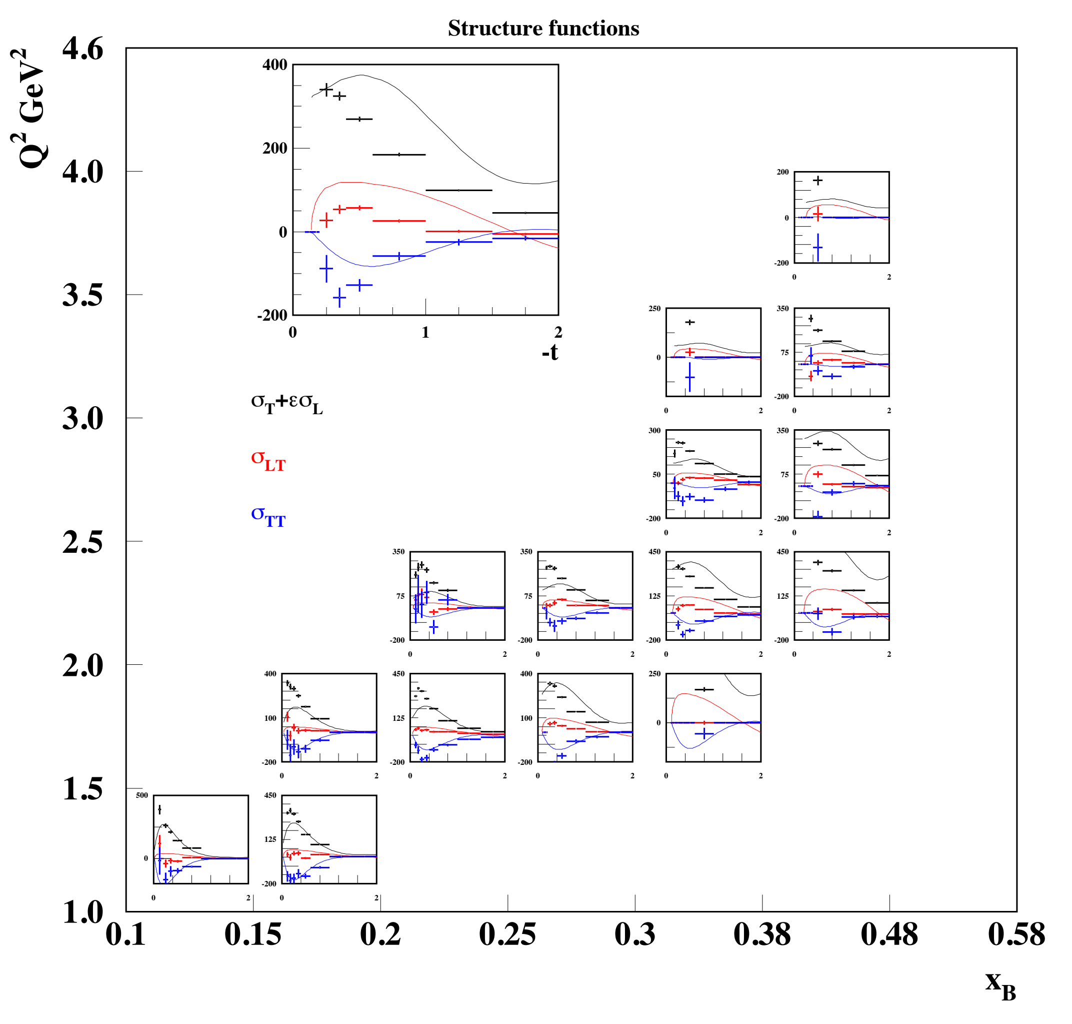
Q^2=1.75
x_B=0.22



-t, GeV^2

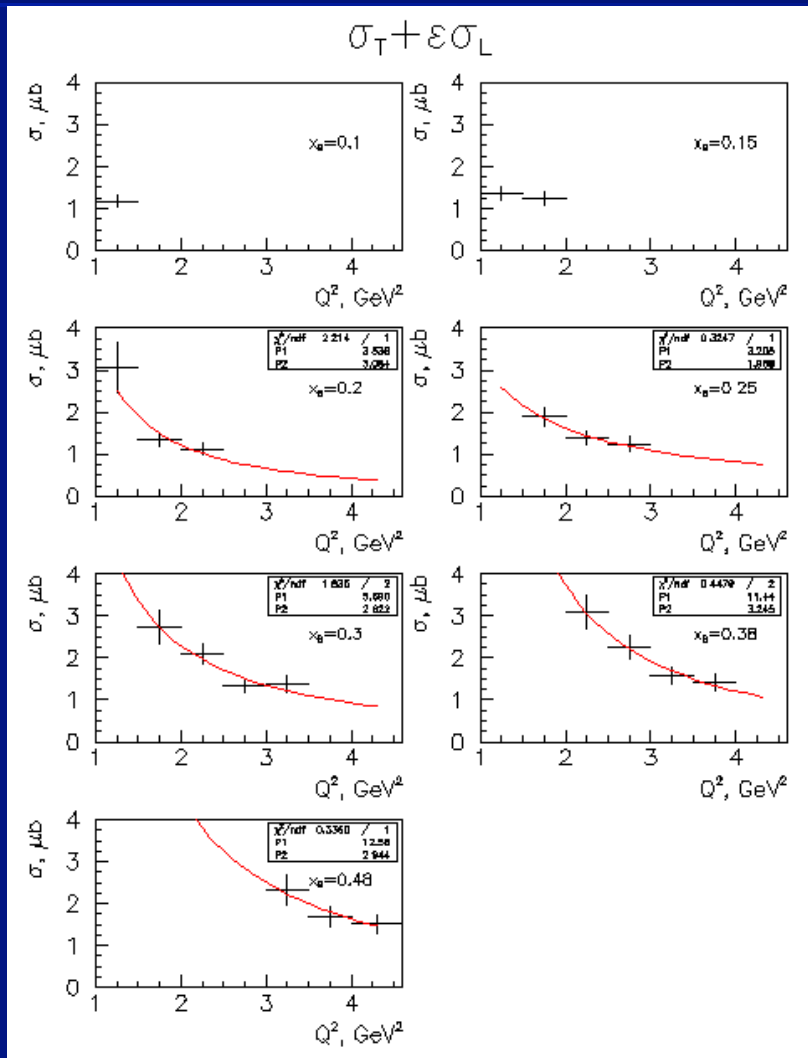
Comparison with J.M. Laget Regge model

- Extracted reduced cross sections were compared with predictions of J.M. Laget Regge Model



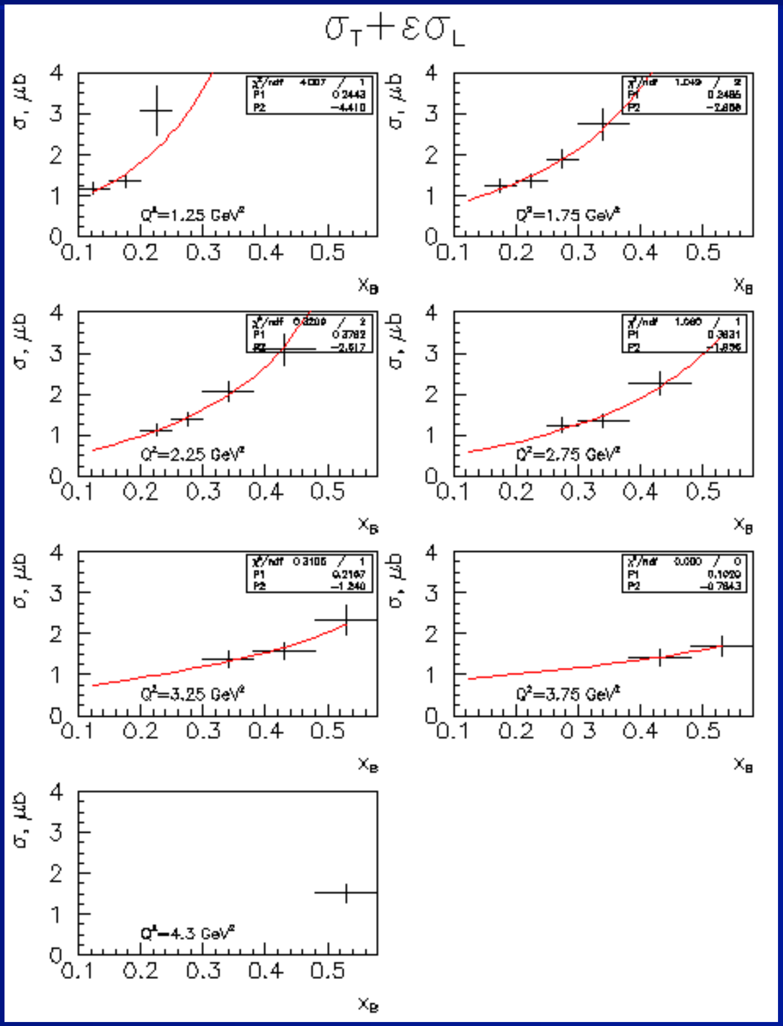
$\gamma^* p \to p\pi^0$

Q2-dependence



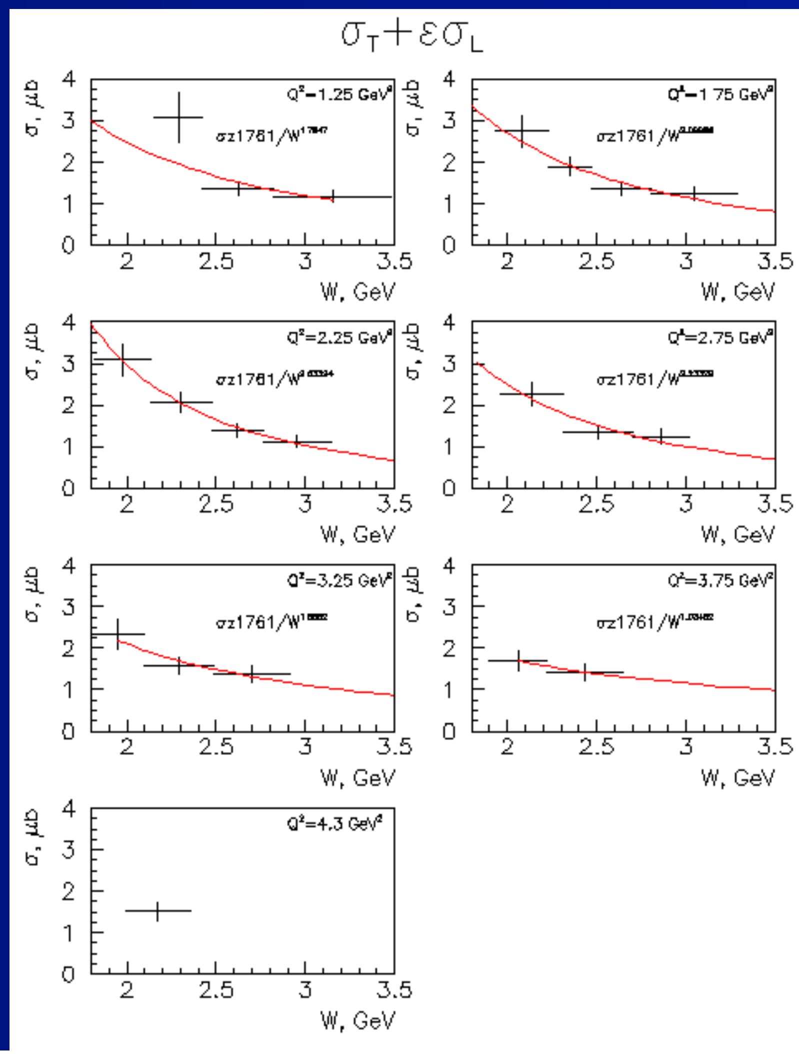
$\gamma^* p \rightarrow p\pi^0$

x_B dependence



$\gamma^* p \rightarrow p\pi^0$

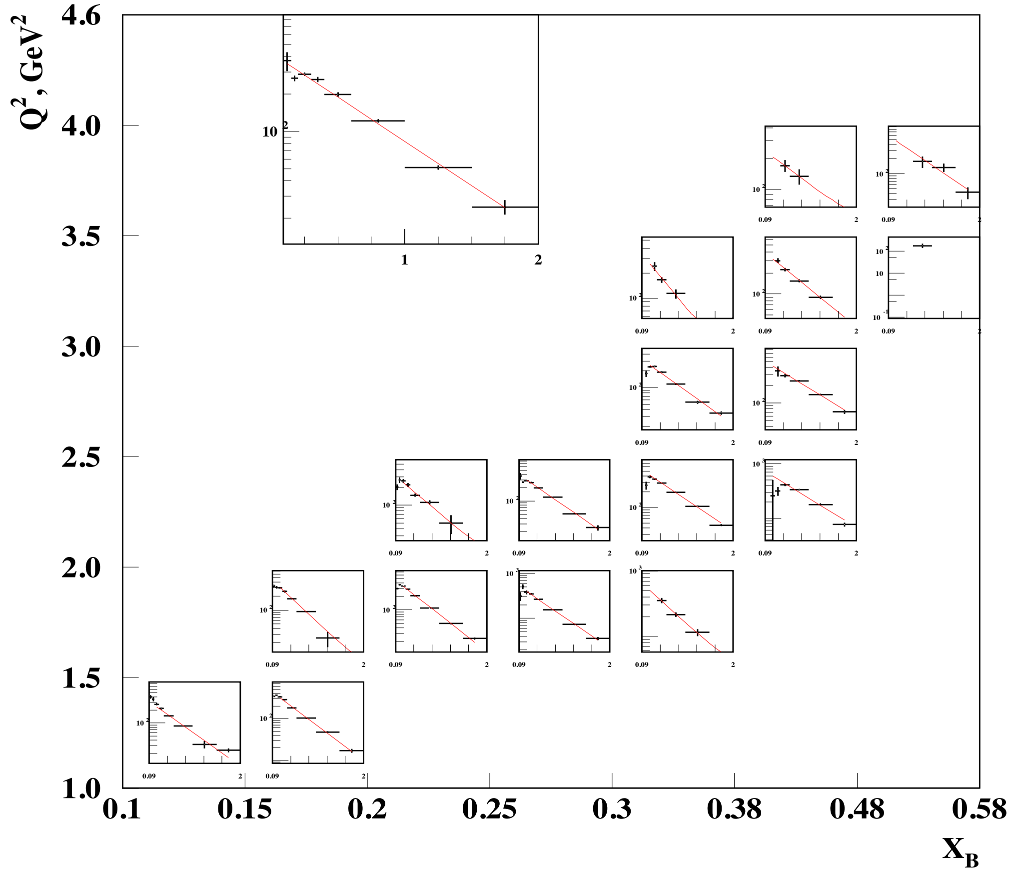
W-dependence



t - distribution

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

$$\frac{d\sigma}{dt} \propto e^{B(x_B,Q^2)t}$$



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

t-Slope Parameter as a Function of x_B and Q^2

$$\frac{d\sigma}{dt} \propto e^{B(x_B,Q^2)t}$$

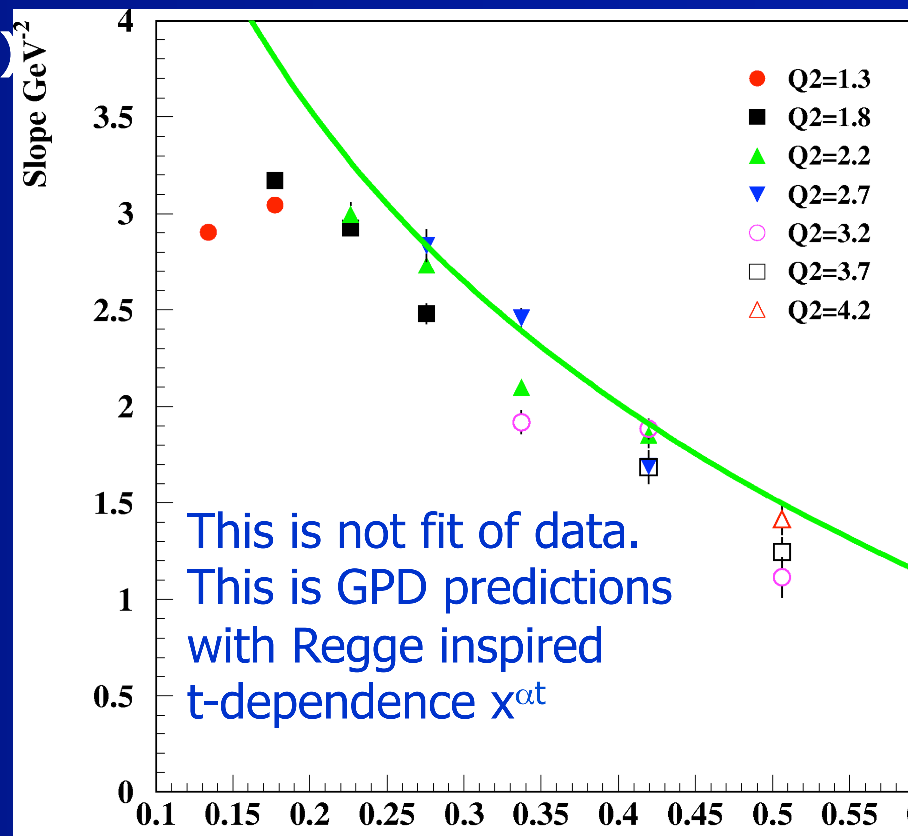
$$f^q(x,t) \propto x^{\alpha_q(t)} \propto x^{\alpha' t}$$

$$\frac{d\sigma}{dt} \propto \left[x^{\alpha' t}\right]^2 = e^{2\alpha' \ln(1/x) t}$$

$$B(x) = 2\alpha' \ln(1/x)$$

$$\alpha' = 1.1$$

$B(x_B, Q^2)$



x_B

- $B(x_B, Q^2)$ is almost independent of Q^2
- $B(x_B)$ is decreasing with increasing x_B

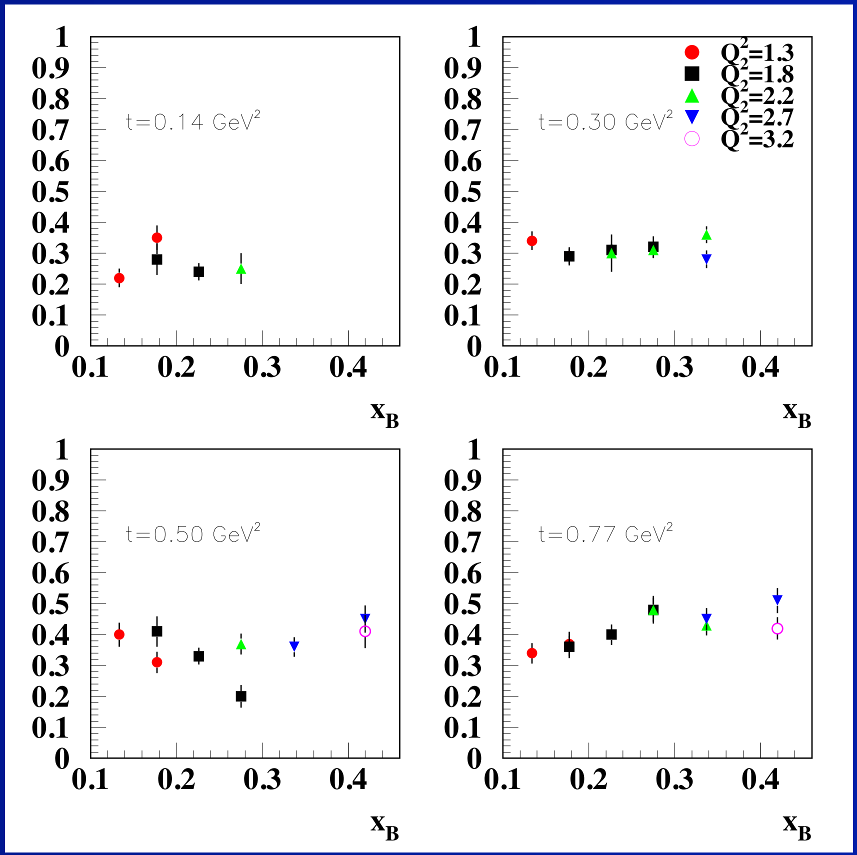
η/π^0 Ratio

$$\frac{\sigma(ep \to ep\,\eta)}{\sigma(ep \to ep\,\pi^0)}$$

Preliminary data on the ratio η/π^0 as a function of x_B for different bins in t.

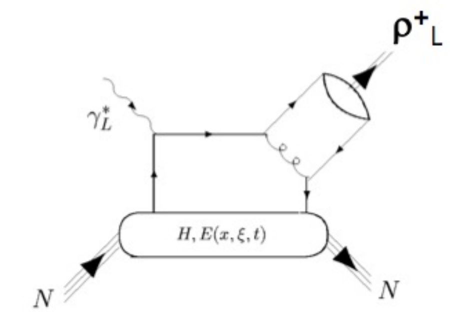
The dependence on the x_B and Q^2 is very week.

Probably we have small positive slope. The ratio in the photoproduction is near 0.2-0.3 (very close to what we have at our smallest Q^2).



Vector Mesons
Quark and Gluon GPDs

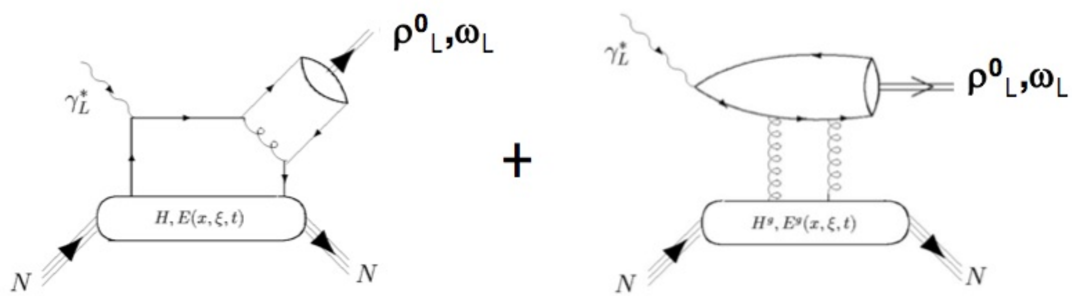
$\gamma^* p \rightarrow n\rho^+$



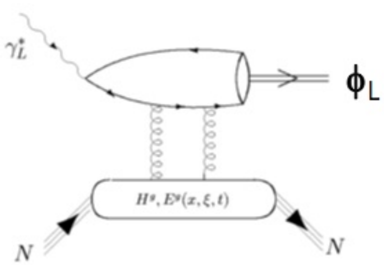
ρ^0	$e_u H^u - e_d H^d$ $e_u E^u - e_d E^d$
ω	$e_u H^u + e_d H^d$ $e_u E^u + e_d E^d$
ρ^+	$H^u - H^d$ $E^u - E^d$

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

$\gamma^* p \rightarrow p\omega$

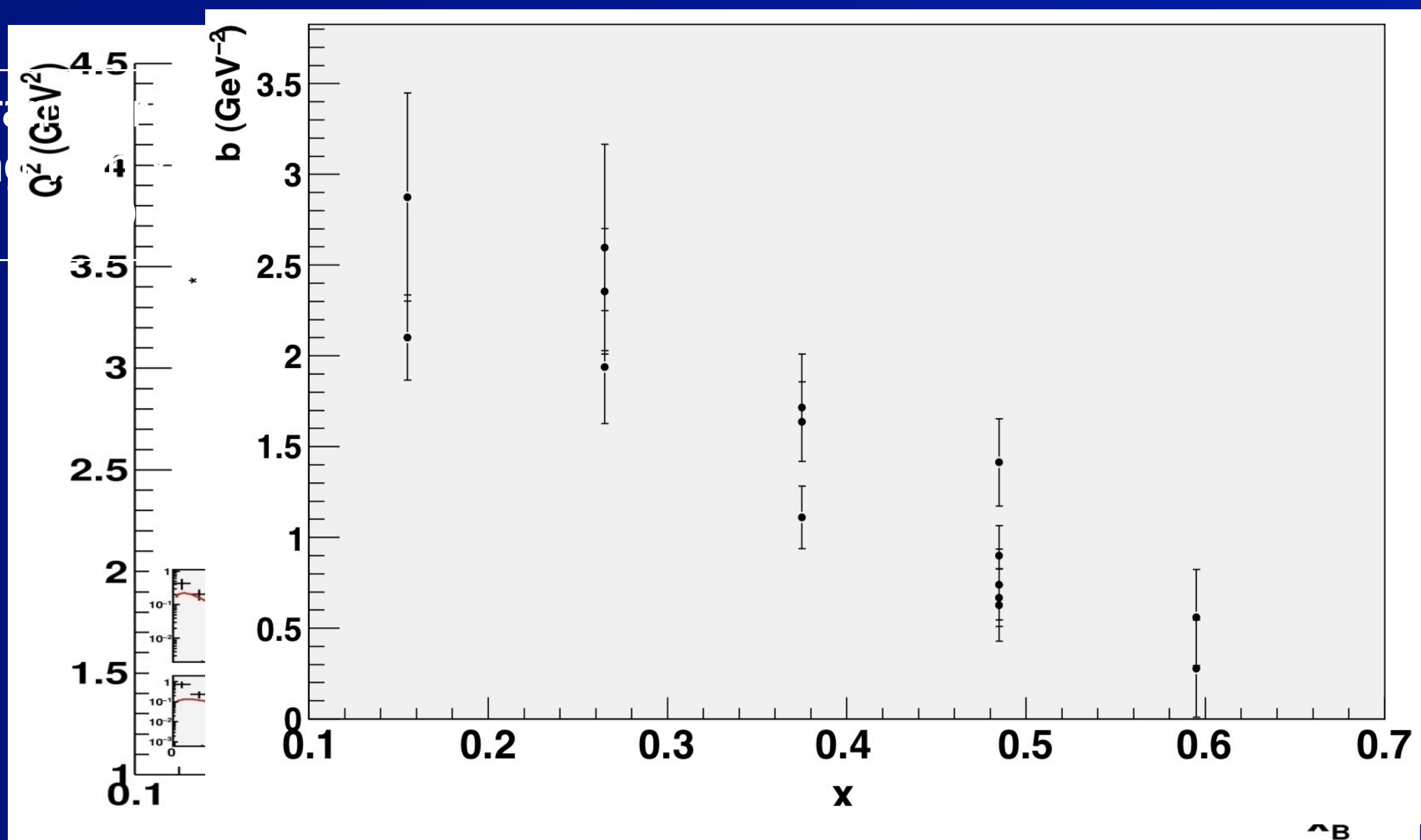


$\gamma^* p \rightarrow p\phi$

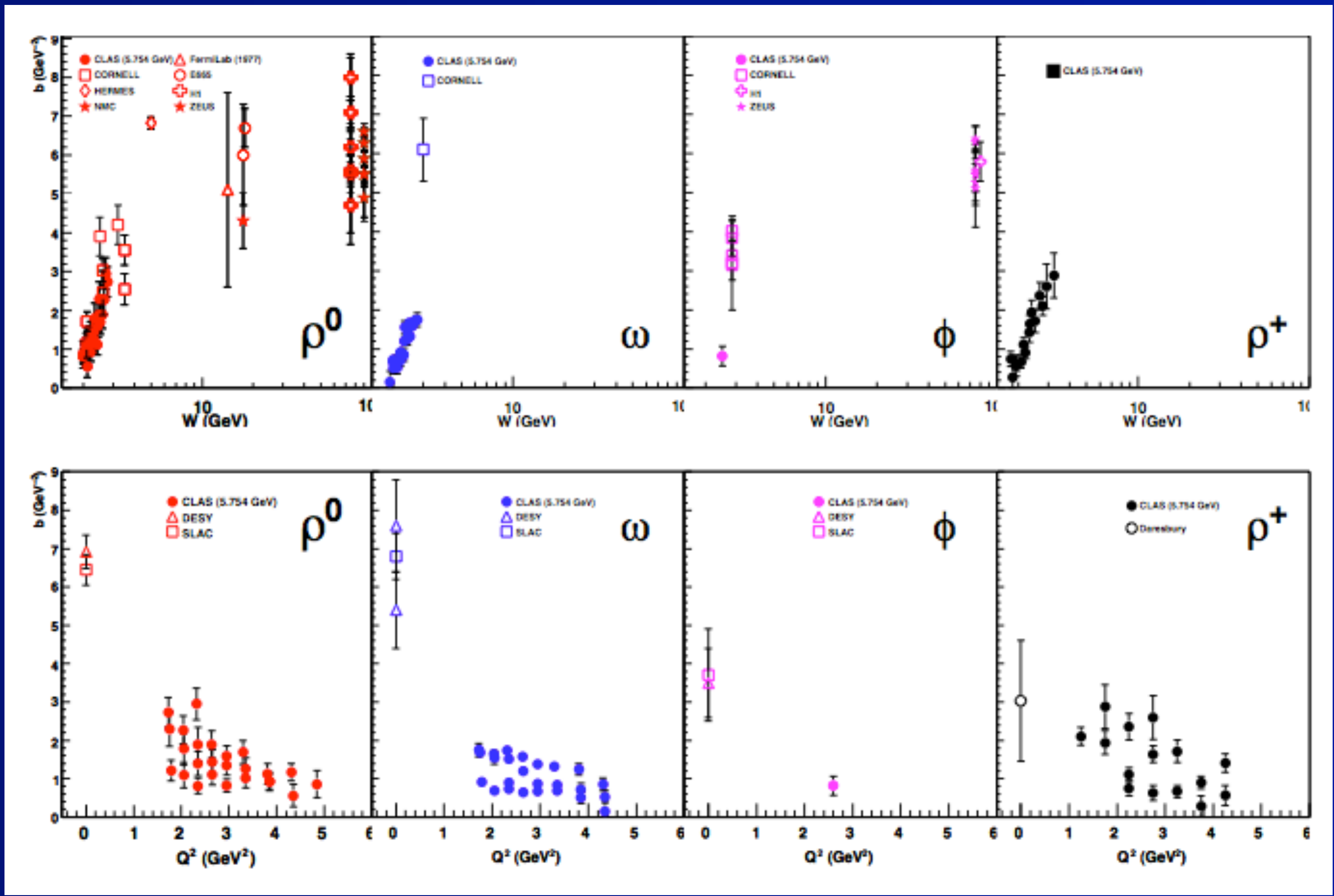


$$\frac{d\sigma}{dt}(\gamma^* p \rightarrow en\rho^+) \propto \sqrt{-t}\, e^{bt}$$

Slope para
decreasin
similar to



Vector mesons b-slope parameter



W

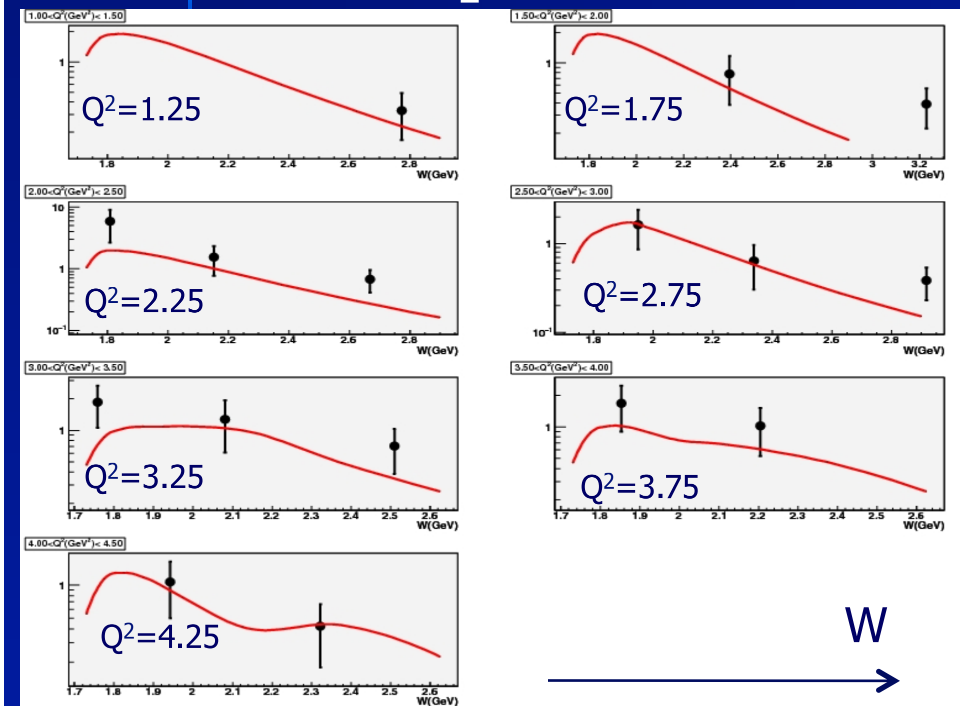
Q^2

σ_L σ_T separation

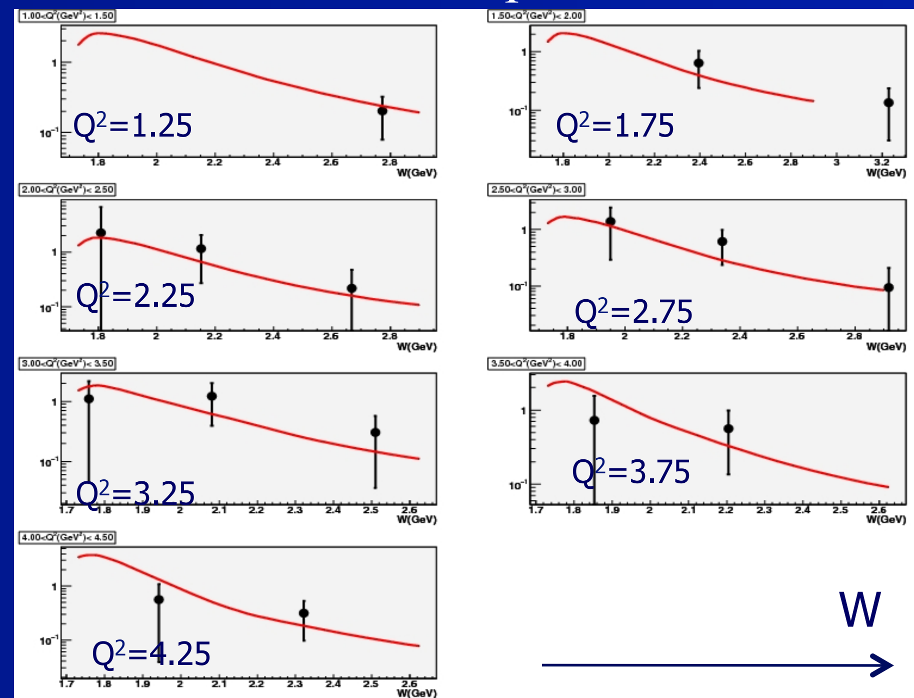
$$\gamma^*_L p \rightarrow p \rho^+$$

SCHC S-channel helicity conservation

σ_L



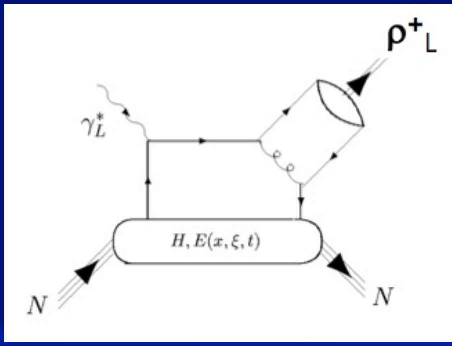
σ_T



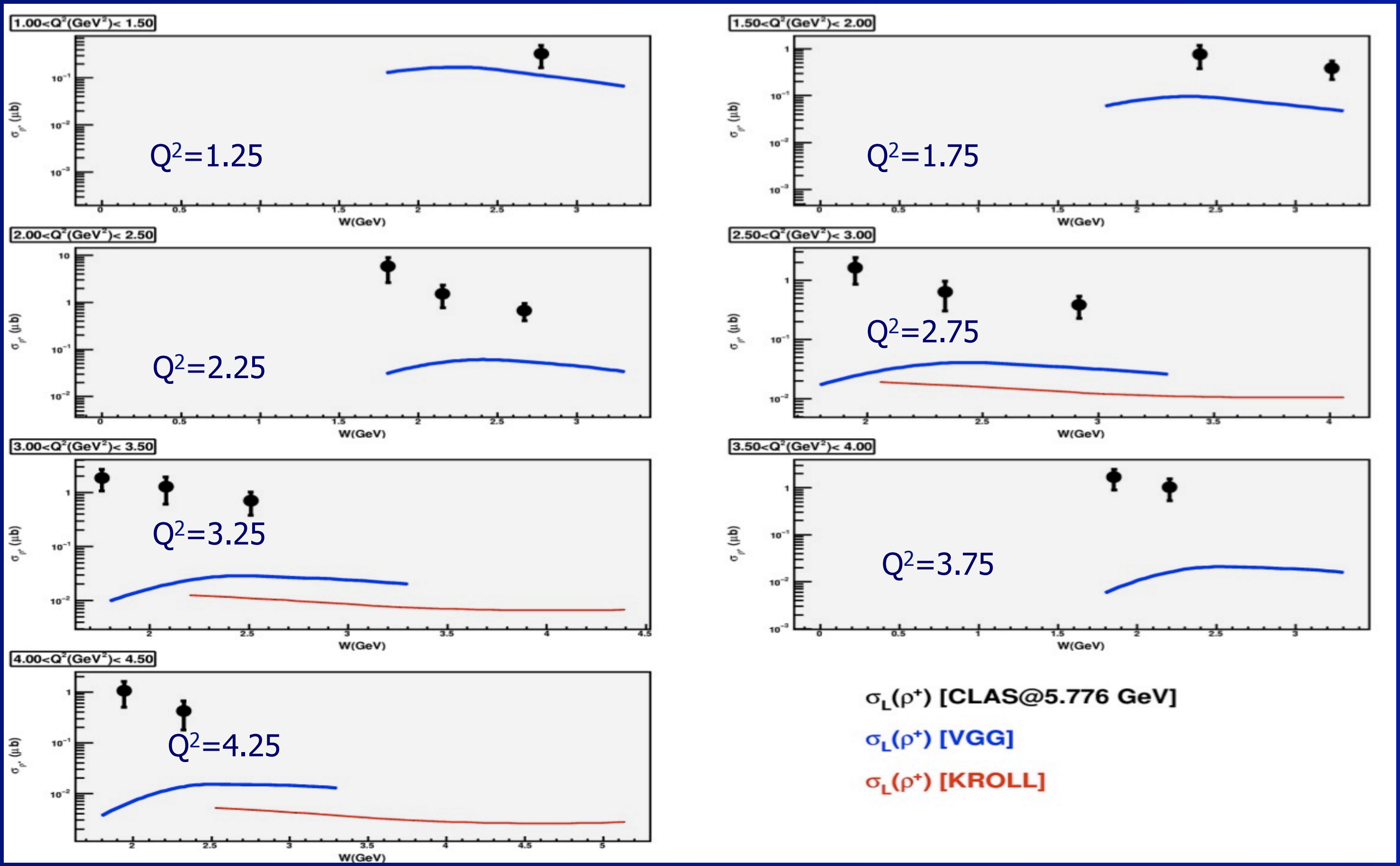
Red lines (Regge model) **:*Laget***, *Phys. Rev.* ***D 65***, *074022 (2002)*

$$\gamma_L^* p \rightarrow n \rho^+$$

CLAS data

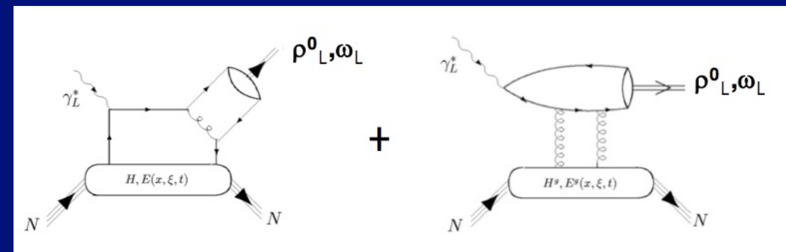


σ_L



GPD fails to describe data by more than order of magnitude

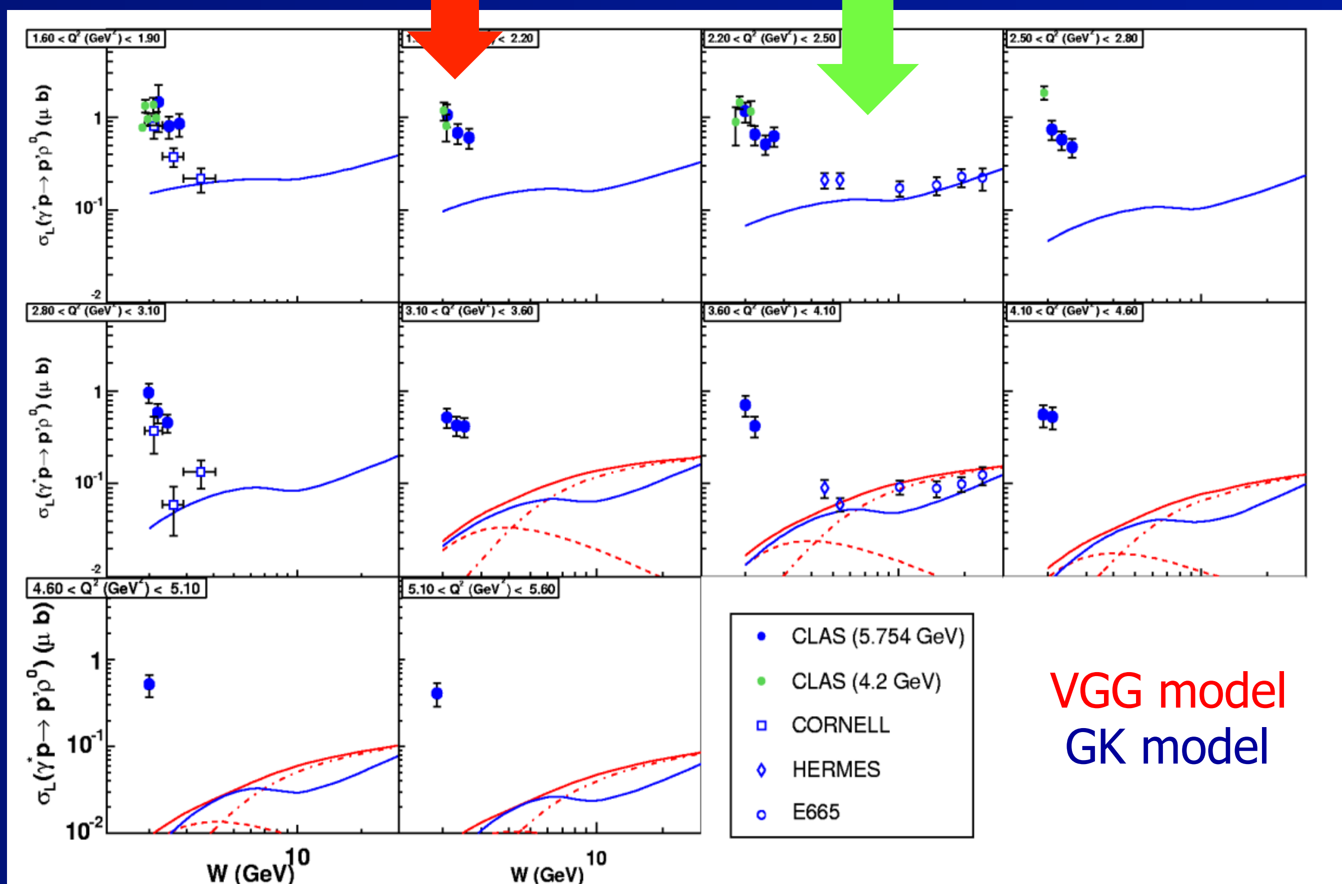
$$\gamma_L^* p \rightarrow p\rho^0$$



Fails to describe data W<5 GeV

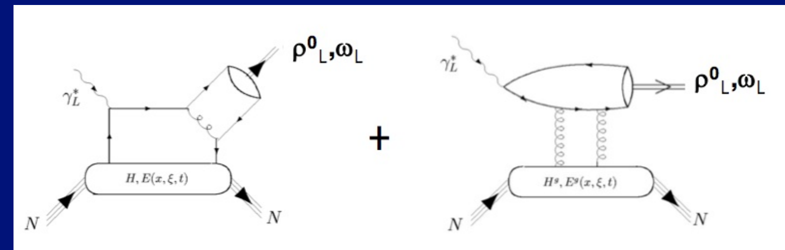
Describes well for W>5 GeV

σ_L



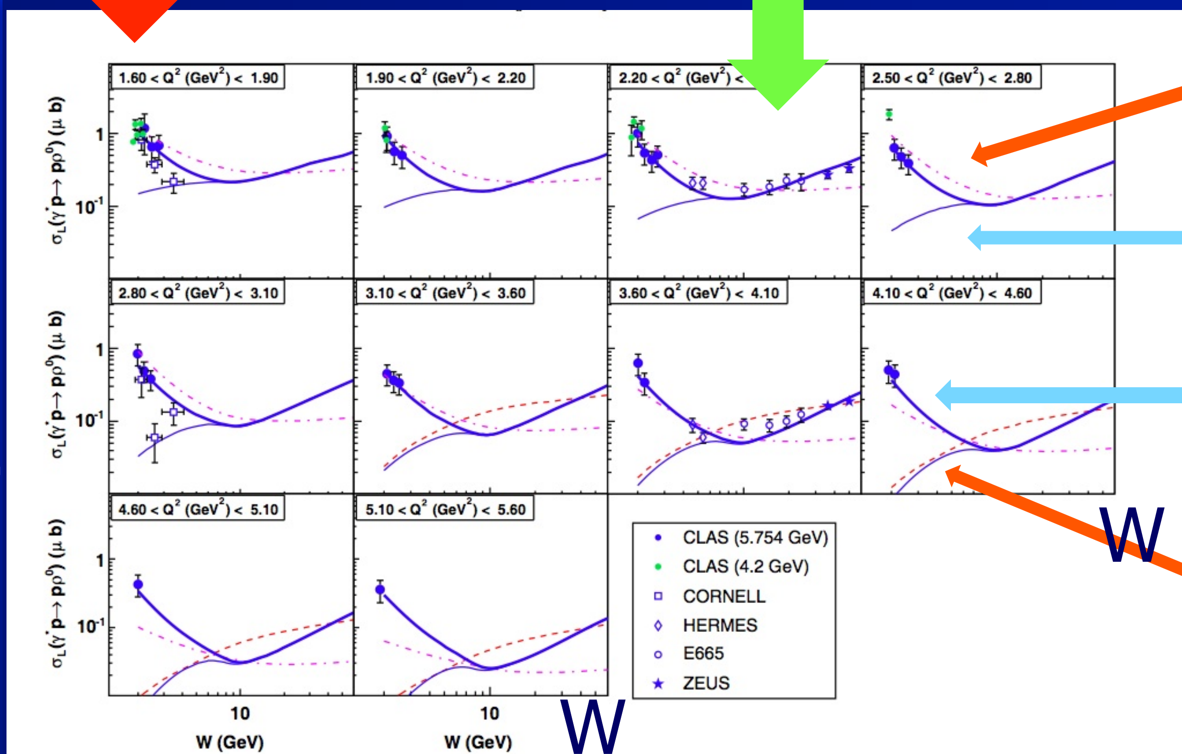
W

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



Fails to describe data W<5 GeV

Describes well for W>5 GeV



σ_L

W

Regge model

VGG model

VGG with D-term

GK model

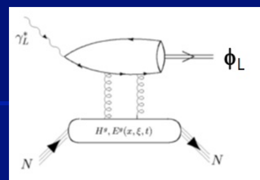
- Popular GK and VGG models can not provide the right W-dependence of the cross-section
- This does not mean that we can’t access GPD in vector meson electroproduction
- For example, adding the so called generalized D-term(M.Guidal) together with standard VGG model successfully describes data

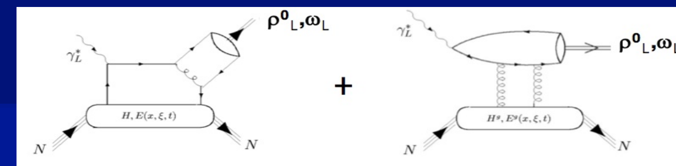
Compare ϕ an ρ^0

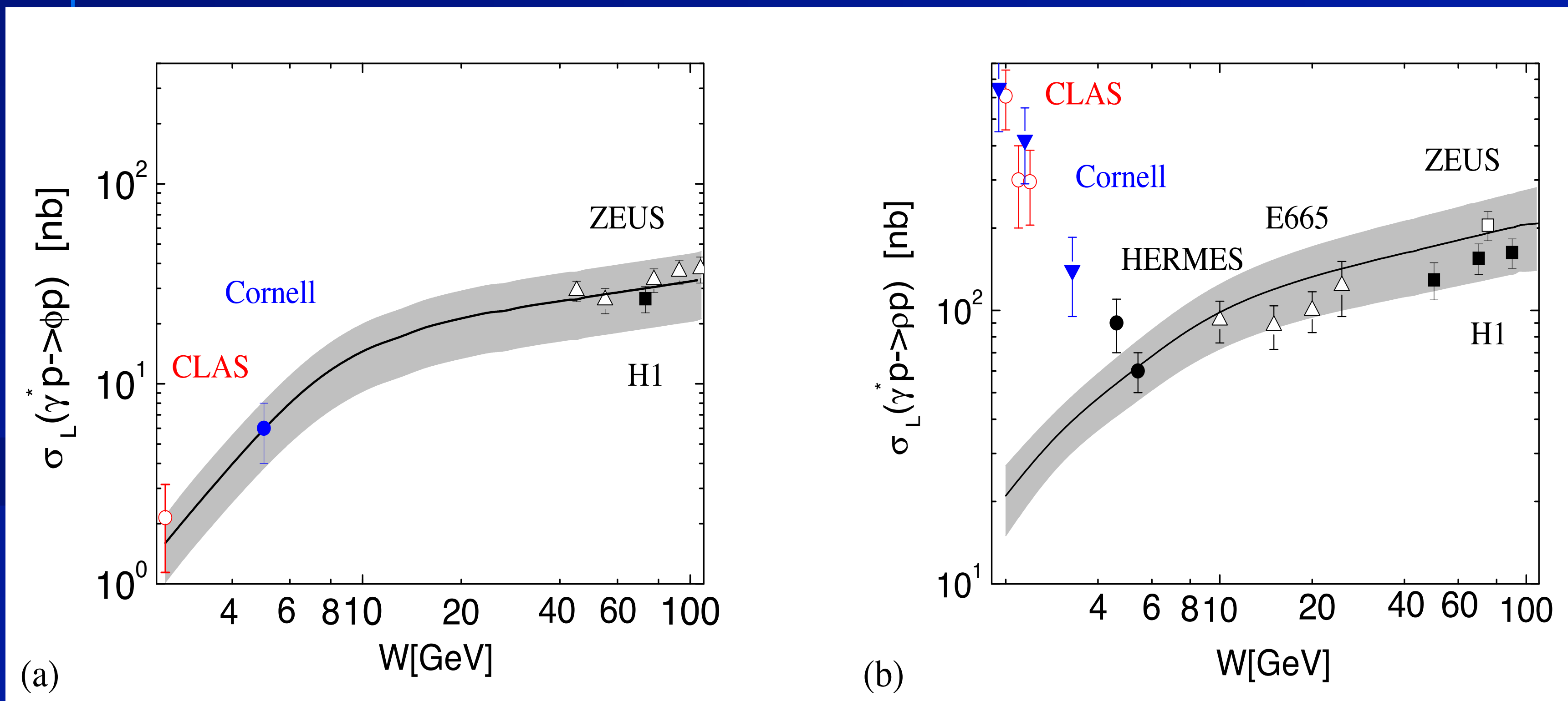
$$\gamma_L^* p \rightarrow p\phi$$

S. V. Goloskokov and P. Kroll

$$\gamma_L^* p \rightarrow p\rho^0$$







- ϕ mesons - gluon GPD are dominant
- ρ^0 and ω – sea quarks and/or gluons dominant.

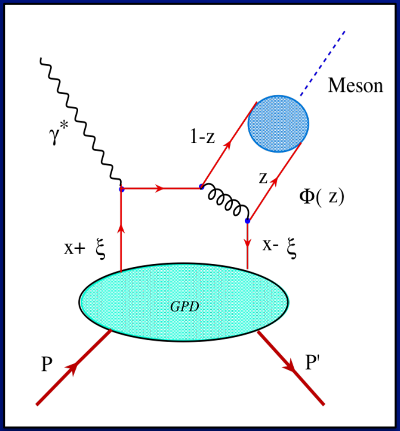
GPD approach describes well data for W>5 GeV

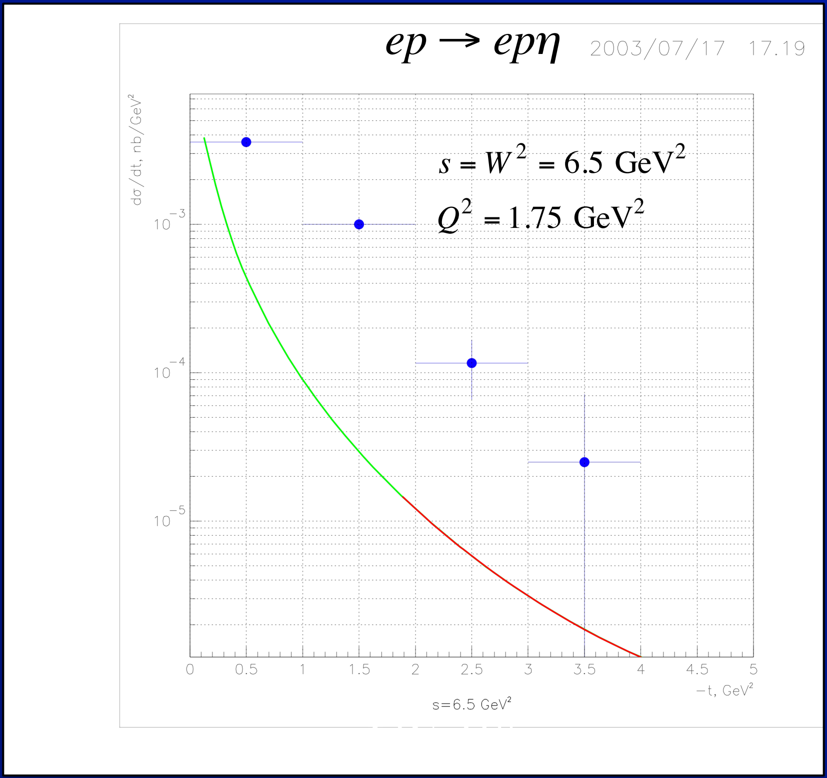
Large angle (high -t), relatively small Q^2

(Analog to WACS where handbag works very well)

$$\frac{d\sigma_L^M}{dt} \propto \int_0^1 d\tau \phi(\tau) R(t,\tau) \qquad R(t) \to R_V^M \, R_V^{Mg} R_A^M \, R_V^M$$

$$R_V^M(t) = \int_{-1}^{1} \sum_q \frac{dx}{x} H^q(x,t) \quad R_T^M(t) = \int_{-1}^{1} \sum_q \frac{dx}{x} E^q(x,t) \quad R_A^M(t) = \int_{-1}^{1} \sum_q \frac{dx}{x} \widetilde{H}^q(x,t)$$





CLAS data: Kubarovsky

GPD model: Huang and Kroll

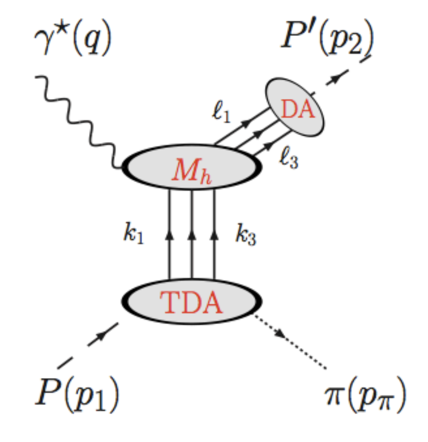
High-t, Large Q^2

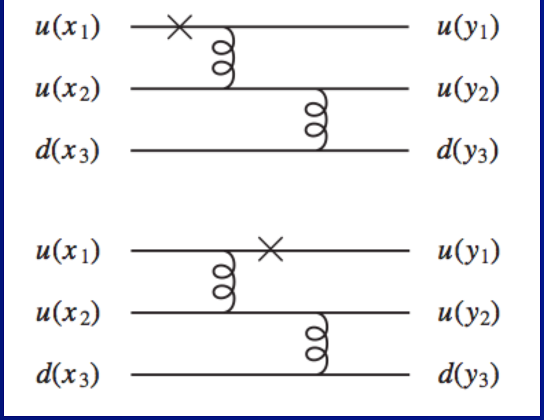
From GPDs to TDAs

- GPDs are not the adequate tool for describing backward hard electroproduction
- Basic difference forward vs backward is the exchange of $q\bar{q}$ vs qqq

TDAs: Transition distribution amplitudes

Lansberg, Pire, Szymanowski



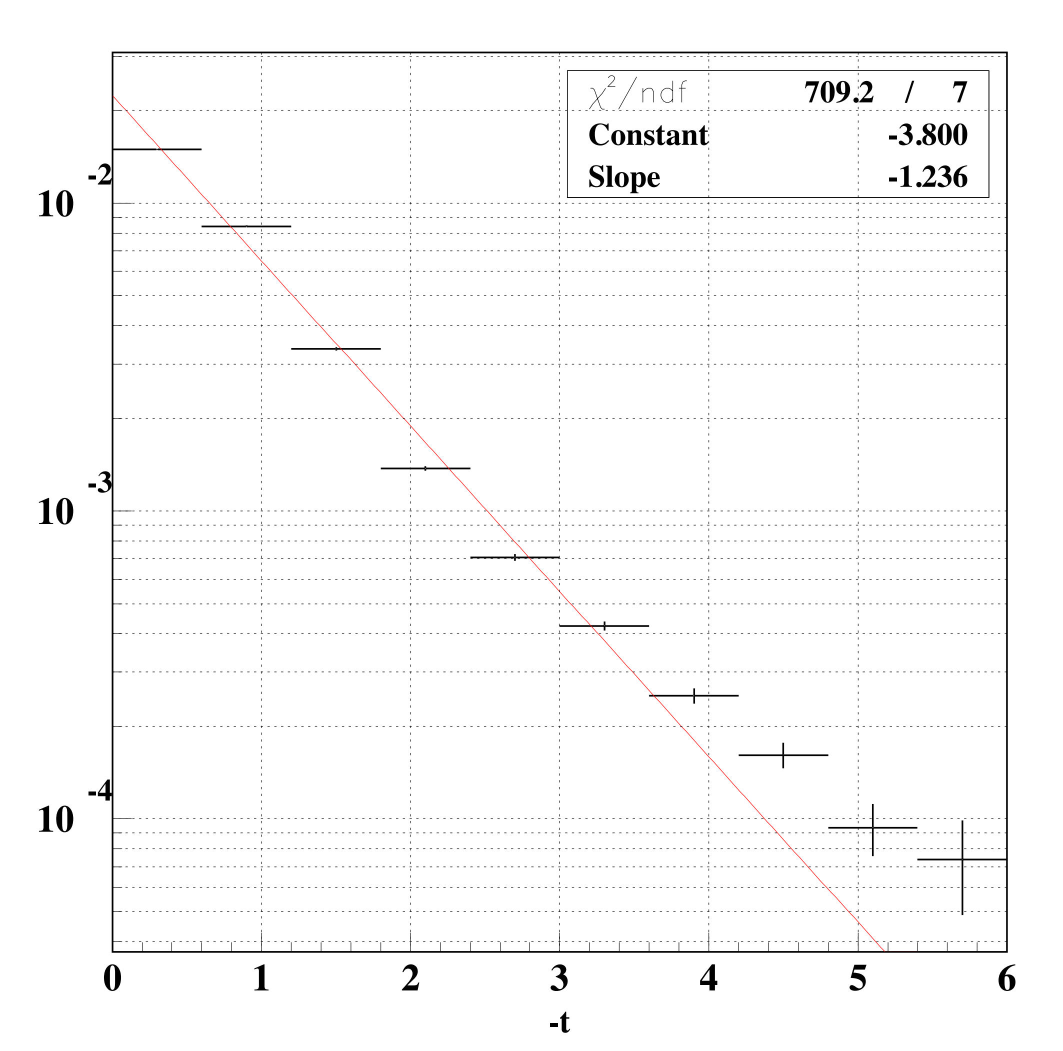


- In backward meson electroproduction there is factorization of a non-perturbative part describing a baryon to meson transition and perturbative part $\gamma^* qqq \rightarrow qqq$ transition
- TDAs provide information on Fock state of the proton with small b_T for quark triplet or how to find a meson in a proton.
- As for GPDs, the t dependence of TDAs maps the transverse position b_T of quarks

t - distribution

$ep \rightarrow ep\pi^0$

Q^2>1 GeV^2
W> 2 GeV
x_B>0.1

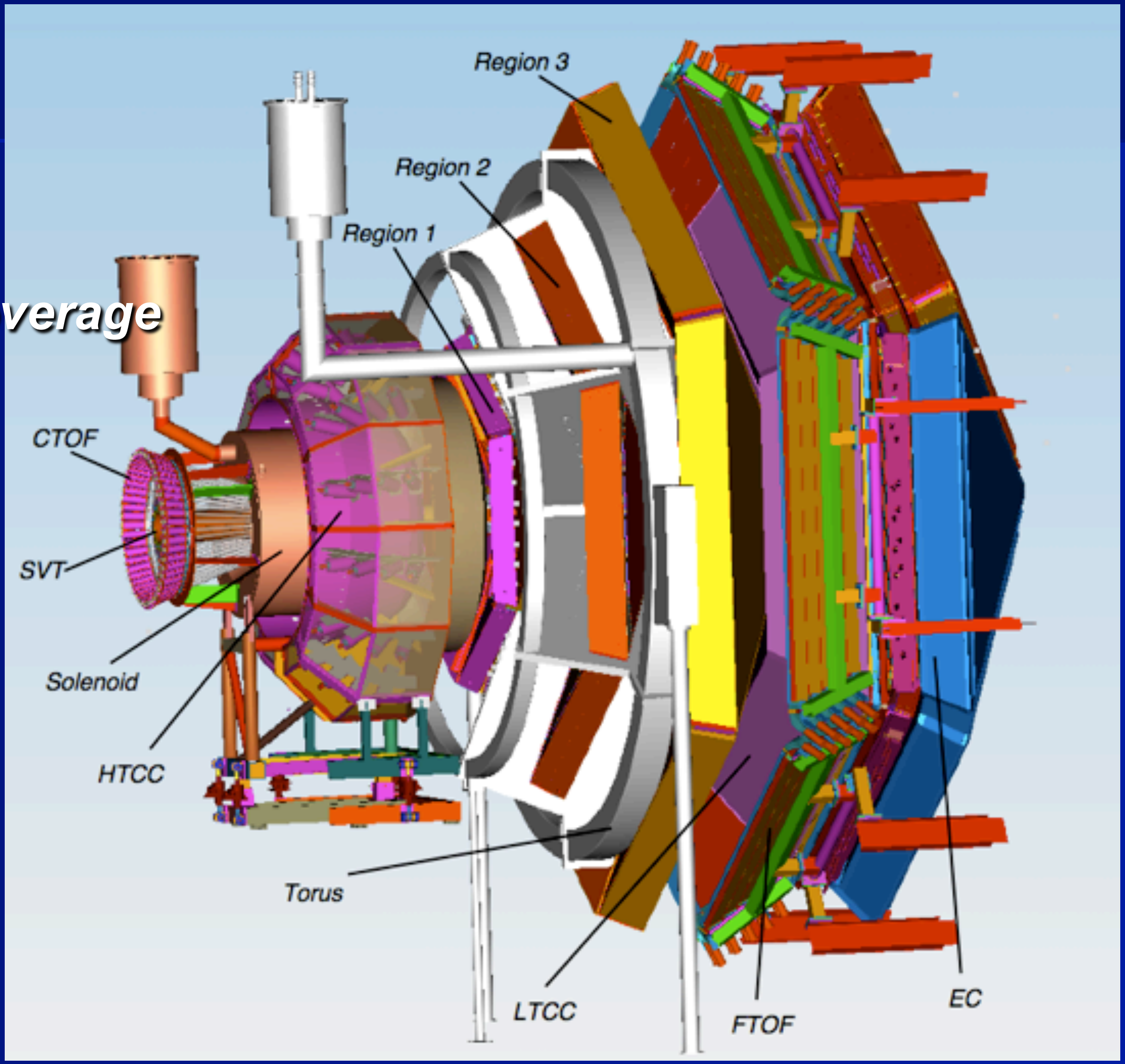


GeV^2

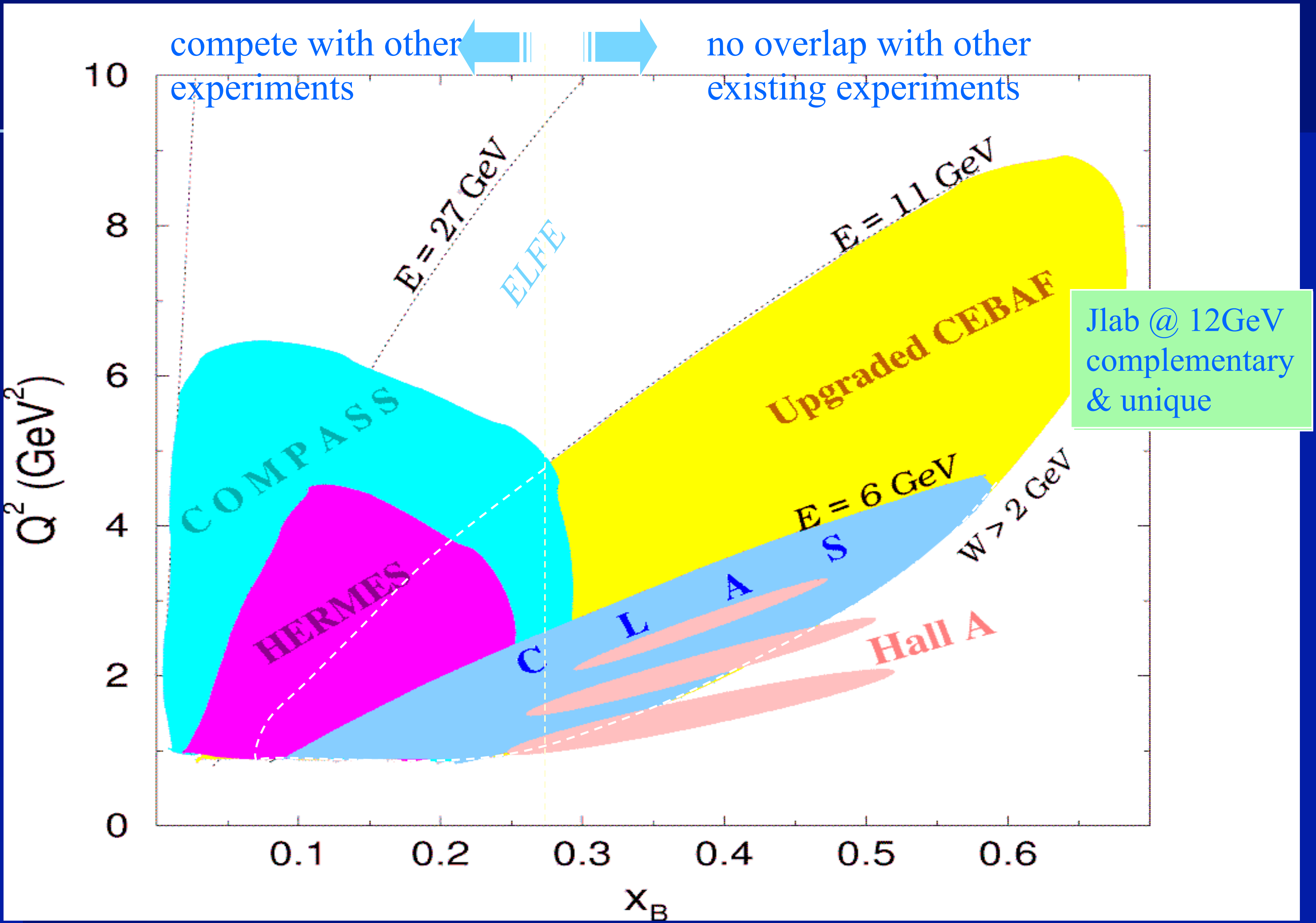
JLab 12 GeV Upgrade

CLAS12

- High luminosity
- Large acceptance
- Wide kinematic coverage
- High precision

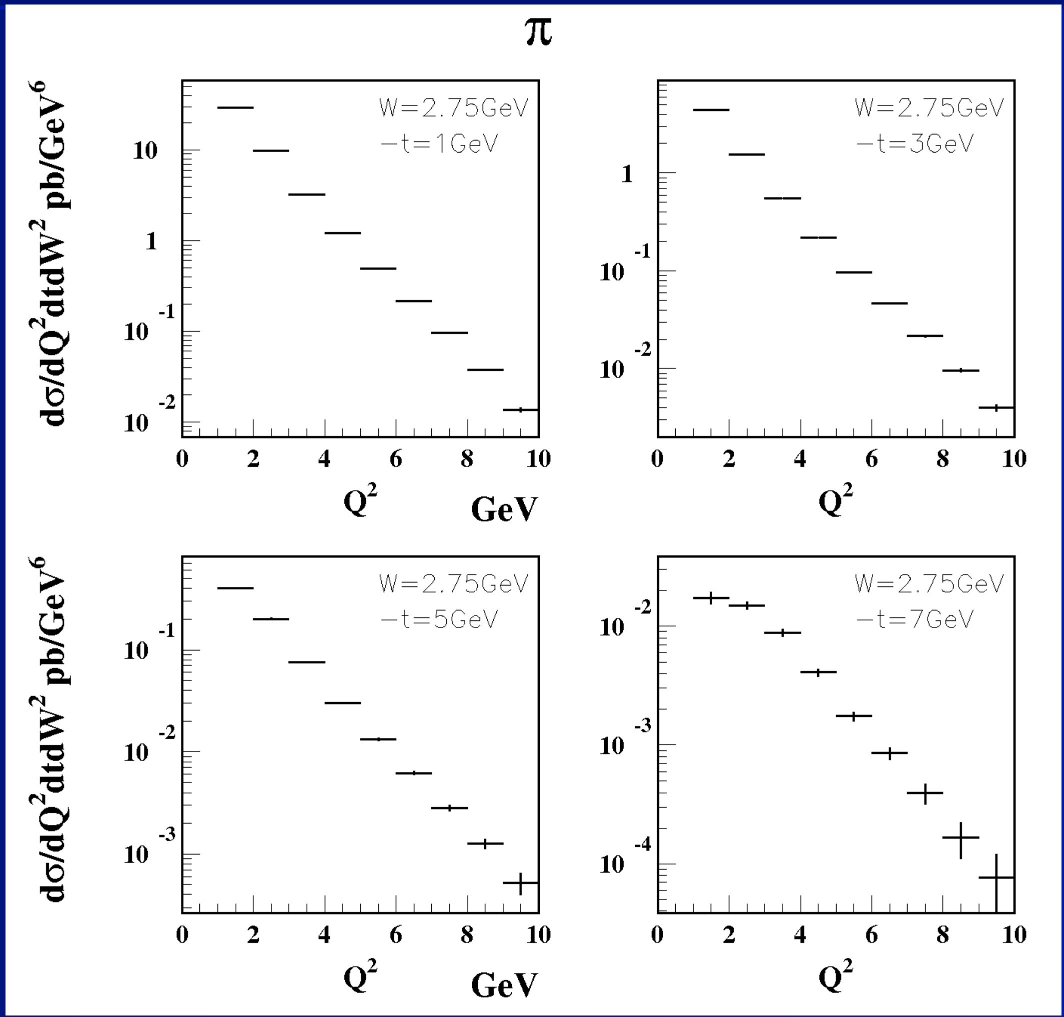


Kinematics coverage for deeply exclusive experiments



Projected measured cross sections.

$ep \rightarrow ep\pi^0$



New PAC38 Proposal (2011)

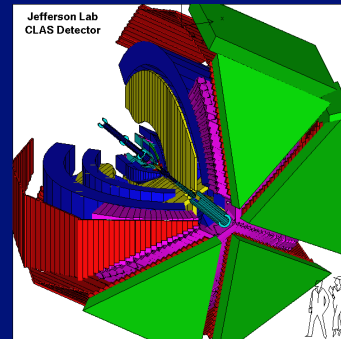
Deep Virtual Exclusive Vector Meson Electroproduction

$$ep \to en\phi, \quad \phi \to K^+K^- \qquad ep \to ep\rho^0, \quad \rho^0 \to \pi^+\pi^-$$

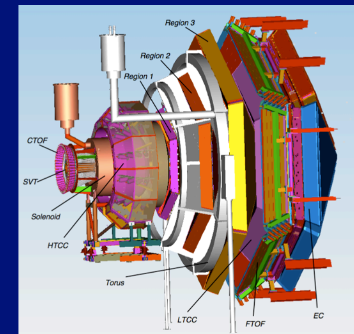
$$ep \to ep\omega, \quad \omega \to \pi^+\pi^-\pi^0 \qquad ep \to en\rho^+, \quad \rho^+ \to \pi^+\pi^0$$

- Kinematics:
  - Q^2 from 3 – 10 GeV^2
  - $-t$ from .5 to 10 Gev^2
  - W from 2-4 GeV^2
- Run simultaneously with DVCS
- Simulations for ϕ, ρ^0 , ρ^+ ,ω are beginning.
- Isolating K's over entire kinematic range.

Summary



2015



- Deeply Virtual Meson Production has the potential to probe the nucleon structure at the parton level, as described by Generalized Parton distributions (GPDs).
- The most extensive set of π^0, η, ρ^+,ρ^0,ω, and f electroproduction to date has been obtained with the CLAS spectrometer.
- The approach to the hard regime can be studied experimentally using model-independent tests which probe qualitative features like t-slope as function of Q^2 and x_B
- CLAS12 program of pseudoscalar and vector electroproduction will provide unique information about the:

  -transition between soft long-range phenomena and hard short range.
  -quark momentum and spin distributions of the nucleons.
  -gluon and quark GPDs