Deeply Virtual Pseudoscalar Meson Electroproduction

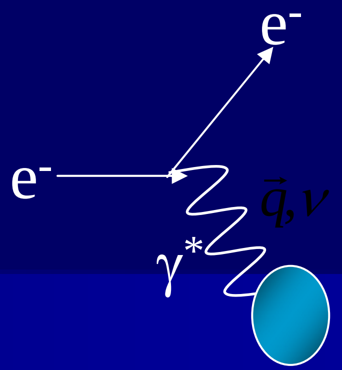
Valery Kubarovsky

Rensselaer Polytechnic Institute / Jlab

Outlook

- Physics Motivation
- e1-dvcs experiment (CLAS/Jlab)
- π/η electroproduction at 5.7 GeV
  - Cross section
  - Beam spin asymmetry
- Current status and future opportunities
- Conclusion

Introduction



- Deeply virtual exclusive reactions

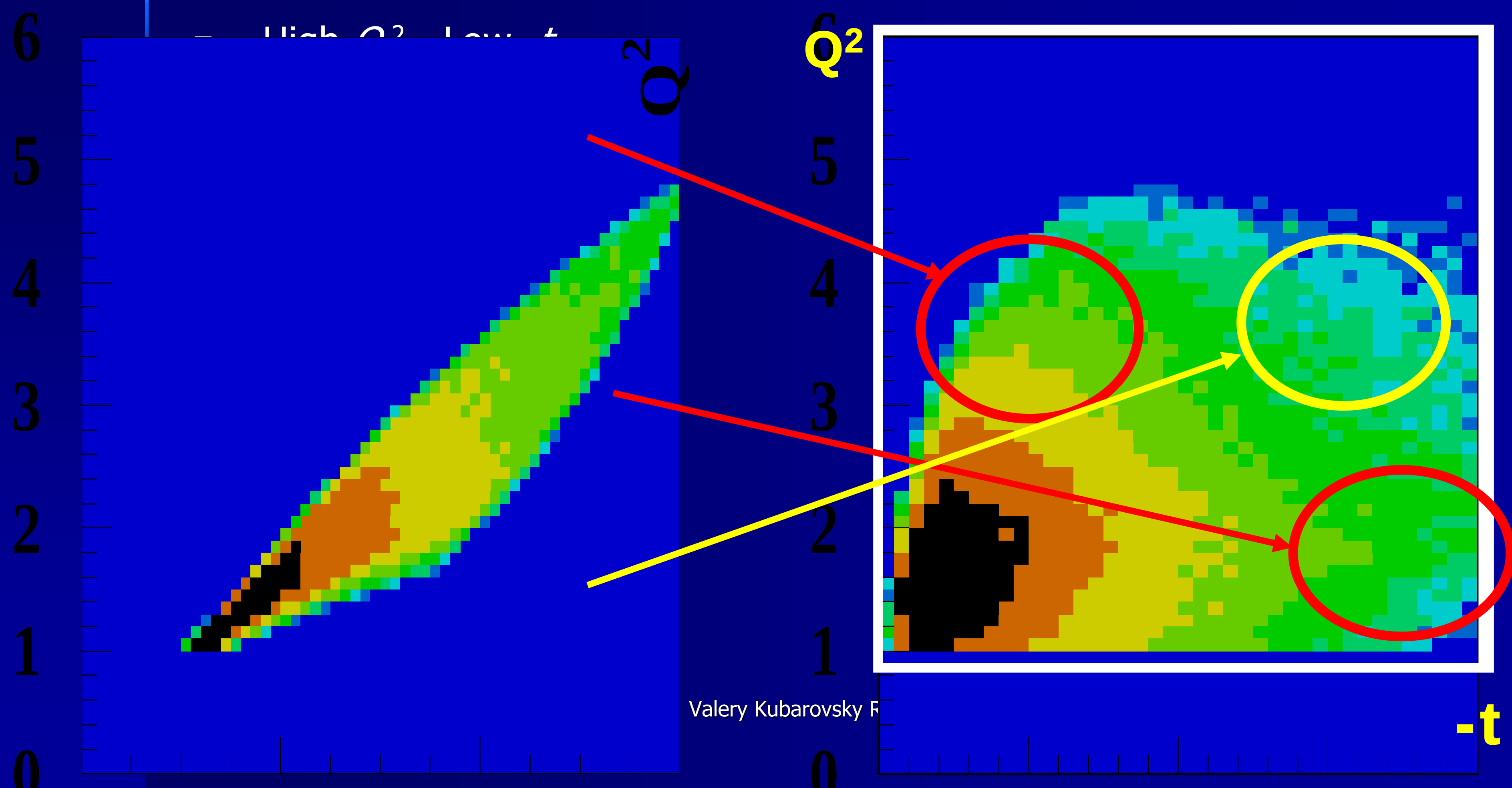
  $$\gamma^*(Q^2) + N \to N + M \quad (M = \gamma, \text{meson})$$

  offer a unique opportunity to study the structure of the nucleon at the parton level as one varies both the size of the probe – the photon virtuality, Q^2 – and the momentum transfer to the nucleon, t
- Such processes can reveal much more information about the structure of the nucleon than either inclusive electroproduction (Q^2 only) or elastic form factors ($t=- Q^2$)
- The basic for these considerations is the existence of the QCD factorization theorems

Kinematic regions (Q^2-t)

Kinematical Coverage

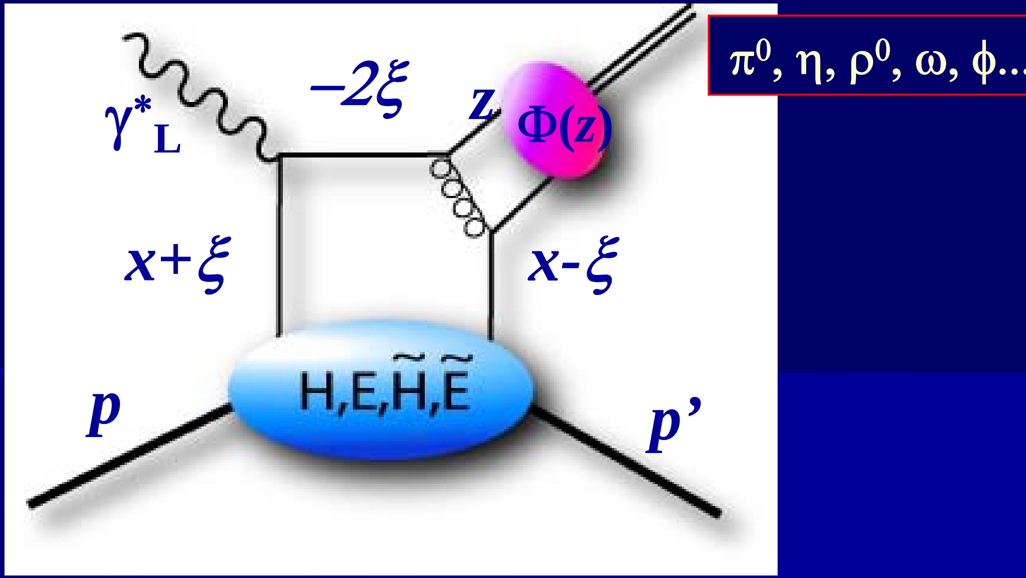
- High Q^2, Low -t



Factorization Theorem

Collins,Frankfurt,Strikman -1997

High Q² Low t Region



- Factorization theorem states that in the limit $Q^2 \rightarrow \infty$ exclusive electroproduction of mesons is described by hard rescattering amlitude, 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
- $Q2 \rightarrow \infty$ $\sigma_L \sim 1/Q^6$, $\sigma_T/\sigma_L \sim 1/Q^2$
- The full realization of this program is one of the major objectives of the 12 GeV upgrade

Factorization in the High t Low Q2 Region

Radyushkin 1998
Diehl et al, 1998
Huang, Kroll, 2000

- It has been argued that exclusive production of photons and mesons at large t, effectively proceeds via a partonic mechanism, and can be again be described in terms the GPD in the nucleon
- Theory predicts σ_L and σ_T in this kinematics

Pseudoscalar Mesons

- In the case of pseudoscalar meson production the amplitude involves the axial vector-type GPDs
- These GPDs are closely related to the distributions of quark spin in the proton. The function $\tilde{H}, \tilde{E}$ reduces to the polarized quark/antiquark densities in the limit of zero momentum transfer
- The Fourier transform with respect to t, the so-called impact parameter distributions, describes the transverse spatial distribution of quark spin in the proton.

Flavor Separation and Helicity-Dependent GPDs

- 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.

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	$2u - d$

$\tilde{H}, \tilde{E}$

H, E

"Precocious Factorization"

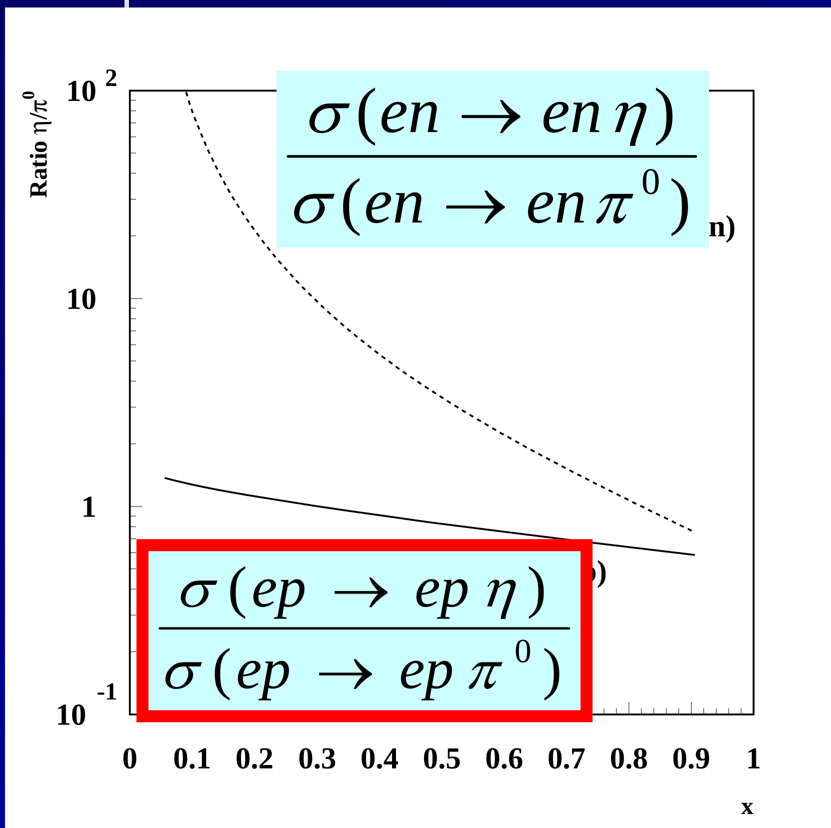
Collins,Frankfurt,Strikman -1997

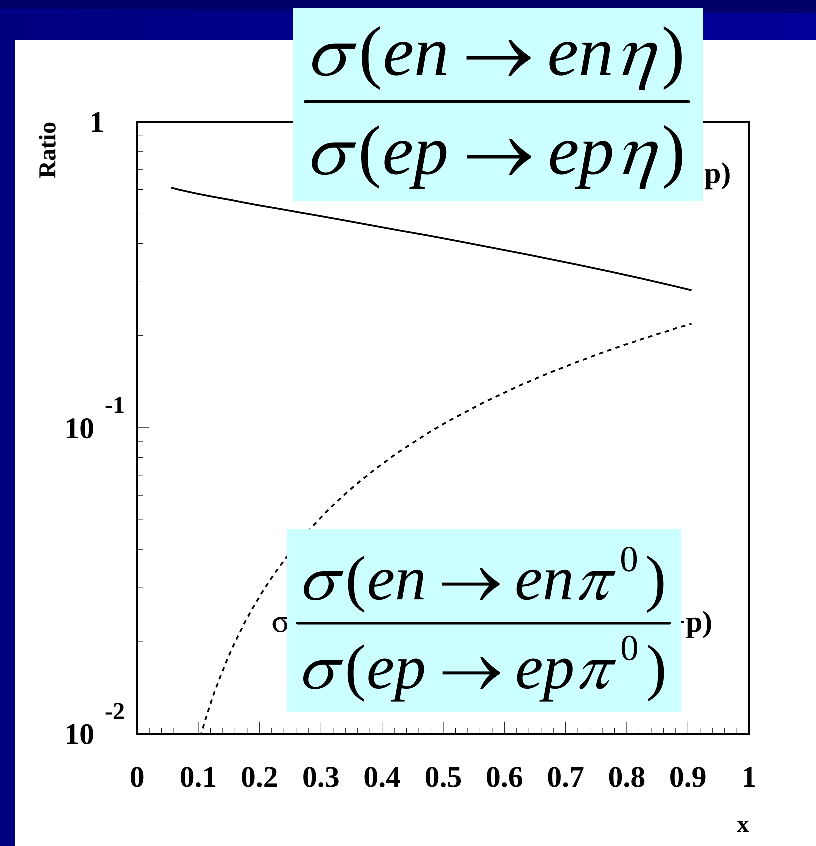
- Precocious factorization could be valid already at relatively low Q^2 especially for ratios of cross sections as a function of x_B
- For example π^0 and η ratio on proton

$$\pi^0 : \eta = \frac{1}{2}\left[\frac{2}{3}\Delta u + \frac{1}{3}\Delta d\right]^2 : \frac{1}{6}\left[\frac{2}{3}\Delta u - \frac{1}{3}\Delta d + \frac{2}{3}\Delta u\right]^2$$

Cross Section Ratios as a function of x_B

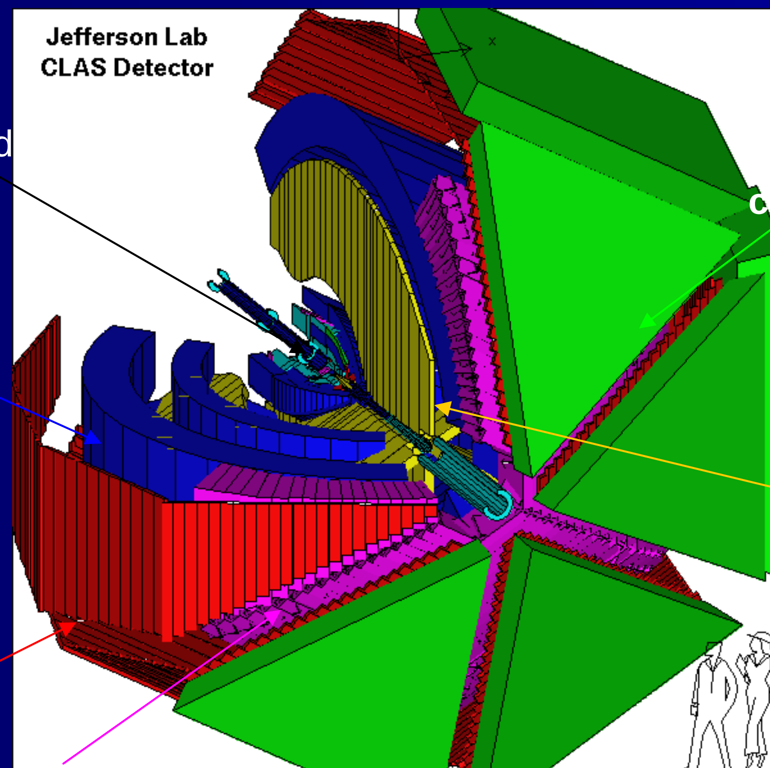
Collins,Frankfurt,Strikman -1997



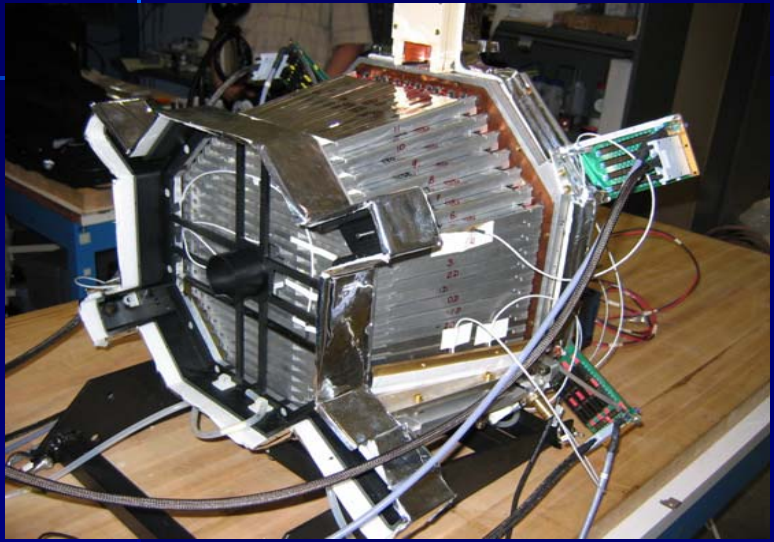


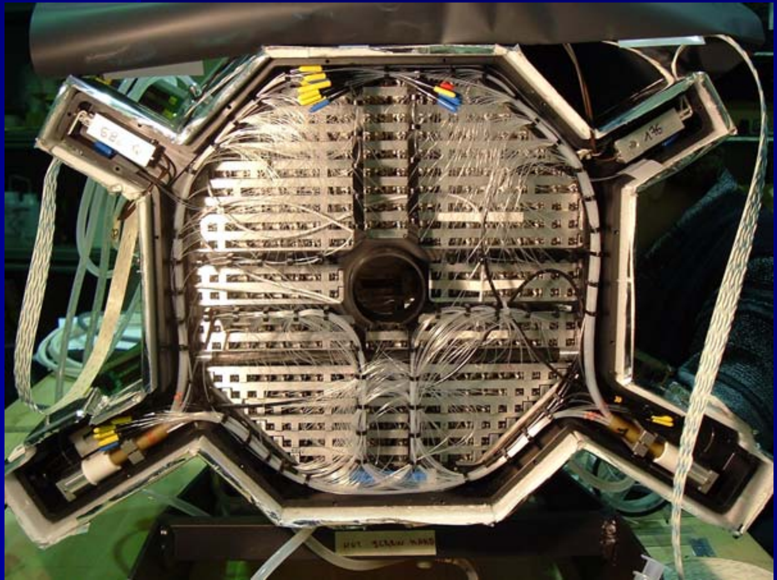
All data are available. η/π^0 ratio from proton data will be released very soon

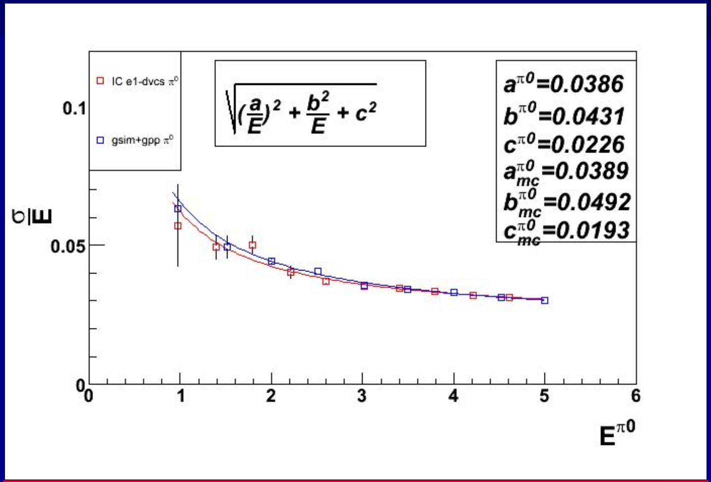
CLAS / Jlab e1-dvcs

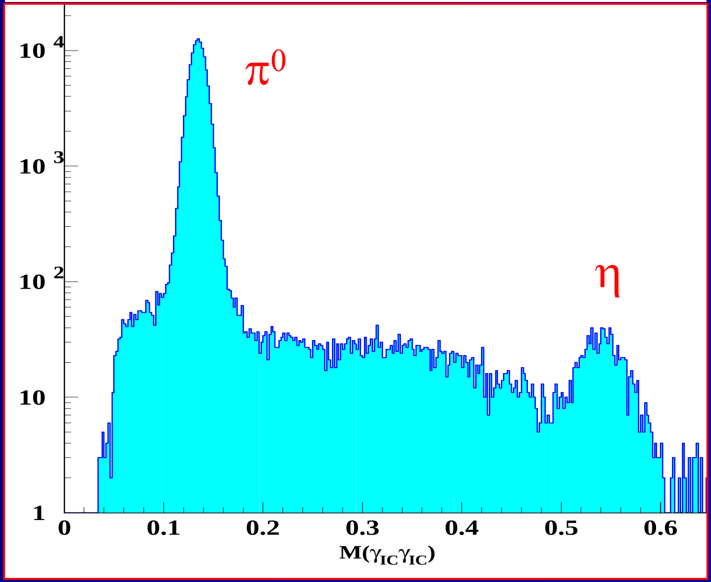


CLAS Lead Tungstate Electromagnetic Calorimeter





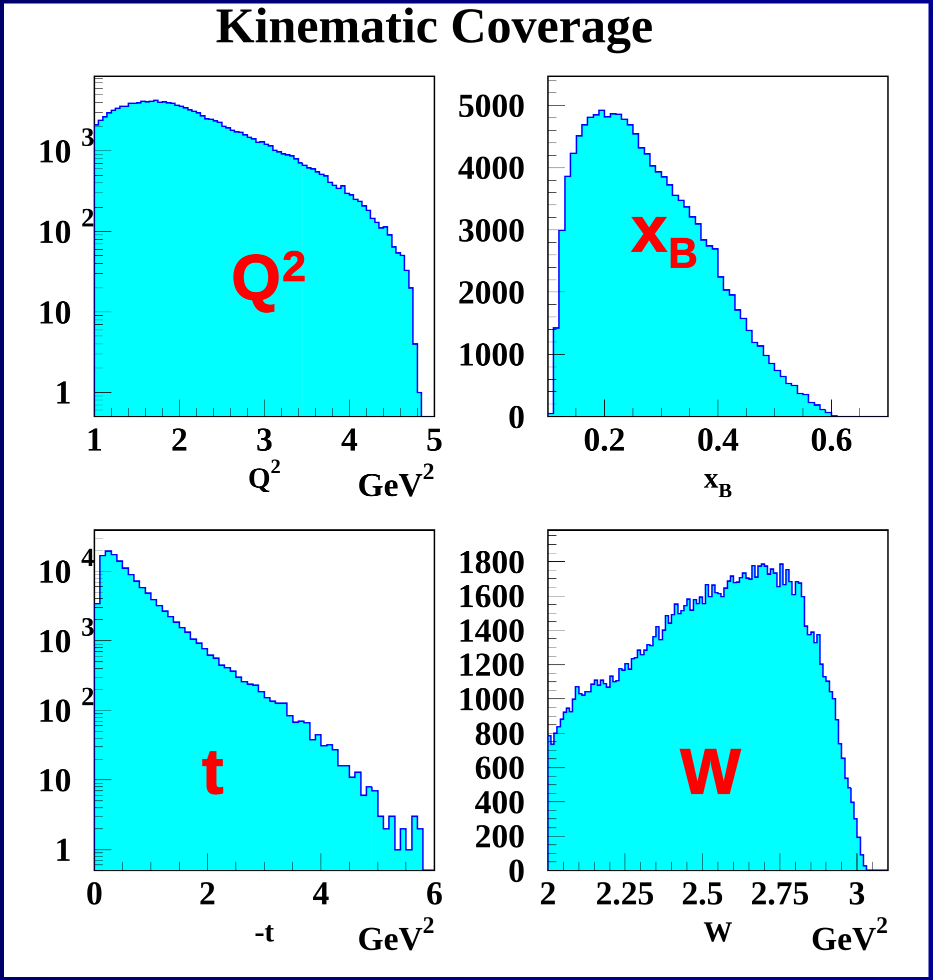




Valery Kubarovsky RPI/Jlab

Kinematic Coverage

4 dimentional grid in Q^2, x_B, t, and ϕ



Remarks on the following slides

- CLAS data
- All data are preliminary
- No radiative correction were applied
- Cross sections are in arbitrary units
- No σ_L/σ_T separation
- 12 GeV: Rosenbluth L/T separation

ϕ Distribution

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

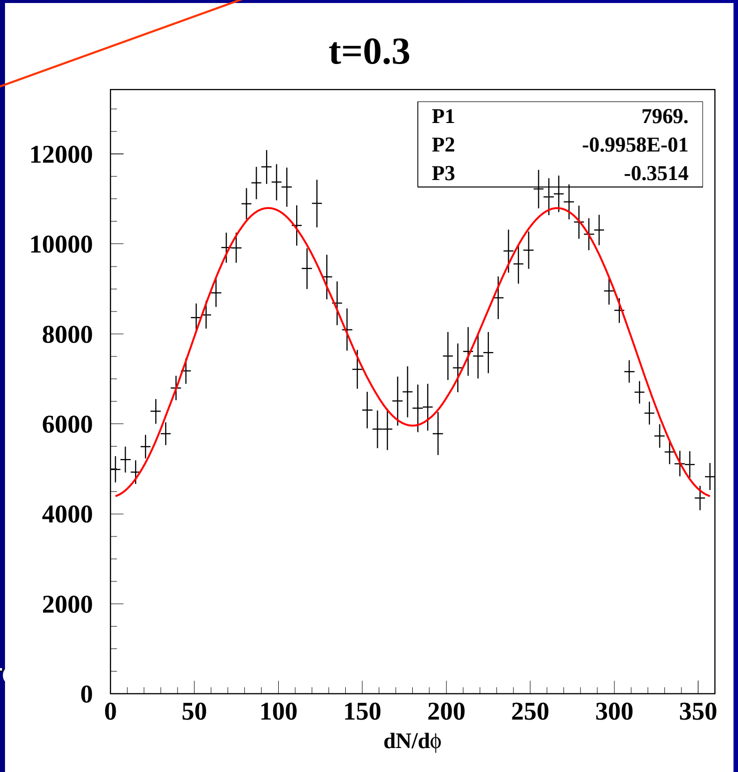
$$\frac{d\sigma}{dt\,d\phi}(Q^2, x, t, \phi) = \frac{1}{2\pi}\left(\frac{d\sigma_T}{dt} + \varepsilon \frac{d\sigma_L}{dt} + \varepsilon \frac{d\sigma_{TT}}{dt}\cos 2\phi + \sqrt{2\varepsilon(\varepsilon+1)}\frac{d\sigma_{LT}}{dt}\cos\phi\right)$$

Fit of the ϕ-distribution gives us three structure functions

$$\frac{d\sigma_T}{dt} + \varepsilon \frac{d\sigma_L}{dt}$$

$$\frac{d\sigma_{TT}}{dt}$$

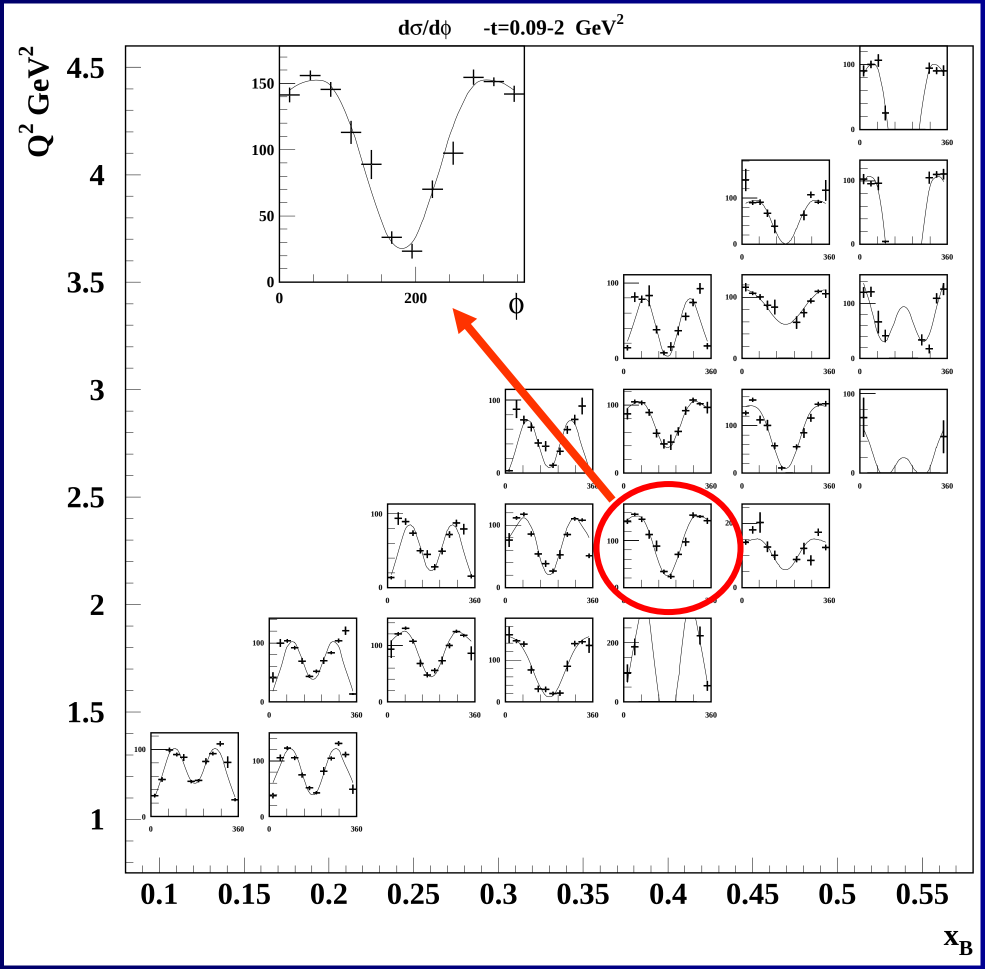
$$\frac{d\sigma_{LT}}{dt}$$



Valery Kubar

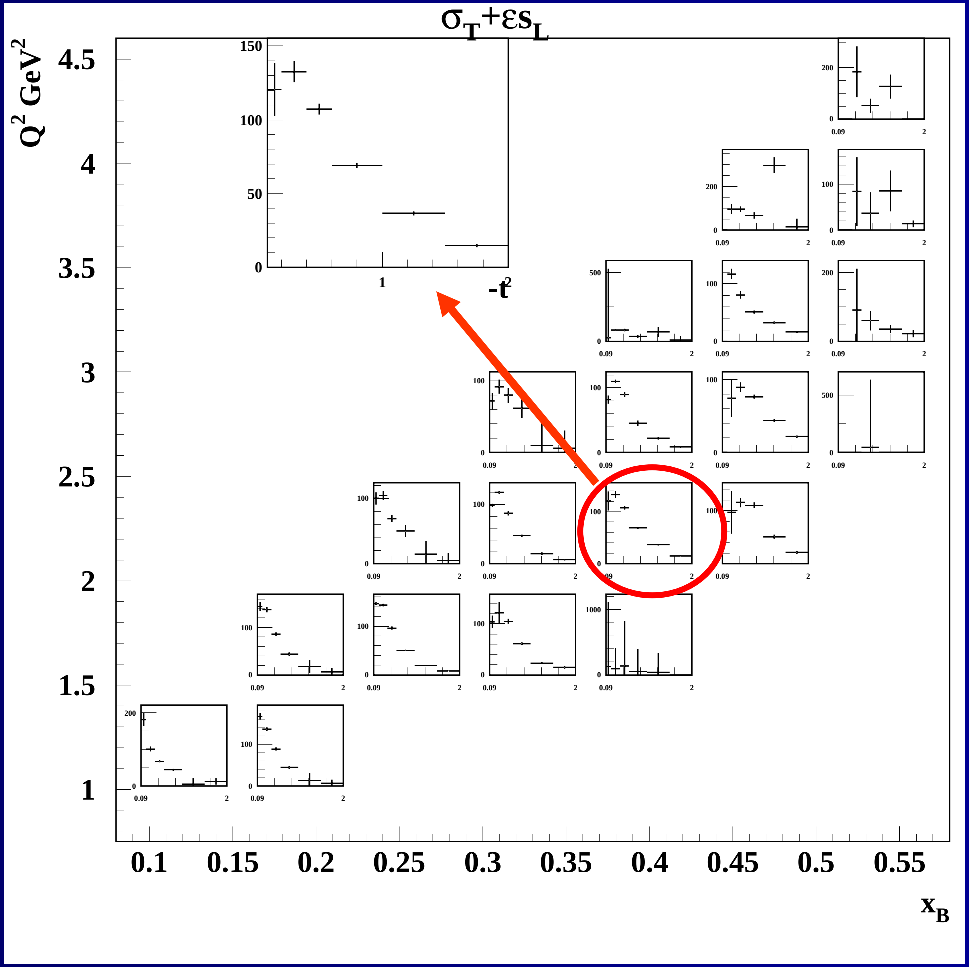
dσ / dϕ

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



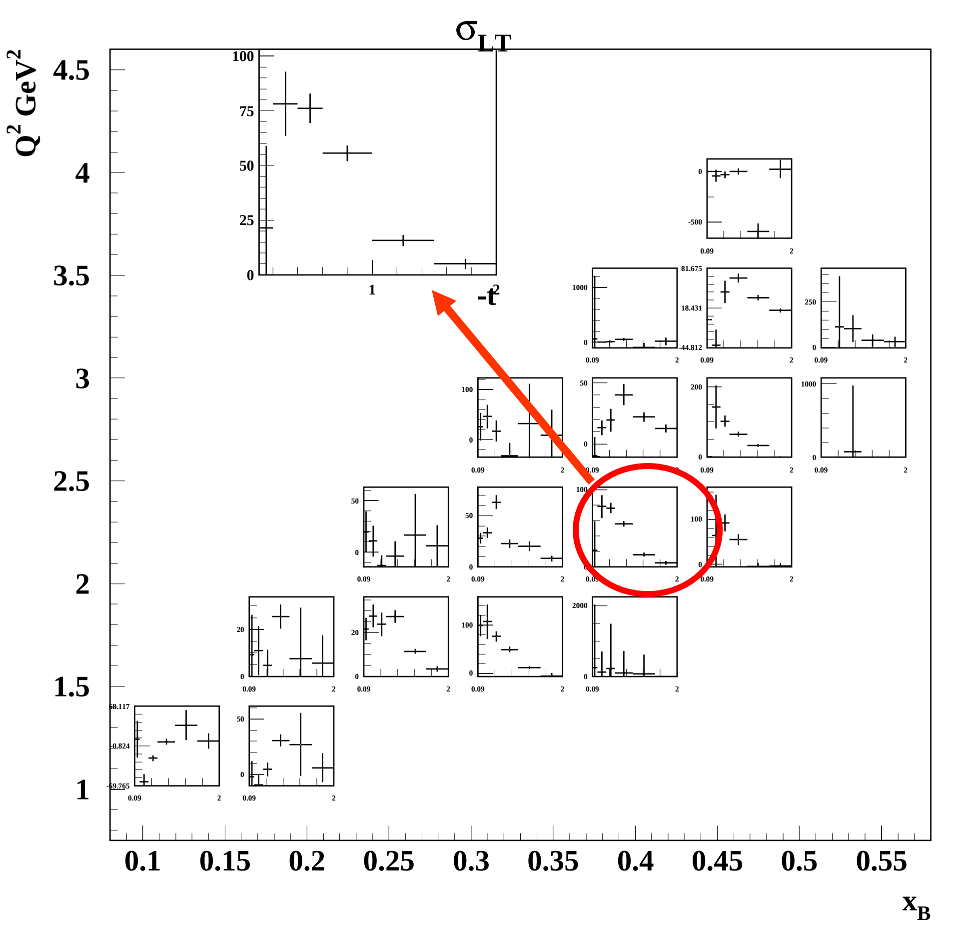
$\gamma^* p \rightarrow ep\pi^0$

$\sigma_T + \varepsilon\sigma_L$ as a function of t



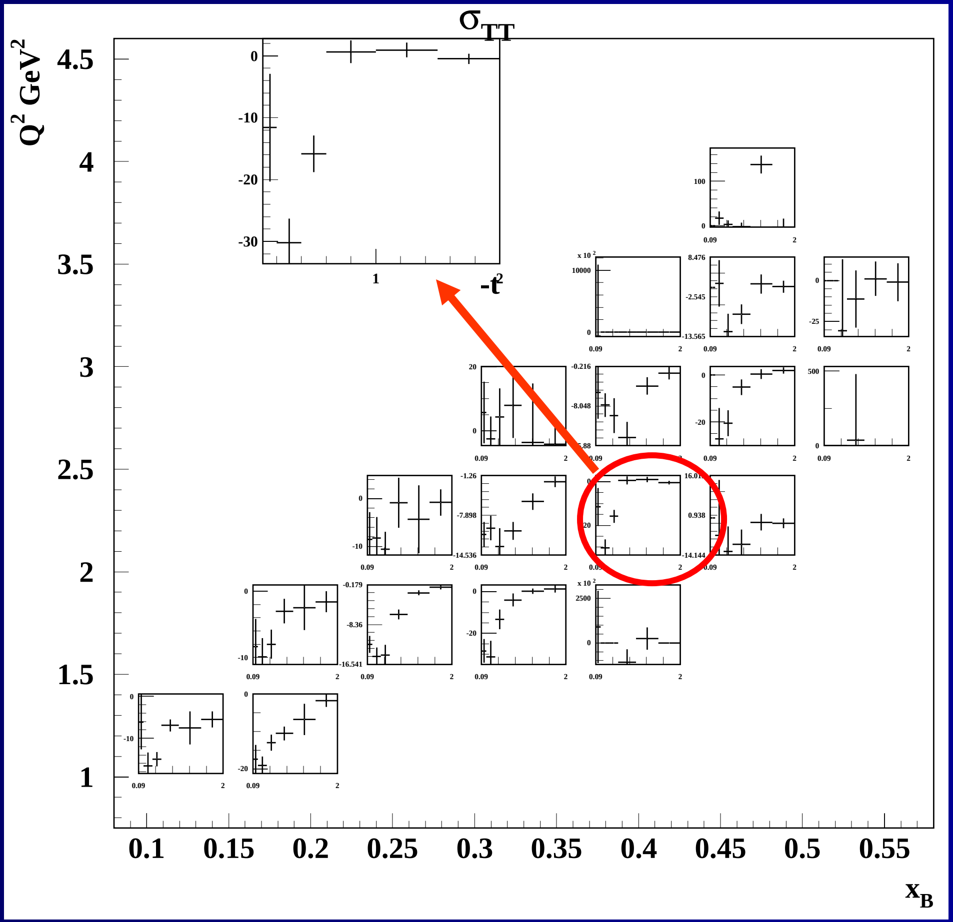
$\gamma^* p \rightarrow e p \pi^0$

σ_{LT} as a function of t



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

σ_{TT} as a function t

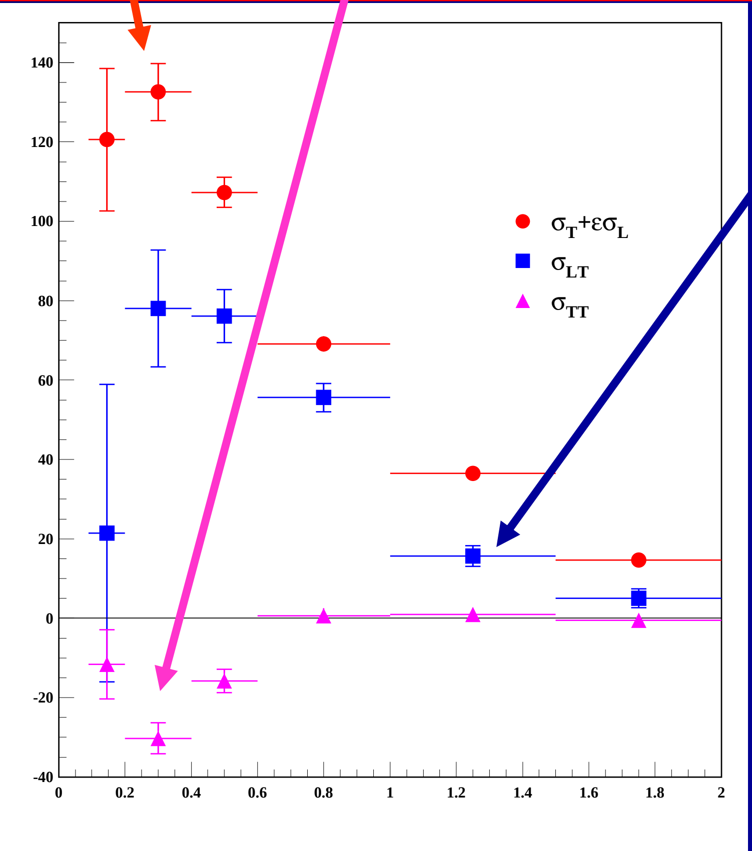


$\gamma^* p \to e p \pi^0$

$(\sigma_T + \varepsilon\sigma_L)$ σ_{TT} σ_{LT} as a function of t

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

Non-zero σ_{TT} and σ_{LT} imply that both transverse and longitudinal amplitudes participate in the process

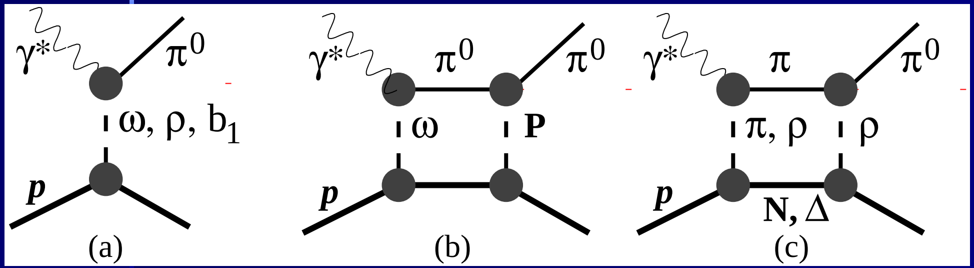


Q^2=2.3
x_B=0.4

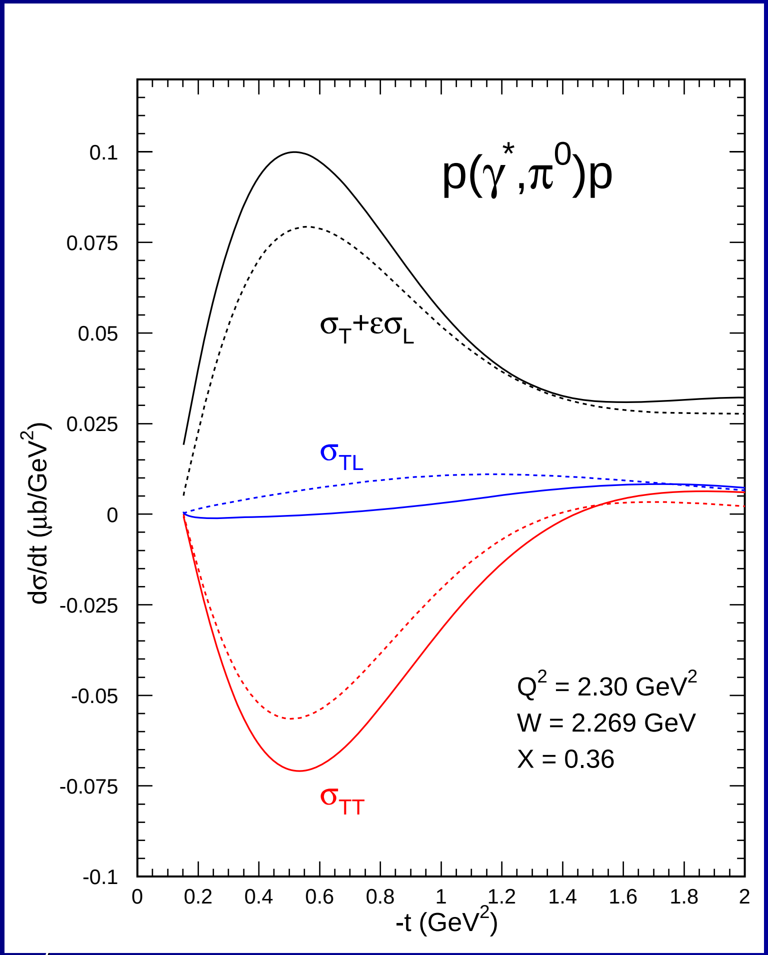
t GeV^2

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

$(\sigma_T + \varepsilon\sigma_L)$ σ_{TT} σ_{LT} in Regge Model (JML)



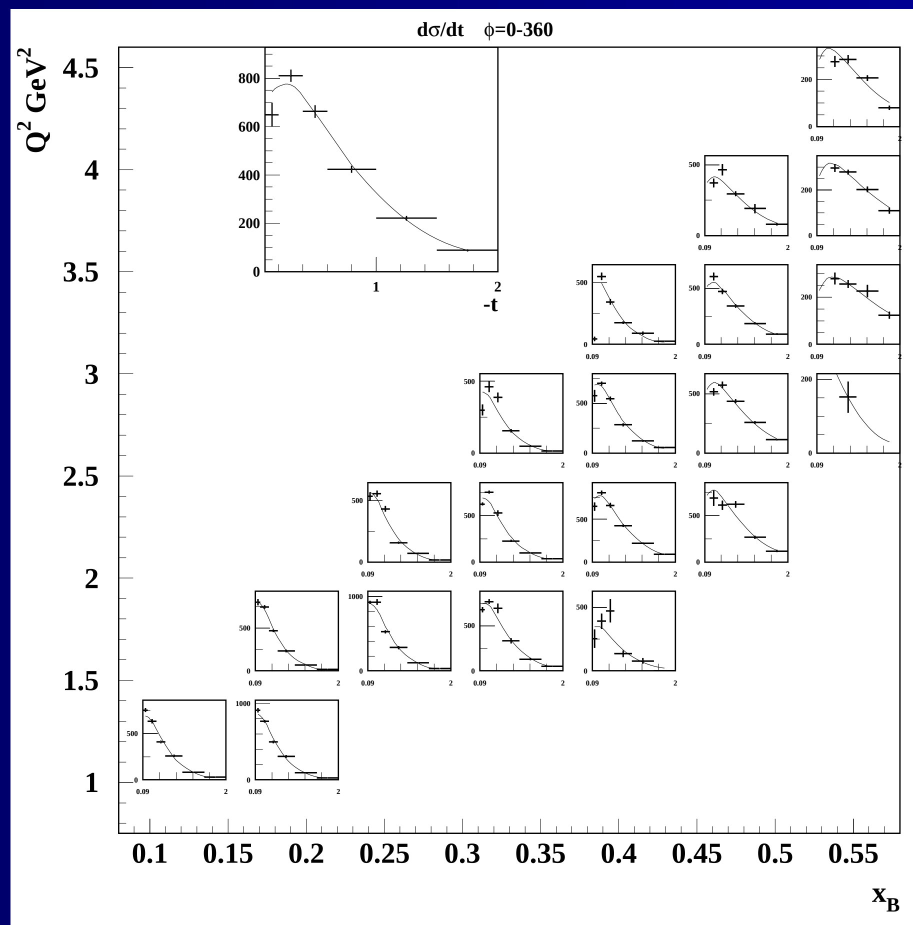
ω/ρ/b1 elastic rescat. charge pion



- The dashed lines correspond to the ω/ρ/b1 Regge poles and elastic rescattering
- The full lines include also charge pion nucleon and Delta intermediate states.
- Regge model qualitatively describes the experimental data

dσ / dt

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



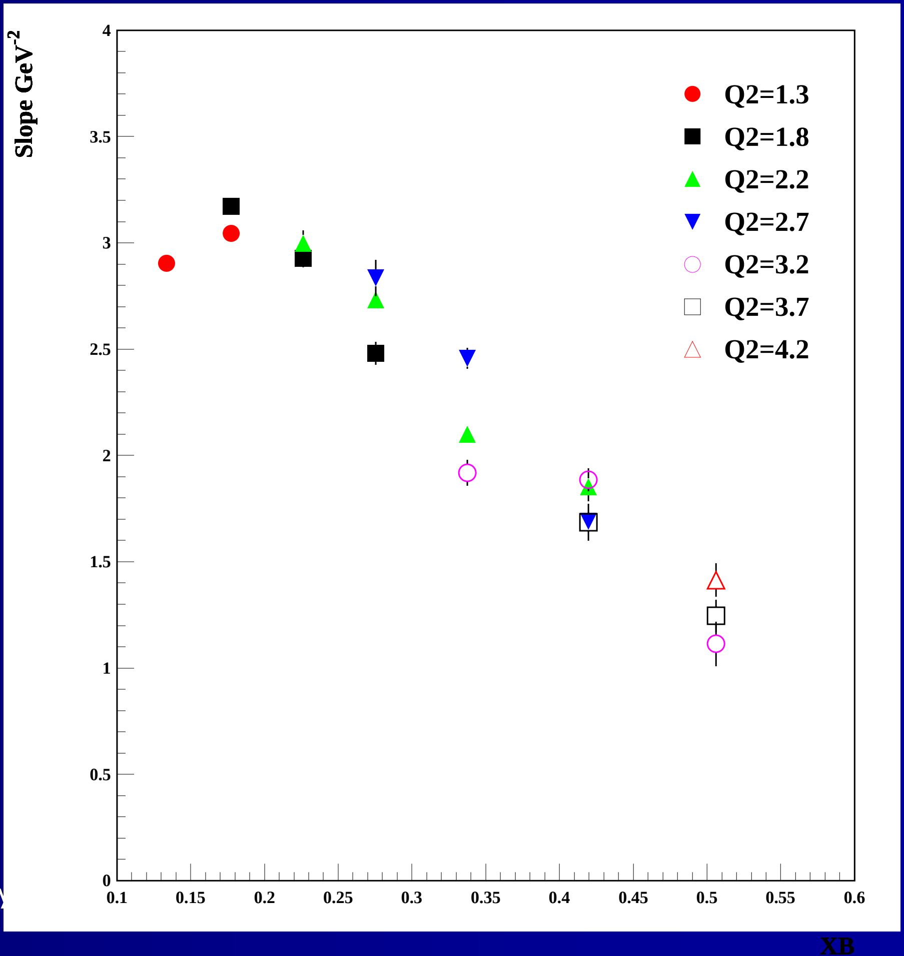
$$\gamma^* p \to e p \pi^0$$

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

$B(x_B, Q^2)$

$$\frac{d\sigma}{dt} \propto e^{B(x)t}$$

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



x_B

Valery

t-dependence in GDP

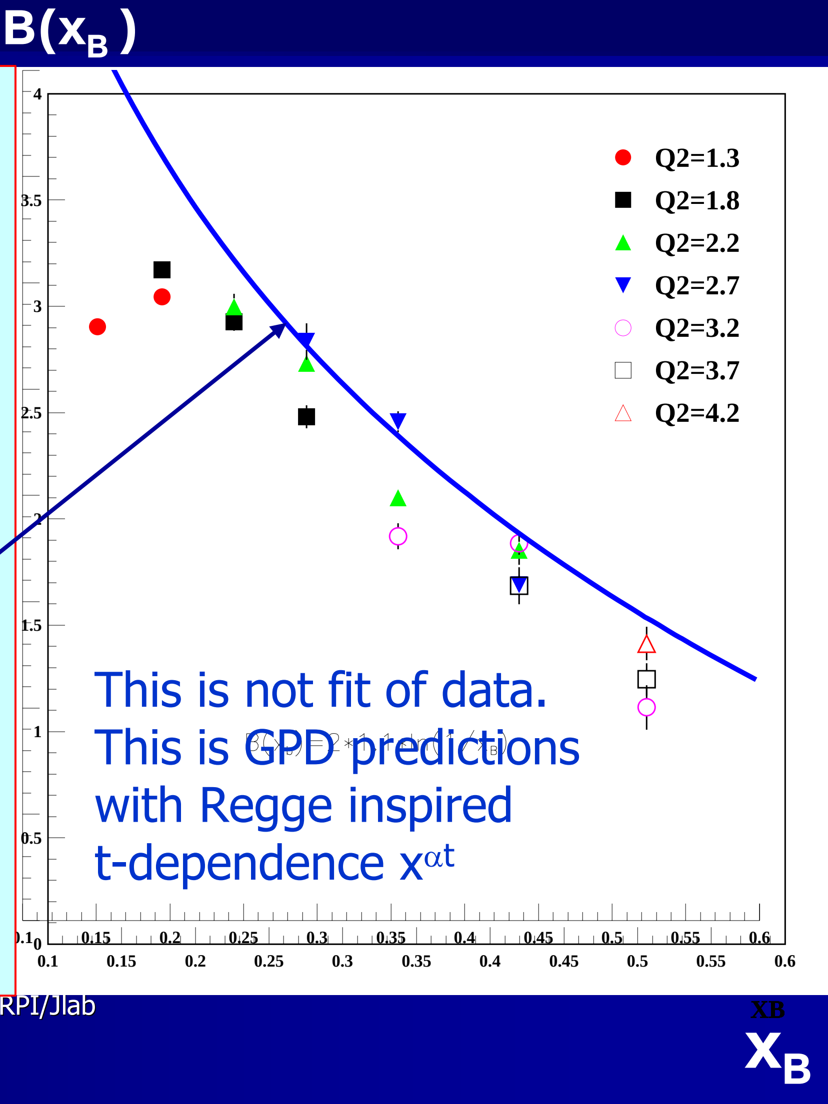
$$\frac{d\sigma}{dt} \propto e^{B(x)t}$$

$$f^q(x,t) \propto x^{\alpha_q(t)} \propto x^{\alpha t}$$

$$\frac{d\sigma}{dt} \propto \left[x^{\alpha t}\right]^2 = e^{2\alpha \ln(1/x)t}$$

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

$$\alpha \approx 1$$



Impact Parameter Dependent PDFs

- Fourier transformation of GPD

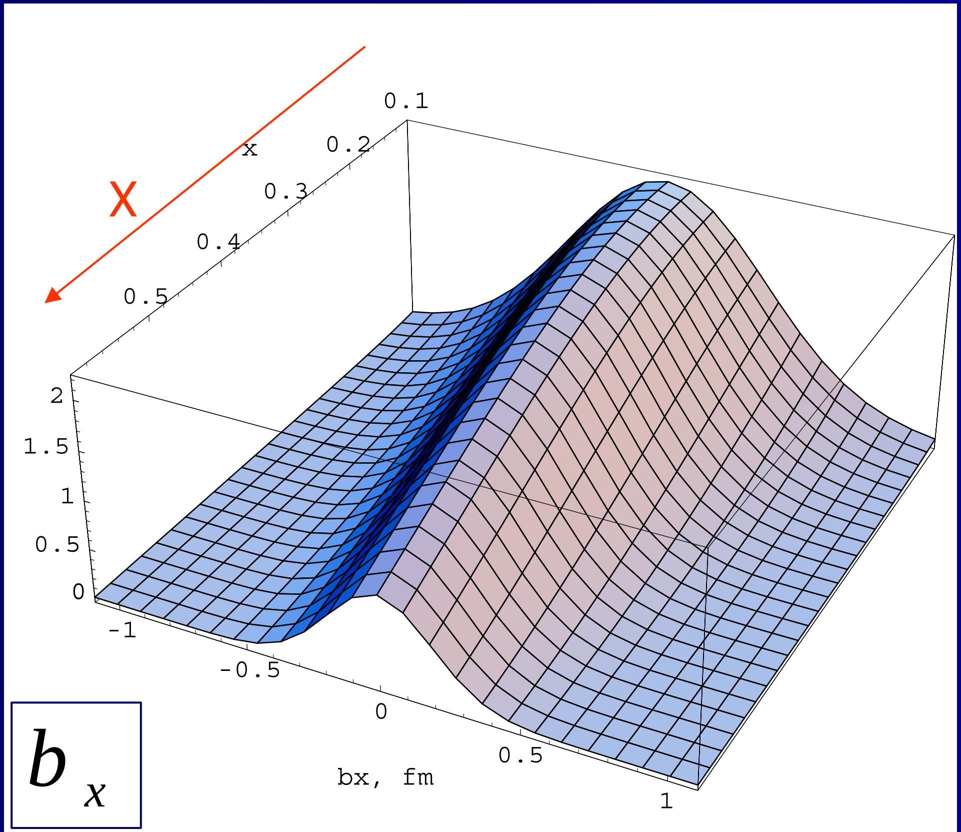
$$IPD(x, b_x, b_y) = \frac{1}{(2\pi)^2} \int d^2\Delta_\perp e^{i\Delta_\perp b_\perp} \tilde{H}(x, 0, \Delta_\perp{}^2)$$

- For impact parameter dependent parton distributions the perp width should go to zero for x→1
- In momentum space, this implies that t-slope should decrease with increasing x, what we observe experimentally

Impact Parameter Dependant Axial Parton Distribution

$$IPD(x, b_x, b_y = 0) = \frac{\Delta q(x, |\Delta_\perp| = 0)}{(2\pi)^2} \int d^2\vec{\Delta}_\perp e^{i\vec{\Delta}_\perp \vec{b}_\perp} x^{0.91|\vec{\Delta}_\perp|}$$

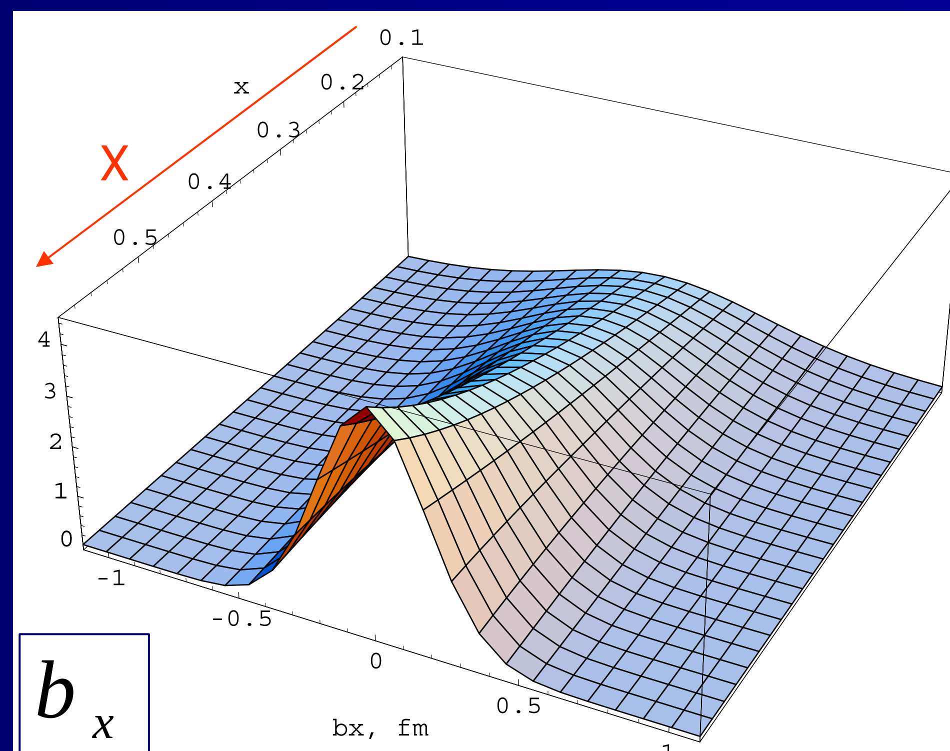
From data fit



Impact Parameter Profile of axial current distribution

$$IPD(x, b_x, b_y = 0) = \frac{1}{(2\pi)^2} \int d^2\vec{\Delta}_\perp e^{i\vec{\Delta}_\perp \vec{b}_\perp} x^{0.91|\vec{\Delta}_\perp|}$$

The curve is what we obtained from experimental data



The size of the proton decreases with increasing x

π^0 and η Beam Spin Asymmetry

$$\frac{d\sigma}{dtd\phi}(Q^2,x,t,\phi)=\frac{1}{2\pi}\left(\frac{d\sigma_T}{dt}+\varepsilon\frac{d\sigma_L}{dt}+\varepsilon\frac{d\sigma_{TT}}{dt}\cos2\phi+\sqrt{2\varepsilon(\varepsilon+1)}\frac{d\sigma_{LT}}{dt}\cos\phi\right.$$
$$\left.+h\sqrt{2\varepsilon(\varepsilon-1)}\sin\phi\frac{d\sigma_{L'T}}{dt}\right)$$

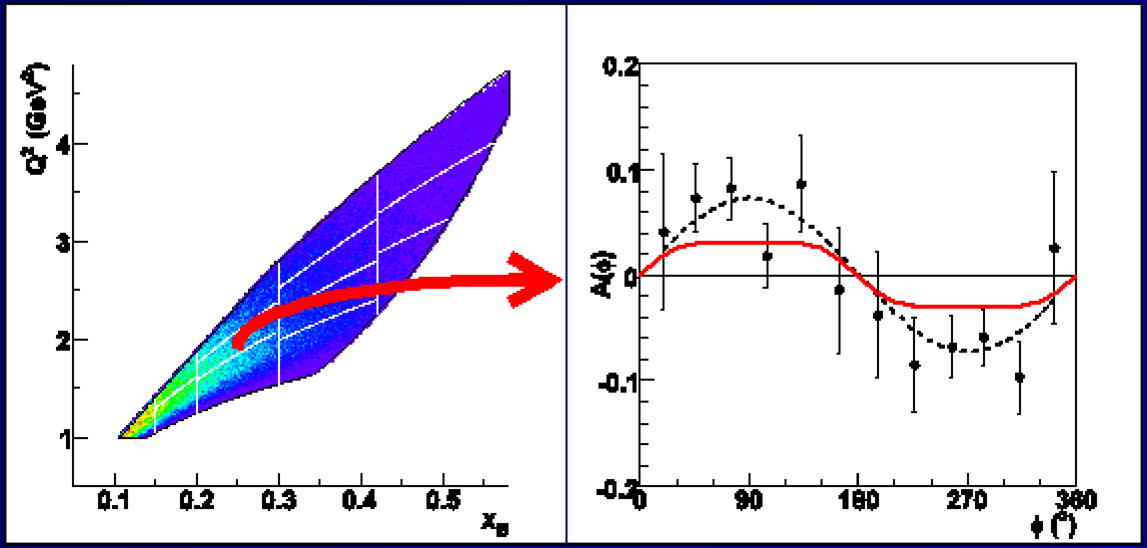
h is the beam helicity

$$A=\frac{d^4\vec{\sigma}-d^4\overleftarrow{\sigma}}{d^4\vec{\sigma}+d^4\overleftarrow{\sigma}}\approx\alpha\sin\varphi$$

Any observation of a non-zero BSA
would be indicative of an L′T interference.
If σ_L dominates, σ_{LT}, σ_{TT}, and $\sigma_{L'T}$ go to zero

π^0 : Kinematical Coverage (Q^2-x_B space)

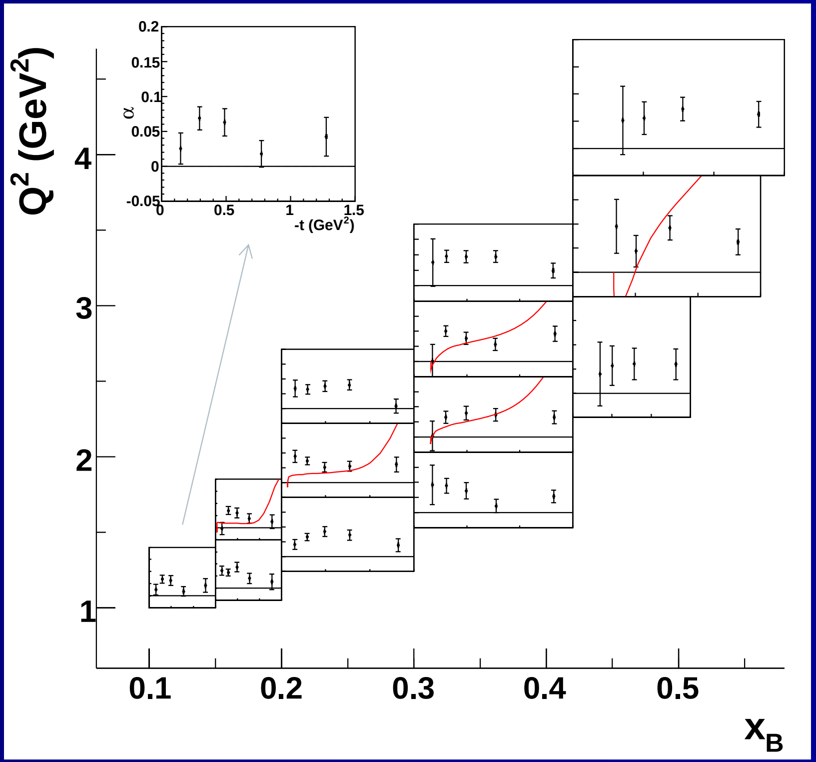
A(ϕ)
X_B=0.25
Q^2=1.95 GeV^2
t=-0.29 GeV^2



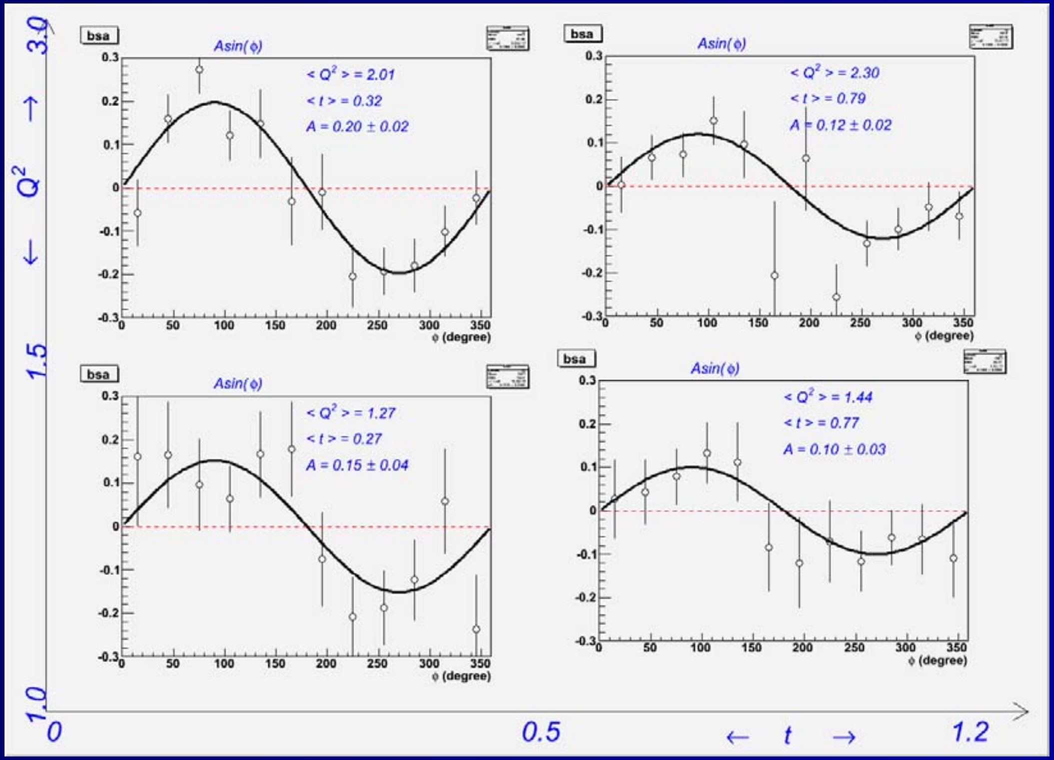
Balck curve – A=αsinϕ
Red curve – Regge model

A=αsinϕ, α as a function of t

- The red curves correspond to the Regge model (JML)
- BSA are systematically of the order of 0.03-0.09 over wide kinematical range in x_B and Q^2



η Beam Spin Asymmetry



Conclusion

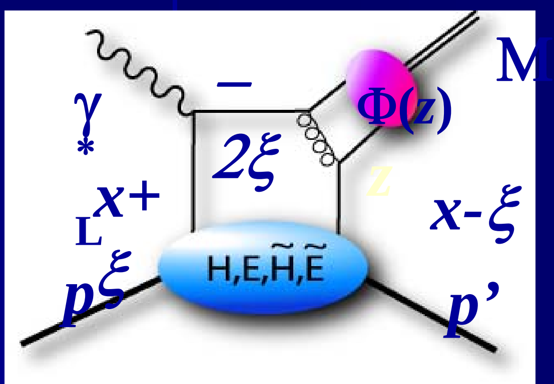
- Cross sections and asymmetries for the π^0 and η exclusive electroproduction in a very wide kinematic range will be released soon
- These data will help us to understand better the transition from soft to hard mechanisms
- Data show that both transverse and longitudinal amplitudes participate in the exclusive processes at accessible kinematics
- The π^0/η cross section ratio will check the hypothesis of precocious scaling

Questions to theory

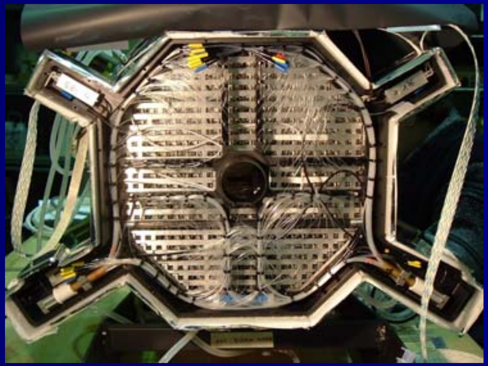
What will our data tell us?

- What does t-slope $B(Q^2,x_B)$ tell us ?
- What can we learn from the Q^2 evolution of cross section?
- Can σ_{LT} and σ_{TT} help us to constrain $R=\sigma_L/\sigma_T$?
- Can we constrain the GPDs within some approximations and corrections which have to be made due to non-asymptotic kinematics?
- How big are the corrections? How close are we to asymptotia?

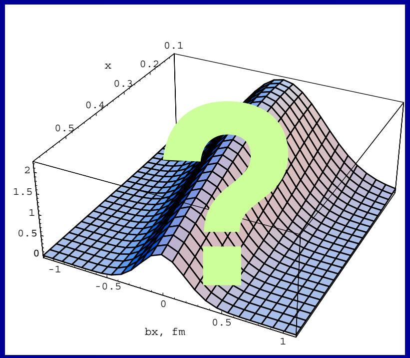
Q: What will come out from our marriage?



+

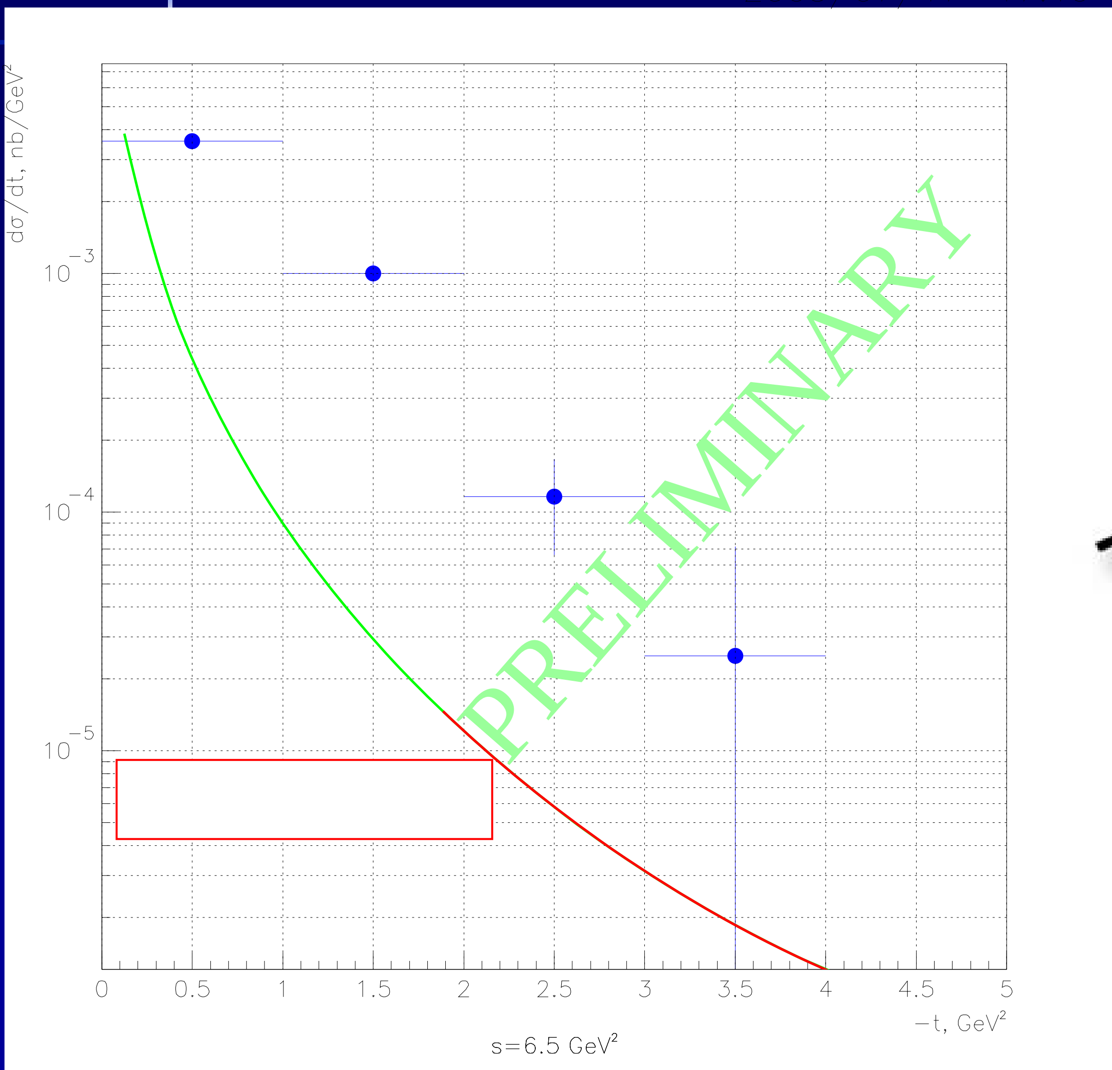


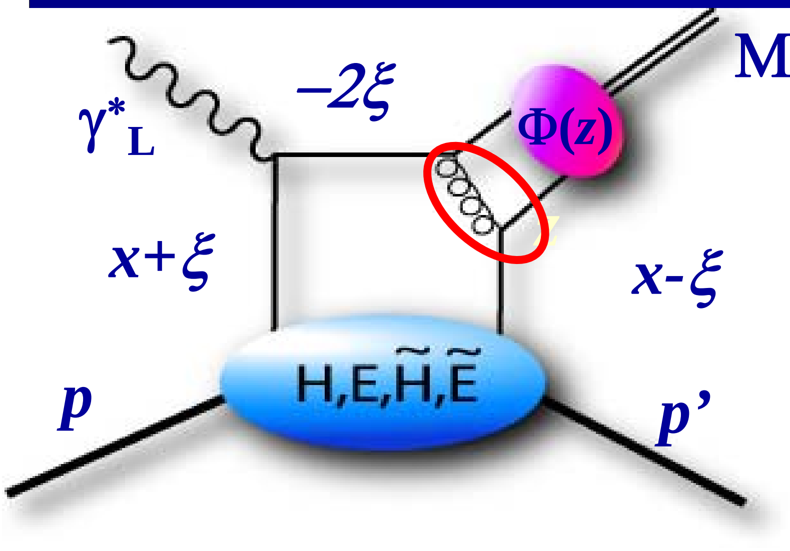
=



THE END

$d\sigma / dt$ $\quad ep \rightarrow ep\,\eta$



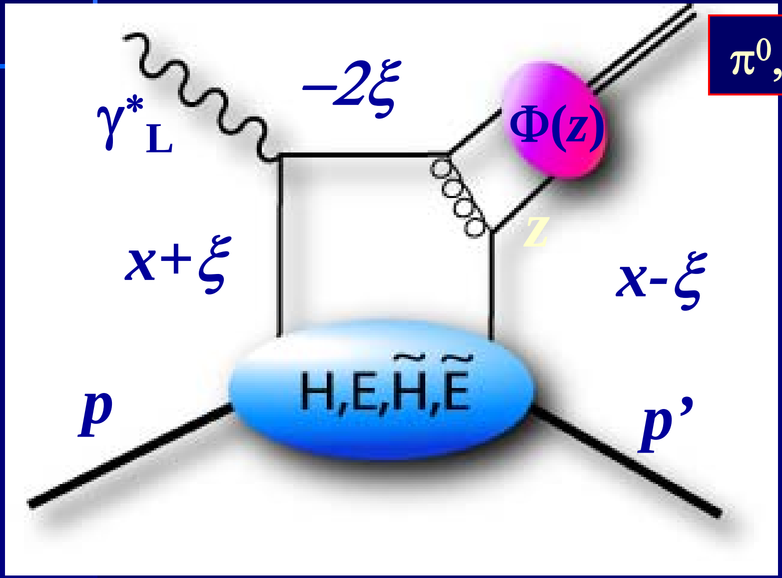


Jlab

GPD and Deeply Exclusive Scattering

- In the past decades of electron-nucleon scattering, experiments dedicated to study the substructure of the nucleon have mainly focused either on the measurements of form factors or on measurements of deep inelastic structure functions
- Form factors and structure functions measure the proton structure in two orthogonal sub-spaces
- The Generalized Parton Distribution functions unite both the transverse spatial and the longitudinal momentum dependence

Factorization Theorem



$\pi^0, \eta, \rho^0, \omega, \phi\ldots$

(Collins, Frankfurt, Strikman)

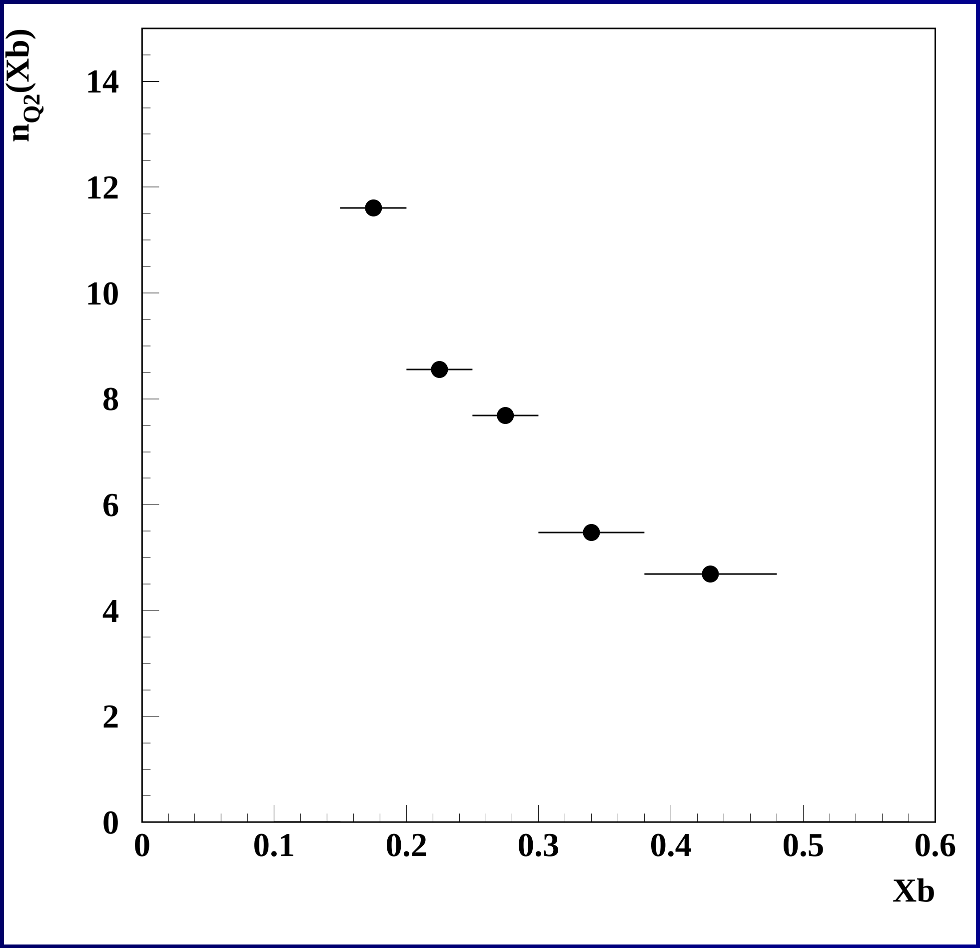
σ_L only

Q2 >>1
-*t* <<1

$$M(\rho_L) \approx \alpha_s \frac{1}{Q}\left[\int du \frac{\Phi(u)}{u}\right]\int_{-1}^{1} dx \frac{1}{x-\xi+i\varepsilon}\{aH(x,\xi,t)+bE(x,\xi,t)\}$$

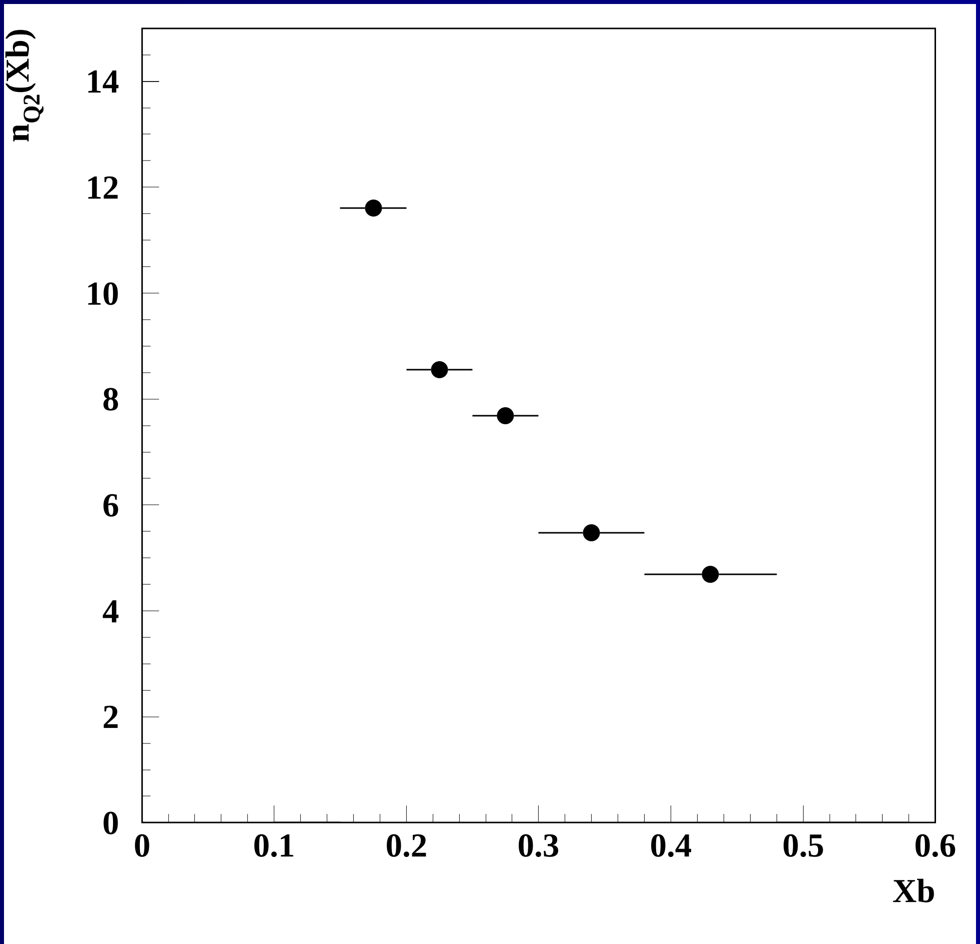
$$\frac{d\sigma}{dt} = \frac{1}{16\pi(s-M^2)}|M|^2 \rightarrow \frac{1}{Q^6}$$

Q^2 slope as a function of x_B



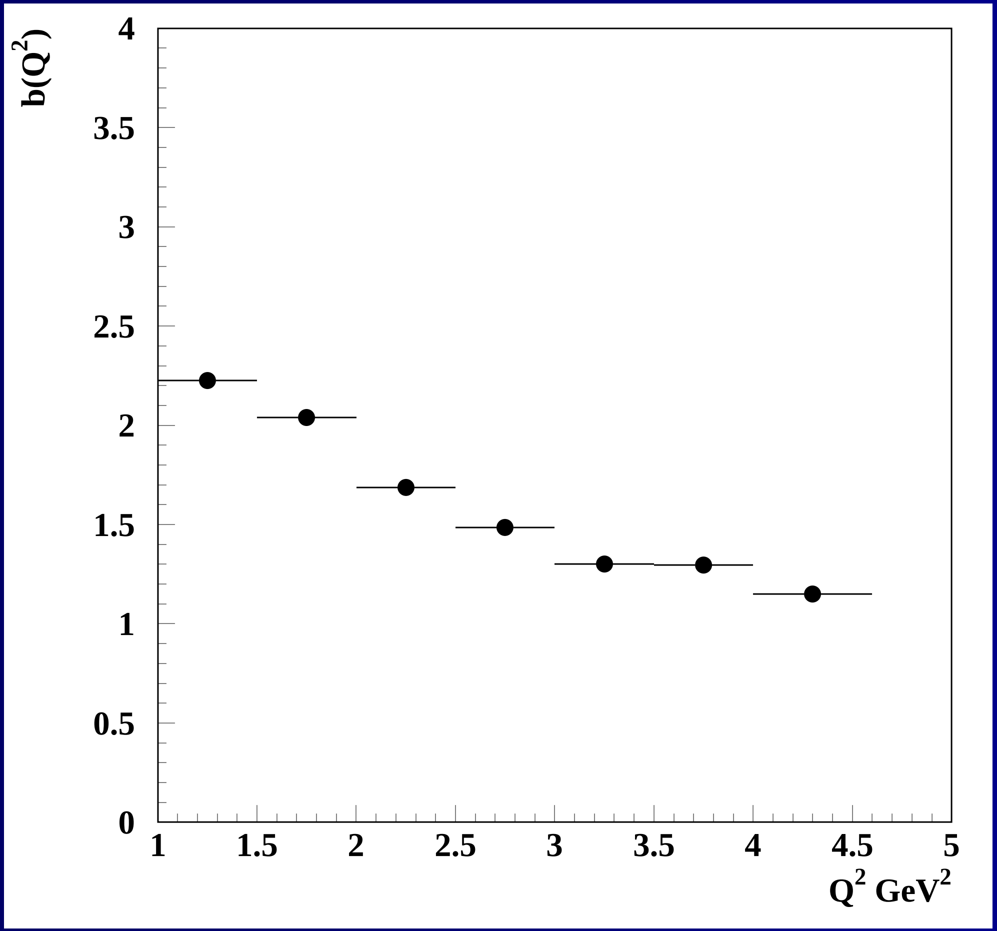
$$\frac{d\sigma}{dQ^2} \approx \frac{1}{Q^{n(x_B)}}$$

Q^2 slope as a function of x_B



$$\frac{d\sigma}{dQ^2} \approx \frac{1}{Q^{n(x_B)}}$$

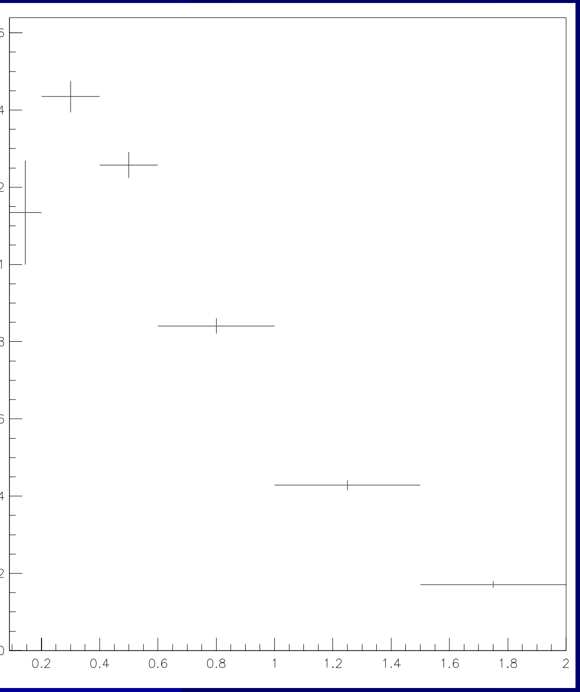
t-slope parameter as a function of Q^2



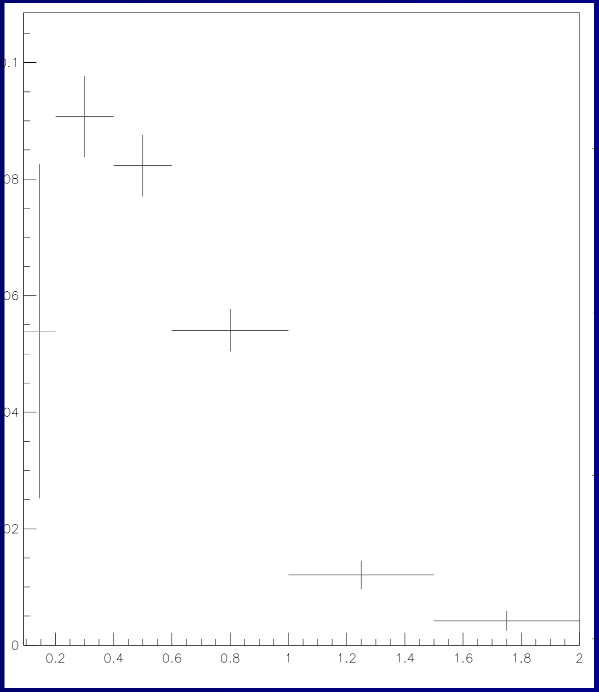
$$\frac{d\sigma}{dt} \approx e^{b(Q^2)t}$$

Reduced cross sections as a function of t

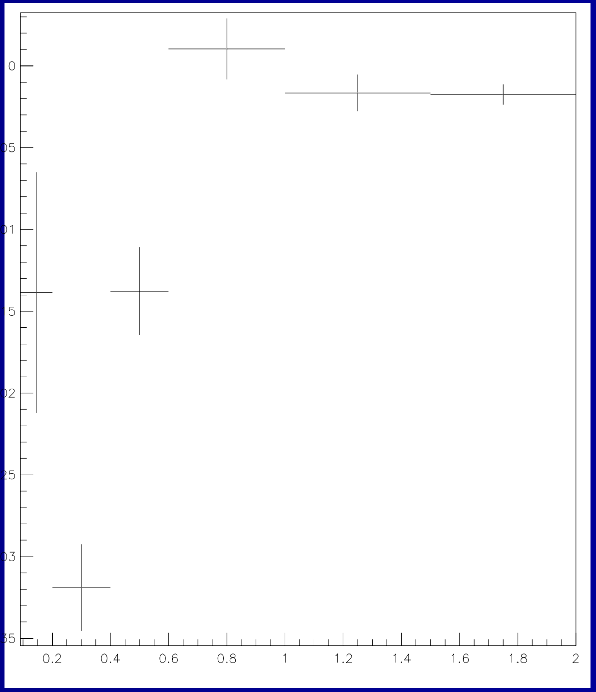
$\sigma_T + \varepsilon\sigma_L$



σ_{LT}



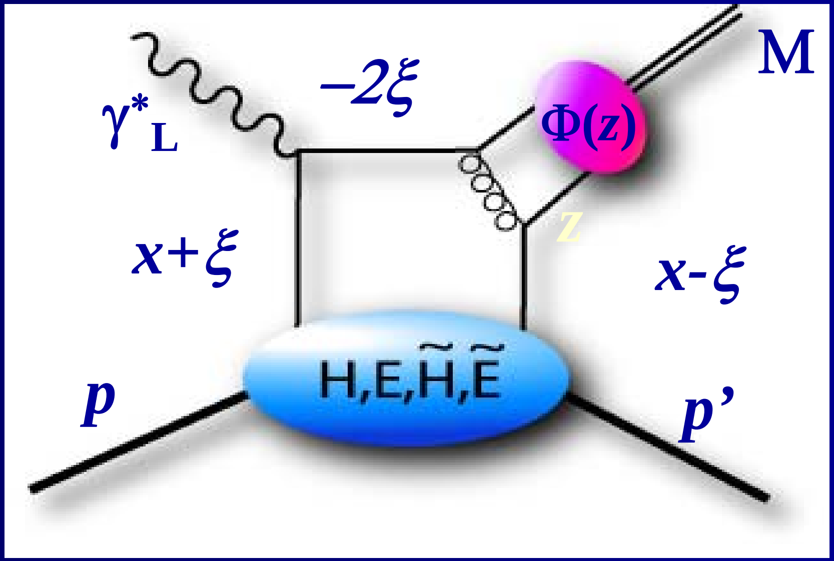
σ_{TT}



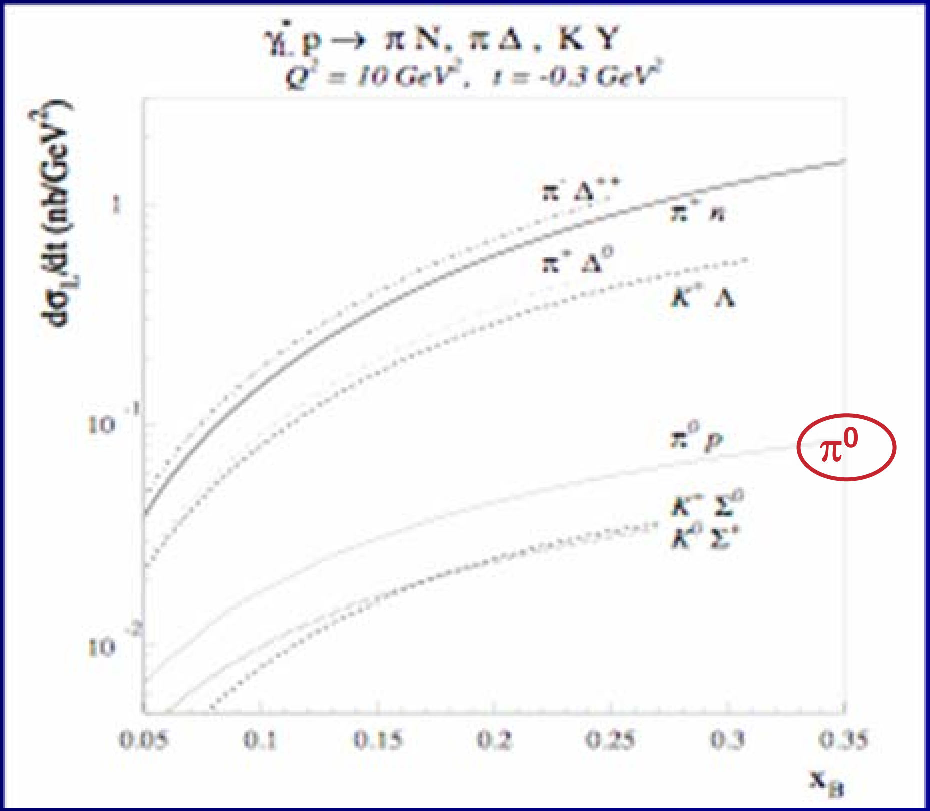
Reduced cross sections

$$\frac{d^4\sigma}{dQ^2 dx dt d\phi} = \Gamma(Q^2, x)\frac{d\sigma}{dt d\phi}(Q^2, x, t, \phi)$$

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

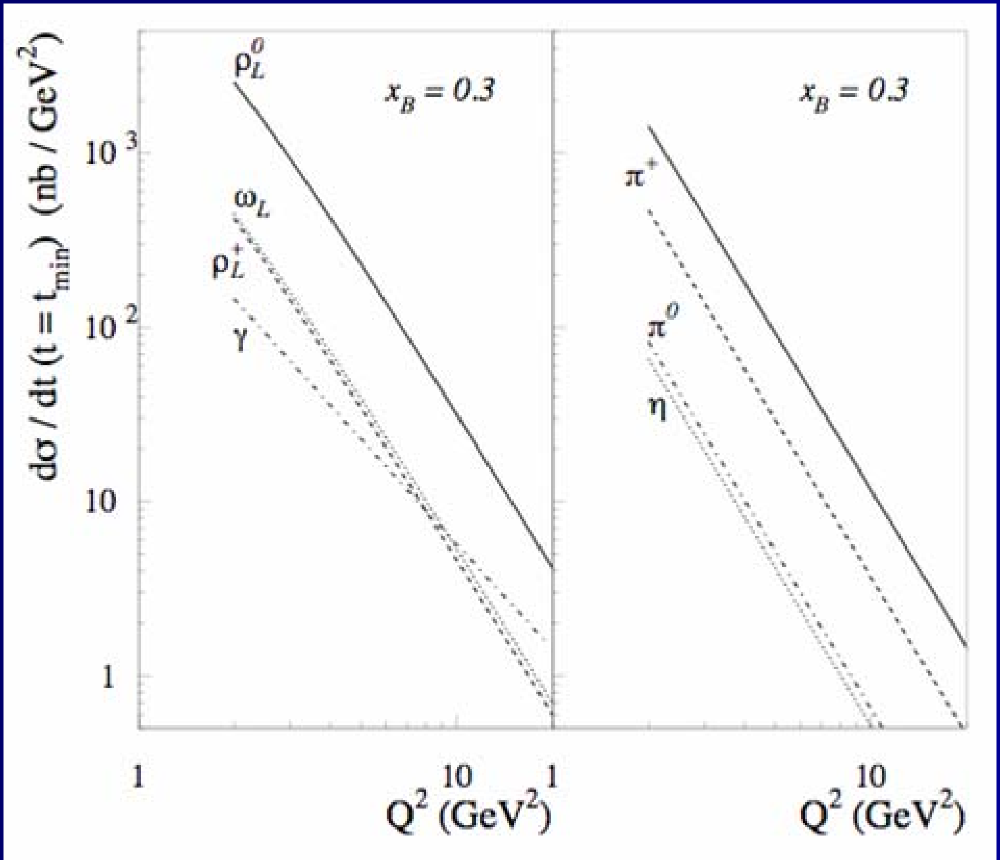


Goeke, Polyakov,Vanderhaeghen (ph-0106012)



Cross Section Predictions

Q^{-6} Scaling



Guichon, Guidal, Vanderhaeghen

High Q2 Low t Region

- The high Q2-low t measurements are closely related to, and complement, to the DVCS experiments.
- The electroproduction of π^0 and η mesons possess a number of unique features. In the partonic regime at high Q2, pseudoscalar production probes the 'polarized' GPDs, which contains information about spatial distributions of the quark spin.