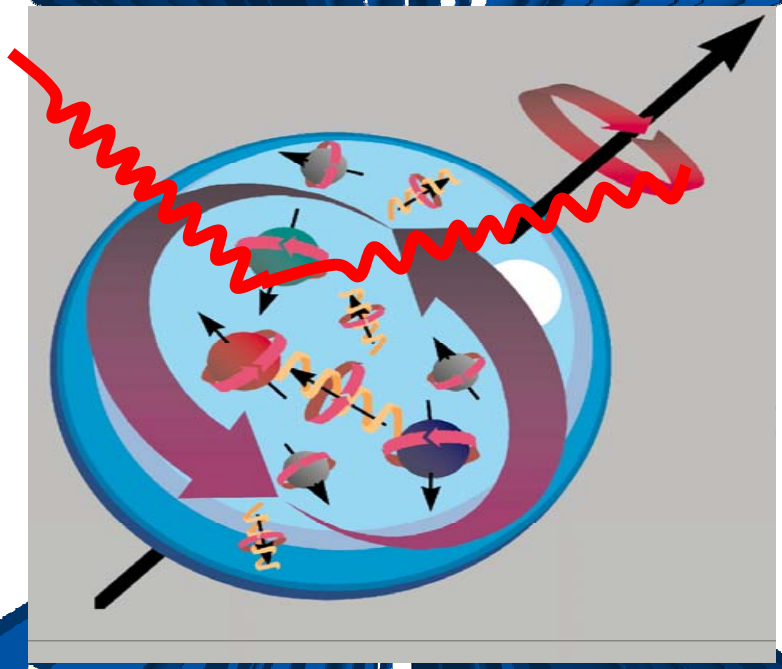
Hard exclusive processes at JLab & Generalized Parton Distributions

Photon2007, 09/07/07



M. Guidal, IPN Orsay

- *1/ A bit of background on GPDs*
- *2/ JLab results on DVCS*
- *3/ JLab ρ^0 electroproduction*
- *4/ Perspectives (JLab@12GeV)*

1/ A bit of background on GPDs

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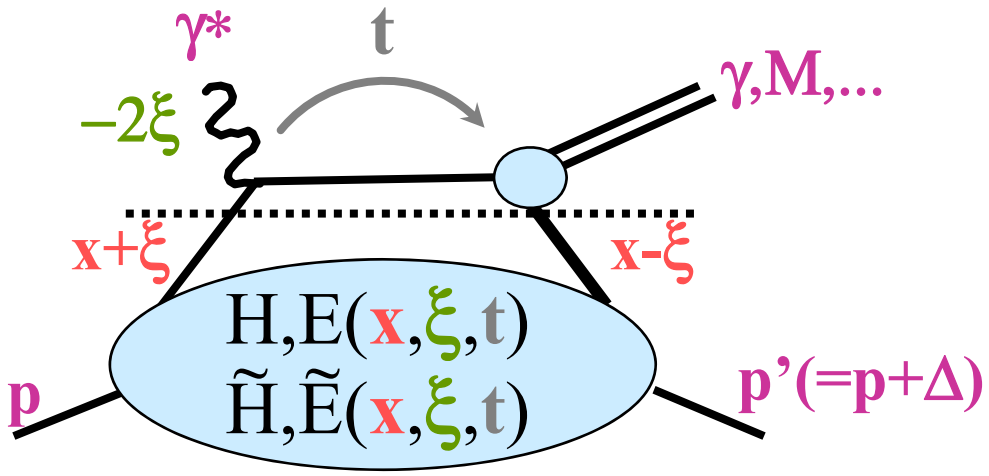
4/ Perspectives (JLab@12GeV)

GPD formalism

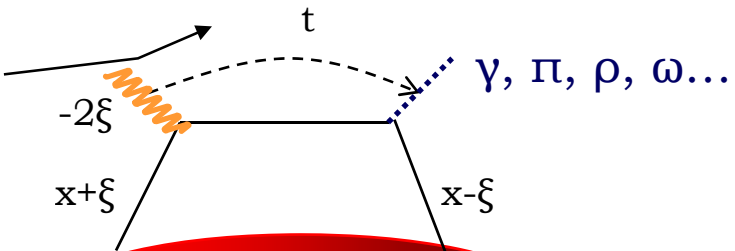
(Ji, Radyushkin, Collins, Strikman, Frankfurt)



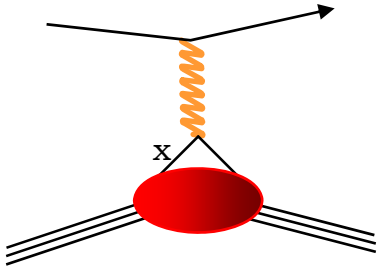
- Large Q^2, small t
- Vector Ms : H,E
- PS Ms : $\tilde{H},\tilde{E}$
- γ : σ_T lead. twist
- Mesons : σ_L

$$\{\gamma^- [H^q(x,\xi,t)\bar{N}(p')\gamma^+ N(p) + E^q(x,\xi,t)\bar{N}(p')i\sigma^{+\kappa}\frac{\Delta_\kappa}{2M}N(p)]$$

$$+\gamma^5\gamma^- [\tilde{H}^q(x,\xi,t)\bar{N}(p')\gamma^+\gamma^5 N(p) + \tilde{E}^q(x,\xi,t)\bar{N}(p')\gamma^5\frac{\Delta^+}{2M}N(p)]\}$$



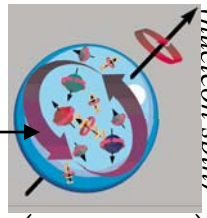
Elastic Form Factors



$\int H(x,\xi,t)dx = F(t)$ $(\forall\ \xi)$

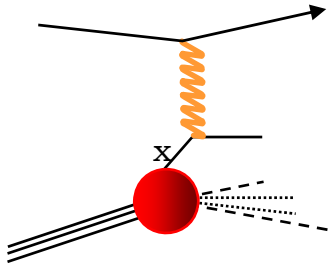
Ji's sum rule

$2J_q = \int x(H+E)(x,\xi,0)dx$



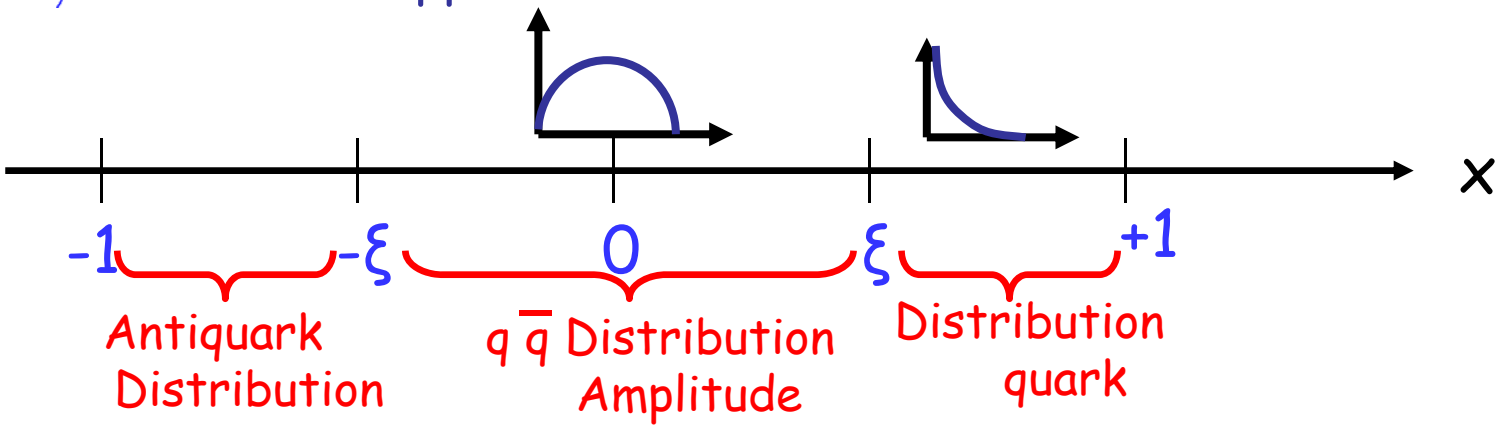
$$\frac{1}{2} = \left(\frac{1}{2}\Delta\Sigma + L_q\right) + \left(\Delta G + L_g\right)$$

Standard Parton Distributions



$H(x,0,0) = q(x)$,
$\tilde{H}(x,0,0) = \Delta q(x)$

E^q , $\tilde{E}^q$: don't appear in DIS : NEW INFORMATION



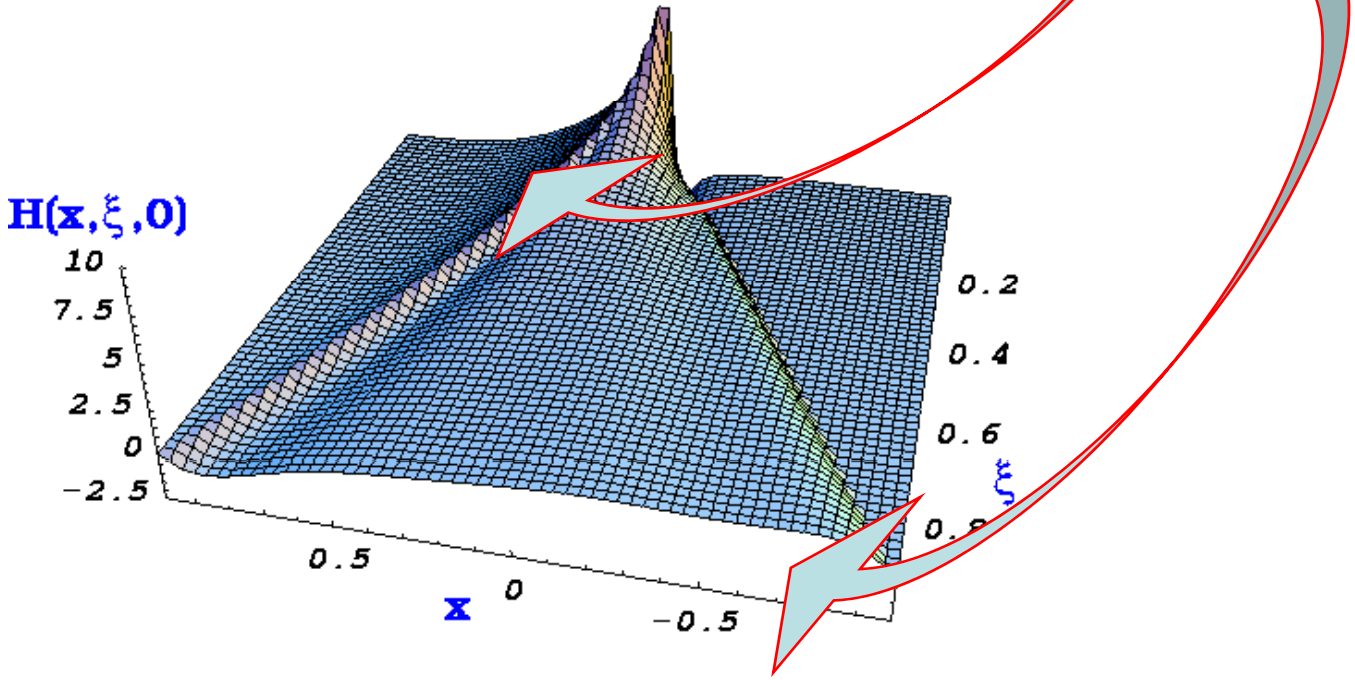
(x,ξ) dependence : Double Distributions

(Radyushkin)

$$H^q(x,\xi,0) \sim \int d\beta \int d\alpha\ \delta(x-\beta-\alpha\xi) DD^q(\alpha,\beta)$$

With : $DD^q(\alpha,\beta,t) = h^b(\alpha,\beta)\, q(\beta)$

and $$h^b(\alpha,\beta) = \frac{\Gamma(2b+2)\left[(1-|\beta|)^2-\alpha^2\right]^b}{2^{2b+1}\Gamma(2b+1)(1-|\beta|)^{2b+1}}$$



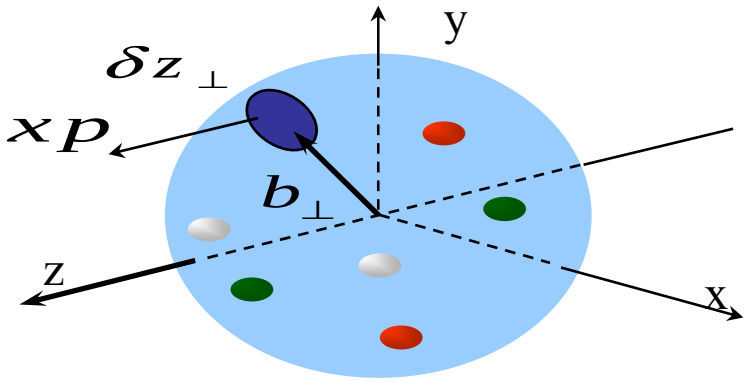
Satisfies relations with DIS and polynomiality

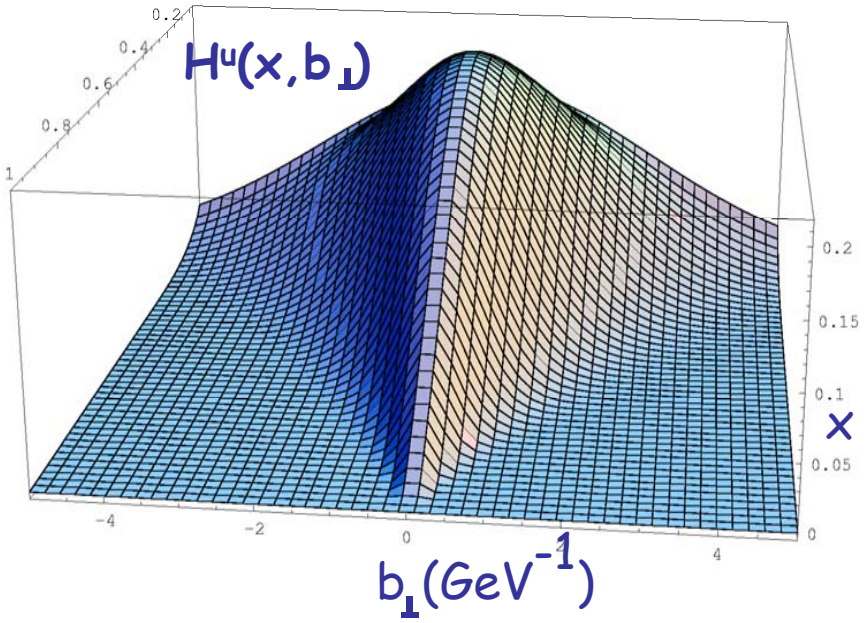
(x,ξ,t) dependence : Reggeized Double Distributions

(Radyushkin, Polyakov, VdH, M.G.)

$$DD^q(\alpha,\beta,t)=q(\beta)\, h^b(\alpha,\beta)\beta^{-\alpha'(1-\beta)t}$$

$$H^q(x,\mathbf{b}_\perp) = \int \frac{d^2\Delta_\perp}{(2\pi)^2} e^{i\mathbf{b}_\perp\cdot\Delta_\perp} H^q(x,\xi=0,-\Delta_\perp{}^2)$$





Satisfies Form Factors sum rule and polynomiality

Global (polarized and unpolarized) data analysis, X-sec, asym., (p,n), (γ,M), to extract the GPDs

$ep \longrightarrow ep\gamma$

$$A = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} = \frac{\Delta\sigma}{2\sigma}$$

$\xi = x_B/(2-x_B)$

$k = -t/4M^2$

Polarized beam, unpolarized target:

$$\Delta\sigma_{LU} \sim \sin\phi\{F_1 H + \xi(F_1+F_2)\tilde{H} + kF_2 E\}d\phi$$

(BSA)

Kinematical suppression

$\Rightarrow$ $H(\xi,\xi,t)$, $\tilde{H}(\xi,\xi,t)$, $E(\xi,\xi,t)$

Unpolarized beam, long. pol. target:

$$\Delta\sigma_{UL} \sim \sin\phi\{F_1\tilde{H} + \xi(F_1+F_2)(H + \ldots\}d\phi$$

(l)TSA

$\Rightarrow$ H, $\tilde{H}$

Unpolarized beam, trans. pol. target:

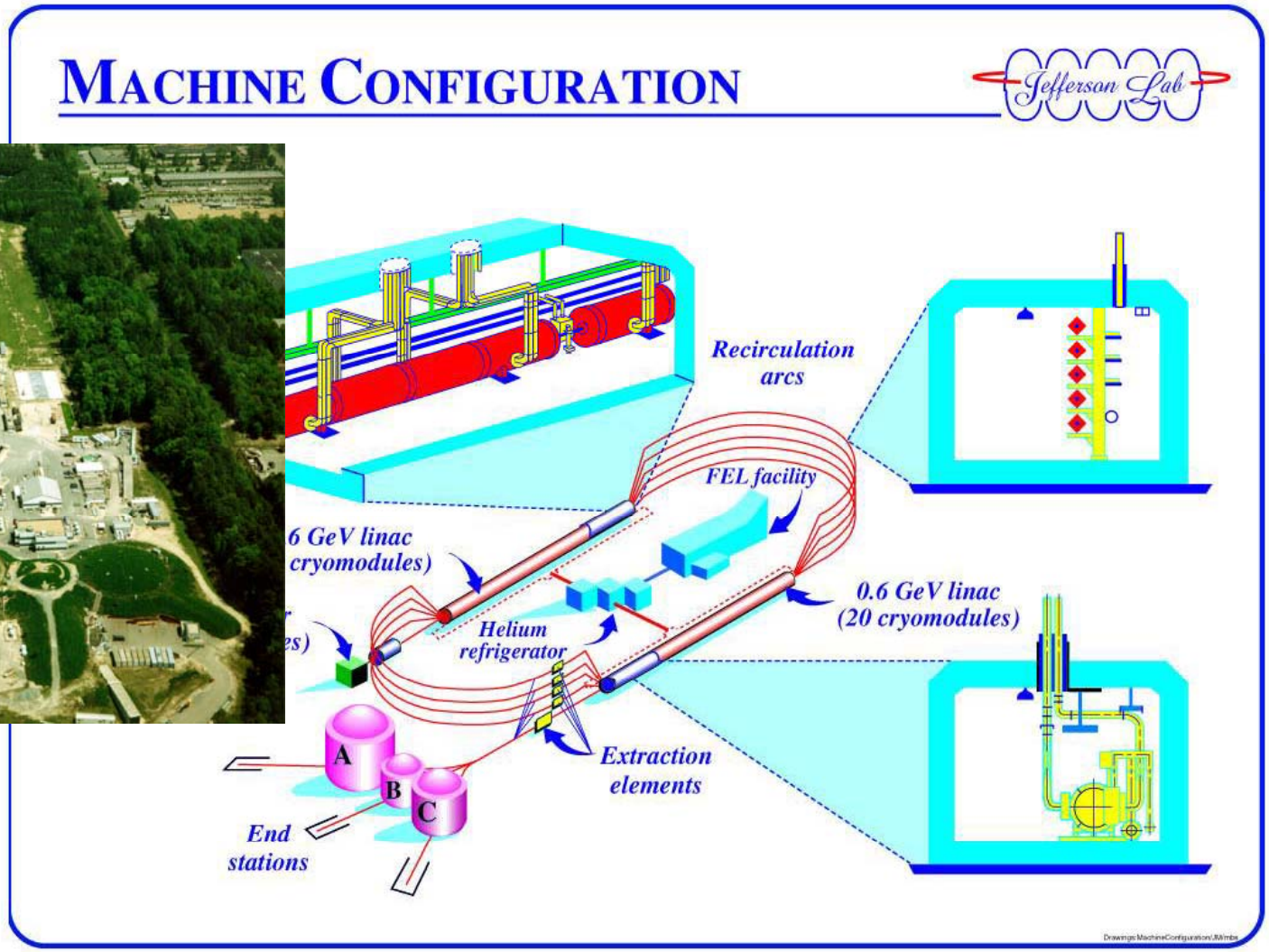
$$\Delta\sigma_{UT} \sim \sin\phi\{k(F_2 H - F_1 E) + \ldots..\}d\phi$$

(t)TSA

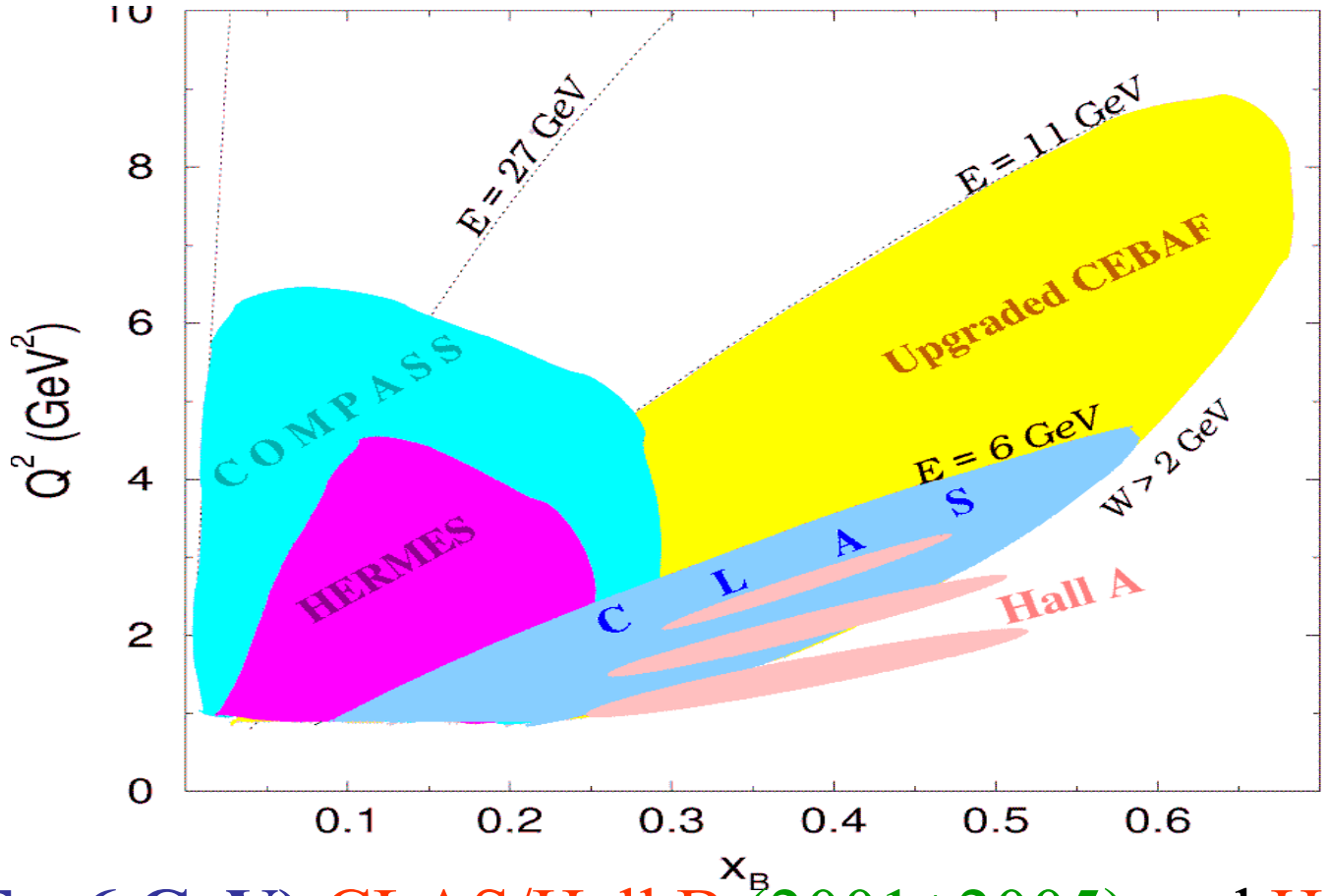
$\Rightarrow$ **H, E**

JLab & Hall B

Duty cycle ~100% E_{max}~6 GeV P_{max}~80%



« GPD » exploration in the world



JLab(E_e=6 GeV):CLAS/Hall B (2001+2005) and Hall A (2004)

HERA (E_e=27 GeV) : HERMES and ZEUS/H1 (up to 2007)

CERN (E_μ=200 GeV) : COMPASS (2009 ?)

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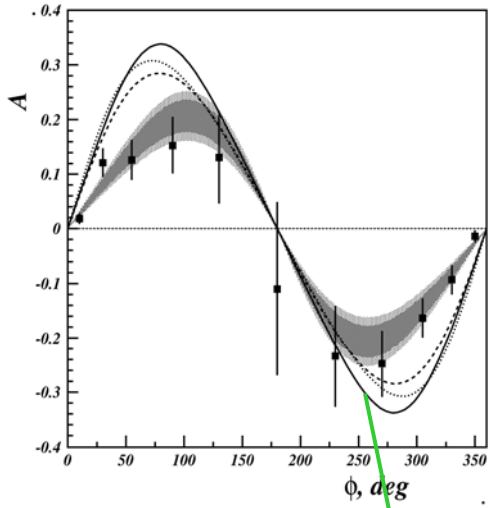
First experimental signatures

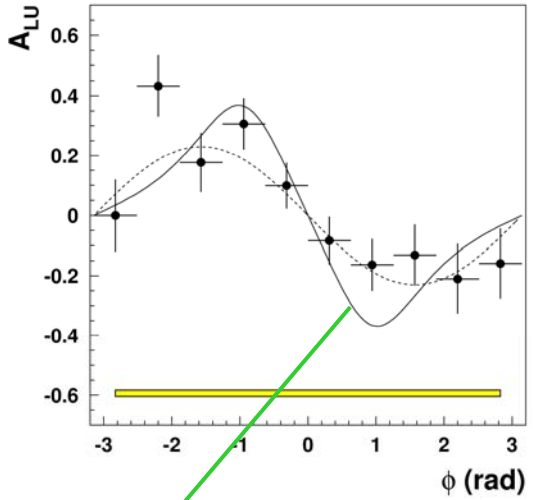
First observations of DVCS beam asymmetries in 2000

CLAS



Q^2 = 1.25 GeV² ,
x_B = 0.19,
-t = 0.19 GeV²

Phys.Rev.Lett.87:182002,2001



Phys.Rev.Lett.87:182001,2001

HERMES

Q^2 = 2.6 GeV² ,
x_B = 0.11,
-t = 0.27 GeV²

twist-2 + twist-3 : Vdh, Guichon, Guidal (1999)
Kivel, Polyakov, Vdh (2000)

Second generation of dedicated experiments (2005-2011)

HALL A

$ep \longrightarrow ep\gamma$

Scattered Electron

Left HRS

LH_2 / LD_2 target

Polarized Electron Beam

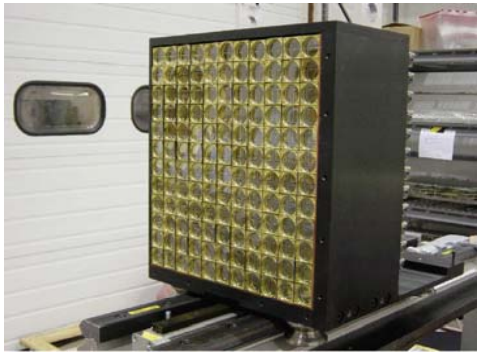
$$M_X^2 = (k + p - k' - q')^2$$

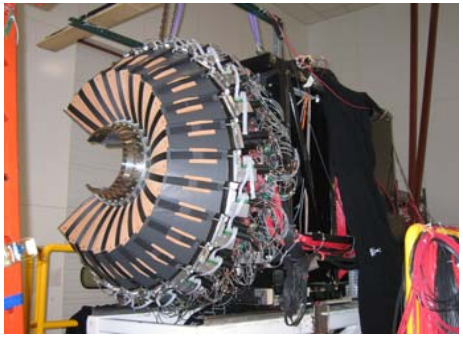
Charged Particle Tagger

γ

$\mathcal{N}$

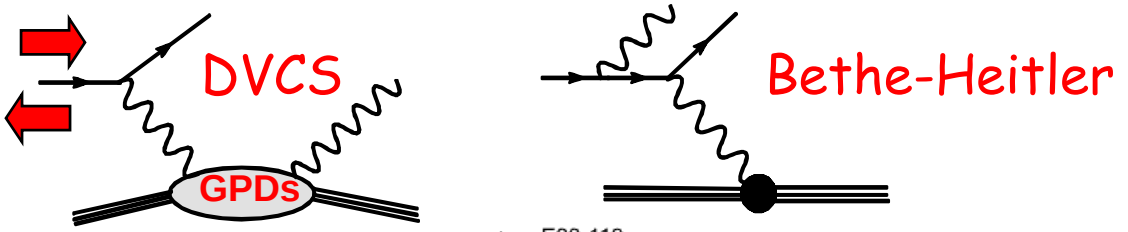
Electromagnetic Calorimeter



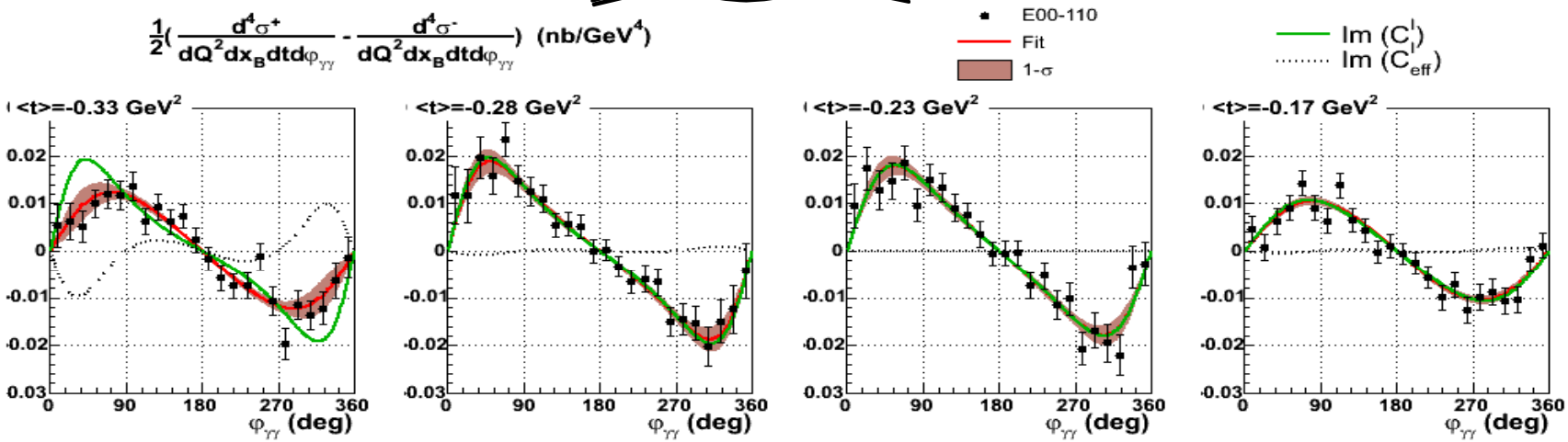


Nucleon Detector

Difference of polarized cross sections

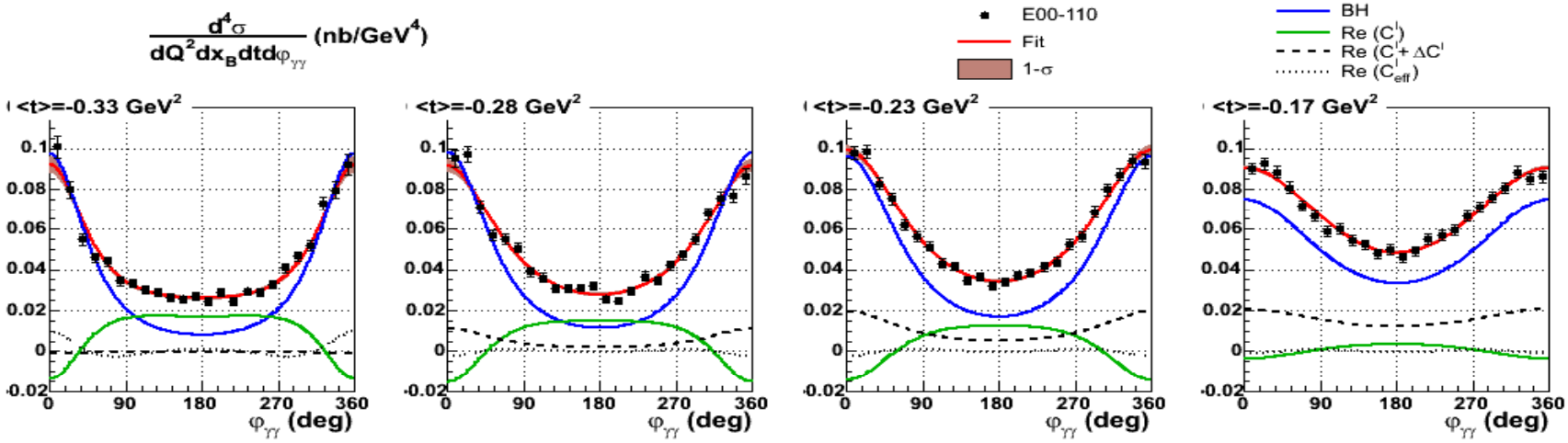


$\frac{1}{2}\left(\frac{d^4\sigma^+}{dQ^2 dx_B dt d\varphi_{\gamma\gamma}} - \frac{d^4\sigma^-}{dQ^2 dx_B dt d\varphi_{\gamma\gamma}}\right)$ (nb/GeV^4)

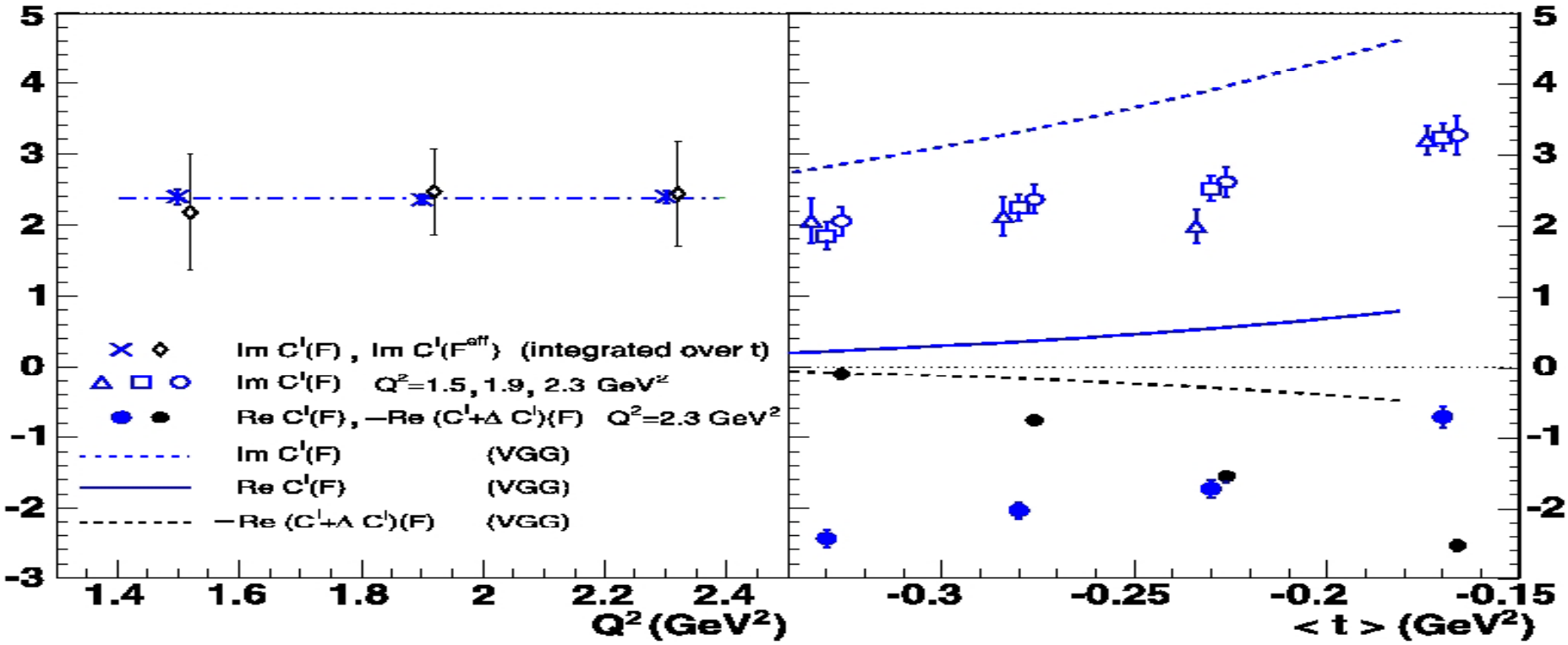


Unpolarized cross sections

$\frac{d^4\sigma}{dQ^2 dx_B dt d\varphi_{\gamma\gamma}}$ (nb/GeV^4)



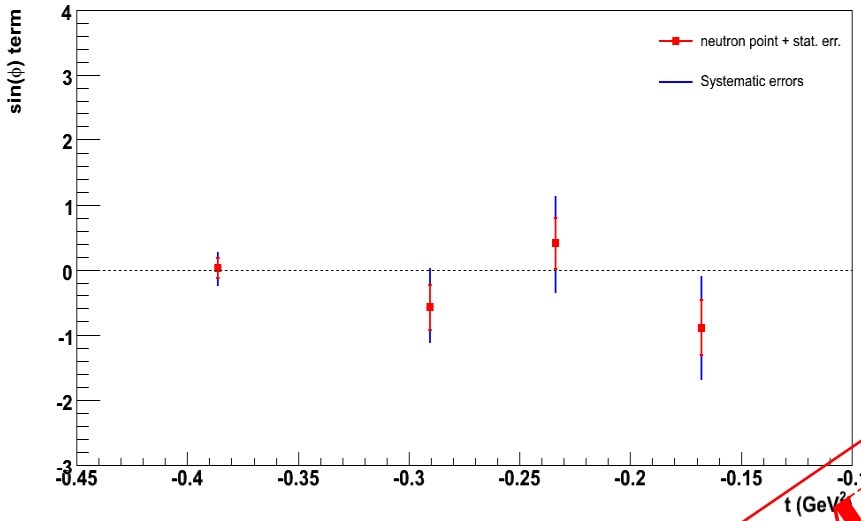
JLab Hall A Collaboration, PRL 97:262002,2006



❖ **Twist-2** terms **dominate** the cross sections and are **independent** of Q^2 in the explored kinematical domain

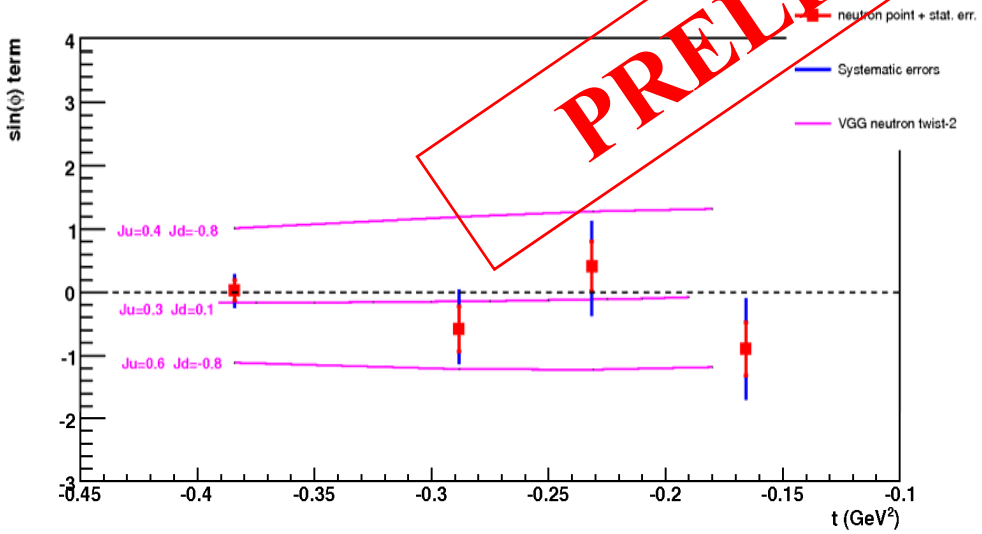
❖ The contribution to the cross section of **twist-3** terms seems **small**.

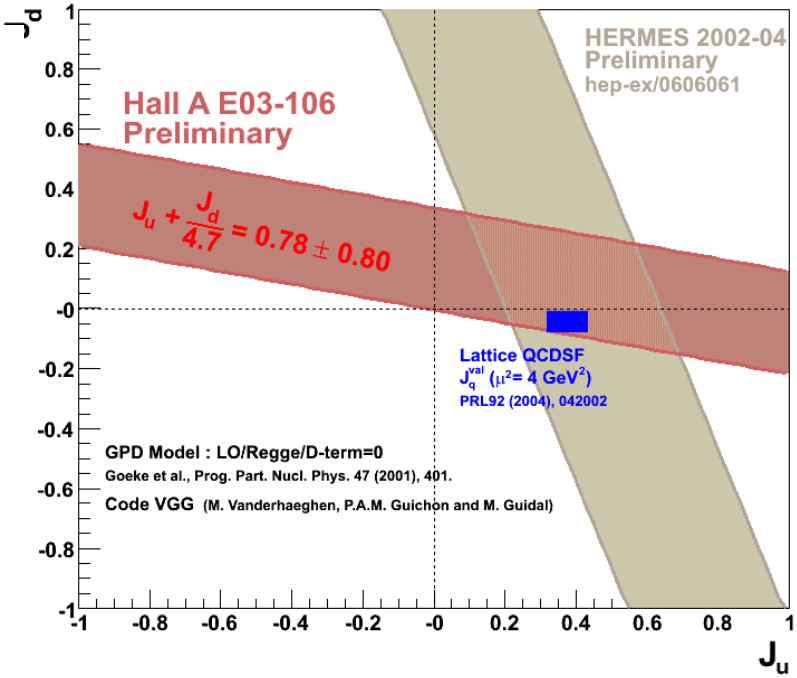
Relatively strong indication in favor of factorisation starting from 2 GeV^2 in the valence region



en ⟶ enγ

PRELIMINARY

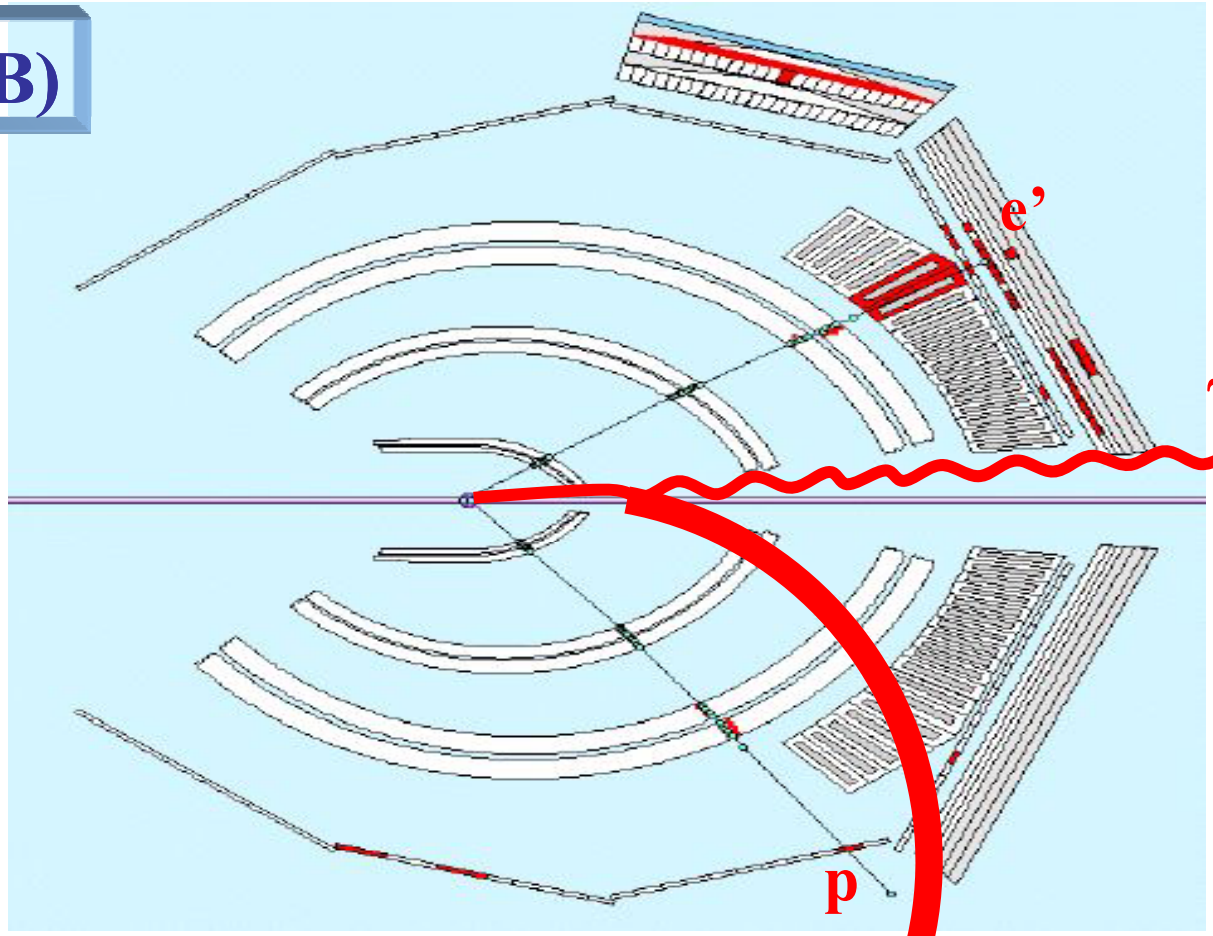




1/ DVCS (Hall B)

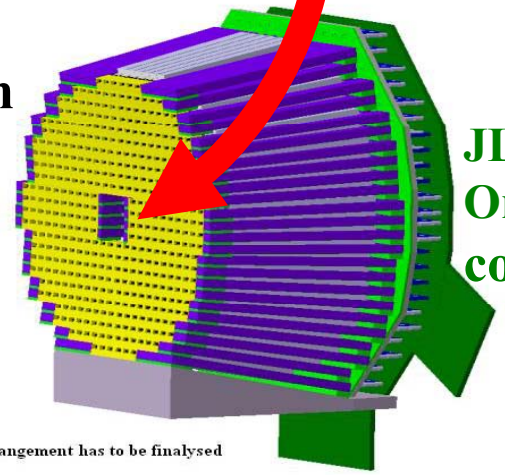
A typical
ep⇨ epγ

event in
CLAS
(Hall B, JLab)



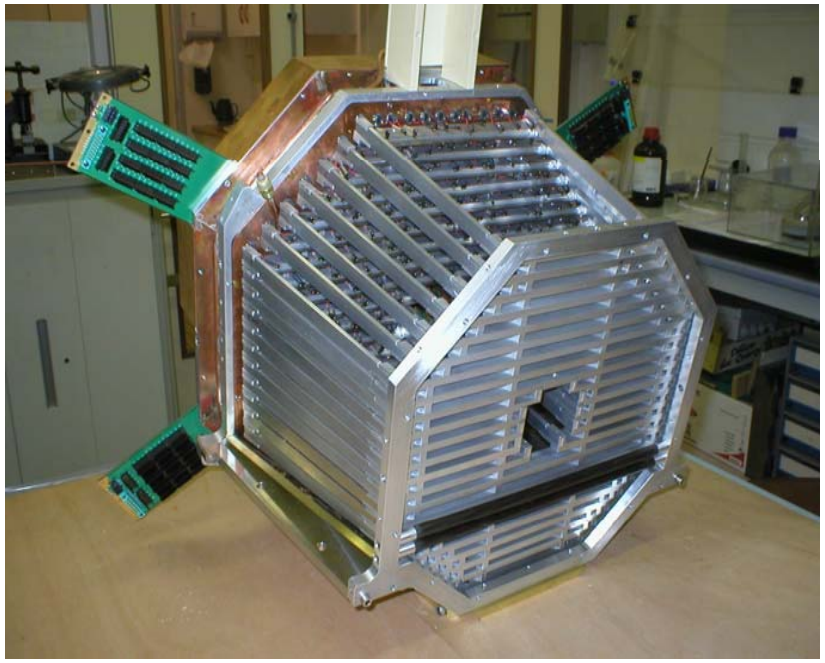
Add an EM calorimeter at forward angles

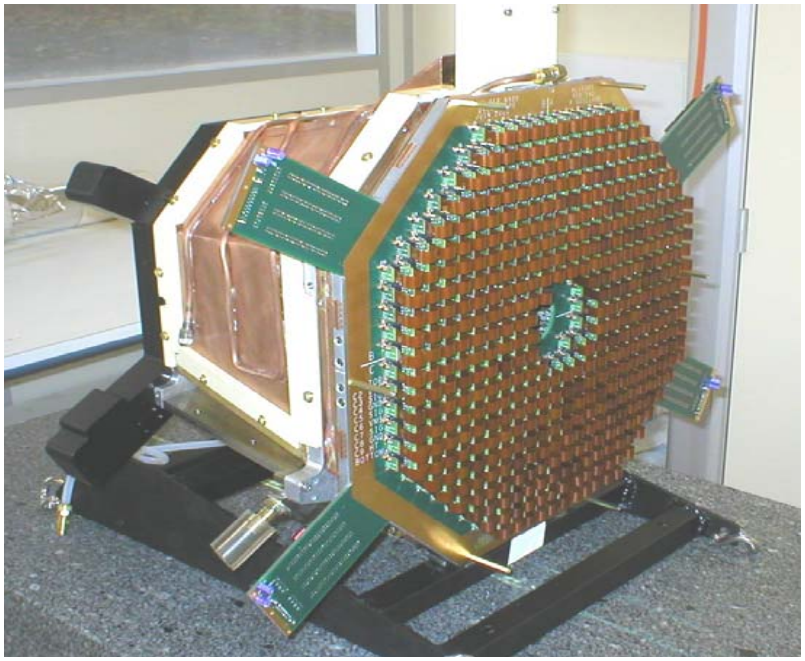
420 $PbWO_4$ crystals : ~10x10 mm^2, l=160 mm
Read-out : APDs +preamps



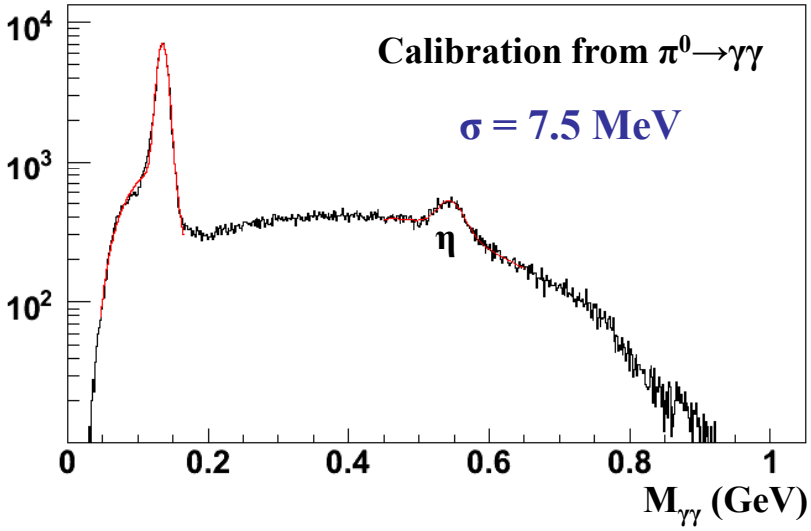
JLab/ITEP/
Orsay/Saclay
collaboration

Add a "Moller shield" solenoid around the target



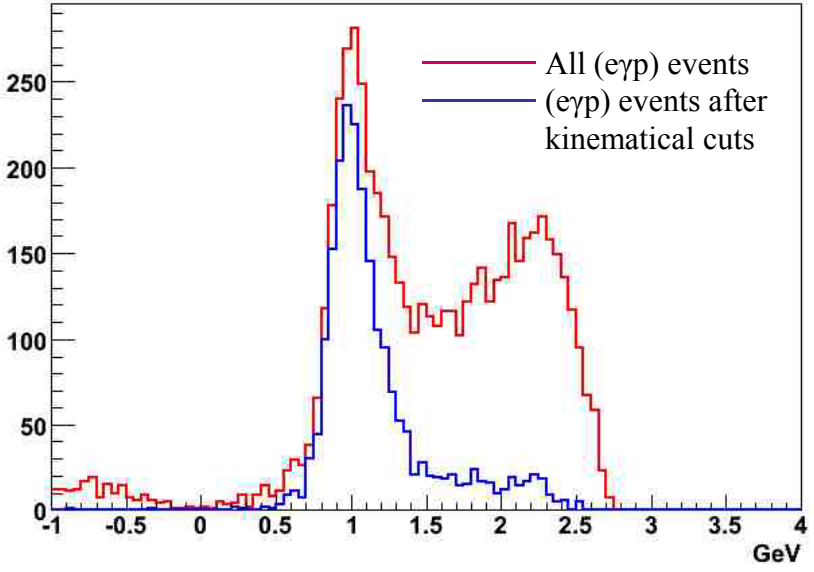


Data taking : March to May 2005



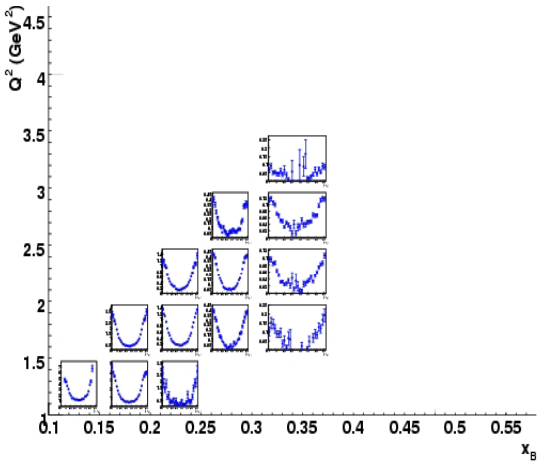
MMeg

CLAS *(preliminary analysis of a 2 hours run)*

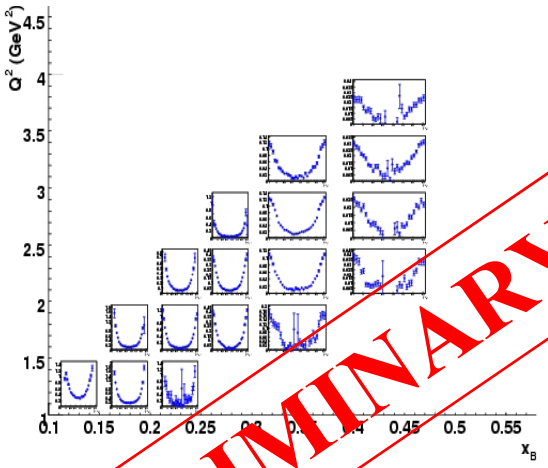


Unpolarized Cross Section $\frac{d^4\sigma_{ep\to ep\gamma}}{dQ^2 dx_B dt d\phi}(\mathrm{nb}/\mathrm{GeV}^4)$ as a function of ϕ

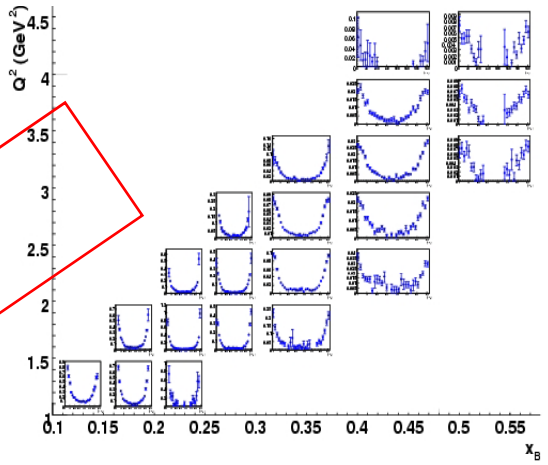
0.09<-t<0.2 GeV²



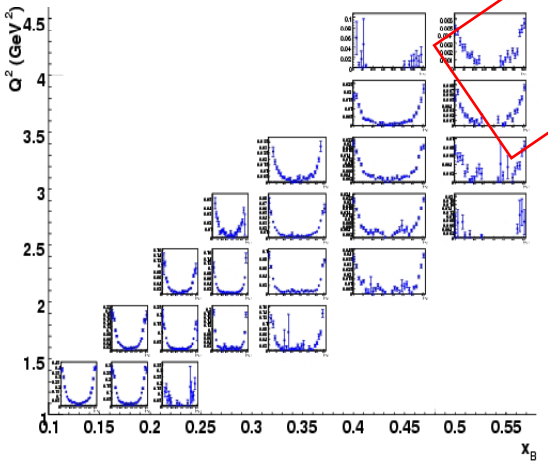
0.2<-t<0.4 GeV²



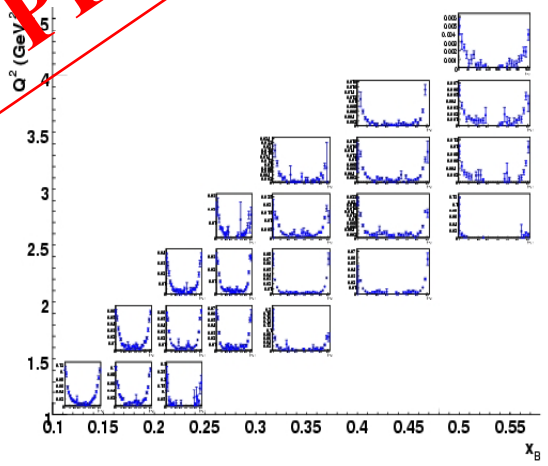
0.4<-t<0.6 GeV²



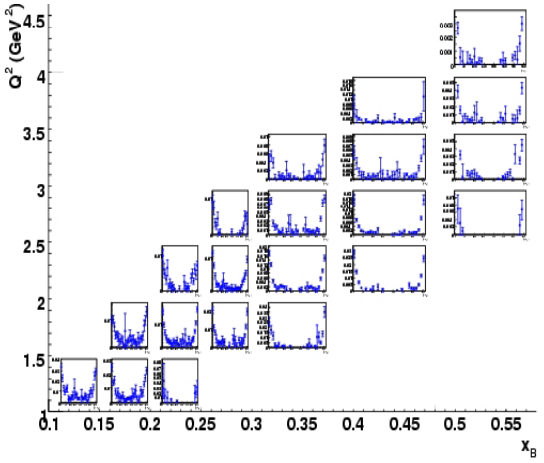
0.6<-t<1 GeV²



1<-t<1.5 GeV²



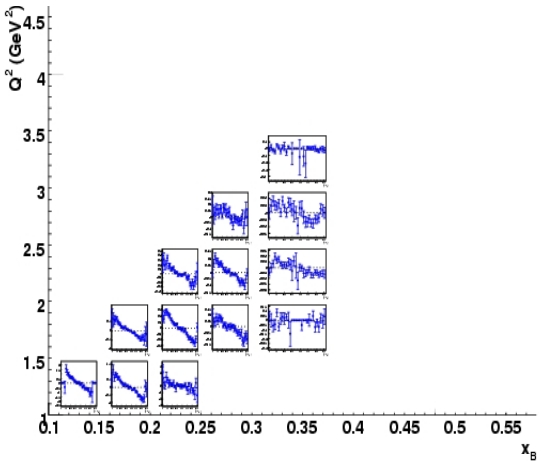
1.5<-t<2 GeV²



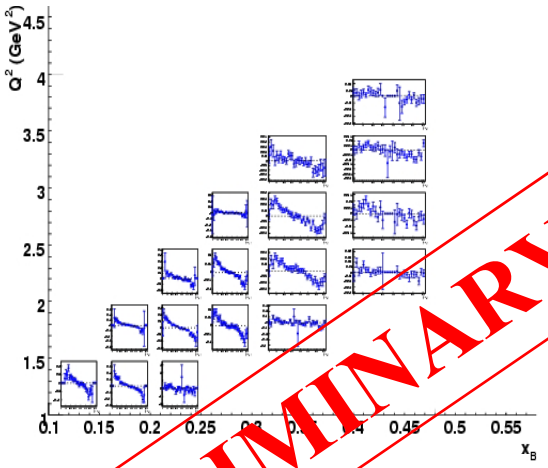
PRELIMINARY

Polarized Cross Sections Difference $\frac{d^4\vec{\sigma}_{ep\to ep\gamma}}{dQ^2 dx_B dt d\phi} - \frac{d^4\bar{\sigma}_{ep\to ep\gamma}}{dQ^2 dx_B dt d\phi}$ (nb / GeV^4) as a function of ϕ

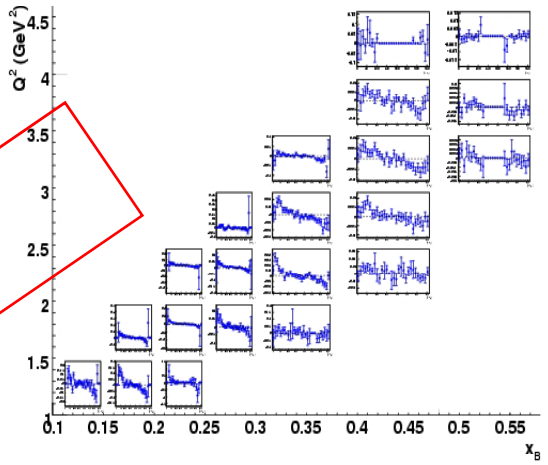
0.09<-t<0.2 GeV²



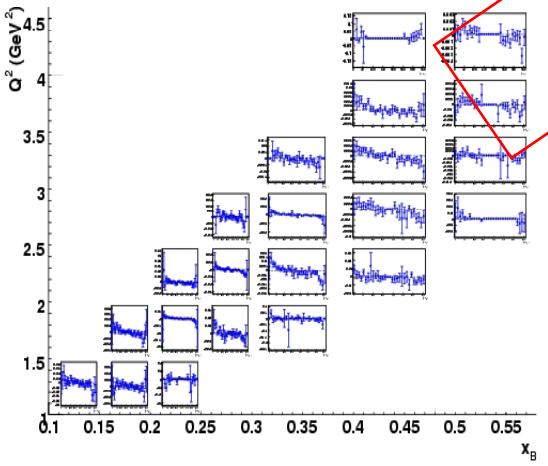
0.2<-t<0.4 GeV²



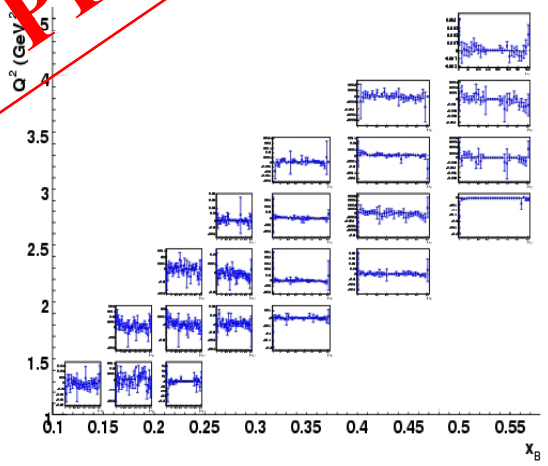
0.4<-t<0.6 GeV²



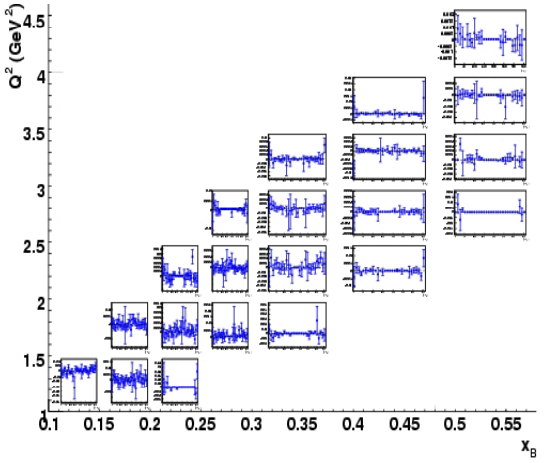
0.6<-t<1 GeV²



1<-t<1.5 GeV²

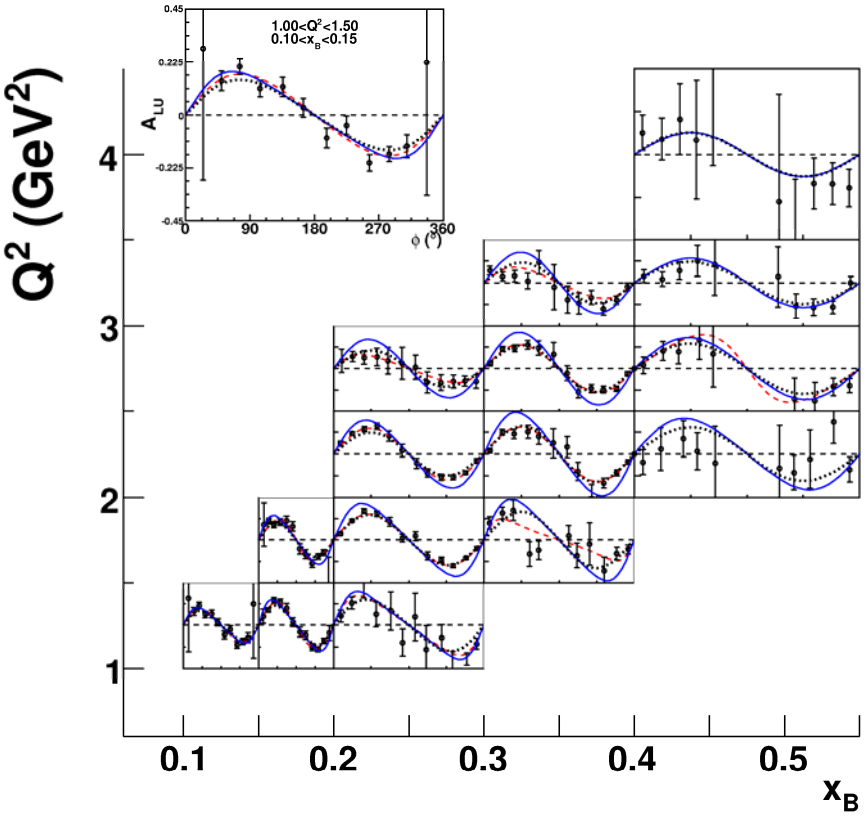


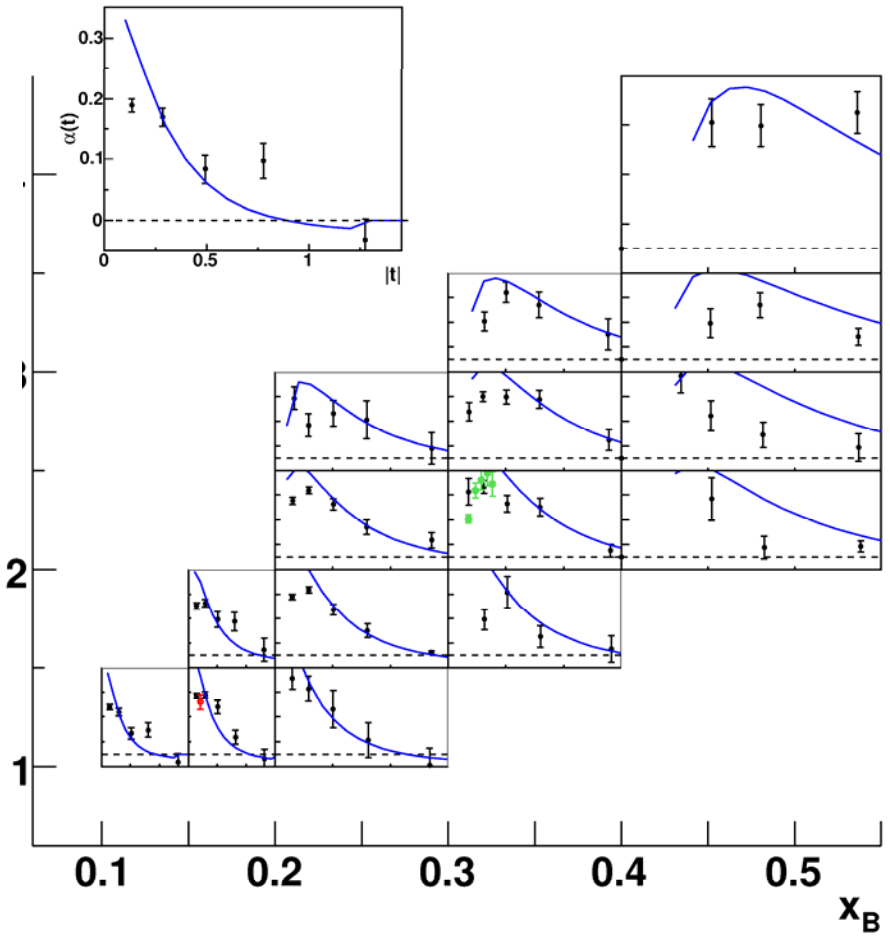
1.5<-t<2 GeV²



PRELIMINARY

Beam Spin asymetries





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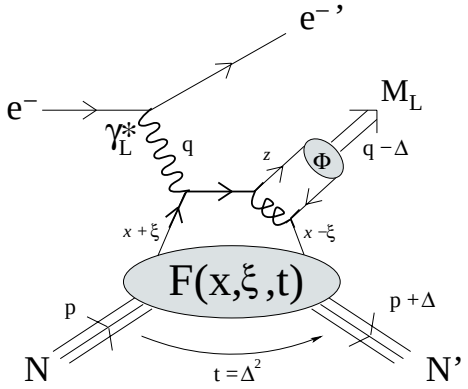
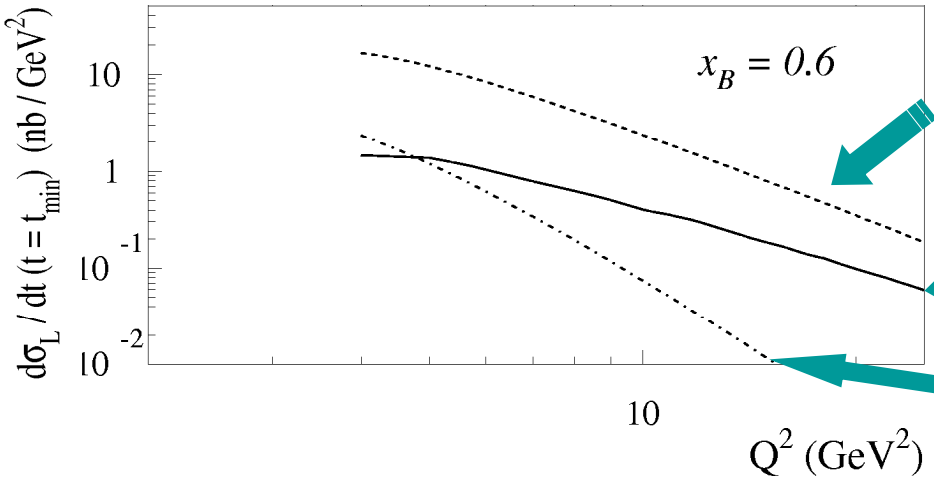
ρ^0_L electroproduction @ CLAS



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

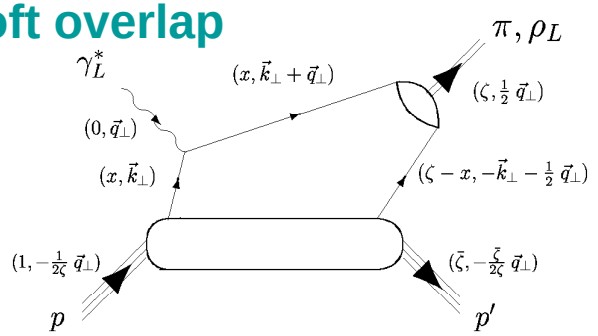
$$F(x,\xi,t) = H_M^N(x,\xi,t)\bar{N}(p')\gamma\cdot nN(p) + E_M^N(x,\xi,t)\bar{N}(p')i\sigma^{\kappa\lambda}\frac{n_\kappa\Delta_\lambda}{2m_N}N(p)$$



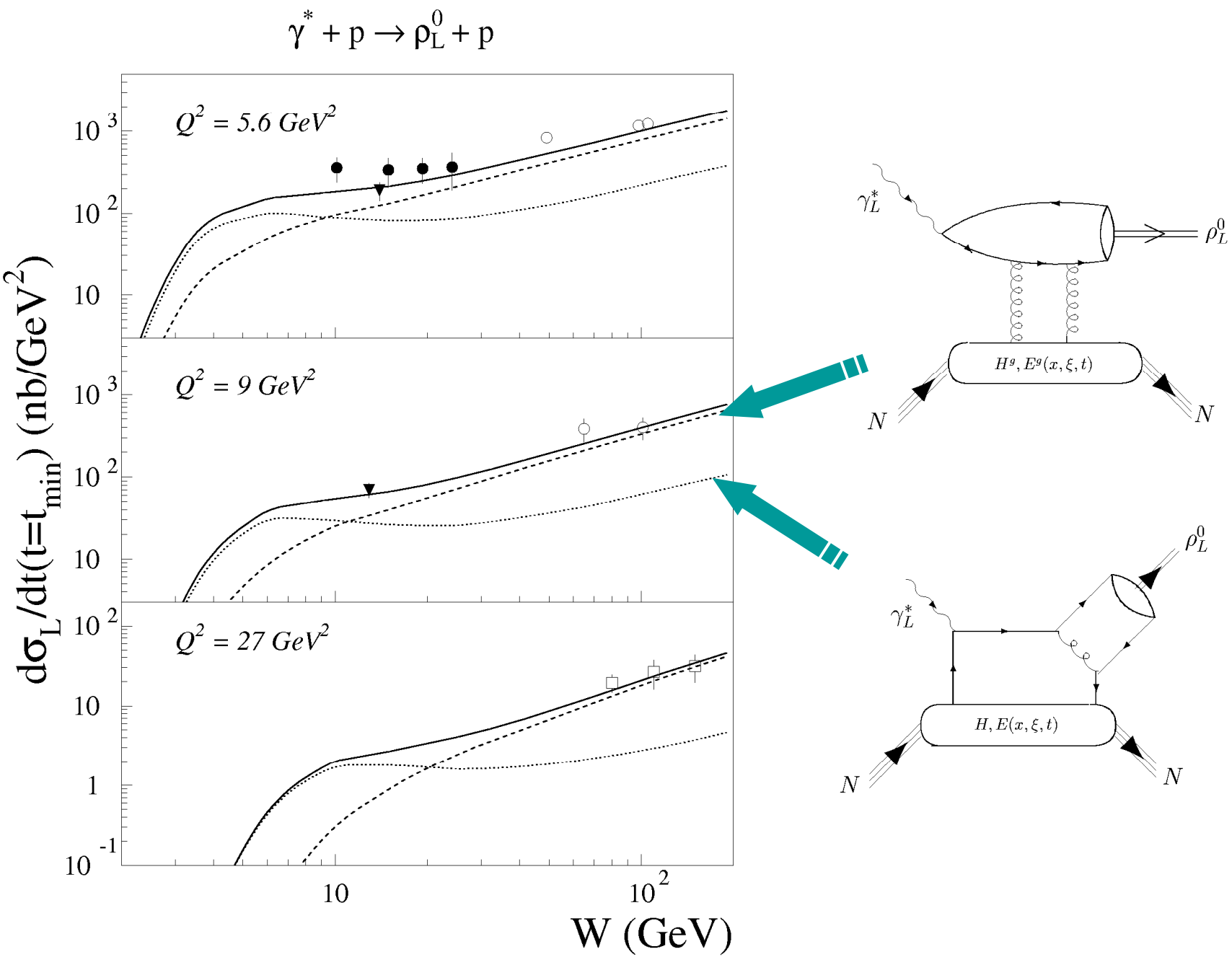
LO (w/o kperp effect)

LO (with kperp effect)

Soft overlap

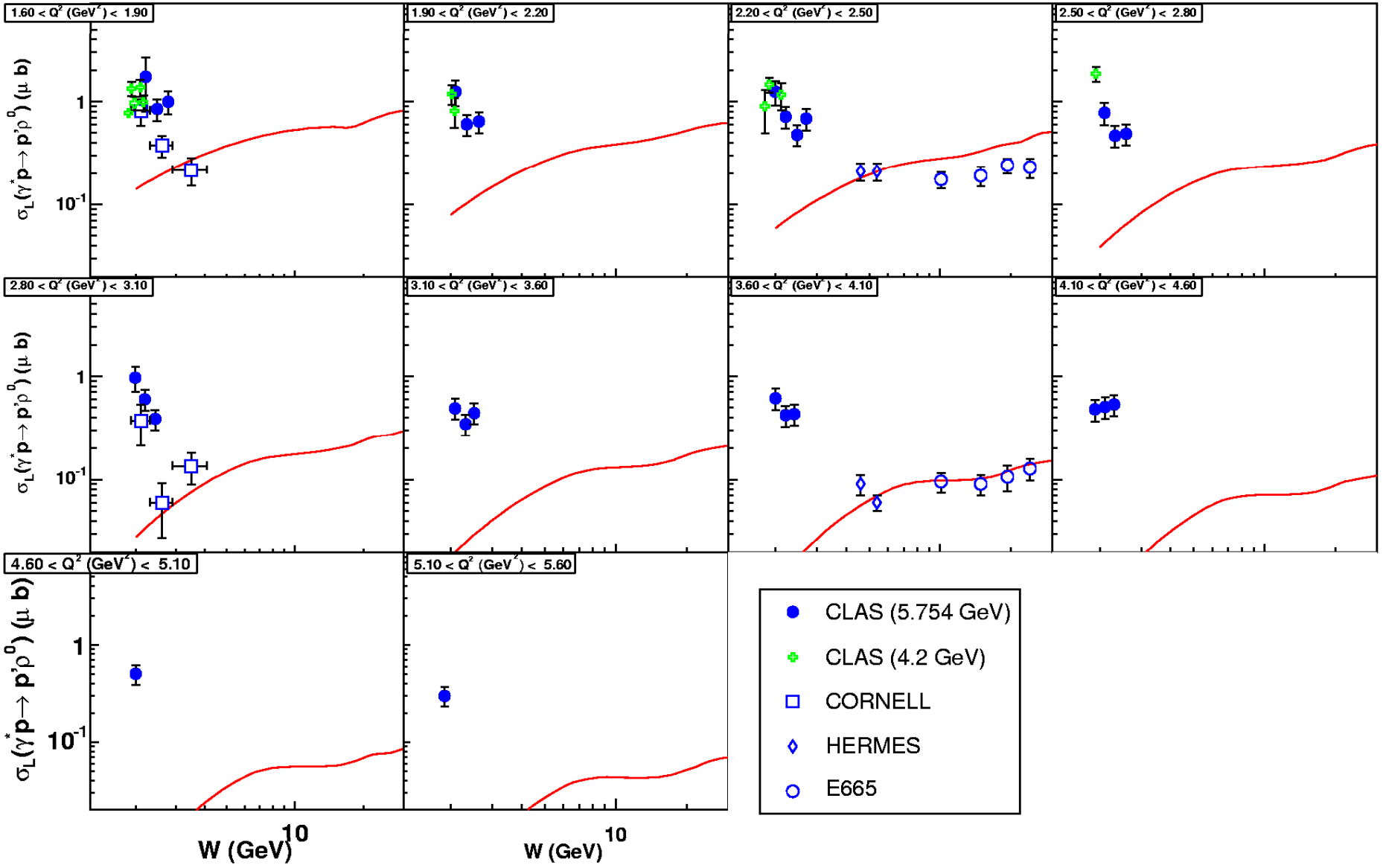


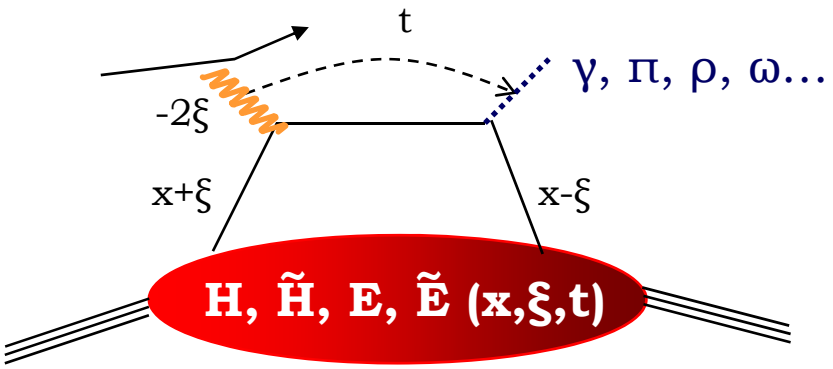
Handbag diagram calculation needs k_{perp} effects to account for preasymptotic effects

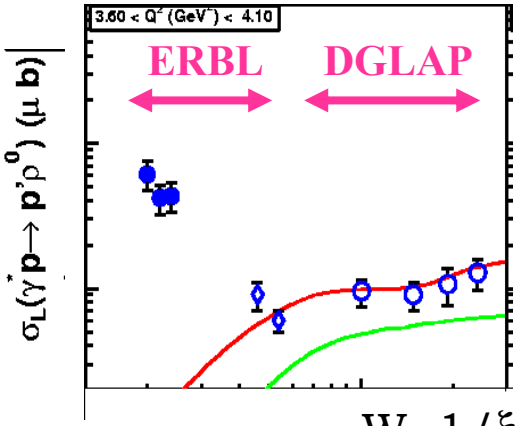


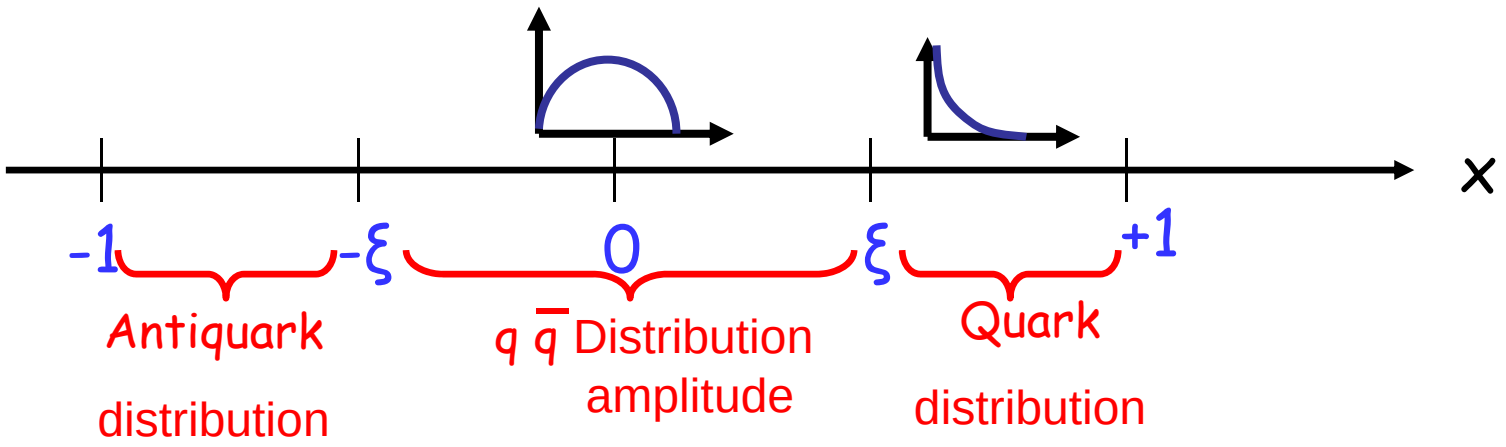
M. Vanderhaeghen, P. Guichon, M.G. (PRD 60:094017,1999)

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





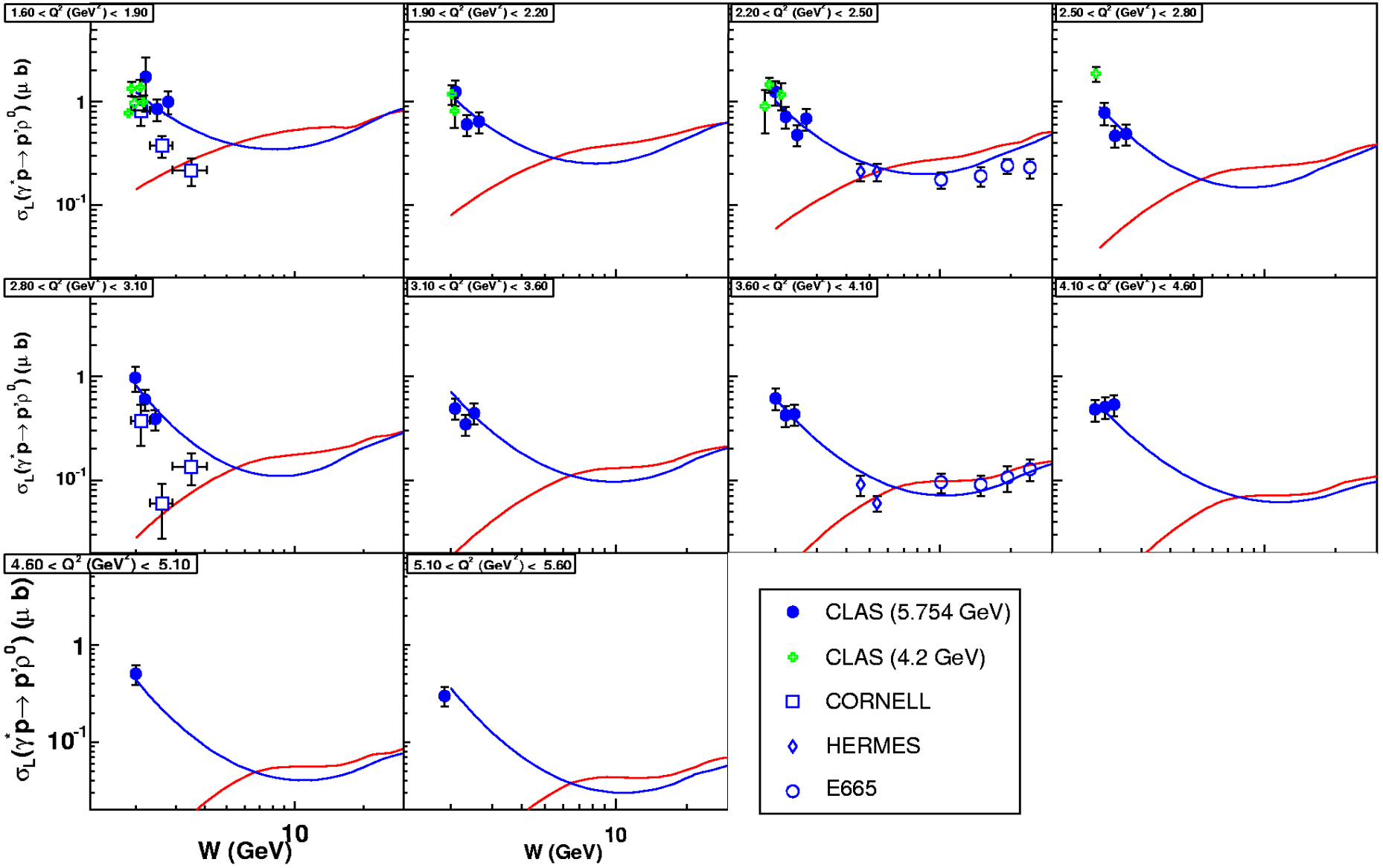




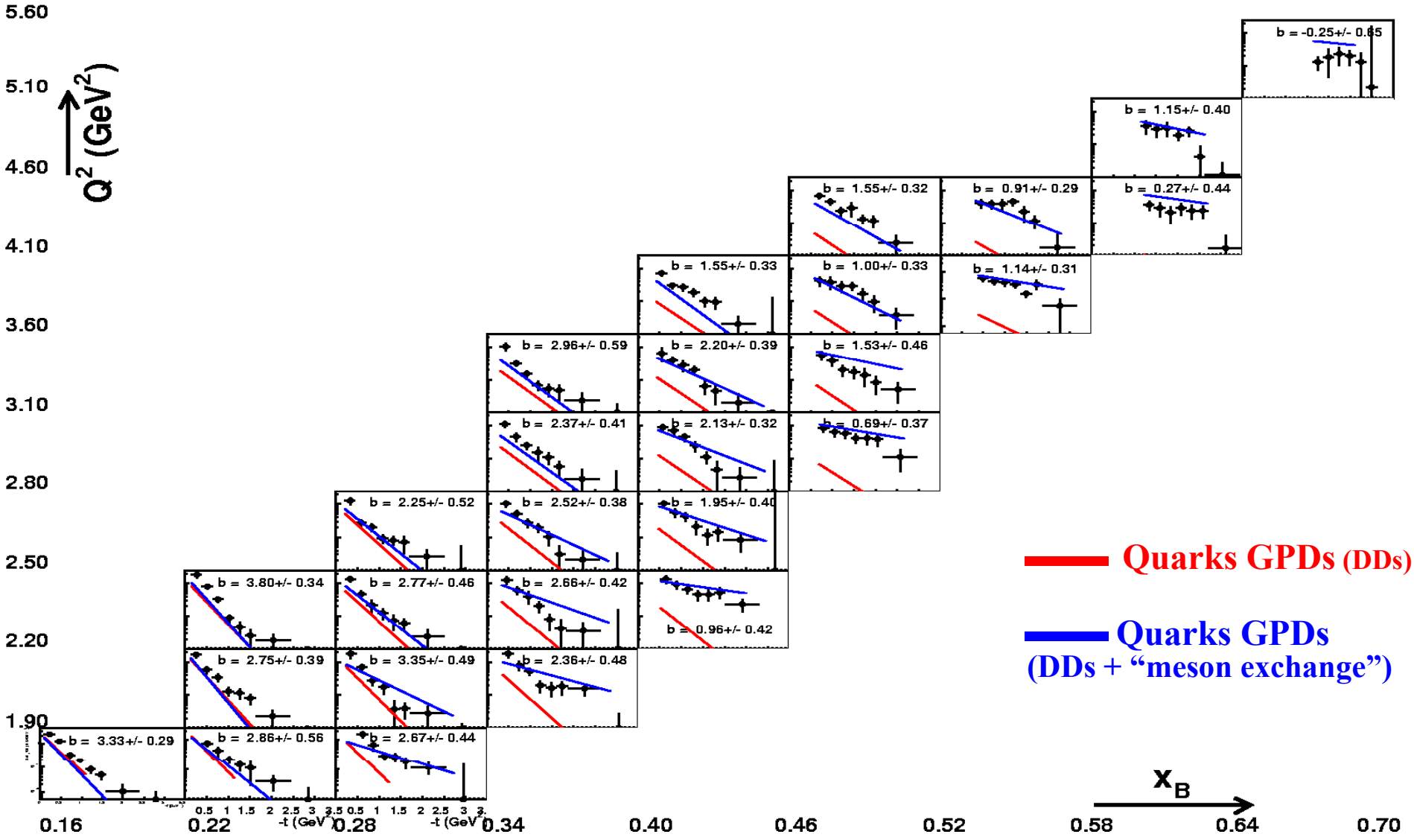
Add (in addition to DDs) (and fit) Gegenbauer (odd) polynomial to H (or/and E) GPD(s)

-Very Poor man's way of introducing $q\bar{q}$ correlations in the ERBL domain of GPDs-

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



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

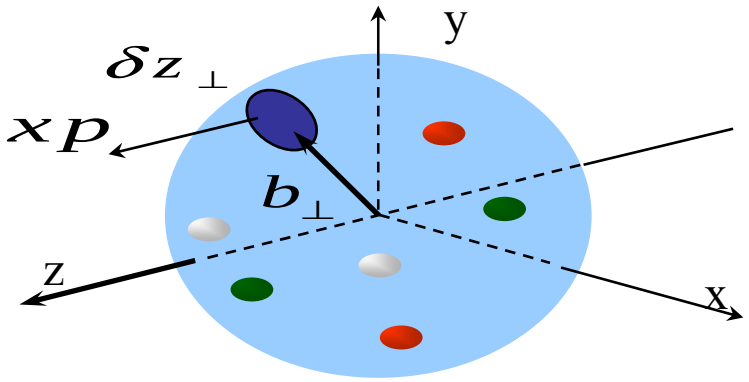


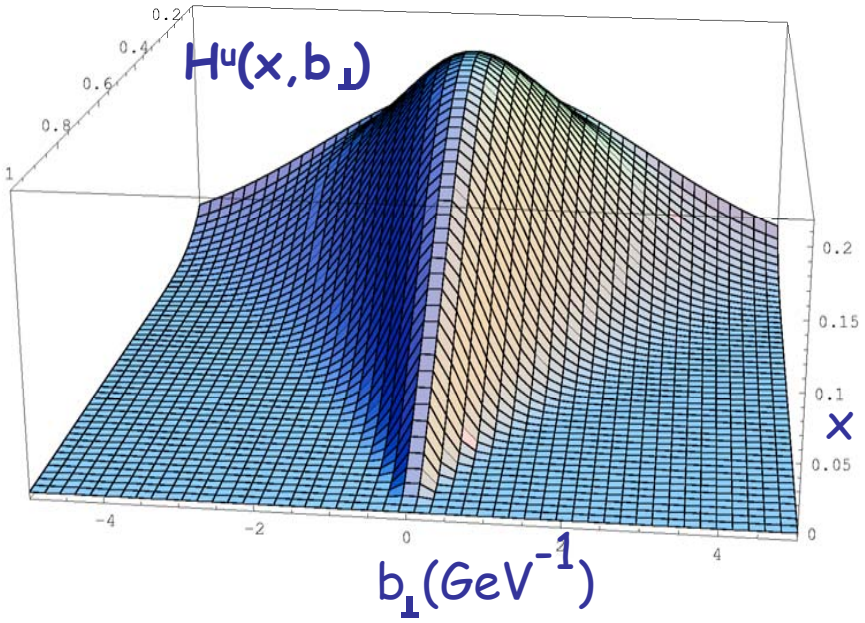
(x,ξ,t) dependence : Reggeized Double Distributions

(Radyushkin, Muller, Polyakov, VdH, M.G.)

$$DD^q(\alpha,\beta,t)=q(\beta)\, h^b(\alpha,\beta)\,\beta^{-\alpha'(1-\beta)t}$$

$$H^q(x,\mathbf{b}_\perp) \;=\; \int \frac{d^2\boldsymbol{\Delta}_\perp}{(2\pi)^2}\, e^{i\mathbf{b}_\perp\cdot\boldsymbol{\Delta}_\perp}\, H^q(x,\xi=0,-\boldsymbol{\Delta}_\perp{}^2)$$





Satisfies Form Factors sum rule and polynomiality

- *1/ A bit of background on GPDs*
- *2/ JLab results on DVCS*
- *3/ JLab ρ^0 electroproduction*
- *4/ Perspectives (JLab@12GeV)*

Short term future (JLab@6 GeV => 2011)

- E05-114 $\vec{p}(\vec{e},e'p\gamma)$

  A. Biselli, L. Elouadrhiri, K.Joo, S. Niccolai et al.

  DVCS with longitudinally polarized target

  Double target-beam spin asymmetry

- E06-003 $p(\vec{e},e'p\gamma)$

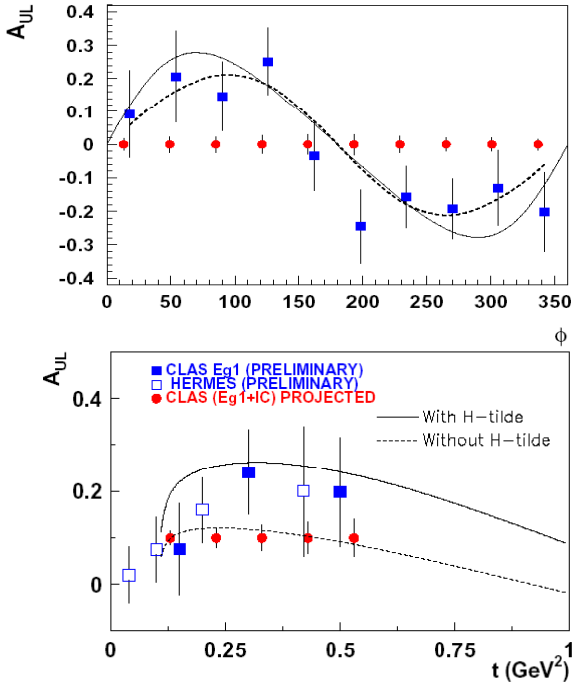
  V. Burkert, L. Elouadrhiri, M. Garçon, R. Niyazov, S. Stepanyan et al.

  Doubling of present statistics

- E07-007 $p(\vec{e},e'p\gamma)$

  C. Munoz, J. Roche, C. Hyde-Wright, P.-Y. Bertin, et al.

  Separation of DVCS^2 and BHxDVCS terms



- Projects

  $n(\vec{e},e'\gamma)n$ **Access to E GPD**

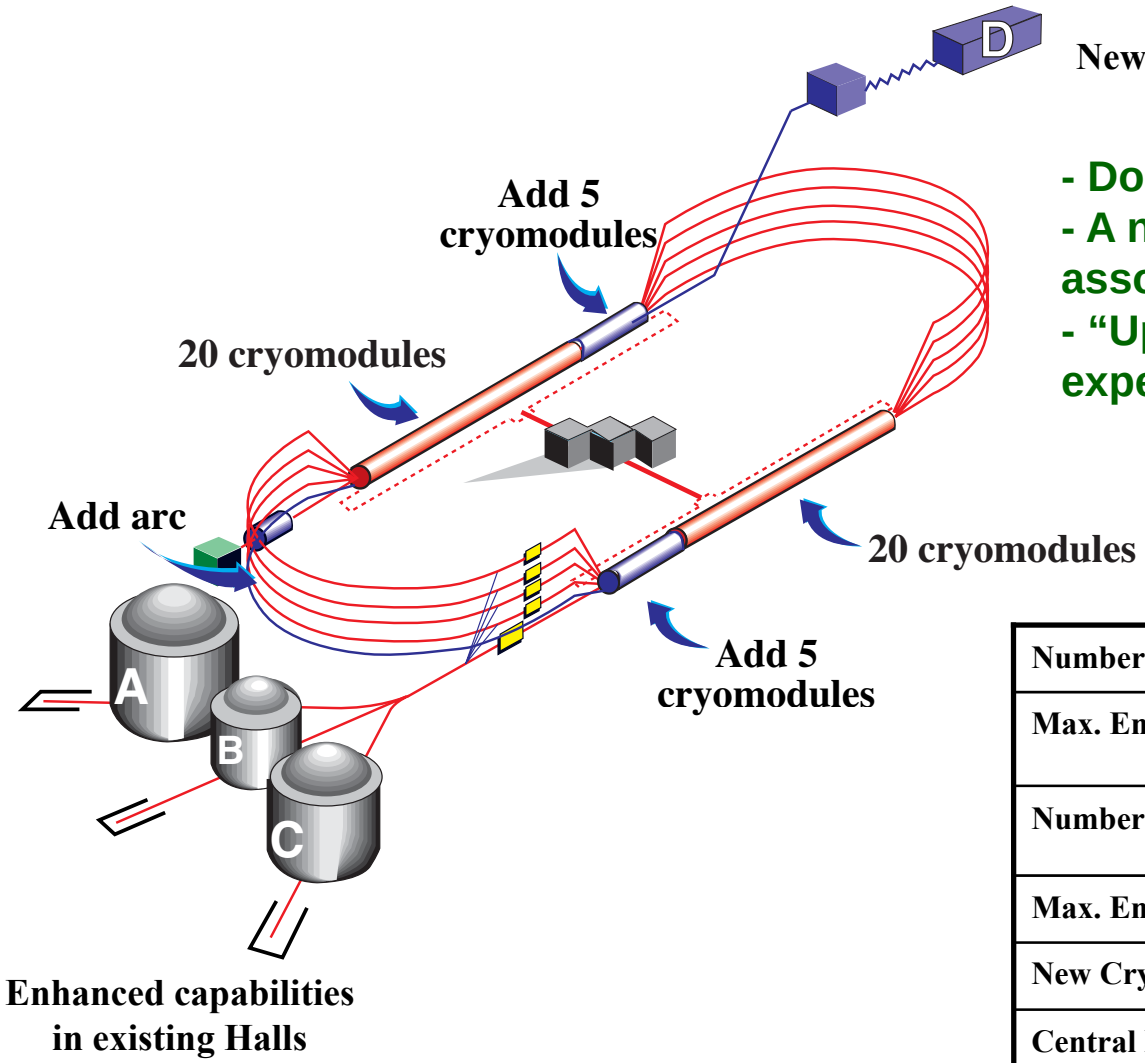
  Meson production (π^0, ω, ρ...)

  Double DVCS (DDVCS)

  ΔVCS, ...

Draw the most out of 6 GeV and prepare the 12 GeV by determining the most appropriate observables
(experimental techniques & methods and sensitivity to GPDs)

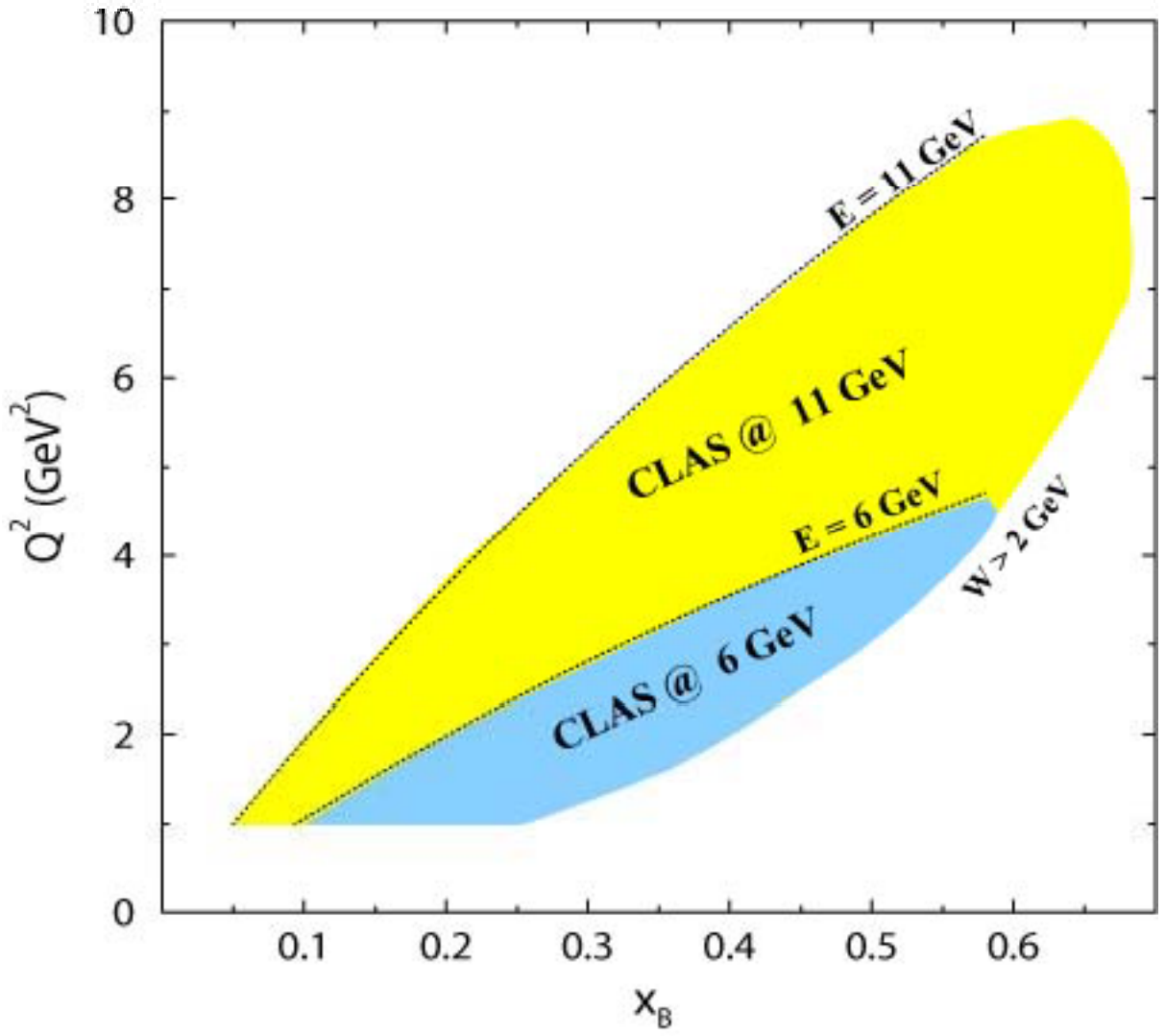
JLab energy upgrade to 12 GeV



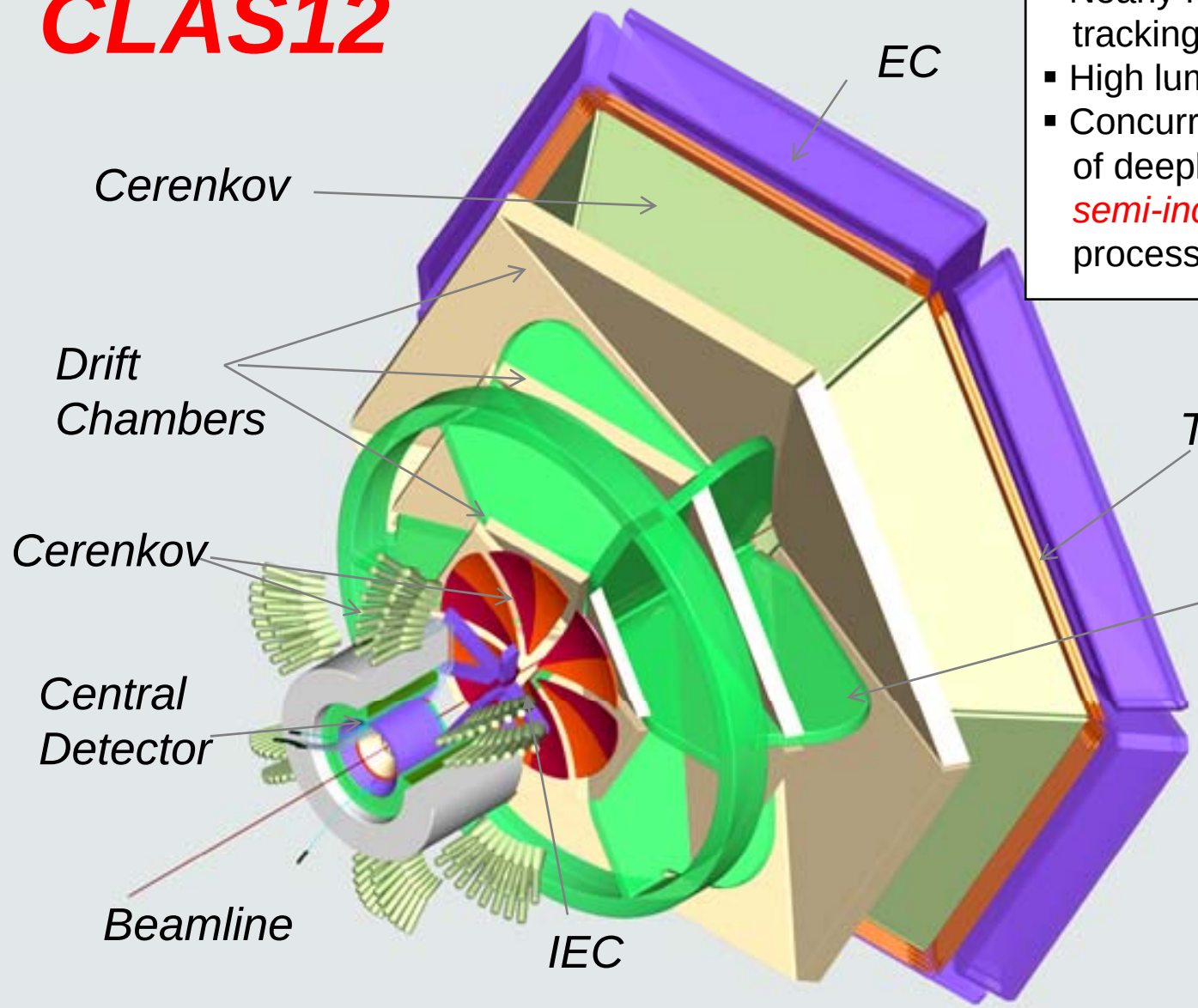
- Doubling the beam energy,
- A new experimental Hall and associated equipment,
- "Upgrade" of the 3 existing experimental Halls

Number of passes for Hall D	5.5 (add a tenth arc)
Max. Energy to Hall D	12 GeV (for 9 GeV photons)
Number of passes for Halls A/B/C	5
Max. Energy to Halls A/B/C	11 GeV
New Cryomodules	10 (5 per linac)
Central Helium Liquefier upgrade	9 kW (from present 4.5 kW)

From 6 to 11 GeV



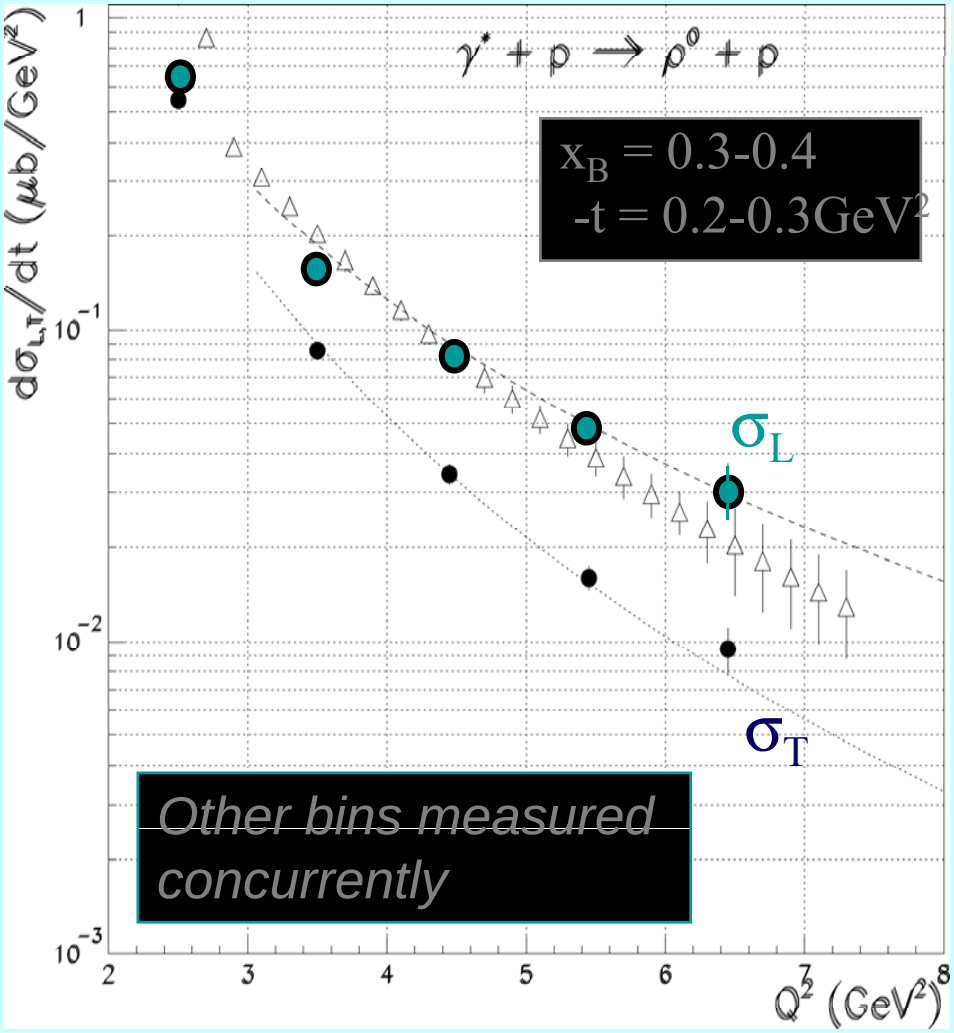
CLAS12



- Nearly full angle coverage for tracking and γ, n detection
- High luminosity, 10^{35} $cm^{-2}s^{-1}$
- Concurrent measurement of deeply virtual *exclusive, semi-inclusive*, and *inclusive* processes.

Design luminosity = $10^{35}cm^{-2}s^{-1}$

CLAS12 - L/T Separation $ep \rightarrow ep\rho^{o}(\pi^{+}\pi^{-})$



Projections for 11 GeV (sample kinematics)

- Test of Bjorken scaling
- Power corrections?

Summary

- ***Largest set ever of data for DVCS and VM (ρ^0, ω, ϕ) e-production in the valence region (BSA, $\sigma_{L,T}$, $d\sigma/dt$,…)***

- ***First hints that "standard" models/parametrizations of GPDs might be too simple***

- ***Large "flow" of more new experimental data to be expected soon (JLab 6&12 GeV, COMPASS, HERMES)***

- ***Theory is lagging behind now !***