The GPD program at a future Electron-Ion Collider Facility

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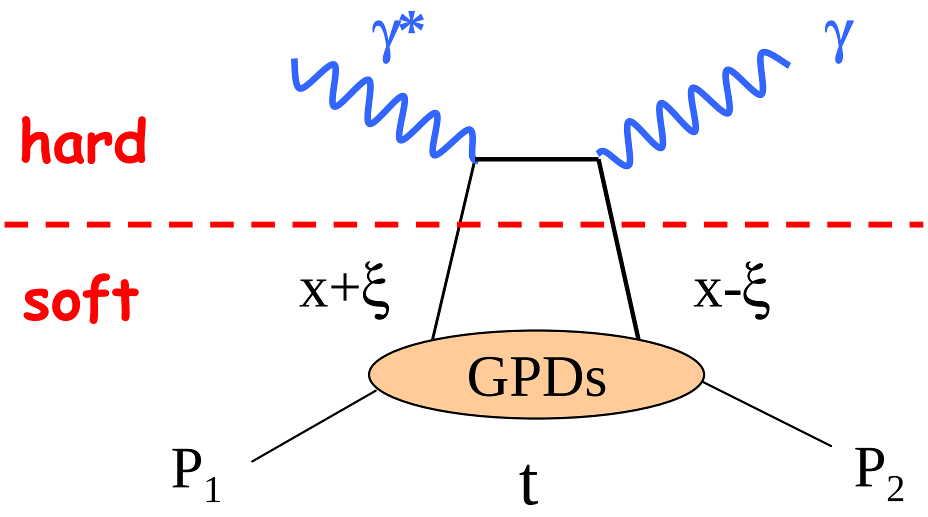
- GPSs, DVCS and Hard Exclusive Meson Production
- Lessons from HERA
- Result of DVCS simulations at eRHIC
- HEMP at a future EIC collider
- Detector requirements
- Conclusions

DIS 2008, 7-11 April 2008, University College London

Generalized Parton Distributions and DVCS



Factorisation:
Q^2 large, $-t<1$ GeV^2

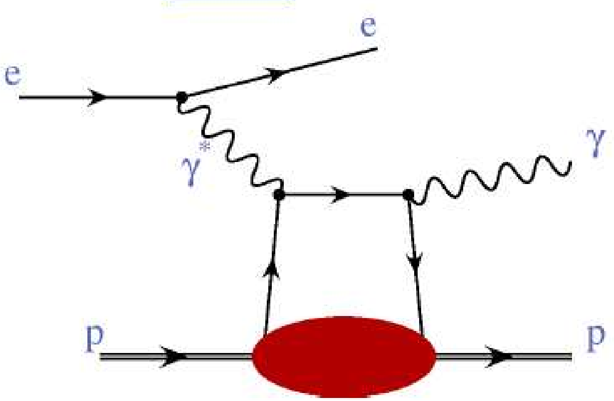
$$\xi = \frac{x_B}{2-x_B}$$

4 Generalised Parton Distributions : $H, E, \tilde{H}, \tilde{E}$ depending on 3 variables: x, ξ, t

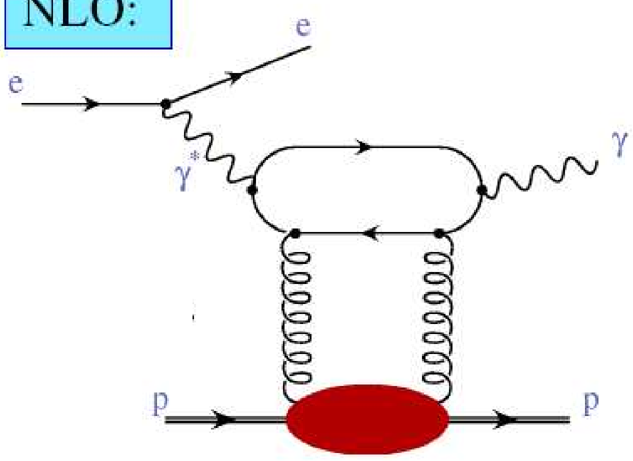
for each quark flavour and for gluons

for DVCS gluons contribute at higher orders in α_s

LO:



NLO:



at EIC

$0.0001 < x_B < 0.1$
$\xi \rightarrow 0$

a) sensitivity to sea quarks and gluons

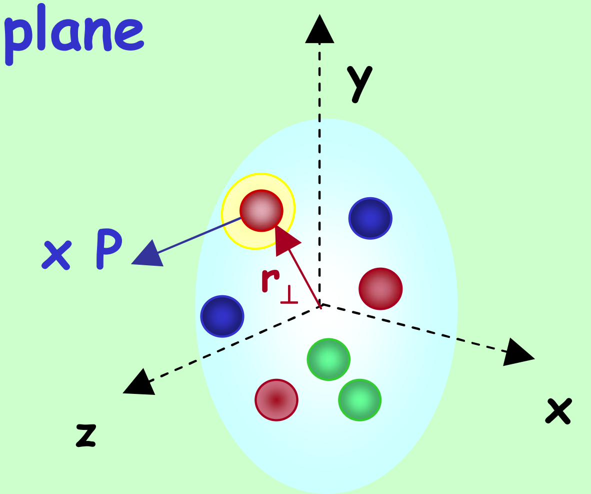
b) 'take out' and 'put back' partons act coherently

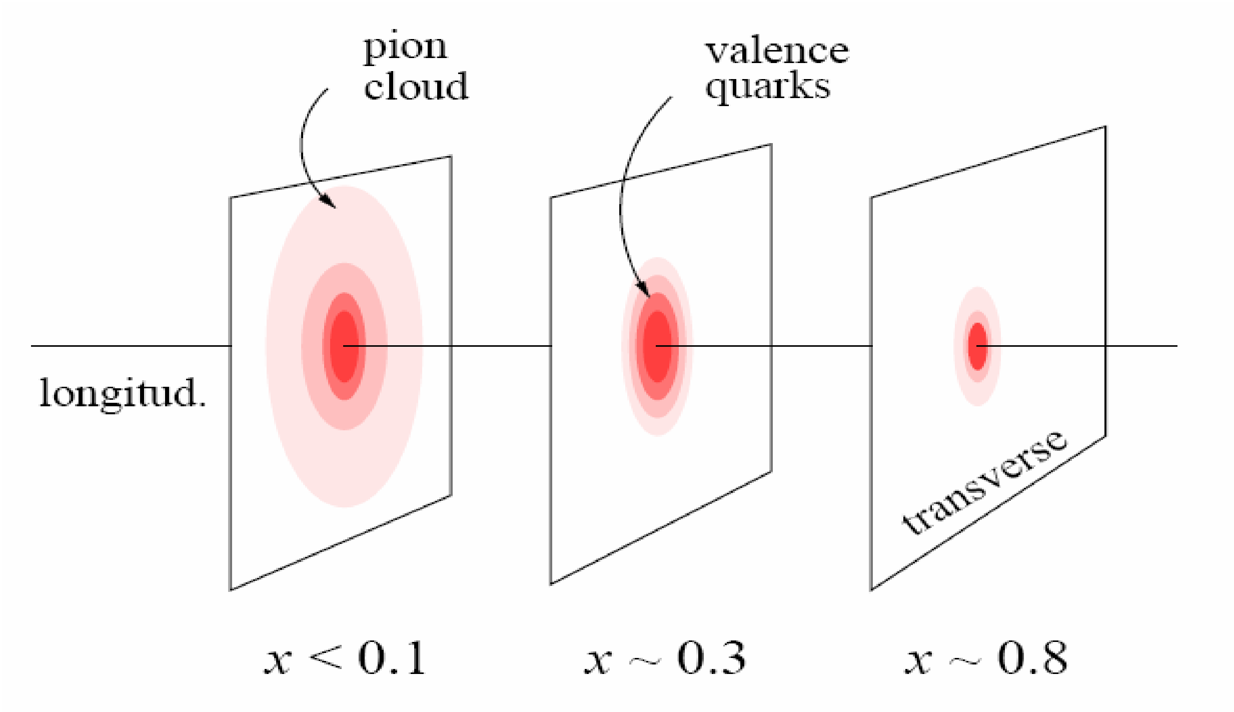
'Holy Grail' of GPD's at EIC

- GPD= a 3-dimensional picture of the partonic nucleon structure or spatial parton distribution in the transverse plane

$$H(x, \xi=0, t) \rightarrow H(x, r_{x,y})$$

probability interpretation
Burkardt



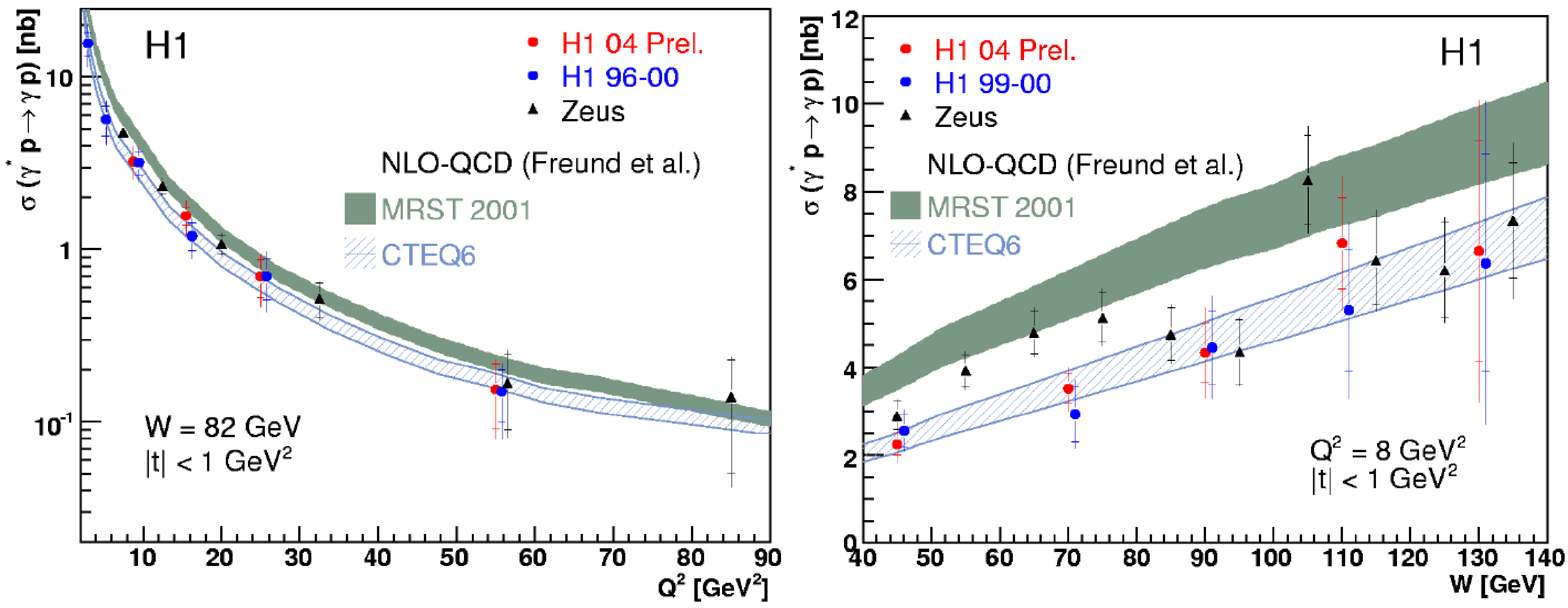


at EIC kinematical range
Transverse Gluon Imaging

Unpolarised DVCS cross sections from HERA

σ_{DVCS} at small x_B (< 0.01) mostly sensitive to H^g, H^{sea}

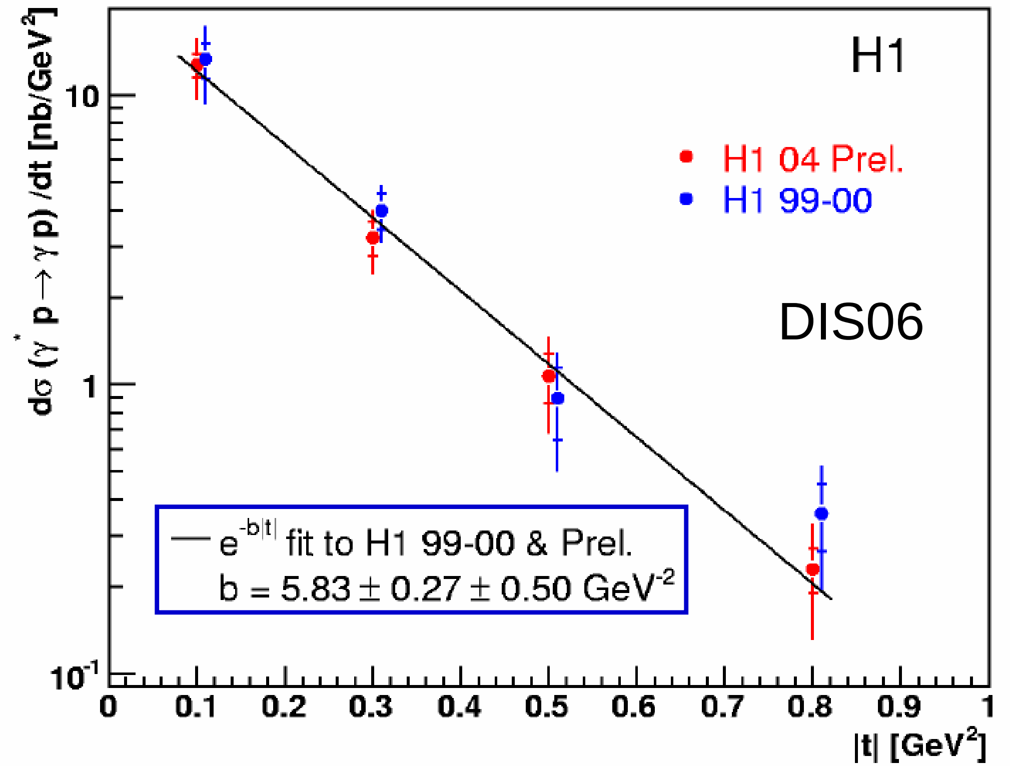
Q^2 and W dependence: NLO predictions



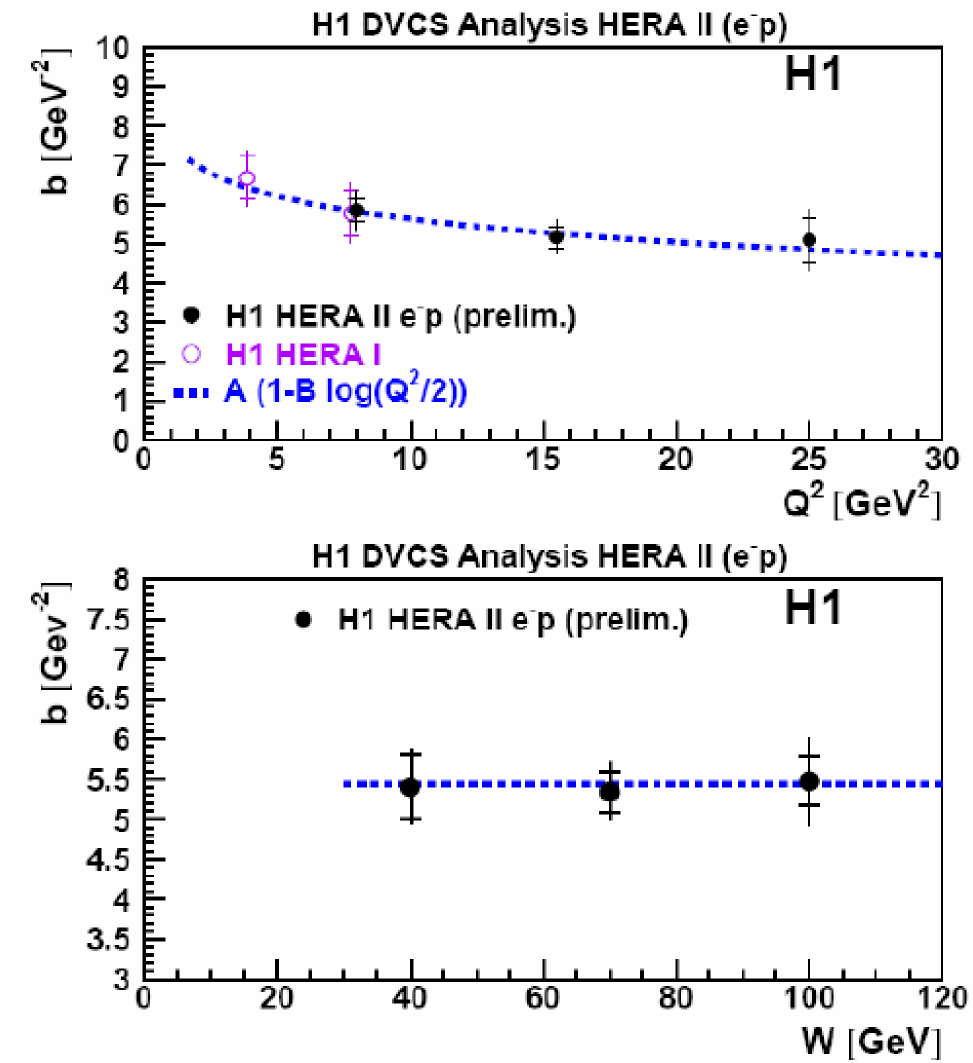
bands reflect experimental error on slope *b*: 5.26 < b < 6.40 GeV^{-2}

- Wide range of Q^2 - sensitivity to QCD evolution of GPDs
- Difference between MRS/CTEQ due to different xG at low x_B
- Meaurements of *b* significantly constrain uncertainty of models

t dependence of DVCS cross section



New H1 results on slopes - DIS07



Lessons from DVCS at H1/ZEUS

- **Good agreement with NLO predictions**

  GPDs ≡ PDFs at low scale; skewing generated by QCD evolution

- **Sensitivity to H^g** ; 15% change of H^g => 10% change of cross section

- Real part of DVCS amplitude – small effect, few%

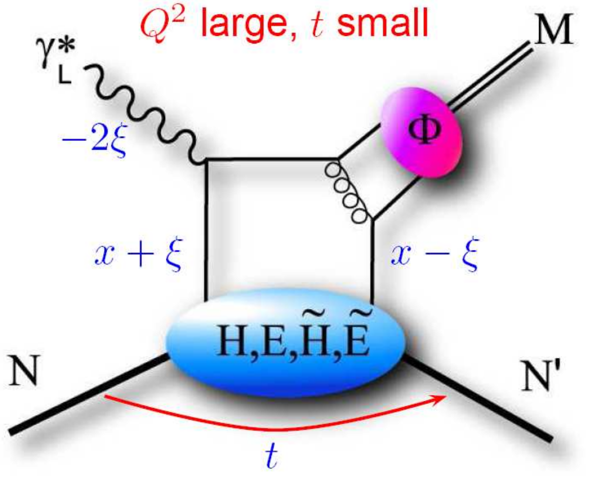
- Skewing parameter R=Im DIS / Im DVCS ~ 0.5

  Interplay of R_s (sea) and R_g (gluons)

- Low sensitivity to b(Q2) vs. b(const.)

- **Color dipole phenomenology (no GPDs) also a satisfacory description**

GPDs and Hard Exclusive Meson Production



- 4 Generalised Parton Distributions (GPDs)
  for each quark flavour and for gluons

- factorisation proven only for σ_L
  σ_T suppressed of by $1/Q^2$
  necessary to extract longitudinal contribution to observables (σ_L , …)

- allows separation $(\text{H,E}) \leftrightarrow (\tilde{\text{H}},\tilde{\text{E}})$ and wrt quark flavours

$\left.\begin{matrix}\text{H}\\ \tilde{\text{H}}\end{matrix}\right\}$ $\left.\begin{matrix}\text{E}\\ \tilde{\text{E}}\end{matrix}\right\}$ Vector mesons (ρ, ω, φ)
Pseudoscalar mesons (π, η)

conserve flip nucleon helicity

Flavour sensitivity of HEMP on the proton

ρ^0	2u+d, 9g/4
ω	2u-d, 3g/4
φ	s, g
ρ^+	u-d
J/ψ	g

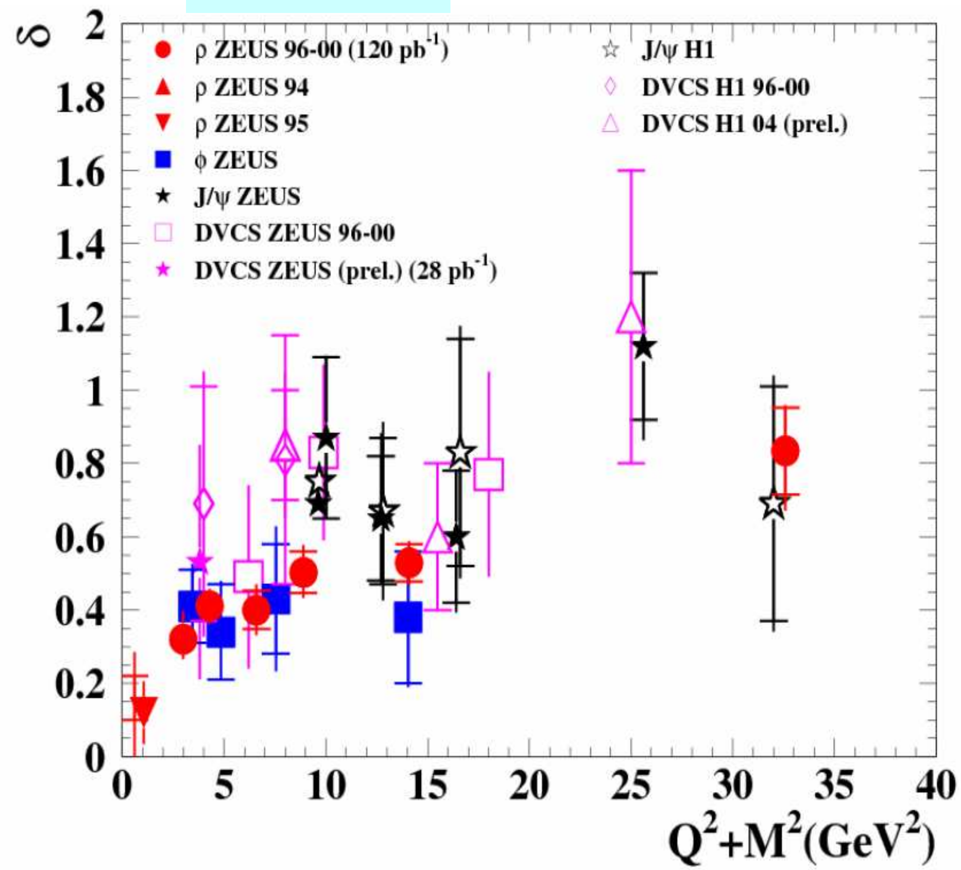
- quarks and gluons enter at the same order of α_S

- at $Q^2 \approx$ few GeV² power corrections/higher order pQCD terms are essential

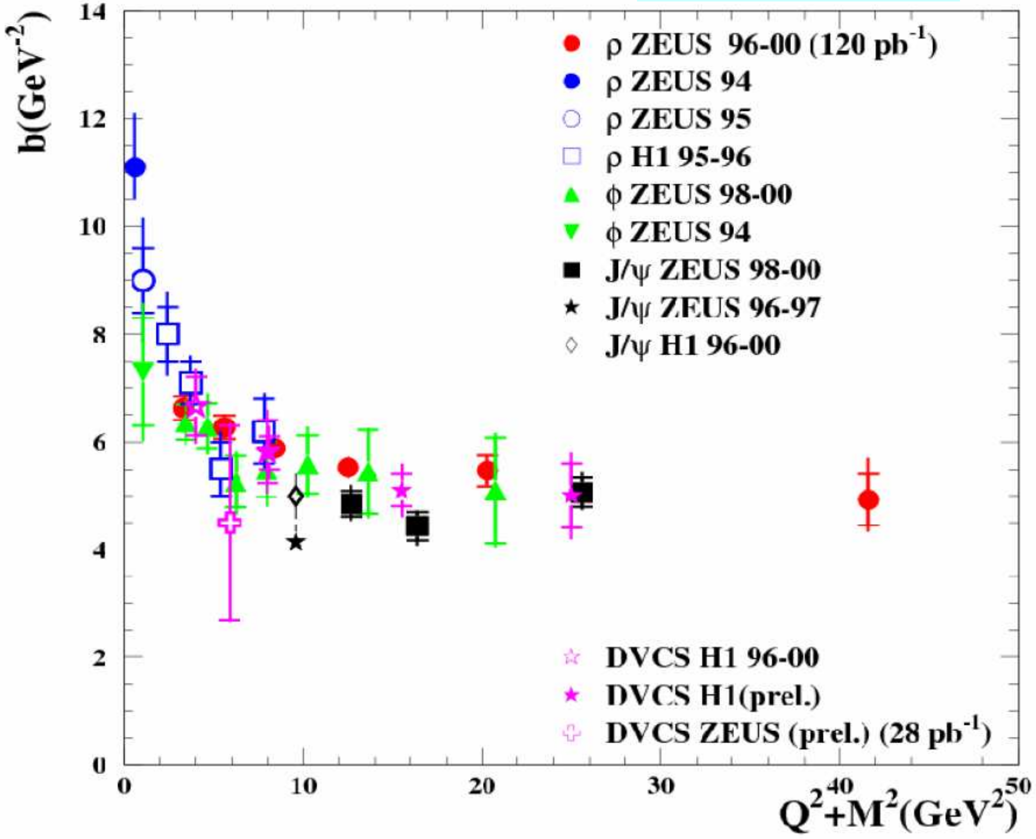
- wave function of meson (DA Φ)
  additional information/complication

Diffractive channels at HERA

$\sigma \propto W^{\delta}$



$d\sigma / dt \propto e^{-b|t|}$



- steep energy dependence in presence of hard scale Q^2 and/or M^2
- b-slopes decrease with increasing scale

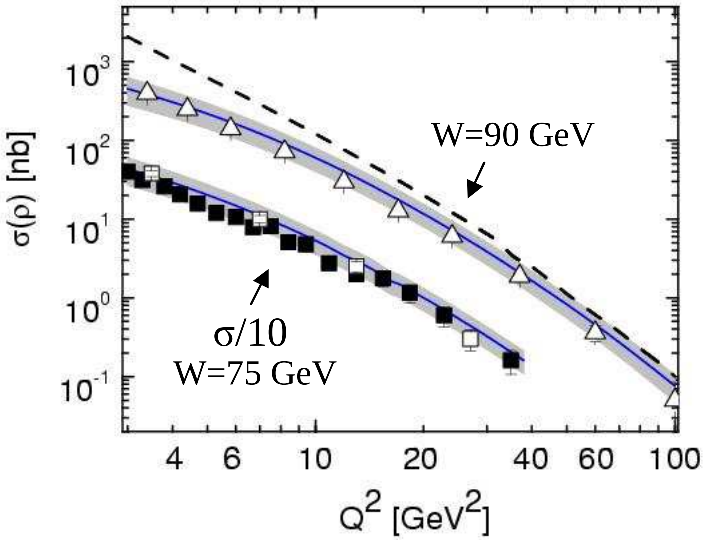
  approaching a limit ≈ 5 GeV^{-2} at large scales
- do we observe 'universality' of energy dependence and b-slopes at small x?

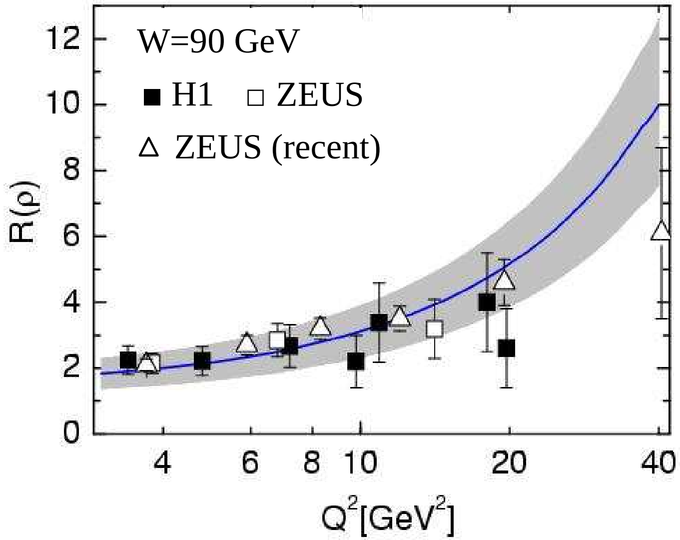
Comparison to a GPD model

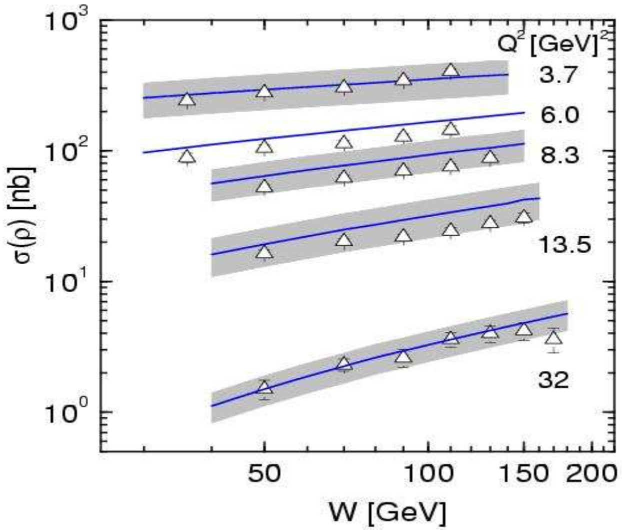
- Goloskokov-Kroll
  arXiv:0708,3569[hep-ph]

'Hand-bag model'; GPDs from DD using CTEQ6
power corrections due to k_t of quarks included

both contributions of γ^*_L and γ^*_T calculated







complete calculation

leading twist only (in collinear approx.)

- leading twist prediction above full calculation, even at $Q^2 = 100$ GeV²
  ≈ 20%
- contribution of σ_T decreases with Q², but does not vanish even at $Q^2 = 100$ GeV²
  ≈ 10%
- sea quark contribution, including interference with gluons, non-negligible
  25% at $Q^2 = 4$ GeV²

Simulations of DVCS at eRHIC

HE setup: $e^{+/-}$ (10 GeV) + p (250 GeV) $\mathcal{L}$ = 4.4 · 10^{32} $cm^{-2}s^{-1}$ 38 pb^{-1}/day

LE setup: $e^{+/-}$ (5 GeV) + p (50 GeV) $\mathcal{L}$ = 1.5 · 10^{32} $cm^{-2}s^{-1}$ 13 pb^{-1}/day

diam. of the pipe - 20 cm, space for Central Detector: ≈ +/- 280 cm from IP

→ acceptance of Central Detector (improved ZDR) **$2° < \theta_{lab} < 178°$**

event generator: FFS (1998)
parameterization with **R=0.5, η = 0.4**
and **b = 6.2 GeV^{-2}**

→ DVCS + BH + INT cross section

acceptance simulated by kinematical cuts

$2° < \theta_{e'} < 178°$	**$2° < \theta_{\gamma} < 178°$**
$E_{e'} > E_{min}$ GeV	**$E_{\gamma} > 0.5$ GeV**

E_{min} = 2 GeV (HE) or 1 GeV (LE)

kinematical **smearing**: parameterization of resolutions of H1 (SPACAL, LArCal) + ZEUS (θ_{γ}, φ_{γ}) + expected for LHC ($\theta_{e'}$, $\varphi_{e'}$)

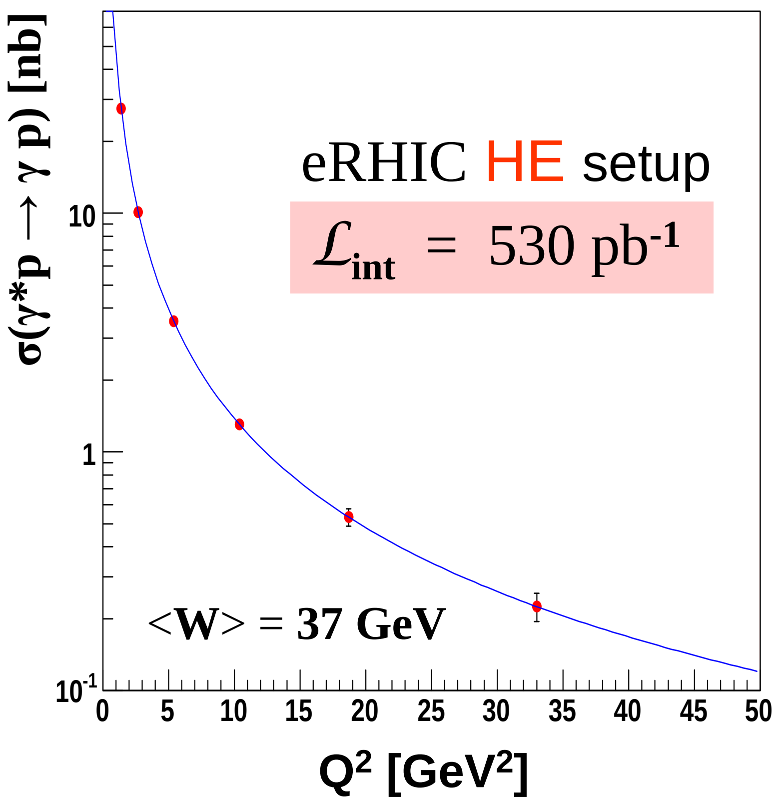
acceptance and 'reasonable' balance between DVCS and BH motivate **kinematical ranges** →

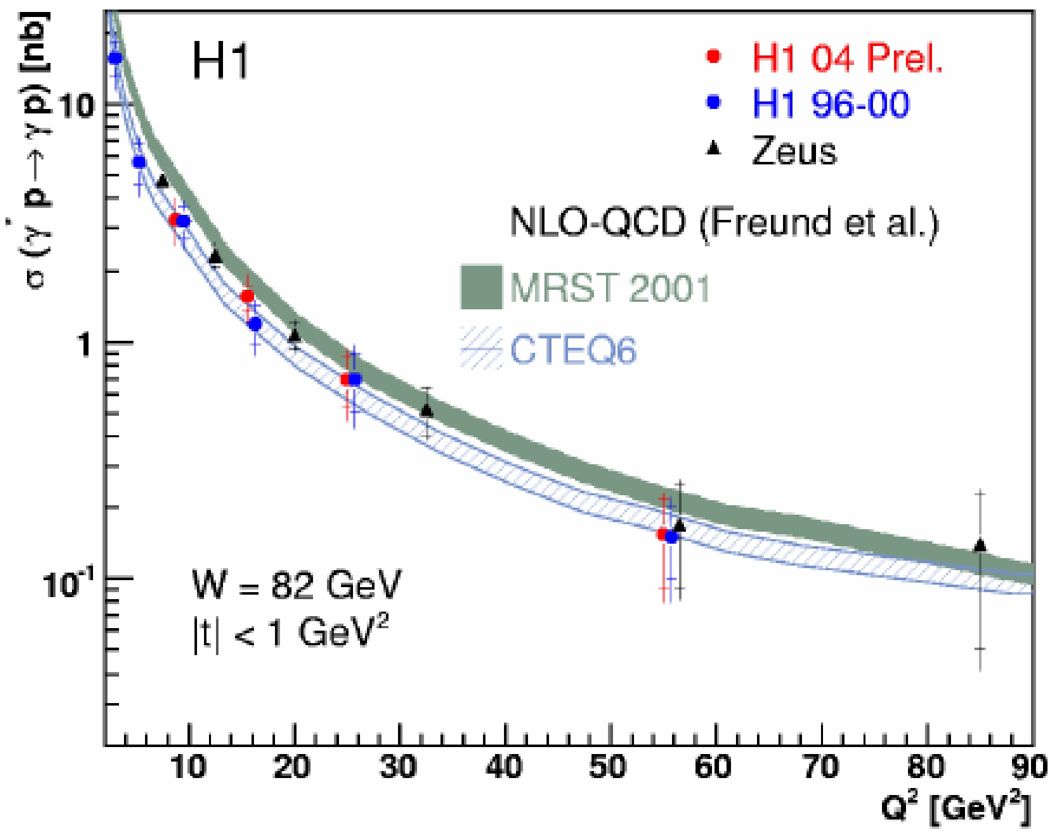
HE setup	LE setup
$1 < Q^2 < 50$ GeV^2	**$1 < Q^2 < 50$ GeV^2**
$10 < W < 90$ GeV	**$2.5 < W < 28$ GeV**
$0.05 < \|t\| < 1.0$ GeV^2	**$0.05 < \|t\| < 1.0$ GeV^2**

Precision of DVCS unpolarized cross sections at eRHIC (1)

HE setup: $e^{+/-}$ (10 GeV) + p (250 GeV) $\mathcal{L} = 4.4 \cdot 10^{32}\ cm^{-2}s^{-1}$ 38 pb^{-1}/day

For one out of 6 W intervals (30 < W < 45 GeV)





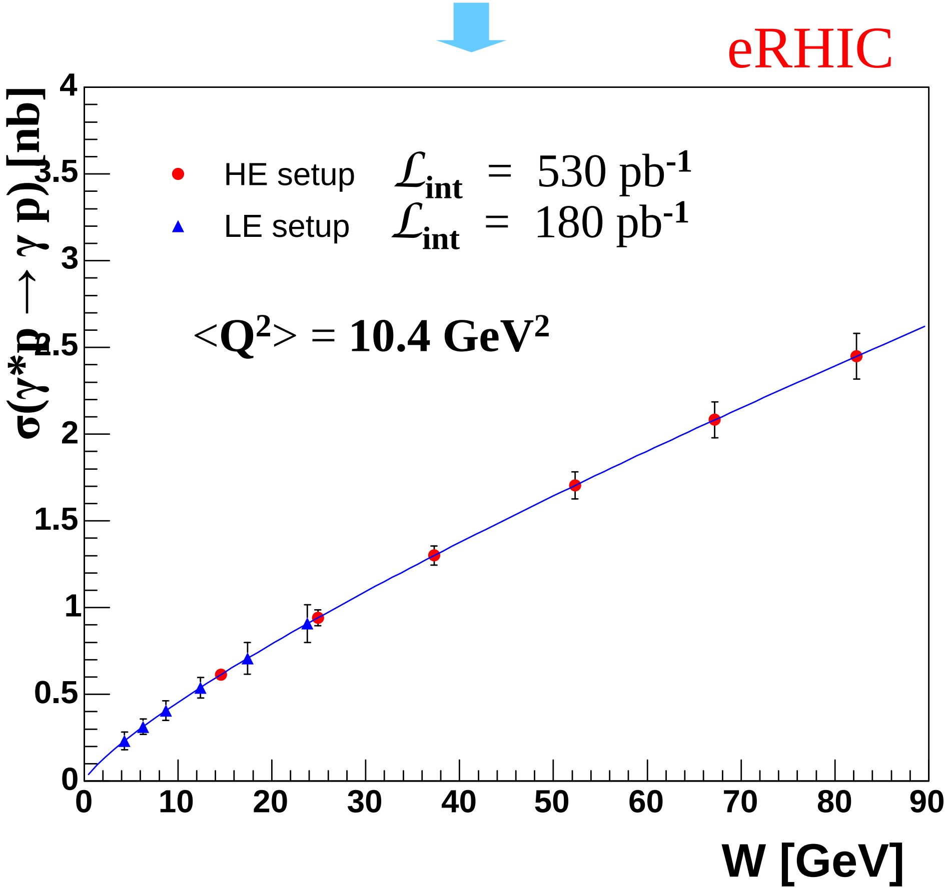
❖ **eRHIC measurements of cross section will provide significant constraints**

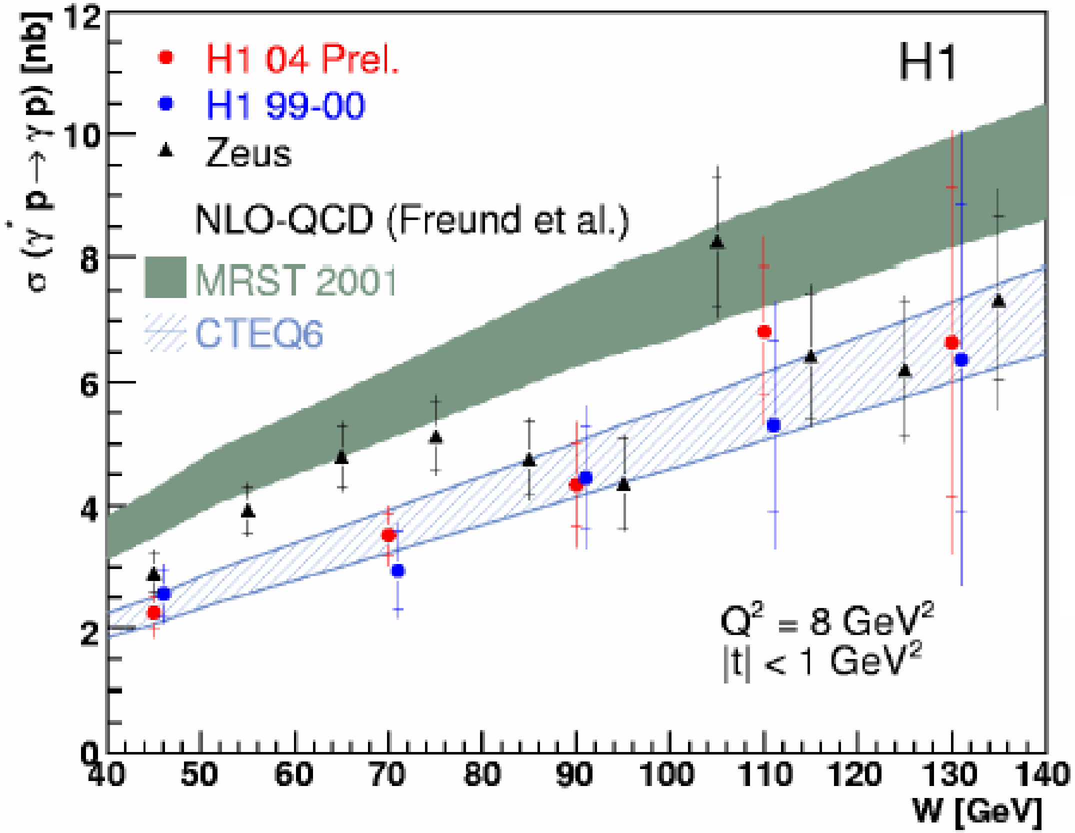
Precision of DVCS unpolarized cross sections at eRHIC (2)

HE setup: $e^{+/-}$ (10 GeV) + p (250 GeV) $\mathcal{L} = 4.4 \cdot 10^{32}$ cm^{-2}s^{-1} 38 pb^{-1}/day

LE setup: $e^{+/-}$ (5 GeV) + p (50 GeV) $\mathcal{L} = 1.5 \cdot 10^{32}$ cm^{-2}s^{-1} 13 pb^{-1}/day

For one out of 6 Q^2 intervals ($8 < Q^2 < 15$ GeV^2)

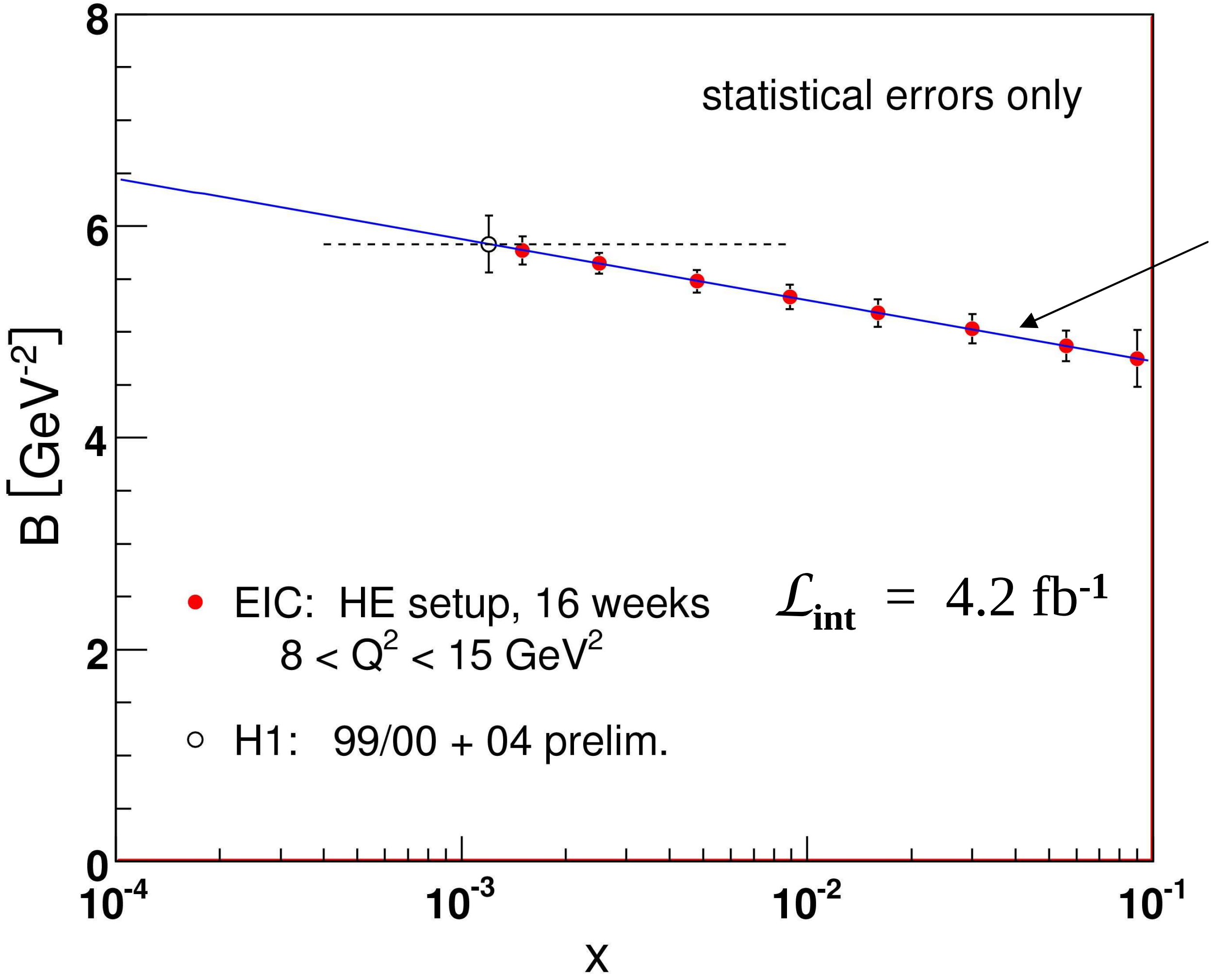




❖ **EIC measurements of cross section will provide significant constraints also significantly extend the range towards small W**

Towards 3D mapping of parton structure of the nucleon at EIC

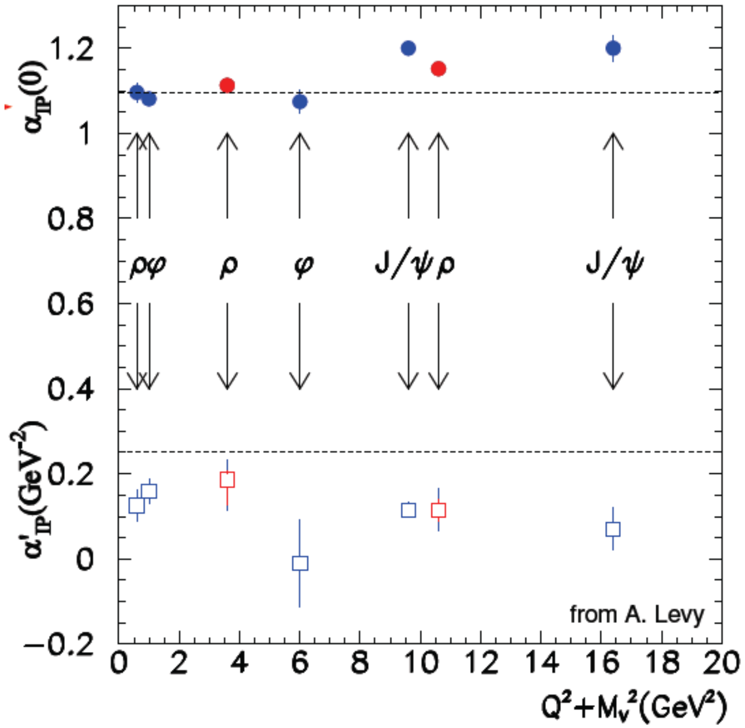
$$d\sigma / dt(\gamma^* p \to \gamma\, p) \propto \exp(-B\,|\,t\,|)$$



(assumed for illustration)

$$B(x) = B(x_o) + 2\alpha' \ln(x_0 / x)$$

α' = 0.125 GeV^{-2}



simultaneous data in several (6) Q^2 bins

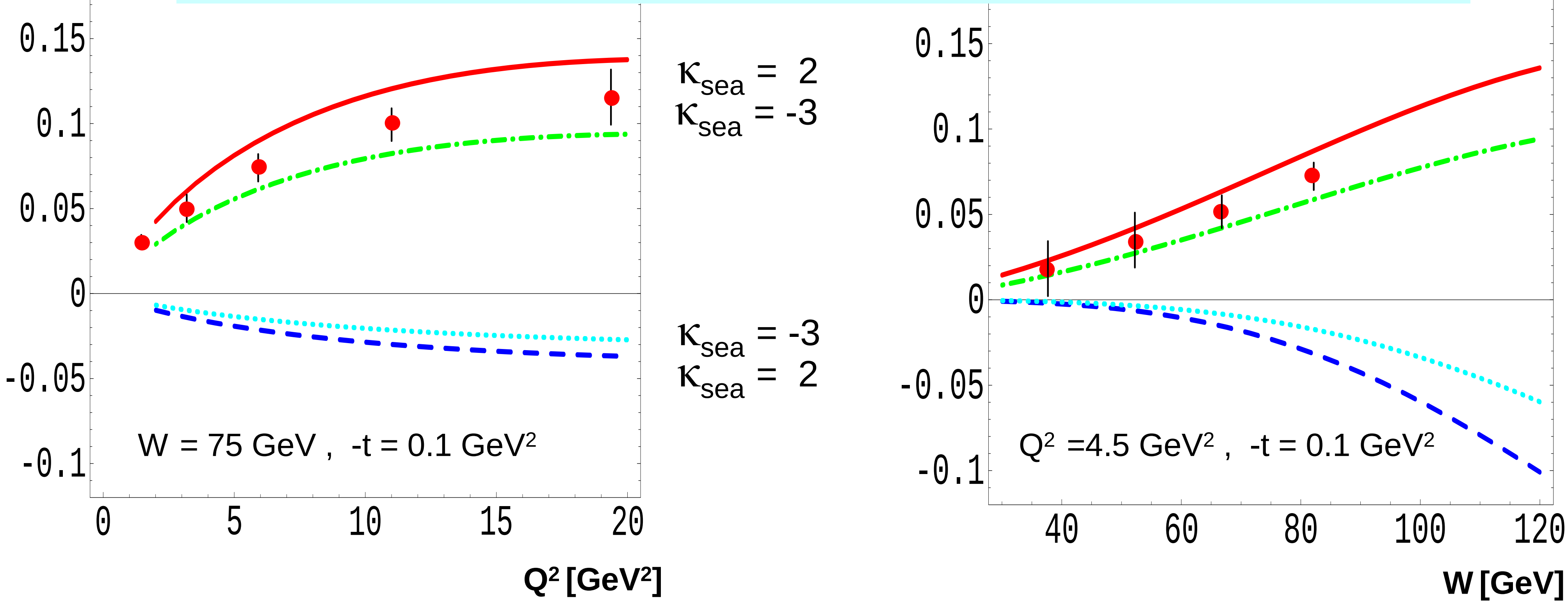
Sufficient luminosity to do triple-differential measurements in x, Q^2, t at EIC!

Lepton charge asymmetry at eRHIC

model of **Belitsky, Mueller, Kirchner** (2002) for **GPDs at small x_B**
parameters of sea-quark sector fixed using H1 DVCS data (PL B517 (2001))
except magnetic moment κ_{sea} $(-3 < \kappa_{sea} < 2)$, which **enters Ji's sum rule for J_q**

BMK use 'improved' charge asymmetries **$A_C^{\cos\varphi}$** and **$A_C^{\sin\varphi}$**

HE setup, $\mathcal{L}_{int} = 530\ \mathrm{pb}^{-1}$ **divided equally between e^+ and e^-**



❖ **measurements of asymmetries at EIC sensitive tool to validate models of GPDs**

Hard Exclusive Meson Production at EIC

- ‘diffractive’ channels $J/\psi, \rho^0, \varphi\ldots$ sensitivity to gluons

  → transverse gluon (and sea quarks) imaging

- ‘non-diffractive’ channels $\pi, \eta, K, \rho^+\ldots$

  → probe spin/flavour/charge non-singlet GPD’s

  by model-independent comparison of channels

  π^0/η $\Delta u/\Delta d$, meson wave functions

  ρ^+/K^* SU(3) symmetry of quark GPD’s

  π^0/π^+ role of the pion pole in GPD

  experimentally more challenging than ‘diffractive’ channels

  smaller cross sections, L/T separation for pseudo-scalar mesons

- advantage of EIC - high Q^2 ; power corrections less important

Detector requirements for exclusive processes

small cross sections
a challenge

- large luminosity
- effective suppression of non-exclusive background

➢ Hermeticity — wide kinematical range and suppression of non-exclusive bkg.

- angular acceptance of Central Detector strongly affects small x region

  $2^o \div 178^o$ ('improved ZDR')

- importance of coverage of low E_γ region (both π^0 bkg. and accept. small W)

  E_γ > 0.5 GeV (?)

- Leading Proton Detector - suppression of bkg. from proton diff. dissociation

  acceptance and t-range strongly dependent

  on beam-line design and on beam tune (β^*)

➢ Particle Identification — necessary minimum - e/μ/h separation

with Calorimetry and Muon Detector

Detector requirements for exclusive processes

- Resolutions

  - in particular important for *dσ/dt* and angular distributions (DVCS and L/R separation for VM)
  - affect choice of exclusivity cuts ⟹ background rejection

Conservative estimates of the resolutions (based on existing experience)

Central Detector

- scattered electrons $\frac{\sigma_E}{E} = \frac{0.071}{\sqrt{E}} \oplus .025$ (H1 SPACAL), $\sigma_\theta = \sigma_\varphi$ = 0.3 mrad (LHC)
- photons $\frac{\sigma_E}{E} = \frac{0.11}{\sqrt{E}}$ (H1 LAr), $\sigma_\theta = \sigma_\varphi$ = 5 mrad (ZEUS)
- charged particles

$$\left.\begin{array}{l} \frac{\sigma_{p_t}}{p_t} = 0.0058\, p_t \oplus 0.0065 \oplus 0.0014 / p_t \\ \sigma_\eta = 0.0015 \oplus 0.0017 / p_t \qquad \sigma_\varphi = 0.0006 \oplus 0.002 / p_t \end{array}\right\} \text{(ZEUS)}$$

Leading Proton Detector

- silicon 100μm microstrip detectors $\sigma_x = \sigma_y$ = 30 μm (PP2PP)

example: for DVCS and 0.1 < t < 0.2 GeV^2 expected resolution in t is 0.06 GeV^2 when determined from CD or 0.02 GeV^2 from LPD

Summary for DVCS and HEPM at an EIC

- Wide kinematical range, overlap with HERA and COMPASS

  $\mathbf{1.5 \cdot 10^{-4} < x_B < 0.15}$ - sensitivity to gluons and sea quarks

  $\mathbf{1 < Q^2 < 50\ GeV^2}$ - sensitivity to QCD evolution

- Significant improvement of precision wrt HERA

- Sufficient luminosity to do tripple-differential measurements in x_B, Q^2, t

- Measurements at both high and low beam energy settings

  will provide kinematical overlap with existing data
  and L/T separation for pseudoscalar meson production

- Full exploratory potential for DVCS at amplitude level

  provided e^+ and e^- beams available as well as
  longitudinaly and transversely polarized protons