DVCS at an electron ion collider

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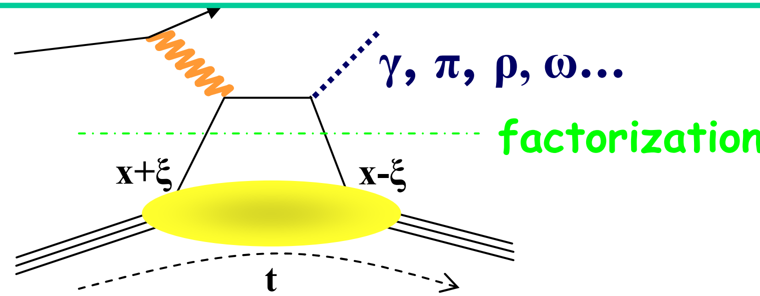
- Introduction
- Results from H1 and ZEUS
- Experimental issues for DVCS at EIC
- Possible impact of the results from EIC

GPDs and relations to the physical observables



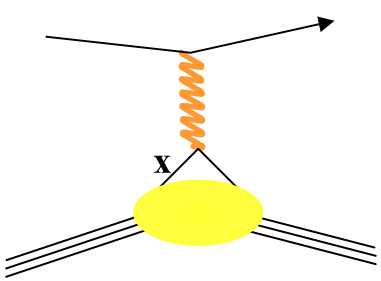
The observables are some integrals of GPDs over x

Dynamics of partons in the Nucleon Models: Parametrization

Fit of Parameters to the data

$H, \widetilde{H}, E, \widetilde{E}\ (x, \xi, t)$

Elastic Form Factors

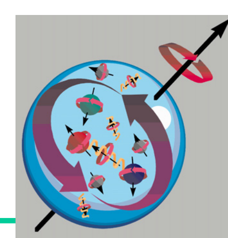


$$\int H(x,\xi,t)dx = F(t)$$

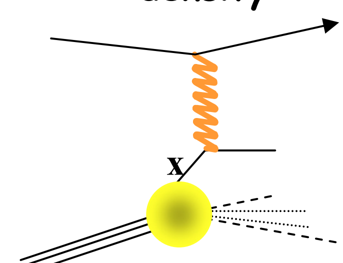
Ji's sum rule

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

$$1/2 = 1/2\ \Delta\Sigma + L_q + \Delta G + L_g$$



"ordinary" parton density



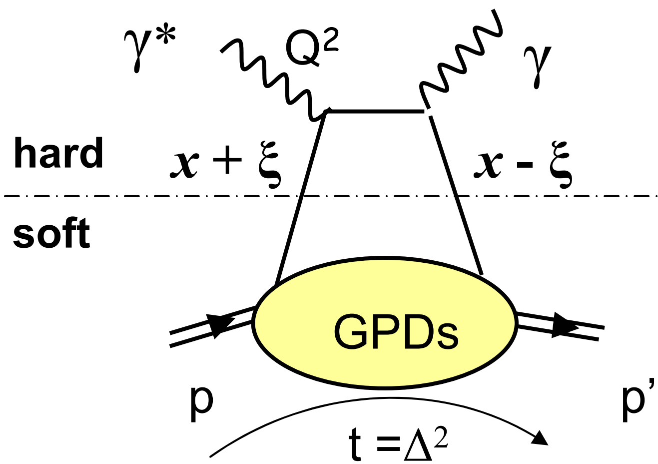
$$H(x,0,0) = q(x)$$

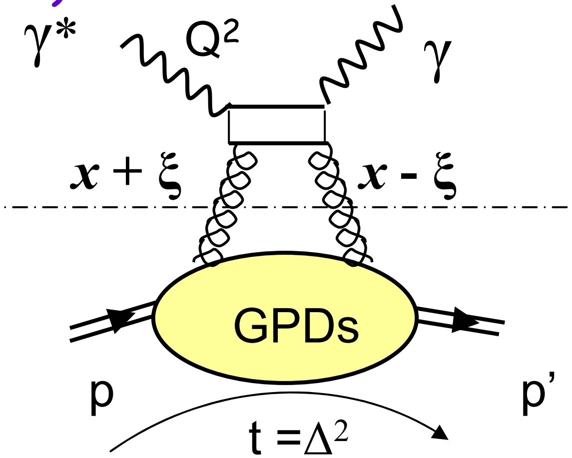
$$\widetilde{H}(x,0,0) = \Delta q(x)$$

Necessity of factorization to access GPDs

Collins *et al.*

Deeply Virtual Compton Scattering (DVCS):

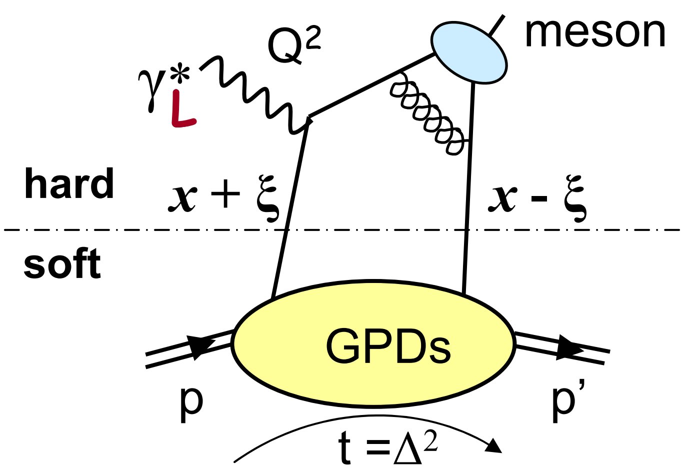


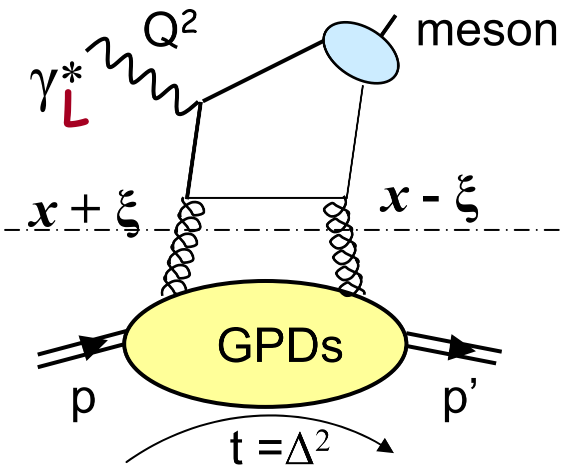


Q² large

t << Q²

Hard Exclusive Meson Production (HEMP):





+ γ^*_L

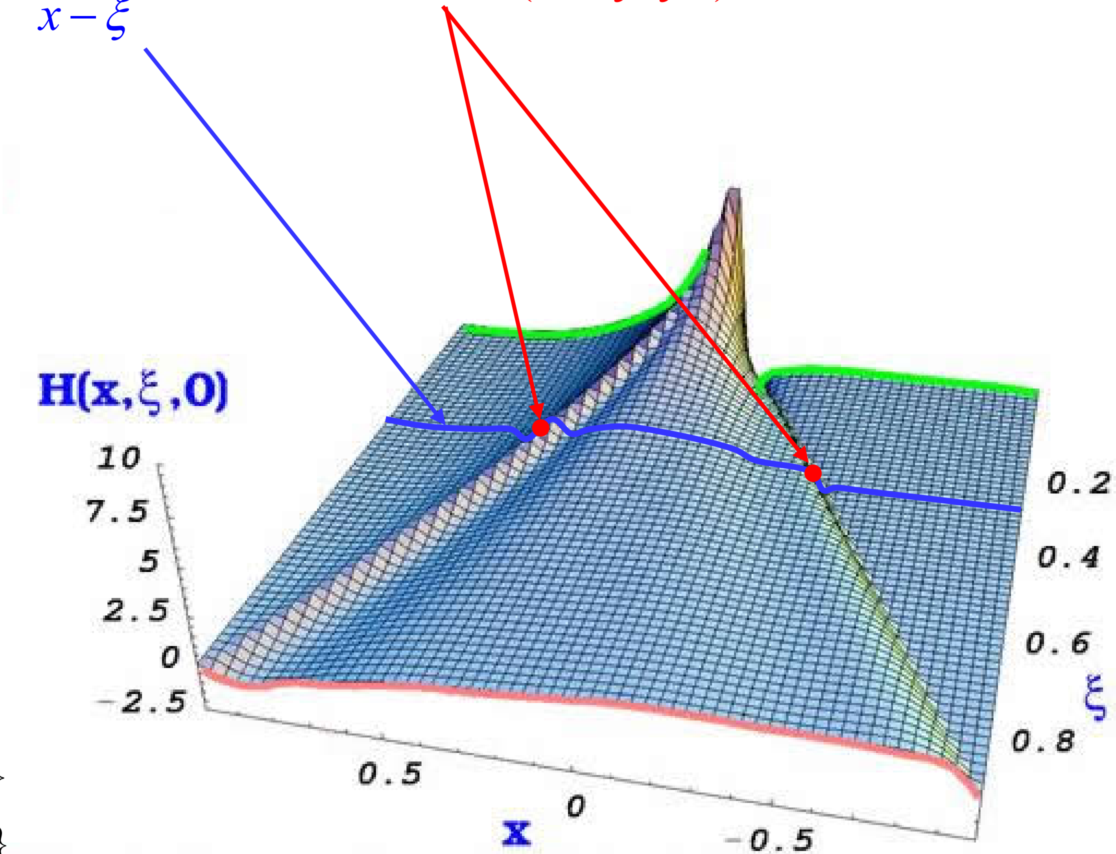
Quark contribution

Gluon contribution

Observables and their relationship to GPDs

$$T^{DVCS} = \int_{-1}^{+1} \frac{GPD(x,\xi,t)}{x-\xi+i\varepsilon}dx \quad + \quad \cdots$$

$$= P\int_{-1}^{+1} \frac{GPD(x,\xi,t)}{x-\xi}dx \quad - \quad i\pi GPD(x=\xi,\xi,t) \quad + \quad \cdots$$

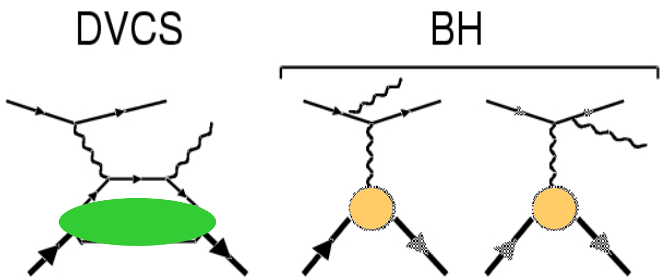


Shorthand notation:

$$T^{DVCS} = \{\mathcal{H}, \widetilde{\mathcal{H}}, \mathcal{E}, \widetilde{\mathcal{E}}\}$$

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

Deeply Virtual Compton Scattering $e\,p \rightarrow e\,p\,\gamma$



The same final state in DVCS and Bethe-Heitler

$$\sigma \propto |T_{BH}|^2 + |T_{DVCS}|^2 + \left(T_{BH} T^*_{DVCS} + T^*_{BH} T_{DVCS}\right)$$

interference $\mathcal{I}$

interference + structure of azimuthal distributions

a powerful tool to disantangle leading- and higher-twist effects and extract DVCS amplitudes including their phases

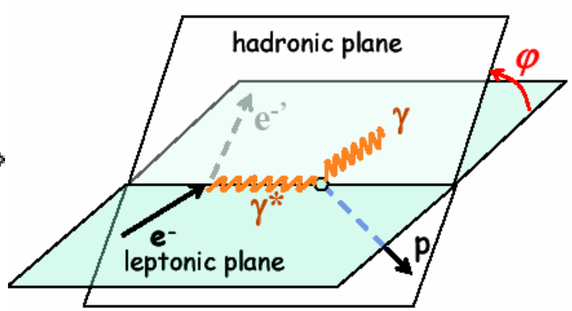
up to twist-3
BMK (2002)

$$|\mathcal{T}_{\rm BH}|^2 = \frac{e^6}{x_{\rm B}^2 y^2 (1+\epsilon^2)^2 \Delta^2 \mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} \left\{ c_0^{\rm BH} + \sum_{n=1}^{2} c_n^{\rm BH} \cos(n\phi) + s_1^{\rm BH} \sin(\phi) \right\}$$

$$|\mathcal{T}_{\rm DVCS}|^2 = \frac{e^6}{y^2 Q^2} \left\{ c_0^{\rm DVCS} + \sum_{n=1}^{2} \left[c_n^{\rm DVCS} \cos(n\phi) + s_n^{\rm DVCS} \sin(n\phi) \right] \right\}$$

$$\mathcal{I} = \frac{\pm e^6}{x_{\rm B} y^3 \Delta^2 \mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} \left\{ c_0^{\mathcal{I}} + \sum_{n=1}^{3} \left[c_n^{\mathcal{I}} \cos(n\phi) + s_n^{\mathcal{I}} \sin(n\phi) \right] \right\}$$

$\mathcal{P}_1(\Phi)$, $\mathcal{P}_2(\Phi)$
BH propagators



harmonics with twist-2 DVCS amplitudes (related to GPDs)
c_0^{DVCS}, $c_1^{\mathcal{I}}$, $s_1^{\mathcal{I}}$ and $c_0^{\mathcal{I}}$ (the last one Q suppresed)

A comprehensive method to extract full set of GPDs

A possible scenario for EIC

Belitsky, Mueller, Kirchner (2002)

- measure e p $\rightarrow$ e p γ cross sections both for e^+ and e^-
  for unpolarized, longitudinally and transversely polarized protons

- $\sigma^+(\varphi) - \sigma^-(\varphi)$ ➡ $I_\Lambda(\varphi)$
  $\sigma^+(\varphi) + \sigma^-(\varphi) - 2\,\sigma_{BH}(\varphi)$ ➡ $2\,\sigma_{DVCS,\Lambda}(\varphi)$

  $\Lambda = \{unp, LP, T_nP, T_sP\}$

- from φ-dependence of I_Λ's extract 8 leading-twist harmonics $c^I_{1,\Lambda}$ $s^I_{1,\Lambda}$

- from these determine all 4 DVCS amplitudes (including their phases)
  which depend on GPDs $H, \widetilde{H}, E, \widetilde{E}$

- another 8 leading-twist harmonics $c^{DVCS}_{0,\Lambda}$ and $c^I_{0,\Lambda}$ ➡ cross check

in an experiment asymmetries simpler than cross sections,
but extraction of DVCS amplitudes more involved

Available experimental data on DVCS (1)

- lepton charge or single spin asymetries at moderate and large $\boldsymbol{x}_\mathbf{B}$

  HERMES and JLAB results ⟶ talks of F. Ellinghaus and H. Avakian

  - beam-charge asymmetry $A_C(\varphi)$

    $$d\sigma(e^+,\phi) - d\sigma(e^-,\phi) \propto \mathrm{Re}[F_1\mathcal{H}]\cdot\cos\phi$$

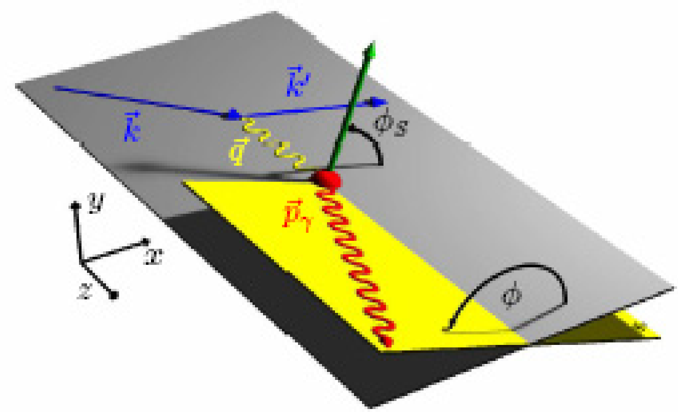
  - beam-spin asymmetry $A_{LU}(\varphi)$

    $$d\sigma(\vec{e},\phi) - d\sigma(\overleftarrow{e},\phi) \propto \mathrm{Im}[F_1\mathcal{H}]\cdot\sin\phi$$

  - longitudinal target-spin asymmetry $A_{UL}(\varphi)$

    $$d\sigma(\overleftarrow{P},\phi) - d\sigma(\vec{P},\phi) \propto \mathrm{Im}[F_1\widetilde{\mathcal{H}}]\cdot\sin\phi$$

  - transverse target-spin asymmetry $A_{UT}(\varphi,\varphi_s)$



$$d\sigma(\phi,\phi_S) - d\sigma(\phi,\phi_S+\pi) \propto \mathrm{Im}[F_2\mathcal{H} - F_1\mathcal{E}]\cdot\sin(\phi-\phi_S)\cos\phi$$
$$+\,\mathrm{Im}[F_2\widetilde{\mathcal{H}} - F_1\xi\widetilde{\mathcal{E}}]\cdot\cos(\phi-\phi_S)\sin\phi$$

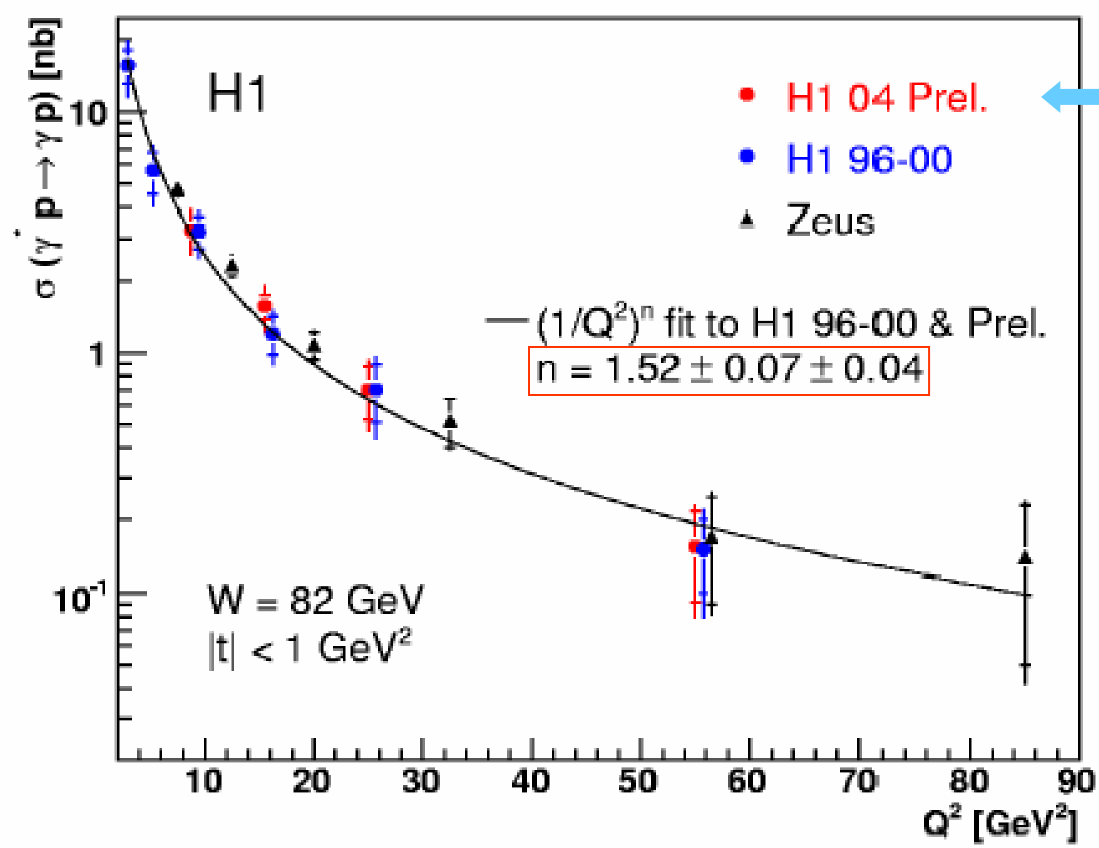
F_1 and *F_2* are Dirac and Pauli proton form factors

Available experimental data on DVCS (2)

- cross section σ_{DVCS} averaged over φ for unpolarised protons H1 and ZEUS

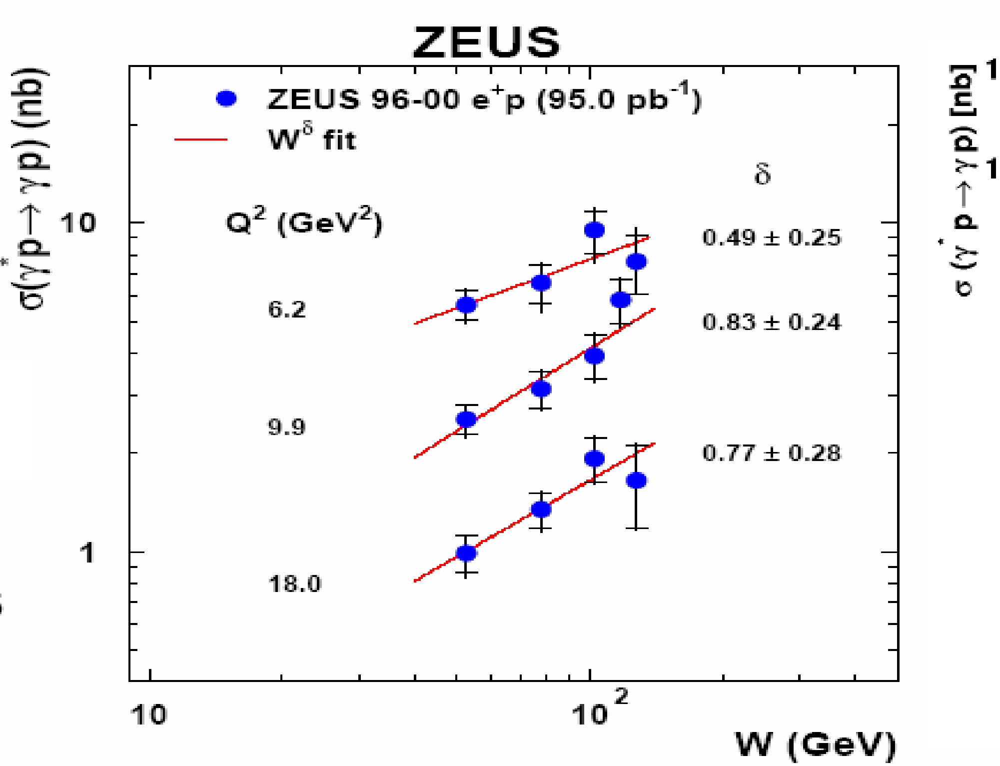
at small x_B (< 0.01) $\sigma^{unp}_{DVCS} \propto 4(\mathcal{H}\mathcal{H}^* + \widetilde{\mathcal{H}}\widetilde{\mathcal{H}}^*) - 2\frac{t}{4M^2}\mathcal{E}\mathcal{E}^*$ → H^{sea}, H^{g}

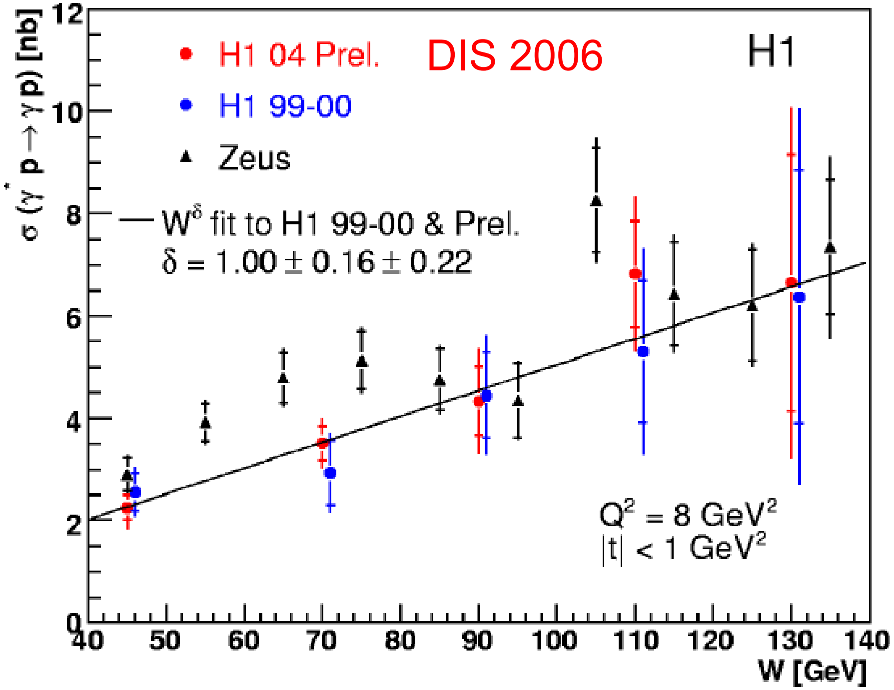
Q² dependence of DVCS cross section



DIS 2006

W dependence of DVCS cross section

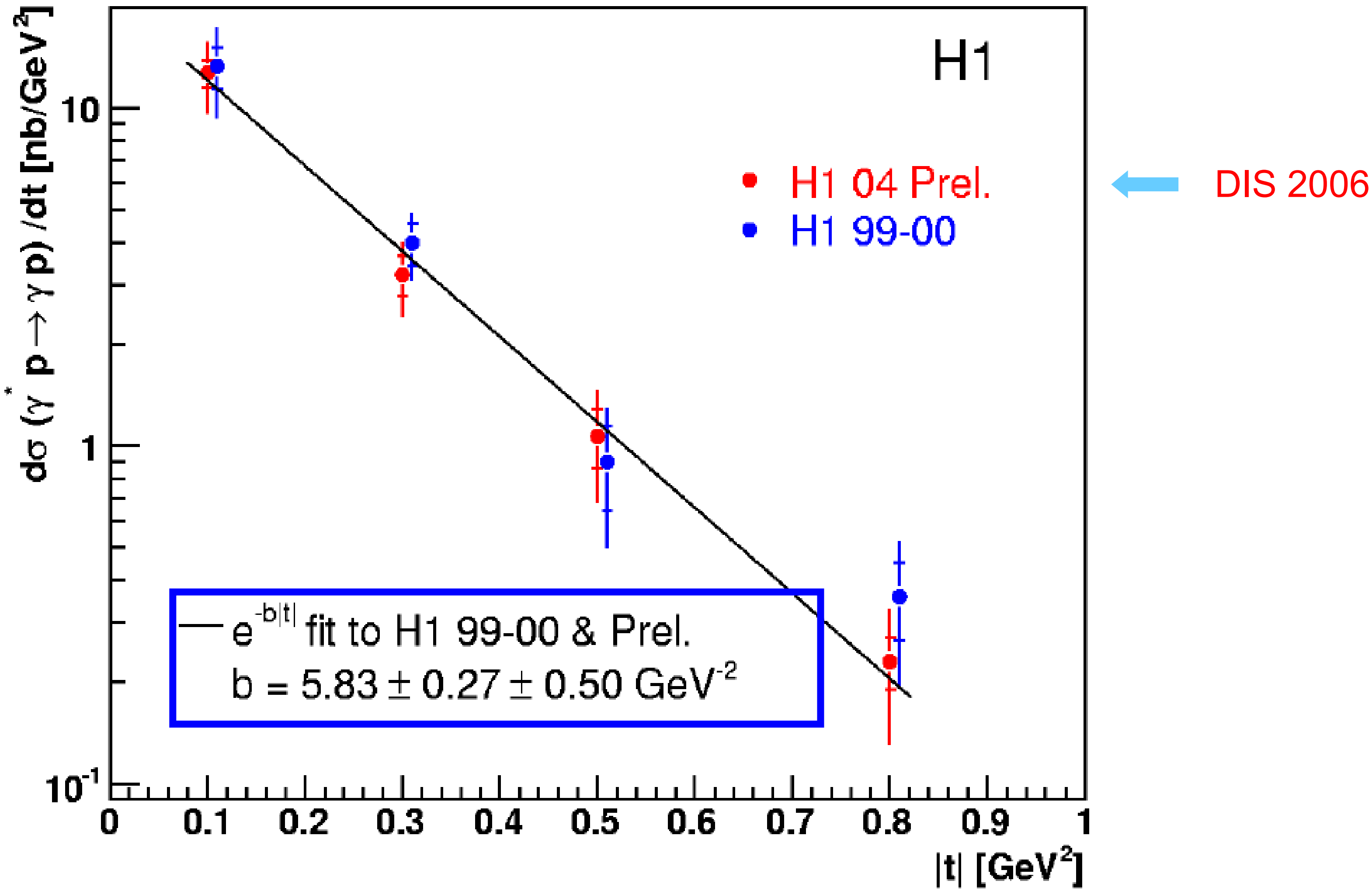




$\sigma \sim$ **$W^{0.8}$** => hard process

(for a ‘soft’ process : $W^{0.3}$)

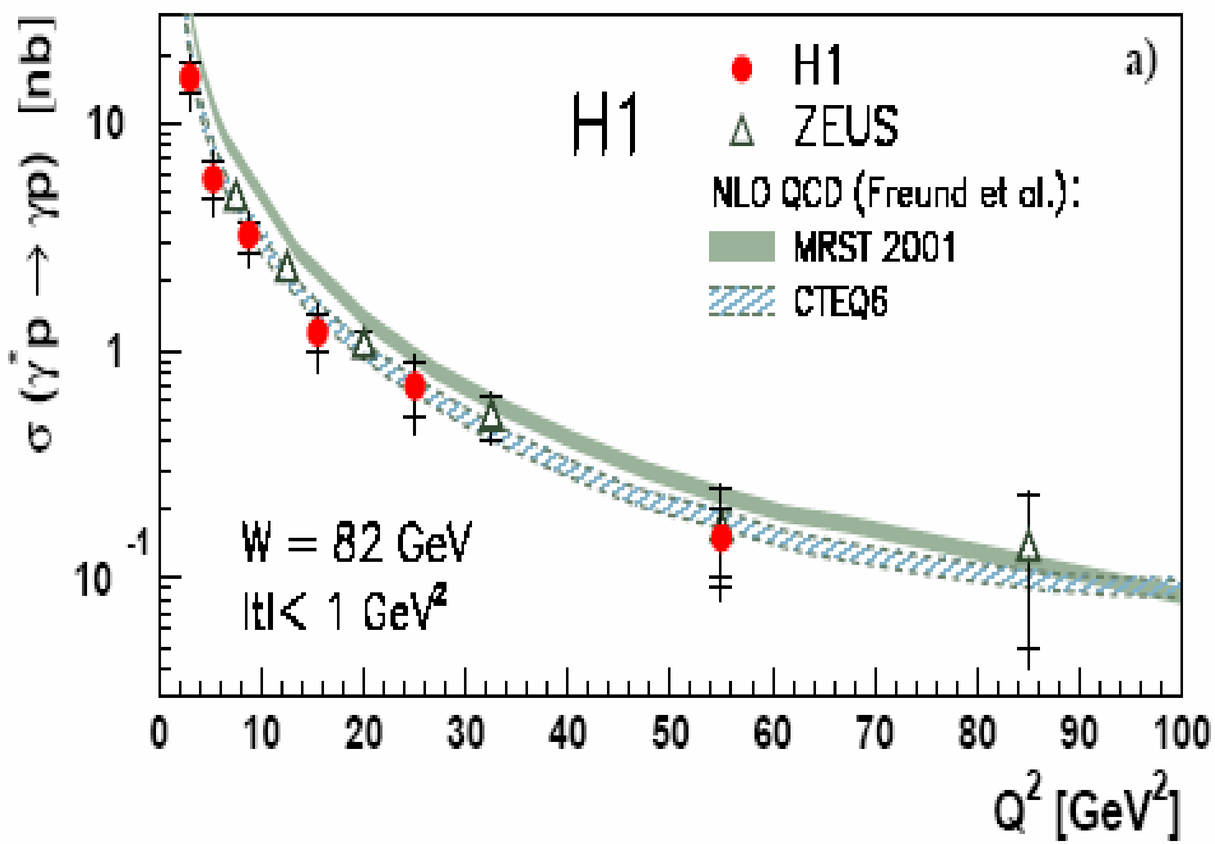
DVCS Cross section (t) : update with the latest H1 data



Combined fit to the H1 99-00 and H1 04 Prel. data using the parametrization:

$$d\sigma/dt\,(t) = d\sigma/dt_{\,|t=0}\, e^{-b|t|}$$

Q² dependence: NLO predictions



b assumed Q^2-independent
no intrinsic skewing

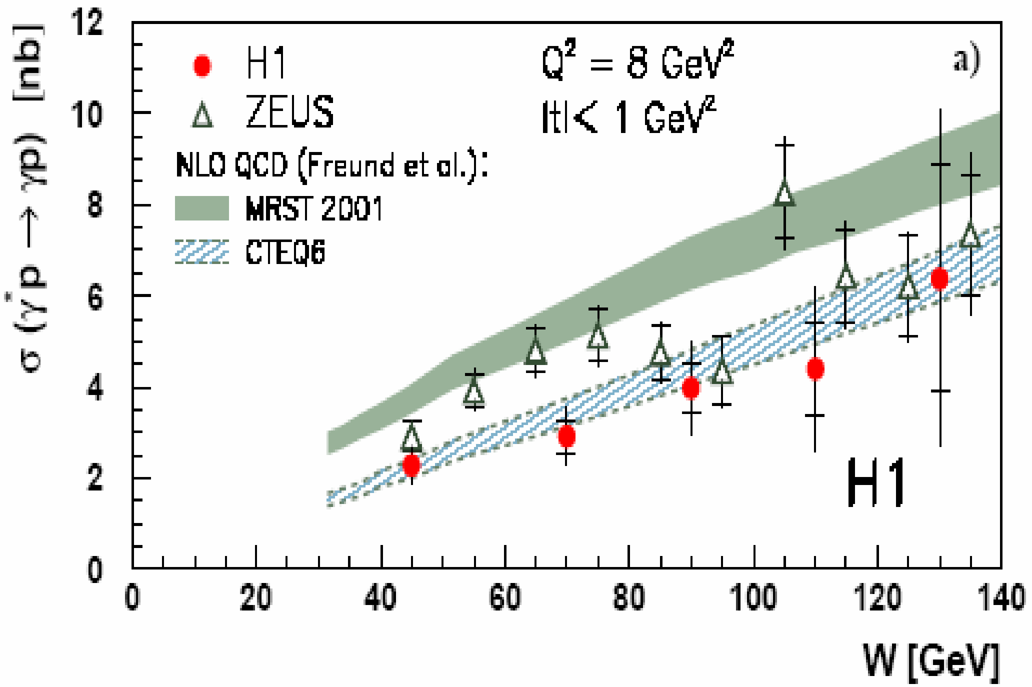
bands reflect experimental error on *b*: 5.26 < b < 6.40

- Wide range of Q^2 - sensitivity to QCD evolution of GPDs

- Cross section in $1/Q^3$ (mix of the trivial kin. dependence $1/Q^4$ and the anomalous dimensions) : well described by the QCD evolution

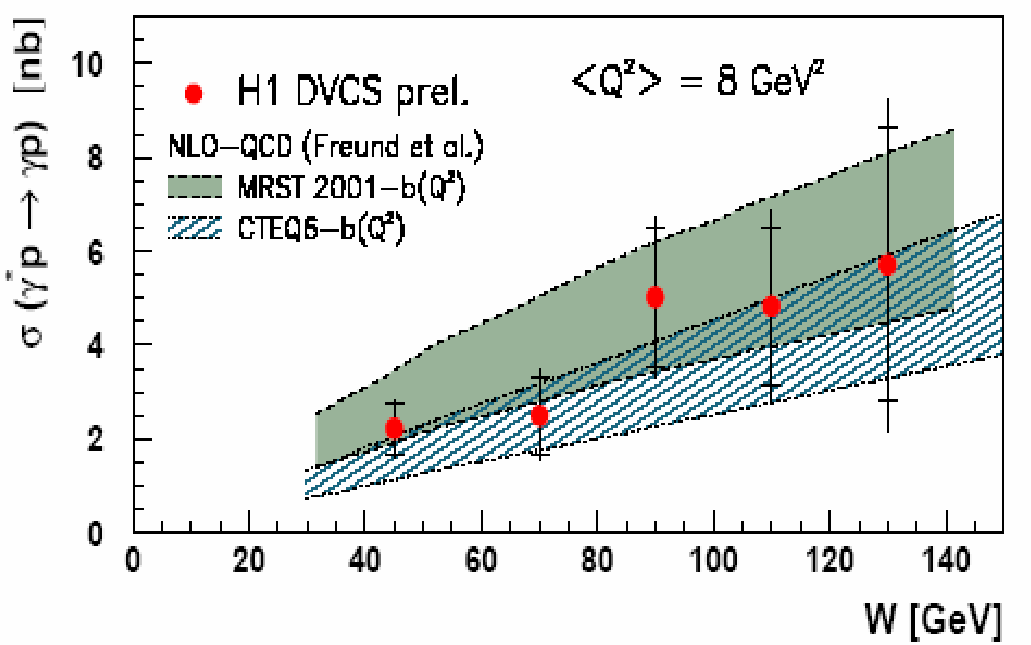
- **Difference between MRS/CTEQ due to different xG at low x_B**

W dependence: NLO predictions



1996-2000

Meaurements of *b* significantly constrain uncertainty of models



Older H1 (prel.) measurement on 2000 data with a ***b*** value in the range [**4 - 7**] GeV ^{2}

Summary for DVCS at H1/ZEUS

L. Schoeffel, GPD2006, Trento

- **Increase of precision** of DVCS cross sections
- **Good agreement with NLO predictions**

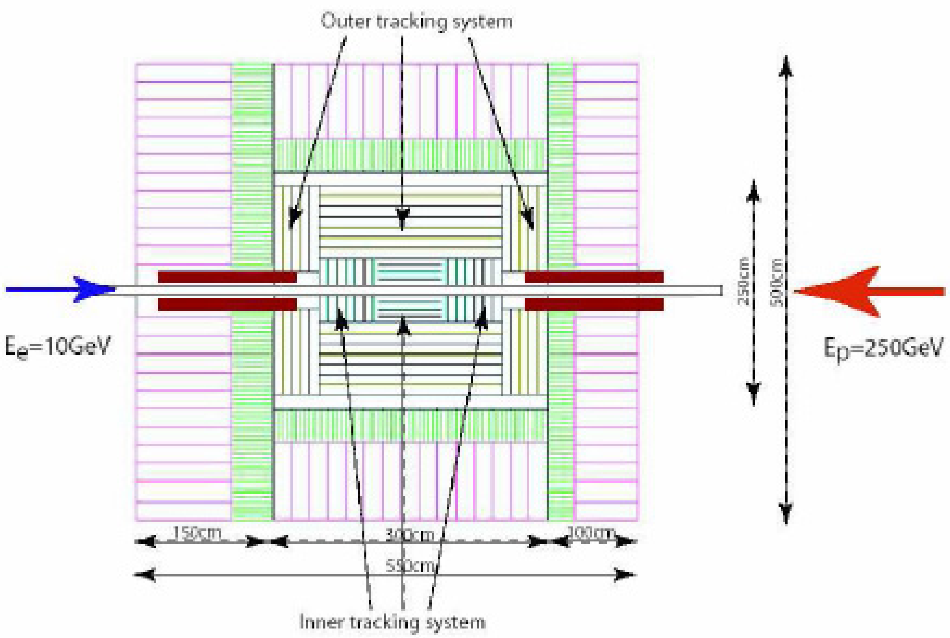
  GPDs ≡ PDFs at low scale; skewing generated by QCD evolution
- **Sensitivity to H^g** ; 15% change of H^g => 10% change of cross section
- Real part of DVCS amplitude – small effect, few%
- Skewing parameter R=Im DIS / Im DVCS ~ 0.5

  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**

Perspectives : with increased statistics more precise b(Q²) and b(W)

A simulation of DVCS at EIC

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



diam. of the pipe - 20 cm, space for detectors close to pipe: +/- 80 cm from the IP →

acceptance of central detector (ZDR) $7° < \theta_{lab} < 173°$

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

$7° < \theta_{e'} < 173°$	$7° < \theta_\gamma < 173°$
$E_{e'} > 2$ GeV	$E_\gamma > 0.5$ GeV

to 'reasonably' balance DVCS vs. BH following **kinematical range** chosen

$1 < Q^2 < 50$ GeV^2

$10 < W < 90$ GeV

$0.05 < |t| < 1.0$ GeV^2

kinematical **smearing**: parameterization of H1 + ZEUS resolutions

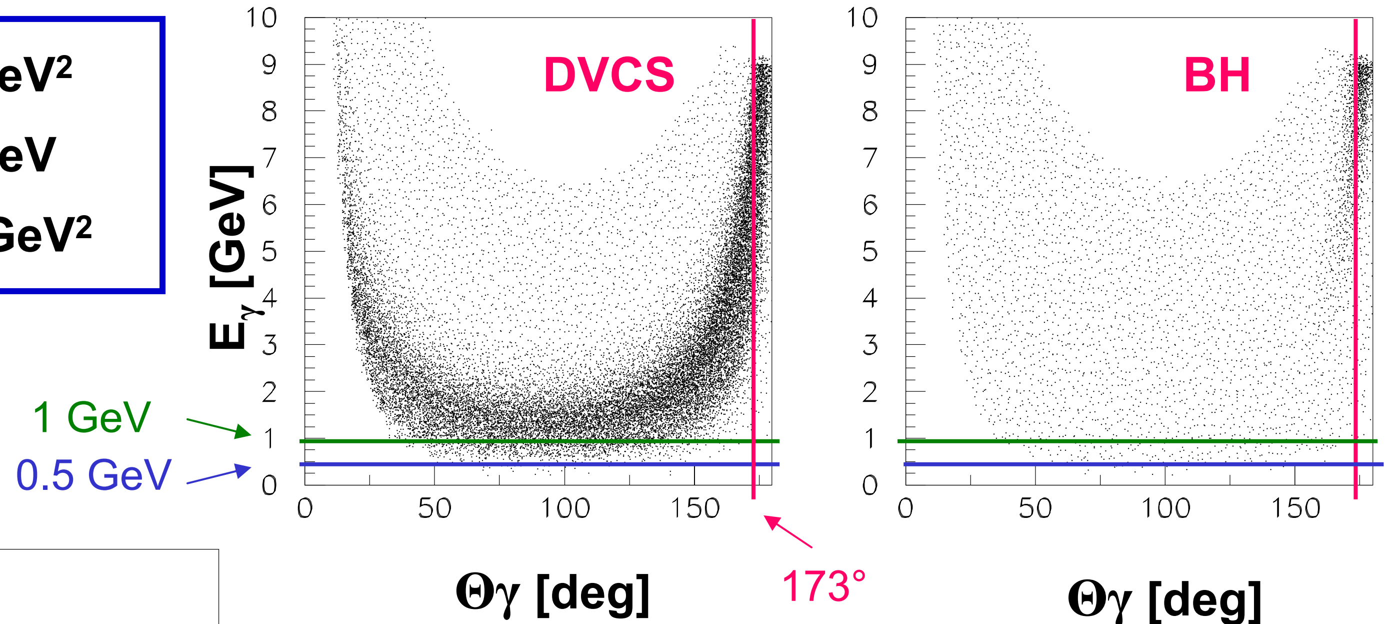
Photon and scattered electron kinematics

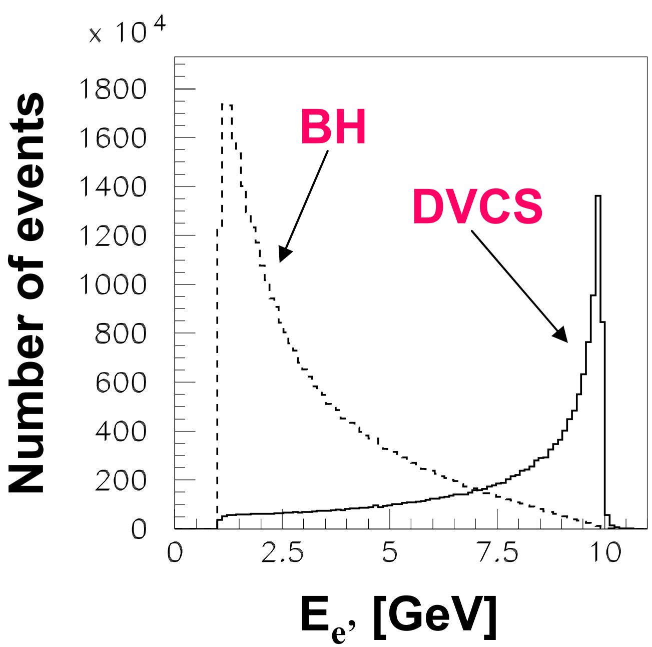
$ep \rightarrow e'p'\gamma$ E_e = 10 GeV E_p=250 GeV

$1 < Q^2 < 50$ GeV^2

$10 < W < 90$ GeV

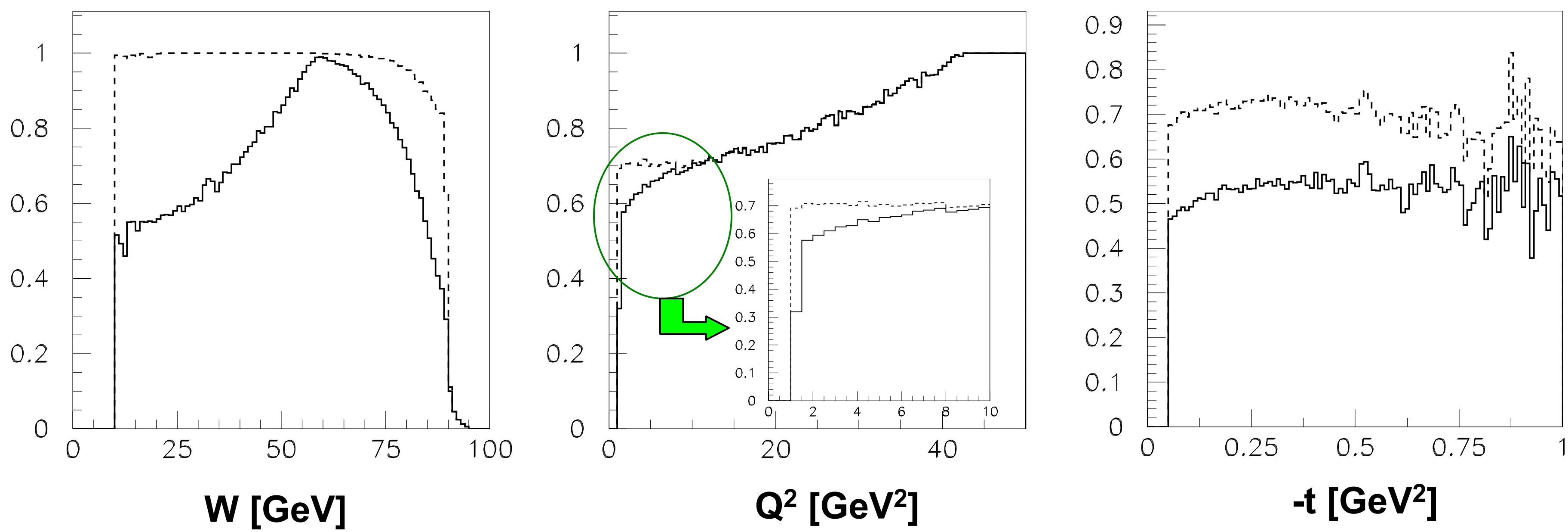
$0.05 < |t| < 1.0$ GeV^2





- **polar angle coverage affects acceptance at $Q^2 < 2$ GeV^2 and both at low and the highest W**
- **low energy photons correlate with low W**
- **increase of lower cut on electron energy allows to diminish fraction of BH, but reduces range at large W**

Accetance of Central Detector



ZDR detector : $7° < \theta < 173°$

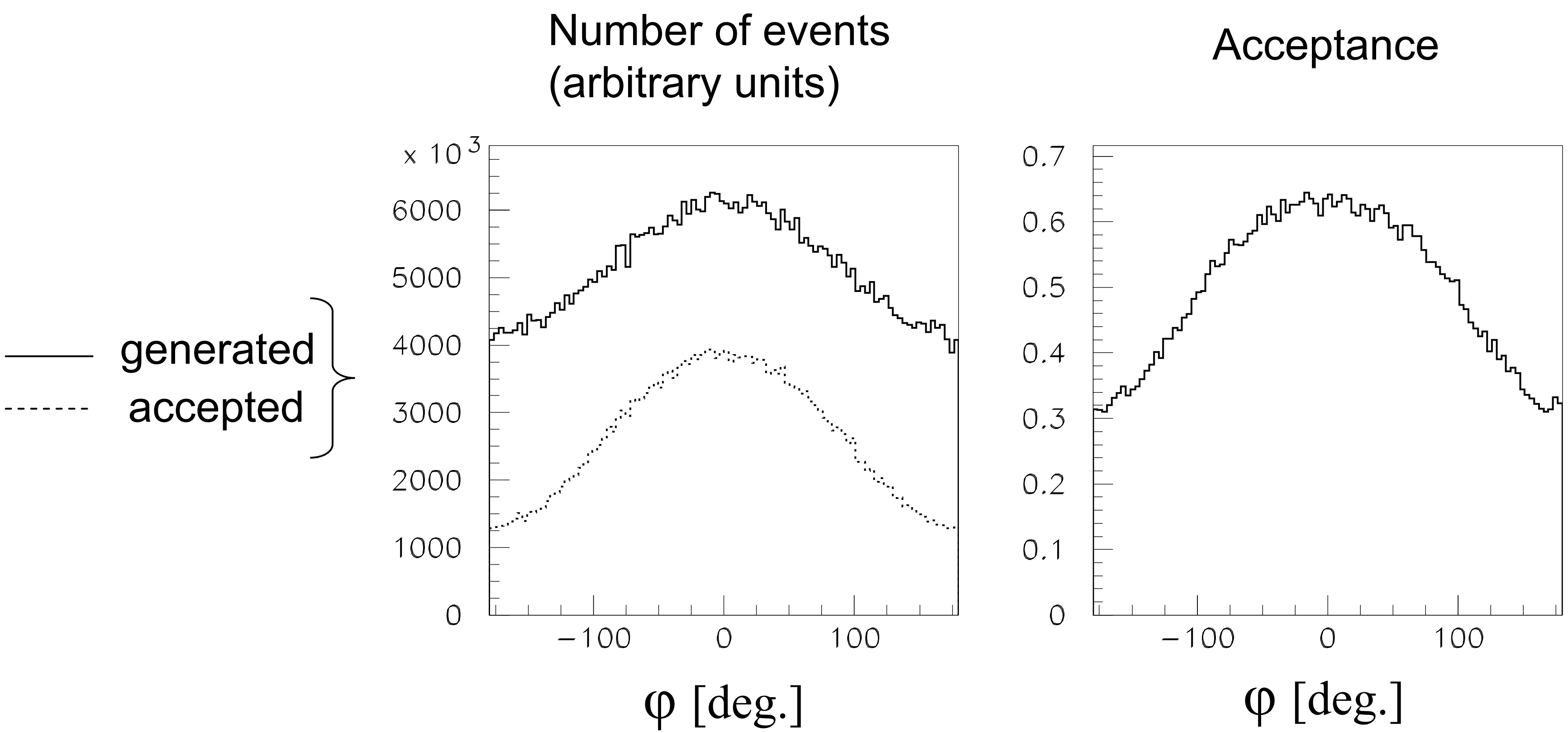
'Ideal' HERA detector: $2.2° < \theta < 176.5°$

Due to angular acceptance the largest losses (about or more than 50%) expected at

a) $Q^2 < 2$ GeV^2

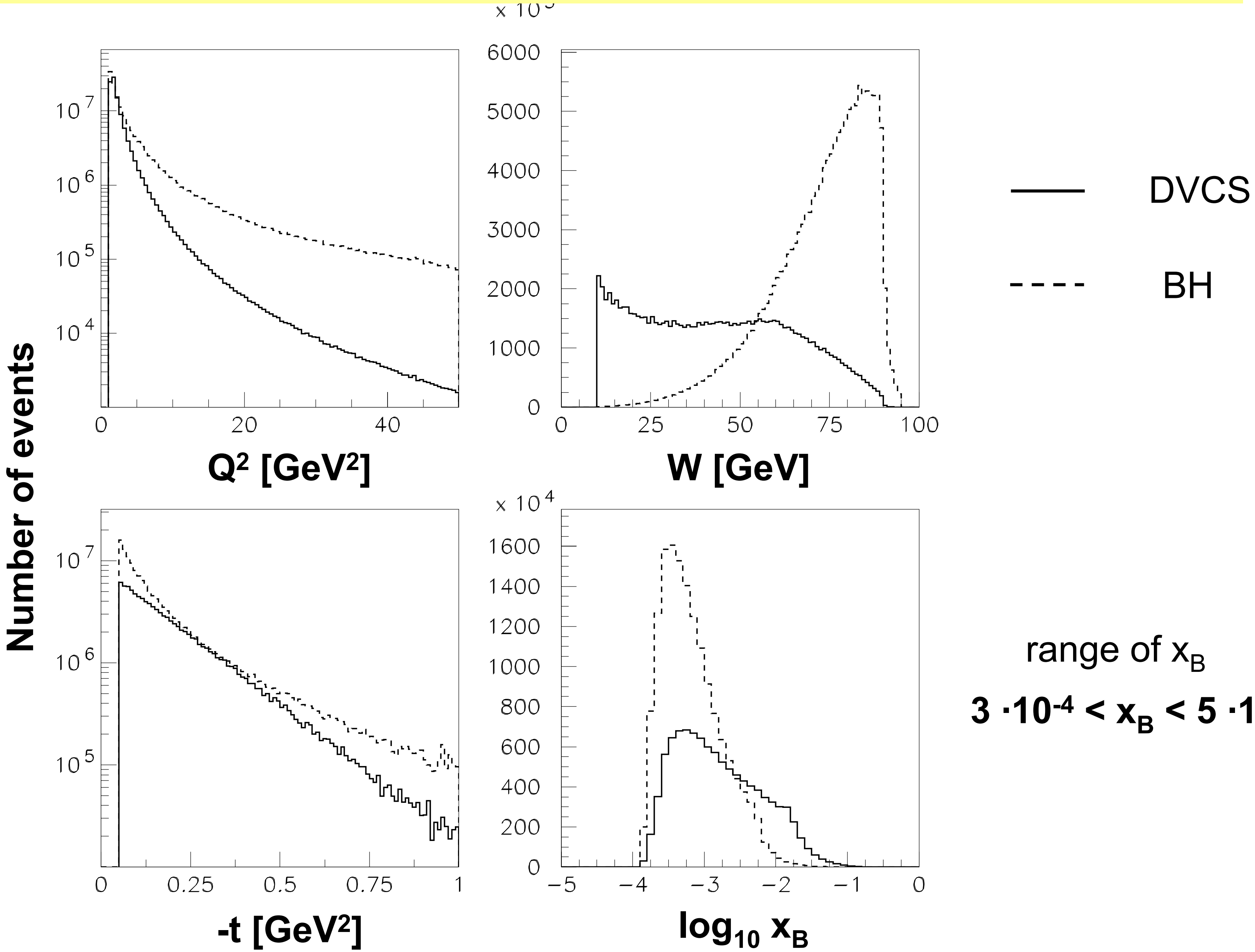
b) low W (≤ 40 GeV) and the highest W (≥ 80 GeV)

φ-dependence for (DVCS+BH+INT)



As acceptance as a function of φ is non-constant, its precise determination crucial both for φ-integrated cross sections and for the Fourier analysis

Kinematical distributions of accepted DVCS and BH events



range of x_B

$3 \cdot 10^{-4} < x_B < 5 \cdot 10^{-2}$

Precision of DVCS unpolarized cross sections at EIC

$Q^2 > 1$ GeV^2

$10 < W < 95$ GeV

$0.05 < |t| < 1.0$ GeV^2

$\sigma(ep \to ep\gamma) = 292$ pb

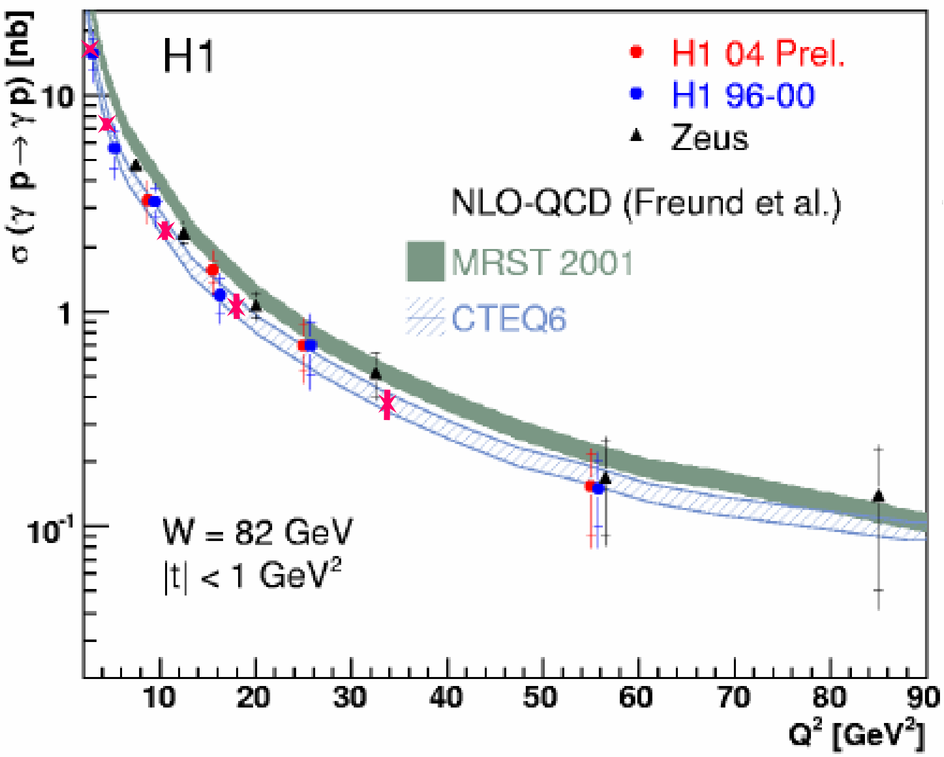
$\mathcal{L}_{int} = 530\ pb^{-1}$ (2 weeks) ~ **90 000** accepted DVCS events

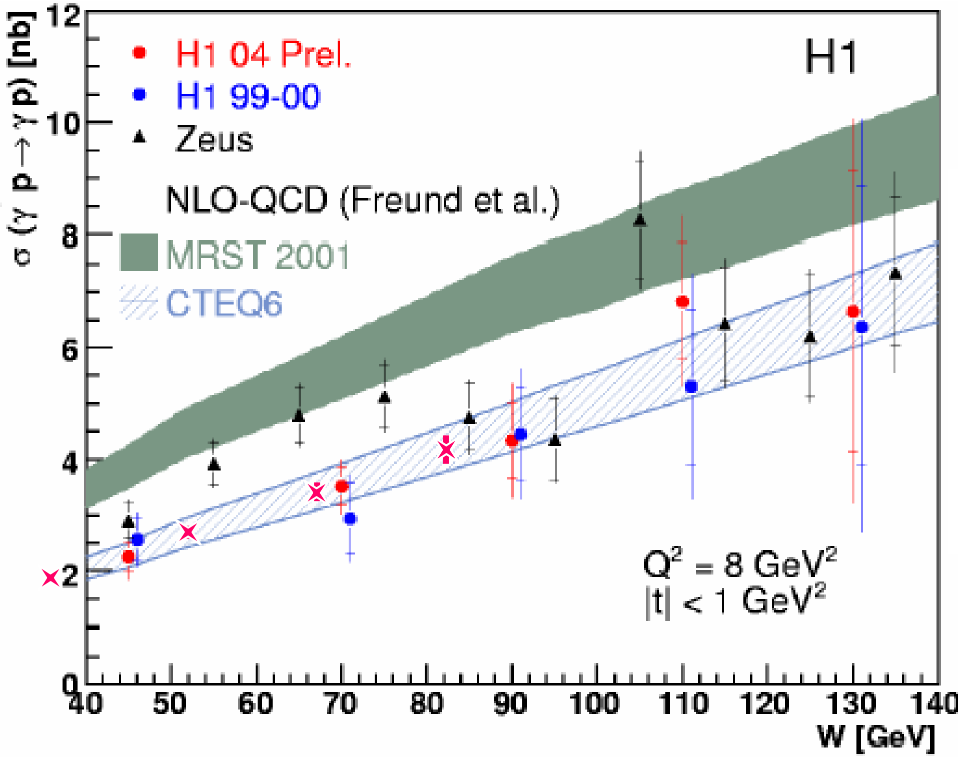
cross section in 6x6 bins of Q^2 and W

statistical error of EIC measurement

$\langle W_{EIC} \rangle$ = **82 GeV** (75 < W_{EIC} < 90 GeV)

$\langle Q^2_{EIC} \rangle$ = **10.4 GeV^2** (8 < Q^2_{EIC} < 15 GeV^2)





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

Lepton charge asymmetry precision at EIC

$$A_C = \{ \int_{-\pi/2}^{\pi/2} (\sigma^+ - \sigma^-) d\phi - \int_{\pi/2}^{3\pi/2} (\sigma^+ - \sigma^-) d\phi \} / \int_0^{2\pi} (\sigma^+ + \sigma^-) d\phi$$

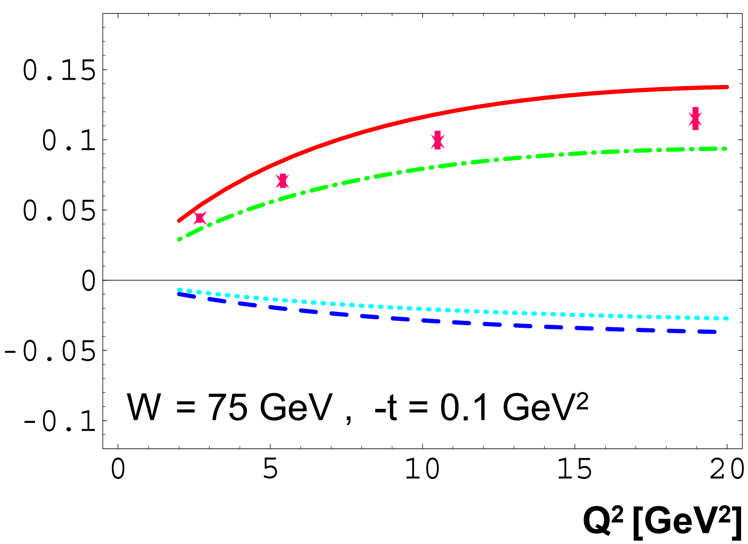
$\mathcal{L}_{int} = 530\ \mathrm{pb}^{-1}$ **divided equally between** e^+ **and** e^-

statistical error of EIC measurement

cross section in 6x6 bins of Q^2 and W

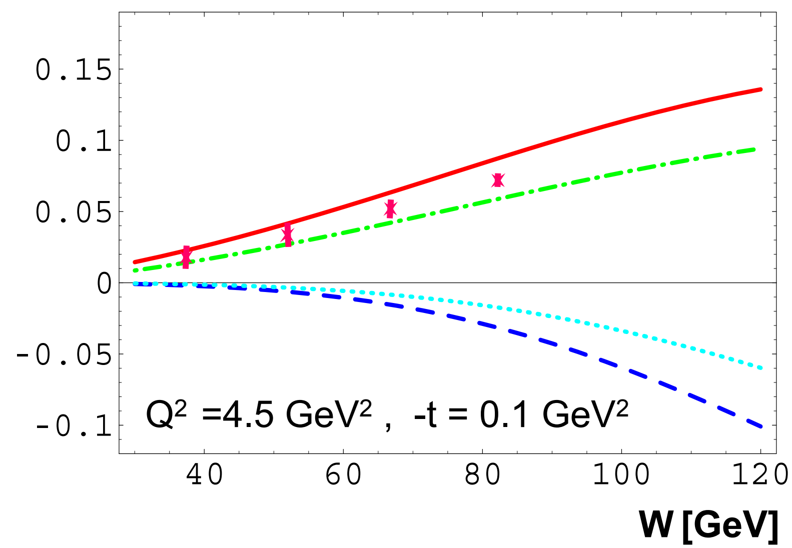
model of **Belitsky, Mueller, Kirchner** (2002) for **GPDs at small x_B**
parameters of sea-quark sector fixed using H1 DVCS data (PL B517 (2001))
except magnetic moment κ_{sea} ($-3 < \kappa_{sea} < 2$), which **enters Ji's sum rule for J_q**

BMK use 'improved' charge asymmetries $\mathbf{CoA^{unp}_{c(1)}}$ and $\mathbf{CoA^{unp}_{s(1)}}$



$\kappa_{sea} = 2$
$\kappa_{sea} = -3$

$\kappa_{sea} = -3$
$\kappa_{sea} = 2$

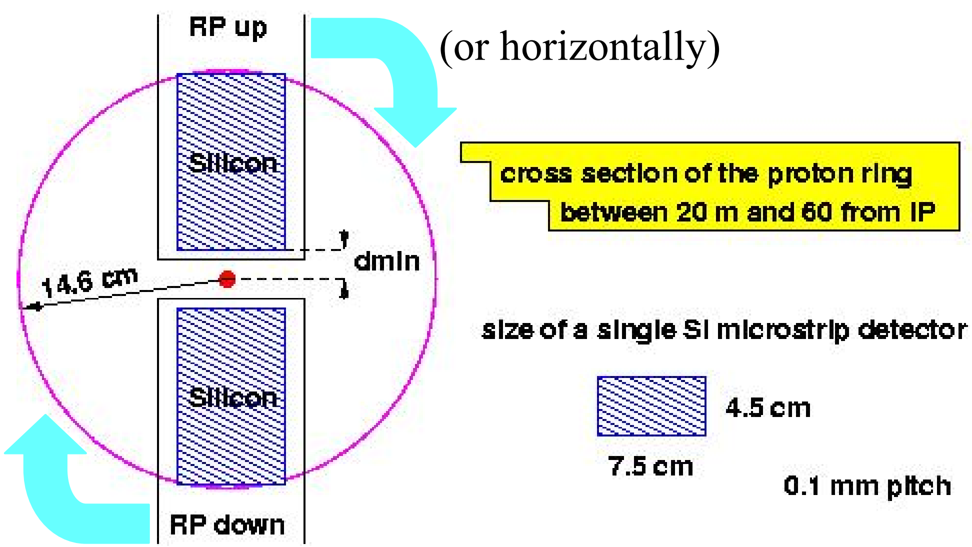


- **measurements of asymmetries at EIC sensitive tool to validate models of GPDs**

Comments on detection of forward protons (1)

- clean subsample of **exclusive events** => control of effects of DD in main sample
- better **resolution** in t and φ

Roman Pot Station



Beam transport matrix

$$\begin{pmatrix} x_D \\ \Theta_D^x \\ y_D \\ \Theta_D^y \end{pmatrix} = \begin{pmatrix} a_{11} & L_{eff}^x & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 \\ 0 & 0 & a_{33} & L_{eff}^y \\ 0 & 0 & a_{43} & a_{44} \end{pmatrix} \begin{pmatrix} x_0 \\ \Theta_x^* \\ y_0 \\ \Theta_y^* \end{pmatrix}$$

↑ at the detector — at the IP ↑

Inspected RP **positions** at **22**, **50** and **56** m from the IP

values of TM elements for EIC -10 GeV **e** + 250 GeV **p** - provided by **S.Tepikian**

Note:

If a **single RP station,** necessary conditions: $a_{11}(a_{33})$ small and L^x_{eff} (L^y_{eff}) large

Not obligatory, if a **telescope** of 2 RP stations (**position and angle at detector**)

Comments on detection of forward protons (2)

Beam parameters ε and β^* as in the ZDR for high energy setup

σ^0_x = 101 μm $\qquad$ σ^0_y = 51 μm

$\sigma^0_{\theta x}$ = 94 μrad $\qquad$ $\sigma^0_{\theta y}$ = 188 μrad

Using beam parameters at IP + Beam Transport Matrix + aperture of magnets

- select optimal position for RP station and its orientation (veritacal or horizontal)
- determine the minimal |t| (depends on the beam spread; 12σ)
- determine the maximal |t| (depends on the apertures of beam line elements between the IP and the RP detector
- calculate acceptance of the RP detector for the above t-range

studies in progress

Summary for DVCS at EIC

- Wide kinematical range, overlap with HERA and COMPASS

  $3 \cdot 10^{-4} < x_B < 5 \cdot 10^{-2}$ - sensitivity to sea (mostly u+ubar) and gluons

  $1 < Q^2 < 50$ GeV^2 - sensitivity to QCD evolution

- DVCS cross sections - significant improvement of precision wrt HERA

- Intereference with BH - pioneering measurements for a collider

  powerfull tool to study DVCS amplitudes

  full exploratory potential, if e^+ and e^- available as well as longitudinaly and transversely polarized protons

- Feasibility of using RP detectors for exclusivity and improved resolution

  studies going on

- Issues to be concerned in more detail

  luminosity detector and absolute cross section determination

  background, in particular from exclusive π^0 production