Prospects for Diffraction at HERA-II

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Hard diffraction is a major success story of HERA-I

New measurements on HERA-I data keep coming (DIS02)

But what does HERA-II have to offer?

Where will we be by DIS07? . . .

New tools with HERA-II

Since mid 2000, HERA has undergone major changes:

Focusing magnets inside H1 / ZEUS: $\rightarrow \mathcal{L} \times 3.5$

New spin rotators and polarimeters

Many components of experiments simultaneously upgraded

Several new tools for Diffraction

- **Factor ~ 10 increase in statistics by end 2006**
- **New proton spectrometer (H1 VFPS)**
- **Polarised leptons**
- **Reduced centre of mass energy running?**

Stable luminosity now achieved at H1 / ZEUS

Working towards increased currents / reduced backgrounds

A factor 10 in Statistics! $\longrightarrow 1\mathrm{fb}^{-1}$

Many diffractive measurements systematically limited after HERA-I:

- $F_2^{D(3)}$ at modest Q^2
- Vector mesons at low Q^2, $|t|$
- Energy flow, particle spectra, event shapes in diffraction

Many exclusive final states remain statistically limited:

- Diffractive D^*
- Exclusive dijet production (Bartels et al.)
- DVCS
- Vector mesons at large Q^2, $|t|$
- Elastic Υ production

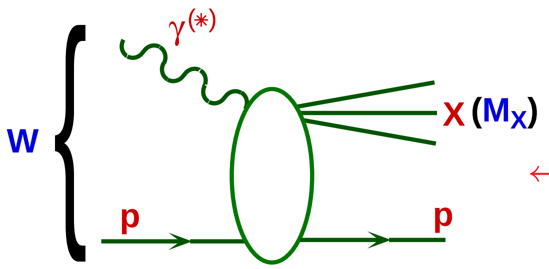
Higher statistics allow more differential measurements:

- e.g. t dependences ($F_2^{D(4)}$)

Proton Tagging

Two complementary measurement techniques used so far ...

1) Measure Hadrons Comprising X

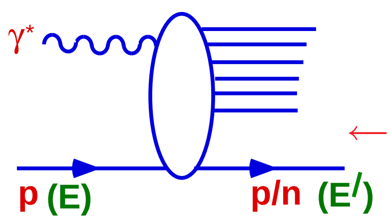


$\longleftarrow$ Rapidity gap $\Delta\eta$

$\Delta\eta$ generally large when $M_X \ll W$

- Ample statistics!
- Large systematics from unseen proton - elastic or dissoc'?
- t measurements not generally possible.
- May be hard to trigger at HERA-II

2) Tag and measure Leading Proton in Dedicated Detectors



No explicit
$\longleftarrow$ gap requirement

$x_{I\!P} = E'/E$
if exclusive p
at proton vertex.

- Provides a means of triggering.
- t, ϕ measurements possible.
- Systematics can be reduced.
- Limited stats up to now due to detector acceptance.

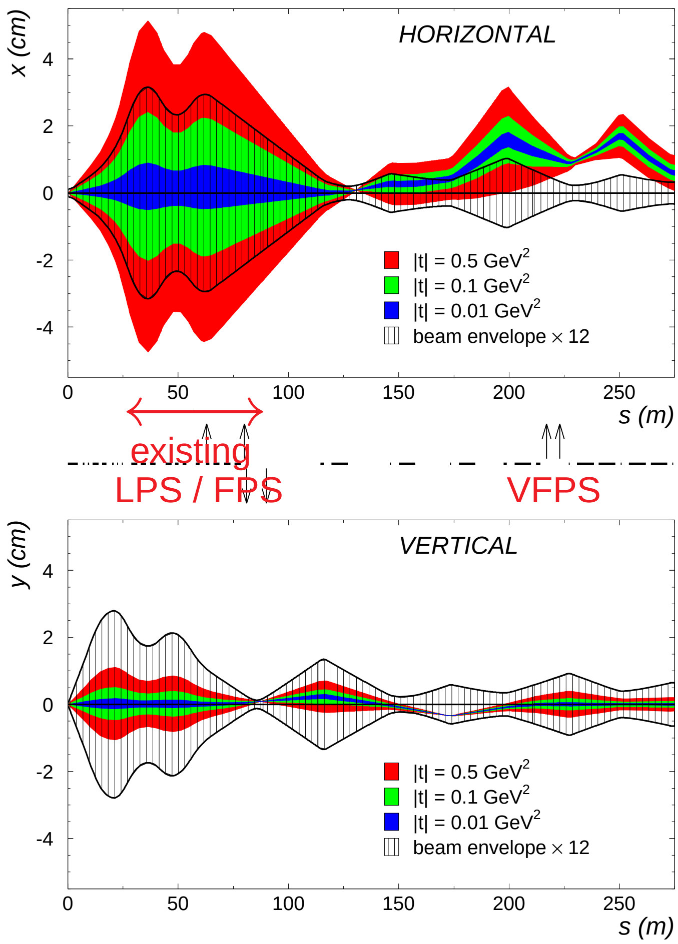
H1 Very Forward Proton Spectrometer

New tool for HERA-II: H1 VFPS

Roman pots at $z \sim 200$ m, Installation end 2002

2 'Roman Pot' insertions to proton beampipe, each with 2 scintillating fibre detectors

Trajectory of Scattered Protons at $x_{I\!P} = 0.01$



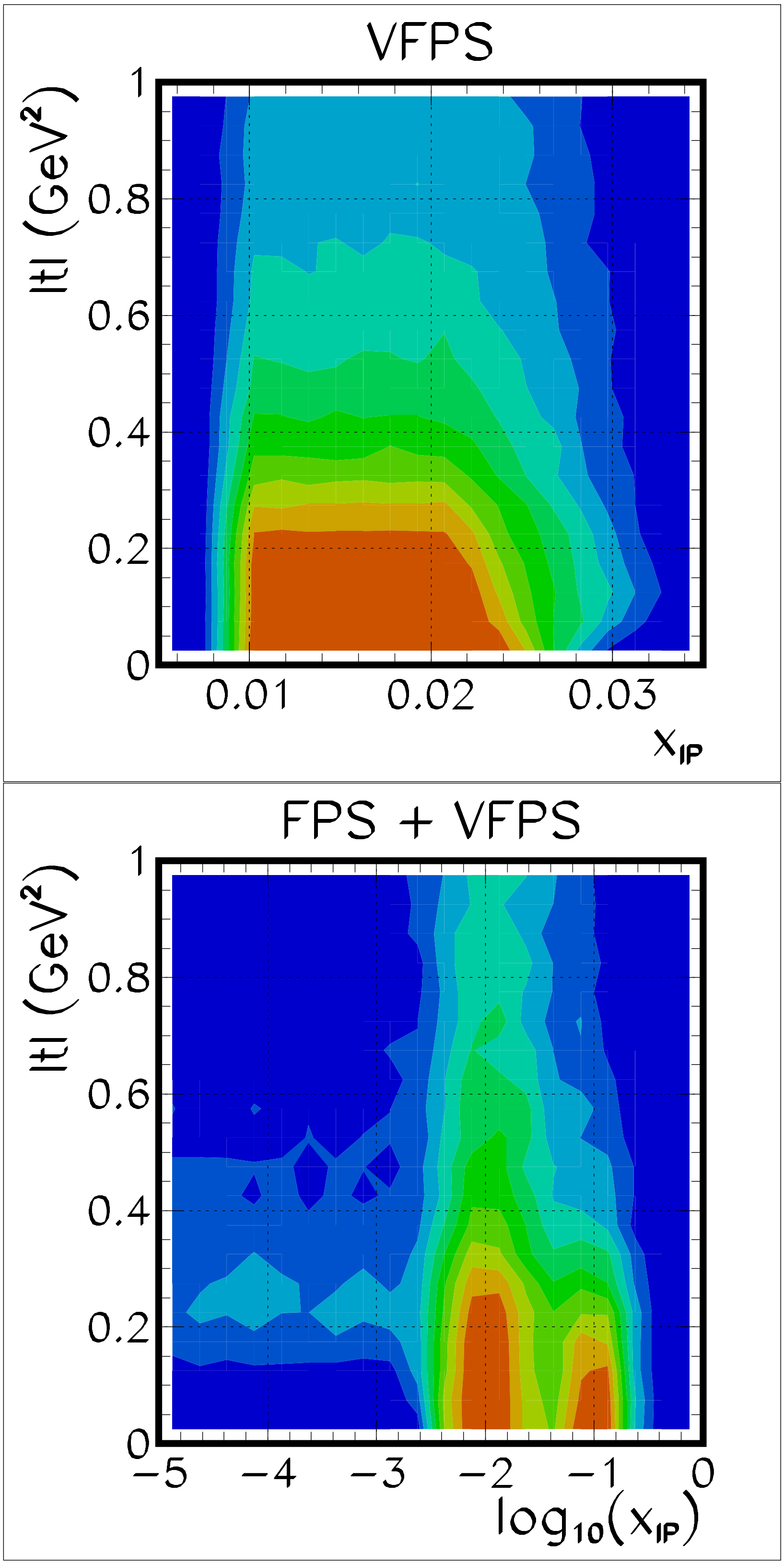
Beam optics used to give dispersion in $x_{I\!P}$

Approaches beam in horizontal plane

Acceptance extends to $t = 0$

Location chosen to optimise acceptance in specified region

Acceptance of VFPS



Acceptance region defined by beam optics and distance of approach of detectors to beam ($3\ \mathrm{mm}$ for coasting beam.)

Close to 100% acceptance achievable for $|t| \lesssim 0.2\ \mathrm{GeV}^2$, $0.01 \lesssim x_{I\!P} \lesssim 0.02$

Complements existing LPS FPS in low $x_{I\!P}$ region . . .

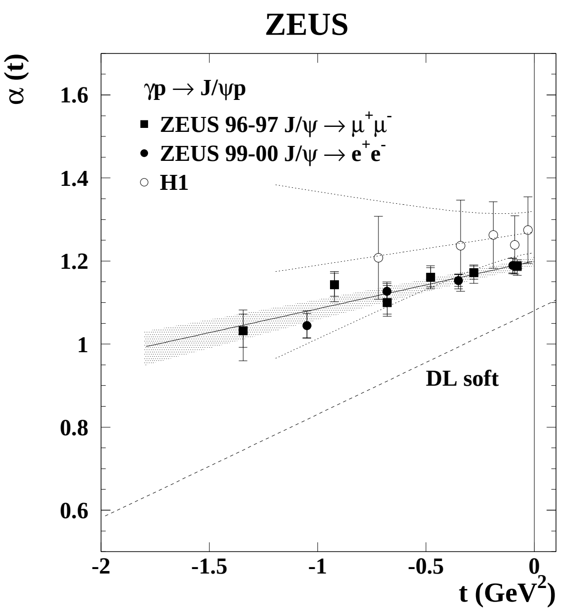
. . . smaller $(x_{I\!P}, t)$ coverage, but higher efficiency.

Higher $x_{I\!P}$ region still covered by H1 vertical FPS.

Measurements of t Dependences

Improved measurements of t dependences crucial . . .

- *Variation* of t slope with other variables ($x_{I\!P}$, W . . .) contains important dynamical information (α', shrinkage)



ZEUS results:

$\psi\ \gamma p: \alpha' = 0.115 \pm 0.018^{+0.008}_{-0.015}\ \mathrm{GeV}^{-2}$

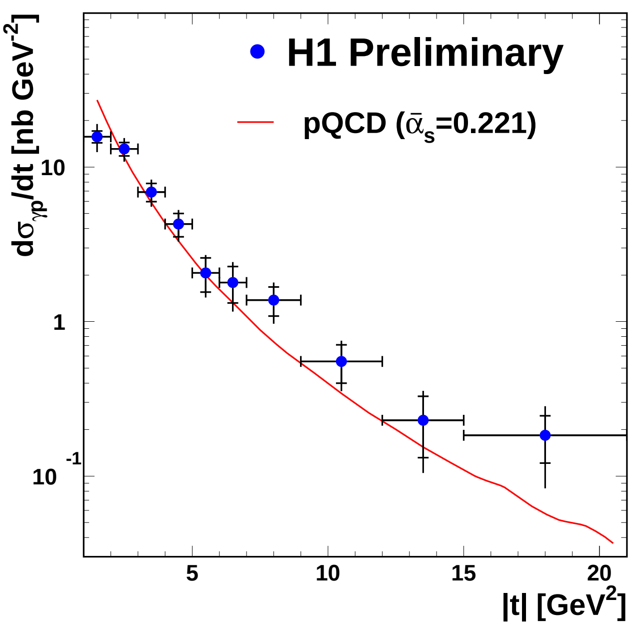
ρ DIS: $\alpha' = 0.04 \pm 0.07^{+0.13}_{-0.04}\ \mathrm{GeV}^{-2}$

Not a soft $I\!P$,

but some shrinkage!

More data needed, esp. in DIS

- Large t region of VM as clean BFKL filter?



Data described by LO BFKL models but large normalisation uncertainties

t dependence $\longrightarrow$ exponential?

Need to measure double differentially.

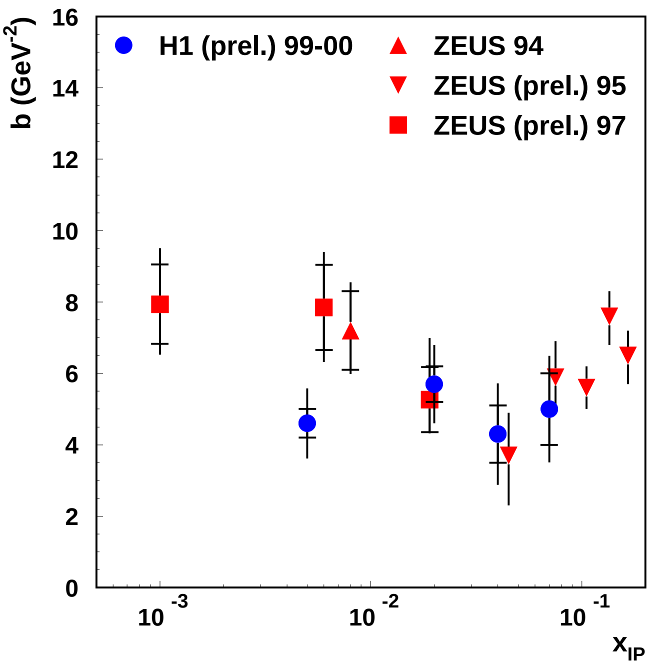
t Dependences of Inclusive Diffraction

Good knowledge of t dependence needed for full understanding

Unknown t dependence can make model comparisons hard.

e.g. Dipole / 2 gluon exchange calculations yield $\left[\frac{d\sigma}{dt}\right]_{t=0}$

Normalisation of predictions $\sim 1/B$



Can we measure $B(\beta, Q^2, x_{I\!P})$?

($B = B_0 + 2\,\alpha' \ln \frac{1}{x_{I\!P}}$)

Data so far inconclusive on shrinkage.

For VM, reconstruct t from decay products

Statistics is the main issue

For inclusive measurements, need proton tagging

Existing LPS / FPS smallest systematics but limited statistics.

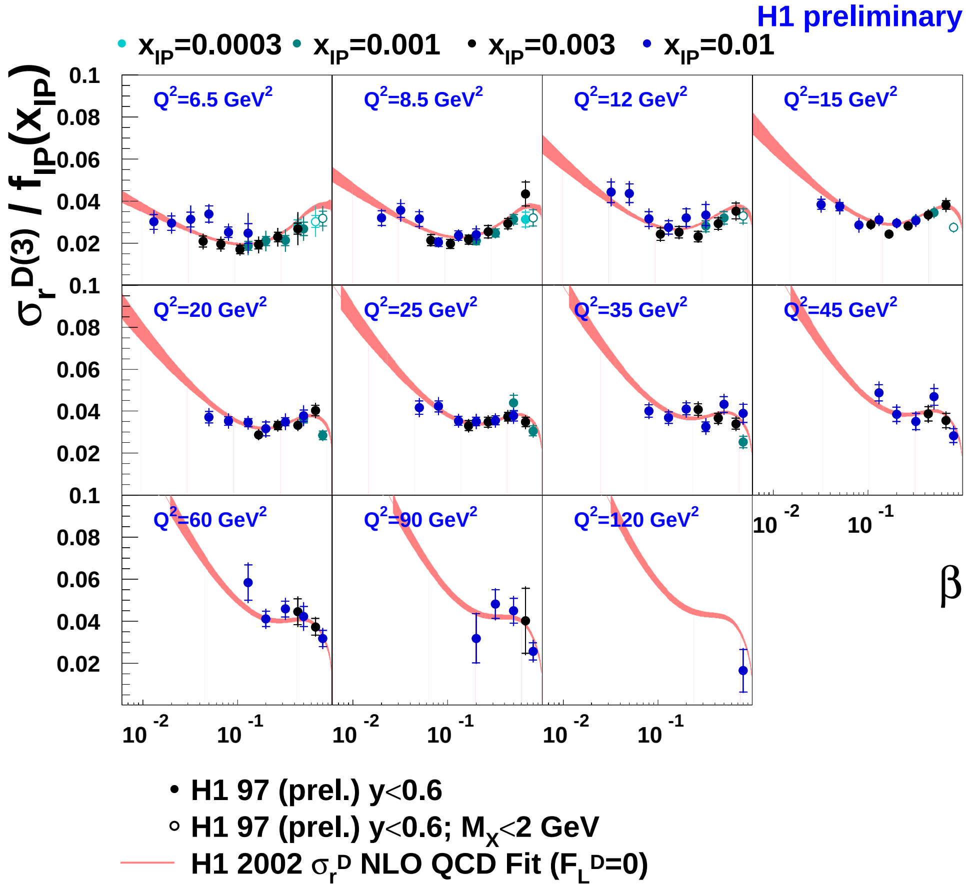
VFPS will give 3-4 bins for $0 < |t| < 0.8\ \mathrm{GeV}^2$.

Inclusive Diffraction and Factorisation

QCD Hard Scattering Factorisation for Semi-Inclusive DIS:-

Diffractive parton densities $p_q^D(x_{I\!P}, t, x, Q^2)$ express *conditional* proton parton probability distributions with constraint of final state proton at particular $x_{I\!P}, t \ldots$

$$\sigma_{\rm DIS}^{\rm Dif} \sim p_q^D(x_{I\!P}, t, x, Q^2) \otimes \hat{\sigma}_{\rm pQCD}$$

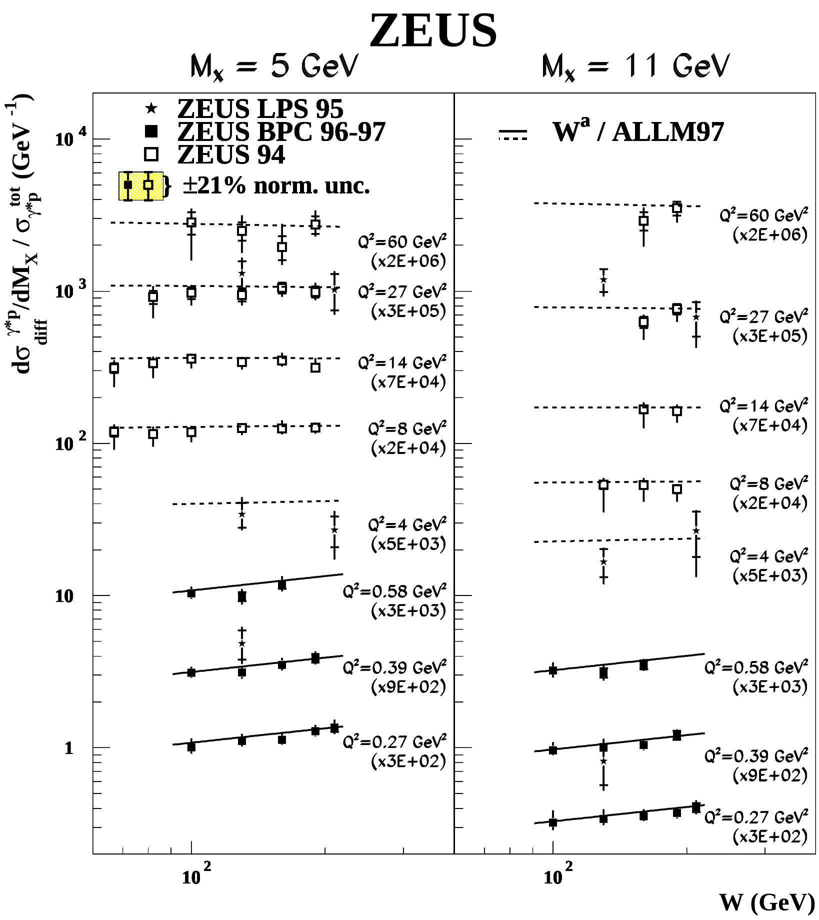


So far, insufficient precision / kinematic range to extract $p_q^D(x_{I\!P}, t, x, Q^2)$ at fixed $x_{I\!P}, t$

Additional Regge factorisation assumption required: $(x_{I\!P}, t)$ dependence $\sim I\!P$ flux

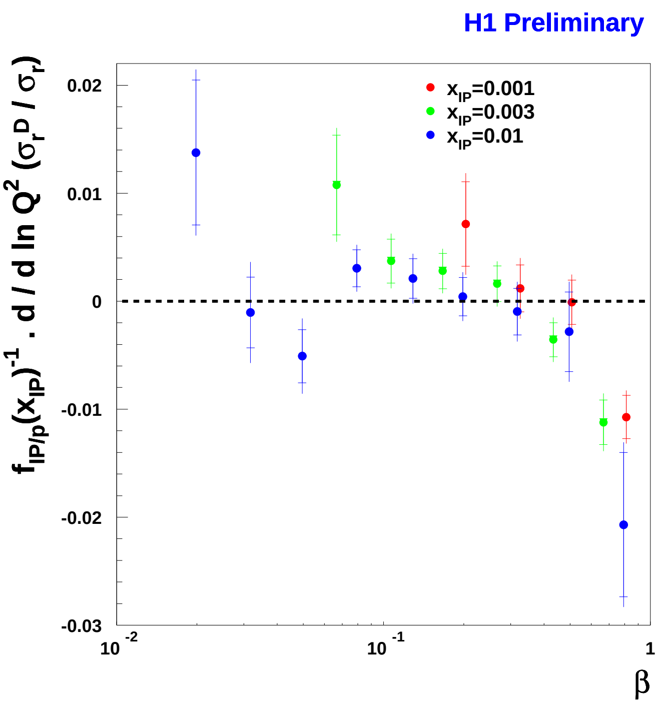
Diffractive to Inclusive Ratio

Remarkable flatness of F_2^D / F_2 over wide kinematic range at large Q^2 requires further investigation . . . deeper reasons?



$d\sigma / dM_X^2 / \sigma^{tot}$ flat

v W at fixed M_X, Q^2



F_2^D / F_2 flat

v Q^2 at fixed $x_{I\!P}, \beta$

QCD Factorisation Tests with VFPS

Restricted $x_{I\!P}$, t ranges, but low systematics due to high acceptance

Precision measurements of (x, Q^2) dependence from central detectors in small well controlled range of ($x_{I\!P}$, t).

Systematics from proton measurement $\sim$ normalisation.

Point-to-point systematics could reach 2-3% level of F_2?

Assume data from 3 years of HERA running, 50% operation efficiency:

$\rightarrow 350\,\mathrm{pb}^{-1}$ $\sim 10^6$ events ($Q^2 \gtrsim 5\,\mathrm{GeV}^2$)

Should be possible to extract diffractive pdfs for fixed $x_{I\!P}$, t

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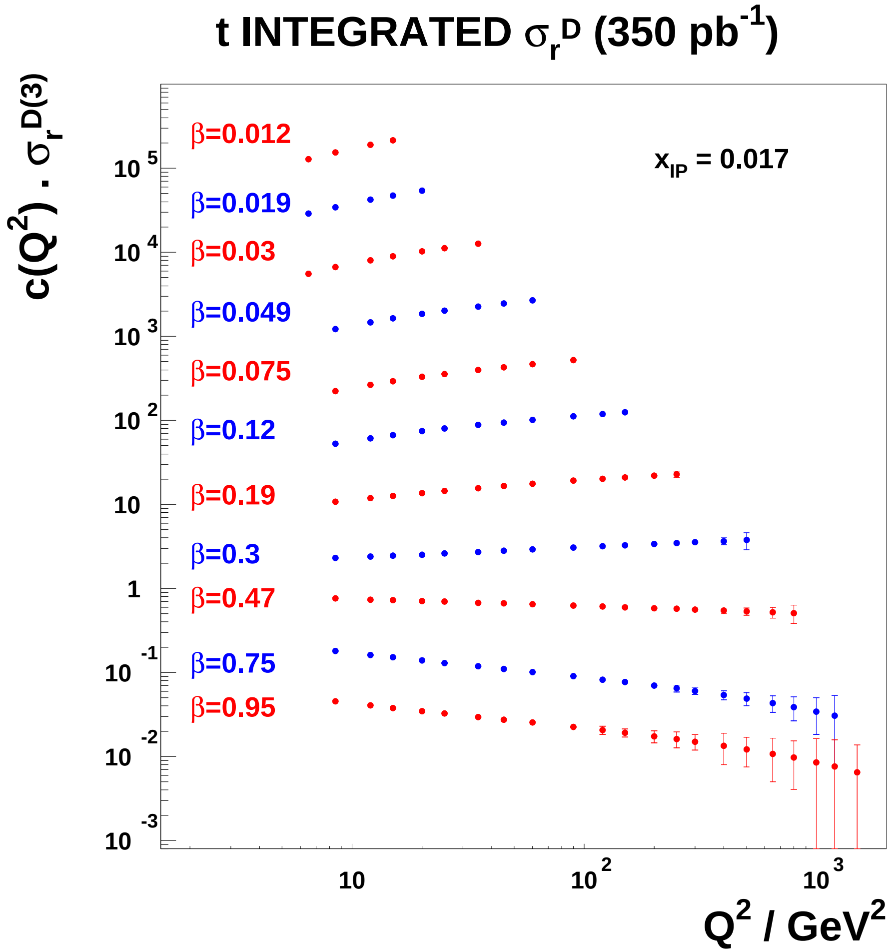
Measured $0.01 \lesssim x_{I\!P} \lesssim 0.02$ region gives high yields of exclusive final state channels to test pdfs

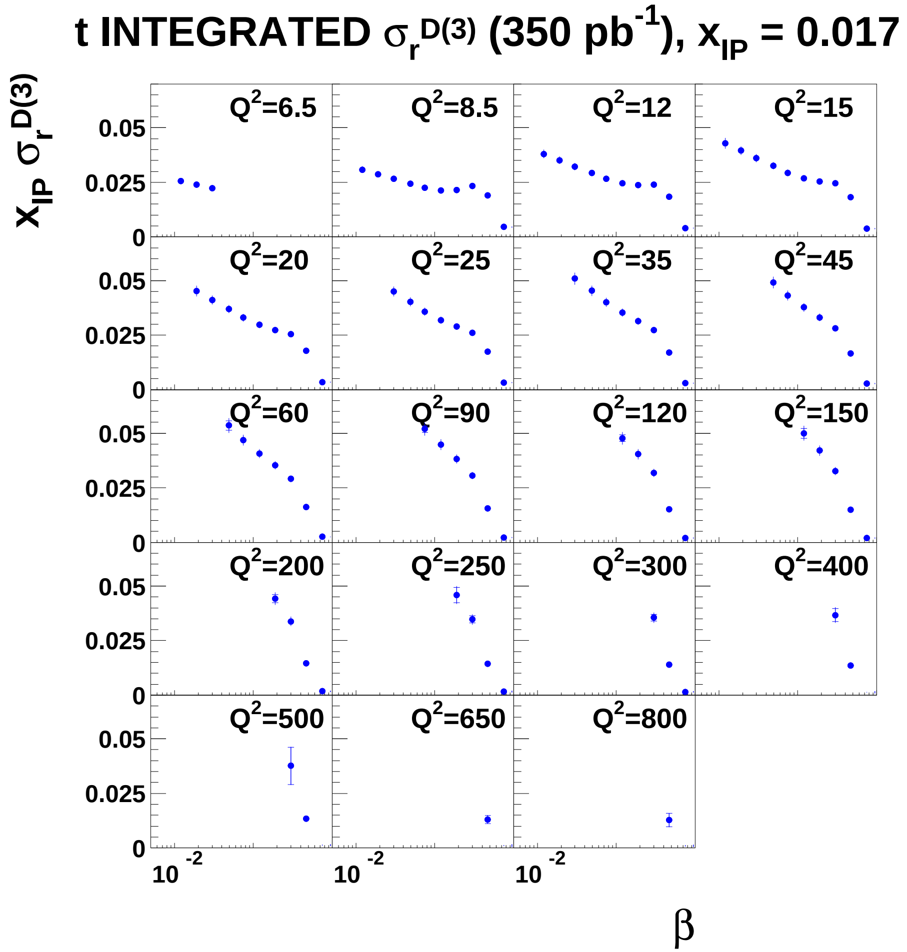
e.g. ~ 30000 DIS dijets, 500 DIS D^*

Same triggers, VFPS selection $\rightarrow$ many systematics cancel in final state comparisons.

Projected Diffractive Cross Section with VFPS

σ_r^D for $x_{I\!P} = 0.017$, $|t| < 1\ \mathrm{GeV}^2$, measuring $x = \beta x_{I\!P}$ and Q^2 in central detector





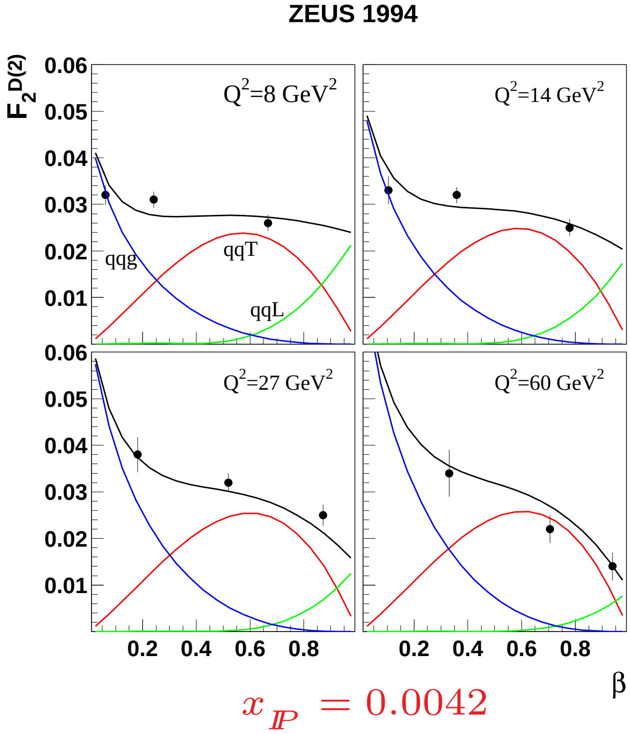
F_L^D Measurements

Inclusive diffraction cannot be fully understood without separating out longitudinal photon contributions:

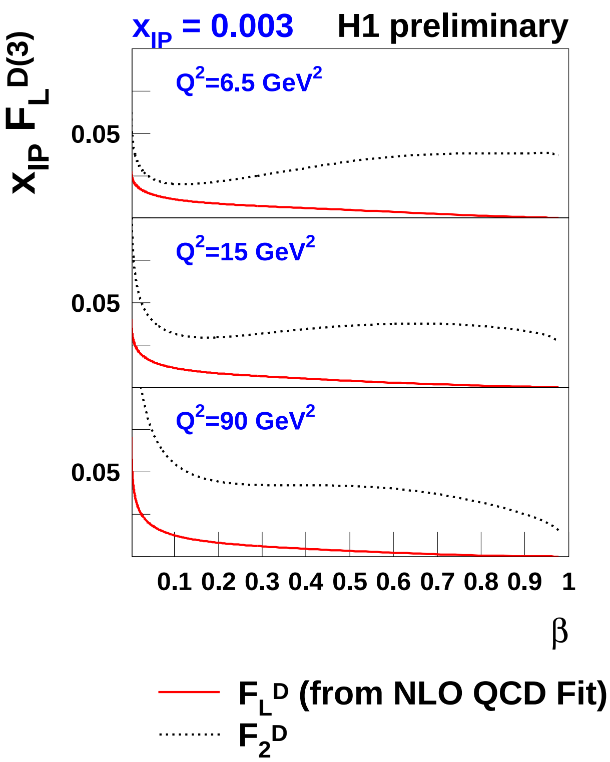
pQCD calculable Higher Twist

σ_L dominant at high

β? (BEKW, Saturation)



Definite predictions for exclusive final states (eg exclusive jets BJLW)



Leading Twist F_L^D

tests hard scattering fac^n

(gluon at NLO)

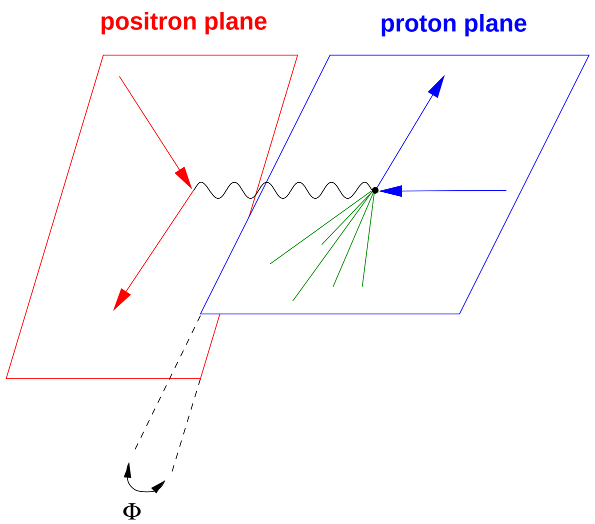
Predictions from NLO fits

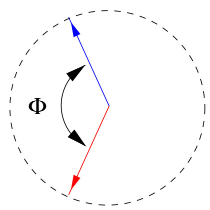
need testing!

F_L^D from Azimuthal Correlations

Interference between transverse and longitudinal photon induced processes leads to modulation in $\cos\phi_{ep}$.

Proton Spectrometers allow measurement of $\cos\phi_{ep}$!



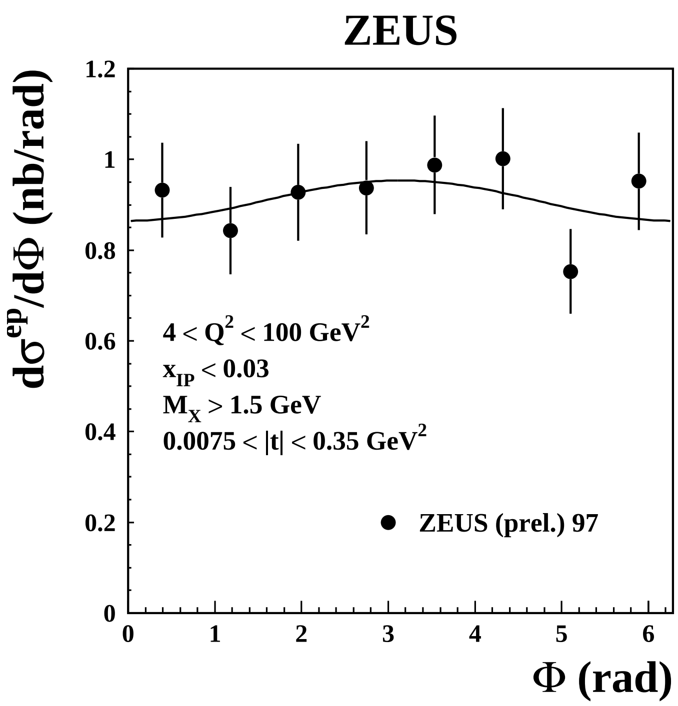


First measurement from ZEUS LPS . . .

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\cos\phi} \propto 1 + A_{LT}\cos\phi$$

$$A_{LT} = -0.049 \pm 0.058\,(\mathrm{stat})\; {}^{+0.056}_{-0.009}\,(\mathrm{syst})$$

Lots more stats needed!



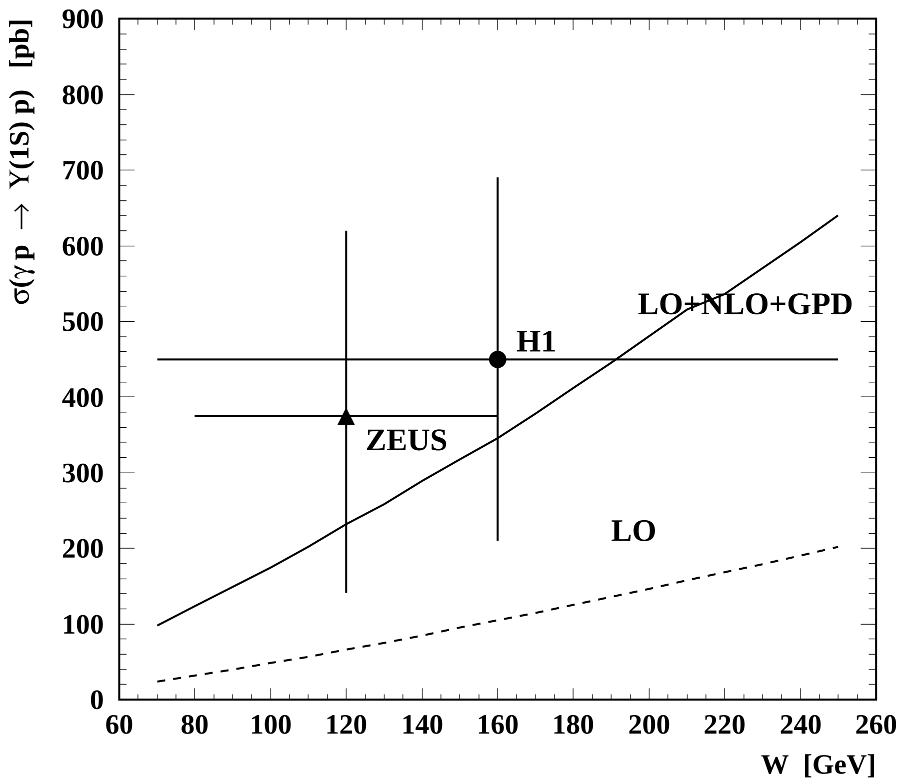
VFPS resolution sufficient for $\cos\phi_{ep}$ in 15 bins at $|t| > 0.2\,\mathrm{GeV}^2$, 10000 events each.

Possibility of high statistics measurmeents differential in β etc

Skewed Parton Effects

For any 2 gluon exchange process, exchange gluon momenta differ by skewing $\xi = (Q^2 + M_X^2)/W^2$

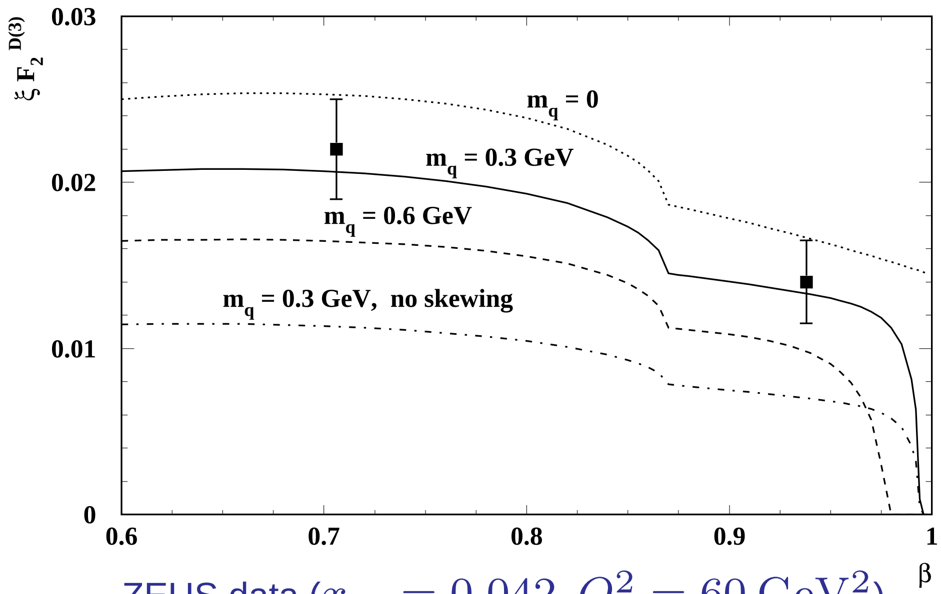
Measurable effects in many processes . . .



e.g. Υ photoproduction

Skewing effect changes predictions by factor ~ 2

(Martin, Ryskin, Frankfirt, McDermott, Strikman)



ZEUS data ($x_{I\!P} = 0.042, Q^2 = 60\ \mathrm{GeV}^2$)

e.g. $F_2^{D(3)}$ as $\beta \to 1$

Inclusive production with $Q^2 \gg M_x^2$, Calculable HT σ_L dominates.

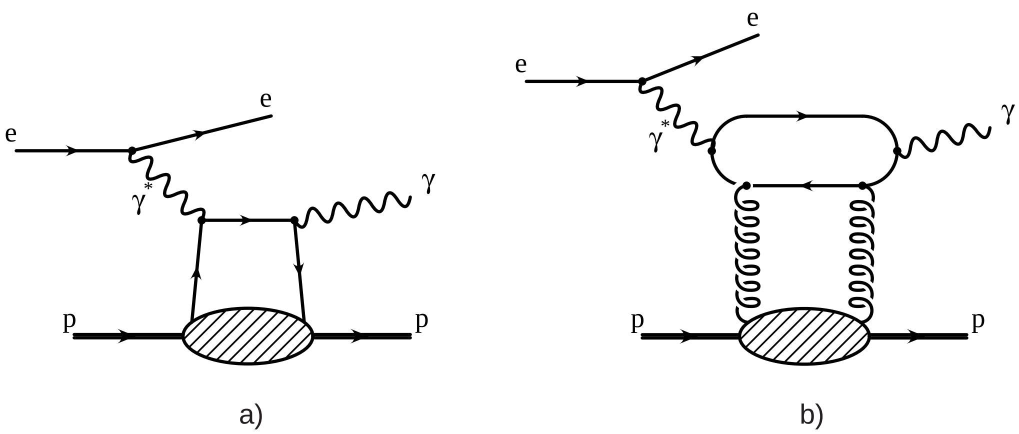
Sensitive to skewed gluon density

Experimental Sensitivity to GPDs

Skewed parton densities / GPDs generating great interest . . .

- New information on proton structure (3D parton structure)
- Parton orbital momentum contribution to proton spin
- New sum rules
- Parton correlations
- Calculable higher twist

Real possibilities of measurements with DVCS, aided by interference with Bethe Heitler process

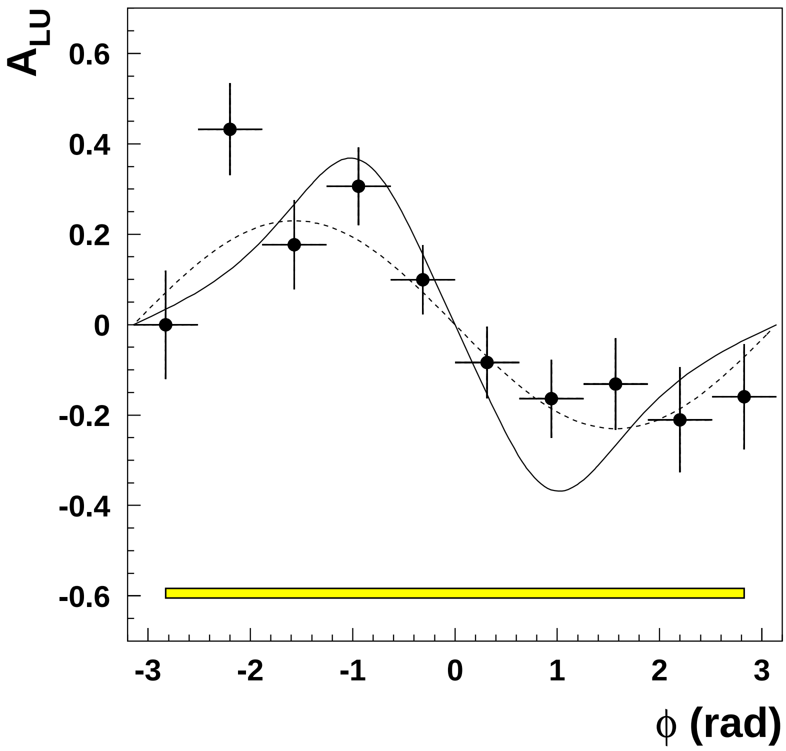


So far, H1, ZEUS measured cross sections integrated over ϕ

Measurement of asymmetries (ϕ, beam charge, beam spin) give access to GPDs.

Full decomposition requires polarised target (HERMES!)

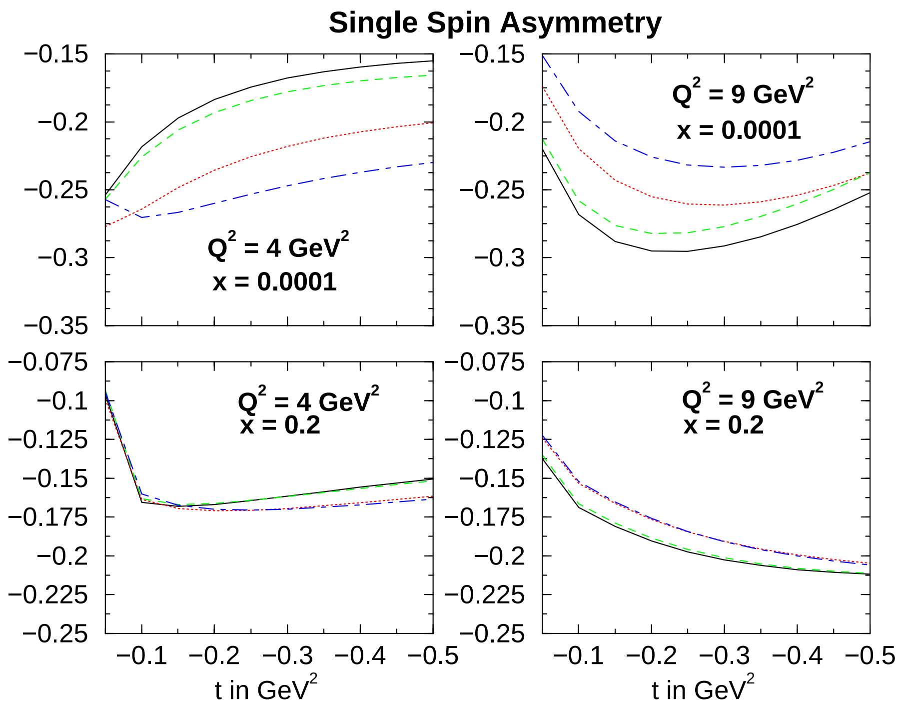
Asymmetry Measurements



HERMES already observed dependence of beam polarisation asymmetry on ϕ

$\longrightarrow$ Imaginary part of BH / DVCS interference term.

Real part from beam charge asymmetry



Large asymmetries expected at HERA II.

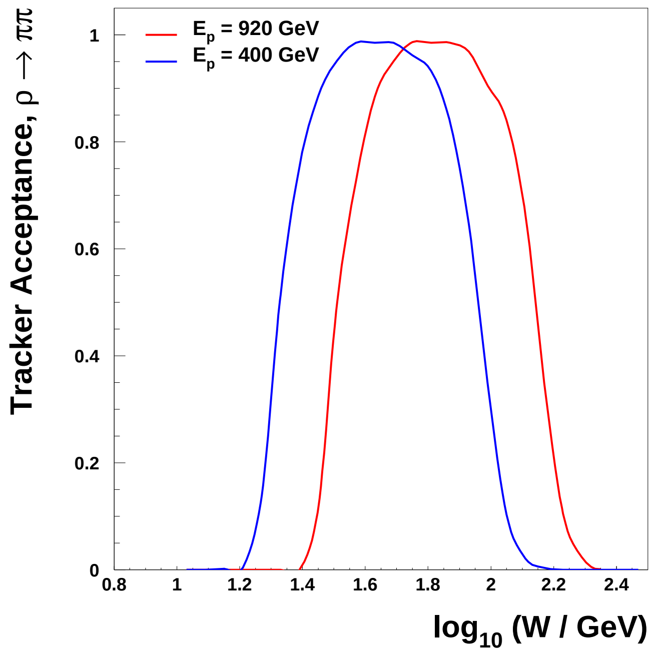
(Freund & McDermott)

Good sensitivity to models of GPDs

Reduced Proton Energy Running

$\lesssim 50\,\mathrm{pb}^{-1}$ may be taken with reduced E_p, for inclusive high x and F_L measurements … Also useful for diffraction!

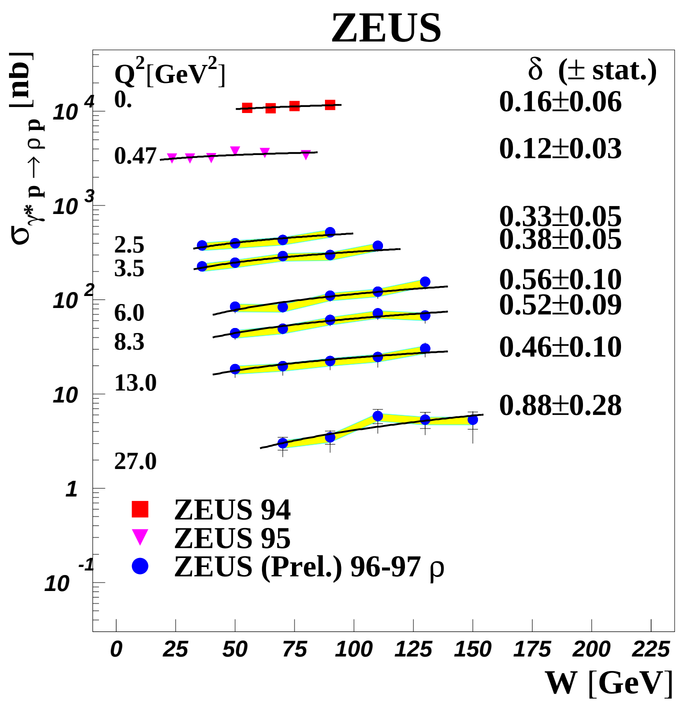
Reducing E_p changes detector acceptance regions in W.



e.g. for $E_p = 400\,\mathrm{GeV}$:

W region of acceptance for $\rho \longrightarrow \pi\pi$ with pions in Central Trackers ($20^\circ < \theta < 160^\circ$), at $Q^2 > 4\,\mathrm{GeV}^2$.

Acceptance $\rightarrow W < 20\,\mathrm{GeV}$



Similar extensions for all channels

… better constraints on $\delta(Q^2)$,

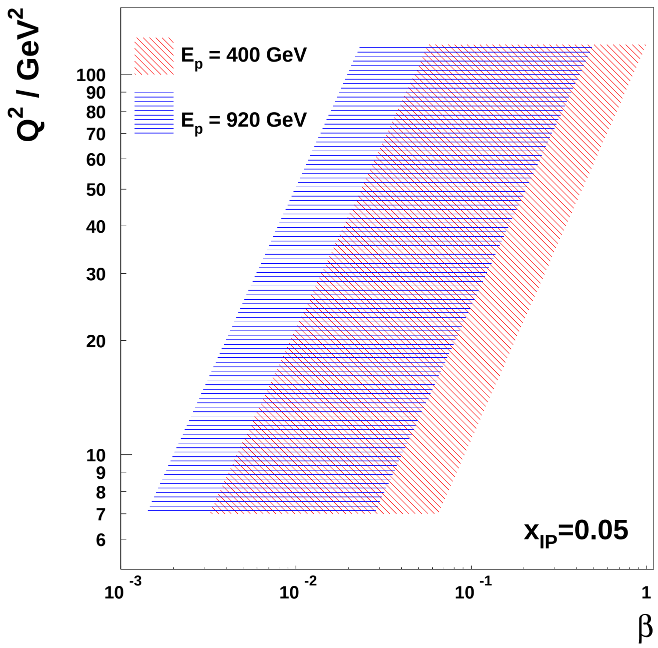
… higher sensitivity to α'

… comparisons with 2-gluon models over wider range in x

…

Reduced E_p and F_2^D

Reduced $E_p \rightarrow F_2^D$ measurements in new kinematic regions.



Acceptance $\rightarrow$ higher $x_{I\!P}$ at fixed β

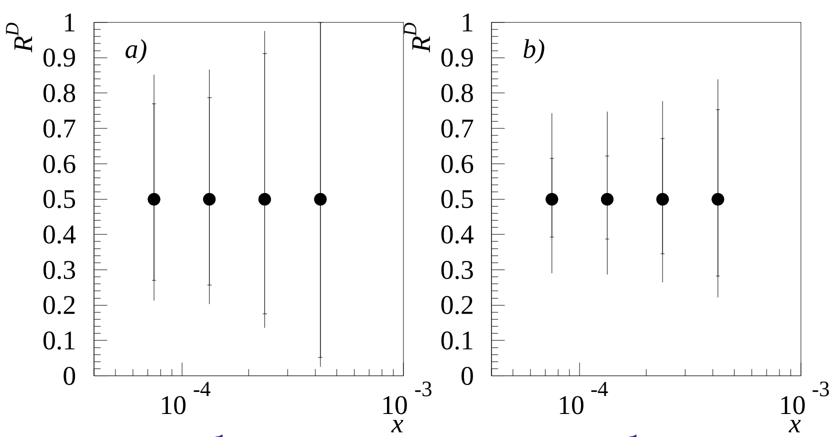
Acceptance $\rightarrow$ higher β at fixed $x_{I\!P}$

...Extended phase space for diffractive pdf extraction at fixed $x_{I\!P}$.

...Improved sensitivity to sub-leading exchange terms.

...Direct F_L^D extraction.

...



$10\,\mathrm{pb}^{-1}$ @ $500\,\mathrm{GeV}$
$50\,\mathrm{pb}^{-1}$ @ $820\,\mathrm{GeV}$

$50\,\mathrm{pb}^{-1}$ @ $500\,\mathrm{GeV}$
$250\,\mathrm{pb}^{-1}$ @ $820\,\mathrm{GeV}$

Vary s to get $\sigma(\beta, Q^2, x_{I\!P})$ at different y

$50\,\mathrm{pb}^{-1}$ at $E_p = 500\,\mathrm{GeV}$

$\sim 40\%$ measurement of $R^D = F_L^D/(F_2^D - F_L^D)$

Comparable stat and syst errors

Outlook

- At HERA-I we started to understand diffraction in QCD
- Many questions do not have final answers:
  - Can semi-inclusive factorisation be tested directly?
  - Where does Regge factorisation break down?
  - What is the precise relationship between F_2^D and F_2?
  - How much does the hard pomeron shrink?
  - Is BFKL unambiguously seen in high $|t|$— VM?
  - How well can GPDs be constrained?
  - ...
- HERA-I still under analysis ($> 100\,\mathrm{pb}^{-1}$ per experiment)
- HERA-II ($\sim 1\,\mathrm{fb}^{-1}$ per experiment by 2006)
- New detectors - H1 VFPS ...
- At HERA-II, precision measurements of diffraction
- Many experimental and phenomenological challenges