Diffractive and Exclusive Processes in ep Scattering at the LHeC

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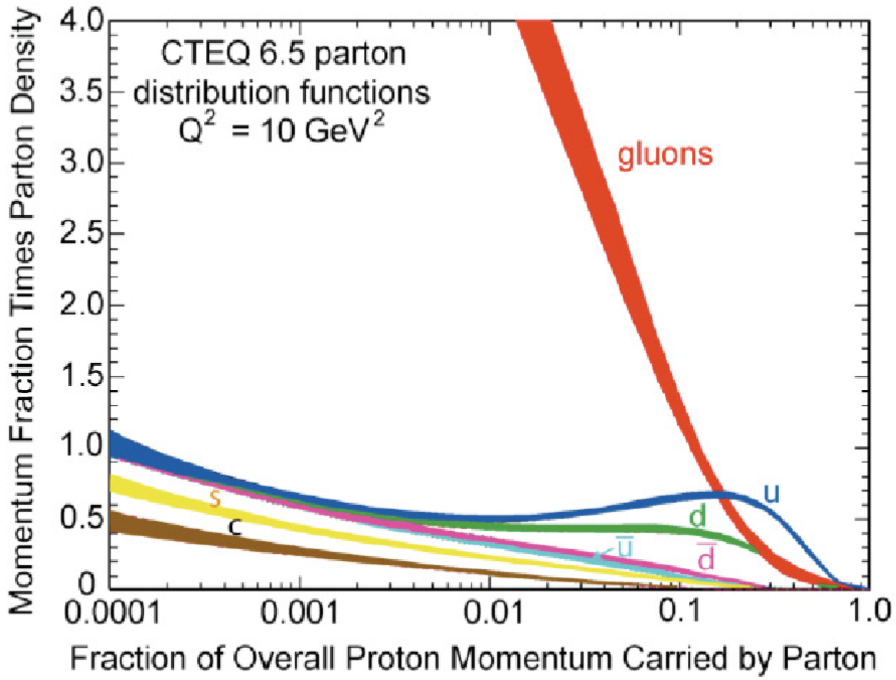
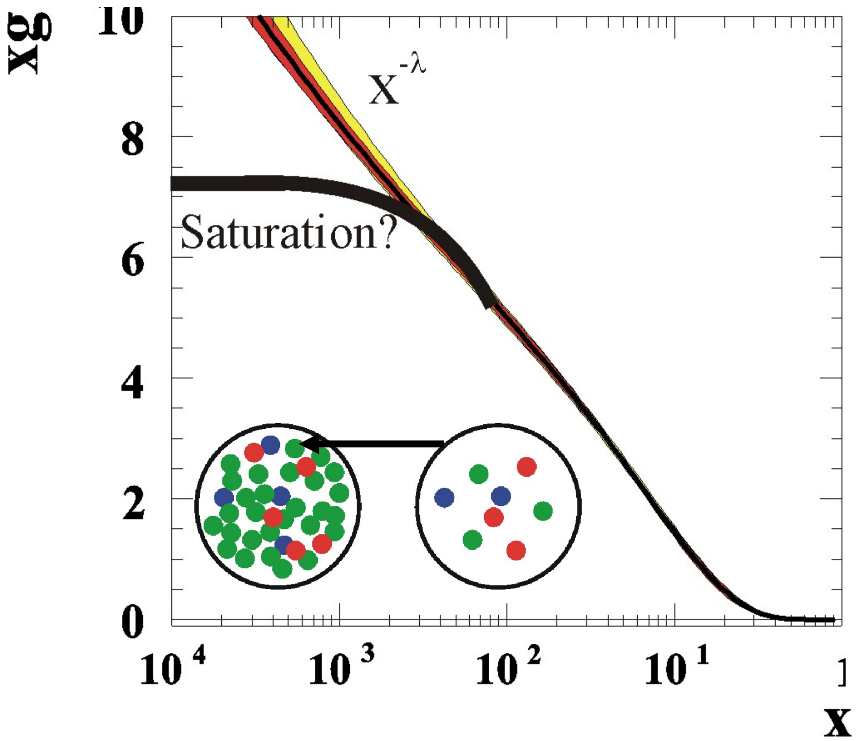
- The Importance of Diffraction to Low x Physics
- Exclusive J/Ψ and Υ production
- Deeply Virtual Compton Scattering
- Inclusive Diffraction

Related LHeC talks: Low x Inclusive Physics (Anna Stasto)
eA Physics (Brian Cole)

Low-x Physics and Non-linear Evolution



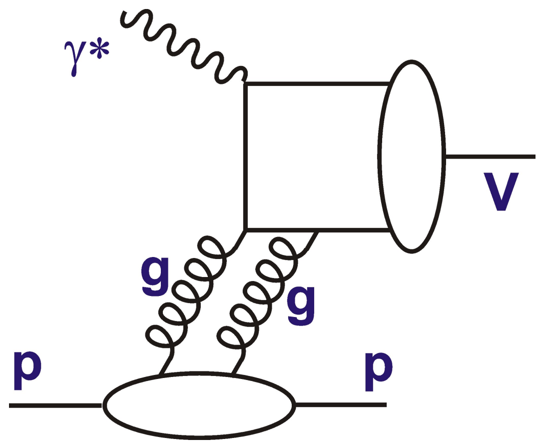


- Somewhere, somehow, low x growth of cross sections must be tamed to satisfy unitarity … non-linear effects
- Dipole model language → **projectile $q\bar{q}$ multiply interacting**
- Parton level language → **recombination gg → g**

- Main aim of low x at LHeC is to observe and understand associated microscopic dynamics → Q^2 as large as possible

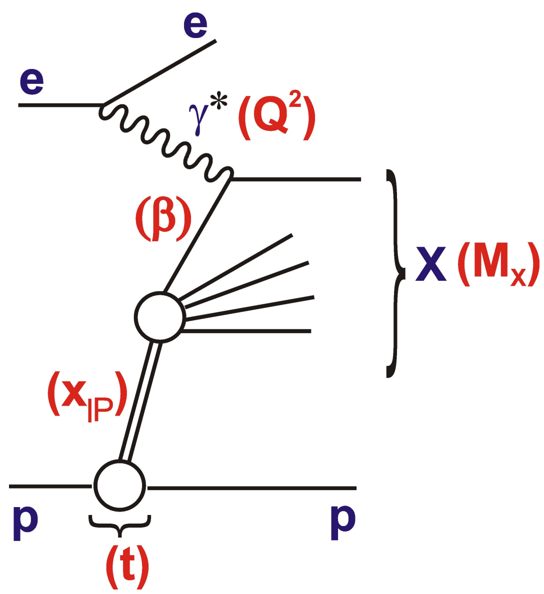
2 Benefits of Diffraction

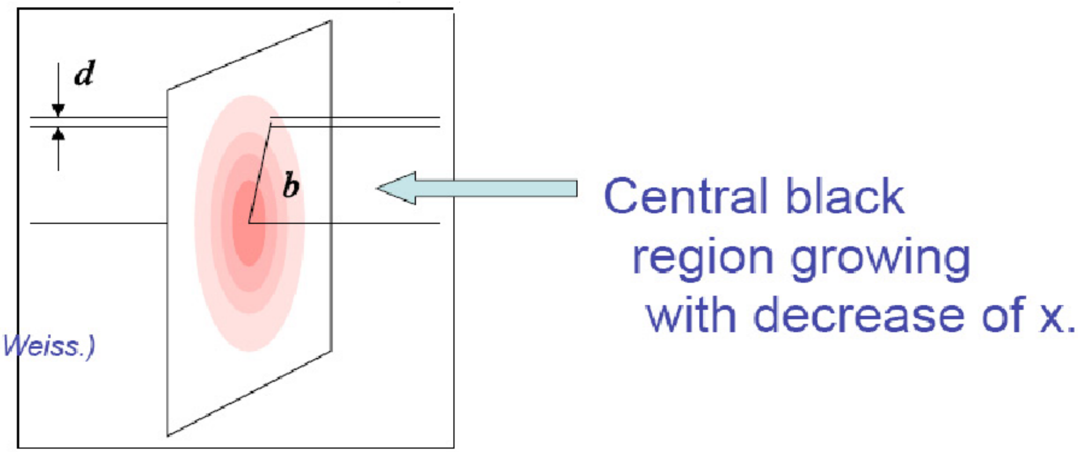
1) [Low-Nussinov] interpretation as 2 gluon exchange enhances sensitivity to low x gluon



2) Additional variable t gives access to impact parameter (b) dependent amplitudes

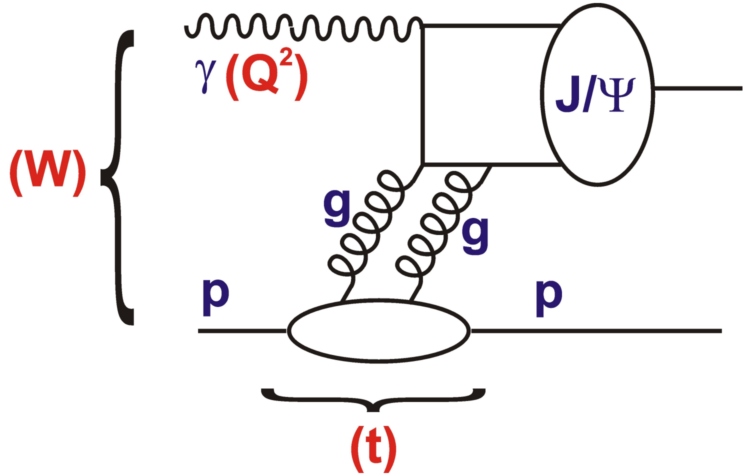
→ Large t (small b) probes densest packed part of proton?





(figure from C. Weiss.)

Elastic J/Ψ Photoproduction: Golden Channel?



• `Cleanly' interpreted as hard 2g exchange coupling to qqbar dipole … enhanced sensitivity to low x gluon

• c and c-bar share energy equally, simplifying VM wavefunction

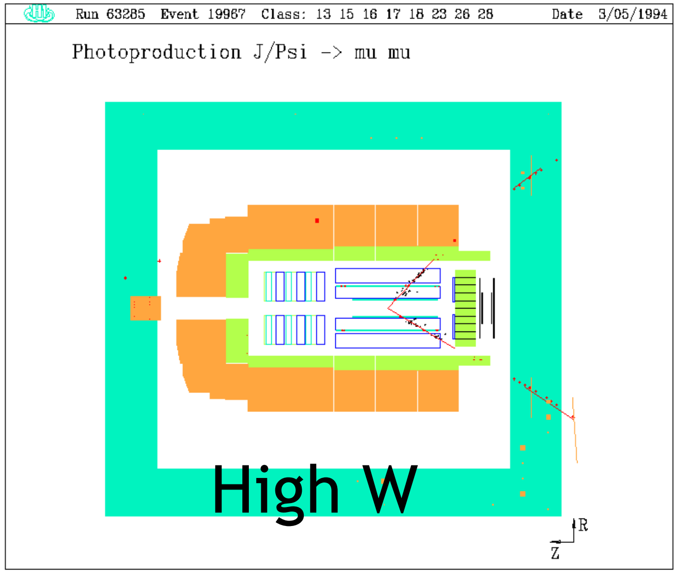
• Clean experimental signature (just 2 leptons)

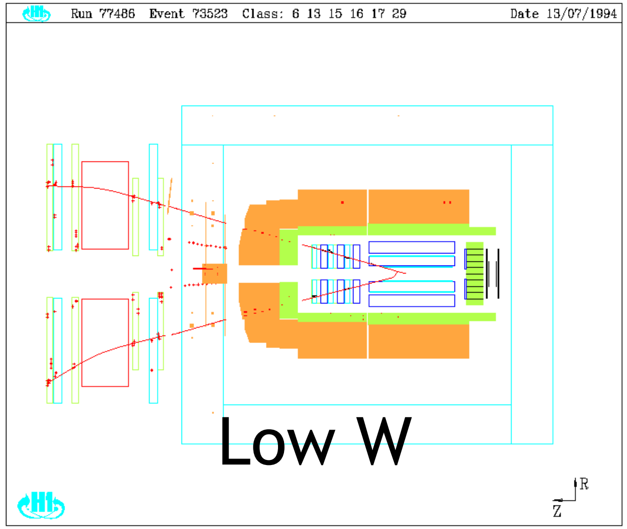
… LHeC reach extends to $x_g \sim 6.10^{-6}$ at $\overline{Q^2} \sim 3\ \mathrm{GeV}^2$

(MNRT etc) $X_g \sim (Q^2 + M_V^2) \;/\; (Q^2 + W^2)$ $\qquad \overline{Q^2} = (Q^2 + M_V^2) \;/\; 4$

• Simulations of elastic J/Ψ → μμ photoproduction
→ scattered electron untagged, 1° acceptance for muons
(similar method to H1 and ZEUS)

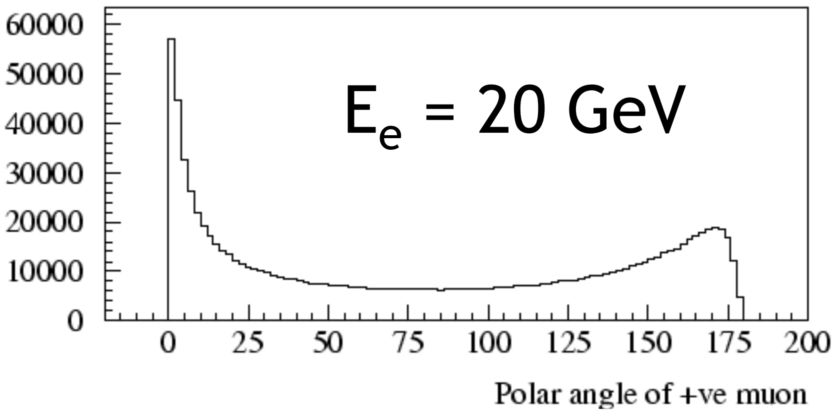
J/Ψ Kinematics

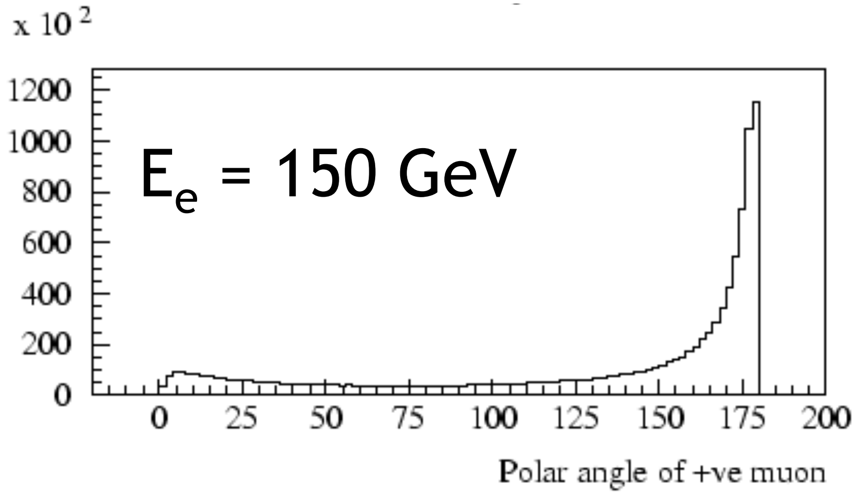




- At fixed $\sqrt{s}$, decay muon direction is determined by $W = \sqrt{s_{\gamma p}}$

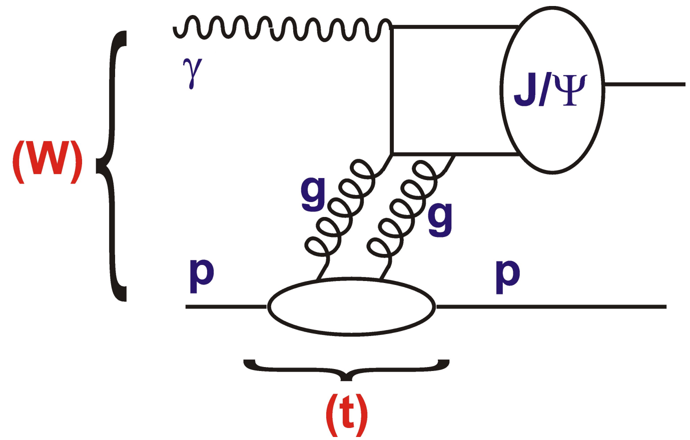
- As E_e increases, higher W accessed; acceptance in outgoing electron beam direction crucial

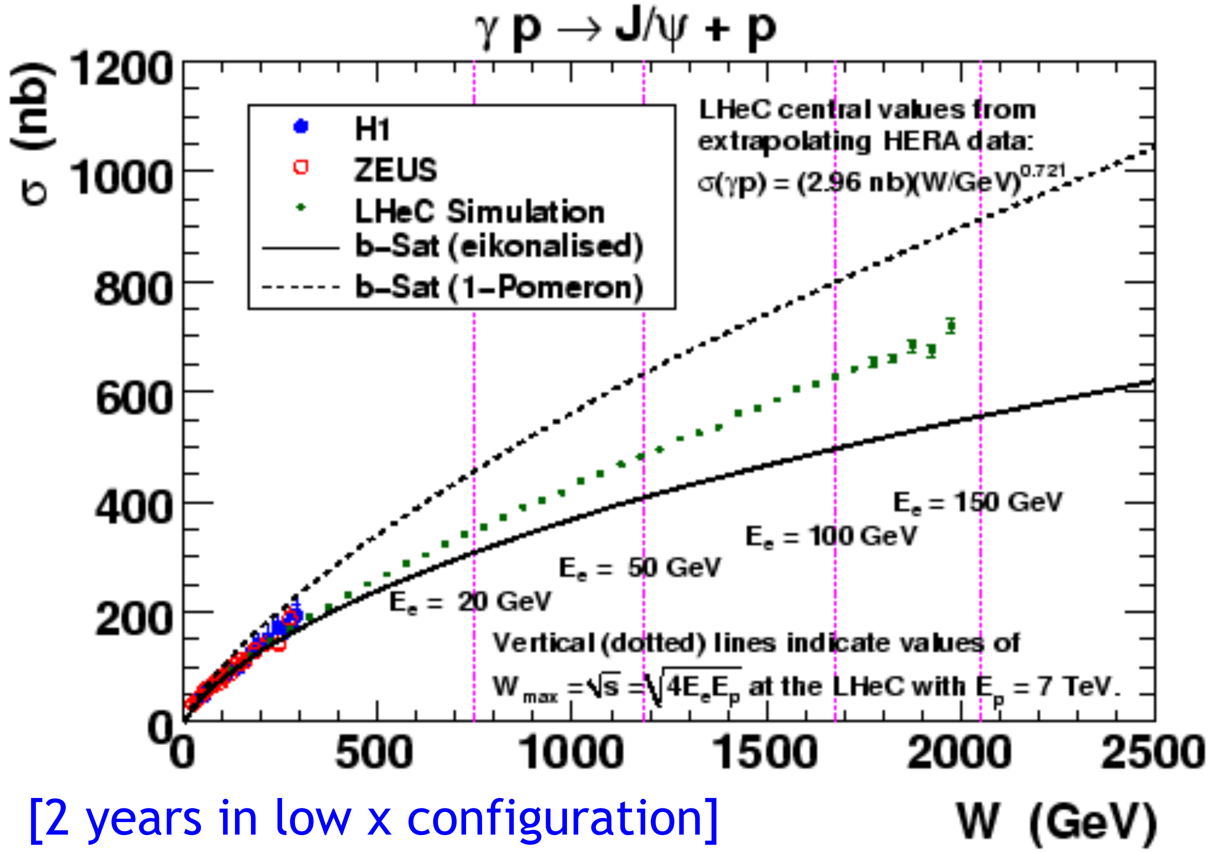




Comparison with Dipole Model Predictions

e.g. "b-Sat" Dipole model
"eikonalised": with impact-parameter dependent saturation
"1 Pomeron": non-saturating





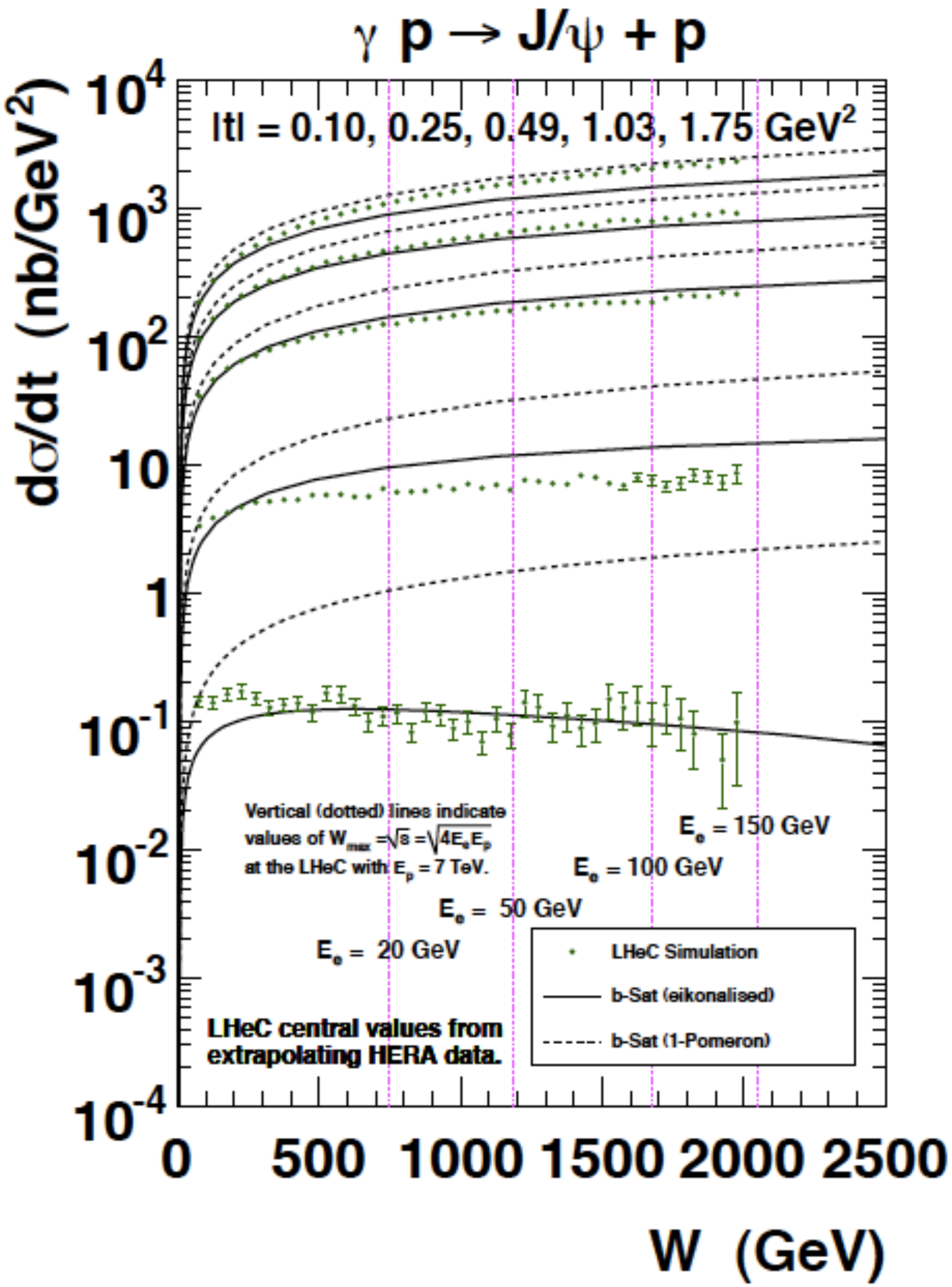
[2 years in low x configuration]

- Significant non-linear effects expected even for t-integrated cross section at LHeC.

[Pseudo-data shown are extrapolations of HERA power law fit]

→ Smoking gun?

t Dependence of Elastic J/ψ Photoproduction

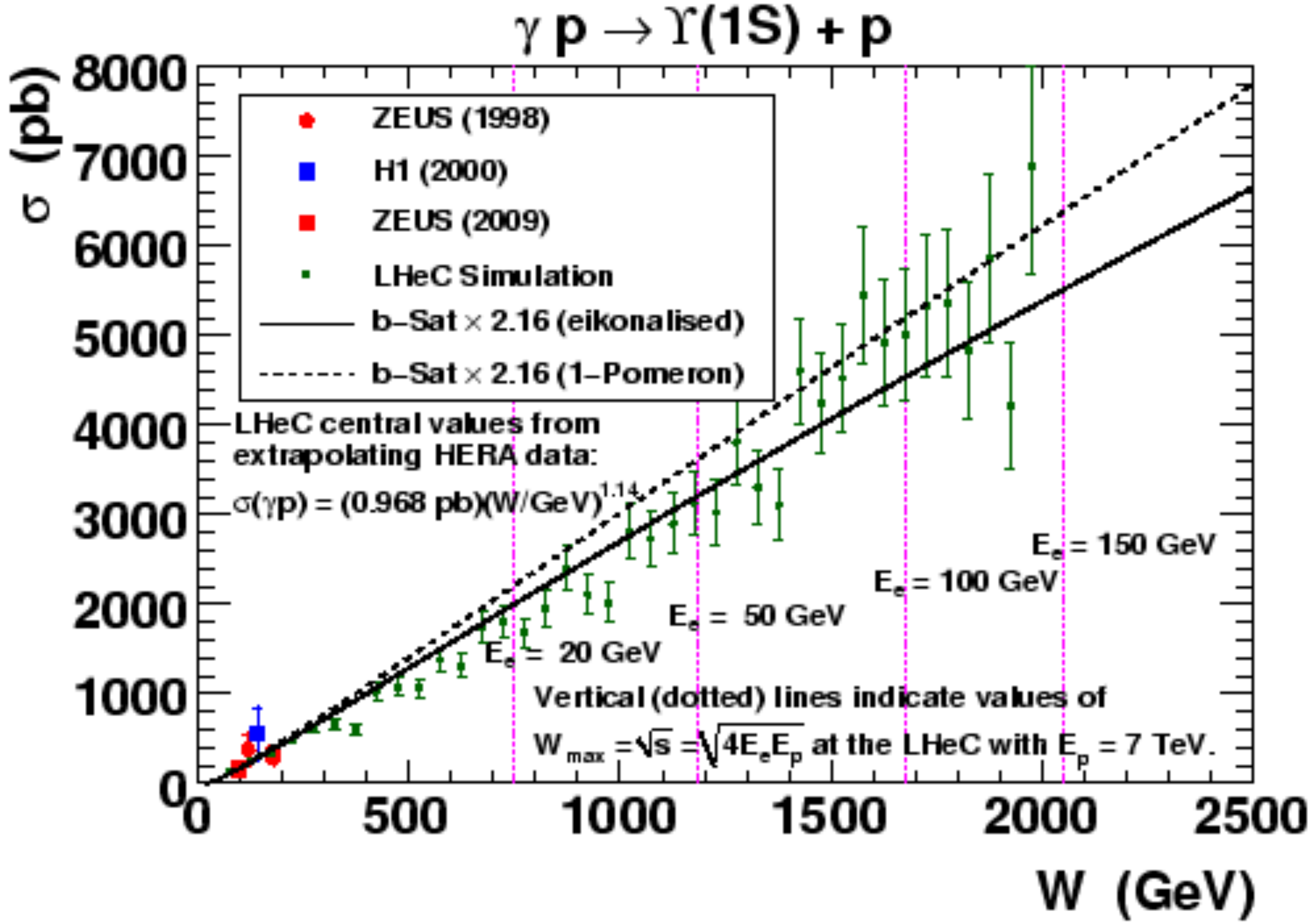


- J/ψ photoproduction double differentially in W and t …

- Precise t measurement from decay μ tracks over wide W range extends to |t| ~ 2 GeV^2 and enhances sensitivity to saturation effects

- Measurements also possible in multiple Q^2 bins

Similar Study for Upsilon



[b-sat curves scaled to match best fit to HERA data]

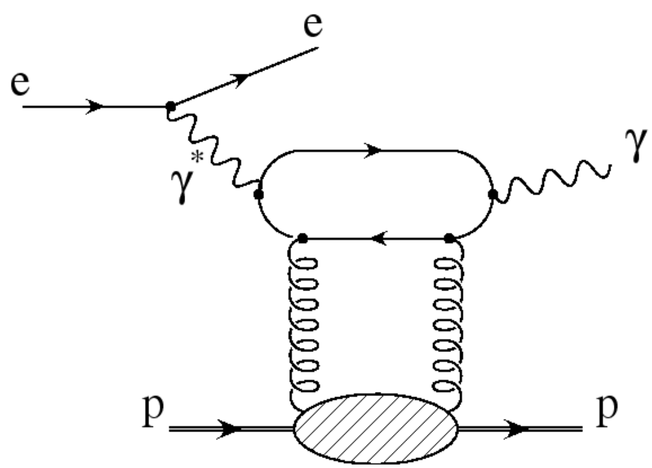
- Sat^n effects smaller than J/Ψ (smaller dipole sizes, higher x).
- Cross sections also much smaller than for J/Ψ.

- Huge increase over HERA range → anomalously large HERA cross sections can be tested.

Deeply Virtual Compton Scattering

- No vector meson wavefunction Complications

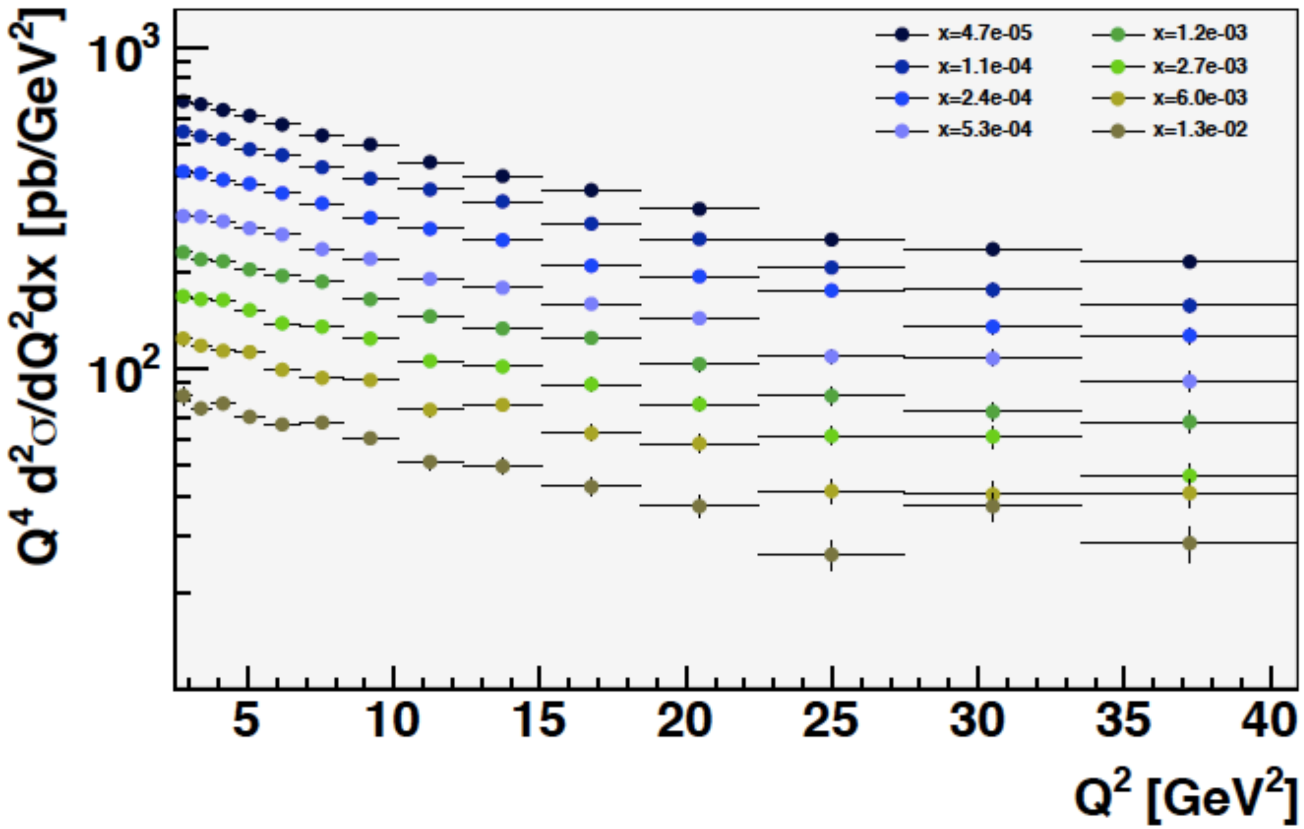
- Cross sections suppressed by photon coupling
  → limited precision at HERA



Simulations based on FFS model in MILOU generator
→ Double differential distributions in (x, Q^2) with
1^o and 10^o cuts for scattered electron
→Kinematic range determined largely by cut on p_T^γ
(relies on ECAL performance / linearity at low energies)

DVCS at low luminosity & high acceptance

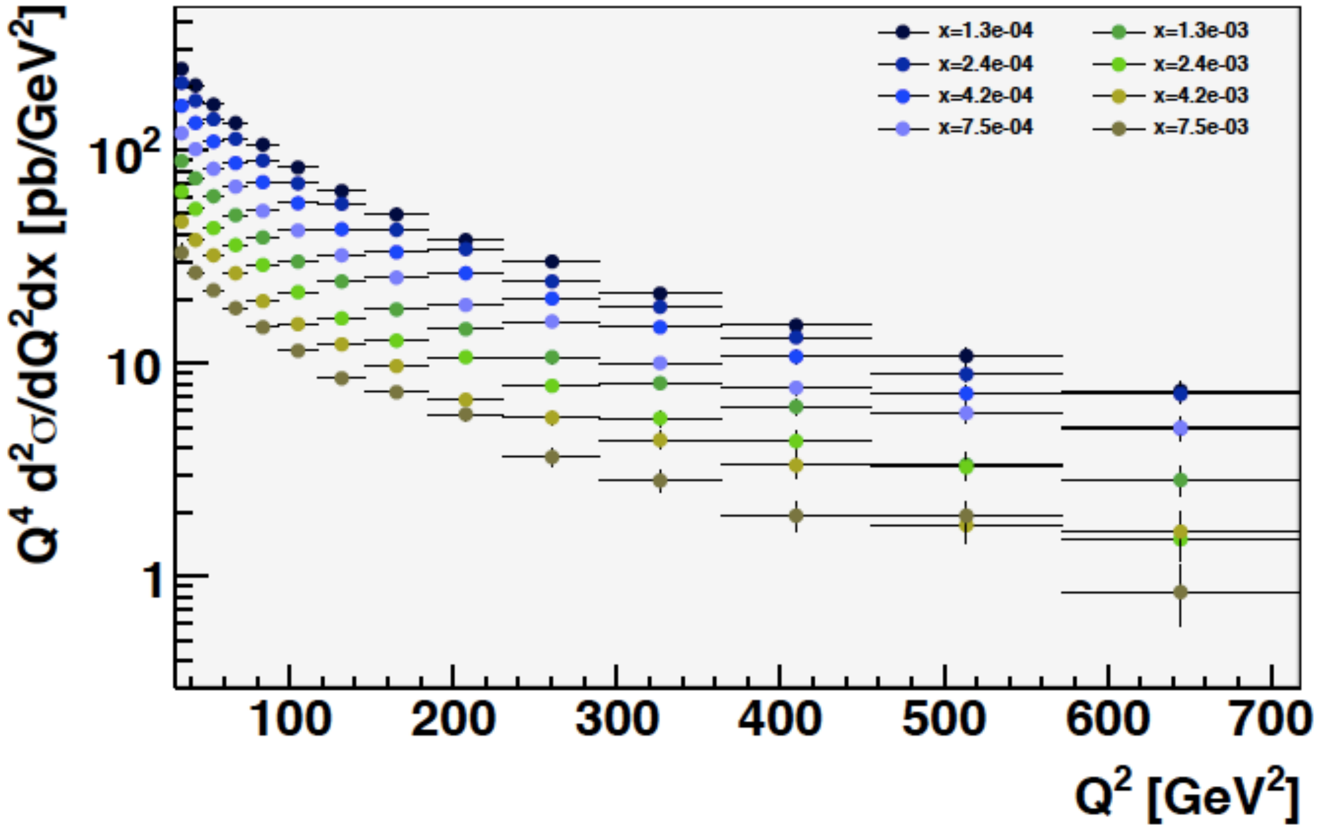
1 fb^{-1}, E_e = 50 GeV, 1° acceptance, p_T^{γ} > 2 GeV



- Precise double differential data in low Q^2 region
- Statistical precision deteriorates for Q^2 >~ 25 GeV^2
- W acceptance to ~ 1 TeV (five times HERA)

DVCS at high luminosity and low acceptance

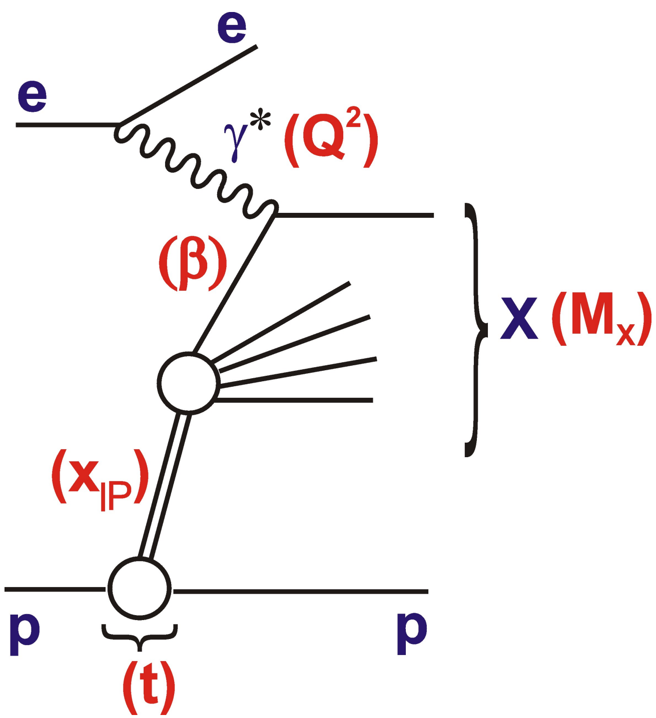
100 fb^{-1}, E_e = 50 GeV, 10° acceptance, p_T^γ > 5 GeV



- Low Q^2 acceptance lost due to focusing magnets
- High lumi gives precision data to Q^2 of several hundred GeV^2

  → Completely unprecedented region for DVCS / GPDs

Inclusive Diffractive Dissociation

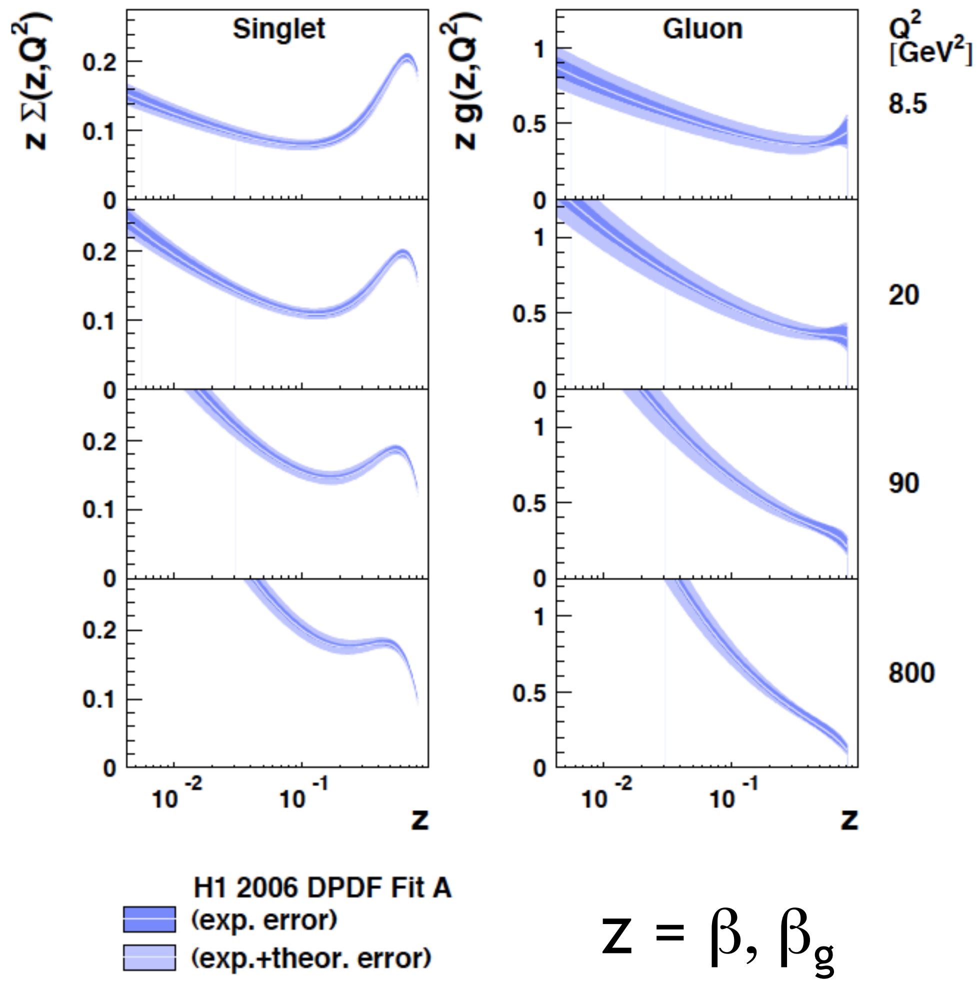


Additional variables …

x_{IP} = fractional momentum loss of proton (fraction IP/p)

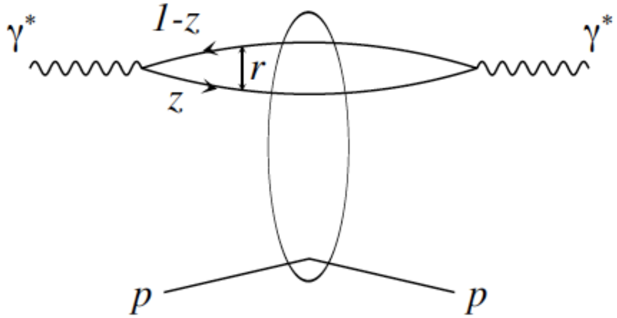
$\beta = x / x_{IP}$ (fraction q/IP)

… used at HERA to extract diffractive parton densities



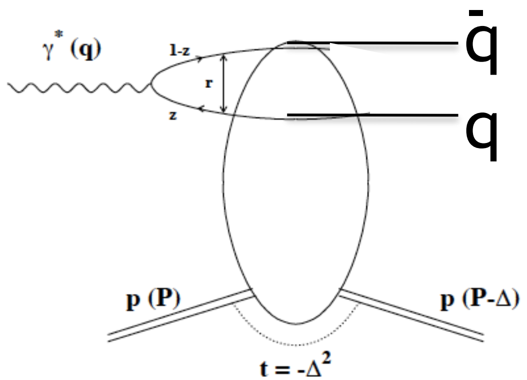
$z = \beta, \beta_g$

Diffractive DIS, Dipole Models & Saturation



Inclusive Cross Section

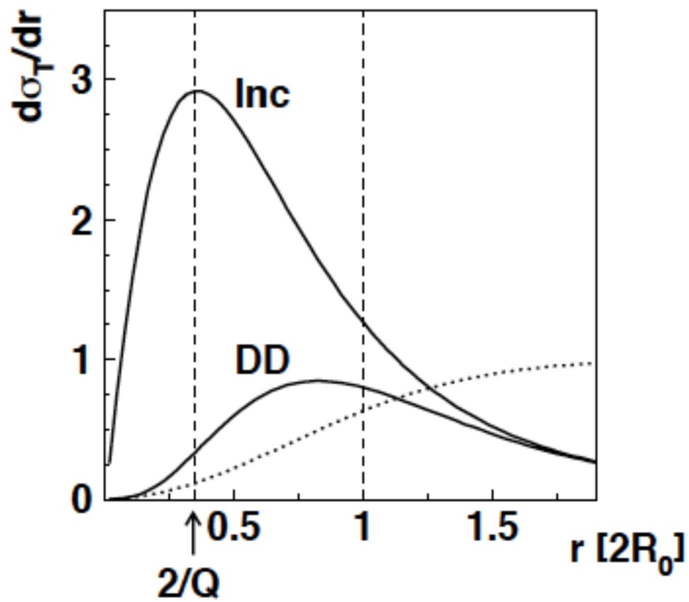
$$\sigma_{T,L}(x,Q^2) = \int d^2\mathbf{r}\int_0^1 d\alpha\,|\Psi_{T,L}(\alpha,\mathbf{r})|^2\hat{\sigma}(x,r^2)$$



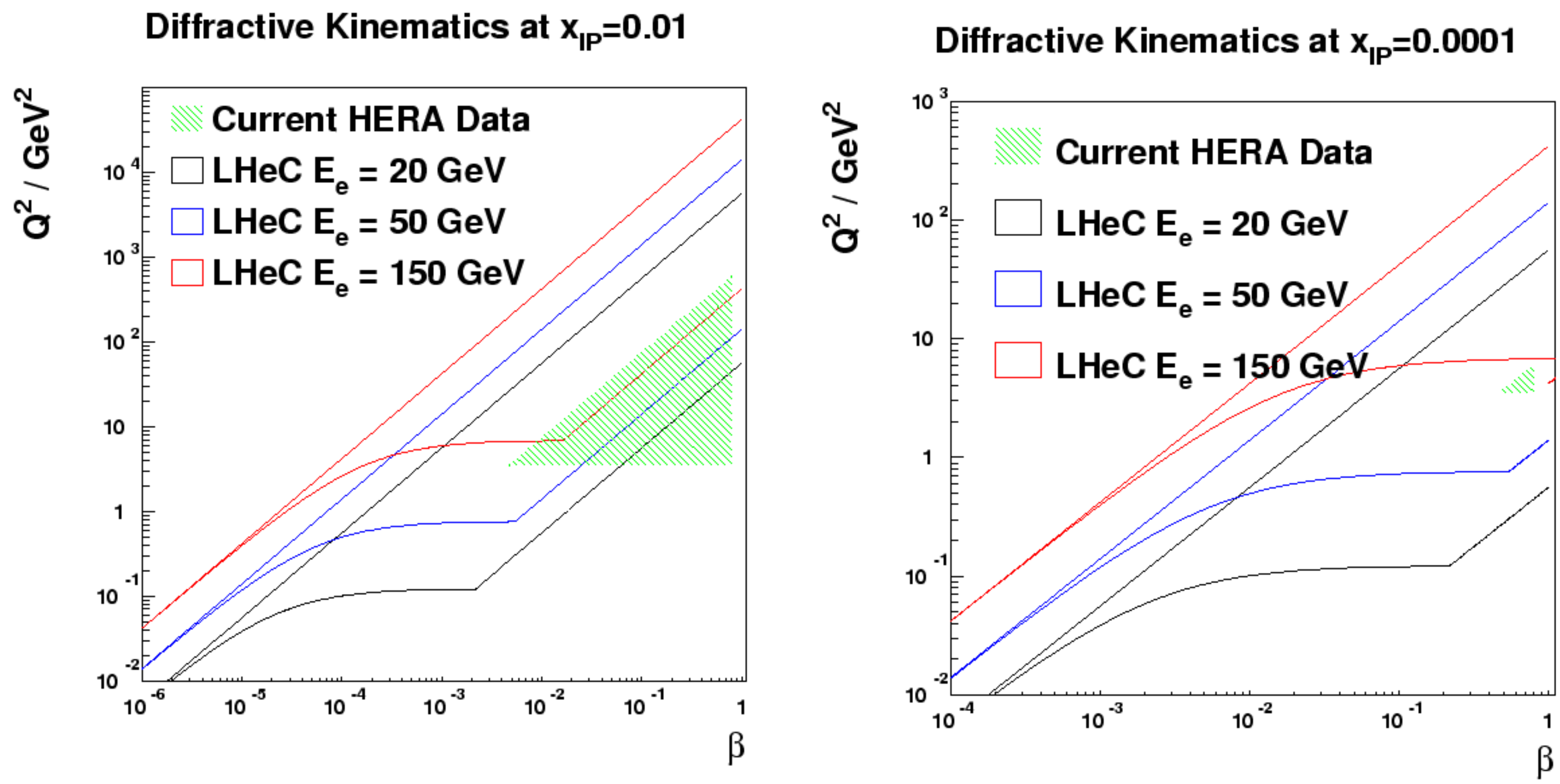
Diffractive DIS

$$\left.\frac{d\sigma^D_{T,L}}{dt}\right|_{t=0} = \frac{1}{16\pi}\int d^2\mathbf{r}\int_0^1 d\alpha\,|\Psi_{T,L}(\alpha,\mathbf{r})|^2\hat{\sigma}^2(x,r^2)$$

Extra factor of dipole cross section weights DDIS cross section towards larger dipole sizes → enhanced sensitivity to saturation effects.



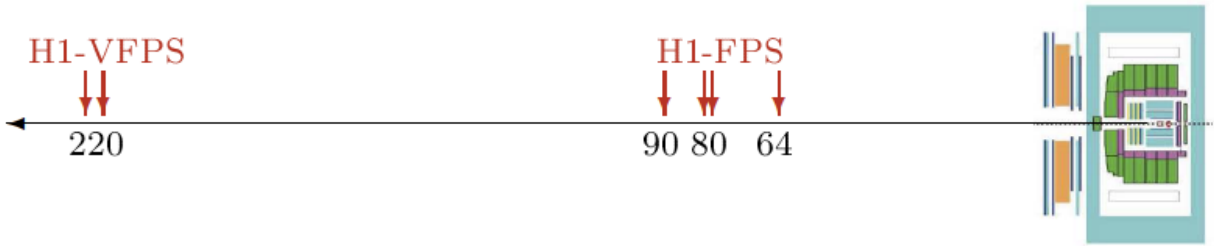
LHeC DDIS Kinematic Plane (1° Acceptance)



- Low x_{IP} → cleanly separate diffraction
- Low β → Novel low x effects … non-linear dynamics?
- High Q^2 → DPDFs: Lever-arm for gluon
  W, Z exchange for flavour separation

Signatures and Selection Methods at HERA

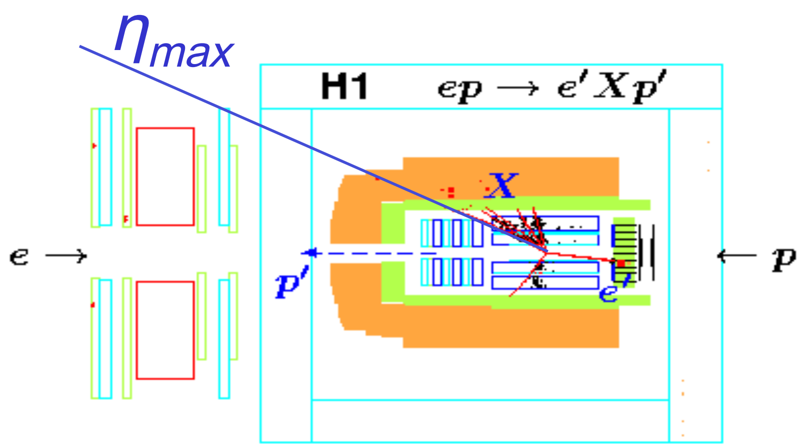
1) Measure scattered Proton in Roman Pots



- Allows t measurement, but limited by stats, p- tagging systs

2) Select Large Rapidity Gaps

-Limited by control over proton dissociation contribution



- Methods have very different systematics → complementary
- What is possible at LHeC?…

LHeC Forward and Diffractive Detectors

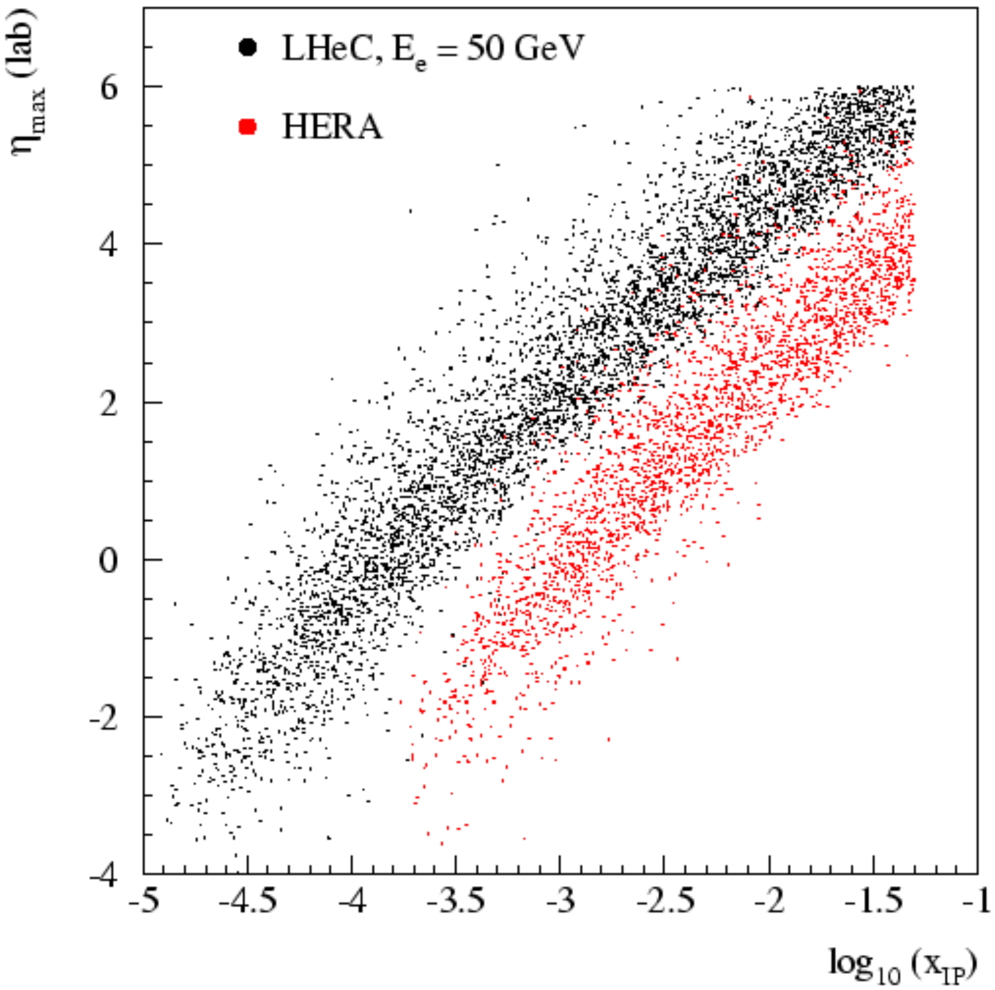
- Large rapidity gap method restricted to low x_{IP}

- Reaching x_{IP} = 0.01 requires η_{max} cut around 5 … corresponds to $\theta > 1^o$

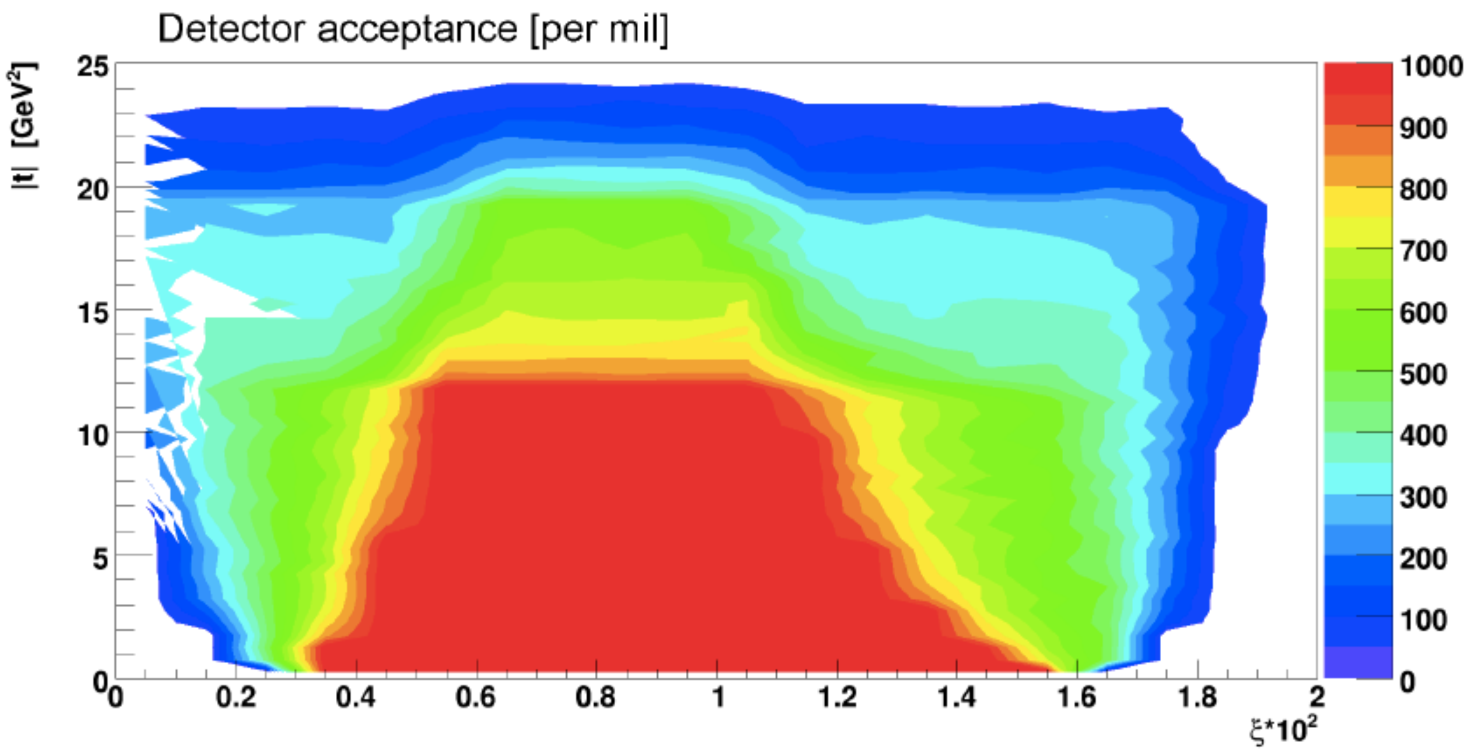
- For x_{IP} = 0.001 need η_{max} cut around 3 … similar to H1 … and still lots of data

- Misses interesting LHeC region at large M_x

η_{max} from LRG selection …



A High Acceptance Proton Spectrometer

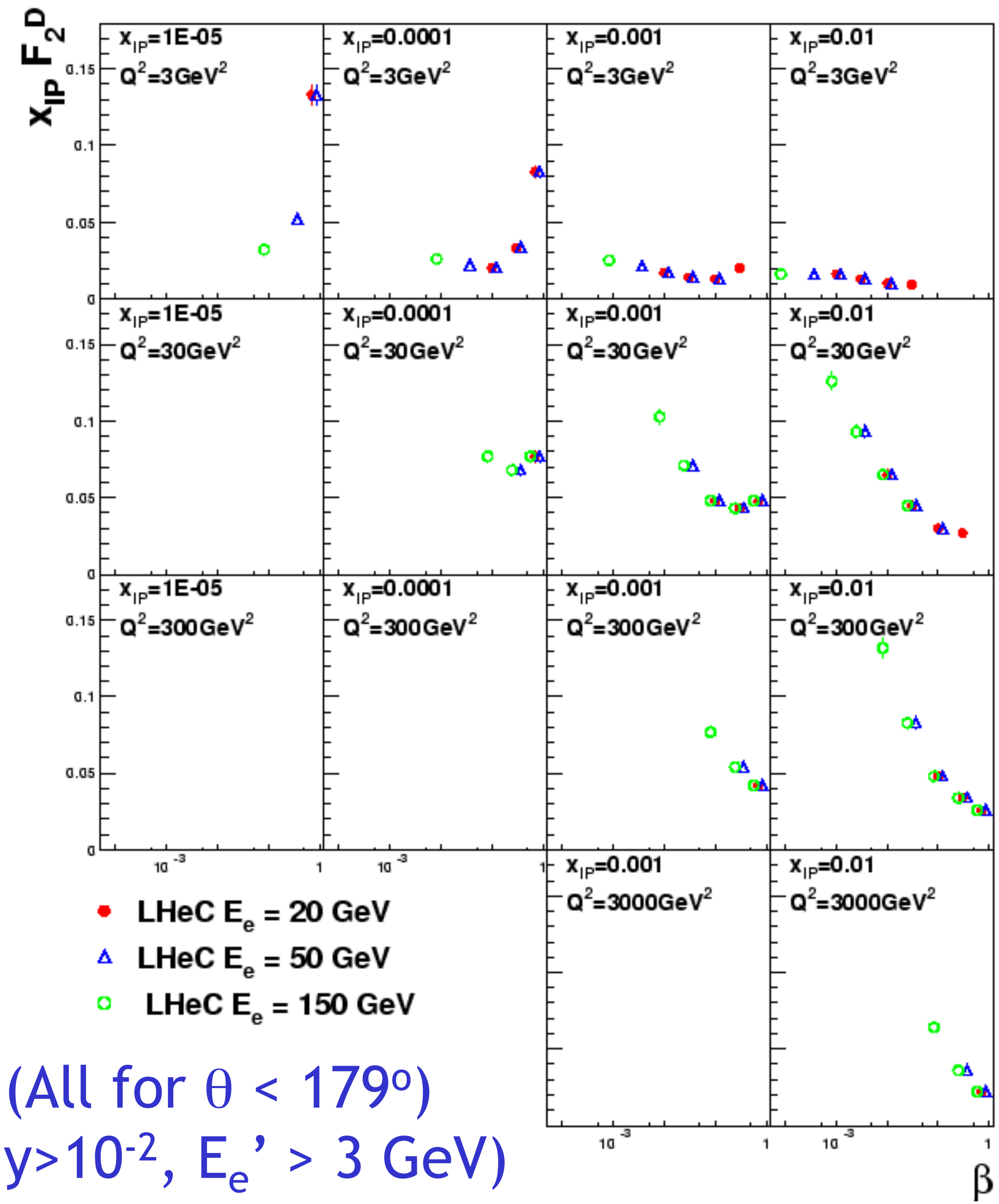


- Proton arm beam optics very similar to ATLAS / CMS

- \`FP420'-style proton spectrometer accesses elastic scattered protons with full acceptance over wide t range at x_{IP} ~ 0.01
→ complementary x_{IP} region to gap method

- Zero Degree Calorimeter for neutrons also included in design

Simulated Data

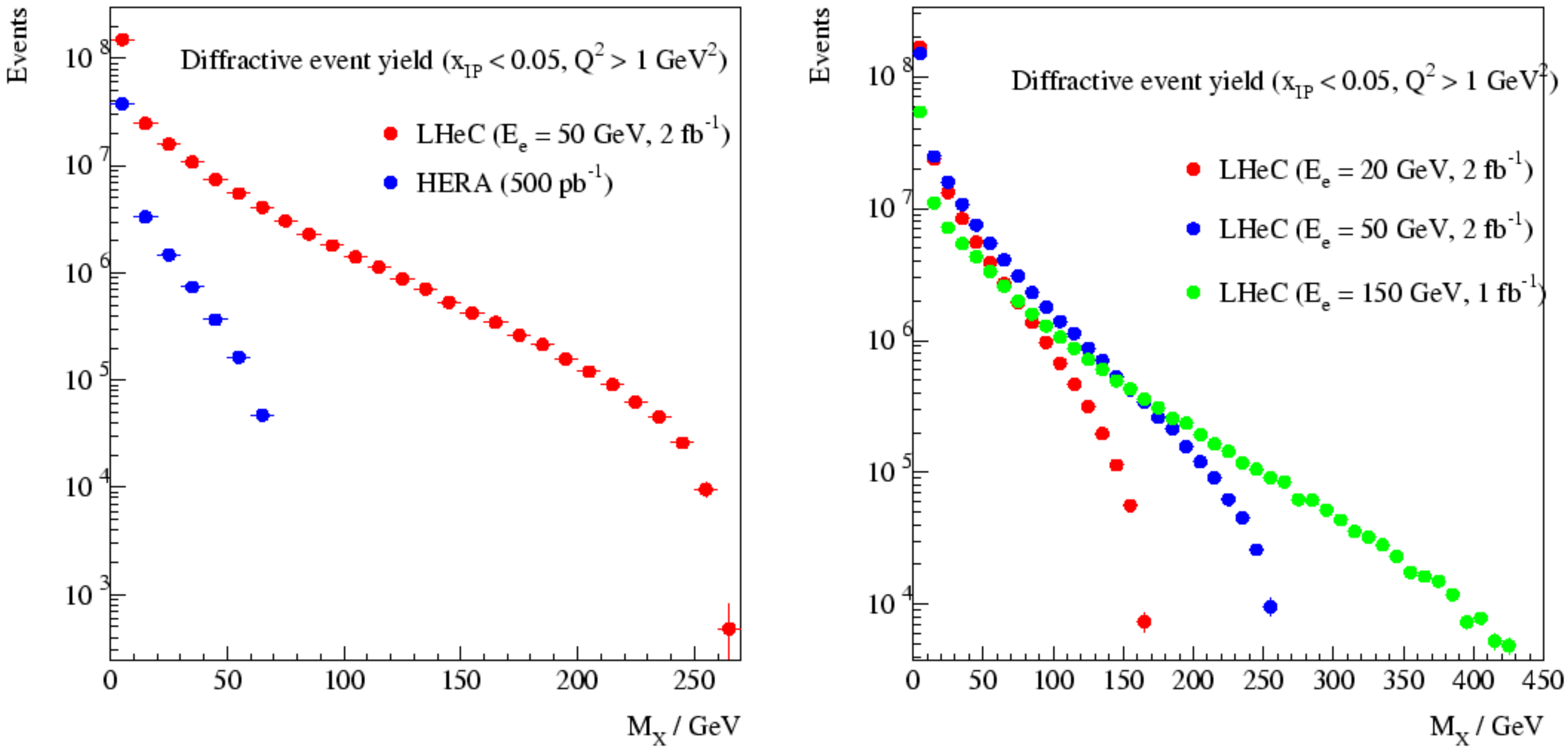


(All for θ < 179°)
$y>10^{-2}$, $E_e' > 3$ GeV)

- Simulated data combining rapidity gap & proton tagging methods
- Small subset of possible bins, emphasising β dependence in 4 wide x_{IP} , Q^2 bins
- Statistical precision not an issue … phase space runs out before data

New region of Diffractive Masses

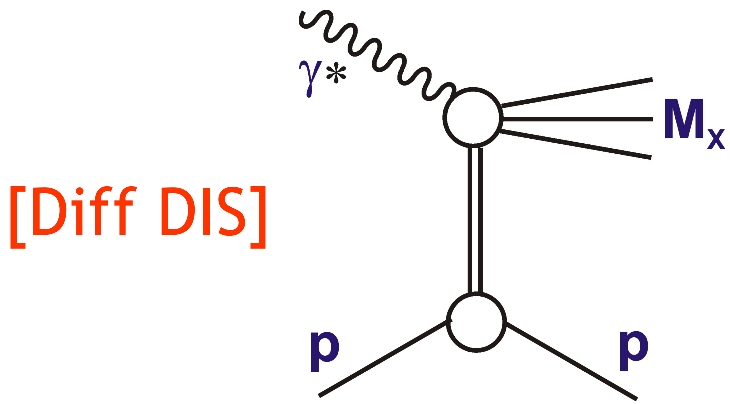
Large x_{IP} region highly correlated with large Mx

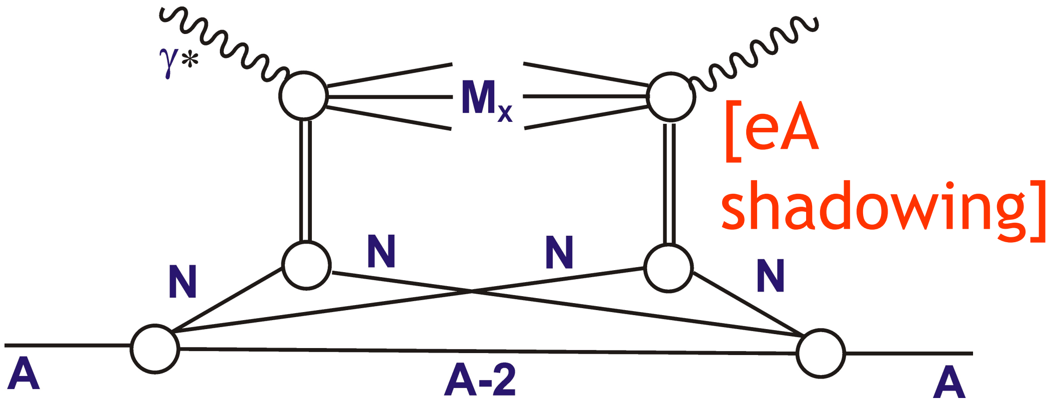


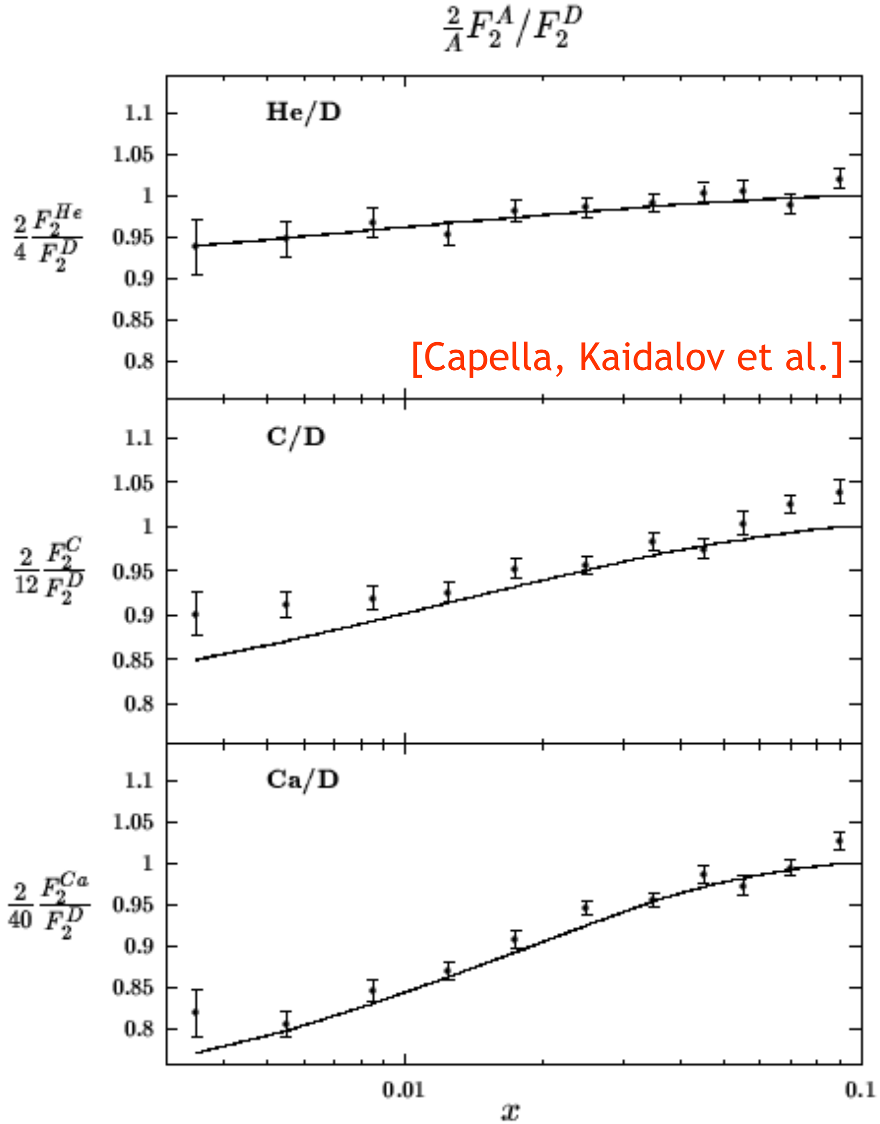
- \`Proper' QCD (e.g. large E_T) with jets and charm accessible
- New diffractive channels … beauty, W / Z bosons
- Unfold quantum numbers / precisely measure new 1^- states

Inclusive Diffraction and the ep / eA Interface

Nuclear shadowing can be described (Gribov-Glauber) as multiple interactions, starting from ep DPDFs







... starting point for extending precision LHeC studies into eA collisions

Summary

• Diffractive ep supplements inclusive data (Anna's talk) to discover / understand non-linear effects in perturbative regime

• Comparison with diffractive eA (Brian's talk) provides a further degree of freedom to unfold effects

• First simulations suggest J/Ψ photoproduction will be key

• Other inclusive and exclusive channels look highly promising

• Diffractive jets, charm, W / Z, light VMs still to be studied

Chapter 7 [Coming soon in LHeC CDR]

Physics at High Parton Densities

Back-Ups Follow

J/psi Statistical Precision

Take one bin for every 50 GeV in W

To crudely predict numbers of events per bin …

- Assume a similar measurement to HERA

- $Q^2 < 2$ GeV^2 … only see 2 muons in detector

- Simple $\gamma^{(*)}$p cross section parameterisation:

$$\sigma(\gamma p \rightarrow Vp) = \sigma_0 \,.\, W^{\delta} \,.\, e^{bt}$$

- Fix $\delta = 0.75$ (J/ψ) and 1.00 (Υ)
  $b = 4.5$ GeV^{-2}
  σ_0 by normalising to HERA data

- Convert to ep cross section with photon flux from Weizsaecker-Williams approximation

J/psi Corrections and Systematics

Require geometric acceptance above 30%

Assume selection efficiency = 50% (20-40% at HERA)

Correct for branching ratios to $\mu\mu$ (ee results would be similar, possibly except for detector acceptance)

Systematics not yet included (depend heavily on detector), but some hints from HERA:

- → Total syst ~ 10% (fairly correlated between bins)
- → Trigger efficiency ~ 5%
- → Selection efficiency ~ 5%
- → Proton dissociation corrections ~ 5%
- → Model dependences on geometric acceptance ~5%
- → Lumi ~ 2%
- → Branching ratio ~ 2%

Leading Neutron Ideas (Buyatyan, Lytkin)

- Size & location determined by available space in tunnel and beam-line appertures
- Requires a straight section at θ~0^o after beam is bent away.
- H1 version → 70x70x200cm Pb-scintillator (SPACAL) @ 100m →θ<0.8mrad (p_t <~ 500 MeV)

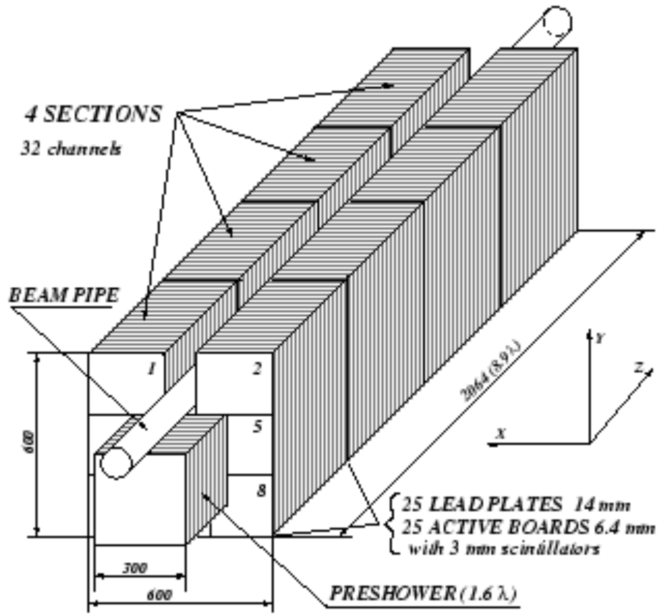


Figure 5: General view of the H1-FNC calorimeter

- LHeC: aim for similar θ range?... more would be nice!
- Need ~ 10λ to contain 95% of 7 TeV shower
- 2λ high granularity pre-sampler to reject EM showers from photon background and get impact point
- Main calorimeter coarser with 4-5 longitudinal segments?
- Achievable resolution could be σ/E ~ 60%/sqrt(E)

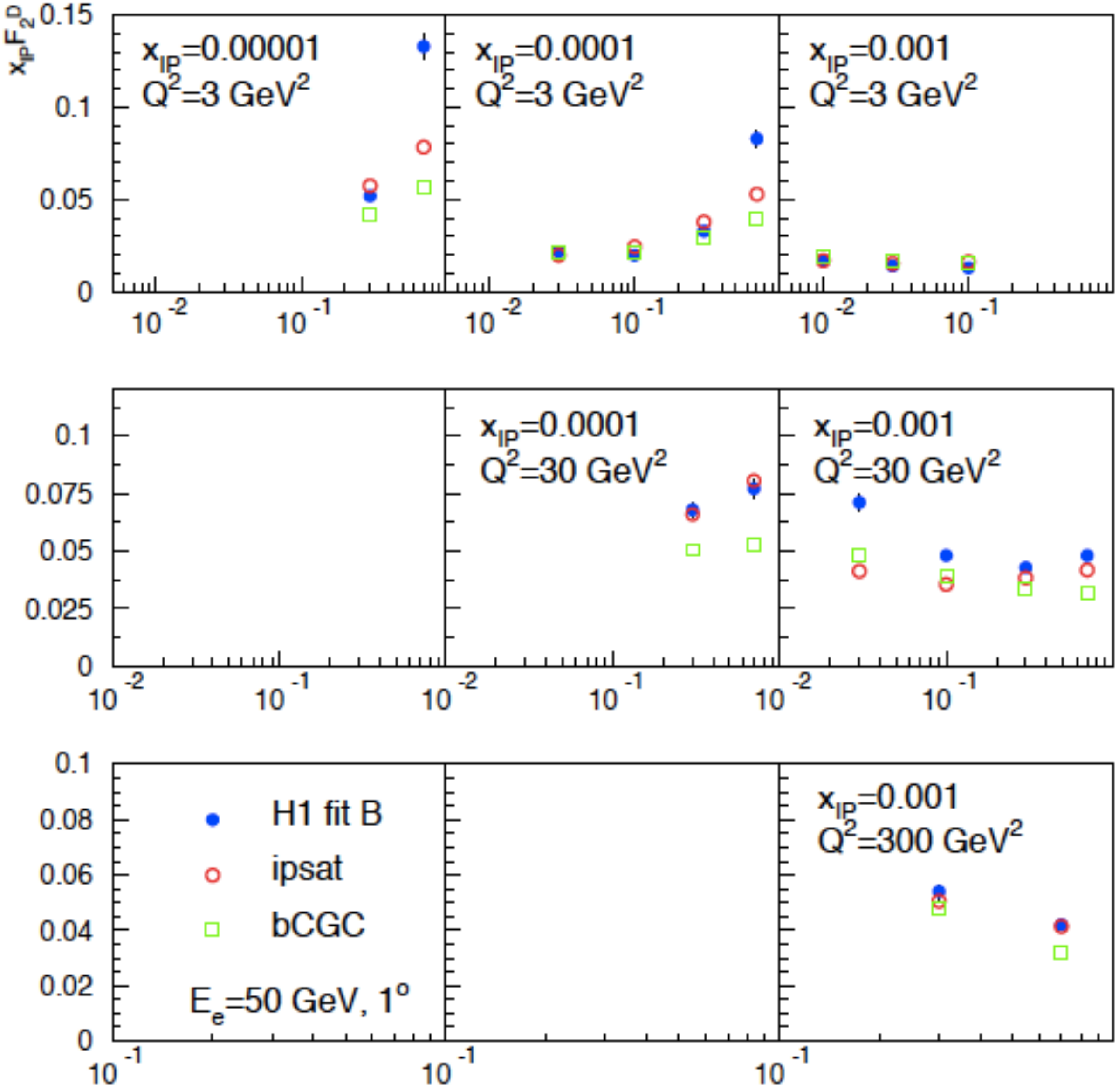
Beam Scenarios for First Physics Studies

Many scenarios under study … two discussed here …

config.	E(e)	E(N)	N	$\int L(e^+)$	$\int L(e^-)$	|Pol|	$L/10^{32}$	P/MW	years	type
A	20	7	p	1	1	-	1	10	1	SPL
B	50	7	p	50	50	0.4	25	30	2	RR hiQ^2
C	50	7	p	1	1	0.4	1	30	1	RR lo x
D	100	7	p	5	10	0.9	2.5	40	2	LR
E	150	7	p	3	6	0.9	1.8	40	2	LR
F	50	3.5	D	1	1	--	0.5	30	1	eD
G	50	2.7	Pb	0.1	0.1	0.4	0.1	30	1	ePb
H	50	1	p	--	1	--	25	30	1	lowEp

ep Studies based on a 20-150 GeV electron beam and lumi of 1-10 fb^{-1} / year

Distinguishing Between Models



Dipole model
Precdictions
Give varying
Results in some
regions