Diffraction at the LHeC and the EIC

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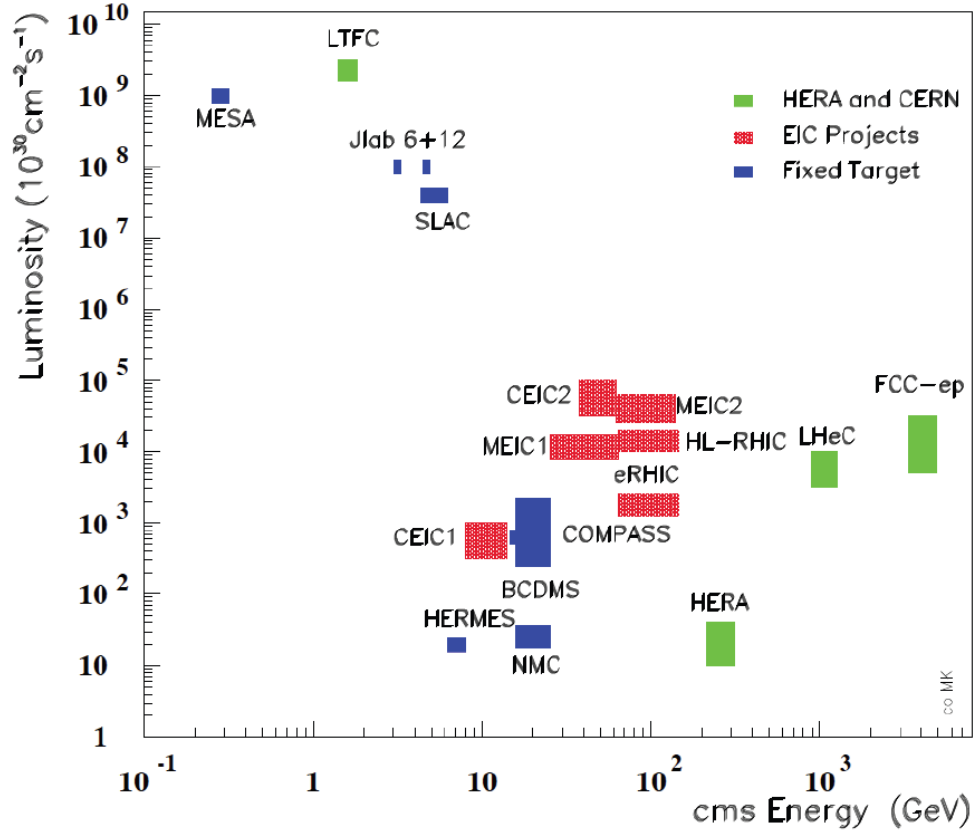


DIS 2017
Birmingham, UK
6 April 2017

… with thanks to Rik Yoshida and Thomas Ullrich

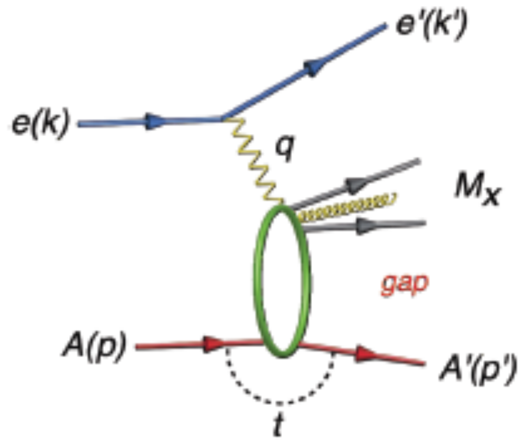
- Motivation
- Diffractive signatures
- EIC
- LHeC
- FCC-eh

Diffactive Physics Motivation (from planned EIC National Academy Talk, April 2017)

Diffraction for the 21st Century

Diffraction is the most precise probe of non-linear dynamics in QCD

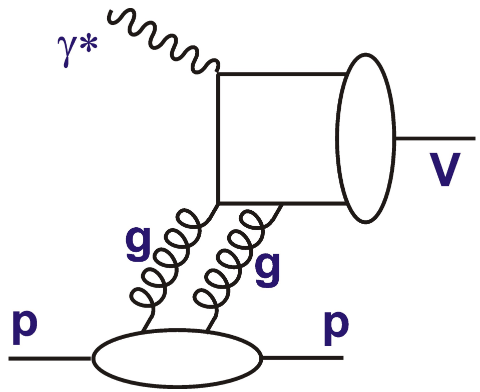
- Diffraction in QCD is far more powerful than in optics or low energy electron scattering. In QCD at high energies, the virtual photon probe itself is a complex superposition of quark,antiquark and gluon states that interact with differing strengths off strong color fields in the target.
- Fluctuations in the composition of the probe enable unprecedented spatial maps of color fluctuations in the target.
- At an EIC, diffractive measurements of hadron final states (with invariant masses $M_X \gg \Lambda_{QCD}$, the QCD scale) provide unique tools to probe the structure of the QCD vacuum over varying length scales.



An inelastic (large M_X) diffractive event: Illustrates color neutral exchange between the virtual photon and the hadron with no activity between scattered hadron and M_X

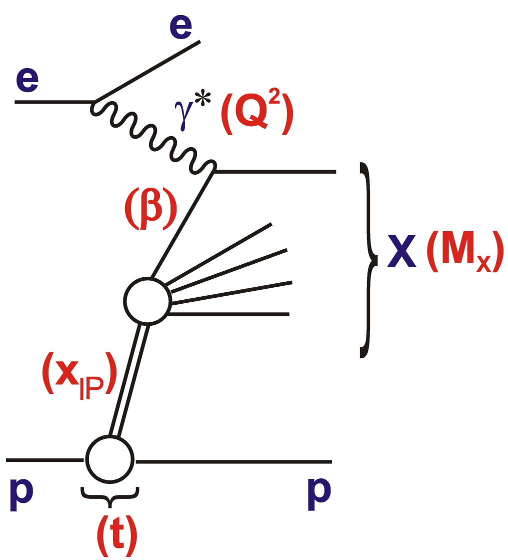
Exclusive / Diffractive Channels and Saturation

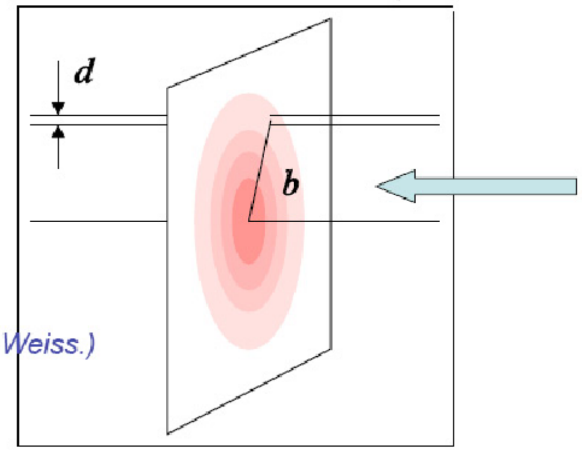
1) [Low-Nussinov] interpretation as 2 gluon exchange enhances sensitivity to low x gluon



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

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



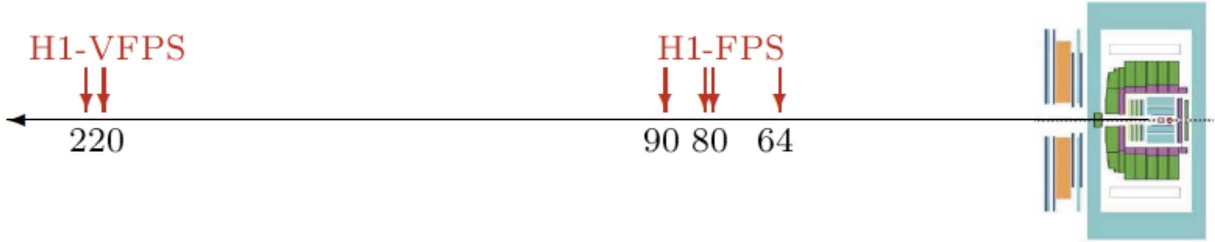


(figure from C. Weiss.)

Central black region growing with decrease of x.

LHeC Intact Proton Selection Methods follow HERA

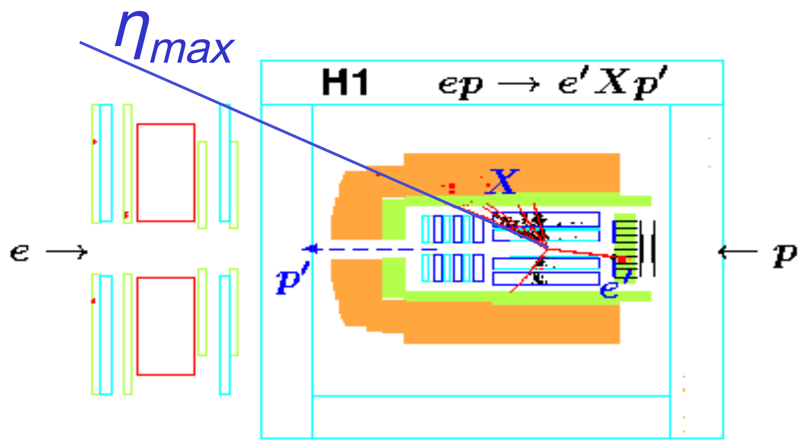
1) Measure scattered Proton in Roman Pots



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

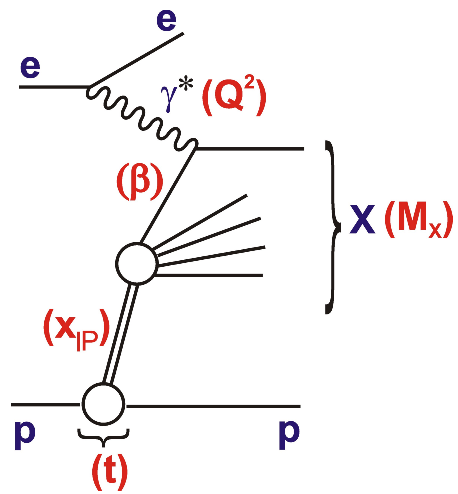
2) Select Large Rapidity Gaps

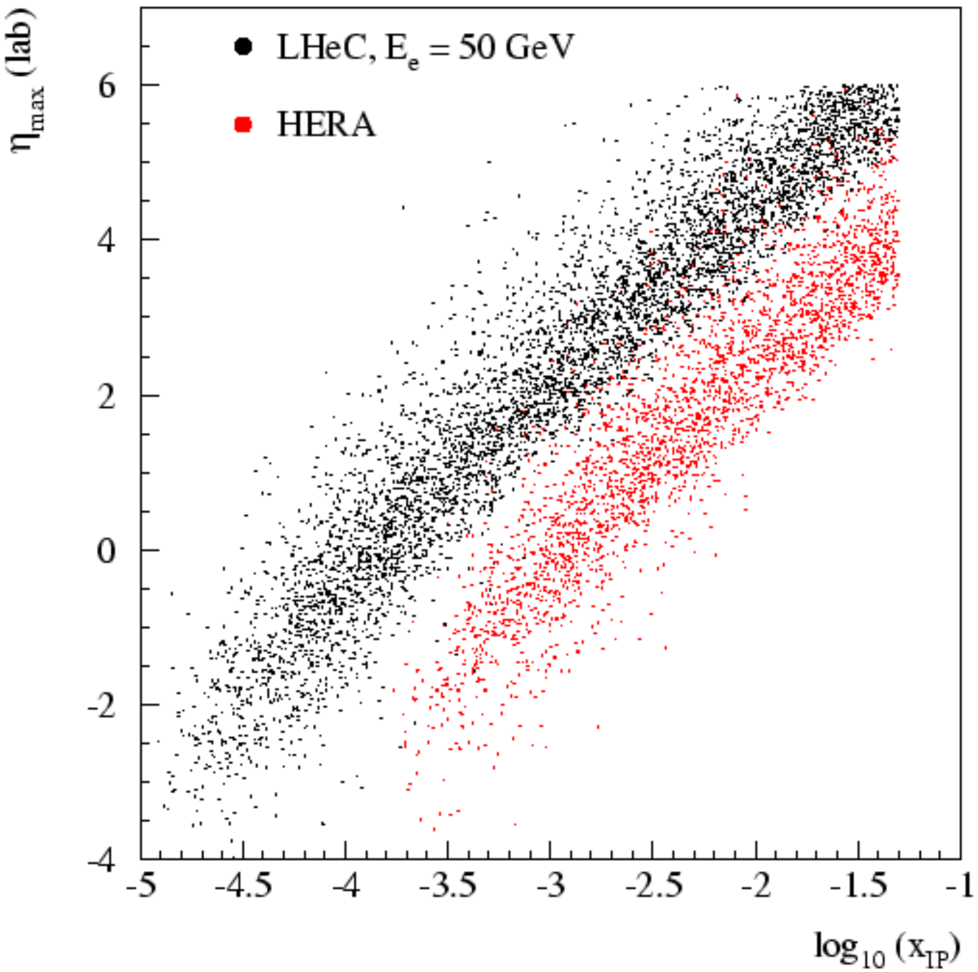
-Limited by control over proton dissociation contribution



- Methods have very different systematics → complementary
- In practice, method 2 yielded lasting results, because of statistical and kinematic range limitations of Roman pots
- Roman pots mainly contrained t distributions
- Different at LHeC & EIC → higher lumi + pot design from outset

Rapidity Gap Selection

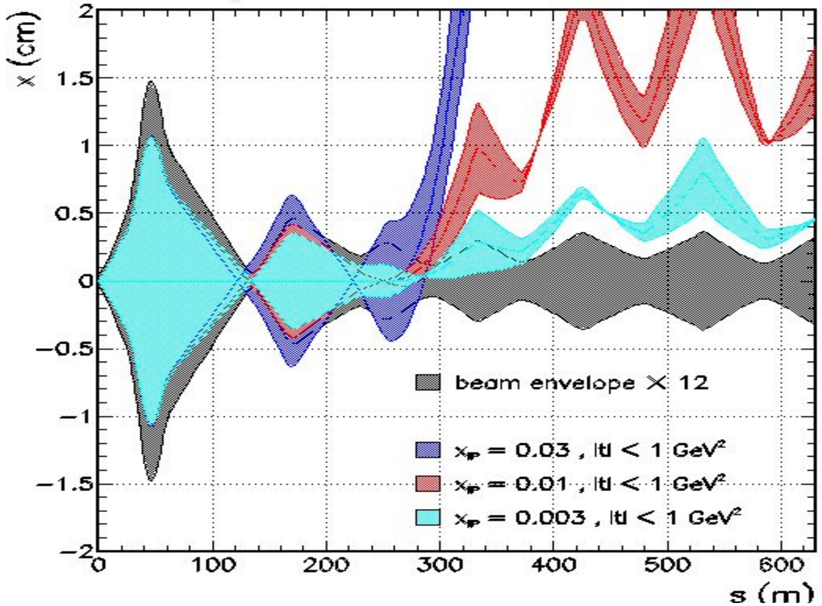




– η_{max} v ξ correlation entirely determined by proton beam energy

- Cut around $\eta_{max} \sim 3$ selects events with x_{IP} <~ 10^{-3} at LHeC (cf x_{IP} <~ 10^{-2} at HERA

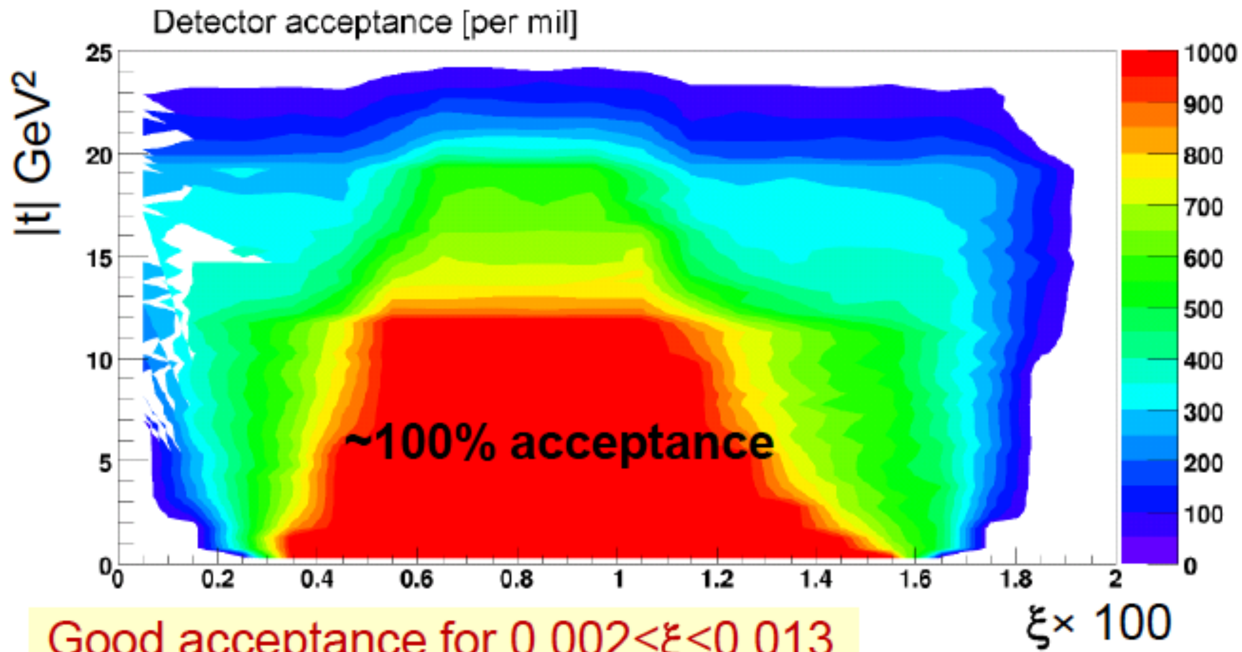
Forward Proton Spectrometer



- Proton spectrometer uses outcomes of FP420 project (proposal for low ξ Roman pots at ATLAS / CMS – not yet adopted)
-
- Approaching beam to 12σ (~250 μm) tags elastically scattered protons with high acceptance over a wide x_{IP}, t range

Complementary acceptance to Large Rapidity Gap method

Together cover full range of interest with some redundancy



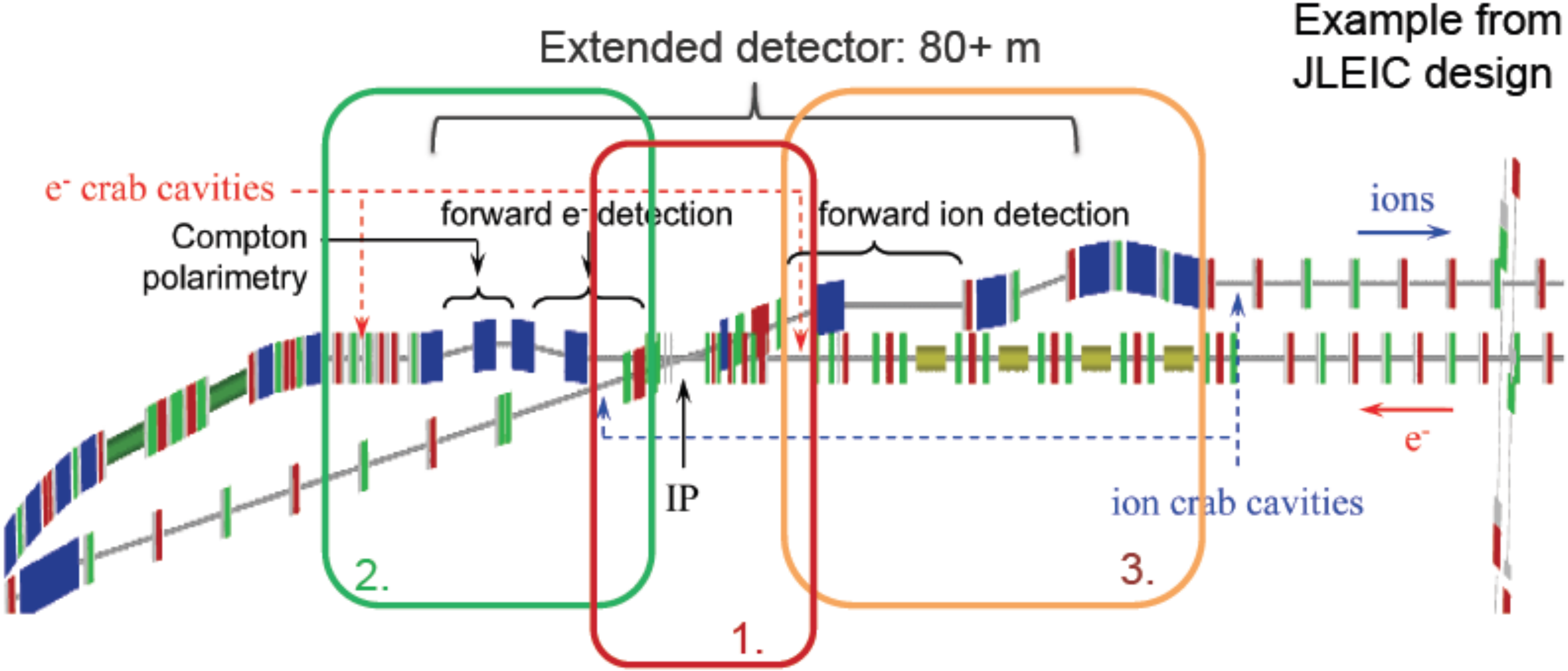
Good acceptance for 0.002<ξ<0.013

EIC Forward Proton Spectrometer

- Beamline instrumentation intrinsic to design from outset
- Many possible access points:

4m , 18m, 38m at eRHIC
12m – 45m at JLEIC

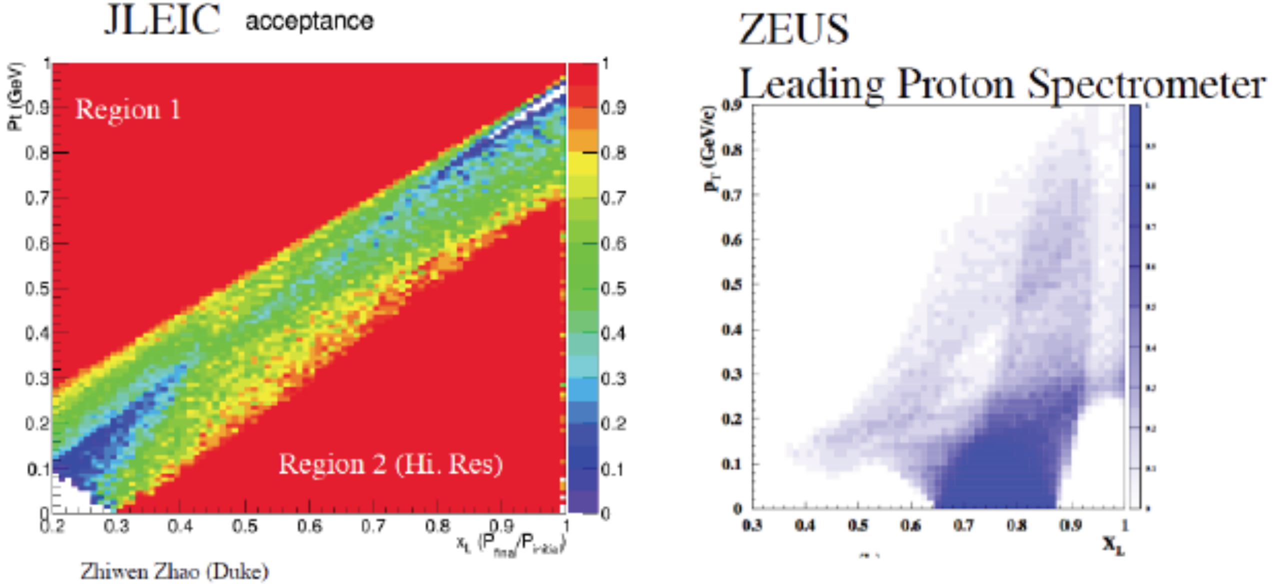
Example from JLEIC design



EIC Forward Proton Spectrometer

Full Acceptance for Forward Physics!

Example: acceptance for p’ in e + p → e’ + p’ + X

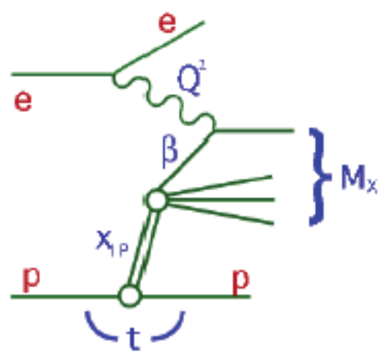


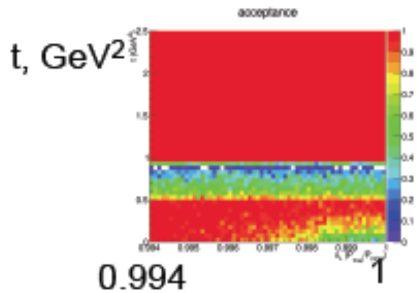
Acceptance in diffractive peak (X_L>~.98)

ZEUS: ~2%

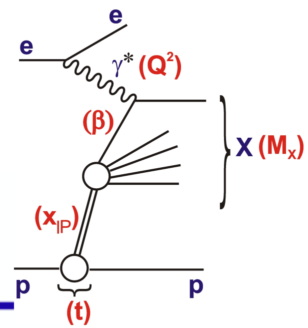
JLEIC: ~100% (also covers much higher X_L than ZEUS)

Diffraction

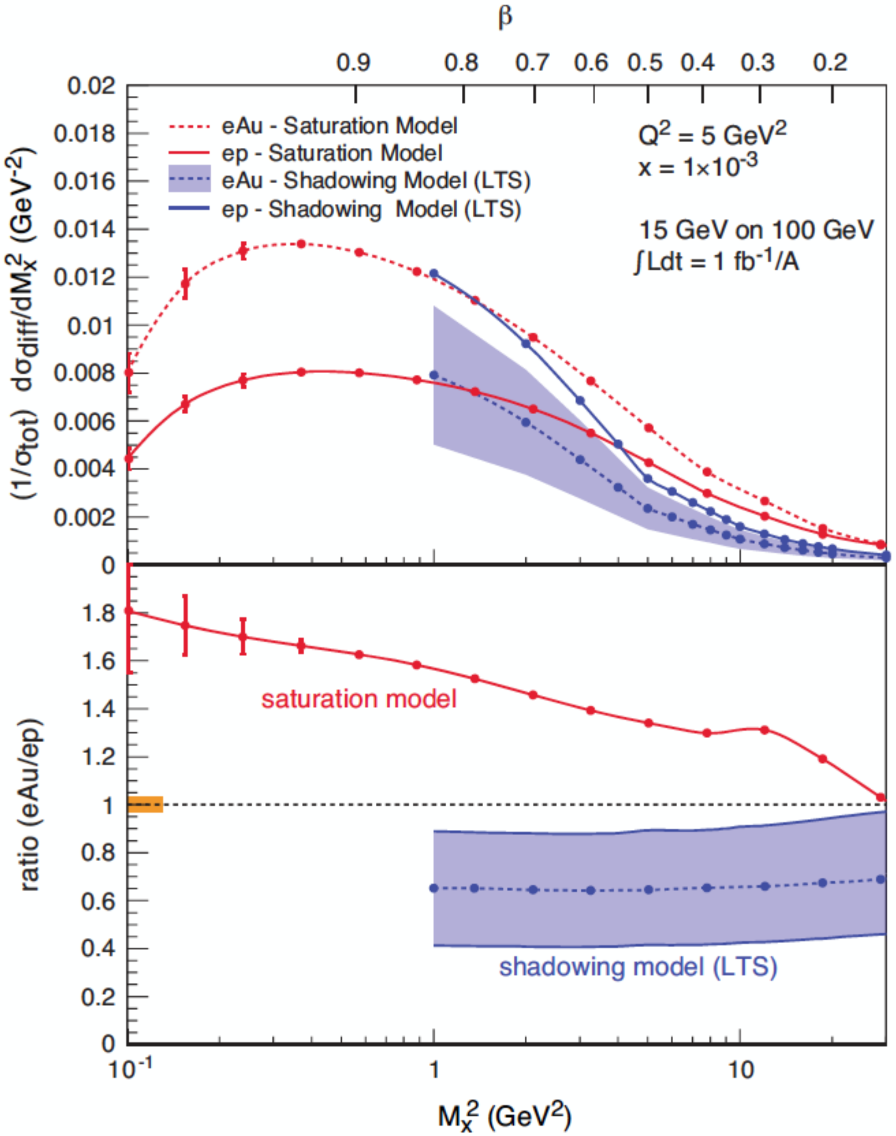




These detectors came of age at LHC: we should be ambitious



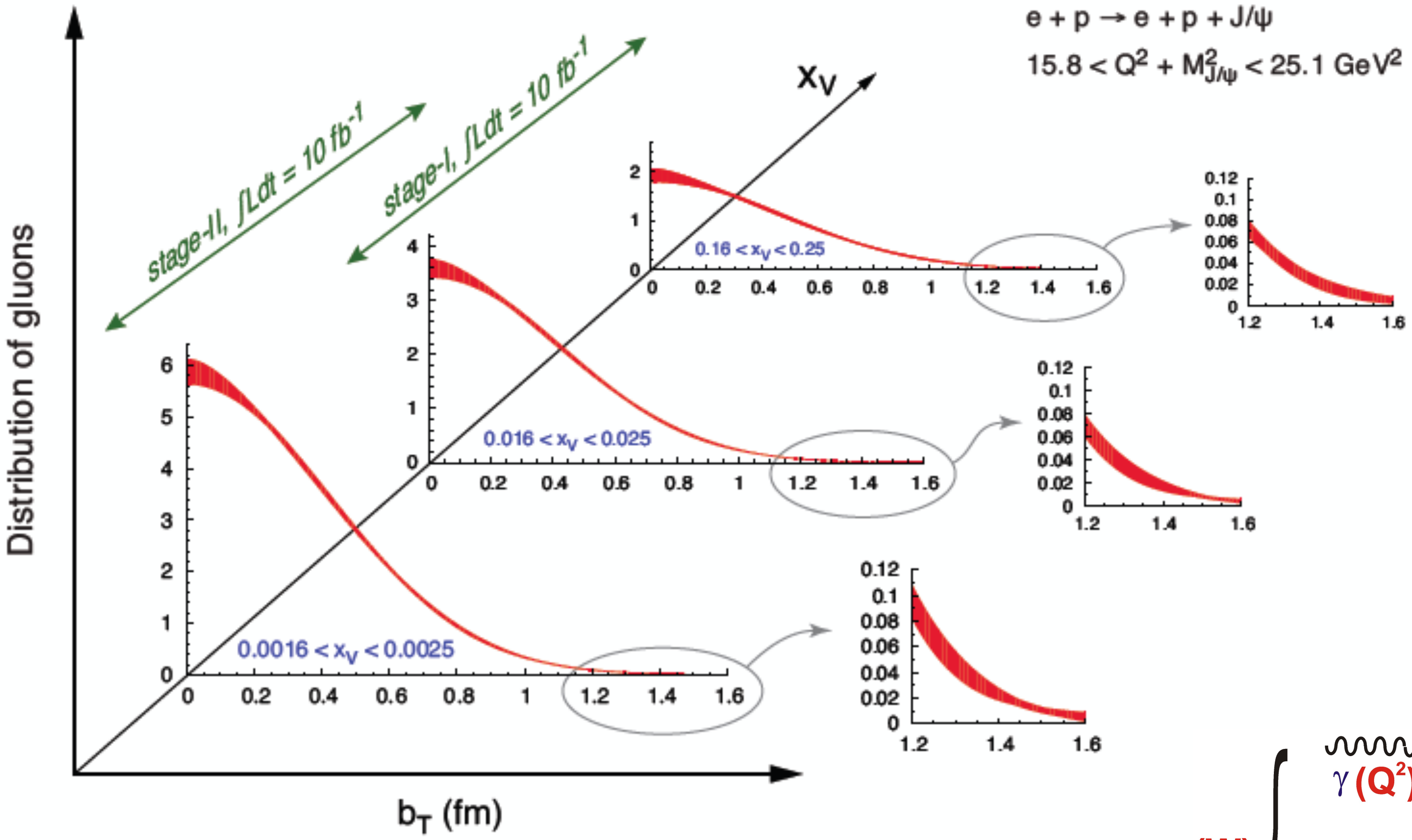
Day 1 Measurement: $\sigma_{diffractive}/\sigma_{total}$

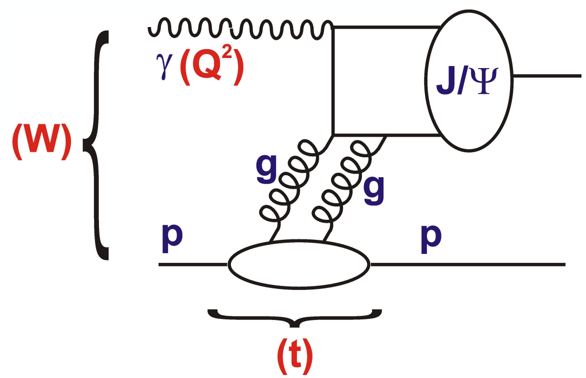


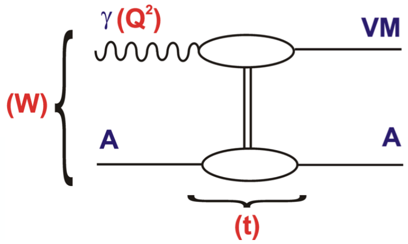
- HERA observed: ~14% of all events are diffractive
- Saturation models (CGC) predict up to $\sigma_{diff}/\sigma_{tot}$ ~ 25% in eA
- Ratio *enhanced* for small M_X and *suppressed* for large M_X
- Standard QCD predicts no M_X dependence and a moderate suppression due to shadowing.

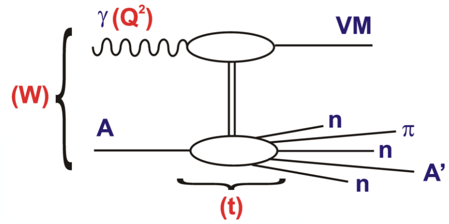
Unambiguous signature for reaching the saturation limit

Spin-dependent 2+1D coordinate space images from diffractive J/ψ production in ep



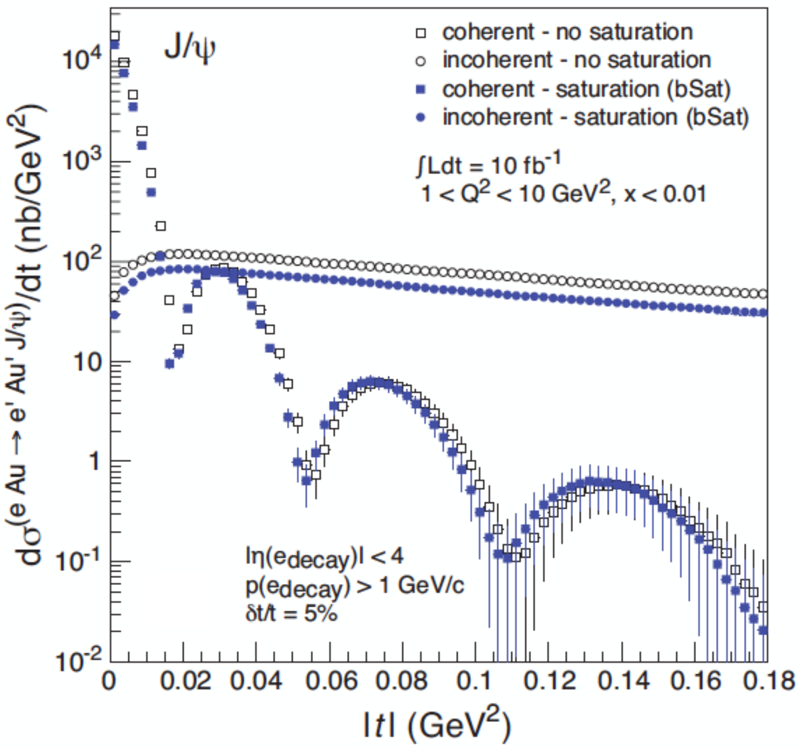






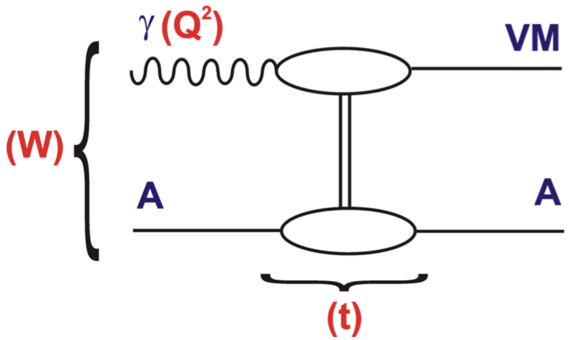
Imaging of Nuclei

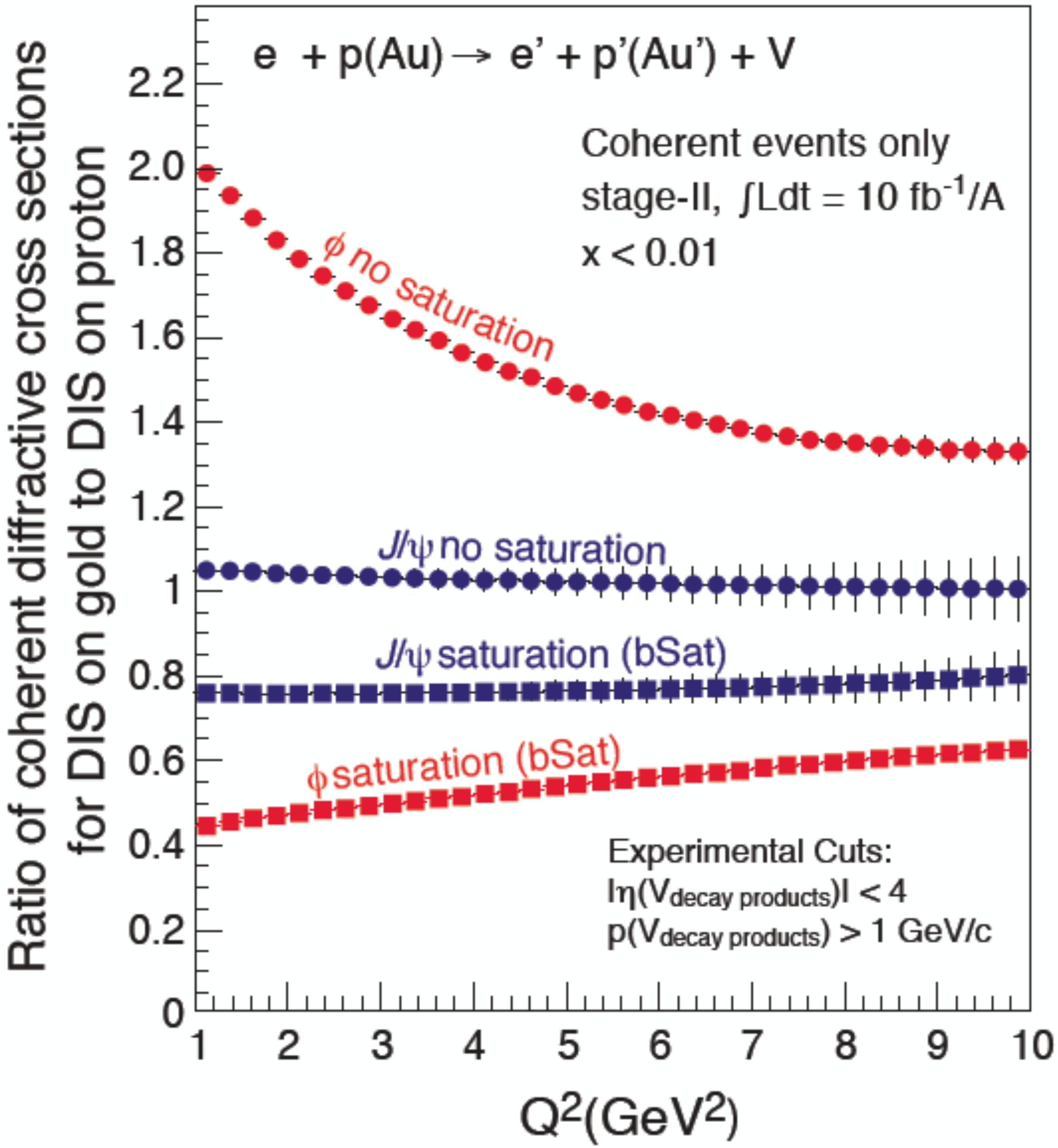
- 1950-60: Measurement of charge (proton) distribution in nuclei
- Ongoing: Measurement of neutron distribution in nuclei
- EIC: Measurement of spatial gluon distribution in nuclei via $d\sigma/dt$ where $t = (\mathbf{p}_{out}-\mathbf{p}_{in})^2$ of nucleus (t conjugate to b_T)



- Other than in ep in eA, measuring the scattered A' is impossible for heavy nuclei (stays in beam pipe)
- Exclusive vector meson production and DVCS are the *only* processes where ***t*** can be extracted: $e+A \rightarrow e'+A'+VM$
- J/ψ is key since it is the least affected by saturation effects and reflects the source best

Probing Q^2 dependence of gluon saturation in diffractive ρ and φ meson production

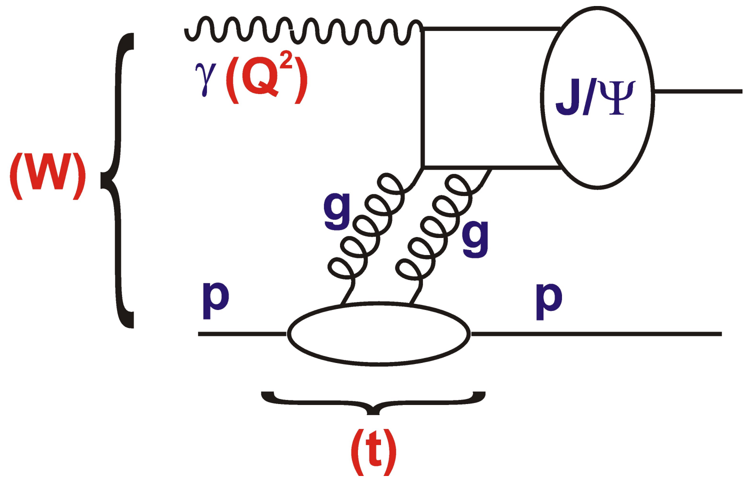




Test Case: Elastic J/Ψ Photoproduction

- `Cleanly' interpreted as hard 2g exchange coupling to qqbar dipole (see HERA/LHC UPC data via MNRT etc)

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



- Clean experimental signature (just 2 leptons)

... LHeC reach extends to: $x_g \sim (Q^2 + M_V^2) / (Q^2 + W^2) \sim 5.10^{-6}$

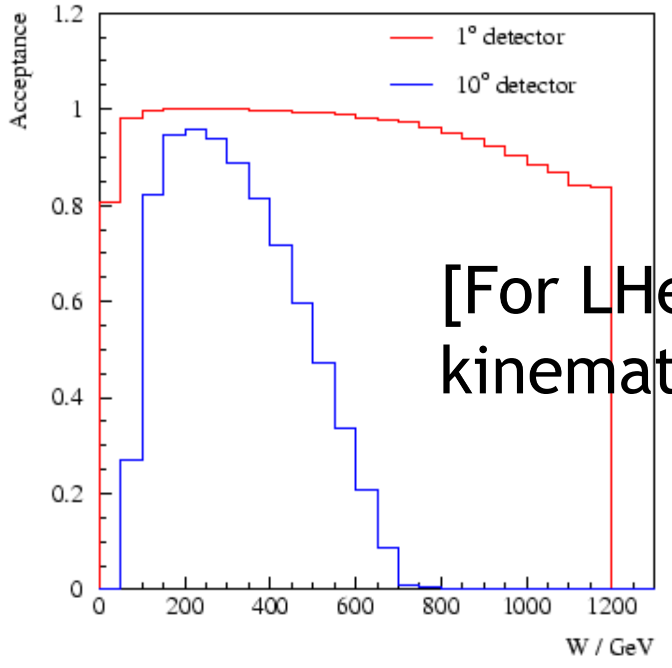
$\overline{Q^2} = (Q^2 + M_V^2) / 4 \sim 3$ GeV^2

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

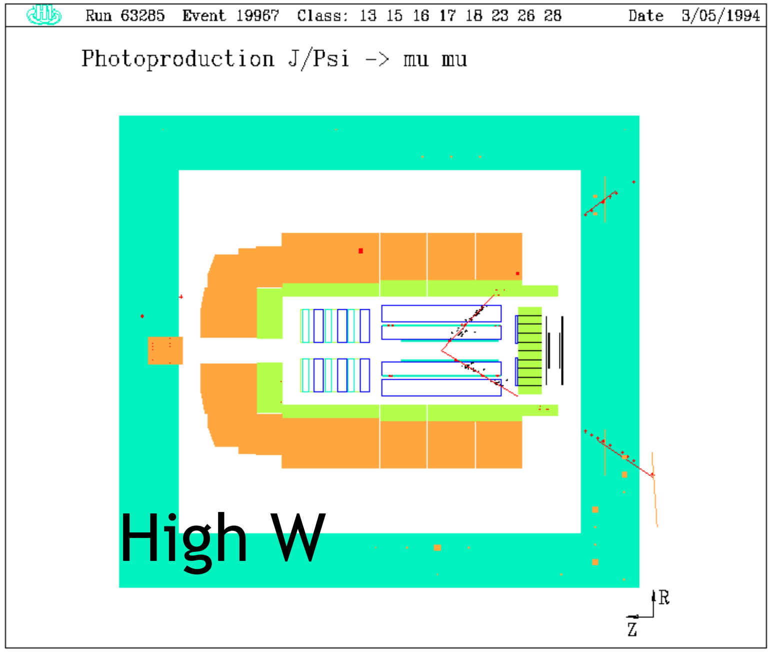
J/Ψ Kinematics

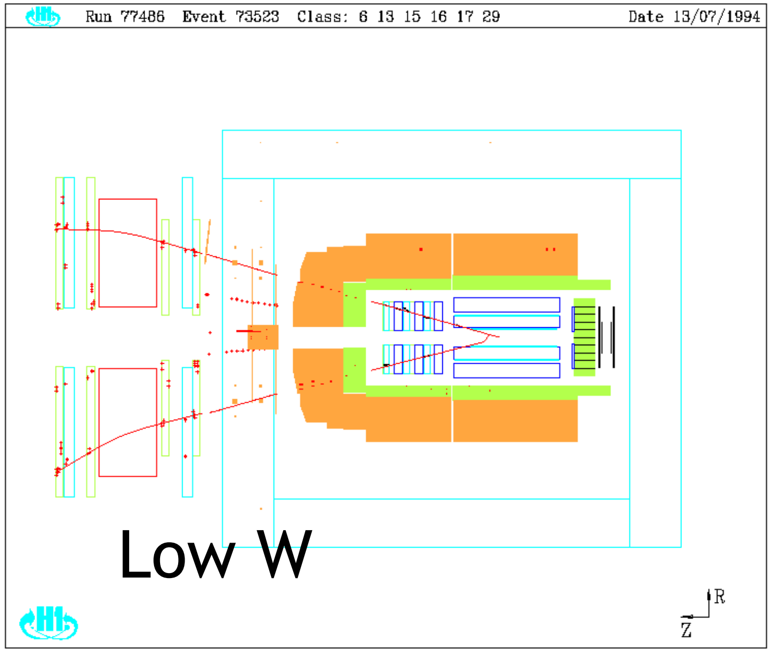
- At fixed $\sqrt{s}$, decay muon direction is determined by $W = \sqrt{s_{\gamma p}}$

- To access highest W, acceptance in outgoing electron beam direction crucial



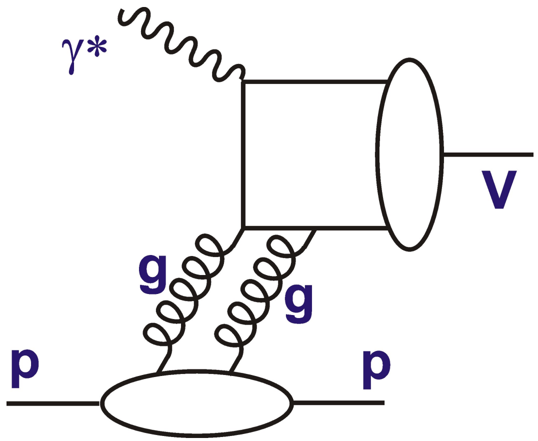
[For LHeC kinematics]

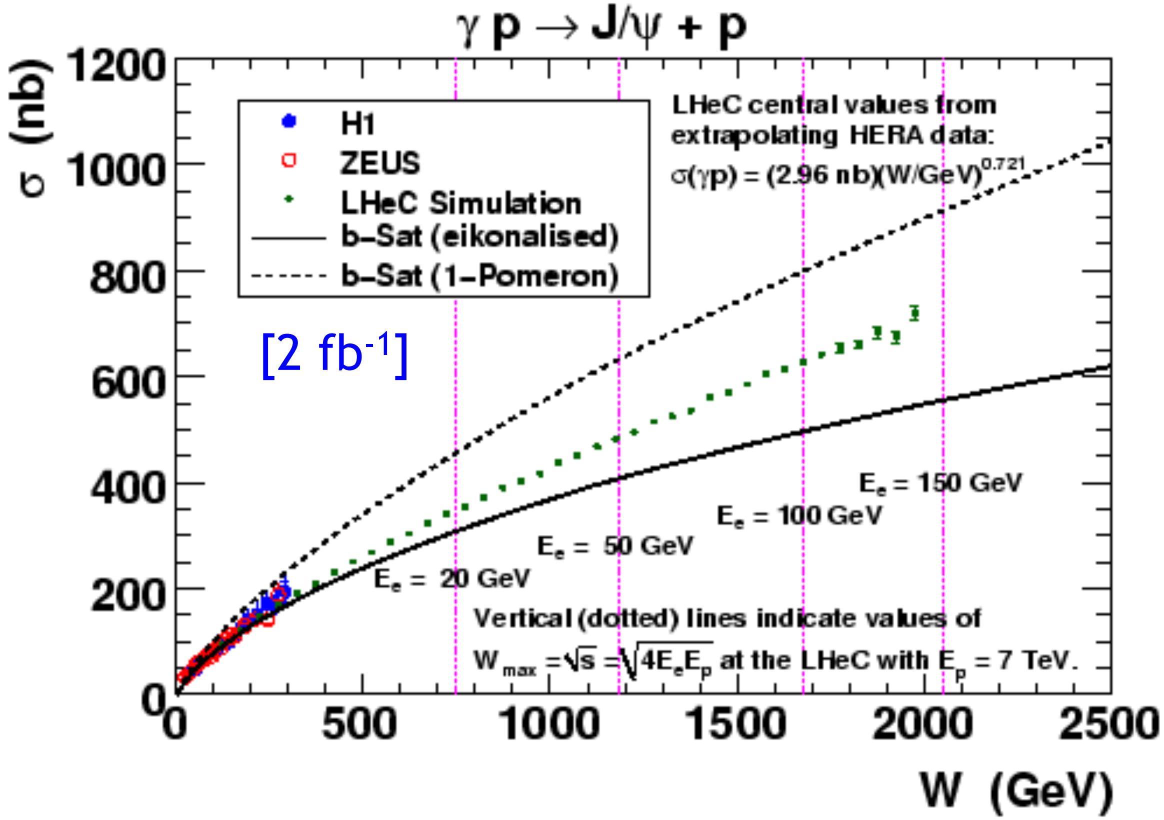




Comparison with Dipole model Predictions

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

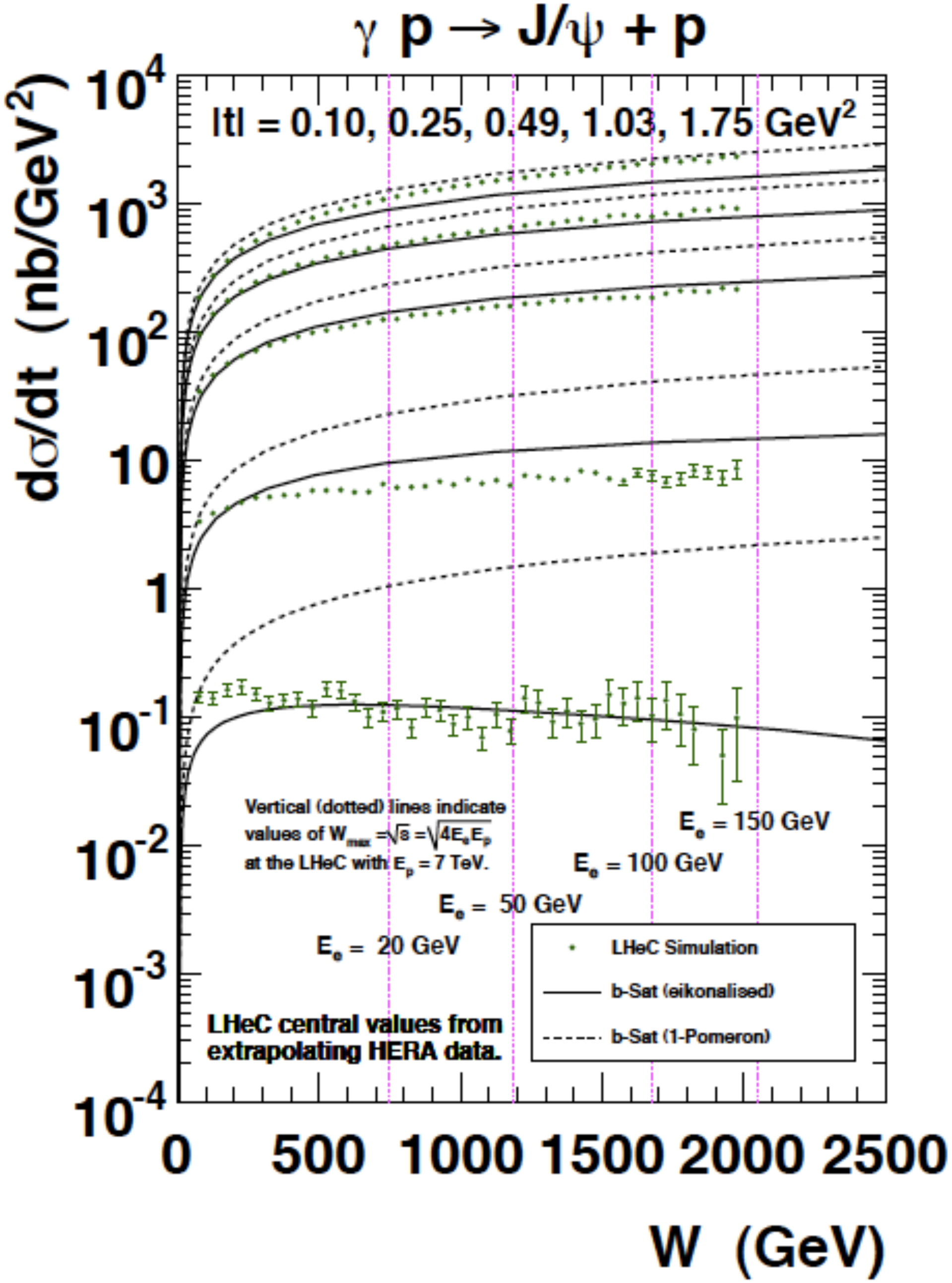




- Significant non-linear effects expected in LHeC kinematic range.

With detailed exploration of ep and eA, including t dependences, this becomes a powerful probe!...

t Dependence of Elastic J/ψ Photoproduction



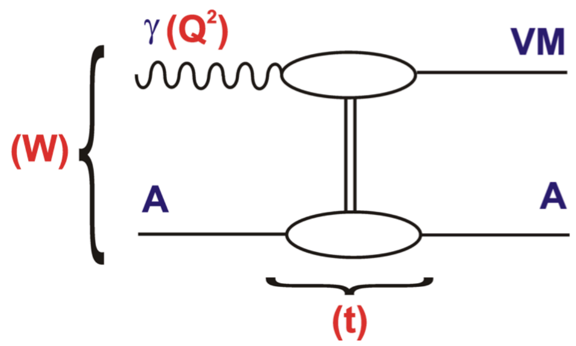
- J/ψ photoproduction double differentially in W and t …

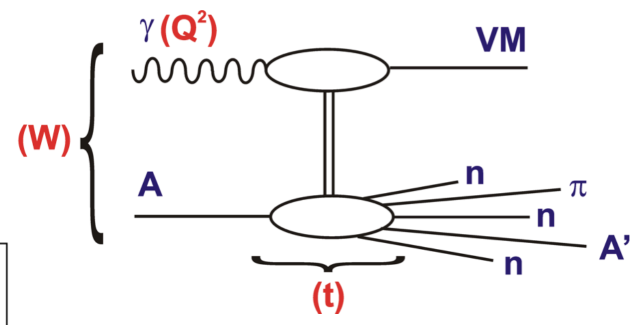
- Precise t measurement from decay μ tracks over wide W range extends to |t| ~ 2 GeV² and enhances sensitivity to saturation effects

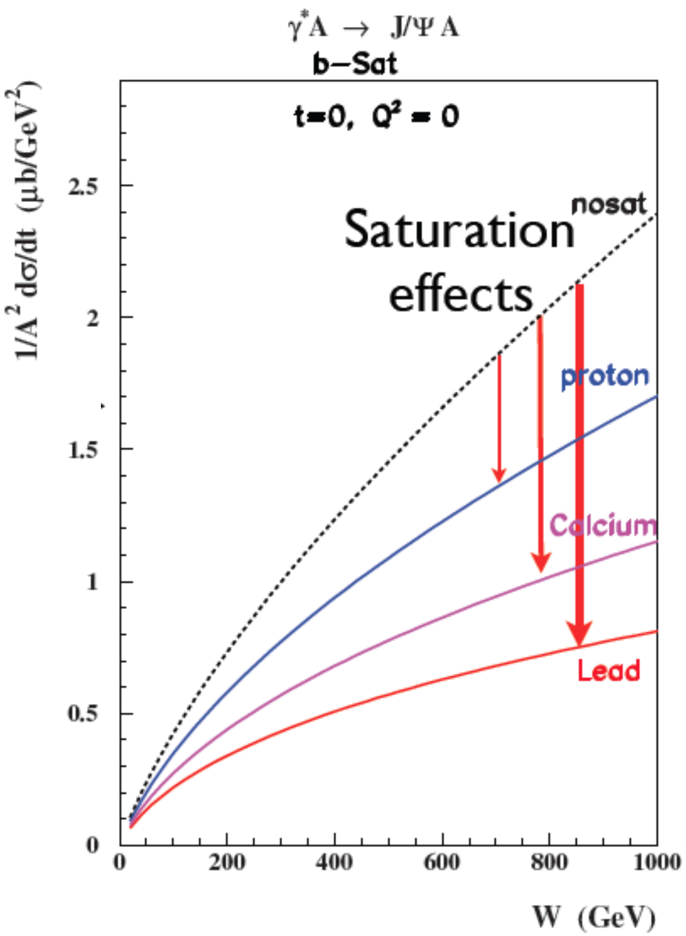
- Measurements also possible in multiple Q^2 bins

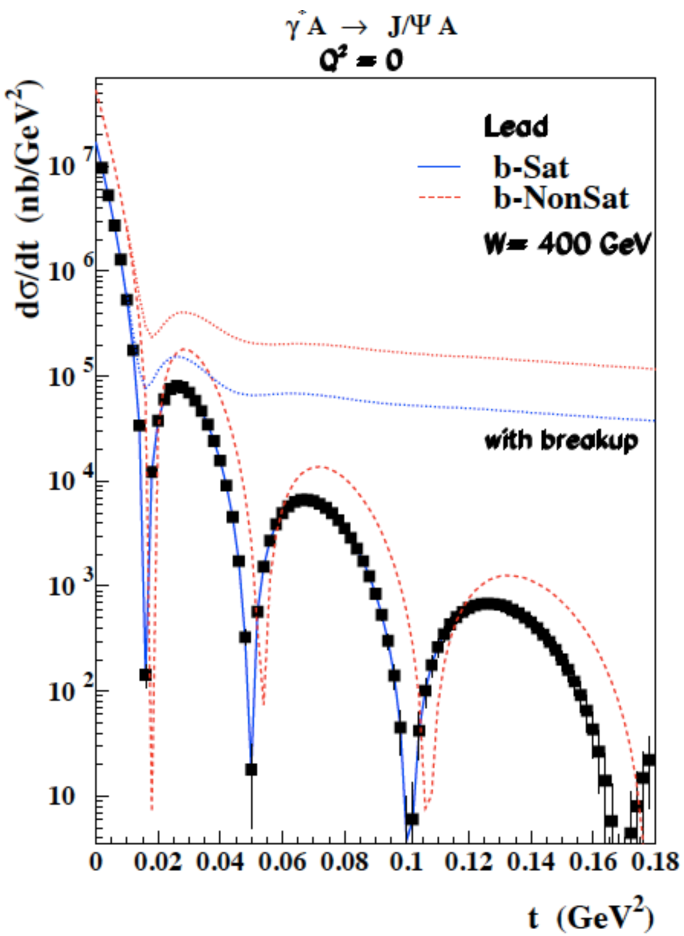
Exclusive Diffraction in eA

Experimentally clear signatures and theoretically cleanly calculable saturation effects in coherent diffraction case (eA → eVA)



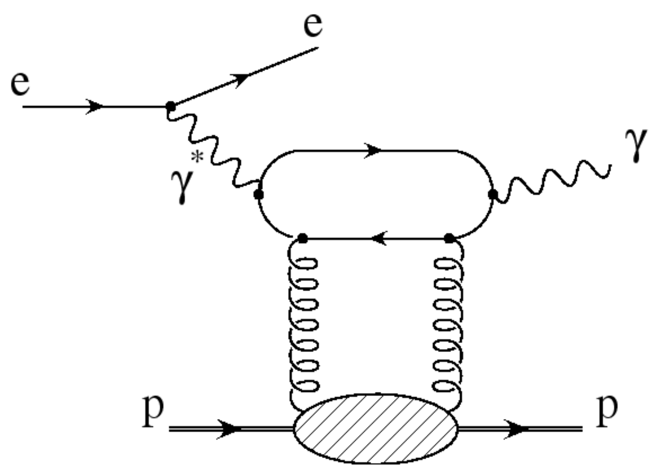






Experimental separation of incoherent diffraction based mainly on ZDC

Deeply Virtual Compton Scattering



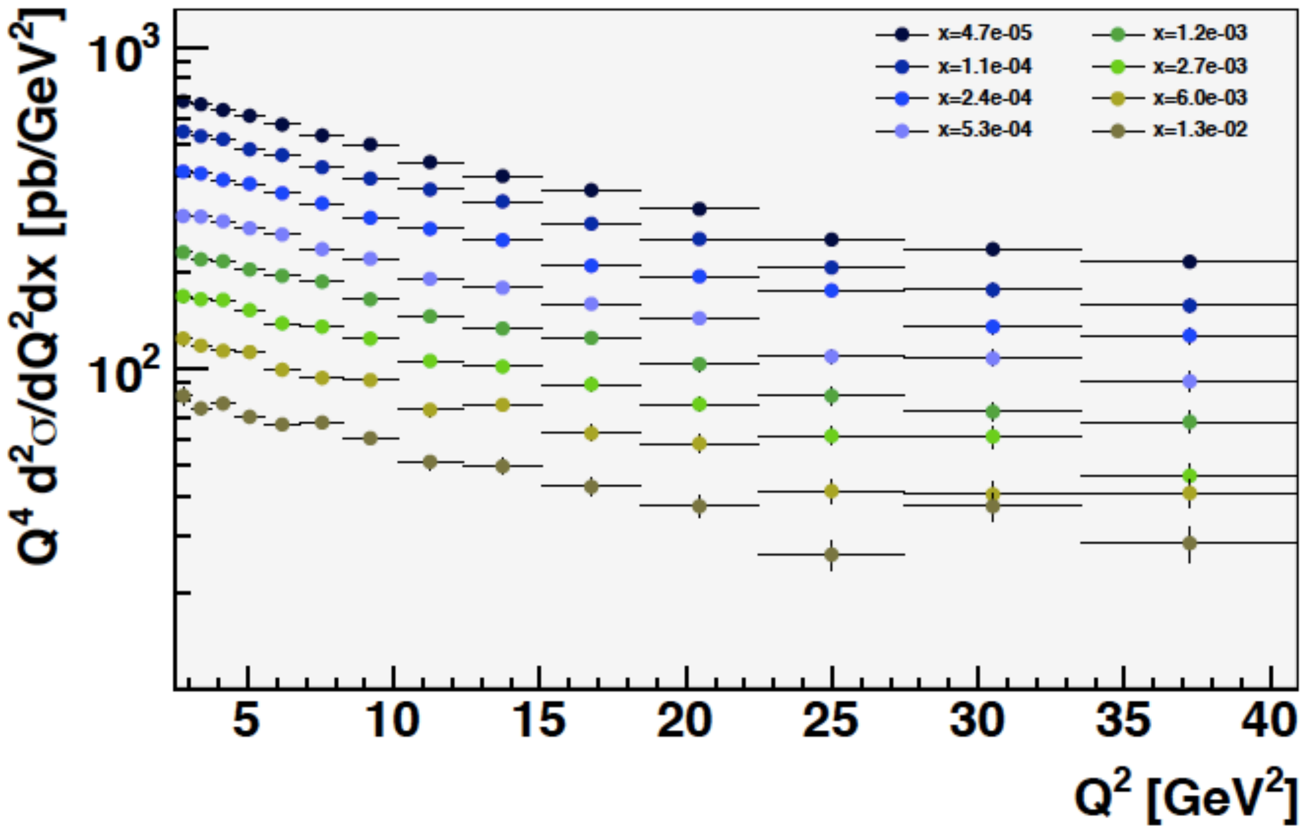
- No vector meson wavefunction complications

- Cross sections suppressed by photon coupling
  → limited precision at HERA
  → would benefit most from high lumi of LHeC and EIC

LHeC 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 with low luminosity & high acceptance

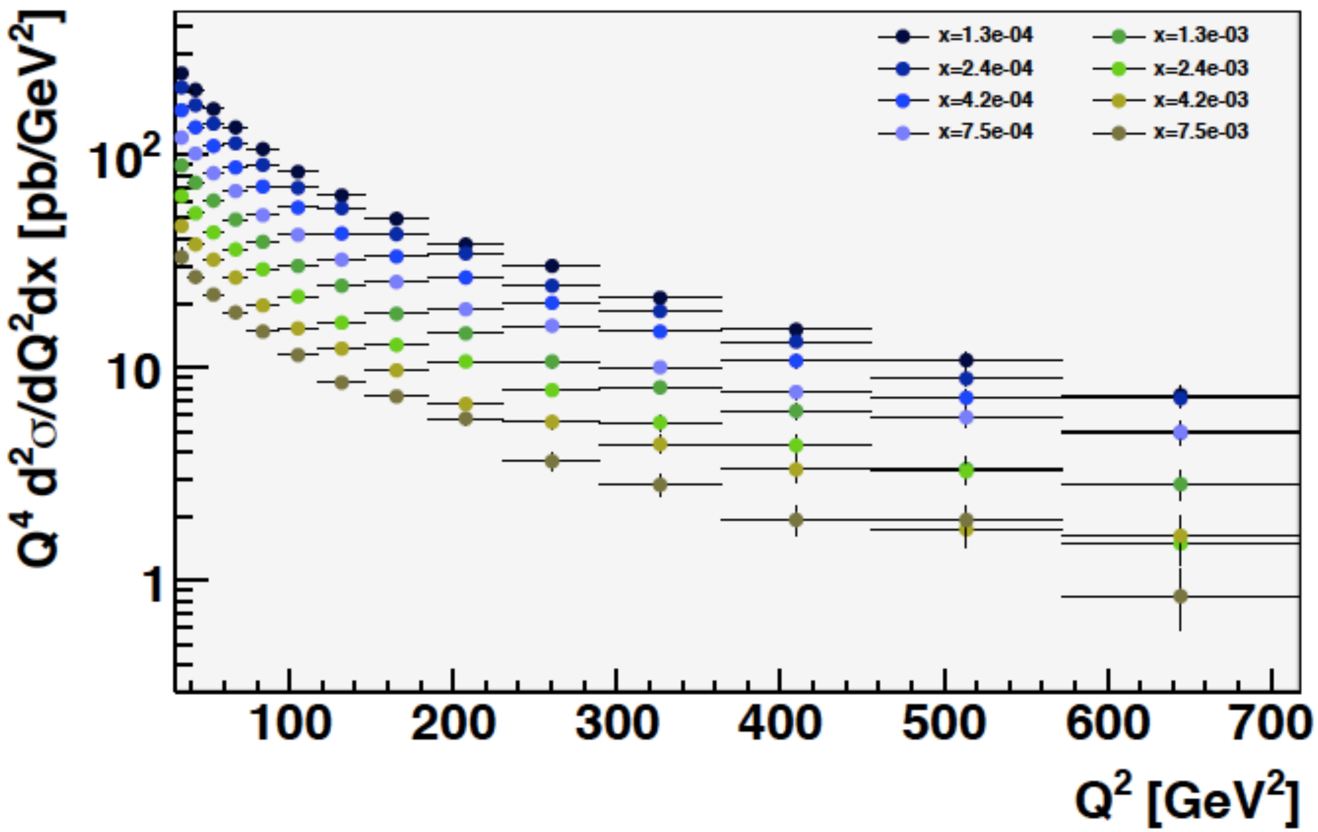
$1\ fb^{-1}$, E_e = 50 GeV, 1° acceptance, p_T^{γ} > 2 GeV



- 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 with high luminosity and low acceptance

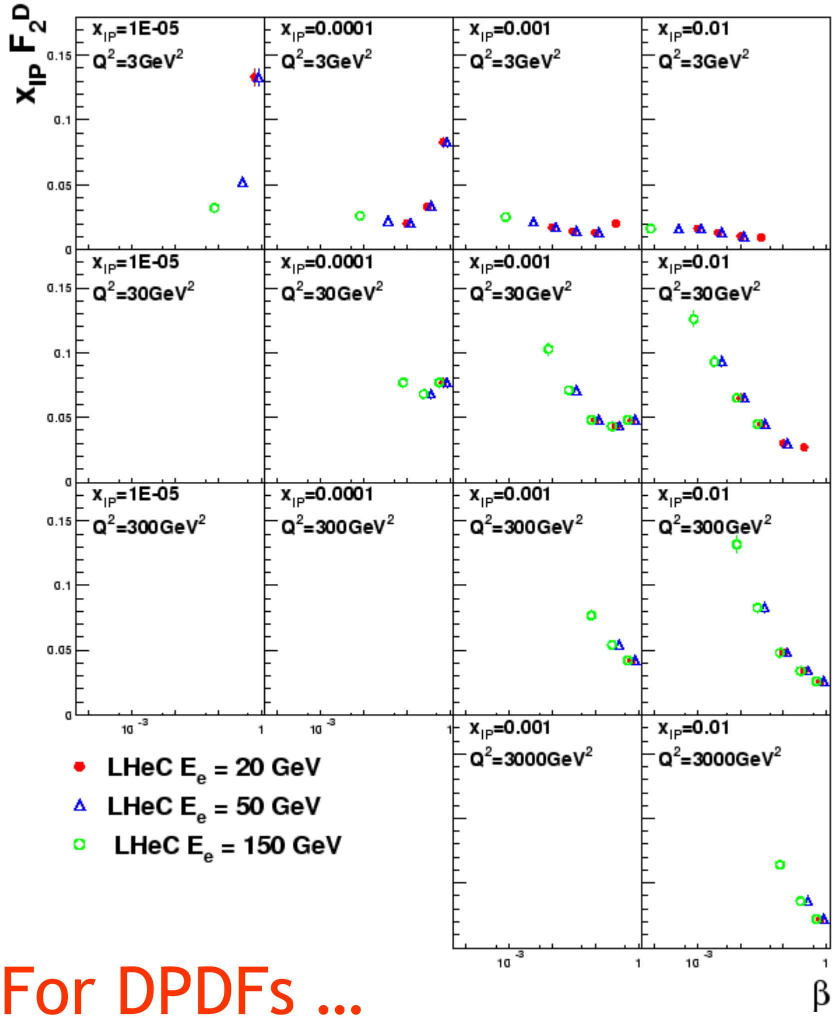
100 fb^{-1}, E_e = 50 GeV, 10° acceptance, p_T^γ > 5 GeV

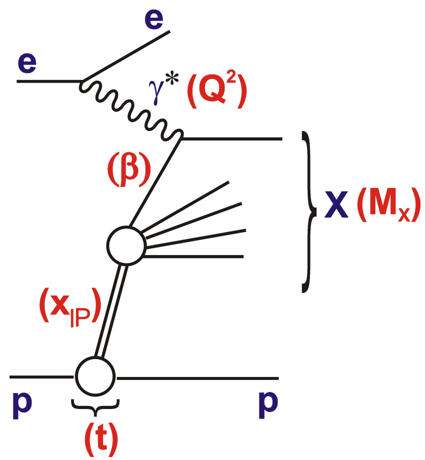


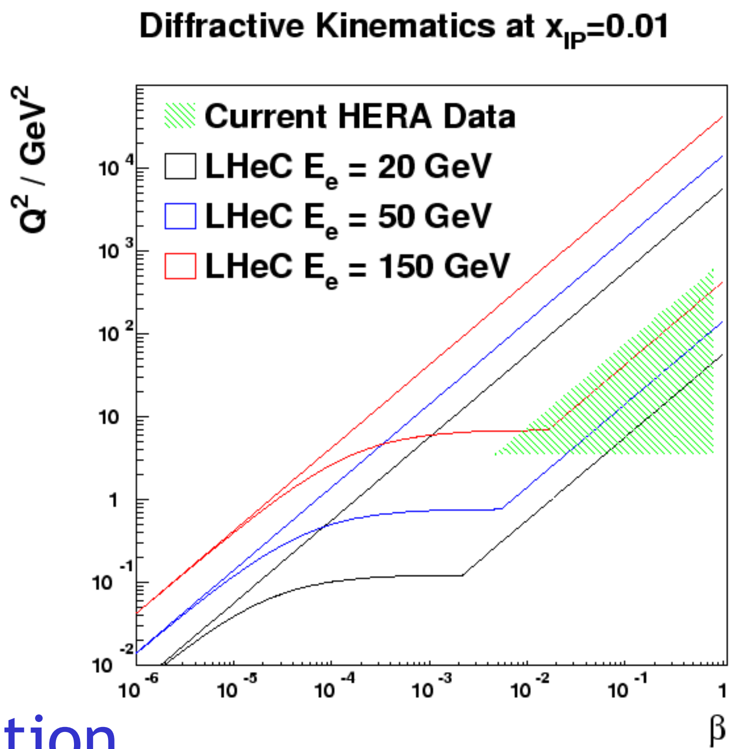
- High lumi gives precision data to Q^2 of several hundred GeV^2

  → Completely unprecedented region for DVCS / GPDs

Inclusive Diffraction / Diffractive PDFs at LHeC







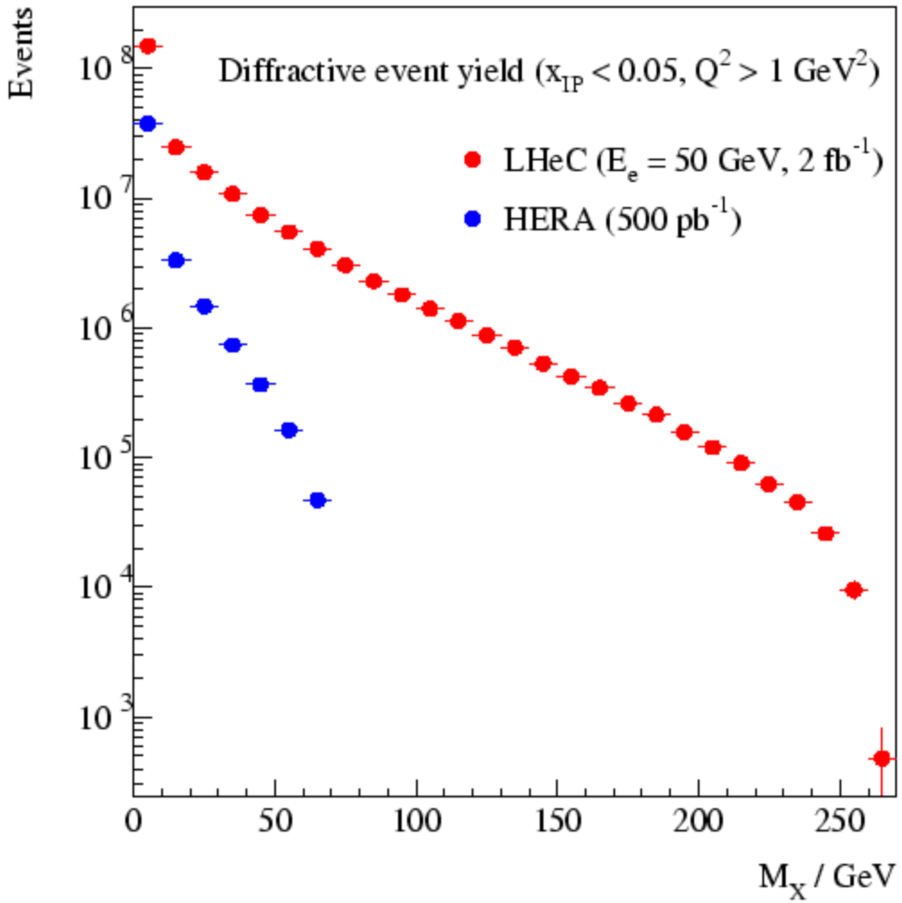
For DPDFs …

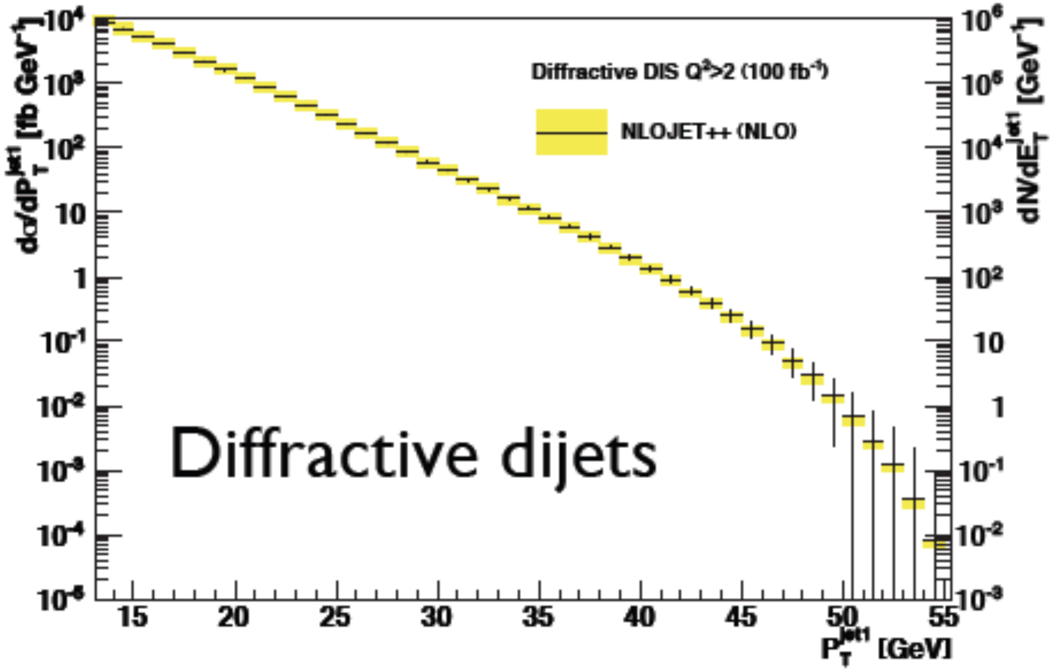
- Low x_{IP} → cleanly separate diffraction
- Low β → Novel low x DPDF effects /non-linear dynamics?
- High Q^2 → Lever-arm for gluon, Flavour separation via EW

Still no detailed DPDF sensitivity study ☹

New Region of Large Diffractive Masses

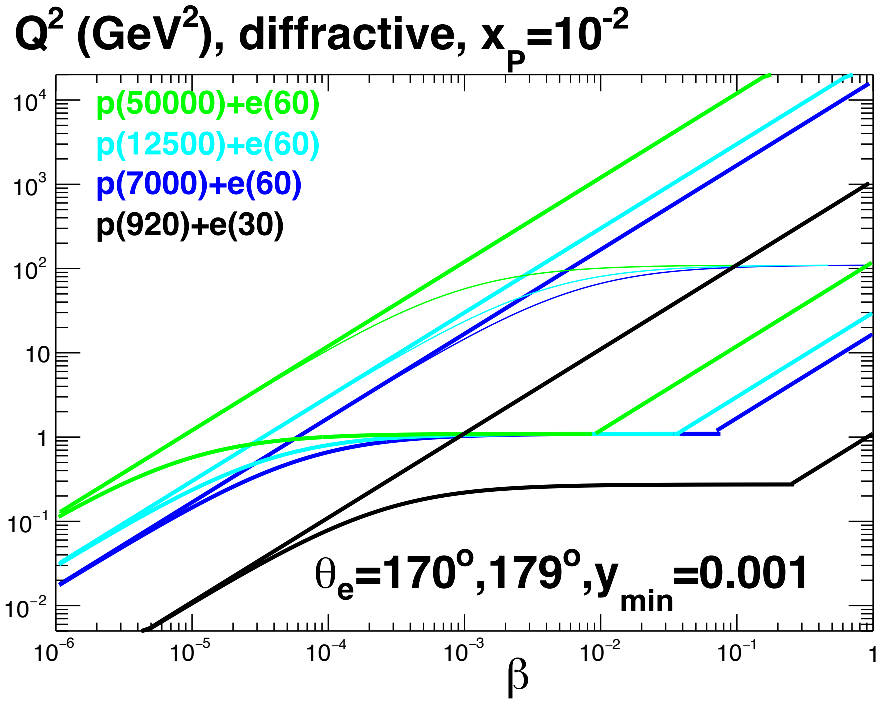
Large x_{IP} region highly correlated with large Mx





- \`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

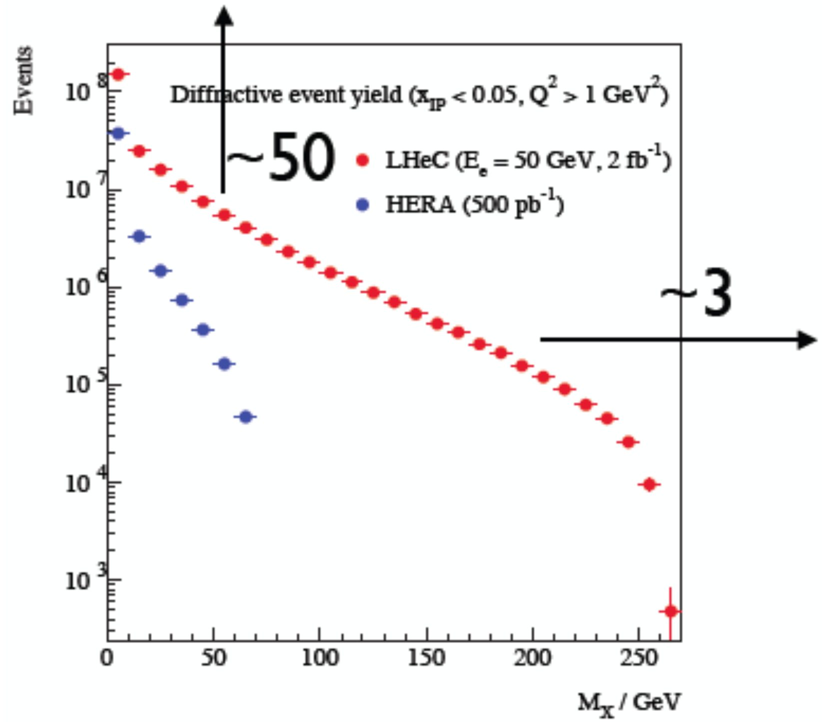
The More Distant Future: ep at a CERN Future Circular Collider



FCC-eh kinematics sensitive to diffractive structure in larger (β, Q^2) range than (x, Q^2) range sampled for the proton @ HERA!

-Similarly for masses and transverse momenta of jets.

- W range for VMs → multi-TeV



Summary

- Diffractive processes play a pivotal role in ep Physics
  - Enhance / complement inclusive data in saturation search
  - Elucidate 3D structure
  - Have a rich standalone QCD physics programme

- There is complementarity between EIC and LHeC

- Lots still to be studied to fully make case in detail
  - Better modelling of simulated measurements
  - Propagation to underlying physics (GPDs, DPDFs)
  - Really detailed detector studies (sensors and layouts)