# Low x & Diffractive Physics at the LHeC

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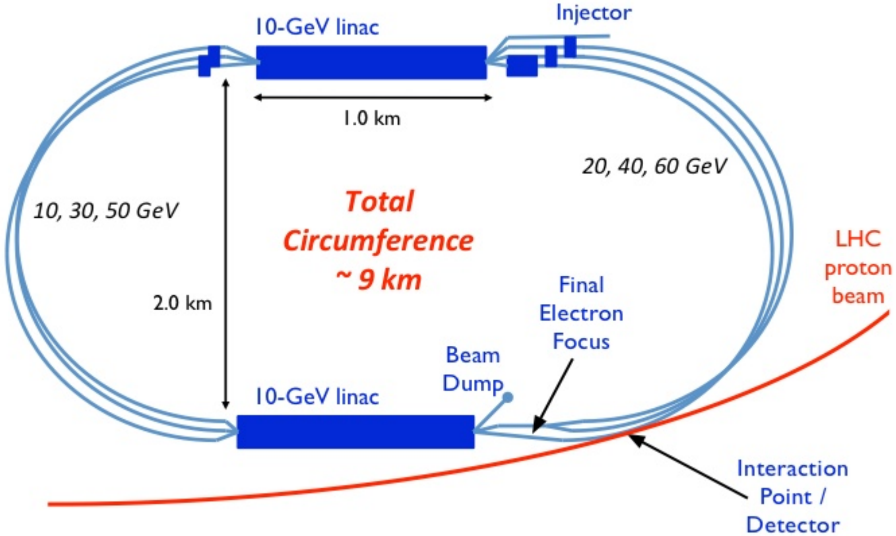
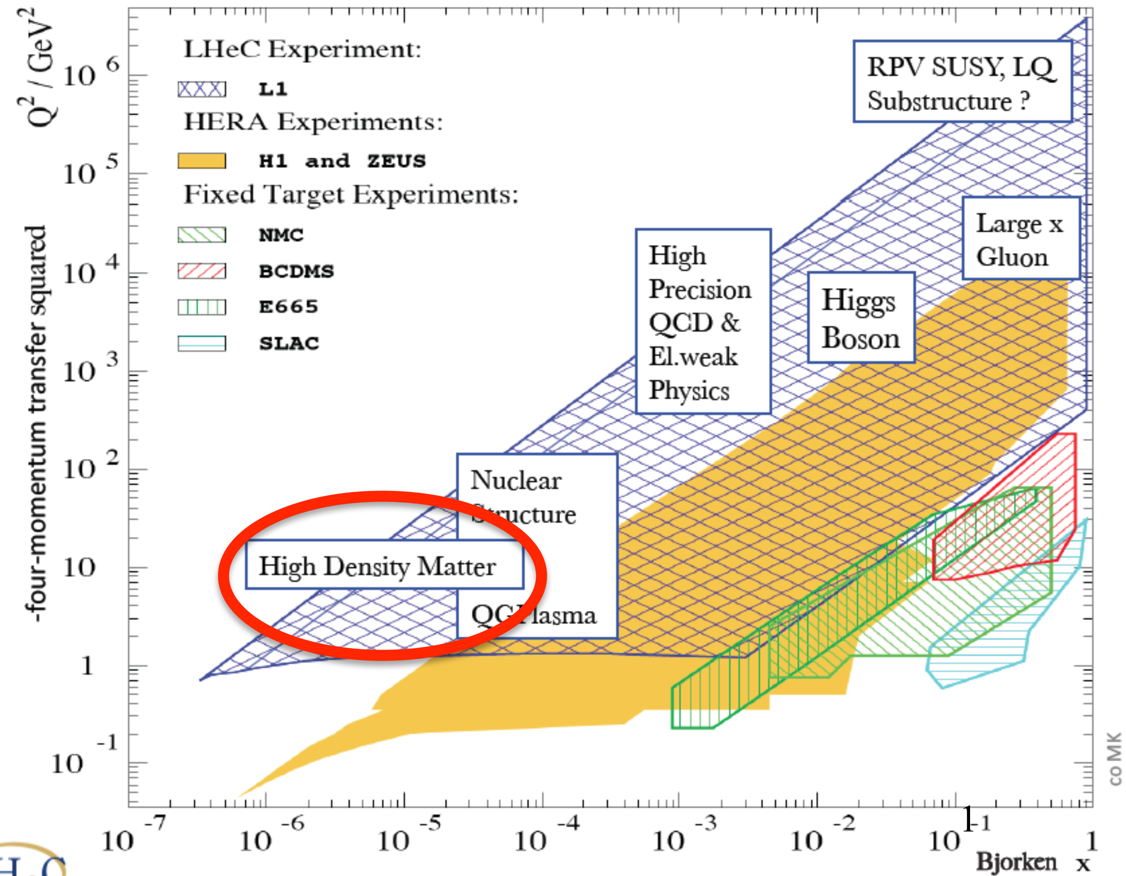
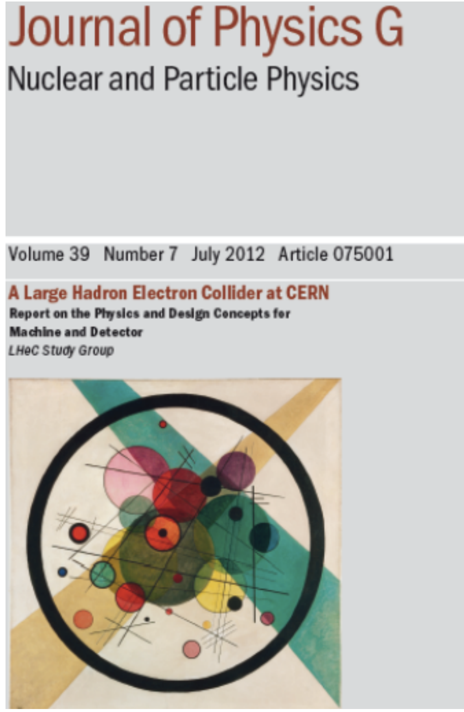



LHeC Workshop
Chavannes-de-Bogis
20 January 2014

# Conceptual Design Report (July 2012)

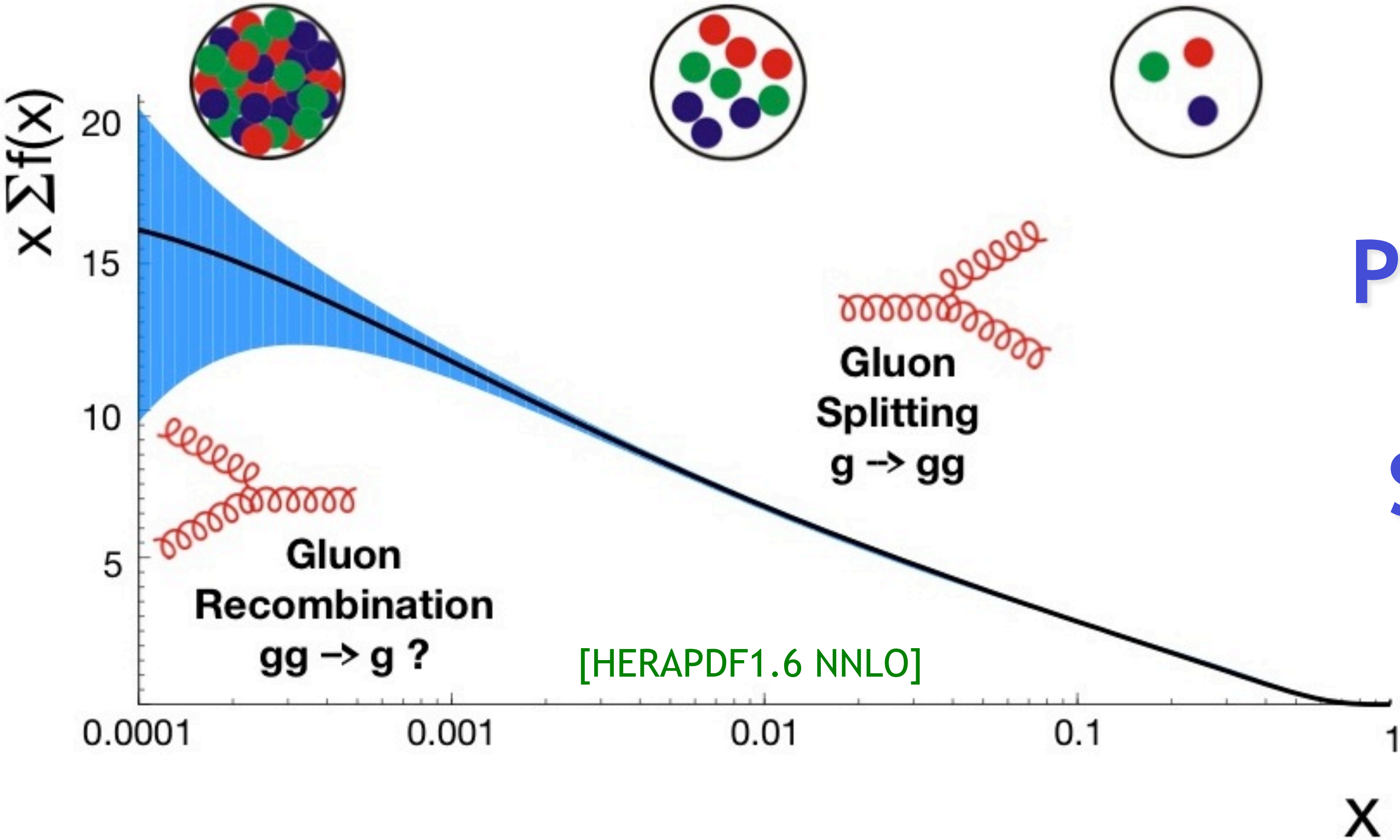
**[arXiv:1206.2913]**




Substantial low x chapter
(81 pages, 34 authors)

See also talks by Nestor and Hannu

A fundamental problem is looming in QCD … rise of low x partons … High energy unitarity issues reminiscent of longitudinal WW scattering in electroweak physics



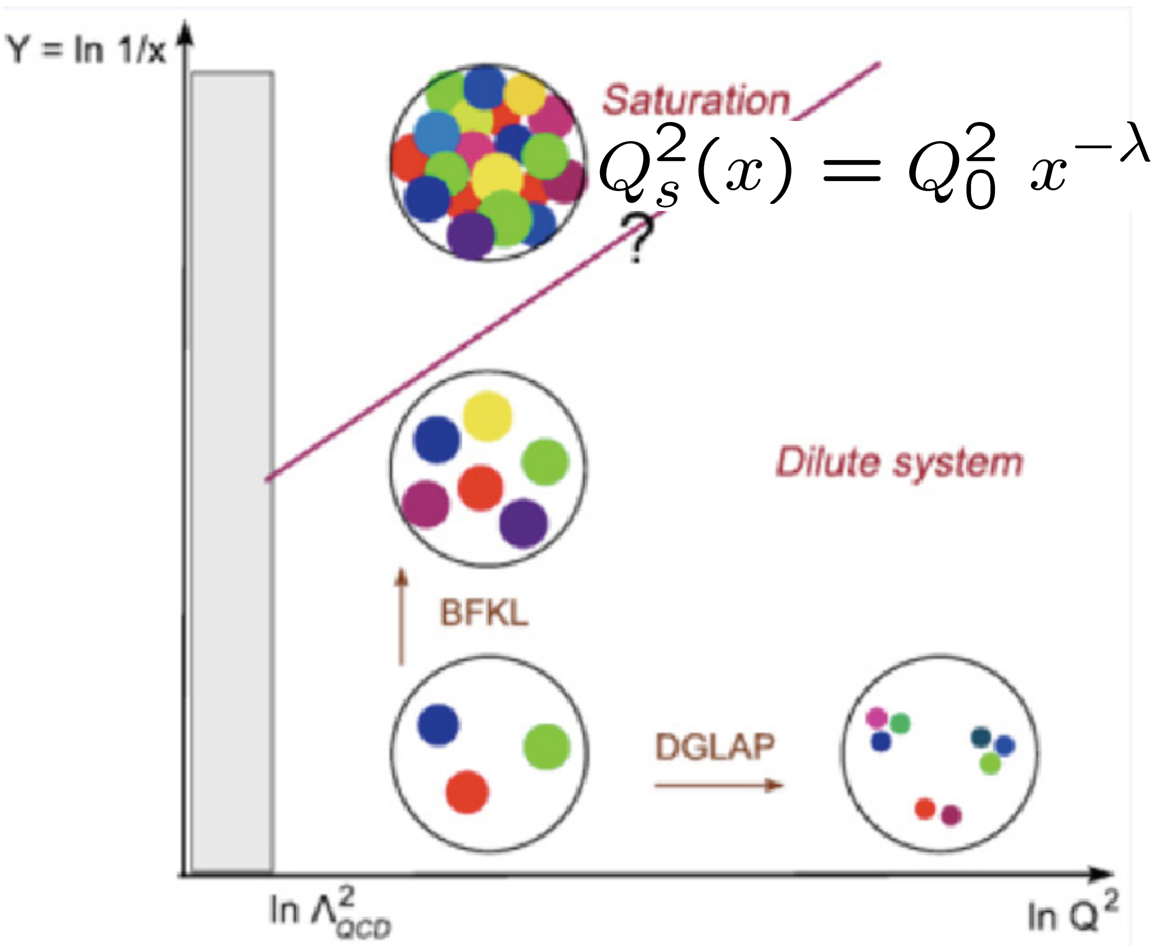

## Low-x Physics and Parton Saturation

… new high density, small coupling parton regime of non-linear parton evolution dynamics (e.g. Colour Glass Condensate)? …

… gluon dynamics → confinement and hadronic mass generation

# Filling up the Proton

Lines of constant 'blackness' ~diagonal in kinemaic plane …
Scattering cross section appears constant along them
(`Geometric Scaling')




Limited previous evidence in ep and eA restricted to small $Q^2$ <~ 1 $GeV^2$.

→ Partonic interpretation precluded

Usual to implement via `dipole models', with saturation built into dipole-proton x-section.

# LHeC: Accessing saturation region at large $Q^2$

LHeC delivers a 2-pronged approach:

Enhance target `blackness' by:

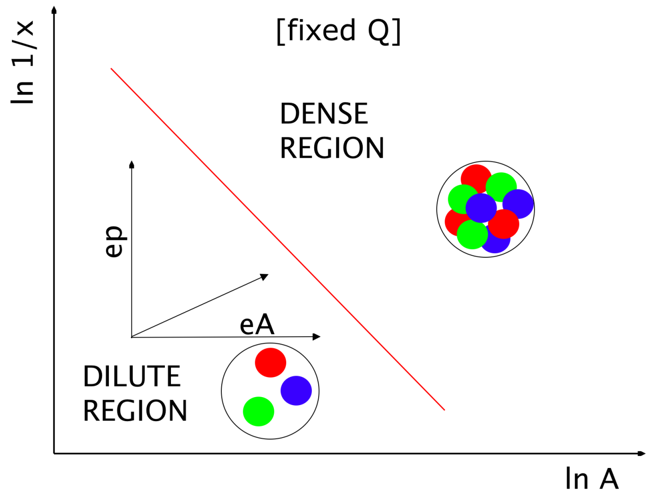
1) Probing lower x at fixed $Q^2$ in ep

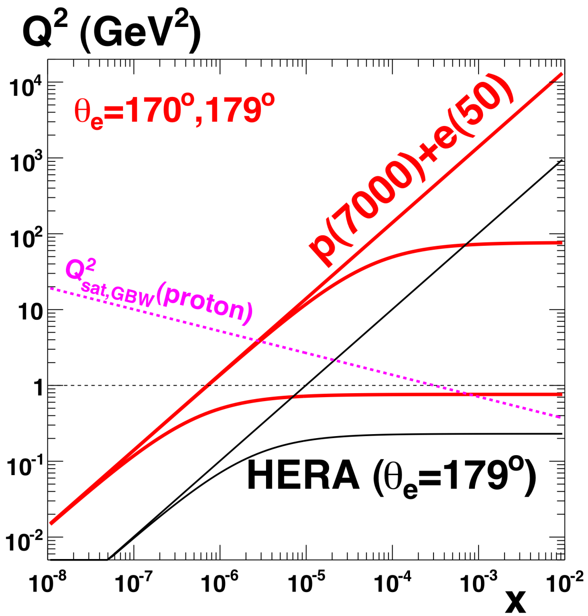
[evolution of a single source]

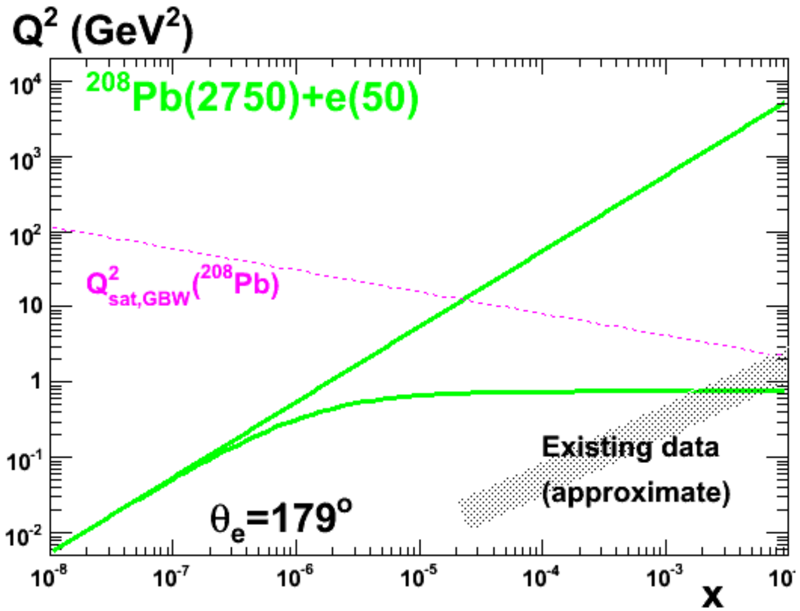
2) Increasing target matter in eA

[overlapping many sources at fixed kinematics …

Density ~ $A^{1/3}$ ~ 6 for Pb … worth 2 orders of magnitude in x]



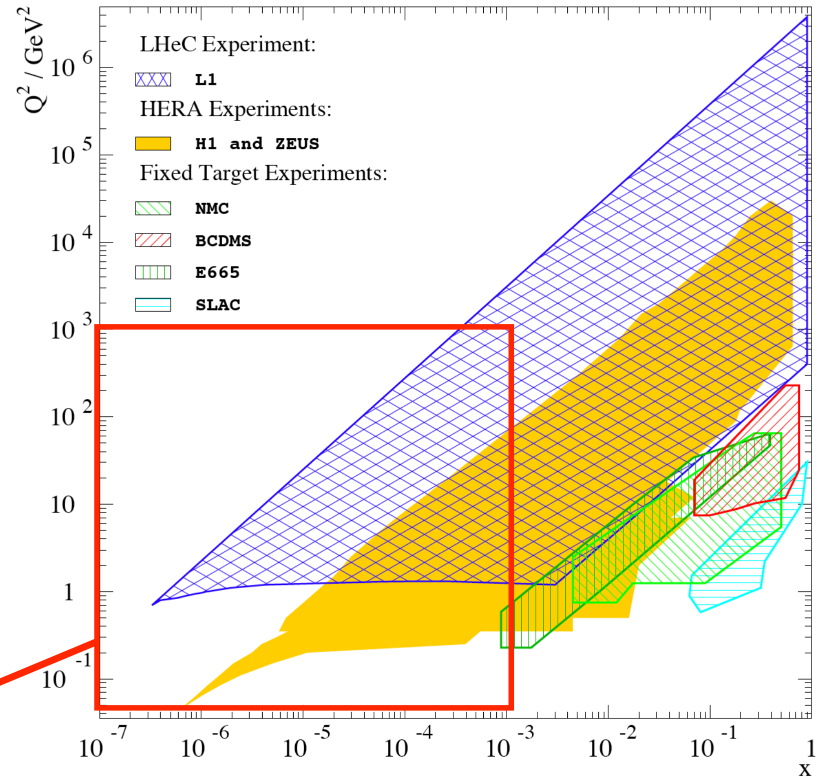



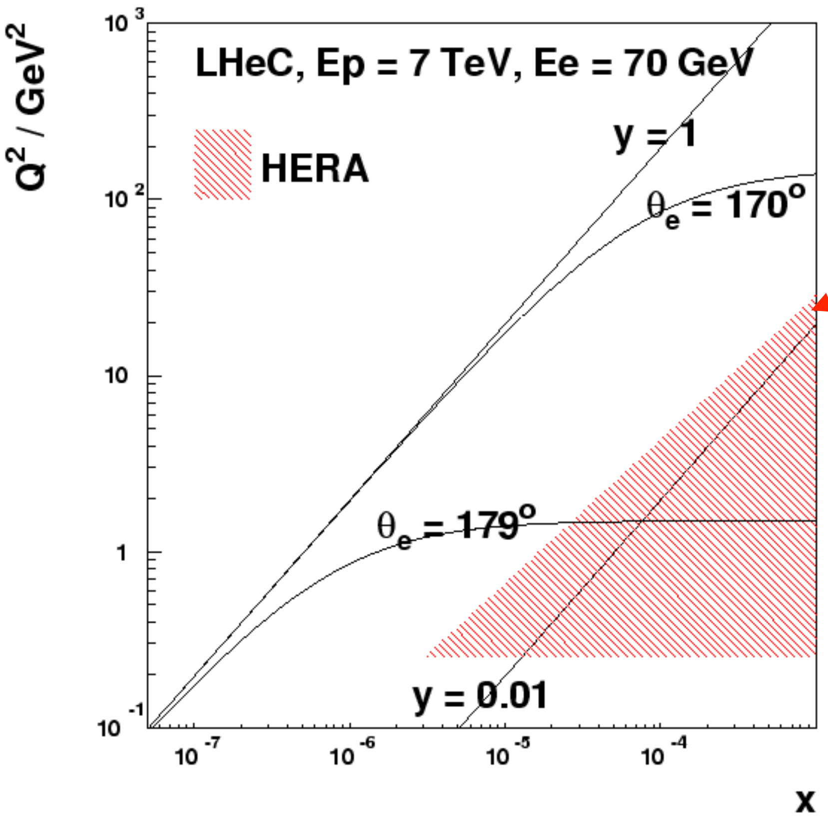




… Reaches saturated region in both ep & eA inclusive data according to models

# Low x Acceptance Requirements

Access to $Q^2$=1 $GeV^2$ in ep mode for all x > 5 x $10^{-7}$ requires scattered electron acceptance to 179°



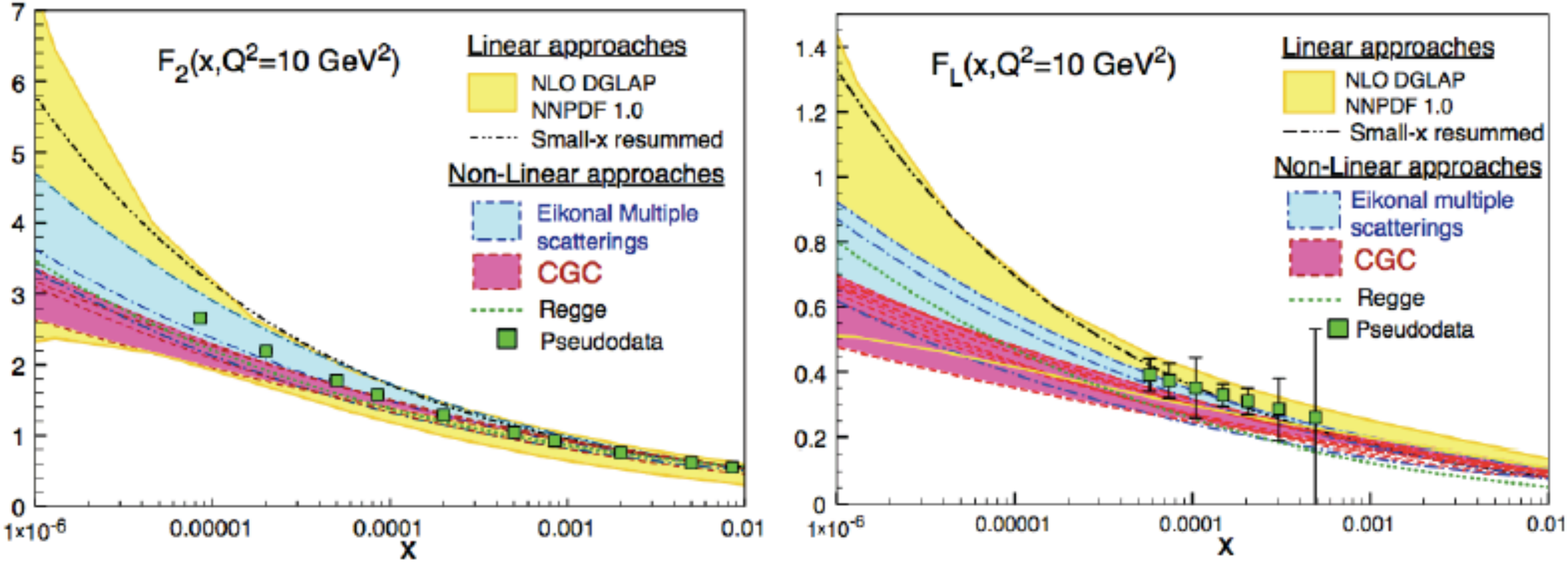




Small angle forward acceptance similarly important for hadronic final state studies - e.g. forward (Mueller-Navalet) jets.

# LHeC Sensitivity to Different Saturation Models

With 1 $fb^{-1}$ (1 month at $10^{33}$ $cm^{-2}$ $s^{-1}$), $F_2$ stat. < 0.1%, syst, 1-3%
$F_L$ measurement to 8% with 1 year of varying $E_e$ or $E_p$

$F_2$ and $F_L$ pseudodata at $Q^2$ = 10 $GeV^2$

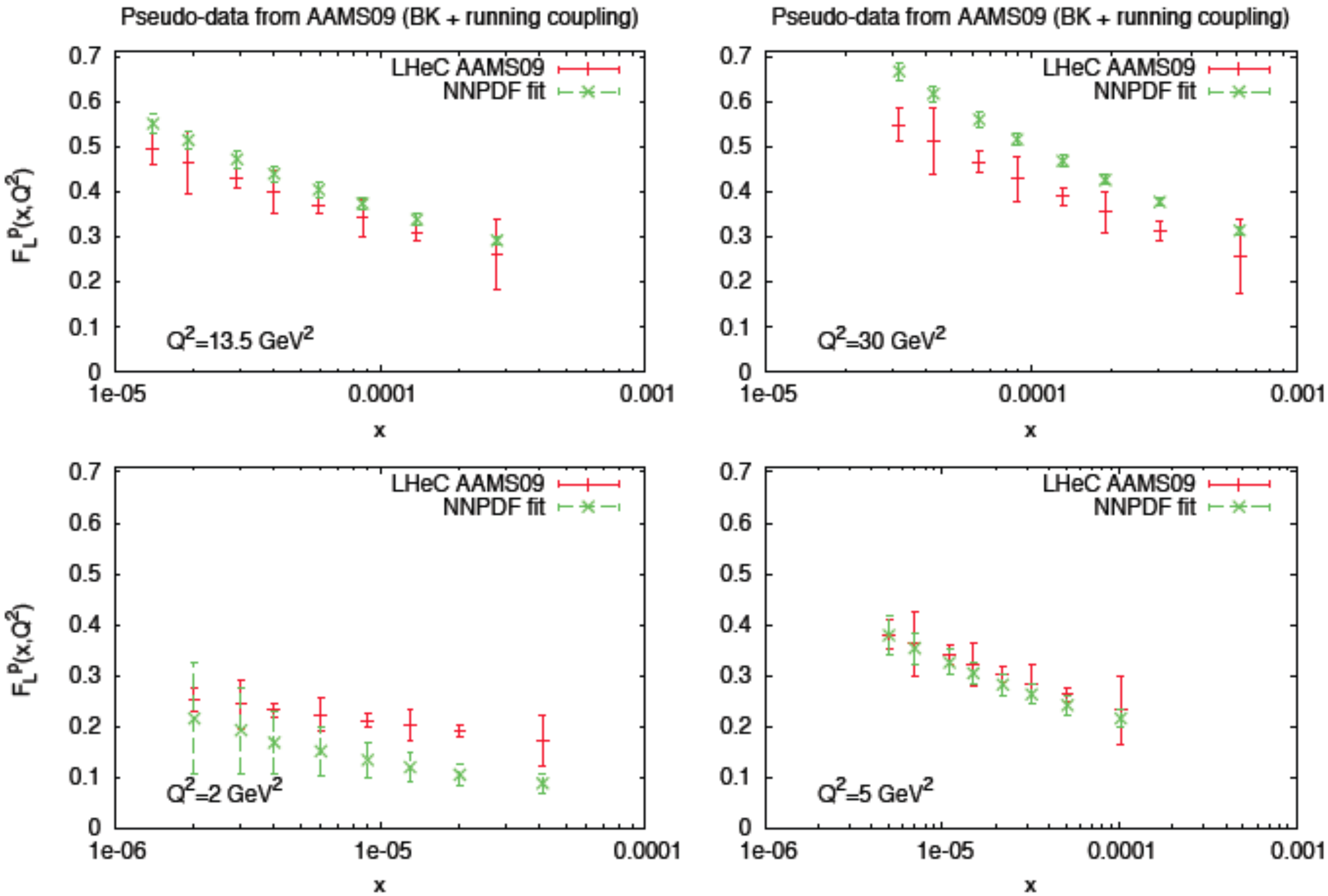



• LHeC can distinguish between different QCD-based models for the onset of non-linear dynamics

… but can $sat^n$ effects hide in standard fit parameterisations?

# Establishing Saturation in Inclusive Data

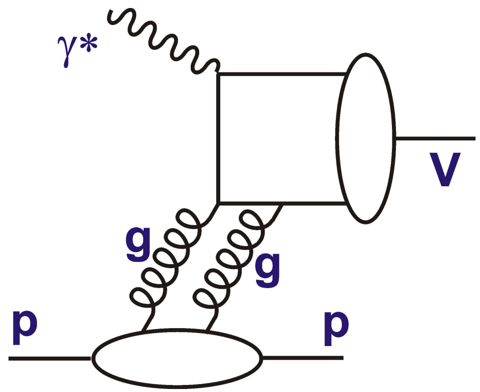
(Lack of) quality of NNPDF fit to $F_2$ and $F_L$ pseudodata with saturation effects included …




• Unambiguous observation of saturation will be based on tension between different observables e.g. $F_2$ v $F_L$ in ep or $F_2$ in ep v eA

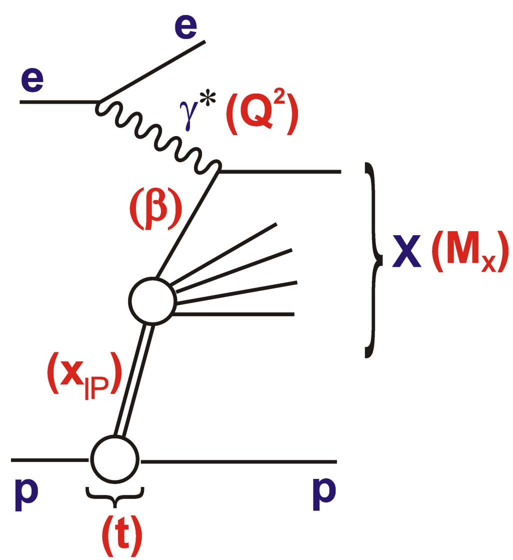
# Exclusive / Diffractive Channels and Saturation

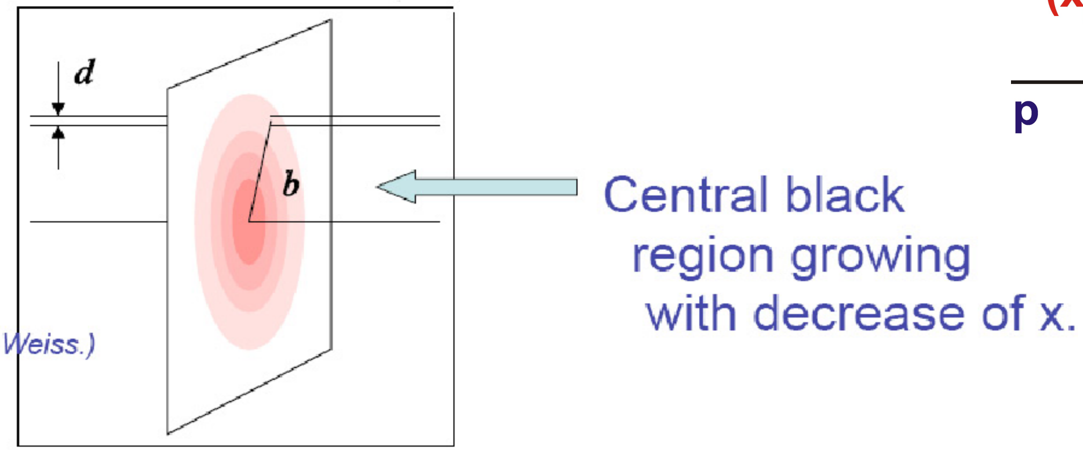
1) [Low-Nussinov] interpretation as 2 gluon exchange enhances sensitivity to low x gluon




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

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

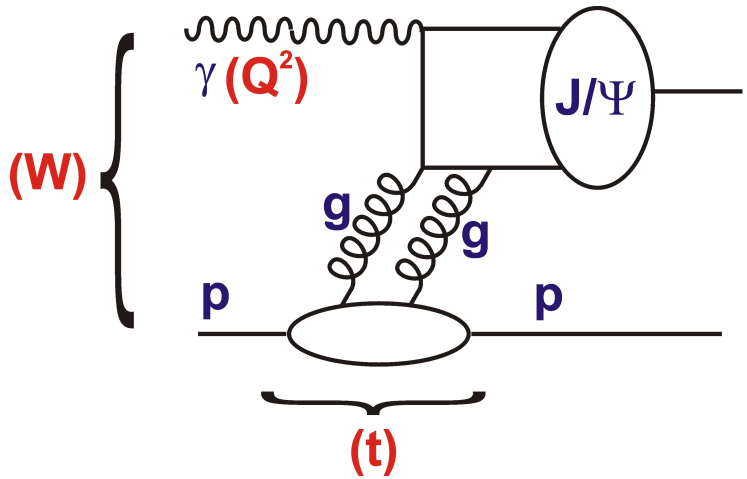



(figure from C. Weiss.)

# e.g. Elastic J/Ψ Photoproduction

- \`Cleanly' interpreted as hard 2g exchange coupling to qqbar dipole (see HERA data via MNRT and others)




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

- Clean experimental signature (just 2 leptons)

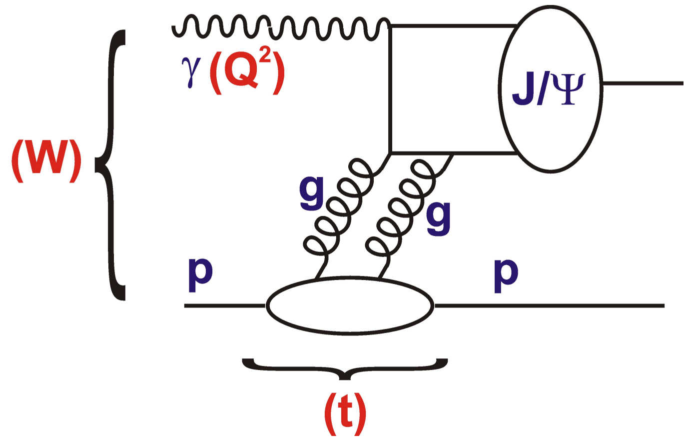
… LHeC reach extends to: $x_g \sim (Q^2 + M_V^2) / (Q^2 + W^2) \sim 5.10^{-6}$

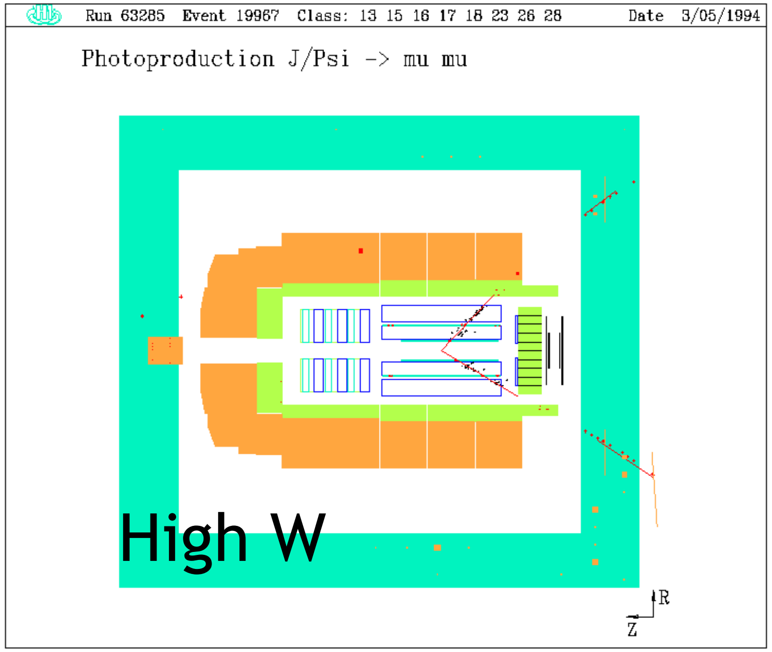
$\overline{Q^2} = (Q^2 + M_V^2) / 4 \qquad \sim 3 \text{ GeV}^2$

- Simulations of elastic J/Ψ → μμ photoproduction

→ scattered electron untagged, 1° acceptance for muons (similar method to H1 and ZEUS)

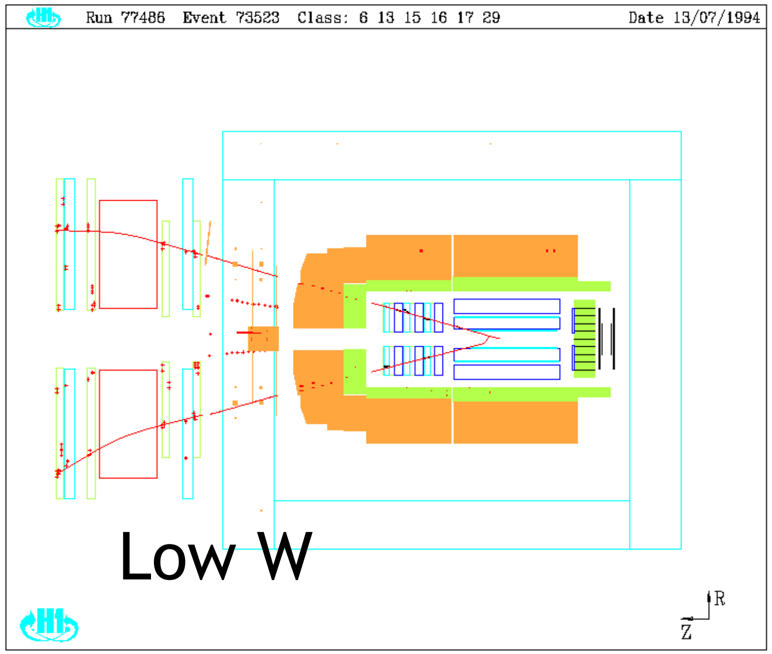
# J/Ψ Kinematics



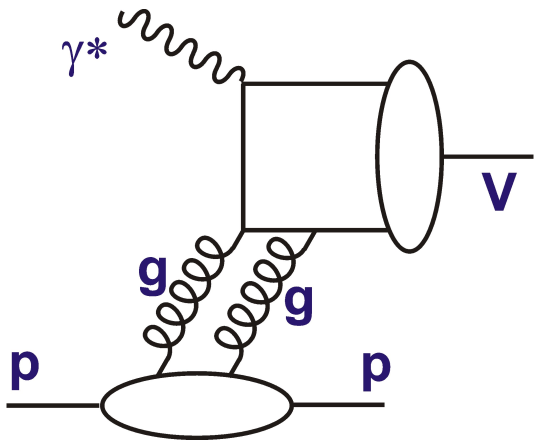

- At fixed $\sqrt{s}$, decay muon direction is determined by $W = \sqrt{s_{\gamma p}}$

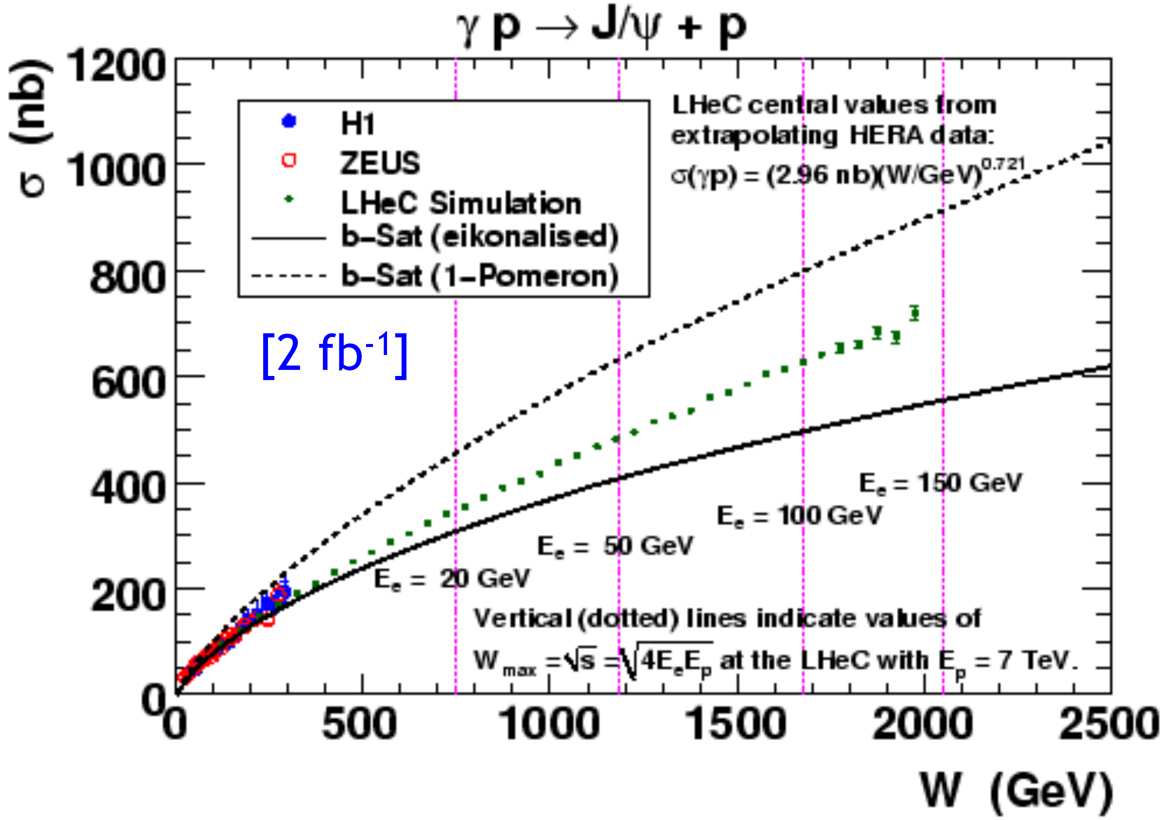
- To access highest W, acceptance in outgoing electron beam direction crucial



# Comparison with Dipole model Predictions

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



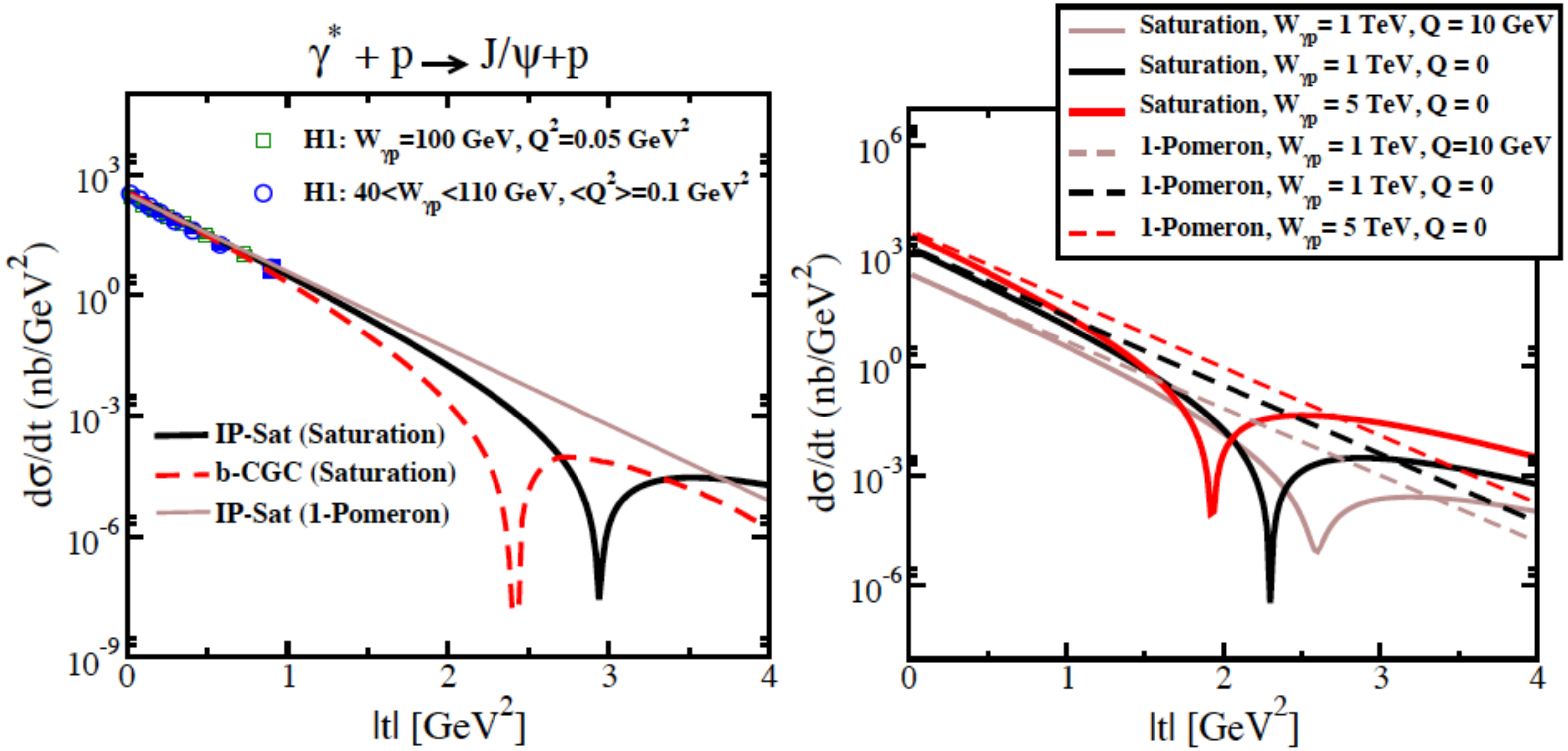

- Significant non-linear effects expected in LHeC kinematic range.

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

# Signals in t Dependences: e.g. J/ψ Photoproduction

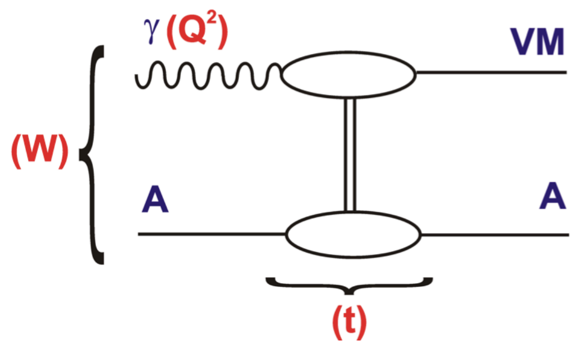
t dependences measure Fourier transform of impact parameter distribution. → Unusual features can arise from deviations from Gaussian matter distribution

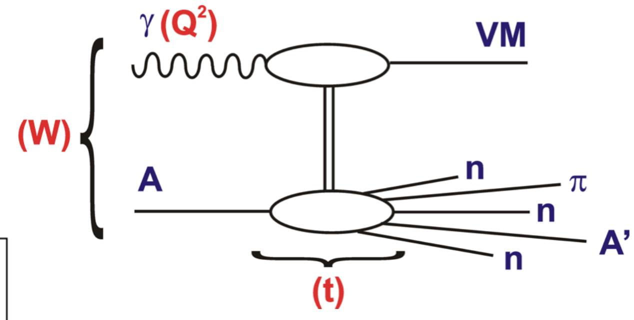
e.g. Characteristic dips in model by Rezaeian et al, (just) within LHeC sensitive t range.

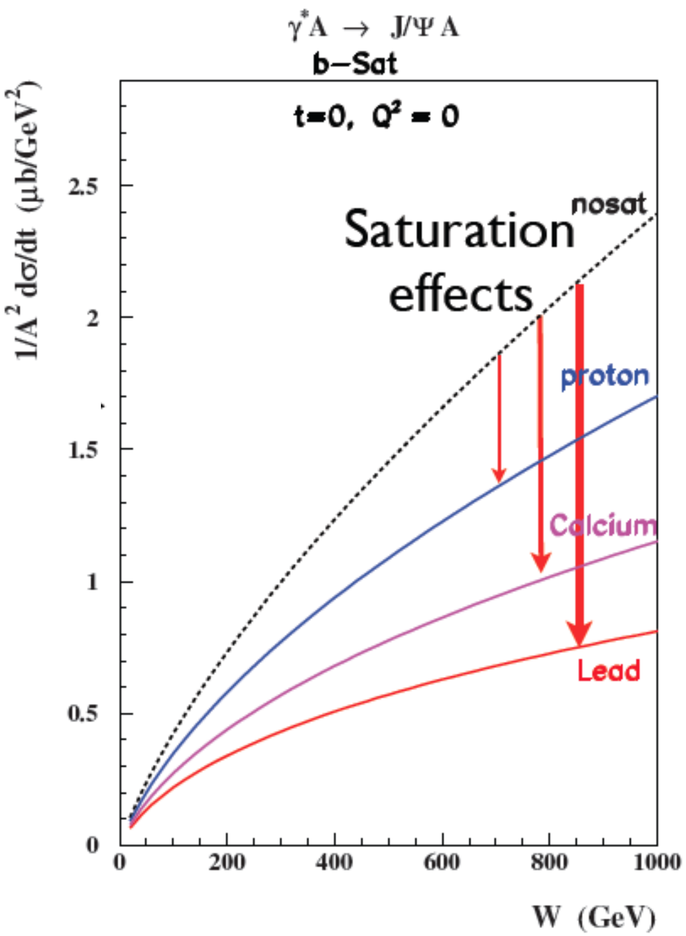


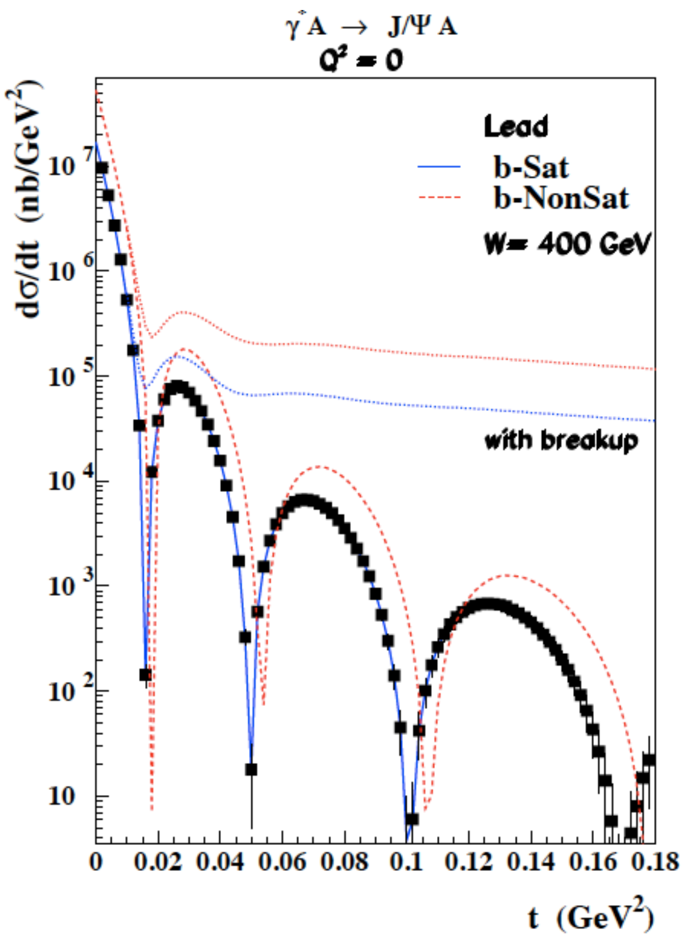
# Exclusive Diffraction in eA

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



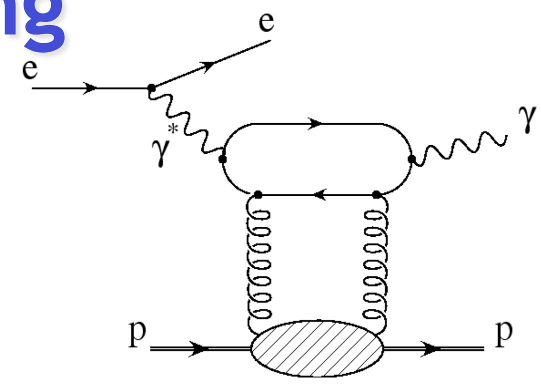



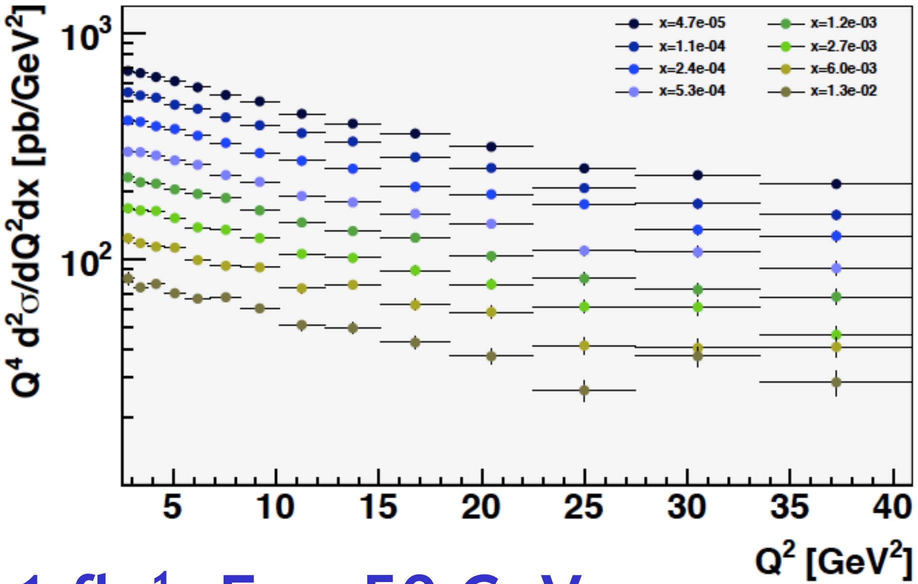

Experimental separation of incoherent diffraction based mainly on ZDC

# Deeply Virtual Compton Scattering

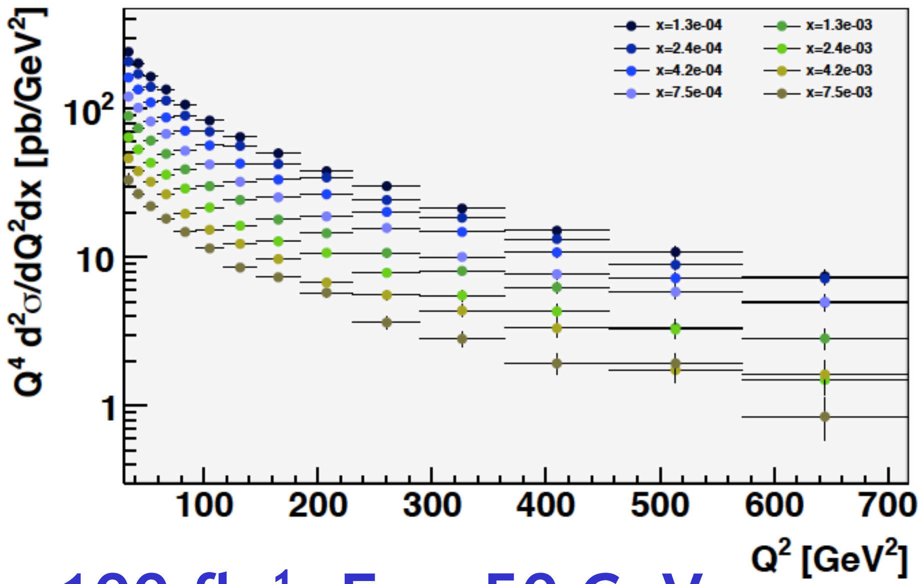



- No VM wavefunction complications
- Exceptionally sensitive to spatial distributions and correlations of partons in proton → Nucleon Tomography

Huge LHeC kinematic range → W~1TeV, $Q^2$~1000 $GeV^2$



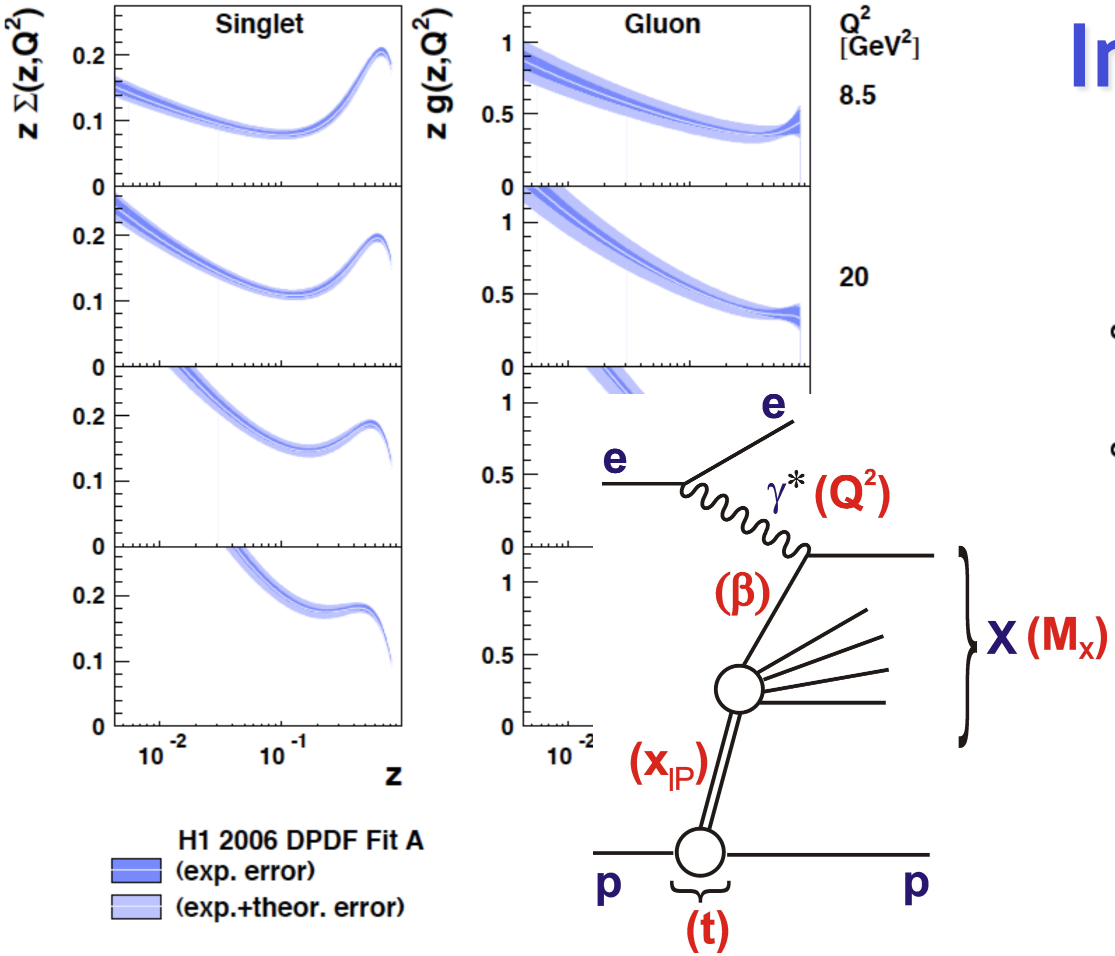

1 $fb^{-1}$, $E_e$ = 50 GeV,
1° acceptance, $p_T^\gamma$ > 2 GeV

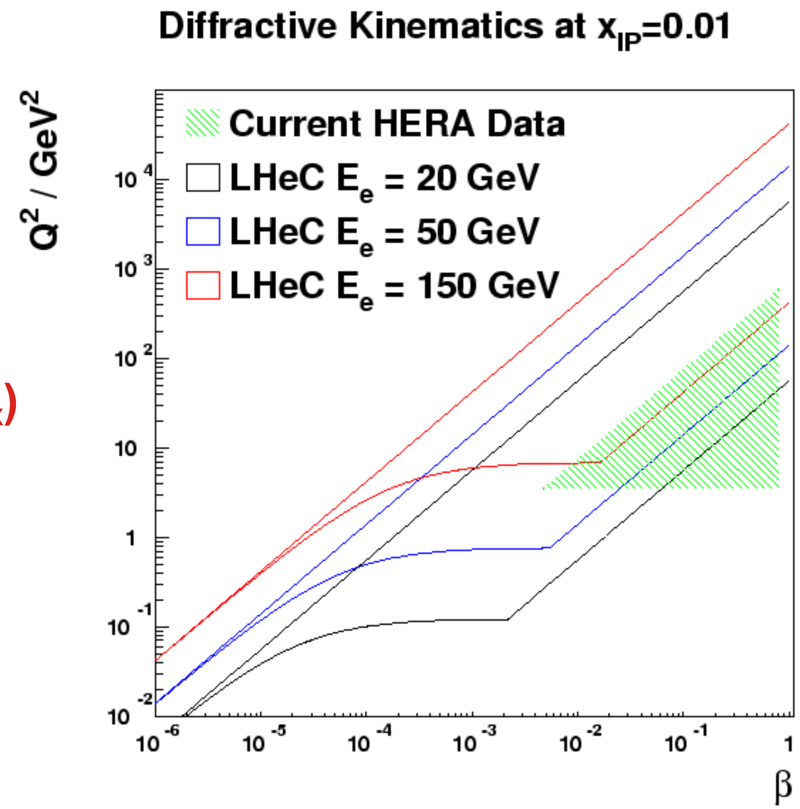



100 $fb^{-1}$, $E_e$ = 50 GeV,
10° acceptance, $p_T^\gamma$ > 5 GeV

**Resulting impact on GPDs etc still to be evaluated**

# Inclusive Diffraction / Diffractive PDFs



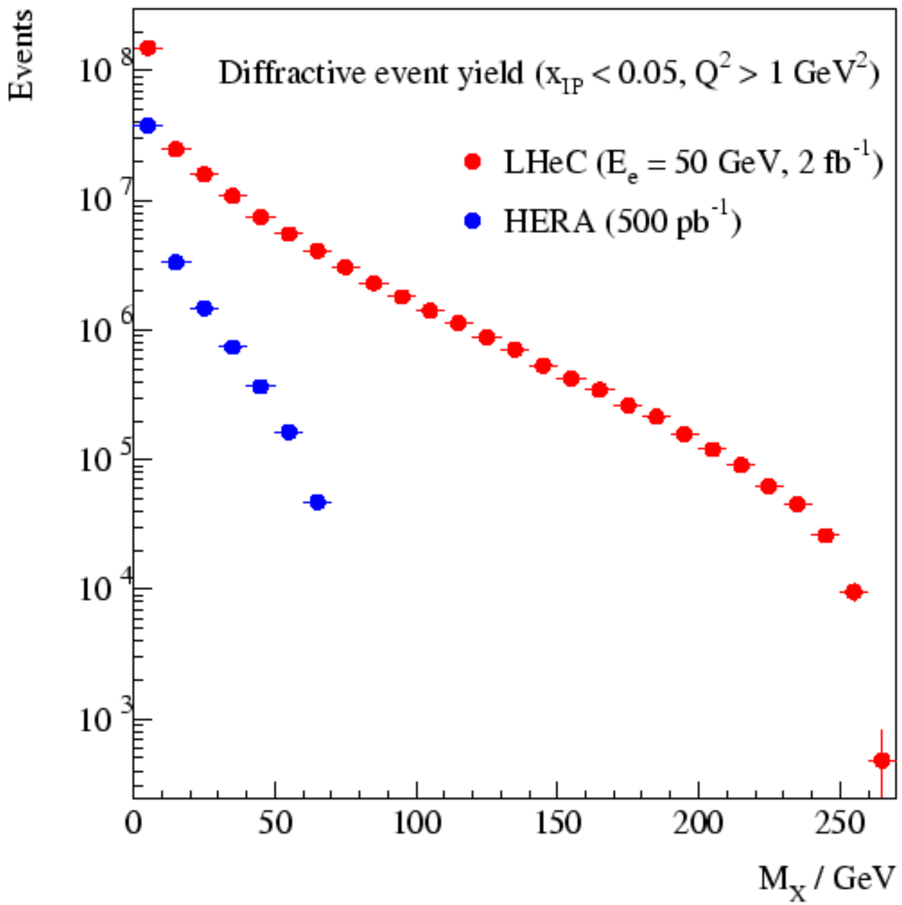

Complementarity of rapidity gap and Roman pot techniques

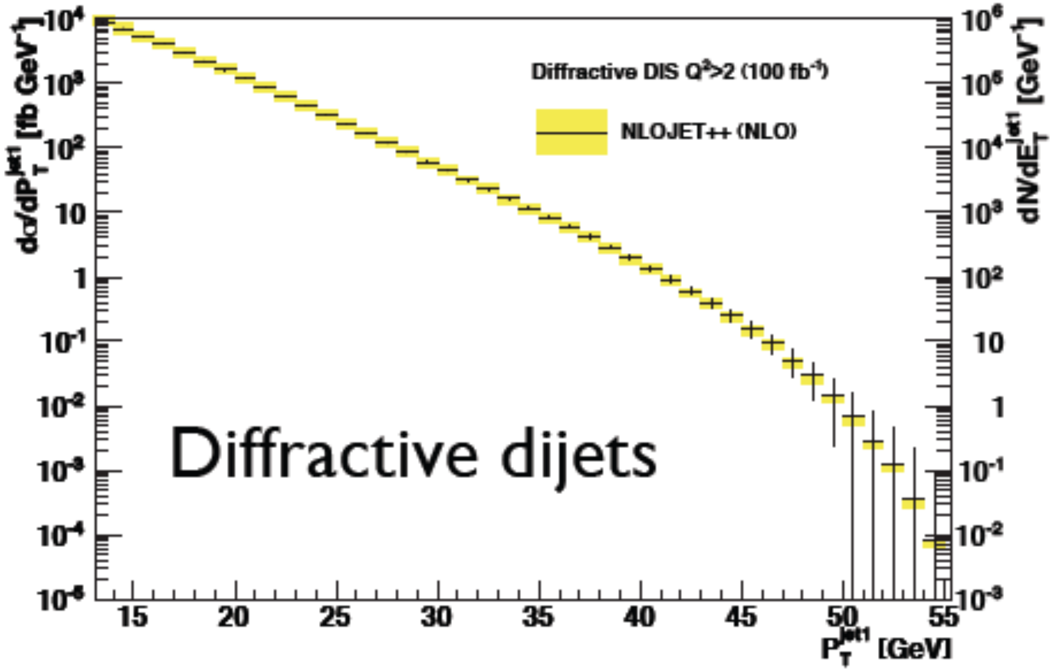
→ Full acceptance for $x_{IP}$ <~ 0.05

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

# New Region of Large Diffractive Masses

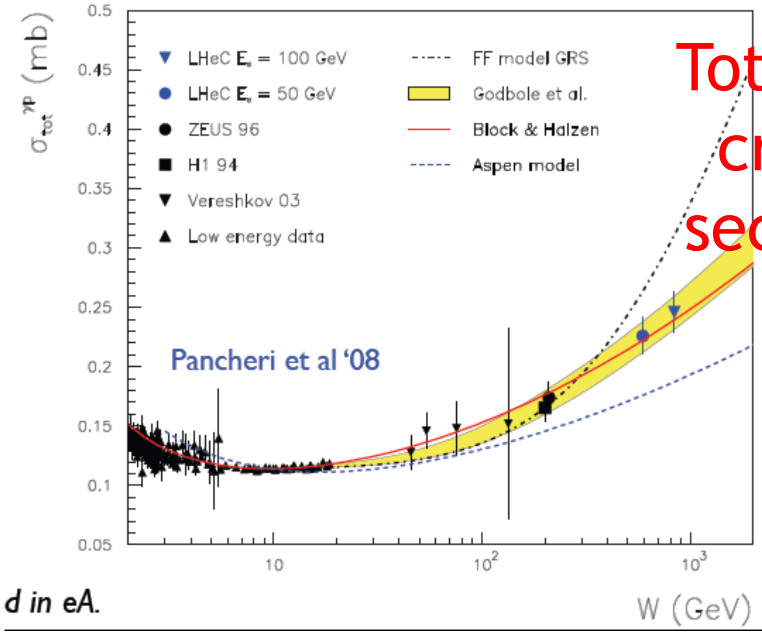
## Large $x_{IP}$ region highly correlated with large Mx



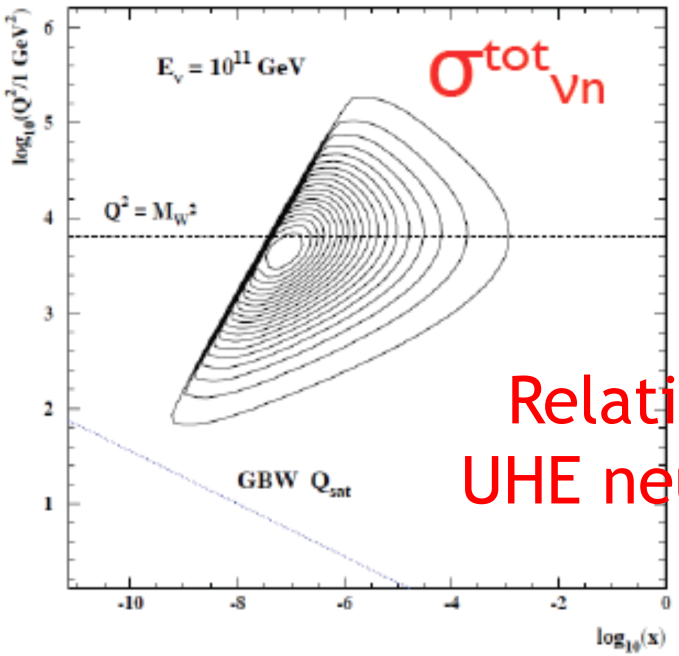

- \`Proper' QCD (e.g. large $E_T$) with jets and charm accessible
- New diffractive channels … beauty, W / Z bosons
- Unfold quantum numbers / precisely measure new $1^-$ states

# Quick Flash of Selected Stuff I didn't cover …



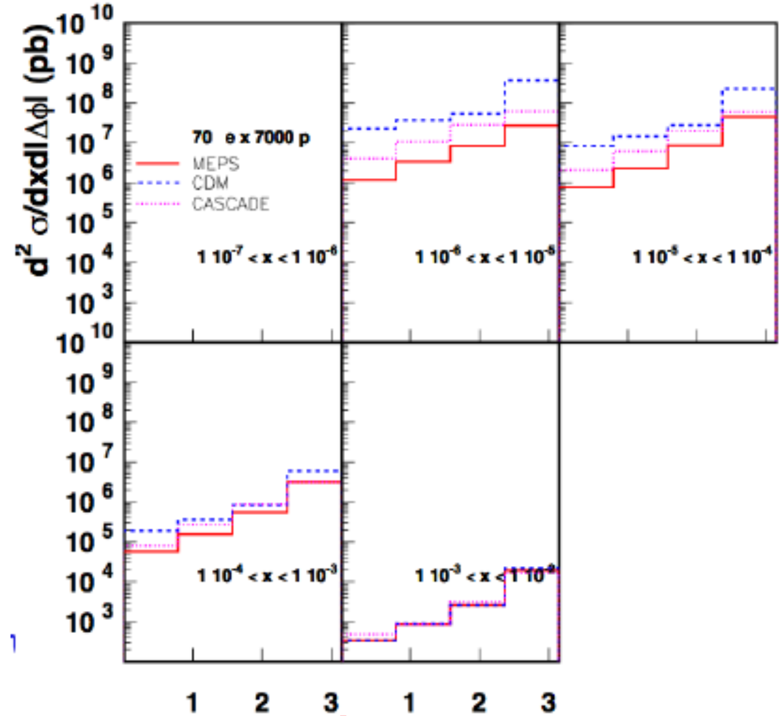

Total $\gamma p$ cross section

d in eA.




$\sigma^{tot}_{\nu n}$

Relation to UHE neutrinos




Forward jets / $\phi$
Azimuthal decorelations / TMD parton densities

+ Diffractive charged currents (next talk by Marketa)

# Summary

- Low x physics is the Strong Interaction energy frontier: lots to be discovered:
  - Dense partonic systems → correlations / interactions
  - Understanding onset of non-linear dynamics
  - Towards the Gribov black-disk limit

    → Confimement, Hadronic mass generation??

- LHeC has unique sensitivity → full potential far from evaluated

- Next step 1) Realistic estimates of systematics
  - MC modelling, in particular of forward region in eA / ep
  - Detailed design / simulation of dedicated detectors

(small angle electrons, beamline protons and neutrons, forward HCAL, forward and backward muons)

- Next step 2) Evaluate sensitivity to underlying physics
  - GPDs, TMDs / unintegrated gluons, DPDFs …