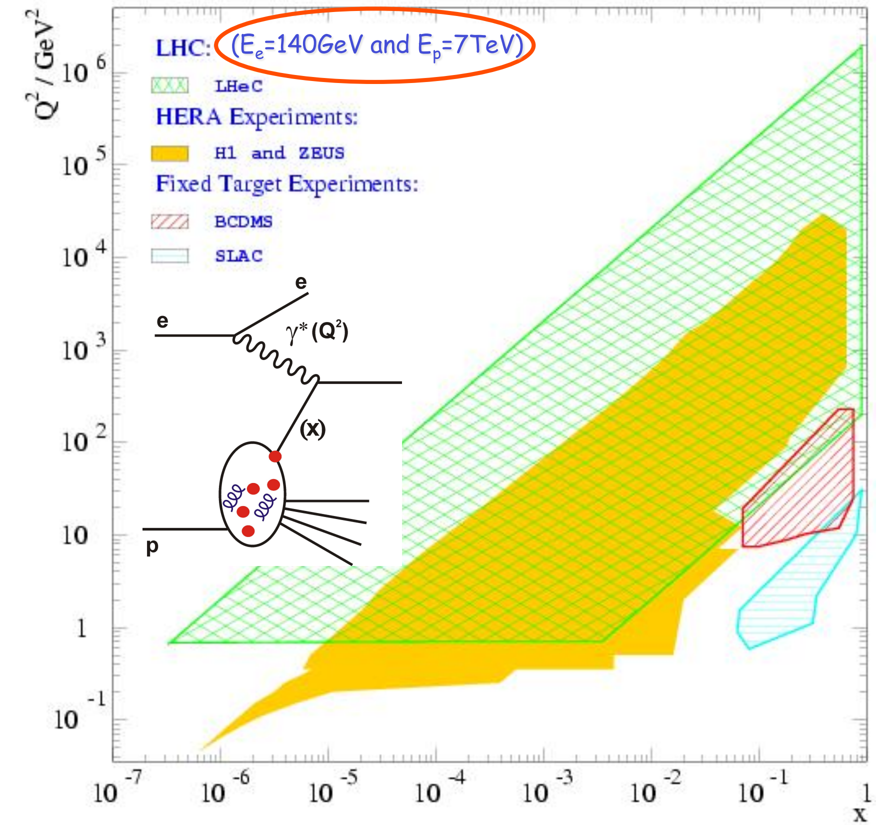
http://cern.ch/lhec



Diffraction and exclusive processes at small x at the LHeC

Anna Stasto (Penn State & RIKEN BNL & Krakow INP)

for the LHeC working group on
Physics at high parton densities (ep and eA)

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03/29/2012 DIS2012, Bonn

LHeC kinematics

ep/ea collisions

$$E_p = 7 \text{ TeV}$$

$$E_A = 2.75 \text{ TeV/nucleon}$$

$$E_e = 60 - 140 \text{ GeV}$$

$$\sqrt{s} \simeq 1 - 2 \text{ TeV}$$

- Requirements:

* Luminosity~10^{33} $cm^{-2}s^{-1}$.   eA: L_{en}~10^{32} $cm^{-2}s^{-1}$

* Acceptance: 1-179 degrees (low-x ep/eA).

* Tracking to 1 mrad.

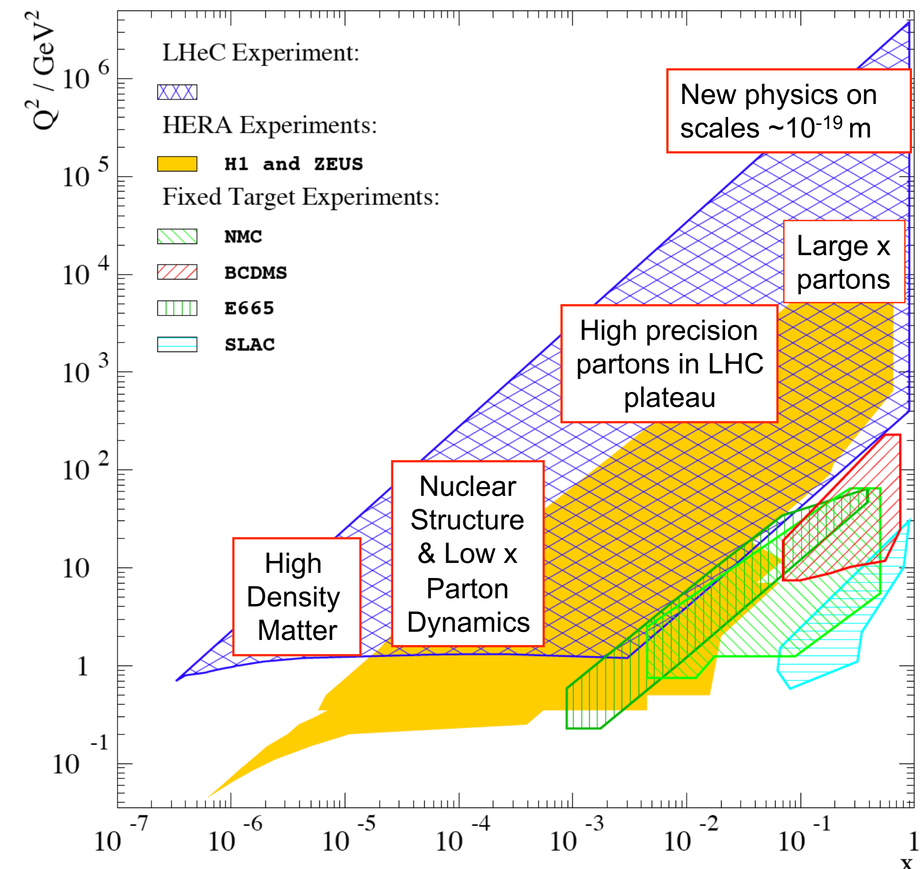
* EMCAL calibration to 0.1 %.

* HCAL calibration to 0.5 %.

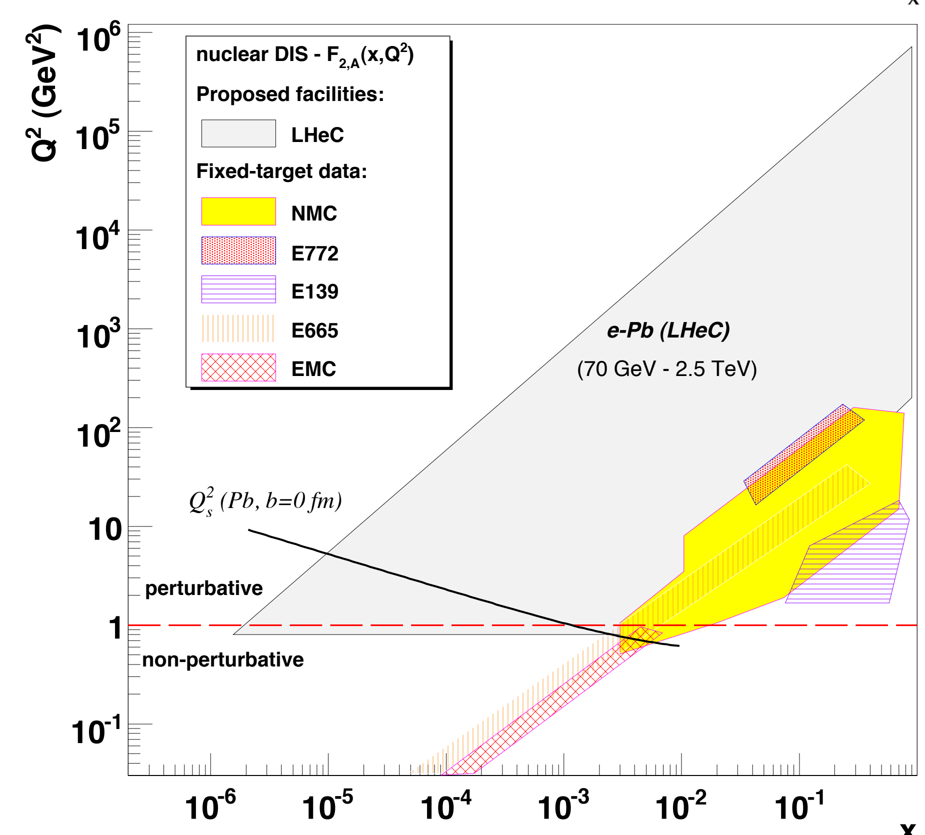
* Luminosity determination to 1 %.

* Compatible with LHC operation.

ep



eA



Small x physics at the LHeC

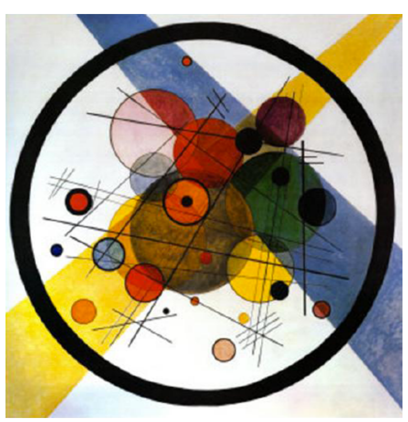
DRAFT 1.1
Geneva, March 24, 2012
CERN report
ECFA report
NuPECC report
LHeC-Note-2011-003 GEN

Draft of the Conceptual Design Report.
Passed referees check.
To be printed this spring.

A Large Hadron Electron Collider at CERN

Report on the Physics and Design
Concepts for Machine and Detector

LHeC Study Group



To be submitted for publication

1

Structure of the small x chapter

talk by Nestor Armesto

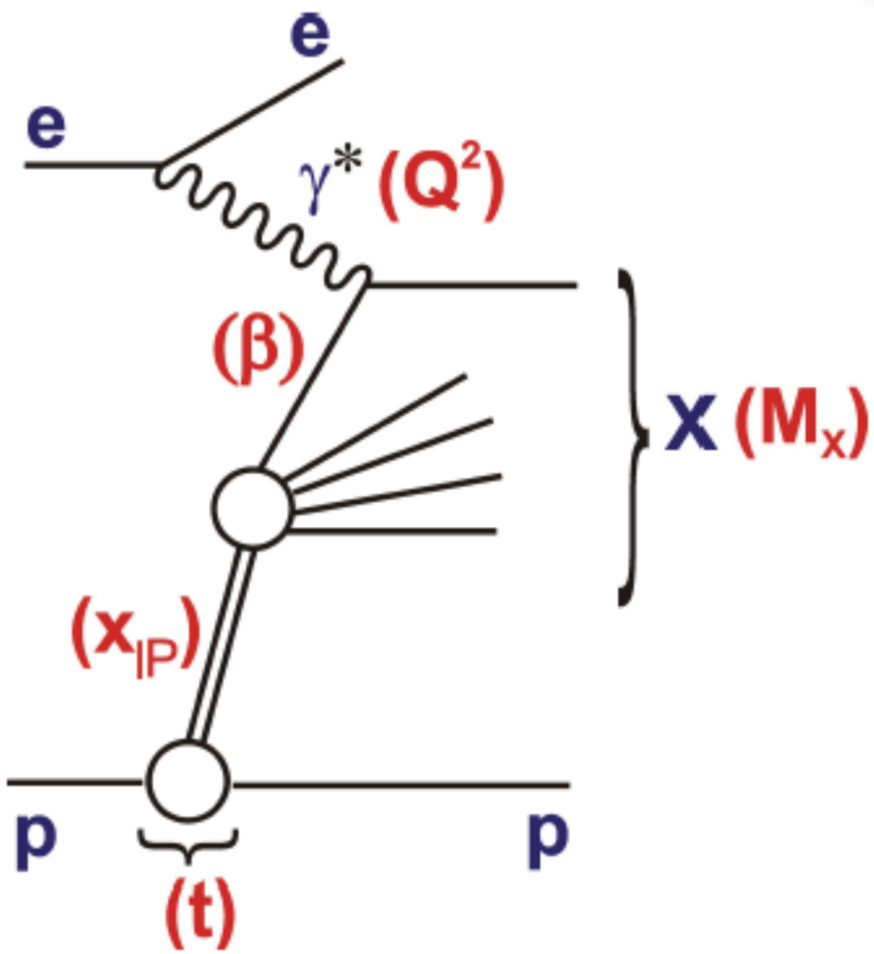
this talk

Small x physics at the LHeC

- Parton Saturation
- PDFs and nonlinear evolution at small x
- Inclusive Diffraction
- Exclusive Production of Vector Mesons
- Deeply Virtual Compton Scattering
- Forward jets and parton dynamics
- DIS on nuclei
- Generalized parton distribution functions
- Unintegrated parton distribution functions

In particular, in order to test/pin down saturation one needs to investigate both inclusive processes (structure functions) and exclusive processes, like vector meson production, which can provide information about impact parameter profile.

Diffraction



$$x_{IP} = \frac{Q^2 + M_X^2 - t}{Q^2 + W^2}$$

momentum fraction of the Pomeron w.r.t hadron

$$\beta = \frac{Q^2}{Q^2 + M_X^2 - t}$$

momentum fraction of parton w.r.t Pomeron

$$x_{Bj} = x_{IP}\beta$$

Theoretical description of such process is in terms color-less exchange : the Pomeron.

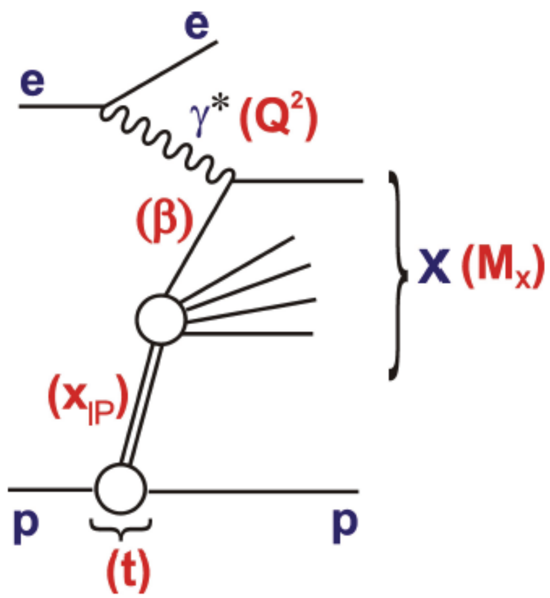
For large scales the QCD factorization was shown.

The diffractive structure functions are convolutions of diffractive pdfs and coefficient functions.

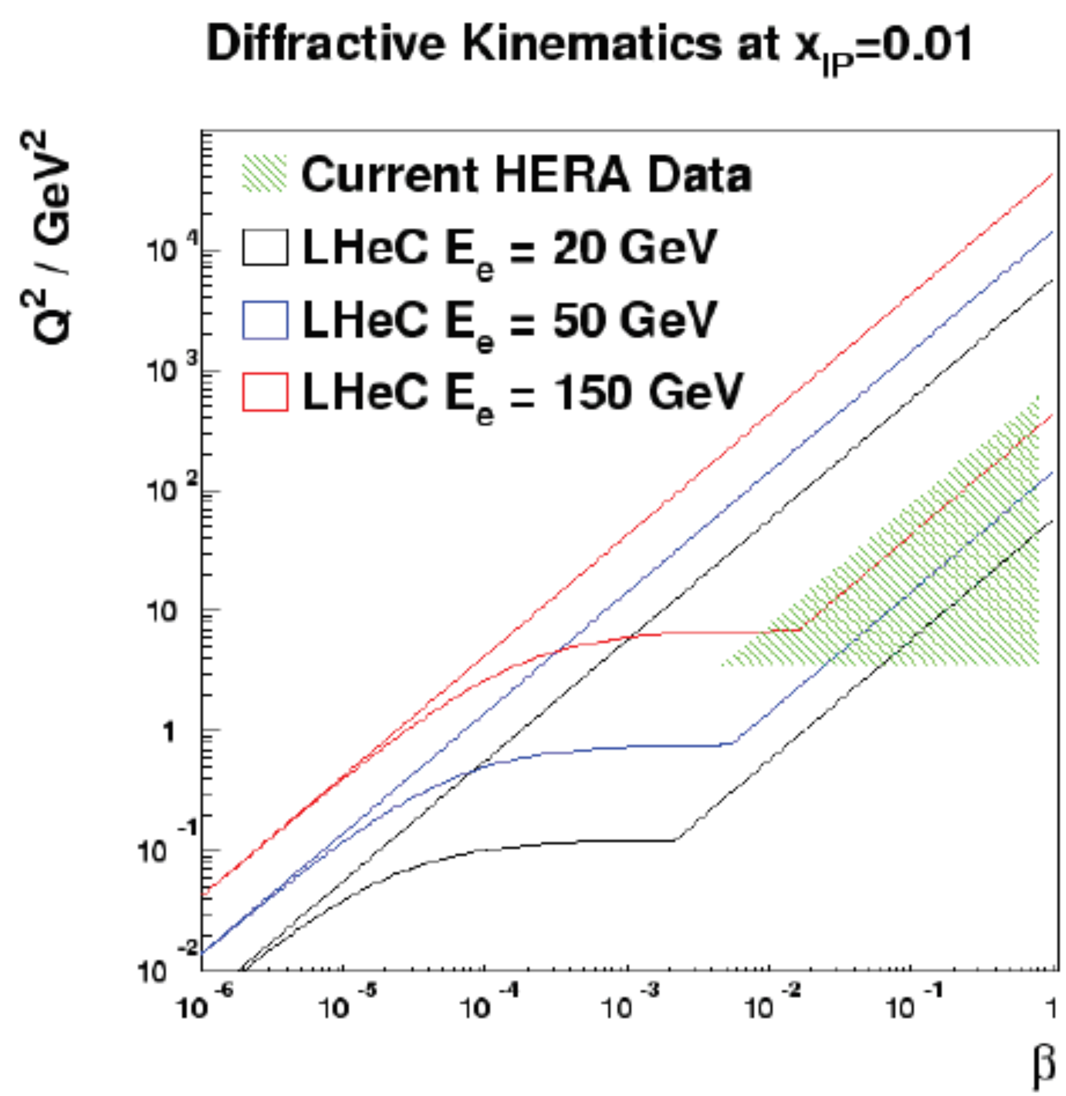
What can be done at LHeC

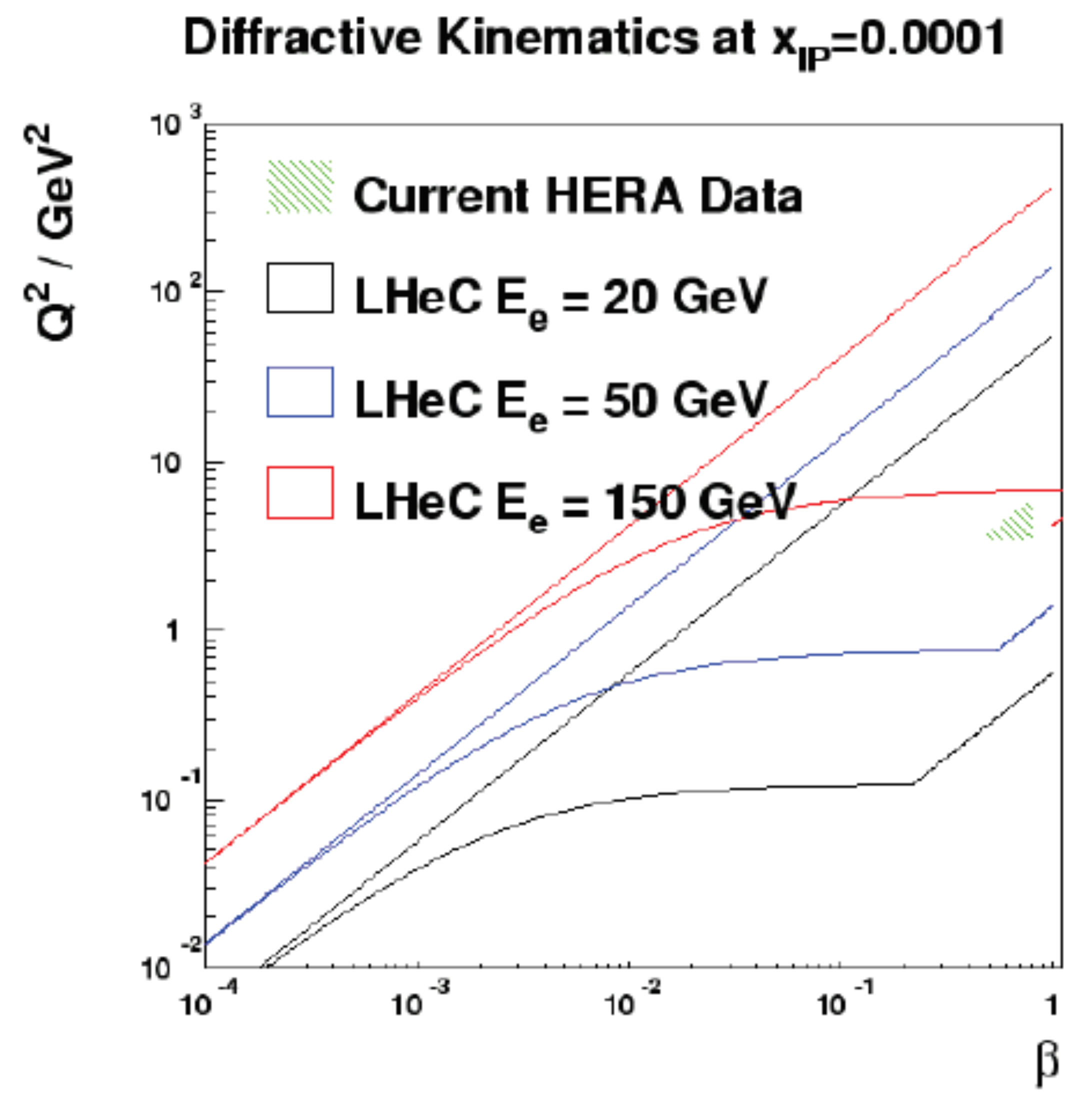
- Tests of factorization of diffractive parton distributions in an extended kinematic range (ep and eA).
- Sensitivity and relation to saturation physics (smaller scales involved).
- New domain for the diffractive masses.
- Study relation between diffraction in ep and shadowing in eA.

Diffractive kinematics



Methods for selection of diffractive events:
Leading proton tagging, large rapidity gap selection





Rapidity gap selection

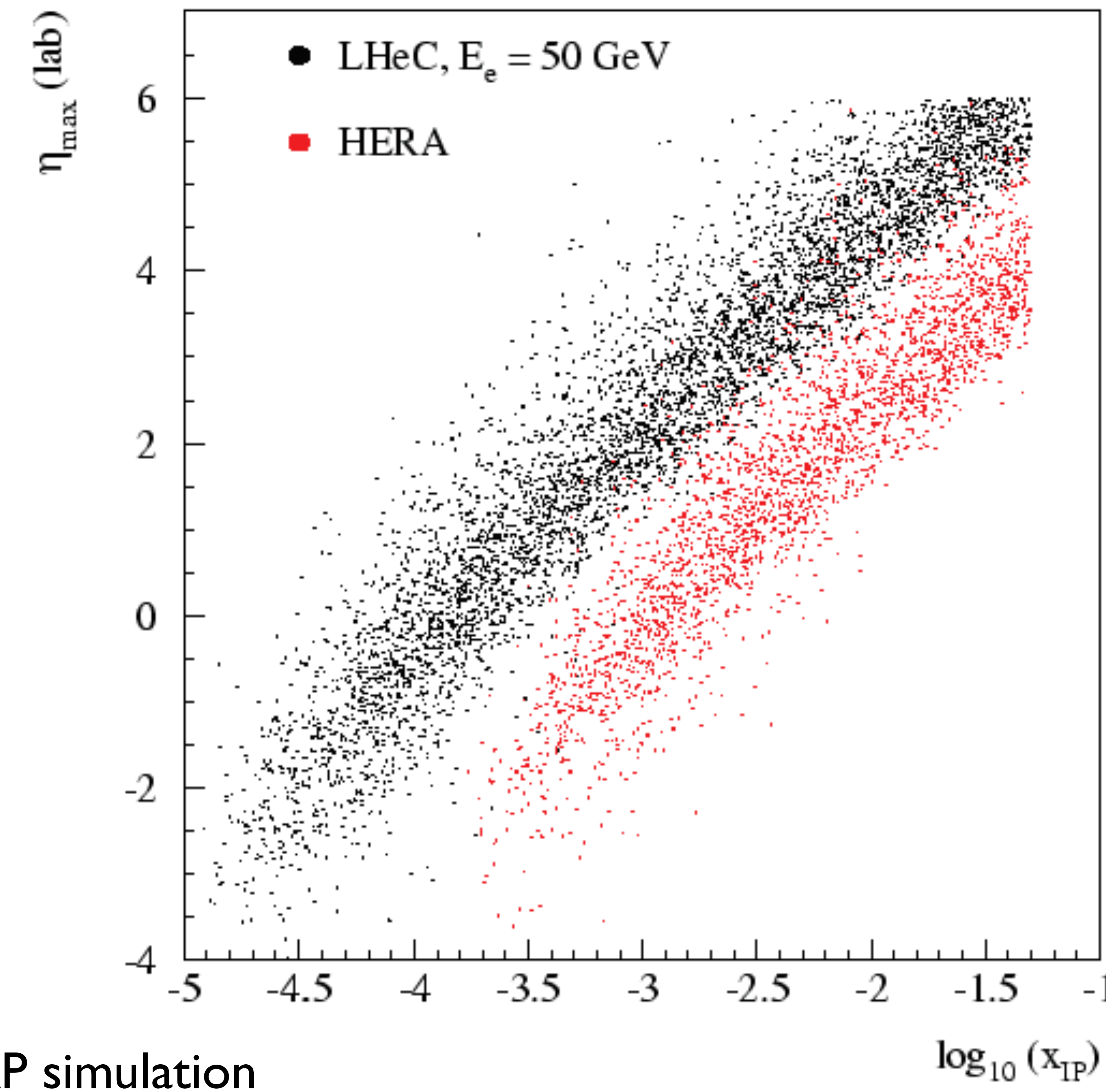
Correlation of x_{IP} with the pseudorapidity of the most forward particle in the diffractive final state $\eta_{\max}$

Cut at $\eta_{\max} = 5$

For larger x_{IP} leading proton method could be used.

Two methods are complementary with some region of common acceptance.

η_{max} from LRG selection ...



RAPGAP simulation

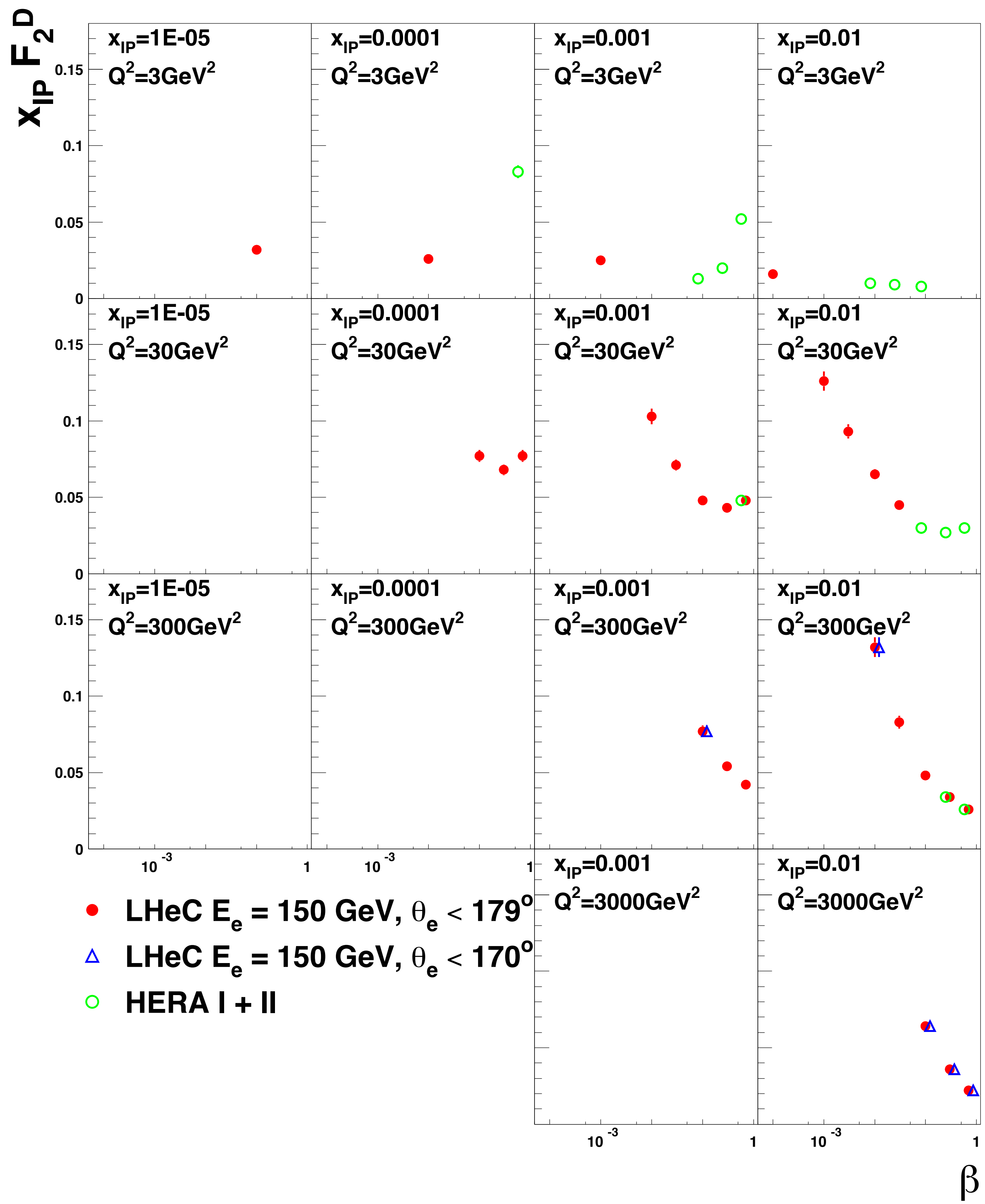
Diffractive structure function

Pseudodata simulated using the large rapidity gap method and leading proton method.

Large differences depending on the acceptance of the detector: 1 vs 10 degree.

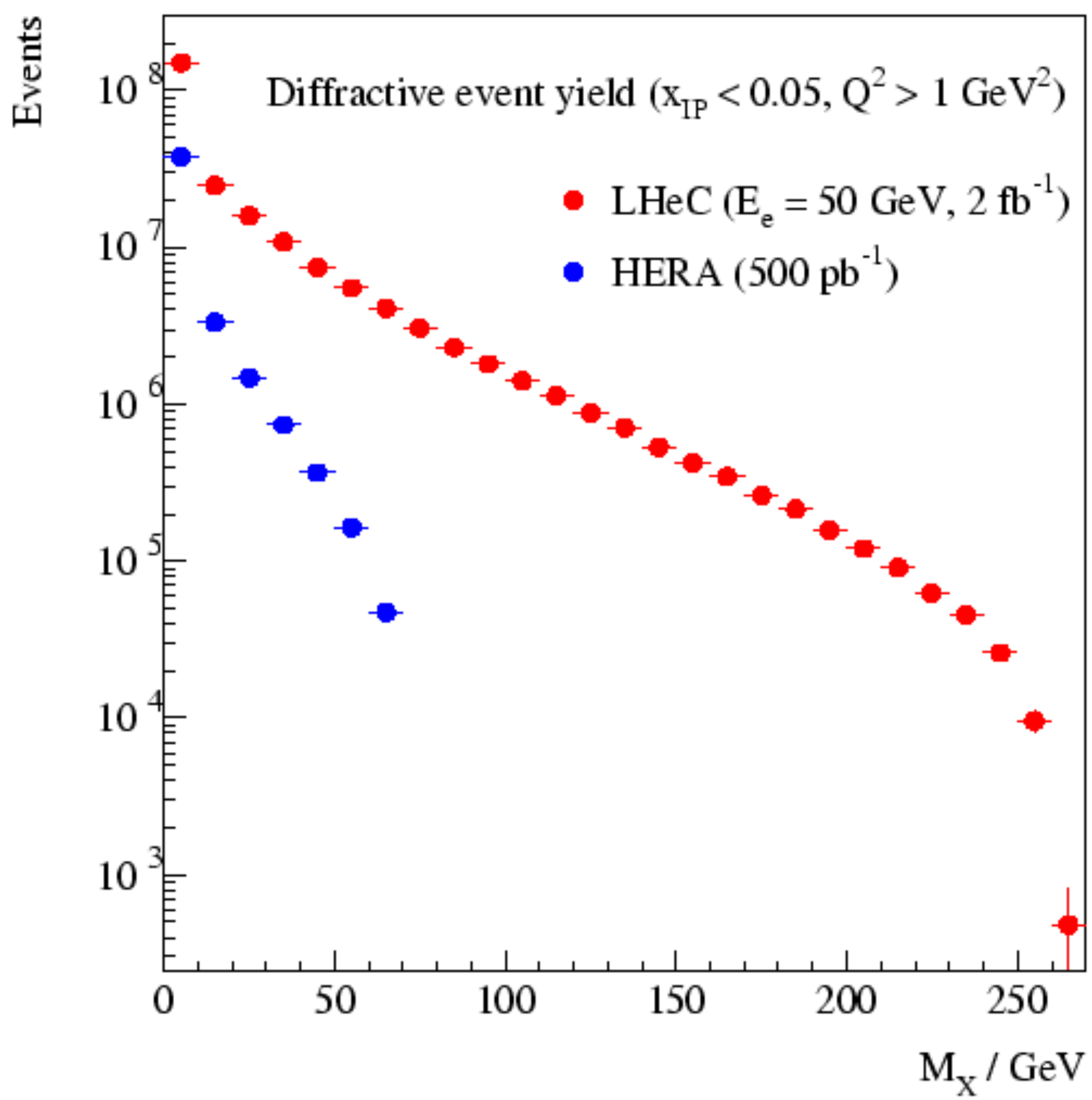
Statistical errors less than 1% for a sample luminosity of $2\ \mathrm{fb}^{-1}$

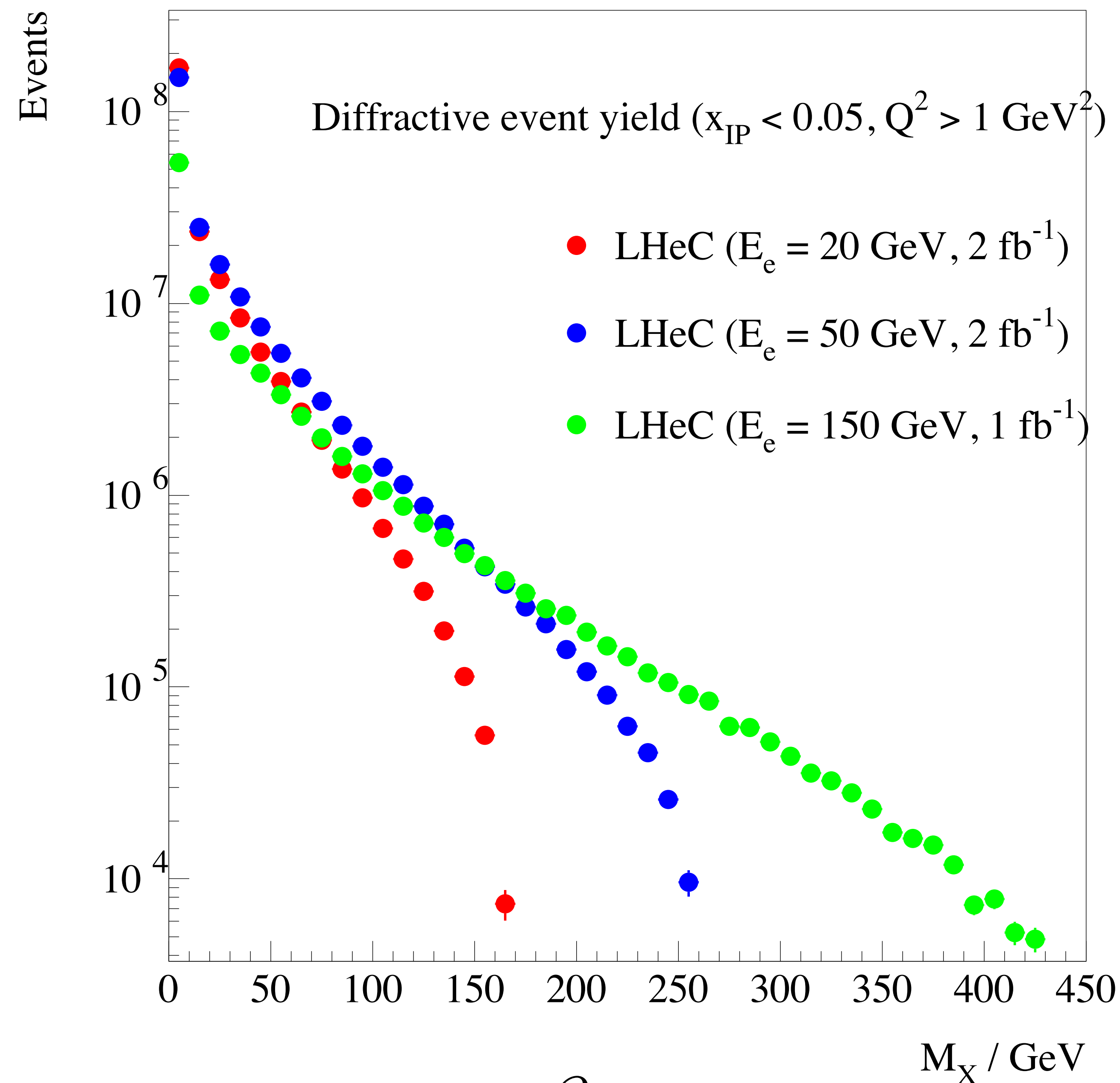
Comparison of HERA data shows huge increase in kinematic range.



Diffractive mass distribution

RAPGAP simulation





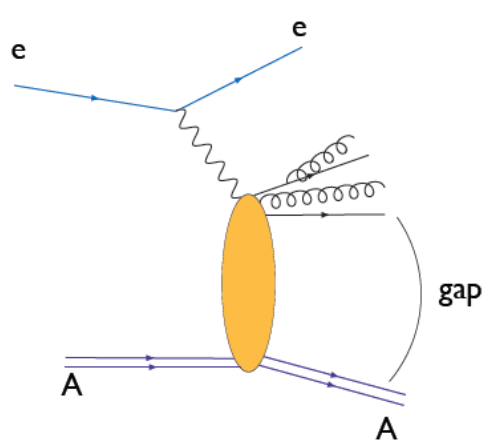
LHeC can explore very low values of β

New domain of diffractive masses.

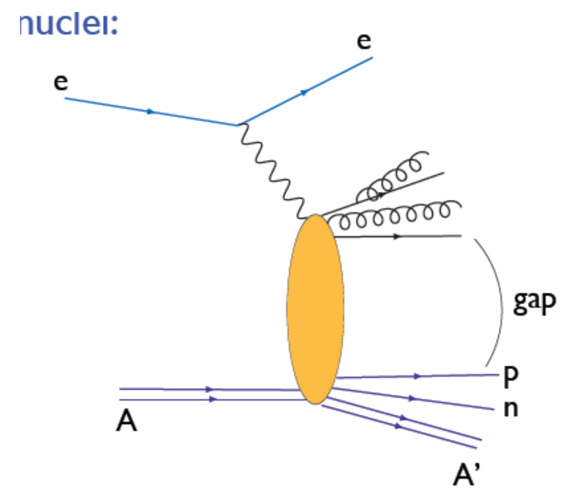
M_X can include W/Z/beauty or any state with 1^-

Inclusive diffraction in eA

Two types of events in the case of scattering off nuclei



coherent



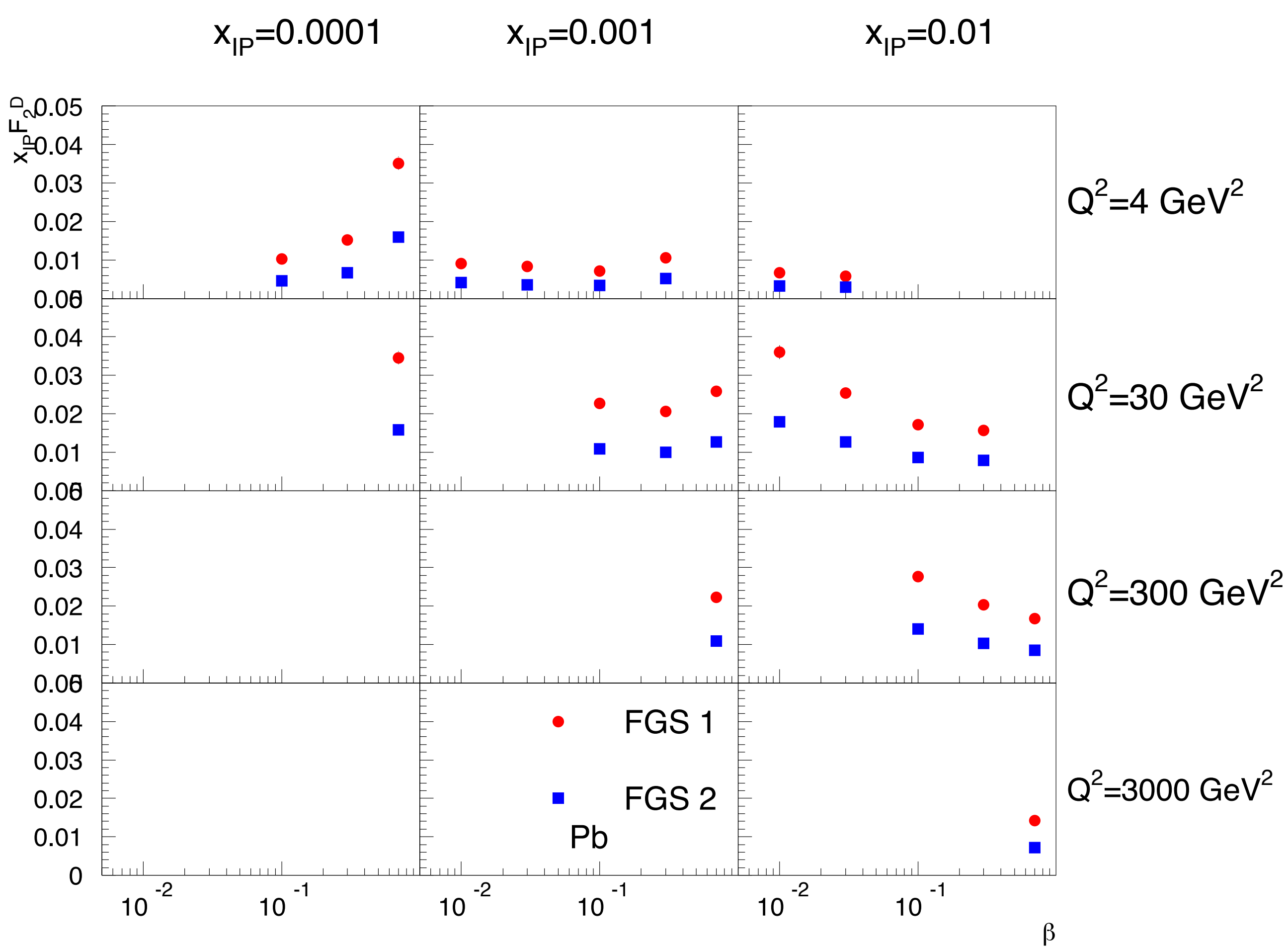
incoherent

Inclusive diffraction on nuclei is an unexplored area.

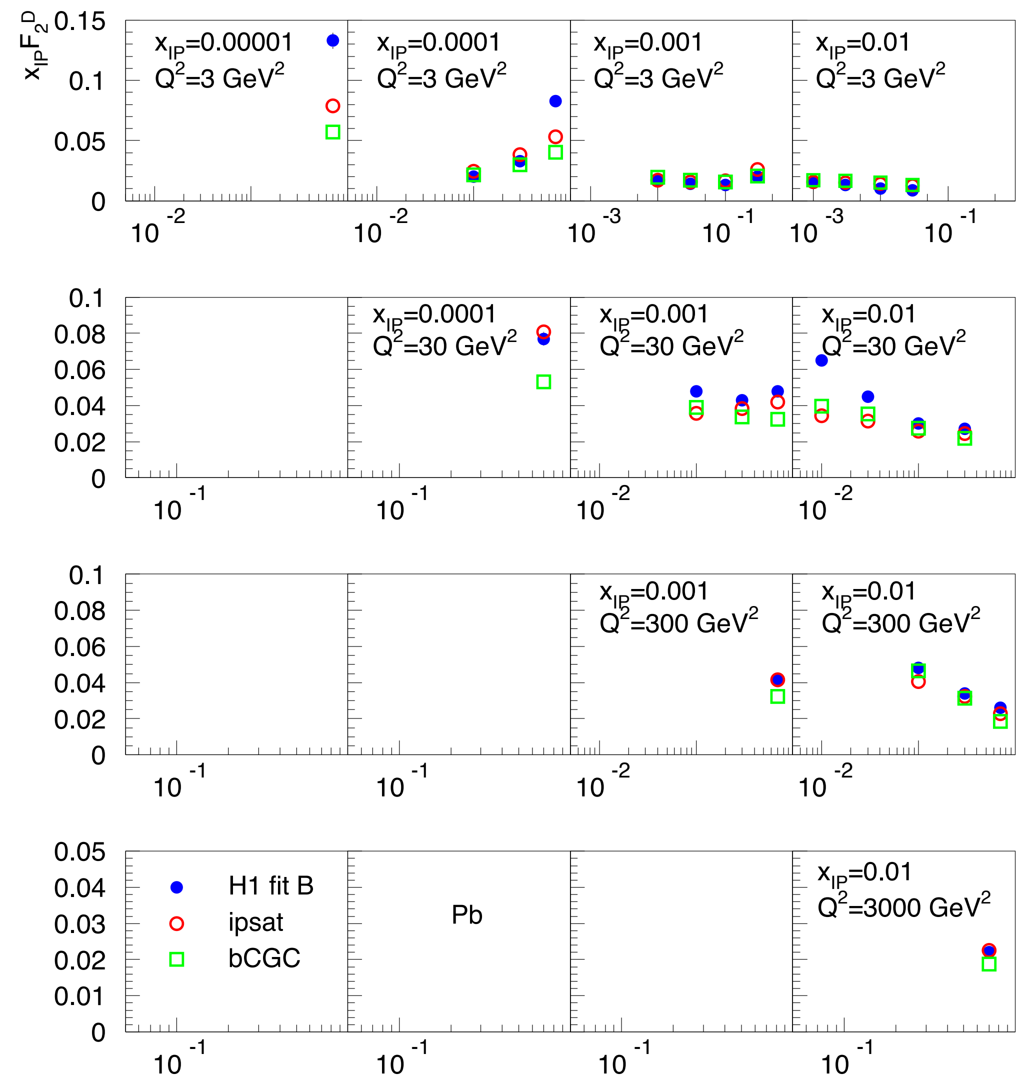
- Can one use factorization for the description of DDIS on nuclei?
- Impact parameter dependence?
- Relation between diffraction in ep and shadowing in eA.
- Current theoretical predictions vary a lot.

Diffractive structure func. in eA

Diffractive structure function for Pb



Frankfurt, Guzey, Strikman. Model based on leading twist shadowing.

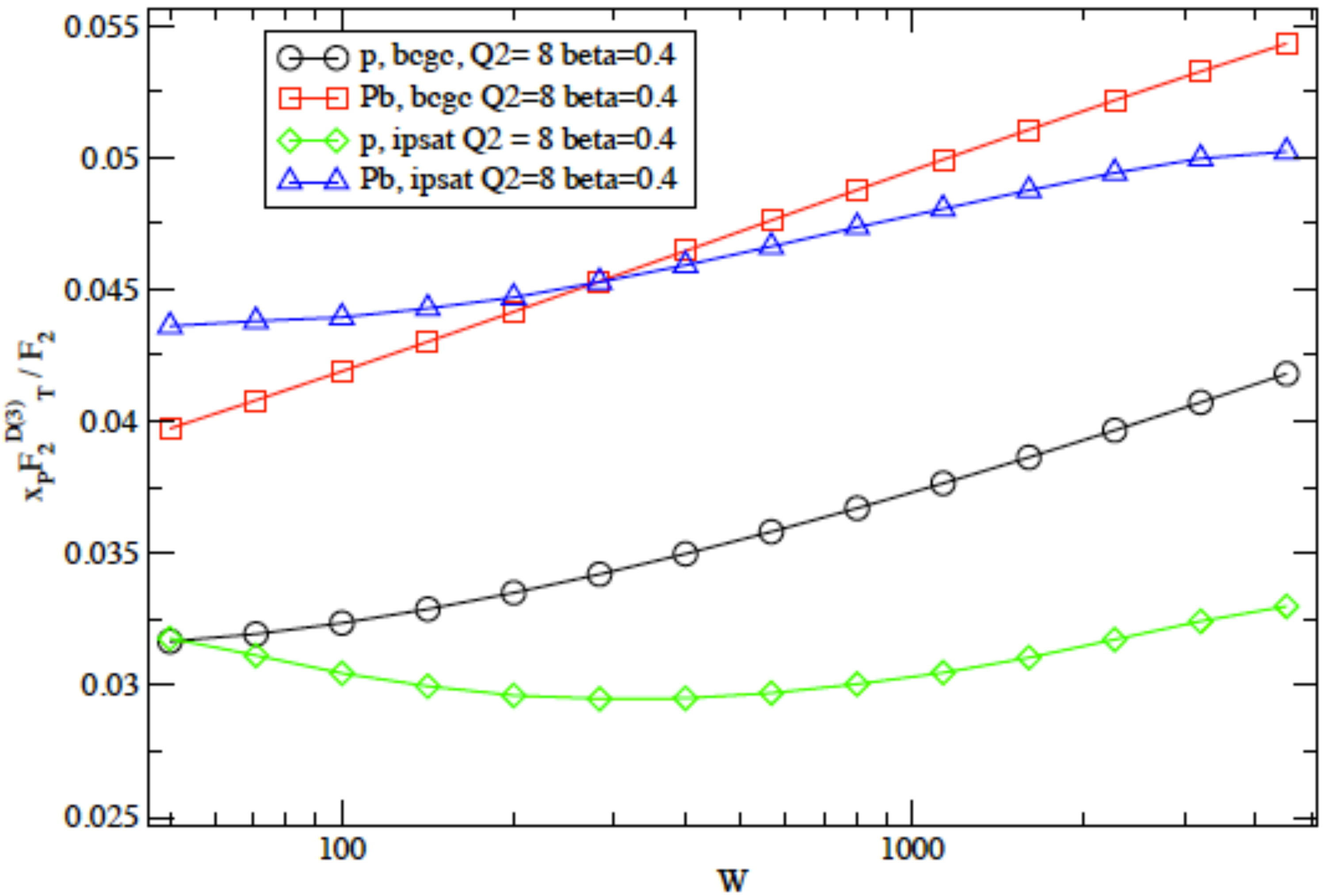


Kowalski, Lappi, Marquet, Venugopalan. Dipole model and Color Glass Condensate.

Models differ a lot in magnitude between the different scenarios within one framework as well as between different frameworks.

Diffractive structure func. in ep/eA

Diffractive to inclusive ratio for protons and Pb



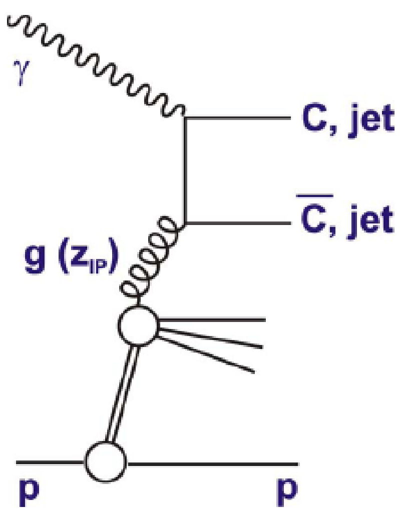
The constant diffractive/total ratio as a function of W can be explained in saturation models: in the black disk limit the energy dependencies approximately cancel in diffractive/total ratio.

Models incorporate saturation but show variation with energy. Large differences between models. Very large sensitivity due to lack of impact parameter information.

Enhanced diffraction in the nuclear case.

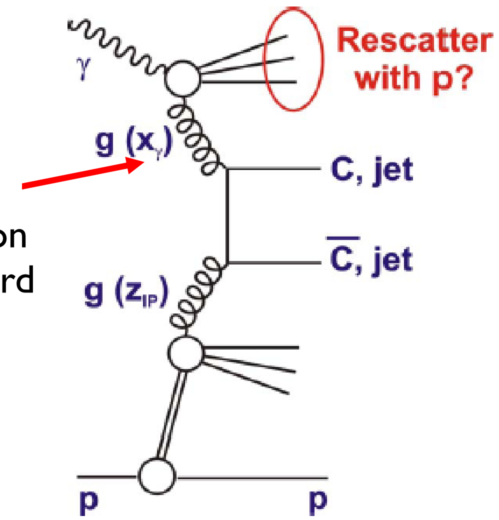
LHeC can provide here essential information on the saturation limit in ep/eA and constrain impact parameter dependence.

Diffractive dijets



direct

fraction of photon momentum in hard subprocess



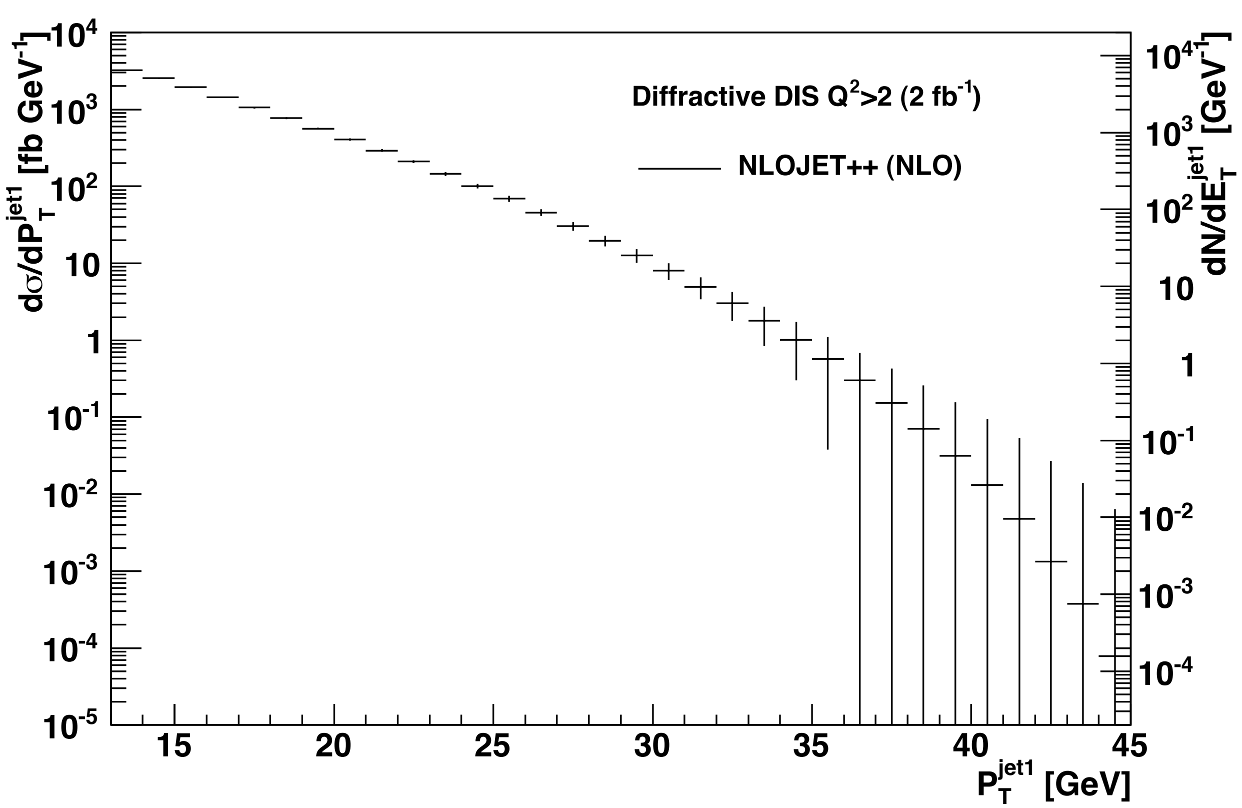
resolved

Factorization in diffraction breaks down at hadron collider.

Is factorization valid for dijet production?

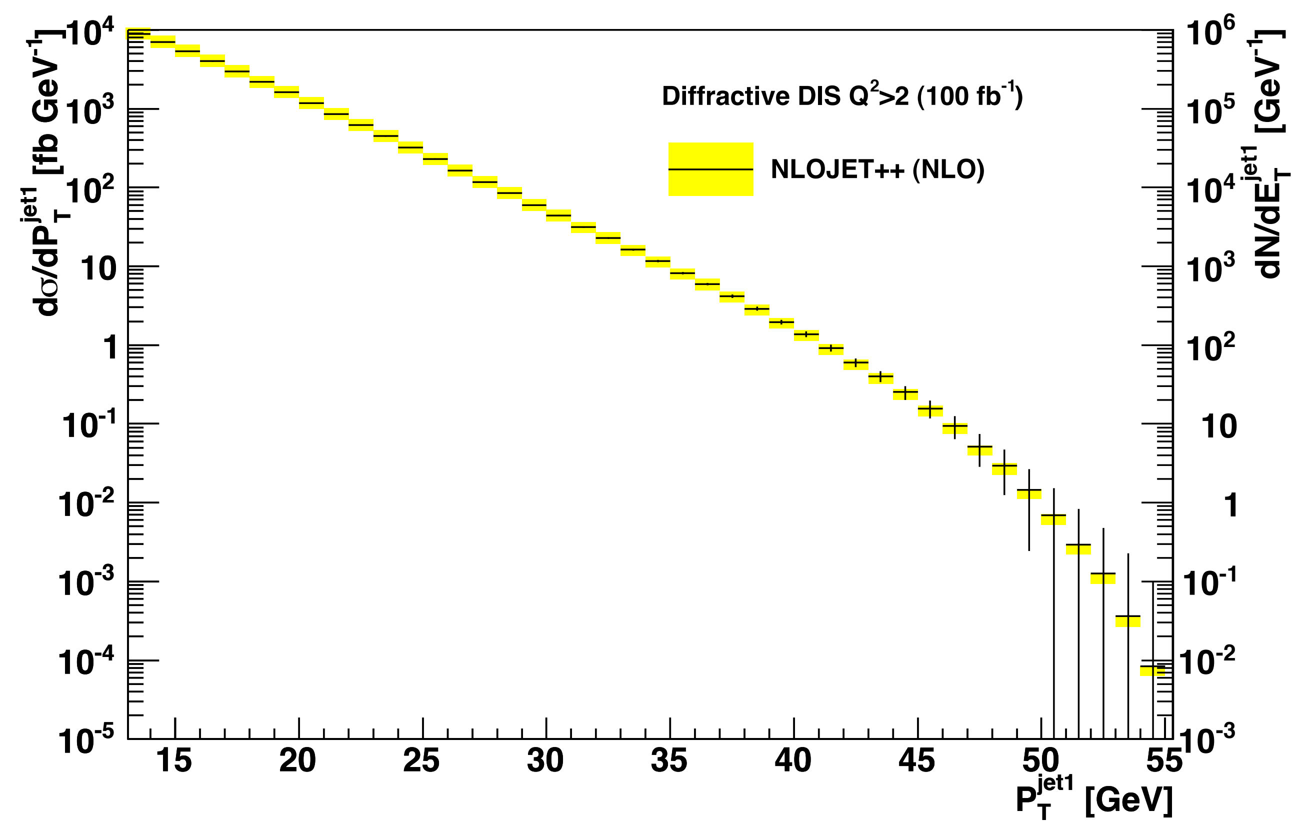
$x_{IP} < 0.01$

$0.2 < y < 0.4$



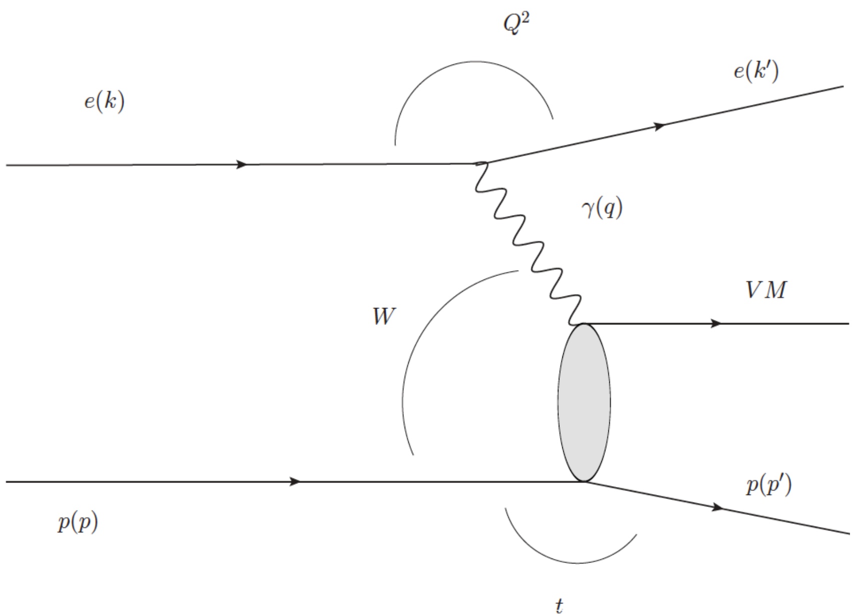
scale uncertainties $0.5\mu, 2\mu$

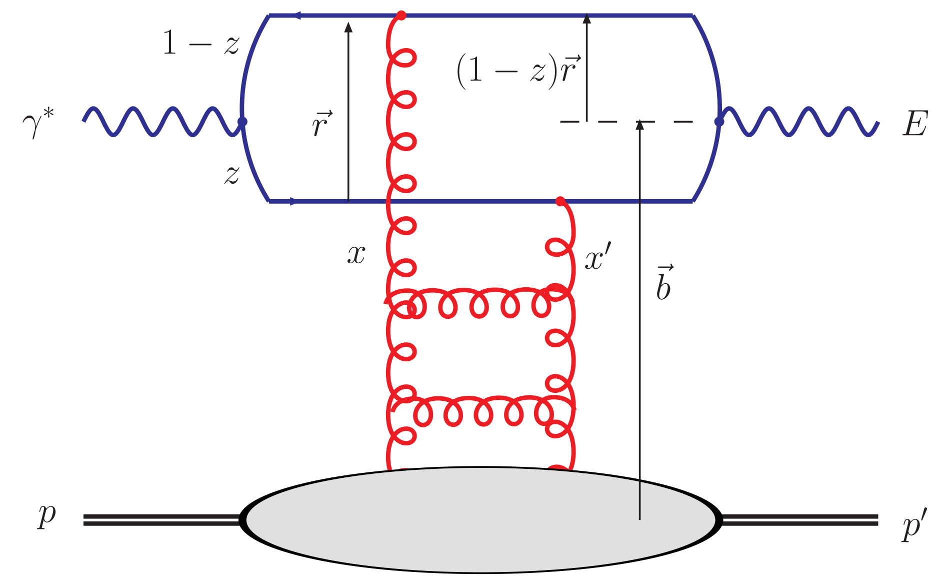
$0.1 < y < 0.7$



Exclusive production of vector mesons

$$\gamma^* p \rightarrow pV \qquad V = \rho, \phi, J/\Psi, \Upsilon$$





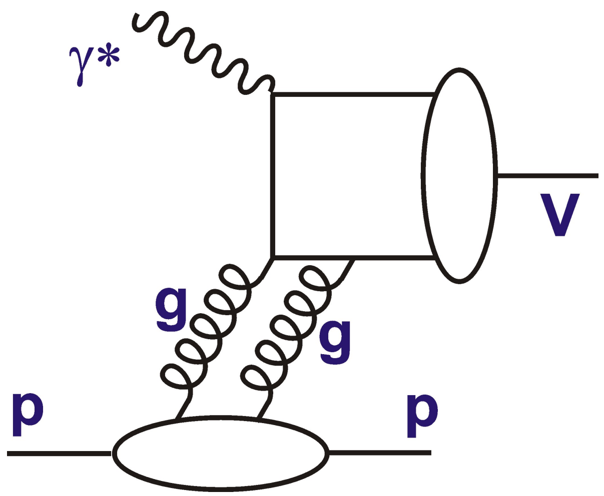
At first approximation described by two gluon exchange

HERA demonstrated that such measurements allow to probe the details of the gluonic structure of the proton.

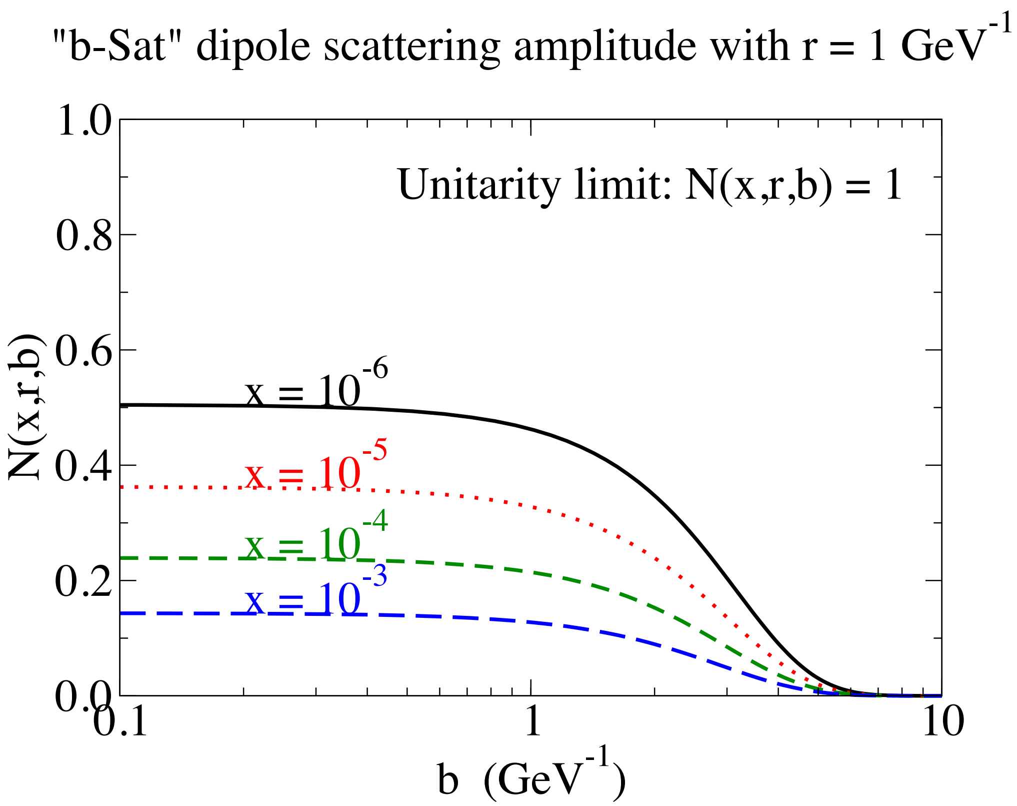
Goals for LHeC:

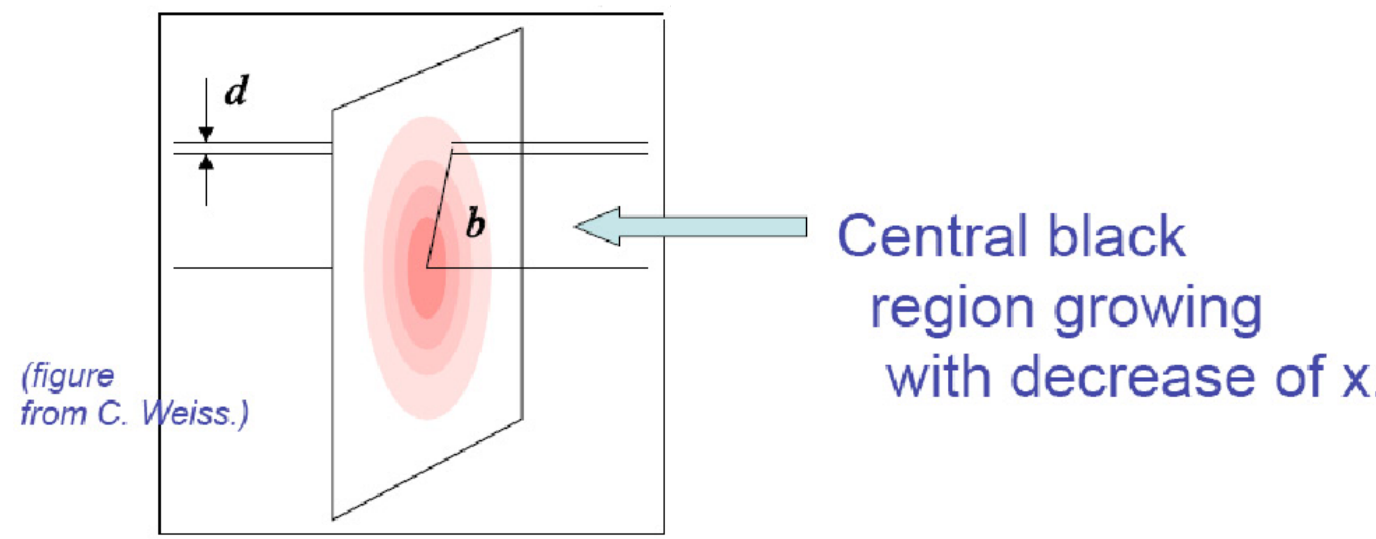
Tests of nonlinear, saturation phenomena.
Tests of GPDs. Large lever arm in Q2 allows to test universality of GPDs.
Impact parameter profile. Diffusion at low x.

Exclusive diffraction and saturation



- Exclusive diffractive production of VM is an excellent process for extracting the dipole amplitude
- Suitable process for estimating the 'blackness' of the interaction.
- t-dependence provides an information about the impact parameter profile of the amplitude.



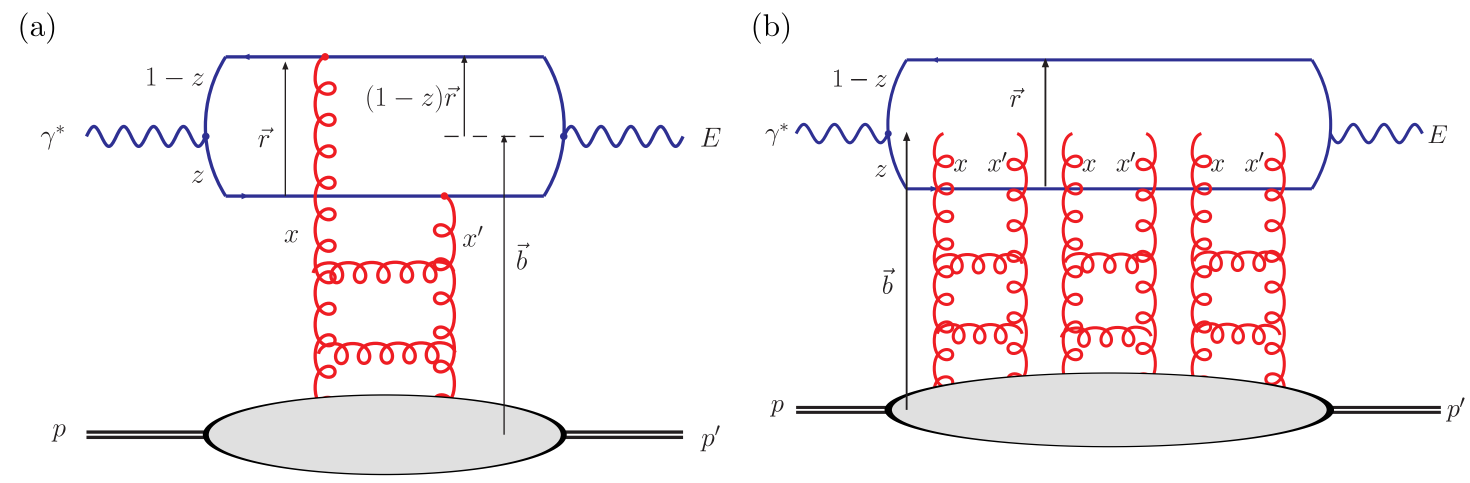


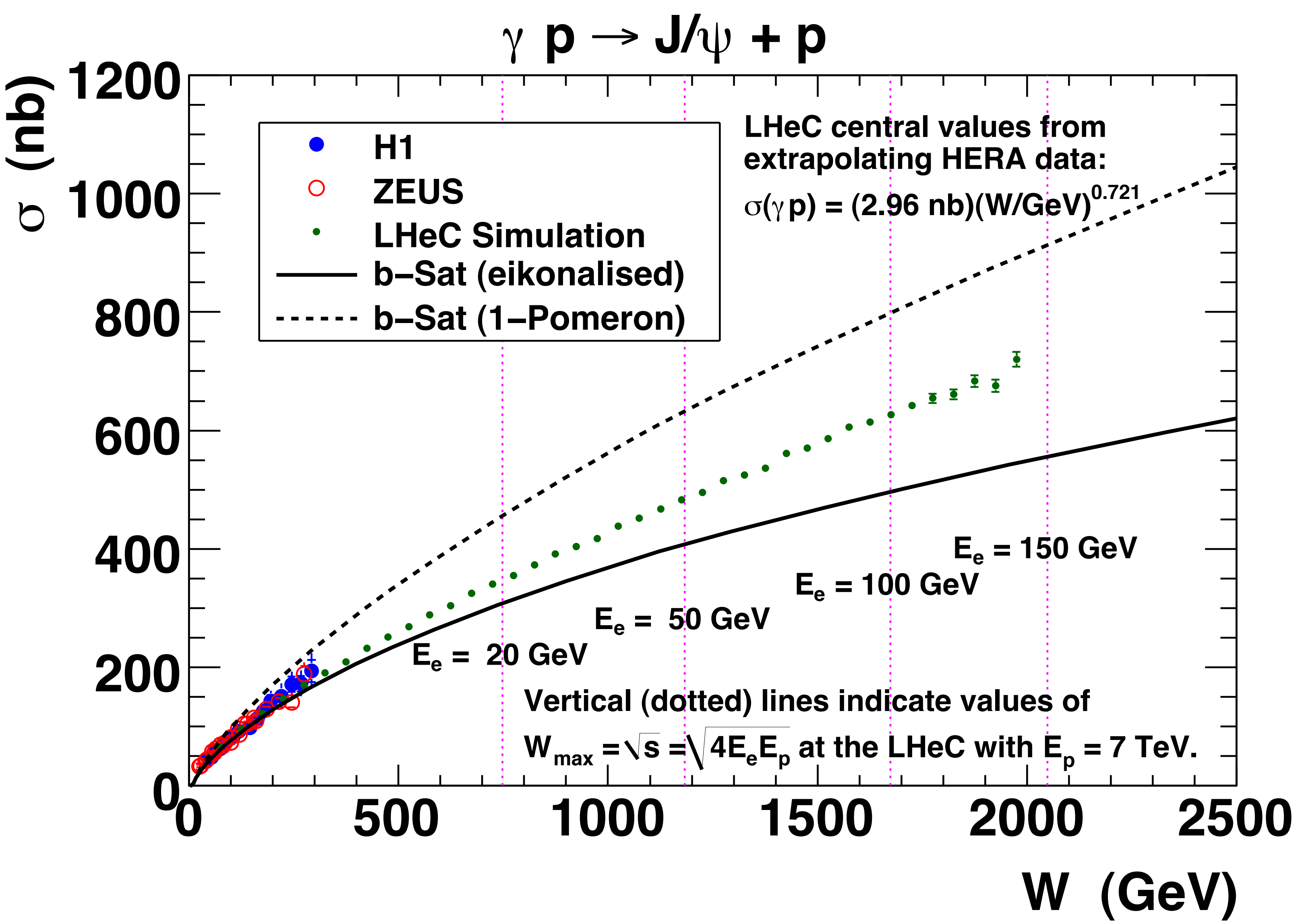
Large momentum transfer t probes small impact parameter where the density of interaction region is most dense.

Exclusive diffraction: vector mesons

$$\sigma^{\gamma p \to J/\Psi + p}(W)$$

- b-Sat dipole model (Golec-Biernat, Wuesthoff, Bartels, Motyka, Kowalski, Watt)
- eikonalised: with saturation
- 1-Pomeron: no saturation





Large effects even for the t-integrated observable.

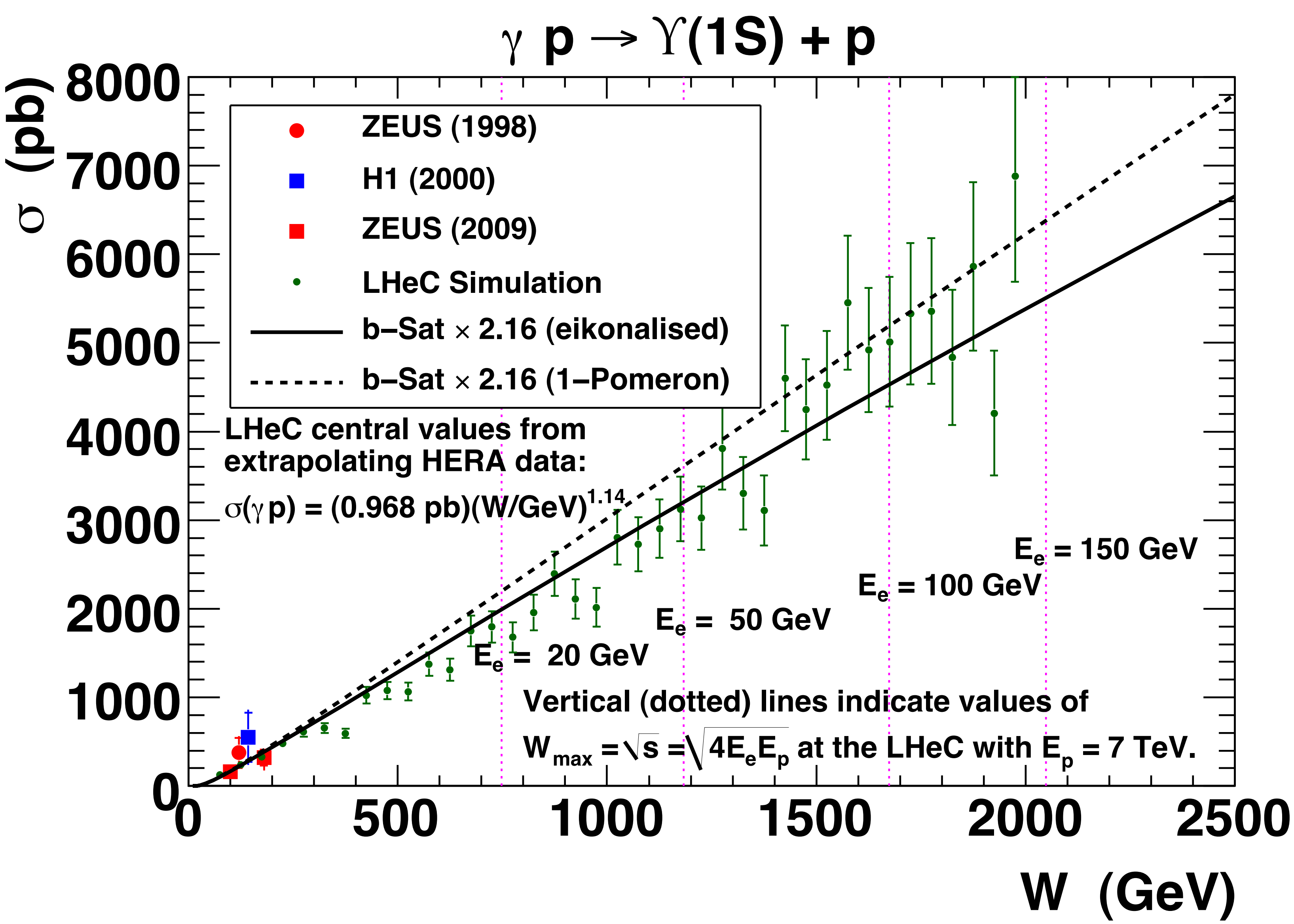
Different W behavior depending whether saturation is included or not.

Simulated data are from extrapolated fit to HERA data

LHeC can distinguish between the different scenarios.

Exclusive diffraction: vector mesons

$$\sigma^{\gamma p \to \Upsilon + p}(W)$$



Similar analysis for heavier states.

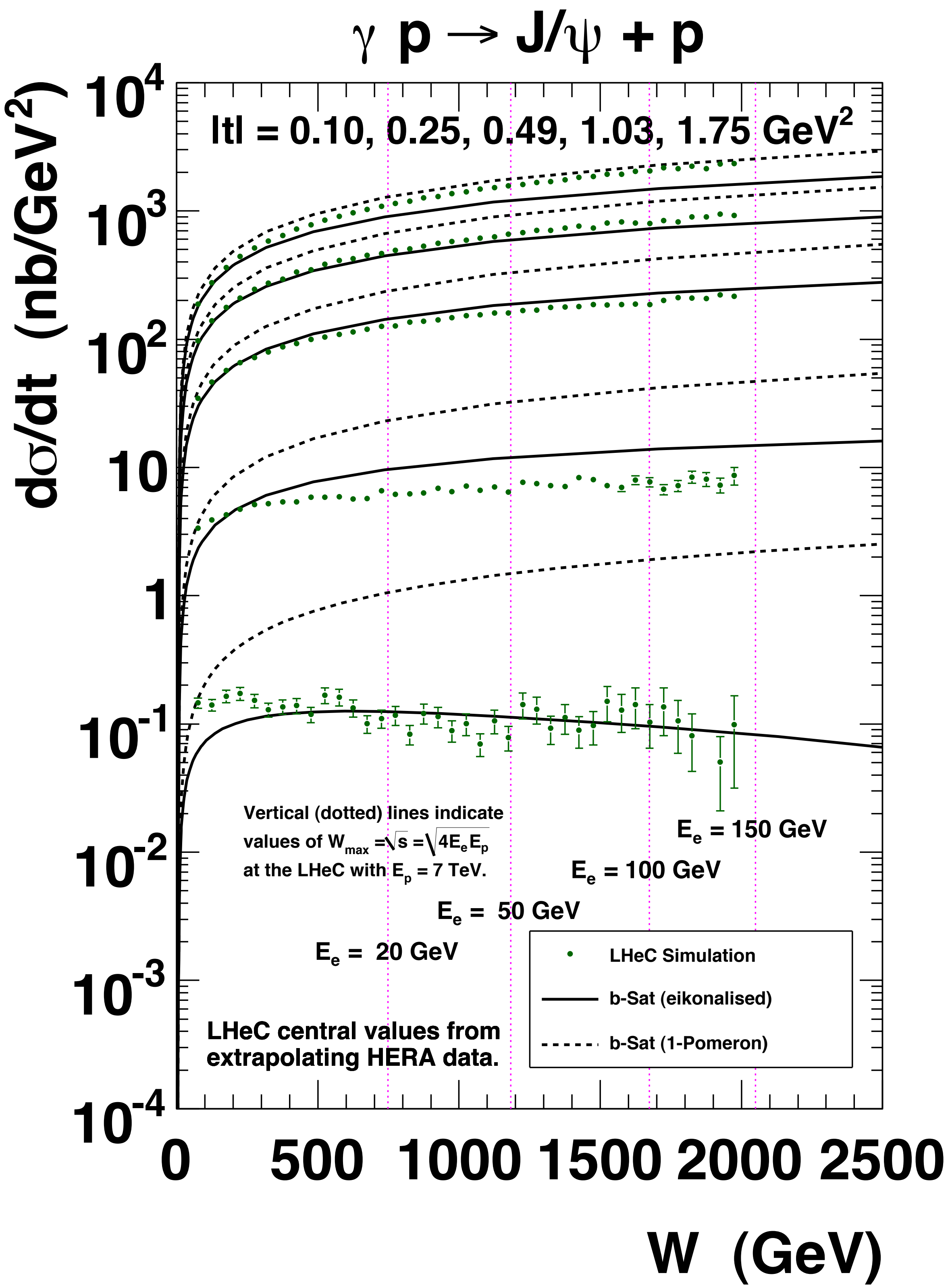
Smaller sensitivity to the saturation effects.

Models do have large uncertainty. Normalization needs to be adjusted to fit the current HERA data.

Precise measurements possible in the regime well beyond HERA kinematics.

Note: the theoretical curves have been rescaled by a factor of 2 to match the data.

Exclusive diffraction: t-dependence

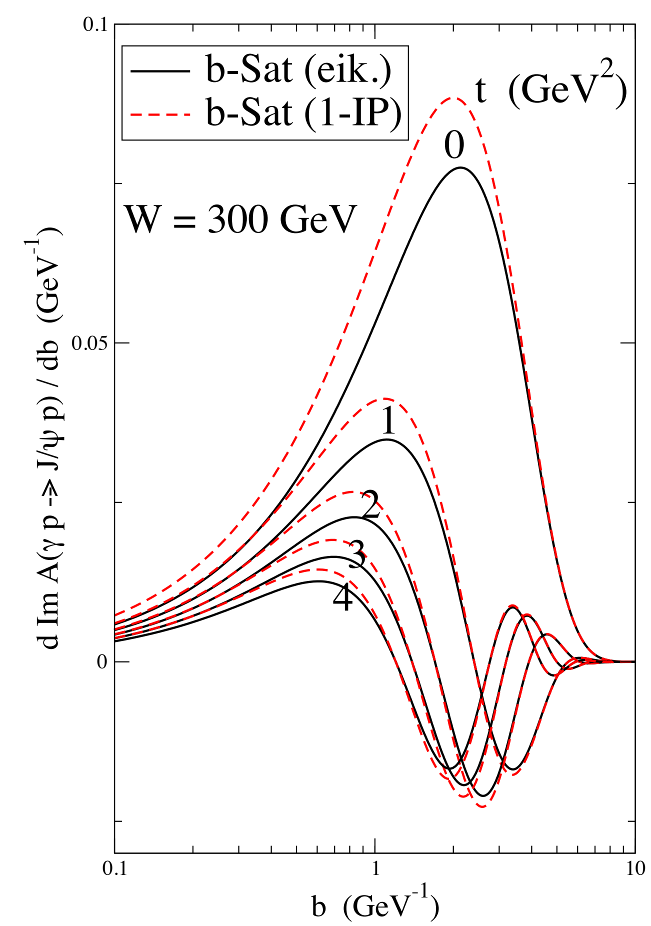


Photoproduction in bins of W and t.

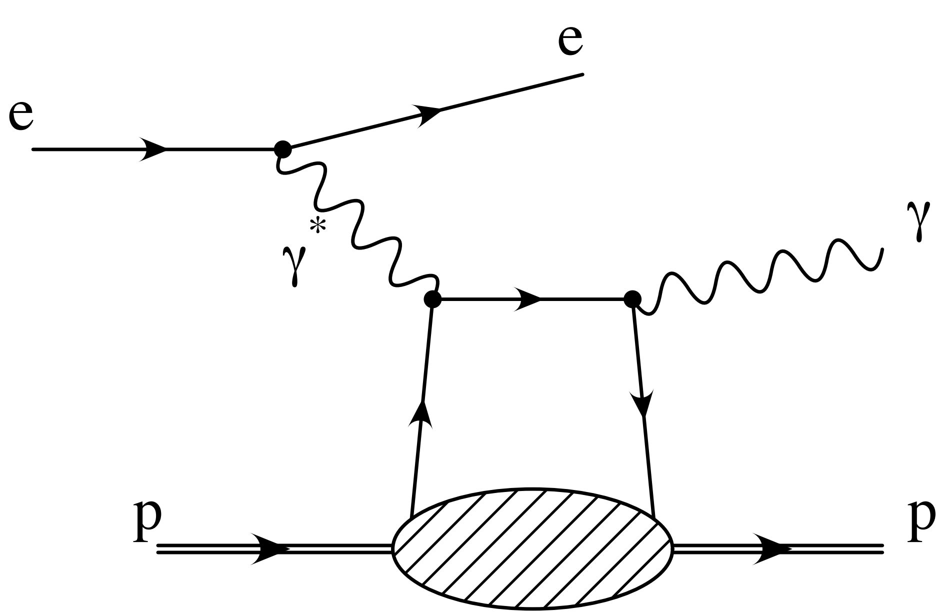
Already for small values of t and smallest energies large discrepancies between the models. LHeC can discriminate.

Large values of t : increased sensitivity to small impact parameters.

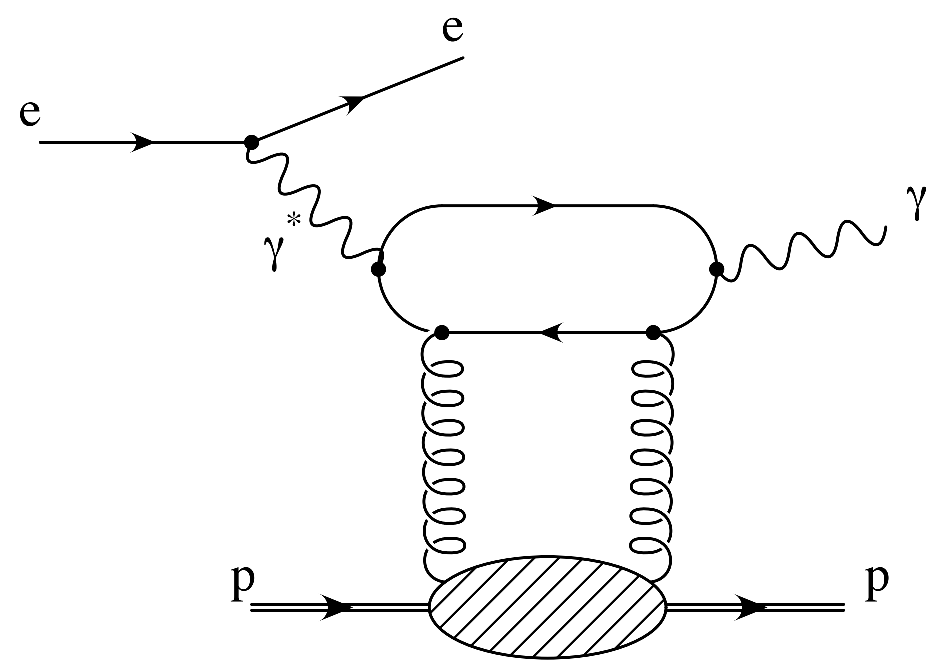
Amplitude as a function of the impact parameter.



Exclusive processes: DVCS



LO



NLO

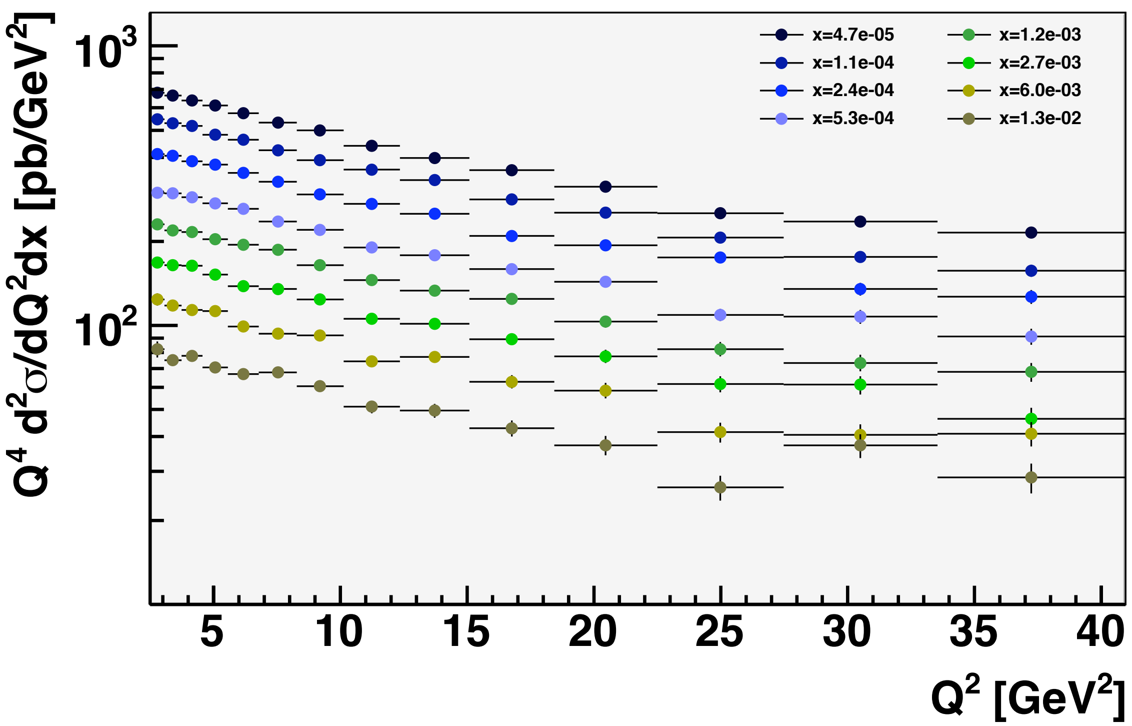
DVCS sensitive to singlet quark and gluon GPDs

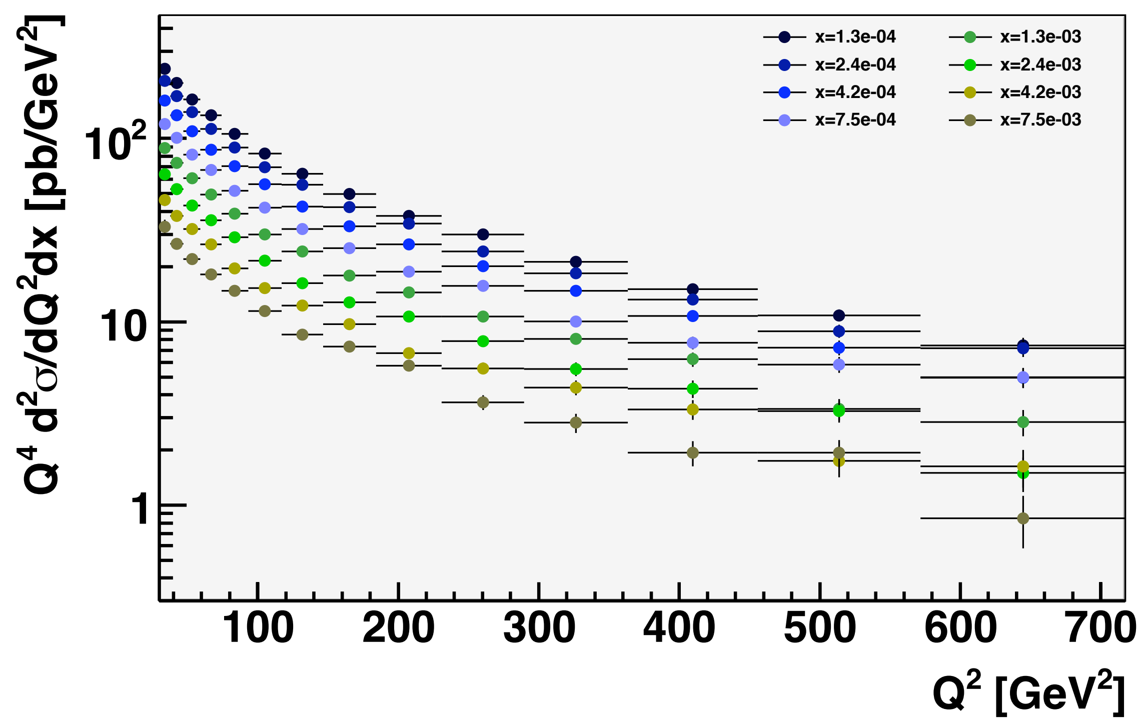
HERA indicate larger size of quark distribution than that of gluons

LHeC could determine the x evolution of both quark and gluon GPDs in a wide kinematic range.

Exclusive processes: DVCS

MILOU generator using Frankfurt, Freund, Strikman model.





$$\mathcal{L} = 1\ \mathrm{fb}^{-1}$$

$$\theta = 1^o$$

$$p_T^\gamma = 2\ \mathrm{GeV}$$

$$2.5 < Q^2 < 40\ \mathrm{GeV}^2$$

low x

$$\mathcal{L} = 100\ \mathrm{fb}^{-1}$$

$$\theta = 10^o$$

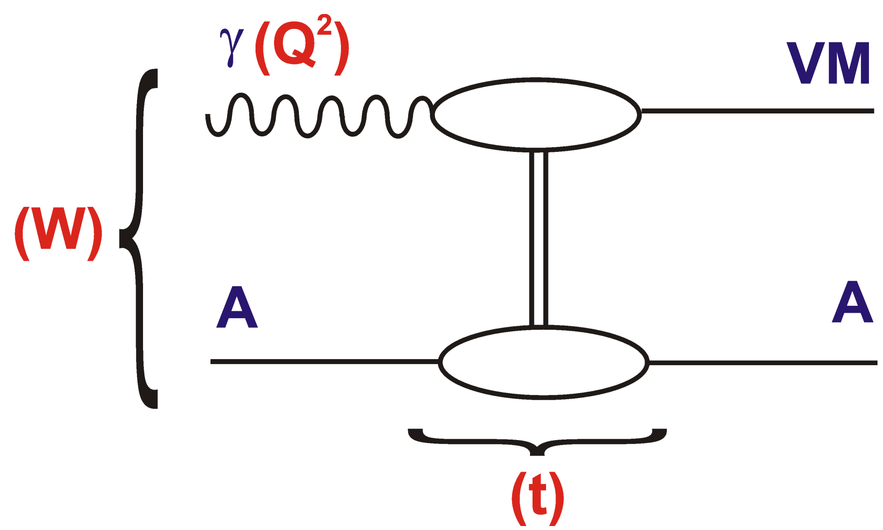
$$p_T^\gamma = 5\ \mathrm{GeV}$$

$$50 < Q^2 \simeq 500\ \mathrm{GeV}^2$$

large scales

Exclusive diffraction on nuclei

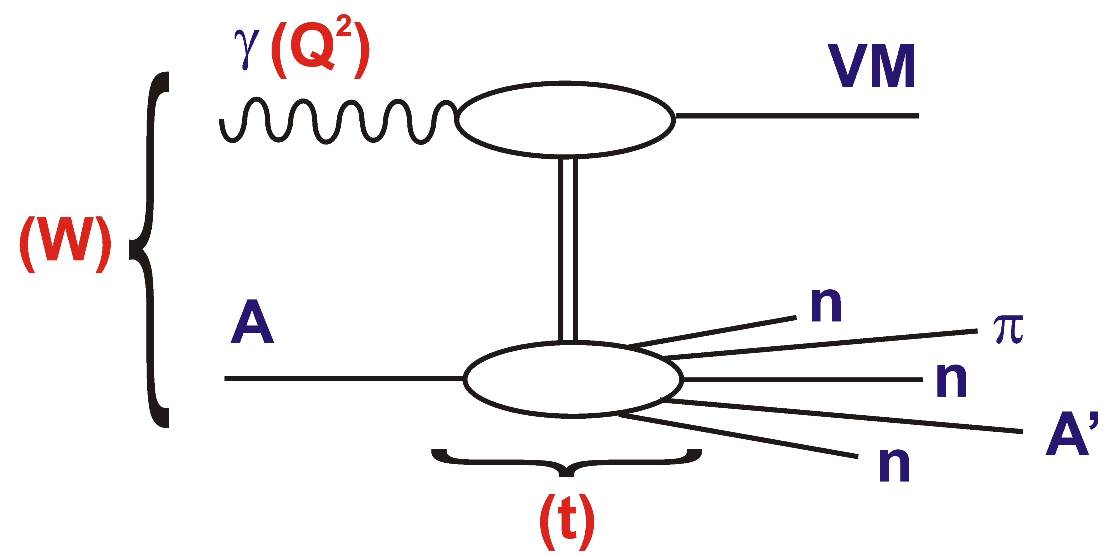
coherent



significant for

$$|t| < 0.02 \text{ GeV}^2$$

incoherent



$$0.05 < |t| < 0.7 \text{ GeV}^2$$

nuclear breakup into nucleons

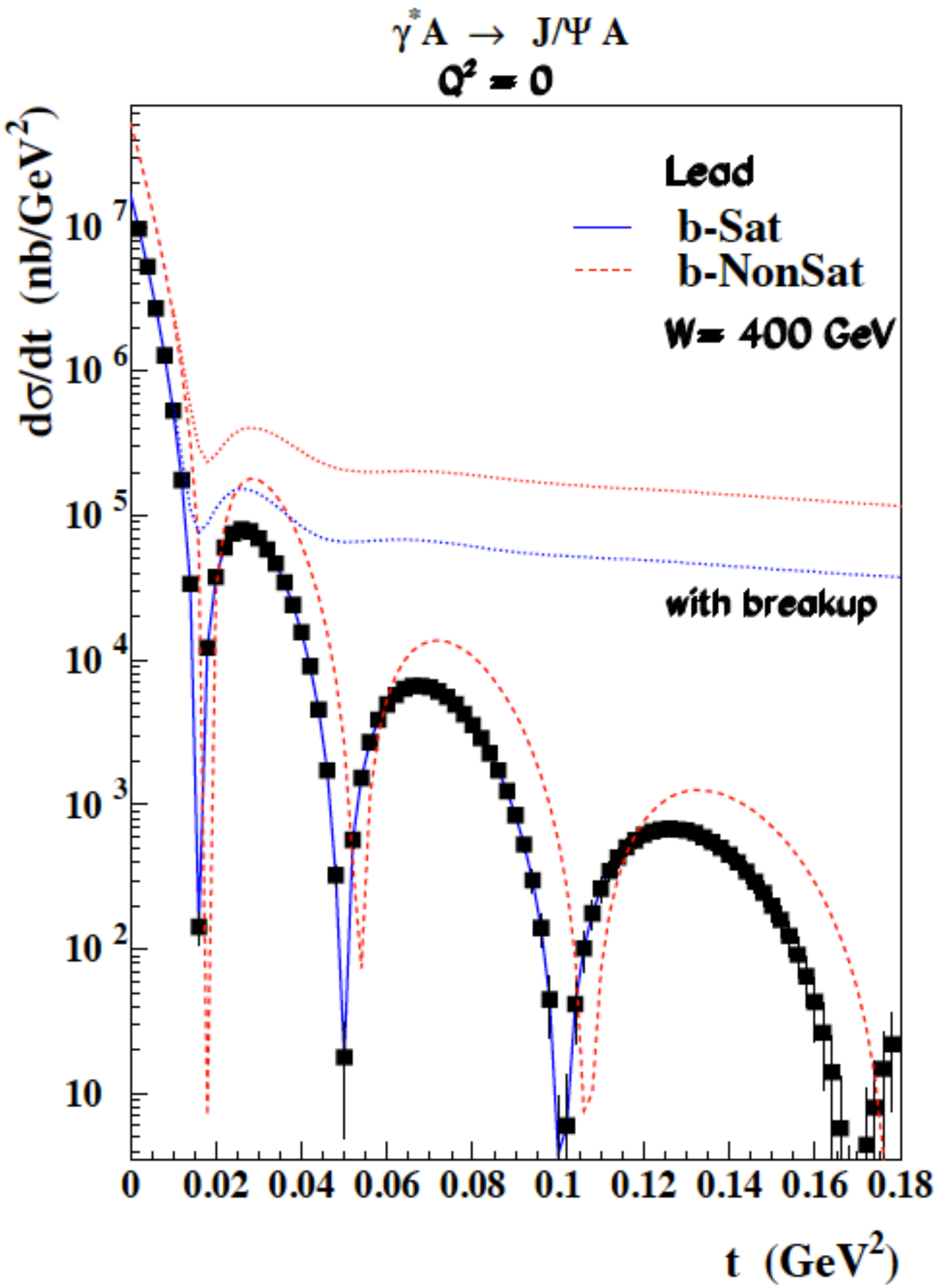
$$|t| > 0.7 \text{ GeV}^2$$

pion production
will become large

Resolving between these two requires forward instrumentation: Zero Degree Calorimeter

Exclusive diffraction on nuclei

Possibility of using this process to learn about the gluon distribution in the nucleus and its spatial distribution. Possible nuclear resonances at small t?



Incoherent production is dominant except for low |t|.

The dip structure is sensitive to details of the impact parameter profile.

Resolving the dips:

$$\Delta t = 2\sqrt{-t}\Delta p_T(J/\Psi)$$

$$\Delta p_T < 10 \text{ MeV}$$

$$\Delta t < 0.01 \text{ GeV}^2$$

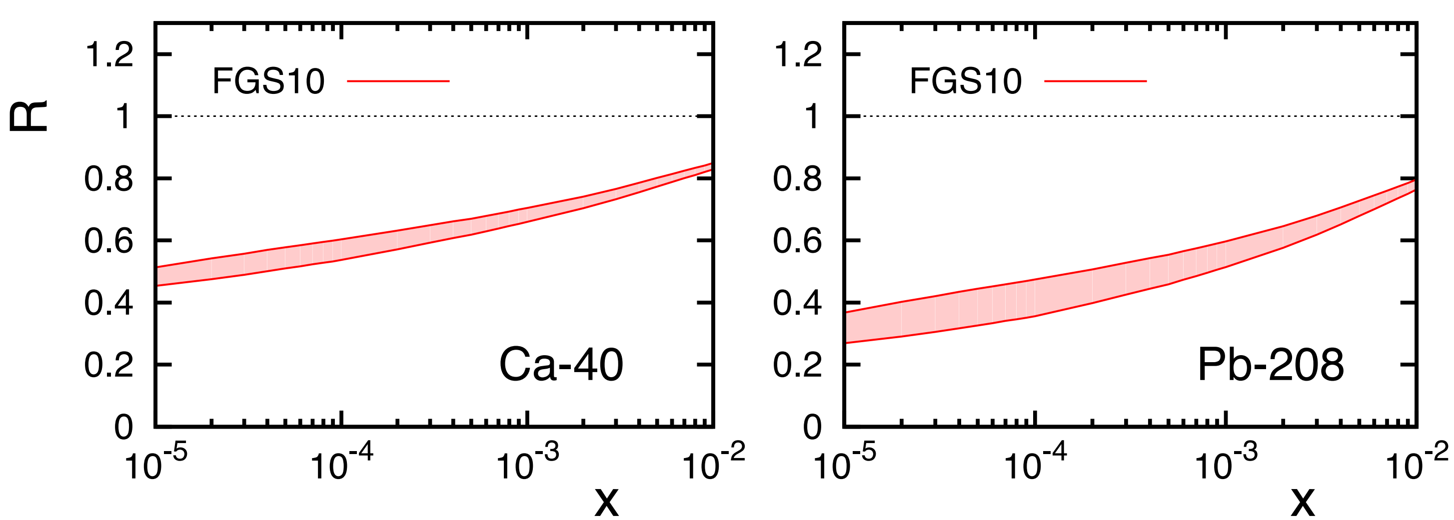
Exclusive diffraction on nuclei

Forward t=0 coherent cross section provides also information about the gluon density in the nucleus.

Strong variation with energy and mass number A.

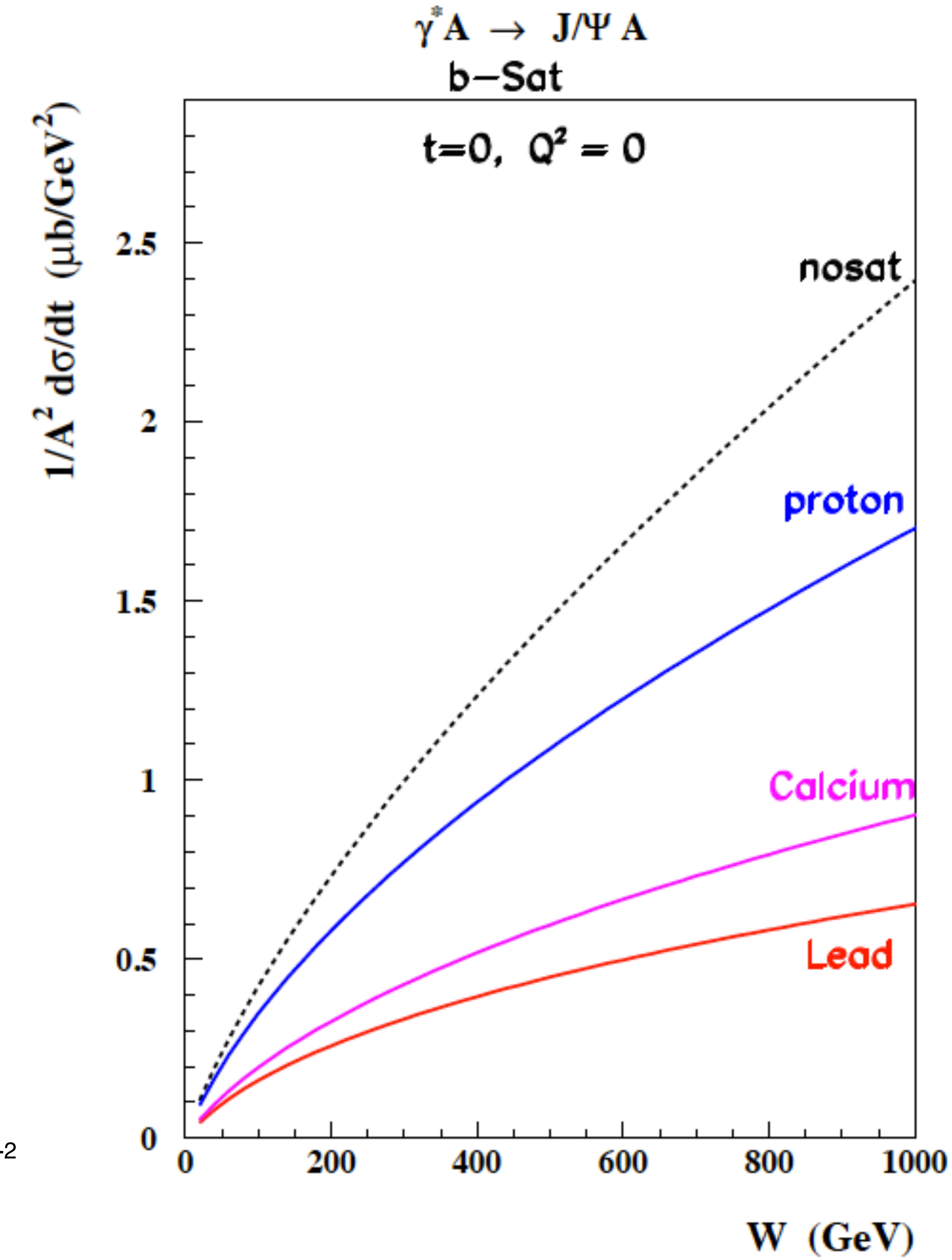
Large sensitivity to saturation and shadowing effects.

Nuclear modification ration for the gluon density squared.



$$Q^2 = M_{J/\Psi}^2$$

Energy dependence for different targets.



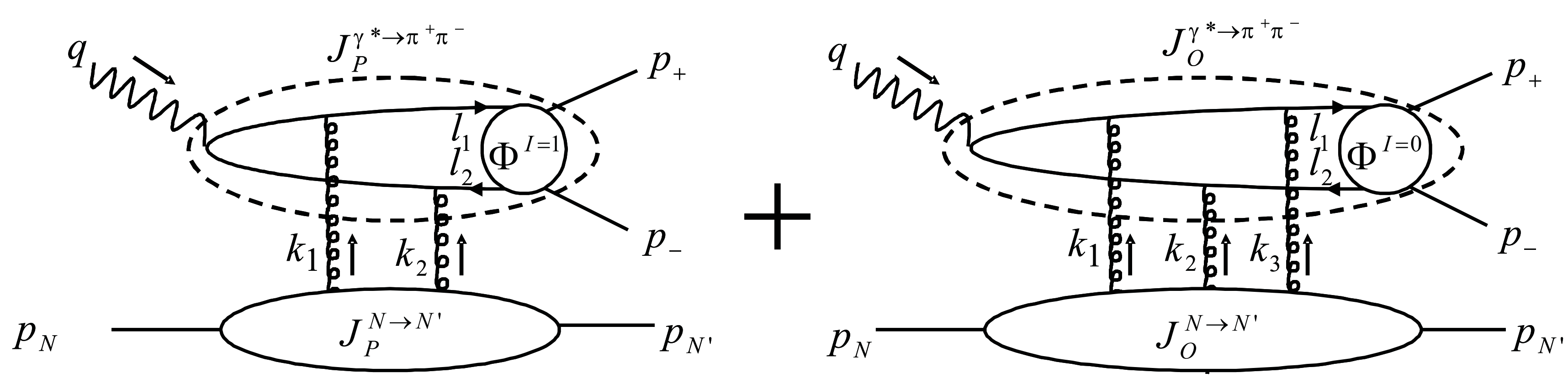
Odderon at the LHeC

- Odderon is a C odd partner of the Pomeron. In QCD in the lowest order it is a system of three non-interacting gluons.
- In leading ln1/x its evolution is given by the Bartels-Kwiecinski-Praszalowicz evolution equation.
- Search performed at HERA, bounds put on the cross sections.
- The cross sections will not grow with energy (should be constant). High luminosity at LHeC will help in searches for different channels.

$$\gamma^* p \to C p \quad C = \pi^0, \eta, \eta', \eta_c, \eta_b$$

Another process: Exclusive photo or electroproduction of two pions

Pair may be in C-symmetric or C-antisymmetric state.
Pomeron contributes to C^+ Odderon contributes to C^-



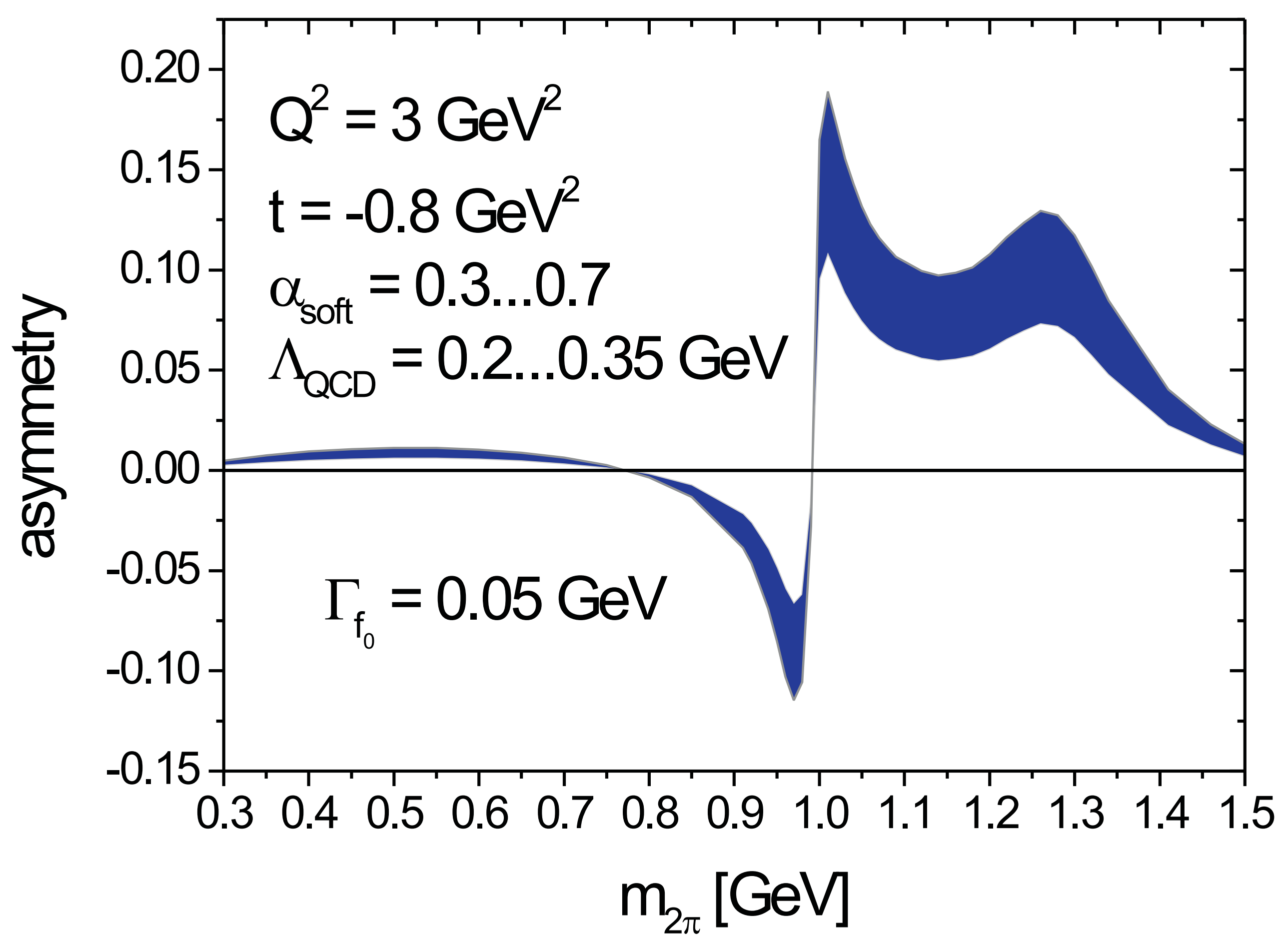
Odderon and charge asymmetry

Charge asymmetry of two pions:

$$A(Q^2, t, m_{2\pi}^2) = \frac{\int \cos\theta \, d\sigma(W^2, Q^2, t, m_{2\pi}^2, \theta)}{\int d\sigma(W^2, Q^2, t, m_{2\pi}^2, \theta)} = \frac{\int_{-1}^{1} \cos\theta \, d\cos\theta \, 2 \, \mathrm{Re}\left[\mathcal{M}_P^{\gamma_L^*} (\mathcal{M}_O^{\gamma_L^*})^*\right]}{\int_{-1}^{1} d\cos\theta \left[|\mathcal{M}_P^{\gamma_L^*}|^2 + |\mathcal{M}_O^{\gamma_L^*}|^2\right]},$$

θ polar decay angle of π^+ in the rest frame of two-pion system

Sensitive to the interference of the amplitudes with Pomeron and Odderon exchange.



Summary

- LHeC has an unprecedented potential for exploring small x physics and high parton density regime.
- Inclusive Diffraction: QCD factorization tests, diffractive parton densities, nonlinear effects.
- Exclusive vector meson production and Deeply Virtual Compton Scattering: constraints on gluon and quark GPDs, impact parameter profile, saturation.
- Other processes: Odderon searches.
- Inclusive diffraction in eA: unexplored regime, huge model dependencies, LHeC can confirm or exclude many scenarios.

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