Exclusive and diffractive observables at small-x at the LHeC

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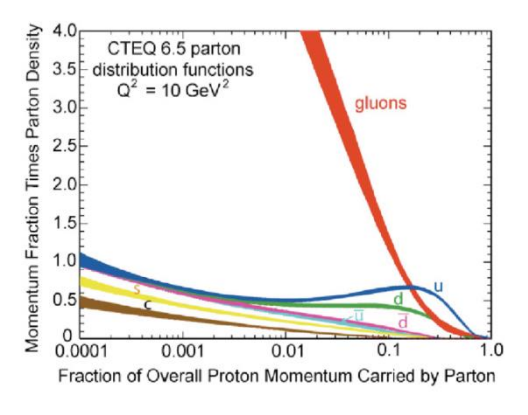
for LHeC Study group

Low x 2013, May-June, 2013, Israel

LHEC KINEMATICS



Web pages: cern.ch/lhec

Somewhere, somehow the low x growth of x-section must be tamed to satisfy unitarity! Non-linear terms in evolution equations?

Main aim of low x at LHeC is to observe and understand:

- associated microscopic dynamics → Q^2 as large as possible
- transition between perturbative and non-perturbative dynamics in QCD

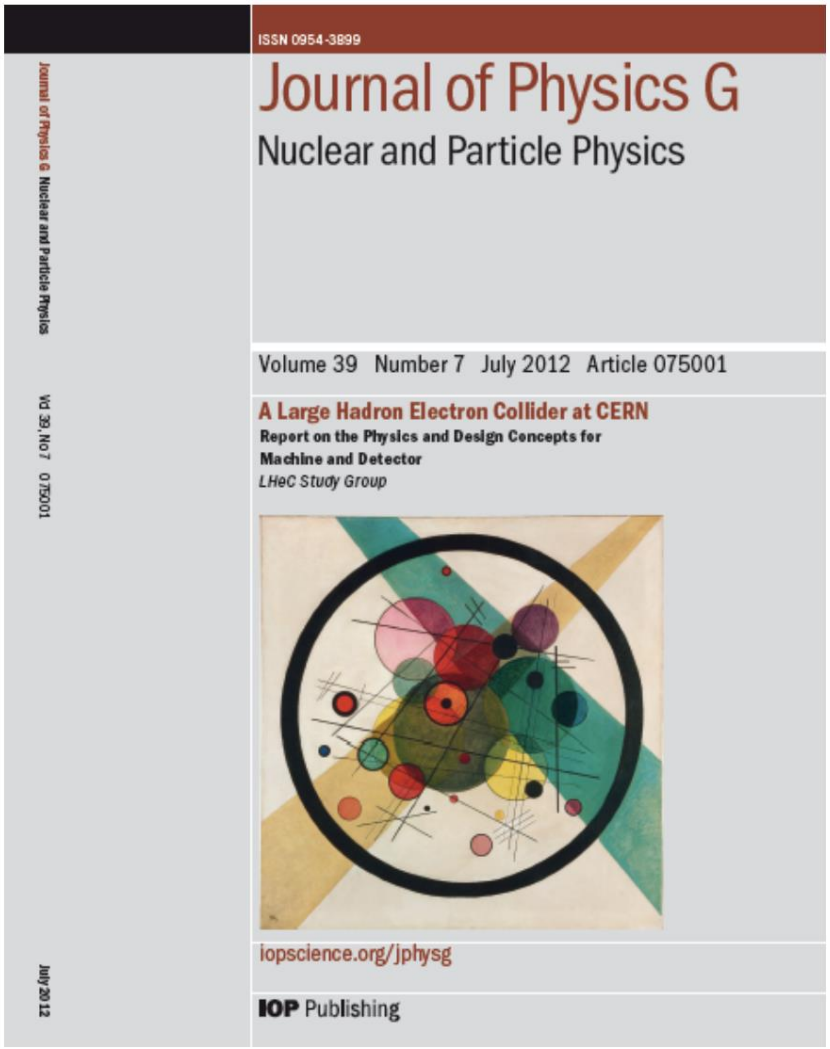
LHeC

ep/eA collisions

E_p = 7 TeV E_A = 2.75 TeV/nucleon

Ee = 60 – 140 GeV $\sqrt{s}$ ~ 1 - 2 TeV

CONCEPTUAL DESIGN REPORT



CERN Referees

Ring Ring Design
Kurt Huebner (CERN)
Alexander N. Skrinsky (INP Novosibirsk)
Ferdinand Willeke (BNL)
Linac Ring Design
Reinhard Brinkmann (DESY)
Andy Wolski (Cockcroft)
Kaoru Yokoya (KEK)
Energy Recovery
Georg Hoffstaetter (Cornell)
Ilan Ben Zvi (BNL)
Magnets
Neil Marks (Cockcroft)
Martin Wilson (CERN)
Interaction Region
Daniel Pitzl (DESY)
Mike Sullivan (SLAC)
Detector Design
Philippe Bloch (CERN)
Roland Horisberger (PSI)
Installation and Infrastructure
Sylvain Weisz (CERN)
New Physics at Large Scales
Cristinel Diaconu (IN2P3 Marseille)
Gian Giudice (CERN)
Michelangelo Mangano (CERN)
Precision QCD and Electroweak
Guido Altarelli (Roma)
Vladimir Chekelian (MPI Munich)
Alan Martin (Durham)
Physics at High Parton Densities
Alfred Mueller (Columbia)
Raju Venugopalan (BNL)
Michele Arneodo (INFN Torino)

2012 LHeC CDR

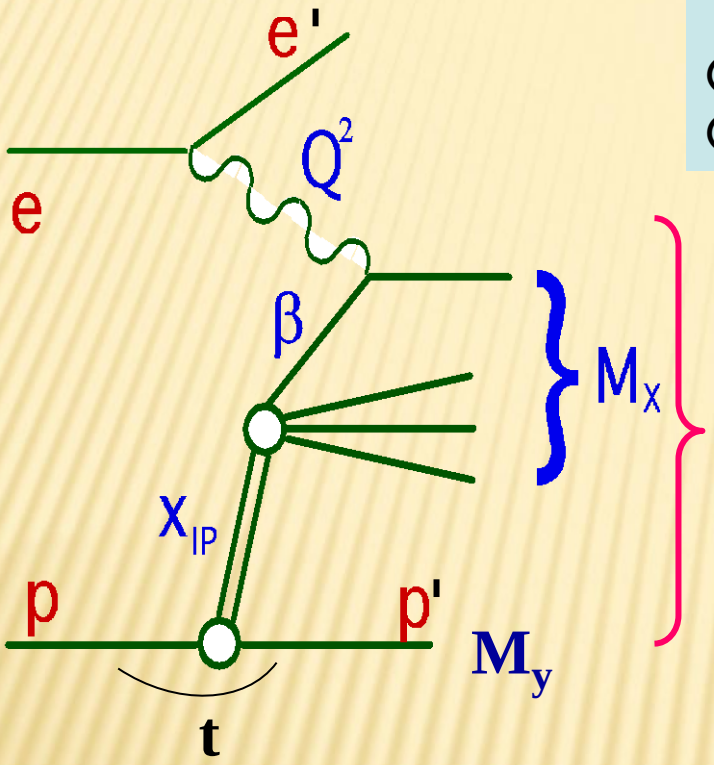
LHeC

- **600 pages report, ~ authors from 70 institutes**

DIFFRACTIVE KINEMATICS

Two kinematic regions of diffractive events:

$Q^2 \sim 0$ GeV^2 → photoproduction
$Q^2 \gg 0$ GeV^2 → deep inelastic scattering (DIS)



HERA: ~10% of events diffractive

$$x_{IP} = \frac{q \cdot (p - p')}{q \cdot p} \approx \frac{Q^2 + M_X^2}{Q^2 + W^2}$$ →

momentum fraction of color singlet exchange

$$\beta = \frac{x}{x_{IP}} \approx \frac{Q^2}{Q^2 + M_X^2}$$ →

fraction of exchange momentum, coupling to γ

$$t = (p - p')^2$$ → 4-momentum transfer squared

$M_y = m_p$ proton stays intact, needs detector setup to detect protons

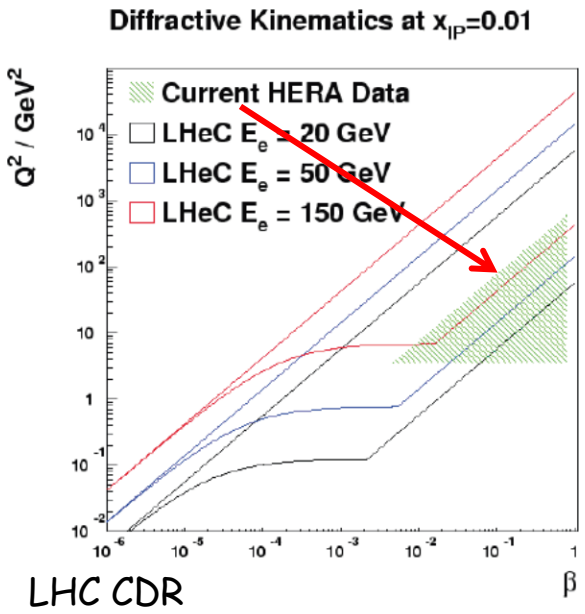
$M_y > m_p$ proton dissociates, contribution should be understood

DIFFRACTION AND LOW X

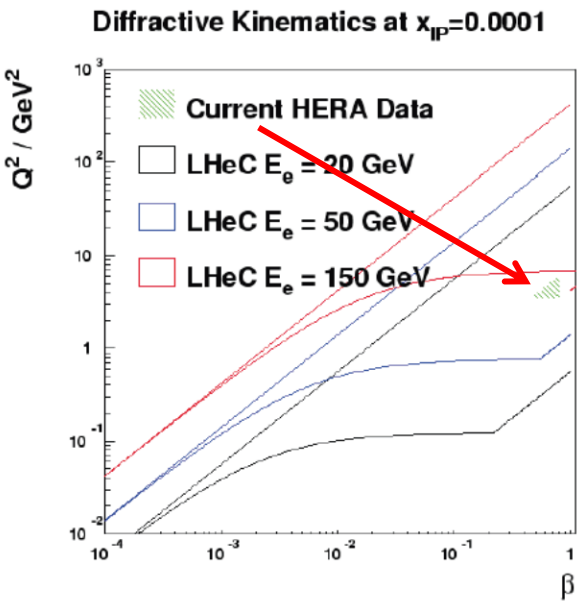
Detector requierements →

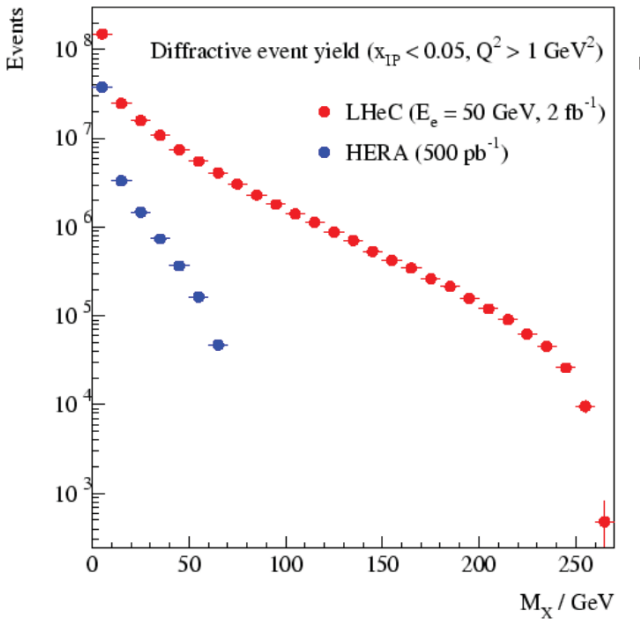
* Luminosity~ 10^{33} $cm^{-2}s^{-1}$. eA: L_{en}~ 10^{32} $cm^{-2}s^{-1}$
* Acceptance: 1-179 degrees (low-x ep/eA).
* Tracking to 1 mrad.
* EMCAL calibration to 0.1 %.
* HCAL calibration to 0.5 %.
* Luminosity determination to 1 %.
* Compatible with LHC operation.

Significant extension of kinematic region of diffraction (as compared to HERA)
New domain for diffractive masses



LHC CDR





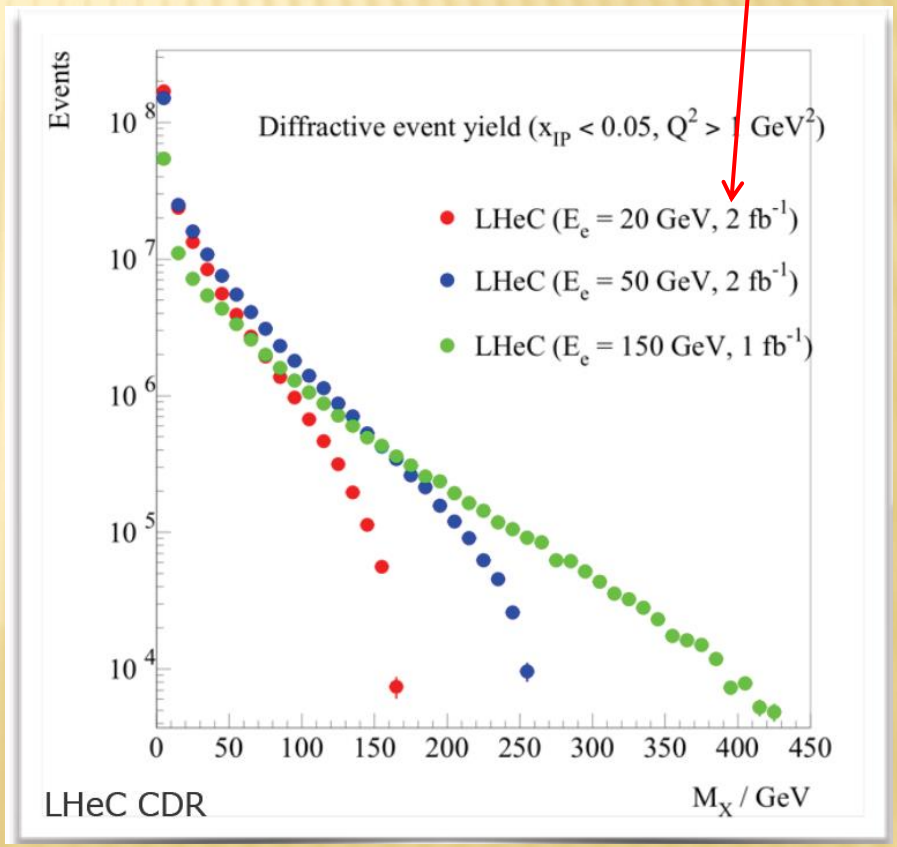
DIFFRACTION AND LOW X

- At LHeC, M_x up to hundreds of GeV can be produced with low x_{IP}
- New diffractive channels …beauty, W/Z
- Measure exclusively produced new/ exotic 1^{--} states (odderon?)

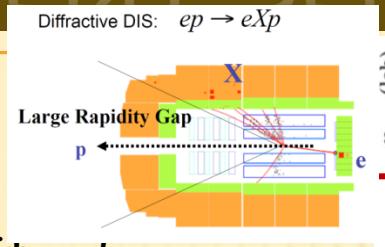
HERE:
- **Diffractive charged currents**
- **Dijets in DIS and Photoproduction**

If some time left →
- Elastic J/ψ photoproduction interpreted as hard 2g exchange, coupling to qq dipole --> **simulations done- see LHeC CDR**
- Deeply Virtual Compton Scattering, **simulations done – see LHeC CDR**

Here integrated lumi is very conservative, with $L=10^{34}cm^{-2}s^{-1}$ can be reached
$L \rightarrow 100fb^{-1}$ - $1000\ fb^{-1}$

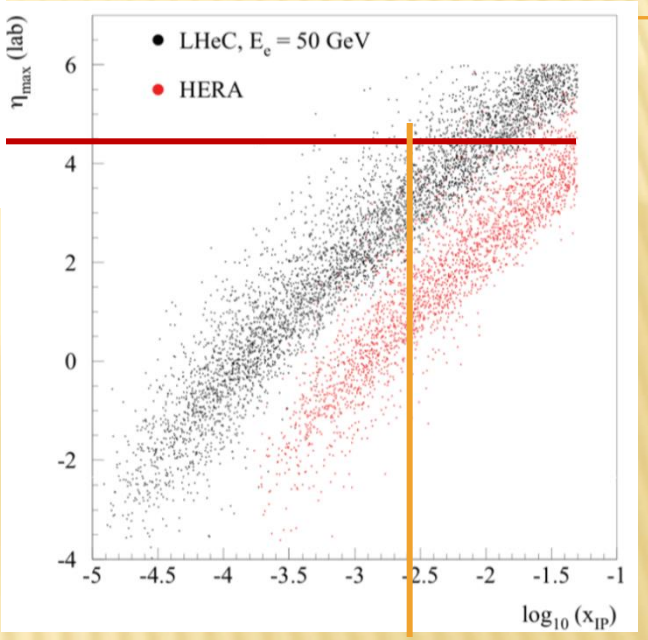


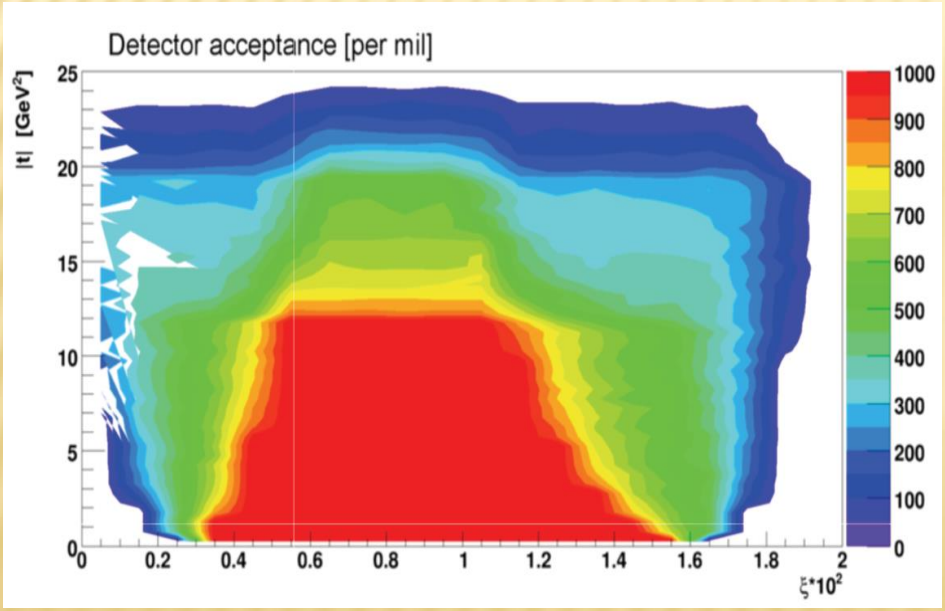
DIFFRACTIVE EVENT SELECTION



Large rapidity gap (LRG)method

- Restricted to low x_{IP}
- Correlation between x_{IP} and rapidity of most forward particle η_{max} of diff. system
- If $\eta_{max} < 5$, measurements up to $x_{IP} \sim 0.01$ (forward instrumentation down to 1° required).
- Misses interesting region of large M_X.

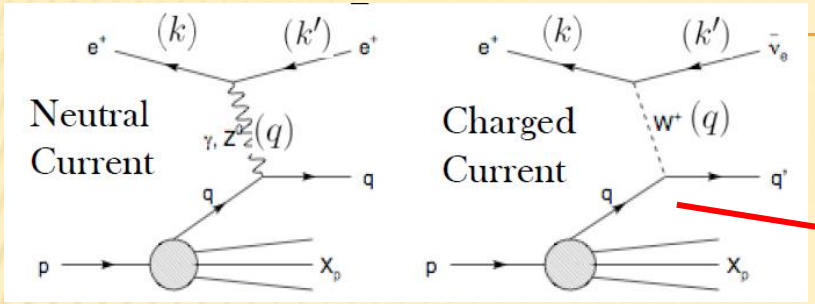


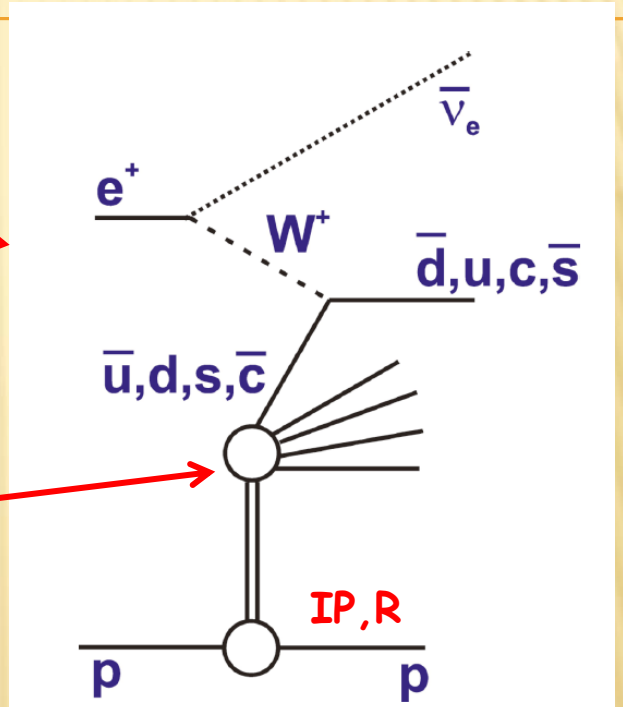


Leading proton detection

- Proton Spectrometer at 420m
- Larger x_{IP} region
- Overlap in x_{IP} with LRG method can be used for the cross-check

NEUTRAL AND CHARGED CURRENTS





Sensitive to flavour decomposition of quark singlet (completely unconstrained by NC data)

Different shapes of dσ/dy for W+ (q / $\bar{q}$) collisions

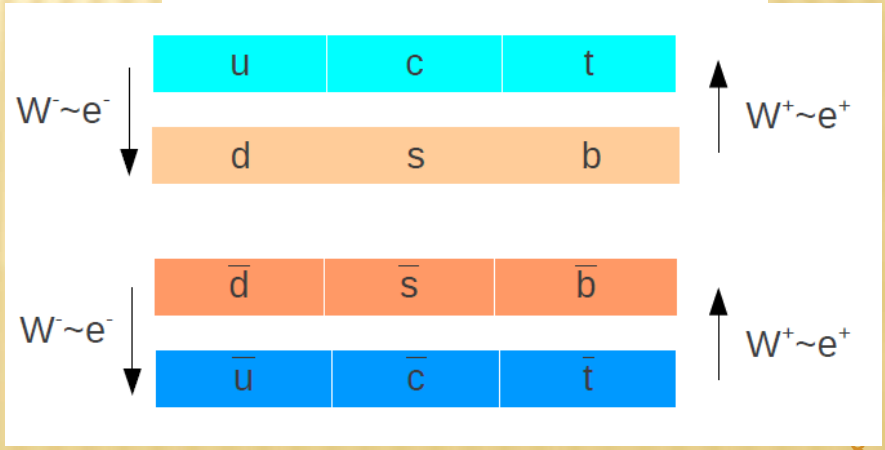
$$\frac{d\sigma}{dy}(e^- q) \propto 1 \qquad \frac{d\sigma}{dy}(e^- \bar{q}) \propto (1-y)^2$$

Suppressed in bwd region

$$\frac{d\sigma}{dxdy}(e^- p) \propto [(d+s)+(\bar{u}+\bar{c})(1-y)^2]$$

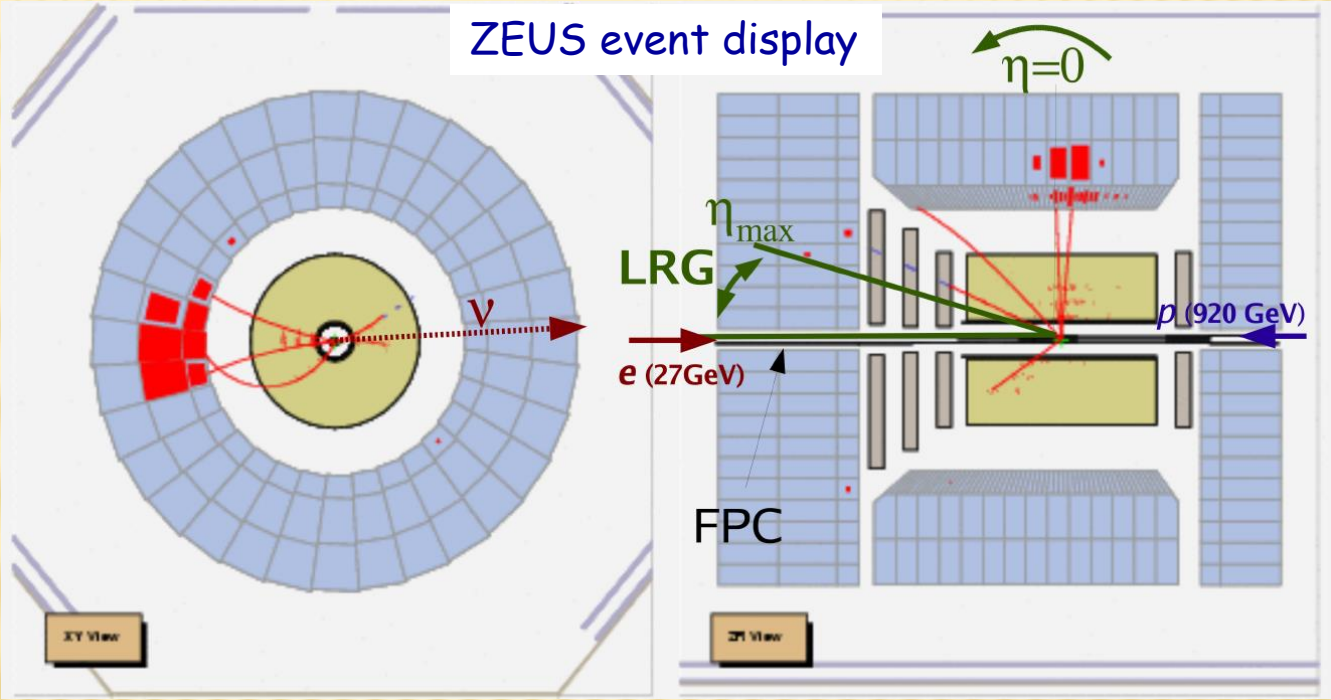
$$\frac{d\sigma}{dxdy}(e^+ p) \propto [(\bar{d}+\bar{s})+(u+c)(1-y)^2]$$

Measurement at different beam energies



CC EVENT TOPOLOGY

- Signature of Charged Current – missing transverse energy E_t
- Diffractive selection – Large Rapidity Gap or detected proton



Kinematics is calculable from diffractive X-system:

$$y=\frac{E^X-p_z^X}{2E_e} \qquad Q^2=\frac{(p_T^X)^2}{1-y} \qquad x_{IP}=\frac{Q^2+2E_e(E^X+p_z^X)}{4E_eE_p} \qquad \beta=\frac{Q^2}{x_{IP}ys}$$

HERA MEASUREMENTS

H1

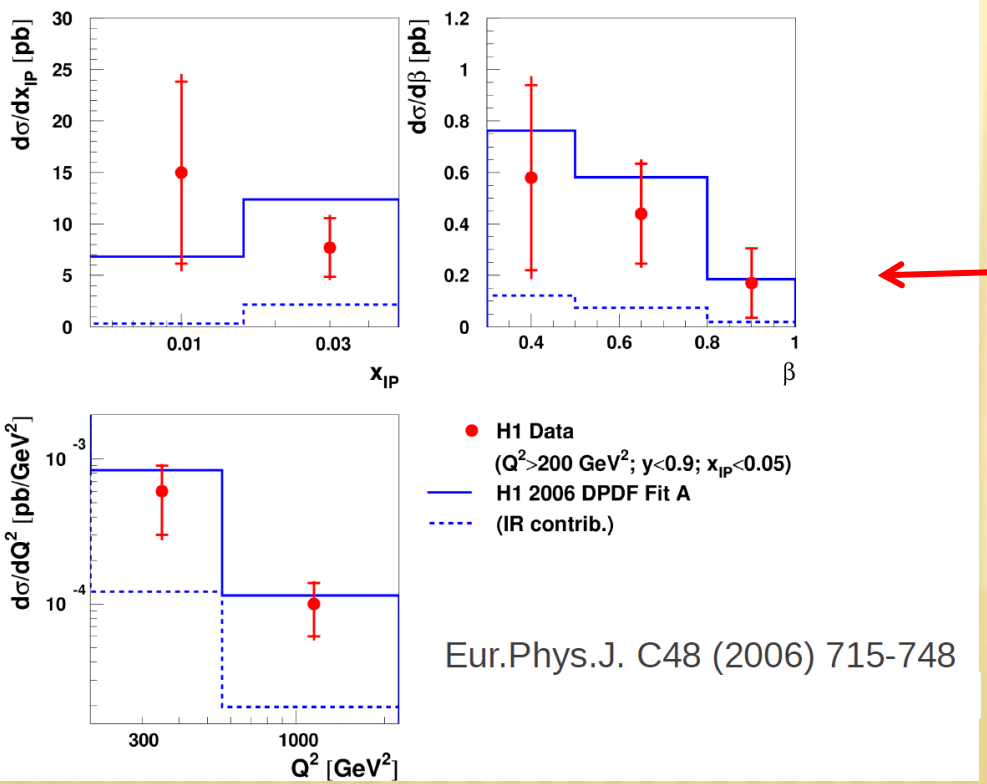
$$\sigma_{H1}^{CCdiff} = 0.39 \pm 0.12\,(stat) \pm 0.07\,(syst)\,\text{pb}$$

10 events

ZEUS

$$\sigma_{ZEUS}^{CCdiff} = 0.49 \pm 0.20\,(stat) \pm 0.13\,(syst)\,\text{pb}$$

9 events



Eur.Phys.J. C48 (2006) 715-748

Analysis cuts

$$Q^2 > 200\,\text{GeV}^2$$
$$y < 0.9$$
$$x_{IP} < 0.05$$

Only about 2% of CC x-section !

Resolved Pomeron model with H1 fits A or B predicts zero e+e- assymmetry. Assymmetry not studied here….

LHEC PREDICTION

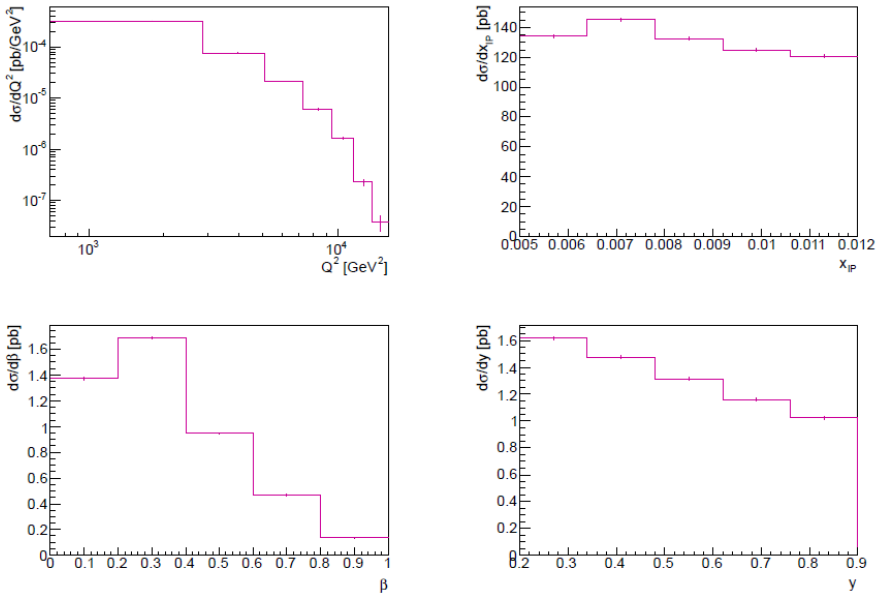
HERA
920+27.5
σ^{CCdiff}(MC) = 338fb
~20 events (60pb^{-1})

MC RAPGAP prediction

cuts:
$Q^2 > 700\ GeV^2$,
$0.005 < x_{IP} < 0.012$
$0.2 < y < 0.9$

Markéta Jansová,
Bachelor work, Prague 2013

LHeC
7000+60
σ^{CCdiff}(MC)= 923fb
~80000 events (100fb^{-1})



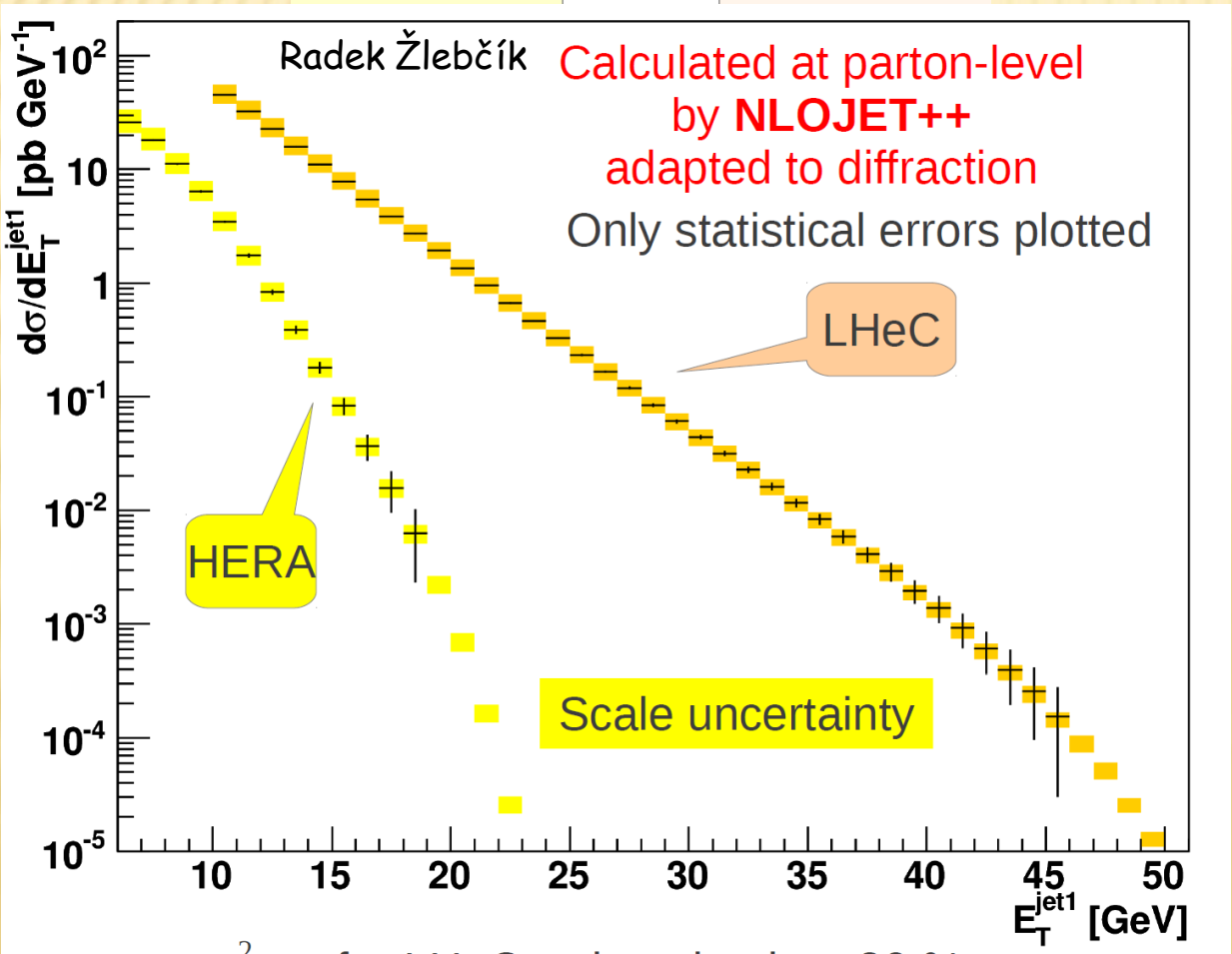
No corrections for detector acceptance and resolution!

Diffractive CC events could be studied in a more detailed way…

DIS DIJETS HERA & LHeC

Higher CMS energy -> higher scales accessible

HERA		LHeC
$E_T^{jet1} \sim 15\,\text{GeV}$	→	$E_T^{jet1} \sim 40\,\text{GeV}$



920 + 27.5 HERA ($400\,\text{pb}^{-1}$)

$Q^2 > 4\,\text{GeV}^2 \wedge 0.1 < y < 0.7$

$x_{IP} < 0.03 \wedge |t| < 1\,\text{GeV}^2$

$M_Y < 1.6\,\text{GeV}$

$E_T^{jet1} > 6\,\text{GeV}$

$E_T^{jet2} > 4\,\text{GeV}$

$-1 < \eta^{jets} < 2$

7000 + 60 LHeC ($10\,\text{fb}^{-1}$)

$Q^2 > 2\,\text{GeV}^2 \wedge 0.1 < y < 0.7$

$x_{IP} < 0.01 \wedge |t| <$ 12 GeV^2

$M_Y < 1.6\,\text{GeV}$

$E_T^{jet1} > 10\,\text{GeV}$

$E_T^{jet2} > 6.5\,\text{GeV}$

$-3 < \eta^{jets} < 3$

Cut Q^2>4 GeV^2 will reduce LHeC x-section by ~20%

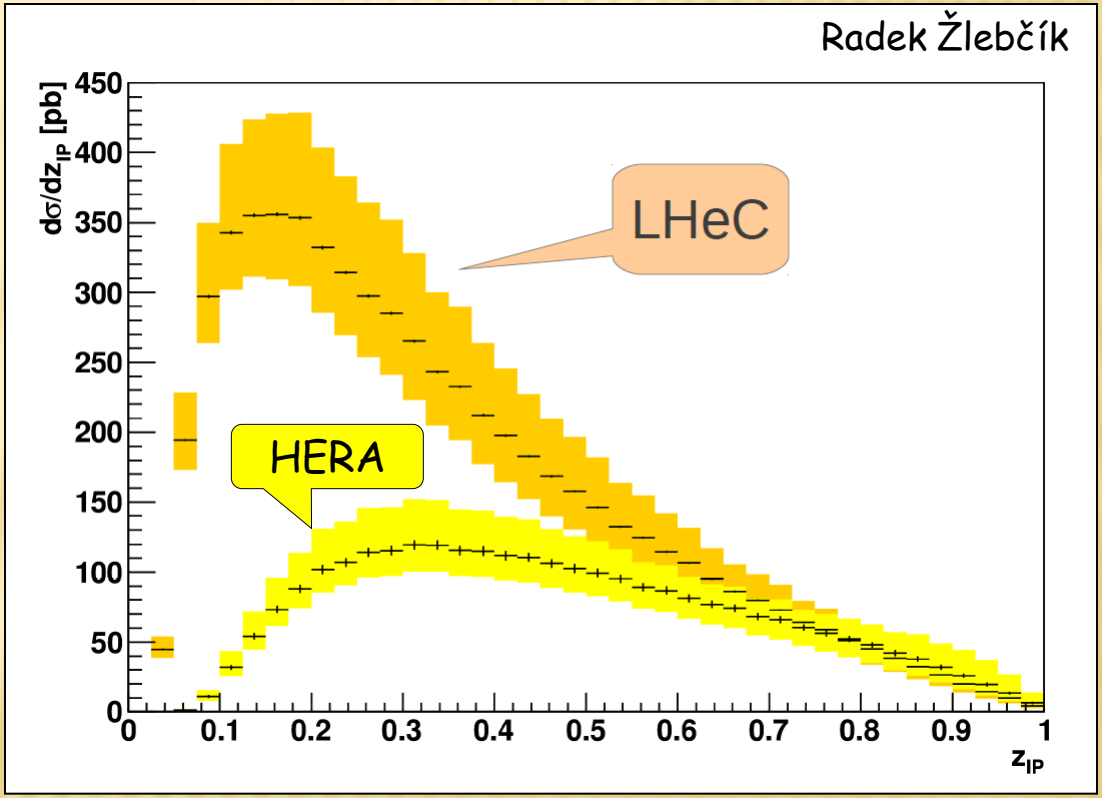
DIS DIJETS HERA & LHeC

At LHeC x-section dominates for small z_{IP}, where gluon part of DPDF weakly constrained from inclusive measurement, dominates.

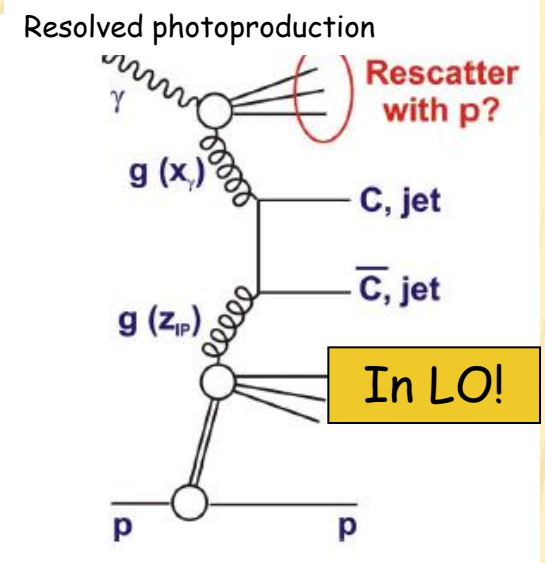
Access to small z_{IP} depends on the ability to measure jets with small E_T

$$z_{IP}^{min} \simeq \frac{\left(E_T^{jet1(min)} + E_T^{jet1(min)}\right)^2}{x_{IP}^{max}\, y^{max}\, s}$$

HERA		LHeC
$z_{IP} \sim 0.07$	→	$z_{IP} \sim 0.02$



PHOTOPRODUCTION DIJETS HERA & LHEC



- Factorization in diffractive dijet photoproduction at HERA not confirmed, 3 independent measurements by H1 obtained , suppression factor $S^2=\sigma(NLO)/\sigma(data) \sim 0.5\text{-}0.7$, (with large theoretical uncertainties), ZEUS measurement consistent with $S^2 \sim 1$

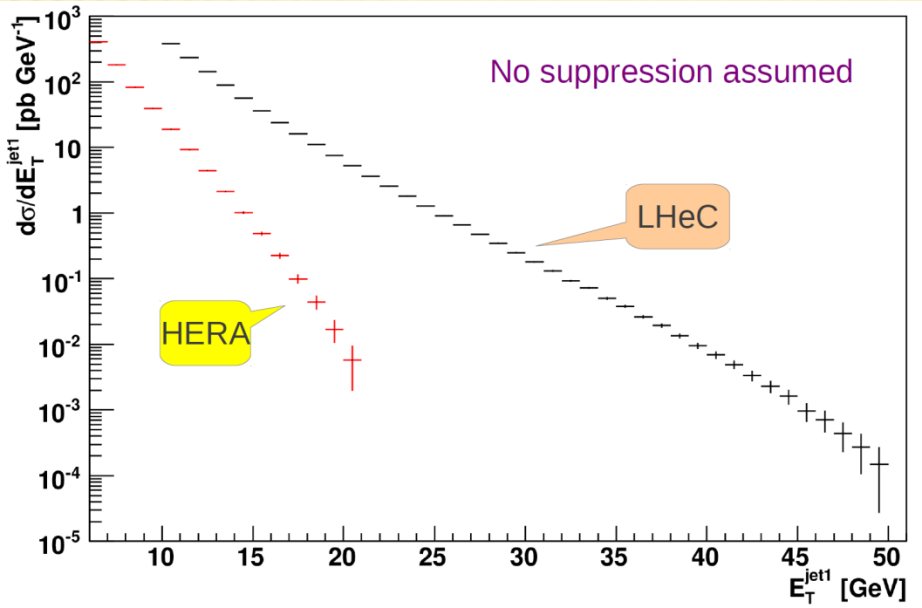
- Theoretically predicted*) dependence of S^2 on x_γ – (fraction of photon's momentum in hard subprocess) not observed neither by H1 nor ZEUS.

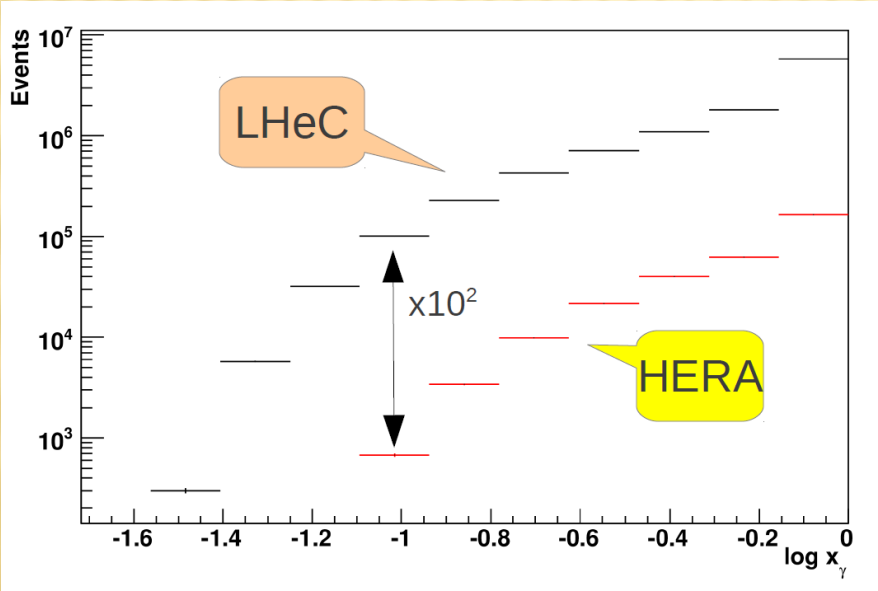
*) see e.g. Kaidalov,Khoze,Martin,Ryskin,European Journal of Physics 66,373 (2010)

LHeC:

Tests of factorization in diffractive dijet photoproduction?

PHOTOPRODUCTION DIJETS HERA & LHEC





R. Žlebčík, Frixione NLO, adapted for diffraction

920 + 27.5 HERA (400 pb^{-1})	7000 + 60 LHeC (10 fb^{-1})
$Q^2<2\,\mathrm{GeV}^2 \wedge 0.2<y<0.8$	$Q^2<2\,\mathrm{GeV}^2 \wedge 0.2<y<0.8$
$x_{IP}<0.03 \wedge \lvert t\rvert<1\,\mathrm{GeV}^2$	$x_{IP}<0.01 \wedge \lvert t\rvert<$ 12 GeV^2
$M_Y<1.6\,\mathrm{GeV}$	$M_Y<1.6\,\mathrm{GeV}$
$E_T^{jet1}>6\,\mathrm{GeV}$	$E_T^{jet1}>10\,\mathrm{GeV}$
$E_T^{jet2}>4\,\mathrm{GeV}$	$E_T^{jet2}>6.5\,\mathrm{GeV}$
$-1<\eta^{jets}<2$	$-3<\eta^{jets}<3$

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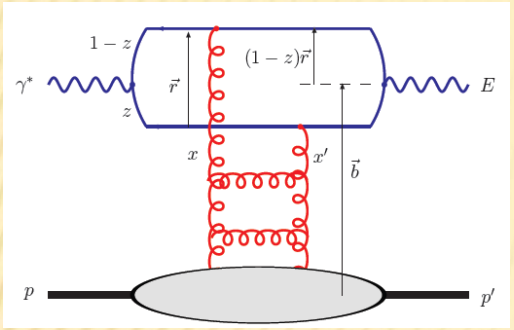
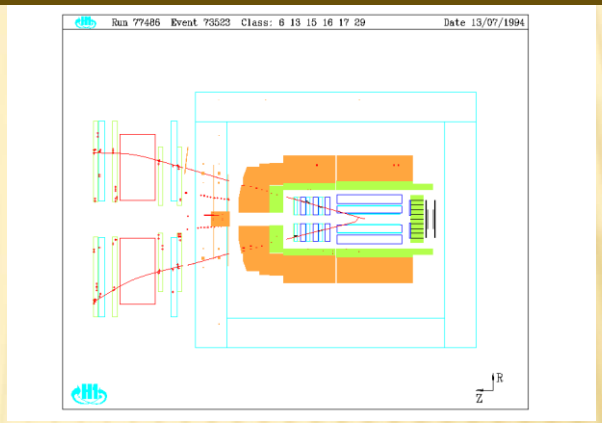
HERA	LHeC
$E_T^{jet1}\sim 17\,\mathrm{GeV}$	$E_T^{jet1}\sim 42\,\mathrm{GeV}$

HERA	LHeC
$x_\gamma\sim 0.09$	$x_\gamma\sim 0.03$

- Higher E_t of jets - smaller scale uncertainties in NLO QCD calc.
- Access to lower values of z_{IP} and x_γ than at HERA

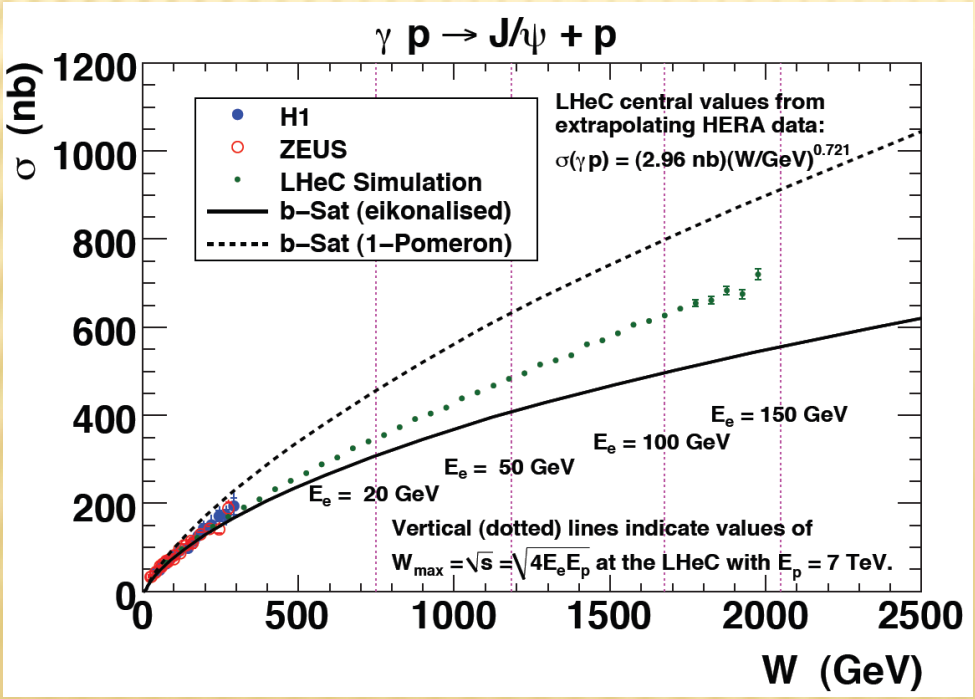
EXCLUSIVE PRODUCTION -VECTOR MESONS





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

- Clean experimental signature –just 2 leptons
- Sensitivity to low x gluon up to x_g- $6 \cdot 10^{-6}$ at Q^2~3GeV^2



- Simulated data are from extrapolated fit to HERA data
- b-Sat dipole model eikonalised *)
  - with saturation, I-Pomeron
  - without saturation

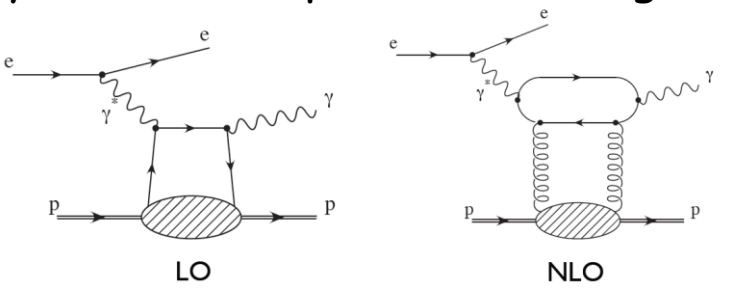
→ **LHeC can distuingish between the different scenarios**

*) Golec-Biernat,Wuesthoff,Bartels,Motyka,Kowalski,Watt

EXCLUSIVE PRODUCTION - DVCS

ep→ eγp

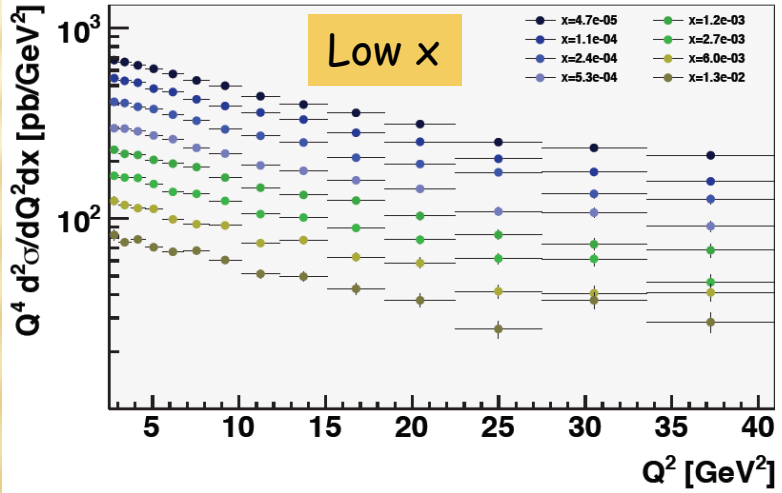
Deeply Virtual Compton Scattering

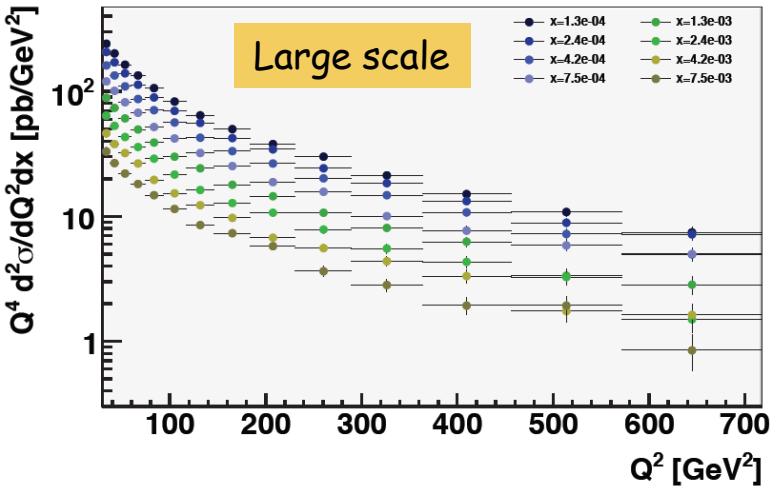


No complications connected with meson wave function
Generalized Parton Densities (GPD)

2 scenarios

MILOU generator using Frankfurt, Freund, Strikman model.





$\mathcal{L}$ =1fb^{-1} θ=1°
P_T^γ=2 GeV 2.5 < Q^2< 40 GeV^2

$\mathcal{L}$ =100fb^{-1} θ=10°
P_T^γ=5 GeV 50 < Q^2< 500 GeV^2

CONCLUSIONS

- LHeC represents a natural extension to HERA and LHC
- LHeC diffraction – access to high masses of diffractive system M_X (depending on the instrumentation in the forward region)
- Large statistics of Charged Current diffractive events in LHeC – the possibility to study e.g. e+/e- assymmetry in CC
- LHeC diffractive dijet DIS production – access to larger scales, E_T of jets up to 40 GeV
- LHeC diffractive dijet photoproduction – better possibilities to test the factorization in photoproduction
- LHeC exclusive production - elastic J/ψ photoproduction, deeply virtual Compton scattering (DVCS), details published in LHeC CDR report