Low x Physics at the LHeC: DIS with E_e=70GeV and E_p=7TeV

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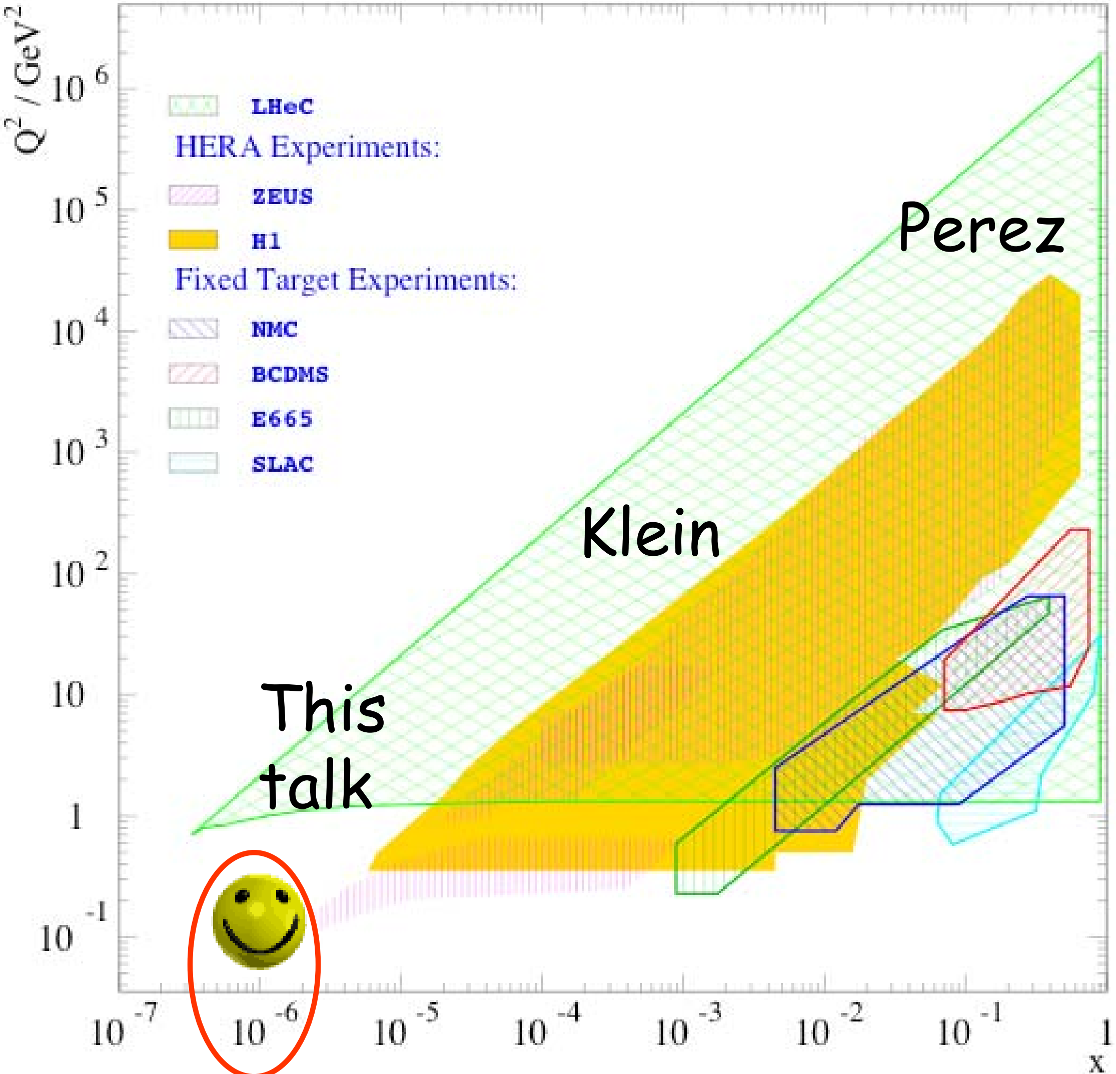
P Newman, Birmingham

DIS2007, Munich
19 April 2007

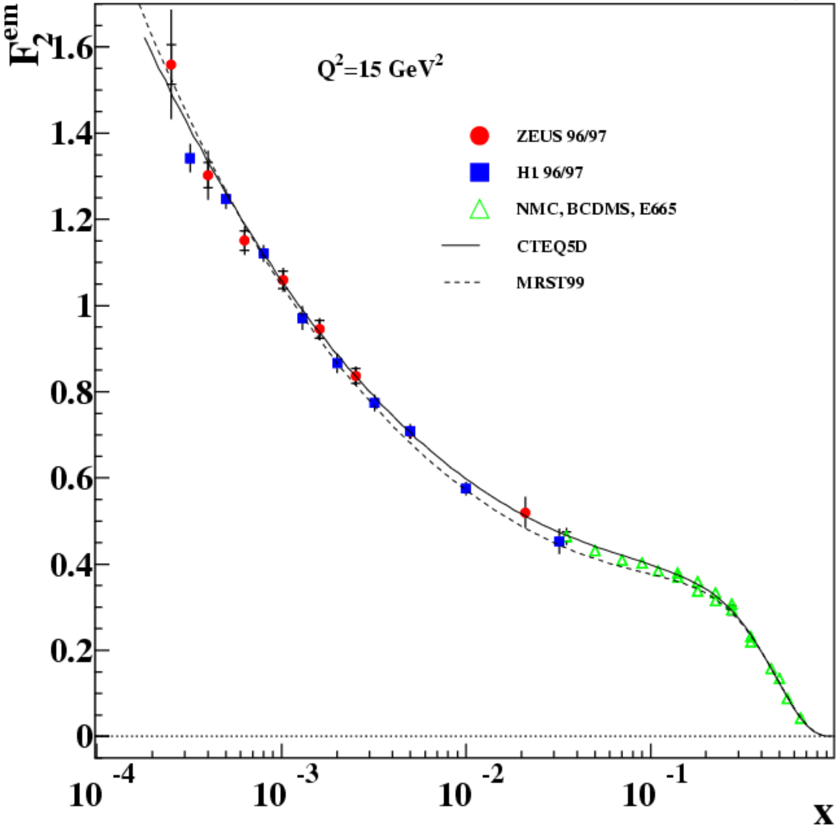
Thanks to E Avsar, J Dainton, M Diehl, M Klein, L Favart, J Forshaw, L Lonnblad, A Mehta, E Perez, G Shaw, F Willeke

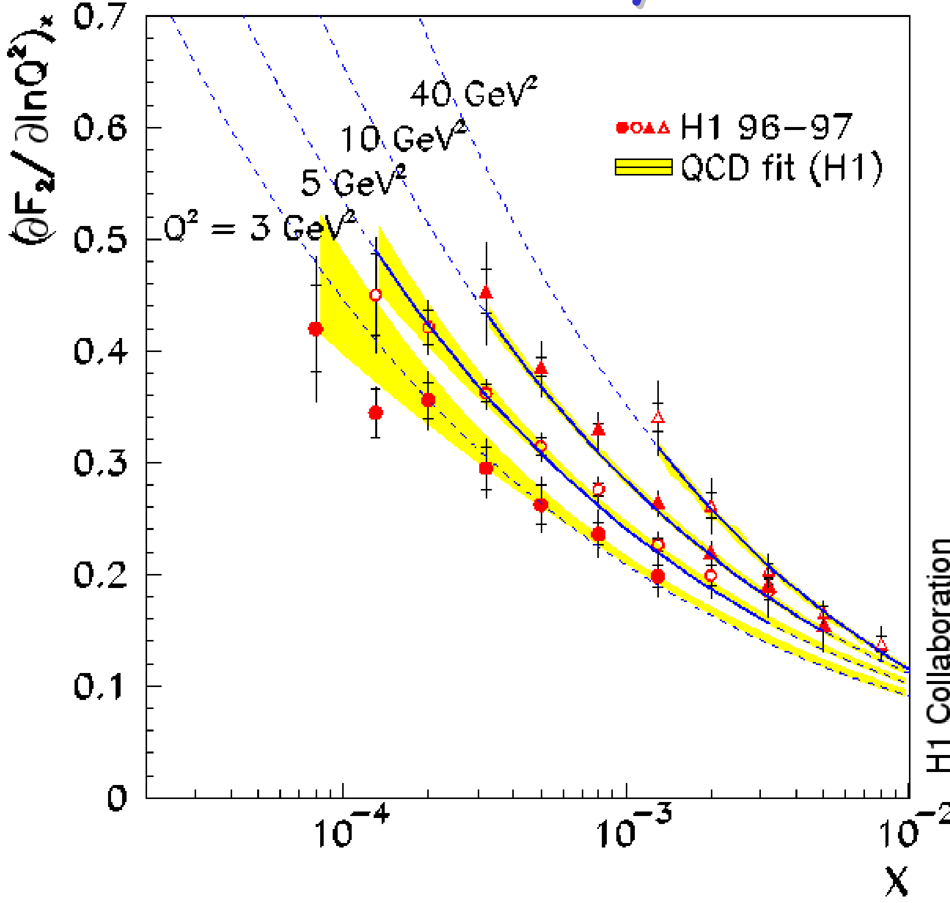


Contents

- What and where is low x Physics?
- The LHeC in overview
- Low x detector considerations
- Some first case studies:
  - F2
  - Geometric Scaling
  - DVCS
  - Diffractive structure functions
  - Diffractive final state observables
  - Forward Jets
  - Beauty production
  - eA
  - A long list of things I missed!

The Birth of Experimental Low x Physics

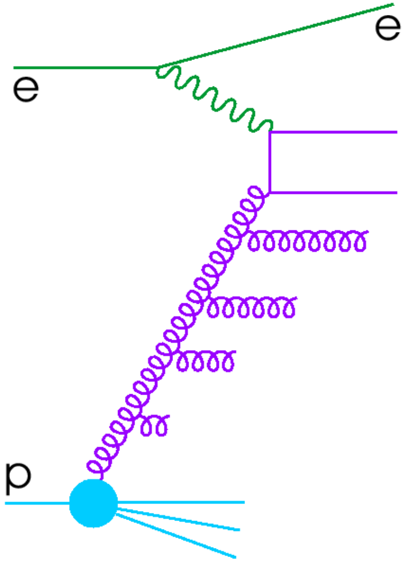




- Biggest HERA discovery: strong increase of quark density (F_2) and gluon density ($d F_2 / d \ln Q^2$) with decreasing x in newly explored regime.

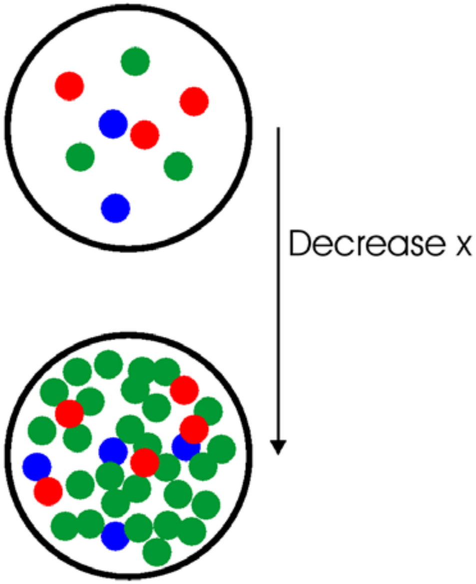
Low x, `large' Q^2 is high density, low coupling limit of QCD …

Current Status of Low x Physics



RHIC, Tevatron and HERA have taught us a lot,
… but many questions are not fully answered…

- Are non-DGLAP parton evolution dynamics visible in the initial state parton cascade?



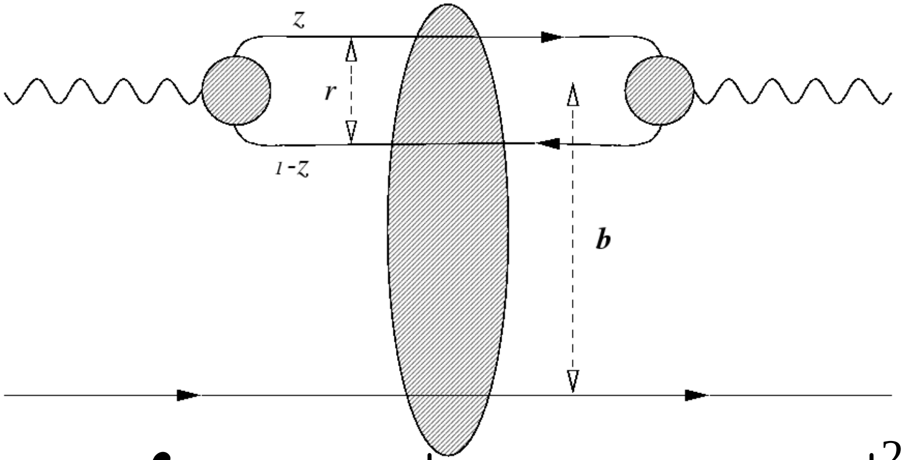
- How and where is the parton growth with decreasing x tamed (unitarity) … barely separated from confinement region?

- Large (~ constant?) fraction of diffraction?

Problem is that low x kinematically correlated to low Q^2, which brings problems with partonic interpretation

Reminder : Dipole models

- Description of interesting low x region, where Q^2 small and partons not appropriate degrees of freedom …



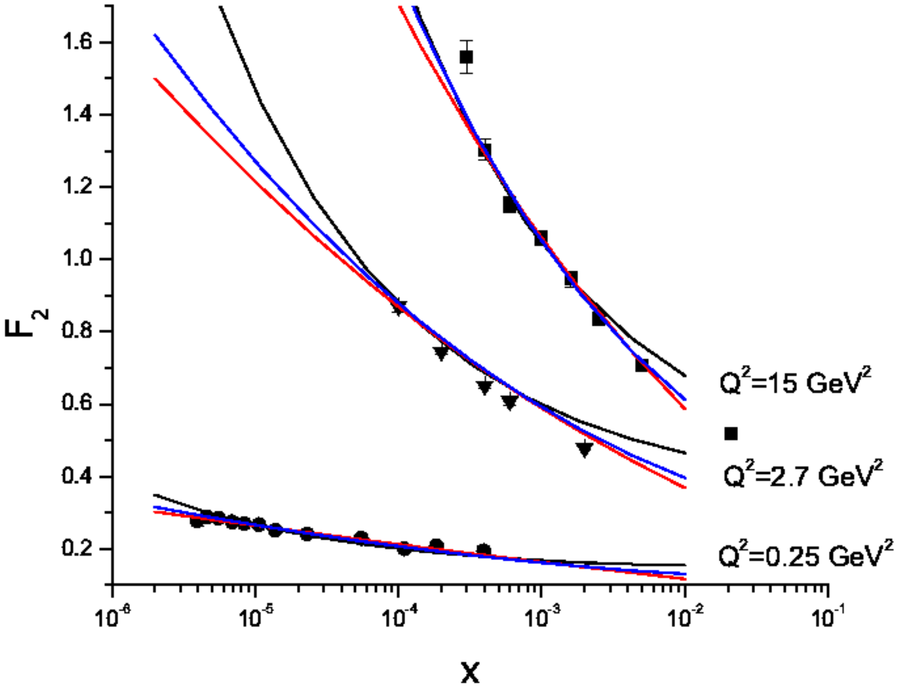
$$\sigma^{T,L}_{\gamma^* p}(x,Q^2) \sim \int \mathrm{dz}\ \mathrm{d}^2 r \ \left|\psi^{T,L}_{\gamma^*}(z,r,Q^2)\right|^2 \sigma_{dipole}(x,r,z)$$

- Simple unified picture of many inclusive and exclusive processes … strong interaction physics in (universal) dipole cross section σ_{dipole}. Process dependence in wavefunction Ψ Factors
- qqbar-g dipoles also needed to describe inclusive diffraction

An Example Dipole Approach to HERA Data

Forshaw, Sandapen, Shaw
hep-ph/0411337,0608161
… used for illustrations here

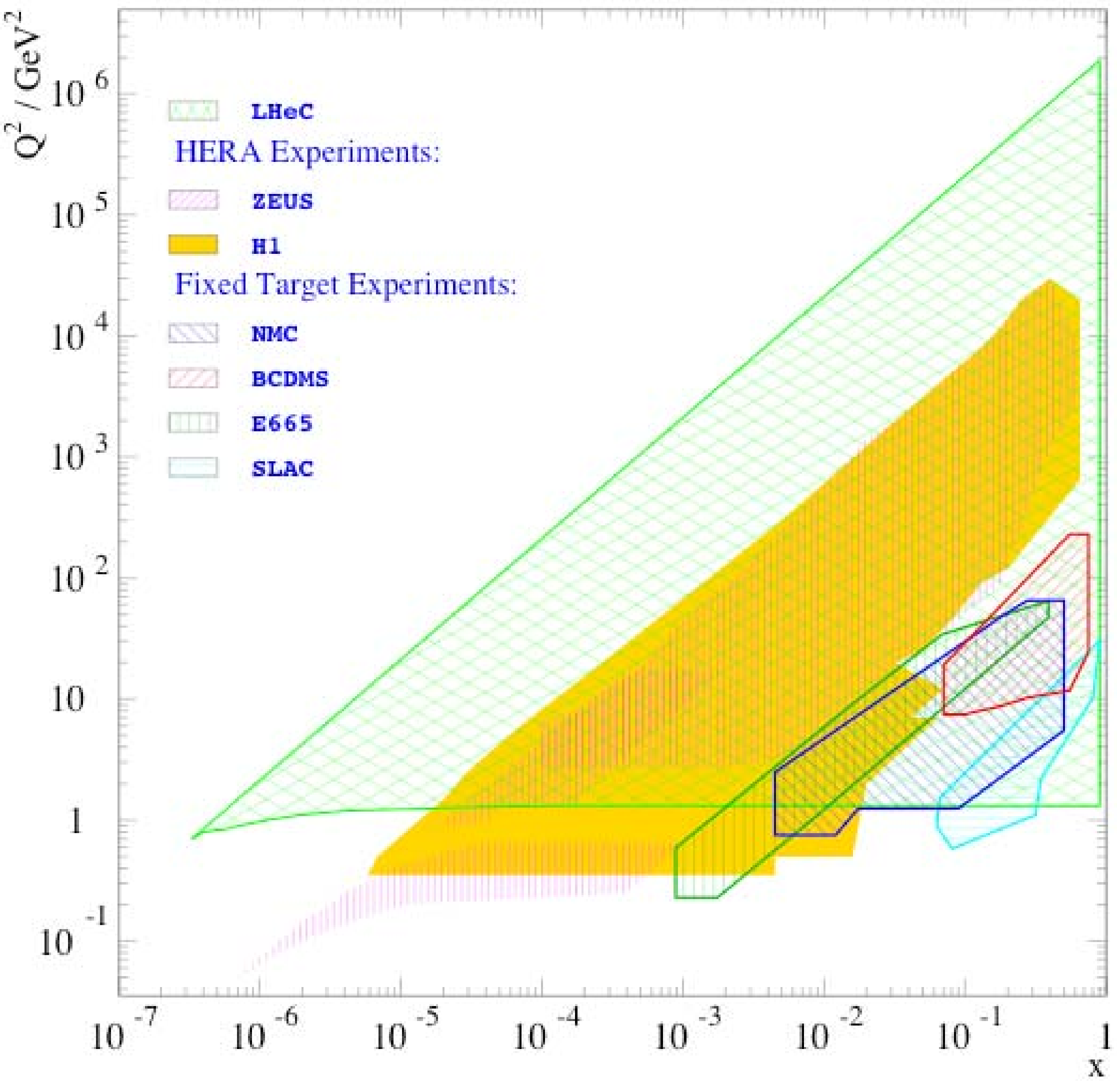
Fit inclusive HERA data with dipole models containing varying assumptions for σ_{dipole}.



—— FS04 Regge (~FKS): 2 pomeron model, no saturation
—— FS04 Satn: Simple implementation of saturation
—— CGC: Colour Glass Condensate version of saturation

- All three models can describe data with $Q^2 > 1 GeV^2$, $x < 0.01$
- Only versions with saturation work for $0.045 < Q^2 < 1$ GeV^2
- Similar conclusions from final state studies

LHeC Inclusive Kinematics



$$E_e = 70 \text{ GeV}$$
$$E_p = 7 \text{ TeV}$$
$$\sqrt{s} = 1.4 \text{ TeV}$$

(5 x HERA)

- Extension to higher Q^2 in x range covered By HERA

- Extension of low x (high W) frontier

$$W \le 1.4 \text{ TeV}$$
$$x \ge 5.10^{-7} \text{ at } Q^2 \le 1 \text{ GeV}^2$$

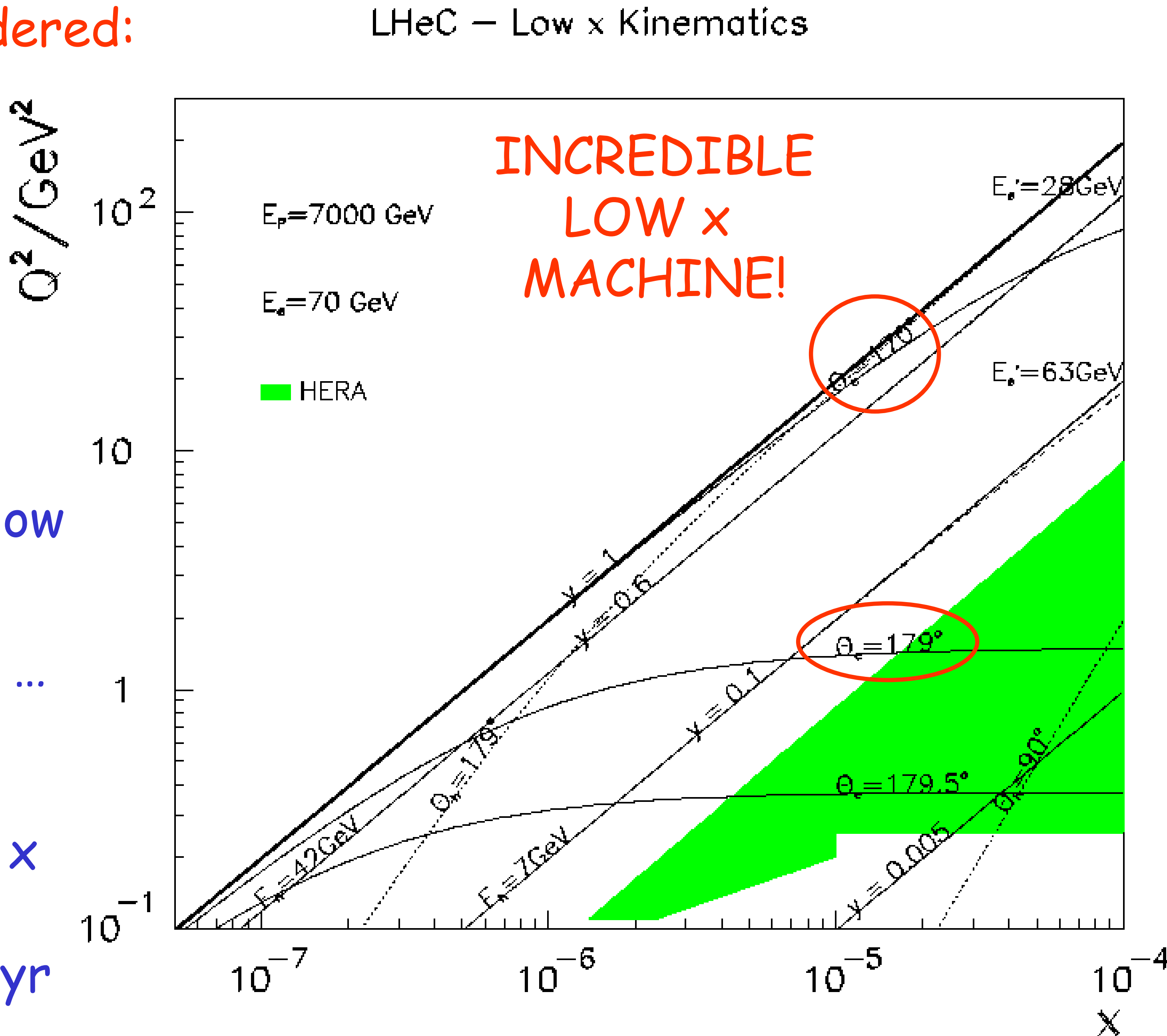
- Unprecedented lumi = 10^{33} cm^{-2} s^{-1} !!!
- eA mode possible using LHC ion beam

The LHeC for Low x Investigations

2 modes considered:

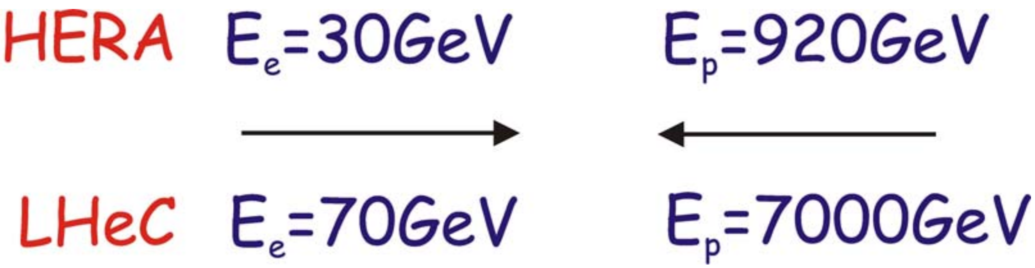
1) Focusing magnet To optimise lumi … detector acceptance to 170° … little acceptance below $Q^2=100$ GeV^2

2) No focusing … acceptance to 179° → access to $Q^2=1$ for all x ($x > 5 \times 10^{-7}$!)
Lumi ~ 1 fb^{-1} / yr



INCREDIBLE LOW x MACHINE!

Hadronic Final State Detector Considerations



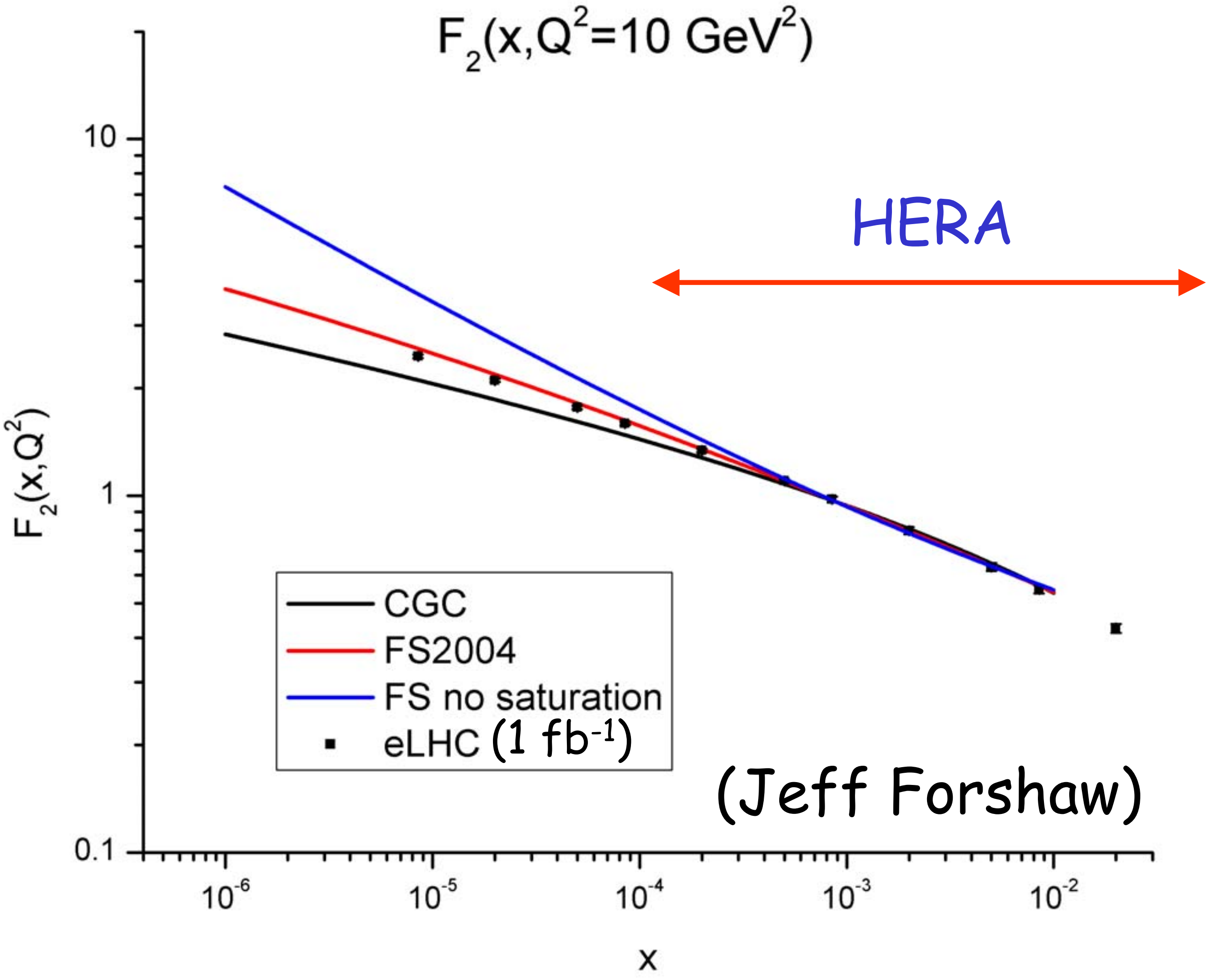
HERA E_e=30GeV E_p=920GeV

LHeC E_e=70GeV E_p=7000GeV

- Considerably more asymmetric beam energies than HERA!
  - Hadronic final state at newly accessed lowest x values goes central or backward in the detector ☺
  - At x values typical of HERA (but large Q2), hadronic final state is boosted more in the forward direction.

- Full Study of low x / Q^2 and of range overlapping with HERA, with sensitivity to energy flow in outgoing proton direction requires forward acceptance for hadrons to 1°

Example F_2 with LHeC Data



(Jeff Forshaw)

Statistical precision < 0.1%, systematics 1-3%

Precise data in LHeC region (1° acceptance)

- Cleanly establish saturation at Q^2 values where partonic language applicable

-Distinguish between models of saturation

Example 2: Interpreting Geometric Scaling

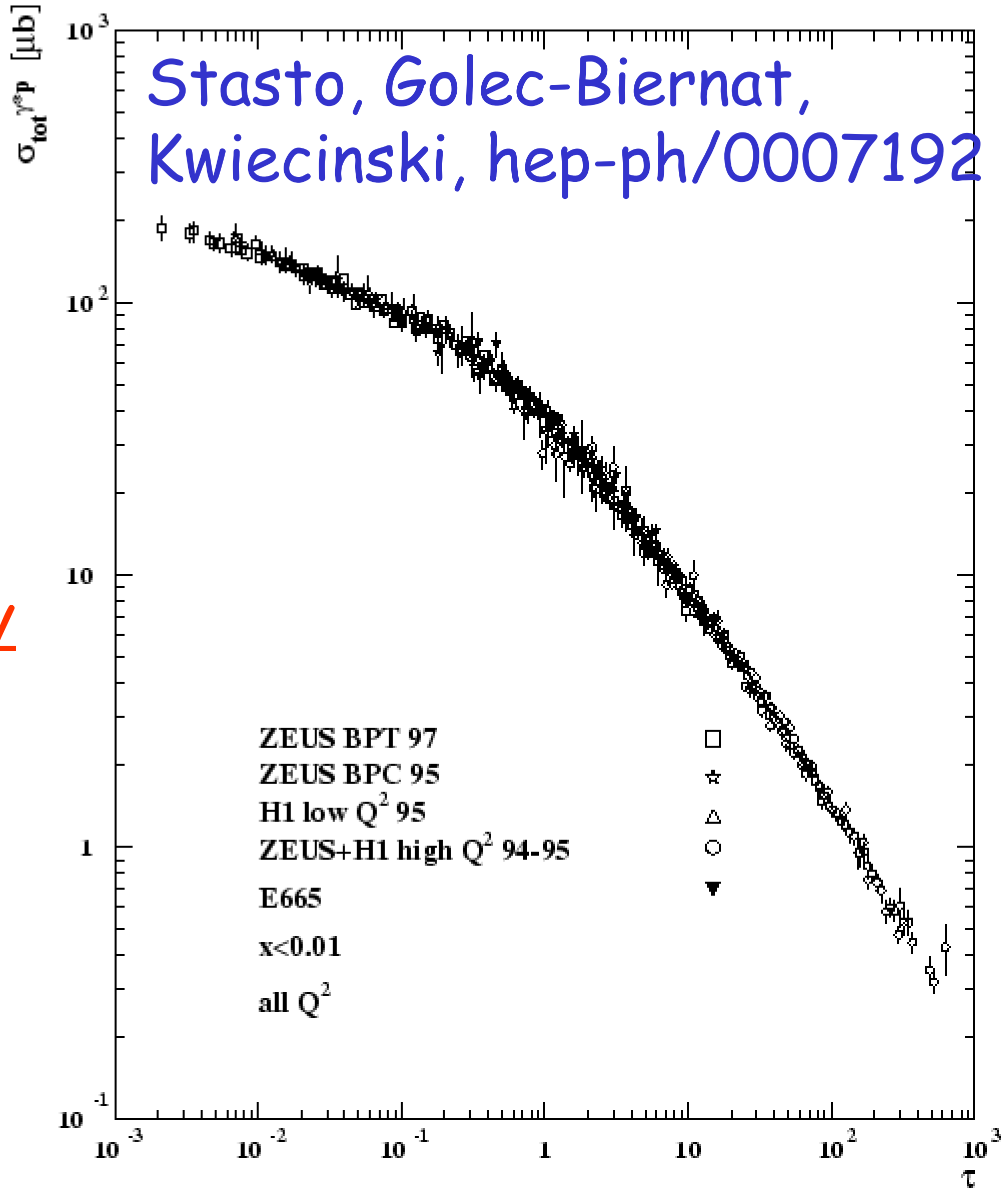
$\sigma_{\gamma^* p}(\tau \text{ only})$, $\tau = Q^2 R_0^2(x)$

$R_0^2(x)$ is "saturation radius"

Change of behaviour near $\tau=1$ often cited as evidence for saturation

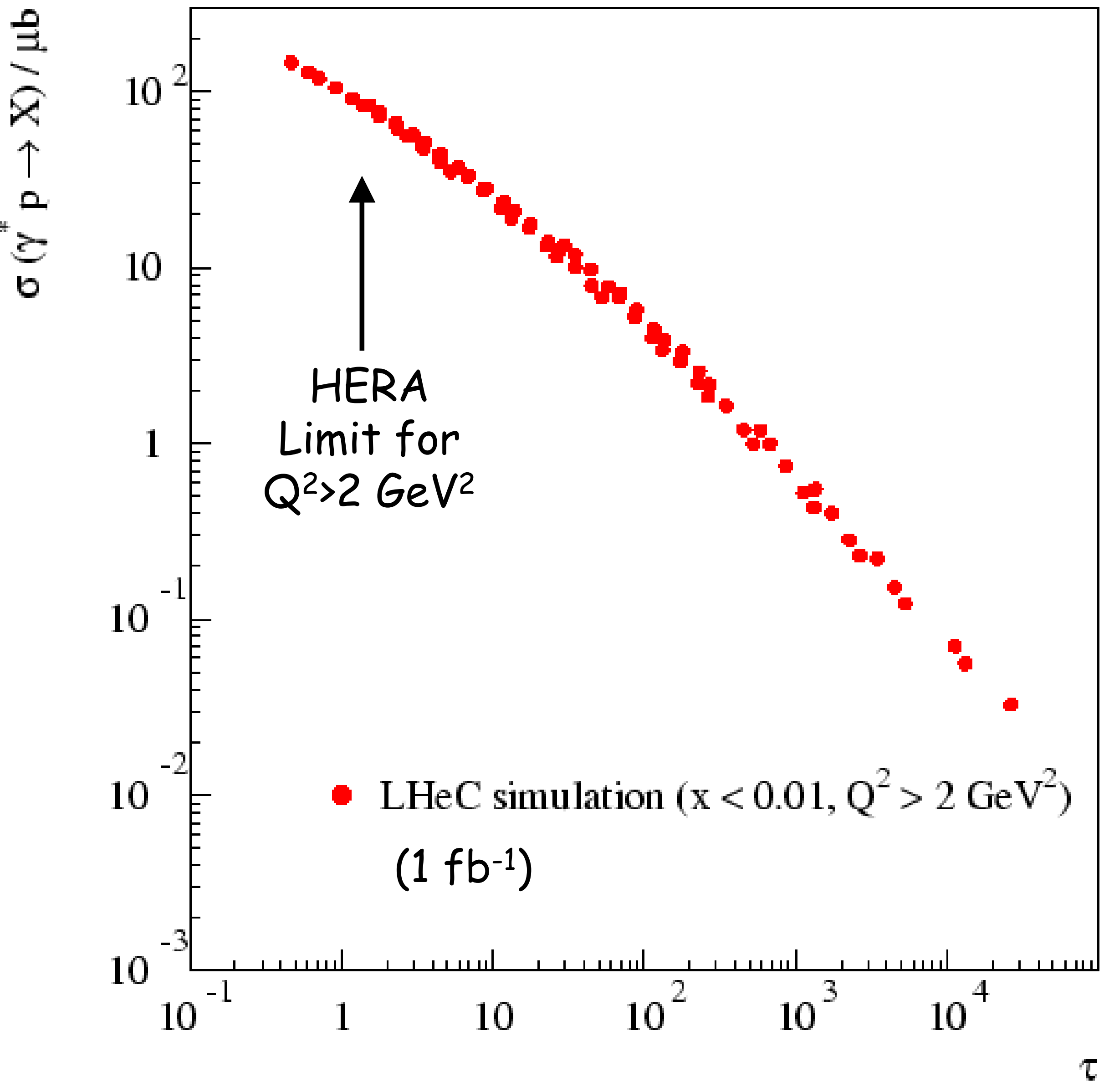
… but data below $\tau = 1$ are <u>very</u> low Q^2 – various theoretical difficulties and confinement / change to hadronic dof's

Need to see transition in a Q^2 region where partonic interpretation unquestionable



Stasto, Golec-Biernat, Kwiecinski, hep-ph/0007192

Geometric Scaling at the LHeC



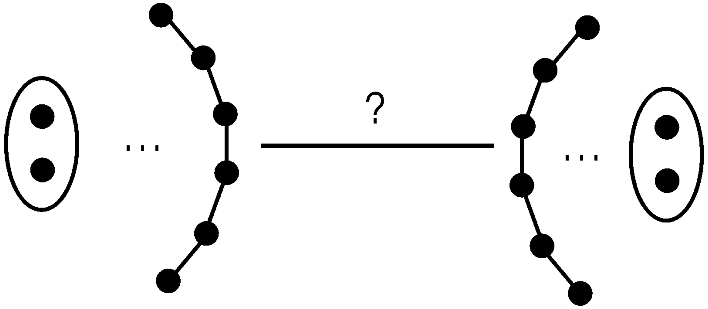
LHeC reaches τ ~ 0.15 for Q^2=1 GeV^2 and τ ~ 0.4 for Q^2=2 GeV^2

Some (though limited) acceptance for $Q^2 < Q^2_s$ with Q^2 "perturbative"

Could be enhanced with nuclei.

$Q^2 < 1$ GeV^2 accessible in special runs?

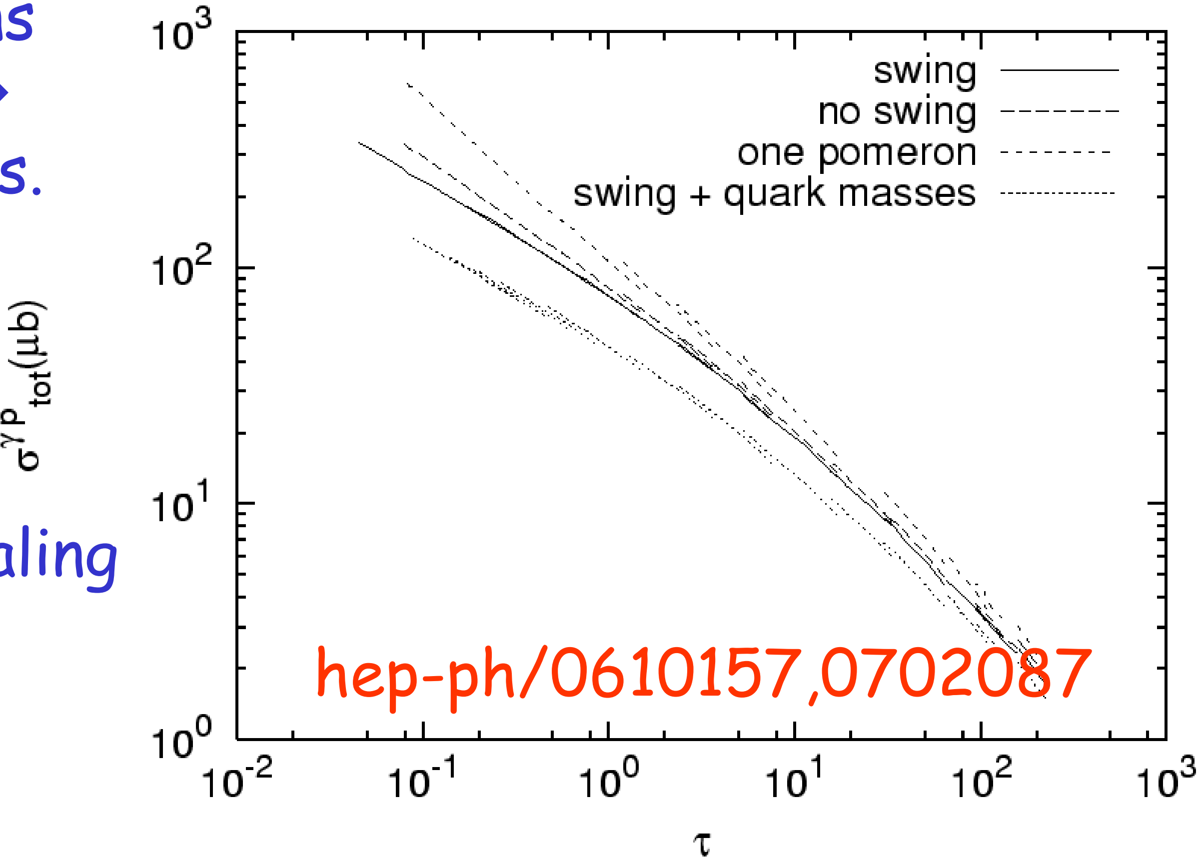
Another Model: Avsar, Gustafson, Lonnblad



Linked Dipole Chain Model (~ CCFM):
Interacting dipole chains in onium-onium scattering
-Linearly ("1 pomeron")
- Non-linearly (~ saturation) via multiple interactions & "swing" mechanism → recoupling within chains.

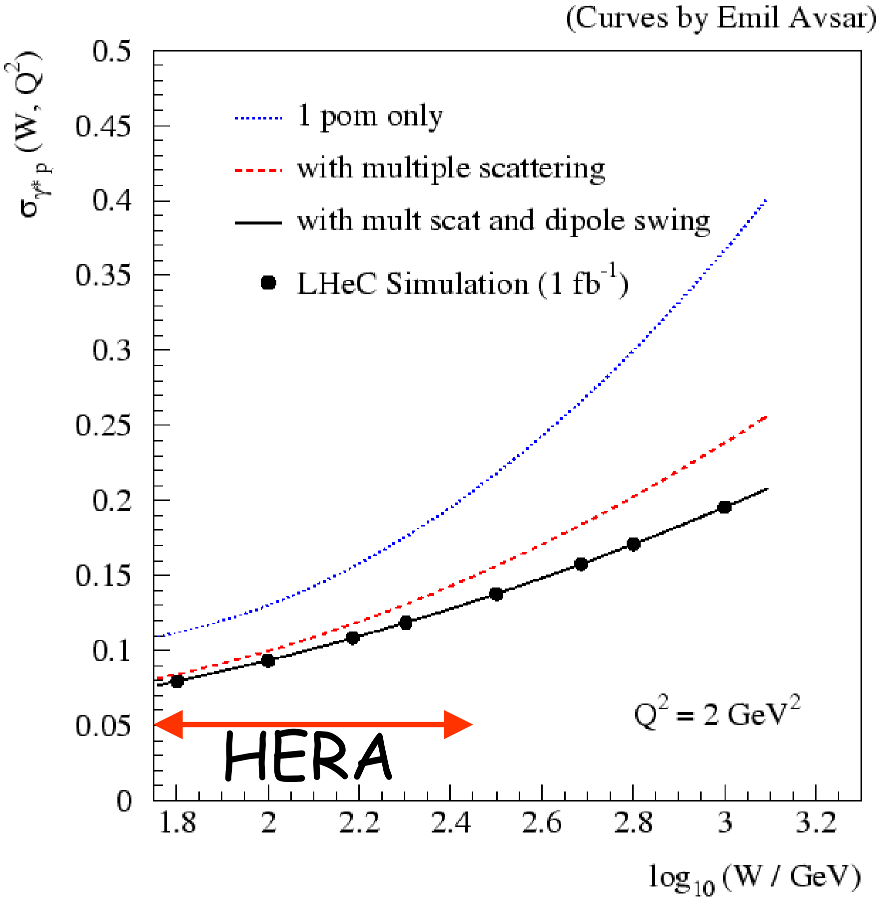
Effects important in saturation curve, but so is (non-scaling) finite quark mass

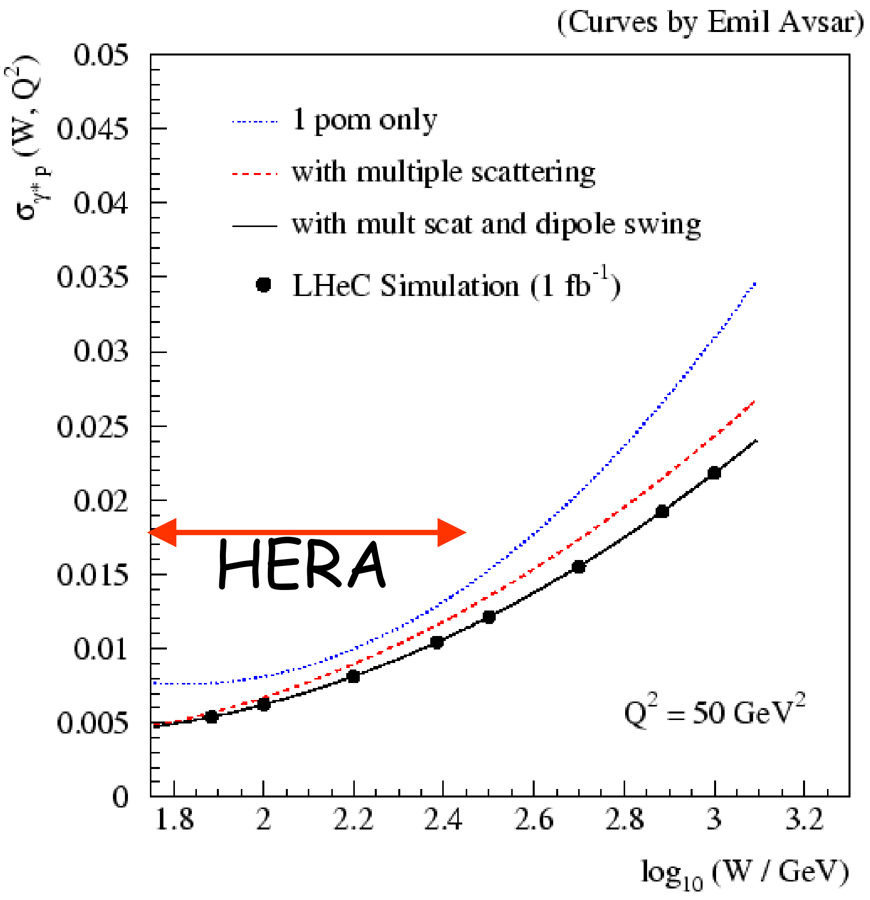
Predict breaking of scaling for $\tau<1$ if data with $Q^2>1$ become available (e.g. from LHeC)



hep-ph/0610157,0702087

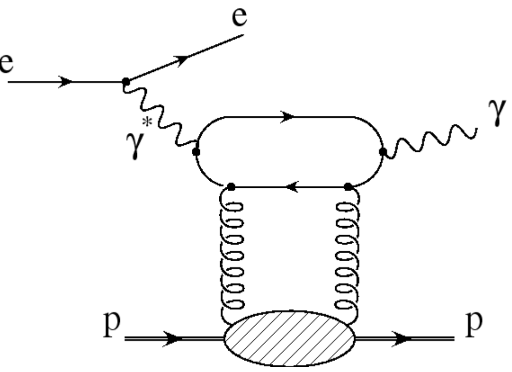
LHeC Comparison with Predictions



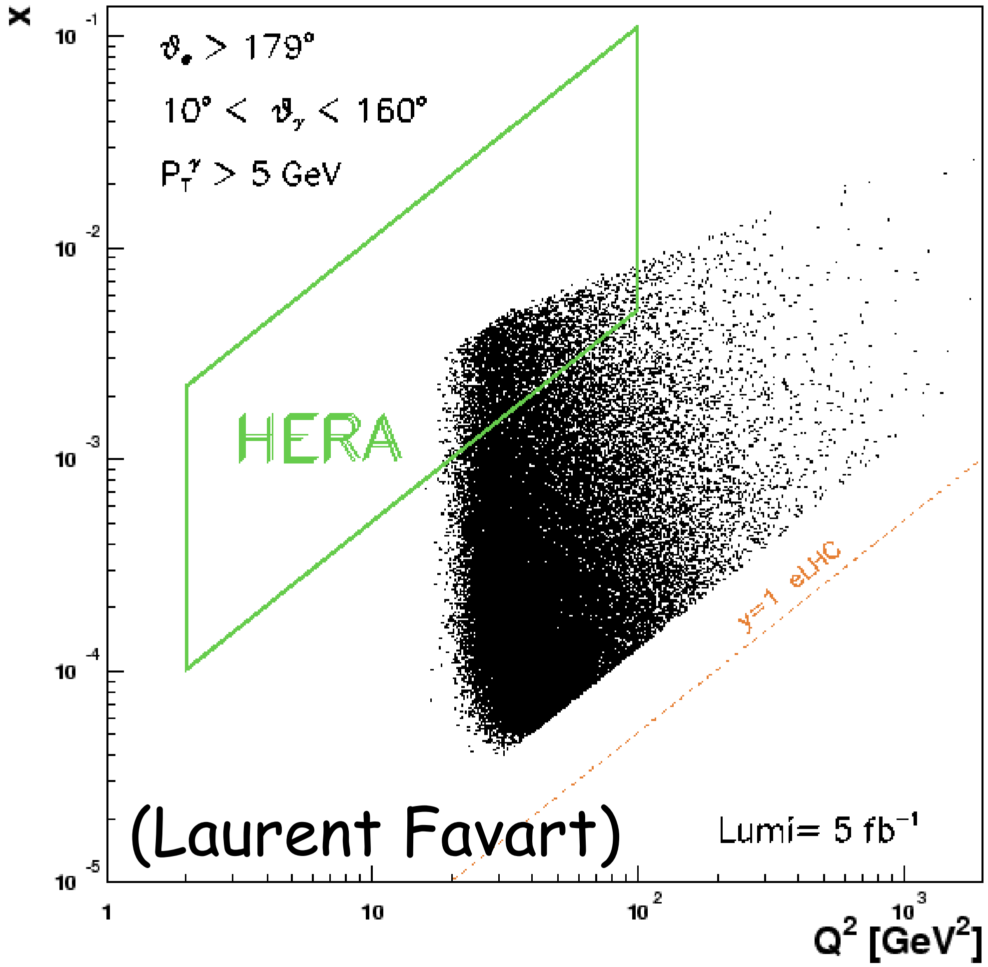


- '1 pom only' already disfavoured at HERA
- Subtle effects such as swing mechanism can be established cleanly at high W (low x) at LHeC

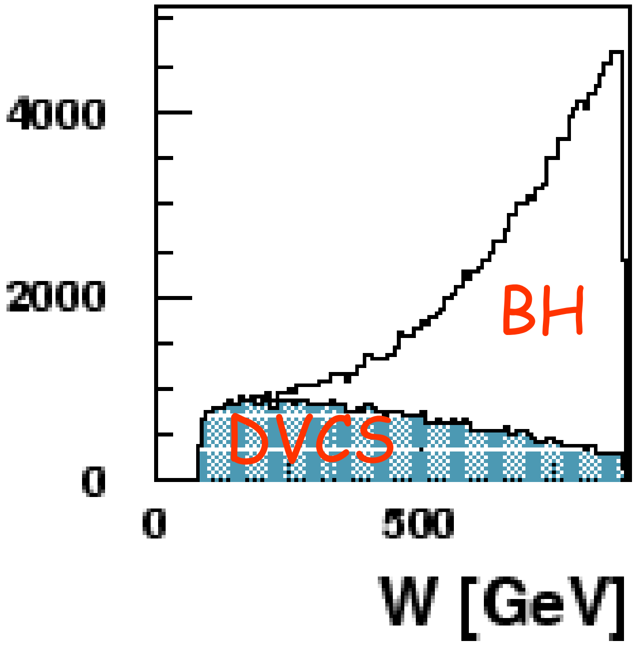
DVCS Measurement



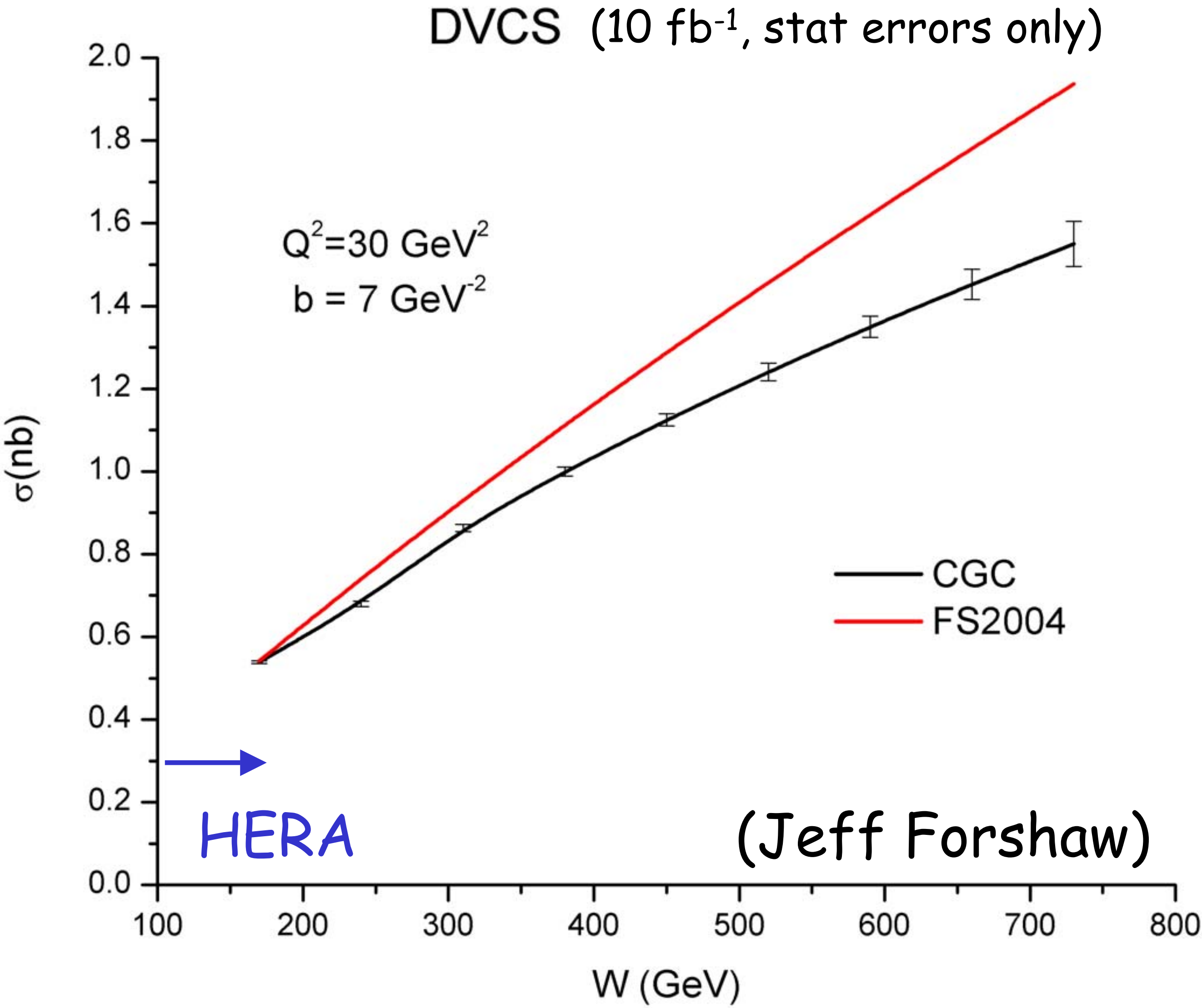
… can be tackled as at HERA through inclusive selection of ep → epγ and statistical subtraction of Bethe-Heitler background



(Laurent Favart)



Example of DVCS at LHeC



HERA

(Jeff Forshaw)

(1° acceptance)

Statistical precision 1-4%

Clearly distinguishes different models which contain saturation.

Interpretation in terms of GPDs much cleaner at larger Q^2 values accessed

VMs similar story

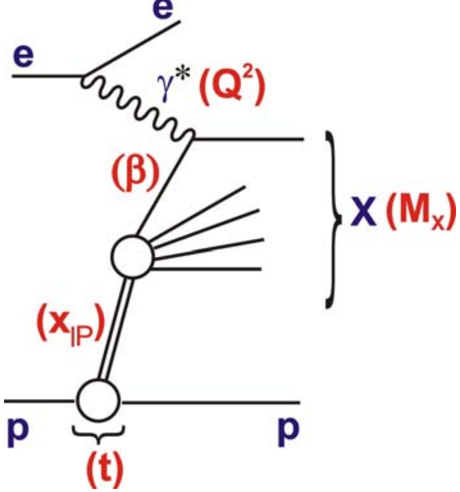
Diffractive DIS at HERA

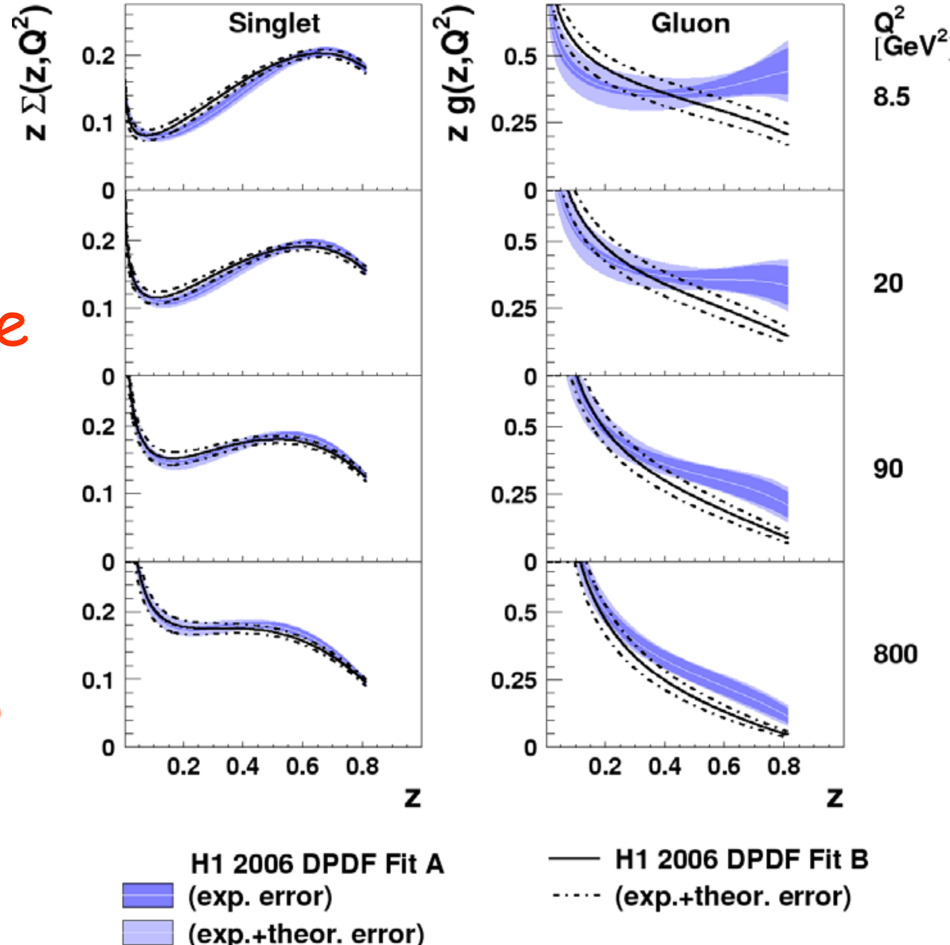
`Discovery' at HERA (~10% of low x events are of type ep -> eXp)

- Parton-level mechanism, relations to diffractive pp scattering, inclusive DIS, confinement still not settled.

- QCD Factorisation: Diffractive parton densities (DPDFs) universal to diffractive DIS (apply to both HERA and LHeC)

… can also be used to predict pp with additional `gap survival' factors

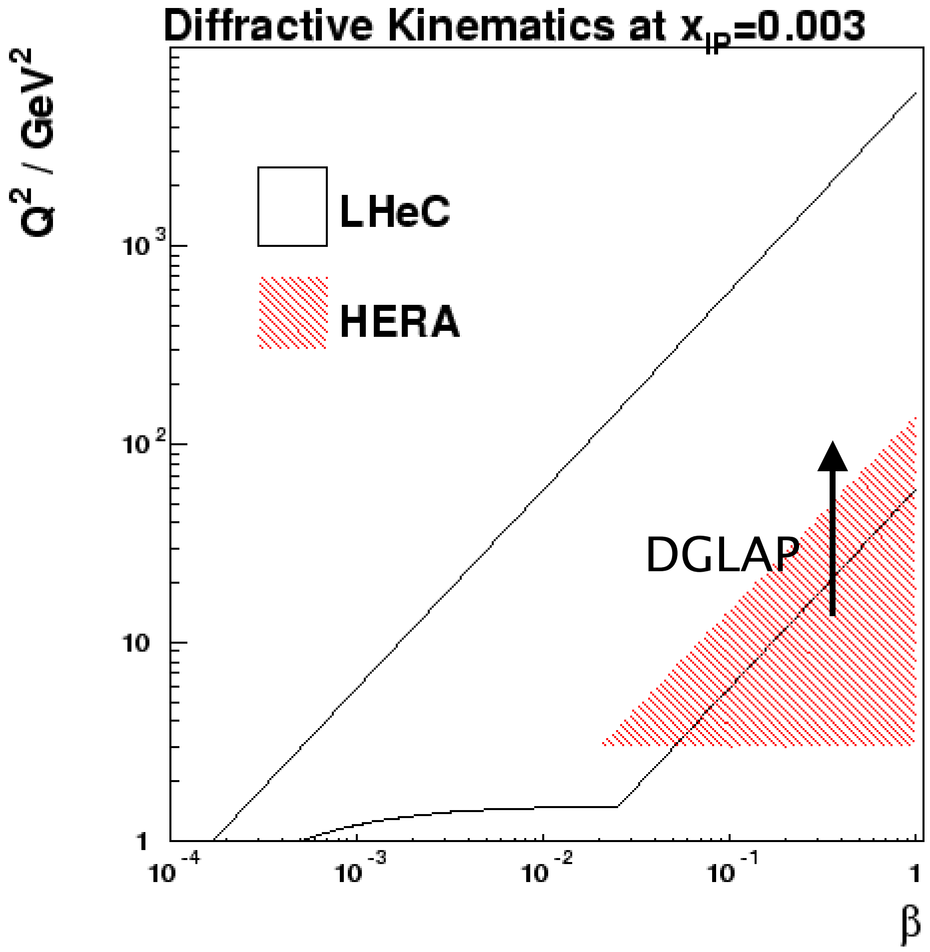




LHeC Diffractive Kinematics

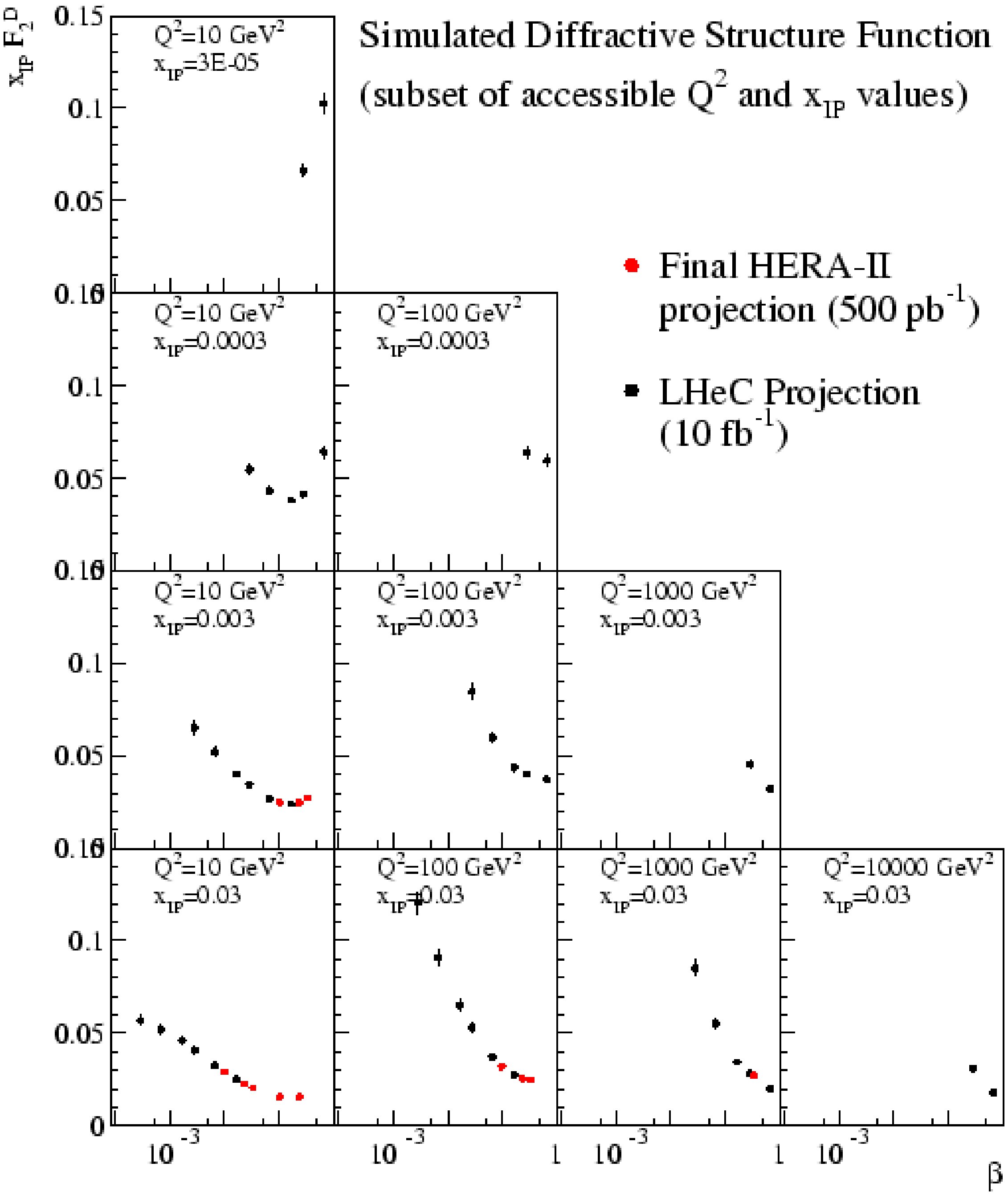
- Tests of factorisation and evolution dynamics: DPDFs extracted at HERA predict LHeC cross section at moderate /large β, higher Q^2 using DGLAP.

- New dynamics: LHeC opens new low β region – parton saturation, BFKL etc showing up first in diffraction?



- Large Diff. Masses: Z, W, b production, studies of new 1^{--} states

LHeC Simulation



Statistical precision not an issue

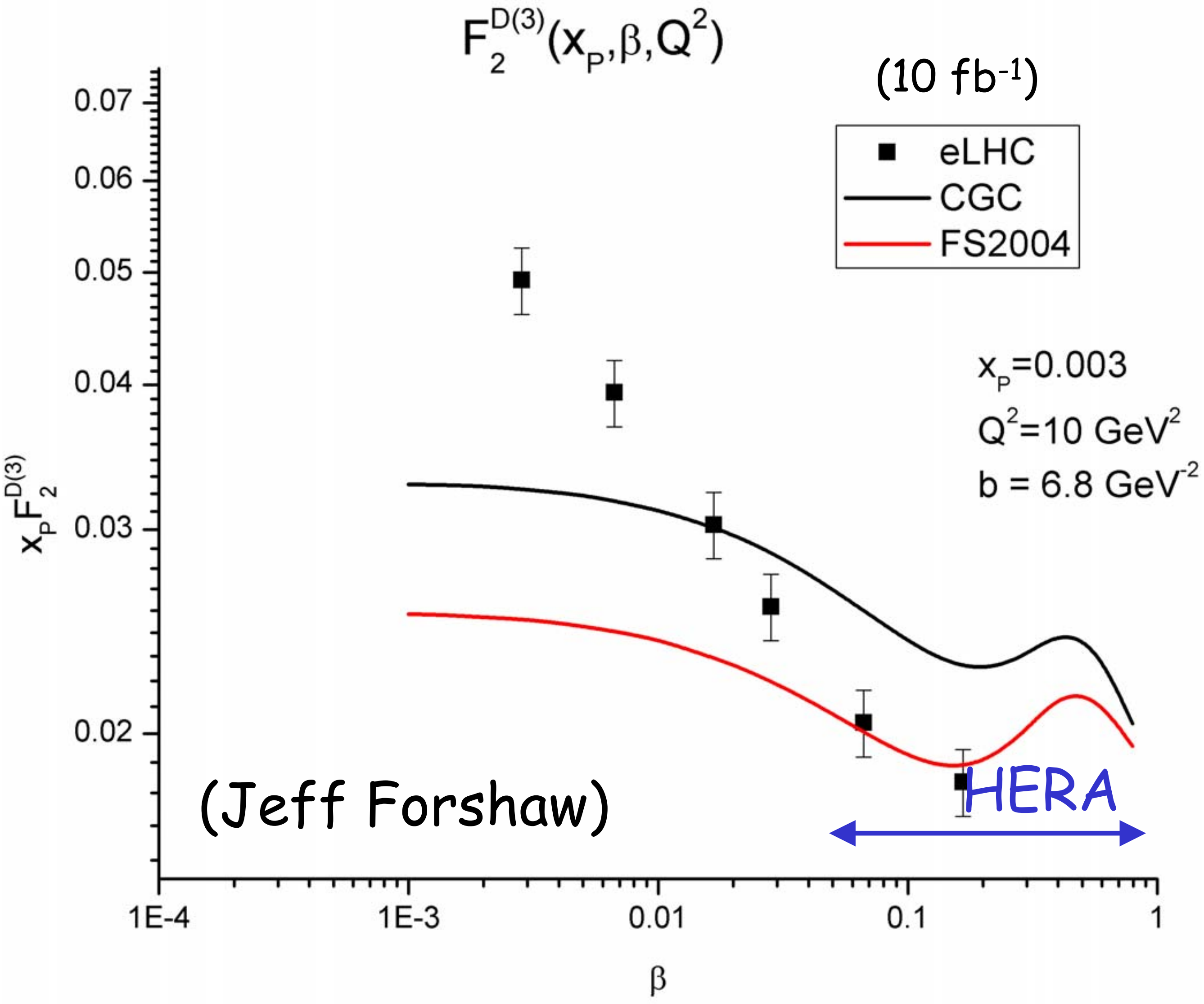
Big extension to lower x_{IP} … cleaner separation of the diffractive exchange

Higher Q^2 at fixed β & x_{IP} → CC (and z in NC) allows flavour decompositions of DPDFs

Lower β at fixed Q^2 & x_{IP}

Example F_2^D with LHeC

(1° acceptance)



(10 fb^{-1})

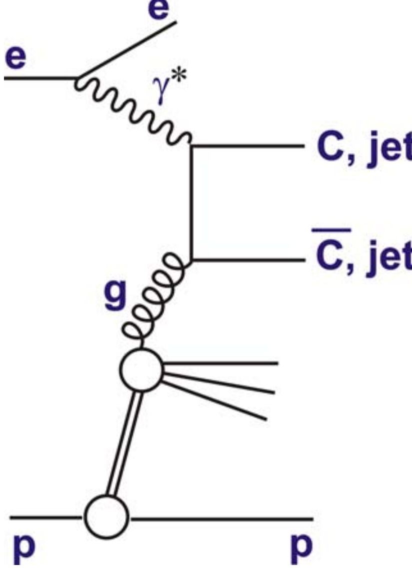
(Jeff Forshaw)

- Diffractive structure function poorly known for β <~ 0.01 … large extrapolation uncertainties.

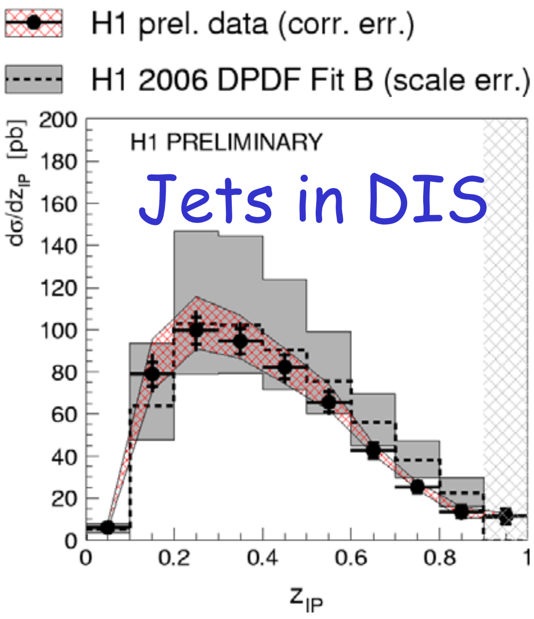
- Plenty to learn from LHeC, including the proper way to saturate a qqbar-g dipole

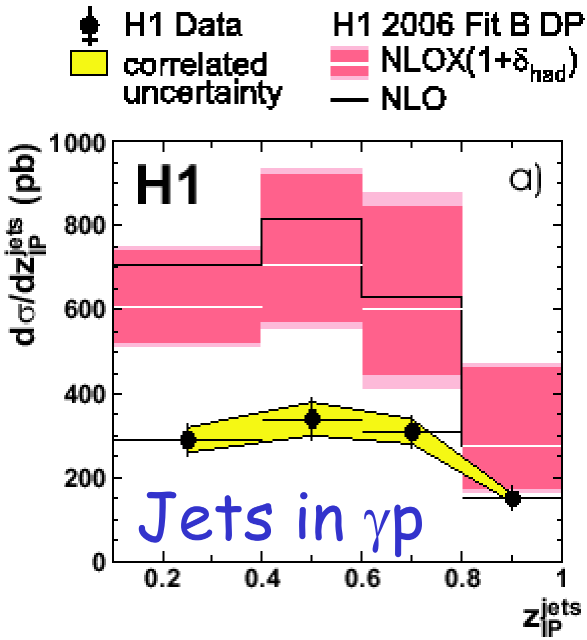
Large Rapidity Gap method assumed.
Statistical precision ~0.1%, systematics ~5%

Final States in Diffraction

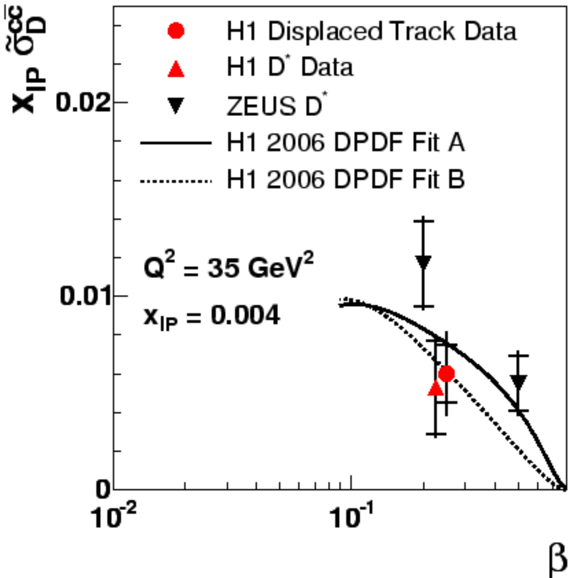


- Factorisation tests done at HERA with gluon initiated jet / charm processes… BUT …
- Kinematically restricted to high β region where F_2^D is least sensitive to the gluon!
- Kinematically restricted to low $p_T < M_X/2$ where scale uncertainties are large.
- γp surprises → understanding gap survival?… Diff H @ LHC?


Jets in DIS


Jets in γp

Charm in DIS



Final States in Diffraction at the LHeC

- At LHeC, diffractive masses M_x up to hundreds of GeV can be produced with low x_{IP}

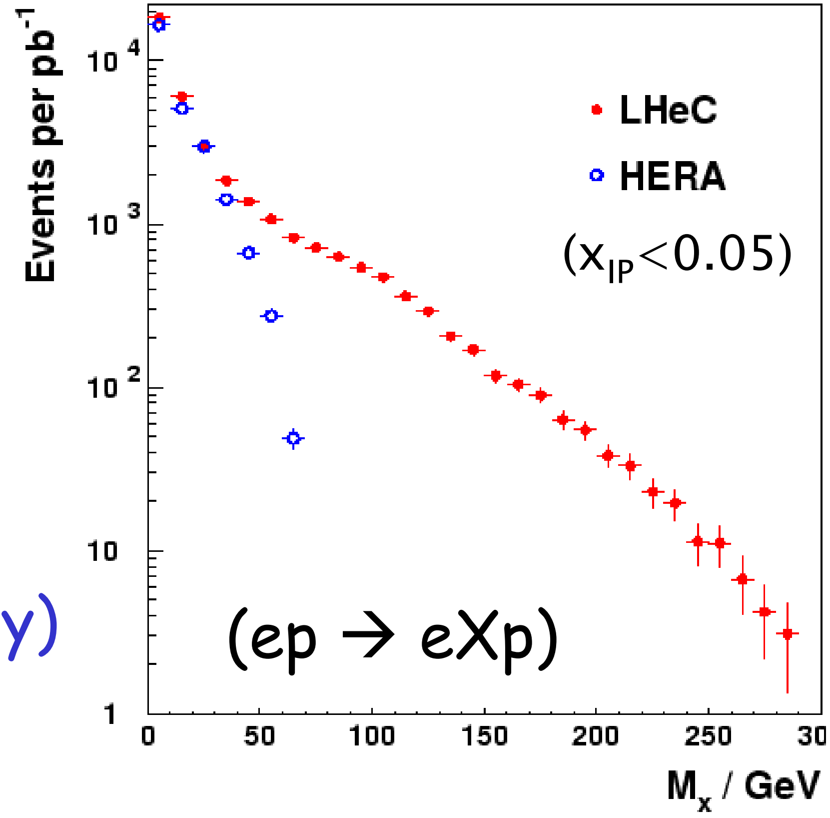
- Low β, low x_{IP} region for jets and charm accessible

- Final state jets etc at higher pt … much more precise factorisation tests and DPDF studies (scale uncty)

- New diffractive channels … beauty, W / Z bosons

- Unfold quantum numbers / precisely measure exclusively produced new / exotic 1^- states

(RAPGAP simulation)



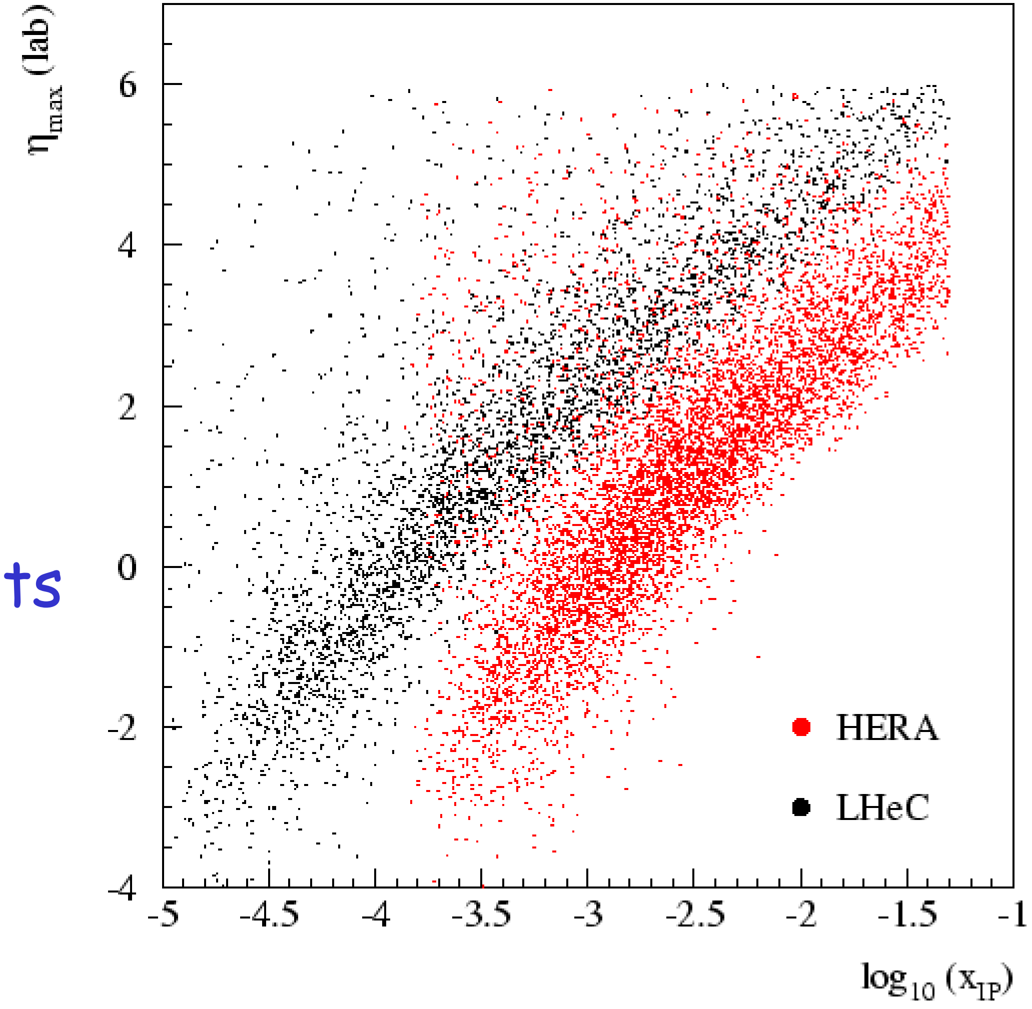
Diffractive Detector Considerations

- Accessing x_{IP} = 0.01 with rapidity gap method requires η_{max} cut around 5 …forward instrumentation essential!

- Roman pots, FNC should clearly be an integral part

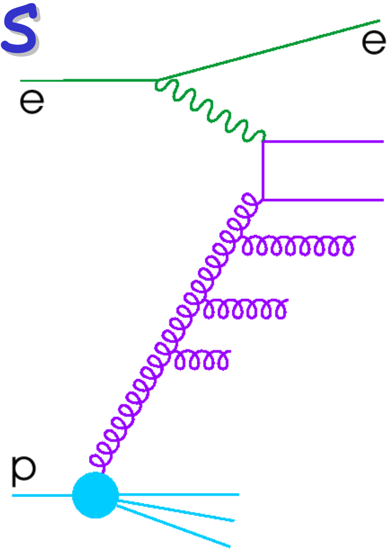
- Not new at LHC: Roman pots already integrated into CDF, Atlas via Totem, FP420, FP220)

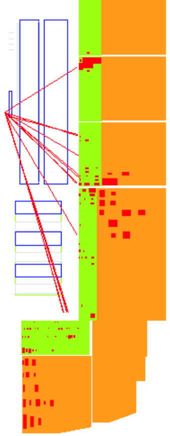
η_{max} and LRG selection …



Forward Jets

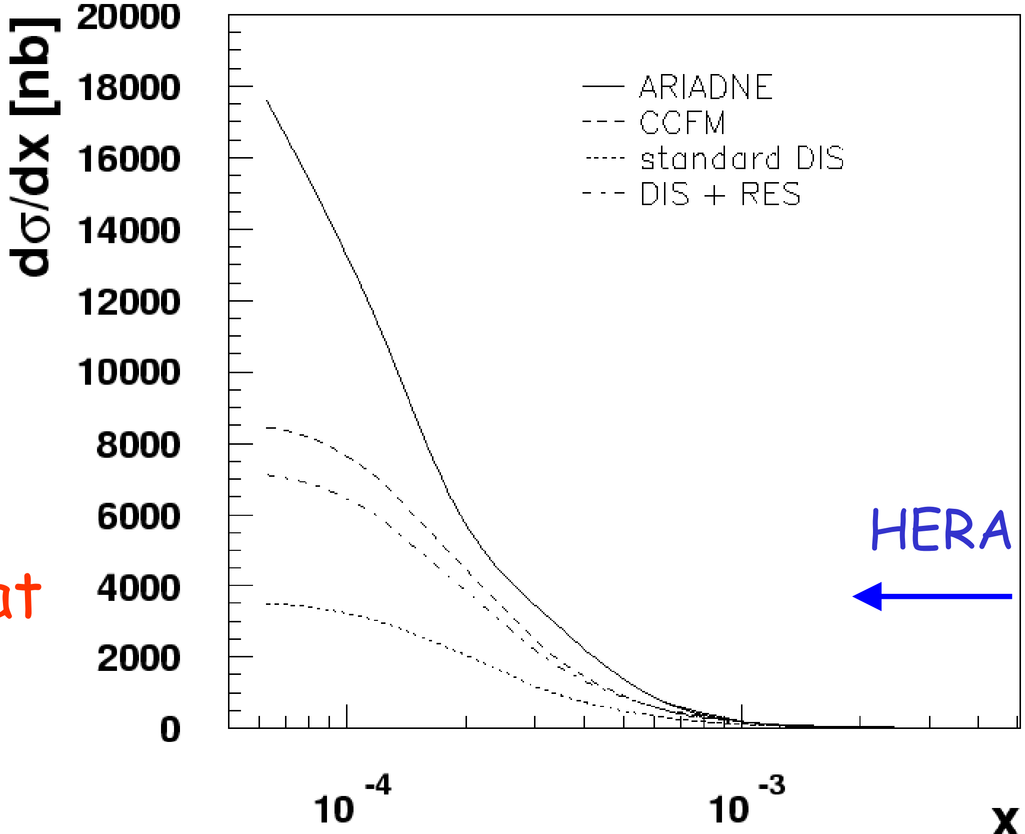
Long HERA program to understand parton cascade emissions by direct observation of jet pattern in the forward direction. … DGLAP v BFKL v CCFM v resolved γ^*…





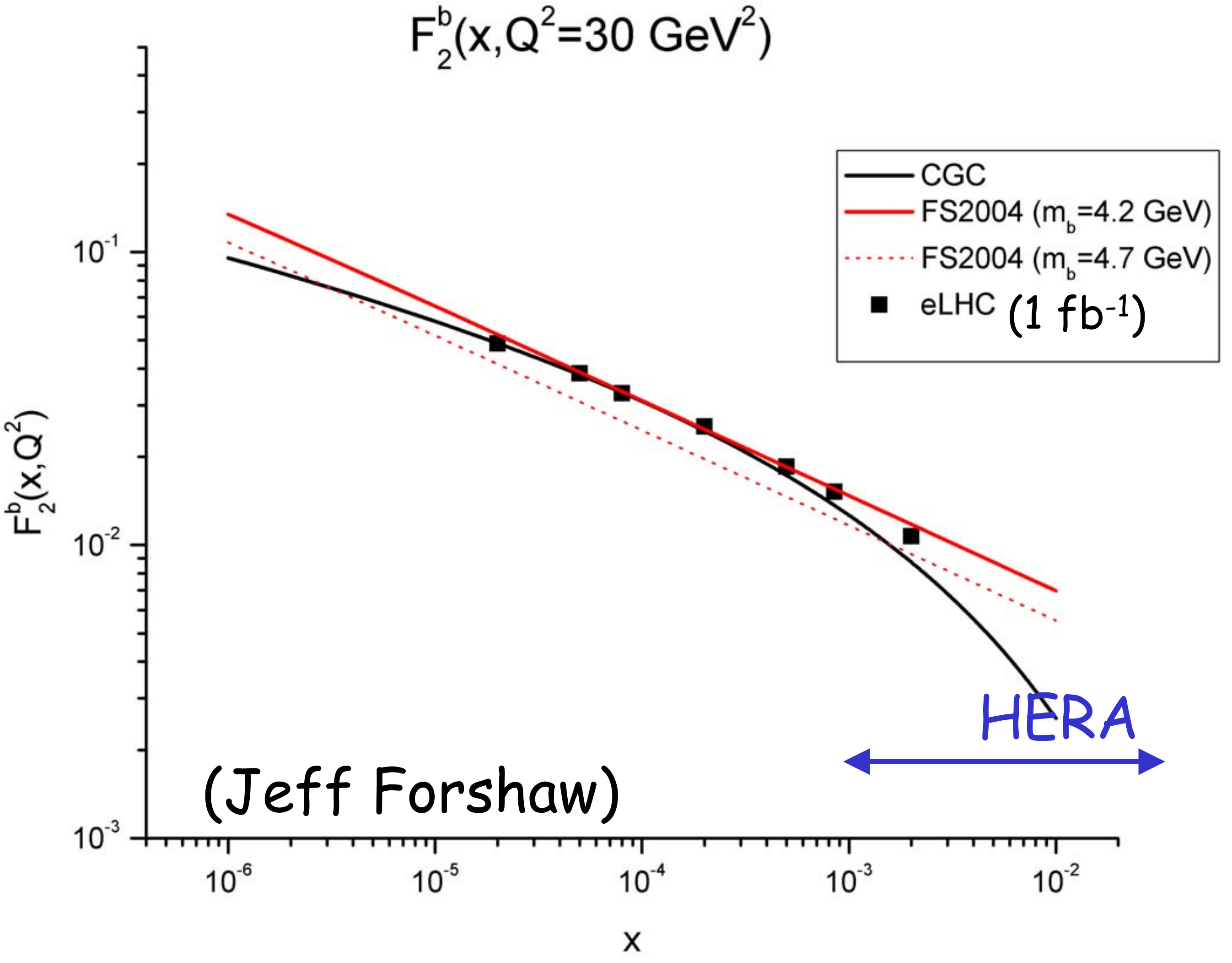
Conclusions limited by kinematic restriction to high x (>~ 2.10^{-3}) and detector acceptance.

At LHeC … more emissions due to longer ladder & more instrumentation →measure at lower x where predictions really diverge.



Beauty as a Low x Observable!!!

(10° acceptance)

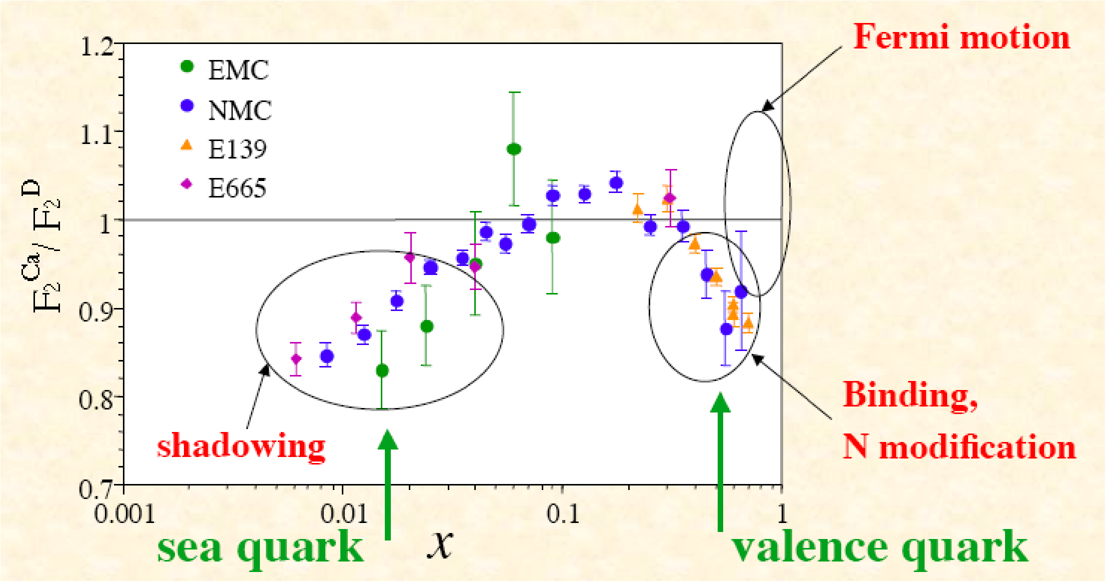


(Jeff Forshaw)

F_2^c and F_2^s also measurable (see Max Klein's talk).

Statistical errors ~1%, systematics ~5%

With AA at LHC, LHeC is also an eA Collider

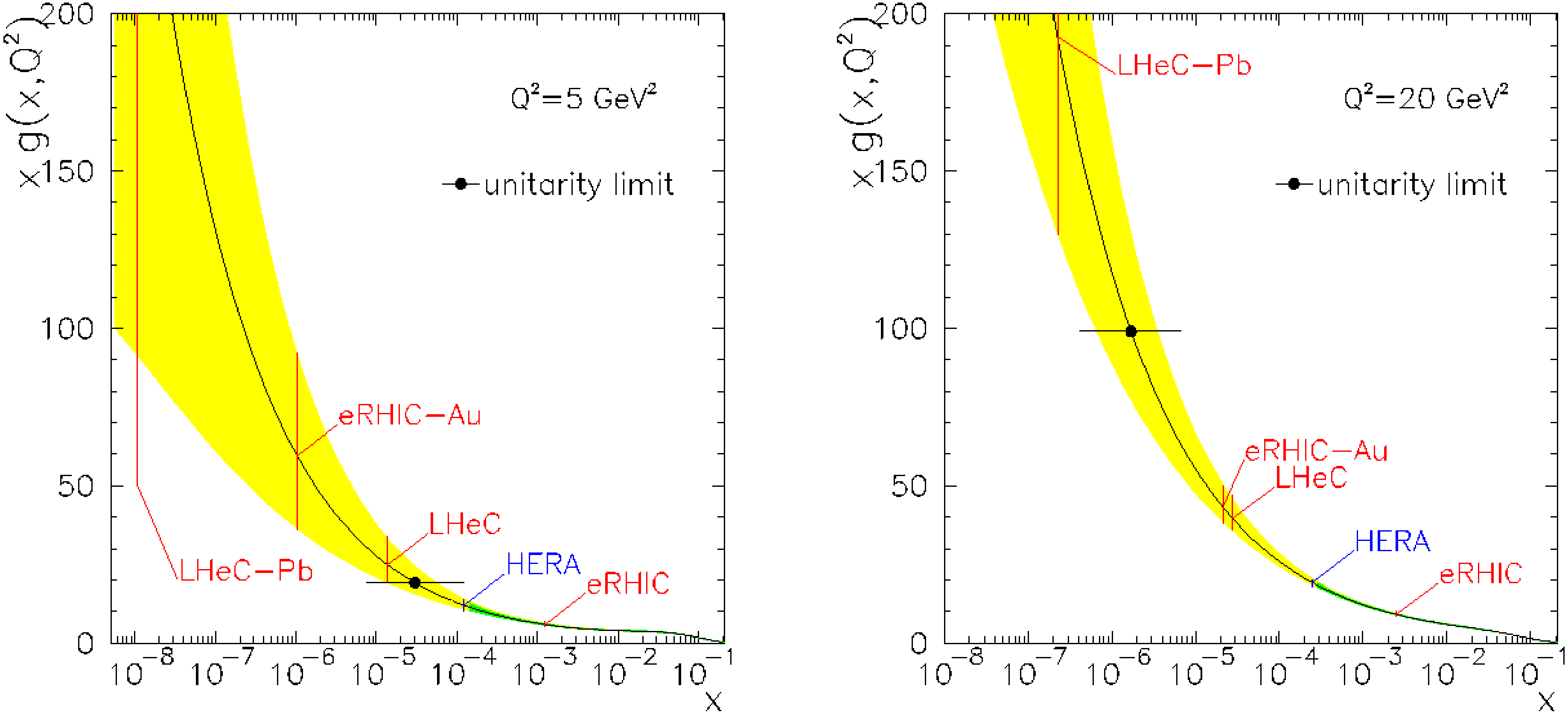


- Rich physics of nuclear parton densities.
- Limited x and Q^2 range so far (unknown For x <~ 10^{-2} and $Q^2 > 1\ GeV^2$)

- LHeC extends by orders of magnitude towards lower x.
- With wide range of x, Q^2, A, opportunity to extract and understand nuclear parton densities in detail
- Symbiosis with ALICE, RHIC, EIC … disentangling Quark Gluon Plasma from shadowing or parton saturation effects

Simple Model of Gluon Saturation

- Saturation point when $xg(x) \sim Q^2 / \alpha_s(Q^2)$
- Nuclear enhancement of gluon density a $A^{1/3}$
- Compare extrapolated (NLO) gluon density from HERA



- Saturation point reached in ep at LHeC for Q^2 <~ 5 GeV^2
- Reached in eA for much higher Q^2

Uncovered Topics

This talk contained an (embarrassingly) limited number of studies, which only scratches the surface of the low x physics potential of the LHeC.

Some obvious omissions:

- Lots of eA physics!
- All sorts of low x jet measurements
- All sorts of low x charm measurements
- F_L
- Prompt photons
- Photoproduction and photon structure
- Leading neutrons and other semi-inclusives
- Exclusive vector meson production

… studies of these and many other topics are very welcome, to evaluate the physics case for such a facility!

Summary

To further pursue low x physics with unpolarised targets, the natural next step is an extension to lower x (i.e. higher energy)

For its relative theoretical cleanliness, ep should be a large feature of this.

For its enhanced sensitivity to high parton densities, eA should also be a large part of the programme.

All of this is possible in the framework of the LHC - a totally new world of energy and luminosity!... Why not exploit it for lepton-hadron scattering?

First conceptual design exists … no show-stopper so far … some encouraging first physics studies shown here.

Much more to be done to fully evaluate physics potential and determine optimum running scenarios!