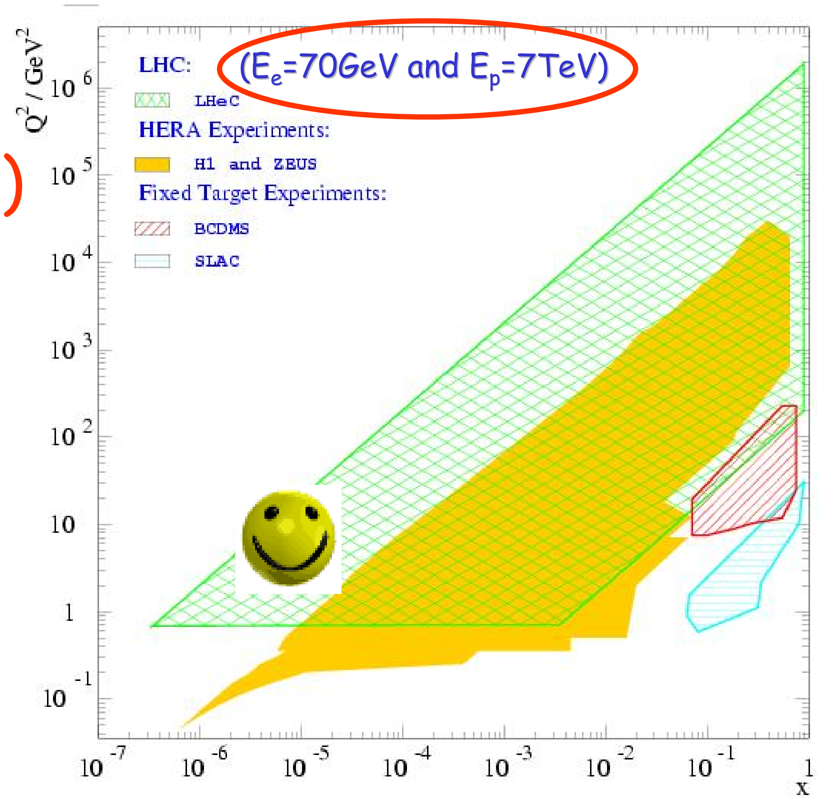
More Low x Observables at the LHeC

Armen Bunyatyan (MPI-Heidelberg)
Laurent Favart (ULB Brussels)
Jeff Forshaw (Manchester)
Max Klein (Liverpool)
Cyrille Marquet (Columbia)
Andrew Mehta (Liverpool)
Paul Newman (Birmingham)

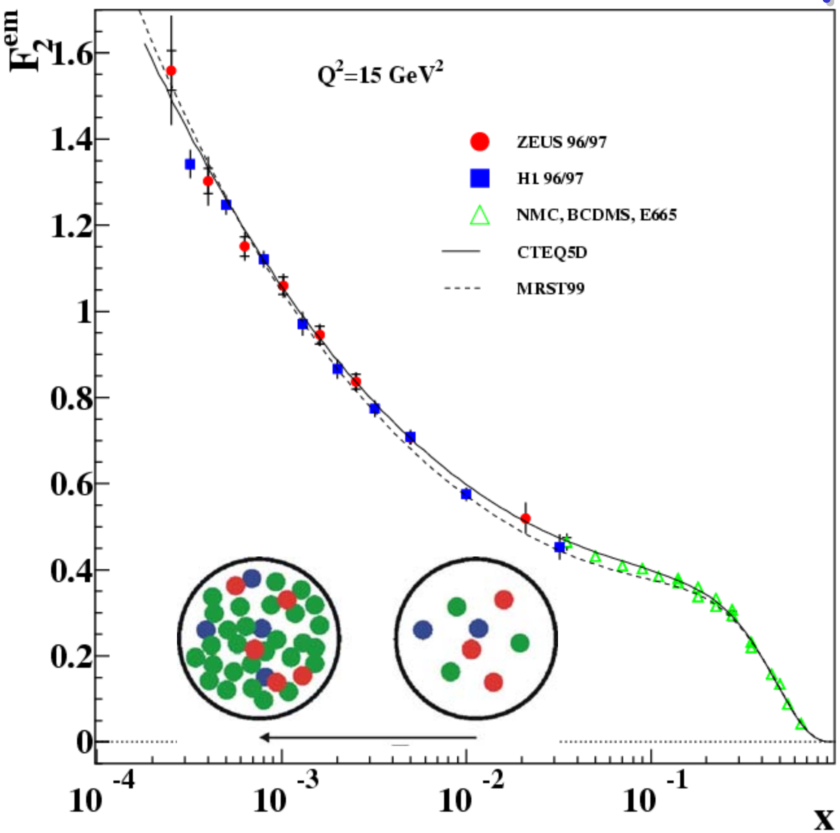


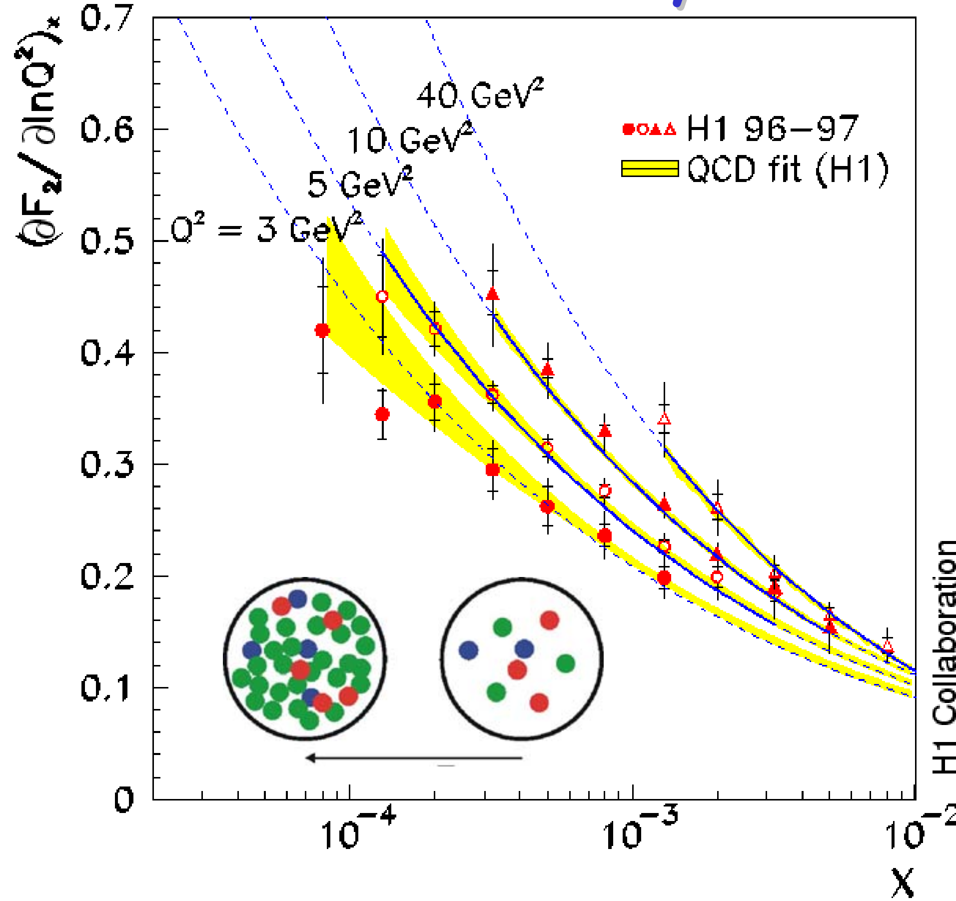
Divonne LHeC Workshop
2 September 2008

A compendium of first studies of a few processes …

- What kinematic range can LHeC cover?
- What sort of precision can be reached?
- Should we care?

The "Birth" of Experimental Low x Physics

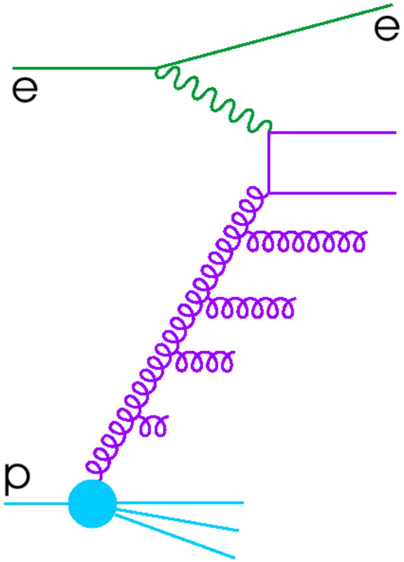




• Biggest HERA discovery?.. strong increase of quark density (F_2) and gluon density ($d F_2 / d \ln Q^2$) with decreasing x.

• Low x, `large' Q^2 region is a new high density, low coupling limit of QCD

Current Status of Low x Physics

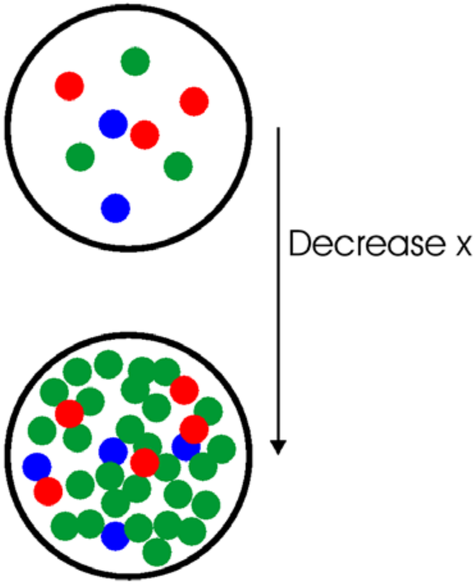


RHIC, Tevatron and HERA have taught us a lot,
… but many questions are not fully answered…

- 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)?

- Large (~ constant?) fraction of diffraction?



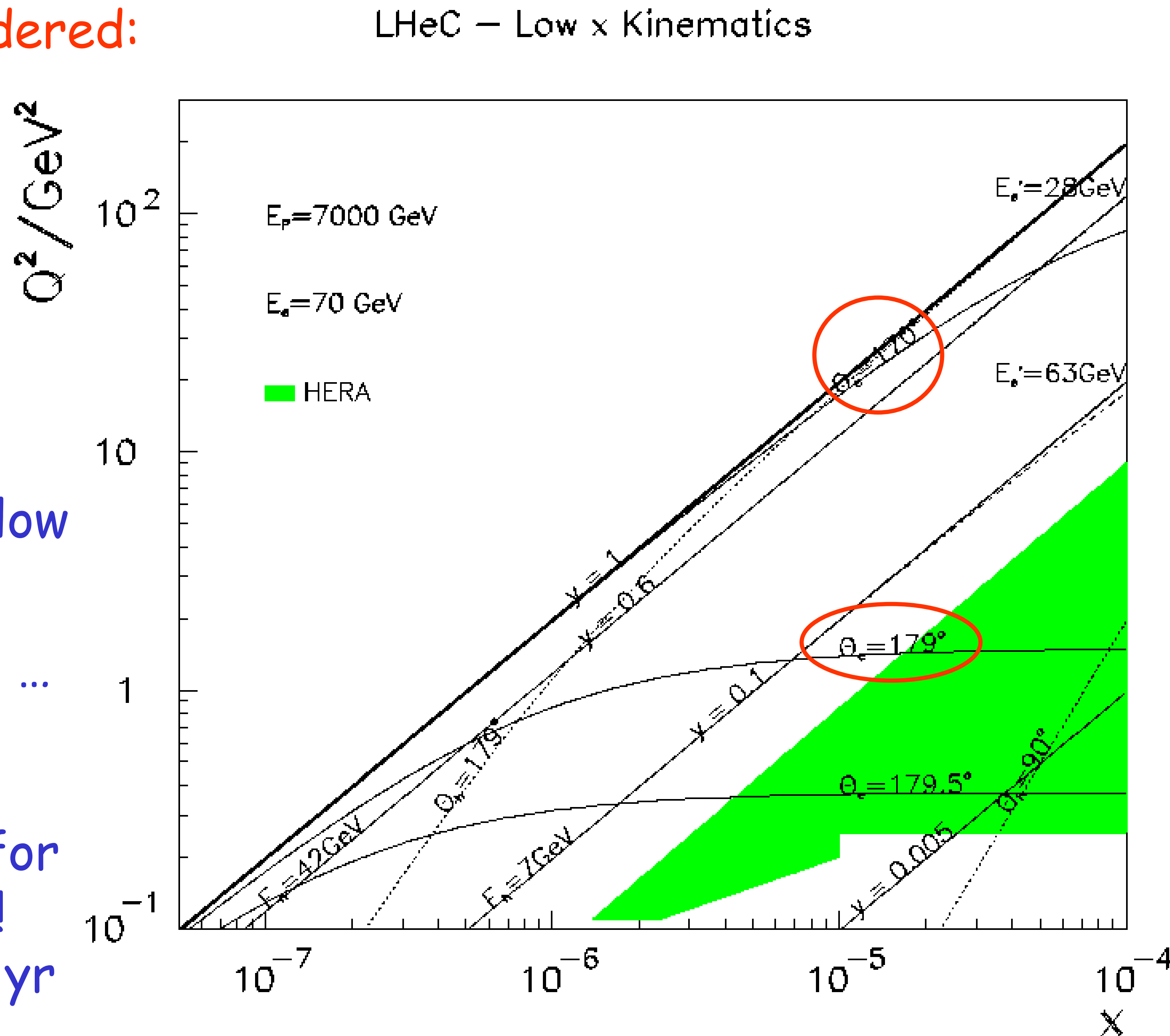
Problem is that low x is kinematically correlated to low Q^2, which brings problems with partonic interpretation

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 GeV^2 for all x > 5 x 10^{-7} ! Lumi ~ 1 fb^{-1} / yr



Some First Low x Detector Considerations

• Low x studies require electron acceptance to 1° to beampipe

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 larger Q^2), hadronic final state is boosted more in the forward direction.

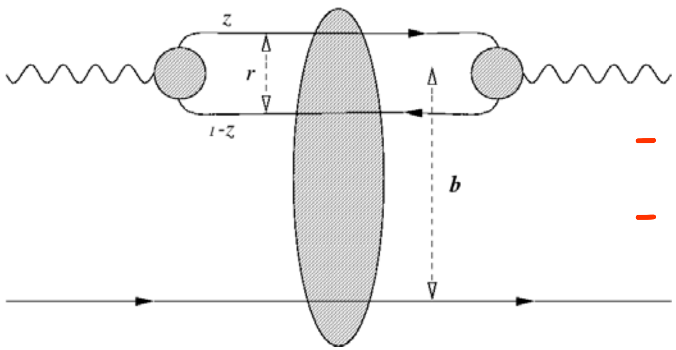
• Study of low x / Q^2 and of range overlapping with HERA, with sensitivity to energy flow in outgoing proton direction requires forward acceptance for hadrons to 1°

… dedicated low x set-up with no (or active?) focusing magnets?

Dipole Model Predictions

• In what follows, comparisons are made with low-x extrapolations of a number of different dipole models, as a simple means of obtaining unified predictions for various inclusive and exclusive processes …

F_2, F_2^c, F_2^b, F_L, high β F_2^D, DVCS, VMs



- qqbar – p interaction in universal σ_{dipole}
- Process dependence in wavefn factors

$$\text{e.g.}\quad \sigma_{\gamma^* p}^{T,L}(x,Q^2) \sim \int \mathrm{dz}\ \mathrm{d}^2 r\ \left|\psi_{\gamma^*}^{T,L}(z,r,Q^2)\right|^2 \sigma_{dipole}(x,r,z)$$

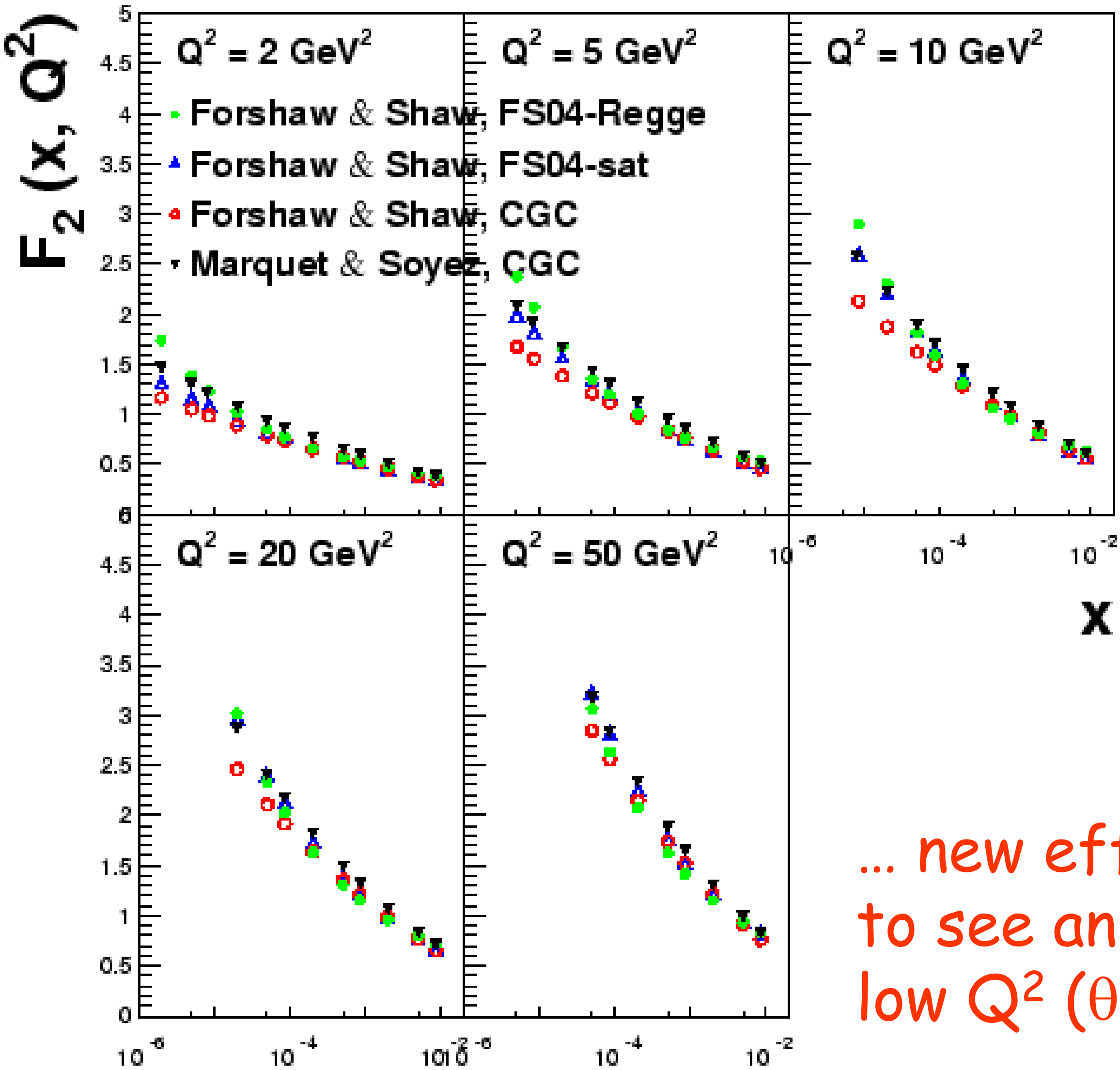
-All such models here are based on fits to HERA data and 'blindly' extrapolated to LHeC range.

-All implement saturation in σ_{dipole} except `FS04-Regge'

… more details in this afternoon's talk

Example low x F_2 with LHeC Data

With 1 fb-1 (1 year at 10^{33} cm^{-2} s^{-1}), 1° detector:
Stat. precision < 0.1%, syst, 1-3% [see Max Klein's talk]



Precise data in LHeC region, x > ~10^{-6}

- Extrapolated FS04, CGC models including sat'n suppressed at low x, Q^2 relative to non-saturating FSRegge

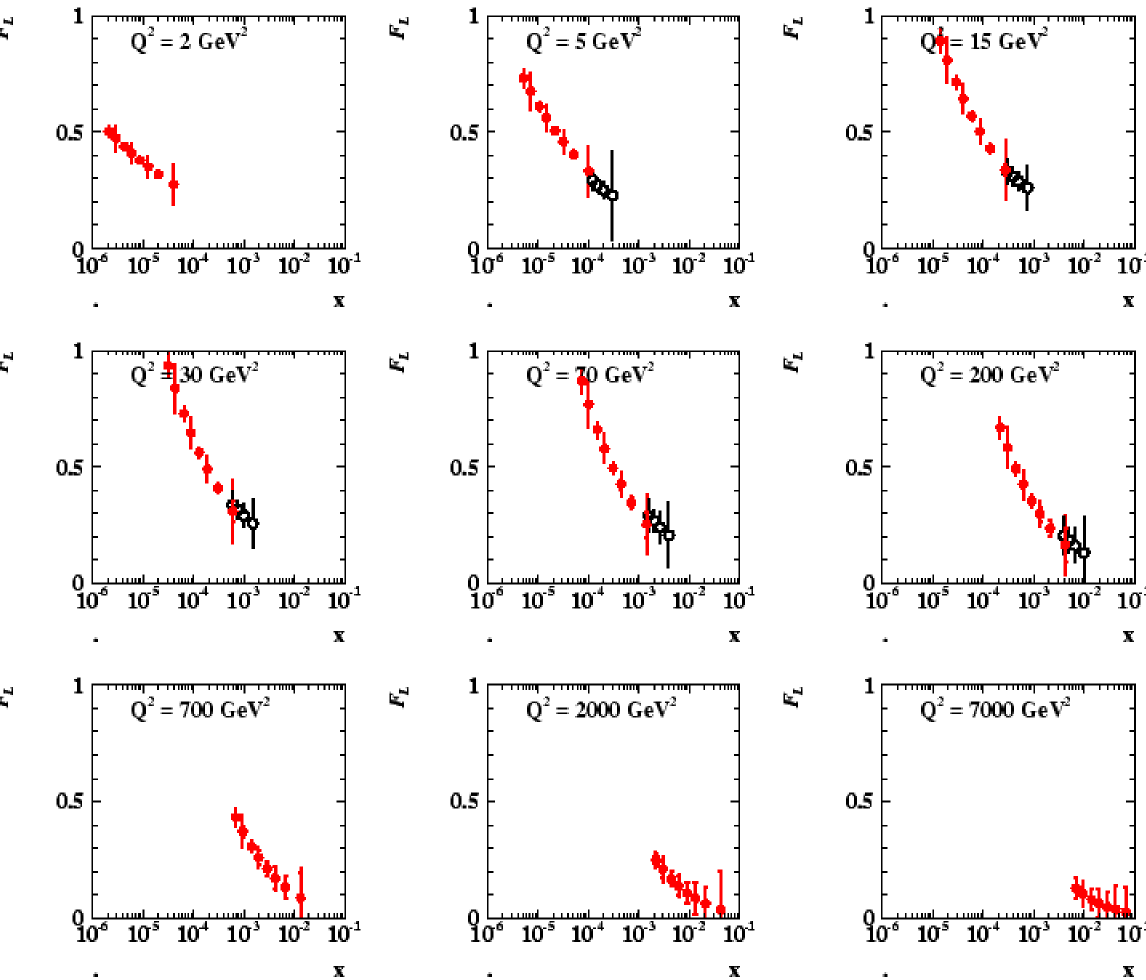
… new effects may not be easy to see and will certainly need low Q^2 ($\theta \rightarrow 179°$) region …

The Gluon from F_L?

[Max Klein]

● LHeC

○ H1 low Ep run (projected)



Vary proton beam energy as recently done at HERA ?...

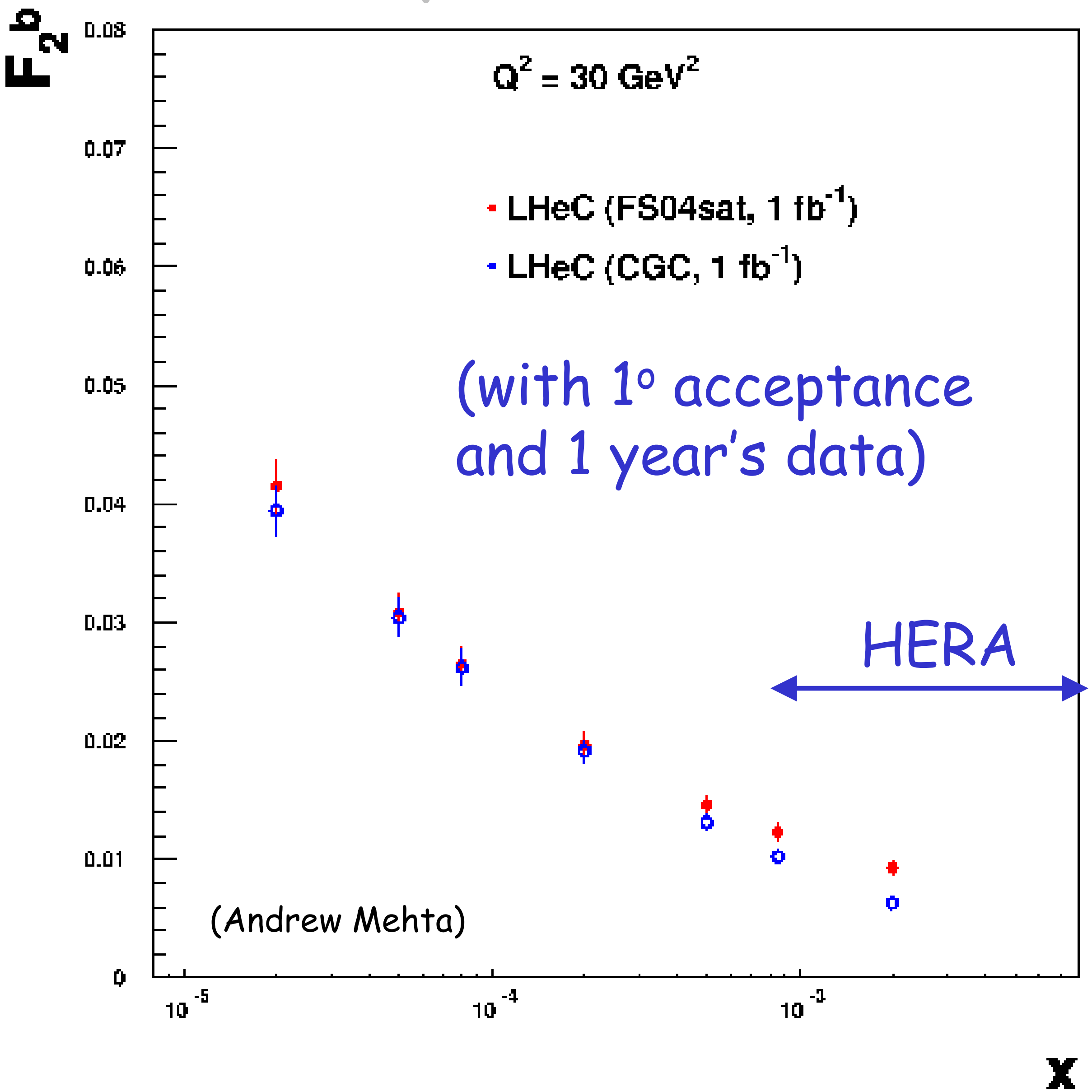
E_p (TeV)	Lumi (fb^{-1})
7	1
4	0.8
2	0.2
1	0.05
[0.45	0.01]

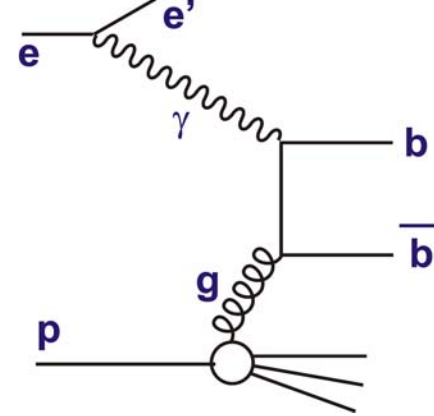
[~ 1 year of running]

Typically lose 1-2 points at high x if E_p = 0.45 TeV not possible

... precision typically 5%, stats limited for Q^2 > 1000 GeV^2

Beauty as a Low x Observable!





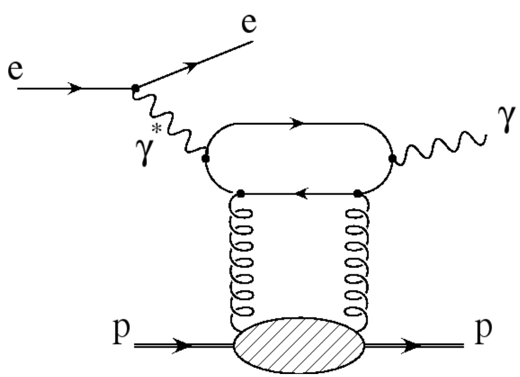
F_2^b can be measured constraining gluon down to x ~ 2.10^{-5}.

F_2^c and F_2^s also measurable [see Max, Olaf's talks]

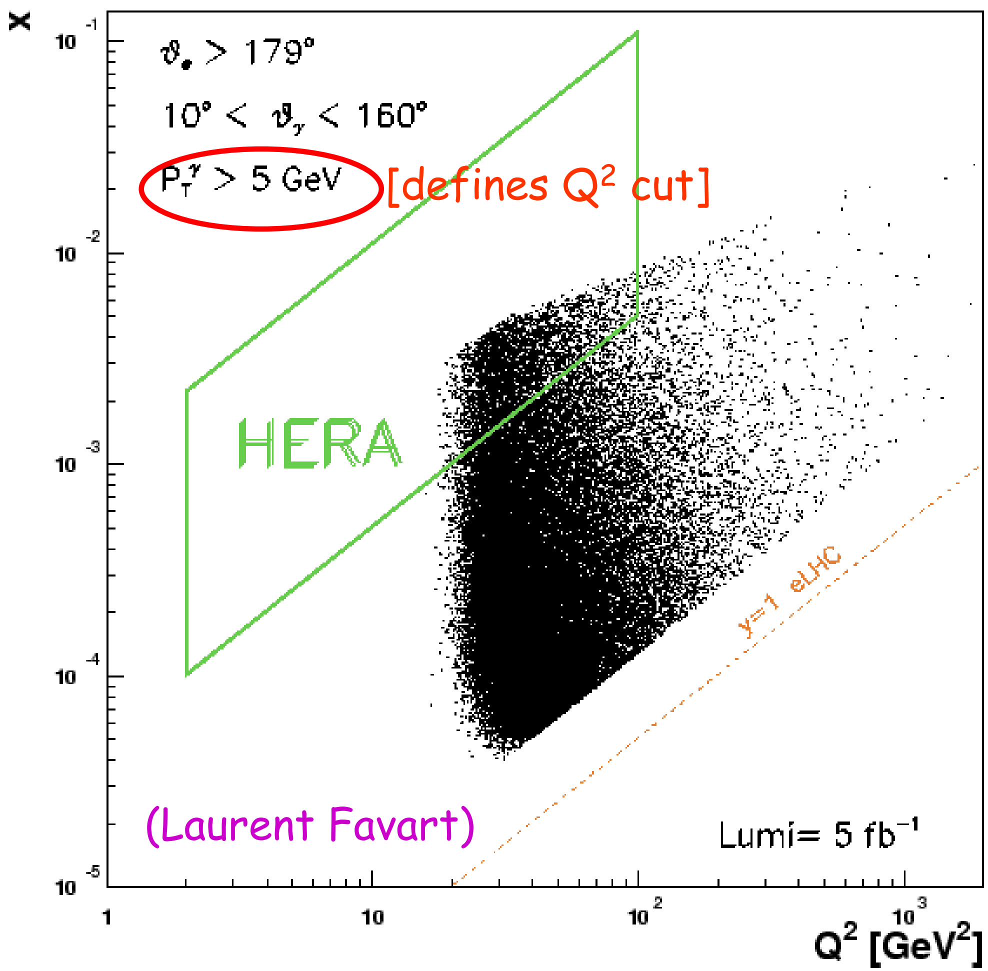
- 50% beauty, 10% charm efficiency
- 1% uds → c mistag probability.
- 10% c → b mistag [optimistic?]

Statistical errors ~2-3%, systematics ~5%

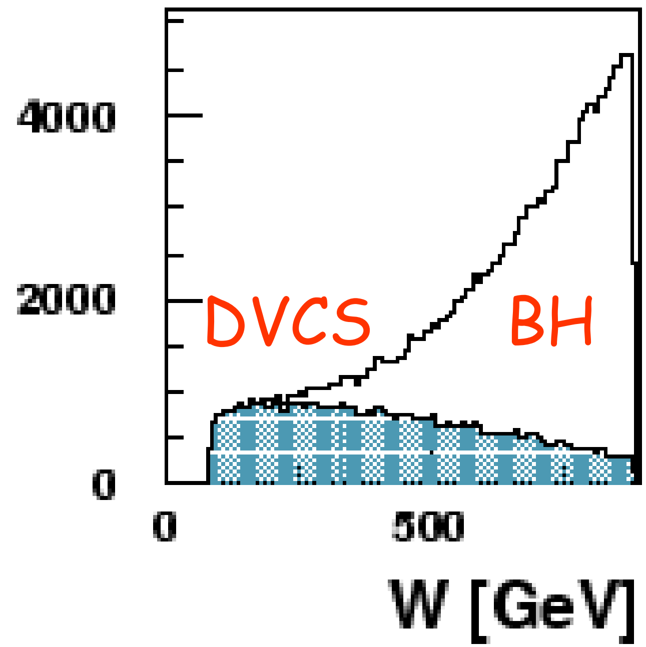
DVCS Measurement



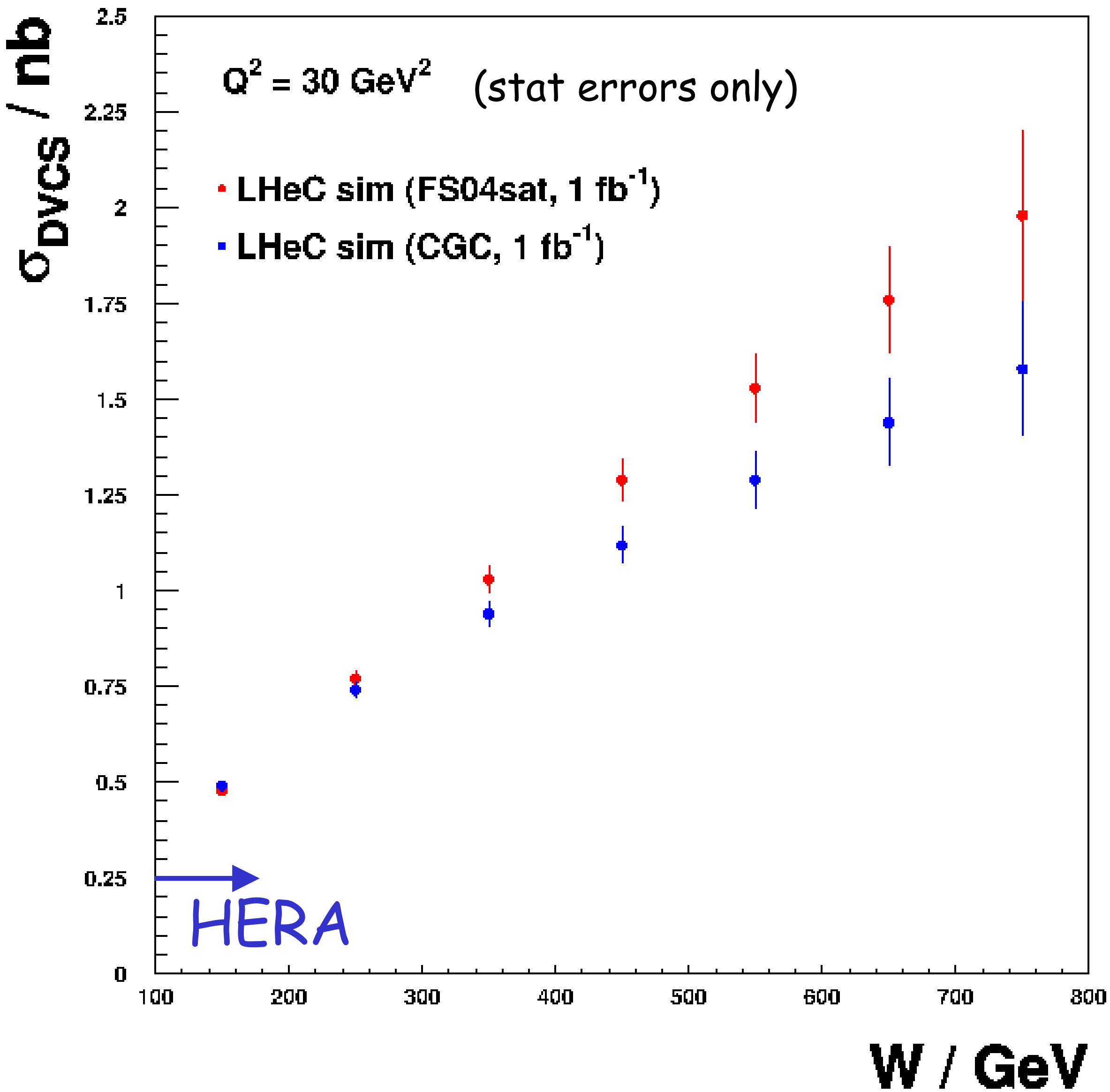
… the classic approach to `generalised parton densities' (GPDs)



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



Example of DVCS at LHeC



(1° acceptance)

Statistical precision with $1 fb^{-1}$ ~ 2-11%

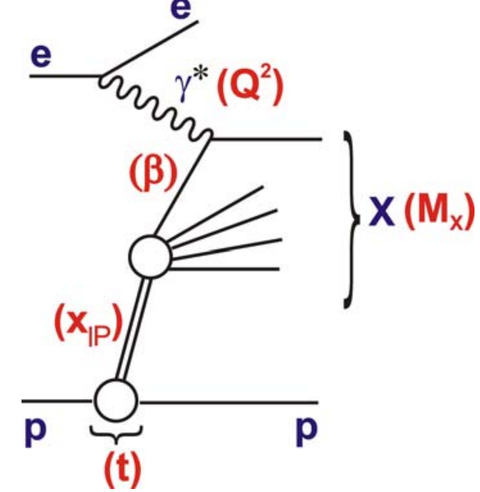
With F_2, F_L, could help establish saturation and distinguish between different models which contain it?

Cleaner interpretation in terms of GPDs at larger LHeC Q^2 values

VMs similar story?...
No work done so far ☹

Diffractive DIS at HERA

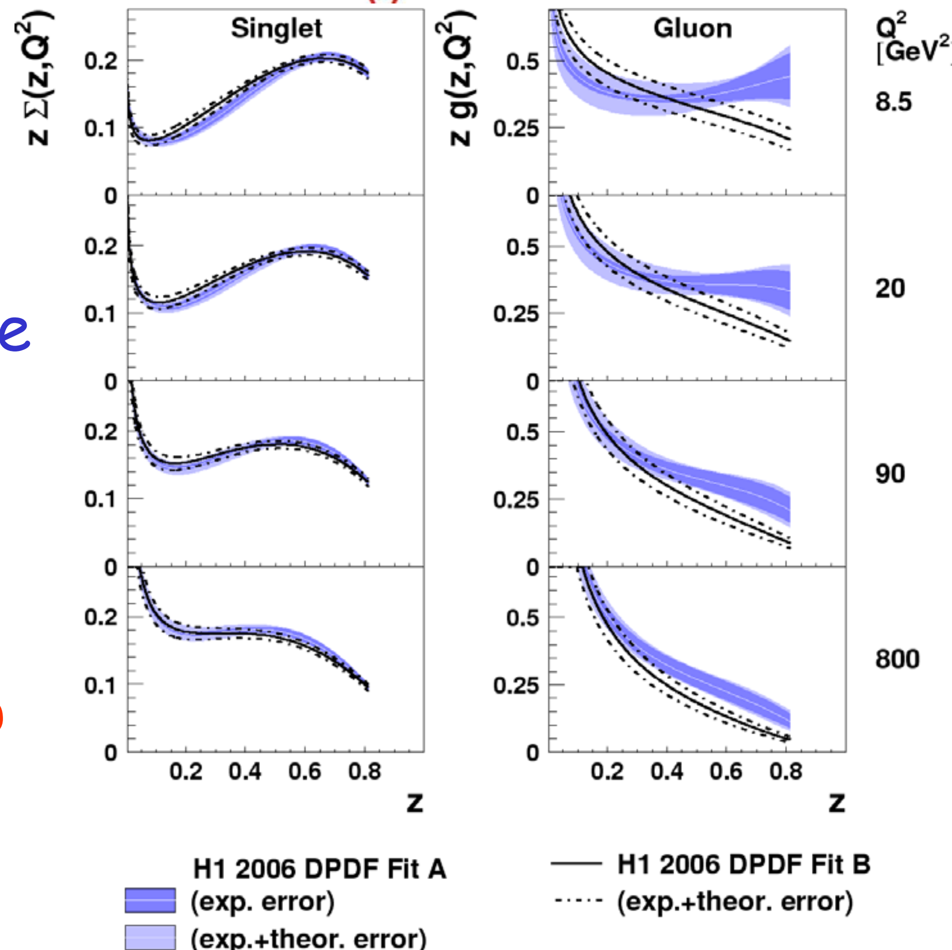
`Discovery' at HERA (~10% of low x events are of type ep -> eXp)



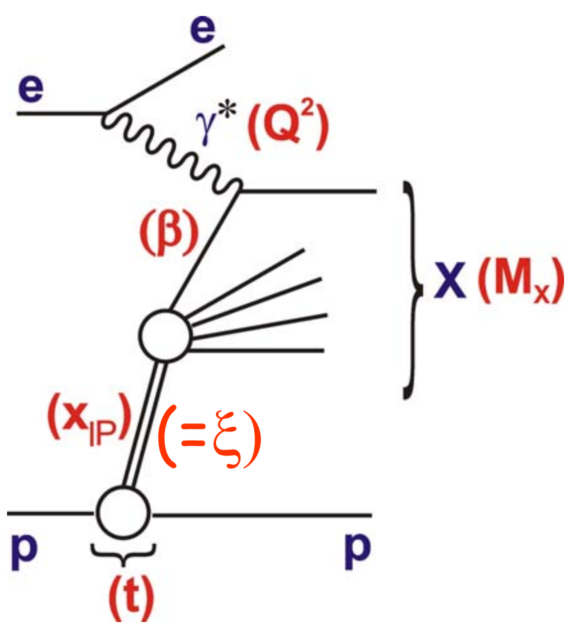
- Parton-level mechanism, relations to diffractive pp scattering, inclusive DIS, confinement still not settled.

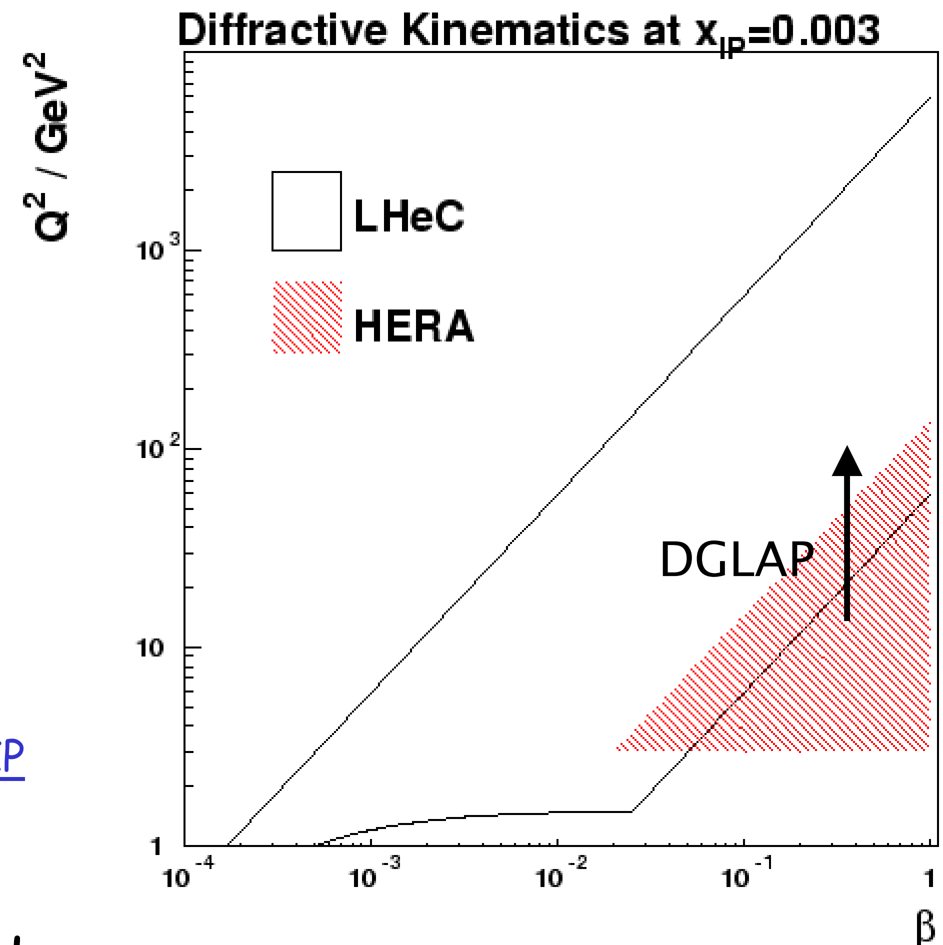
- QCD Factorisation: Diffractive parton densities (DPDFs) universal to diffractive DIS (apply to both HERA and LHeC)

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



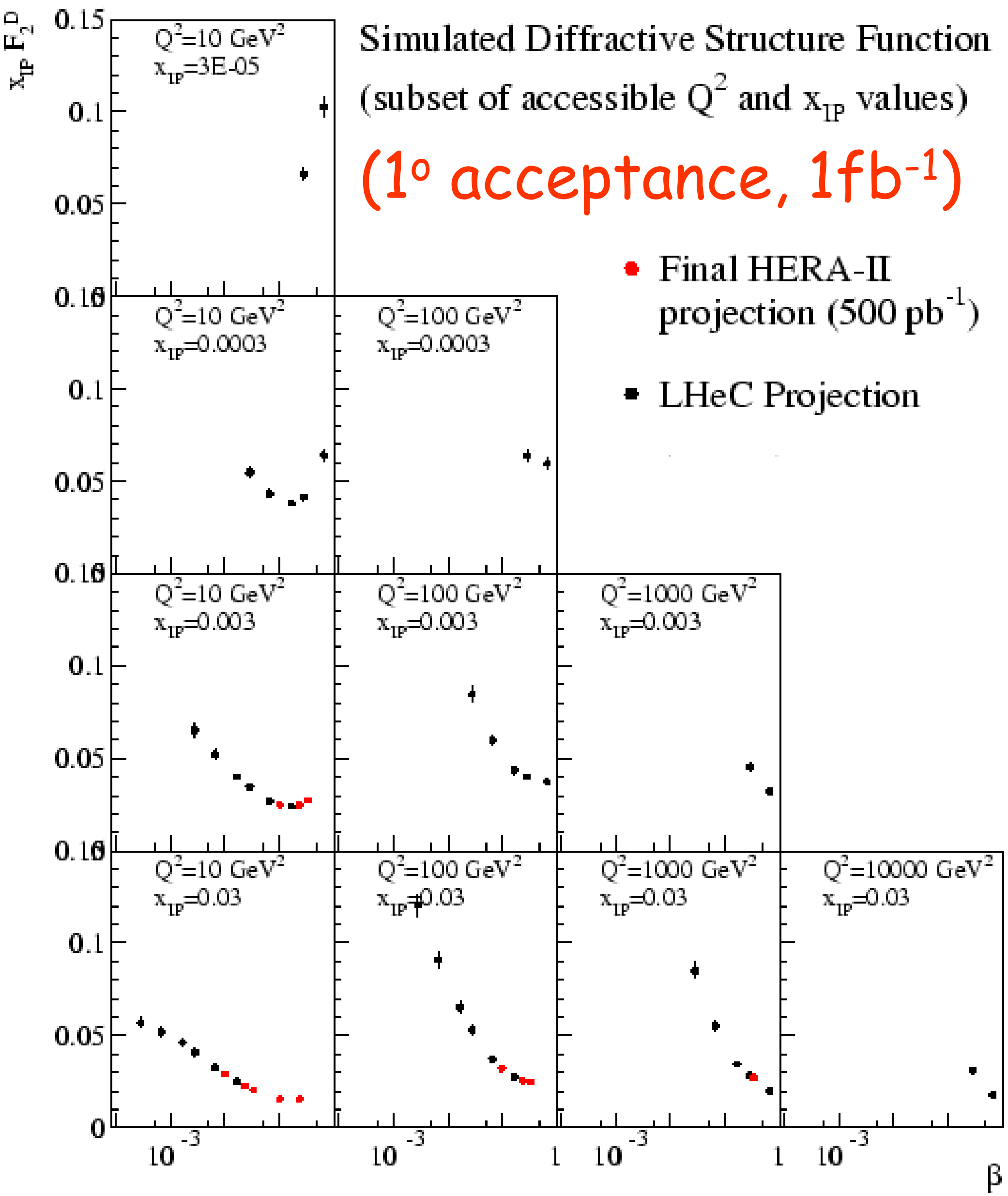
LHeC Diffractive DIS Kinematics





1) <u>Higher Q^2 at fixed β, x_{IP}</u>
→ gluon from DGLAP
→ quark flavour decomposition (CC and Z effects in NC)

LHeC Simulation



(1° acceptance, 1fb^{-1})

2) Lower β at fixed Q^2, x_{IP}

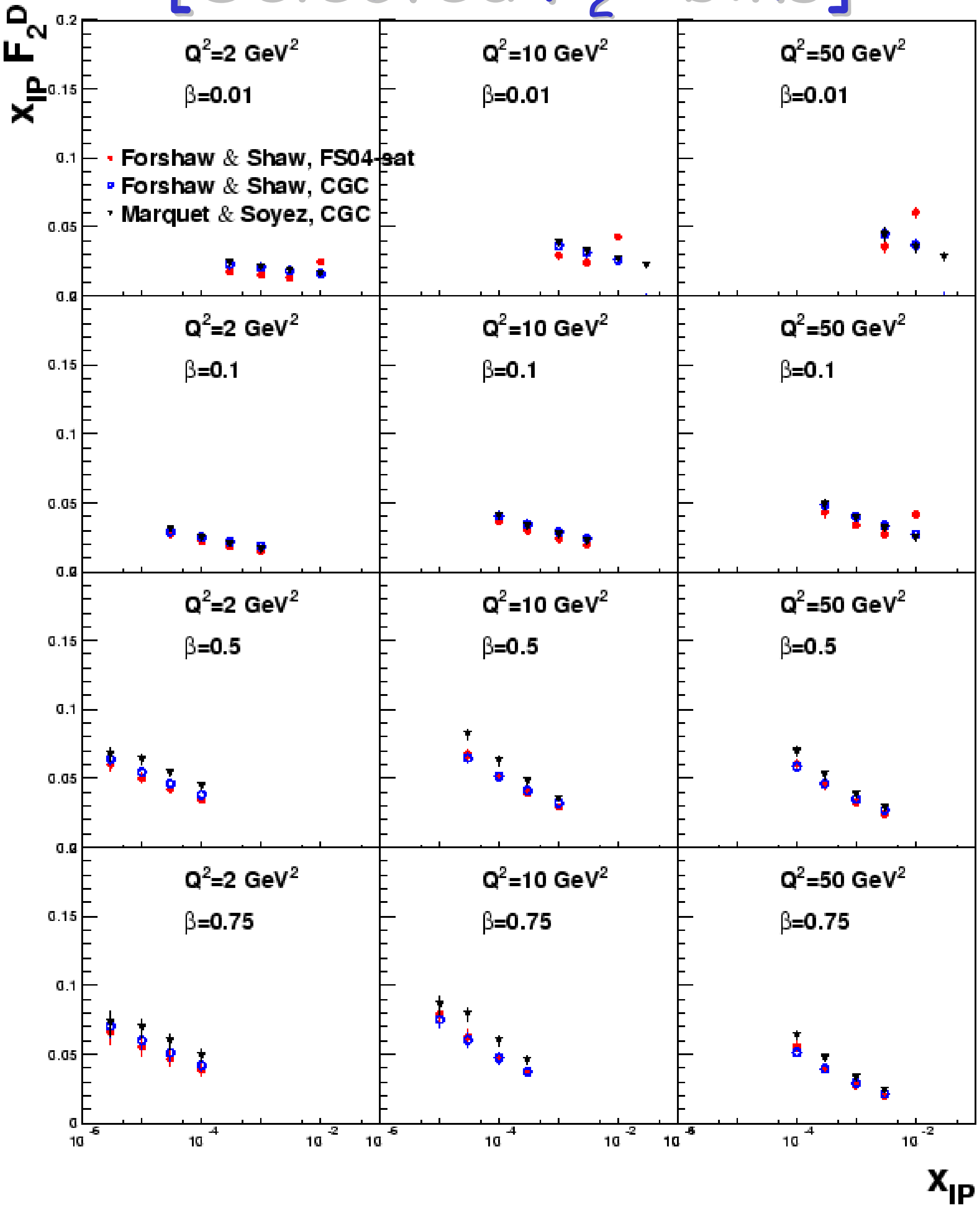
… almost complete lack of information on DPDFs with β<0.01 so far …
LHeC offers $\beta \rightarrow 5.10^{-4}$ …

→ Clearer novel QCD (gluon) dynamics?
→How does a q-qbar-g dipole saturate?

… Statistical precision <1%, systs 5-10% depending strongly on forward detector design

(Large rapidity gap method assumed here)

[Selected F_2^D bins]



3) Extension to lower x_{IP}

→ $x_{IP}=10^{-5}$ @ high β

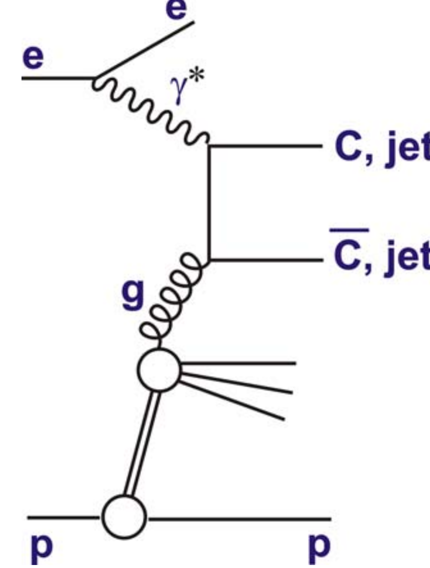
- Cleaner separation of diffractive exchange

- x dependence of diffractive:inclusive ratio at fixed M_x, Q^2

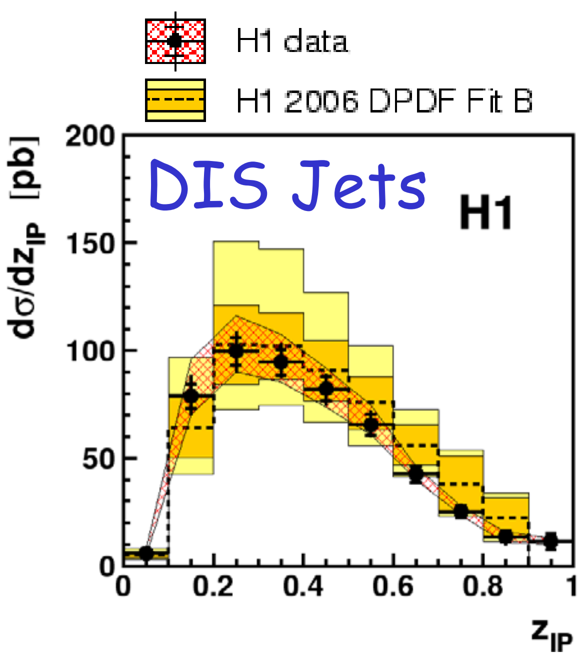
- Surprising agreement between models at high β
  - qqbar dipoles dominate?
  - well measured $(1/x_{IP})^n$ for extrapolation in HERA β, Q^2 range?

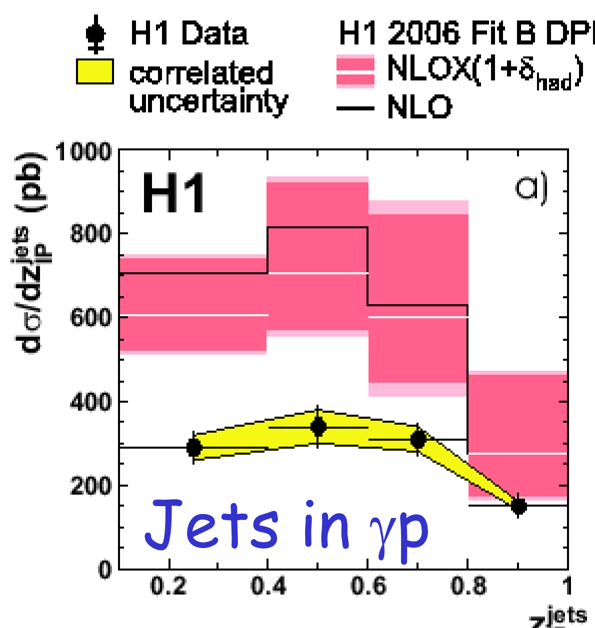
(LRG method assumed)

Final States in Diffraction

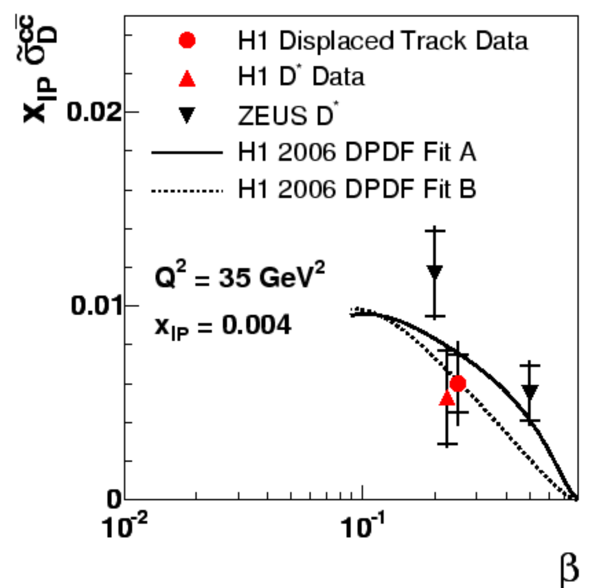


- Factorisation tests done at HERA with gluon initiated jet / charm processes… BUT …
- Kinematically restricted to high β region where F_2^D is least sensitive to the gluon!
- Kinematically restricted to low $p_T < M_X/2$ where scale uncertainties are large.
- γp surprises → understanding gap survival?…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





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}

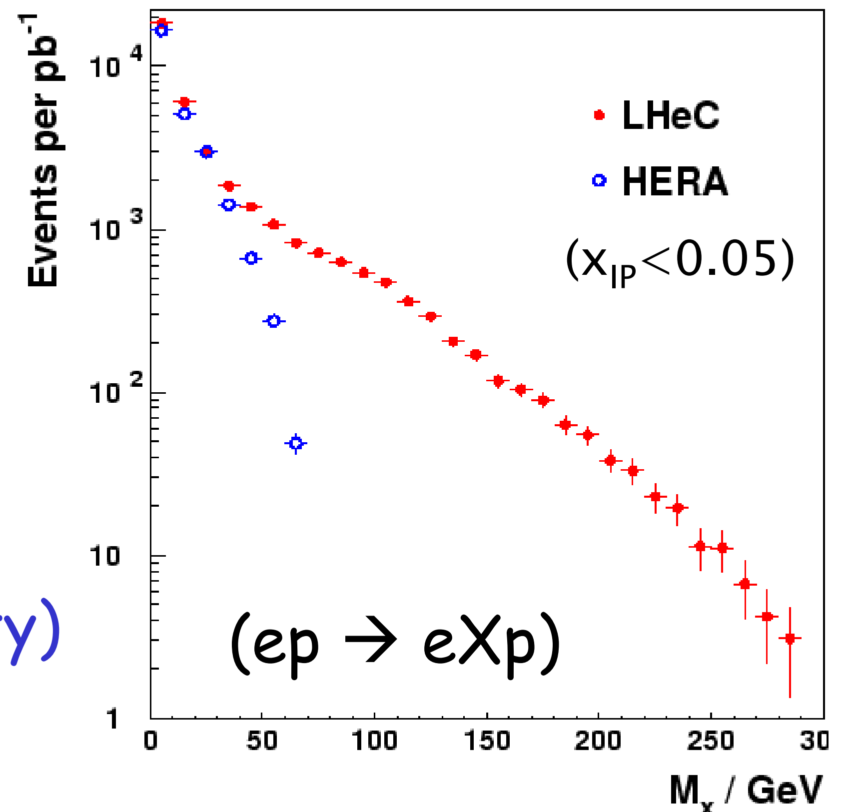
- Low β, low x_{IP} region for jets and charm accessible

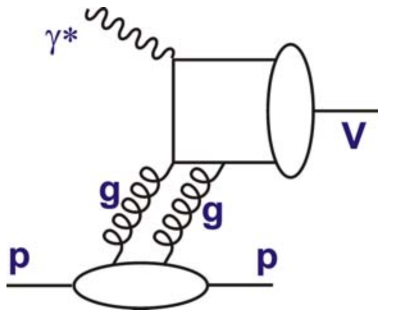
- Final state jets etc at higher p_t … much more precise factorisation tests and DPDF studies (scale uncty)

- New diffractive channels … beauty, W / Z / H(?) bosons

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

(RAPGAP simulation)





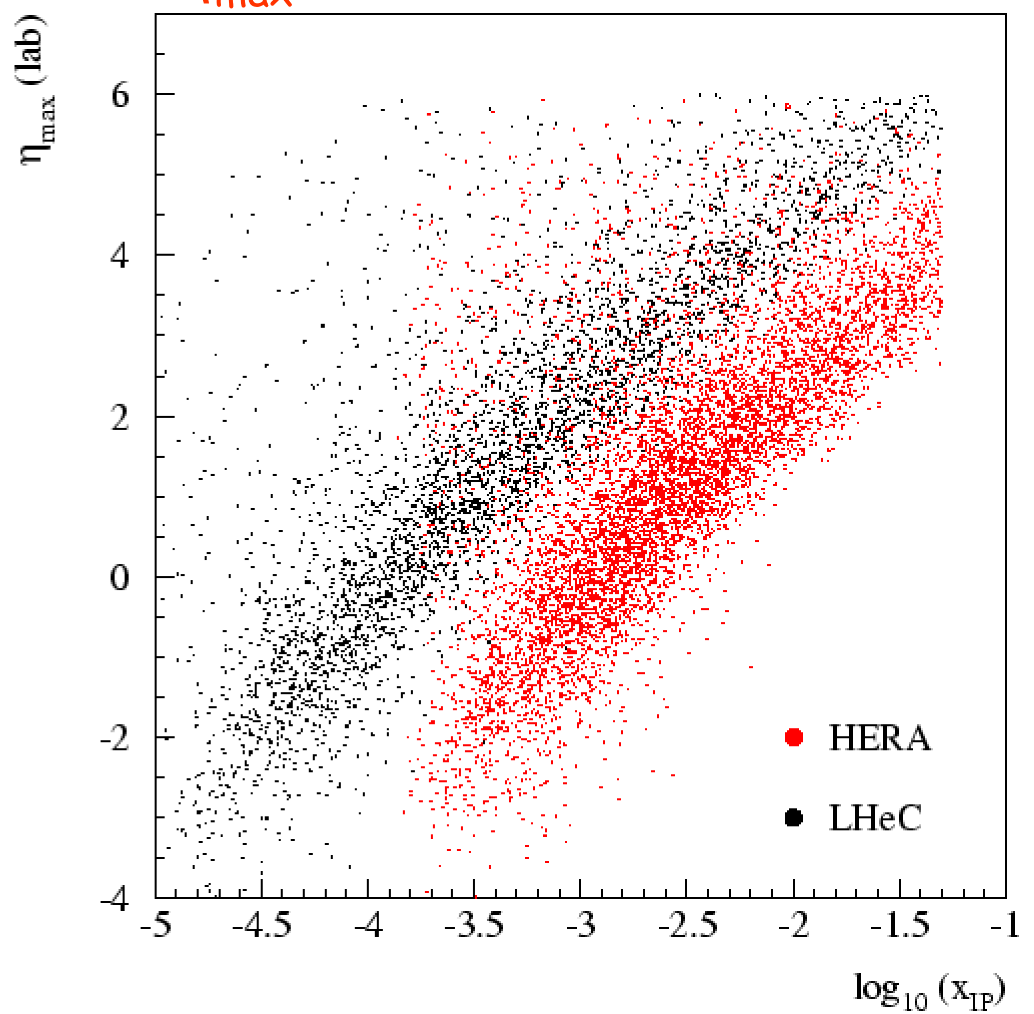
Forward and Diffractive Detectors

- Very forward tracking / calorimetry with good resolution …
- Proton and neutron spectrometers …

- Reaching $x_{IP} = 1 - E_p'/E_p = 0.01$ in diffraction with rapidity gap method requires η_{max} cut around 5 …forward instrumentation essential!

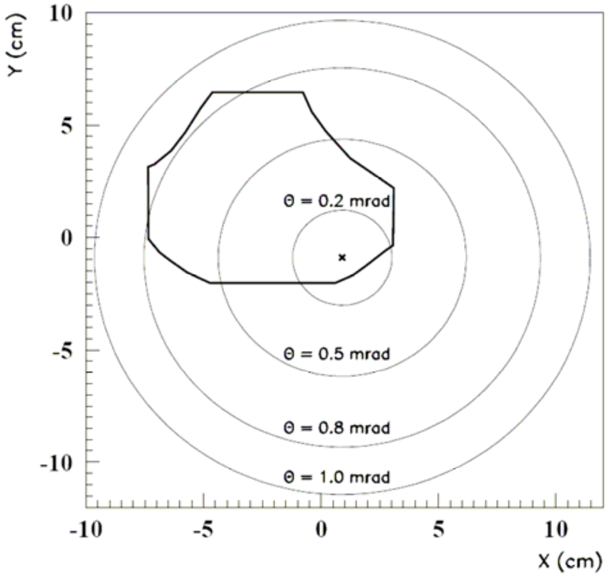
- Roman pots, FNC should clearly be an integral part.
  - Also for t measurements
  - Not new at LHC ☺
  - Being considered integrally with interaction region

η_{max} from LRG selection …



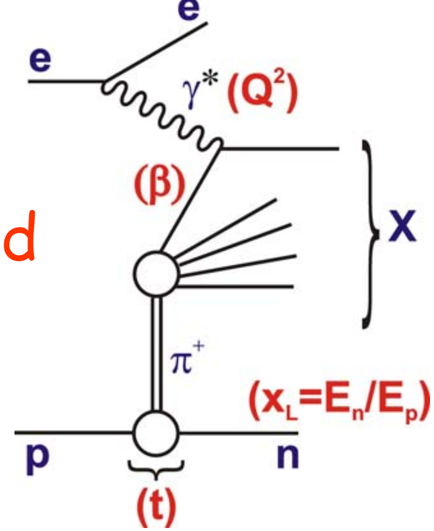
Leading Neutrons: Experience at HERA

- Size and location determined by available space in tunnel…
- Requires a straight section at θ~0° after beam is bent away.
- H1 version → 70x70x200cm Pb-scintillator (SPACAL) calorimeter with pre-shower detector 100m from IP.
- Geometrical acceptance limited to θ<0.8mrad by beamline appertures

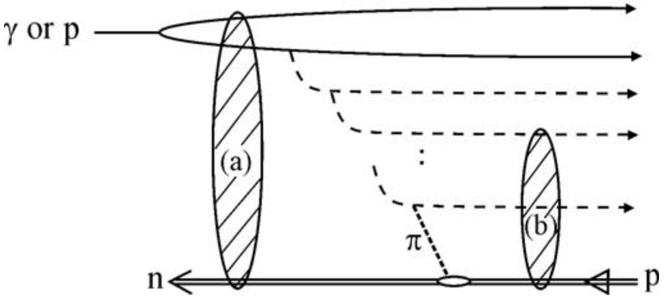


Very radiation hard detectors needed for LHC environment
c.f. Similar detectors (ZDCs) at ATLAS and CMS

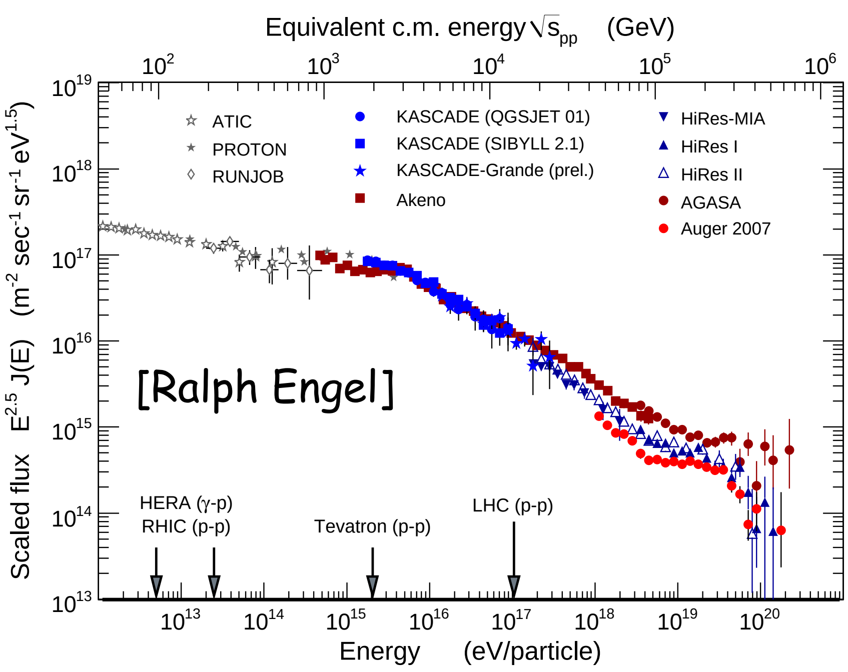
Why Leading Neutrons?



- Sensitivity to p → πn fluctuations and the π structure function



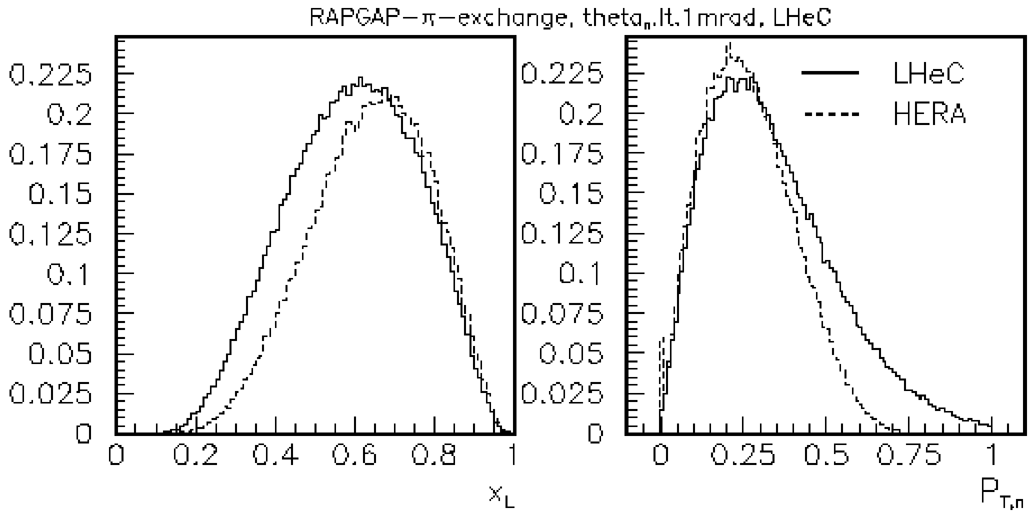
- Sensitivity to absorptive effects and rapidity gap survival issues

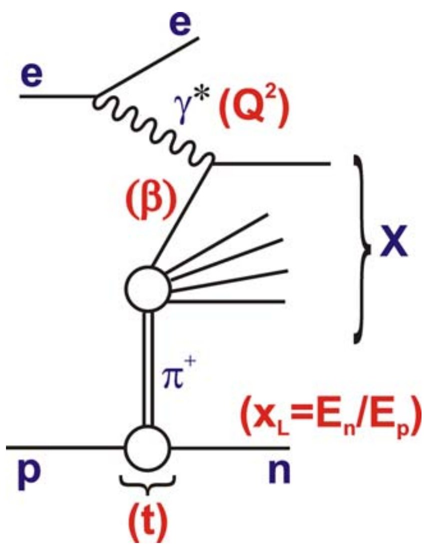


- Tests of cosmic ray models relating observed shower particles (neutrons) to primaries (beam Protons)
  c.f. HERA studies v x_L
  c.f. dedicated LHCf experiment

Study with π Exchange

[Armen Bunyatyan]

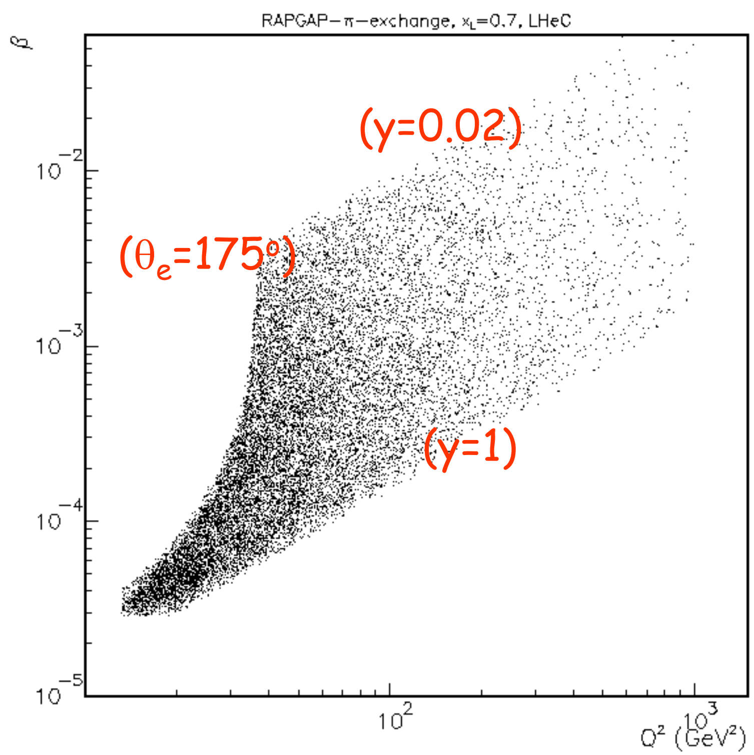




(RAPGAP MC model, E_p=7TeV, E_e=70GeV)

- With θ_n < 1 mrad, similar x_L and p_t ranges to HERA (a bit more p_t lever-arm for π flux).

- Extentions to lower β and higher Q^2 as in leading proton case. → F_2^π At β<5.10^{-5} (cf HERA reaches β~10^{-3})



Summary / Uncovered Topics

This talk (and Jung, Klein, Kluge, Behnke) contained only limited first studies:

- LHeC accessible kinematic ranges assessed for most low x channels which have been important at HERA
- LHeC extends, clarifies, maybe yields breakthroughs
- Statistics are rarely a problem
- Forward / backward acceptance and beamline instrumentation are fundamentally important

Some obvious omissions – e.g. completely unstudied so far:

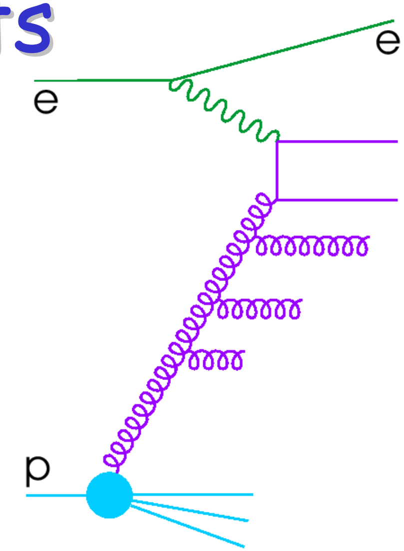
- Prompt photons
- Photoproduction and photon structure
- Exclusive vector meson production

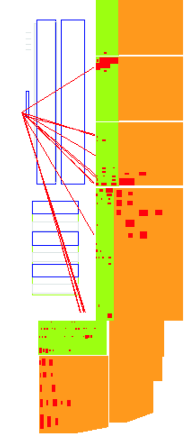
Much more detailed studies needed for the rest. – We only scratched the surface so far.

Spares

Forward Jets

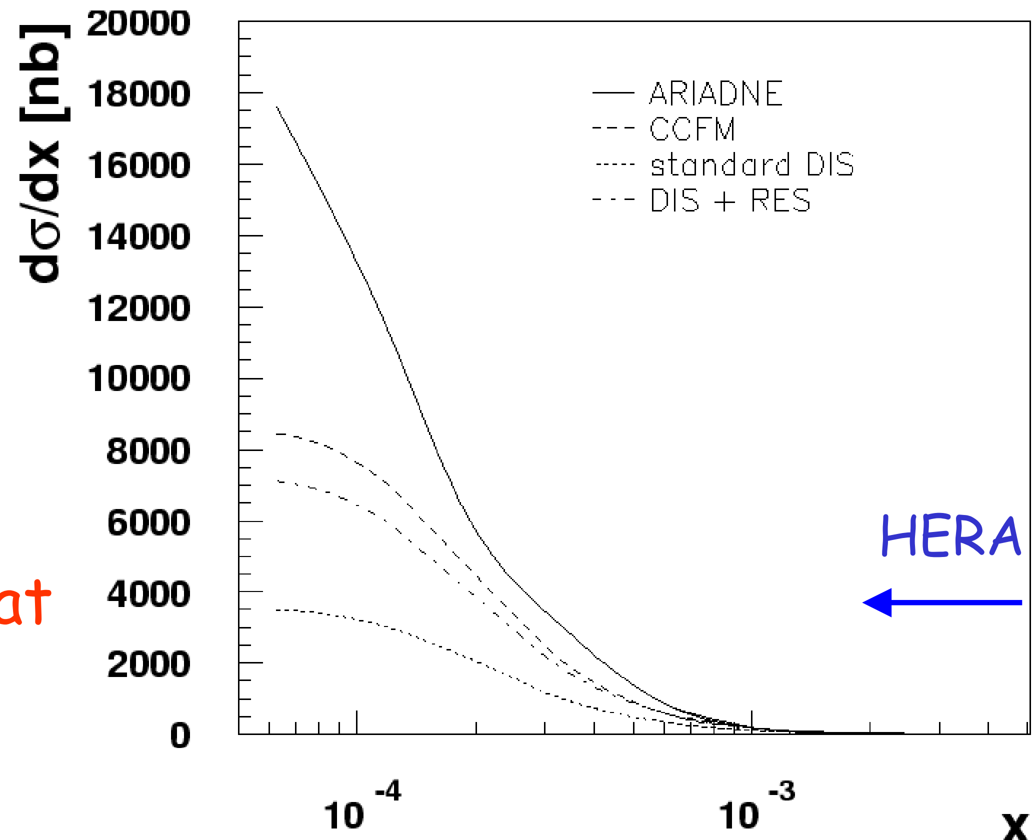
Long HERA program to understand parton cascade emissions by direct observation of jet pattern in the forward direction.
… DGLAP v BFKL v CCFM v resolved γ^*…





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.



Systematic Precision Requirements

e.g. Requirements based on reaching per-mil α_s (c.f. 1-2% now)

The new collider …

- should be 100 times more luminous than HERA …

… achievable using low β focusing quad's (acceptance → 170°)

The new detector

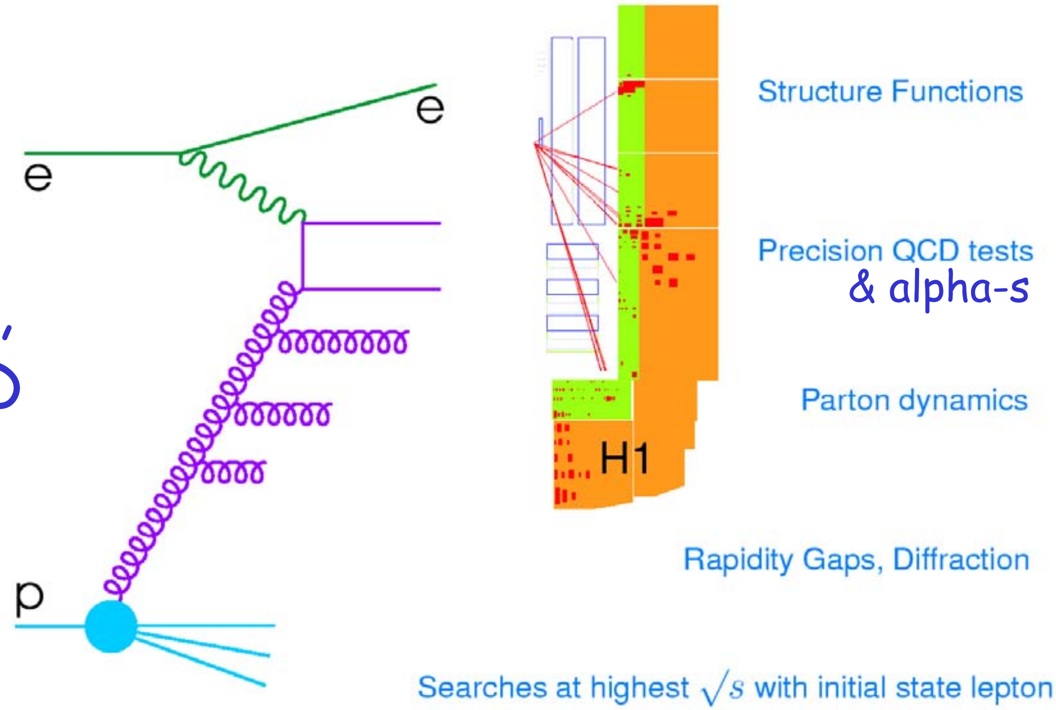
- should be at least 2 times better than H1 / ZEUS

Redundant determination of kinematics from e and X is a huge help in calibration etc!

Lumi = 10^{33} cm^{-2} s^{-1}	(HERA 1-5 x 10^{31} cm^{-2} s^{-1})
Acceptance 10-170° (→179°?)	(HERA 7-177°)
Tracking to 0.1 mrad	(HERA 0.2 – 1 mrad)
EM Calorimetry to 0.1%	(HERA 0.2-0.5%)
Had calorimtry to 0.5%	(HERA 1%)
Luminosity to 0.5%	(HERA 1%)

Beyond Inclusive Measurements

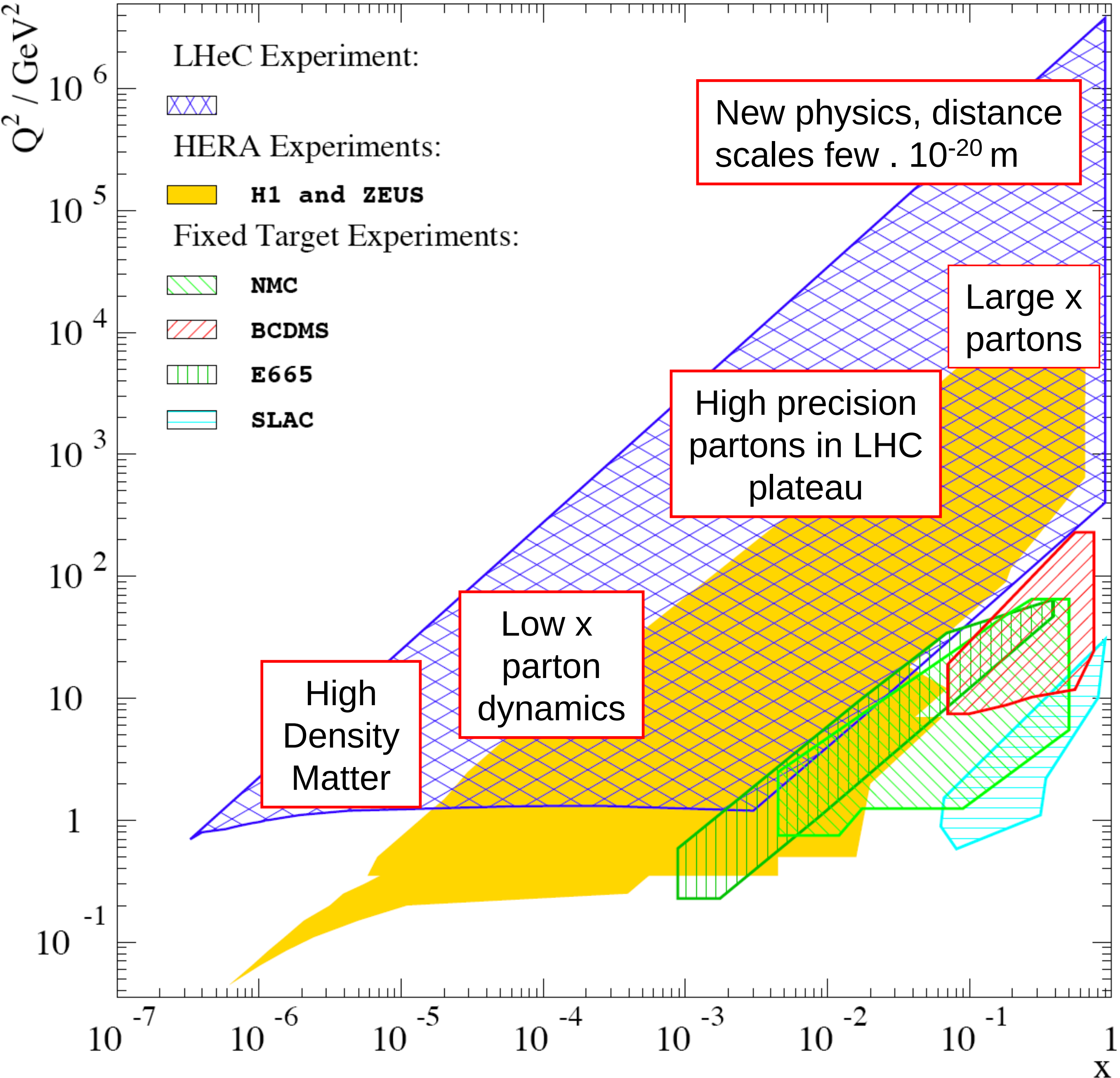
- Hadronic Final States:
  - Jets, heavy flavours → complementary pdf info, gluon directly, how to treat HF in QCD
  - ? Usefulness of HERA data often limited by scale uncties in theory



- Forward Jets,
  - Direct tests of assumed parton evolution patterns
  - ? Understanding limited by instrumentation near beam-pipe

- Diffraction
  - Unique clean probe of gap dynamics and elastic scattering
  - ? Understanding limited by (forward) detectors …

Inclusive Kinematics for 70 GeV x 7 TeV



$$\sqrt{s} = 1.4 \text{ TeV}$$

$$W \leq 1.4 \text{ TeV}$$

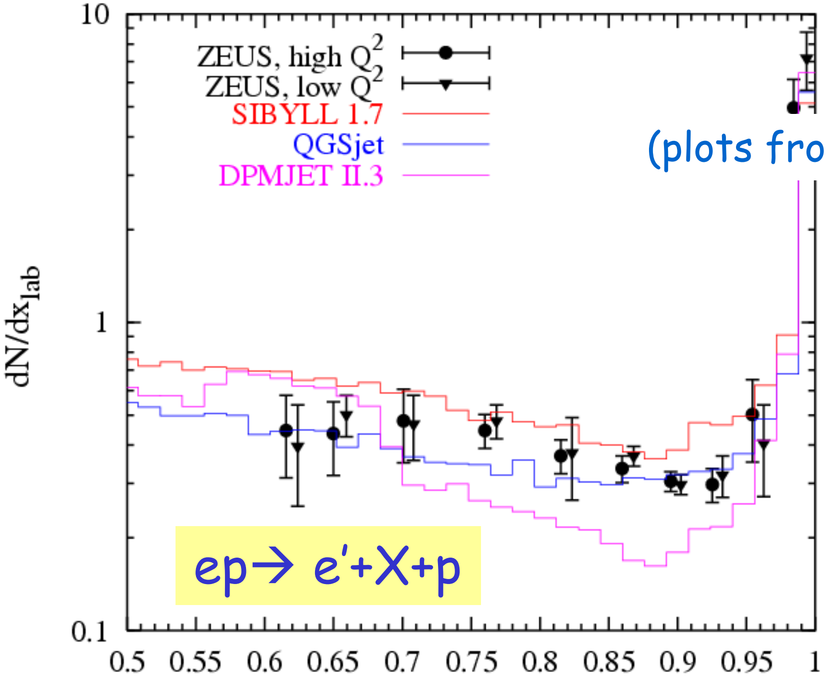
$$x \geq 5.10^{-7} \text{ at } Q^2 \leq 1 \text{ GeV}^2$$

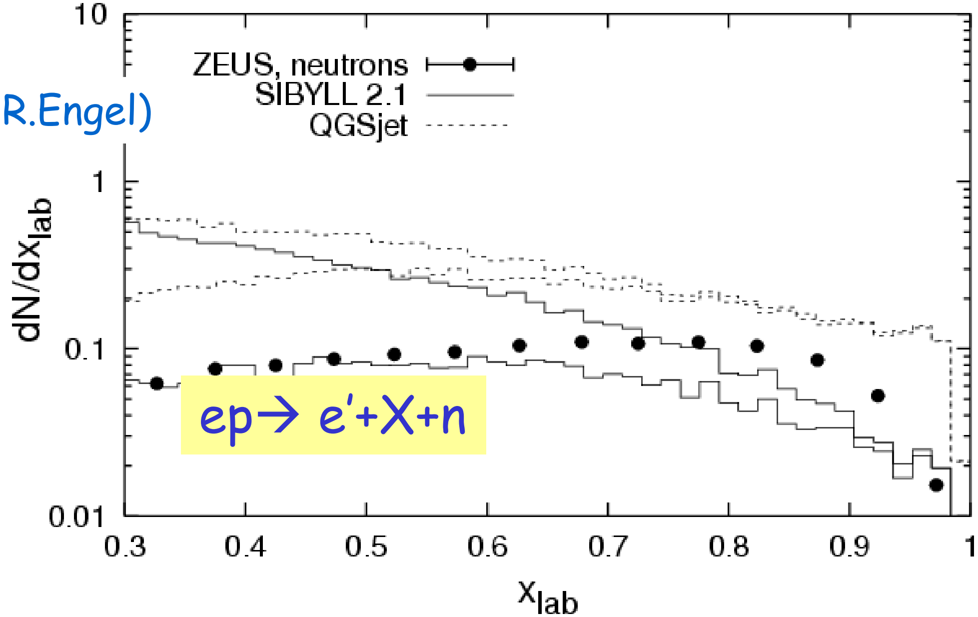
- High mass (Q^2) frontier
- Q^2 lever-arm at moderate x
- Low x (high W) frontier

Forward particles at HERA and models for cosmic rays

Important observable for shower development: 'elasticity' – ratio between the energy of leading particle to that of incoming particle Elead/E
In a model with Feynman scaling in forward region elasticity does not depend on energy

(plots from R.Engel)





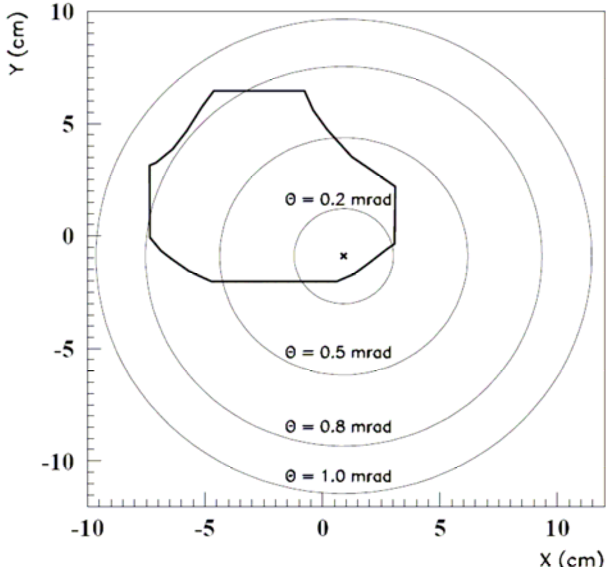
x_{lab} =energy fraction carried by the leading proton or neutron

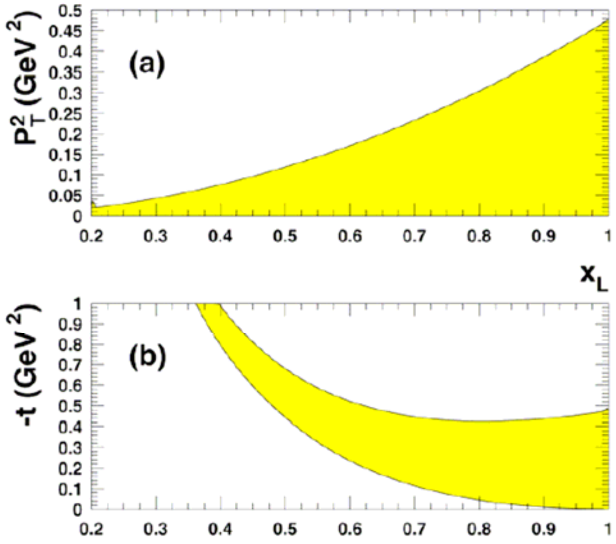
Comparison of HERA data with the MC models used for cosmic ray physics:
-For leading protons- reasonable agreement between the measurements and the models - the HERA data discriminate between the models
-For leading neutrons – none of models describe the data
→ room for improvement, common effort from CR and HERA needed

Forward Neutron Calorimeter (FNC)

Size and weight of FNC defined by the space available in the HERA tunnel:
- position– 105m from the interaction point,
- size ~ 70 x 70 x 200cm^3, weight <10t

- geometrical acceptance is limited by beam-line elements <0.8mrad





$x_L = E_n/E_P$

Structure of H1-FNC

Longitudinal segmentation: 'Preshower' + 4 modules of 'Main' calorimeter

Material	Depth (mm)	Nuclear interaction lengths λ_I
e/m part		
PbSb4	7.5 × 12	0.52
scintillator	2.6 × 13	0.04
Tyvek paper	0.3 × 12	0.00
air	1.2 × 12	0.00
total e/m part	142	0.56
hadron part		
PbSb4	14. × 12	0.98
scintillator	5.2 × 12	0.07
Tyvek paper	0.3 × 12	0.00
air	0.6 × 12	0.00
total hadr.part	251	1.05
total	393	1.6

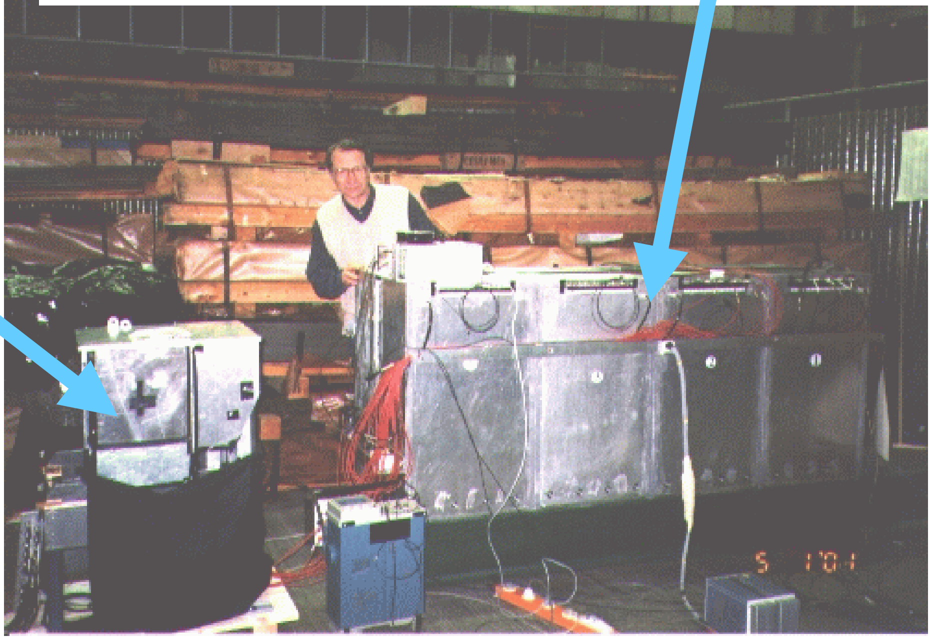
Material	Depth (mm)	Nuclear interaction lengths λ_I
PbSb4	14 × 100	8.20
scintillator	3.0 × 100	0.34
Tyvek paper	0.3 × 100	0.00
steel	0.6 × 100	0.36
air	2.0 × 100	0.00
total	2000	8.9

'Main' calorimeter

- 4 modules, each 60 x 70 x 50 cm^3 (2.2λ)
- 8 readout towers for each module

'Preshower'

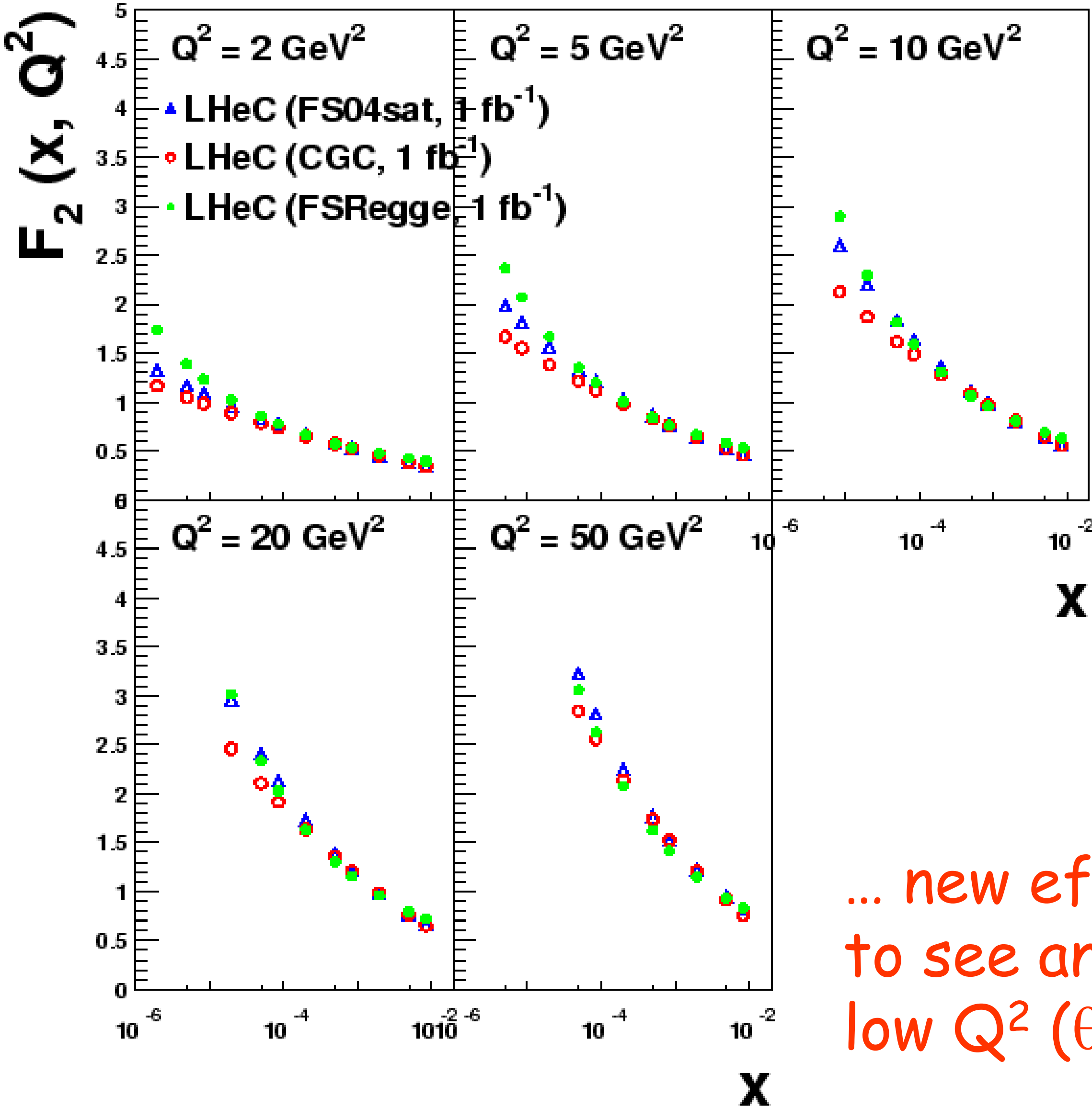
- 26 x 26 x 38.6 cm^3 (1.6λ)
- 12 x-layers, 12 y-layers, each layer has 9 readout strips
- ~40% of hadronic shower is deposited in Preshower
- allows separation of e/m and hadronic showers



Example low x F_2 with LHeC Data

With 1 fb-1 (1 year at 1033 cm-2 s-1), 1° detector:
Stat. precision < 0.1%, syst, 1-3%

[see Max Klein's talk]



Precise data in LHeC region, $x > \sim 10^{-6}$

- Extrapolated FS04, CGC models including sat'n suppressed at low x, Q^2 relative to non-saturating FSRegge

… new effects may not be easy to see and will certainly need low Q^2 ($\theta \rightarrow 179°$) region …

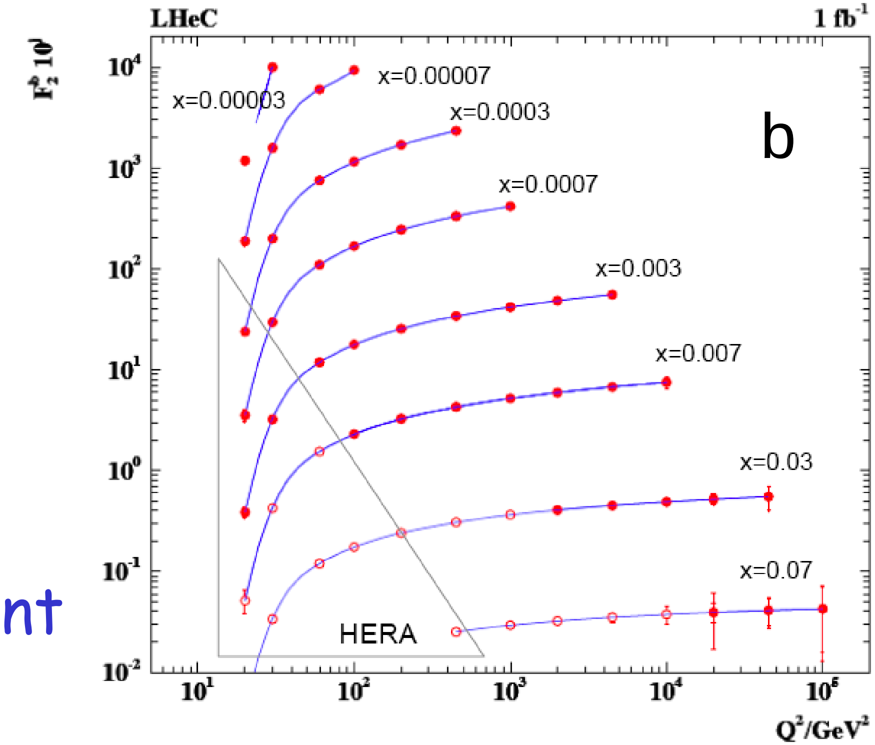
Heavy Quarks: LHeC

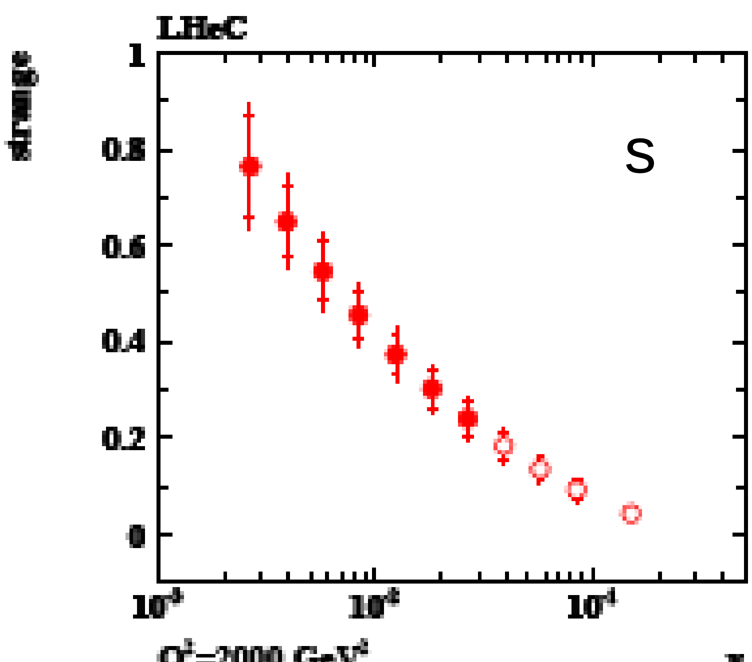
High precision c, b measurements (modern Si trackers, beam spot 15 * 35 μm^2 , increased rates at larger scales).

Systematics at 10% level

→beauty is a low x observable!

→s (& sbar) from charged current

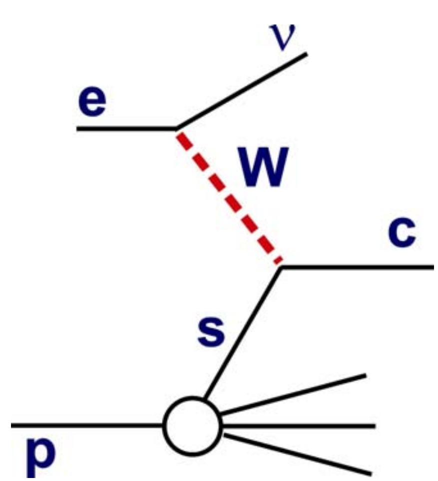




● LHeC 10° acceptance

○ LHEC 1° acceptance

(A. Mehta, M. Klein)



(Assumes 1 fb^{-1} and
- 50% beauty, 10% charm efficiency
- 1% uds → c mistag probability.
- 10% c → b mistag)