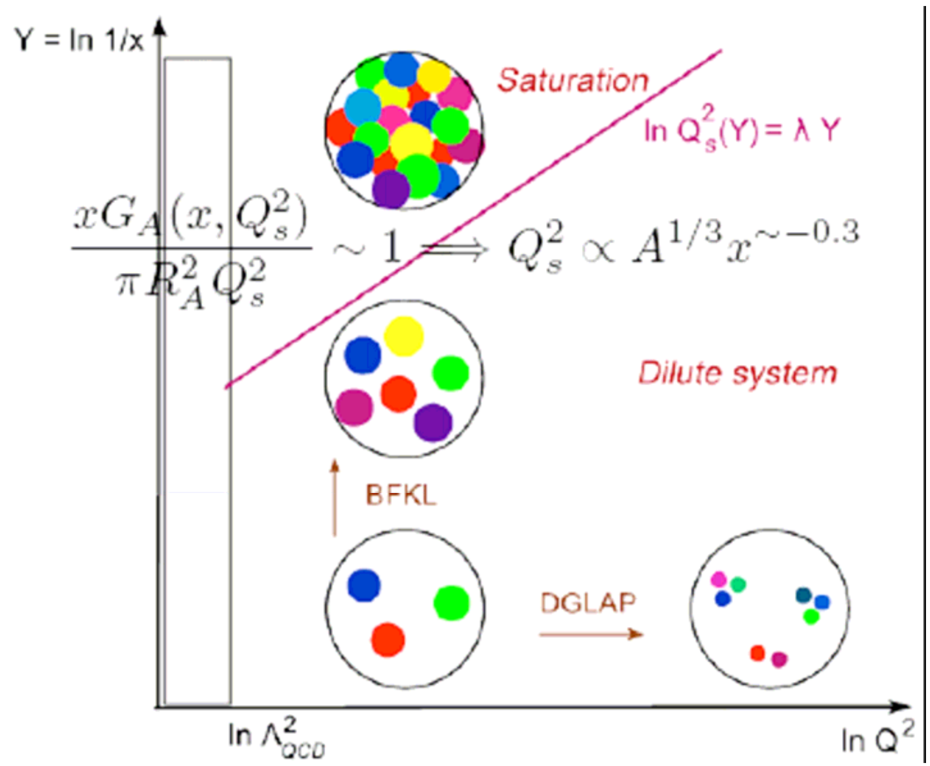
Physics at High Parton Densities II

Nestor Armesto
Brian Cole
Paul Newman
Anna Stasto

Divonne LHeC Workshop
3 September 2008



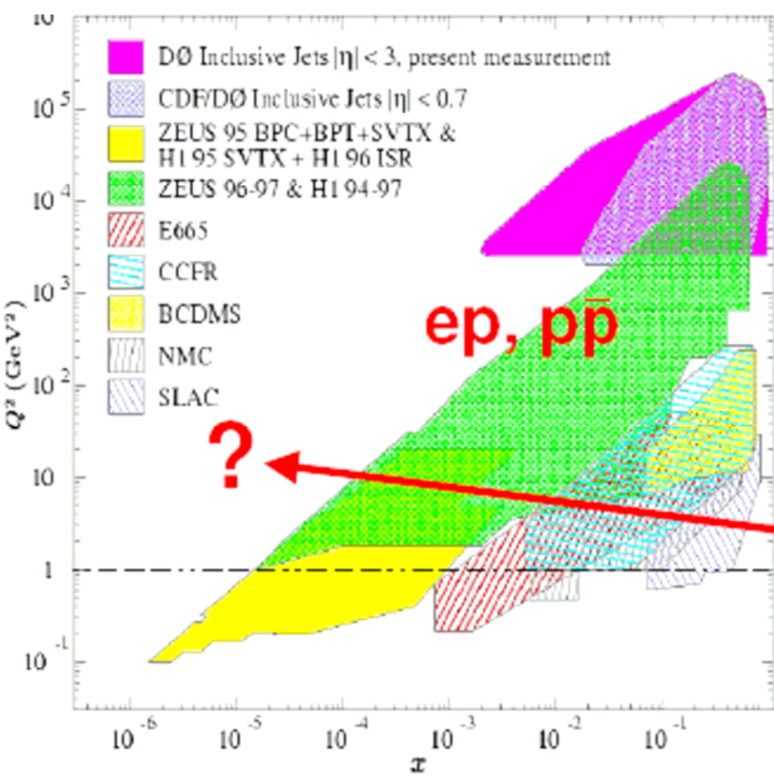
Some experimental considerations …

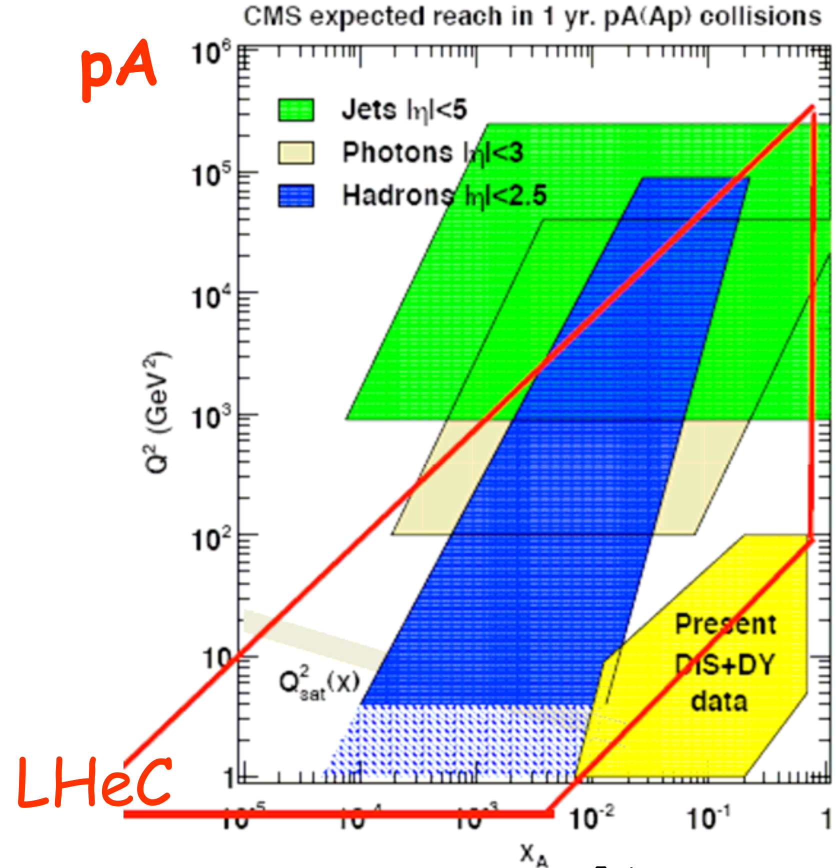
- Where is saturation and how can we tell?
- What are the most important low x observables?
- What are the implications for the detector?

Expected Saturation Hints at LHC

pp: $Q^2_s \sim 1\ GeV^2$ @ $y=0$,
$\sim 3\ GeV^2$ @ $y=5$

[d'Enterria]





[Armesto, Arleo]

LHC forward rapidities:

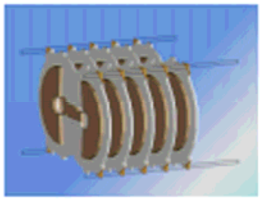
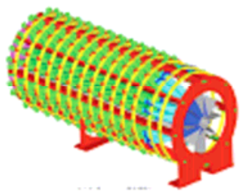
e.g. y ~ 6, Q ~ 10 GeV

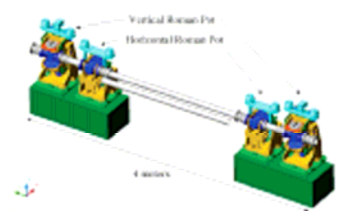
x down to 10^{-6} !

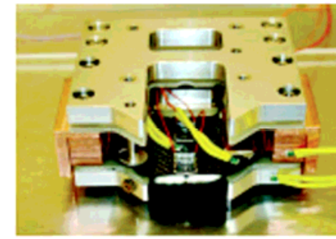
Forward Instrumentation at LHC

[Campanelli]

TOTEM -T2 CASTOR ZDC/FwdCal TOTEM-RP FP420





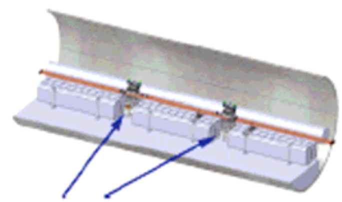
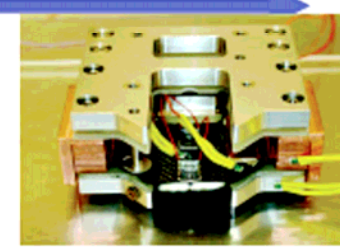
CMS

TOTEM

I P 5

14 m 16 m 140 m 147m - 220 m 420 m

I P 1

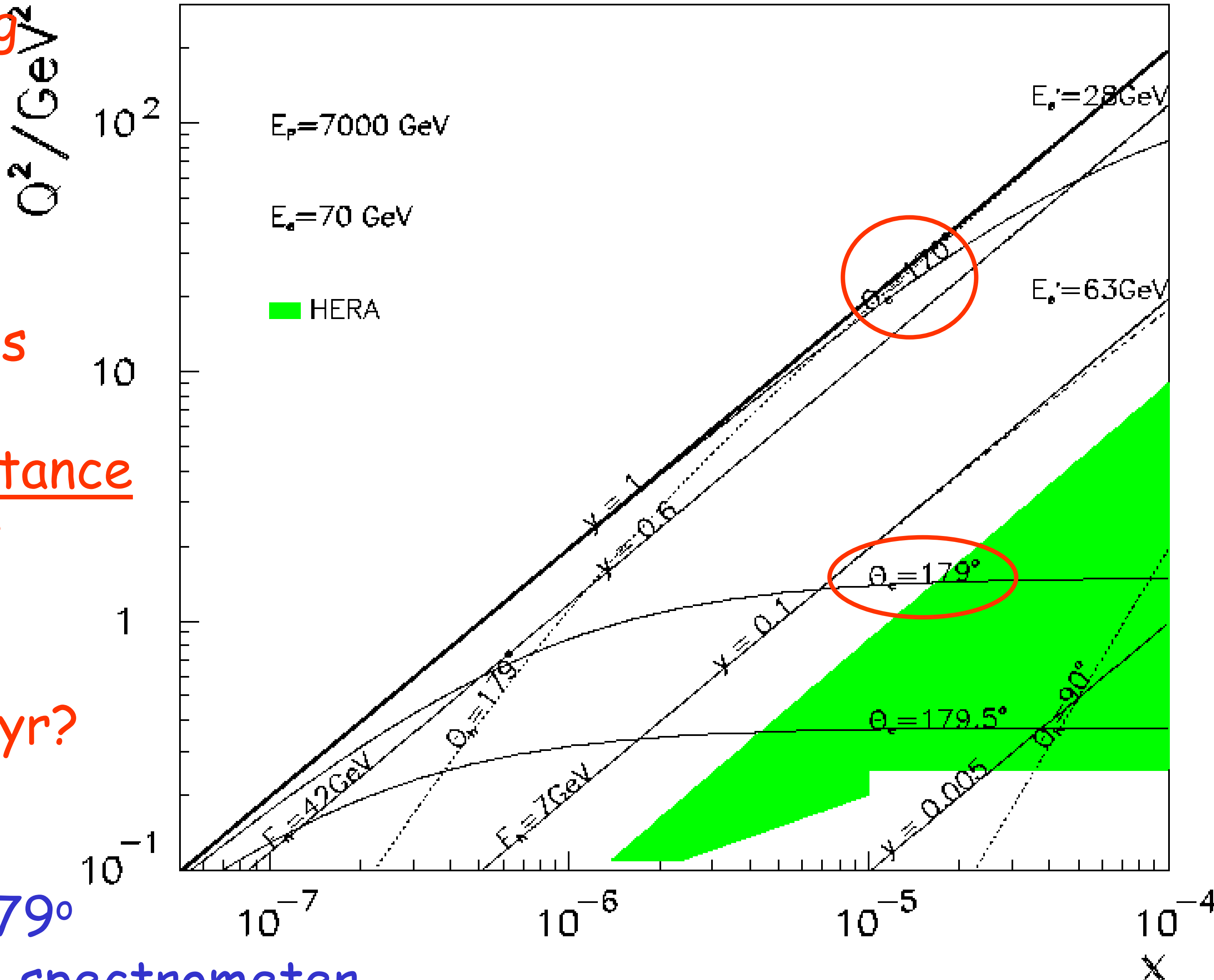
ATLAS

LUCID ZDC ALFA/RP220 FP420

Need to learn from / reuse LHC forward detector technology!

Detector requirements for Low x

- With focusing magnets and electron acceptance to 170°, most of Low x physics is invisible.
- With e acceptance to 179°, access $Q^2=1\ GeV^2$ for all $x > 5 \times 10^{-7}$! Lumi ~ 1 fb^{-1} / yr?



- Can we go further than 179° e.g. with dipole spectrometer or beam-line (eTag) calorimeters?

More 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.

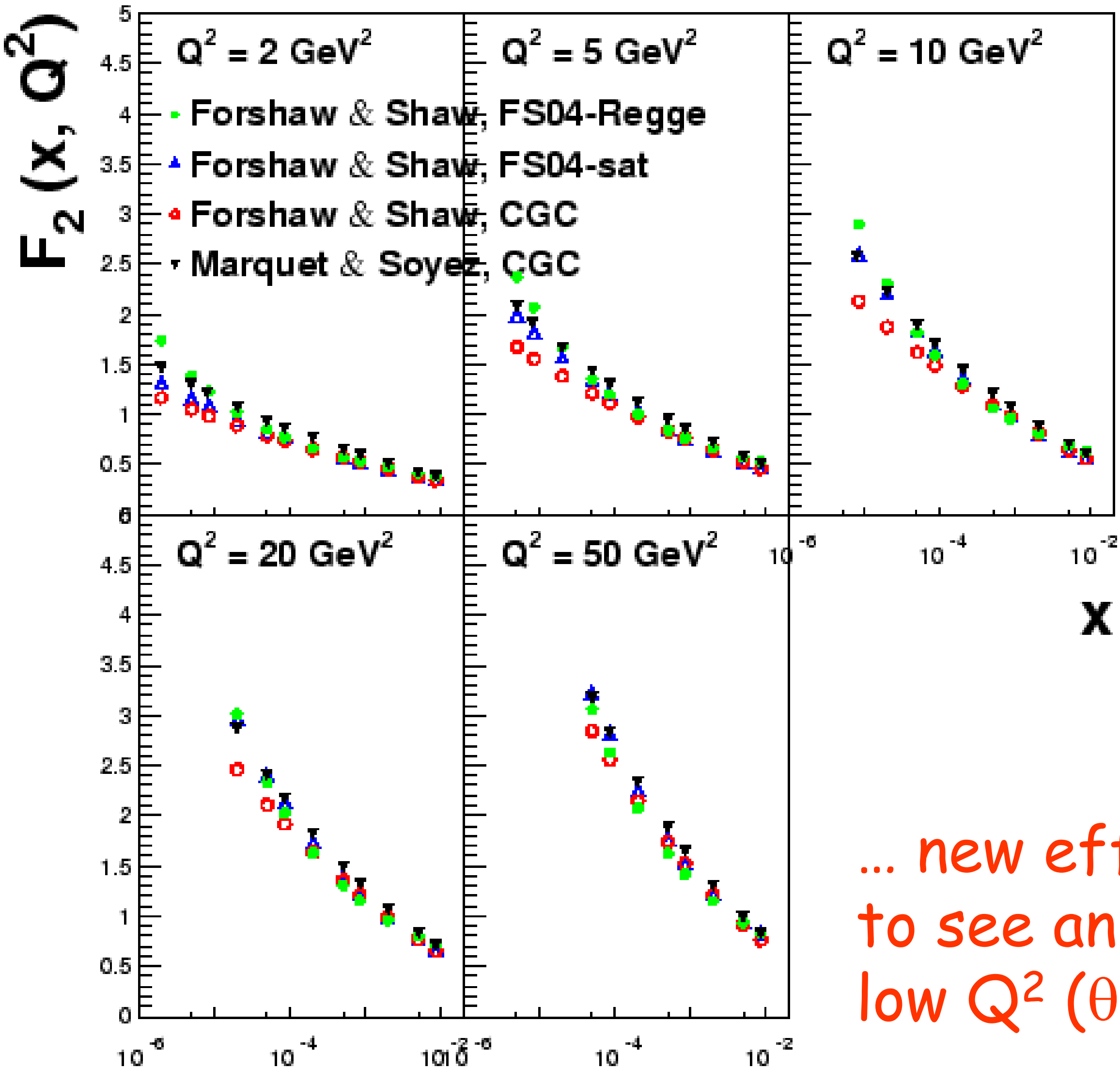
- Study of low x / Q^2 and of range overlapping with HERA, with sensitivity to energy flow in outgoing proton direction requires <u>forward acceptance for hadrons to 1°</u>

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

Some models of 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%

[Klein, Forshaw, Marquet …]



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 FS04-Regge

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

How to establish Saturation be at LHeC?

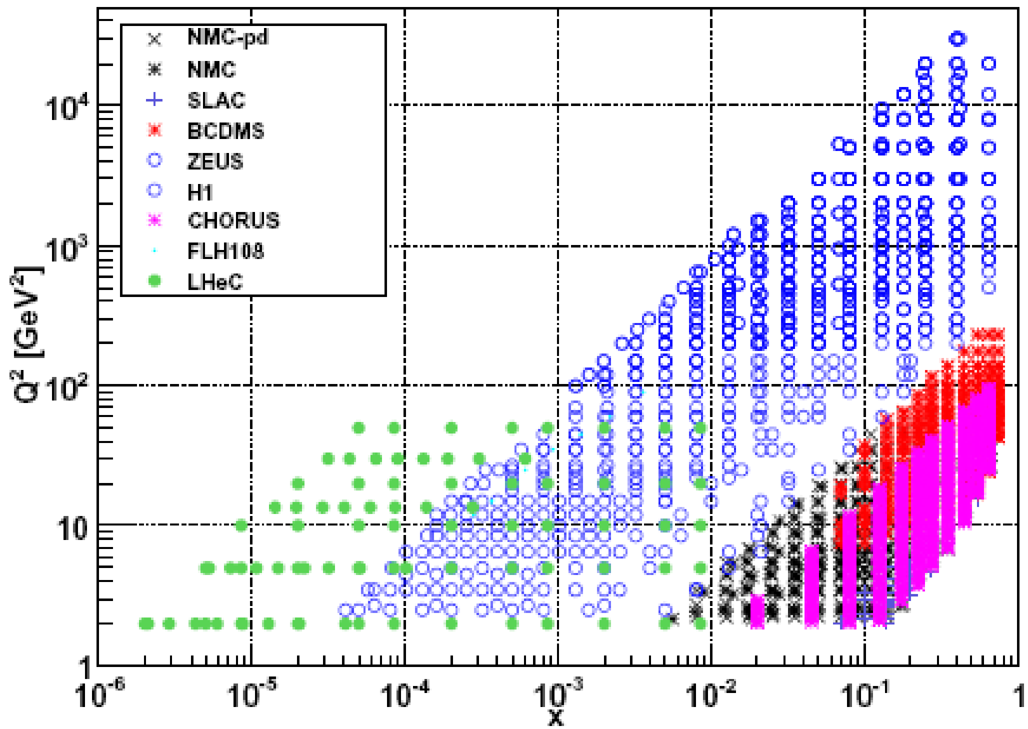
… effects may not be so large in ep → and may be hard to establish unambiguously with inclusive observables only

… $A^{1/3}$ amplification in gluon in eA (~6 for Pb) may be needed

… Two first studies using F_2 and F_L in ep only …

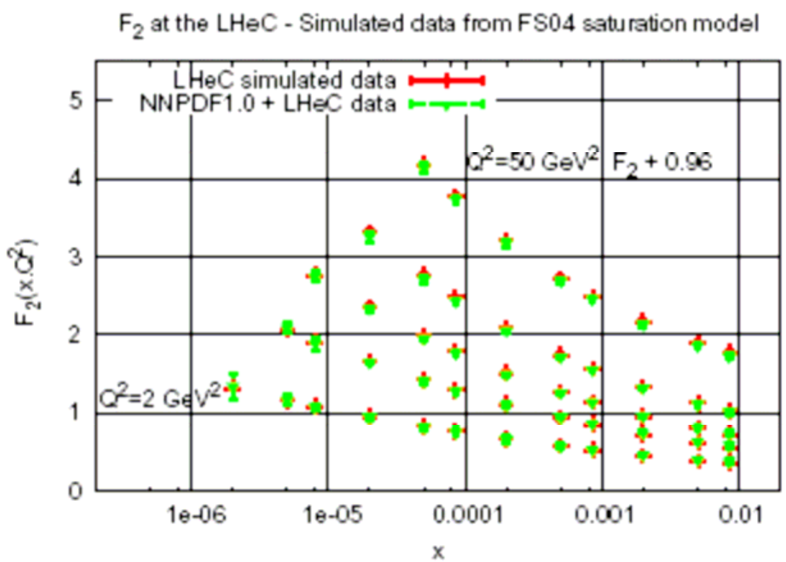
Can saturation effects at LHeC (FS04-sat) be absorbed into NNPDF1.0 DGLAP PDF analysis?

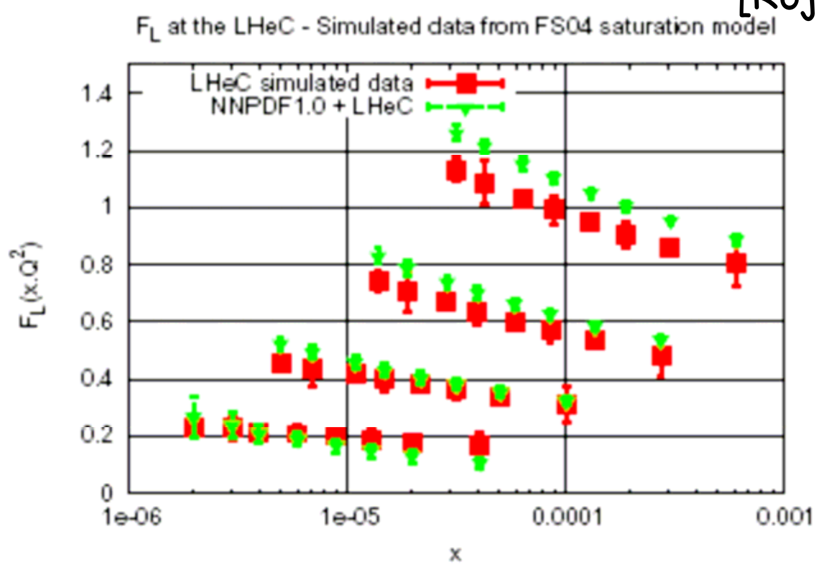
[Rojo]



NNPDF Fits including LHeC-Sat Pseudo-Data

[Rojo]





NLO DGLAP + NNPDFs seem to be able to reproduce $F_2^{\rm sat}(x, Q^2)$, but more difficulties for $F_L^{\rm sat}(x, Q^2)$

Lesson II :

1. $F_L(x, Q^2)$ crucial observable to understand low-x QCD at LHeC (But require precise measurements)
2. Not all observables equivalent to disentangle saturation

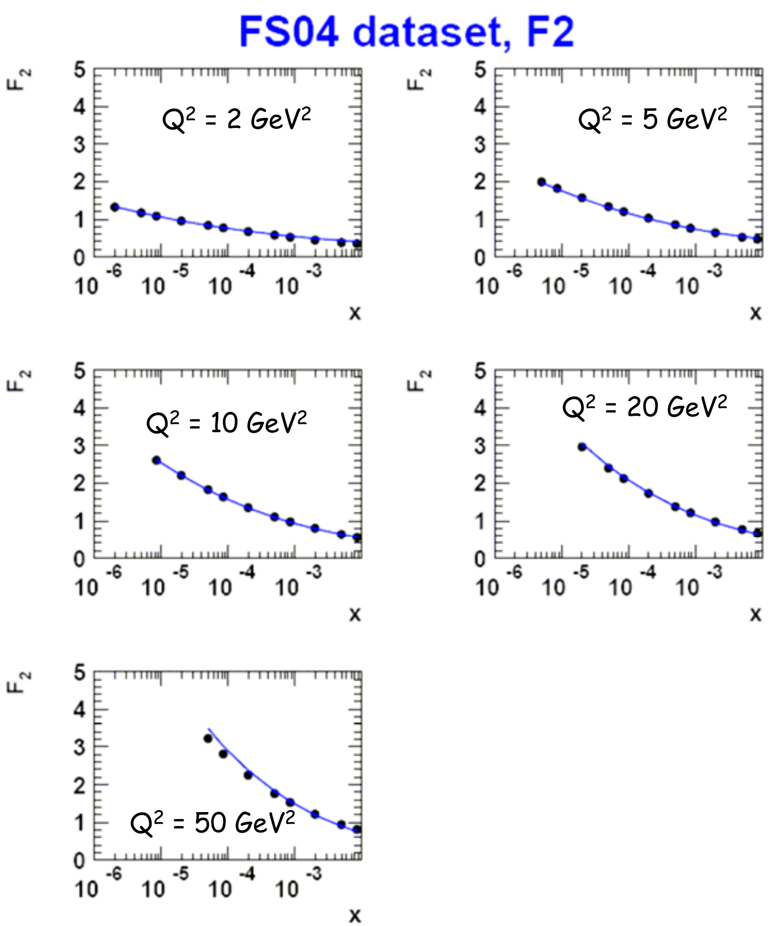
Next step could be to incorporate flavour decomposed LHeC data (F_2^b, F_2^c, F_2^s ...)

Can DGLAP adjust to fit LHeC sat models?

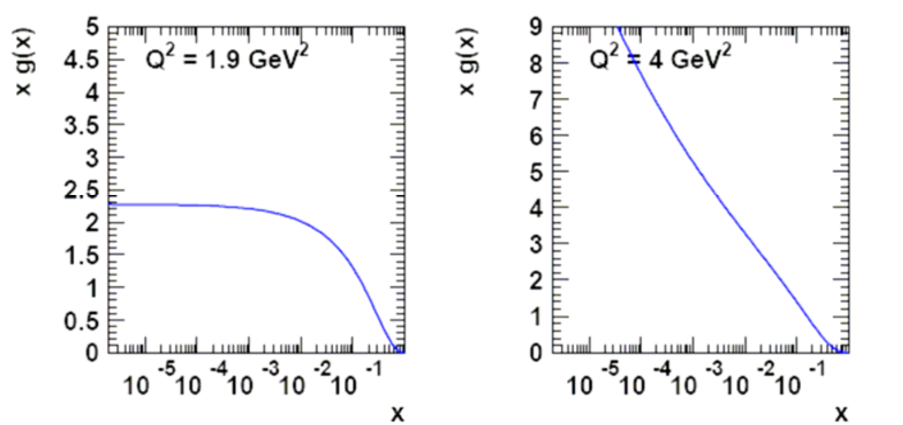
[Forshaw et al.]

- Attempt to fit ZEUS and LHeC saturation model data in increasingly narrow (low) Q^2 region until good fit obtained
- Use dipole-like (GBW) gluon parameterisation at Q_0^2

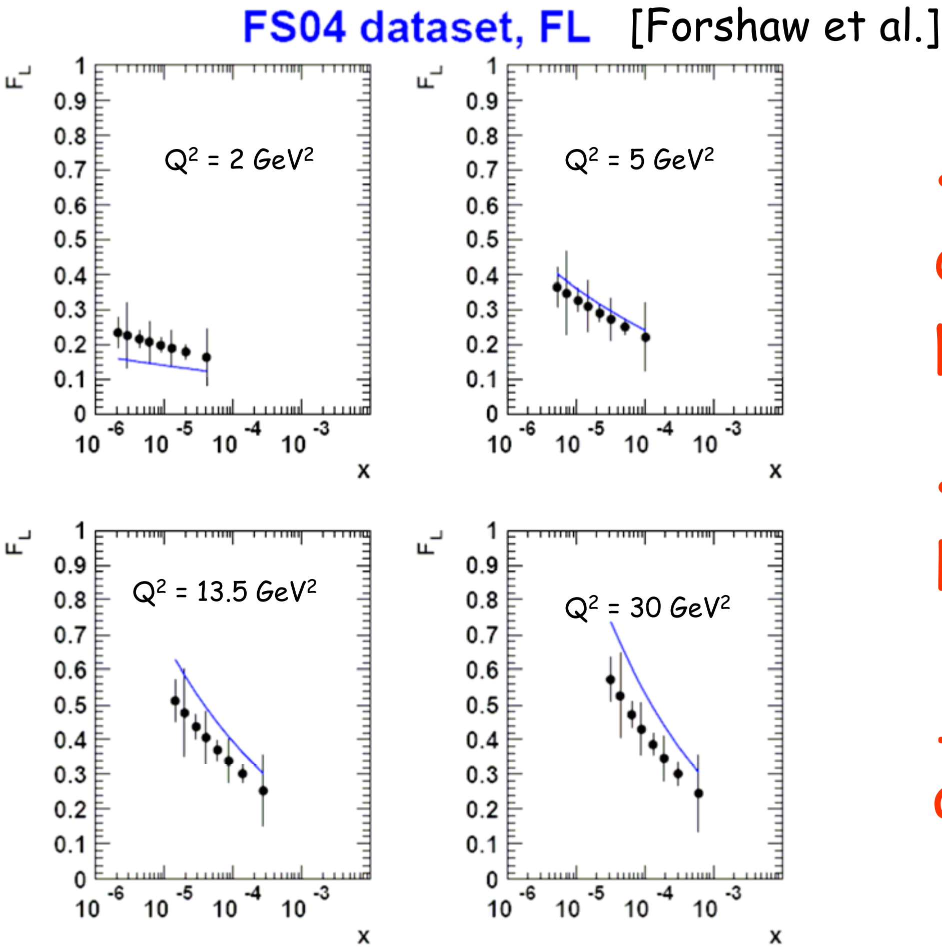
$$xg(x, Q_0^2) = A_g \left(1 - \exp\left[-B_g \log^2\left(\frac{x}{x_0}\right)^{\lambda}\right]\right)(1-x)^{C_g}$$



- Even when fitting F_2 only, a good fit can only be obtained in a limited Q^2 range (in this case $2 < Q^2 < 20$ GeV^2)



F_L Prediction from ZEUS + FS04 DGLAP fit



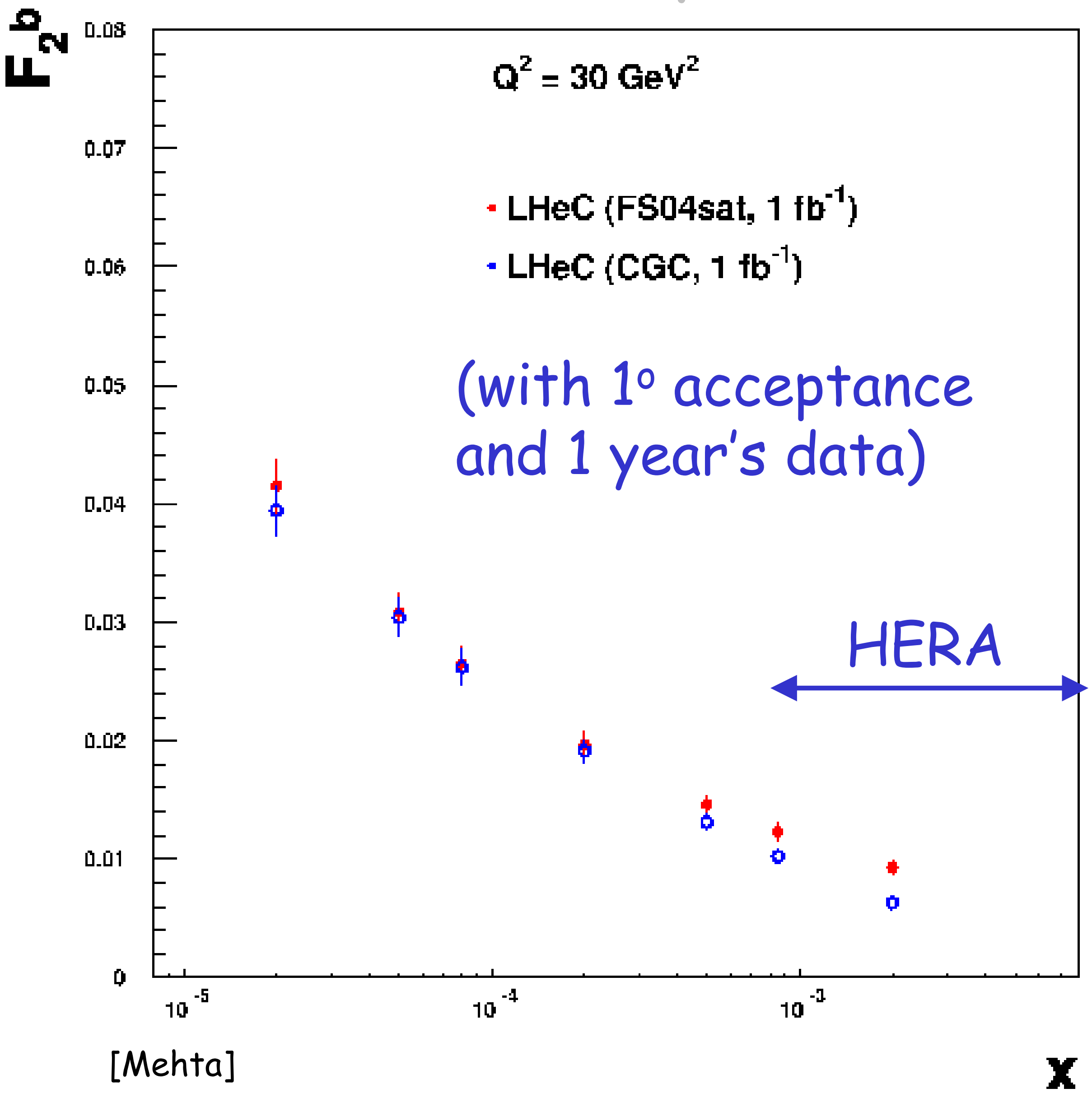
• Q^2 dependence of this fit doesn't describe LHeC F_L pseudo-data

• Also not well described when F_L included in fit

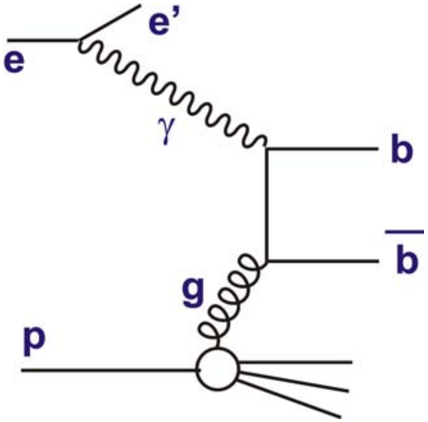
… F_2 and F_L together are a powerful combination!

• General agreement that we should look beyond F_2 and F_L at final state observables (changing the beam energy for F_L probably not an early phase LHeC measurement!)

Jets and Heavy Flavours



[Mehta]



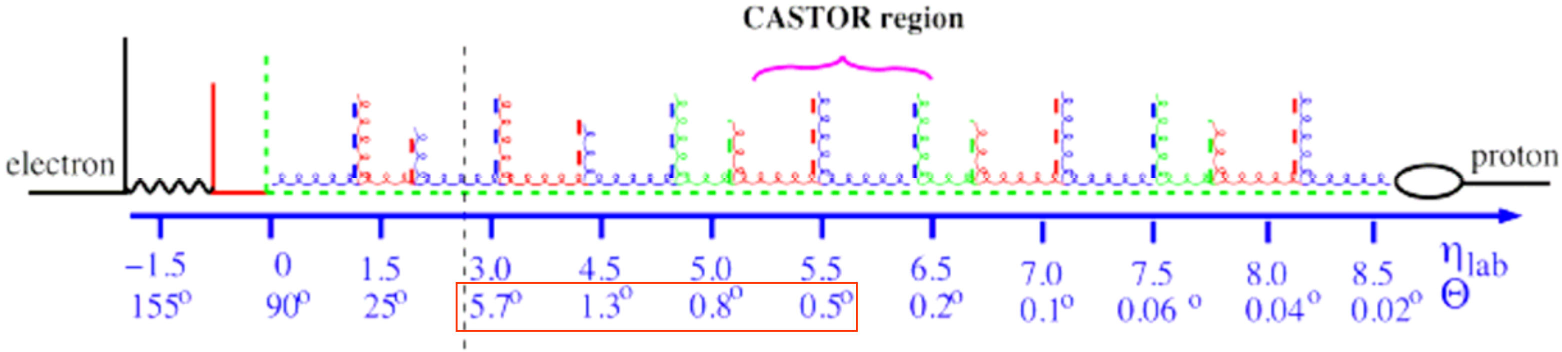
Constrain gluon through jets and heavy flavour measurements

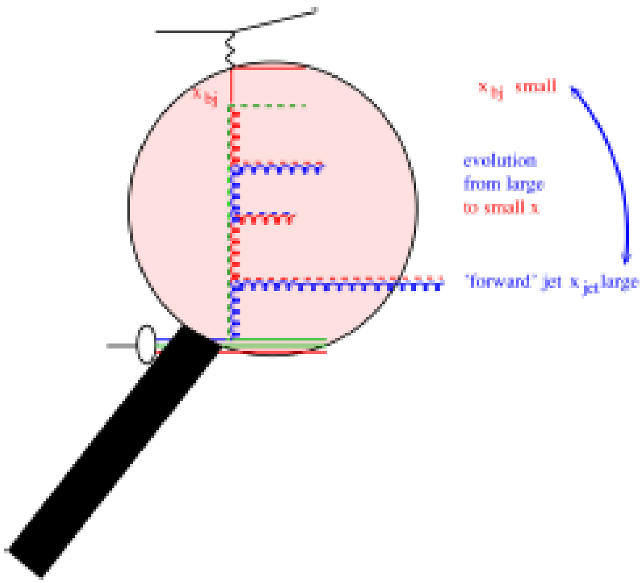
e.g. F_2^b to a few % constraining gluon down to x ~ 2.10^{-5}.

Much more in QCD/EW summary

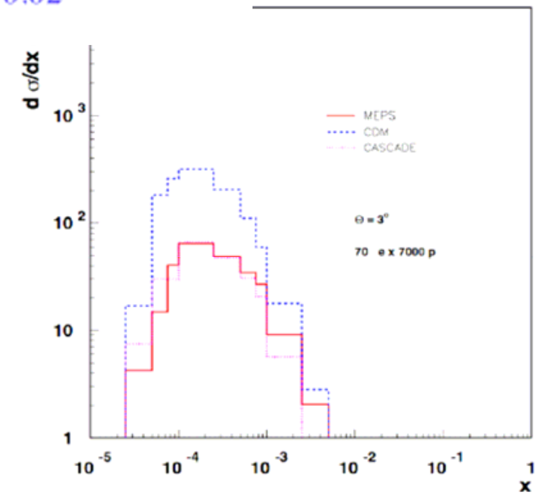
Forward Instrumentation and Jets

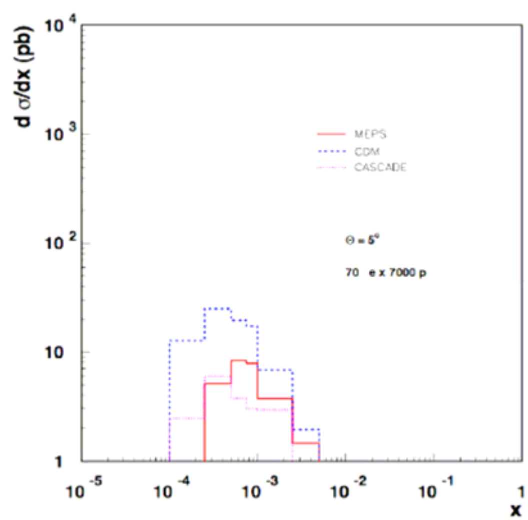
[Jung]

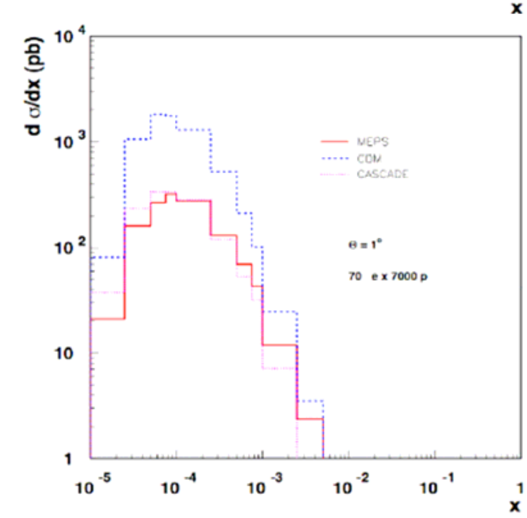




x range and discriminatory power strongly depend on θ cut





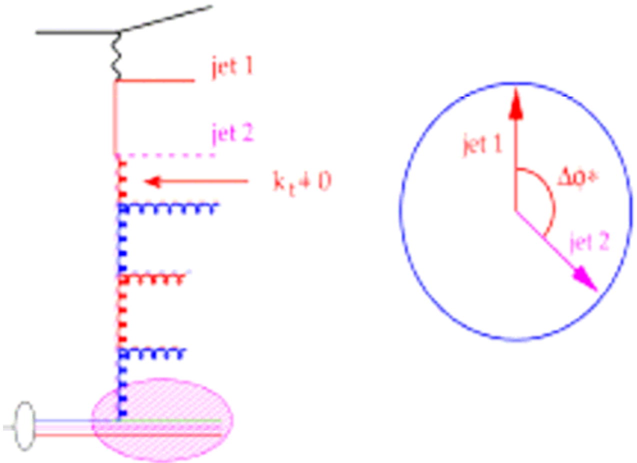


- DIS and forward jet:

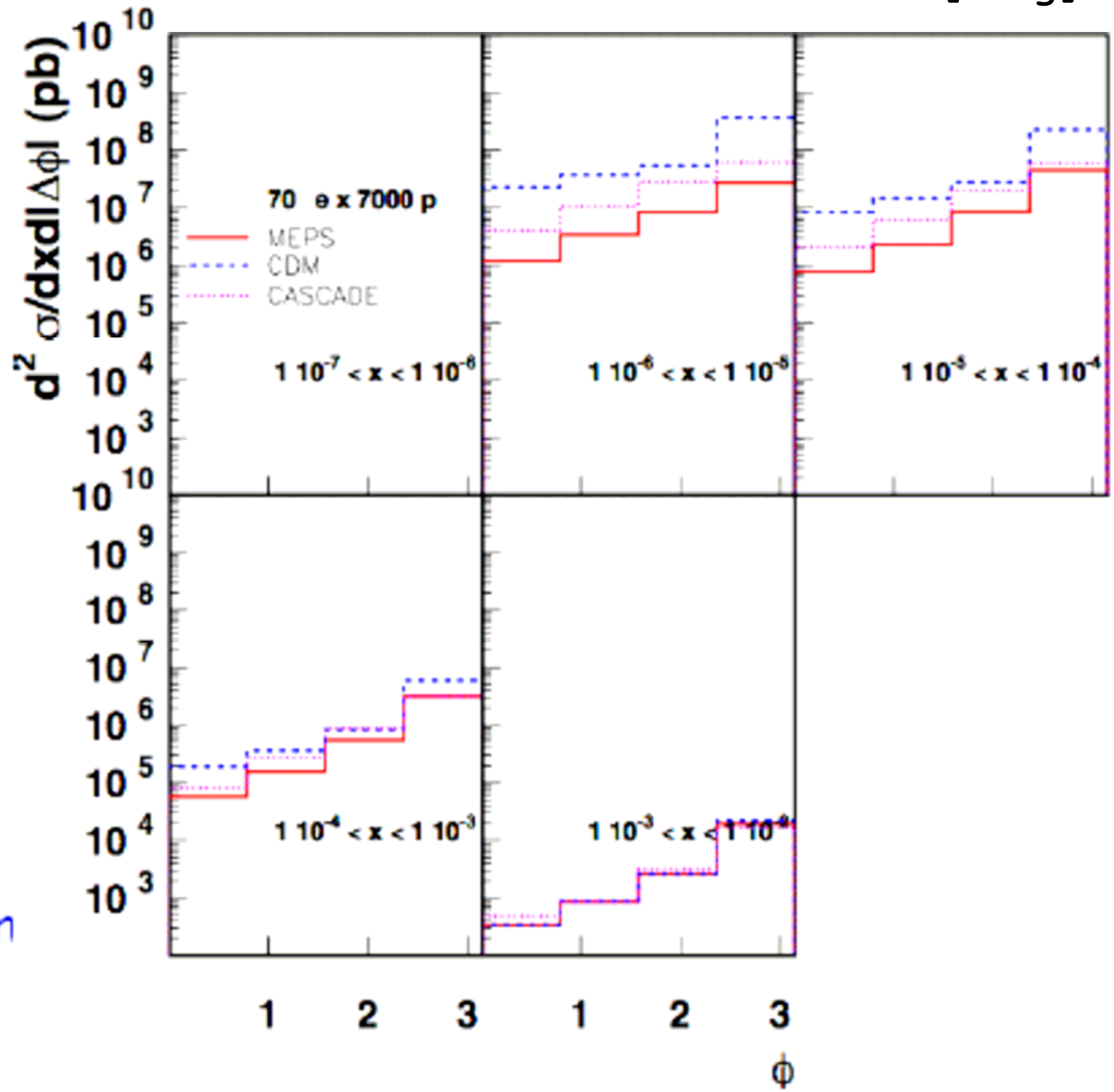
$$x_{jet} > 0.03$$

$$0.5 < \frac{p_{t\,jet}^2}{Q^2} < 2$$

Azimuthal (de)correlations between Jets



[Jung]

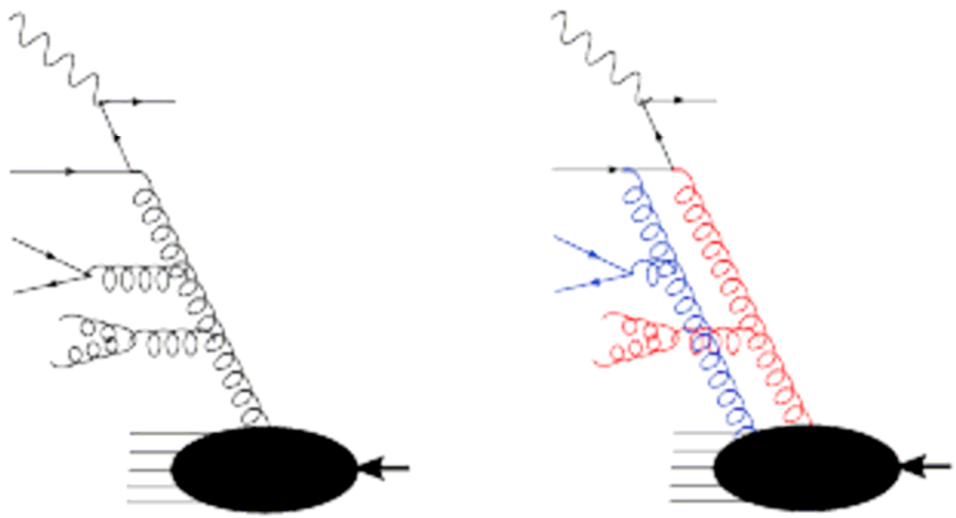


- $5 < Q^2 < 100\ \text{GeV}^2$
  $-1 < \eta < 2.5$
  $E_T > 5\ \text{GeV}$
- small k_t $\to \Delta\phi \sim 180$
- large k_t from evolution

More on Jet Correlations

[Bartels]

Suggestion: measure
correlations (e.g. two-jet) as reliable signal of saturation (multiple interactions):

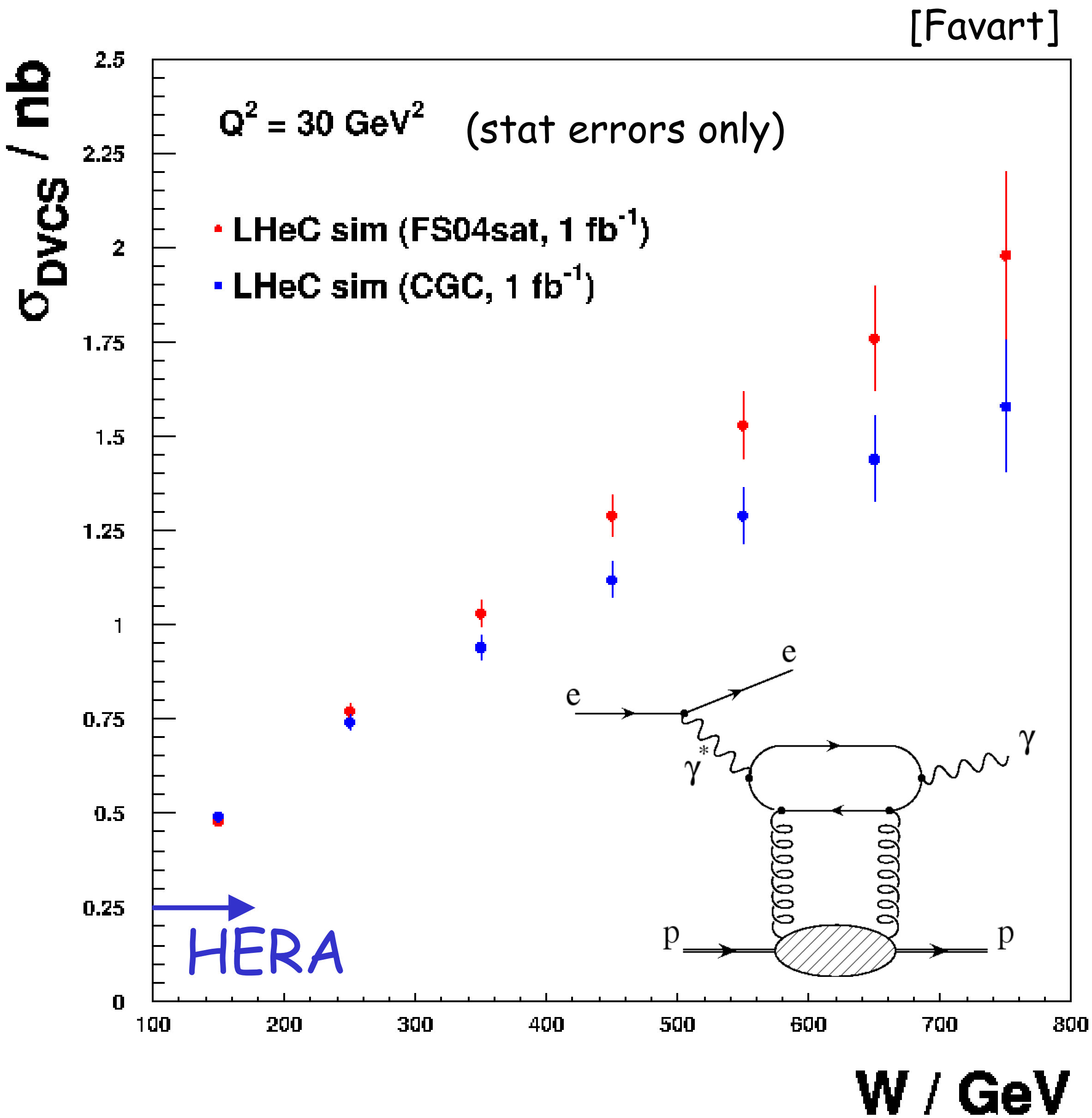


Correlations in rapidity, angle.
Was difficult at HERA (for larger Q^2),
for LHeC factor 2.0 in $1/x$ will help.

… to be simulated
and investigated …

DVCS at LHeC

(1° acceptance)



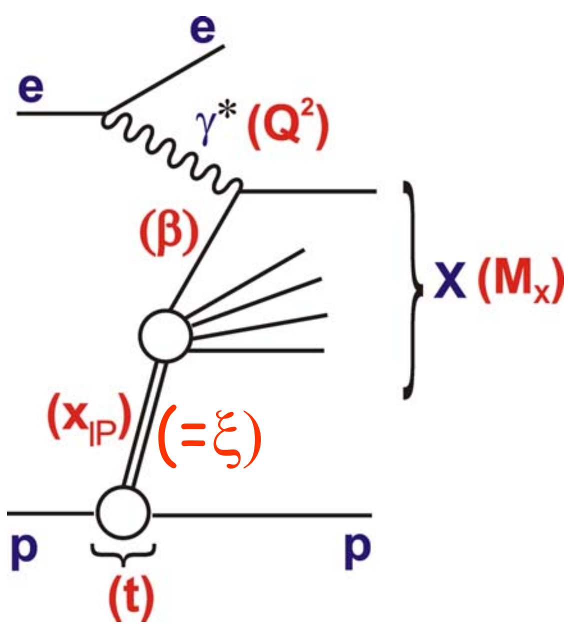
Statistical precision with 1fb^{-1} ~ 2-11%

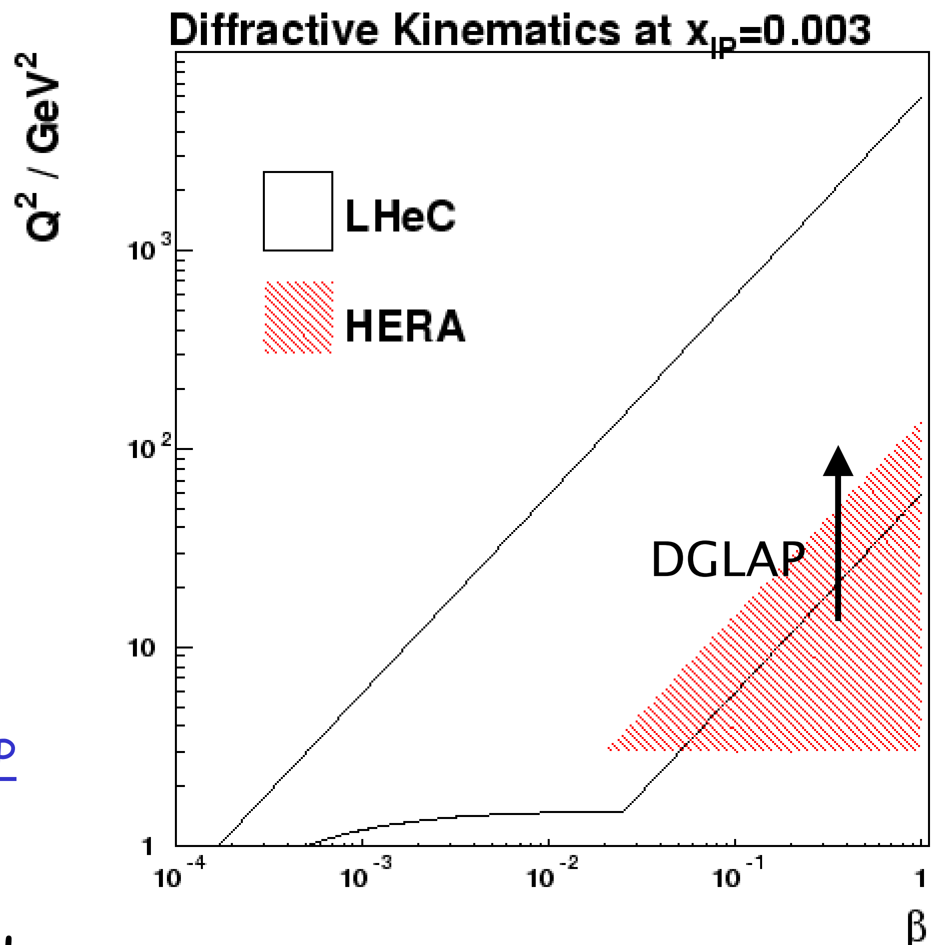
With F_2, F_L, could help establish saturation and distinguish between different models which contain it?

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

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

LHeC Diffractive DIS Kinematics



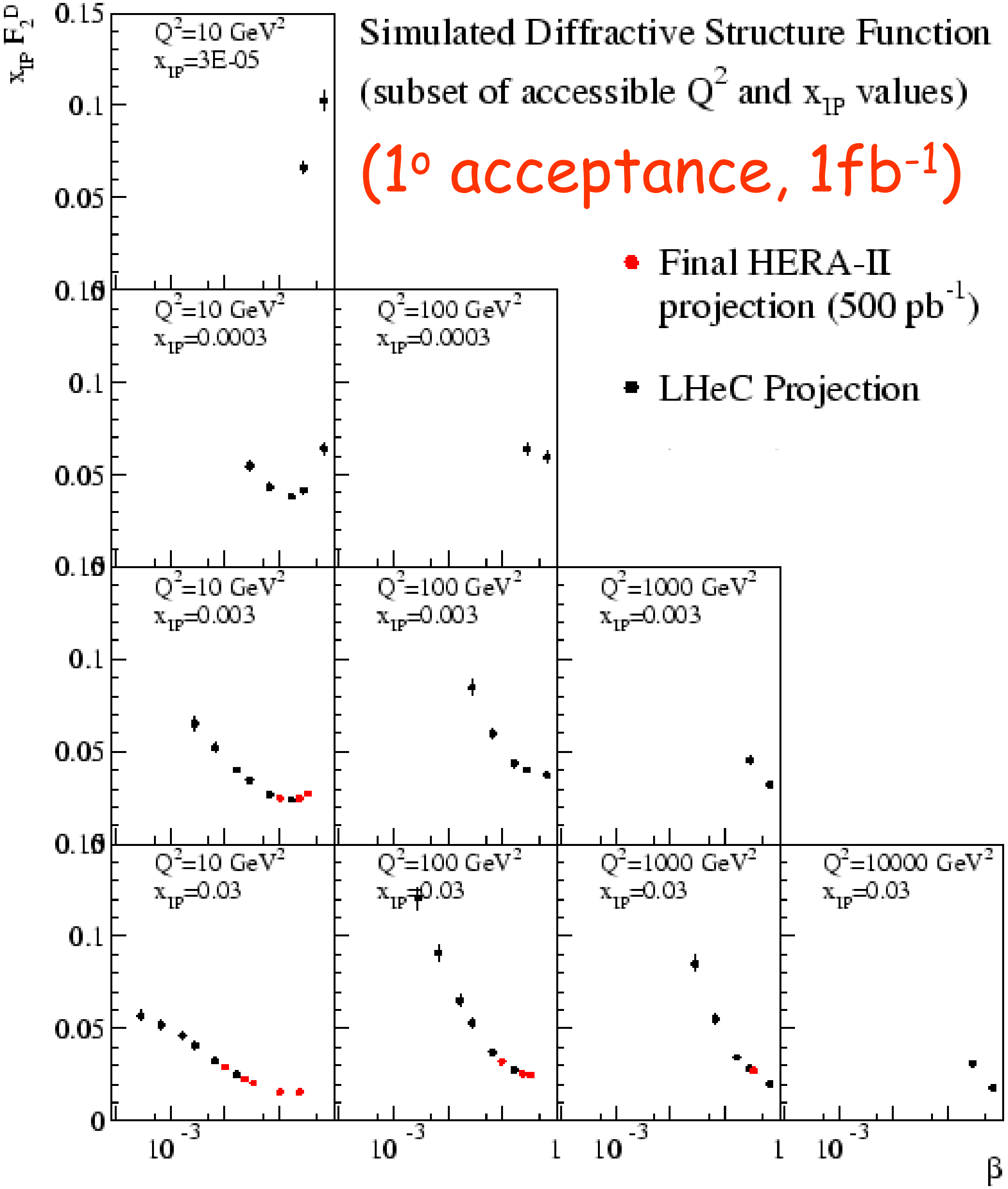


1) Higher Q^2 at fixed β, x_{IP}

→ gluon from DGLAP

→ quark flavour decomposition (CC and Z effects in NC)

LHeC Simulation



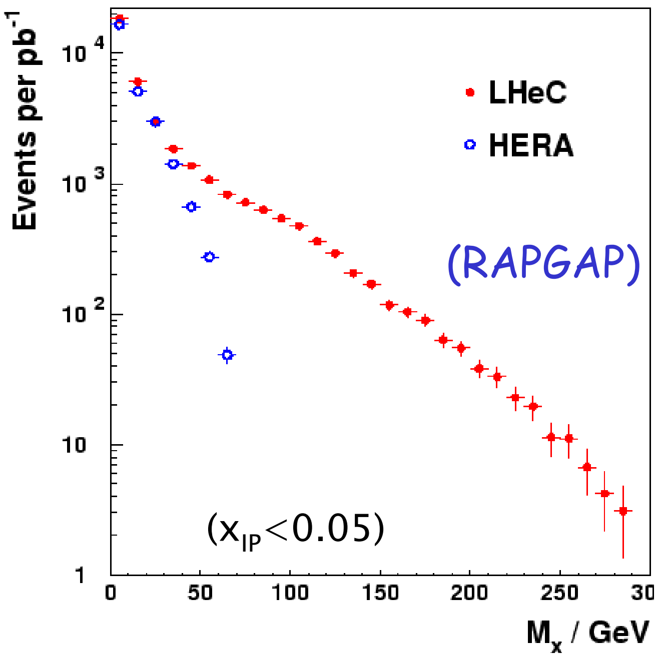
2) Extension to lower x_{IP}
→ cleaner separation of diffractive exchange
→ diff/inc @ fixed M_x, Q^2

3) Lower β at fixed Q^2, x_{IP}
→parton saturation?
→BFKL type dynamics?

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

(Large Rapidity Gap selection assumed here)

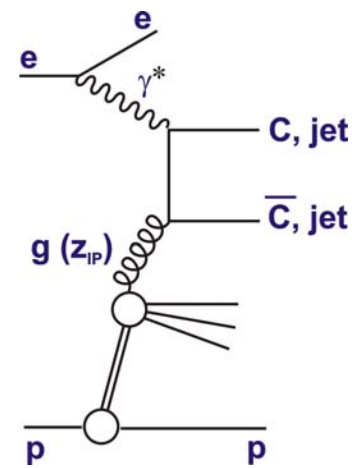
Diffractive Final States

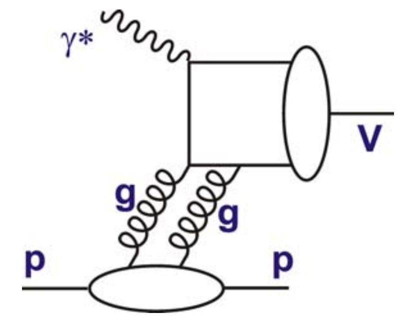


- M_x up to hundreds of GeV at LHeC …

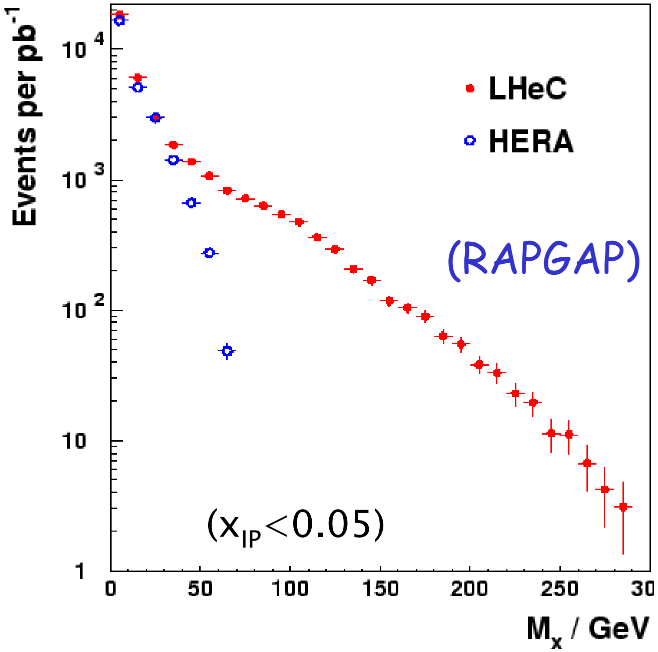
→ Diffractive jets And charm at high Pt and low zIP

→ New diffractive channels (b,W,Z, excl 1^-)





Diffractive Final States



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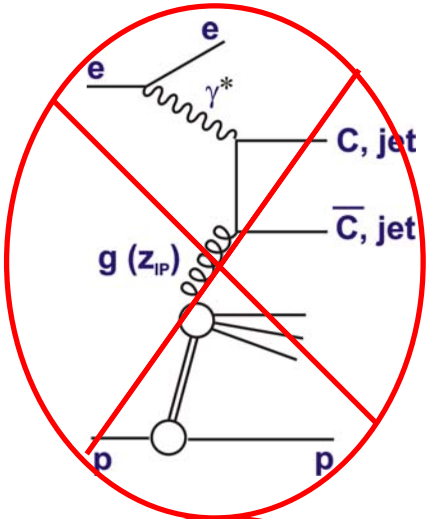
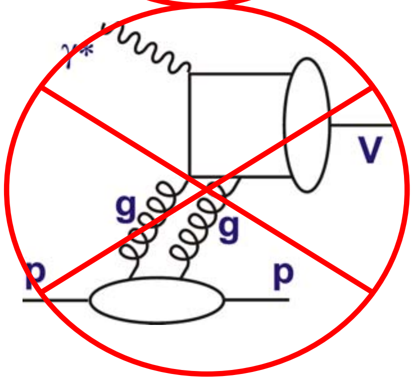
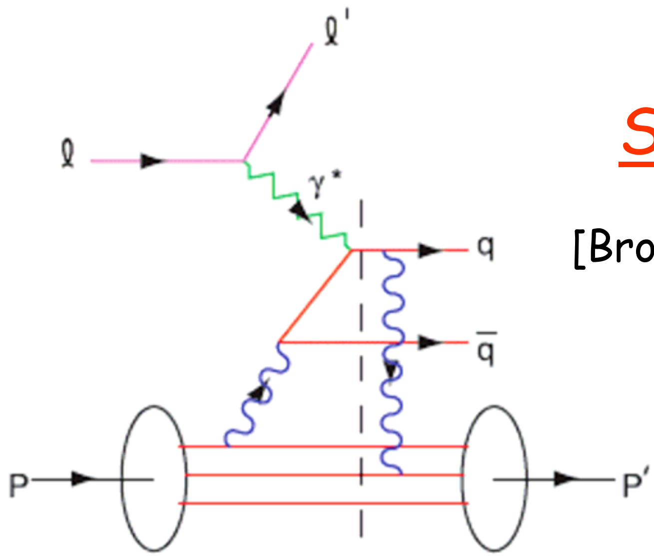






Something to search for in sat^n limit…

[Brodsky] "Final state interactions not in target wavefunction … … destroying factorisation (not only in diffraction!)"

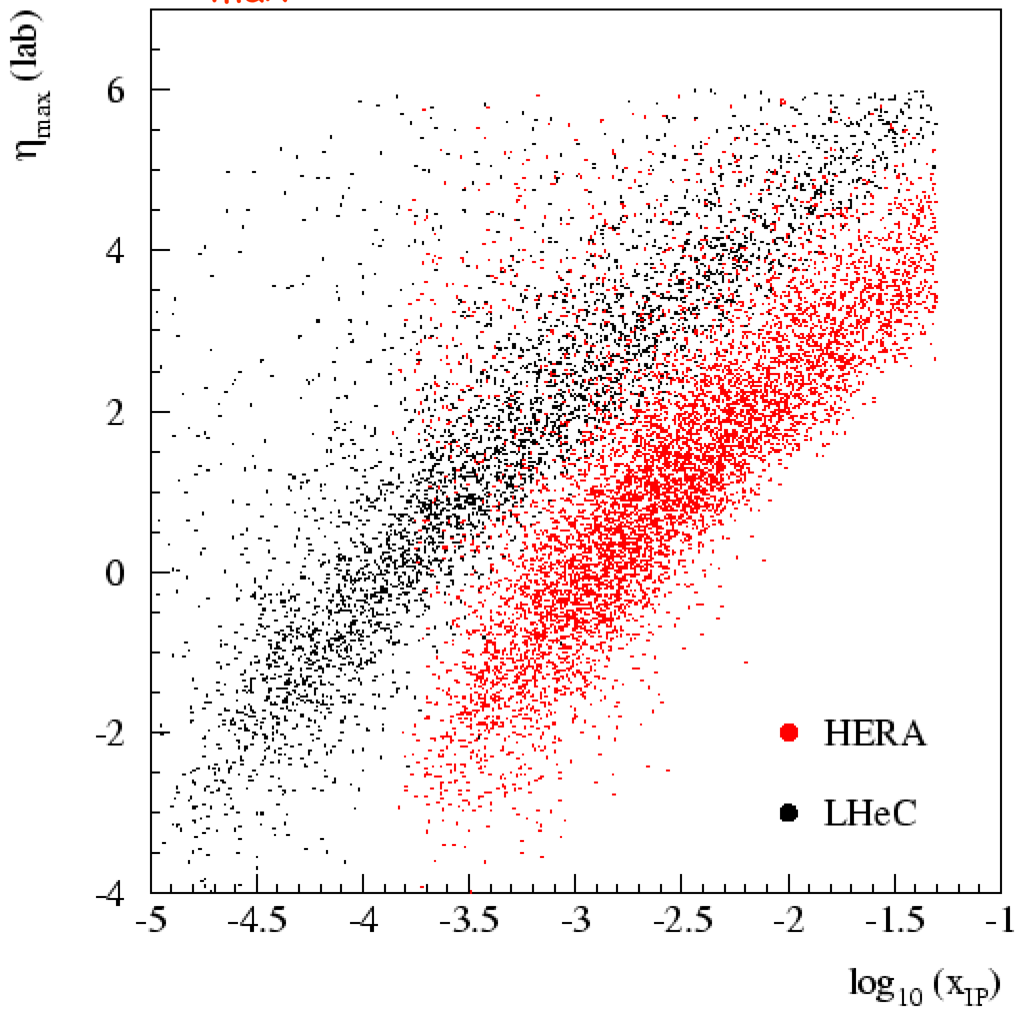
Forward and Diffractive Detectors

- 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!

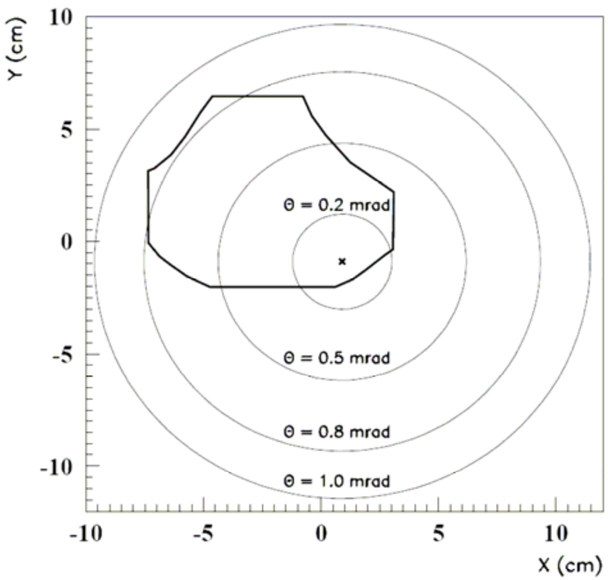
• Roman pots, FNC should clearly be an integral part.
  - Also for t measurements
  - Not new at LHC ☺
  - Being considered integrally with interaction region

η_{max} from LRG selection …



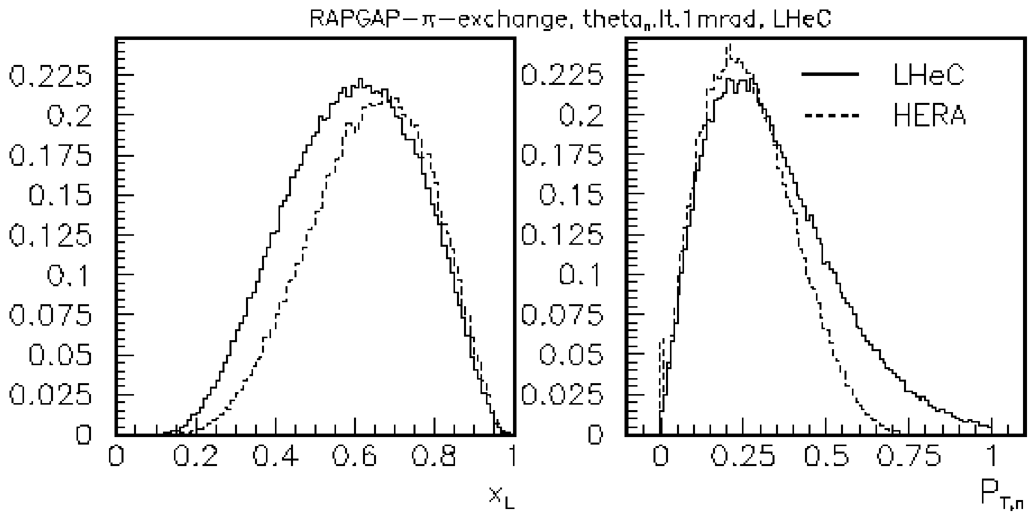
Leading Neutrons: Experience at HERA

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



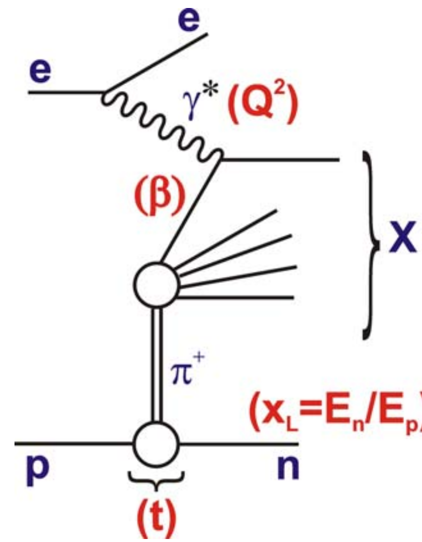
Very radiation hard detectors needed for LHC environment
c.f. Similar detectors (ZDCs) at ATLAS and CMS

π Structure with Neutrons



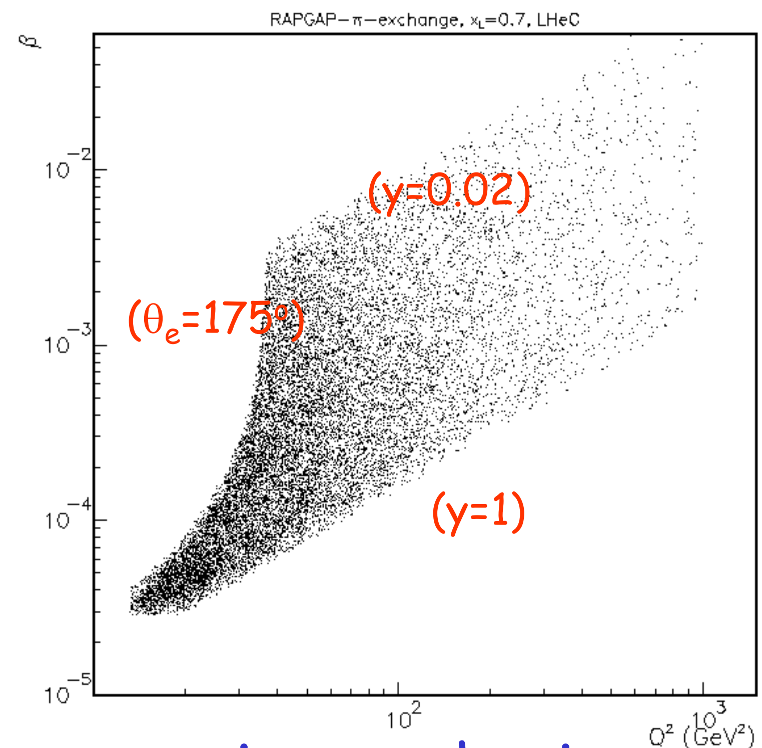
[Bunyatyan]

(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})



Also relevant to absorptive corrections, cosmic ray physics …

Overall Status and Plans

At this meeting, we saw some nice first studies:

→ LHeC kinematic coverage and precision
→ How might we establish parton saturation?

All needs to be studied in much more detail!

Some obvious complete omissions:

→ All eA possibilities
→ Exclusive diffraction (Vector mesons)
→ Leading protons with Roman pots (e.g. t dist'ns)
→ Photoproduction
→ Fragmentation functions

Plans to meet again before next workshop (DIS'08 plus one before and one after?)

Many important points not covered here → see original slides
Thanks to all contributors ... It was an education!