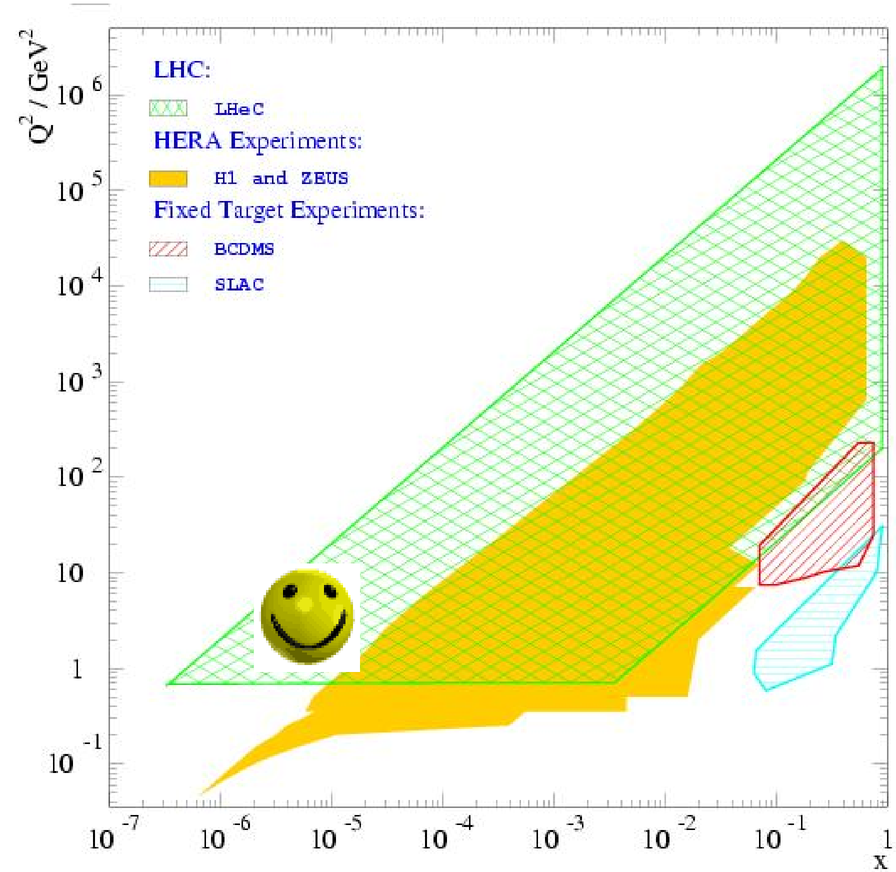
Low x and Diffractive Physics at an LHeC

Paul Newman (Birmingham)

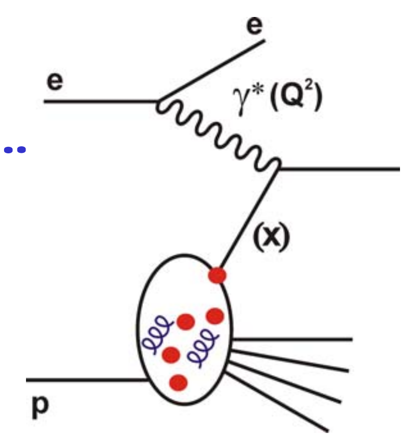
with Nestor Armesto,
Brian Cole & Anna Stasto



EDS'09 (CERN), 1 July 2009

A compendium of some first physics studies ..

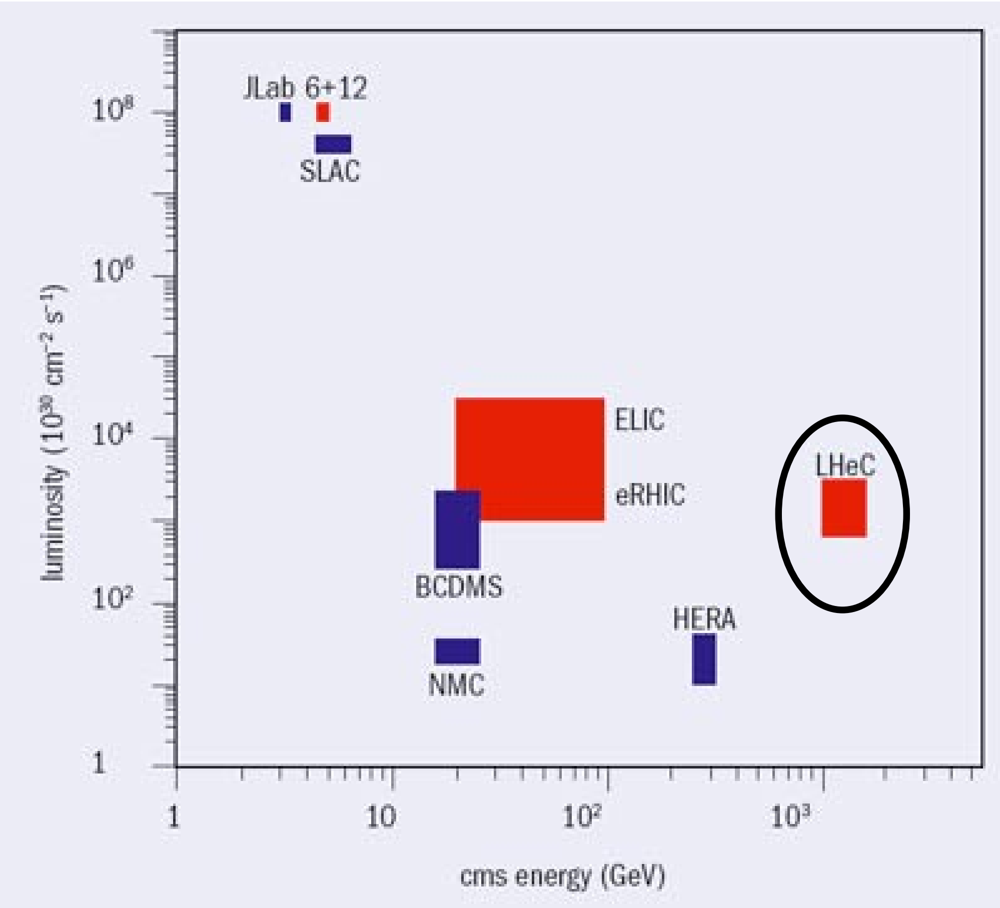
- Kinematic coverage?
- Achievable precision?
- Physics objectives?



http://www.lhec.org.uk

LHeC and TeV Scale ep Scattering

The LHeC is not the first proposal for TeV scale DIS, but it is the first with the potential for significantly higher luminosity than HERA …



DESY 06-006
Cockcroft-06-05

Deep Inelastic Electron-Nucleon Scattering at the LHC*

J. B. Dainton[1], M. Klein[2], P. Newman[3], E. Perez[4], F. Willeke[2]

[1] Cockcroft Institute of Accelerator Science and Technology, Daresbury International Science Park, UK
[2] DESY, Hamburg and Zeuthen, Germany
[3] School of Physics and Astronomy, University of Birmingham, UK
[4] CE Saclay, DSM/DAPNIA/Spp, Gif-sur-Yvette, France

… achievable with a new electron accelerator at the LHC …

[JINST 1 (2006) P10001]

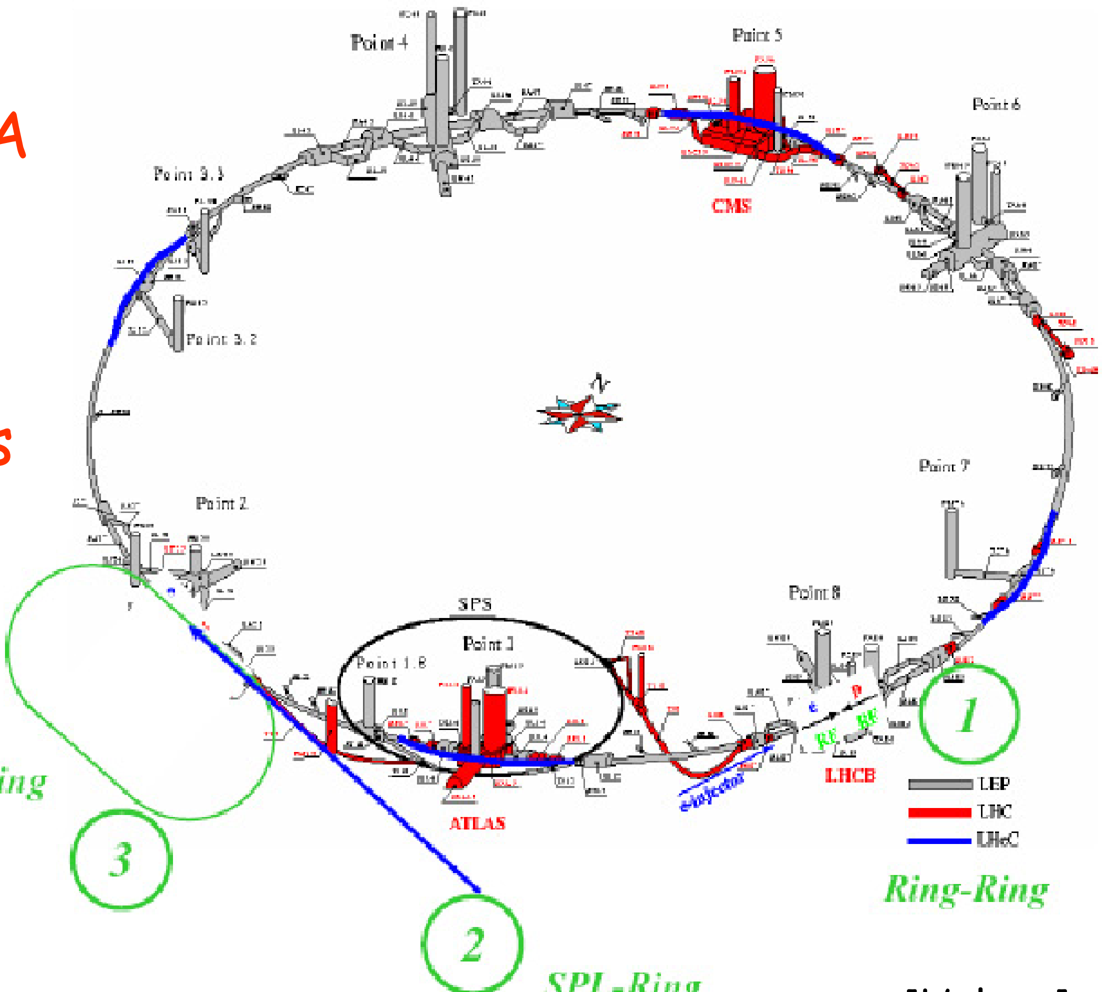
Three Possible Lay-outs for Collisions at IP2

Increasingly detailed design under constraints of simultaneous ep (eA) and pp (AA) running at power < 100 MW

1) Lumi ~ 3.10^{33} cm^{-2} s^{-1} at E_e = 50 GeV with HERA style focusing magnets and 10^o acceptance.
… or Lumi ~ 10^{32} cm^{-2} s^{-1} without focusing magnets and 1^o acceptance

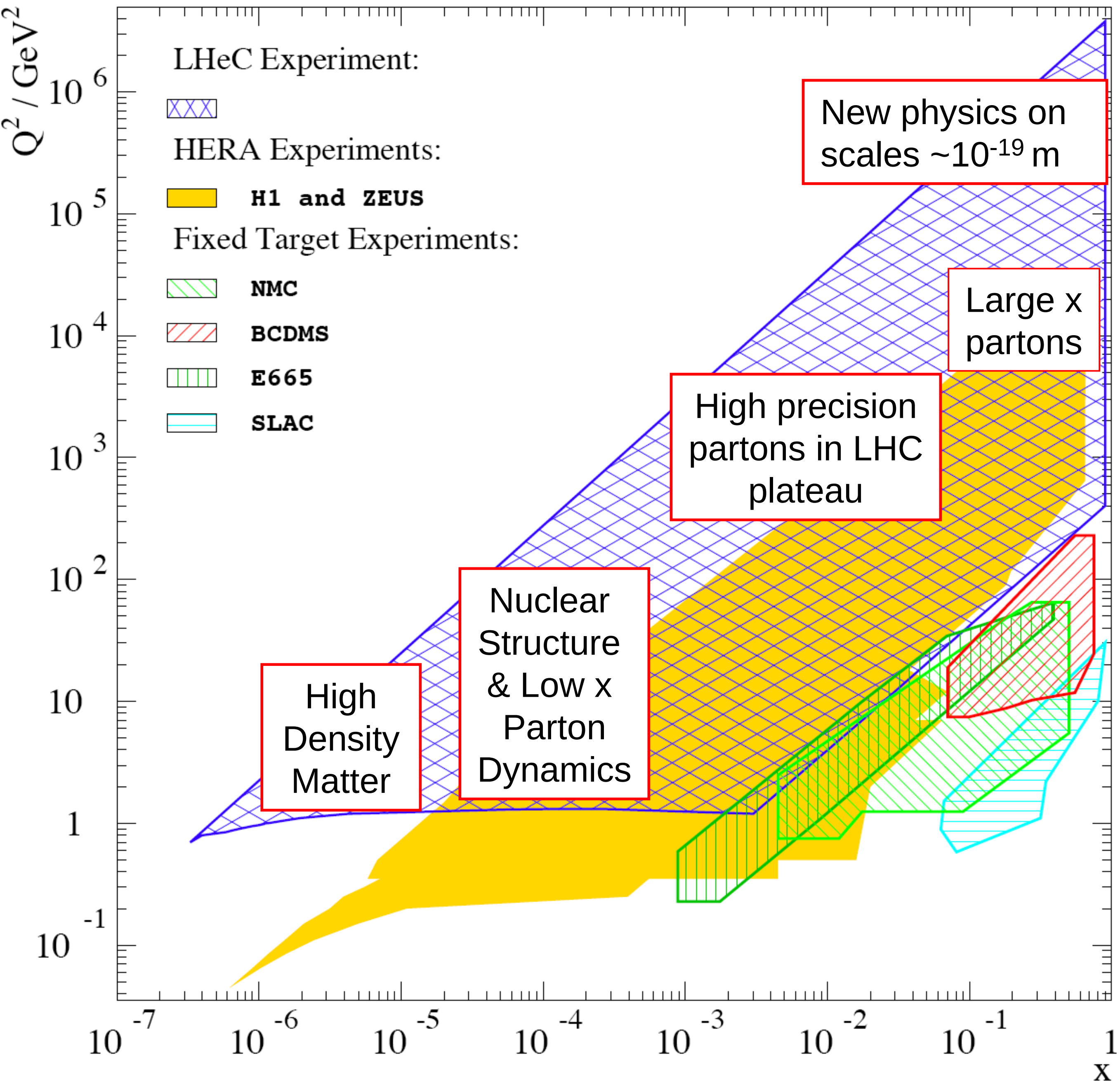
2) Lumi ~ 10^{32} cm^{-2} s^{-1} At E_e = 20 GeV

3) Lumi ~ 3.10^{32} cm^{-2} s^{-1} at E_e = 100 GeV



[Holzer]

Kinematics & Motivation (140 GeV x 7 TeV)

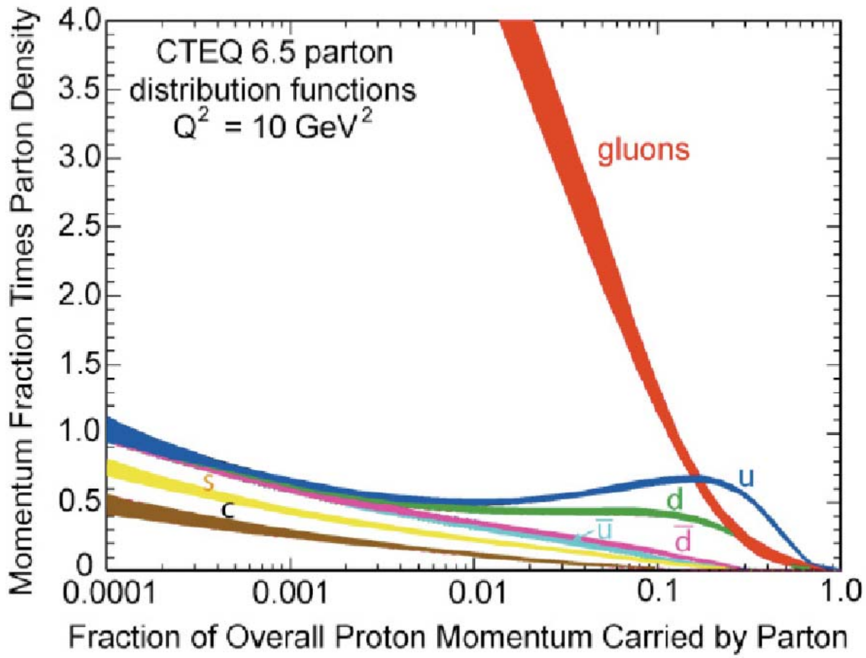


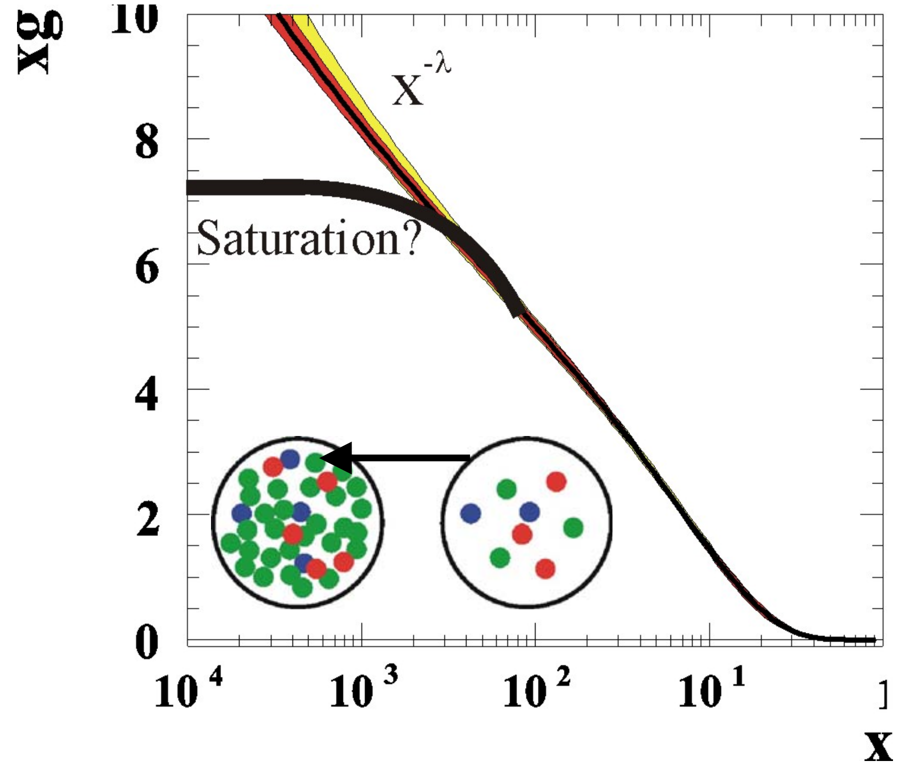
$\sqrt{s} = 2$ TeV

- High mass (M_{eq}, Q^2) frontier
- EW & Higgs
- Q^2 lever-arm at moderate & high x → PDFs
- Low x and eA Frontier → novel QCD …

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

Low-x Physics and Non-linear Evolution

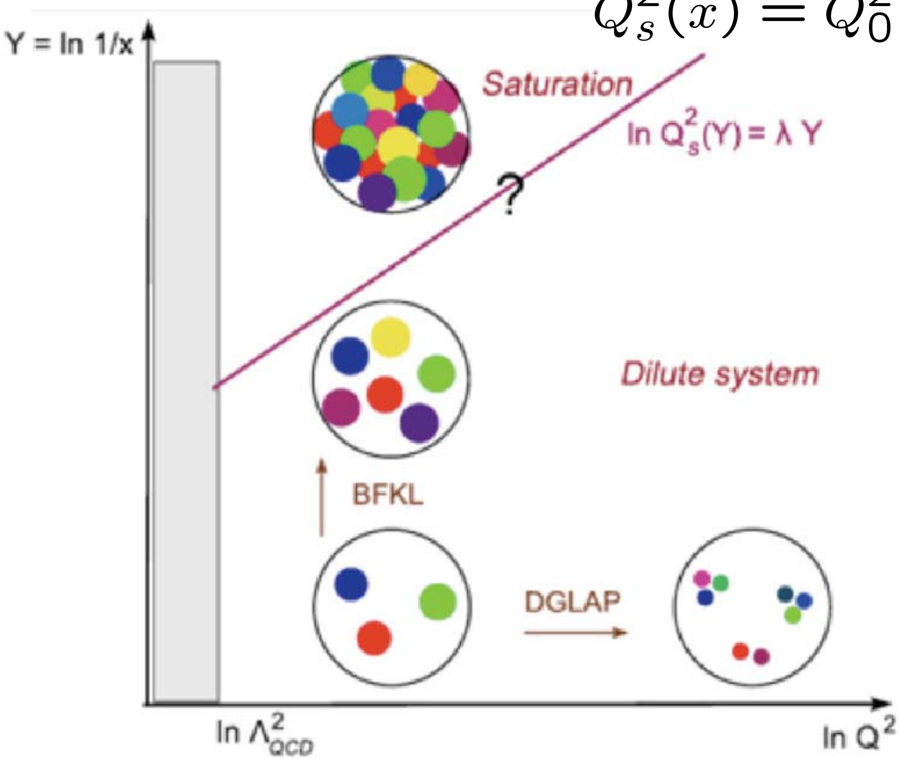




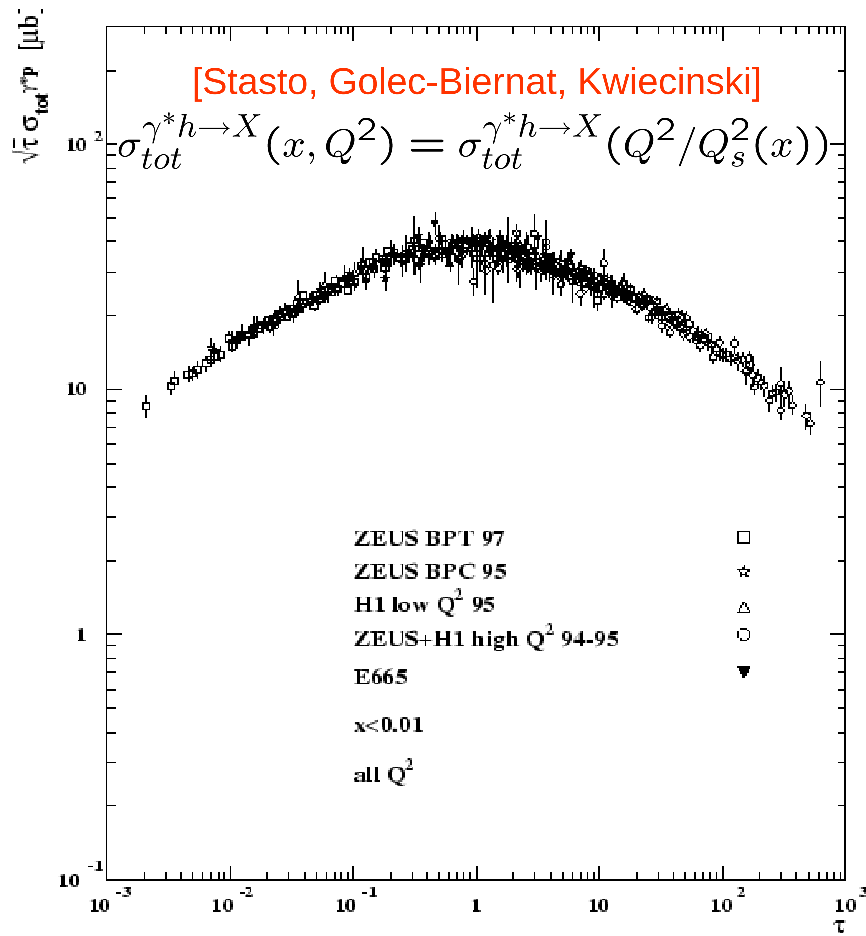
- Somewhere & somehow, the low x growth of cross sections must be tamed to satisfy unitarity … non-linear effects
- Parton level manifestation? e.g. recombination ***gg*** → ***g***?
- Usually characterised in terms of an energy dependent "saturation scale", $Q^2_s(x)$, to be determined experimentally

Non-linear effects @ HERA

$$Q_s^2(x) = Q_0^2\ x^{-\lambda}$$



Lines of constant density are diagonal … scattering cross section appears constant along them



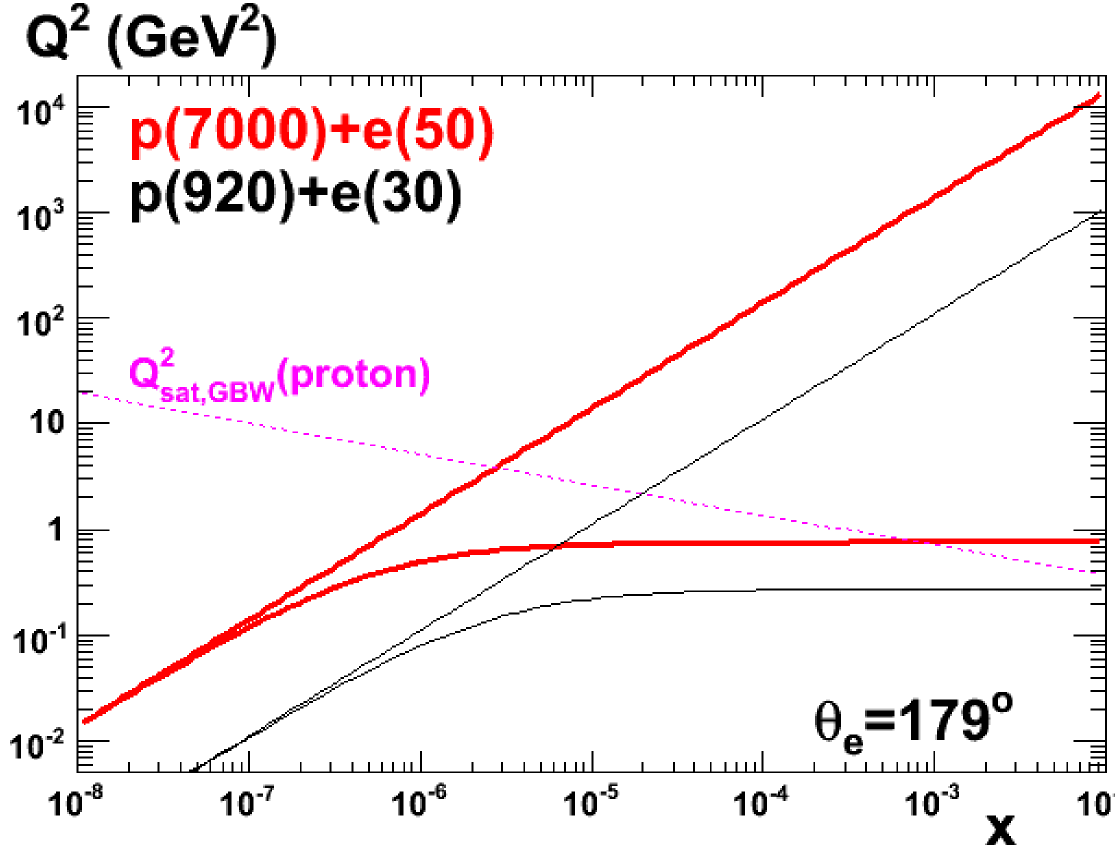
Something appears to happen around $\tau = Q^2/Q_s^2 = 1\ \text{GeV}^2$ (confirmed in many analyses).
BUT … Q^2 small for $\tau <\sim 1\ \text{GeV}^2$
… not easily interpreted in QCD

LHeC Kinematics for Low x Investigations

Access to Q^2=1 GeV^2 in ep mode for all $x > 5 \times 10^{-7}$ if we have acceptance to 179°

Luminosity ~ 1 fb^{-1} / yr … ample for most low x studies … definitive low x and diffractive facility!

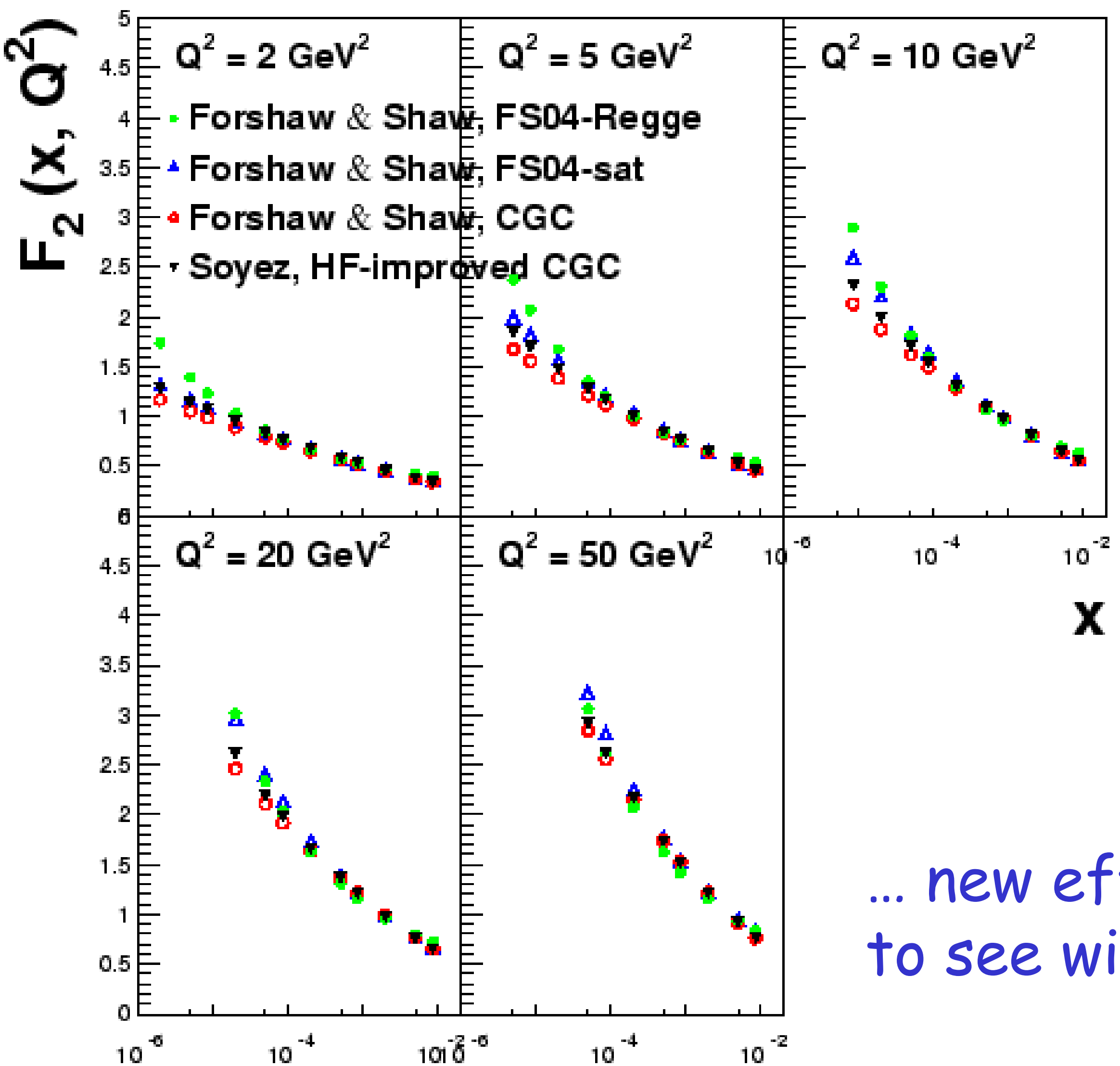
→parton saturation
→novel QCD evolution
→Diffractive ep, eA
→…



Some models of low x F_2 with LHeC Data

With 1 fb^{-1} (1 year at 10^{32} cm^{-2} s^{-1}), 1^o detector:
stat. precision < 0.1%, syst, 1-3%

[Forshaw, Klein, PN, Soyez]



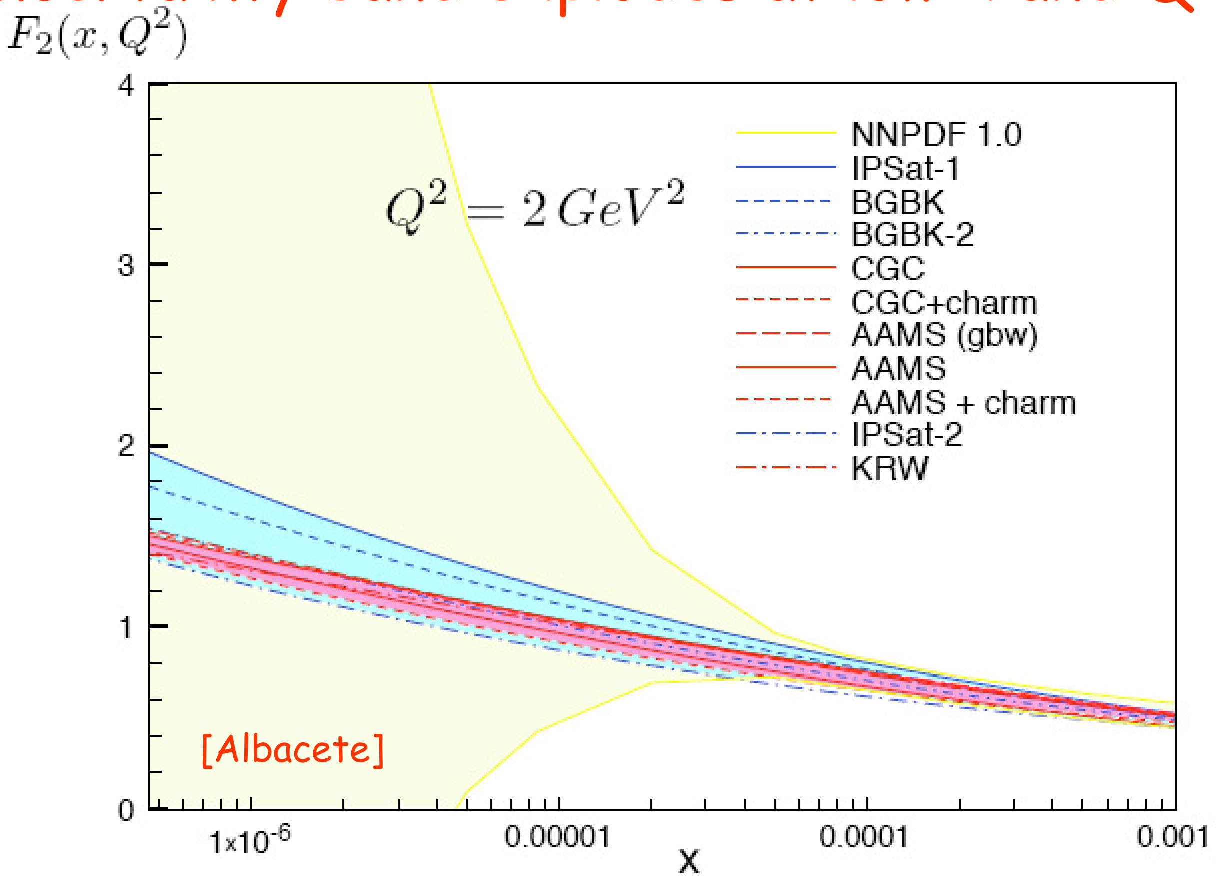
Precise data in LHeC region, x >~ 10^{-6}

- Extrapolated HERA dipole models …
- FS04, CGC models including saturation suppressed at low x & Q^2 relative to non-sat FS04-Regge

… new effects may not be easy to see with F_2 alone …

Another look at Extrapolations of F_2

NNPDF parameter-free NLO DGLAP QCD fit …
uncertainty band explodes at low x and Q^2



Very wide range of possibilities allowed by pQCD …
… whilst retaining a good fit to to HERA data

F_L Simulation

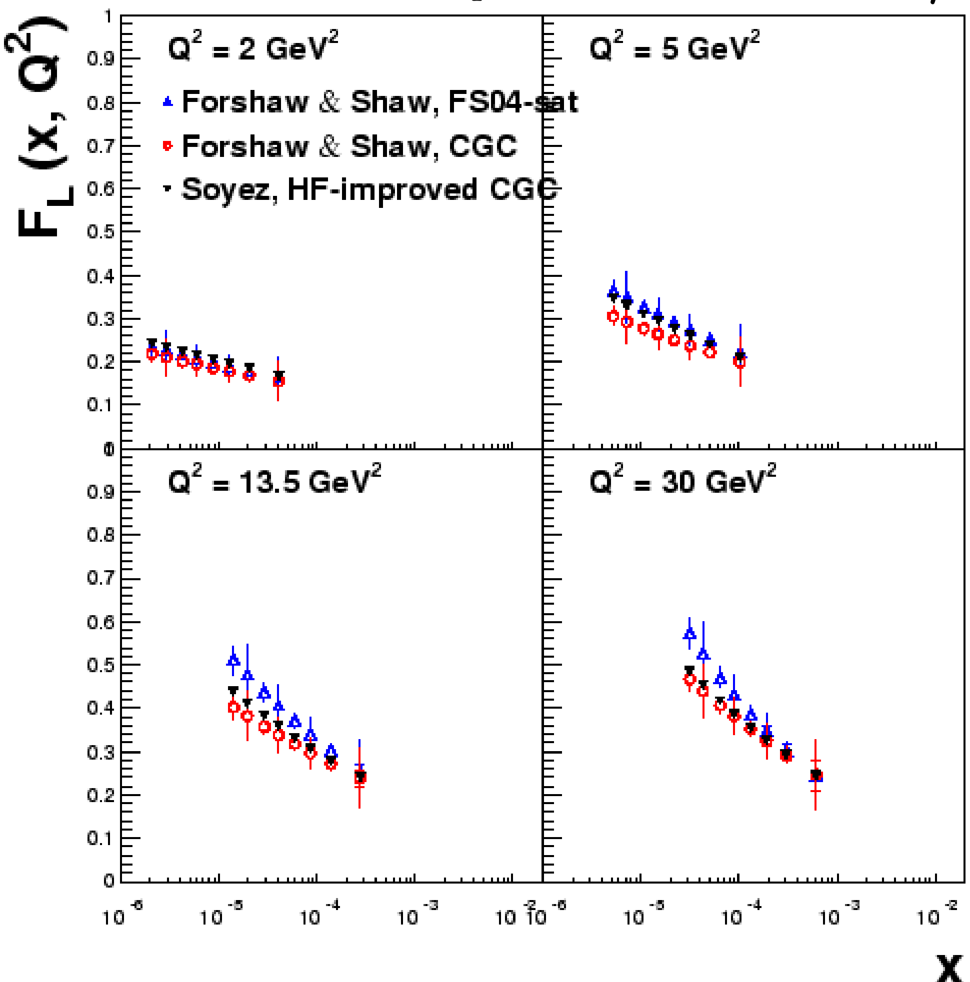
More observables needed to distinguish non-linear partonic effects from change in behaviour of low Q^2 non-perturbative input

Gluon-sensitive observables (e.g. F_2^c, F_L) are best to complement (quark-sensitive) F_2

e.g. Vary sqrt(s) as recently done at HERA ?...
→ example for 1 year run

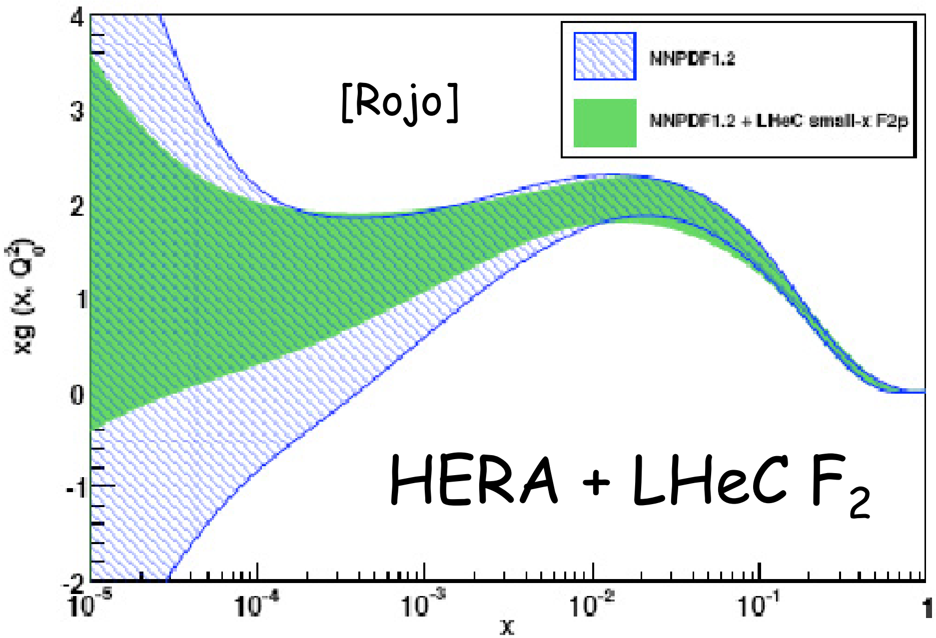
… selected lowest x F_L data compared with 3 dipole models including saturation …

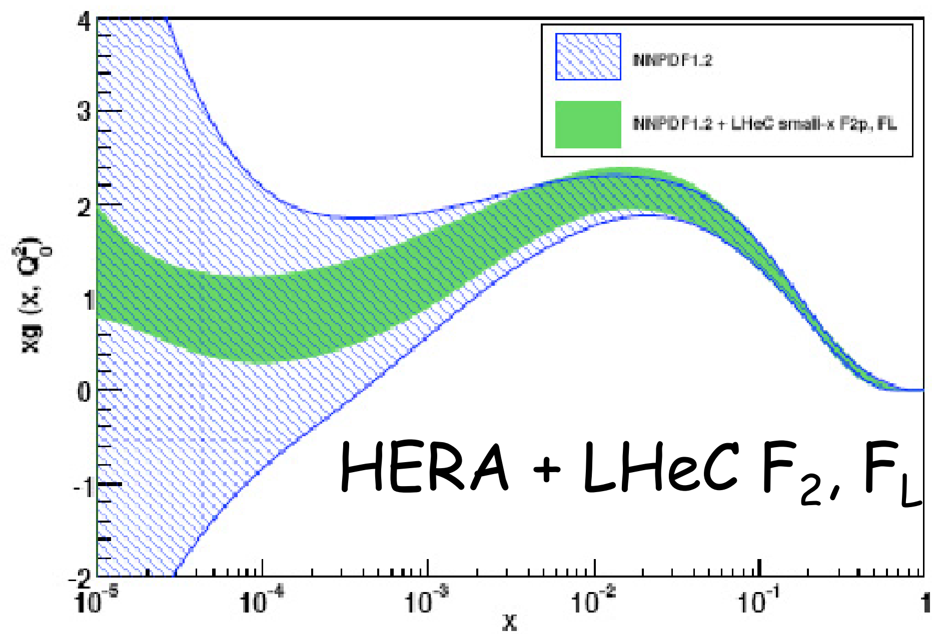
[Forshaw, Klein, PN, Soyez]



… precision typically 5% … stats limited for $Q^2 > 1000$ GeV^2

Constraining the Gluon with LHeC F_2 and F_L





($Q^2 = 2\ GeV^2$)

Including LHeC data in NNPDF DGLAP fit approach …

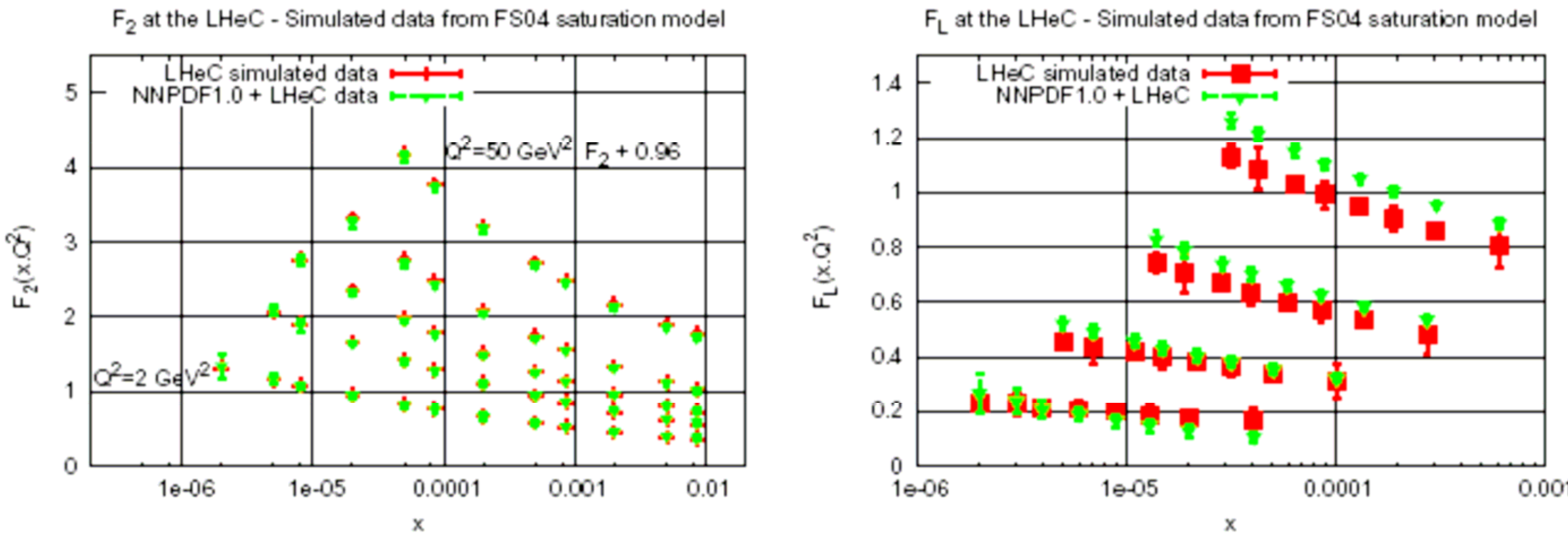
… sizeable improvement in error on low x gluon when both LHeC F_2 & F_L data are included.

… but would DGLAP fits fail if non-linear effects present?

Can Parton Saturation be Established @ LHeC?

Simulated LHeC F_2 and F_L data based on a dipole model containing low x saturation (FS04-sat)…

… NNPDF (also HERA framework) DGLAP QCD fits cannot accommodate saturation effects if F_2 and F_L both fitted

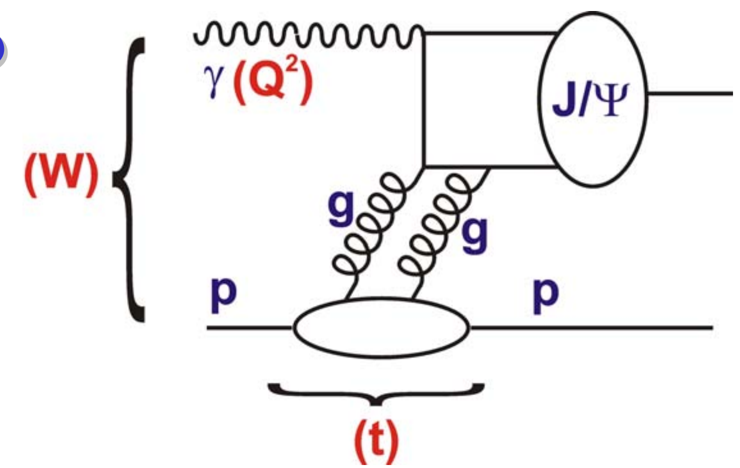


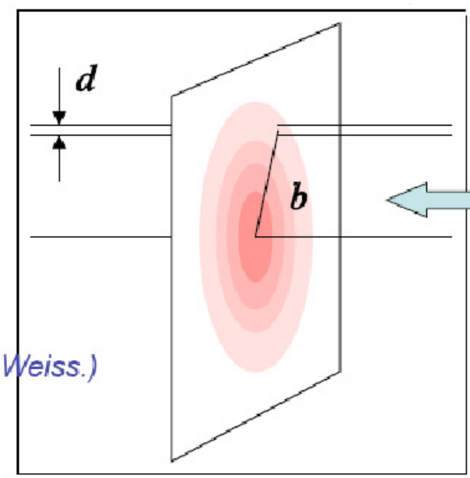
[Rojo]

… even with LHeC low x region, multiple ep (& eA) observables will be required for a clear picture of non-linear dynamics.

What about Diffraction?

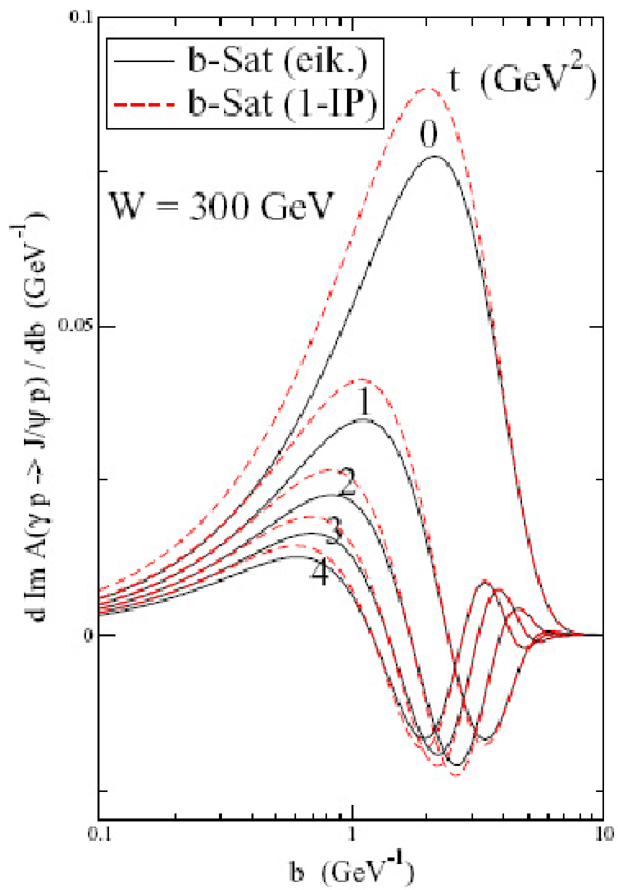
Additional variable t gives access to impact parameter (b) dependent amplitudes





(figure from C. Weiss.)

Central black region growing with decrease of x.



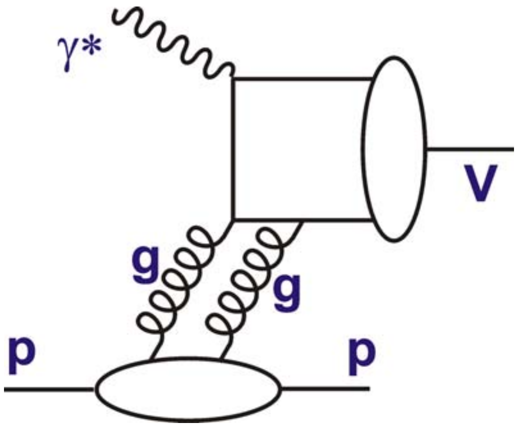
Large t (small b) probes densest packed part of proton?
c.f. inclusive scattering probes median $b \sim 2\text{-}3\ \text{GeV}^{-1}$

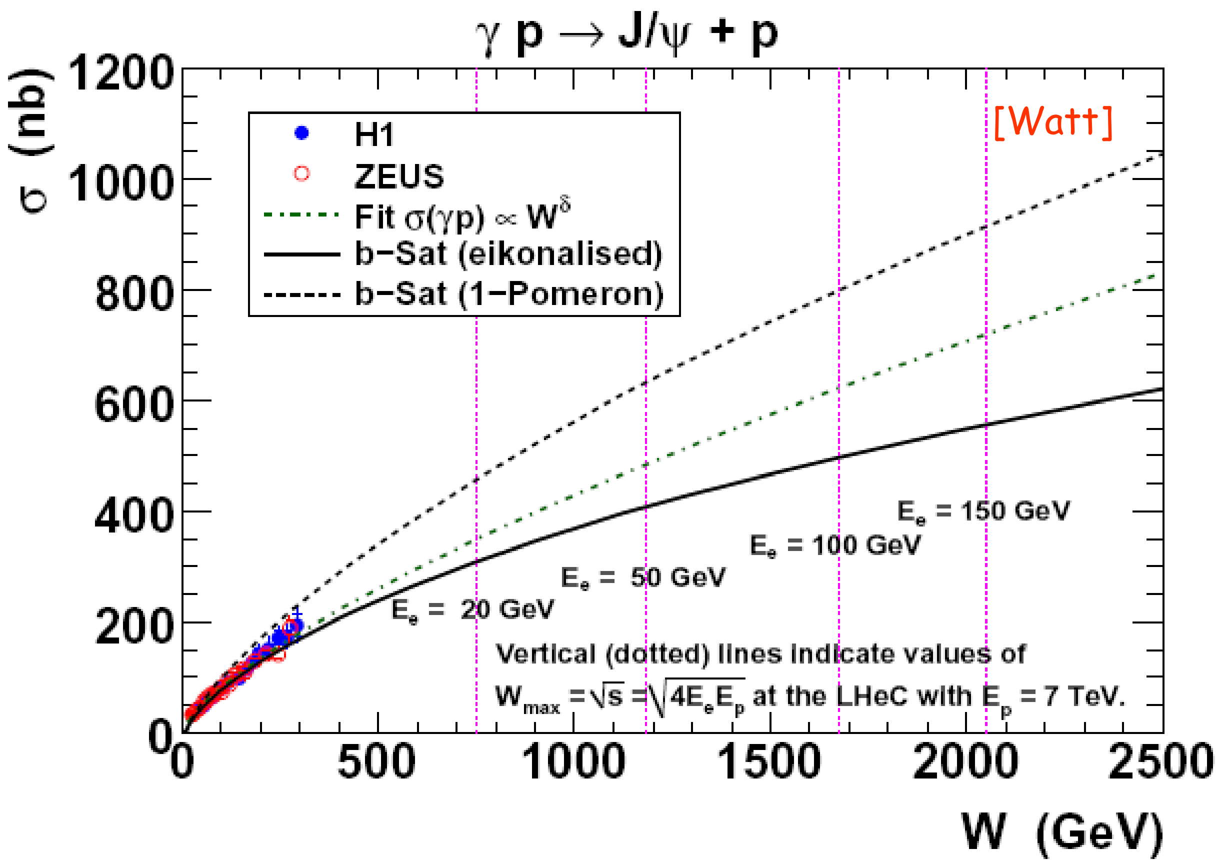
e.g. J/ψ Photoproduction

e.g. "b-Sat" Dipole model [Golec-Biernat, Wuesthoff, Bartels, Teaney, Kowalski, Motyka, Watt] ...

"eikonalised": with impact-parameter dependent saturation

"1 Pomeron": non-saturating

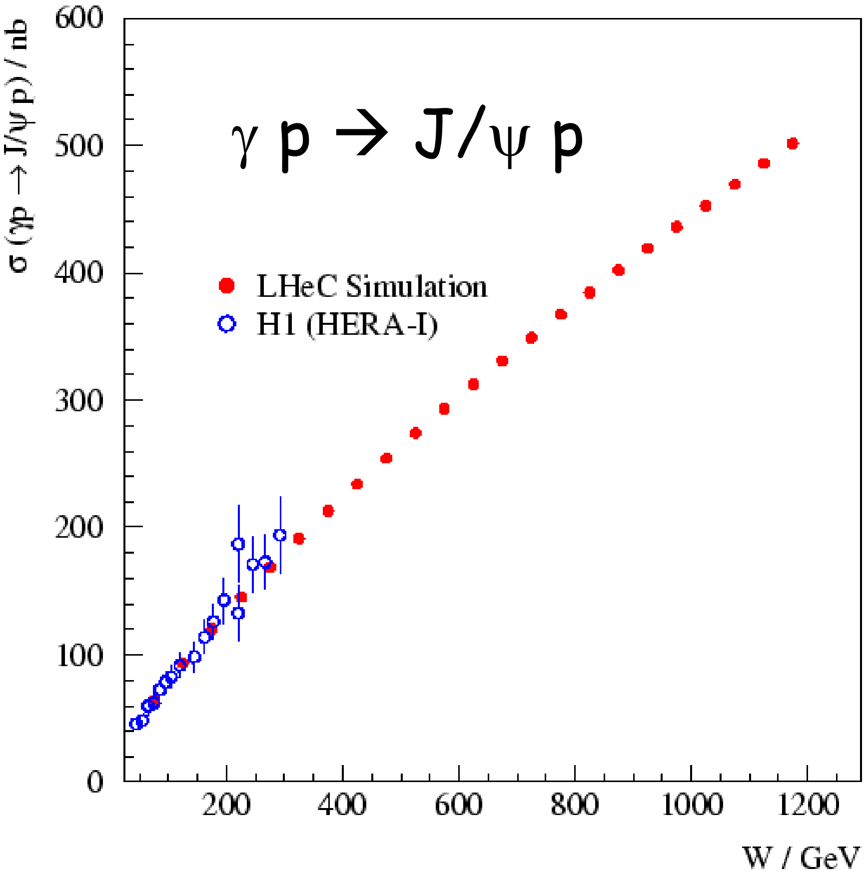


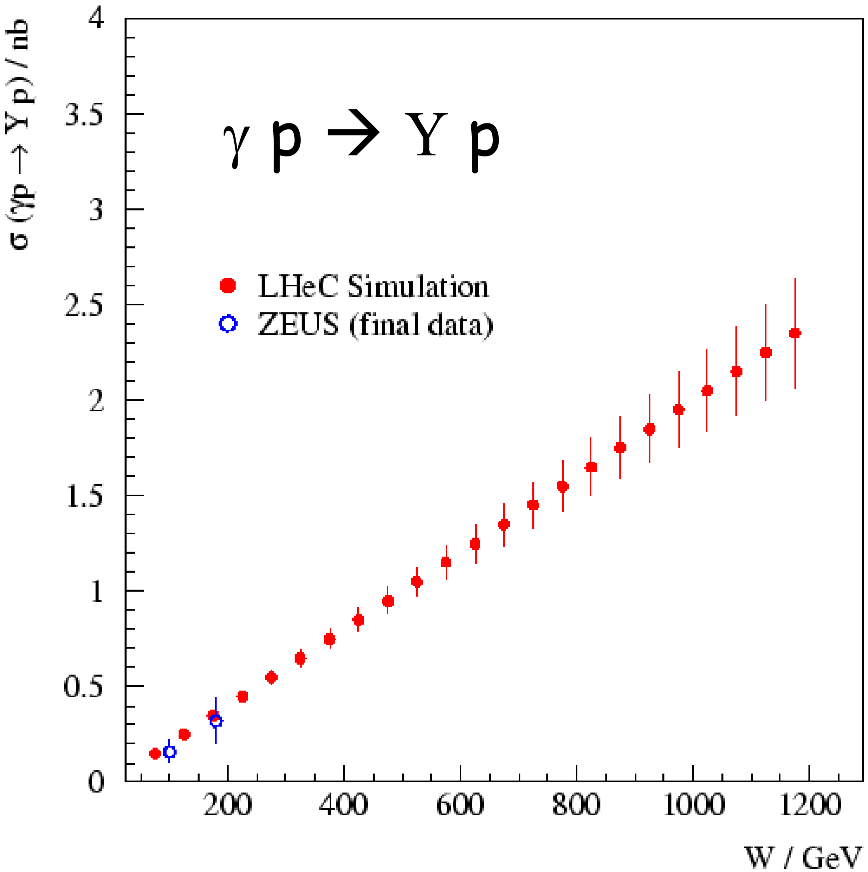


Significant non-linear effects expected even for t-integrated cross section in LHeC kinematic range.

LHeC J/ψ & Υ Photoproduction Simulation

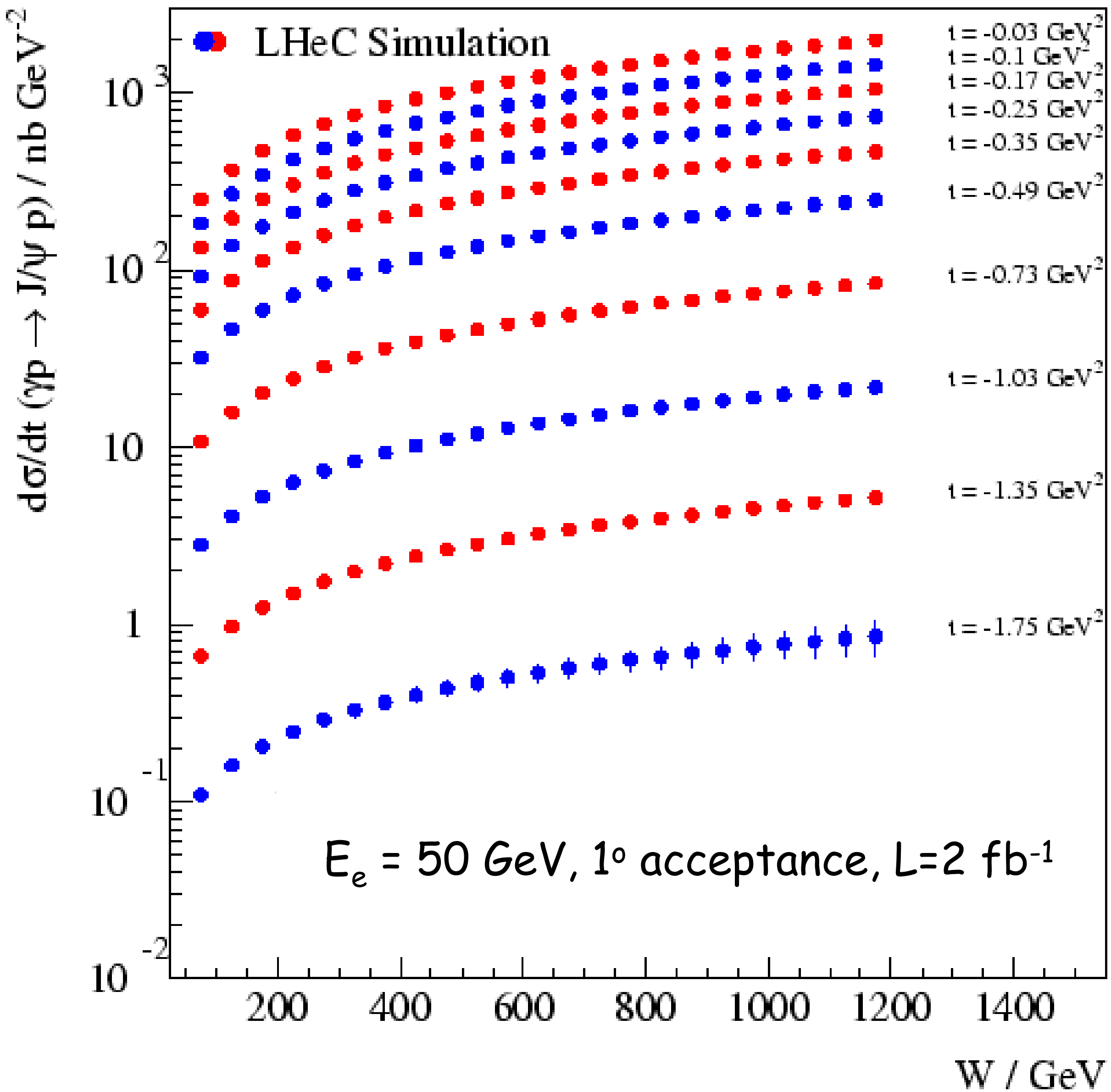
- Simulated data with heavy vector meson decays to μμ.
- Detector acceptance to within 1° of beampipe,
- Lumi = 2 fb^{-1} (2 years) E_e = 50 GeV





Precise measurements (even for Υ) well into sensitive region

Elastic J/ψ Production more Differentially



J/ψ photoproduction double differentially in W and t …

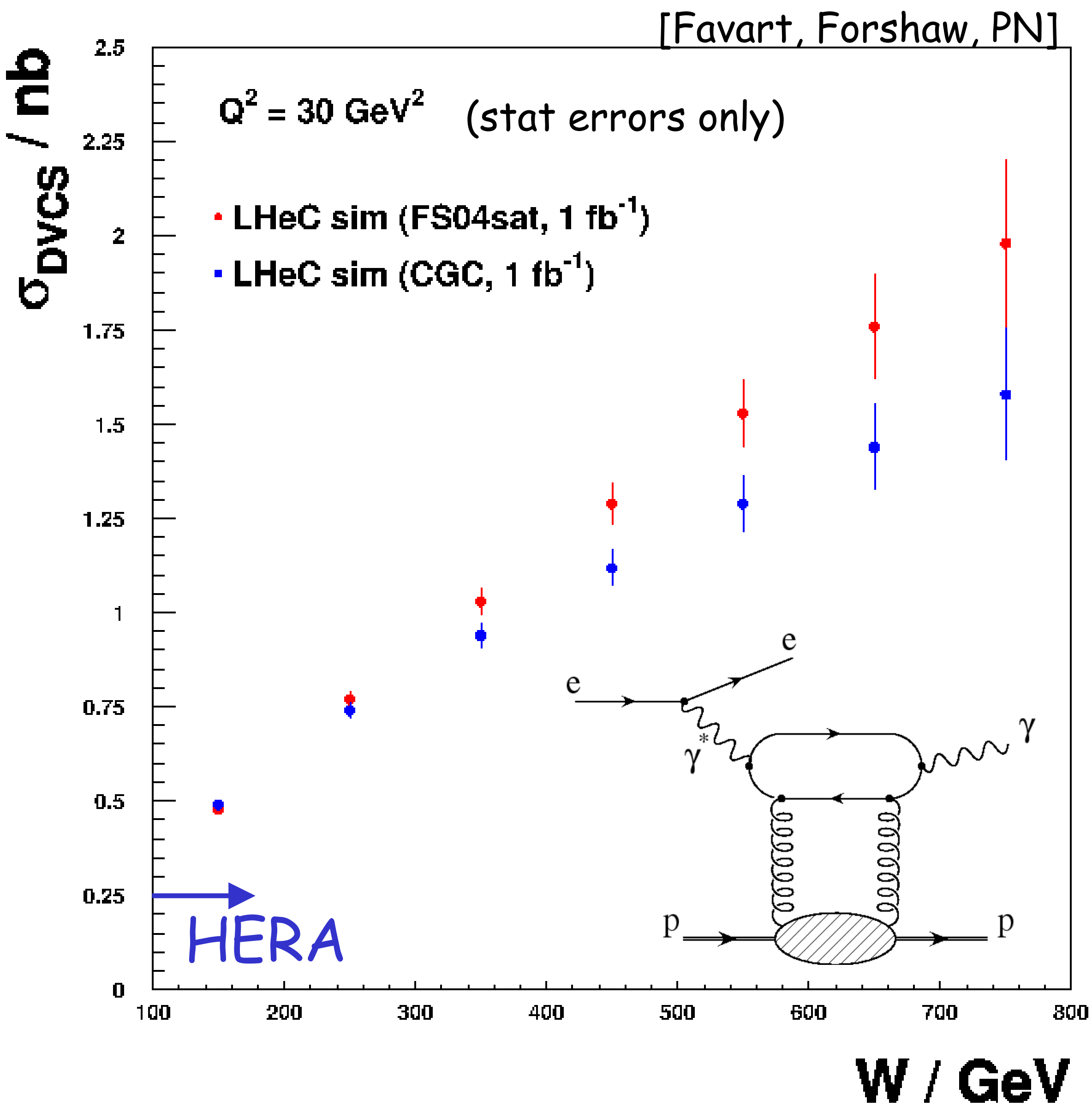
Inclusive cross sec probes to $x_g \sim 6.10^{-6}$

$Q^2_s \sim 3\ GeV^2 \sim m_\psi^2/4$

Precise t dependence will be crucial to study sat^n effects!

Also possible in several Q^2 bins

DVCS at LHeC



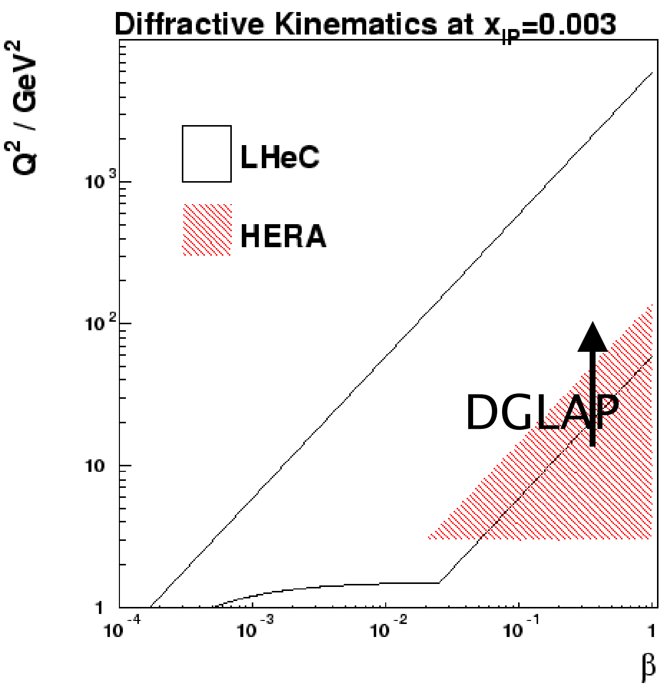
(1^o acceptance)

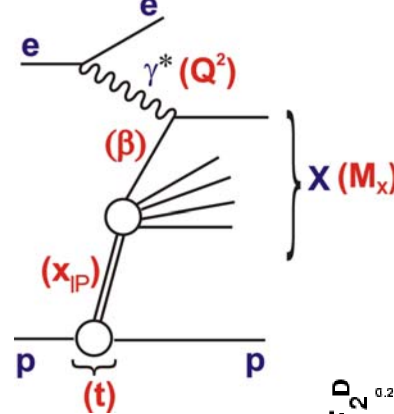
Statistical precision with 1fb^{-1} ~ 2-11%

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

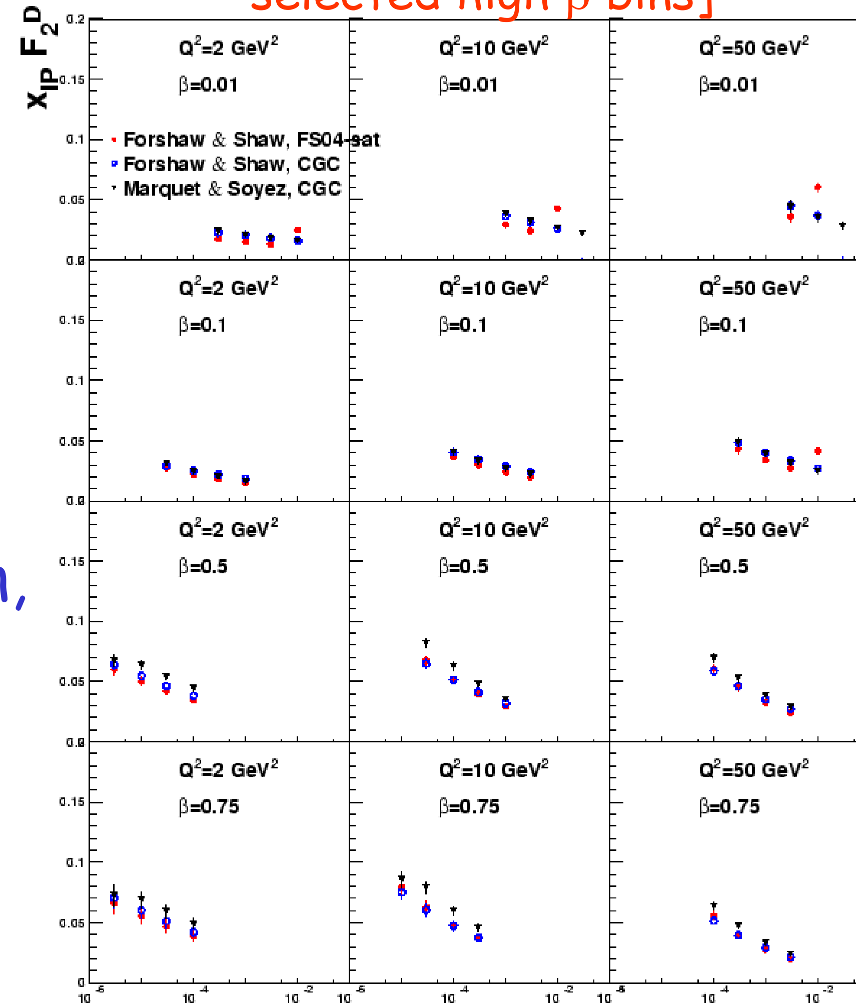
Cleaner interpretation in terms of GPDs at larger LHeC Q^2 values

(Semi)-Inclusive Diffractive DIS





[1° acceptance, 1 fb^{-1}, E_e = 70 GeV, selected high β bins]

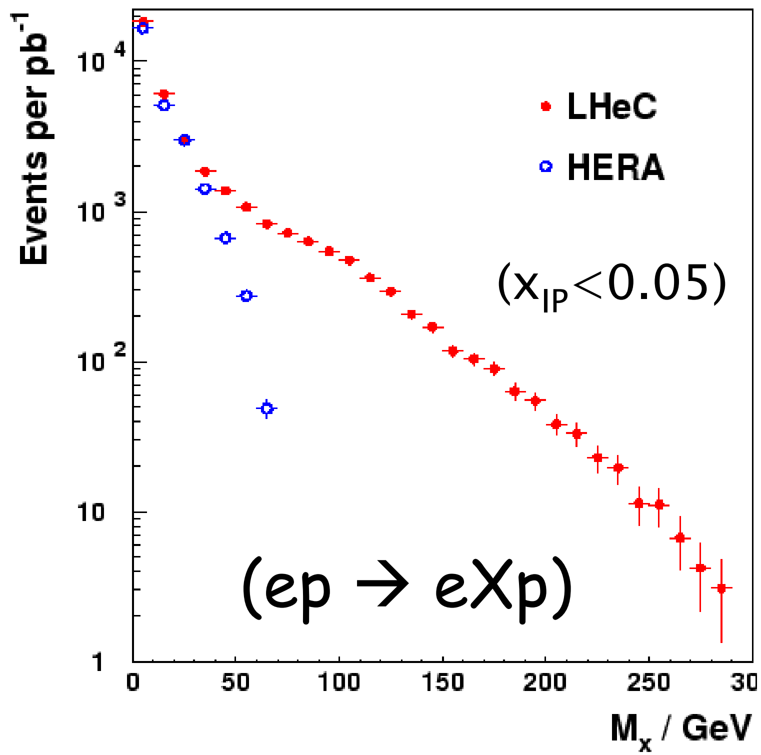


[Forshaw, Marquet, PN]

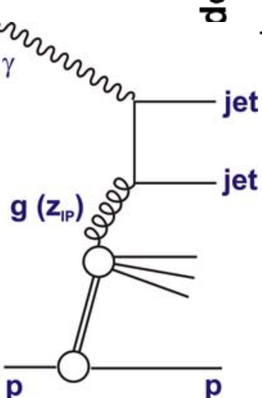
- DPDFs currently very poorly known for β < 0.01.
- Clearer window on factorisation, gluon, flavour decomposition & electroweak effects
- Enhanced sensitivity to non-linear effects / saturation (qqbar-g dipoles and beyond).

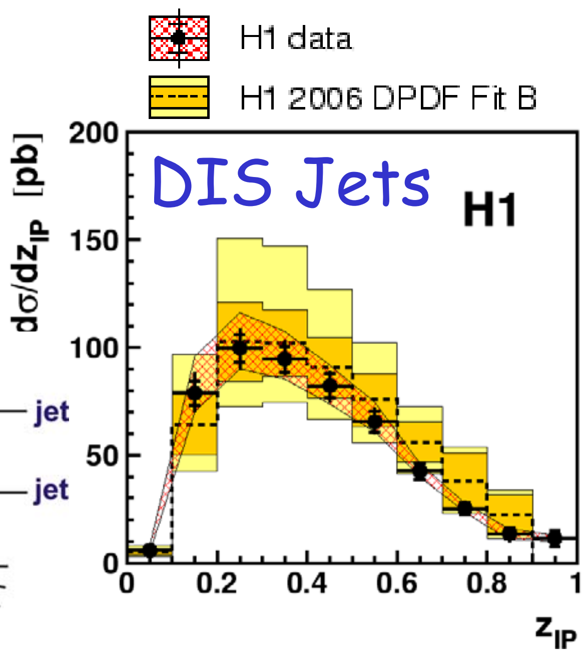
Final States in Diffraction at the LHeC

[RAPGAP simulation]



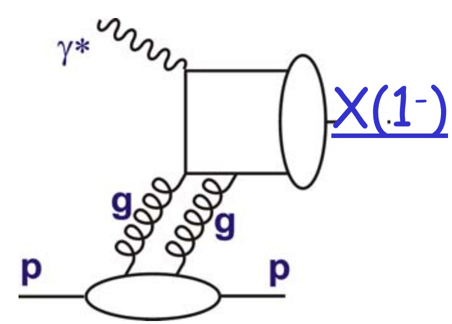
- Diffractive masses M_x up to hundreds of GeV can be produced with low x_{IP}
- Final states (e.g. jets) at higher p_t and lower β … much more precise factorisation and DPDF tests





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

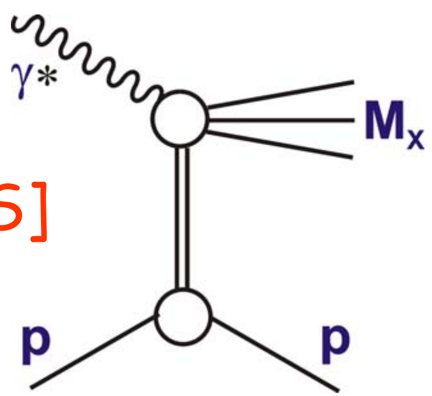
- Unfold quantum numbers / precisely measure new exclusive 1^- states

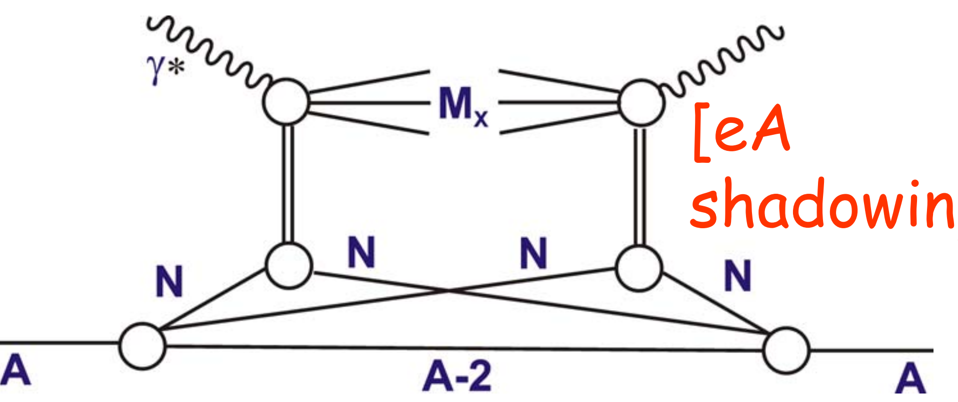


F_2^D and Nuclear Shadowing

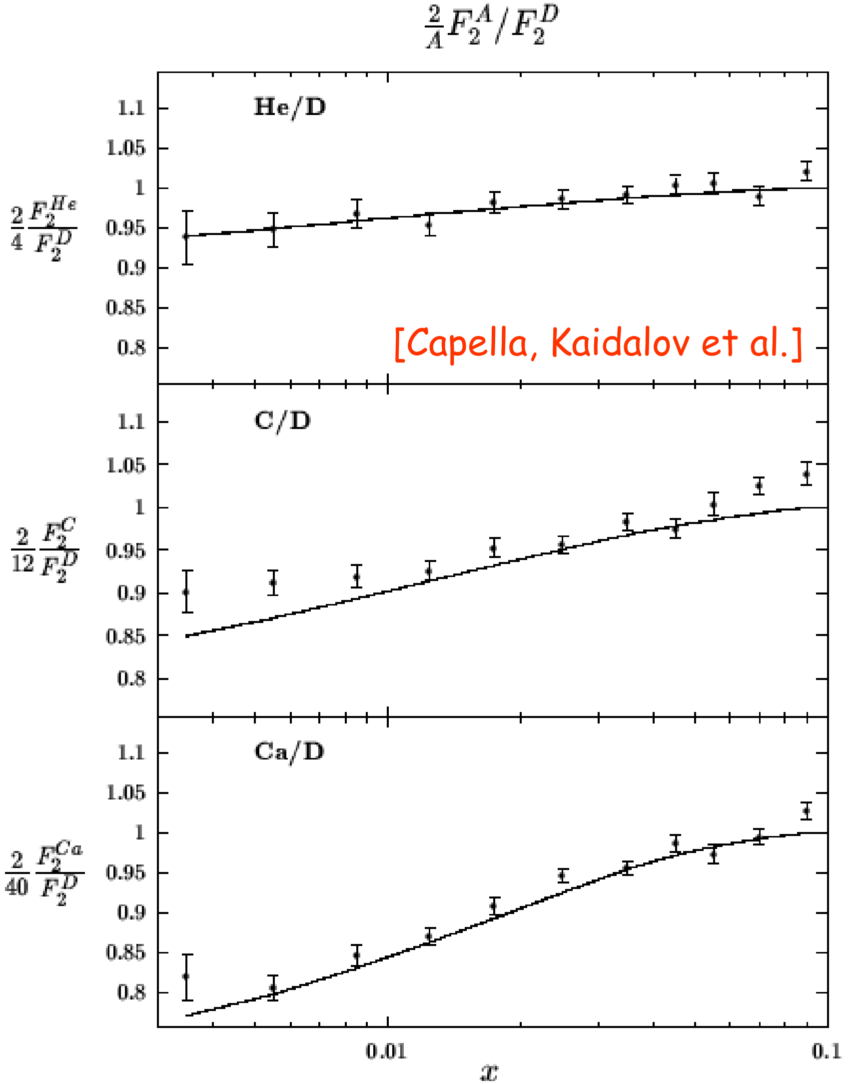
Nuclear shadowing can be described (Gribov-Glauber) as multiple interactions, starting from ep DPDFs

[Diff DIS]





[eA shadowing]



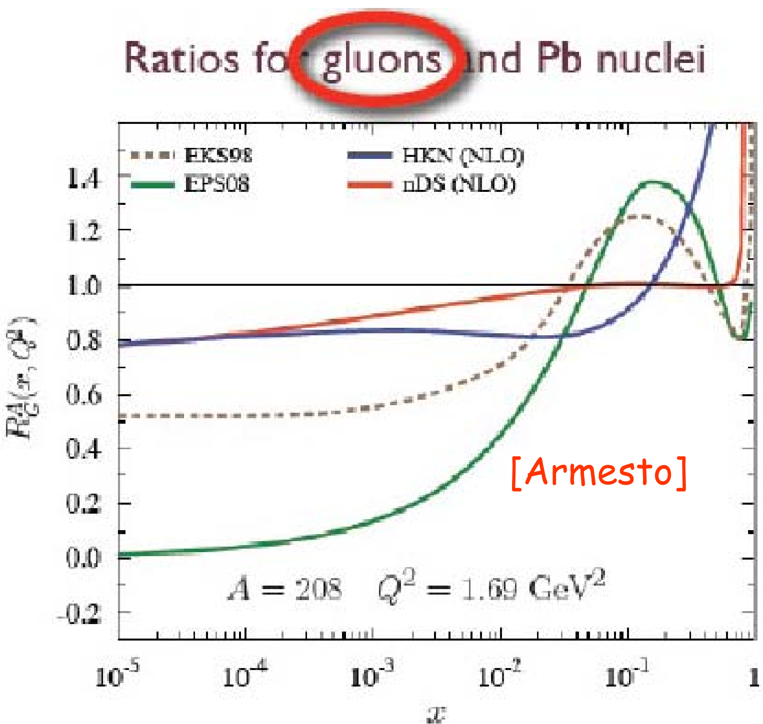
[Capella, Kaidalov et al.]

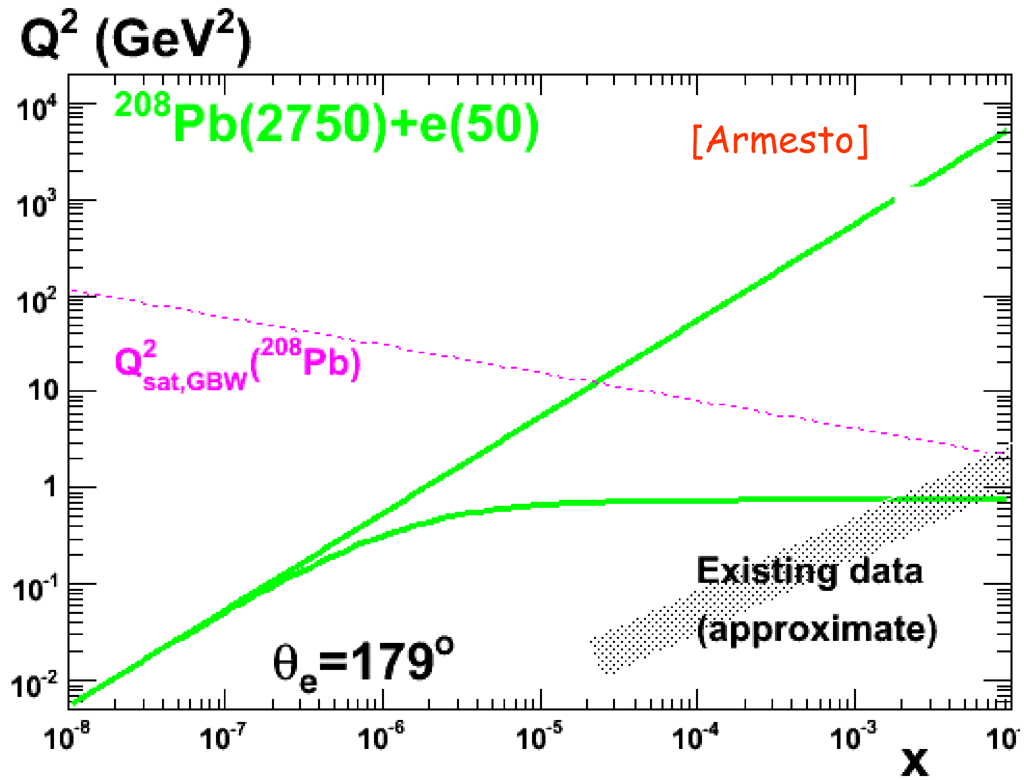
… starting point for Extending precision LHeC studies into eA collisions

With AA at LHC, LHeC is also an eA Collider

• Very limited x, Q^2 and A range for F_2^A (quarks unknown for x <~ 10^{-2}, gluon very poorly known)

Initial state of LHC AA collisions ~ unconstrained!

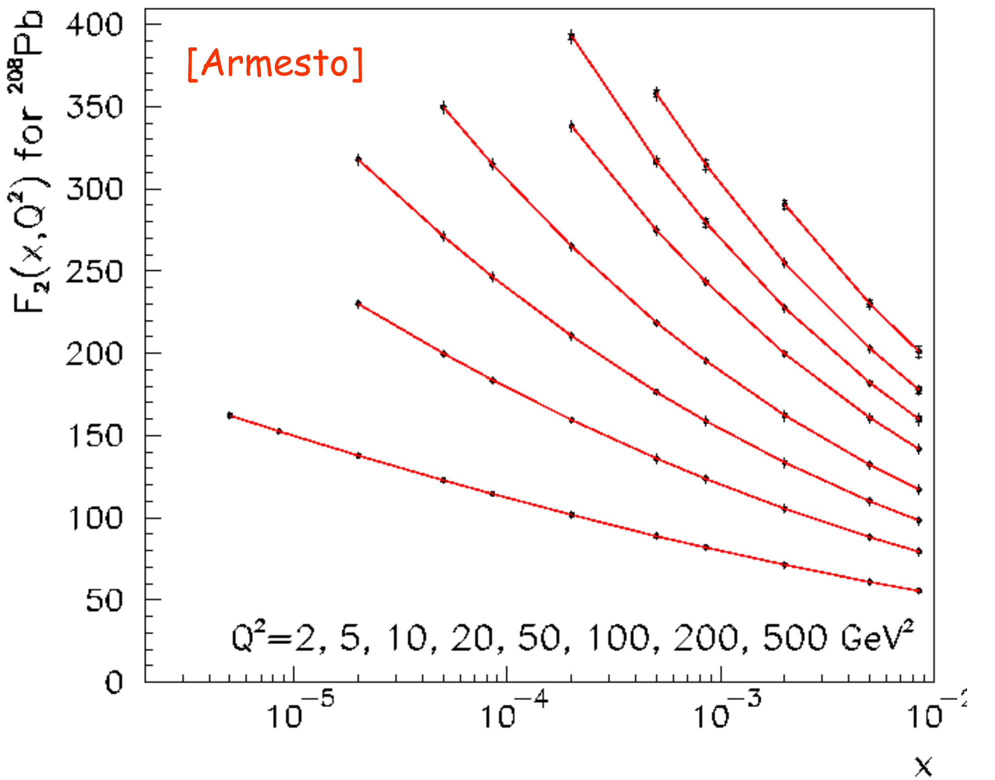


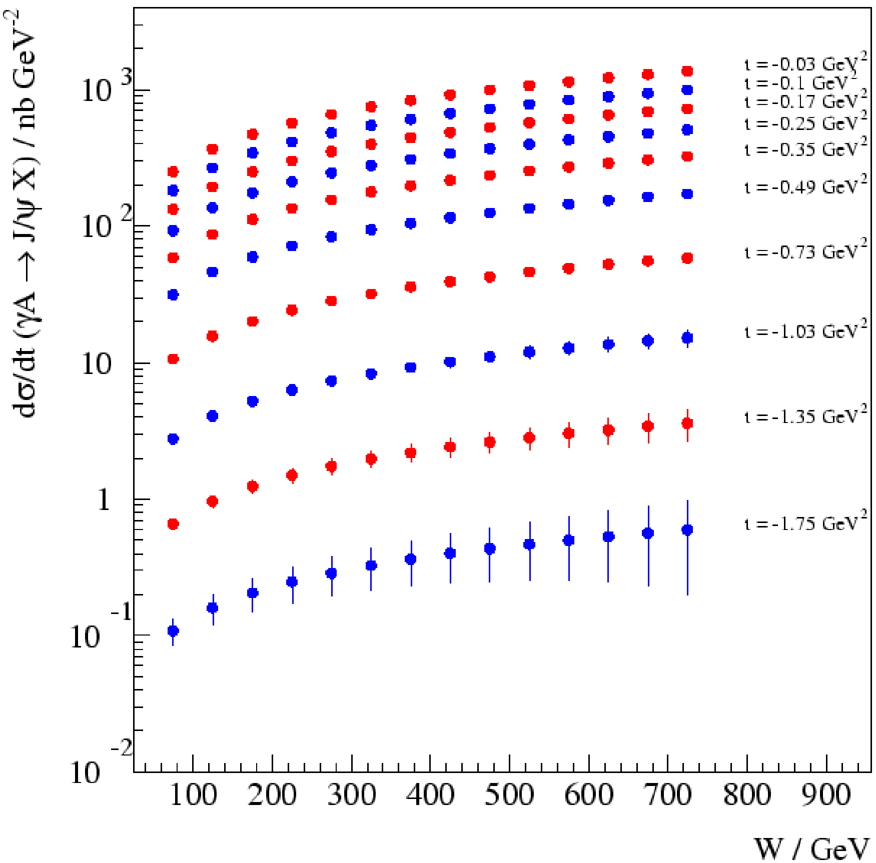


Parton density grows like $A^{1/3}$ ~ 6 for lead!… big enhancement in saturation effects!

First ePb Simulations (Ee = 50 GeV, 2 fb^{-1})

Precise inclusive data over vast new eA kinematic range





Very promising J/ψ cross section: to W_{gp} ~ 700 GeV and t > 1 GeV^2 … well within expected saturation region

Summary

• LHC is a totally new world of energy and luminosity! LHeC project aims to exploit it for TeV lepton-hadron scattering

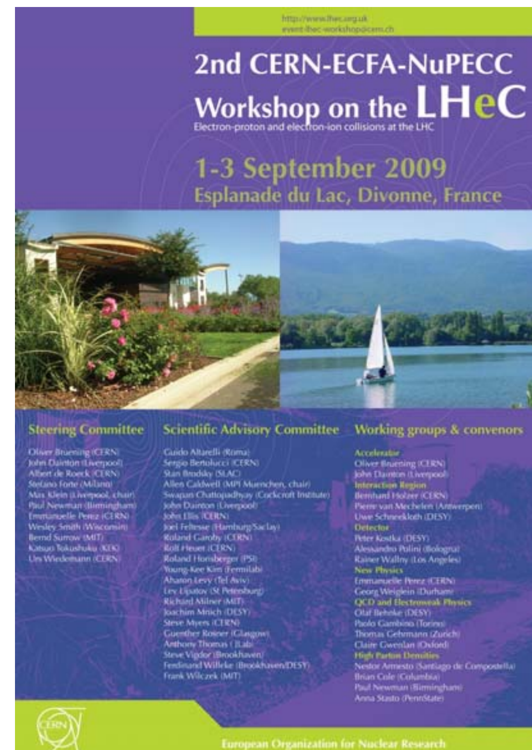
• Measuring multiple observables (F_2, F_L, F_2^c, F_2^D, VM …) in ep and eA can lead to a microscopic understanding of non-linear evolution, unitarity constraints and parton saturation.

• Ongoing CERN-ECFA-NuPECC workshop aims at CDR 2010

→ Working groups on new physics, precision SM, detector design, accelerator, interaction region

→Next major meeting in Divonne, September 2009

→All ideas and involvement welcome!



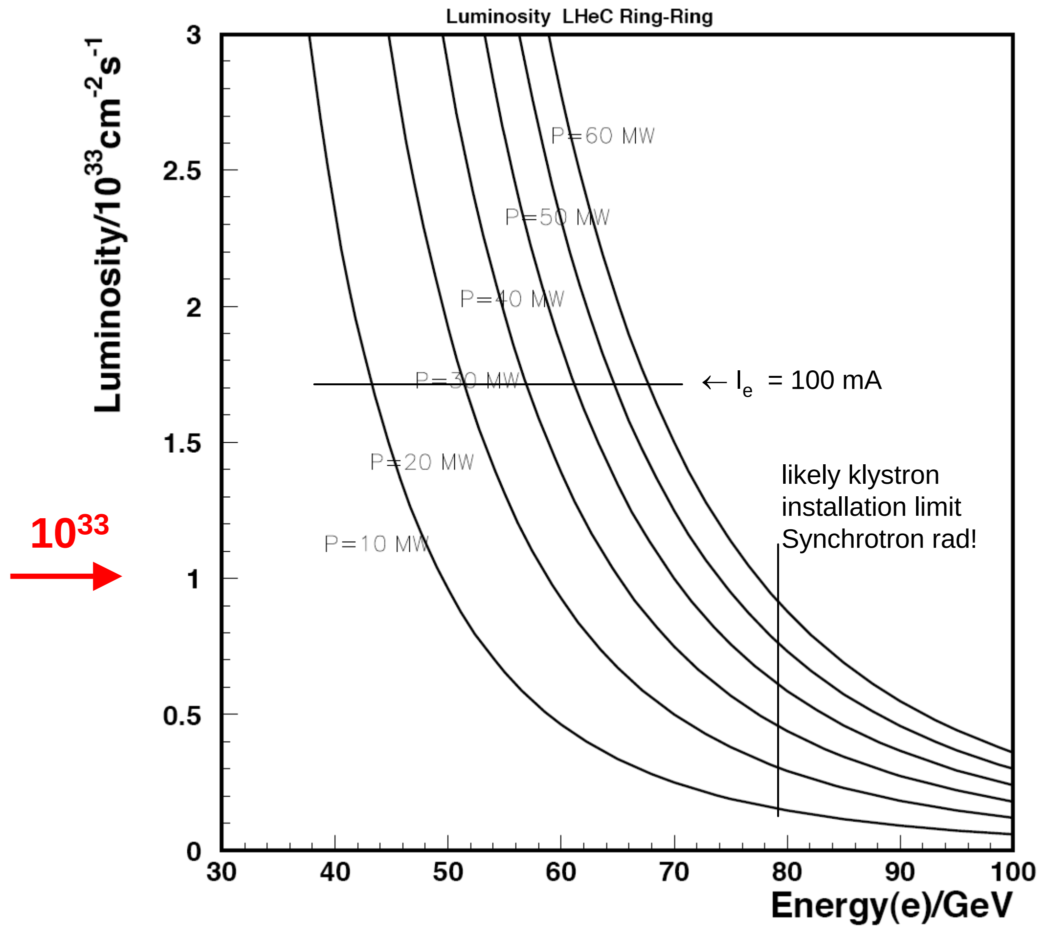
[More at www.lhec.org.uk]

Back-Ups Follow

Luminosity: Ring-Ring

$$L = \frac{N_p \gamma}{4\pi e \varepsilon_{pn}} \cdot \frac{I_e}{\sqrt{\beta_{px}\beta_{py}}} = 8.3 10^{32} \cdot \frac{I_e}{50mA} \frac{m}{\sqrt{\beta_{px}\beta_{pn}}} cm^{-2}s^{-1}$$

$$\varepsilon_{pn} = 3.8\mu m$$
$$N_p = 1.7 \cdot 10^{11}$$
$$\sigma_{p(x,y)} = \sigma_{e(x,y)}$$
$$\beta_{px} = 1.8m$$
$$\beta_{py} = 0.5m$$



$$I_e = 0.35mA \cdot \frac{P}{MW} \cdot \left(\frac{100GeV}{E_e}\right)^4$$

10^{33} can be reached in RR
E_e = 40-80 GeV & P = 5-60 MW.

HERA was 1-4 10^{31} cm^{-2} s^{-1}
huge gain with SLHC p beam

F.Willeke in hep-ex/0603016:
Design of interaction region
for 10^{33} : 50 MW, 70 GeV

May reach 10^{34} with ERL in
bypasses, or/and reduce power.
R&D performed at BNL/eRHIC

cf also A.Verdier 1990, E.Keil 1986

Luminosity: Linac-Ring

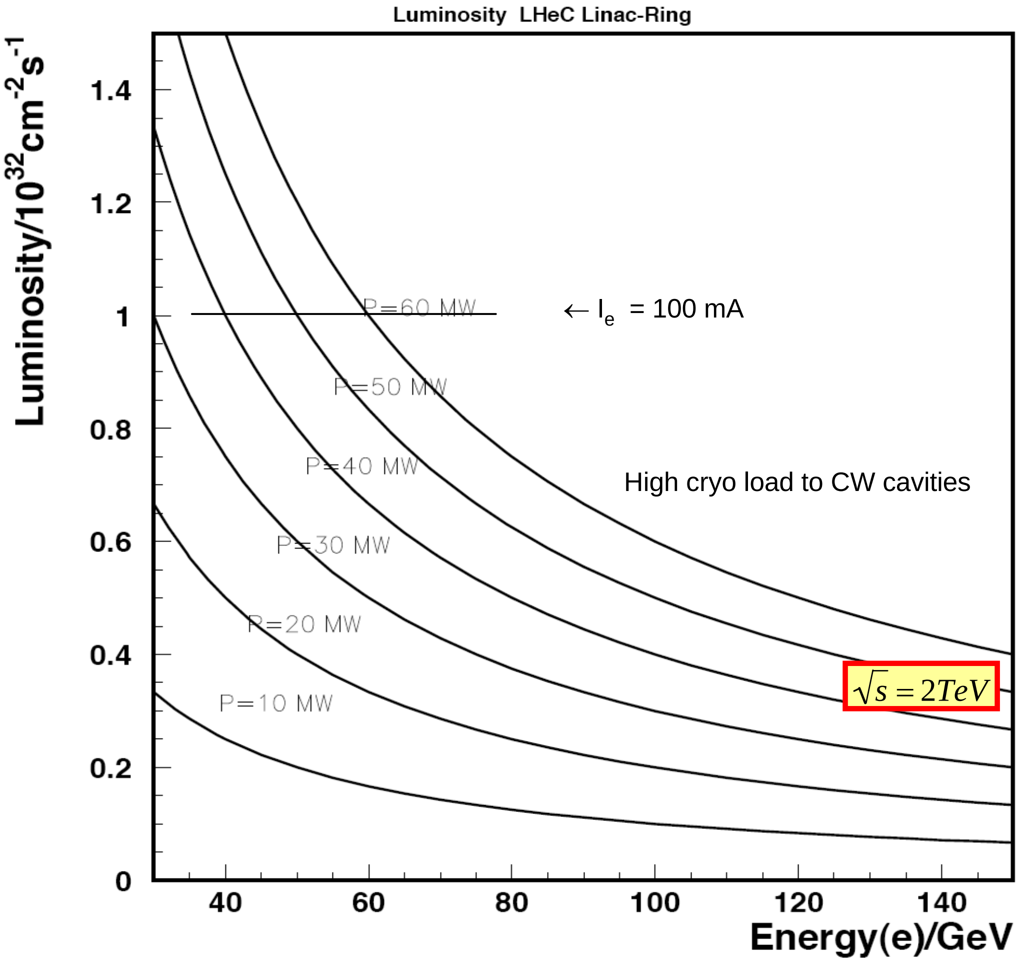
$$L = \frac{N_p \gamma}{4\pi e \varepsilon_{pn} \beta^*} \cdot \frac{P}{E_e} = 1 \cdot 10^{32} \cdot \frac{P/MW}{E_e/GeV} cm^{-2} s^{-1}$$

$\varepsilon_{pn} = 3.8 \mu m$

$N_p = 1.7 \cdot 10^{11}$

$\beta^* = 0.15 m$

$$I_e = 100 mA \cdot \frac{P}{MW} \cdot \frac{GeV}{E_e}$$



LHeC as Linac-Ring version can be as luminous as HERA II:

4 10^{31} can be reached with LR:
E_e = 40-140 GeV & P=20-60 MW
LR: average lumi close to peak

140 GeV at 23 MV/m is 6km +gaps

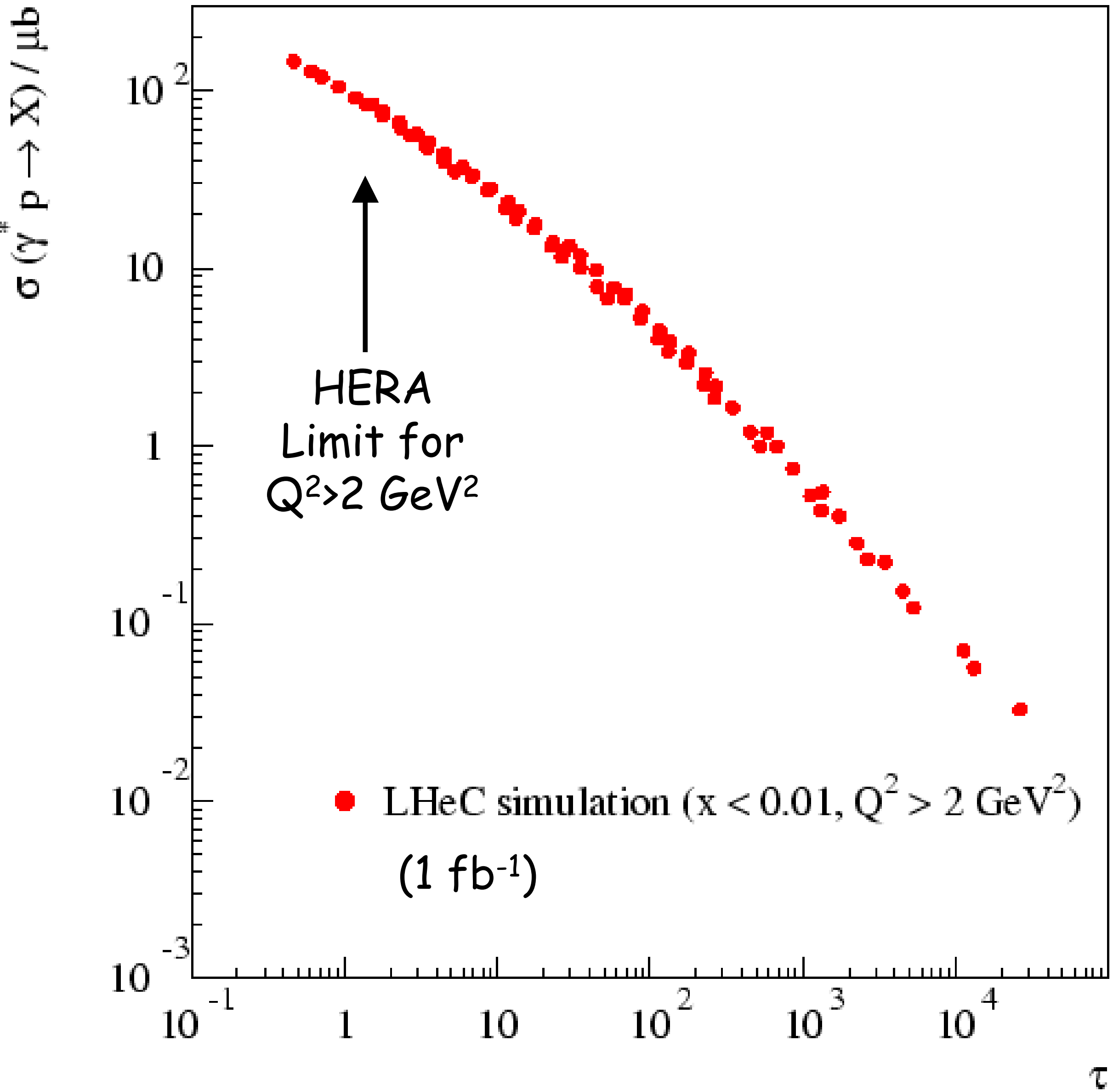
Luminosity horizon: high power: ERL (2 Linacs?)

Overview of LHeC Parameters

Table 3: *Main Parameters of the Lepton-Proton Collider*

Property	Unit	Leptons	Protons
Beam Energies	GeV	70	7000
Total Beam Current	mA	74	544
Number of Particles / bunch	10^{10}	1.04	17.0
Horizontal Beam Emittance	nm	7.6	0.501
Vertical Beam Emittance	nm	3.8	0.501
Horizontal β-functions at IP	cm	12.7	180
Vertical β-function at the IP	cm	7.1	50
Energy loss per turn	GeV	0.707	$6 \cdot 10^{-6}$
Radiated Energy	MW	50	0.003
Bunch frequency / bunch spacing	MHz / ns	40 / 25	
Center of Mass Energy	GeV	1400	
Luminosity	$10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$	1.1	

Geometric Scaling at the LHeC



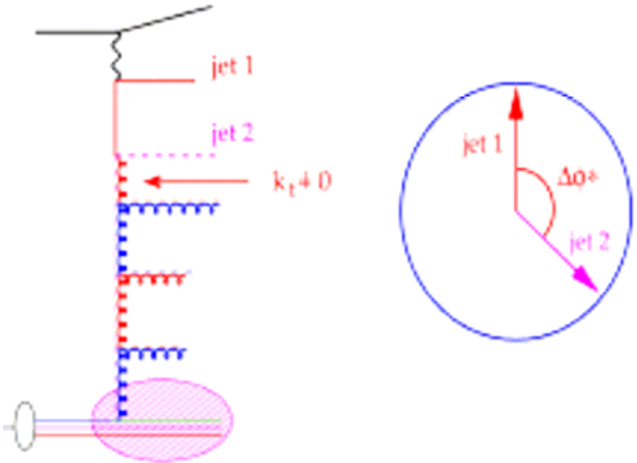
LHeC reaches $\tau \sim 0.15$ for Q^2=1 GeV^2 and $\tau \sim 0.4$ for Q^2=2 GeV^2

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

Could be enhanced with nuclei.

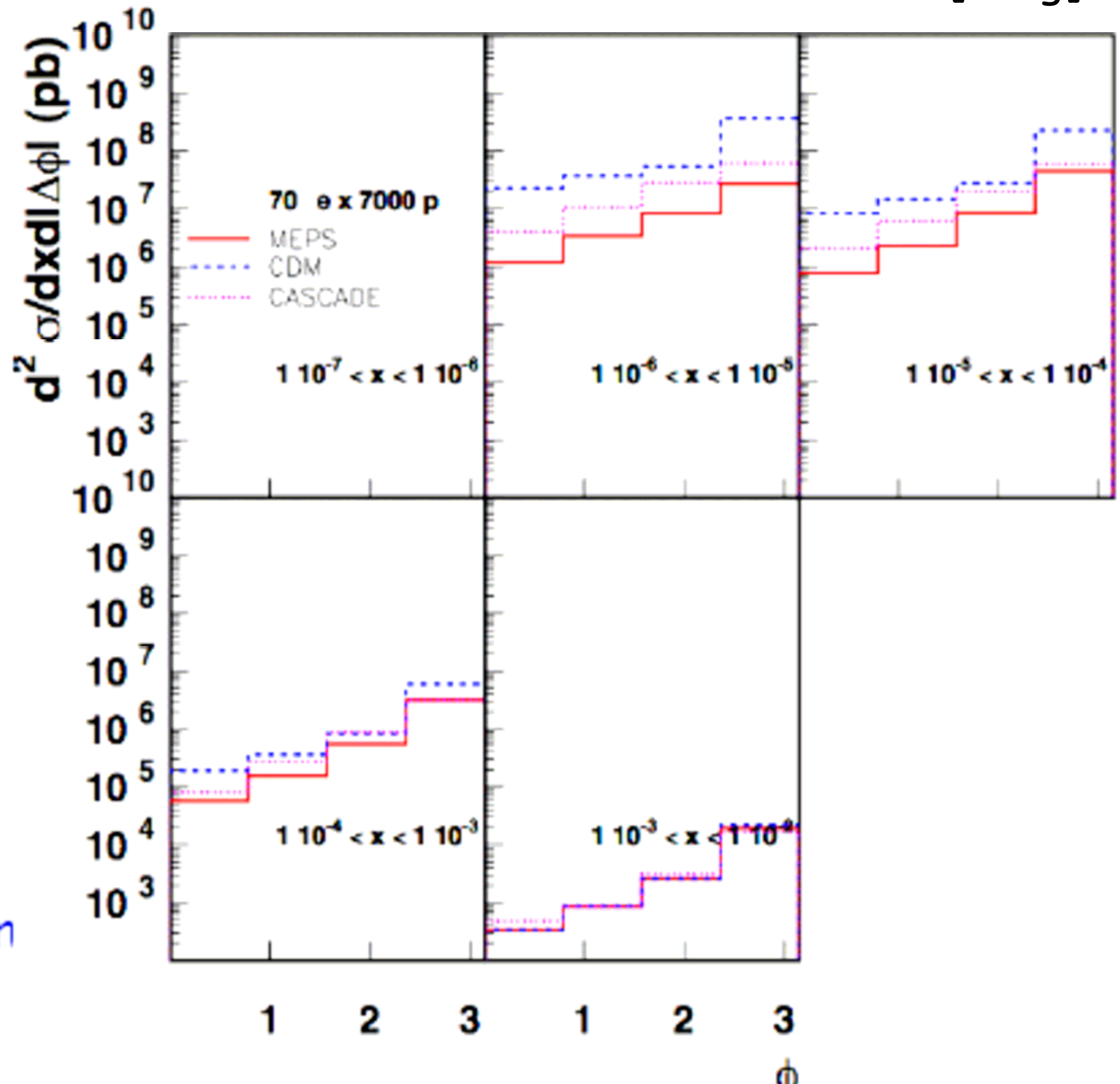
$Q^2 < 1$ GeV^2 accessible in special runs?

Azimuthal (de)correlations between Jets

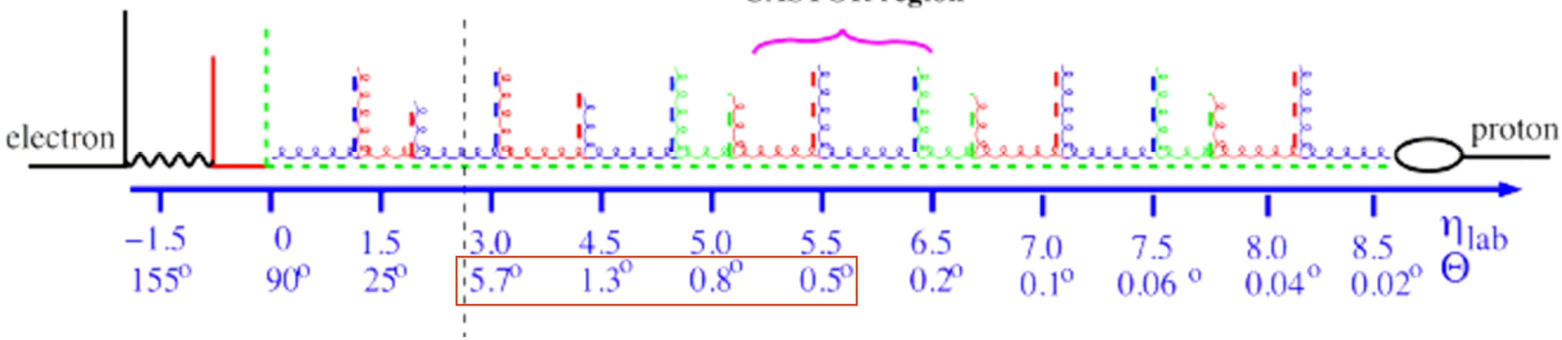


- $5 < Q^2 < 100 \text{ GeV}^2$
  $-1 < \eta < 2.5$
  $E_T > 5 \text{ GeV}$
- small k_t $\rightarrow \Delta\phi \sim 180$
- large k_t from evolution

[Jung]



Forward Instrumentation and Jets



[Jung]

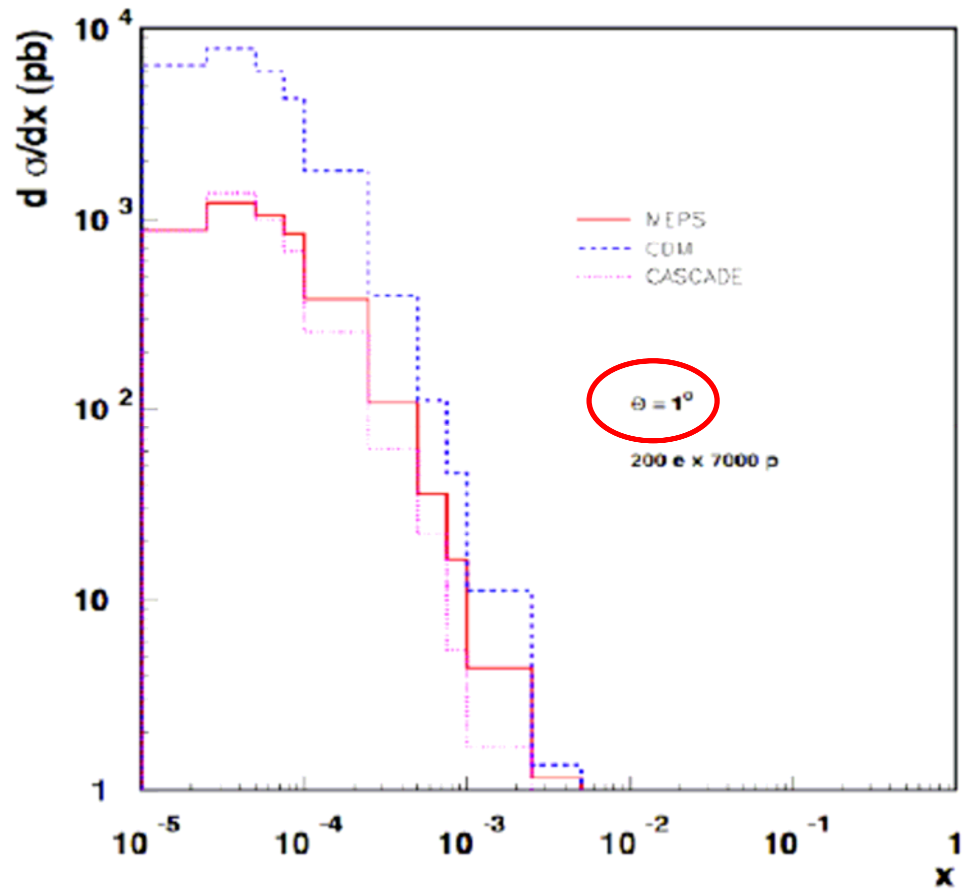
- DIS and forward jet:

$$x_{jet} > 0.03$$

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

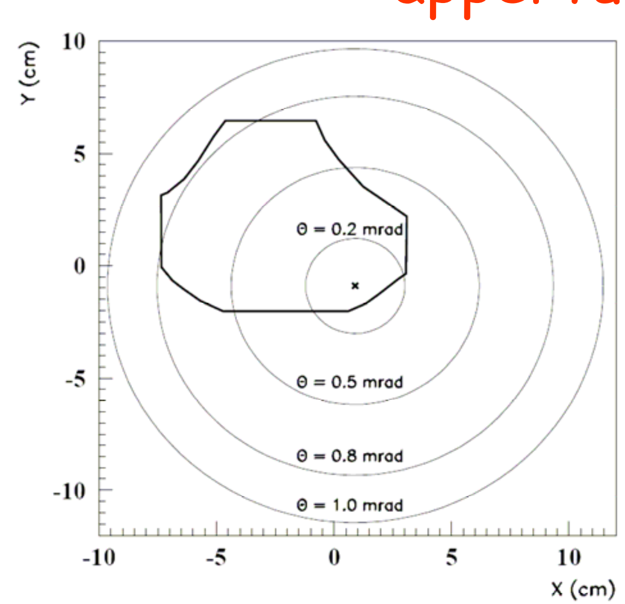
x range (and sensitivity to novel QCD effects) strongly depend on θ cut

Similar conclusions for Δϕ decorrelations between jets



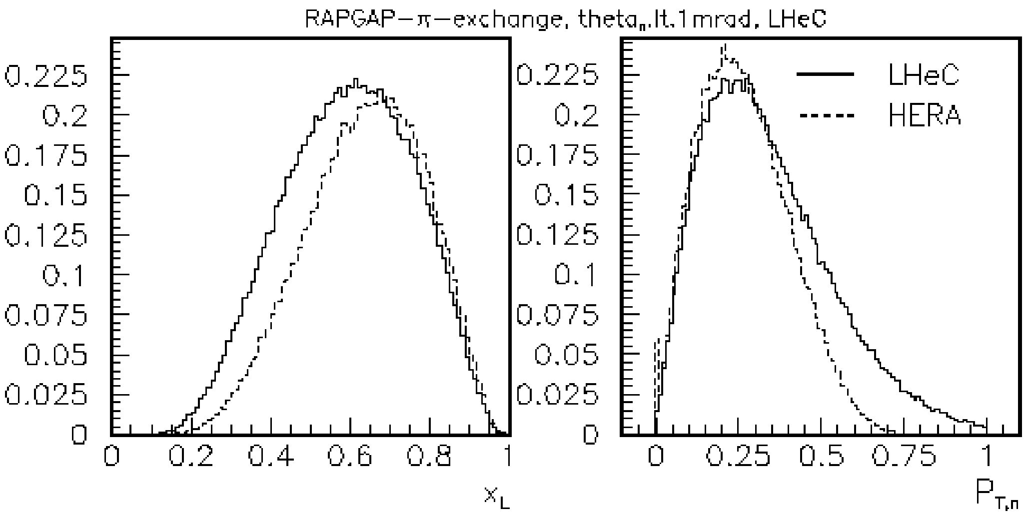
Leading Neutrons: Experience at HERA

- 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

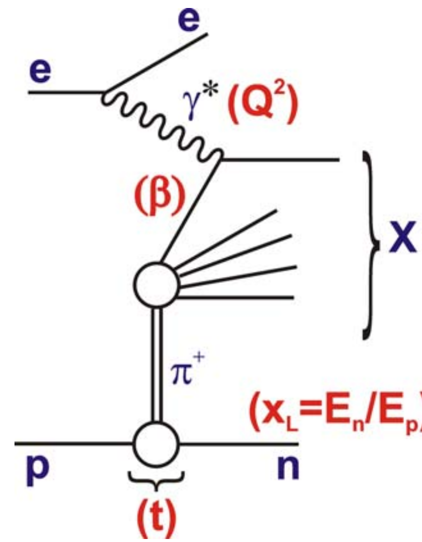


Very radiation hard detectors needed for LHC environment
c.f. Similar detectors (ZDCs) at ATLAS and CMS

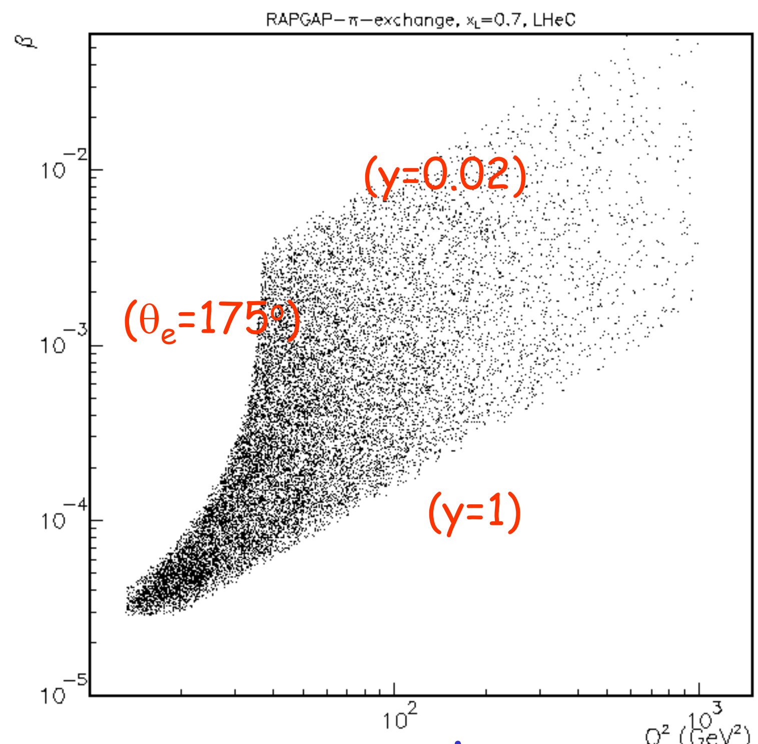
π Structure with Leading Neutrons



[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).

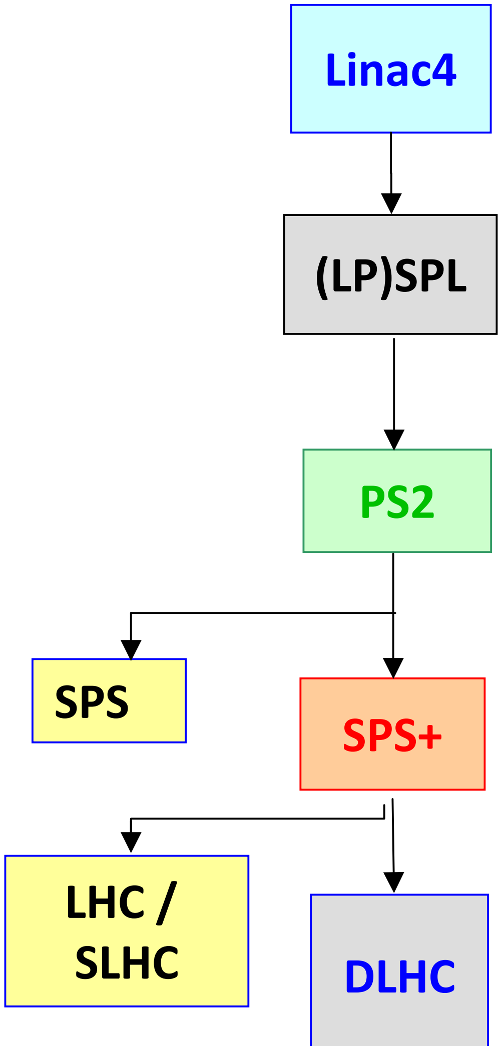
- Extentions to lower β and higher Q^2 as in leading proton case. → F_2^π At β<5.10^{-5} (cf HERA reaches β~10^{-3})

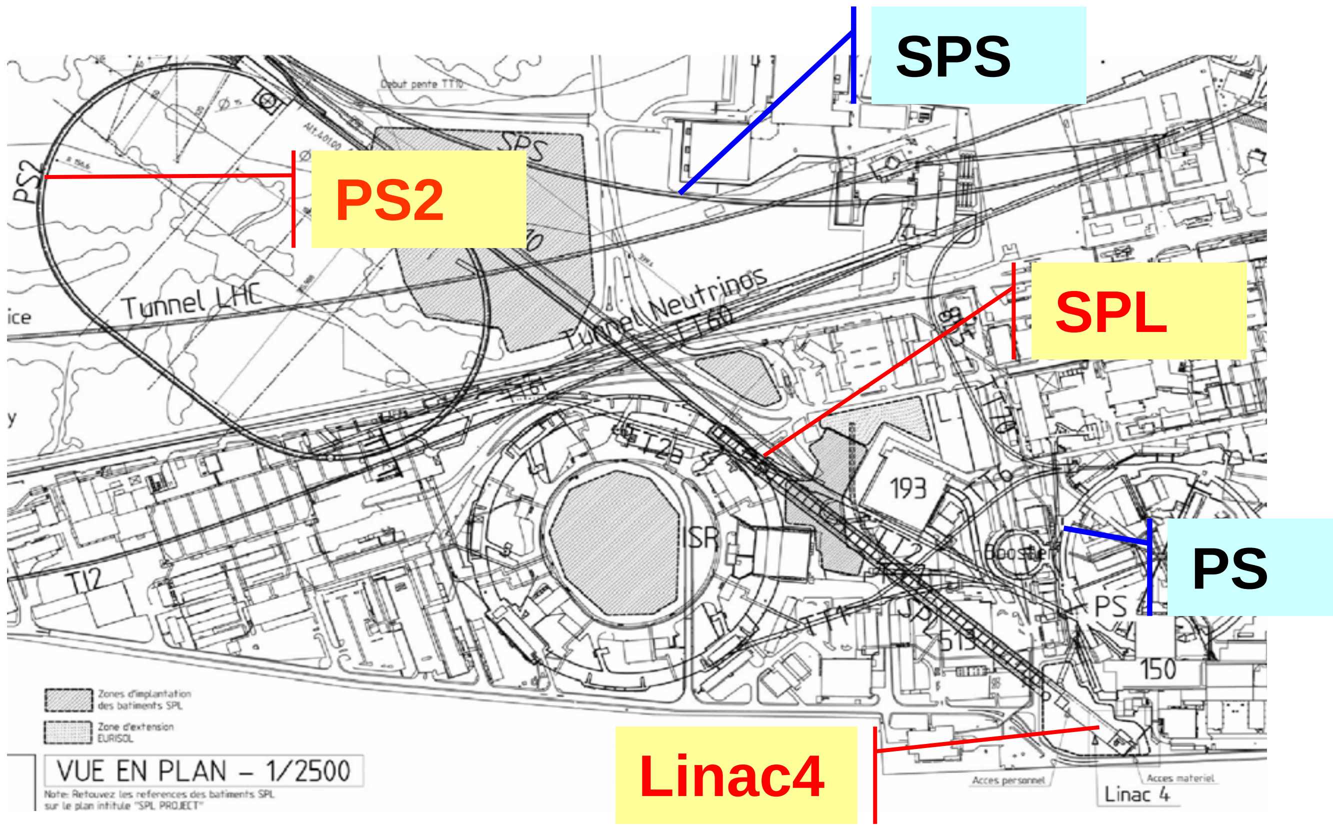
Also relevant to absorptive corrections, cosmic ray physics …

Electrons in the SPL?

SPL (Superconducting Proton Linac) is part of proposed CERN p-accelerator upgrade programme.

… could be used with simple transfer line as electron **injector** or to provide up to **~30 GeV electrons** for collisions





R. Garoby, CARE-HHH BEAM07, October'07; L. Evans, LHCC, 20 Feb '08

Ring-Ring Solution

- Benefits from long experience of colliding beam facilites

- By-passes around ATLAS and CMS
Based on existing survey tunnels
(~1.5km of new tunnelling)

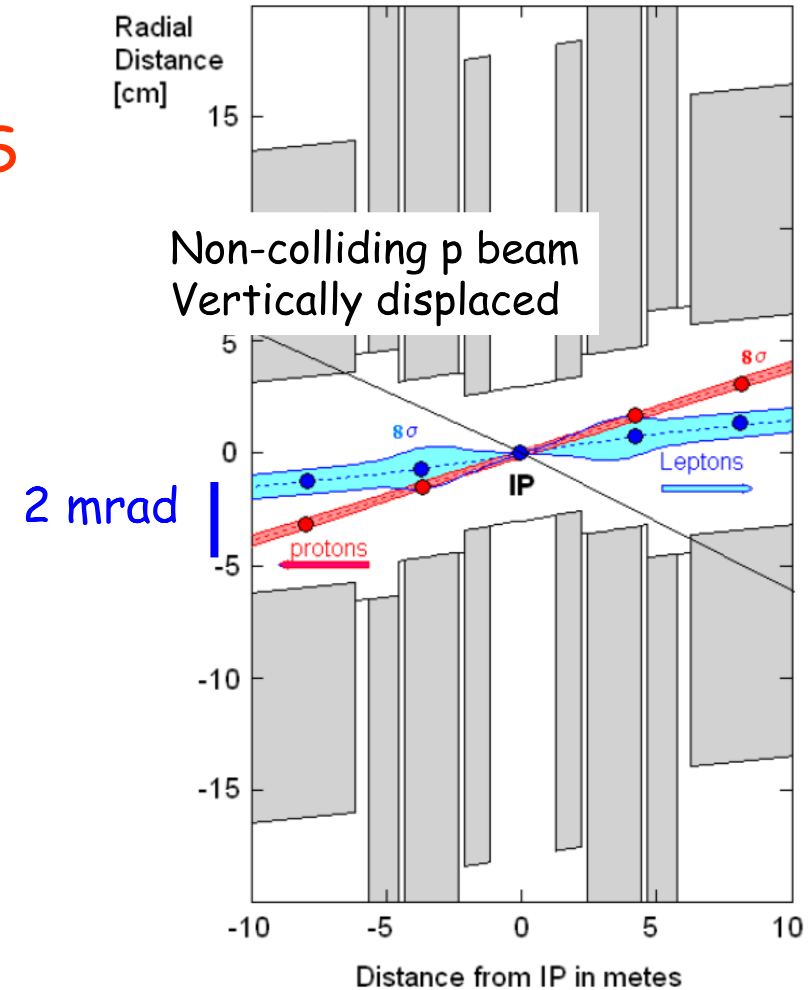
- LHC fixes p beam parameters,
e beam matches p shape & sizes

- Fast separation of beams with tolerable synchrotron power requires ~2 mrad crossing angle

- E_e ~ 50 GeV for acceptable synchrotron power at 3.10^{33} cm^{-1} s^{-1}

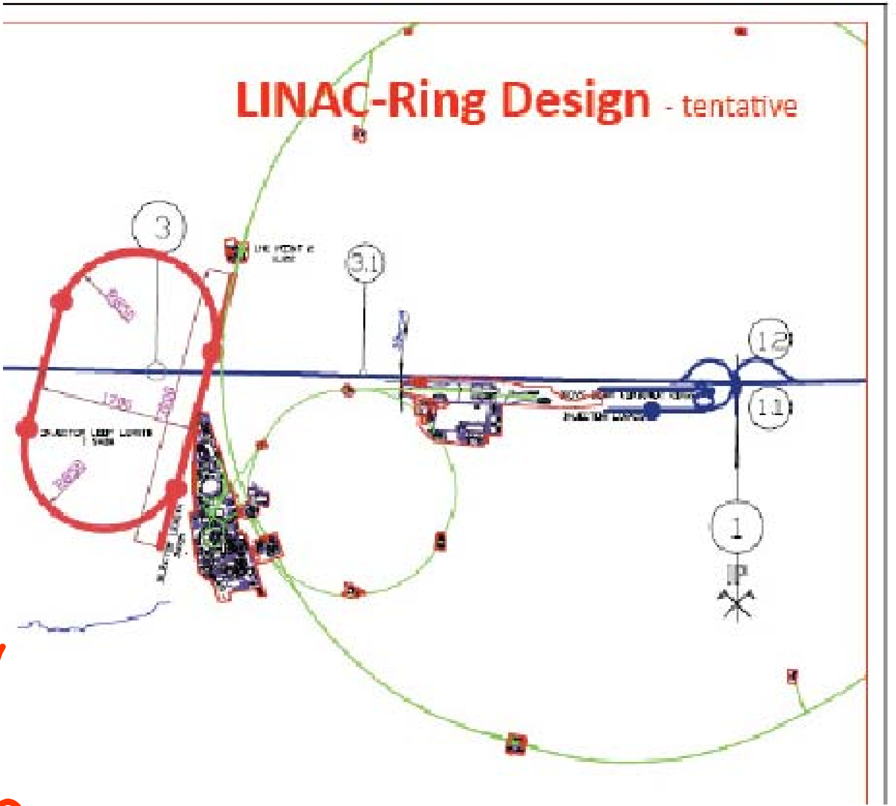
[Willeke, Holzer et al.]

Top view



Linac-Ring Solutions

[Zimmermann et al.]



Many lay-outs proposed

Tentative design with acceleration of electrons via racetrack construction

Somewhat reduced lumi ~ 3.10^{32} cm^{-2} s^{-1} for E_e ~ 100 GeV at acceptable power consumption → energy recovery?

Higher energy (→ E_e = 150 GeV) possible at reduced lumi

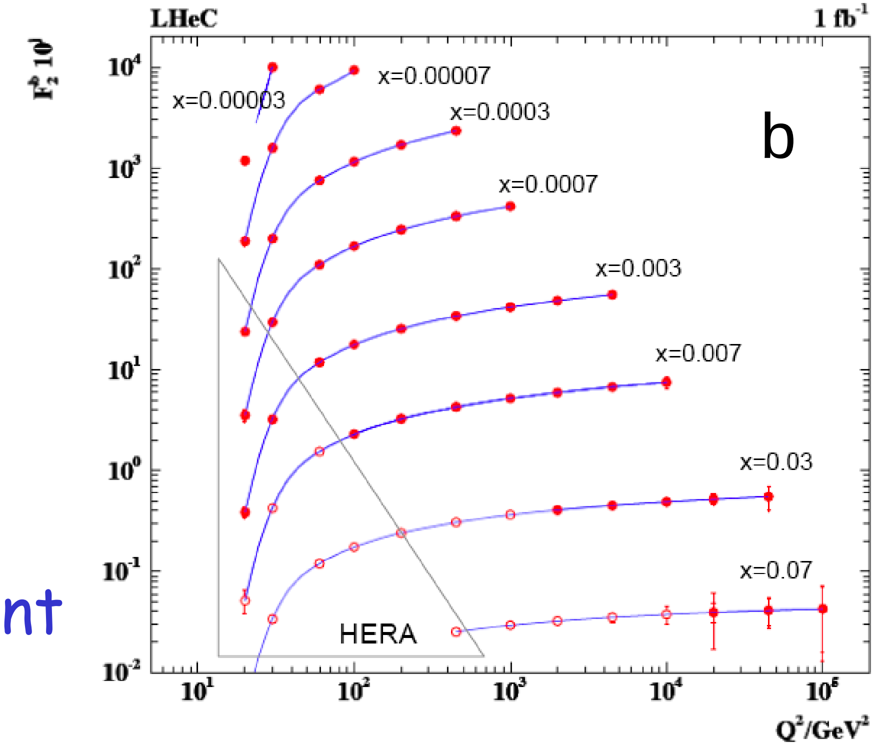
New concept for colliders … lots of R&D required …

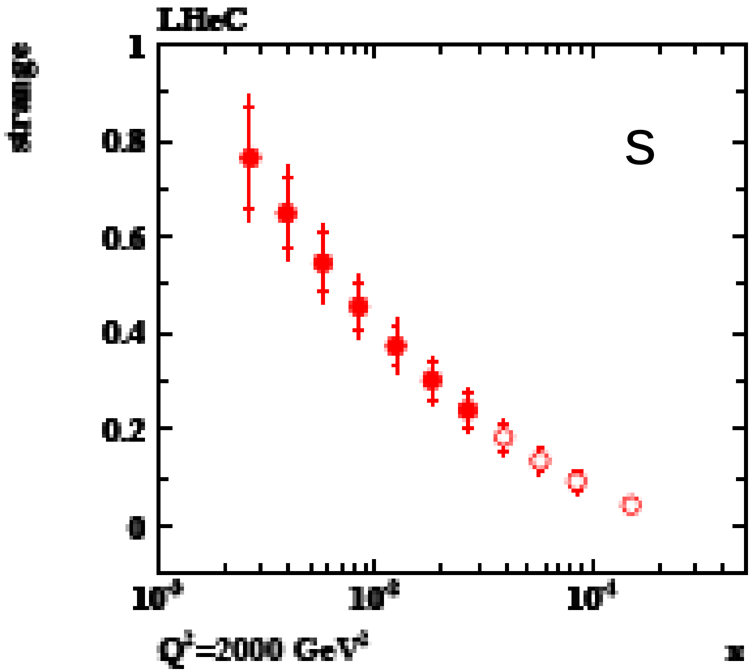
Flavour Decomposition

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

Systematics at 10% level

- →beauty is a low x observable!
- →s (& sbar) from charged current
- → Similarly Wb → t?

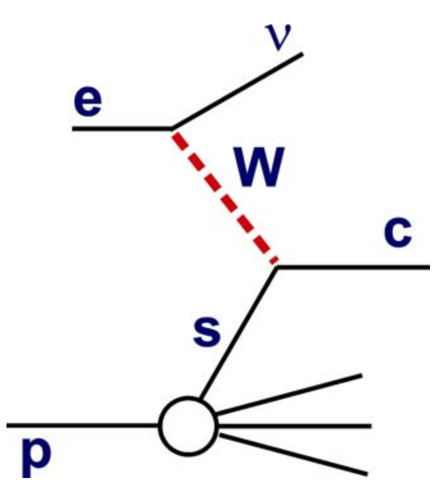




● LHeC 10° acceptance

○ LHEC 1° acceptance

[Mehta, Klein]

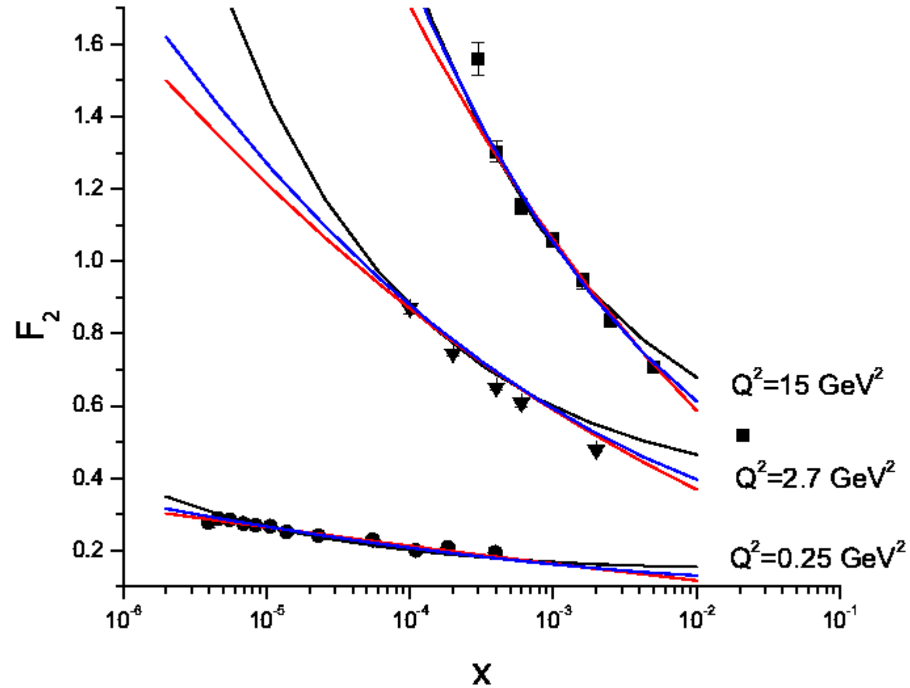


(Assumes 1 fb^{-1} and
- 50% beauty, 10% charm efficiency
- 1% uds → c mistag probability.
- 10% c → b mistag)

Parton Saturation after HERA?

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

Fit inclusive HERA data using dipole models with and without parton saturation effects



FS04 Regge (~FKS): 2 pomeron model, <u>no saturation</u>

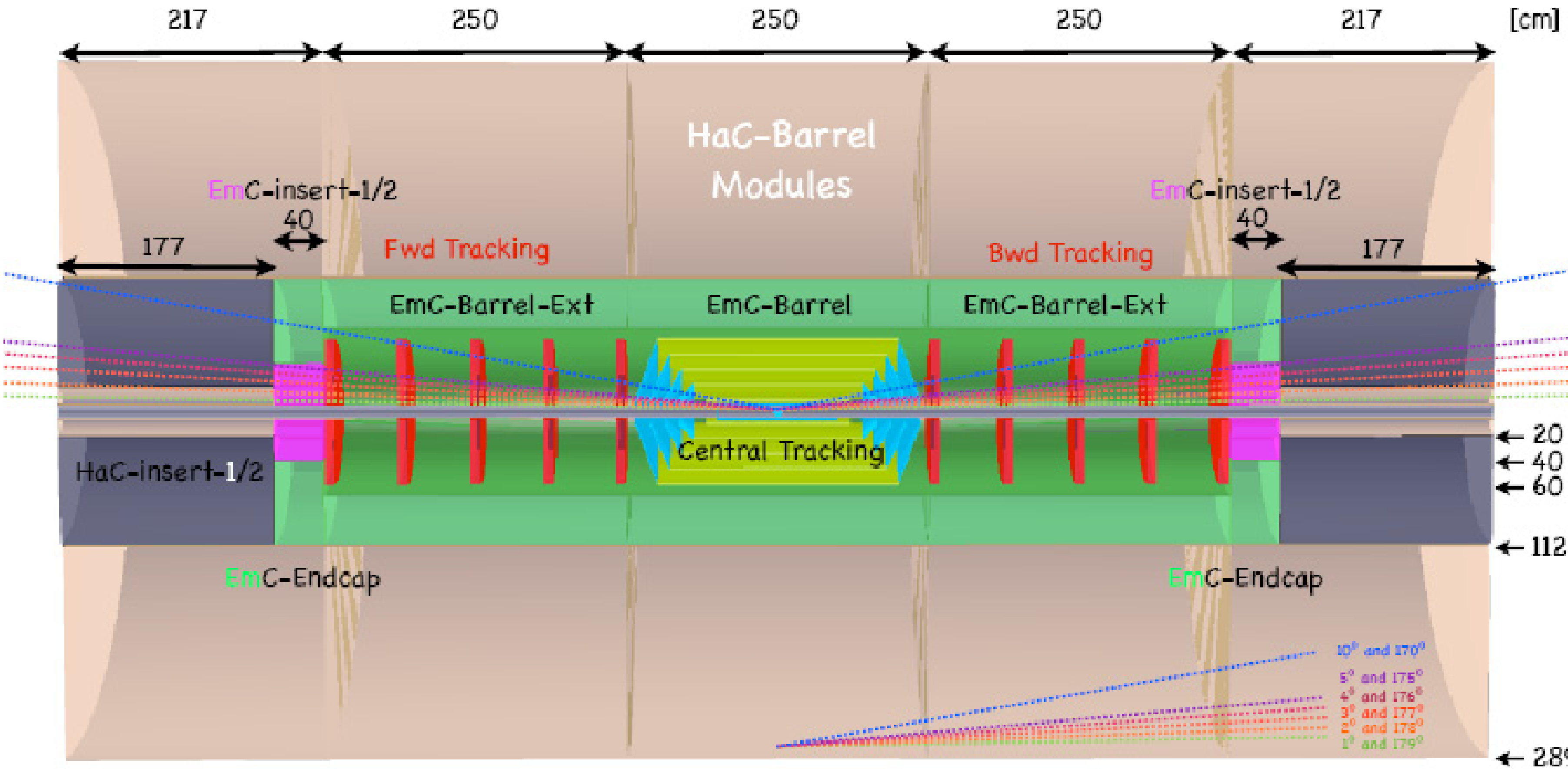
FS04 Satn: <u>Simple implementation of saturation</u>

CGC: <u>Colour Glass Condensate version of saturation</u>

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

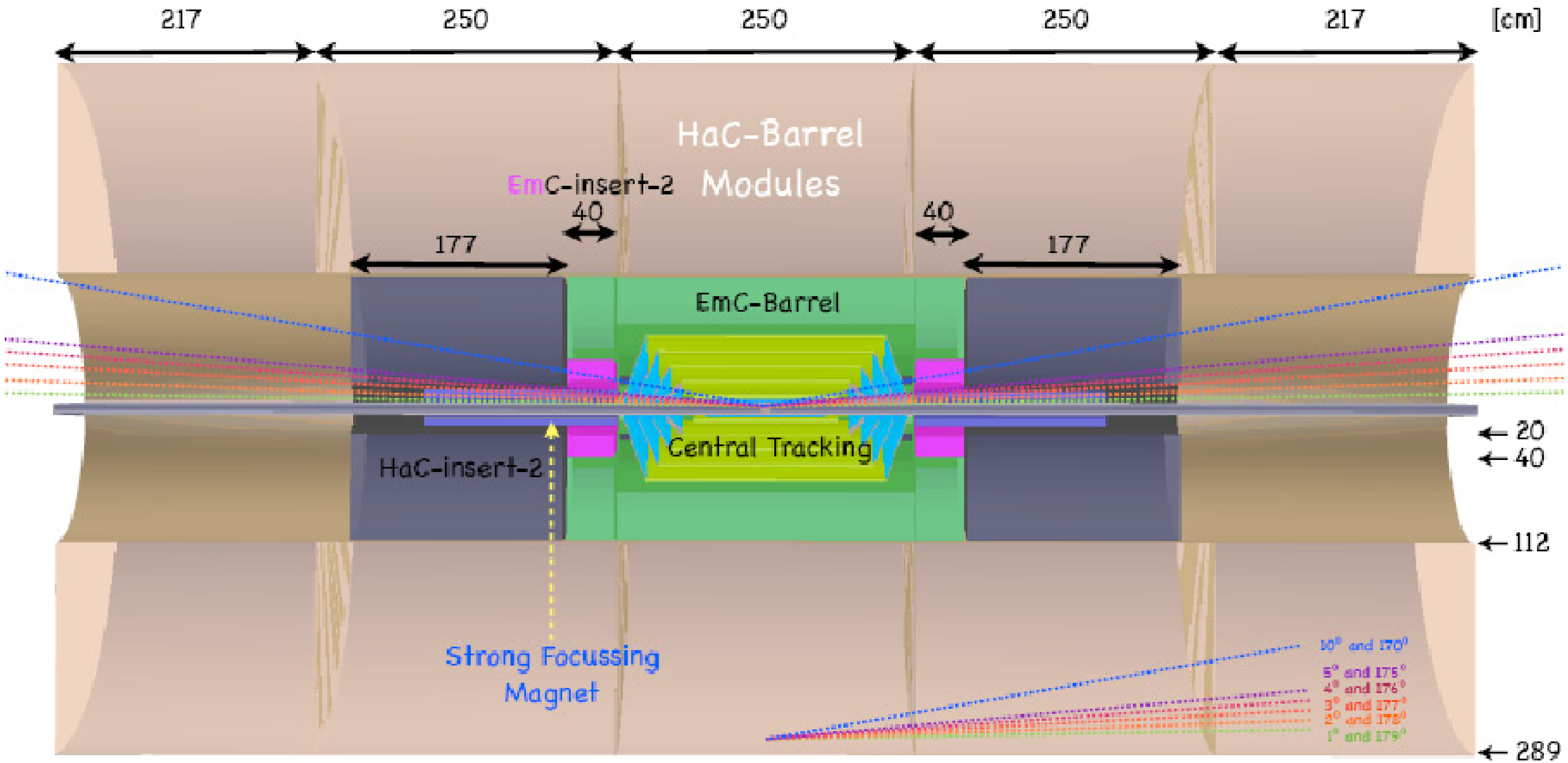
<u>… any saturation at HERA not easily interpreted partonically</u>

First Detector Concepts - Low x Optimised



- Full angular coverage, long tracking region → 1°
- Dimensions determined by synchrotron radiation fan
- Modular Low material budget High precision
- Technologies under discussion (lots of ideas!)

First Detector Concepts - High Q^2 Optimised



- Sacrifice low angle acceptance to beam focusing magnets
- Calorimeter inserts slide inwards
- 2 phases of operation a la HERA?
- Alternatively 2 interaction points (RR only)?

What is the LHeC?

Scientific Advisory Committee

Guido Altarelli (Rome)
Sergio Bertolucci (CERN)
Stan Brodsky (SLAC)
Allen Caldwell -chair (MPI Munich)
Swapan Chattopadhyay (Cockcroft)
John Dainton (Liverpool)
John Ellis (CERN)
Jos Engelen (CERN)
Joel Feltesse (Saclay)
Lev Lipatov (St.Petersburg)
Roland Garoby (CERN)
Roland Horisberger (PSI)
Young-Kee Kim (Fermilab)
Aharon Levy (Tel Aviv)
Karlheinz Meier (Heidelberg, ECFA)
Richard Milner (Bates)
Joachim Mnich (DESY)
Steven Myers, (CERN)
Guenter Rosner (Glasgow, NuPECC)
Alexander Skrinsky (Novosibirsk)
Anthony Thomas (Jlab)
Steven Vigdor (BNL)
Frank Wilczek (MIT)
Ferdinand Willeke (BNL)

Steering Committee

Oliver Bruening	(CERN)
John Dainton	(Cockcroft)
Albert DeRoeck	(CERN)
Stefano Forte	(Milano)
Max Klein - chair	(Liverpool)
Paul Newman	(Birmingham)
Emmanuelle Perez	(CERN)
Wesley Smith	(Wisconsin)
Bernd Surrow	(MIT)
Katsuo Tokushuku	(KEK)
Urs Wiedemann	(CERN)

History and Organisation

The Large Hadron Electron Collider Project

1990: LEP*LHC (Aachen Workshop)
2001: THERA (TESLA TDR)
2005: LHeC: * DIS, Madison
2006: $10^{33}cm^{-2}s^{-1}$: 2006 JINST 1 10001
2007 CERN Council and [r]ECFA
2008 Divonne I, NuPECC, ICFA,ECFA
2009 Divonne II (1.-3.9.), ECFA 11/09

→ **2010: Conceptual Design Report**

http://www.lhec.org.uk

Please join/register for Divonne II – 1.-3.9.09

Working Group Convenors

Accelerator Design [RR and LR]
Oliver Bruening (CERN),
John Dainton (CI/Liverpool)

Interaction Region and Fwd/Bwd
Bernhard Holzer (DESY),
Uwe Schneeekloth (DESY),
Pierre van Mechelen (Antwerpen)

Detector Design
Peter Kostka (DESY),
Rainer Wallny (UCLA),
Alessandro Polini (Bologna)

New Physics at Large Scales
Emmanuelle Perez (CERN),
Georg Weiglein (Durham)

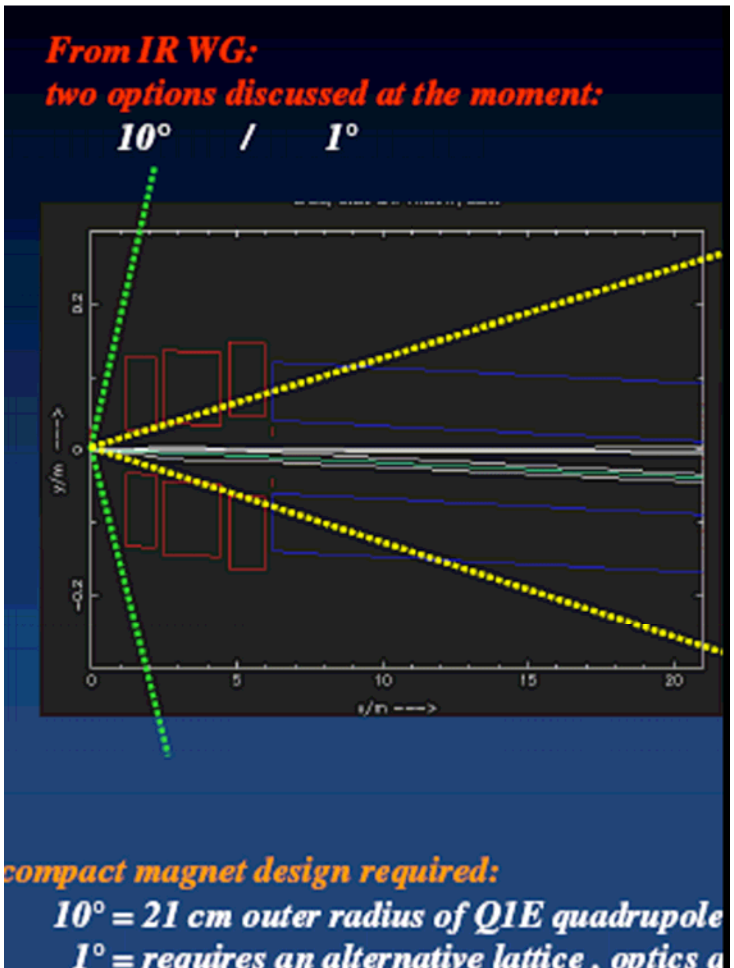
Precision QCD and Electroweak
Olaf Behnke (DESY),
Paolo Gambino (Torino),
Thomas Gehrmann (Zuerich)
Claire Gwenlan (Oxford)

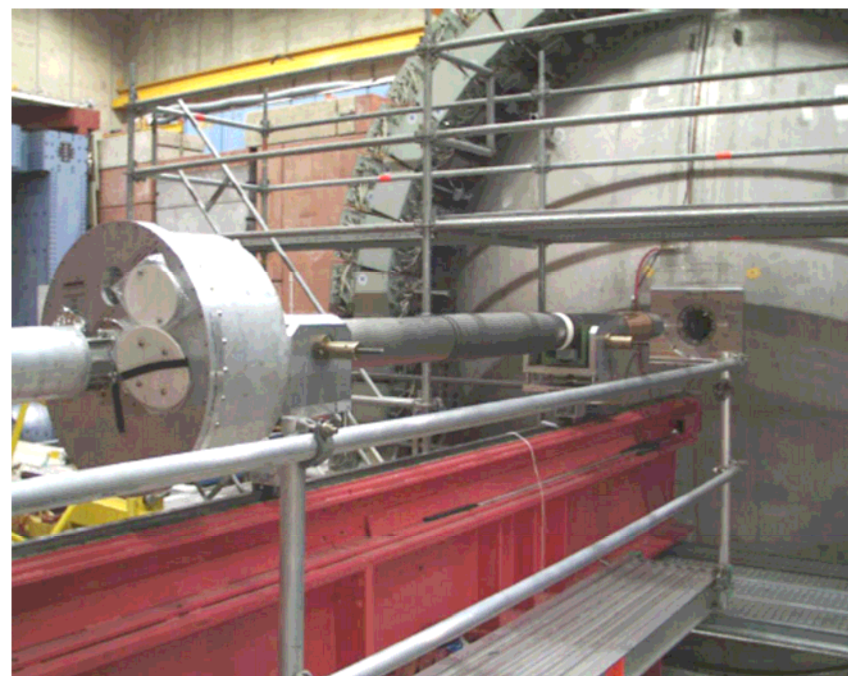
Physics at High Parton Densities
Nestor Armesto (CERN),
Brian Cole (Columbia),
Paul Newman (Birmingham),
Anna Stasto (MSU)

The Luminosity v Acceptance Question

- As for HERA-I v HERA-II, low β focusing beam elements around interaction region can improve lumi by a factor ~10
- However, acceptance near beam-pipe is compromised

→ loss of low x / Q^2 acceptance
→ loss of high M acceptance
→ poorer HFS measurements





Scenario for Experimental Precision

Requirements to reach a per-mil α_s (c.f. 1-2% now) …

[Klein, Kluge …]

The new collider …

- should be ~100 times more luminous than HERA

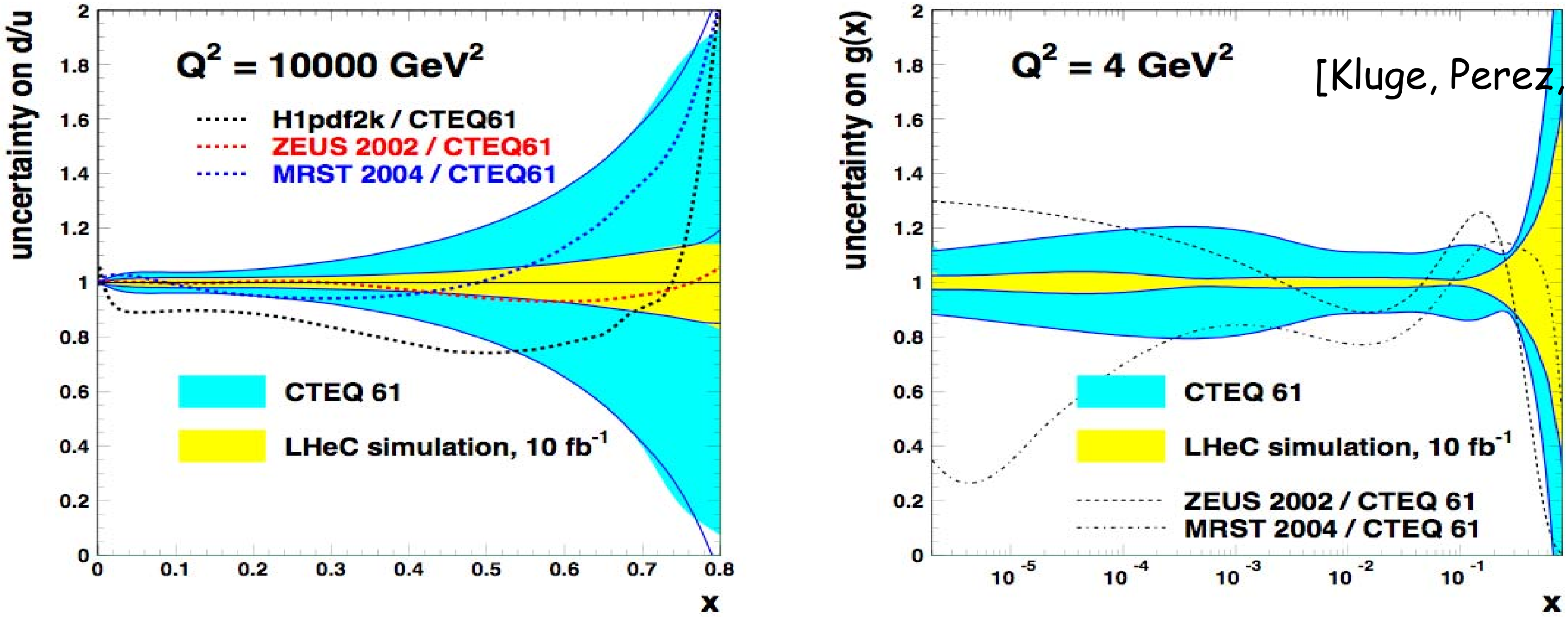
The new detector

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

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%)

First `pseudo-data' for F_2, F_L, F_2^D …produced on this basis …

LHeC Impact on High x Partons and α_s



[Kluge, Perez, Klein]

Full NC/CC sim (with systs giving per mil α_s) & NLO DGLAP fit using H1 technology…

… full flavour decomposition possible

… high x pdfs → may help clarify LHC discoveries through interpretation of new states?

[Some of highest x improvement from param^n extrapolation]

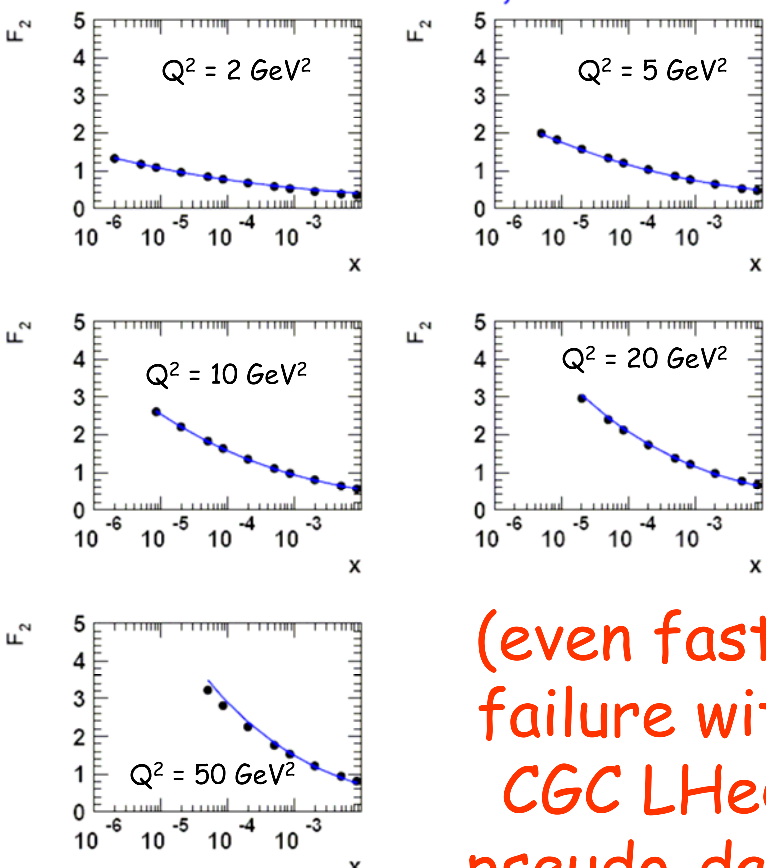
Can DGLAP adjust to fit LHeC sat models?

[Forshaw, Klein, PN, Perez]

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

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

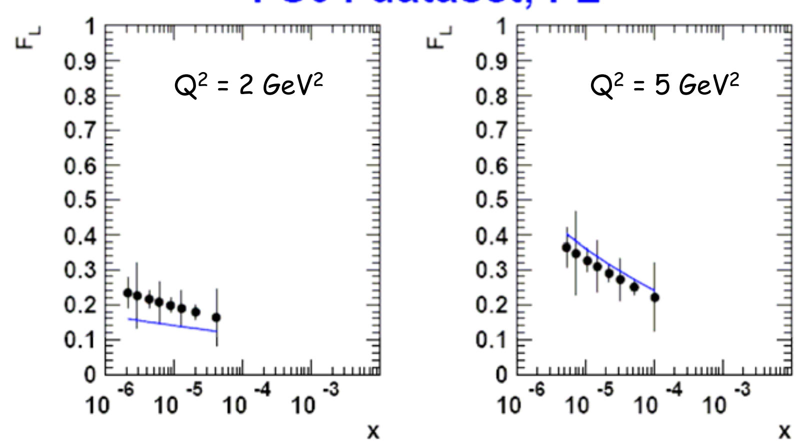
FS04 dataset, F2



- Fitting F_2 only, a good fit cannot be obtained beyond the range $2 < Q^2 < 20$ GeV^2
- This fit fails to describe F_L

(even faster failure with CGC LHeC pseudo-data)

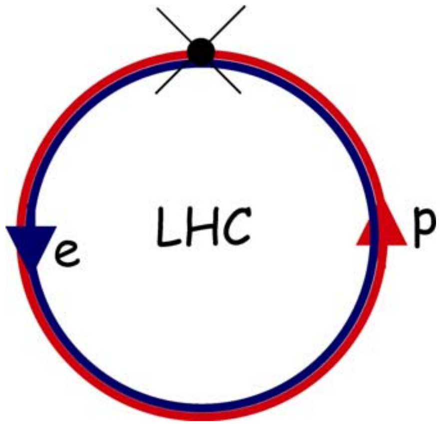
FS04 dataset, FL



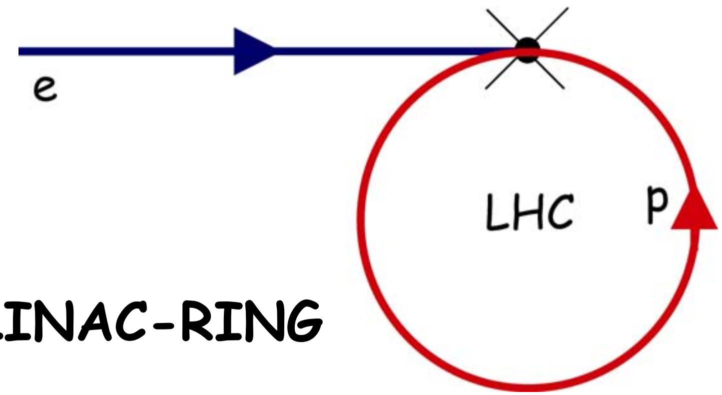
How Could ep be Done using LHC?

… whilst allowing simultaneous ep and pp running …

RING-RING



LINAC-RING



- First considered (as LEPxLHC) in 1984 ECFA workshop
- Main advantage: high peak lumi obtainable (~3.10^{33} cm^{-2} s^{-1})
- Main difficulties: building round existing LHC, e beam energy (50GeV?) and lifetime limited by synchrotron radiation

- Previously considered as `QCD explorer' (also THERA)
- Main advantages: low interference with LHC, high E_e (→ 150 GeV?) and lepton polarisation, LC relation
- Main difficulties: lower luminosity ~3.10^{32} cm^{-2} s^{-1} (?) at reasonable power, no previous experience exists

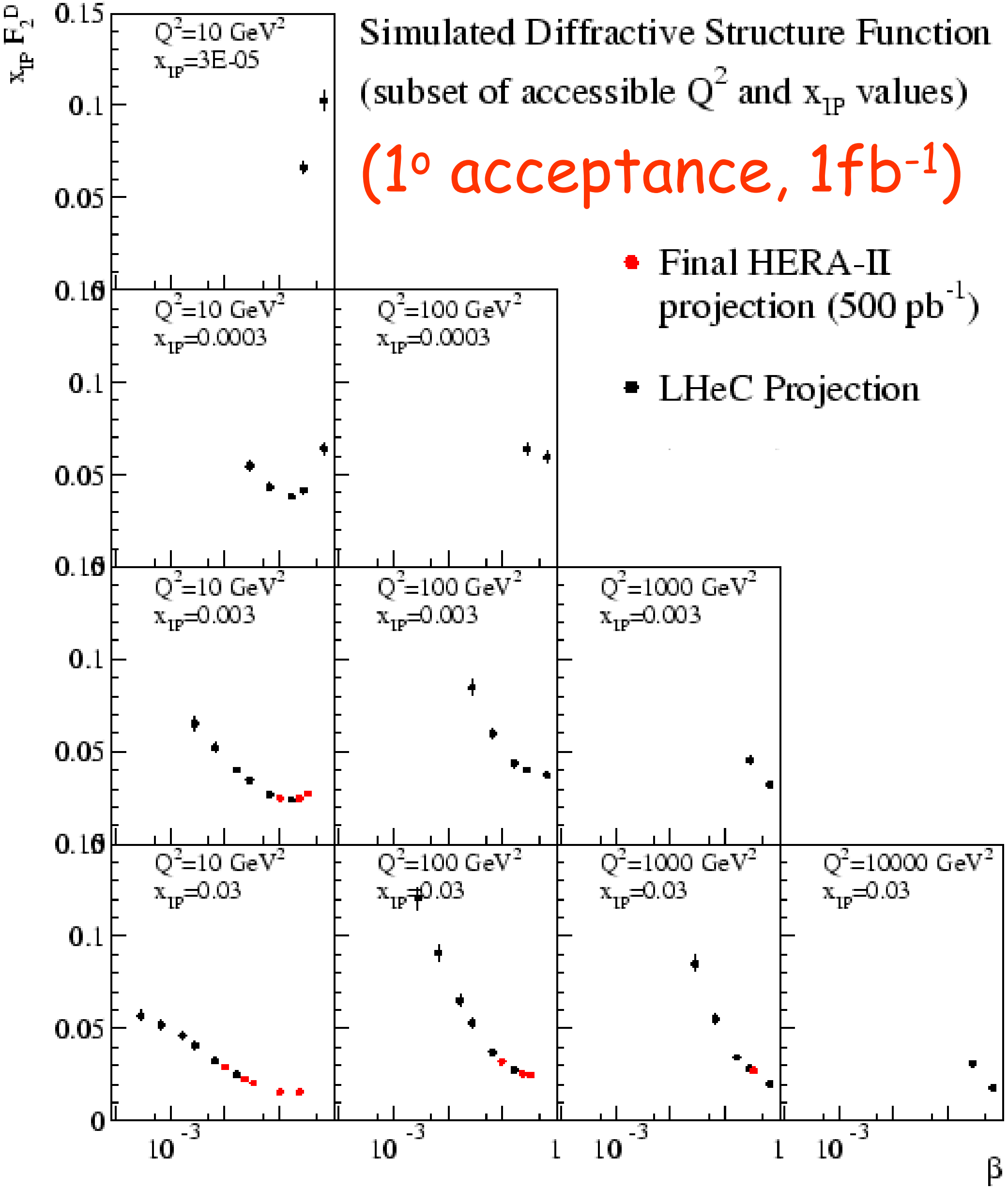
Beam Scenarios for First Physics Studies

Several scenarios under study … see later for justification

config.	E(e)	E(N)	N	$\int L(e^+)$	$\int L(e^-)$	|Pol|	$L/10^{32}$	P/MW	years	type
A	20	7	p	1	1	-	1	10	1	SPL
B	50	7	p	50	50	0.4	25	30	2	RR hiQ^2
C	50	7	p	1	1	0.4	1	30	1	RR lo x
D	100	7	p	5	10	0.9	2.5	40	2	LR
E	150	7	p	3	6	0.9	1.8	40	2	LR
F	50	3.5	D	1	1	--	0.5	30	1	eD
G	50	2.7	Pb	0.1	0.1	0.4	0.1	30	1	ePb
H	50	1	p	--	1	--	25	30	1	lowEp

ep Studies based on a 20-150 GeV electron beam and lumi of 1-10 fb^{-1} / year

LHeC Simulation



2) Lower β at fixed Q^2, x_{IP}

… almost complete lack of information on DPDFs with β<0.01 so far …
LHeC offers β→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)

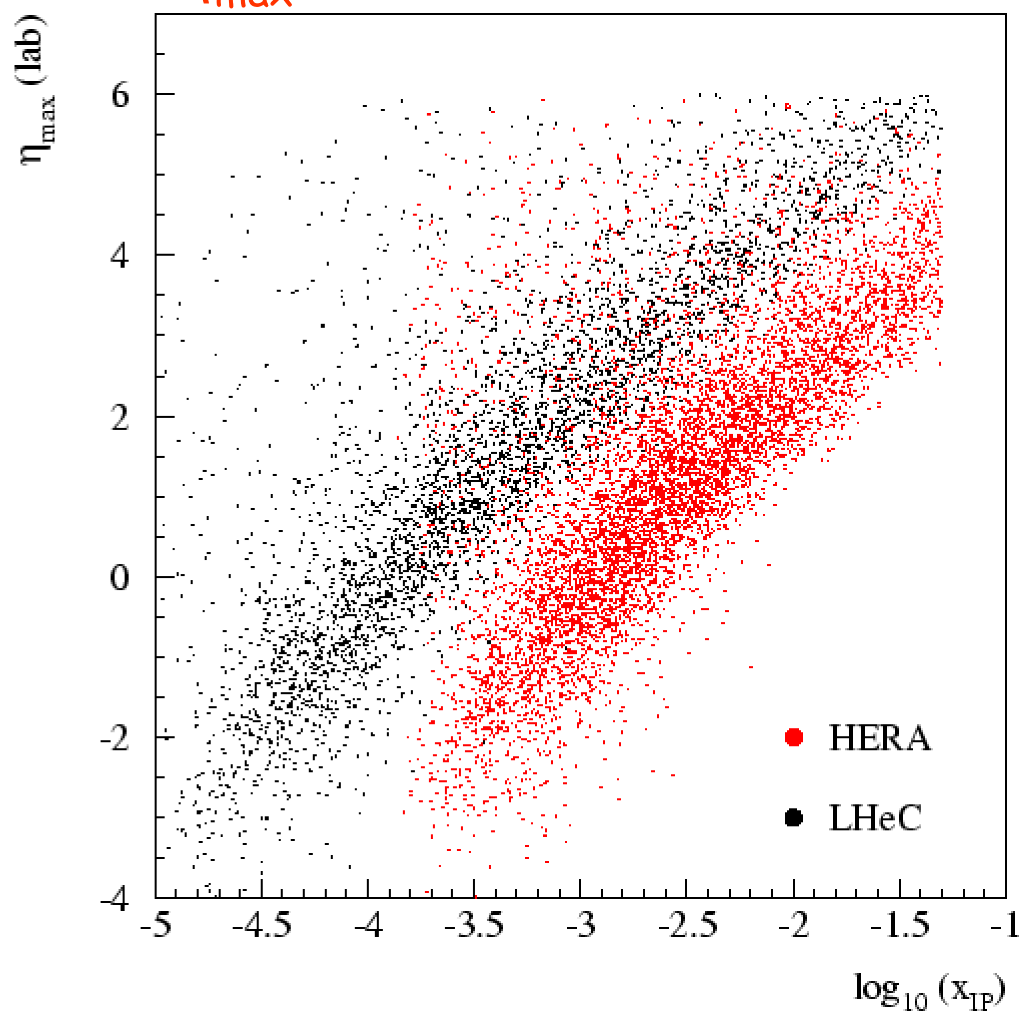
Forward and Diffractive Detectors

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

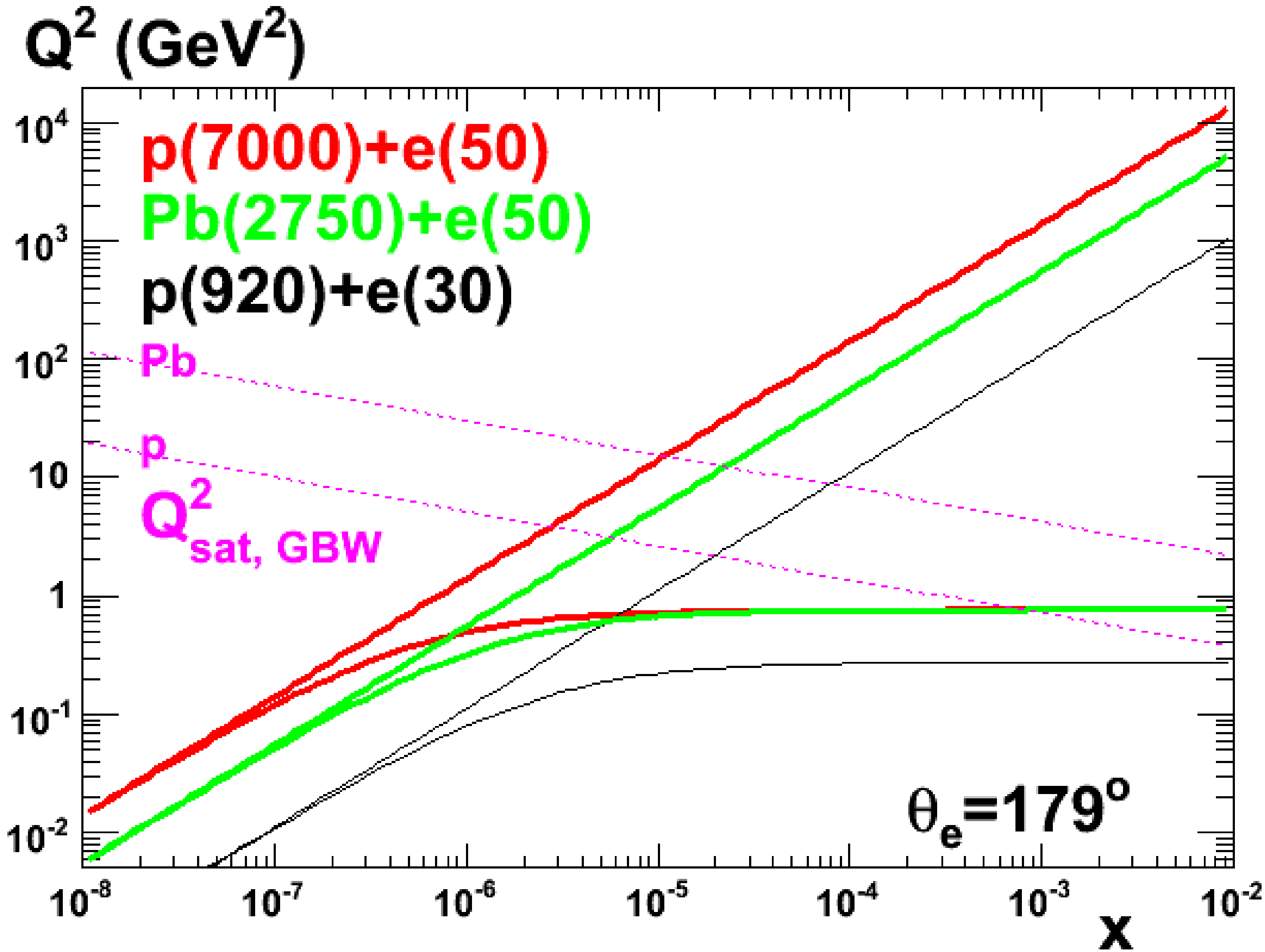
- Reaching $x_{IP} = 1 - E_p'/E_p = 0.01$ in diffraction with rapidity gap method requires η_{max} cut around 5 …forward instrumentation essential!

- 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 …



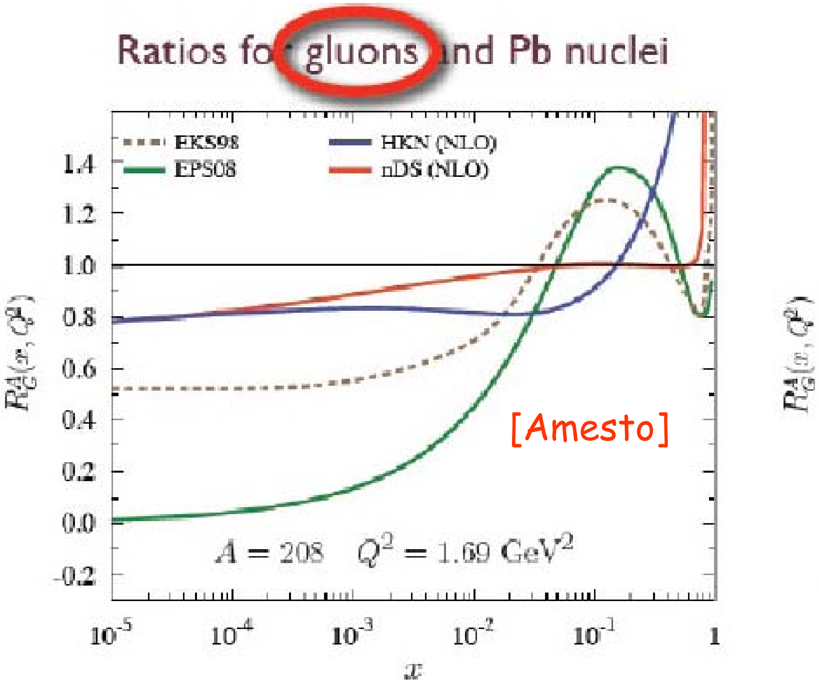
LHeC Kinematics for Low x Investigations

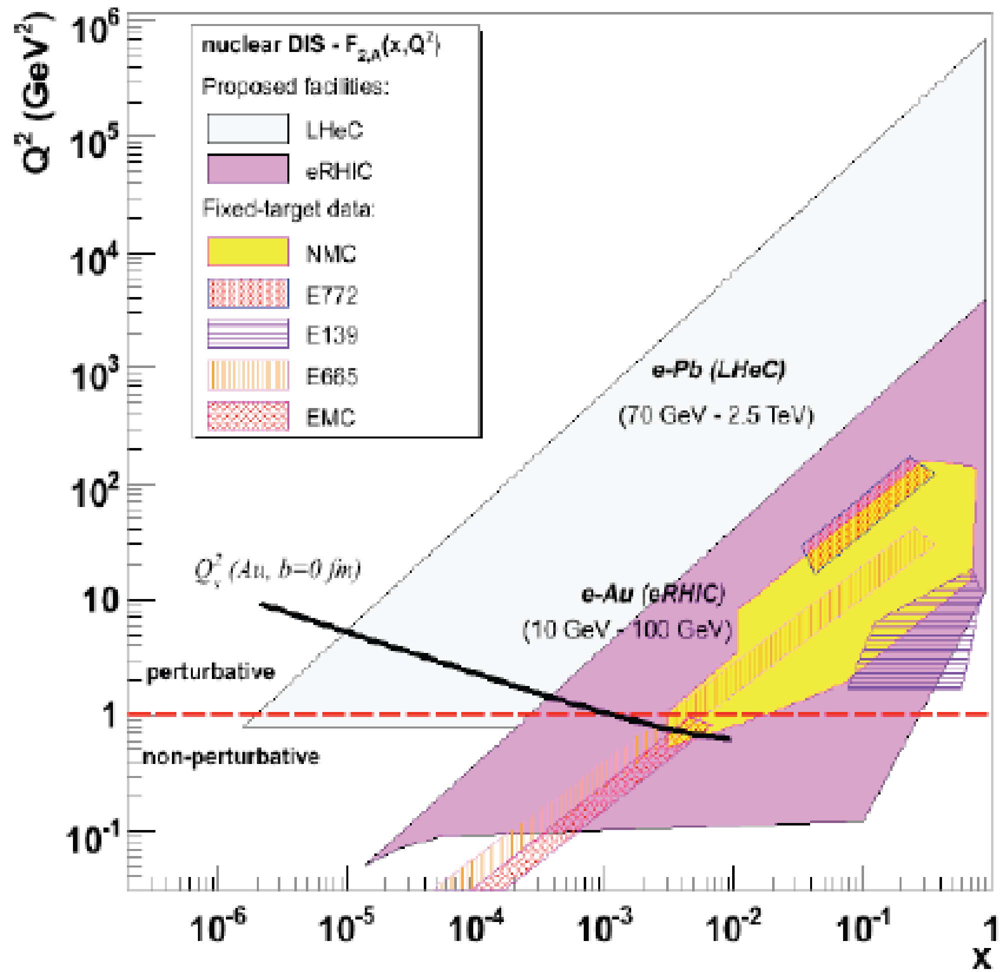


With AA at LHC, LHeC is also an eA Collider

- Very limited x, Q^2 and A range for F_2^A (quarks unknown for x <~ 10^{-2}, gluon very poorly known)

Initial state of LHC AA Collisions ~ unconstrained!





Parton density grows like A $^{1/3}$ ~ 6 for lead!... big enhancement in saturation effects!