The LHeC Project: Deep Inelastic Scattering with E_e=70GeV and E_p=7TeV

P.Newman, Birmingham

… with …

J. Dainton, M. Klein, E. Perez, F. Willeke

- Context of LHeC
- Physics Motivation
- Machine Considerations

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Deep Inelastic Electron-Nucleon Scattering at the LHC*

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Abstract

The physics, and a design, of a Large Hadron Electron Collider (LHeC) are sketched. With high luminosity, $10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, and high energy, $\sqrt{s}$ = 1.4 TeV, such a collider can be built in which a 70 GeV electron (positron) beam in the LHC tunnel is in collision with one of the LHC hadron beams and which operates simultaneously with the LHC. The LHeC makes possible deep-inelastic lepton-hadron (ep, eD and eA) scattering for momentum transfers Q^2 beyond $10^6\,\mathrm{GeV}^2$ and for Bjorken x down to the 10^{-6}. New sensitivity to the existence of new states of matter, primarily in the lepton-quark sector and in dense partonic systems, is achieved. The precision possible with an electron-hadron experiment brings in addition crucial accuracy in the determination of hadron structure, as described in Quantum Chromodynamics, and of parton dynamics at the TeV energy scale. The LHeC thus complements the proton-proton and ion programmes, adds substantial new discovery potential to them, and is important for a full understanding of physics in the LHC energy range.

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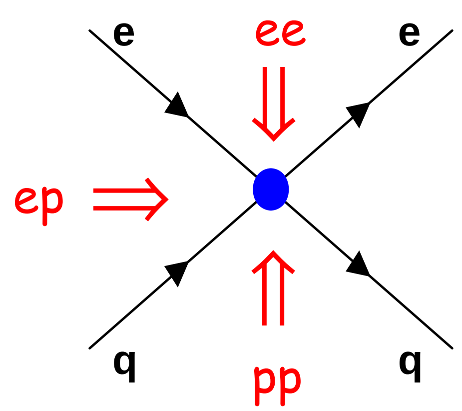
hep-ex/0603016, Submitted to JINST.

Historical Development of Particle Physics always involved ep interactions together with pp and e^+e^-

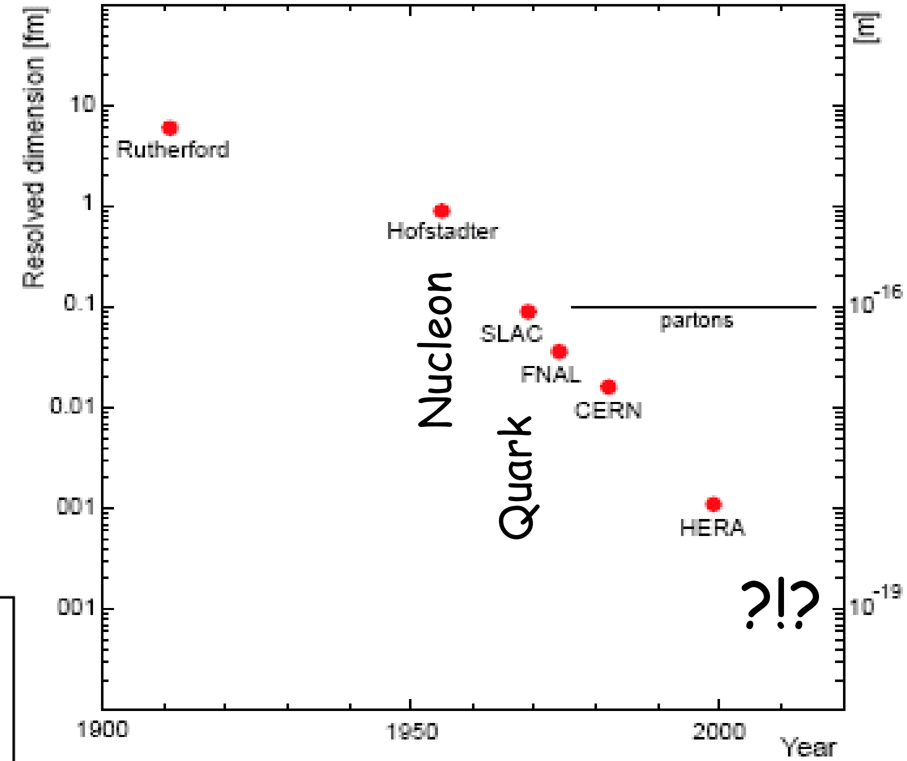


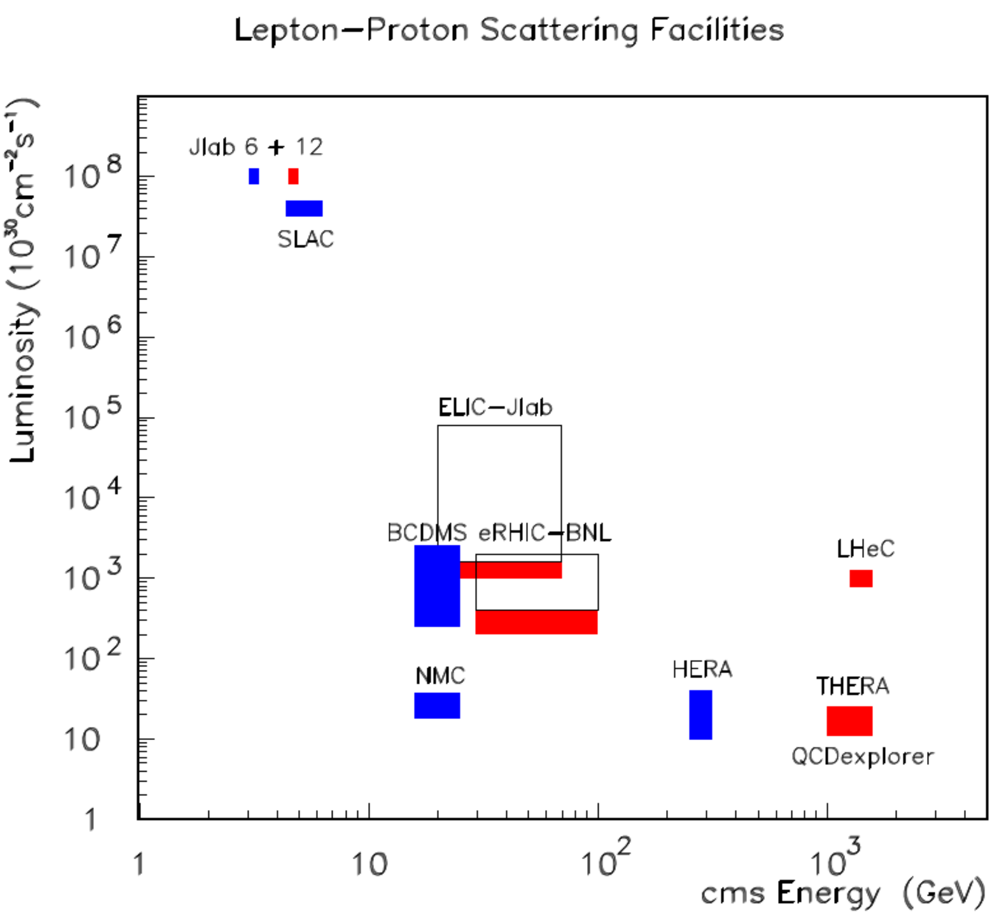
	1970		2000	2015
DIS	Bjorken scaling – QPM neutral currents asymptotic freedom	....	(high) parton densities low x and diffraction QCD	?
e^+e^-	J/Ψ gluons	.....	3 neutrinos electroweak theory	... ILC
pp	charm, W,Z, bottom top		LHC ...	

No agreed high energy ep programme after mid 2007!

LHeC Context

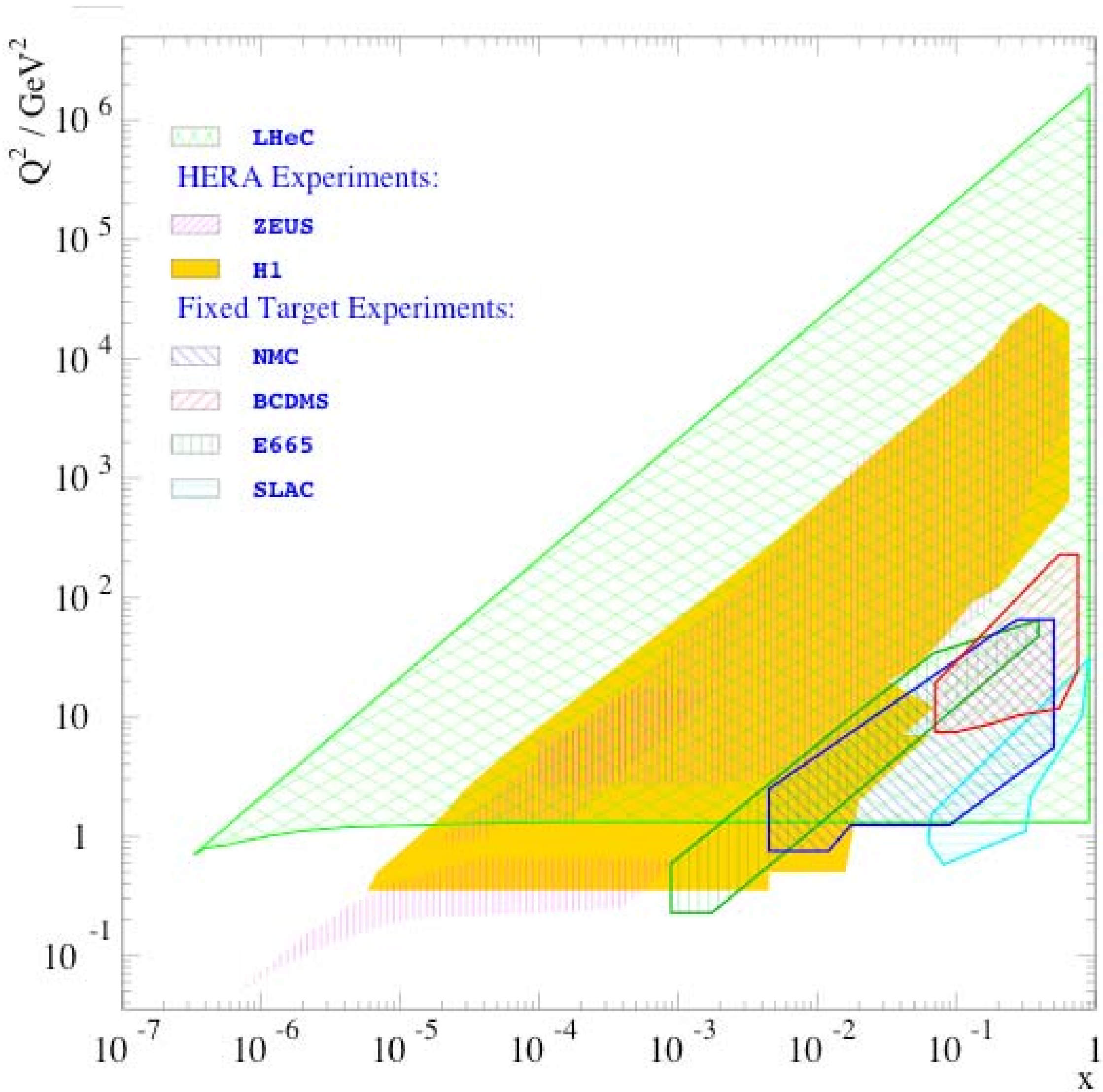
Latest of several proposals to take ep physics into the TeV energy range …
… but with unprecedented lumi!





- Combining the LHC protons with an electron beam is natural next step in pushing the frontiers of ep physics: small resolved dimensions, high Q^2 and low x
- Can be done without affecting pp running

Inclusive Kinematics



$E_e = 70$ GeV

$E_p = 7$ TeV

$\sqrt{s} = 1.4$ TeV

High Q^2 Frontier

$M_{eq} \leq 1.4$ TeV

$Q^2 \leq 2.10^6$ GeV^2

Low x Frontier

$W \leq 1.4$ TeV

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

Overview of Physics Motivations

-New Physics in the eq Sector
  leptoquarks, RP violating SUSY, quark compositeness

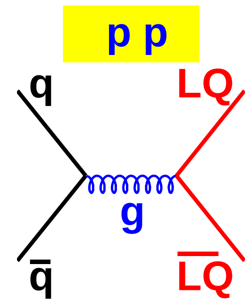
-The Low x Limit of Quantum Chromodynamics
  high parton densities with low coupling
  parton saturation, new evolution dynamics

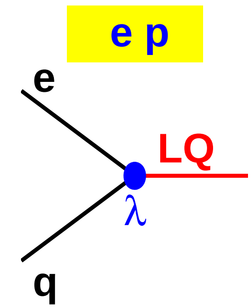
-Quark-Gluon Dynamics and the Origin of Mass
  confinement and diffraction

-Precision Proton Structure for the LHC
  essential to know the initial state precisely!
  including heavy flavour (b), gluon

-Nuclear Parton Densities
  eA with AA -> partons in nuclei, Quark Gluon Plasma

Lepton-quark Bound States





Yukawa coupling, λ

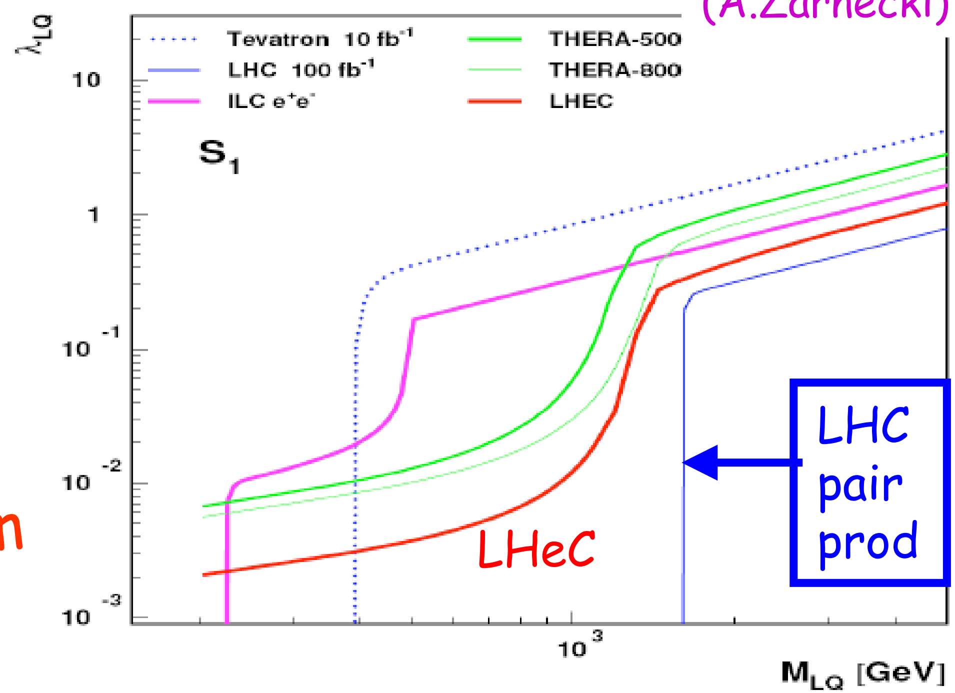
- Leptoquarks appear in many extensions to SM… explain apparent symmetry between lepton and quark sectors.

- Scalar or Vector color triplet bosons carrying L, B and fractional Q, complex structures likely!

- (Mostly) pair produced in pp, single production in ep.

- LHC sensitivity (to ~2TeV) extends beyond LHeC, but difficult to determine quantum numbers / spectroscopy!

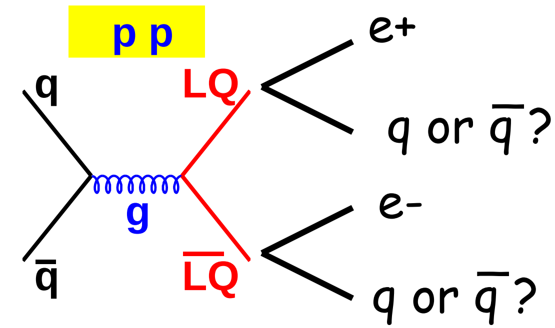
(A.Zarnecki)

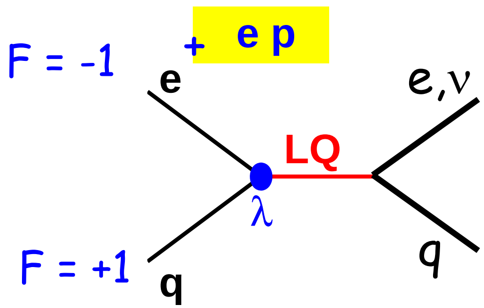


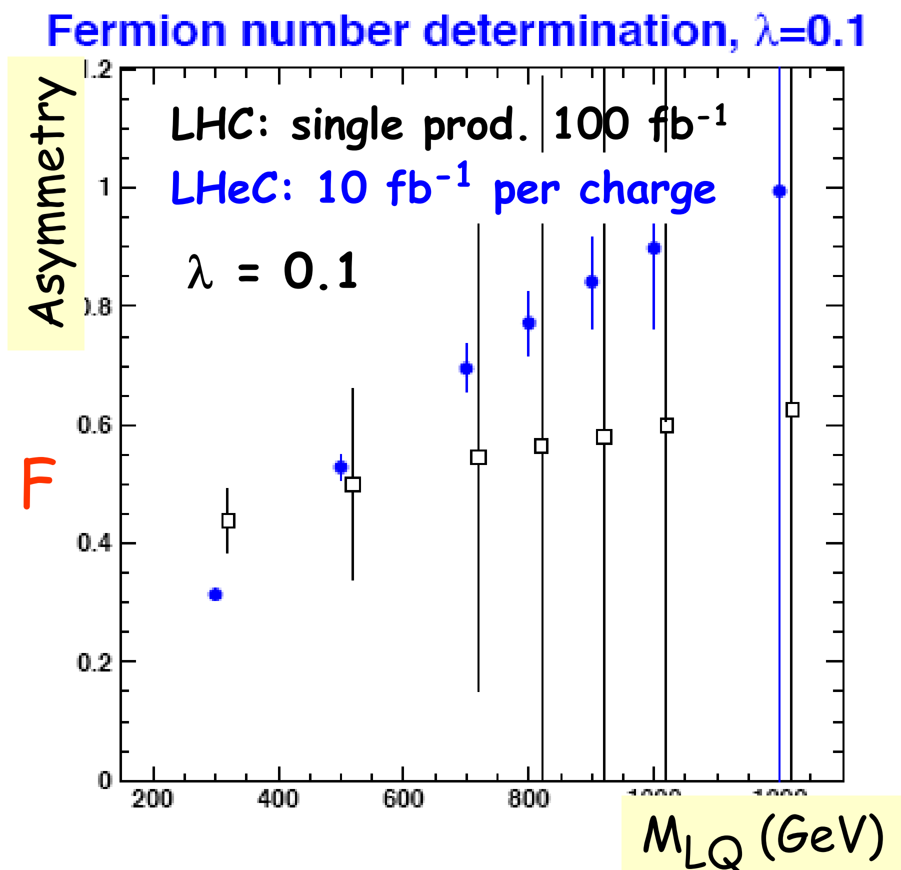
Leptoquark Properties

LHC: - Hard to determine quantum numbers from pair production.

- Single production cross sections tiny.



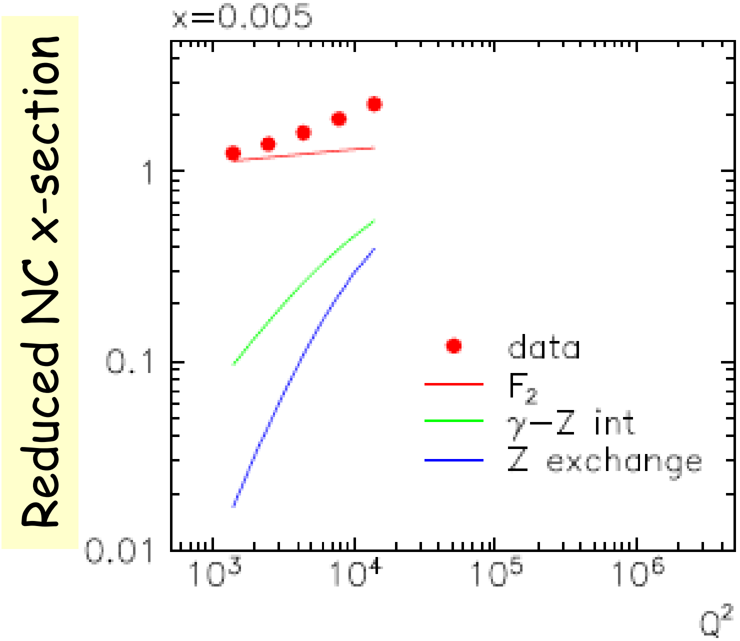


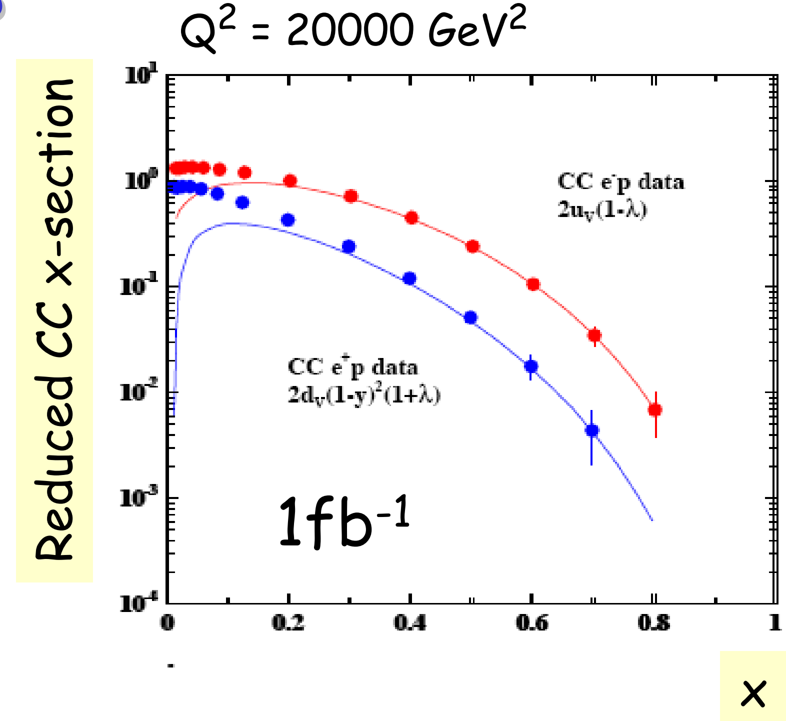


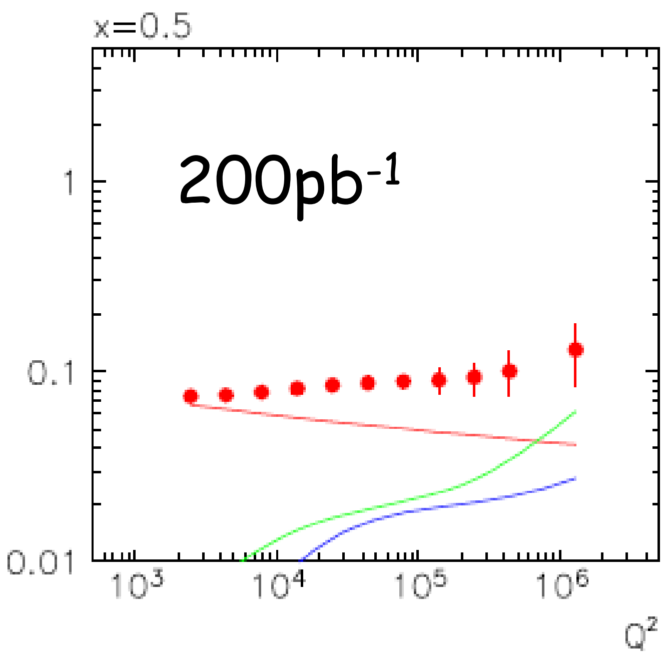
LHeC: - Resonant production at high x implies q rather than qbar. Sign of e^+p / e^-p asymmetry thus determines fermion number F

- Disentangle scalar / vector from angular distributions.
- Disentangle chiral couplings by varying beam polarisation

Inclusive Cross Sections



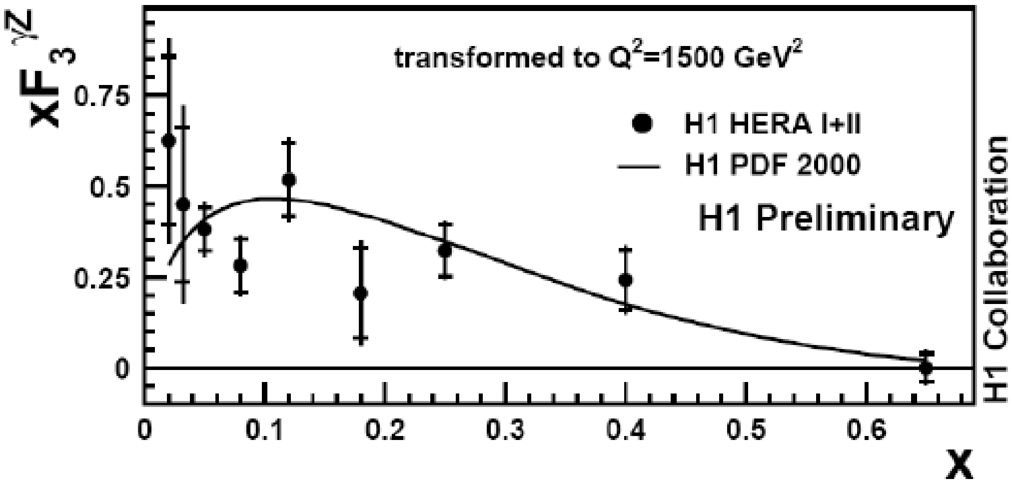




- LHeC is a genuine electroweak collider … exploit helicity and W exchange for quark flavour and q / qbar decomposition.

- It provides high NC and CC rates up to large values of x, for e.g. d/u determination

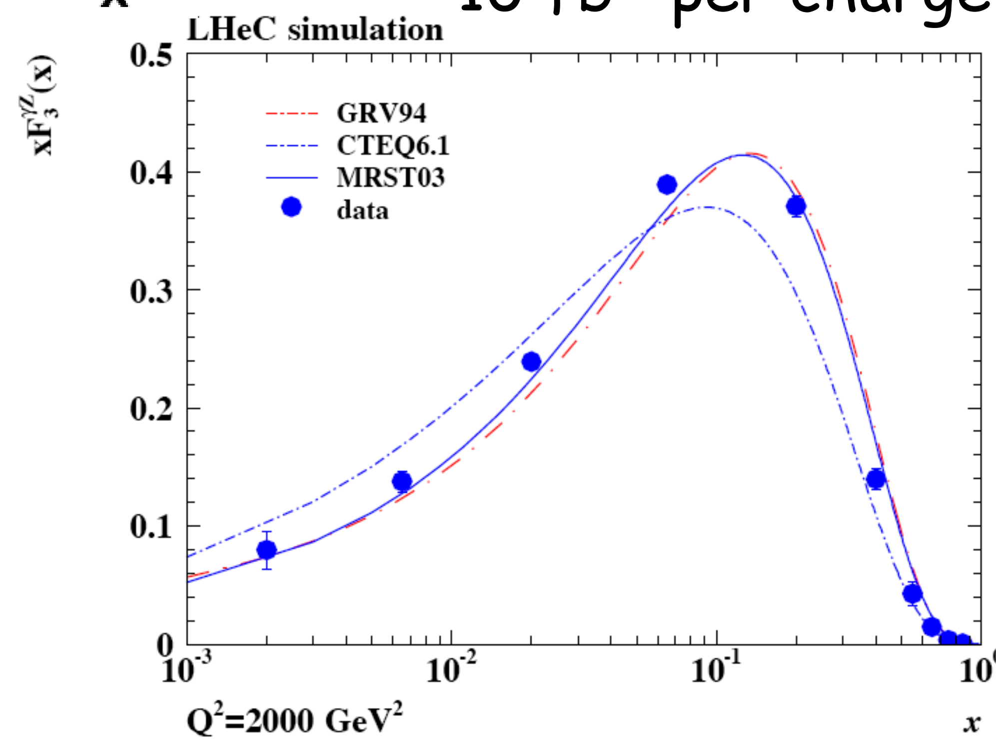
Example Proton Structure Constraint: xG_3



$$xG_3 \sim a_u e_u (u - \bar{u}) + a_d e_d (d - \bar{d})$$

Extracted from e^+p / e^-p NC cross section asymmetry … example data from HERA

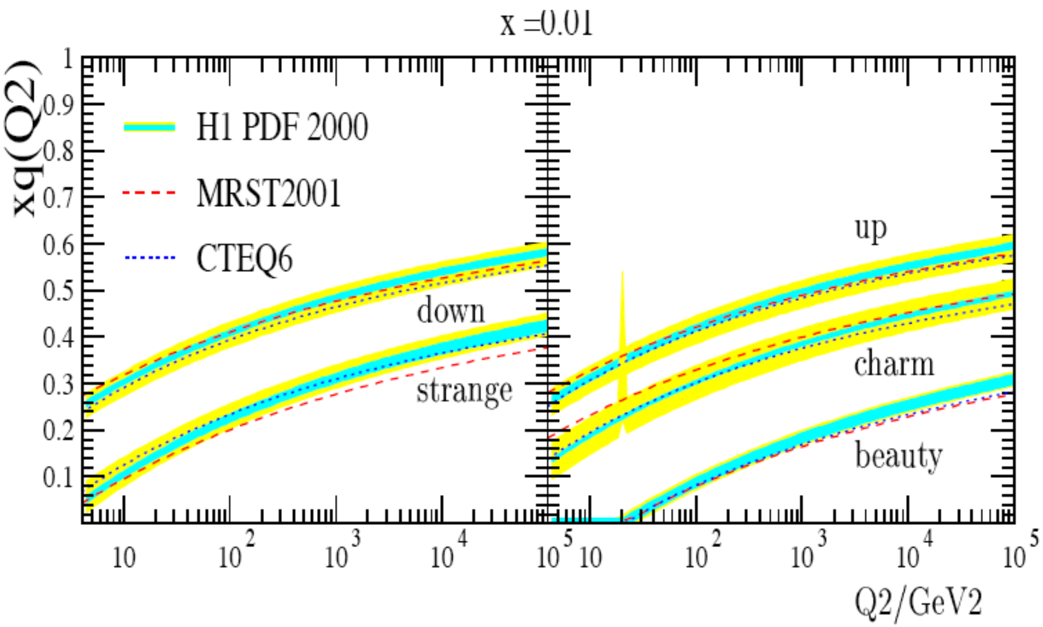
10 fb^{-1} per charge

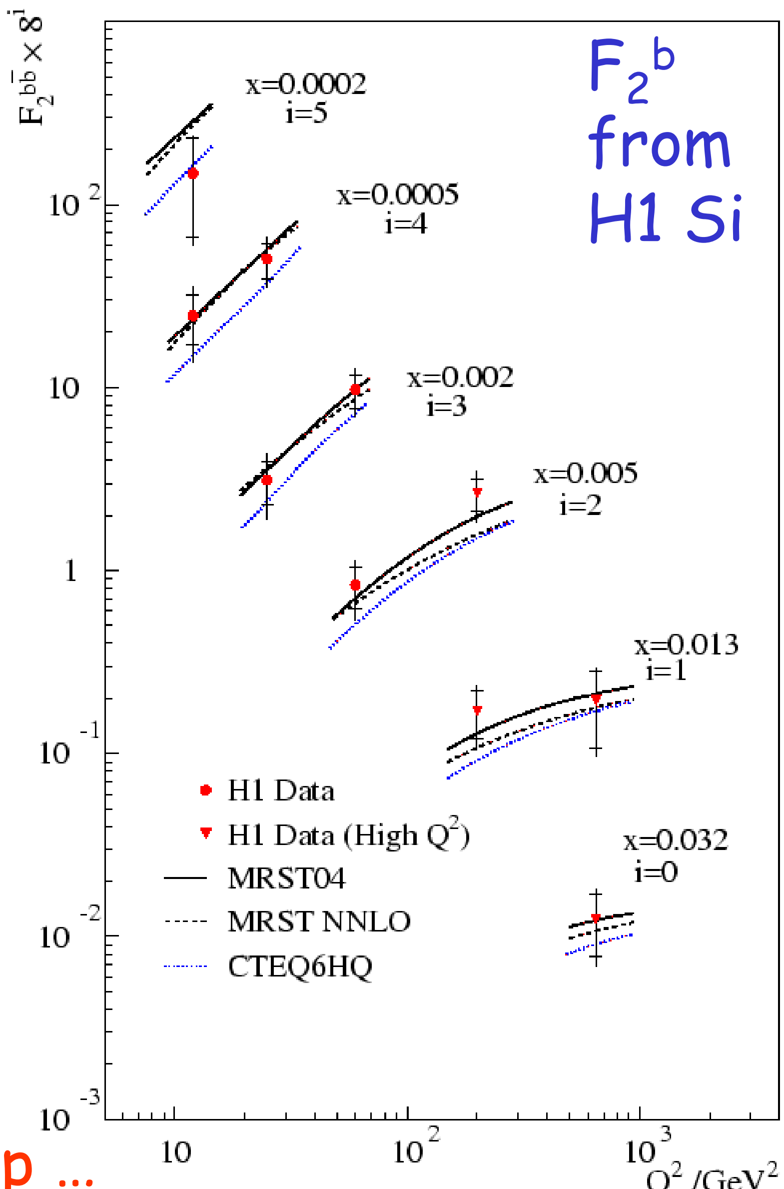


Improved precision and extension to lower x at LHeC

Tests symmetry of q and qbar in sea and / or measures valence density at very low x

Heavy Flavour Constraints for LHC





- At Q^2 values of LHC and LHeC, charm and beauty important

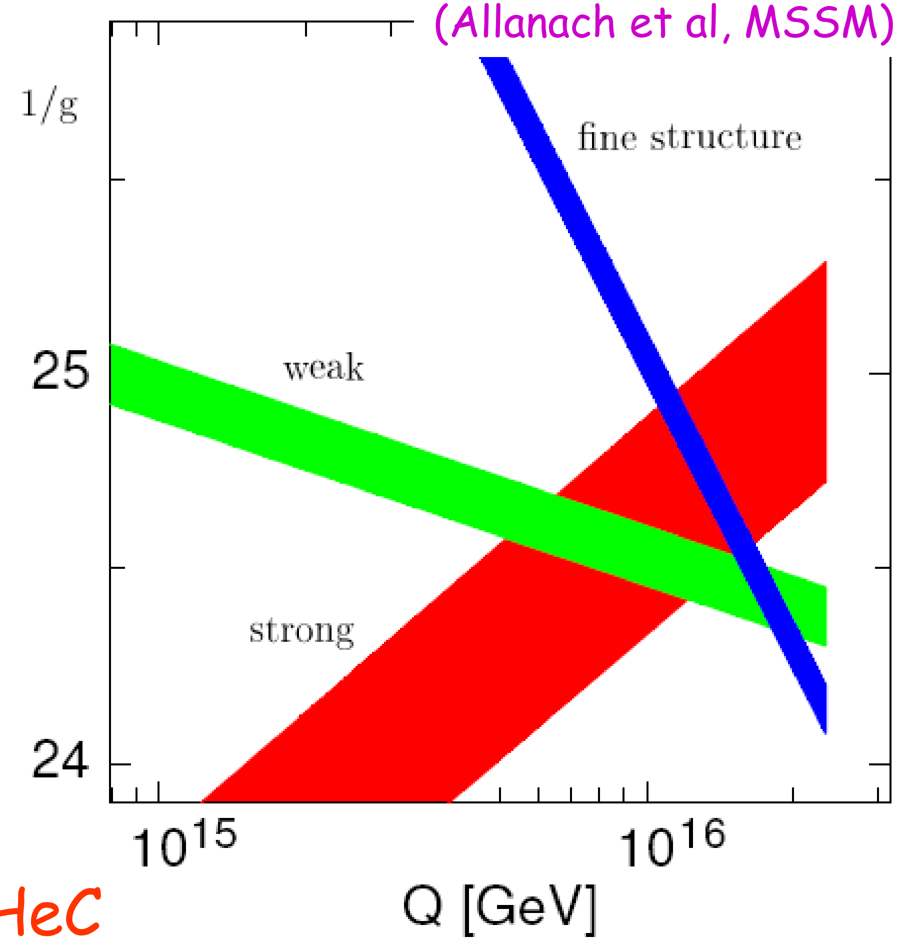
- Crucial for understanding initial state of many new processes (e.g. bbbar->H) and background rates.

- Precise knowledge available from ep …

Strong Coupling Constant

2006 α @ 10^{-9}
2006 G_F @ 10^{-5}
2006 G @ 0.02%
2006 α_s @ 1-2%
LHeC α_s few/mil

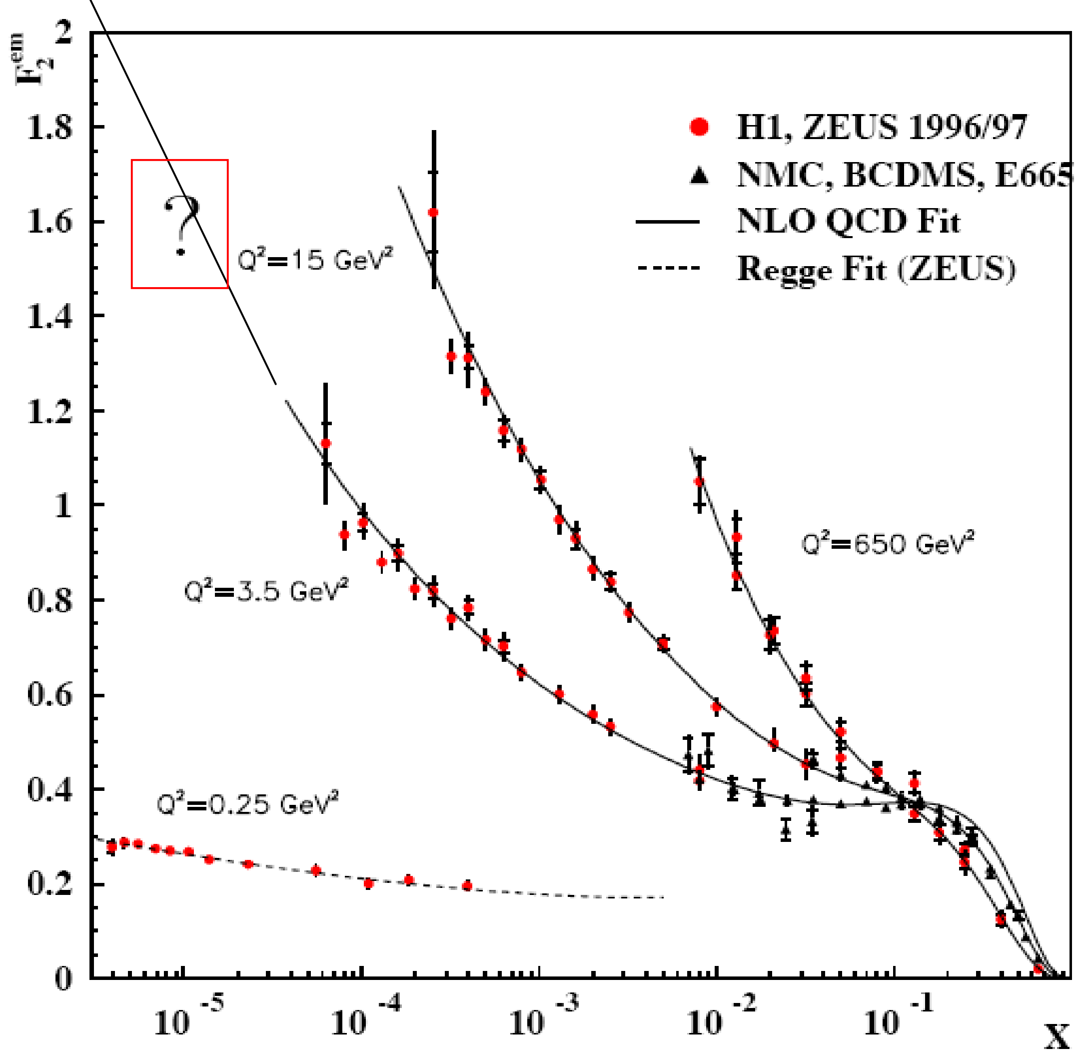
(Allanach et al, MSSM)



- Improved precision at the LHeC due to increased lever arm in x and Q^2, < 1% experimental precision and NNLO theory

- Unification?... α_s precision limits extrapolations to GUT scale

Low x Physics



- HERA `discovered' rise of F_2 towards low x … high parton density, low coupling limit of QCD … but many questions left unanswered…

- Parton saturation?

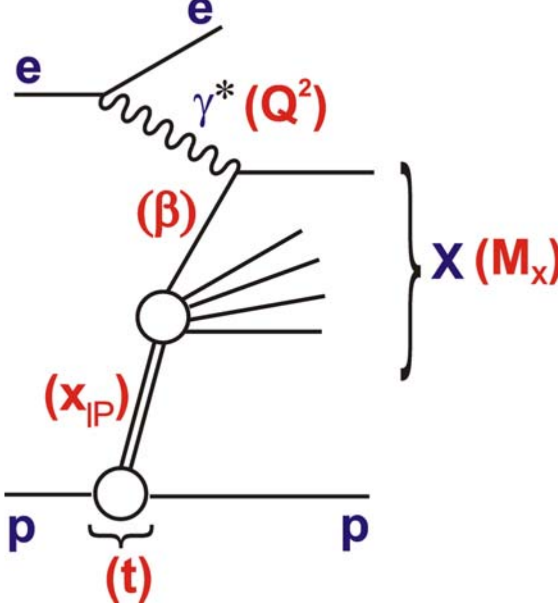
- Non-DGLAP evolution dynamics?

- Diffraction?

… LHeC at x < 10^{-6}!

Example: Diffraction

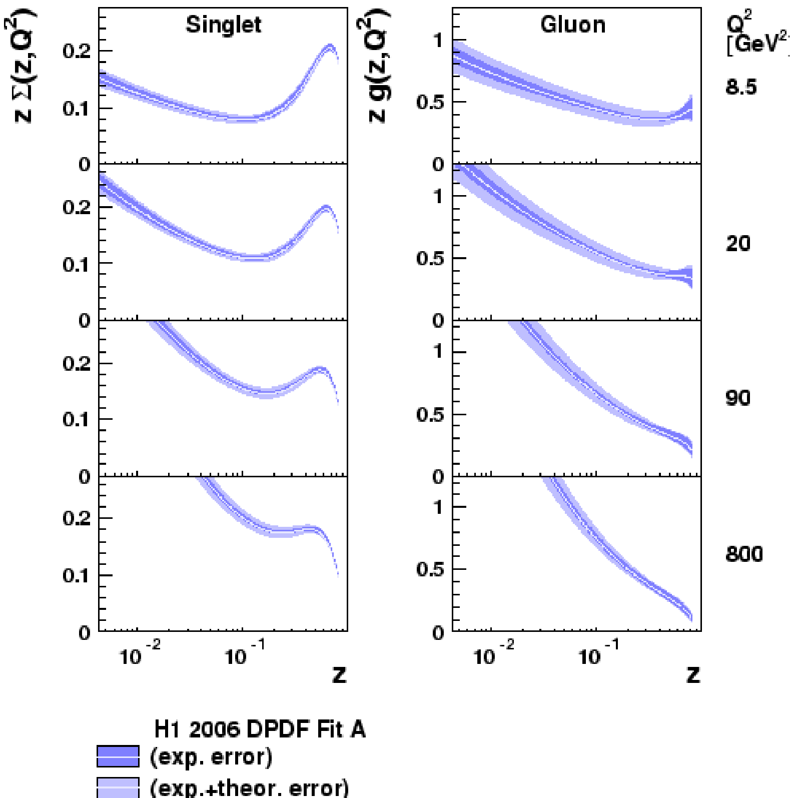
- Diffractive DIS `discovered' at HERA (~10% of events are ep -> eXp)



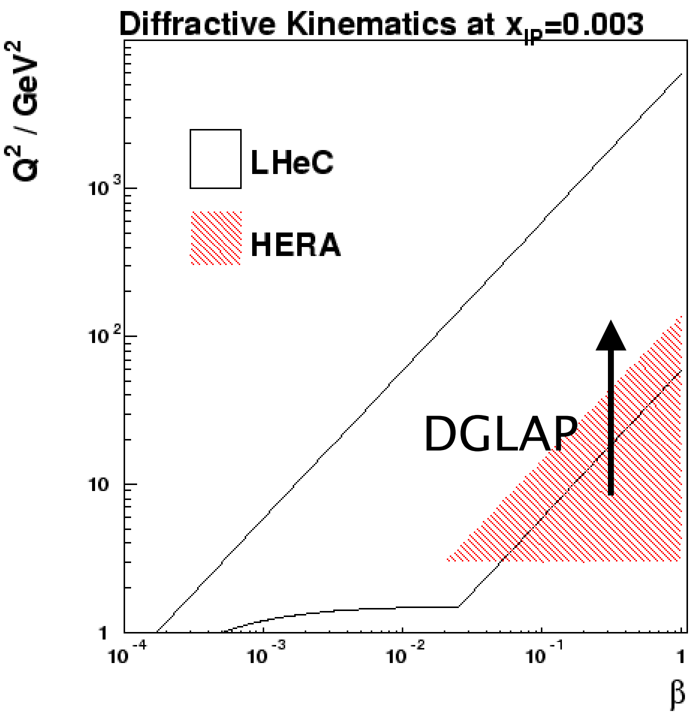
- Parton-level mechanism and relation to diffractive pp scattering, inclusive DIS, confinement still not settled

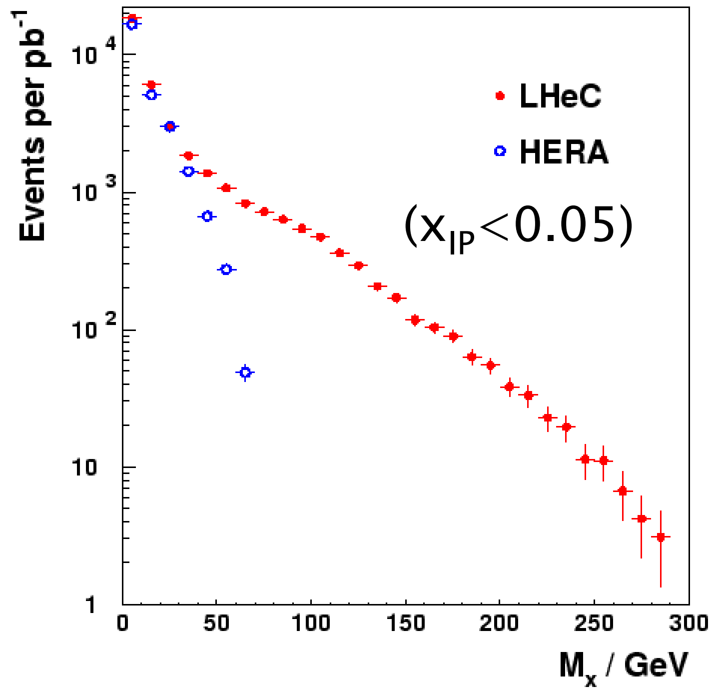
- Factorisable diffractive parton densities (DPDFs) work well in describing diffractive DIS at HERA

- At LHeC, DPDFs and theoretical models can be tested in detail and possibly contribute to discovery potential



LHeC Diffractive Kinematics





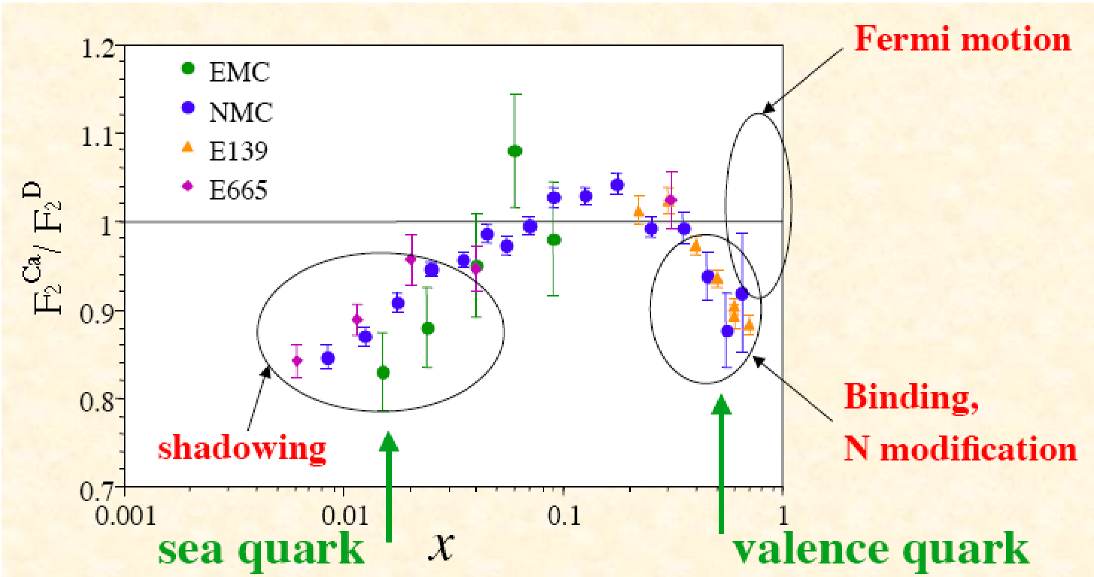
• Factorisation tests / gluon: DPDFs extracted at HERA data predict LHeC cross section at moderate /large β, higher Q^2.

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

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

•GPDs: Massive extension in x, W ranges for VMs, DVCS

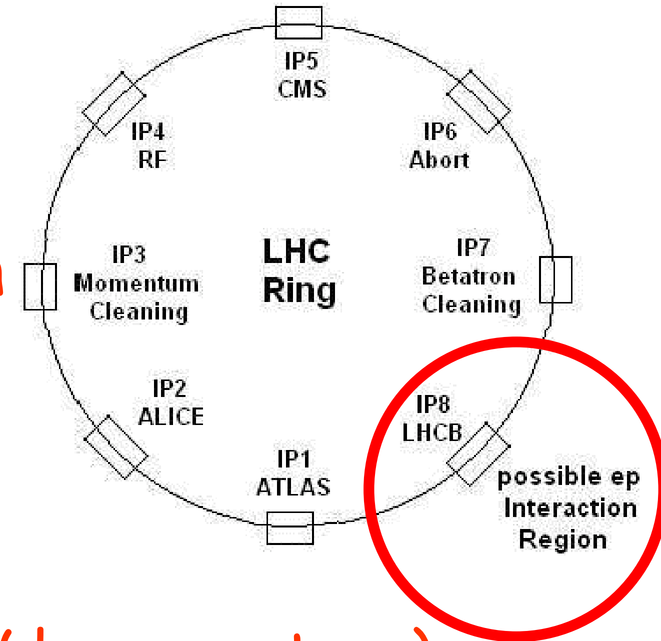
With AA at LHC, LHeC is also an eA Collider



- Rich physics of nuclear parton densities.
- Limited x and Q^2 range so far

- LHeC extends by 4 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, eRHIC … disentangling Quark Gluon Plasma from shadowing or parton saturation effects

LHeC Basic Principle

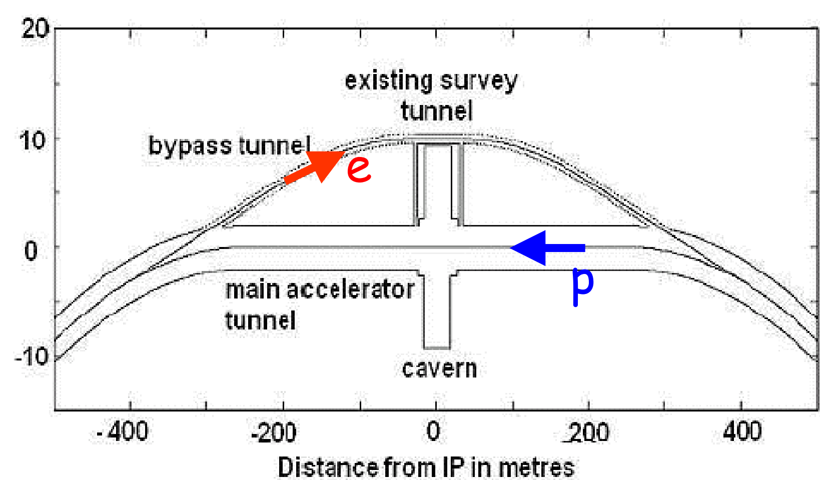


- On timescale of LHC upgrades
- ep in parallel with standard pp operation
- Proton beam parameters fixed by LHC
- 70 GeV electron beam, compromising between energy and synchrotron (0.7 GeV loss per turn)

Superconducting RF cavities then consume 50MW for Ie=70mA

New detector possibly replaces LHCb at end of their programme?

Electron beam by-passes other experiments via existing survey tunnels



Interaction Region

• Matching electron and proton beam shapes and sizes determines β^* x emittance for electron beam

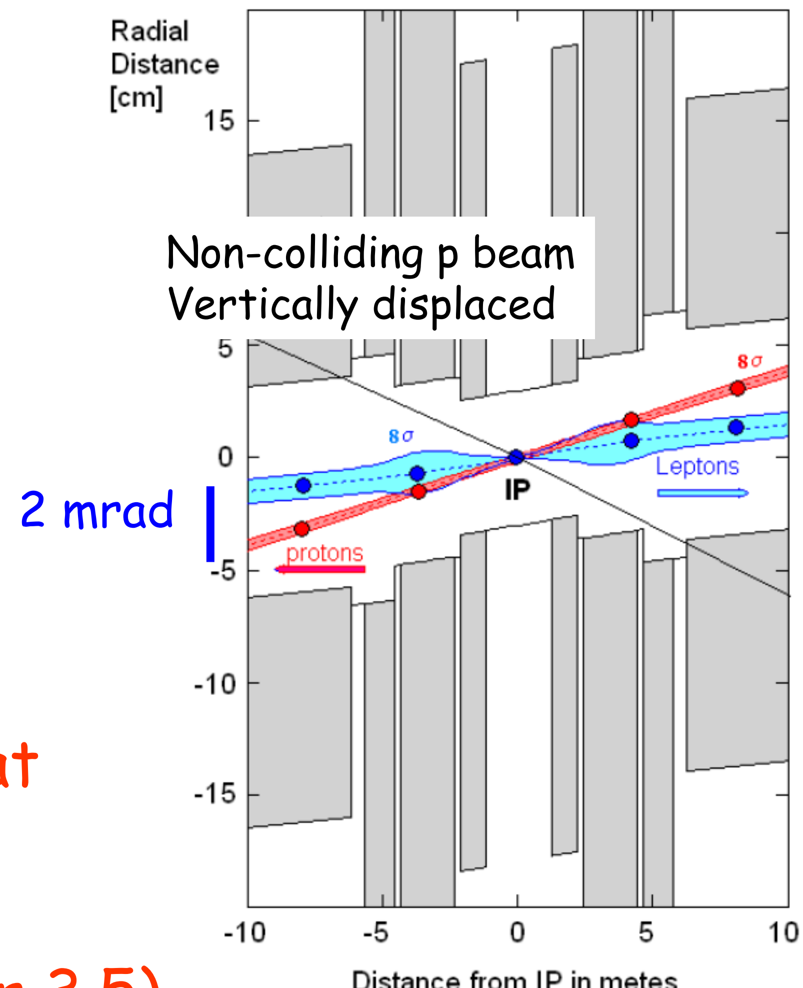
• High luminosity requires low β quadrupoles close to interaction point (1.2 m)

• Fast separation of beams with tolerable synchrotron power requires finite crossing angle

• 2 mrad angle gives 8σ separation at first parasitic crossing

• Resulting loss of luminosity (factor 3.5) partially compensated by "crab cavities" … -> 10^{33} cm^{-2} s^{-1}

Top view



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	$10^{33}\text{cm}^{-2}\text{s}^{-1}$	1.1	

e accelerator similar to LEP … FODO structure with 376 cells @ 60m (LEP 290 cells)

Detector Considerations

Magnet free space of ± 1.2 m -> detector acceptance to 10°

HERA	E_e=30GeV →	← E_p=920GeV
LHeC	E_e=70GeV	E_p=7000GeV

- Considerably more asymmetric than HERA!

- Study of low x / Q2 and of energy flow in outgoing proton direction require more (1°) … but luminosity less important, so dedicated alternative set-up possible?

- Diffractive Proton (and neutron) tagging should be integral to design

Summary

LHC is a totally new world of energy and luminosity! LHeC proposal aims to exploit this for lepton-hadron scattering

New discoveries expected at LHC … interpretation may require ep, eA in comparable energy range

LHeC naturally extends low x and high Q^2 frontiers of ep physics … new precision in our understanding of QCD

First conceptual design exists … no show-stopper so far

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

Tentative plan to hold a workshop (October 26-28?) All invited to think about the possibilities and / or contribute!