

# Towards the CDR on the LHeC

Open questions under study and the programme of Divonne 2

Max Klein

ATLAS, H1  
University of Liverpool

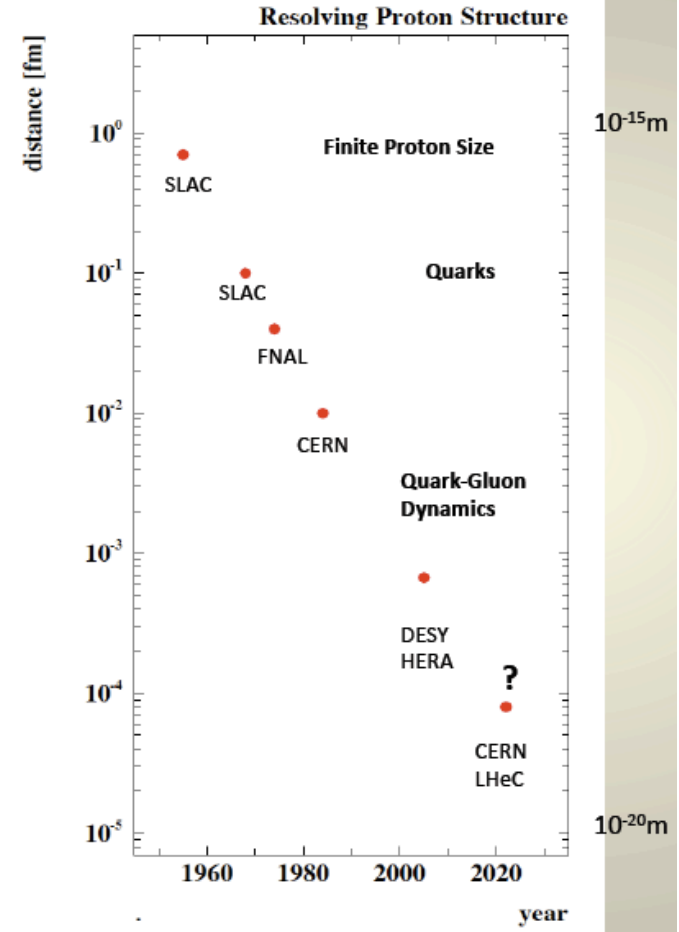
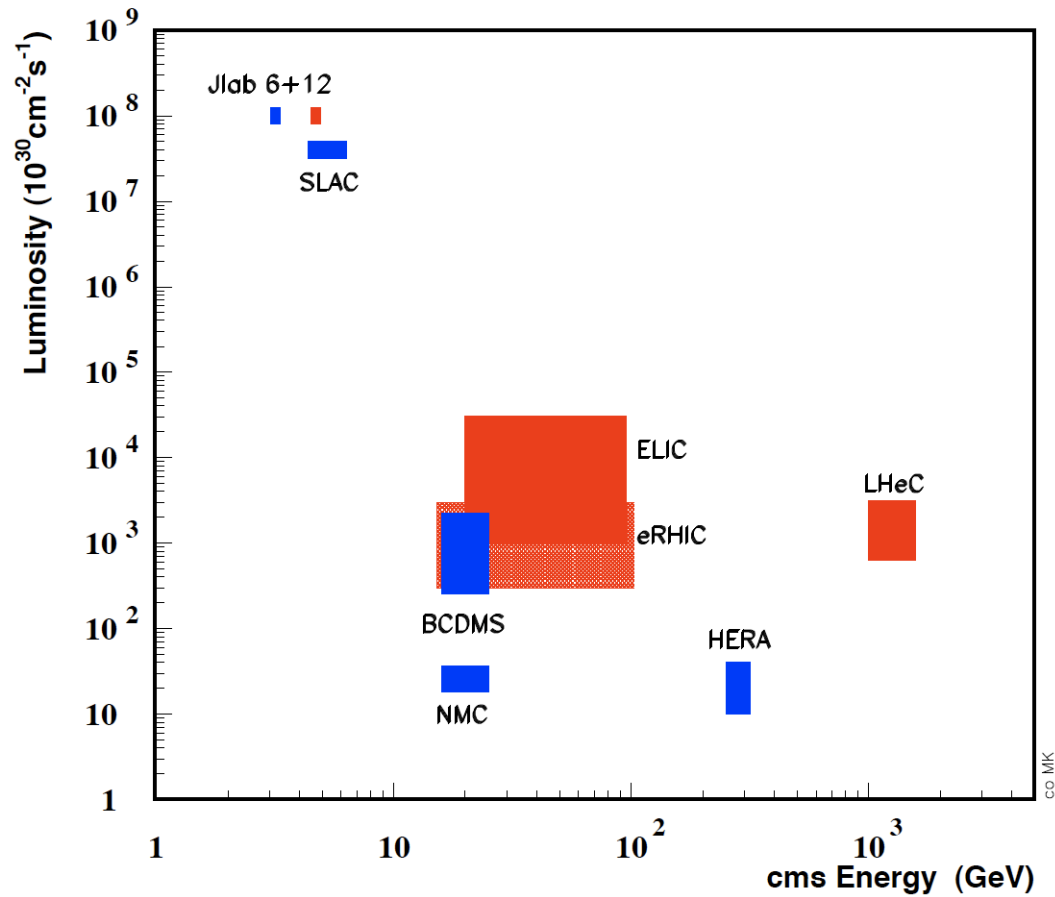
Oliver Bruening	(CERN)
John Dainton	(Cockcroft)
Albert DeRoeck	(CERN)
Stefano Forte	(Milano)
Max Klein - chair	(Liverpool)
Paul Newman	(Birmingham)
Emmanuelle Perez	(CERN)
Wesley Smith	(Wisconsin)
Bernd Surrow	(MIT)
Katsuo Tokushuku	(KEK)
Urs Wiedemann	(CERN)

Report of the Steering Group to the CERN-ECFA-NuPECC Workshop on the LHeC

Divonne, France, 1<sup>st</sup> of September 2009

# Basic LHeC

Lepton-Proton Scattering Facilities



Tera scale:

pp, ee, ep: high E and high L  
[like Tevatron, LEP, HERA]

LHeC in parallel to LHC  
High precision eq scattering

100 MW ,  $E_{\text{max}}$  150 GeV, p,D,A

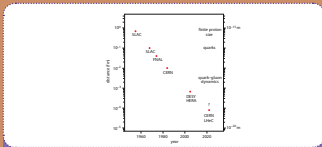
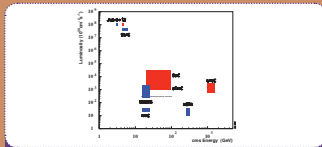
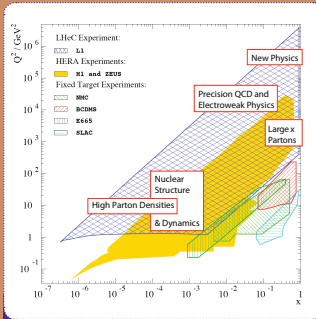


# Electron-Nucleon Scattering at the Tera Scale

CERN-ECFA-NuPECC: Preparing a Conceptual Design Report on the LHeC

The Large Hadron Electron Collider (LHeC) is a new colliding beam facility, based on the LHC at CERN, exploiting Tera scale cms energies in the electron-quark system in order to pursue a rich and luminous programme of inelastic, polarised electron/positron-proton, deuteron and heavy ion scattering measurements. By reaching momentum transfer squared values of  $Q^2$  above  $10^4 \text{ GeV}^2$  and correspondingly low values of Bjorken  $x$ , the LHeC is seen as a natural complement to the LHC and to an envisaged new lepton collider. This poster illustrates part of the still ongoing work on the machine, interaction region and detector designs as well as on the

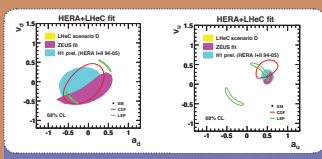
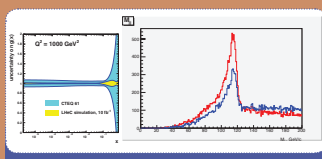
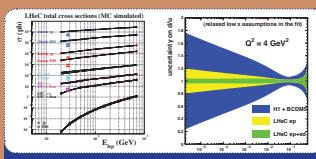
physics potential of the LHeC at high scales, high parton densities and with high precision eq measurements. This work, pursued in a wide international collaboration under the auspices of CERN, ECFA, NuPECC and a Scientific Advisory Committee, is directed to a Conceptual Design Report by 2010, as part of the deliberations of the HEP community on its future programme of exploring the energy frontier with accelerators which is reminiscent to the exploration of the Fermi scale with HERA, the Tevatron and LEP. More information on the LHeC is collected at [www.lhec.org.uk](http://www.lhec.org.uk). The next workshop will be held at Divonne 1-3.9.2009.



**LHeC Physics and Kinematics:** Kinematic phase in Bjorken- $x$  and resolving power  $Q^2$ , showing the coverage of fixed target experiments, HERA and the LHeC. The mapping of the planned physics programme onto this phase is also indicated.

**Lepton-Proton Scattering:** Comparison of the energies and luminosities of selected present (blue) and proposed future (red) lepton-proton scattering facilities. The LHeC moves DIS into the Tera scale with about 100 times the luminosity of HERA.

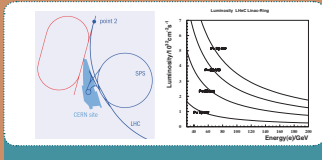
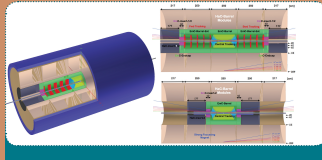
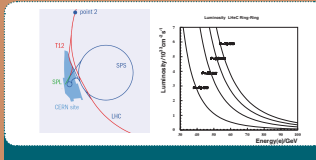
**Resolving Proton's Structure:** Distance scales resolved in successive lepton-nucleon scattering experiments since the 1950s, and some of the new physics revealed. The LHeC will resolve distances below  $10^{-10}$  m, more than 10000 times smaller than the proton's radius and 50 times below HERA.



**Direct Measurement of Partons:** The LHeC permits the complete resolution of the light and heavy quark, member of the nucleon. It will enable precision measurements of the baryon density, the first ever measurements of strange and anti-strange quark densities or the u/d densities at low and at large  $x$ . The LHeC is a single top end-of-pipe quark factory.

**Complementing the LHC:** The LHeC complements the LHC with precision measurements, e.g. on the gluon density and the partonization of the triplets. With the LHeC, new physics phenomena possibly occurring at the LHC can be distinguished reliably from mere variations of partonic behaviour, currently subject to extrapolation and parametrisation uncertainties.

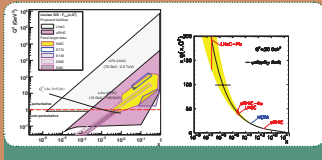
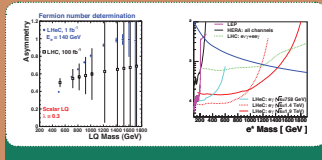
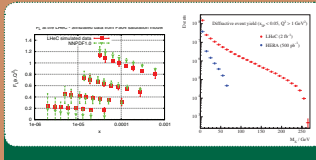
**Exploring Multi-TeV Scales:** Exploration of ultrahigh energy scales with precision measurements in deep-inelastic and diffractive interactions. Precision determination of light weak neutral current couplings. Unification of coupling constants at the Planck scale may be tested with alpha. A measured order of magnitude mismatch would be clear.



**LHeC as Ring-Ring Collider:** The LHeC as a Ring-Ring Collider may use the SPS as an injector and will have to bypass around LHC experiments, in which the ring may be placed. A new type of dipole magnet is considered for installation on top of the proton ring. The luminosity is estimated to be above  $10^{31} \text{ cm}^{-2} \text{ s}^{-1}$ , with an assumed level of 100 MW wall plug power.

**A New Detector for ep/eA:** The detector is modular for fast installation down the pit and to cope with the requirements of high luminosity and large acceptance near the beam line. Design work is ongoing on the interaction region to allow the simultaneous operation of ep, LHeC and ep/LHeC beams.

**LHeC as Linear-Ring Collider:** The LHeC as a Linear-Ring Collider is considered to be possible via a symmetric arrangement of LC-type superconducting Linacs. The luminosity is in excess of  $10^{31} \text{ cm}^{-2} \text{ s}^{-1}$  with a power level of 100 MW based on the LHeC upgrade. It may be envisaged with energy recovery techniques. The luminosity diminishes as 1/E with the electron beam energy and the time may therefore surpass the energy reach of the ring.



**Saturation of Parton Densities:** At small Bjorken  $x$  the rise of the parton densities is predicted to be limited by unitarity. A new class of matter governed by modified parton dynamics, with relations to nuclear and neutron analogies. This may be discovered in eq with precision measurements of  $F_2$  and  $F_L$  vector meson measurements of diffractive scattering in a relevant transverse range of phase space and momentum.

**Flavor number determination:** Single produced meson states, such as  $\pi$  mesons or excited leptons, have a much higher cross section at an intermediate phase space, which will allow the determination of quantum numbers of new states and possibly give access to a complementary phase space. If baryons and hadrons are low form of matter (AdS/CFT), an LHeC is called to detect related effects.

**Partonic Structure of Nuclei:** The LHeC extends the experimental knowledge on the partonic structure of nuclei by many orders of magnitude in DIS. The gradual enhancement of the gluon density at low and very high energies at the LHeC allow parton saturation effects to be studied both in ep and eA interactions and thus to identify separate nuclear from unitarity effects in deep inelastic scattering.

## After Divonne 2008

2008

September NuPECC Meeting at Glasgow

October ICFA Seminar at SLAC

November ECFA Plenary at CERN

December Convenor's Meeting at CERN

2009

March Visit at SLAC

April DIS09 at Madrid  
LHeC premeeting, parallel, SAC,  
plenary panel (arXiv:0908.2877 [hep-ex])  
April PAC09 at Vancouver - Papers, Talk, Proceedings

May Visit at BNP Novosibirsk  
NuPECC decides to join the LHeC CDR Workshop

June Low  $x$  / HPD meeting at CERN, pre-Blois

July Talk and Poster at EPS09 at Cracow

August Poster at Lepton-Photon09 at Hamburg

Continuous development of the web page. [www.lhec.org.uk](http://www.lhec.org.uk)

# Conceptual Design Report Large Hadron Electron Collider (LHeC) at CERN

DRAFT - February 2009

## 1. Introduction

## 2. Particle Physics and Deep Inelastic Lepton-Nucleon Scattering

1. DIS from 1 to 100 GeV
2. Status of the Exploration of Nucleon Structure
3. Tera Scale Physics

## 3. The Physics Programme of the LHeC

1. New Physics at Large Scales
2. Precision QCD and Electroweak Physics
3. Physics at High Parton Densities

## 4. Design Considerations

1. Acceptance and Kinematics
2. A Series of Measurements
3. Compatibility with the LHC
4. Proton, Deuteron and Ion Beams

## 5. A Ring-Ring Collider Concept

1. Injector
2. Lepton Ring
3. Synchrotron Radiation
4. Interaction Region
5. Installation
6. Infrastructure and Cost

## 6. A Linac-Ring Collider Concept

1. Electron and Positron Sources, Polarisation
2. Linac
3. Interaction Region
4. Beam Dump
5. Infrastructure and Cost

## 7. A Detector for the LHeC

1. Dimensions and General Requirements
2. Coil
3. Calorimeters
4. Tracking
5. Options for the Inner Detector Region
6. Detector Simulation and Performance

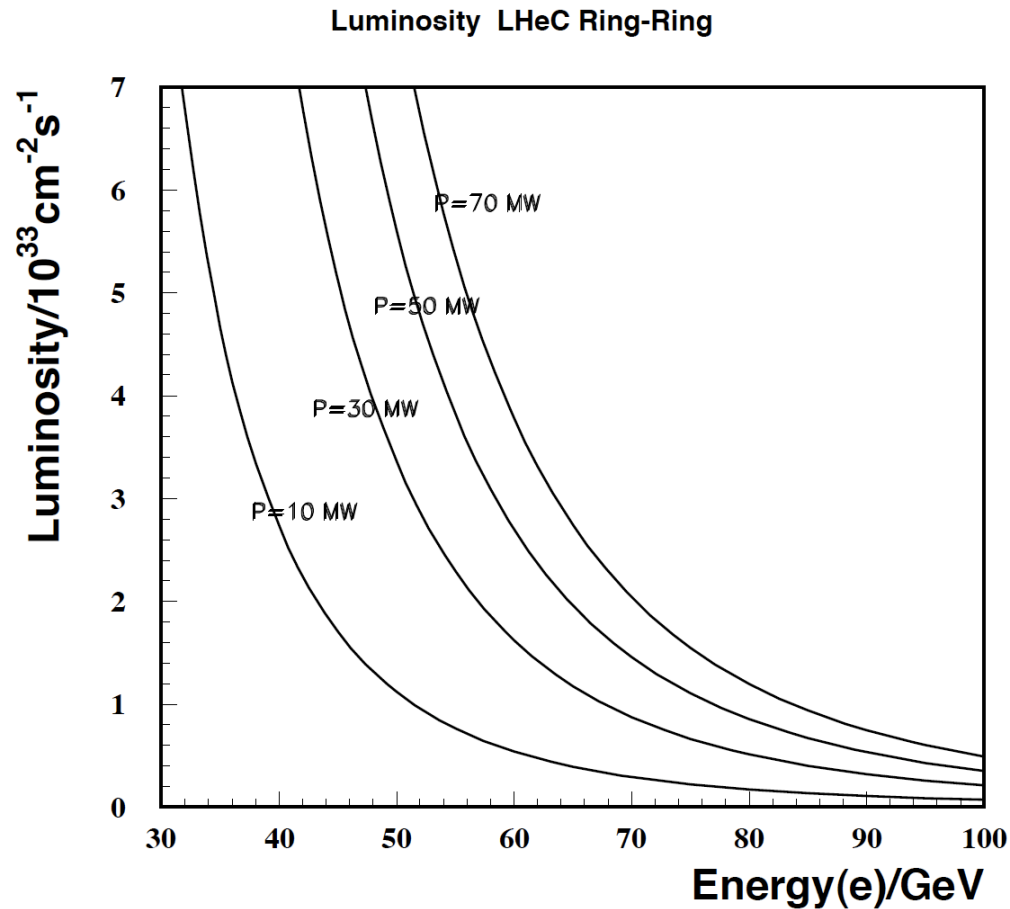
## 8. Summary

1. Physics Highlights
2. Parameters
3. Concluding Remarks

## Appendix

1. Tasks for a TDR
2. Building and Operating the LHeC

# Ring-Ring Luminosity



High L confirmed in detailed studies  
[FW: 70 GeV 50MW, BH: 50 GeV 14 MW (s)LHC]

Energy limited to 70-80 GeV (700m rf) -  $I_e \sim P/E^4$

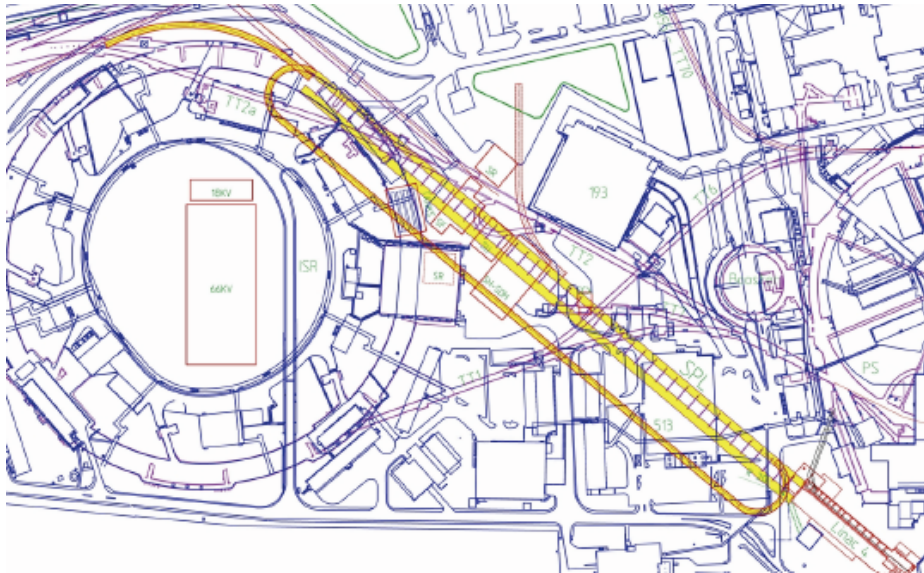
With 50 MW, 50 GeV reach  $5 \cdot 10^{33} \text{ cm}^{-2}\text{s}^{-1}$ .

This is 100 times HERA at its best day  
and  $50 \text{ fb}^{-1}$  in a typical year.

It can be reached with the standard LHC p beam.

Polarisation

# Injector to Ring



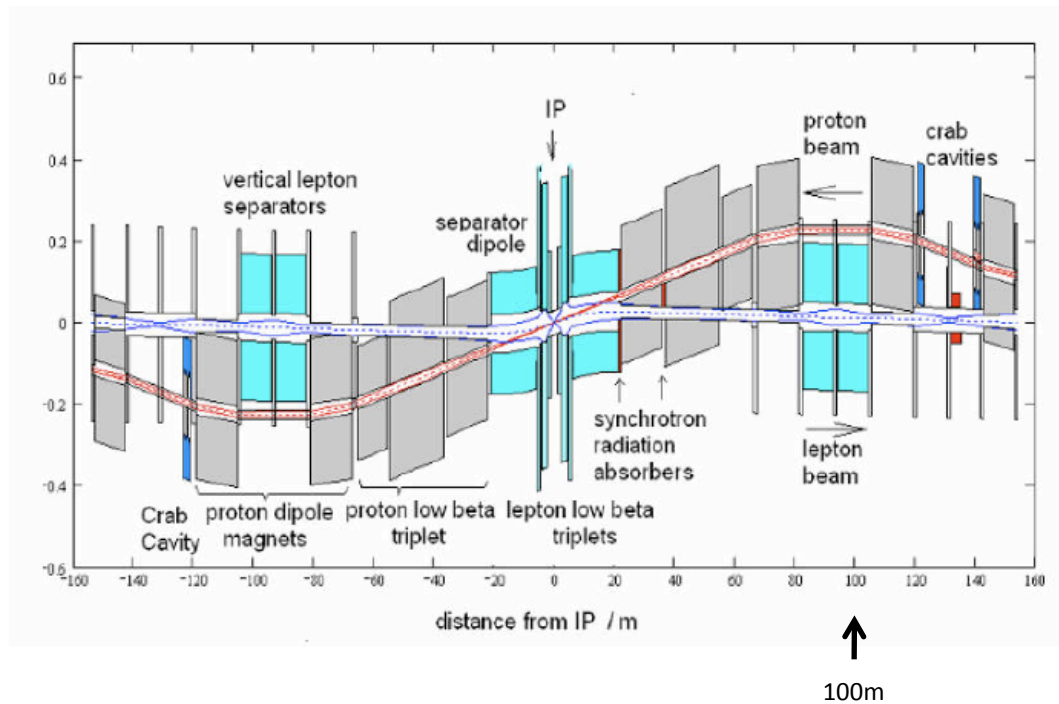
SPL

Possibly include alternative  
(e.g. ELFE downscaled HB DIS08)

Bunch intensity modest  
 $1.4 \cdot 10^{10}$  vs  $4 \cdot 10^{11}$  (LEP)

Injection energy of order 10 GeV

# Interaction Region



Interaction region design for **simultaneous pp and ep operation**  
 (FW. JINST06, BH et al Divonne08)

← 50cm

Separation requires  $\sim 2\text{mrad}$  xing angle

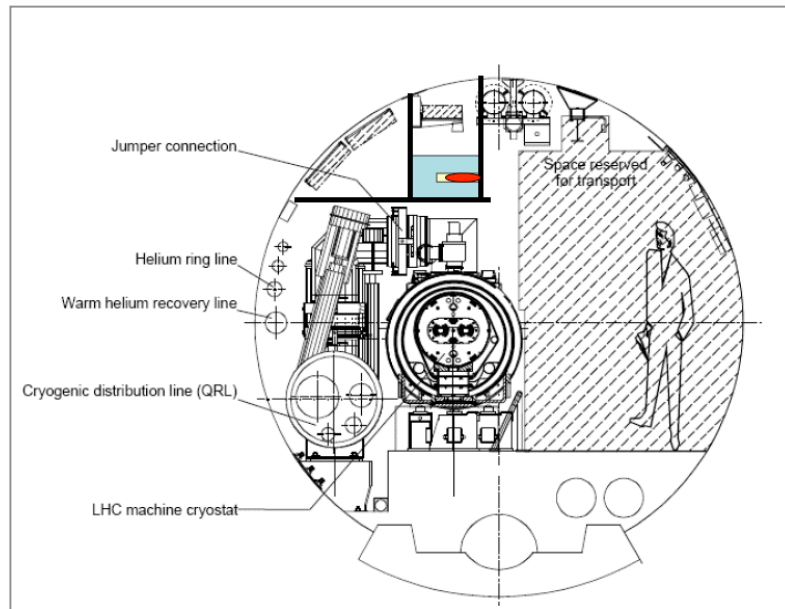
Crab cavities for compensation ( $\sim 2?$ )

Measurement of  $ep \rightarrow e\gamma$  ?

(Backscattering of) syn.rad  
 beam pipe dimension  $\rightarrow$  detector size!

Large angle IR (“ $1^\circ$  or low x IR”)

# Ring Installation



Detailed inspection of LHC installation

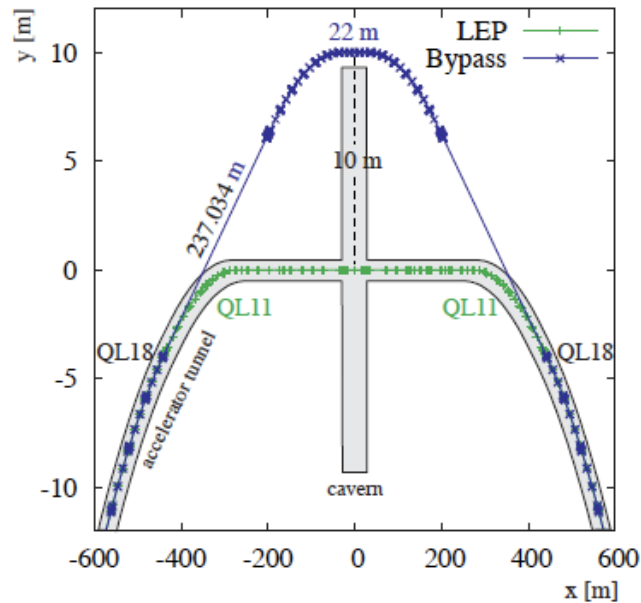
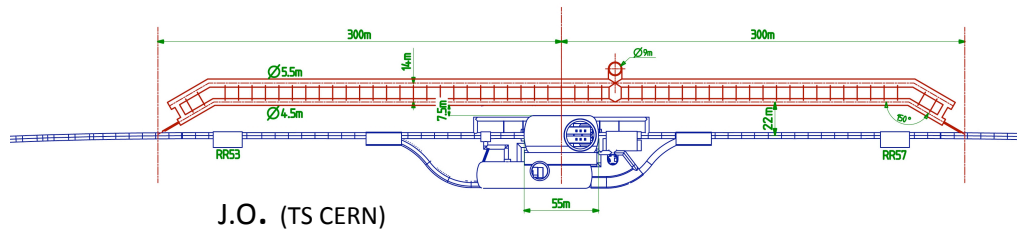
New dipole magnet design

LEP: 5.75m long steel concrete cores, 4.6 tons  
LHeC: reduce aperture, new concepts → lighter

**Visit to BNP Novosibirsk in May 09**



# Bypasses



H.B DIS08

Decouple from ATLAS, CMS..

1 shaft, excavation during operation

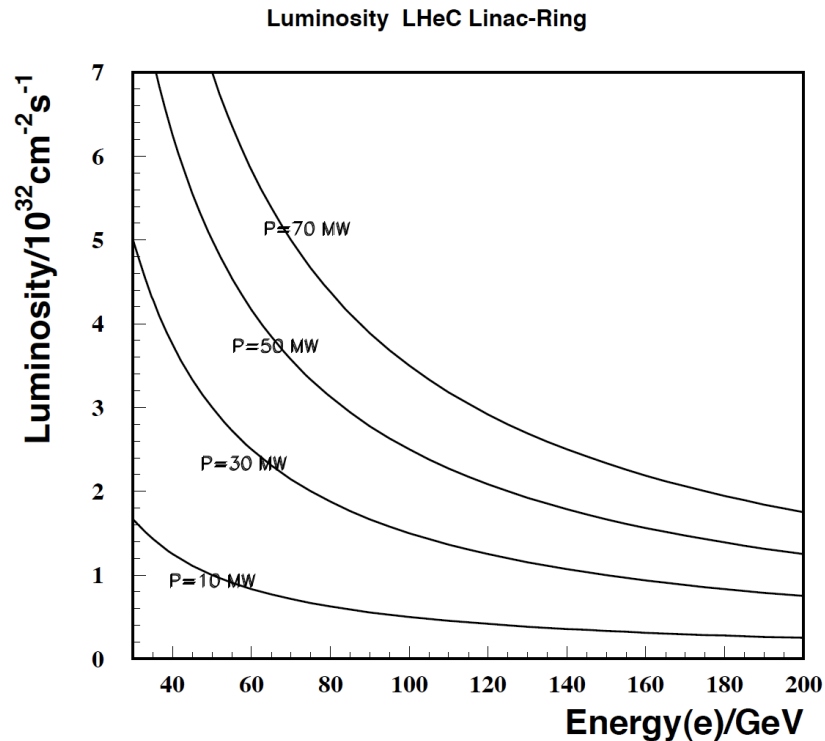
Rf installation (~ 500m for 70 GeV)

Bigger distance to beam:

New lattice

Detailed consideration of tunnel intersection

# Linac Ring Luminosity



LR Lumi estimates use LHC\*

With 50 MW, 50 GeV  
 may reach  $5 \cdot 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$   
 which is equivalent to  $10^{33}$  for ring-ring.  
 May have more than  $10^{32}$  at high energies ( $\sim P$ )

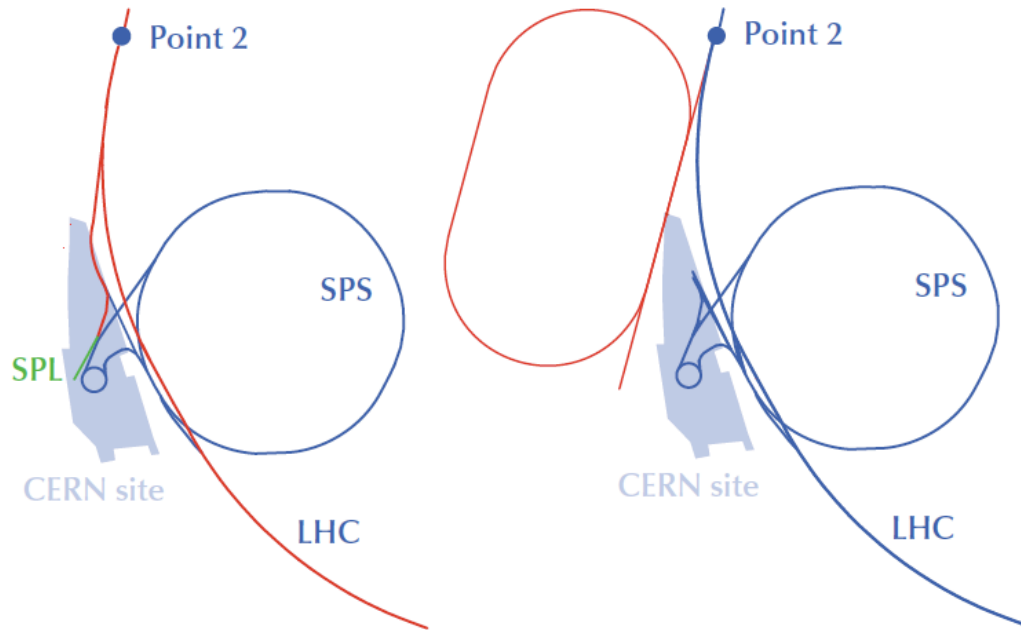
Basic Layout (different Linacs for different E)  
 visit to SLAC (March 09), contact to Cornell

Positron intensity [10 times ILC, large number of bunches]

Polarisation

	$N_{b,p}$	$T_{\text{sep}}$	$\epsilon_p \gamma_p$	$\beta_{p,\text{min}}^*$
LHC	$1.7 \times 10^{11}$	25 ns	$3.75 \mu\text{m}$	0.25 m
LHC*	$5 \times 10^{11}$	50 ns	$3.75 \mu\text{m}$	0.10 m

# Linac Layout



Fix main parameters for CDR

Consider also highest “possible” E  
Note that tangential to Point 8 is more space

Injection to p ring

IR for Linac-Ring

Photon-Nucleon Collider

Table 2: Recirculating linac parameters for LHeC-RL.

LHeC-RL scenario	lumi	baseline	energy
final energy [GeV]	60	100	140
cell length [m]	24	24	24
cavity fill factor	0.7	0.7	0.7
tot. linac length [m]	3000	2712	3024
cav. gradient [MV/m]	13	25	32
operation mode	CW (ERL)	pulsed	pulsed

# Accelerator Work Packages

## RING-RING

1. Lattice Design
2. Rf
3. Injector
4. Injection areas and beam dumps
5. Beam-beam effects
6. Impedance
7. Vacuum
8. Integration and machine protections
9. Magnet Design
10. Powering

## LINAC RING

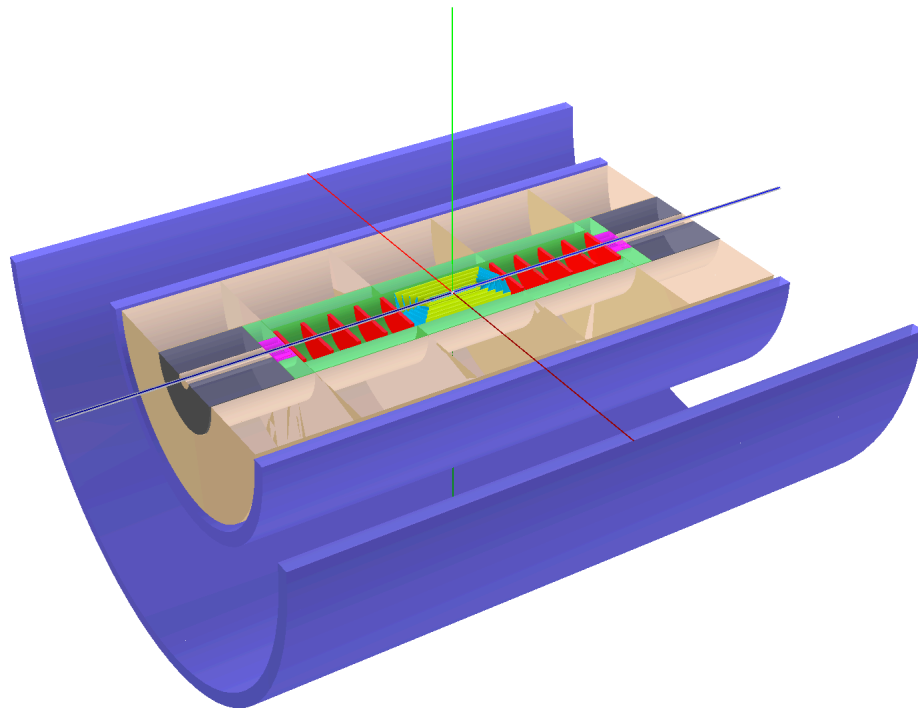
1. Baseline e+p
2. Rf
3. Source
4. Lattice and Impedance
5. Beam-beam effects
6. Vacuum
7. Integration and machine protections
8. IR
9. Magnet Design
10. Powering

Draft 4/09 - OB

Contact persons for work packages [BE-ABP, RF, BT, VAC, PO]

Collaboration: Novosibirsk, EPFL Lausanne, SLAC , CI, DESY, BNL, Cornell

# Detector



IR → beam pipe → detector layout

Choices of technologies

Coil(s)

Forward Tracking (high x)

Fwd (p,n,d) / bwd (e, $\gamma$ ) Taggers

GEANT 4 simulation – link to physics

# Scenarios

config.	E(e)	E(N)	N	$\int L(e^+)$	$\int L(e^-)$	Pol	L/10 <sup>32</sup>	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 <sup>2</sup>
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

For DIS09:

Complete simulation  
of NC and CC including  
systematic errors

[Det. two times better than H1  
and wider fwd/bwd acc.]

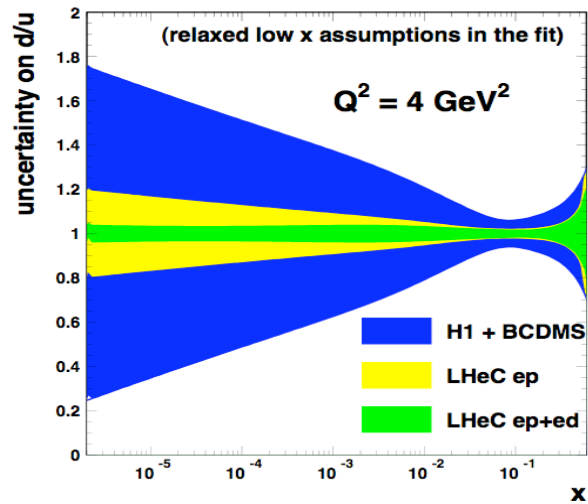
Separately  $F_L$ ,  $F_2^{QQ}$

Shall fix or modify these  
settings 'now'

<http://hep.ph.liv.ac.uk/~mklein/simdis09/lhecsim.Dmp.CC>, readfirst

high x!

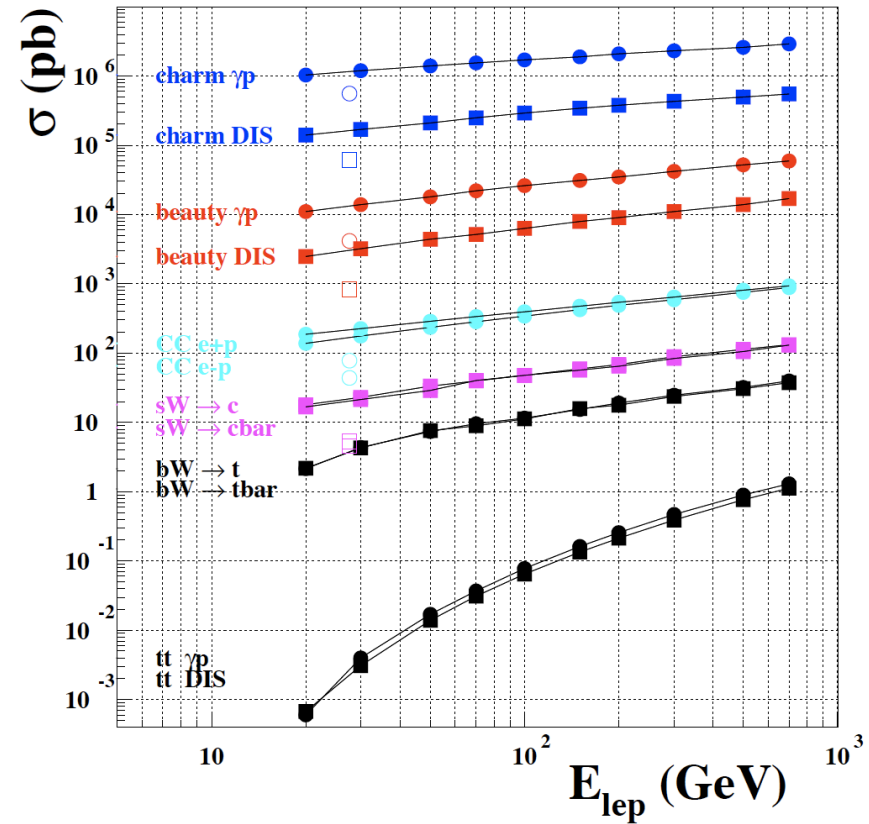
# Unfolding the Partonic Structure of the Proton



$u_v, \bar{u}, d_v, \bar{d}$ ,  
 $s, \bar{s}, c, b$ , single  $t$

$p, d, c, b$  tag, NC, CC

## LHeC total cross sections (MC simulated)



Plots wrt current knowledge  
 (data-data, NNPDF)

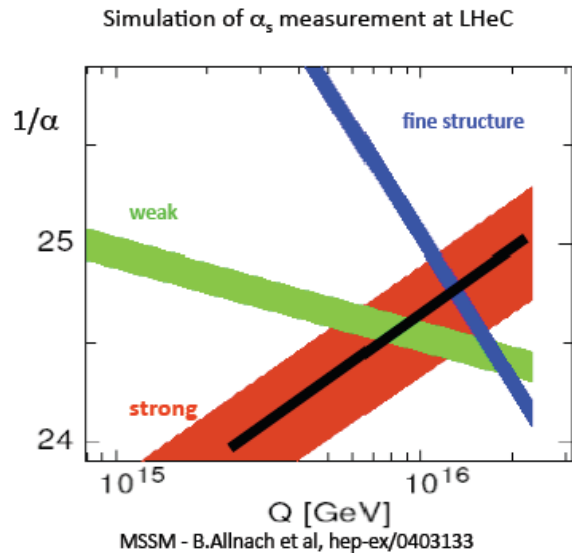
Zoom into high  $x$

Importance of deuterons

GPD's – DVCS

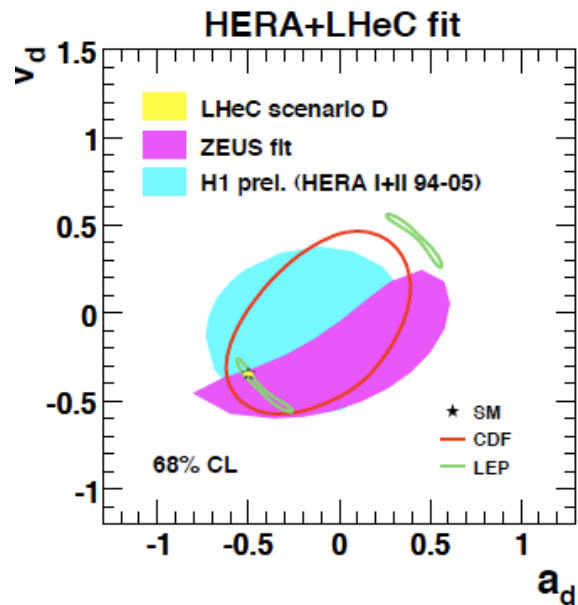
Photon Structure

# Exploration of Superhigh Energy Scales



**Precision** measurement of  $\alpha_s$  [incl + jets]  
Independent of BCDMS

→ SUSY predictions for grand unification



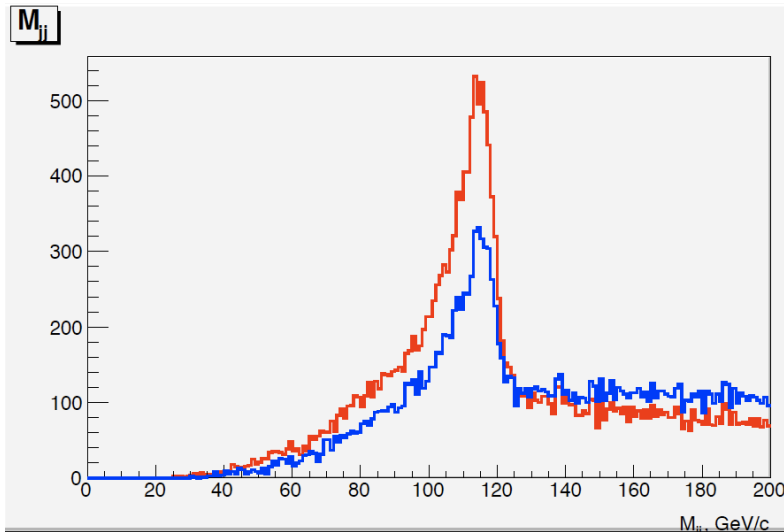
**Precision** electroweak measurements

→ effective couplings, flavour dependence..

Contact Interactions and extra dimensions  
(DIS08 FZ)



# Complementing the LHC

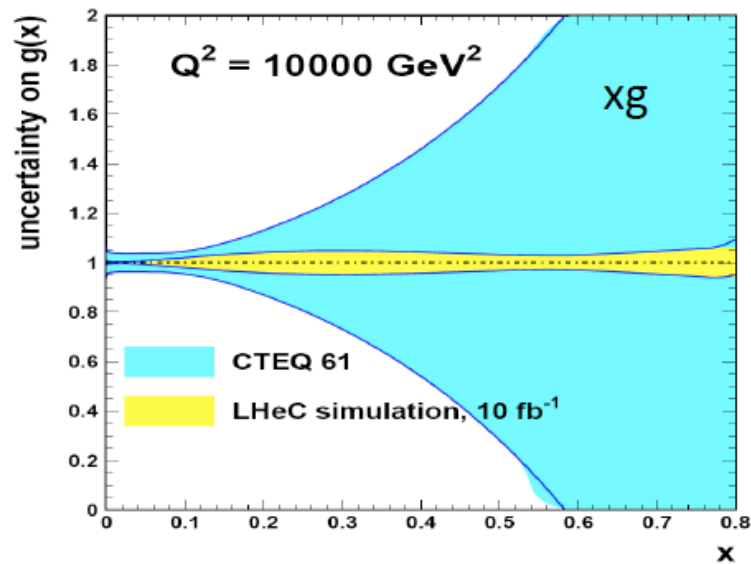


Higgs to  $b\bar{b}$  in CC background and ep detector

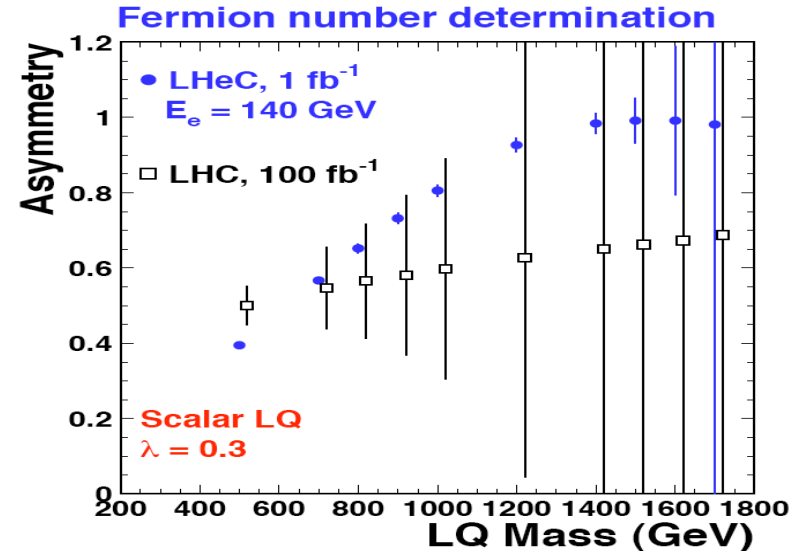
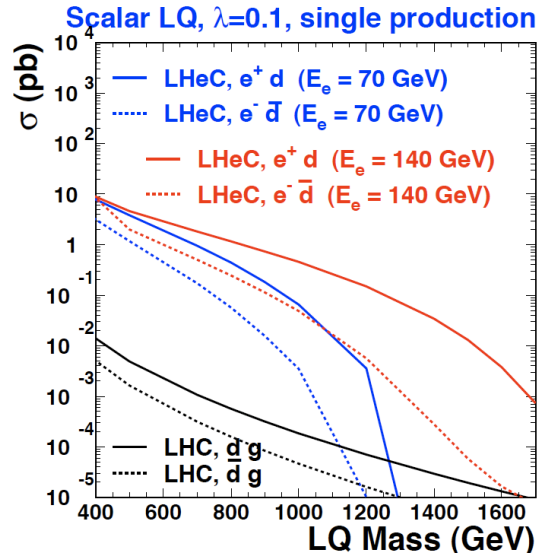
What about no Higgs?

PDFs and new physics (CI-pdf's, ED's)

Understanding QCD (parton dynamics)



# New Physics at the LHeC



Singly produced states:

Excited fermions [ $e^*$ ,  $\nu^*$ ,  $q^*$ ]

RPV SUSY

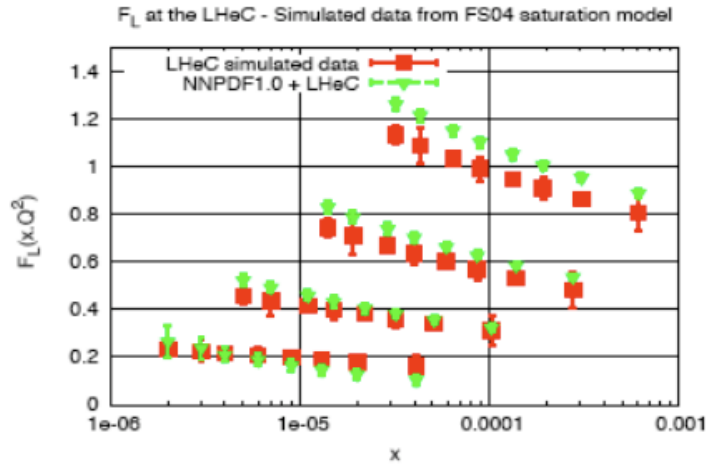
Fermion number: charge asymmetry

Spin: angular distributions

Chiral structure: polarisation

Review-further study potential of pp vs ep [a decade after ATLAS, CMS]

# Parton Saturation at Low x



Two analyses – FKNP, NNPDF – ‘unify’

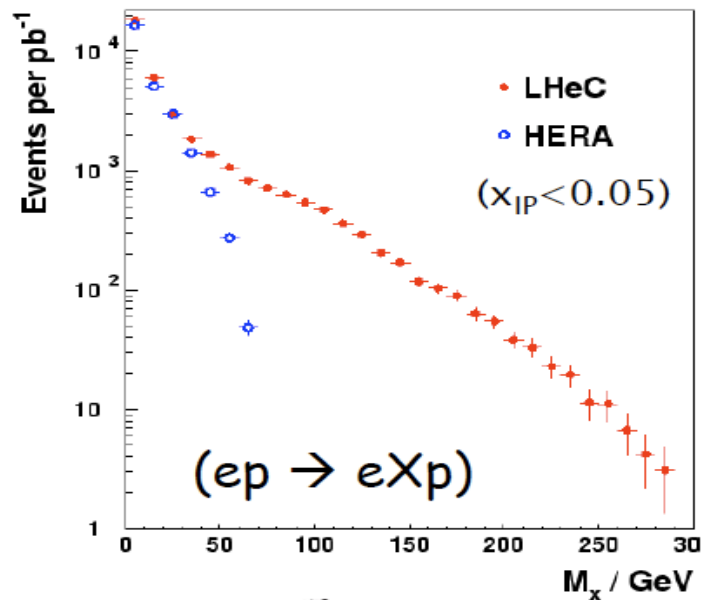
DVCS

Vector Mesons

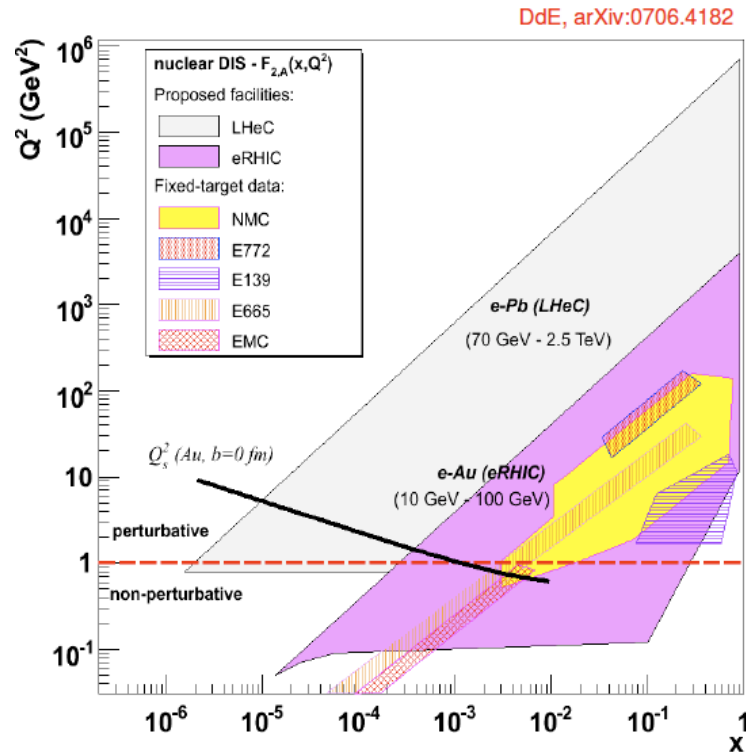
Diffraction b,W,Z,H?

Forward jets and hot spots in p?

Illustrate BB limit ( $F_2$ , J/Psi, 50% Diffraction)



# Nuclei [eA]



Saturation in DIS region!

Nuclear parton distributions

Relation to AA at the LHC

Amplification of  $xg - x_{\text{eff}} \sim 10^{-8}$

Link to superhighE neutrino physics

## DRAFT **Steps to Complete the CDR in 2010** (tbc)

Divonne 09: Fix parameters of the Machine

[50-150 GeV  $E_e$ , 100 MW wall plug, p (7 TeV), D, Ca, Pb -- Scenarios. Acc to 1-179° ]

30. January: Fix Machine Lattice and Main Parameters for RR and LR

15. April: Draft of all Chapters for:

Presentation to Physics and ACC Communities at DIS10 and IPAC10

30. May: Draft of CDR Chapters to Referees

1. September: Referee Reports and final review (3<sup>rd</sup> Workshop)

30. October: Finalization of CDR

November 10: Final Reports to CERN, ECFA, NuPECC

Print of CDR and handover to whom Rolf (CERN), Tatsuya (EFCA) and Guenther (NuPECC) appoint  
timing should be in accord with European Strategy update, LHC, NuPECC long term plan..

Convenors+Steering group meet tomorrow. **Input + full support are essential**

## Organisational Matters

For documentation:

**LHeC Notes:** ACC, DET, PHY, GEN, INT: LHeC-ACC-007-05-2009

**Offices:** CERN provides 4 offices and a meeting room in hut 561

Next **ECFA progress report** expected in November 2009

If it comes to a TDR, the organisation will have to be adapted.  
So far it is suggested in agreement with CERN to keep the structure we work with, i.e. the Steering group, Working Groups and the Scientific Advisory Committee

# Working Groups and Convenors

## **ACC - Accelerator Design**

Oliver Bruening (CERN)

John Dainton (CI/Liverpool)

## **IRF - Interaction Region and Fwd/Bwd**

Bernhard Holzer (DESY)

Uwe Schneekloth (DESY)

Pierre van Mechelen (Antwerpen)

## **DET - Detector Design**

Peter Kostka (DESY)

Rainer Wallny (UCLA)

Alessandro Polini (Bologna)

## **NUP - New Physics at Large Scales**

Georges Azuelos (Montreal)

Emmanuelle Perez (CERN)

Georg Weiglein (Durham)

## **QCE - Precision QCD and Electroweak**

Olaf Behnke (DESY)

Paolo Gambino (Torino)

Thomas Gehrmann (Zuerich)

Claire Gwenlan (Oxford)

## **HPD - Physics at High Parton Densities**

Nestor Armesto (CERN)

Brian Cole (Columbia)

Paul Newman (Birmingham)

Anna Stasto (MSU)

**Welcome to Claire and Georges**

# Scientific Advisory Committee

Guido Altarelli (Rome)  
Sergio Bertolucci (CERN)  
Stan Brodsky (SLAC)  
Allen Caldwell **Chair** (MPI Munich)  
Swapam Chattopadhyay (Cockcroft)  
John Dainton (Liverpool)  
John Ellis (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)  
Richard Milner (Bates)  
Joachim Mnich (DESY)  
Steven Myers (CERN)  
Tatsuya Nakada (Lausanne, ECFA)  
Guenter Rosner (Glasgow, NuPECC)  
Alexander Skrinsky (Novosibirsk)  
Anthony Thomas (Jlab)  
Steven Vigdor (BNL)  
Frank Wilczek (MIT)  
Ferdinand Willeke (BNL)

## Welcome to

**Sergio Bertolucci (CERN)**  
**Tatsuya Nakada (ECFA)**  
**Joachim Mnich (DESY)**

## Thanks to

**Jos Engelen (ex CERN)**  
**Karlheinz Meier (ex ECFA)**  
**Rolf Heuer (ex DESY)**

The **meeting with SAC at DIS09** was an attempt to establish closer relations and get in time advice from the committee for the CDR and the project. This will be followed closer for the CDR finalization. Various **members of the SAC have made invaluable contributions** to our work, and we count on the committee's advice and insight in the development of particle physics.



## In 3 sentences

The physics of the LHeC is unique, fundamental and complementary to pp,  $e^+e^-$ .

The LHeC is a very serious candidate for a further TeV collider, as it may be built using known technology at not exceedingly high cost.

For the deliberations on the future of HEP, with the LHC opening a new dimension, the Conceptual Design Report has been requested by (r)ECFA and CERN. It may be delivered if we keep working together and the LHeC receives the support it deserves.

**Think of ~1 word instead of 3 sentences –  
Is that the worlds' new microscope?**

Thank you for coming here.

Thanks to all for the many contributions and thoughts on the ep/eA collider including those who are engaged in lower energy and polarised EIC's.

Thanks to CERN, Rolf, Sergio, Steve, to ECFA and NuPECC

Thanks to Patricia and Antonella

**Enjoy Divonne and the dinner, today at 8pm.**