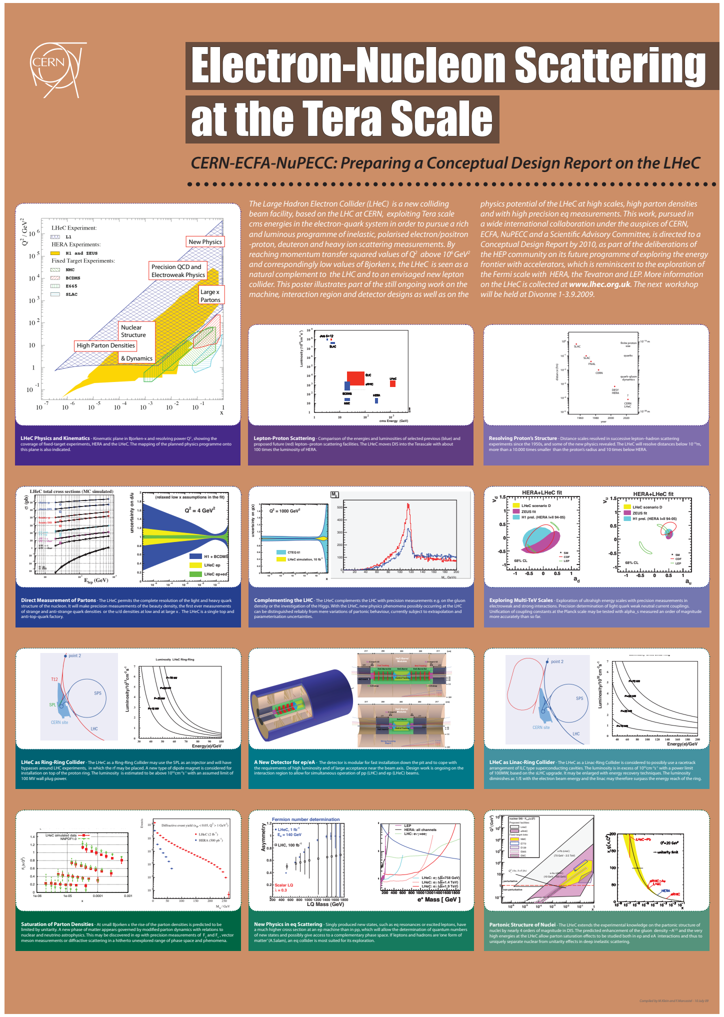
Large Hadron Electron Collider

Progress Report to ECFA



Poster at EPS09 and Lepton-Photon09

www.lhec.cern.ch

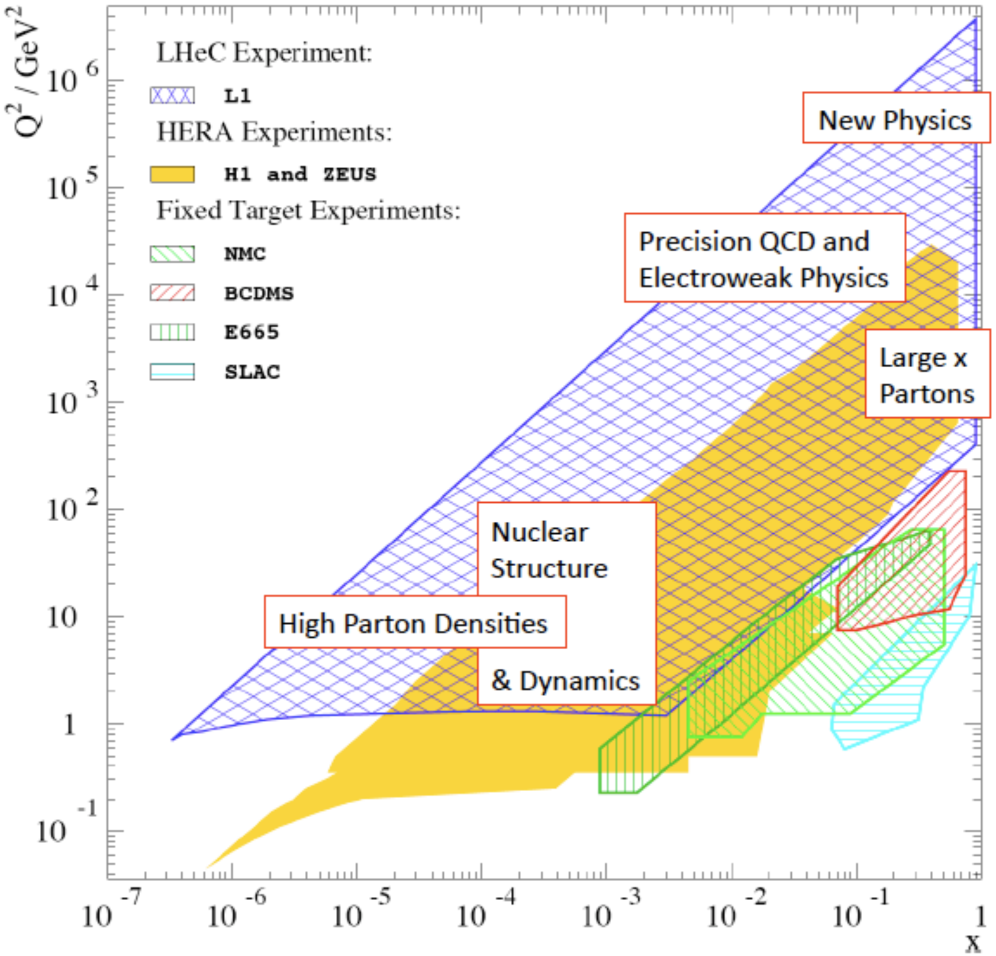
Max Klein

for the LHeC Group

UNIVERSITY OF LIVERPOOL

ECFA at CERN Geneva 27. November 2009

Kinematics and Recent Developments



2008

September	Divonne workshop; NuPECC Meeting at Glasgow
October	ICFA Seminar at SLAC
November	**ECFA Plenary at CERN**
December	Convenor's Meeting at CERN

2009

March	Visit to SLAC [Linac]
April	DIS09 at Madrid: LHeC premeeting, parallel, SAC plenary panel (M.K. arXiv:0908.2877 [hep-ex])
April	PAC09 at Vancouver - Papers, Talk, Proceedings
May	Visit to BINP Novosibirsk [Ring Magnets]
June	Low x / HPD meeting at CERN, pre-Blois
September	**Divonne II (CERN-ECFA-NuPECC Workshop)** ~80 talks from ~ 100 participants
October	NuPECC Long Range Planning Workshop

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

DRAFT - February 2009

Extended version by Mid December09

Physics Programme of the LHeC

+ Unfolding completely the **parton structure of the proton** (and of the neutron and photon) and search for sub-substructure down to 6 10^{-20}m

+ Exploration of **new symmetries and the grand unification** of particle interactions with electroweak and strong interaction measurements of unprecedented precision.

+ Search for and exploration of **new, Terascale physics**, in particular for new states with lepton qu.numbers (RPV SUSY, LQ, excited fermions), complementary to the LHC

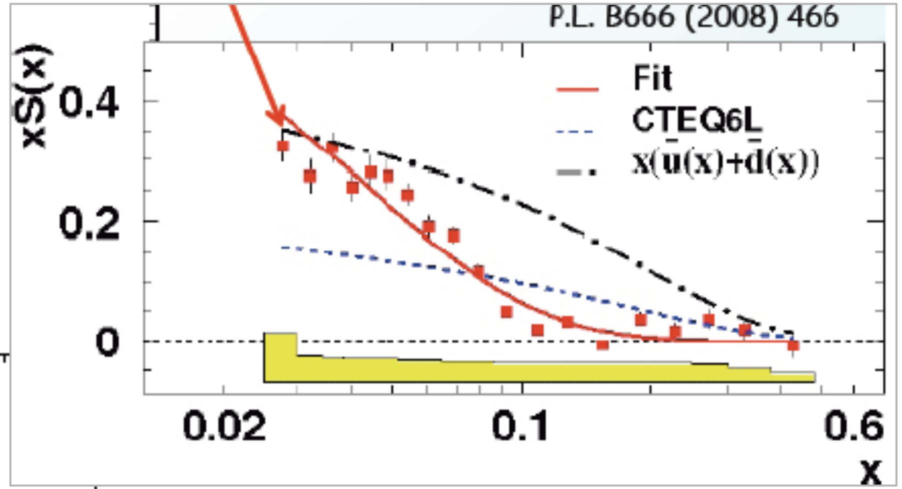
+ Exploration of **high density matter** [low x physics beyond the expected unitarity limit for the growth of the nucleon gluon density]

+ Unfolding the substructure and **parton dynamics inside nuclei** by an extension of the kinematic range by four orders of magnitude [initial state of the QGP]

Large amount of studies done and ongoing, without aiming at complete list.
Follows an example per point each. Note that these are final when written up**.**

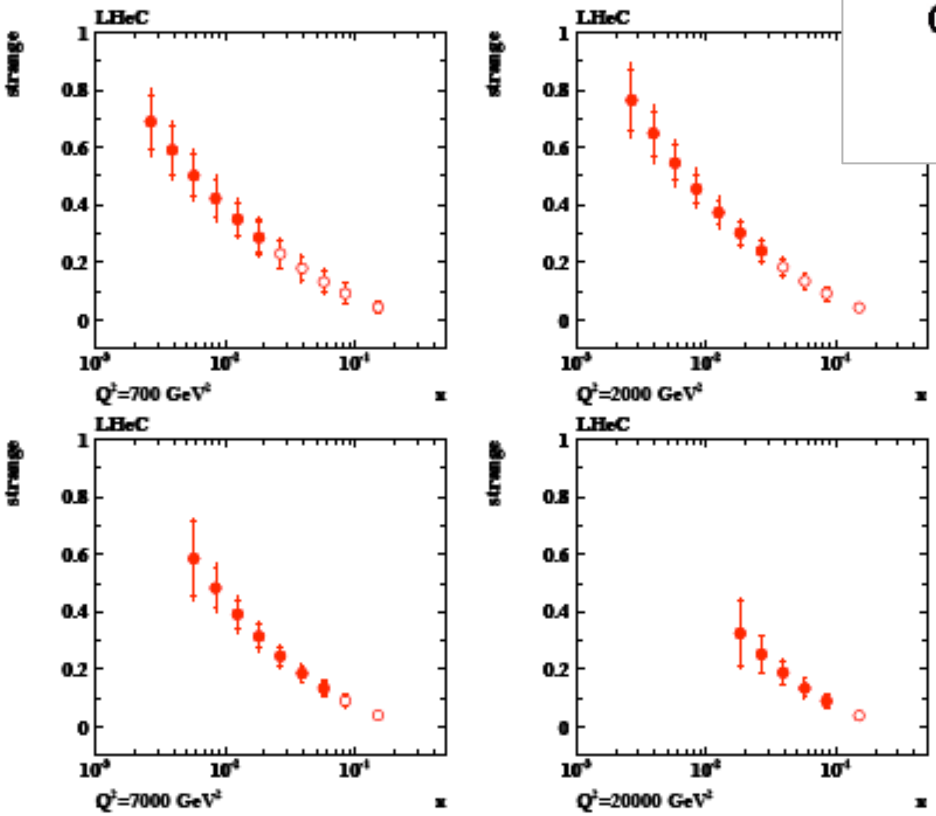
Strange and Anti-Strange Quark Distributions

Not measured with H1,ZEUS
HERMES (N_K): s much larger?
Dimuon data: s ≠ sbar?



HERMES, K.Rith EPS09

$Q^2 \sim 1\ \text{GeV}^2$

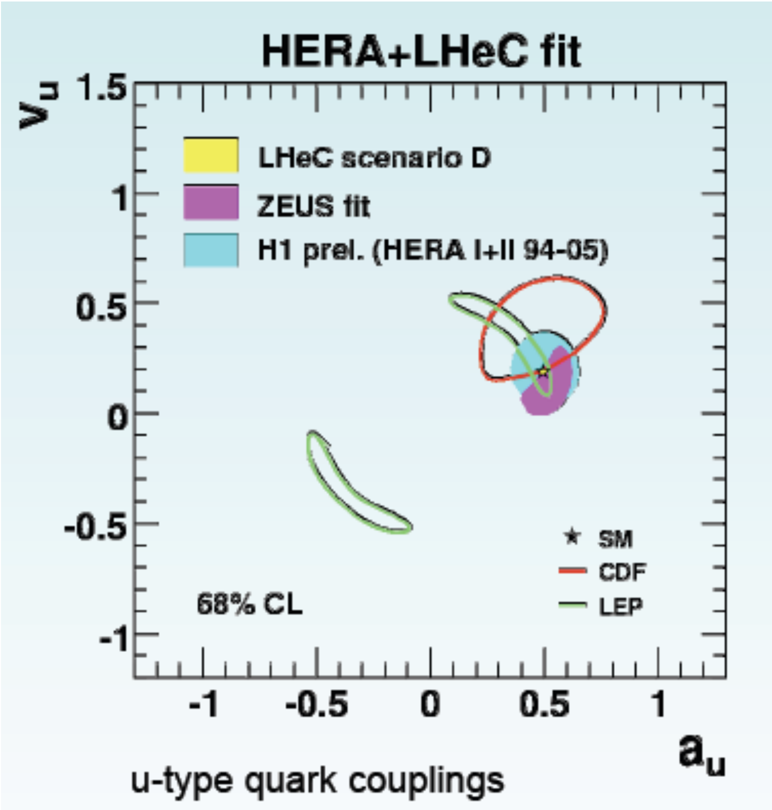


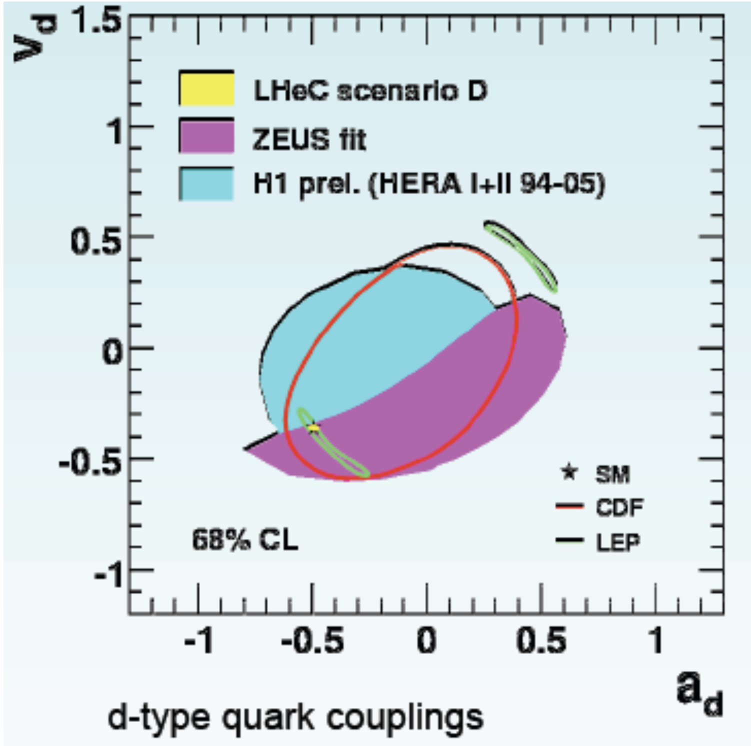
$W^- sbar \rightarrow cbar$
$1 fb^{-1}$
$\varepsilon_c = 0.1$
$\varepsilon_q = 0.01$
$\delta_{syst} = 0.1$
$\circ - \vartheta_h \geq 1^o$
$\bullet - \vartheta_h \geq 10^o$

W,Z sensitive to s

LHeC: measure both strange and anti-s with high precision for the first time

High Precision Electroweak Physics

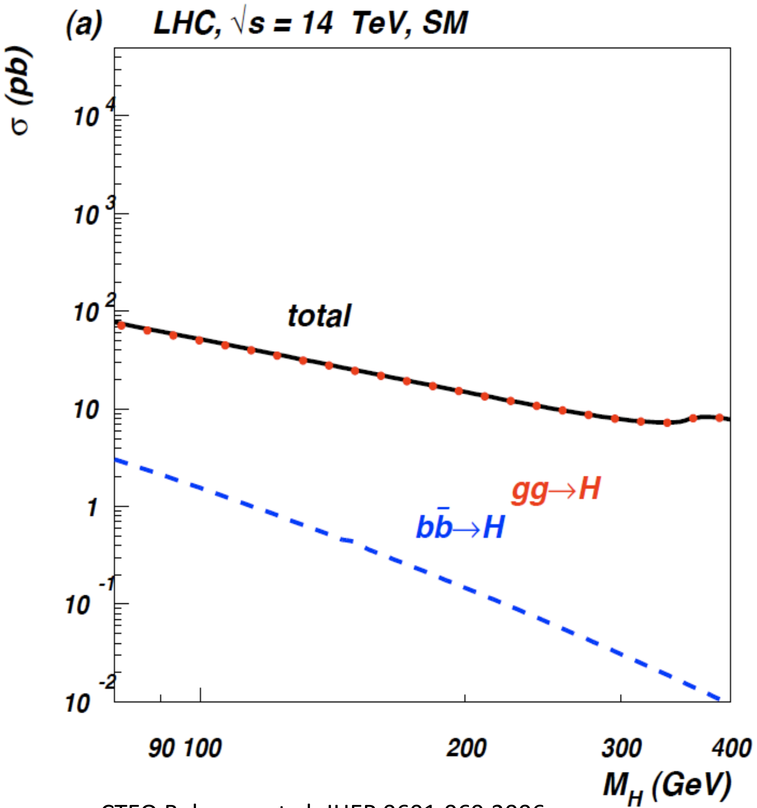




Precision measurement of weak neutral current couplings (+pdf's): access to new electroweak physics.

40 TeV limits on Contact Interactions and correspondingly on extra dimensions

Gluon - SM Higgs

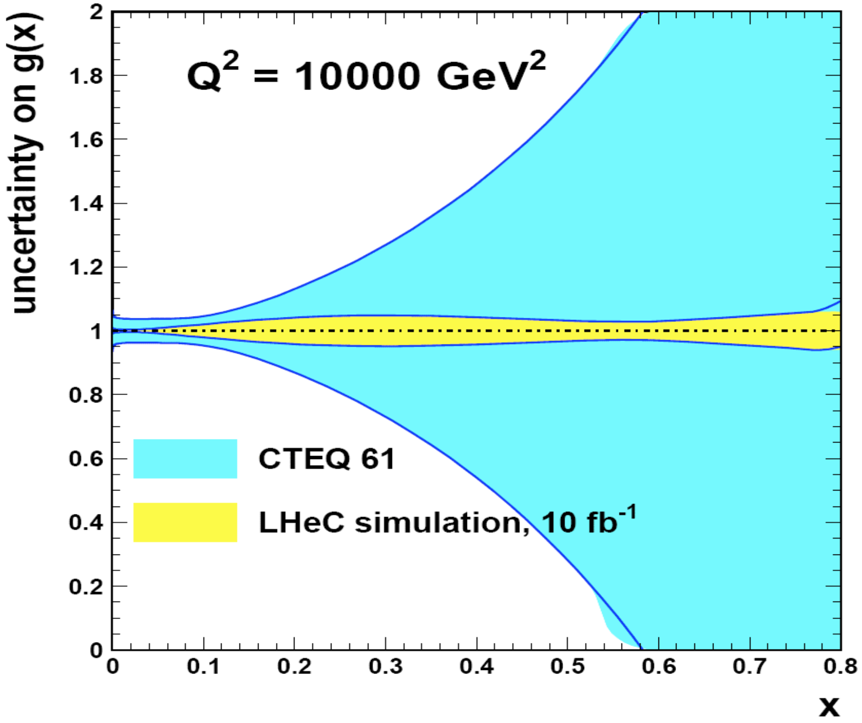


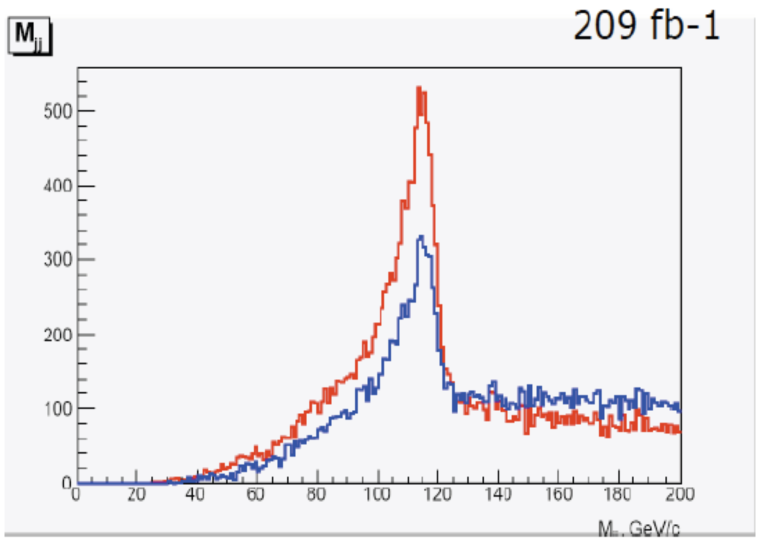
CTEQ Belyayev et al. JHEP 0601:069,2006

In SM Higgs production is gluon dominated

LHeC: huge x,Q^2 range for xg determination

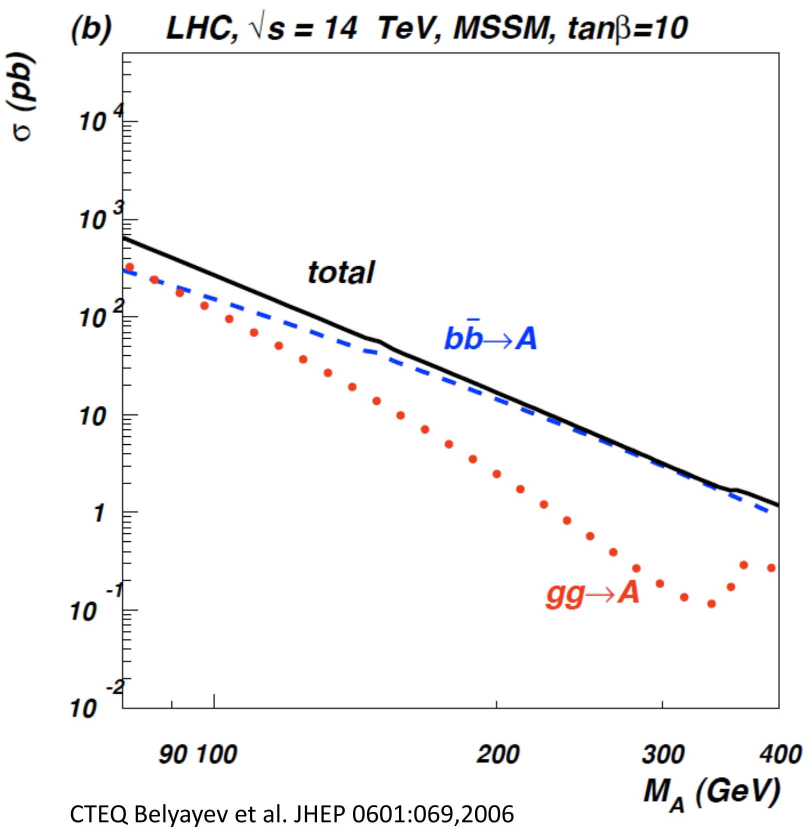
WW to Higgs fusion has sizeable ep xsection



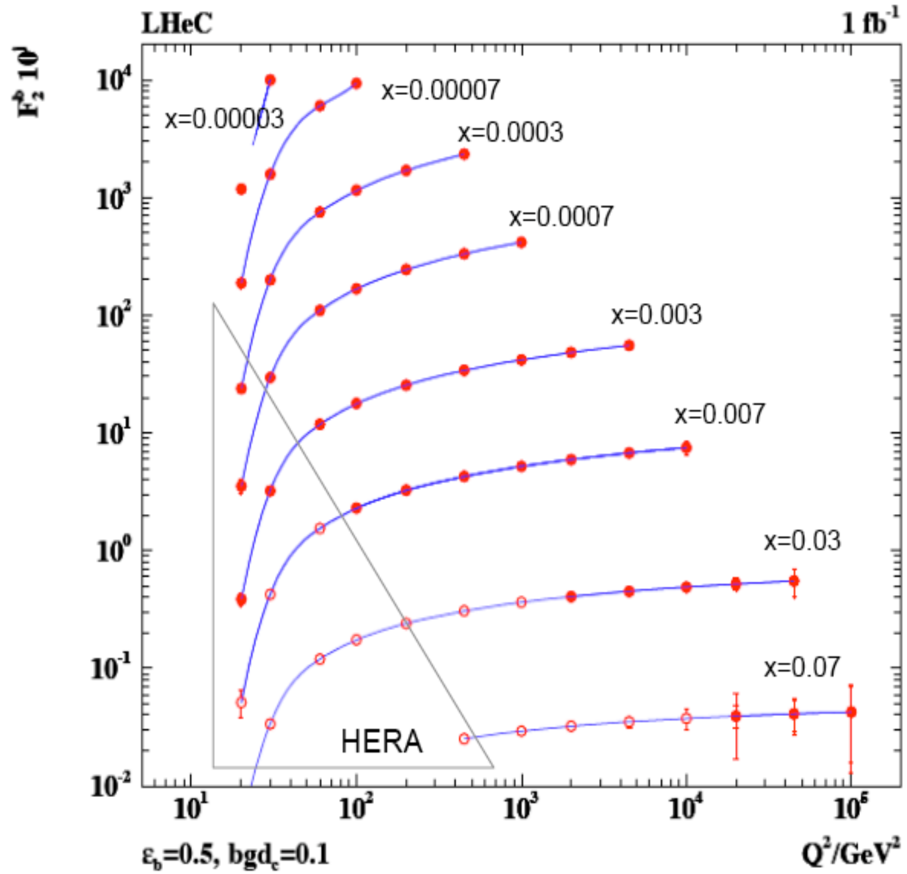


Cf Divonne 09 for QCD bgd studies + btagging

Beauty - MSSM Higgs



CTEQ Belyayev et al. JHEP 0601:069,2006

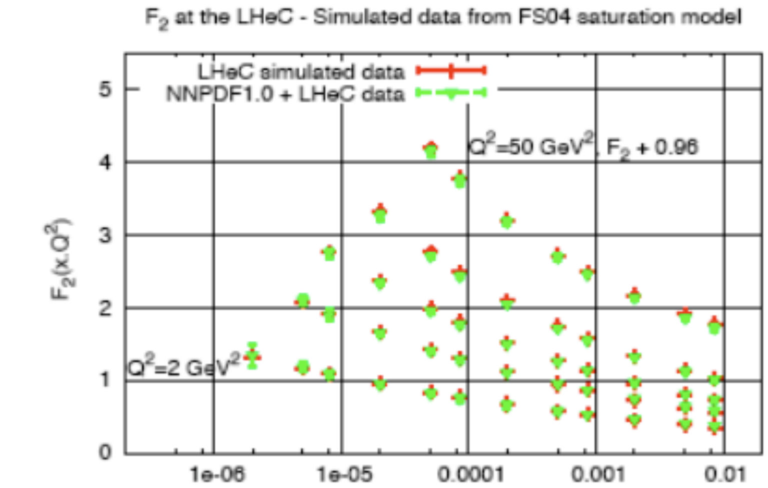


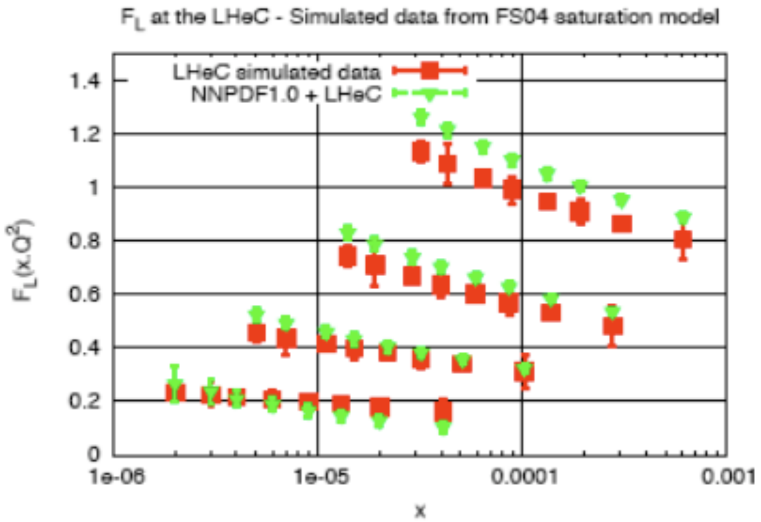
In MSSM Higgs production is b dominated

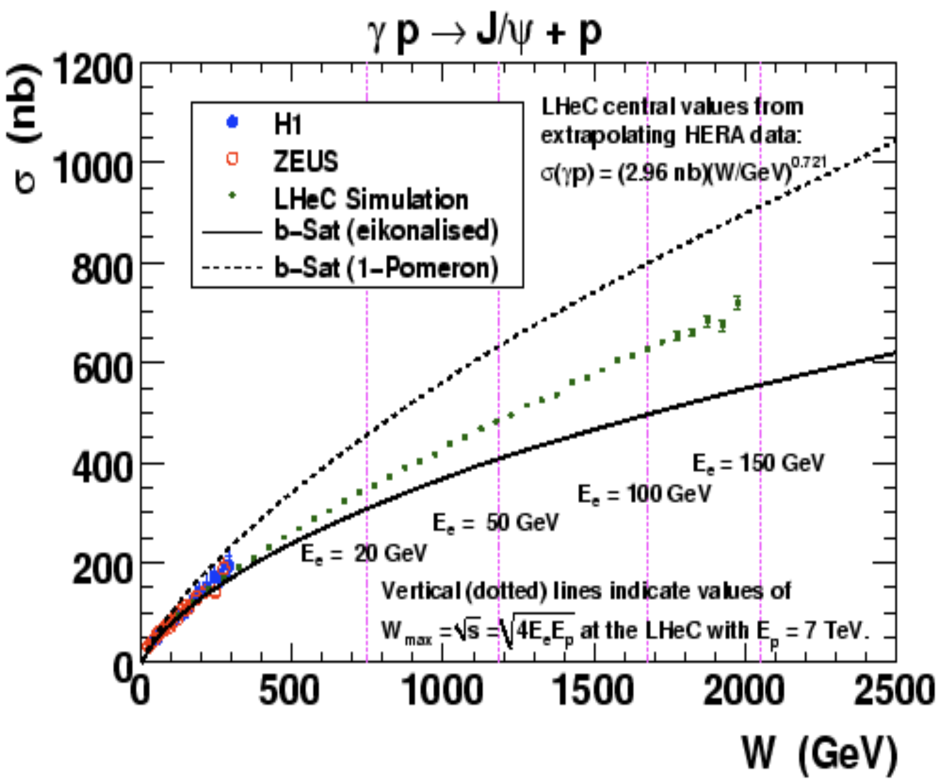
First measurement of b at HERA can be turned to precision measurement.

LHeC: higher fraction of b, larger range, smaller beam spot, better Si detectors

Discovery of Parton Saturation – ep, low x



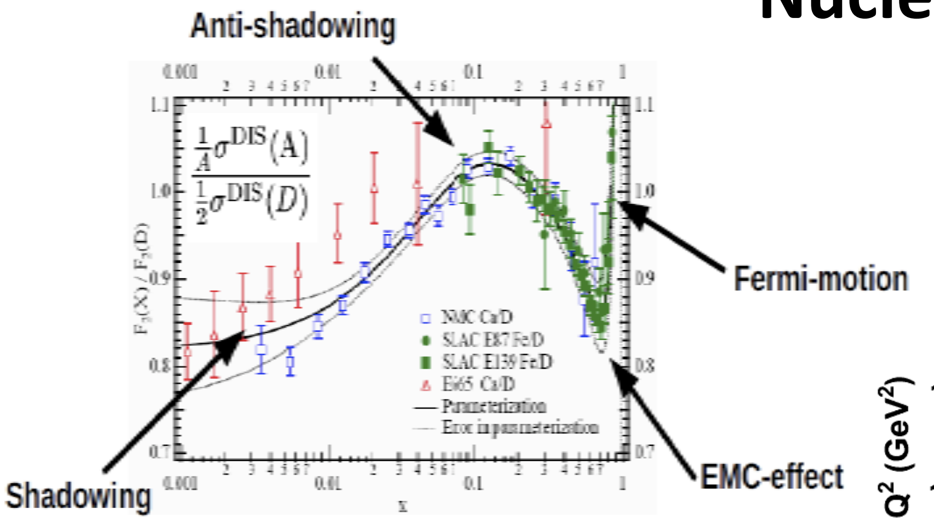


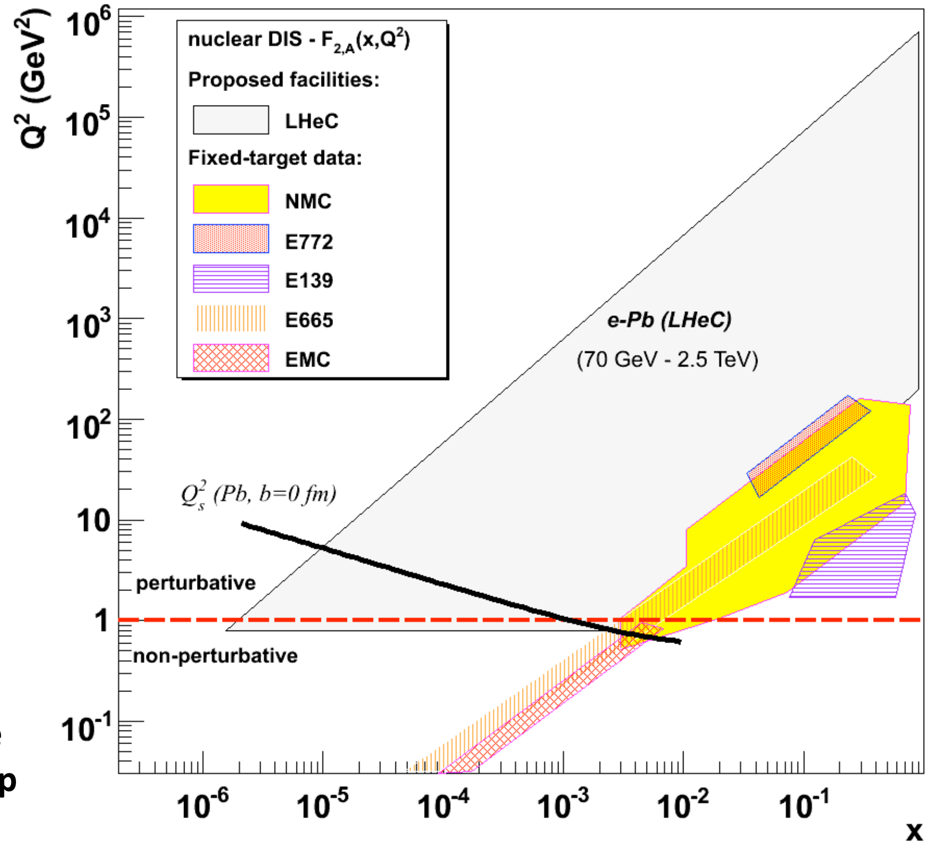


Full simulation of F_2 and F_L

Both together must reveal saturation

Nuclear Structure and Dynamics





Extension of Q^2, 1/x range by 10^4

Fermi motion -- p tagging
Shadowing -- diffraction

p, D, Ca, Pb beams

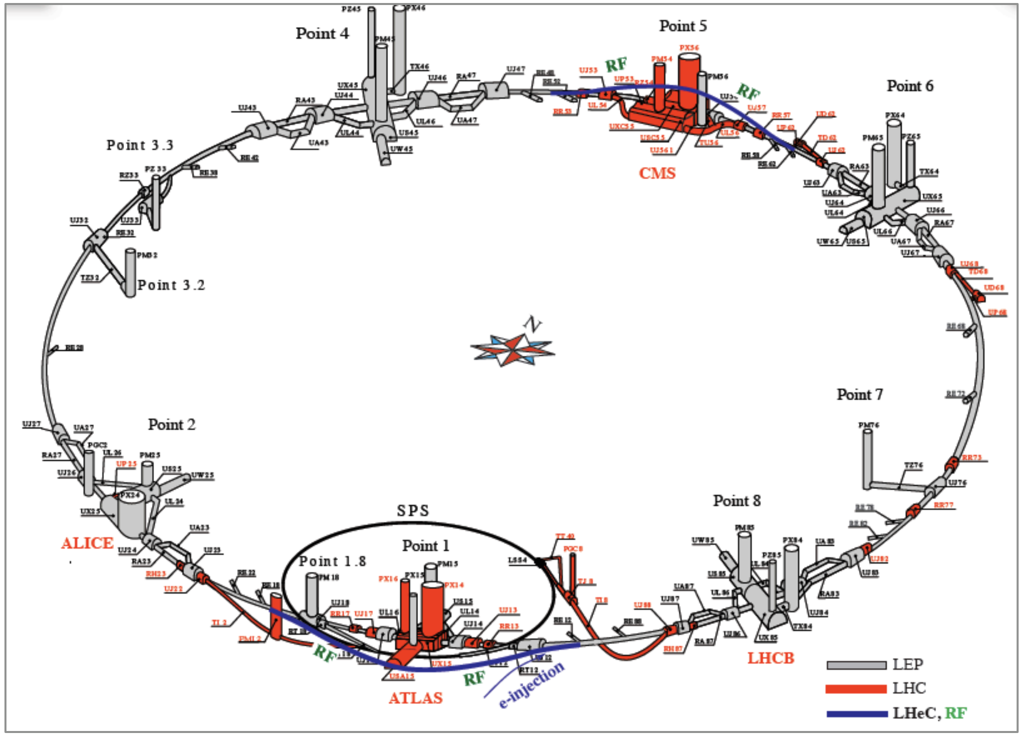
Complete determination of nPDFs into nonlinear regime
LHeC is bound to discover parton saturation in eA AND ep

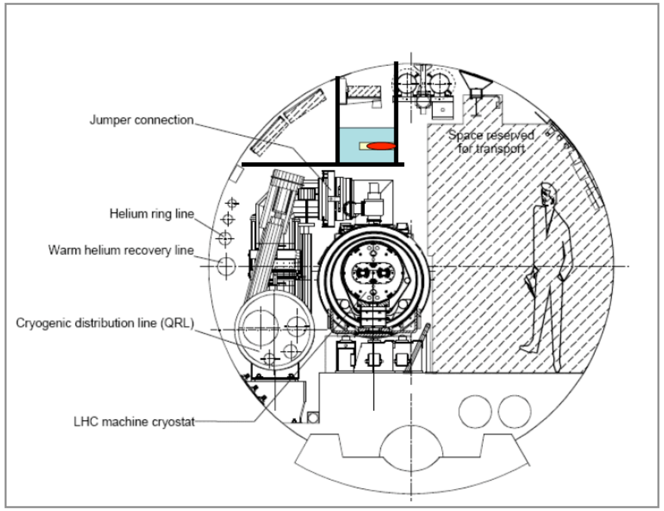
Accelerator and Detector Design

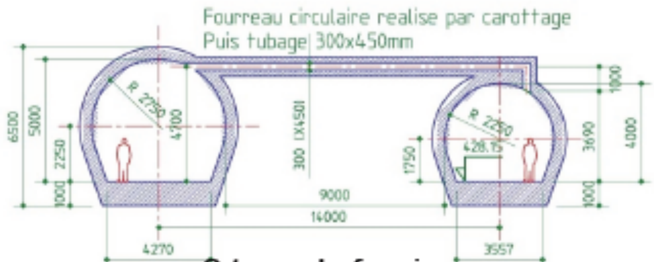
Collaborations of CERN
with experts from Cockcroft, BNL, DESY, KEK Lausanne, Novosibirsk, SLAC, TAC

20 workpackages with identified responsibles

Ring-Ring ep/eA







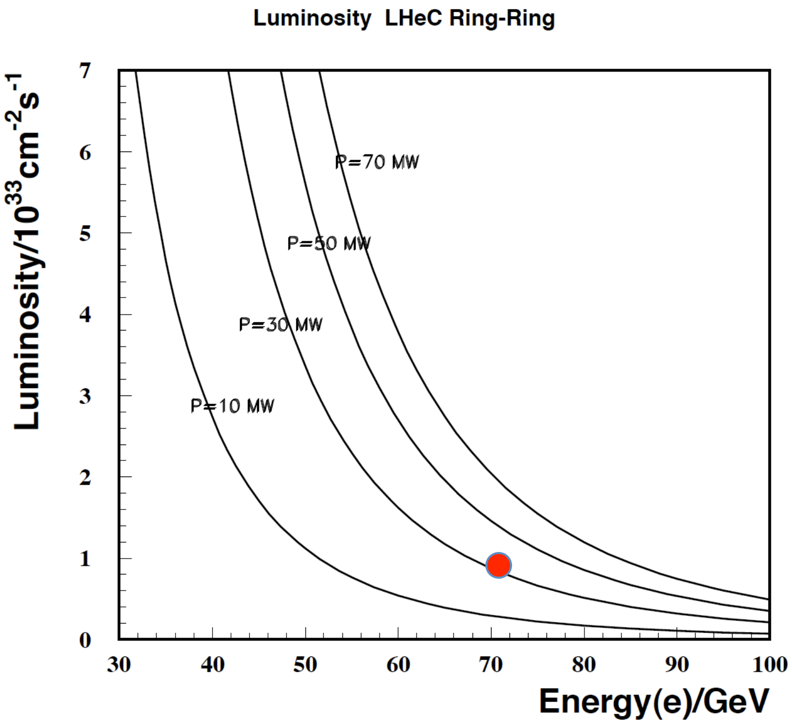
2 tunnels for ring and shielded rf

E_e=10 … 70 GeV. L_{ep}~$10^{33}cm^{-2}s^{-1}$ (100 times HERA)

Injector: dedicated or SPL based.

Detailed first design study in JINST P1001 (2006)

RR Luminosity and Parameters



Luminosity for $e^{\pm}p$ safely above $10^{33} cm^{-2} s^{-1}$

Used "ultimate" LHC beam parameters

Energy limited by injection and syn.rad losses

Power limit set to 100 MW

Small p tuneshift: simultaneous pp and ep

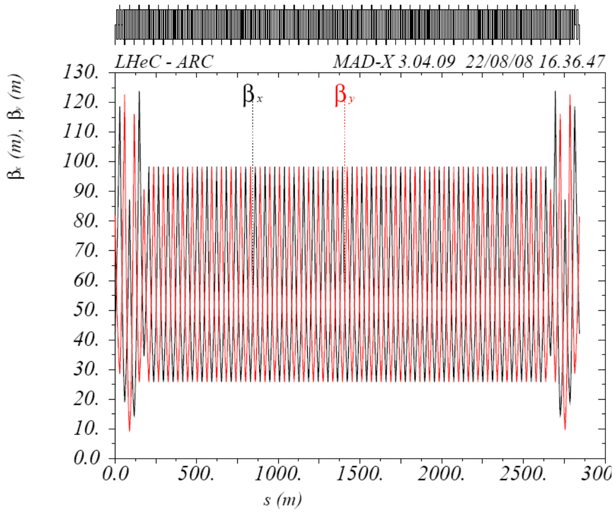
Ultimate Parameter	*Protons*	*Electrons*	
	$N_p=1.7*10^{11}$	$N_e=1.4*10^{10}$	$n_b=2808$
	$I_p=860mA$	$I_e=71mA$	
Optics	$\beta_{xp}=230$ cm	$\beta_{xe}=12.7$ cm	
	$\beta_{yp}=60$ cm	$\beta_{ye}=7.1$ cm	
	$\varepsilon_{xp}=0.5$ nm rad	$\varepsilon_{xe}=9$ nm rad	
	$\varepsilon_{yp}=0.5$ nm rad	$\varepsilon_{ye}=4$ nm rad	
Beamsize	$\sigma_x=34\ \mu m$		
	$\sigma_y=17\ \mu m$		
Tuneshift	$\Delta\nu_x=0.00061$	$\Delta\nu_x=0.056$	
	$\Delta\nu_y=0.00032$	$\Delta\nu_y=0.062$	
Luminosity	$L=1.03*10^{33}$		

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

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

e Ring – Optics

Optics in the arcs

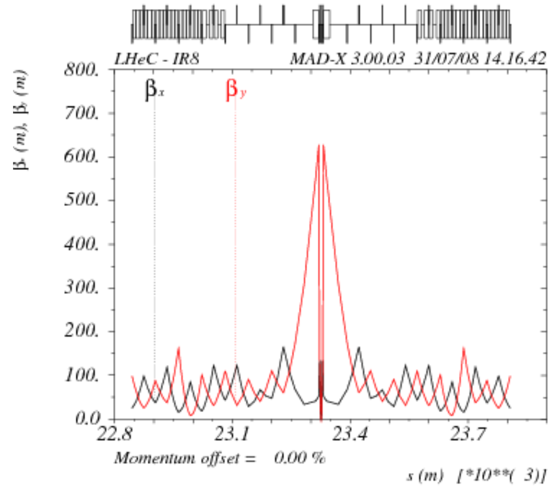


2009: optimisation of FODO cell

Dispersion reduced to 20-50cm

emittance ε_x=7.5nm ε_y=3.7 nm

MEDIUM or WEAK BEND SOLUTION

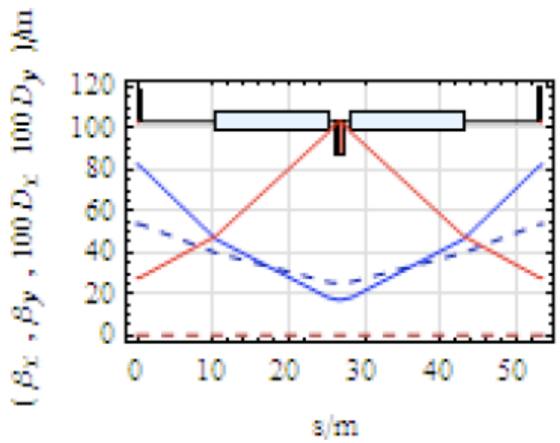


β functions for LHeC - 2008

Dispersion was 50-90cm

and horiz. emittance 22 nm

384 60m long cells

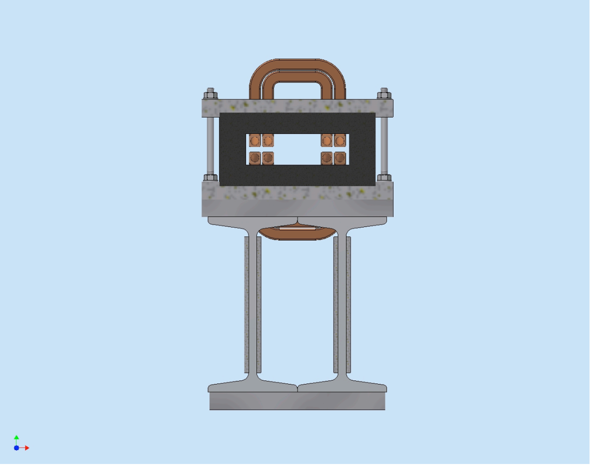


Optimisation ongoing

“inner” triplet focus
β_x=7.1cm β_y=12.7cm

Mini beta design

Dipole Magnets

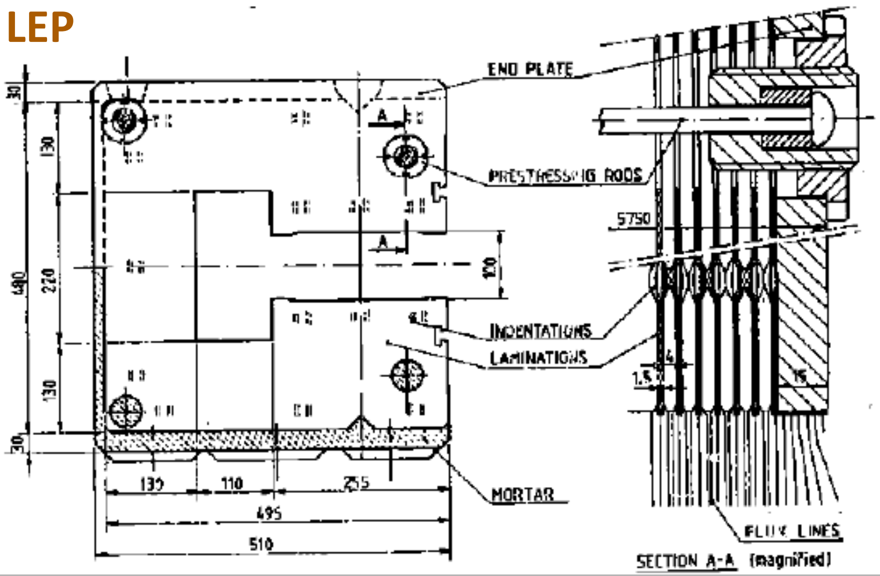


O-shaped magnet with ferrite core [BINP-CERN]

Accelerator	LEP	LHeC
Cross Section/ cm²	50 x 50	20 x 10
Magnetic field/ T	0.02-0.11	0.02-0.135
Energy Range/GeV	20-100	10-70
Good Field Area/cm²	5.9 x 5.9	6 x 3.8
FODO length/m	76	53
Magnet length/m	2 x 34.5	2 x 14.76
segmentation	6 cores	14
Number of magnets	736	488
Weight / kg/m	800	240

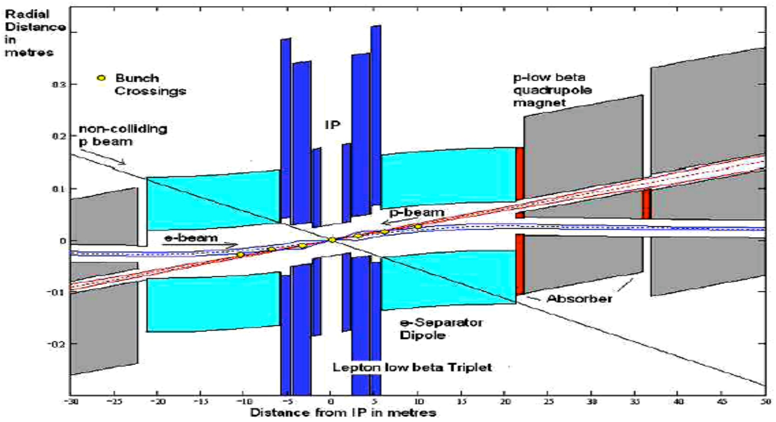
Prototype design under way at Novosibirsk, May 2010

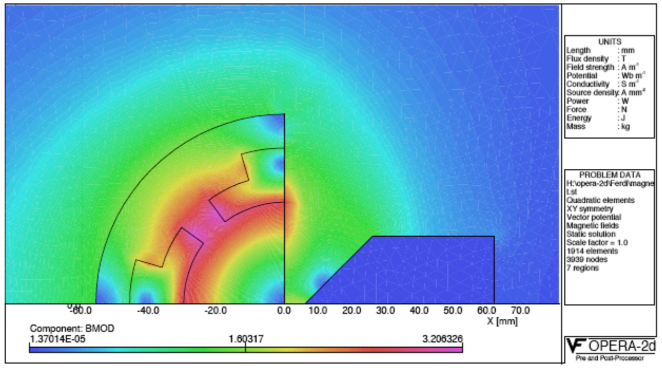
LEP



Ring – Work in progress

Interaction region design

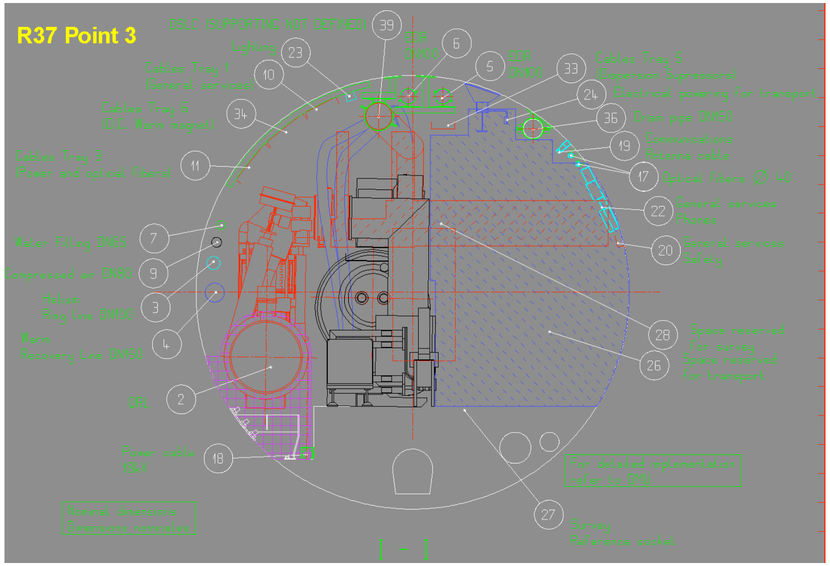




Installation study

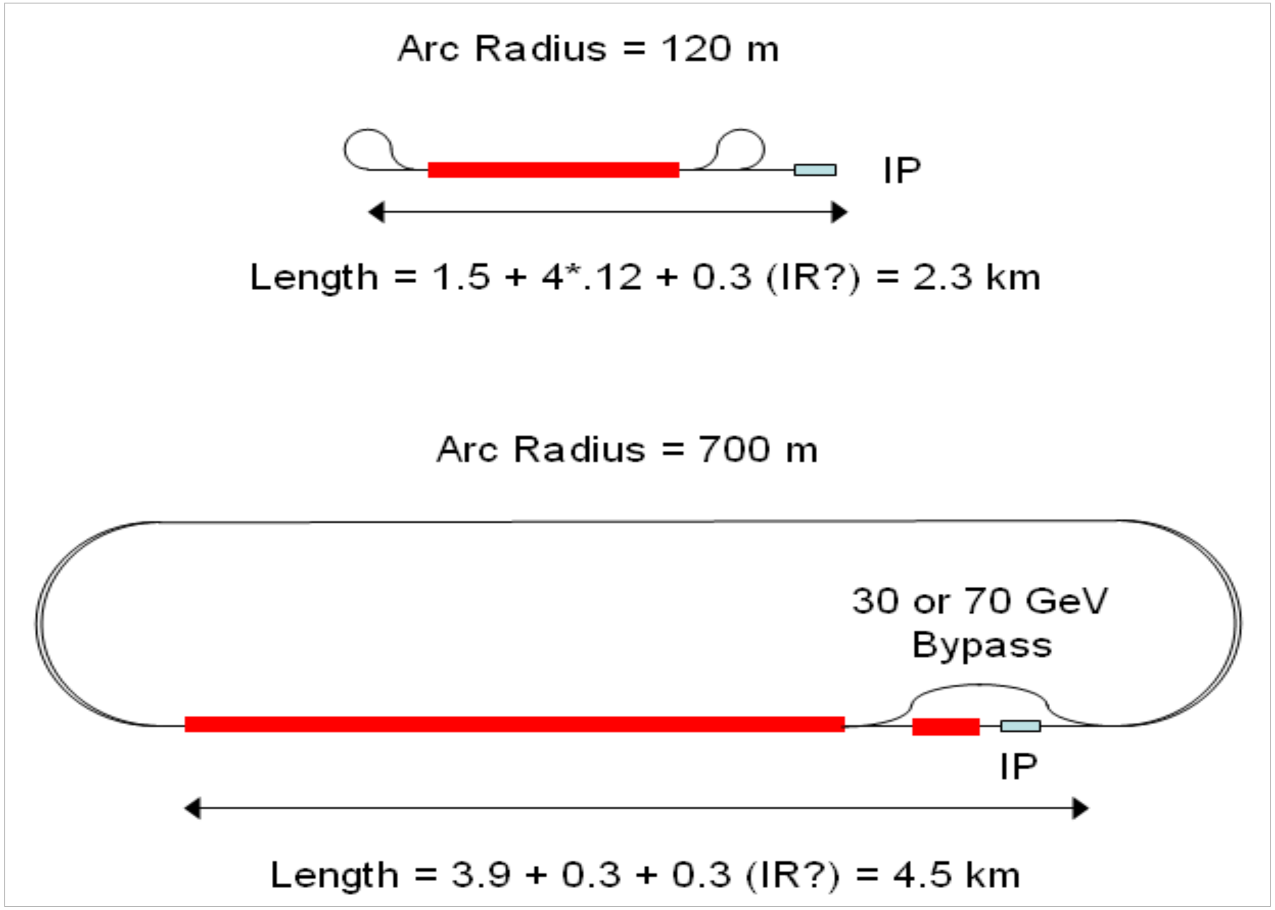
Systematic investigation of clashes with LHC installation and possible ways 'around'

Installation sequence - timeline



Polarisation

Two LINAC Configurations [CERN-SLAC]



60 GeV
31 MV/m, pulsed
two passes

60 GeV
13 MV/m CW ERL
4 passes

140 GeV
31 MV/m, pulsed
2 passes

LINAC-Ring Parameters

Configuration	60 GeV, pulsed	60 GeV CW ERL	140 GeV pulsed
N_e/bunch/ 10^9/50ns	4	1.9	2
gradient MV/m	32	13	32
normalised ε/ μm	50	50	100
cryo power/MW	3	20	6
effective beam power/MW	50	$40/(1-\eta_{ERL})$	50

Luminosity for ultimate beam

$$N_p = 1.7 \cdot 10^{11}, \varepsilon_p = 3.8 \mu m, \beta^* = 0.2 m, \gamma = 7000/0.94$$

$$L = 8 \cdot 10^{31} cm^{-2} s^{-1} \cdot \frac{N_p 10^{-11}}{1.7} \cdot \frac{0.2}{\beta^* / m} \cdot \frac{P/MW}{E_e / GeV}$$

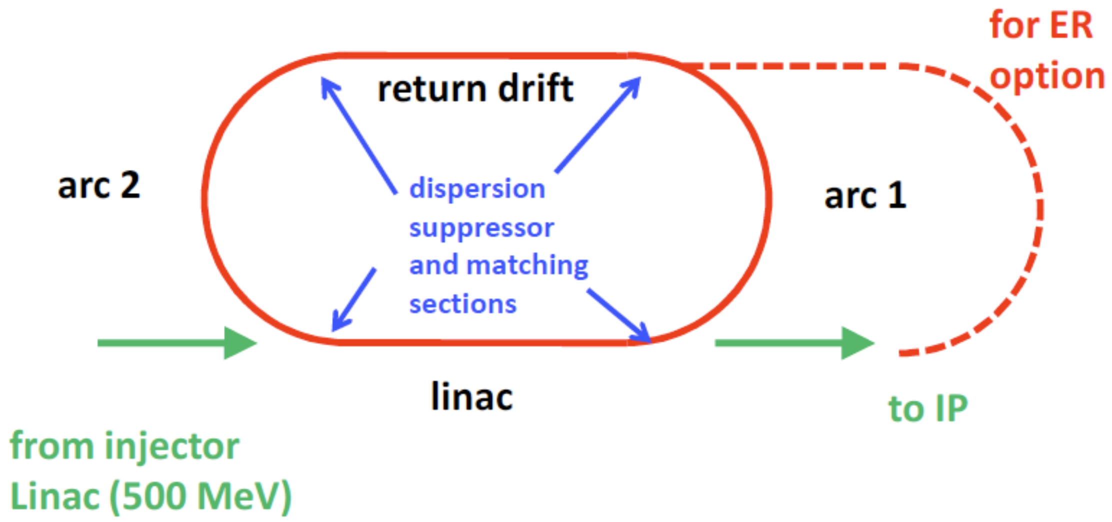
An Electron-Proton Collider in the TeV Range

M. Tigner, Cornell Univ., Ithaca, NY
B. Wiik, F. Willeke, DESY, Hamburg, FRG

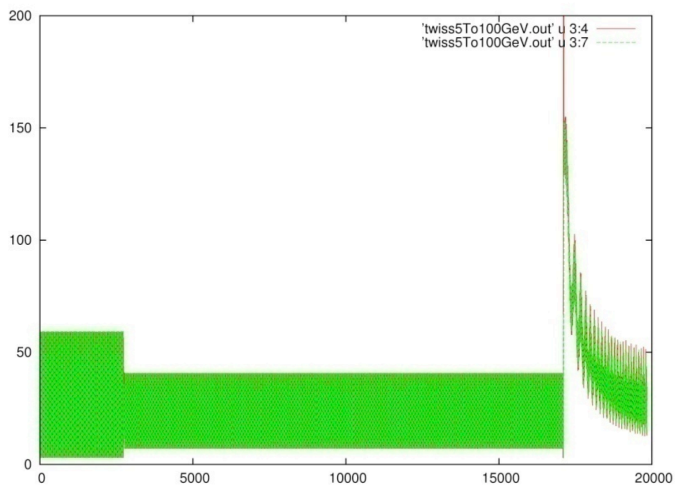
As the era of e-p colliders begins we need to begin a search for practical schemes for increasing the available center of mass energies. The use of an SC linac on SC proton ring approach may offer a practical possibility while maintaining a favorable electron to proton beam energy ratio.

The LR combination yet requires a still better p beam or/and E_e recovery to come to luminosity beyond $10^{32} cm^{-2} s^{-1}$

e Optics for LINAC

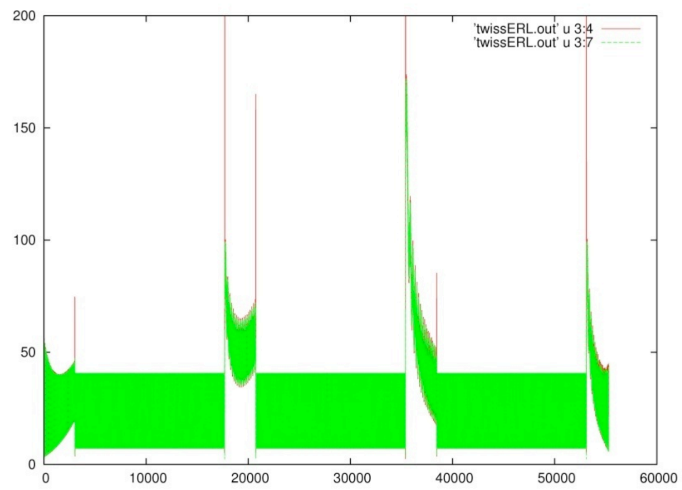


$\beta_{x,y}$



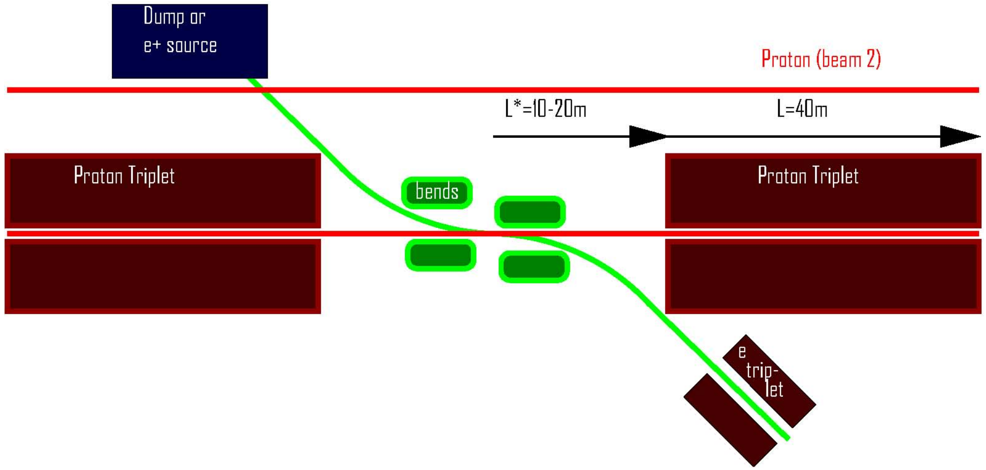
2 passes

$\beta_{x,y}$



4 passes - ERL

LINAC - Work in Progress



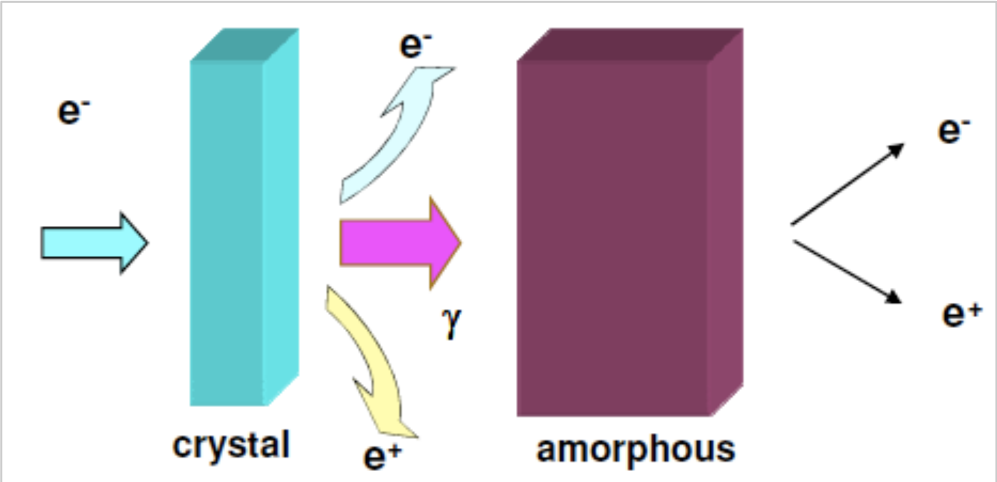
IR Options:

Head on → dipoles

Crossing → like RR IR

Positron source

Difficult to reach high intensity. Perhaps best suited: hybrid target production of unpolarised positrons. Several stations? cf Divonne



LHeC Detector

version for low x and eA

Muon chambers
(fwd,bwd,central)

Coil (r=3m l=11.8m, 3.5T)
[Return Fe not drawn,
2 coils w/o return Fe studied]

<u>Central Detector</u>

Pixels
Elliptic beam pipe (~3cm - or smaller)

Silicon (fwd/bwd+central)
[Strip or/and Gas on Slimmed Si Pixels]
[0.6m radius for 0.03% * pt in 3.5T field]

El.magn. Calo (Pb,Scint. 9-12X_0)
Hadronic Calo (Fe/LAr; Cu/Brass-Scint. ~30λ)

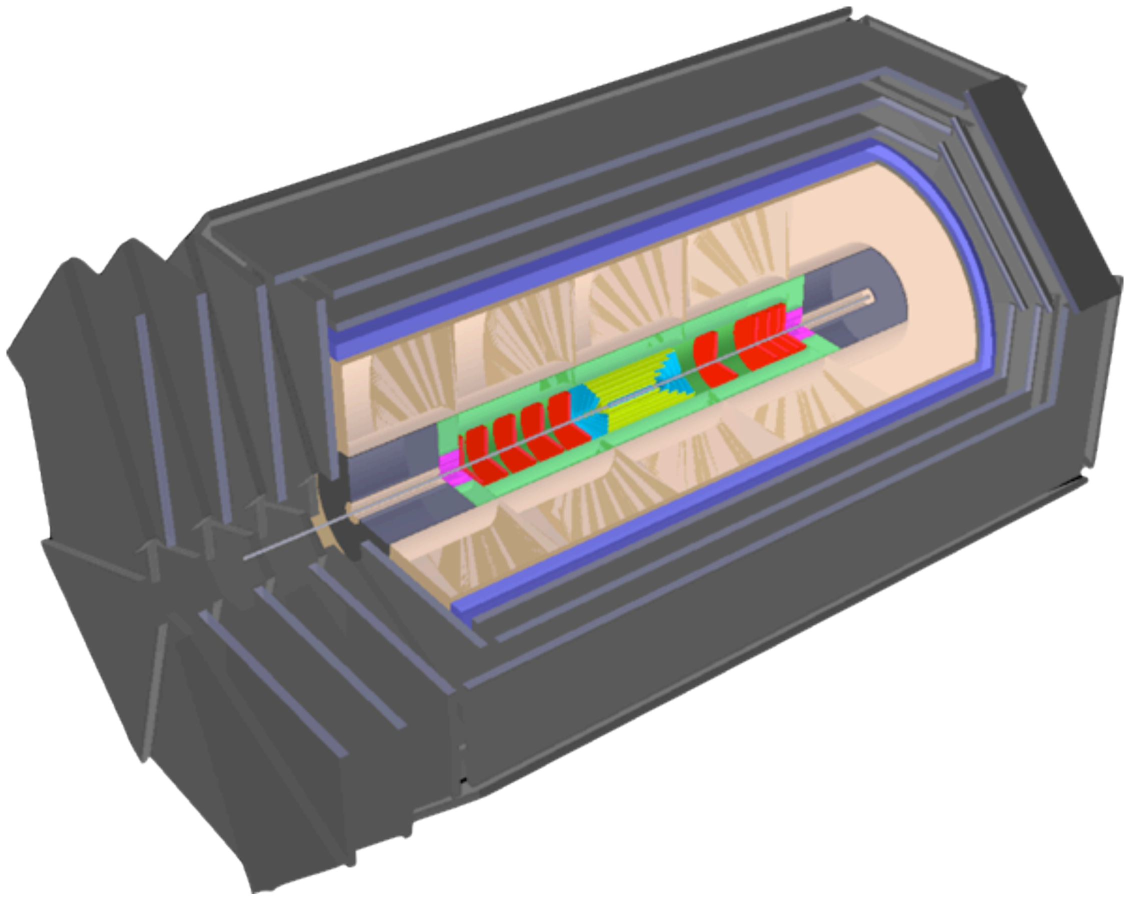
<u>Fwd Detectors</u>

(down to 1^o)
Silicon Tracker
[Pix/Strip/Strixel/Pad Silicon or/and Gas on Slimmed Si Pixels]

Calice (W/Si); dual ReadOut - Elm Calo
FwdHadrCalo:
Cu/Brass-Scintillator

<u>Bwd Detectors</u>

(down to 179^o)
Silicon Tracker
[Pix/Strip/Strixel/Pad Silicon or/and Gas on Slimmed Si Pixels]
Cu/Brass-Scintillator,
Pb-Scintillator (SpaCal - hadr, elm)



Extensions in fwd direction (tag p,n,d) and backwards (e,γ) under study.

Completion of the CDR

Steps to go in 2010

1. Finalise physics and technical studies
2. DIS10 Firenze [April] and IPACC Japan [May]
3. Draft CDR June 2010
4. Divonne III – Updates and Discussion with referees
5. November 10: Final report to ECFA
6. Submit CDR to CERN, ECFA, NuPECC

LHeC relies on expertise and enthusiasm of many colleagues and support by ECFA, NuPECC and CERN

LHeC barack 561

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)
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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)

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Emmanuelle Perez	(CERN)
Wesley Smith	(Wisconsin)
Bernd Surrow	(MIT)
Katsuo Tokushuku	(KEK)
Urs Wiedemann	(CERN)

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)

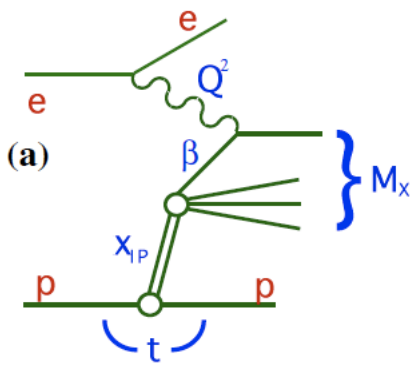
New Physics at Large Scales
George Azuelos (Montreal)
Emmanuelle Perez (CERN),
Georg Weiglein (Hamburg)

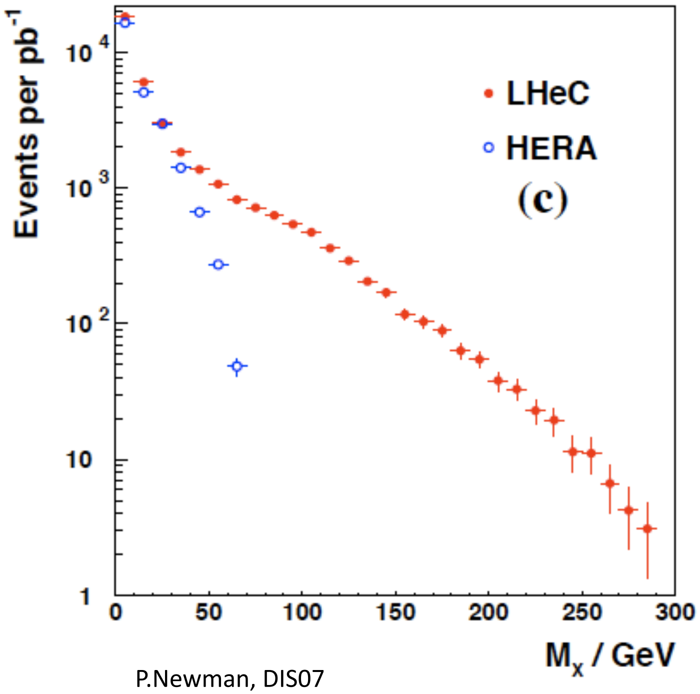
Precision QCD and Electroweak
Olaf Behnke (DESY),
Paolo Gambino (Torino),
Thomas Gehrmann (Zuerich)
Claire Gwenlan (Oxford)

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

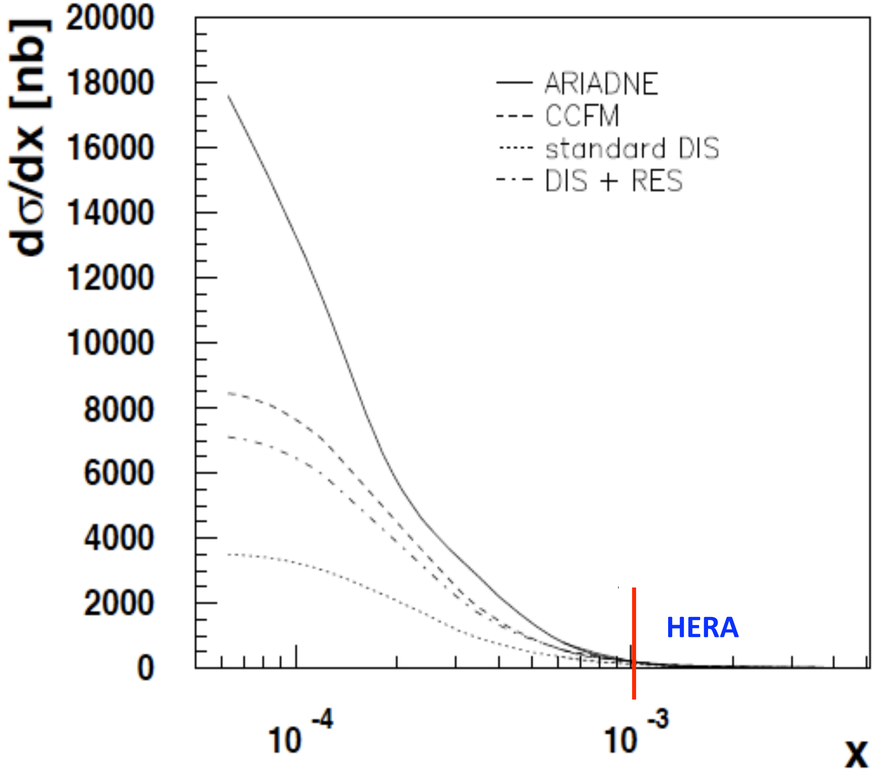
Backup slides

Quark-Gluon Dynamics - Diffraction and HFS (fwd jets)





P.Newman, DIS07



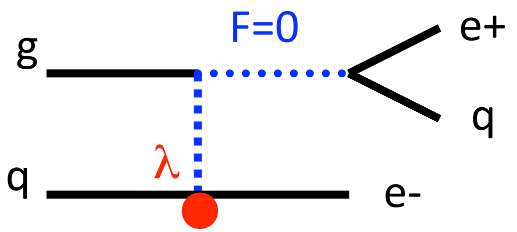
H.Jung, L.Loennblad, THERA study

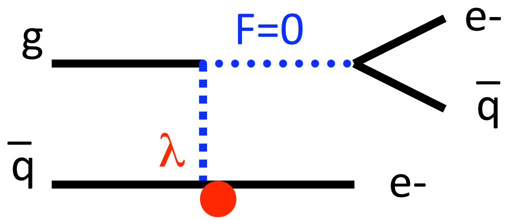
Diffraction to accompany (SUSY) Higgs fwd physics at LHC

Understand multi-jet emission (unintegr. pdf's), tune MC's
At HERA resolved γ effects mimic non-kt ordered emission
Crucial measurements for QCD, and for QCD at the LHC

Determination of LQ properties in single production: e.g. Fermion Number

In pp: look at signal separately when resonance is formed by (e^+ + jet) and (e^- + jet) :



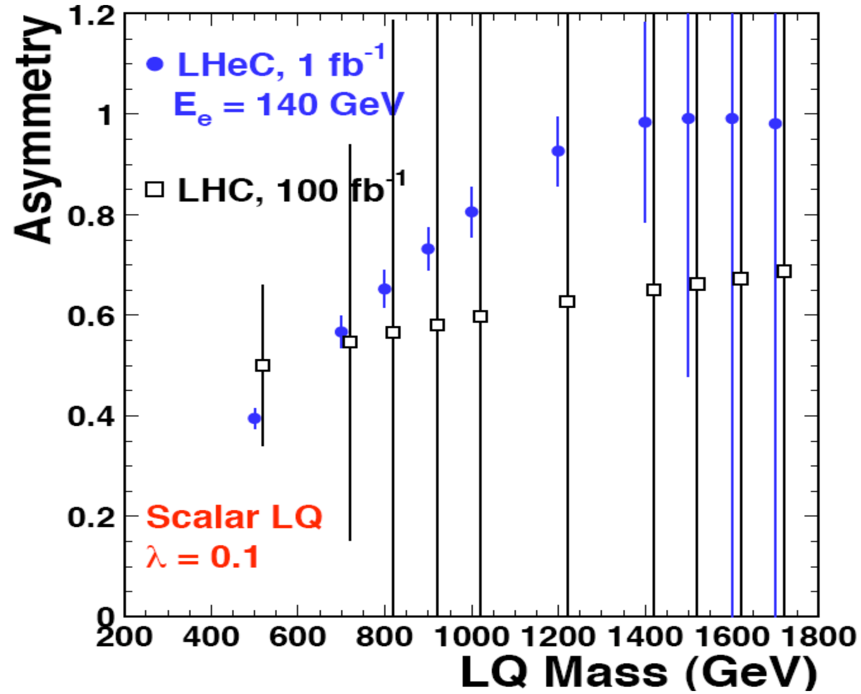


$\sigma(e^+_{out}) > \sigma(e^-_{out})$
for F=0

Sign of the asymmetry gives F, but could be statistically limited at LHC. (*)

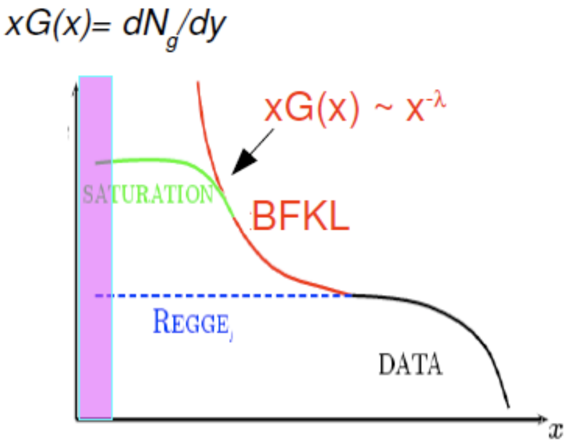
Easier in ep ! Just look at the signal with incident e+ and incident e-, build the asymmetry between $\sigma(e^+_{in})$ and $\sigma(e^-_{in})$.

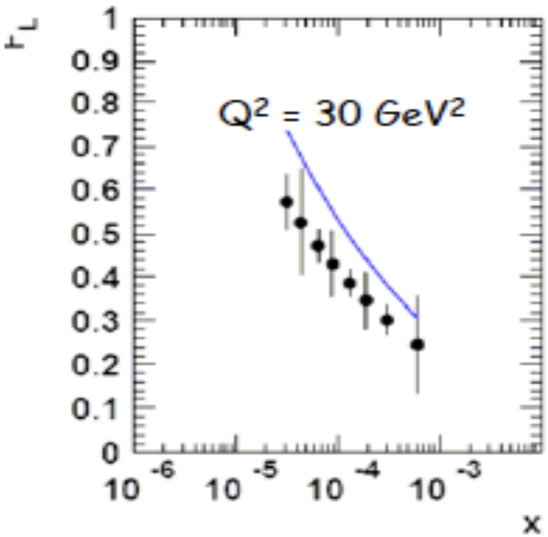
If LHC observes a LQ-like resonance,
M < 1 - 1.5 TeV, LHeC could determine F
if λ not too small.



(*) First rough study done for the 2006 paper.
Need to check / refine with a full analysis of signal and backgrounds.

Quark-Gluon Dynamics (saturation, GPDs) - ep

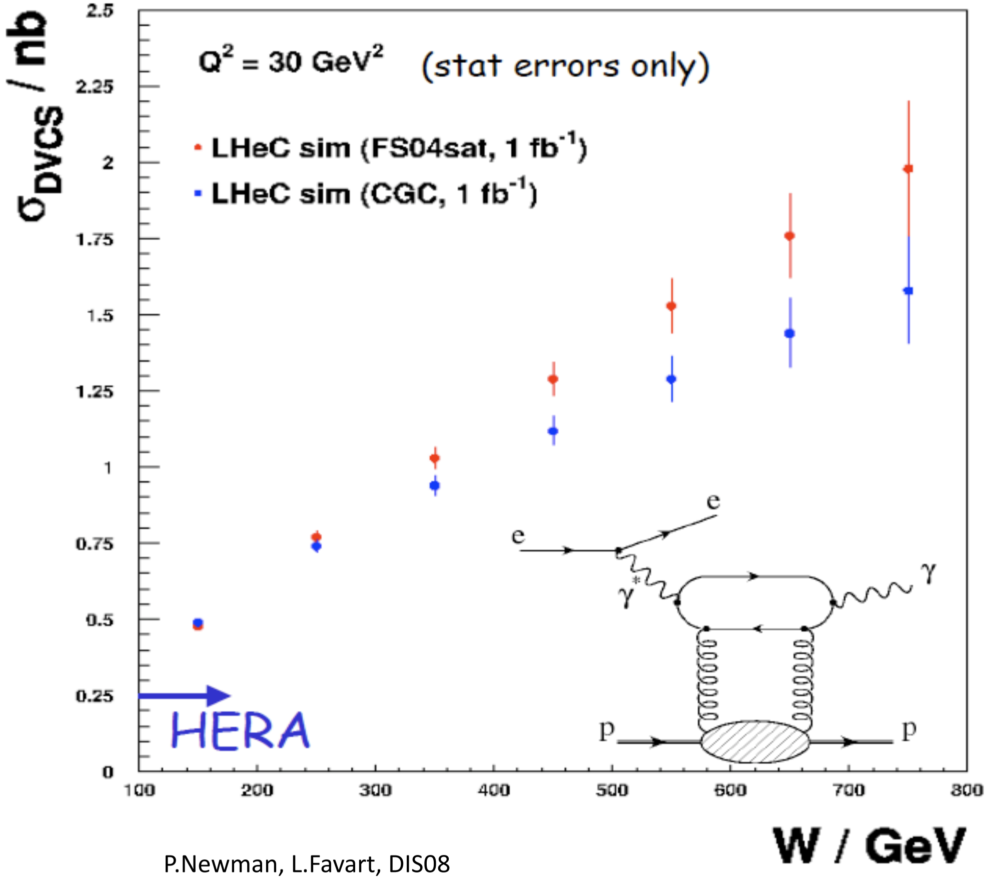




J.Forshaw et al, DIS08

LHeCsat data in NNPDF1.0

Divonne 08



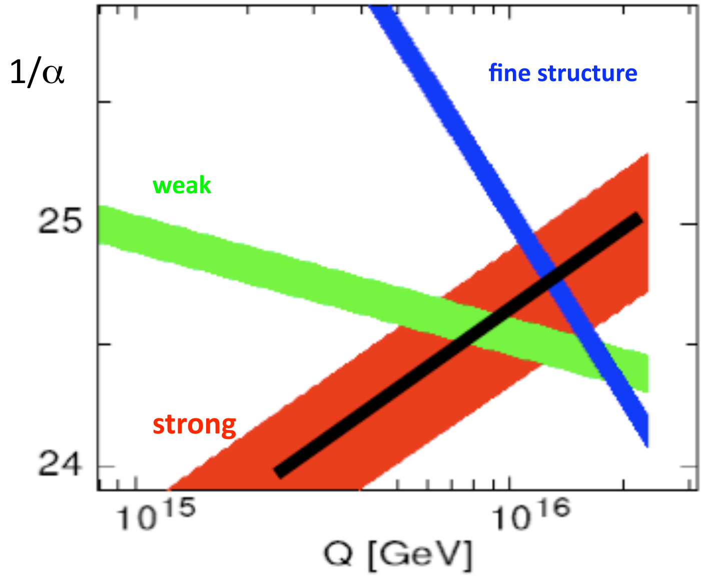
P.Newman, L.Favart, DIS08

LHeC opens phase space to discover saturation in DIS
J.Bartels at Divonne on low x theory

High luminosity, polarisation, accuracy for GPD's (DVCS)

Strong Coupling Constant

Simulation of α_s measurement at LHeC



MSSM - B.Allnach et al, hep-ex/0403133

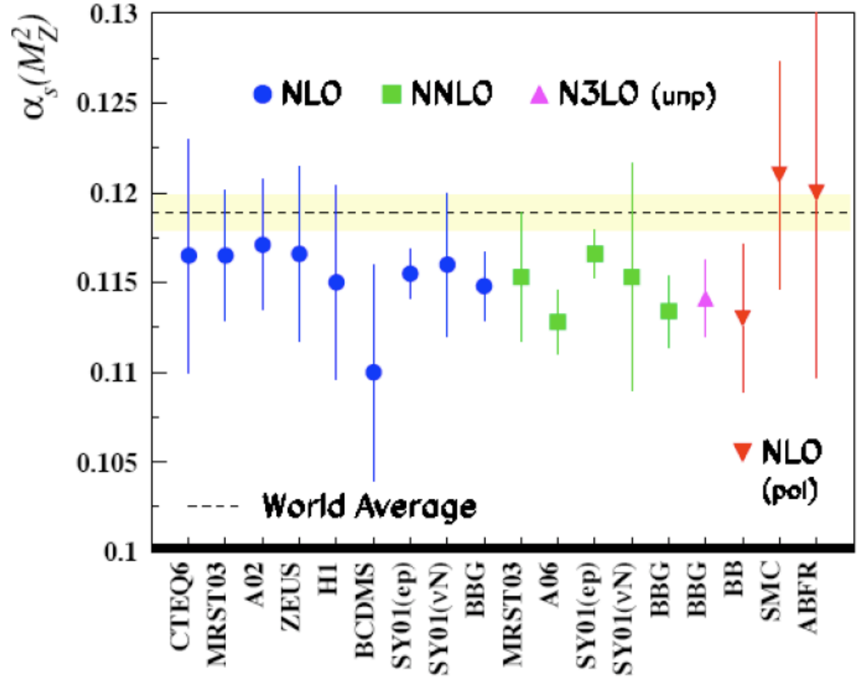
DATA	exp. error on α_s
NC e⁺ only	0.48%
NC	0.41%
NC & CC	**0.23% :=(1)**
(1) $\gamma_h > 5°$	0.36% :=(2)
(1) +BCDMS	0.22%
(2) +BCDMS	0.22%
(1) stat. *= 2	0.35%

α_s least known of coupling constants
Grand Unification predictions suffer from $\delta\alpha_s$

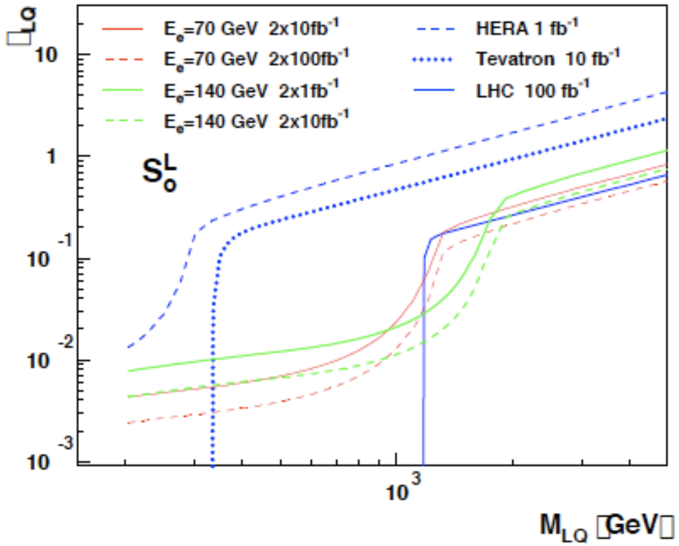
DIS tends to be lower than world average

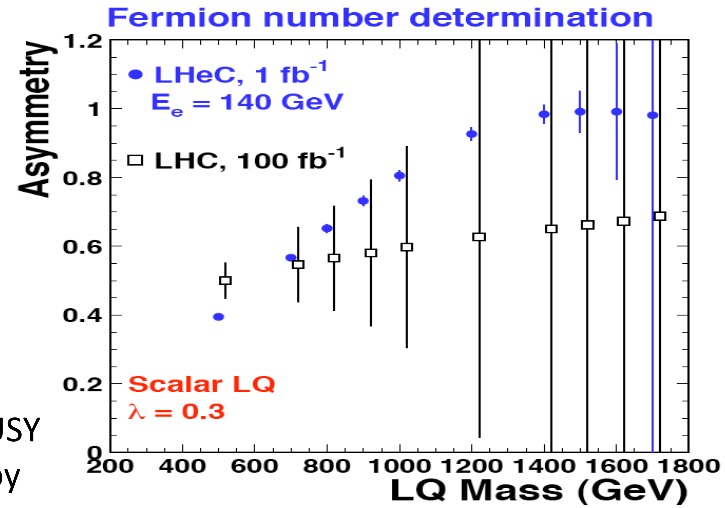
LHeC: per mille accuracy indep. of BCDMS.
Challenge to experiment and to h.o. QCD

Blumlein et al '06



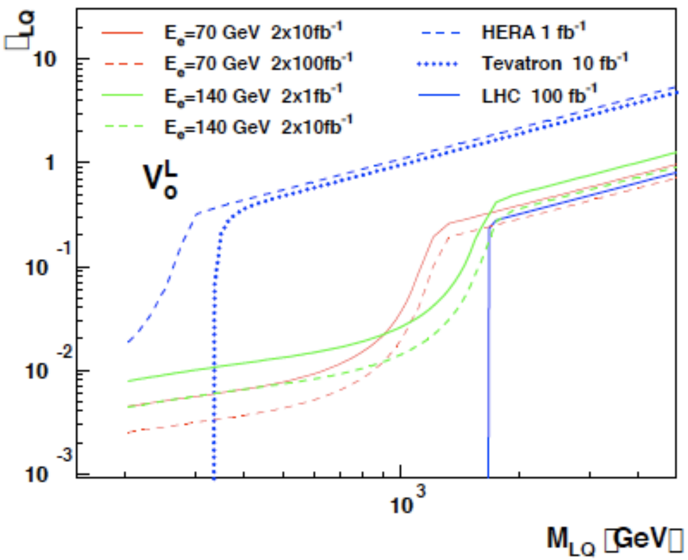
New Physics in the eq Sector

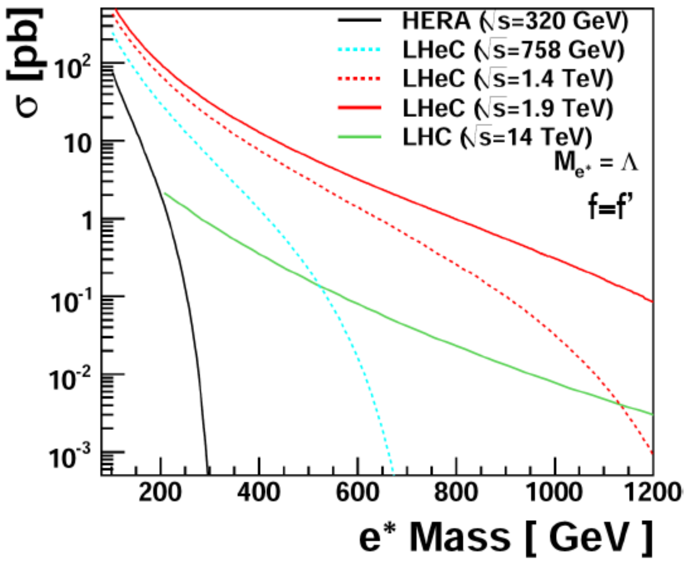




?LQ, RPV SUSY Spectroscopy

?Excited fermions





Exact knowledge of pdf's may be crucial to understand CI's