Large Hadron Electron Collider

DRAFT 26.11.
7pm CERN

Progress Report to ECFA

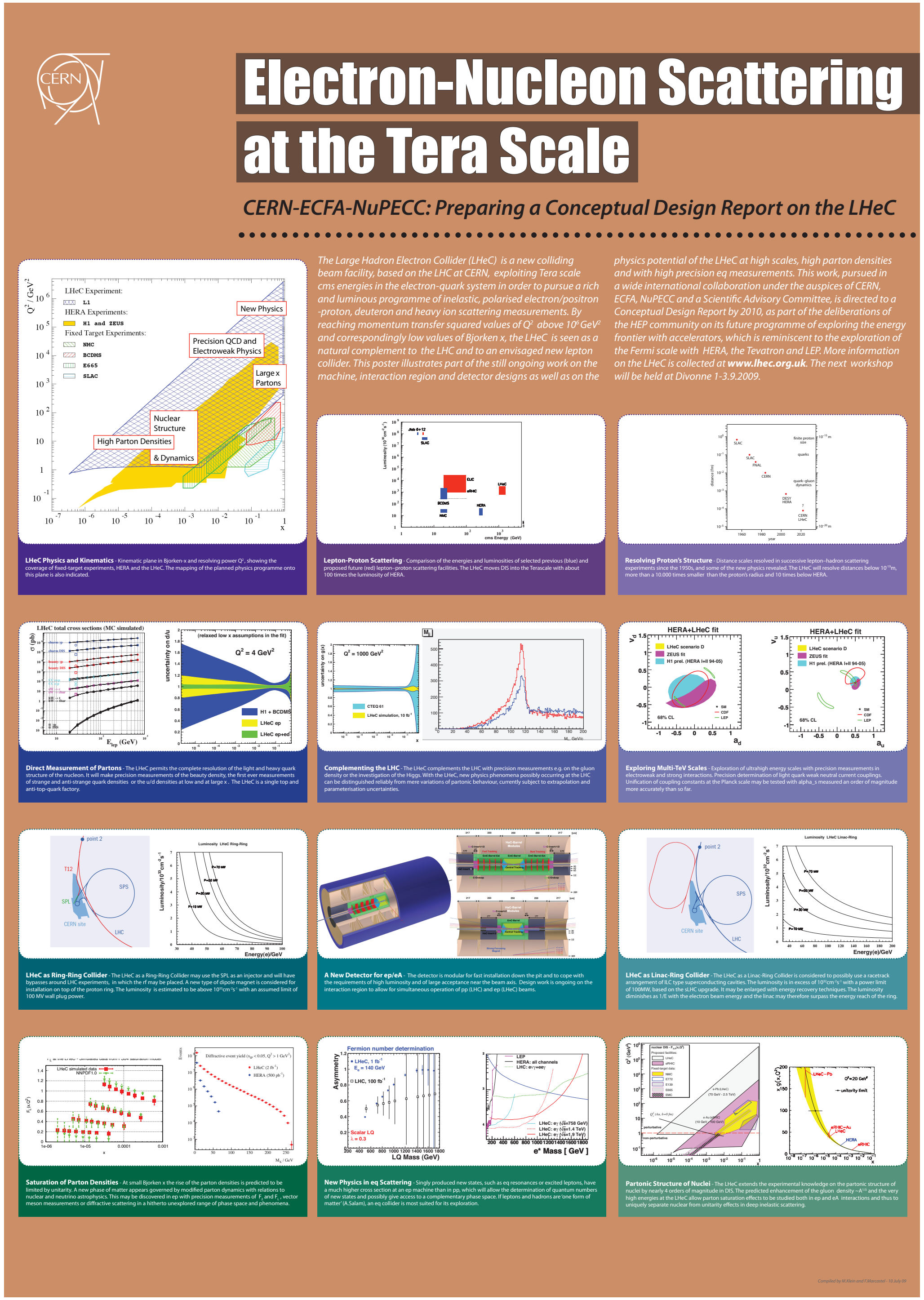
Max Klein

for the LHeC Group

UNIVERSITY OF LIVERPOOL

CERN Geneva 27. November 2009

www.lhec.cern.ch



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 at 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 at BNP Novosibirsk [Ring Magnets]

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

July — Talk and Poster at EPS09 and Lepton-Photon

September — **Divonne II (CERN-ECFA-NuPECC Workshop)**

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 ten times below HERA's limit

+ 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 singly produced new states (RPV SUSY, LQ, excited fermions) complementary to the LHC

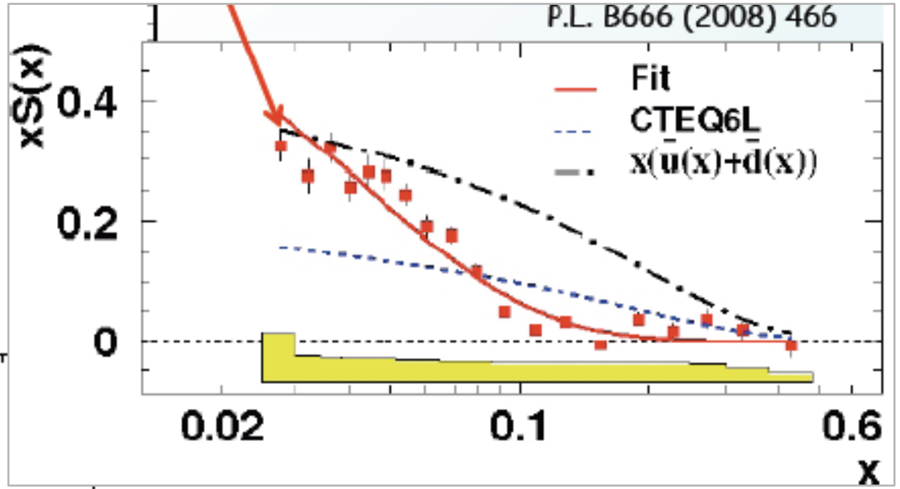
+ Exploration of **high density matter** [low x physics beyond the expected unitarity limit for the growth of the nucleon gluon density]

+ 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]

Huge amount of studies done and ongoing. Follows one example per point each

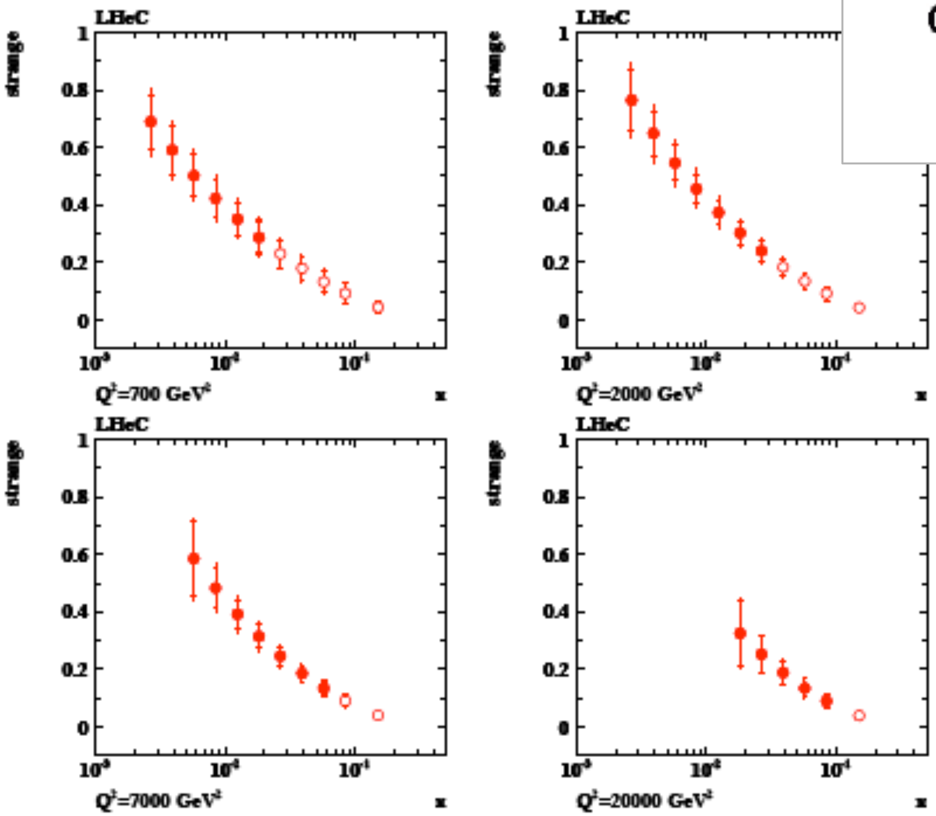
Strange and Anti-Strange Quark Distributions

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



HERMES, K.Rith EPS09

Q^2~ 1 GeV^2



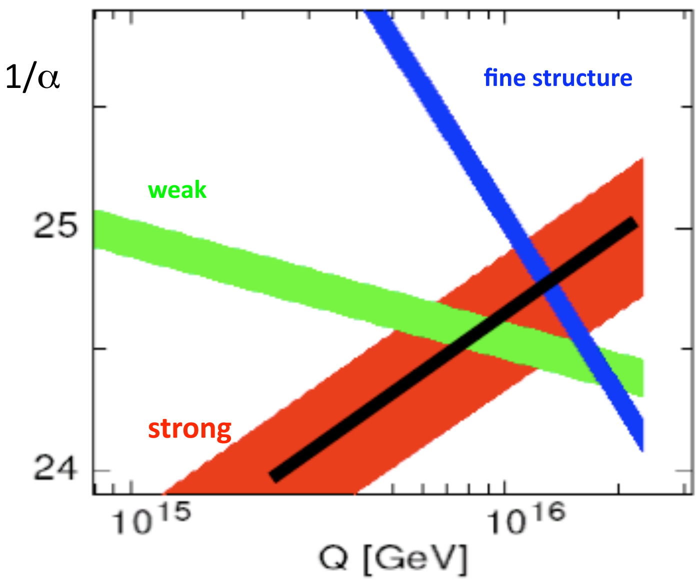
$W^{-} sbar \rightarrow cbar$
$1 fb^{-1}$
$\varepsilon_c = 0.1$
$\varepsilon_q = 0.01$
$\delta_{syst} = 0.1$
$\circ - \vartheta_h \geq 1^o$
$\bullet - \vartheta_h \geq 10^o$

W,Z sensitive to s

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

Strong Coupling Constant

Simulation of α_s measurement at LHeC



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

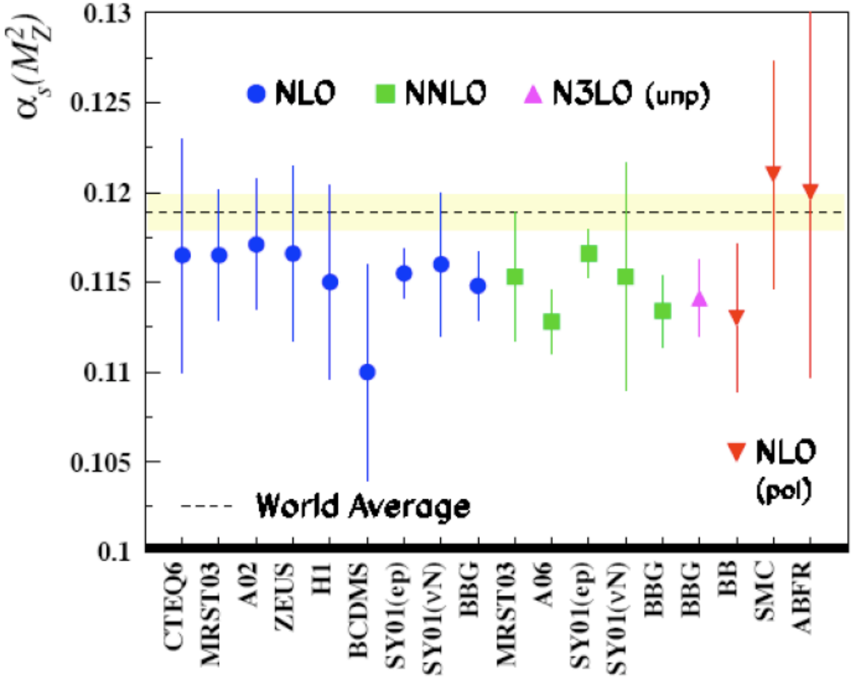
DATA	exp. error on α_s
NC e^+ only	0.48%
NC	0.41%
NC & CC	**0.23% :=(1)**
(1) $\gamma_h > 5°$	0.36% :=(2)
(1) +BCDMS	0.22%
(2) +BCDMS	0.22%
(1) stat. *= 2	0.35%

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

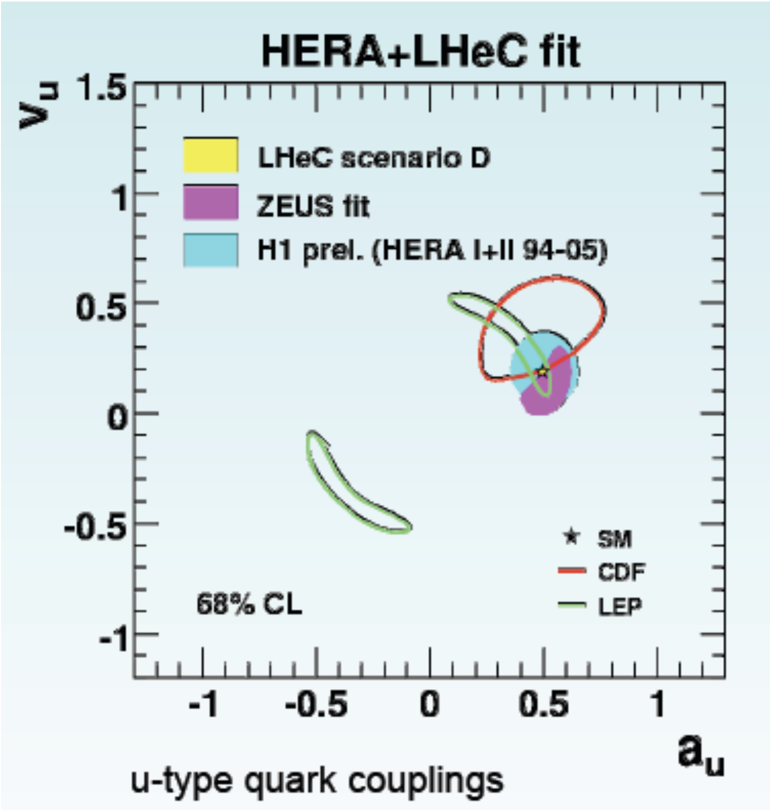
DIS tends to be lower than world average

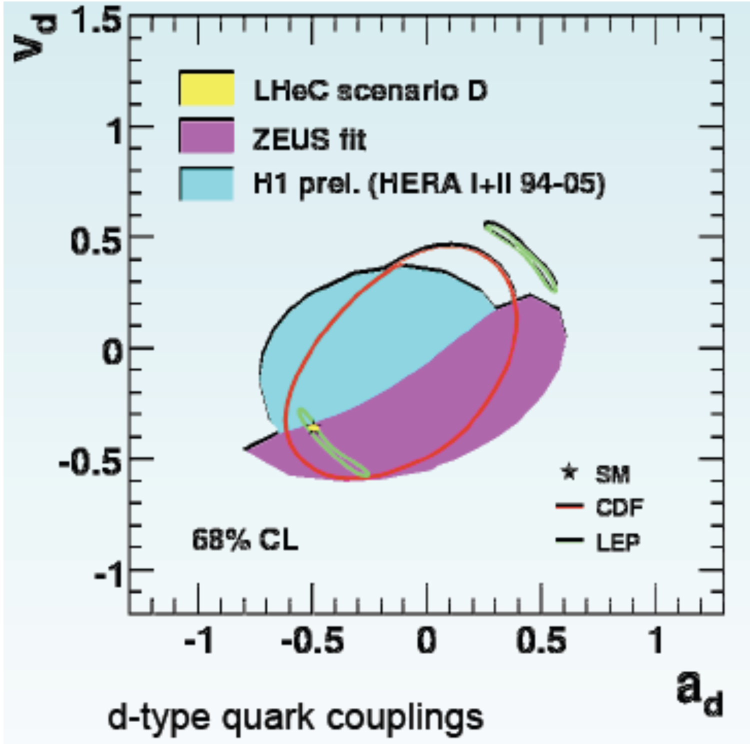
LHeC: per mille accuracy indep. of BCDMS.
Challenge to experiment and to h.o. QCD

Blumlein et al '06



High Precision Electroweak Physics



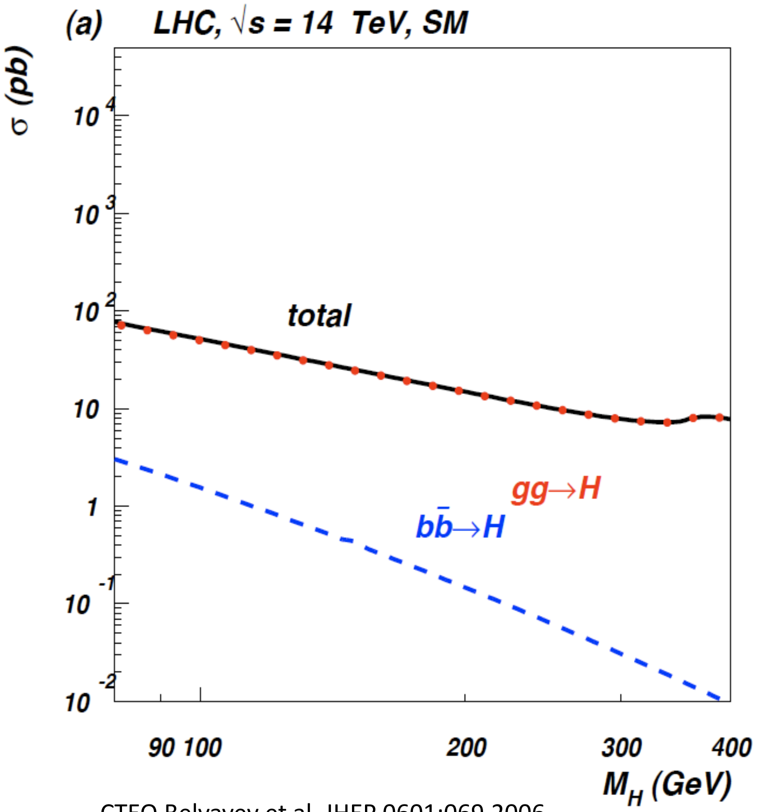


Precision measurement of weak neutral current couplings (+pdf's): access to new el.weak physics.

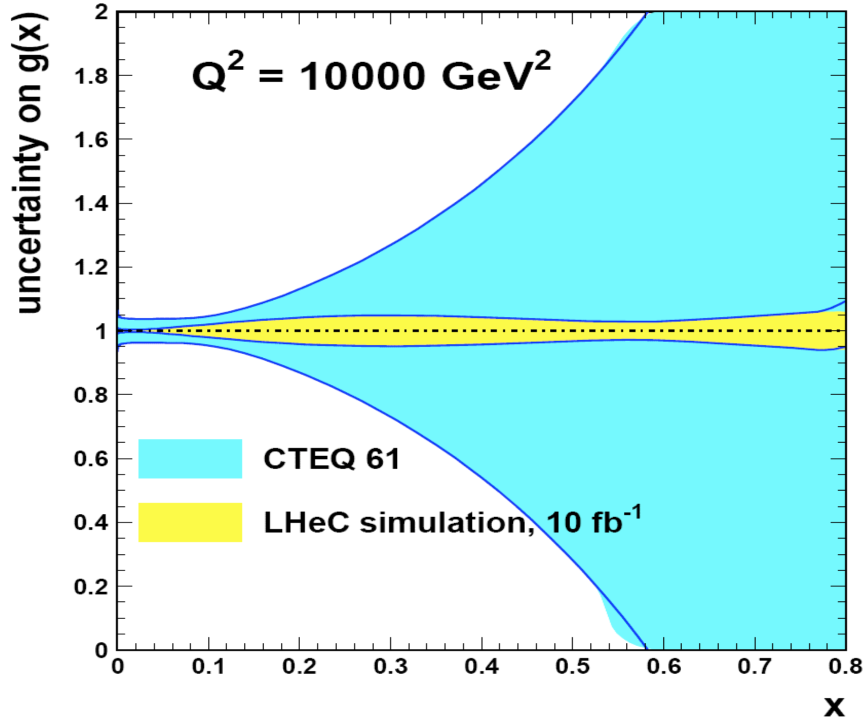
40 TeV limits on Contact Interactions and correspondingly on extra dimensions

Search for eq bound states and sub-substructure to 6 10^{-20}m – **LHeC: the world's new microscope**

Gluon - SM Higgs



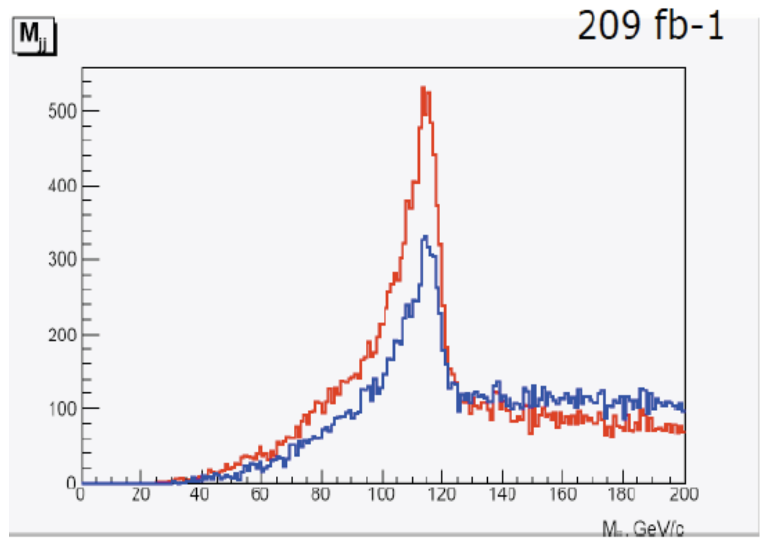
CTEQ Belyayev et al. JHEP 0601:069,2006



In SM Higgs production is gluon dominated

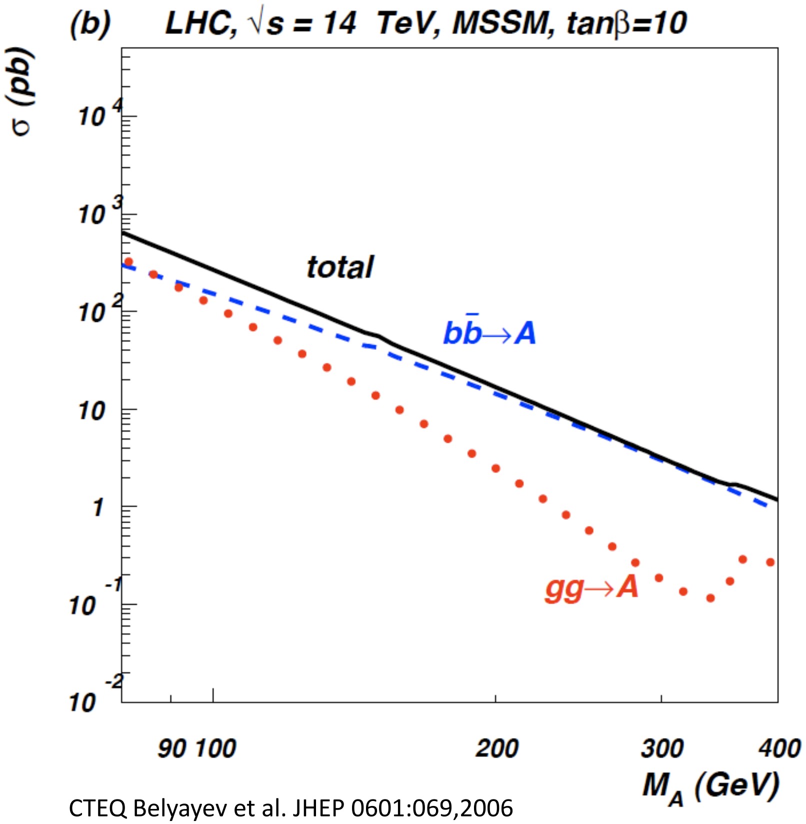
LHeC: huge x,Q^2 range for xg determination

WW to Higgs fusion has sizeable ep xsection

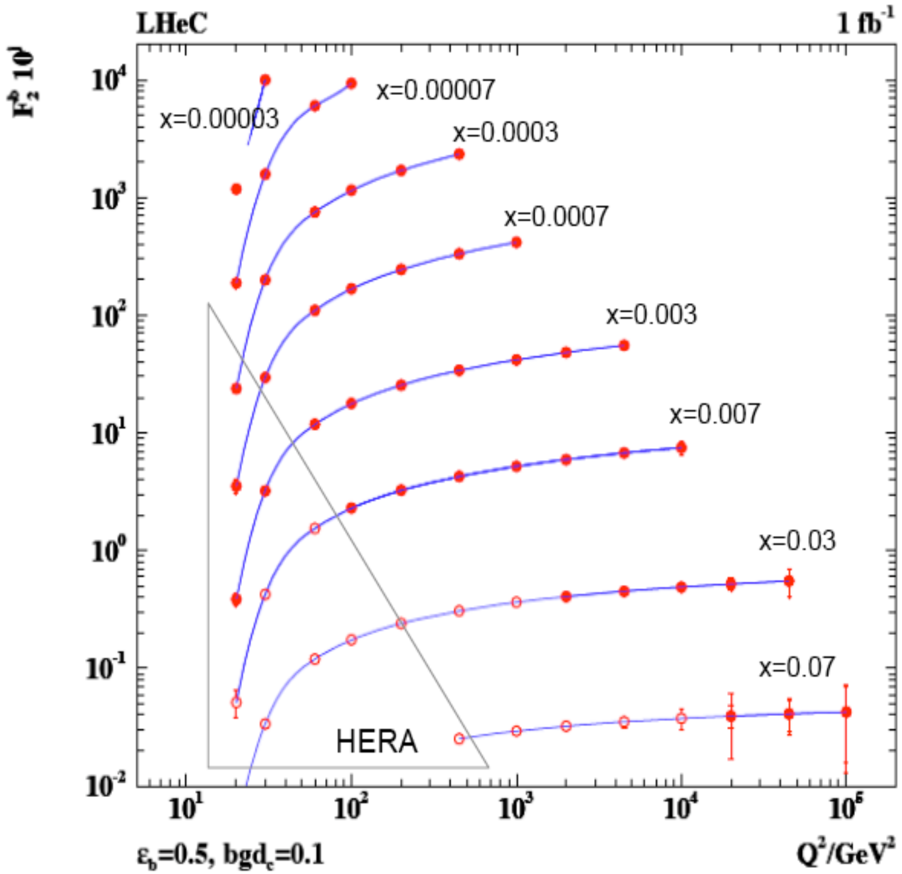


Cf Divonne 09 for QCD bgd studies + btagging

Beauty - MSSM Higgs



CTEQ Belyayev et al. JHEP 0601:069,2006

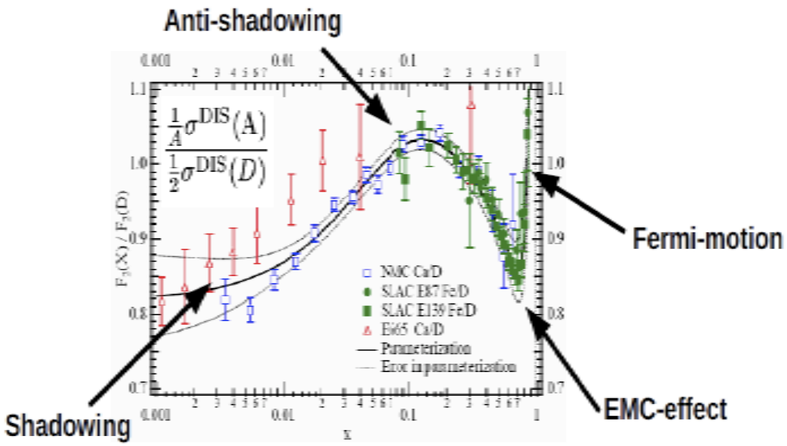


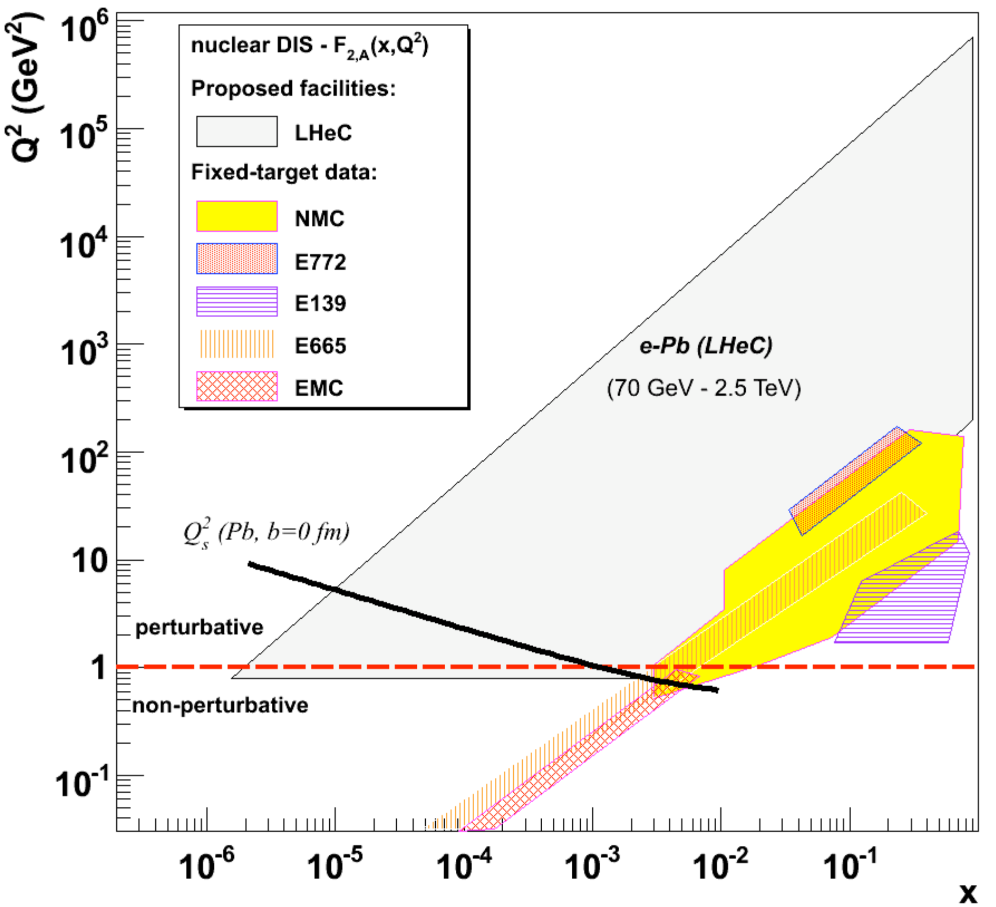
In MSSM Higgs production is b dominated

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

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

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
Determination of the initial state of the Quark Gluon Plasma

Physics – Work in Progress

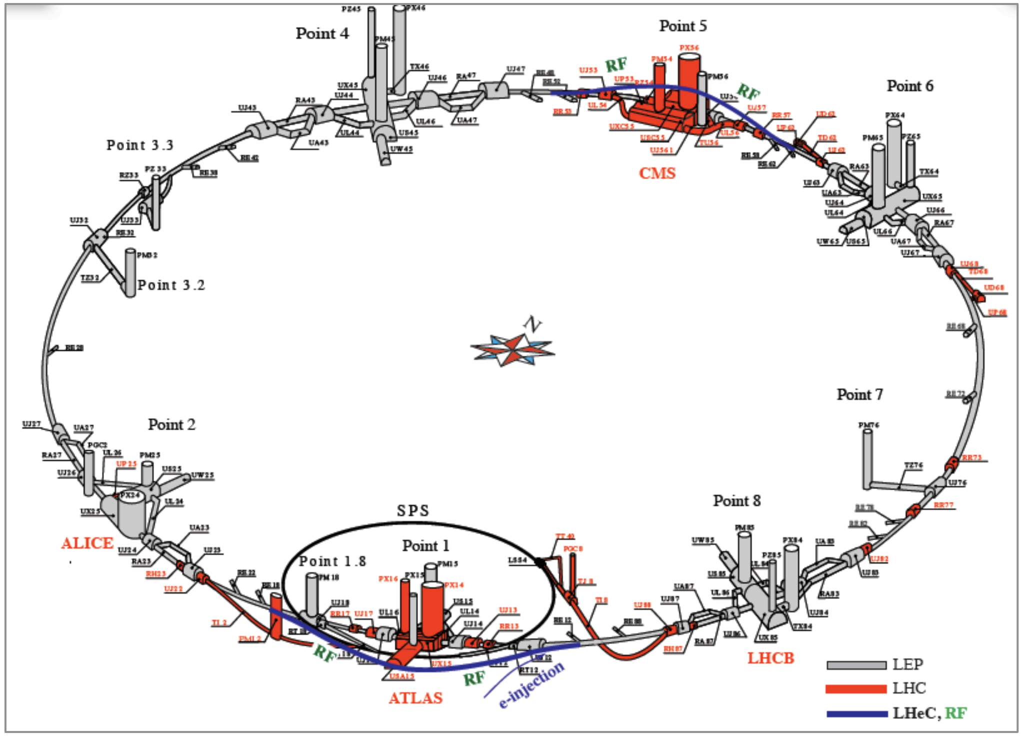
Various subjects are being completed

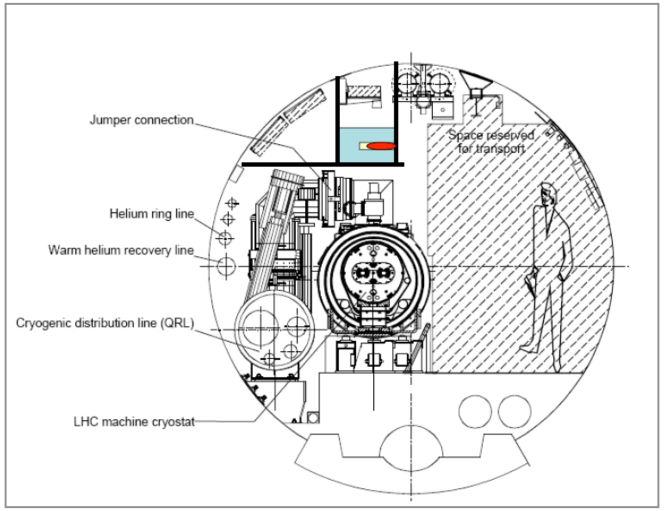
Higgs background
Single top reconstruction
RPVSUSY
4th generation fermions
Photoproduction (real and virtual)
…

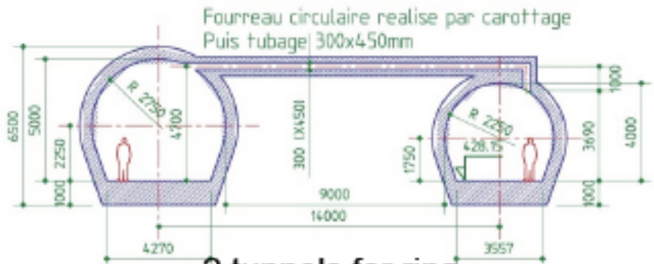
Closer link to detector (Simulation efforts)

Closer look to LHC-LHeC complementarity

Ring-Ring ep/eA







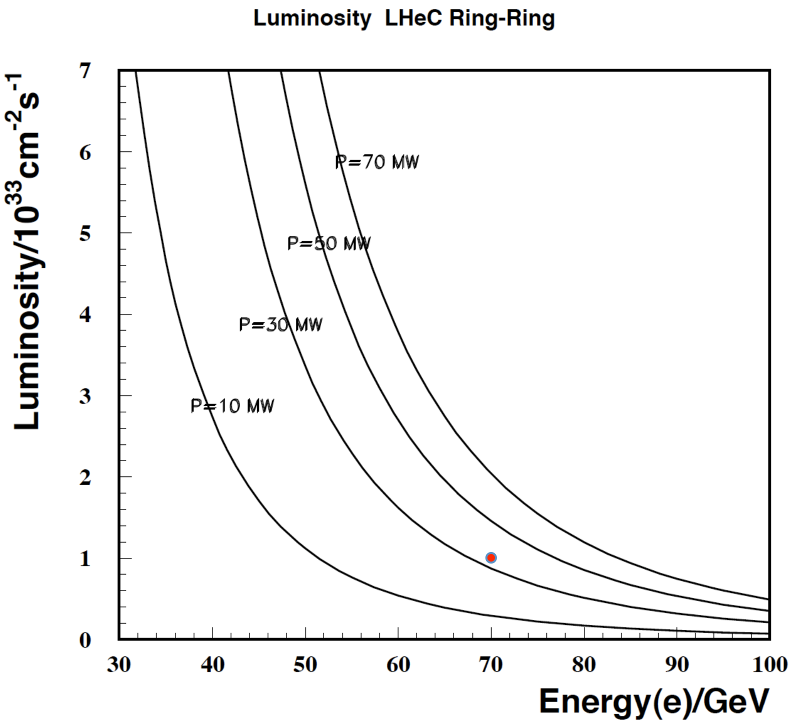
2 tunnels for ring
and shielded rf

E_e=10 … 80 GeV. L_{ep}~$10^{33}cm^{-2}s^{-1}$ (100 times HERA)

1/x and Q^2 ~ $10^{4(2)}$ times larger in eA (ep) than so far

Collaborations of CERN with Cockcroft, DESY, Lausanne, Novosibirsk, SLAC accelerator experts

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 rf (<80 GeV)

Power limit set to 100 MW

Small p tuneshift – simultaneous pp and ep

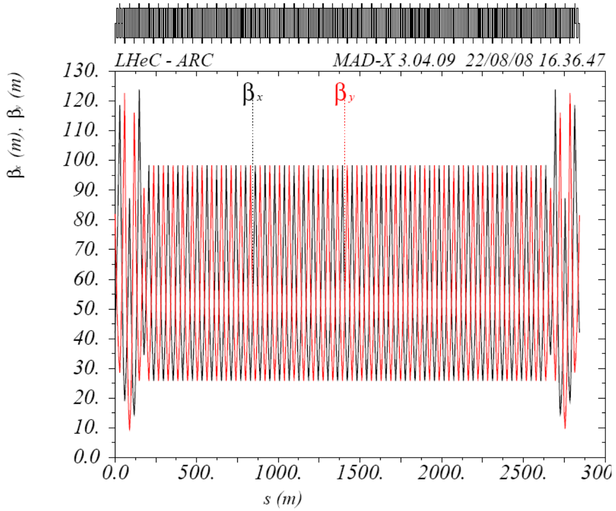
Ultimate Parameter	*Protons*	*Electrons*	
	*Np=1.7*10^11*	*Ne=1.4*10^10*	*nb=2808*
	Ip=860mA	*Ie=71mA*	
Optics	*βxp=230 cm*	*βxe=12.7 cm*	
	βyp= 60 cm	*βye= 7.1 cm*	
	εxp=0.5 nm rad	*εxe=9 nm rad*	
	εyp=0.5 nm rad	*εye=4 nm rad*	
Beamsize	*σx=34 μm*		
	σy=17 μm		
Tuneshift	*Δνx=0.00061*	*Δνx=0.056*	
	Δνy=0.00032	*Δνy=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



β functions for LHeC - 2008

Dispersion was 50-90cm

and horiz. emittance 22 nm

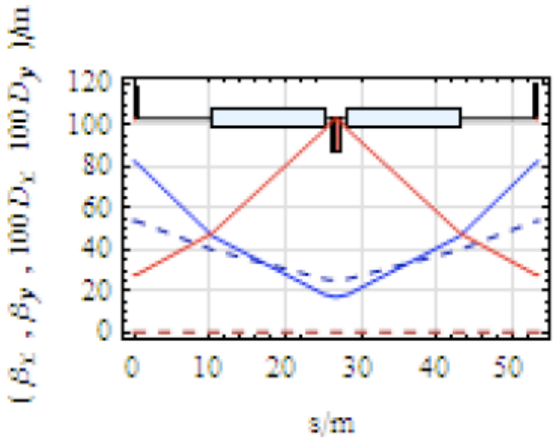
384 60m long cells

2009: optimisation of FODO cell

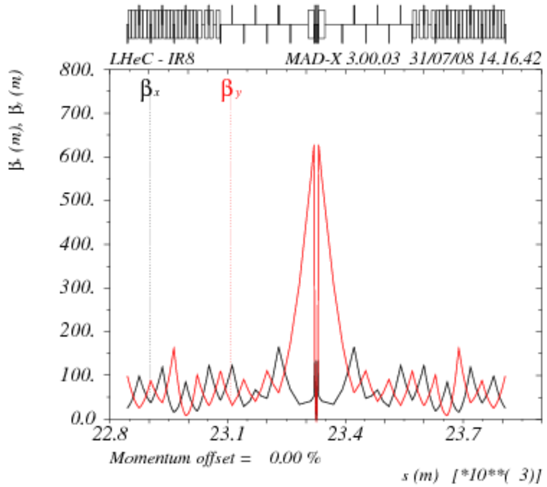
Dispersion reduced to 20-50cm

emittance ε_x=7.5nm ε_y=3.7 nm

MEDIUM or WEAK BEND SOLUTION



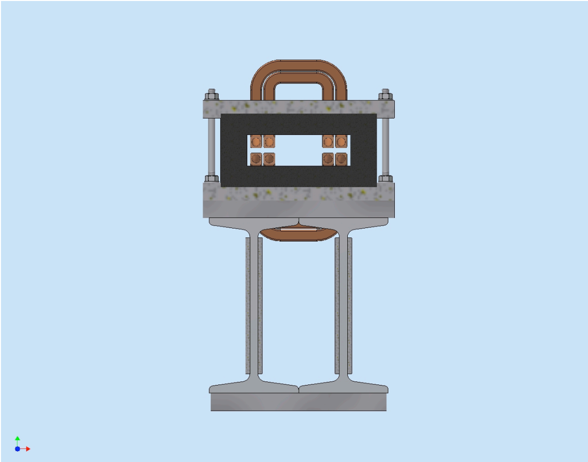
FODO optimisation



"inner" triplet focus
β_x=7.1cm β_y=12.7cm

Mini beta design

Dipole Magnets

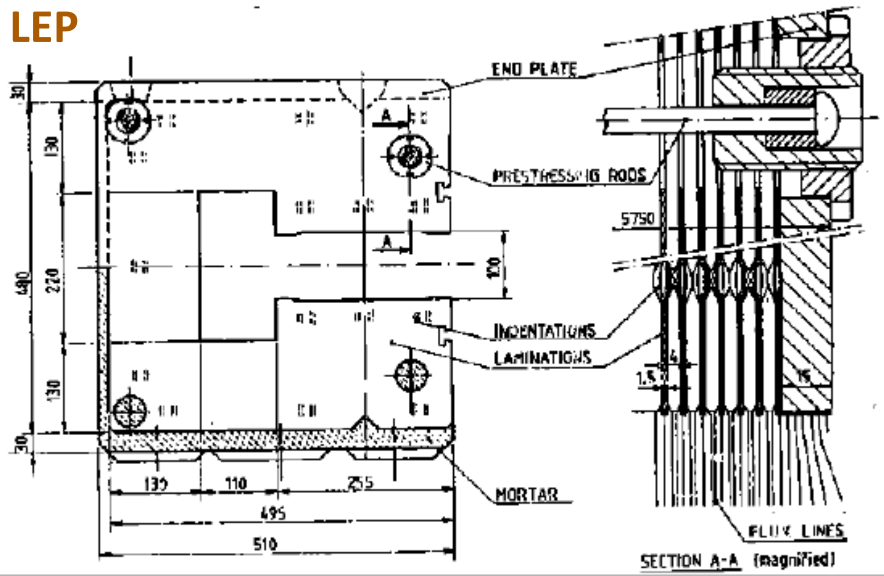


O-shaped magnet with ferrite core [BNP-CERN]

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

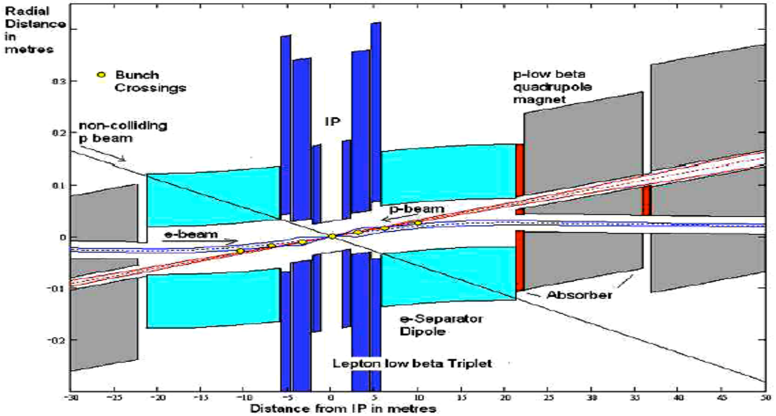
Prototype design under way at Novosibirsk, May 2010

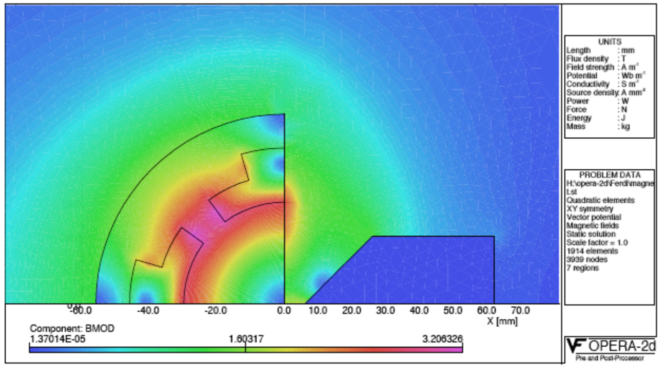
LEP



Ring – Work in progress

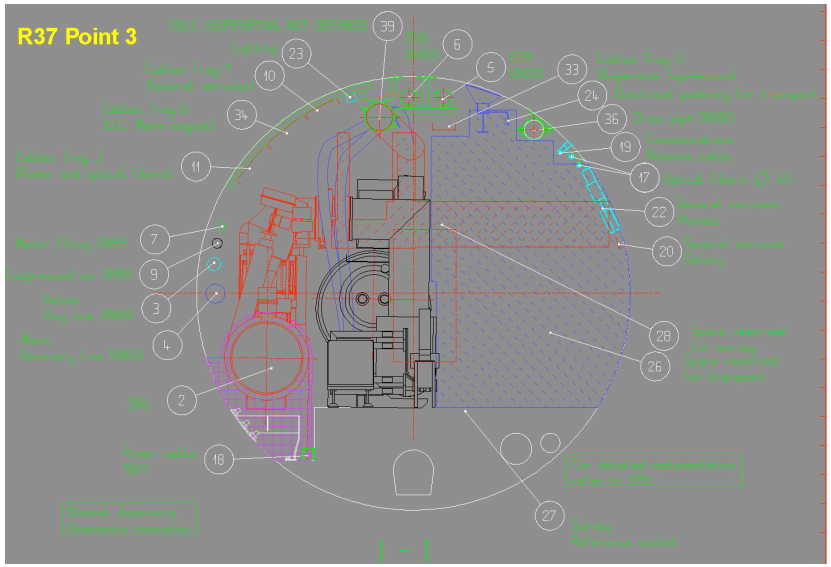
Interaction region design





Installation study

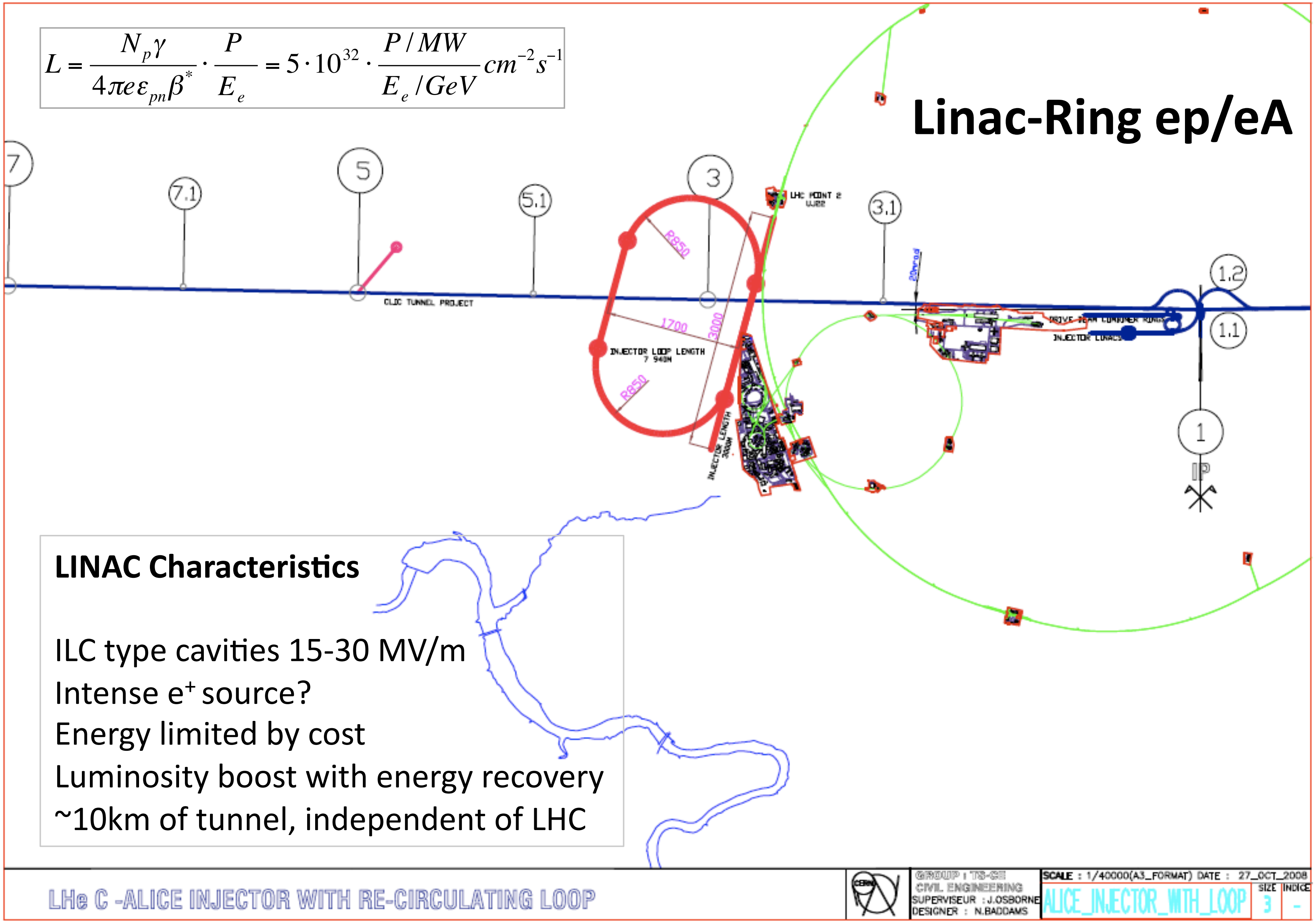
Systematic investigation of clashes with LHC installation and possible ways 'around'



Polarisation

$$L = \frac{N_p \gamma}{4\pi e \varepsilon_{pn} \beta^*} \cdot \frac{P}{E_e} = 5 \cdot 10^{32} \cdot \frac{P/MW}{E_e/GeV} cm^{-2}s^{-1}$$

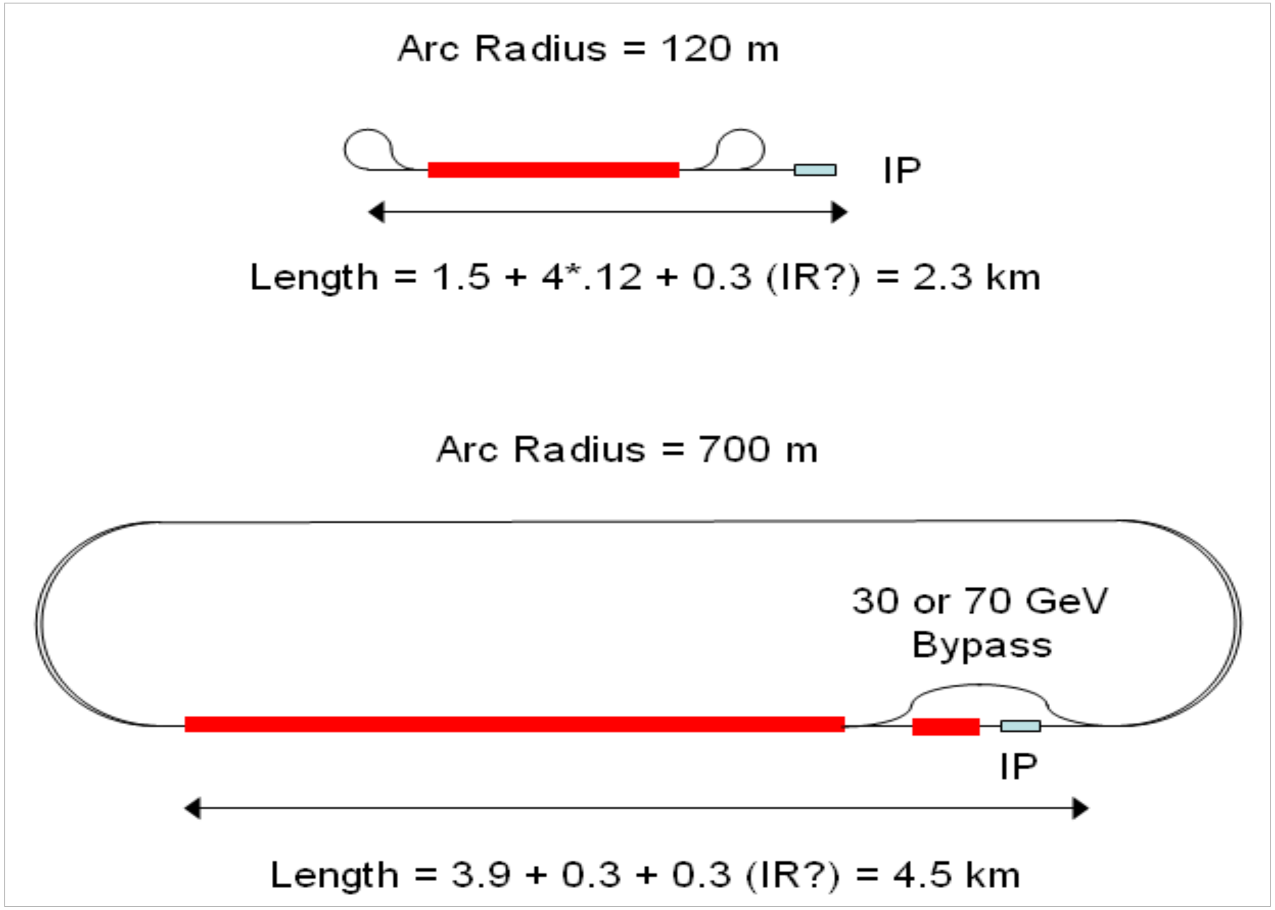
Linac-Ring ep/eA



LINAC Characteristics

ILC type cavities 15-30 MV/m
Intense e^+ source?
Energy limited by cost
Luminosity boost with energy recovery
~10km of tunnel, independent of LHC

Three LINAC Configurations in Two Tunnels [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	30	13	30
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

$$L = \frac{1}{4\pi} \cdot \frac{N_p}{\varepsilon_p} \cdot \frac{1}{\beta^*} \cdot \gamma \cdot \frac{I_e}{e}$$

$$\gamma = \frac{E_p}{M_p}, \frac{I_e}{e} = \frac{P}{E_e} = fN_e$$

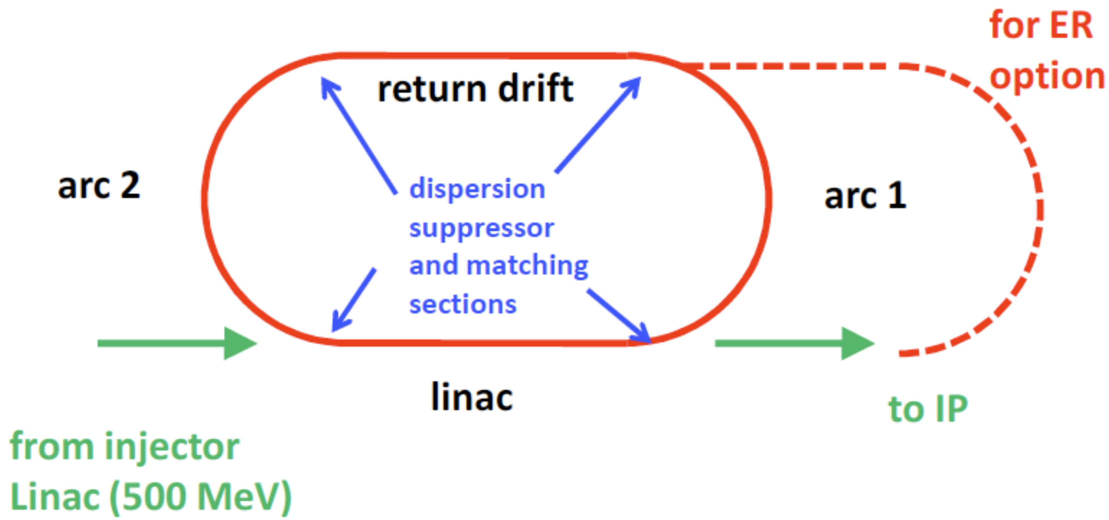
$$I_e = mA \frac{P/MW}{E_e/GeV}$$

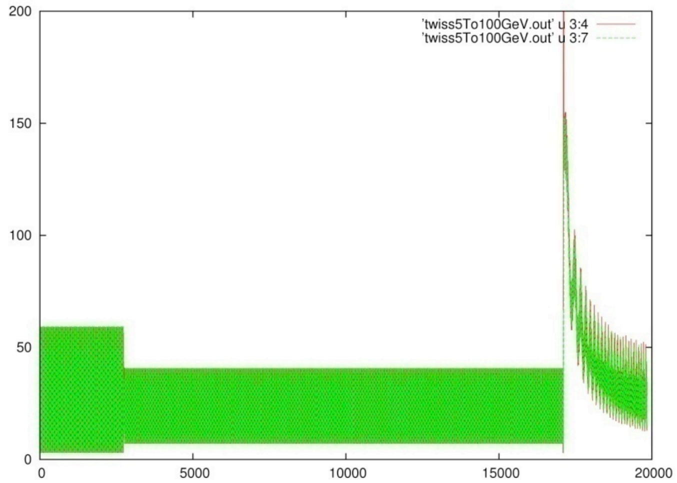
$$N_p = 1.7 \cdot 10^{11}, \varepsilon_p = 3.8 \mu m, \beta^* = 0.2 m, \gamma = 7000/0.94$$

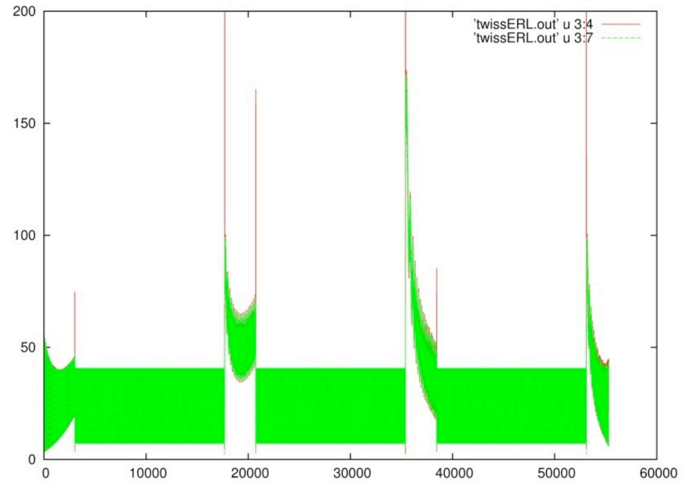
$$L = 8 \cdot 10^{31} cm^{-2} s^{-1} \cdot \frac{N_p 10^{-11}}{1.7} \cdot \frac{0.2}{\beta^*/m} \cdot \frac{P/MW}{E_e/GeV}$$

[intend some graphics to do]

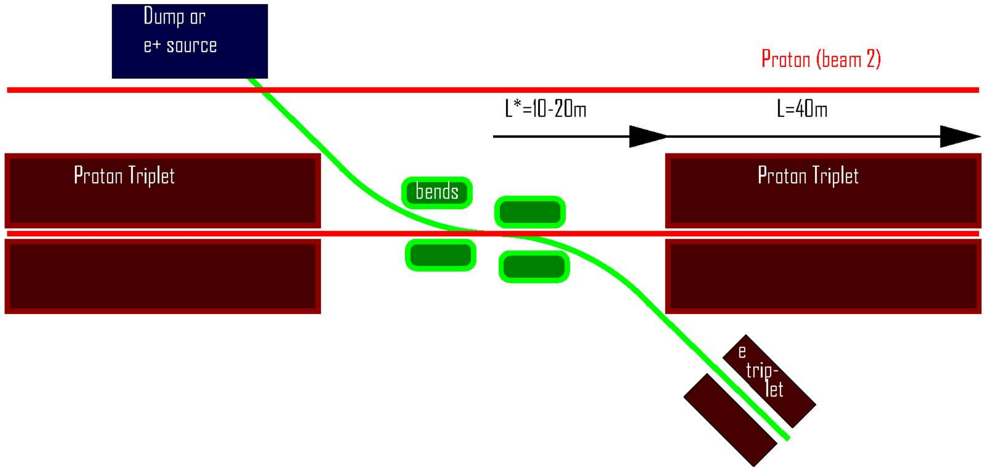
Optics and Emittance Growth





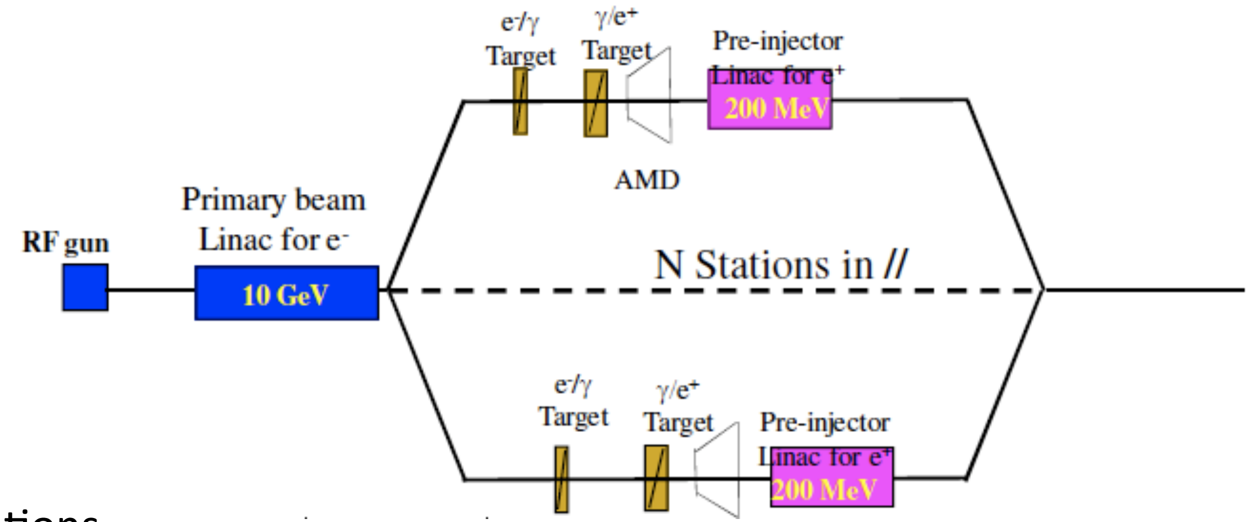


LINAC Work in Progress



Interaction region:
Head on – dipoles

Crossing – like RR IR



Positron source.
may reach
15 10^9 with 5 stations
unpolarised.

Muon chambers
(fwd,bwd,central)

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

Central Detector

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)

Fwd Detectors

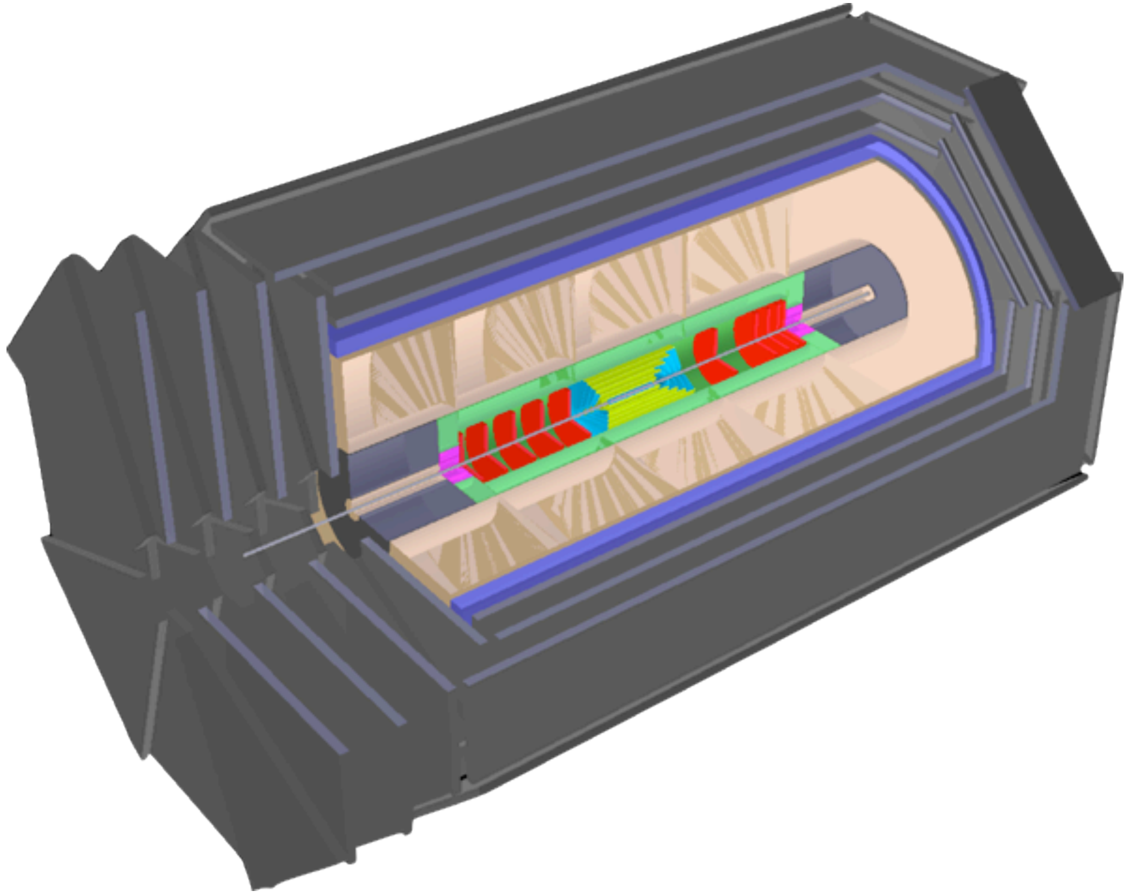
(down to 1°)
Silicon Tracker
[Pix/Strip/Strixel/Pad Silicon or/and Gas on Slimmed Si Pixels]

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

Bwd Detectors

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

LHeC Detector: version for low x and eA



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

Completion of the CDR

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)
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)

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)

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

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 (Durham)

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)

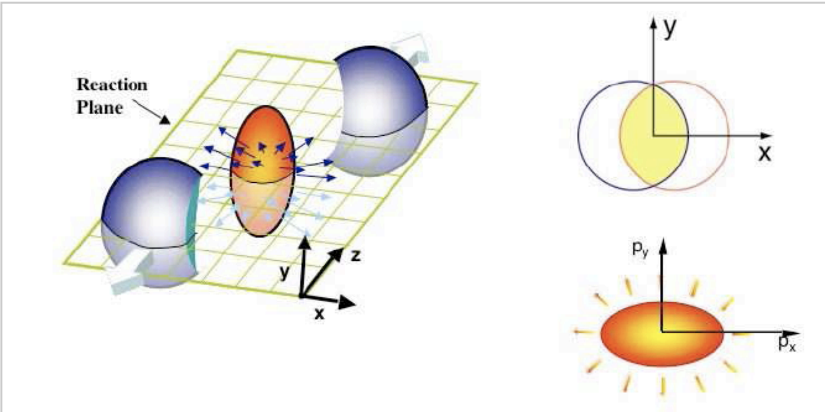
Backup slides

Dipole Magnet Comparison

Accelerator	LEP	LHeC
Cross Section/ cm^2	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/cm^2	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

Quark Gluon Plasma

Landau 1953. **RHIC**: QGP strongly coupled plasma with liquid behaviour instead of weakly interacting gas of partons



M.Tannenbaum, Rept.Prog.Phys 65 (2006) 2005

Related to cold atoms and to superstring theory [AdS/CFT]

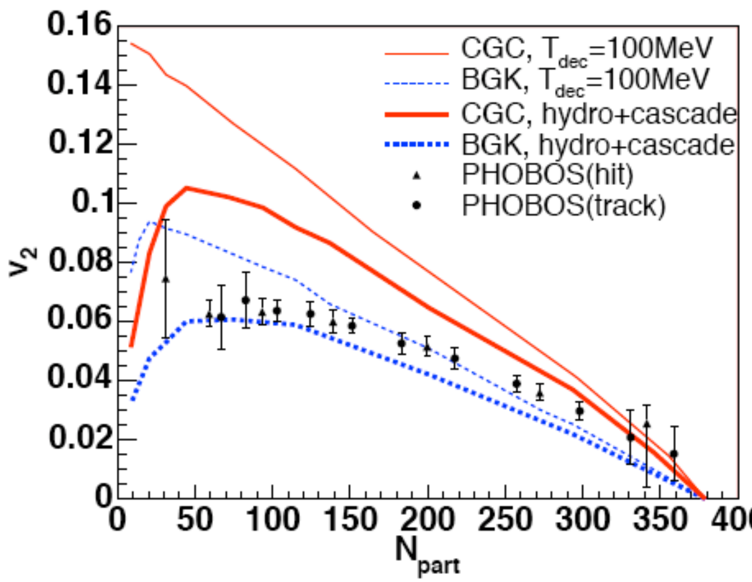
Collective flow in non-central collisions anisotropic

Anisotropy proportional to 1/viscosity of fireball, dominantly elliptic ("v_2" coefficient)

QGP most perfect liquid – smallest shear viscosity/entropy

Conclusions depend on initial fireball eccentricity

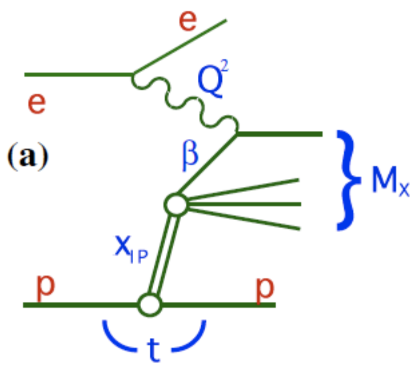
eA to measure the initial conditions of QGP.

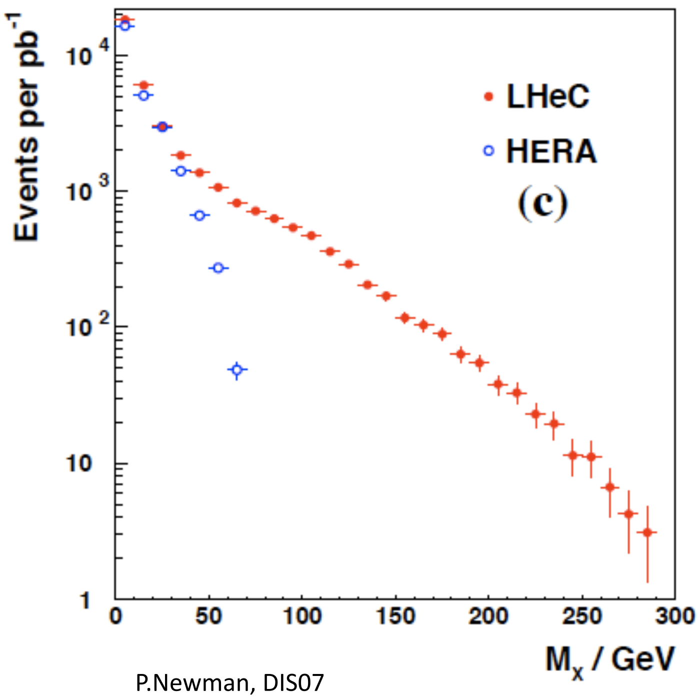


Hirano et al, Phys.Lett.B636(2006)299

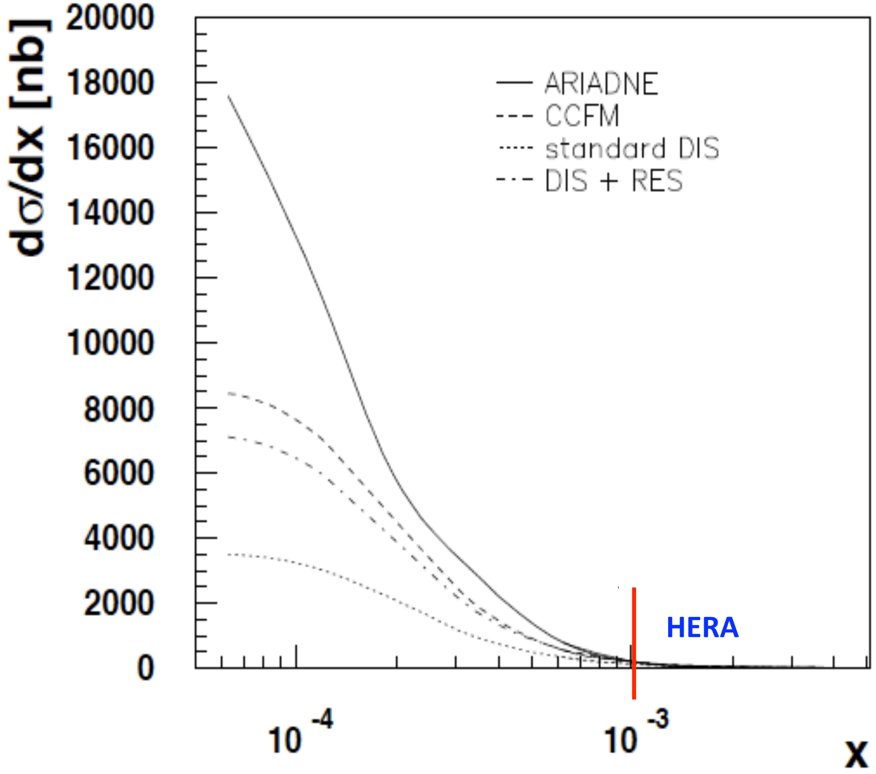
U.Heinz arXiv:0907.4256 (nucl.th)

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





P.Newman, DIS07

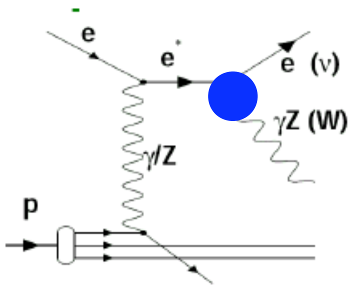


H.Jung, L.Loennblad, THERA study

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

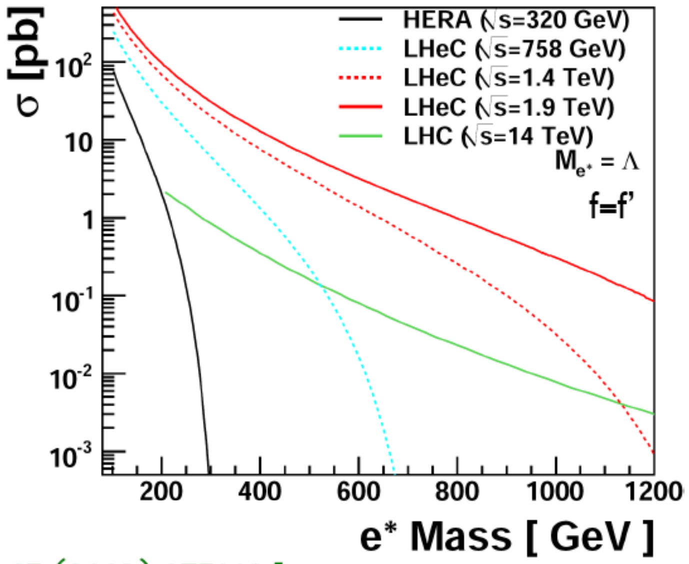
Electron-Boson Resonances : excited electrons



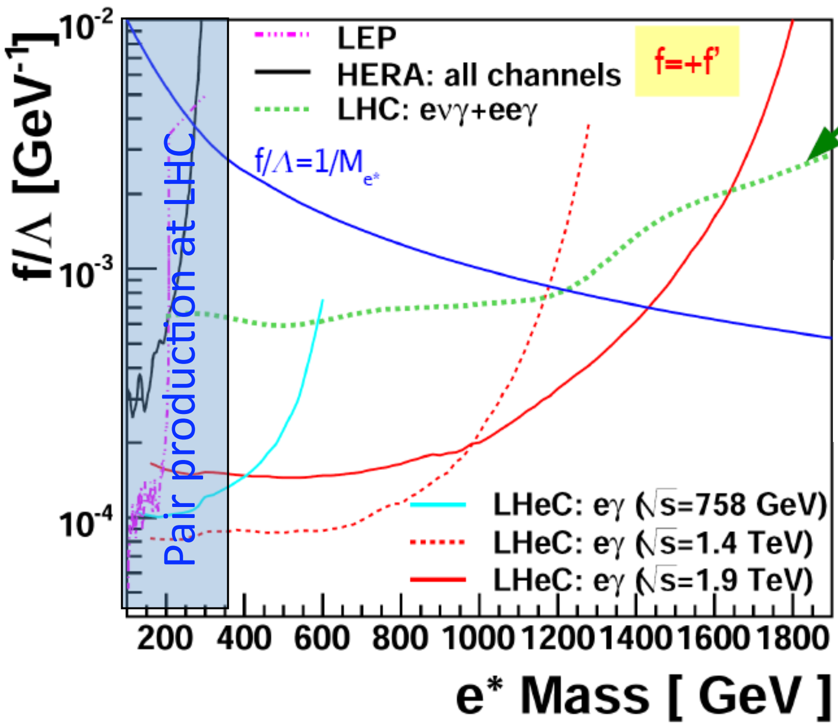
coupling
~ f / Λ

N. Trinh, E. Sauvan, Divonne

Single e* production x-section in ep is high.



LHeC prelim. analysis, looking at e* → eγ



[Phys. Rev D 65 (2002) 075003]

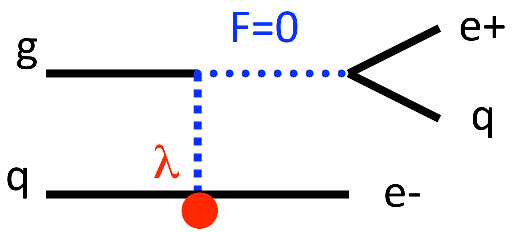
-If LHC discovers (pair prod) an e*: LHeC would be sensitive to much smaller f/Λ couplings

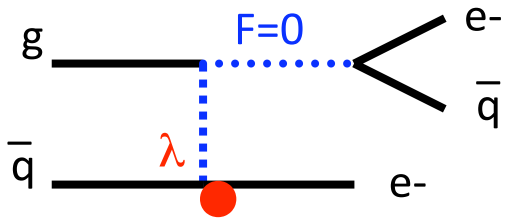
-Discovery potential for higher masses. needs high electron beam energy

L assumed 10 (1) fb^{-1} with 20/70 (140) GeV

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) :



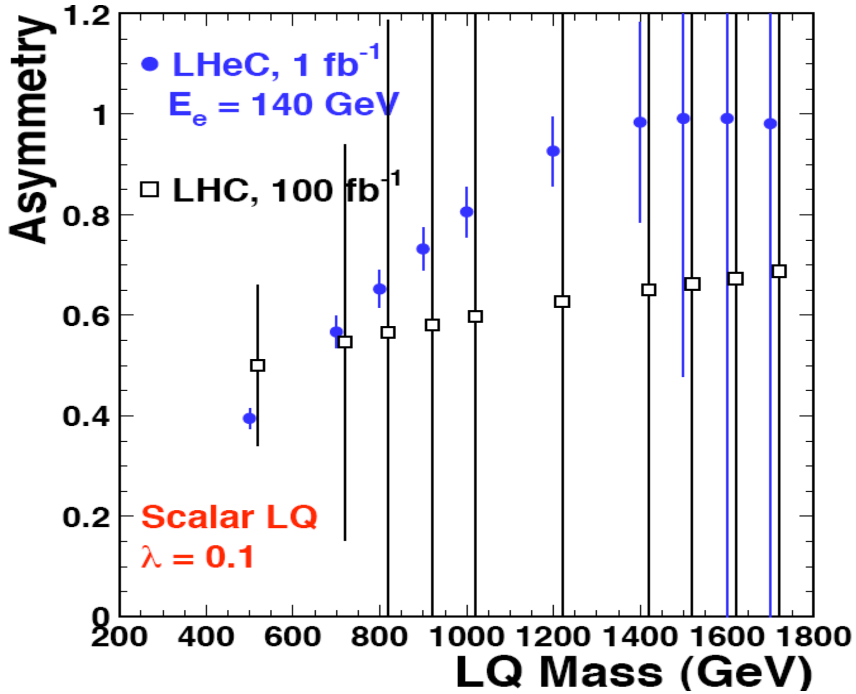


$\sigma(e^+_{out}) > \sigma(e^-_{out})$
for F=0

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

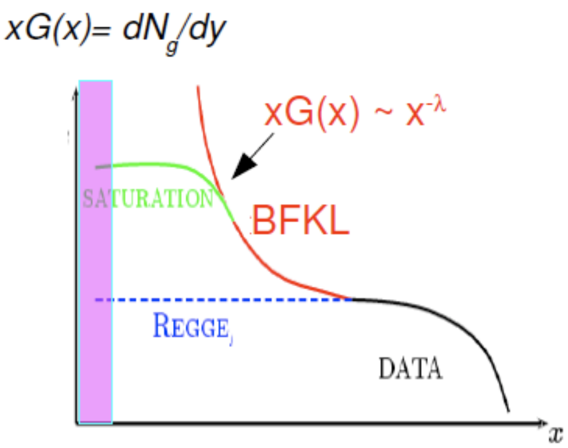
Easier in ep ! Just look at the signal with incident e+ and incident e-, build the asymmetry between $\sigma(e^+_{in})$ and $\sigma(e^-_{in})$.

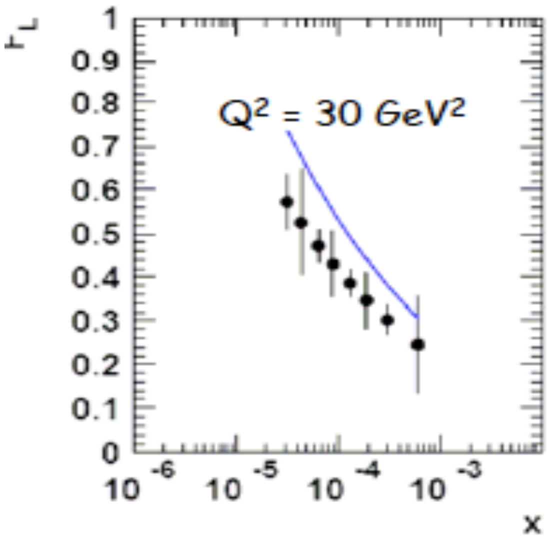
If LHC observes a LQ-like resonance,
M < 1 - 1.5 TeV, LHeC could determine F
if λ not too small.



(*) 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

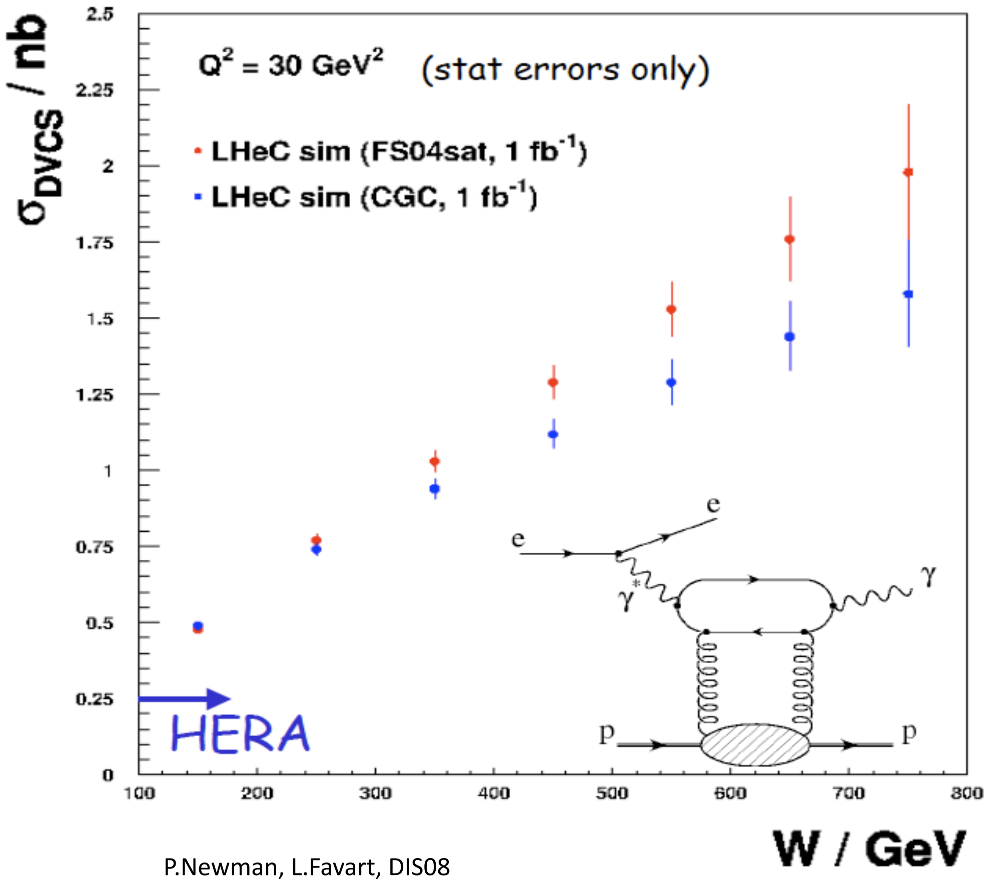




J.Forshaw et al, DIS08

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)