A Large Hadron electron Collider at the LHC

LHeC: 20-140 GeV on 1-7 TeV $e^{\pm}p$, also eA

Report of the Steering Group

First ECFA-CERN LHeC Workshop
Divonne (France) 1.-3.9.2008

Max Klein

UNIVERSITY OF LIVERPOOL

klein@ifh.de

The Questions

If a hadron collider will be built in the LEP tunnel then ep collisions are really a must

G.Altarelli et al, Lausanne LHC workshop 1984, Proc. p549

THE UNCONFINED QUARKS AND GLUONS

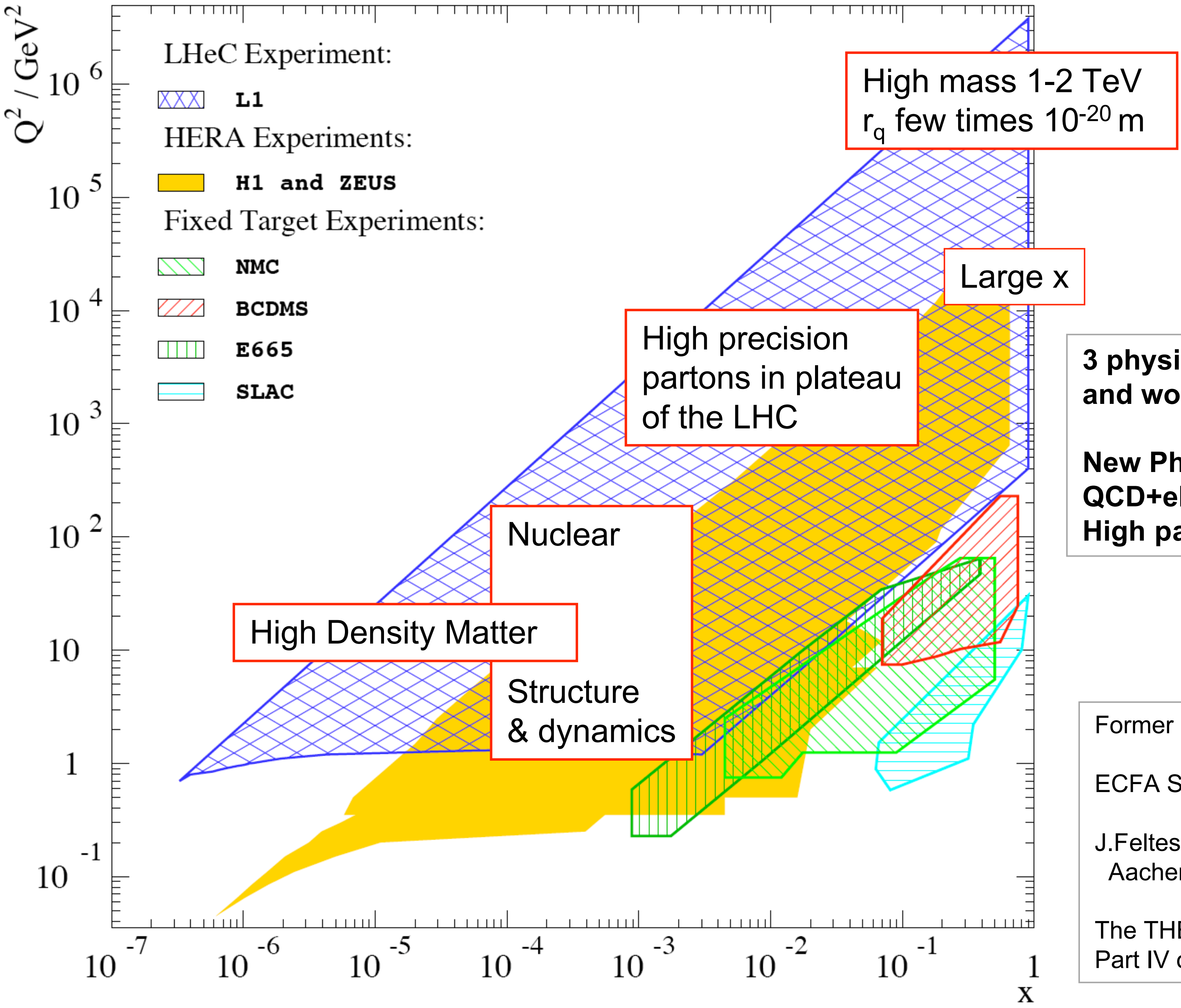
Abdus Salam

International Centre for Theoretical Physics,
Trieste, Italy and Imperical College, London,
England

1. Introduction

Leptons and hadrons share equally three of the basic forces of nature: electromagnetic, weak and gravitational. The only force which is supposed to distinguish between them is strong. Could it be that leptons share with hadrons this force also, and that there is just one form of matter, not two?

Now that a hadron collider is built in the LEP tunnel, are ep collisions still a must?
Why? and if so, how would we realise them with the present knowledge?



3 physics subjects and working groups:

New Physics
QCD+electroweak
High parton densities

Former considerations:

ECFA Study 84-10

J.Feltesse, R.Rueckl: Aachen Workshop (1990)

The THERA Book (2001)& Part IV of TESLA TDR

Many thanks to the SAC and Sgroup members for nearly two years of collaboration and support

Many thanks to
Patricia Mage-Granados
Jill Karlson Forestier
Urs Wiedemann
Albert De Roeck for preparing the organisation of the Divonne meeting

Please see
http://www.lhec.org.uk
for proper references, talks and papers.
Many thanks to
Paul Newman for the LHeC web page

So far this project relies on enthusiasm not on Funding, apart from the CERN grant to this Meeting.

Summary and Proposal as endorsed by ECFA (30.11.2007)

As an add-on to the LHC, the LHeC delivers in excess of 1 TeV to the electron-quark cms system. It accesses high parton densities 'beyond' what is expected to be the unitarity limit. Its physics is thus fundamental and deserves to be further worked out, also with respect to the findings at the LHC and the final results of the Tevatron and of HERA.

First considerations of a ring-ring and a linac-ring accelerator layout lead to an unprecedented combination of energy and luminosity in lepton-hadron physics, exploiting the latest developments in accelerator and detector technology.

It is thus proposed to hold two workshops (2008 and 2009), under the auspices of ECFA and CERN, with the goal of having a Conceptual Design Report on the accelerator, the experiment and the physics. A Technical Design report will then follow if appropriate.

The Goal of the Workshops is a CDR by December 2009.

Accelerator Design [RR and LR]

Closer evaluation of technical realisation: injection, magnets, rf, power efficiency, cavities, ERL…

What are the relative merits of LR and RR? Recommendation.

Interaction Region and Forward/Backward Detectors

Design of IR (LR and RR), integration of fwd/bwd detectors into beam line.

Infrastructure

Definition of infrastructure - for LR and RR.

Detector Design

A conceptual layout, including alternatives, and its performance [ep and eA].

New Physics at Large Scales

Investigation of the discovery potential for new physics and its relation to the LHC and ILC/CLIC.

Precision QCD and Electroweak Interactions

Quark-gluon dynamics and precision electroweak measurements at the TERA scale.

Physics at High Parton Densities [small x and eA]

QCD and Unitarity, QGP and the relations to nuclear, pA/AA LHC and SHEν physics.

Divonne, 1.-3.9.08

Workshop Convenors

Accelerator Design [RR and LR]

Oliver Bruening (CERN), John Dainton (Cockcroft/Liverpool)

Interaction Region and Forward/Backward Detectors

Bernhard Holzer (DESY), Uwe Schneeekloth (DESY), Pierre van Mechelen (Brussels)

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 Interactions

Olaf Behnke (DESY), Paolo Gambino (Torino), Thomas Gehrmann (Zuerich)

Physics at High Parton Densities [small x and eA]

Nestor Armesto (CERN), Brian Cole (Columbia), Paul Newman (B’ham), Anna Stasto (MSU)

Many thanks for accepting this despite the busy times in which we all live.

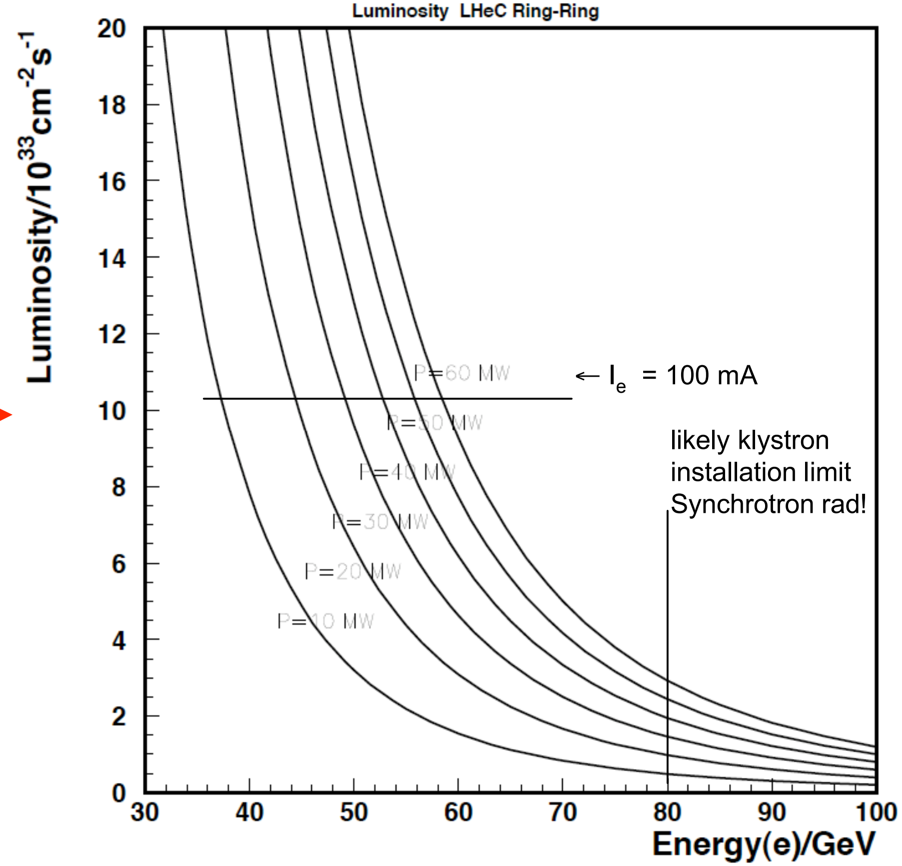
Luminosity: Ring-Ring

$$L = \frac{N_p \gamma}{4\pi e \varepsilon_{pn}} \cdot \frac{I_e}{\sqrt{\beta_{px}\beta_{py}}} = 2.4 \cdot 10^{33} \cdot \frac{I_e}{50mA} \frac{m}{\sqrt{\beta_{px}\beta_{pn}}} cm^{-2} s^{-1}$$

$$\varepsilon_{pn} = 3.8\mu m$$
$$N_p = 5 \cdot 10^{11}$$
$$\sigma_{p(x,y)} = \sigma_{e(x,y)}$$
$$\beta_{px} = 1.8m$$
$$\beta_{py} = 0.5m$$

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

10^{34}



Luminosity beyond 10^{33} in RR

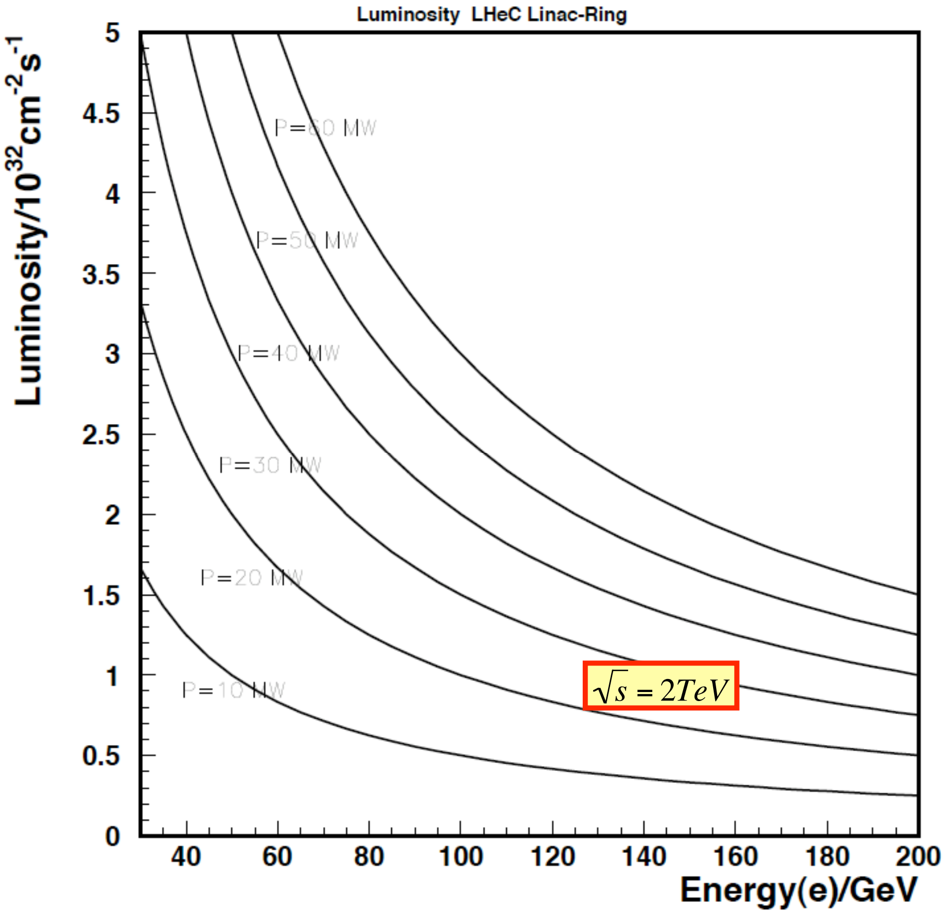
HERA was 1-4 10^{31} cm^{-2} s^{-1}
Gain O(100) with SLHC p beam

Power requirement may be modest e.g.:70 GeV with 20 MW: ~ 2 10^{33} for the upgraded (super) p beam.

cf also A.Verdier 1990, E.Keil 1996

Luminosity: Linac-Ring

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



SLHC

$$\varepsilon_{pn} = 1.9 - 3.8 \mu m$$
$$N_p = 3 - 5 \cdot 10^{11}$$
$$\beta^* = 0.10 - 0.15 m$$

cf R.Garoby EPS07, J.Koutchouk et al PAC07

LINAC is not physics limited in energy, but somehow cost + power limited

Note: positron source challenge:

SLC 10^{13} /sec
ILC 10^{14} /sec
LHeC at few 10^{32} needs 10^{15} /sec

10^{32} are in reach with a LINAC. The 'exact' luminosity depends much on the realisation details.
cf EPAC, ACC session here.

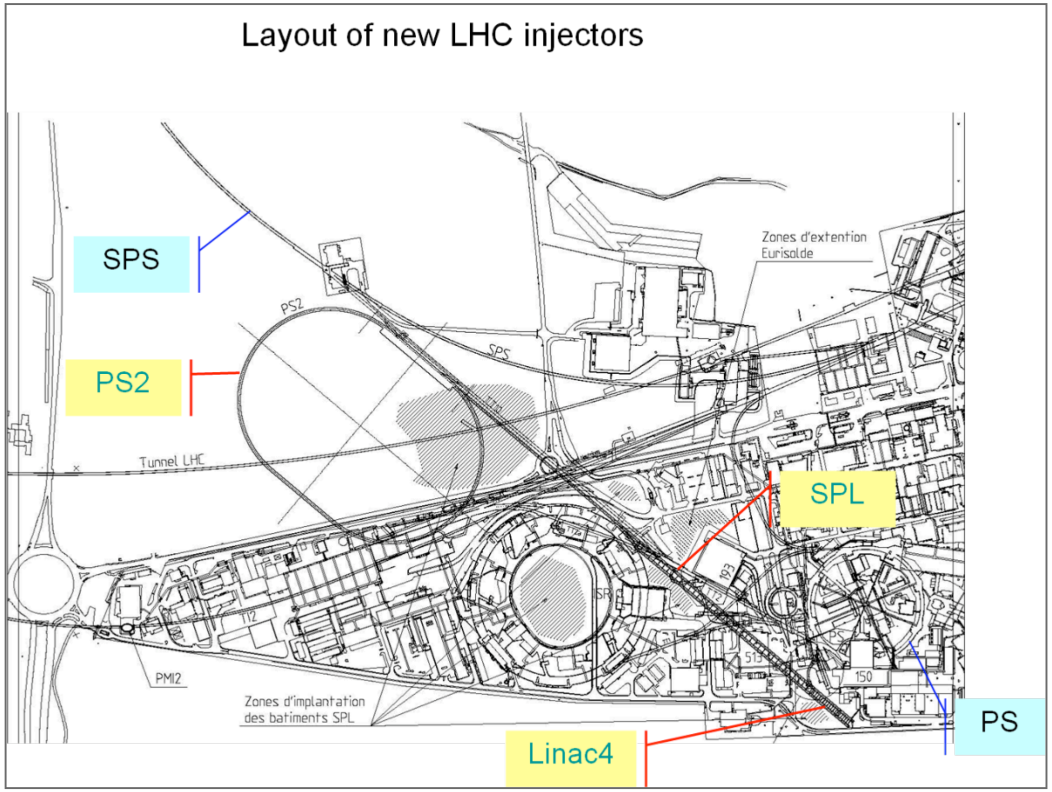
Parameters for pulsed Linacs for 140 GeV, $10^{32}cm^{-2}s^{-1}$

SC technology **NC technology**

	X FEL 20 GeV	LHeC 140 GeV, $10^{32}cm^{-2}s^{-1}$	LHeC 140 GeV, $10^{32}cm^{-2}s^{-1}$
I_{Beam} during pulse	5 mA	11.4 mA	0.4 A
N_E	$0.624\cdot10^{10}$	$5.79\cdot10^{10}$	$6.2\cdot10^{10}$
Bunch spacing	0.2 μs	0.8 μs	25 ns
Pulse duration	0.65 ms	1.0 ms	4.2 μs
Repetition rate	10 Hz	10 Hz	100 Hz
G	23.6MV/m	23.6MV/m	20.0 MV/m
Total Length	1.27 km	8.72 km	8.76 km
P_{Beam}	0.65 MW	16.8 MW	16.8 MW
Grid power for RF plant	4 MW	59 MW	96 MW
Grid power for Cryoplant	3 MW	20 MW	-
P_{Beam}/P_{AC}	10%	21%	18%

H.Braun, DIS08 workshop, cf also EPAC paper and F.Zimmermann here.

Accelerator



cf JINST 06 paper and 3 papers
presented to EPAC08, Genua

For ECFA07 no showstopper was found for e Ring. Promises highest luminosity, requires ~5 bypasses each of 500m length.

Running synchronous with pp is possible, dedicated running too.

The LINAC is not limited in energy. As for the LHC (Rubbia, Lausanne 84) there is a discussion on energy range and luminosity reach. High intensity positron sources are an issue for the LINAC.

Power will become more and more valuable and energy recovery is an important means. Two opposite LINACs? E recovery using the ring?

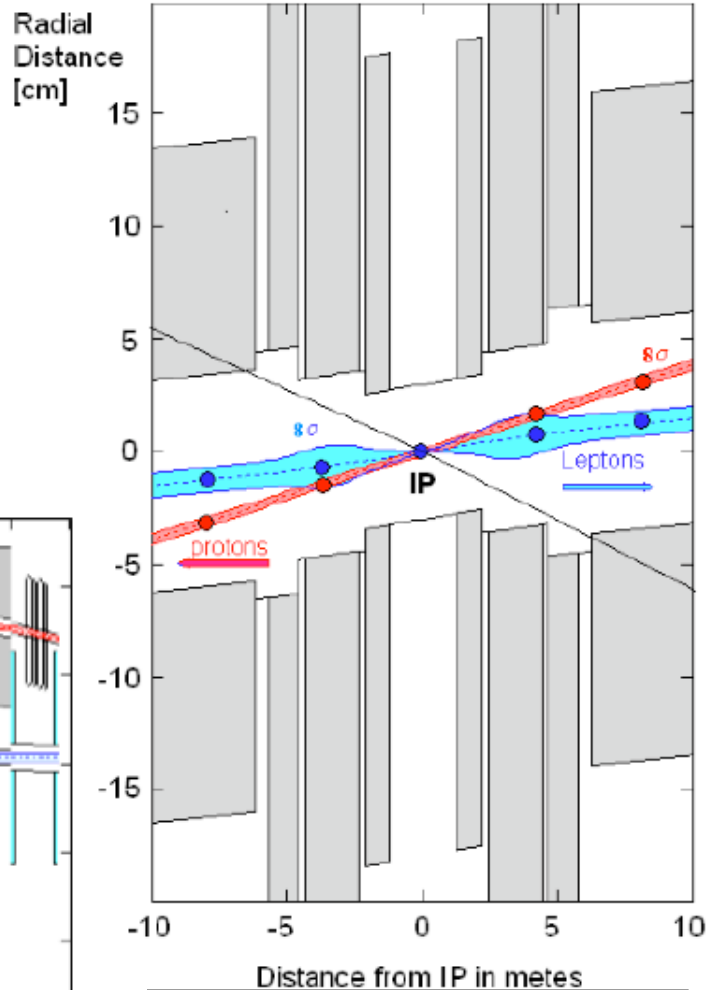
Time schedule is often discussed. One can think of starting with 5 GeV from SPL (this is low x, ~HERA III), perhaps add 4 fold circulator to reach 20 GeV, but the LHeC programme requires the maximum e energy and maximum luminosity to 'fly'.

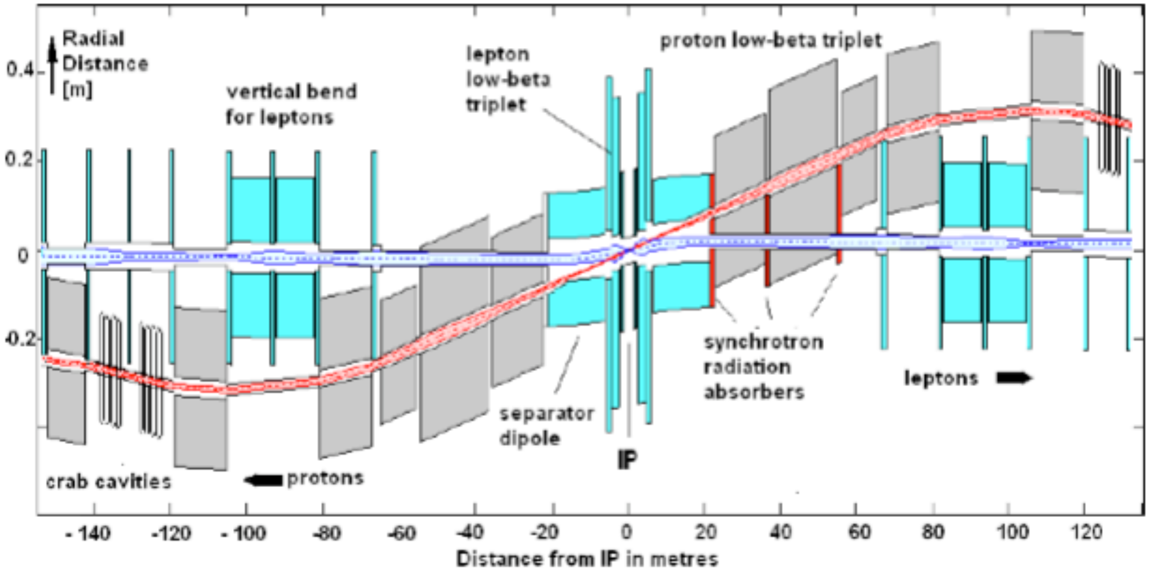
A first phase yet with a detector ready 'soon' deserves further consideration.

Ring-Ring LHeC Interaction Region Design

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

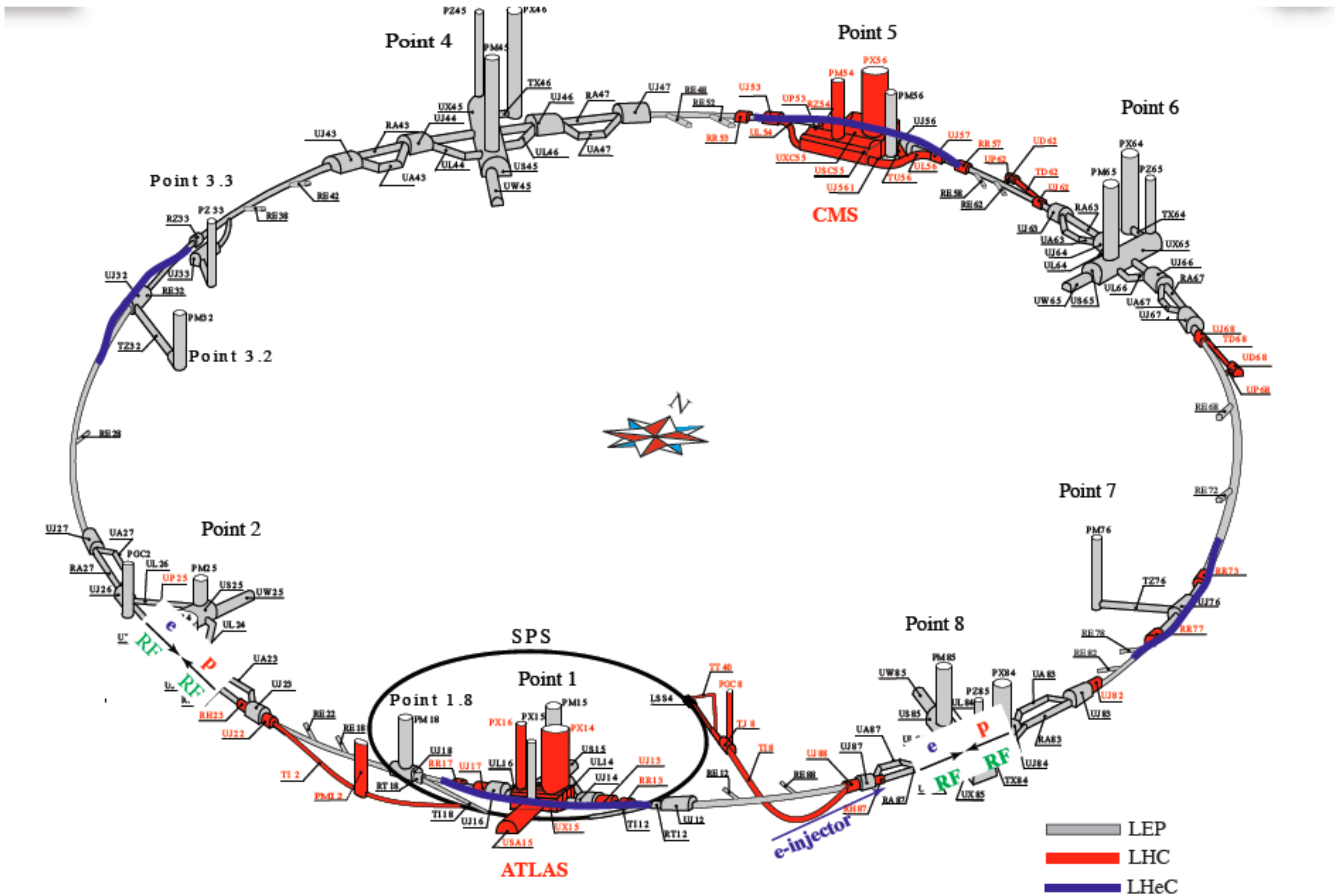
Property	Unit	Leptons	Protons
Beam Energies	GeV	70	7000
Total Beam Current	mA	74	544
Number of Particles / bunch	10^{10}	1.04	17.0
Horizontal Beam Emittance	nm	7.6	0.501
Vertical Beam Emittance	nm	3.8	0.501
Horizontal β-functions at IP	cm	12.7	180
Vertical β-function at the IP	cm	7.1	50
Energy loss per 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	$10^{33}cm^{-2}s^{-1}$	1.1	





allows for simultaneous operation of pp and ep

J.Dainton .. F.Willeke, JINST 1 P10001 (2006)



Divonne 1.9.2008 M.Klein

Interaction Region and Fwd/Bwd Detectors

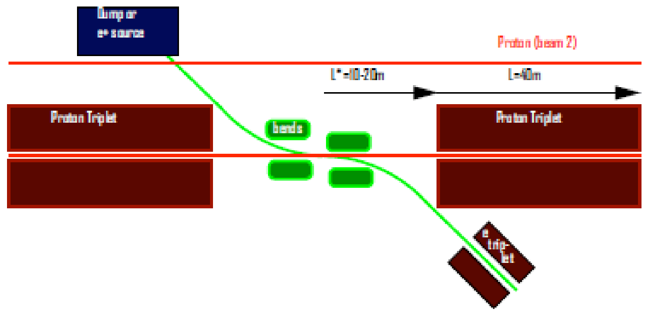
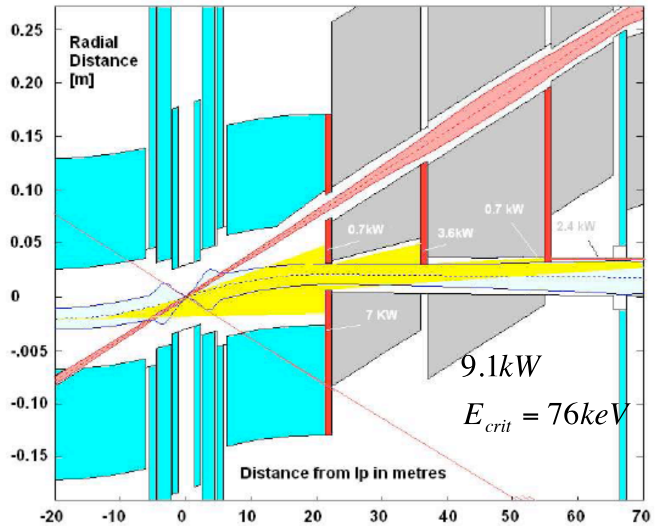


Figure 8: Schematic of linac-ring interaction region.

FZ: EPAC08



FW: JINST06

Kinematics requires that there is an active detector down to about 10-20mrad (cf LEP-LHC Aachen, it didn't change..)

Luminosity requires that focusing is brought near to vertex region.

Does this require 2 LHeC phases (as HERA I and II)? In the JINST 06 design a region of +-10 degrees (175mrad) is free of detector elements. Removal is about a 10 times reduction of lumi, but a gain in cross section (cf below)

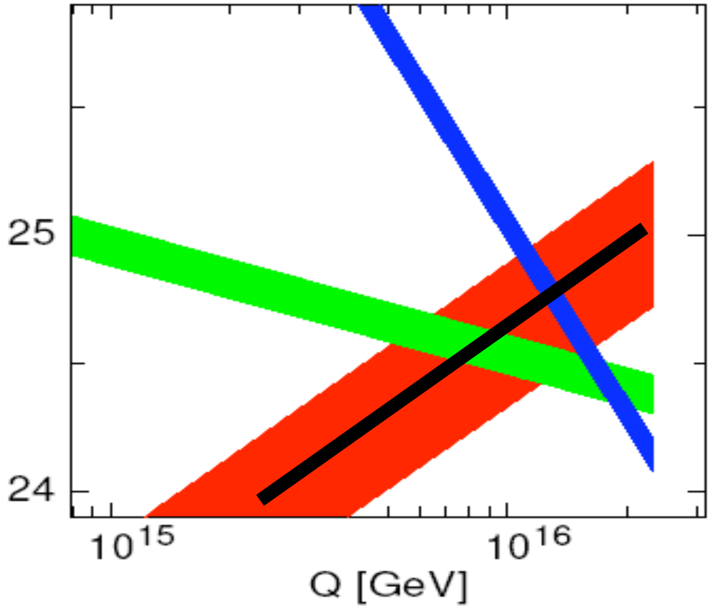
Can one build 'active focussing magnets'?

HERA lost 2 years until it was understood that ions, emitted due to synchradition, better are not seen by the p beam…

How can we build forward p,n detectors and how can me measure the luminosity to 0.5% (the theoretical limit in NLO) ? Experience from LHC and HERA.

cf W.Bartel Aachen 90

Strong Coupling



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

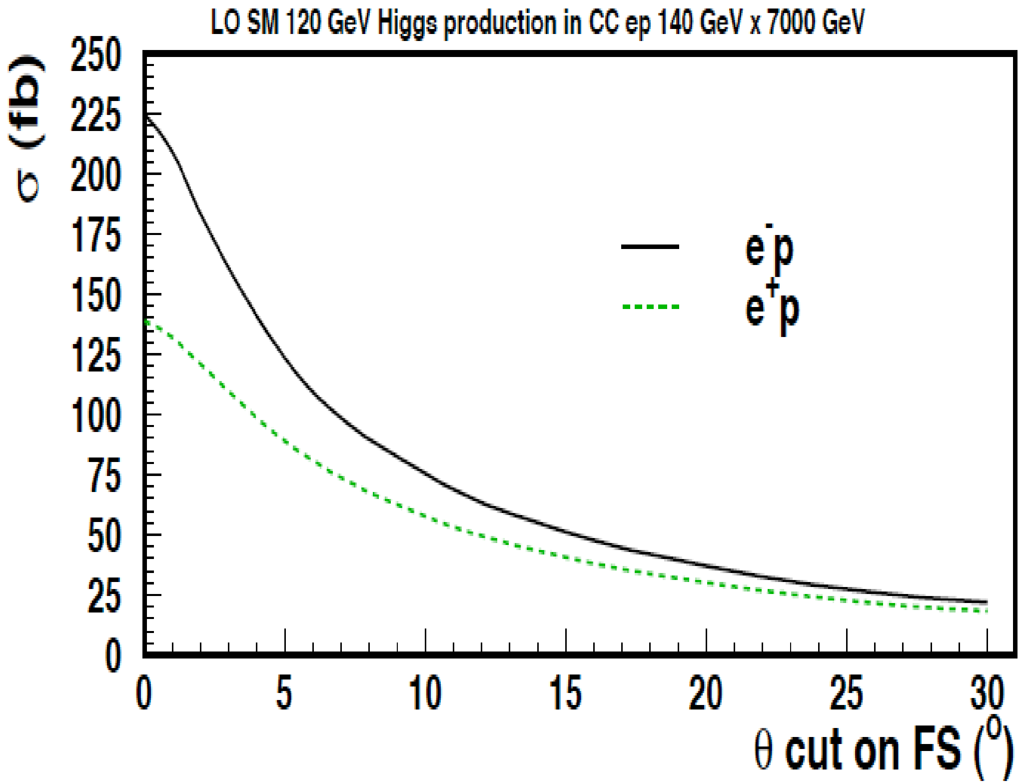
T.Kluge, MK, DIS08

Detector Requirements

	LHeC	HERA
Largest possible acceptance	1-179°	7-177°
High resolution tracking	0.1 mrad	0.2-1 mrad
Precision electromagnetic calorimetry	0.1%	0.2-0.5%
Precision hadronic calorimetry	0.5%	1%
High precision luminosity measurement	0.5%	1%

The LHeC is a high precision device!
Remember e.g. elweak u,d couplings from HERA or the gain in discovery reach at the LHC from precision pdf's.

Detector



Higgs production cross section in charged currents vs the minimum allowed polar angle for all final state particles (MadGraph - U.Klein)

The 7 TeV proton beam energy determines the size of the (fwd+central) detector. It is rather CMS than ZEUS, and thus **a fantastic challenge for the next decade.**

There is hardly pile-up. SLHC is 50ns.

Inclusive kinematics instructive (cf JINST06)

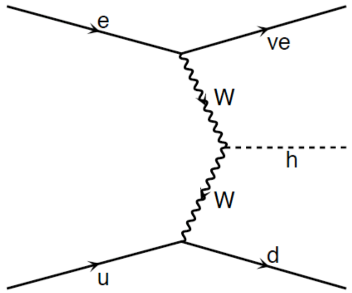
Fwd: similar to CMS/ATLAS (calo coverage to η=4.9 (about 1°) with few TeV jets). Tracking desirable (large x), but who has mastered fwd tracking really?

Bwd: up to max perhaps 100 or 200 GeV electron energy and rather quiet in terms of hadrons. The Central part is in between..

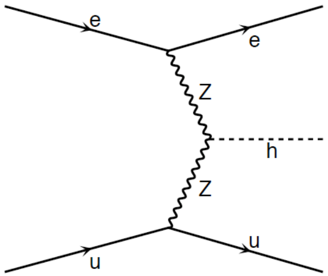
Tagging of charm and beauty necessary, note very small beam spot size.

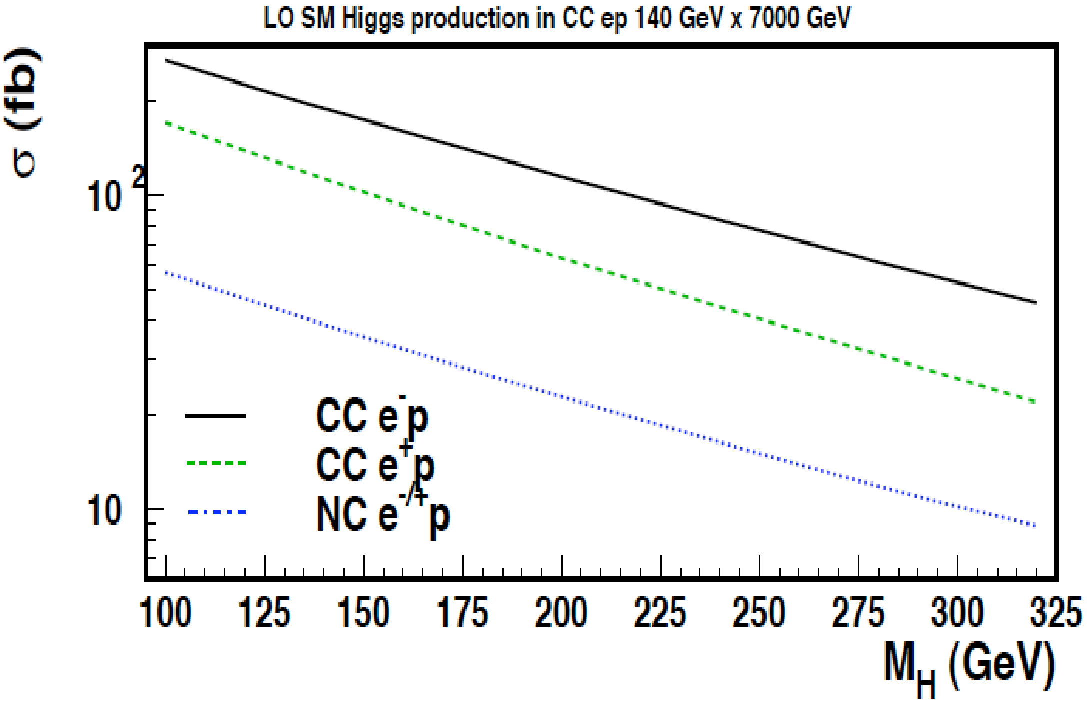
Installation in ALICE or LHCb hall, smaller than ATLAS,CMS caverns, may fit still.

Magnetic field in bwd part - different from central or extended solenoid (cf EIC studies and THERA, CMS + ATLAS) ?



SM Higgs in CC and NC





The LHeC at high lumi is well suited for W/Z-Higgs production.

How can this be utilised?
Dijet resolution

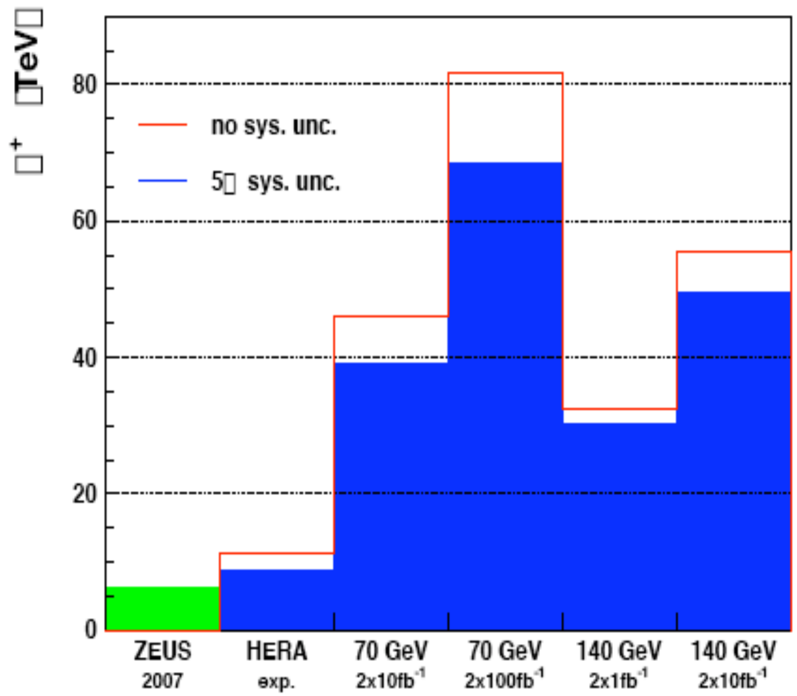
e Polarisation of interest.

70 GeV is about half of 140 GeV cross section.

E.Perez and U.Klein, cf also Aachen Workshop, G.Grindhammer et al.

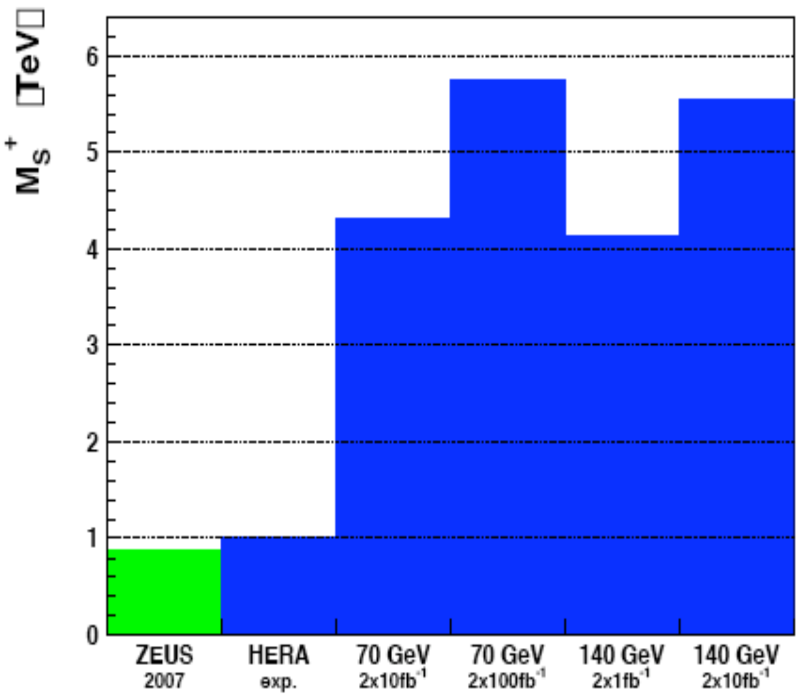
CI and Leptoquarks

VV model (conserving parity)



Big step wrt HERA, relation to LHC.?

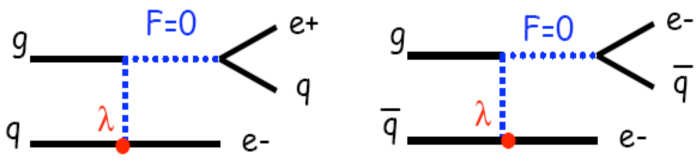
AAD model (Large Extra Dimensions)

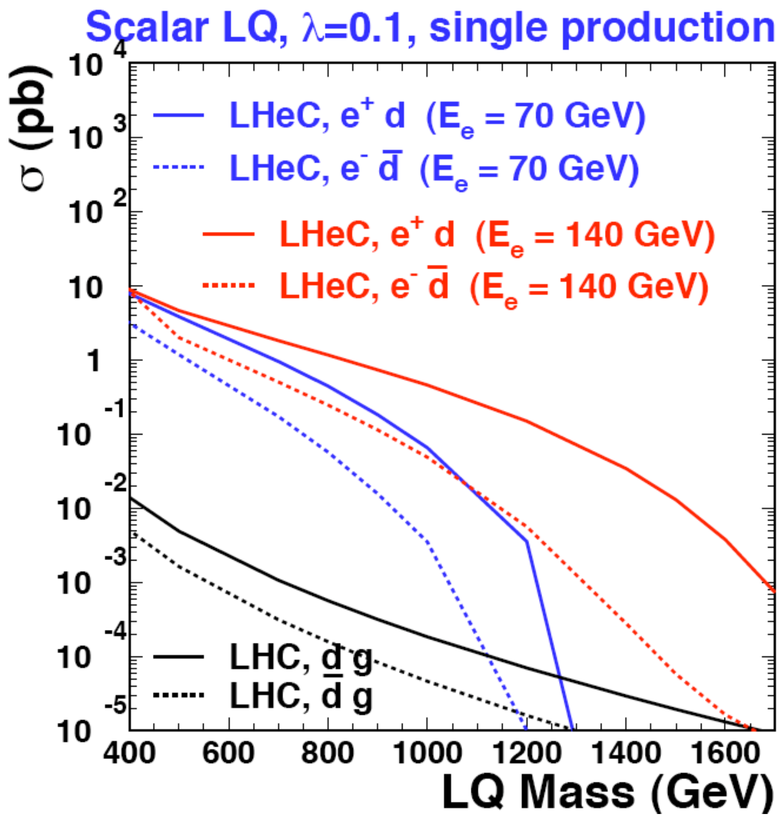


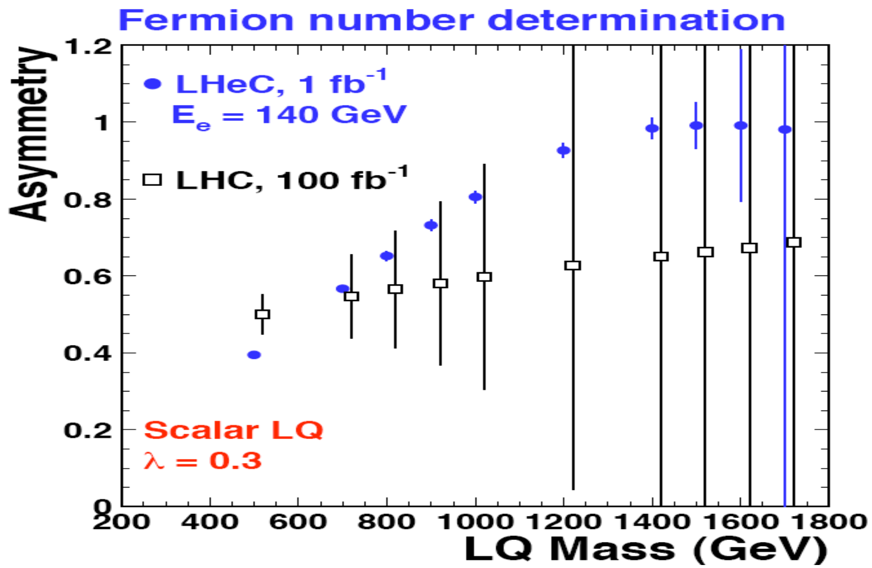
Similar limits for M_S^-

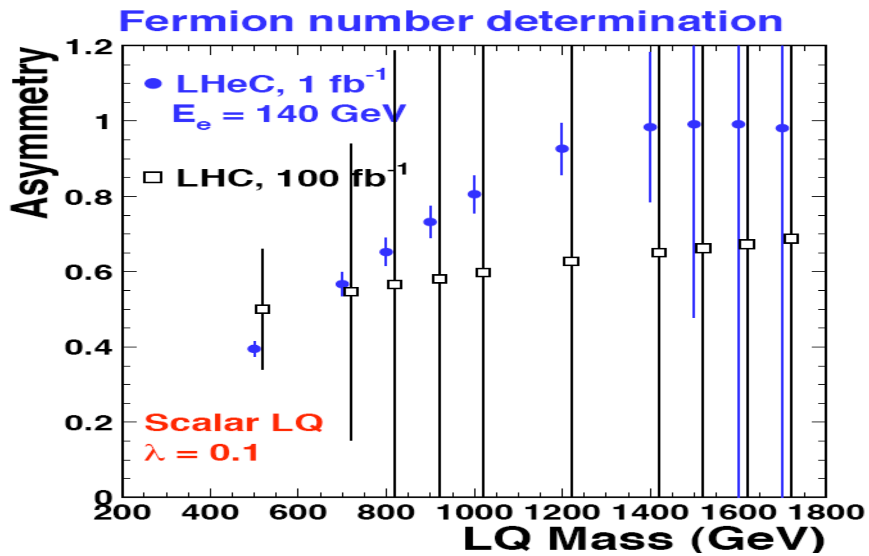
A.Zarnecki DIS08

Quantum Numbers









Charge asymmetry much cleaner in ep than in pp. Similar for simultaneous determination of coupling and quark flavour

E.Perez, DIS07

HERA*) - 'an unfinished business'

Low x: DGLAP holds though ln1/x is large
Saturation not proven

High x: would have required much higher luminosity
[u/d ?, xg ?]

Neutron structure not explored

Nuclear structure not explored

New concepts introduced, investigation just started:
-parton amplitudes (GPD's, proton hologram)
-diffractive partons
-unintegrated partons

Instantons not observed

Odderons not found

…

Lepton-quark states not observed

Need:

Higher energy
($Q^2 = sxy$, $x \geq Q^2/s$)

High Luminosity

e^+ and e^-

lepton polarisation

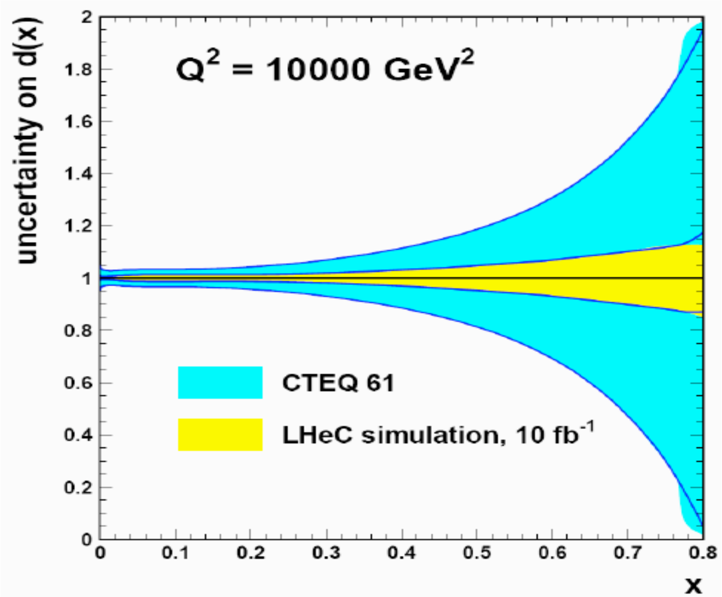
p, D, A

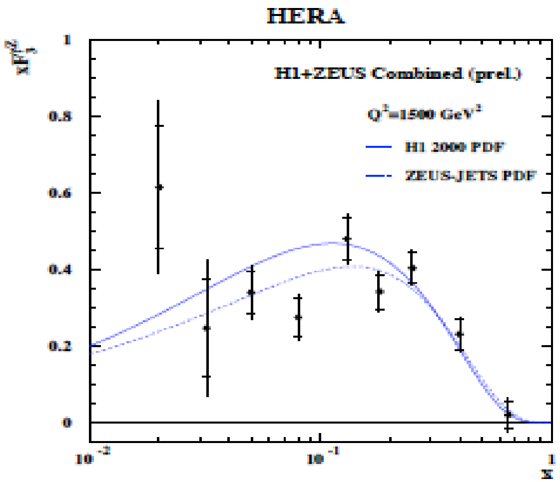
The LHC is the right place for an ep/A collider to be considered

*) M.K., R.Yoshida, 'Collider Physics at HERA''
arXiv 0805.3334 [hep-ex], Prog.Part.Nucl.Phys.

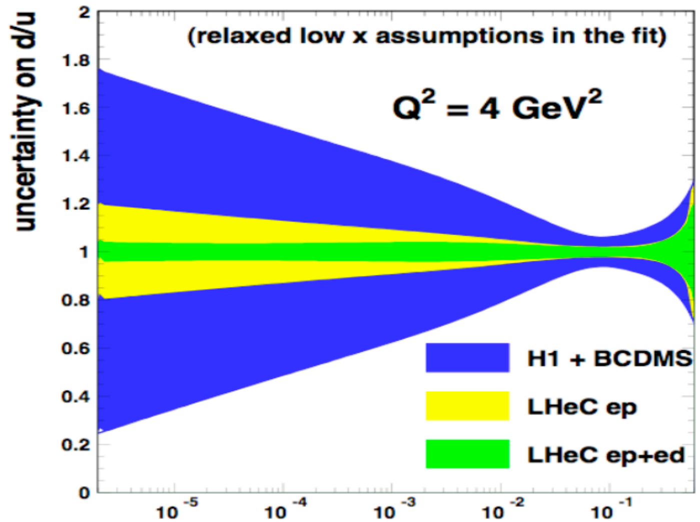
HERA II analysis still ongoing

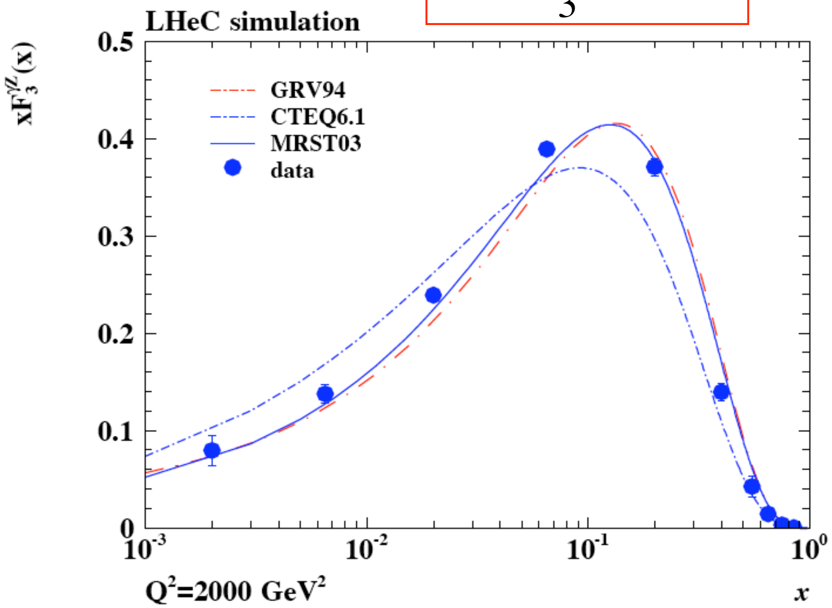
The (in)famous u/d ratio and the valence quarks





$$xF_3^{\gamma Z} = \frac{x}{3}(2u_v + d_v)$$

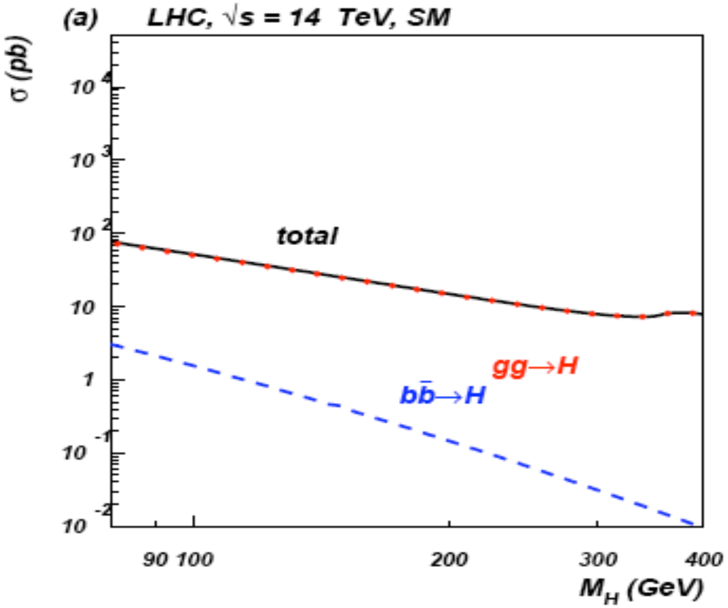




Shadowing related to diffraction

Gluon

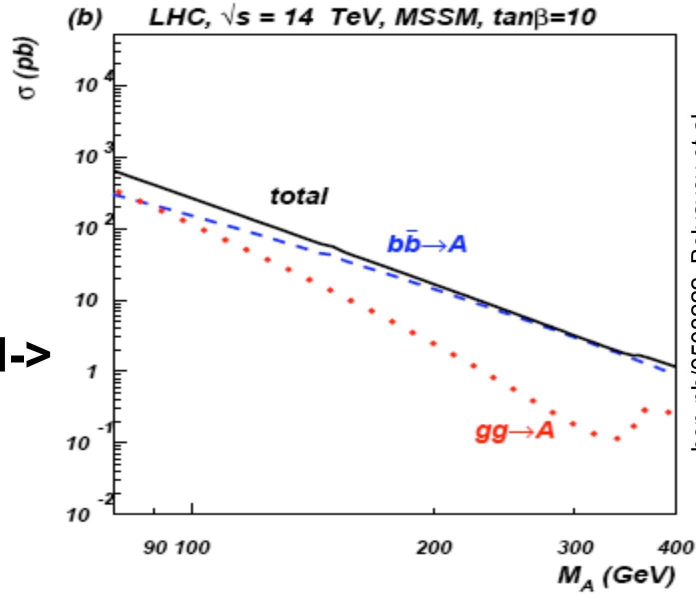
Beauty



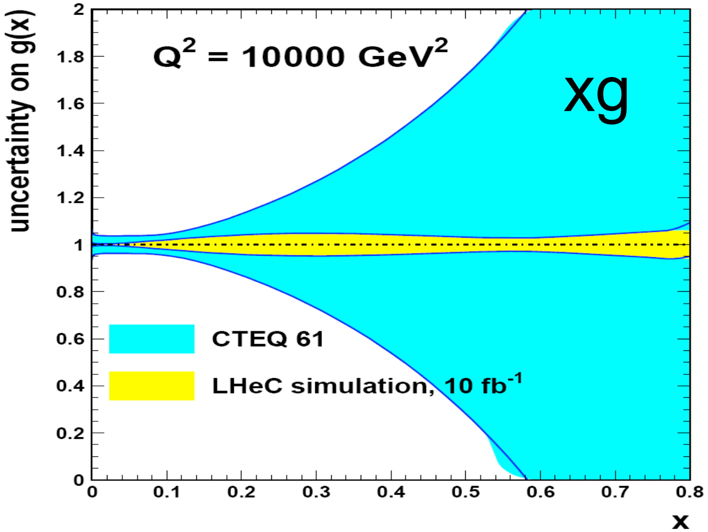
Higgs

<-SM

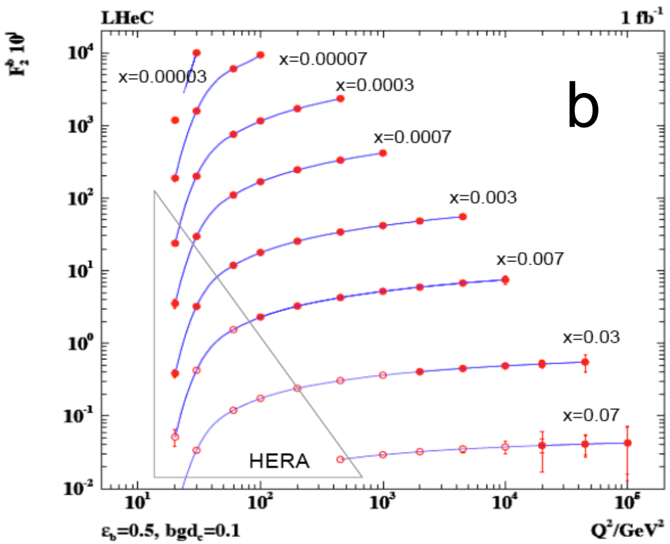
MSSM->



hep-ph/0508222, Belyayev et al

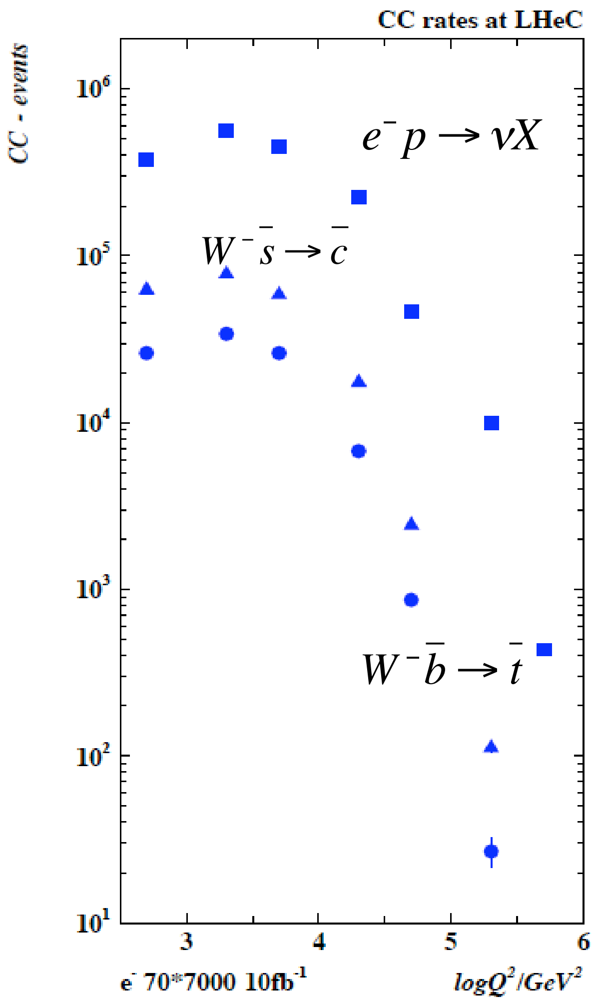


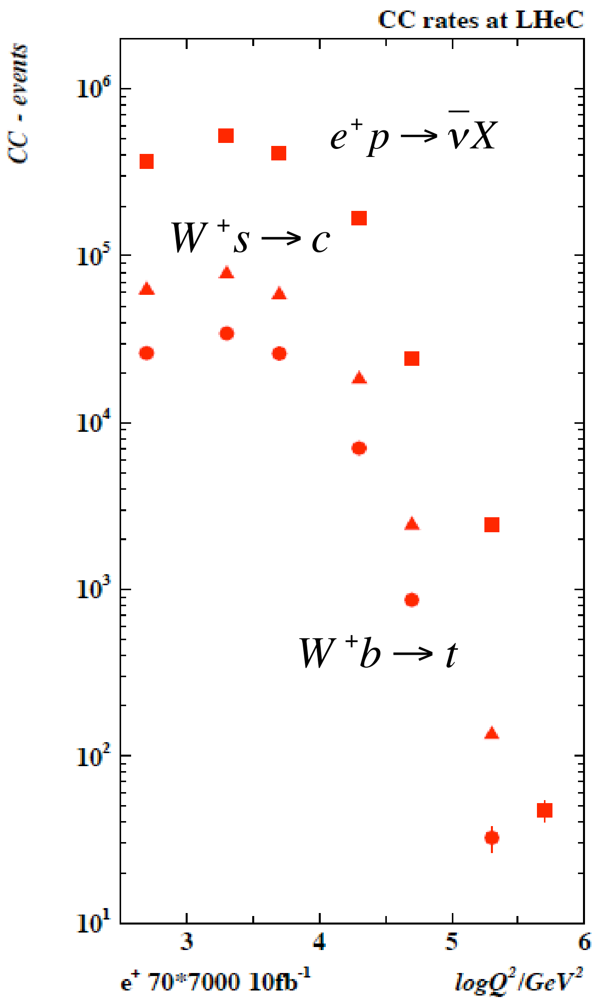
E.Perez DIS07

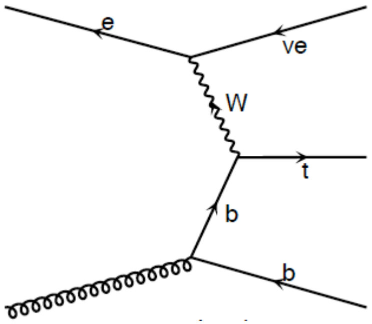


Divonne 1.9.2008 M.Klein

$\overline{\text{Top}}$ and Top Production at the LHeC (cc)

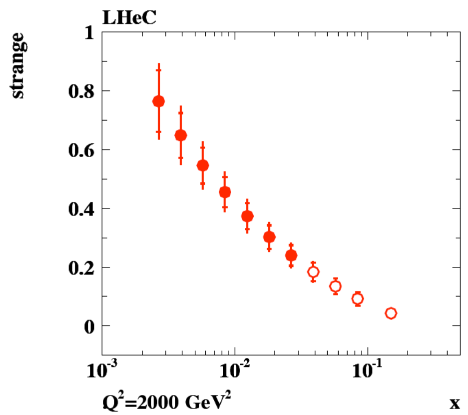


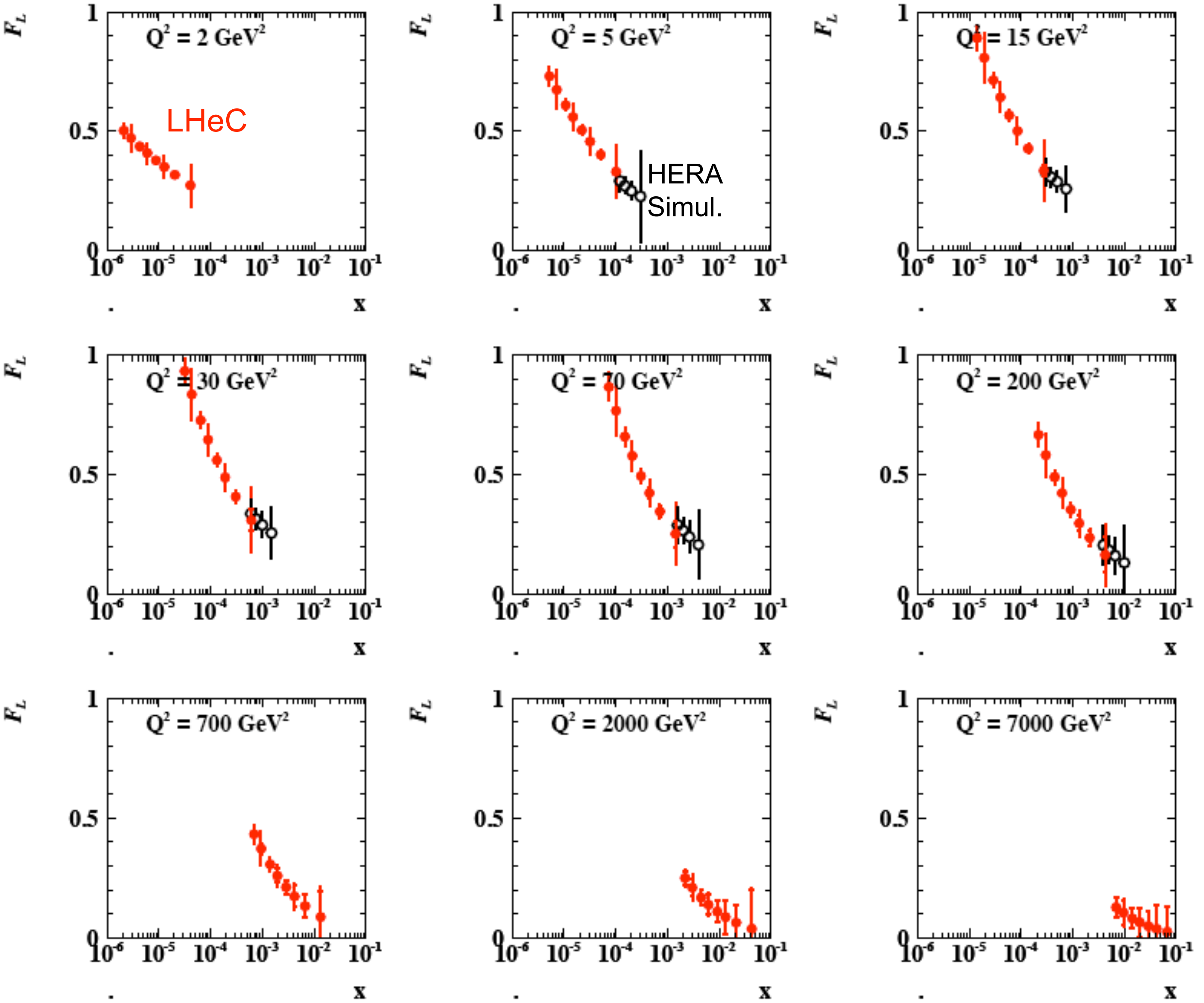




LHeC is a single top and tbar quark factory **with a CC cross section of O(10)pb - worth studying further**

Strange q for the 1st time.





DIS08
J.Forshaw
et al.

May not be able to simultaneously fit the two proton structure functions F2 and FL when these represent a saturation CDM

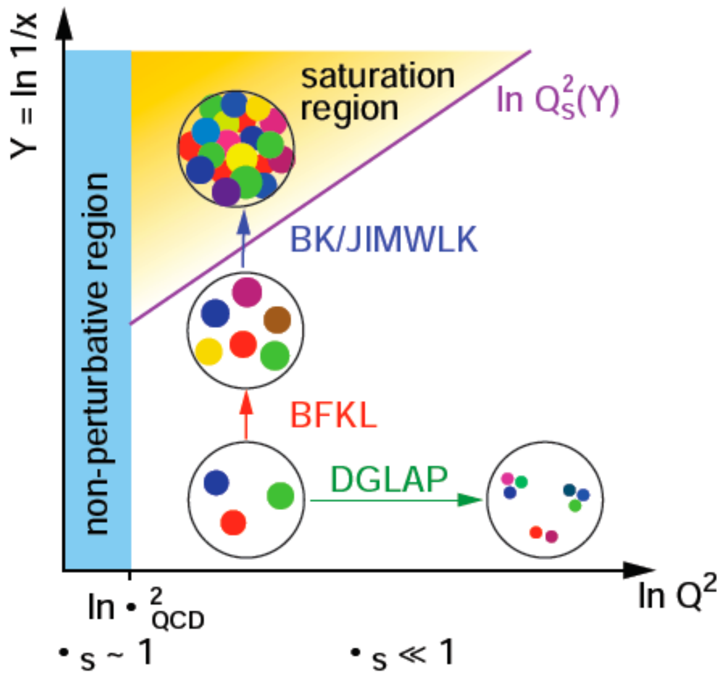
With enlarged energy, saturation scale moves into DIS region and DGLAP may truly be shown to fail when confronted with very low x data.

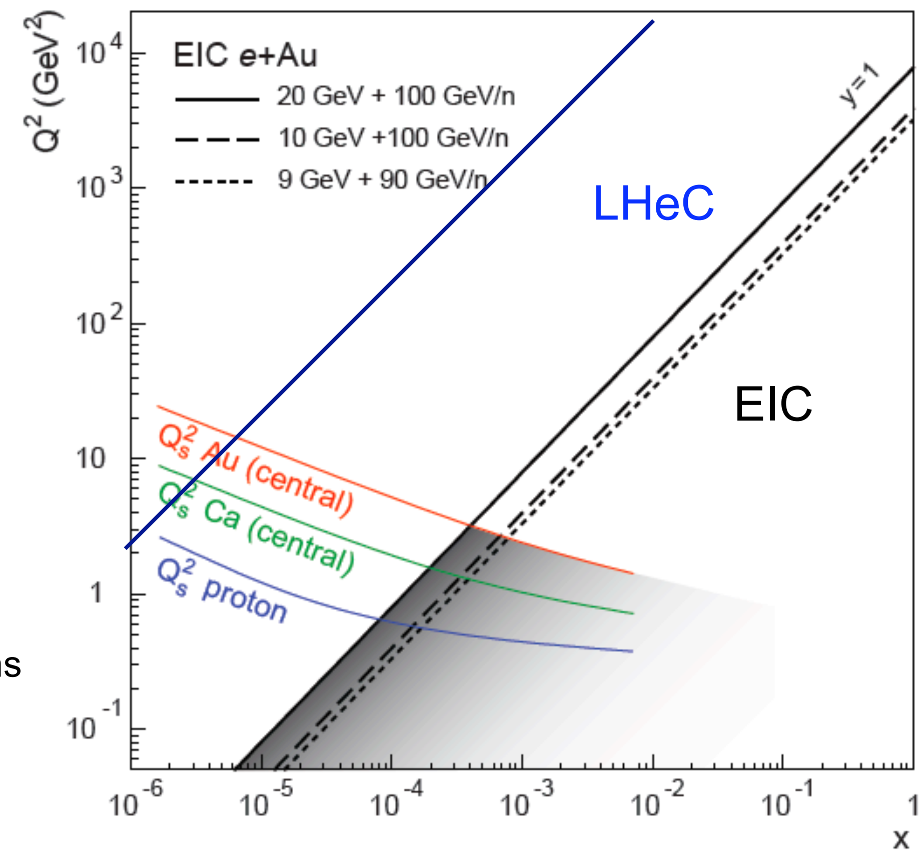
F_L takes long (1986-2008)…

Welcome to the NuPECC study group

Tullio Bressani, INFN, Torino Univ.
Jens Jørgen Gaardhøje, Niels Bohr Inst.
Günther Rosner, Glasgow Univ. (chair)
Hans Ströher, FZ Juelich

eA@LHeC

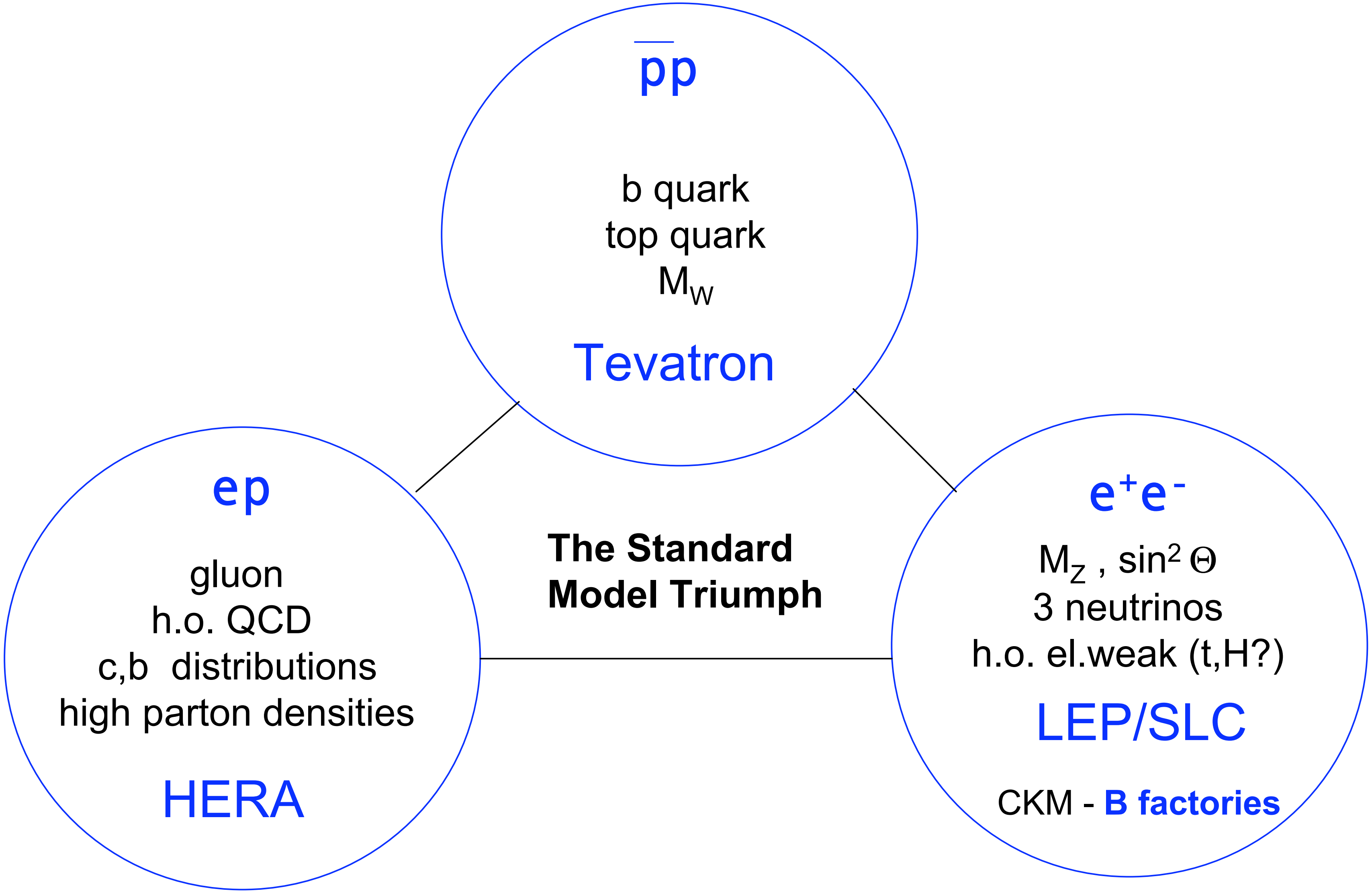




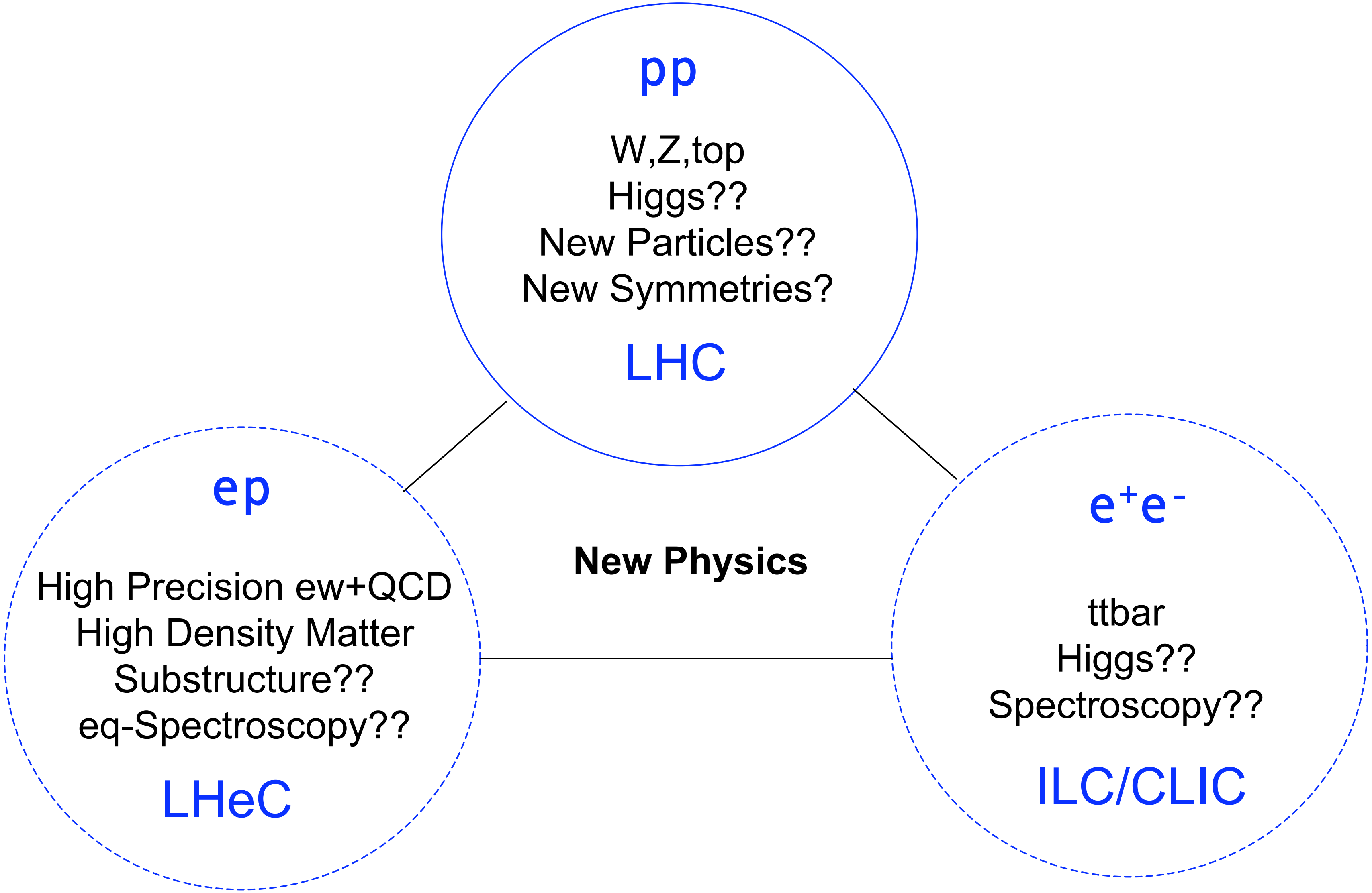
Measurement of nuclear parton distributions
Non-linear effects (xg 'beyond' unitarity)
50% diffraction ..

The LHeC extends the measurement of nuclear structure in lA by four orders of magnitude as HERA did skip the eA phase. eA in relation to ALICE programme and the EIC

The Past - Fermi Scale [1985-2010]



The Future - TeV Scale [2008-2033..]



Divonne 1.9.2008 M.Klein

Final Remarks

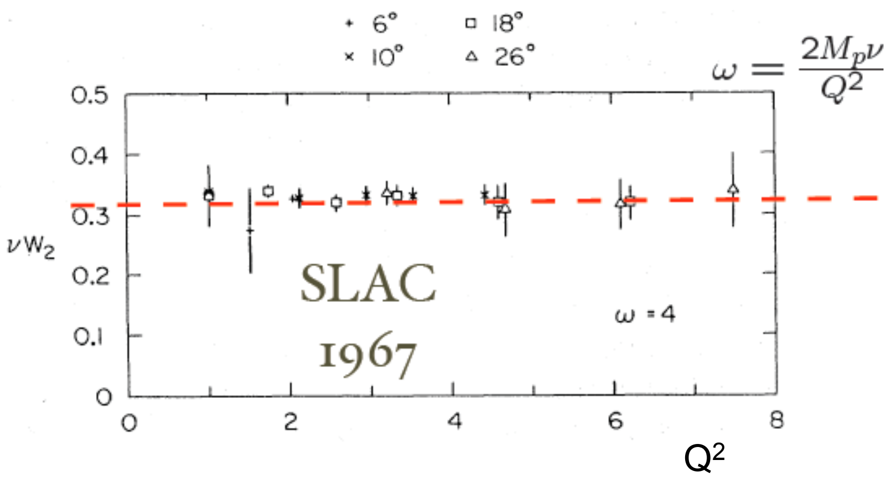
The goal of the CDR by 09 is to contribute to the debate about the future of our field by presenting a realistic way for DIS to conquer the Tera Scale physics.

It seems possible to achieve above a TeV in the eq system within the lifetime of the older generation here present. We have to make clearer which are the unique goals of the LHeC and how it would complement the LHC and a future lepton collider. This to first approximation depends on the findings and also the performance of the LHC.

Physics as the technical working groups, in a world where many read no more than a line or two, **need to focus on the main arguments and options. These can be detailed should a technical design report follow. We then will also see much clearer which scenario may possibly be realised.**

Next steps: **ICFA 08, NuPeCC08, ECFA 08,**
a second workshop (Sept.09??)
CDR December 2009

The LHeC is a PeV equivalent fixed target ep scattering experiment, at 50 000 times higher energy than the pioneering SLAC MIT experiment. It may need a LINAC not much longer than the 2mile LINAC to the right, perhaps a ring. Its physics potential is extremely rich. Its technology is at hand, apart from some desirable further developments.



That proposal was remarkably humble..

The LHeC would be a tribute to Pief P. and Bjoern W.