A Large Hadron electron Collider at the LHC

40-140 GeV on 1-7 TeV $e^{\pm}p$, also eA

Progress since DIS07 and News from DIS08

On November 30th, 2007, ECFA has unanimously endorsed the proposal to work out a Conceptual Design Report for the LHeC, supported by CERN. NuPECC has formed a study group to investigate the prospects for the LHeC in Europe and the EIC in the United States as part of the long range planning for European Nuclear Physics.

Max Klein

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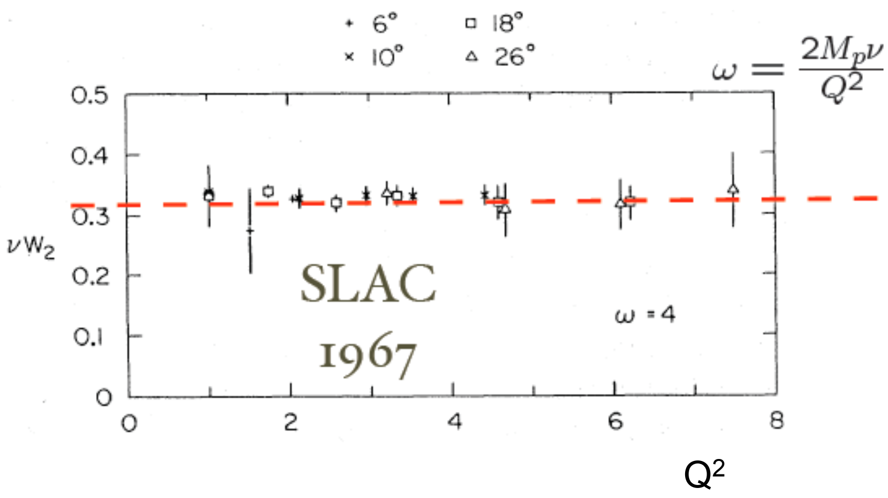
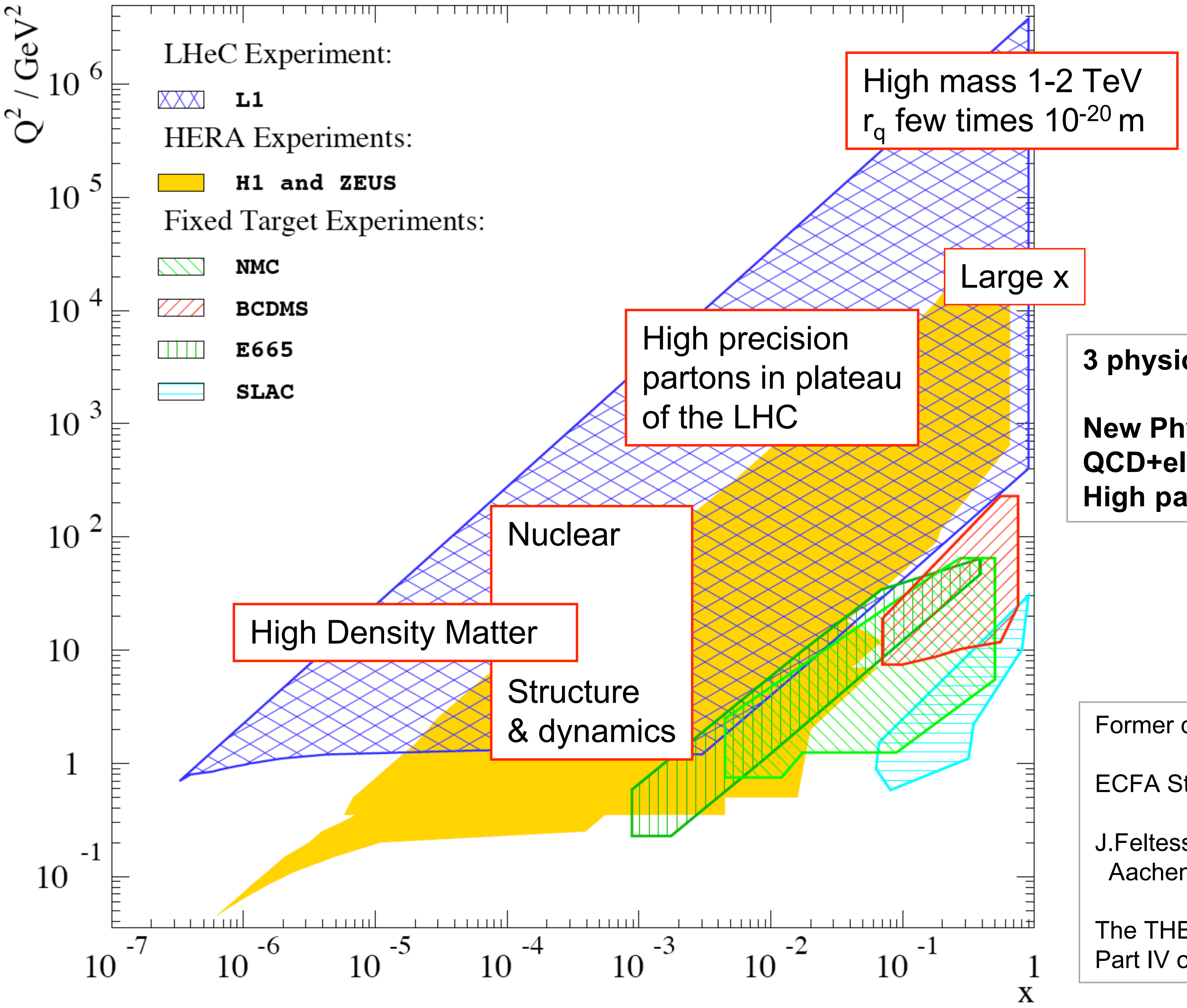
The LHeC is a PeV equivalent fixed target ep scattering experiment, at 50 000 times higher energy than the pioneering SLAC MIT experiment. It may need a LINAC not much longer than the 2mile LINAC to the right. Its physics potential is extremely rich.



Pief



3 physics subjects:

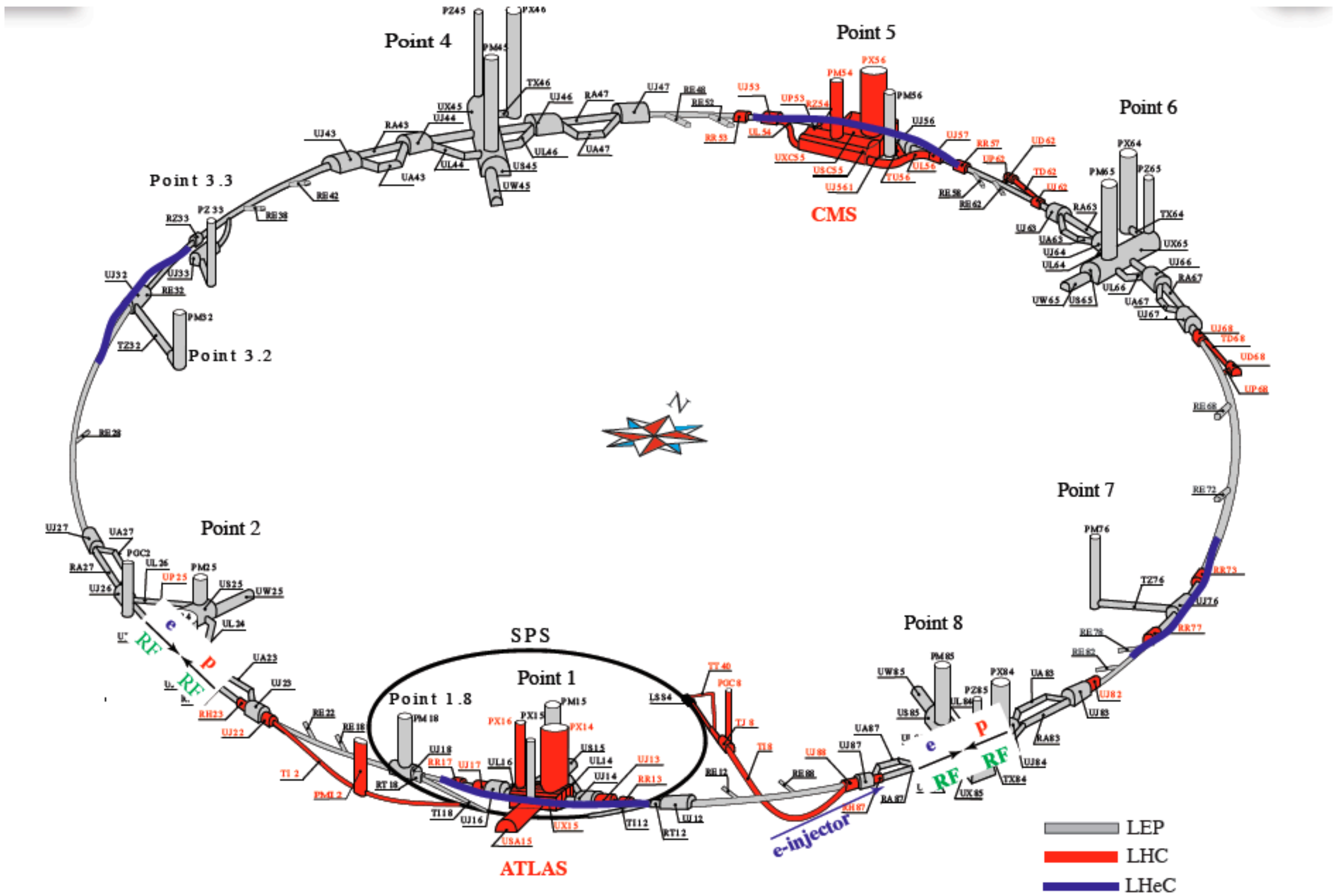
New Physics
QCD+electroweak
High parton densities

Former considerations:

ECFA Study 84-10

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

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

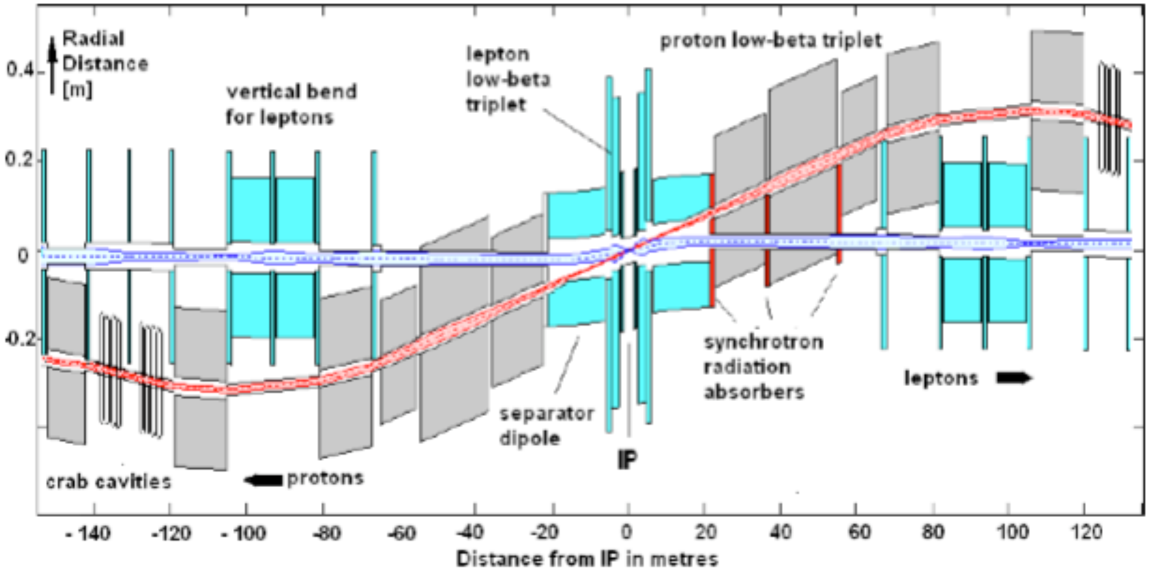


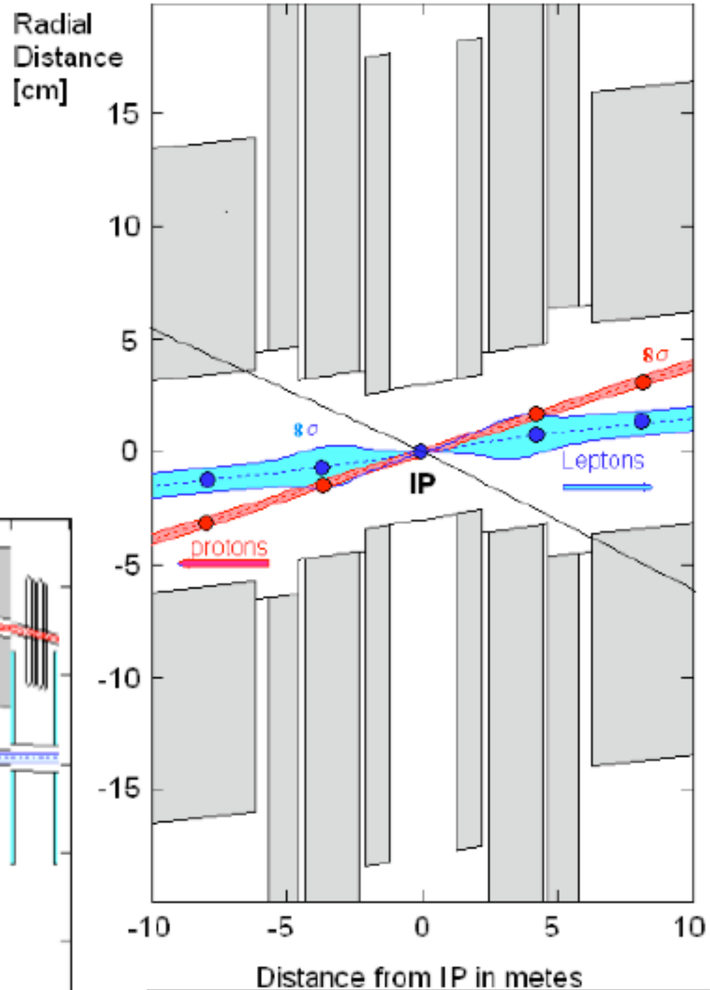
Point 4
Point 5
Point 6
Point 3.3
Point 3.2
CMS
N
Point 7
Point 2
Point 8
SPS
Point 1
Point 1.8
ATLAS
e
p
RF
e-injector
LEP
LHC
LHeC

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

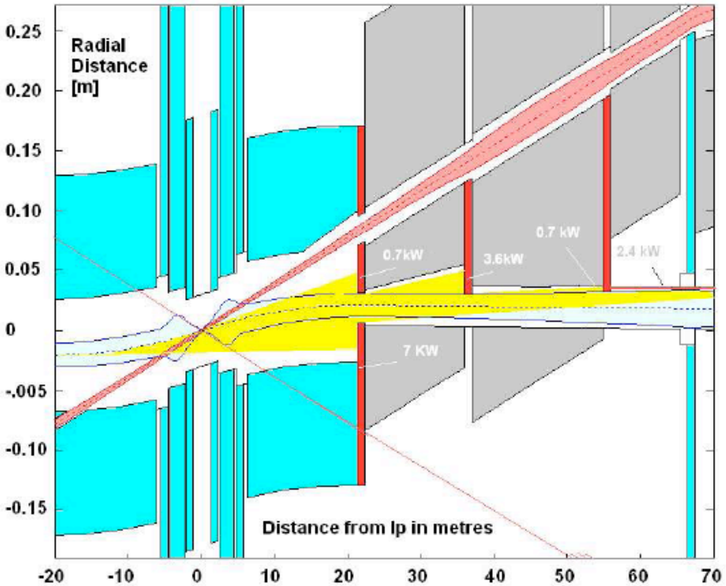


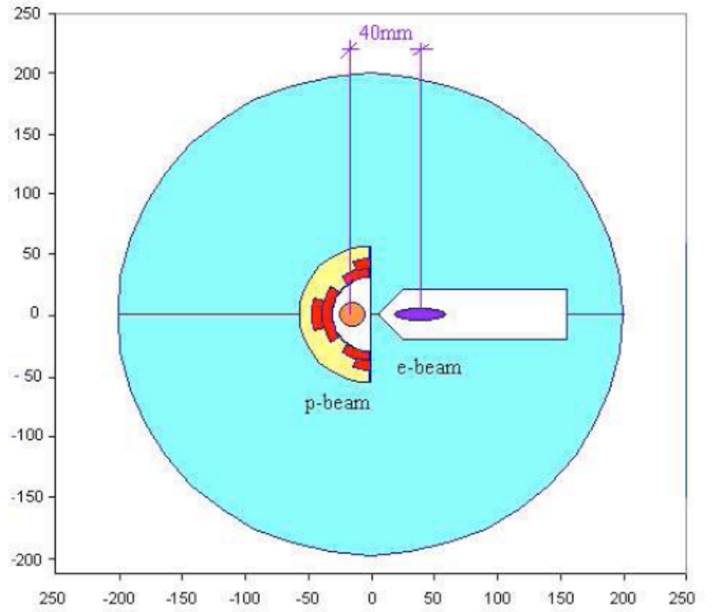


foresees simultaneous operation of pp and ep

J.Dainton et al, JINST 1 P10001 (2006)

Design Details





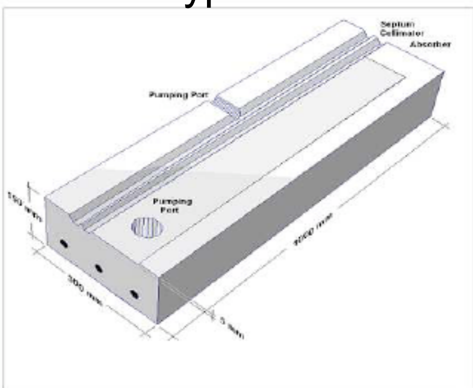
Synchrotron radiation fan

and HERA type absorber

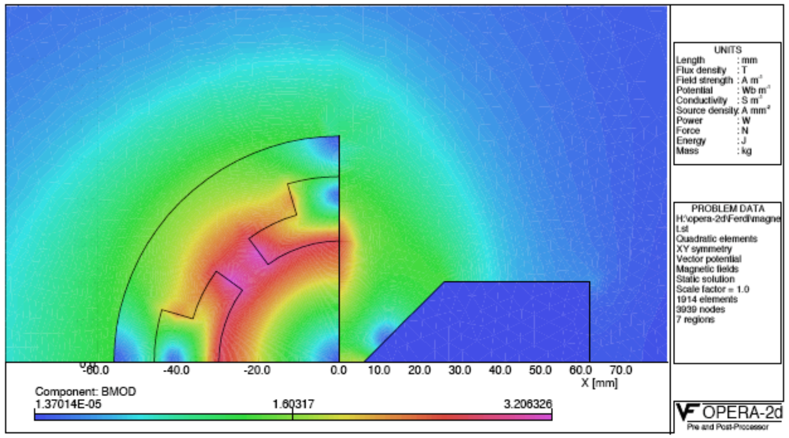
$9.1kW$

$E_{crit} = 76keV$

First p beam lens: septum quadrupole.
Cross section and Field calculation



100W/mm^2



cf also W.Bartel
Aachen 1990

Accelerator (RR) questions considered

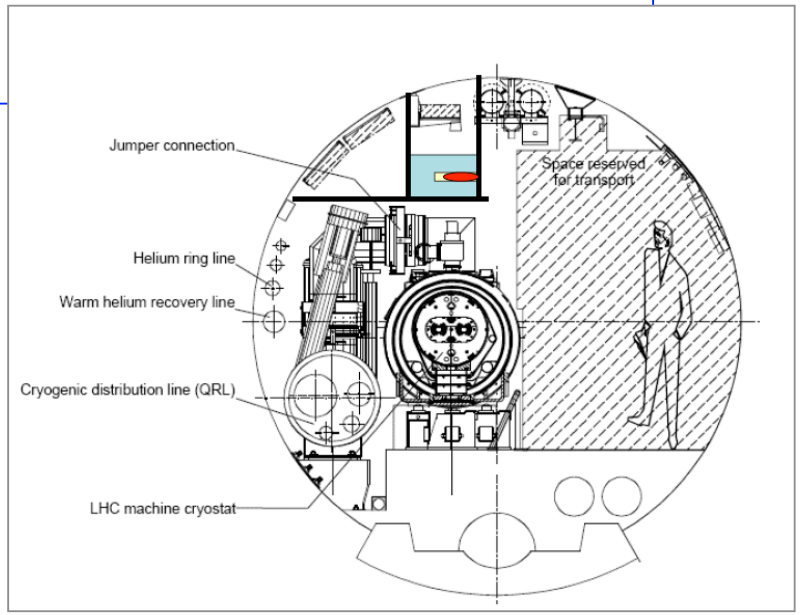
Power: 25ns: nx40MHz rf frequency. Imax 100 mA: 60 klystrons with 1.3MW coupler of perhaps 0.5MW, 66% efficient… need space for rf in bypasses

Injection: LEP2 was N= 4 10^{11} in 4 bunches, LHeC is 1.4 10^{10} in 2800 bunches may inject at less than 20 GeV. Injection is no principal problem regarding power and technology (ELFE, KEK, direct?)

Synchrotron load to LHC magnets: can be shielded (water cooled Pb)

Bypasses: for ATLAS and CMS but also for further Pi. l~500m start in the arcs. May ensure same length of e ring as p with ~ -20cm radius of e ring.

Space: first look at the installation on top of LHC

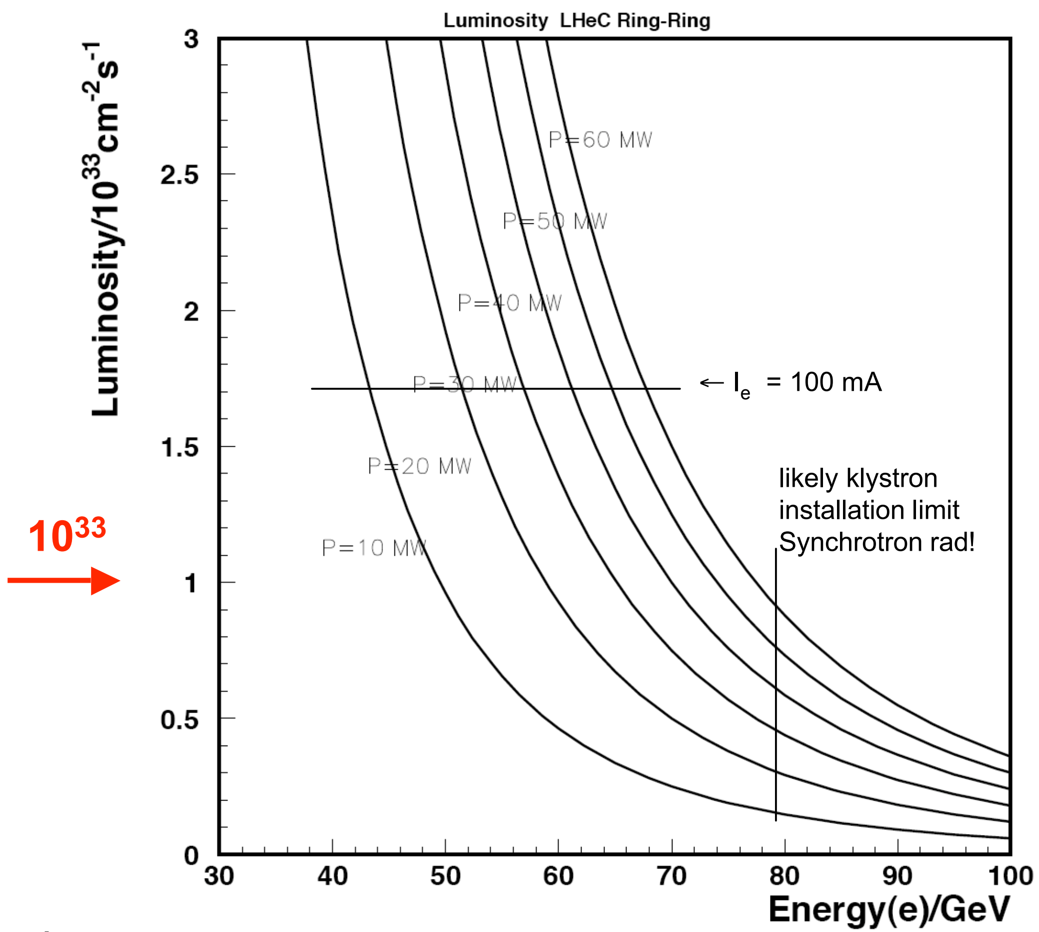


Luminosity: Ring-Ring

$$\varepsilon_{pn} = 3.8\mu m$$
$$N_p = 1.7 \cdot 10^{11}$$
$$\sigma_{p(x,y)} = \sigma_{e(x,y)}$$
$$\beta_{px} = 1.8m$$
$$\beta_{py} = 0.5m$$

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

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



10^{33} can be reached in RR
E_e = 40-80 GeV & P = 5-60 MW.

HERA was 1-4 10^{31} cm^{-2} s^{-1}
huge gain with SLHC p beam

F.Willeke in hep-ex/0603016:
Design of interaction region
for 10^{33} : 50 MW, 70 GeV

Factor of 5 possible to gain with intensity and beam emittance (cf H.Braun this workshop).
May relax power requirement.

cf also A.Verdier 1990, E.Keil 1986

about 20 GeV injection energy

be able to fill reasonably fast - say within 10 min

low intensity 1.4×10^{10} / bunch – could do without accumulation

many (2800) bunches, 25 ns spacing, total intensity 3.92×10^{13} el

injection scheduling :

analog to protons (3 - 4 batches of nominally 72 bunches)

- what about CLIC clictable2007.html

high gradient 100 MV/m in 85% of LINAC ; L = 235 m to reach 20 GeV

N = 3.72e9 / bun; k = 312 bun/train ; Linac repetition rate of 50 Hz : 5.83e13 Elec/ sec. Significant overhead for drive beam generation - probably not very economic for a relatively short LINAC.

- 20 GeV SC linac, inspired by ILC

gradient 31.5 MV/m (ILC BCD) in 85% of LINAC : L = 747 m

N = 2e10 / bun, k = 2820 bun /train ; repetition rate of 5 Hz : 2.82e14 Elec/secs

modify to match LHC batch structure

LHeC injector

$f_{rf} \sim 1$ GHz, gradient 31.5 MV/m

Linac L = 150 m 7× shorter

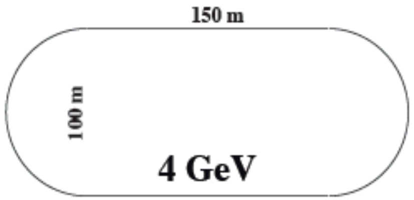
$V_{rf} = 4$ GV, 5 passes ; last 16 GeV

$\varrho = (16/21.5)^{\wedge}4\times56.9$ m = 17.5 m

or 3.3× shorter

significantly downscaled $L \approx 600$ m

and simplified (5 passes) version of ELFE@CERN



recirculating LINAC

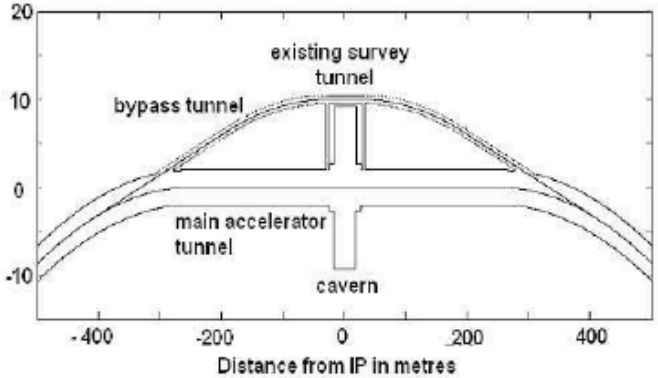
more cost effective (?) than single LINAC

+ extra phys. potential

H.Burkhardt DIS08

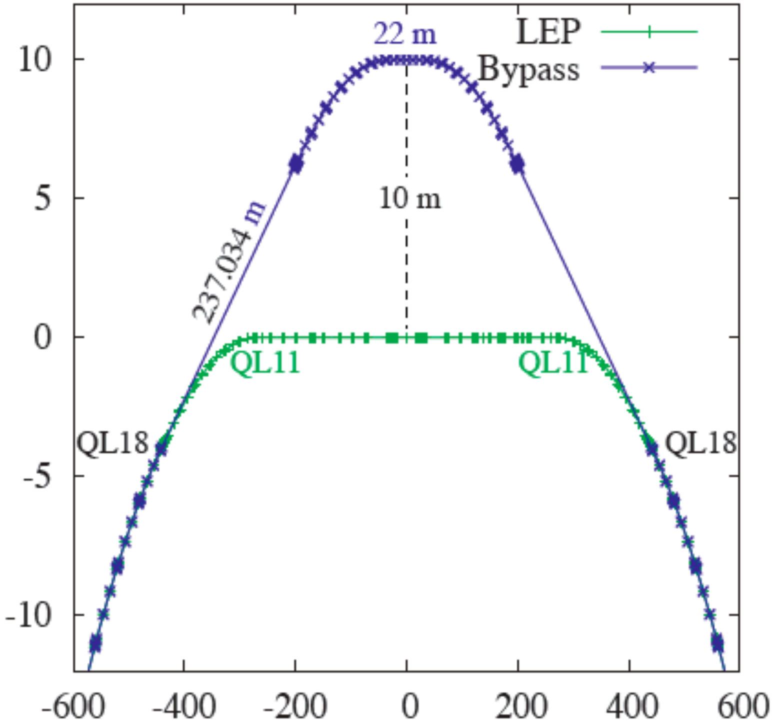
Bypass Layout Study - based on LEP lattice - no extra bends

schematic layout
Dainton / Willeke et al.



LEP lattice

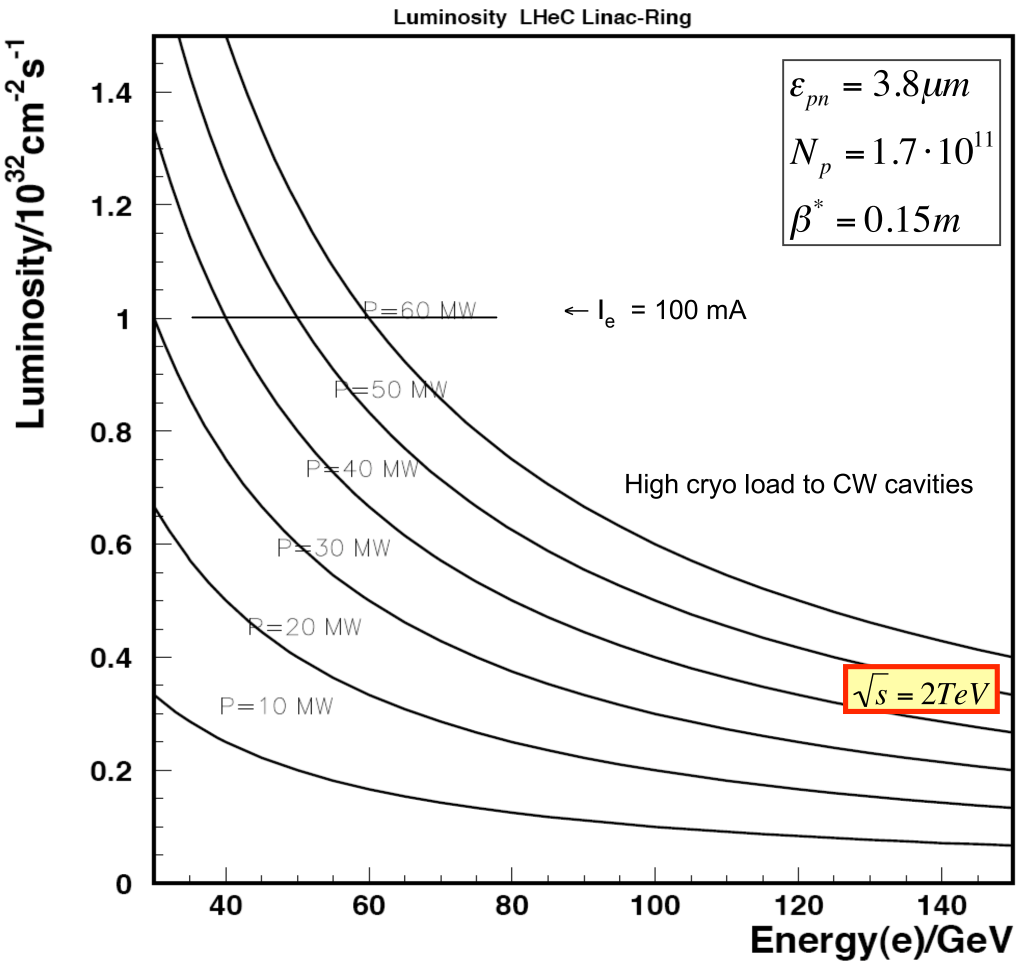
Point	•	• •	• s IP5, m
QD24.L5	0.1100390391	0.0113064017	677.879431
QF23.L5	0.09873263743	0.0113064017	638.379431
QD22.L5	0.08742623577	0.0113064017	598.879431
QF21.L5	0.07611983411	0.0113064017	559.379431
QD20.L5	0.06481343245	0.0113064017	519.879431
QF19.L5	0.0535070308	0.0113064017	480.379431
QL18.L5	0.04220062914	0.0113064017	440.479431
QL17.L5	0.03843462774	0.0037660014	408.049431
QL16.L5	0.03089842621	0.0075362015	380.979431
QL15.L5	0.02336222468	0.0075362015	353.909431
QL14.L5	0.01582602315	0.0075362015	326.839431
QL13.L5	0.008289821623	0.0075362015	299.769431
QL12.L5	0.0007536200942	0.0075362015	272.699431
QL11.L5	0.0	0.0007536201	245.629431



H.Burkhardt DIS08

Luminosity: Linac-Ring

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



DIS08, H.Braun

$\varepsilon_{pn} = 1.9\mu m$

$N_p = 3.4 \cdot 10^{11}$

$\beta^* = 0.10m$

New p injector chain, LHC Luminosity Upgrade.

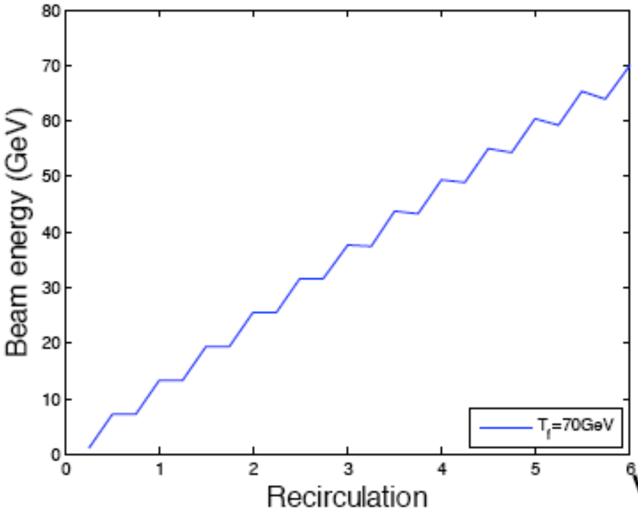
2 10^{32} may be reached with LR:
E_e = 40-140 GeV & P=20-60 MW
LR: average lumi close to peak!
-> 10 times HERA II luminosity.

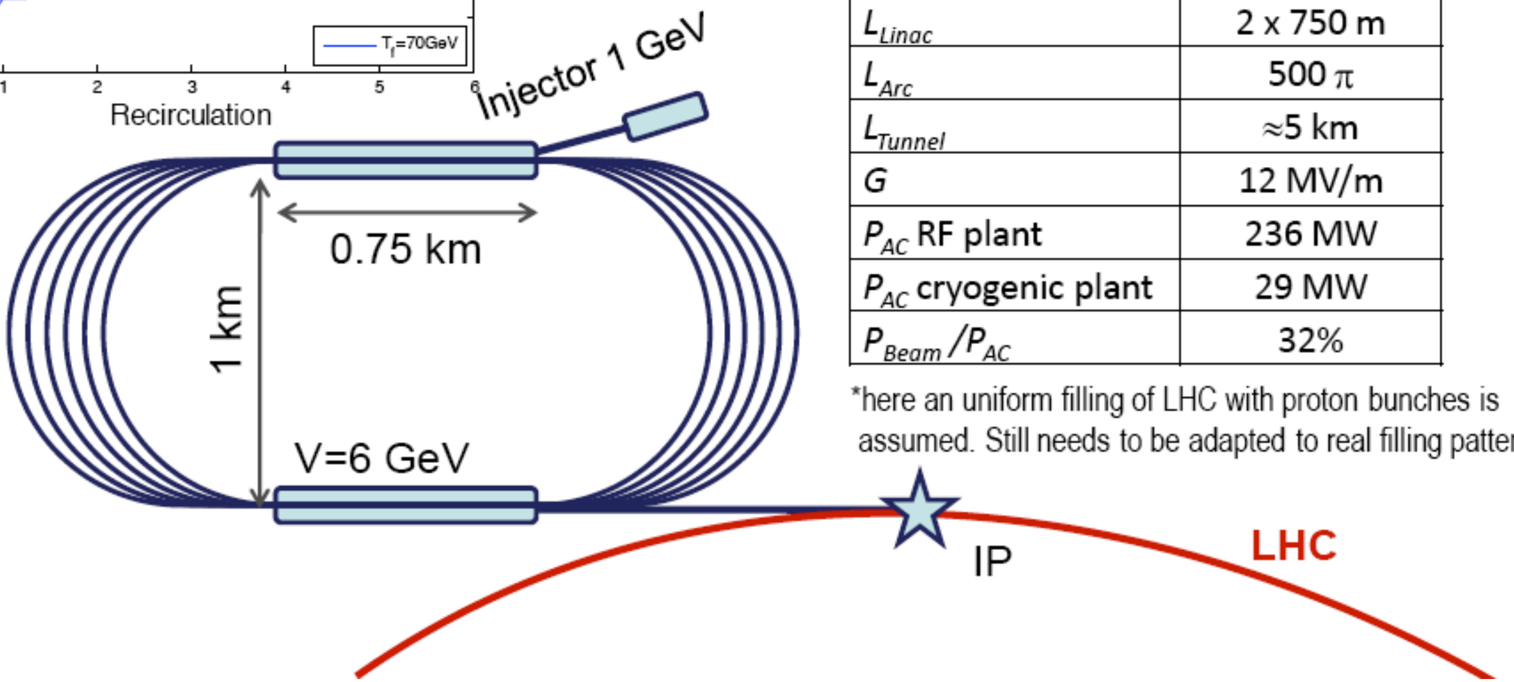
LINAC is not physics limited in energy, but cost + power limited
140 GeV at 23 MV/m: 6km +gaps

Note: positron source challenge:

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

Recirculated superconducting c.w. Linac for LHeC





Tentative parameter set for $10^{33}cm^{-2}s^{-1}$

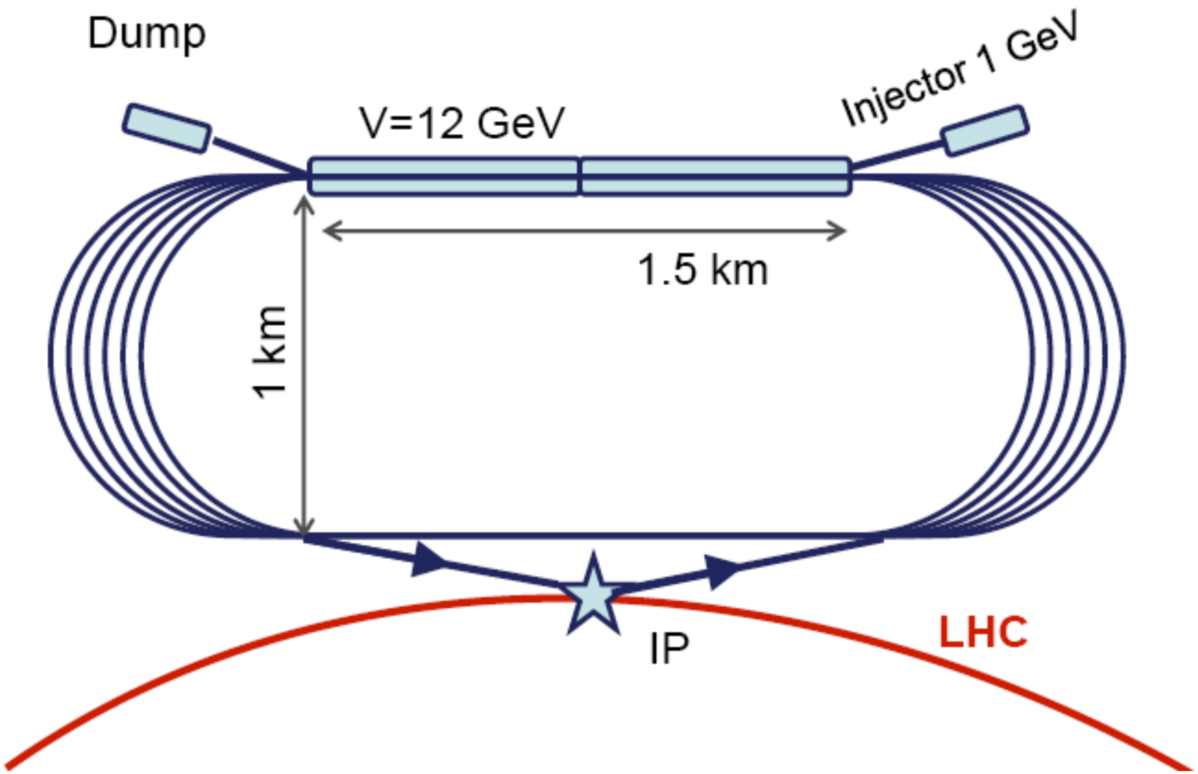
E	70 GeV
$E_{Injector}$	1 GeV
I_{Beam}	1.2mA
N_B	1.87 10^8
Bunch spacing*	25ns
P_{Beam}	84 MW
P_{SR}	5.6 MW
$N_{Recirculation}$	6
V_{Linac}	2 x 6.14 GeV
L_{Linac}	2 x 750 m
L_{Arc}	500 π
L_{Tunnel}	≈5 km
G	12 MV/m
P_{AC} RF plant	236 MW
P_{AC} cryogenic plant	29 MW
P_{Beam} /P_{AC}	32%

*here an uniform filling of LHC with proton bunches is assumed. Still needs to be adapted to real filling pattern.

H.Braun, this workshop

Can this be combined with energy recovery scheme to reduce RF power and beam dump requirements ?

Not easily, because of energy imbalance due to SR losses but this needs further studies.



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

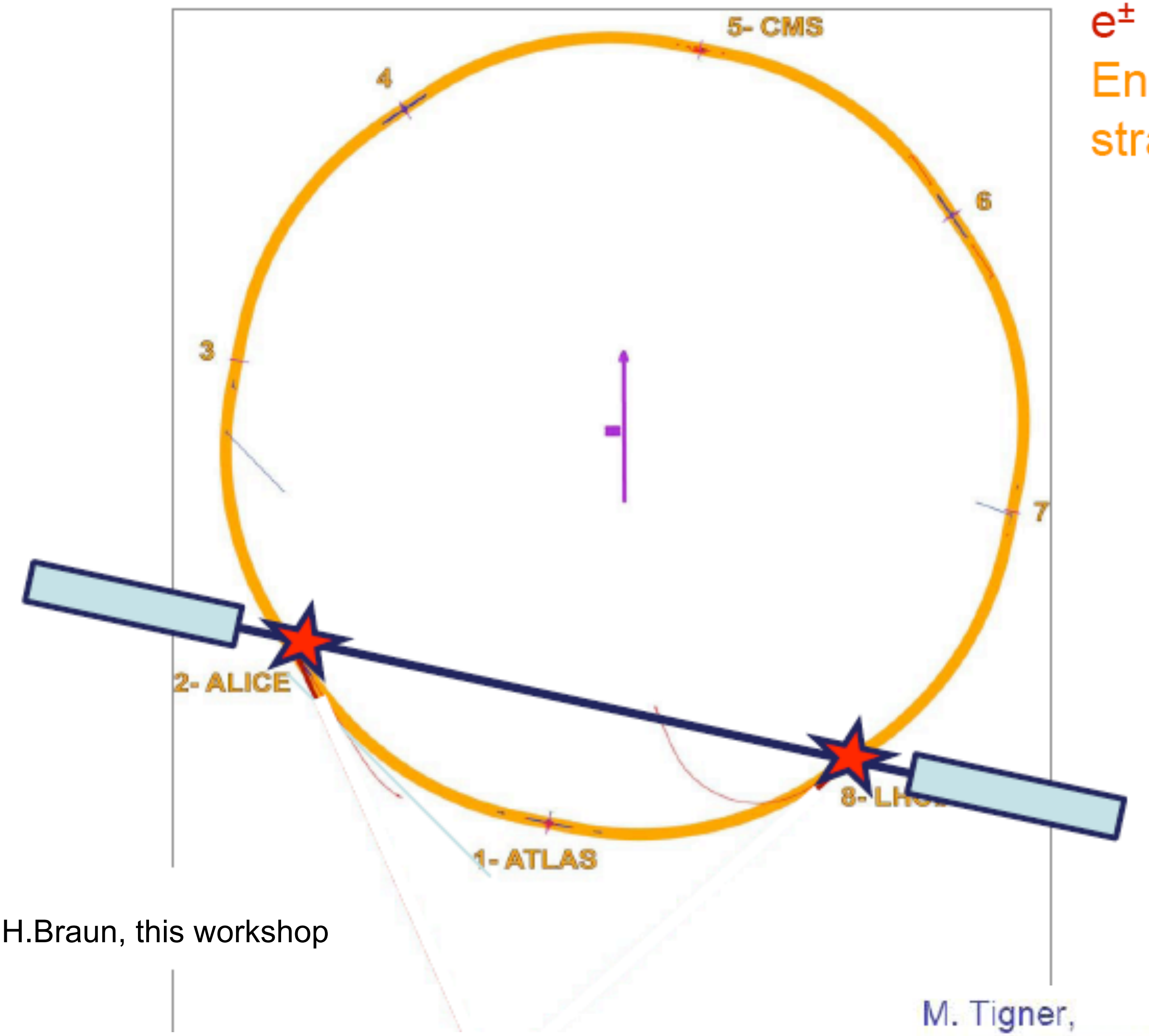
SC technology

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	$0.624 \cdot 10^{10}$	$5.79 \cdot 10^{10}$	$6.2 \cdot 10^{10}$
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, this workshop

$e^{\pm}$ Linac - p/A ing
Energy recover
straight version

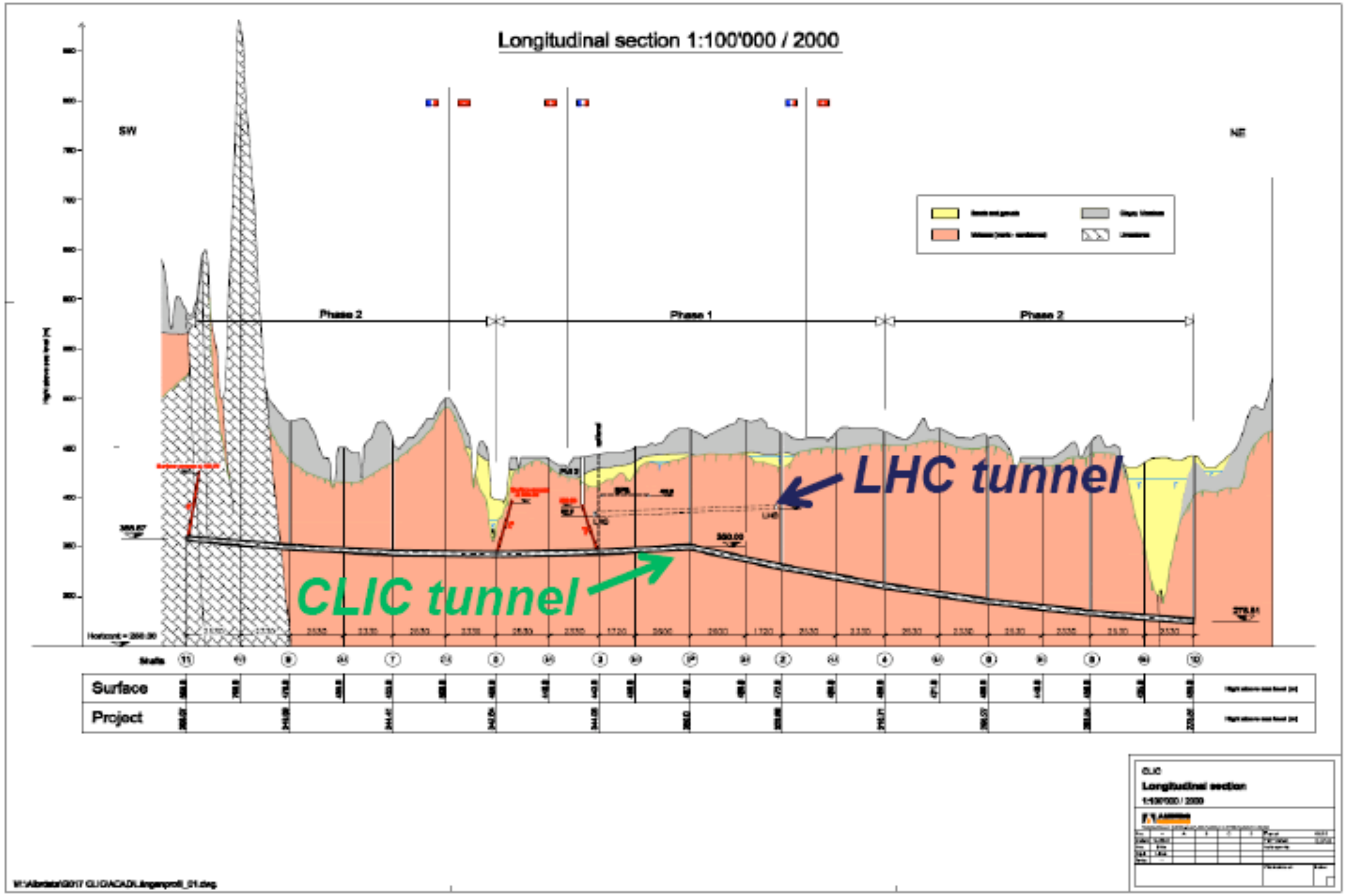


H.Braun, this workshop

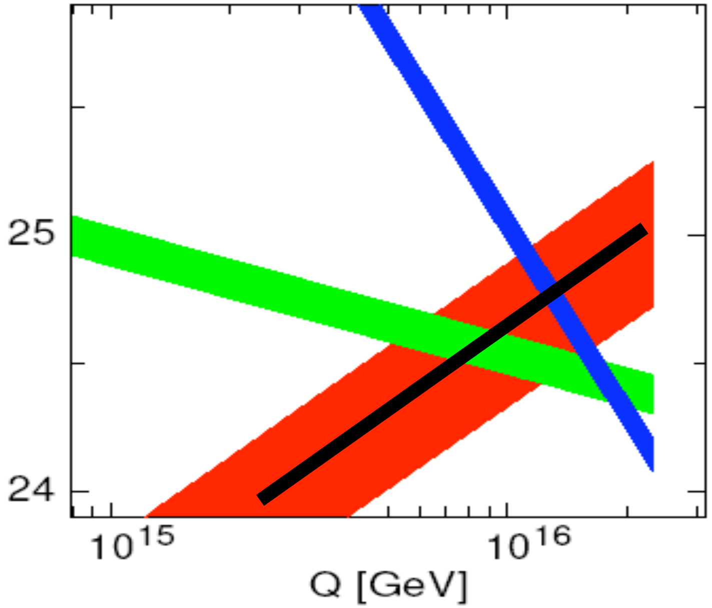
M. Tigner,
Nuovo Cimento 37 (1965) 1228.

Can tunnel for LHeC Linac be build as first part of a LC tunnel at CERN ?

Tunnel studies for CLIC and ILC at CERN both have tunnels which are deeper underground than LHC and seen from top they both pass close to LHC ring center. Therefore they are not suited to send e⁻ beam tangential to LHC ring.



Strong Coupling



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%

T.Kluge, MK, DIS08

Detector Requirements

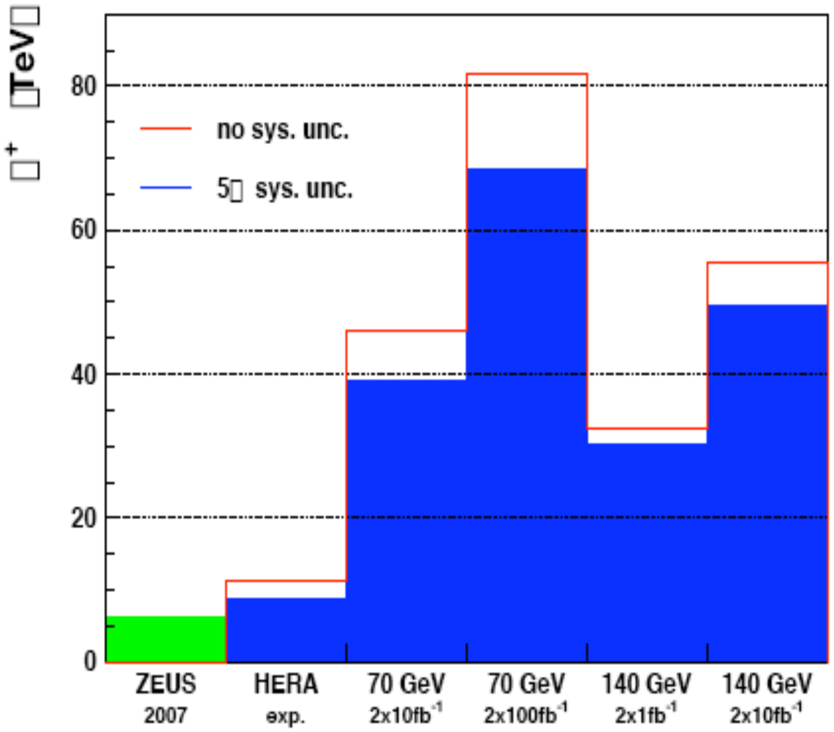
Largest possible acceptance	
$1\text{-}179^{o}$	$7\text{-}177^{o}$
High resolution tracking	
0.1 mrad	0.2-1 mrad
Precision electromagnetic calorimetry	
0.1%	0.2-0.5%
Precision hadronic calorimetry	
0.5%	1%
High precision luminosity measurement	
0.5%	1%
LHeC	HERA

extended kinematic range
uncertainties 1/2 of H1

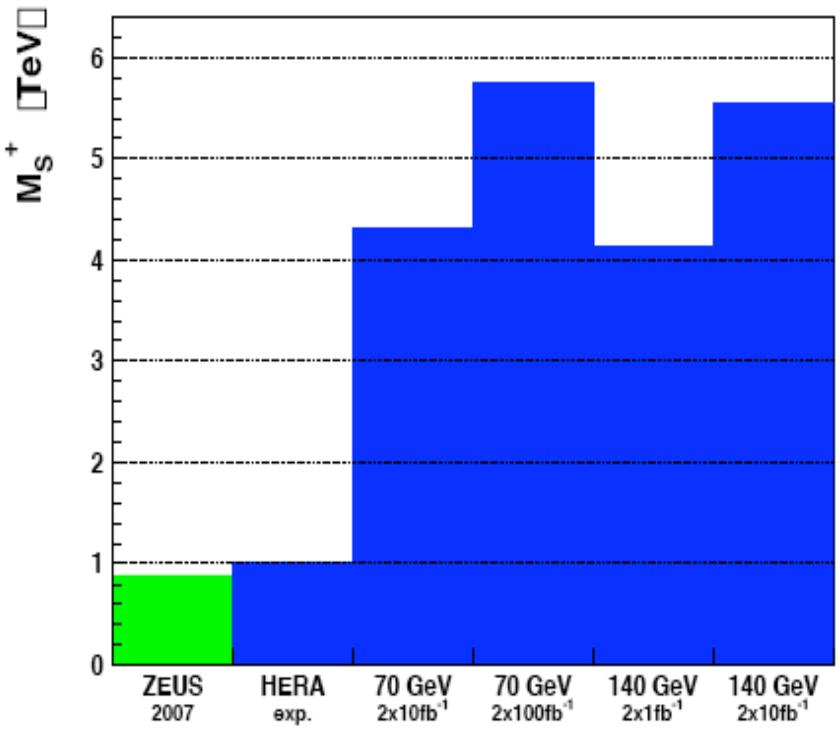
Exp + Thy challenge N^3LO

CI and Leptoquarks

VV model (conserving parity)



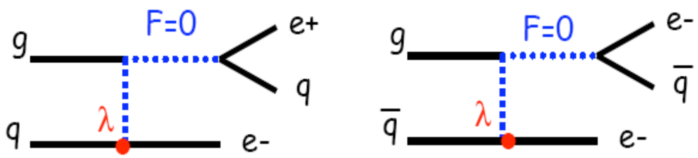
AAD model (Large Extra Dimensions)

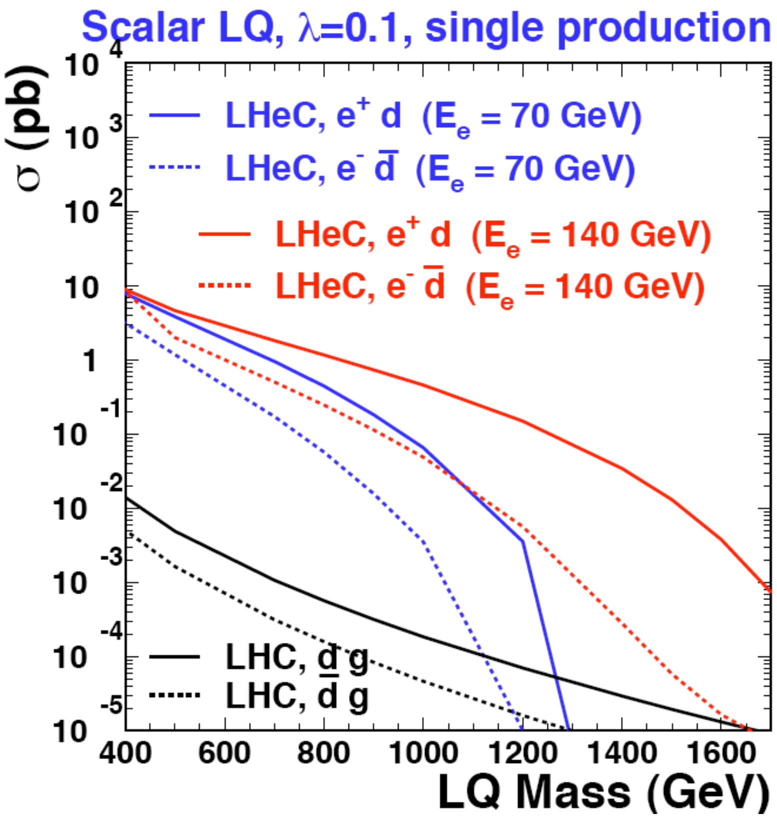


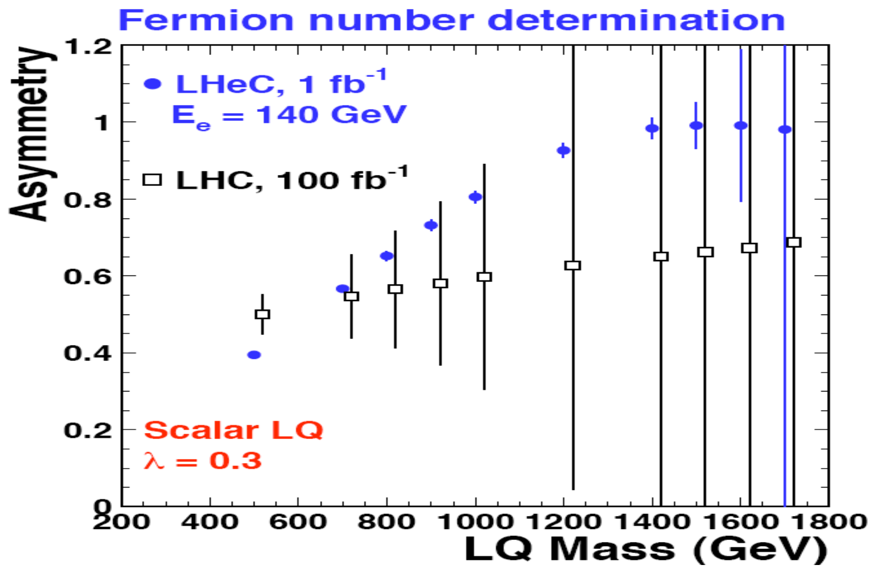
Similar limits for M_S^-

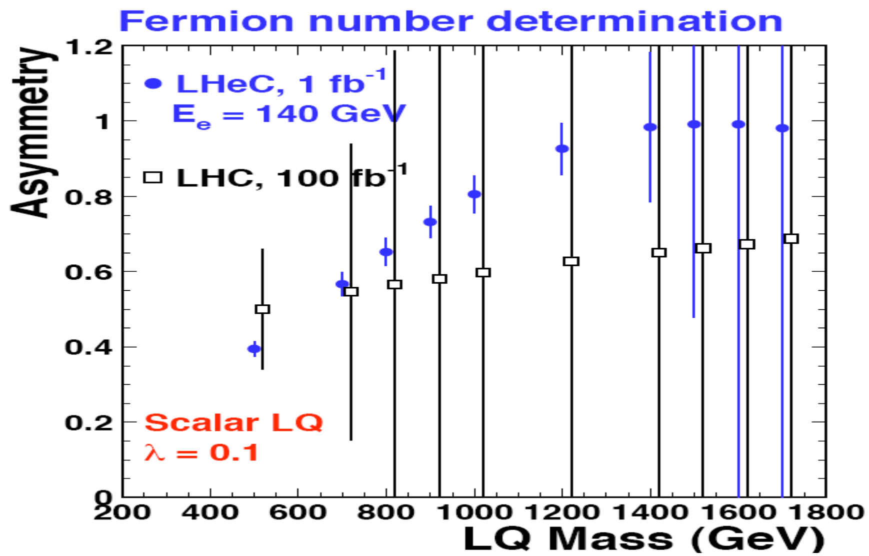
A.Zarnecki DIS08

Quantum Numbers









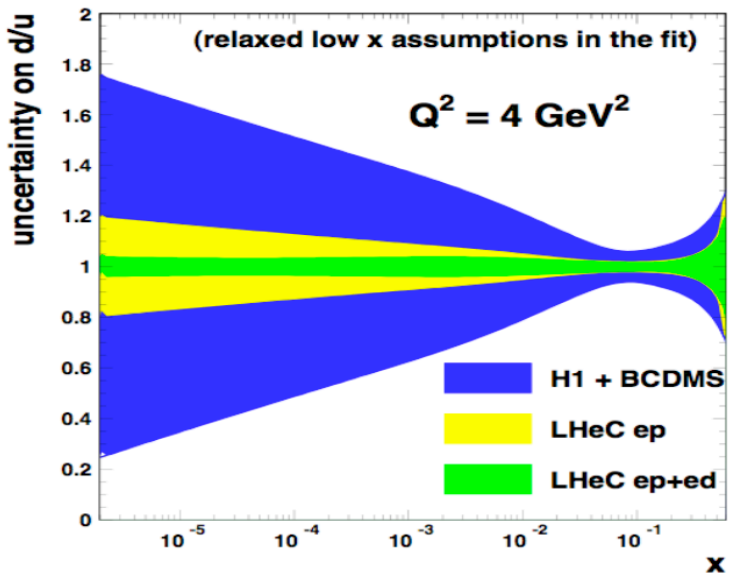
Charge asymmetry much cleaner in ep than in pp. Similar for simultaneous determination of coupling and quark flavour

E.Perez, DIS07

A new level of quark distribution measurements unfolding and parton amplitudes (GPDs)

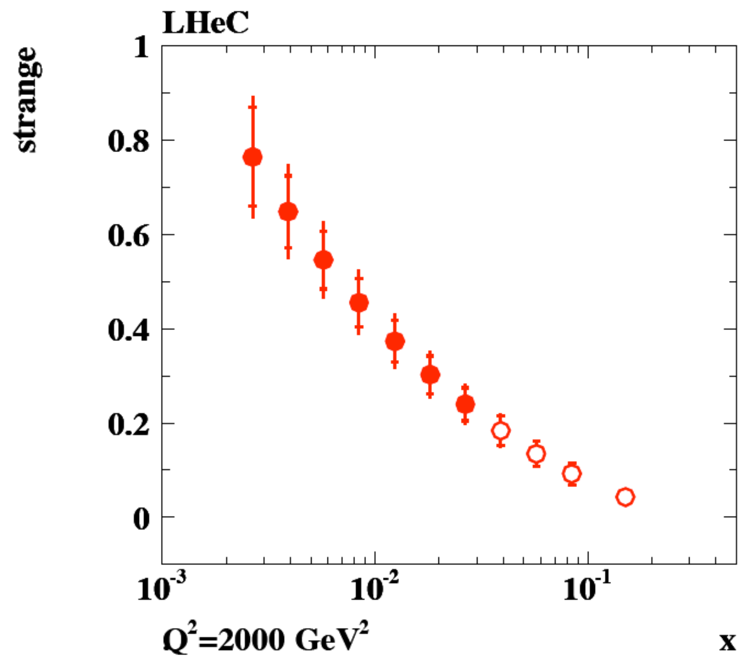
$$\bar{u}(x) \neq \bar{d}(x)$$
$$\bar{s}(x) \neq s(x)$$

d/u at low x from deuterons



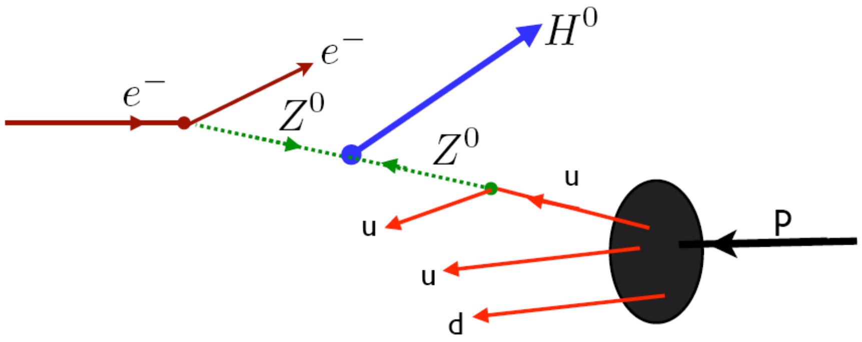
Shadowing related to diffraction

Strange & Antistrange from CC

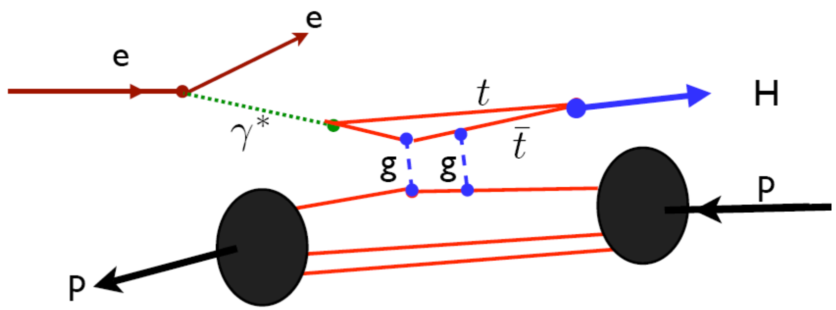


SB's non intrinsic wishlist for the LHeC

Inclusive Higgs

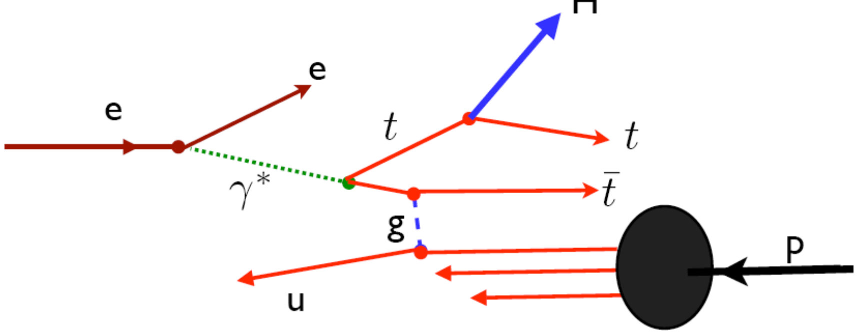


Diffractive Higgs



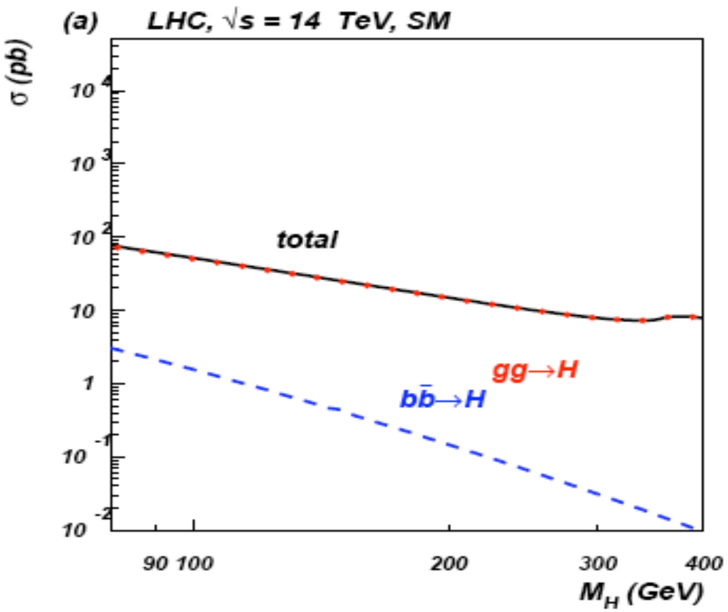
Kopeliovich, Schmidt, sjb

Higgs ttbar



Gluon

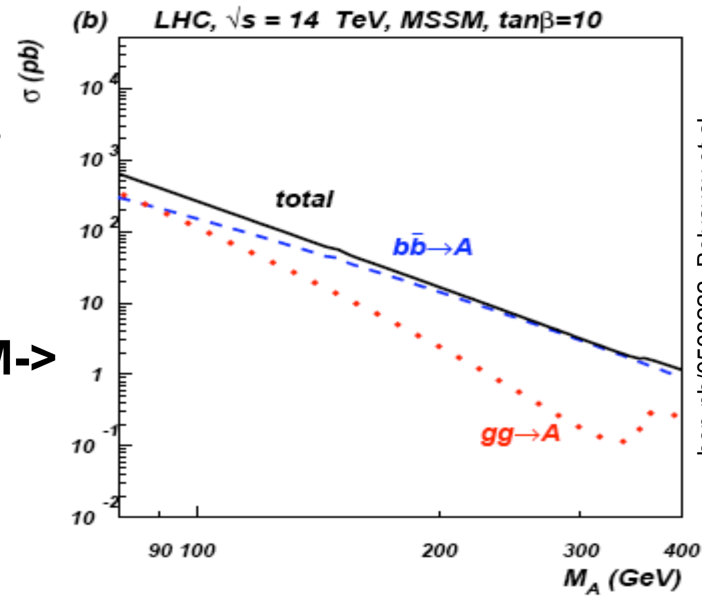
Beauty



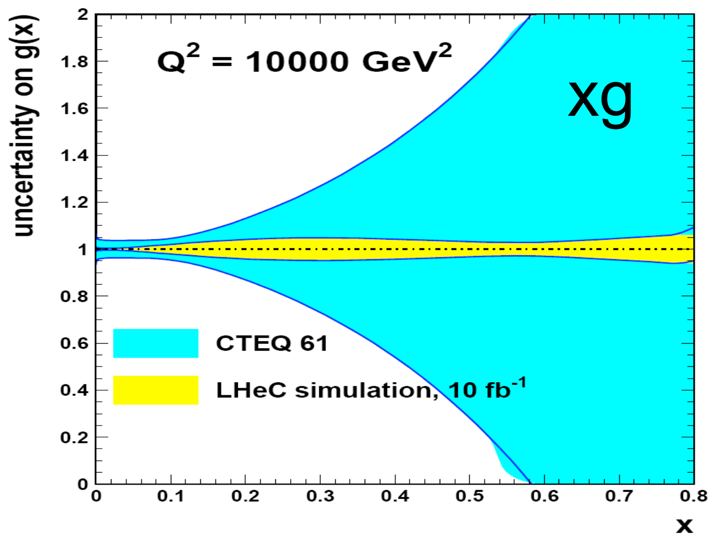
Higgs

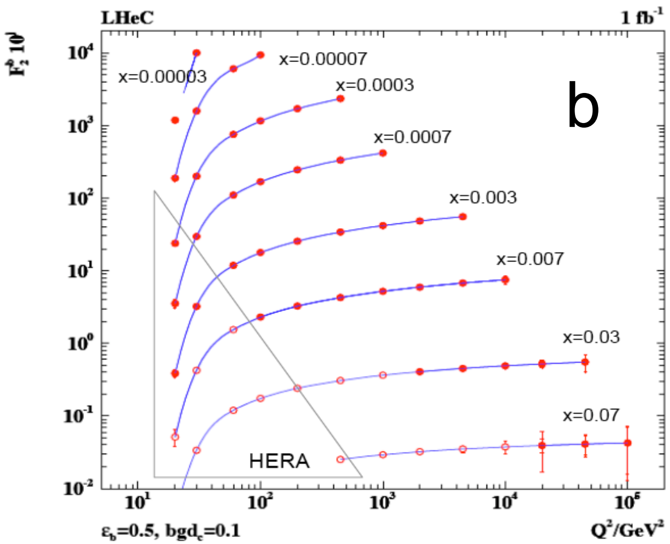
<-SM

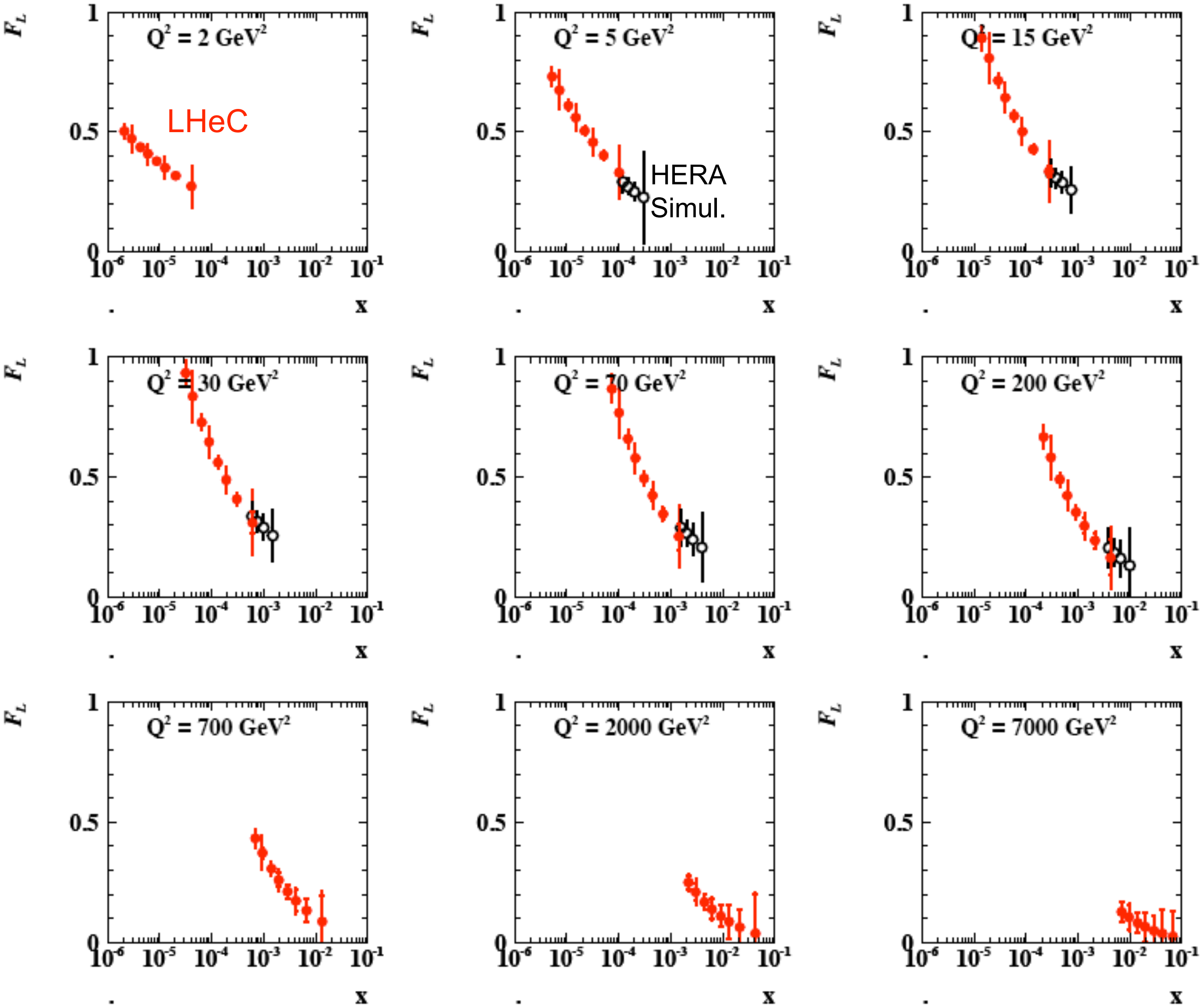
MSSM->



hep-ph/0508222, Belyayev et al







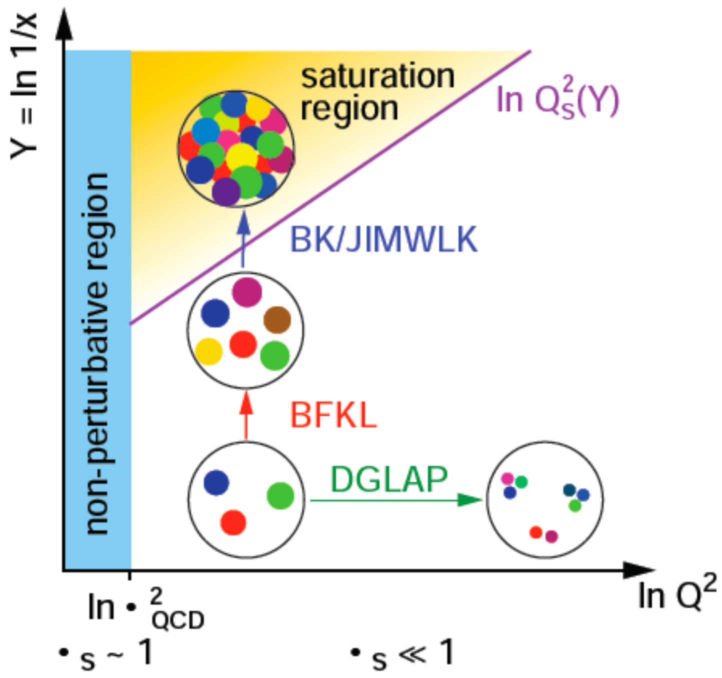
DIS08
J.Forshaw
et al.

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)…

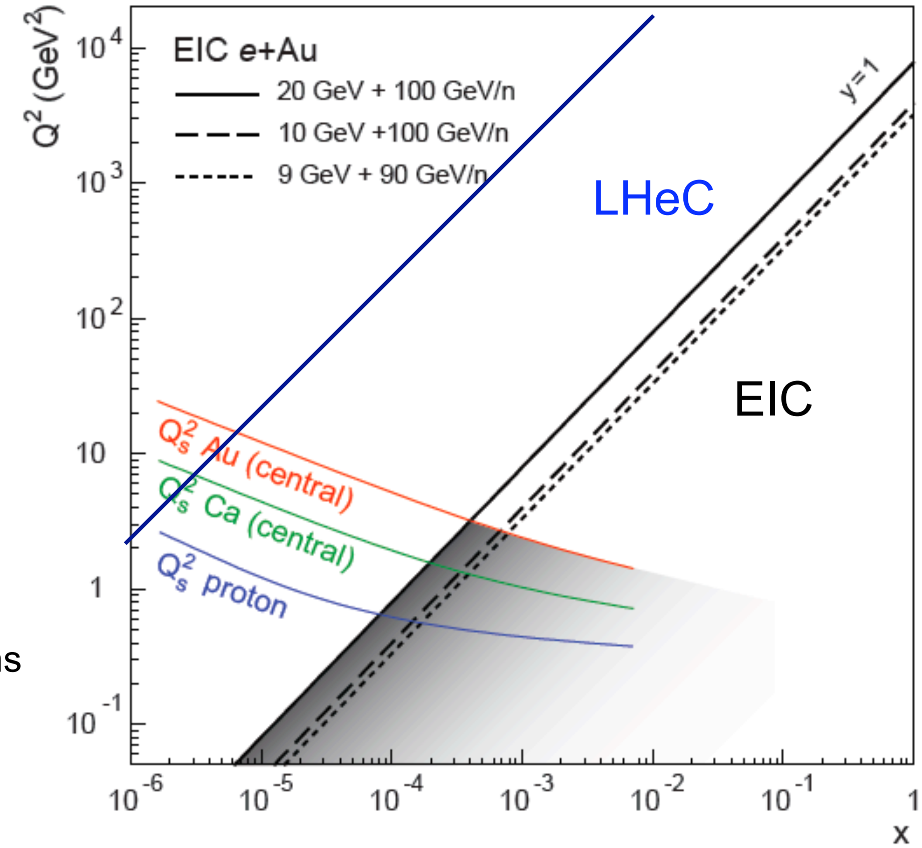
eA@LHeC+EIC



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

NuPECC study group

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



This workshop: cf M.Lamont

The Goal of the ECFA-CERN Workshop(s) is a CDR by 2009/2010.

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. **Workpackages**

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

ECFA CERN Workshop at Divonne 1.-3.9.2008

http://www.lhec.org.uk

Opening

J.Engelen (CERN)
K.Meier (ECFA)
G.Altarelli (Roma): DIS in the LHC time

1.9. 2pm

Indico=31463

Email:
event-lhec-workshop@cern.ch
Patricia Mage-Granados
Jill Karlson Forestier
Urs Wiedemann
Max Klein

http://indico.cern.ch/event/LHeC_workshop

Concluding Remarks

The LHeC has survived expert scrutiny and gets momentum in terms of accelerator concepts, next EPAC Genua June 2008

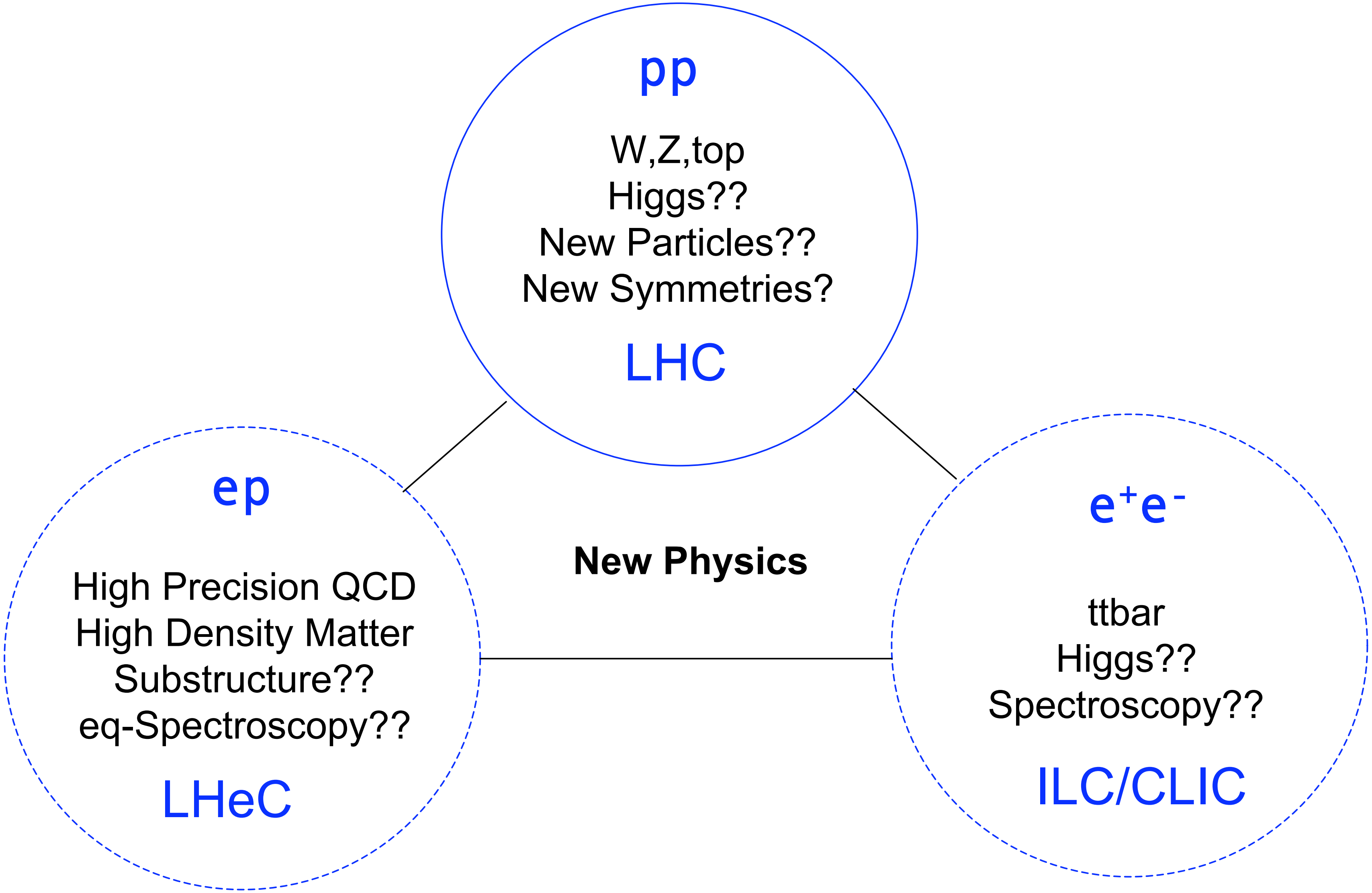
ECFA and CERN have expressed an interest in a Conceptual Design Report for the LHeC by 2009/10. An organisational structure has been put in place which will allow further developments of the machine, IR, detector and physics ideas. A technical design may follow if appropriate.

The LHeC requires the LHC to be a success and the CERN accelerator complex to function and be upgraded. It will have to attract world wide efforts for becoming realised while the pp LHC operation is still ongoing.

The physics will be worked out and emphasis will be given to the complementarity with the LHC and also ILC/CLIC.

Deep Inelastic Scattering in the LHC time may become reality.

The TeV Scale [2008-2033..]



ECFA CERN 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), MM (tbc)

Infrastructure

John Osborne (CERN)

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 to many people

http://www.lhec.org.uk

backup

Summary and Proposal to ECFA

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.

Improvement of LHC proton parameters II

➢ *Increased proton bunch charge*

New LHC p-injector chain with LINAC 4, SPL and PS2 will allow to double

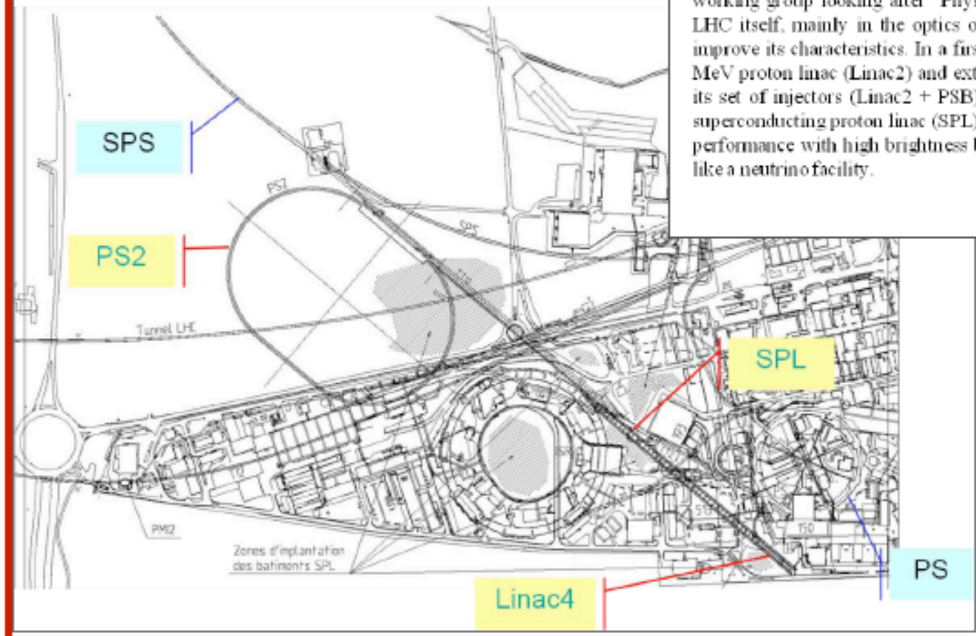
N_B at injection of LHC. We assume therefore $N_B = 3.4 \cdot 10^{11}$

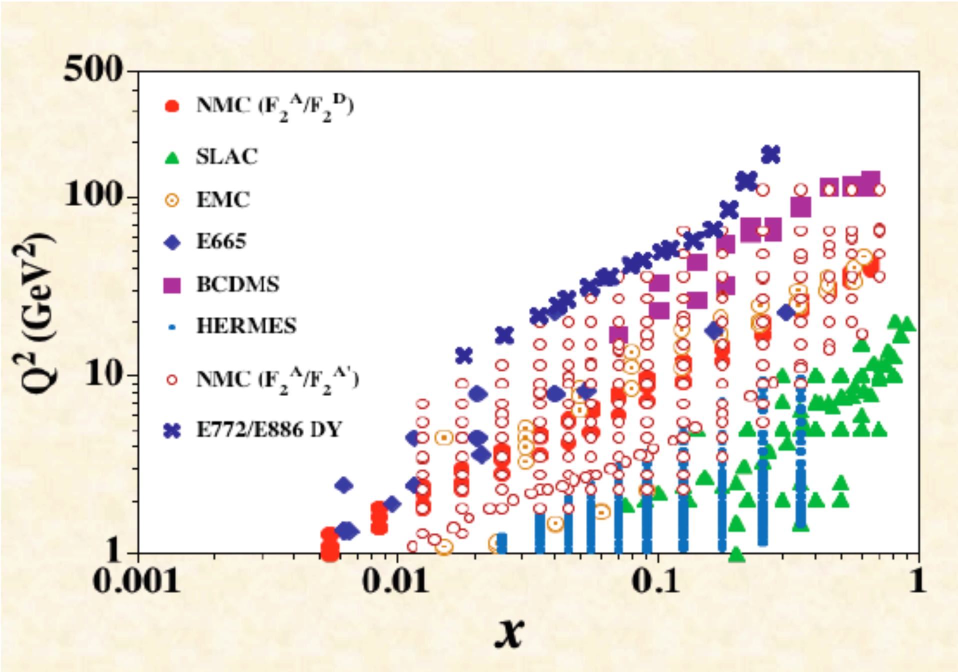
Plans for Upgrading the CERN Proton Accelerator Complex

R. Garoby, *HEP 2007 – 19-25 July 2007 – Manchester/GB*

With the construction of the Large Hadron Collider (LHC) in its final phase at CERN, it is now time to prepare for increasing its performance as much as possible and for preparing for the future needs of physics. A basic plan has been proposed by the working group on "Proton Accelerators of the Future", using the input from an ad'hoc physics working group looking after "Physics Opportunities with Future Proton Accelerators". Apart from upgrades in the LHC itself, mainly in the optics of the insertions, the proposal is to renew the injector complex and significantly improve its characteristics. In a first phase, a new 160 MeV H- linac (Linac4) will be built to replace the present 50 MeV proton linac (Linac2) and extensive consolidation will be made. In a second phase, the present 26 GeV PS and its set of injectors (Linac2 + PSB) are planned to be replaced with a ~50 GeV synchrotron (PS2) with a ~4 GeV superconducting proton linac (SPL) as injector. The SPS itself will be upgraded for injection at 50 GeV and for better performance with high brightness beams. These proposals will be described as well as their potential for other uses like a neutrino facility.

Layout of new LHC injectors





Nuclear Structure

Striking effects predicted:
bj -> black disc limit $F_2 \to Q^2 \ln(1/x)$
~50% diffraction
colour opacity, change of $J/\Psi(A)$

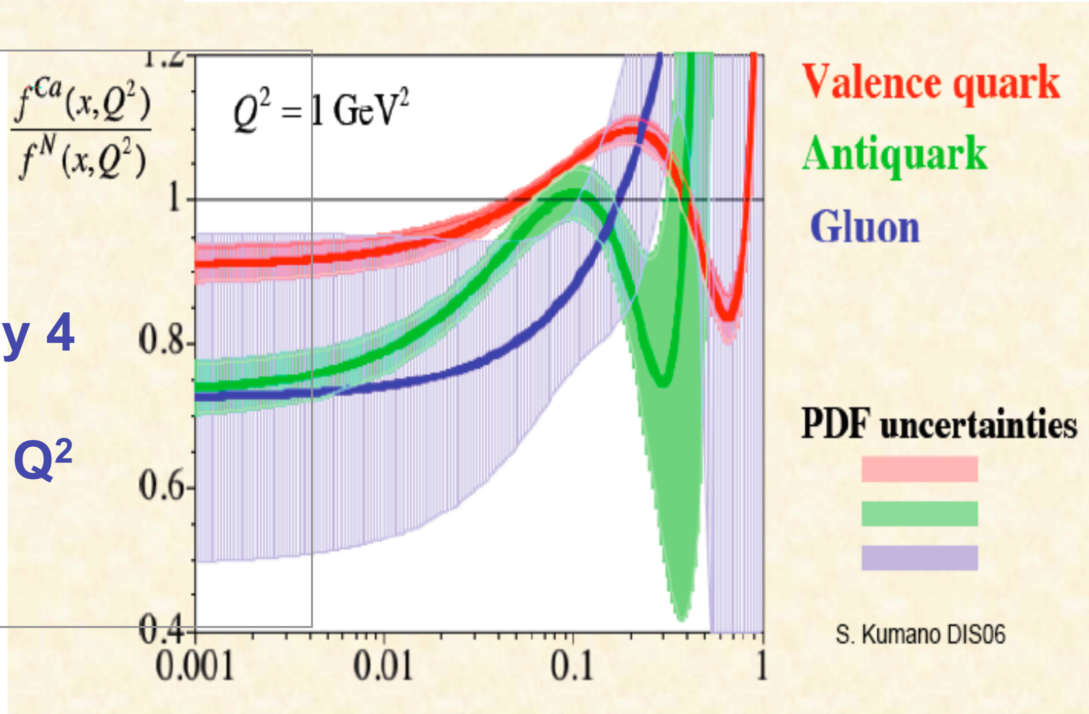
$$xg(x,Q^2) \leq \frac{1}{\pi N_c \alpha_s(Q^2)} Q^2 R^2 \simeq \frac{Q^2}{\alpha_s}$$

unitarity limit

NuPECC study group

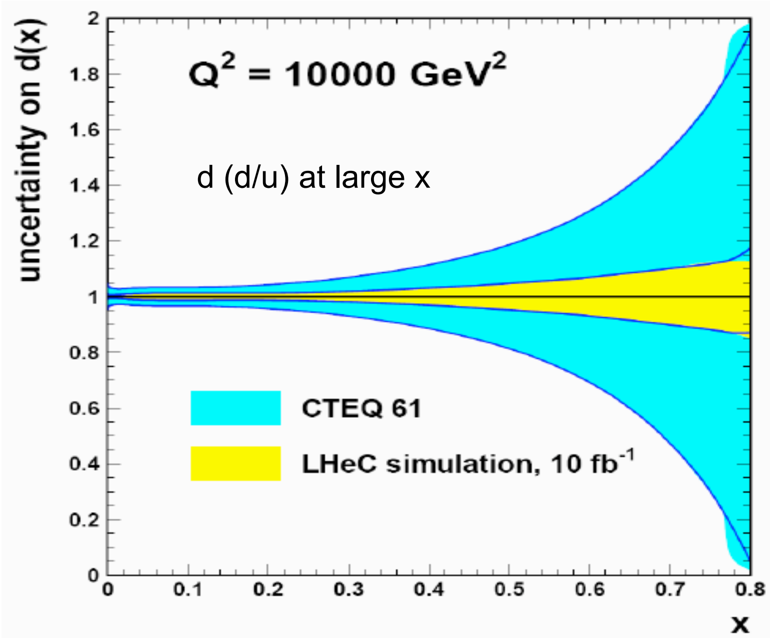
Tullio Bressani, INFN, Torino Univ.
Jens Jørgen Gaardhøje, Niels Bohr Inst.
Günther Rosner, Glasgow Univ. (chair)
Hans Ströher, FZ Juelich

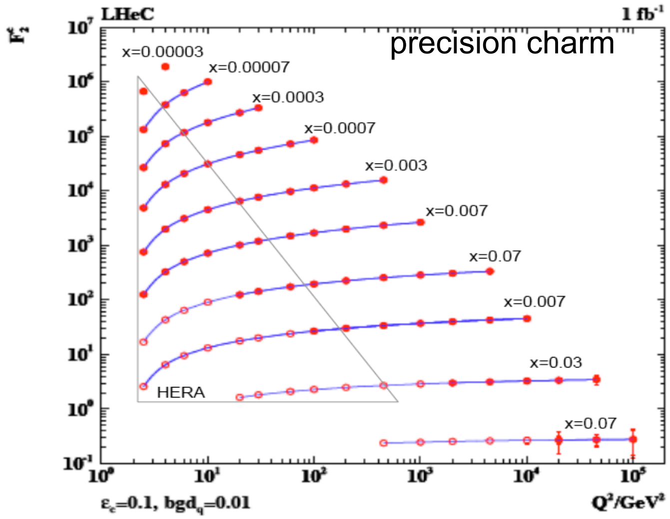
extension of x range by 4 orders of magnitude and huge extension in Q^2

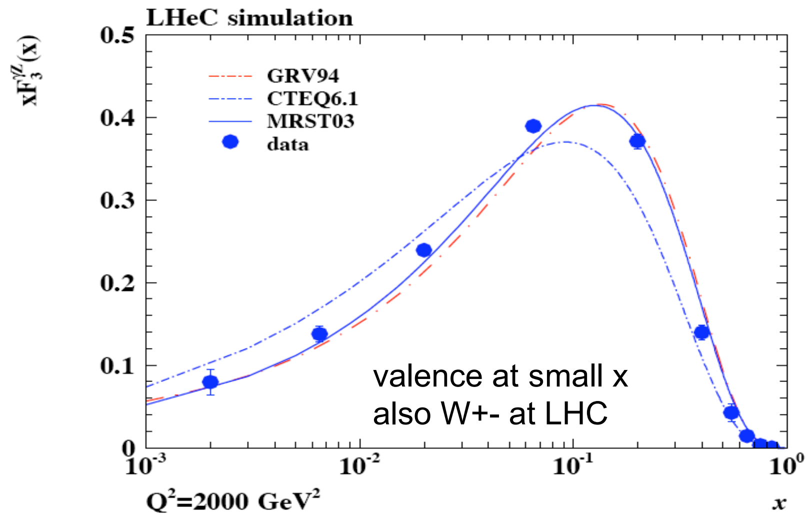


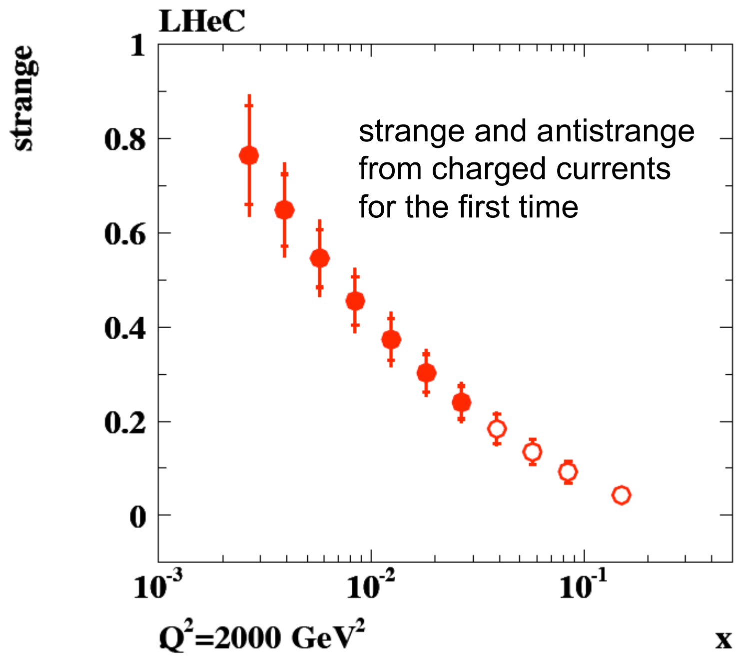
This workshop: cf M.Lamont

Complete Unfolding of the Quark Content of the Nucleon (NC,CC) at PeV energies









The Fermi Scale [1985-2010]

$\bar{p}p$

b quark
top quark
M_W

Tevatron

ep

gluon
h.o. QCD
c,b distributions
high parton densities

HERA

The Standard Model Triumph

e^+e^-

M_Z , $\sin^2\Theta$
3 neutrinos
h.o. el.weak (t,H?)

LEP/SLC

CKM - **B factories**