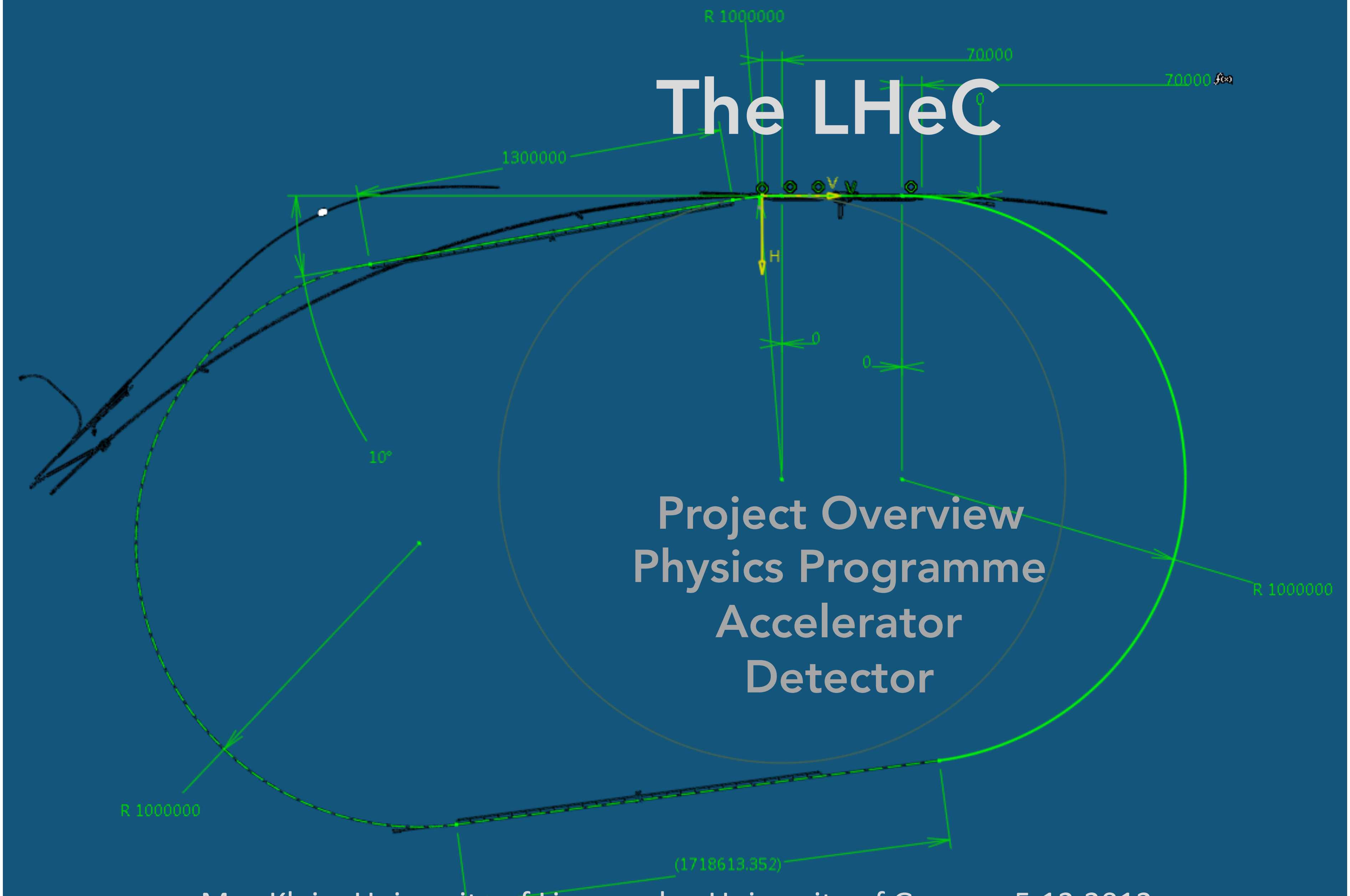
The LHeC



Project Overview
Physics Programme
Accelerator
Detector

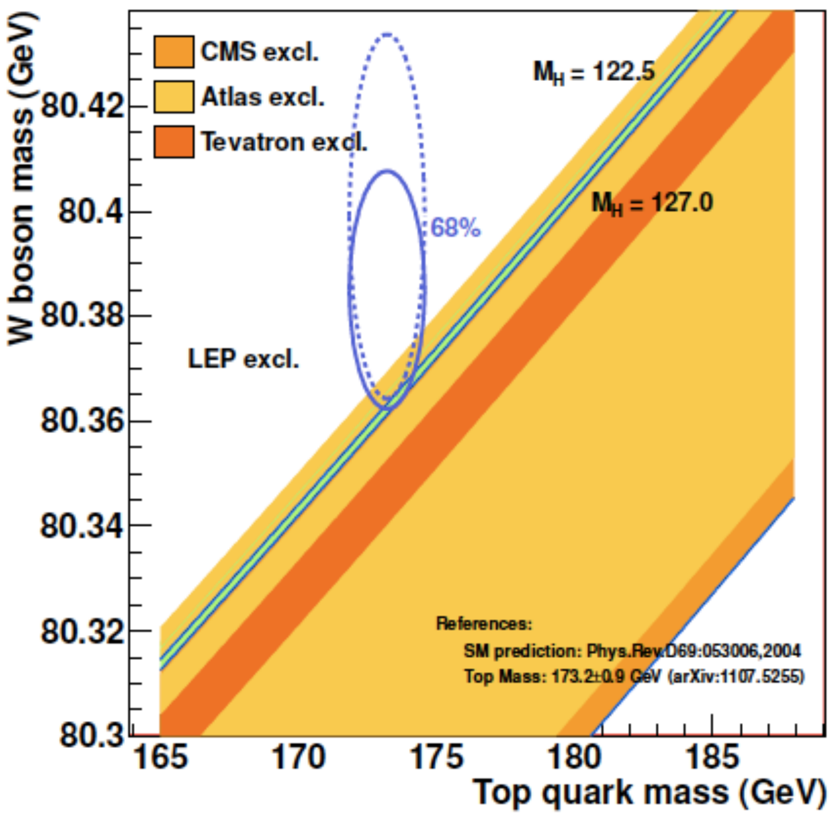
Max Klein, University of Liverpool - University of Geneva, 5.12.2012

Colliders explored the Fermi Energy Scale

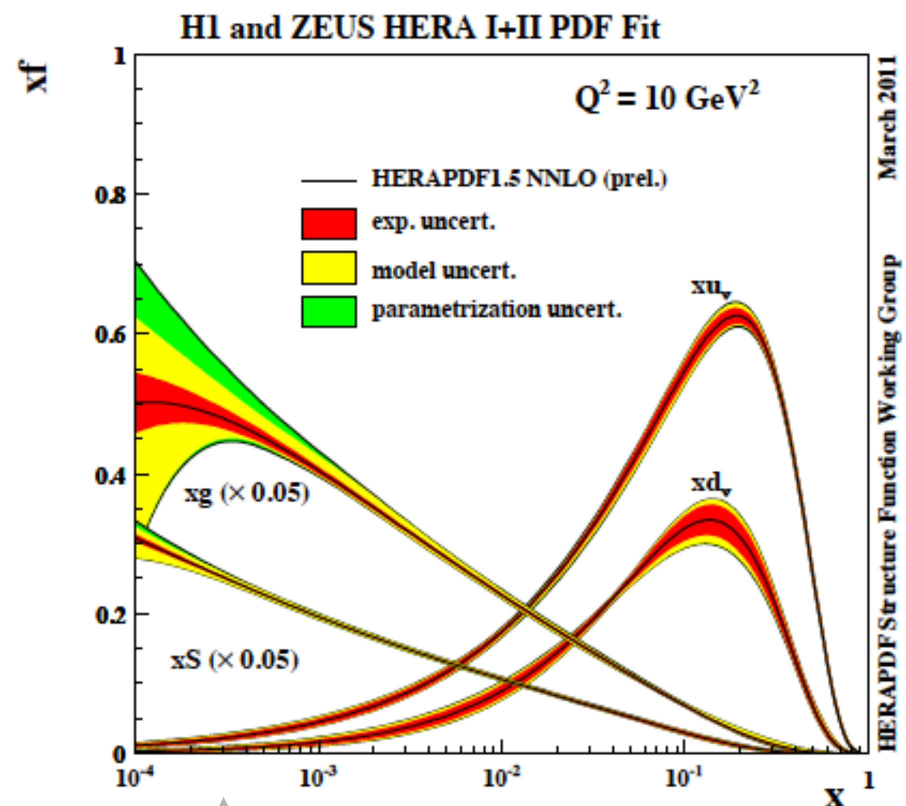
Tevatron to find SUSY and BSM; **LEP/SLC** to find SUSY and the Higgs; **HERA** to find Lepto-Quarks

probable legacy plots/numbers

NNLO!



R.Lopes de Sa (Moriond 11.3.12)



Practical end of HERA xg sensitivity

M_Z=91.1876±0.0021 GeV (PDG2010)

What HERA could not do or has not done

HERA in one box
the first ep collider

$E_p * E_e =$
$920*27.6 GeV^2$
$\sqrt{s} = 2\sqrt{E_e E_p} = 320$ GeV

$L = 1..4\ 10^{31} cm^{-2} s^{-1}$
$\rightarrow \Sigma L = 0.5 fb^{-1}$
1992-2000 & 2003-2007

$Q^2 = [0.1 -- 3 * 10^4]\ GeV^2$
-4-momentum transfer^2

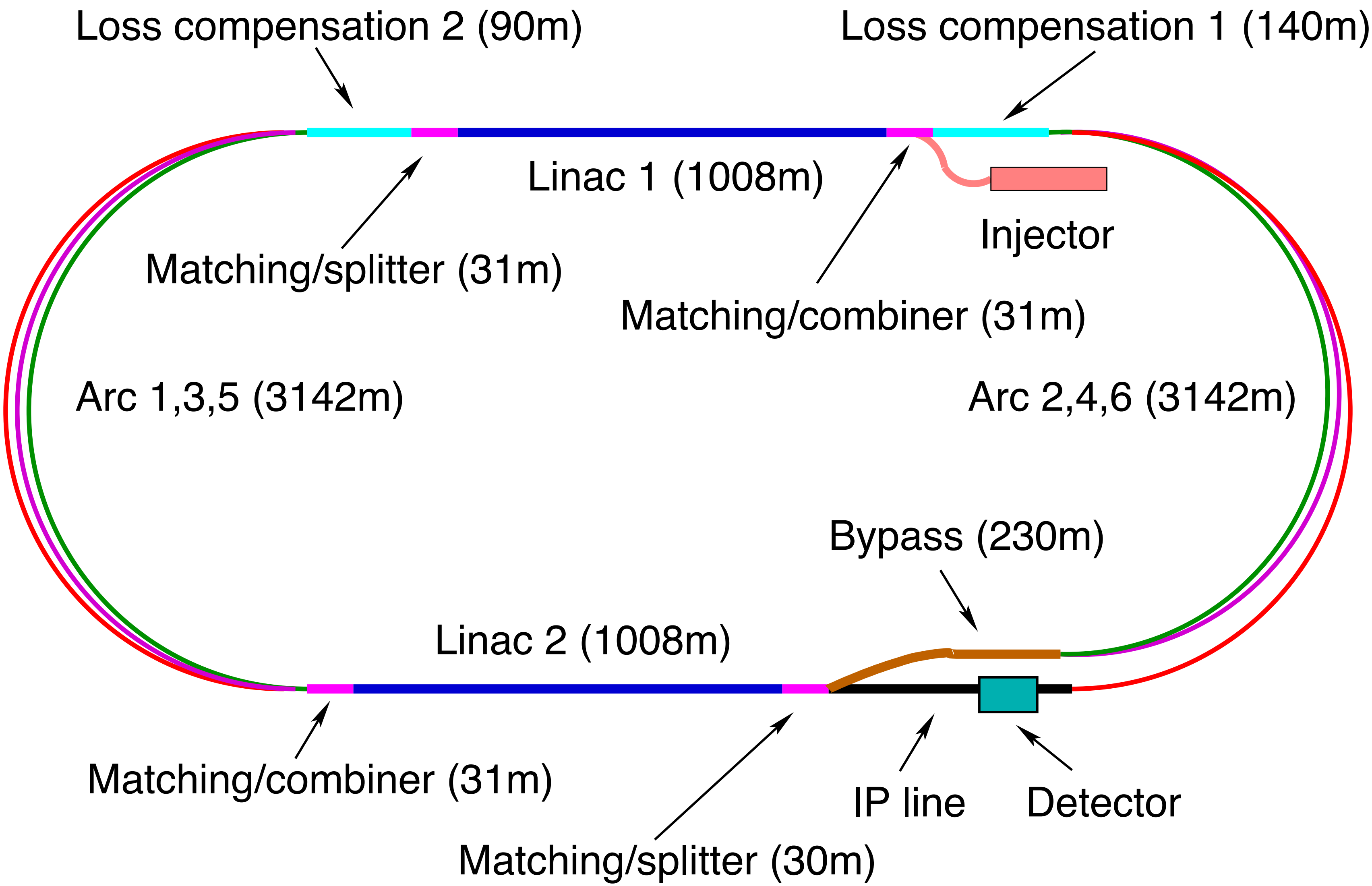
$x = Q^2/(sy) \cong 10^{-4} .. 0.7$
Bjorken x

$y \cong 0.005 .. 0.9$
inelasticity

Test of **the isospin symmetry** (u-d) with eD - no deuterons
Investigation of the q-g dynamics in **nuclei** - no time for eA
Verification of **saturation** prediction at low x – too low s
Measurement of the **strange** quark distribution – too low L
Discovery of **Higgs** in WW fusion in CC – too low cross section
Study of **top** quark distribution in the proton – too low s
Precise measurement of $\mathbf{F_L}$ – too short running time left
Resolving d/u question at **large Bjorken x** – too low L
Determination of **gluon distribution at hi/lo x** – too small range
High precision measurement of $\boldsymbol{\alpha_s}$ – overall not precise enough
Discovering **instantons, odderons** – don't know why not
Finding **RPV SUSY** and/or leptoquarks – may reside higher up
…

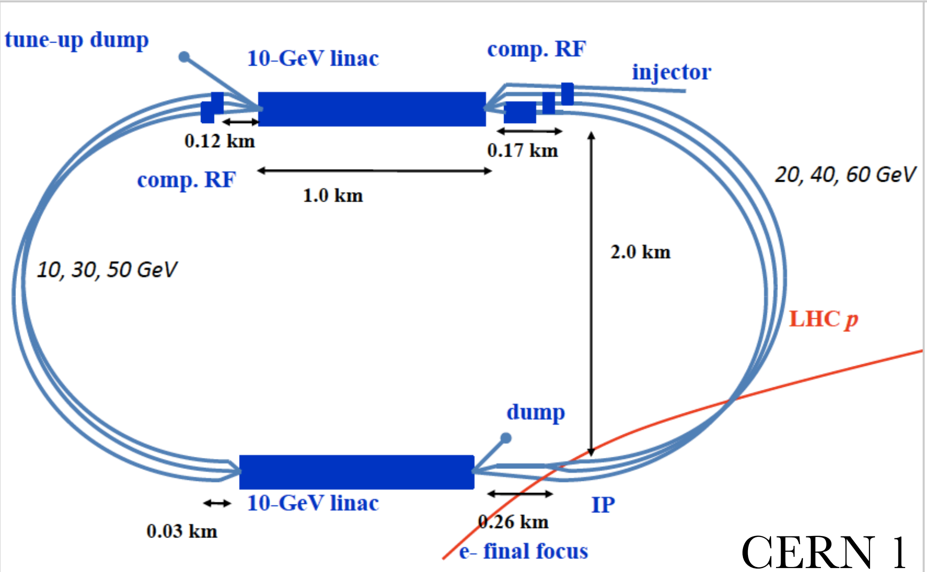
The H1 and ZEUS apparatus were basically well suited
The machine had too low luminosity and running time

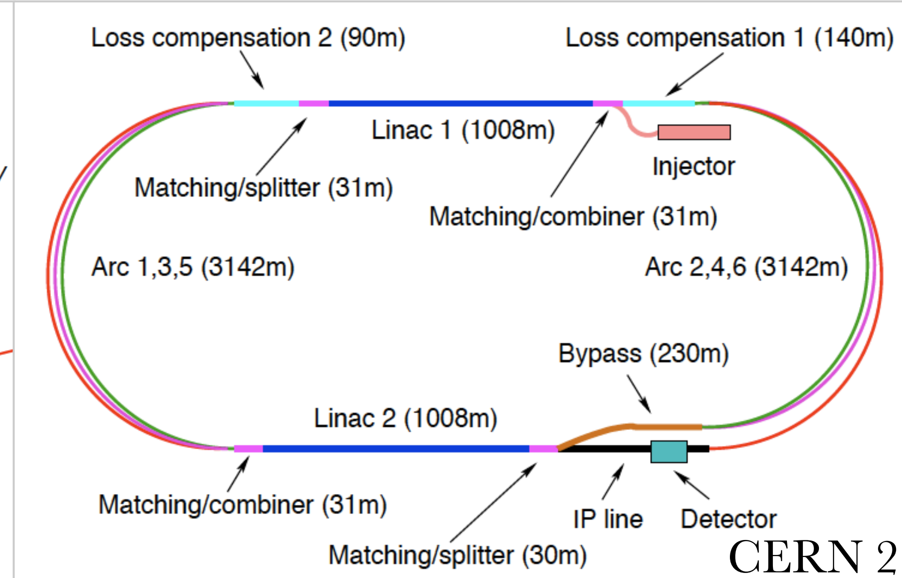
HEP needs a TeV energy scale machine with 100 times higher luminosity than HERA to develop DIS physics further and to complement the physics at the LHC. The **Large Hadron Collider p and A beams offer a unique opportunity to build a second ep and first eA collider** at the energy frontier [discussed at DIS since Madison 2005]

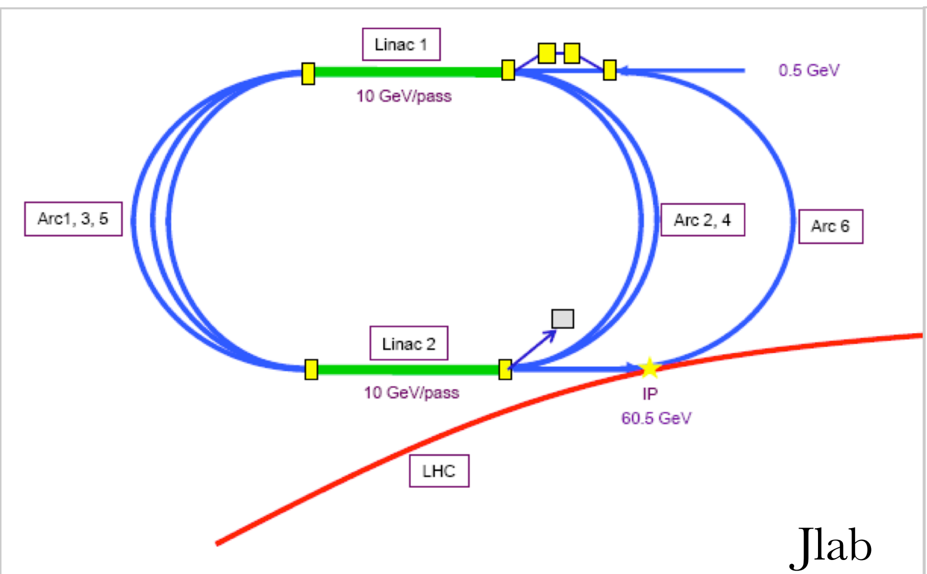


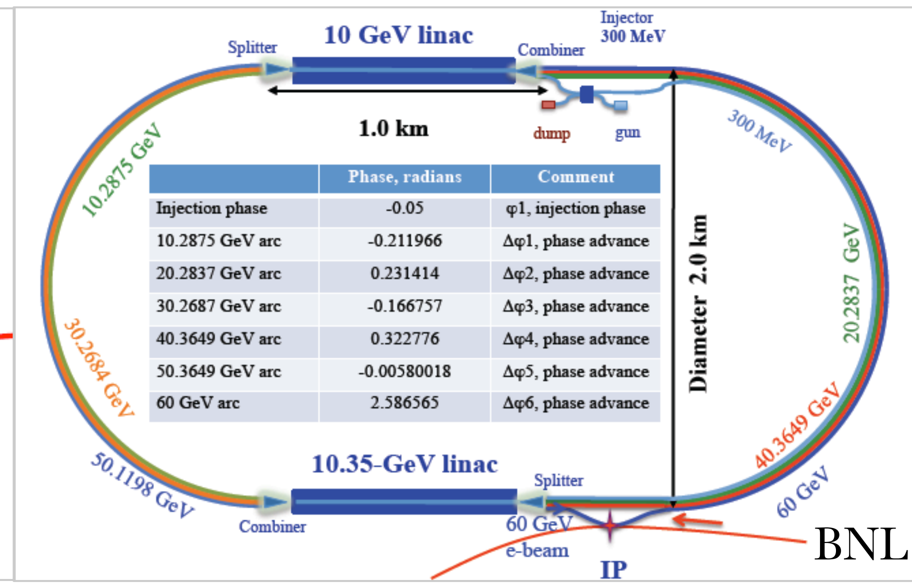
60 GeV electron beam energy, L= 10^{33} $cm^{-2}s^{-1}$, $\sqrt{s}$=1.3 TeV: Q^2_{max} 10^6 GeV^2, $10^{-6} < x < 1$
Recirculating linac (2 * 1km, 2*60 cavity cryo modules, 3 passes, P < 100 MW, ERL)

60 GeV Energy Recovery Linac



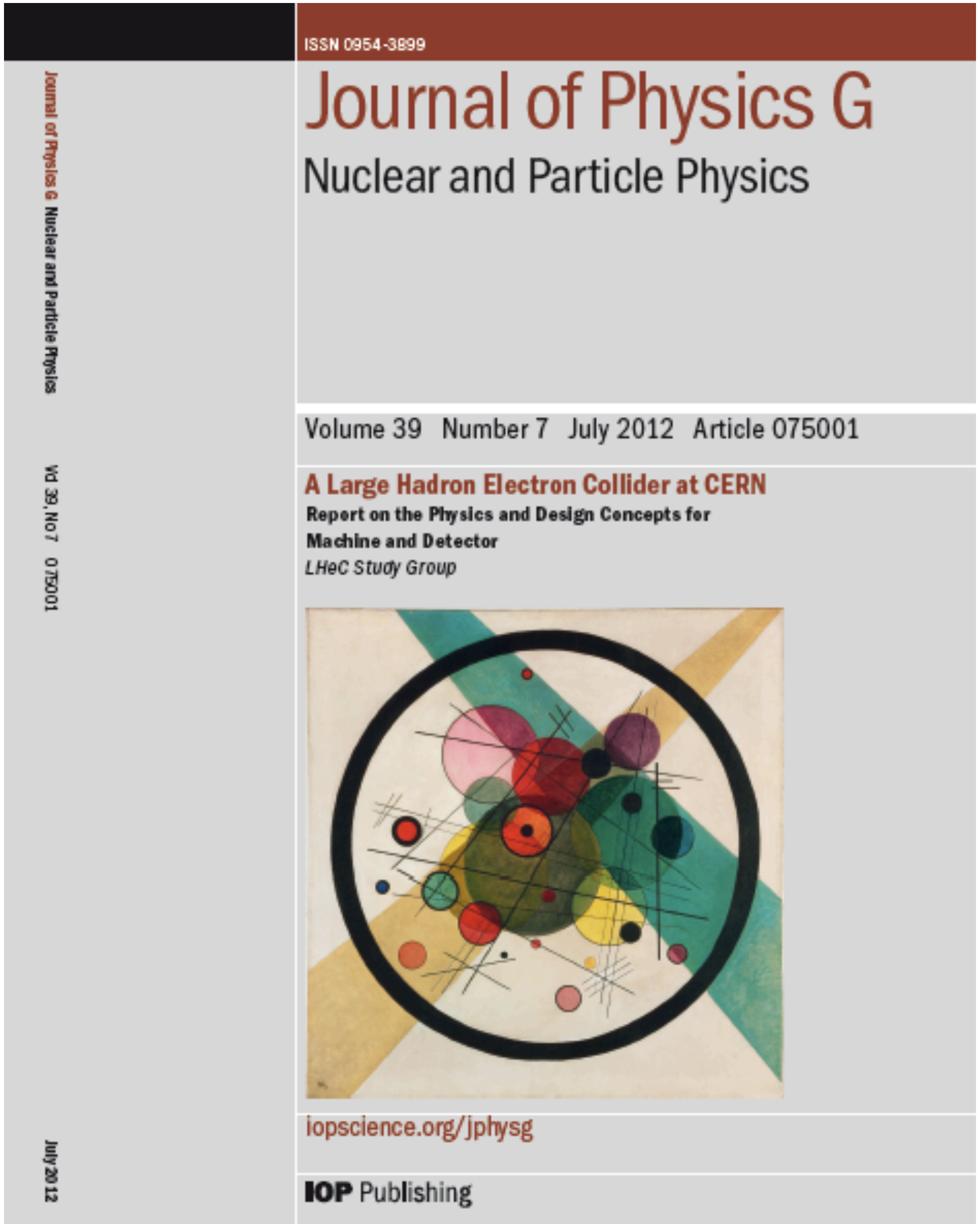






	Phase, radians	Comment
Injection phase	-0.05	φ1, injection phase
10.2875 GeV arc	-0.211966	Δφ1, phase advance
20.2837 GeV arc	0.231414	Δφ2, phase advance
30.2687 GeV arc	-0.166757	Δφ3, phase advance
40.3649 GeV arc	0.322776	Δφ4, phase advance
50.3649 GeV arc	-0.00580018	Δφ5, phase advance
60 GeV arc	2.586565	Δφ6, phase advance

Two 10 GeV energy recovery Linacs, 3 returns, 720 MHz cavities



CERN Referees

Ring Ring Design
Kurt Huebner (CERN)
Alexander N. Skrinsky (INP Novosibirsk)
Ferdinand Willeke (BNL)
Linac Ring Design
Reinhard Brinkmann (DESY)
Andy Wolski (Cockcroft)
Kaoru Yokoya (KEK)
Energy Recovery
Georg Hoffstaetter (Cornell)
Ilan Ben Zvi (BNL)
Magnets
Neil Marks (Cockcroft)
Martin Wilson (CERN)
Interaction Region
Daniel Pitzl (DESY)
Mike Sullivan (SLAC)
Detector Design
Philippe Bloch (CERN)
Roland Horisberger (PSI)
Installation and Infrastructure
Sylvain Weisz (CERN)
New Physics at Large Scales
Cristinel Diaconu (IN2P3 Marseille)
Gian Giudice (CERN)
Michelangelo Mangano (CERN)
Precision QCD and Electroweak
Guido Altarelli (Roma)
Vladimir Chekelian (MPI Munich)
Alan Martin (Durham)
Physics at High Parton Densities
Alfred Mueller (Columbia)
Raju Venugopalan (BNL)
Michele Arneodo (INFN Torino)

Published 600 pages conceptual design report (CDR) written by 200 authors from 60 Institutes and refereed by 24 world experts on physics, accelerator and detector, which CERN had invited.

“BFKL evolution and Saturation in DIS”

Circles in a circle
V. Kandinsky, 1923
Philadelphia Museum of Art

“Critical gravitational collapse”

5d tiny black holes and perturbative saturation
Talk by A.S.Vera at LHeC Workshop 2008

Project Development

2007: Invitation by SPC to ECFA and by (r)ECFA to work out a design concept

2008: First CERN-ECFA Workshop in Divonne (1.-3.9.08)

2009: 2nd CERN-ECFA-NuPECC Workshop at Divonne (1.-3.9.09)

2010: Report to CERN SPC (June)
3rd CERN-ECFA-NuPECC Workshop at Chavannes-de-Bogis (12.-13.11.10)
NuPECC: LHeC on Longe Range Plan for Nuclear Physics (12/10)

2011: Draft CDR (530 pages on Physics, Detector and Accelerator) (5.8.11)
refereed and being updated

2012: Discussion of LHeC at LHC Machine Workshop (Chamonix)
Publication of CDR + 2 Contributions to European Strategy [arXiv]
Chavannes workshop (June14-15, 2012) – **CERN**: **Linac+TDR Mandate**
ECFA final endorsement of CDR

http://cern.ch/lhec

LHC Schedule for the coming decade

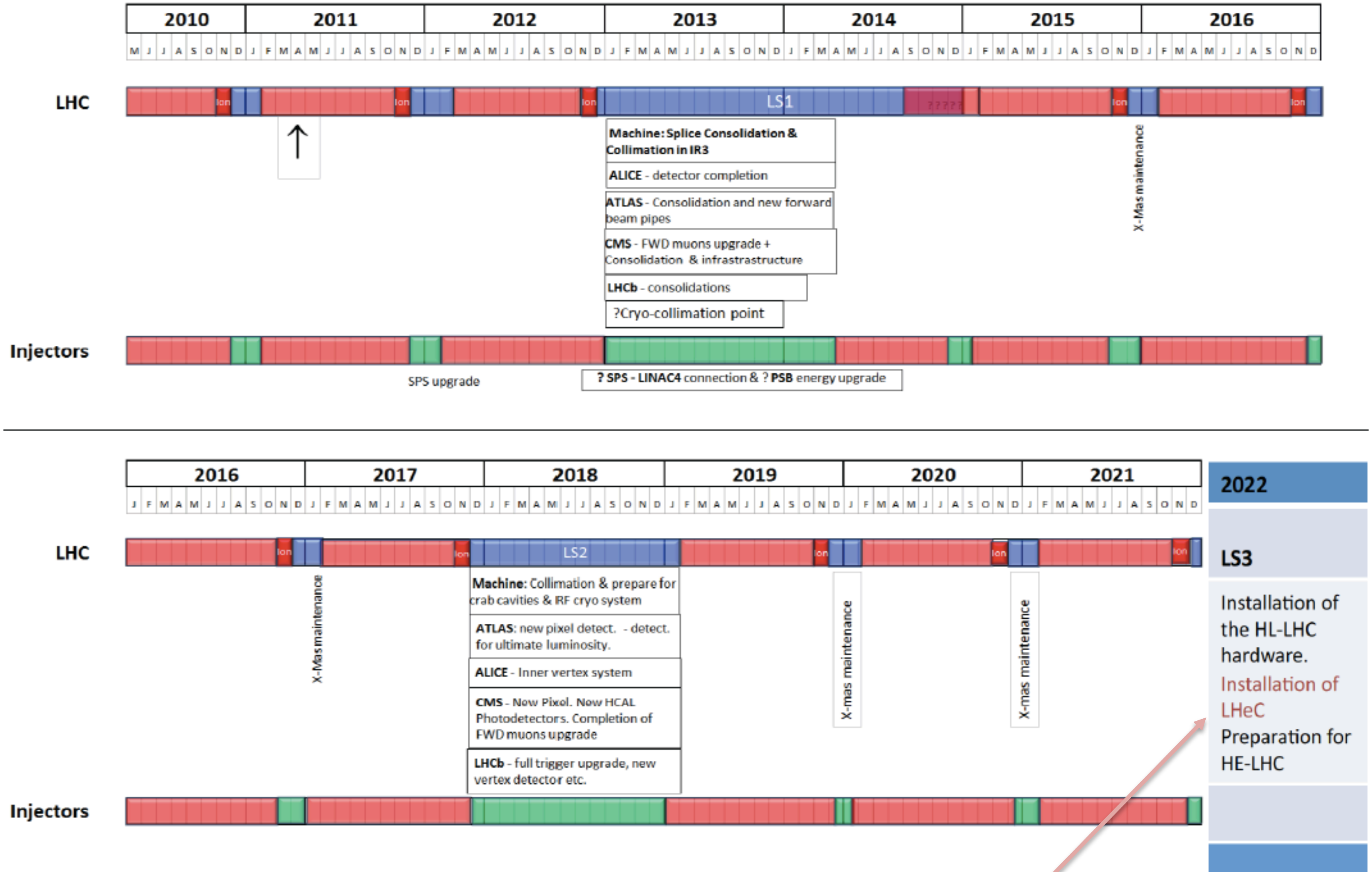
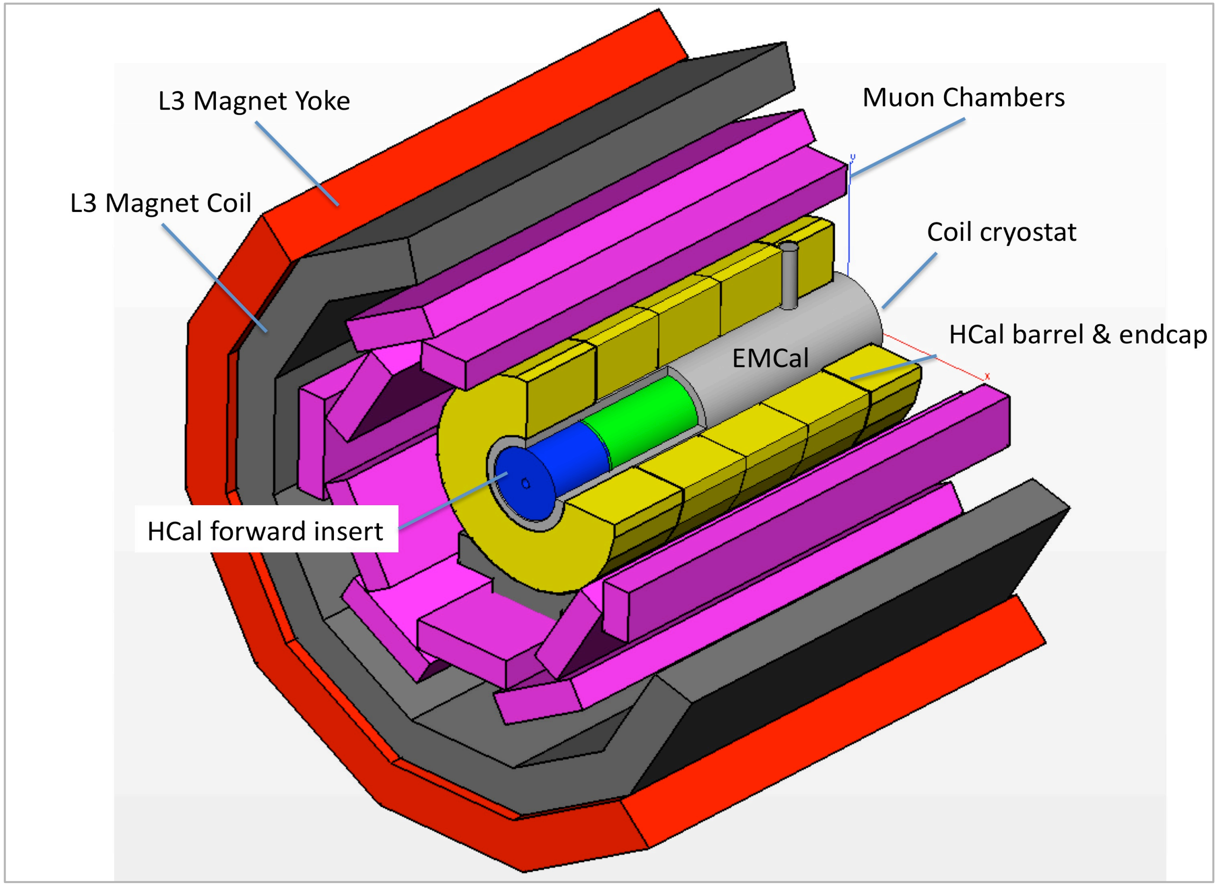


Figure 11.1: CERN medium term plan (MTP), draft as of July 2011

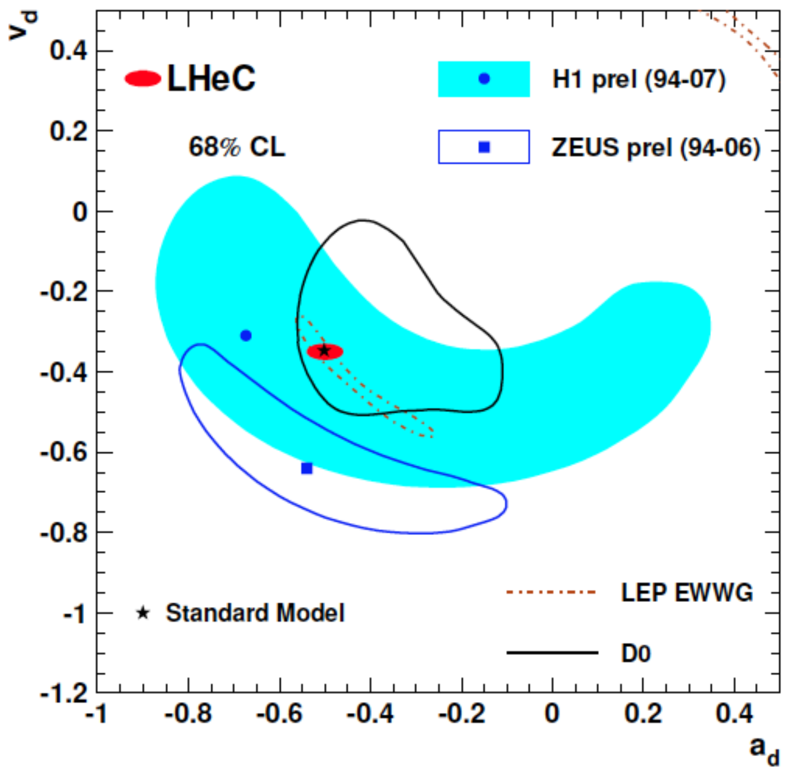
as shown by S. Myers at EPS 2011 Grenoble - Principal guidance of CDR [+N years..]

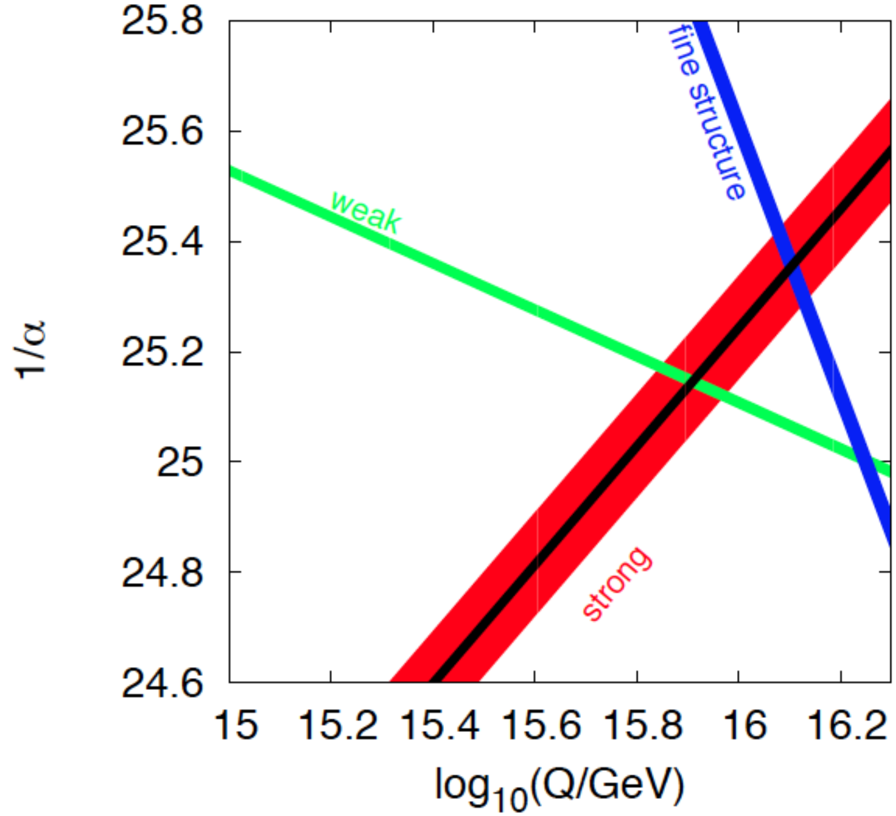
Detector supported by L3 Magnet



Installation study in CDR (Herve, Ghaddi): 30 months for removal and installation which is compatible with LHC shutdown for HL-LHC ("LS3")

High Precision DIS





$Q^2 >> M_{Z,W}^2$, hi luminosity, large acceptance
Unprecedented precision in NC and CC
Contact interactions probed to 50 TeV
Scale dependence of $\sin^2\theta$ left and right to LEP

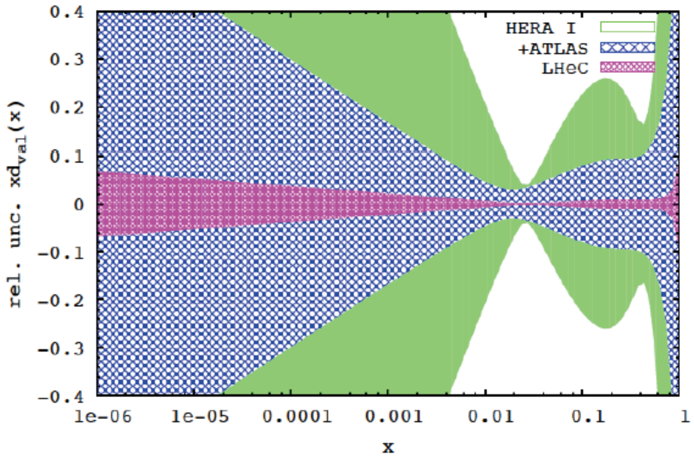
→ **A renaissance of deep inelastic scattering** ←

Solving a 40 year puzzle:
α_s small in DIS or high with jets?
Per mille measurement accuracy
Testing QCD lattice calculations
Constraining GUT (CMSSM40.2.5)
Charm mass to 3MeV, N^3LO

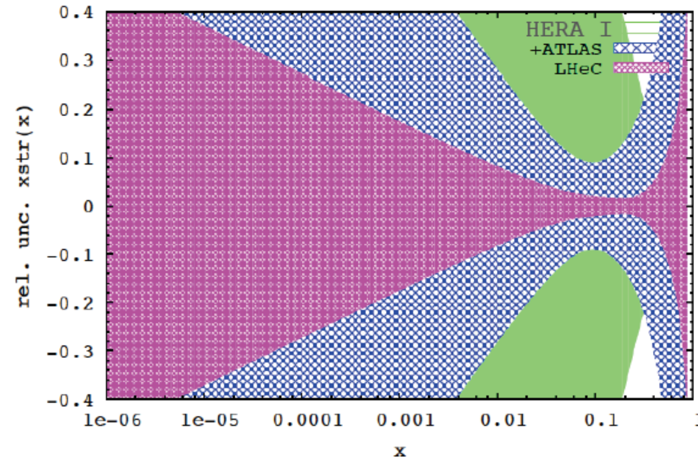
PDFs from HERA+LHC and LHeC

QCD fit with free u,d,s, HERA plus ultimate ATLAS and full systematic error simulation on LHeC

d valence



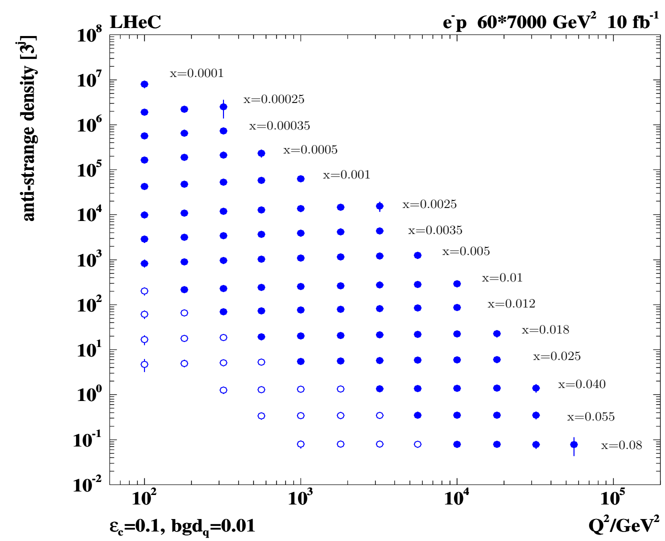
strange



DIS is the appropriate process to determine PDFs (just compare HERA – Tevatron PDF constraints)

LHeC: first time ever to fully determine PDFs, free of symmetry and ad hoc assumptions in huge and unexplored kinematic range

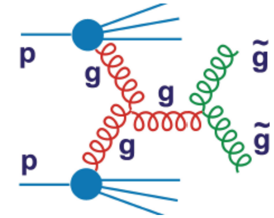
LHC: precision Drell-Yan data provide constraints *(cf for example the ATLAS determination of s/d)* Yet, high precision (<1%) only achievable at W,Z scale (miss the evolution) and large eweak-QCD theory uncertainties complicate interpretation

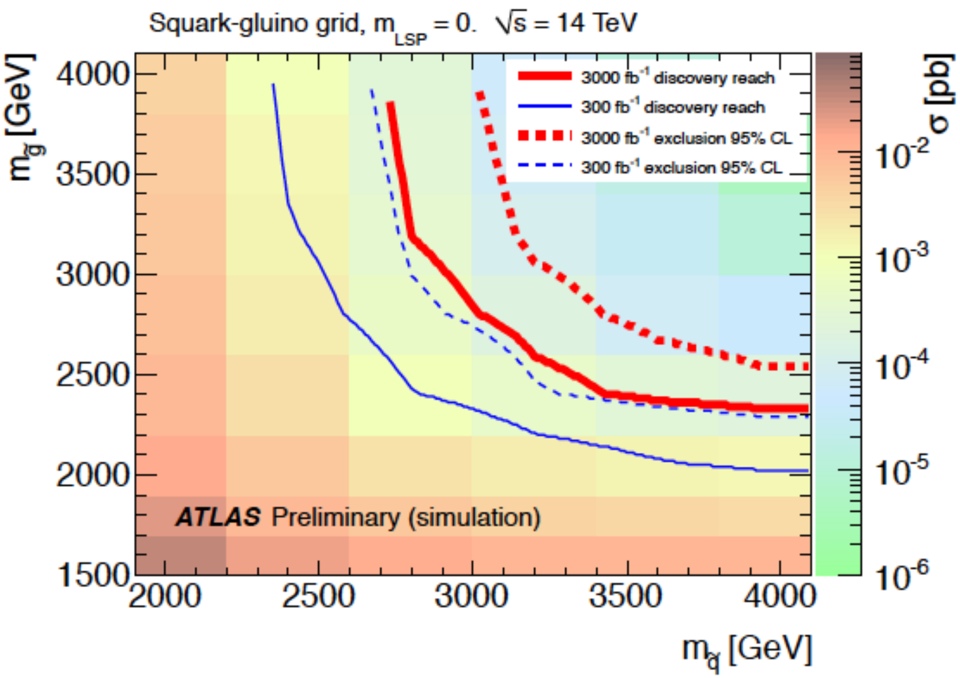


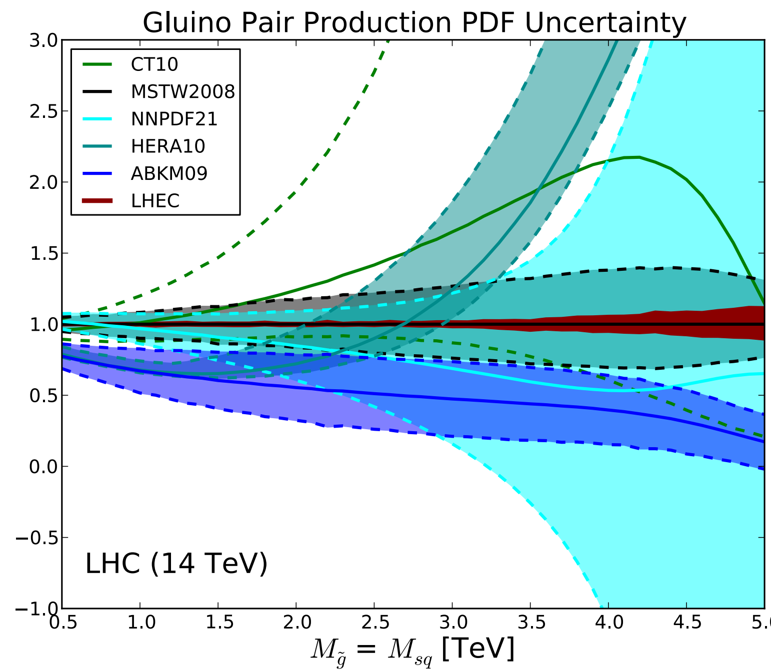
Direct strange measurement from charged current

Ws→c in ep → νcX [high lumi, large range, small spot ~7μm^2]

LHeC and the HL-LHC (SUSY searches)







With high energy and luminosity, the LHC search range will be extended to high masses, up to 5 TeV in pair production. At correspondingly high x (> 0.5) the PDFs are unknown to a considerable extent [cf gg luminosity → g̃g̃ and gluon density from LHeC (10% at x=0.6)]

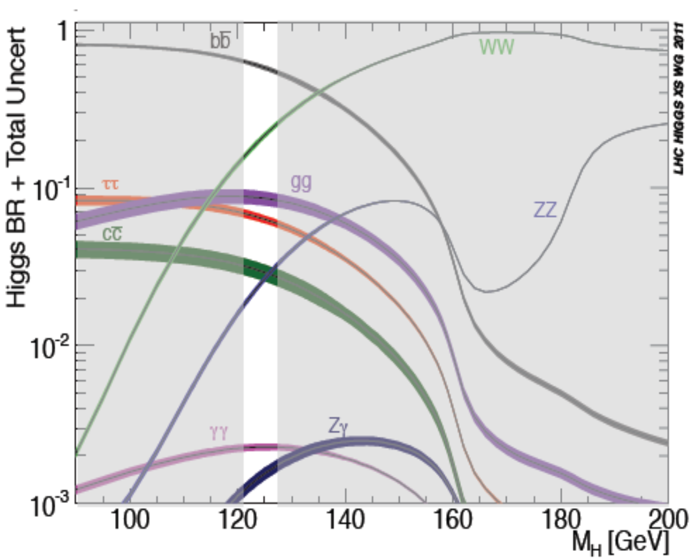
The HL-LHC (search) programme requires a much more precise understanding of QCD, which the LHeC provides (strong coupling, gluon, valence, factorisation, saturation, diffraction..)

Higgs and LHeC

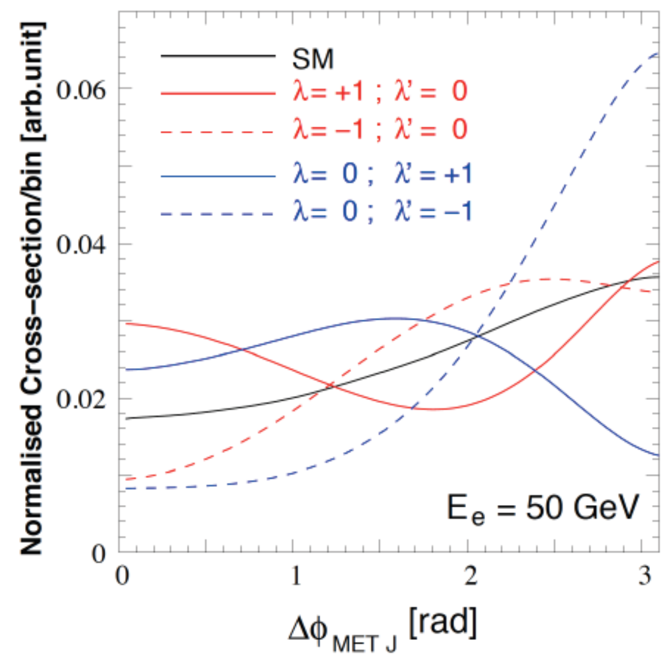
Precision measurements of couplings in WW and ZZ production (so far: bb in CC to 4%)
Measurement of CP properties ($J^{PC}=0^{++}$ in SM; MSSM has 2 CP-even and 1 CP-odd states)
Reduction of theoretical uncertainties for pp measurements

Initial study of WW → H → bb

PGS for detector, cut based analysis,
S/N =1, 500 H-bb events for $100fb^{-1}$



$$\Gamma^{(\mathrm{BSM})}_{\mu\nu}(p,q) = \frac{-g}{M_W}\left[\lambda\,(p.q\,g_{\mu\nu} - p_\nu q_\mu) + i\,\lambda'\,\epsilon_{\mu\nu\rho\sigma}p^\rho q^\sigma\right]$$

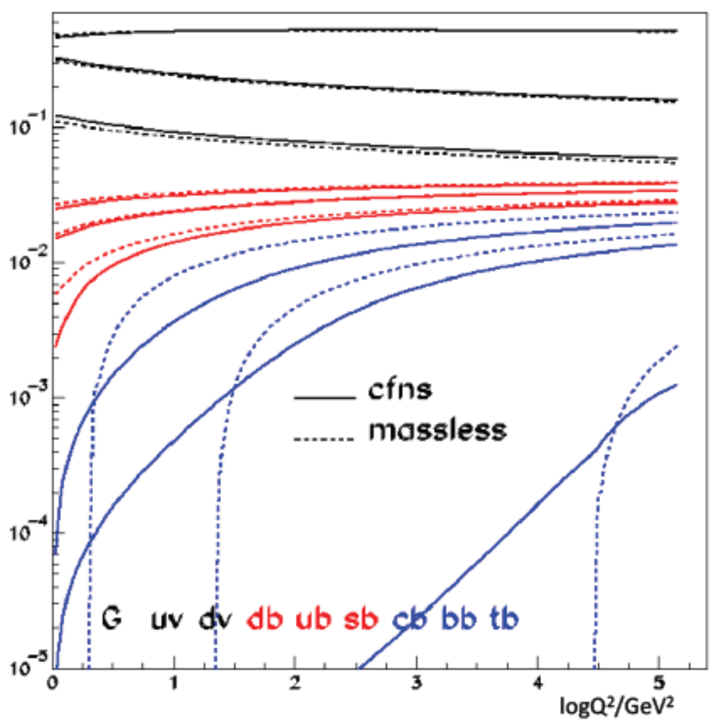


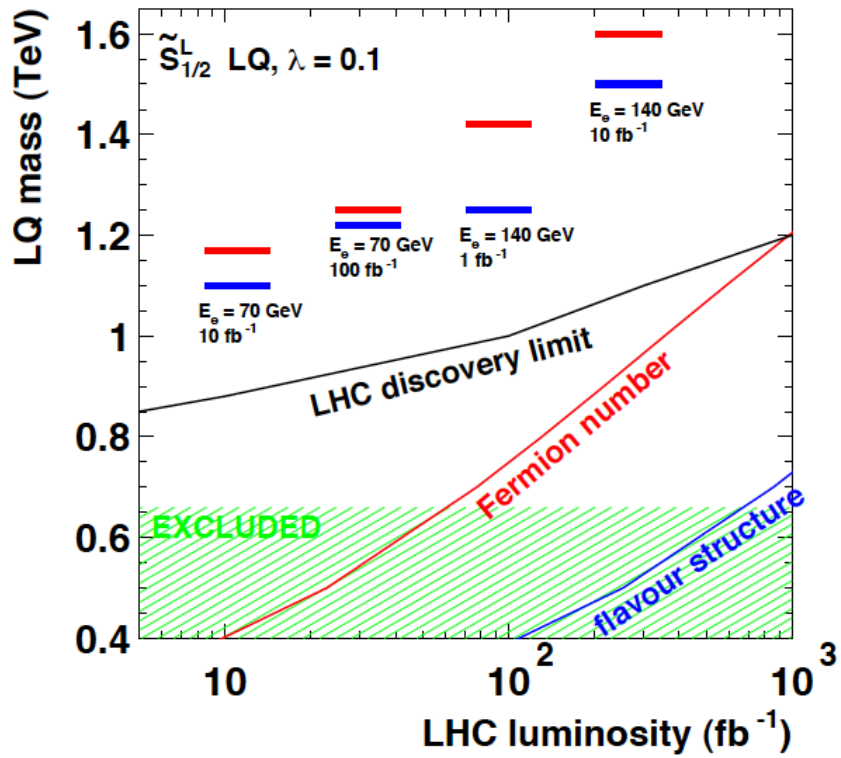
ICHEP12: J Campbell: ultimate limitation of Higgs measurements from LHC by PDFs/QCD

With high luminosity the LHeC has a huge potential for precision Higgs physics, which is being further evaluated.

Top Quark and Leptoquarks

The LHeC is a (single) top quark production factory, via Wb → t. Top was never observed in DIS. With ep: top-PDF → 6 flavour VFNS, precision M_t direct and from cross section, anomalous couplings

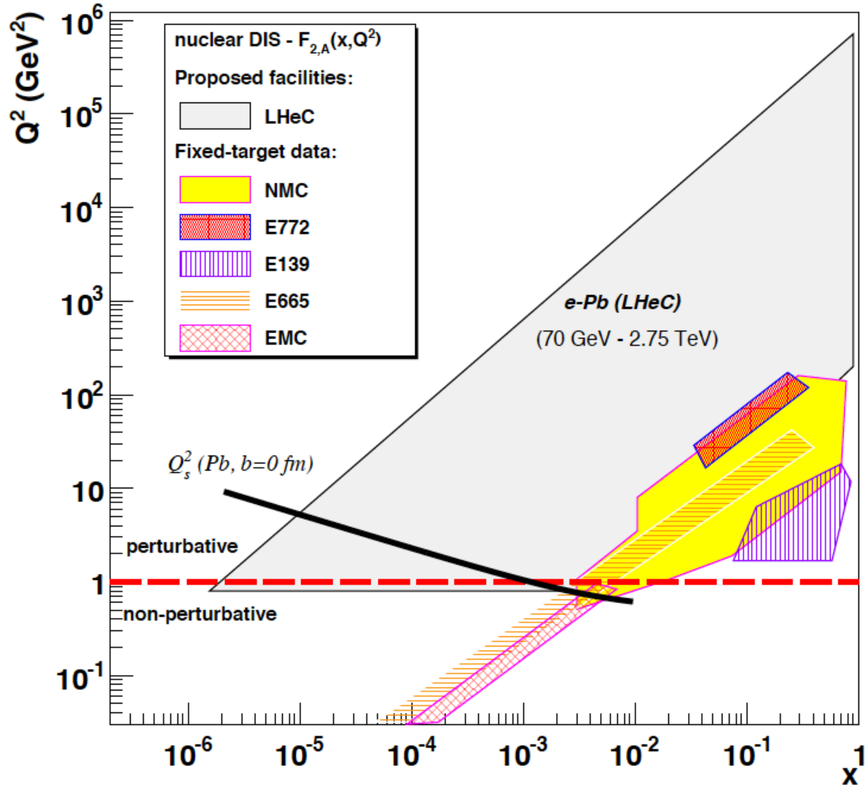




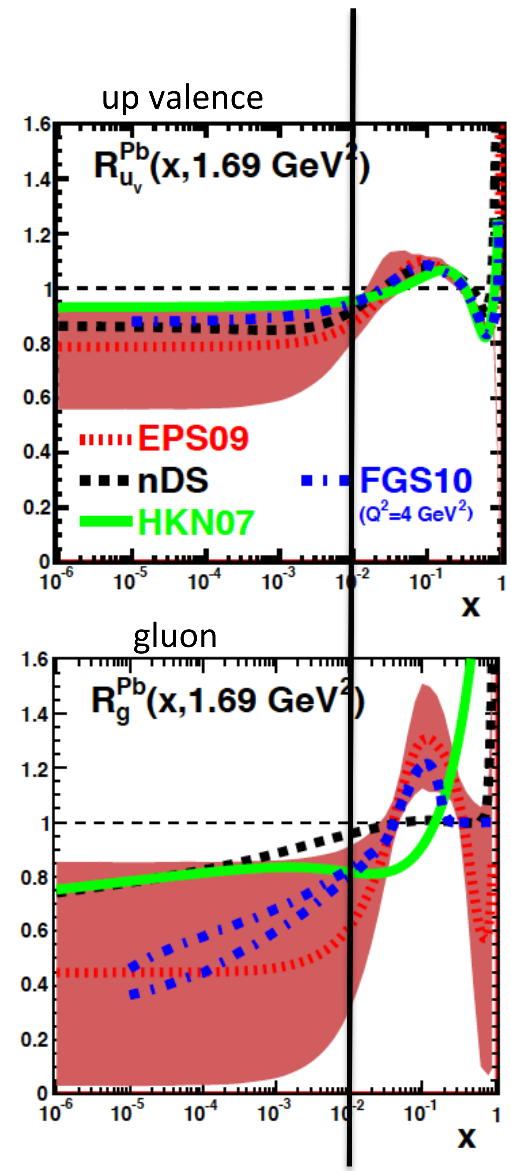
Leptoquarks (-gluons) are predicted in RPV SUSY, E6, extended technicolour theories or Pati-Salam.

The LHeC is the appropriate configuration to do their spectroscopy, should they be discovered at the LHC.

Heavy Ion Physics

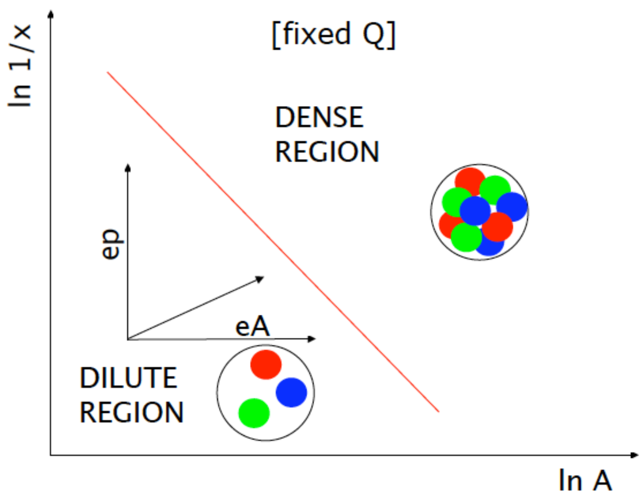


eA physics is essentially not done yet (no eA at HERA)
LHeC has huge discovery potential for new HI physics
(bb limit, saturation, deconfinement, hadronisation..)
It will put nPDFs on completely new ground and
constrain the initial conditions of the Quark-Gluon Plasma

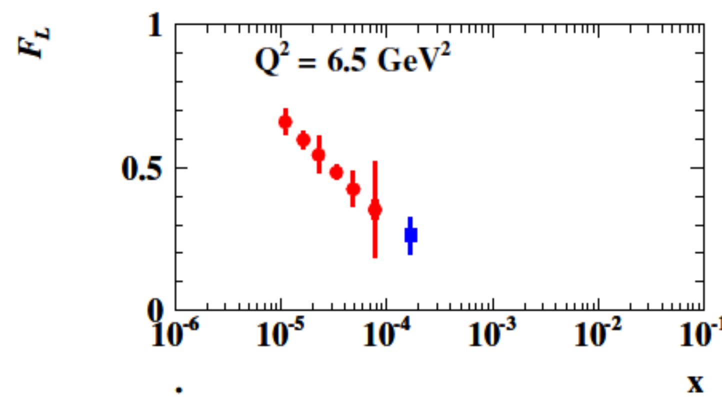


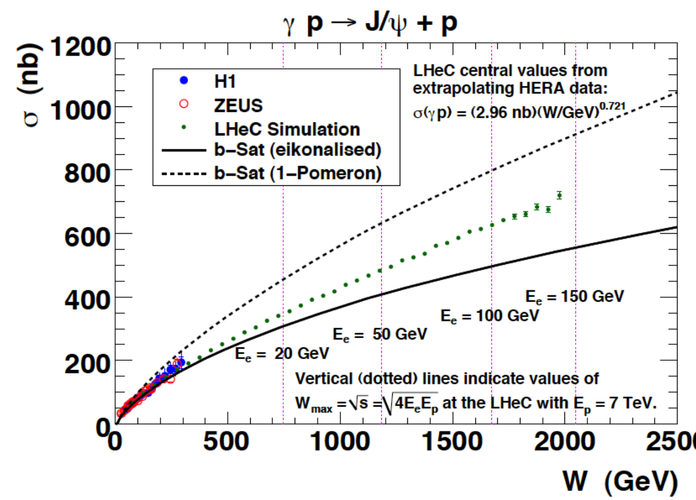
unmeasured | known?

Saturation – Low x Physics



Precision Measurements of crucial observables (F_2, F_L, J/ψ..





New phase of matter: small coupling but non-linear parton-parton interactions:

- End of DGLAP ? BFKL?
- Access to 10 TeV scale SUSY via BFKL ("DP") arXiv:1205.6713 Kowalski, Lipatov, Ross
- Restauration of unitarity?
- Relevant for UHE neutrino scattering

Candidates for Surprises and Discoveries

PDFs (t, s, $q\text{-}\bar{q}$, val, xg)
Odderon
Instanton
(no) saturation, QCD
QGP initial state

The study of deep inelastic *ep* scattering is important for the investigation of the nature of the Pomeron and Odderon, which are Regge singularities of the t-channel partial waves $f_j(t)$ in the complex plane of the angular momentum j. The Pomeron is responsible for a growth of total cross sections with energy. The Odderon describes the behaviour of the difference of the cross sections for particle-particle and particle-antiparticle scattering which obey the Pomeranchuck theorem. In perturbative QCD, the Pomeron and Odderon are the simplest colorless reggeons (families of glueballs) constructed from two and three reggeized gluons, respectively. Their wave functions satisfy the generalized BFKL equation. In the next-to-leading approximation the solution of the BFKL equation contains an infinite number of Pomerons and to verify this prediction of QCD one needs to increase the energy of colliding particles. In the N=4 supersymmetric generalization of QCD, in the t'Hooft limit of large N_c, the BFKL Pomeron is equivalent to the reggeized graviton living in the 10-dimensional anti-de-Sitter space. Therefore, the Pomeron interaction describing the screening corrections to the BFKL predictions, at least in this model, should be based on a general covariant effective theory being a generalization of the Einstein-Hilbert action for general relativity. Thus, the investigation of high energy *ep* scattering could be interesting for the construction of a non-perturbative approach to QCD based on an effective string model in high dimensional spaces.

Lev Lipatov in the CDR…

Factorization pp-ep
LQs, RPV SUSY
e^*
Higgs CP
α_s indeed small (GUT)

Ultra high precision (detector, e-h redundancy) - new insight
Maximum luminosity and much extended range - rare, new effects
Deep relation to (HL-) LHC (precision+range) - complementarity
→ **LHeC brings a substantial enrichment of LHC physics**

Summary of LHeC Physics [arXiv:1211:4831+5102]

The LHeC represents a new laboratory for exploring a hugely extended region of phase space with an unprecedented high luminosity in high energy DIS. It builds the link to the LHC and a future pure lepton collider, similar to the complementarity between HERA and the Tevatron and LEP, yet with much higher precision in an extended energy range. Its physics is fundamentally new, and it also is complementary especially to the LHC, for which the electron beam is an upgrade. Given the broad range of physics questions, there are various ways to classify these, partially overlapping. An attempt for a schematic overview on the LHeC physics programme as seen from today is presented in Tab. 3. The conquest of new regions of phase space and intensity has often lead to surprises, which tend to be difficult to tabulate.

QCD Discoveries	$\alpha_s < 0.12$, $q_{sea} \neq \overline{q}$, instanton, odderon, low x: (n0) saturation, $\overline{u} \neq \overline{d}$
Higgs	WW and ZZ production, $H \to b\overline{b}$, $H \to 4l$, CP eigenstate
Substructure	electromagnetic quark radius, e^*, ν^*, W?, Z?, top?, H?
New and BSM Physics	leptoquarks, RPV SUSY, Higgs CP, contact interactions, GUT through α_s
Top Quark	top PDF, $xt = x\overline{t}$?, single top in DIS, anomalous top
Relations to LHC	SUSY, high x partons and high mass SUSY, Higgs, LQs, QCD, precision PDFs
Gluon Distribution	saturation, $x \simeq 1$, J/ψ, Υ, Pomeron, local spots?, F_L, F_2^c
Precision DIS	$\delta\alpha_s \simeq 0.1\,\%$, $\delta M_c \simeq 3\,\mathrm{MeV}$, $v_{u,d}$, $a_{u,d}$ to $2-3\,\%$, $\sin^2\Theta(\mu)$, F_L, F_2^b
Parton Structure	Proton, Deuteron, Neutron, Ions, Photon
Quark Distributions	valence $10^{-4} \lesssim x \lesssim 1$, light sea, d/u, $s = \overline{s}$?, charm, beauty, top
QCD	N^{3}LO, factorisation, resummation, emission, AdS/CFT, BFKL evolution
Deuteron	singlet evolution, light sea, hidden colour, neutron, diffraction-shadowing
Heavy Ions	initial QGP, nPDFs, hadronization inside media, black limit, saturation
Modified Partons	PDFs "independent" of fits, unintegrated, generalised, photonic, diffractive
HERA continuation	F_L, xF_3, $F_2^{\gamma Z}$, high x partons, α_s, nuclear structure, ..

Table 3: Schematic overview on key physics topics for investigation with the LHeC.

LHeC Accelerator Design: Participating Institutes

CERN

SLAC NATIONAL ACCELERATOR LABORATORY

NTNU
Norwegian University of Science and Technology

CLIC

The Cockcroft Institute of Accelerator Science and Technology

Jefferson Lab
Thomas Jefferson National Accelerator Facility

ANKARA ÜNİVERSİTESİ 1946

NİĞDE ÜNİVERSİTESİ 1992

ULUDAĞ ÜNİVERSİTESİ 1975

TOBB ETU

INFN Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Legnaro

DESY

LAL Physique des accélérateurs

ECFA

EPFL
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

UNIVERSITY OF LIVERPOOL

BROOKHAVEN NATIONAL LABORATORY

СИБИРСКОЕ ОТДЕЛЕНИЕ РАН
ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ
им. Г.И.Будкера
630090 Новосибирск

KEK

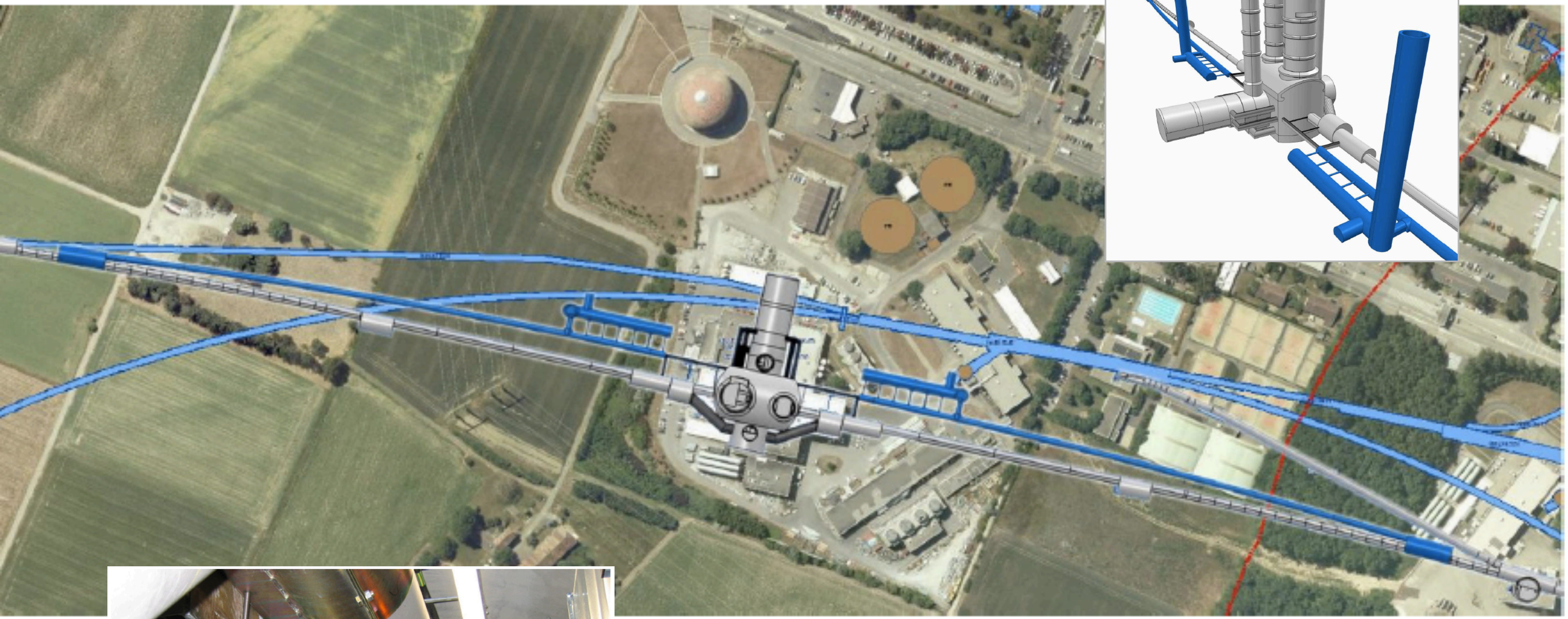
LHeC Parameters

electron beam 60 GeV	Ring	Linac
e^- (e^+) per bunch N_e [10^9]	20 (20)	1 (0.1)
e^- (e^+) polarisation [%]	40 (40)	90 (0)
bunch length [mm]	6	0.6
tr. emittance at IP $\gamma\epsilon^e_{x,y}$ [mm]	0.59, 0.29	0.05
IP β function $\beta^*_{x,y}$ [m]	0.4, 0.2	0.12
beam current [mA]	100	6.6
energy recovery efficiency [%]	–	94
proton beam 7 TeV		
protons per bunch N_p [10^{11}]	1.7	1.7
transverse emittance $\gamma\epsilon^p_{x,y}$ [μm]	3.75	3.75
collider		
Lum e^-p (e^+p) [10^{32}cm^{-2}s^{-1}]	9 (9)	10 (1)
bunch spacing [ns]	25	25
rms beam spot size $\sigma_{x,y}$ [μm]	45, 22	7
crossing angle θ [mrad]	1	0
$L_{eN} = A\ L_{eA}$ [10^{32}cm^{-2}s^{-1}]	0.45	1

Source	Power [MW]
Cryogenics (linac)	21
Linac grid power	24
SR compensation	23
Extra RF cryopower	2
Injector	6
Arc magnets	3
Total	**78**

CDR: Two options for electron beam: Ring or (Racetrack) Linac with E-recovery for L > 10^{33}cm^{-2}s^{-1}
Synchronous operation of pp and ep in HL-LHC phase. e Ring required bypassing pp experiments

Ring-Ring



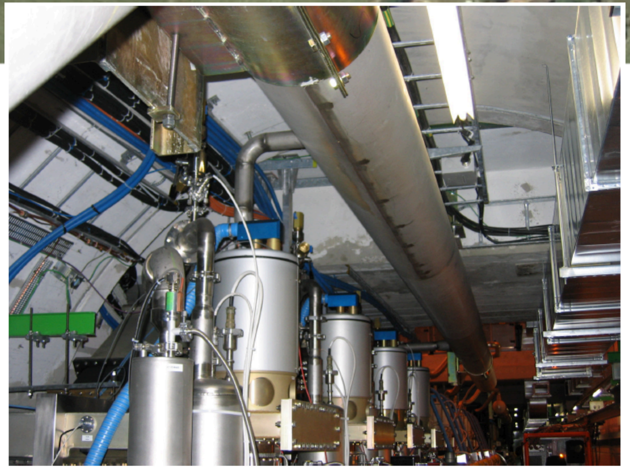


Figure 7.60: Tight space restriction in Point 4 due to the LHC proton RF installation.

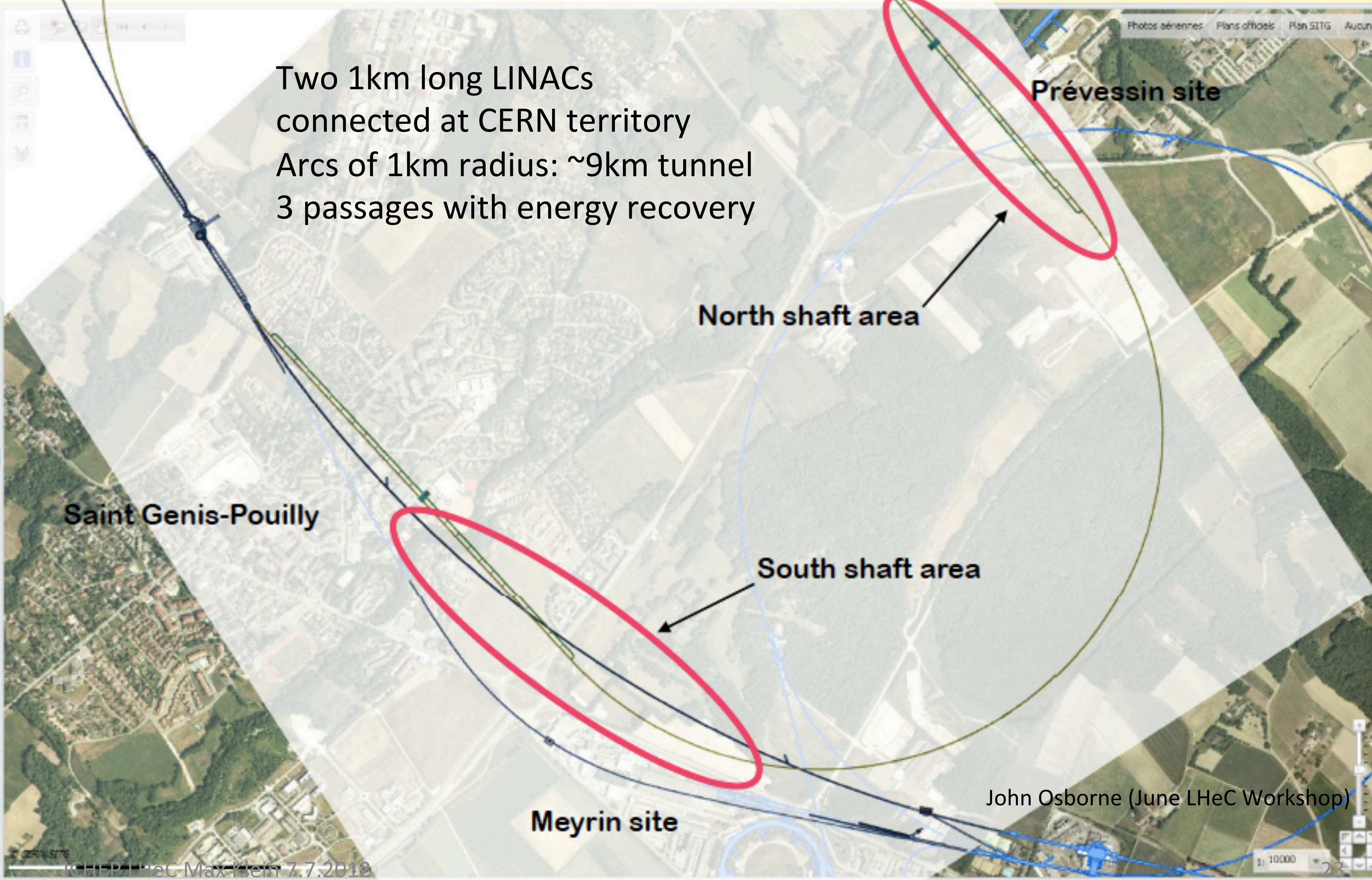
Civil engineering studied and reviewed by CH company Amber, both for ring and for linac options. Bypass in ring option used to house rf. ~4years of installation

Quite some interference with LHC: cryo jumpers (asymmetric FODO), connection of bypasses, access to LHC, proton dump area (point 3), RF (point 4), .. Cf CDR

June workshop, after CDR: RR not preferred, design LR

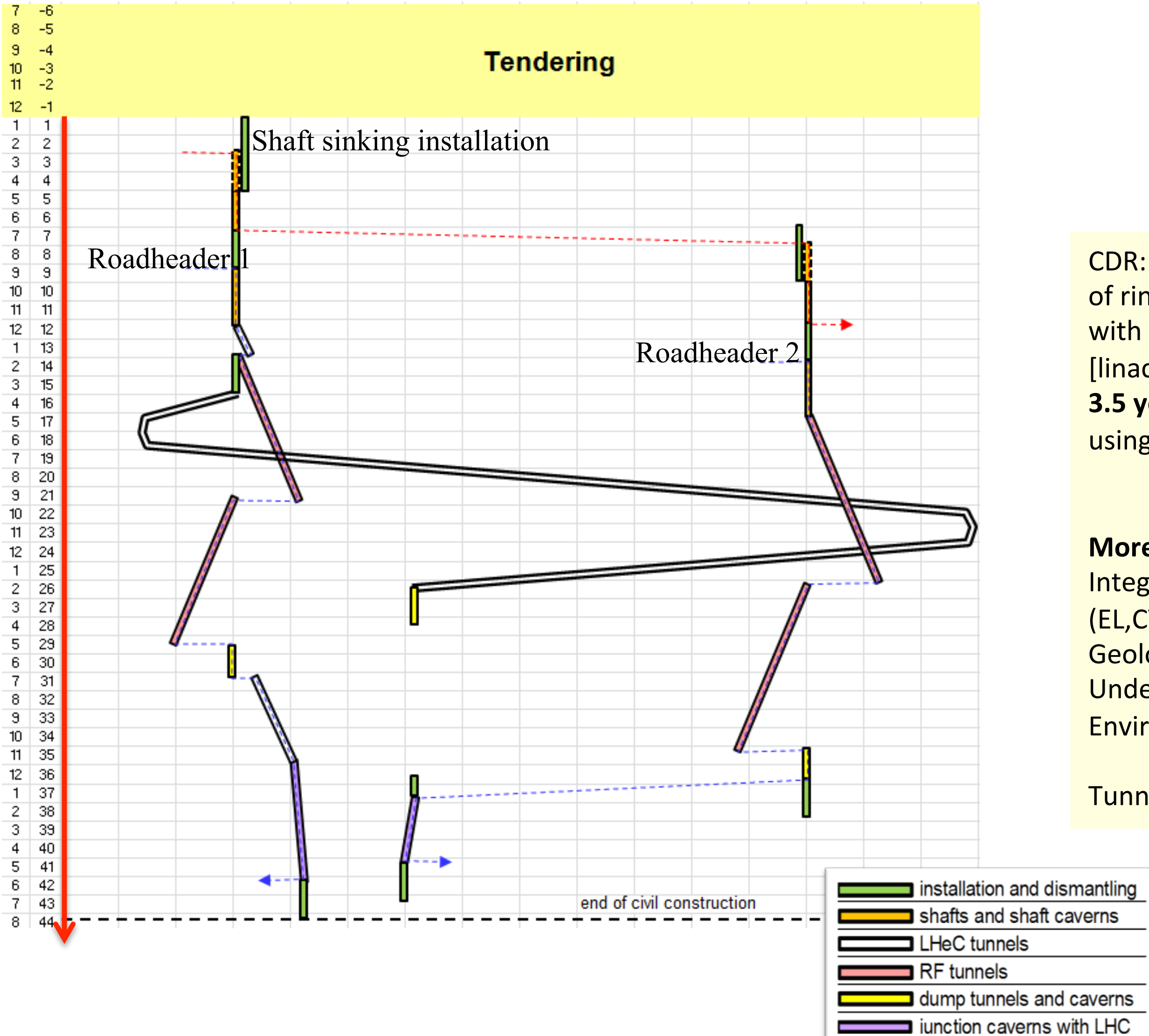
60 GeV Electron Accelerator

Two 1km long LINACs
connected at CERN territory
Arcs of 1km radius: ~9km tunnel
3 passages with energy recovery



John Osborne (June LHeC Workshop)

Civil Engineering until 2015



CDR: Evaluation of CE, analysis of ring and linac by Amber Zurich with detailed cost estimate [linac CE: 249,928 kSF..] and time: **3.5 years for underground works** using 2 roadheaders and 1 TBM

More studies needed for
Integration with all services (EL,CV, transport, survey etc).
Geology
Understanding vibration risks
Environmental impact assessment

Tunnel connection in IP2

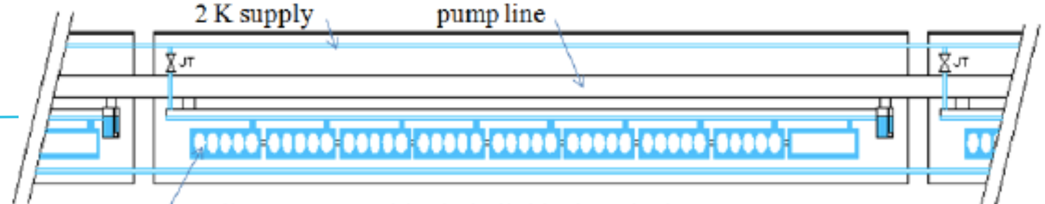
J.Osborne, Chavannes

Chapter 9 of CDR

Components and Cryogenics

	Ring	Linac
magnets		
number of dipoles	3080	3504
dipole field [T]	0.013 – 0.076	0.046 – 0.264
number of quadrupoles	968	1514
RF and cryogenics		
number of cavities	112	960
gradient [MV/m]	11.9	20
linac grid power [MW]	–	24
synchrotron loss compensation [MW]	49	23
cavity voltage [MV]	5	20.8
cavity R/Q [Ω]	114	285
cavity Q_0	–	$2.5\ 10^{10}$
cooling power [kW]	5.4@4.2 K	30@2 K

Jlab: $4\ 10^{11}$



Need to develop LHeC cavity (cryo-module)

systems will consist of a complex task. Further cavities and cryomodules will require a limited R&D program. From this we expect improved quality factors with respect to today's state of the art. The cryogenics of the L-R version consists of a formidable engineering challenge, however, it is feasible and, CERN disposes of the respective know-how.

from CDR LHeC

CERN Mandate – TDR by ~2015

The mandate for the technology development **includes studies and prototyping of the following key technical components:**

- Superconducting RF system for CW operation in an Energy Recovery Linac, (high Q0 for efficient energy recovery). The studies require design and prototyping of the cavity, couplers and cryostat.
- Superconducting magnet development of the insertion regions of the LHeC with three beams. The studies require the design and construction of short magnet models.
- Studies related to the experimental beam pipes with large beam acceptance in a high synchrotron radiation environment.
- The design and specification of an ERL test facility for the LHeC.
- The finalization of the ERL design for the LHeC including a finalization of the optics design, beam dynamic studies and identification of potential performance limitations.

The above technological developments require close collaboration between the relevant technical groups at CERN and external collaborators.

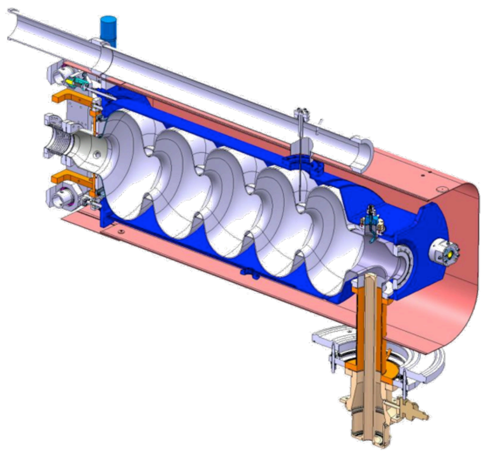
Given the rather tight personnel resource conditions at CERN **the above studies should exploit where possible synergies within existing CERN studies** (e.g. SPL and ESS SC RF, HL-LHC triplet magnet development and collaboration with ERL test facility outside CERN).

S.Bertolucci at Chavannes workshop 6/12 based on
CERN directorate's decision to include LHeC in the MTP

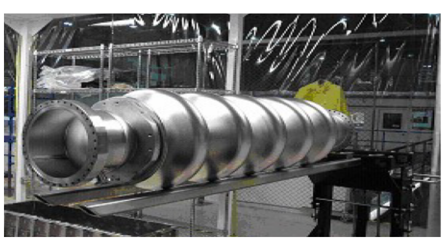
RF Development

Frequency choice: *n* * 120.237 MHz
N=6: 721 MHz, n=11: 1.3GHz (XFEL)

SPL cryomodule 704 MHz



BNL 704 MHz cavity (20 MV/m with high Q0 demonstrated)



Detailed comparison (threshold current, cryo power, Rf power, size, cost, collaboration, synergy..)

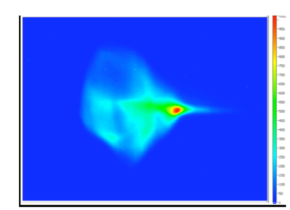
ALICE 1.3 GHz, not CW – only EU ERL facility operational
Daresbury develops cryomodule for ESS (700 MHz)
CERN: in house collaboration with SPL, and eRHIC/BNL

Accelerator physics motivation:
- ERL demonstration, FEL, γ-ray source, e-cooling demo!
- Ultra-short electron bunches

One of the 1st low-frequency, multi-pass SC-ERL
- synergy with SPL/ESS and BNL activities

High energies (200 … 400 MeV) & CW
Multi-cavity cryomodule layout – validation and gymnastics
Two-Linac layout (similar to LHeC)
MW class power coupler tests in non-ER mode
Complete HOM characterization and instability studies!
Cryogenics & instrumentation test bed … E.Jensen

Steps: Design of LHeC ERL TF, cavity-cryo module (hi Q), lattice, optics, magnets, source, ….
Watch out for surprises as humming bird:
Building international collaboration
(CERN,Daresbury, Jlab, others?)

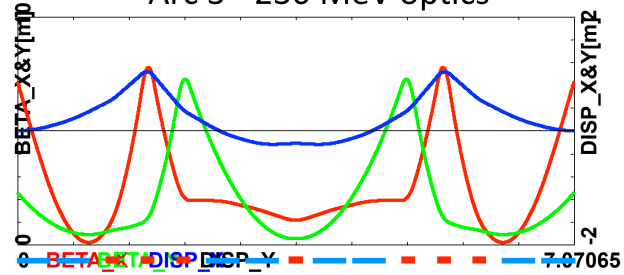


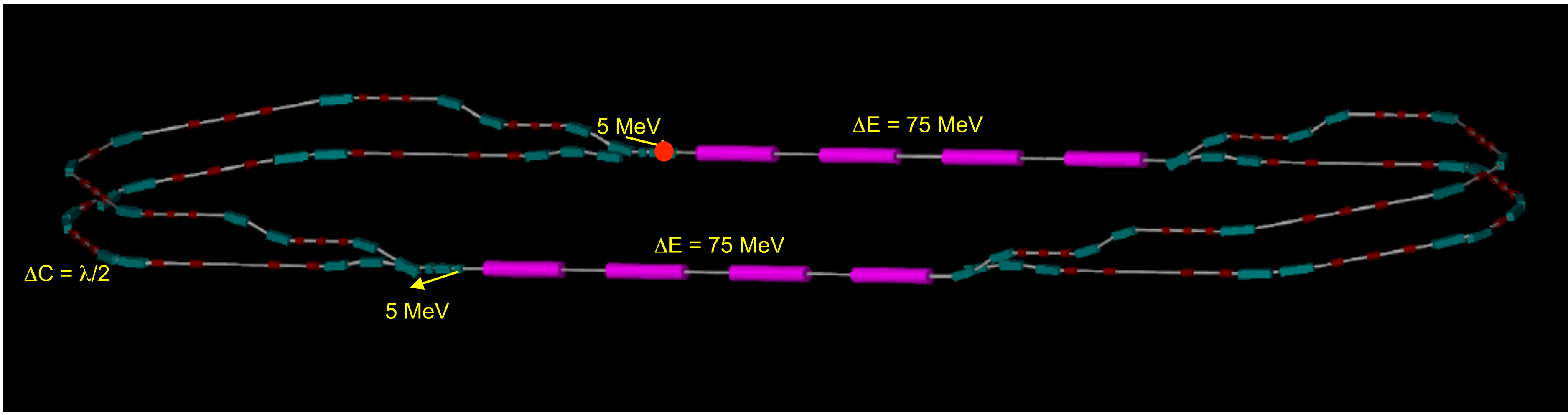
beam structure at ALICE with 230-kV DC gun voltage

LHeC - ERL-TF

Tentative study of multipass optics and lattice

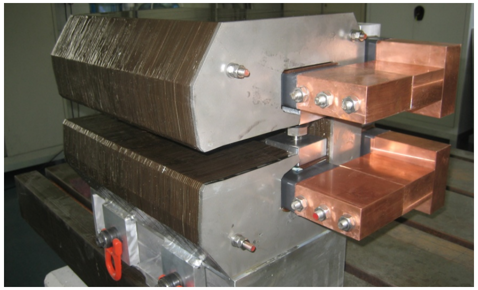
Arc 3 - 230 MeV optics



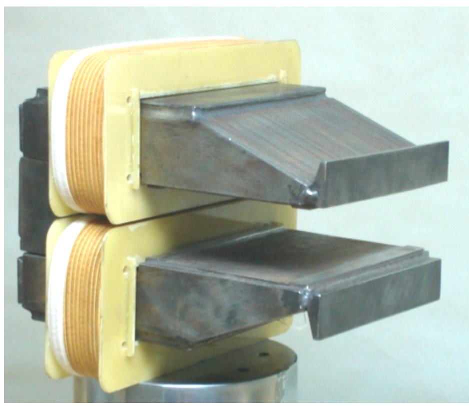


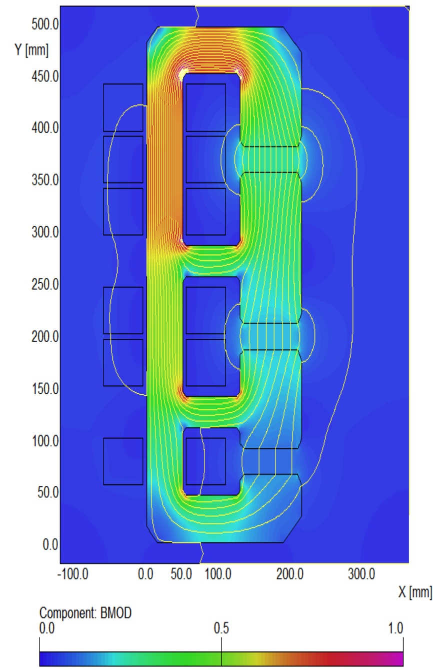
Development of LHeC Testfacility at CERN in international collaboration (ASTeC, Jlab, +)

Magnets Developments



Prototypes for Ring dipoles
Fabricated and tested by
CERN (top) and Novosibirsk





flux density in the gaps	0.264 T 0.176 T 0.088 T
magnetic length	4.0 m
vertical aperture	25 mm
pole width	85 mm
number of magnets	584
current	1750 A
number of turns per aperture	1 / 2 / 3
current density	0.7 A/ mm^2
conductor material	copper
resistance	0.36 mΩ
power	1.1 kW
total power 20 / 40 / 60 GeV	642 kW
cooling	air

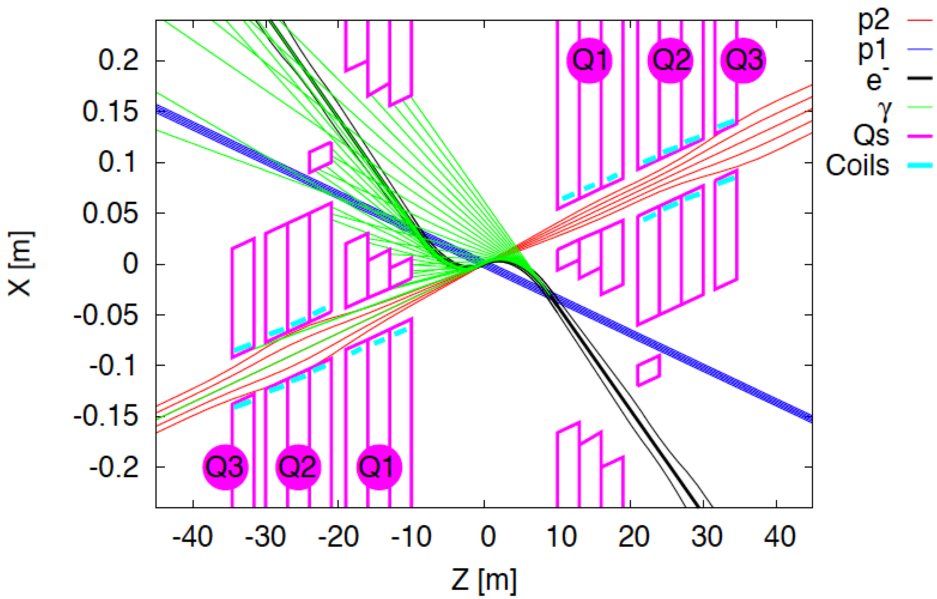
LR recirculator dipoles and quadrupoles
New requirements (aperture, field)?
Combined apertures?
Combined functions (for example, dipole + quad)?
LR linac quadrupoles and correctors
New requirements (aperture, field)?
More compact magnets, maybe with at least two families for quadrupoles?
Permanent magnets / superconducting for quads?
A.Milanese, Chavannes workshop

1/2m dipole model
Full scale prototype
Quadrupole for Linac

Magnets for ERL test stand

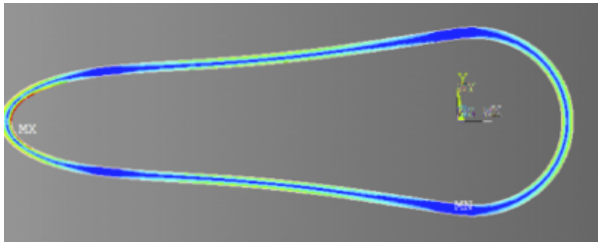
Collaboration of CERN, Daresbury and Budker (Novosibirsk)

Interaction Region Developments



Beam pipe: in CDR 6m, Be, ANSYS calculations

Composite material R+D, prototype, support..
→ Essential for tracking, acceptance and Higgs



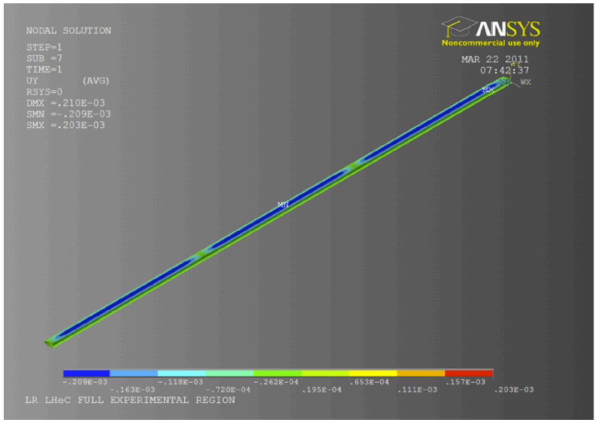


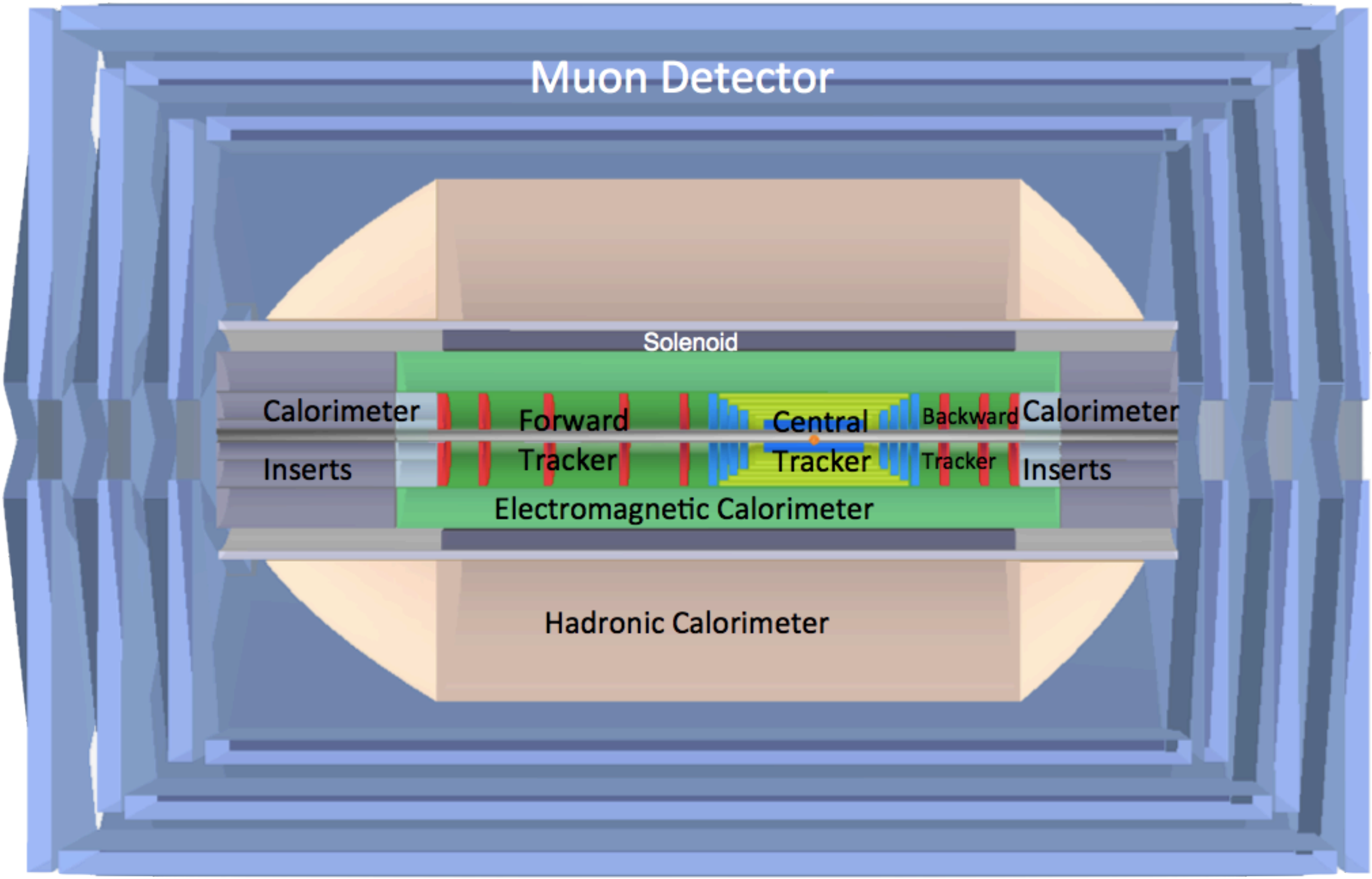
Figure 9.32: 3-D view of the LR geometry showing contours of bending displacement [m].

Have optics compatible with LHC and β*=0.1m
Head-on collisions mandatory →
High synchrotron radiation load, dipole in detector

Specification of Q1 – NbTi prototype (with KEK?)
Revisit SR (direct and backscattered),
Masks+collimators
Beam-beam dynamics and 3 beam operation studies

Optimisation: HL-LHC uses IR2 quads to squeeze IR1
("ATS" achromatic telescopic squeeze) Start in IR3.? R.Tomas et al.

LHeC Detector Overview



Detector option 1 for LR and full acceptance coverage

Forward/backward asymmetry in energy deposited and thus in geometry and technology
Present dimensions: LxD =14x9m^2 [CMS 21 x 15m^2 , ATLAS 45 x 25 m^2]
Taggers at -62m (e),100m (γ,LR), -22.4m (γ,RR), +100m (n), +420m (p)

Detector Magnets

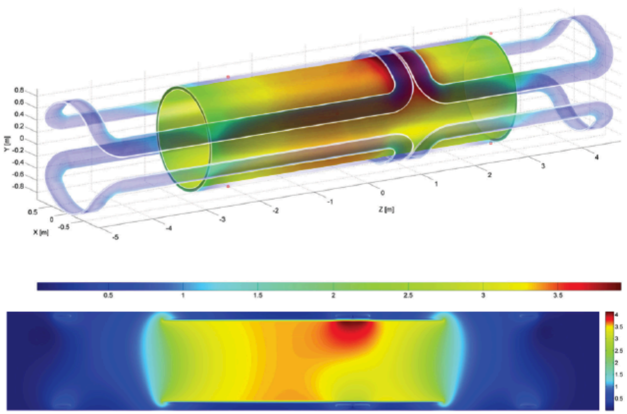


Figure 13.13: Magnetic field of the magnet system of solenoid and the two internal superconducting dipoles at nominal currents (effect of iron ignored). The position of the peak magnetic field of 3.9 T is local due to the adjacent current return heads on top of the solenoid where all magnetic fields add up.

Dipole (for head on LR) and solenoid in common cryostat, perhaps with electromagnetic LAr

3.5T field at ~1m radius to house a Silicon tracker

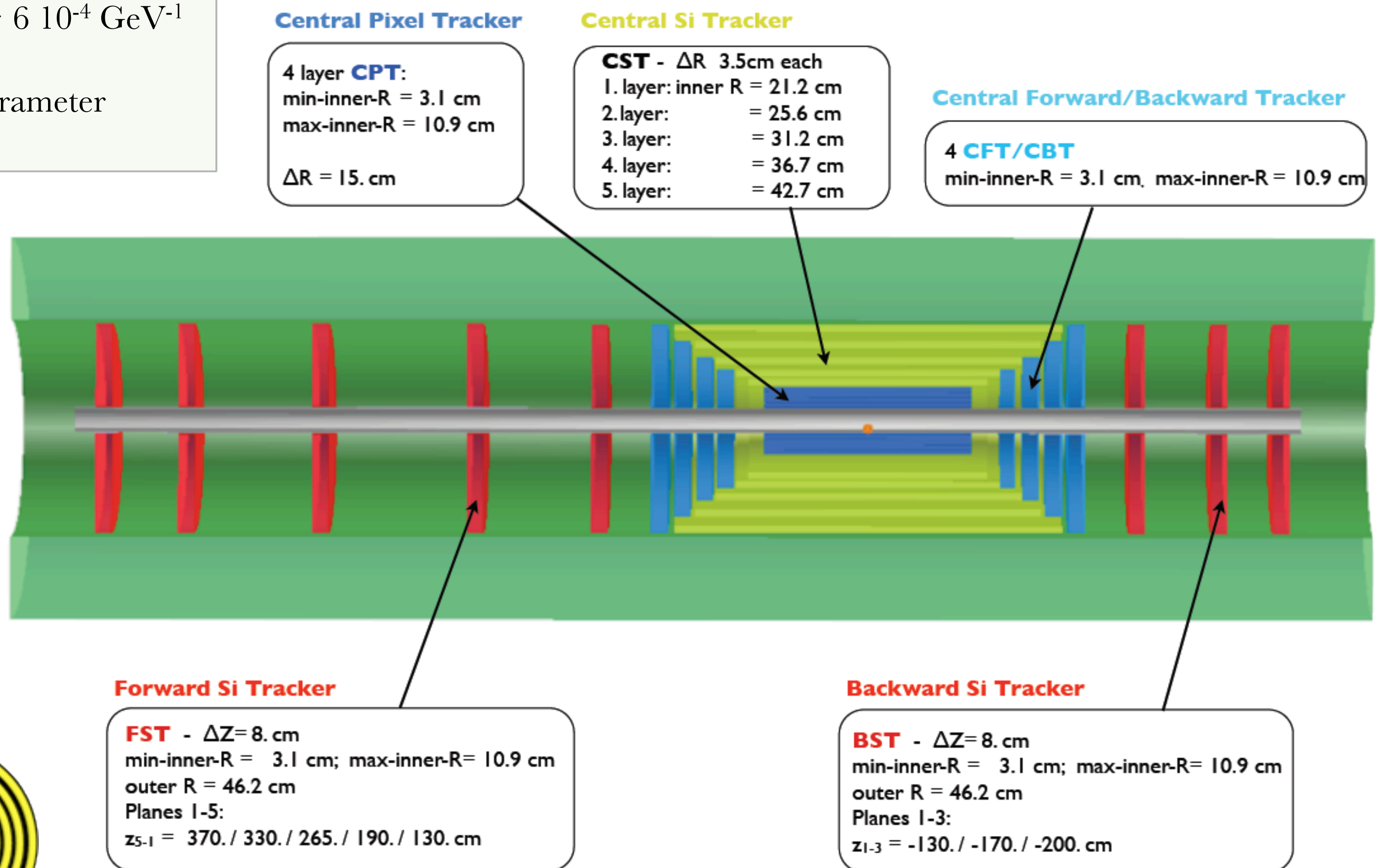
Based on ATLAS+CMS experience

Property	Parameter	value	unit
Dimensions	Cryostat inner radius	0.900	m
	Length	10.000	m
	Outer radius	1.140	m
	Coil windings inner radius	0.960	m
	Length	5.700	m
	Thickness	60.0	mm
	Support cylinder thickness	0.030	m
	Conductor section, Al-stabilized NbTi/Cu + insulation	30.0×6.8	mm^2
	Length	10.8	km
	Superconducting cable section, 20 strands	12.4×2.4	mm^2
	Superconducting strand diameter Cu/NbTi ratio = 1.25	1.24	mm
Masses	Conductor windings	5.7	t
	Support cylinder, solenoid section + dipole sections	5.6	t
	Total cold mass	12.8	t
	Cryostat including thermal shield	11.2	t
	Total mass of cryostat, solenoid and small parts	24	t
Electro-magnetics	Central magnetic field	3.50	T
	Peak magnetic field in windings (dipoles off)	3.53	T
	Peak magnetic field in solenoid windings (dipoles on)	3.9	T
	Nominal current	10.0	kA
	Number of turns, 2 layers	1683	
	Self-inductance	1.7	H
	Stored energy	82	MJ
	E/m, energy-to-mass ratio of windings	14.2	kJ/kg
	E/m, energy-to-mass ratio of cold mass	9.2	kJ/kg
	Charging time	1.0	hour
	Current rate	2.8	A/s
	Inductive charging voltage	2.3	V
Margins	Coil operating point, nominal / critical current	0.3	
	Temperature margin at 4.6 K operating temperature	2.0	K
	Cold mass temperature at quench (no extraction)	~ 80	K
Mechanics	Mean hoop stress	~ 55	MPa
	Peak stress	~ 85	MPa
Cryogenics	Thermal load at 4.6 K, coil with 50% margin	~ 110	W
	Radiation shield load width 50% margin	~ 650	W
	Cooling down time / quench recovery time	4 and 1	day
	Use of liquid helium	~ 1.5	g/s

Table 13.1: Main parameters of the baseline LHeC Solenoid providing 3.5 T in a free bore of 1.8 m.

Silicon Tracker and EM Calorimeter

Transverse momentum
$\Delta p_t/p^2_t \rightarrow 6\ 10^{-4}\ \text{GeV}^{-1}$
transverse
impact parameter
$\rightarrow$ 10μm



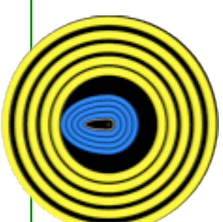


Figure 13.18: Tracker and barrel Electromagnetic-Calorimeter rz view of the baseline detector (Linac-Ring case).

LHeC-LHC: no pile-up, less radiation, smaller momenta apart from forward region

Liquid Argon Electromagnetic Calorimeter

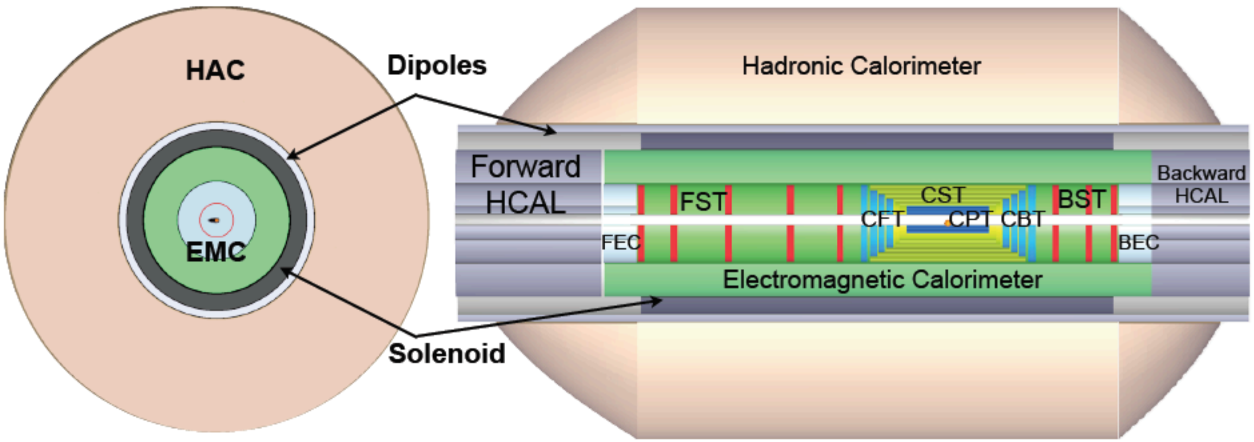


Figure 13.30: x-y and r-z view of the LHeC Barrel EM calorimeter (green).

Inside Coil
H1, ATLAS experience.

Barrel: Pb, 20 X_0 , 11m^3

fwd/bwd inserts:

FEC: Si -W, 30 X_0 ,0.3m^3

BEC: Si -Pb, 25 X_0,0.3m^3

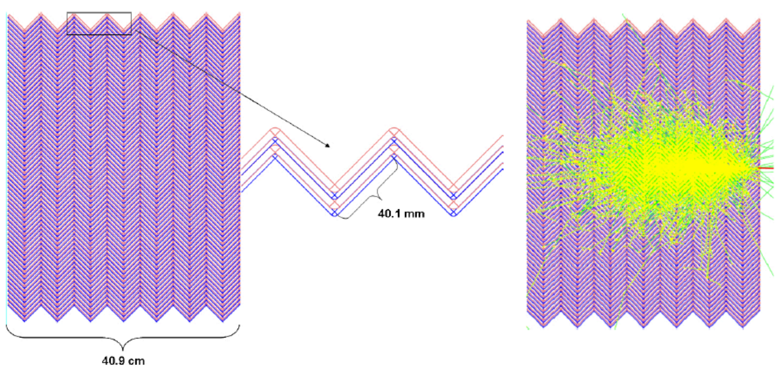


Figure 13.35: View of the parallel geometry accordion calorimeter (left) and simulation of a single electron shower with initial energy of 20 GeV (right).

GEANT4 Simulation

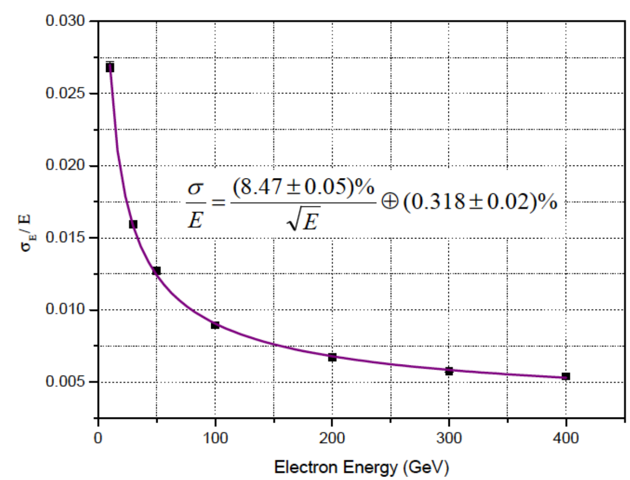
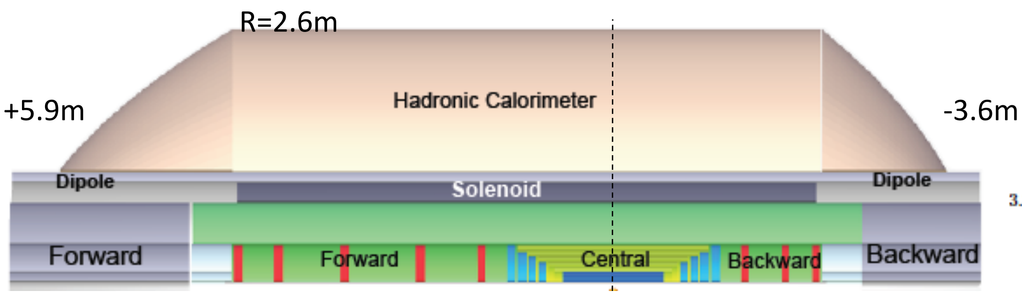


Figure 13.36: LAr accordion calorimeter energy resolution for electrons between 10 and 400 GeV.

Hadronic Tile Calorimeter

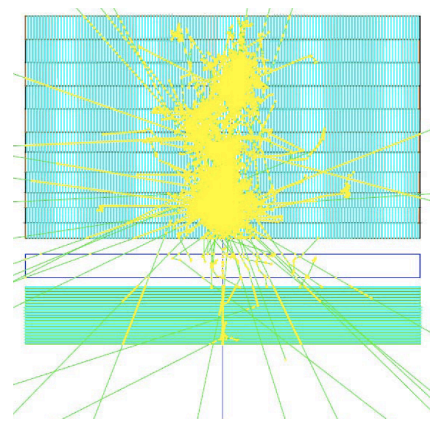
E-Calo Parts	FEC1	FEC2		EMC		BEC2	BEC1
Min. Inner radius R [cm]	3.1	21		48		21	3.1
Min. polar angle θ [°]	0.48	3.2		6.6/168.9		174.2	179.1
Max. pseudorapidity η	5.5	3.6		2.8/-2.3		-3.	-4.8
Outer radius [cm]	20	46		88		46	20
z-length [cm]	40	40		660		40	40
Volume [m^3]	0.3			11.3		0.3	
H-Calo Parts barrel			FHC4	HAC	BHC4		
Inner radius [cm]			120	120	120		
Outer radius [cm]			260	260	260		
z-length [cm]			217	580	157		
Volume [m^3]				121.2			
H-Calo Parts Inserts	FHC1	FHC2	FHC3		BHC3	BHC2	BHC1
Min. inner radius R [cm]	11	21	48		48	21	11
Min. polar angle θ [°]	0.43	2.9	6.6		169.	175.2	179.3
Max/min pseudorapidity η	5.6	3.7	2.9		-2.4	-3.2	-5.
Outer radius [cm]	20	46	88		88	46	20
z-length [cm]	177	177	177		117	117	117
Volume [m^3]		4.2				2.8	

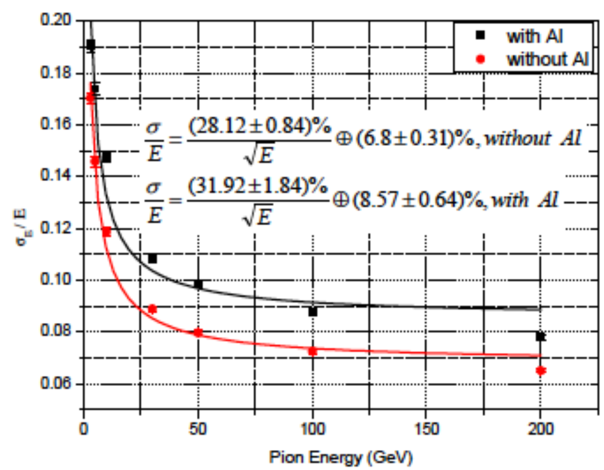
Table 13.6: Summary of calorimeter dimensions.
The electromagnetic barrel calorimeter is currently represented by the barrel part EMC (LAr-Pb module); the setup reaches $X_0 \approx 25$ radiation length) and the movable inserts forward FEC1, FEC2 (Si-W modules ($X_0 \approx 30$) and the backward BEC1, BEC2 (Si-Pb modules; $X_0 \approx 25$).
The hadronic barrel parts are represented by FHC4, HAC, BHC4 (forward, central and backward - Scintillator-Fe Tile modules; $\lambda_I \approx 8$ interaction length) and the movable inserts FHC1, FHC2, FHC3 (Si-W modules; $\lambda_I \approx 10$), BHC1, BHC2, BHC3 (Si-Cu modules, $\lambda_I \approx 8$) see Fig. 13.9.



Outside Coil: flux return

Modular. ATLAS experience.



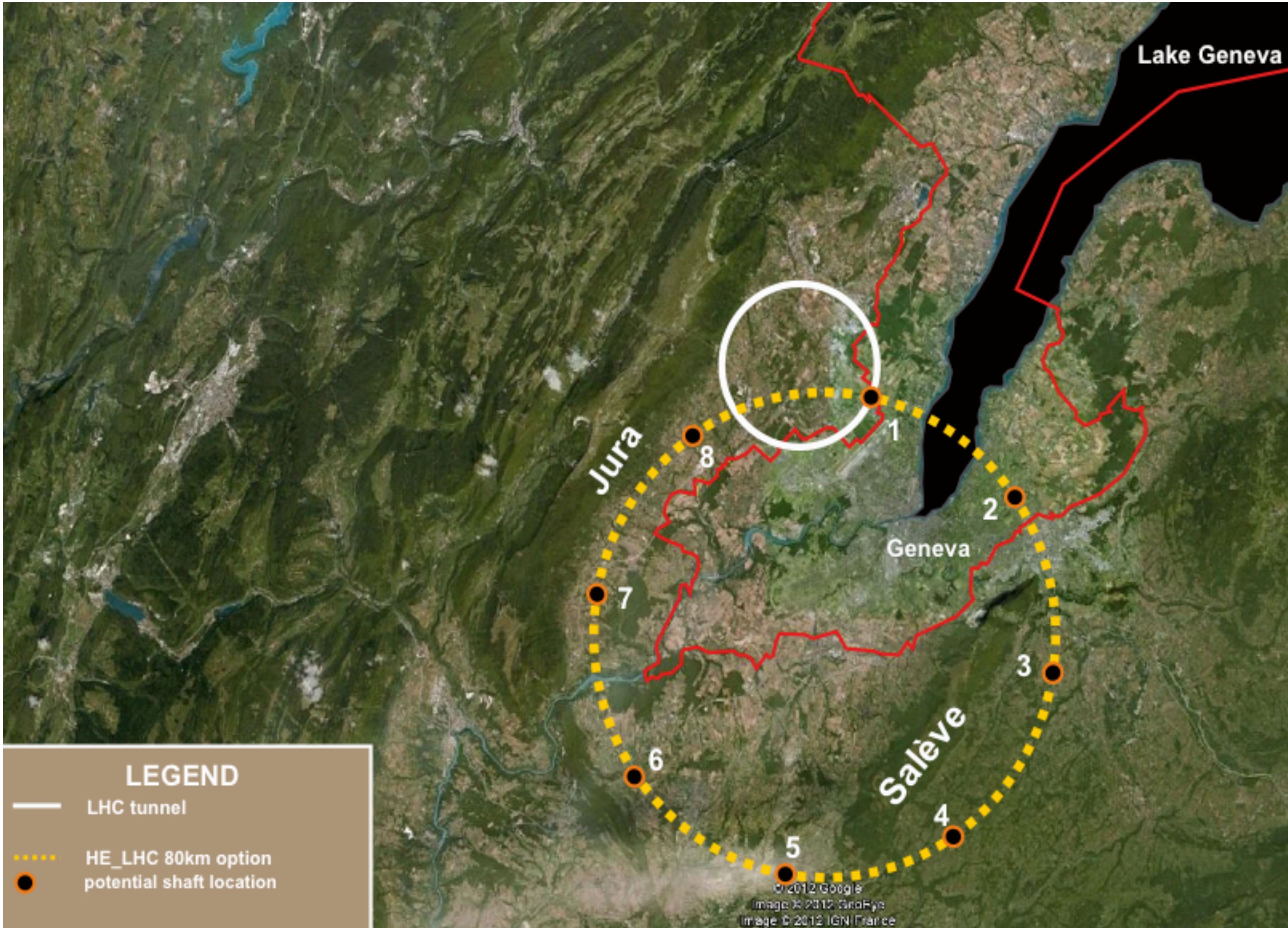


3.37: Accordion and Tile Calorimeter energy resolution for pions with and without 14cm Al block.

Combined GEANT4 Calorimeter Simulation

Schematic layouts for several potential future projects are shown on this Google Earth view of the Geneva region around CERN :

- CLIC (Compact Linear Collider) at collision energies of 500GeV and 3 TeV.
- ILC (International Linear Collider) at 500GeV energy
- The Linac-Ring Solution of LHeC (A new electron beam supplied via a 60 GeV



The LHeC is an upgrade of the LHC, to operate with it, and not the next world project

Summary

The LHeC has a unique physics programme (QCD, Higgs, BSM, HI).
It has a rich synergy with the LHC, SPL,ESS.. and links NP and PP.
The now published design report moved the dream of a TeV scale electron-hadron collider to the "real axis" (SB). It can be done. The LHeC is the only new collider for CERN which can live with the LHC.

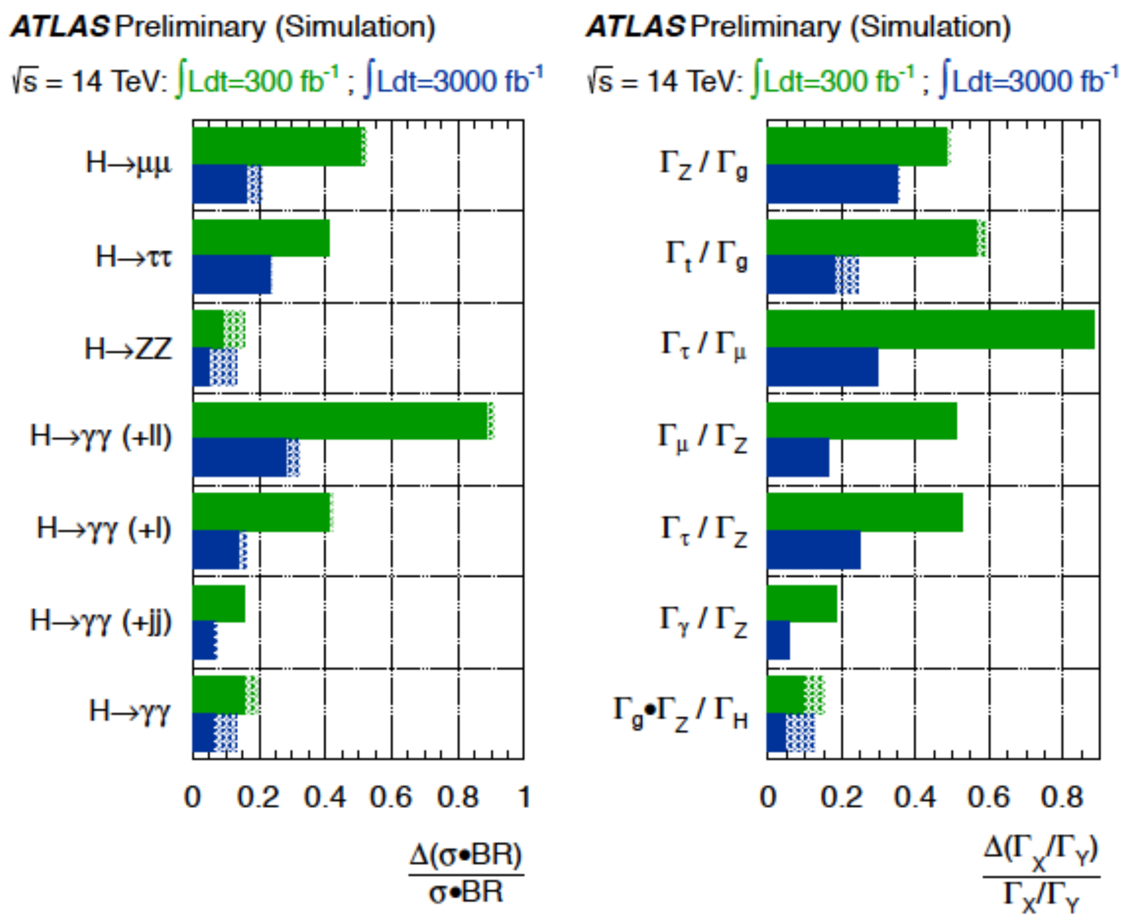
Many thanks to CERN, NuPECC, ECFA and to the expanding LHeC Group

↔ "Energy frontier,
Precision,
QCD,
QGP"
Tatsuya Nakada
Cracow 9/12 ESG

J.L.Abelleira Fernandez[16,23], C.Adolphsen[57], A.N.Akay[03], H.Aksakal[39], J.L.Albacete[52], S.Alekhin[17,54], P.Allport[24], V.Andreev[34], R.B.Appleby[14,30], E.Arikan[39], N.Armesto[53,a], G.Azuelos[33,64], M.Bai[37], D.Barber[14,17,24], J.Bartels[18], O.Behnke[17], J.Behr[17], A.S.Belyaev[15,56], I.Ben-Zvi[37], N.Bernard[25], S.Bertolucci[16], S.Bettoni[16], S.Biswal[41], J.Blümlein[17], H.Böttcher[17], A.Bogacz[36], C.Bracco[16], G.Brandt[44], H.Braun[65], S.Brodsky[57,b], O.Brüning[16], E.Bulyak[12], A.Buniatyan[17], H.Burkhardt[16], I.T.Cakir[02], O.Cakir[01], R.Calaga[16], A.Caldwell[70], V.Cetinkaya[01], V.Chekelian[70], E.Ciapala[16], R.Ciftci[01], A.K.Ciftci[01], B.A.Cole[38], J.C.Collins[48], O.Dadoun[42], J.Dainton[24], A.De.Roeck[16], D.d'Enterria[16], P.DiNezza[72], A.Dudarev[16], A.Eide[60], R.Enberg[63], E.Eroglu[62], K.J.Eskola[21], L.Favart[08], M.Fitterer[16], S.Forte[32], A.Gaddi[16], P.Gambino[59], H.García Morales[16], T.Gehrmann[69], P.Gladkikh[12], C.Glasman[28], A.Glazov[17], R.Godbole[35], B.Goddard[16], T.Greenshaw[24], A.Guffanti[13], V.Guzey[19,36], C.Gwenlan[44], T.Han[50], Y.Hao[37], F.Haug[16], W.Herr[16], A.Hervé[27], B.J.Holzer[16], M.Ishitsuka[58], M.Jacquet[42], B.Jeanneret[16], E.Jensen[16], J.M.Jimenez[16], J.M.Jowett[16], H.Jung[17], H.Karadeniz[02], D.Kayran[37], A.Kilic[62], K.Kimura[58], M.Klein[24], U.Klein[24], T.Kluge[24], F.Kocak[62], M.Korostelev[24], A.Kosmicki[16], P.Kostka[17], H.Kowalski[17], G.Kramer[18], D.Kuchler[16], M.Kuze[58], T.Lappi[21,c], P.Laycock[24], E.Levichev[40], S.Levonian[17], V.N.Litvinenko[37], A.Lombardi[16], J.Maeda[58], C.Marquet[16], B.Mellado[27], K.H.Mess[16], A.Milanese[16], S.Moch[17], I.I.Morozov[40], Y.Muttoni[16], S.Myers[16], S.Nandi[55], Z.Nergiz[39], P.R.Newman[06], T.Omori[61], J.Osborne[16], E.Paoloni[49], Y.Papaphilippou[16], C.Pascaud[42], H.Paukkunen[53], E.Perez[16], T.Pieloni[23], E.Pilicer[62], B.Pire[45], R.Placakyte[17], A.Polini[07], V.Ptitsyn[37], Y.Pupkov[40], V.Radescu[17], S.Raychaudhuri[35], L.Rinolfi[16], E.Rizvi[71], R.Rohini[35], J.Rojo[16,31], S.Russenschuck[16], M.Sahin[03], C.A.Salgado[53,a], K.Sampei[58], R.Sassot[09], E.Sauvan[04], U.Schneekloth[17], T.Schörner-Sadenius[17], D.Schulte[16], A.Senol[22], A.Seryi[44], P.Sievers[16], A.N.Skrinsky[40], W.Smith[27], H.Spiesberger[29], A.M.Stasto[48,d], M.Strikman[48], M.Sullivan[57], S.Sultansoy[03,e], Y.P.Sun[57], B.Surrow[11], L.Szymanowski[66,f], P.Taels[05], I.Tapan[62], T.Tasci[22], E.Tassi[10], H.Ten.Kate[16], J.Terron[28], H.Thiesen[16], L.Thompson[14,30], P.Thompson[06], K.Tokushuku[61], R.Tomás García[16], D.Tommasini[16], D.Trbojevic[37], N.Tsoupas[37], J.Tuckmantel[16], S.Turkoz[01], T.N.Trinh[47], K.Tywoniuk[26], G.Unel[20], J.Urakawa[61], P.VanMechelen[05], A.Variola[52], R.Veness[16], A.Vivoli[16], P.Vobly[40], J.Wagner[66], R.Wallny[68], S.Wallon[43,46,f], G.Watt[16], C.Weiss[36], U.A.Wiedemann[16], U.Wienands[57], F.Willeke[37], B.-W.Xiao[48], V.Yakimenko[37], A.F.Zarnecki[67], Z.Zhang[42], F.Zimmermann[16], R.Zlebcik[51], F.Zomer[42]

Backup slides

ATLAS Higgs projections



ATL-PHYS-PUB-2012-001

Updated in October 2012

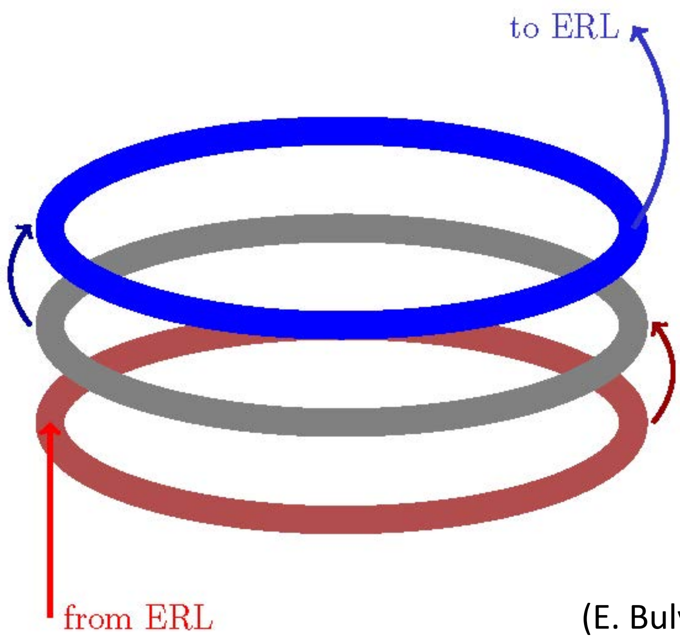
Precision Measurements

source of uncertainty	error on the source or cross section
scattered electron energy scale $\Delta E'_e/E'_e$	0.1 %
scattered electron polar angle	0.1 mrad
hadronic energy scale $\Delta E_h/E_h$	0.5 %
calorimeter noise (only $y < 0.01$)	1-3 %
radiative corrections	0.5%
photoproduction background (only $y > 0.5$)	1 %
global efficiency error	0.7 %

Table 2: Assumptions used in the simulation of the NC cross sections on the size of uncertainties from various sources. These assumptions correspond to typical best values achieved in the H1 experiment. The total cross section error due to these uncertainties, e.g. for $Q^2 = 100\,\mathrm{GeV}^2$, is about 1.2, 0.7 and 2.0 % for $y = 0.84,\ 0.1,\ 0.004$.

linac e^+ source options

- recycle e+ together with energy, multiple use,
  damping ring in SPS tunnel w $\tau_\perp$~2 ms (D. Schulte) (Y. Papaphilippou)
- Compton ring, Compton ERL, coherent pair production, or undulator for high-energy beam
- 3-ring transformer & cooling scheme (H. Braun, E. Bulyak, T. Omori, V. Yakimenko)



extraction ring (*N* turns)

fast cooling ring (*N* turns)

accumulator ring (*N* turns)

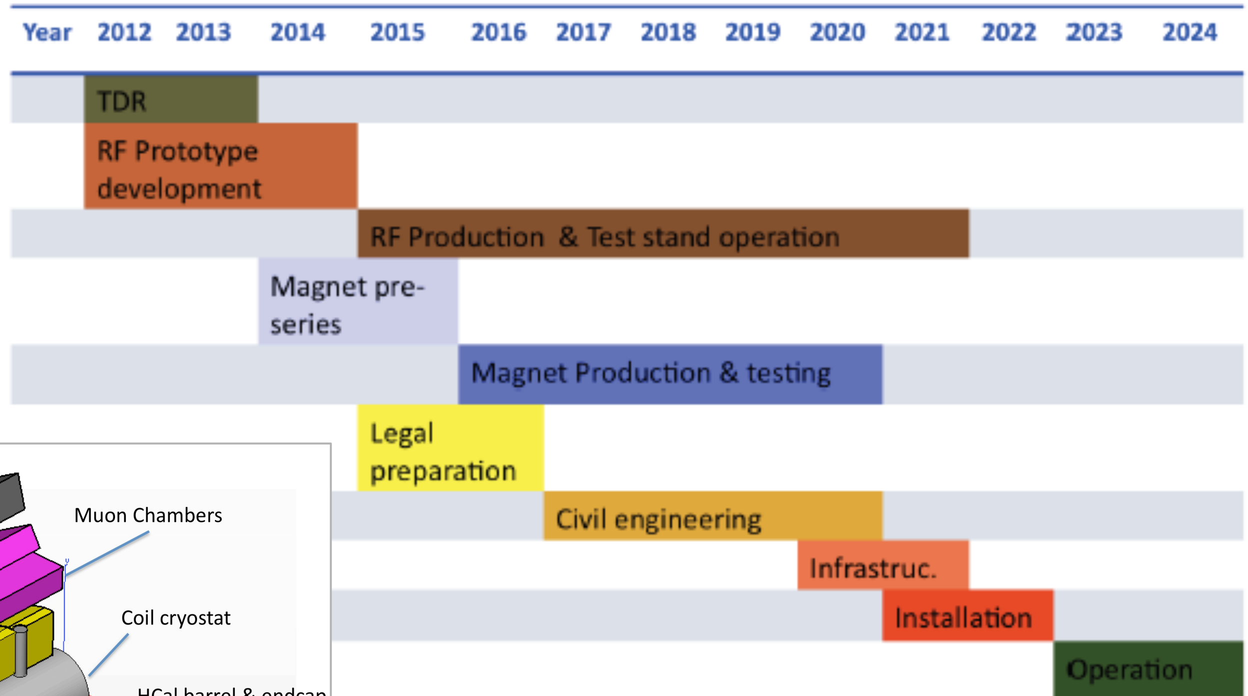
(E. Bulyak)

ERL Test Facilities

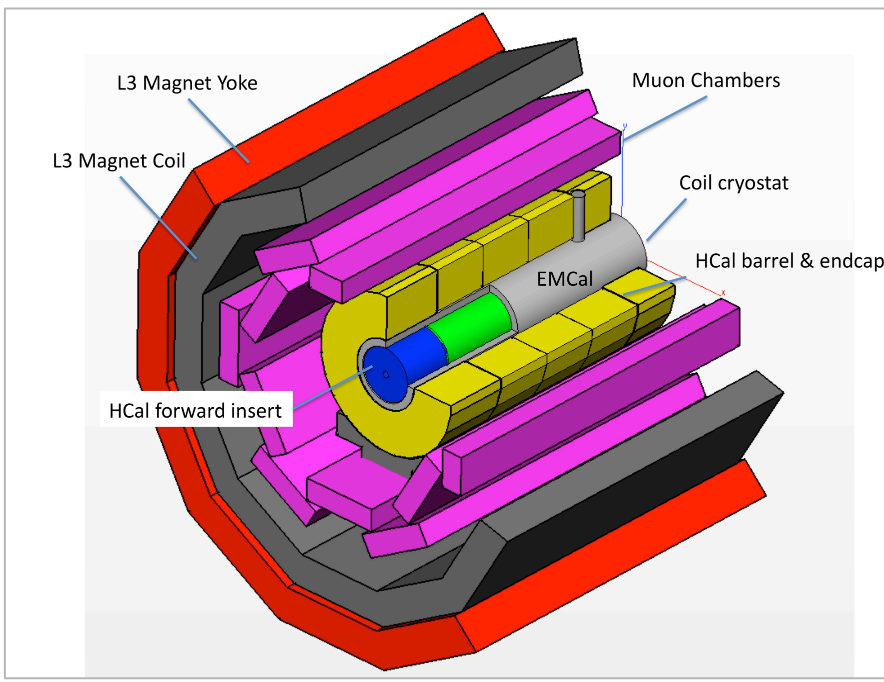
IHEP ERL-TF	HZB BERLinPro	BINP	Peking FEL	BNL ERL-TF	KEK cERL	Daresbury ALICE	JAERI	CERN ERL-TF
35 MeV	100 MeV	11-40 MeV	30 MeV	20 MeV	245 MeV	10 MeV	17 MeV	300 MeV
1.3 GHz 9 cell	1.3 GHz	180 MHz	1.3 GHz 9-cell	704 MHz 5-cell	1.3 GHz 9-cell	1.3 GHz 9-cell	500 MHz	721 MHz 2x4x5 cell
10 mA	100 mA	30 mA	50 mA	50-500 mA	10-100 mA	13 µA	5-40 mA	2-6 mA
60 pC	10-77 pC	0.9-2.2 nC	60 pC	0.5-5 nC	77 pC	80 pC	400 pC	500 pC
1 pass	1-2 pass	4 passes	1 pass	1 pass	2 passes	1 pass	1 pass	2 passes
under construction	planned / construction	operating		under construction	under construction	operating	operating	first ideas

E.Jensen

CDR - Time Schedule*)



Detector installation study for IP2, reuse of L3 magnet as support for LHeC. Estimated 30 months



LHeC is to operate synchronous with HL-LHC

LS3 requires 2-3 years for ATLAS+. It is the one extended time period, which will allow installation and connection of LHeC

*) LS3 → schedule most likely shifted by +2 years

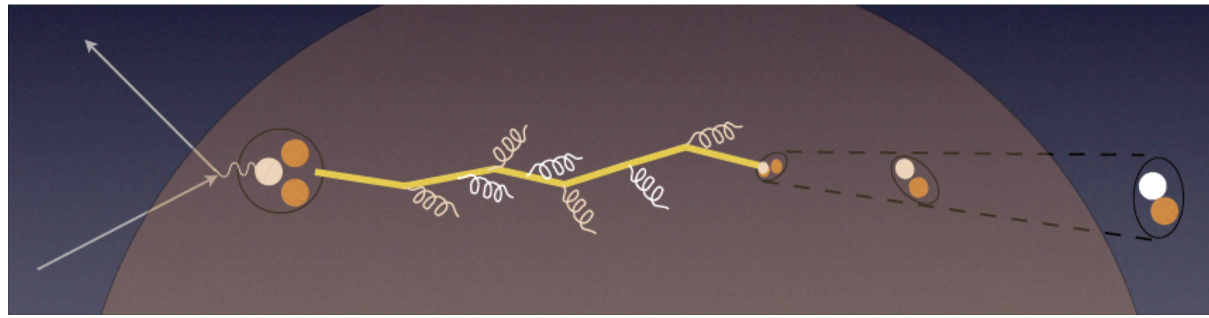
In-medium Hadronisation

The study of particle production in eA (fragmentation functions and hadrochemistry) allows the study of the space-time picture of hadronisation (the final phase of QGP).

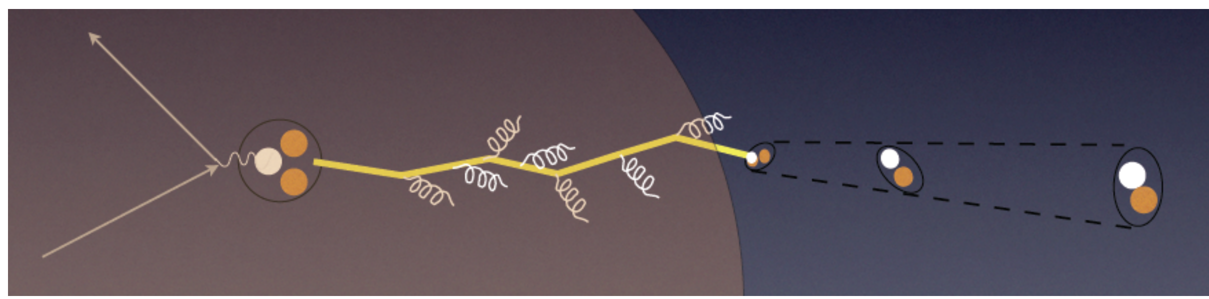
Low energy (ν): need of hadronization inside.

Parton propagation: pt broadening

Hadron formation: attenuation



High energy (ν): partonic evolution altered in the nuclear medium.



W.Brooks, Divonne09

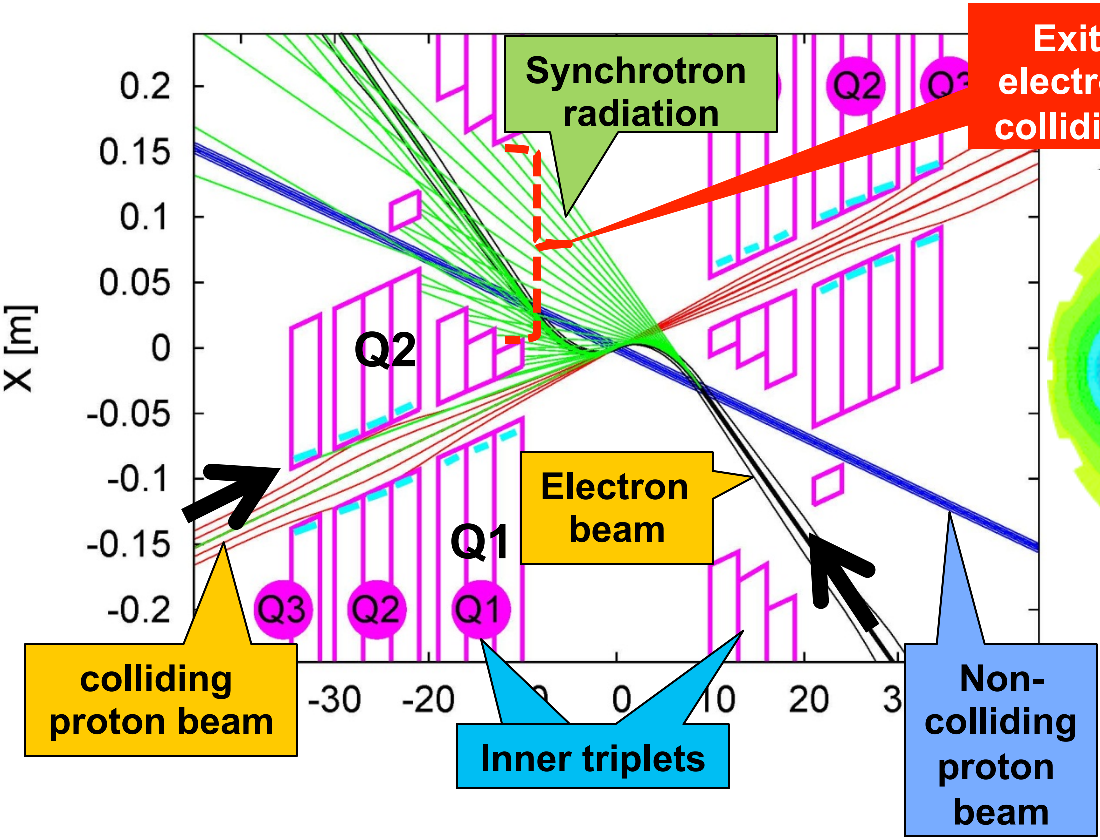
LHeC :

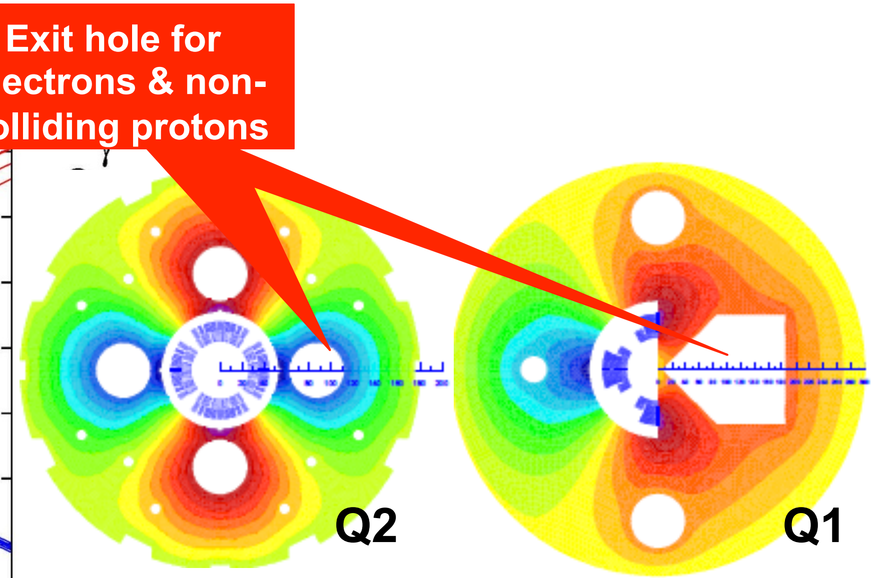
+ study the transition from small to high energies in much extended range wrt. fixed target data

+ testing the energy loss mechanism crucial for understanding of the medium produced in HIC

+ detailed study of heavy quark hadronisation …

LR LHeC IR layout & SC IR quadrupoles





Nb_3Sn (HFM46): 5700 A, 175 T/m, 4.7 T at 82% on LL (4 layers), 4.2 K	Nb_3Sn (HFM46): 8600 A, 311 T/m, at 83% LL, 4.2 K
46 mm (half) ap., 63 mm beam sep.	23 mm ap.. 87 mm beam sep.
0.5 T, 25 T/m	0.09 T, 9 T/m

High-gradient SC IR quadrupoles based on Nb_3Sn for colliding proton beam with common low-field

As shown by F. Zimmermann at Chamonix12

http://cern.ch/lhec

LHeC Study Group

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About 180 Experimentalists and Theorists from 60 Institutes
Tentative **list of those who contributed to the CDR**

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UK Accelerator Engagement

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Topics of joint interest and priority
Meeting ASTEC/CI 5.9.12 at CERN

Electron source for TF

Design of IR, Optics for p beams, synrad tracking

Test facility design (OPAC fellow)

Sc cavity design, coupler, HOM damper, tuner..

Instrumentation for TF…

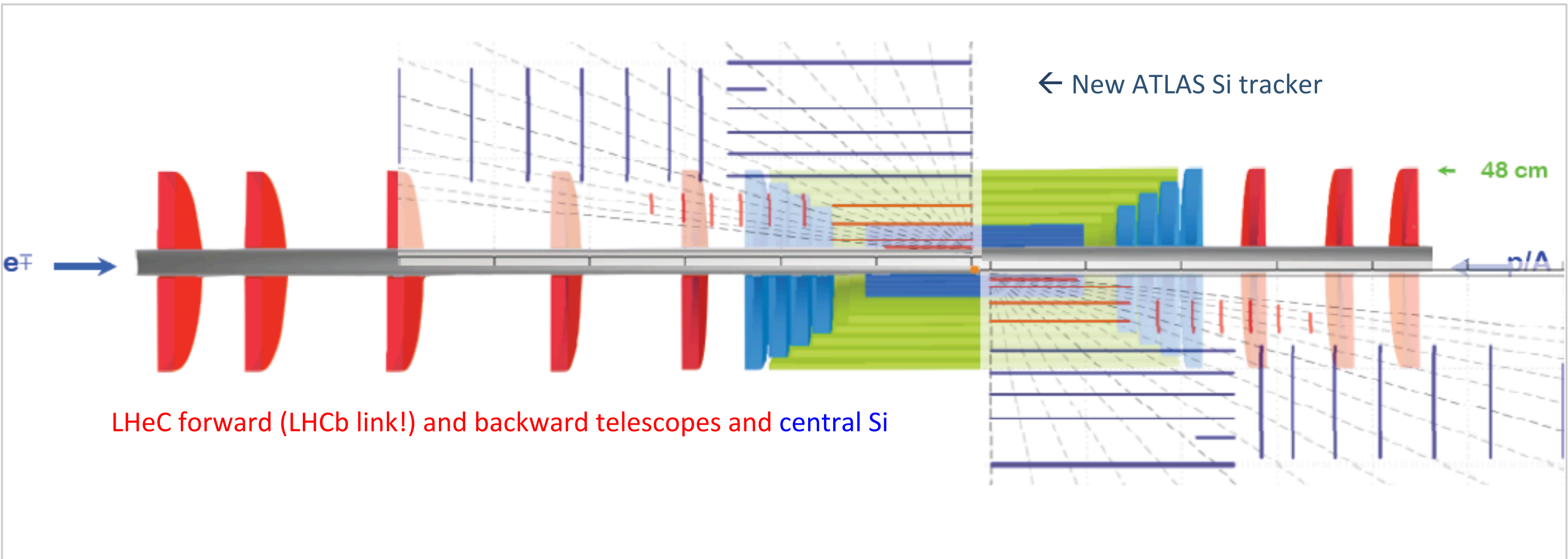
With only somewhat reduced priority: beam dynamics, positron source, magnets ..

Preparation of MoU, with view also to other partners

The LHeC represents a unique opportunity for the Daresbury Campus (ASTEC and CI), but also for the wider UK accelerator community (A.Seryi co-author of CDR) to be at the forefront of accelerator developments, building on their unique expertise, a very welcome strong expression of interest, and its strong links to Universities, CERN and industry.

ATLAS and LHeC Silicon Trackers

Tentative designs as of 2012



LHeC: no pile-up, less radiation, smaller momenta apart from forward region