

DRAFT 1.0
Geneva, September 3, 2011
CERN report
ECFA report
NuPECC report
LHeC-Note-2011-003 GEN



A Large Hadron Electron Collider at CERN

Report on the Physics and Design
Concepts for Machine and Detector

LHeC Study Group

THIS IS THE VERSION FOR REFEREEING, NOT FOR DISTRIBUTION



IPAC, San Sebastian, 7.9.11 - Dedicated to Gus Weber (1925-2011)

The LHeC Project at CERN

Design Concepts for the LHeC [WEODA03]

Max Klein (U.Liverpool+CERN)

for the LHeC Study Group

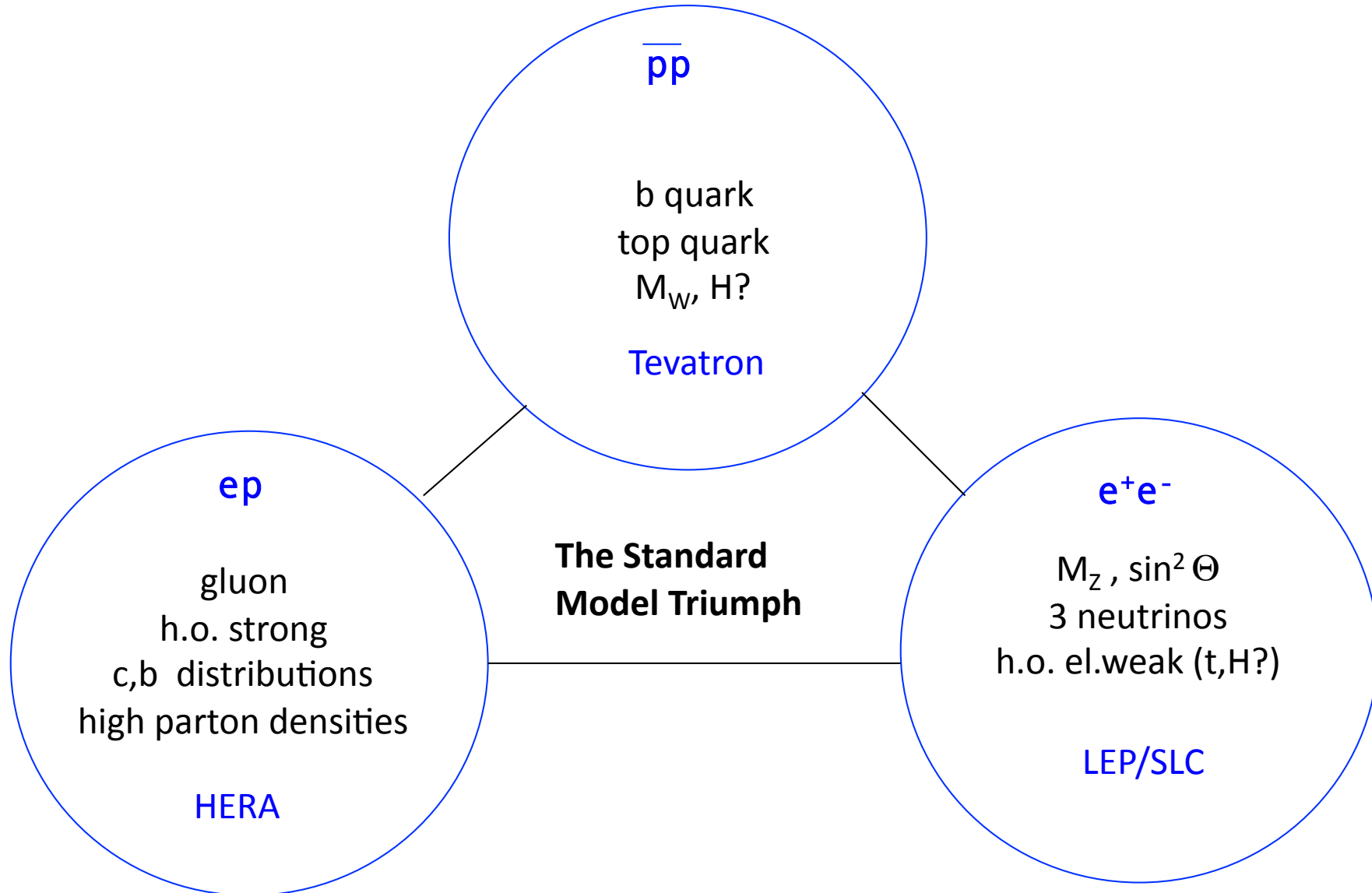


TUPC017

Civil Engineering Studies for Major Projects after LHC

Considerations
Physics
Accelerator
Detector
Time Schedule

The Fermi Scale [1985-2010]



Two Options

$$L = \frac{N_p \gamma}{4\pi \epsilon \epsilon_{pn}} \cdot \frac{I_e}{\sqrt{\beta_{px} \beta_{py}}}$$

$$N_p = 1.7 \cdot 10^{11}, \epsilon_p = 3.8 \mu m, \beta_{px(y)} = 1.8(0.5)m, \gamma = \frac{E_p}{M_p}$$

$$L = 8.2 \cdot 10^{32} \text{ cm}^{-2} \text{ s}^{-1} \cdot \frac{N_p 10^{-11}}{1.7} \cdot \frac{m}{\sqrt{\beta_{px} \beta_{py}}} \cdot \frac{I_e}{50 \text{ mA}}$$

$$I_e = 0.35 \text{ mA} \cdot P[\text{MW}] \cdot (100/E_e[\text{GeV}])^4$$

Ring-Ring

Power Limit of 100 MW wall plug
 “ultimate” LHC proton beam
60 GeV e[±] beam

$$\rightarrow L = 2 \cdot 10^{33} \text{ cm}^{-2} \text{ s}^{-1} \rightarrow O(100) \text{ fb}^{-1}$$

LINAC Ring

Pulsed, **60 GeV**: $\sim 10^{32}$

High luminosity:

Energy recovery: $P = P_0 / (1 - \eta)$

$\beta^* = 0.1 \text{ m}$

[5 times smaller than LHC by
 reduced I*, only one p squeezed
 and IR quads as for HL-LHC]

$$L = 10^{33} \text{ cm}^{-2} \text{ s}^{-1} \rightarrow O(100) \text{ fb}^{-1}$$

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

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

$$L = 8 \cdot 10^{31} \text{ cm}^{-2} \text{ s}^{-1} \cdot \frac{N_p 10^{-11}}{1.7} \cdot \frac{0.2}{\beta^* / \text{m}} \cdot \frac{I_e / \text{mA}}{1}$$

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

Synchronous ep and pp operation (small ep tuneshifts)

The LHC p beams provide 100 times HERA’s luminosity

e Ring- p/A Ring

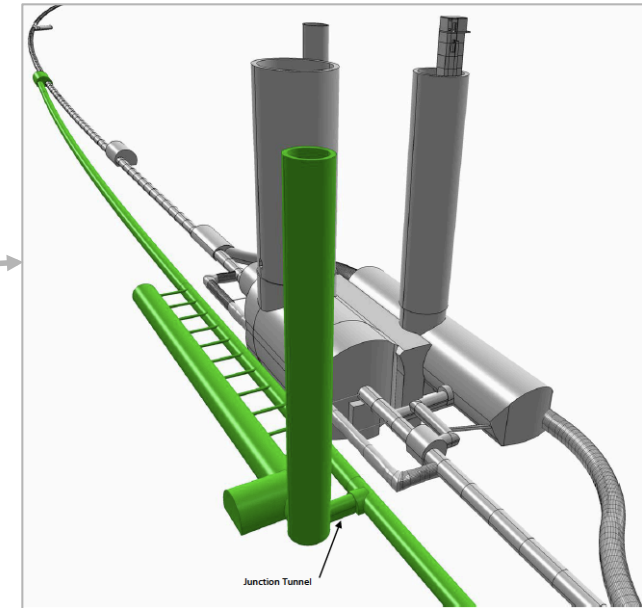
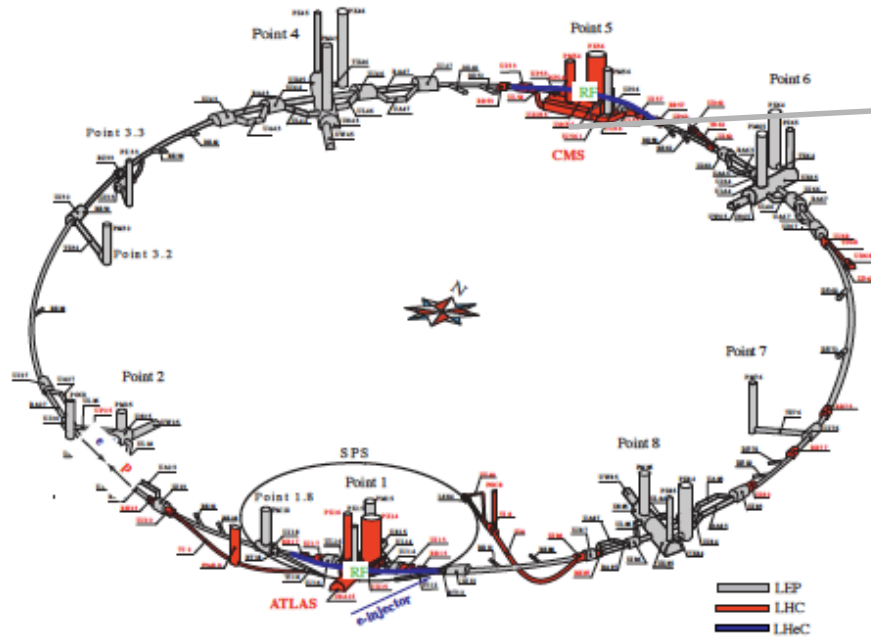
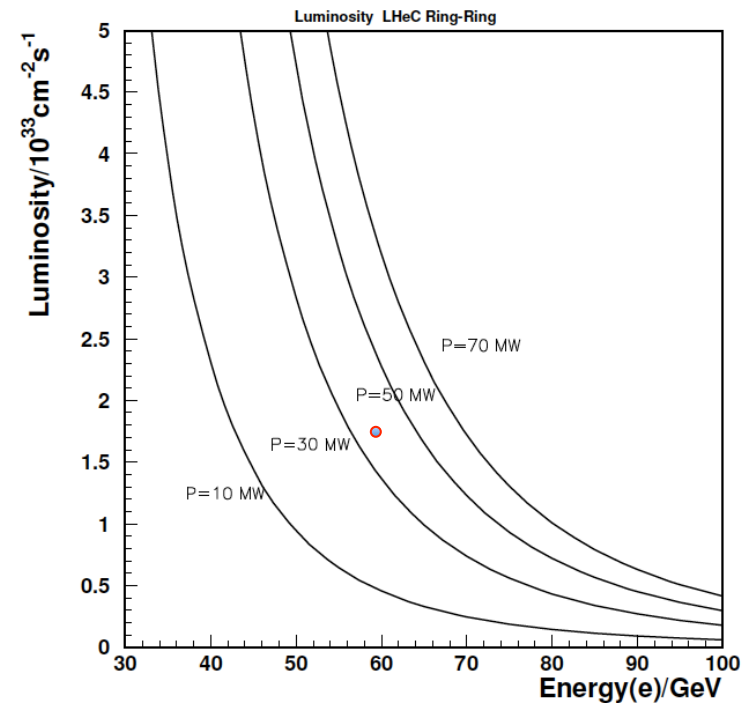
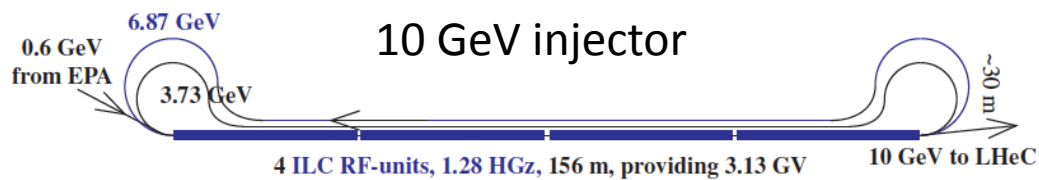
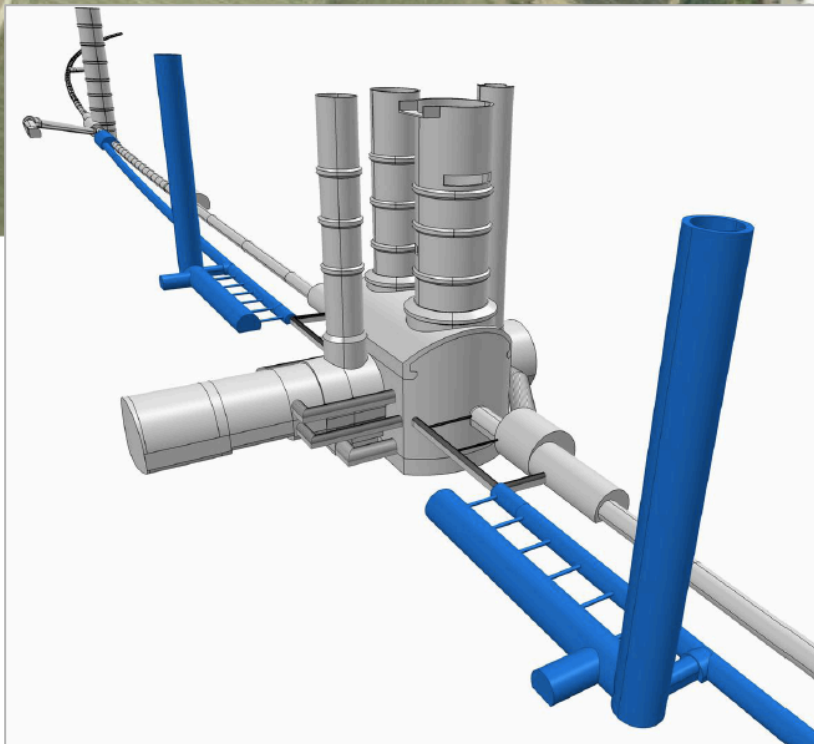
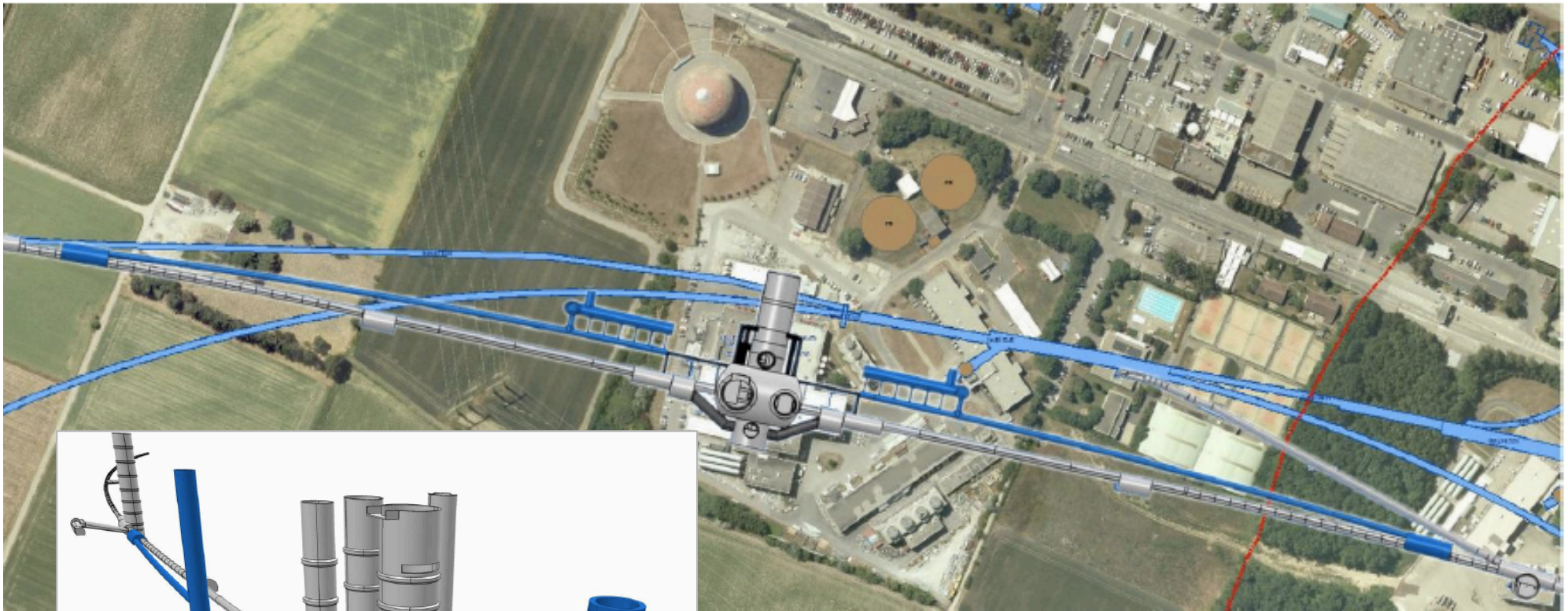


Figure 1: Schematic Layout of the LHC (grey/red) with the bypasses of CMS and ATLAS for the ring electron beam (blue) in the RR version. The e injector is a 10 GeV superconducting linac in triple racetrack configuration which is considered to reach the ring via the bypass around ATLAS.

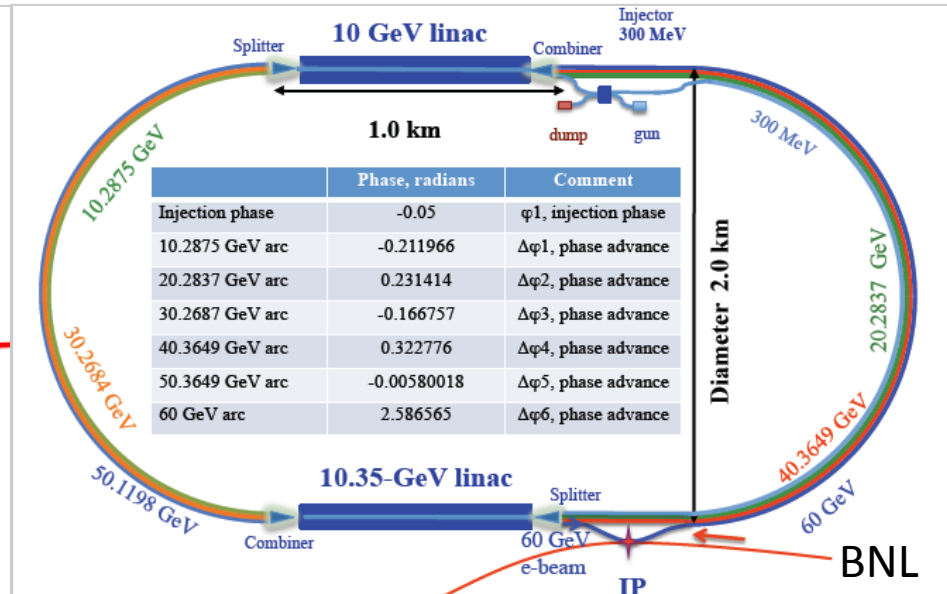
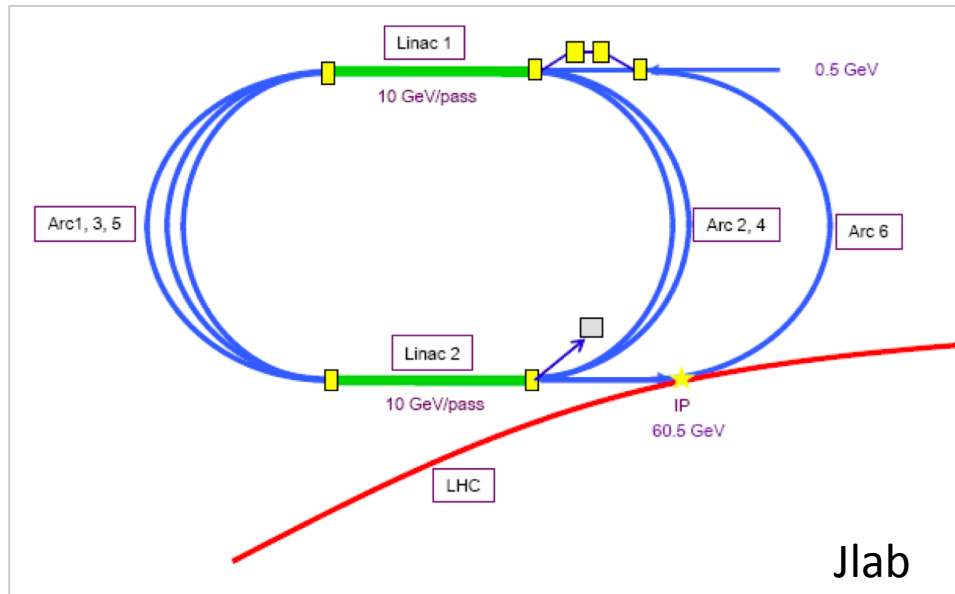
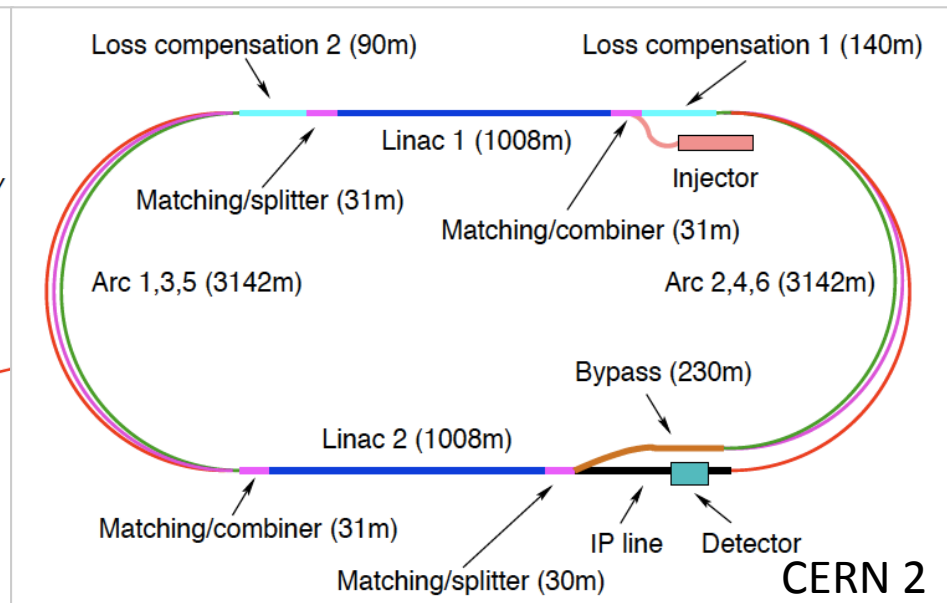
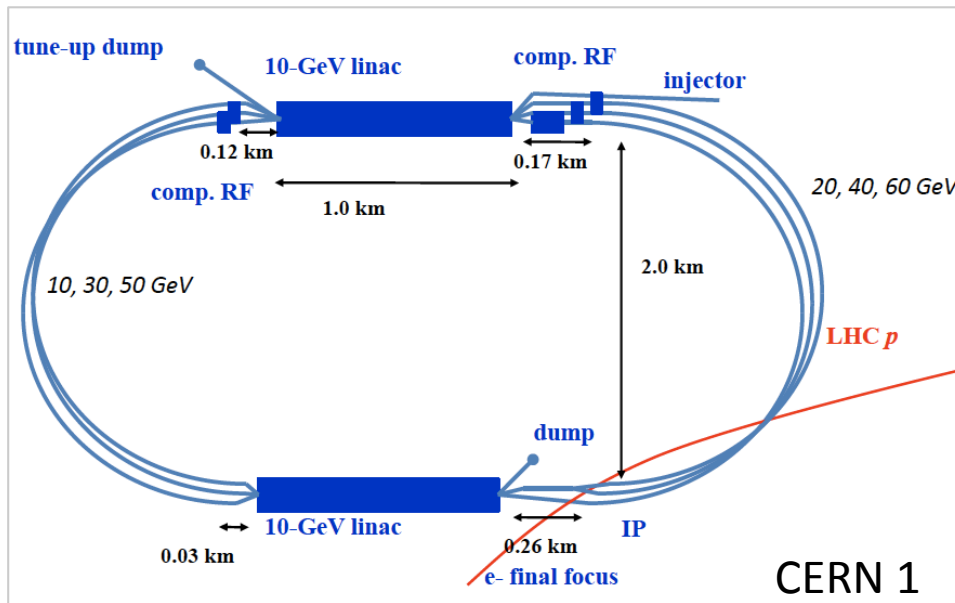


Bypassing ATLAS



For the CDR the bypass concepts were decided to be confined to ATLAS and CMS

60 GeV Energy Recovery Linac

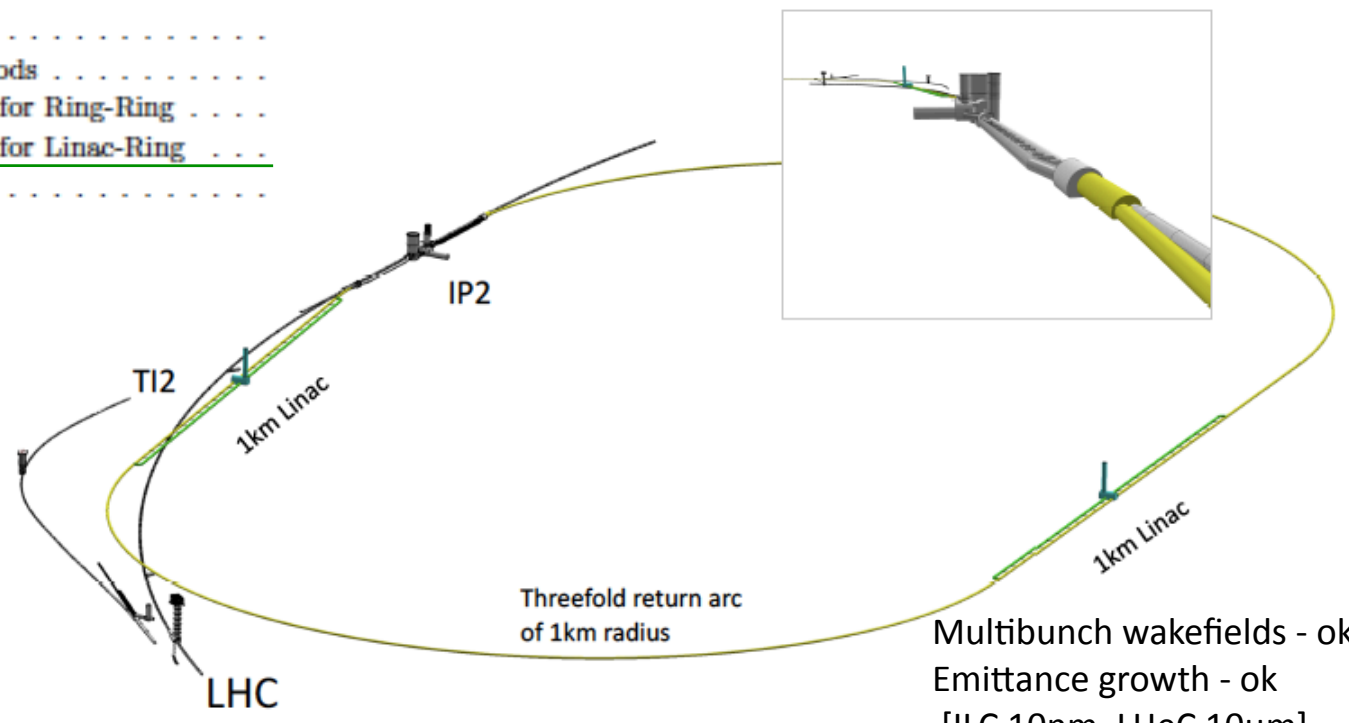


Two 10 GeV energy recovery Linacs, 3 returns, 720 MHz cavities

10 Civil Engineering and Services

- 10.1 Overview
- 10.2 Location, Geology and Construction Methods
 - 10.2.1 Location
 - 10.2.2 Land Features
 - 10.2.3 Geology
 - 10.2.4 Site Development
 - 10.2.5 Construction Methods
- 10.3 Civil Engineering Layouts for Ring-Ring
- 10.4 Civil Engineering Layouts for Linac-Ring
- 10.5 Summary

$$U_{\text{LHeC}} = U_{\text{LHC}}/3 : 1.5 \times \text{HERA}$$

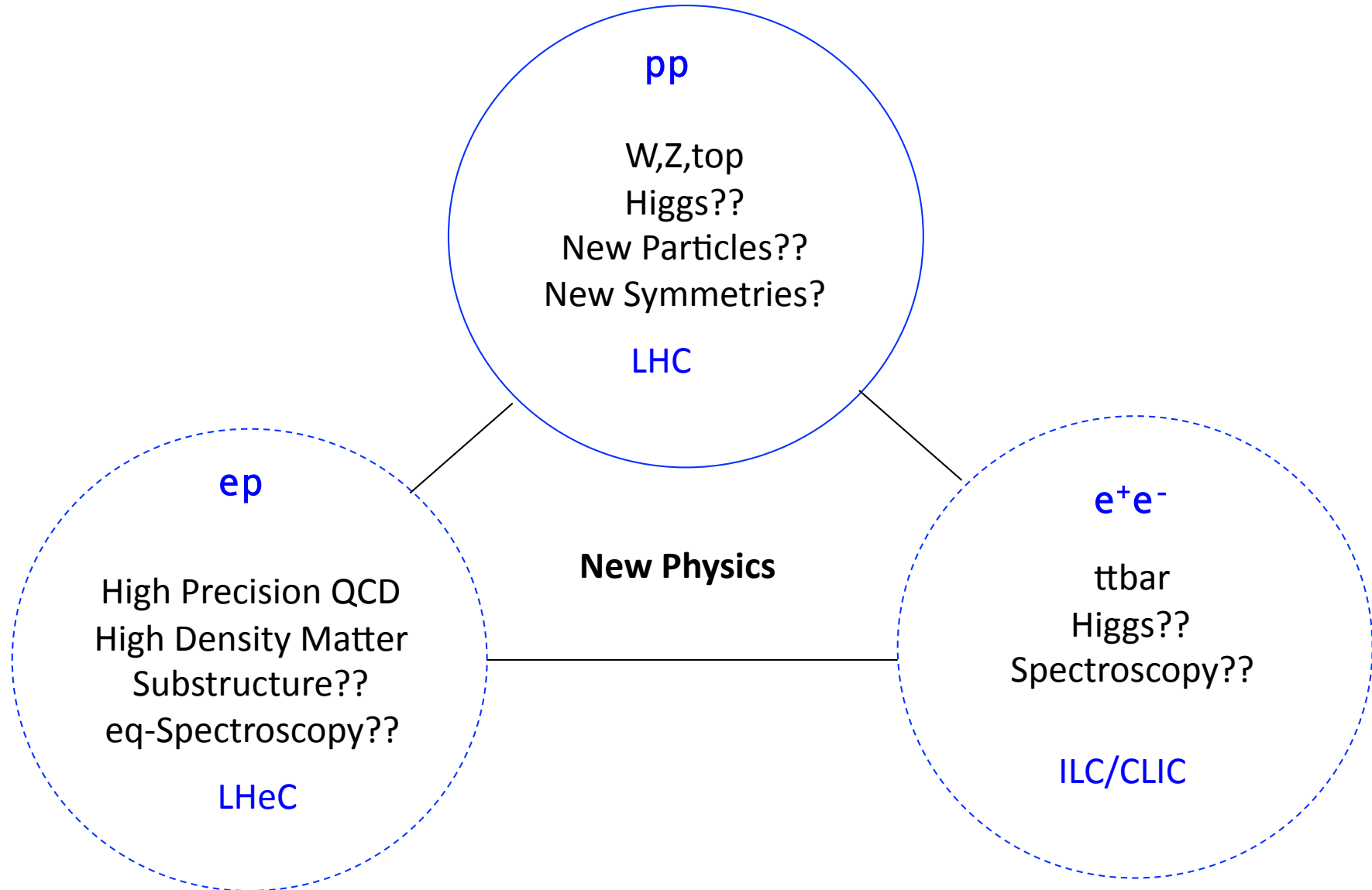


944 cavities
 59 cryo modules per linac
 721 MHz
 20 MV/m CW

Multibunch wakefields - ok
 Emittance growth - ok
 [ILC 10nm, LHeC 10 μ m]
 36 σ separation at 3.5m - ok
 Fast ion instability - probably ok
 with clearing gap (1/3)

Figure 10.11: View on the ERL placed inside the LHC ring and tangential to IP2. TI2 is the injection line into the LHC. The insert shows the view towards IP2, which currently houses the ALICE experiment, from the direction of the protons colliding with the electron beam incoming from behind.

The TeV Scale [2010-2035..]



I Introduction

1 Lepton-Hadron Scattering

- 1.1 Development and Contributions . . .
- 1.2 Open Questions

2 Design Considerations

- 2.1 DIS and Particle Physics
- 2.2 Synchronous pp and ep operation
- 2.3 Choice of Electron Beam Energy
- 2.4 Detector Constraints
- 2.5 Two Electron Beam Options
- 2.6 Luminosity and Power

Default energy: $E_e = 60 \text{ GeV}$

So far LQ limits $\sim 0.5 \text{ TeV}$

$$Q^2 \gg M_Z^2$$

Gluon saturation at $x \sim 10^{-5}$
in the DIS region $Q^2 > M_p^2$

Synchrotron radiation $\sim E_e^4$

Cost and Luminosity:

$$L = 100 L_{\text{HERA}}, Q^2 \text{ and } 1/x = 20 \text{ HERA}$$

[LHC in 2014 may affect that choice.]

Why differ leptons from quarks? (Leptopartons)

Higgs? (production via gg (SM), bb(MSSM), quartic selfcoupling)

Mapping of the Gluon Field (next slide)

Non pQCD – 10 dim string theory (BFKL, odderon)

Ultimate precision of α_s and $\sin^2\Theta$ (0.1%, μ dependence)

Determination of ALL quark distributions

Confinement?? (Diffraction)

Generalised parton distributions (DVCS)

DGLAP \rightarrow BFKL? (saturation of gluon density)

Structure of the neutron (no eD at HERA)

Partons in nuclei (4 orders of magnitude extended range)

New singly produced states (e^*)

Unfolding of Contact interaction effects (up to 50 TeV)

...

The LHeC has an outstanding, unique programme, which is complementary to the LHC. It requires:

High energy, high luminosity, polarised e^\pm , p, D, A.

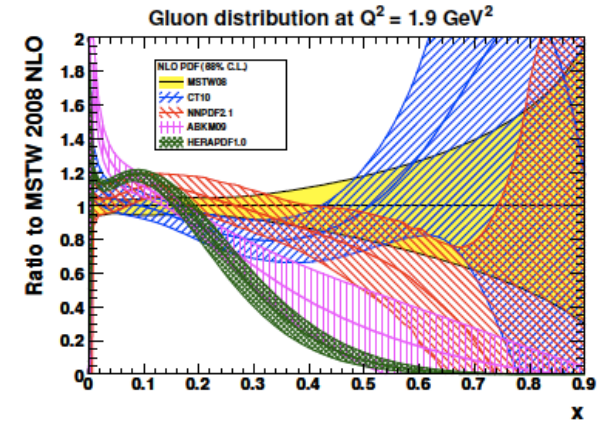
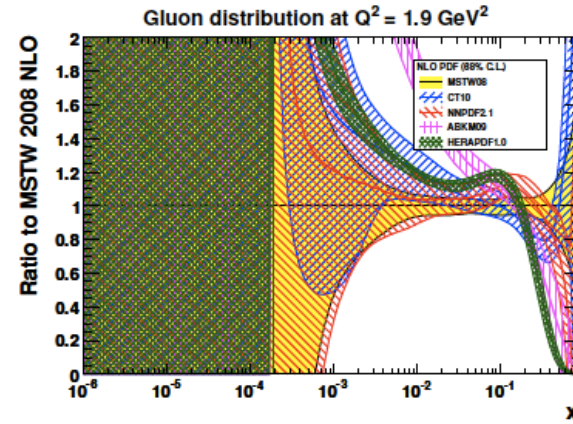
The LHC provides all of that if complemented by an intense, high energy electron beam. This determines the schedule, and the site is no question.

II Physics

4 Precision QCD and Electroweak Physics

- 4.1 Inclusive Deep Inelastic Scattering
 - 4.1.1 Cross Sections and Structure Functions
 - 4.1.2 Neutral Current
 - 4.1.3 Charged Current
 - 4.1.4 Cross Section Simulation and Uncertainties
 - 4.1.5 Longitudinal Structure Function F_L
- 4.2 Determination of Parton Distributions
 - 4.2.1 QCD Fit Ansatz
 - 4.2.2 Valence Quarks
 - 4.2.3 Strange Quarks
 - 4.2.4 Top Quarks
- 4.3 Gluon Distribution
- 4.4 Prospects to Measure the Strong Coupling Constant
 - 4.4.1 Status of the DIS Measurements of α_s
 - 4.4.2 Simulation of α_s Determination
- 4.5 Electron-Deuteron Scattering
- 4.6 Charm and Beauty production
 - 4.6.1 Introduction and overview of expected highlights
 - 4.6.2 Total production cross sections for charm, beauty and top quarks
 - 4.6.3 Charm and Beauty production in DIS
 - 4.6.4 Intrinsic Heavy Flavour
 - 4.6.5 D^* meson photoproduction study
- 4.7 High p_t jets
 - 4.7.1 Jets in ep
 - 4.7.2 Jets in γA
- 4.8 Total photoproduction cross section
- 4.9 Electroweak physics
 - 4.9.1 The context
 - 4.9.2 Light Quark Weak Neutral Current Couplings
 - 4.9.3 Determination of the Weak Mixing Angle

now



then

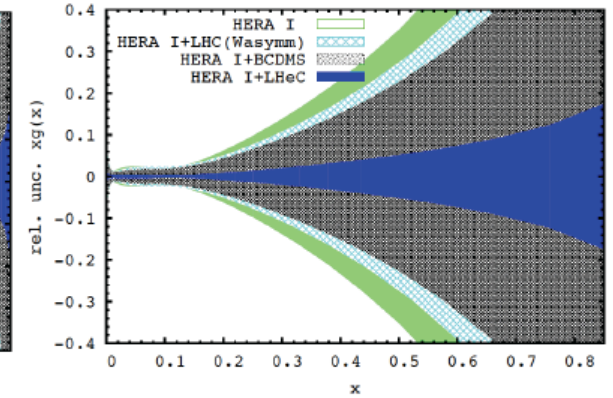
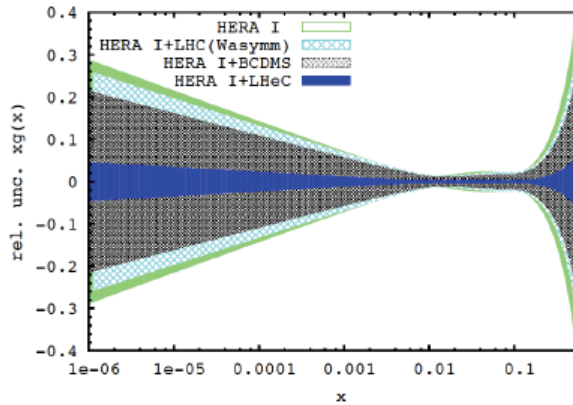


Figure 4.17: Relative uncertainty of the gluon distribution at $Q^2 = 1.9 \text{ GeV}^2$, as resulting from an NLO QCD fit to HERA (I) alone (green, outer), HERA and BCDMS (crossed), HERA and LHC (light blue, crossed) and the LHeC added (blue, dark). Left: logarithmic x , right: linear x .

5 New Physics at Large Scales

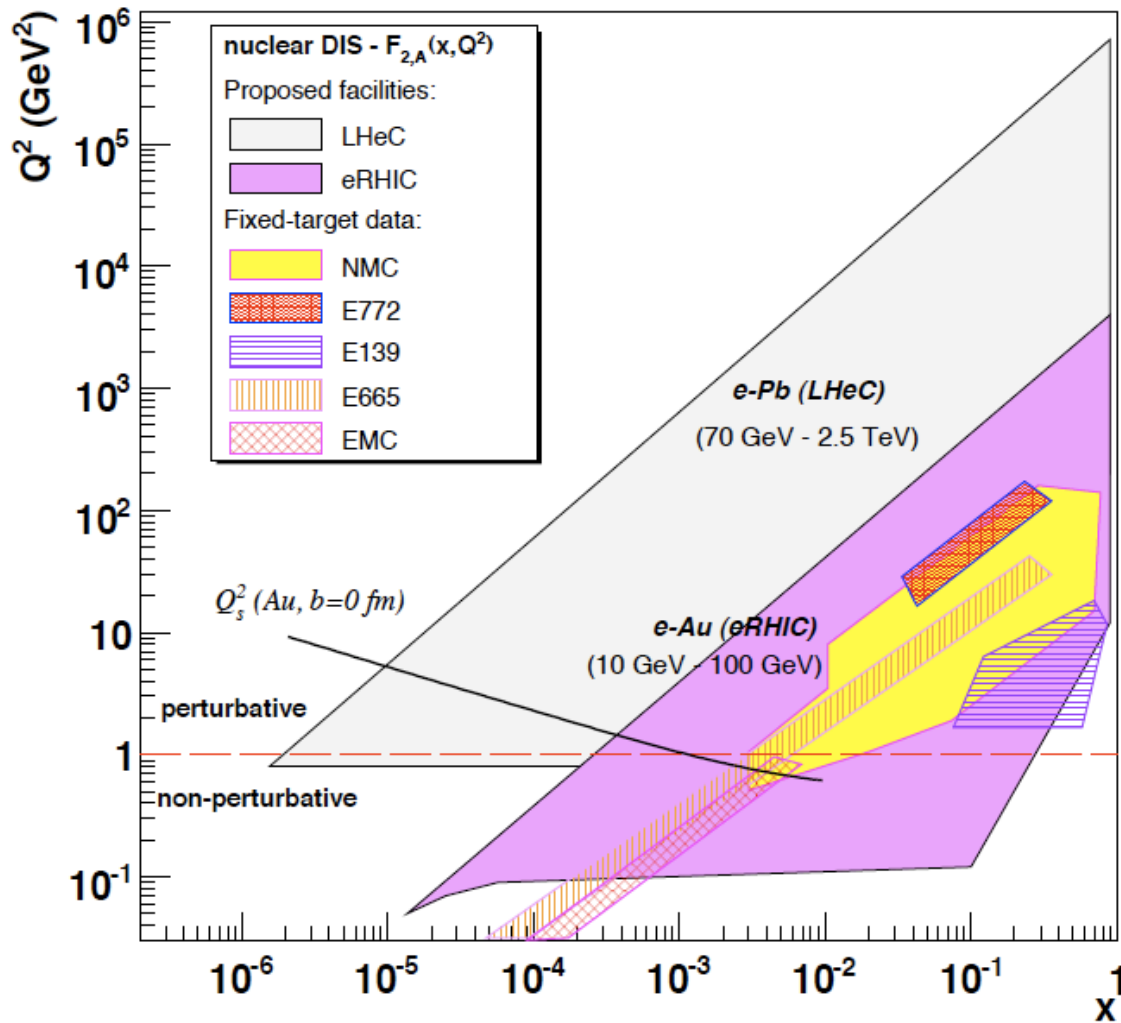
- 5.1 New Physics in inclusive DIS at high Q^2
 - 5.1.1 Quark substructure
 - 5.1.2 Contact Interactions
 - 5.1.3 Kaluza-Klein gravitons in extra-dimensions
- 5.2 Leptoquarks and leptogluons
 - 5.2.1 Phenomenology of leptoquarks in ep collisions
 - 5.2.2 The Buchmüller-Rückl-Wyler Model
 - 5.2.3 Phenomenology of leptoquarks in pp collisions
 - 5.2.4 Current status of leptoquark searches
 - 5.2.5 Sensitivity on leptoquarks at LHC and at LHeC
 - 5.2.6 Determination of LQ properties
 - 5.2.7 Leptogluons
- 5.3 Excited leptons and other new heavy leptons
 - 5.3.1 Excited Fermion Models
 - 5.3.2 Simulation and Results
 - 5.3.3 New leptons from a fourth generation
- 5.4 New physics in boson-quark interactions
 - 5.4.1 An LHeC-based γp collider
 - 5.4.2 Anomalous Single Top Production at the LHeC Based γp Collider
 - 5.4.3 Excited quarks in γp collisions at LHeC
 - 5.4.4 Quarks from a fourth generation at LHeC
 - 5.4.5 Diquarks at LHeC
 - 5.4.6 Quarks from a fourth generation in Wq interactions
- 5.5 Sensitivity to a Higgs boson
 - 5.5.1 Higgs production at LHeC
 - 5.5.2 Observability of the signal
 - 5.5.3 Probing Anomalous HWW Couplings at the LHeC

6 Physics at High Parton Densities

- 6.1 Physics at small x
 - 6.1.1 Unitarity and QCD
 - 6.1.2 Status following HERA data
 - 6.1.3 Low- x physics perspectives at the LHC
 - 6.1.4 Nuclear targets
- 6.2 Prospects at the LHeC
 - 6.2.1 Strategy: decreasing x and increasing A
 - 6.2.2 Inclusive measurements
 - 6.2.3 Exclusive Production
 - 6.2.4 Inclusive diffraction
 - 6.2.5 Jet and multi-jet observables, parton dynamics and fragmentation
 - 6.2.6 Implications for ultra-high energy neutrino interactions and detection

Precision measurement of gluon density to extreme $x - \alpha_s$
 Low x : saturation? radical change of understanding
 High x : xg and valence quarks most crucial for new states
 Gluon in Pomeron, odderon, photon, nuclei.. Local spots in p ?
 Heavy quarks intrinsic or only gluonic

Electron-Ion Scattering: $eA \rightarrow eX$

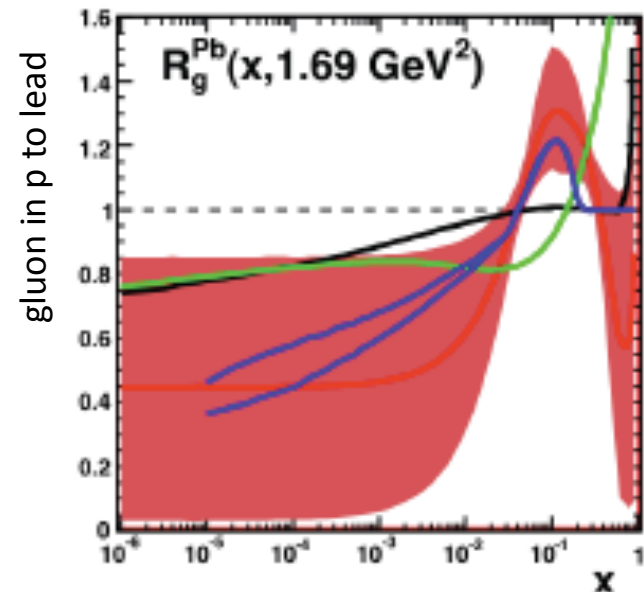


$Q^2 = 4\text{momentum transfer}^2$ Bjorken x : fraction of p 's momentum

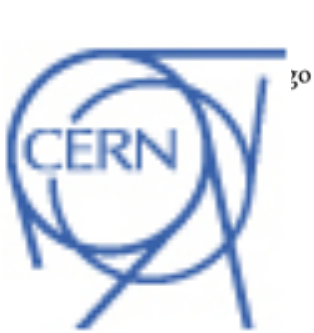
Extension of kinematic range by 3-4 orders of magnitude into saturation region (with p and with A)

Qualitative change of behaviour

- Bb limit of F_2
- Saturation of cross sections amplified with $A^{1/3}$
- Rise of diffraction to 50%?
- partons in nuclei – widely unknown



LHeC Accelerator Design: Participating Institutes



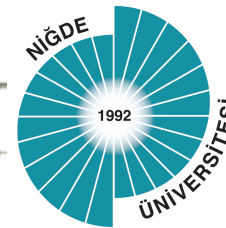
Norwegian University of Science and Technology



The Cockcroft Institute of Accelerator Science and Technology



Thomas Jefferson National Accelerator Facility



TOBB ETU



Laboratori Nazionali di Legnaro



Physique des accélérateurs



ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE



UNIVERSITY OF LIVERPOOL

BROOKHAVEN
NATIONAL LABORATORY



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

630090 Новосибирск



KEK



TUPC017 Civil Engineering Studies for Major Projects after LHC

John Andrew Osborne, Frederic Magnin, Eliseo Perez-Duenas

TUPC045 Recirculating Electron Linacs (REL) for LHeC and eRHIC

Dejan Trbojevic, Joanne Beebe-Wang, Yue Hao, Dmitry Kayran,
Vladimir N. Litvinenko, Vadim Ptitsyn, Nicholas Tsoupas

TUPC054 LHeC ERL Design and Beam-dynamics Issues

Alex Bogacz, Ilkyoung Shin, Daniel Schulte, Frank Zimmermann

WEODA03 Design Concepts for the Large Hadron Electron Collider

Max Klein for the LHeC Study Group

WEPZ013 Design Status of LHeC Linac-Ring Interaction Region

Rogelio Tomas, Jose Luis Abelleira, Stephan Hans Russenschuck,
Frank Zimmermann, Nathan Rogers Bernard

THPZ014 LHeC Lattice Design

Miriam Fitterer, Oliver Sim Bruening, Helmut Burkhardt,
Bernhard Johannes Holzer, John M. Jowett, Karl Hubert Mess,
Thys Risselada, Anke-Susanne Mueller, Max Klein

THPZ015 Synchrotron Radiation in the Interaction Region for a Ring-Ring and Linac-Ring LHeC

Nathan Rogers Bernard, Bernhard Johannes Holzer, Rogelio Tomas,
Frank Zimmermann, Peter Kostka, Max Klein, Boris Nagorny,
Uwe Schneekloth, Robert Appleby, Luke Thompson

THPZ016 Interaction Region Design for a Ring-Ring LHeC

Luke Thompson, Bernhard Johannes Holzer, Miriam Fitterer,
Peter Kostka, Max Klein, Nathan Rogers Bernard, Robert Appleby

THPZ023 LHeC Spin Rotator

Mei Bai, Rogelio Tomas, Frank Zimmermann

**Contributions
to IPAC11**

- 7 Ring-Ring Collider
 - 7.1 Baseline Parameters and Configuration
 - 7.2 Geometry
 - 7.2.1 General Layout
 - 7.2.2 Electron Ring Circumference
 - 7.2.3 Idealised Ring
 - 7.2.4 Bypass Options
 - 7.2.5 Bypass Point 1
 - 7.2.6 Bypasses Point 5
 - 7.2.7 Matching Proton and Electron Ring Circumference
 - 7.3 Layout and Optics
 - 7.3.1 Arc Cell Layout and Optics
 - 7.3.2 Insertion Layout and Optics
 - 7.3.3 Bypass Layout and Optics
 - 7.3.4 Chromaticity Correction
 - 7.3.5 Working Point
 - 7.3.6 Aperture
 - 7.3.7 Complete Lattice and Optics
 - 7.4 Interaction Region Layout
 - 7.4.1 Beam Separation Scheme
 - 7.4.2 Crossing Angle
 - 7.4.3 Beam Optics and Luminosity
 - 7.4.4 High Luminosity IR Layout
 - 7.4.5 High Acceptance IR Layout
 - 7.4.6 Comparison of High Luminosity and High Acceptance Opt
 - 7.4.7 Synchrotron radiation and absorbers
 - 7.5 Beam-beam effects in the LHeC
 - 7.5.1 Head-on beam-beam effects
 - 7.5.2 Long range beam-beam effects
 - 7.6 Performance as an electron-ion collider
 - 7.6.1 Heavy nuclei, e-Pb collisions
 - 7.6.2 Electron-deuteron collisions
 - 7.7 Spin polarisation – an overview
 - 7.7.1 Self polarisation
 - 7.7.2 Suppression of depolarisation – spin matching
 - 7.7.3 Higher order resonances
 - 7.7.4 Calculations of the e^\pm polarisation in the LHeC
 - 7.7.5 Spin rotator concepts for the LHeC
 - 7.7.6 Further work
 - 7.7.7 Summary
 - 7.8 Integration and machine protection issues
 - 7.8.1 Space requirements
 - 7.8.2 Impact of the synchrotron radiation on tunnel electronics
 - 7.8.3 Compatibility with the proton beam loss system
 - 7.8.4 Space requirements for the electron dump
 - 7.8.5 Protection of the p-machine against heavy electron losses
 - 7.8.6 How to combine the Machine Protection of both rings?
 - 7.9 LHeC Injector for the Ring-Ring option
 - 7.9.1 Injector
 - 7.9.2 Required performance
 - 7.9.3 Source, accumulator and acceleration to 0.6 GeV
 - 7.9.4 10 GeV injector

FODO (half LHC size, asy dipoles, 23 arc cells)

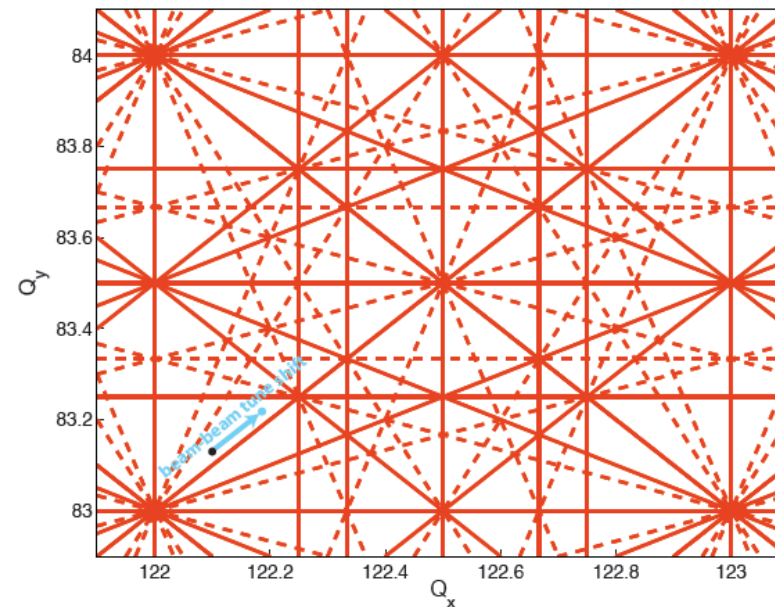
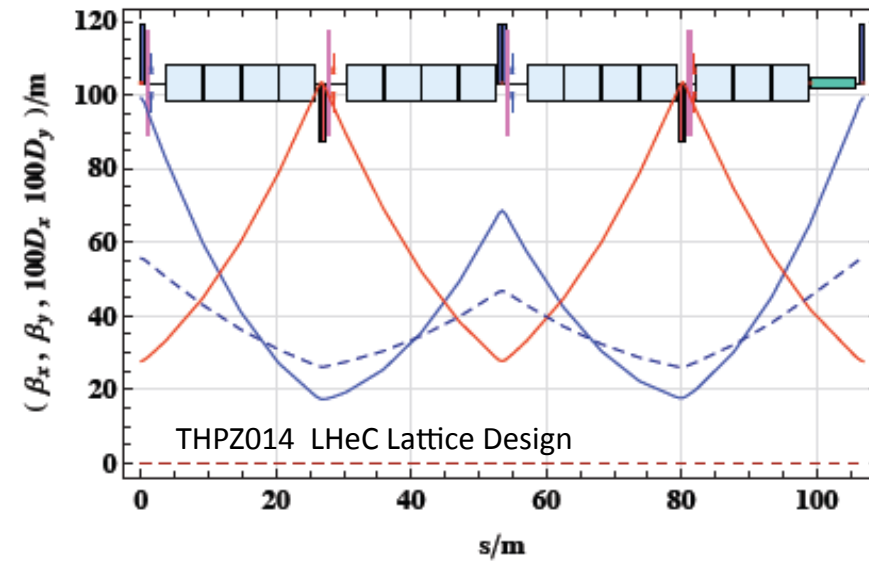


Figure 7.15: Working Point for the 1° optics. The dashed lines are the coupling resonances up to 4th order, the solid lines the constructive resonances up to 4th order. The black dot indicates the working point without beam-beam tune shift and the blue one with beam-beam tune shift.

7	Ring-Ring Collider
7.1	Baseline Parameters and Configuration
7.2	Geometry
7.2.1	General Layout
7.2.2	Electron Ring Circumference
7.2.3	Idealised Ring
7.2.4	Bypass Options
7.2.5	Bypass Point 1
7.2.6	Bypasses Point 5
7.2.7	Matching Proton and Electron Ring Circumference
7.3	Layout and Optics
7.3.1	Arc Cell Layout and Optics
7.3.2	Insertion Layout and Optics
7.3.3	Bypass Layout and Optics
7.3.4	Chromaticity Correction
7.3.5	Working Point
7.3.6	Aperture
7.3.7	Complete Lattice and Optics
7.4	Interaction Region Layout
7.4.1	Beam Separation Scheme
7.4.2	Crossing Angle
7.4.3	Beam Optics and Luminosity
7.4.4	High Luminosity IR Layout
7.4.5	High Acceptance IR Layout
7.4.6	Comparison of High Luminosity and High Acceptance Opt
7.4.7	Synchrotron radiation and absorbers
7.5	Beam-beam effects in the LHeC
7.5.1	Head-on beam-beam effects
7.5.2	Long range beam-beam effects
7.6	Performance as an electron-ion collider
7.6.1	Heavy nuclei, e-Pb collisions
7.6.2	Electron-deuteron collisions
7.7	Spin polarisation – an overview
7.7.1	Self polarisation
7.7.2	Suppression of depolarisation – spin matching
7.7.3	Higher order resonances
7.7.4	Calculations of the e^{\pm} polarisation in the LHeC
7.7.5	Spin rotator concepts for the LHeC
7.7.6	Further work
7.7.7	Summary
7.8	Integration and machine protection issues
7.8.1	Space requirements
7.8.2	Impact of the synchrotron radiation on tunnel electronics
7.8.3	Compatibility with the proton beam loss system
7.8.4	Space requirements for the electron dump
7.8.5	Protection of the p-machine against heavy electron losses
7.8.6	How to combine the Machine Protection of both rings?
7.9	LHeC Injector for the Ring-Ring option
7.9.1	Injector
7.9.2	Required performance
7.9.3	Source, accumulator and acceleration to 0.6 GeV
7.9.4	10 GeV injector

Constraints:

Bypass existing LHC experiments

$U_p = U_e \rightarrow$ shift of e ring to inside

100kg/m tunnel load limit: support from below (HERA)

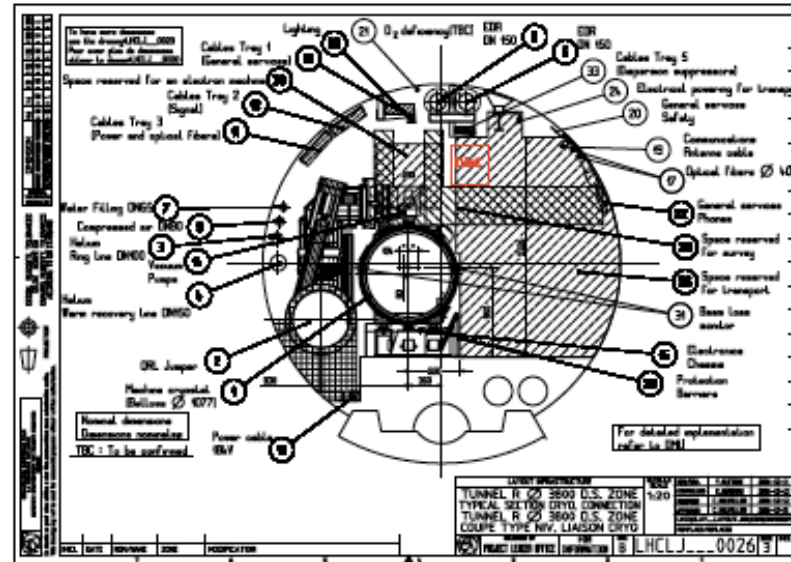


Figure 7.47: Cross-section of the LHC tunnel with the original space holder for the electron beam installation directly above the LHC cryostat and the shifted new required space due to the additional bypass in IR1 and IR5 and the need to keep the overall circumference of the electron ring identical to that of the proton beams.

Issues:

QRL service with jumper – asymmetric FODO

transport: magnets ok, cryo equipment full height

occurs during warmup – shift locally e beam?

dump area – reroute cables

proton rf -- e “just a pipe”

SEU’s from e: shielding, LHC power converters then out

IP3, LSS7, p collimation ...

no show stopper found but challenging and CAD needed next

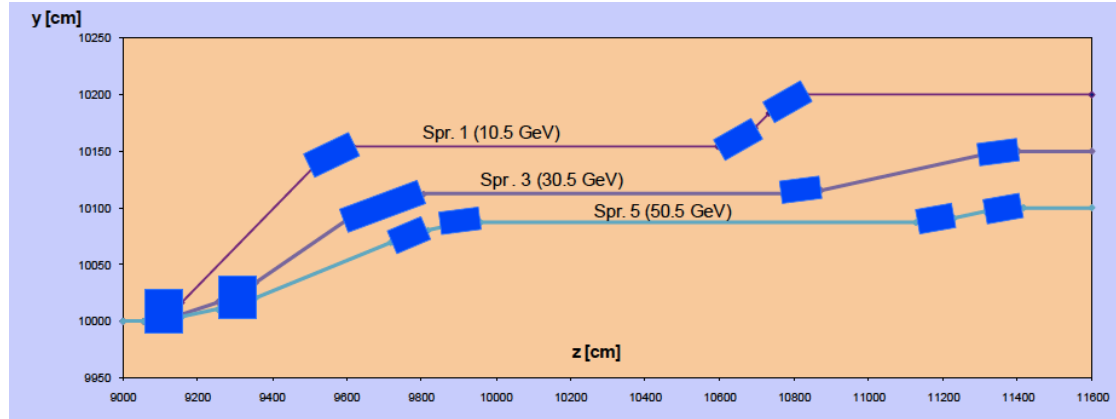
8 Linac-Ring Collider

- 8.1 Basic Parameters and Configurations
- 8.1.1 General Considerations
- 8.1.2 ERL Performance and Layout
- 8.1.3 Polarization
- 8.1.4 Pulsed Linacs
- 8.1.5 Highest-Energy LHeC ERL Option
- 8.1.6 γ - p/A Option
- 8.1.7 Summary of Basic Parameters and Configurations
- 8.2 Interaction region
- 8.2.1 Layout
- 8.2.2 Optics
- 8.2.3 Modifications for γp or γ - A
- 8.2.4 Synchrotron radiation and absorbers
- 8.3 Linac Lattice and Impedance
- 8.3.1 Overall Layout
- 8.3.2 Linac Layout and Lattice
- 8.3.3 Beam Break-Up
- 8.3.4 Imperfections
- 8.4 Performance as a Linac-Ring electron-ion collider
- 8.4.1 Heavy nuclei, e-Pb collisions
- 8.4.2 Electron-deuteron collisions
- 8.5 Polarized-Electron Injector for the Linac-Ring LHeC
- 8.6 Spin Rotator
- 8.7 Positron Options for the Linac-Ring LHeC
- 8.7.1 Motivation
- 8.7.2 LHeC Linac-Ring e^+ Requirements
- 8.7.3 Mitigation Schemes
- 8.7.4 Positron Production Schemes
- 8.7.5 Targets
- 8.7.6 Conventional Scheme based on e^- Beam Hitting Target
- 8.7.7 Compton Sources
- 8.7.8 Undulator Source
- 8.7.9 Source based on Coherent Pair Creation
- 8.7.10 Conclusions

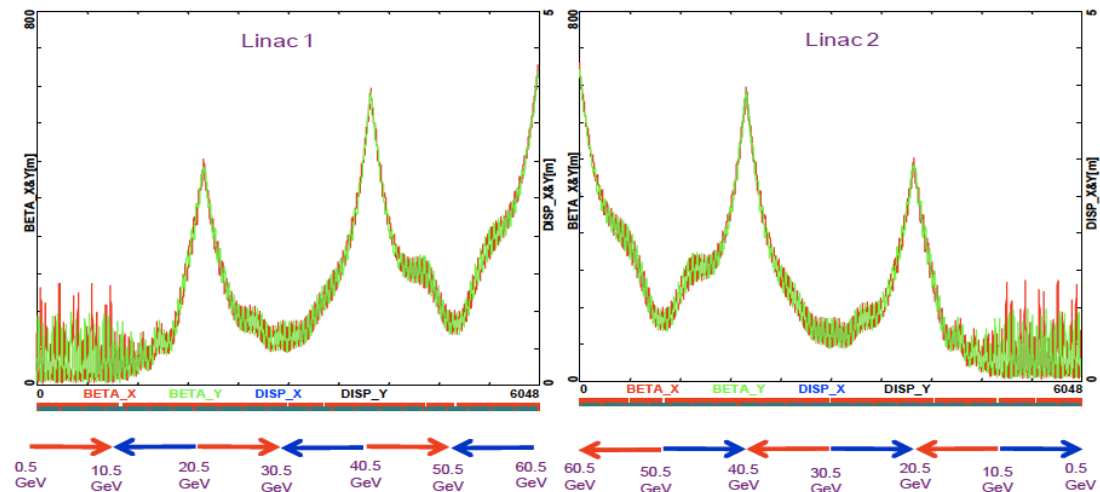
ERL stores energy while ring stores electrons

Same RF for acc and deacc. \rightarrow rf acc power independent of I

Switchyard: two-step spreaders and mirror symmetric recomb.



Multipass linear optics: sharing of arcs by acc/deacc. passes



Cumulative transverse deflections from each cavity so far ok to 5mA

TUPC054

LHeC ERL Design and Beam-dynamics Issues

Figure 2: Multi-pass linac optics optimized for 3-pass ERL As a virtue of ER, Linac 1 and 2 are mirror reflections.

9 System Design

- 9.1 Magnets for the Interaction Region
 - 9.1.1 Introduction
 - 9.1.2 Magnets for the ring-ring option
 - 9.1.3 Magnets for the linac-ring option
- 9.2 Accelerator Magnets
 - 9.2.1 Dipole Magnets
 - 9.2.2 BINP Model
 - 9.2.3 CERN Model
 - 9.2.4 Quadrupole and Corrector Magnets
- 9.3 Ring-Ring RF Design
 - 9.3.1 Design Parameters
 - 9.3.2 Cavities and klystrons
- 9.4 Linac-Ring RF Design
 - 9.4.1 Design Parameters
 - 9.4.2 Layout and RF powering
 - 9.4.3 Arc RF systems
- 9.5 Crab crossing for the LHeC
 - 9.5.1 Luminosity Reduction
 - 9.5.2 Crossing Schemes
 - 9.5.3 RF Technology
- 9.6 Vacuum
 - 9.6.1 Vacuum requirements
 - 9.6.2 Synchrotron radiation
 - 9.6.3 Vacuum engineering issues
- 9.7 Beam Pipe Design
 - 9.7.1 Requirements
 - 9.7.2 Choice of Materials for beampipes
 - 9.7.3 Beampipe Geometries
 - 9.7.4 Vacuum Instrumentation
 - 9.7.5 Synchrotron Radiation Masks
 - 9.7.6 Installation and Integration
- 9.8 Cryogenics
 - 9.8.1 Ring-Ring Cryogenics Design
 - 9.8.2 Linac-Ring Cryogenics Design
 - 9.8.3 General Conclusions Cryogenics for LHeC
- 9.9 Beam Dumps and Injection Regions
 - 9.9.1 Injection Region Design for Ring-Ring Option
 - 9.9.2 Injection transfer line for the Ring-Ring Option
 - 9.9.3 60 GeV internal dump for Ring-Ring Option
 - 9.9.4 Post collision line for 140 GeV Linac-Ring option
 - 9.9.5 Absorber for 140 GeV Linac-Ring option
 - 9.9.6 Energy deposition studies for the Linac-Ring option
 - 9.9.7 Beam line dump for ERL Linac-Ring option
 - 9.9.8 Absorber for ERL Linac-Ring option

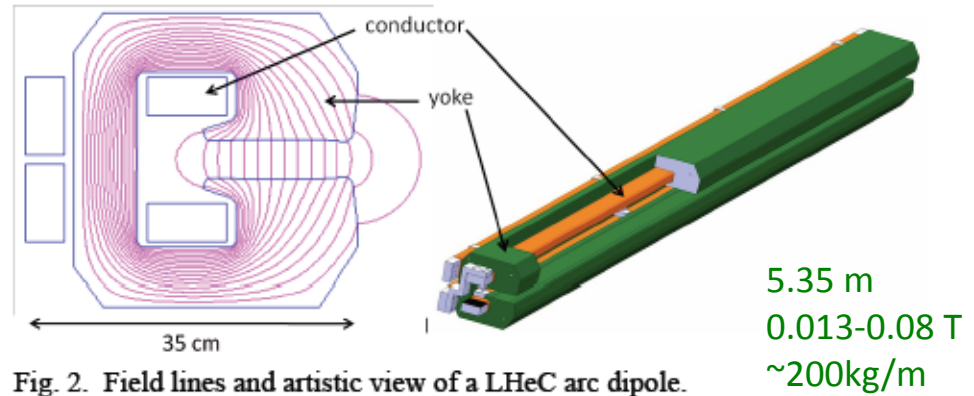


Fig. 2. Field lines and artistic view of a LHeC arc dipole.

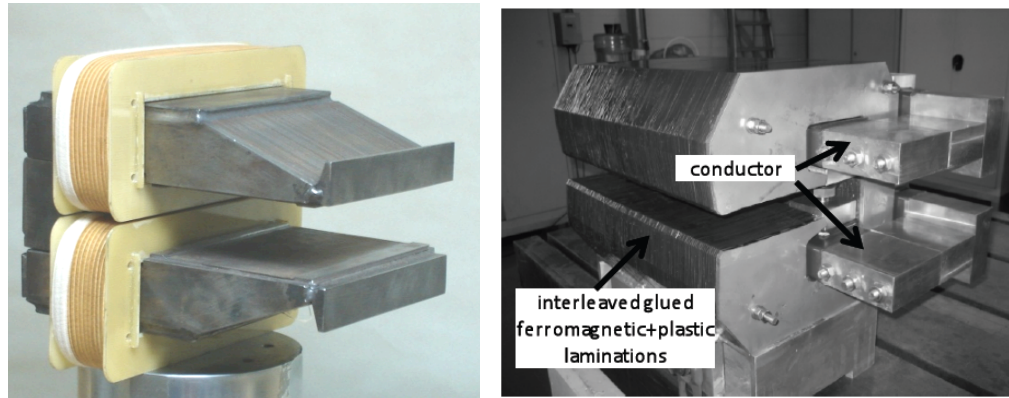


TABLE II REPRODUCIBILITY OF MAGNETIC FIELD OVER 8 CYCLES

Model	Low field	High fields
Maximum Relative Deviation from Average		
Model 1 (NiFe steel)	$5 \cdot 10^{-5}$	$4 \cdot 10^{-5}$
Model 2 (Low carbon steel)	$6 \cdot 10^{-5}$	$6 \cdot 10^{-5}$
Model 3 (Grain oriented 3.5% Si steel)	$4 \cdot 10^{-5}$	$6 \cdot 10^{-5}$
Standard Deviation from Average		
Model 1 (NiFe steel)	$3 \cdot 10^{-5}$	$3 \cdot 10^{-5}$
Model 2 (Low carbon steel)	$4 \cdot 10^{-5}$	$5 \cdot 10^{-5}$
Model 3 (Grain oriented 3.5% Si steel)	$2 \cdot 10^{-5}$	$4 \cdot 10^{-5}$

Prototypes from BINP and CERN: function to spec's

Table 2: Components of the Electron Accelerators

	Ring	Linac
magnets		
beam energy	60 GeV	
number of dipoles	3080	3600
dipole field [T]	0.013 – 0.076	0.046 – 0.264
total nr of quads	866	1588
RF and cryogenics		
number of cavities	112	944
gradient [MV/m]	11.9	20
RF power [MW]	49	39
cavity voltage [MV]	5	21.2
cavity R/Q [Ω]	114	285
cavity Q_0	–	$2.5 \cdot 10^{10}$
cooling power [kW]	5.4@4.2 K	30@2 K

9 System Design

9.1 Magnets for the Interaction Region

9.1.1 Introduction

9.1.2 Magnets for the ring-ring option

9.1.3 Magnets for the linac-ring option

9.2 Accelerator Magnets

9.2.1 Dipole Magnets

9.2.2 BINP Model

9.2.3 CERN Model

9.2.4 Quadrupole and Corrector Magnets

9.3 Ring-Ring RF Design

9.3.1 Design Parameters

9.3.2 Cavities and klystrons

9.4 Linac-Ring RF Design

9.4.1 Design Parameters

9.4.2 Layout and RF powering

9.4.3 Arc RF systems

9.5 Crab crossing for the LHeC

9.5.1 Luminosity Reduction

9.5.2 Crossing Schemes

9.5.3 RF Technology

9.6 Vacuum

9.6.1 Vacuum requirements

9.6.2 Synchrotron radiation

9.6.3 Vacuum engineering issues

9.7 Beam Pipe Design

9.7.1 Requirements

9.7.2 Choice of Materials for beampipes

9.7.3 Beampipe Geometries

9.7.4 Vacuum Instrumentation

9.7.5 Synchrotron Radiation Masks

9.7.6 Installation and Integration

9.8 Cryogenics

9.8.1 Ring-Ring Cryogenics Design

9.8.2 Linac-Ring Cryogenics Design

9.8.3 General Conclusions Cryogenics for LHeC

9.9 Beam Dumps and Injection Regions

9.9.1 Injection Region Design for Ring-Ring Option

9.9.2 Injection transfer line for the Ring-Ring Option

9.9.3 60 GeV internal dump for Ring-Ring Option

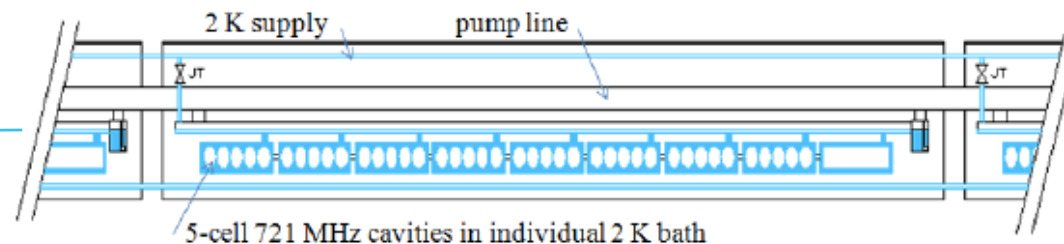
9.9.4 Post collision line for 140 GeV Linac-Ring option

9.9.5 Absorber for 140 GeV Linac-Ring option

9.9.6 Energy deposition studies for the Linac-Ring option

9.9.7 Beam line dump for ERL Linac-Ring option

9.9.8 Absorber for ERL Linac-Ring option



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.

IV Detector

12 Detector Requirements

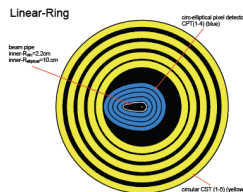
- 12.1 Requirements on the LHeC Detector
- 12.1.1 Installation and Magnets
- 12.1.2 Kinematic reconstruction
- 12.1.3 Acceptance regions - scattered electron
- 12.1.4 Acceptance regions - hadronic final state
- 12.1.5 Acceptance at the High Energy LHC
- 12.1.6 Energy Resolution and Calibration
- 12.1.7 Tracking Requirements
- 12.1.8 Particle Identification Requirements
- 12.1.9 Summary of the Requirements on the LHeC Detector

13 Central Detector

- 13.1 Basic Detector Description
- 13.1.1 Baseline Detector Layout
- 13.1.2 An Alternative Solenoid Placement - Option B
- 13.2 Magnet Design
- 13.2.1 Magnets configuration
- 13.2.2 Detector Solenoid
- 13.2.3 Detector integrated e-beam bending dipoles
- 13.2.4 Cryogenics for magnets and calorimeter
- 13.2.5 Twin Solenoid System
- 13.3 Tracking Detector
- 13.3.1 Tracking Detector - Baseline Layout
- 13.3.2 Performance
- 13.3.3 Tracking detector design criteria and possible solutions
- 13.4 Calorimetry
- 13.4.1 The Barrel Electromagnetic Calorimeter
- 13.4.2 The Hadronic Barrel Calorimeter
- 13.4.3 Endcap Calorimeters
- 13.5 Calorimeter Simulation
- 13.5.1 The Barrel LAr Calorimeter Simulation
- 13.5.2 The Barrel Tile Calorimeter Simulation
- 13.5.3 Combined Liquid Argon and Tile Calorimeter Simulation
- 13.5.4 Lead-Scintillator Electromagnetic Option
- 13.5.5 Forward and Backward Inserts Calorimeter Simulation
- 13.6 Calorimeter Summary
- 13.7 Muon Detector
- 13.7.1 Muon detector design
- 13.7.2 The LHeC muon detector options
- 13.7.3 Forward Muon Extensions
- 13.7.4 Muon Detector Summary
- 13.8 Event and Detector Simulations
- 13.8.1 Pythia6
- 13.8.2 1 MeV Neutron Equivalent
- 13.8.3 Nearest Neighbor
- 13.8.4 Cross Checking
- 13.8.5 Future Goals

14 Forward and Backward Detectors

- 14.1 Luminosity Measurement and Electron Tagging
- 14.1.1 Options
- 14.1.2 Use of the Main LHeC Detector
- 14.1.3 Dedicated Luminosity Detectors in the tunnel
- 14.1.4 Small angle Electron Tagger
- 14.1.5 Summary and Open Questions
- 14.2 Polarimeter
- 14.2.1 Polarisation from the scattered photons
- 14.2.2 Polarisation from the scattered electrons
- 14.3 Zero Degree Calorimeter
- 14.3.1 ZDC detector design
- 14.3.2 Neutron Calorimeter
- 14.3.3 Proton Calorimeter
- 14.3.4 Calibration and monitoring
- 14.4 Forward Proton Detection



Requirements High Precision (resolution, calibration, low noise, tagging of b,c)
 Modular for 'fast' installation
 State of the art technology - 'no' R+D (HERA,LHC upgrade)
 1-179° acceptance for low Q^2 , high x (beam pipe, synrad)

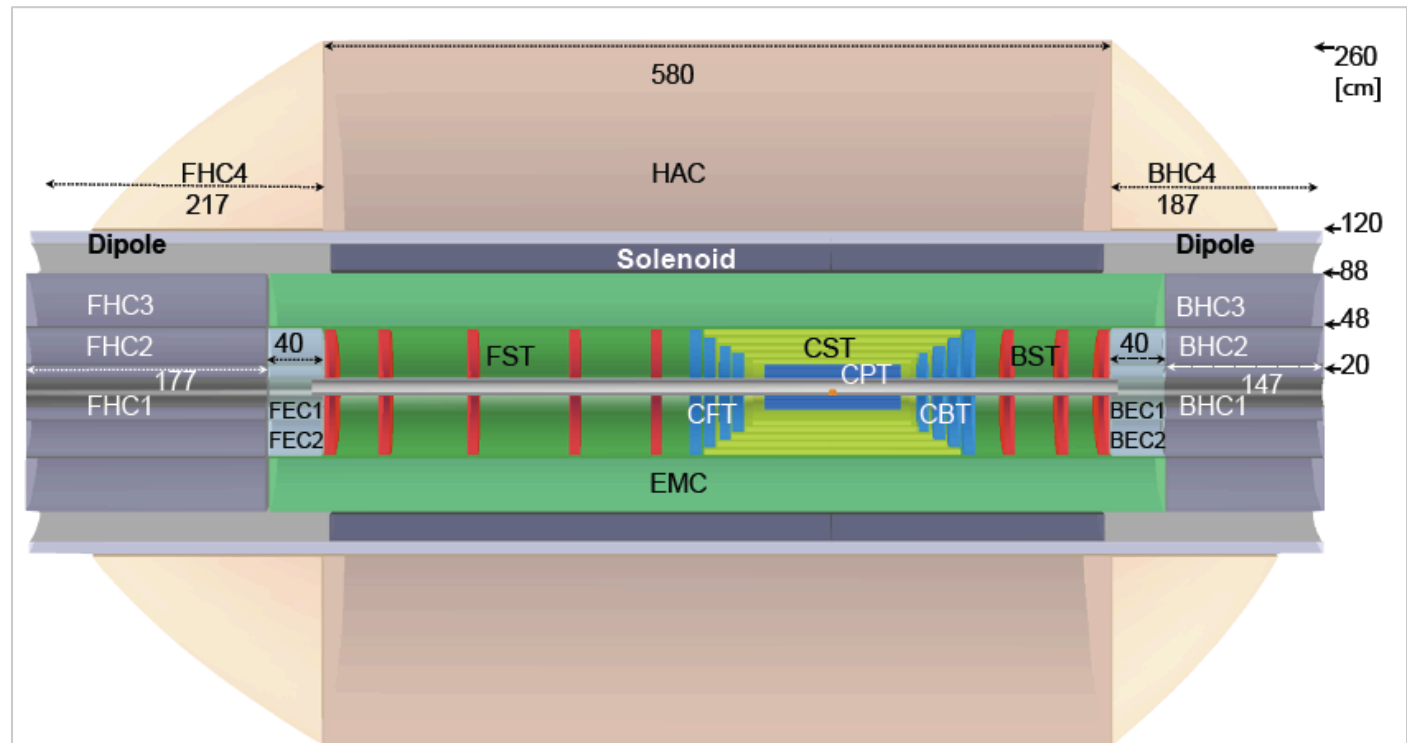
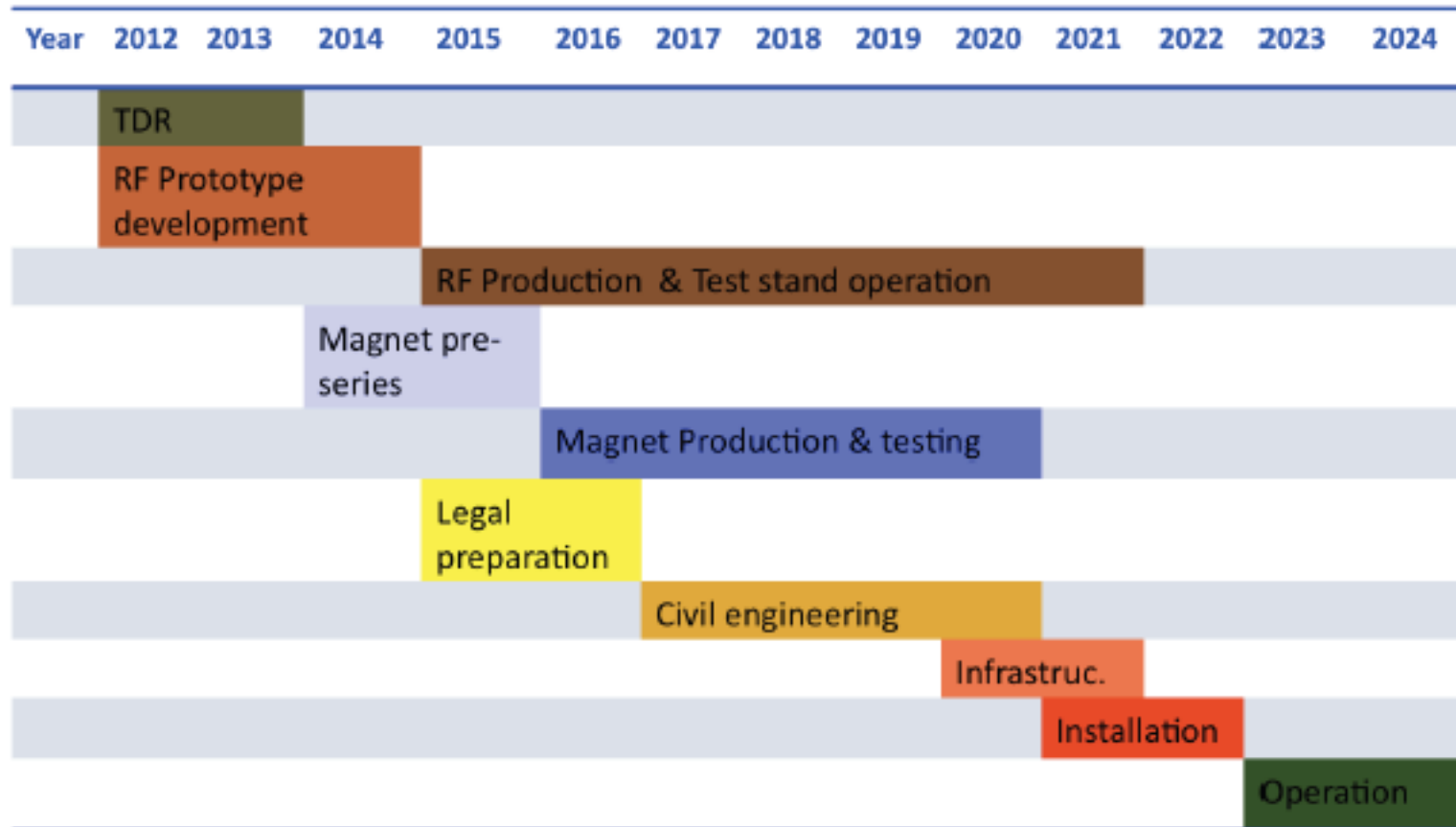


Figure 13.9: An rz cross section of the LHeC detector, in its baseline configuration (A). In

Si tracker, LAr elm cal, sc coil 3.5T, Tile hcal, Muon detector not shown

**Present dimensions: $L \times D = 14 \times 9 \text{ m}^2$ [CMS $21 \times 15 \text{ m}^2$, ATLAS $45 \times 25 \text{ m}^2$]
 Taggers at -62m (e), 100m (γ ,LR), -22.4m (γ ,RR), +100m (n), +420m (p)**

LHeC Tentative Time Schedule



LS3 --- HL LHC →

We base our estimates for the project time line on the experience of other projects, such as (LEP, LHC and LINAC4 at CERN and the European XFEL at DESY and the PSI XFEL)

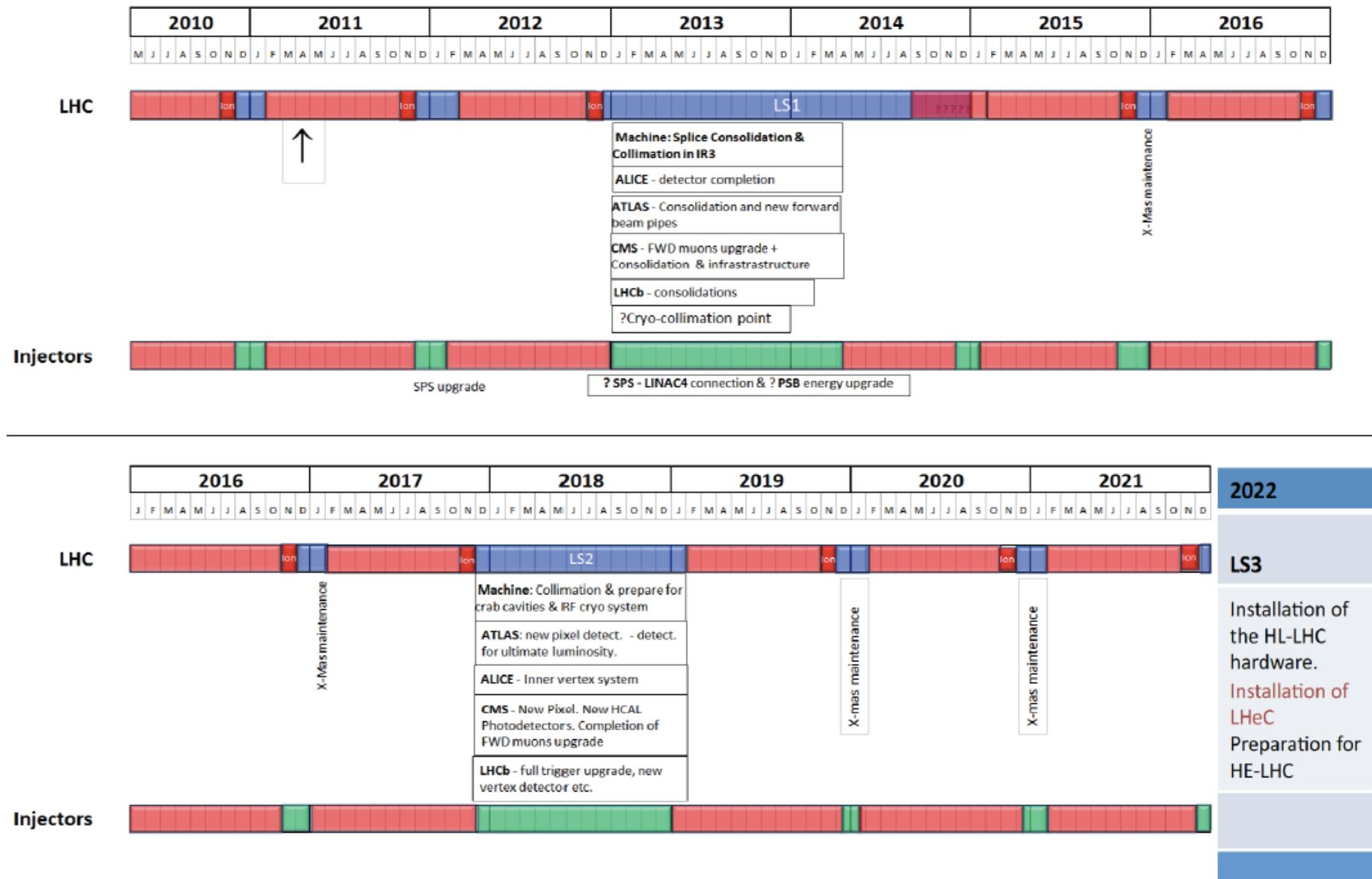


Figure 11.1: CERN medium term plan (MTP), draft as of July 2011

Table 1: Parameters of the RR and RL Configurations

	Ring	Linac
electron beam		
beam energy E_e	60 GeV	
e^- (e^+) per bunch N_e [10^9]	20 (20)	1 (0.1)
e^- (e^+) polarisation [%]	40 (40)	90 (0)
bunch length [mm]	10	0.6
tr. emittance at IP $\gamma\epsilon_{x,y}^e$ [mm]	0.58, 0.29	0.05
IP β function $\beta_{x,y}^*$ [m]	0.4, 0.2	0.12
beam current [mA]	131	6.6
energy recovery intensity gain	—	17
total wall plug power	100 MW	
syn rad power [kW]	51	49
critical energy [keV]	163	718
proton beam		
beam energy E_p	7 TeV	
protons per bunch N_p	$1.7 \cdot 10^{11}$	
transverse emittance $\gamma\epsilon_{x,y}^p$	$3.75 \mu\text{m}$	
collider		
Lum $e^- p$ ($e^+ p$) [$10^{32} \text{cm}^{-2} \text{s}^{-1}$]	9 (9)	10 (1)
bunch spacing	25 ns	
rms beam spot size $\sigma_{x,y}$ [μm]	30, 16	7
crossing angle θ [mrad]	1	0
$L_{eN} = A L_{eA}$ [$10^{32} \text{cm}^{-2} \text{s}^{-1}$]	0.3	1

Both the ring and the linac are feasible and both come very close to the desired performance. The pleasant challenge is to soon decide for one.

CERN-ECFA-NuPECC:

CDR Draft (530pages) being refereed
Publish early 2012

Steps towards TDR (tentative)

- Prototype IR magnet (3 beams)
- Prototype Dipole (1:1)
- Develop Cavity/Cryomodule
- Civil Engineering, ...

Build international collaborations

for the accelerator and detector development. Strong links to ongoing accelerator and detector projects.

The LHC offers the unique perspective for a further TeV scale collider. The LINAC's are of about 2mile length, yet the Q^2 is 10^5 times larger than was achieved when SLAC discovered quarks. Particle physics needs pp, ll and ep.

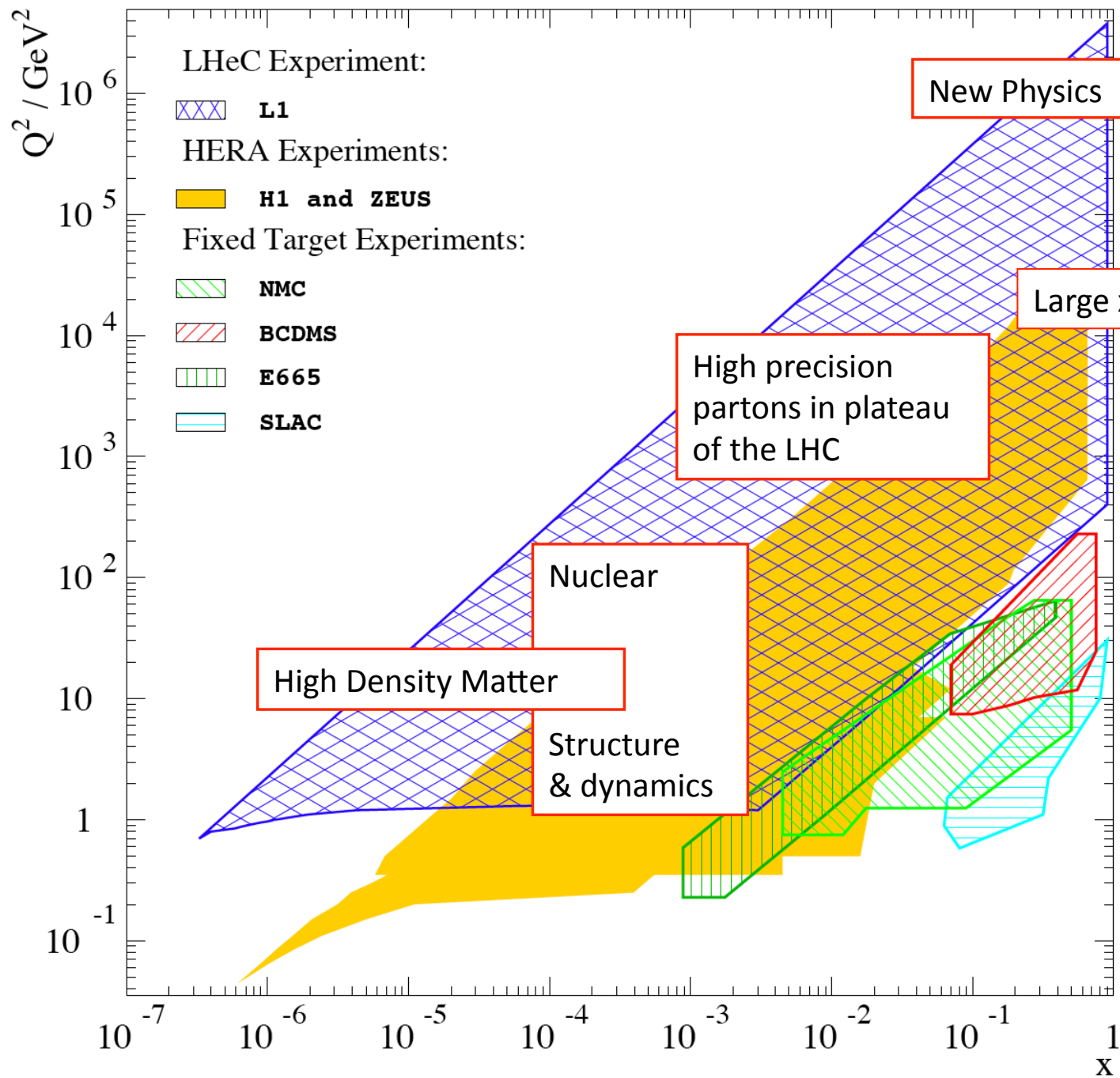
Here is a realistic prospect to progress.

LHeC Study Group

J. Abelleira Fernandez^{10,15}, C.Adolphsen³⁹, S.Alekhin^{40, 11}, A.N.Akai⁰¹, H.Aksakal³⁰, P.Allport¹⁷, J.L.Albacete³⁷, V.Andreev²⁵, R.B.Appleby²³, N.Armento³⁸, G.Azuelos²⁶, M.Bai⁴⁷, D.Barber¹¹, J.Bartels¹², J.Behr¹¹, O.Behnke¹¹, S.Belyaev¹⁰, I.BenZvi⁴⁷, N.Bernard¹⁶, S.Bertolucci¹⁰, S.Bettoni¹⁰, S.Biswal³², J.Bluemlein¹¹, H.Boettcher¹¹, H.Braun⁴⁸, S.Brodsky³⁹, A.Bogacz²⁸, C.Bracco¹⁰, O.Brueening¹⁰, E.Bulyak⁰⁸, A.Bunyatian¹¹, H.Burkhardt¹⁰, I.T.Cakir⁵⁴, O.Cakir⁵³, R.Calaga⁴⁷, E.Ciapala¹⁰, R.Ciftci⁰¹, A.K.Ciftci⁰¹, B.A.Cole²⁹, J.C.Collins⁴⁶, J.Dainton¹⁷, A.De.Roeck¹⁰, D.d'Enterria¹⁰, A.Dudarev¹⁰, A.Eide⁴³, E.Eroglu⁴⁵, K.J.Eskola¹⁴, L.Favart⁰⁶, M.Fitterer¹⁰, S.Forte²⁴, P.Gambino⁴², T.Gehrmann⁵⁰, C.Glasman²², R.Godbole²⁷, B.Goddard¹⁰, T.Greenshaw¹⁷, A.Guffanti⁰⁹, V.Guzey²⁸, C.Gwenlan³⁴, T.Han³⁶, Y.Hao⁴⁷, F.Haug¹⁰, W.Herr¹⁰, B.Holzer¹⁰, M.Ishitsuka⁴¹, M.Jacquet³³, B.Jeanneret¹⁰, J.M.Jimenez¹⁰, H.Jung¹¹, J.M.Jowett¹⁰, H.Karadeniz⁵⁴, D.Kayran⁴⁷, F.Kocac⁴⁵, A.Kilic⁴⁵, K.Kimura⁴¹, M.Klein¹⁷, U.Klein¹⁷, T.Kluge¹⁷, G.Kramer¹², M.Korostelev²³, A.Kosmicki¹⁰, P.Kostka¹¹, H.Kowalski¹¹, D.Kuchler¹⁰, M.Kuze⁴¹, T.Lappi¹⁴, P.Laycock¹⁷, E.Levichev³¹, S.Levonian¹¹, V.N.Litvinenko⁴⁷, A.Lombardi¹⁰, C.Marquet¹⁰, B.Mellado⁰⁷, K.H.Mess¹⁰, S.Moch¹¹, I.I.Morozov³¹, Y.Muttoni¹⁰, S.Myers¹⁰, S.Nandi²⁶, P.R.Newman⁰³, T.Omori⁴⁴, J.Osborne¹⁰, Y.Papaphilippou¹⁰, E.Paoloni³⁵, C.Pascaud³³, H.Paukkunen³⁸, E.Perez¹⁰, T.Pieloni¹⁵, E.Pilicer⁴⁵, A.Polini⁰⁴, V.Ptitsyn⁴⁷, Y.Pupkov³¹, V.Radescu¹³, S.Raychaudhuri²⁷, L.Rinolfi¹⁰, R.Rohini²⁷, J.Rojo²⁴, S.Russenschuck¹⁰, C.A.Salgado³⁸, K.Sampegi⁴¹, E.Sauvan¹⁹, M.Sahin⁰¹, U.Schneekloth¹¹, A.N.Skrinsky³¹, T.Schoerner Sadenius¹¹, D.Schulte¹⁰, H.Spiesberger²¹, A.M.Stasto⁴⁶, M.Strikman⁴⁶, M.Sullivan³⁹, B.Surrow⁰⁵, S.Sultansoy⁰¹, Y.P.Sun³⁹, W.Smith²⁰, I.Tapan⁴⁵, P.Taels⁰², E.Tassi⁵², H.Ten.Kate¹⁰, J.Terron²², H.Thiesen¹⁰, L.Thompson²³, K.Tokushuku⁴⁴, R.Tomas.Garcia¹⁰, D.Tommasini¹⁰, D.Trbojevic⁴⁷, N.Tsoupas⁴⁷, J.Tuckmantel¹⁰, S.Turkoz⁵³, K.Tywoniuk¹⁸, G.Unel¹⁰, J.Urakawa⁴⁴, P.VanMechelen⁰², A.Variola³⁷, R.Veness¹⁰, A.Vivoli¹⁰, P.Vobly³¹, R.Wallny⁵¹, G.Watt¹⁰, G.Weiglein¹², C.Weiss²⁸, U.A.Wiedemann¹⁰, U.Wienands³⁹, F.Willeke⁴⁷, V.Yakimenko⁴⁷, A.F.Zarnecki⁴⁹, F.Zimmermann¹⁰, F.Zomer³³

backup

Physics



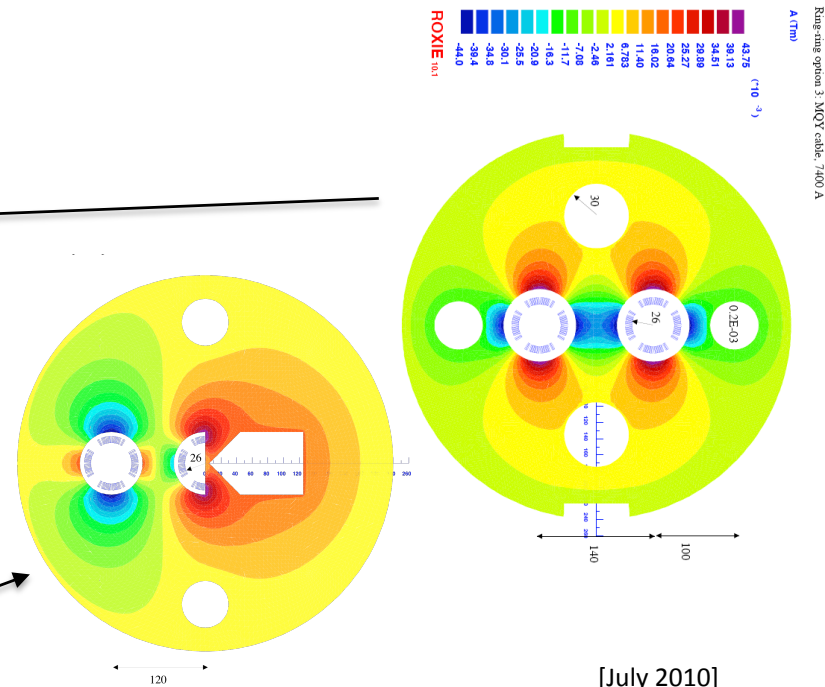
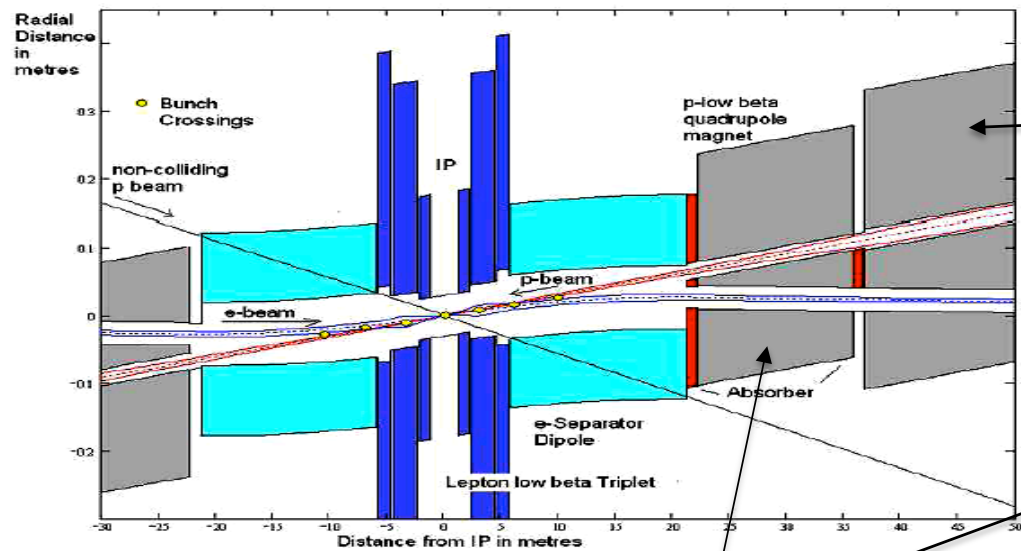
$Q^2 = 4\text{momentum transfer}^2$

$x = \text{Bjorken } x: \text{ fraction of } p\text{'s momentum}$

- eQ states
- GUT ($\delta\alpha_s=0.1\%$)
- Excited fermions
- Hot/cold spots
- Single top
- Higgs
- PDFs
- Multi-Jets
- DVCS
- Unintegrated partons
- Saturation
- Vector Mesons
- IP - graviton
- Odderons
- NC couplings
- $\sin^2\Theta$
- Beauty
- Charm
- Partons in nuclei
- Shadowing
-

Interaction Region(s)

RR - Small crossing angle $\sim 1\text{mrad}$ (25ns) to avoid first parasitic crossing ($L \times 0.77$)
 LR – Head on collisions, dipole in detector to separate beams
 Synchrotron radiation – direct and back, absorption simulated (GEANT4) ..



1st sc half quad (focus and deflect)
 separation 5cm, $g=127\text{T/m}$, MQY cables, 4600 A

2nd quad: 3 beams in horizontal plane
 separation 8.5cm, MQY cables, 7600 A