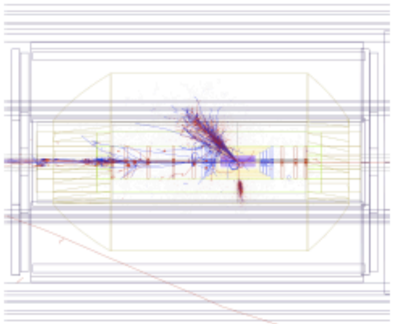
DRAFT 0.8
July 10, 2011
CERN report
ECFA report
NuPECC report

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



Max Klein (U.Liverpool)

Report to PPAP (Birmingham 11.7.11)

View of a (draft) leptoquark event in the LHeC Detector modelled in GEANT4

Dedicated to F.K.

Project Development

Lausanne 84, Aachen 90,
2007: (r)ECFA/CERN/NuPECC:
Divonne 08/09, Chavannes 10 → CDR

The draft CDR of yesterday had:

182 pages on Physics
237 pages on Accelerator
91 pages on Detector

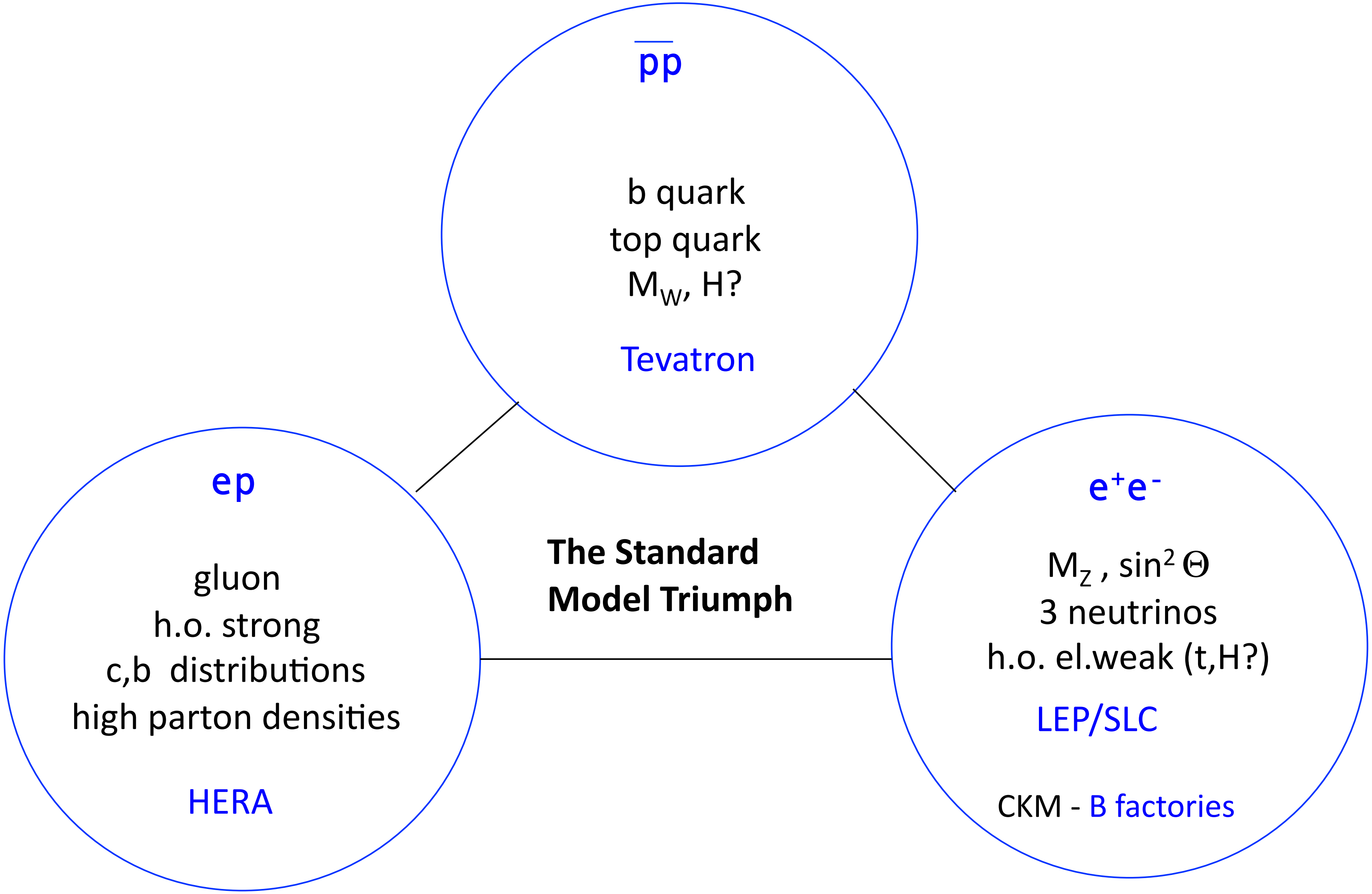
161 authors from 47 institutes

18.7.: Draft 1.0 to 24 referees
appointed by CERN

Fall: Update → CERN/ECFA/NuPECC
[Future of HEP and the LHC]

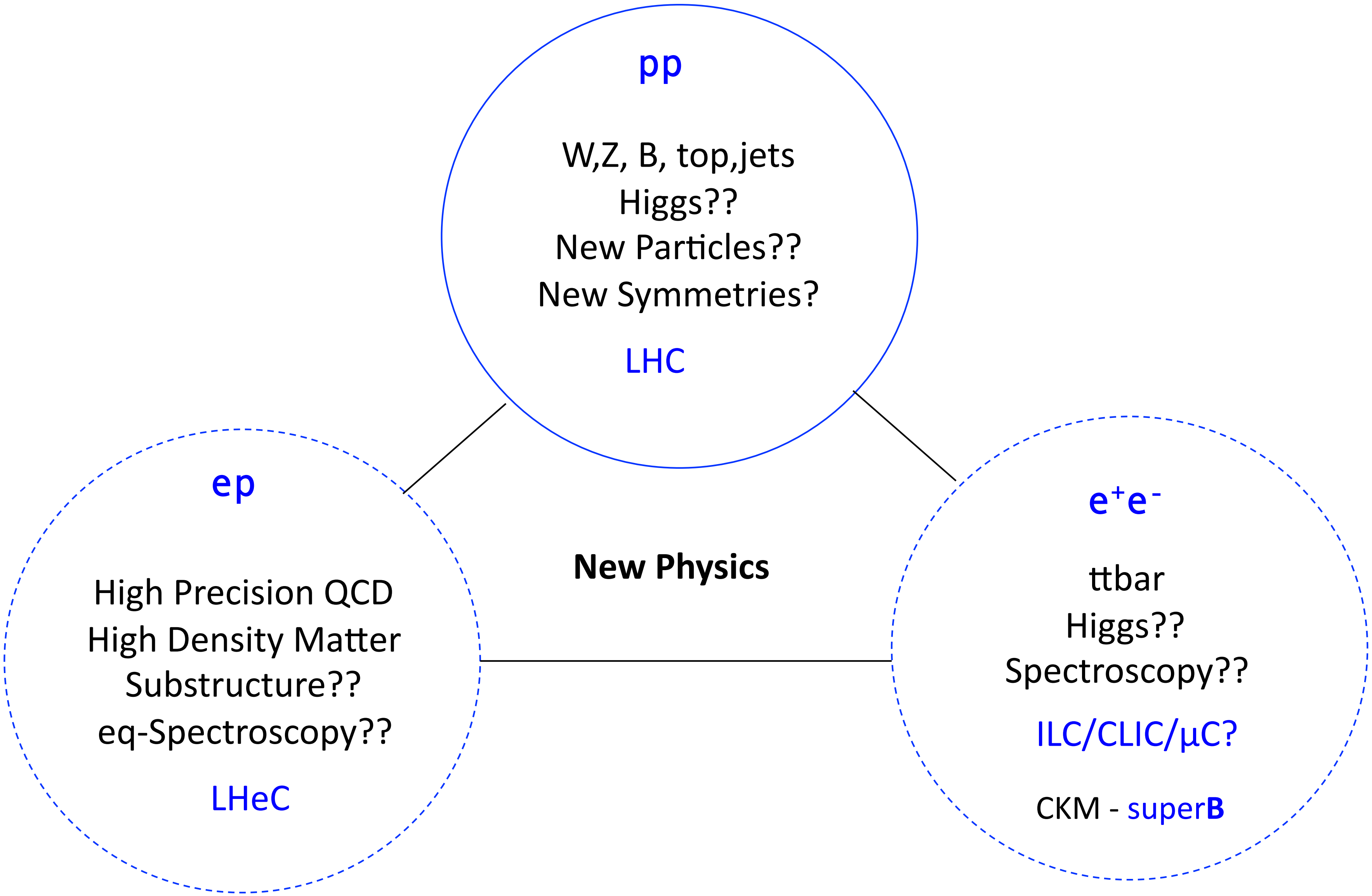
Next steps:
Study Group → Collaboration
International Accelerator R+D at CERN

The Fermi Scale [1985-2011]



Colliders at the energy frontier

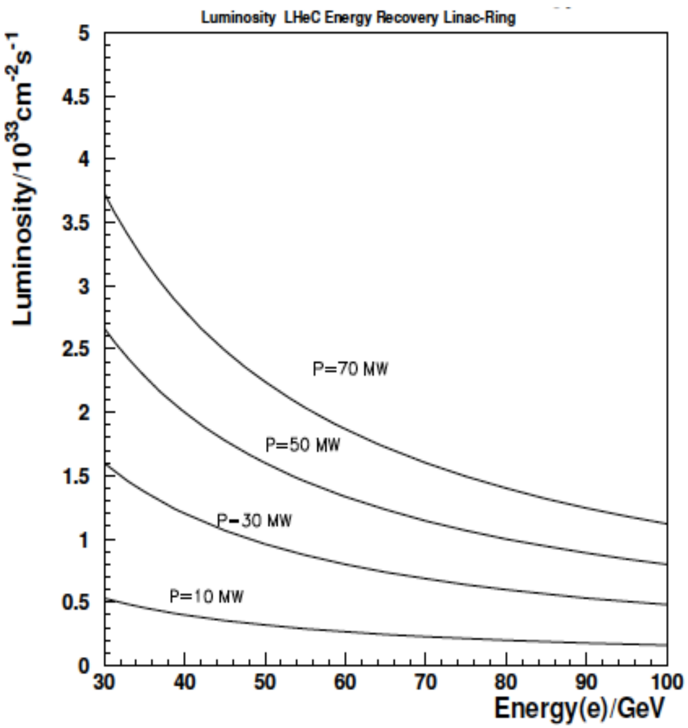
The TeV Scale [2010-2035..]



1 Lepton-Hadron Scattering

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 . . . .

10^{33}cm^{-2}s^{-1} 100MW (w/plug)



1. Grand unification? α_s to per mille accuracy: jets vs inclusive
   ultraprecision DIS programme: N^{k}LO, c, b, ep/eD, sin$^2\theta$(Q)

2. Complete unfolding of partonic content of the proton,
   direct and in QCD and **mapping of the gluon field**

3. A **new phase of hadronic matter**: high densities, small α_s
   saturation of the gluon density? BFKL-Planck scale
   superhigh-energy neutrino physics (p-N)

4. **Partons in nuclei** (4 orders of magnitude extension)
   saturation in eA ($A^{1/3}$?), nuclear parton distributions
   black body limit of F_2, colour transparency, …

5. Search for **novel QCD phenomena**
   instantons, odderons, hidden colour, sea=antiquarks (strange)

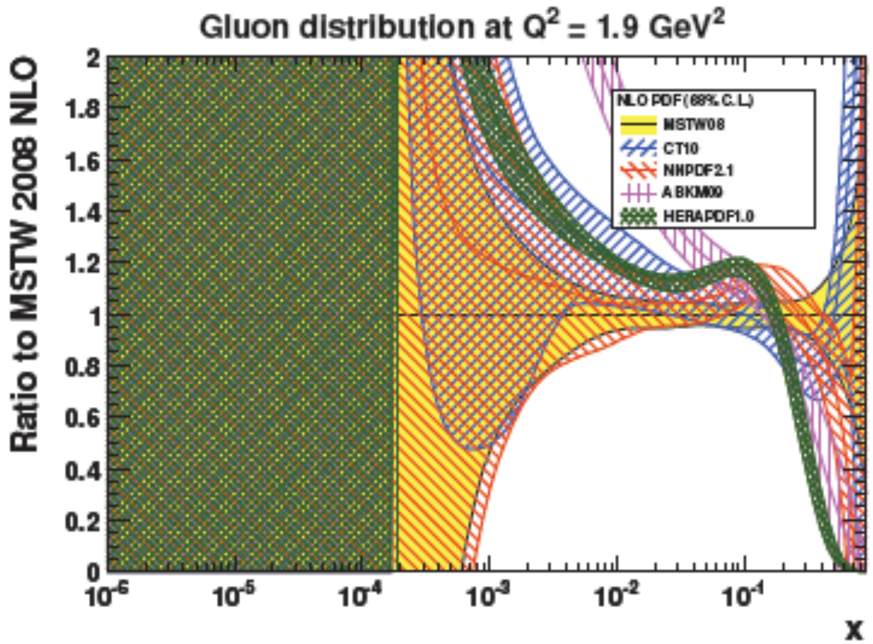
6. Complementarity of LHeC to LHC for **new physics BSM**
   LQ spectroscopy, eeqq CI, Higgs, e^*

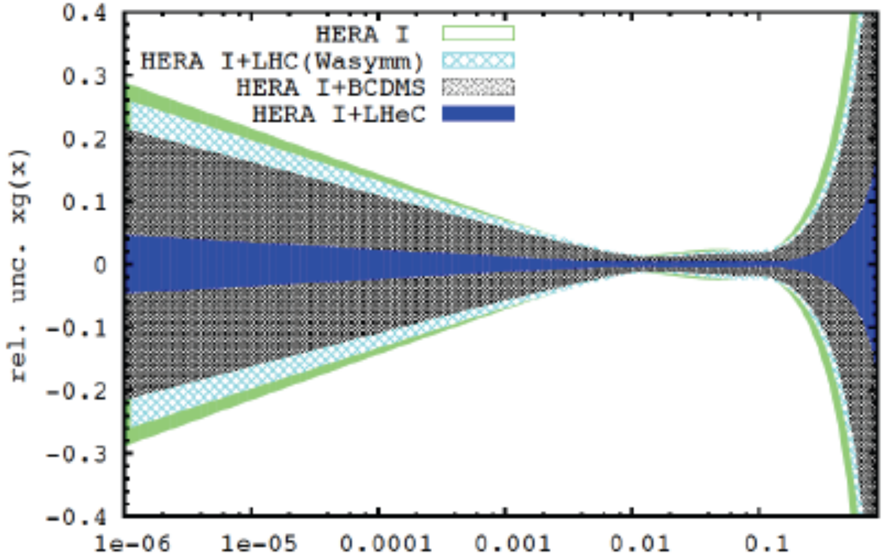
7. - 12..

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 . . . .

case	cut [Q^2 in GeV^2]	relative accuray in %
HERA only (14p)	$Q^2 > 3.5$	1.94
HERA+jets (14p)	$Q^2 > 3.5$	0.82
LHeC only (14p)	$Q^2 > 3.5$	0.15
LHeC only (10p)	$Q^2 > 3.5$	0.17
LHeC only (14p)	$Q^2 > 20.$	0.25
LHeC+HERA (10p)	$Q^2 > 3.5$	0.11
LHeC+HERA (10p)	$Q^2 > 7.0$	0.20
LHeC+HERA (10p)	$Q^2 > 10.$	0.26

10fold improvement in δ (α_s) from inclusive DIS



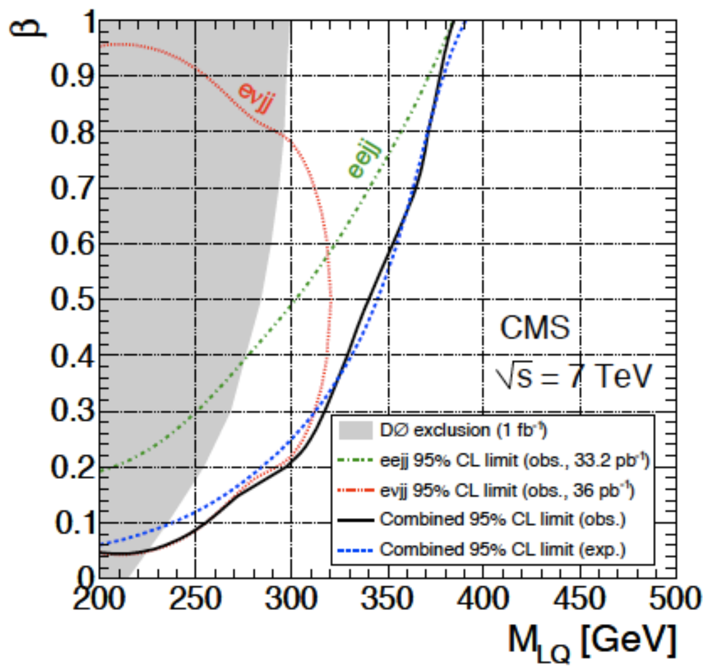


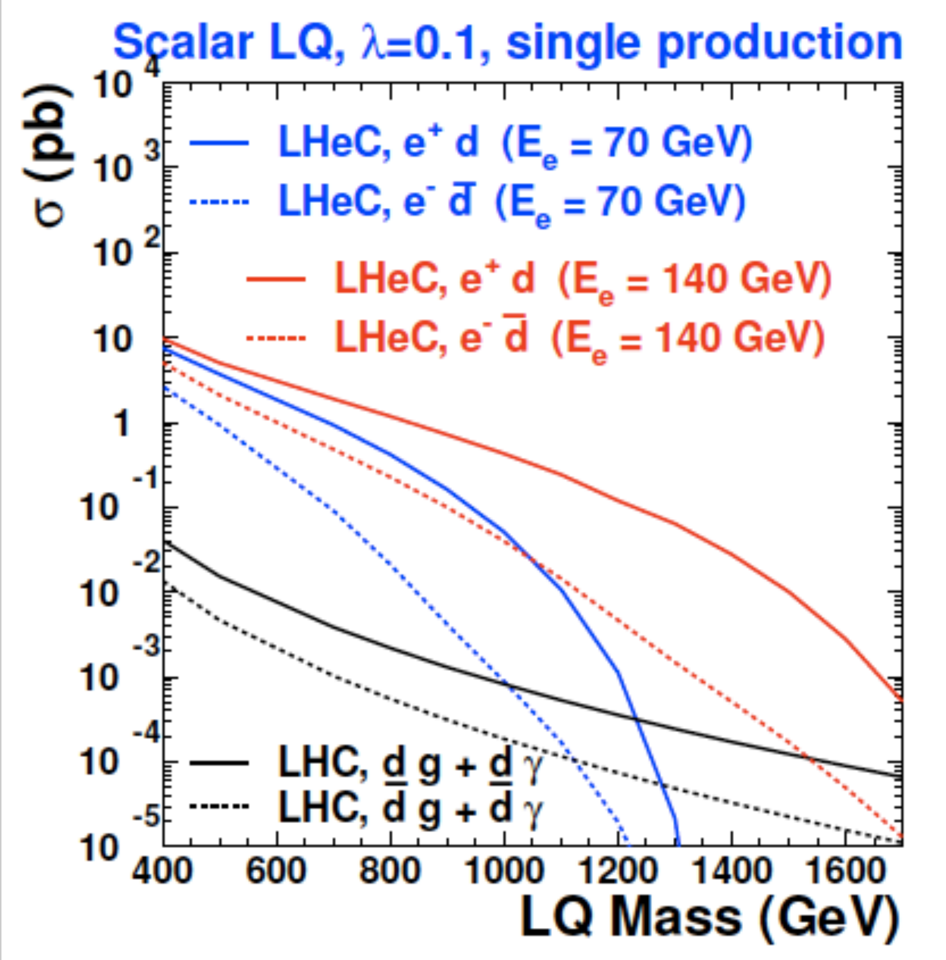
The whole art of describing p structure needs completely new experimental basis

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

Charge asymmetry → flavour
y distribution → spin

single LQ/G to M ≤√s





Prospects at the LHeC 148
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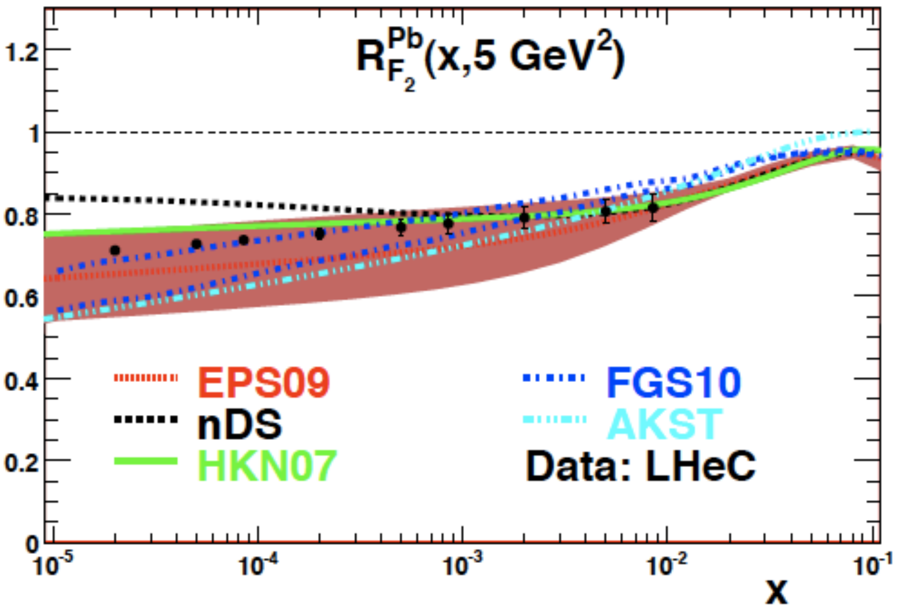
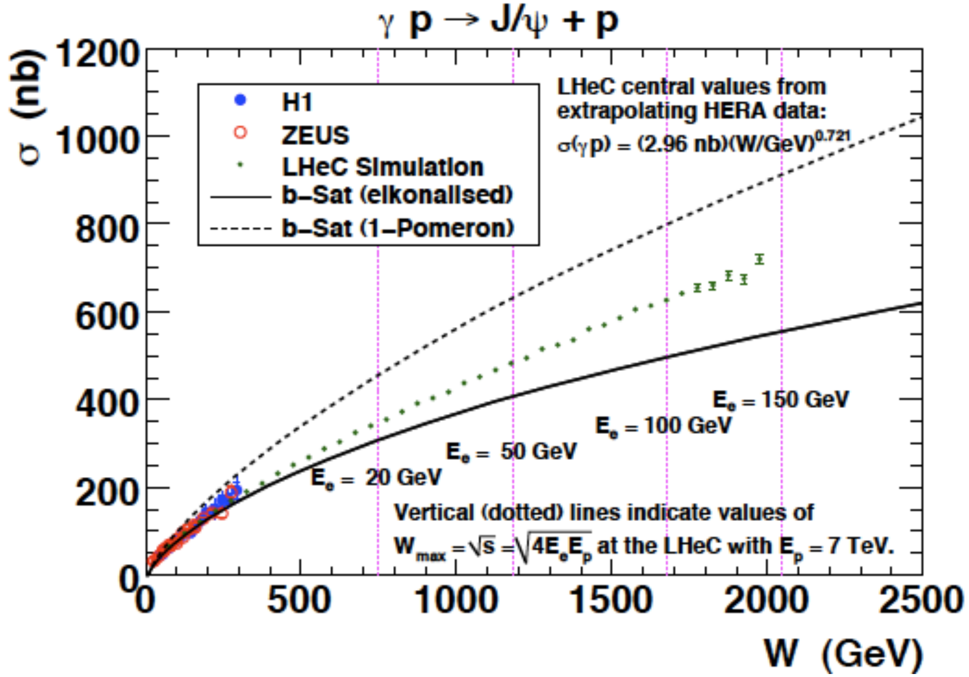
Partonic structure of nuclei (n) – unknown

The LHeC eA programme naturally follows AA



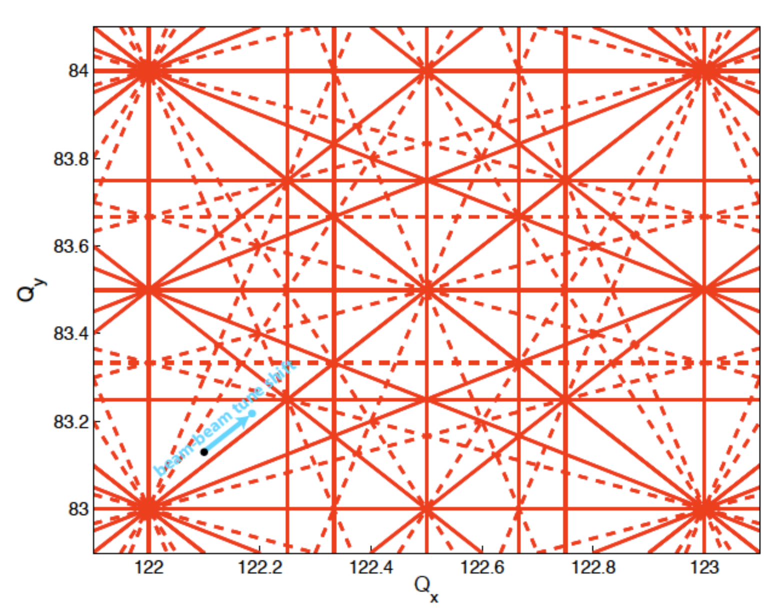
Theory of low x gluon interactions - untested



At small x the gluon distributions can be described in terms of the solutions of the BFKL equation for the Pomeron wave function. The QCD Pomeron is a composite state of reggeized gluons. The investigation at the LHeC of the odderon and

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

Working point for ring accelerator mounted on top of the LHC ("RR")



Coupling and constructive resonances up to 4th order

Beam energy	60 GeV
No. of particles per bunch	1.98×10^{10}
No. of bunches	2808
Circumference	26658.8832 m
Syn. rad. loss per turn	437.2 mev
Power	43.72 MW
Damping partition $j_x/j_y/j_e$	1.5/1/1.5
Coupling constant κ	0.5
Damping time τ_x	0.016 s
Damping time τ_y	0.024 s
Damping time τ_e	0.016 s
Polarization time	61.7 min
Horizontal emittance (no coupling)	5.53 nm
Horizontal emittance ($\kappa = 0.5$)	4.15 nm
Vertical emittance ($\kappa = 0.5$)	2.07 nm
RF voltage V_{RF}	500 MV
RF frequency f_{RF}	721.421 MHz
Energy spread	0.00116
Momentum compaction	0.00008084
Synchrotron tune	0.058
Bunch length	6.88 mm
Max. hor. beta	141.94 m
Max. ver. beta	138.43 m
Max. hor. dispersion	1.66 m
Vert. dispersion	0 m
Max. hor. beam size (5/2.5 nm emittance)	2.1 mm
Max. ver. beam size (5/2.5 nm emittance)	0.59 mm

Table 7.8: LHeC Optics Parameters

7.12.4 10 GeV injector

For the acceleration to 10 GeV we propose a re-circulating LINAC, designed as a downscaled, low energy version of the 25 GeV ELFE at CERN design [?] using modern ILC-type RF-technology.

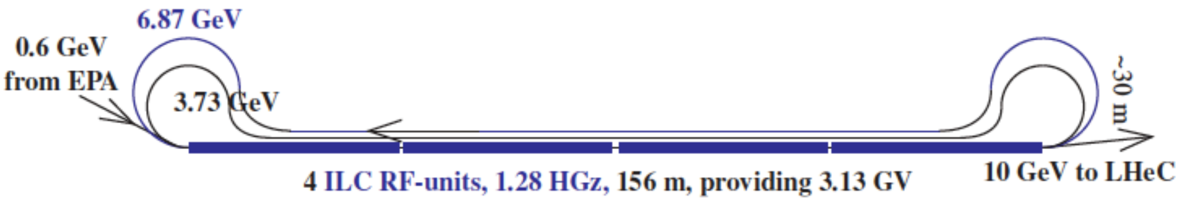
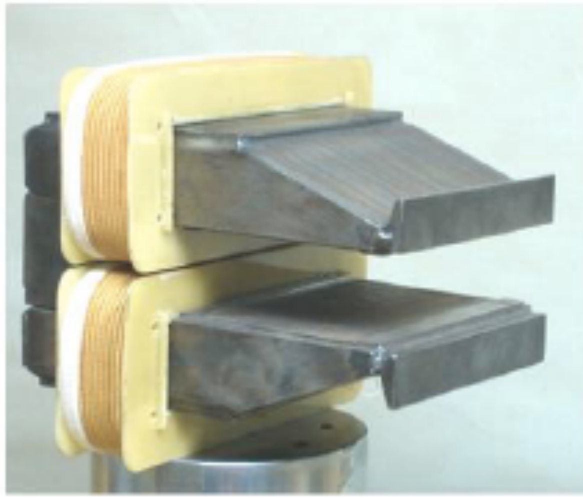


Figure 7.62: Recirculator using 4 ILC modules.

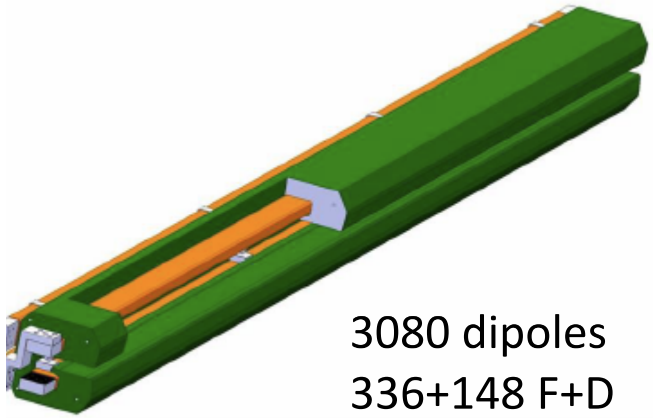
LINAC racetrack – injector – close to Linac design [R+**D**]



Parameter	Value	Units
Beam Energy	10-60	GeV
Magnetic Length	5.35	Meters
Magnetic Field	0.0127-0.0763	Tesla
Number of magnets	3080	
Vertical aperture	40	mm
Pole width	150	mm
Number of turns	2	
Current @ 0.763 T	1300	Ampere
Conductor material	copper	
Magnet inductance	0.15	milli-Henry
Magnet resistance	0.16	milli-Ohm
Power @ 60 GeV	270	Watt
Total power consumption @ 60 GeV	0.8	MW
Cooling	air or water	depends on tunnel ventilation

Table 9.4: Main parameters of bending magnets for the RR Option.

Novosibirsk dipole prototype
measured field reproducible
to the required 2 10^{-4}
CERN prototype under test



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

Table 8.2: IP beam parameters

	protons	electrons
beam energy [GeV]	7000	60
Lorentz factor γ	7460	117400
normalizwed emittance $\gamma\epsilon_{x,y}$ [μm]	3.75	50
geometric emittance $\epsilon_{x,y}$ [nm]	0.,40	0.43
a IP beta function $\beta^*_{x,y}$ [m]	0.10	0.12
rms IP beam size $\sigma^*_{x,y}$ [μm]	7	7
initial rms IP beam divergence $\sigma^*_{x',y'}$ [μrad]	70	58
beam current [mA]	$\geq$430	6.4
bunch spacing [ns]	25 or 50	(25 or) 50
bunch population [ns]	1.7×10^{11}	(1 or) 2×10^9

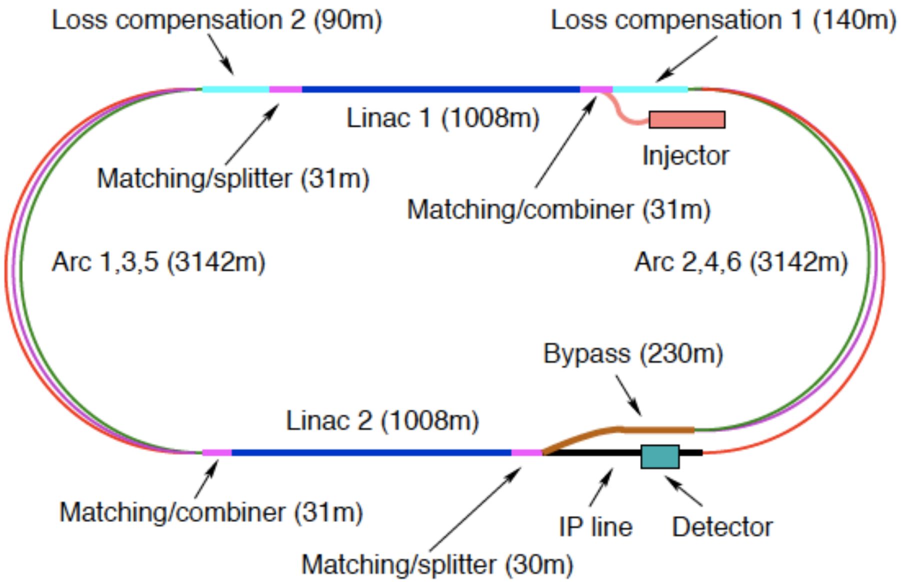
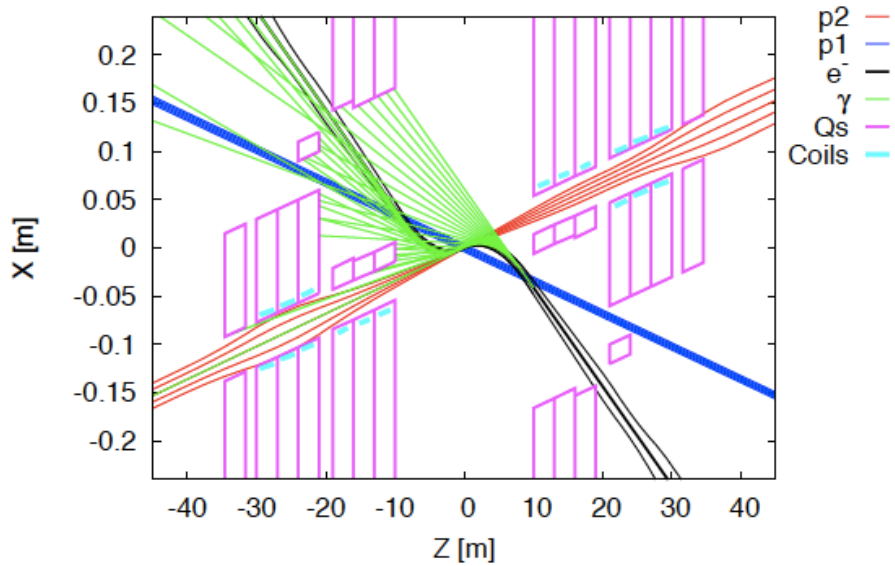


Figure 8.29: The schematic layout of the recirculating linear accelerator complex.

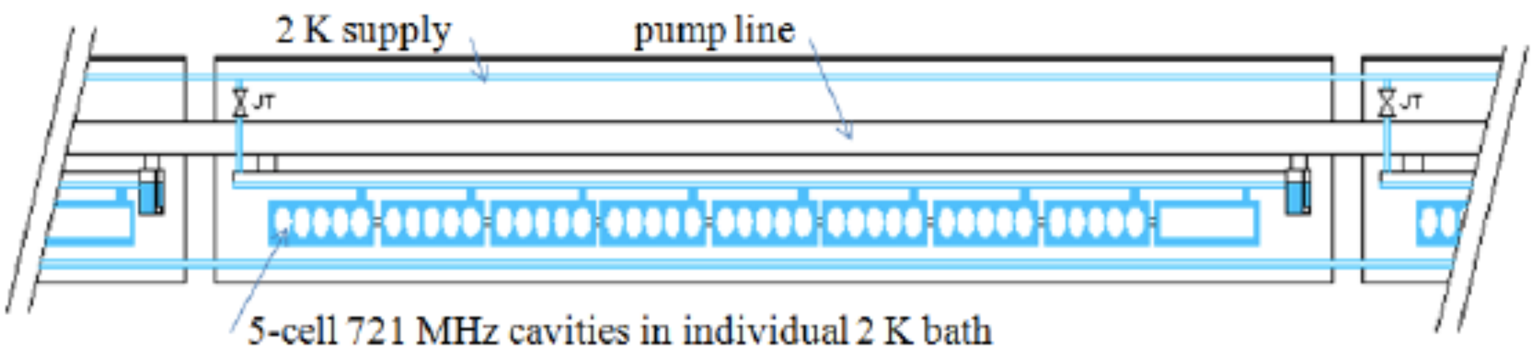


required for high luminosity, the linac must be based on superconducting (SC) radiofrequency (RF) technology. The development and industrial production of its components can exploit synergies with numerous other advancing SC-RF projects around the world, such as the DESY XFEL, eRHIC, ESS, ILC, CEBAF upgrade, CESR-ERL, JLAMP, and the CERN HP-SPL.

9.2 Ring-Ring RF Design . . . . . .
9.2.1 Design Parameters . . . .
9.2.2 Cavities and klystrons . .
9.3 Linac-Ring RF Design . . . . . .
9.3.1 Design Parameters . . . .
9.3.2 Layout and RF powering
9.3.3 Arc RF systems . . . . .

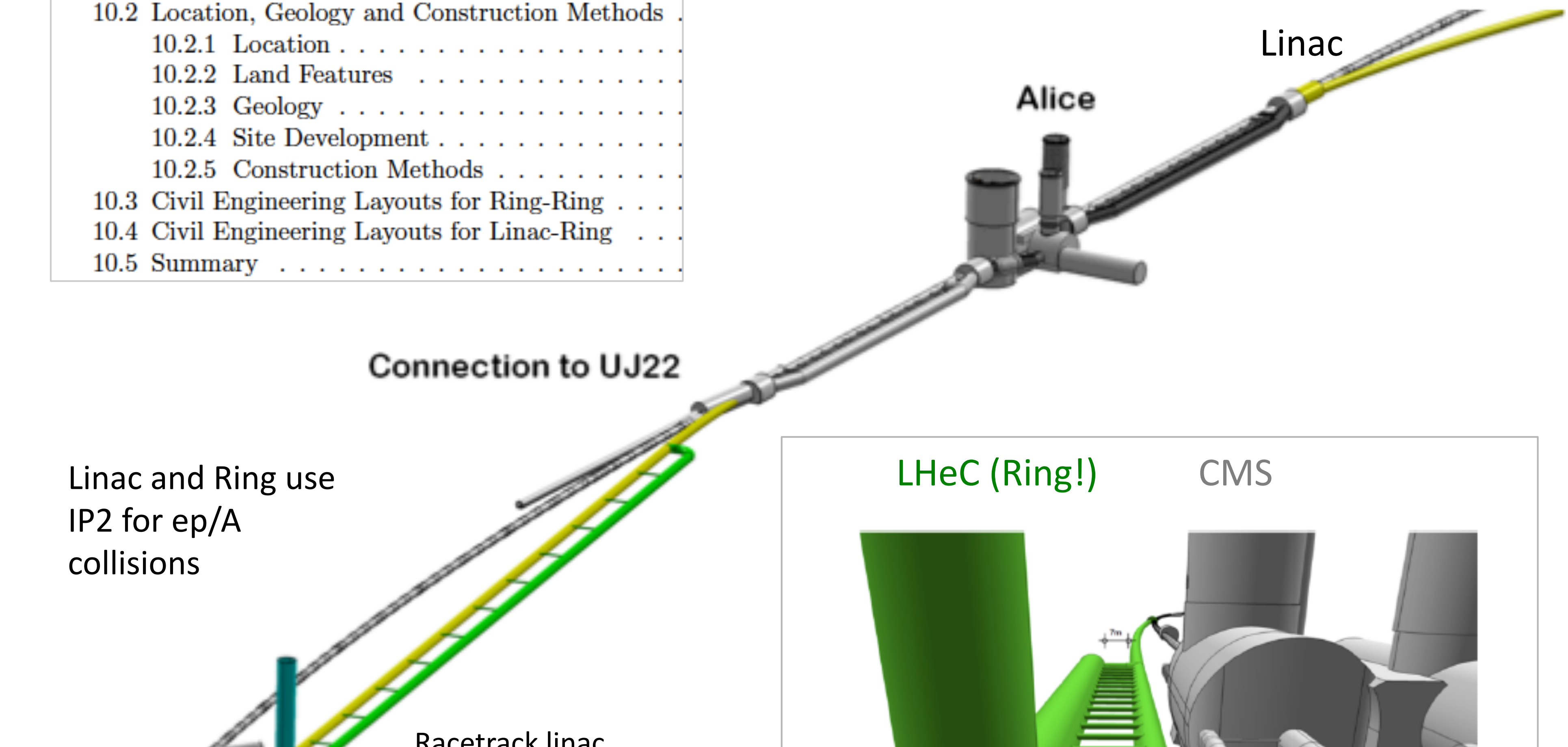
9.7 Cryogenics . . . .
9.7.1 Ring-Ring Cryogenics Design . . . .
9.7.2 Linac-Ring Cryogenics Design . . . .
9.7.3 General Conclusions Cryogenics for LHeC .

Parameter	Value
Two linacs	length 1 km
5-cell cavities	length 1.04 m
Number	944
Cavities/ cryomodule	8
Number cryomodules	118
Length cryomodule	14 m
Voltage per cavity	21.2 MV
R/Q	285Ω
Cavity Q0	$2.5 \cdot 10^{10}$
Operation	CW
Bath cooling	2 K
Cooling power/cav.	32 W @2 K
Total cooling power (2 linacs)	30 kW @2 K



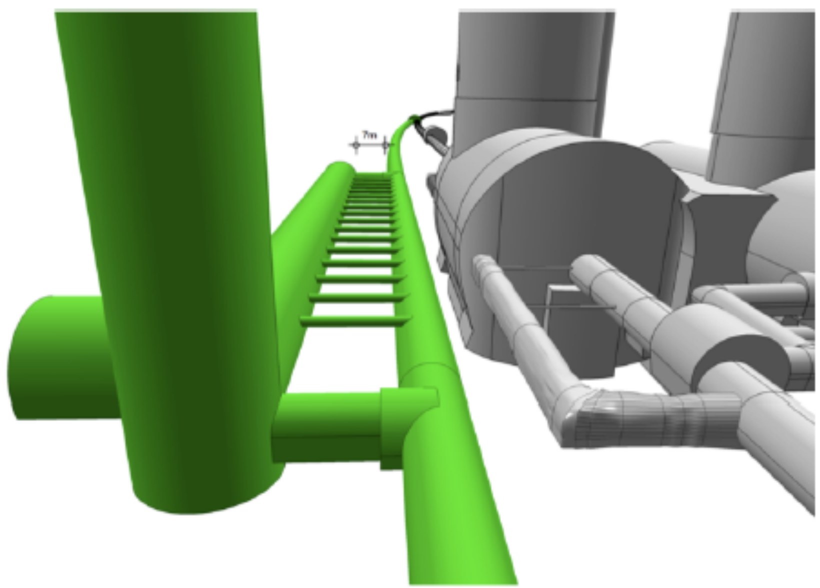
systems will consist of a complex task. Further cavities and cryomodules will require a limited R&D program. From this we expect improved quality factors with respect to today's state of the art. The cryogenics of the L-R version consists of a formidable engineering challenge, however, it is feasible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

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



Linac and Ring use IP2 for ep/A collisions

Racetrack linac inside LHC and shafts on CERN territory



CMS bypass for RR option with rf tunnel section

IV Detector

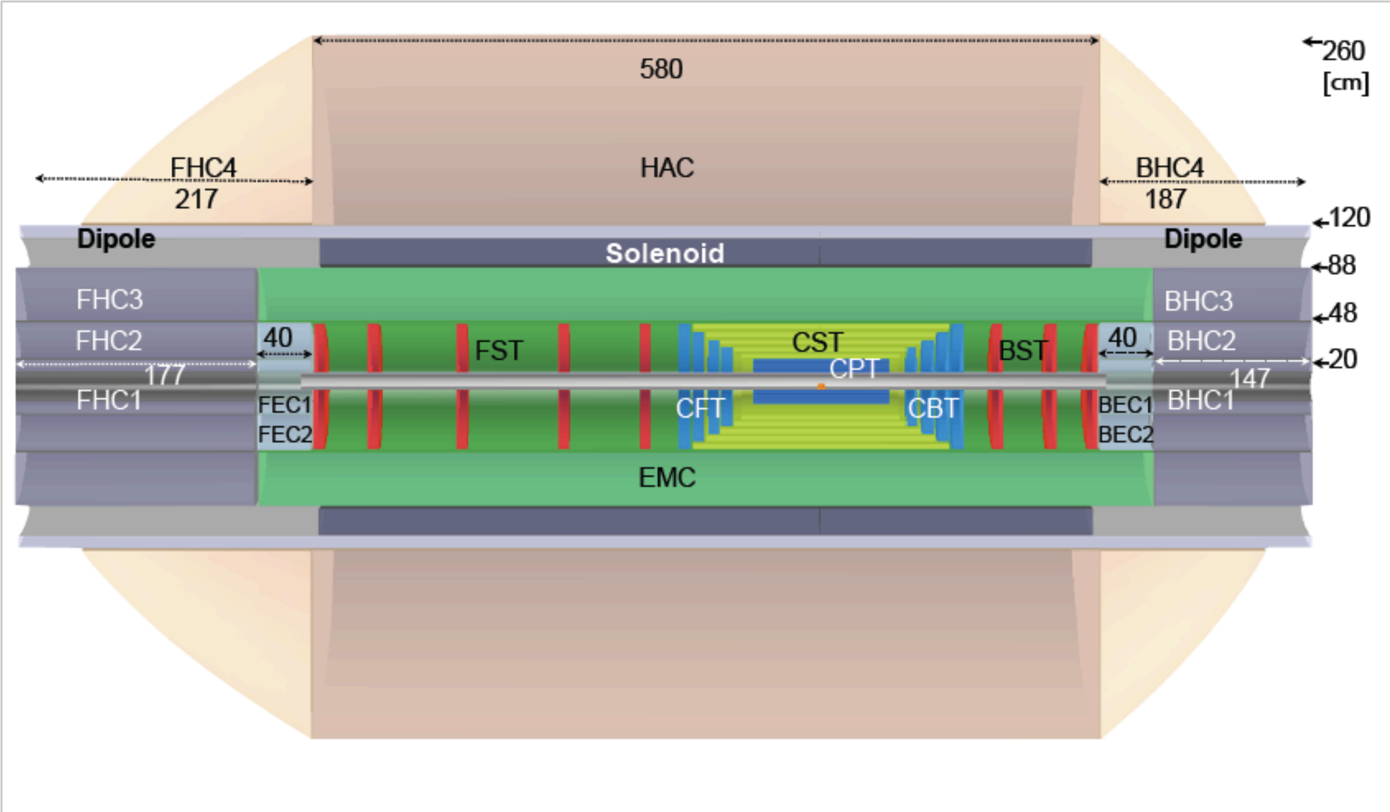


Figure 13.9: An *rz* cross section of the LHeC detector, in its baseline configuration (A). In

Requirements

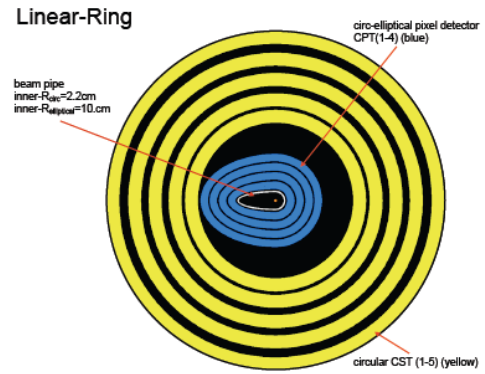
High Precision (resolution, calibration, low noise at low y tagging of b,c)

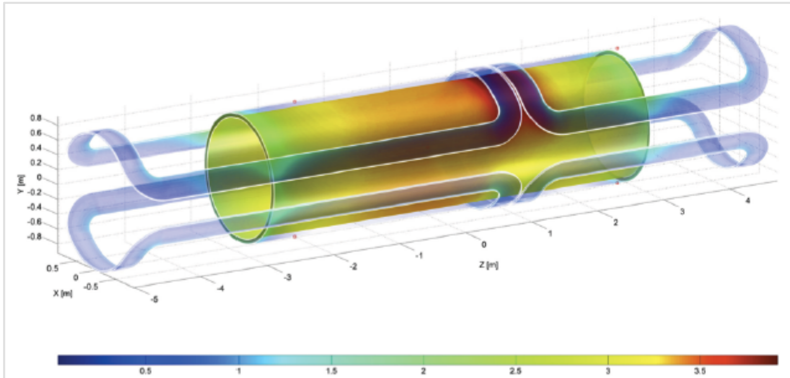
Modular for 'fast' installation

State of the art for 'no' R+D

1-179° acceptance for low Q^2, high x

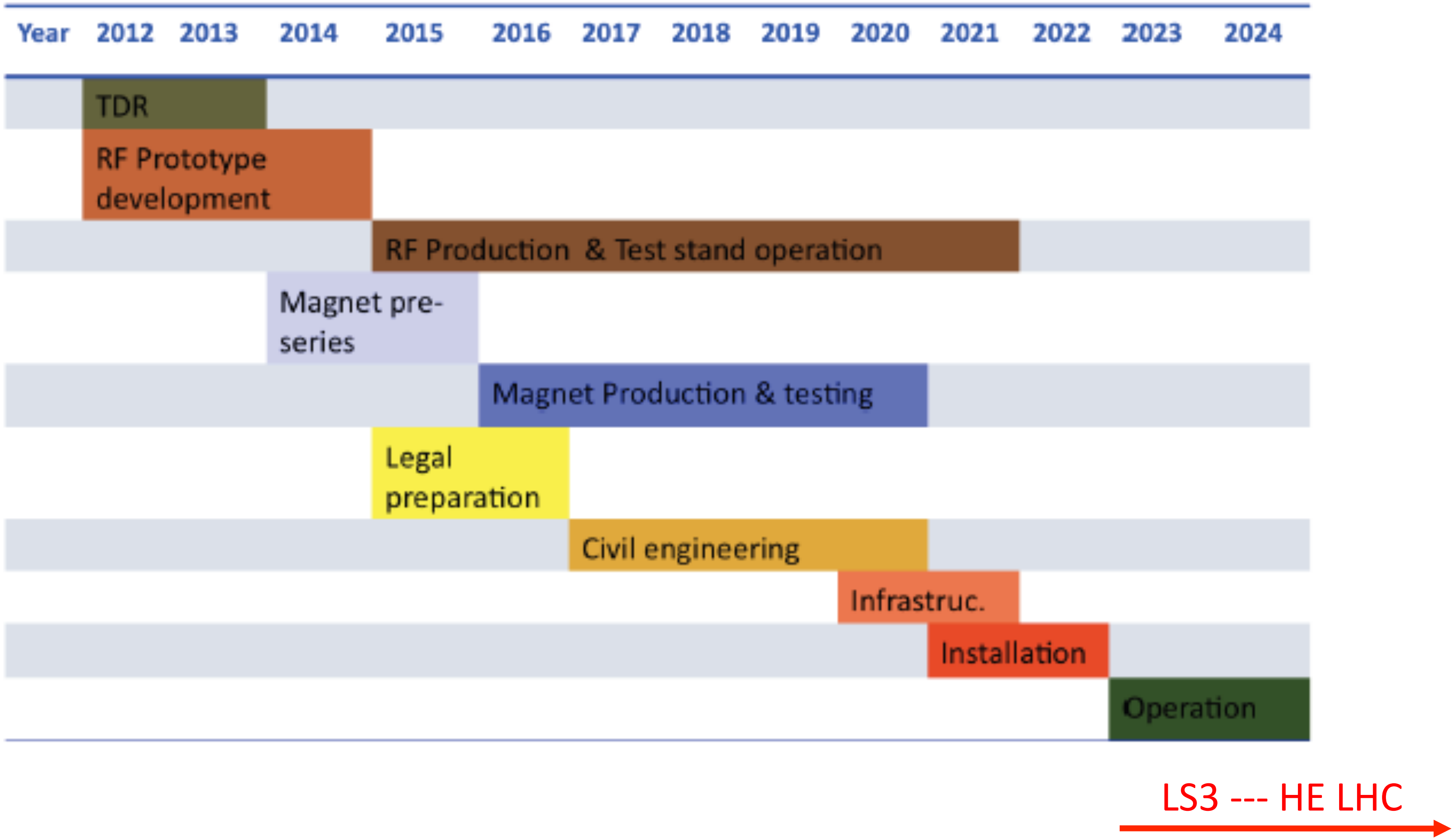
Affordable





Present dimensions: LxD =14x9m² [CMS 21 x 15m², ATLAS 45 x 25 m²]
Taggers at -62m (e),100m (γ,LR), -22.4m (γ,RR), +100m (n), +420m (p)

11 Project Planning



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). In

LHeC Accelerator: 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
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KEK

The striking advantage of an extension from LHC to a LHeC lies, apart from the new physics, in the comparatively small investment cost, the possibility of quasi undisturbed continuation of LHC hadron physics and the fact that the technologies are largely already at hand today. This applies also to the cryogenic part. No so-called "show-stoppers" could be detected during

Conclusion of the cryo section (page 403) of the draft CDR

http://cern.ch/lhec

With thanks and compliments to the efforts and competence of all engineers, experimentalists and theorists, involved and engaged.

Thanks to the 3 CERN directors, ECFA and NuPECC for interest, much support and guidance.