LHeC Detector Design

CDR design 2012

Detector now including FCC-he

Tracker and Calorimeters

Project Development – Next Steps

LHeC:
E_e=60 GeV
E_p= 7 TeV

For references,
please consult
lhec.web.cern.ch

LHeC CDR
arXiv:1206.2913
J.Phys. G39 (2012) 075001

Max Klein
University of Liverpool

for the LHeC Study Group

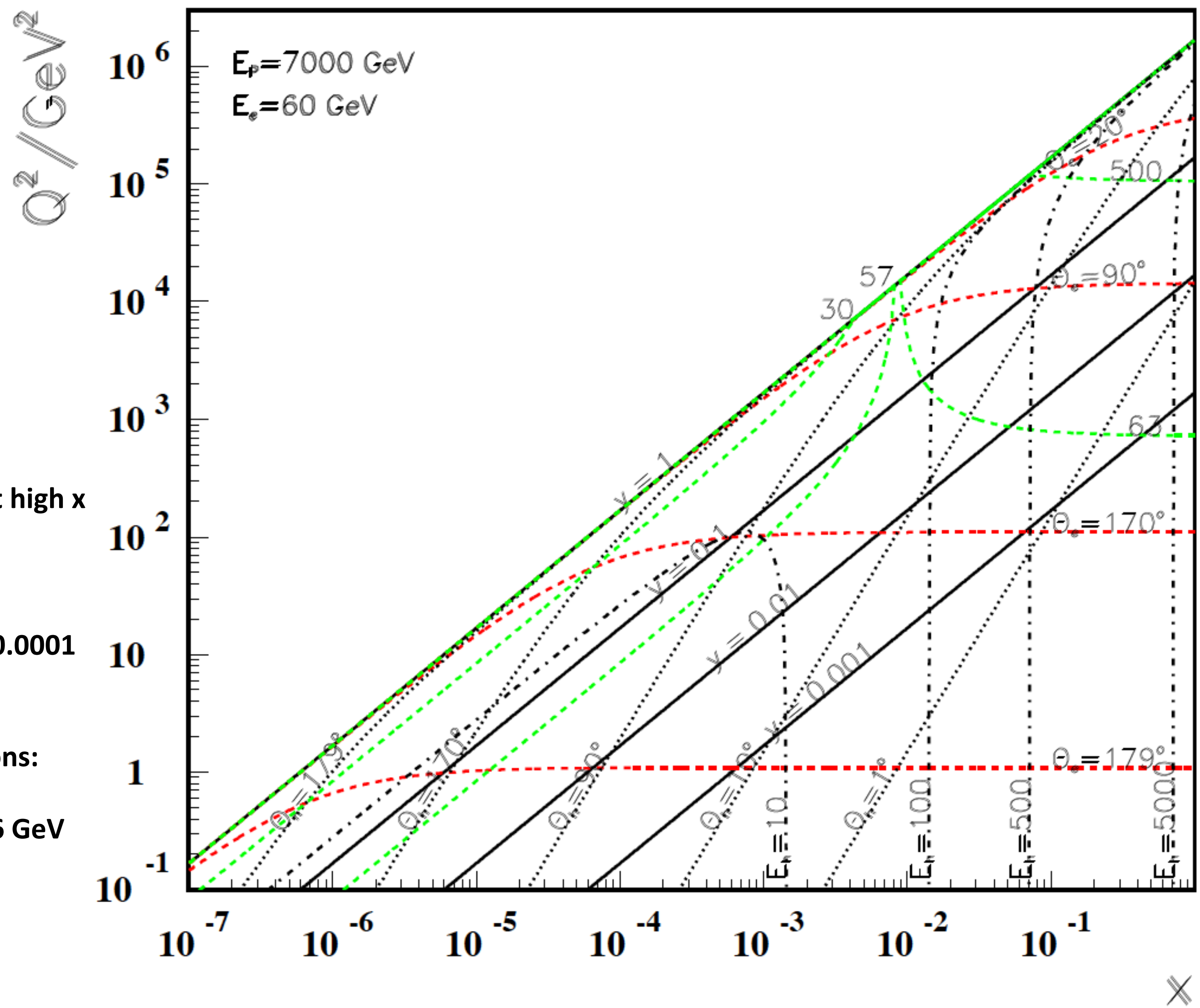
FCC_eh:
E_e =60 GeV
E_p =50 TeV

HE LHC:
E_p=14 TeV

Development of the LHeC Detector, DIS17, Brum, 5th of April 2017

Kinematics at LHeC

default energies



Observations

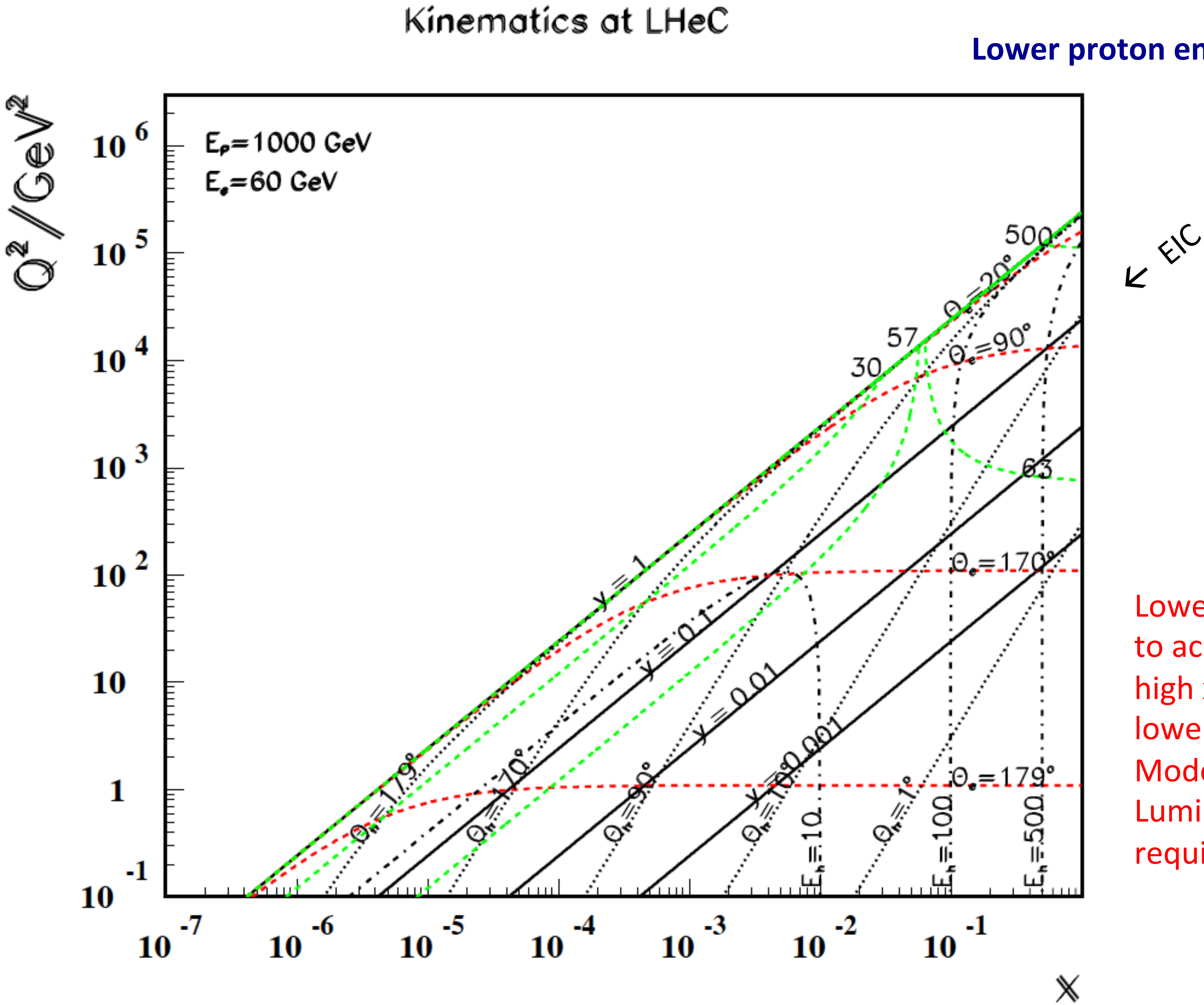
Good angular coverage but at high x low Q2

High Q^2 to 10^6
CC at large x > 0.0001

Low Q^2 High x
Very fwd hadrons:

High y =0.9 → 6 GeV
F_L “easy”

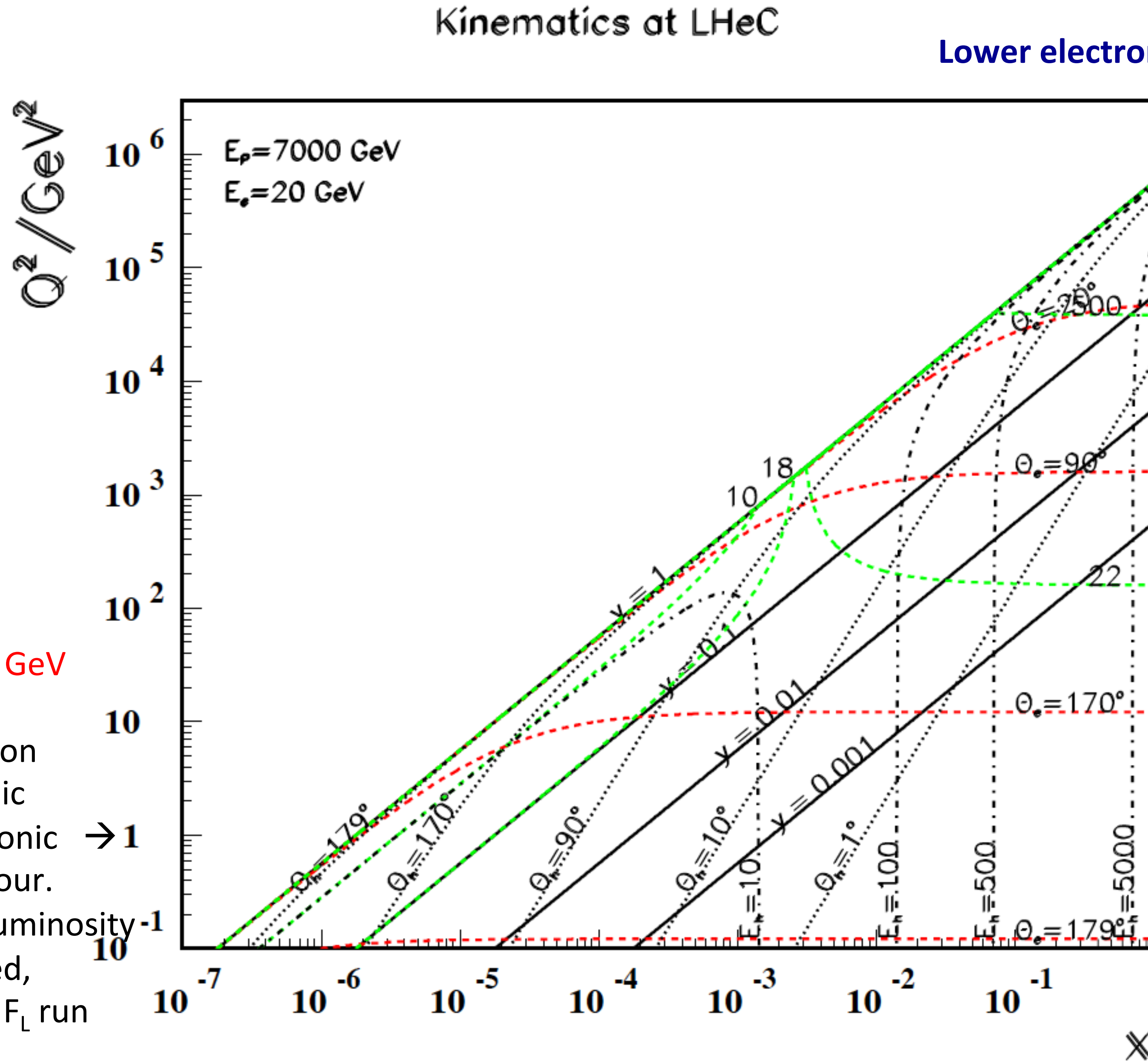
Lower proton energy



Lower E_p to access high x at lower Q^2

Modest Luminosity required

Lower electron energy



E_e = 20 GeV

Covers transition hadronic to partonic → behaviour.

"NO" luminosity required, part of F_L run

NC Cross Section Correlated Uncertainties (Q^2=2 GeV^2)

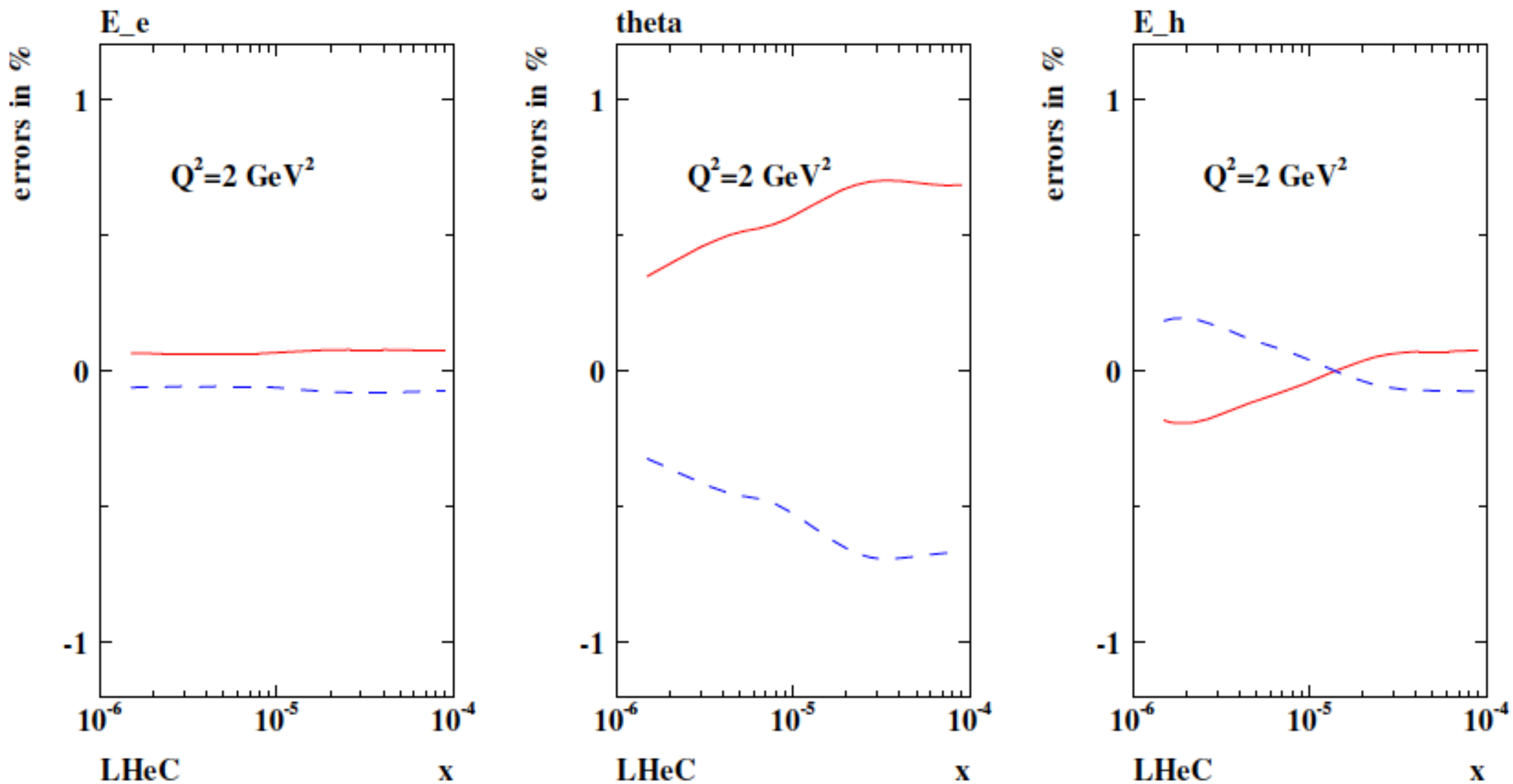


Figure 3.2: Neutral current cross section errors, calculated for $60 \times 7000\,\mathrm{GeV}^2$, resulting from scale uncertainties of the scattered electron energy $\delta E'_e/E'_e = 0.1\,\%$, of its polar angle $\delta\theta_e = 0.1\,\mathrm{mrad}$ and the hadronic final state energy $\delta E_h/E_h = 0.5\,\%$, at low $Q^2 = 2\,\mathrm{GeV}^2$ and correspondingly low x.

From LHeC CDR

NC Cross Section Correlated Uncertainties (Q^2=20000 GeV^2)

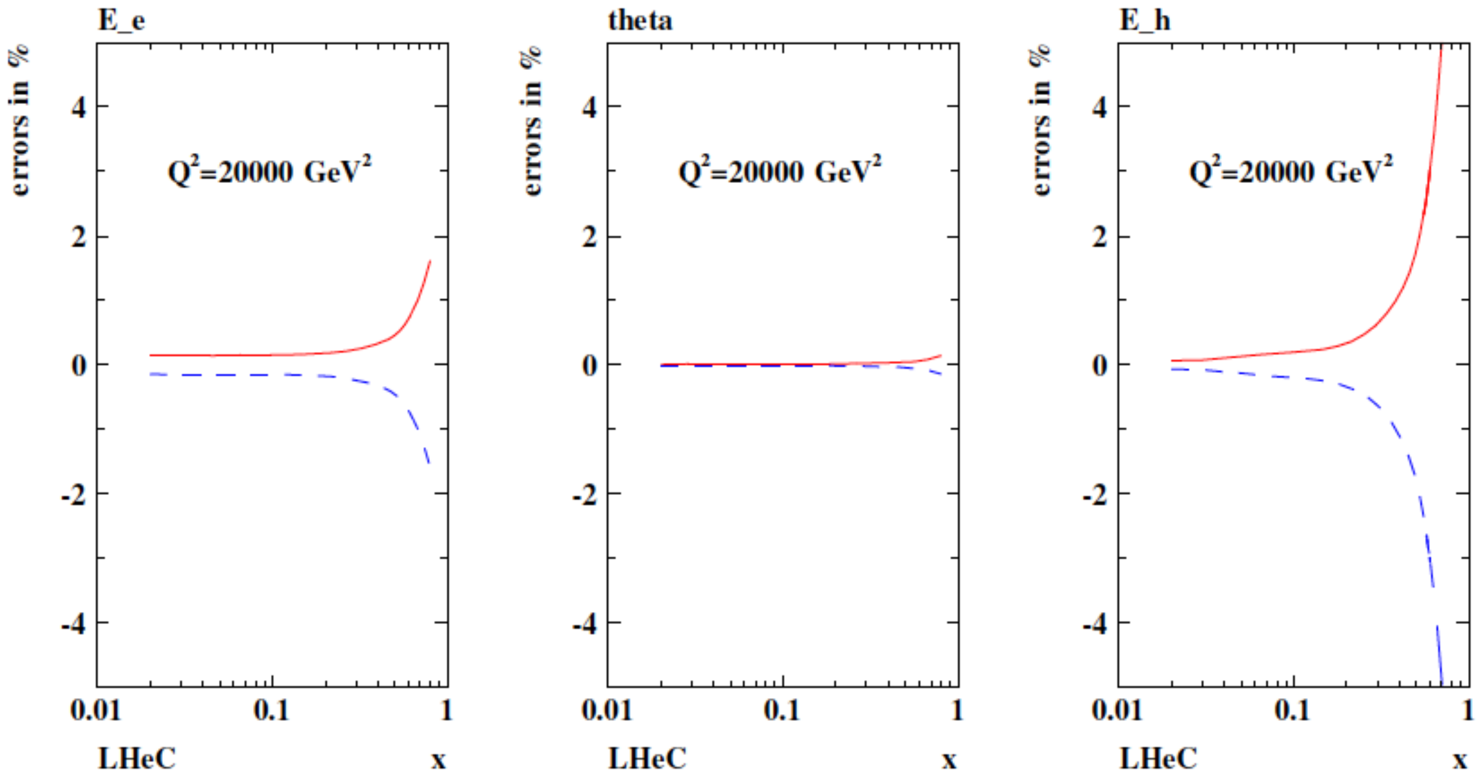


Figure 3.3: Neutral current cross section errors, calculated for $60 \times 7000\,\mathrm{GeV}^2$ unpolarised $e^- p$ scattering, resulting from scale uncertainties of the scattered electron energy $\delta E'_e/E'_e = 0.1\,\%$, of its polar angle $\delta\theta_e = 0.1\,\mathrm{mrad}$ and the hadronic final state energy $\delta E_h/E_h = 0.5\,\%$, at large $Q^2 = 20000\,\mathrm{GeV}^2$ and correspondingly large x. Note that the characteristic behaviour of the relative uncertainty at large x, i.e. to diverge $\propto 1/(1-x)$, is independent of Q^2, i.e. persistently observed at $Q^2 = 200000\,\mathrm{GeV}^2$ for example too.

From LHeC CDR

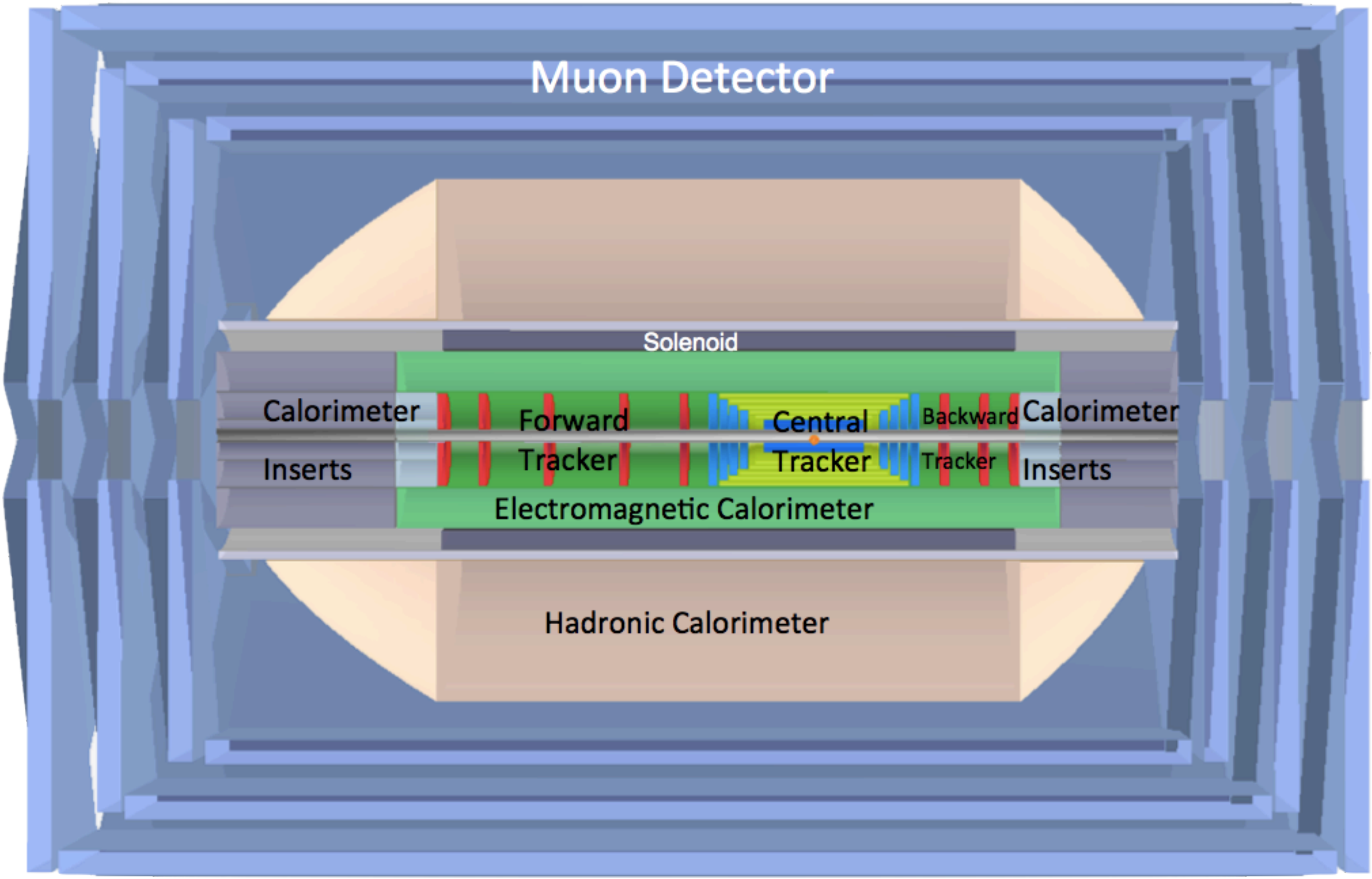
Detector in the CDR

kinematics and requirements

region of detector	backward	barrel	forward
approximate angular range / degrees	179 - 135	135 -45	45-1
scattered electron energy/GeV	3-100	10-400	50-5000
x_e	$10^{-7} - 1$	$10^{-4} - 1$	$10^{-2} - 1$
elm scale calibration in %	0.1	0.2	0.5
elm energy resolution $\delta E/E$ in % $\cdot\sqrt{E/GeV}$	10	15	15
hadronic final state energy/GeV	3-100	3-200	3-5000
x_h	$10^{-7} - 10^{-3}$	$10^{-5} - 10^{-2}$	$10^{-4} - 1$
hadronic scale calibration in %	2	1	1
hadronic energy resolution in % $\cdot\sqrt{E/GeV}$	60	50	40

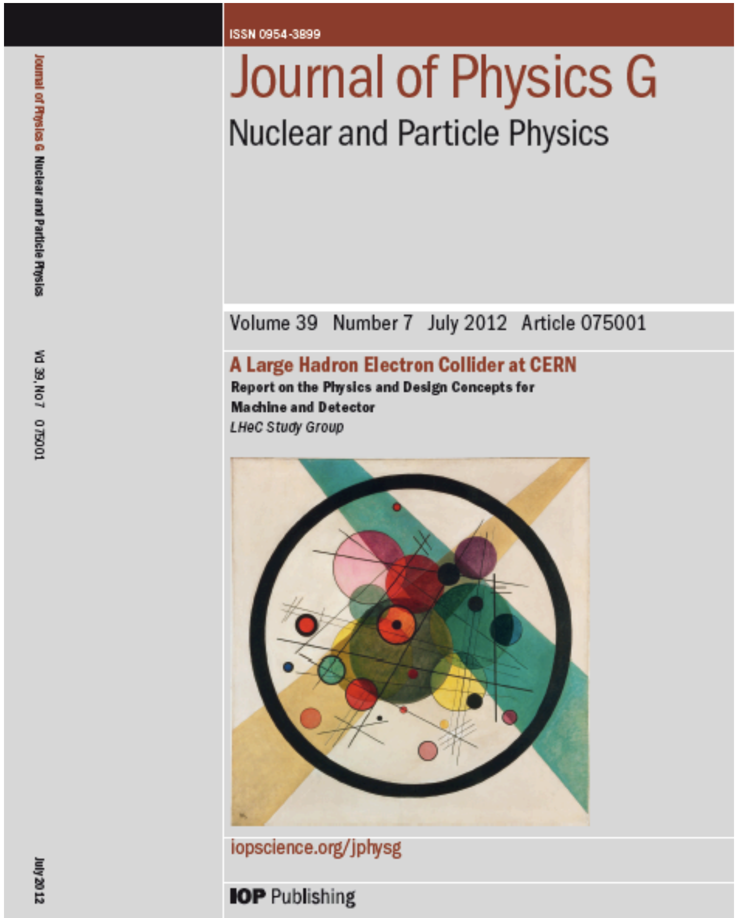
Now: Higgs: maximum fwd acceptance (p direction), better hadronic resolution, crucial c and b tagging capabilities. Still muon tag only (but muon momentum for FCC-eh for H)

LHeC Detector in the CDR (2012)



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)

Design Report 2012



arXiv:1206.2913

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)

600 pages. Physics, Detector and Two Accelerator Options
ring-ring which may be of interest in the HE-LHC context and linac-ring, the default LH(e)C

LHeC Study Group

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], V.Cetinkaya[01], 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], 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], 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], 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], 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], 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]

CDR authors

LHeC Detector in the CDR (1206.2913)

Detector Magnets

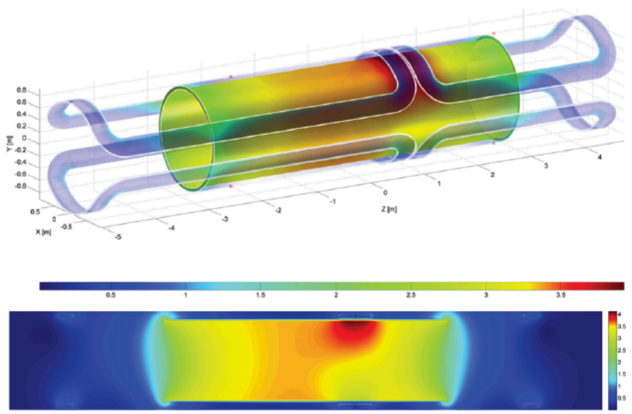


Figure 13.13: Magnetic field of the magnet system of solenoid and the two internal superconducting dipoles at nominal currents (effect of iron ignored). The position of the peak magnetic field of 3.9 T is local due to the adjacent current return heads on top of the solenoid where all magnetic fields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

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

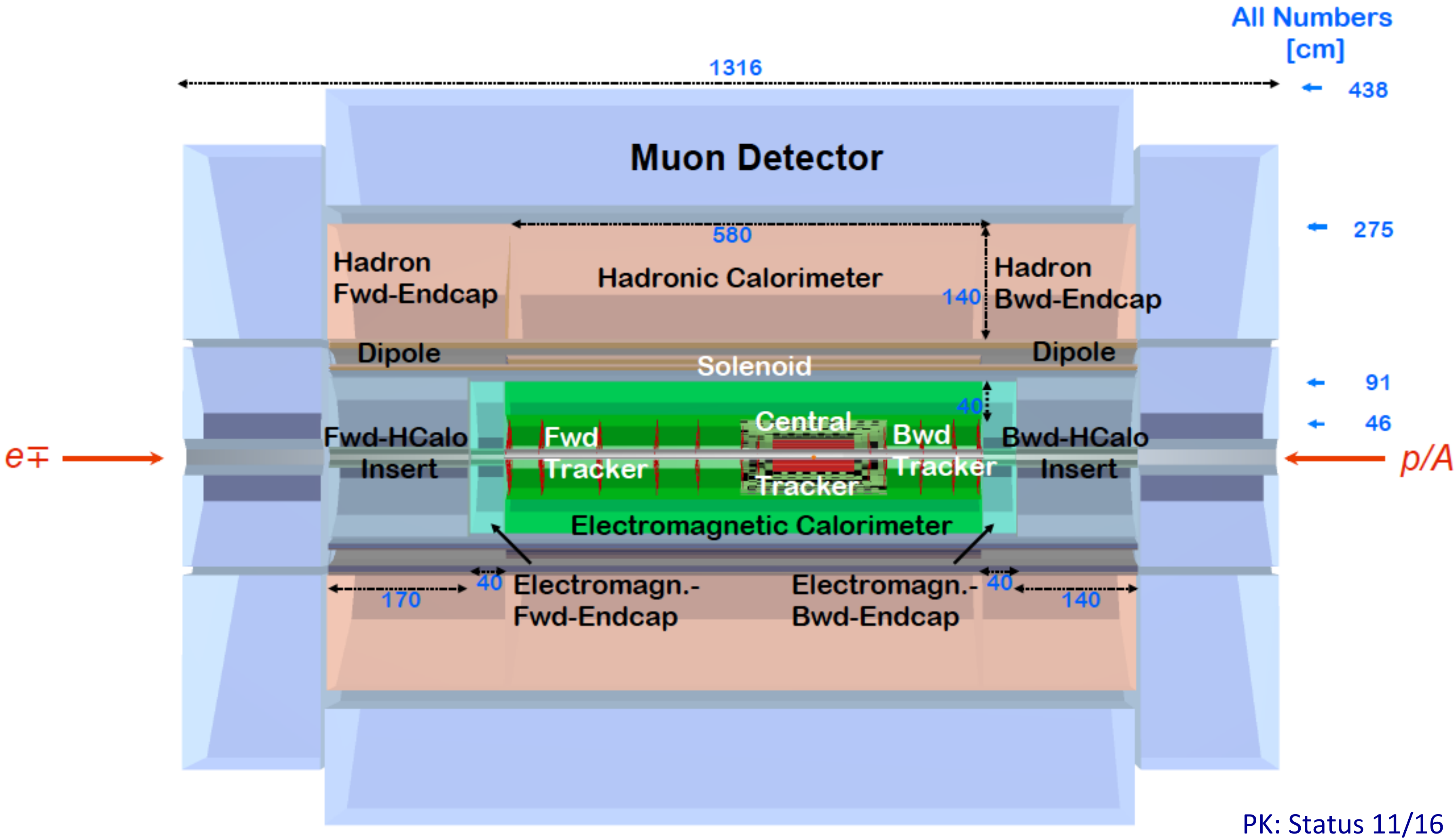
3.5T field at ~1m radius to house a Silicon tracker

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.

LHeC Detector 2016



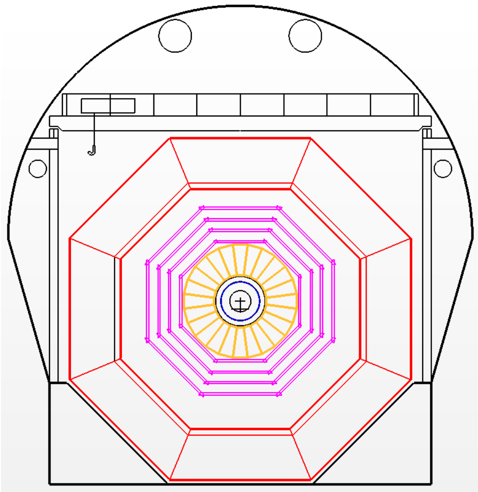
PK: Status 11/16

Dimensions and Multitudes - LHeC

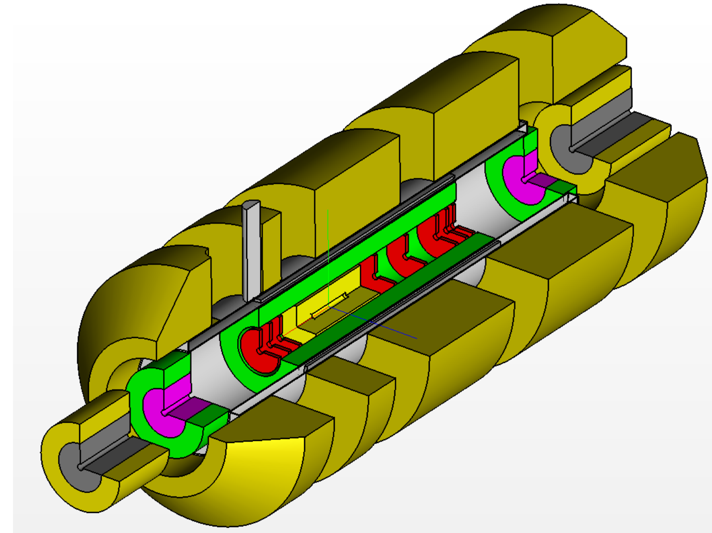
Tracker	FST_{pix}	FST_{strix}	CFT_{pix}	CPT_{pix}	CST_{strix}	CBT_{pix}	BST_{strix}	BST_{pix}
#Wheels	5		2	–	–	2	3	
#Rings/Wheel	2_{inner}	3_{outer}	3/4	–	–	3/4	3_{outer}	2_{inner}
#Layers	–	–	–	4	5	–	–	–
$\theta_{min/max}$ $[^0]$	0.7	3.8	3.0	5.1	24/155	177.8	173.1	178.7
$\eta_{max/min}$	5.1	3.4	3.6	±3.1	±1.4	-3.6	-2.8	-4.5
$Si_{pix/strix}$ $[m^2]$	6.9	9.5	2.8	5.4	33.7	2.8	5.7	4.1
Sum-Si $[m^2]$	70.9 double layers taken into account							

Calo	FHC_{SiW}	FEC_{SiW}	$EMC_{SciPb/LAr}$	HAC_{SciFe}	BEC_{SiPb}	BHC_{SiFe}
$\theta_{min/max}$ $[^0]$	0.61	0.68	8/166	14.2/160	178.7	178.9
$\eta_{max/min}$	5.2	5.1	2.7/-2.1	2.1/-1.7	-4.5	-4.7
Volume $[m^3]$	6.7	1.6	15.1	165	1.6	5.8
Sum-Si $[m^2]$	197.4					

Installation Study

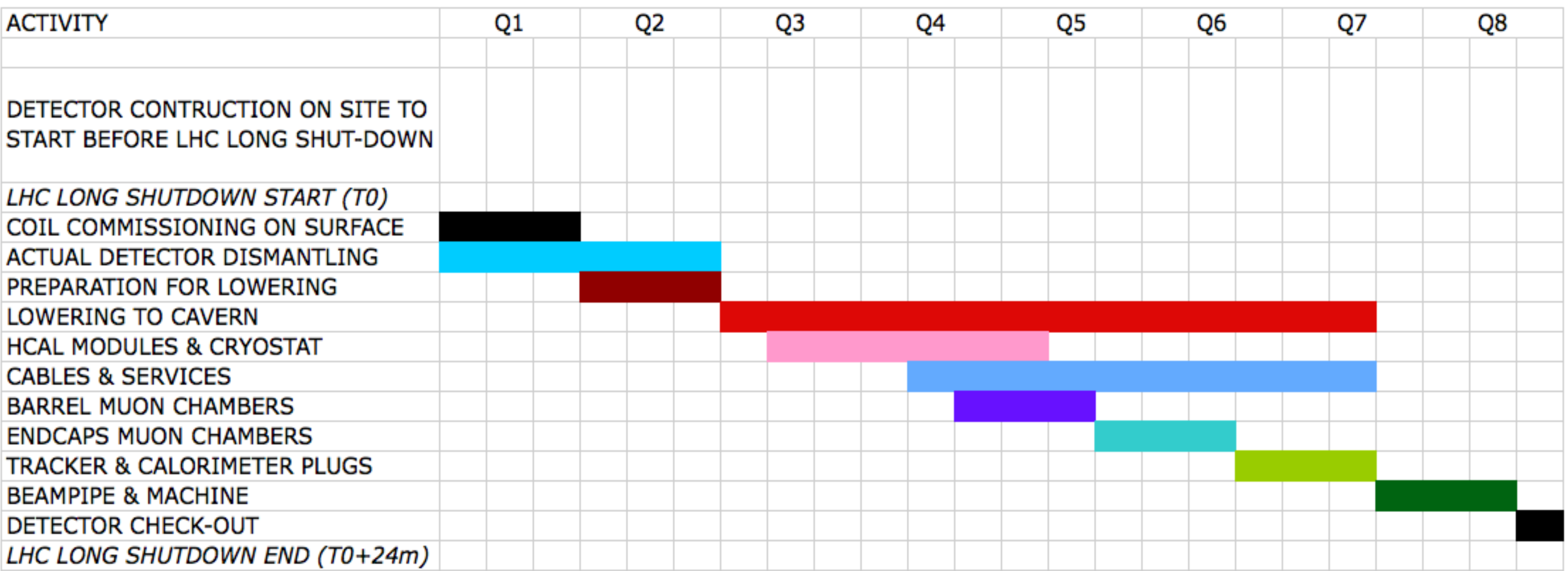


Detector fits in L3 magnet support

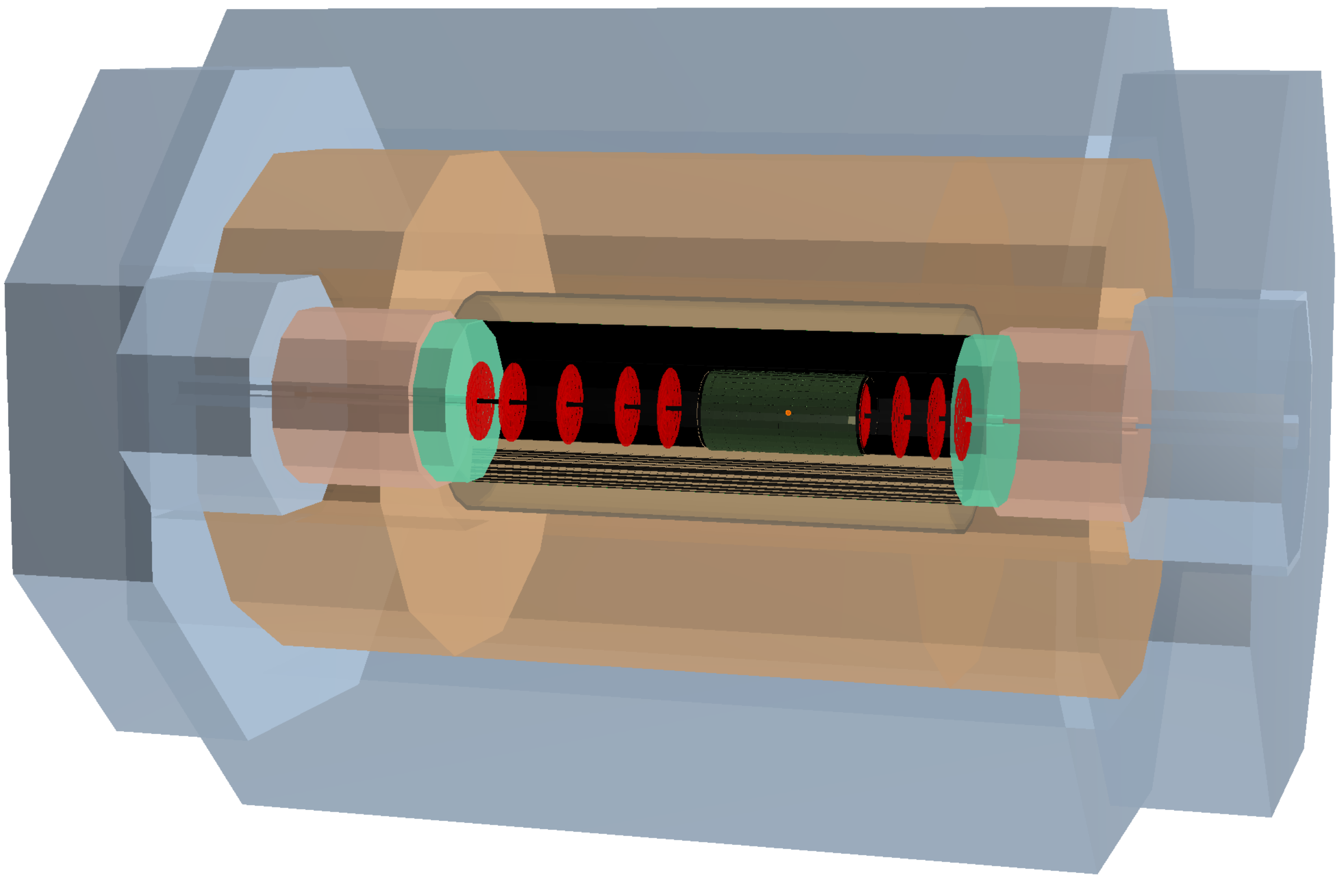


Modular structure

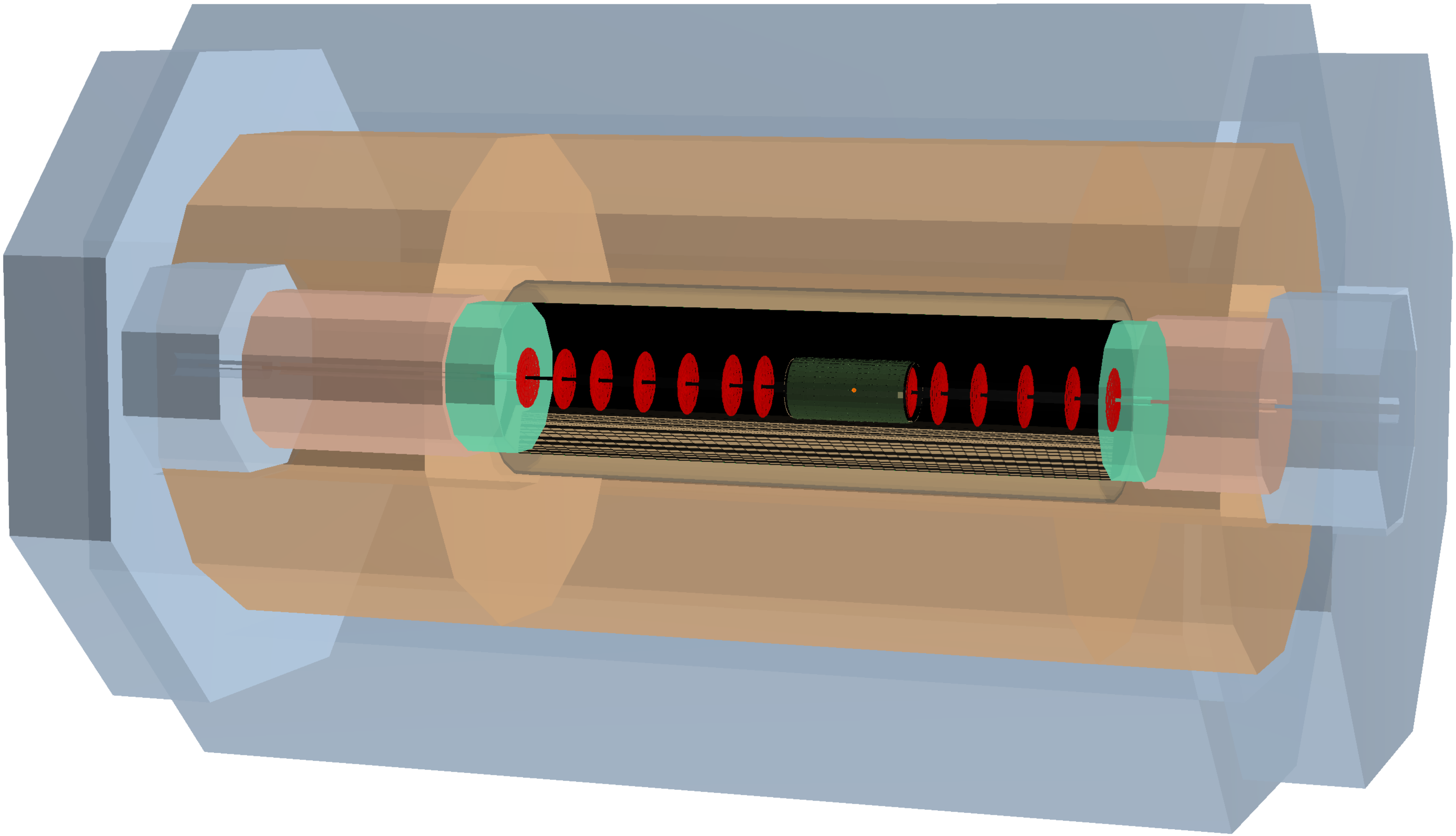
LHeC INSTALLATION SCHEDULE



LHeC Detector



FCC-eh Detector

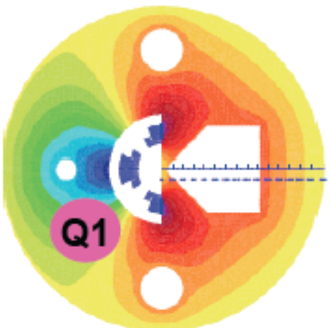


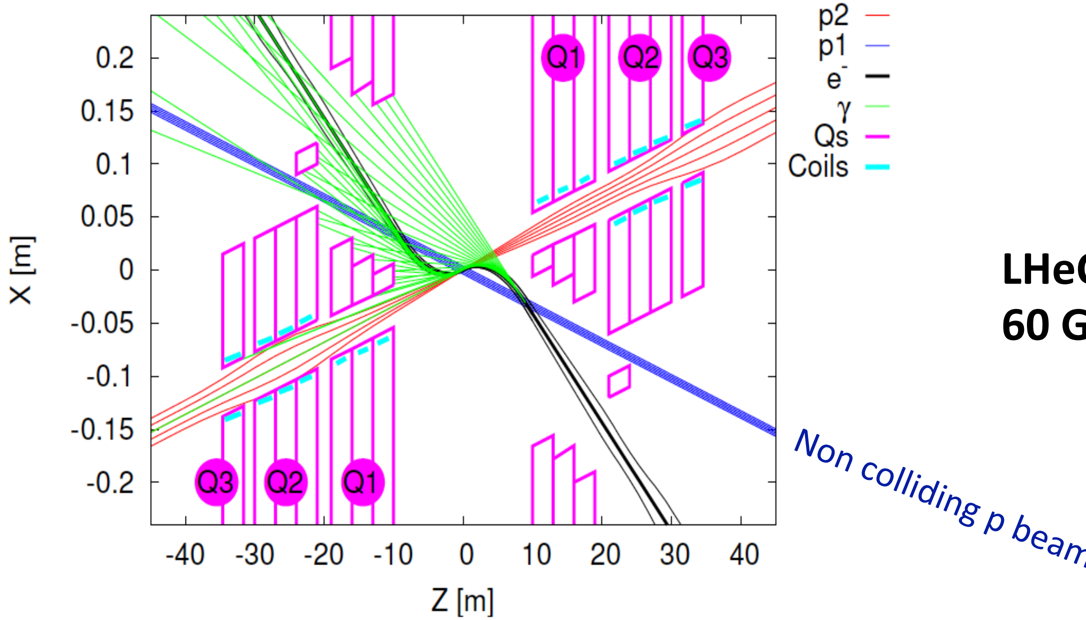
Dimensions and Multitudes – FCC-eh

Tracker	FST_{pix}	FST_{strix}	CFT_{pix}	CPT_{pix}	CST_{strix}	CBT_{pix}	BST_{strix}	BST_{pix}
#Wheels	7		2	–	–	2	5	
#Rings/Wheel	2_{inner}	3_{outer}	3/4	–	–	3/4	3_{outer}	2_{inner}
#Layers	–	–	–	4	5	–	–	–
$\theta_{min/max}$ $[^0]$	0.5	3.8	3.6	5.1	24/155	176.4	173.1	179.3
$\eta_{max/min}$	5.4	3.4	3.5	±3.1	±1.4	-3.5	-2.8	-5.2
$Si_{pix/strix}$ $[m^2]$	9.7	13.3	2.8	5.4	33.7	2.8	9.7	6.9
Sum-Si $[m^2]$	84.3 double layers taken into account							

Calo	FHC_{SiW}	FEC_{SiW}	$EMC_{SciPb/LAr}$	HAC_{SciFe}	BEC_{SiPb}	BHC_{SiFe}
$\theta_{min/max}$ $[^0]$	0.3	0.4	5.6/173.4	8.6/167	179.4	179.6
$\eta_{max/min}$	6.0	5.6	3.0/-2.7	2.5/-2.2	-5.3	-5.6
Volume $[m^3]$	13.2	3.1	28.8	407	1.98	7.0
Sum-Si $[m^2]$	461					

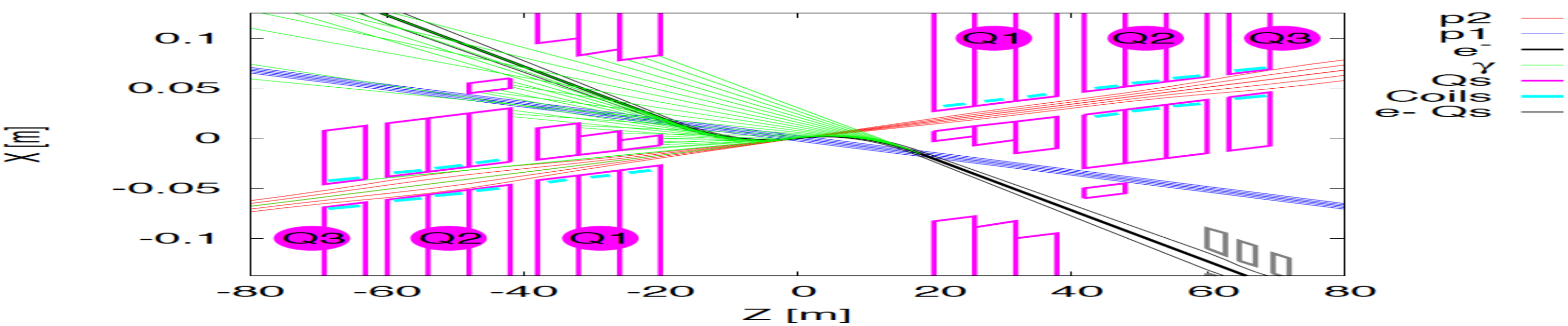
Interaction Regions for ep with Synchronous pp Operation





LHeC (CDR)
60 GeV * 7 TeV

Still work in progress: may not need half quad if L*(e) < L*(p)

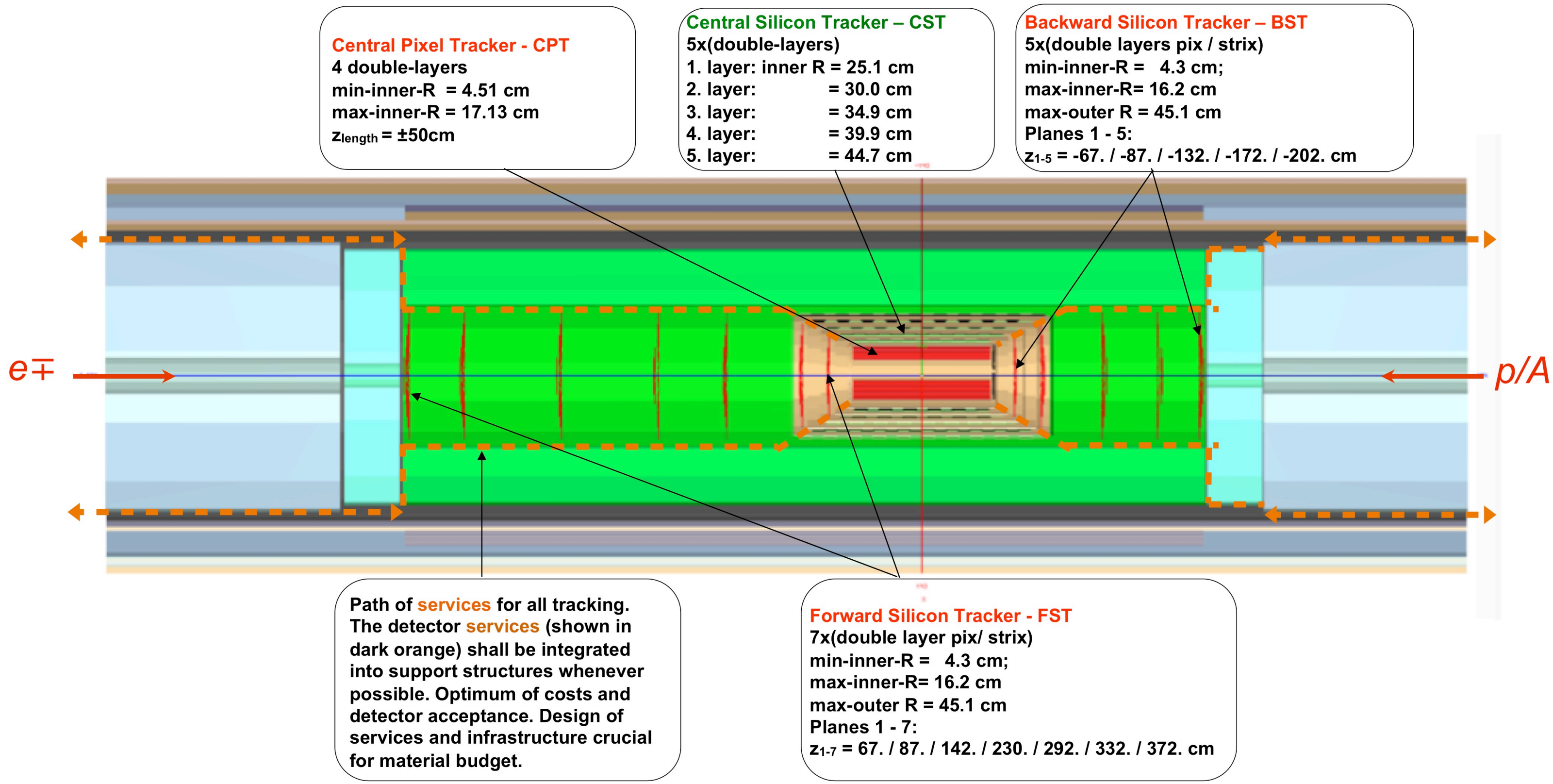


FCC-he (ERL)
60 GeV * 50 TeV

Tentative: ε_p=2μm, β*=20cm → σ_p=3μm ≈σ_e matched! ε_e=5μm ..

Rogelio Tomas et al

Detector design: Inner Silicon Tracker (status 3/16)

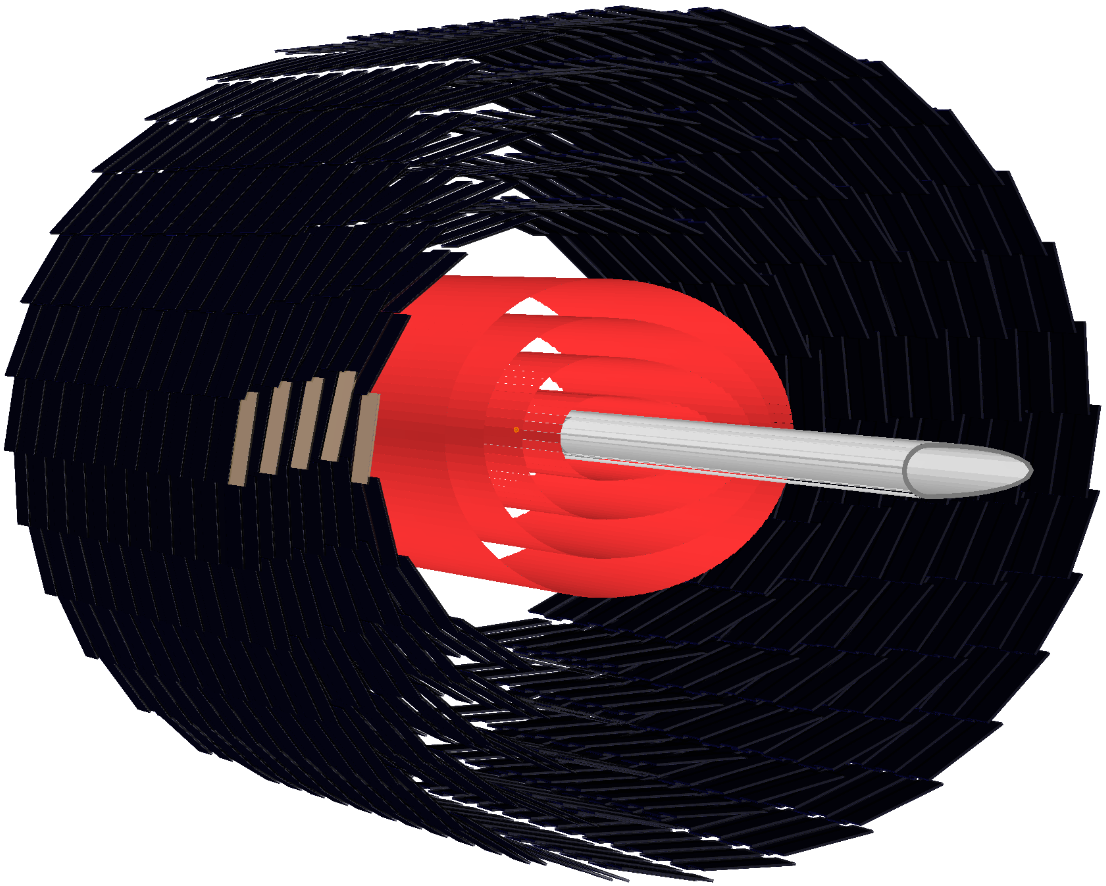


More detailed designs for other components too. DD4HEP software developments..

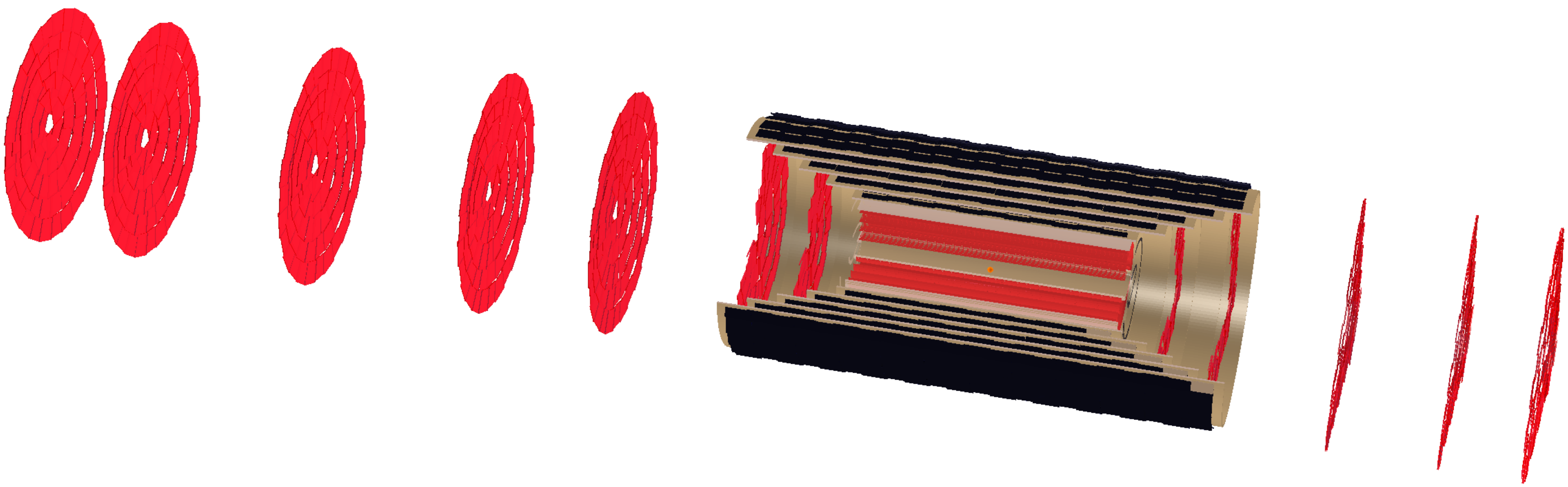
An opportunity for R+D and building a novel, challenging 4π detector in the twenties.

Profit from HL LHC detector upgrades, also ILC, with no pileup and small radiation load

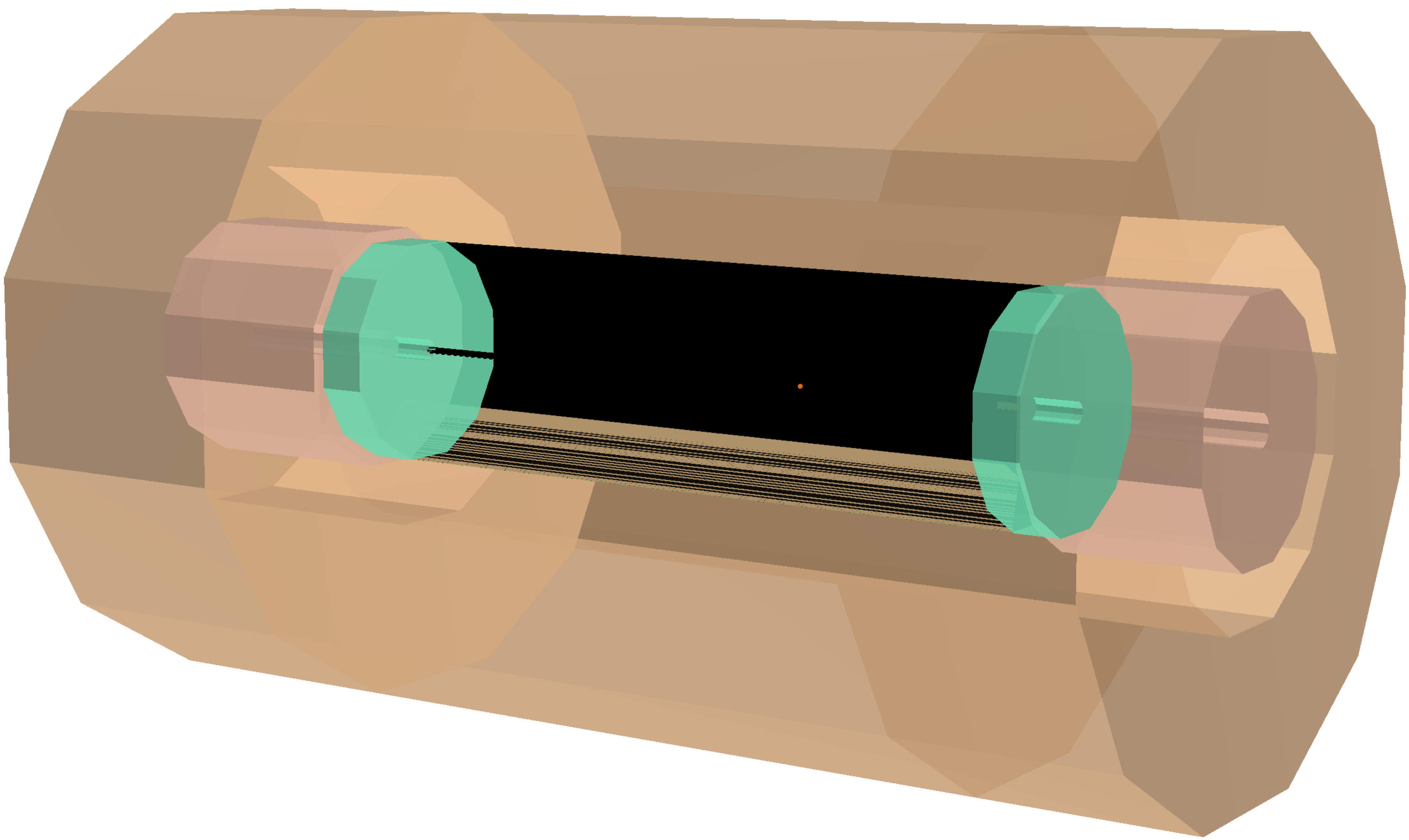
LHeC Silicon Tracker



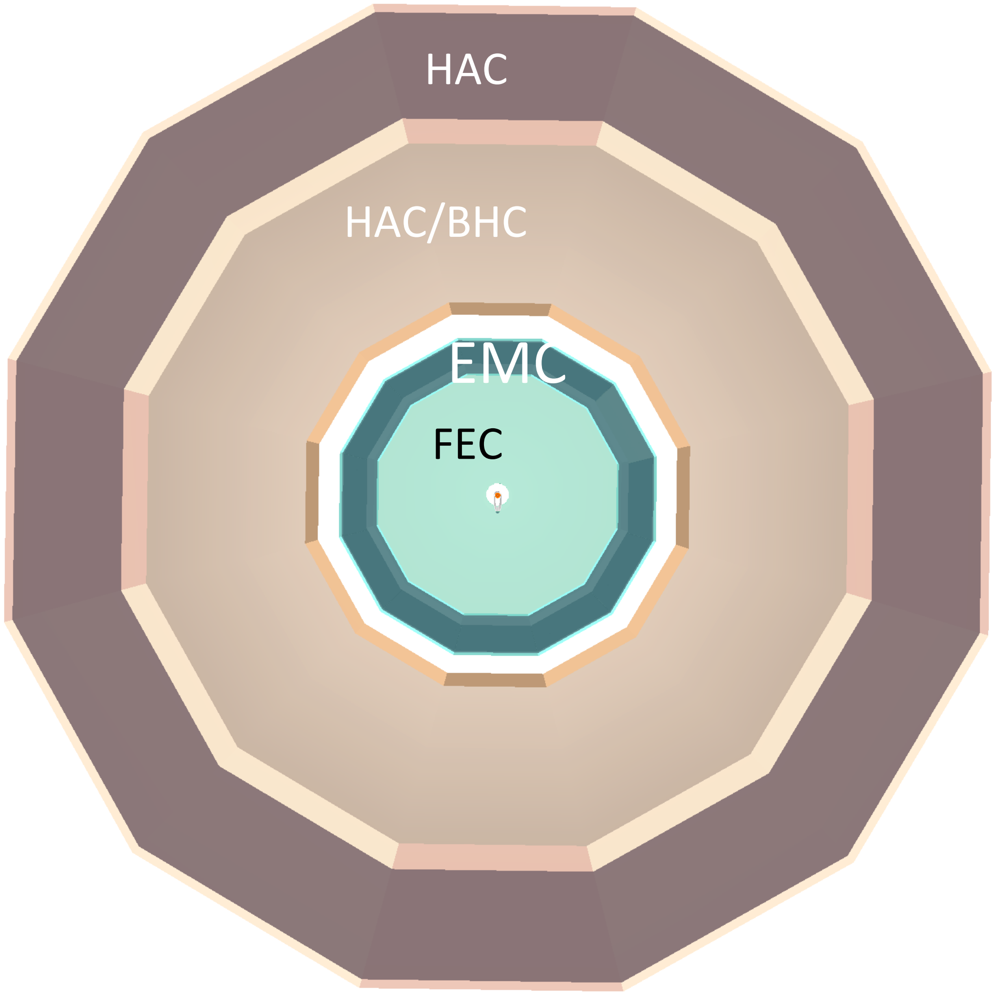
The LHeC Silicon Tracker



LHeC Calorimeters



Cut through Calorimeters at z=510cm



Outer radius: 3.6m

Software Status

Software based on DD4hep/DDG4 - pre-release software [AIDASoft/DD4hep]; Python, C++

LHeC/FCC detector geometry, material description, R/O description as needed, segmentations and surfaces - ingredients for reconstruction;

DDEve - event display tool for quality judgment and control …

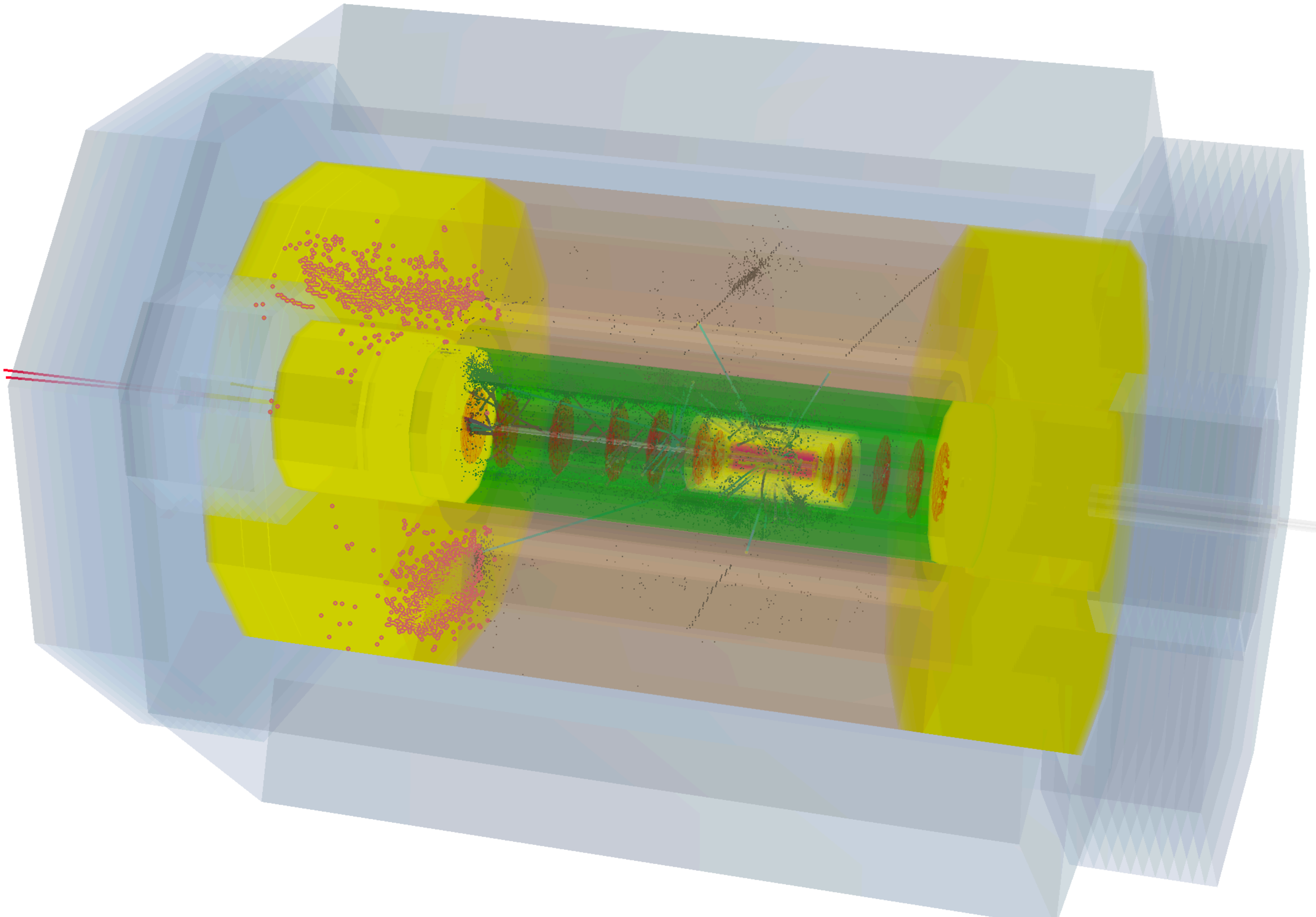
Follow the main developments & build a detector model answering physics questions (reuse of experience and implementations)

Collaboration inside the FCC-Software effort at CERN - information @ http://fccsw.web.cern.ch/fccsw/

Synergies when following closer the FCC-SW initiative - new EDM, geometry/material definitions based of DD4hep as well, using GAUDI for overall steering; aspects of commonly used tracking software (ACTS); fast and detailed simulation ….

Hardware optimisation according to latest R&D (HL-LHC …)

H→ bb in LHeC Detector



Next Steps

Interaction region update

Finish ep Detector software link to Higgs, top, PDF.. physics study

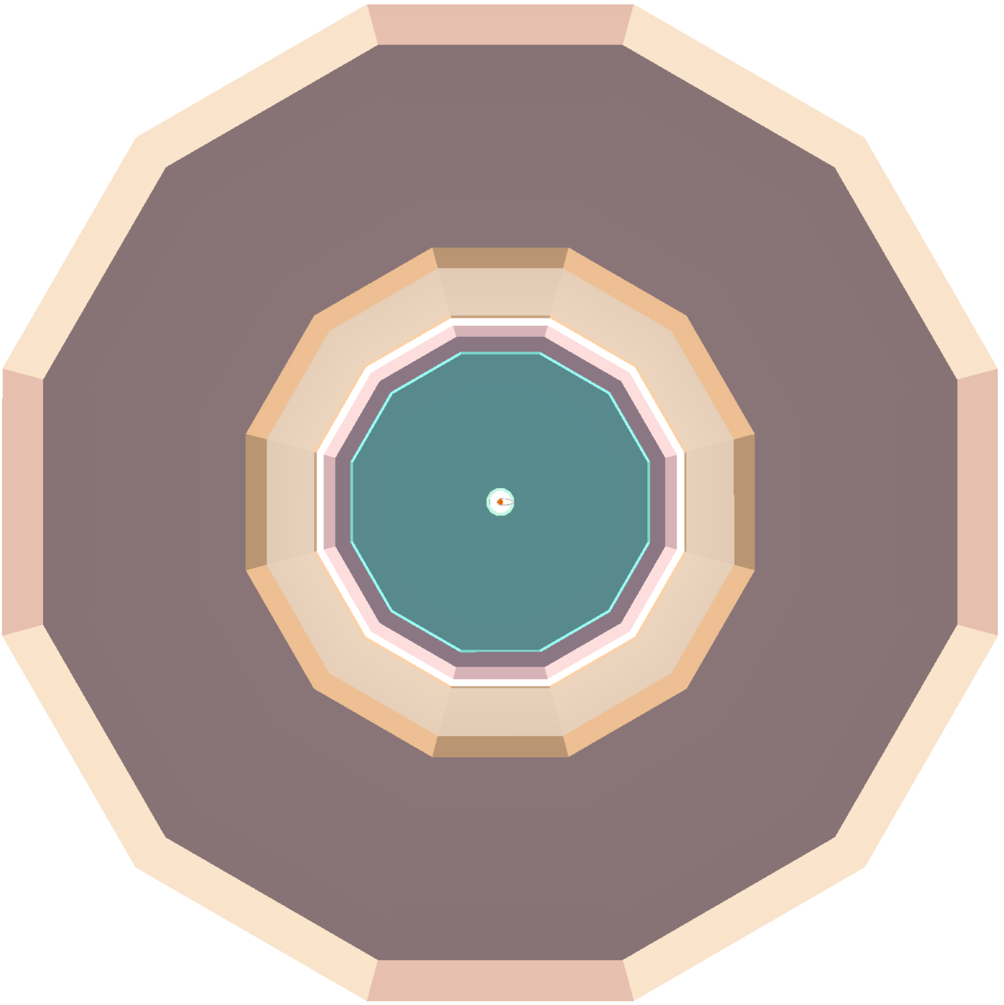
Technology choices for novel, high tech, high precision detector post HL-LHC

CDR for FCC-eh Detector (I/2018)

Update of LHeC Detector Design (IV/2018) − will include cost-energy-physics study

Many thanks to
Andrea Gaddi, Hermann ten Kate, Peter Kostka, Ercan Pilcer,
Brett Parker, Alessandro Polini, Stefan Russenschuck, RogelioTomas and many others

title



title