# The LHeC Detector.

A detector design for the Large Hadron-electron Collider at CERN

LHeC

**David South (DESY)**
**on behalf of the LHeC Study Group**

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HELMHOLTZ
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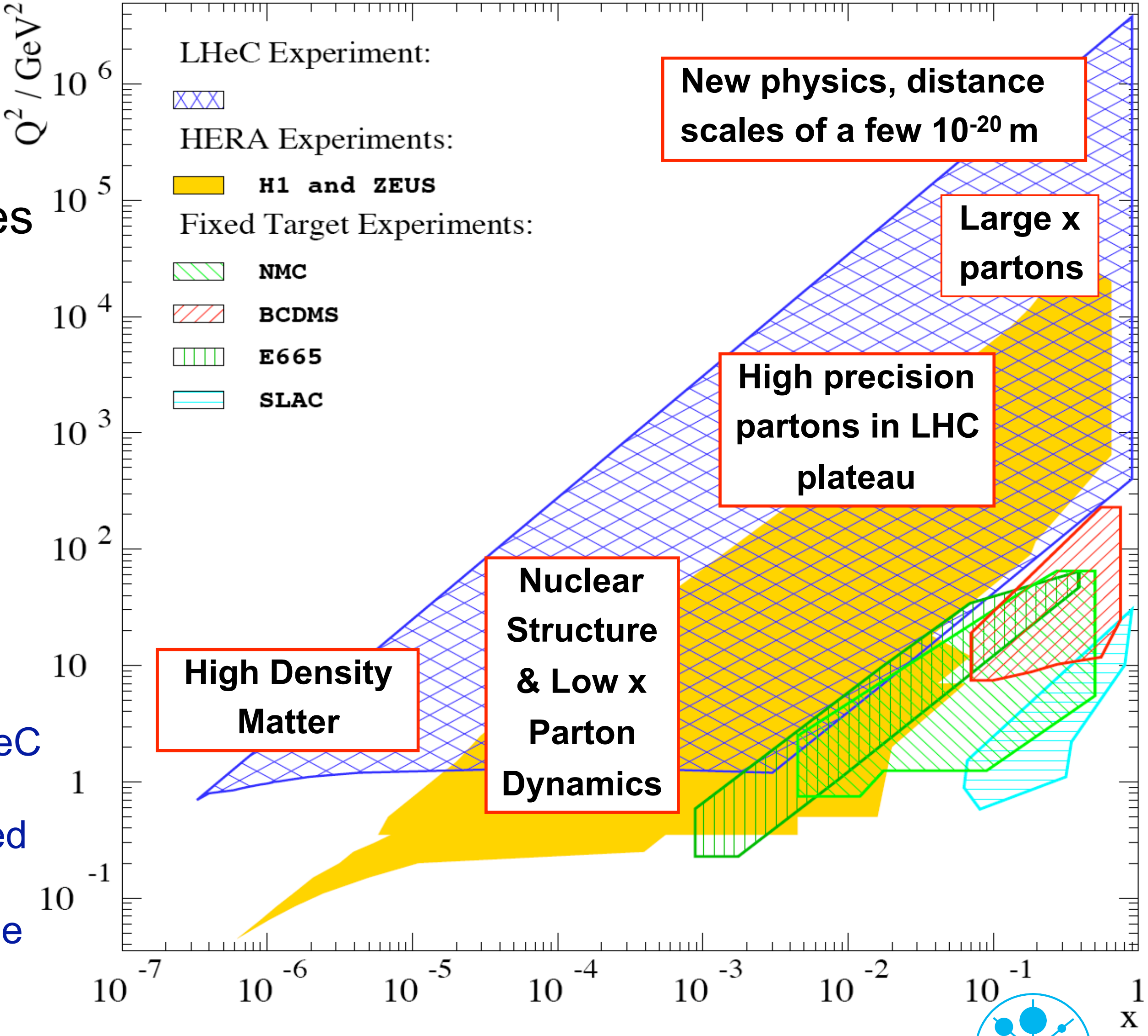
XXI International Workshop on
Deep-Inelastic Scattering and
Related Subjects
Marseille Congress Centre April 22-26 2013

DESY

# The LHeC physics programme

- LHeC: High energy, high precision and high luminosity DIS... and a lot more besides
  - QCD measurements and discoveries, PDF determination, Higgs physics, top quark measurements, BSM physics including LQs, RPV SUSY, CI..., as well as a dedicated heavy-ion programme
  - More details in the LHeC CDR and in Table 3 of the document submitted to the Cracow ESG Review 09/12, available at *arXiV:1211.4831*
- More details talk by M. Klein



New physics, distance scales of a few $10^{-20}$ m

Large x partons

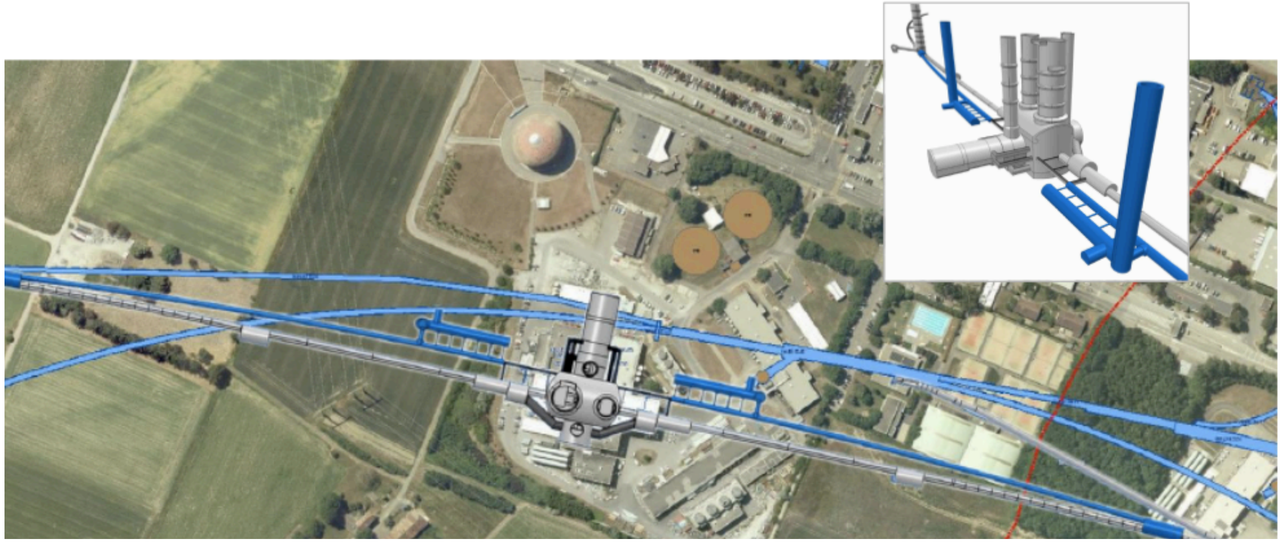
High precision partons in LHC plateau

Nuclear Structure & Low x Parton Dynamics

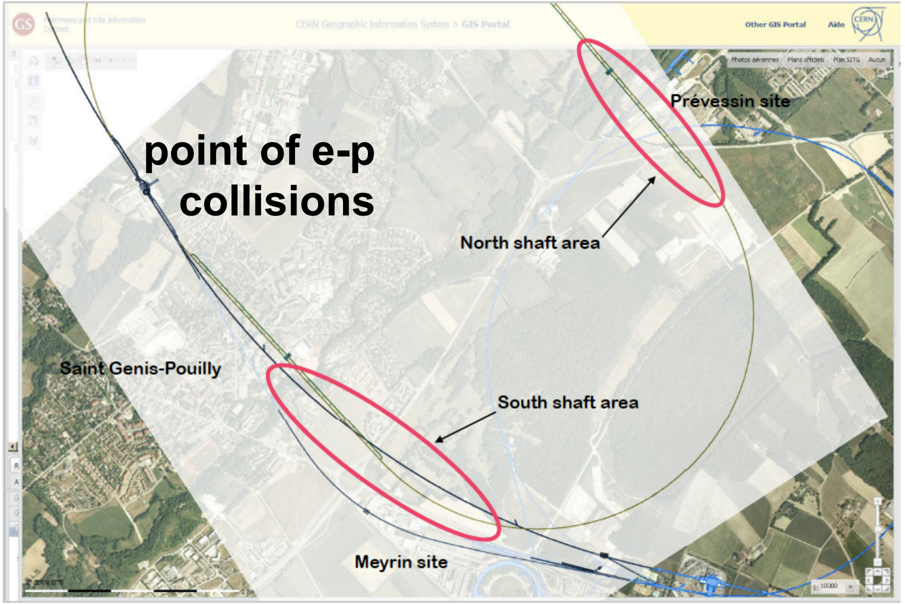
High Density Matter

# The LHeC accelerator design: Ring-Ring or Linac-Ring

- Two alternative designs prepared for 60 GeV lepton beam
- Ring-ring approach more like HERA, but constrained by existing LHC tunnel

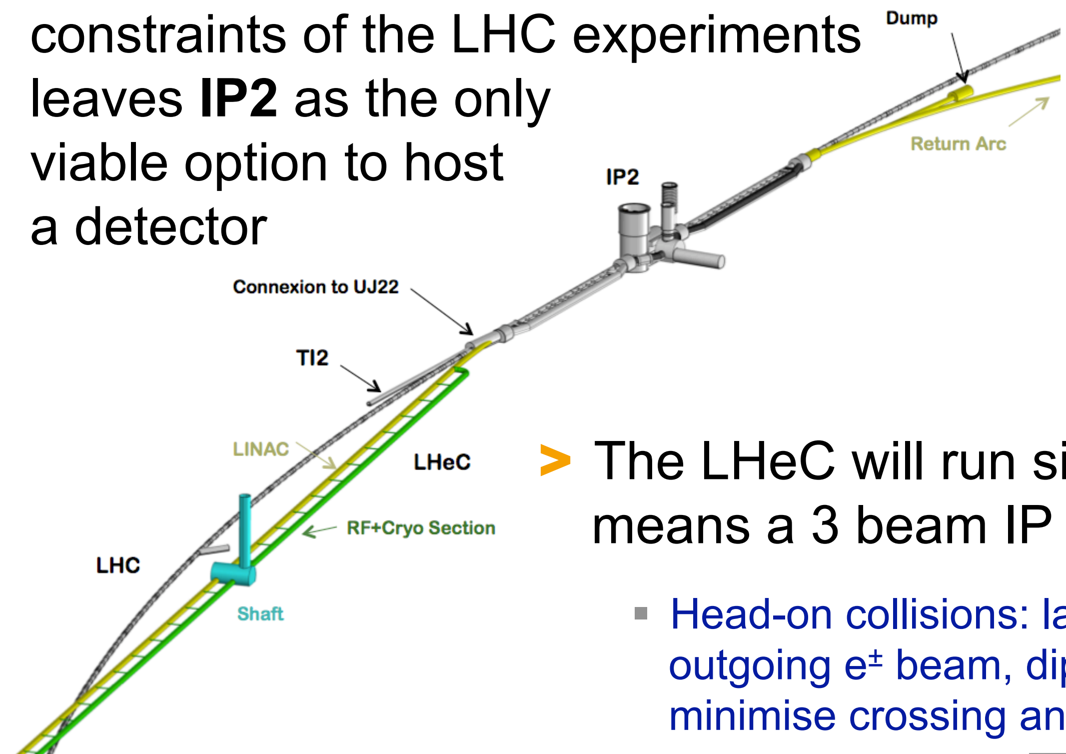


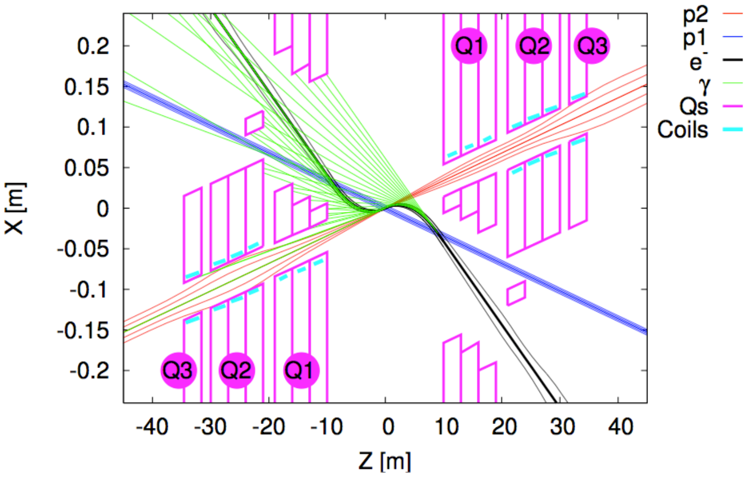
- Linac-ring design employs two 1km long Linacs, with energy recovery
  - Novel new accelerator design
  - Favoured option due to reduced impact on the LHC schedule
  - Lower luminosity for positron running
- More details in talk by O. Brüning



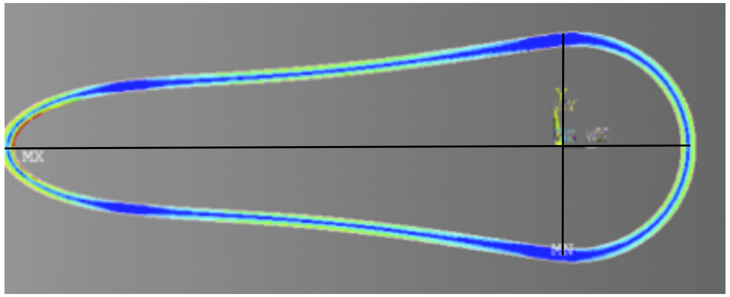
# The LHeC detector location and interaction region

- Civil engineering, access, and constraints of the LHC experiments leaves **IP2** as the only viable option to host a detector





- The LHeC will run simultaneously with the LHC, means a 3 beam IP with compatible optics
  - Head-on collisions: large synchrotron radiation fan from outgoing e± beam, dipoles along the whole beam-pipe to minimise crossing angle and to get high luminosity



- Elliptical beam-pipe design necessary:
  - Inner dimensions employed: circular(x)=2.2cm, elliptical(-x)=10cm, (y)=2.2cm
  - CDR: 6m length, Beryllium 2.5-3mm thickness, composites also investigated

# Key elements to the detector design

- To provide a baseline detector design, which satisfies not only the **physics requirements** but fits the **machine and interaction region constraints** for running during phase 2 of the LHC

- The detector needs to be designed, constructed and **ready for use 12 years from now**, to be able to **run concurrently** with the other LHC *pp* and *pA* experiments, in order to record the respective *ep* and *eA* data

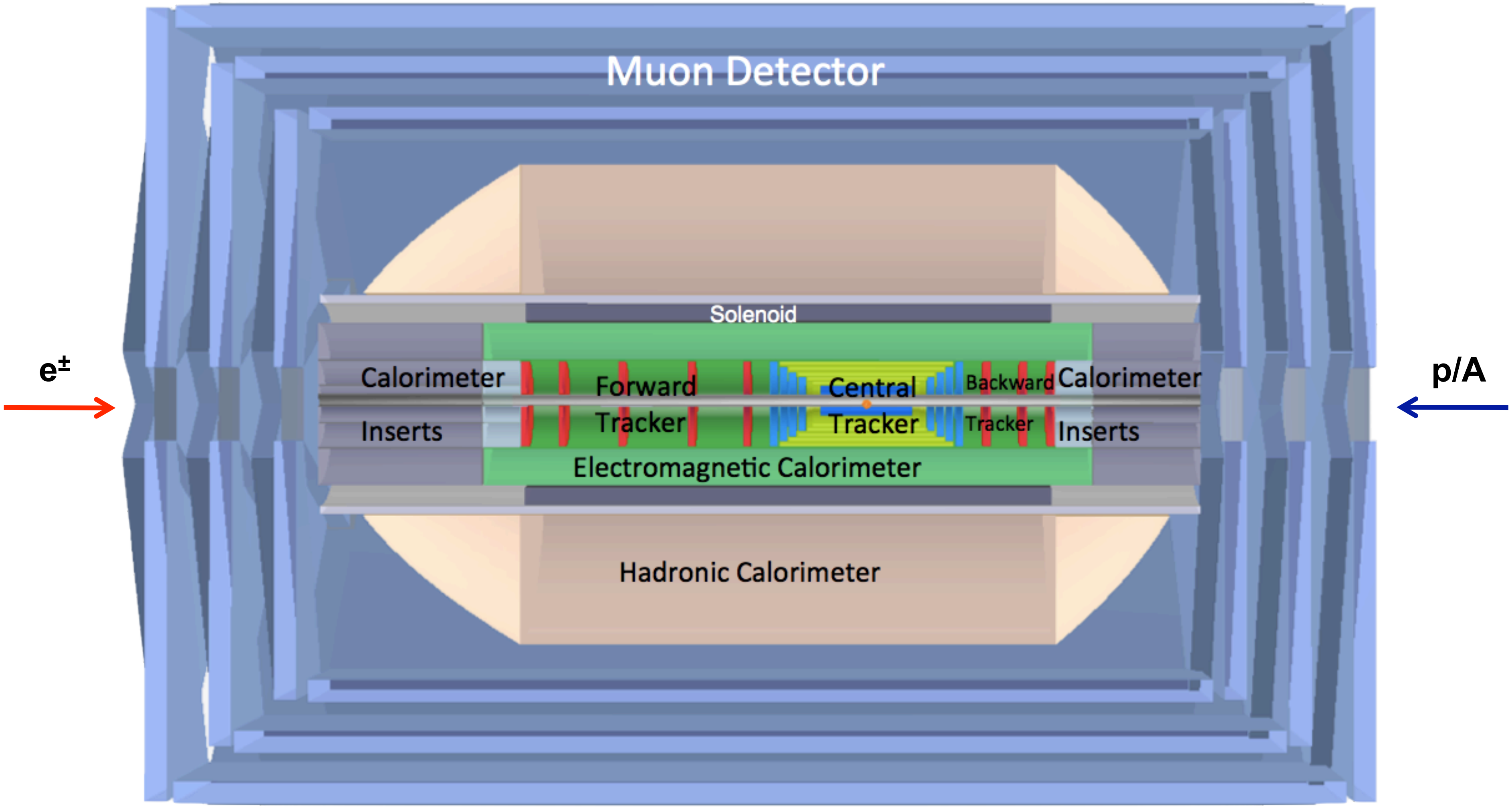
- Such a timescale **prohibits a dedicated, large scale R&D programme**, but the **LHeC detector can profit** from current and upgrade LHC technologies, as well as ILC development, and the HERA experience

- The LHeC detector therefore should be **modular and flexible in design**, with **assembly above ground**, be able to accommodate upgrade programmes and **be affordable**, with a comparatively reasonable cost

# Key detector requirements from the physics programme

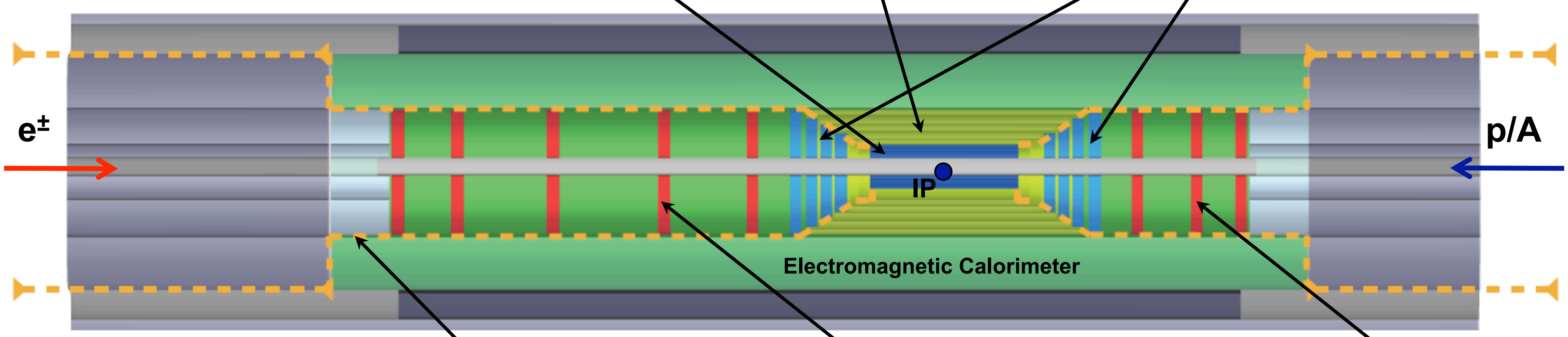
- A high resolution tracking system
  - **Excellent primary vertex resolution** and resolution of **secondary vertices** down to small angles in forward direction for high x heavy flavour physics and searches
  - **Precise $P^T$ measurement** and matching to calorimeter signals, calibrated and aligned to an accuracy of **1 mrad**
- Full coverage calorimetry
  - **Electron energy** measured to 10%/ √ E, calibrated using the kinematic peak and double angle method to the **per-mil level**
  - **Hadronic energy** measured to 40%/√ E, calibrated $P^T$ balance to an **accuracy of 1%**
  - Tagging of **backward scattered photons and electrons** for a precise measurement of luminosity and photoproduction physics
  - Tagging of **forward scattered protons, neutrons and deuterons** to fully investigate diffractive and deuteron physics
- A baseline muon system
  - For **tagging and combination with tracking**, no independent momentum measurement

# LHeC detector overview



- Forward/backward asymmetry in energy deposited and thus in geometry and technology
- Present dimensions: L x D = 14m x 9m  (compared to CMS 21m x 15m , ATLAS 45m x 25 m)
- Not shown: Taggers at -62m (e), -100m (B-H photons), +100m (n) and +420m (p)

# High acceptance tracking design



**Central Pixel Tracker**

4 layers CPT, ΔR = 2cm / layer, 15cm total

Min-inner-R = 3.1 cm

Max-inner-R = 10.9 cm

**Central Silicon Tracker**

5 layers CST, ΔR = 3.5cm / layer

Inner R of layers at 21.2 / 25.6 / 31.2 / 36.7 / 42.7 cm

**Central Forward/Backward Tracker**

4 planes CFT/CBT, ΔZ = 7.0 cm

Min-inner-R = 3.1 cm

Max-inner-R = 10.9 cm

Path of services indicated by dashed line - - - - - - - - - -

Integrated into support structures where possible

Optimum between costs and detector acceptance

Design of service and infrastructure crucial to material budget

**Forward and Backward Silicon Trackers**

5 planes FST, 3 planes BST, ΔZ = 8.0 cm

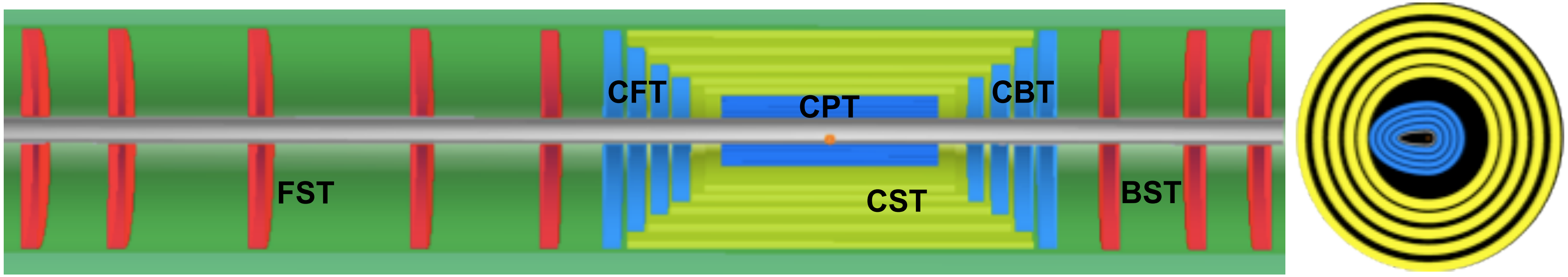
Min-inner-R = 3.1 cm; max-inner-R= 10.9 cm; outer R = 46.2 cm

FST planes 1 - 5: $z_{5-1}$ = 370 / 330 / 265 / 190 / 130 cm

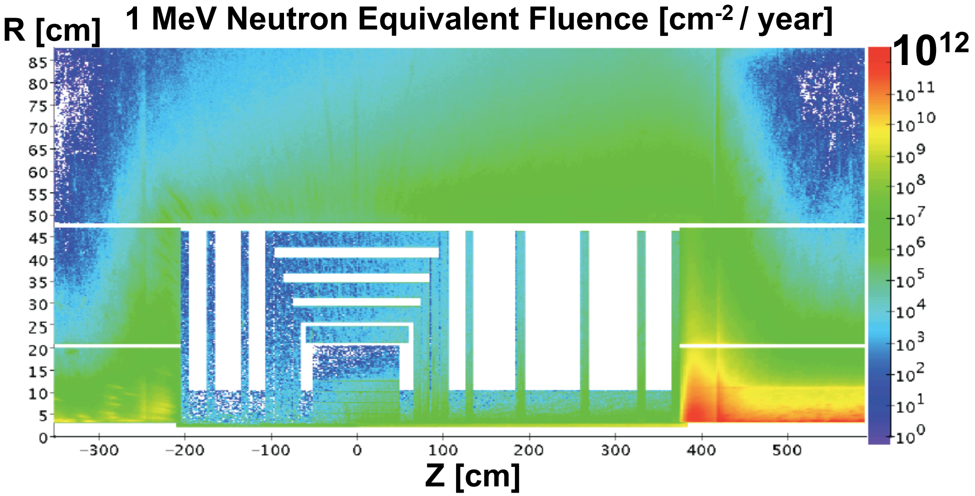
BST planes 1 - 3: $z_{1-3}$ = -130 / -170 / -200 cm

- Very compact design, contained within the electromagnetic calorimeter
- More coverage in the proton direction: dense forward jet production

# Tracker technology



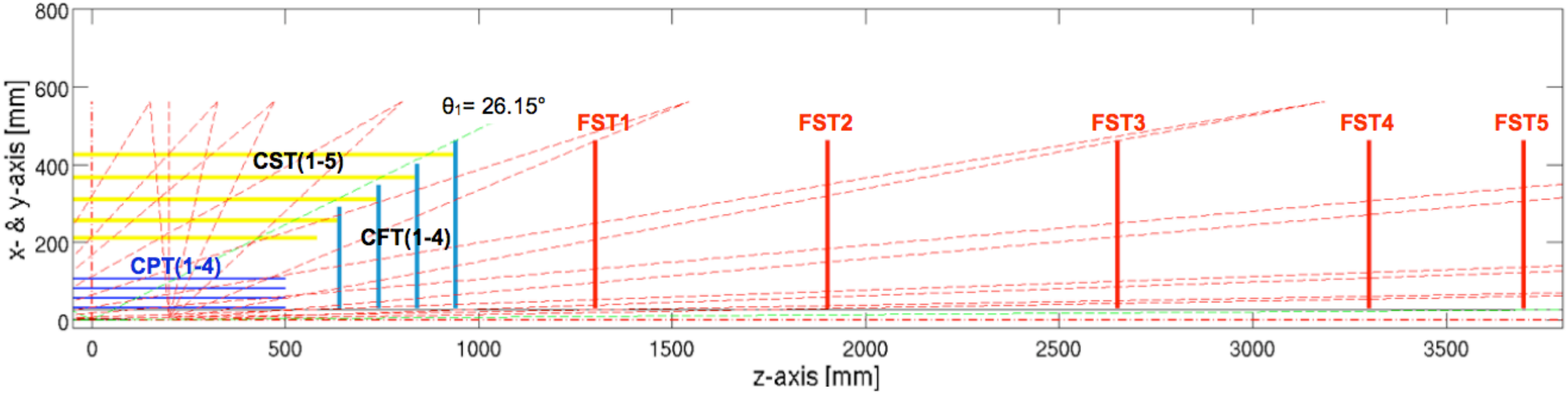
- All Silicon design, employing (e.g) pixel and strip detectors, using available technologies from the LHC experiments
  - Advantages of Silicon: compact design, low material budget, radiation hard
  - Elliptical shape of CPT due to beam-pipe; then the CST is circular

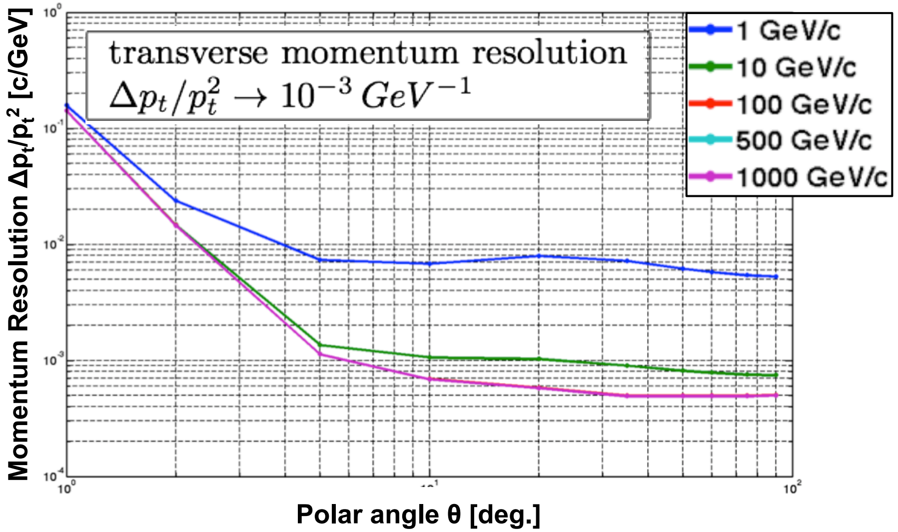


- Radiation hardness in LHeC not as challenging as for the LHC
- Study of neutron fluences using GEANT4 and FLUKA show rates far lower than LHC (~ 5 x $10^{14}$)

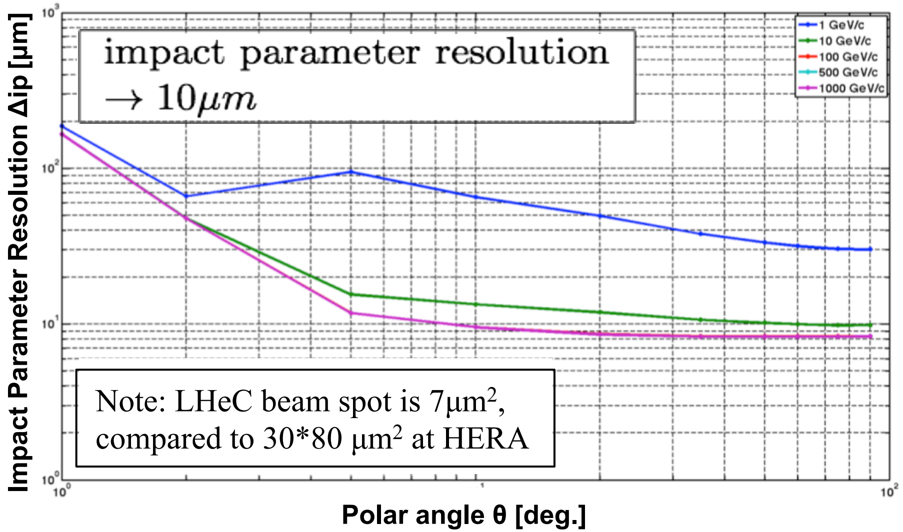
# Tracker simulation

- Studies of tracker design using LicToy2, shown here for the forward region





transverse momentum resolution $\Delta p_t/p_t^2 \rightarrow 10^{-3}\,GeV^{-1}$

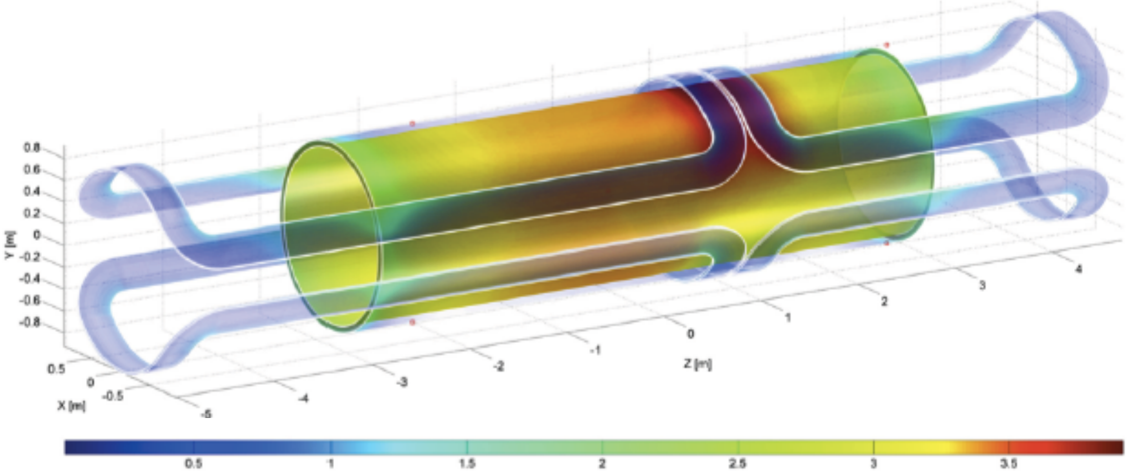


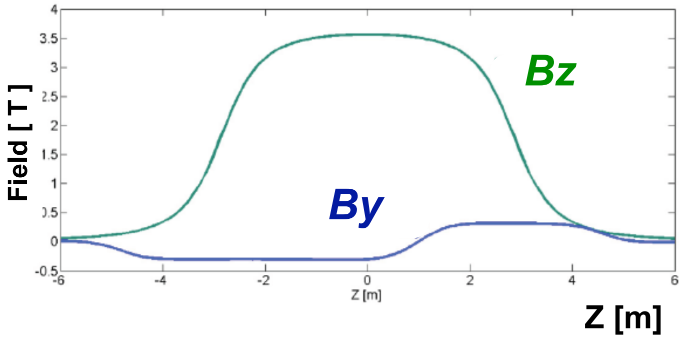
impact parameter resolution $\rightarrow 10\mu m$

Note: LHeC beam spot is 7μm$^2$, compared to 30*80 μm$^2$ at HERA

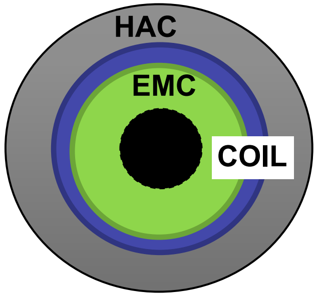
# Detector magnets: solenoid and dipoles

- Both large and small 3.5 T coil options considered, placing either the complete calorimeter or just the EMC part within the solenoid
  - Large coil: Containing full calorimeter, precise muon measurement, large return flux
  - Small coil: Cheaper, less iron for return flux, solenoid and diploes conveniently within the same cold vacuum vessel, but no muon measurement

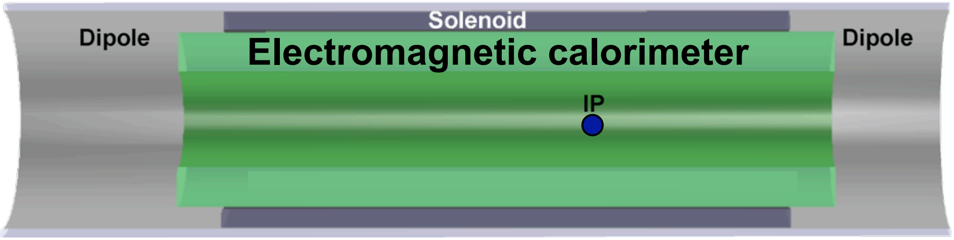


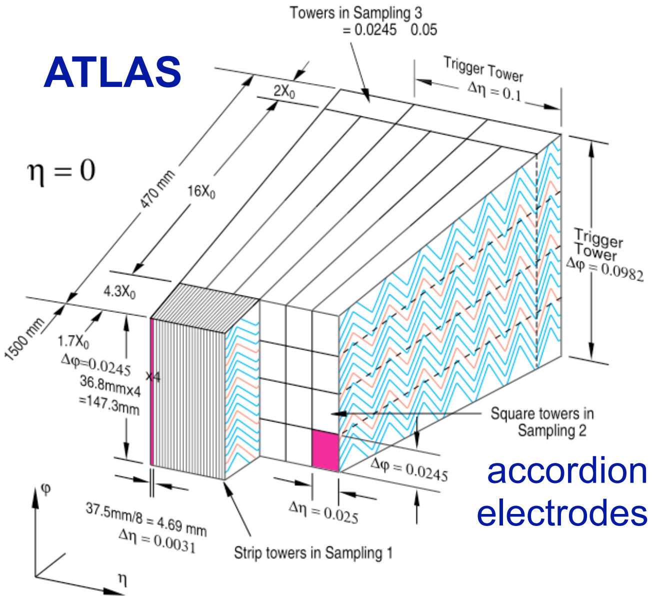


- Baseline design: small coil solenoid + dual dipole
  - Magnets embedded into the EMC LAr cryogenic system
  - Impact of having dead material between EMC and HAC under study



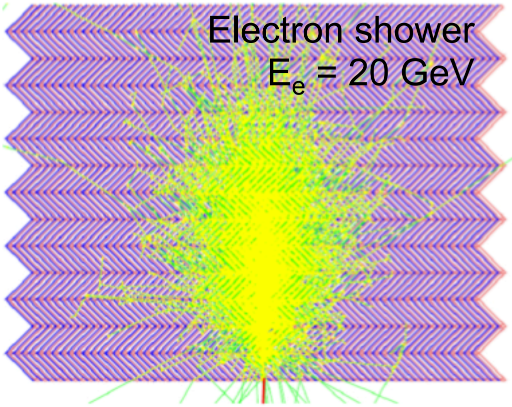
# Electromagnetic calorimeter

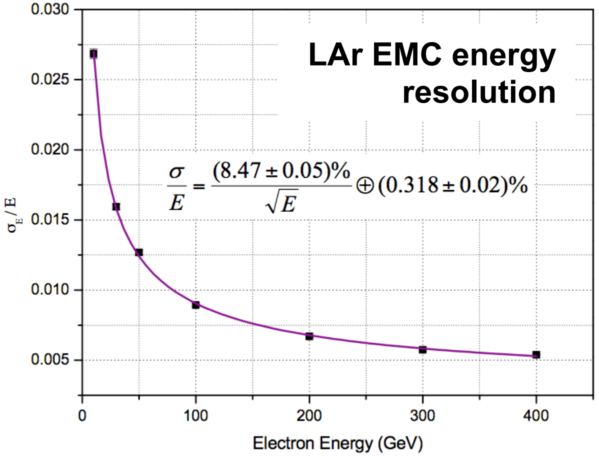




- Main EMC, in the barrel region: $2.8 < \eta < -2.3$
  - Based on LAr/Pb design used in ATLAS, ~25-30 $X_0$
  - Employs 3 different granularity sections longitudinally
  - Alternative design using Pb/Scintillator also investigated
- Simulation studies of simplified design with respect to ATLAS

**LHeC**





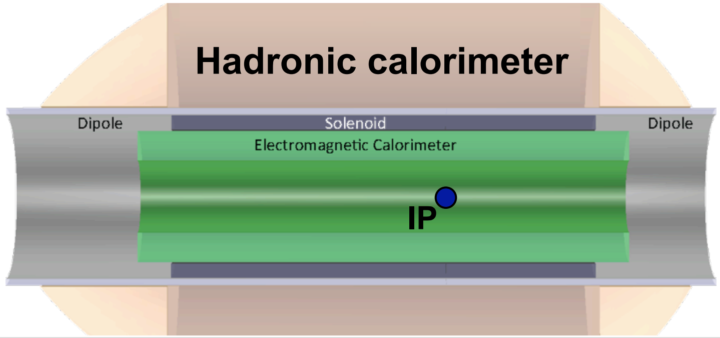
*Calorimeter resolution:*

$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus b$$

*stochastic term, a*
*constant term, b*

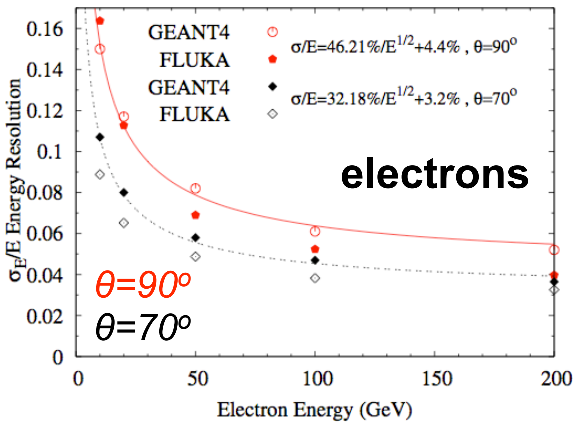
# Hadronic calorimeter

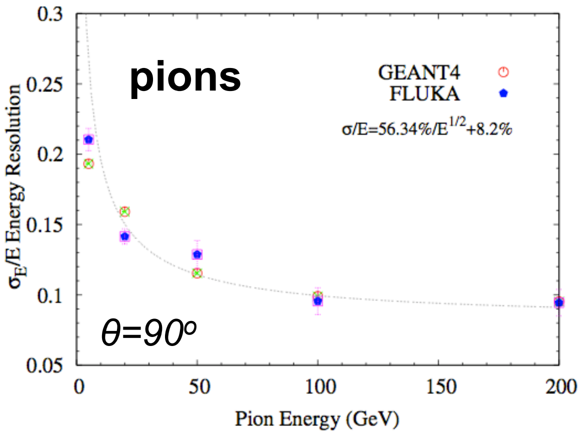
- Baseline design uses steel absorber and scintillator sampling plates
  - Similar to the TILE calorimeter in ATLAS
  - Steel structure provides support for inner detectors and return flux for the solenoid
  - Interaction lengths of ~ 7-9 $\lambda_I$

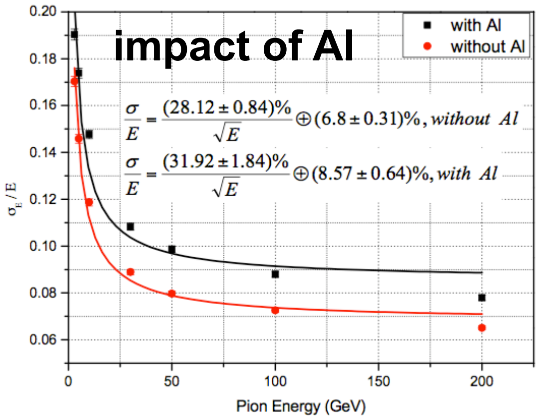


| Tile Rows | Height of Tiles in Radial Direction | Scintillator Thickness |
|---|---|---|
| 1-3 | 97 mm | 3 mm |
| 4-6 | 127 mm | 3 mm |
| 7-11 | 147 mm | 3 mm |

- Many simulation studies performed with GEANT4+FLUKA: details in CDR
  - Performance optimisation: containment, resolution, combined HAC & EMC (Pb/Sci) response, effect of Al solenoid, dependence position of solenoid/dipoles/cryostat..

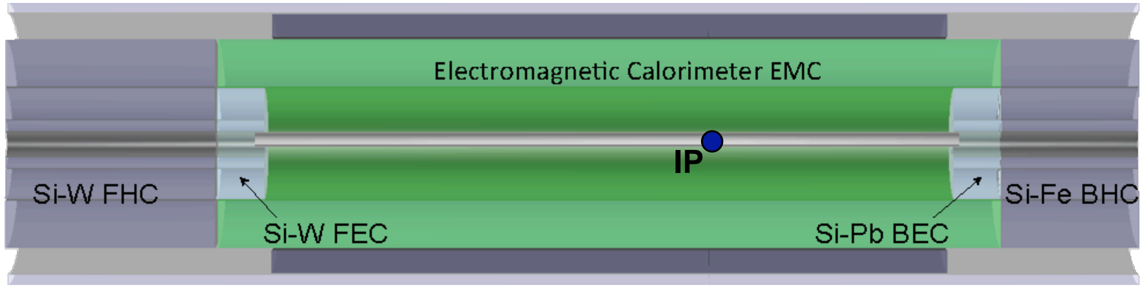






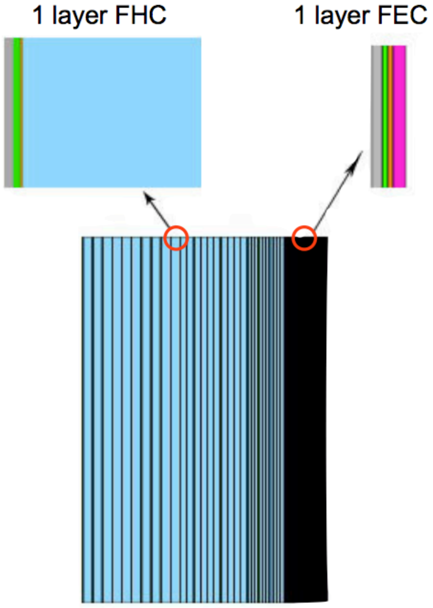
# Forward and backward calorimetry

FEC: ~30 $X_0$
FHC: ~ 8-10 $\lambda_I$



BEC: ~25 $X_0$
BHC: ~ 6-8 $\lambda_I$

- Both electromagnetic and hadronic inserts in forward, backward regions
  - FEC+FHC: High granularity radiation hard Si-W, high jet energy resolution
  - BEC+BHC: Needed for precise e-tagging, Si-Pb (BEC) and Si-Fe/Cu (BHC)



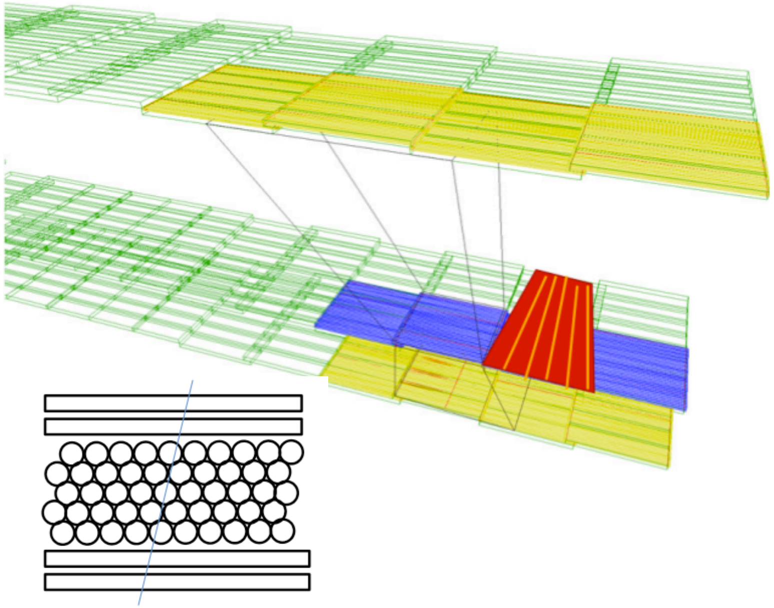
FHC & FEC composite Calorimeter

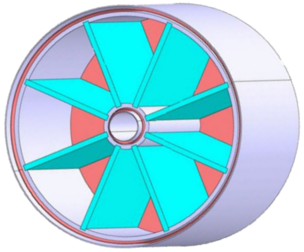
- GEANT4 simulation performed
  - Forward region: Containment and multi-track resolution
  - Backward region: e-tagging and energy measurement

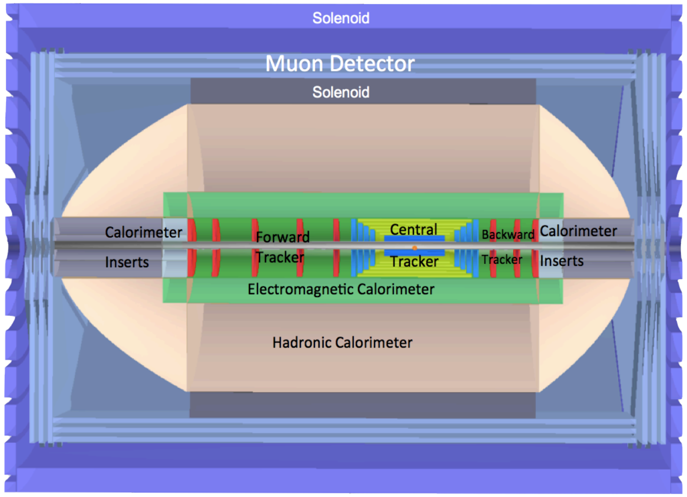
| Calorimeter Module (Composition) | Parameterised Energy Resolution |
|---|---|
| Electromagnetic Response | |
| $\text{FEC}_{(\mathbf{W-Si})}$ | $\frac{\sigma_E}{E} = \frac{(14.0 \pm 0.16)\%}{\sqrt{E}} \oplus (5.3 \pm 0.049)\%$ |
| $\text{BEC}_{(\mathbf{Pb-Si})}$ | $\frac{\sigma_E}{E} = \frac{(11.4 \pm 0.5)\%}{\sqrt{E}} \oplus (6.3 \pm 0.1)\%$ |
| Hadronic Response | |
| $\text{FEC}_{(\mathbf{W-Si})}$ & $\text{FHC}_{(\mathbf{W-Si})}$ | $\frac{\sigma_E}{E} = \frac{(45.4 \pm 1.7)\%}{\sqrt{E}} \oplus (4.8 \pm 0.086)\%$ |
| $\text{FEC}_{(\mathbf{W-Si})}$ & $\text{FHC}_{(\mathbf{Cu-Si})}$ | $\frac{\sigma_E}{E} = \frac{(46.0 \pm 1.7)\%}{\sqrt{E}} \oplus 6.1 \pm 0.073)\%$ |
| $\text{BEC}_{(\mathbf{Pb-Si})}$ & $\text{BHC}_{(\mathbf{Cu-Si})}$ | $\frac{\sigma_E}{E} = \frac{(21.6 \pm 1.9)\%}{\sqrt{E}} \oplus (9.7 \pm 0.4)\%$ |

# Muon system

- Muon system with 2-3 super-layers, possible layout: each with double trigger layer and a layer for measurements
  - Baseline design: muon momentum from inner tracker, also in combination with signals from muon system, no independent measurement
  - Use technologies as at LHC (and elsewhere): Thin Gap Chambers, Resistive Plate Chambers, Drift tubes..



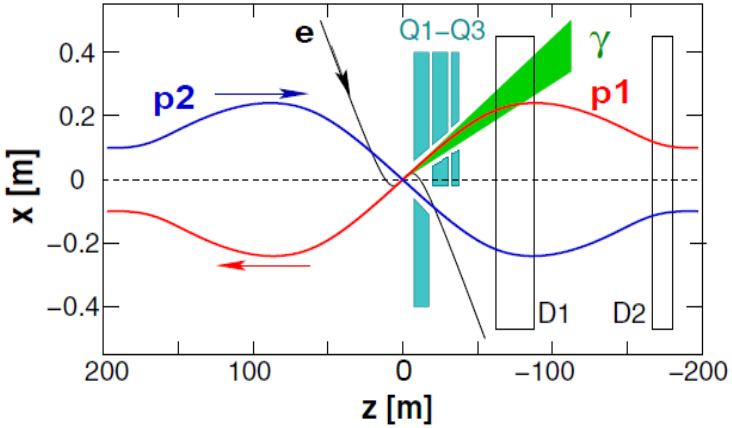


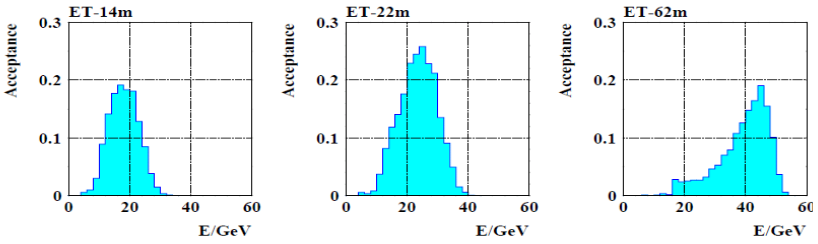


- Several muon system extensions possible, including:
  - Independent momentum measurement
  - Larger solenoid or dual coil system (with all of calorimeter within inner coil)
  - Forward toroid (air core design)

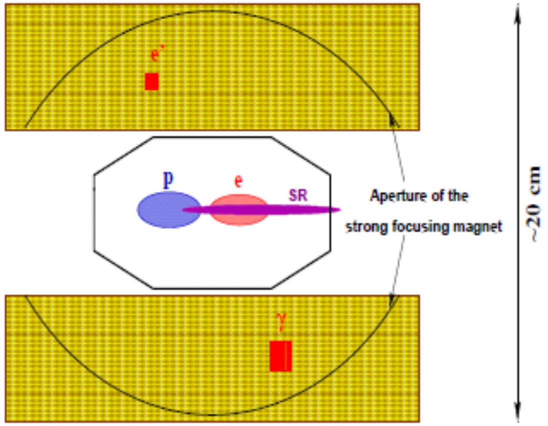
# Backward detectors: luminosity measurement and e-tagger

- **Bethe-Heitler:** collinear photon emission, ep→eγp
  - Zero crossing angle in L-R LHeC, photons travel along the p-beam and are detected at z≈-120m, after proton bending dipole
  - Geometrical acceptance of 95% is possible, total luminosity error δL≈1%
  - E-tagger could also be installed to detect the scattered electron in BH - and for γp physics!
  - Three possible positions simulate, acceptances reasonable (up to 20-25%), z=-62m preferred





- **QED Compton:** wide angle bremsstrahlung, ep→eγp
  - Lower cross section, scattered electron and photon measured in the main detector (backward calorimeter)
  - Additional 'QEDC tagger' could be installed at z≈-6m to increase visible cross section

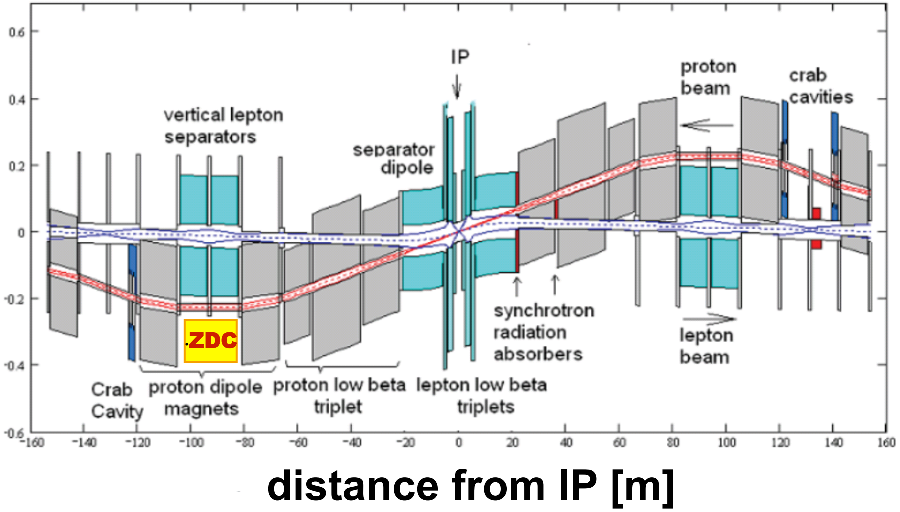


Two moveable sections approaching the beam-pipe from top and bottom, good energy linearity in 10-60 GeV range

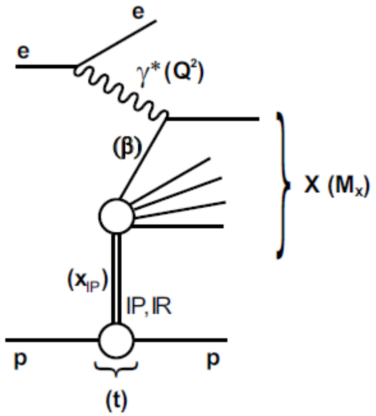
# Forward detectors: proton and neutron detection

## > Zero degree neutron calorimeter

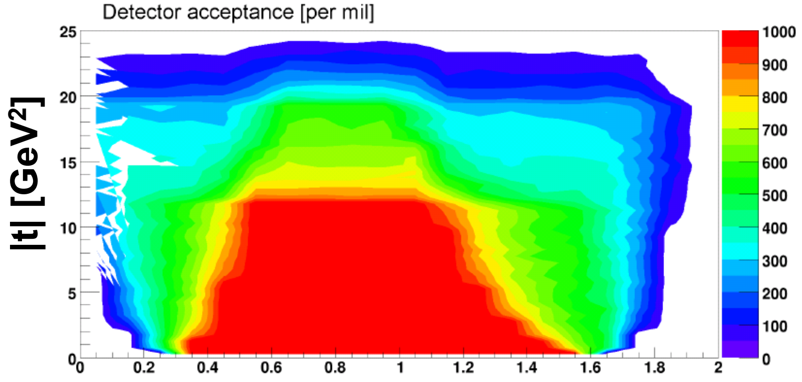
- Measure the energy and angles of very forward particles in tunnel at z≈100m
- Operates in a very demanding radiation environment: Tungsten-Quartz design
- Position and detector dimensions depend on the space available for installation (only ~90mm between two beam-pipes)
- Requires detailed simulation of beam-line



## > Forward proton detection



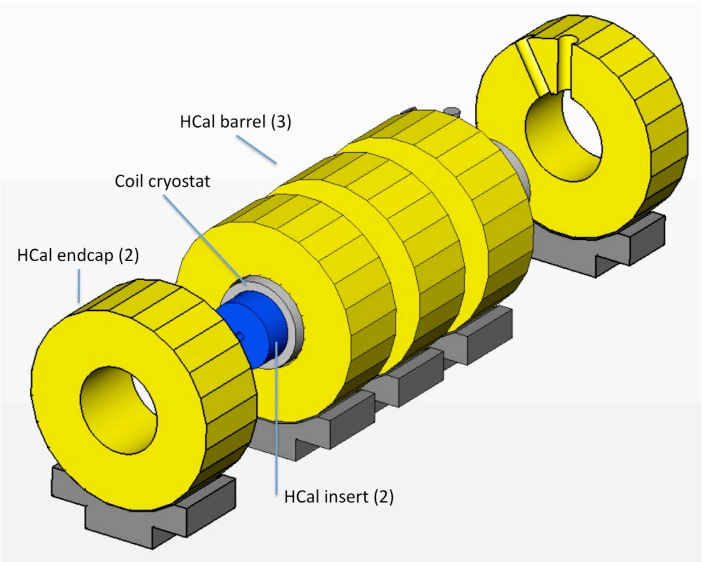
- Interesting for diffractive physics, p-tagging in rapidity gap events
- Relevant R&D detector studies performed at the LHC
- Excellent acceptance at 420m for momentum loss $0.002 < \xi < 0.013$ for |t| values up to about 12

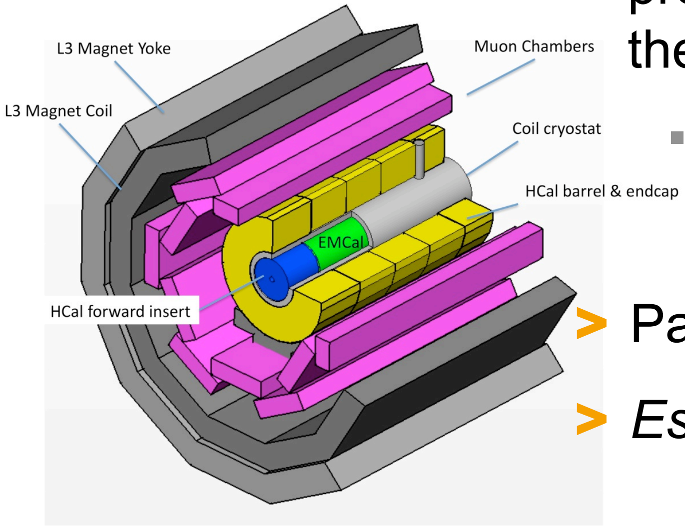


$$x_{offset} = D_x * \xi$$

# Main detector assembly and integration

- Detector assembled on the surface as much as possible: approximately 16 months
  - Split the detector into three main parts:
    1. Coil cryostat, including the superconducting coil, the two dipoles and eventually the EMC (LAr)
    2. Three barrel wheels and two end-caps of the HAC, fully instrumented and cabled
    3. Two HAC inserts, forward and backward



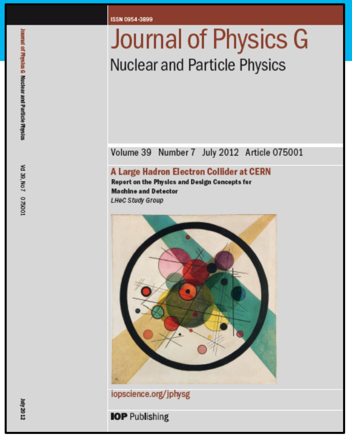


- Three months commissioning of coil system on site; preparation for lowering one month; lowering each of the 8 pieces: one week
  - Underground completion of the integration of the main detector elements inside the L3 magnet would require a further 2 months for cabling and connection to services
- Parallel installation of muons, tracker, EMC: 6 months
- *Estimated total time:* 30 months (+ 1 month for B-map)

# Status and outlook

## > Current Status

- A LHeC baseline detector concept has been worked out, as described in the CDR *J. Phys. G39 (2012) 075001, arXiv:1206.2913*
- The design depends heavily on the constraints from the machine and the interaction region and the LHC activities



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Nuclear and Particle Physics

Volume 39 Number 7 July 2012 Article 075001

A Large Hadron Electron Collider at CERN

Report on the Physics and Design Concepts for Machine and Detector

*LHeC Study Group*

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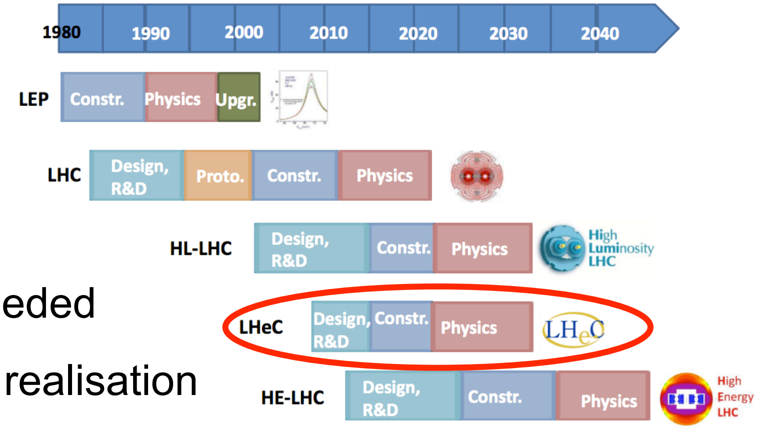
- A feasible and affordable concept, fulfilling the physics requirements has been presented
- With respect to the baseline many improvements may become available; a more precise design will follow from more detailed simulations, engineering and knowledge of machine constraints



1980 1990 2000 2010 2020 2030 2040

LEP: Constr. | Physics | Upgr.

LHC: Design, R&D | Proto. | Constr. | Physics

HL-LHC: Design, R&D | Constr. | Physics — High Luminosity LHC

LHeC: Design, R&D | Constr. | Physics — LHeC

HE-LHC: Design, R&D | Constr. | Physics — High Energy LHC

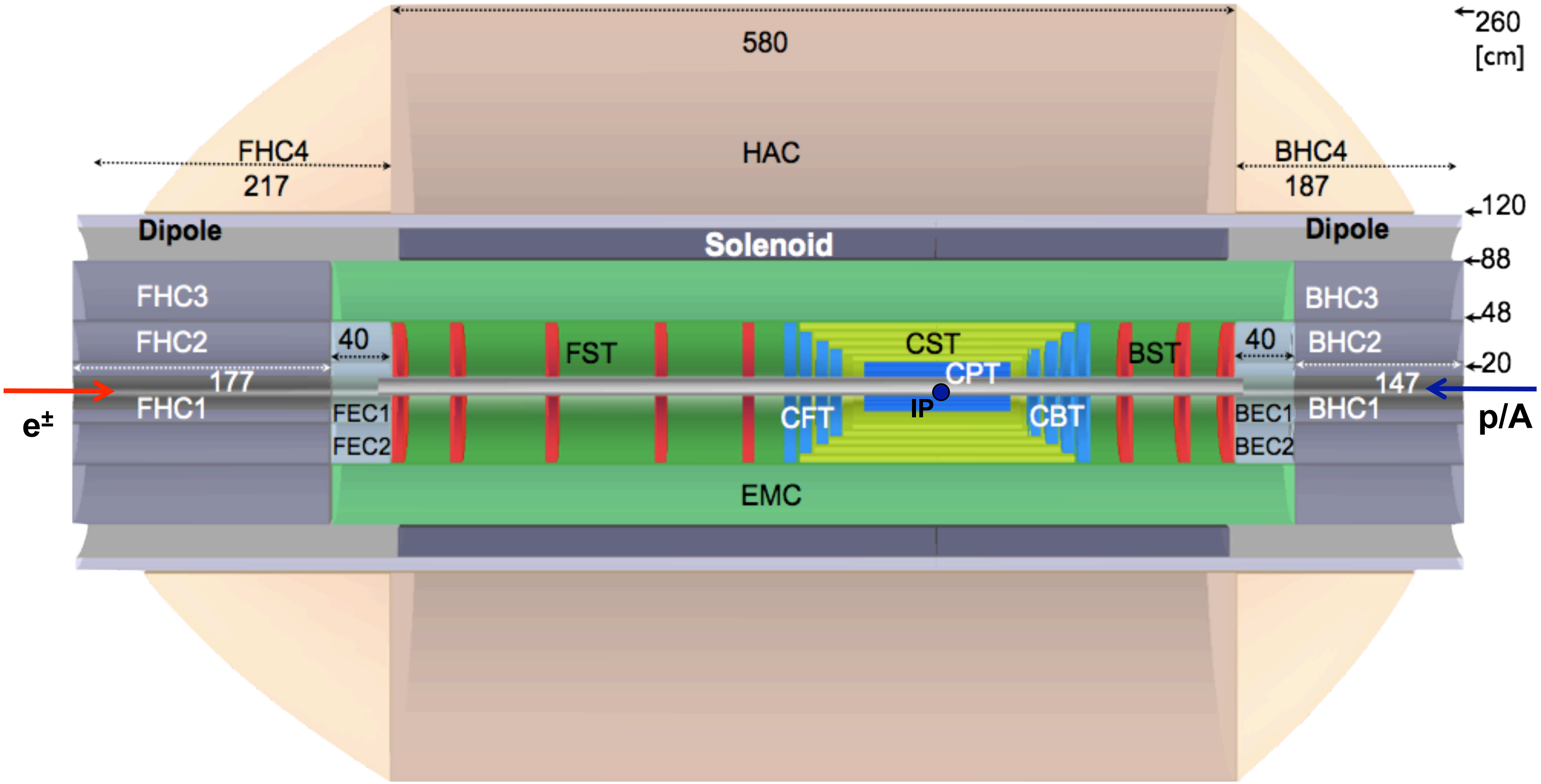
## > Future Steps

- Start a new phase in detector design
- Complete software simulation environment now needed
- Identify, address critical items, discuss timeline for realisation
- Build a collaboration, move towards a Technical Design

*Many thanks to Max Klein, Peter Kostka and Alessandro Polini*

# Back up

# Baseline design of main detector



# Machine parameters

| | Ring-Ring<br>Hi Lumi/Hi Acc | Linac-Ring |
|---|---|---|
| Luminosity [$10^{33}cm^{-2}s^{-1}$] | 1.3/0.7 | 1 |
| Detector acceptance [deg] | 10/1 | 1 |
| Polarization [%] | 40 | 90 |
| IP beam sizes [μm] | 30, 16 | 7 |
| Crossing angle [mrad] | 1 | 0 |
| e- L* [m] | 1.2/6.2 | 30 |
| Proton L* [m] | 23 | 15 |
| e- beta*$_{x,y}$ [m] | 0.2,0.1/0.4,0.2 | 0.12 |
| Proton beta*$_{x,y}$ [m] | 1.8, 0.5 | 0.1 |
| Synchrotron power [kW] | 33/51 | 10 |

# Software framework

- Status:
  - Interaction region simulation → synchrotron radiation ← GEANT4, IRSYN(MadX)
  - Detector volumes, flux calculation: ROOT → GDML → GEANT4 (→ FLUKA)
  - For interaction region, beam-pipe optics, synchrotron radiation, calorimetry description
  - General detector Dedicated tools (LicToy, PGS).
  - Need complete detector simulation (simulation of real detector effects, busy events, pile-up, and so on..)
- On-going:
  - Computer development & experiences of others
  - TGeo package interfacing GEANT3,4,(5) and FLUKA - backbone
  - Make use of experiences whenever possible

Optimise detector granularity, incorporate HL-LHC optics: interaction region design

DAQ/Trigger: physics, hardware / software driven decisions depend on the granularity needed, pre-processing, trigger & bandwidth requirements

- Benchmark channels dictate the required solutions
- b tagging & maximal acceptance