LHeC Detector: Preliminary Engineering Study

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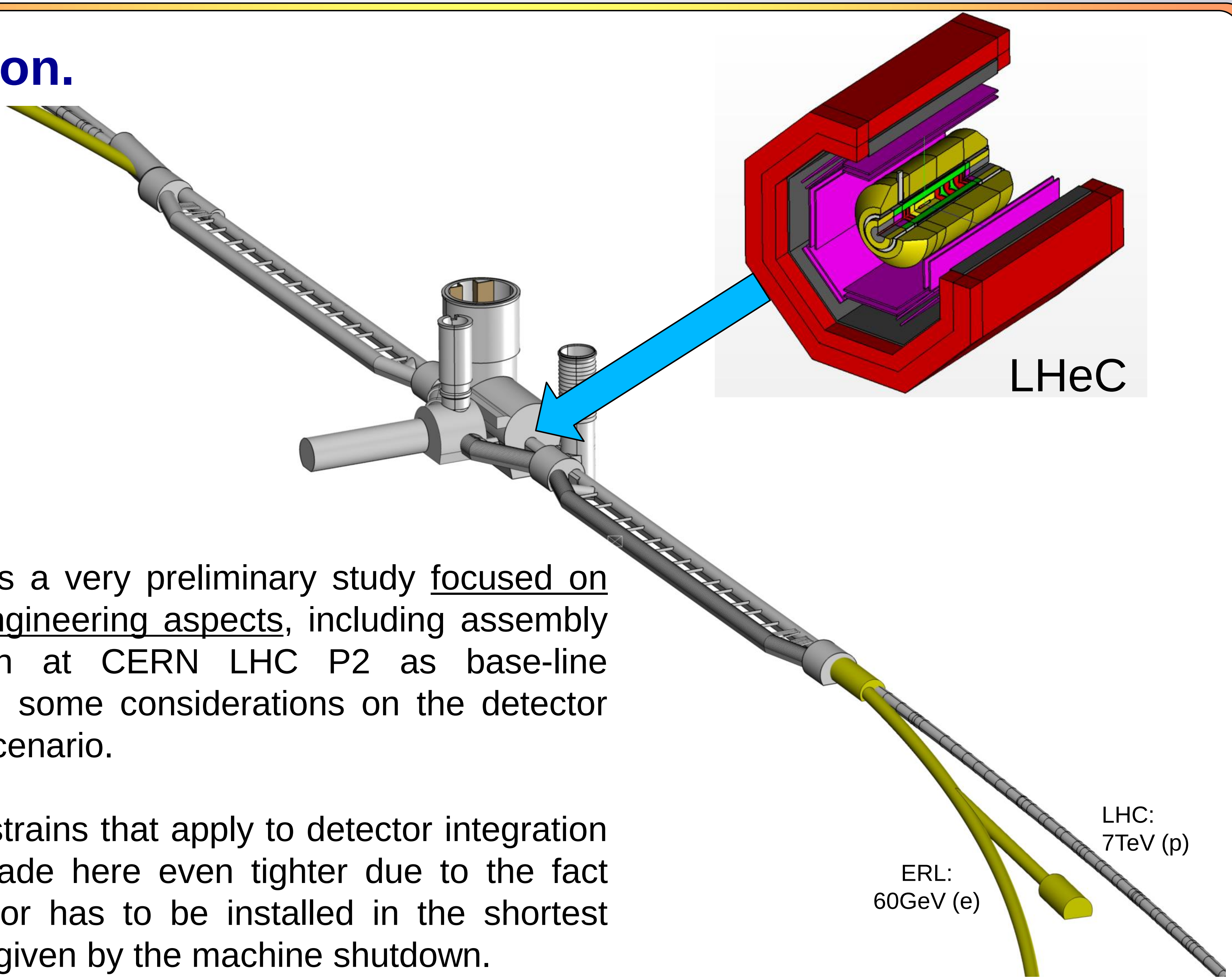
Introduction.



The following is a very preliminary study focused on the detector engineering aspects, including assembly and integration at CERN LHC P2 as base-line constraint, with some considerations on the detector maintenance scenario.

The usual constrains that apply to detector integration studies, are made here even tighter due to the fact that the detector has to be installed in the shortest allowable time given by the machine shutdown.

Detector design criteria.

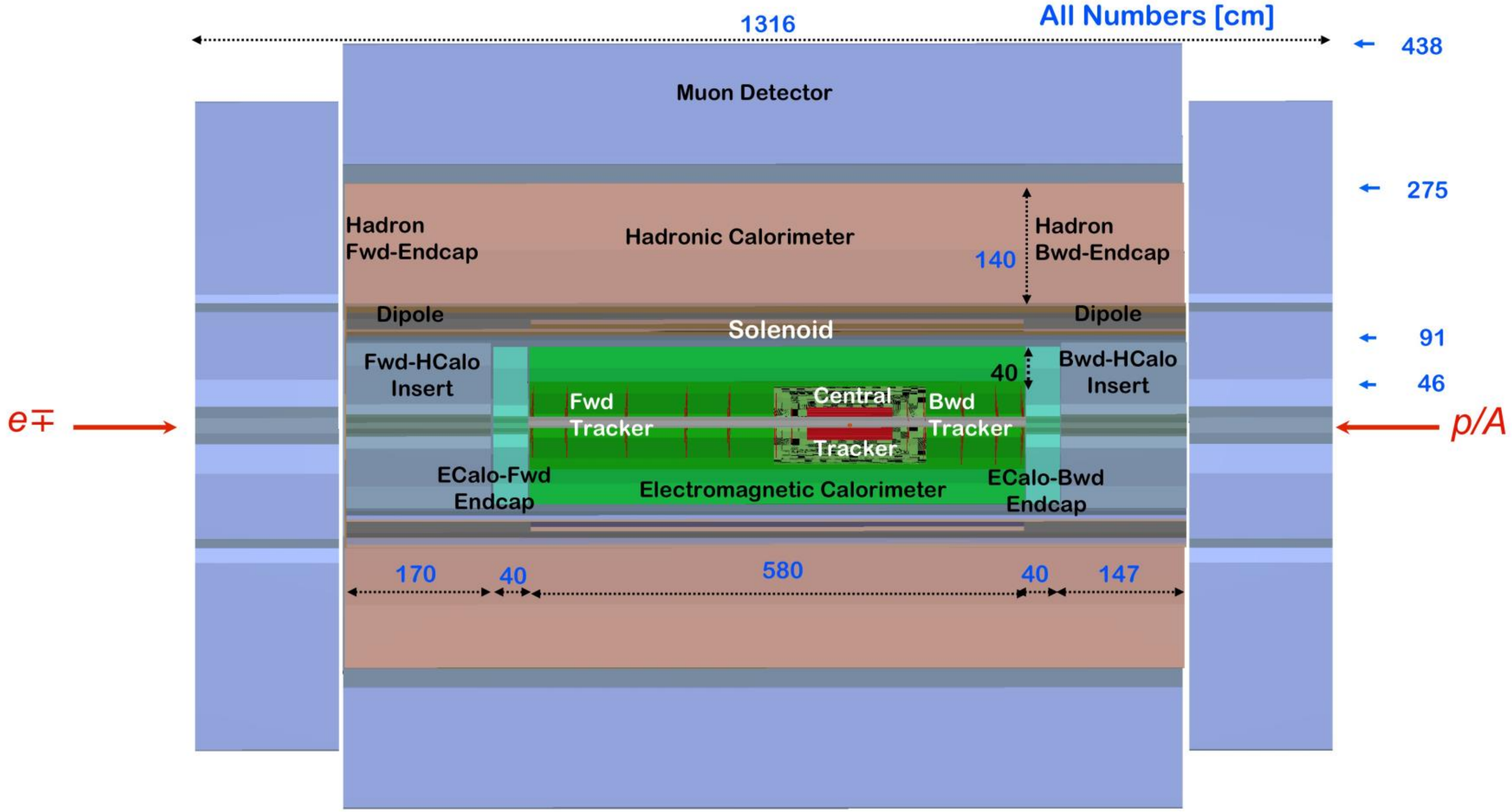
- Detector designed for high precision e-p and e-A physics
- Very large acceptance => Eta coverage from -4.5 (backward) to 5.1 (forward)
- Modularity in design & construction
- Based on existing or coming technology (LHC detectors upgrades, but with less radiation & pileup)
- Current focus on Interaction Region design & Machine-Detector Interface plus integration into modern software for simulation, reconstruction & analysis.
- 150 pages dedicated to detector description in CDR, issued on 2012

A Large Hadron Electron Collider at CERN

Report on the Physics and Design Concepts for Machine and Detector

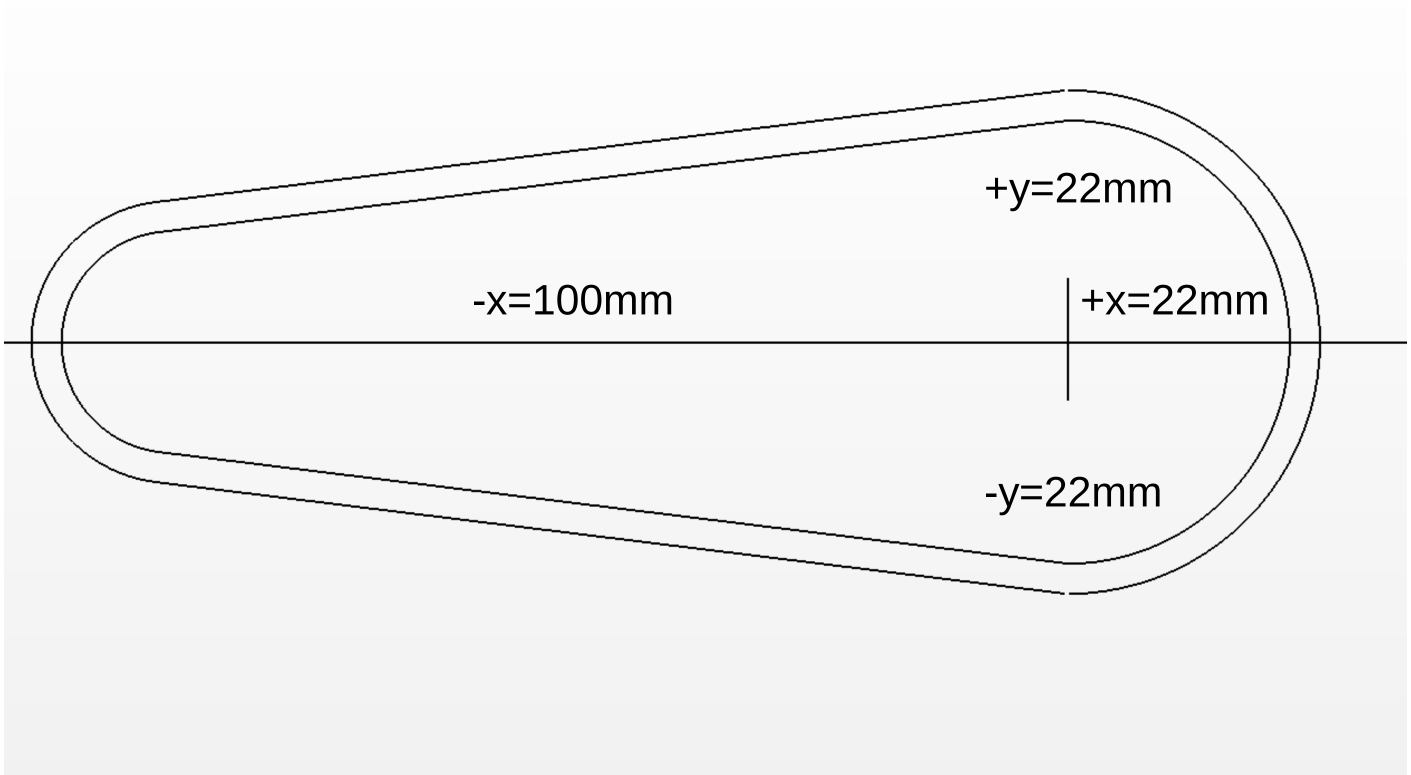
LHeC Study Group

Detector description.



- Forward / backward asymmetry reflecting beam energies (870mm offset)
- Dipole for head-on e-p collisions and central solenoid in common cryostat
- Present size fits inside 14m x 9m (c.f. CMS 21m x 15m, ATLAS 45m x 25m)

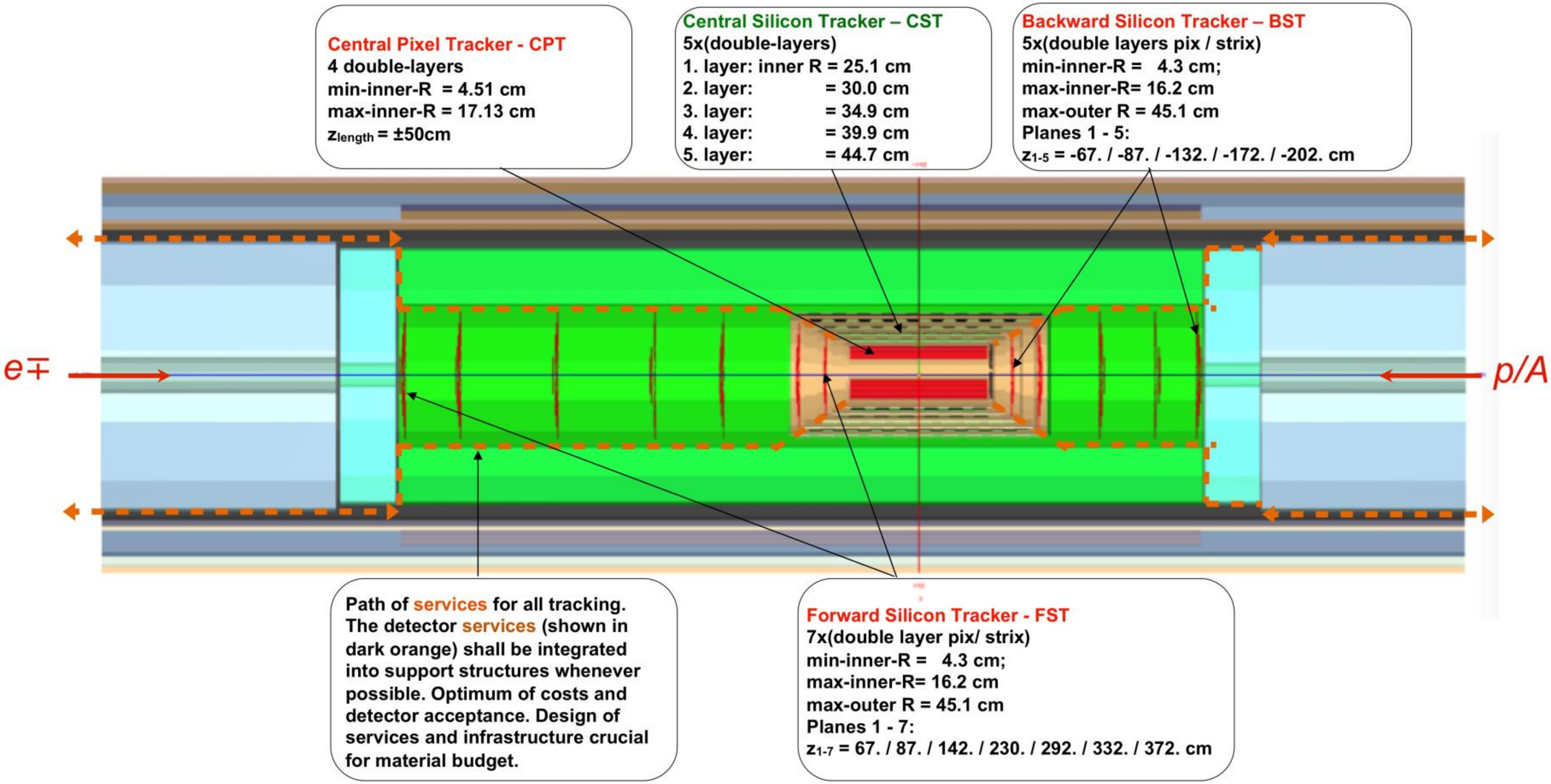
Beam-pipe.



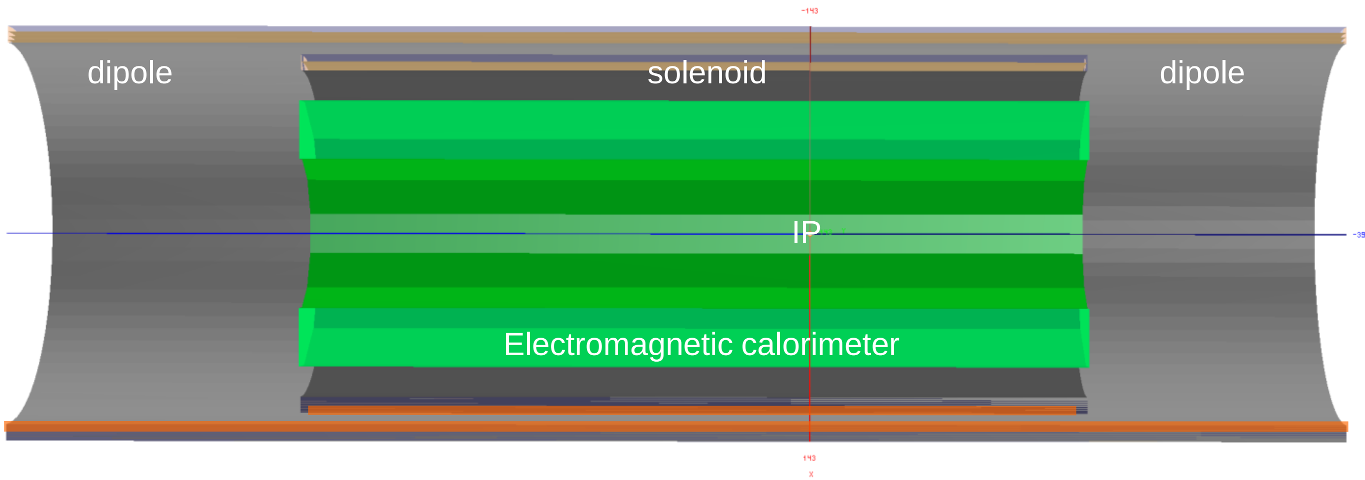
CDR Design:

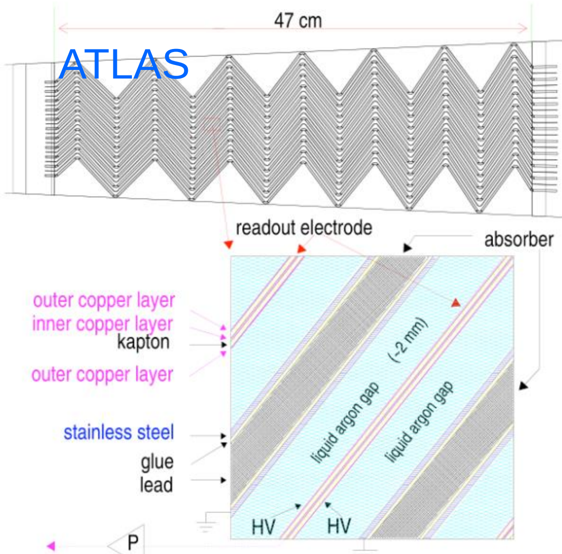
- Shaped to minimize effects of synchrotron radiation.
- Beryllium 2.5-3 mm thickness
- Central beam pipe ~ 6 meters length
- Constant cross-section along z
- TiZrV NEG coated for distributed vacuum pumping
- Wall protected from primary SR (upstream masks)
- Minimised end flanges, minimised supports

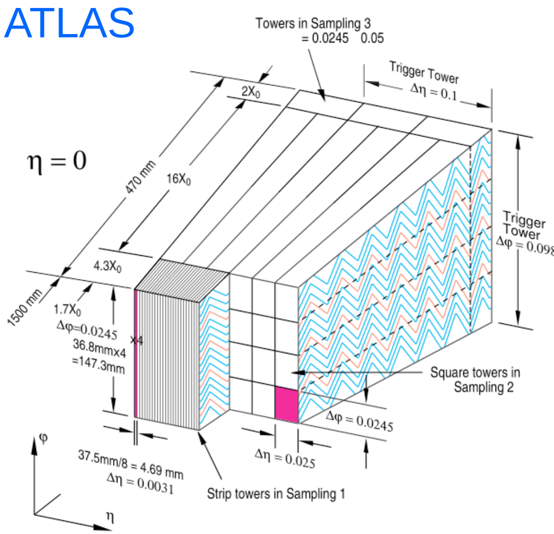
Silicon Tracker.



Electromagnetic barrel calorimeter.

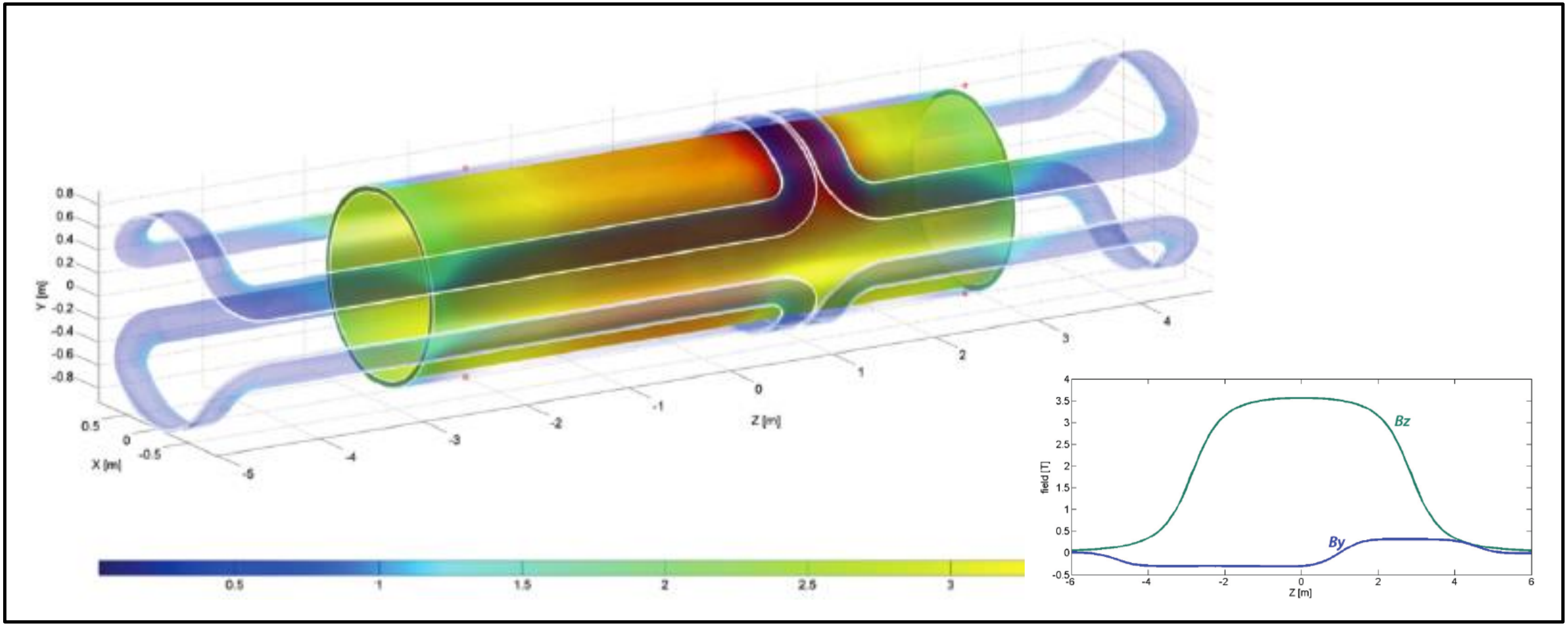






- L-Ar for barrel EMCal – ATLAS (25-30 X_0)
- Same cryostat used for solenoid and dipoles
- Simulation results compatible with ATLAS
- 3 different granularity sections longitudinally
- Warm (Pb/Sci) option also investigated 30X_0 (X_0(Pb)=0.56 cm; 20 layers)

Coil & dipoles.



- Solenoid (3.5 T) + dual dipole 0.3 T to steer the e-beam.
- Magnets embedded into EMC LAr Cryogenic System.

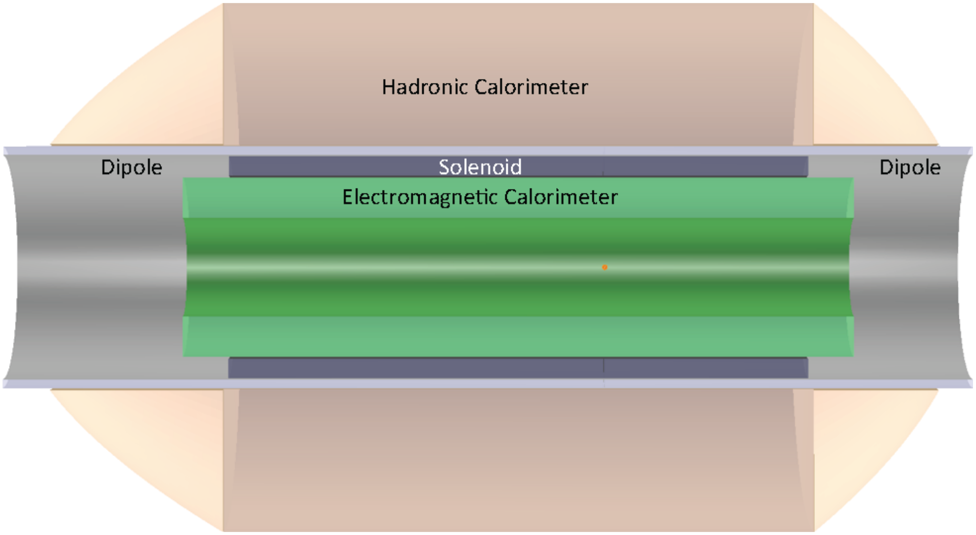
➔ Need to study the Calorimeter Performance and impact of dead material between EMC and HAC sections.

Hadronic central calorimeter.

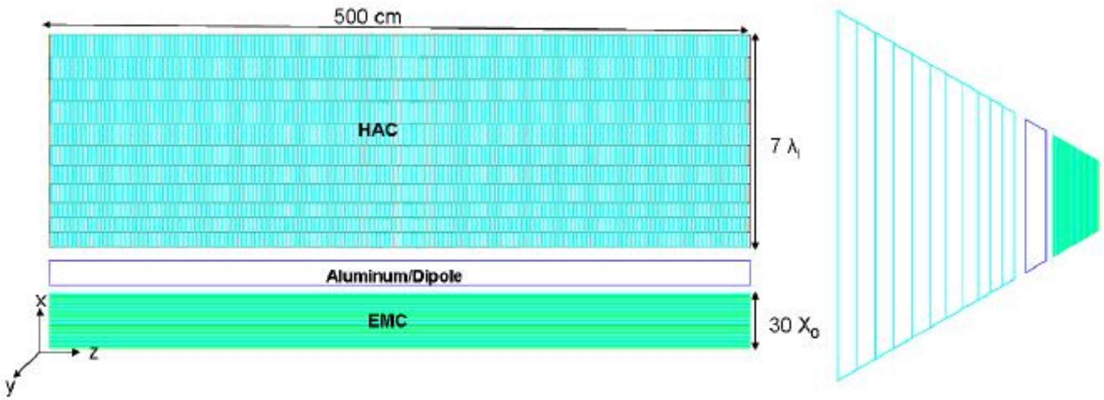
HAC iron absorber (magnet return flux)

Scintillating plates (similar to ATLAS TILE CAL)

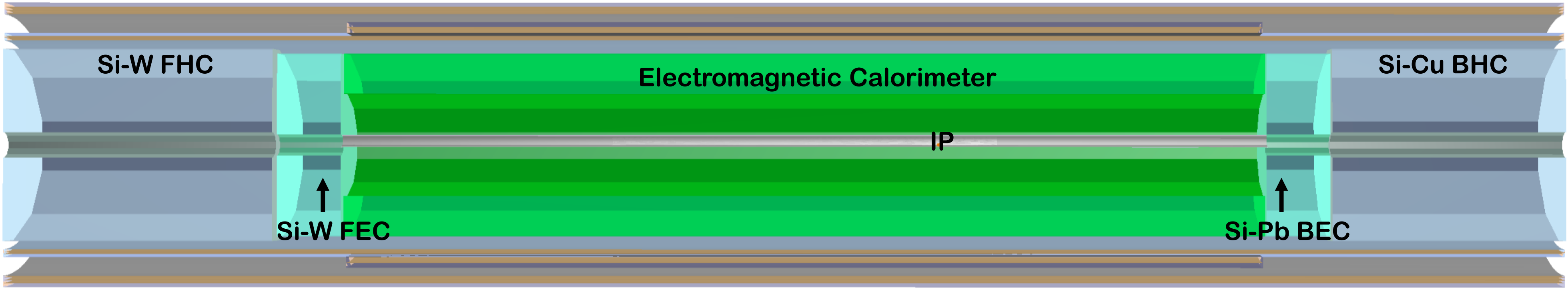
Interaction Length: ~7-9 λ_I



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



HCal/EMCal forward calorimeters.



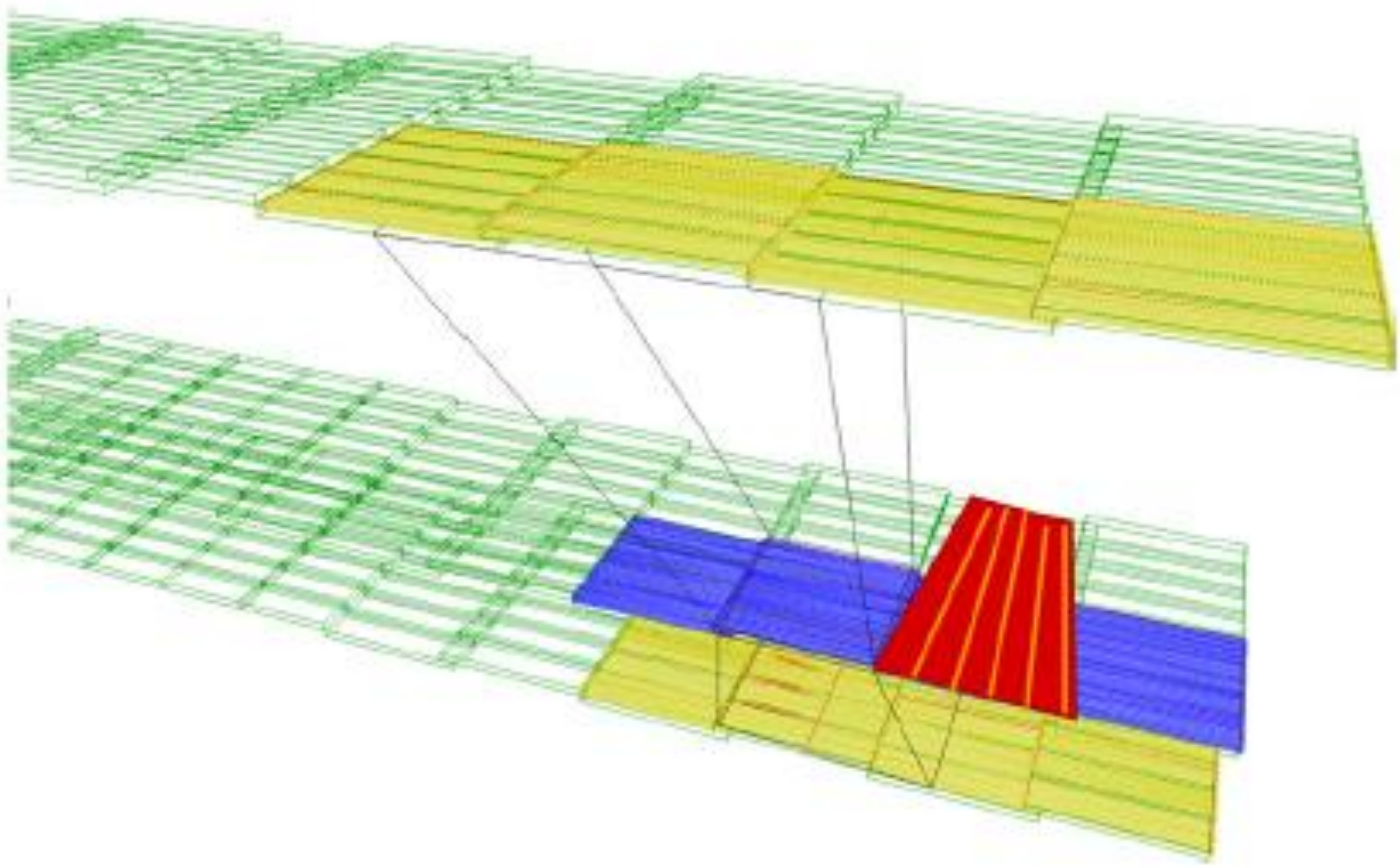
Forward FEC + FHC:

- tungsten high granularity
- Si (rad-hard)
- high energy jet resolution
- FEC: ~30X_0; FHC: ~8-10 λ_I

Backward BEC + BHC:

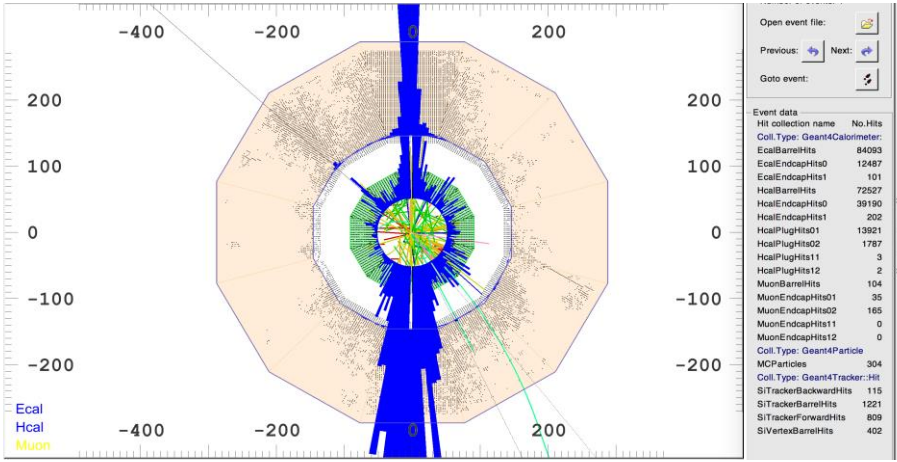
- need precise electron tagging
- Si-Pb, Si-Cu (~25X_0, 6-8 λ_I)

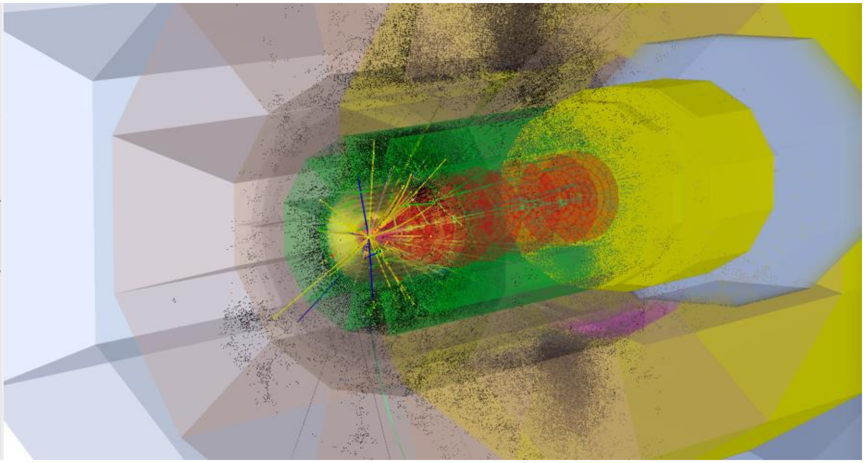
Muon tagging.



- Muon system providing tagging, no independent momentum measurement
- Momentum measurement done in combination with inner tracking
- Present technologies in use in LHC experiments & their upgrades sufficient (RPC, TGC, MDT, etc.)

Detector Software.



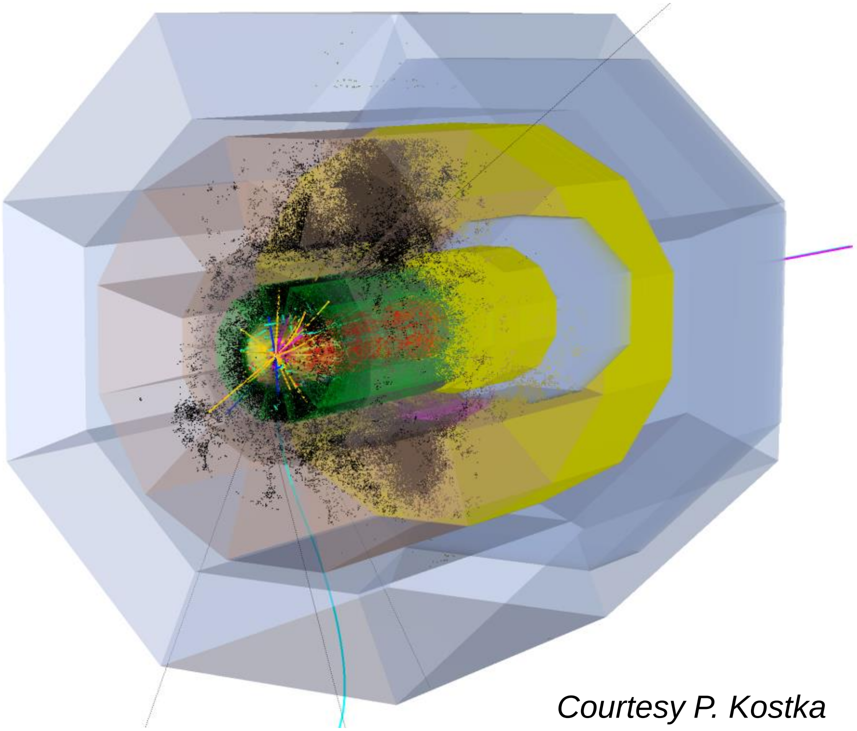


Simulation of Higgs->bb from LHeC e-p

•**A compact DD4hep/DDG4 detector model mimic/simulate the response on physics, on reconstruction schemes, on analysis chains (ROOT/GEANT4 based)**

•**The DD4hep/DDG4 toolbox covers**

- **full detector description:**
  geometry, materials, visualisation, readout, alignment, calibration …
- **single source of detector information for simulation, reconstruction, analysis**
- **support of all phases of the experiment life cycle: detector concept development, detector optimization, construction, operation**



Courtesy P. Kostka

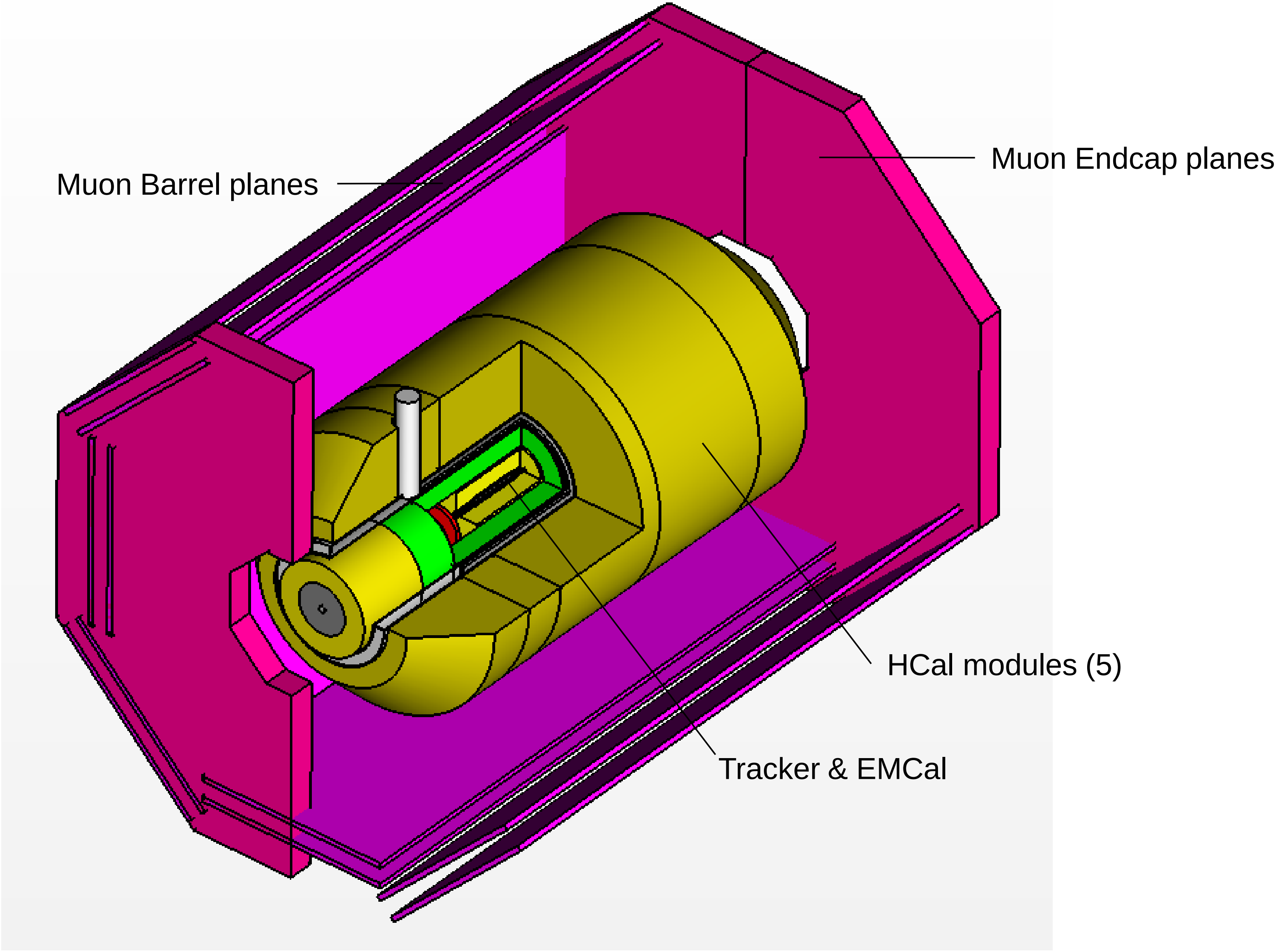
LHeC Detector assembly on surface.

The strategy proposed to minimize the installation time is to complete as much as possible the assembling and testing of the detector on surface, where the detector construction can proceed without impacting on the LHC physics runs.

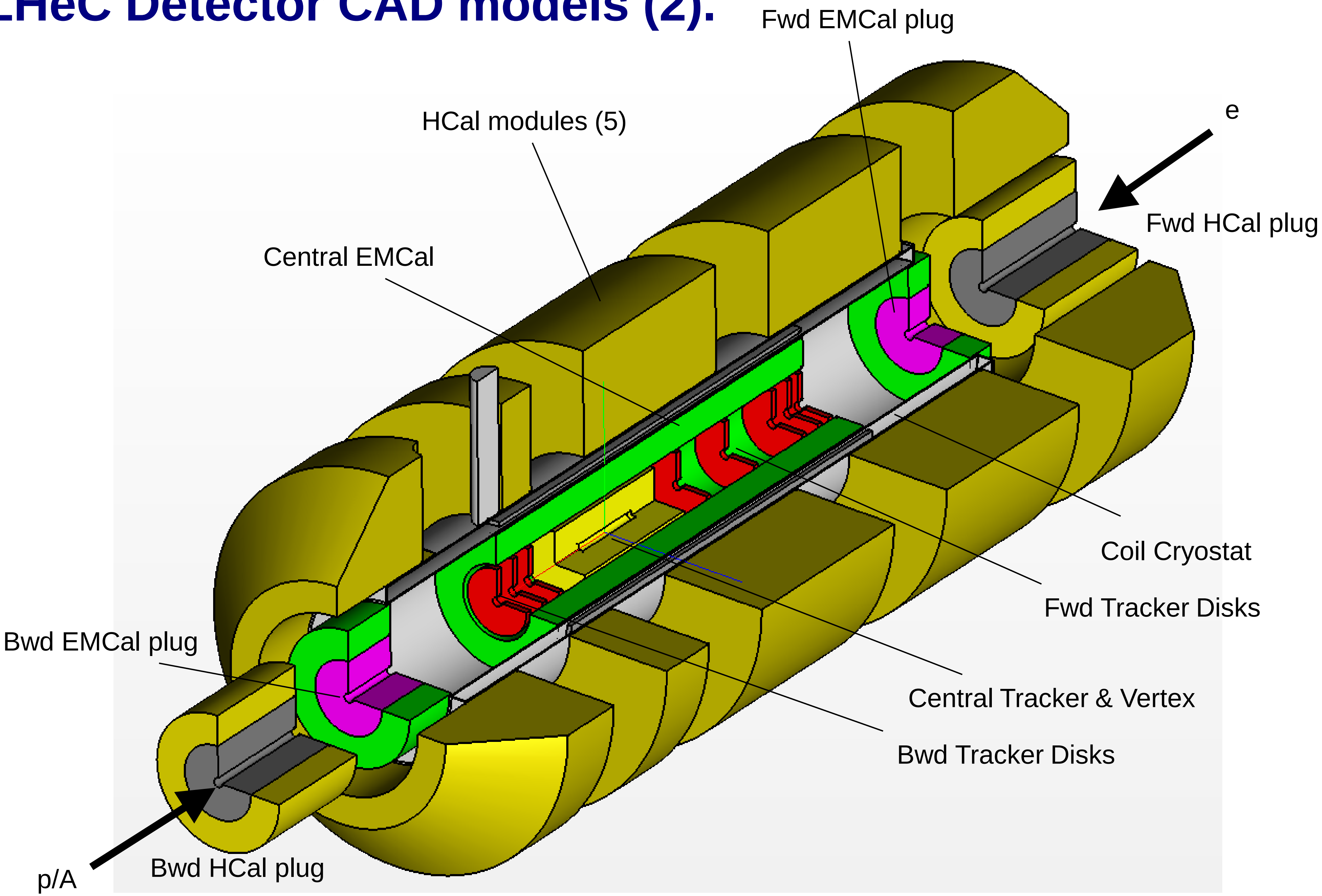
The detector has been split in the following main parts (15):

1) Coil cryostat, including the superconducting coil, the two integrated dipoles and eventually the EMCal, *if the L-Ar version is retained* (1).
2) Five HCal tile calorimeter modules, fully instrumented and cabled (5).
3) Two HCal plugs, forward and backward (2).
4) Two EMCal plugs, forward and backward (2).
5) Tracker & Vertex detector (1).
6) Beam-pipe (1).
7) Central Muon detector (1).
8) Endcaps Muon detector (2).

LHeC Detector CAD models (1).

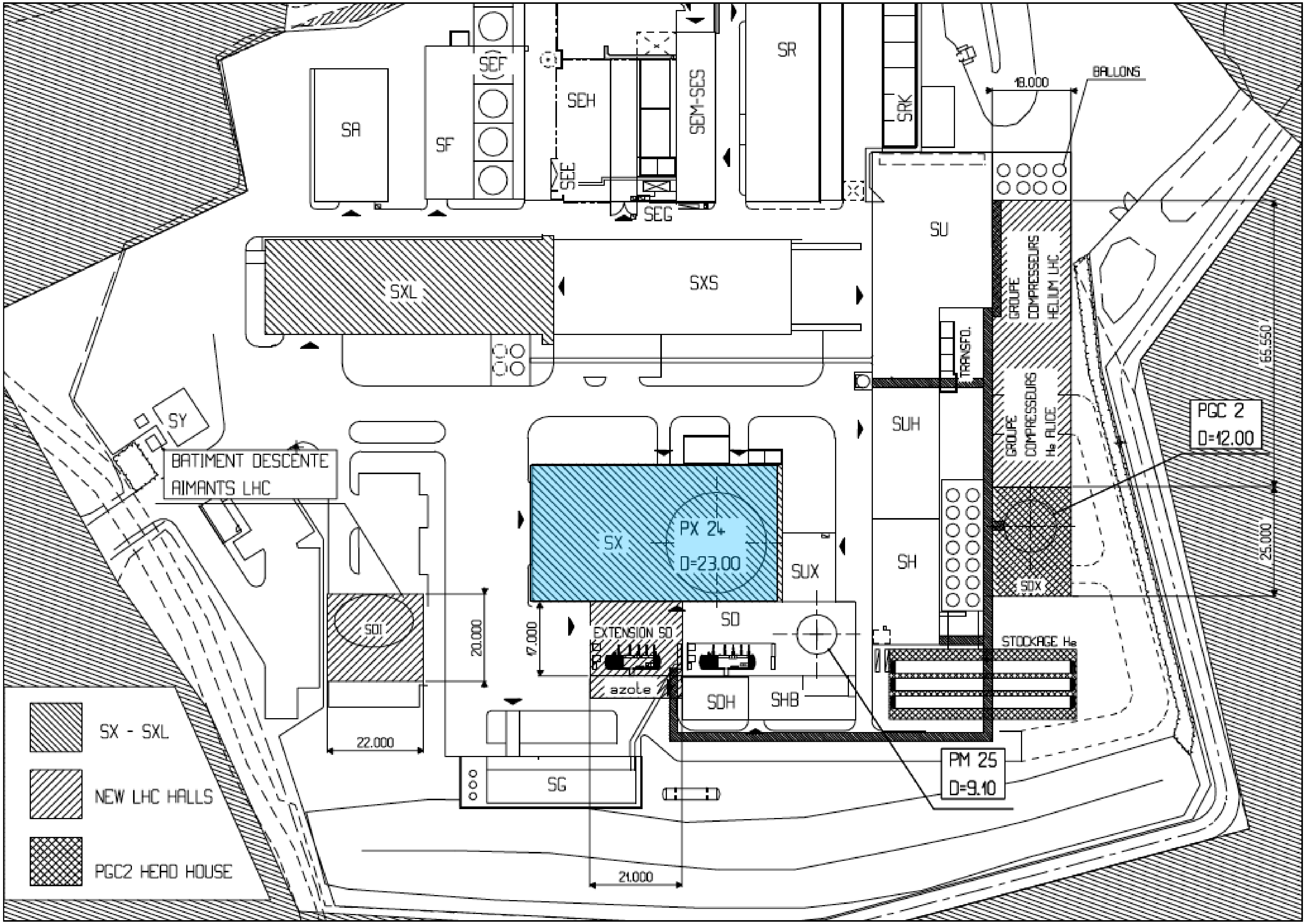


LHeC Detector CAD models (2).



P2 facilities on surface.

Crane capacity on surface b.SX2: 65tons.



Coil tests on surface.

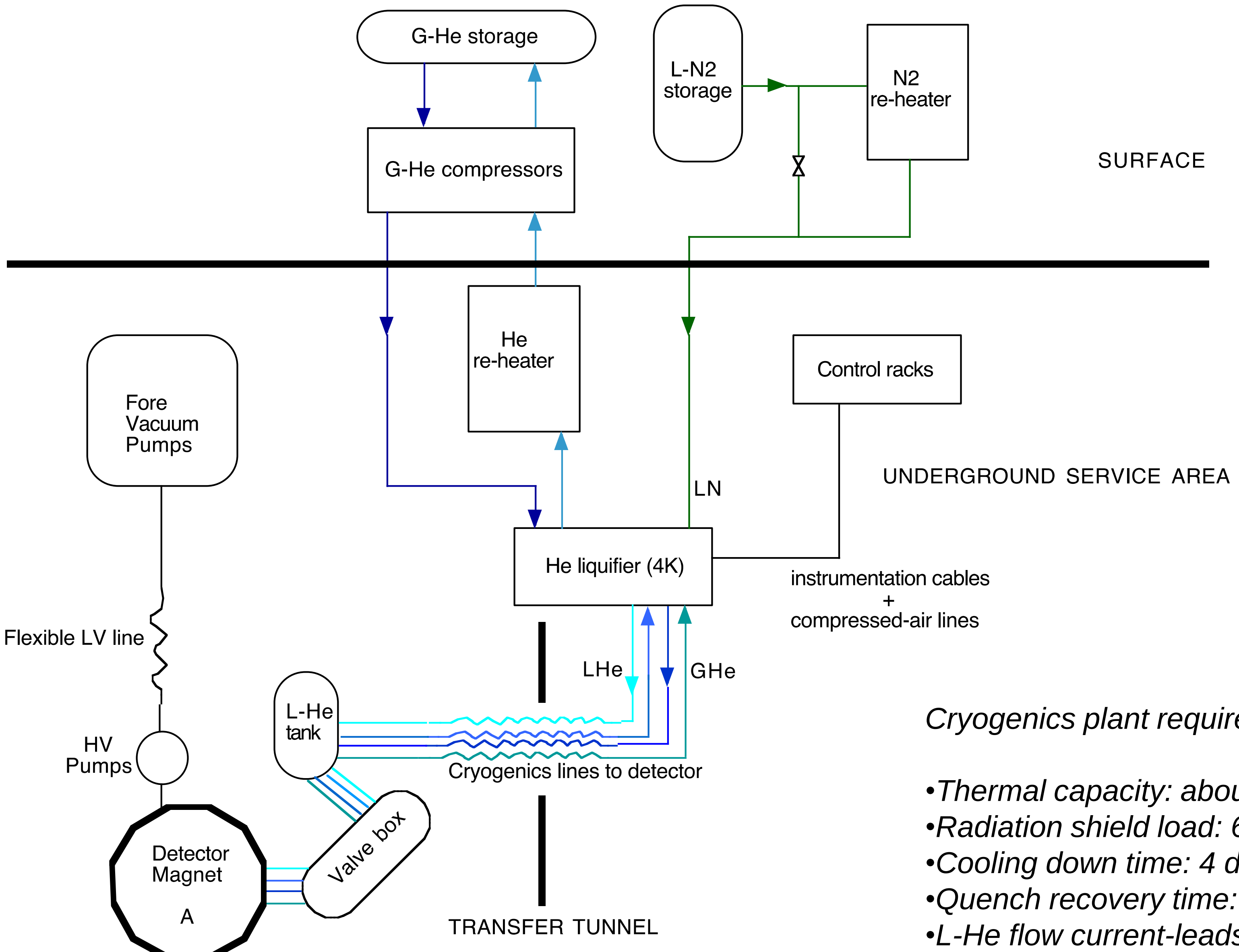
The superconducting coil and the two integrated dipoles can be tested at nominal current on surface, including the field mapping. The electrical tests on surface will include:

- Progressive powering ramps to nominal current.
- Progressive discharge ramps (fast & slow).
- Measurement of the operating temperature and current margins.

Cryogenic plant and magnets power supply availability are key features.

The suggested procedure will follow what done at CMS in 2006.

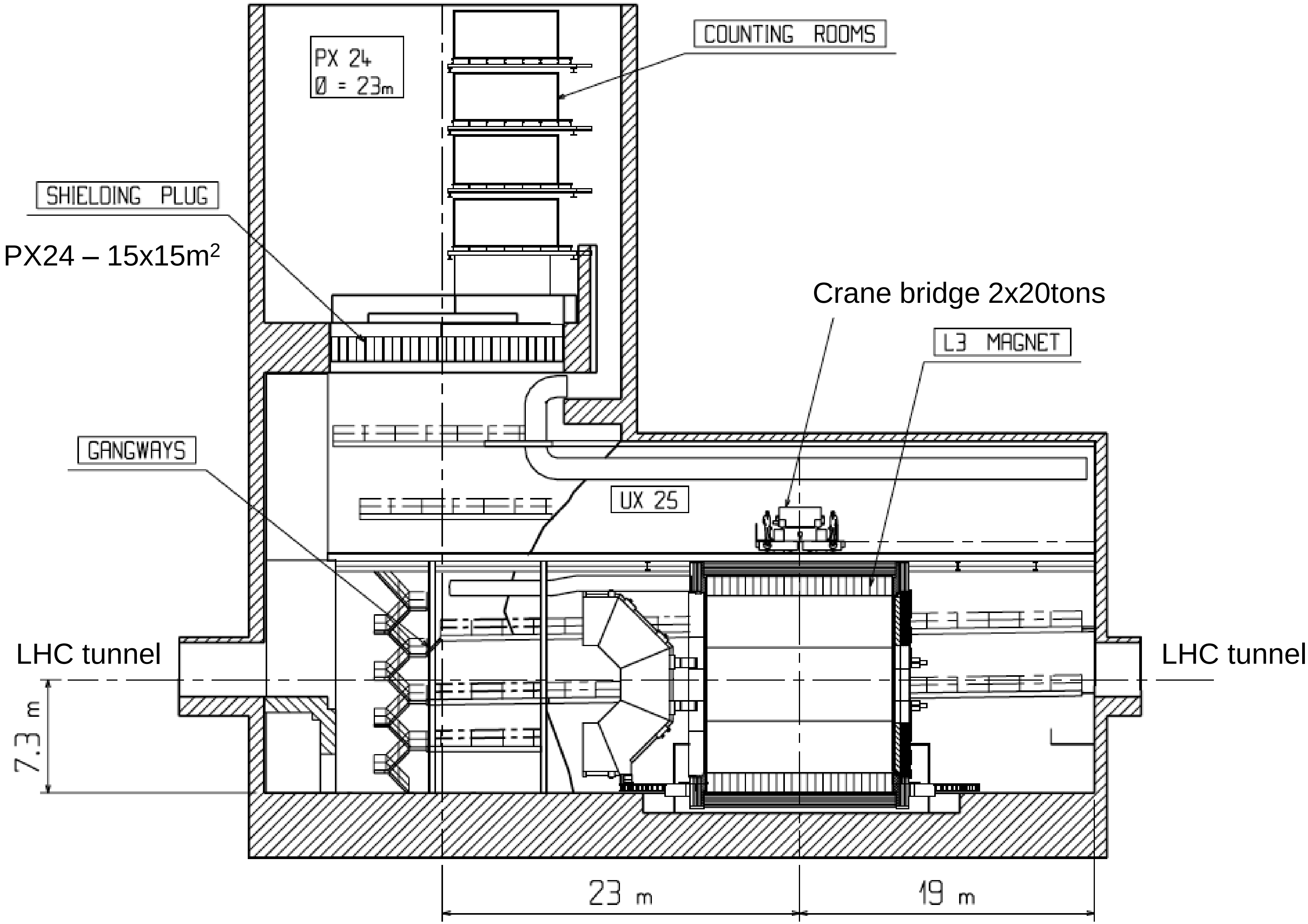
Cryogenics plant schematics.



Cryogenics plant requirements

- *Thermal capacity: about 110W at 4.6K*
- *Radiation shield load: 650W at 60K*
- *Cooling down time: 4 days*
- *Quench recovery time: 1 day*
- *L-He flow current-leads: 1.5g/s*

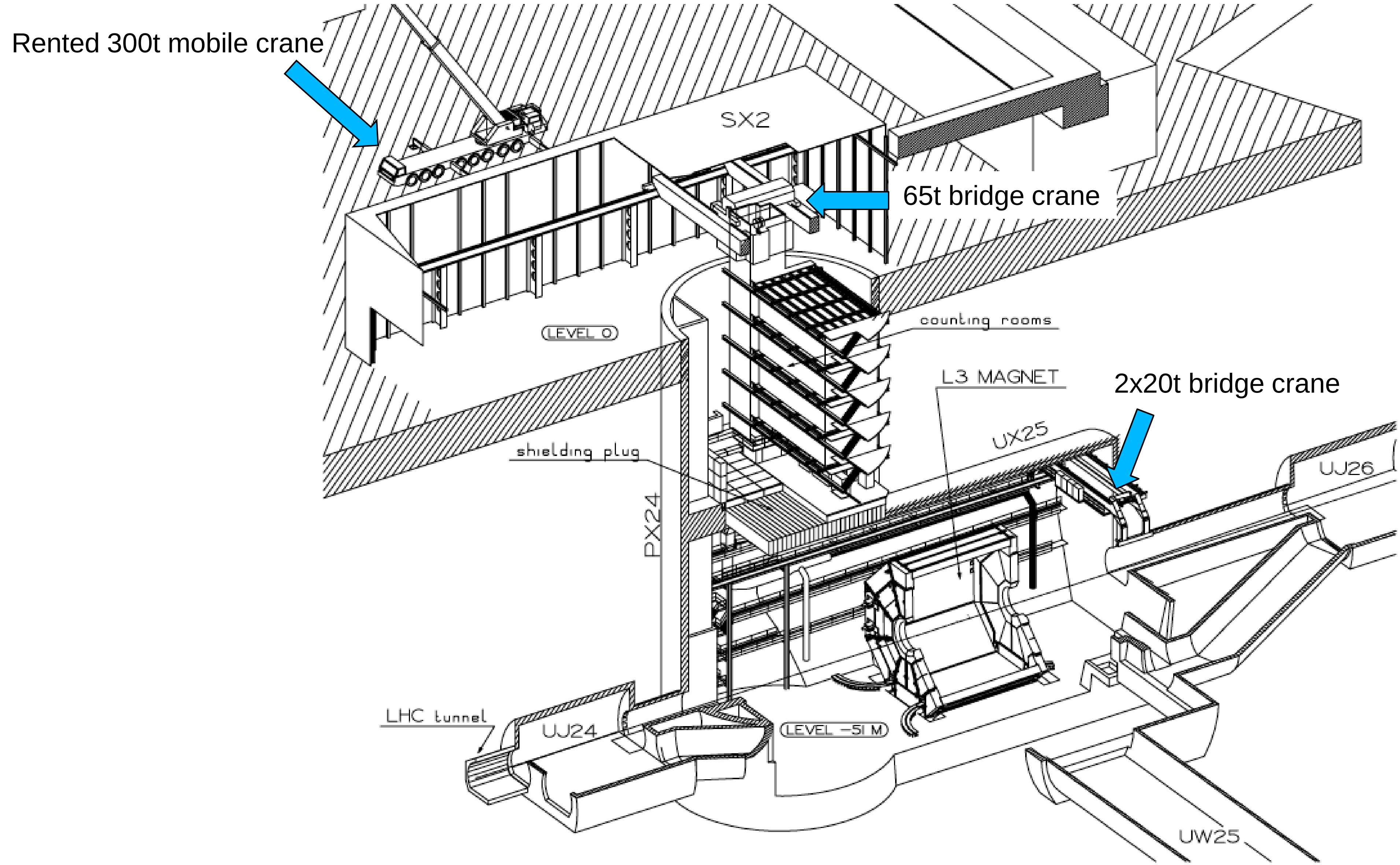
Underground facilities LHC-P2.



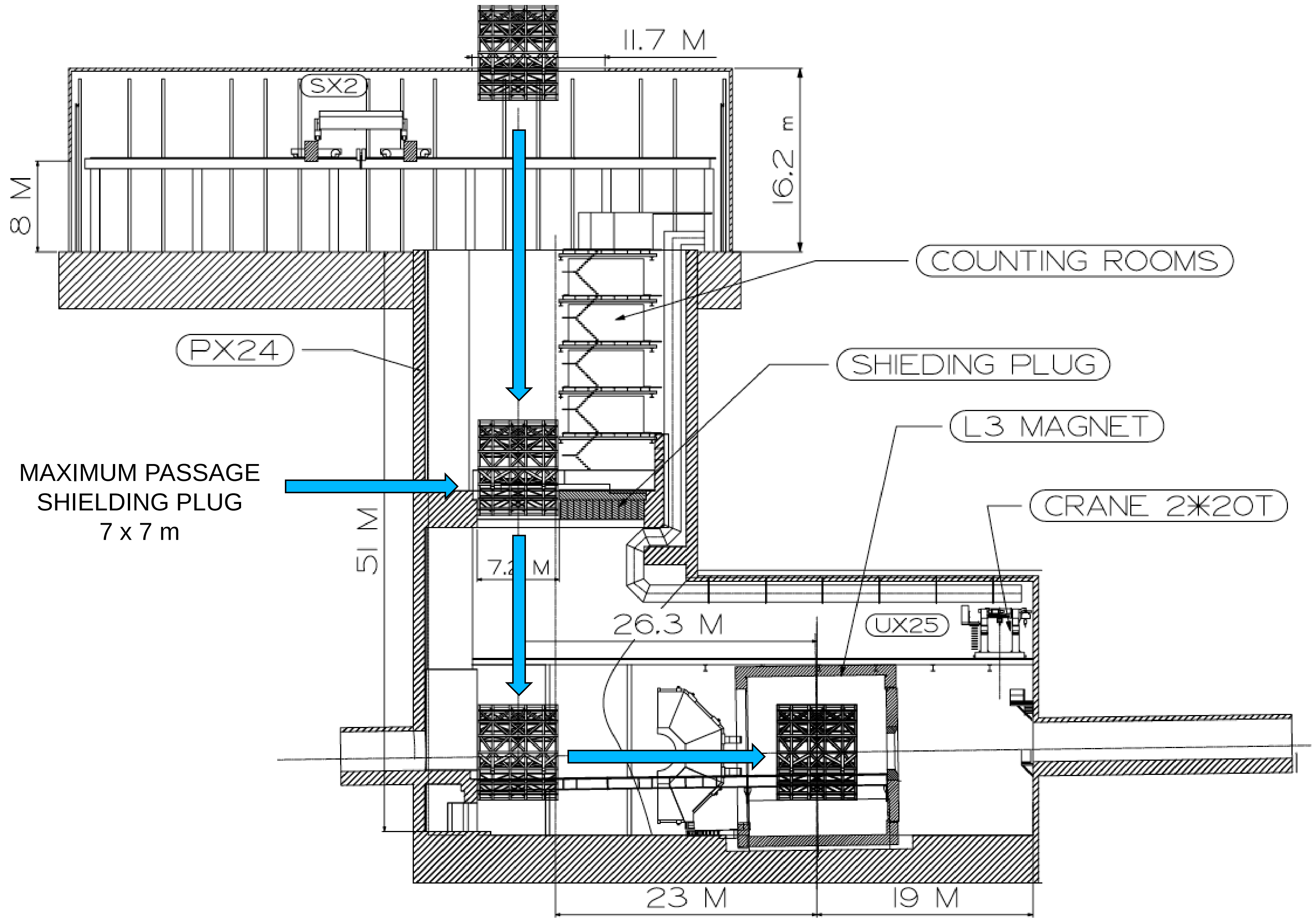
Heavy detector elements lowering.

The maximum weight of a single detector element to be lowered from surface to underground has been limited to 300 tons, in order to make possible the lowering by renting a commercial crane, as already applied by L3 for its barrel HCal.

Heavy detector elements lowering.



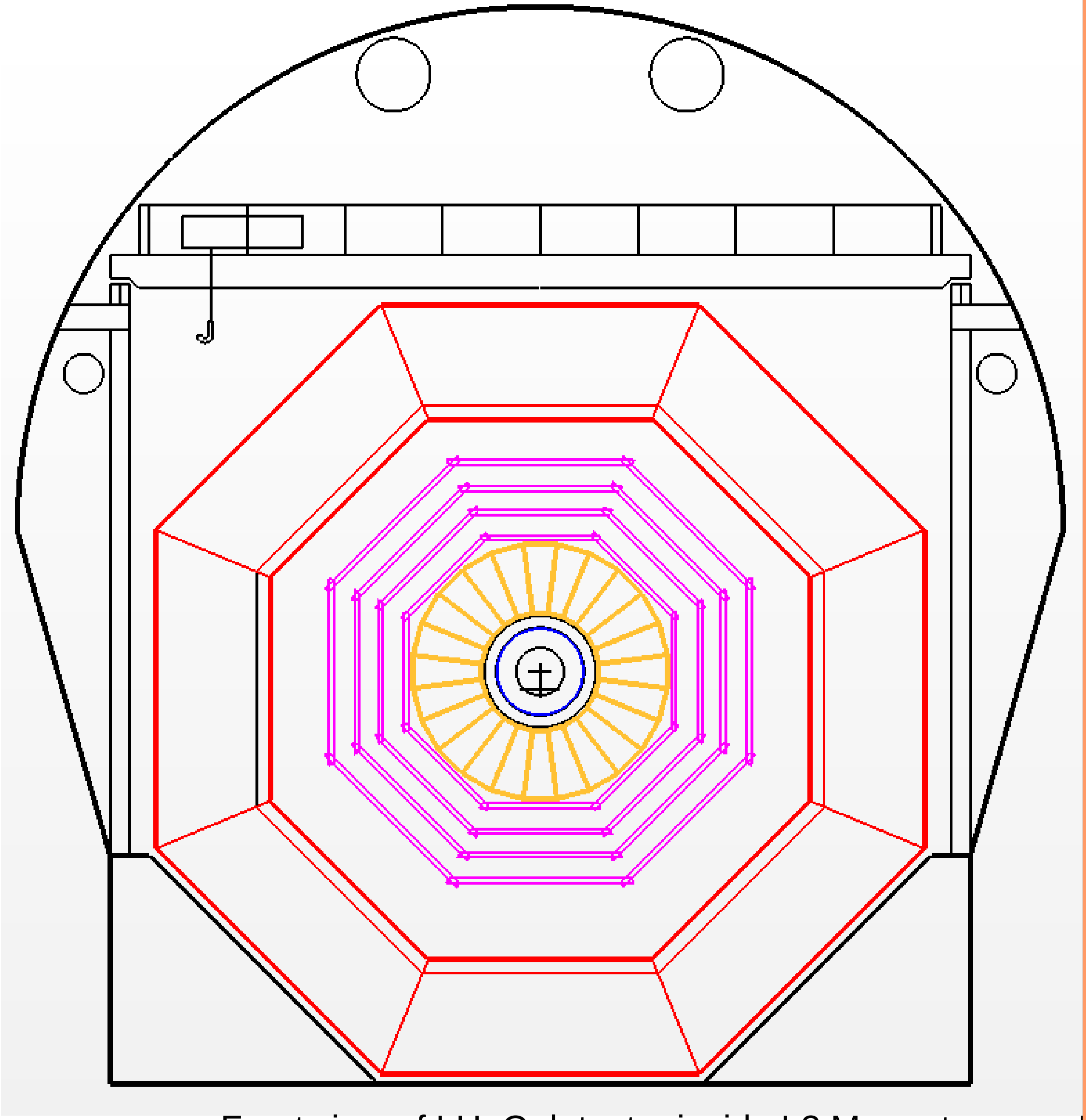
Detector elements lowering *(Alice space-frame example)*.



Detector integration in the L3 Magnet.

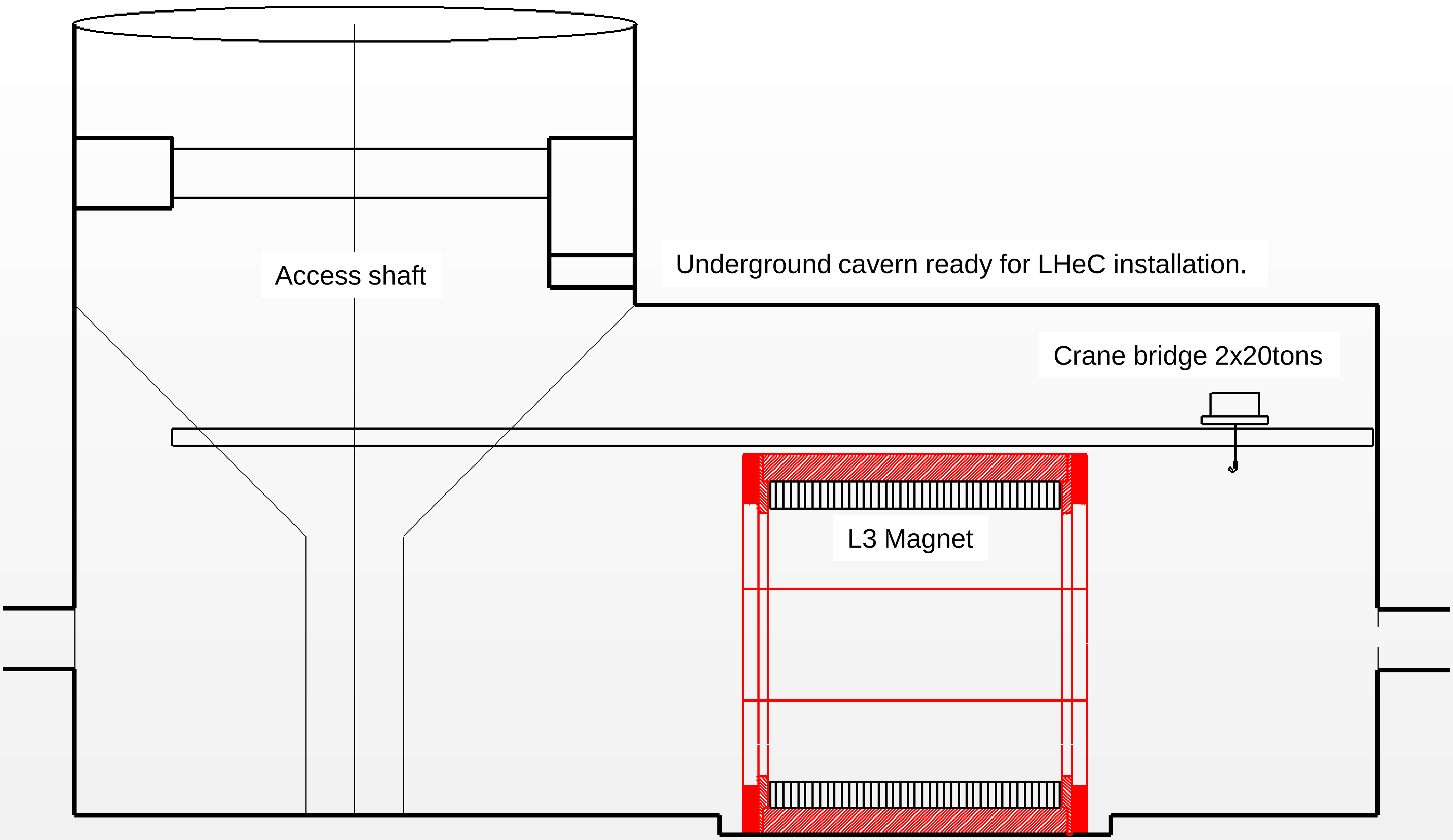
The LHeC detector, including the Muon chambers, fits inside the former L3 Magnet Yoke, once the two large doors are taken away. The goal is to prevent losing time in dismantling the L3 Magnet barrel yoke and to make use of its sturdy structure to hold the detector central part on a platform supported by the magnet crown, whilst the Muon chambers will be inserted into self-standing lightweight structures (space-frames).

To be noted: the LHeC interaction point has an offset of 300mm along Y and 870mm along Z, with respect to the centre of the L3 Magnet Yoke.

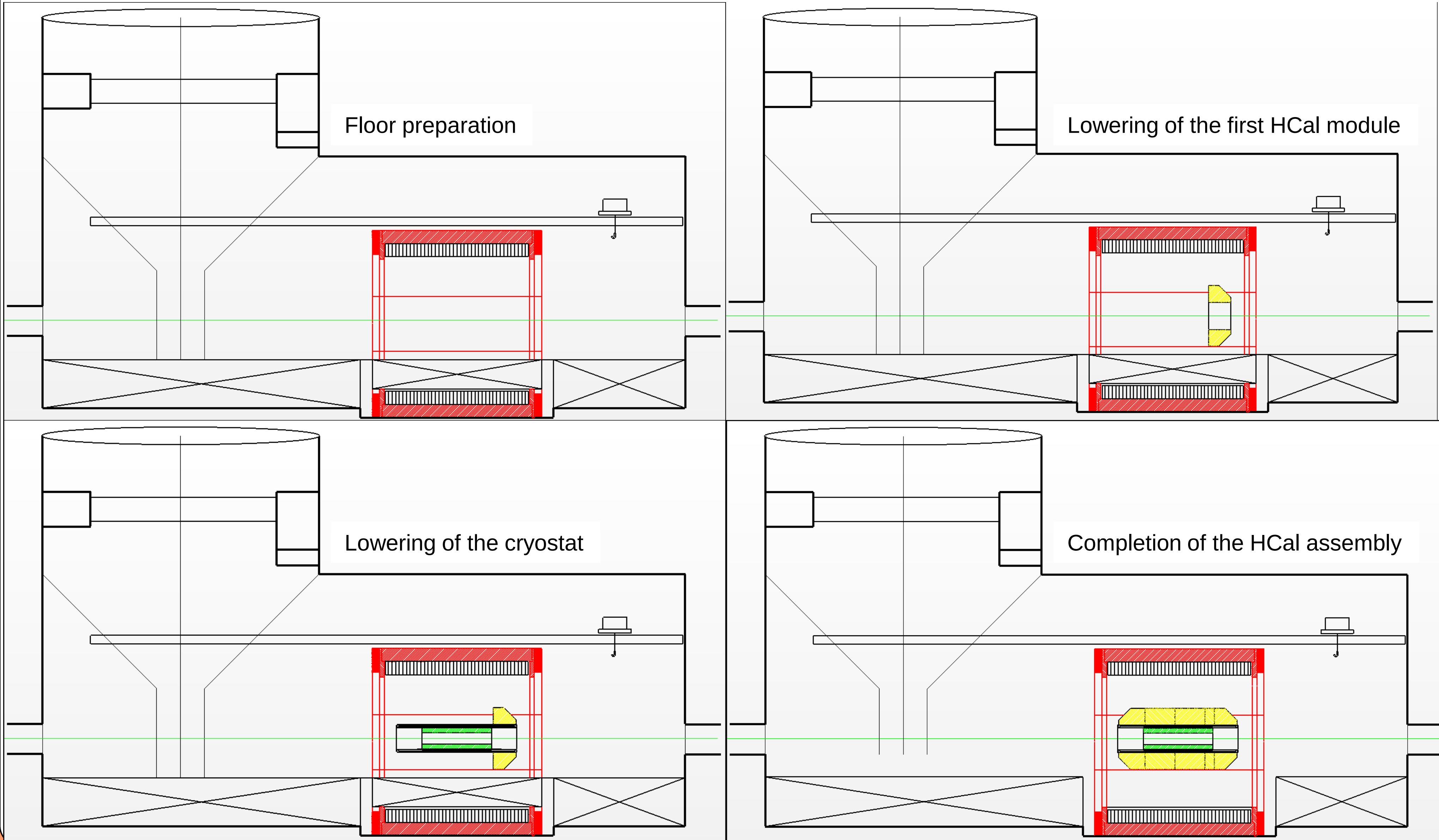


Front view of LHeC detector inside L3 Magnet

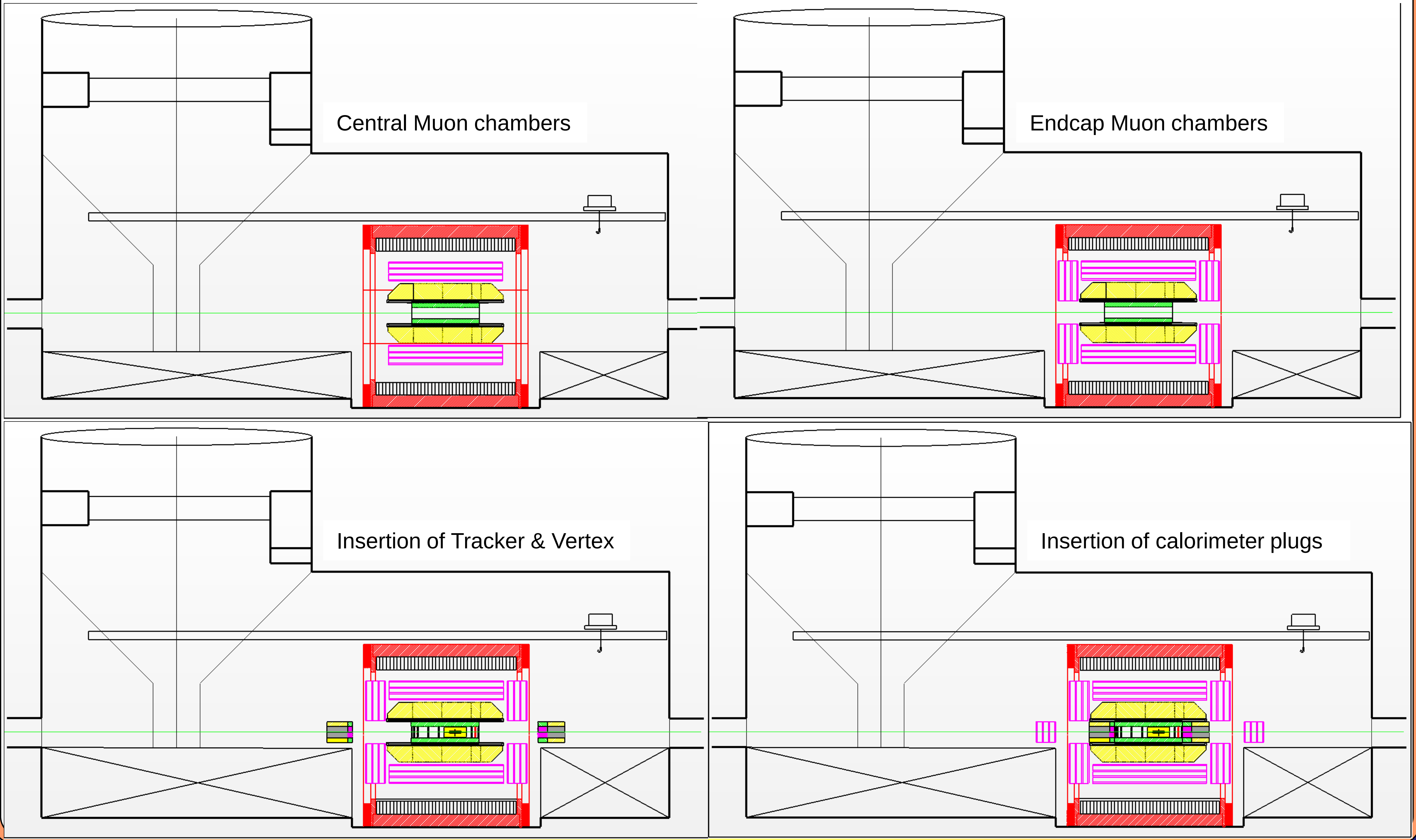
Detector lowering & integration underground (1).



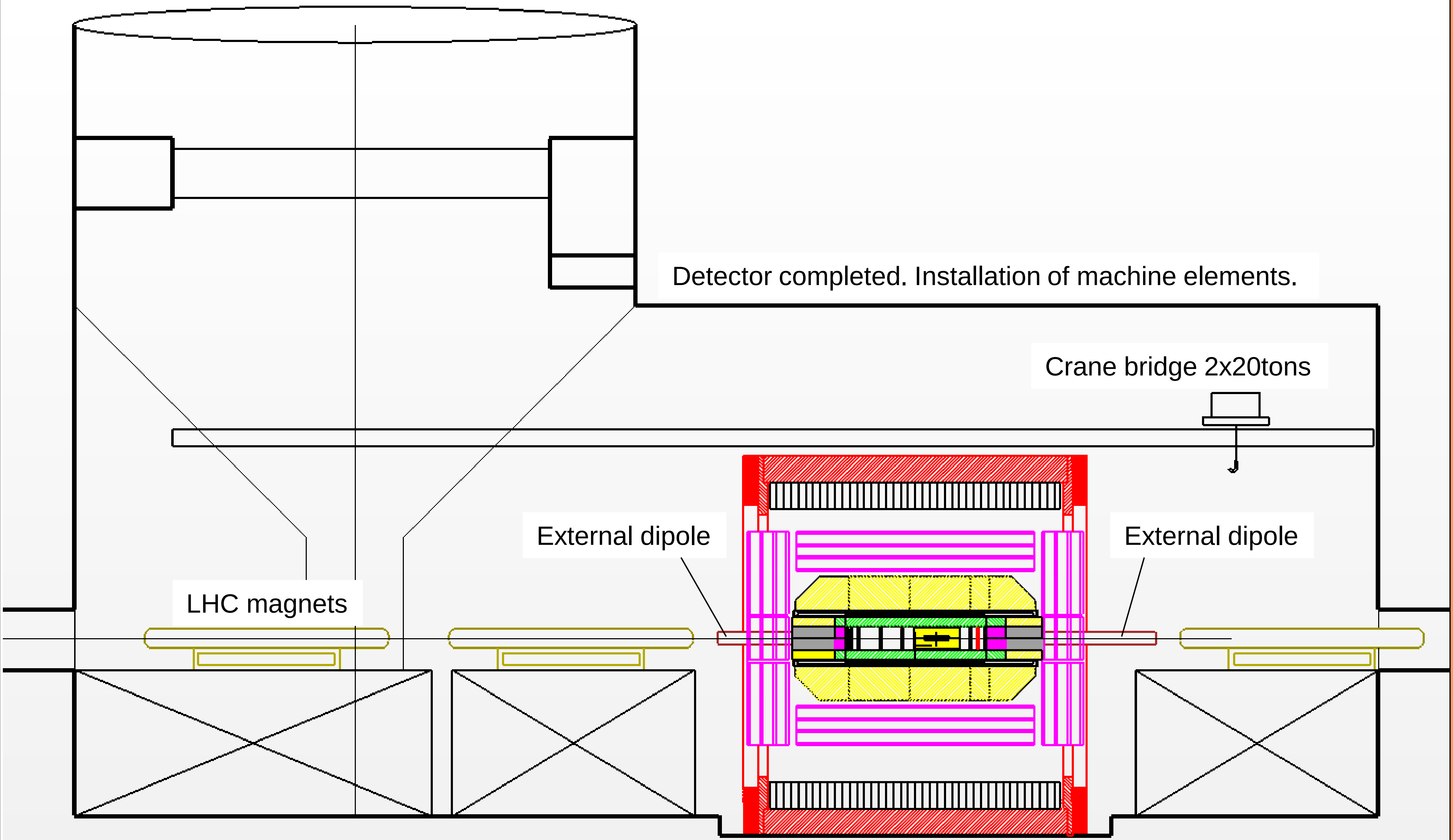
Detector lowering & integration underground (2).



Detector lowering & integration underground (3).



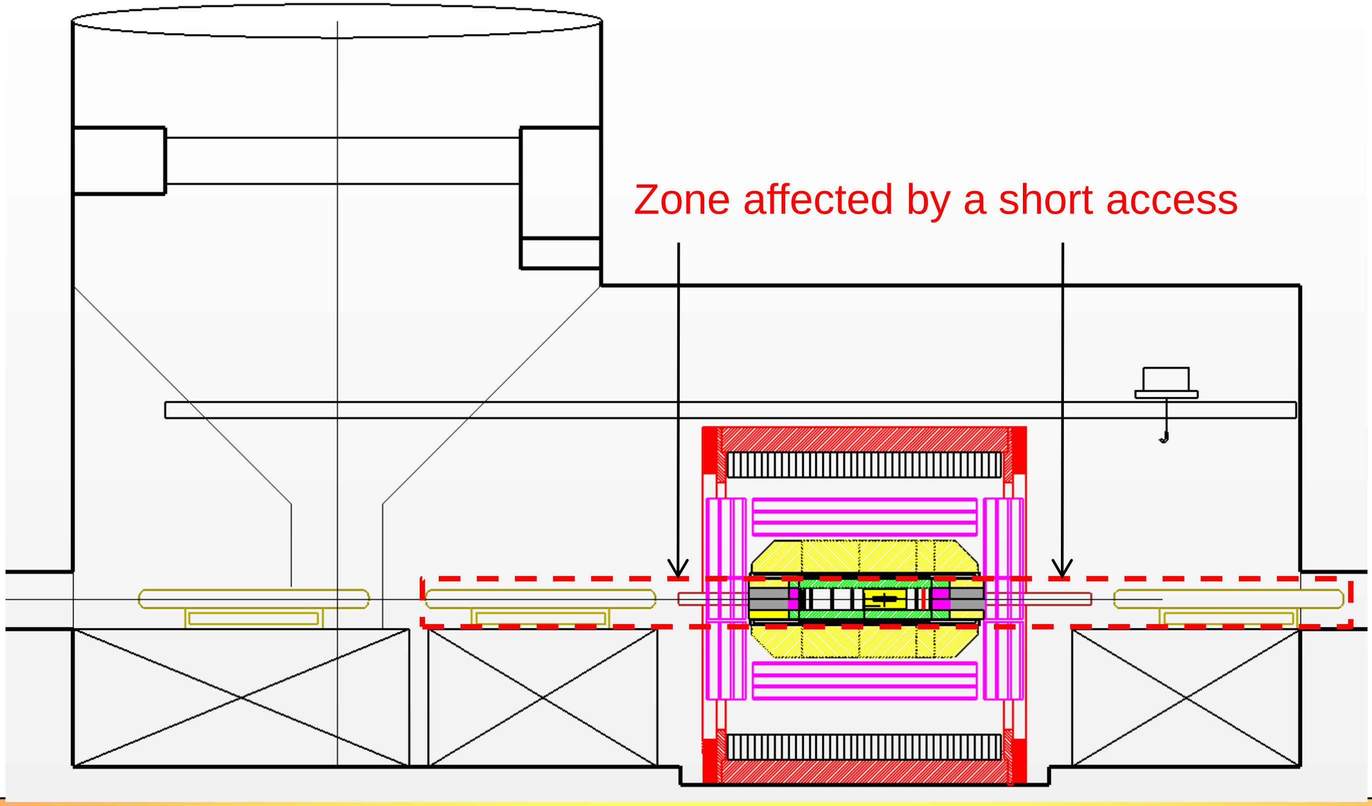
Detector lowering & integration underground (4).



Maintenance & opening scenario.

A minimal maintenance scenario has been analysed. This foresees the possibility of opening the detector to get access to the Central Tracker & the Vertex. To allow this, the two heavy HCal inserts have to be removed from inside the cryostat and moved along z on the platform that supports the last machine elements, in particular the external dipoles. These elements have to be previously disconnected from the beam-pipe and moved away on the same platform along x. To avoid disconnecting the HCal inserts form the main services, cable-chains will accomodate extra-lengths of cables, fibres and services.

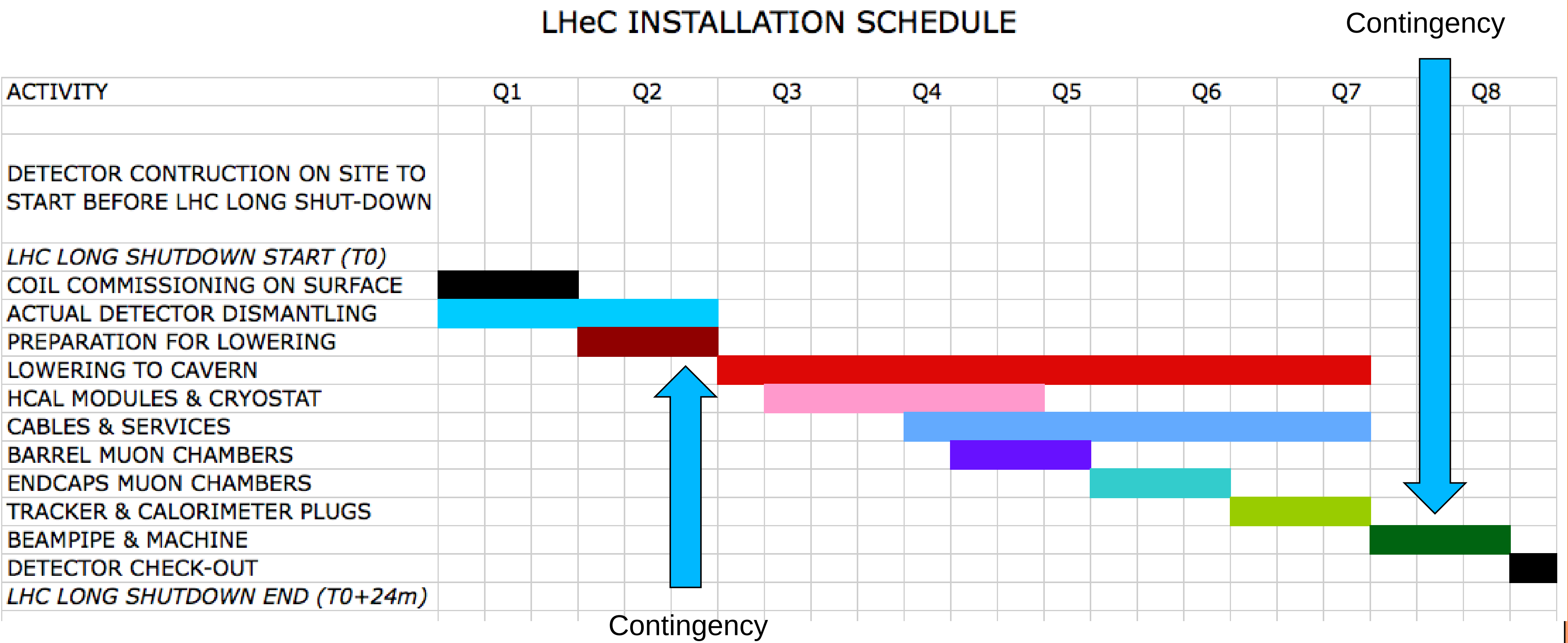
Additional work is needed to better define a reliable detector maintenance scenario.



Timelines.

The assembly on surface of the main detector elements, as previously defined, can start at any time, providing that the surface facilities are available, without sensible impact on the LHC run. The Coil system commissioning on site (T=0) could request 3 months and preparation for lowering 3 months, including some contingency. In the same time (6 months, *tbv – the delay depends on the level of activation and the procedure adopted for dismantling the existing detector*) the L3 Magnet will be freed up and prepared for the new detector. Detector components lowering is supposed to take one week per piece (15 pieces in total). Underground integration of the central detector elements inside the L3 Magnet would require about 6 months, cabling and connection to services some 10 months, in parallel with the installation of the Muon chambers, the Tracker and the Calorimeter Plugs.
The total estimated time, from the starting of the commissioning of the Coil system on surface to the commissioning of the detector underground is thus 20 months. The beam-pipe bake out & vacuum pumping could take another 3 months and the final detector check-out an additional month. Some contingency (2 – 3 months in total) is foreseen at the beginning and the end of the installation period.

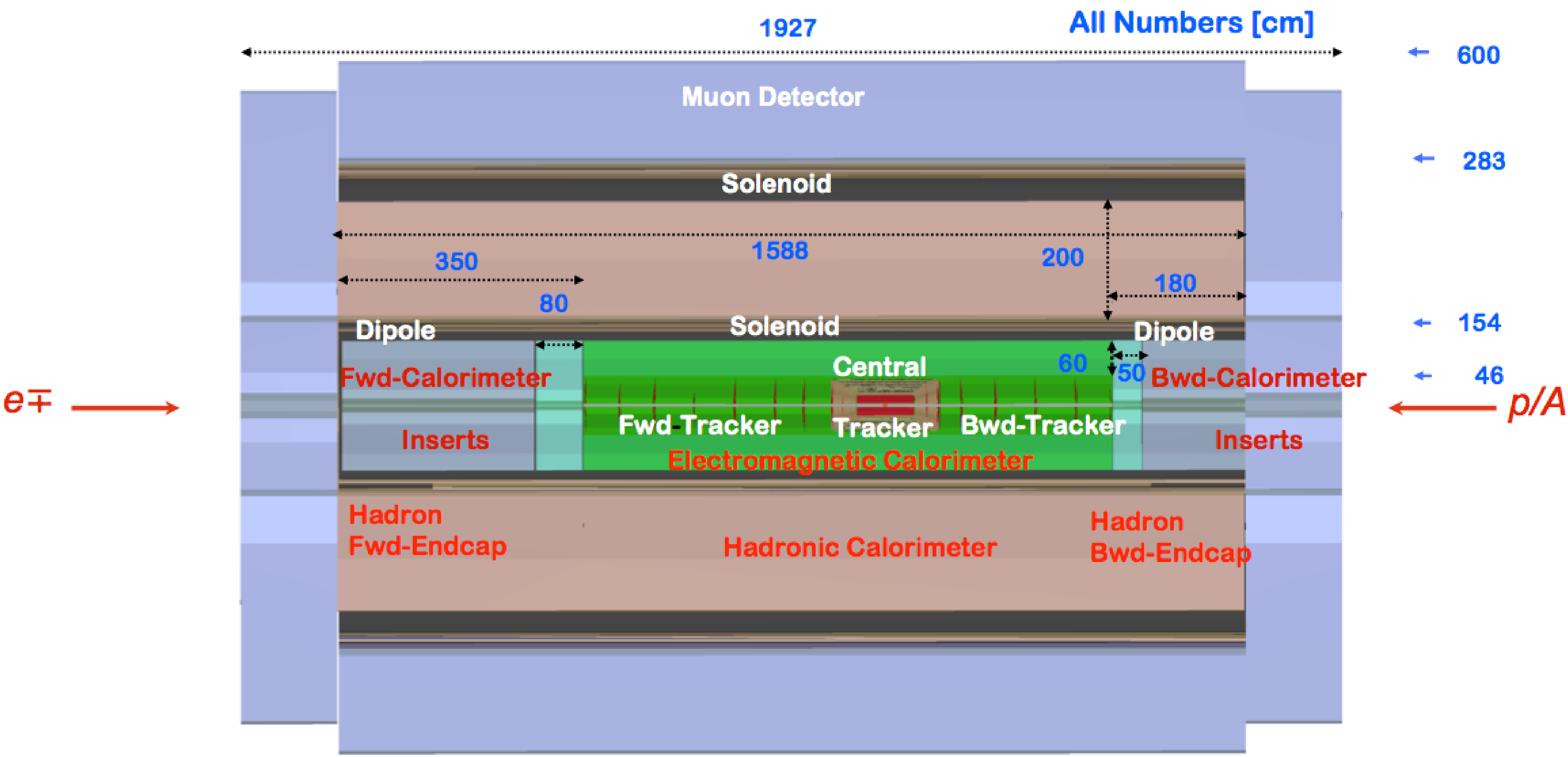
Tentative schedule.



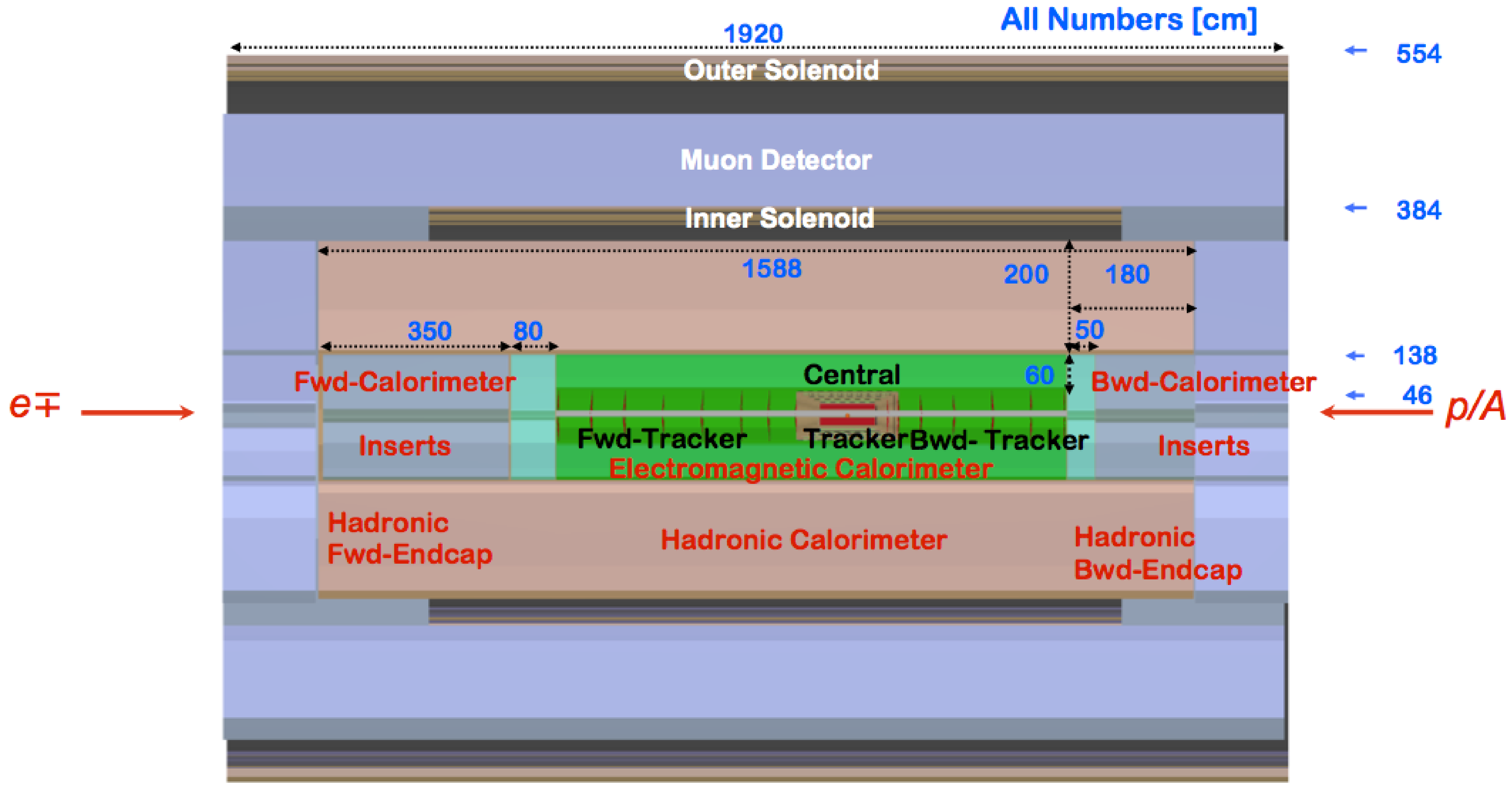
Main technological challenges.

1. Shaped beam-pipe (mechanical & vacuum stability)
2. Extra-thin coil & dipoles + cryostat
3. Maintenance scenario (external dipoles vs forward plugs opening)
4. Schedule

FCC-he study (version 1).



FCC-he study (version 2).



Conclusions.

A first study is reported about the principle of pre-assembling the detector at the surface, lowering and installing it at LHC-P2. The LHeC detector fits inside the former L3 Magnet, this would avoid the dismantling of the heavy iron structure that could be re-used as a stiff support for the new detector. The layout is also compatible with a minimal maintenance scenario, allowing access to the LHeC inner detectors in a relatively short time (although the last machine elements have to be disconnected form the beam-pipe and displaced aside a few meters).
The schedule for detector installation & commissioning underground could finally be contained within 24 months, providing that most of the detector is previously completed at surface, including the coil and the cold dipoles that shall be tested before lowering.

FCC-he study is at a very early stage. The size of the detector would significantly increase and one of the most technological challenge (common to the other FCC-pp detectors) would be represented by the huge (and costly) magnet system.

Back-up slides.

Detector geometry table 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					

FCC-he detector preliminary table.

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					

Coil/dipoles table LHeC.

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.