Installation Issues of eh Detectors: preliminary Engineering Study for the three options.

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Introduction & disclaimer.

The following is a very preliminary study focused on the detector installation engineering aspects, including assembly and integration at CERN LHC P2, as base-line for HL-LHC and/or HE-LHC, and at FCC Point L, with some considerations on the detector maintenance scenario.

Many parameters are still evolving (specially for HE-LHC and FCC-he), thus the study is based on what we know now and it is obviously incomplete. The main goal is to check the compatibility of the proposal with the other stakeholders and define a rough timeline for the detector installation.

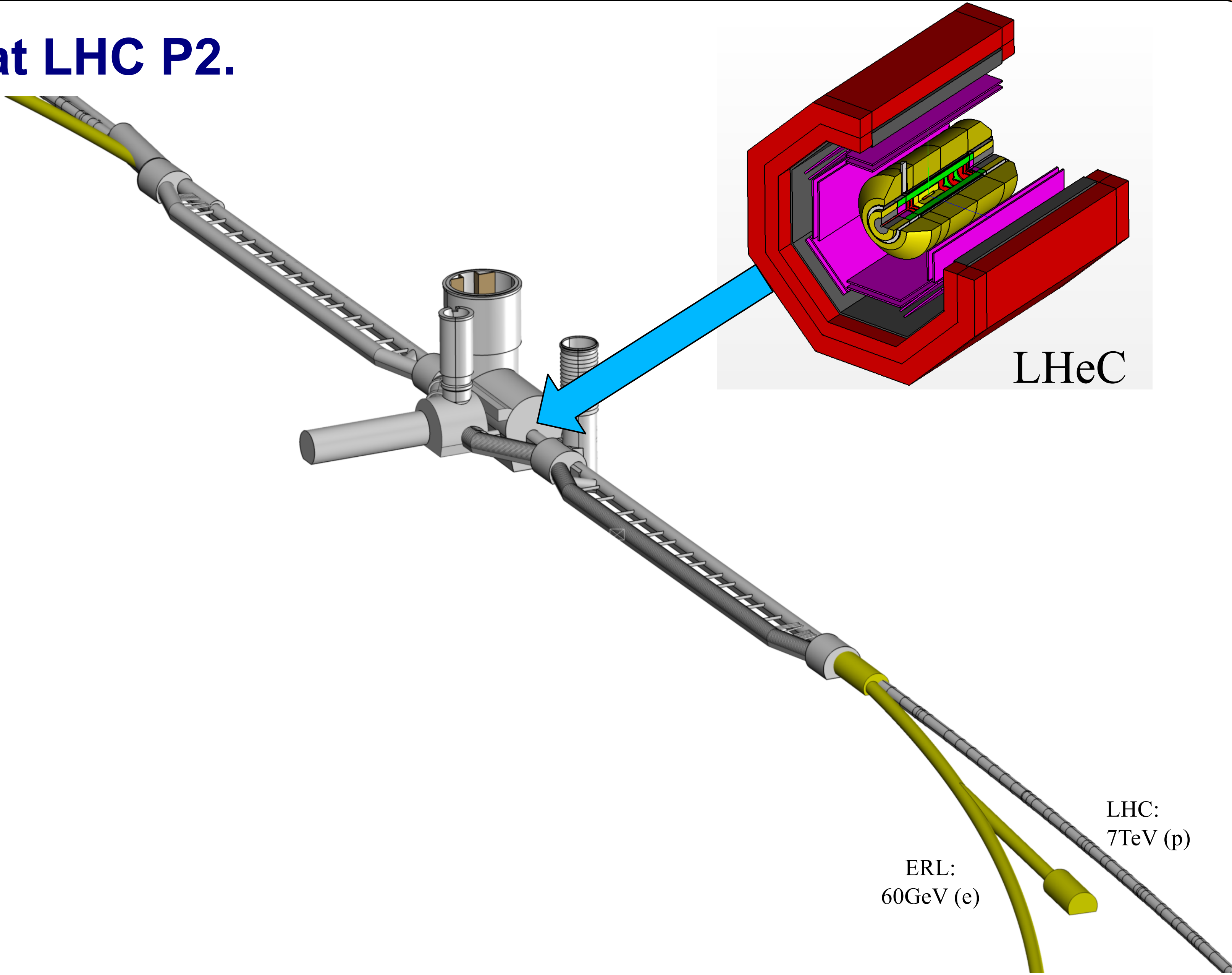
Introduction (cont'd).

At this stage, two main considerations are made:

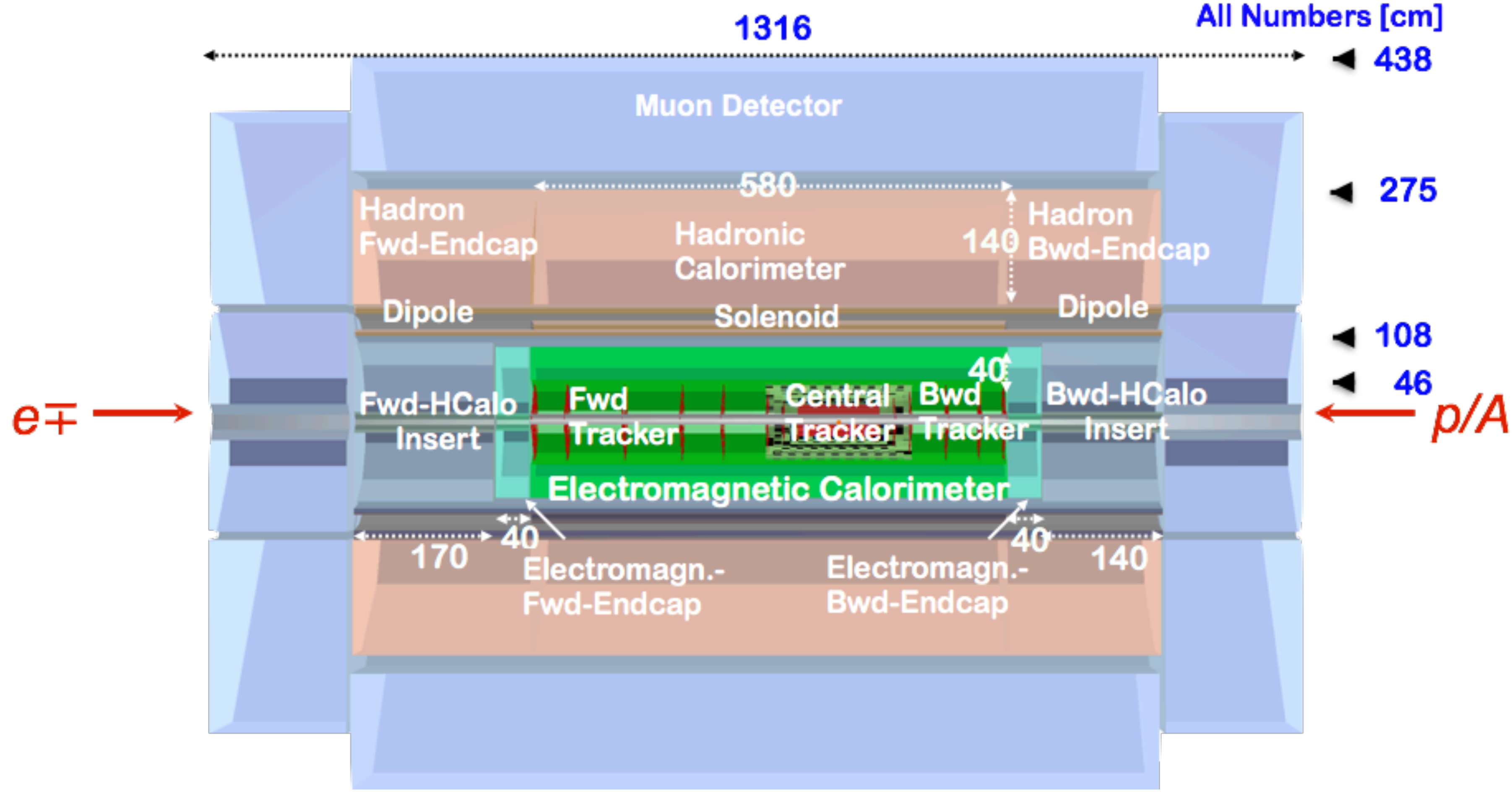
- The dimensions of the largest object to be lowered in the experiment cavern as single piece set the diameter of the shaft (e.g. CMS Central wheel => 21 m). In the same way, the weight of the heaviest object to be lowered in the experiment cavern as single piece sets the crane capacity (e.g. CMS Central wheel => 2,200 tons).

- The assembly scenario (on-surface, underground, mixed) sets the dimensions of the experiment cavern and the number of shafts. Also the MDI layout, up to approx. 30m from IP, has an impact on the detector opening scenario, and consequently on cavern size, for long and short shutdowns. In particular, the length of the Tracker sets the overall opened detector foot-print.

Detector at LHC P2.

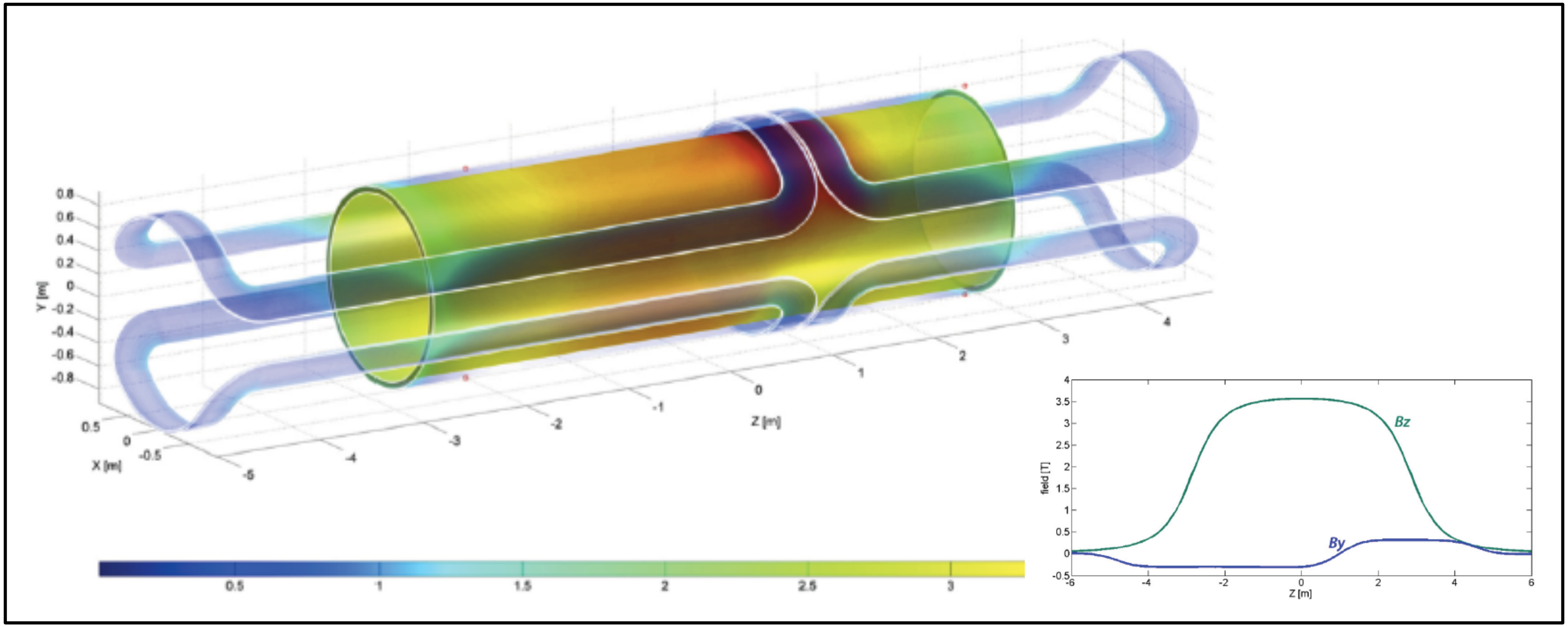


HL-LHC Detector description.



- 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)

Coil & dipoles integrated in single cryostat.



- Solenoid (3.5 T) + dual dipole 0.3 T to steer the e-beam.
- Windings embedded into L-Ar EMC Cryogenic System.
- Overall length < 10m, diameter < 2m, weight with cryostat 24t.
- Largest single piece object.

LHeC Detector assembly on surface (HL-LHC).

The usual constraints 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.

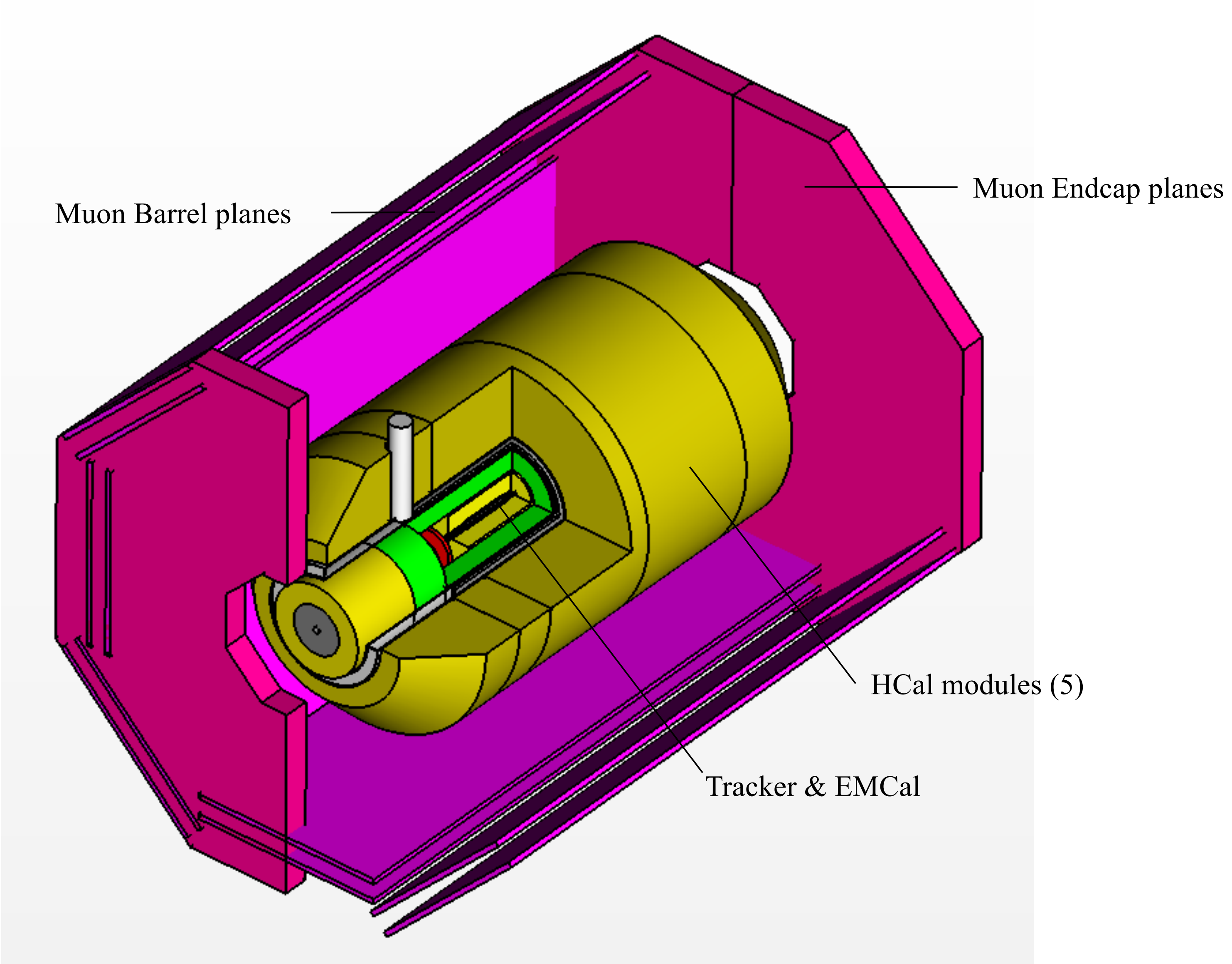
The strategy proposed to minimize the installation time is to complete as much as possible the assembling and testing of the detector on surface, where the detector construction can proceed without impacting on the LHC physics runs.

LHeC Detector assembly on surface (cont'd).

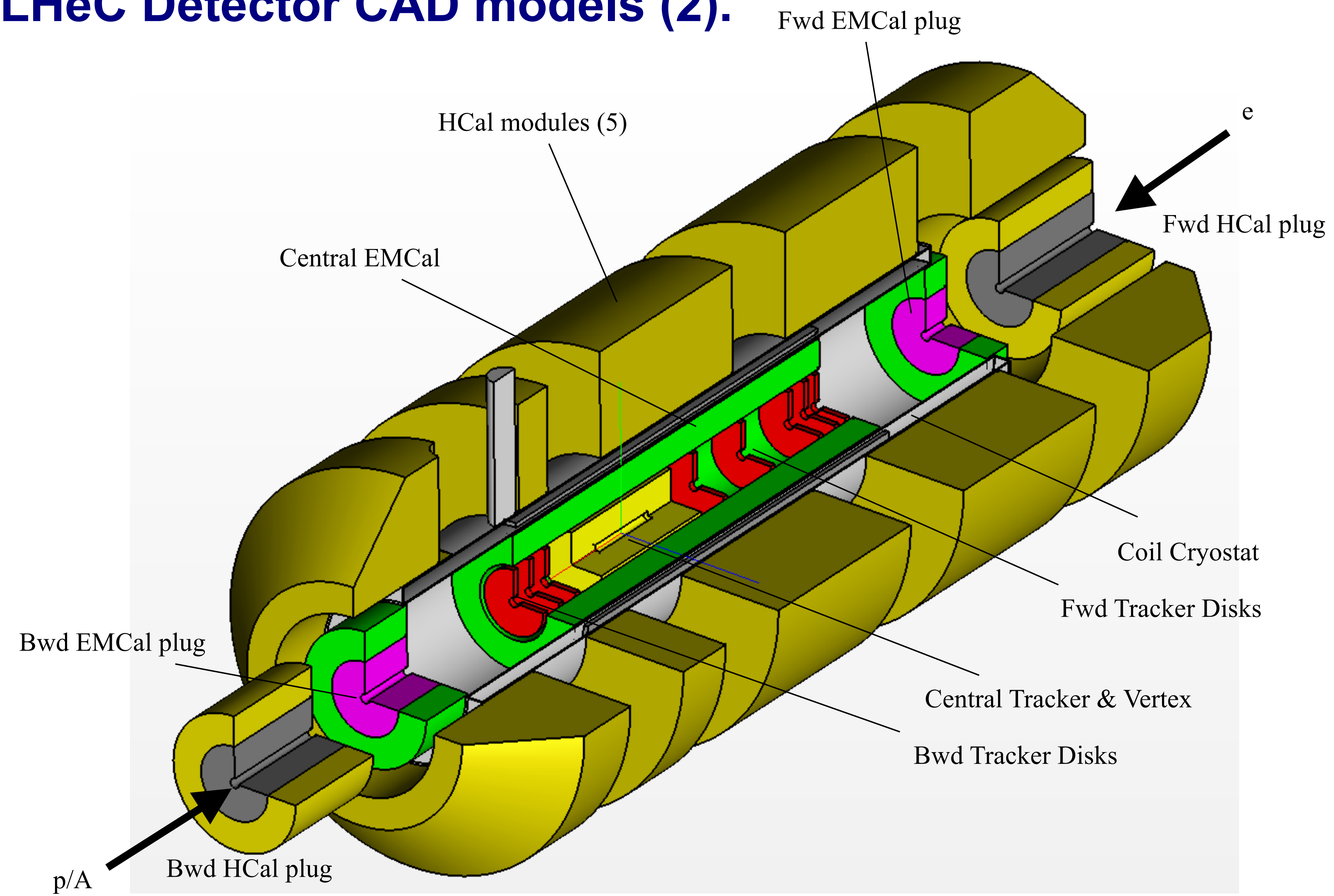
The detector has been split in the following main parts (15):

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).

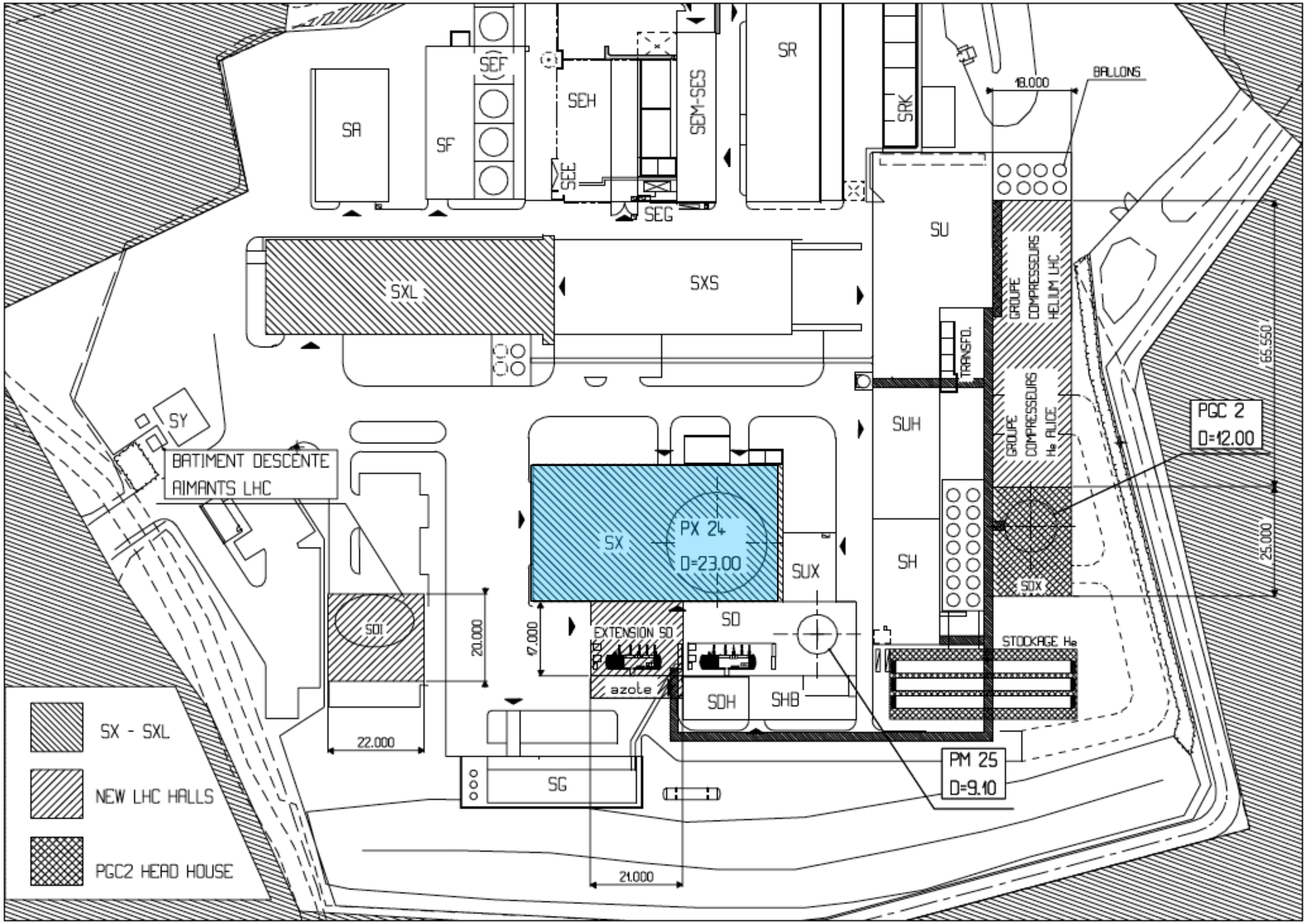


LHeC Detector CAD models (2).

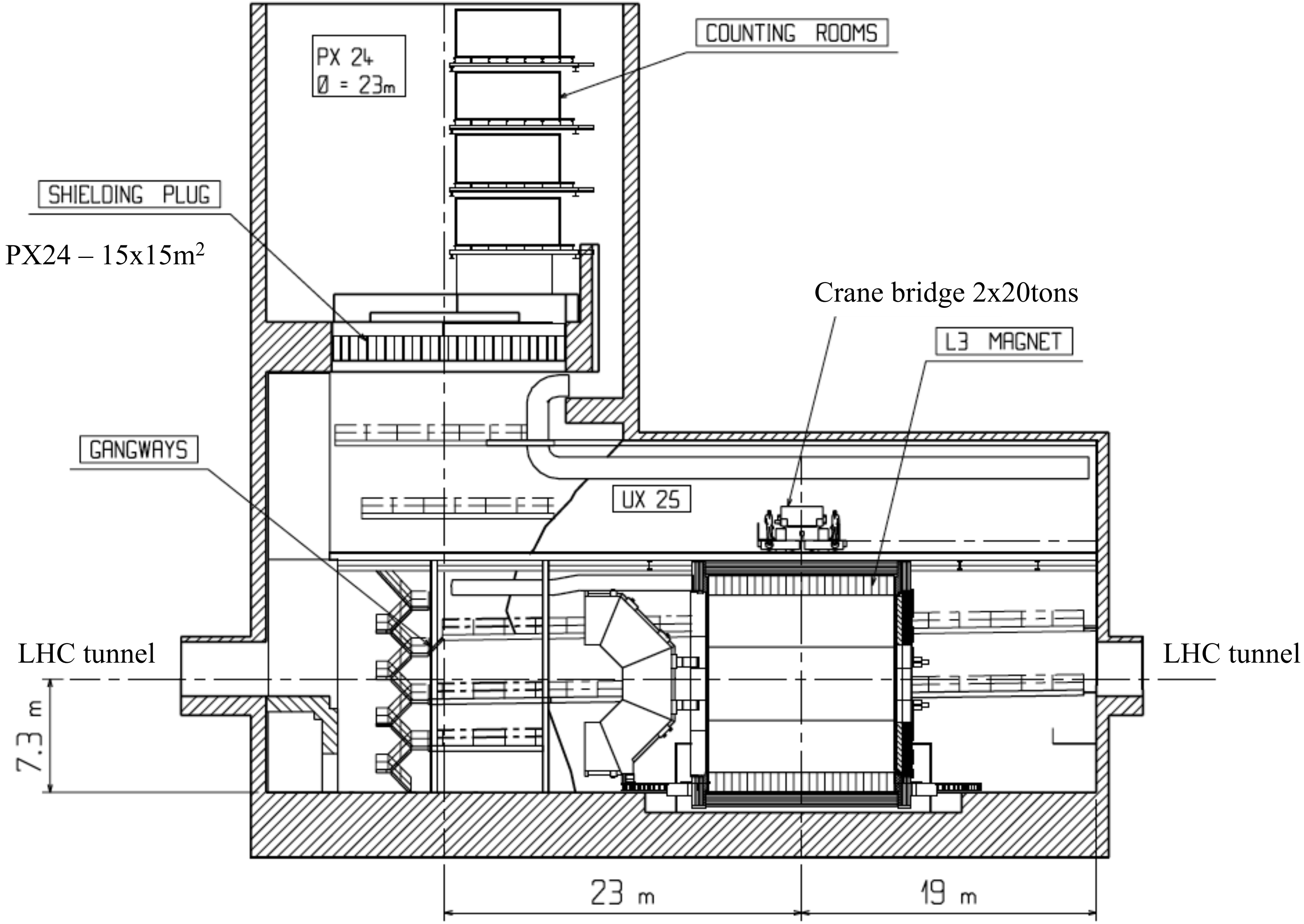


P2 facilities on surface.

Crane capacity on surface b.SX2: 65tons.

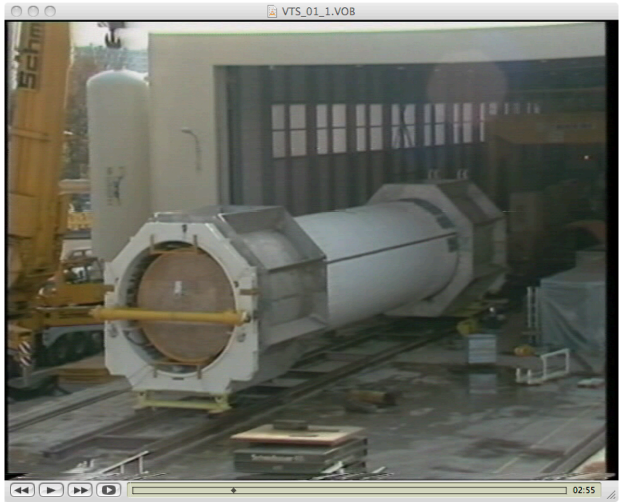


Underground facilities LHC-P2.



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.

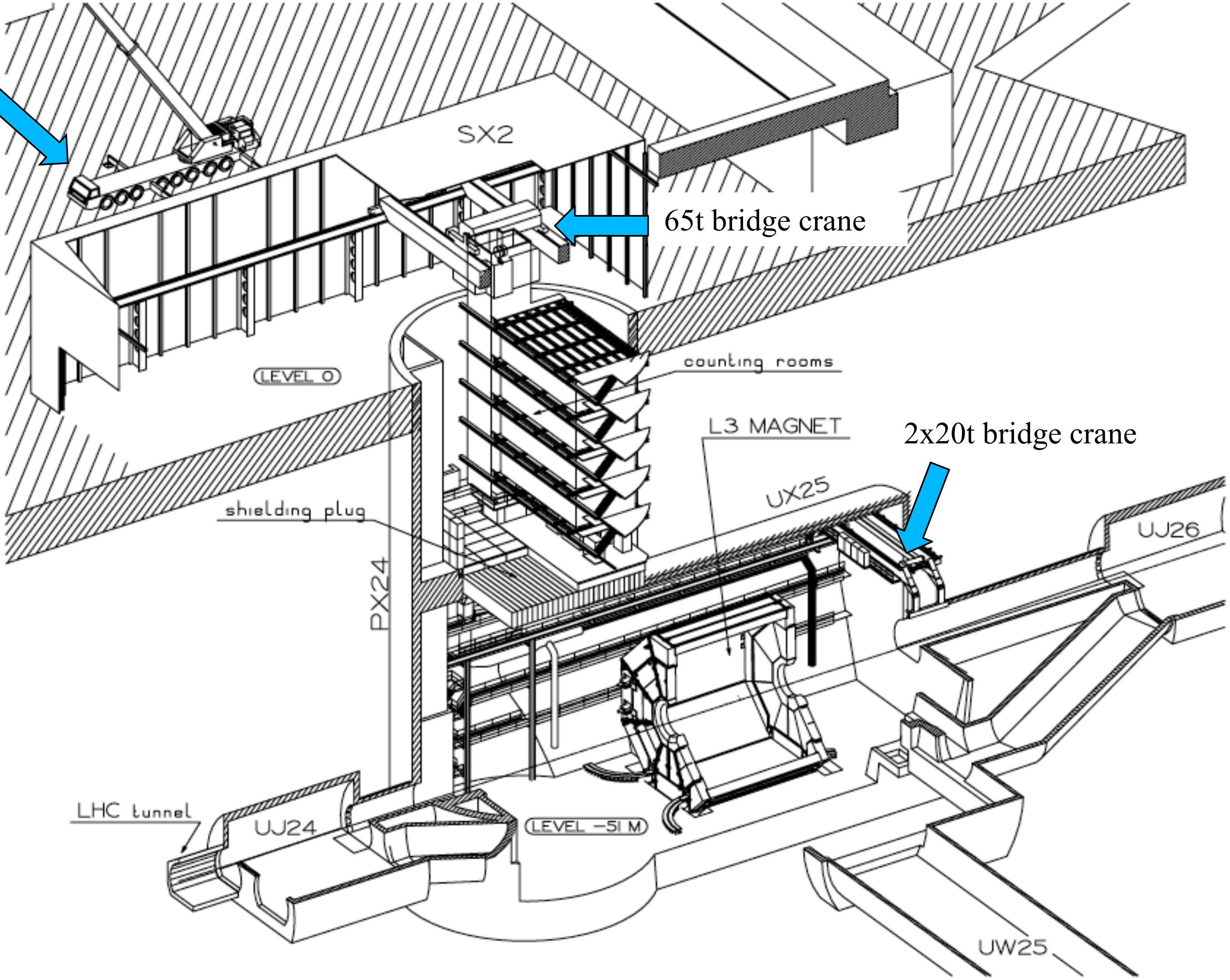


Heavy detector elements lowering.

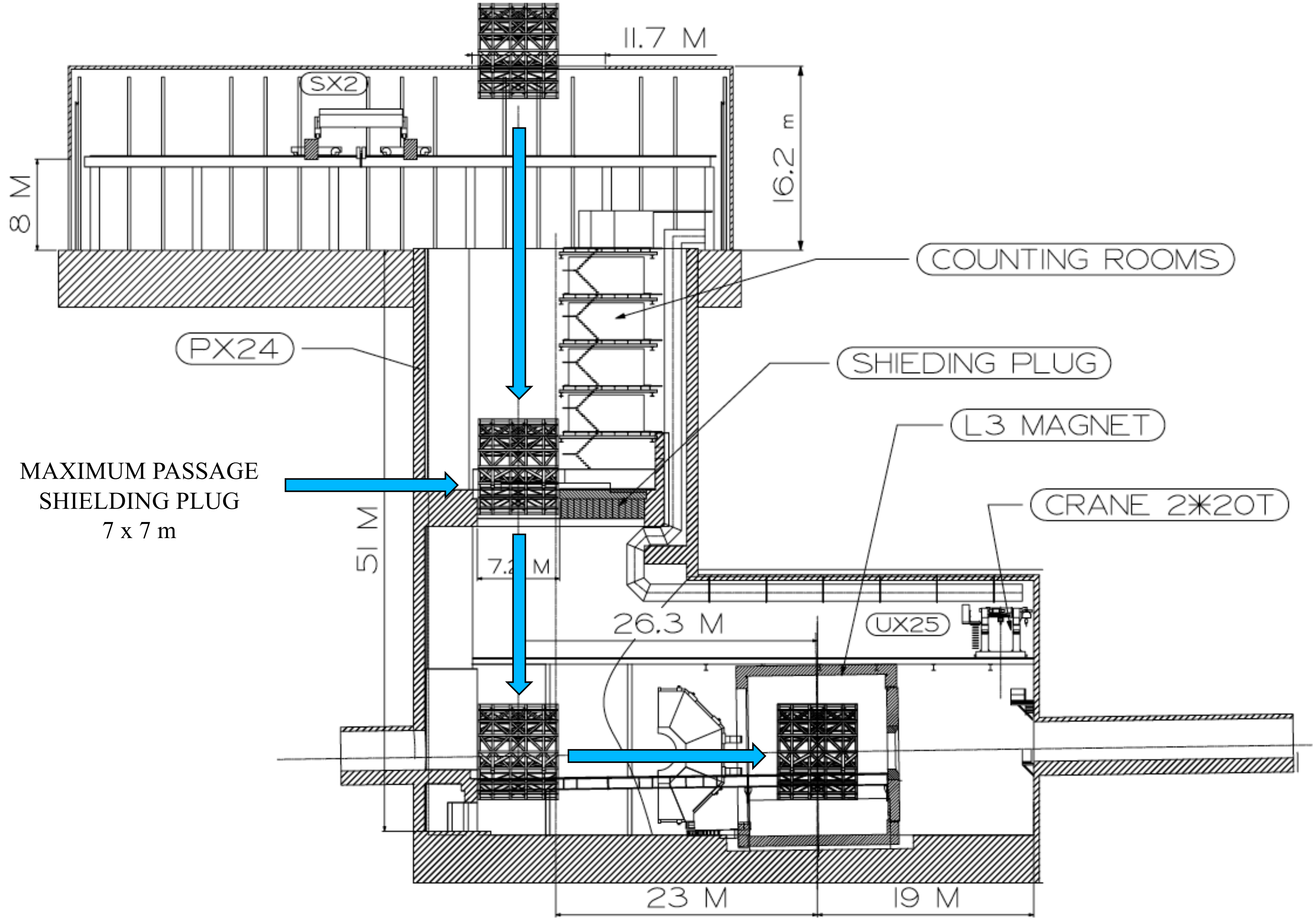
Rented 300t mobile crane

65t bridge crane

2x20t bridge crane



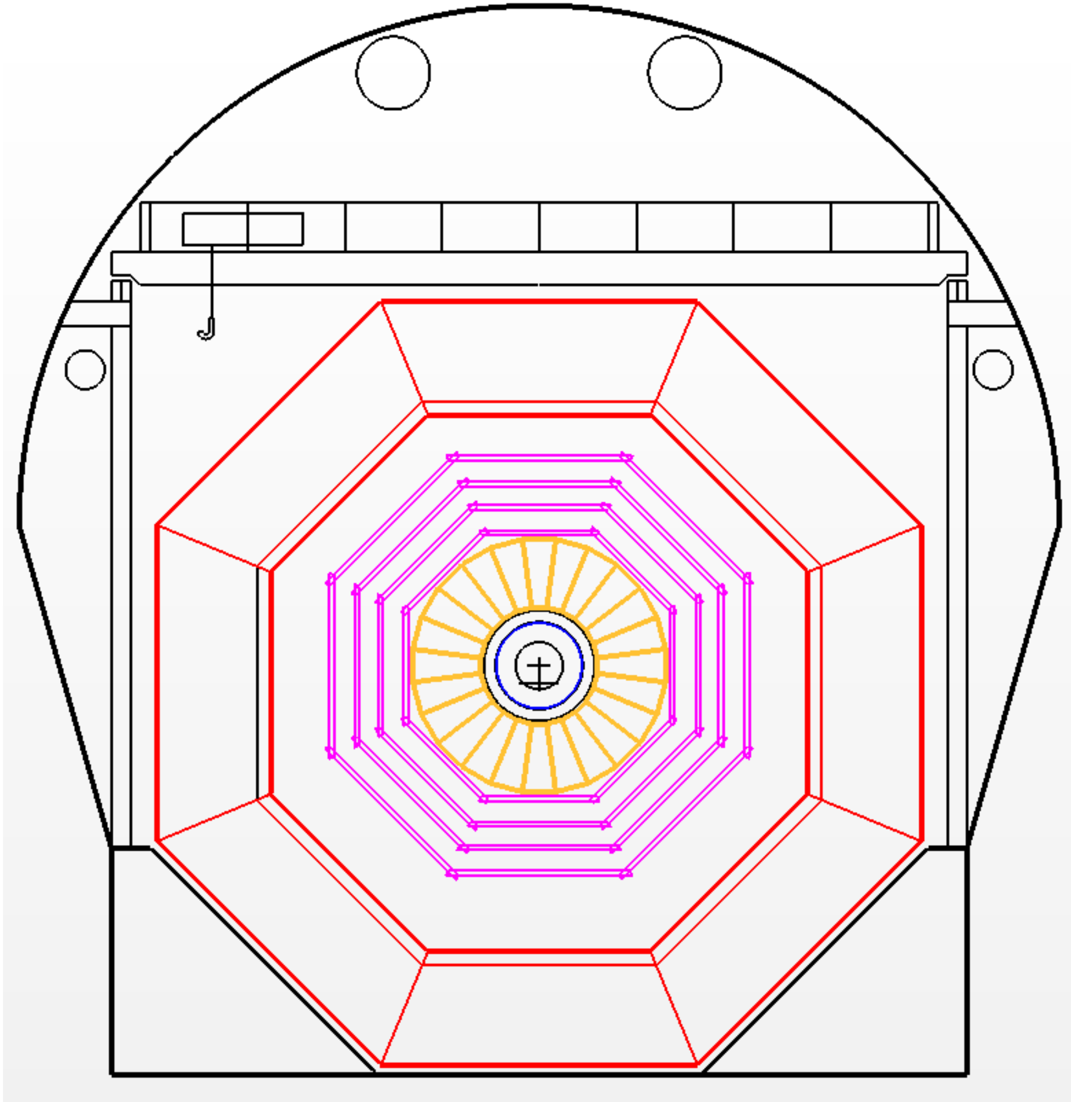
Detector elements lowering *(Alice space-frame example)*.



Detector integration in the L3 Magnet.

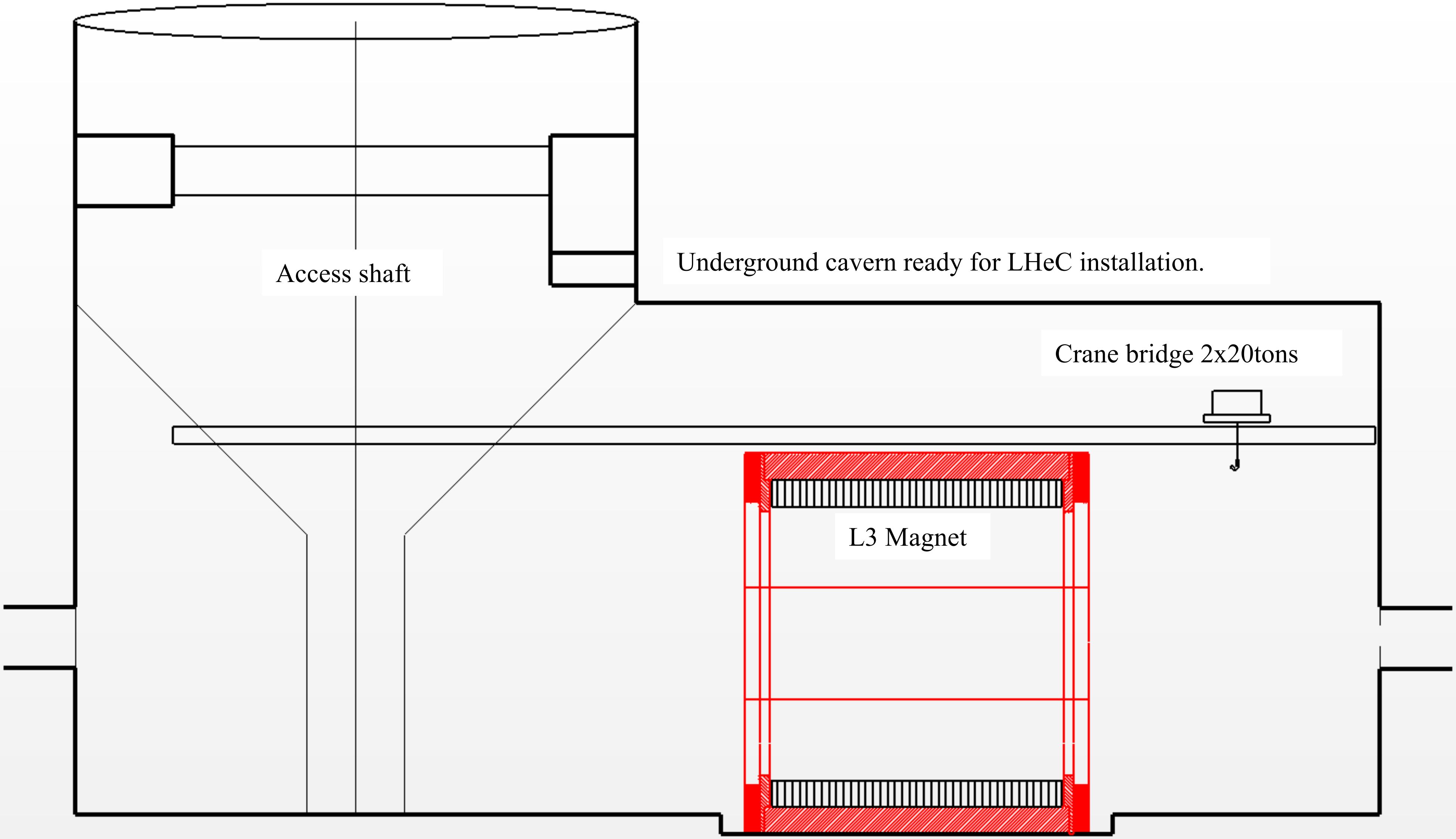
The LHeC detector, including the Muon chambers, fits inside the former L3 Magnet Yoke, once the two large doors are taken away. The goal is to prevent losing time in dismantling the L3 Magnet barrel yoke and to make use of its sturdy structure to hold the detector central part on a platform supported 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.

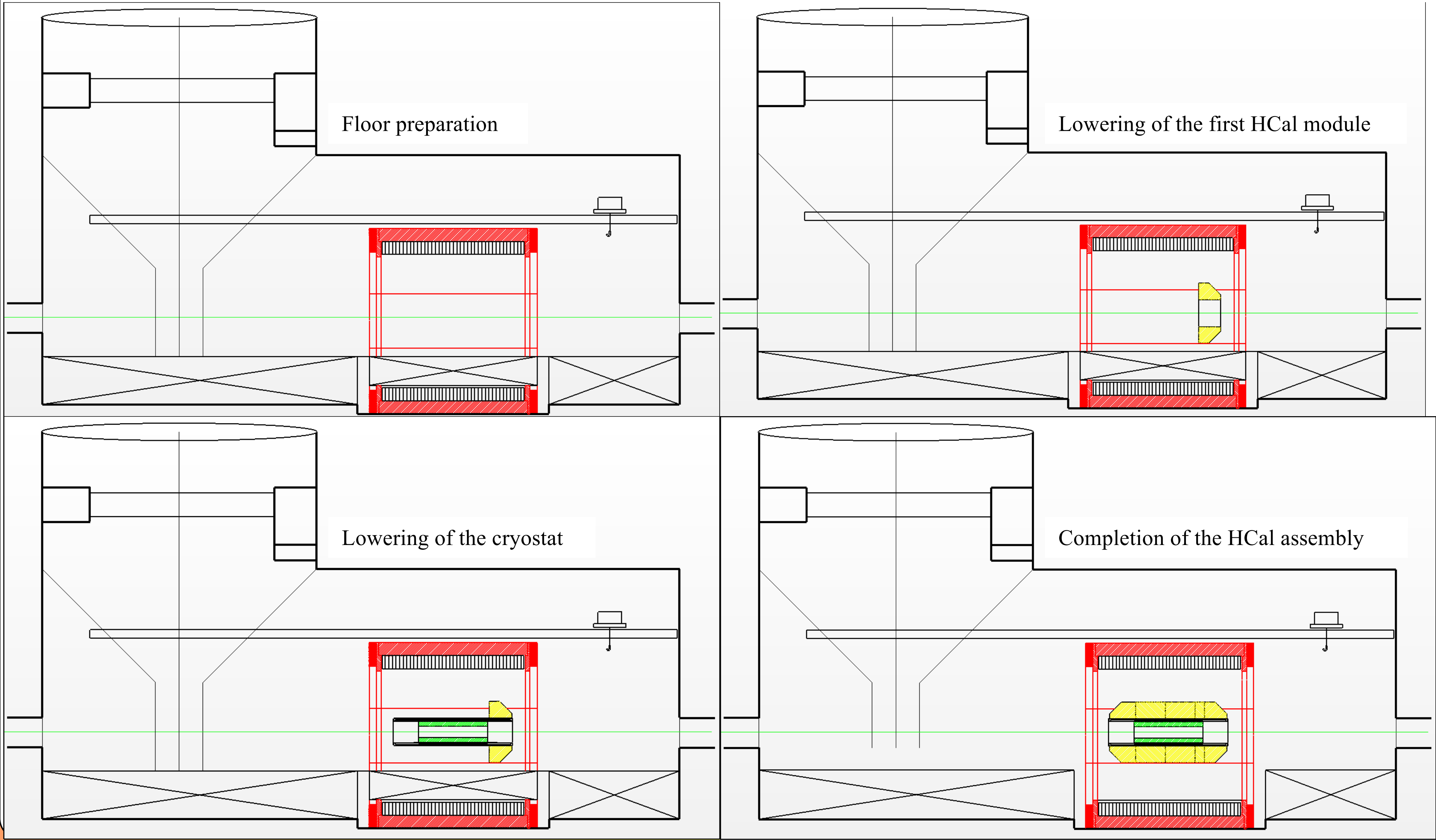


Front view of LHeC detector inside L3 Magnet

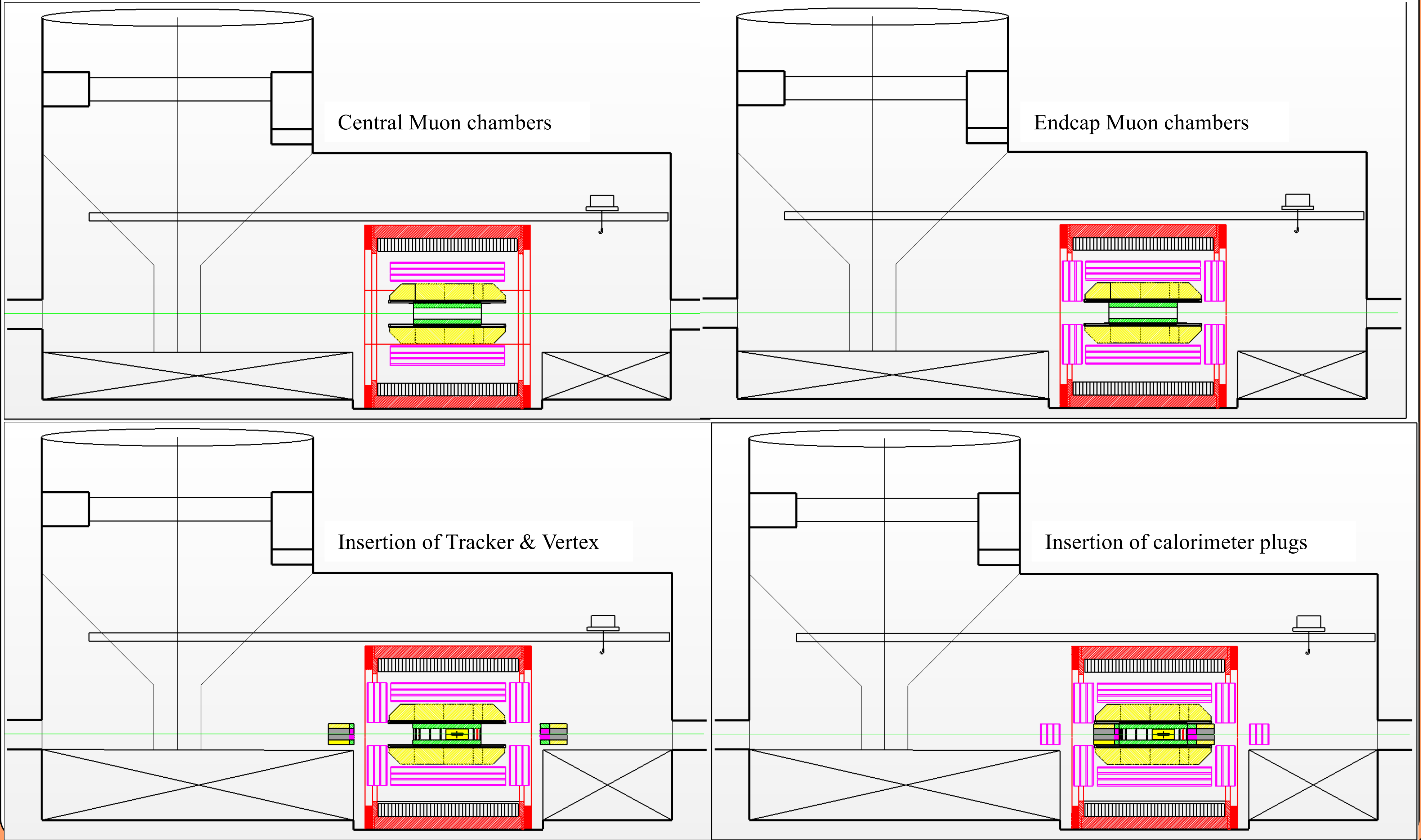
Detector lowering & integration underground (1).



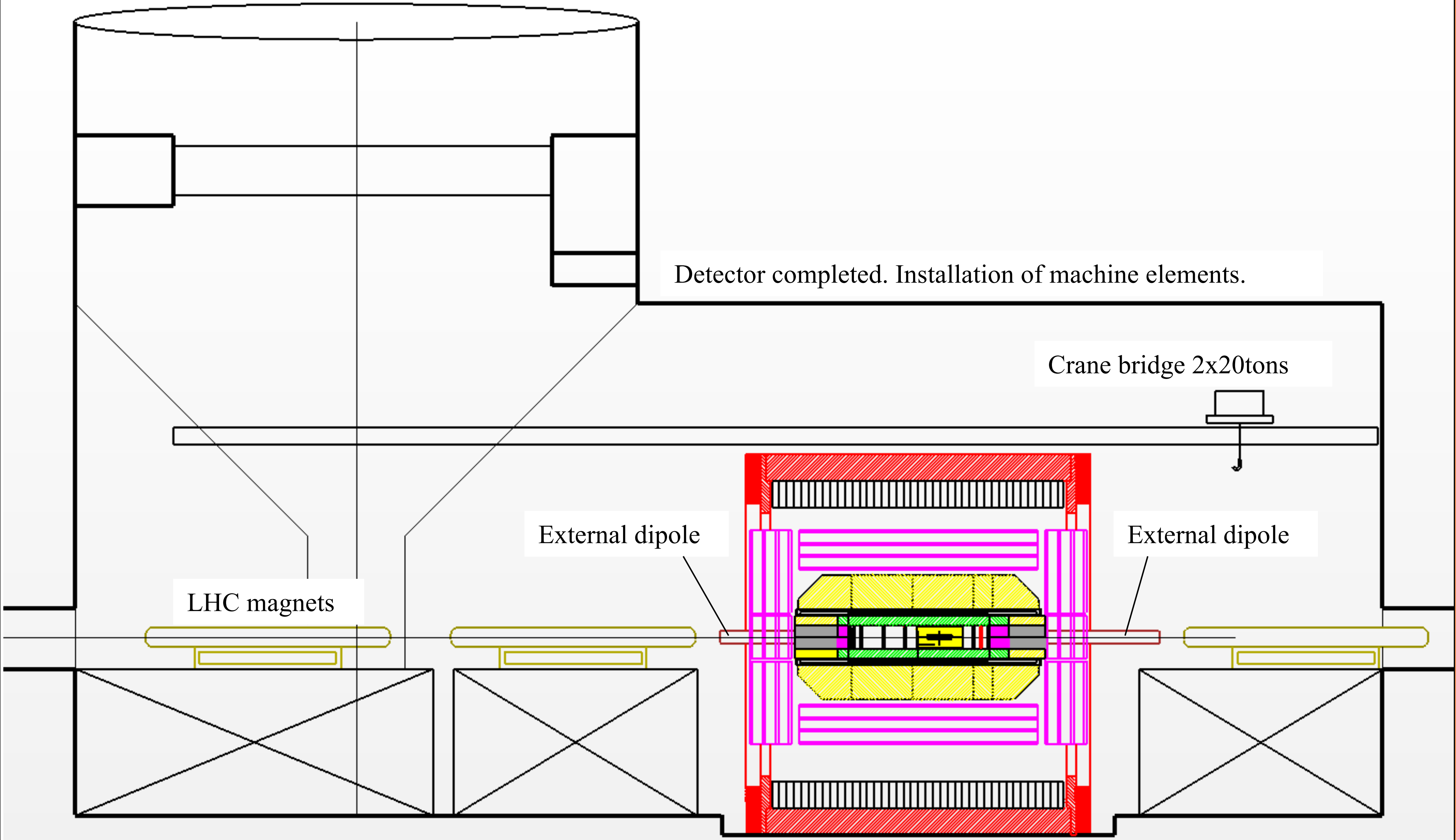
Detector lowering & integration underground (2).



Detector lowering & integration underground (3).



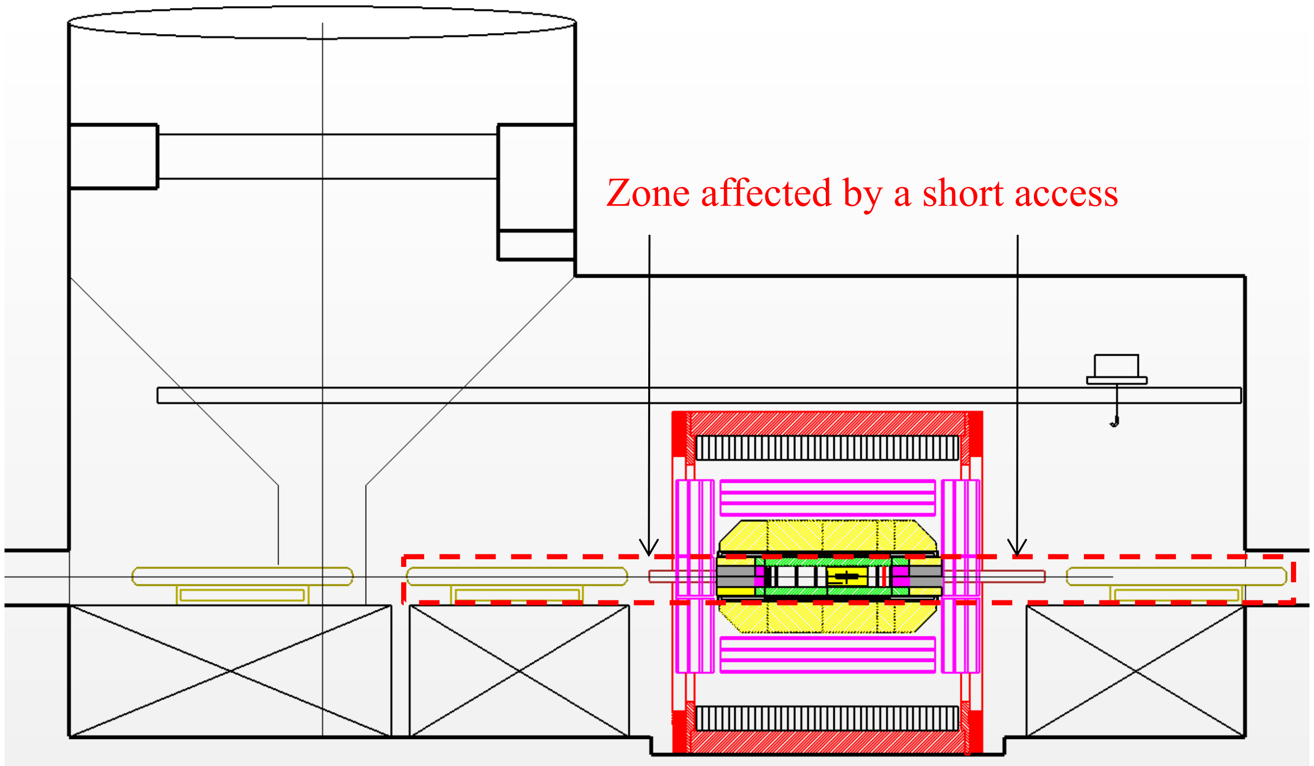
Detector lowering & integration underground (4).



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.



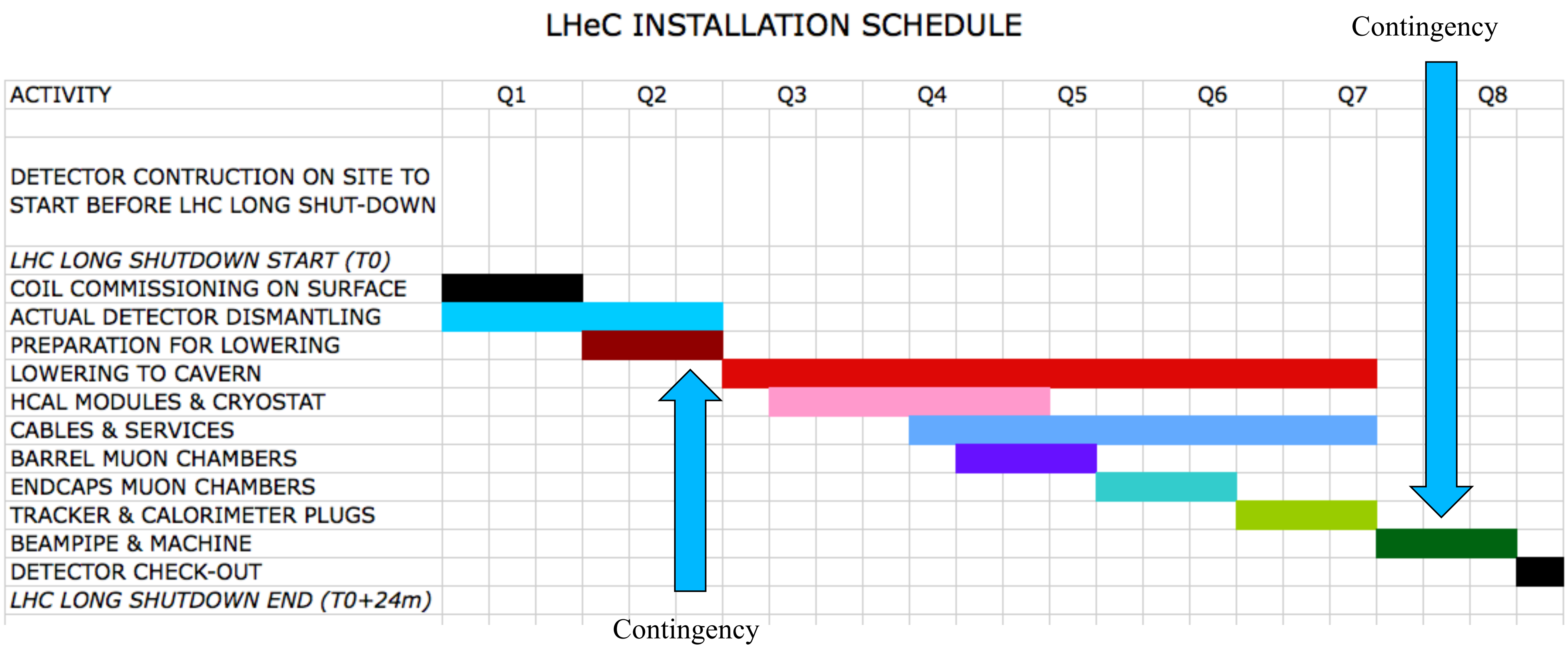
Timelines.

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 other 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 one additional month. Some contingency (2 – 3 months in total) is foreseen at the beginning and the end of the installation period.

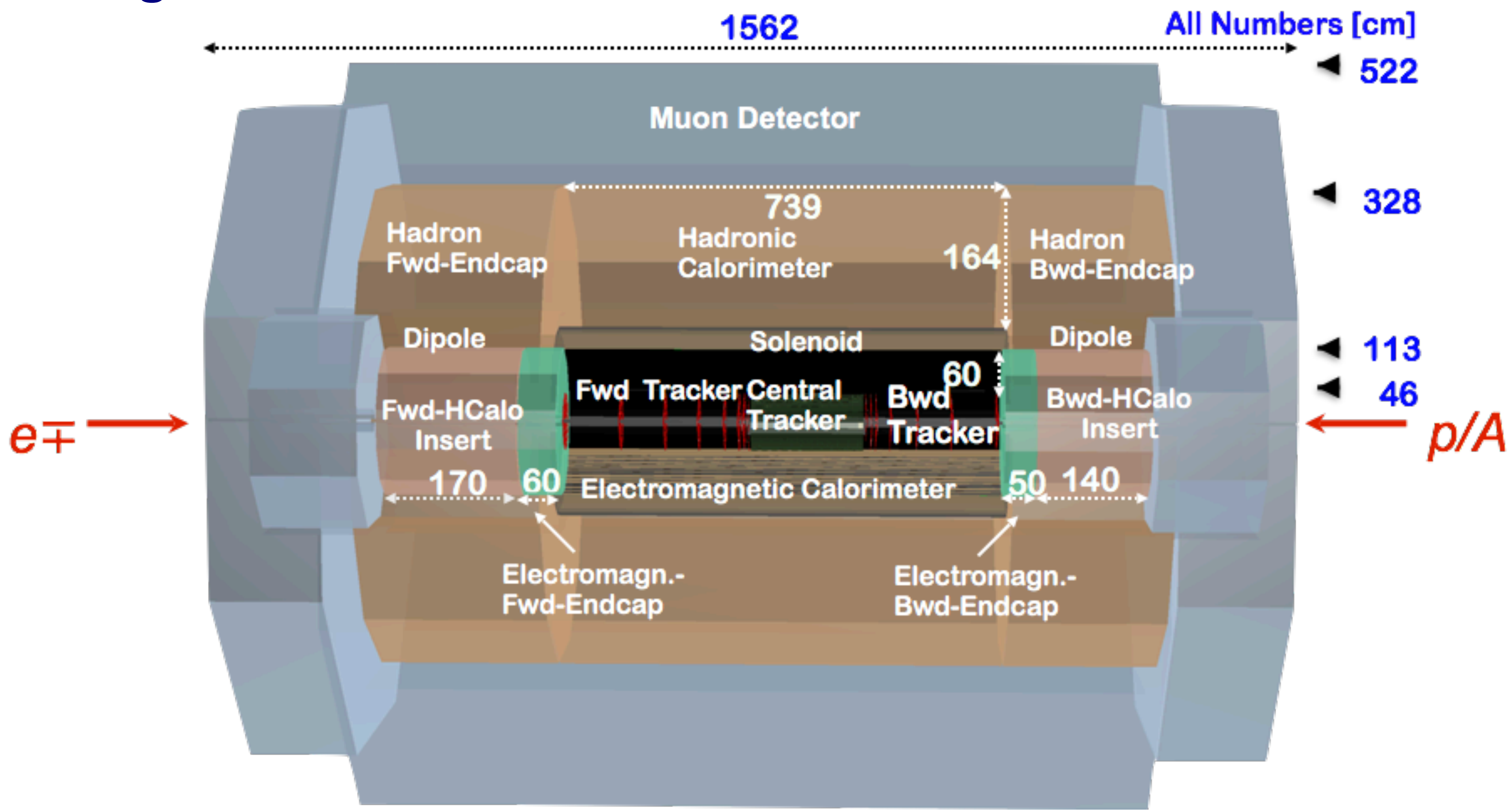
Tentative schedule.



Changes from HL-LHC to HE-LHC.

- With a proton beam-energy at 12.5TeV, the detector stretches on the z-axis and also slightly grows in radius. This may bring to the necessity of partially dismantling the L3 octagonal Magnet *(tbv)*.
- The Detector Magnet being one of the most expensive element, it shall be designed to both uses. It is unrealistic to change the detector magnet from HL to HE-LHC.
- The MDI region may also look more complex and thus add some constraints on the maintenance scenario.
- On the positive side, the installation underground can be done in the shadow of the HE-LHC activities and likely benefit from some extra-months wrt the HL-LHC baseline.
- All these considerations deserve more detailed studies.

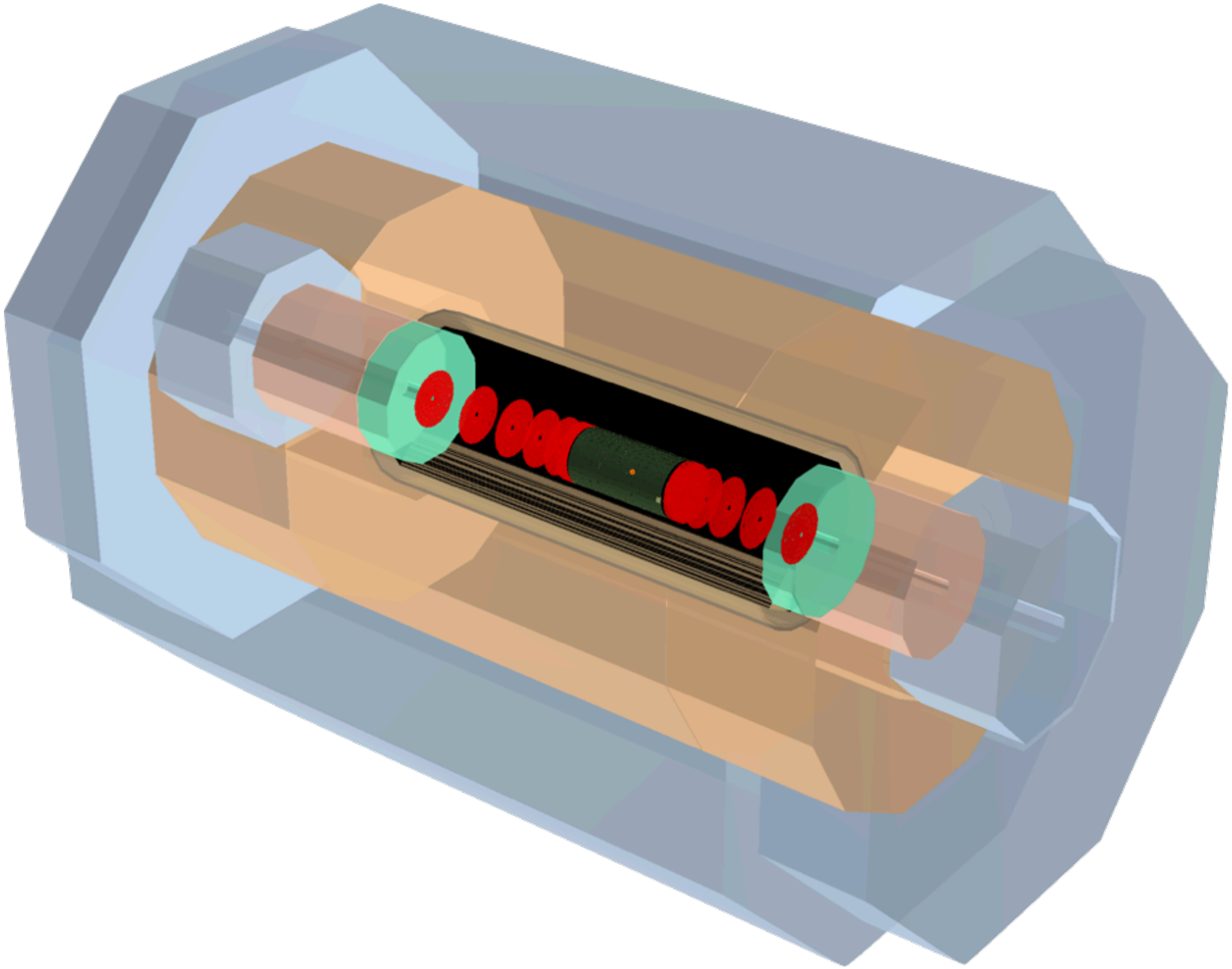
Changes from HL-LHC to HE-LHC.



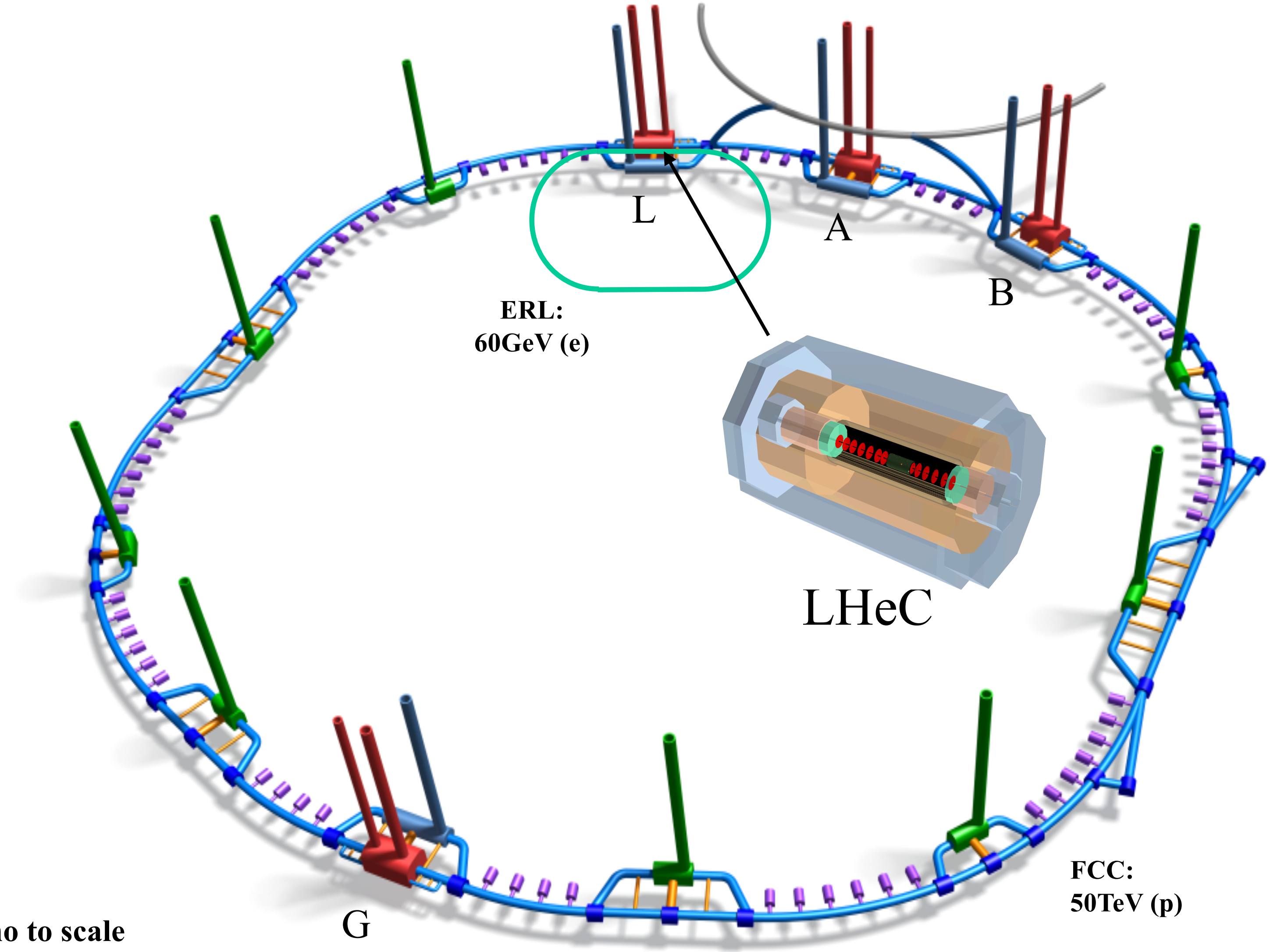
Overall Detector length +2.5m

Detector diameter +2m

3D model of HE-LHC Detector.

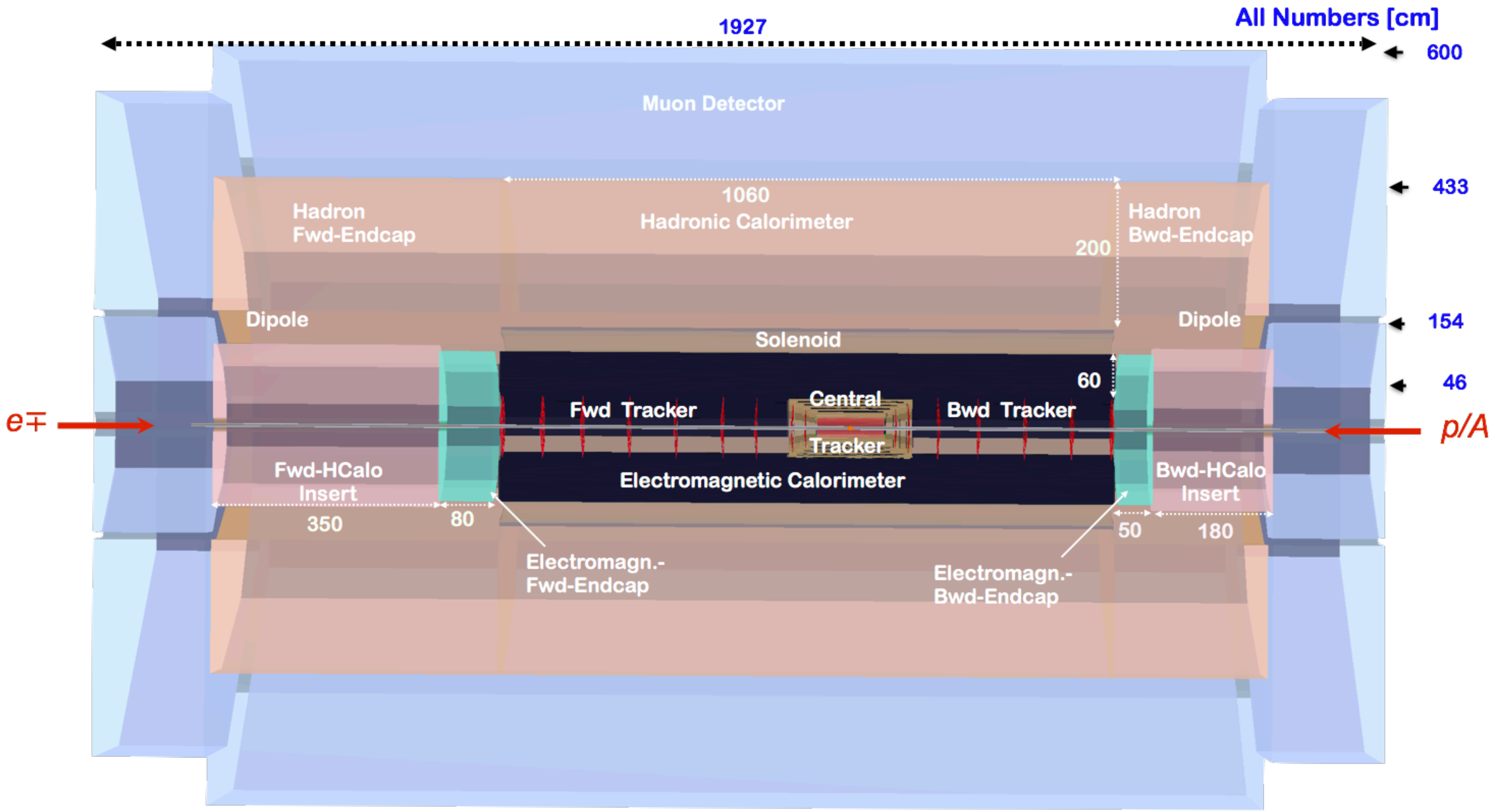


LHeC Detector at FCC P/L.

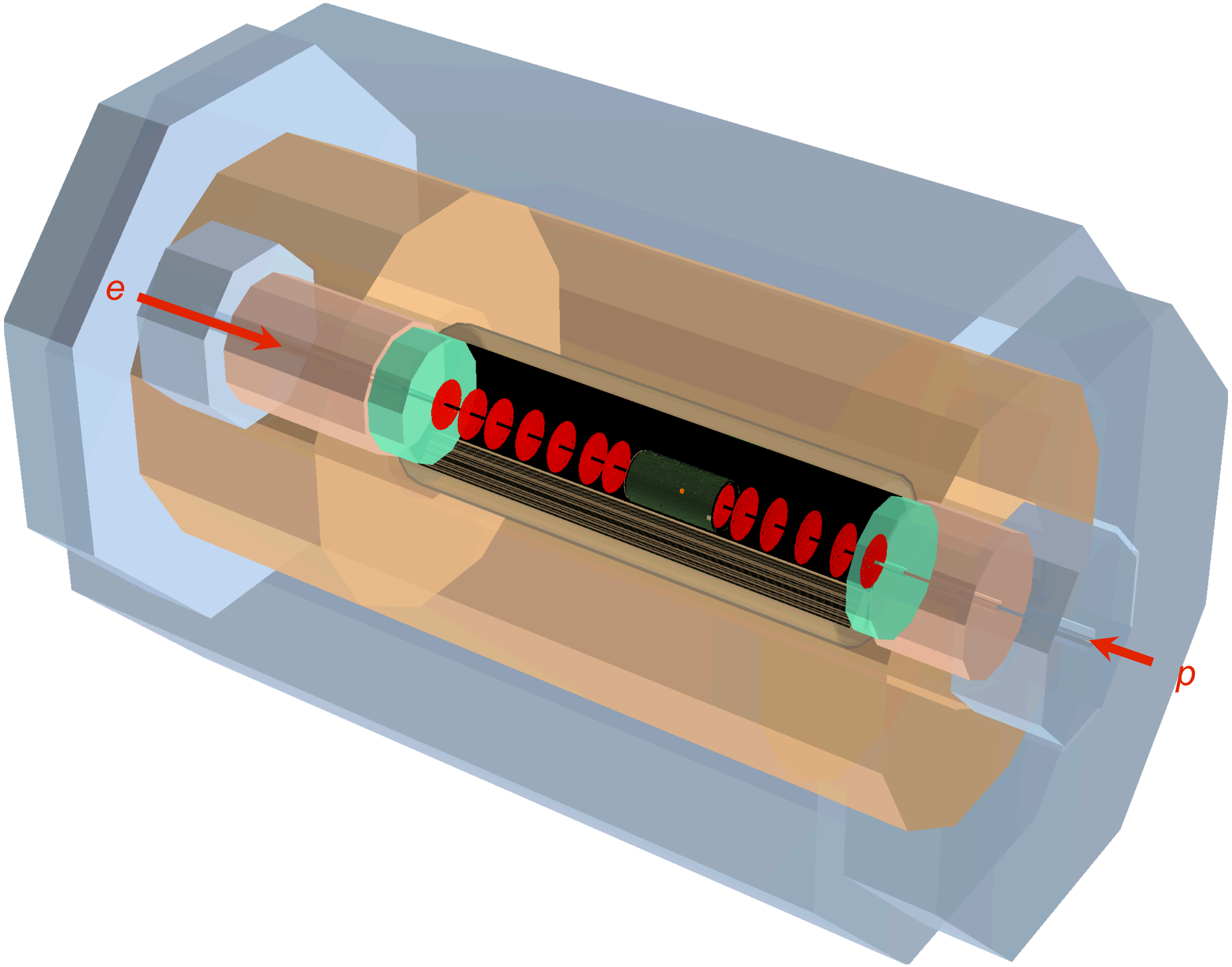


nb: no to scale

FCC-he Detector base-line.



3D model of FCC-he Detector.



Civil Engineering baseline dimensions for caverns/shafts.

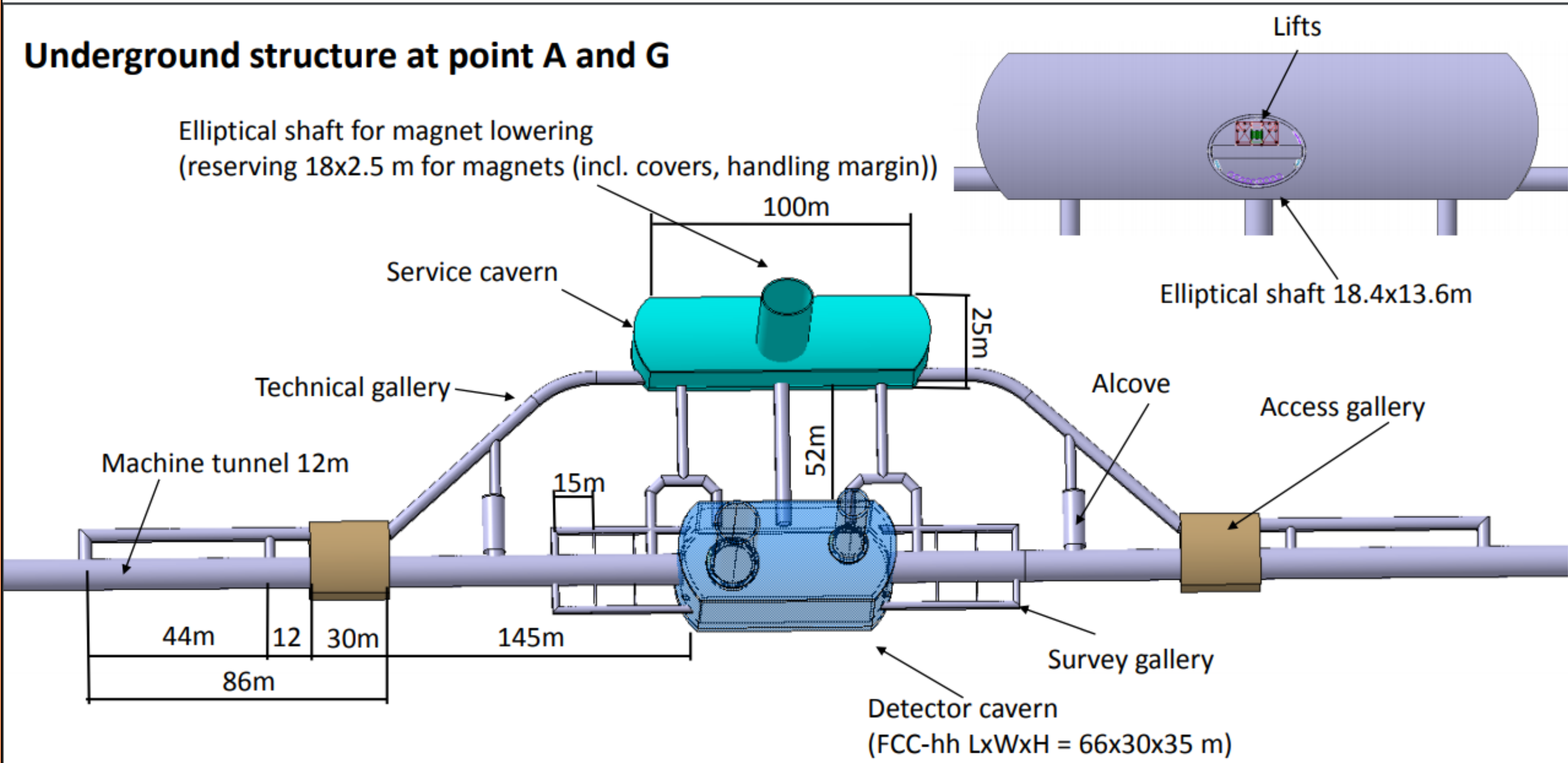
Point	Function	LSS length [km]	Depth [m]	Detector shaft Ø [m]	Access shaft Ø [m][1]	Detector cavern LxWxH [m]	Service cavern[2] LxWxH [m]	Technical galleries [km][3]
A	Main experiment	1.4	152	15; 10	18	66x35x35	1XXx25x15	?
B	Side experiment; injection	1.4	121	15; 10	12	66x30x35	1XXx25x15	?
C	Mid-arc technical point	-	127	-	12	-	XXx25x15	-
D	Beam extraction	2.8	205	-	12	-	XXx25x15	± 1.4
E	Mid-arc technical point	-	89	-	12	-	XXx25x15	-
F	RF	1.4	476	-	12	-	XXx25x15	± 0.7
G	Main experiment	1.4	307	15; 10	18	66x35x35	1XXx25x15	?
H	Momentum collimation	1.4	266	-	12	-	XXx25x15	± 0.7
I	Mid-arc technical point	-	198	-	12	-	XXx25x15	-
J	Betatron collimation	2.8	248	-	12	-	XXx25x15	± 1.4
K	Mid-arc technical point	-	88	-	12	-	XXx25x15	-
L	Side experiment; injection	1.4	172	15; 10	12	66x30x35	1XXx25x15	?

1) Subject to outcome of transport and logistics study

2) Single combined service cavern (experiment/machine)

3) Waiting for replies from accelerator systems

Underground structure at point A and G



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Compatibility with CE baseline dimensions.

Largest FCC-he object (Coil Cryostat) 16m vs. Shaft diameter 15m ☹

I consider 15m shaft as totally unrealistic for assembly any kind of FCC-xx detector. For comparison CMS has one 21m shaft & Atlas has two shafts (18m & 13m).

Detector width 12m vs. Cavern width: 30m ☺

Adding metallic structures on the detector and on the cavern side walls for personnel access still leaves enough clearance.

Detector maximum opening during assembly/long-shutdown (allowing Tracker extraction) 40m vs Cavern length 66m ☺

Although the MDI layout is likely to make the detector opening during shutdowns quite complicate, the margin is good enough.

Assembly scenario for FCC-he Detector.

The dimensions of the shaft and the experiment cavern, along with the MDI layout, affect the way the detector is assembled and maintained.

For the FCC-he Detector, as it is for HL and HE-LHC versions, it is assumed that the Detector Magnet can be lowered as a single piece, same for the HCal rings. On the contrary, the Muon wheels have to be lowered in modules and assembled underground. On the basis of what shown for the HL-LHC version, a time span of about 3 years seems to be realistic [(1)].

(1) *From the hand-over of the cavern to the Detector completion.*
Pre-construction on surface to start before T0.

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.
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 integrated in the same cryostat and tested before lowering.

For HE-LHC the sligthly increased dimensions shall not be a problem, but we have to check that it still fits inside the former L3 Magnet. Also the Detector Magnet has to be compatible for the two cases.

FCC-he study is at a very early stage. The size of the detector has significantly increased but it fits in the base-line design of the experiment cavern. The size of the shaft shall be increased to 18m to allow the lowering of the Coil Cryostat. The installation scenario is eventually not very different with respect to the LHC-type, as most of the assembly can be done on-surface.

Back-up slides.

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

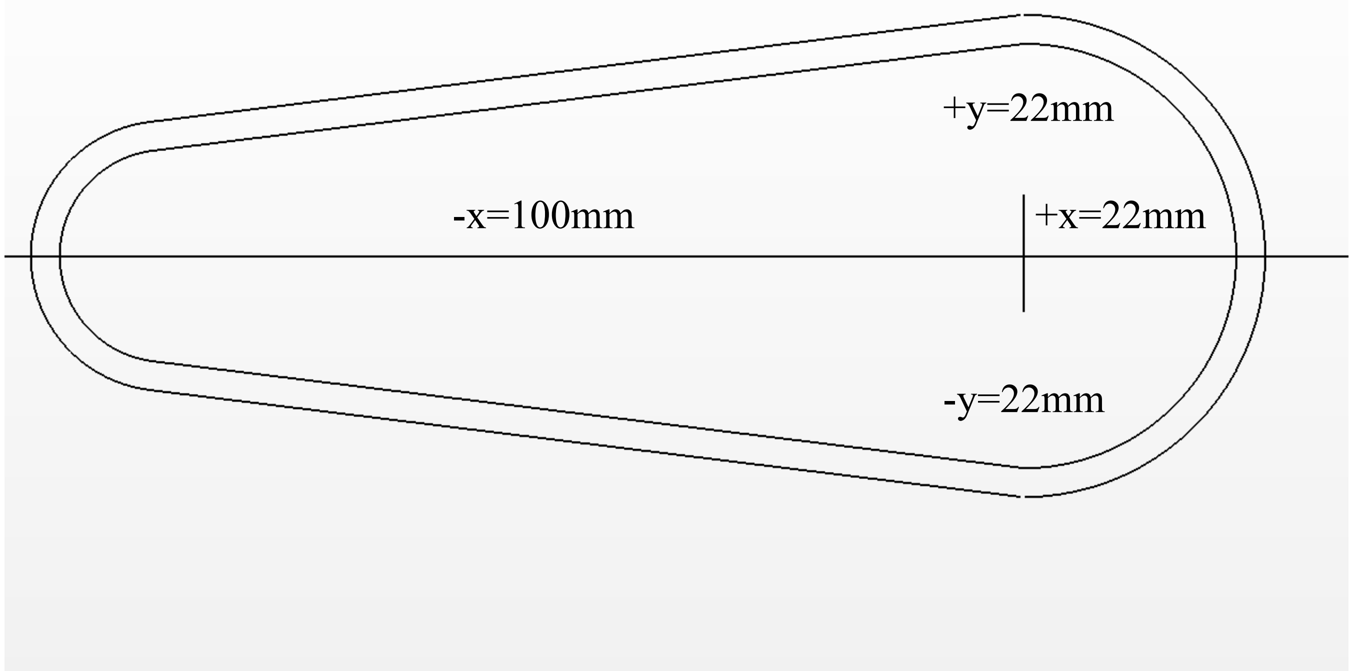
LHeC Study Group

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

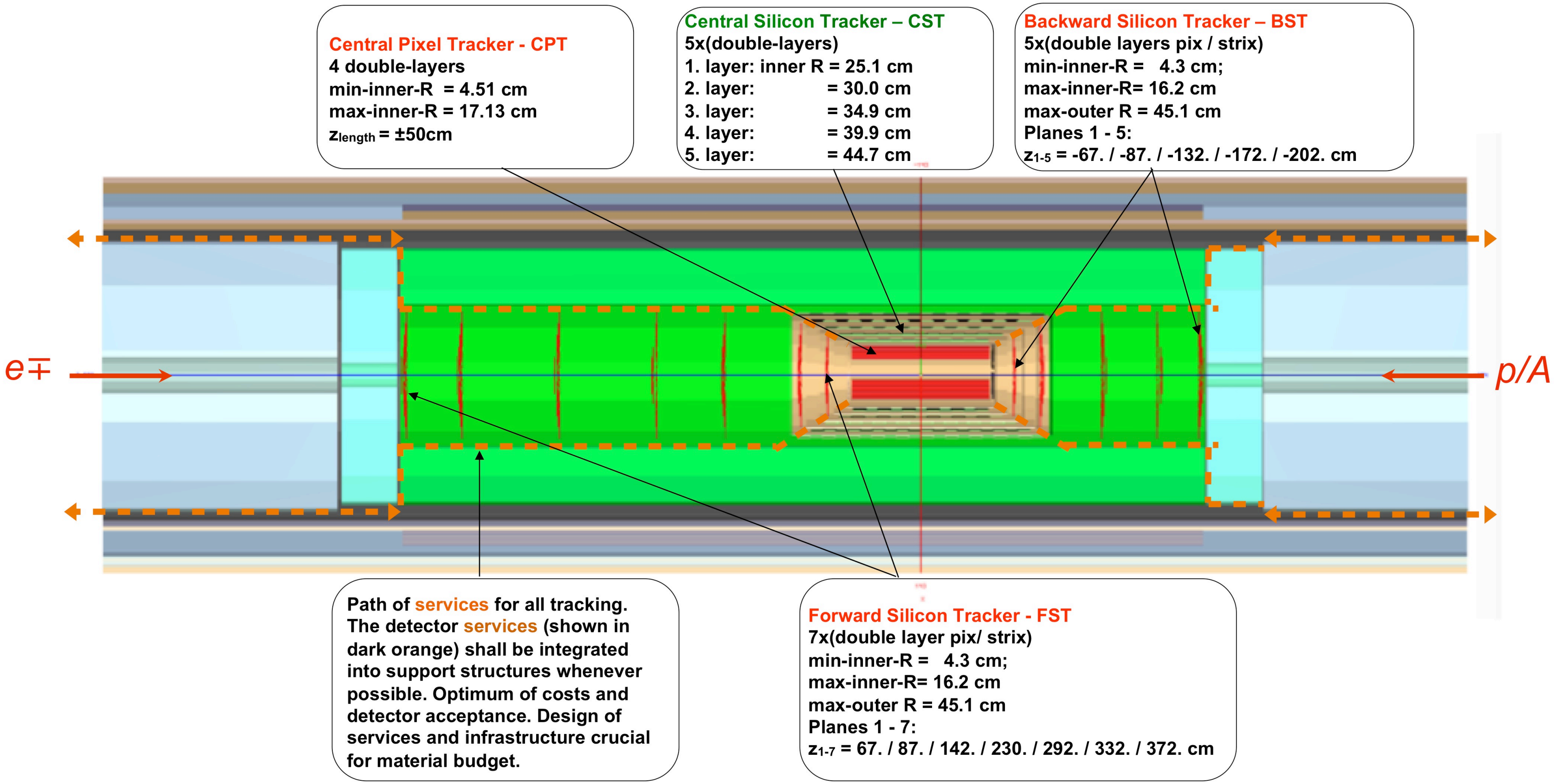
Beam-pipe.

CDR Design:

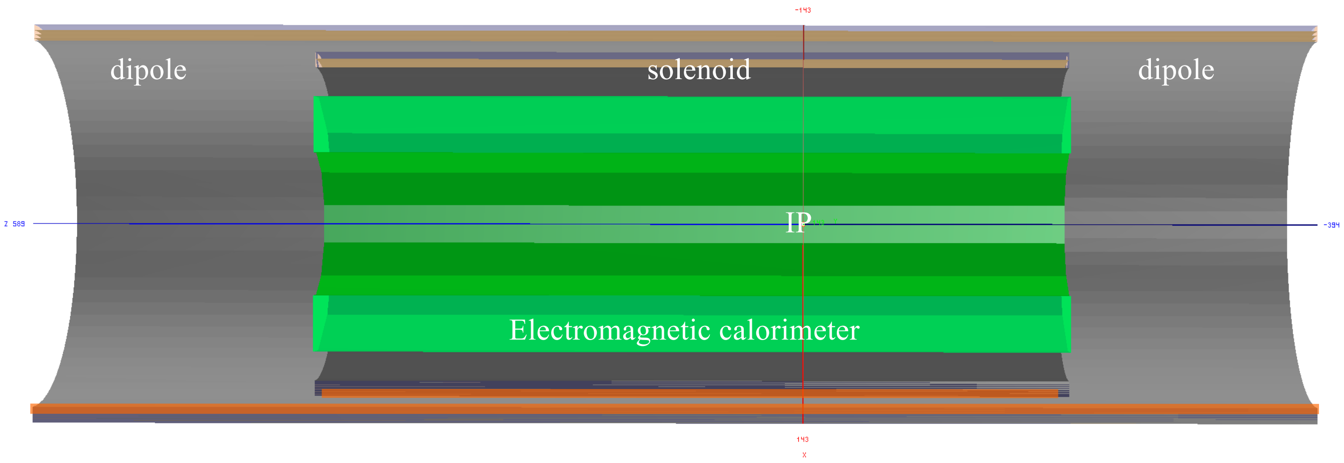


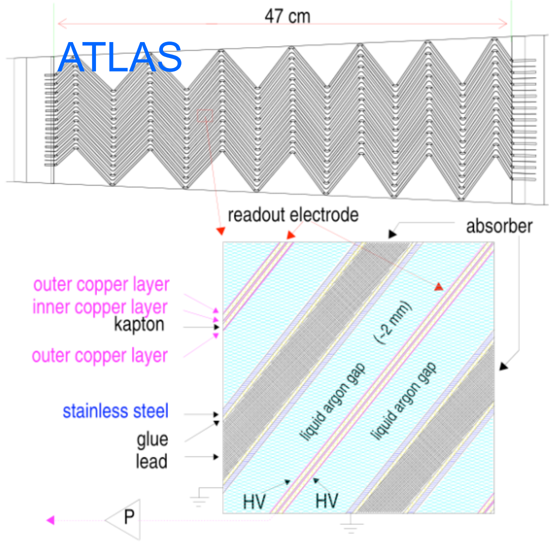
- Shaped to minimize effects of synchrotron radiation.
- Beryllium 2.5-3 mm thickness
- Central beam pipe ~ 6 meters length
- Constant cross-section along z
- Ti-Zr-V NEG coated for distributed vacuum pumping
- Wall protected from primary SR (upstream masks)
- Minimised end flanges, minimised supports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

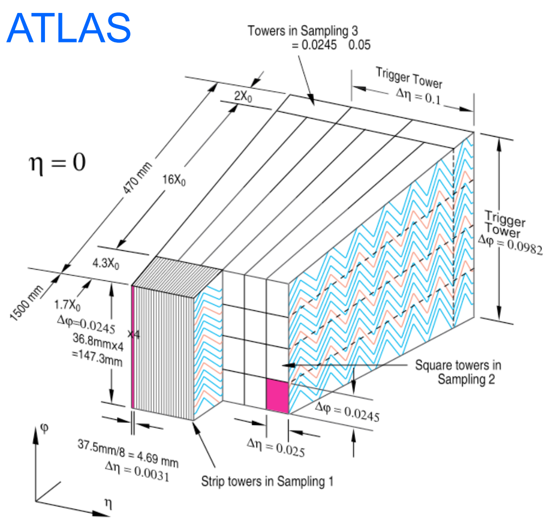
Silicon Tracker.



Electromagnetic barrel calorimeter.

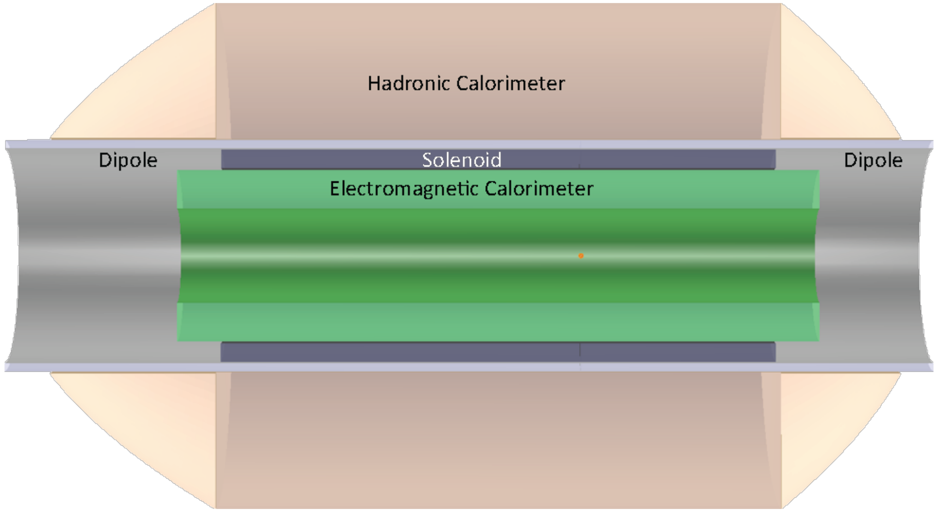




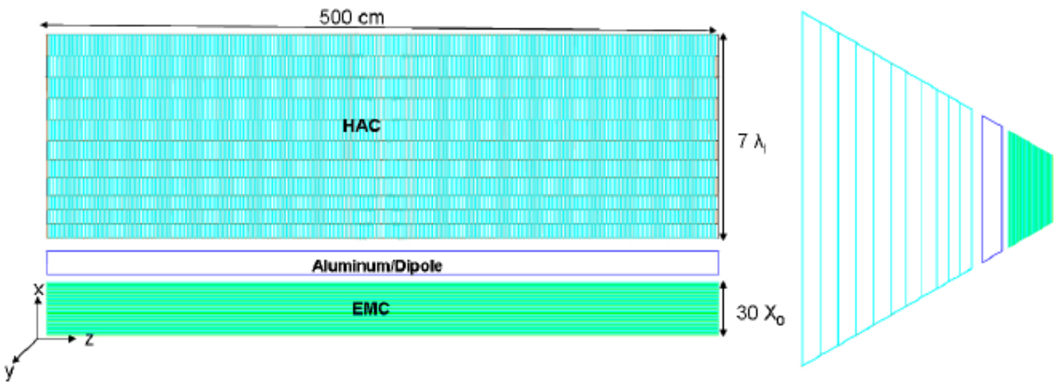


- L-Ar for barrel EMCal – ATLAS (25-30 X_0)
- Same cryostat used for solenoid and dipoles
- 3 different granularity sections longitudinally
- Warm (Pb/Sci) option also investigated 30X_0 (X_0(Pb)=0.56 cm; 20 layers)

Hadronic central calorimeter.



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

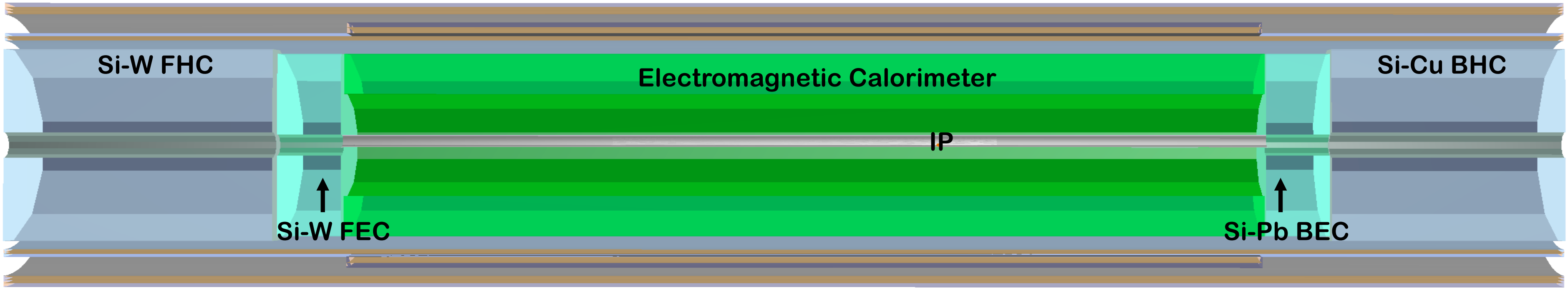


HAC iron absorber (acting also as magnet return flux)

Scintillating plates (similar to ATLAS Tile Cal)

Interaction Length: ~7-9 λ_I

HCal/EMCal forward calorimeters.



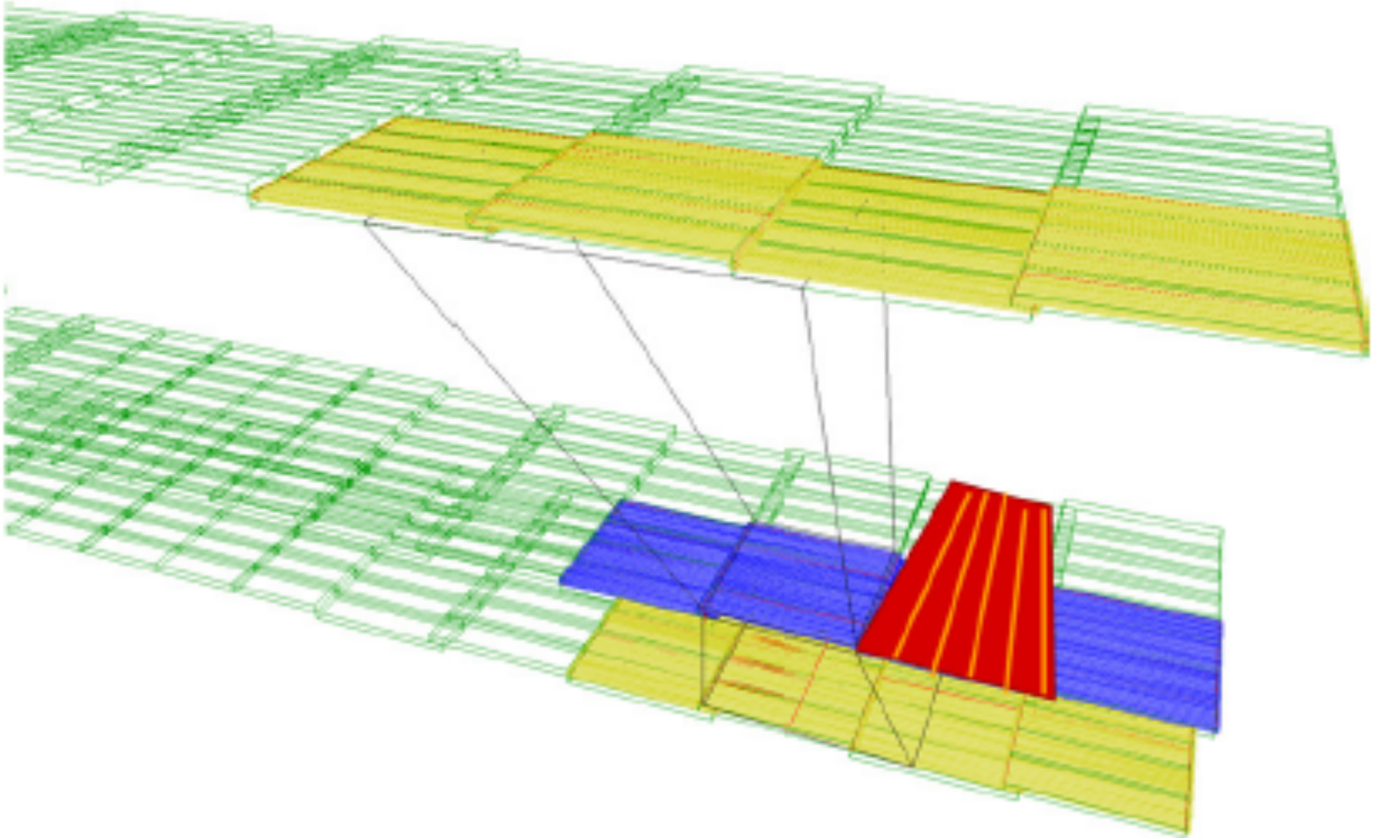
Forward FEC + FHC:

- 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 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.

Coil tests on surface.

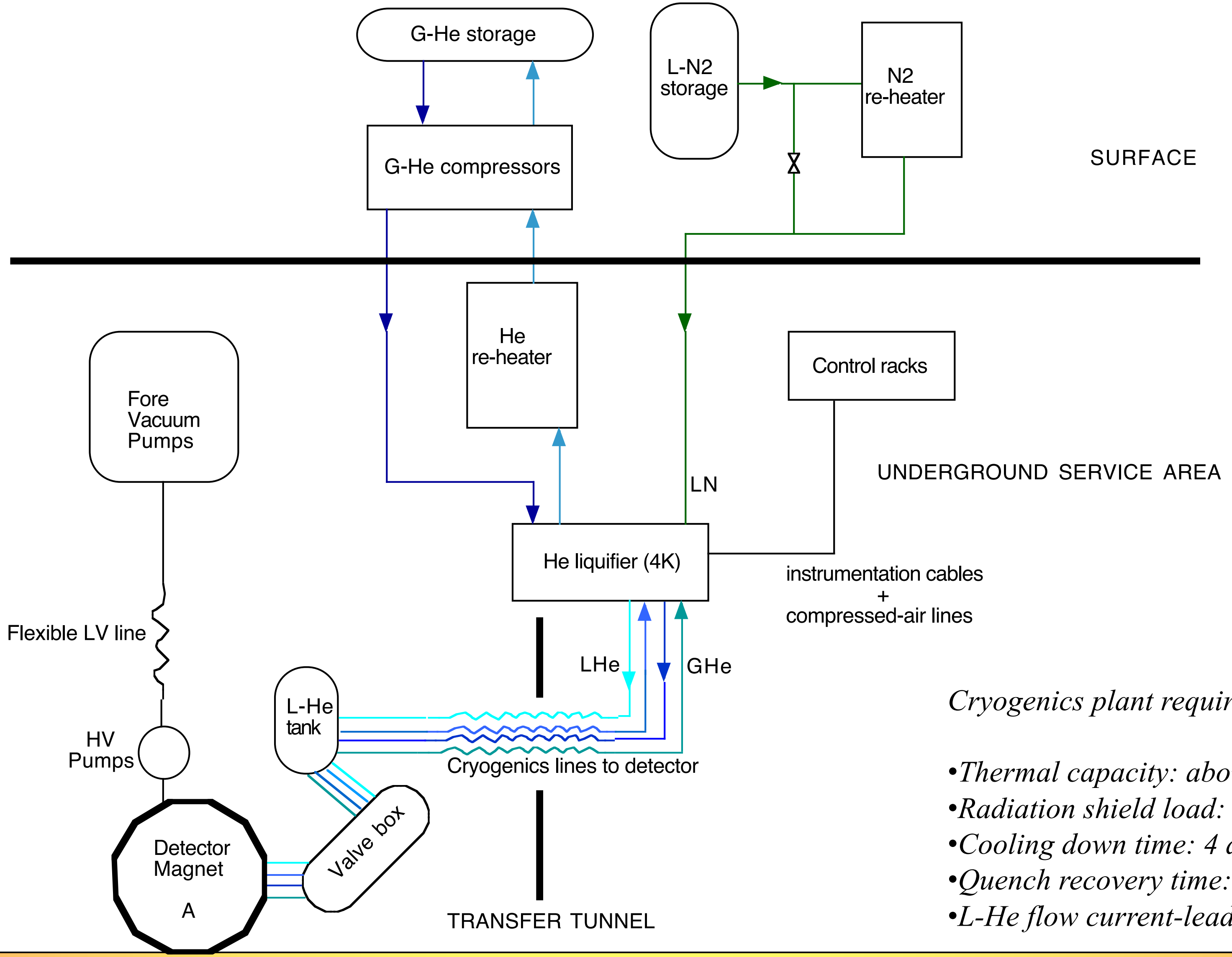
The superconducting coil and the two integrated dipoles shall be tested at nominal current on surface, including the field mapping. The electrical tests on surface will include:

- 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 for the commissioning of the CMS in 2006, prior to the detector lowering in the experiment cavern.

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*