LHeC Detector Magnet system

a 3.5 T Superconducting Solenoid,
eventually two end cap Toroids,
e-beam bending Dipoles

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(on behalf of the LHeC detector magnets study group)

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- LHeC detector magnet options
- Solenoid and e-Dipoles
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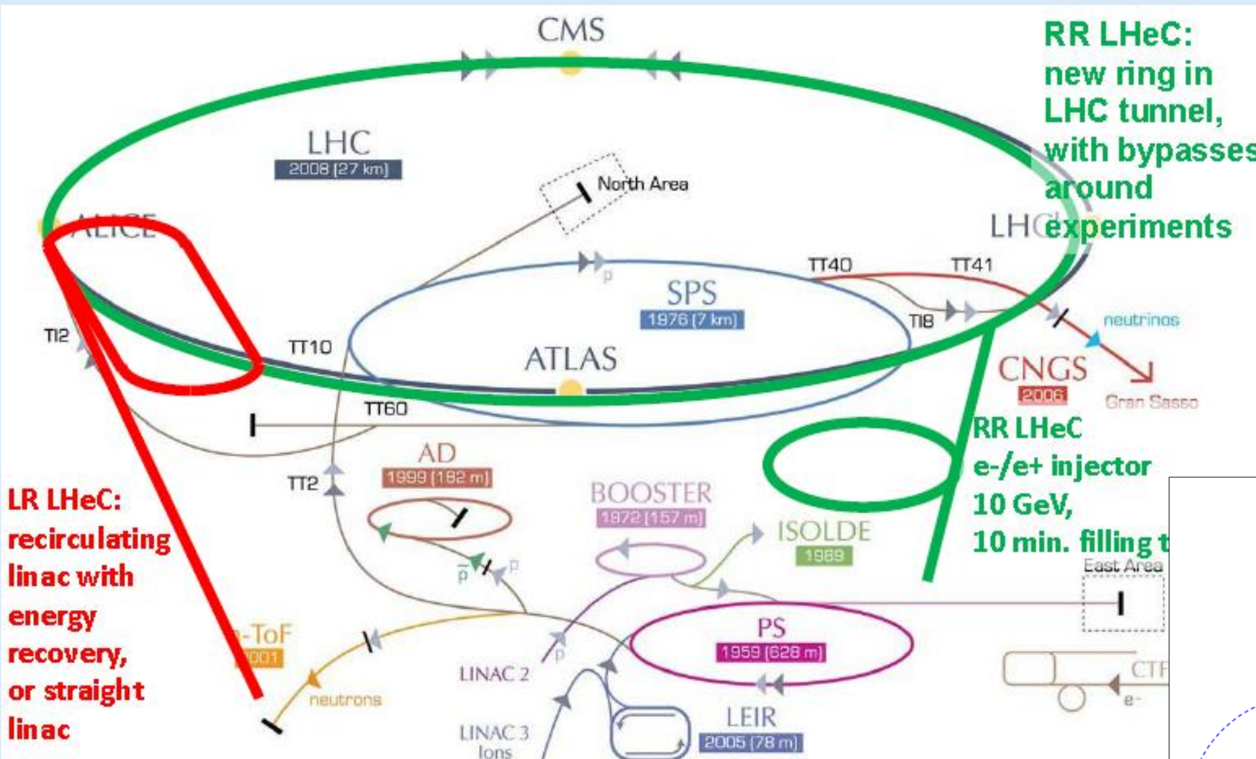
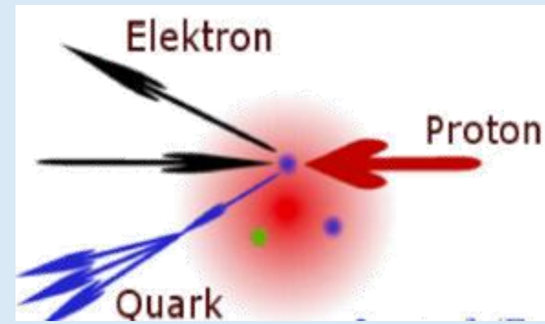
- Cryogenics
- Conclusion

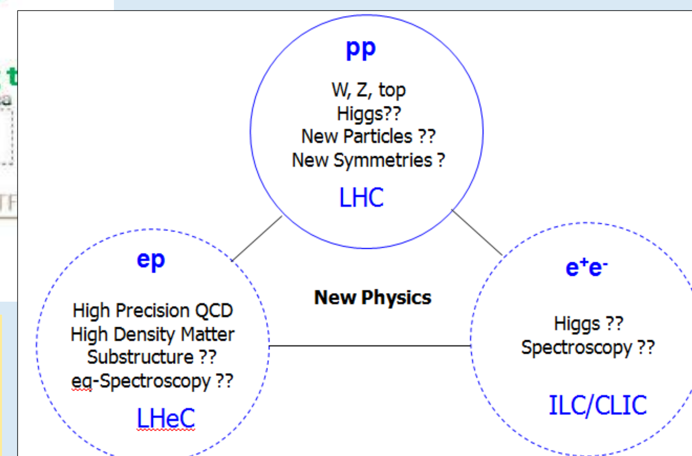
LHeC: motivation and options

A new Physics Experiment is proposed making use of the present proton beams in the LHC by adding a new electron beam generated by an e-ring or by a e-linac (most likely), a natural extension of the LHC complex





….featuring 60 GeV x 7 TeV e-p+e-A collisions at a new scale far beyond the HERA ep collider



e-Linear / p-Ring Interaction Region

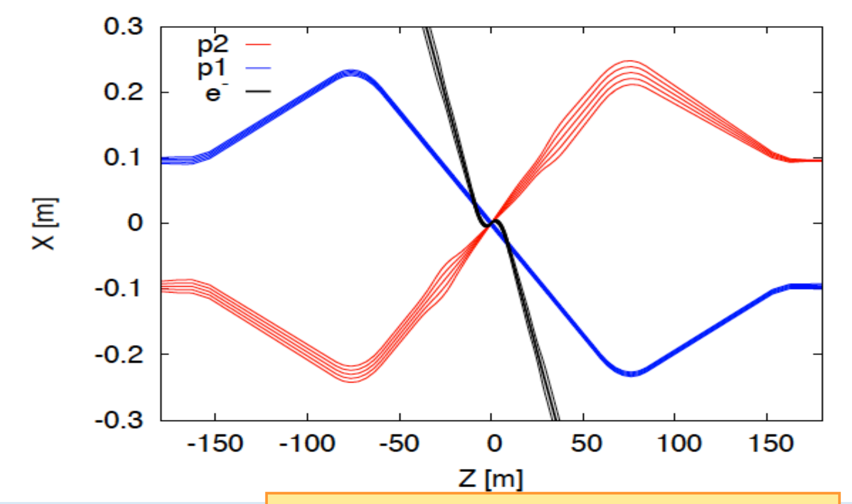
Special attention for the interaction region:

- 3 beams: e + p1 + p2
  also heavy ions
- synchrotron radiation
- beam pipe design

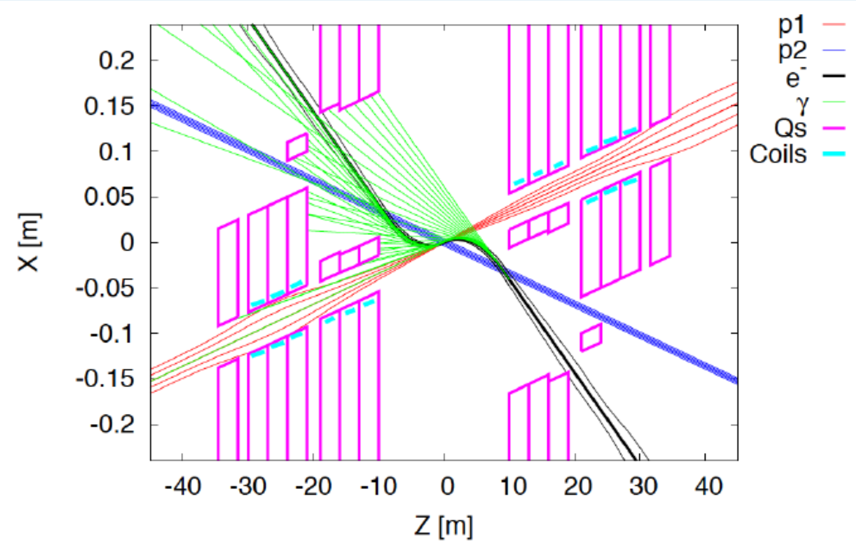
Special dipole magnets around the collision point are required:

- to guide the e-beam in and out
- for making electrons collide head-on with *p-beam 2*
- to safely extract the electron beam

➢ Two dipoles making 2 x 1 Tm, 0.3 T covering 2 x 9 m

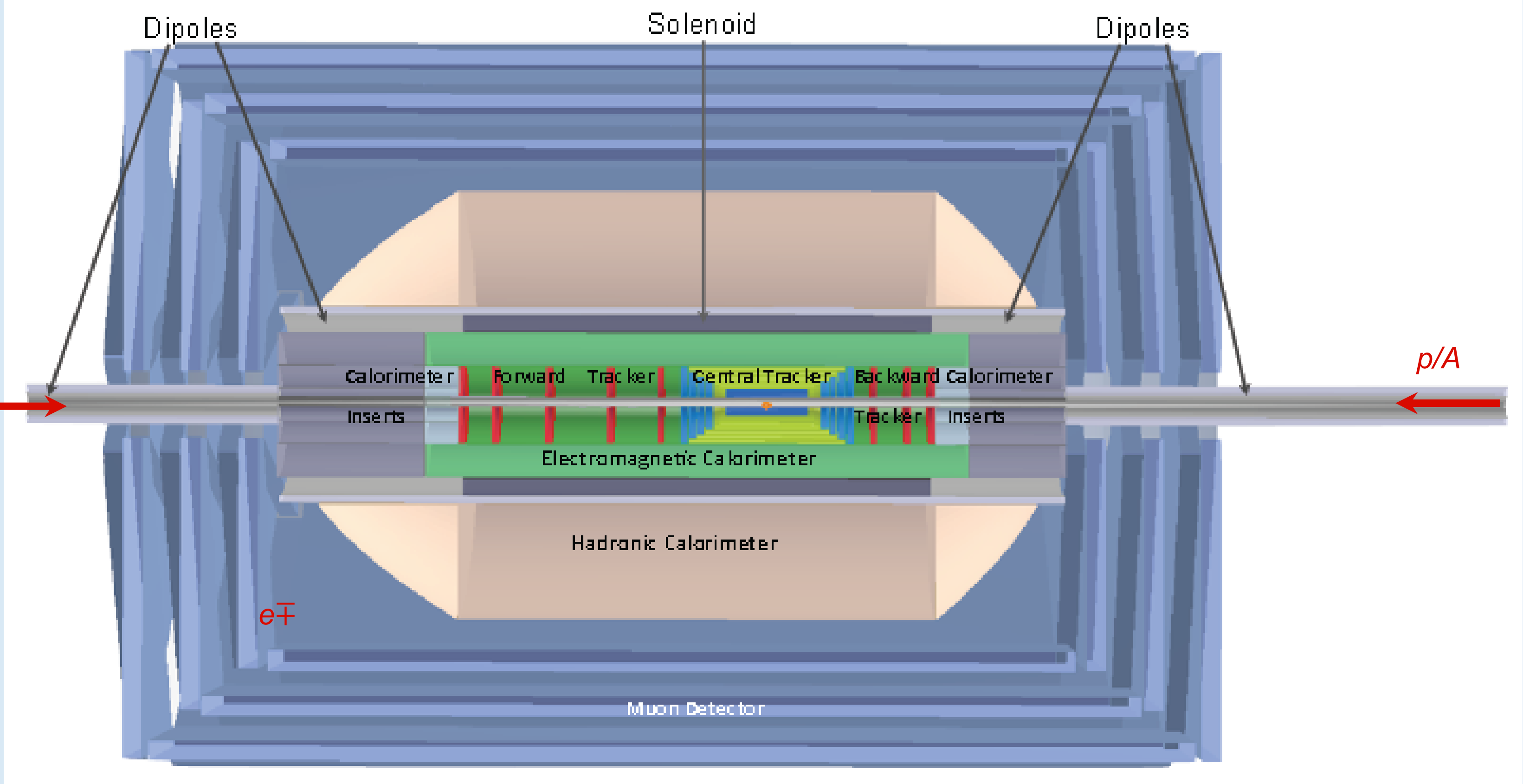


3 beams, head-on collisions



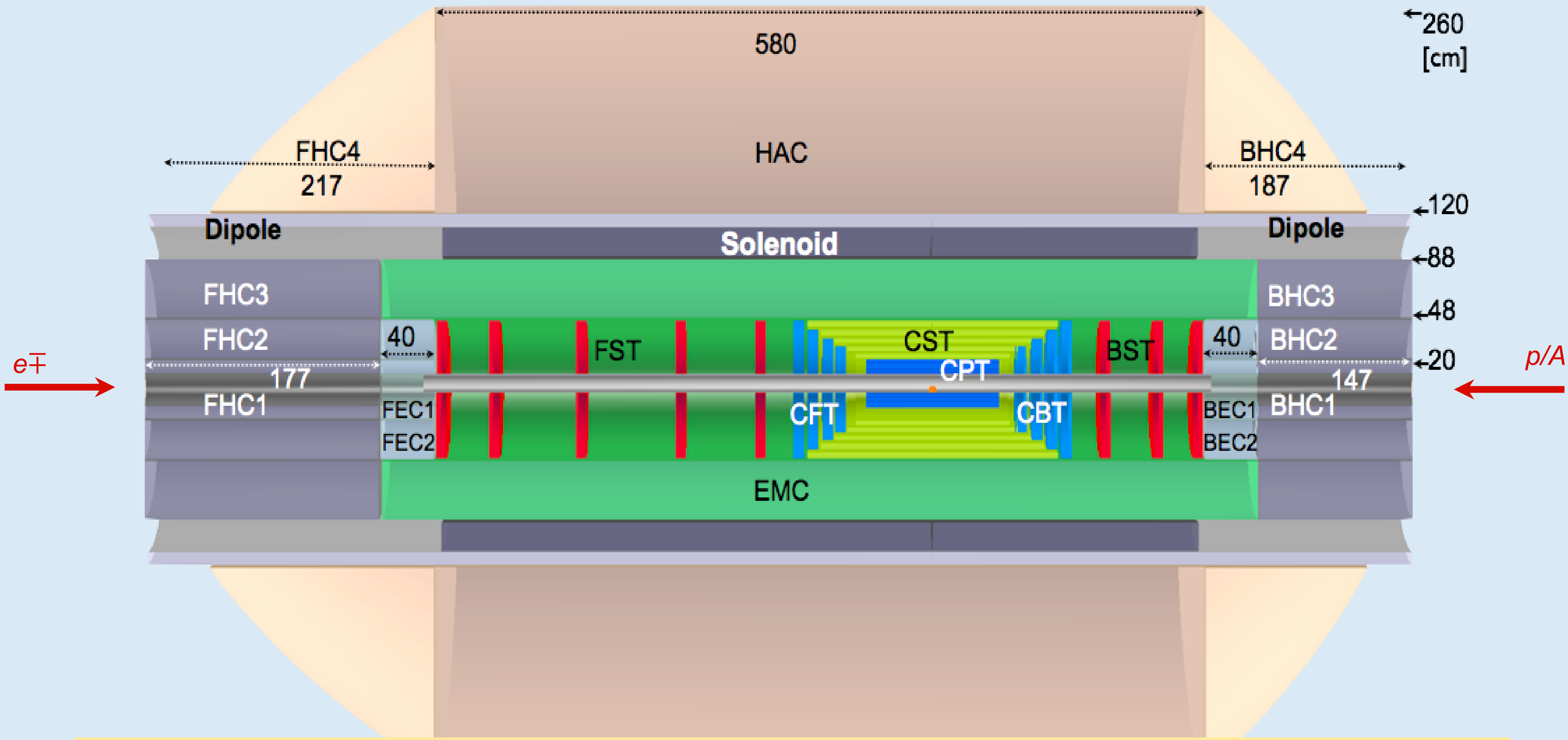
0.3T dipole field to allow head-on collision

Detector baseline layout



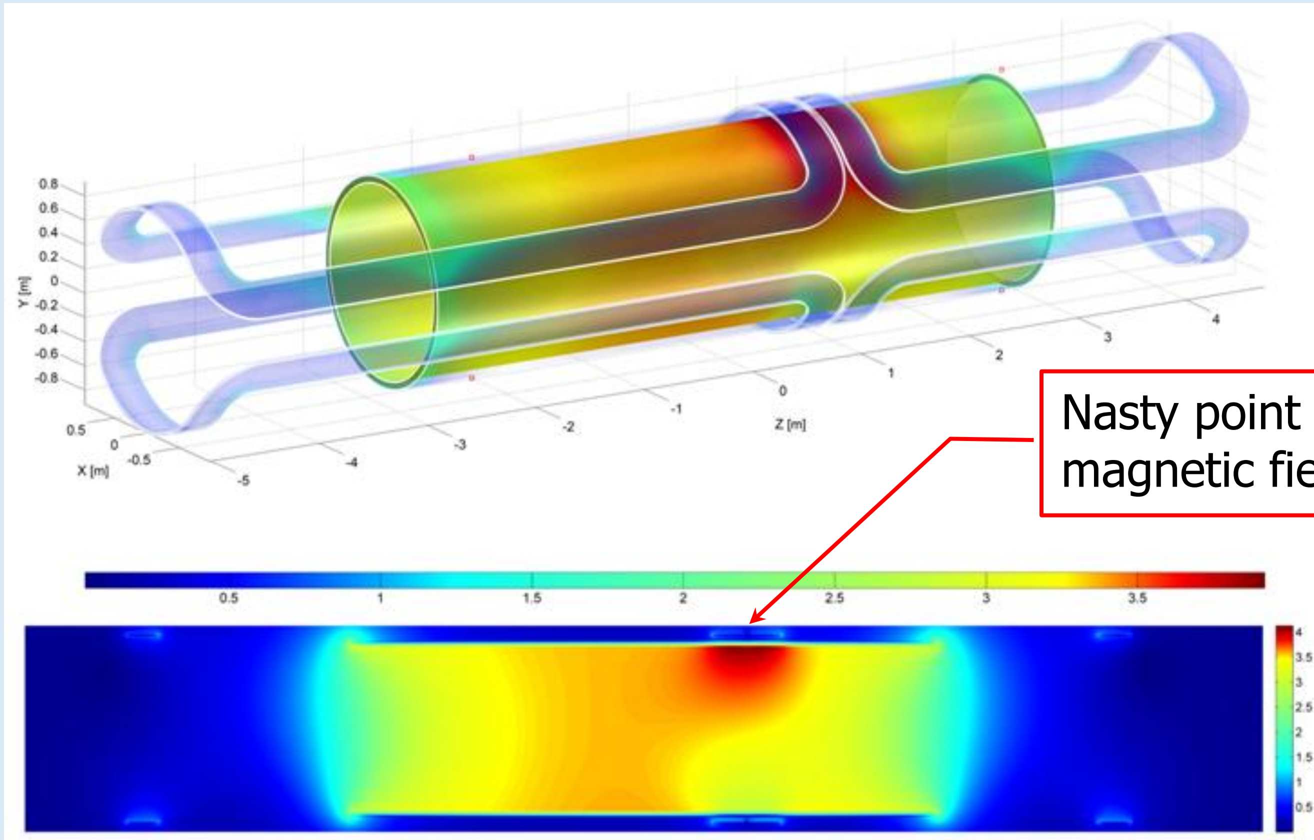
- Minimize cost, minimize R&D and risk, rely on present technology for detectors, magnets and infrastructure.
- 3.5 T Solenoid and 2 Dipoles in same cryostat around the EMC
- Muon tagging chambers in outer layer.

Baseline detector dimensions



- 3.5 T Solenoid + 0.3 T dual dipole for the e-linac / p-ring option.
- Magnets embedded in the EMC Liquid Argon cryogenic system.
- Still to study the Calorimeter Performance and impact on detector of dead material between EMC and HAC sections.

Magnetic field in the Solenoid-Dipole set

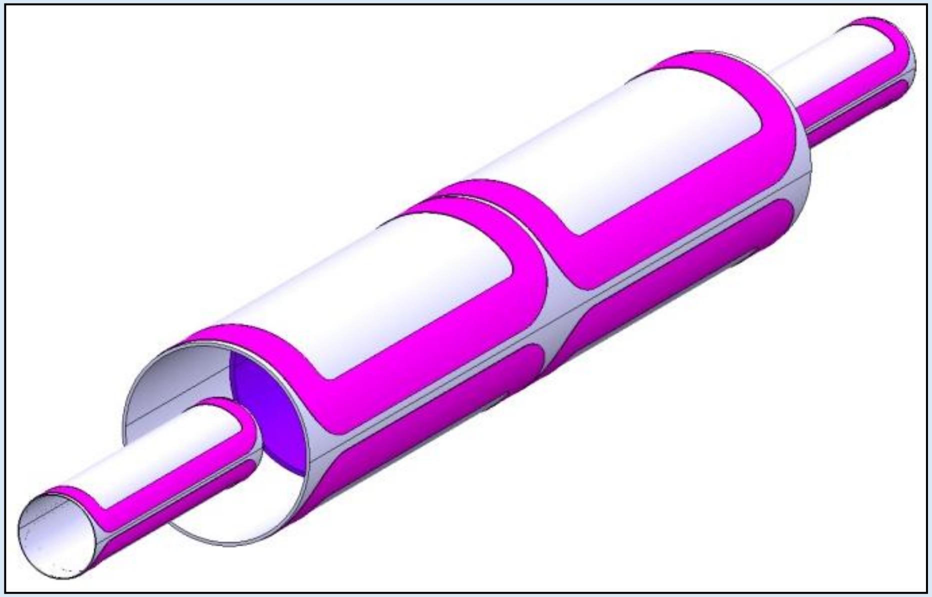


LHeC detector for the Linac-Ring option, showing the positions of the 3.5 T solenoid and the 0.3 T inner superconducting dipole sections.

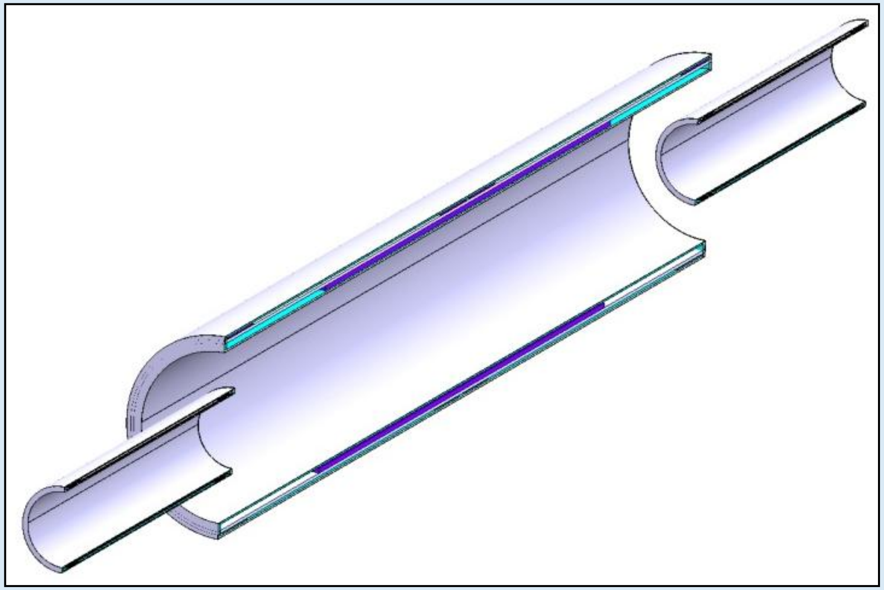
Solenoid and dipoles on a common support cylinder, in a single cryostat, free bore of 1.8 m, extending along the entire detector with a length of 10 m.

Single cold mass and cryostat

- Dipoles wound on top of Solenoid (low return field), single cold mass and cryostat, effective thickness ~150 mm Al alloy
- Identical side dipoles in separate cryostats positioned at either side of the detector complete the required 1 Tm across 9 m



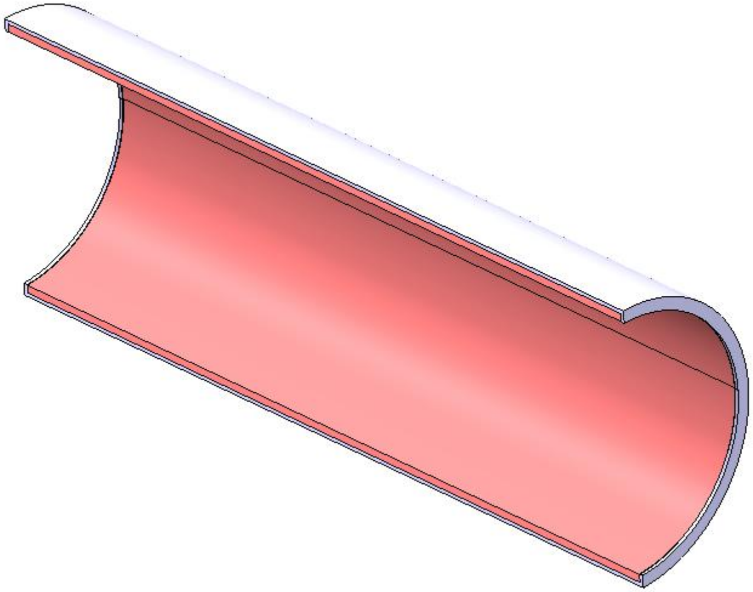
Solenoid and Dipoles on 1 coil former
12 m long central part
and 6 m side coils



Cryostat longitudinal section
About 250 mm thick
including ~150 mm Al alloy material

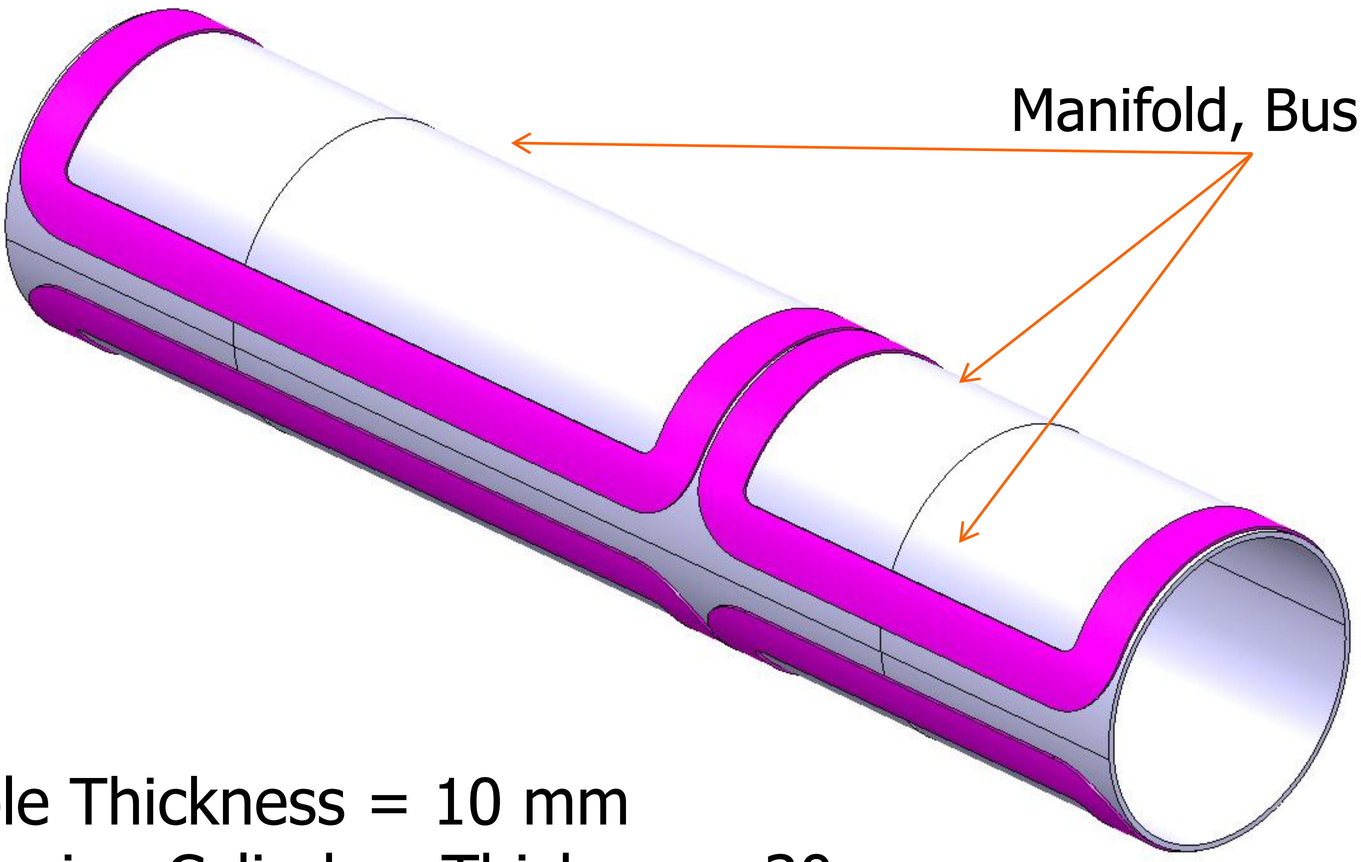
Solenoid (8.8 t)

Mass of conductor=5.7 t
Mass of Support Cylinder= 3.1 t



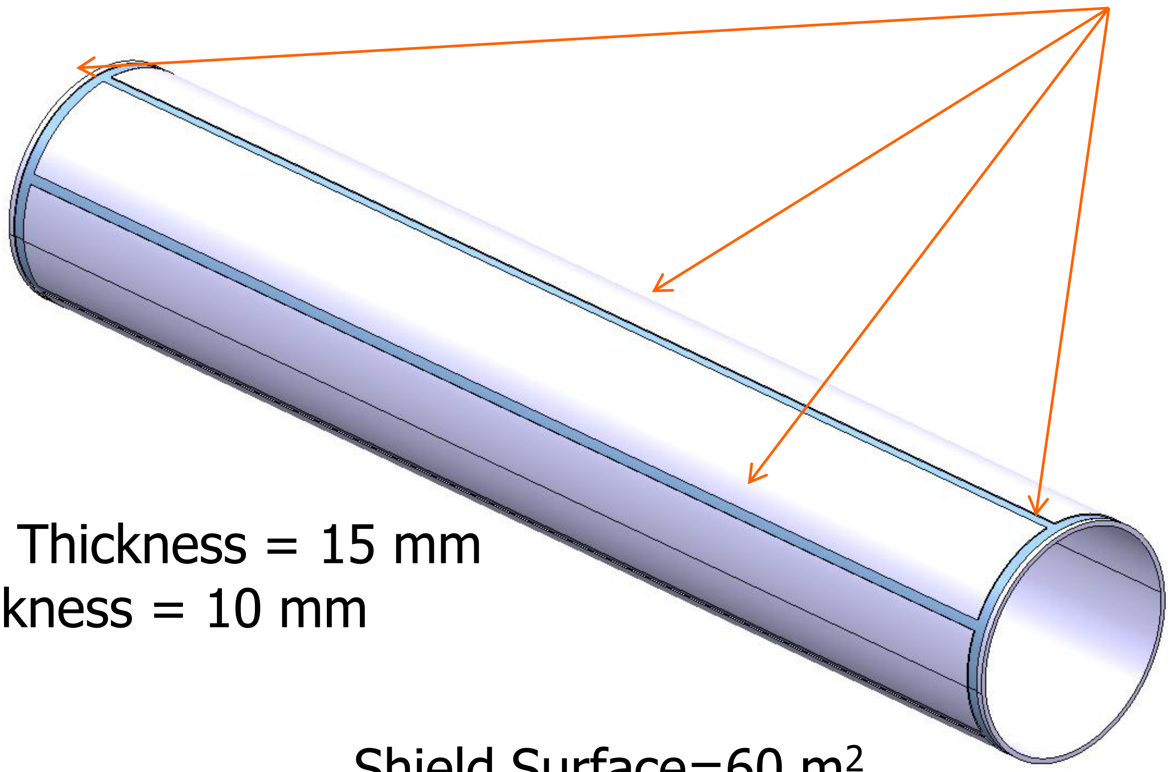
Al Thickness = 90 mm

Cold Mass (12.8 t)



Dipole Thickness = 10 mm
Extension Cylinders Thickness=30 mm

Inner Vessel and Shield (3.8 t)

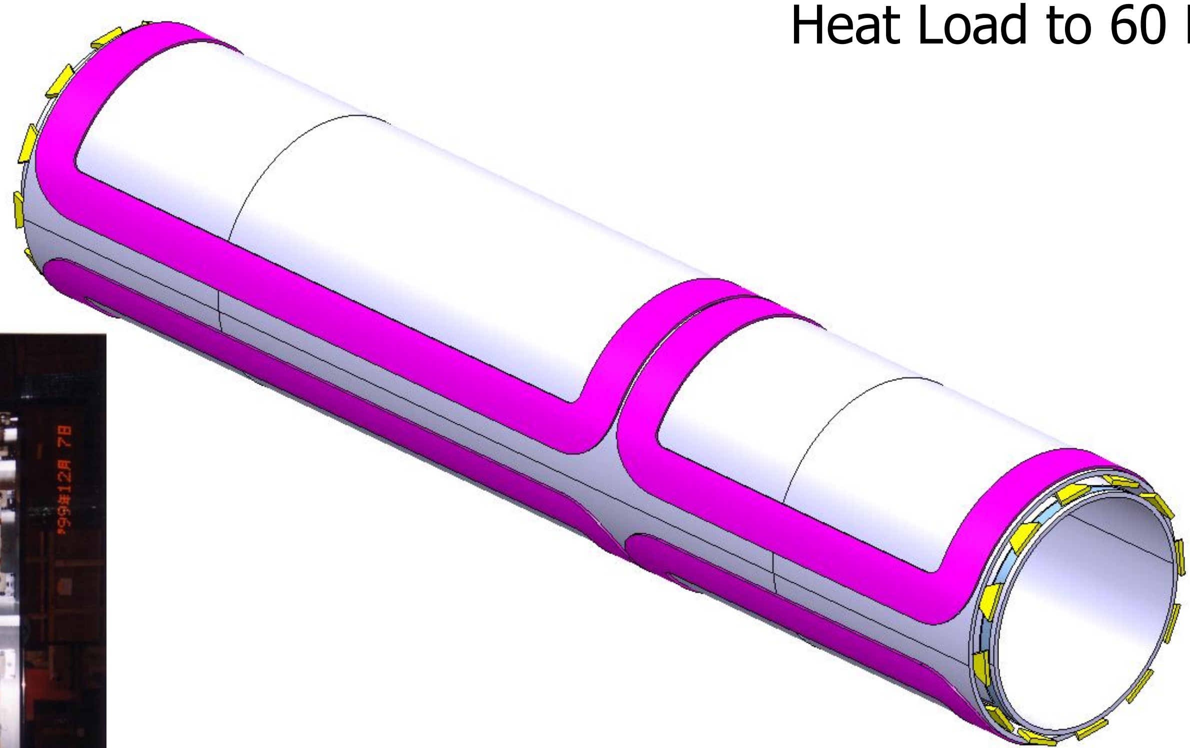


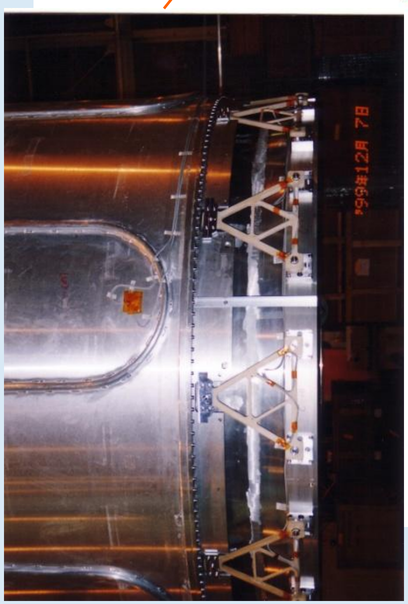
Inner Shell Thickness = 15 mm
Shield Thickness = 10 mm

Shield Surface=60 m^2
Heat Load to 60 K = 180 W

Triangle Supports

Heat Load to 4.5 K= 5 W
Heat Load to 60 K= 50 W

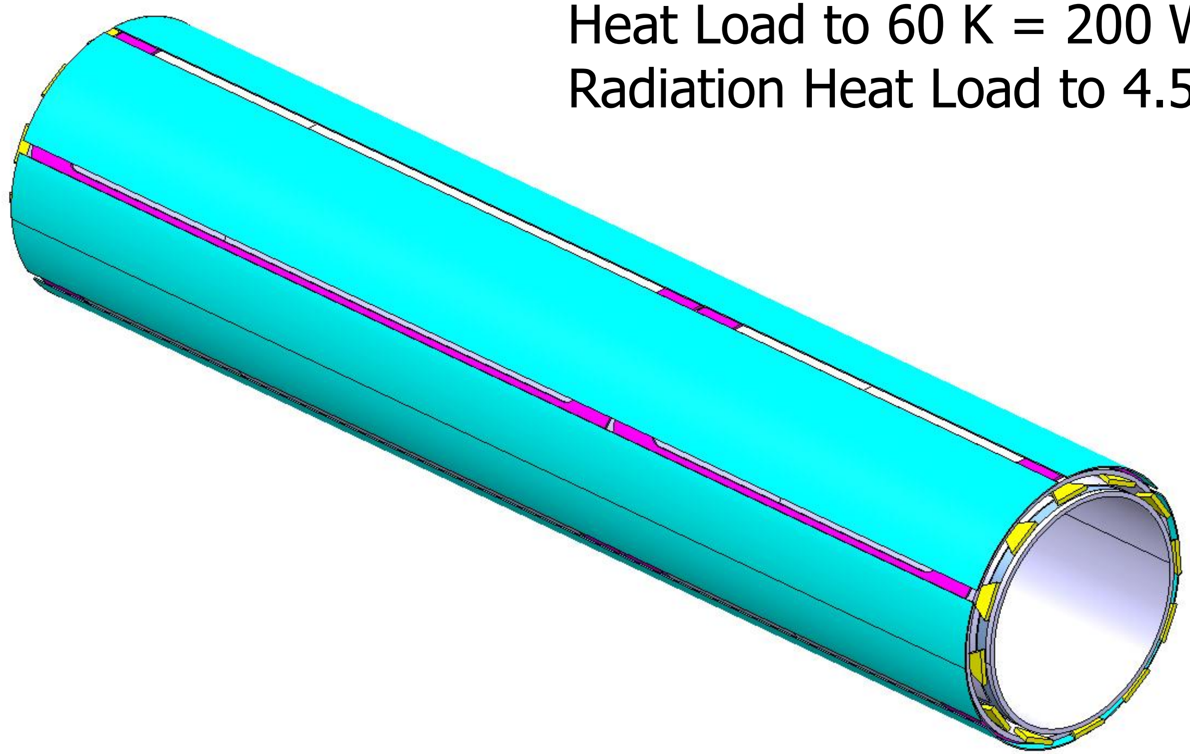




Radiation Heat Load to 4.5 K= 18 W

Outer Shield

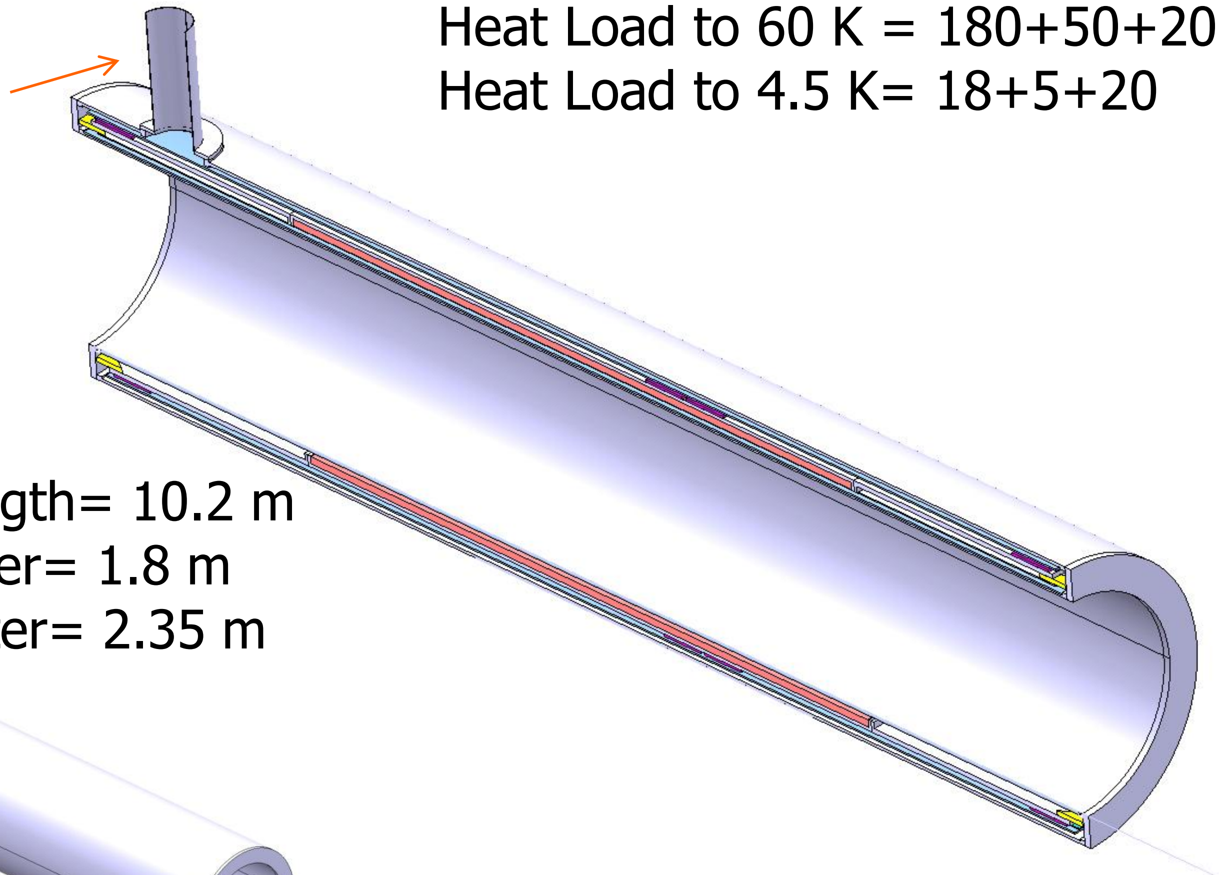
Shield Surface = 70 m^2
Heat Load to 60 K = 200 W
Radiation Heat Load to 4.5 = 20 W



Shield Thickness = 10 mm

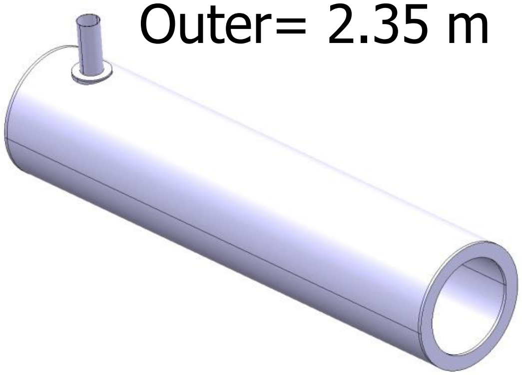
Cryostat (24 t)

Turret
for
services



Heat Load to 60 K = 180+50+200=430 W
Heat Load to 4.5 K= 18+5+20 = 43 W

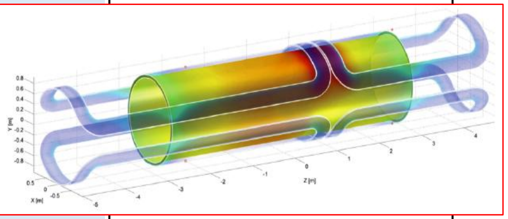
Length= 10.2 m
Inner= 1.8 m
Outer= 2.35 m



Al Thickness=10+10+60+30+10+10+20=150mm

Solenoid parameters 1

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



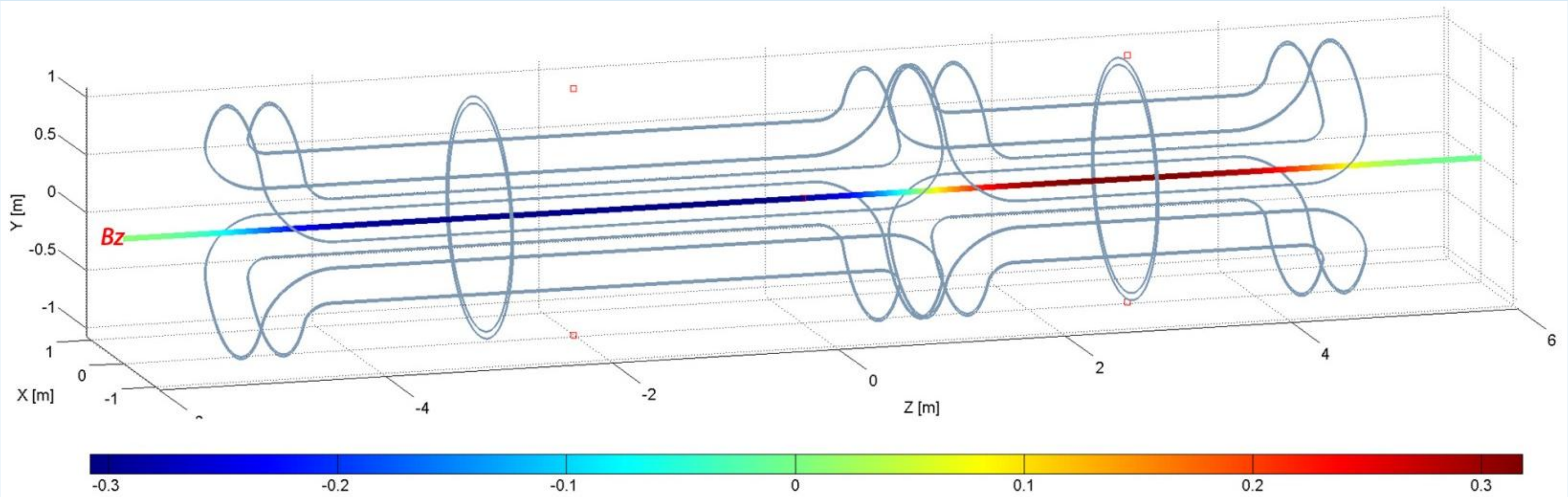
The coil technology is based on Al-stabilized NbTi cables, conduction cooled and operated at around 4.6 K, like the ATLAS Solenoid.

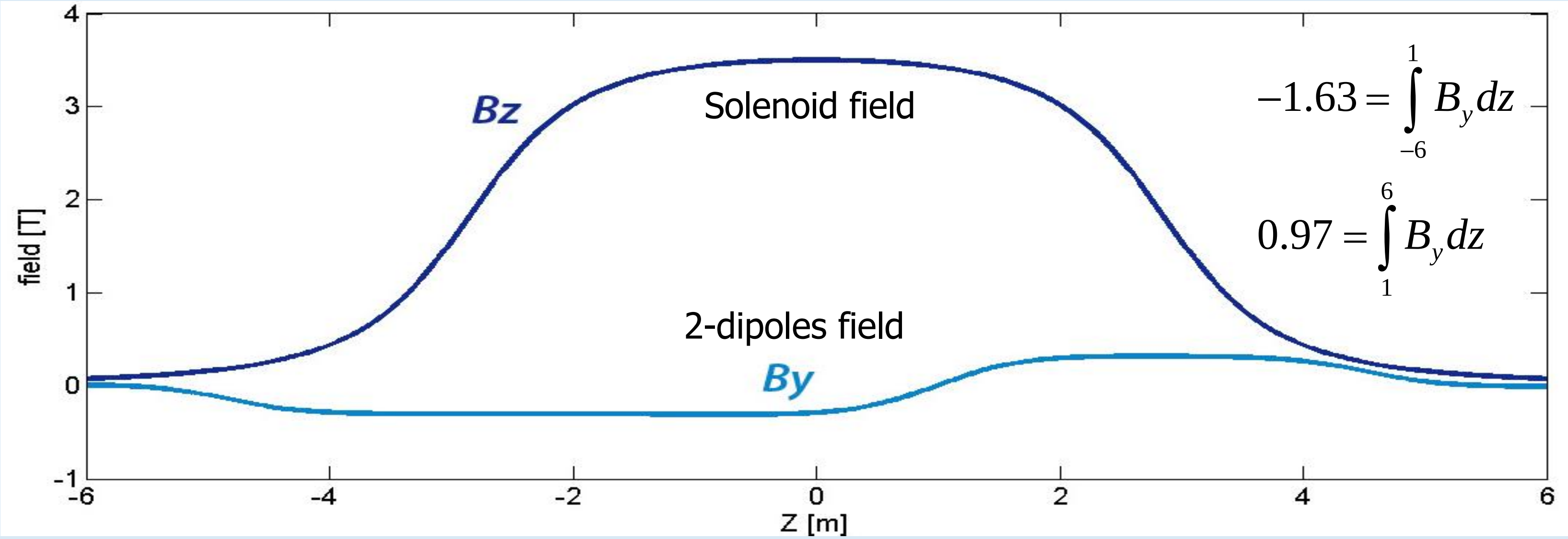
Solenoid parameters 2

	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

The numbers raised are conservative and no particular problems are foreseen in the construction of this solenoid.

Magnetic field on beam axis





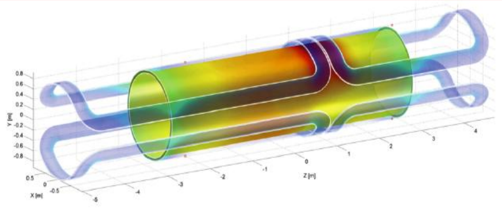
Duo dipoles specifications

Table 4.2 Main design parameters of the set of superconducting electron beam bending dipoles

	Long dipole coil	Short dipole coil	
Magnetic field on axis	0.3		T
Peak magnetic field in windings (solenoid off)	0.7		T
Peak magnetic field in windings (solenoid on)	2.6		T
Dipole length (including external sections)	9.0		m
Field integral internal section (sc dipole)	1.6	1.0	Tm
Field integral external section (iron magnet)	1.1	1.7	Tm
Operating current	2.0		kA
Stored Energy	1.9	1.2	MJ
Coil inductance	0.95	0.61	H
Windings engineering current density	55	55	A/mm^2
Coil inner / outer radius	1.042 / 1052		m
Coil length	6.00	3.70	m
NbTi/Cu cable (12 strands Rutherford cable)	1.44 x 4.31		mm^2
Conductor length	5.4	3.6	km

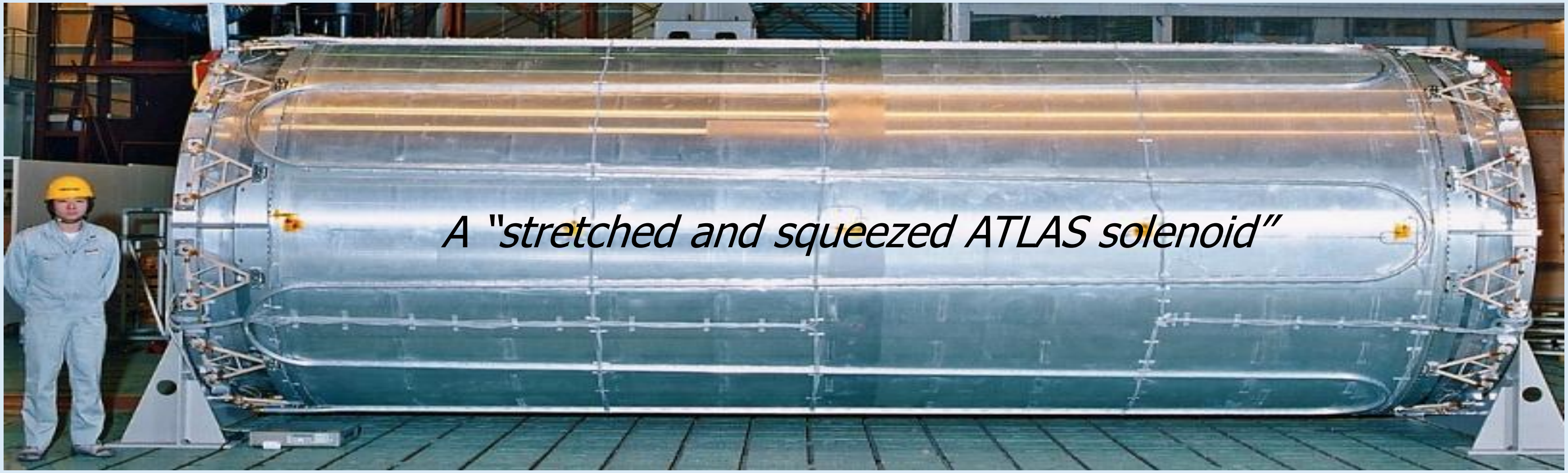
Dipoles are classical NbTi windings, 2 kA cable.

A worry is the tensile/pulling-off forces caused by combined field but seems manageable with proper support and qualification test.



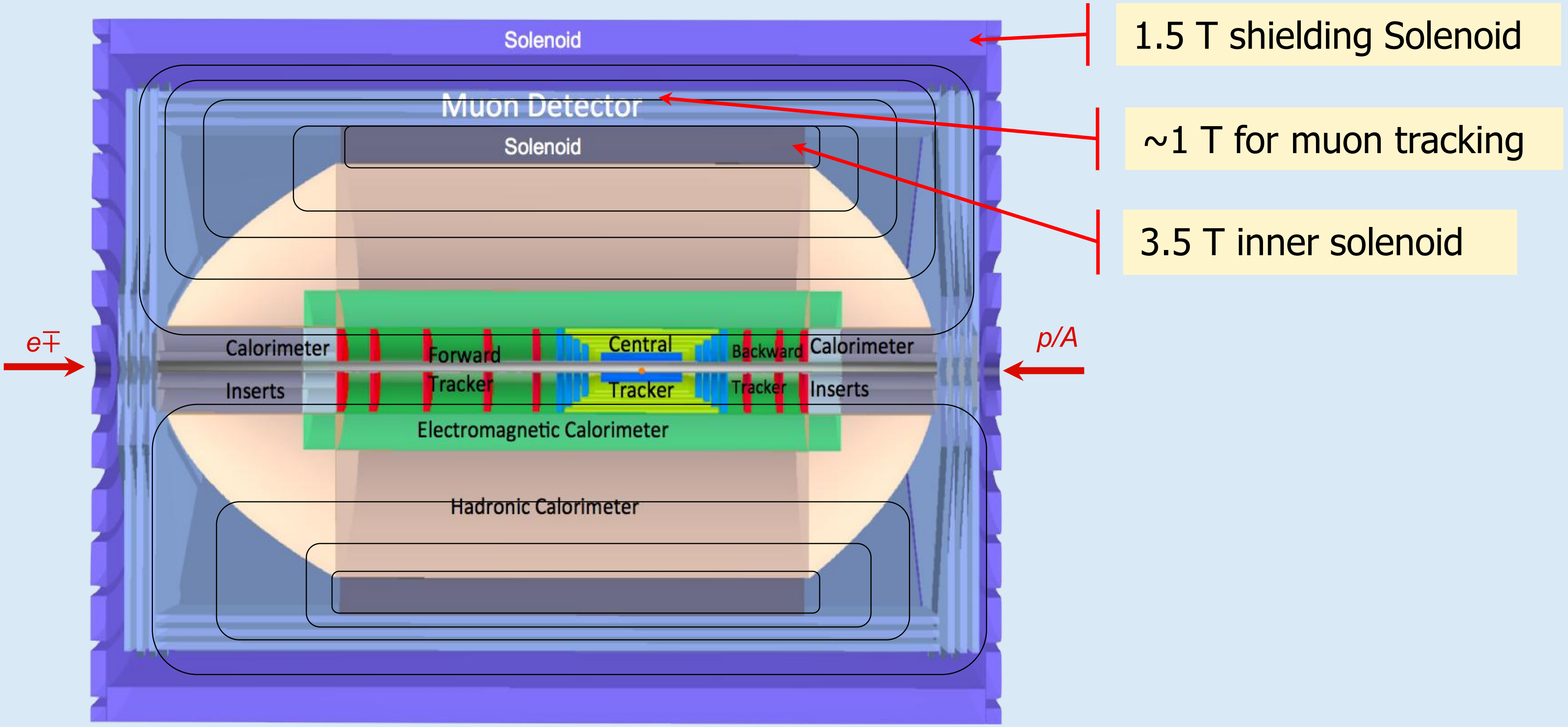
LHeC Solenoid 3.5 T - 2.24 m D - 7.1 m L

It will look like…..an extended ATLAS solenoid, 2 T scaled up to 3.5T (needs 2 layers instead of 1, slightly less free bore but longer)



- Relatively small diameter but long, thus very efficient coil
- 1.8 m free bore, 7.1 m long (~8 m external size)
- ~ 11 km Al stabilized NbTi/Cu superconductor for 10 kA
- ~ 80 MJ stored energy
- ~ 24 tons weight including cryostat.

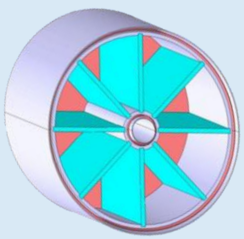
Dual Solenoid Option (avoiding iron)



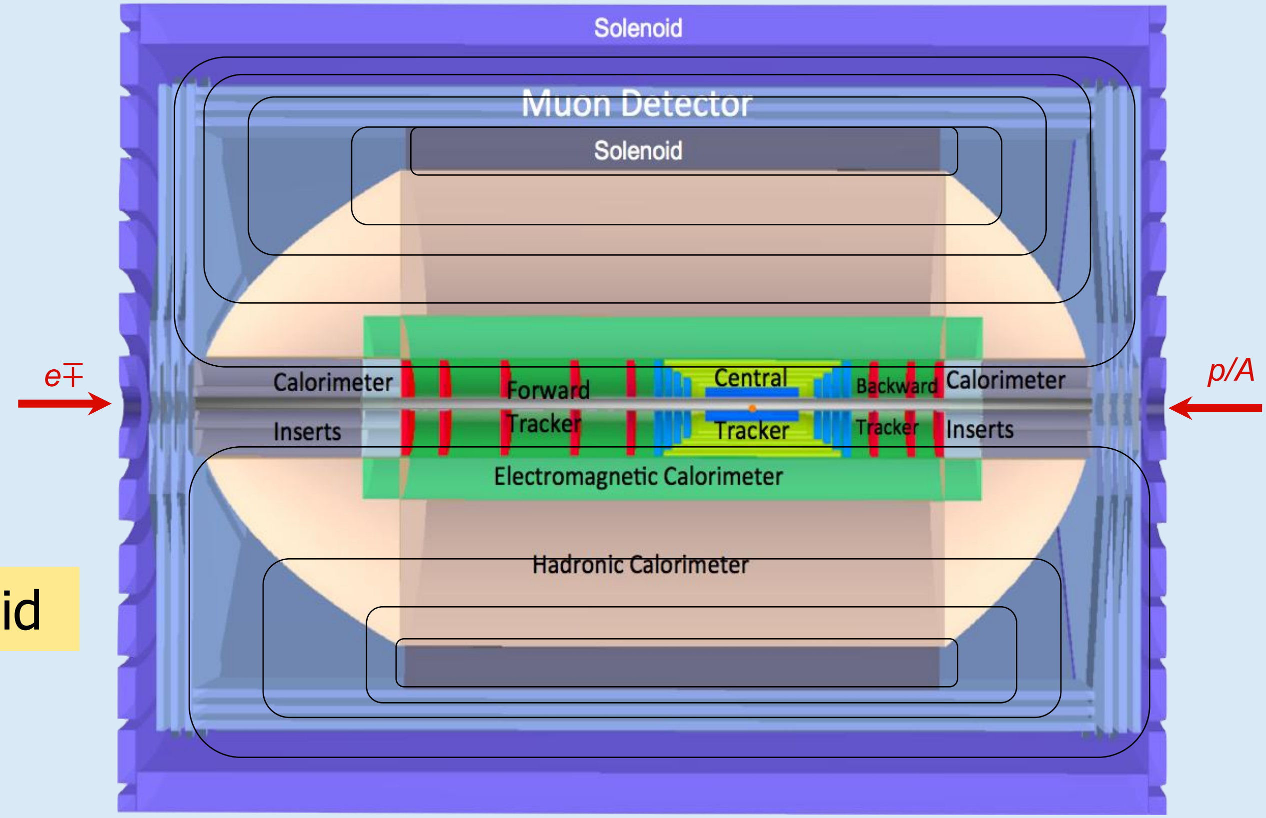
When choosing for the Large 3.5T Solenoid enclosing all calorimeters:

- Iron flux return yoke is massive > 10,000 tons → use an active shield
- Dual Solenoid is light <1000 tons, is much smaller in diameter AND provides nice space for muon tracking…….

Muon System Extensions



2 T, ~1 m^3 toroid



Extensions:

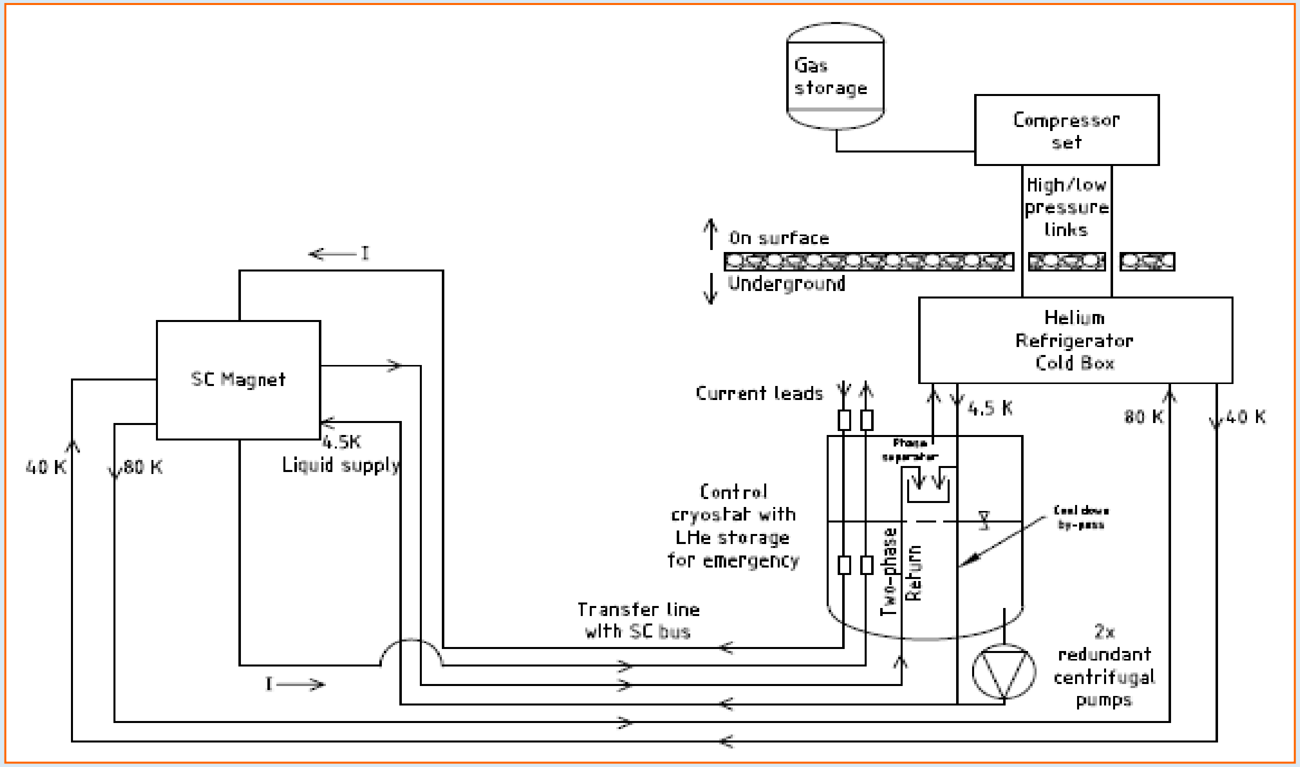
- Independent muon momentum measurement
- Large solenoid (incompatible with LR dipoles)
- Dual Coil System (homogeneous return field)
- Forward Toroid System

Helium cryogenics for LHeC detector

Classical He production and circulation system:

- a 200 W / 1.5 g/s He liquefier,
- A cold He pump enforcing circulation.

Component heat load at temperature		4.5 K	20-300 K	40-80 K
Magnets	static	45 W		430 W
	dynamic	30 W		
Transfer line/bus	static	10 W		150 W
Valve box cryostat	static	10 W		150 W
Helium pump	static	40 W		
Current leads	static		1.0 g/s	
Sums with and extra 50% contingency		200 W	1.5 g/s	1100 W



Conclusion

- A proposed extension of the LHC physics reach is to add an extra electron beam and allow e-p/A collisions (following HERA) but now at a much higher energy
- The conceptual design of the magnet system for an LHeC Experiment is completed aiming at lowest cost, low risk, relatively fast production allowing readiness by 2023-2025
- A 3.5 T Solenoid, 1.8 m bore, 10 m long, is combined with the necessary 0.3 T, 2x9 m long e-bending dipoles to guide the e-beam
- When a large 3.5 T Solenoid is preferred, a novel light and compact design is proposed using an actively shielded solenoid
- An elegant engineering solution is proposed which is feasible as it builds on the present technology of detector magnets for the LHC
- Next steps: magnet R&D approval; integration study with present structures in cavern; completing an engineering design to prepare the production when requested.