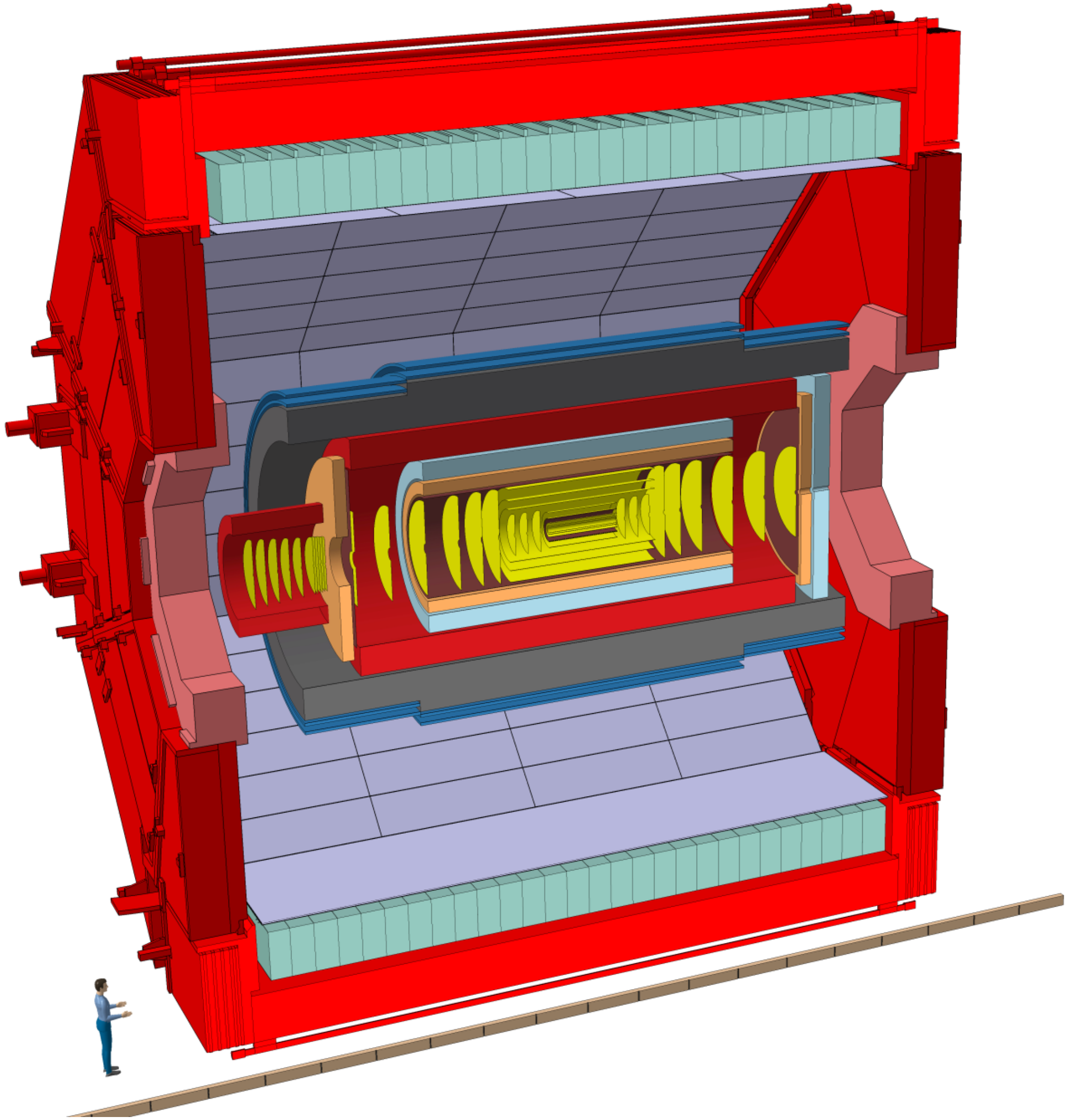
The ALICE3 detector



W. Riegler, CERN

Superconducting Detector Magnet Workshop
Sept. 12-14, 2022, CERN

ALICE Experiment at the LHC

ALICE is one of the 4 large LHC experiments, dedicated to Heavy Ion collisions and the study of the Quark Gluon Plasma (QGP).

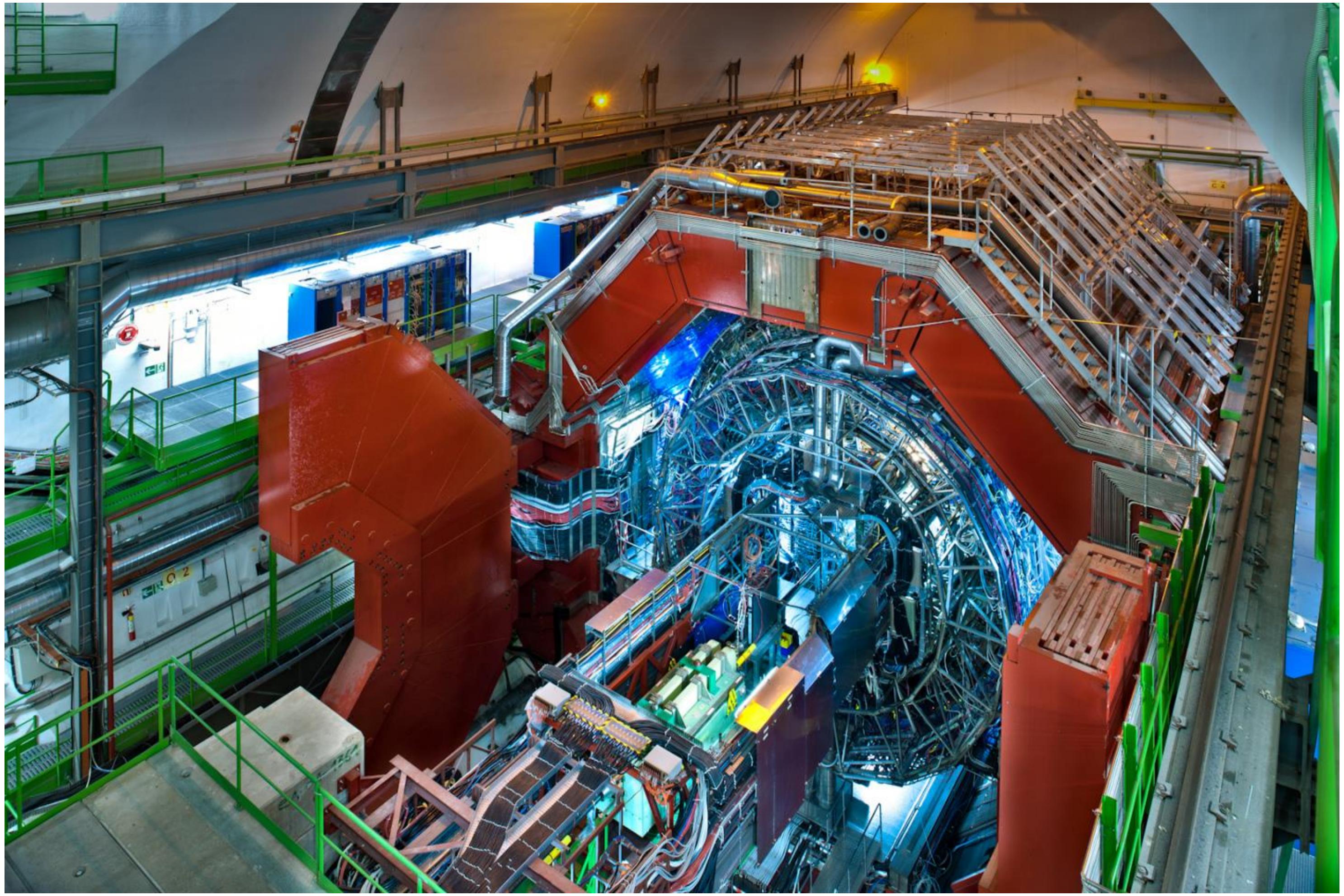
For about 4 weeks per year, the LHC is accelerating and colliding Pb Nuclei.

All LHC experiments take are part in this physics program.

ALICE also has an important proton-proton physics program.

→ ALICE is operating the detector during the entire LHC operation period.

ALICE Experiment at the LHC



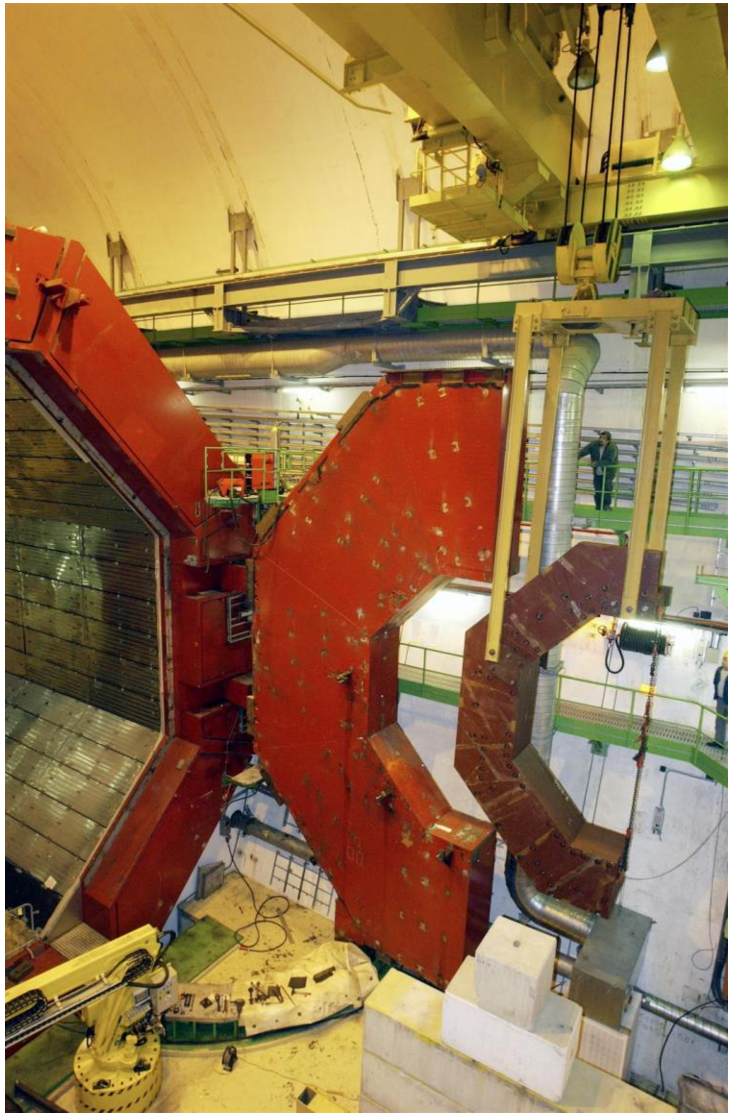
The ALICE experiment is installed at LHC P2, in the cavern that housed the L3 experiment during the LEP operation from 1988 to 2000.

L3 Magnet

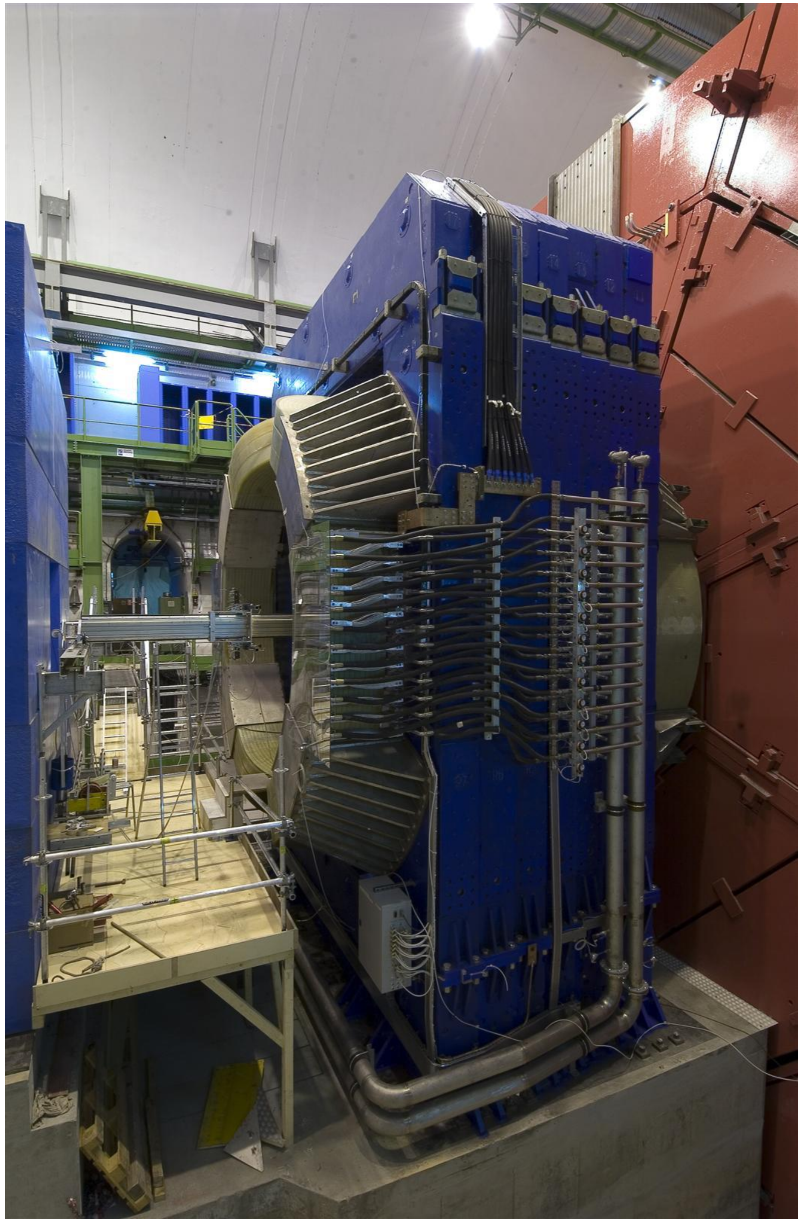
ALICE has ‘inherited’ the L3 cavern and the L3 magnet.

Some Iron was added to the Magnet Yoke (Doors) to improve the field quality.

0.5T
4MW
30kA



ALICE Dipole Magnet

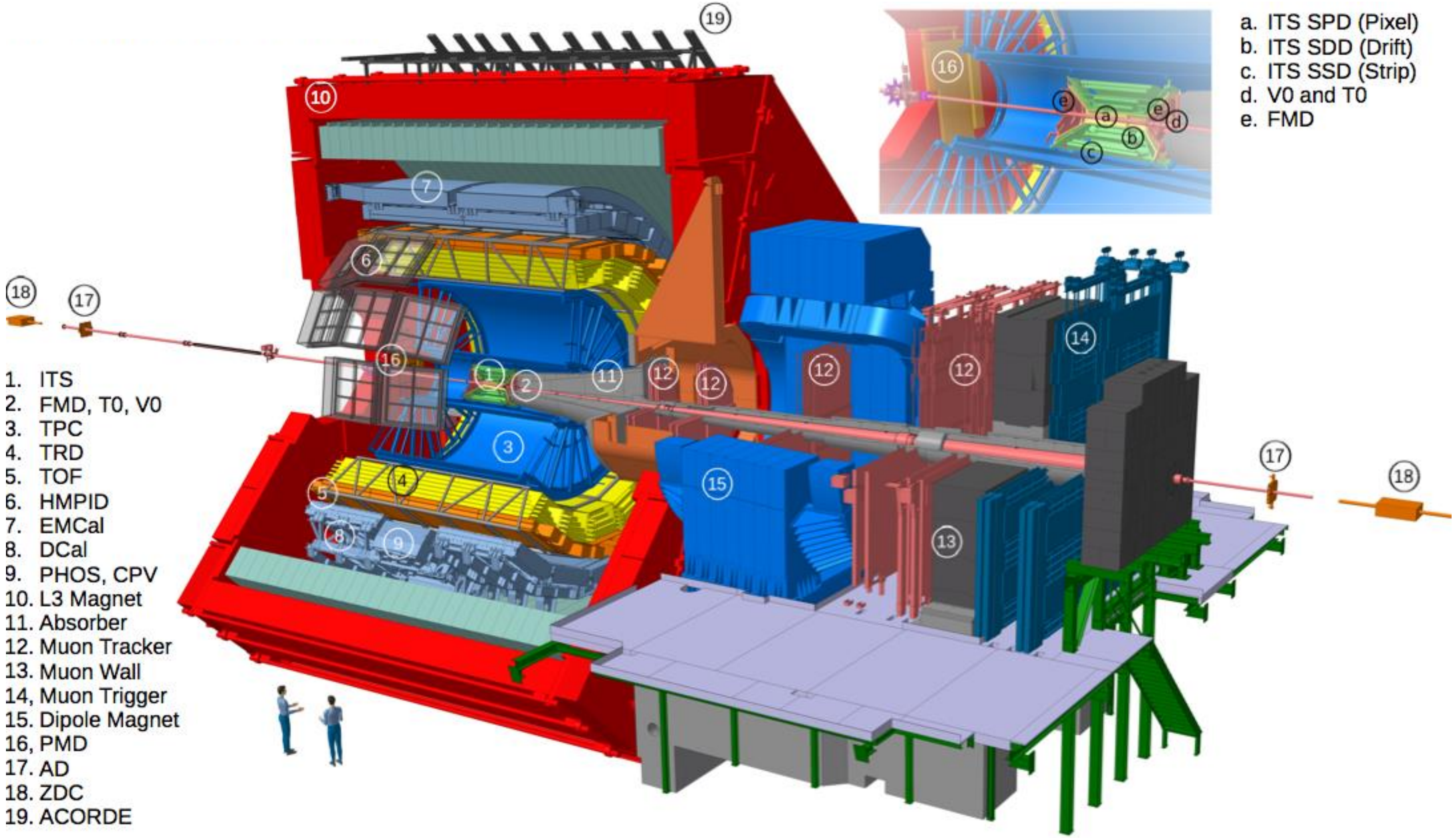


The ALICE Collaboration installed a new Dipole Magnet for the Forward Muon Spectrometer.

Like the L3 magnet, it is a warm, water-cooled magnet.

0.7T horizontal field
4MW
6kA

The ALICE Run1/Run2 (2009-2018)



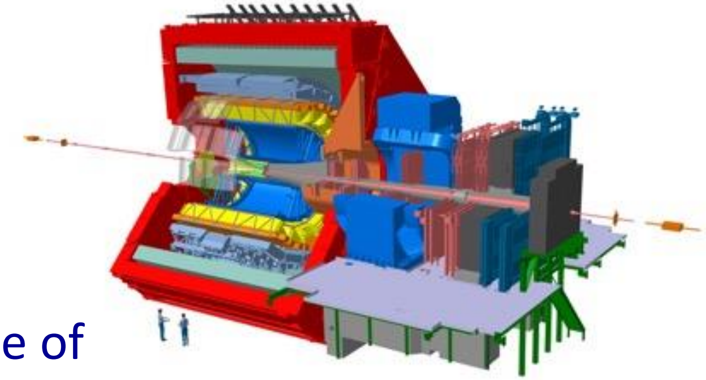
Run1+Run2 goal: 1nb^{-1} of PbPb collisions

PbPb min. bias readout rate ≈ 1kHz with RCU2

ALICE Upgrade during LS2 (2019-2021)

Goal:

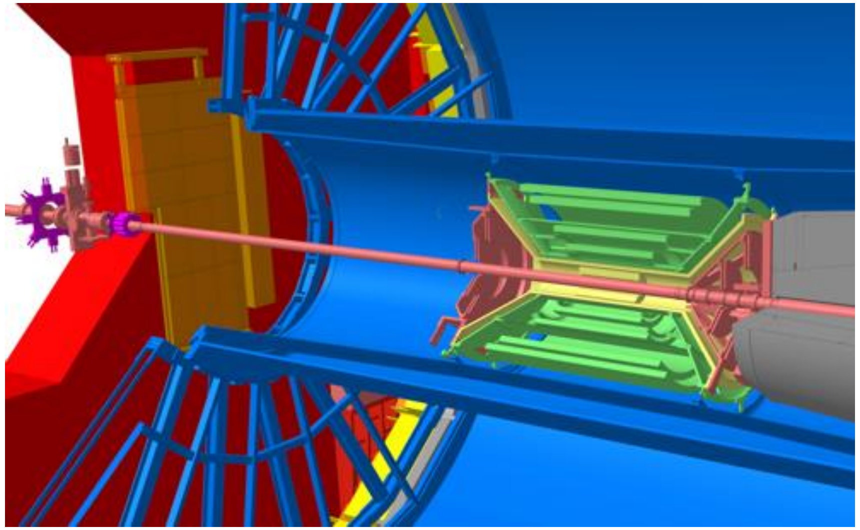
- High precision measurements of rare probes at low $p_{T,}$ which cannot be selected with a trigger. Target a recorded Pb-Pb luminosity $\geq 10\ nb^{-1}$ ➡ 8×10^{10} events to gain a factor 100 in statistics over the Run1+Run2 programme and
- Significant improvement of vertexing and tracking capabilities



Detector:

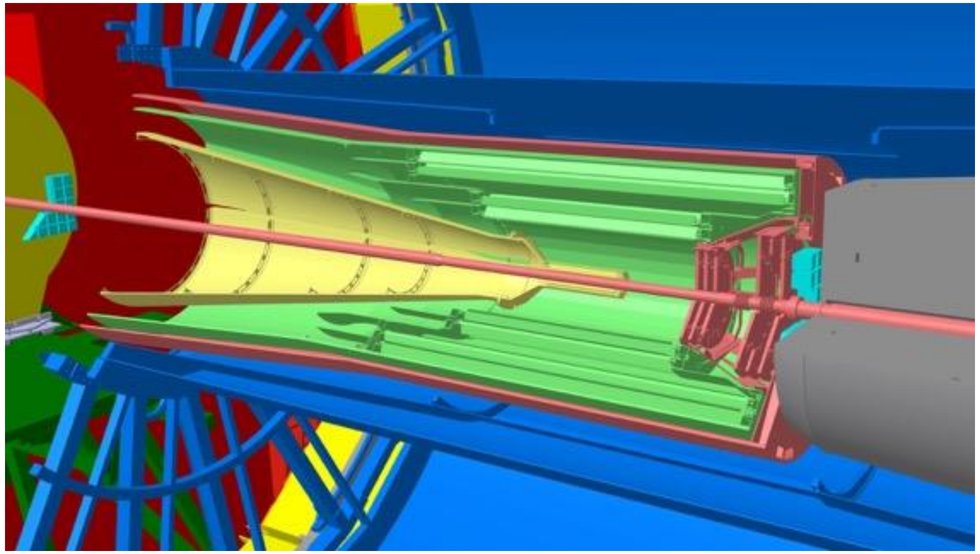
- Read out all Pb-Pb interactions at a maximum rate of 50kHz (i.e. $L = 6x10^{27}\ cm^{-1}s^{-1}$) continuously or upon a minimum bias trigger.
- Perform online data reduction based on reconstruction of clusters and tracks.
- Improve vertexing and tracking at low p_T →New Inner Tracking System (ITS).
- Improve Muon Performance → MFT

ITS upgrade and MFT



New Inner Tracking System (ITS)

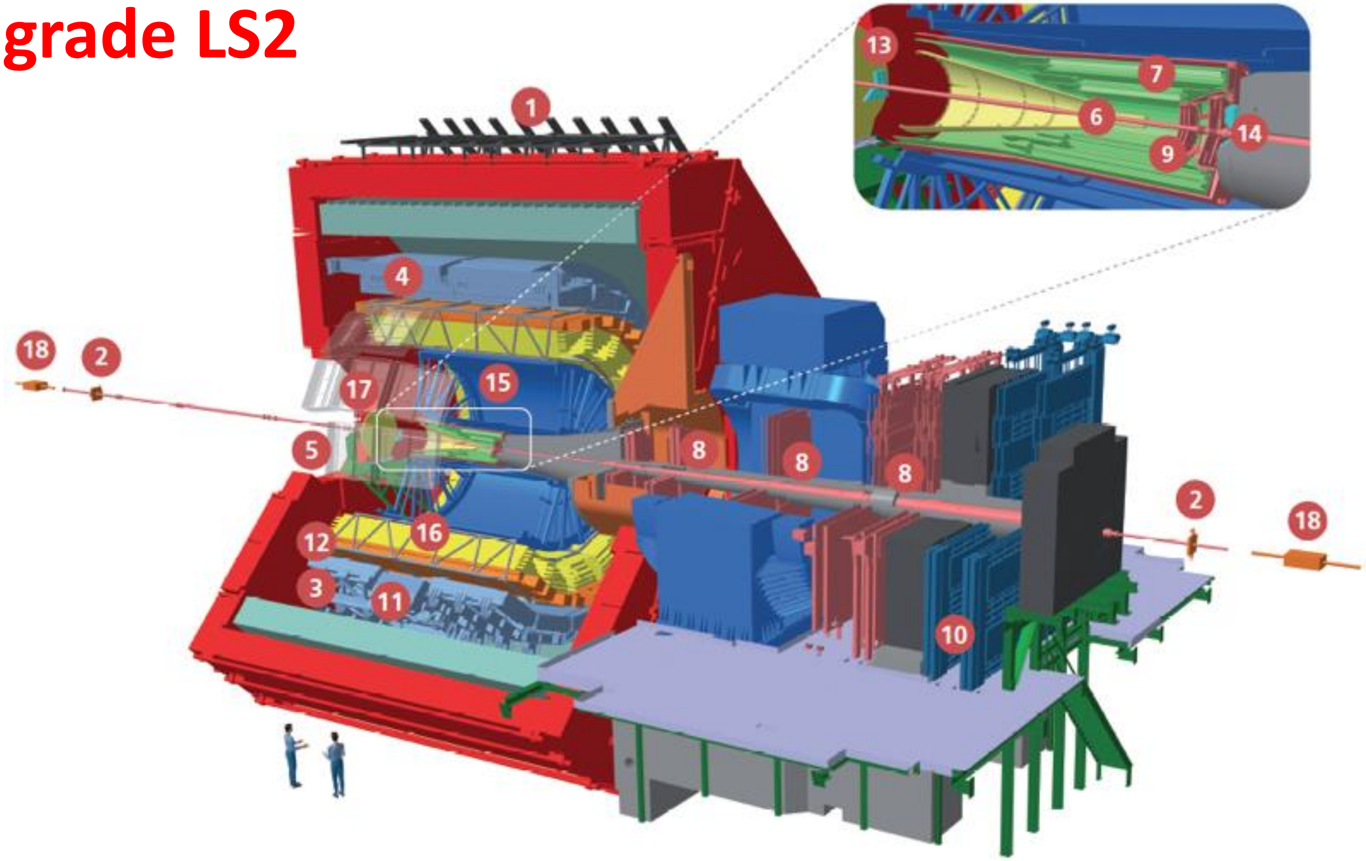
- improved pointing precision
- Monolithic CMOS sensors (ALPIDE) with very small material budget
- Smaller beampipe, 1st layer closer



Muon Forward Tracker (MFT)

- New tracker based on ALPIDE
- Improved MUON pointing precision, promt vs. decay muons

ALICE Upgrade LS2



①	**ACORDE**	ALICE Cosmic Rays Detector
②	**AD**	ALICE Diffractive Detector
③	**DCal**	Di-jet Calorimeter
④	**EMCal**	Electromagnetic Calorimeter
⑤	**HMPID**	High Momentum Particle Identification Detector
⑥	**ITS-IB**	Inner Tracking System - Inner Barrel
⑦	**ITS-OB**	Inner Tracking System - Outer Barrel
⑧	**MCH**	Muon Tracking Chambers
⑨	**MFT**	Muon Forward Tracker
⑩	**MID**	Muon Identifier
⑪	**PHOS / CPV**	Photon Spectrometer
⑫	**TOF**	Time Of Flight
⑬	**T0+A**	Tzero + A
⑭	**T0+C**	Tzero + C
⑮	**TPC**	Time Projection Chamber
⑯	**TRD**	Transition Radiation Detector
⑰	**V0+**	Vzero + Detector
⑱	**ZDC**	Zero Degree Calorimeter

Time Projection Chamber (TPC)

- New readout chambers using GEM technology
- New electronics for continuous readout (SAMPA)

MUON ARM

- New electronics for Muon Chambers (SAMPA)
- New electronics for Muon Trigger

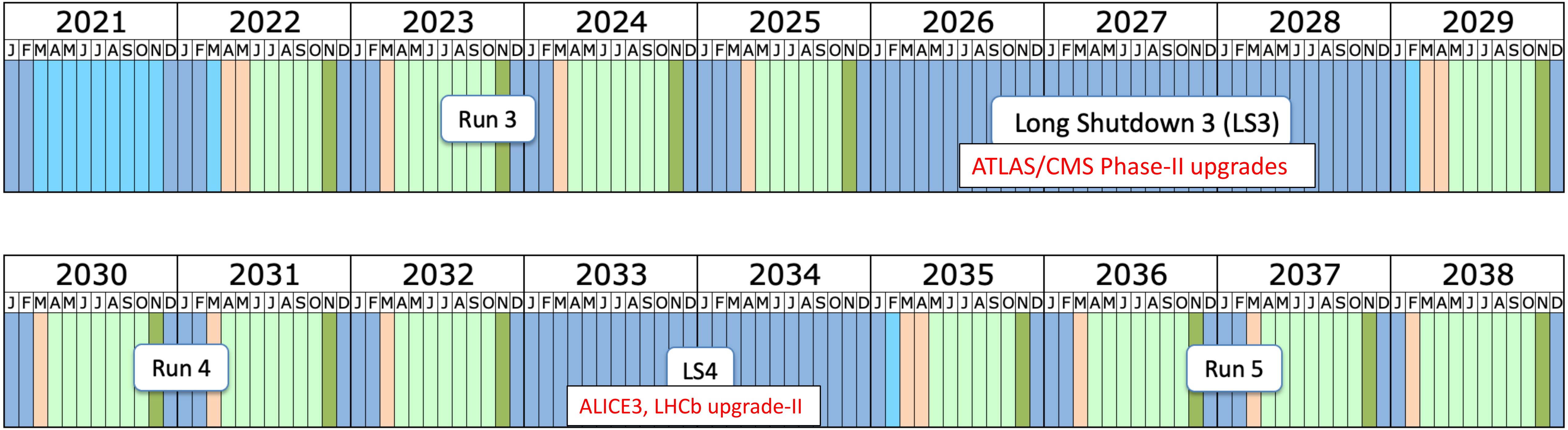
Online Offline (O2) system

- new computing facility
- on line tracking & data compression
- 50kHz PbPb event rate

Common Projects:
Common Readout Unit (CRU) for all detectors (PCI card)
SAMPA common FE chip for TPC and Muon arm

New Trigger Detectors (FIT)
New Central Trigger Processor (CTP)
TOF, TRD new readout electronics
PHOS, EMCAL, CPV, HMPID improvement of readout rate with existing electronics

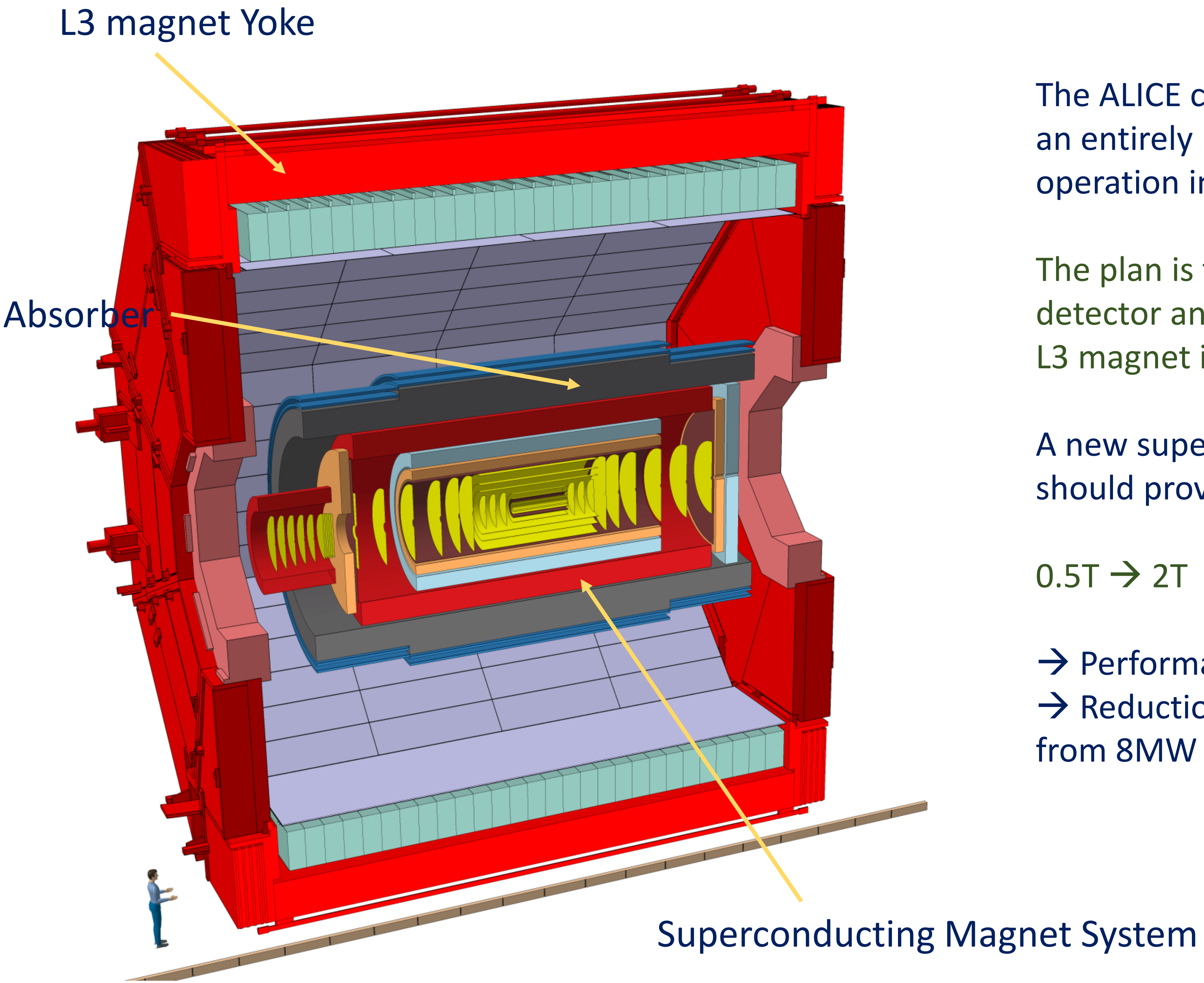
LHC long term plan



Last updated: January 2022

🟦 Shutdown/Technical stop
🟩 Protons physics
🟩 Ions
🟧 Commissioning with beam
🟦 Hardware commissioning/magnet training

The ALICE3 Detector LS4 (2033-2034)



The ALICE collaboration plans to install an entirely new detector during LS4 for operation in Run5 and Run6.

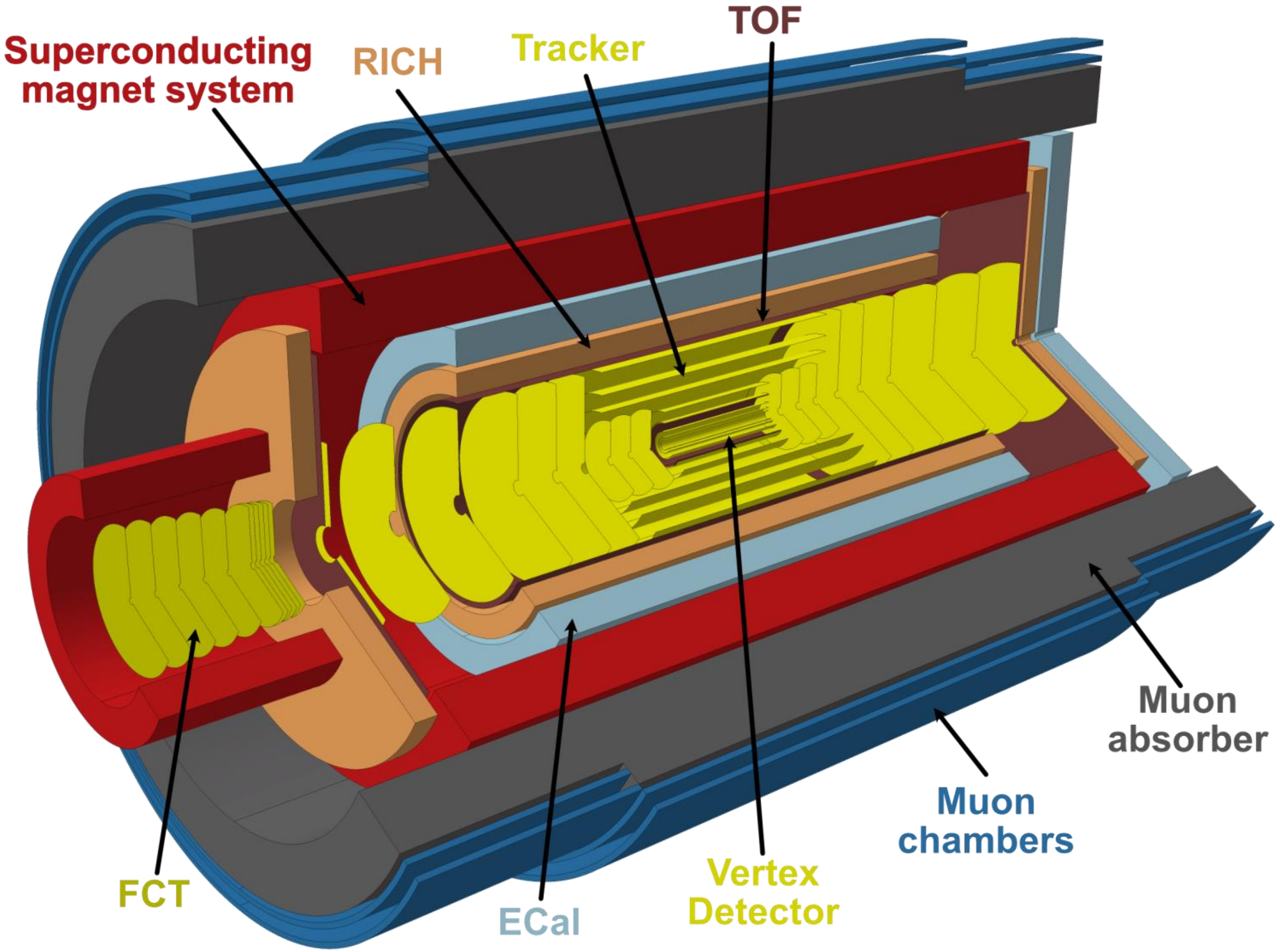
The plan is to remove the entire ALICE detector and just keep the yoke of the L3 magnet in place.

A new superconducting magnet system should provide a field of 2T.

0.5T → 2T

→ Performance increase
→ Reduction of power consumption from 8MW to around 0.5MW.

The ALICE3 Detector



ALICE3 Crossection

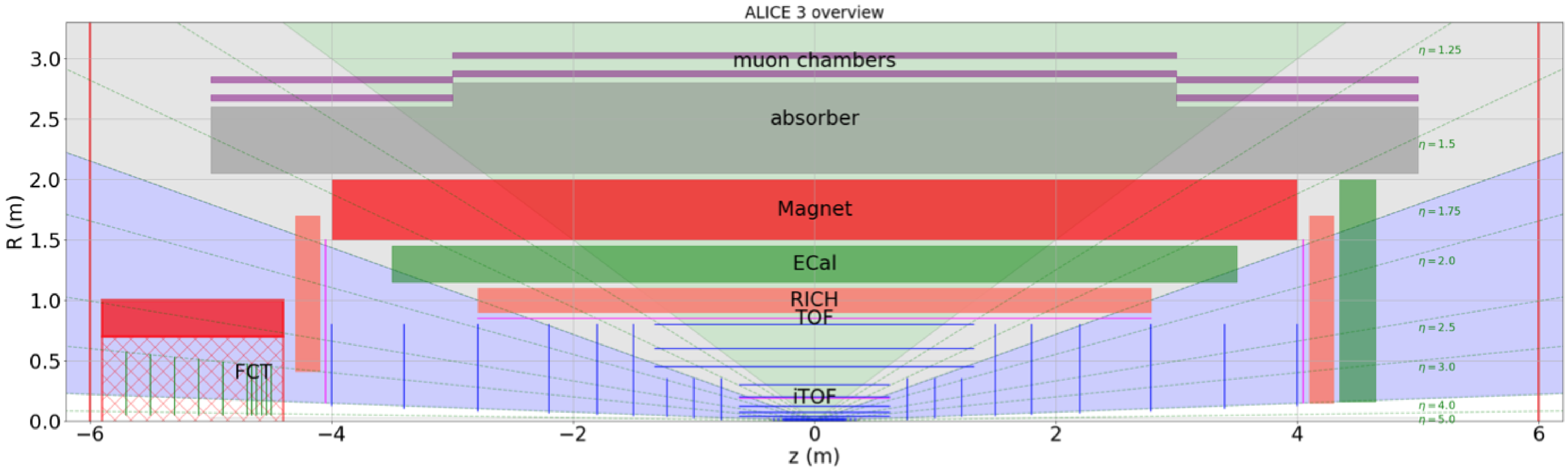


Figure 73: Longitudinal cross section of the ALICE 3 detector: The MAPS-based tracker is complemented by PID detectors (inner and outer TOF, RICH), all of which are housed in the field from a superconducting magnet system. In addition, the elm. calorimeter (ECal), the muon identifier, and the Forward Conversion Tracker (FCT) are shown.

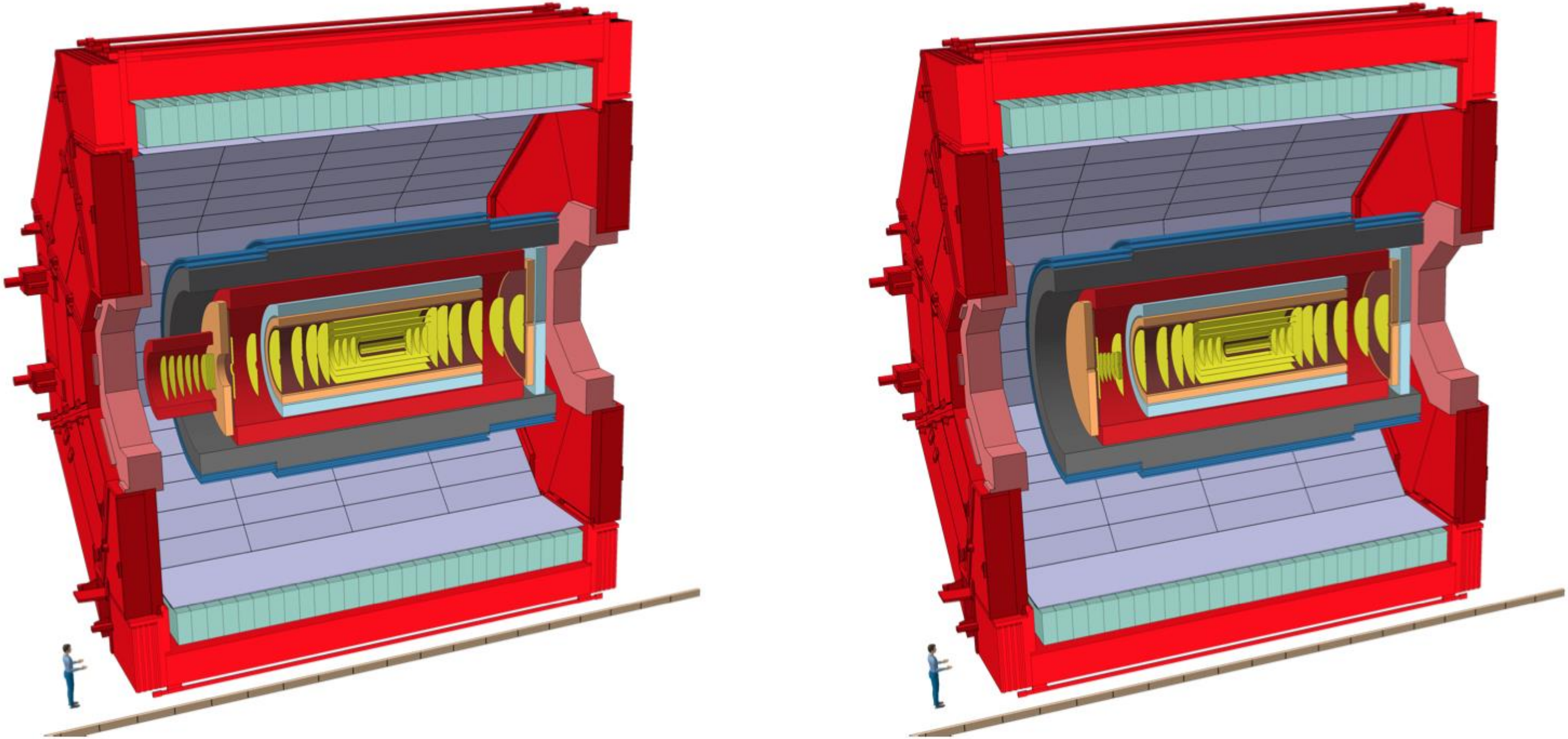


Figure 74: The ALICE3 detector installed inside the L3 magnet yoke. The left figure shows the detector layout with a solenoid and a dedicated dipole magnet for the FCT. The right figure shows the detector layout with a solenoid and two dipoles integrated in the main magnet system.

Solenoid vs. Solenoid+Dipoles

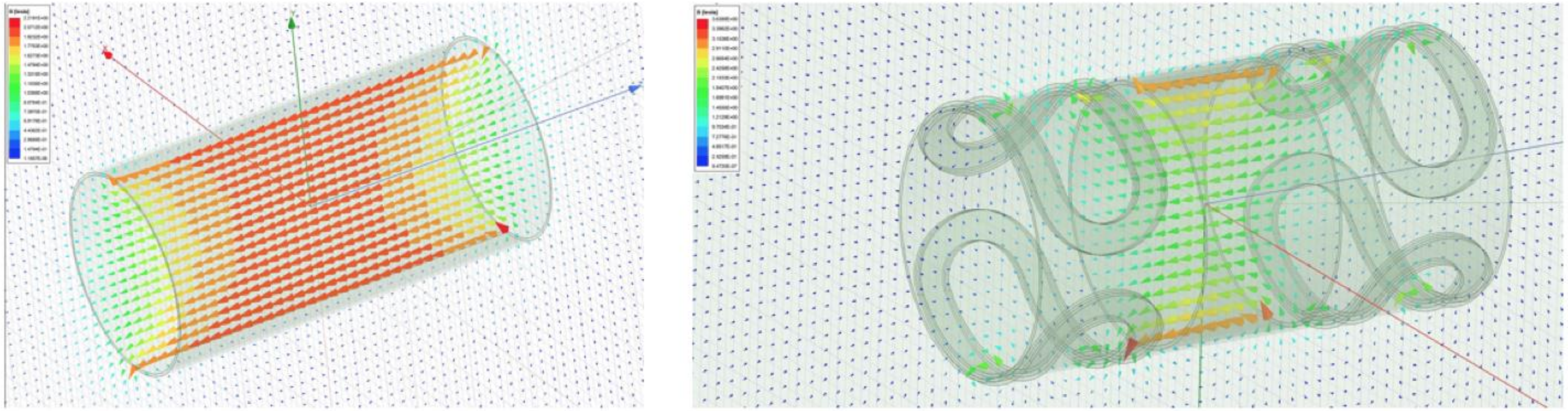
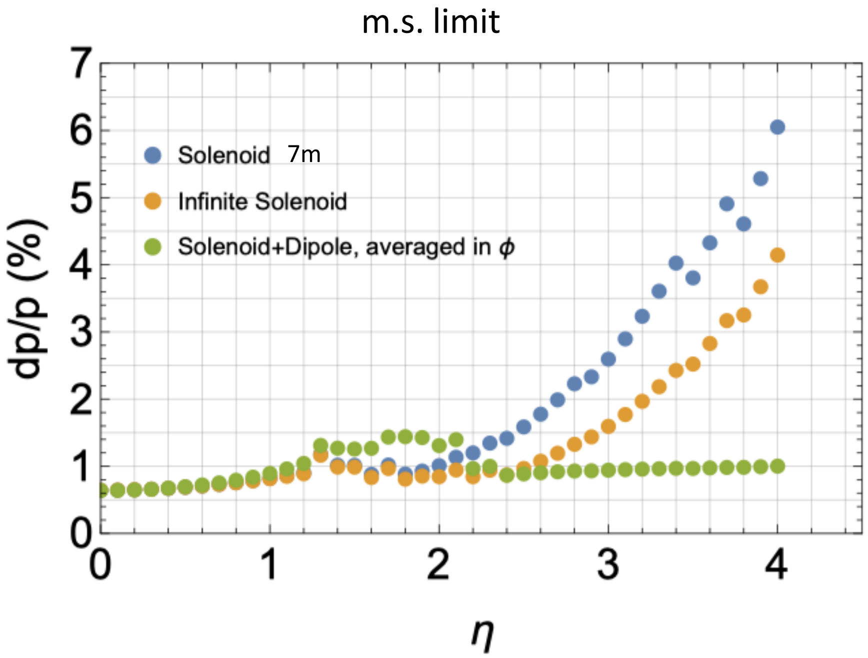
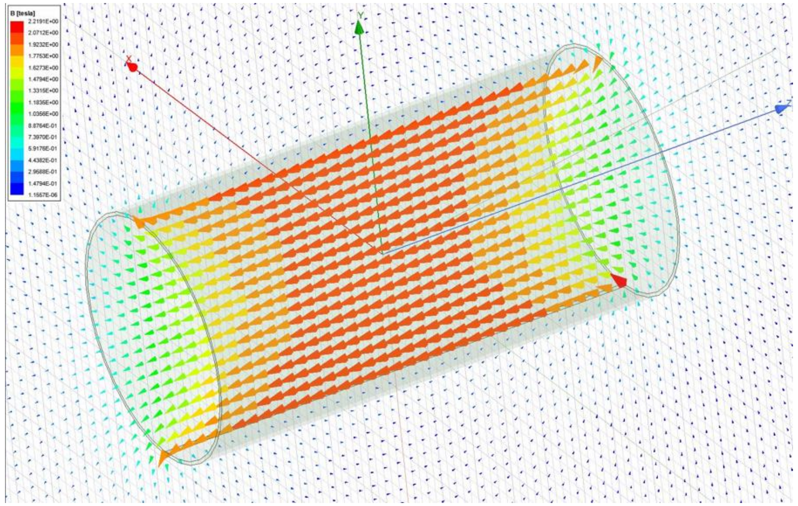


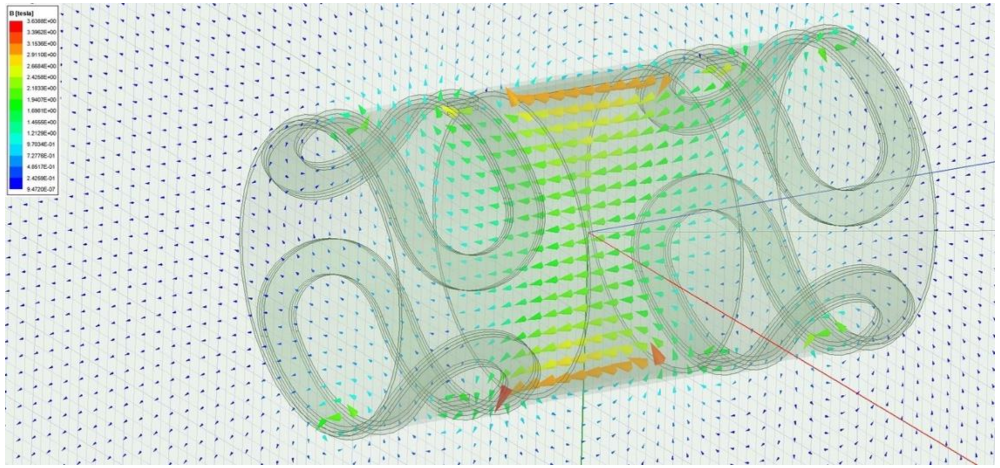
Figure 75: Superconducting magnet system: Solenoid (left) and solenoid + dipoles (right).



	Unit	Solenoid	Solenoid + Dipole
Central magnetic field	T	2	2
Cold mass length	m	7.5	7
Length of coil	m	7.5	2 + 2 + 2
Free bore radius	m	1.5	1.5
Stored magnetic energy	MJ	144	86
Operating current	kA	20	20
Inductance	H	0.6	0.43
Cold mass weight estimate	t	10	20
Vacuum vessel, radial thickness	m	0.5	0.5
Peak field on conductor (excl. self-field)	T	2.5	3.9

Solenoid vs. Solenoid+Dipoles


SC solenoid, 2T


SC solenoid+dipole, 2T + 1Tm

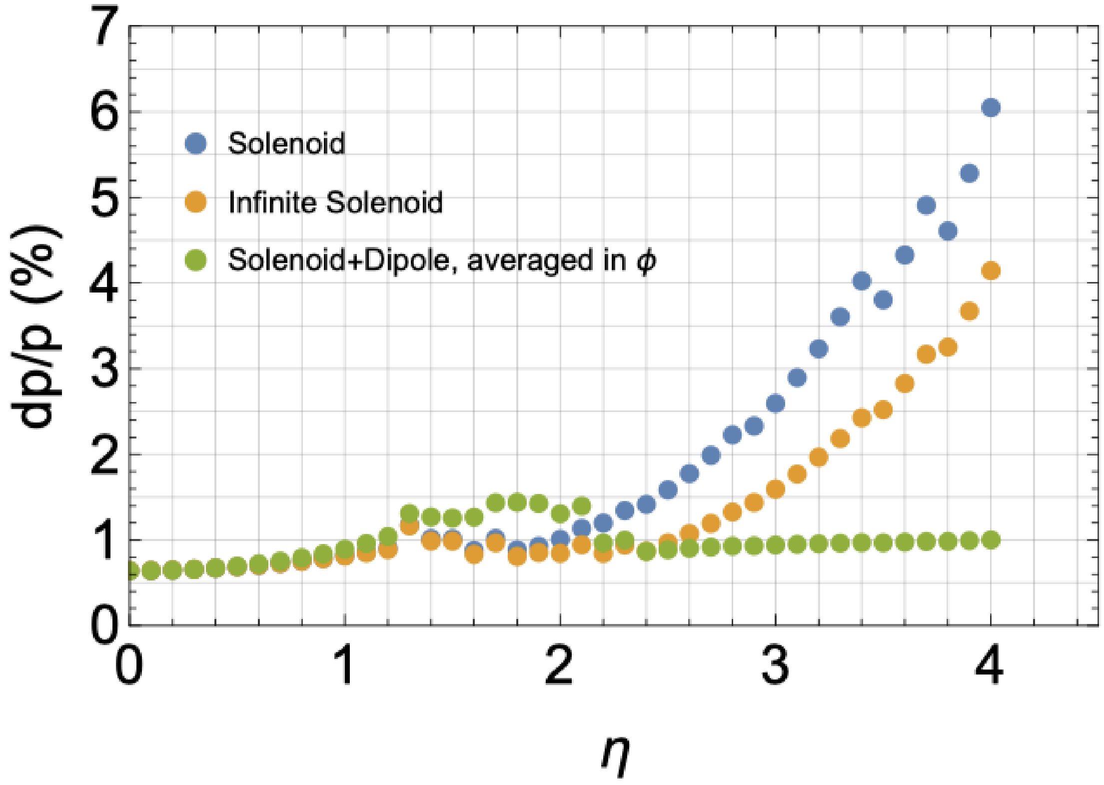
The peak field in the conductor is a key cost driver for superconducting magnets.

Solenoids are very ‘efficient’ i.e. the peak field in the conductor not much larger than the solenoid field.

‘Large open dipoles’ are very ‘inefficient’ – in this case with a peak field for tracking of 0.5T and a peak field in the conductor of almost 4T. This is a big cost driver for dipoles. Since the dipole increases also the peak field in the solenoid it also increases the cost of the solenoid.

For solenoids the forces are ‘easy’ to deal with – the coils want to open, so by winding them inside a cylinder the forces are well contained. For dipoles, especially in presence of a solenoid, there are larger and more complex forces to deal with.

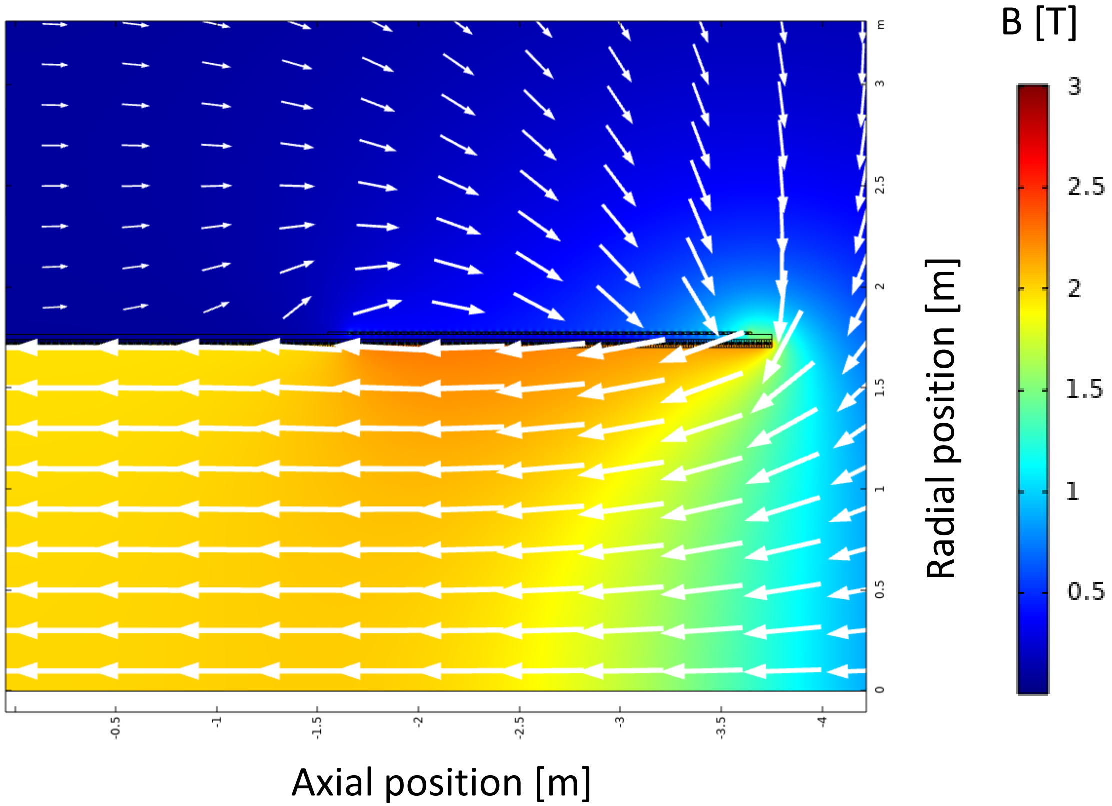
Additional windings at the coil ends

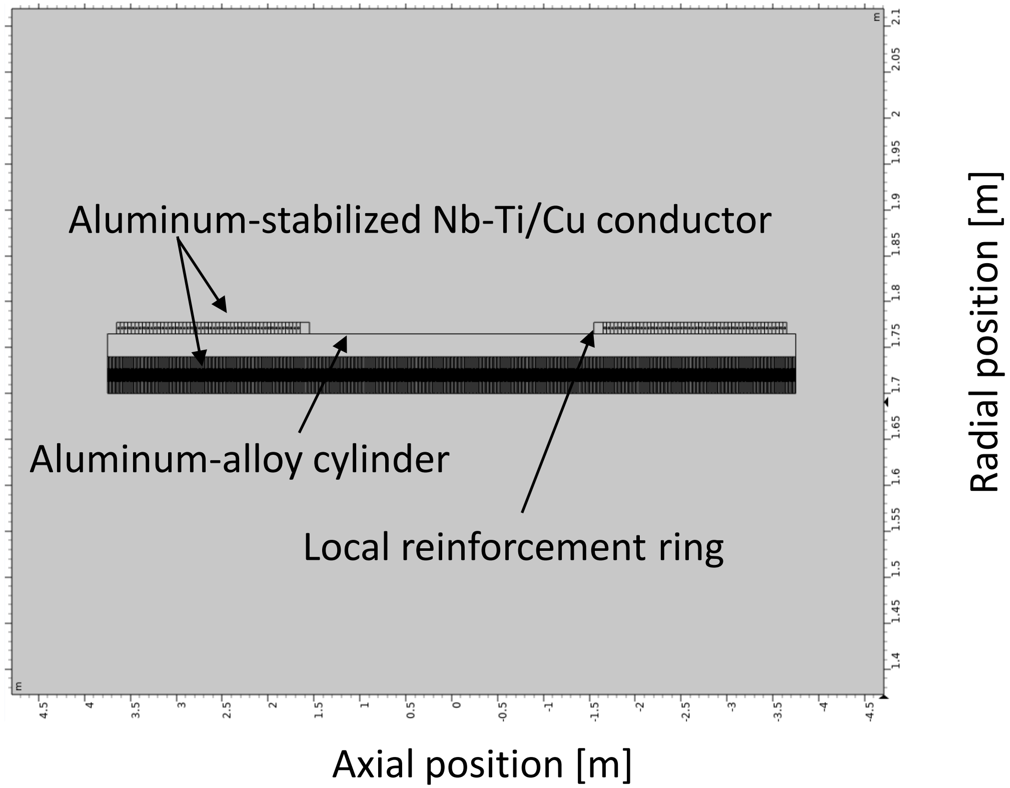


By adding windings at the end of the solenoid one can approximate in ‘infinite’ solenoid, i.e. a solenoid of almost uniform 2T field in it’s entire bore volume.

This would allow to arrive at 1.5% momentum resolution at eta=3, which might be sufficient for the ALICE3 tracking performance.

Geometry




Aluminum-stabilized Nb-Ti/Cu conductor

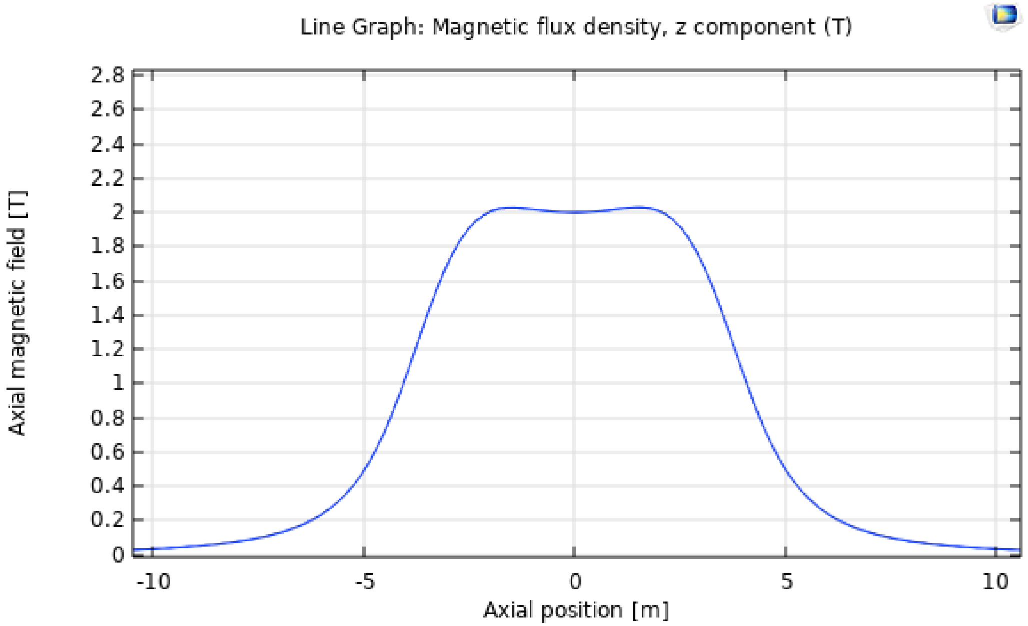
Aluminum-alloy cylinder

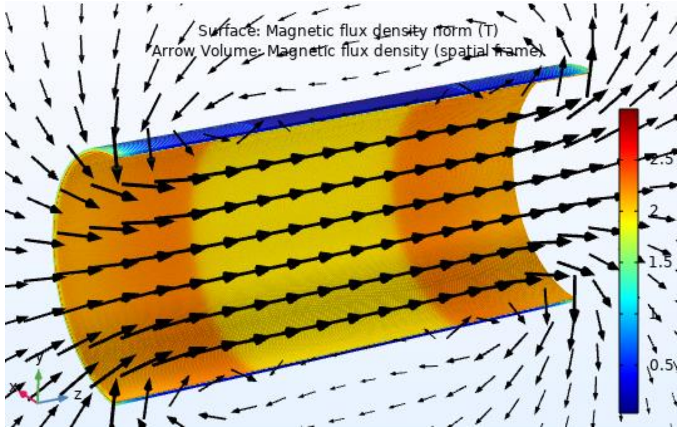
Local reinforcement ring

To achieve enhanced field at the edges: Additional windings at the edges, on the outside of the cylinder

M. Mentink

Overview





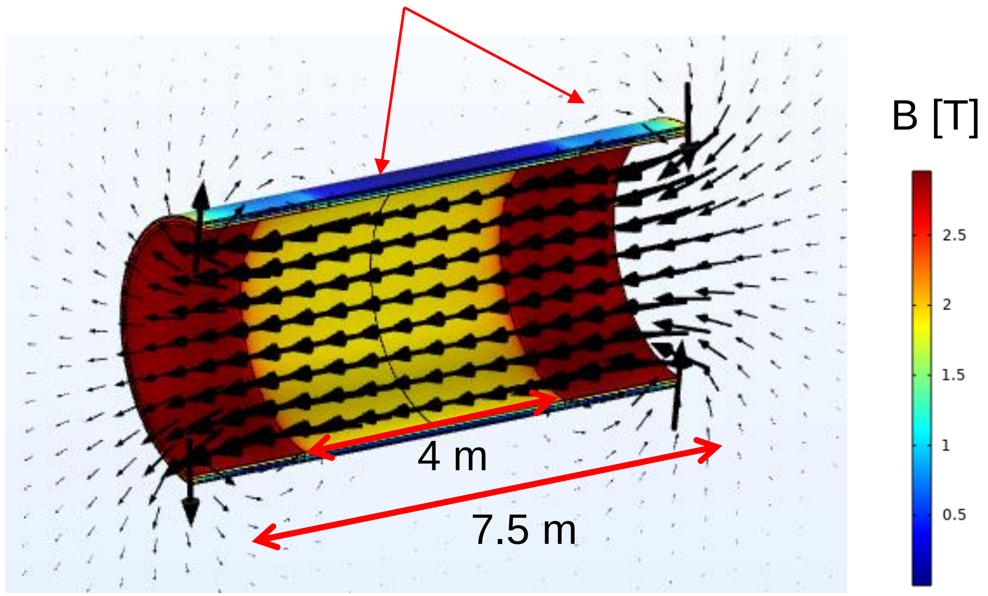
Property	Value
Center field [T]	2
Stored magnetic energy [MJ]	130
Energy density, approximate [kJ/kg]	7.4
Cold mass weight, approximate [t]	18
Conductor length (excluding joints, busbars etc) [km]	7.6
Operating current [kA]	20.4
Inductance [H]	0.62

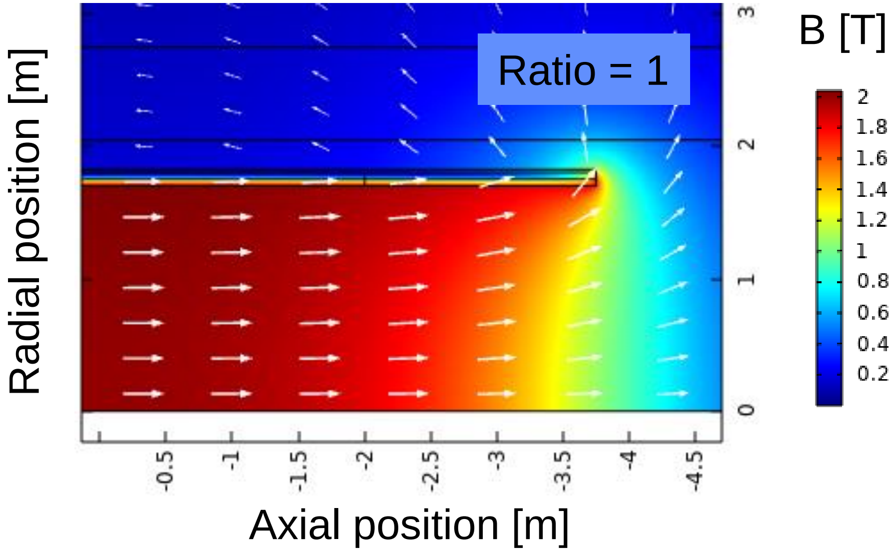
- At 7.6 kJ/kg, the energy density considered here is lower than CMS (CMS = 11.7 kJ/kg), to accommodate the somewhat unusual stress distribution resulting from the extra windings at the edge
- The peak stresses of 74 MPa and peak tensile strain of 0.76% look conservative, and not overly aggressive. Nevertheless, a reinforced conductor (i.e. with nickel-doping or alloying of the aluminum) is needed
- For quench protection options, either quench heaters or energy extraction are feasible, and, given the energy density, quench protection does not look overly challenging

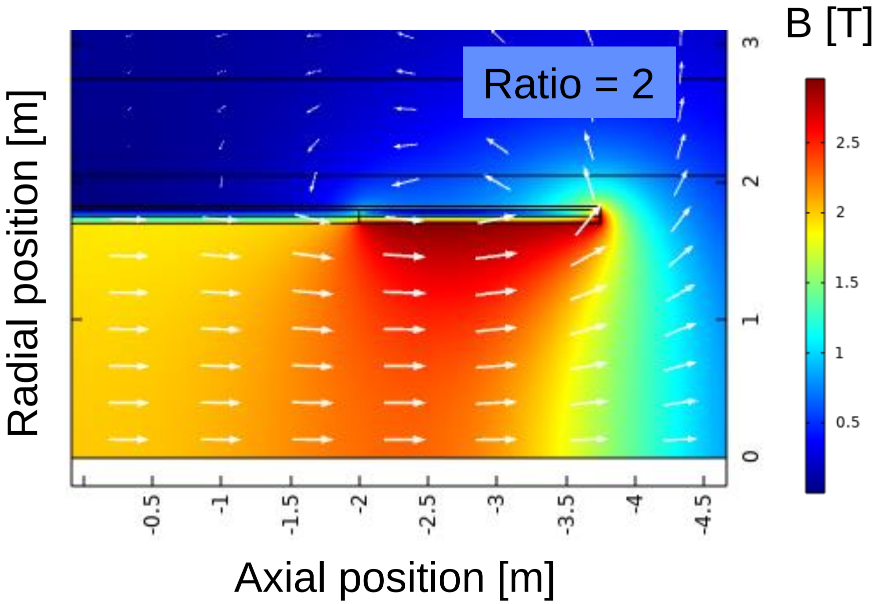
M. Mentink

Alice3, infinite solenoid option, magnetic configuration

Higher current density at edge
(Here: Current ratio = 2)



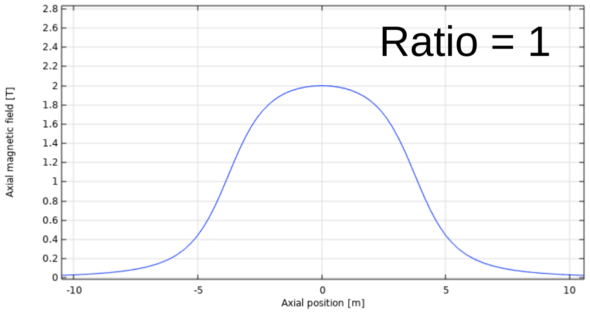


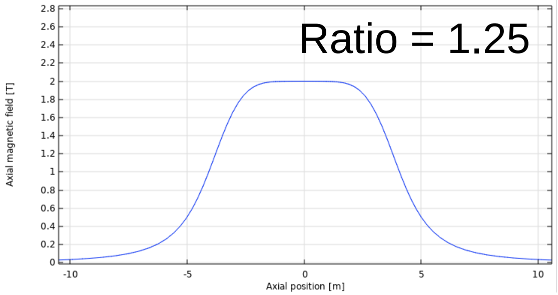


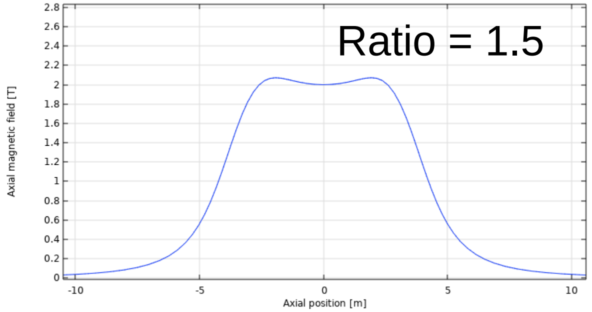
Field along axis

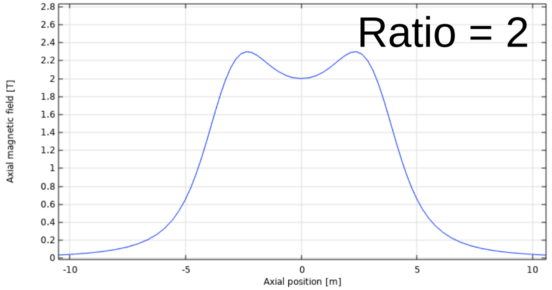
Current ratio between middle and edge windings	Stored magnetic energy [MJ]	Peak field on the conductor, considering homogeneous current density [T]
1	113	2.1
1.25	128	2.2
1.5	144	2.5
2	177	3
3	244	3.8

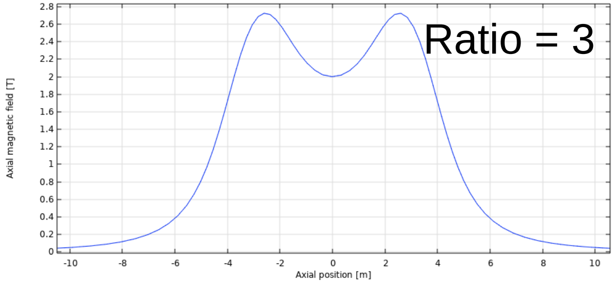
- Ratio = Edge coil current density / Center coil current density, considering an equally thick winding
- In all cases, the overall current density is adjusted so that BCenter = 2 T





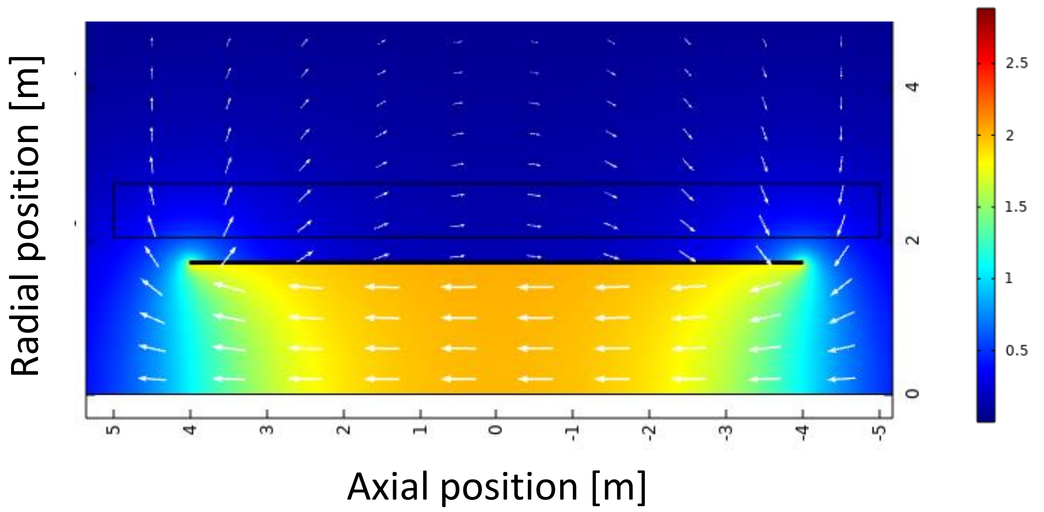




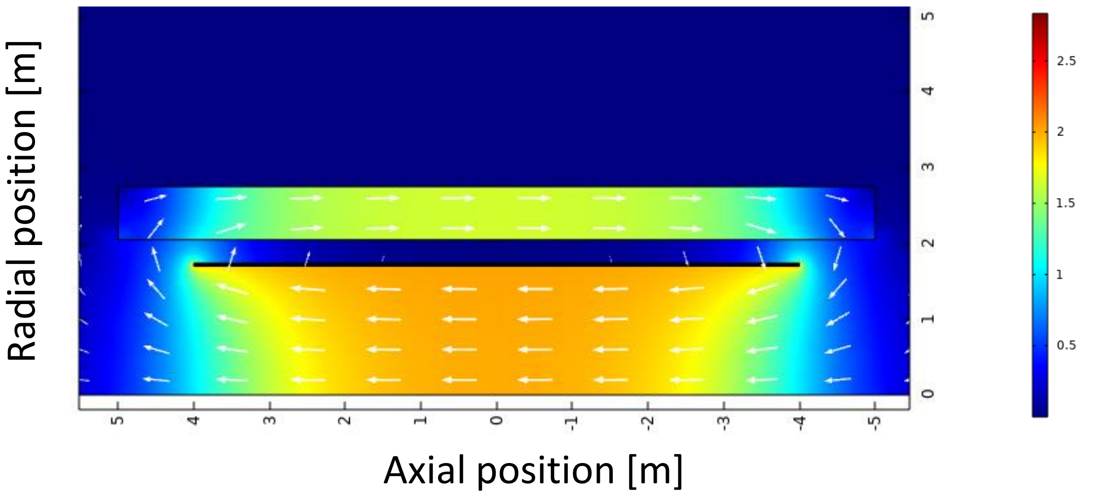


Absorber from magnetic or non-magnetic Iron ?

8 m 2 T solenoid, without iron, U_{Stored} = 117 MJ



8 m 2 T solenoid, with iron, U_{Stored} = 110 MJ



The B-field in the bore is to first order not affected by the magnetic/non-magnetic Iron.

The propagation of the muons through the iron to the detector planes will of course be affected.

Since we are only interested in Muon ID, and since we have a very coarse granularity requirement O(cm) we would not expect a significant performance difference (of course to be verified).

The choice will be made on practical grounds. Present baseline is non magnetic iron.

Conclusion

The ALICE3 detector plans to use a superconducting magnet system for reasons of tracking performance and energy consumption.

Both, a solenoid and a solenoid+dipole magnet system were studied.

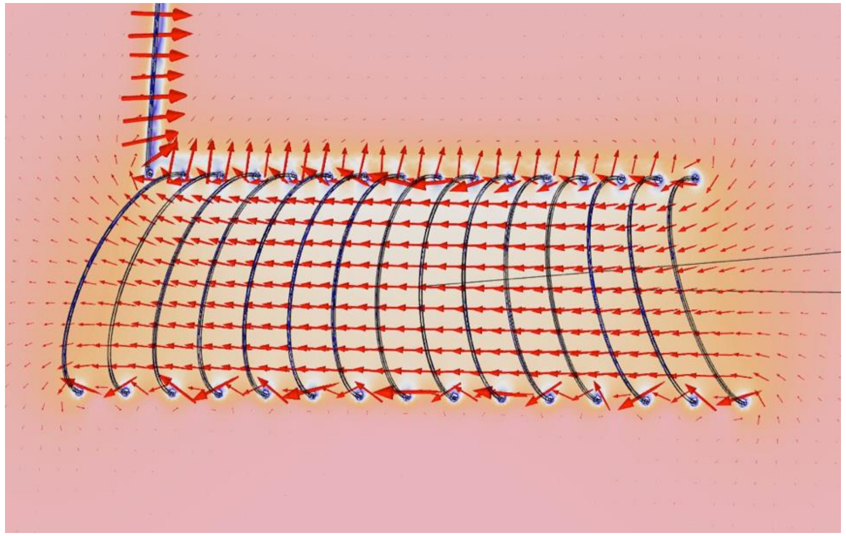
A 2T solenoid of 7m length with additional windings at the ends is used as a baseline at this moment.

The magnet system must be installed in the cavern in July 2033.

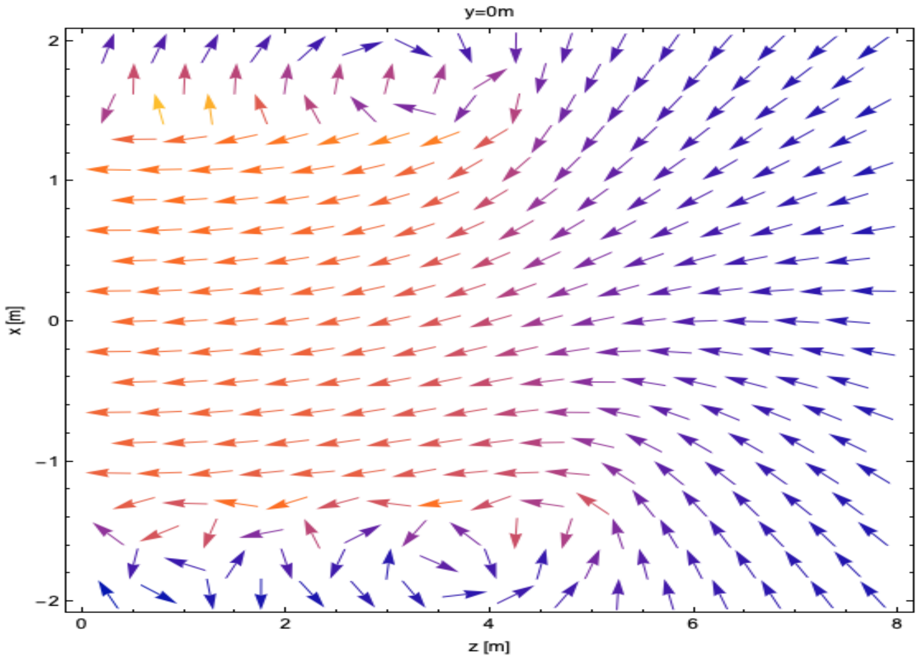
At this moment, the ALICE collaboration is in the process of getting organised for this project.

Backup

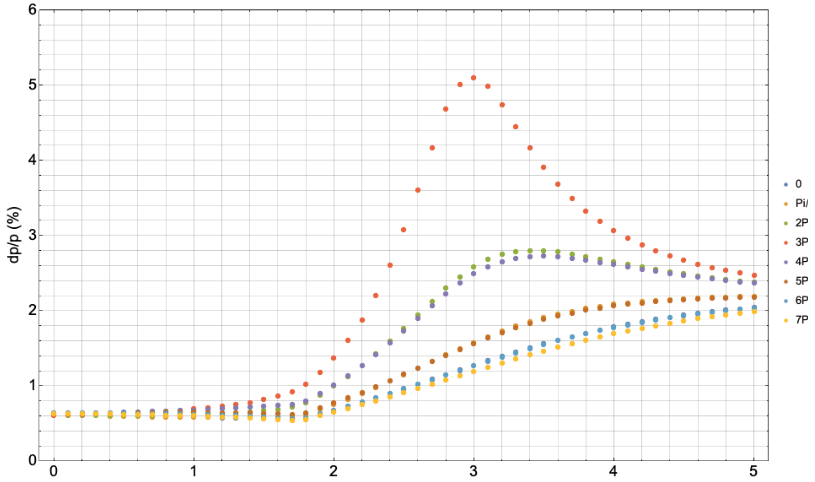
Alternatives, canted solenoid (preliminary)



By continuously inclining the solenoid coils one can produce a dipole component.



11 equidistant layers, 11% X0 for all eta



Preliminary …
Strong dependence
on azimuth

ALICE3 tracker