The ALICE3 detector

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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.
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
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
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 $\geq 10 \text{ nb}^{-1}$ $\Rightarrow 8 \times 10^{10}$ 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. $L = 6 \times 10^{27} \text{ cm}^{-1}\text{s}^{-1}$) continuously or upon a minimum bias trigger.

- Perform online data reduction based on reconstruction of clusters and tracks.

- Improve vertexing and tracking at low $p_T$ $\Rightarrow$ New Inner Tracking System (ITS).

- Improve Muon Performance $\Rightarrow$ 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, prompt vs. decay muons
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

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

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

2021-2038

Run 3
Long Shutdown 3 (LS3)
ATLAS/CMS Phase-II upgrades
Run 4
LS4
ALICE3, LHCb upgrade-II
Run 5

ShUTDOWN/TECHNICAL STOP
PROTONS PHYSICS
IONS
COMMISSIONING WITH BEAM
HARDWARE COMMISSIONING/MAGNET TRAINING

Last updated: January 2022
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.

\[ 0.5T \rightarrow 2T \]

→ Performance increase
→ Reduction of power consumption from 8MW to around 0.5MW.
The ALICE3 Detector
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.
**Figure 75:** Superconducting magnet system: Solenoid (left) and solenoid + dipoles (right).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Solenoid</th>
<th>Solenoid + Dipole</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central magnetic field</td>
<td>T</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Cold mass length</td>
<td>m</td>
<td>7.5</td>
<td>7</td>
</tr>
<tr>
<td>Length of coil</td>
<td>m</td>
<td>7.5</td>
<td>2 + 2 + 2</td>
</tr>
<tr>
<td>Free bore radius</td>
<td>m</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Stored magnetic energy</td>
<td>MJ</td>
<td>144</td>
<td>86</td>
</tr>
<tr>
<td>Operating current</td>
<td>kA</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Inductance</td>
<td>H</td>
<td>0.6</td>
<td>0.43</td>
</tr>
<tr>
<td>Cold mass weight estimate</td>
<td>t</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Vacuum vessel, radial thickness</td>
<td>m</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Peak field on conductor (excl. self-field)</td>
<td>T</td>
<td>2.5</td>
<td>3.9</td>
</tr>
</tbody>
</table>
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.
To achieve enhanced field at the edges: Additional windings at the edges, on the outside of the cylinder.

M. Mentink
Overview

- 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.

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

M. Mentink
Higher current density at edge (Here: Current ratio = 2)
Field along axis

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

- 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?

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% $X_0$ for all $\eta$

Preliminary ...
Strong dependence on azimuth

ALICE3 tracker