ALICE upgrade strategy

The Collaboration prepares a major upgrade for the LHC LS2 (2019-2020)

**Motivation:** QGP precision studies
High precision measurements of rare probes from low to high transverse momentum

**Requirements:**
- Excellent tracking efficiency and resolution at low $p_T$
- Large statistics
- PID capability (even at high rate)
ALICE upgrade strategy

- Target for upgrade programme (LHC Run3+Run4):
  - Pb-Pb luminosity $> 10 \text{ nb}^{-1} \rightarrow 8 \times 10^{10}$ events

- Upgrade detectors, readout systems and online systems to:
  - readout all Pb-Pb interactions at the maximum rate of 50 kHz ($L=6 \times 10^{27} \text{ cm}^{-2}\text{s}^{-1}$) with MB trigger. At present the rate is 500 Hz

- Gain a factor 100 in statistics over the originally approved programme Run1+Run2

- Significant improvement of vertexing and tracking capabilities at low $p_T$ (150 MeV/c)

The new Inner Tracking System (ITS)

TDR endorsed by LHCC

The construction matches the LHC LS2
ALICE: the current setup

Detector:
- Size: 16 x 26 meters
- Weight: 10,000 tons

Collaboration:
- > 1000 Members
- > 100 Institutes
- > 30 countries
ALICE: the current setup

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Size: 16 x 26 meters
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ALICE: the new ITS

DETECTORS USED IN THIS ANALYSIS:
- ITS
- (|K| < 0.9)
- 6 layers of silicon detectors: trigger, tracking, vertex, PID (dE/dx)

Livio Bianchi
WWND 2016
Guadaloupe

ALICE: the new ITS

Size: 16 x 26 meters
Weight: 10,000 tons

Collaboration:
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> 30 countries

Upgrade" of "the "ALICE "Inner" Tracking" System"

Motivations:
- Increase vertex resolution and tracking efficiency
- Increase readout rate capabilities (x100)

To be installed in ALICE in 2020

MAPS
ITS upgrade design objectives

1. Improve impact parameter resolution by a factor of ~3
   • Get closer to IP (position of first layer): 39mm $\Rightarrow$ 23mm
   • Reduce $X/X_0$/layer: $\sim$1.14% $\Rightarrow$ $\sim$ 0.3% (for inner layers)
   • Reduce pixel size: currently 50$\mu$m x 425$\mu$m $\Rightarrow$ O(30$\mu$m x 30$\mu$m)

2. Improve tracking efficiency and $p_T$ resolution at low $p_T$
   • Increase granularity:
     • 6 layers $\Rightarrow$ 7 layers
     • silicon drift and strips $\Rightarrow$ pixels

3. Fast readout
   • readout Pb-Pb interactions at $>100$ kHz and pp interactions at $\sim$ several $10^5$ Hz (currently limited at 1kHz with full ITS)

4. Fast insertion/removal for yearly maintenance
   • possibility to replace non functioning detector modules during yearly shutdown
Fundamental improvement of the impact parameter resolution (left) and tracking efficiency (right) from the old to the new ITS.

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~40 μm at p_T=500 MeV
ITS – Physics Performance

- $\Lambda_c$ ($\tau=60 \, \mu m$) currently inaccessible in Pb-Pb, most promising channel $\Lambda_c \rightarrow pK^+\pi^+$;
- Ability to reconstruct $\Lambda_c \rightarrow$ also $\Lambda_b$ production can be measured from $p_T$ of 5-7 GeV/c.
- Other decay channels and other baryon species (e.g. $\chi_c$) will be investigated.

First measurements of $\Lambda_c$ in Pb-Pb collisions at LHC
### Example: $D^0 \rightarrow K^- p^+$

**Legend:**
- **Current ITS**
- **Upgraded ITS (hybrid MC)**
- **Upgraded ITS (full MC)**

<table>
<thead>
<tr>
<th>Observable</th>
<th>Current, 0.1 nb$^{-1}$</th>
<th>Upgrade, 10 nb$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p_T^{\text{min}}$ (GeV/c)</td>
<td>statistical</td>
<td>uncertainty</td>
</tr>
<tr>
<td>D meson $R_{AA}$</td>
<td>1</td>
<td>10 %</td>
</tr>
<tr>
<td>$D_s$ meson $R_{AA}$</td>
<td>4</td>
<td>15 %</td>
</tr>
<tr>
<td>D meson from B $R_{AA}$</td>
<td>3</td>
<td>30 %</td>
</tr>
<tr>
<td>$J/\psi$ from B $R_{AA}$</td>
<td>1.5</td>
<td>15 % ($p_T$-int.)</td>
</tr>
<tr>
<td>$B^+$ yield</td>
<td>not accessible</td>
<td>3</td>
</tr>
<tr>
<td>$\Lambda_c$ $R_{AA}$</td>
<td>not accessible</td>
<td>2</td>
</tr>
<tr>
<td>$\Lambda_c/D^0$ ratio</td>
<td>not accessible</td>
<td>2</td>
</tr>
<tr>
<td>$\Lambda_b$ yield</td>
<td>not accessible</td>
<td>7</td>
</tr>
<tr>
<td>D meson $v_2$ ($v_2 = 0.2$)</td>
<td>1</td>
<td>10 %</td>
</tr>
<tr>
<td>$D_s$ meson $v_2$ ($v_2 = 0.2$)</td>
<td>not accessible</td>
<td>&lt; 2</td>
</tr>
<tr>
<td>D from $B$ $v_2$ ($v_2 = 0.05$)</td>
<td>not accessible</td>
<td>2</td>
</tr>
<tr>
<td>$J/\psi$ from $B$ $v_2$ ($v_2 = 0.05$)</td>
<td>not accessible</td>
<td>1</td>
</tr>
<tr>
<td>$\Lambda_c$ $v_2$ ($v_2 = 0.15$)</td>
<td>not accessible</td>
<td>3</td>
</tr>
</tbody>
</table>

**Dielectrons**
- Temperature (intermediate mass) | not accessible | 10 %
- Elliptic flow ($v_2 = 0.1$) | not accessible | 10 %
- Low-mass spectral function | not accessible | 0.3 | 20 %

**Hypermultiplets**
- $^3$H yield | 2 | 18 % | 2 | 1.7 %
ITS new layout

12.5 G-pixel camera (~10 m²)
~24,000 pixel chips

7-layer barrel geometry based on MAPS

r coverage: 23 – 400 mm

η coverage: |η| ≤ 1.22
for tracks from 90% most luminous region

3 Inner Barrel layers (IB)
4 Outer Barrel layers (OB)

Material /layer : 0.3% X₀ (IB), 1% X₀ (OB)
ITS Pixel Chip – Architecture Choice

CMOS Pixel Sensor using TowerJazz 0.18μm CMOS Imaging Process

Tower Jazz 0.18 μm CMOS
- feature size 180 nm
- metal layers 6
  ➔ Suited for high-density, low-power
- Gate oxide 3nm
  ➔ Circuit rad-tolerant

- High-resistivity (> 1kΩ cm) p-type epitaxial layer (18μm to 30μm) on p-type substrate
- Small n-well diode (2 μm diameter), ~100 times smaller than pixel => low capacitance
- Application of (moderate) reverse bias voltage to substrate (contact from the top) can be used to increase depletion zone around NWELL collection diode
- Deep PWELL shields NWELL of PMOS transistors to allow for full CMOS circuitry within active area
ITS new layout

ITS layers are (azimuthally) segmented in staves, which are mechanically independent.

Radial coverage 23mm±405mm
Inner Barrel

Space Frame total weight 1.5 gr

Length 290 mm

Mean \( X/X_0 = 0.282\% \)
Inner Barrel: full-scale prototype
Outer Barrel

Material budget: ~ 0.8 %

Length 1500 mm

Space Frame total weight 30 gr

Mean $X/X_0 = 0.816\%$
Flexible Printed Circuit (FPC) interconnection

Laser soldering machine
(Dr. Mergenthaler GMBH)

Laser soldering

2 Layers, Vacuum deposition

Coverlay
Metal
Polyimide
Metal
Coverlay

Chip

20 μm
25 μm
75 μm
25 μm
20 μm
50 μm
Flux-less soldering of 200 μm diameter Sn/Ag (96.5/3.5) balls (227 °C melting T) in vacuum (<10^{-1} mbar)

IR diode laser, 976 nm, 25 W, 50 μm focal length, 250 μm beam spot size

Laser power modulated by pyrometer, programmable T profile ensures precise limitation of heating

Solder provides both electrical and mechanical connection

Pre-melting? Conductive glue? Wire-bonding? ... possible options
Flexible Printed Circuit (FPC) interconnection

Optical and electrical inspection together with the quality of metallization is according to required spec.

Laser Soldering not mature enough to guarantee an adequate yield.

Many issues were solved:
- Quality of the metallization of FPC VIAs
- Excessive warping of pixel chip
- Assembly jigs out of tolerance

Yield continues to be below requirements:
=> too often “cold” soldering or partial wetting of the pad.
New baseline: wire bonding

- The chip is glued on the electrical substrate (FPC)
- Electrical interconnection to the FPC using standard wedge (Al) wire bonding through the FPC VIAs

Tests with pALPIDE-3 single-chip HIC
- 5 assemblies with 25µm Al wire and standard wedge tool (Bari)
- 1 assembly with 25µm Al wire and deep access wedge tool (Trieste)
- Results: all working according to specs
Responsibilities and schedule

- Test Chip
- Module Assembly & Test
  - CERN
  - Bari
  - Strasbourg
  - Liverpool
  - Pusan
  - Wuhan
- Stave Assembly & Test
  - CERN
  - Frascati
  - Torino
  - Daresbury
  - Nikhef
  - LBNL
- Detector Barrel Assembly & Test
  - CERN

Chip series test @ Seoul

2015
- Completion of R&D, production and construction tests

2016

2017
- Production, integration and commissioning at surface

2018

2019

2020
- Installation in ALICE
pALPIDE Characterization

Intensive test beam campaign:

- PS: 5-7 GeV $\pi^-$
- SPS: 120 GeV $\pi^-$
- PAL (Korea): 60 MeV $e^-$
- BTF (Frascati): 450 MeV $e^-$
- DESY: 5.8 GeV $e^+$
- SLRI (Thailand): 1.2 GeV

Scan of main parameters $\rightarrow$ ~ 200 settings

Irradiation studies at: Legnaro, Louvain La Neuve, Prague, PSI, LBNL
Test Beam: ALPIDE-3

Efficiency and fake hit rate

\[ \lambda_{\text{fake}} \ll 10^{-5} \text{/ event/pixel and } \varepsilon_{\text{det}} > 99\% \text{ over a wide threshold range} \]

Chip of 50 \( \mu \text{m} \) thick: 3 non irradiated and 3 irradiate with neutrons to \( 10^{13} \) (1MeV \( n_{eq} \))/cm\(^2 \) \( \rightarrow \) excellent performance also after the irradiation
Test Beam: ALPIDE-2

Spatial resolution and cluster size

Spatial point resolution (including tracking error $\sim 3 \, \mu m$) $< 5 \, \mu m$

Chip of 50 $\mu m$ thick: 3 non irradiated and 3 irradiate with neutrons to $10^{13}$ (1MeV $n_{eq}$)/cm$^2$ $\rightarrow$ excellent performance also after the irradiation
Spatial resolution and cluster size

epi = 30 μm, V_{BB} = -6V, spacing = 4 μm

Space point resolution (including tracking error ~3 μm) < 5 μm

Chip of 50 μm thick: 3 non irradiated and 3 irradiate with neutrons to $10^{13}$ (1MeV n_{eq})/cm$^2$ → excellent performance also after the irradiation
Conclusions

- ALICE is going to extend his already excellent capabilities to measure high-energy nuclear collisions at the LHC
- The ITS plays a key role in the upgrade in order to achieve precision measurements of rare probes over a large kinematic range

The new ITS represents one of the most advanced solid state detectors

- 7 layers of 24,000 monolithic CMOS pixel sensors over 10 m² surface
- An intensive R&D program is presently being completed
- The production will start at the beginning of 2017. The detector will be ready for the LHC LS2 in 2019-2020