Upgrade of the ALICE Inner Tracking System (ITS)

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on behalf of the ALICE collaboration
Outline

• ALICE ITS upgrade requirements and expected performance
• Pixel chip technology and prototype performance
• Module construction for inner and outer barrel
• Summary
ALICE upgrade program

The ALICE collaboration prepares a major upgrade for LHC LS2 (2019-2020)

Motivation: QGP precision study
High precision measurement of rare probes from high to very low transverse momentum.

Requirements:
• Excellent tracking efficiency and resolution at low $p_T$
• Large statistics with minimum bias trigger to gain a factor 100 over present program
  ▪ Pb-Pb recorded luminosity $\geq 10 \, \text{nb}^{-1}$ plus p-p and p-A data
• Preserve PID capabilities at high rate

Strategy:
• Readout all Pb-Pb interactions at max. rate (50 kHz) with minimum bias trigger
  ▪ Upgrade of the detector readout and online and offline systems
• Large improvement of vertexing and tracking capability
  ▪ New Inner Tracking System (ITS) and Muon Forward Tracker (MFT)
ALICE upgrade

TPC: readout with GEM’s
See talk by C. Garabatos Cuadrado

Online and offline systems (O²)

Readout electronics: TOF, TRD, MUON, ZDC, EMCal, PHOS

Present ITS:
6 layers of silicon detectors
(hybrid pixel, drift, strips)

New ITS: installation during LS2
ALICE ITS upgrade design requirements

**Improve impact parameter resolution** by a factor of ~3 in (r-\(\phi\)) and ~5 in (z)
- Get closer to IP: 39 mm \(\rightarrow\) 21 mm (layer 0)
- Reduce beampipe radius: 29 mm \(\rightarrow\) 18.2 mm
- Reduce material budget: 1.14 \% \(X_0\) \(\rightarrow\) 0.3 \% \(X_0\) (inner layers)
- Reduce pixel size: (50 \(\mu m\) x 425 \(\mu m\)) \(\rightarrow\) O(30 \(\mu m\) x 30 \(\mu m\))

**High standalone tracking efficiency and \(p_T\) resolution**
- Increase granularity and radial extension \(\rightarrow\) 7 pixel layers

**Fast readout**
- Readout of Pb-Pb interactions at 50 kHz (presently 1kHz) and 400 kHz in p-p interactions

**Radiation levels (layer 0)**
- TID: 2.7 Mrad, NIEL: 1.7 \(\times\) 10\(^{13}\) 1 MeV \(n_{eq}\) cm\(^{-2}\) (safety factor 10)

**Fast insertion/removal for yearly maintenance**
- Possibility to replace non functioning detector modules during yearly shutdown
**ALICE ITS upgrade tracking performance**

**Impact parameter resolution**

Improved impact parameter resolution

**Track reconstruction efficiency**

High standalone tracking efficiency

P. Riedler, CERN for the ALICE collaboration
Physics performance studies - examples

- $\Lambda_c$ ($c\tau=60\,\mu m$) 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. $\Xi_c$) will be investigated.

First measurements of $\Lambda_c$ in Pb-Pb collisions at LHC
Physics performance studies - examples

Beauty performance with new ITS

Invariant mass distribution for (eeK^±) in 0-2 GeV/c.

Nuclear modification factor of beauty mesons via displaced J/ψ at forward rapidity, shown together with the expected performance in the displaced D^0 channel at central rapidity.

P. Riedler, CERN for the ALICE collaboration
New ALICE ITS

7 layers based on Monolithic Active Pixel Sensors (MAPS)

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

$\eta$ coverage $|\eta| \leq 1.22$
for tracks from 90% most luminous region

$\sim 10 \text{ m}^2$

12.5 G pixel
ALICE ITS pixel technology

MAPS produced in CMOS 0.18 µm process by TowerJazz

- Deep p-well allows to have PMOS and NMOS inside the pixel cell
- High resistivity epi layer
- Chip size: 15 mm x 30 mm, thinned to 50 µm
- Pixel pitch ~ 30 µm
- Spatial resolution < 5 µm

Cluster Signal [ADC]
0 200 400 600 800 1000
0.000 0.001 0.002 0.003 0.004 0.005 0.006
Cluster Signal (5x5), Explorer-1, A1-E2, Sector 5

3.2 GeV/c electron test beam, pixel size 20 µm x 20 µm
J. Van Hoorne, PoS (TIPP2014) 125
ALPIDE prototype chip (baseline)

- Pixel size: 29 x 27 µm² with low power front-end (40 nW)
- Asynchronous sparsified digital readout
- Power density ~20 mW/cm² (OB) to 40 mW/cm² (IB)
- Minimized inactive area on the edge due to pads-over-matrix design (~ 1.1 mm x 30 mm)
- Full size prototypes produced in 3 engineering runs (ALPIDE1-3) on different epitaxial wafers
- Partial depletion of the sensitive region due to back bias → charge collection by drift
- Extensive tests before and after irradiation

In the course of the R&D a prototype chip based on rolling shutter readout (MISTRAL) has been developed and will be submitted in Q4/2015 (backup).
ALPIDE prototype chip – experimental results

ALPIDE2 testbeam measurement, 25 μm epitaxial layer, -6V back bias, before and after irradiation

- Efficiency > 99.5% and fake hit rate << 10^{-5} over wide threshold range
- Excellent performance also after irradiation to 10^{13} (1MeV n_{eq}/cm^2)
ALPIDE prototype chip – experimental results

ALPIDE2 testbeam measurement, 30 µm epitaxial layer, -6V back bias, before and after irradiation

- Space point resolution <5 µm over wide threshold range
- Excellent performance also after irradiation to $1.7 \times 10^{13}$ (1MeV $n_{eq}$)/cm$^2$
ITS Inner Barrel (IB)

4.1.1 Inner Barrel Stave

Each IB Stave will be instrumented with one HIC, which consists of nine Pixel Chips in a row connected to the FPC, hence covering a total active area of 15 mm $\times$ 270.8 mm (Tab. 1.1) including the 100 $\mu$m gap between adjacent chips along $z$. The interconnection between Pixel Chips and FPC is achieved via laser soldering, described in Sec. 4.4. The HIC is glued to the Cold Plate with the Pixel Chips facing it in order to maximise the cooling efficiency. Figure 4.1 shows a schematic layout of the IB Stave. An extension of the FPC, not shown in Fig. 4.1, connects the Stave to a patch panel that is served by the electrical services entering the detector from one side only. A mechanical connector at each end of the Stave allows the fixation and alignment of the Stave itself on the end-wheels, as described in Chap. 5. The inlet and outlet of the closed-loop cooling circuitry are located at the same end of the Stave because also the cooling is served only from the same side as all other services.

The prototyping of the IB Stave is well advanced. Figure 4.2 shows the detail of the end-Stave with and without the mechanics connector and the cooling ducts.

Material budget

The design of the Stave accounts for the tight requirement on the material budget, which is limited to 0.3% $X_0$. Table 4.1 reports the estimated contributions of the IB Stave to the material budget.

A detailed study of the material distribution across the Stave has been performed after the optimisation of each component. In Fig. 4.3 the azimuthal distribution of the Layer 0 material traversed by the particles at $\phi = 0$ is shown. Neighbouring Staves are partially superimposed to ensure the detector hermeticity. The highest peaks correspond to the overlap of the reinforced

- 3 layers – 48 staves
- Radial coverage: 21 – 39 mm
- z-length: 270 mm (9 chips per stave)
- 50 $\mu$m thin silicon chips, 2 layer Al/polyimide flex, carbon fiber space frame and cold plate with integrated polyimide cooling ducts
Inner Barrel/Outer Barrel Chip-Flex Connection

- Data and signal connections of each chip connected via solder balls (laser soldering) to 2-layer kapton/Aluminum flex cable

- Laser soldering adapted for ALICE ITS: flux-less soldering of ~200 μm diameter Sn/Ag(96.5/3.5) balls

IB stave: first electrical tests with chips soldered onto flex ongoing
ITS Outer Barrel

- 2 double layers – 144 staves
- Radial coverage: 194 – 405 mm
- z-length: 843 and 1475 mm
- 1692 Modules of 2 x 7 chips

Staves consist of **two rows of modules**

Full stave assembly procedure tested:

Carbon fibre space frame positioning onto modules

OB prototype module with pad chips: silicon chip side
• The upgrade of the ALICE ITS will provide excellent tracking capabilities, significantly improving the impact parameter resolution and reading out Pb-Pb events at 50 kHz interaction rate.

• The new ITS will help to extend the physics reach to new observables and to improve the accuracy of existing ones.

• The new, 10 m² large silicon detector is entirely based on monolithic silicon pixel detectors.

• An intensive R&D program is presently being completed and production will start in the second half of 2016.
ALICE upgrade presentations at QM 2015

Talks:
• C. Garabatos Cuadrado, *The ALICE TPC: from wires to GEMs*

Posters:
• E. Bartsch, *Ion backflow and energy resolution in stacks of four GEM detectors for the upgrade of the ALICE TPC*
• J. Harris, *Combined Gas Electron Multipliers and MicroMeGas as Gain Elements in a High Rate Time Projection Chamber*
• M. Hirano, *Detector R&D of the Forward Calorimeter with PAD readout for the ALICE upgrade*
• H. Ljunggren, *Performance simulation studies for the ALICE TPC GEM Upgrade*
• A. Uras, *Prospects for ALICE with the Muon Spectrometer Upgrade and the new Muon Forward Tracker*
• G. Tambave, *Upgrade of ALICE TPC and its readout electronics for RUN3 in 2018*
• W. Trzaska, *Performance of Fast Interaction Trigger for ALICE Upgrade*
• S. Yano, *The Muon Forward Tracker performance for the low mass dimuon physics*
• C. Zhang, *FoCal - a high-granularity electromagnetic calorimeter for forward direct photon measurements at LHC*
Backup
ALICE ITS pixel chip requirements

- Chip size: 15 mm x 30 mm
- Sensor thickness: 50 µm
- Spatial resolution: 5 µm
- Detection efficiency: >99 %
- Fake hit rate: < 10^{-5} evt^{-1} pixel^{-1}
- Integration time: < 30 µs
- Power density: < 300 mW/cm² (IB), < 100mW/cm² (OB)
- Operation temperature: 20-30°C
- TID: 2.7 Mrad (IB, layer 0)
- NIEL: 1.7 x 10^{13} 1 MeV n_{eq} cm^{-2} (IB, layer 0)
IB material budget

Inclination angle: 17.42°
Overlap with neighbouring stave

Mean X/X₀ = 0.302%

Mean X/X₀ = 0.346%
Present ALICE Performance

Limitations:

- Charmed hadrons difficult for $p_T \to 0$ (background is too large)
- Resolution not sufficient for charmed baryons, $\Lambda_c (c\tau \sim 60 \mu m)$ impossible in Pb-Pb collisions, at the limit in pp (only high $p_T$)
- $\Lambda_b$ impossible in Pb-Pb collisions (insufficient statistics and resolution)
- Indirect B measurement via electrons, B/D separation difficult, especially at low $p_T$ (e PID + vertexing)

ALICE ITS upgrade secondary vertex resolution

$D^0 \rightarrow K\pi^+$ secondary vertex position resolution
→ large improvement with upgraded ITS

$D^0 \rightarrow K\pi^+$ secondary vertex position resolution
→ large improvement with upgraded ITS
Laser Soldering

- **Industrial technique adapted for ALICE ITS**

- **Flux-less soldering** of ~200 mm 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 mm focal length, 250 mm beam spot size

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

- **Soldering mask** (in Macor® or Rubalit ®) used to push FPC on chip and guide soldering balls inside FPC vias

- Solder provides **electrical and mechanical connection** → no glue