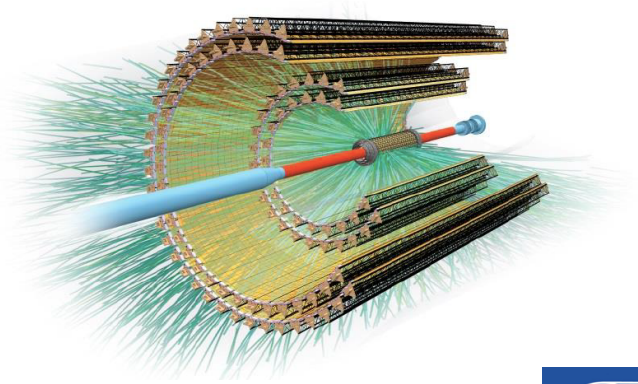
QUARK MATTER 2015

The XXVth International Conference on Ultrarelativistic Nucleus-Nucleus Collisions

Upgrade of the ALICE Inner Tracking System (ITS)

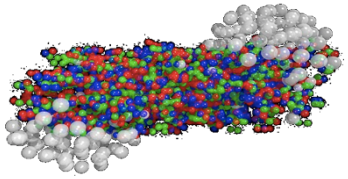


P. Riedler, CERN
Switzerland
on behalf of the ALICE collaboration

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



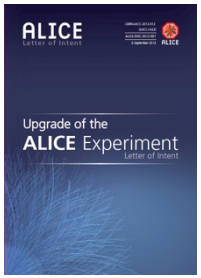
The ALICE collaboration prepares a major upgrade for LHC LS2 (2019-2020)

Motivation: QGP precision study

High precision measurement of rare probes from high to very low transverse momentum.

Requirements:

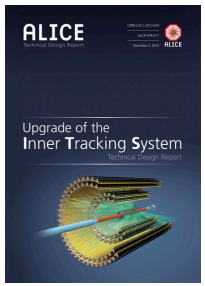
- Excellent tracking efficiency and resolution at low p_T
- Large statistics with minimum bias trigger to gain a factor 100 over present program
  - Pb-Pb recorded luminosity ≥10 nb^{-1} plus p-p and p-A data
- Preserve PID capabilities at high rate



LoI: Sept. 2012

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)

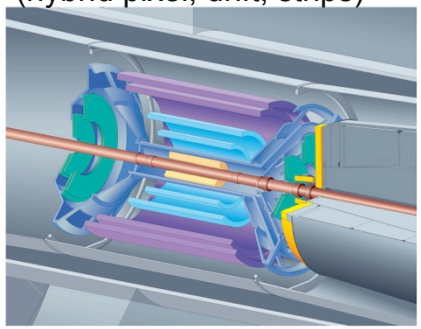


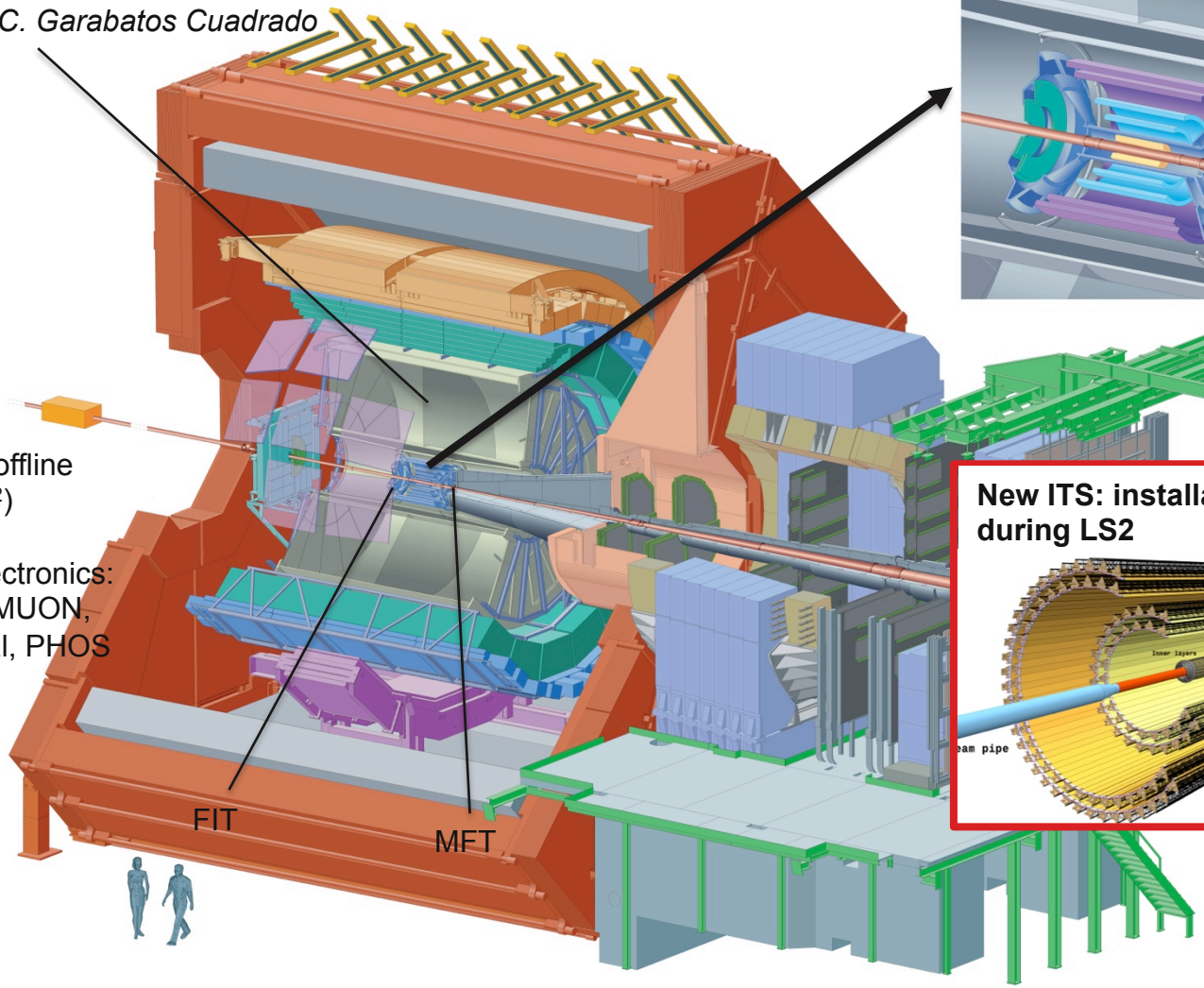
CERN-LHCC-2013-24

ALICE upgrade

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

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

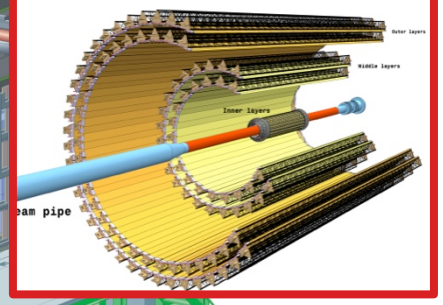




Online and offline
systems (O^2)

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

New ITS: installation during LS2



ALICE ITS upgrade design requirements

Improve impact parameter resolution by a factor of ~3 in (r-ϕ) and ~5 in (z)

- Get closer to IP: 39 mm → 21 mm (layer 0)
- Reduce beampipe radius: 29 mm → 18.2 mm
- Reduce material budget: 1.14 % X_0 → 0.3 % X_0 (inner layers)
- Reduce pixel size: (50 µm x 425 µm) → O(30 µm x 30 µm)

High standalone tracking efficiency and p_T resolution

- Increase granularity and radial extension → 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)

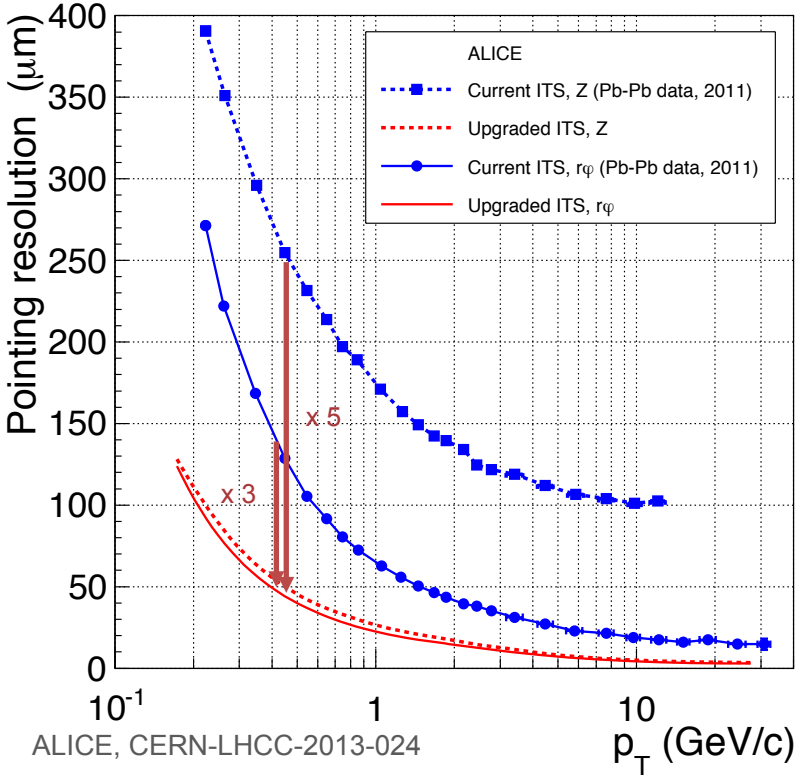
- TID: 2.7 Mrad, NIEL: 1.7 x 10^{13} 1 MeV n_{eq} cm^{-2} (safety factor 10)

Fast insertion/removal for yearly maintenance

- Possibility to replace non functioning detector modules during yearly shutdown

ALICE ITS upgrade tracking performance

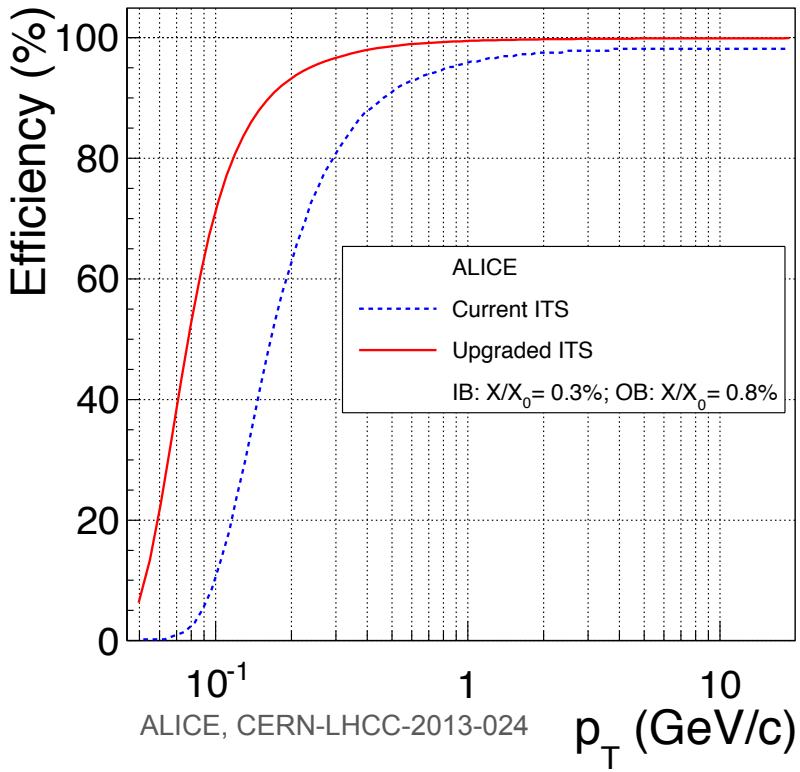
Impact parameter resolution



ALICE, CERN-LHCC-2013-024

Improved impact parameter resolution

Track reconstruction efficiency



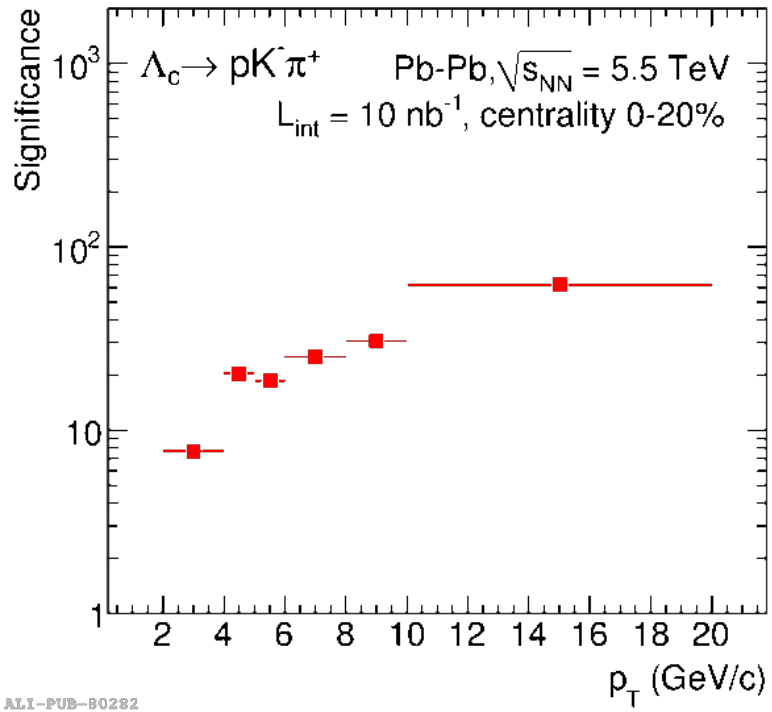
ALICE, CERN-LHCC-2013-024

High standalone tracking efficiency

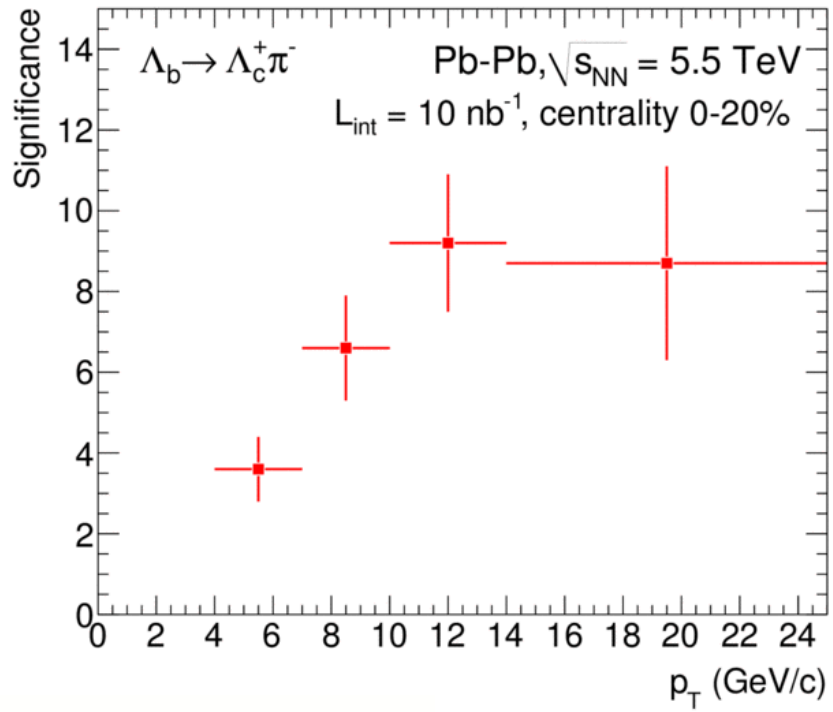
Physics performance studies - examples

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

charm



beauty

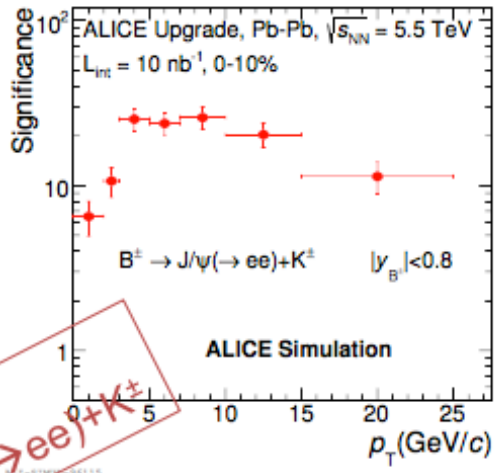


ALICE ITS upgrade TD, CERN-LHCC-2013-024 ; ALICE-TDR-017

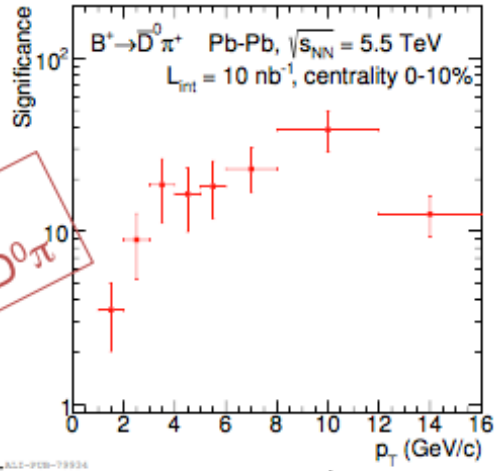
First measurments of Λ_c in Pb-Pb collisions at LHC

Physics performance studies - examples

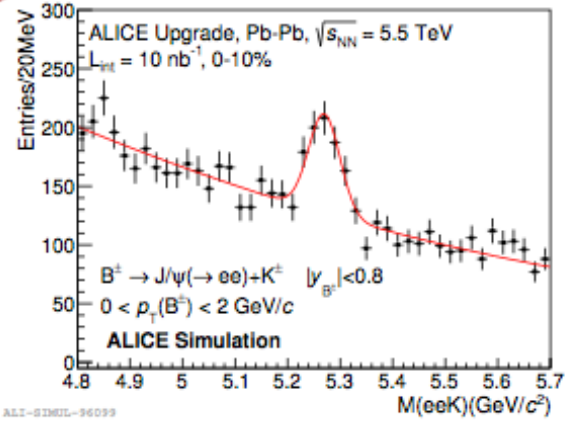
Beauty performance with new ITS



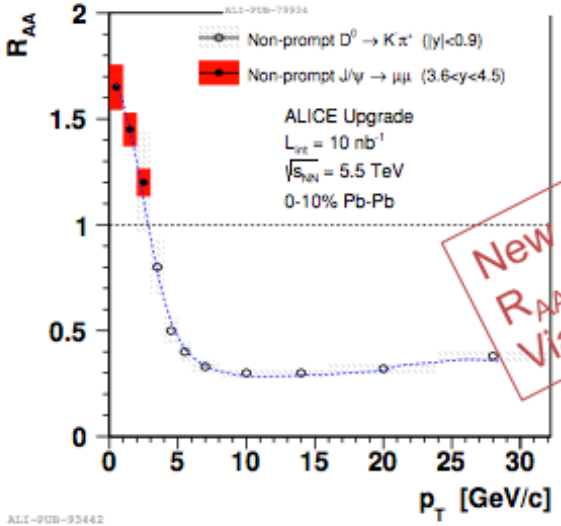
New $B^{\pm} \to (J/\psi \to ee)+K^{\pm}$



New $B^{+} \to D^{0}\pi^{+}$



Invariant mass distribution for (eeK$^{\pm}$) in 0-2 GeV/c.



New R_{AA} of beauty mesons via displaced J/ψ

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

P. Riedler, CERN for the ALICE collaboration

New ALICE ITS

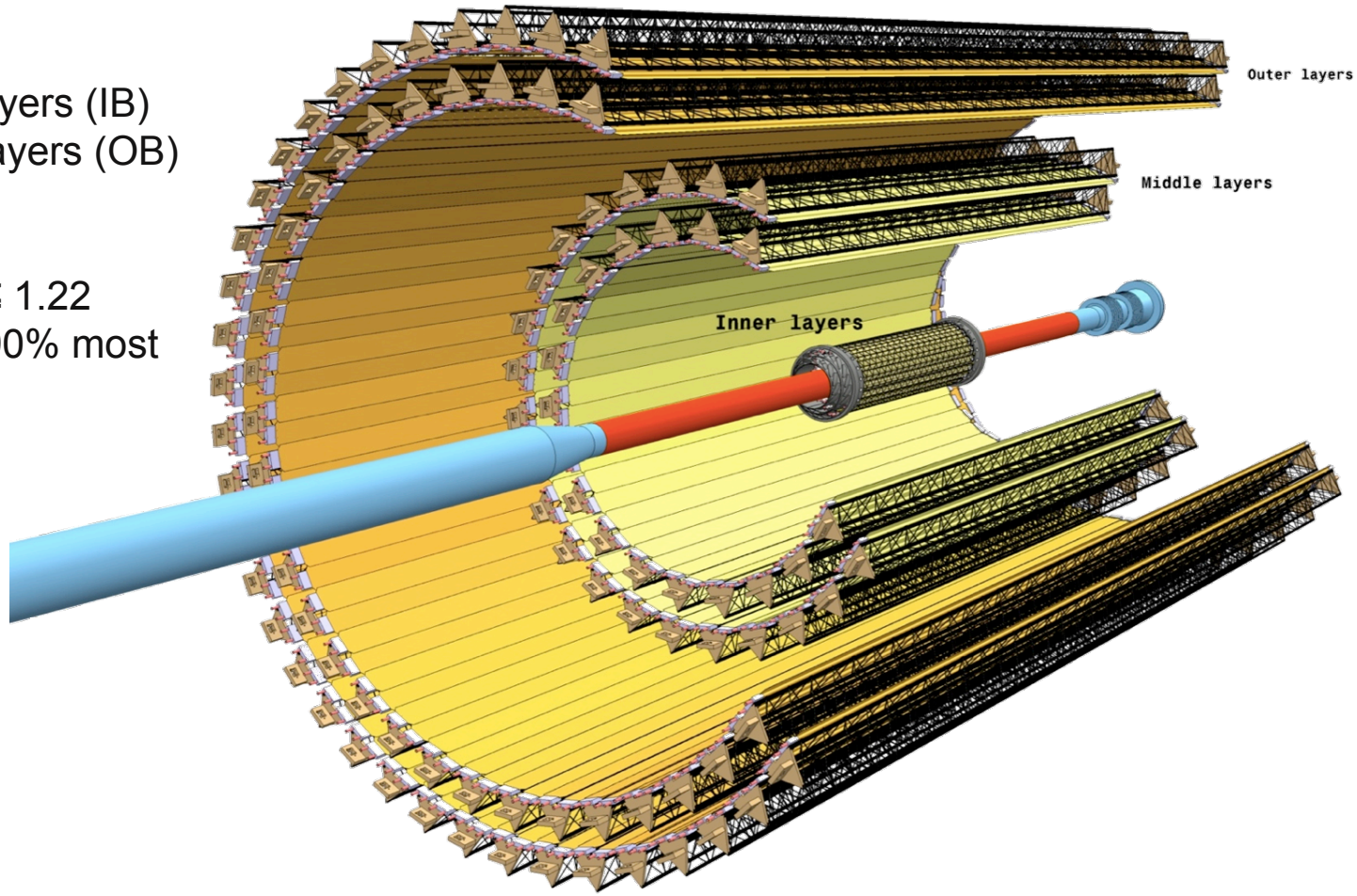
7 layers based on Monolithic Active Pixel Sensors (MAPS)

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

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

~ 10 m^2

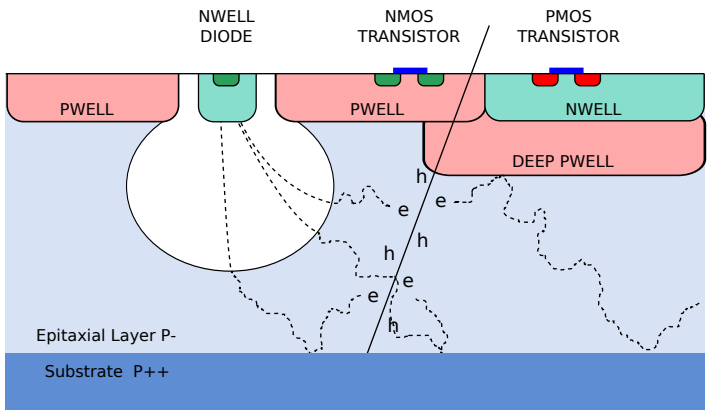
12.5 G pixel

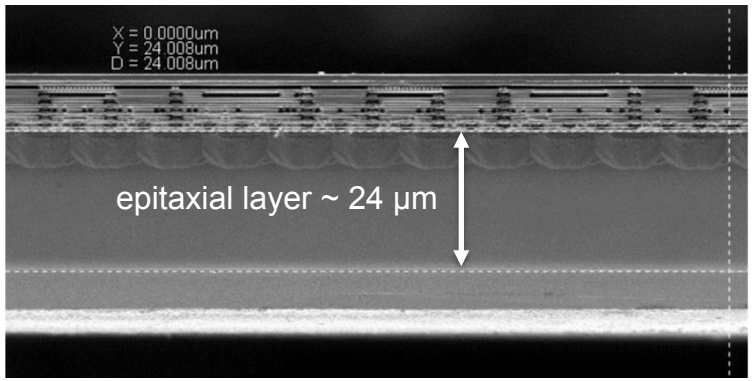


ALICE ITS pixel technology

MAPS produced in CMOS 0.18 µm process by TowerJazz

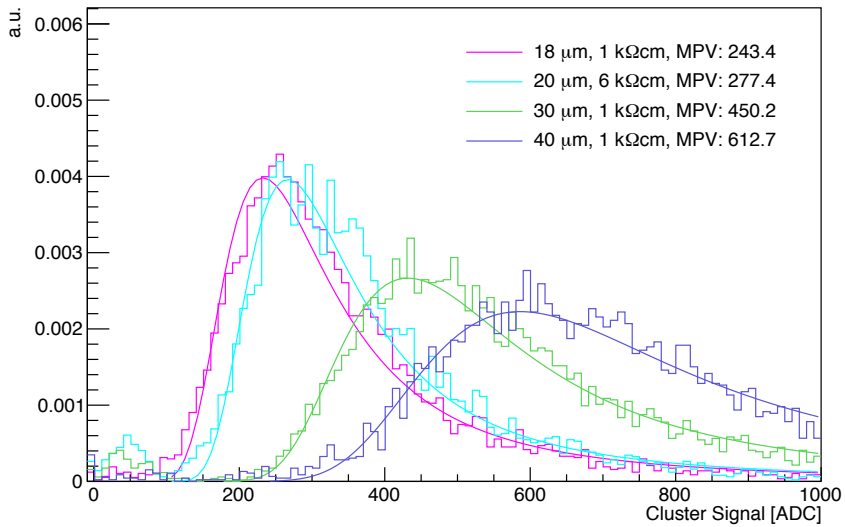
- Deep p-well allows to have PMOS and NMOS inside the pixel cell
- High resistivity epi layer
- Chip size: 15 mm x 30 mm, thinned to 50 µm
- Pixel pitch ~ 30 µm
- Spatial resolution < 5 µm





ALICE ITS, SEM picture of prototype chip

Cluster Signal (5x5), Explorer-1, A1-E2, Sector 5

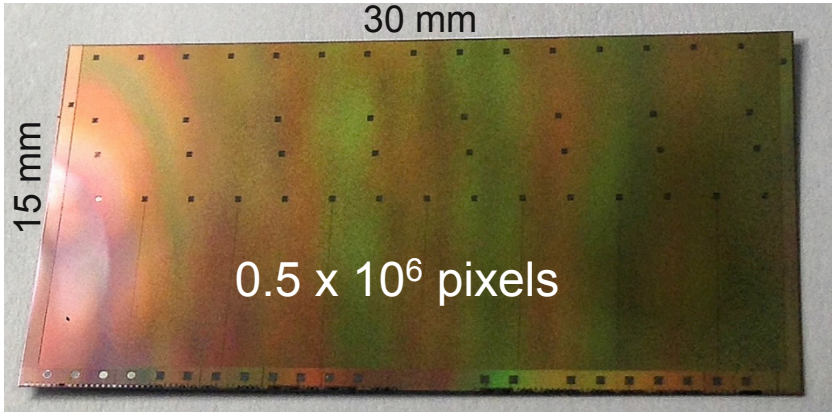


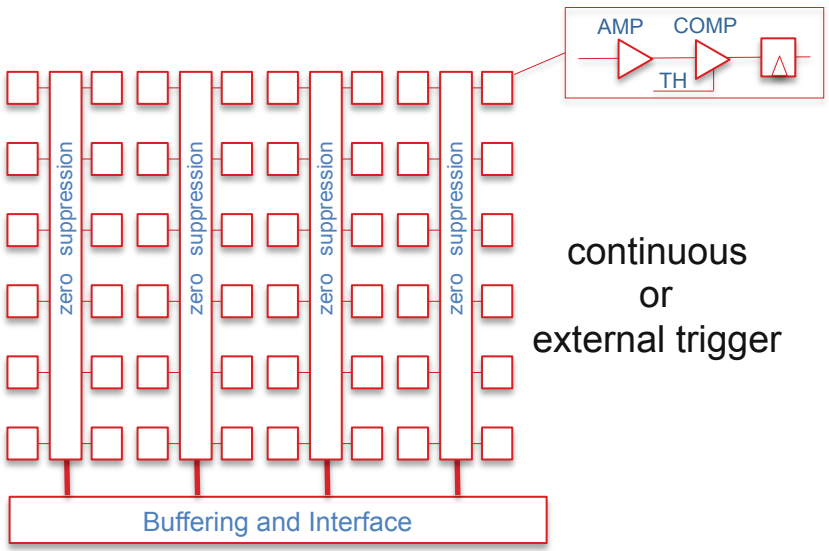
3.2 GeV/c electron test beam, pixel size 20 µm x 20 µm
J. Van Hoorne, PoS (TIPP2014) 125

ALPIDE prototype chip (baseline)

- Pixel size: 29 x 27 μm^2 with low power front-end (40 nW)
- Asynchronous sparsified digital readout
- Power density ~20 mW/cm^2 (OB) to 40 mW/cm^2 (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).

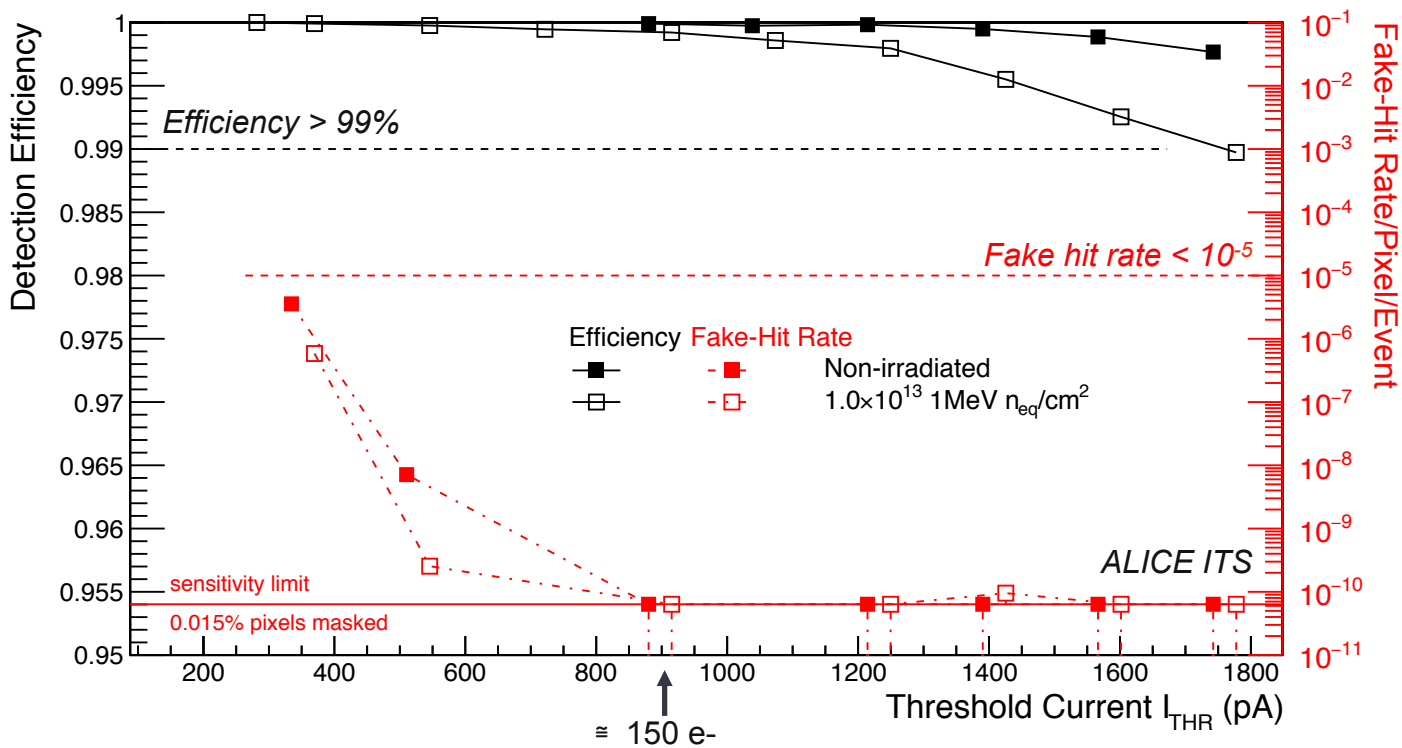




continuous
or
external trigger

ALPIDE prototype chip – experimental results

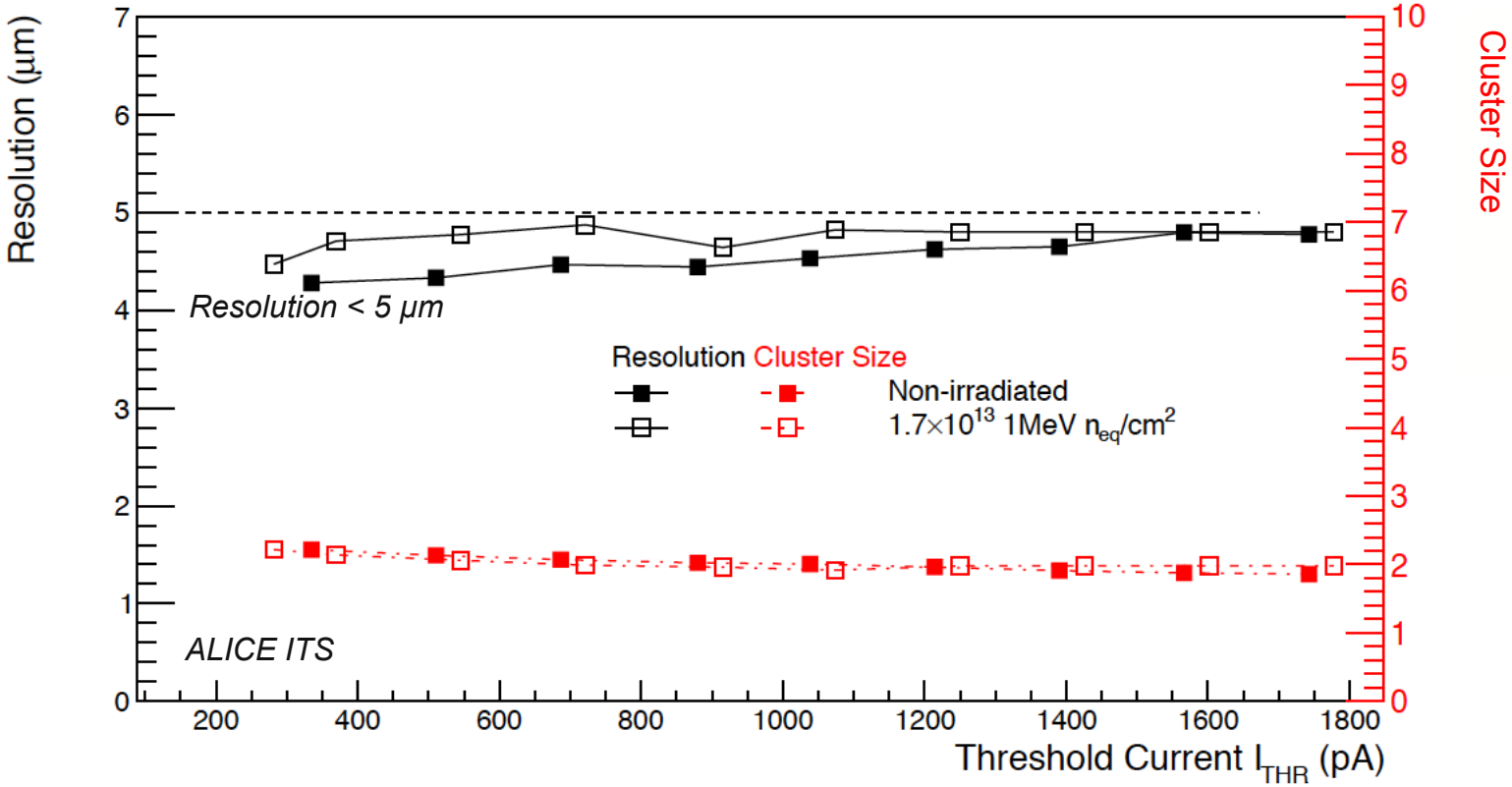
ALPIDE2 testbeam measurement, 25 µm epitaxial layer, -6V back bias, before and after irradiation



- **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**

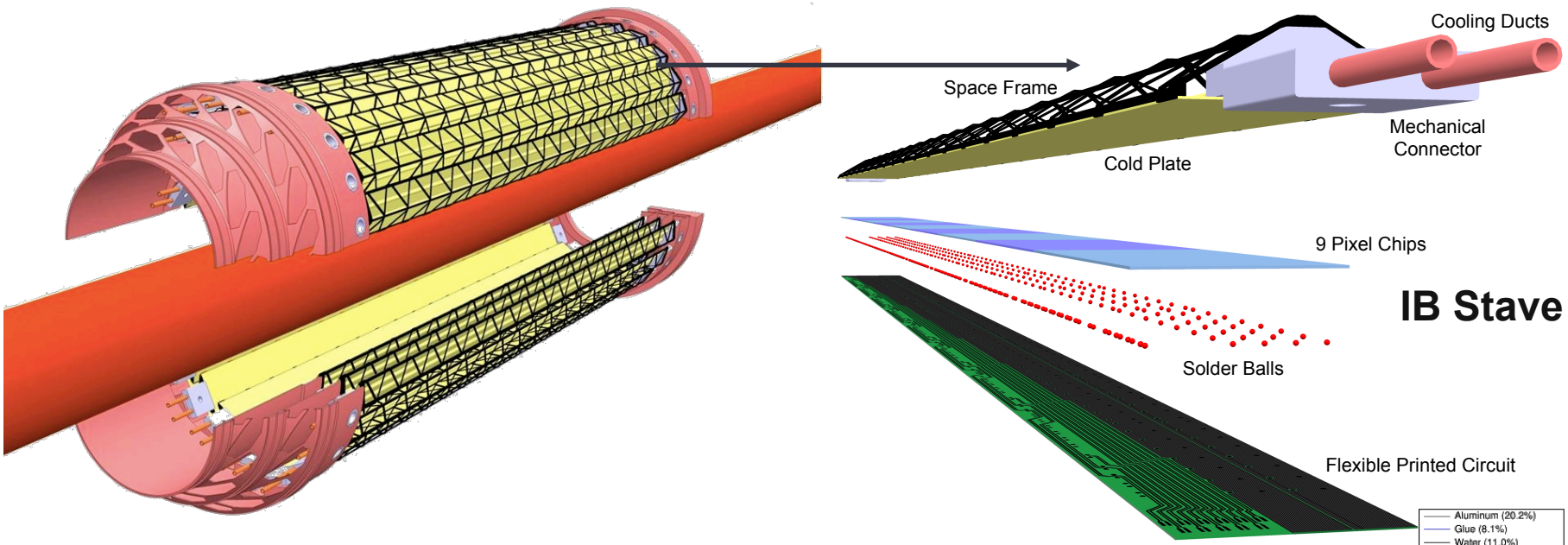
ALPIDE prototype chip – experimental results

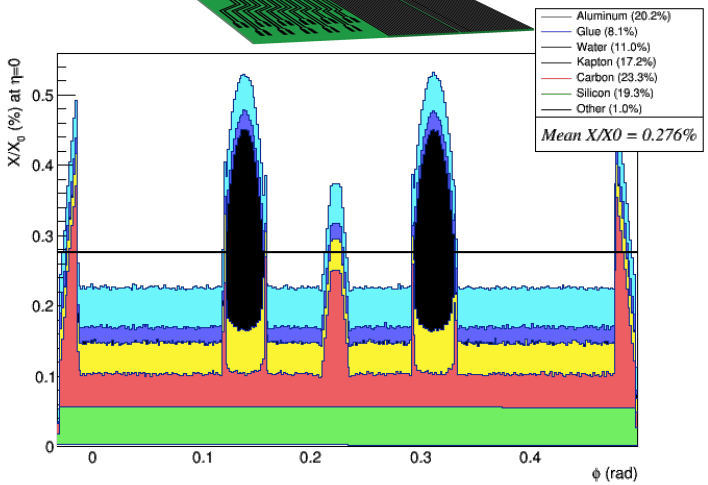
ALPIDE2 testbeam measurement, 30 µm epitaxial layer, -6V back bias, before and after irradiation



- **Space point resolution <5 µm over wide threshold range**
- **Excellent performance also after irradiation to 1.7 x 10^{13} (1MeV n_{eq})/cm^2**

ITS Inner Barrel (IB)



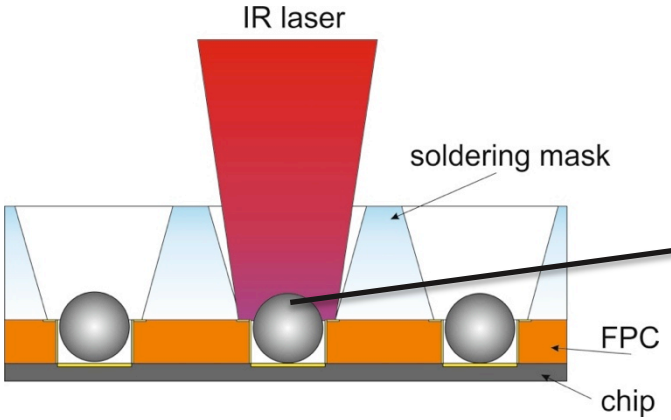


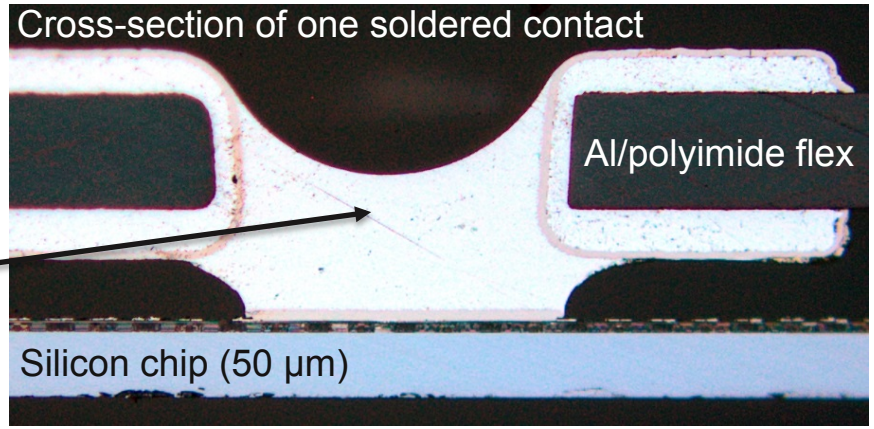
- **3 layers – 48 staves**
- Radial coverage: 21 – 39 mm
- z-length: 270 mm (9 chips per stave)
- 50 µm thin silicon chips, 2 layer Al/polyimide flex, carbon fiber space frame and cold plate with integrated polyimide cooling ducts

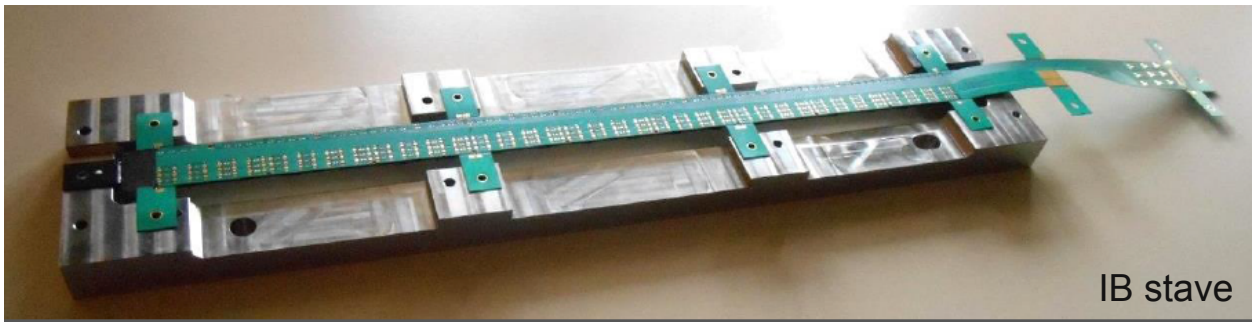
Inner Barrel/Outer Barrel Chip-Flex Connection

- 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

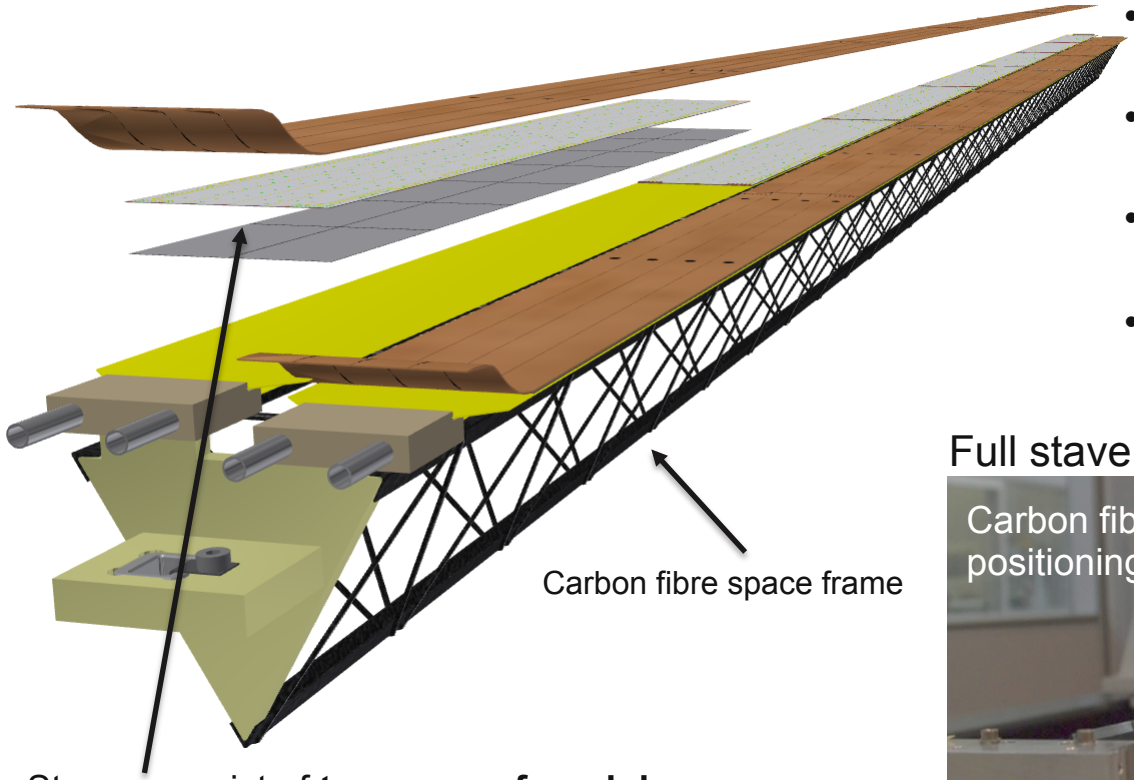




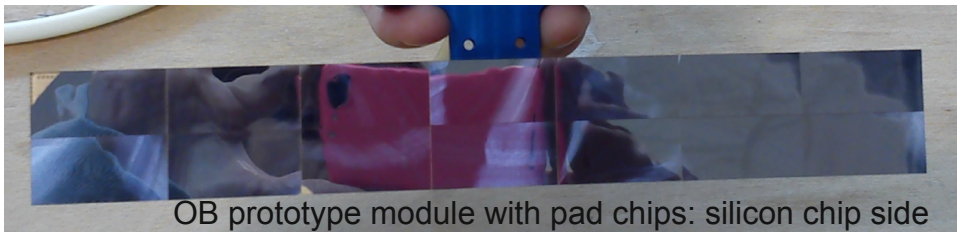


IB stave:
first electrical tests with chips soldered onto flex ongoing

ITS Outer Barrel

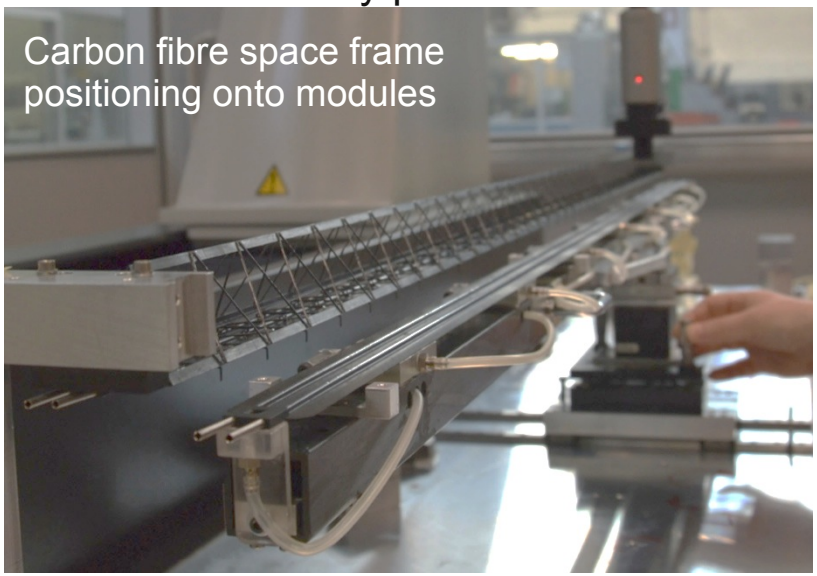


Staves consist of **two rows of modules**

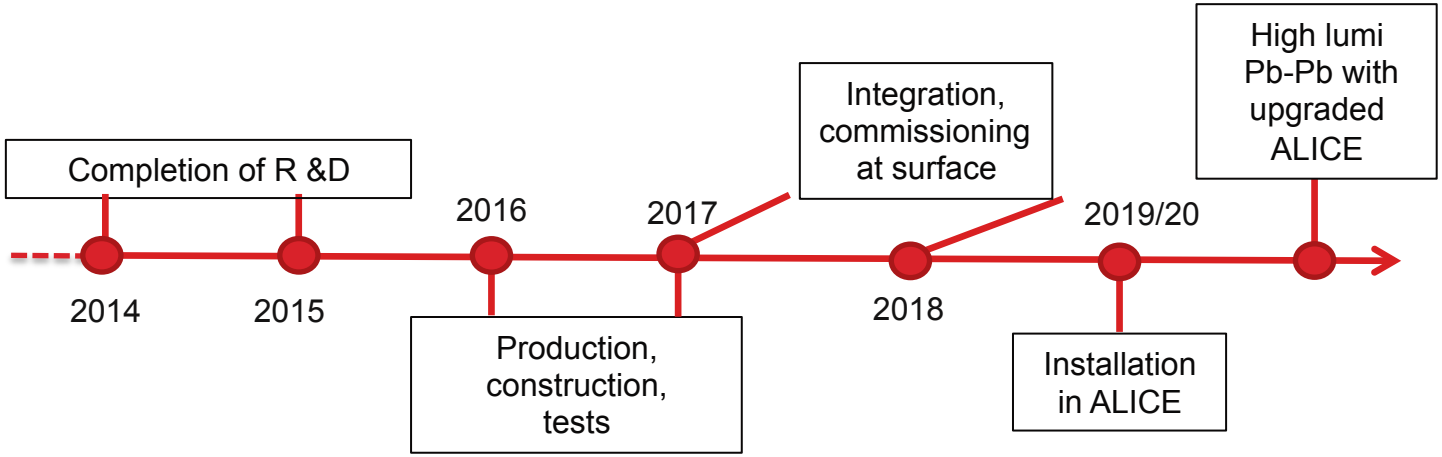

OB prototype module with pad chips: silicon chip side

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

Full stave assembly procedure tested:



Summary



- 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 m^2 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:

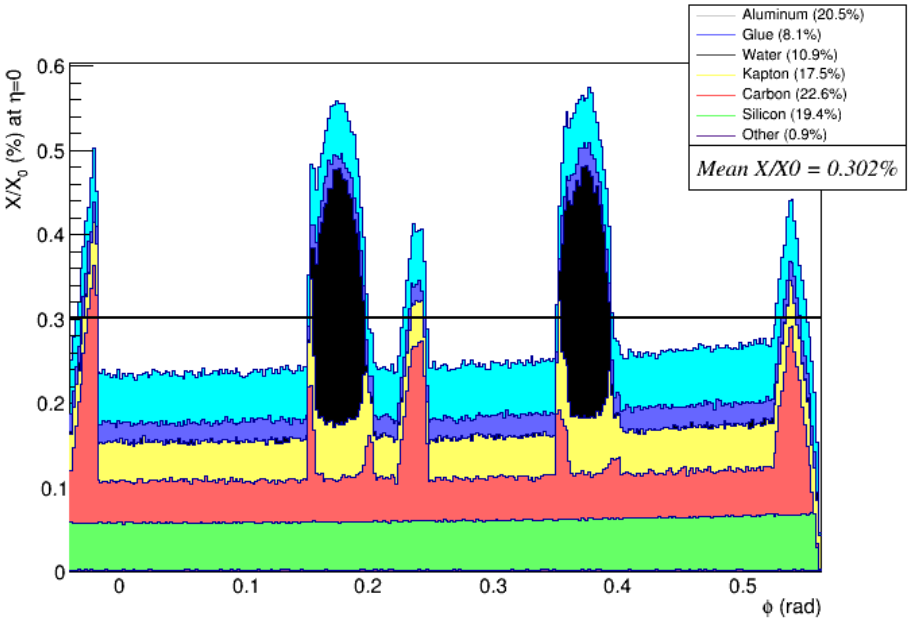
- E. Bartsch, *Ion backflow and energy resolution in stacks of four GEM detectors for the upgrade of the ALICE TPC*
- J. Harris, *Combined Gas Electron Multipliers and MicroMeGas as Gain Elements in a High Rate Time Projection Chamber*
- M. Hirano, *Detector R&D of the Forward Calorimeter with PAD readout 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

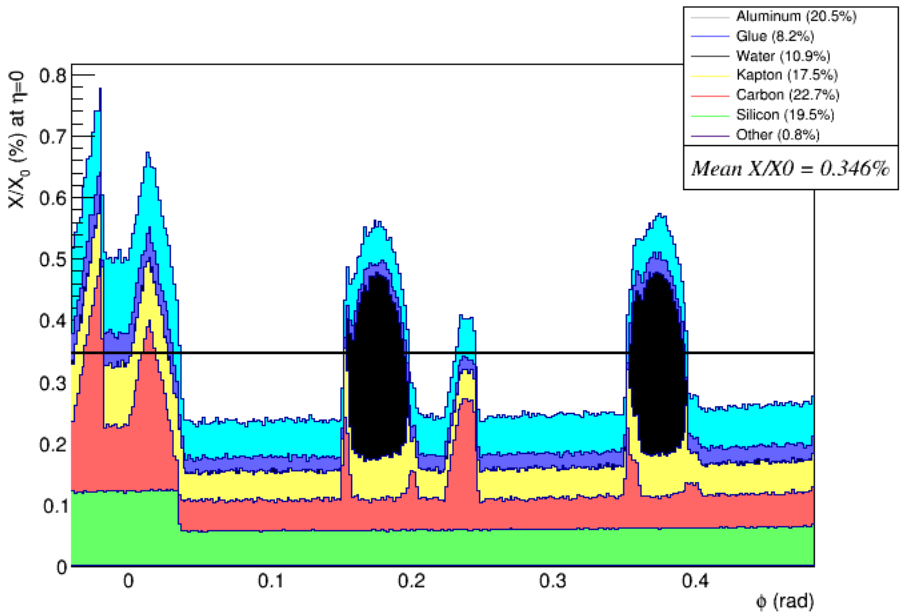
ALICE ITS pixel chip requirements

- 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/cm^2 (IB), < 100mW/cm^2 (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

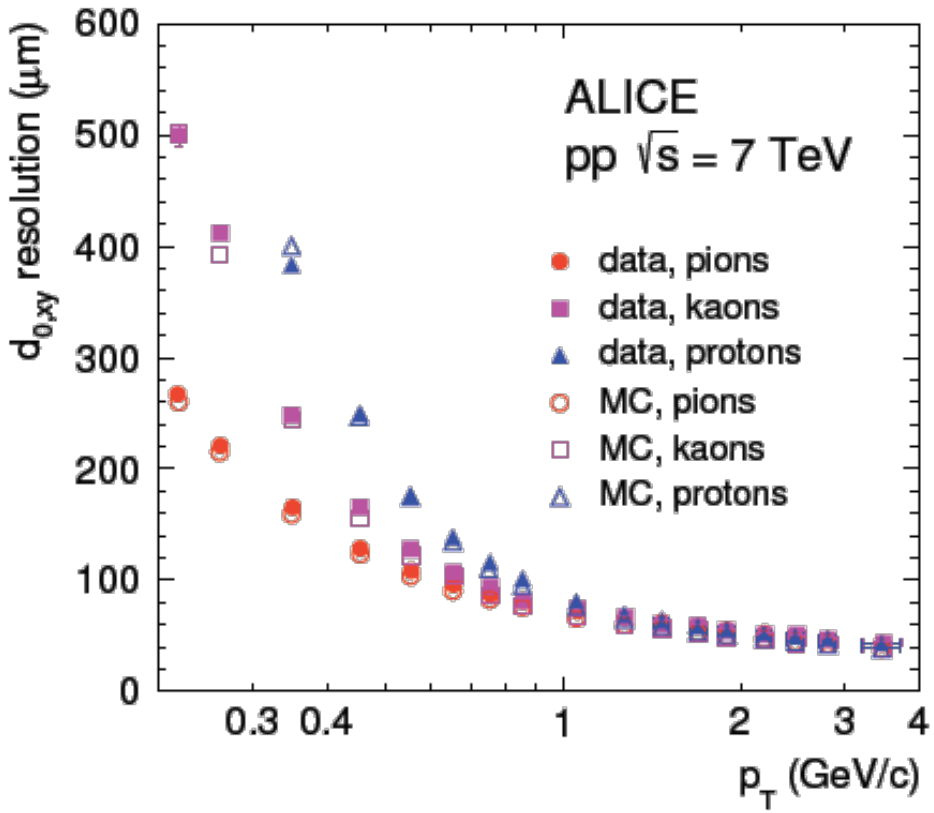


Inclination angle: 17.42°



Inclination angle: 17.42°
Overlap with neighbouring stave

Present ALICE Performance



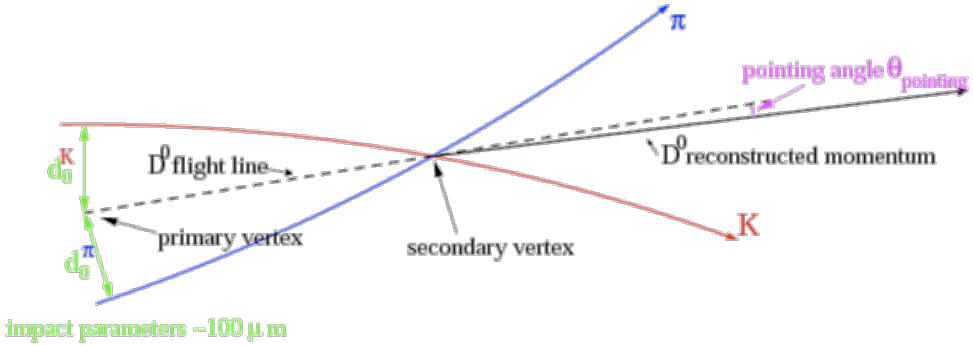
ALICE, Int. J. Mod. Phys. A29 (2014) 1430044

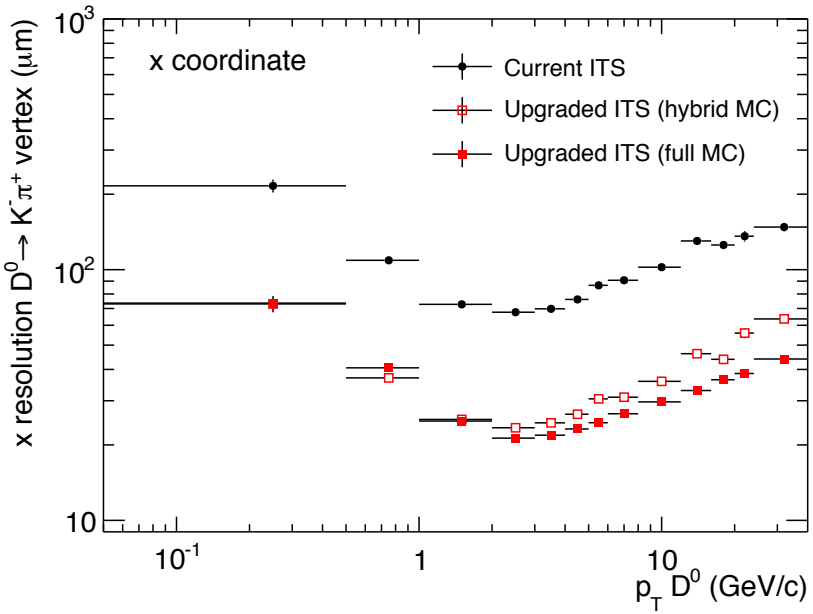
Limitations:

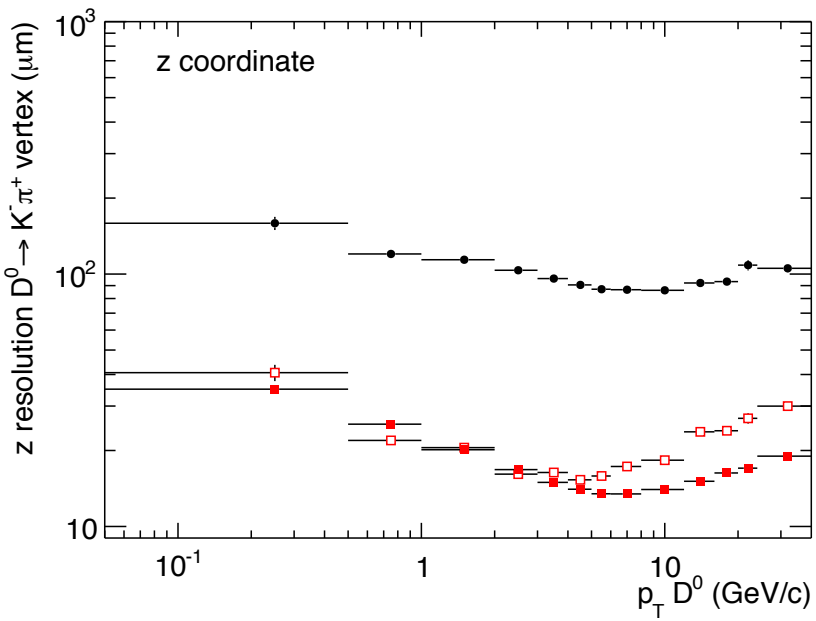
- Charmed hadrons difficult for $p_T \rightarrow 0$ (background is too large)
- resolution not sufficient for charmed baryons, Λ_c ($c\tau \sim 60\mu m$) impossible in Pb-Pb collisions , at the limit in pp (only high p_T)
- Λ_b impossible in Pb-Pb collisions (insufficient statistics and resolution)
- 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







ALICE ITS upgrade TD, CERN-LHCC-2013-024 ; ALICE-TDR-017

Laser Soldering

- **Industrial technique adapted for ALICE ITS**
- **Flux-less soldering** of ~200 mm diameter Sn/Ag(96.5/3.5) balls (227 ^{o}C melting T) in vacuum ($\leq 10^{-1}$ 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