Upgrade of the ALICE Inner Tracking System

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on behalf of the ALICE Collaboration

ALICE

INFN Istituto Nazionale di Fisica Nucleare Laboratori Nazionali di Frascati

XII TH & THE QUARK CONFINEMENT HADRON SPECTRUM

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 nb^{-1} → $8x10^{10}$ events

- Upgrade detectors, readout systems and online systems to:
  - readout all Pb-Pb interactions at the maximum rate of 50 kHz (L=$6x10^{27}$ $cm^{-2}s^{-1}$) with MB trigger. At present the rate is 500 Hz

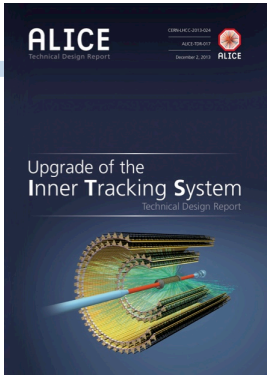
- Gain a factor 100 in statistics over the originally approved programme Run1+Run2

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

The new Inner Tracking System (ITS)

TDR endorsed by LHCC

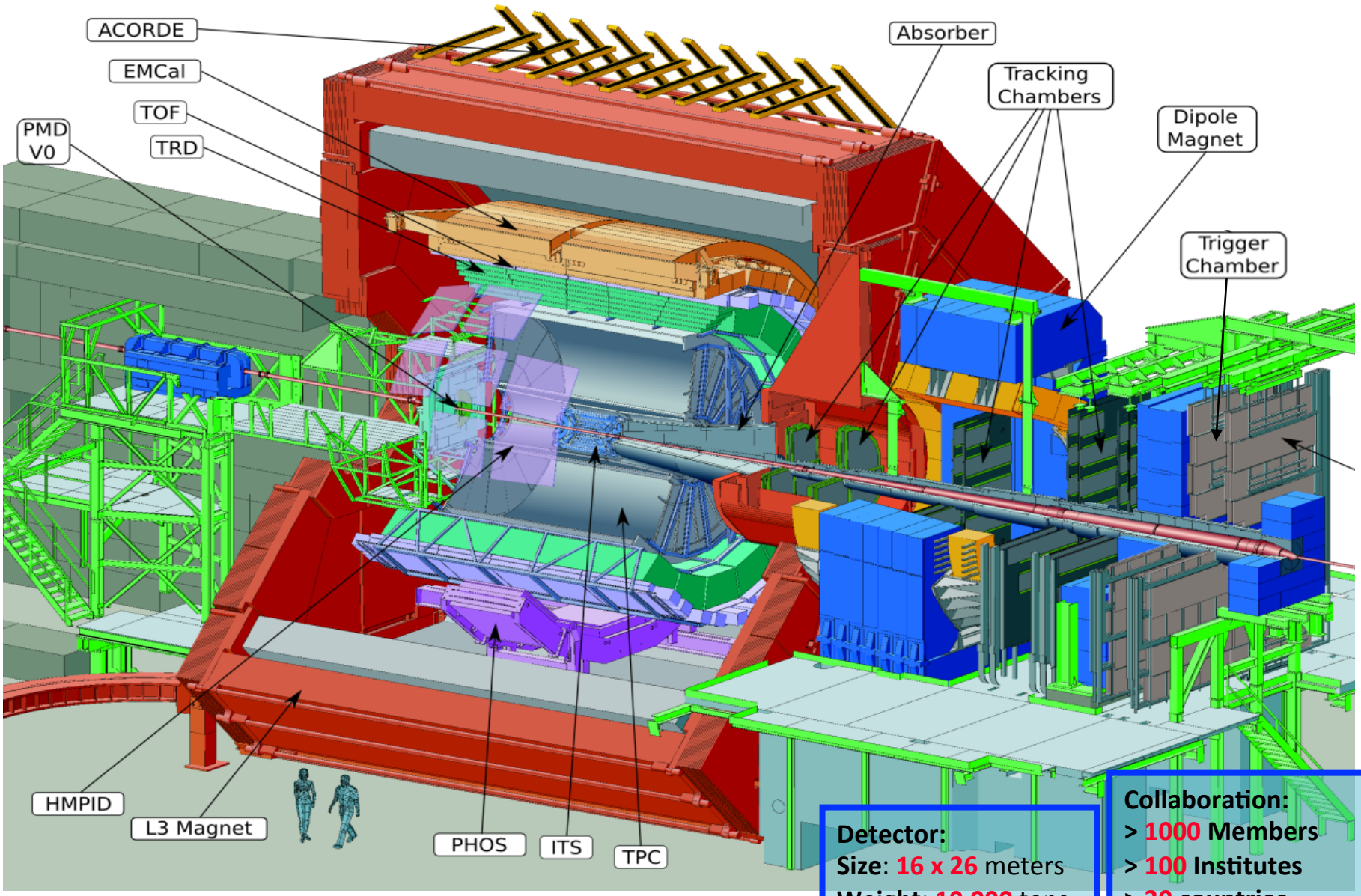
The construction matches the LHC LS2



CERN-LHCC-2013-24

J. Phys. G (41) 087002

ALICE: the current setup



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

Collaboration:
> 1000 Members
> 100 Institutes
> 30 countries

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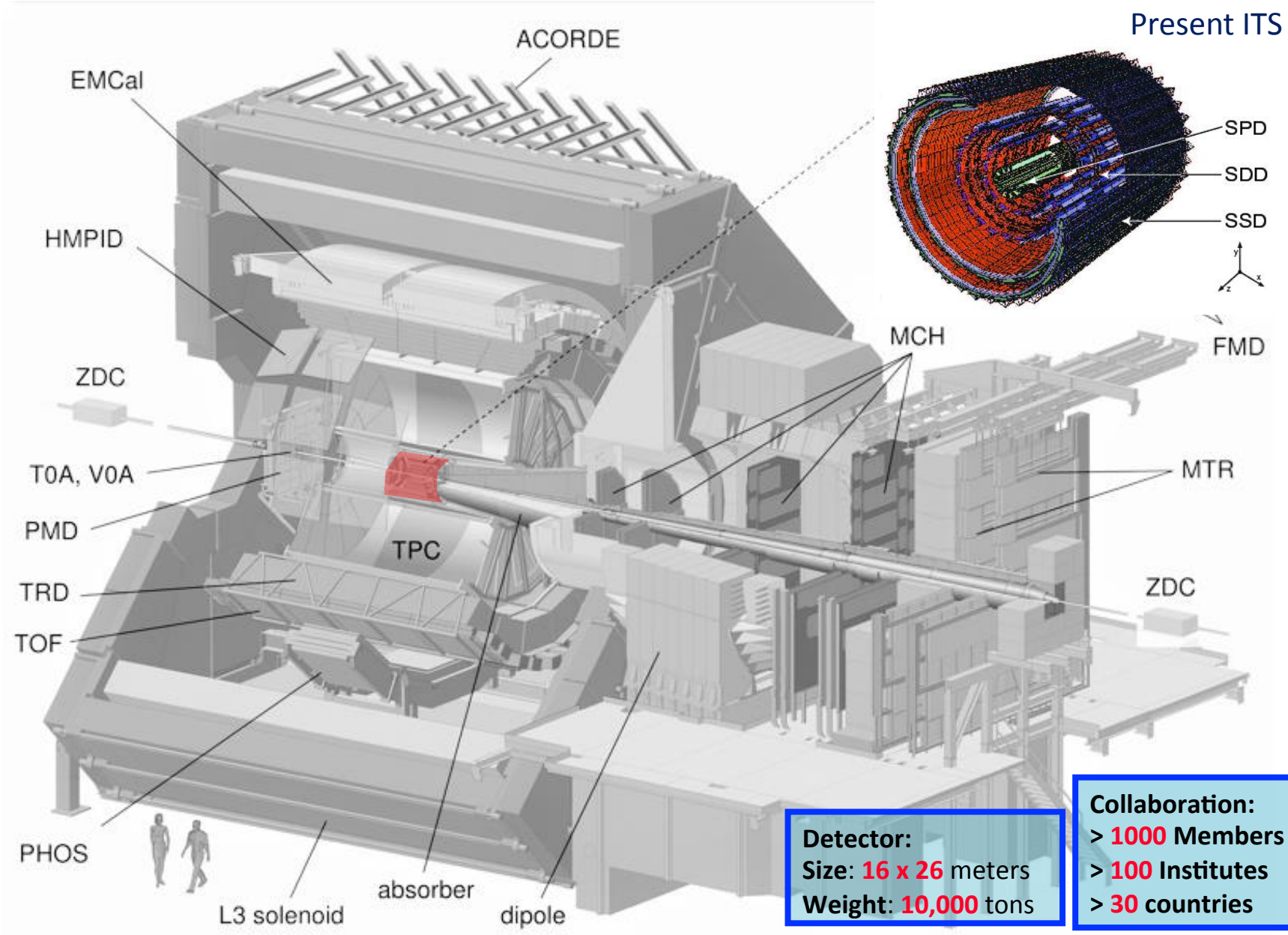

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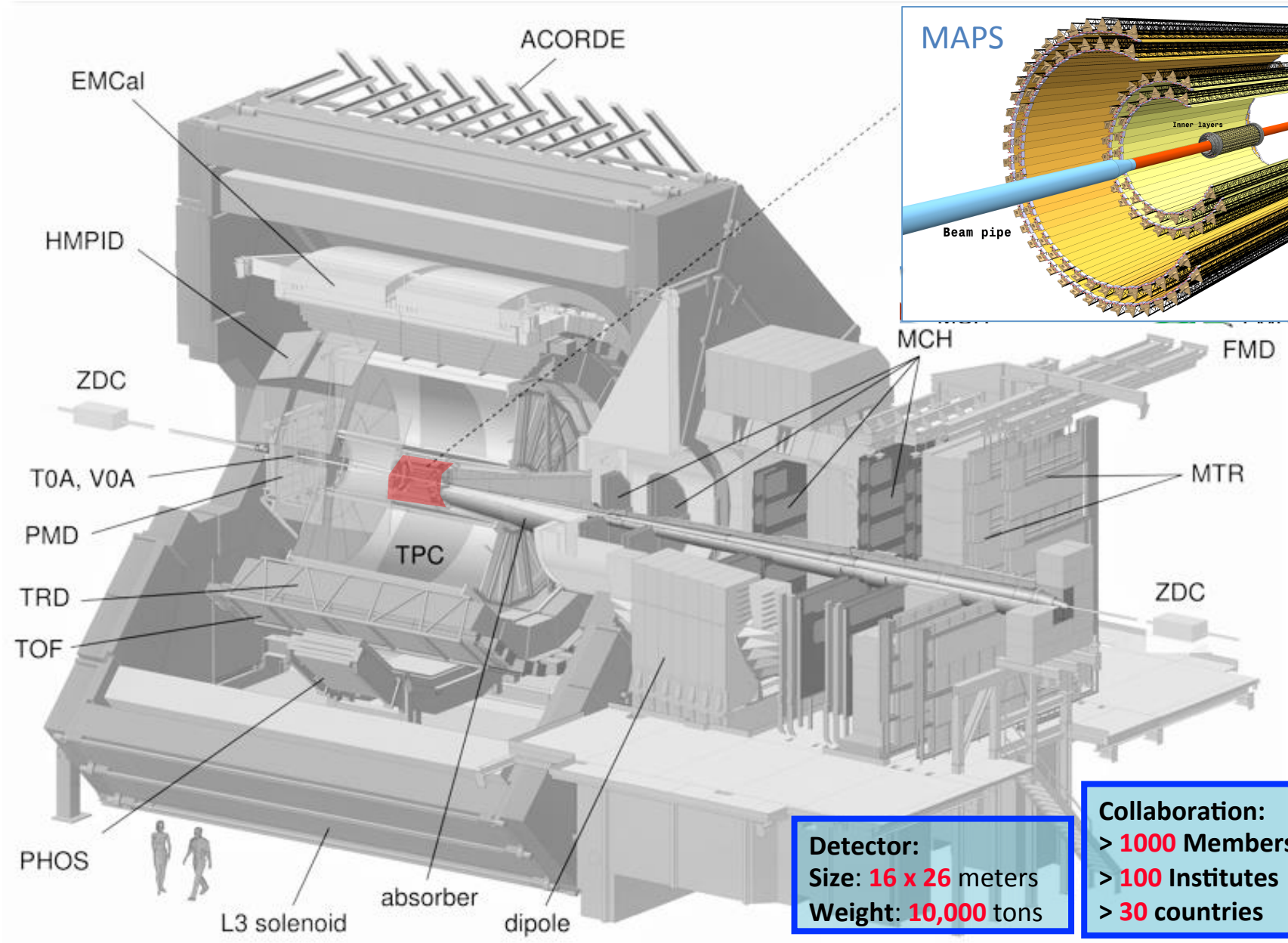

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ITS upgrade design objectives

1. Improve impact parameter resolution by a factor of ~3

- Get closer to IP (position of first layer): 39mm ➡ 23mm
- Reduce X/X_0 /layer: ~1.14% ➡ ~ 0.3% (for inner layers)
- Reduce pixel size: currently 50μm x 425μm ➡ O(30μm x 30μm)

2. Improve tracking efficiency and p_T resolution at low p_T

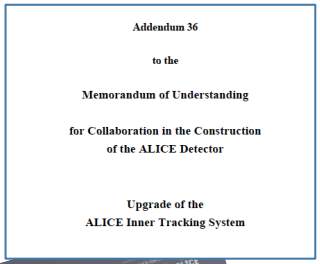
- Increase granularity:
  - 6 layers ➡ 7 layers
  - silicon drift and strips ➡ pixels

3. Fast readout

- readout Pb-Pb interactions at > 100 kHz and pp interactions at ~ 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

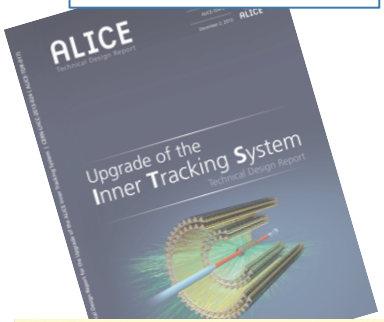

Addendum 36

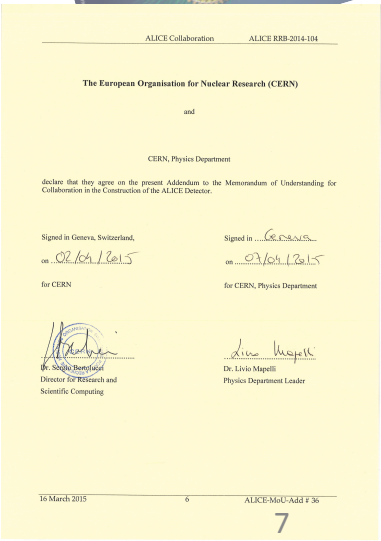
to the

Memorandum of Understanding

for Collaboration in the Construction of the ALICE Detector

Upgrade of the ALICE Inner Tracking System




ALICE Collaboration ALICE RRB-2014-104

The European Organisation for Nuclear Research (CERN)

and

CERN, Physics Department

declare that they agree on the present Addendum to the Memorandum of Understanding for Collaboration in the Construction of the ALICE Detector.

Signed in Geneva, Switzerland, on 02/04/2015 for CERN

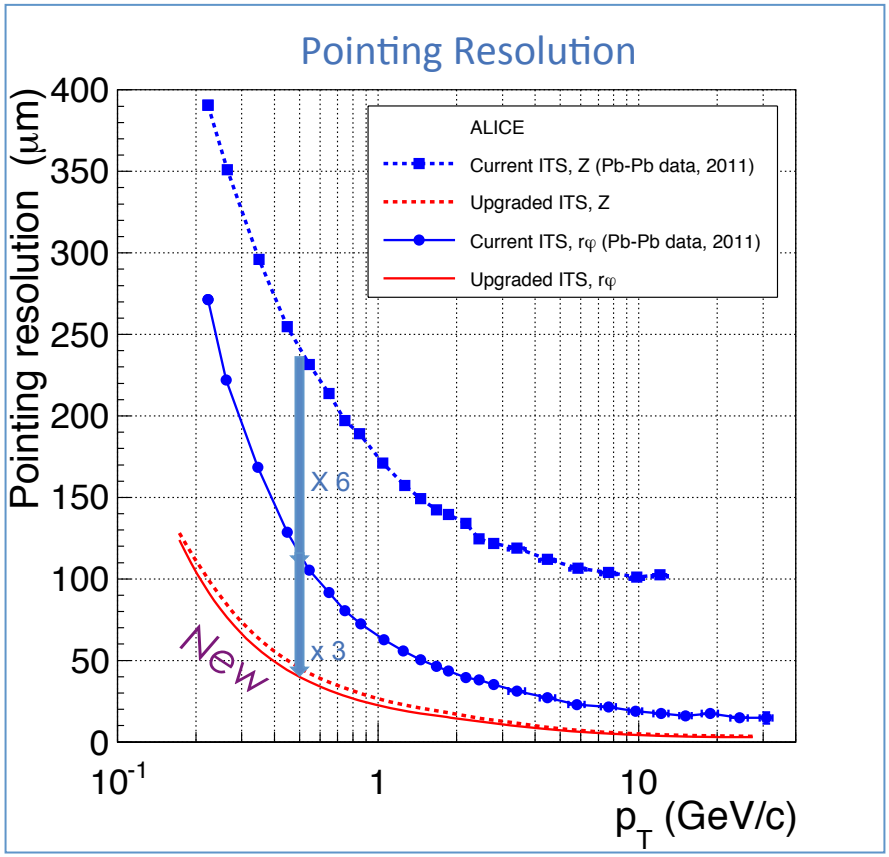
Dr. Sergio Bertolucci, Director for Research and Scientific Computing

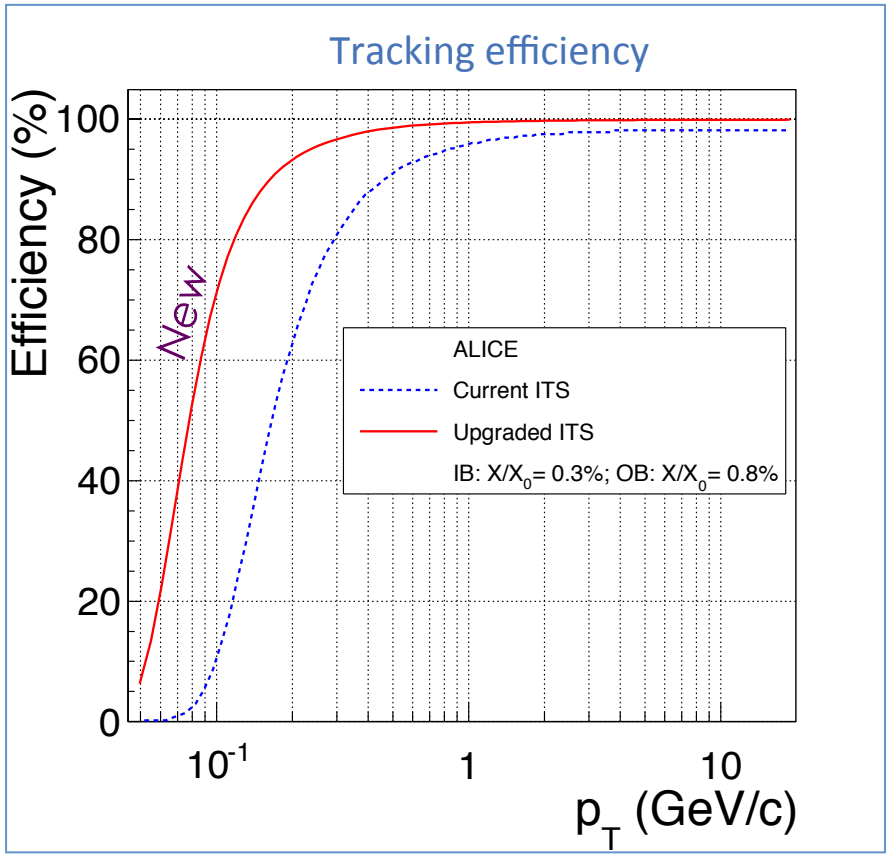
Signed in Geneva on 07/04/2015 for CERN, Physics Department

Dr. Livio Mapelli, Physics Department Leader

16 March 2015 6 ALICE-MoU-Add # 36

ITS – Performance of new detector





~40 μm a p_T=500 MeV

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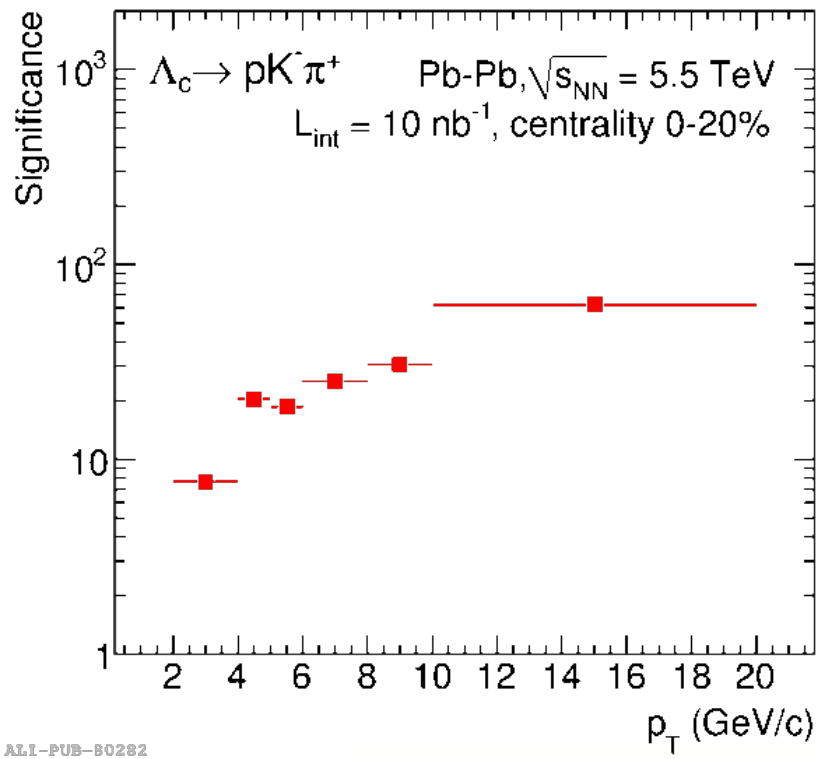
Fundamental improvement of the impact parameter resolution (left) and tracking efficiency (right) from the old to the new ITS

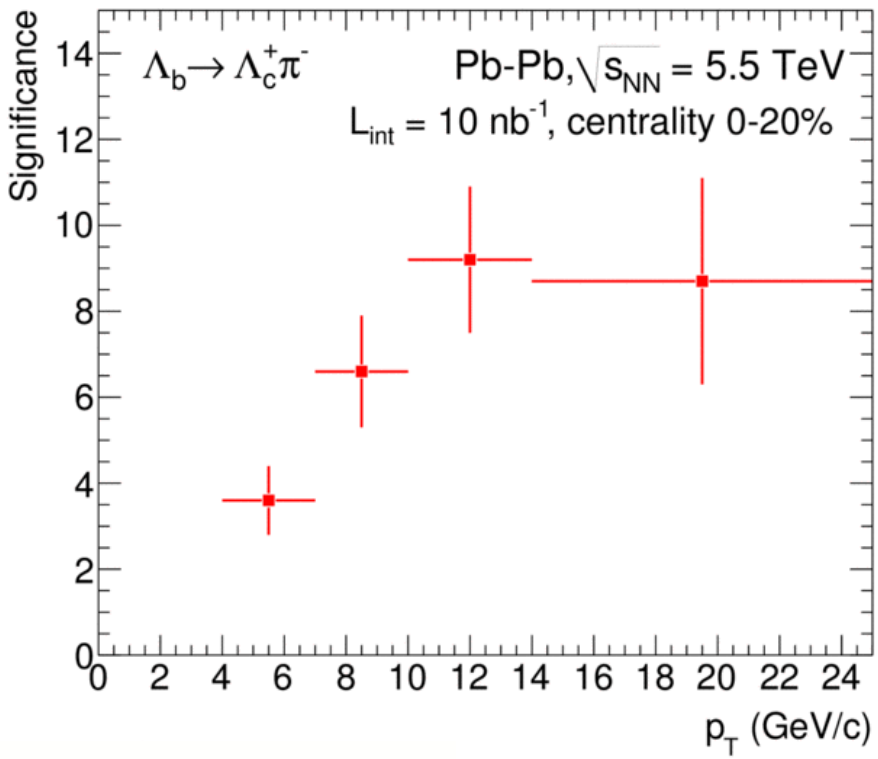
ITS – Physics Performance

- 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. χ_c) will be investigated.

charm



beauty

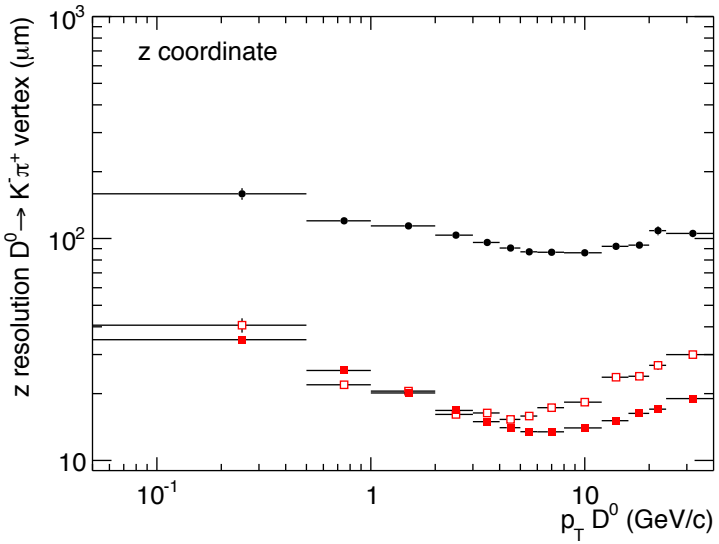


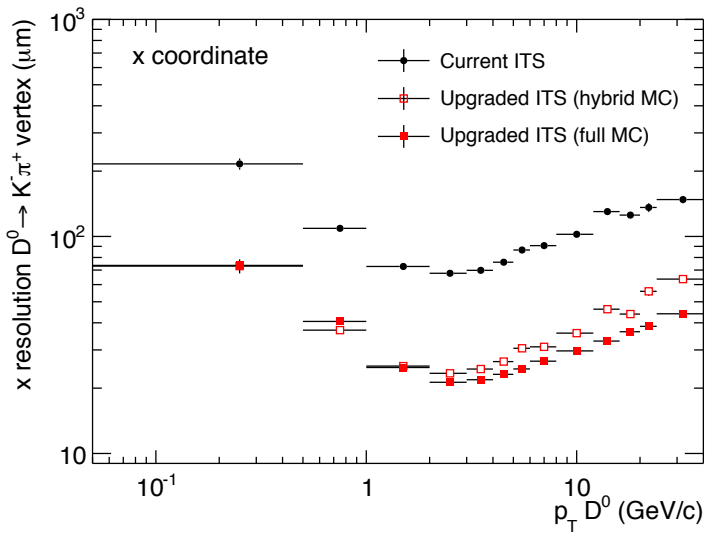
ALICE ITS upgrade TD, CERN-LHCC-2013-024 ; ALICE-TDR-017

First measurements of Λ_c in Pb-Pb collisions at LHC

ITS – Physics Performance

Example: $D^0 \rightarrow K^- p^+$





Observable	Current, 0.1 nb^{-1}		Upgrade, 10 nb^{-1}	
	p_T^{min} (GeV/c)	statistical uncertainty	p_T^{min} (GeV/c)	statistical uncertainty
Heavy Flavour				
D meson R_{AA}	1	10 %	0	0.3 %
D_s meson R_{AA}	4	15 %	< 2	3 %
D meson from B R_{AA}	3	30 %	2	1 %
J/ψ from B R_{AA}	1.5	15 % (p_T-int.)	1	5 %
B^+ yield	not accessible		3	10 %
Λ_c R_{AA}	not accessible		2	15 %
Λ_c/D^0 ratio	not accessible		2	15 %
Λ_b yield	not accessible		7	20 %
D meson v_2 ($v_2 = 0.2$)	1	10 %	0	0.2 %
D_s meson v_2 ($v_2 = 0.2$)	not accessible		< 2	8 %
D from B v_2 ($v_2 = 0.05$)	not accessible		2	8 %
J/ψ from B v_2 ($v_2 = 0.05$)	not accessible		1	60 %
Λ_c v_2 ($v_2 = 0.15$)	not accessible		3	20 %
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 %
Hypernuclei				
${}^3_\Lambda H$ yield	2	18 %	2	1.7 %

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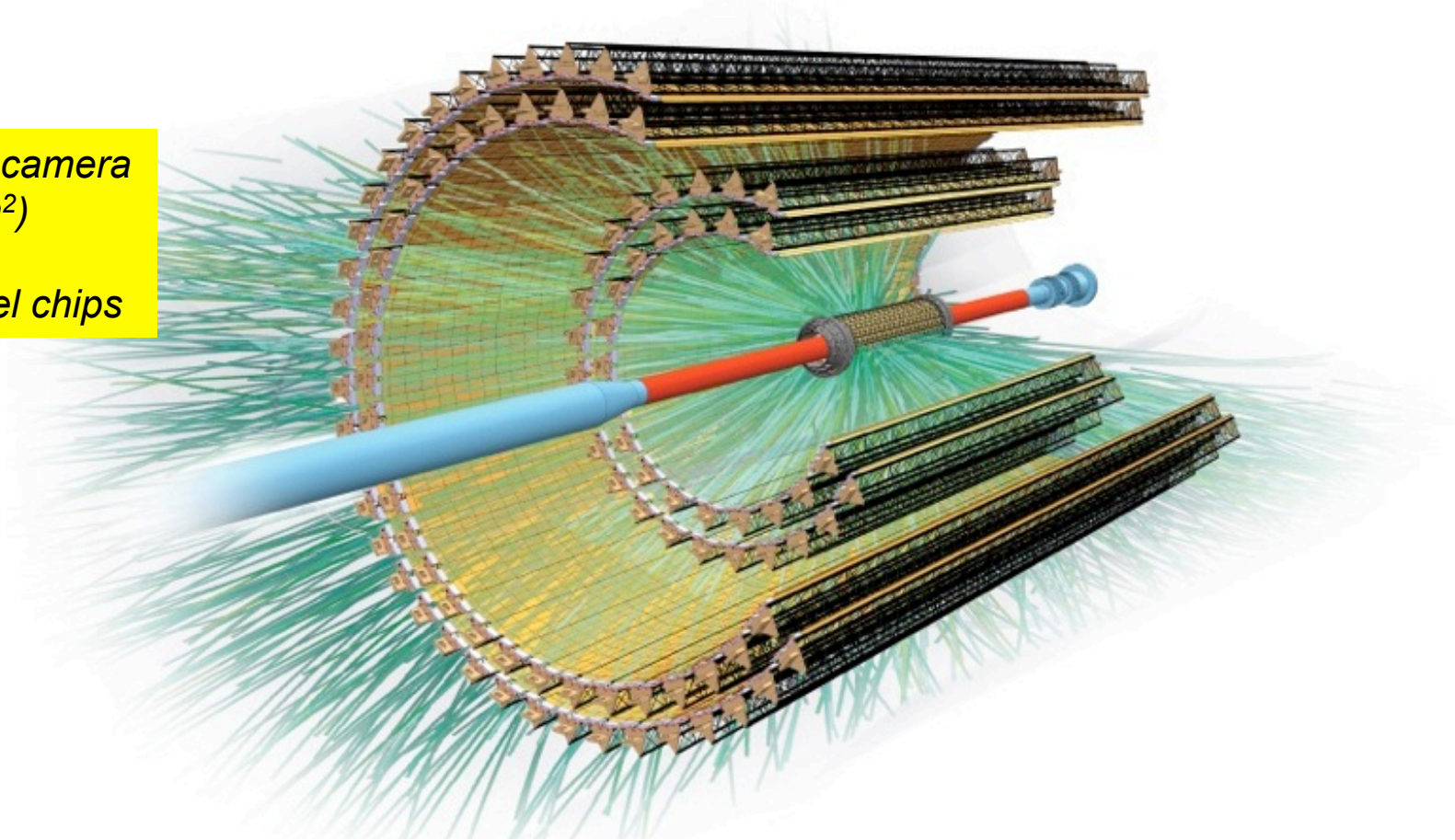
ITS new layout

12.5 G-pixel camera (~10 m^2)

~24.000 pixel chips



7-layer barrel geometry based on MAPS

r coverage: 23 – 400 mm

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

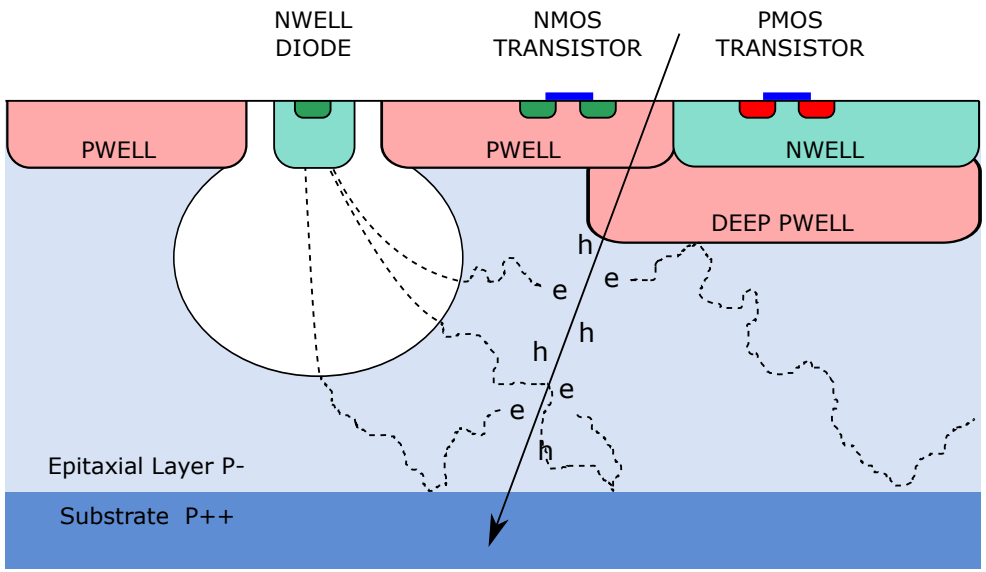
3 Inner Barrel layers (**IB**)

4 Outer Barrel layers (**OB**)

Material /layer : 0.3% X_0 (IB), 1% X_0 (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

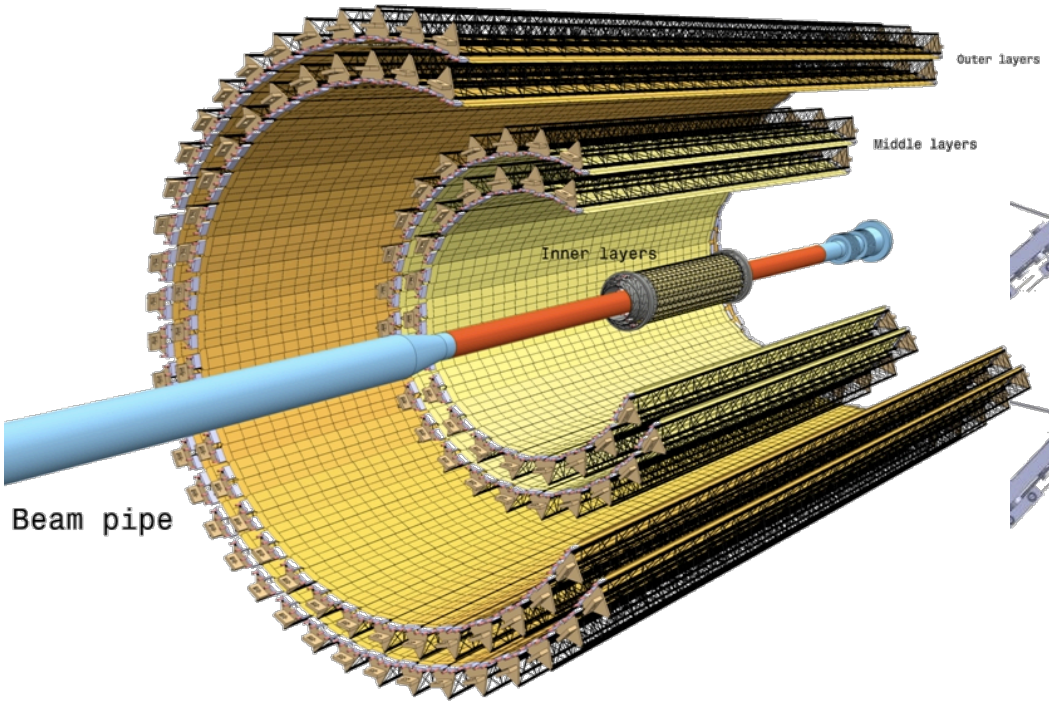
➔ Suited for high-density, low-power

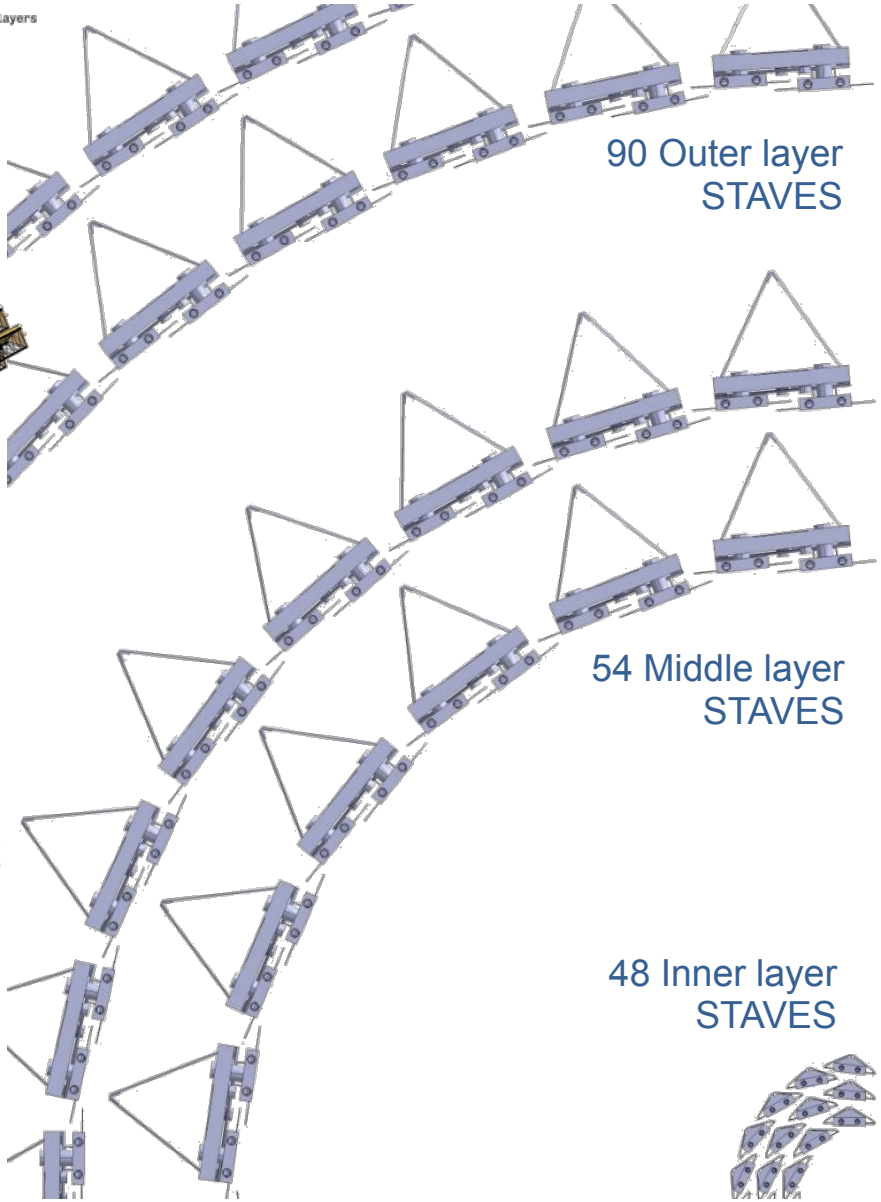
- Gate oxide 3nm

➔ 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

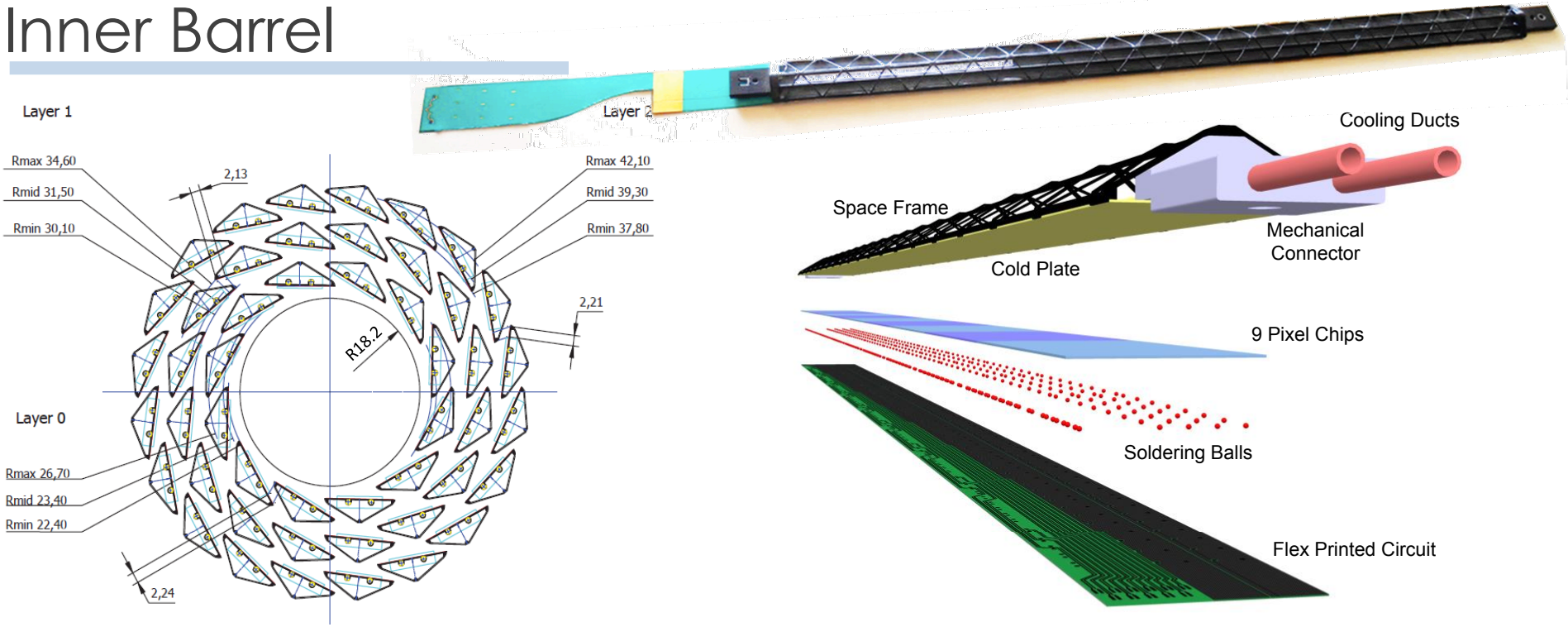




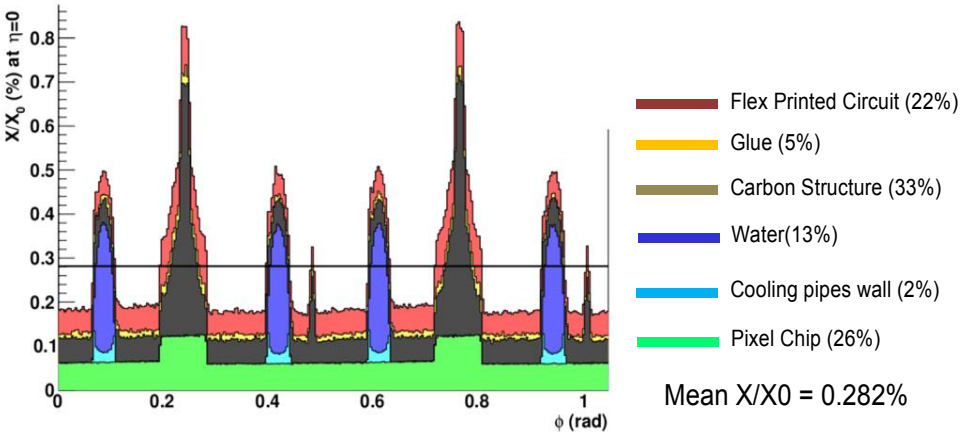
ITS layers are (azimuthally) segmented in staves, which are mechanically independent

Radial coverage 23mm÷405mm

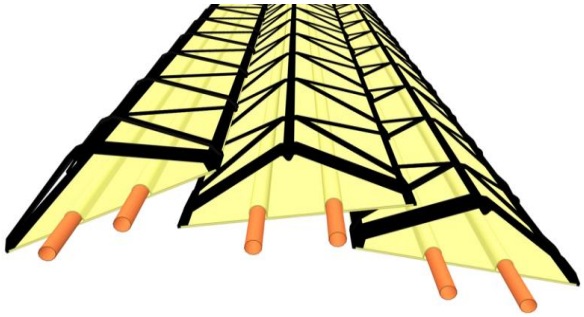
Inner Barrel

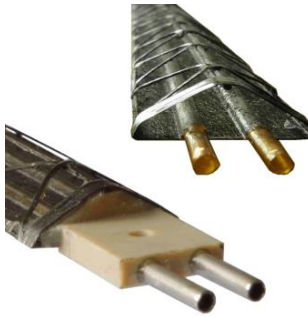


Inner Barrel Stave



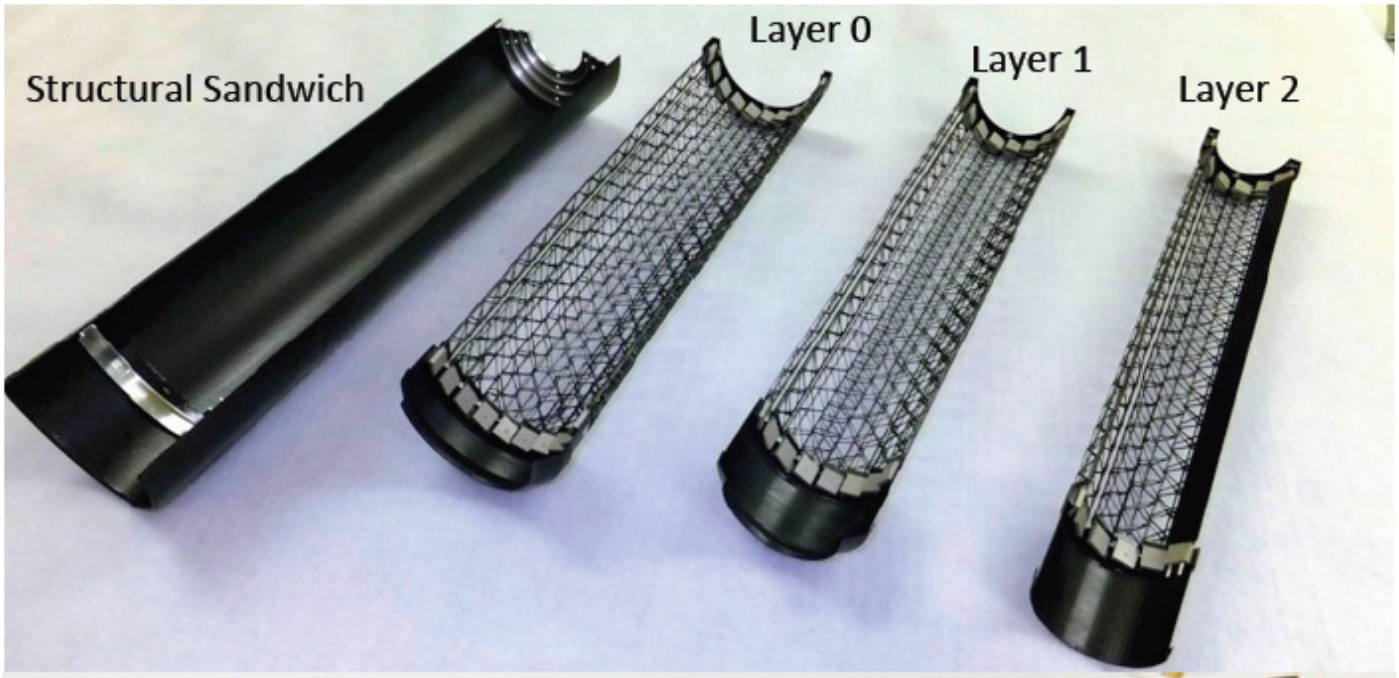
Mean X/X0 = 0.282%

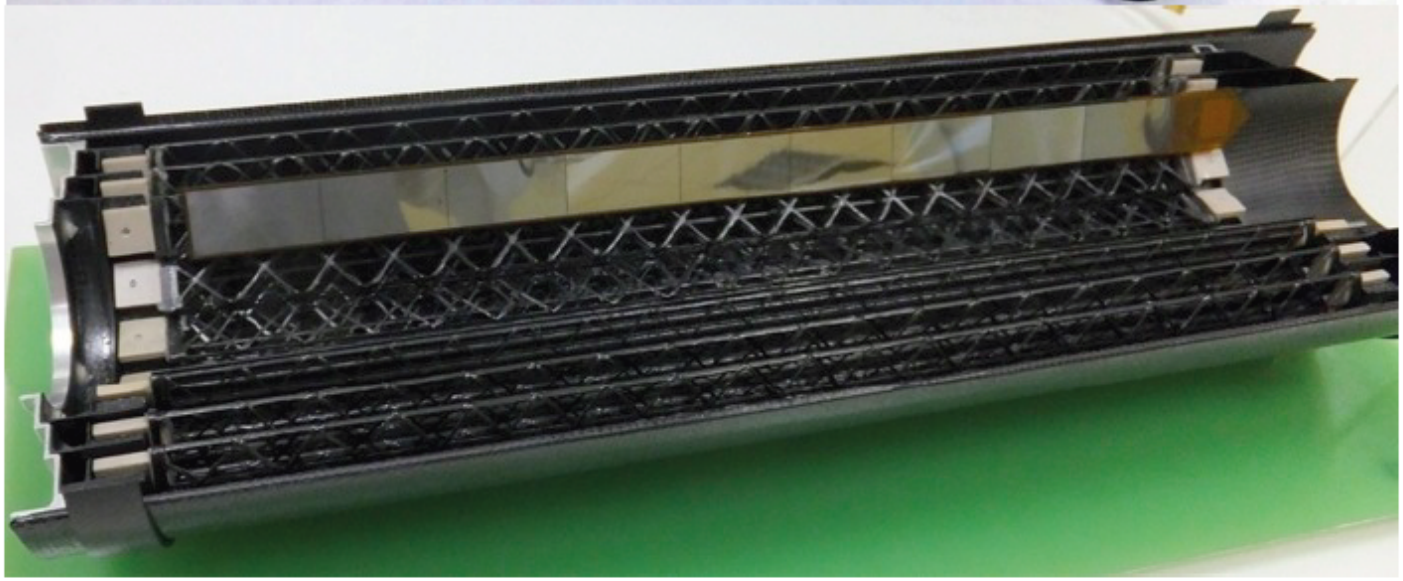




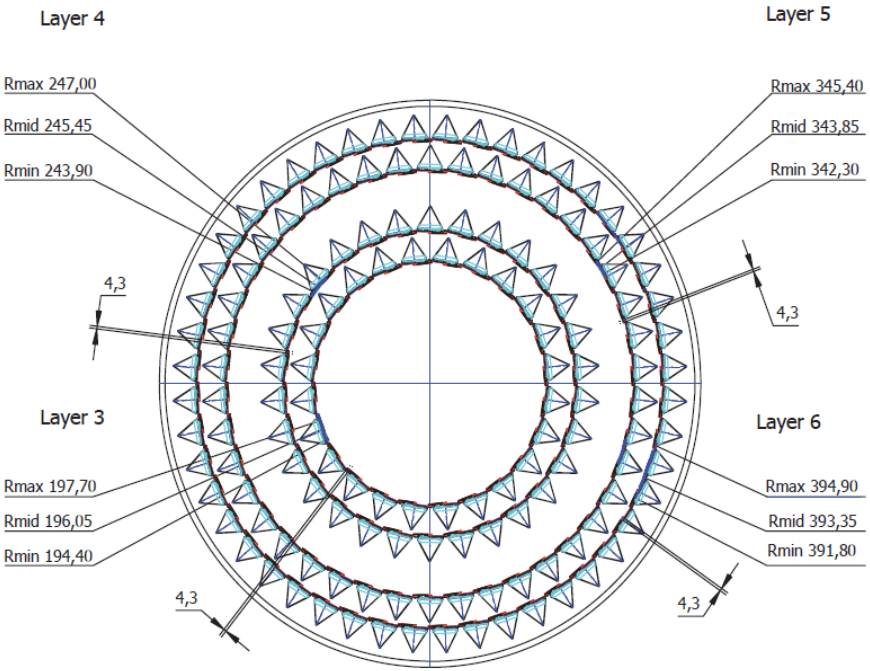
Length 290 mm
Space Frame total weight 1.5 gr

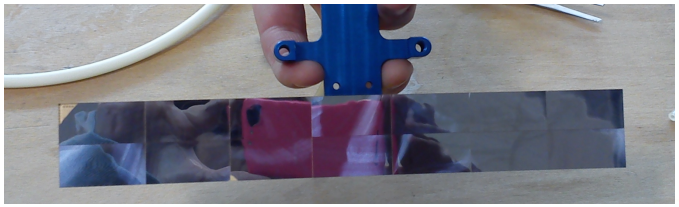
Inner Barrel: full-scale prototype

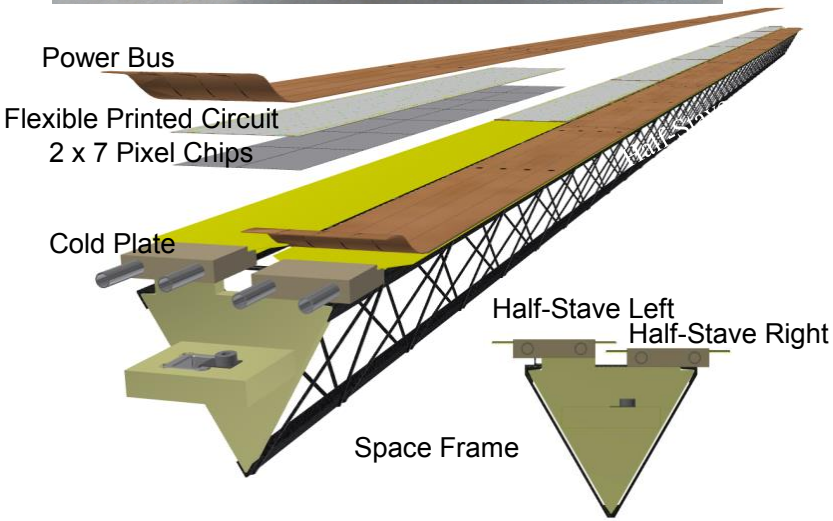




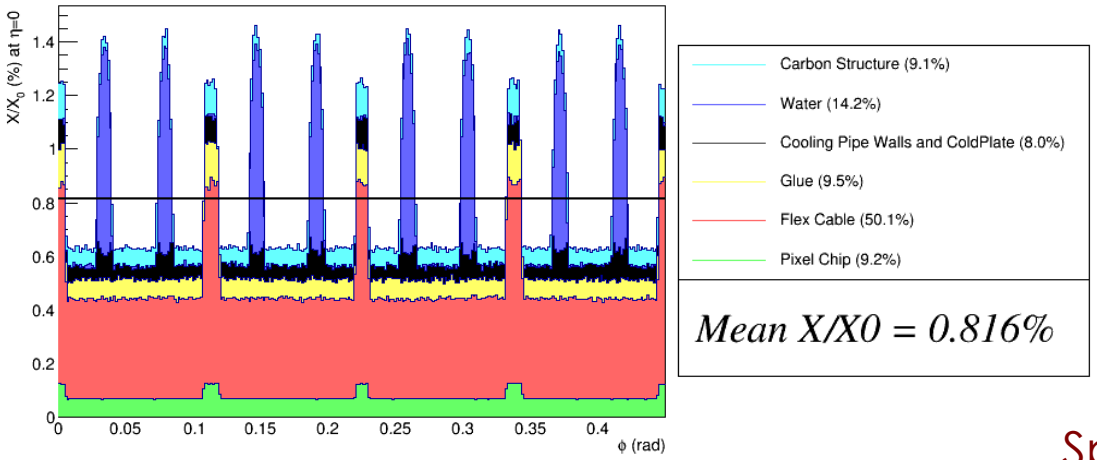
Outer Barrel

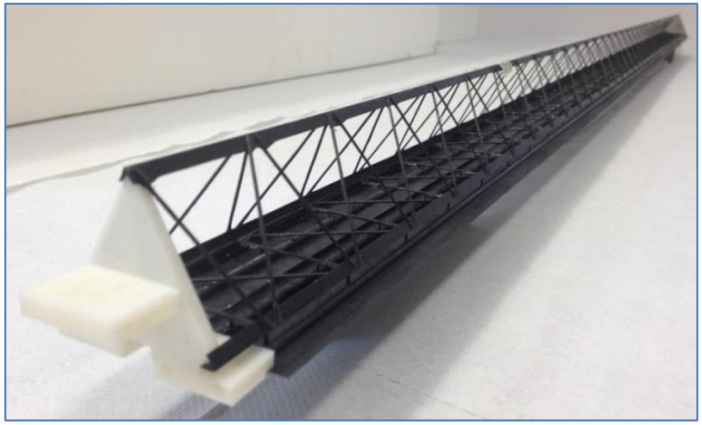




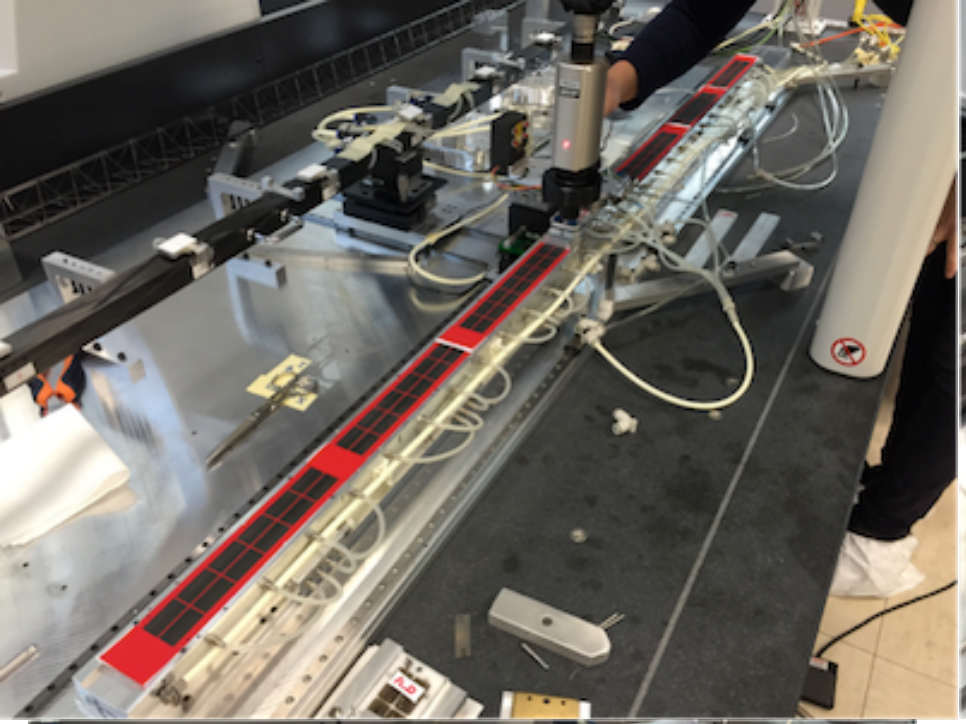


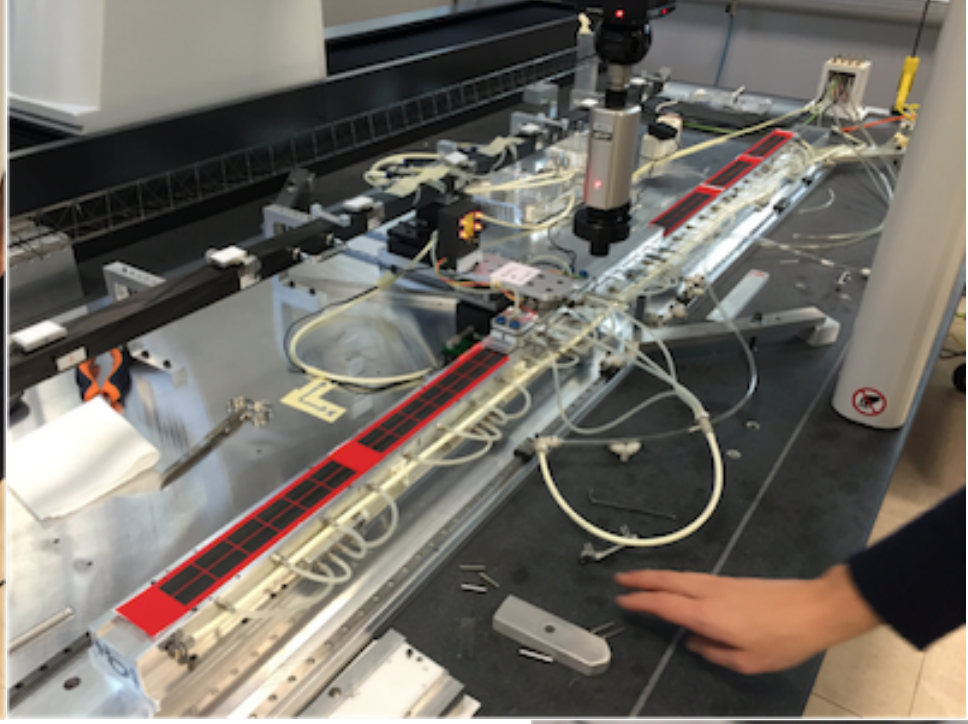
Outer Barrel Stave

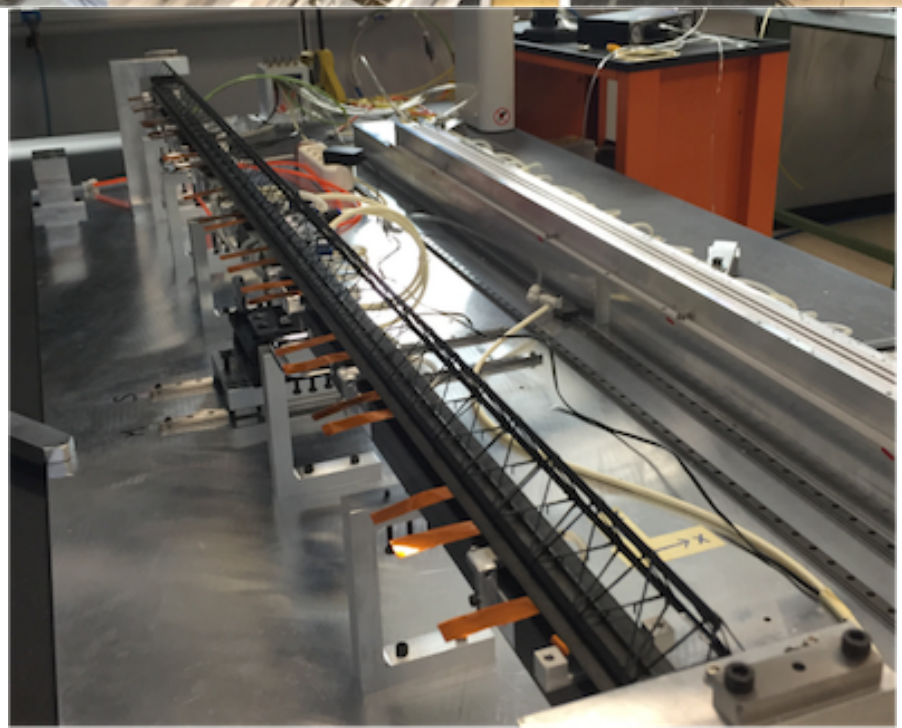


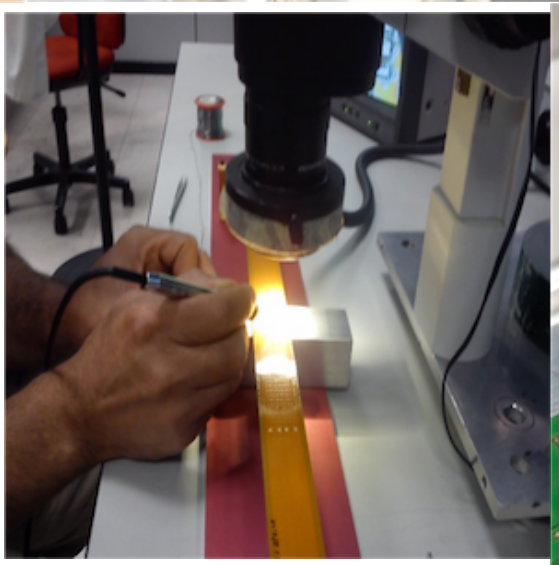


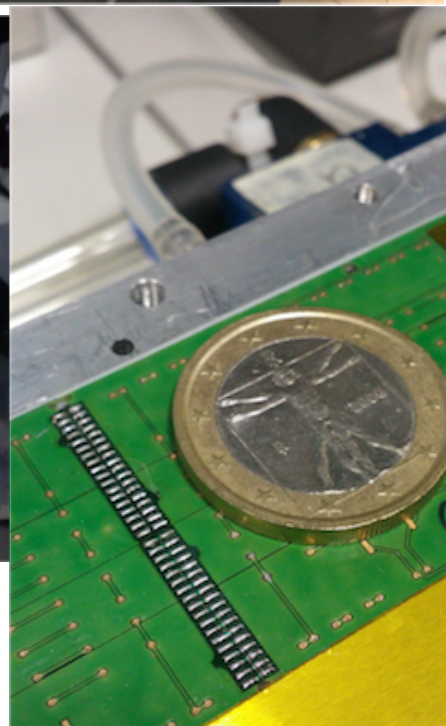
Length 1500 mm
Space Frame total weight 30 gr





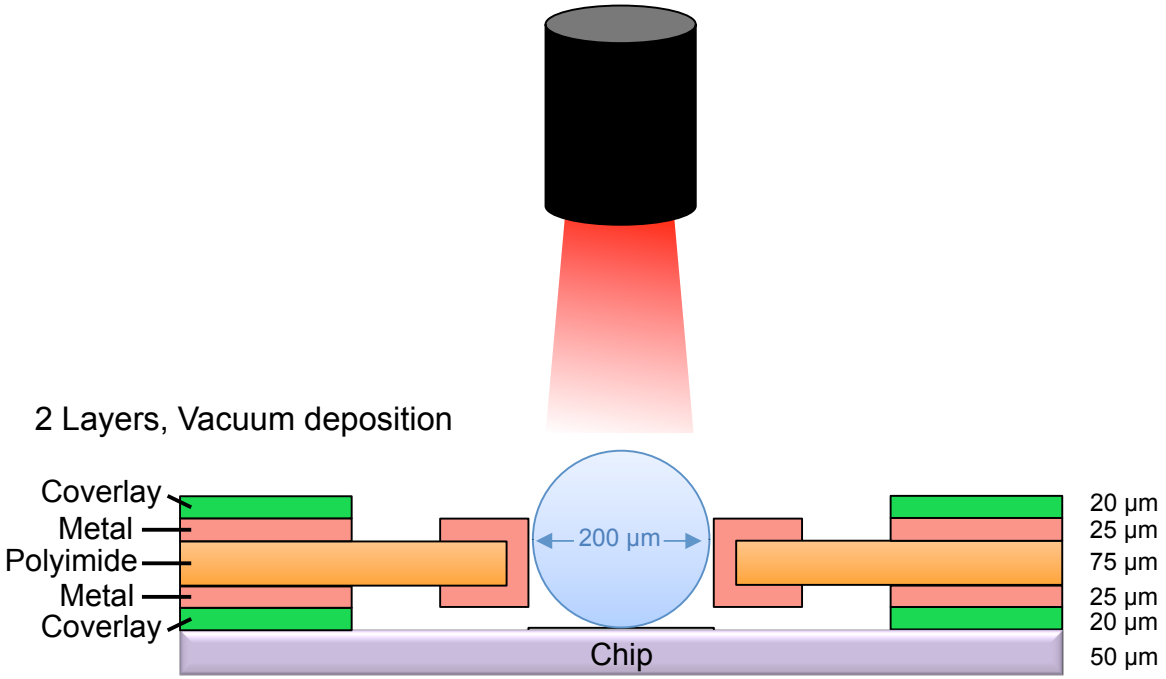


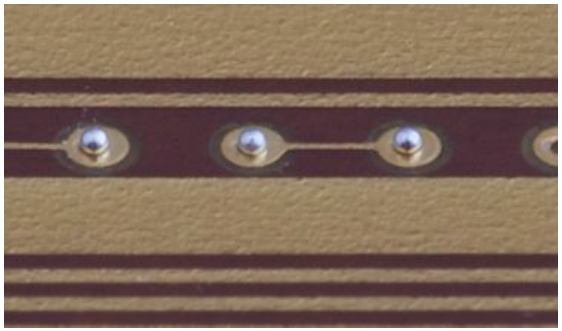


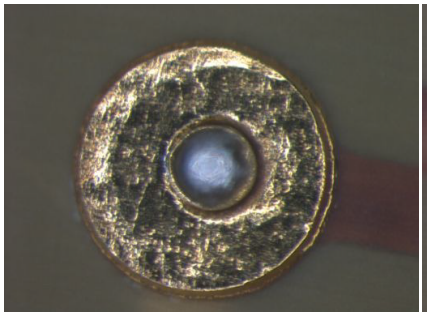


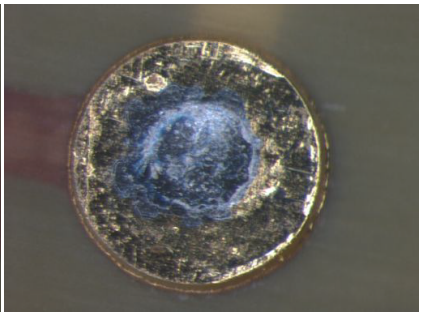
Flexible Printed Circuit (FPC) interconnection

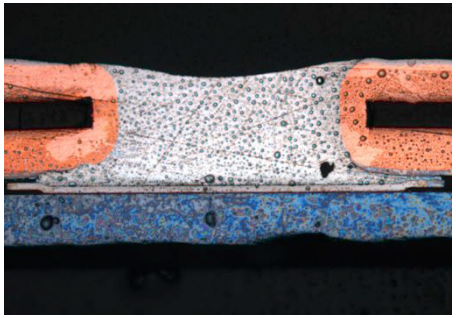
Laser soldering





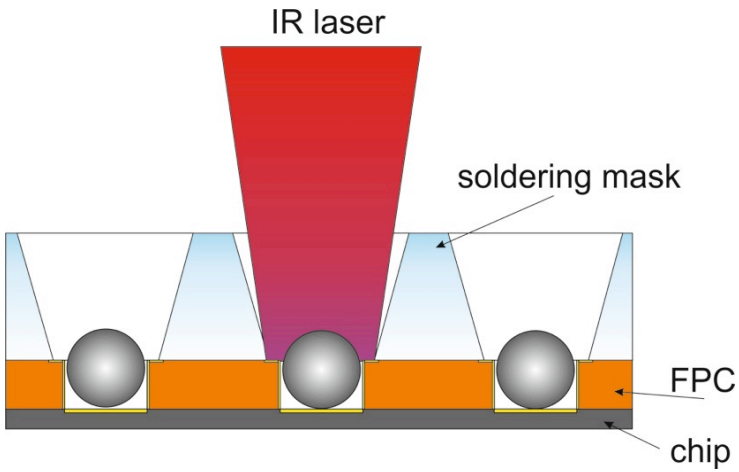


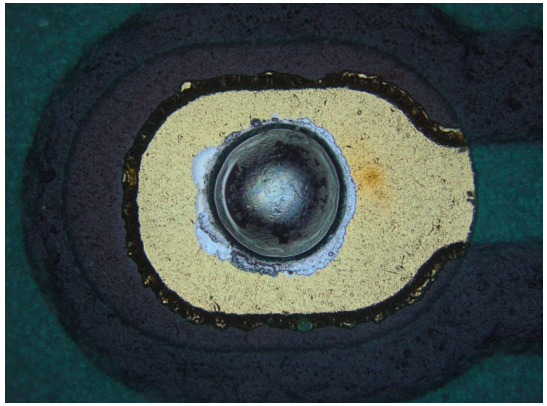


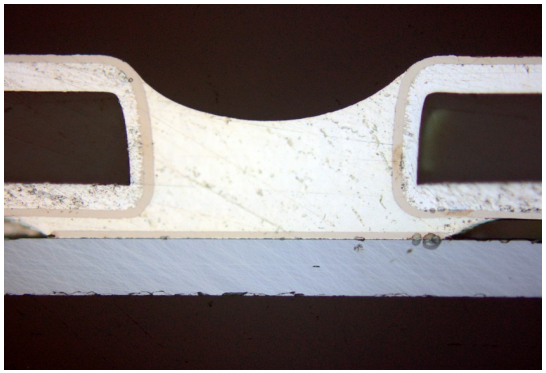


Flexible Printed Circuit (FPC) interconnection

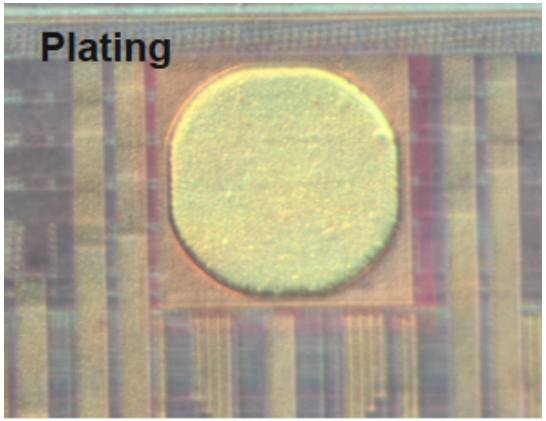
- Flux-less soldering of 200 μm diameter Sn/Ag (96.5/3.5) balls (227 °C melting T) in vacuum (<10^{-1} mbar)
- IR diode laser, 976 nm, 25 W, 50 μm focal length, 250 μm beam spot size
- Laser power modulated by pyrometer, programmable T profile ensures precise limitation of heating
- Solder provides both electrical and mechanical connection
- Pre-melting ? Conductive glue? Wire-bonding? … possible options

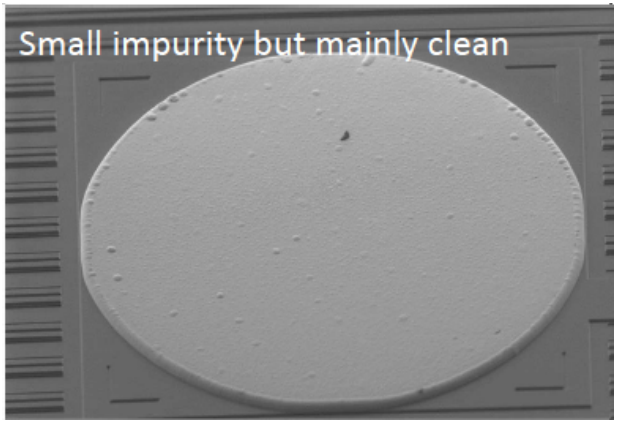


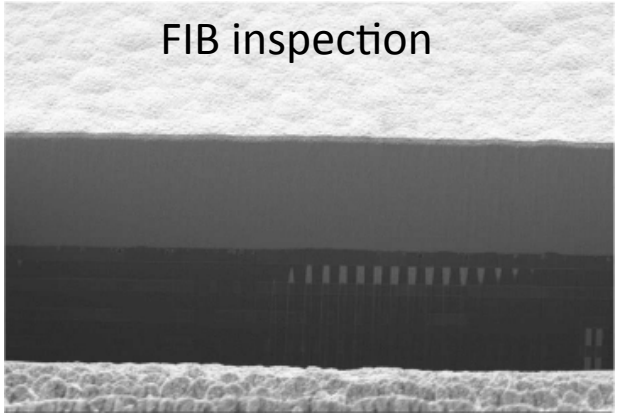




Flexible Printed Circuit (FPC) interconnection







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

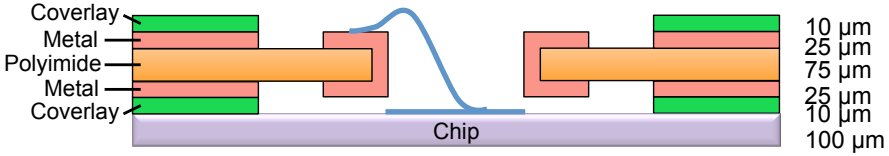
=> too often “cold” soldering or partial wetting of the pad

Interconnection of pixel chip to flex PCB

A Large Ion Collider Experiment

ALICE

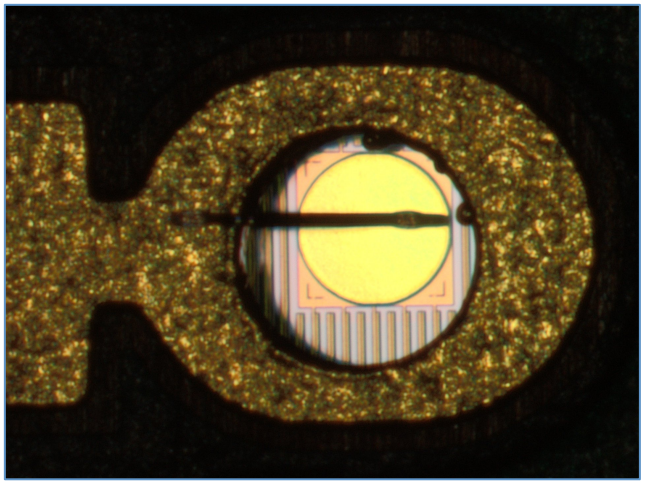
New baseline: wire bonding



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

Tests with pALPIDE-3 single-chip HIC

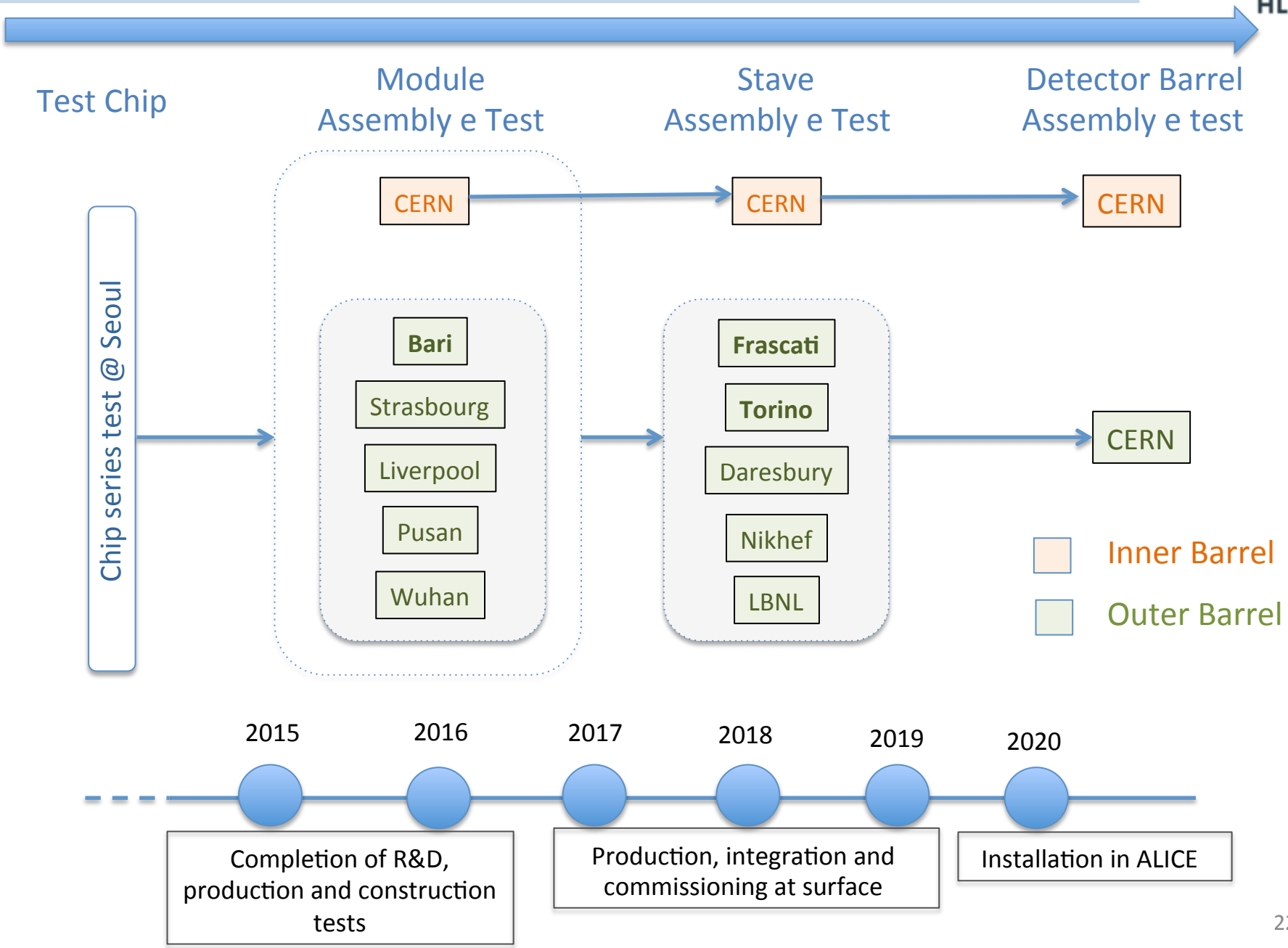
- 5 assemblies with 25µm Al wire and standard wedge tool (Bari)
- 1 assembly with 25µm Al wire and deep access wedge tool (Trieste)
- **Results: all working according to specs**



Wire Bonding

There will be multiple connections

Responsibilities and schedule



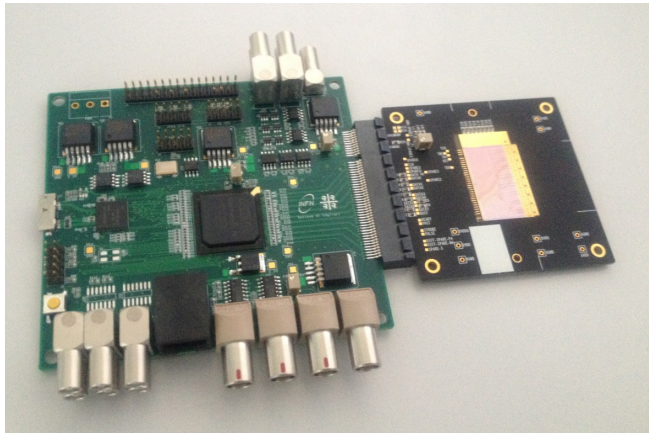
pALPIDE Characterization

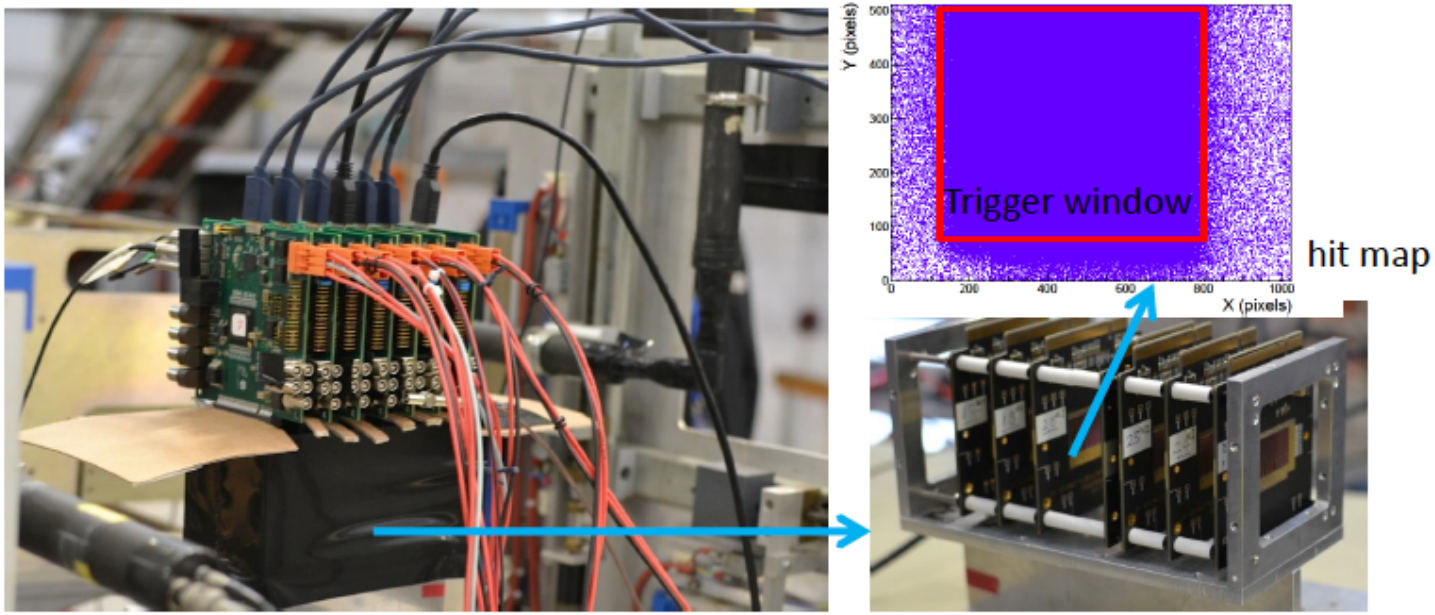
Intensive test beam campaign:

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

Scan of main parameters ➔ ~ 200 settings

7-plane telescope based on pALPIDE chip

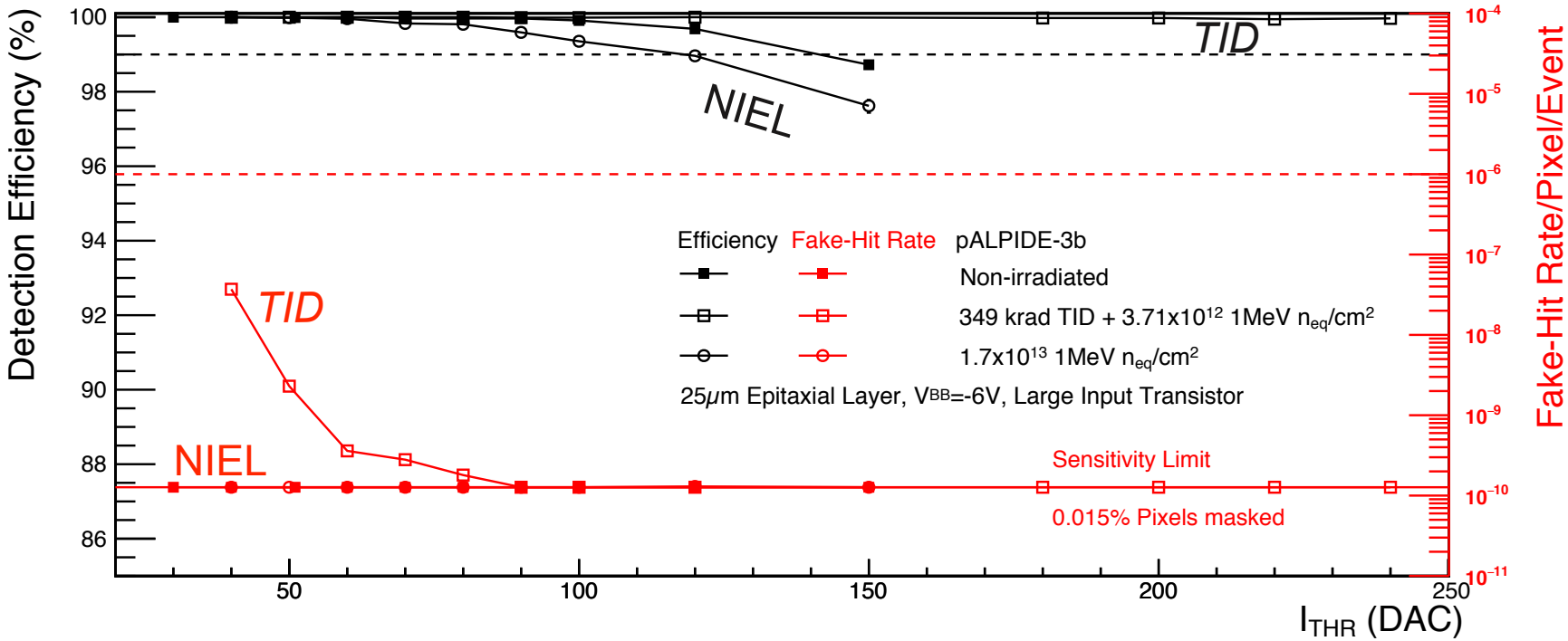




Irradiation studies at: Legnaro, Louvain La Neuve, Prague, PSI, LBNL

Test Beam: ALPIDE-3

Efficiency and fake hit rate



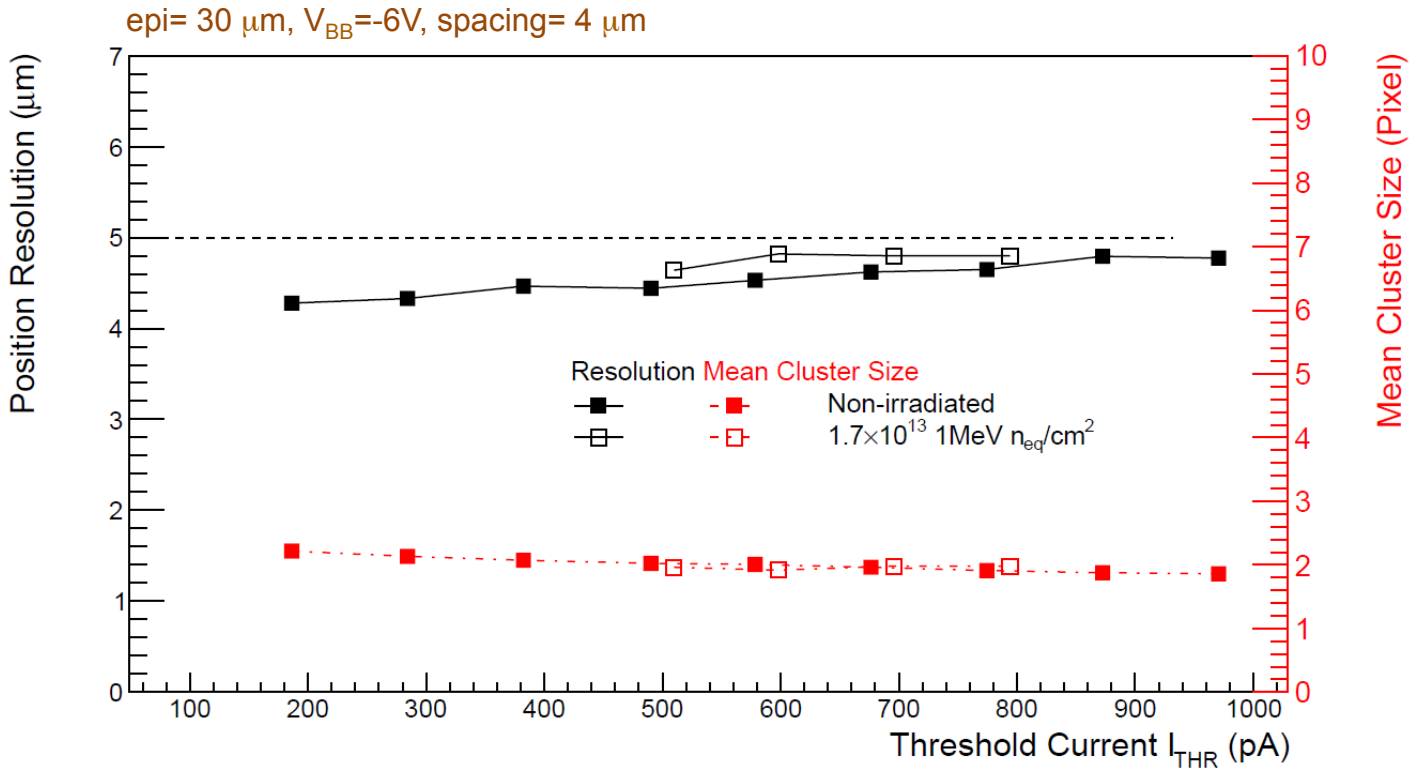
large margin over design requirements

λ_{fake} << 10^{-5} / event/pixel and ε_{det}>99% over a wide threshold range

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

Test Beam: ALPIDE-2

Spatial resolution and cluster size

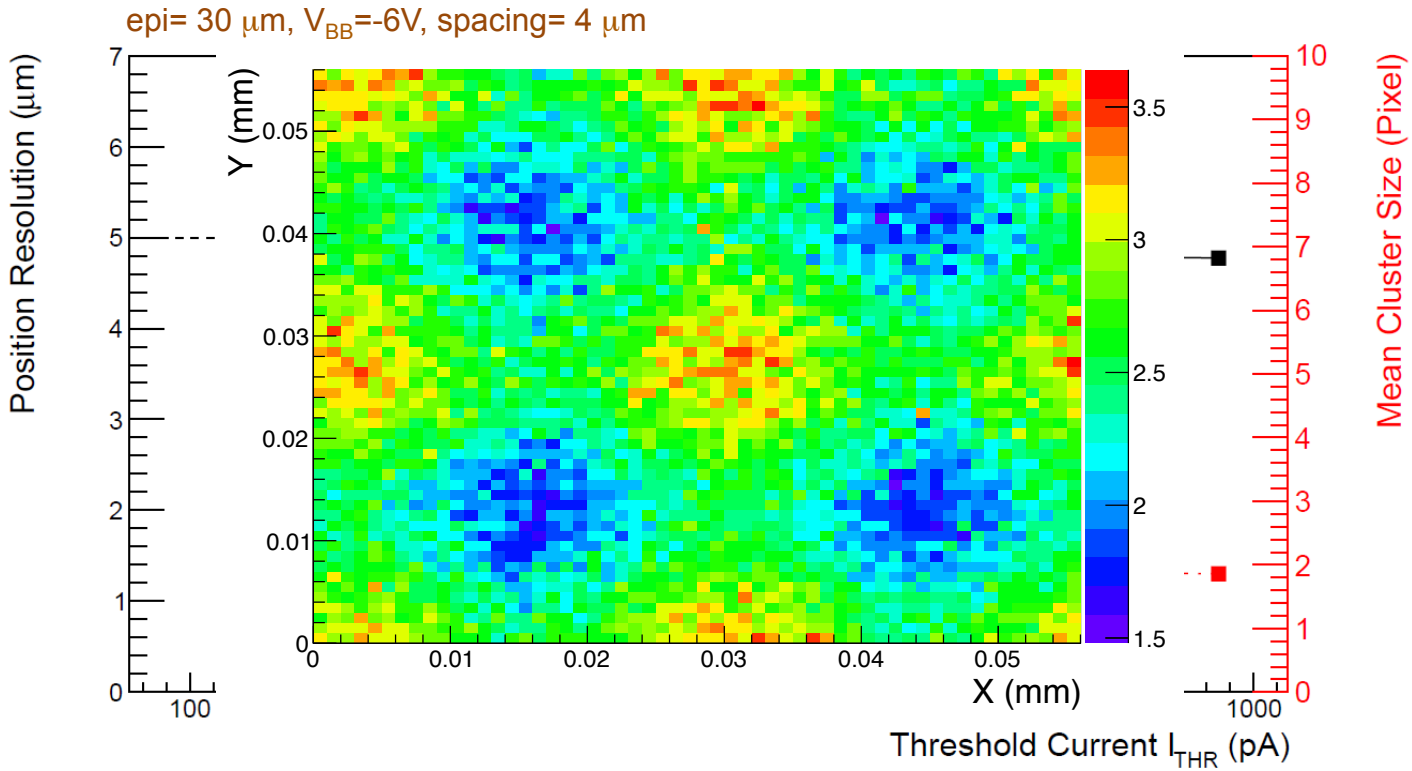


Space point resolution (including tracking error ~3 μm) < 5 μm

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

Test Beam: ALPIDE-2

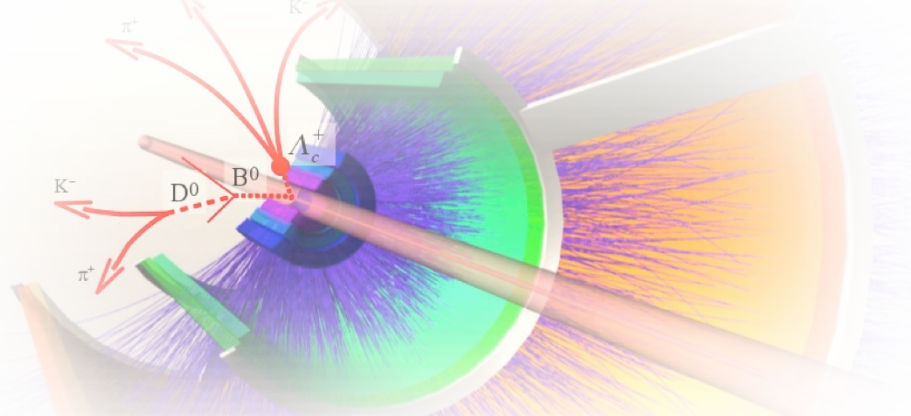
Spatial resolution and cluster size



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

<u>The new ITS represents one of the most advanced solid state detectors</u>

- ✓ *7 layers of 24.000 monolithic CMOS pixel sensors over 10 m^2 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*