The ALICE ITS Upgrade:
System Aspects & State-of-the-art in the Construction

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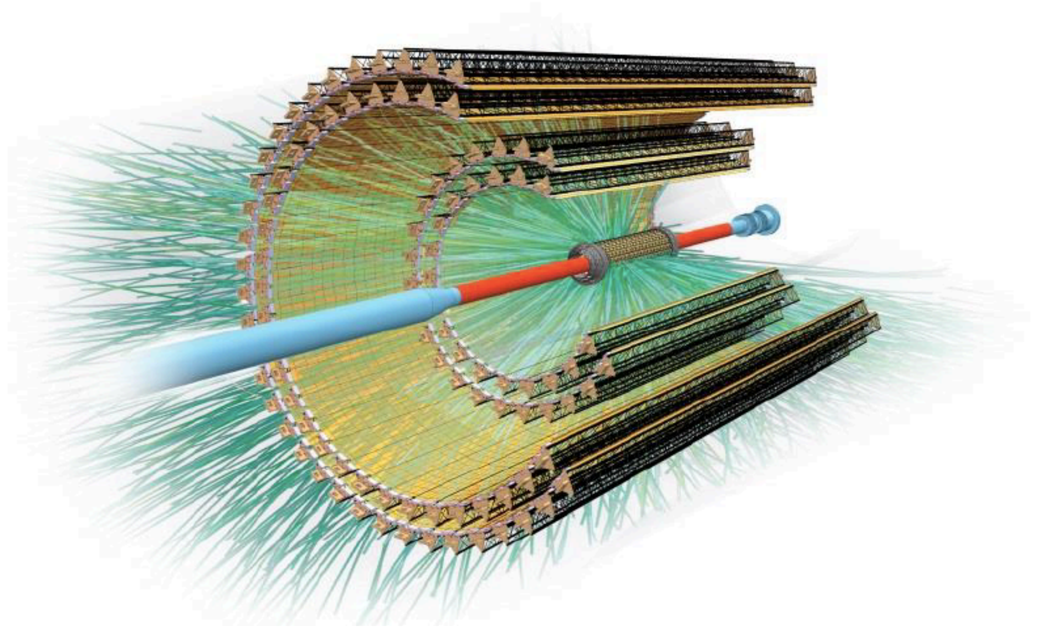
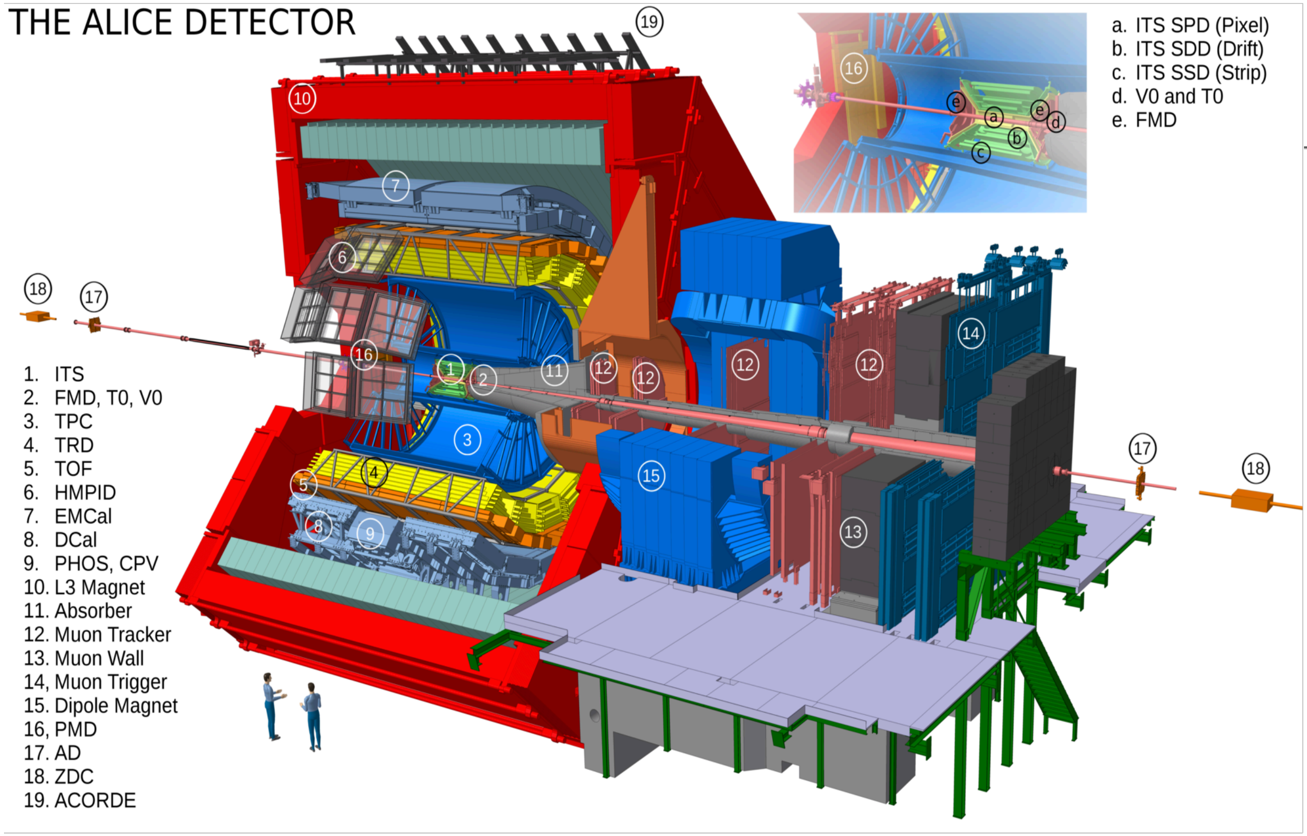
Central China Normal University



ALICE in Run 1 and Run 2



Run 1 (2009 – 2013)
Pb-Pb @ $\sqrt{s_{NN}}$ = 2.76 TeV
p-Pb @ $\sqrt{s_{NN}}$ = 5.02 TeV
pp @ $\sqrt{s}$ = 0.9, 2.76, 7, 8 TeV

Run 2 (2015 – 2018)
Pb-Pb @ $\sqrt{s_{NN}}$ = 5.02 TeV Xe-Xe @ $\sqrt{s_{NN}}$ = 5.44 TeV
p-Pb @ $\sqrt{s_{NN}}$ = 5.02, 8.16 TeV
pp @ $\sqrt{s}$ = 5, 13 TeV

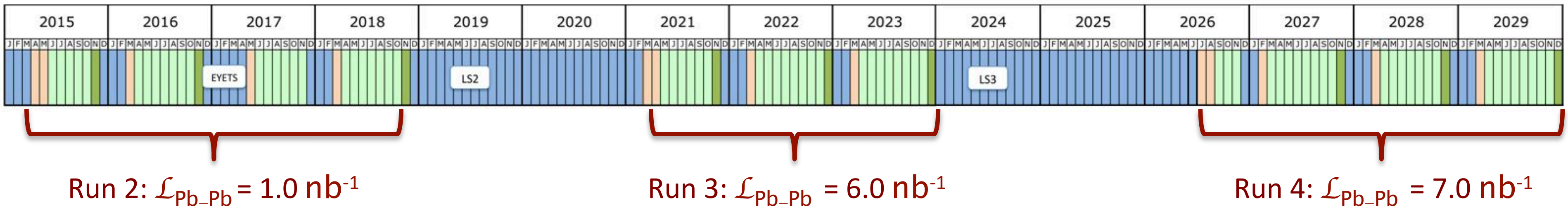
ALICE Detector:

- ✓ Central Barrel: $|\eta| < 0.9$
- ✓ Muon spectrometer: $-4.0 < \eta < -2.5$
- ✓ Forward detectors: trigger, centrality

Operation in Run 1 and Run 2:

- ✓ Tracking and PID in large kinematic range
- ✓ High resolution vertex reconstruction

ALICE Upgrade Motivations



ALICE strategy for Run 3 + Run 4

- ✓ 50 kHz Pb-Pb interaction rate (current < 10 kHz)
- ✓ Collect $\mathcal{L}_{Pb\_Pb} \geq 13.0\ nb^{-1}$
- ✓ Experiment upgrades during LS2

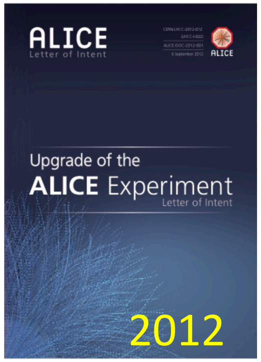
ALICE physics goal → High-precision measurements of QGP properties

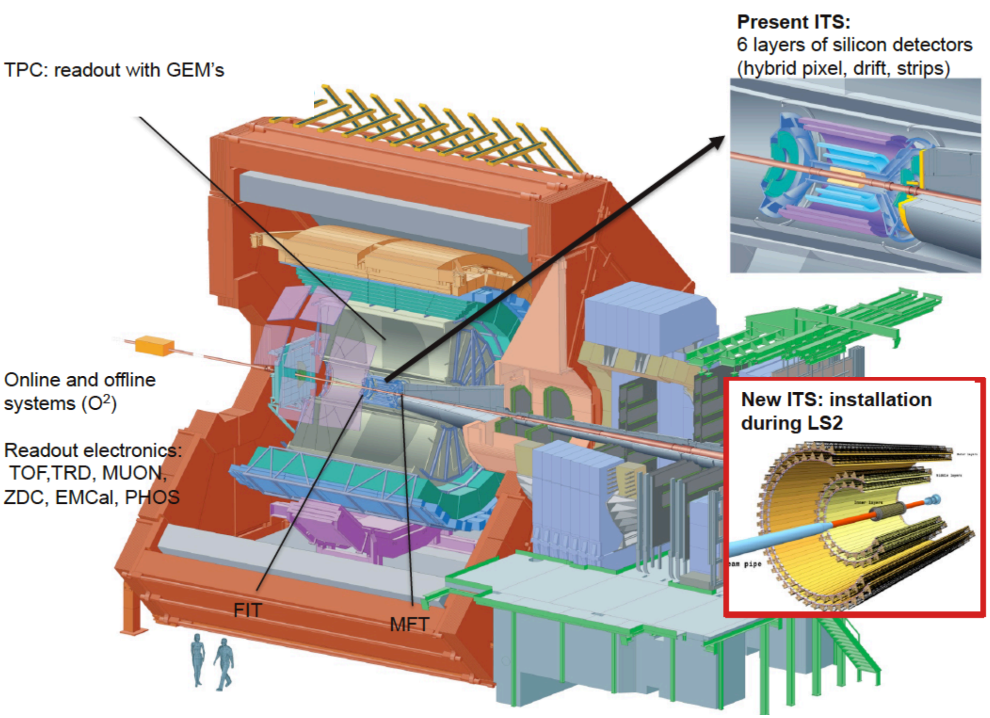
- Heavy-flavour and Quarkonia at very low p_T
  - Mechanism of quark-medium interactions
  - Dissociation/regeneration as tool to study de-confinement and medium temperature
- Low-mass vector mesons and low-mass di-leptons
  - Chiral symmetry restoration, initial temperature and EOS
- High-precision measurement of light nuclei and hyper-nuclei
  - QGP nucleosynthesis, exotics

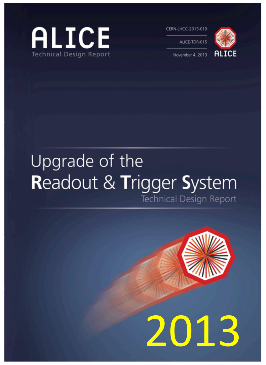
ALICE Upgrade Motivations

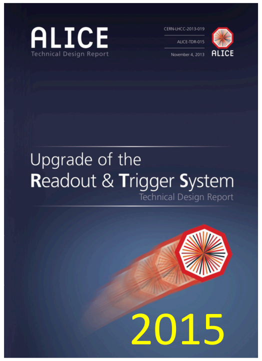
Main detector requirements

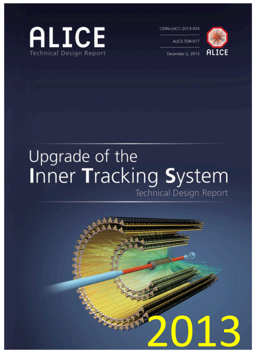
- High tracking efficiency and resolution at low p_T
  - ❖ Increase granularity, reduce material thickness
- High-statistics, un-triggered data sample
  - ❖ Increase readout rate, reduce data size (online data reduction)
- Preserve excellent particle id capabilities
  - ❖ Consolidate and “speed-up” PID detectors

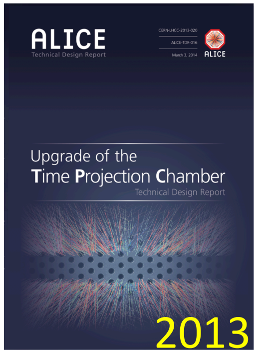


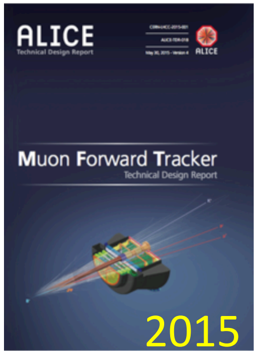








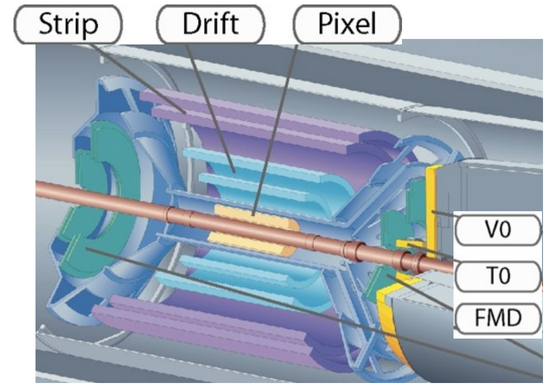




ALICE ITS Upgrade

1. Improve impact parameter resolution by a factor of 3 (5) in *rφ* (z)

- Reduce beam pipe radius: 29mm ➡18.2 mm
- Get closer to IP (position of first layer): 39 mm ➡23 mm (layer 0)
- Reduce material budget: ~1.14% ➡ ~ 0.3% (for inner layers)
- Reduce pixel size: 50mm x 425mm ➡ 29 mm x 27 mm

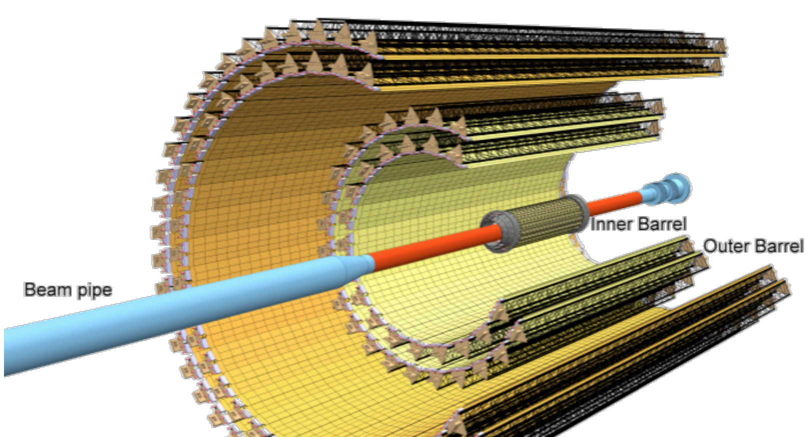


Current ITS

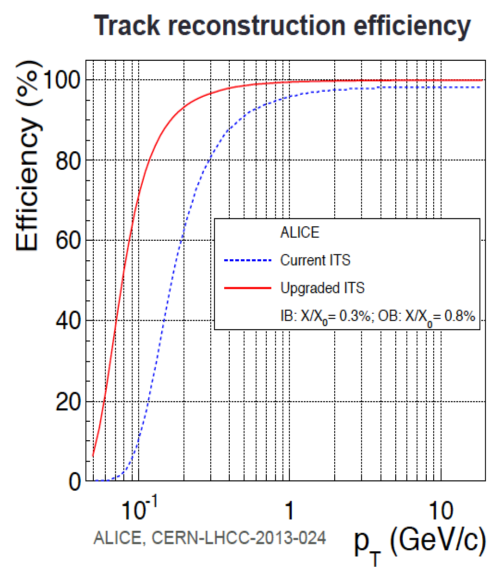
2. Improve tracking efficiency and p_T resolution at low p_T

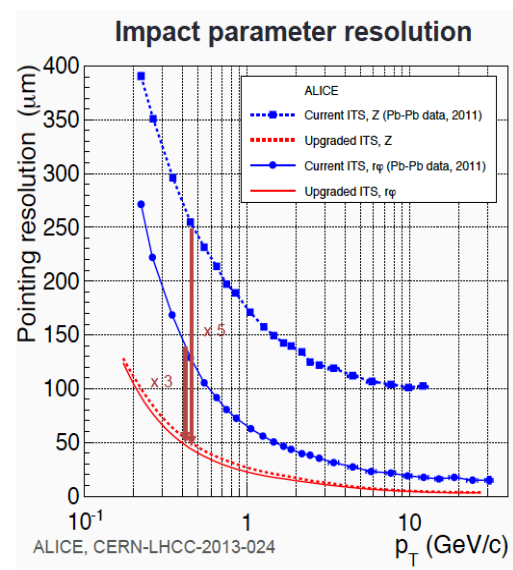
- Improved integration time: < 10 μs
- Increase granularity and radial extension: 6 layers ➡ 7 MAPS layers

3. Fast readout: 50 kHz @ Pb-Pb



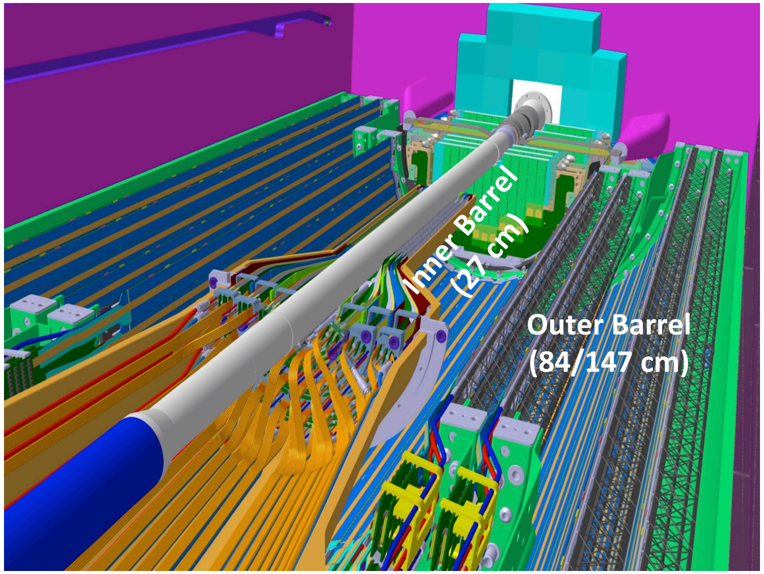
New ITS
7 layers of MAPS
12.5G pixels, ~10 m² active area

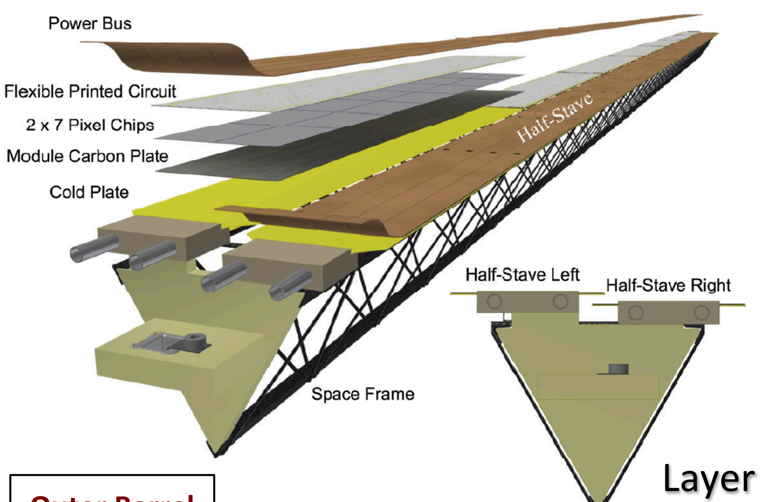




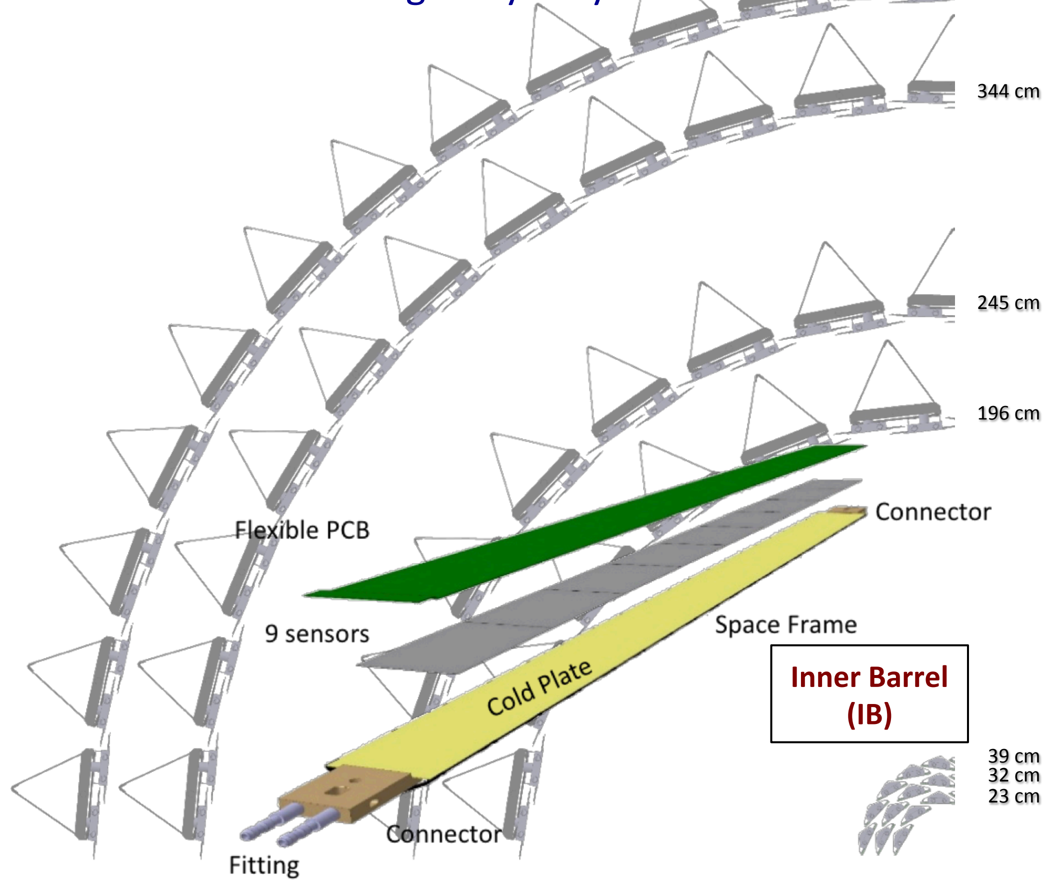
New ITS Layout

- ✓ Ultra-lightweight support structure and cooling
- ✓ Possible to remove and re-install the detector for maintenance during the yearly shutdowns





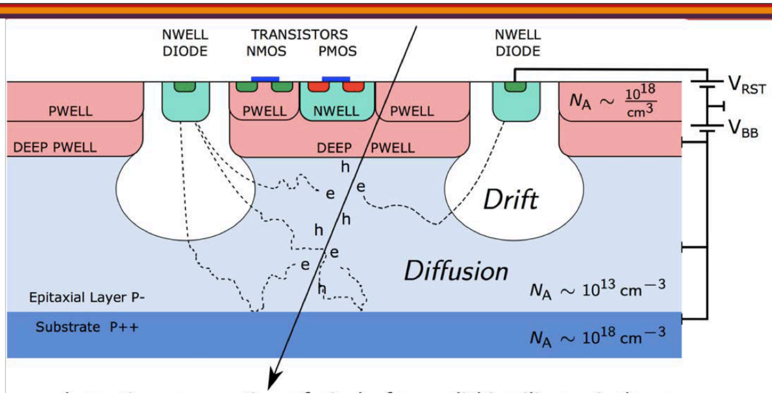
Outer Barrel (OB)



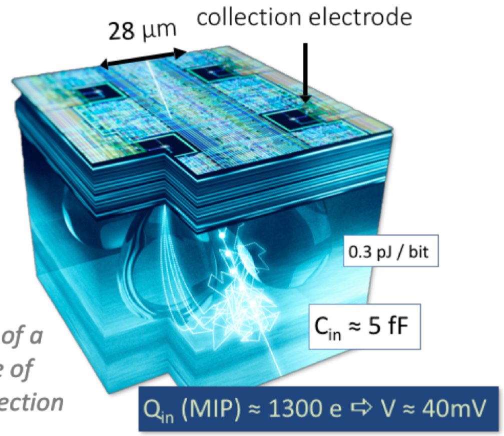
Inner Barrel (IB)

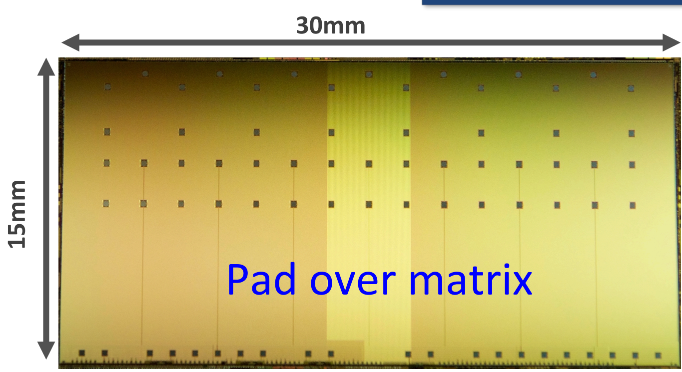
Layer #	6	5	4	3	2	1	0
N. of Stave	48	42	30	24	20	16	12

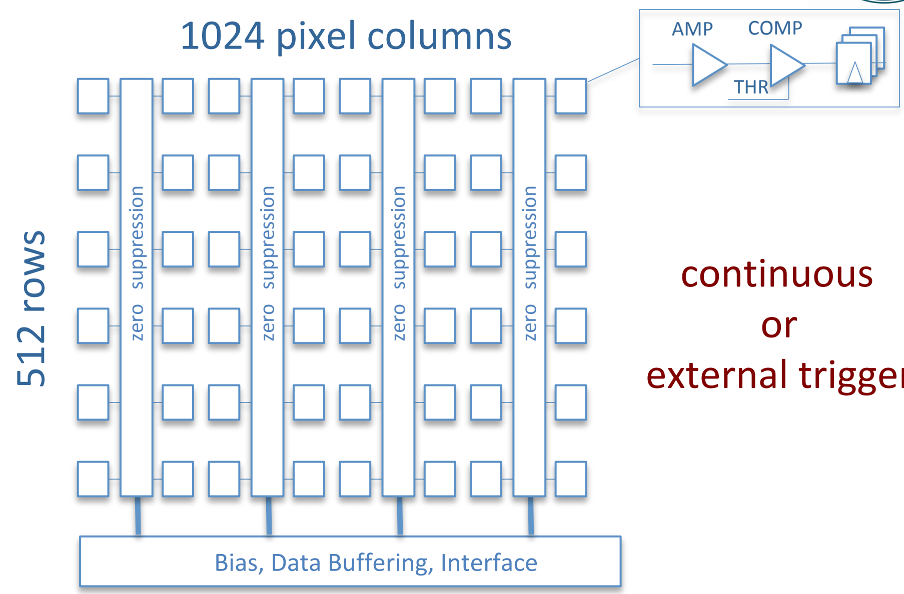
CMOS MAPS – ALICE PIxel Detector (ALPIDE)



MAPS manufactured in Tower-Jazz 180nm CMOS





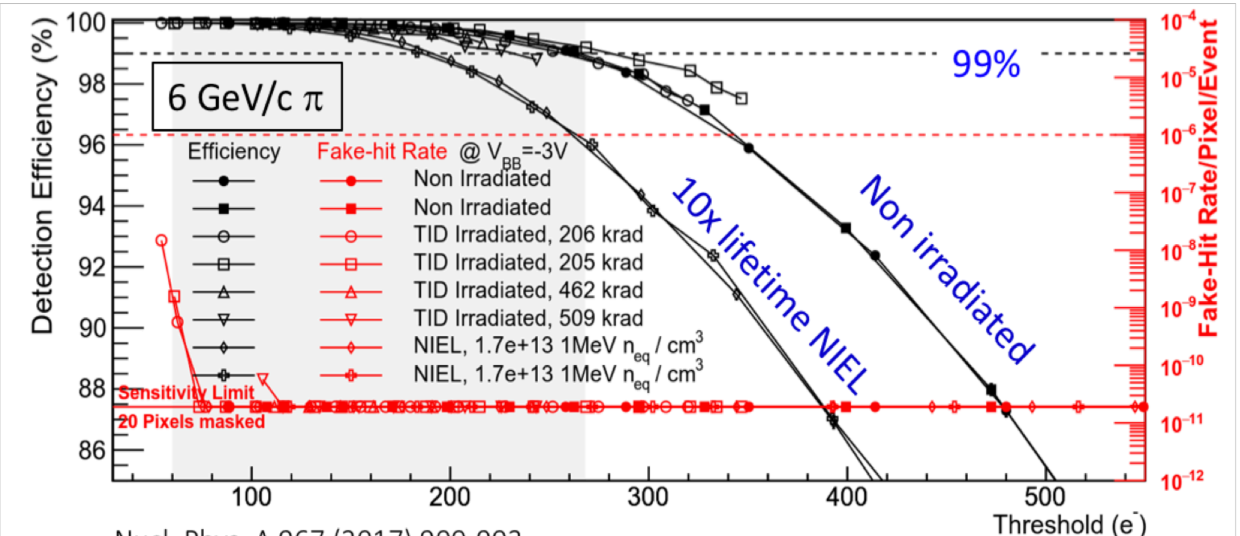


continuous
or
external trigger

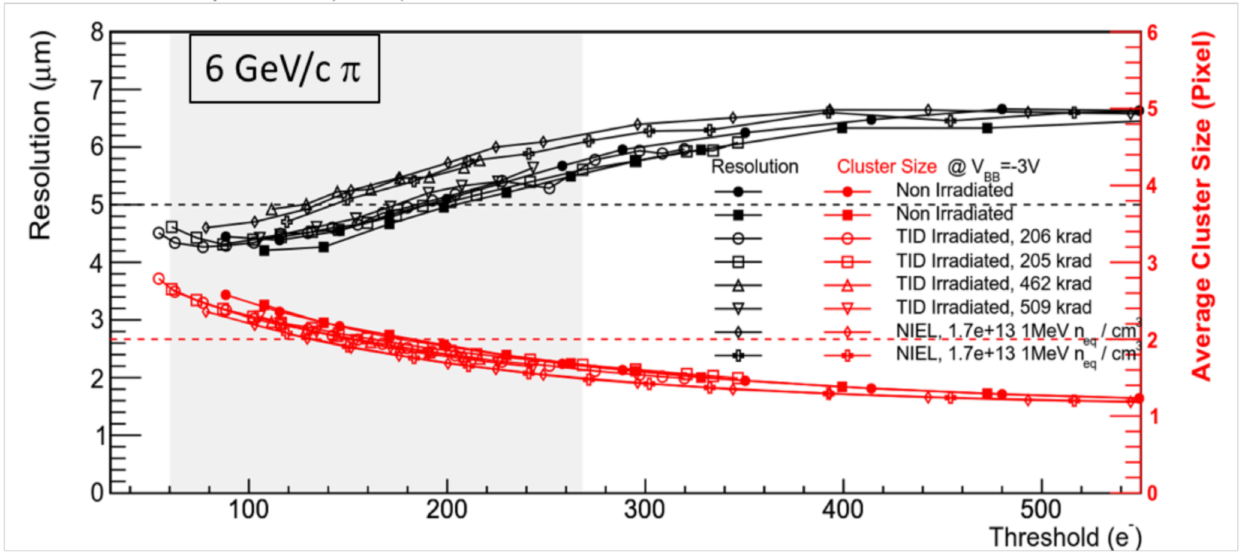
Key Features:

- Dimensions: 30mm x 15mm x 50 (100) μm
- Pixel pitch: 29μm x 27μm
- Spatial resolution: ~ 5 μm (3-D)
- Fake-hit rate: ~10^{-10} pixel/event
- Ultra-low power (entire chip): < 40mW/cm^2
- Global shutter: triggered acquisition (200 kHz) or continuous (integration time <10μs)

ALPIDE radiation tolerance:



Nucl. Phys. A 967 (2017) 900-903



- Radiation requirements:
  - 270 krad
  - 1.7×10^{12} 1 MeV n_{eq} / cm^2
- After 10x lifetime NIEL irradiation

  Fake hit rate: 10^{-10} hit/event with 0.002% masked pixels
- Spatial resolution: 5 μm
- Negligible chip to chip variations
- Excellent detector performance before/after irradiation over a wide range of operational setting

CMOS MAPS – ALICE PIxel Detector (ALPIDE)

1500 raw wafers — **Raw Wafer Production** → 5% → **Raw Wafer QA** TMEC (Thailand)

~1200 CMOS wafers — **CMOS Manufacturing** TowerJazz (Israel) → 8% (2/25) → **Wafer Probe Testing** CERN

60,000 chips — **Thinning & Dicing** FUREX (South Korea)

Pick & Place FUREX (South Korea), tbc. → 100% → 100 µm **Chip Series Testing** Yonsei, Pusan/Inha (South Korea)

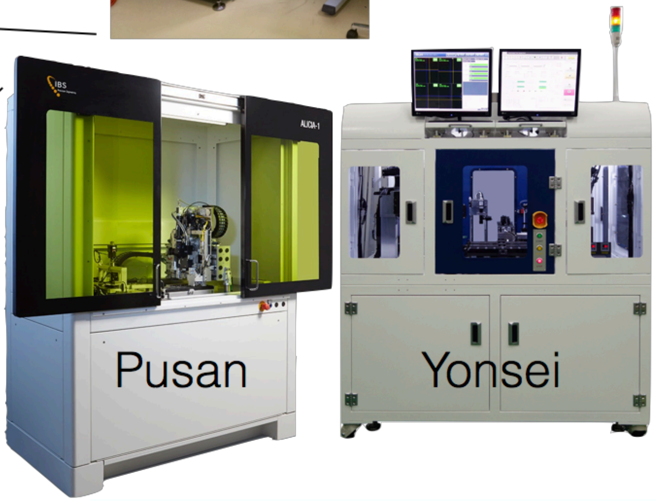
Detector assembly

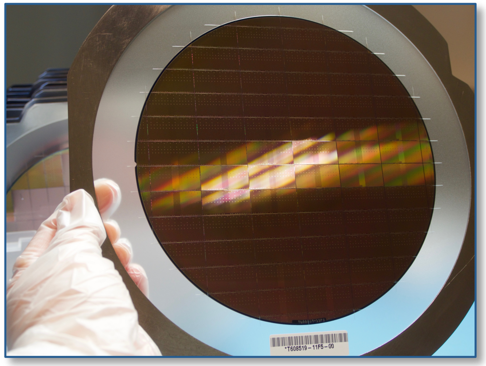
(Bari, Liverpool, Pusan, Strasbourg, Wuhan)

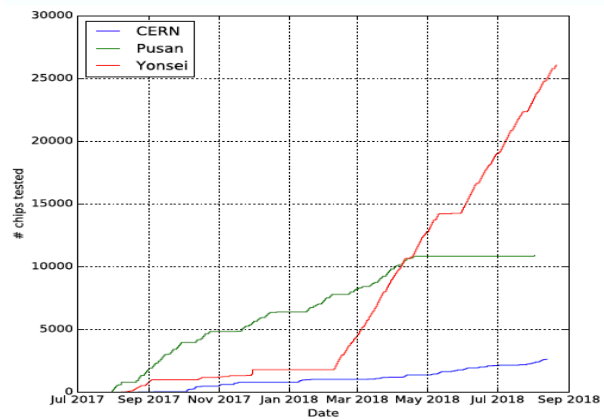
50 µm ↓ **Chip Series Testing** CERN

Detector assembly

(CERN)



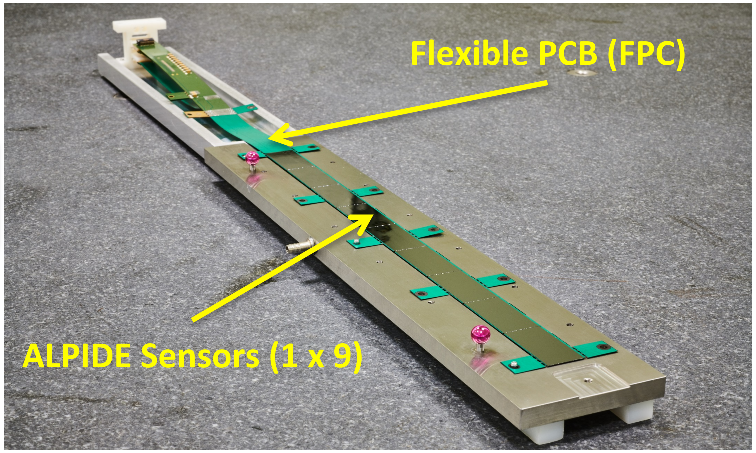


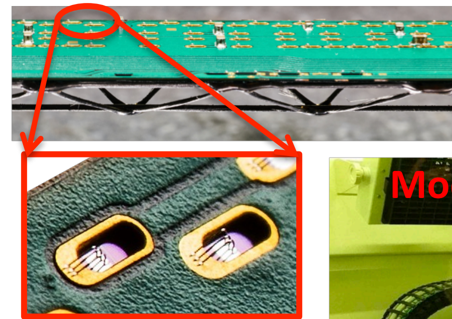


ALPIDE production started in 2017

Construction – Inner Barrel HIC Modules and Staves

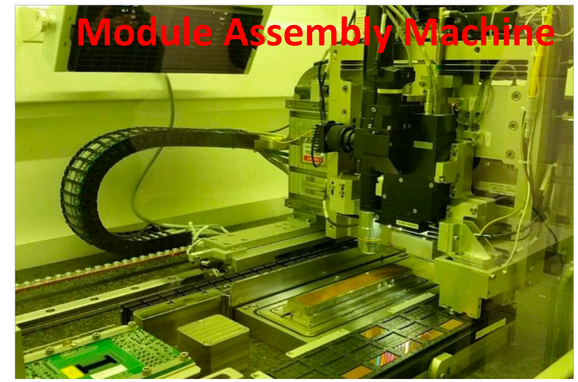
Module Assembly



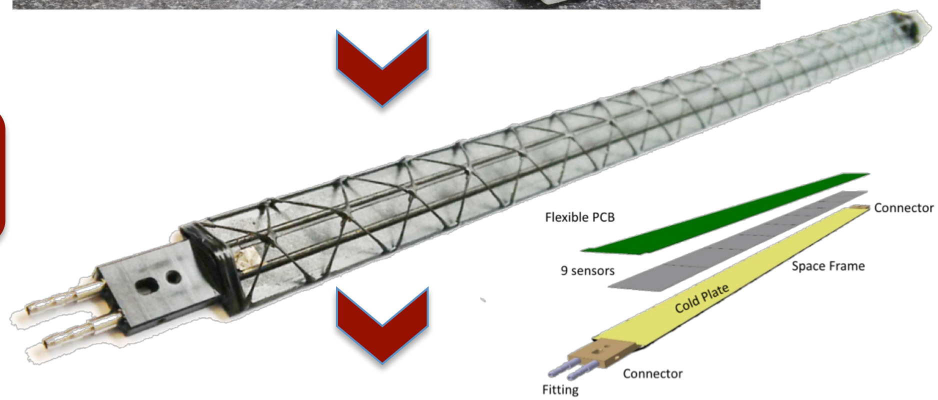


HIC: Hybrid Integrated Circuit
(IB: 9 chips + FPC; OB: 14 chips + FPC)

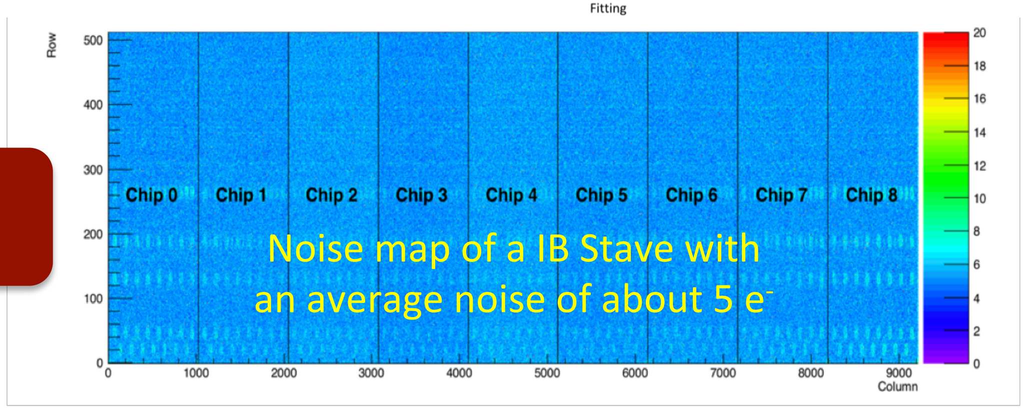
ALICIA:



Stave Assembly



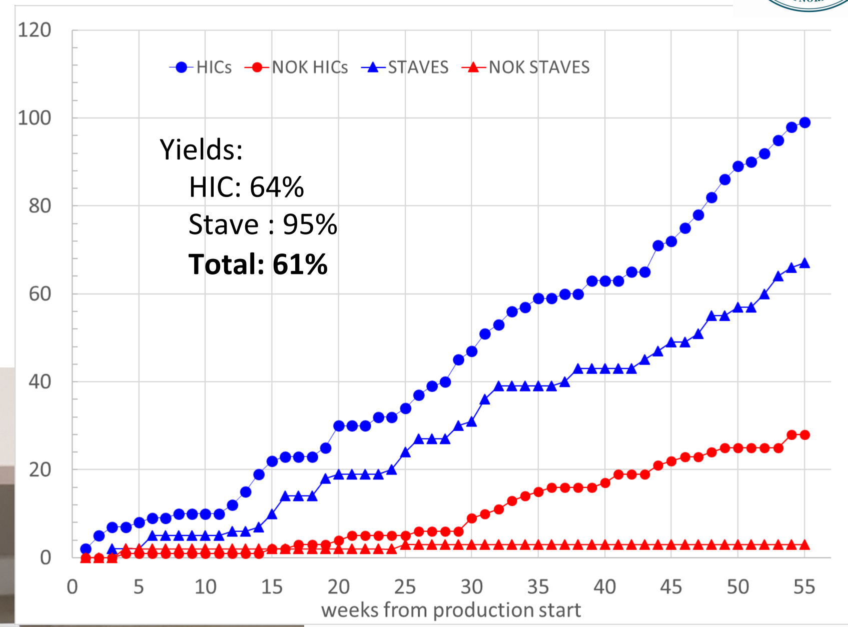
Testing

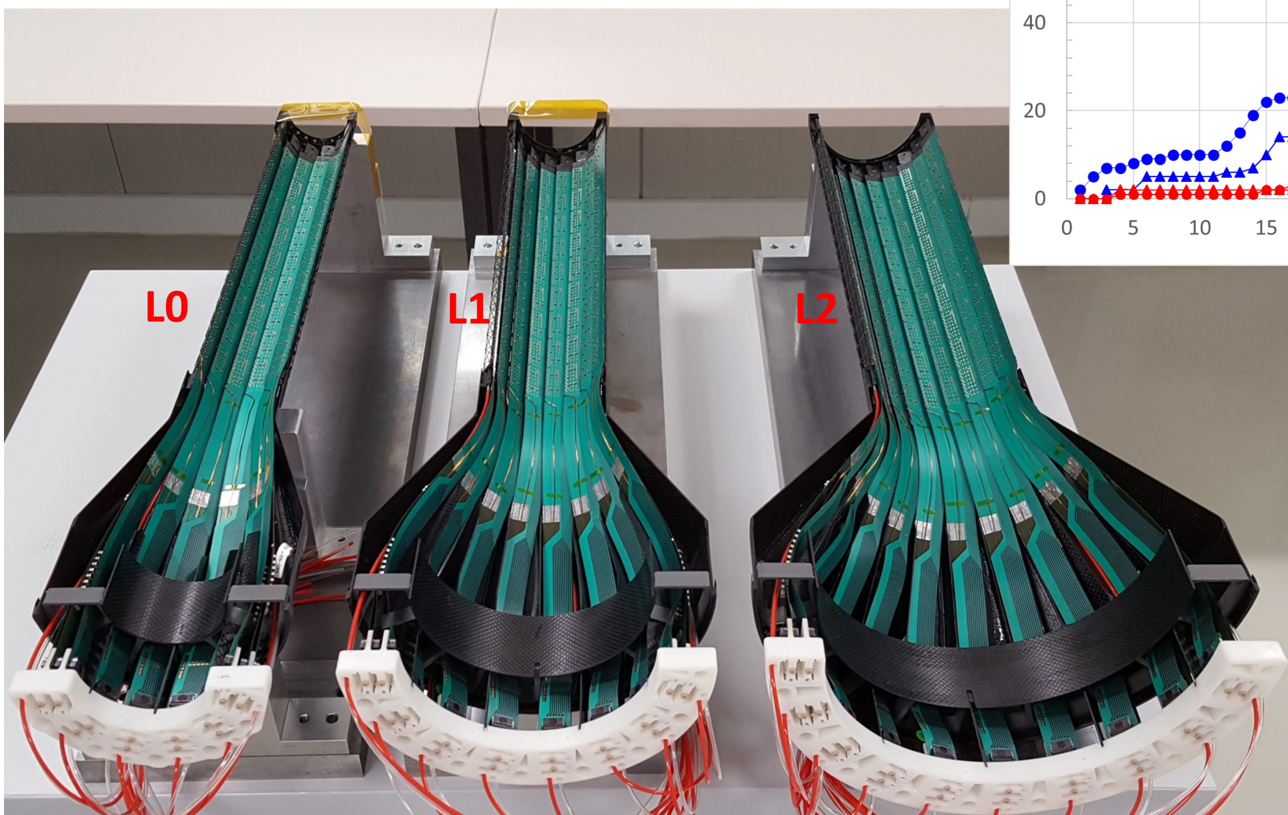


- Required production quantity
  - 120 HICs (48 staves per Inner Barrel, 2 Inner Barrels, plus spares)
- Sensor alignment in a custom designed Module Assembly Machine (ALICIA):
  - 5 µm precision chip placement
  - 6 machines were installed at HIC construction sites (IB: CERN; OB: Bari, Liverpool, Pusan, Strasbourg, Wuhan)
- HIC/Stave testing
  - using dedicated test setup
  - classification scheme according to the results of various functional tests

Construction – Inner Barrel Production and Commissioning

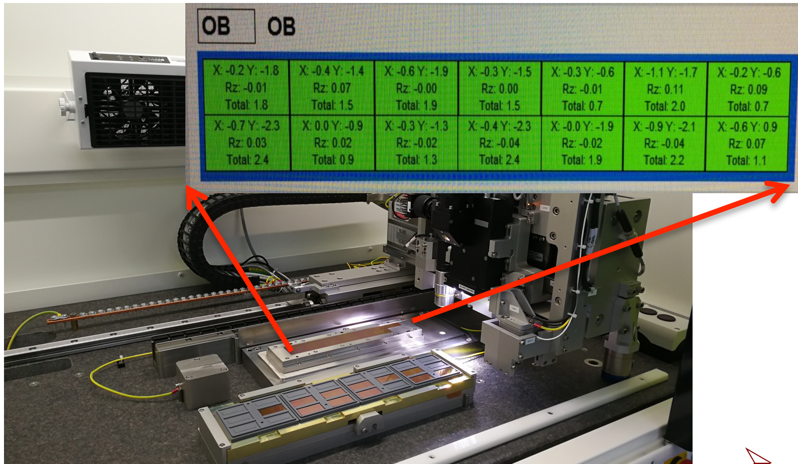
- Staves for 1st Inner Barrel (IB1) completed
- Commissioning ongoing:
  - ✓ Assembly und support structures
  - ✓ Cabling and connection to readout units (RU)
  - ✓ Commissioning of Central Readout Units (CRU) and First Level Processor (FLP)

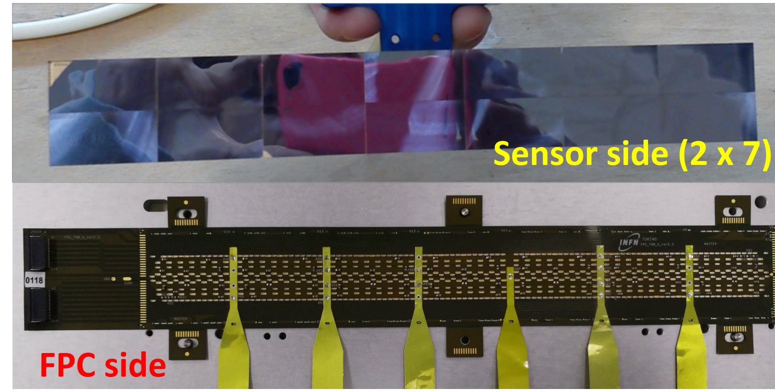




Construction – Outer Barrel HIC Modules

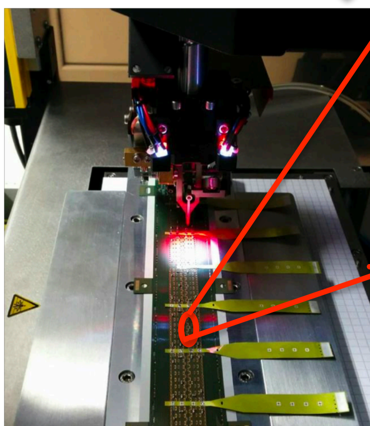
Chip Alignment

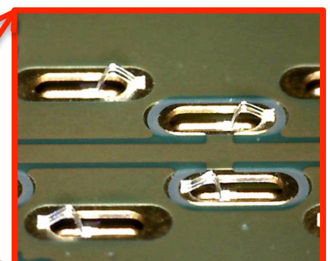




- **OB HIC Production**
  - 1692 HIC modules required
  - 5 HIC production sites: Bari, Liverpool, Strasbourg, Wuhan, Pusan
  - Target rate: 2 HICs per day per site

Wire Bonding

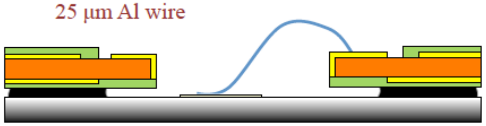




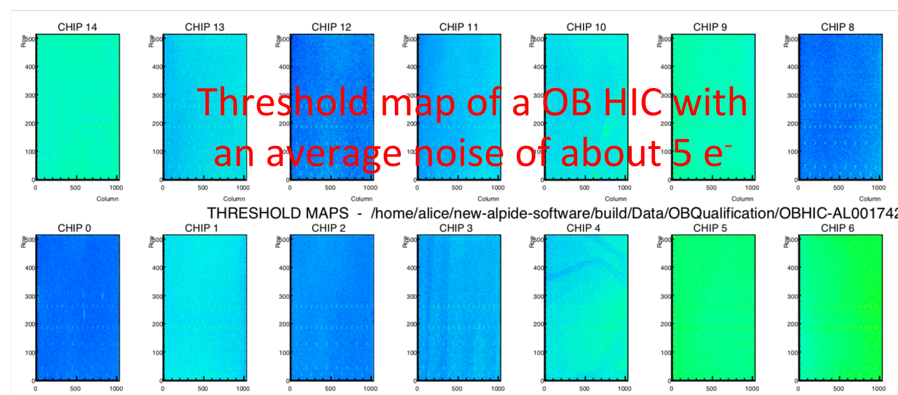
FPC-to-ALPIDE interconnection

Wire-bonding through vias

25 μm Al wire



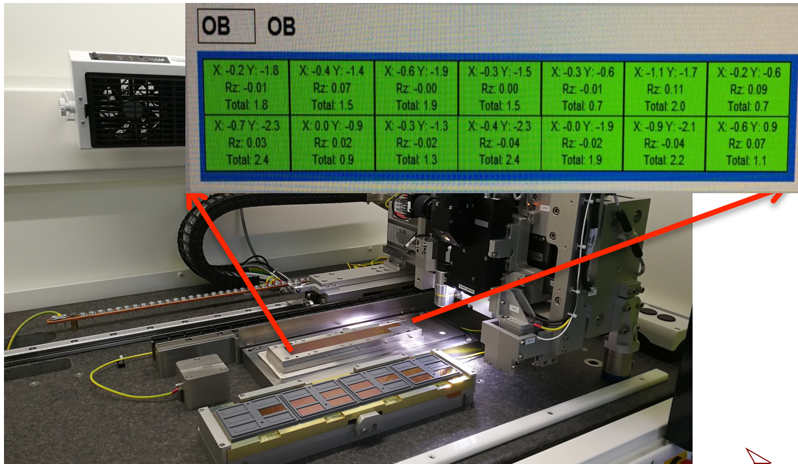
Testing

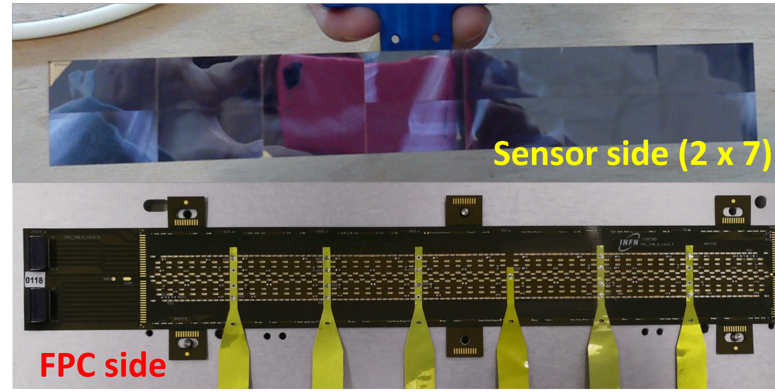


Threshold map of a OB HIC with an average noise of about 5 e$^-$

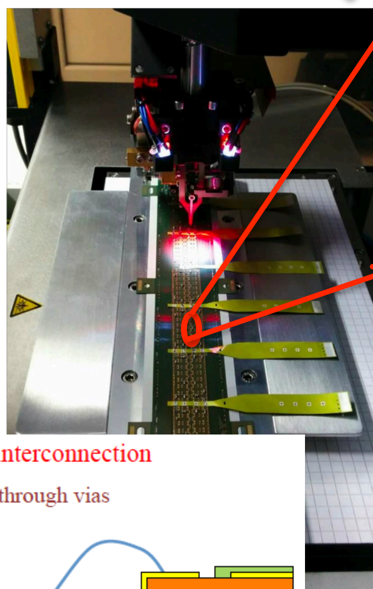
Construction – Outer Barrel HIC Modules

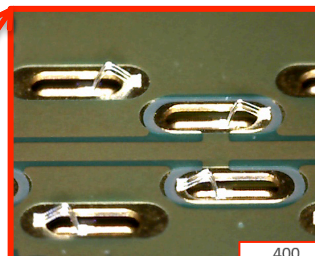
Chip Alignment





Wire Bonding

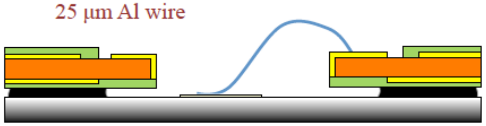




FPC-to-ALPIDE interconnection

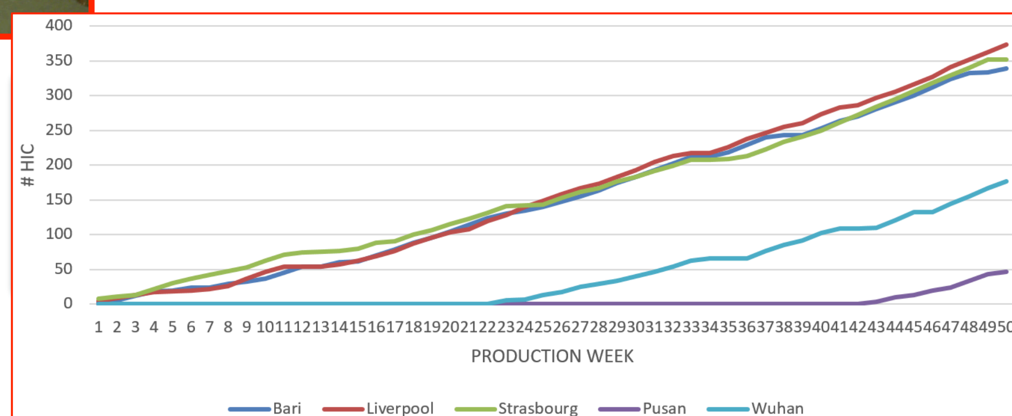
Wire-bonding through vias

25 µm Al wire

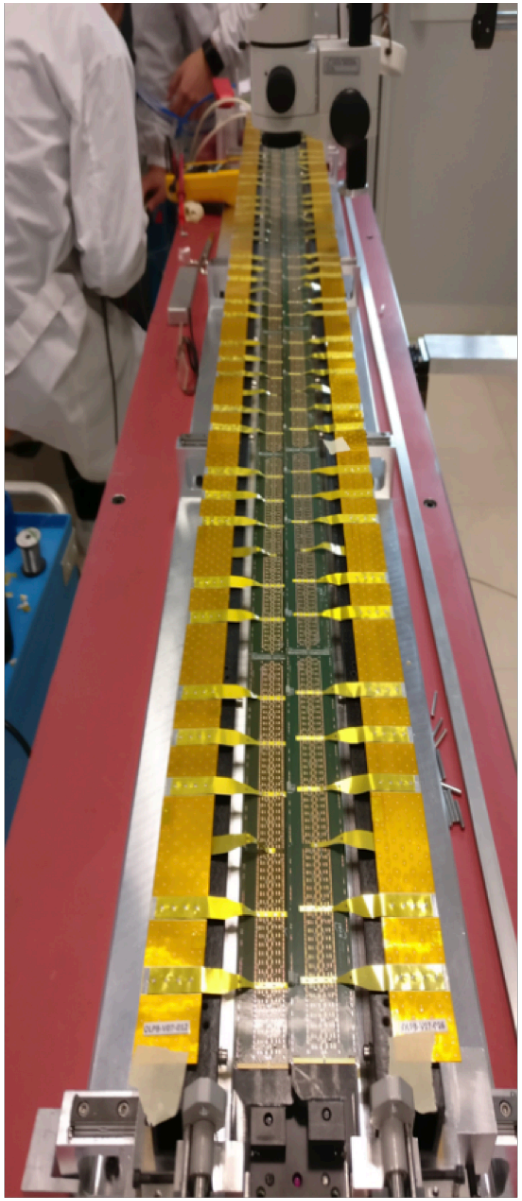


➢ OB HIC Production

- 1692 HIC modules required
- 5 HIC production sites: Bari, Liverpool, Strasbourg, Wuhan, Pusan
- Target rate: 2 HICs per day per site
- So far, about 1300 HICs produced with a yield about 85% (Target 2580 HICs)
- Production end Feb – Mar 2019

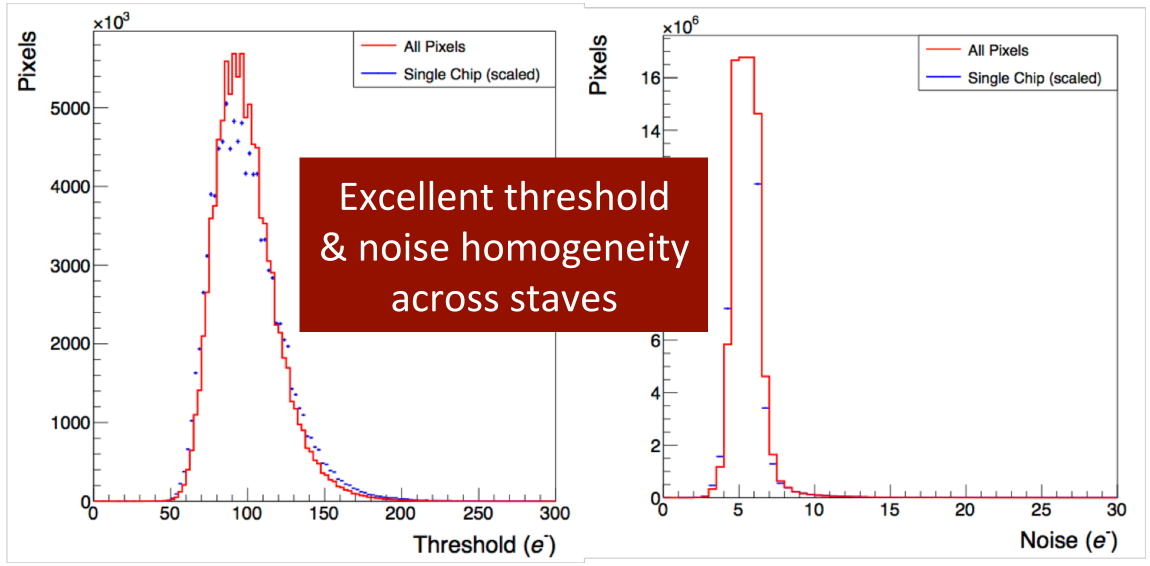


Construction – Outer Barrel Staves

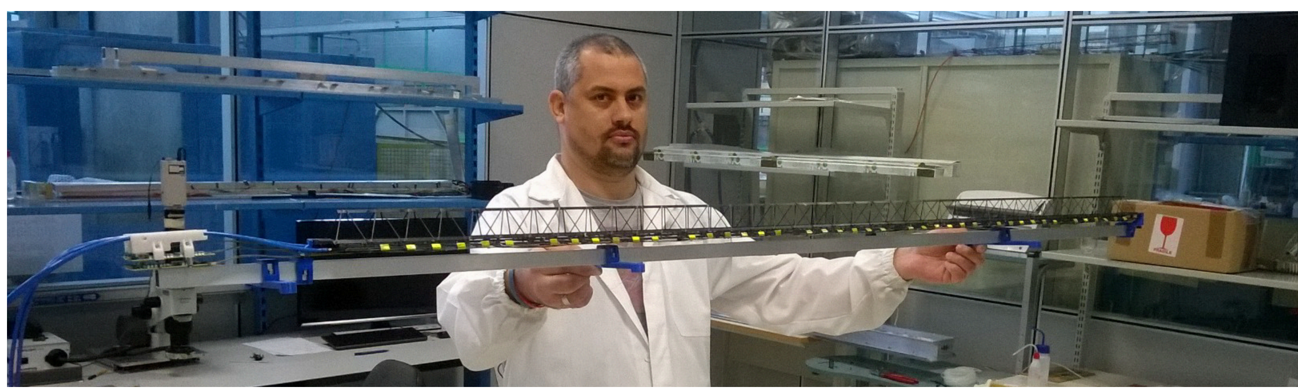


➢ Required amount of staves:

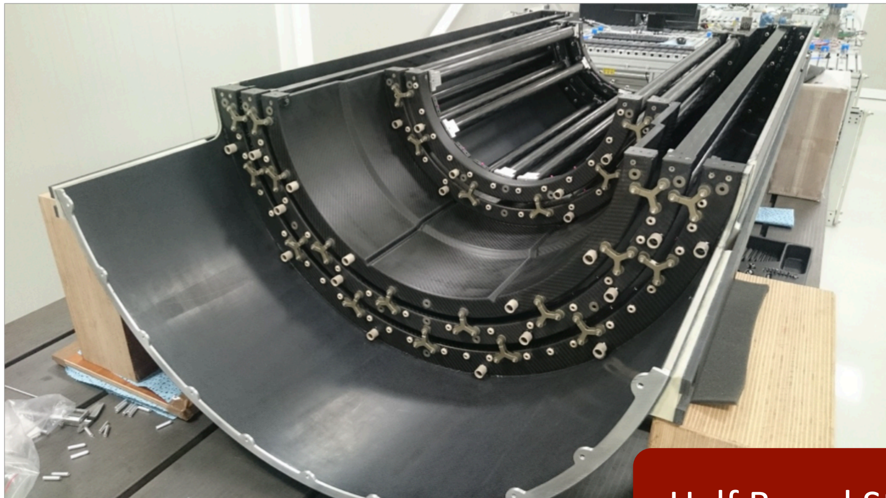
- 54 Middle Layer (ML) staves, 112 chips in 2x4 modules, 59M pixel, 84cm long
- 90 Outer Layer (OL) staves, 196 chips in 2x7 modules, 103M pixel, 147 cm long
- ~ 10% spares, production end in August 2019
- 5 stave production sites: Berkeley, Daresbury, Frascati, Nikhef, Torino

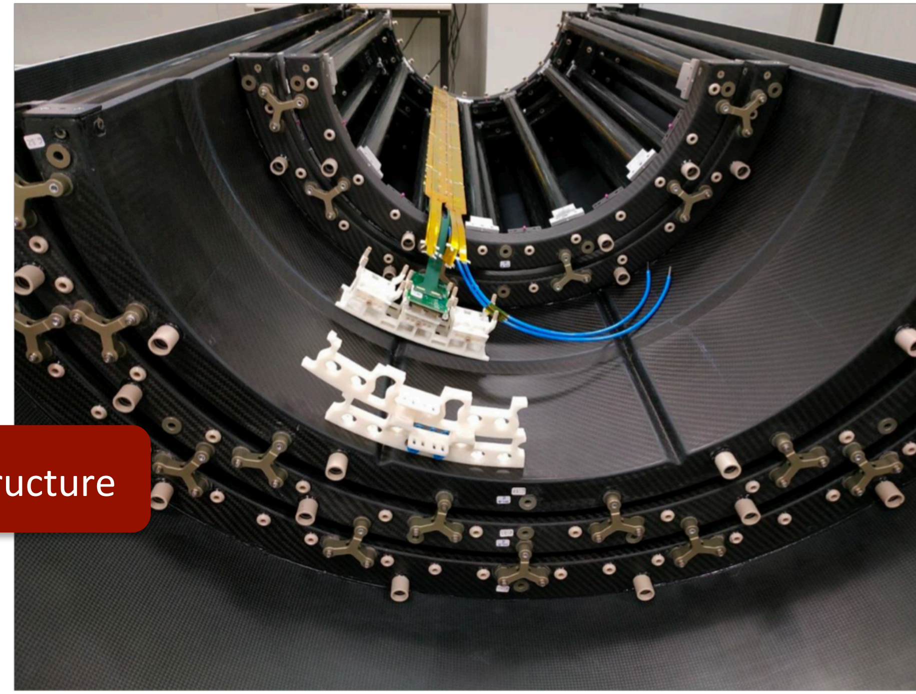


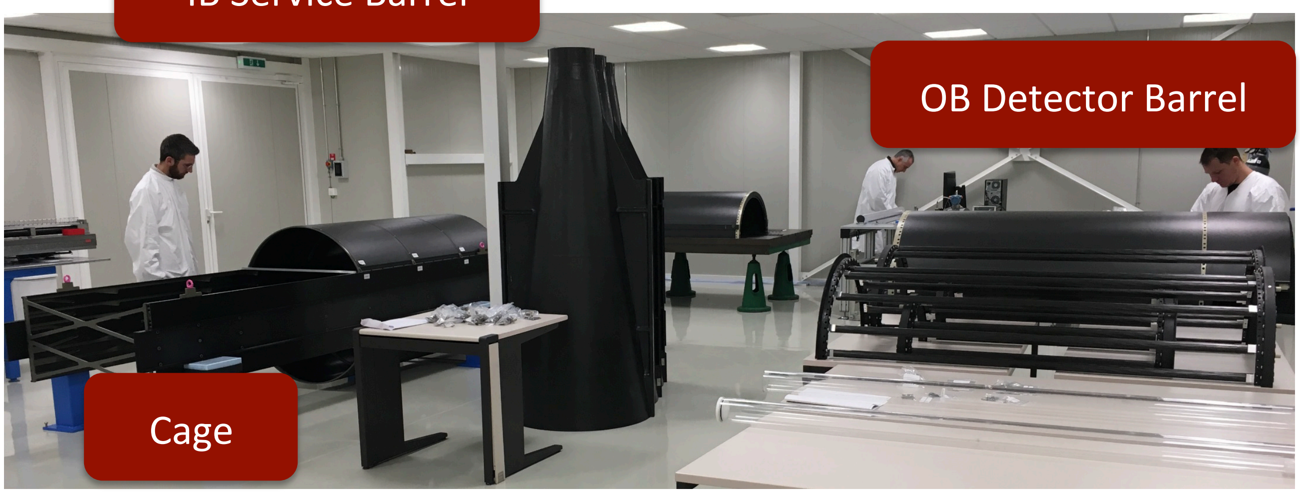
Excellent threshold & noise homogeneity across staves



Construction – Mechanical Support Structures



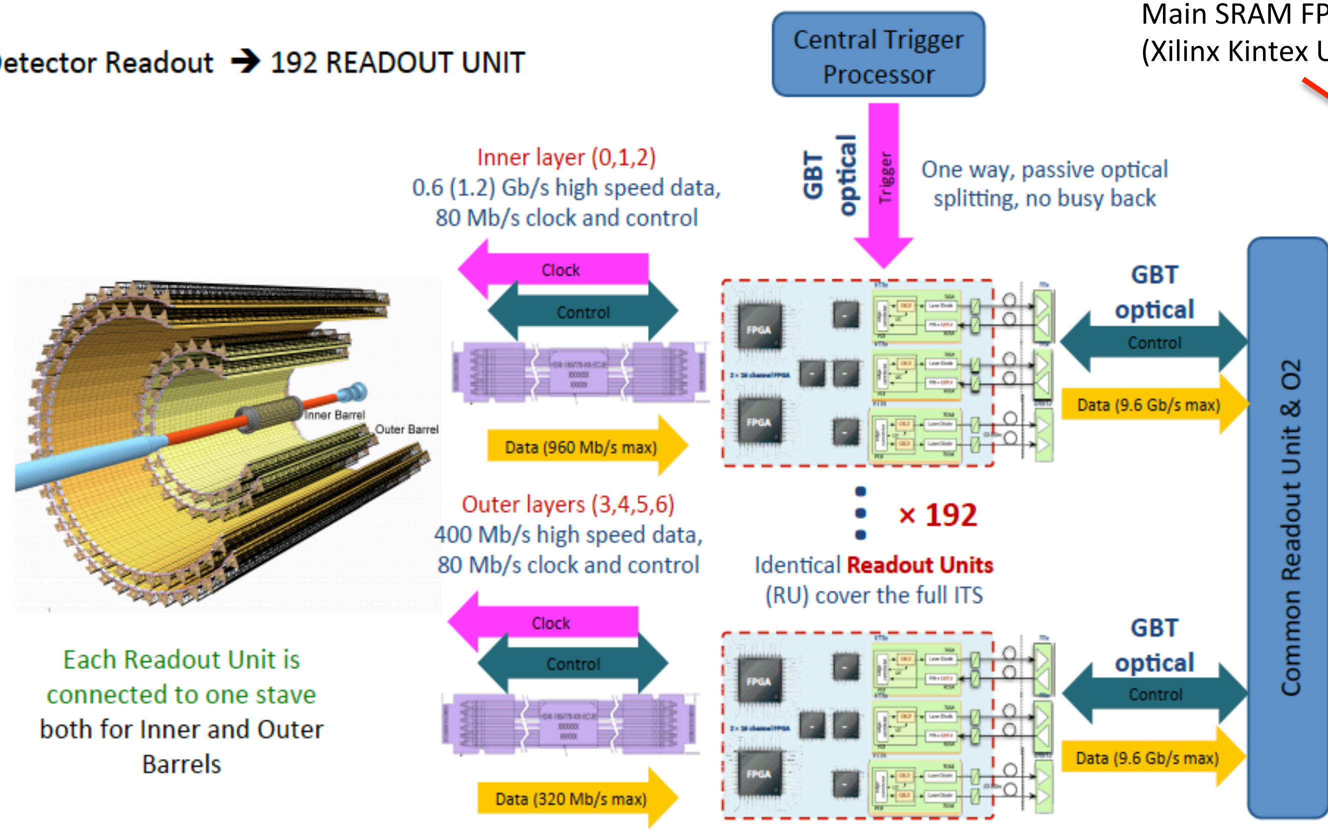


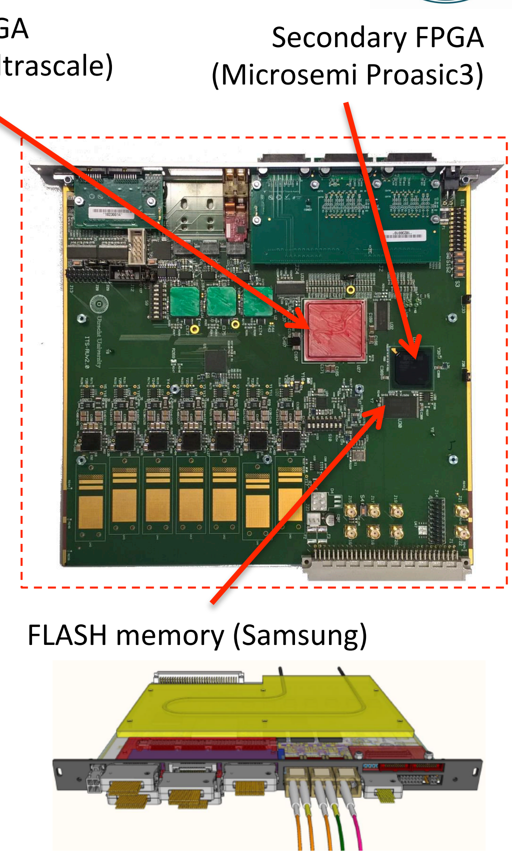


- Mechanical support structure completed
- Infrastructure for stave reception and assembly ready
- Stave reception tests at CERN started
- Installation in the cavern at May 2020

Construction – Readout Electronics

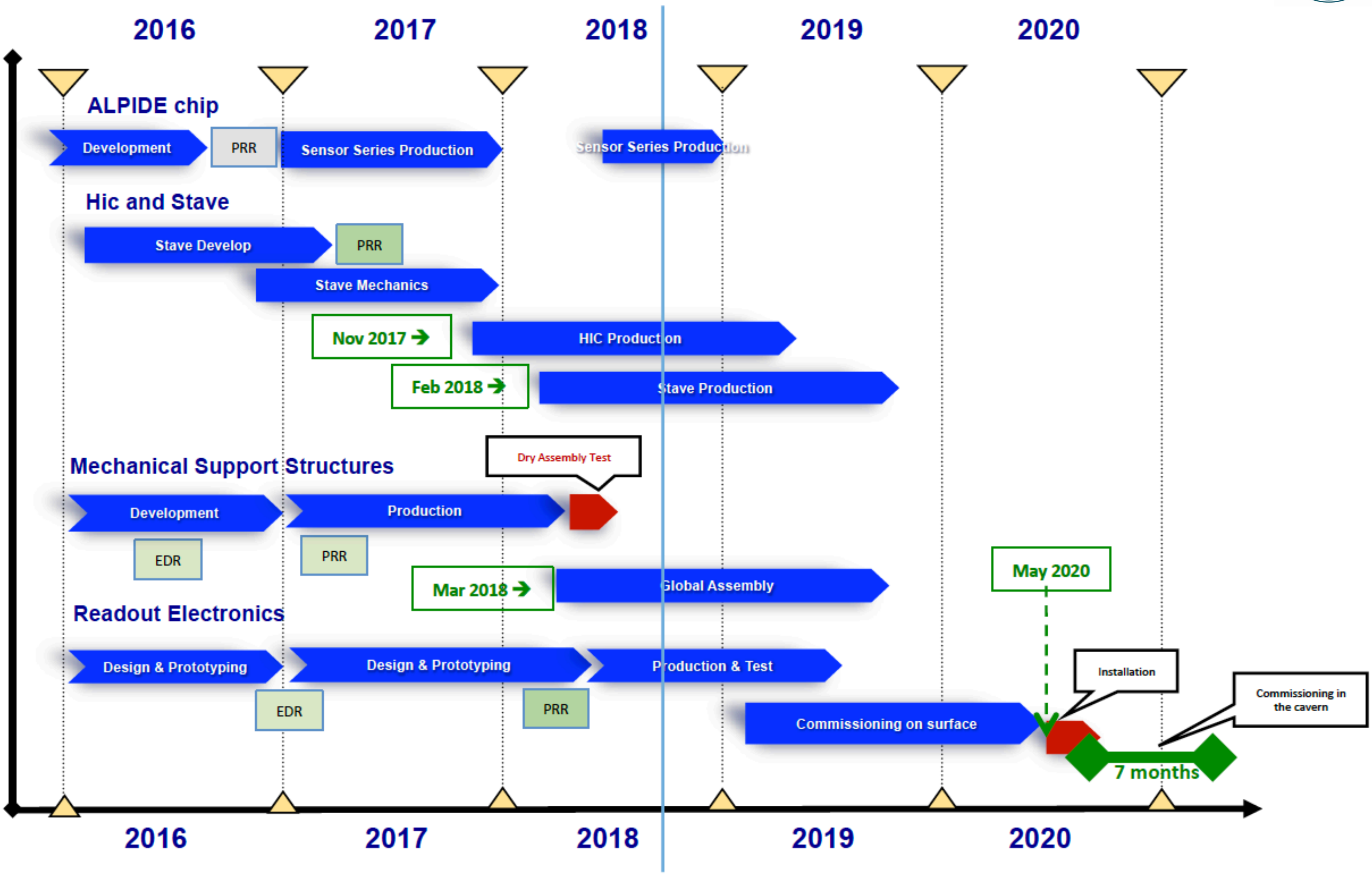
Detector Readout ➔ 192 READOUT UNIT





- ITS Frontend Electronics is subdivided into 192 Readout Unit (RU) modules, each connected to and control a stave and optically interfaced to the Common Readout Unit (CRU) and to the Central Trigger Processor (CTP)
- RU distributes trigger and control signals, interface data links to ALICE DAQ, control power supply of chips
- Expected radiation levels at RU position: 10 krad TID, $1.7\text{x}10^{11}$ NIEL, 1 kHz/cm^2 high energy hadron (HEH) flux (> 20MeV)
- Mass production and testing ongoing (started in Sept 2018, will complete in April 2019)

Construction – Schedule



Summary and Outlook

- A new faster, less material budget, better spatial resolution and radiation hard Inner Tracking System (ITS) has been constructing for the ALICE upgrade in Run 3 and Run 4.

- The ALPIDE MAPS sensor produced at TowerJazz using 180nm CIS technology have been selected for the ALICE ITS upgrade.
  - ✓ Excellent performance in terms of detection efficiency, fake-hit rate and spatial resolution before/after irradiation over a wide range of operational setting
  - ✓ Mass production and testing are close to be completed

- Mass production of HIC modules and staves have been started in full swing, and will be completed in March 2019

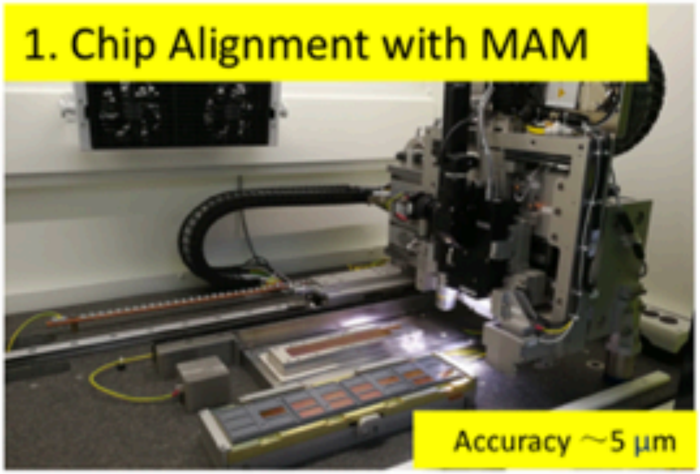
- Readout Unit production started recently and complete in April 2019

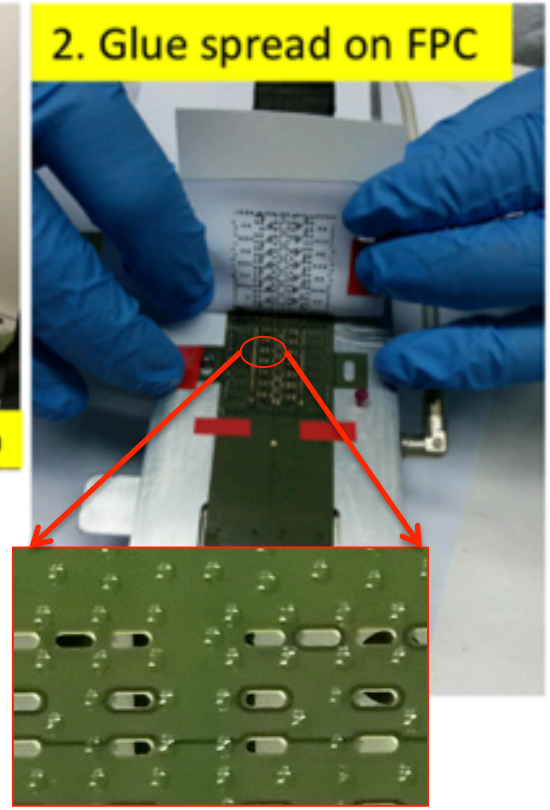
- Infrastructure for layer assembly, testing and commissioning under preparation

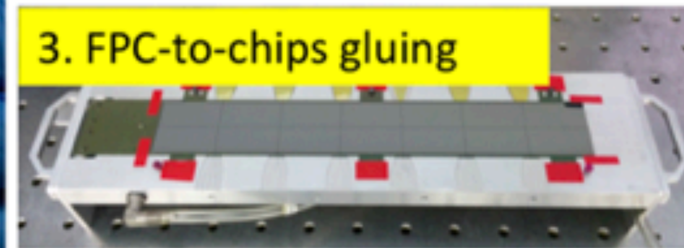
Thanks for your attention!

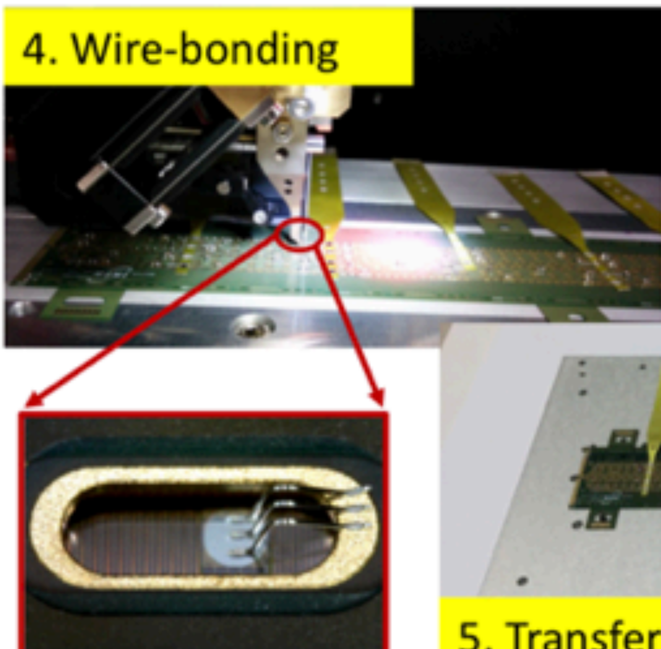
Spare Slides

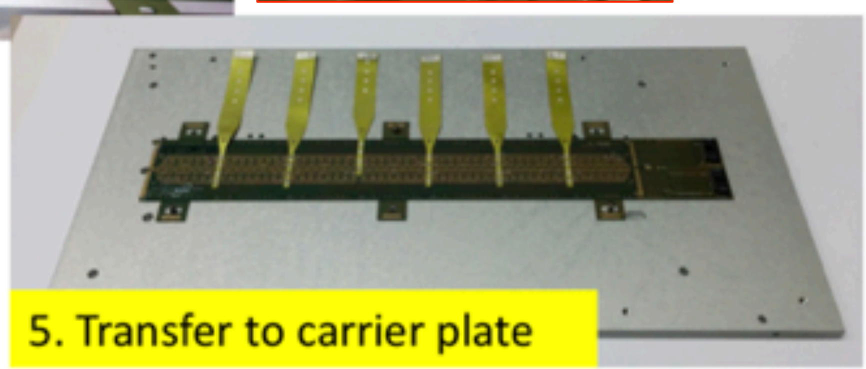
HIC Assembly Procedure

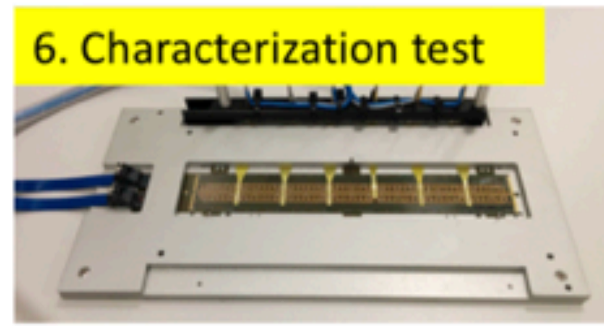


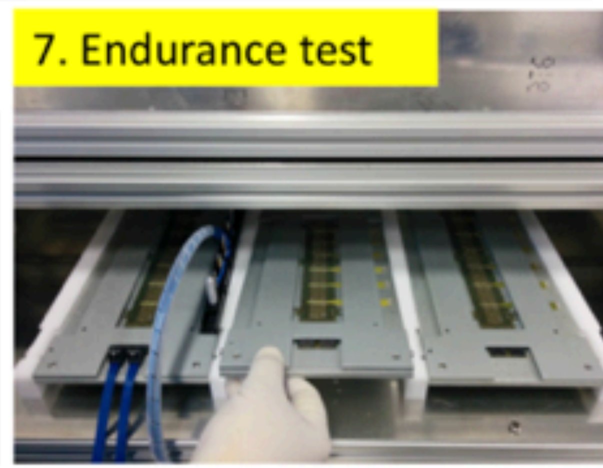












New ITS Readout Chain