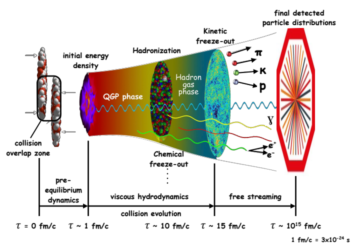
Università degli Studi di Torino

ALICE ITS Upgrade, design and physics performance

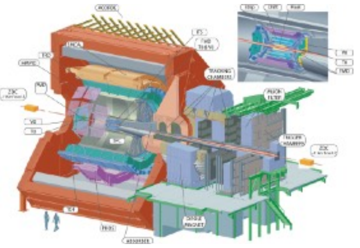
Interview for postdoc position at Los Alamos

Candidate: Dr. Yasser Corrales Morales

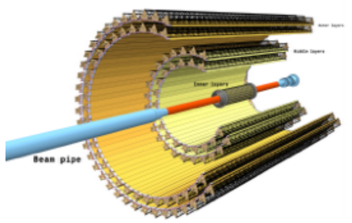
Overview



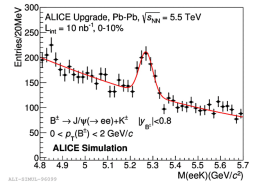
Physics motivation - Quark Gluon Plasma



Current ALICE detector



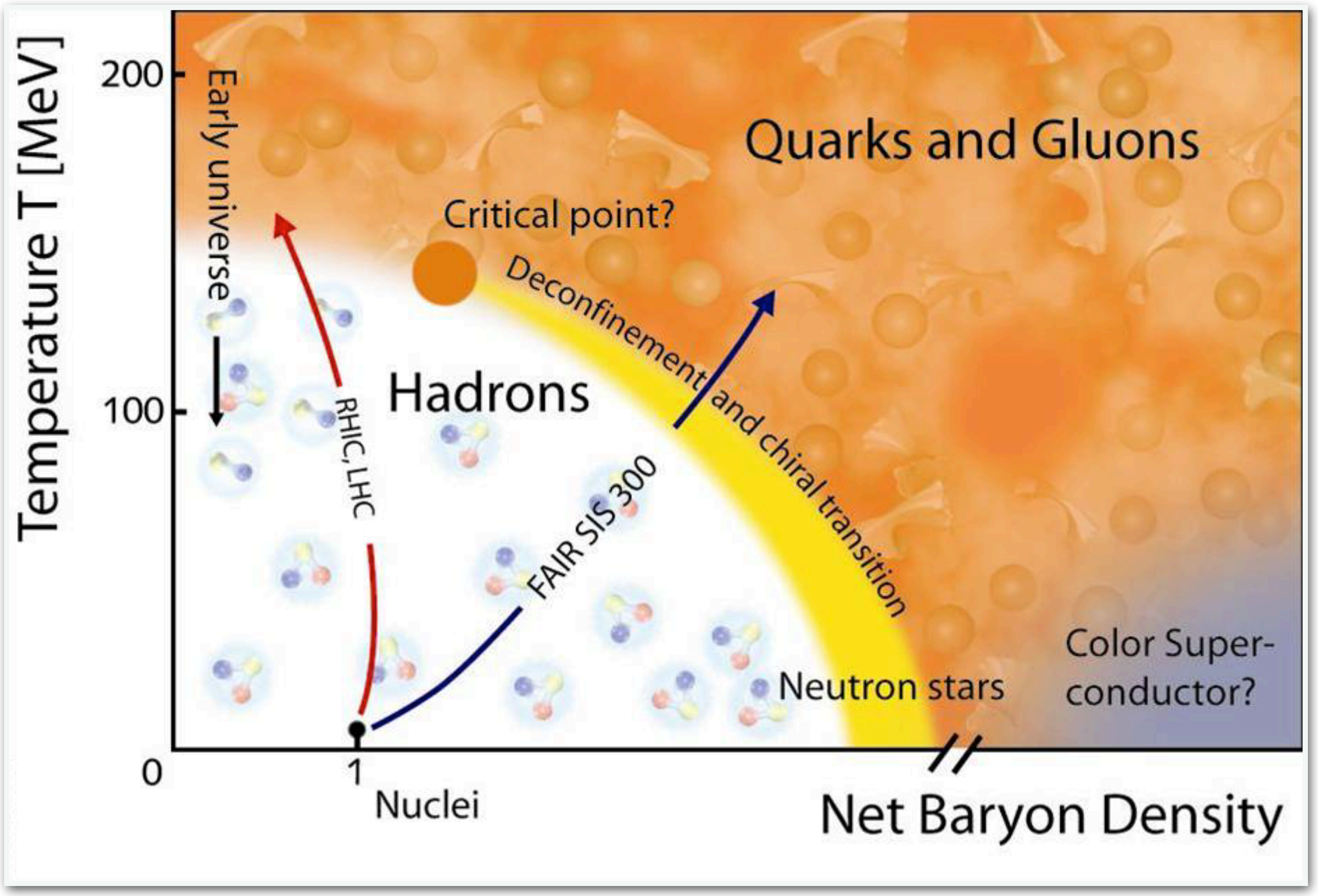
ALICE ITS Upgrade project



Physics performance with new ALICE ITS

Physics motivation: QGP

Lattice-QCD predicts that strongly-interacting matter under extreme conditions of density and temperature undergoes a phase transition into a new state of matter, the Quark Gluon Plasma (QGP)



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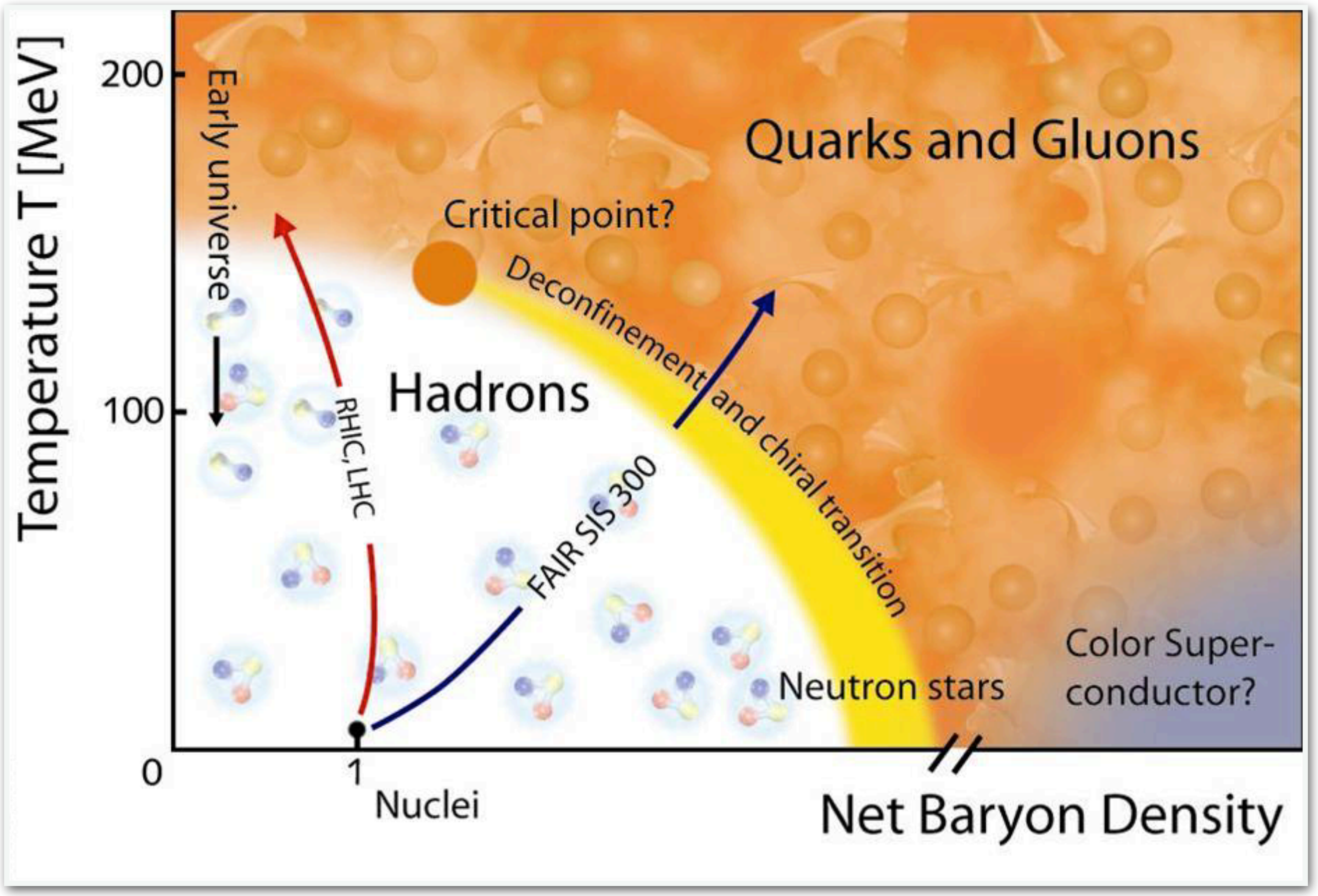


In the QGP quarks and gluons are no longer confined inside the hadron and they are free to move over “long” distance

Why heavy ion collisions?

HIC provide the conditions required to study the QGP system experimentally

Ultra-relativistic
Heavy Ion Collisions

strongly interacting system
(large cross-section for hard scattering)

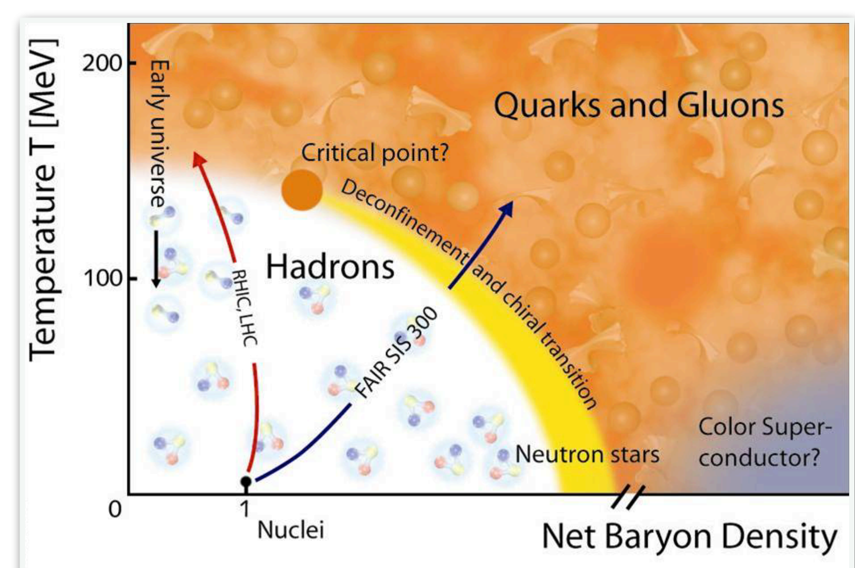
dense medium
(Many scatterings -> thermal equilibrium)

“Hot” medium
($T>T_c$)

At LHC energies, the colliding nucleons have enough energy to move far from the interaction region.

→ the system created is characterised by a small net baryon content (at mid-rapidity)

→ at vanishing μ_B, transition is predicted to occur at a $T_c \approx 160$ MeV and $\varepsilon_c \approx 1$ GeV/fm^3



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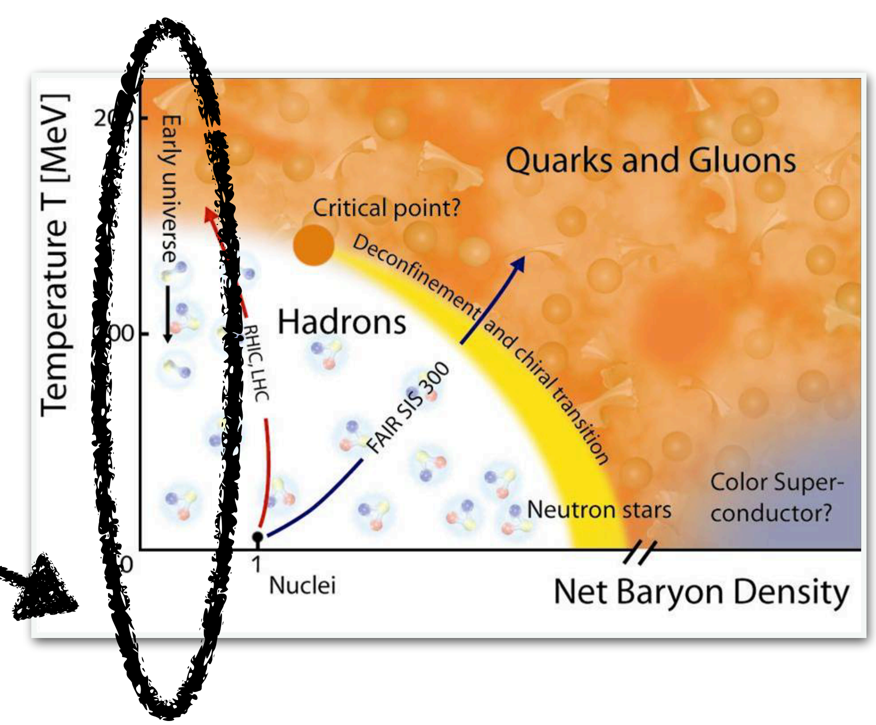
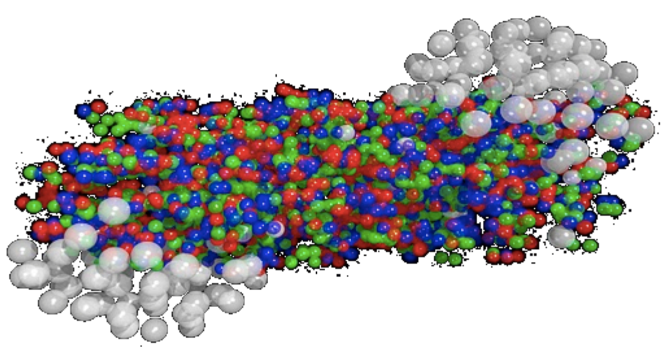
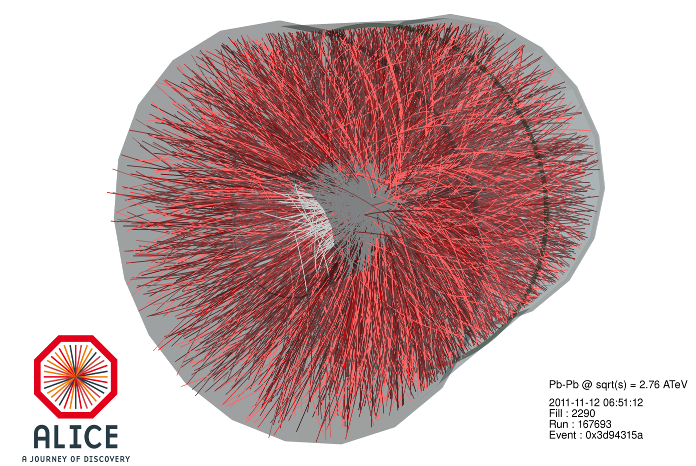


ALICE: Study QGP properties

ALICE is designed to study the properties of the QGP at LHC conditions, using A-A, p-A and pp collisions

ALICE confirms basic picture: observation of hot hadronic matter at unprecedented values of temperatures, densities and volumes ....



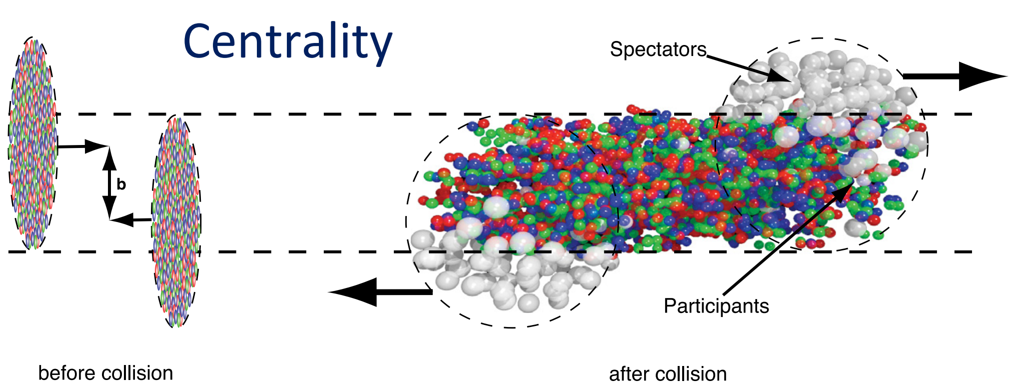


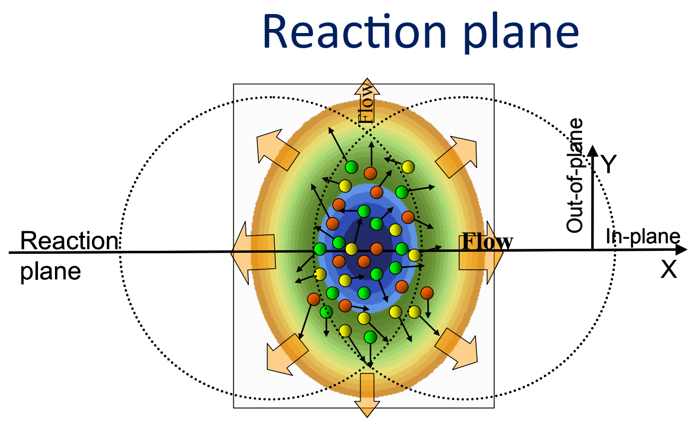
- ➢ Excellent capabilities to measure high-energy nuclear collisions at LHC

ALICE: New Perspectives

Progress towards quantitative characterisation of QGP properties requires:

- precision measurements of rare probes
- over a large kinematic range (from high to very low transverse momenta)
- and as function of multi-differential observables: centrality, reaction plane...





Examples:

- Open HF (charm & beauty, mesons & baryons), Quarkonia down to zero p_T

  thermalisation, hadronization, recombination, temperature evolution of the QGP
- Vector mesons and low-mass di-leptons

  chiral symmetry restoration, virtual thermal photons
- High-precision measurement of light (anti-)nuclei and hyper-nuclei

  nucleo synthesis, exotics

➢ *Upgrade needed!!*

ALICE Upgrade strategy

This requires statistics (luminosity) and precision measurements

Target for upgrade programme (Run3 + Run4)

- Pb-Pb recorded luminosity ~10 nb^{-1}, $8x10^{10}$ events

I. Upgrade detectors, readout systems and online systems to

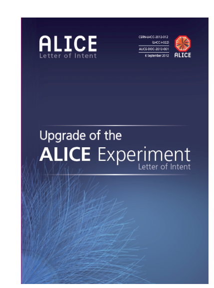
- readout all Pb-Pb interactions at a maximum rate of 50kHz with a minimum bias trigger (at present 1kHz)

➢ Gain a factor ~ 50 in statistics over originally approved programme (Run1 + Run2)

II. Significant improvement of vertexing and tracking capabilities at low p_T

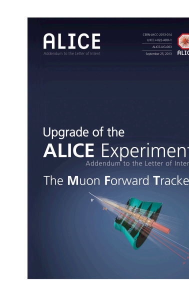
- New Inner Tracking System

It targets LHC 2nd Long Shutdown (2019/20)



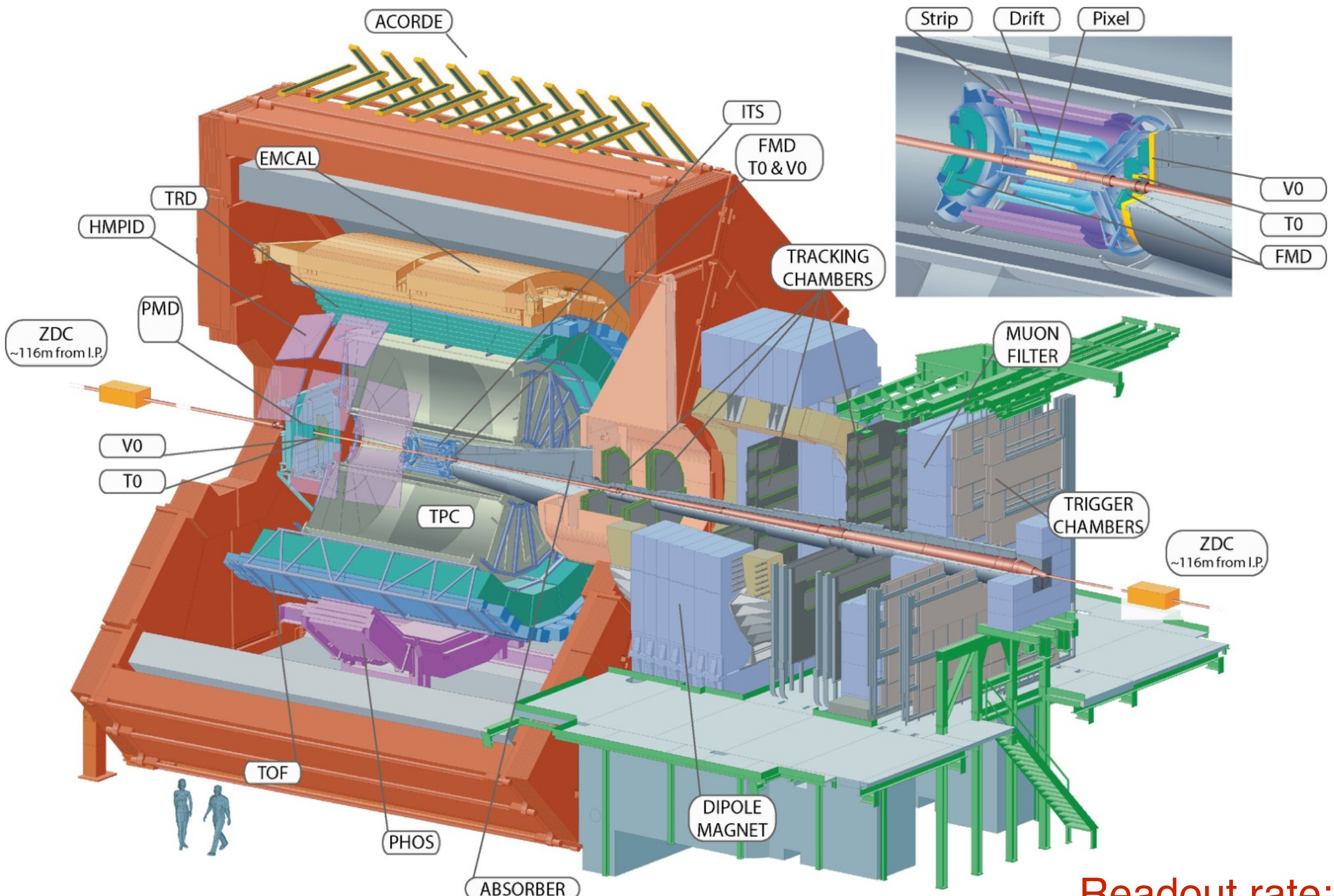
ALICE Upgrade LoI
September 2012

Addendum
September 2013



The current ALICE detector

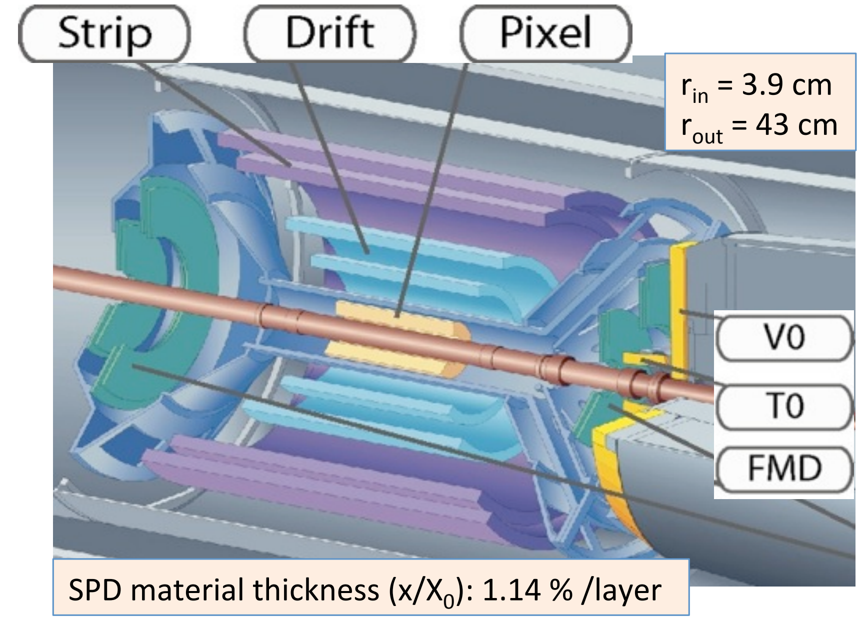
the dedicated heavy-ion experiment at the LHC



Readout rate: ~ 1kHz

Central barrel detector operates in a 0.5 T solenoid field

Current ALICE ITS



Inner Tracking System

Si detector made of 6 layers of three different types

- pixel (SPD) -> 240 modules
- drift (SDD) -> 260 modules
- strip double-side (SSD) -> 1698 modules

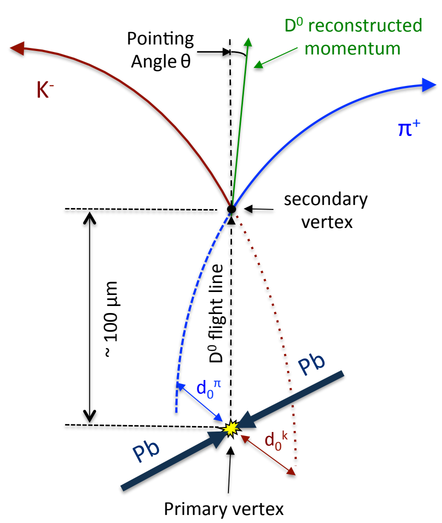
Aims:

- Primary and secondary (decay particles) vertex reconstruction
- Excellent resolution on the distance of closest approach (DCA) to the primary vertex.

  crucial to separate primary and secondary particles

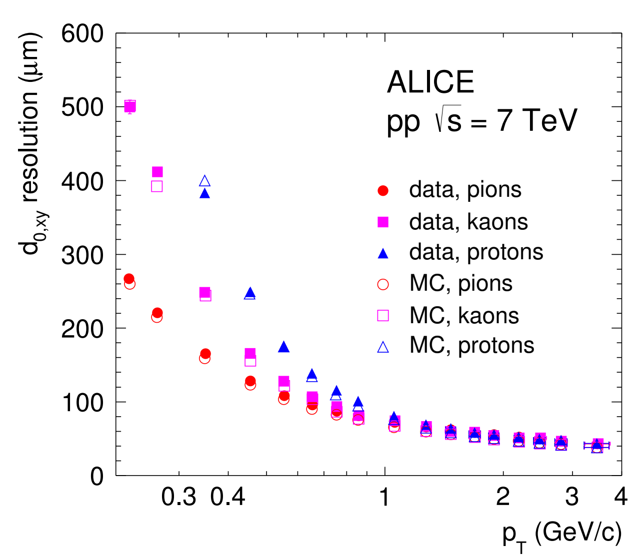
- Recover low p_T (< 200 MeV/c) tracks that are inaccessible to TPC tracking.

Example: D^0 meson



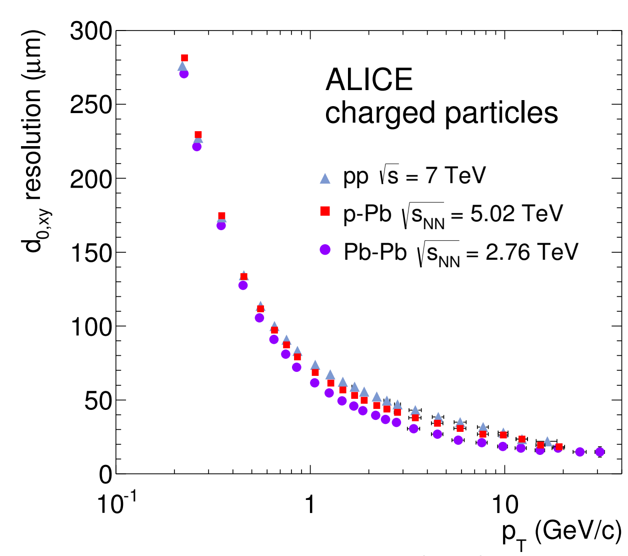
Analysis based on decay topology and invariant mass technique

Very good MC description



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

Very weak dependence on the colliding system



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

70 μm at p_T = 1 GeV/c

ITS Upgrade Design Objectives

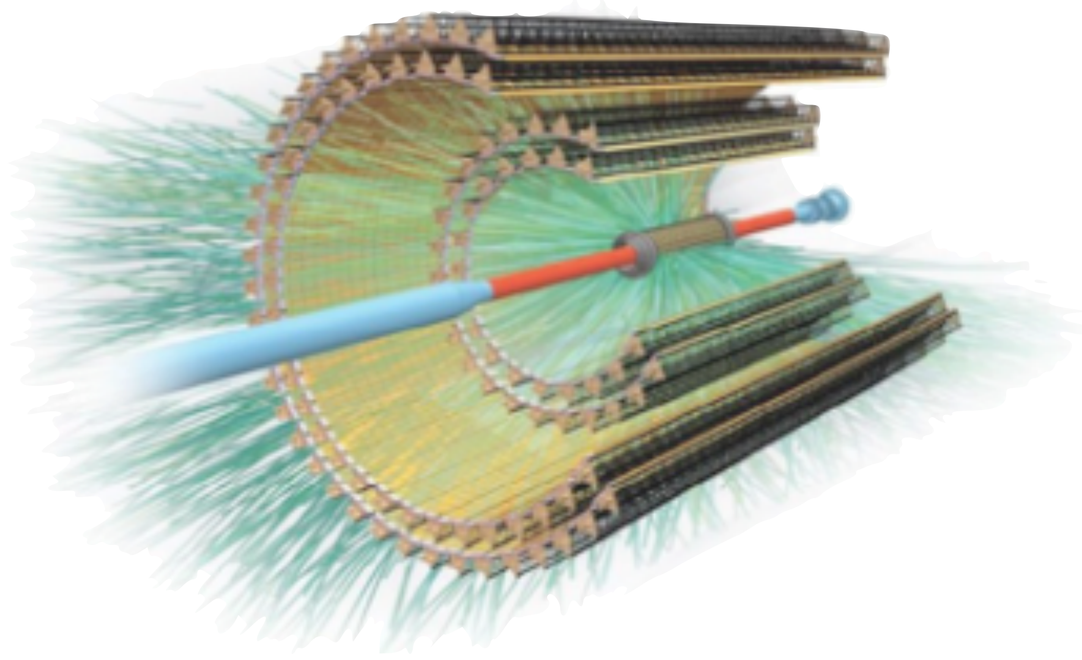
ALICE

Improve impact parameter resolution:

by a factor ~3 in rϕ and ~5 in z at p_T=500MeV/c

1. get closer to IP: 39mm ➔ 23mm (innermost layer)
2. reduce material budget: ~1.14% X_0 ➔ ~0.3% X_0 (inner layers)
3. reduce pixel size: 50x425μm² ➔ O(30x30 μm²)
4. Spatial resolution:

   currently 12 μm x 100 μm (SPD) ➔ 5 μm x 5 μm



Improve tracking efficiency and p_T resolution at low p_T

increase granularity: 6 layers ➔ 7 pixel layers

Exploit LHC luminosity increase ➔ Fast readout

readout of Pb-Pb at up to 100 kHz (presently 1kHz) and 200kHz for pp

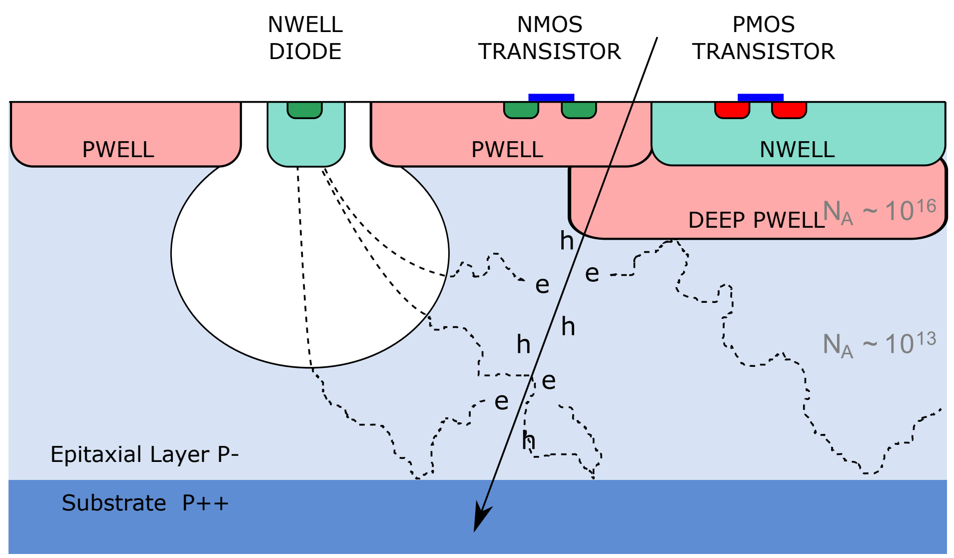
Withstand radiation load (10 years operation):

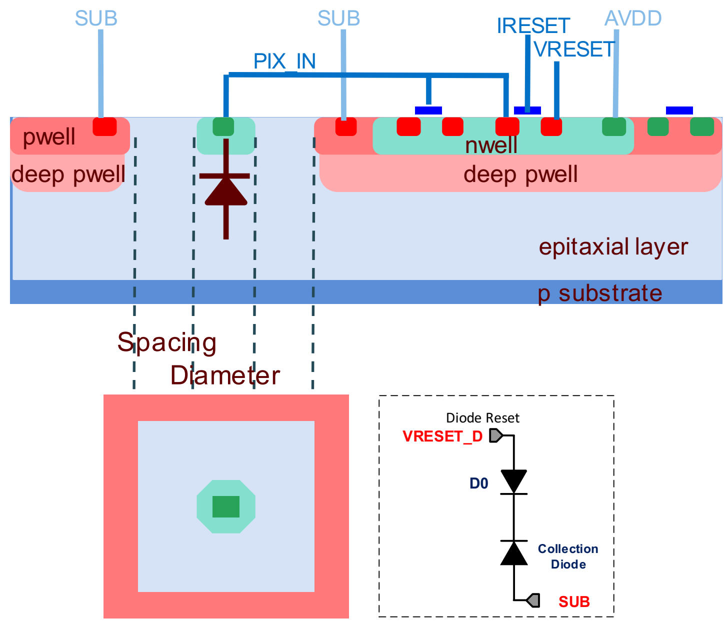
TID: ~ 270 krad, NIEL: ~1.7×10^{12} 1MeV n_{eq}/ cm²

Fast insertion and removal

possibility to replace non-functioning detector staves during yearly shutdown

ALPIDE- Technology and Pixel Layout





CMOS Pixel Sensor - TowerJazz 0.18µm CMOS Imaging Process

- High-resistivity (> 1kΩ cm) p-type epitaxial layer (25µm) on p-type substrate
- Small n-well diode (2 µm diameter), ~100 times smaller than pixel => low capacitance (~fF)
- Reverse bias voltage ($-6V < V_{BB} < 0V$) to substrate (contact from the top) to increase depletion zone around NWELL collection diode
- Deep PWELL shields NWELL of PMOS transistors (full CMOS circuitry within pixel active area)

ALPIDE - Final Version

Key Features

In-pixel:

- amplification
- discrimination
- multi event buffer

In-matrix zero suppression

- (priority encoding)

Ultra-low power (entire chip):

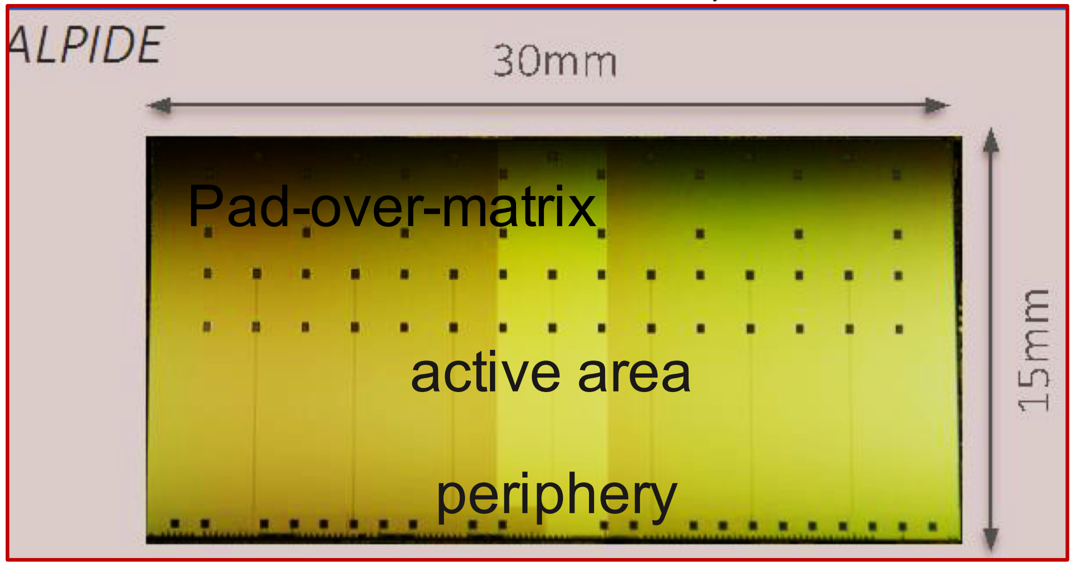
- < 40mW/cm^2 (140mW full chip)

triggered acquisition (200 kHz Pb-Pb, 1 MHz pp) or
continuous (integration time 1µs-> ∞)

High speed serial data output (HSO)

- OB: 400 Mbit/s
- IB: 600 Mbit/s or 1.2 Gbit/s

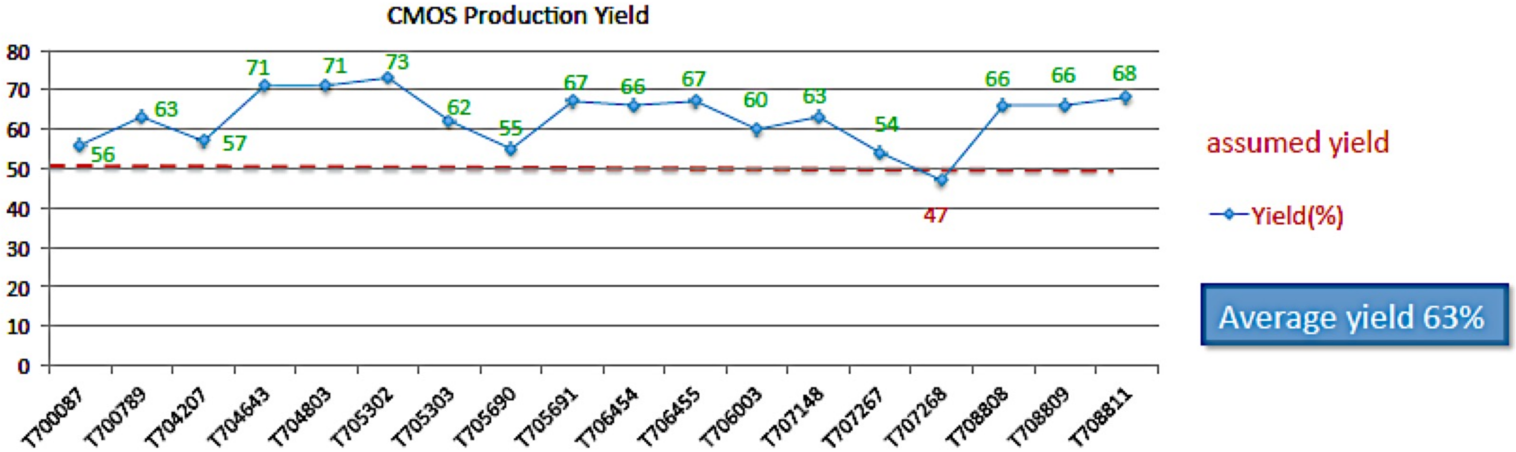
Pixel size: 29x27μm^2



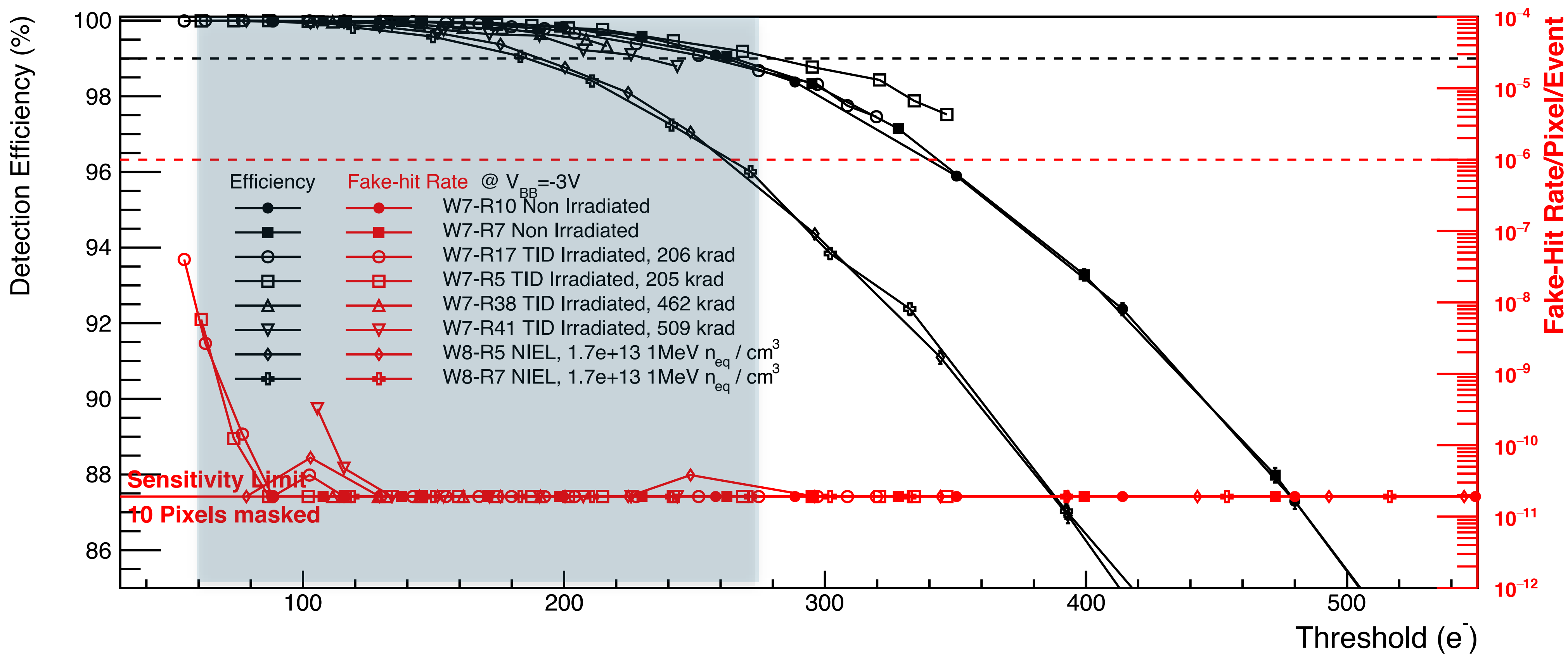
Inner Barrel: 50 µm thick

Outer Barrel: 100 µm thick

Full production order: 1200 wafers
2 wafer of each lot are shipped to CERN (monitor yield)
Remaining wafers are sent to Korea for thinning and dicing

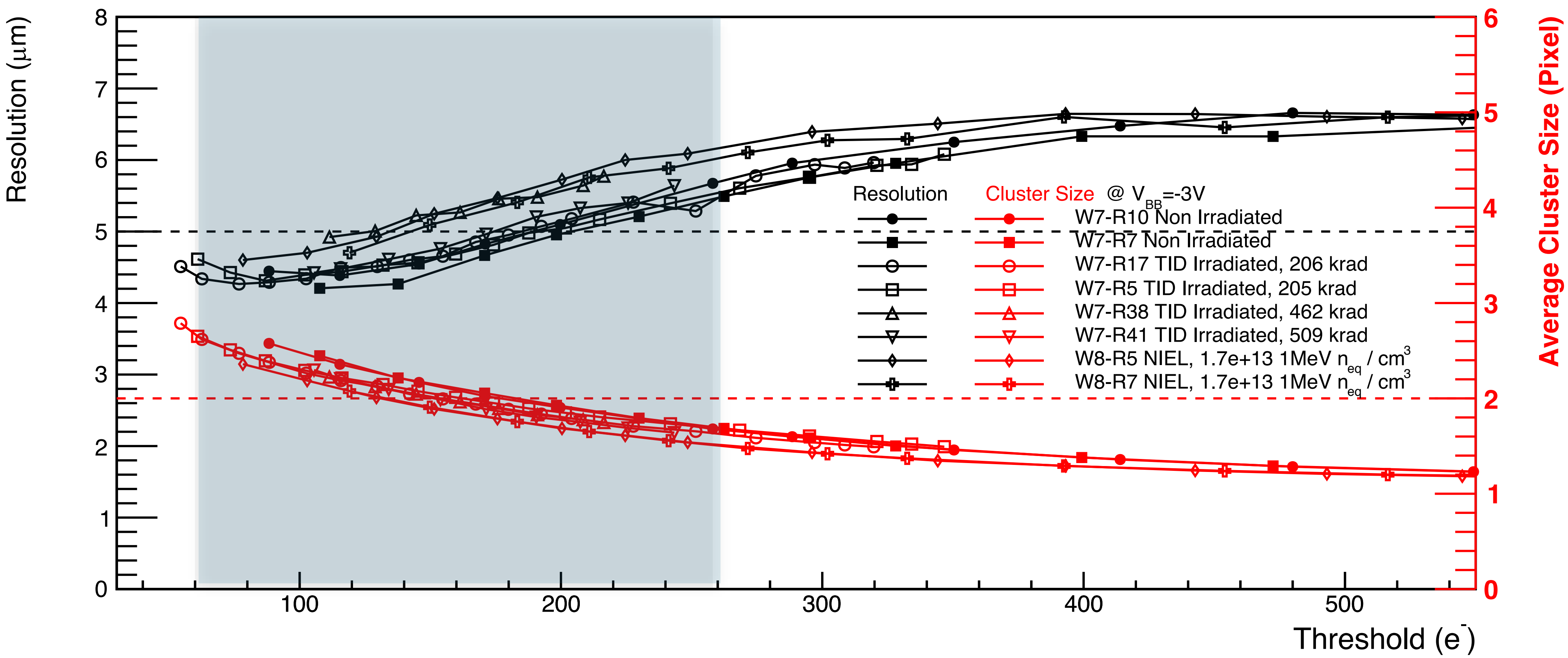


ALPIDE - Detection Efficiency and Fake-Hit Rate



- Big operational margin with only 10 masked pixels (0.002%)
- Chip-to-chip fluctuations negligible
- Non-irradiated and NIEL/TID chips show similar performance
- Sufficient operational margin after 10x lifetime NIEL dose

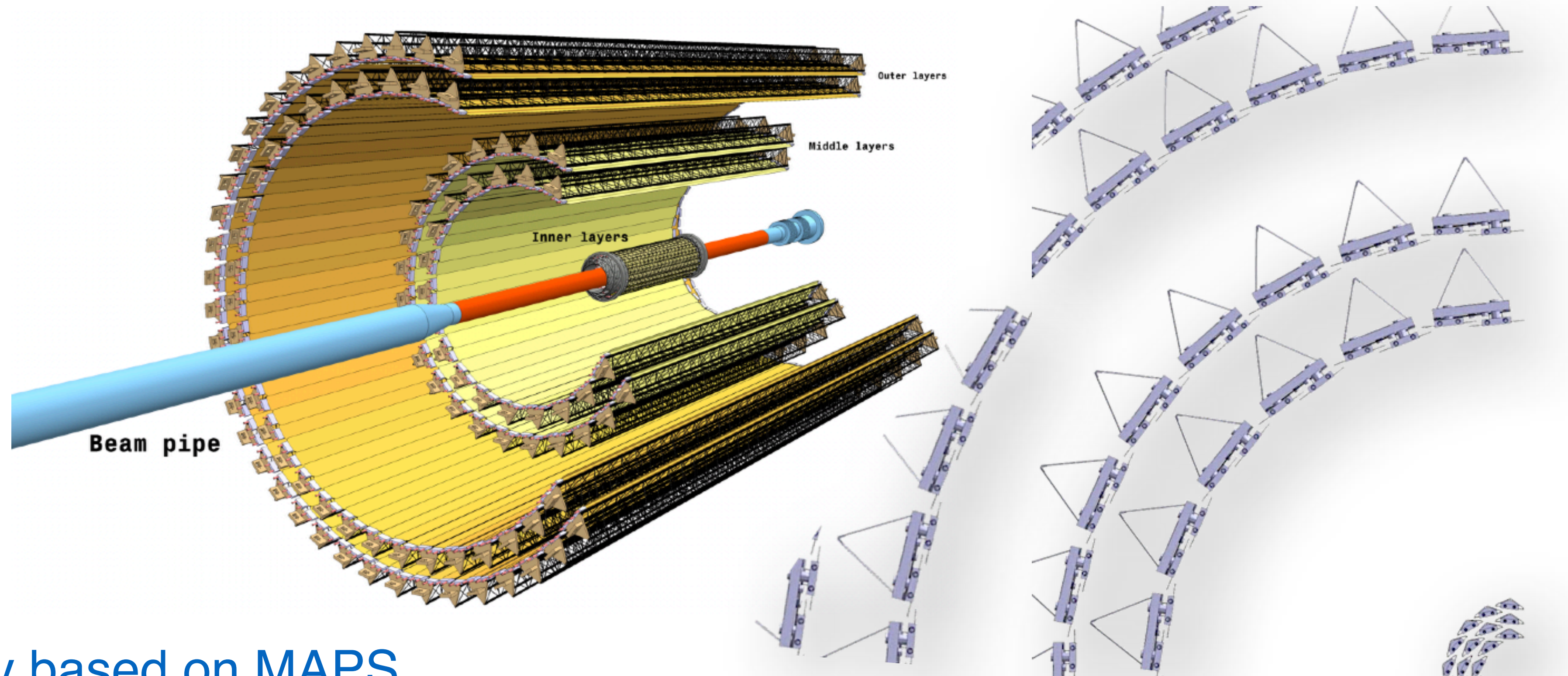
ALPIDE - Resolution and cluster size



- Chip-to-chip fluctuations negligible
- Non-irradiated and TID/NIEL chips show similar performance
- Resolution of about 5μm at a threshold of 200 electrons
- Sufficient operational margin even after 10x lifetime NIEL dose

New ITS Layout

12.5 G-pixel camera
(~10 m²)



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

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% X_0 (IB), 1% X_0 (OB)

90 Outer layer STAVES

54 Middle layer STAVES

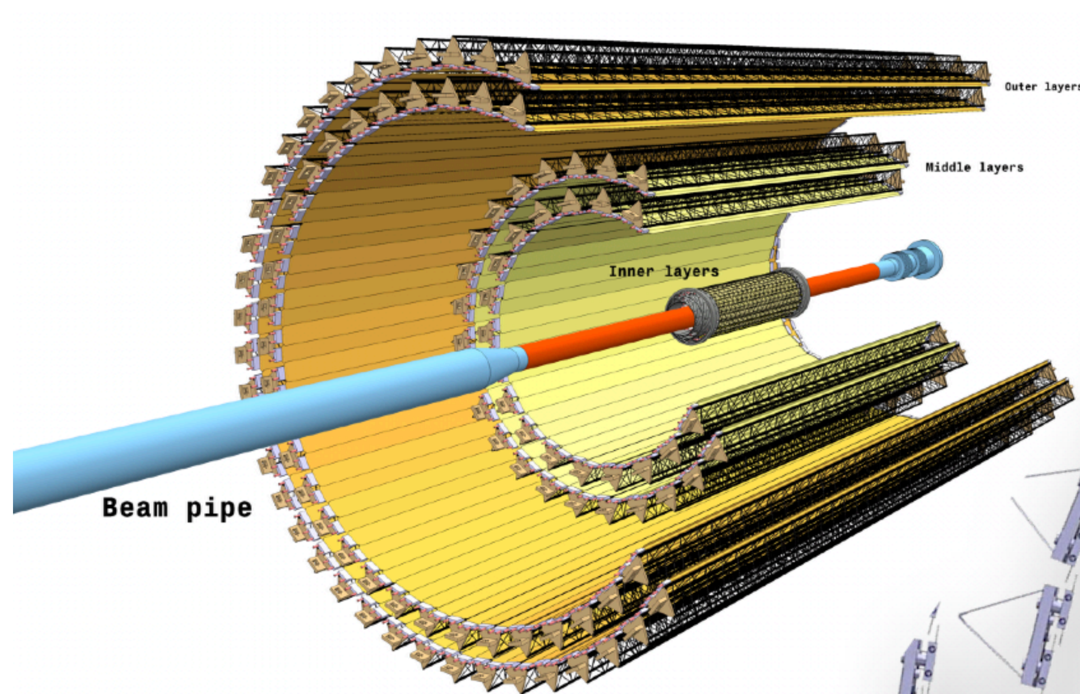
48 Inner layer STAVES

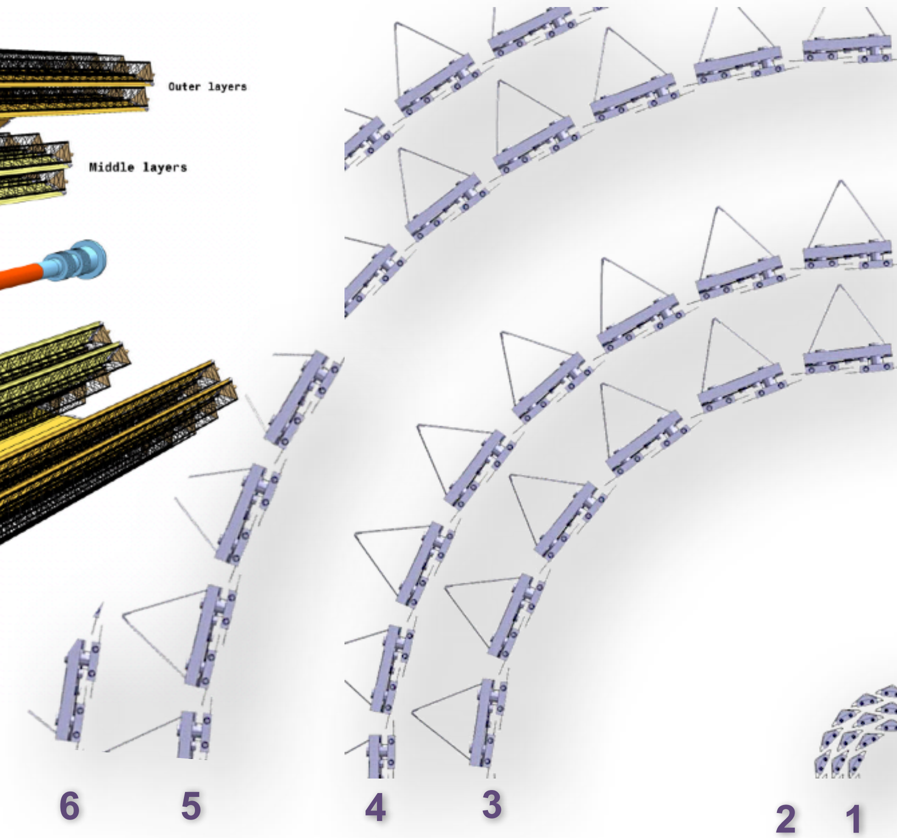
ITS layers are (azimuthally) segmented in staves, which are mechanically independent

Radial coverage 23mm÷405mm

New ITS Layout

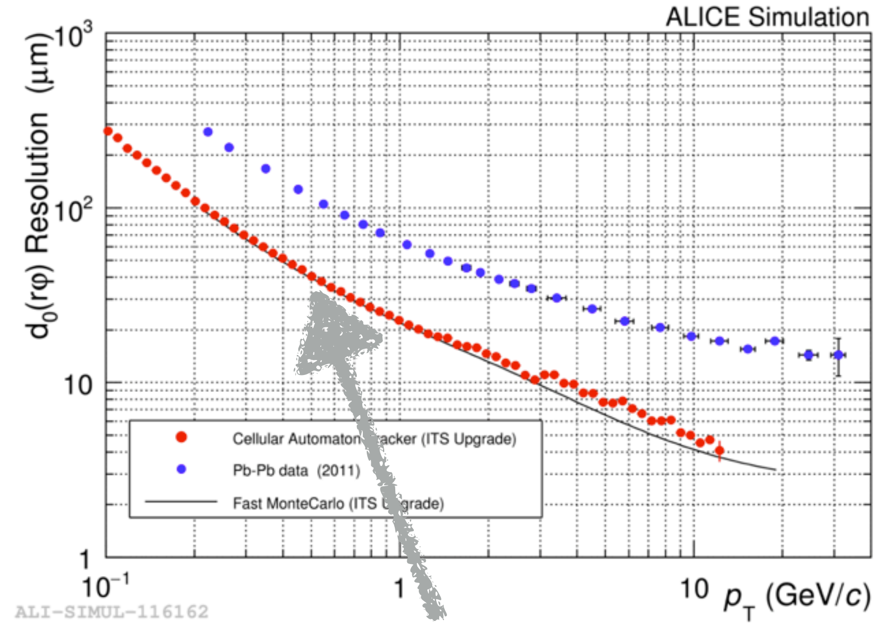
12.5 G-pixel camera
(~10 m²)





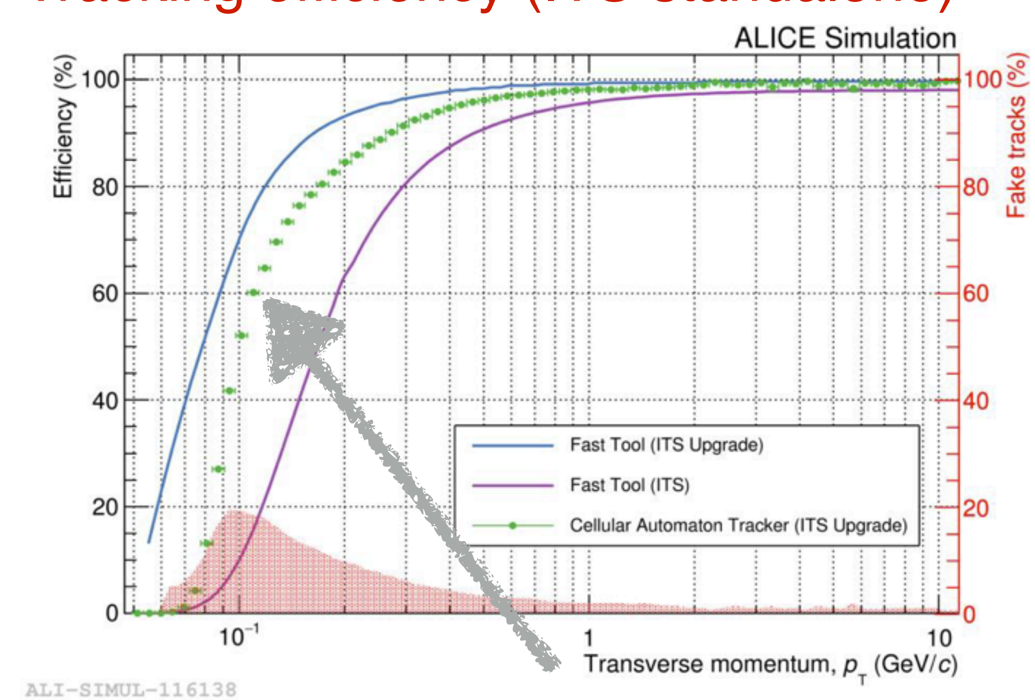
Performance of new ITS (MC simulations)

Impact parameter resolution



40 μm at p_T = 500 MeV/c

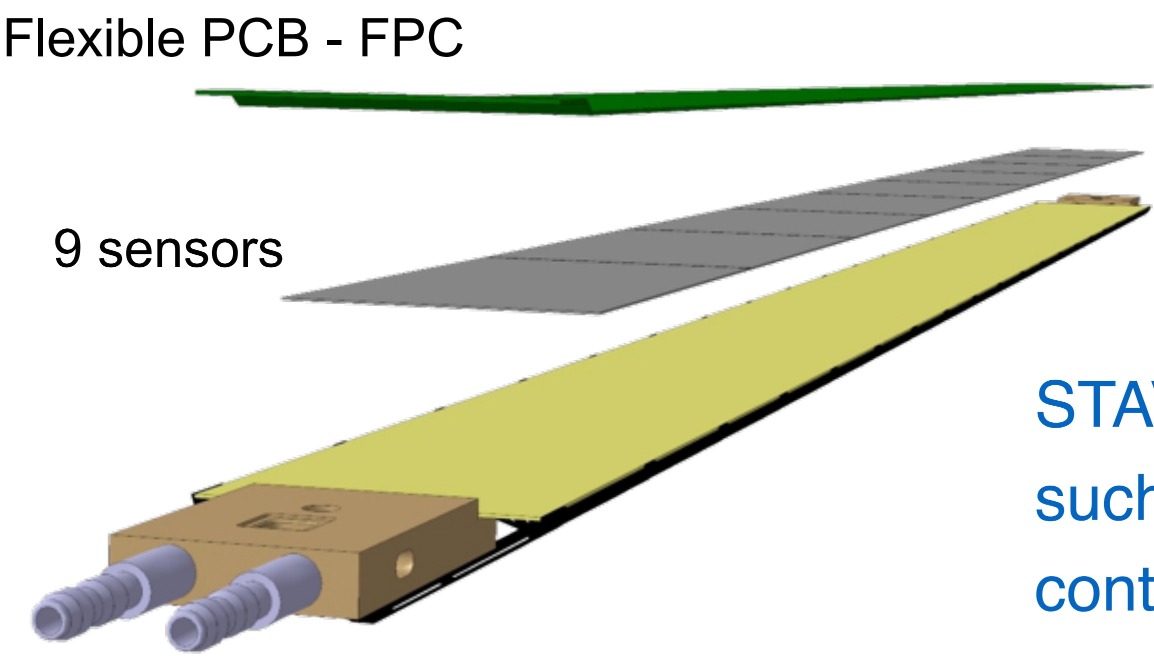
Tracking efficiency (ITS standalone)

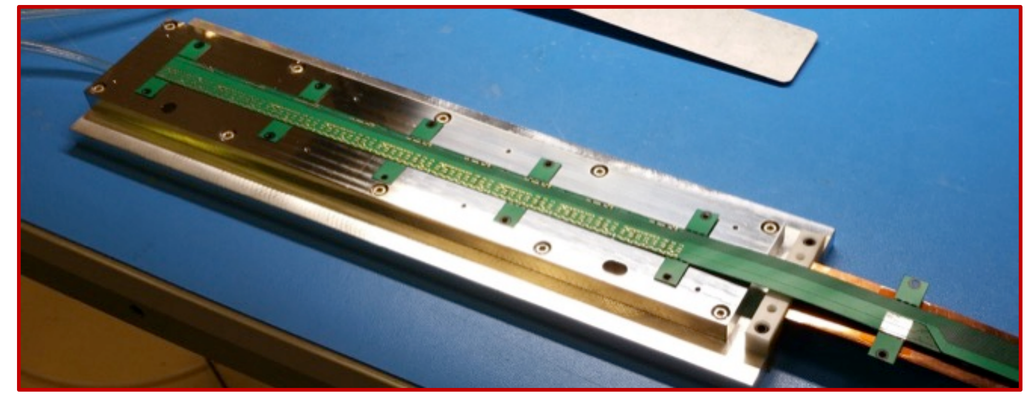


~60% at p_T= 100 MeV/c

Detector HICs and staves - Inner Barrel

HIC: Hybrid Integrated Circuit





STAVE: HIC glued to the IB spaceframe & coldplate, such to provide HIC support, alignment, and thermal contact to the coldplate

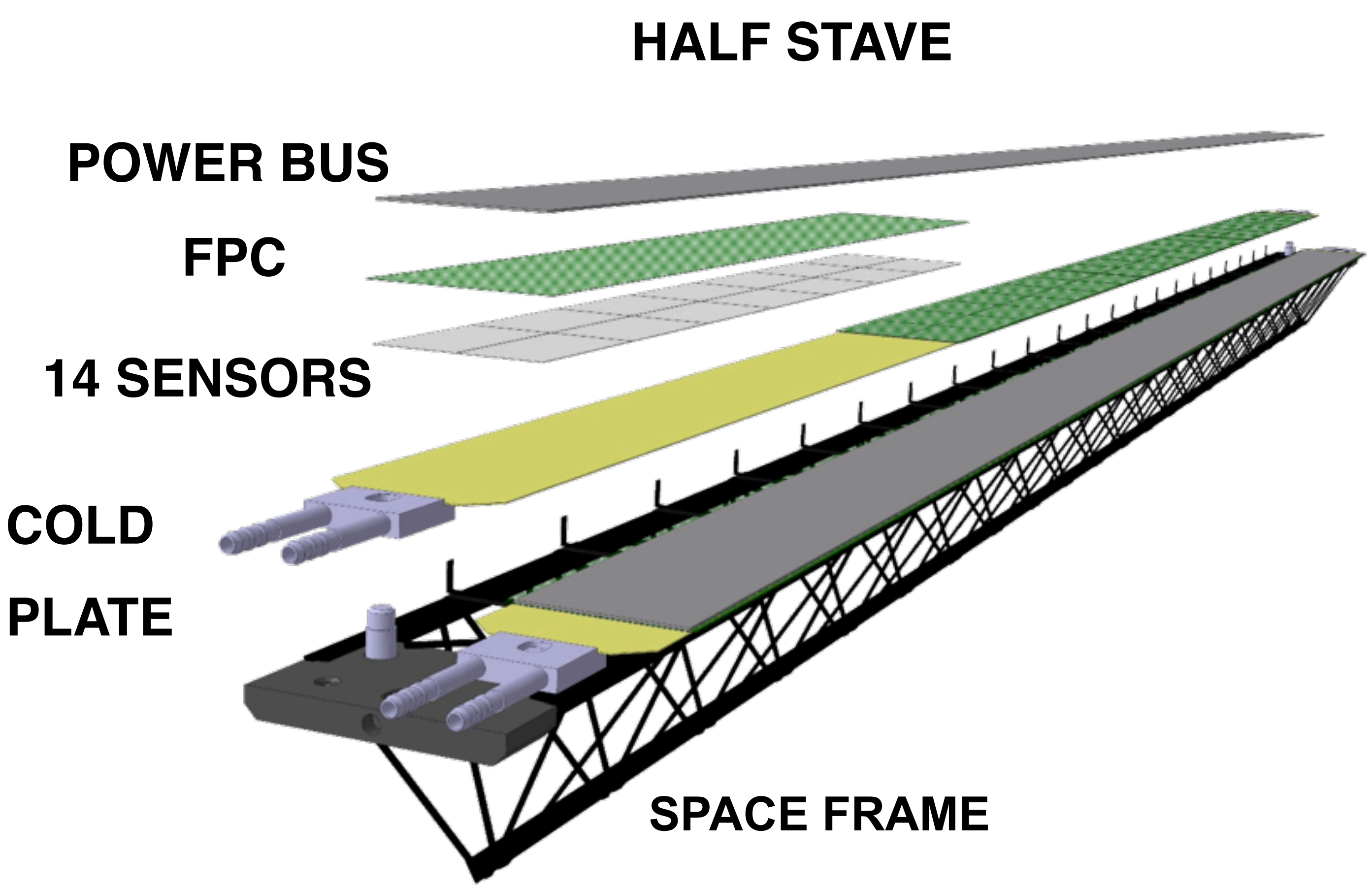
Cold Plate

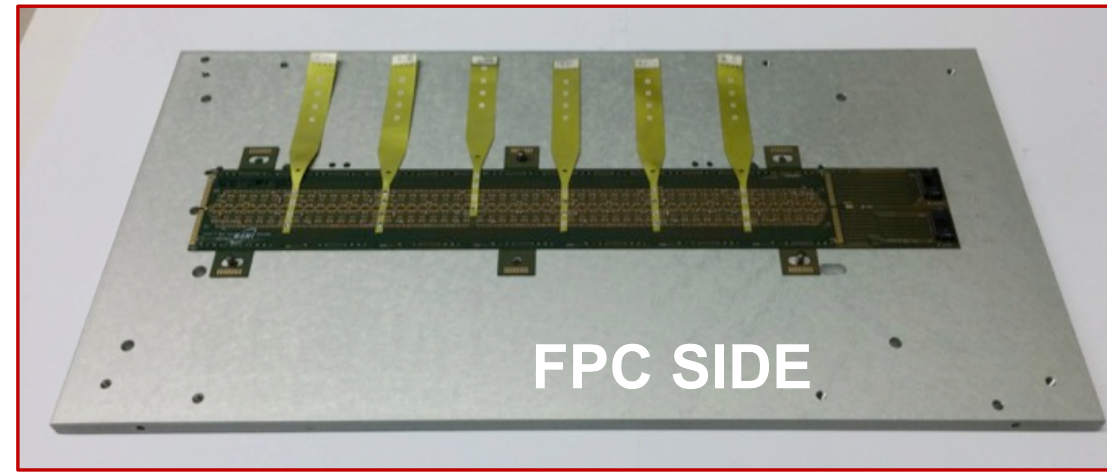
Space Frame

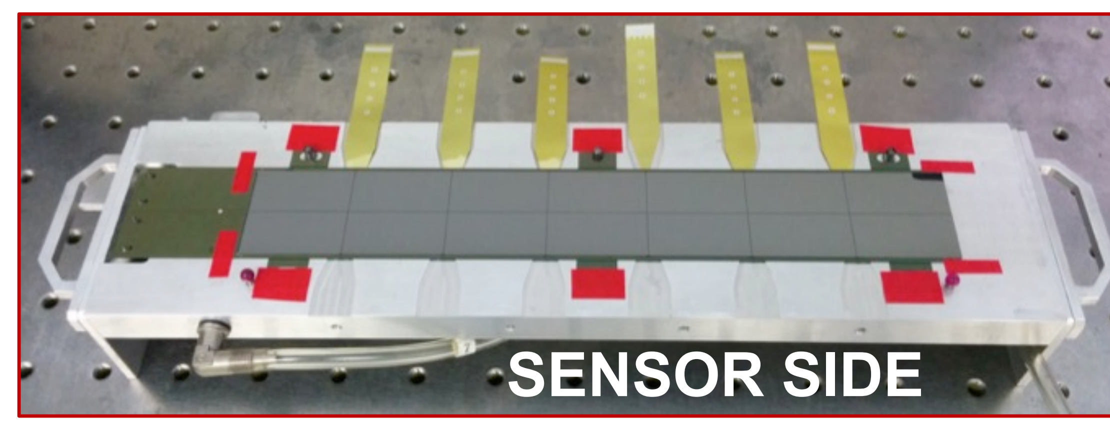
48 Inner layer STAVES

Detector HICs and staves- Outer Barrel

HIC: Hybrid Integrated Circuit





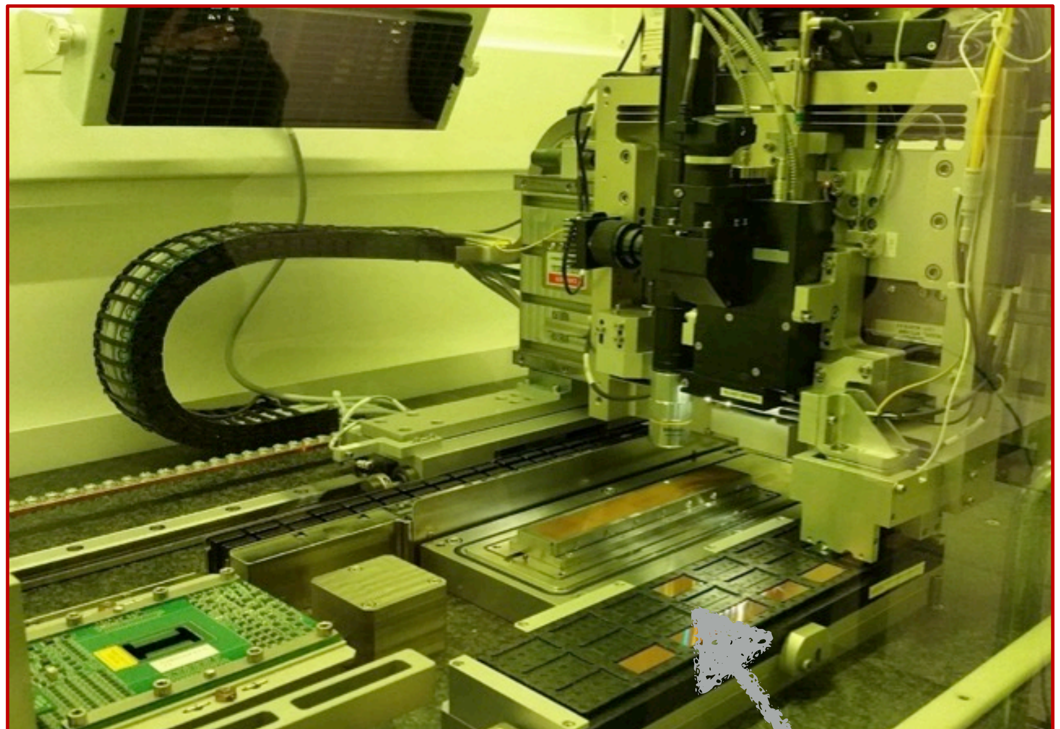


90 Outer layer STAVES

54 Middle layer STAVES

HIC Assembly (IB & OB)

Automated module assembly
(custom-made machine)

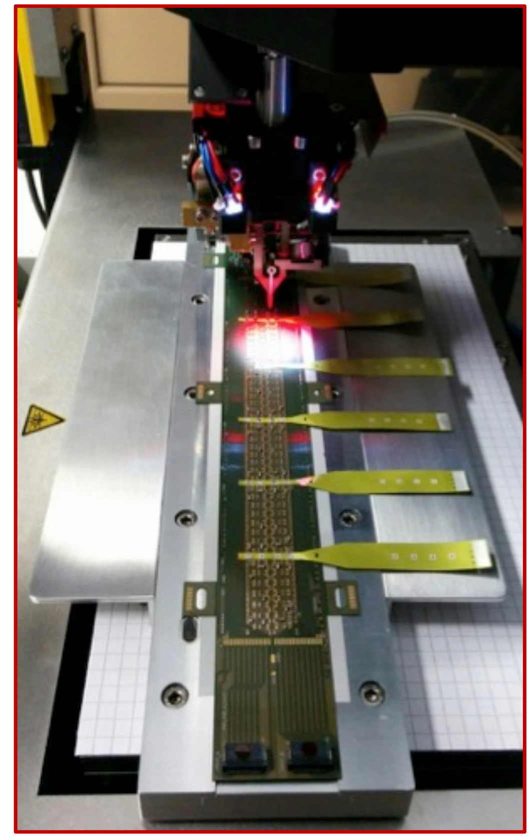


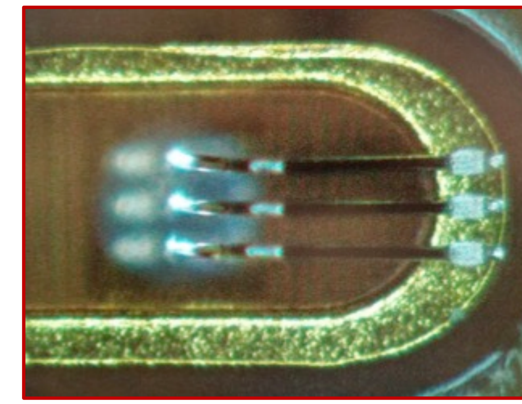
Probe card

Chip tray

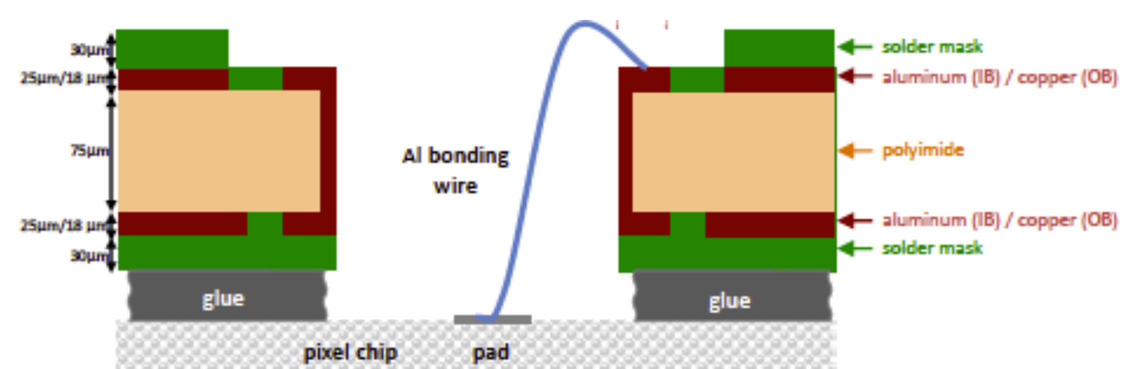
Assembly table

Electrical interconnection
(wire bonding)





Wire bond: chip (pad over logic) to FPC



- Production of IBHIC and stave is done at CERN
- OBHIC production takes place in 5 sites: Bari, Liverpool, Strasbourg, Pusan/Inha, Wuhan

➢ Infrastructure are ready and final tooling are available in each site

HIC preparation for production

After HIC Production Readiness Review (April 2017)

IB HICs pre-production

> 30 functional HICs and 10 functional staves (overall yield ~ 90%)

OB HICs pre-production

> 50 functional HICs (overall yield ~ 90%)

Optimisation of layouts and procedures after HIC PRR:

OB FPC layout: minor changes

- new design will allow for separation of analog and digital GND planes
- first production lot delivered end of October

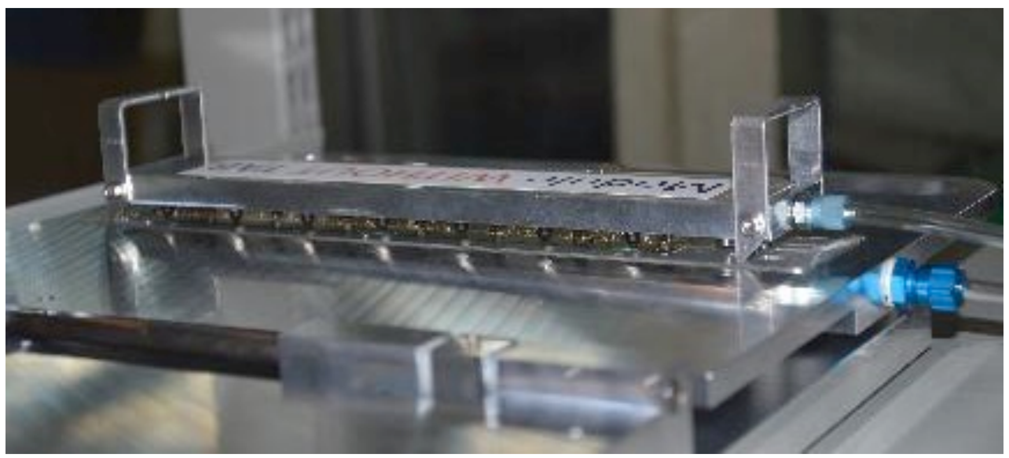
Chip to FPC gluing procedure

- optimisation of the layout of the glue deposition mask
- change of glue (ABLESTIK45 -> ARALDITE 2011)
  1. Ablestik45 didn't pass ageing tests
  2. ARALDITE extensively used by ATLAS and CMS

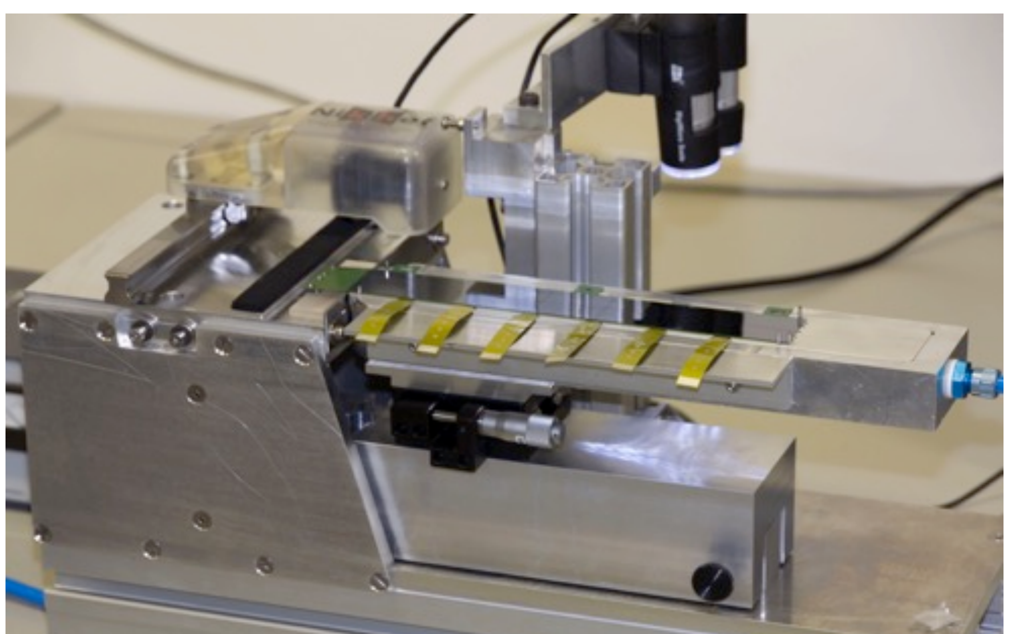
OB STAVE assembly: TAB CUT

TAB

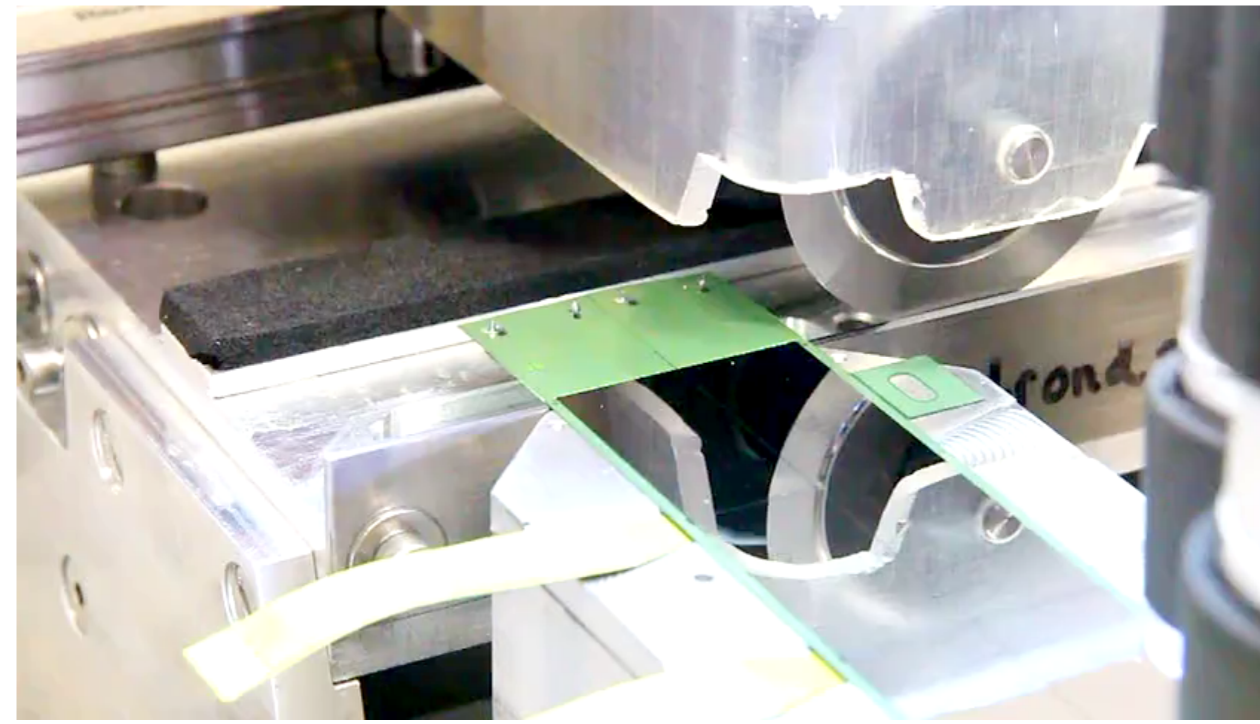
1. Module gripper



2. TAB CUTTER



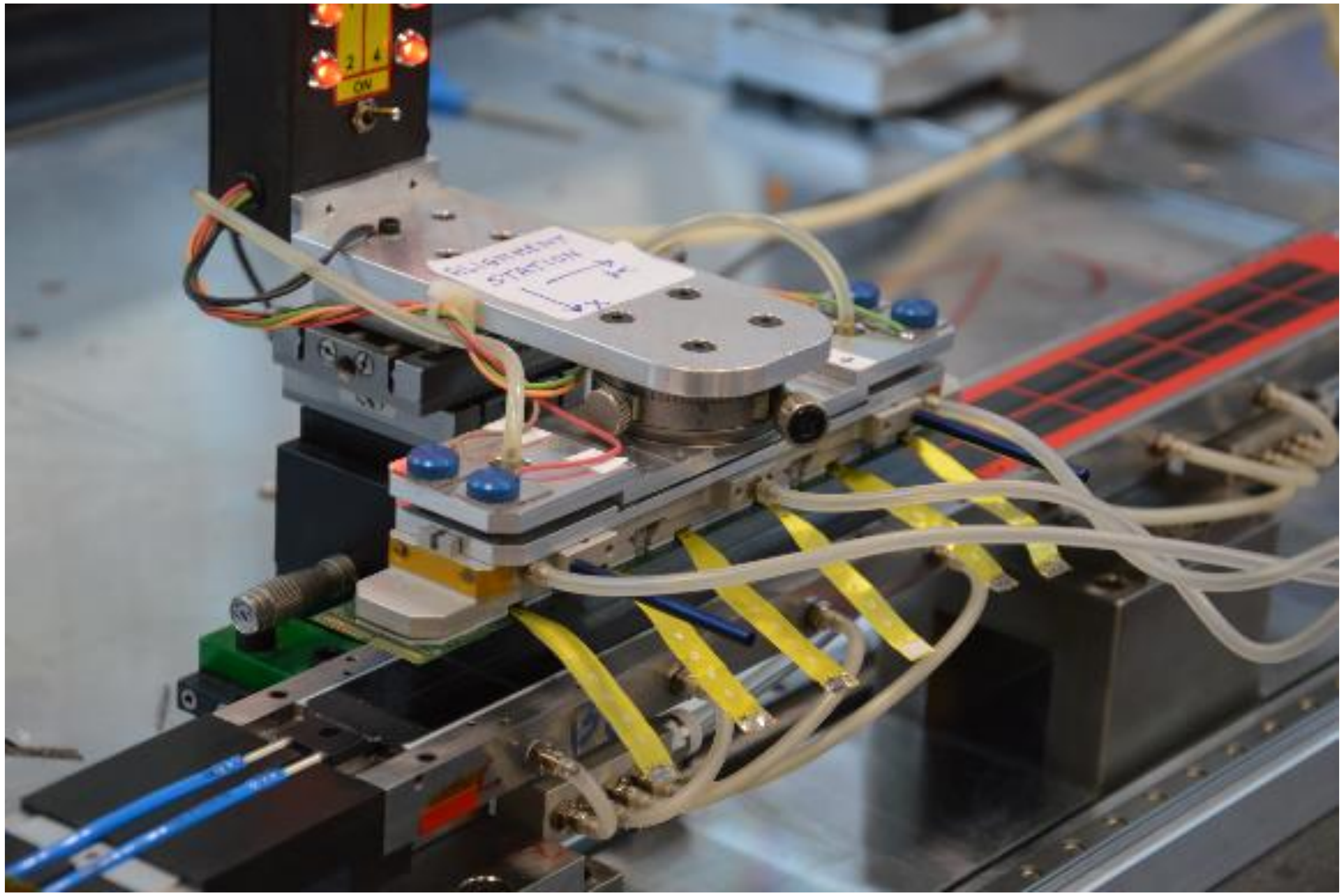
TAB CUT PROCEDURE



- The FPC TAB, used for HIC test, must be cut before the HIC assembly on the CP
- TAB CUTTER allows alignment of the HIC with a precision of 10 µm by means of video-cameras placed on the cut line.

OB STAVE assembly: HIC alignment

ALICE



HICs are placed on a carbon fiber cold plate which includes kapton pipes for cooling purpose

Micrometric move stages allow for HIC positioning precision within 10-20µm

The procedure makes use also of custom made tools machined with a precision of 100mm along 1.5m

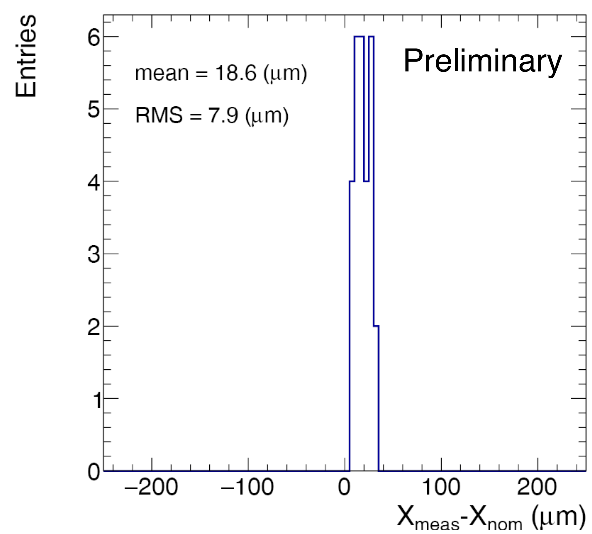
All the production steps are surveyed by means of CMM machines with a precision of 1µm along 5m.

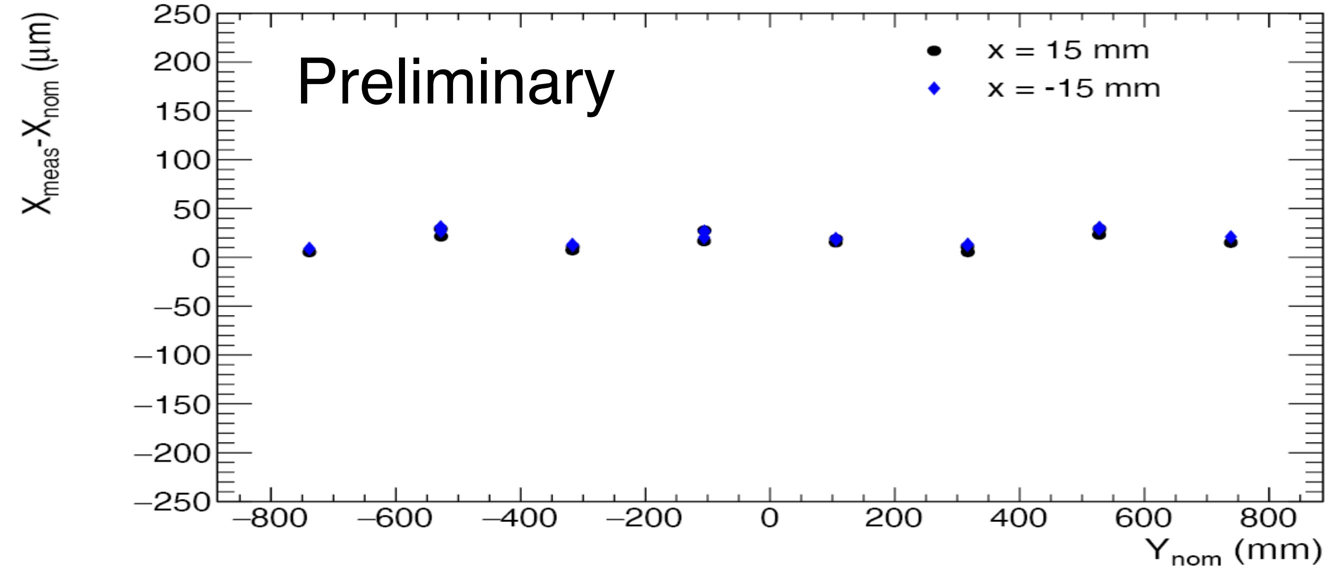
- Pre-series production allowed to validate the Assembly procedure: 2 dummy and 2 functional staves produced (in progress)
- All production sites ready to start stave assembly soon

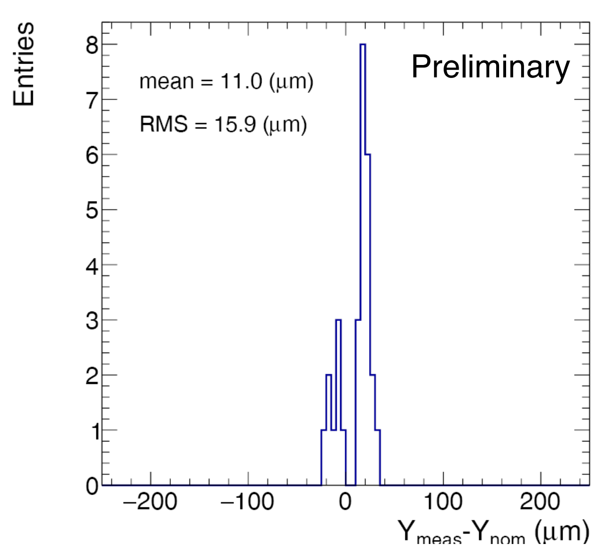
Daresbury, LBNL, LNF, NIKHEF, Torino

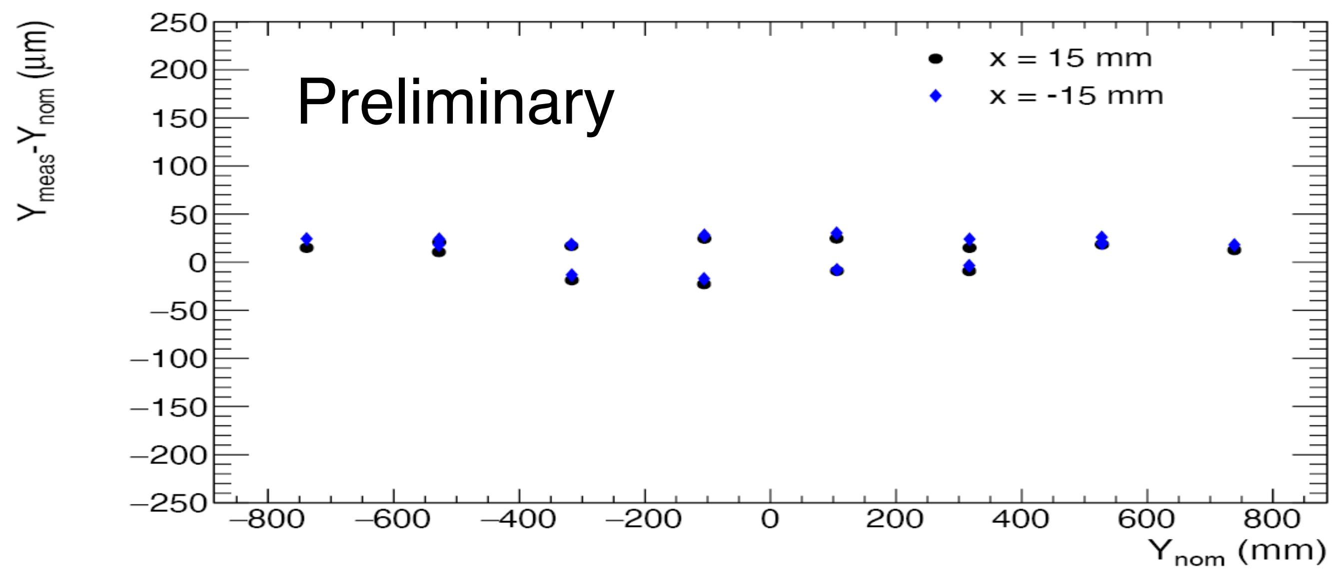
OB STAVE assembly: HIC alignment

HS3_L assembly at Torino: HIC alignment precision



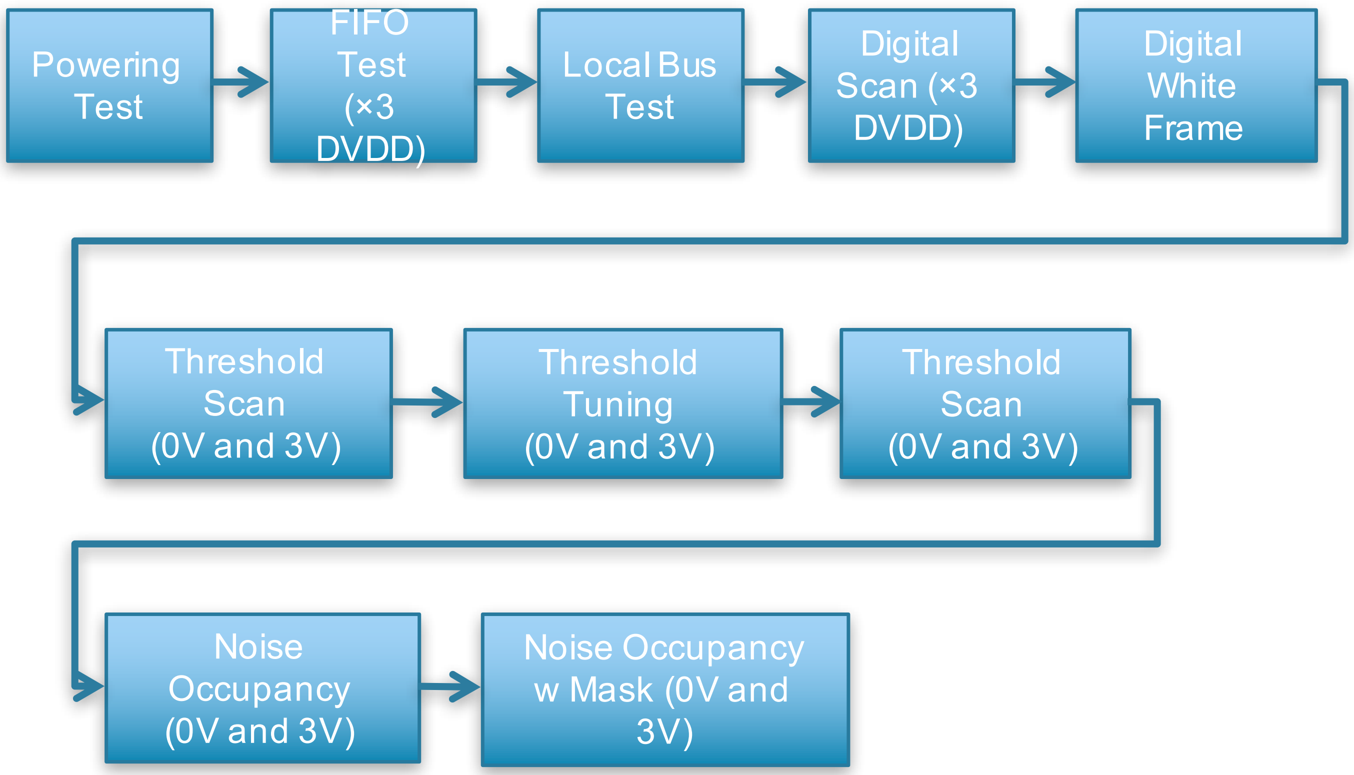






➢ Final HIC alignment on x&y coordinates (~20μm) far below alignment tolerance (< 50μm)

HIC and Staves testing protocol and set-up

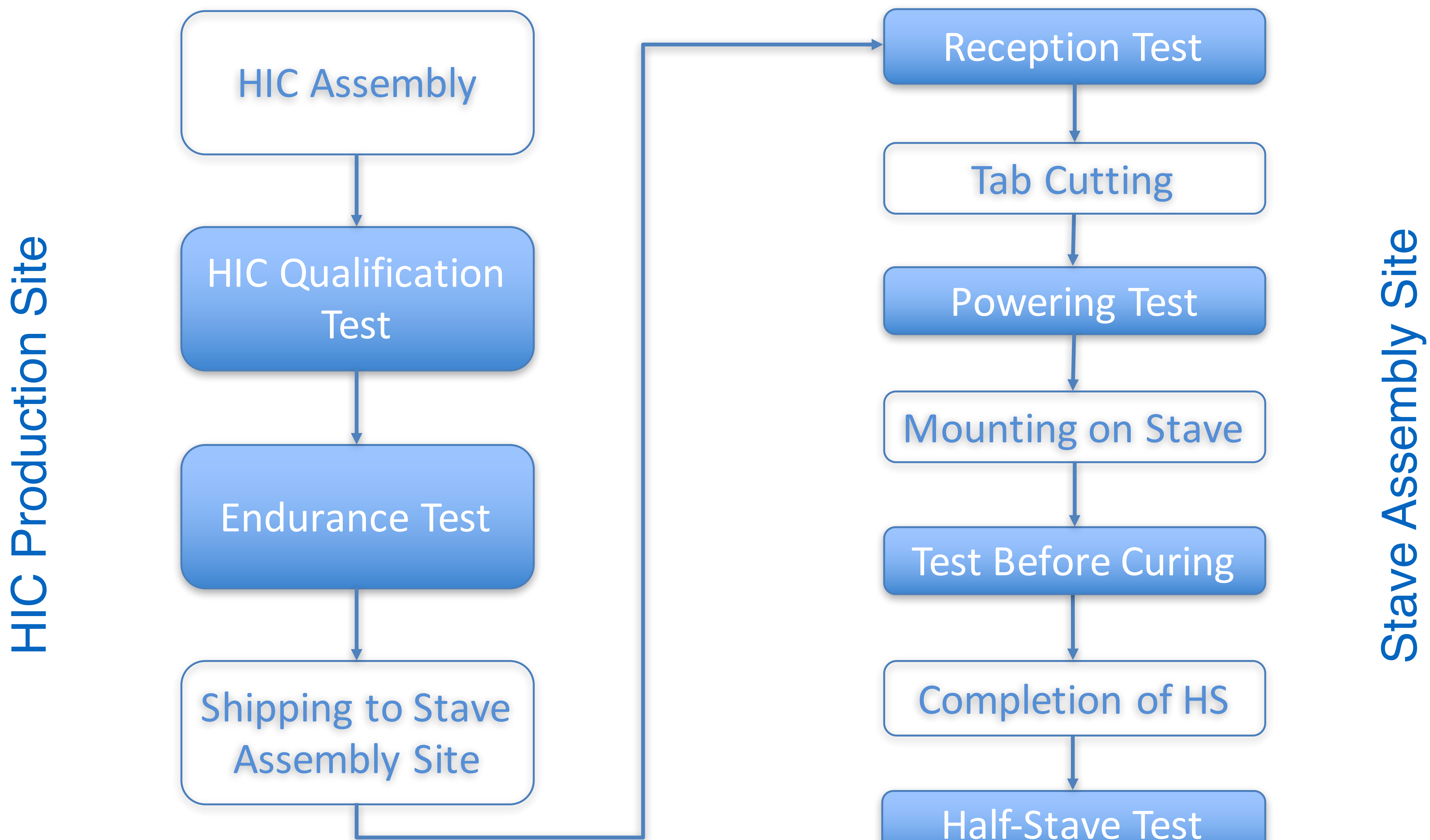


HIC test flow

- Each scan has a dedicated analysis which creates a result, including a classification
  - classes: green – orange – red
  - Classification based on configurable cut values
- For each test result parameters and attachments are written to the production database

GUI interface to test set-up

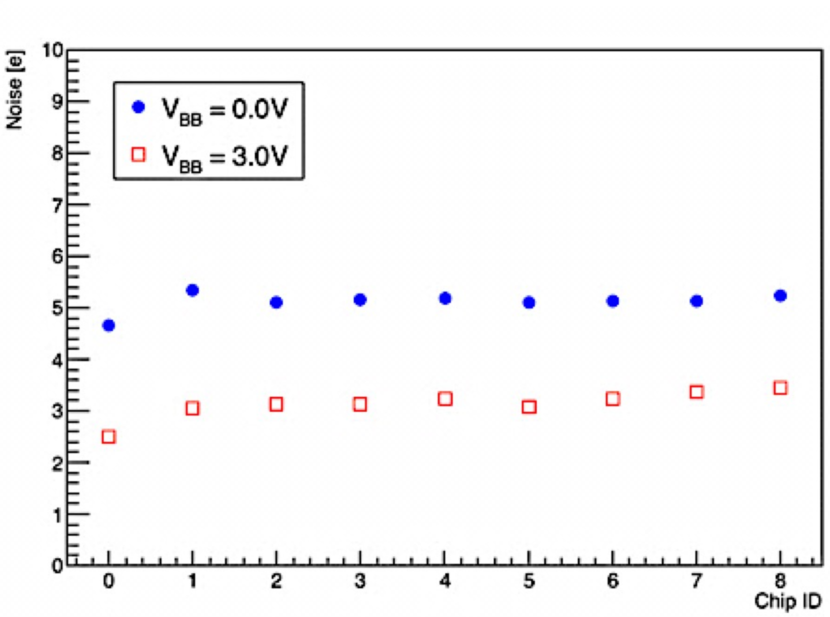
HIC and Staves testing protocol and set-up



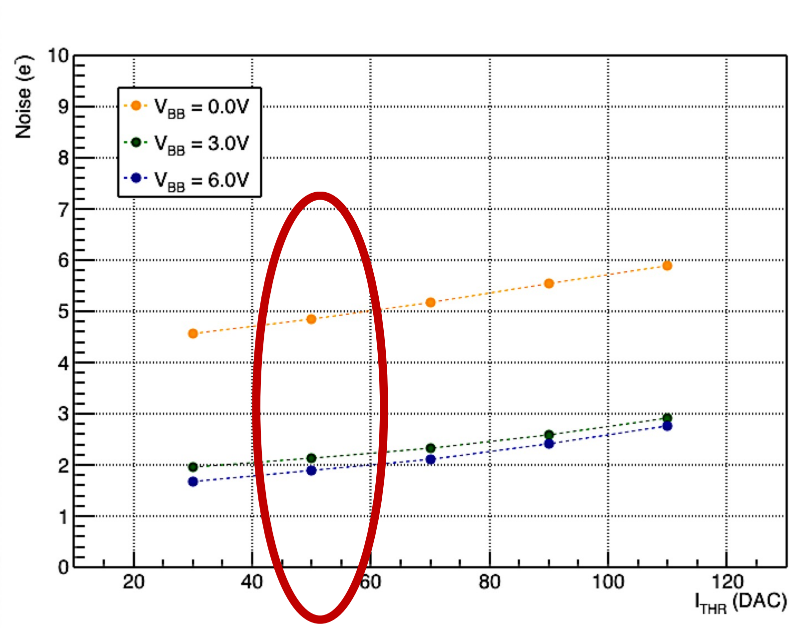
Test Results: HICs noise

Noise extracted from threshold scan (s-curve fit) for IB HICs:

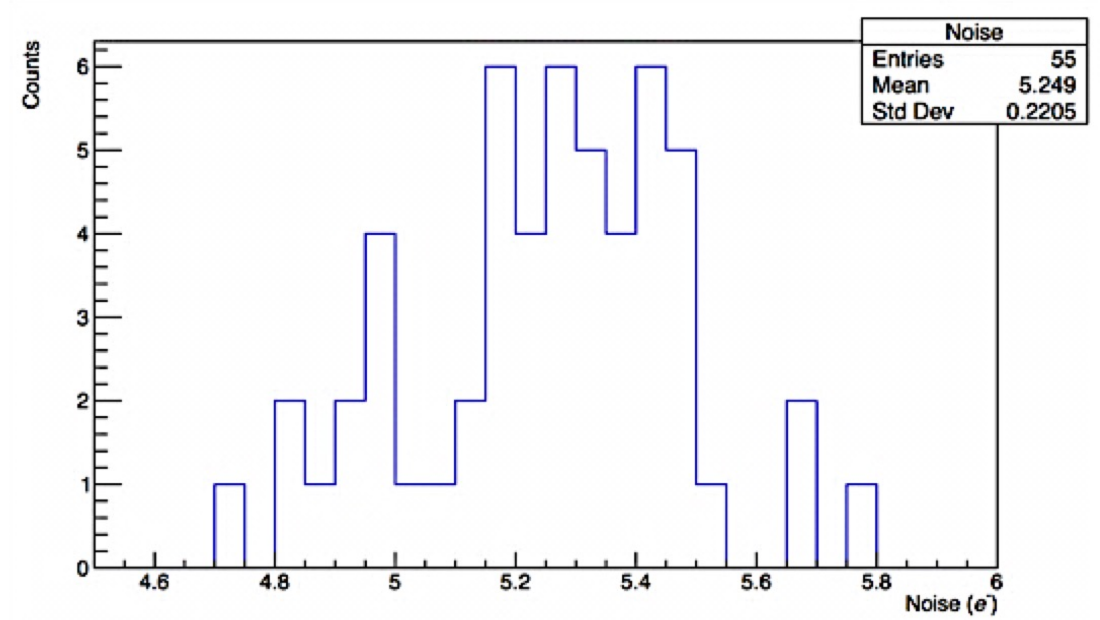
- Measured noise values ~5e without back bias, ~3e with 3V back bias
- Noise independent on position of chip on HIC
- Noise values in good agreement with values measured on single chip



Avg. noise of chips on HIC as a function of chip position



From ALPIDE PRR (for comparison): Noise of single ALPIDE chips as a function of ITHR

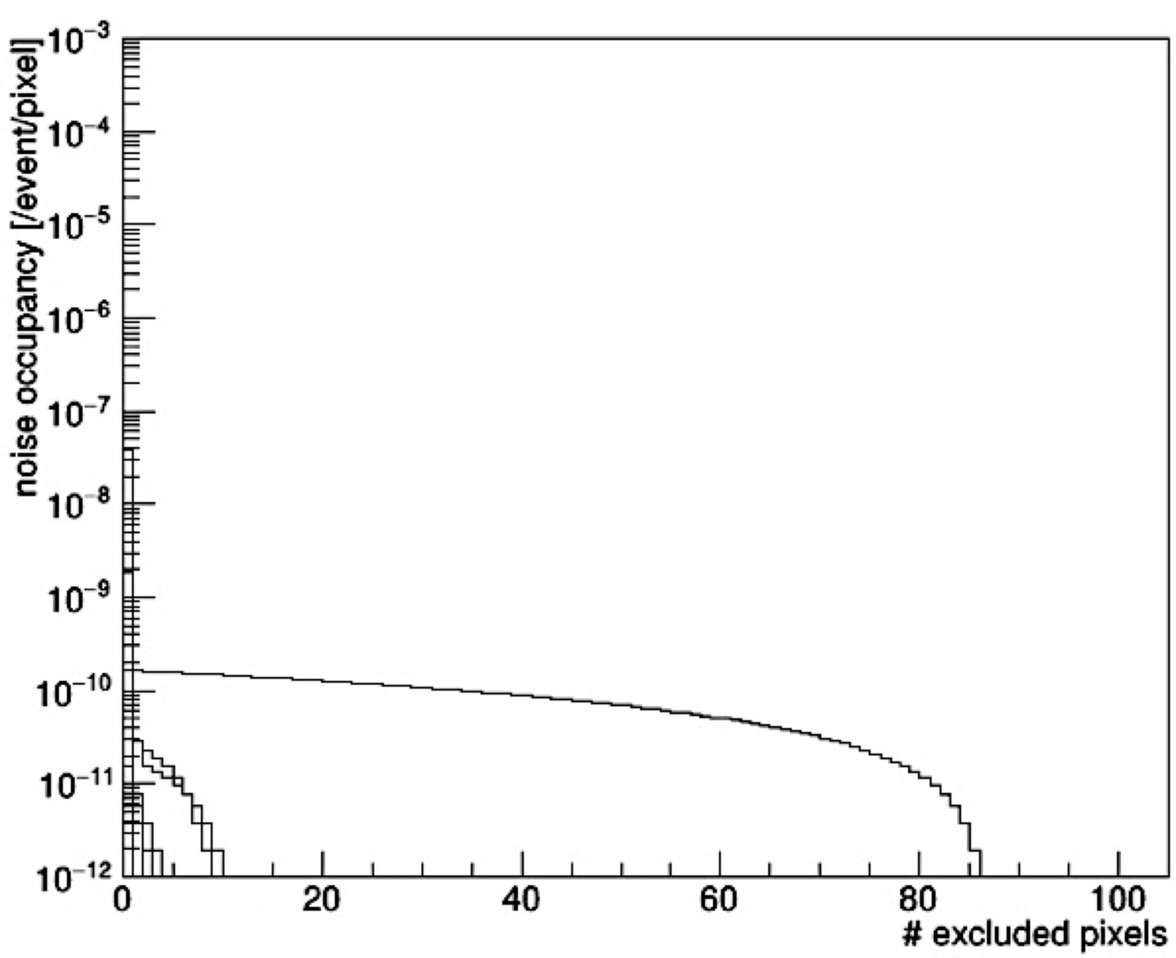


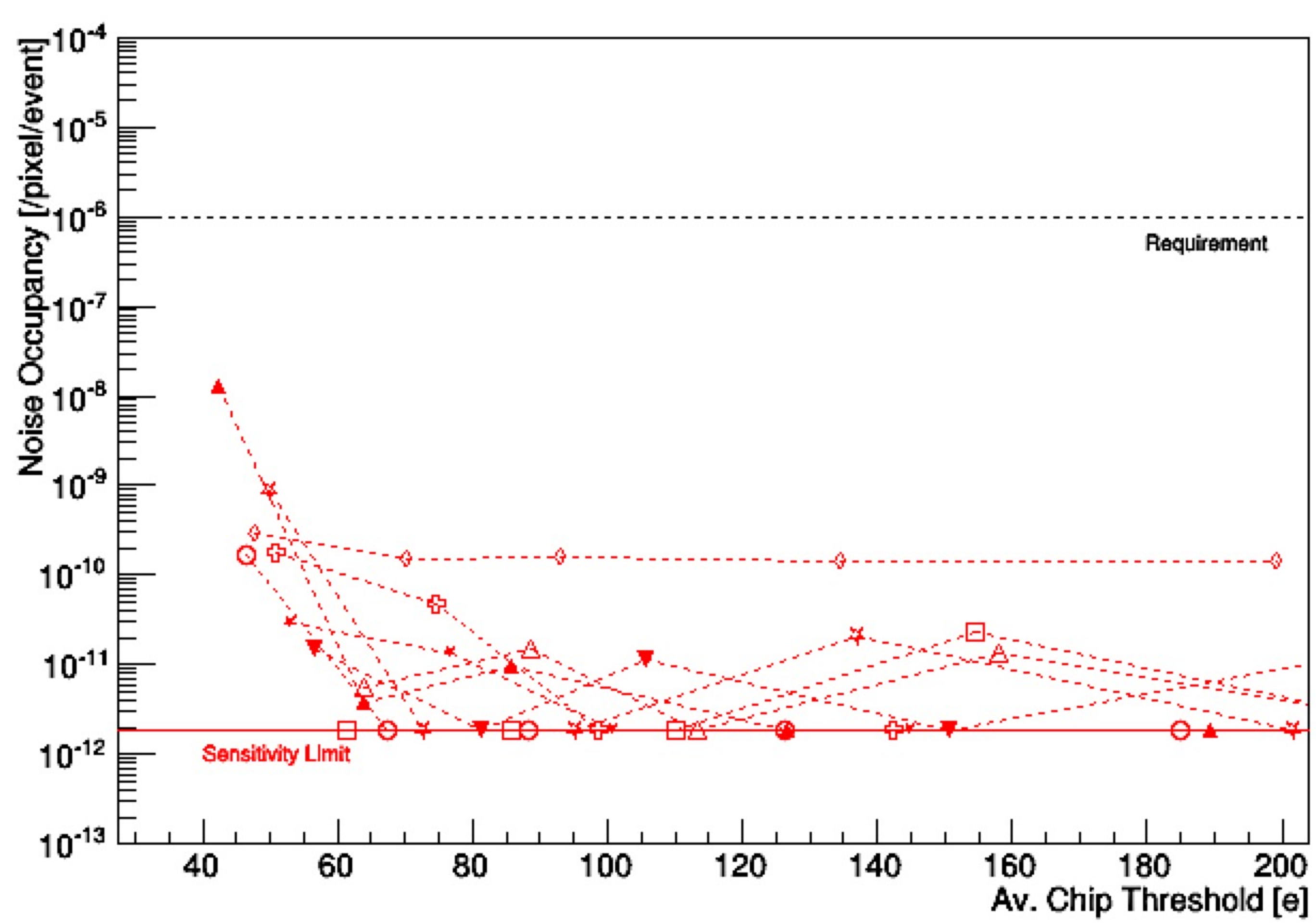
Noise homogeneous over all tested HICs
(here: average noise values for the chips of 7 HICs)

Test Results: IB HICs noise occupancy

Noise occupancy measured from data taking with 1M random triggers:

- Left plot: noise occupancy as function of masked pixels
  -> in most cases noise concentrated in < 10 noisy pixels
- Right plot: noise occupancy with 5 pixels (i.e. 1/100000) masked as a function of threshold



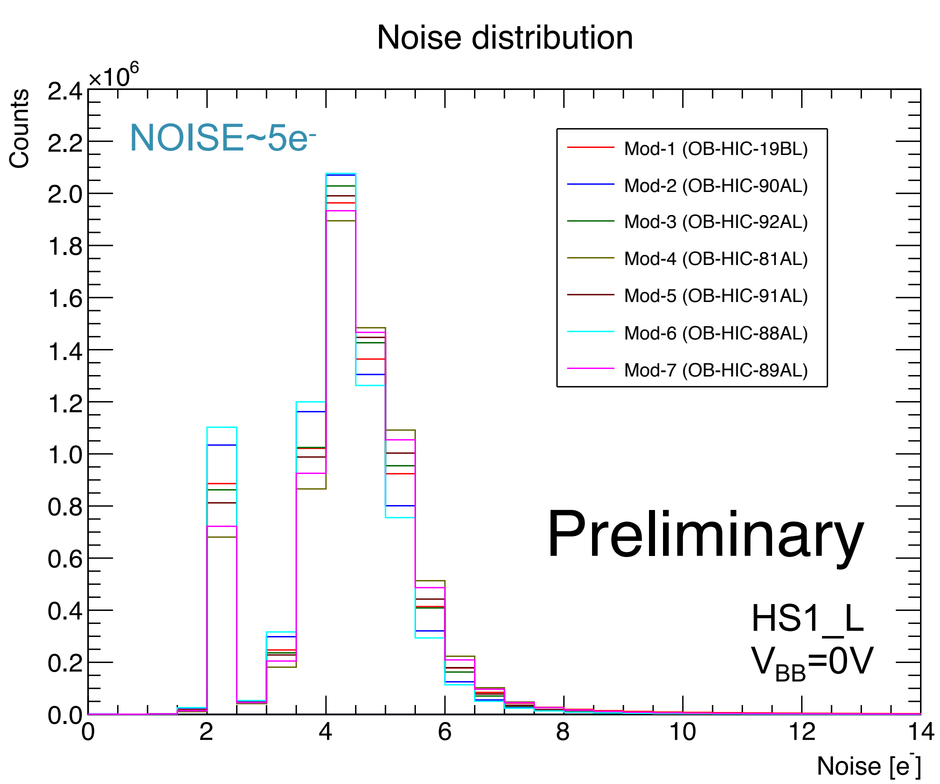


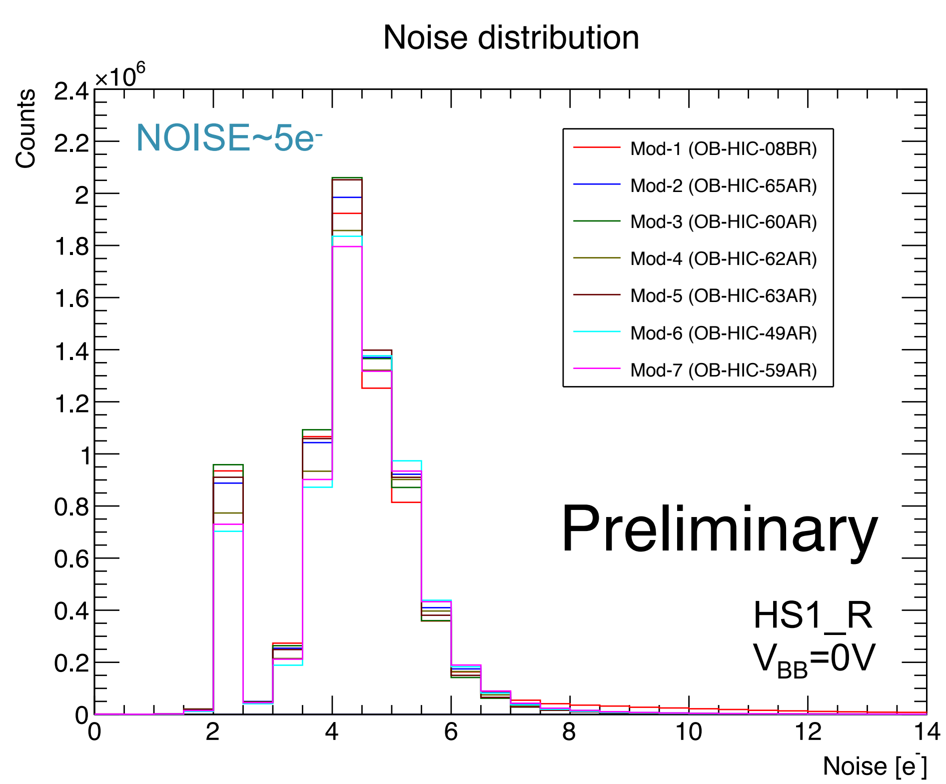
Test results: OB staves

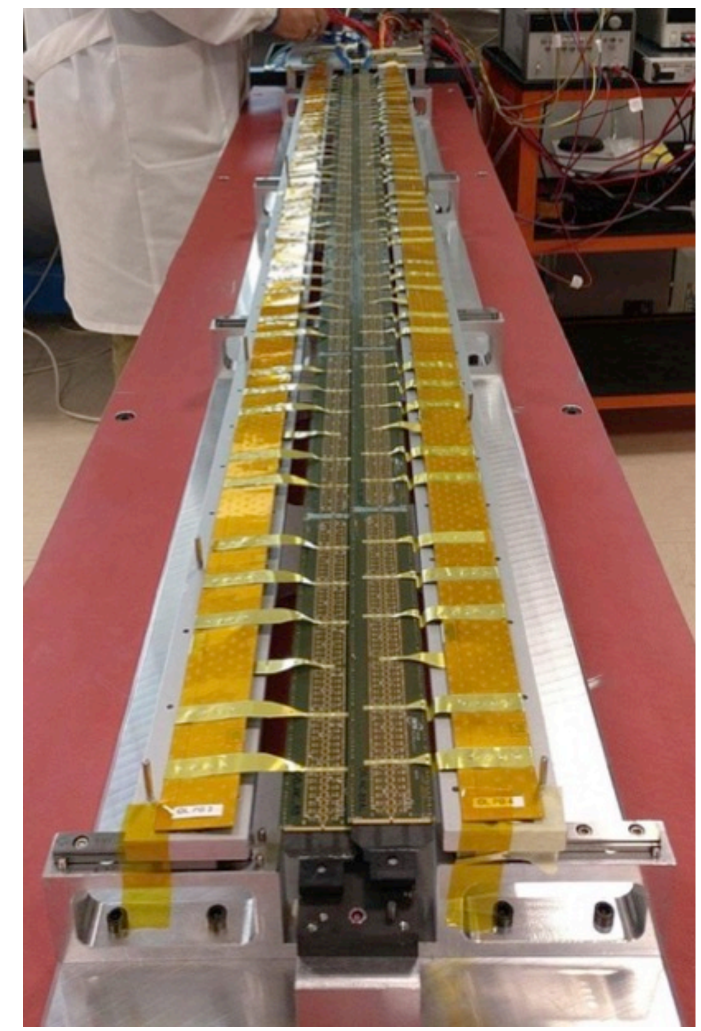
ALICE

Stave 1 tested in Torino:

- 195/196 chips responding (102M pixels !!)
  - 1chip had few wire bonds damaged during assembly
  - issue understood and new procedure developed
- results of tests, though preliminary, are very encouraging:
  - noise distribution measured in threshold scan on all 195 chips operated concurrently
  - Threshold scan tests both readout and analogue performance
  - Noise and threshold values are comparable to single chip ones

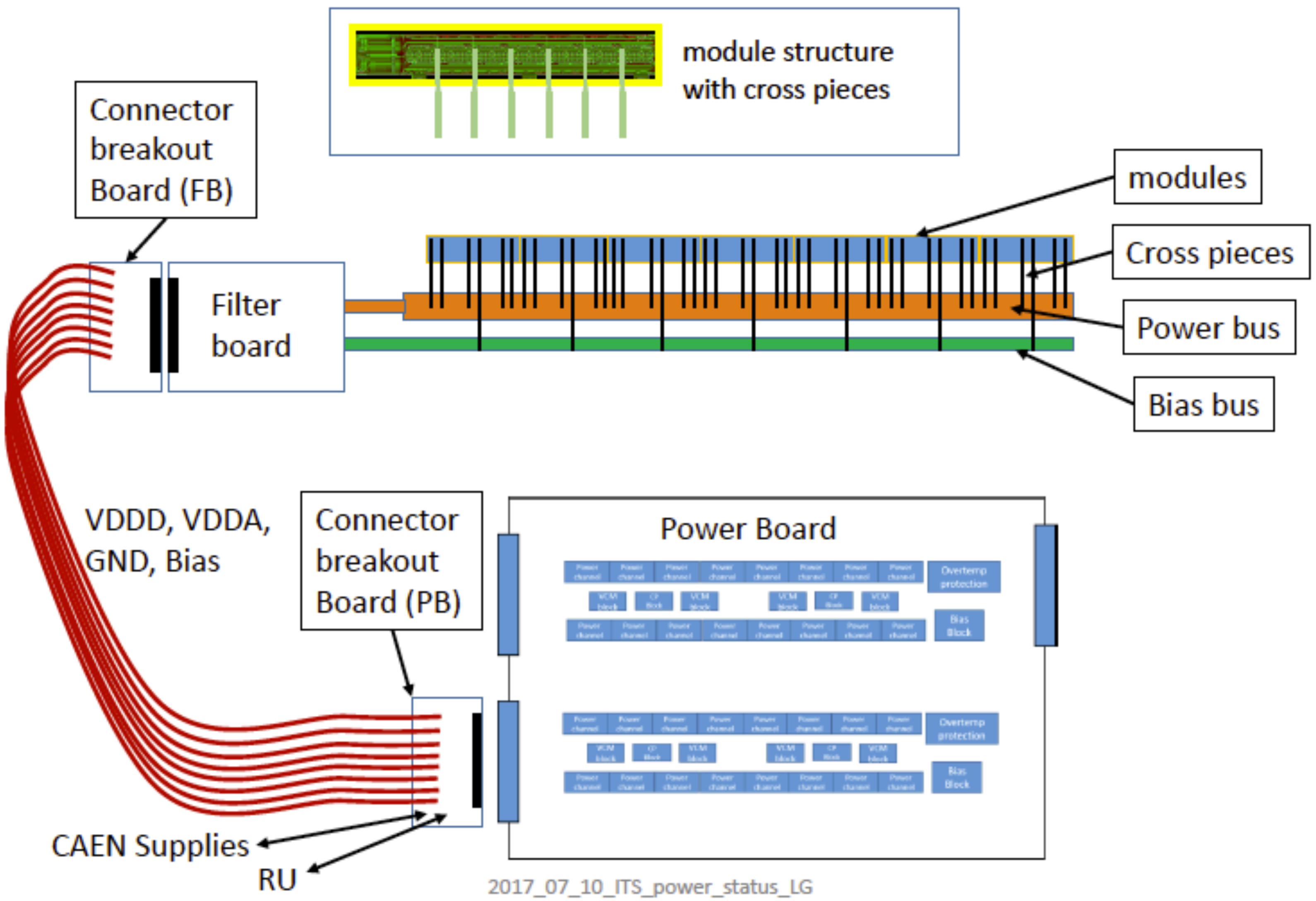






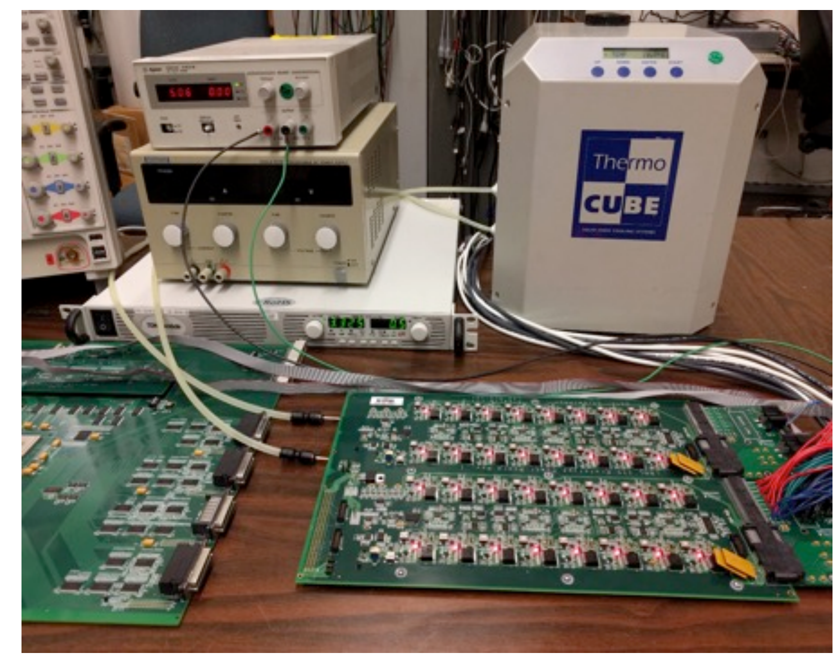
Powering system

Basic half-stave power system components (representational)



POWER BUS – BIAS BUS

CROSS CABLES

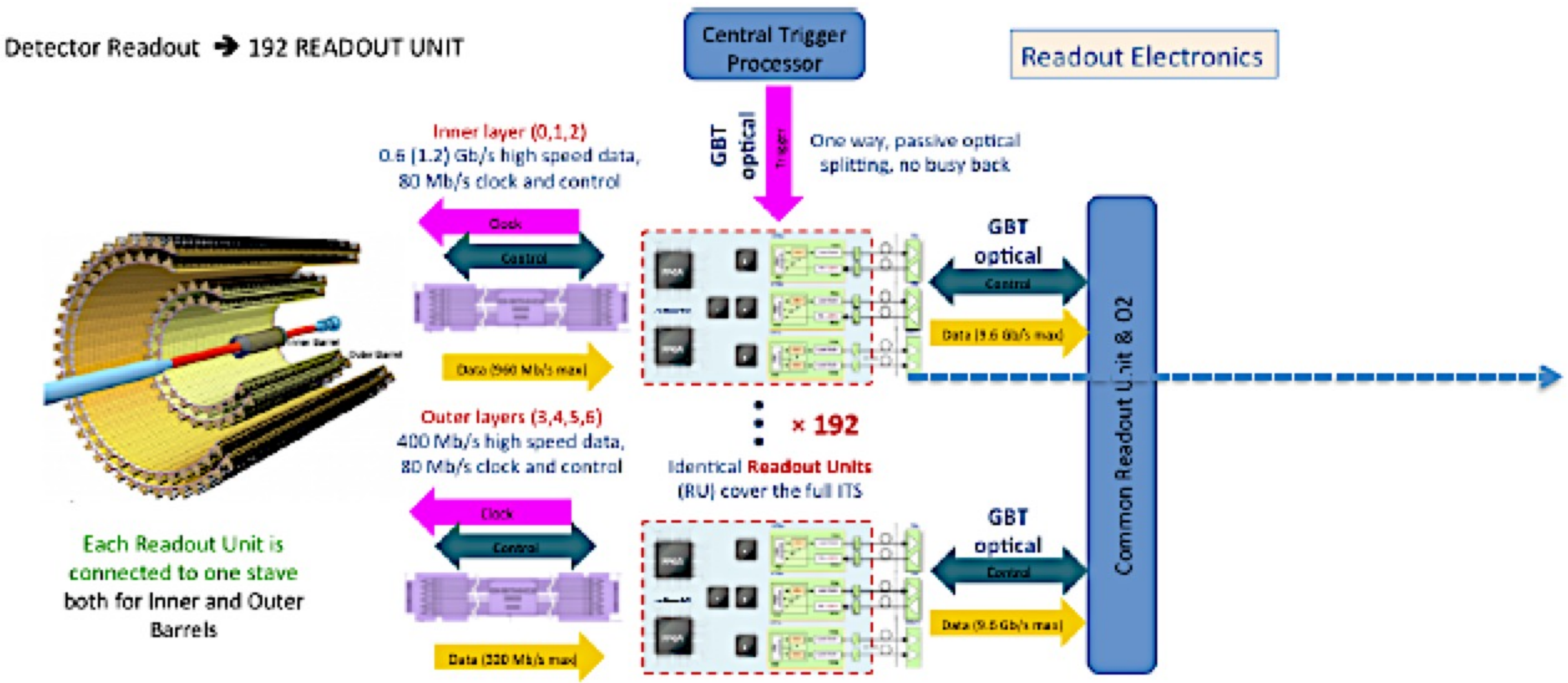


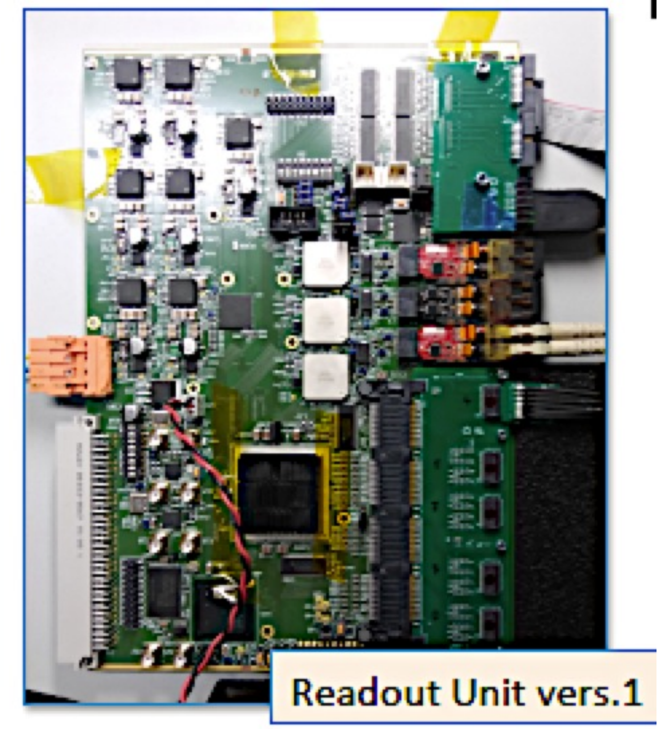
POWER BOARD

- Development of the full chain required 2 years of R&D
- Prototype version of Power Boards tested on HICs and Staves
- Testing power board kits already shipped to all the HIC/STAVE production sites

  (Bari, CERN, Strasbourg, Pusan, Liverpool, LNF, Torino, Nikhef, Daresbury)
- 2 power board prototypes will be used for full board radiation testing

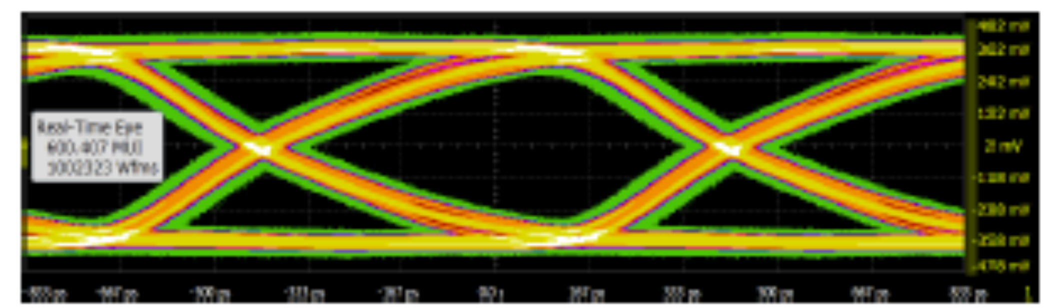
Read-out electronics





Characterization ongoing

EYE diagram of signal propagated over 5m-long cable



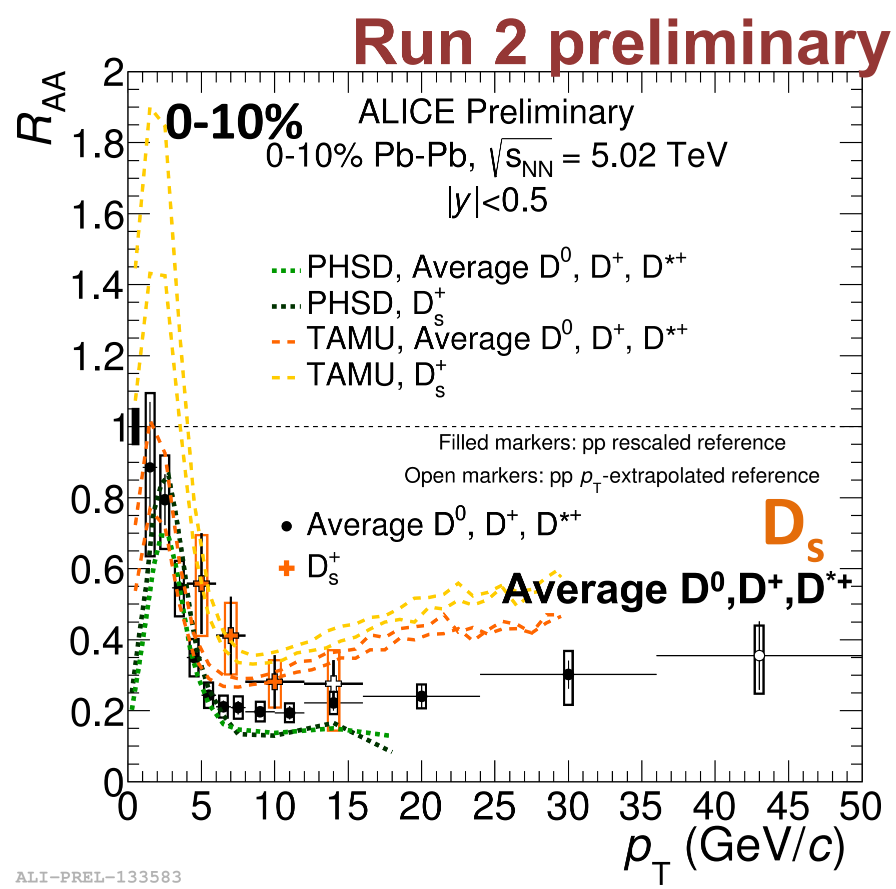
ALPIDE will be the only electronics component around the interaction point, the off detector electronics will sit 5m away

- Communication between sensors (ALPIDE) and off-detector electronics via SAMTEC firefly cables
- Distribution of CLK and slow-control at 40MHz
- Data read-out:
  - 1.2 Gb/s (IB)
  - 0.4Gb/s (OB)

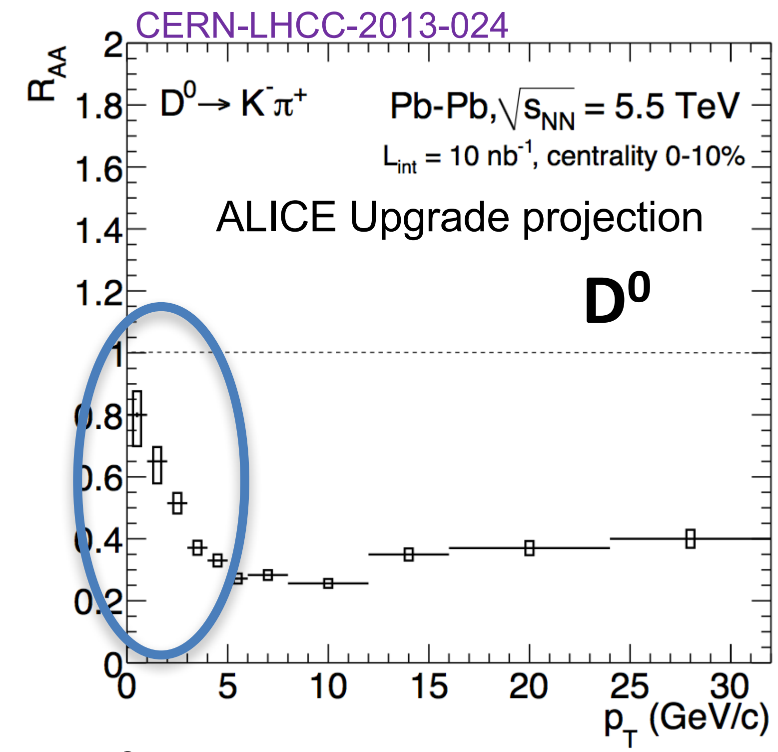
- Single chip (109 hours of integrity measurements)
  - BER ≤ 9.8 10^{-15} with a Confidence Level (CL) of 99 %.
- Inner Barrel Stave prototypes (250 h)
  - BER ≤ 7.9 10^{-16} (CL 99 %)
- Outer Barrel Stave prototypes (preliminary)
  - BER ≤ 4.2 10^{-15} (CL 99 %)

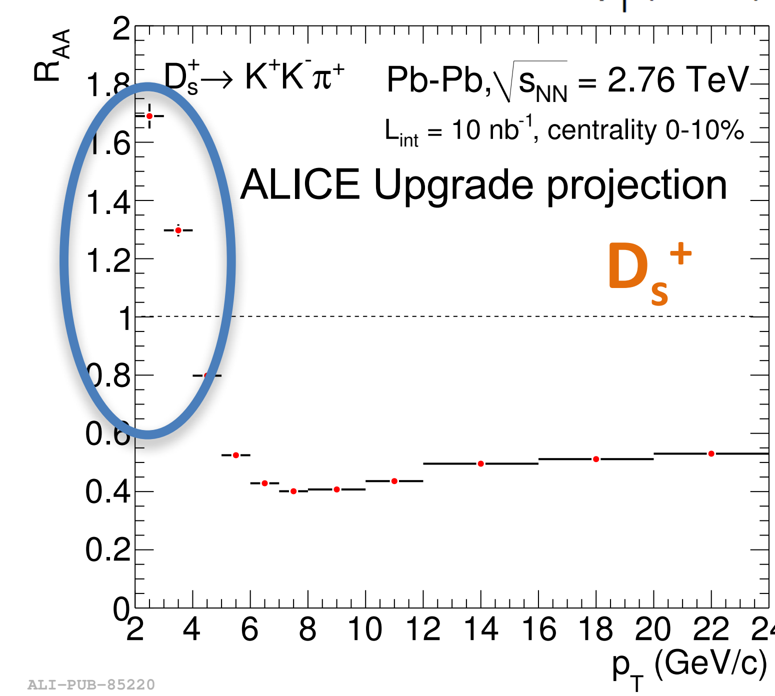
Physics performance with the new ITS (MonteCarlo)

D mesons



Projections (from ITS TDR)





Precise measurements down to p_T=0

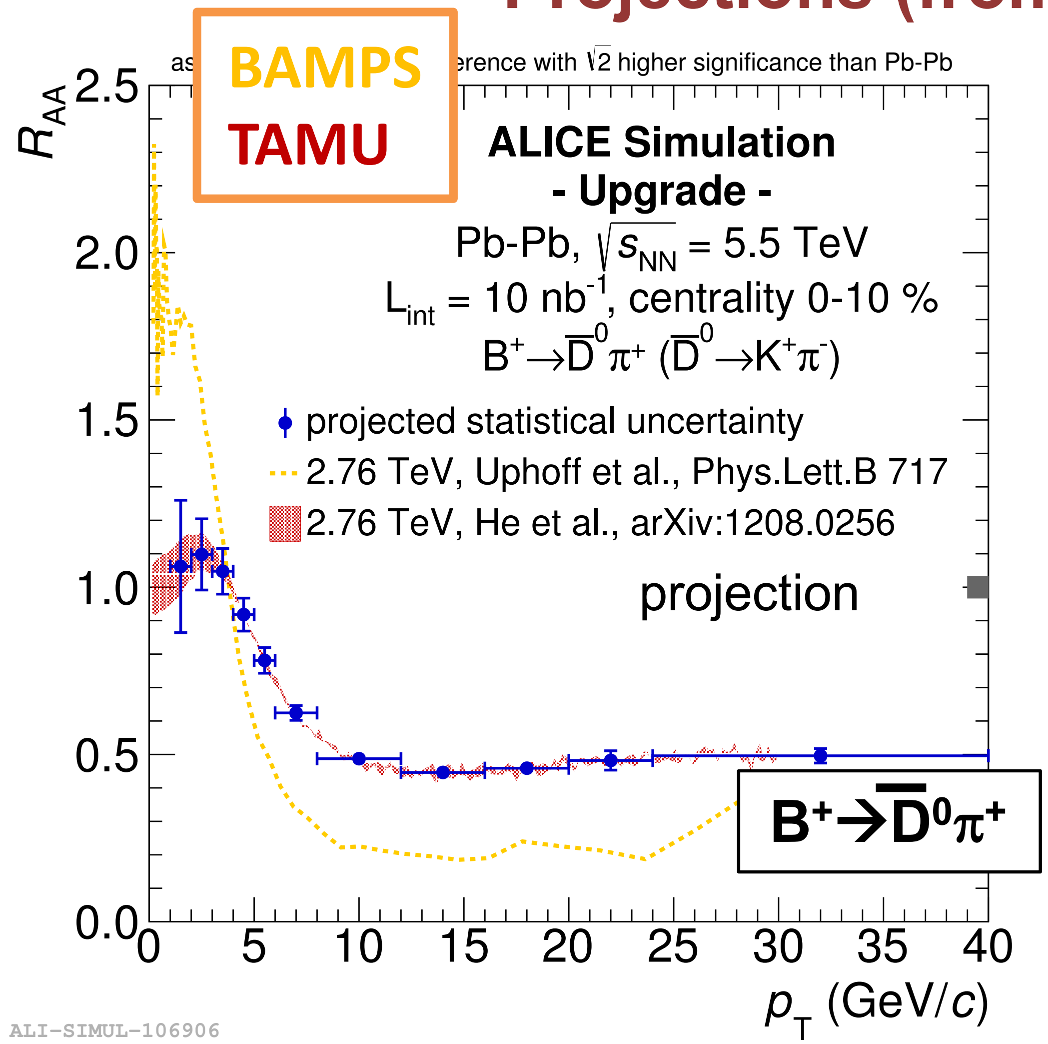
- Discriminate models to quantify microscopic interactions with the medium
- Total charm cross section
  - All charmed particles relevant (role of recombination for D_S, Λ_C,..?)
  - Reference for charmonium measurements

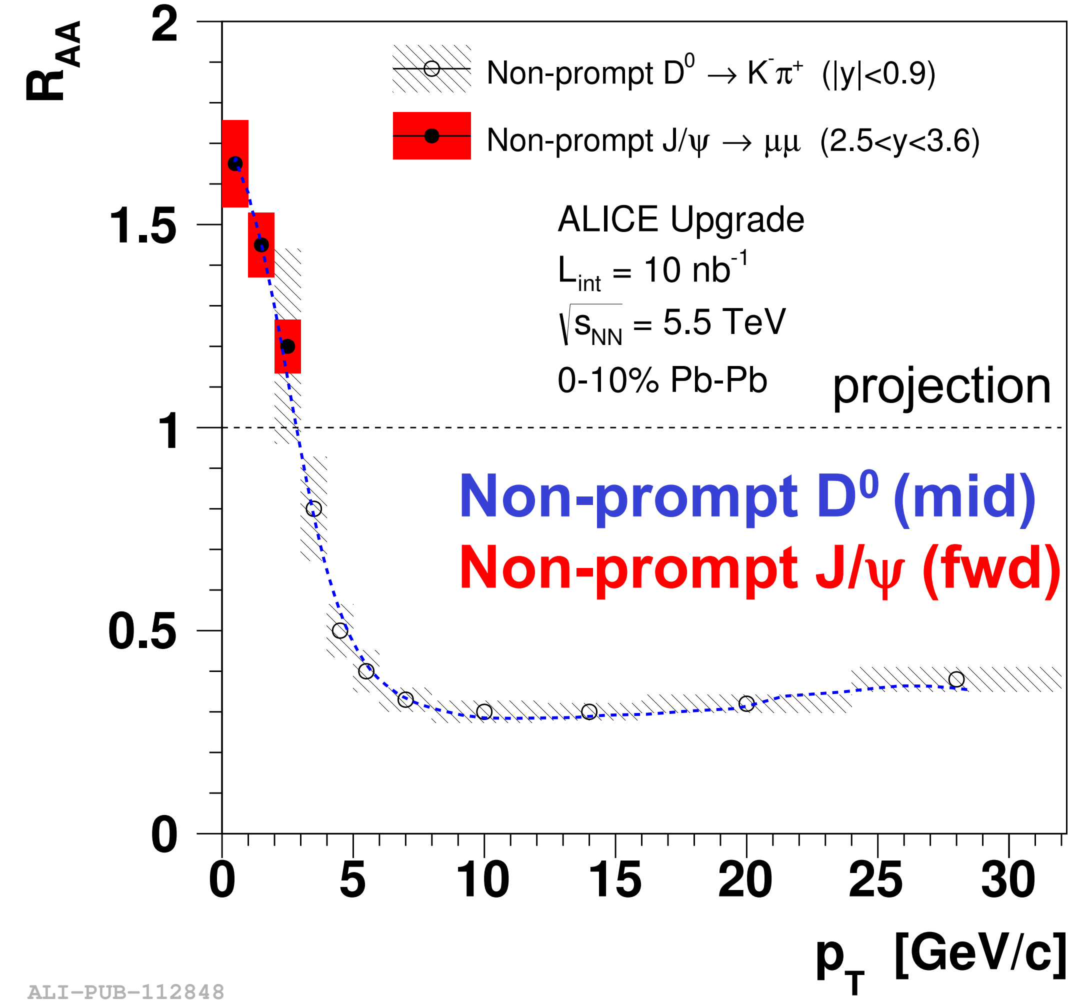
Physics performance with the new ITS (MonteCarlo)

B mesons

Projections (from ITS, MFT TDR, PhD theses)

CERN-LHCC-2013-024
CERN-LHCC-2015-001
CERN-THESIS-2016-037



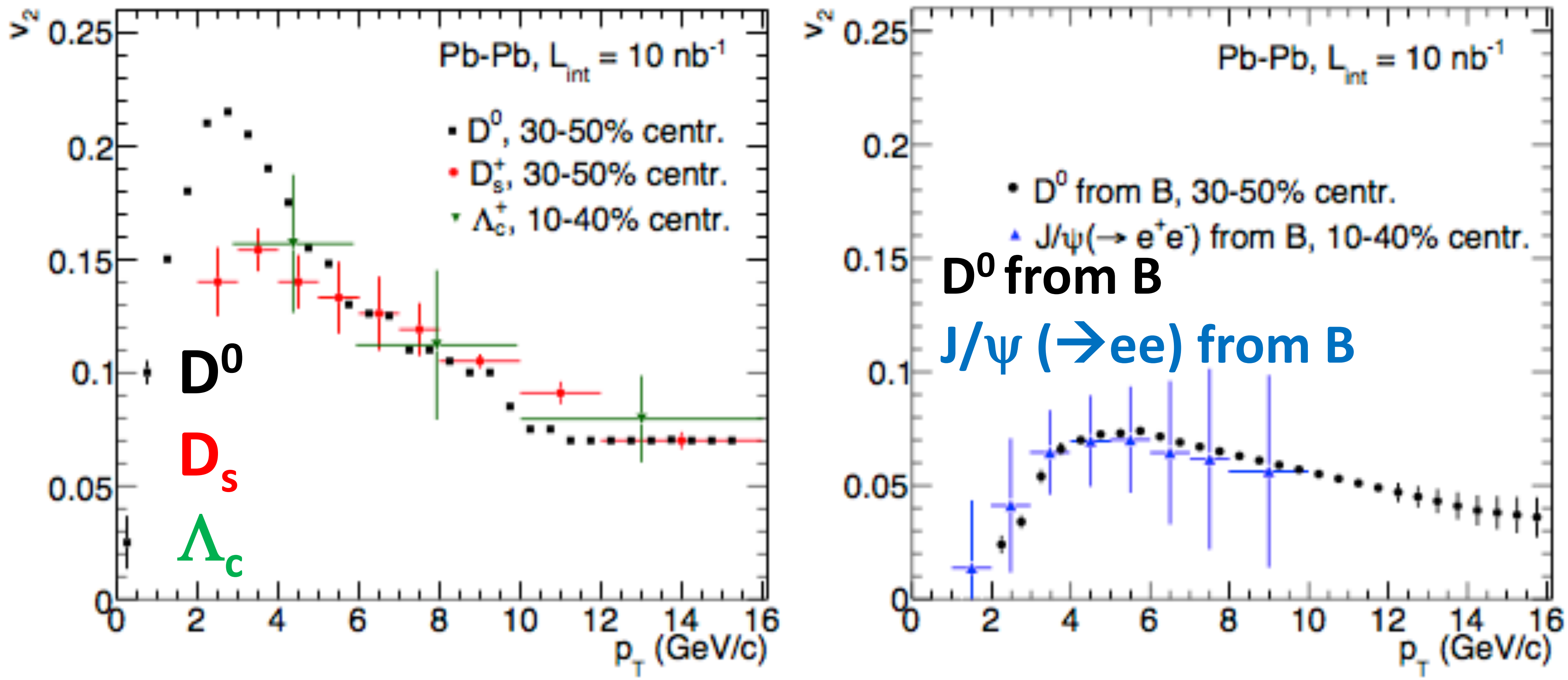


- Beauty via Dπ, J/ψK, non prompt D and J/ψ, combining measurements at mid and forward rapidity
- Precise R_{AA} and v_2 can discriminate models at low p_T, where parton mass plays a role, constrain the b-quark diffusion coefficient and probe b-quark thermalisation

Physics performance with the new ITS (MonteCarlo)

Elliptic flow

Projections (from ITS, MFT TDR)



Provide the strongest constrain on the c and b quark diffusion coefficients and path-length dependence of the parton energy loss

Summary

- The ALICE ITS upgrade project has successfully completed the R&D phase
- SENSOR:
  - The ALPIDE sensor meets all the requirements
  - The production of ALPIDE chips is progressing well (average yield ~63%)
- HICs:
  - IB and OB HIC production has started (series production in all sites started in November 2017)
  - OB Stave pre-production is ongoing, series production started in all sites in December 2017
- MECHANICS:
  - Fabrication of Cold Plates and Space Frame is finished
  - Fabrication of large composite structures has started and is progressing well and on track
- Development of Readout Electronics and Power Distribution Systems are generally progressing well and on track for the overall project schedule
- Physics performance from MC simulations with new ALICE ITS show encouraging perspective to quantify the properties of QGP during the Run3 + Run 4

The project is well on track for installation starting middle 2020


Thank you