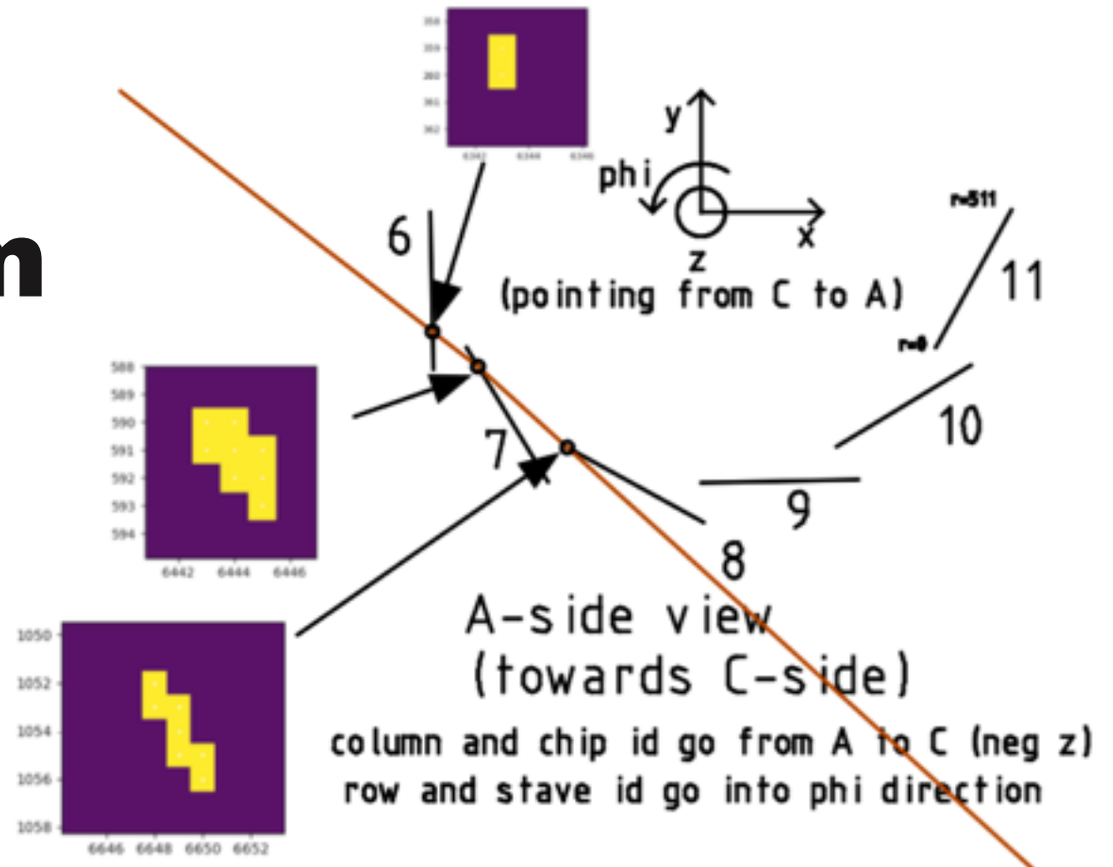
Strangeness in Quark Matter
Bari (Italy), 10 to 15 June 2019

ALICE Inner Tracking System upgrade

Construction and commissioning



FIRST COSMIC RAY DETECTED BY NEW ITS

Domenico Colella
Istituto Nazionale di Fisica Nucleare, Sezione di Bari
on behalf of the ALICE Collaboration

ALICE upgrade

Physics motivations for the **Upgrade** ➔ High precision measurements of rare probes over broad p_T range

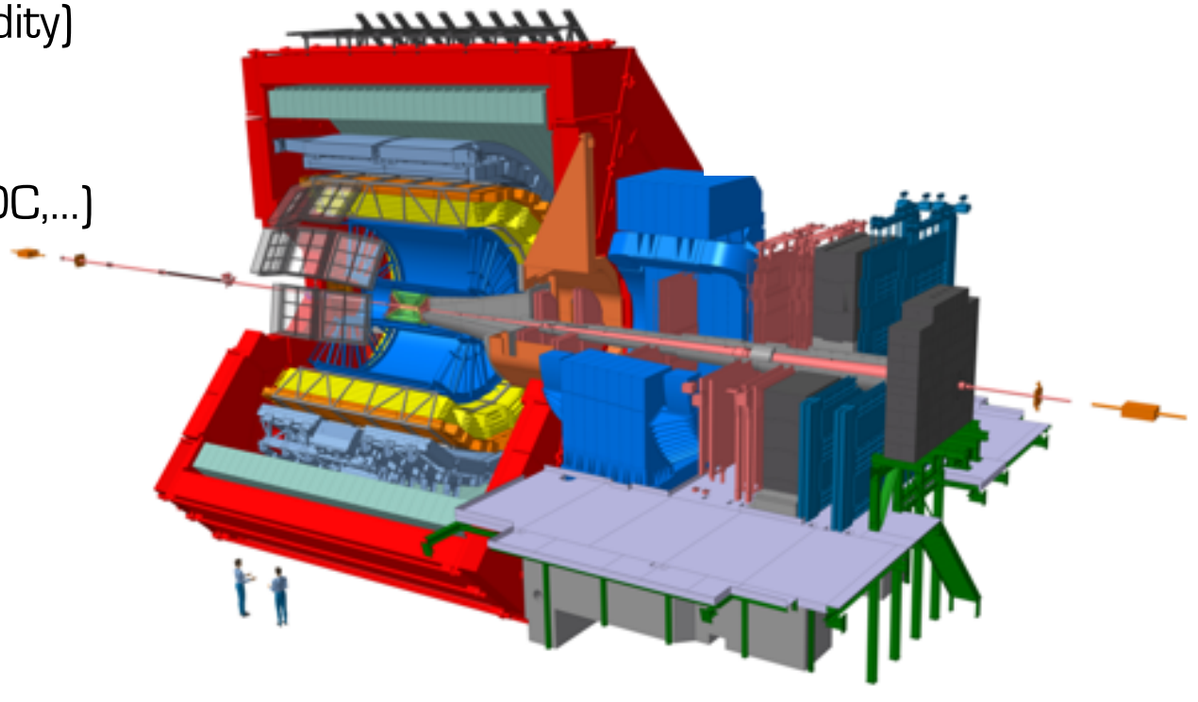
- » Heavy flavour mesons and baryons down to very low p_T
- » Charmonium and Bottomonium states
- » Low mass di-leptons
- » Light (anti-)nuclei and hyper-nuclei

Main upgrade requirements

- » Continuos read-out to fully exploit the LHC **50 kHz Pb—Pb interaction rate**
- » Improved tracking performance down to very low p_T

Upgrade strategy

- » New silicon trackers: **ITS** (mid-rapidity), MFT (forward rapidity)
- » New TPC read-out chambers (GEMs) and electronics
- » New Fast Interaction Trigger (FIT)
- » Fast read-out of other detectors (TOF, TRD, Muon arm, ZDC,...)
- » New Online plus Offline system (O^2 project)



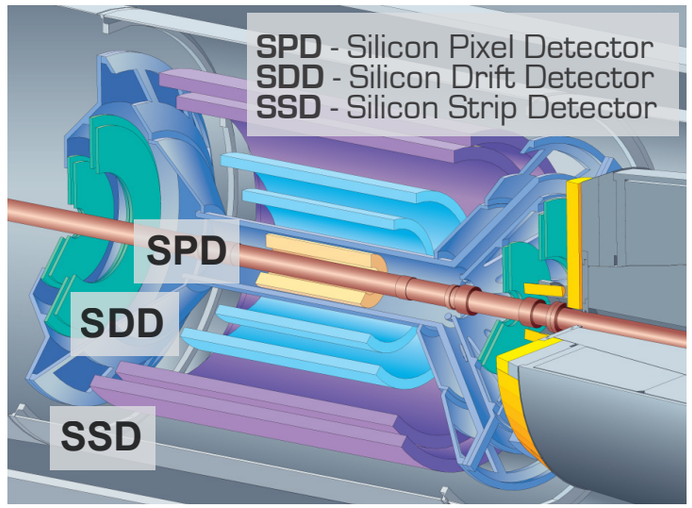
G. MARTINEZ-GARCIA at SQM2017
https://indico.cern.ch/event/576735/contributions/2566943/attachments/1492972/2321904/GinesMARTINEZ_SQM2017.pdf

ITS upgrade - Improvements vs ITS (Run1/Run2)

ITS upgrade **requirements**

- » Improve impact parameter resolution
  - Reduce distance from IP to first layer ➔ new beam pipe
  - Reduce material budget
  - Reduce pixel size
- » Improve tracking efficiency and p_T resolution at low p_T
  - Increase granularity ➔ from 6 to 7 layers, all pixels
- » Increase read-out capabilities

ITS (Run1/Run2)

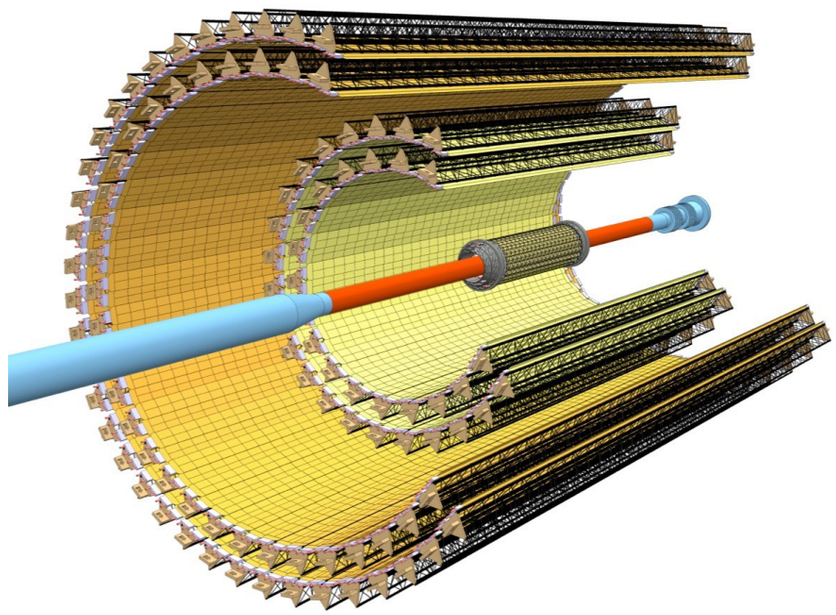


	ITS (Run1/Run2)	ITS Upgrade
Number of layers	6 (pixel, drift, μstrip)	7 (MAPS*)
Rapidity range	$\|\eta\| < 0.9$	$\|\eta\| < 1.3$
Material budget per layer	1.14% (SPD)	0.35% (IL)
Distance to interaction point	39 mm	22 mm
Pixel size	50 x 425 μm^2	29 x 27 μm^2
Spatial resolution	12 μm x 100 μm *	5 μm x 5 μm
Max. readout speed Pb-Pb	1 kHz	100 kHz

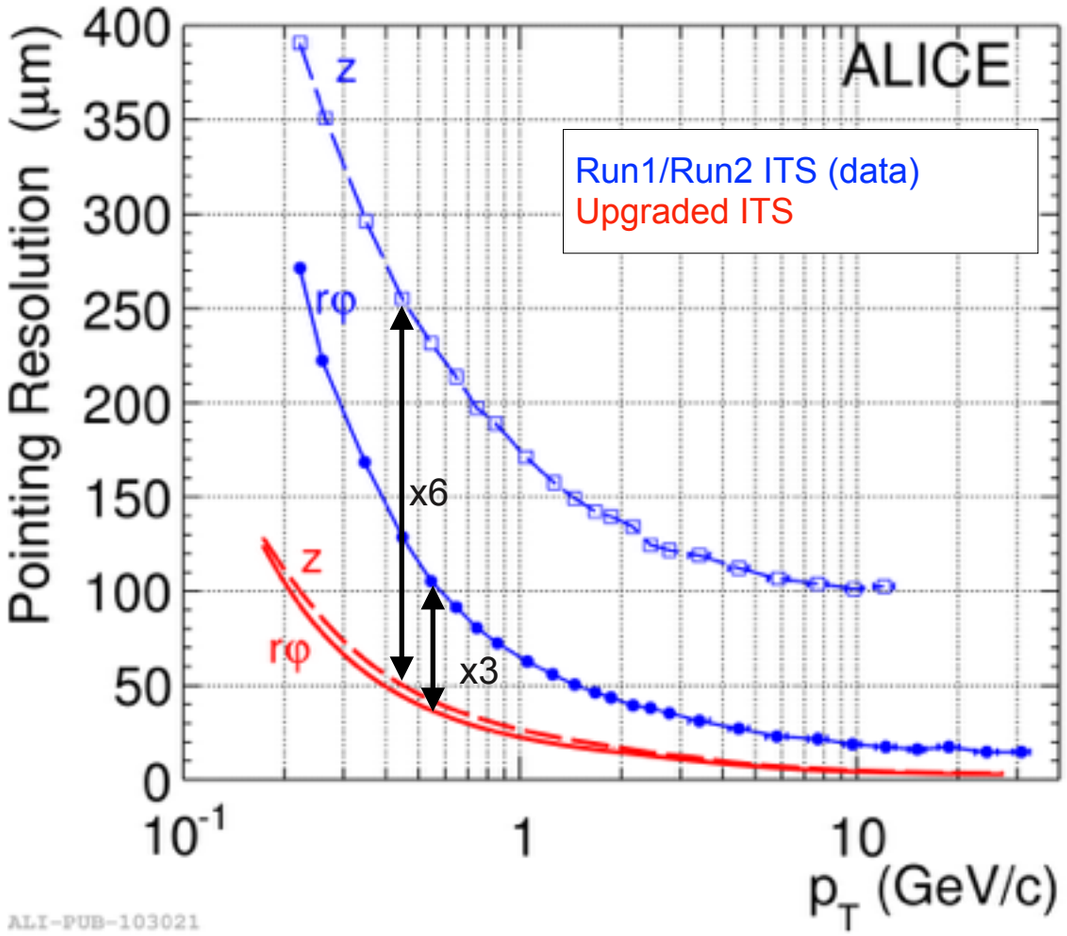
* SPD

* Monolithic Active Pixel Sensors

ITS Upgrade

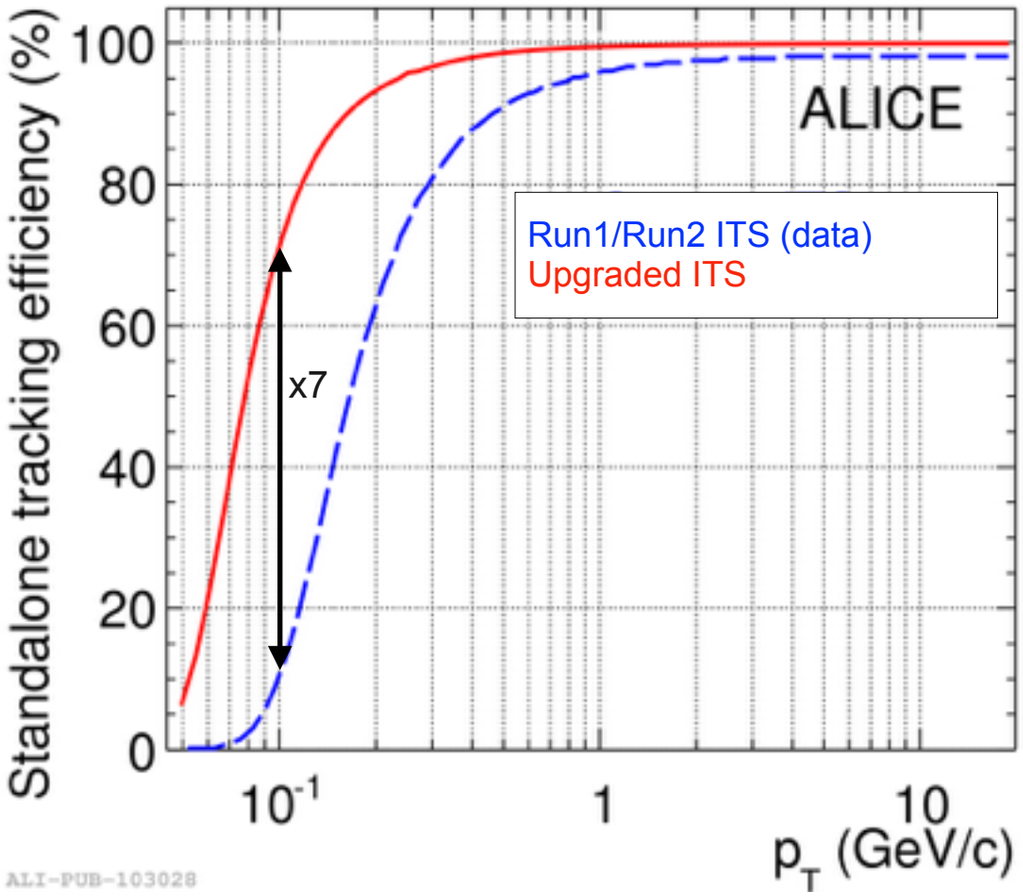


ITS upgrade - Detector performance



» Pointing resolution improved by
- 6 times in z direction for $p_T < 1$ GeV/c
- 3 times in rϕ direction for $p_T < 1$ GeV/c

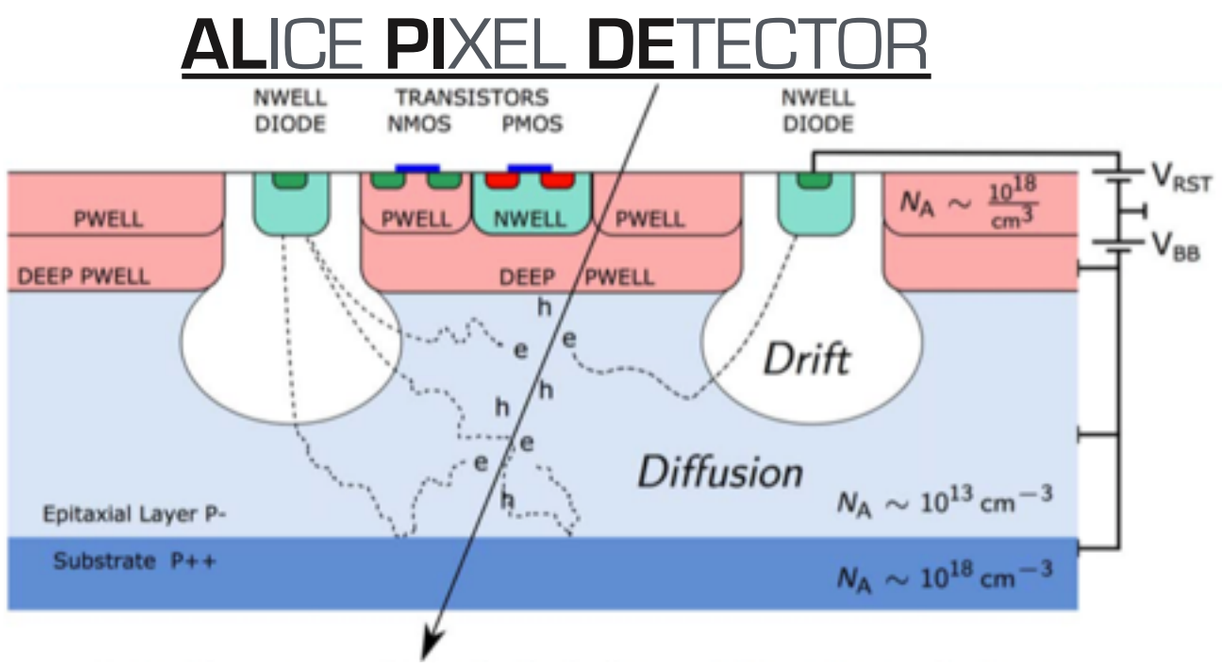
» ITS standalone tracking efficiency significantly increased for $p_T < 1$ GeV/c

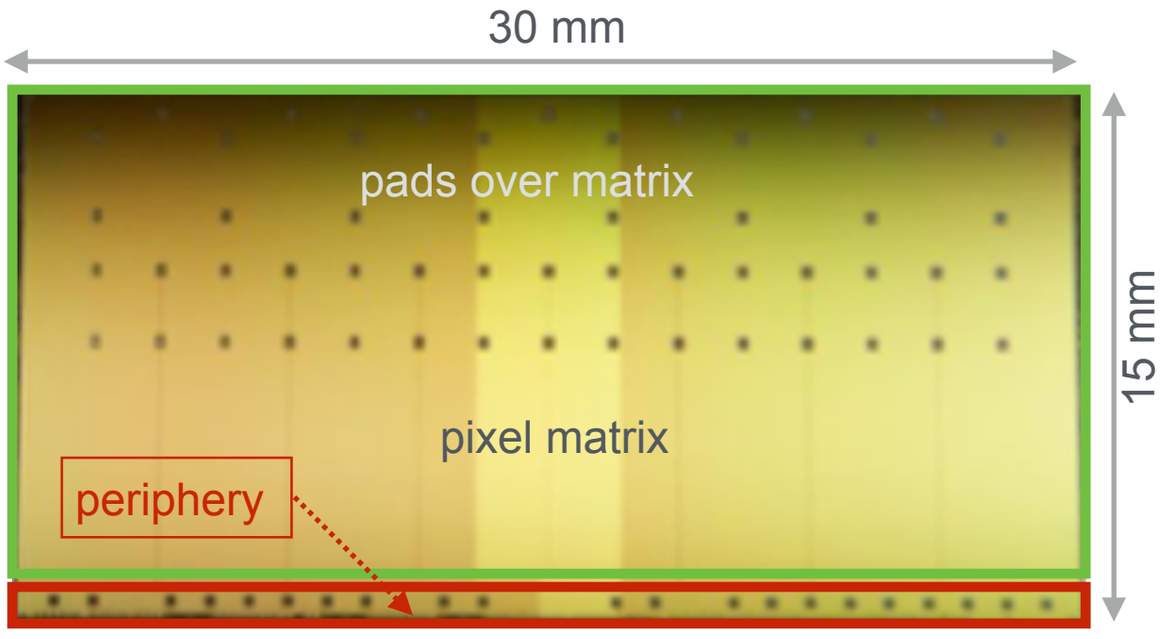


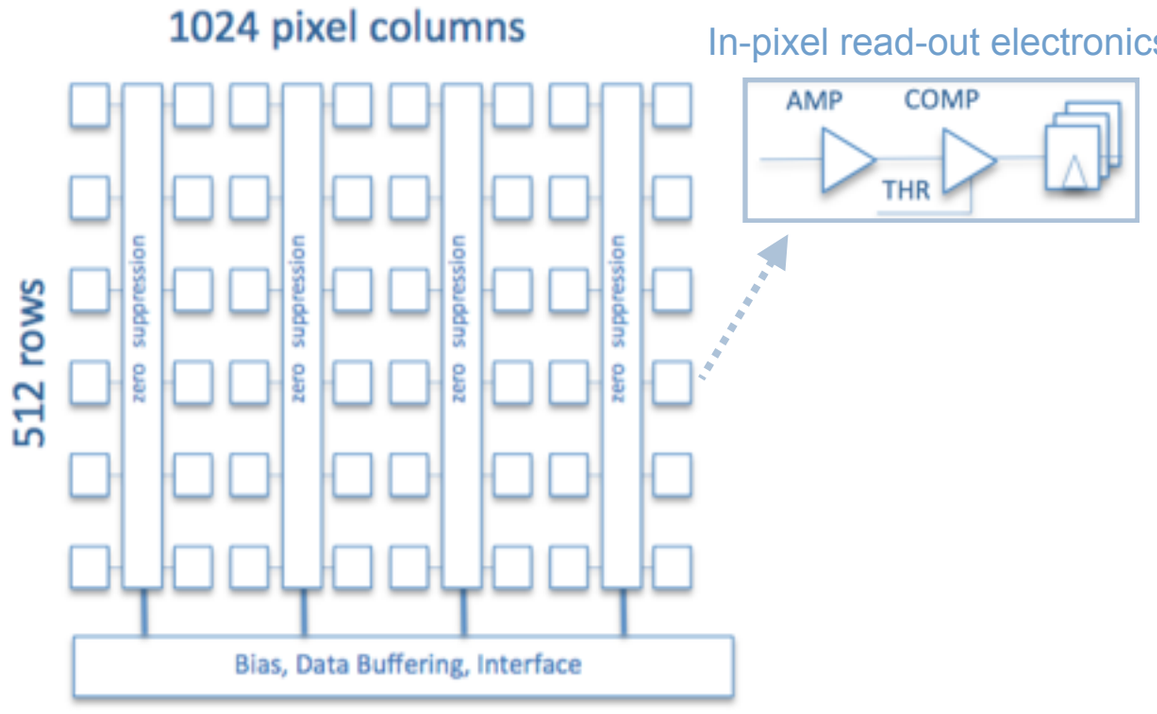
ITS upgrade - ALPIDE chip

Monolithic chip

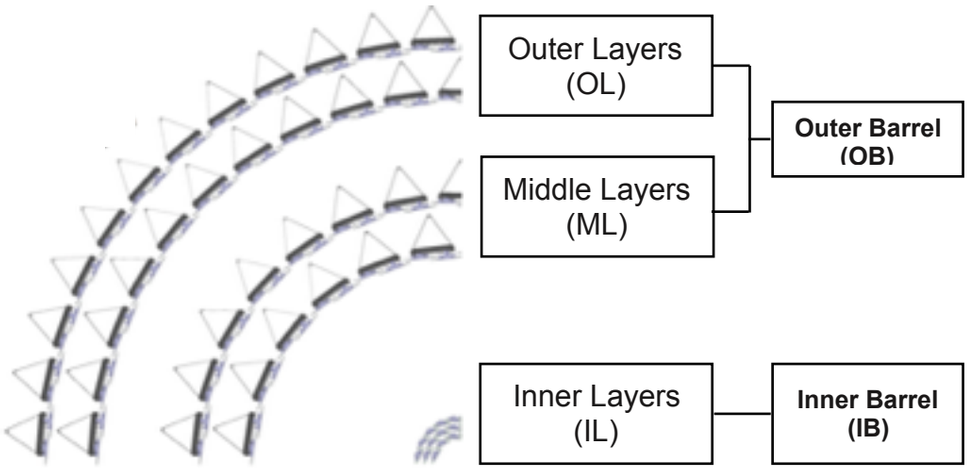
» Deep p-well layer → full CMOS in-pixel read-out circuit
» Data buffering and configuration circuit in periphery
» On-chip high speed data link (1.2 Gb/s)
» Power consumption 40 mW/cm^2
» Irradiated chips (NIEL 1.7x10^{13} MeV n_{eq}/cm^3) show large operational margin and chip-to-chip negligible fluctuations







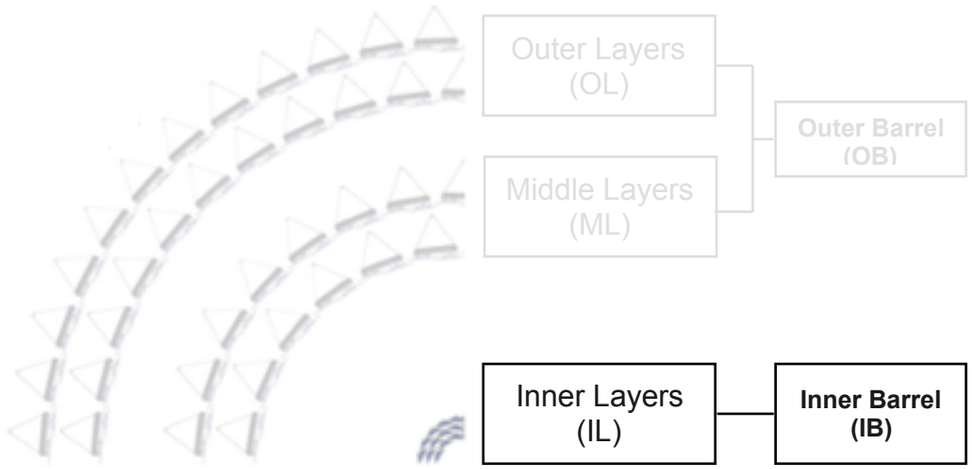
ITS upgrade - Layout and components



7-layer barrel geometry based on MAPS

- Inner Barrel (**IB**) : 3 layers
- Outer Barrel (**OB**) : 4 layers
- r coverage: (min) 22 – (max) 394 mm
- η coverage: (min) 1.3 – (max) 2.5
- 12.6 Gigapixels
- Total active area ~ 10 m^2

ITS upgrade - Layout and components



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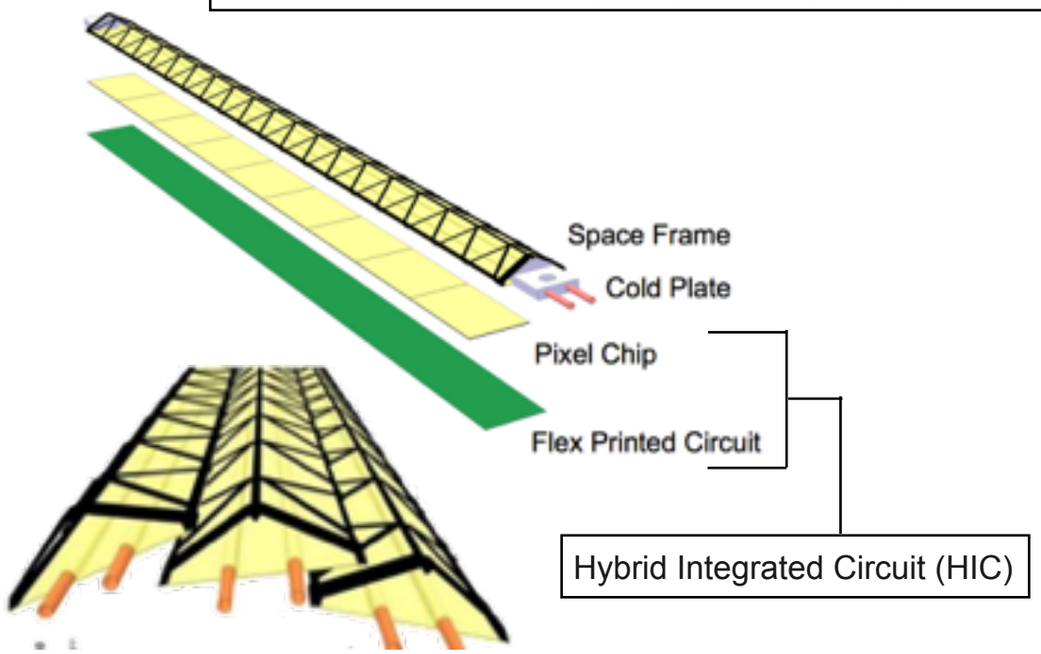
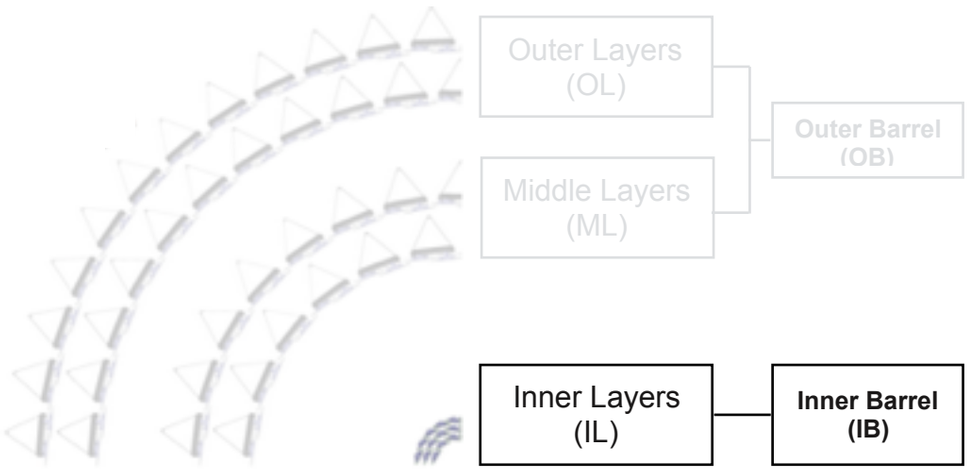
Inner Barrel

- 48 staves
- 9 ALPIDE chips on 1 row per stave
- chip thickness: 50 μm
- stave length: 290 mm
- distance from IP: (min) 22 – (max) 42 mm



Tilted staves with overlap

ITS upgrade - Layout and components



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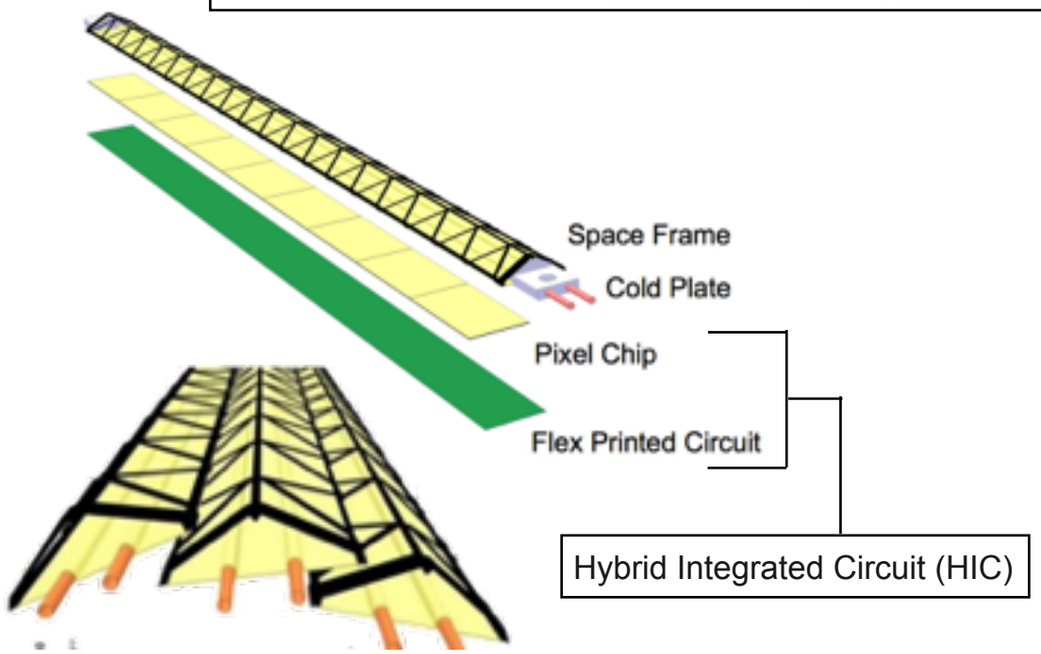

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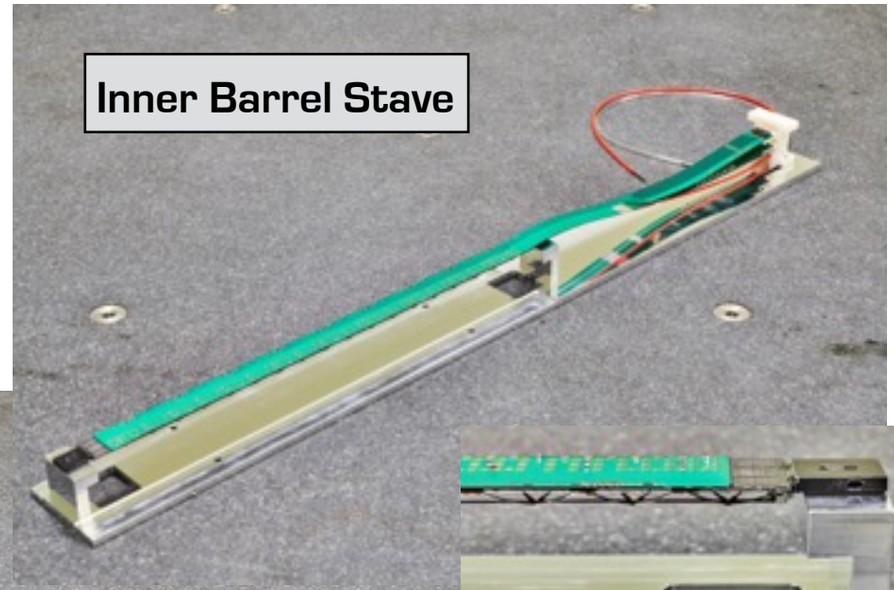

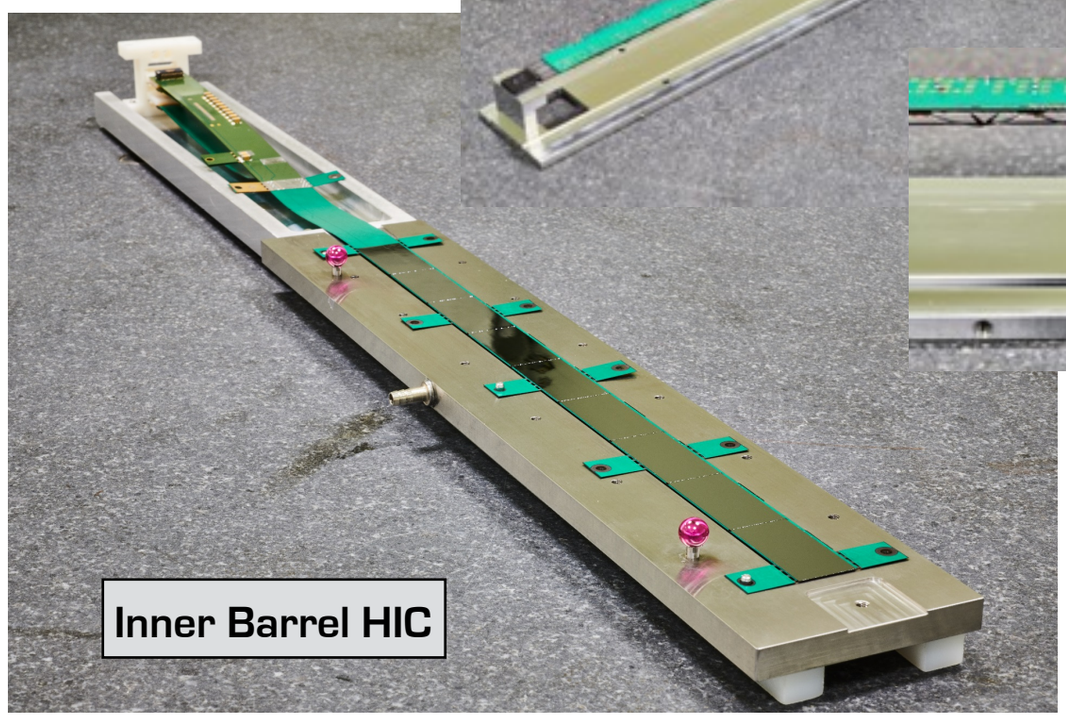

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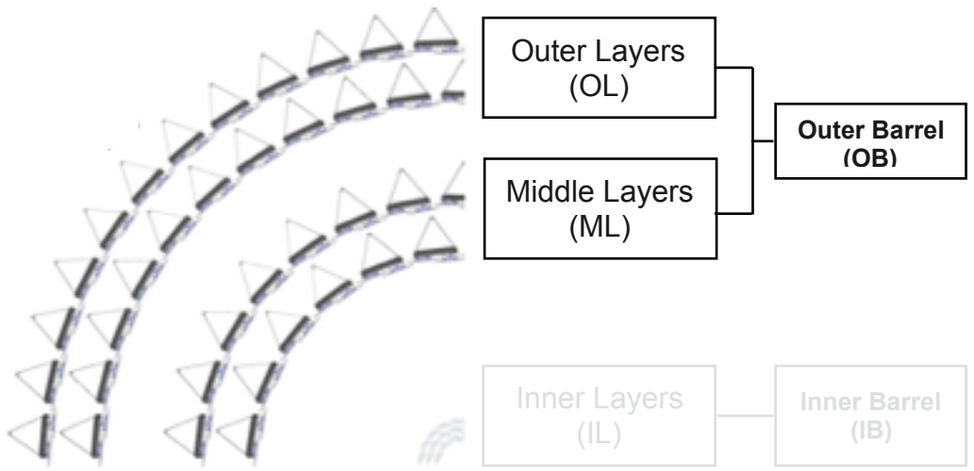

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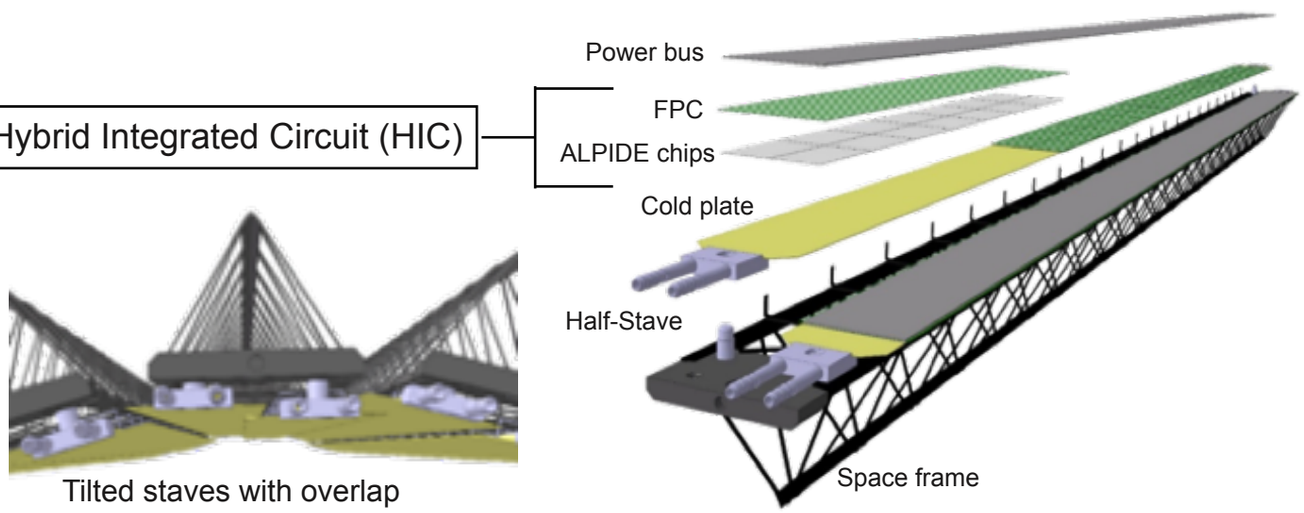
Outer Barrel

- 54 staves in ML + 90 staves in OL
- ML: 56 ALPIDE chips on 2 rows per stave in ML
- OL: 98 ALPIDE chips on 2 rows per stave in OL
- chip thickness: 100 μm
- stave length: 843 – 1473 mm
- distance from IP: (min) 194 – (max) 394 mm



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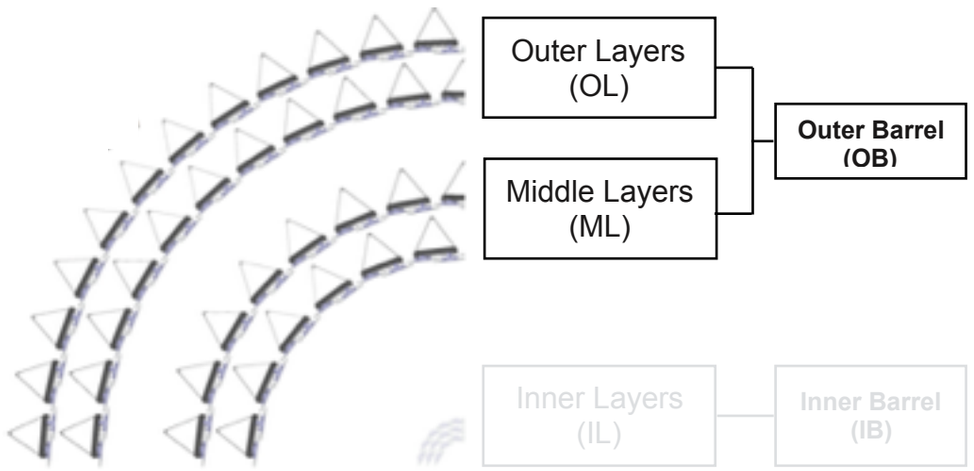
ITS upgrade - Layout and components



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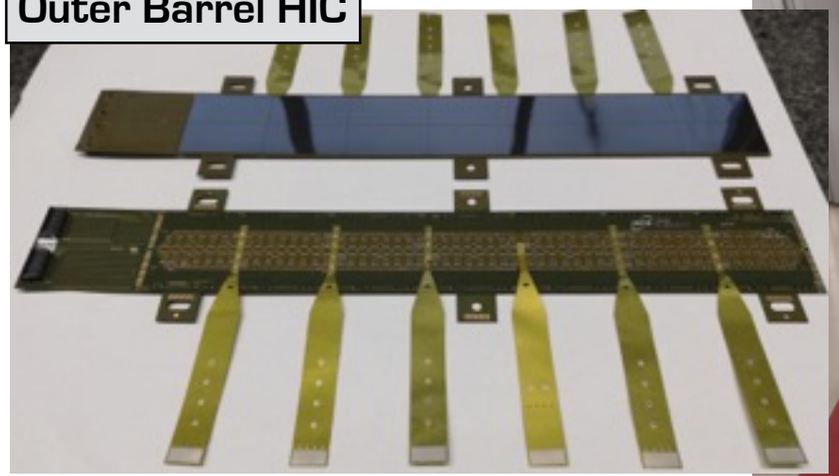
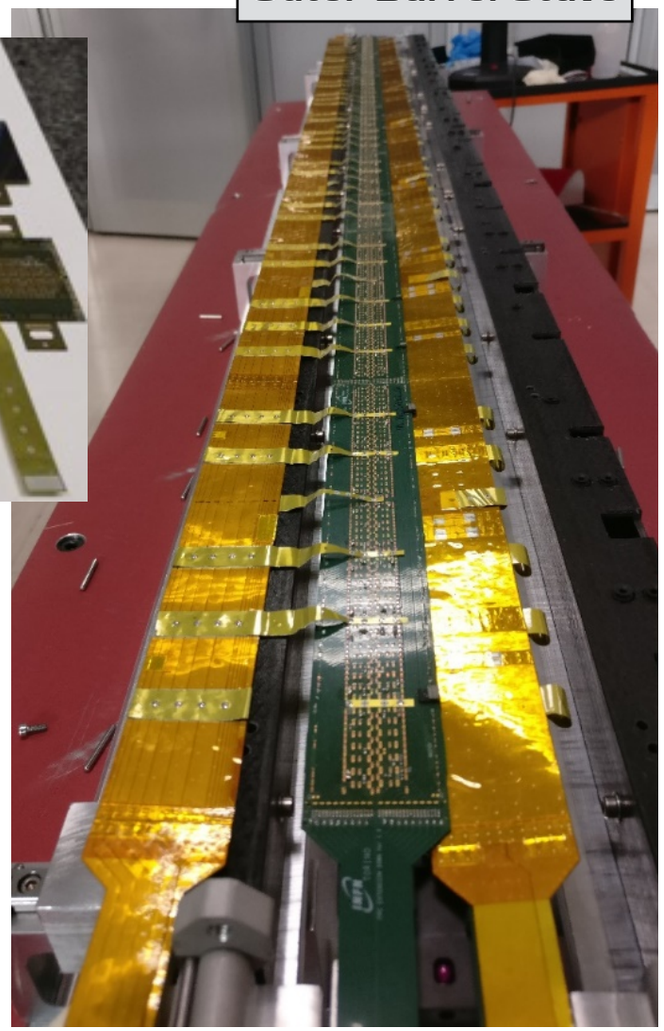
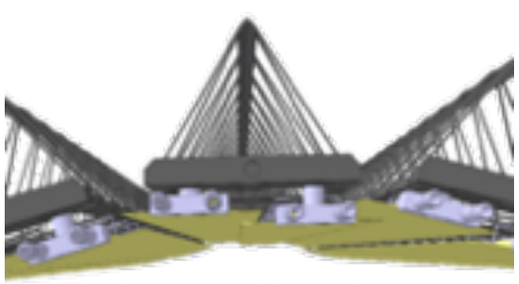
Outer Barrel HIC

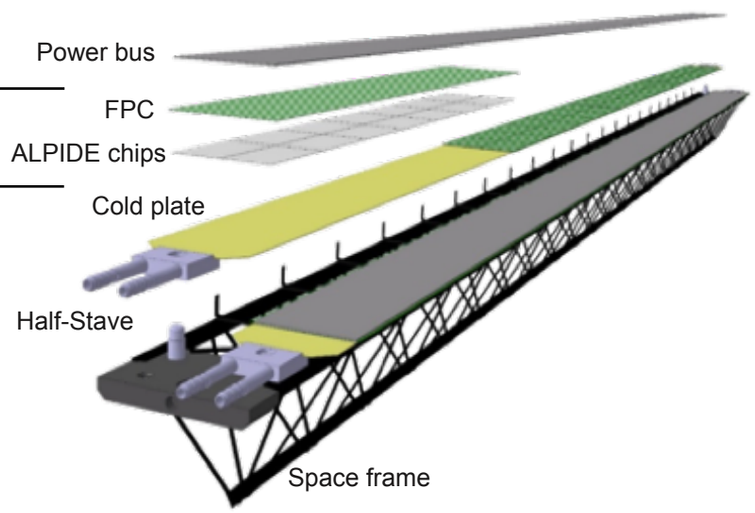


Outer Barrel Stave

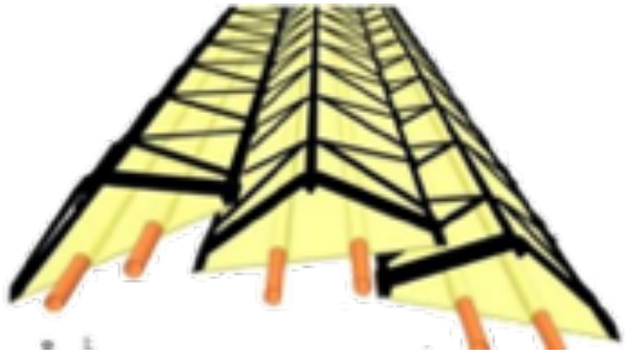




Tilted staves with overlap



ITS upgrade - Layout and components



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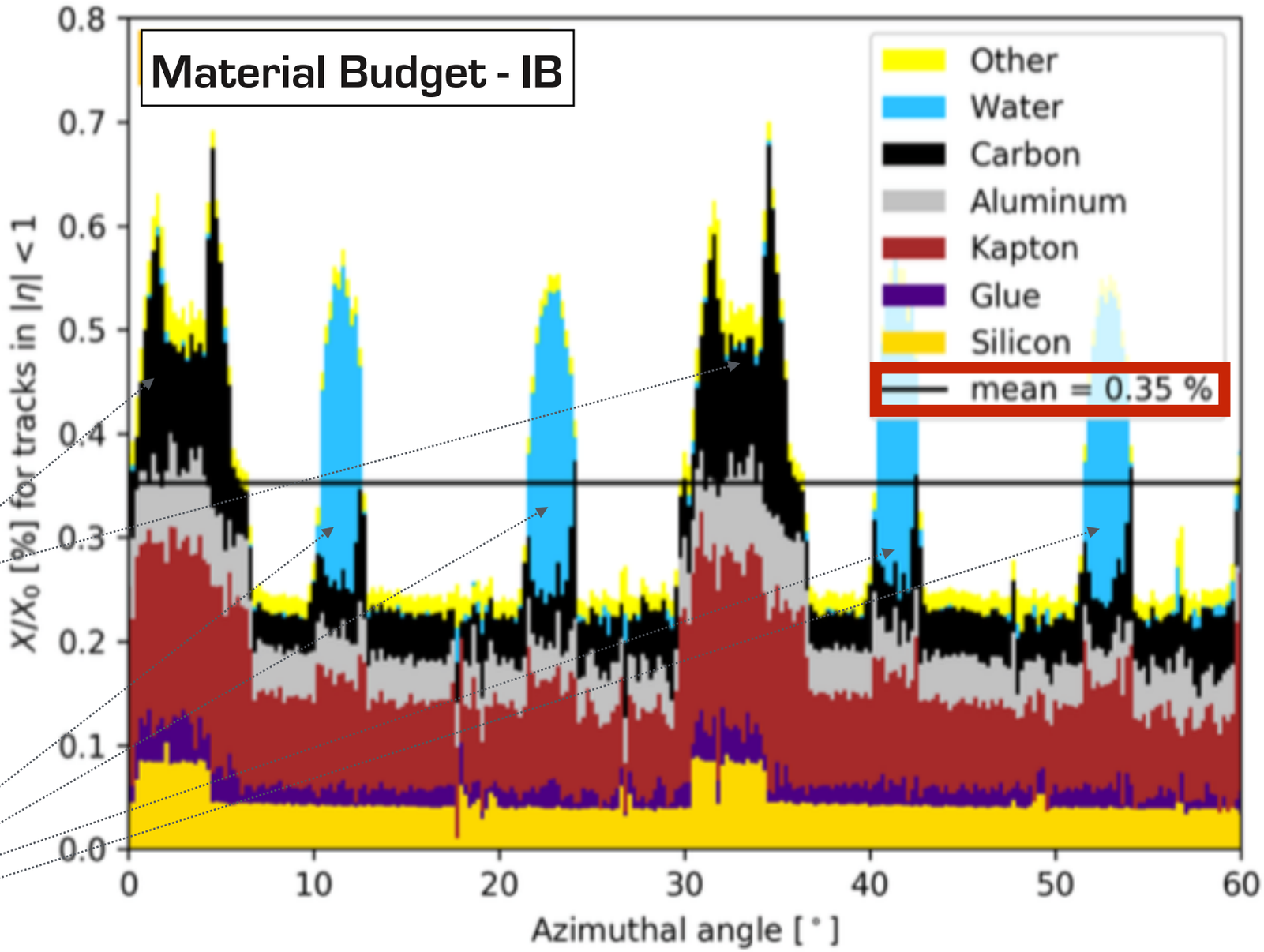
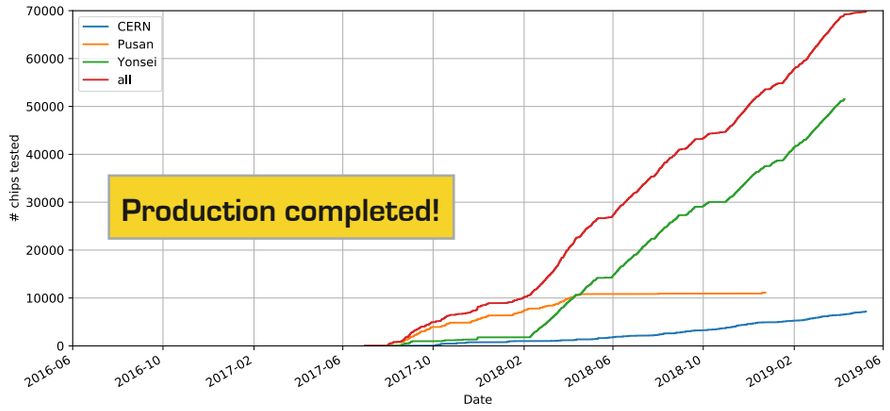


ITS upgrade - Component production status

ALPIDE chips

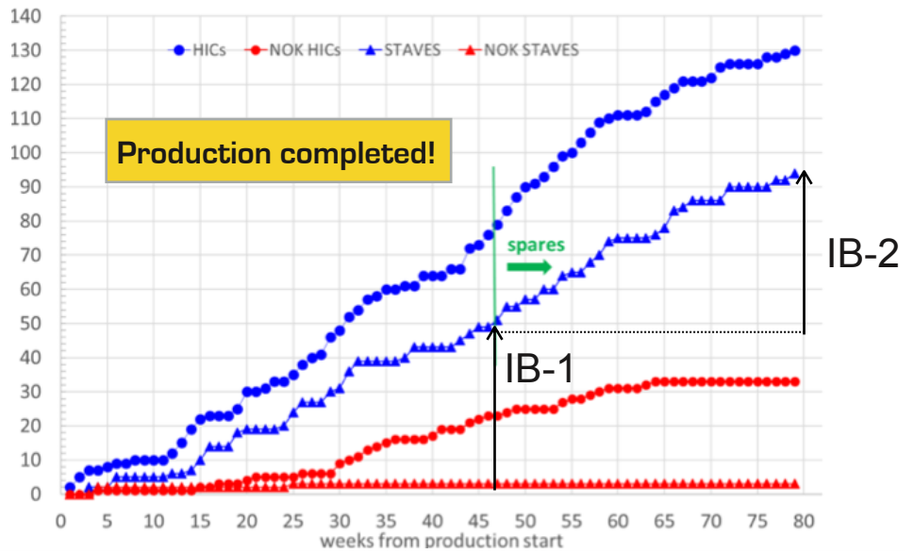
» Institutes:
50 μm: CERN
100 μm: Yonsei, Pusan

» Total # of chips tested: ~70000
» Total # of wafers: ~1700
» Total yield: 63.7%
» Series test ended in mid 2018



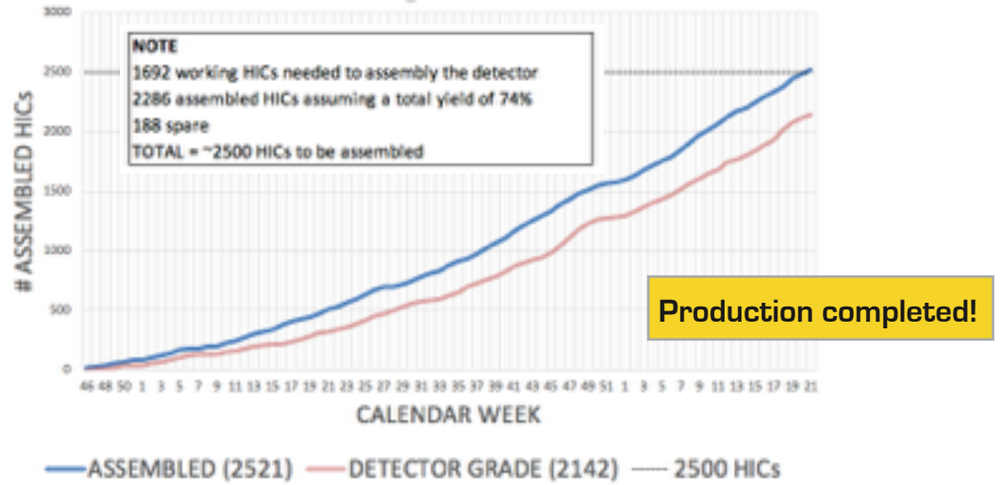
Inner Barrel HICs and Staves

» Institutes: CERN
» 95 staves assembled with a yield of 73%
» Enough for 2 fully working copies of IB

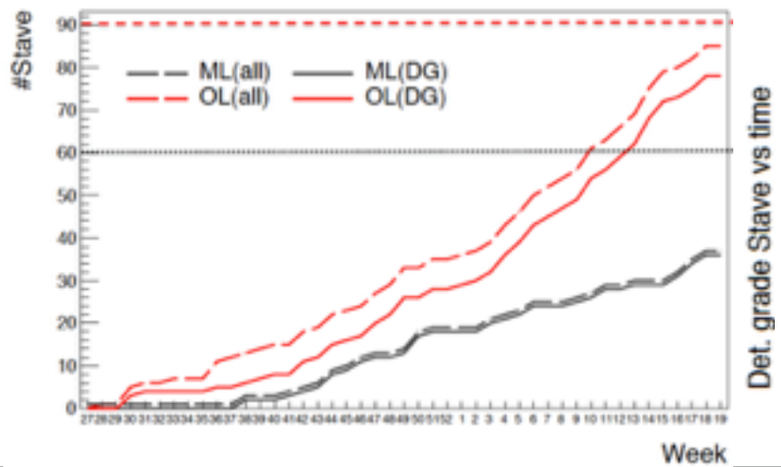


Outer Barrel HICs and Staves

» HIC institutes:
Bari (IT), Liverpool (UK), Pusan (KR), Strasbourg (FR), Wuhan (CN), Trieste (IT)
» ~2500 HICs assembled with a yield of 85%



» Stave institutes:
Berkeley (US), Daresbury (UK), Frascati (IT), Nikhef (NL), Turin (IT)
» Yield above 90%
» OL stave production almost completed
» ML stave production will end by September 2019

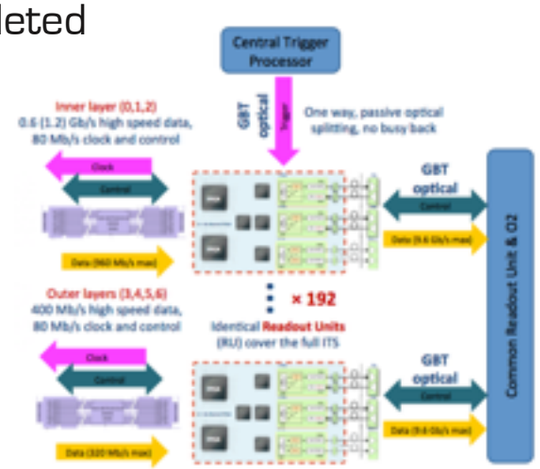


ITS upgrade - Component production status

Readout electronics

Production completed!

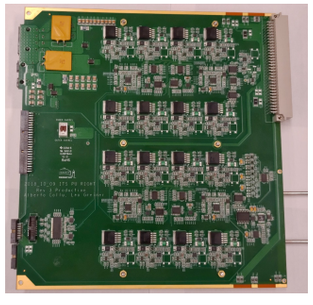
» Institutes:
Austin (US), Bergen (NO), CERN, Nikhef (ND), Padova (IT)
» 192 FPGA based RUs, operating in a mild radiation environment (<10 krad, <10^{12} 1 MeV n_{eq})
» Board production completed
» Functional test ongoing

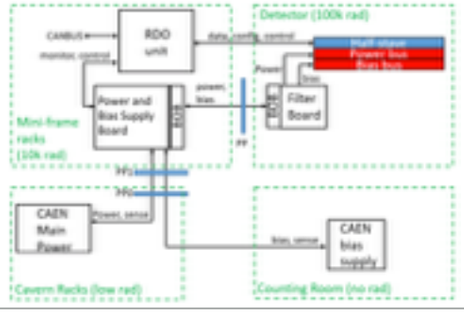


Power System

Production completed!

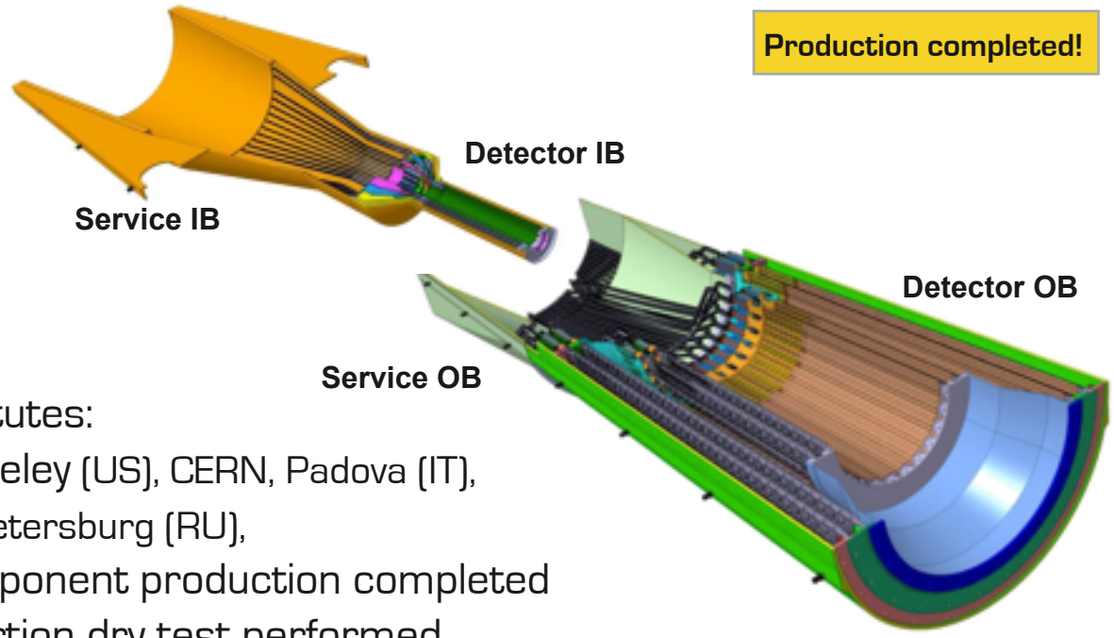
» Institute: Berkeley (US)
» CAEN powering modules available and in use in commissioning setup
» Power board production completed
» Functional test ongoing (until July 2019)



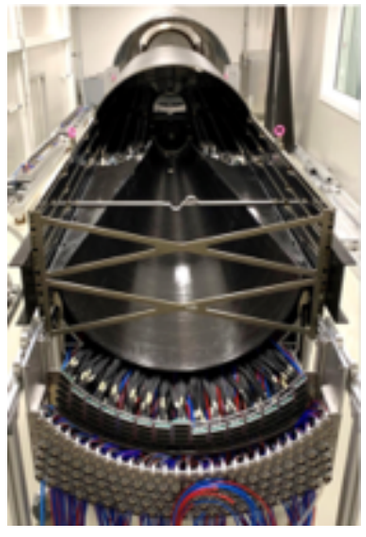


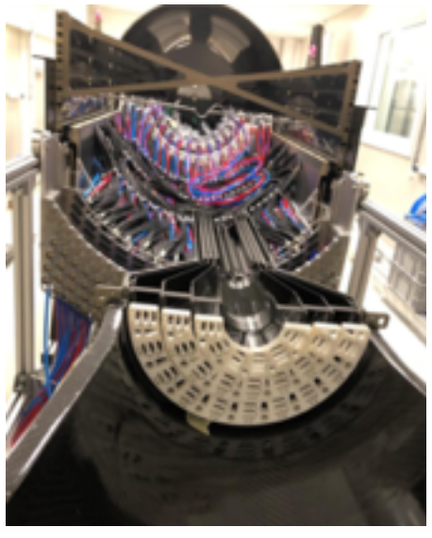
Support structures

Production completed!

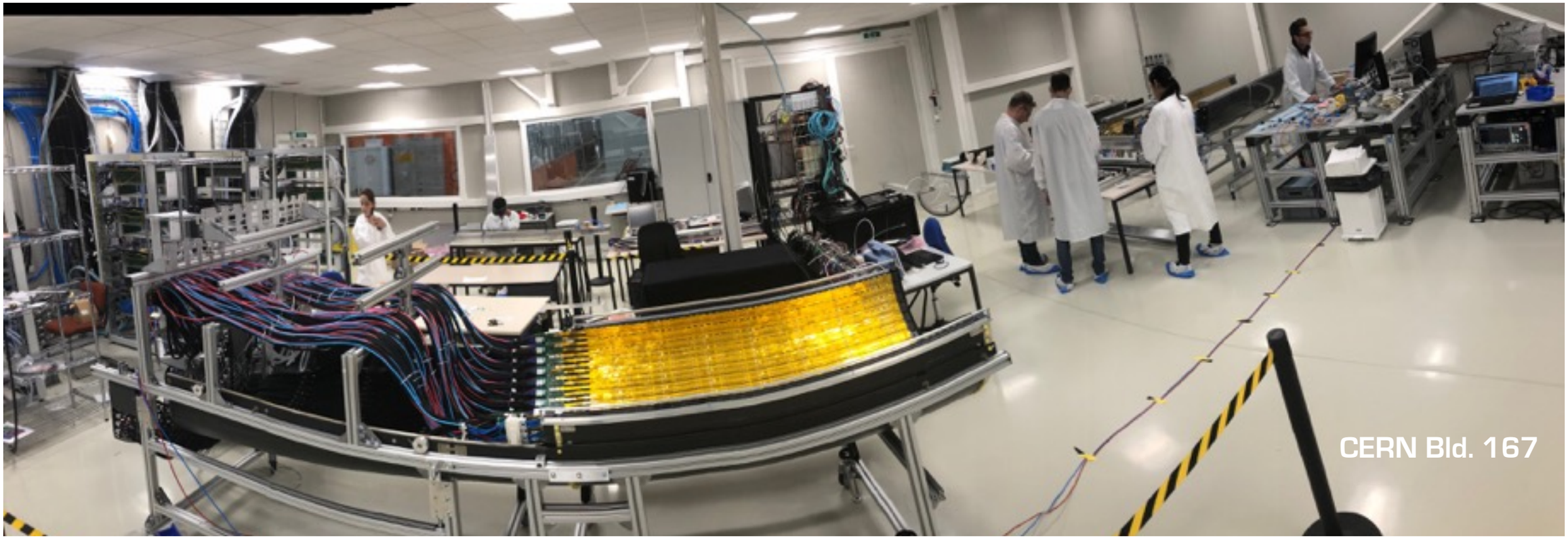


» Institutes:
Berkeley (US), CERN, Padova (IT),
St. Petersburg (RU),
» Component production completed
» Insertion dry test performed





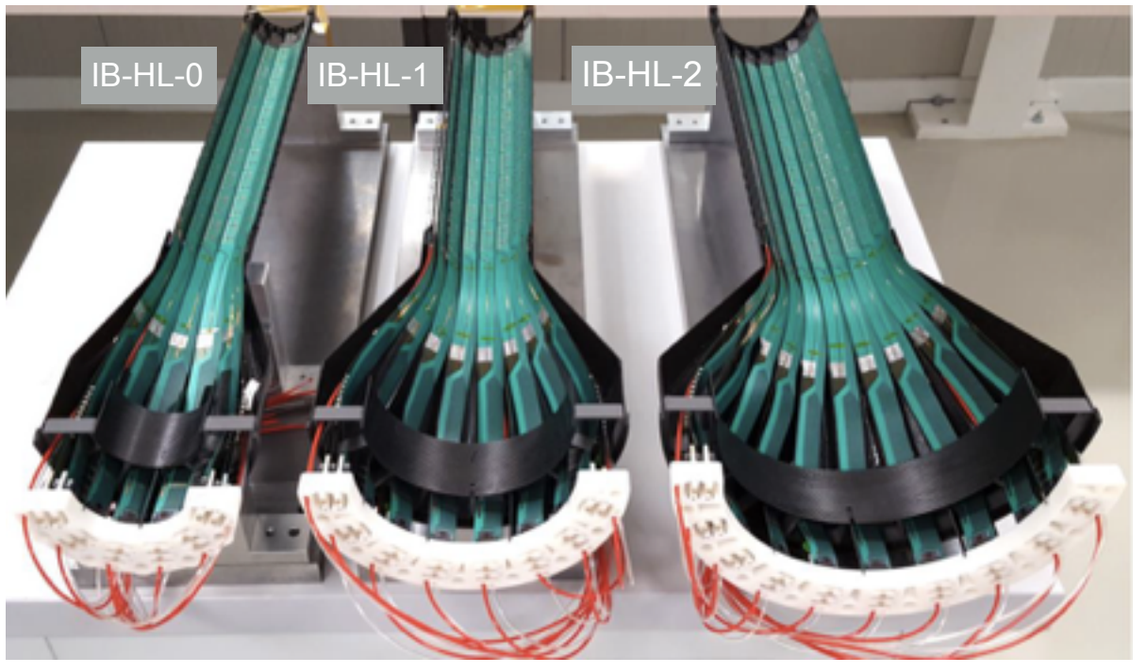
ITS upgrade - Assembly and commissioning

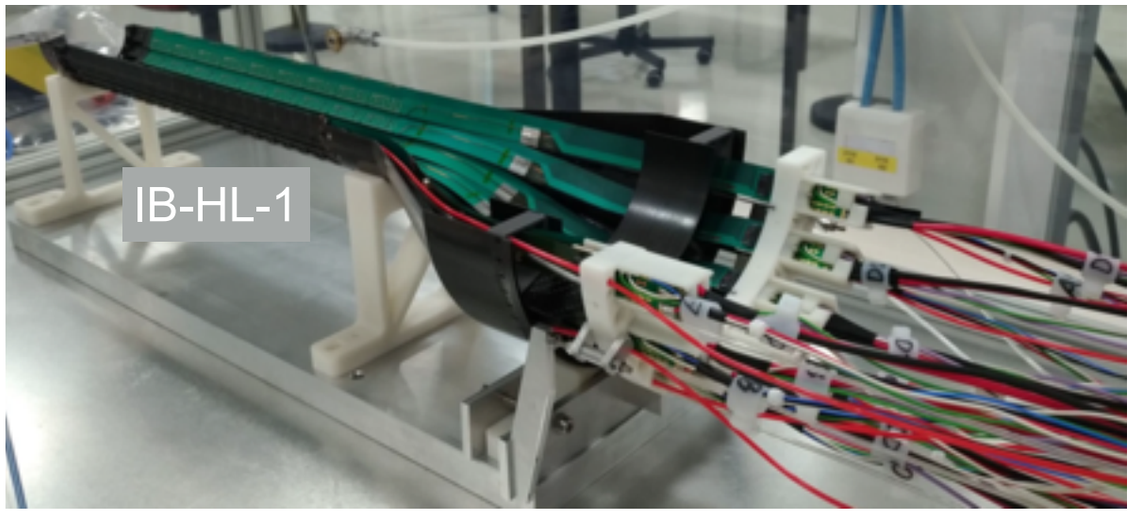


» Fully equipped clean-room at CERN (Bld. 167) for layer assembly and commissioning
→ **Same backend system that will be used in the experiment (Cooling plant, Power and Read-out racks, Trigger and DAQ system)**
» Layer assembly proceeds with the availability of staves (Outer Barrel)
» DCS and DAQ systems: development of full functionalities ongoing
» Commissioning before installation
  » continuos operation 24/7
  » data taking with cosmic rays and calibration scans
» Fully automatised data quality control flow under preparation

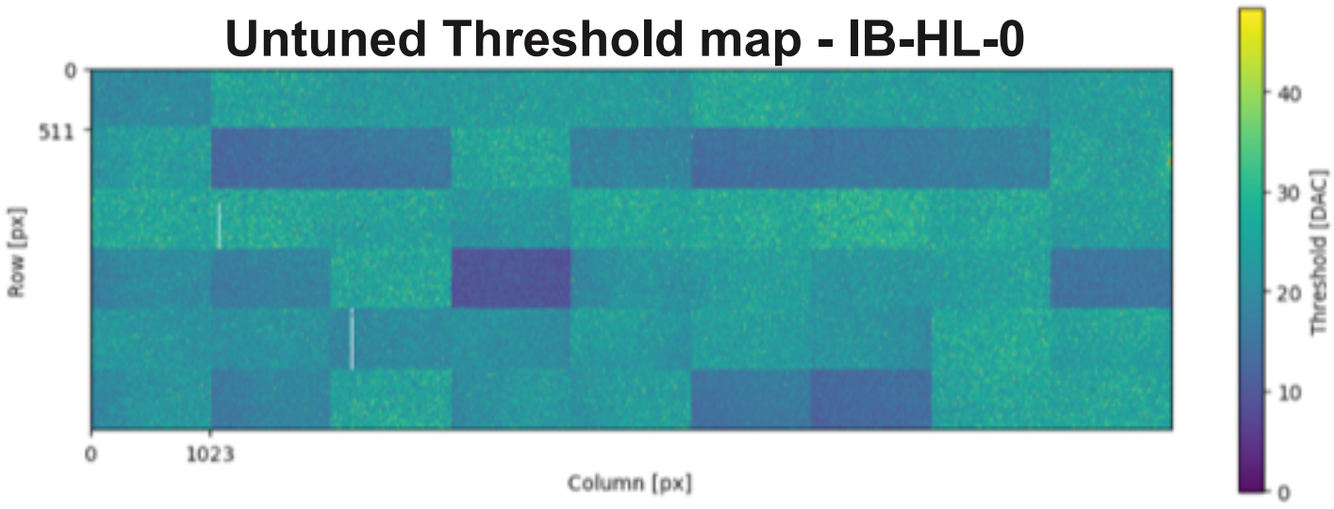
ITS upgrade - Assembly and commissioning

Inner Barrel



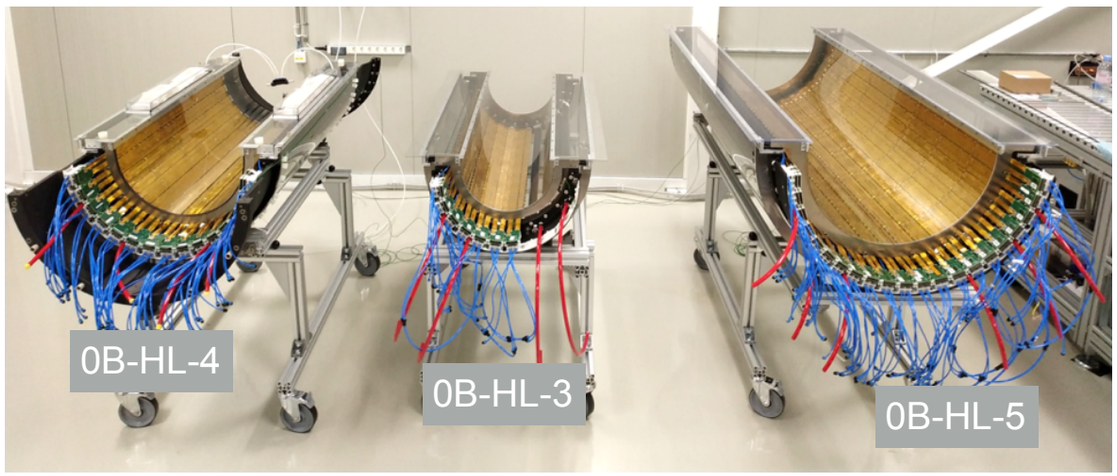


- All staves and mechanical supports available
- IB-HL-0: able to read out all staves
  - Final powering and read-out chain
- IB-HL-1: fully connected to electronics and under test
- IB-HL-2 : connection under preparation
- Remaining HLs will follow with the availability of RUs
- Commissioning ongoing of IB-HL-0

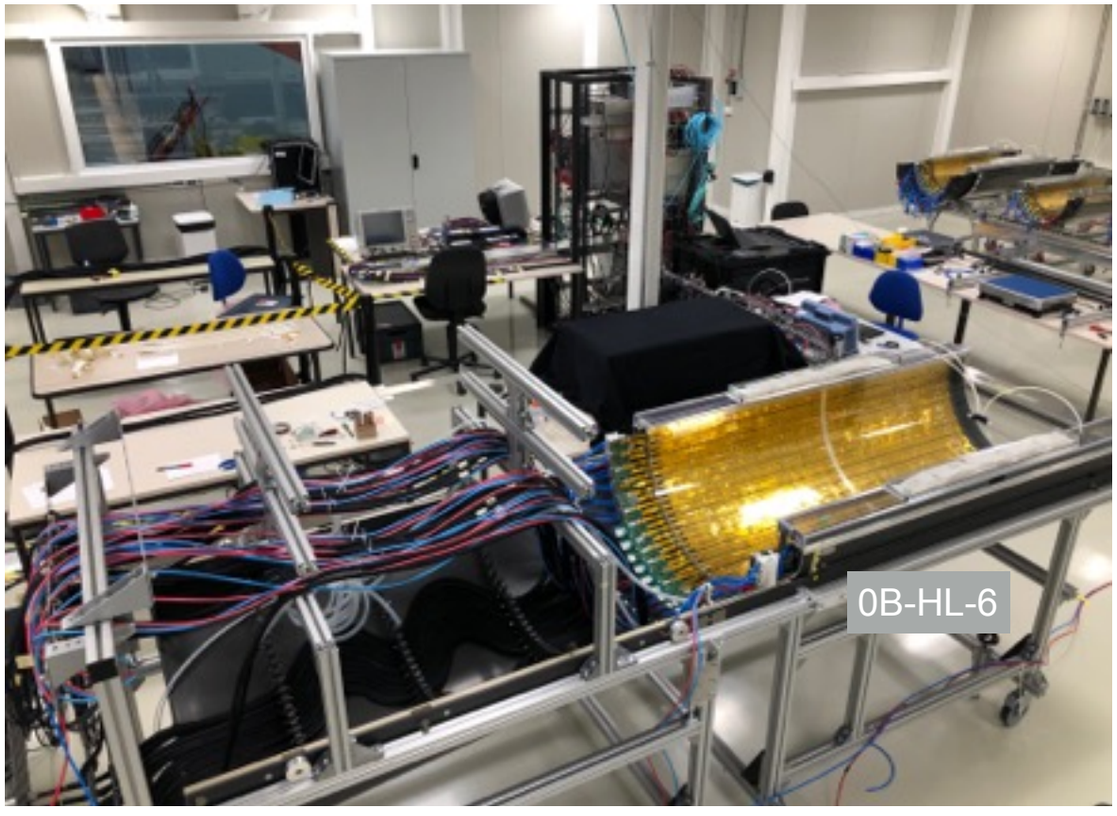


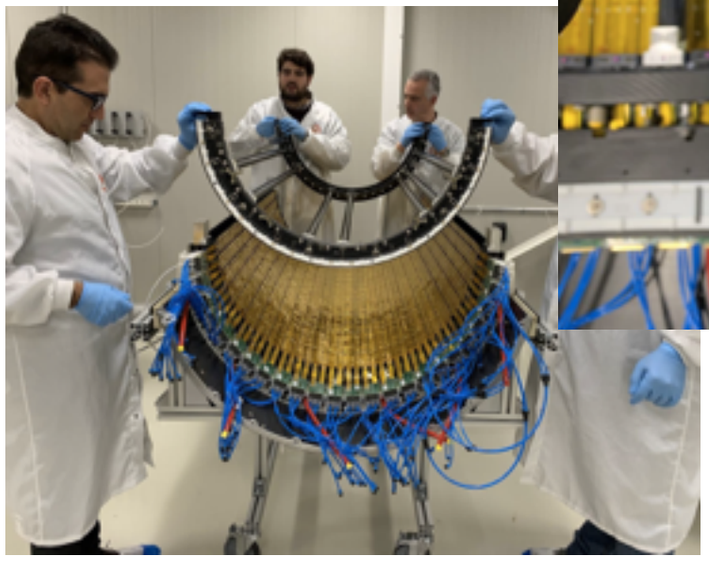
ITS upgrade - Assembly and commissioning

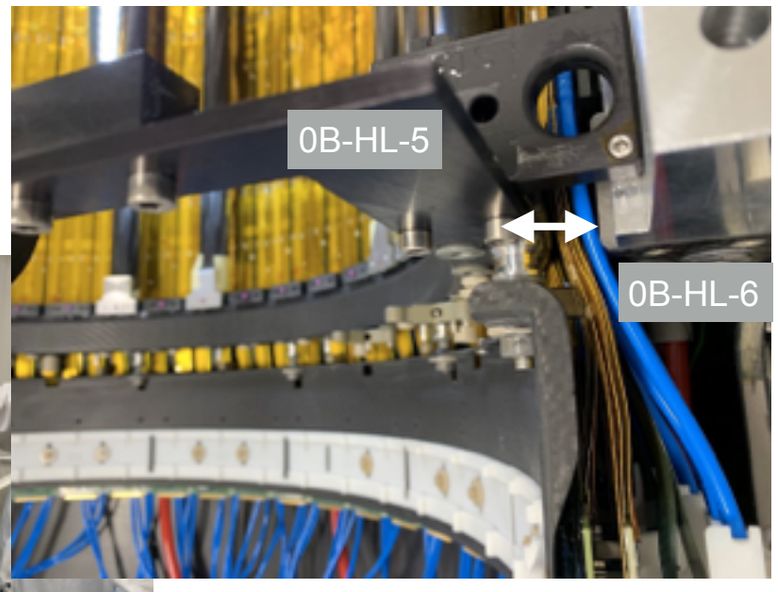
Outer Barrel



» Staves assembled on following half-layers
  » OB-HL-3 → Integration ongoing
  » OB-HL-4 → **Completed!**
  » OB-HL-5 → **Completed!**
  » OB-HL-6 → **Completed!**
» Cabling ongoing on OB-HL-6
  » Next HL to be included in the commissioning



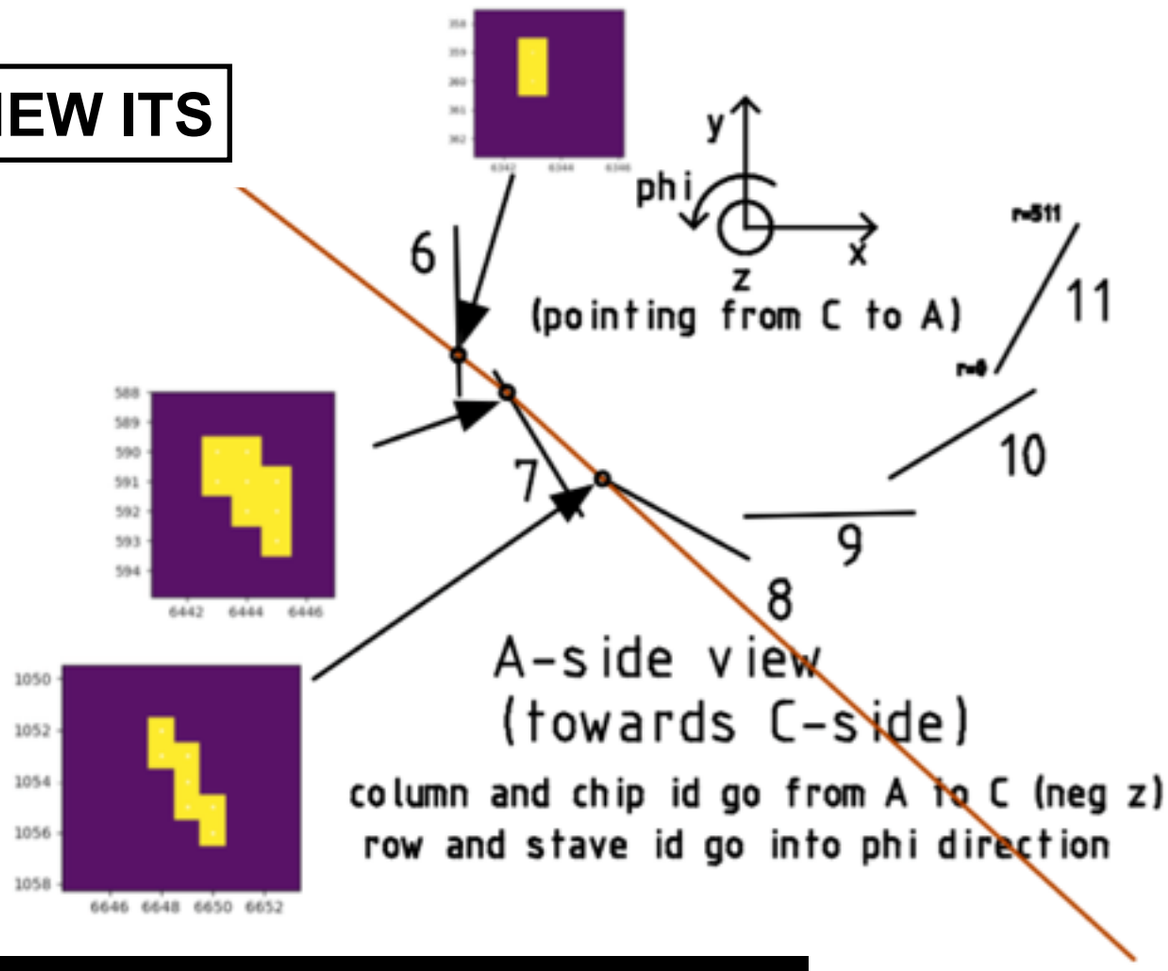


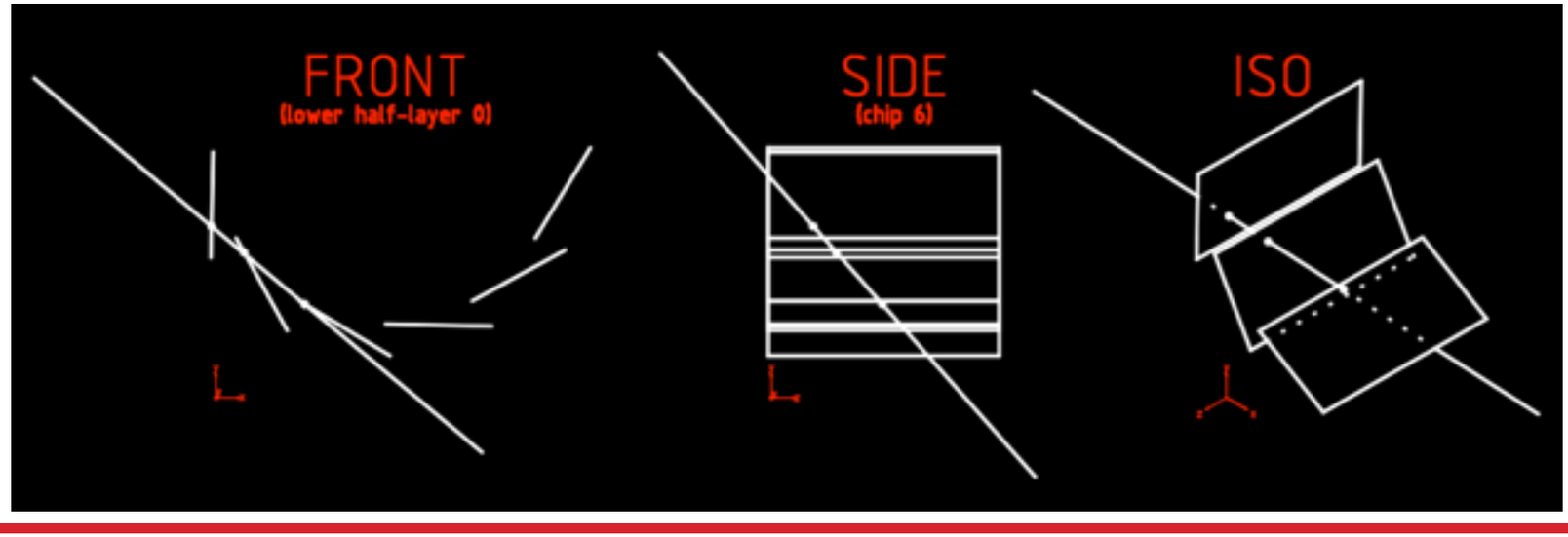


ITS upgrade - Status of the commissioning

FIRST COSMIC RAY DETECTED BY NEW ITS

- First reconstructed cosmic ray track in the IB-HL-0
- Thanks to the overlap between adjacent staves
- Three aligned pixel clusters observed in staves 6, 7 and 8 as shown in the figures

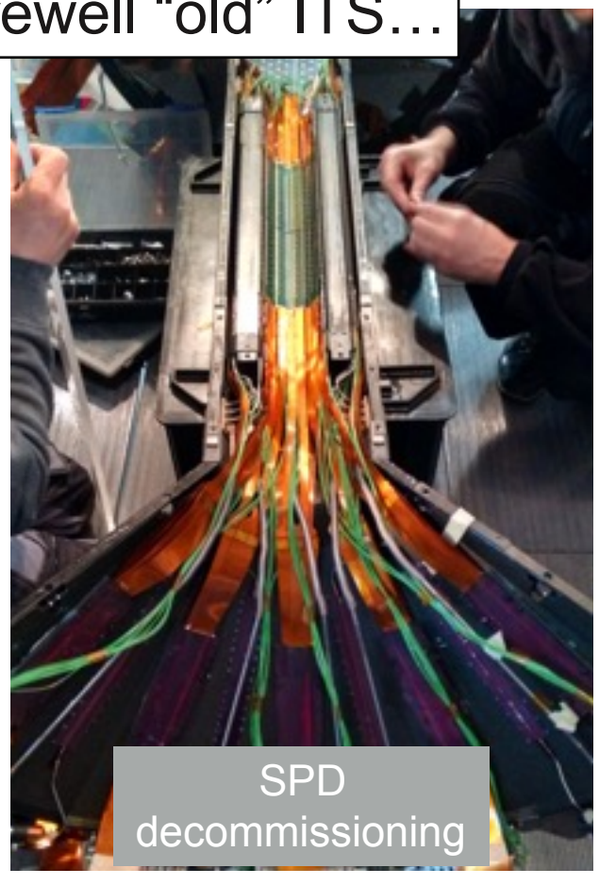




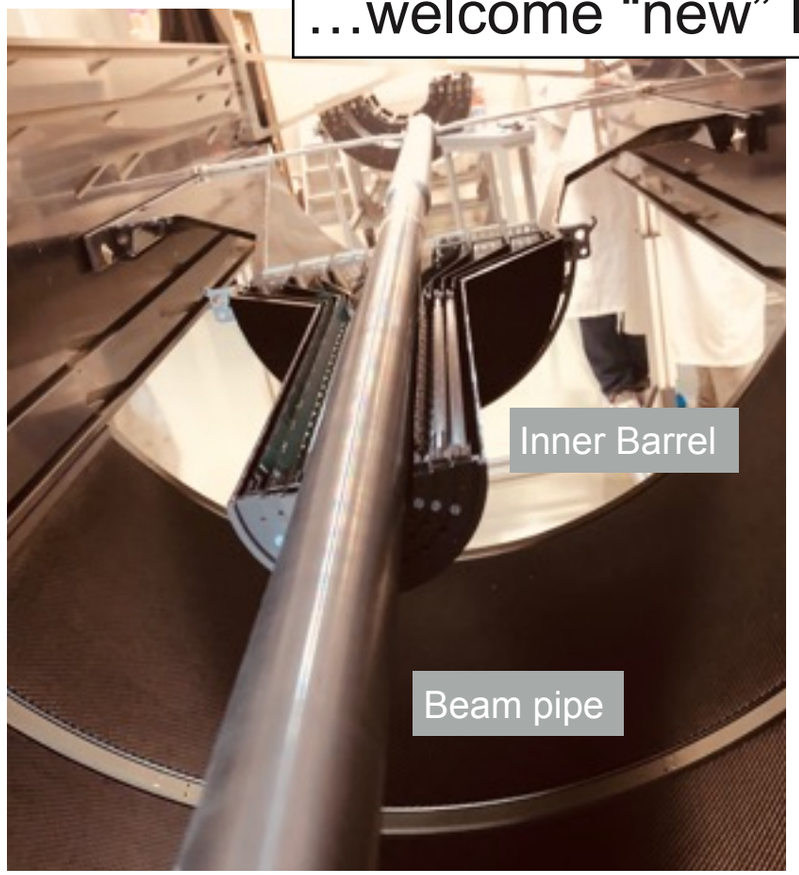
ITS upgrade - Conclusion and outlook

» Detector component production completed
» Stave integration progressing
» Commissioning on surface started in May 2019 → until May 2020
» Preparation of P2 services for detector installation on schedule
→ 6 months of commissioning after installation in ALICE

Farewell “old” ITS…



…welcome “new” ITS



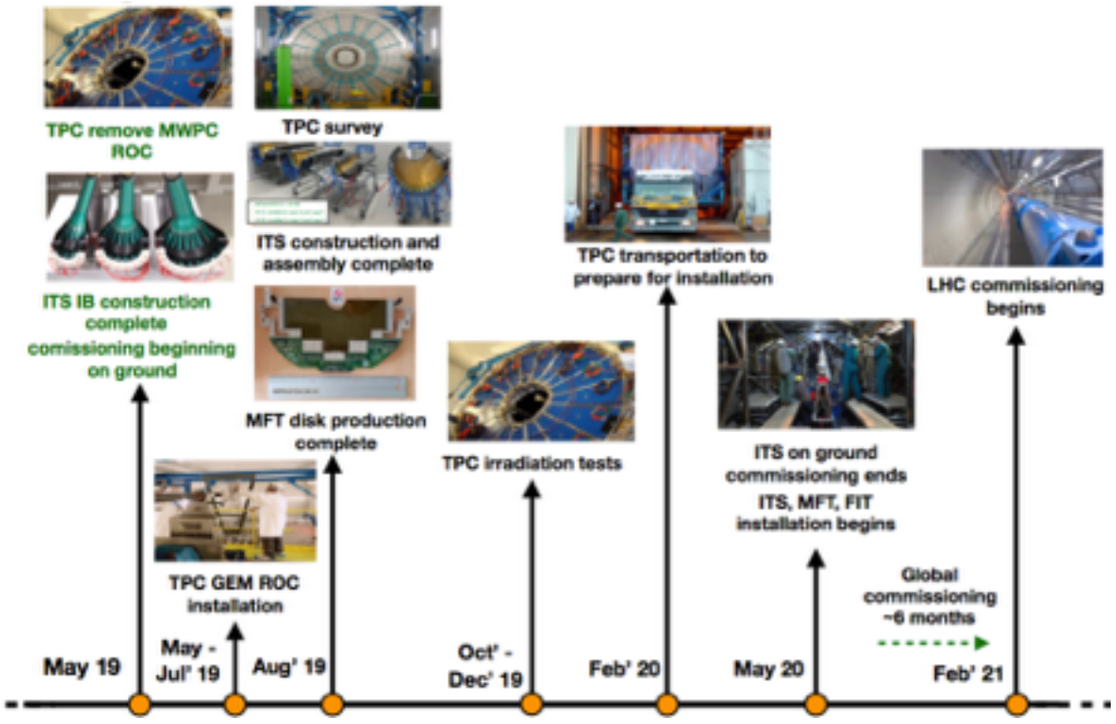
Backup

Backup

LHC Run3/4 program and ALICE Upgrade strategy

4 key objectives identified by HL/HE-LHC working group 5 for high-density QCD at LHC after LS2

1. Characterising the microscopic long-wavelength QGP properties with unprecedented precision
2. Accessing the microscopic parton dynamics underlying QGP properties
3. Developing a unified picture of partial production from small (pp) to larger (p-A and A-A) systems
4. Probing parton densities in nuclei in a broad (x, Q2) kinematic range and searching for possible onset of parton saturation

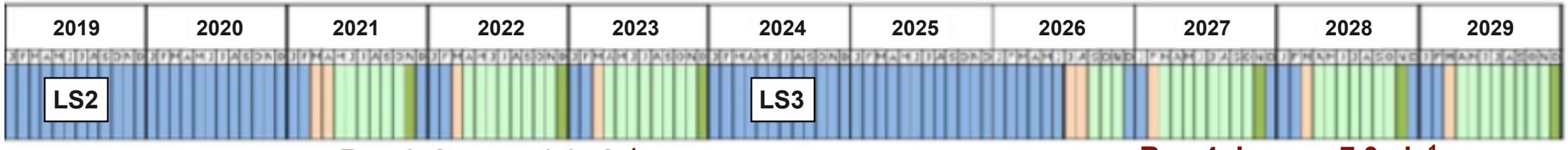


Proposed run schedule for Run 3/4

System	√s, √sNN	L_{int}	Note
Pb-Pb	5.5 TeV	13 nb^{-1}	3 nb^{-1} low B-field
p-Pb	8.8 TeV	1.2 pb^{-1}	
pp	14 TeV	200 pb^{-1}	High-multiplicity triggered
	8.8 TeV	3 pb^{-1}	
	5.5 TeV	6 pb^{-1}	
O-O	7 TeV	500 μb^{-1}	pilot run
p-O	9.9 TeV	200 μb^{-1}	

ALICE Upgrade strategy

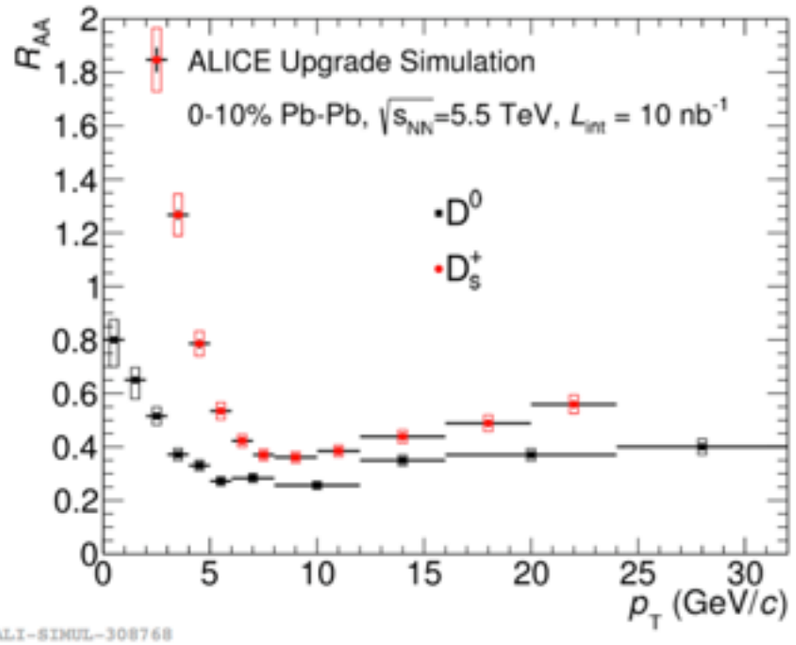
- New silicon trackers: ITS (mid-rapidity), MFT (forward rapidity)
- New TPC read-out chambers (GEMs) and electronics
- New Fast Interaction Trigger (FIT)
- New Read-out of other detectors (TOF, TRD, Muon arm, ZDC,...)
- Upgrade of Online and Offline systems (O^2 project)

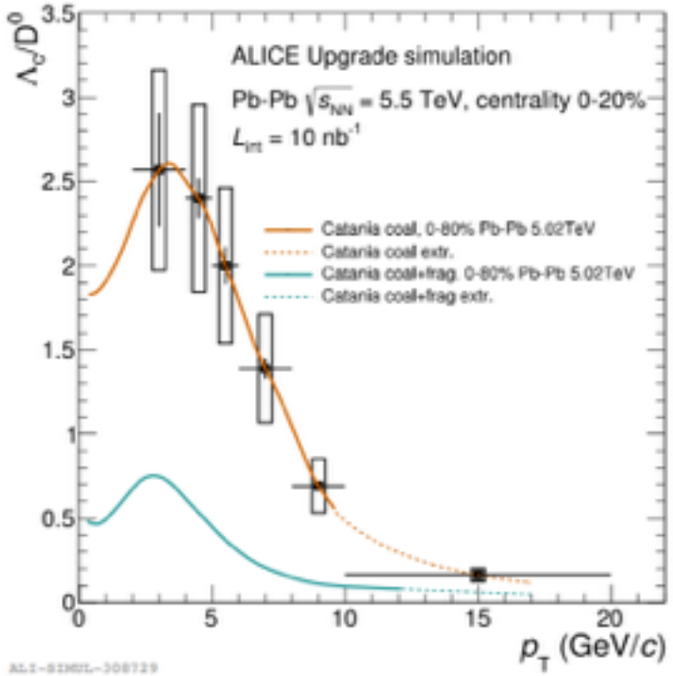


Run 3: $L_{Pb\text{-}Pb}$ = 6.0 nb^{-1} **Run 4: $L_{Pb\text{-}Pb}$ = 7.0 nb^{-1}**

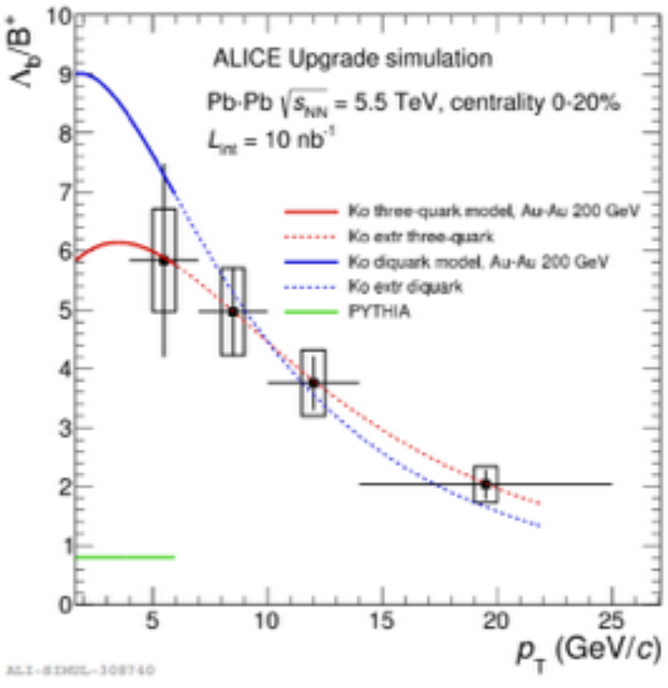
ITS upgrade - Physics performance

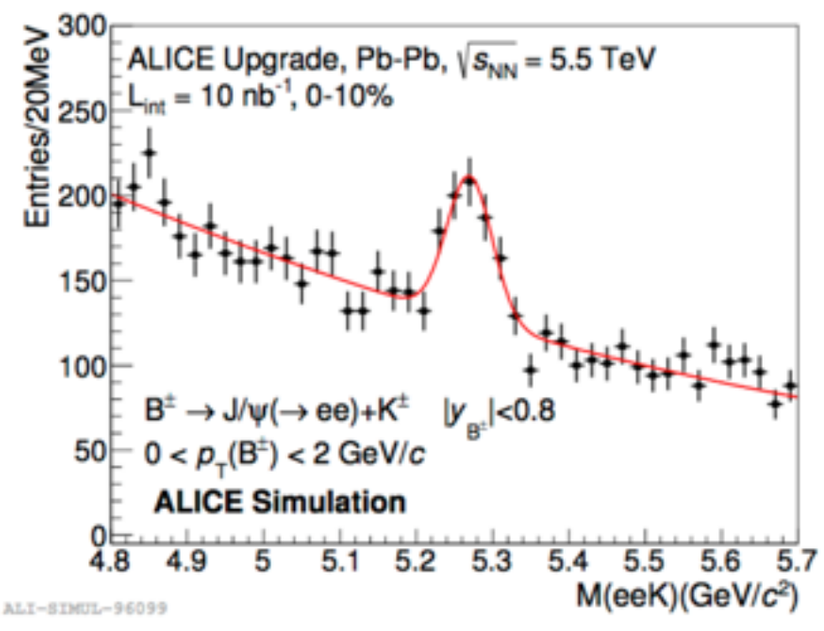
» Improvement in the signal extraction for heavy flavour particles, like D^0 and D^+_S

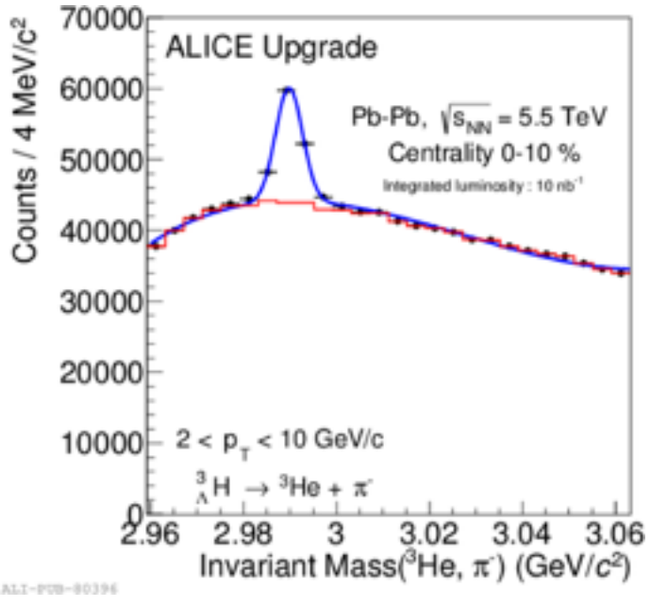




» Allowing measurement of particles not accessible during Run1/Run2, like $^3_\Lambda$H, B or Λ_b







ITS upgrade - Stave assembly workflow

ALICE

» Similar assembly procedure for stave in IL, ML and OL
» Extensive characterisation and quality checks in many assembly steps

1 Chip alignment

2 Gluing to the FPC (HIC)

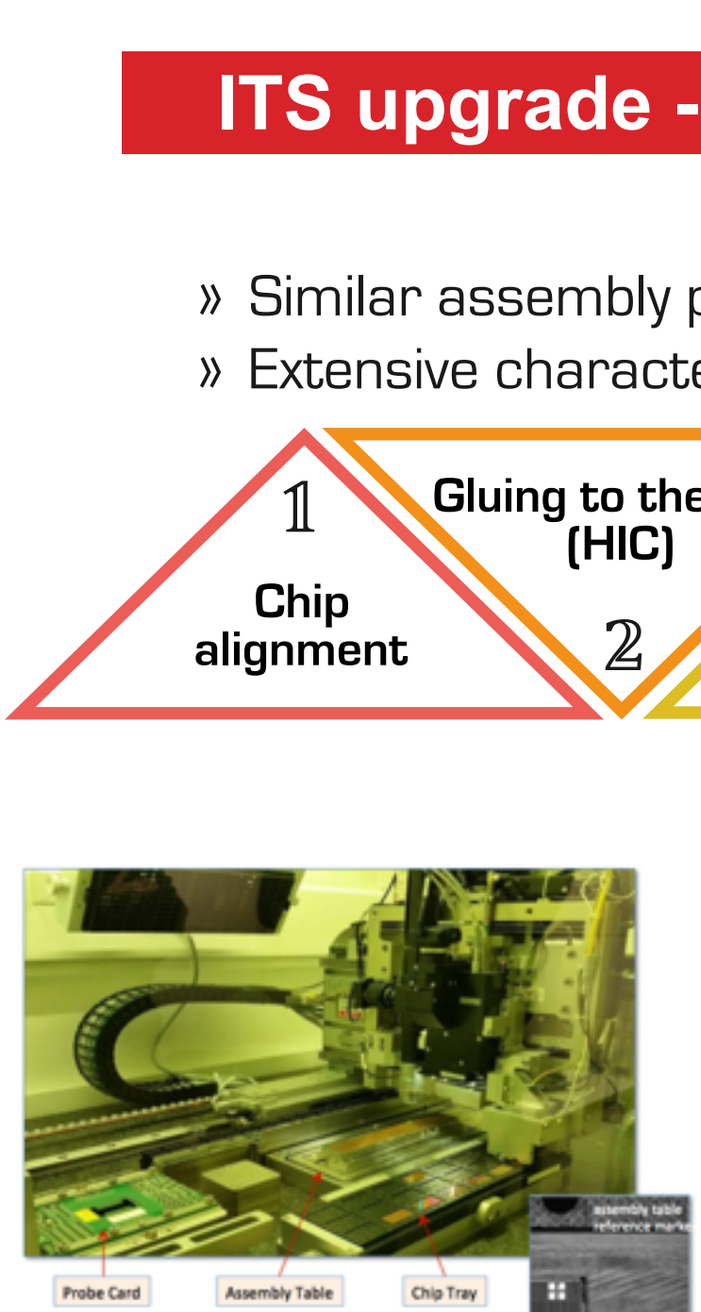
3 Electrical connection

4 HICs alignment and gluing to the Cold Plate

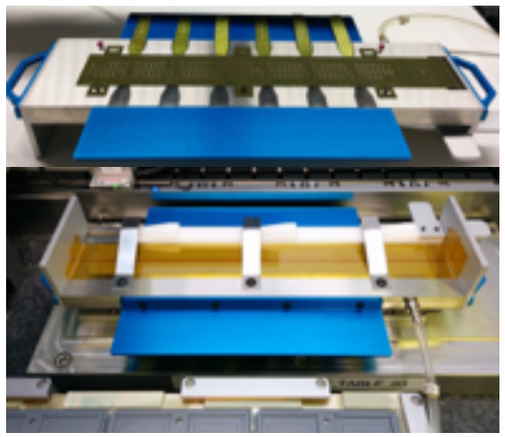
5 HICs Electrical interconnection

6 Space Frame gluing

7 Power bus soldering and folding

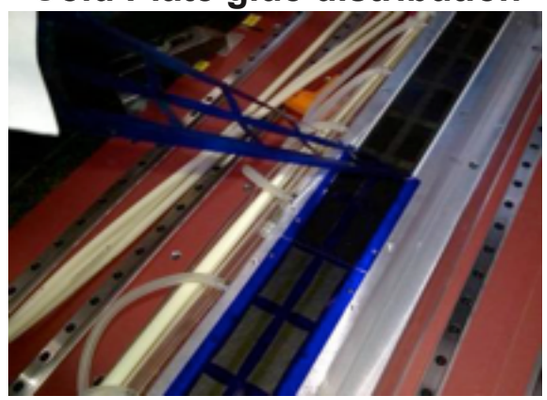


Module **A**ssembly **M**achine
» 5 μm precision chip placement
» Automatic chip inspection
» Chip electrical test

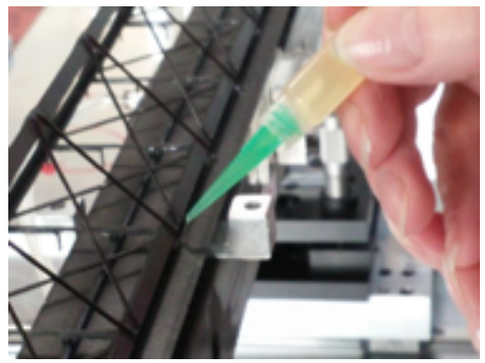


FPC gluing to chips

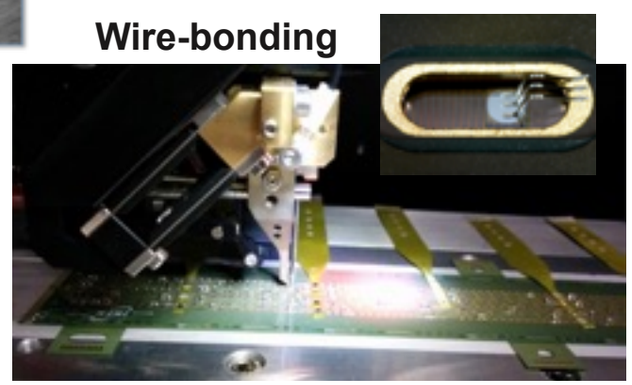
Cold Plate glue distribution

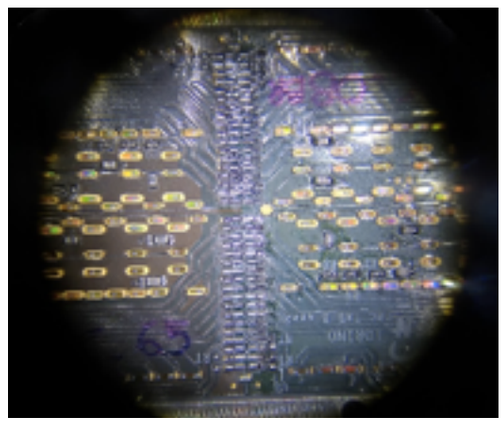


Space Frame gluing

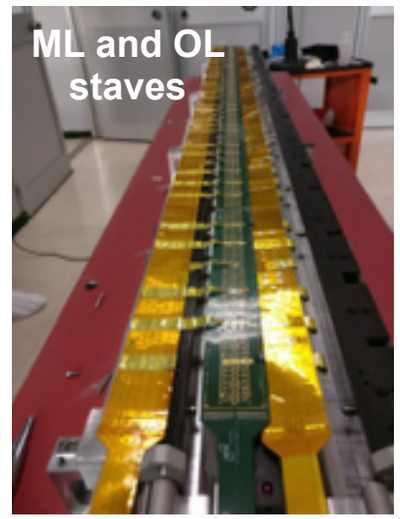


Wire-bonding





HICs electrical interconnection

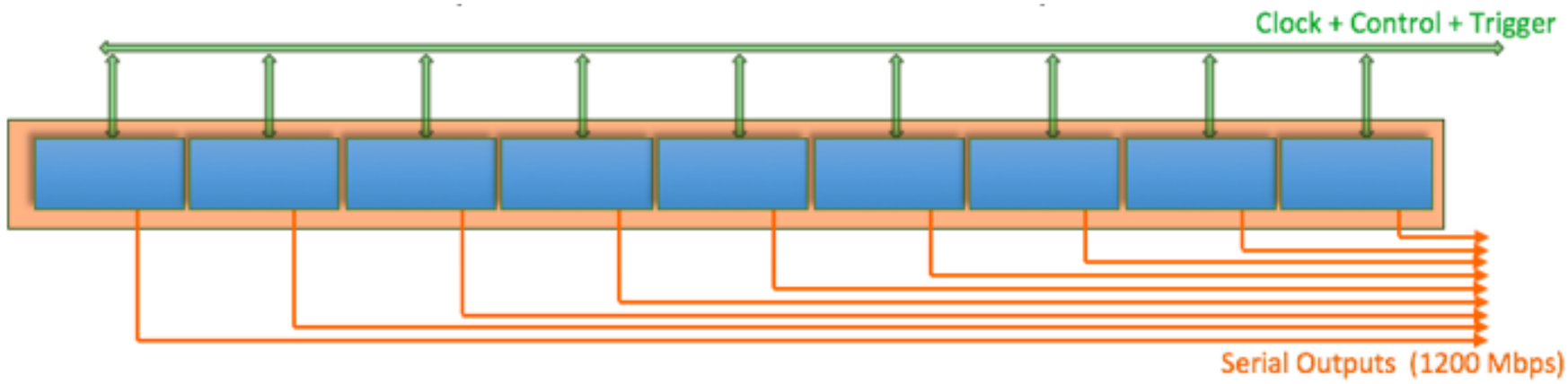


Power bus folding

Backup

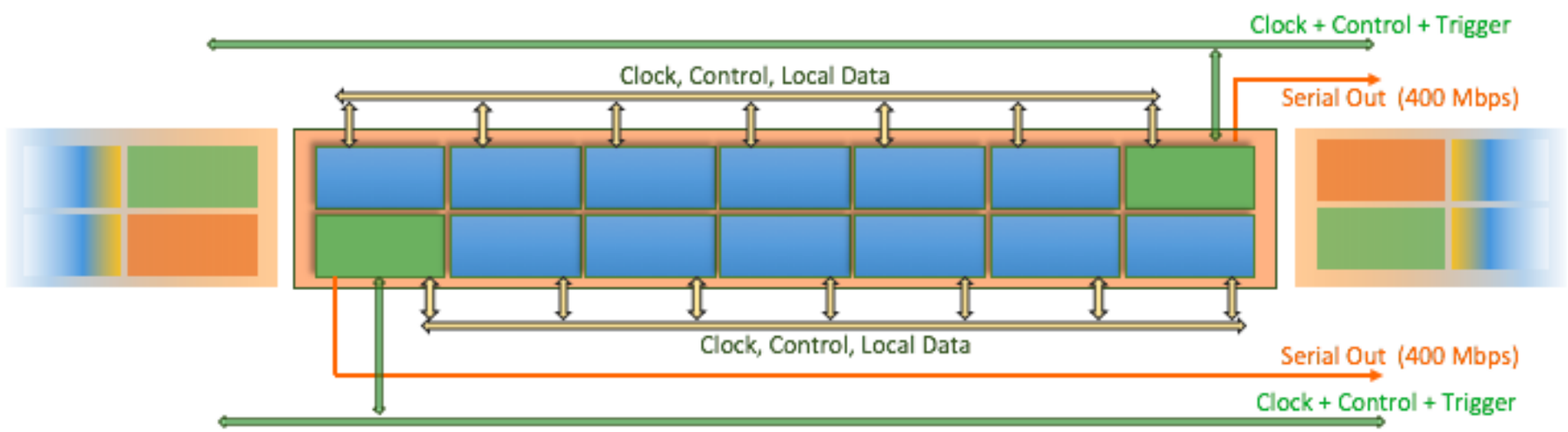
Modules (HICs) readout

ITS Inner Barrel Module – 9 chips, common clock and control, independent data lines



ITS Outer Barrel Module – 2 groups of chips, Master + 6 Slaves

Only the Master interfaces to the external world and bridges control and data transfer



Backup

Online tracking and vertexing

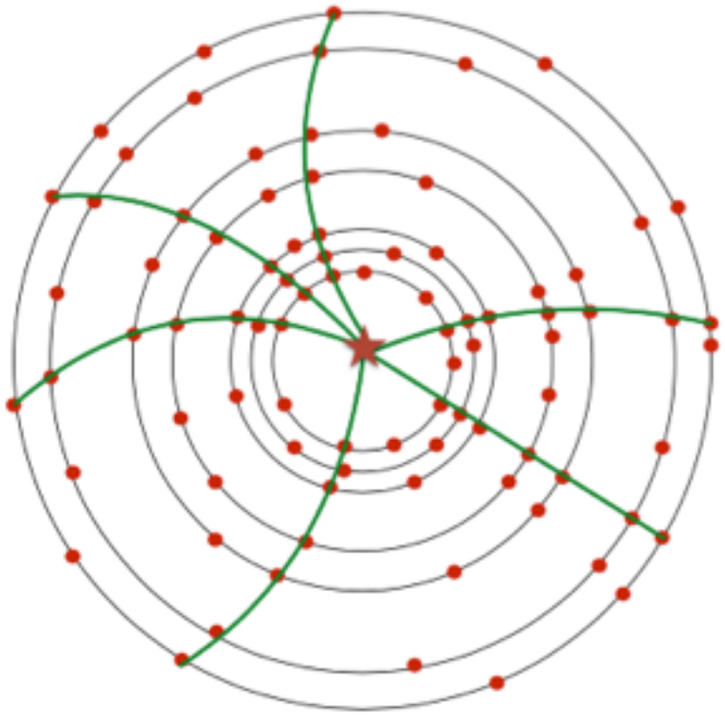
» Starting from Run3 we expect Pb-Pb collisions at peak rate of 50 kHz
  - 1.1 TB/s of data will be collected

» Data volume must be reduced before writing to tape
  - Online processing is the only option

» ALICE is running GPU based online track reconstruction in the TPC since 2010 with good performance

» From Run 3 on also the reconstruction of tracks and vertices in the ITS will be done on GPU

Tracking in ITS Upgrade



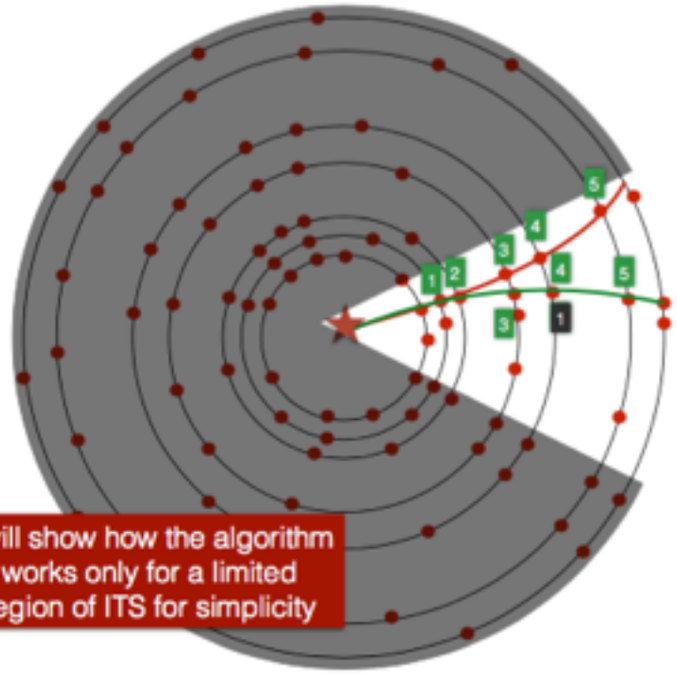
Determination of the primary vertex with fast algorithms

Using a pattern recognition method, find track candidates

Fitting of the candidates using Kalman Filter in three passes (inward, outward, inward)

Candidates with the best χ^2 are saved as tracks

Cellular Automata in the ITS Upgrade



I will show how the algorithm works only for a limited region of ITS for simplicity

For each cluster on each layer a 2D window is opened. Then the clusters are joined with those on the next layer within the window

Subsequent doublets are combined in cells (3 points seed) and track params are computed

Each cell has an index representing the number of connected inner cells + 1

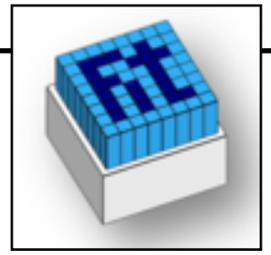
Longest, continuous sequences of indices represent candidates

KF Fitting

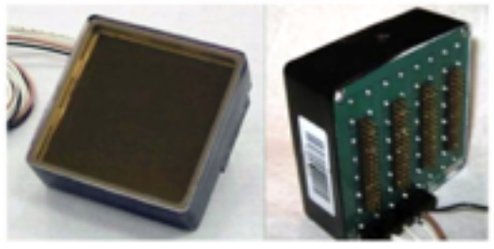
Backup - ALICE upgrade

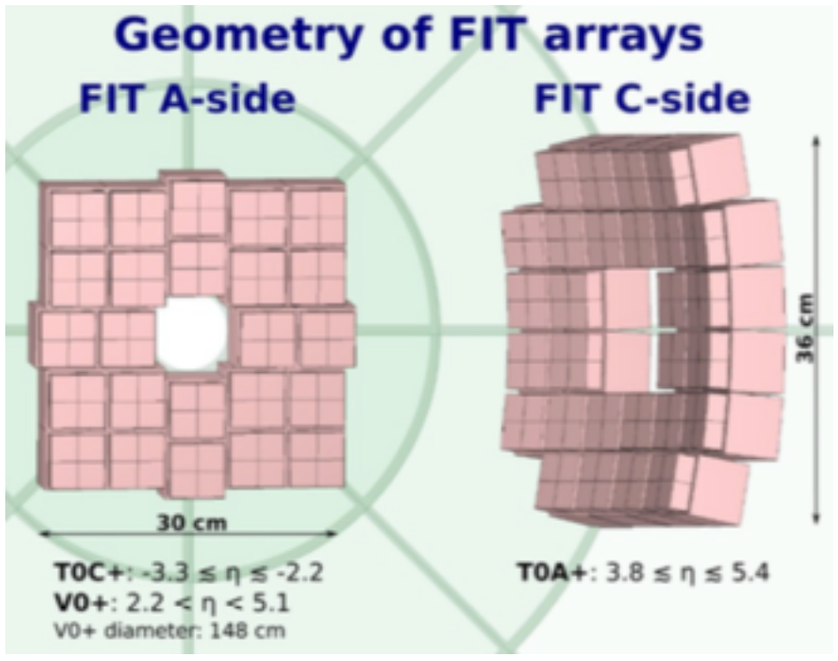
Muon Forward Tracker (MFT) and Fast Interaction Trigger (FIT)

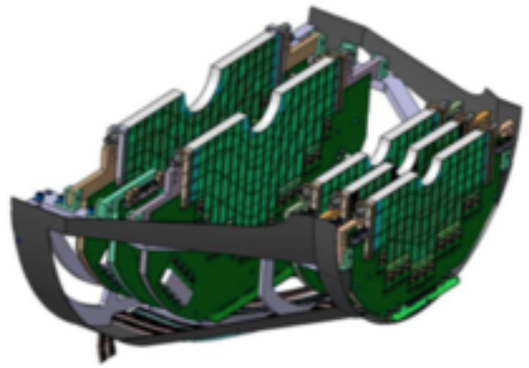
ALICE

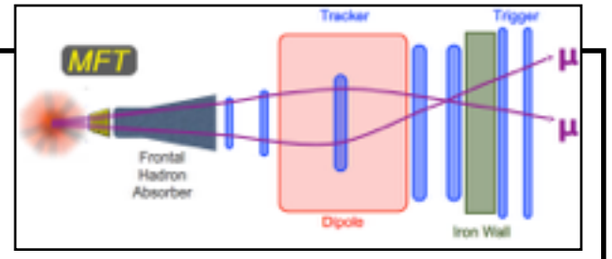


» Minimum Bias Trigger
- Efficiency 100% (~83%) in Pb—Pb (pp) collisions
- Centrality triggering
- Vertex online location
- Time resolution < 50 ps
- Event plane determination
- No ageing over Run3 and Run4 periods



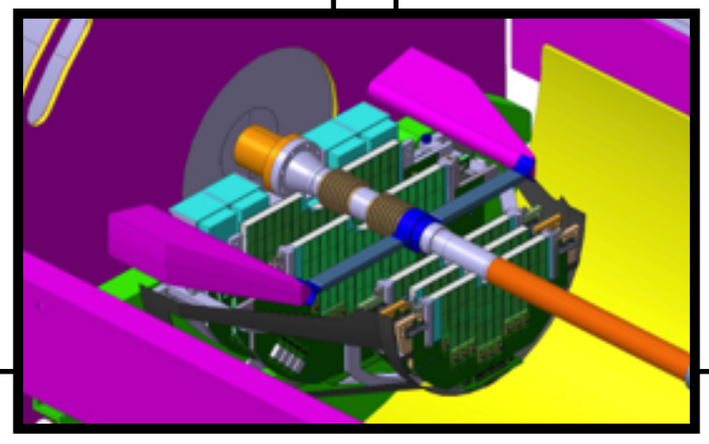






» Muon tracks are matched between the Muon Spectrometer and MFT
» MFT adds high pointing accuracy for muon tracks
- Measurement of displaced vertex position
- Strong Lorentz boost effect at forward rapidity, event fior $p_T = 0$
- Measurement of beauty down to $p_T = 0$ from displaced J/Ψ vertices
- Measurement of $\Psi(2S)$

» 10 Half-disks, distributed in 2 detector planes, equipped with 920 ALPIDE chips

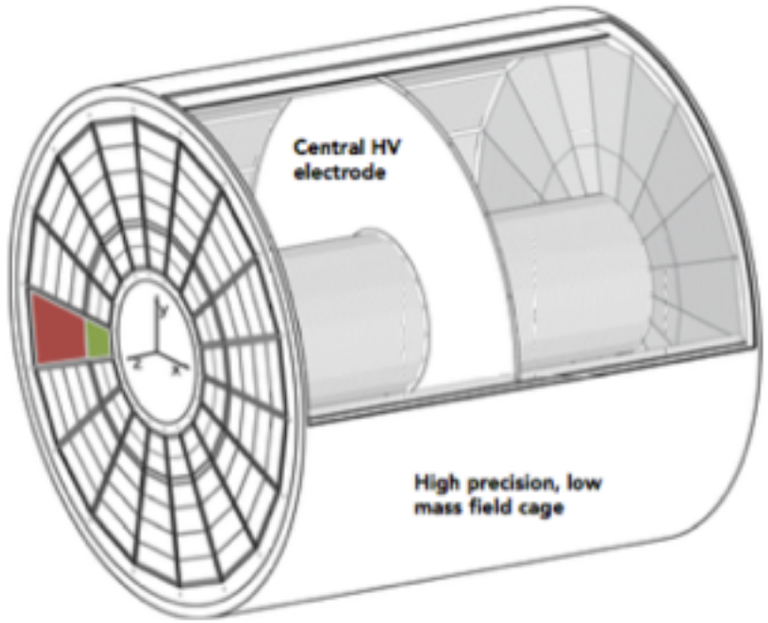


Backup - ALICE upgrade

Time Projection Chamber read-out chamber upgrade

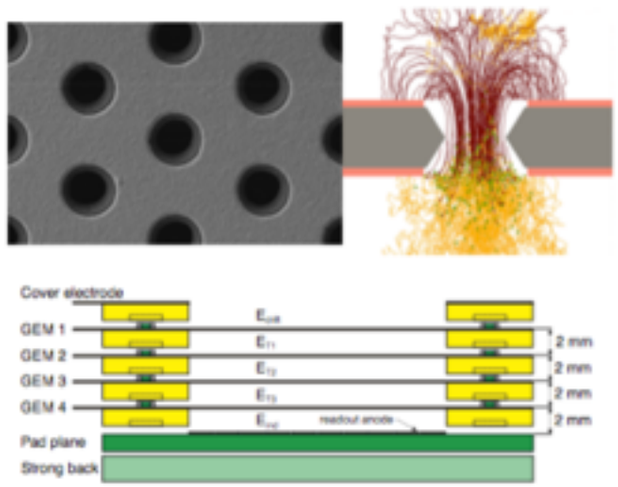
Limitation of the ion backflow

» Diameter: 5 m, Length: 5 m, Electron drift time: 100 μs, Ion drift time: 160 ms
» Gating grid to collect ion back flow need 300 μs → Intrinsic limitation at 3 kHz interaction rate
» Present RO limits to 300 Hz for central Pb-Pb collisions
» Low Ion back flow of Gas Electron Multipliers (GEMs) allows to avoid gating grid
» New RO architecture: continuos readout → ~3 TByte/s
» Online calibration, reconstruction and data compression needed (O^2 project)



GEM technology

» Quadrupole GEM chambers
» GEMs technology intrinsically blocks ion backflow
» Similar performances as MWPC
» 640 GEM foils needed for the TPC RO upgrade



Backup - ALICE upgrade

O^2 project

Requirements

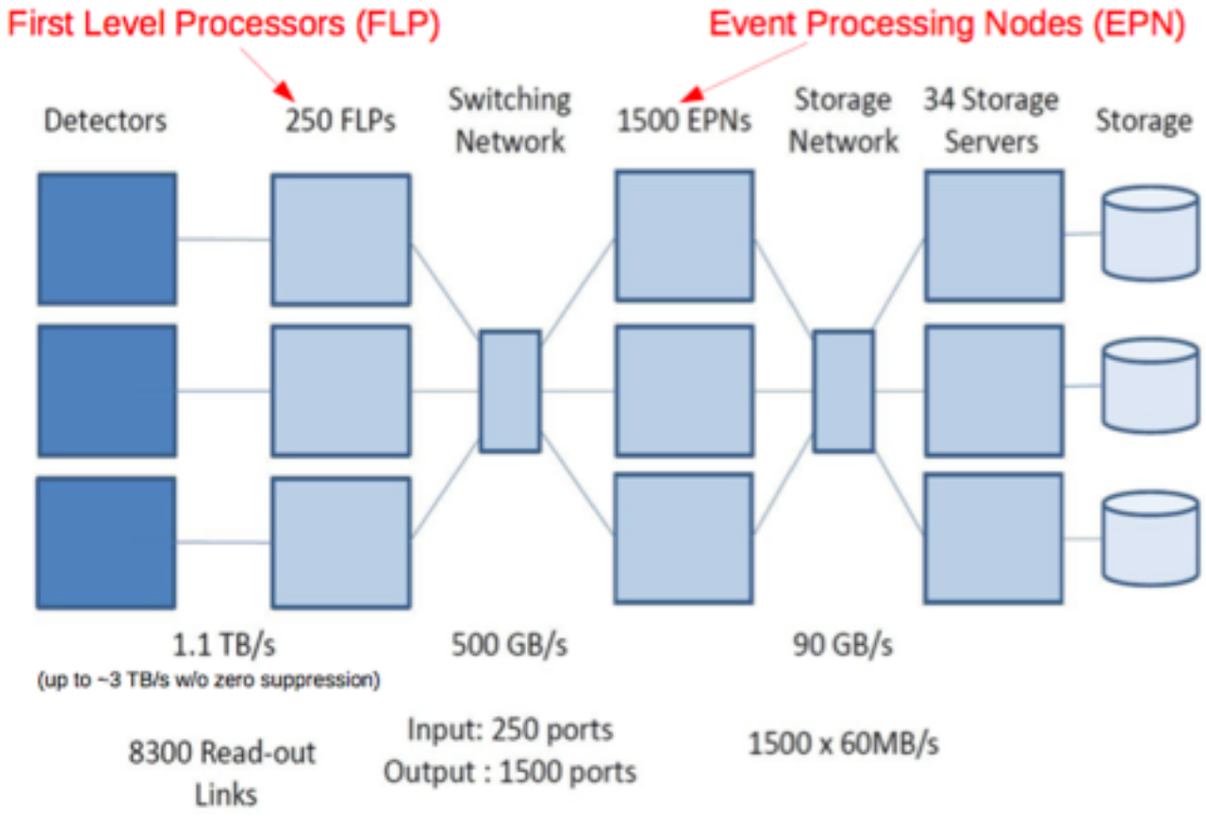
1. LHC min. bias Pb-Pb at 50 kHz, ~100 x more data than Run1/2
2. Rare physics processes with very small signal over background ratio
3. Triggering techniques very inefficient if not impossible
4. TPC inherent rate > 50 kHz → Support for continuous read-out

New computing system

➡ Read-out the data of all interactions

➡ Compress these data intelligently by online reconstruction

➡ One common online-offline computing system: O^2



- First Level Processors (FLP) receive continuous data from parts of detectors and perform local tasks like cluster-finding, mask creations etc.
- Each FLP chops the output data to SubTimeFrames (~20 ms long) and dispatches STF of the same time stamp to one of the Event Processing Nodes (EPN)
- EPN performs full TPC reconstruction to compress the data and **partial (a few % only)** reconstruction of other detectors to produce enough calibration data.
  Aggregates STF to single TimeFrame (TF).
  1500 EPNs → ~30 s of real time to process TF

- Calibration data of different EPNs aggregated, CCDB populated with calibration objects
- Final reconstruction in all detectors, matching, vertexing performed for each TF
- Compact AODs written per TF (up 1000 consecutive events in Pb-Pb @ 50kHz)
- AOD design will be aimed at storage minimization