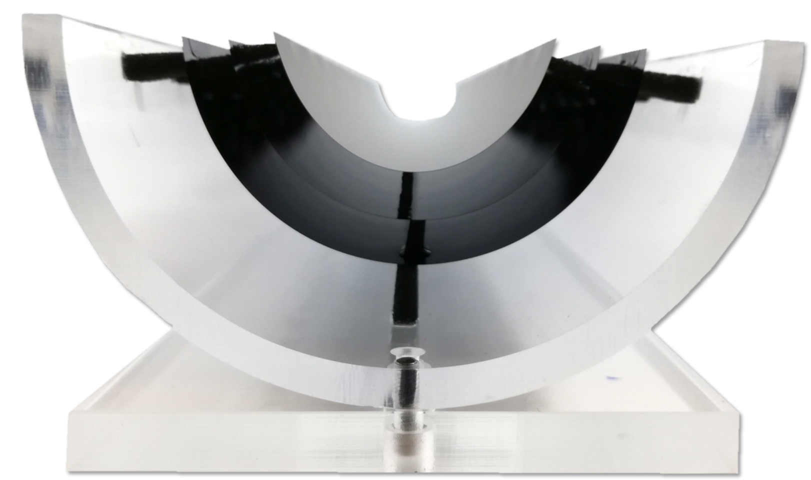
ALICE

ALICE ITS3
the first truly cylindrical inner tracker



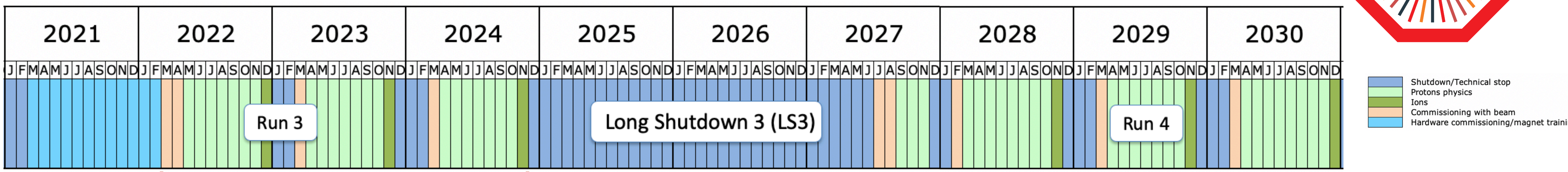
Domenico Colella

Politecnico and INFN Bari

on behalf of the ALICE Collaboration

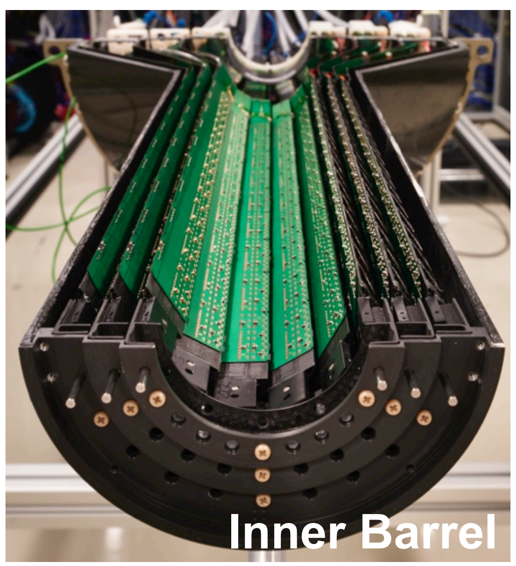
INFN BARI
Istituto Nazionale di Fisica Nucleare
Sezione di Bari

ALICE Inner Tracking upgrade roadmap

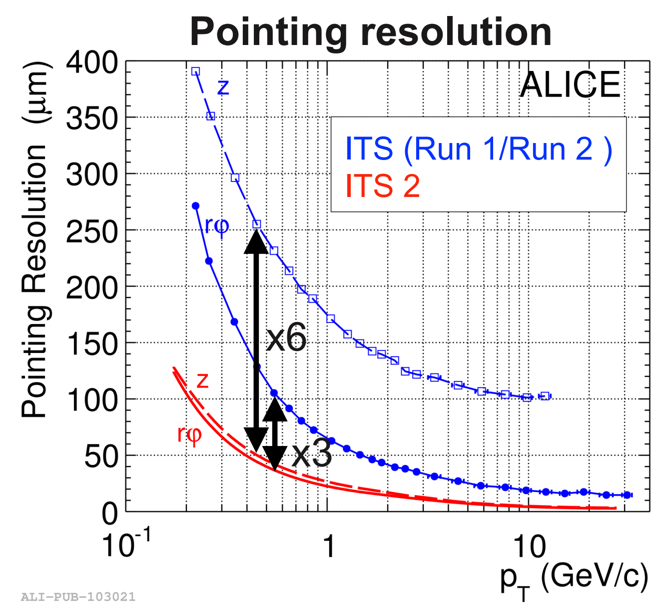


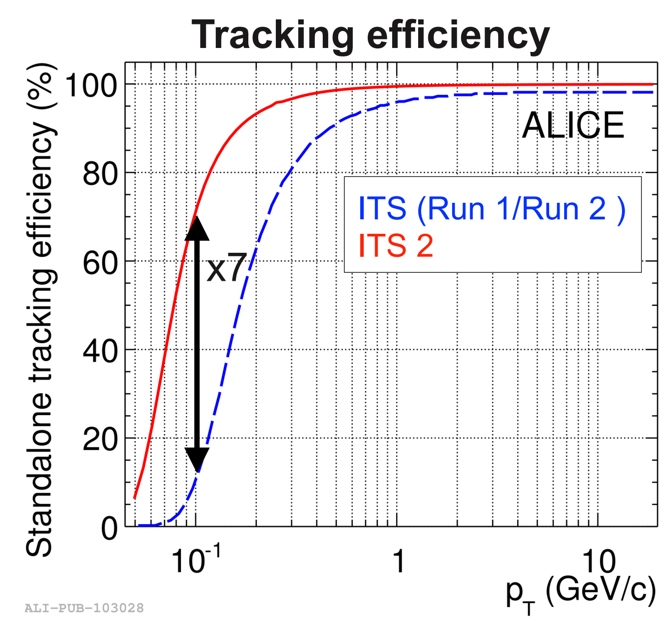
ALICE 2

ITS2 for LHC Run 3



ITS2 installed and under commissioning



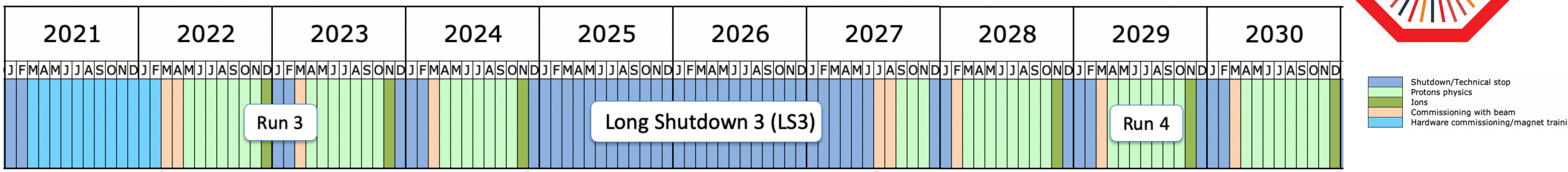


ITS2 will provide unprecedented performances

→ pointing resolution: 15 µm at p_T of 1 GeV/c

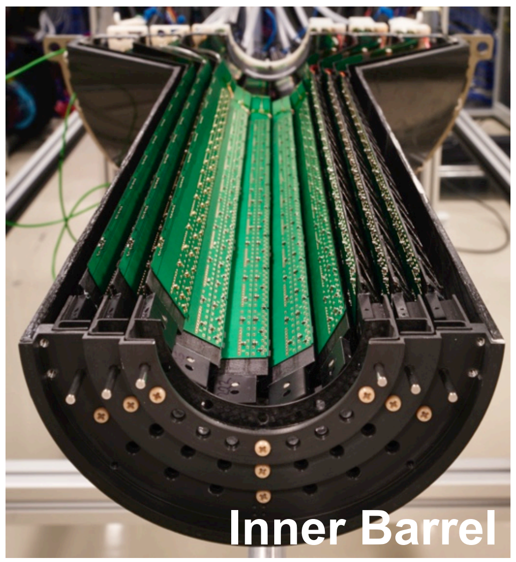
→ tracking efficiency: above 90% for p_T > 200 MeV/c

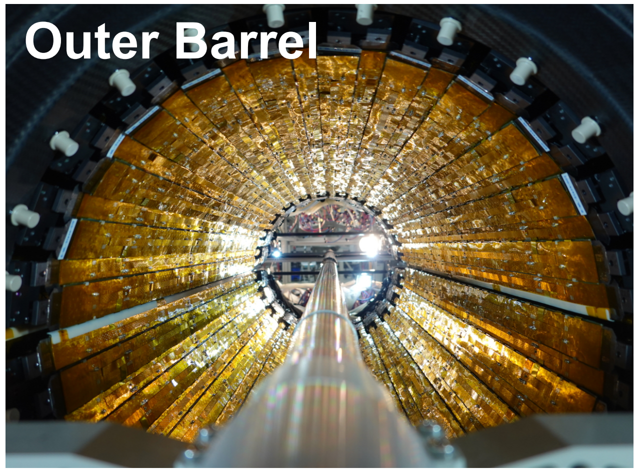
ALICE Inner Tracking upgrade roadmap



ALICE 2
ITS2 for LHC Run 3

ALICE 2.1
ITS3 for LHC Run 4

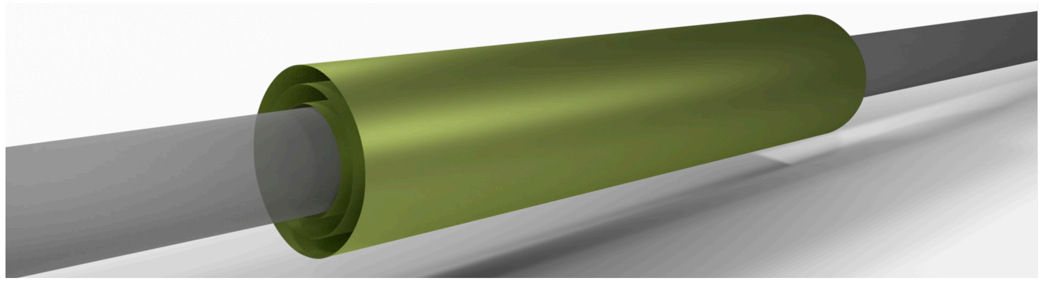




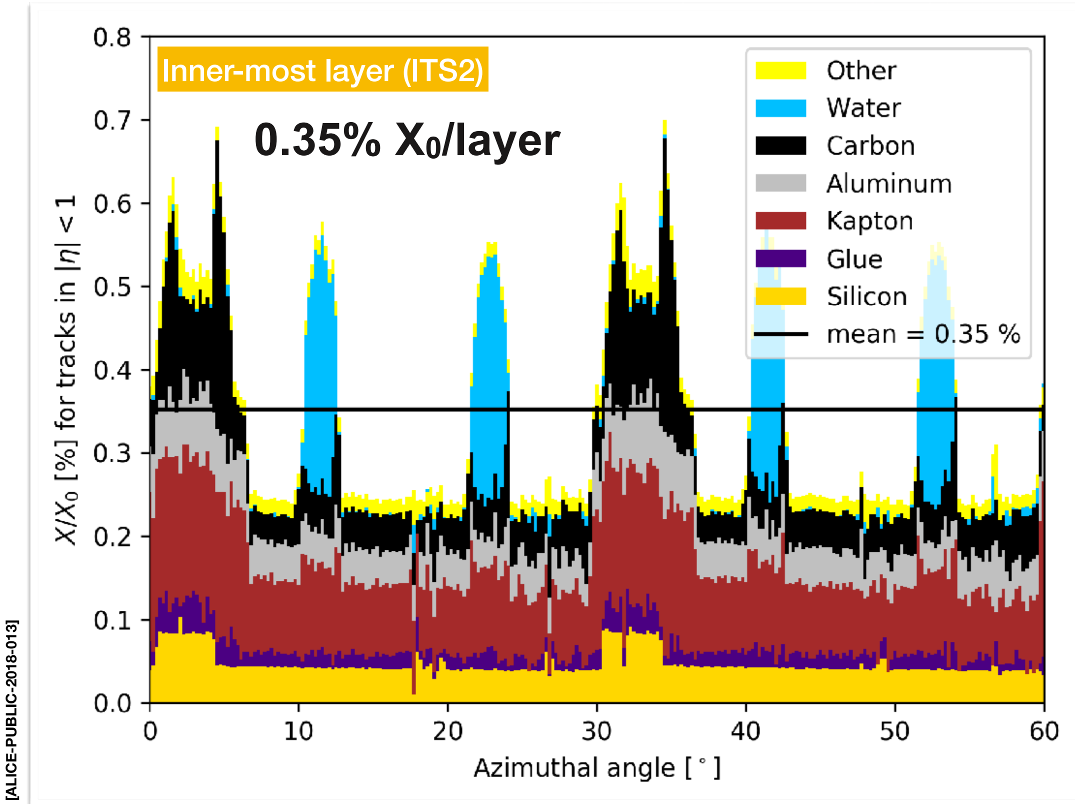
ITS2 installed and under commissioning

Can we get closer to the IP?
Can we reduce the material budget?

The way: replace detector staves (3 innermost layers) by wafer-scale sensors bent around the beam pipe



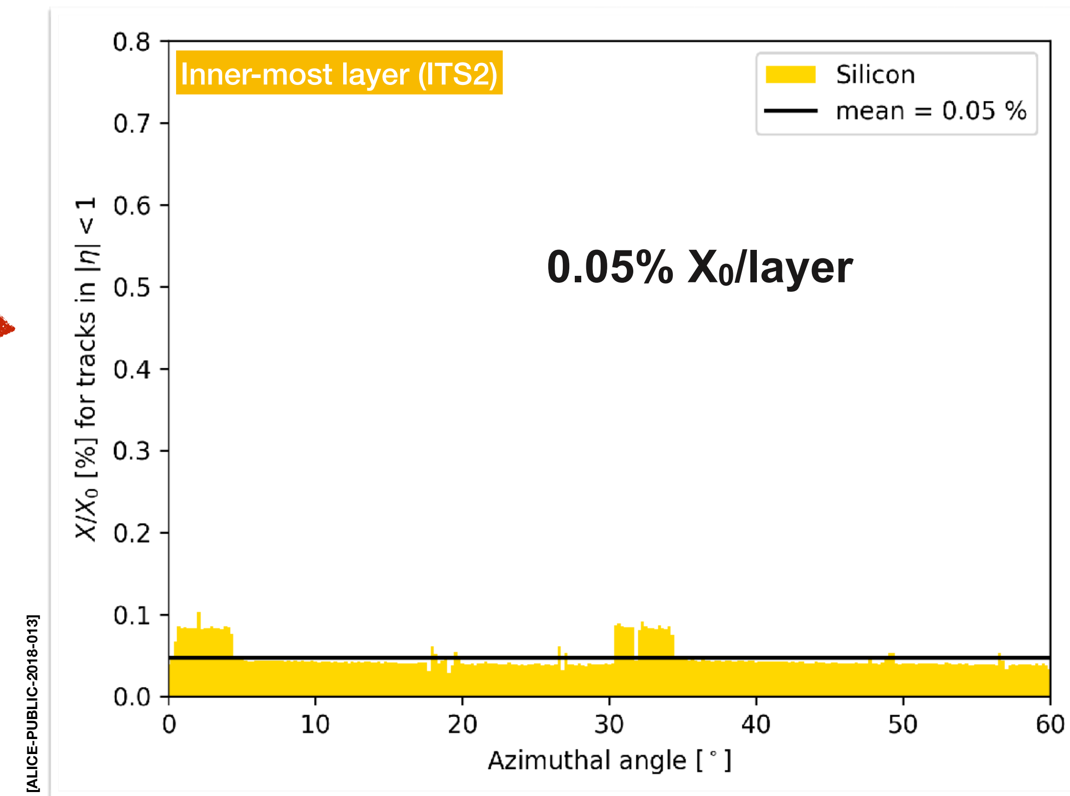
Motivation for ITS3



Observations

» Silicon makes only about 15% of total material

» Irregularities due to support/cooling and overlap



Improvements

» *Removal of water cooling*

→ **possible** if power consumption stays below 20 mW/cm^2

→ move to (low flow) air cooling system

» *Removal circuit board* (power+data)

→ **possible** if integrated on chip

» *Removal of mechanical support*

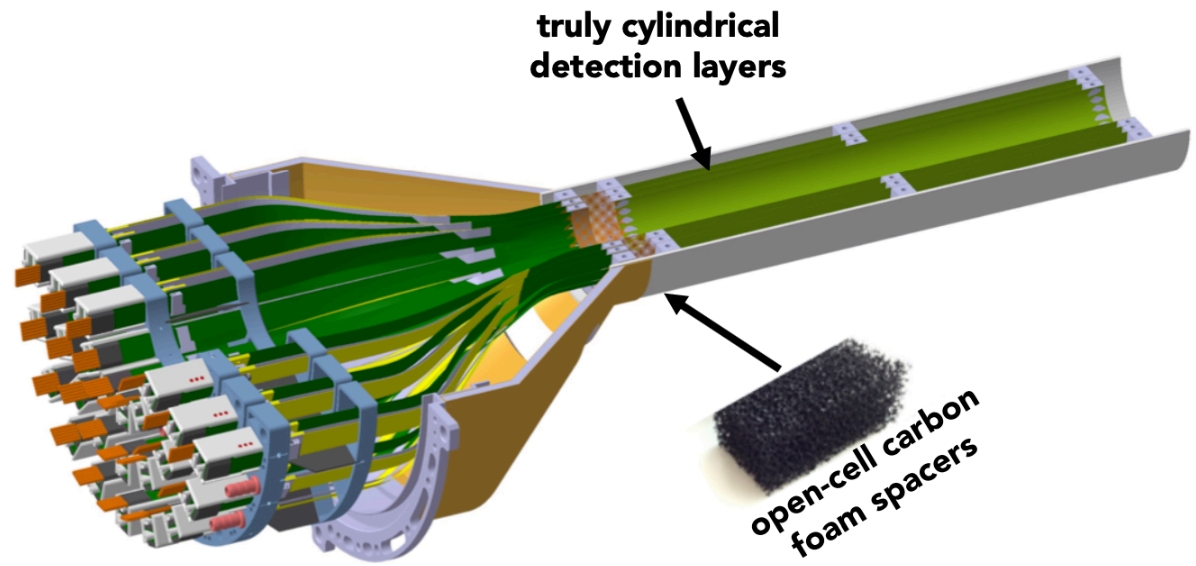
→ **benefit** from increased stiffness by rolling Si wafers

ITS3 detector concept

Key ingredients

» Wafer-scale chips (up to ~28x10 cm), fabricated using stitching
» Sensor thickness 20-40 μm
» Chips bent in cylindrical shape at target radii
» Si MAPS sensor based on 65 nm technology
» Carbon foam structures
» Smaller beam pipe diameter and wall thickness (0.14% X_0)

The whole detector will comprise six chips (current ITS IB: 432) and barely anything else!

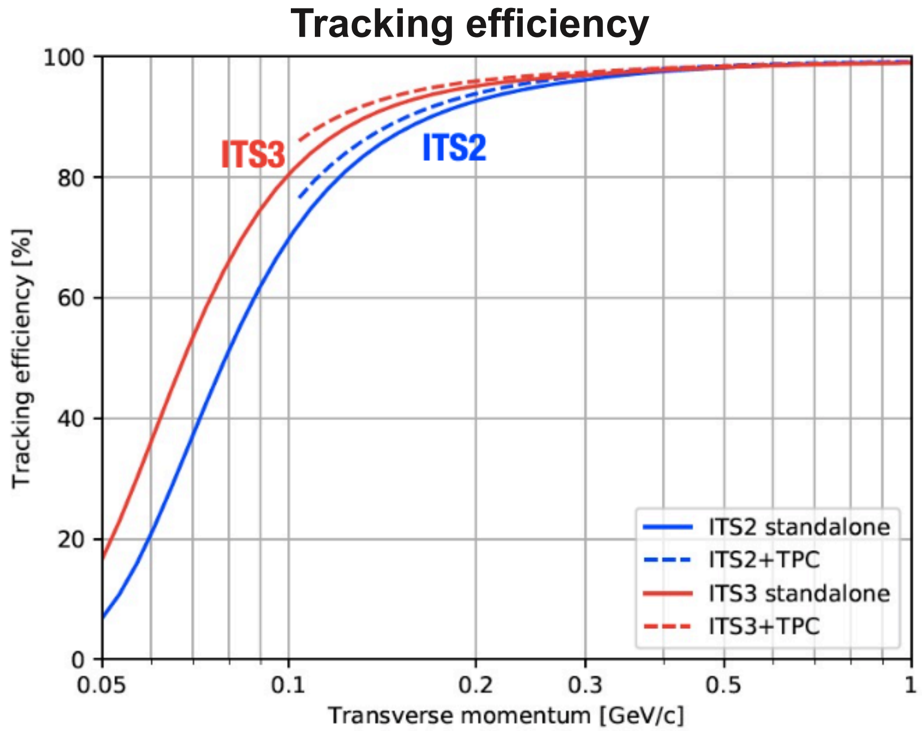


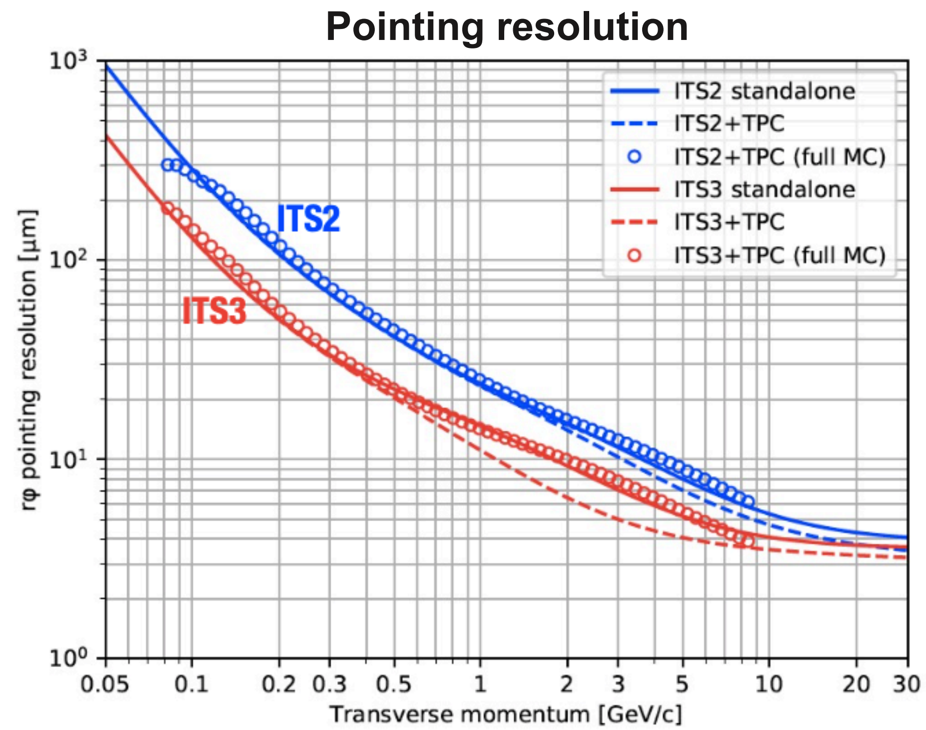
Key benefits

» Extremely low material budget: 0.02-0.04% X_0
» Homogeneous material distribution: negligible systematic error from material distribution

Beam pipe inner/outer radius (mm)	16.0/16.5		
IB Layer Parameters	Layer 0	Layer 1	Layer 2
Radial position (mm)	18.0	24.0	30.0
Length of sensitive area (mm)	300.0		
Pseudo-rapidity coverage	±2.5	±2.3	±2.0
Active-area (cm^2)	610	816	1016
Pixel sensor dimension (mm^2)	280 × 56.5	280 x 75.5	280 x 94
Number of sensors per layer	2		
Pixel size (μm^2)	O (10 x 10)		

ITS3 performance

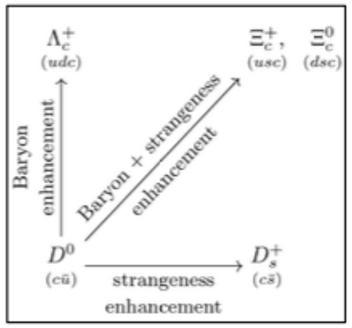


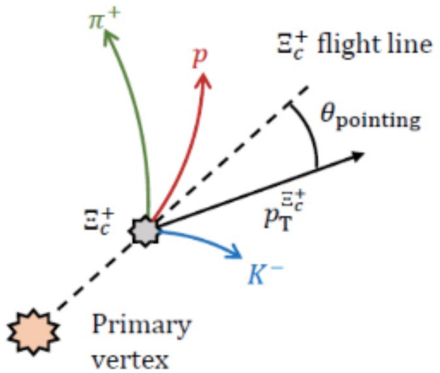


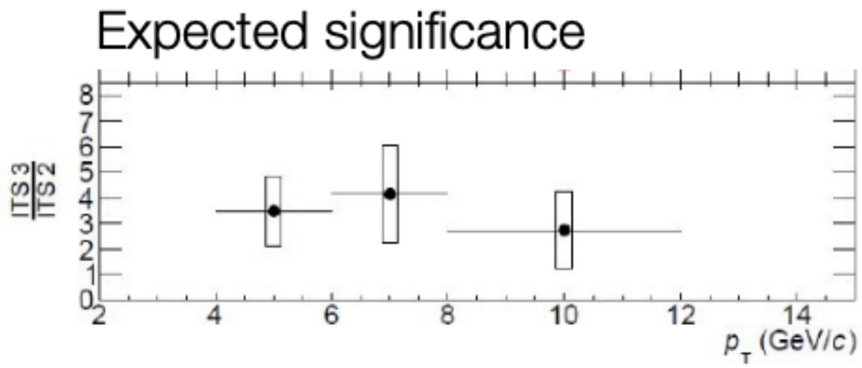
Improved pointing resolution and tracking efficiency for low momenta (×2 at all p_T)

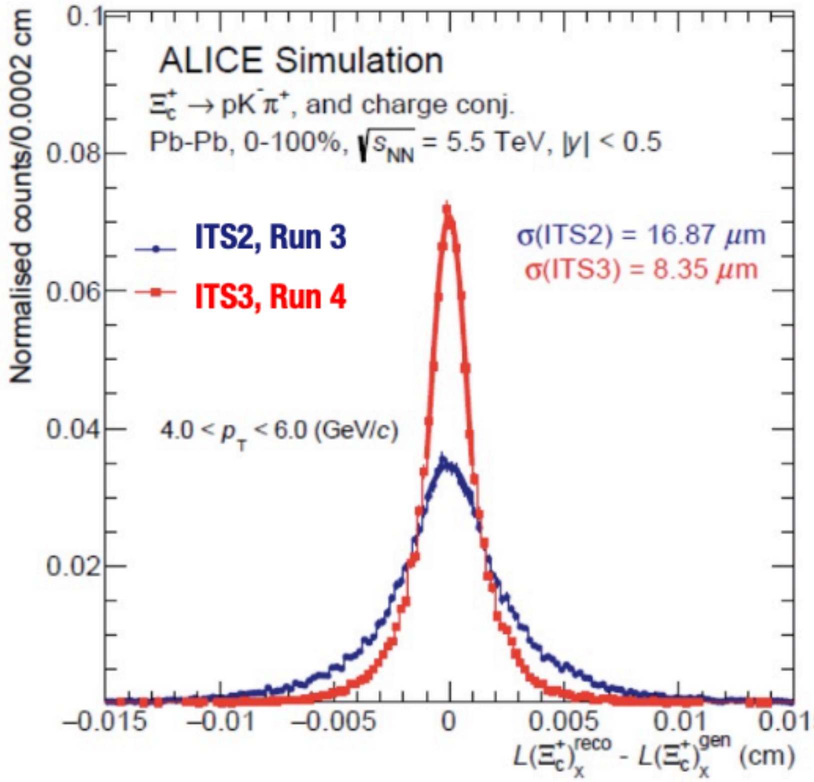
Study of the enhancement of charm quarks in heavy-ion collisions

- Λ_C^+ and D_S^+ used to study baryon and strangeness enhancement (compared to D^0)
- Ξ_C might set very powerful constraints to test HF coalescence models





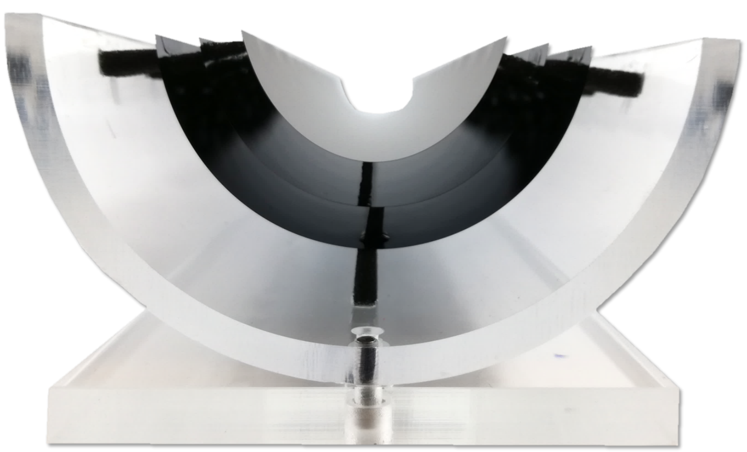




ITS3 R&D lines

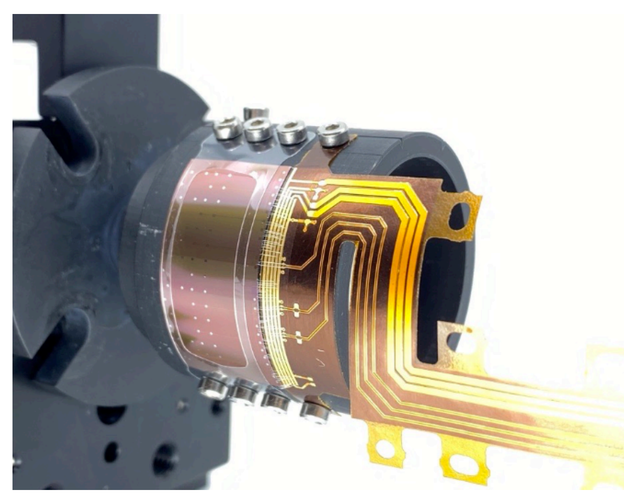
Detector Integration

Tests with wafer-scale dummy chips for mechanical integration



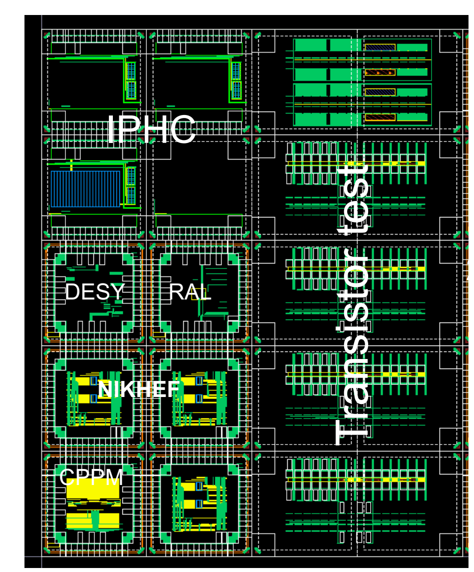
Sensor performance

Tests with existing bent ALPIDE chips (ITS2) for (in-beam) performance assessment



Chip design

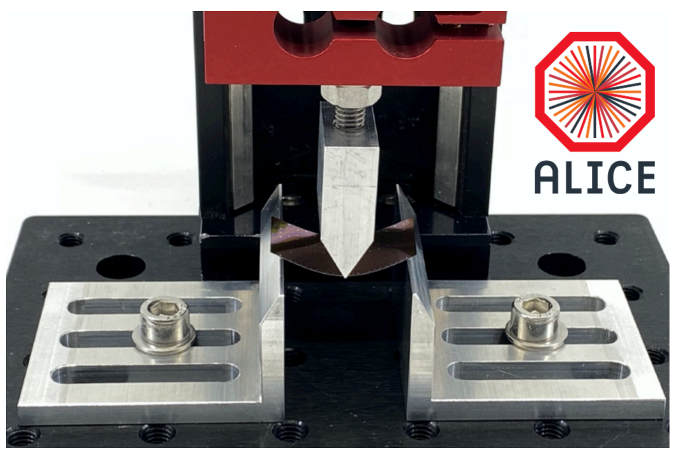
New, stitched sensor in 65 nm technology on 300 mm wafers

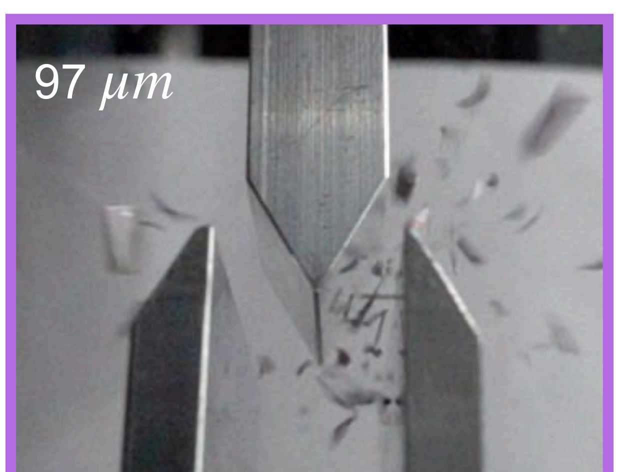


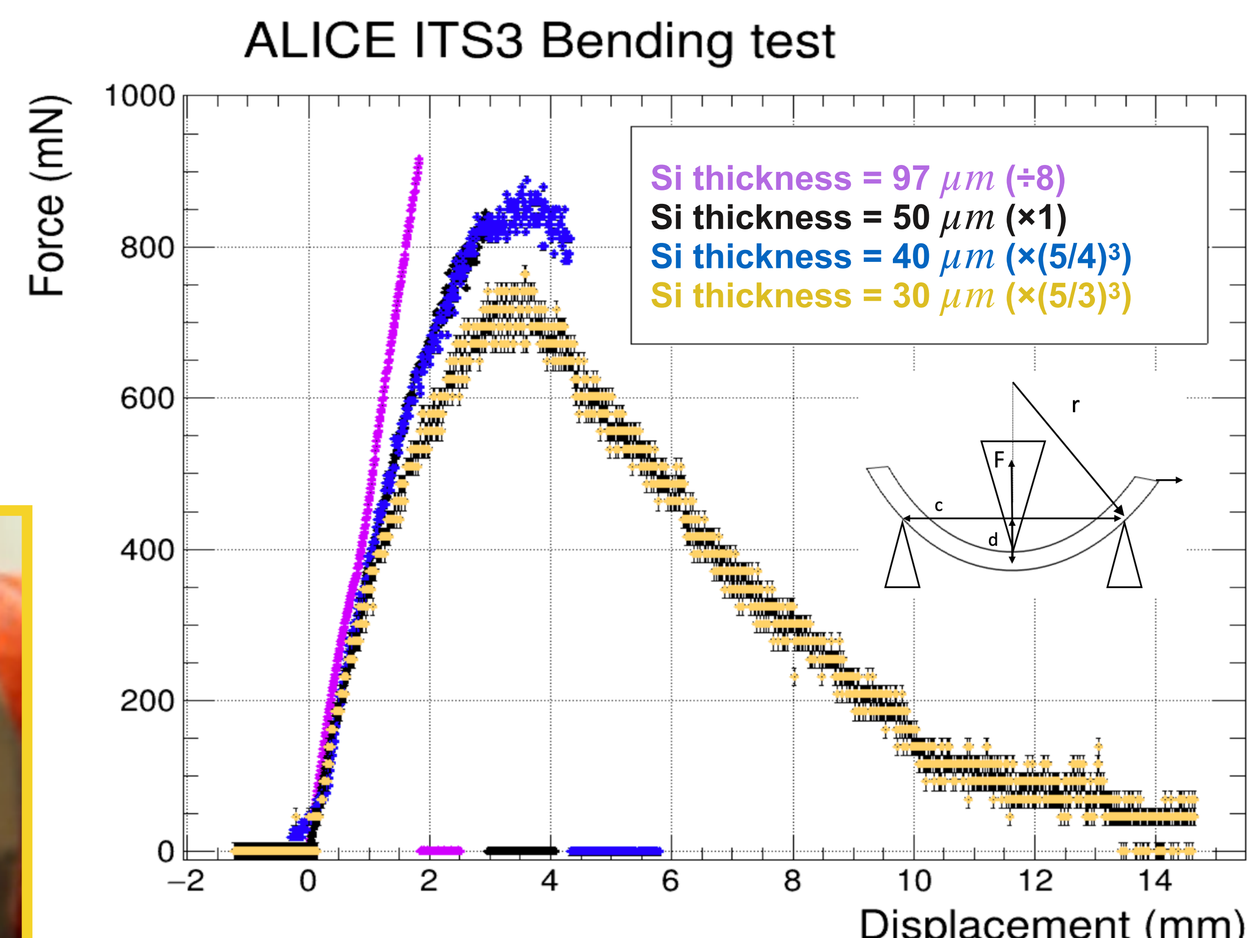
ITS3 R&D lines - Detector Integration

ALPIDE CHIP BENDING

- MAPS at thickness used in current detectors (~50 μm) are quite flexible
- Large benefit from going even a bit thinner: the bending force scales with thickness to the third power
- The breaking point moves to smaller bending radii when going thinner
- Project goal thicknesses and desired bending radii are in a “not breaking” regime

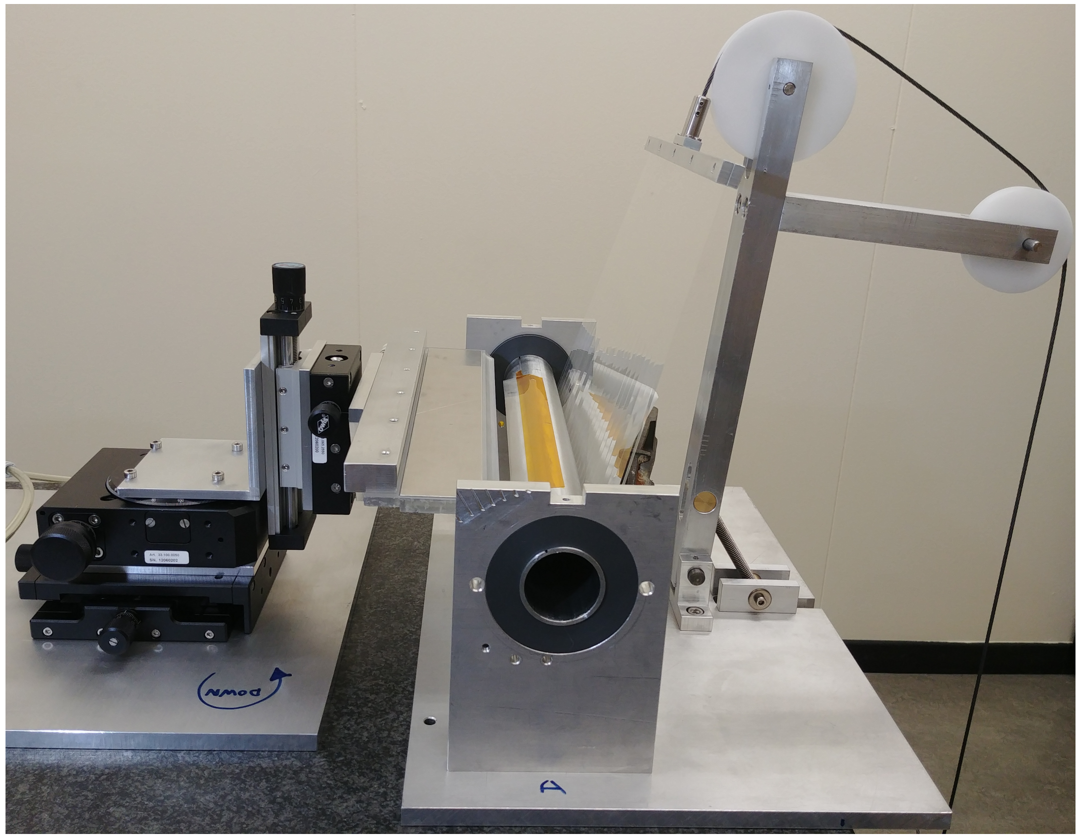


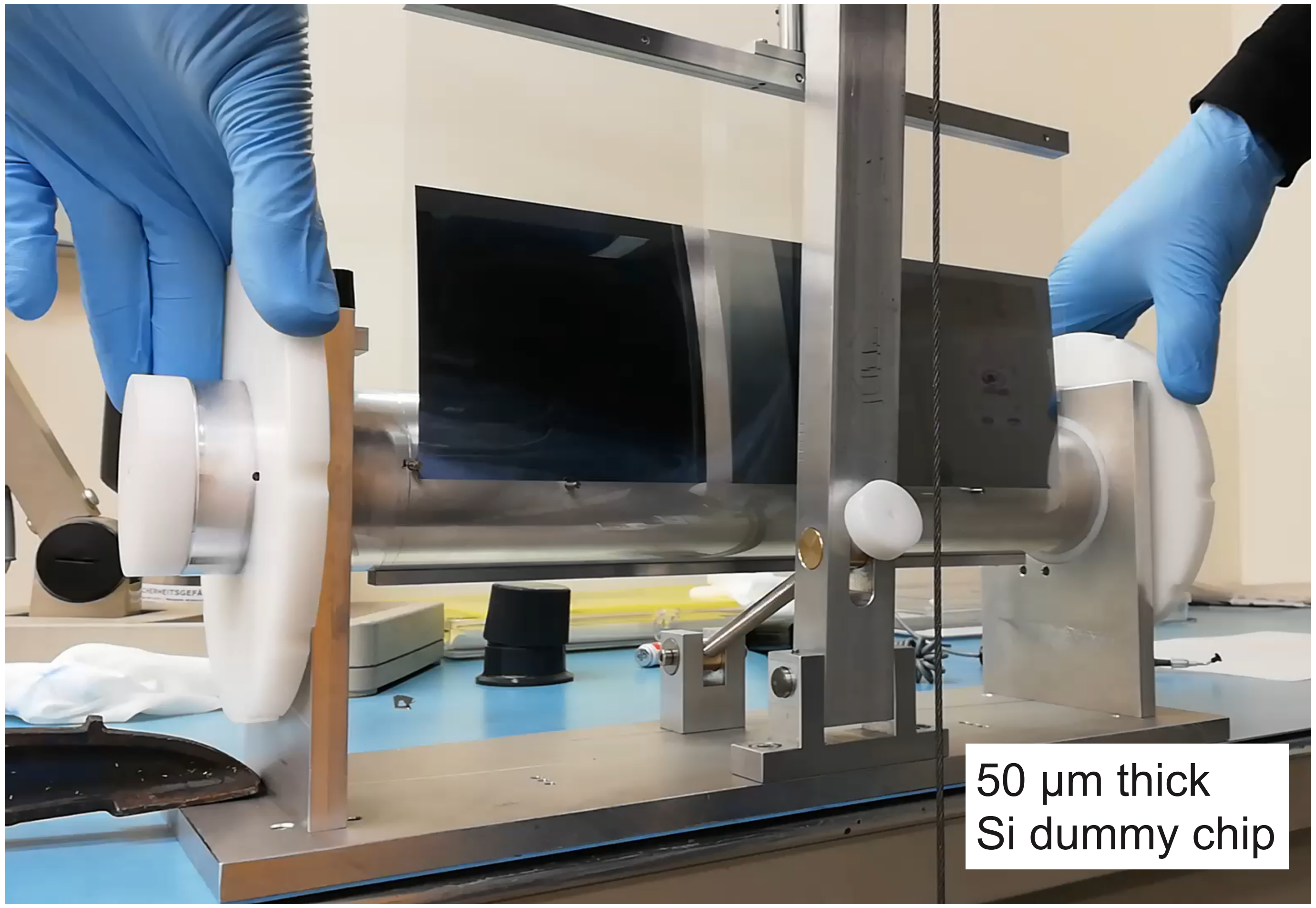




WAFER-SCALE CHIPS BENDING

» Developed procedure allows silicon bending in a repeatable reliable way
» Bending tool: tensioned mylar foil wrapping around a cylindrical mandrel



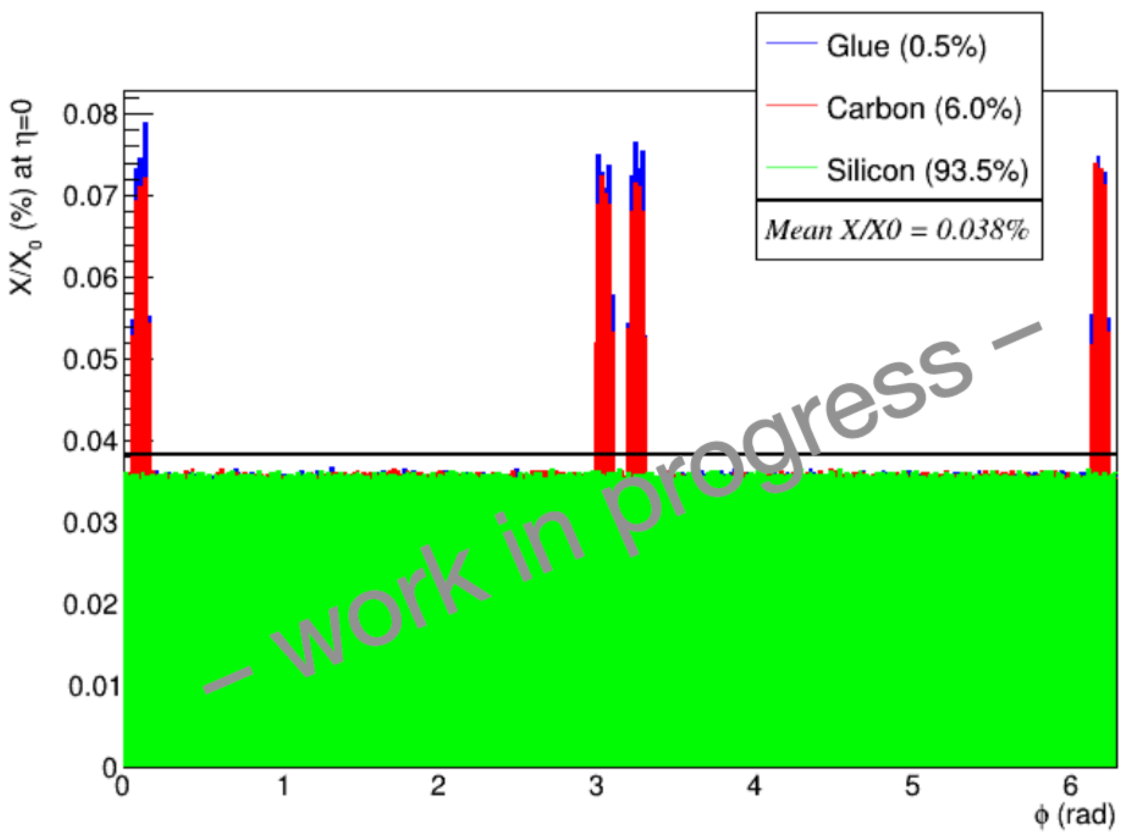


50 µm thick
Si dummy chip

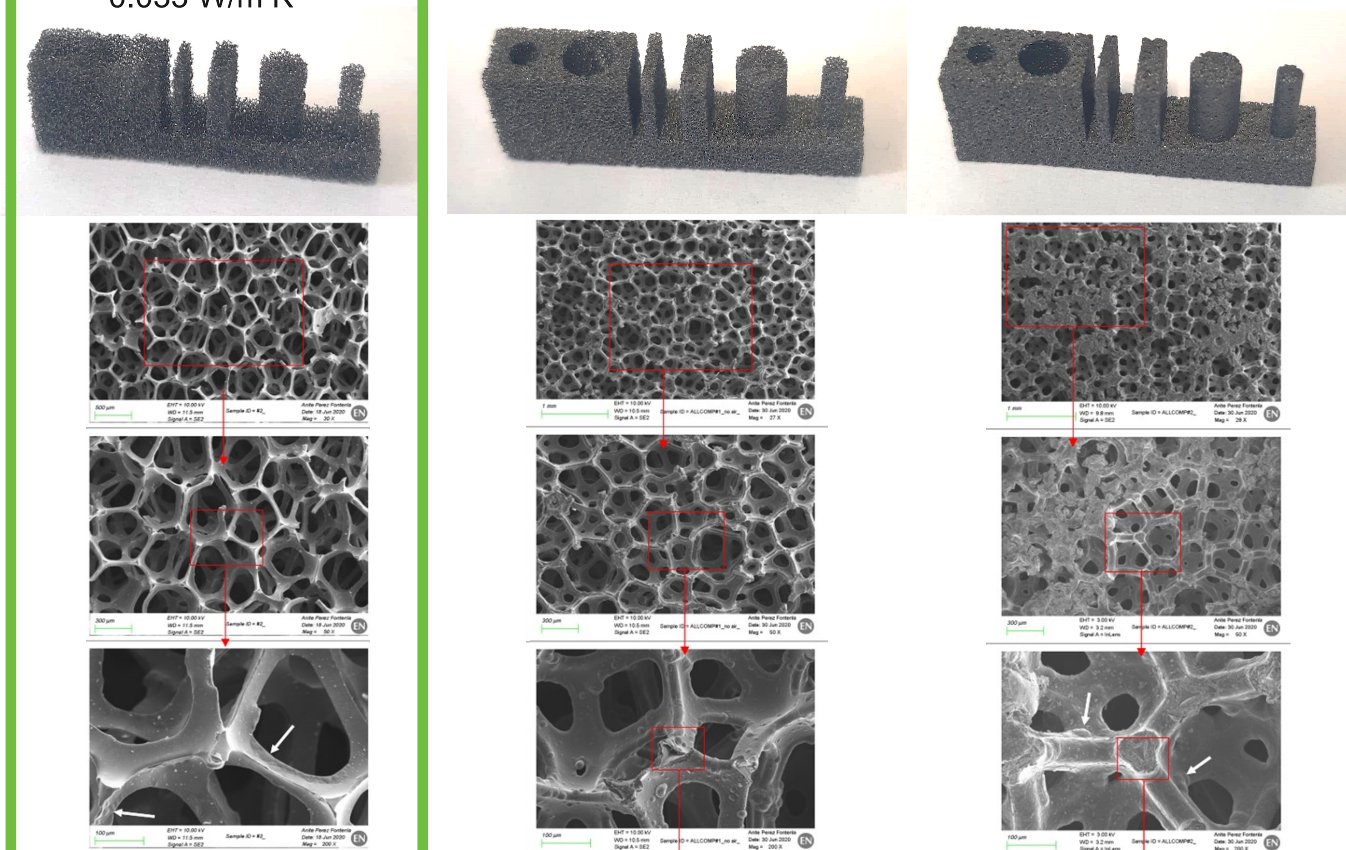
ITS3 R&D lines - Detector Integration

CARBON FOAM SUPPORT STRUCTURE

- » Different foams characterised for machinability and thermal properties
- » Baseline is ERG DUOCEL_AR, which also features the largest radiation length



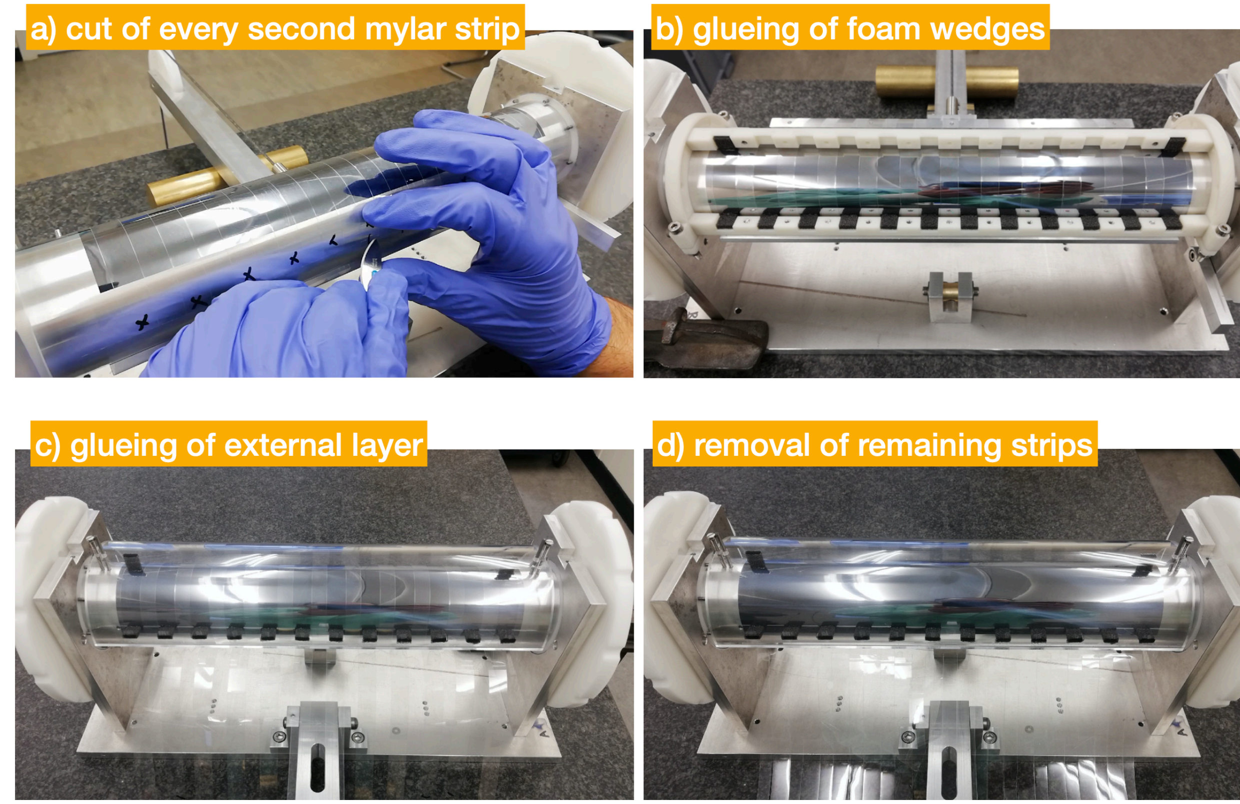
ERG DUOCEL_AR	ALLCMPO_LD	ALLCMPO_HD
0.06 kg/dm^3	0.2-0.26 kg/dm^3	0.45-0.68 kg/dm^3
0.033 W/m·K	>17 W/m·K	85-170 W/m·K

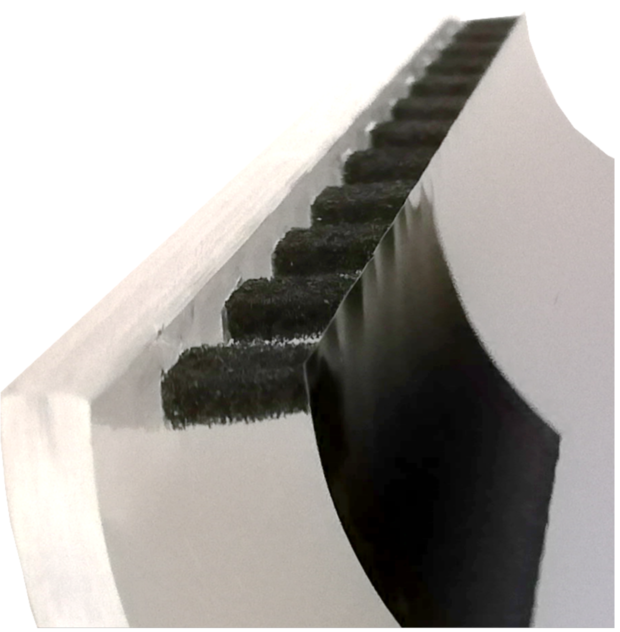


ITS3 R&D lines - Detector Integration

LAYER ASSEMBLY PROCEDURE

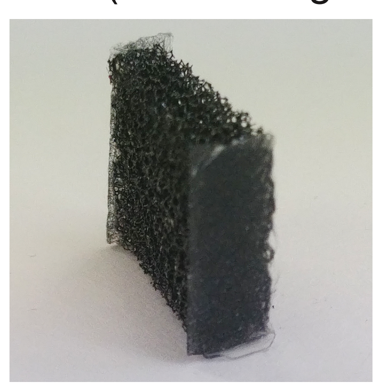
- Different options under study (including vacuum clamping)
- Currently working solution based on segmented mylar foil

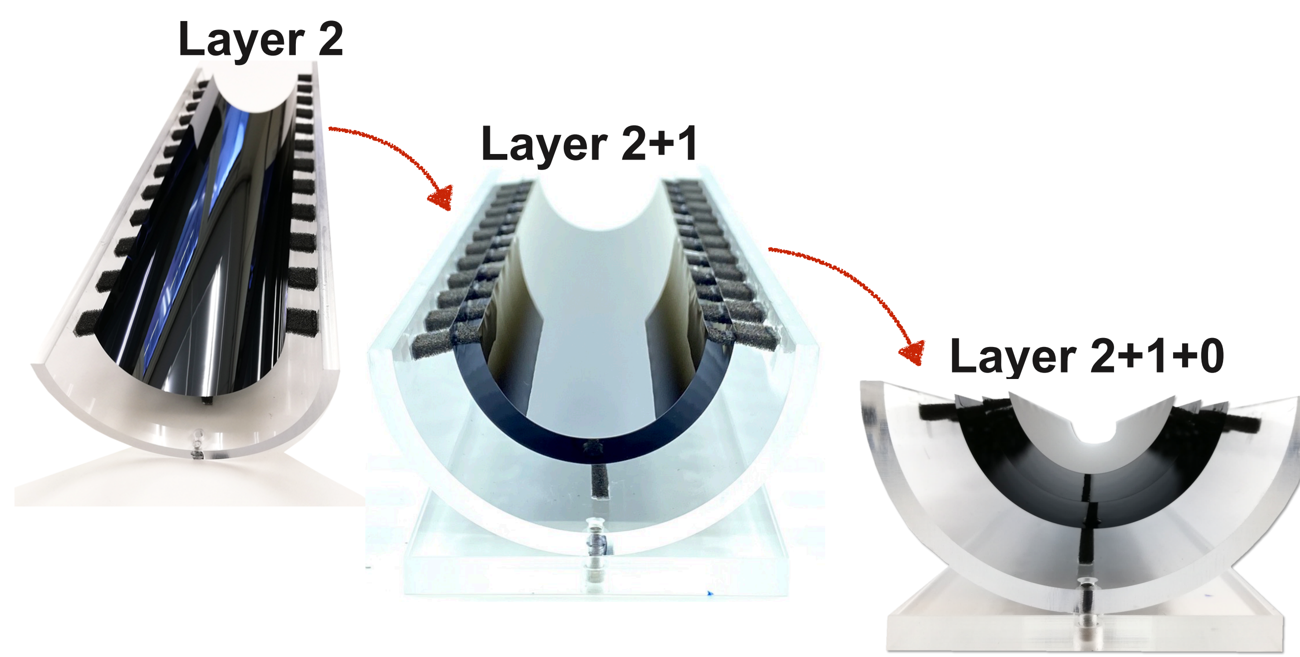




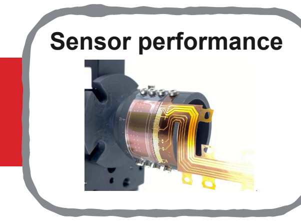
footprint effect
+ bending between wedges

Carbon foam wedges
+ fleece (to reduce glue)



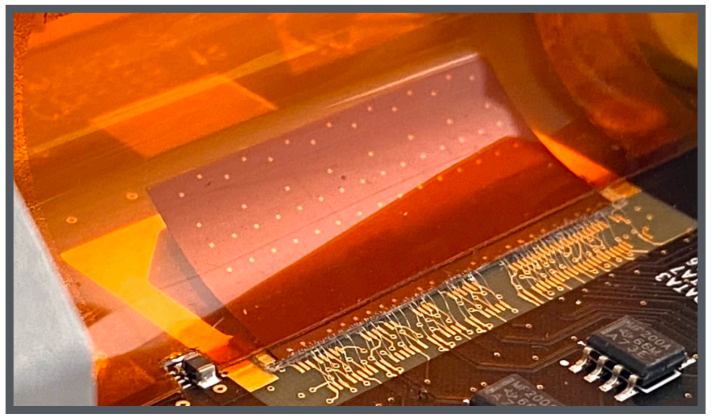


ITS3 R&D lines - Sensor performance

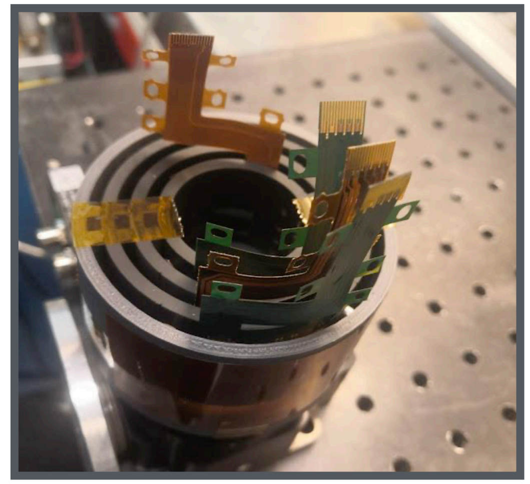


TEST BEAMS

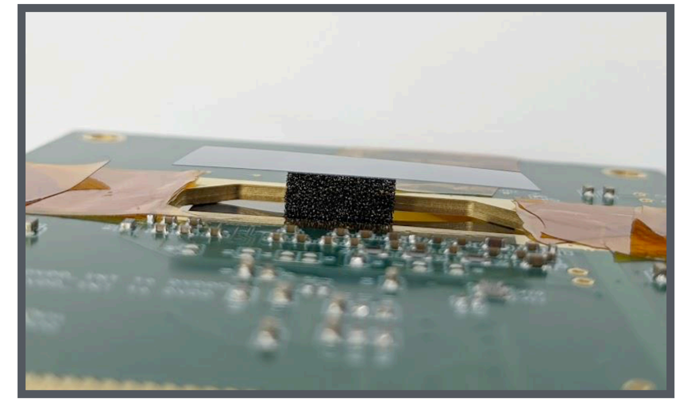
» Rich test beam campaign with different DUTs, in different configurations and carbon foam effect study



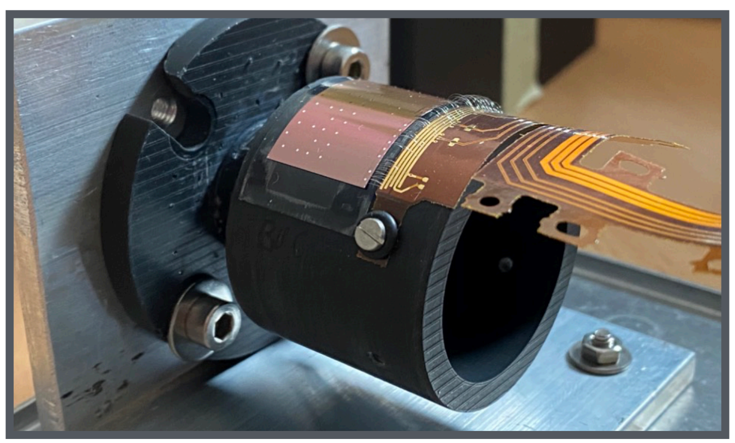
first bent ALPIDE on “standard carrier”



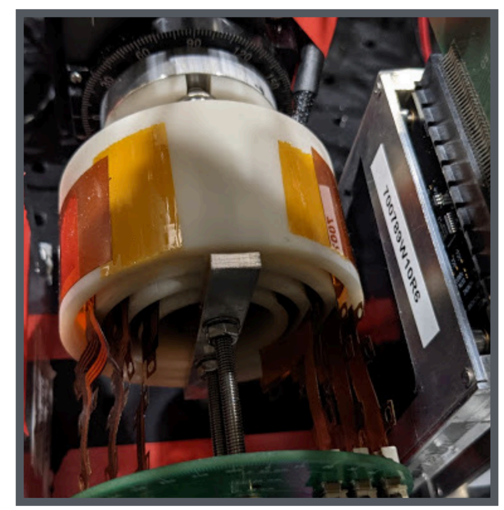
µITS3 with 4 ALPIDE
+ carbon foam



carbon foam



bent ALPIDE on cylindrical mount



µITS3 with 6 ALPIDE + target

Jun 2020 @DESY

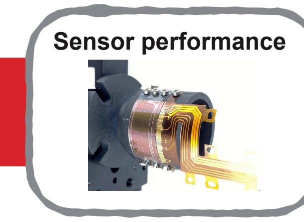
Aug/Dec 2020 @DESY

Jul 2021 @SPS

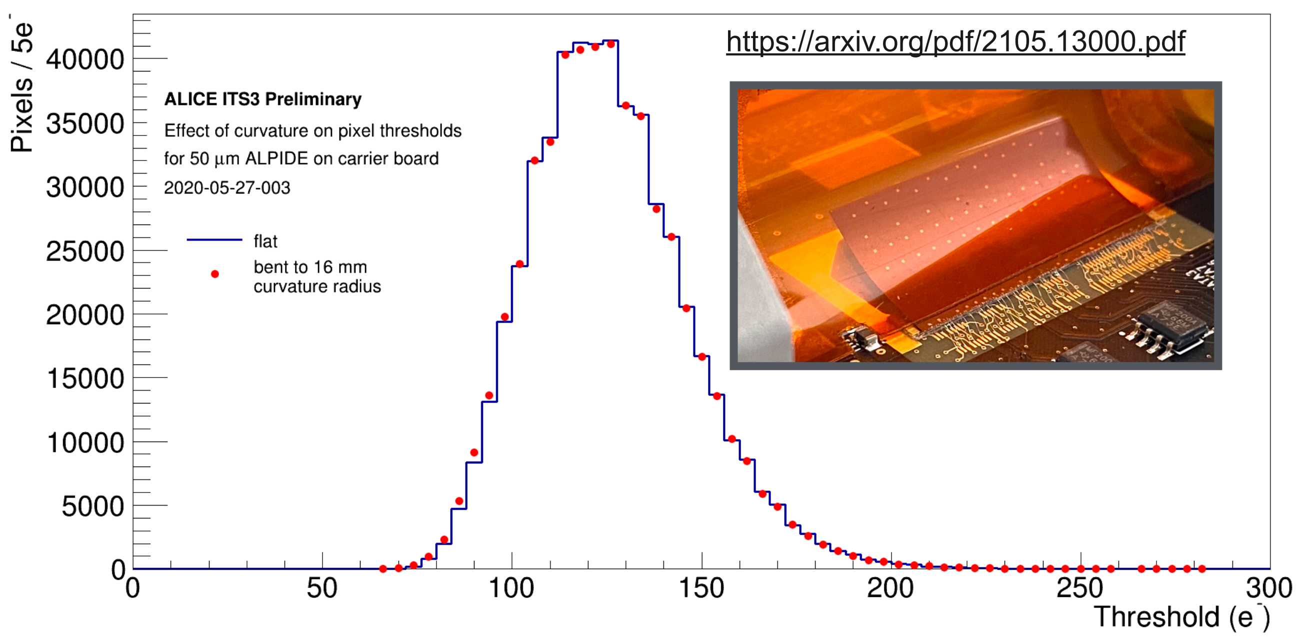
Apr 2021 @DESY

Sep 2021 @DESY

ITS3 R&D lines - Sensor performance

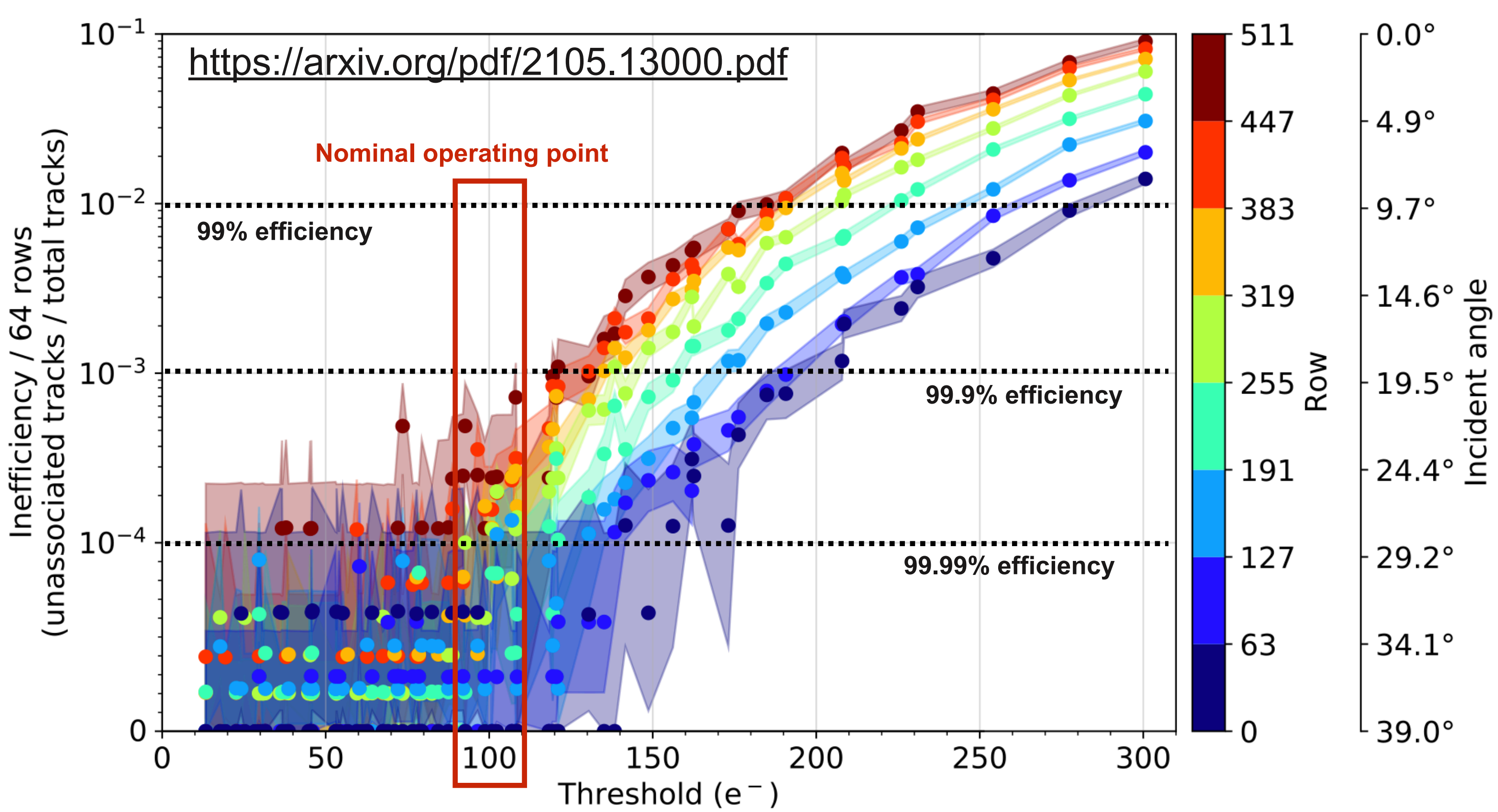


TEST BEAMS

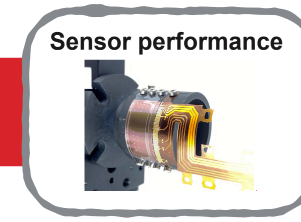


» Laboratory and test beam measurements (Jun 2020) allow to conclude that **chip performance doesn't change after bending**

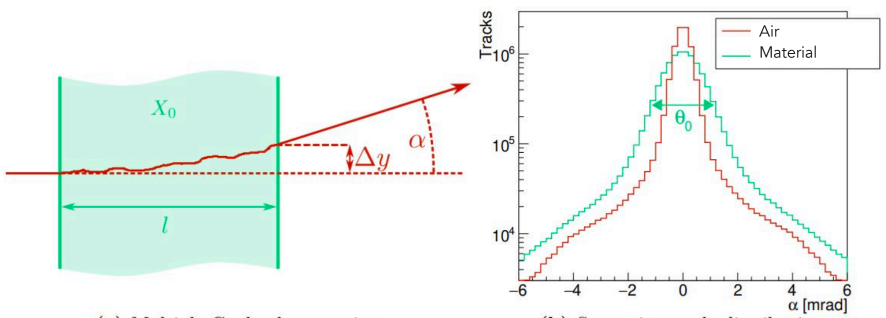
- Pixel matrix threshold distribution does not change when sensor is bent
- Efficiency above 99.9% at a threshold of 100 e⁻ (normal operating point)



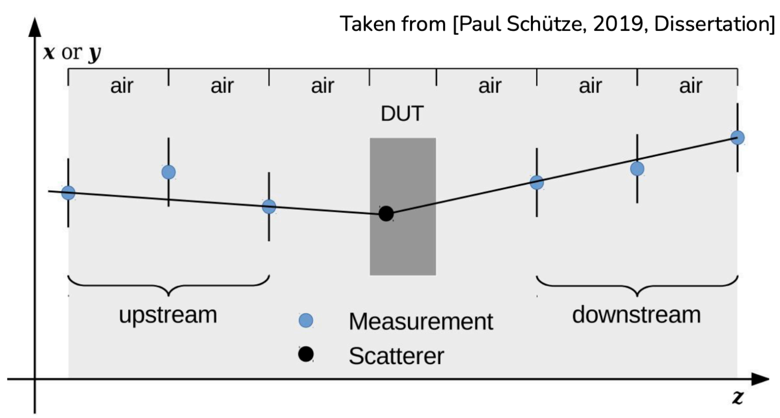
ITS3 R&D lines - Sensor performance

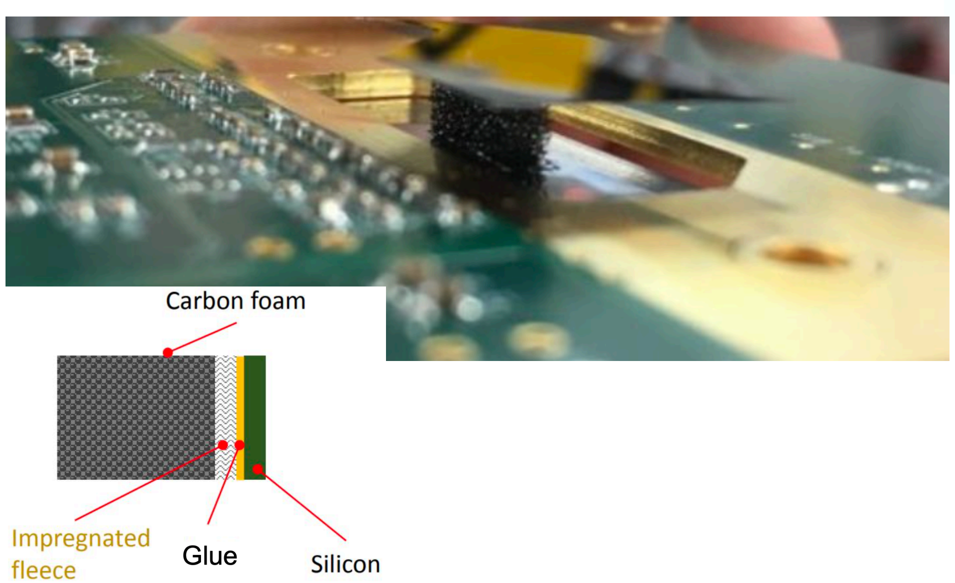


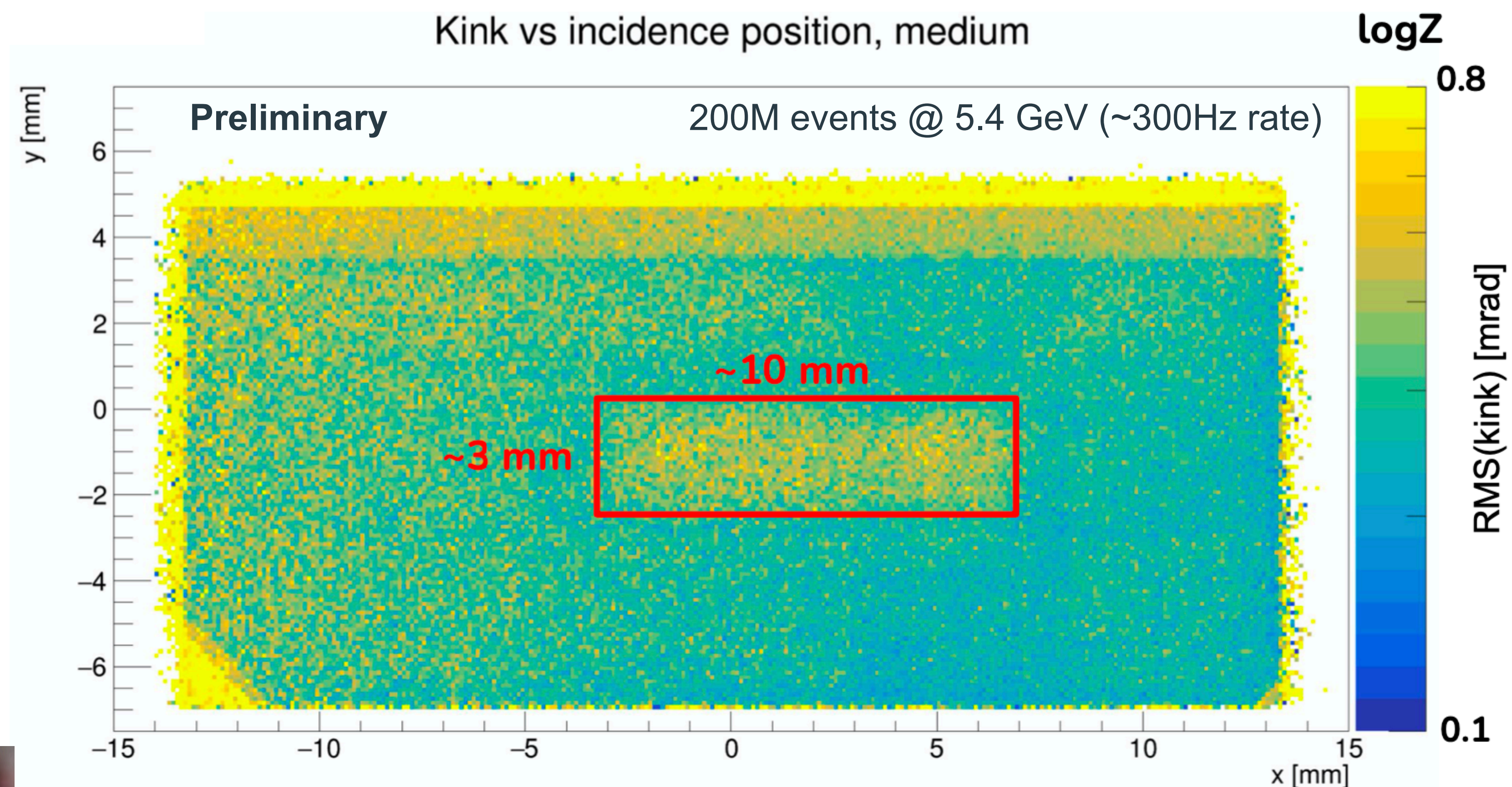
TEST BEAMS



(a) Multiple Coulomb scattering (b) Scattering angle distribution

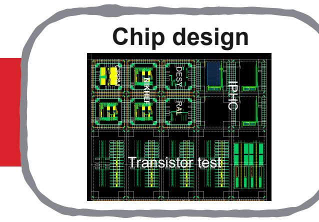






» Analysis of the kink angle distributions at the position of a scatterer
» Material budget image: represents the widths of the scattering angle distribution of all particles traversing a given bin

ITS3 R&D lines - Chip design

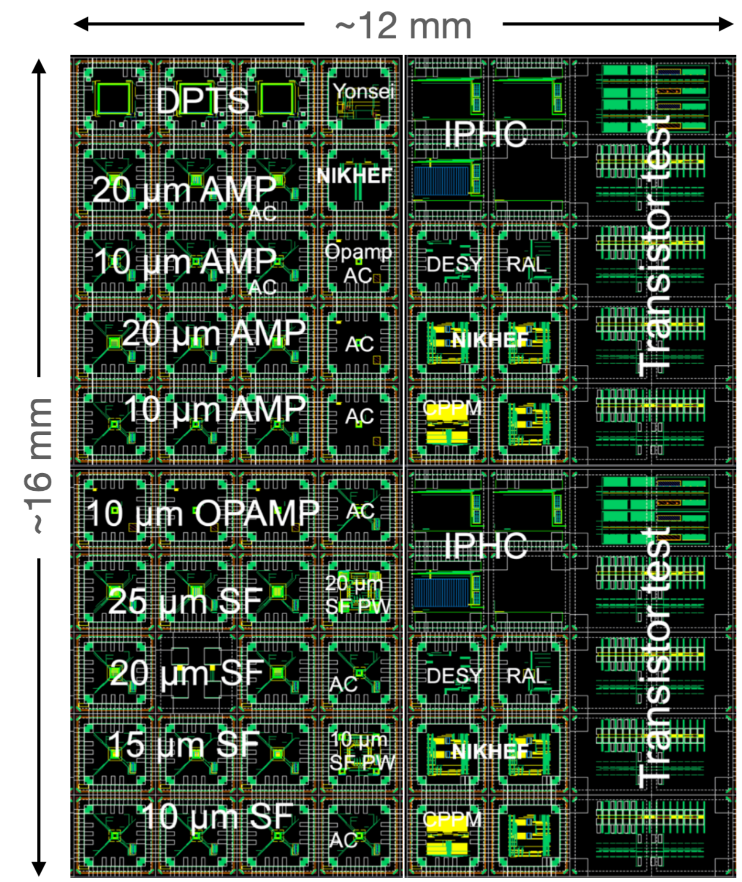


MLR1 SUBMISSION AND TEST + ER1

» MLR1 is the first submission in the TowerJazz 65 nm technology
- scoped within CERN EP R&D WP1.2, but significant drive from ITS3
- this technology will allow to build larger sensors (300 mm wafers)

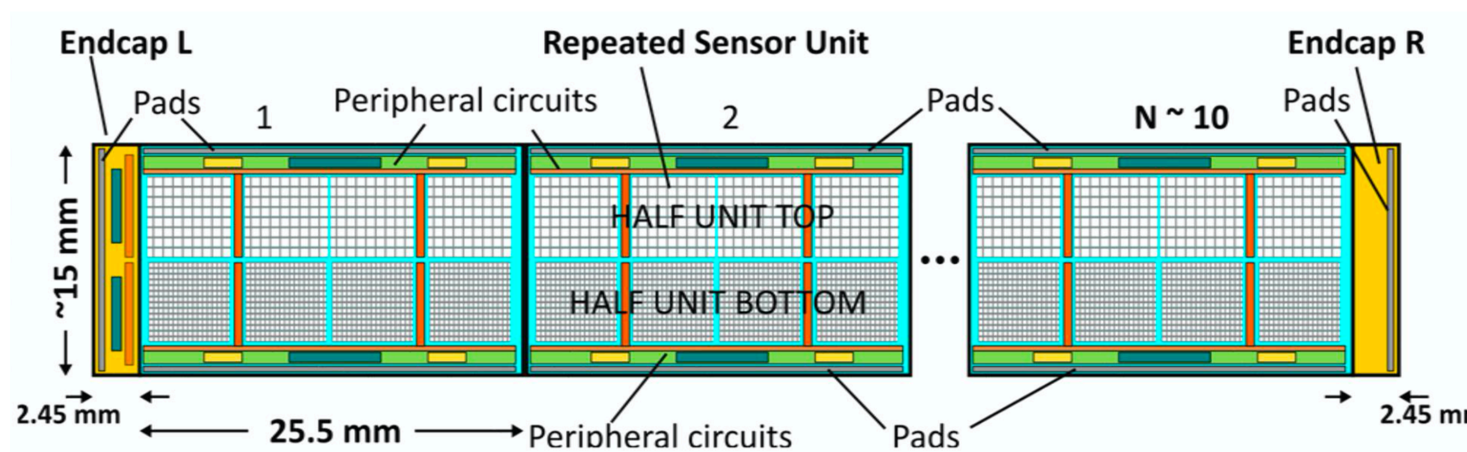
» More than just “first test structures”
- transistor test structures
- analog building blocks (band gaps, LVDS drivers, etc.)
- various diode matrices (small and large)
- digital test matrices
- ➡ Essentially covers the initial goals of MPW1 and MPW2

» First wafers received
- laboratory characterisation ongoing
- test beam campaign (PS, SPS and DESY) in Oct-Dec 2021
- characterisation of bent test structure



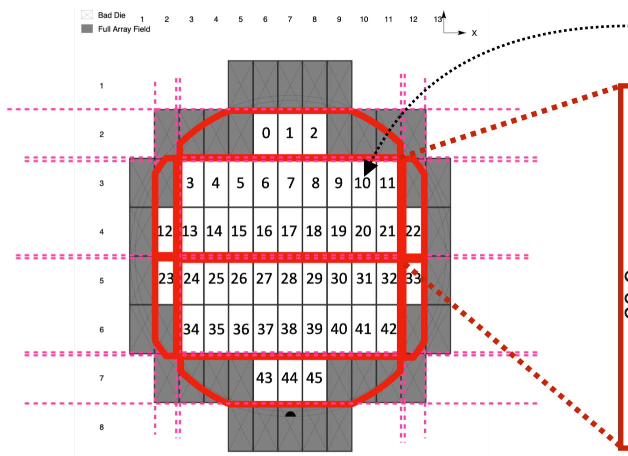
expect O(300) dies per wafer

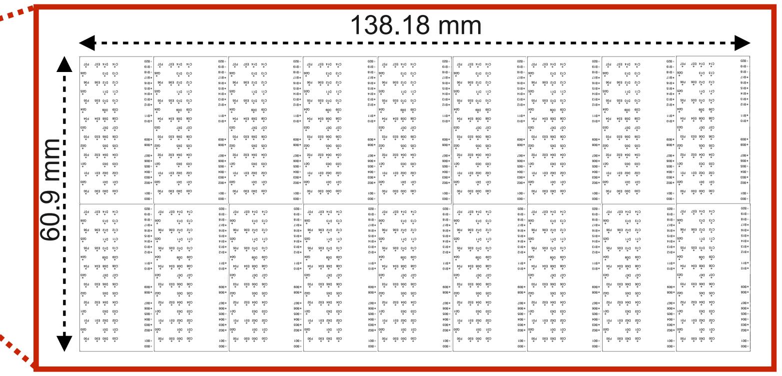
» ER1 Stitched Sensor prototype
- Key requirements and architectures defined (sensor, primary features, dimensions and floorpan, powering scheme, I/Os and global busses)
- Mock submission by end of November



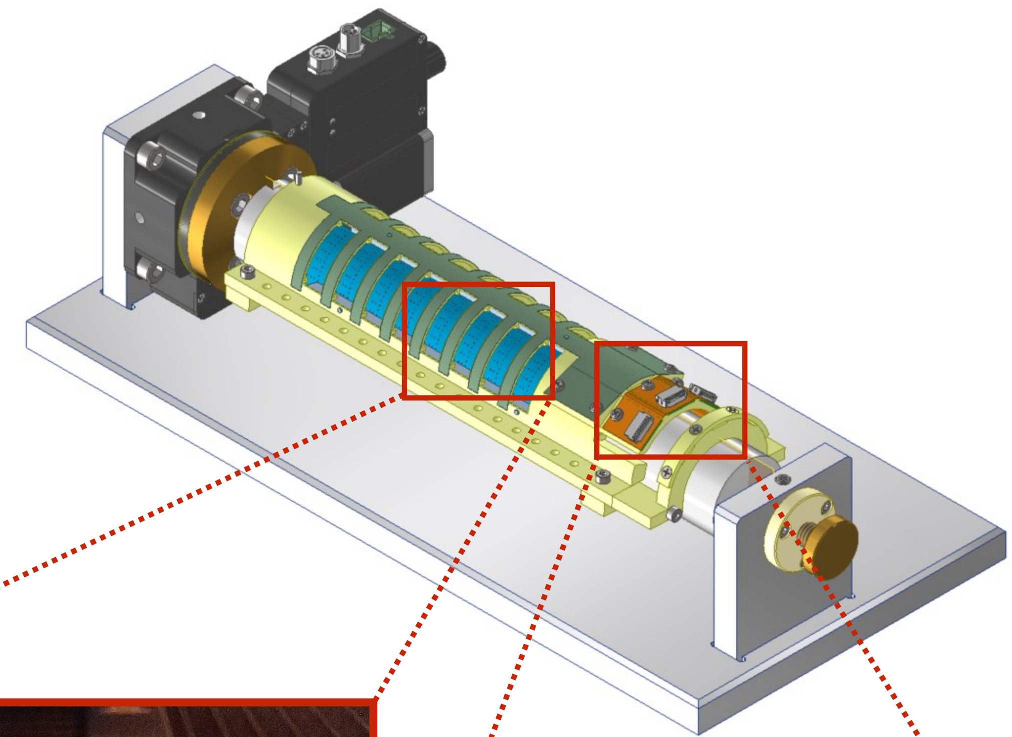
ITS3 R&D lines - Super ALPIDE

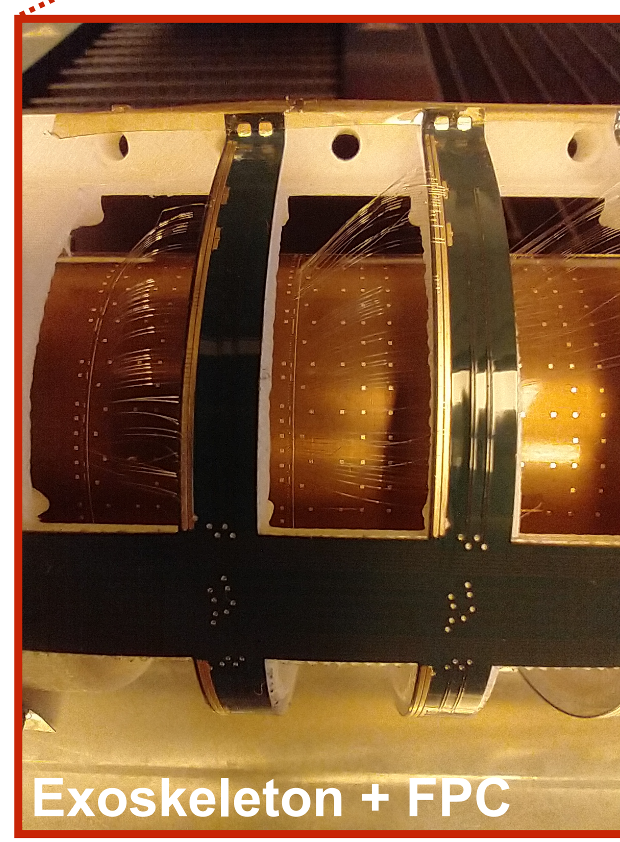
TOWARD FIRST WORKING LARGE DIMENSION SENSOR

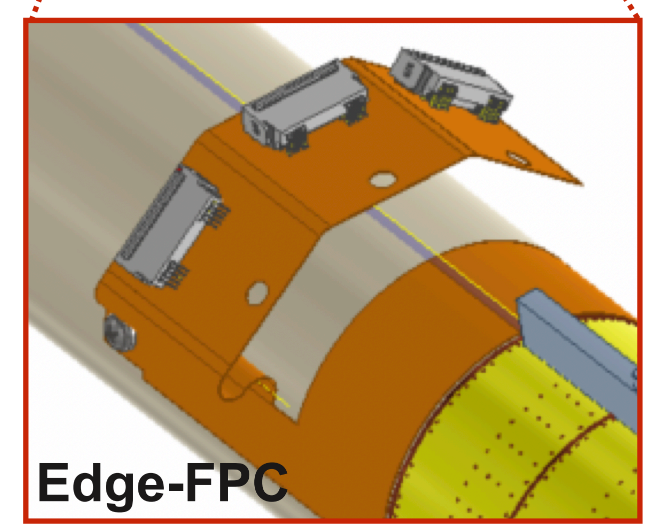




Super-ALPIDE: 18 not diced ALPIDE chips







» Super-ALPIDE
- 18 not diced ALPIDE chips
- dimensions close to the ones for L0 sensor

» Goals
- verify bending tools for large-size working chips
- verify mechanical support alignment tools
- develop wire-bonding over bent surface tools
- develop first bent flex prototype (for powering and data streaming)
- assemble first working large dimension bent sensor

SUMMARY

» ALICE proposes to build the next-generation inner tracking detector, based on **300 mm wafer-scale, 20-40 µm thin, bent MAPS**

» **R&D** is making rapid progress on all fronts
- successful **in-beam verification of bent MAPS**
- **full-size mechanical mockups**

» **First prototype chips** fabricated in **65 nm** are available for testing
- significant drive from the ITS3 community to push this technology

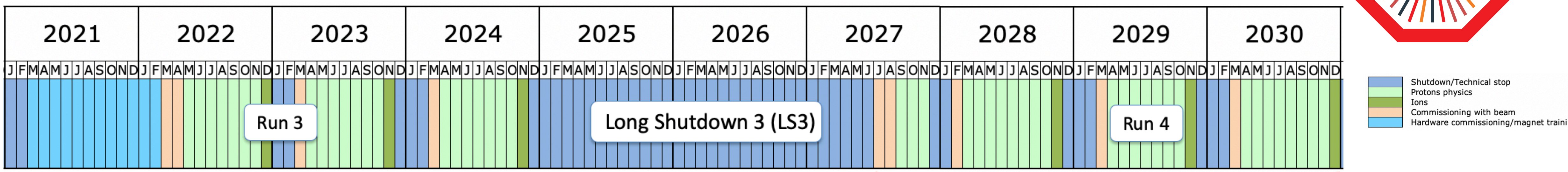
See also (at this conference):

"Testbeam performance results of bent ALPIDE MAPS in view of the ALICE Inner Tracking System 3"
Mihail Bogdan Blidaru
Poster
ITS3

"Efficiency measurements of the Outer Barrel of the ALICE Inner Tracking System using cosmic muons"
James Philip Iddon
Poster
ITS2

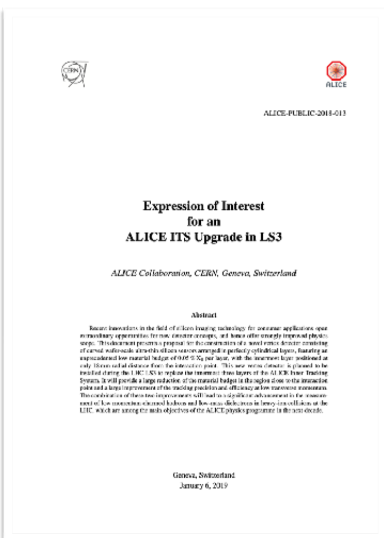
Backup

ALICE Inner Tracking upgrade roadmap



ALICE 2.1

Expression of Interest

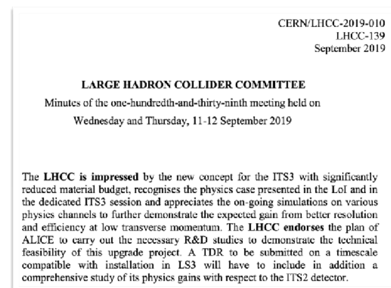


[ALICE-PUBLIC-2018-013]
https://cds.cern.ch/record/2644611

Letter of Intent

[CERN-LHCC-2019-018 ; LHCC-I-034]
https://cds.cern.ch/record/2703140/

LHCC 139 (Sep 2019)



CERN/LHCC-2019-010
LHCC-139
September 2019

LARGE HADRON COLLIDER COMMITTEE

Minutes of the one-hundredth-and-thirty-ninth meeting held on Wednesday and Thursday, 11-12 September 2019

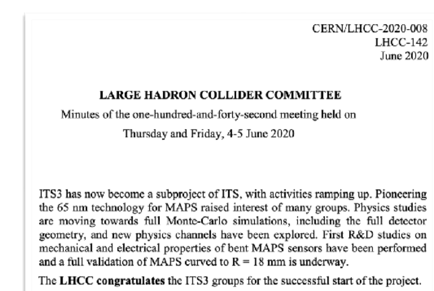
The **LHCC is impressed** by the new concept for the ITS3 with significantly reduced material budget, recognises the physics case presented in the LoI and in the dedicated ITS3 session and appreciates the on-going simulations on various physics channels to further demonstrate the expected gain from better resolution and efficiency at low transverse momentum. The **LHCC endorses** the plan of ALICE to carry out the necessary R&D studies to demonstrate the technical feasibility of this upgrade project. A TDR to be submitted on a timescale compatible with installation in LS3 will have to include in addition a comprehensive study of its physics gains with respect to the ITS2 detector.

"The LHCC is **impressed** by the new concept for the ITS3…"

Project setup (spring 2020)

- Project leaders
- Work packages conveners
- Institutes joining

LHCC 142 (Jun 2020)



CERN/LHCC-2020-008
LHCC-142
June 2020

LARGE HADRON COLLIDER COMMITTEE

Minutes of the one-hundred-and-forty-second meeting held on Thursday and Friday, 4-5 June 2020

ITS3 has now become a subproject of ITS, with activities ramping up. Pioneering the 65 nm technology for MAPS raised interest of many groups. Physics studies are moving towards full Monte-Carlo simulations, including the full detector geometry, and new physics channels have been explored. First R&D studies on mechanical and electrical properties of bent MAPS sensors have been performed and a full validation of MAPS curved to R = 18 mm is underway.

The **LHCC congratulates** the ITS3 groups for the successful start of the project.

"The LHCC **congratulates** the ITS3 groups for the successful start of the project."

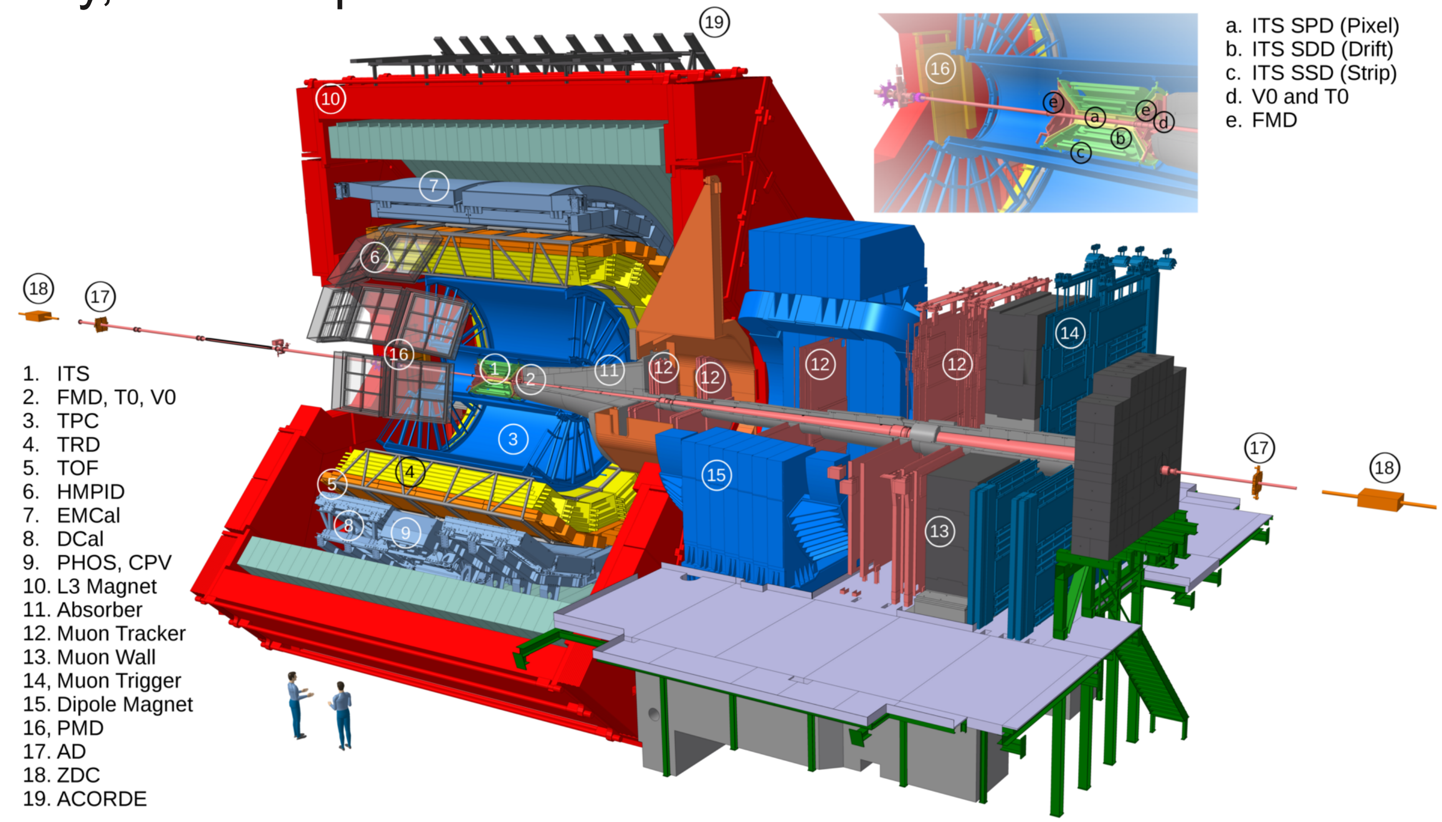
Oct 2018 — Sep 2019 — Sep 2019 — Dec 2019 — Spring 2020 — Jun 2020

Backup

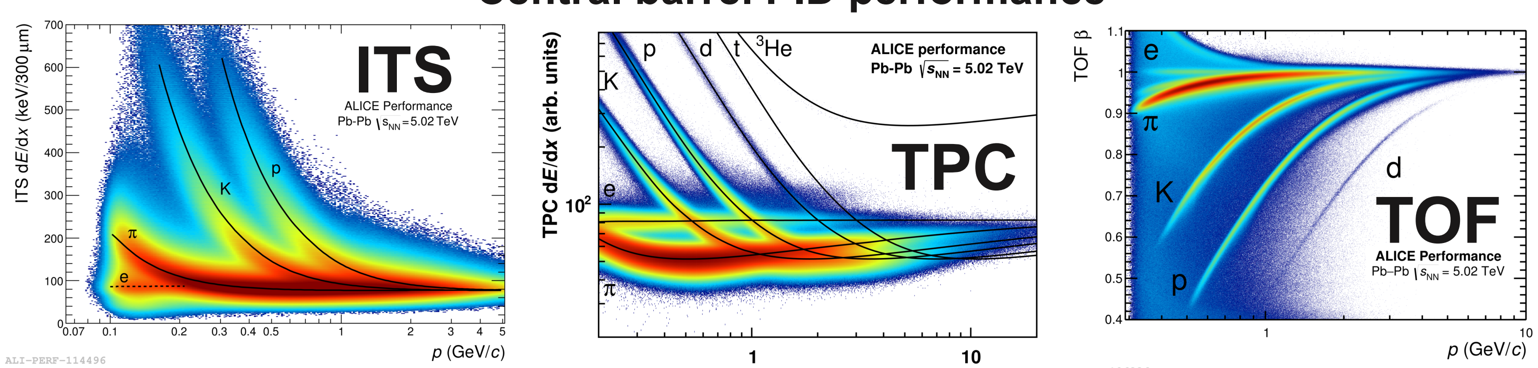
» Central barrel ($-0.9 < \eta < 0.9$)
» Muon spectrometer ($-4.0 < \eta < -2.5$)
» Forward detectors: trigger, centrality, luminosity, reaction plane

» Tracking and PID per large kinematic range
» High resolution vertex reconstruction

LHC Run 1 and Run 2 data taking		
Colliding System	**Year(s)**	**$\sqrt{s_{NN}}$ (TeV)**
Pb-Pb	2010-2011 2015-2018	2.76 5.02
Xe-Xe	2017	5,44
p-Pb	2013 2016	5.02 5.02, 8.16
pp	2009-2013 2015, 2017 2015-2018	0.9, 2.76, 7, 8 5.02 13

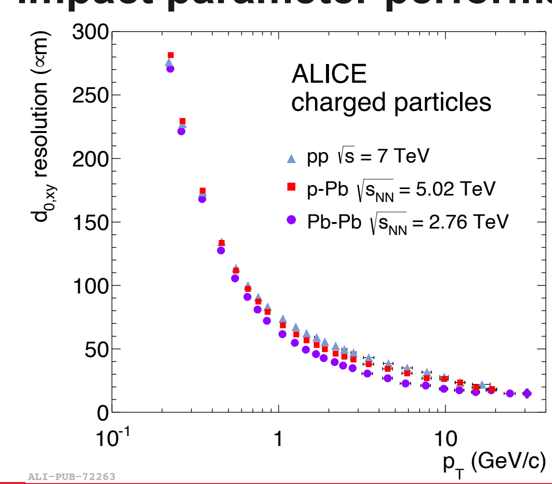


Central barrel PID performance

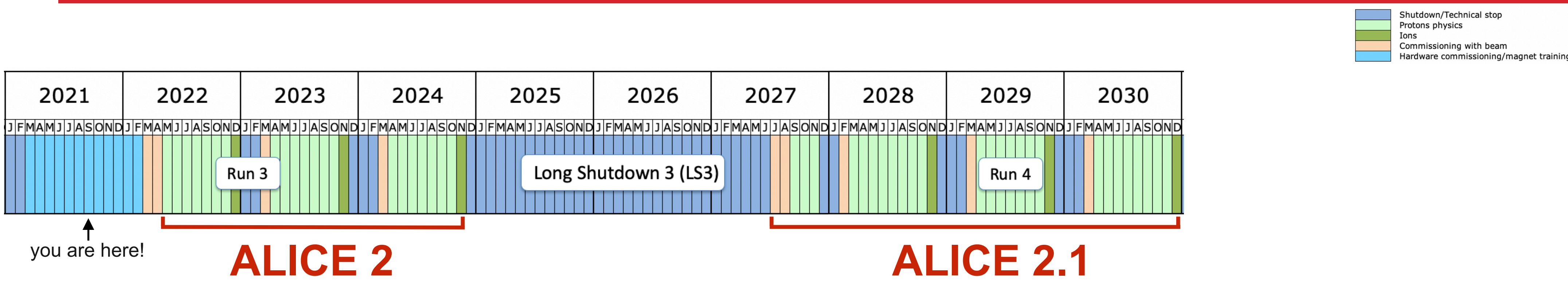


ITS $\sigma_{dE/dx}$ ~ 10-15%   TPC $\sigma_{dE/dx}$ ~ 5%   TOF $\sigma_{Time\ Of\ Flight}$ ~ 56 ps

ITS impact parameter performance



Backup



Data taking strategy

» **Record large minimum-bias data sample**

→ read out all Pb-Pb interactions up to maximum LHC collision rate of 50 kHz (was ~1 kHz in the central barrel)

→ increase Pb-Pb Run 2 minimum-bias sample by factor 50-100

Colliding System	Integrated luminosity	Comment
Pb-Pb @ $\sqrt{s_{NN}}$ = 5 - 5.5 TeV	13 nb^{-1}	Plus pp reference data
p-Pb @ $\sqrt{s_{NN}}$ = 8 - 8.8 TeV	0.6 pb^{-1}	Plus pp reference data
pp @ $\sqrt{s}$ = 14 TeV	200 pb^{-1}	Focus on high multiplicity and rare signals

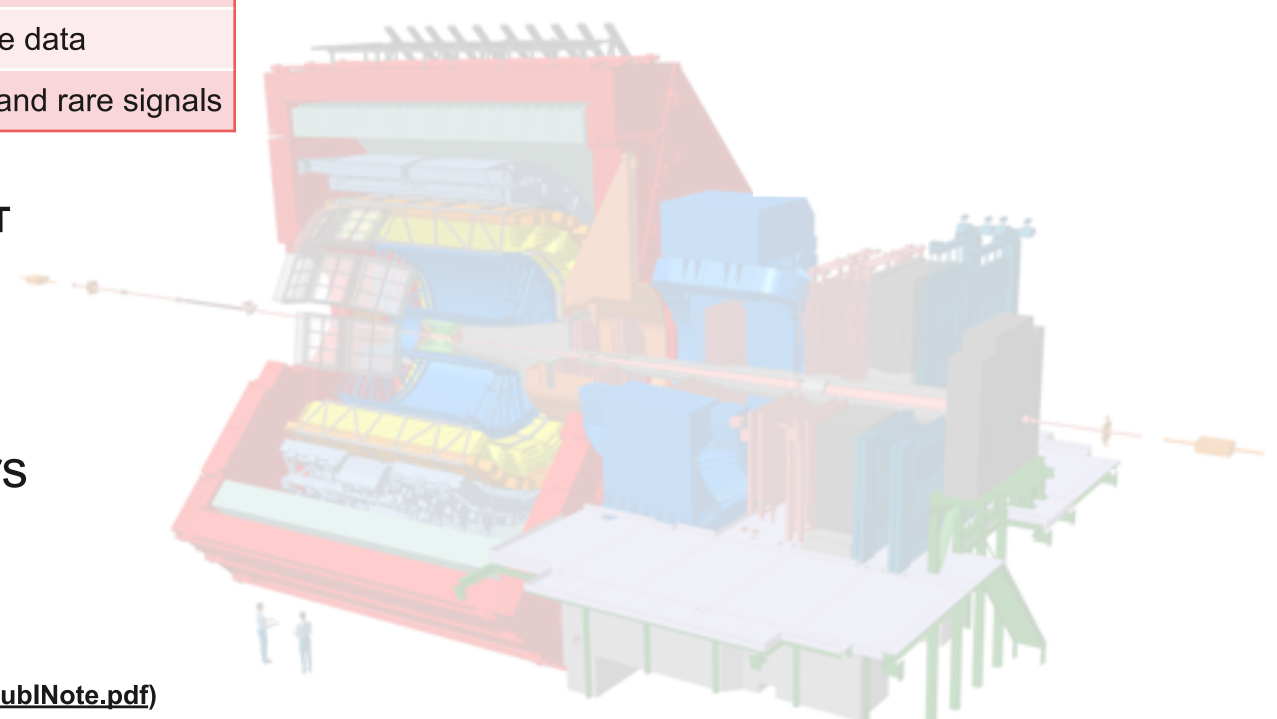
» **Improve tracking efficiency and resolution at low-p_T**

→ increase tracking granularity

→ reduce material thickness

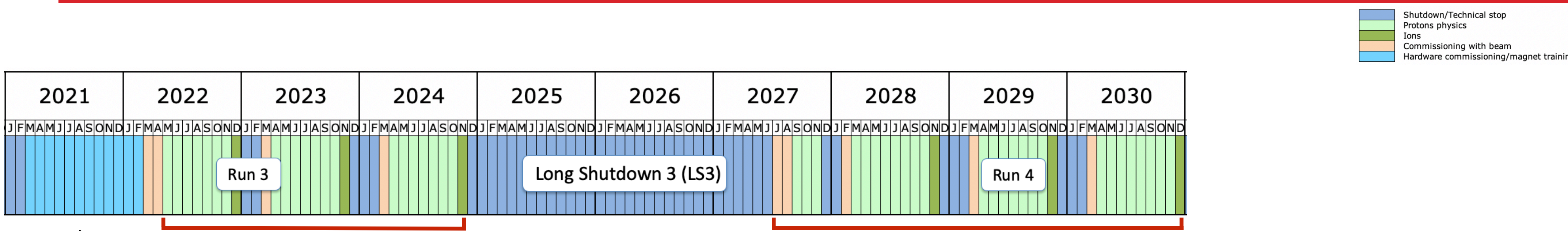
» **Preserve Particle IDentification (PID)**

→ consolidate and speed-up main ALICE PID detectors



Programme is presented in CERN Yellow Report (https://arxiv.org/abs/1812.06772)
Future high-energy pp programme with ALICE (https://cds.cern.ch/record/2724925/files/ALICE_HEpp_PublNote.pdf)
LHC schedule

Backup

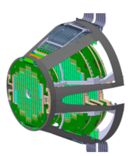


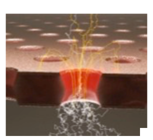
ALICE 2

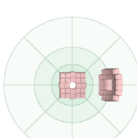
ALICE 2.1

LS 2 upgrades for Run 3

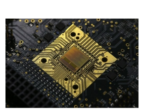

New Inner Tracking System (ITS 2)

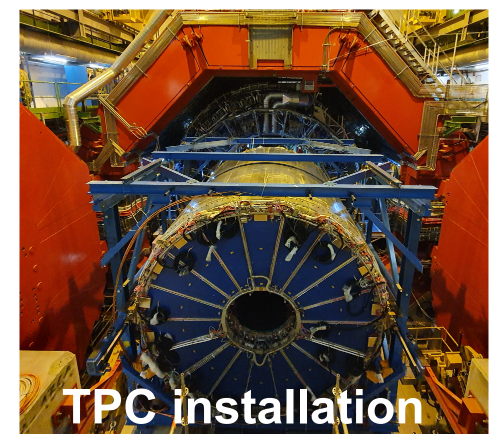

New Muon Forward Tracker (MFT)

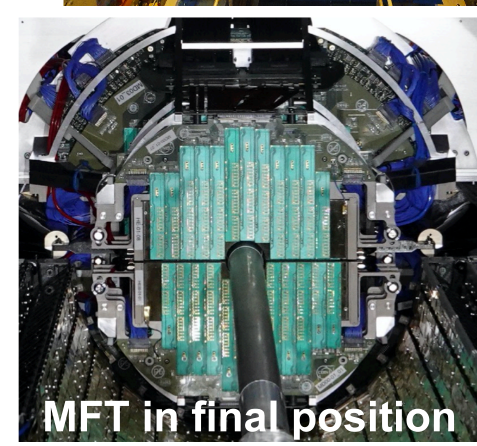

New TPC Readout Chambers (ROCs)

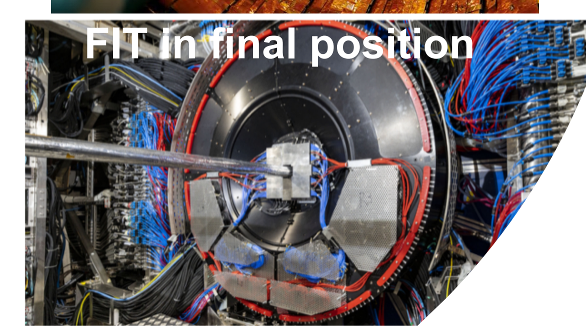

New Fast Interaction Trigger (FIT) detector

Integrated Online-Offline system (O^2)


Readout upgrade for other detectors







Installation completed
Commissioning ongoing

Backup

New Inner Tracking System (ITS 2)

<u>Based on the ALPIDE Monolithic Active Pixel Sensor</u>

» In-pixel amplification, shaping discrimination and Multiple-Event Buffers (MEB)

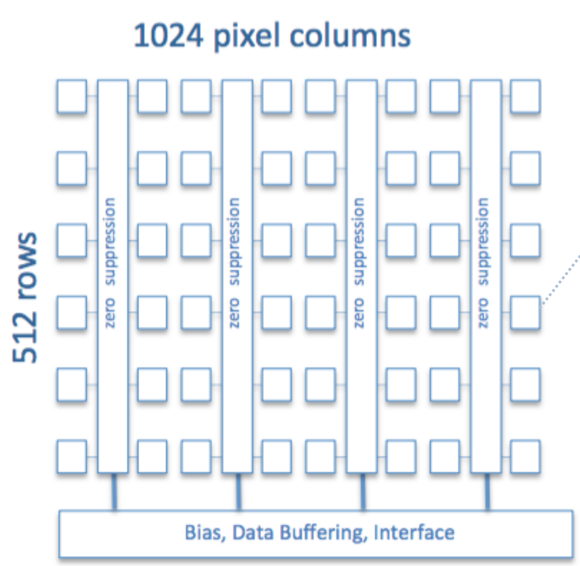
» In-matrix data sparsification

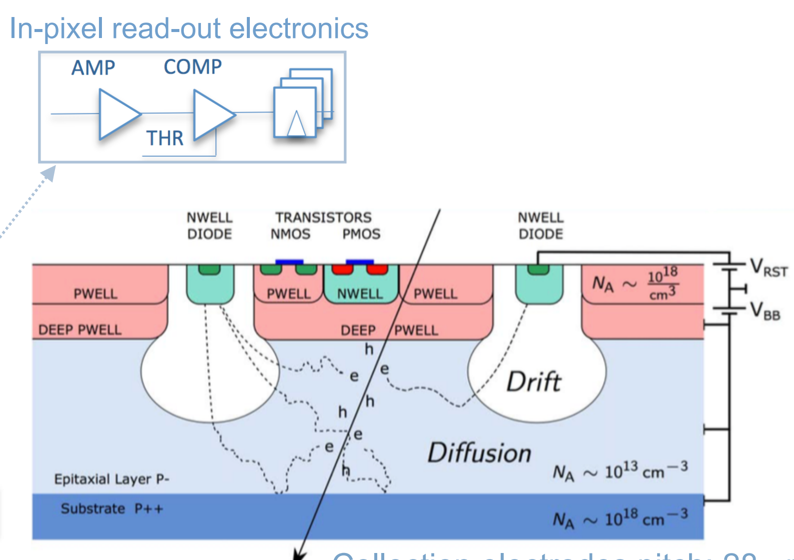
» High detection efficiency (>99%) and low fake-hit rate ($\ll 10^{-6}$ /pixel/event)

» Radiation tolerant:
  > 270 krad TID
  > 1.7×10^{12} 1 MeV/n_{eq} NIEL

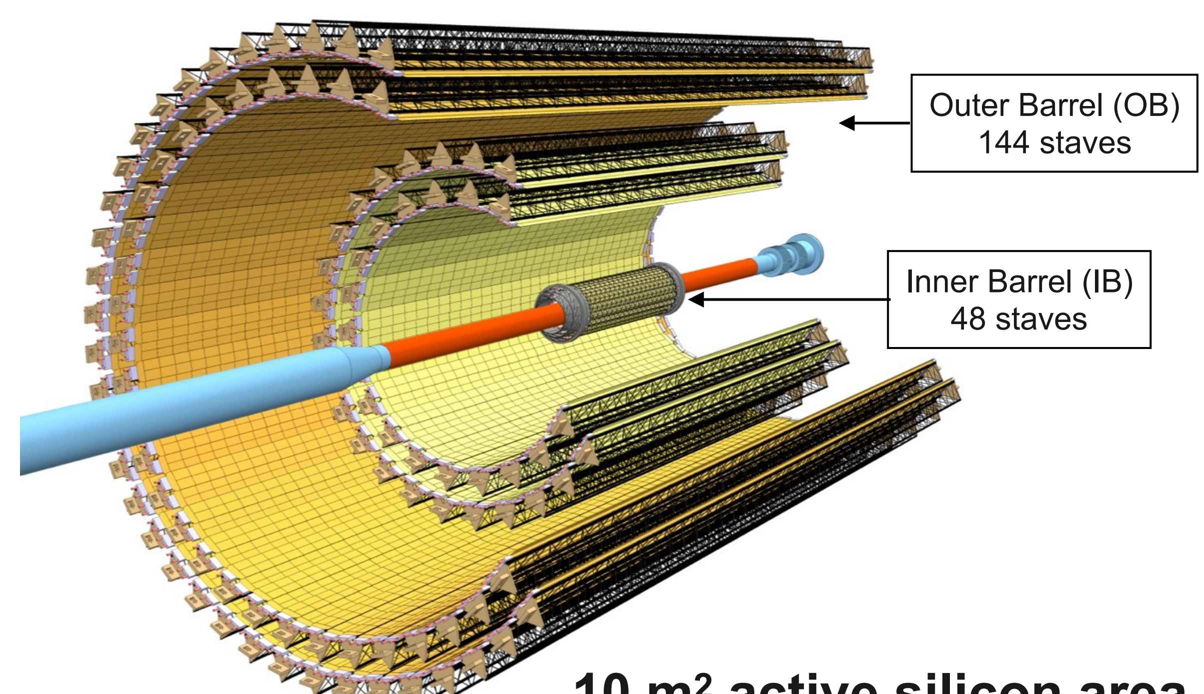
» Low power consumption ~40 mW/cm^2

	ITS (Run 1/Run 2)	ITS 2
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% (IB)
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





Collection electrodes pitch: 28 μm
Input capacitance Cin = 5 fF
Input charge Q_{in}(MIP) = 1300 e$^-$ → V = 40 mV



10 m^2 active silicon area
12.5×10^9 pixels

Backup

New Inner Tracking System (ITS 2)

Detector Construction and Assembly
- » ~72000 chips → ~2600 Hybrid Integrated Circuits (HIC) → ~280 Staves (chip yield ~ 65%, HIC yield ~ 85%, Stave yield ~ 95%)
- » >10 production sites in Asia, Europe and Unites States of America
- » Stave integration completed in January 2020

Jan '20

On-surface commissioning with final services ongoing until December 2020

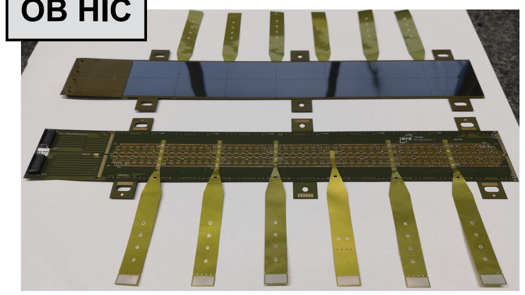
Dec '20

Installation in ALICE cavern

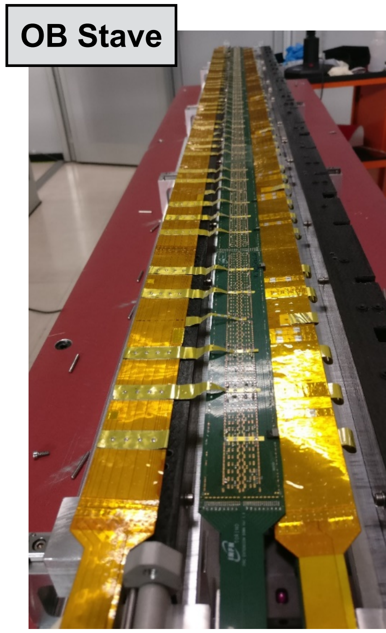
Mar '21

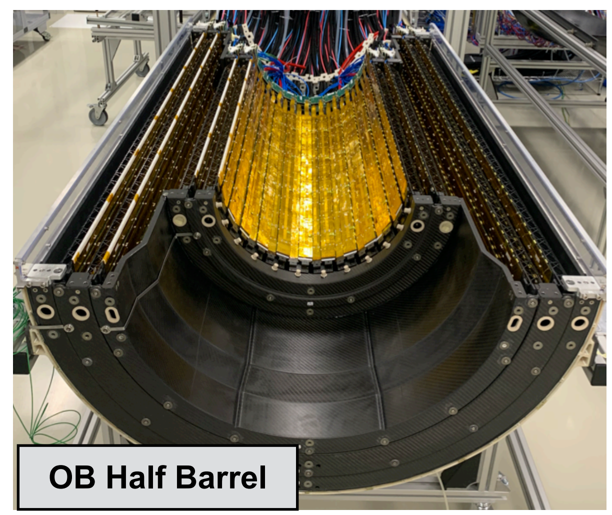
Global commissioning in ALICE

OB HIC

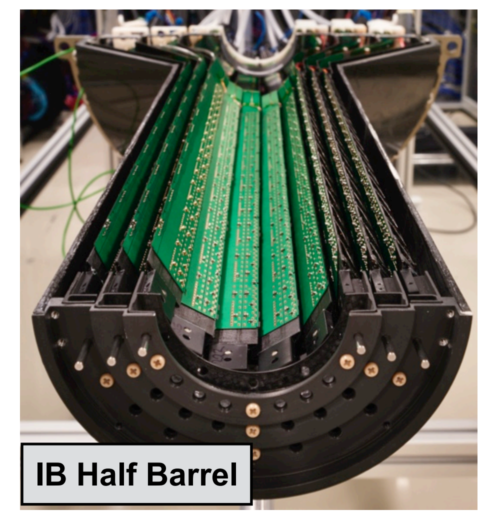


OB Stave



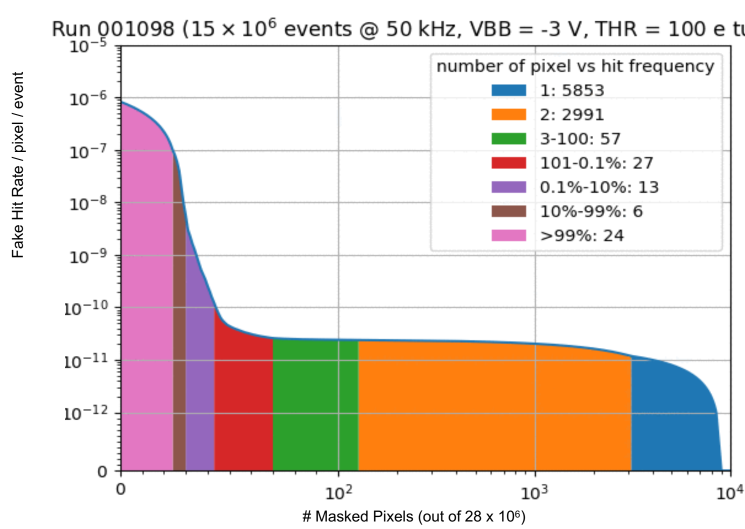


OB Half Barrel

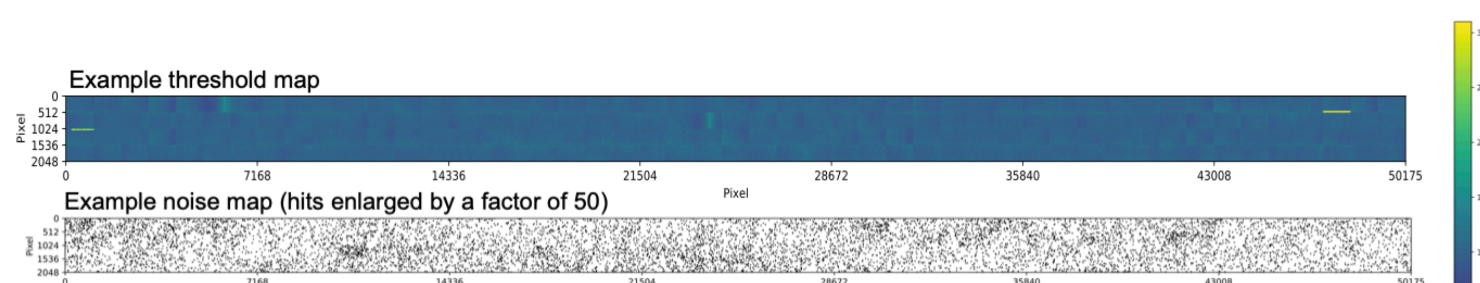


IB Half Barrel

Performance



Inner Barrel (IB)

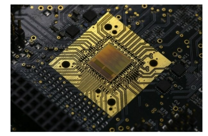


Fake-hit rate < 10^{-9} /pixel/event masking less than 200 pixel/chip (average ~50 pixel/chip)
Threshold tuning to 100 e^- working to 2 e^- precision (on-chip spread: 20 e^-)

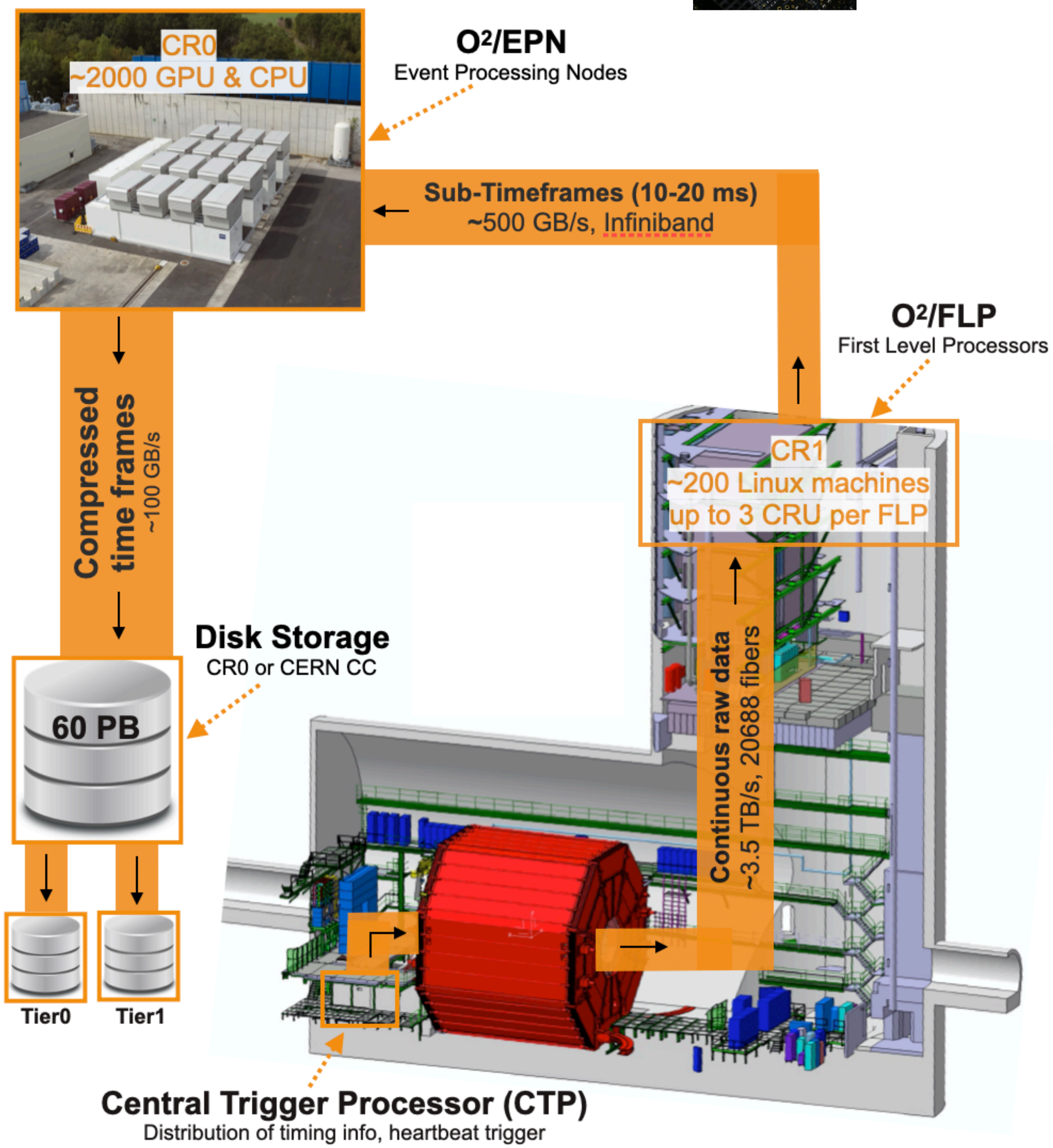
Outer Barrel (OB)

Backup

Integrated Online-Offline system (O²)



Readout upgrade for other detectors

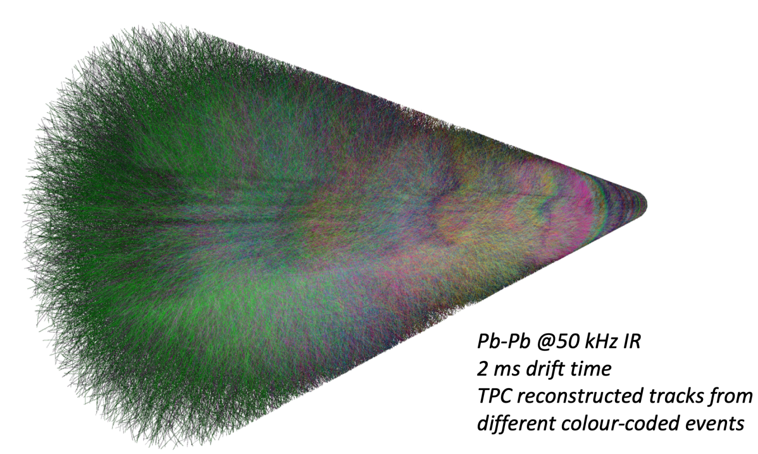


» **Continuous readout**
- Upgrade of all detector readout boards
- Heartbeat from CTP
- Timeframe (instead of events)

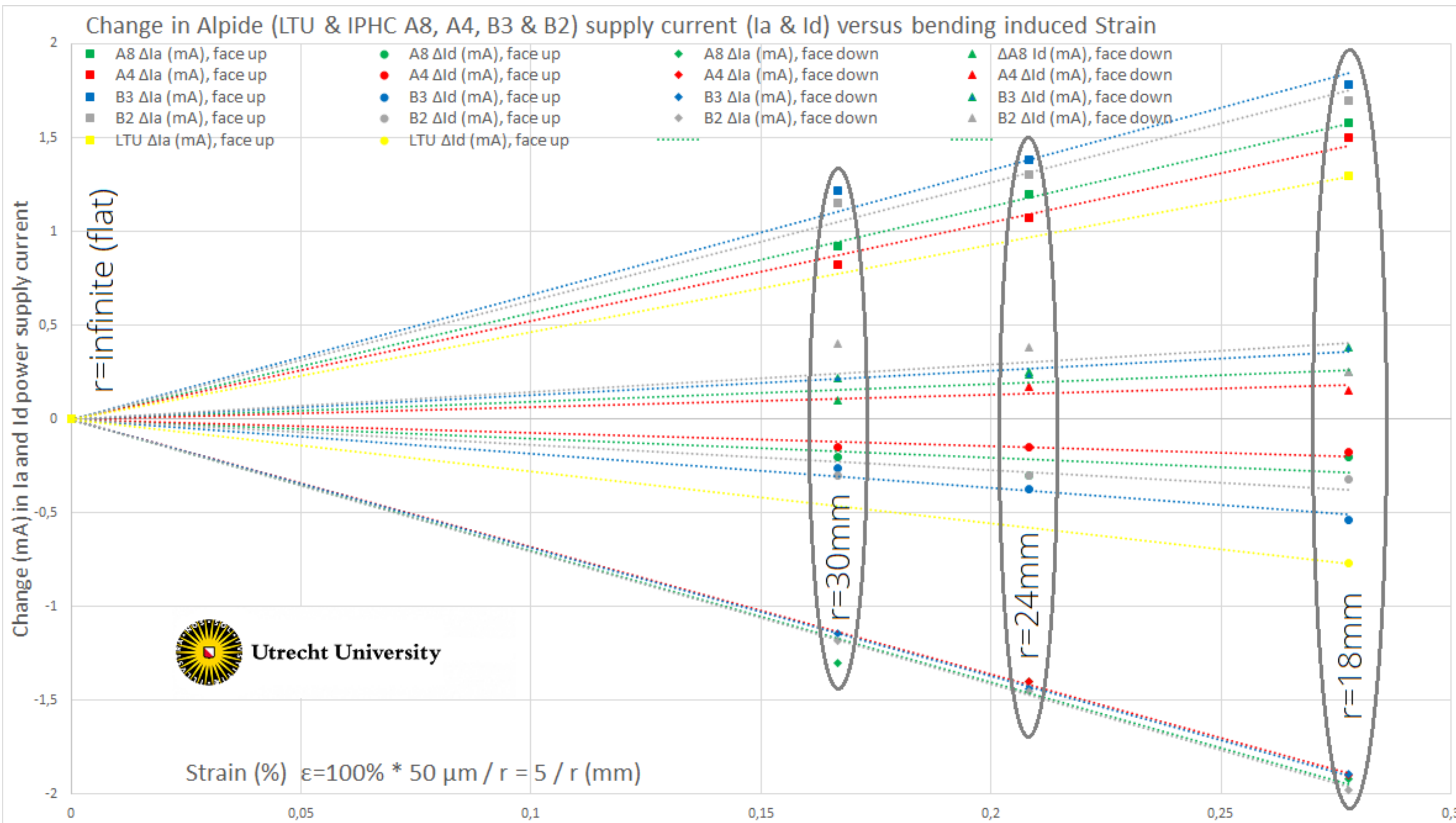
» **Multi-step reconstruction chain**
- Detector → FLP → EPN → Storage

» **Synchronous processing (EPN farm)**
- Data volume reduction (factor 35)
- Online calibration
- Clusterization and tracking (using GPUs)
  → Compressed Time Frames (CTF)

» **Asynchronous processing (EPN farm/T0/T1)**
- Final refined reconstruction
  → Analysis Object Data (AOD)



Backup


Change in Alpide (LTU & IPHC A8, A4, B3 & B2) supply current (Ia & Id) versus bending induced Strain
A8 ΔIa (mA), face up
A4 ΔIa (mA), face up
B3 ΔIa (mA), face up
B2 ΔIa (mA), face up
LTU ΔIa (mA), face up
A8 ΔId (mA), face up
A4 ΔId (mA), face up
B3 ΔId (mA), face up
B2 ΔId (mA), face up
LTU ΔId (mA), face up
A8 ΔIa (mA), face down
A4 ΔIa (mA), face down
B3 ΔIa (mA), face down
B2 ΔIa (mA), face down
ΔA8 Id (mA), face down
A4 ΔId (mA), face down
B3 ΔId (mA), face down
B2 ΔId (mA), face down
r=infinite (flat)
r=30mm
r=24mm
r=18mm
Utrecht University
Change (mA) in Ia and Id power supply current
Strain (%) ε=100% * 50 µm / r = 5 / r (mm)
2
1,5
1
0,5
0
-0,5
-1
-1,5
-2
0
0,05
0,1
0,15
0,2
0,25
0,3