Nuclear Physics Mid Term Plan in Italy

LNF session, 1-2 December 2022

Silicon detectors for high energy experiments

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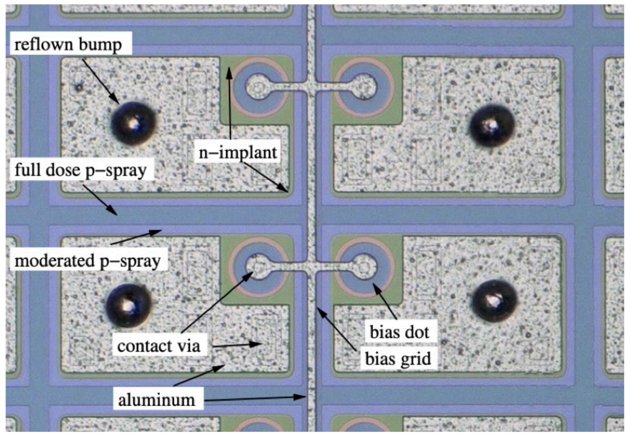
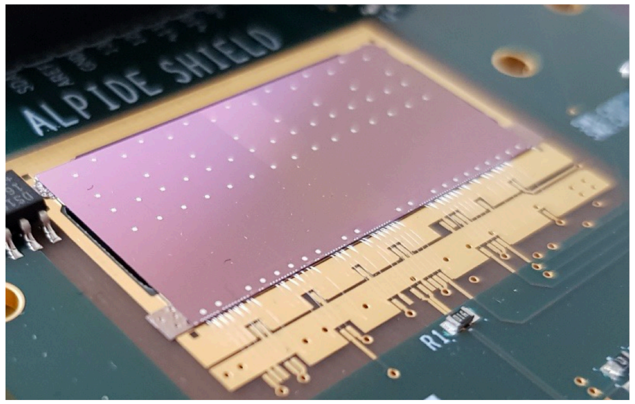
Contents

- **Silicon sensors for tracking/vertexing detectors**
  - ➡ hybrid vs monolithic technologies
  - ➡ planar vs 3D internal structure
  - ➡ large dimensions
  - ➡ timing information
- **Detector integration**
  - ➡ truly cylindrical detector

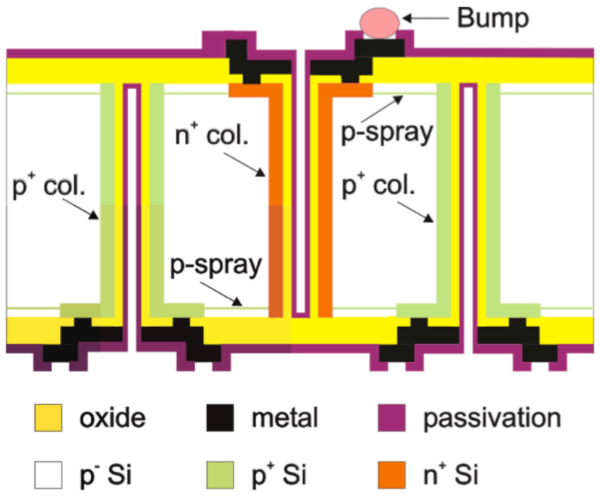
Silicon sensors for tracking/vertexing detectors



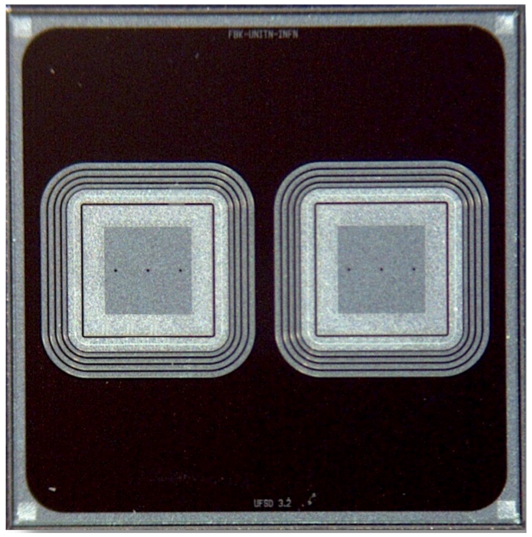
CMS Pixel sensor



ALPIDE MAPS



ATLAS FBK 3D sensor


35 µm FBK LGAD

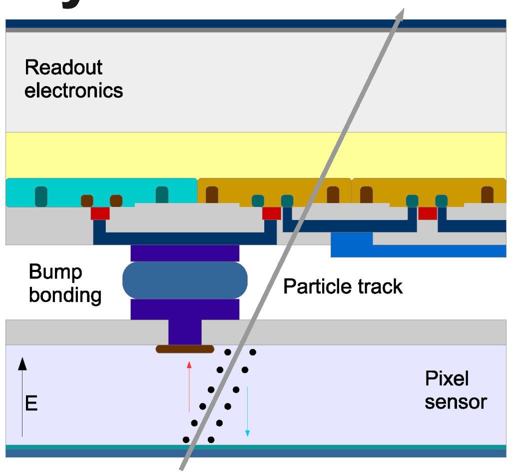
Silicon sensors for tracking/vertexing detectors

Hybrid vs Monolithic sensors

Characteristics of a sensor for tracking/vertexing

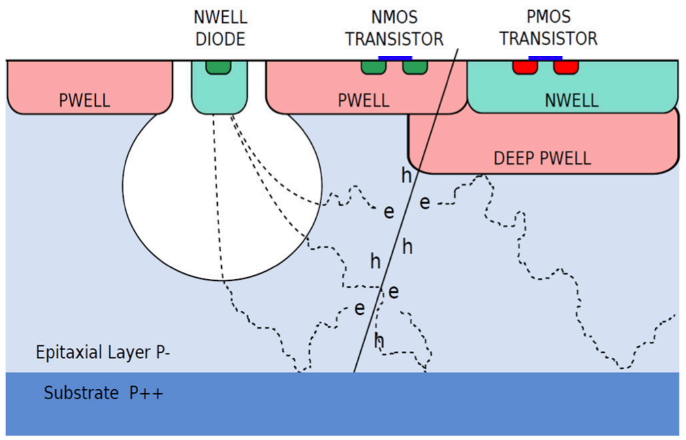
- High space point resolution (~10 μm)
- High detection efficiency (~100%) and low fake-hit rate
- Low material budget (< 0.1%)
- Low power density (→ material budget) } ⇅
- Time resolution
- Radiation hardness (HL-LHC ~2×10^{16} 1 MeV n_{eq}/cm^2)

Hybrid sensor



- **pro** - optimisation of readout and electronics
- **pro** - large signal
- **cons** - large material budget
- **cons** - large power consumption

Monolithic sensor

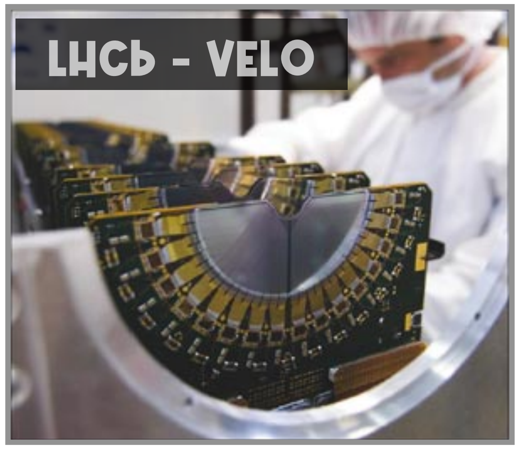


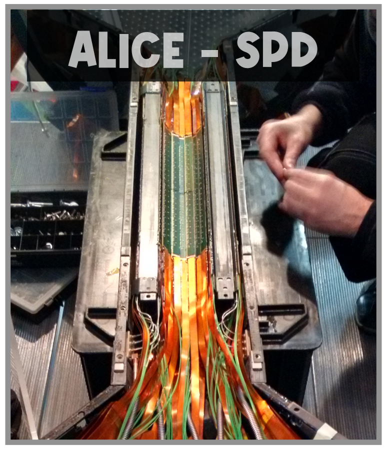
- **pro** - standard CMOS readout integration
- **pro** - low material budget
- **pro** - low power consumption
- **pro** - low noise
- **cons** - small signal
- **cons** - limited radiation tolerant
- **cons** - slow (charge collection by diffusion)

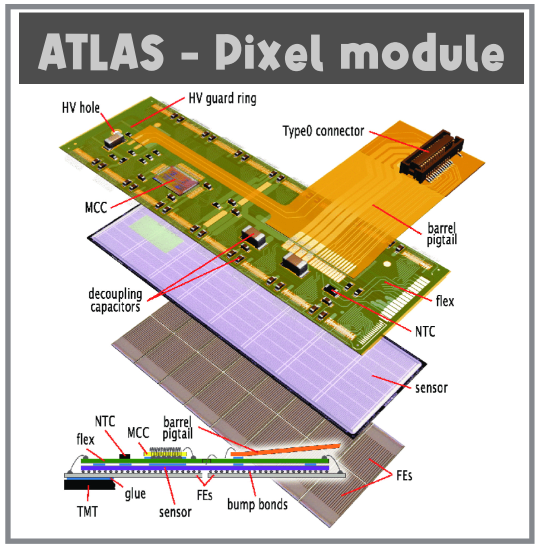
Silicon sensors for tracking/vertexing detectors

Hybrid sensor

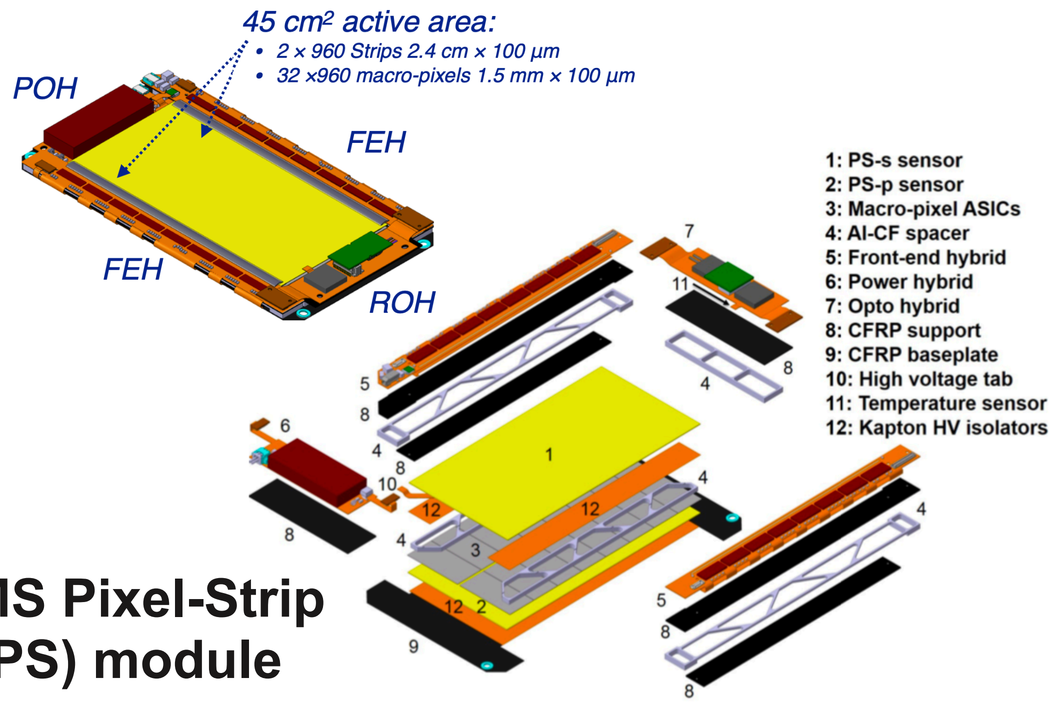
» State of the art for all LHC detectors during Run1 and Run2







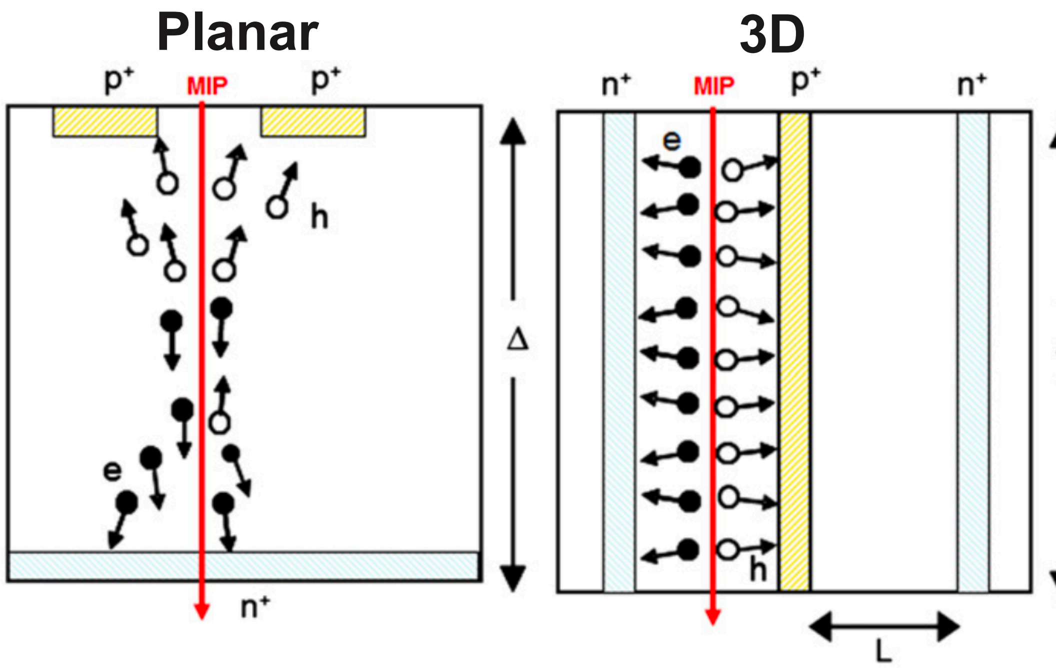
» Future upgrades:
CMS Phase II OT



CMS Pixel-Strip (PS) module

Silicon sensors for tracking/vertexing detectors

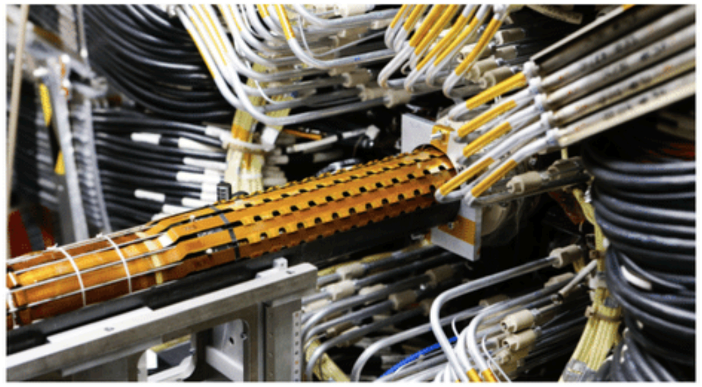
3D sensors to improve radiation hardness

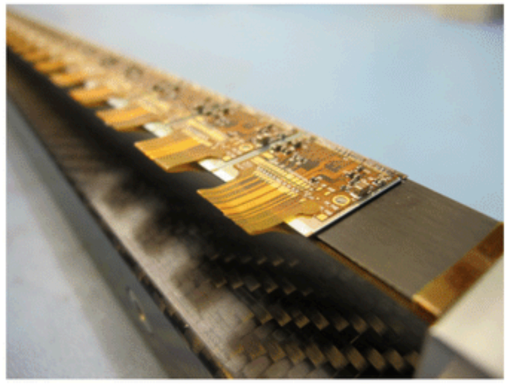


J NIMA 395 (1997) 328–343
J NIMA 694 (2012) 321–330

» 3D sensors: depletion region grows laterally between the electrodes, whose distance is much smaller than the substrate thickness → depletion voltage dramatically reduced with respect to planar sensors

ATLAS Insertable B-Layer (IBL)





CERN-LHCC-2010-0013

» First 3D sensor application in ATLAS innermost layer (2014)

- >200 V needed to fully deplete the sensor, while 1000 V for a 200 µm thick planar

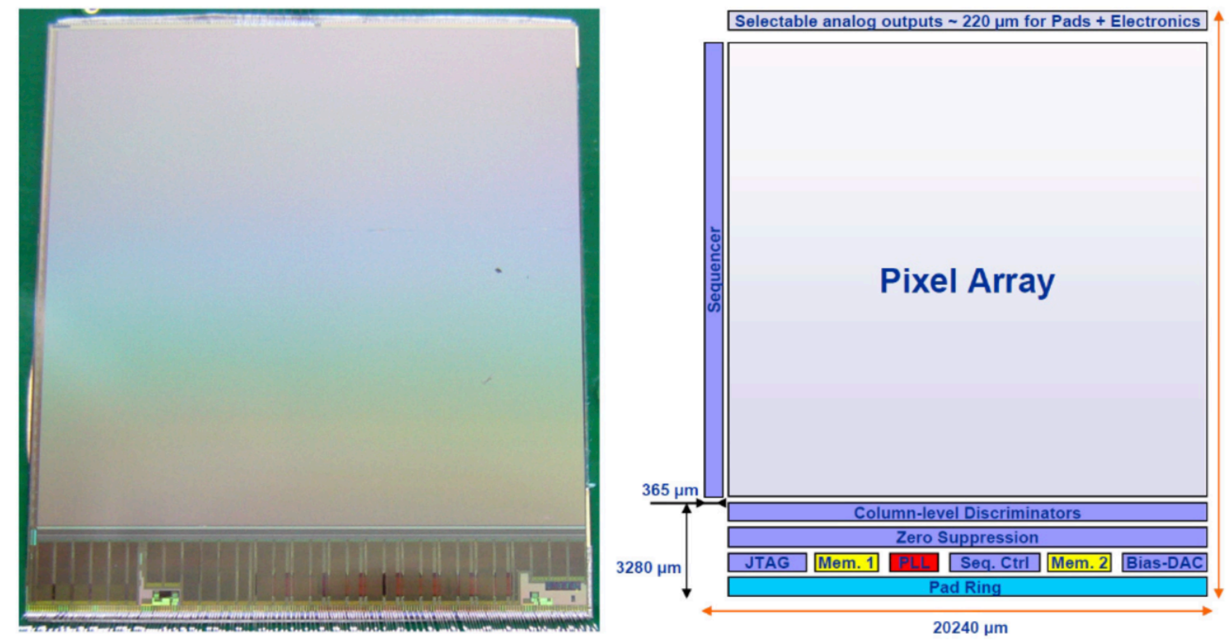
» During **HL-LHC** (2029) innermost tracking layers of ATLAS and CMS will have to cope with extreme radiation fluences (up to 2×10^{16} 1 MeV n_{eq}/cm^2)
→ 3D sensors are good candidates but needs improvements:
increased pixel granularity, reduced material budget and better geometrical efficiency

J NIMA 824 (2016) 386–387

Silicon sensors for tracking/vertexing detectors

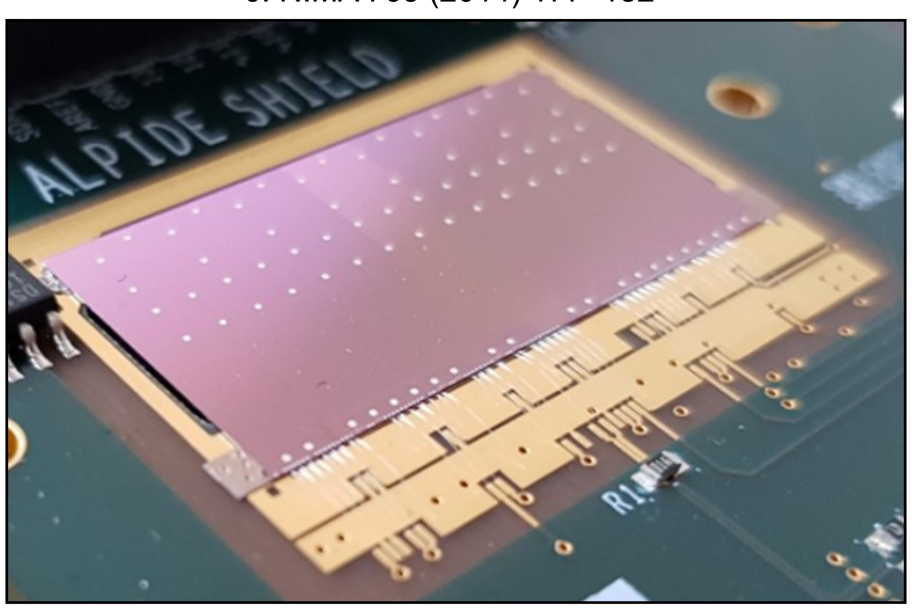
Monolithic Active Pixel Sensor (MAPS)

J. NIMA 907 (2018) 60–80



» First application of MAPS technology in a collider environment for STAR HFT PXL detector @RHIC (2014) → **Mimosa28**
- pixel pitch: 20.7 µm
- matrix: 928 × 960 pixels
- CMOS technology: twin well, 0.35 µm
- readout: rolling-shutter fashion in 185.6 µs
- power budget: 150 mW/cm^2

J. NIMA 765 (2014) 177–182

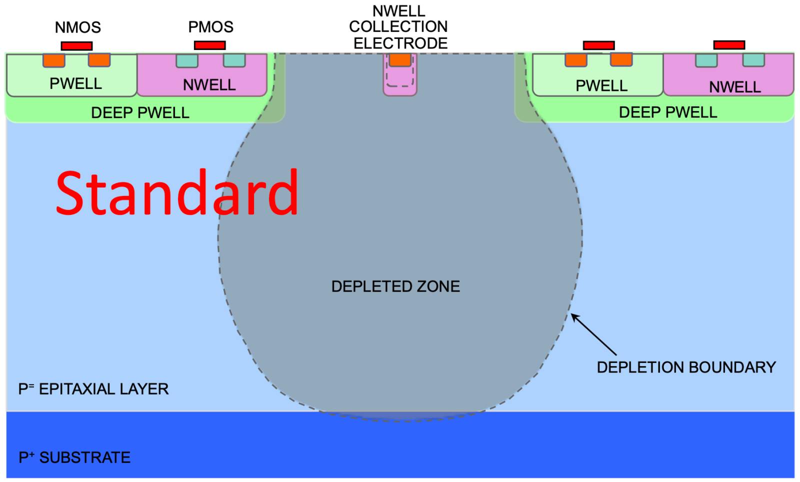


» MAPS development for ALICE ITS2 detector @LHC (2021) → **ALPIDE**
- pixel pitch: 28 µm
- matrix: 512 × 1024 pixels
- CMOS technology: TowerJazz 0.18 µm
- readout: continuous or triggered global-shutter (priority encoder)
- power budget: 40 mW/cm^2
- several applications: sPHENIX, protonCT, calorimetry, test beam telescopes

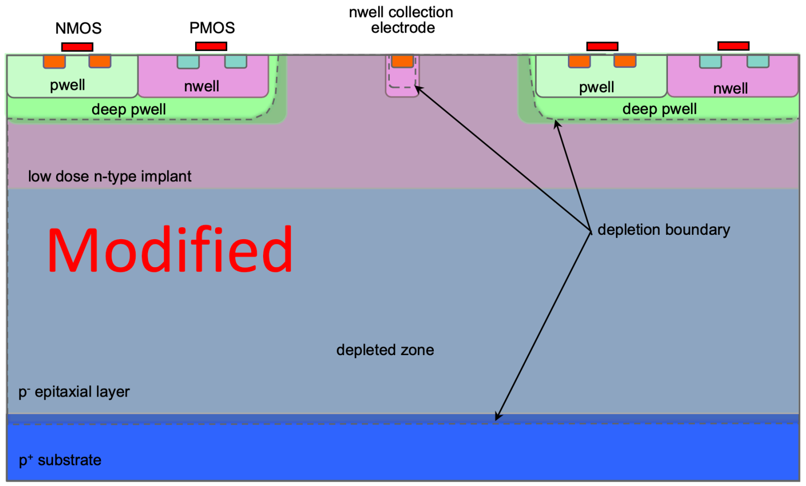
Silicon sensors for tracking/vertexing detectors

Monolithic Active Pixel Sensor (MAPS)

» **Standard** process, partially depleted epitaxial layer → doesn't allow full charge collection by drift, mandatory for more extreme radiation tolerance
- Charge collection time < 30 ns
- Operational up to 10^{14} 1 MeV n_{eq}/cm^2

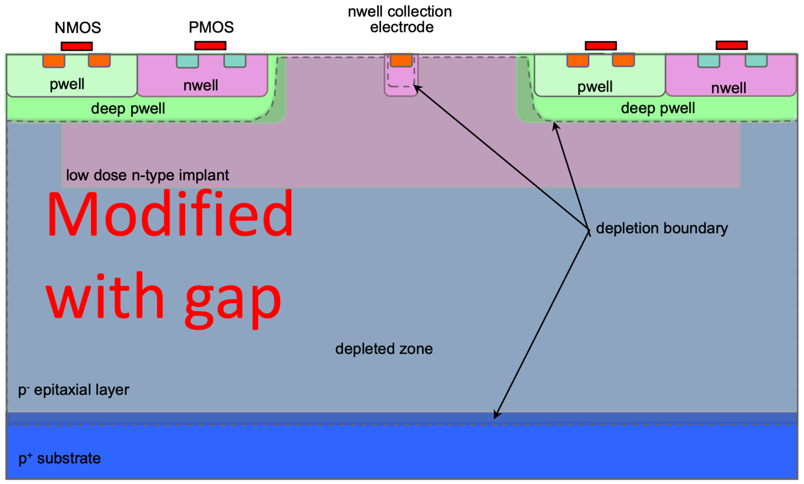


» **Modified** process, toward fully depleted epitaxial layer (still keepings small collection electrode) → planar junction separated from the collection electrode in the epitaxial layer
- Charge collection time < 1 ns
- Operational up to 10^{15} 1 MeV n_{eq}/cm^2



J. NIMA 871 (2017) 90–96

» **Modified with gap**
- In modified process electric field in sensor reaches a minimum in the pixel corners → degraded timing resolution and efficiency loss after irradiation
- A gap in the deep n-implant increases the lateral electric field at the pixel borders

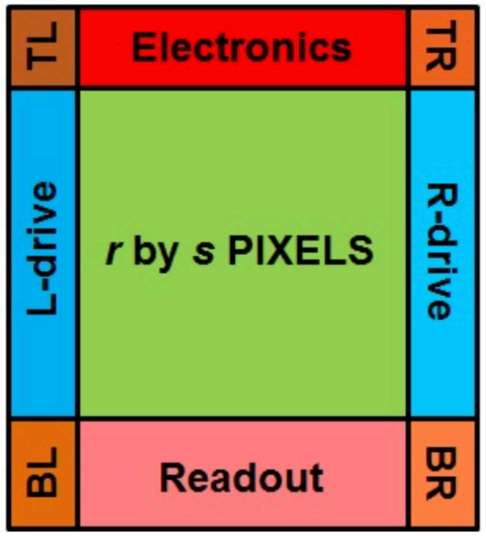


2019 JINST 14 C05013

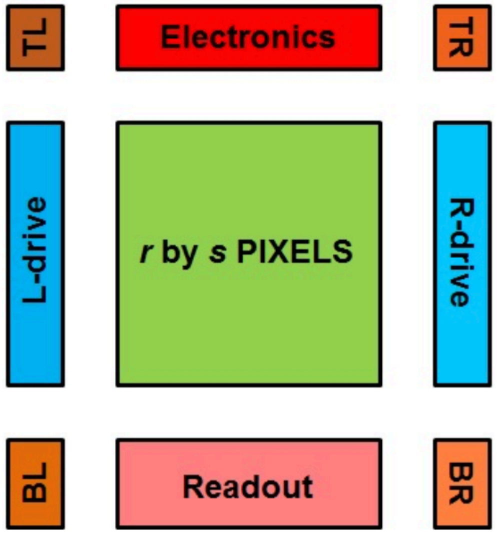
» Modified process further pursued with MALTA, CLICpix, FastPix, ITS3…

Large dimensions sensors

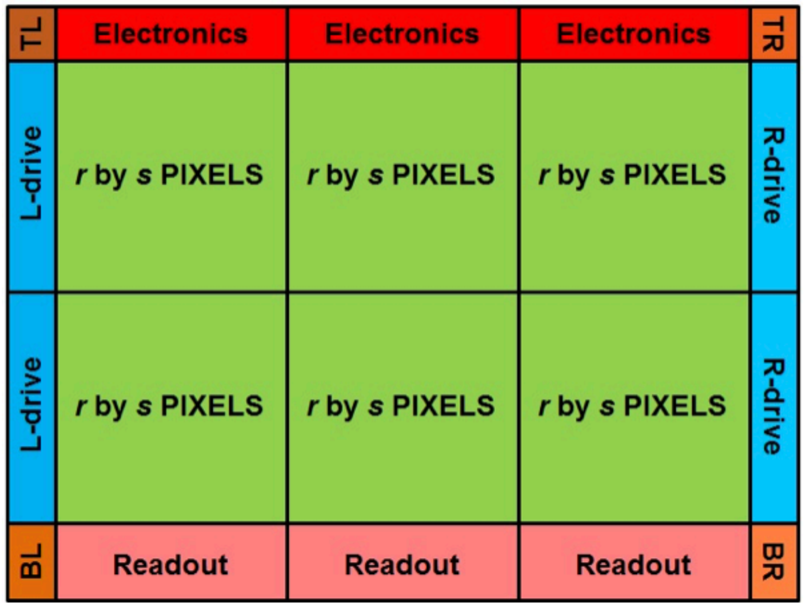
- » Chip size limited by field of exposure of photolithography equipment (~20 x 20 mm²)
- » **Stitching** technique allow sensor size exceeding the photolithography limitations
  - Building blocks are integrated in the photolithography mask as different mask regions



Sketch of an image sensor design



Isolated building blocks put separately on the reticle

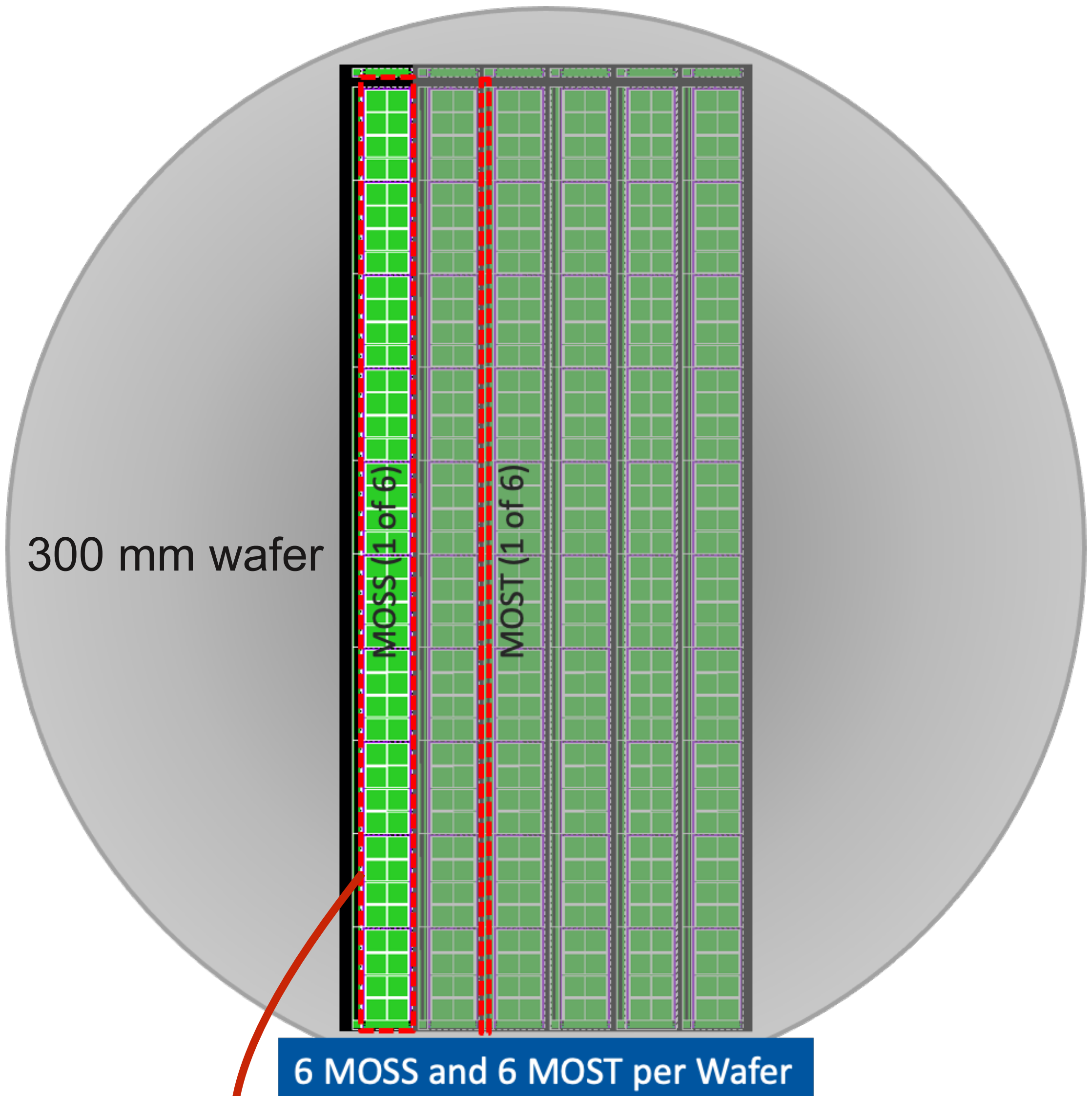


Extending the size of the sensor beyond the reticle field of view

Tower Semiconductor Ltd, Stitching design rules for forming interconnect layers, US Patent 6225013B1 (2001)

Silicon sensors for tracking/vertexing detectors

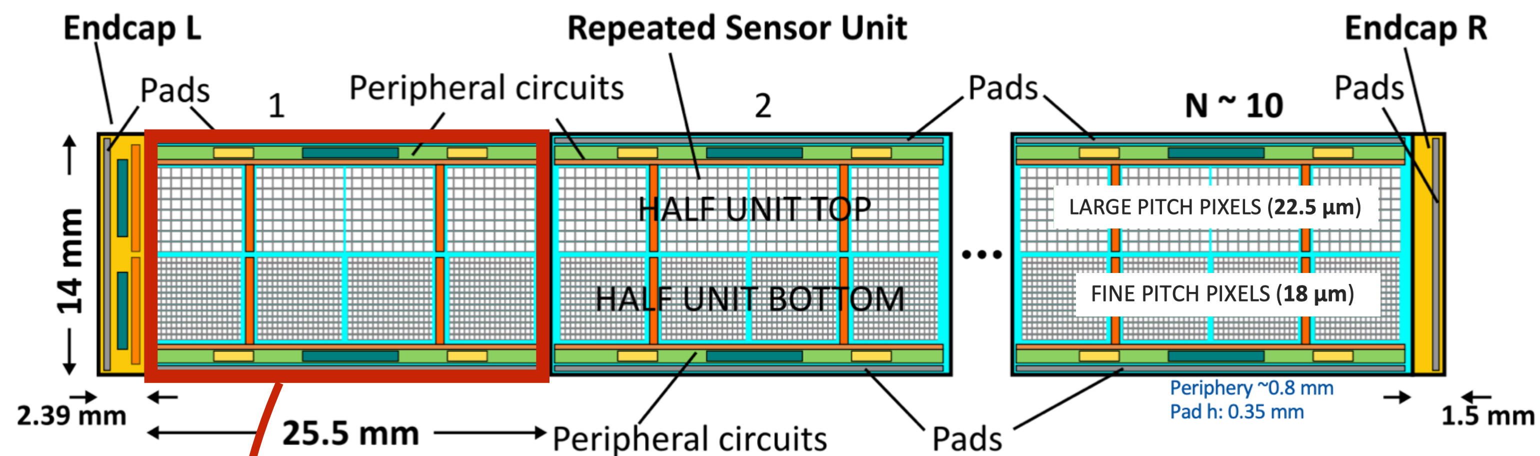
Large dimensions sensors

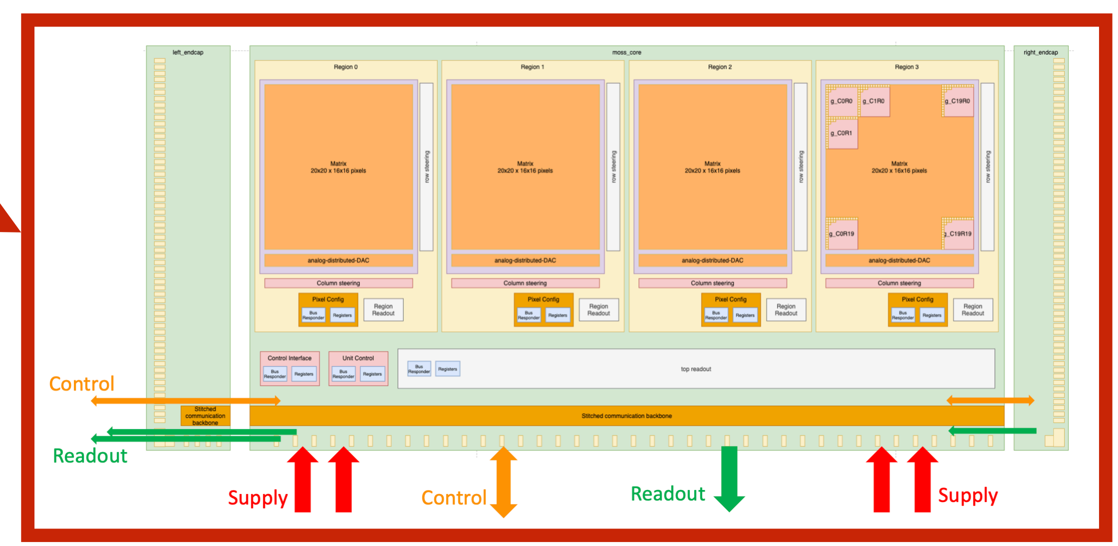


MOSS dimensions
14 mm × 25.9 cm

ALICE ITS3 stitched sensor

MOSS Monolithic Stitched Sensor Prototype



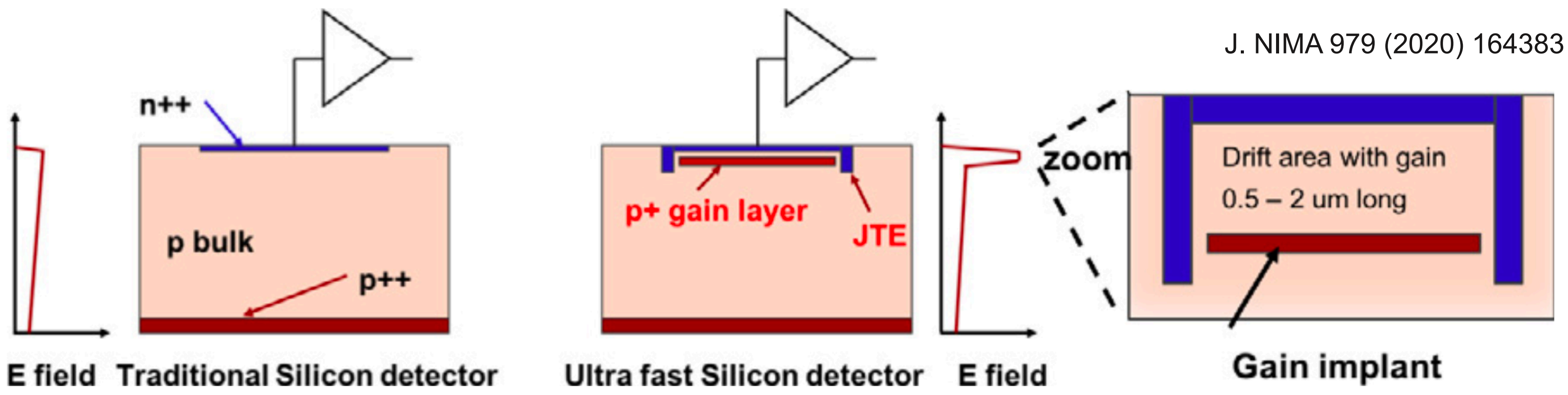


» Primary goals
- Learn Stitching technique to make a particle detector
- Interconnect power and signals on wafer scale sensor
- Learn about yield

Silicon sensors for tracking/vertexing detectors

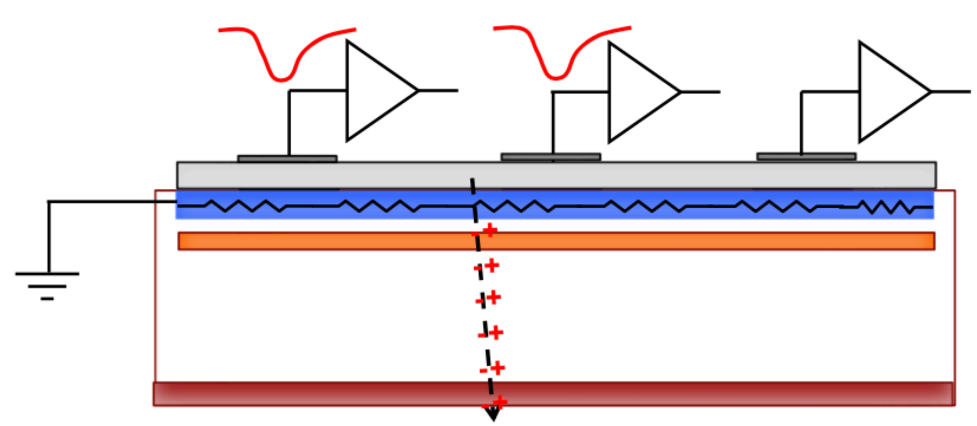
Timing information for 4D tracking

J. NIMA 979 (2020) 164383



- **Low Gain Avalanche Diodes:** additional moderately doped deep p-implant → In the region between this implant and the read-out electrode, the electric field is high enough for generating multiplication of the drifting electrons
- Low gain allows segmenting and keeping the shot noise below electronic noise → low leakage current
- Could reach ~30 ps resolution (sensor) and 20-30 ps (ASIC)

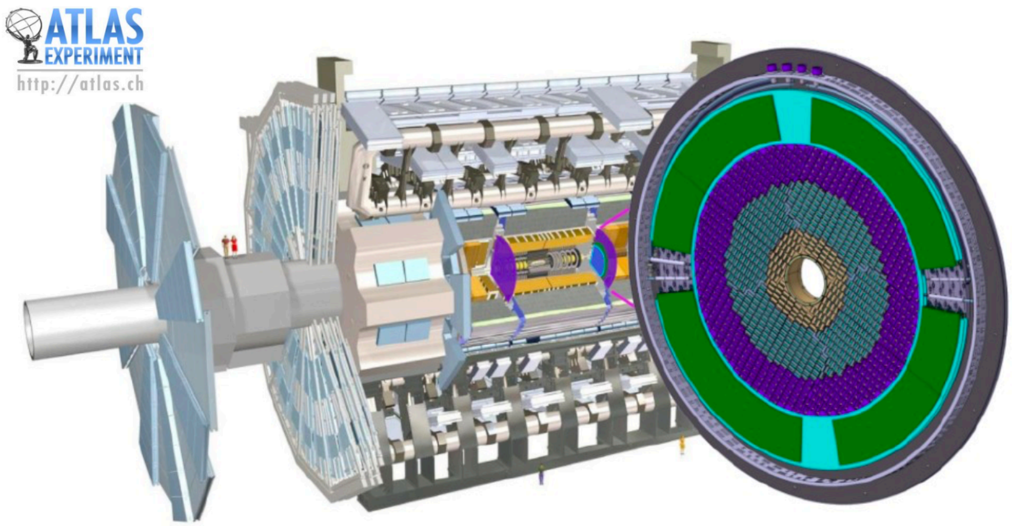
- New design, AC-LGAD architecture, uses charge sharing to achieve excellent time and spatial resolutions while reducing the number of channels by more than a factor of 10.



Silicon sensors for tracking/vertexing detectors

Timing information for 4D tracking

CERN-LHCC-2020-007
CERN-LHCC-2019-003

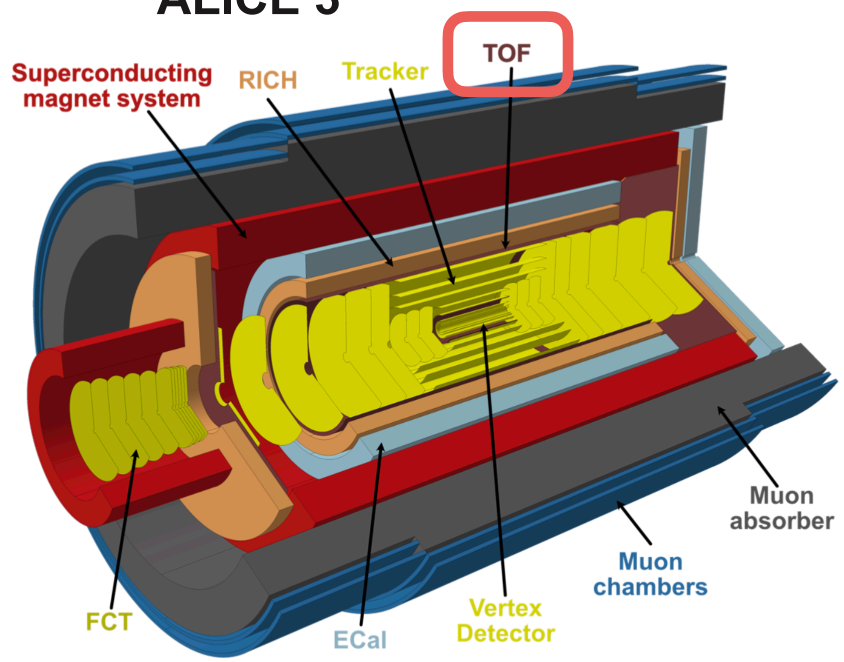


ATLAS High Granularity Timing Detector (HGTD)

» At HL-LHC: average 1.6 collisions/mm
- trackers mostly mitigates pile-up effect, but still challenging, specially, in the forward region
- timing information (~30 ps) can be used to mitigate the effect of pile-up

» ATLAS and CMS proposing timing detector systems for HL-LHC

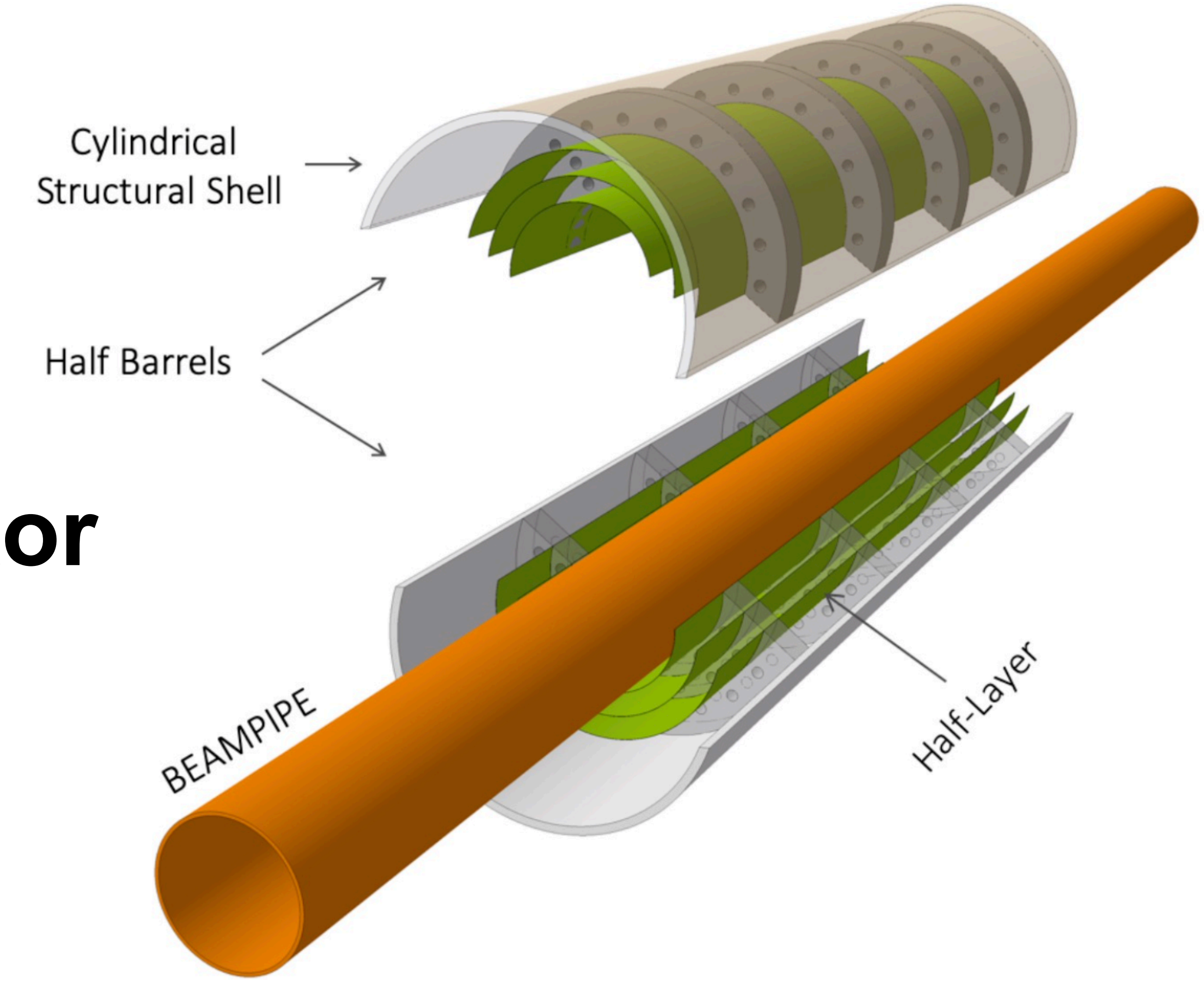
ALICE 3



CERN-LHCC-2022-009
2022 JINST 17 P10019

» Future experiments like ePIC@EIC and ALICE3@LHC foresee a Time-Of-Flight PID detector, requiring ~20 ps timing resolution
- LGAD technology is explored
- Fully depleted MAPS also under investigation

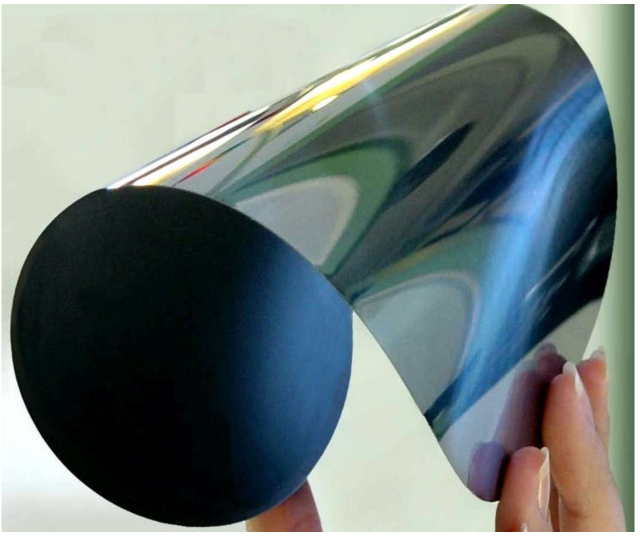
Detector integration:
a truly cylindrical detector

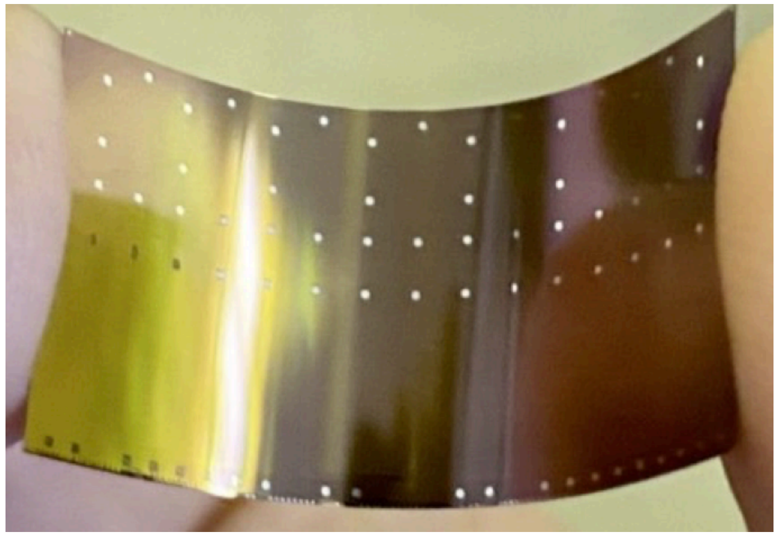


Detector integration: a truly cylindrical detector

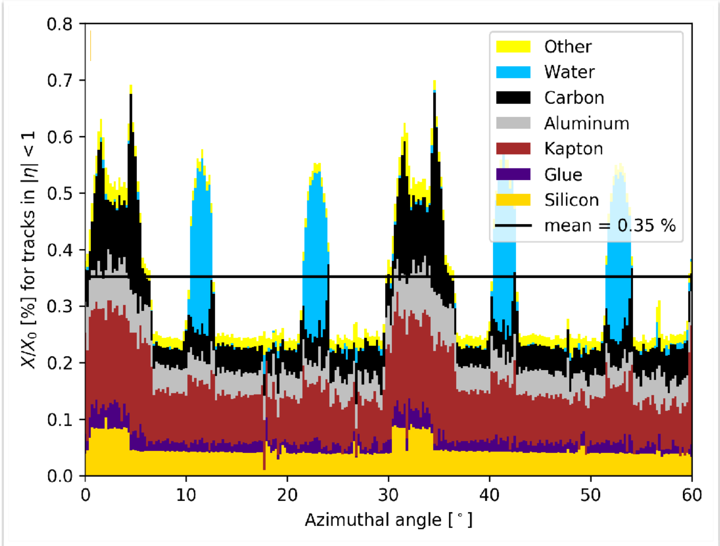
Motivations

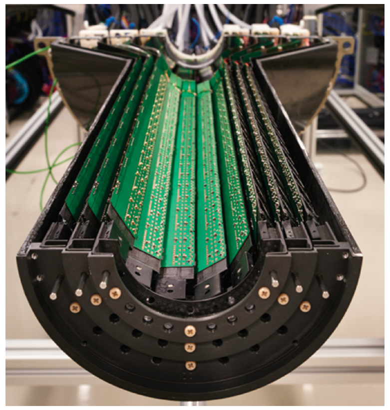
» It is well known that thin silicon (<50 μm) can be bent without mechanical damages

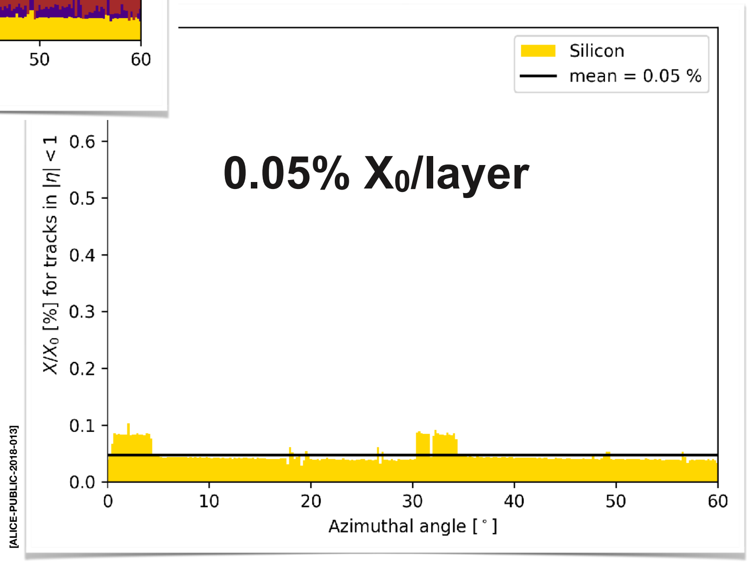




ALICE ITS2 Inner Barrel







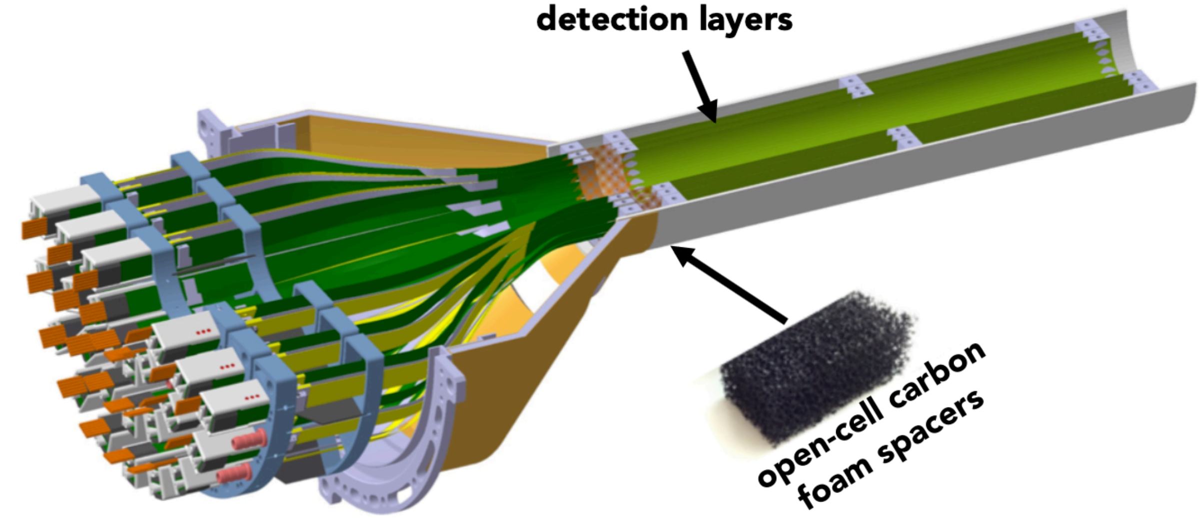
» Silicon makes only about 15% of total material

» Irregularities due to support/cooling and overlap of adjacent modules

Detector integration: a truly cylindrical detector

How to realise it?

ALICE ITS3 implementation



Key ingredients

» Wafer-scale chips using stitching (~28x10 cm)
» Sensor thickness 20-40 μm
» Chips bent in cylindrical shape at target radii
» Si MAPS sensor based on 65 nm technology
» Carbon foam support structures

The whole detector will comprise six chips and barely anything else!

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)		

Detector integration: a truly cylindrical detector

How to realise it?

EIC ePIC SVT implementation

Same ITS3 sensors dimensions but larger layer radii → More sensors needed per layer

Key ingredients

» Wafer-scale chips using stitching (~28x10 cm)
» Sensor thickness 20-40 μm
» Chips bent in cylindrical shape at target radii
» Si MAPS sensor based on 65 nm technology
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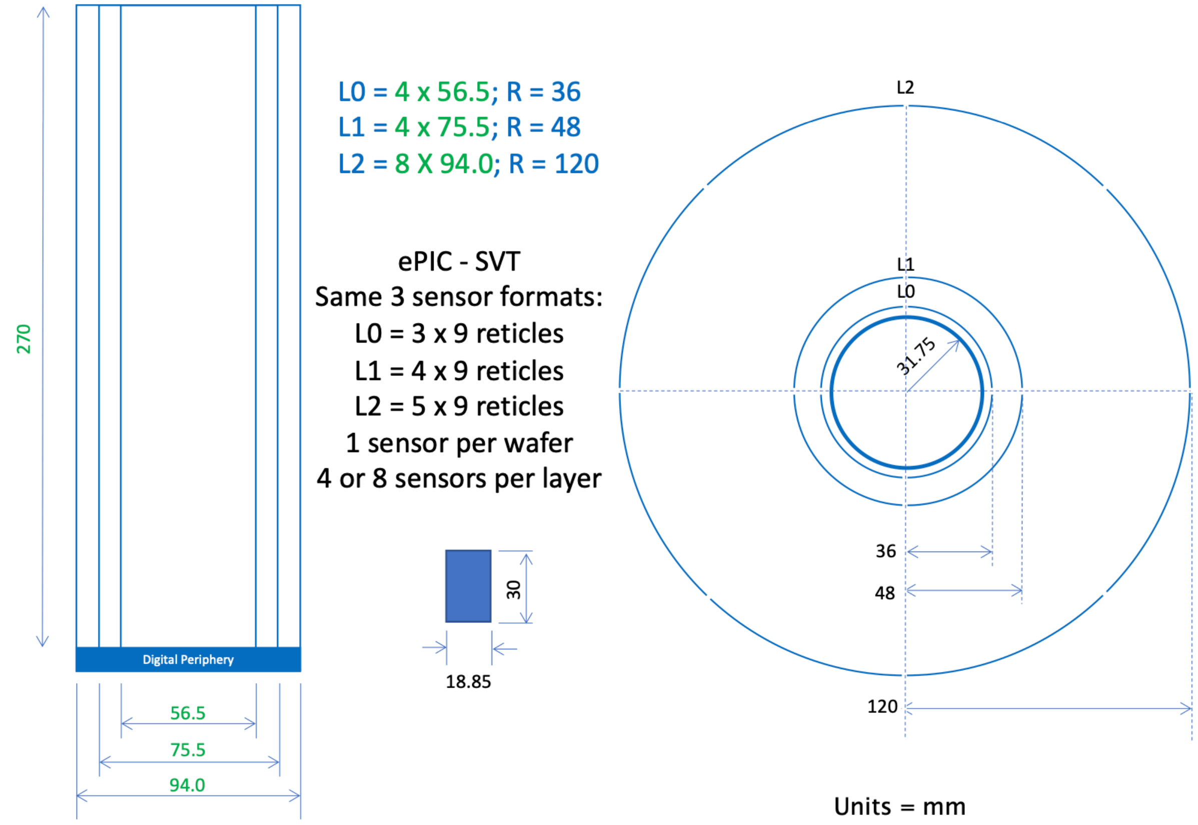
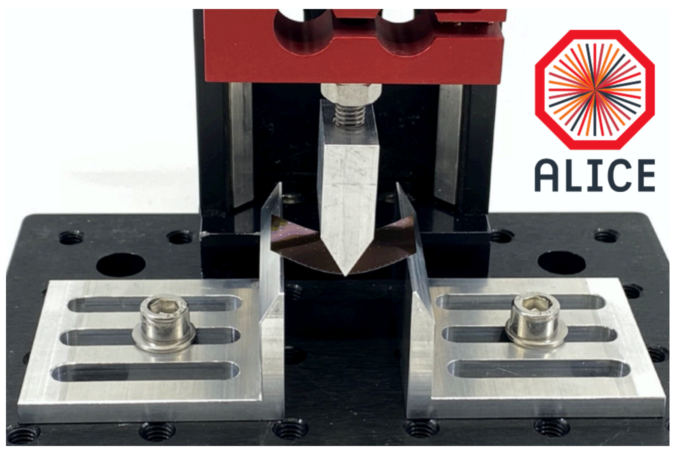
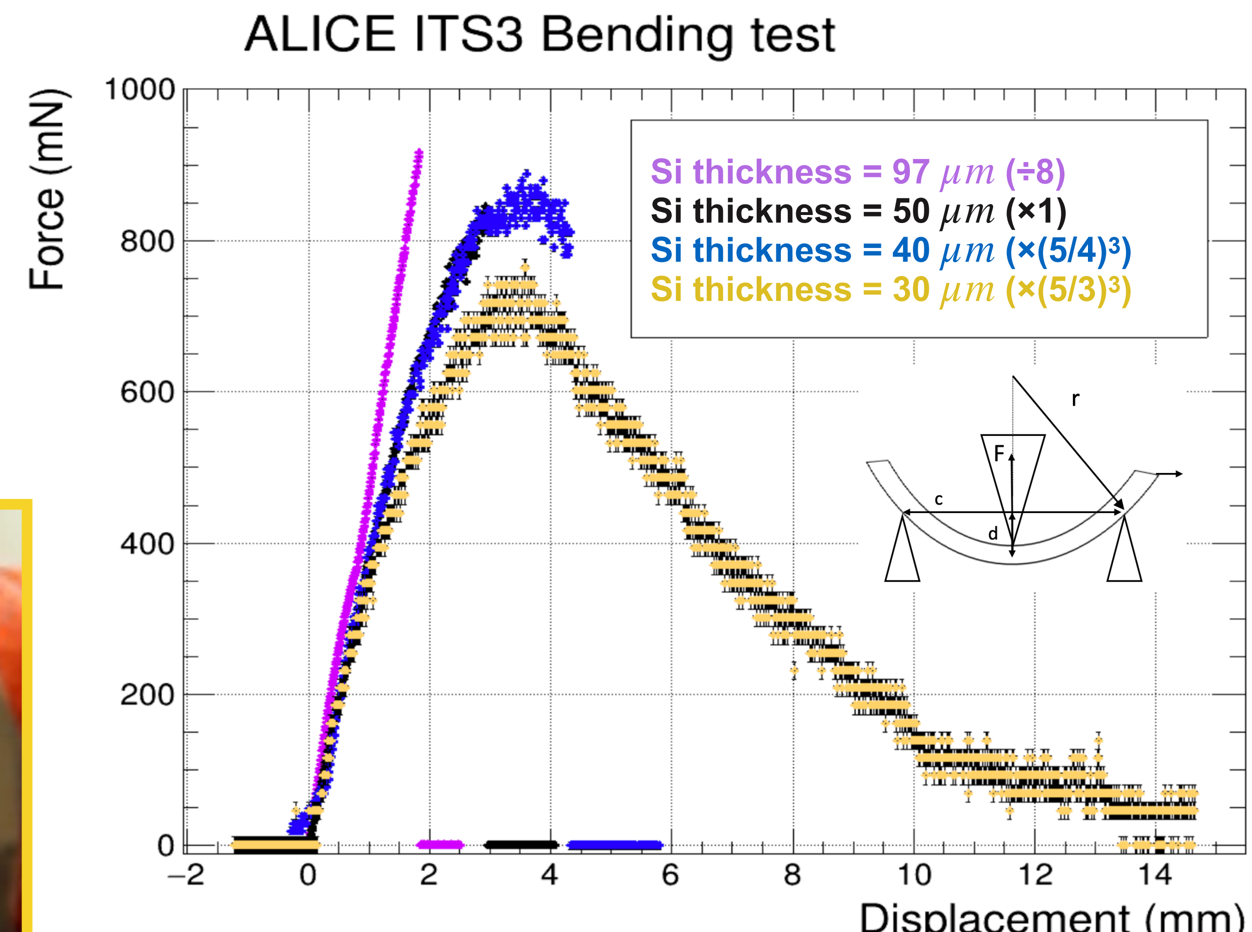


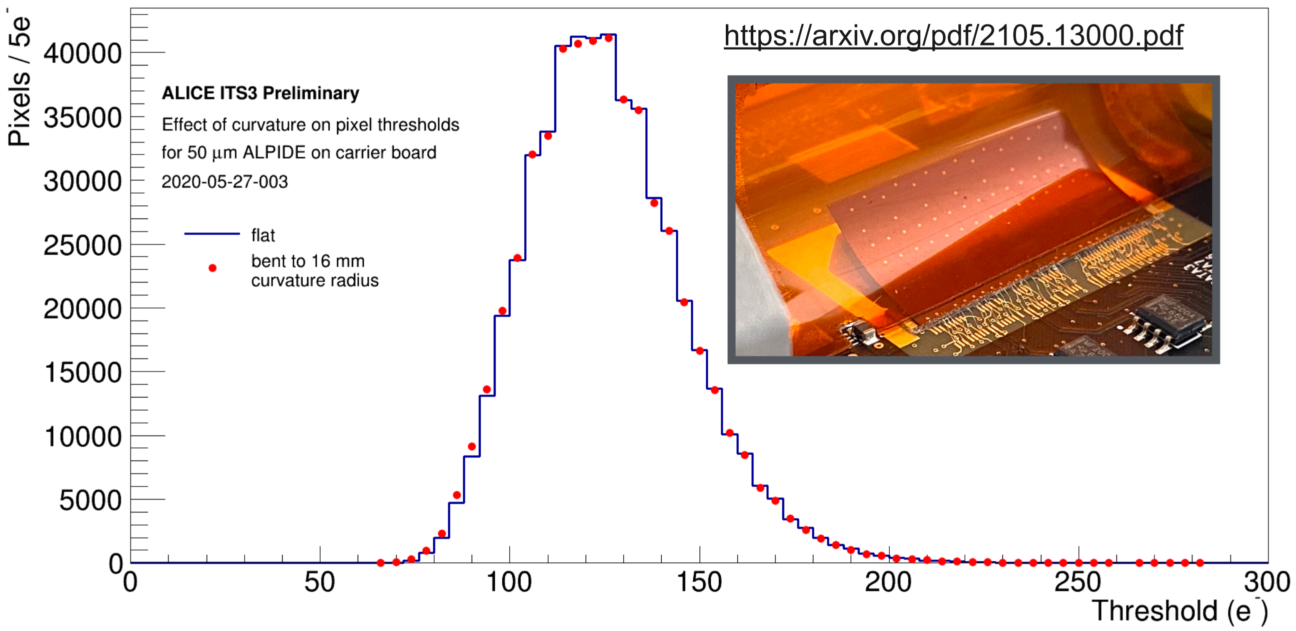
R&D activities - ALPIDE chip bending

- 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

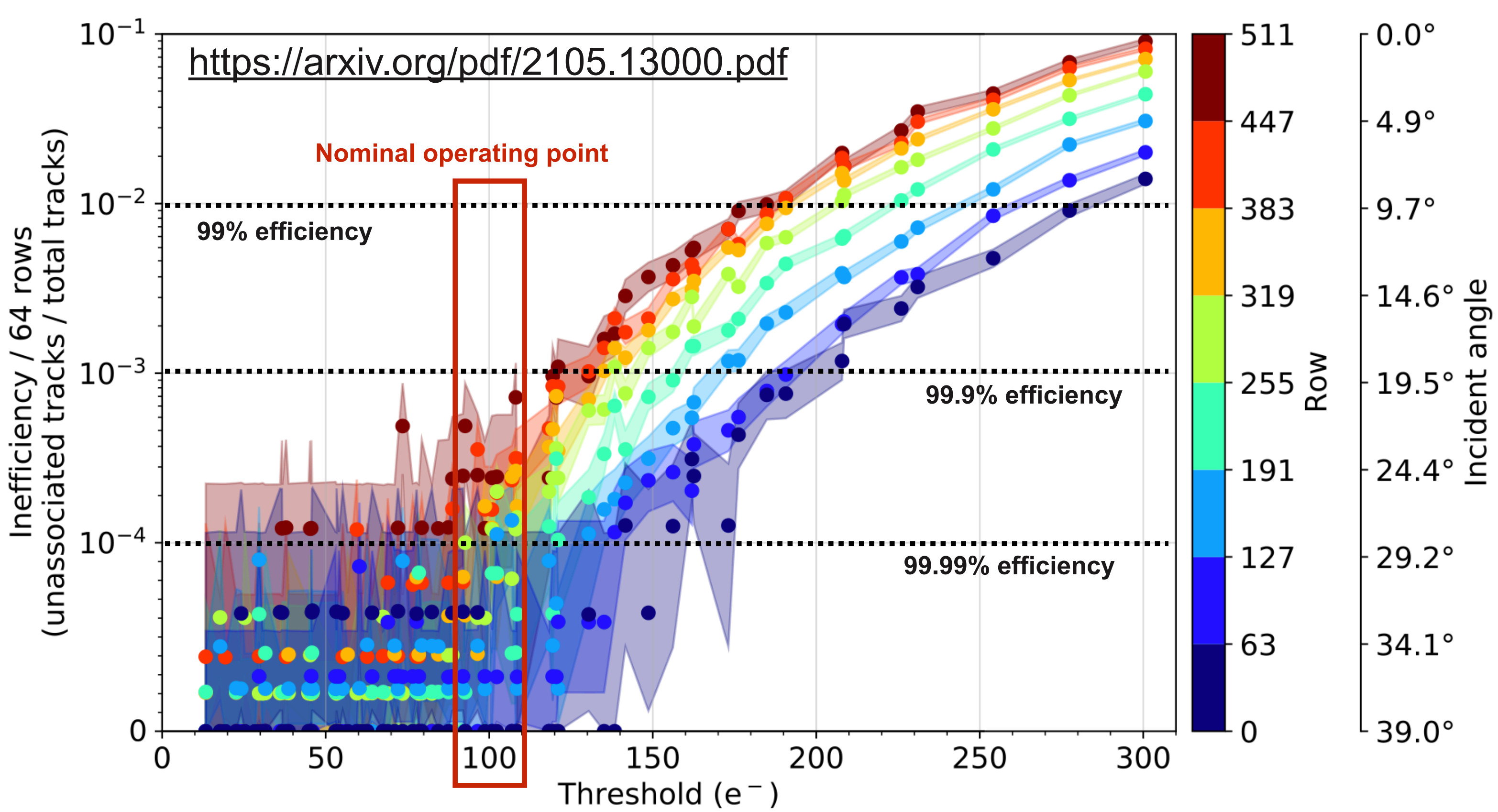




R&D activities - ALPIDE chip bending



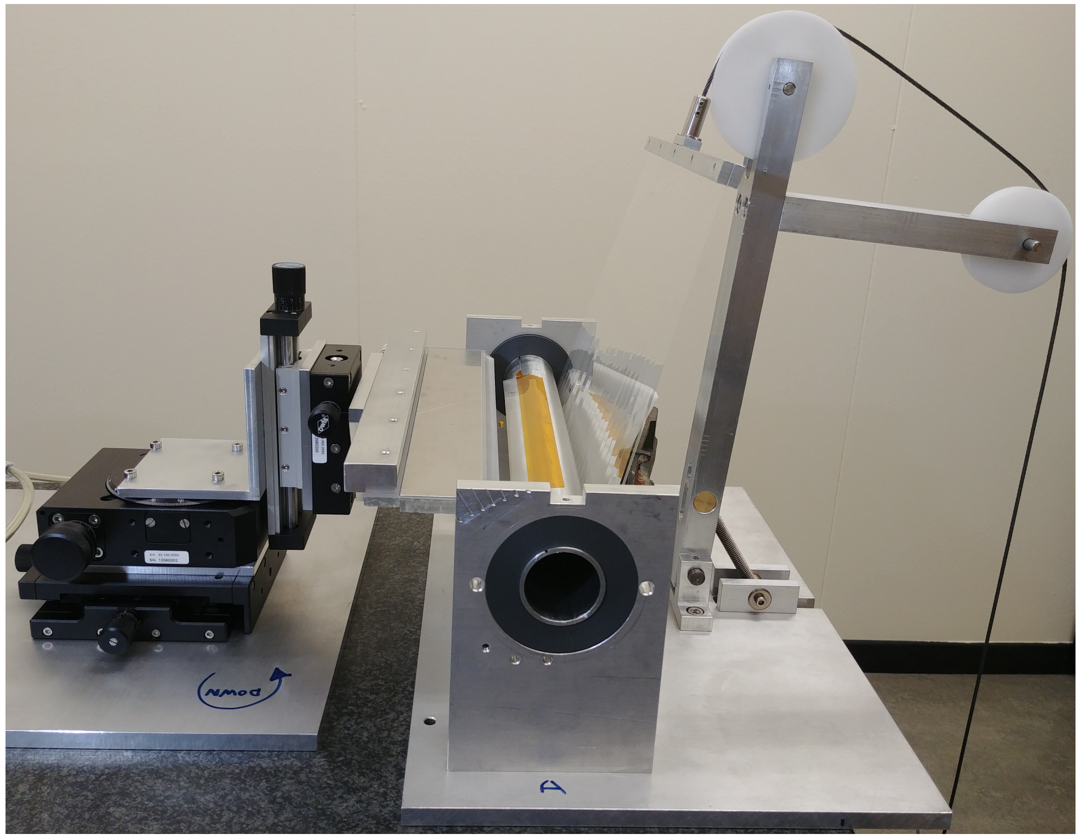
- Laboratory and test beam measurements (Jun 2020) allow to conclude that **chip performance doesn't change after bending**
  - Pixel matrix threshold distribution does not change when sensor is bent
  - Efficiency above 99.9% at a threshold of 100 e^- (normal operating point)

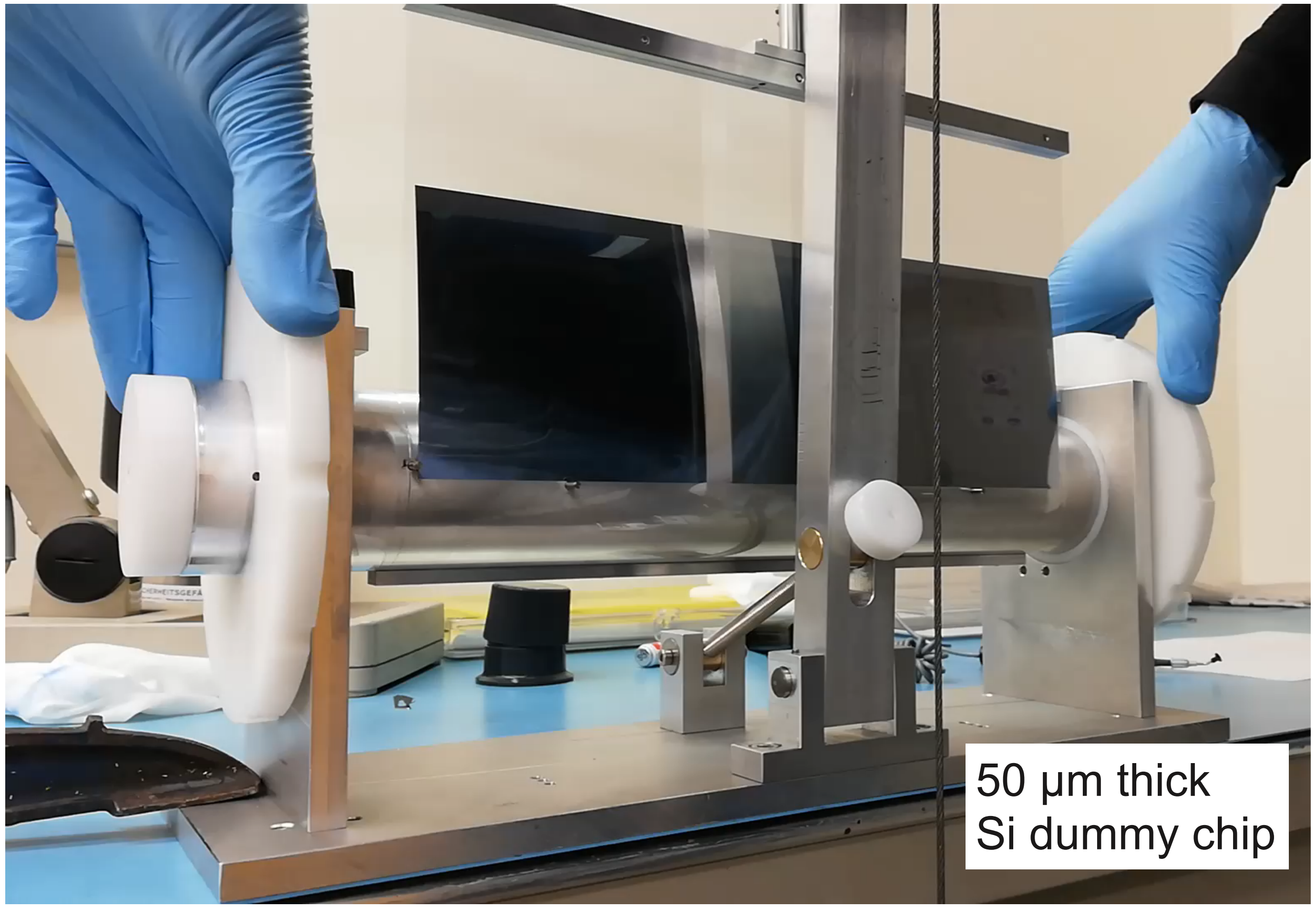


Detector integration: a truly cylindrical detector

R&D activities - Wafer-scale silicon bending

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



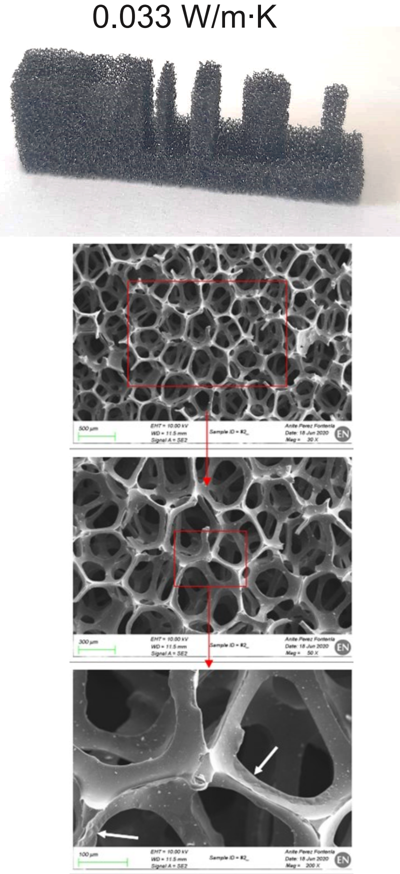


Detector integration: a truly cylindrical detector

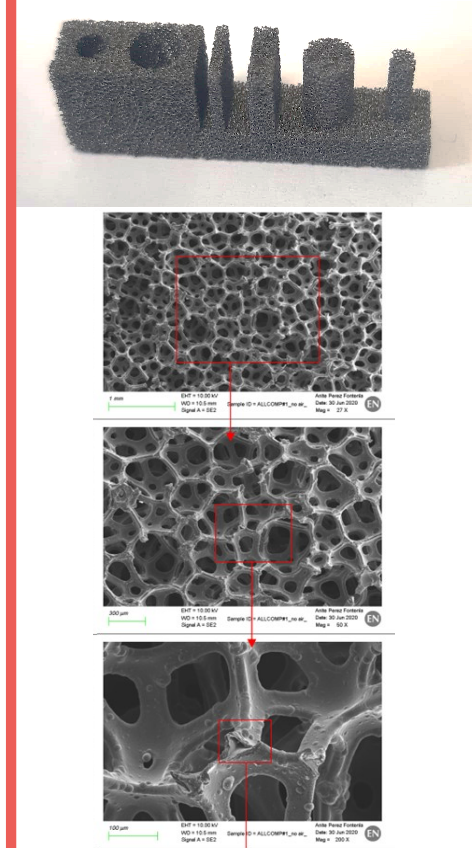
R&D activities - Carbon foam characterisation

» Different foams characterised for machinability and thermal properties

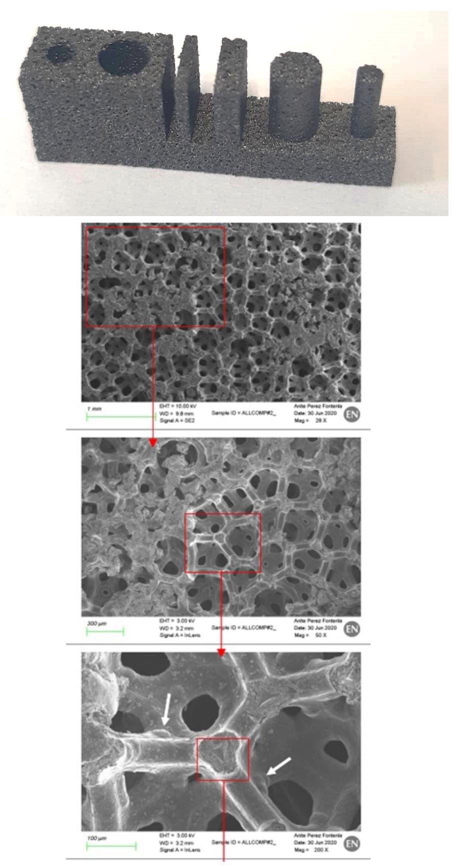
ERG DUOCEL
0.06 kg/dm^3
0.033 W/m·K



ALLCOMP LD
0.2-0.26 kg/dm^3
>17 W/m·K



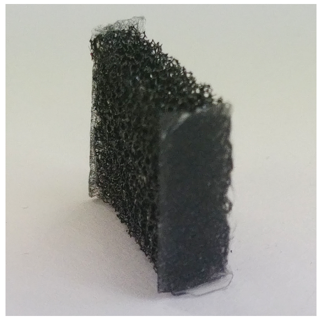
ALLCOMP HD
0.45-0.68 kg/dm^3
85-170 W/m·K



Longerons and wedge ← ERG DUOCEL
Support

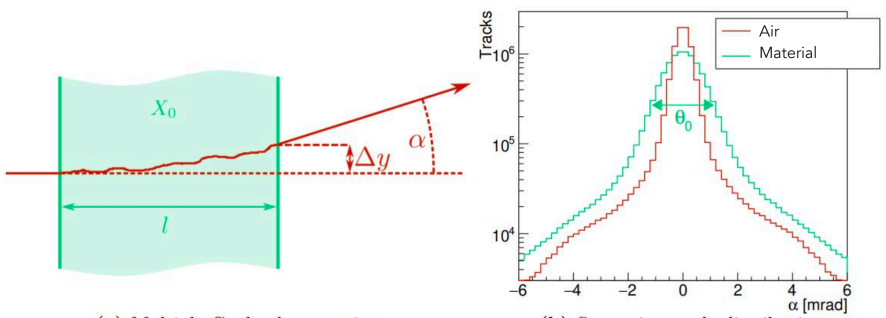
Half-ring ← ALLCOMP LD
Support + Cooling

Fleece to reduce glue



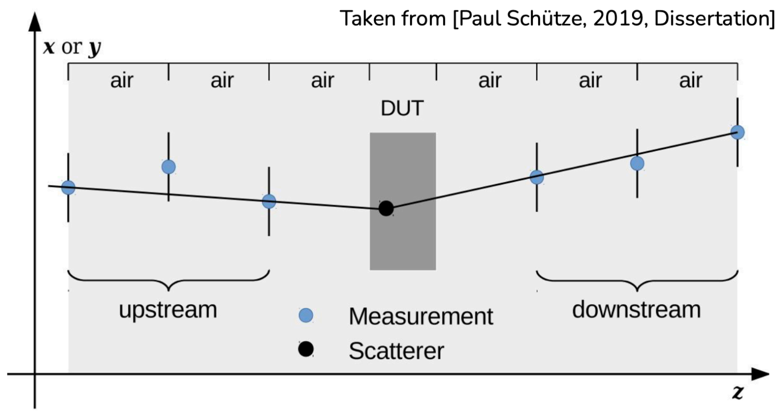
Detector integration: a truly cylindrical detector

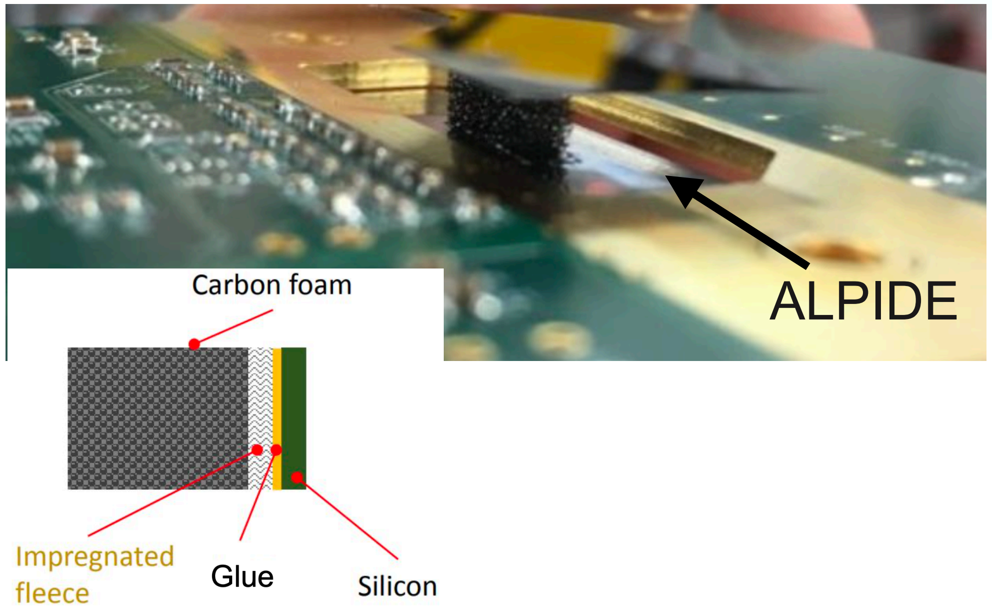
R&D activities - Carbon foam characterisation

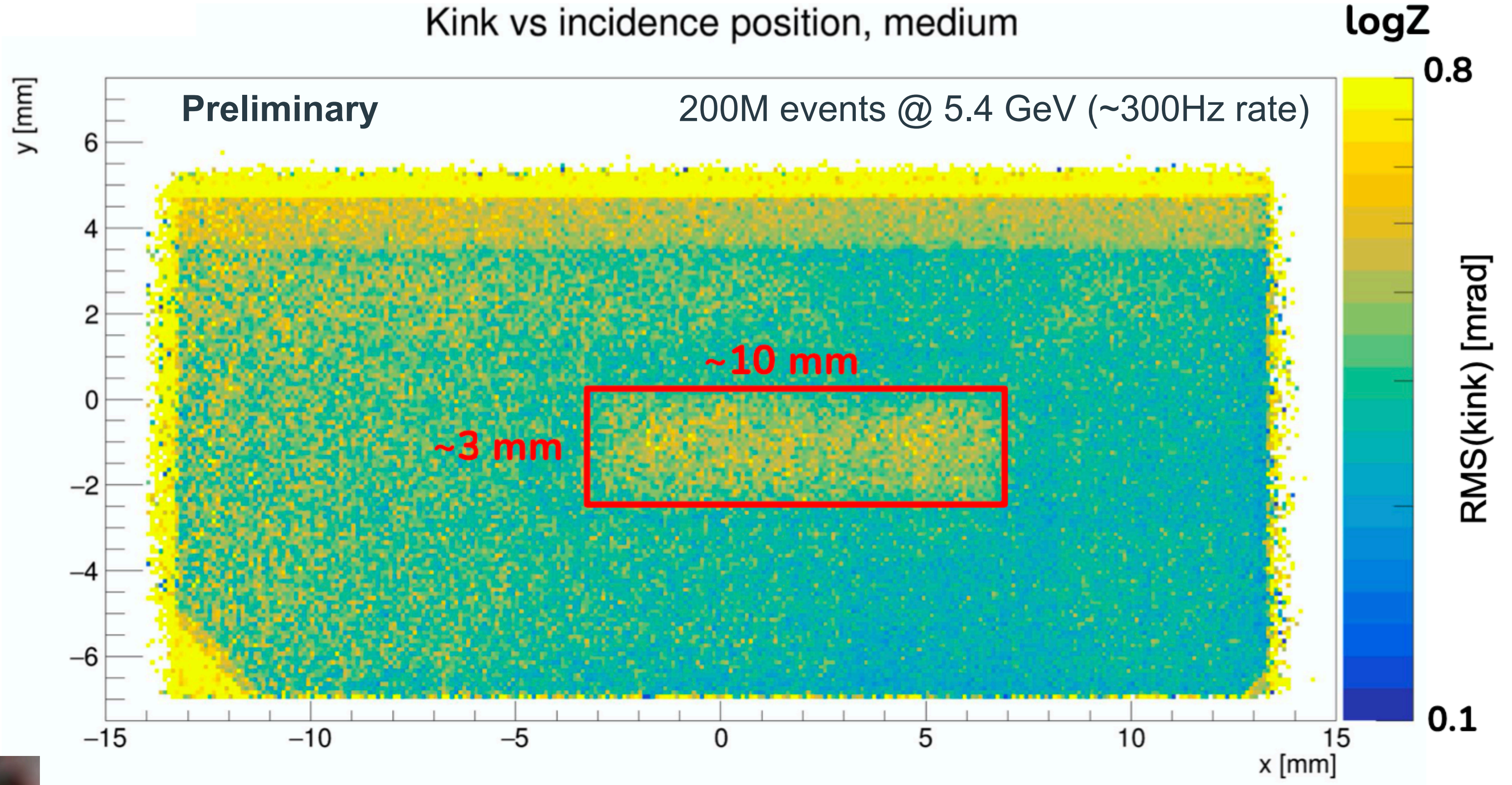


(a) Multiple Coulomb scattering (b) Scattering angle distribution

Taken from [Paul Schütze, 2019, Dissertation]





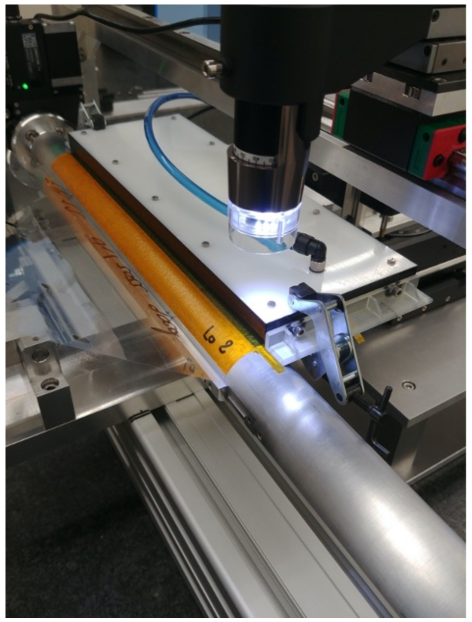
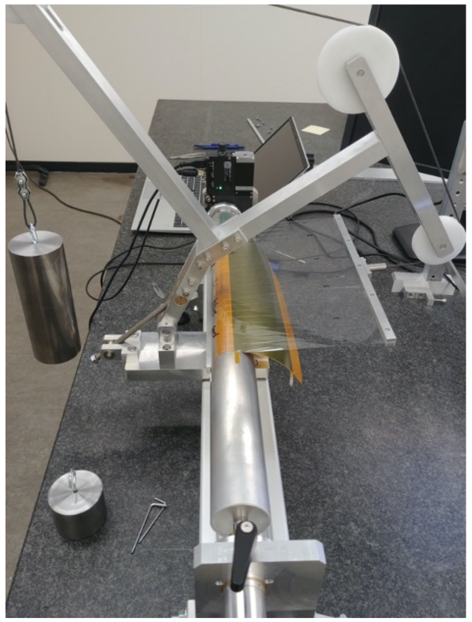


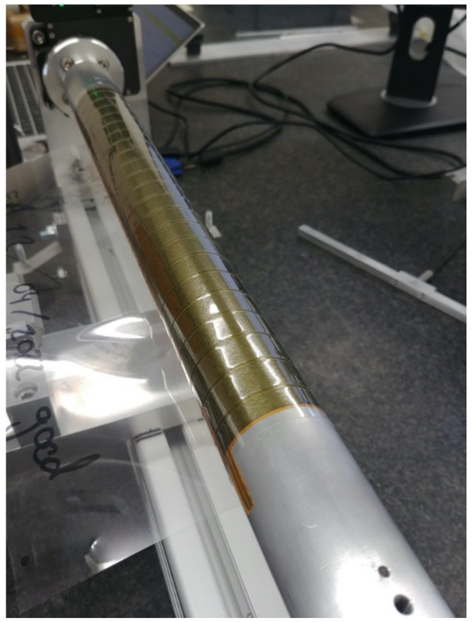
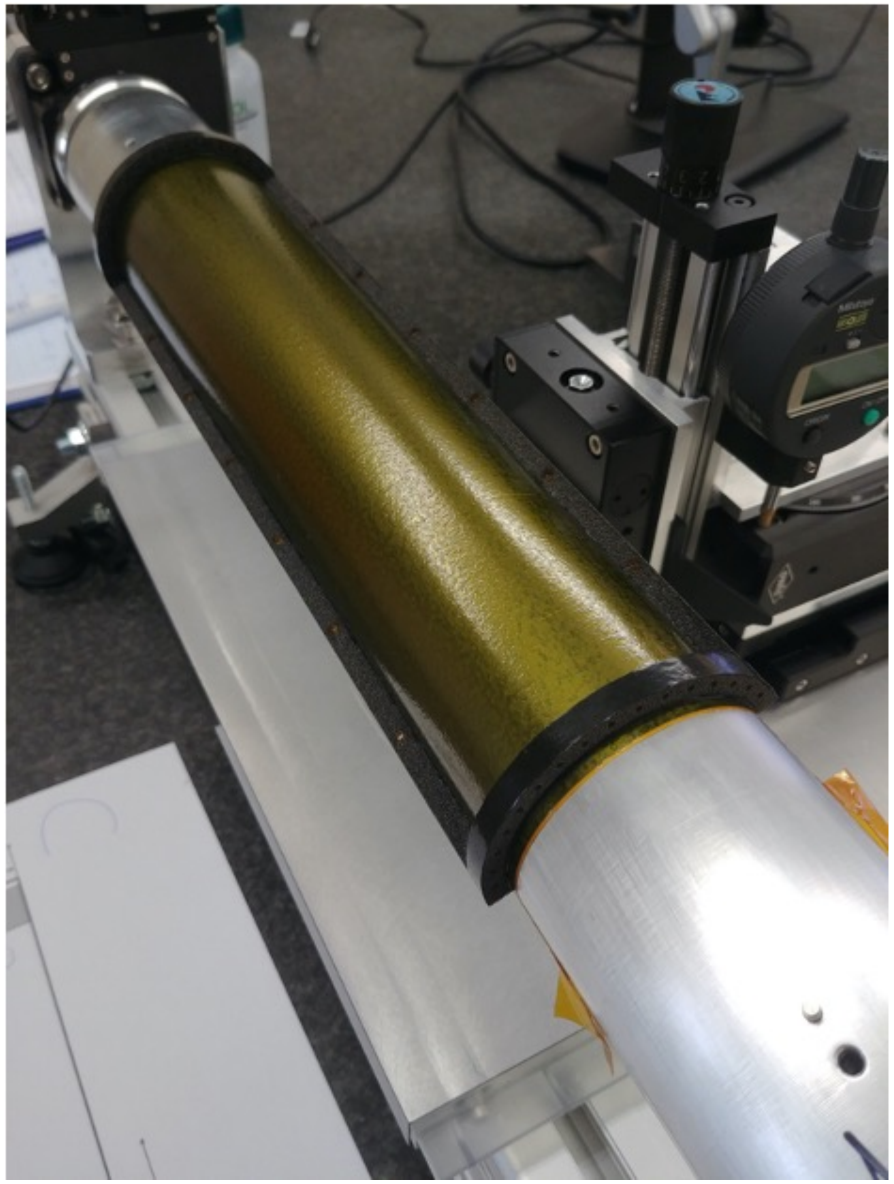
» Analysis of the kink angle distributions at the position of a scatterer
» Material budget image: represents the widths of the scattering angle distribution of all particles traversing a given bin

Detector integration: a truly cylindrical detector

R&D activities - Layer assembly procedure

» Different options under study (including vacuum clamping)
» Currently working solution based on adhesive caption tape

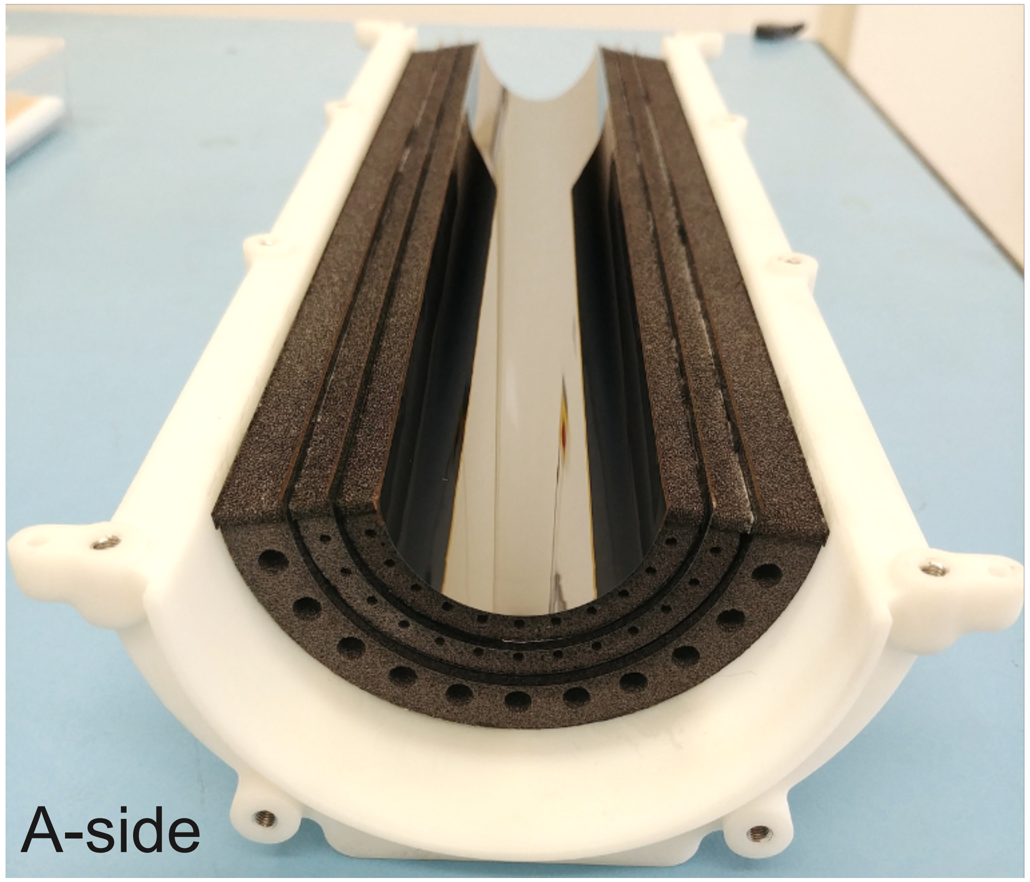



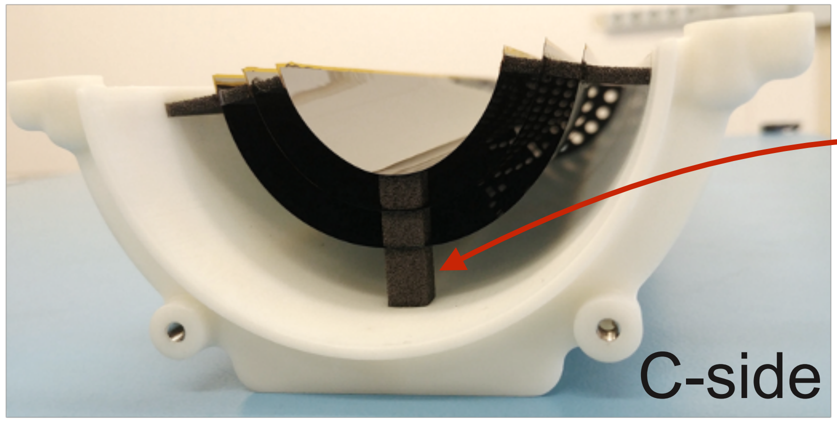



Detector integration: a truly cylindrical detector

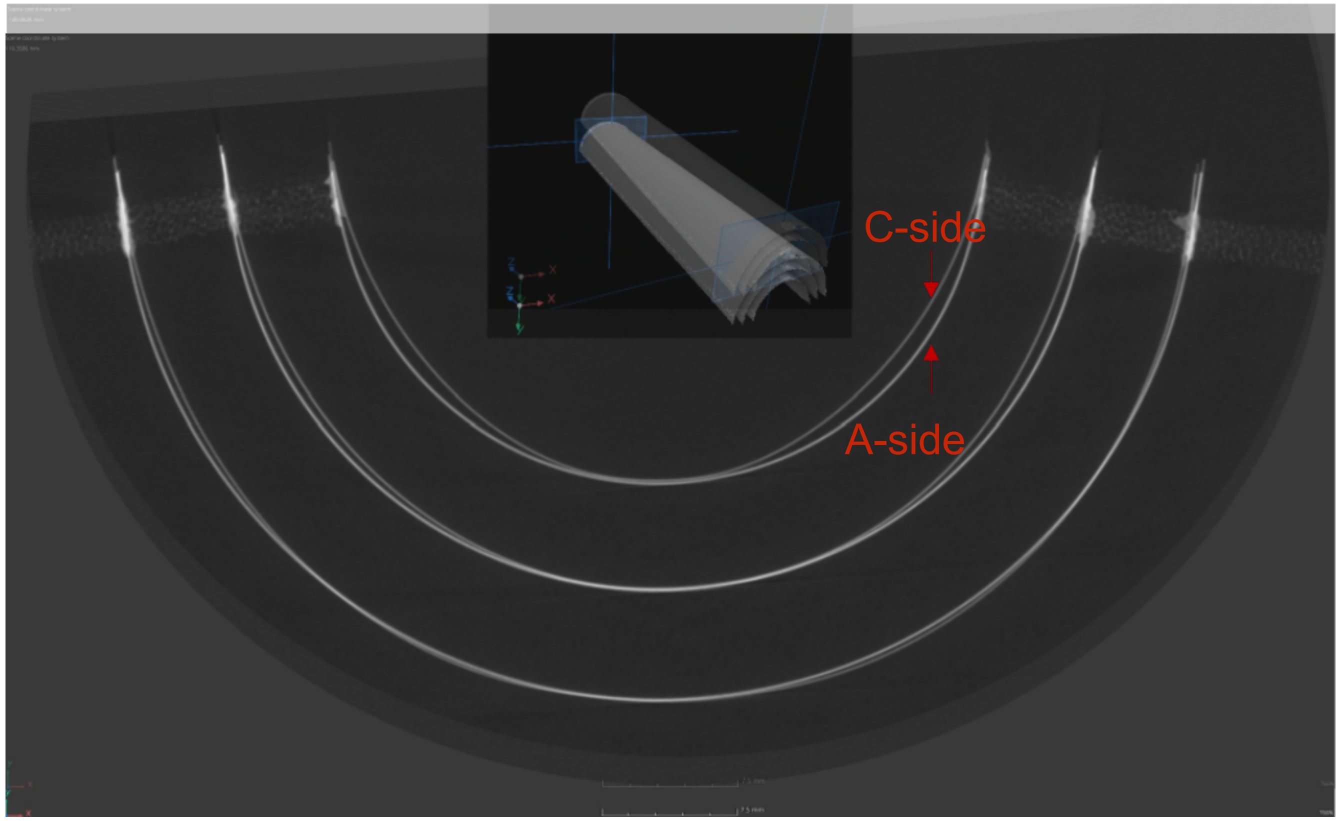
R&D activities - Layer assembly procedure

» Different options under study (including vacuum clamping)
» Currently working solution based on adhesive caption tape



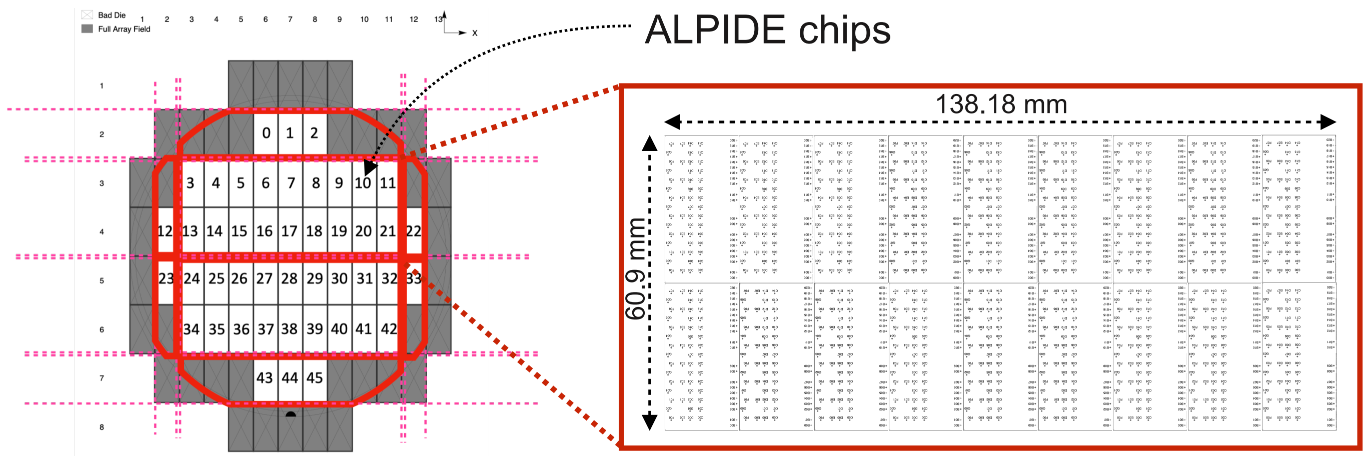


Wedges replaced with half-ring due to excessive deformation from cylindrical shape

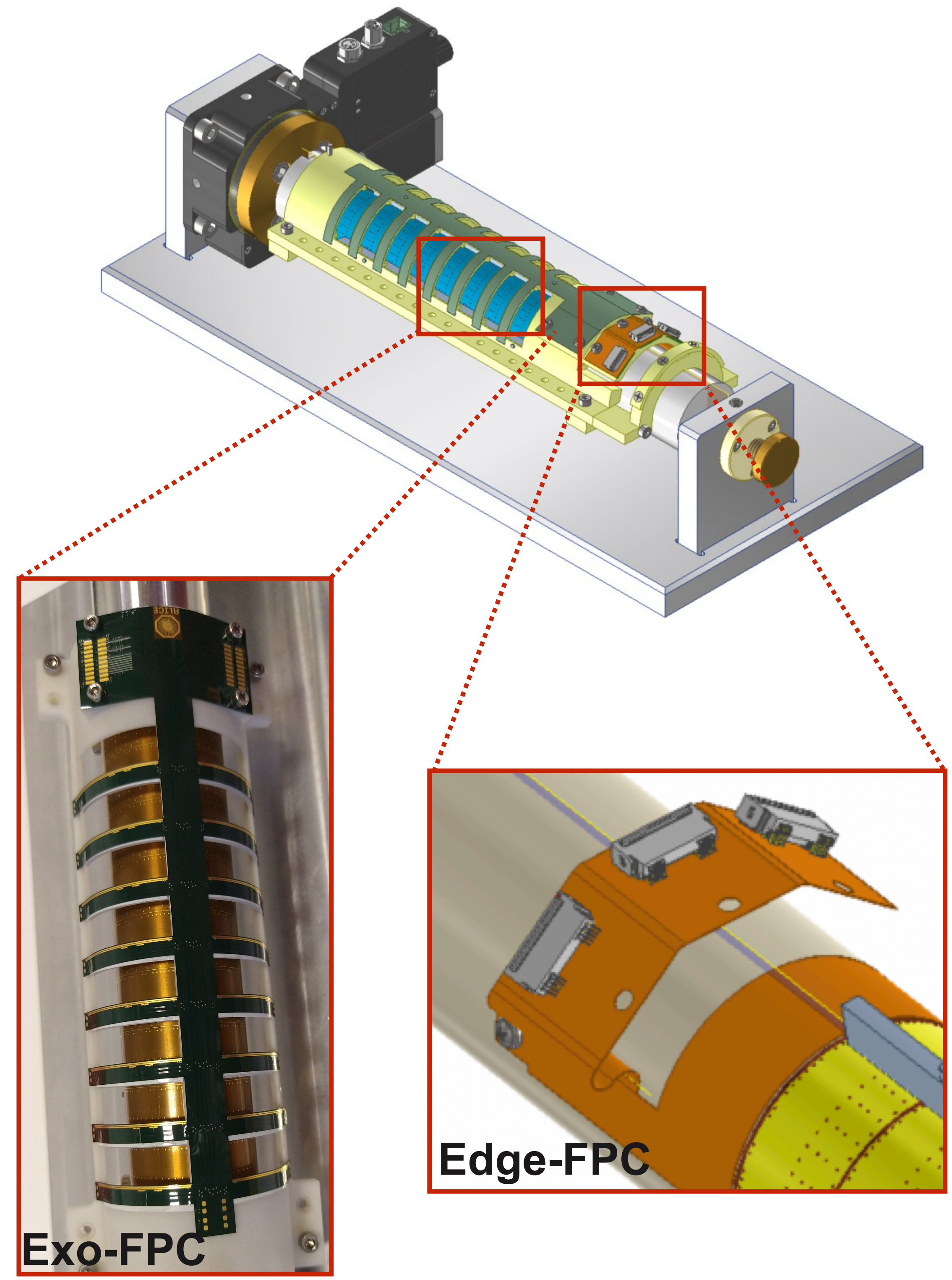


Detector integration: a truly cylindrical detector

TOWARD FIRST WORKING LARGE DIMENSION SENSOR



Super-ALPIDE: 18 not diced ALPIDE chips

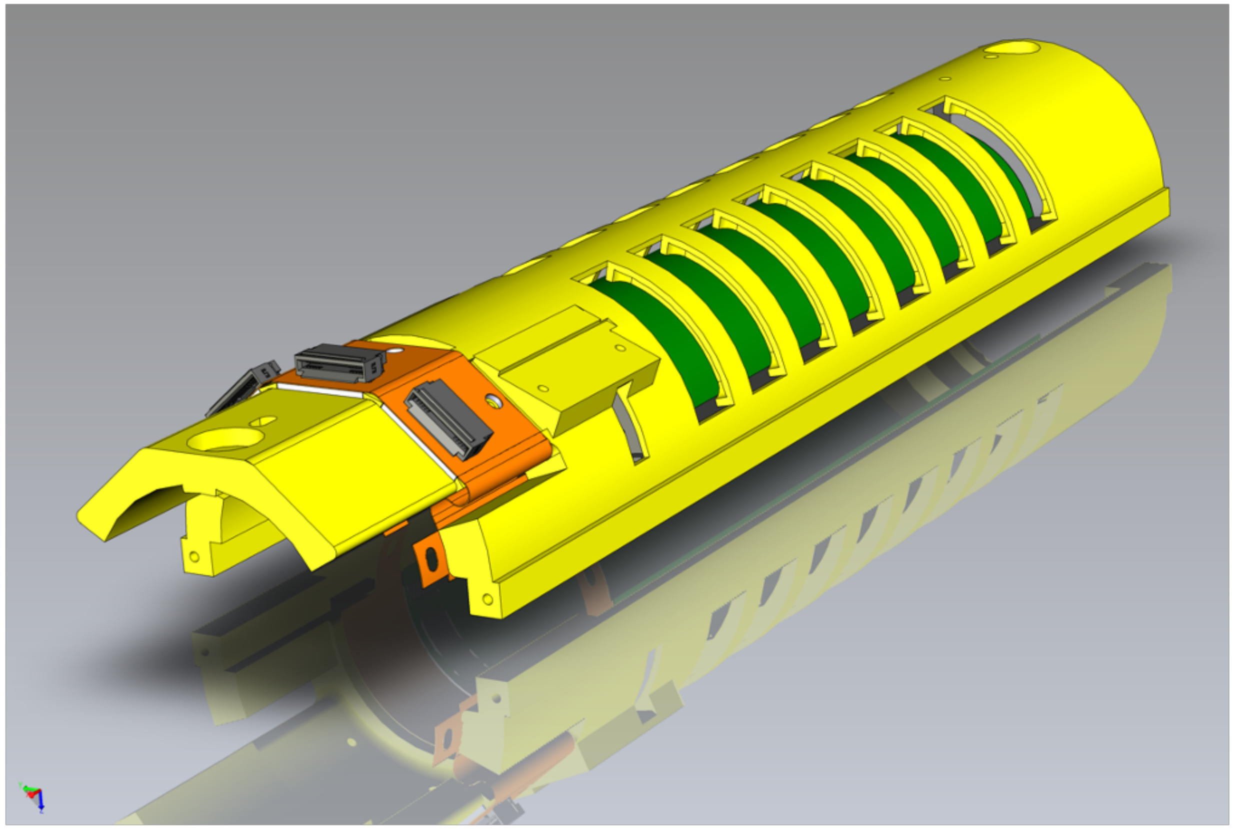


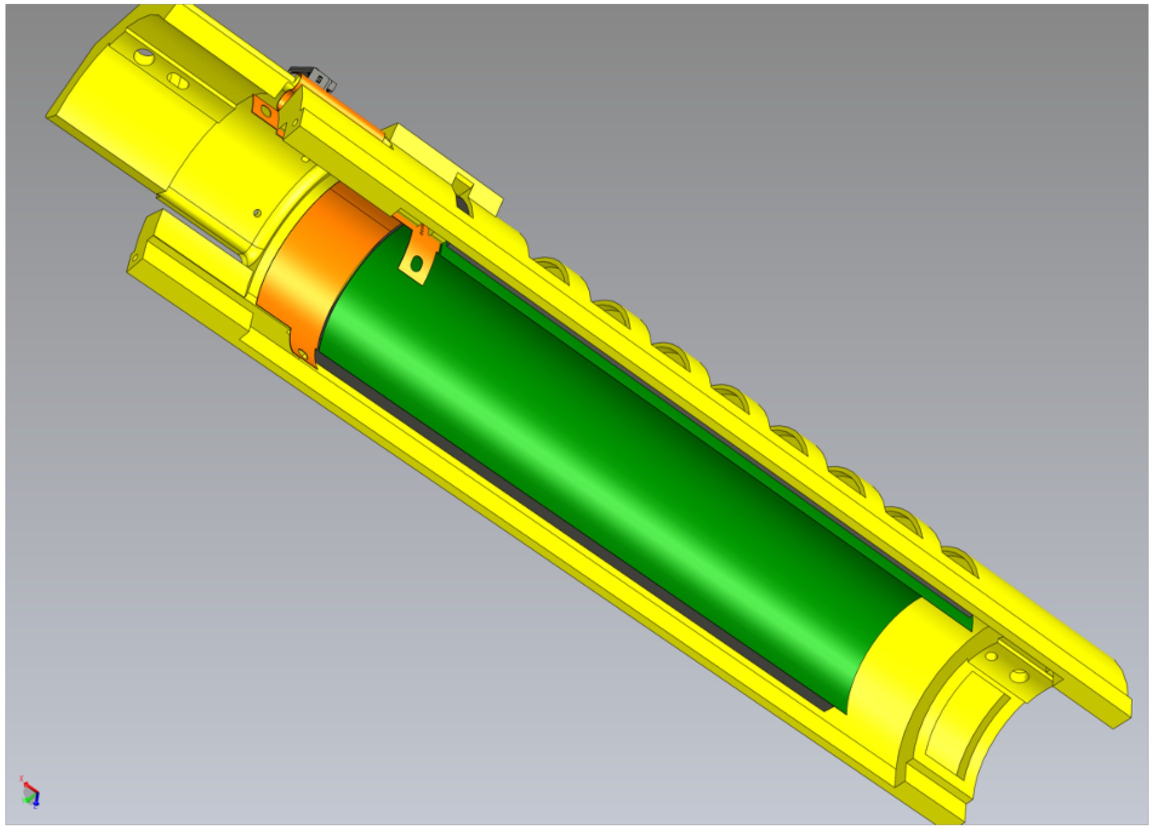
» **Super-ALPIDE**
- 18 not diced ALPIDE chips
- dimensions close to the ones for L0 sensor

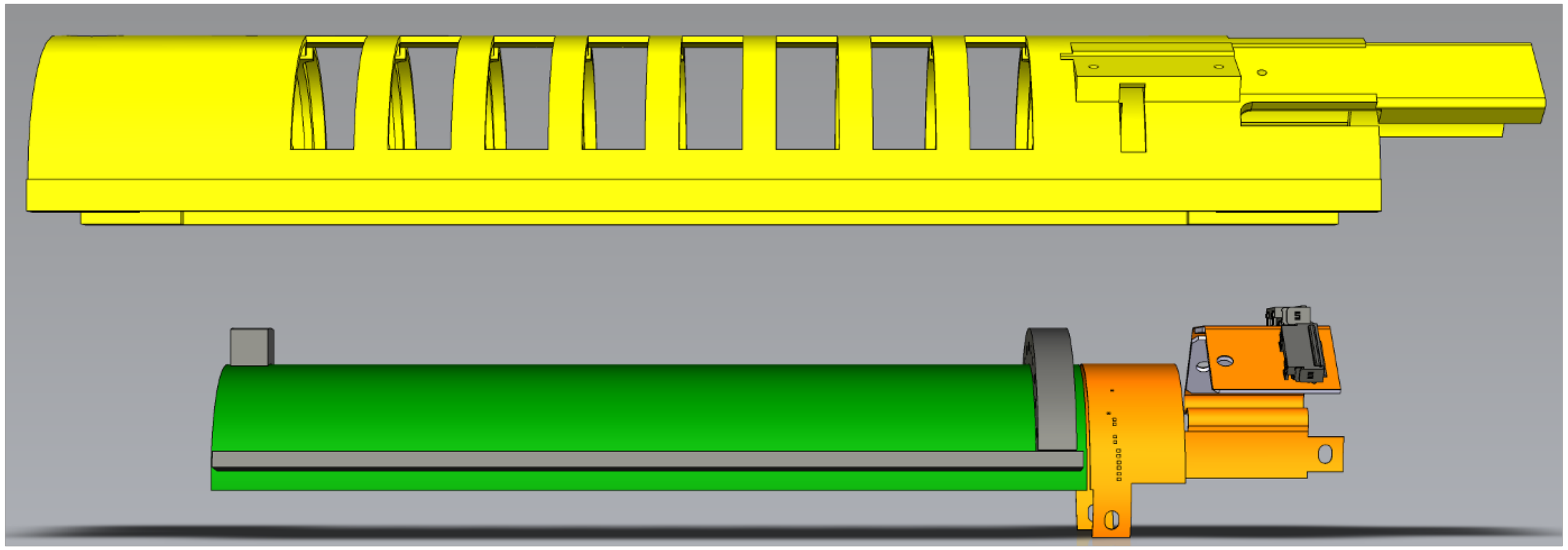
» Goals
- verify bending tools for large-size working chips
- verify mechanical support alignment tools
- develop wire-bonding over bent surface tools
- develop first bent flex prototype (for powering and data streaming)
- assemble first working large dimension bent sensor

Detector integration: a truly cylindrical detector

TOWARD FIRST WORKING LARGE DIMENSION SENSOR



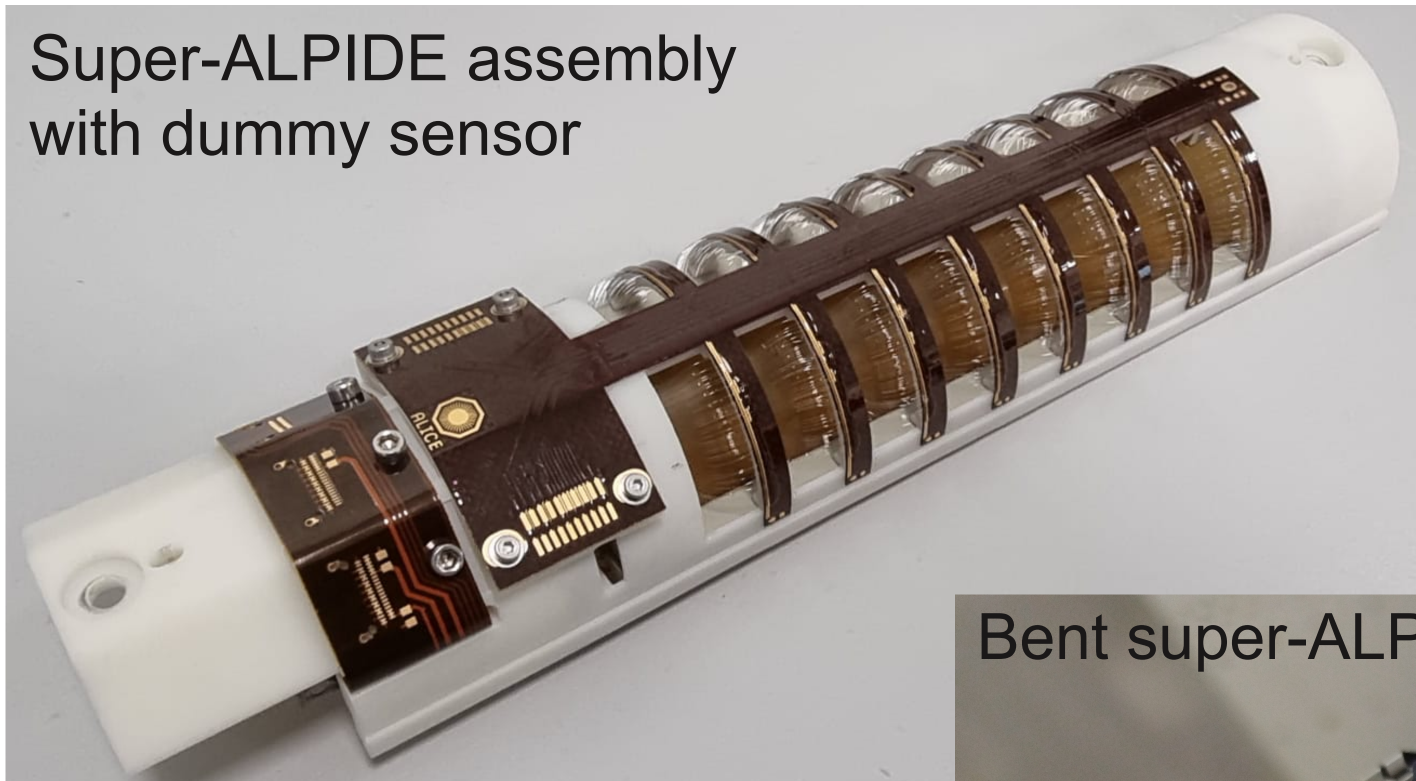


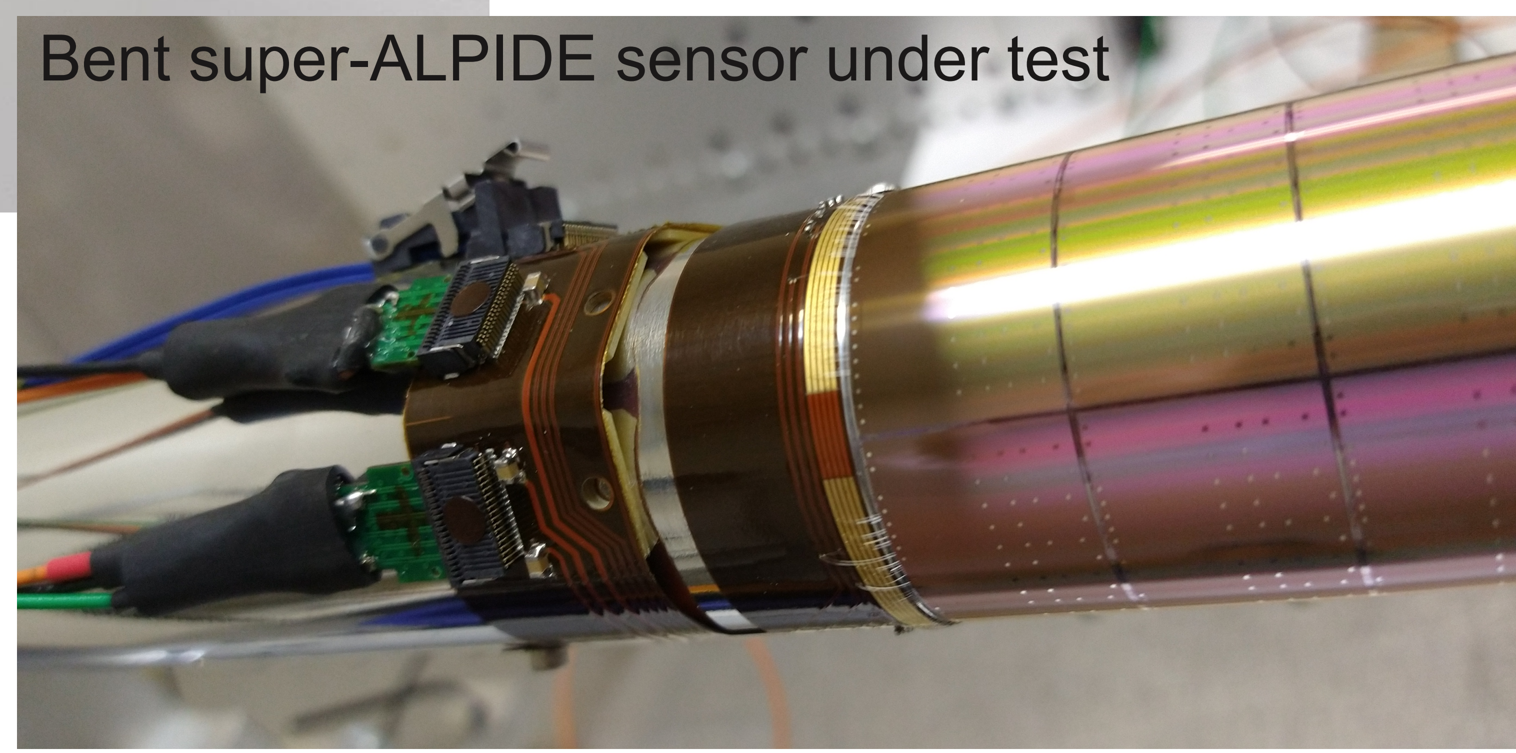


Five main components
- super-ALPIDE
- support structures
- exoskeleton
- edge-FPC
- exo-FPC (not shown)

Detector integration: a truly cylindrical detector

TOWARD FIRST WORKING LARGE DIMENSION SENSOR

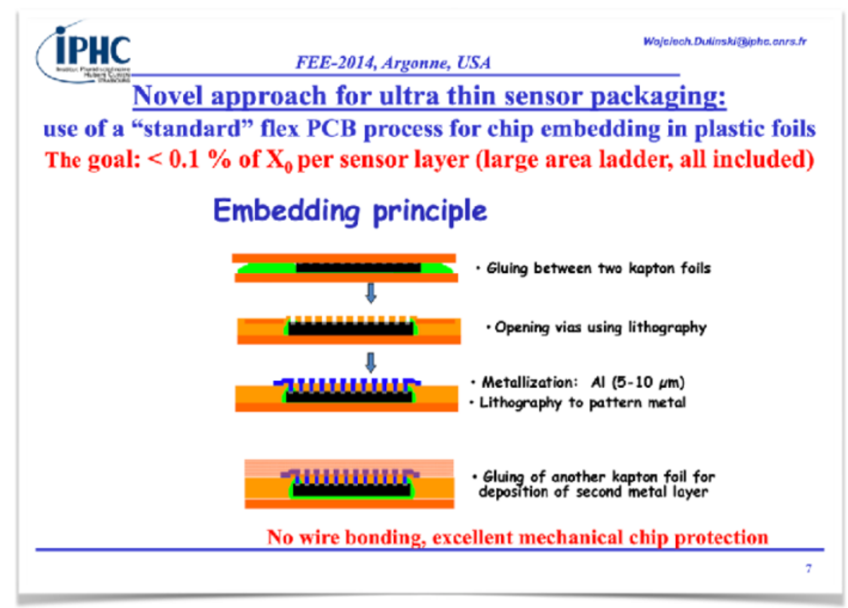

Super-ALPIDE assembly with dummy sensor

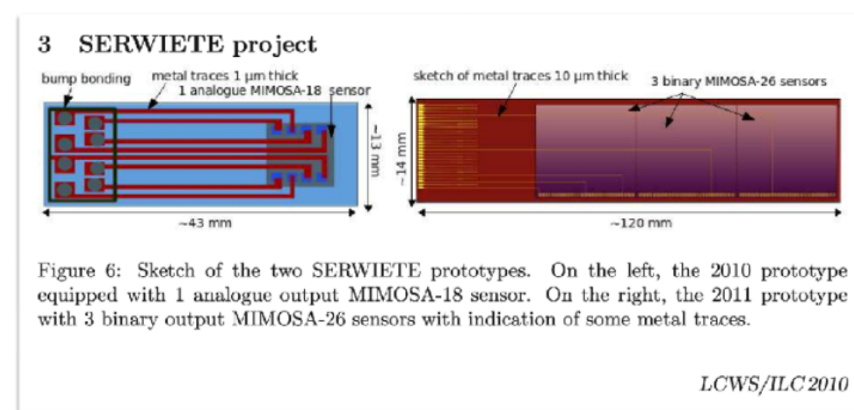

Bent super-ALPIDE sensor under test

R&D activities - Embedded MAPS

Idea
and history

- I learned about a similar technique *(and forgot about it in-between)*, at FEE2014 (Argonne): https://indico.cern.ch/event/276611/contributions/622863/attachments/502969/694527/dulinski_FEE-2014.pdf
- This actually followed the SERWIETE idea: https://arxiv.org/abs/1006.5424
- To my knowledge it was not followed up much further, and had two difficulties:
  - redistribution layer on the chips was necessary since the chips had small pads
  - It required on Al metallisation (good for material budget, bad for using standard techniques)



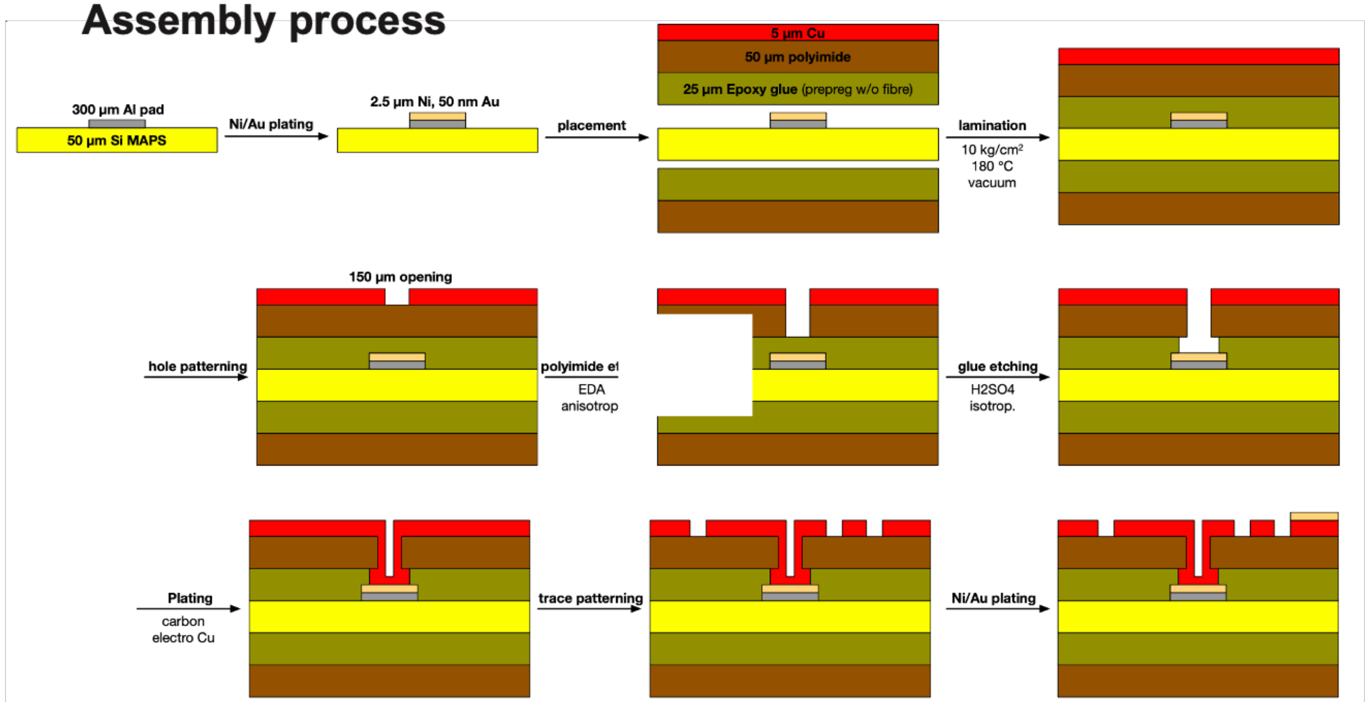


Magnus Mager (CERN) | ITS3 WP4 | 28.04.2022 | 2

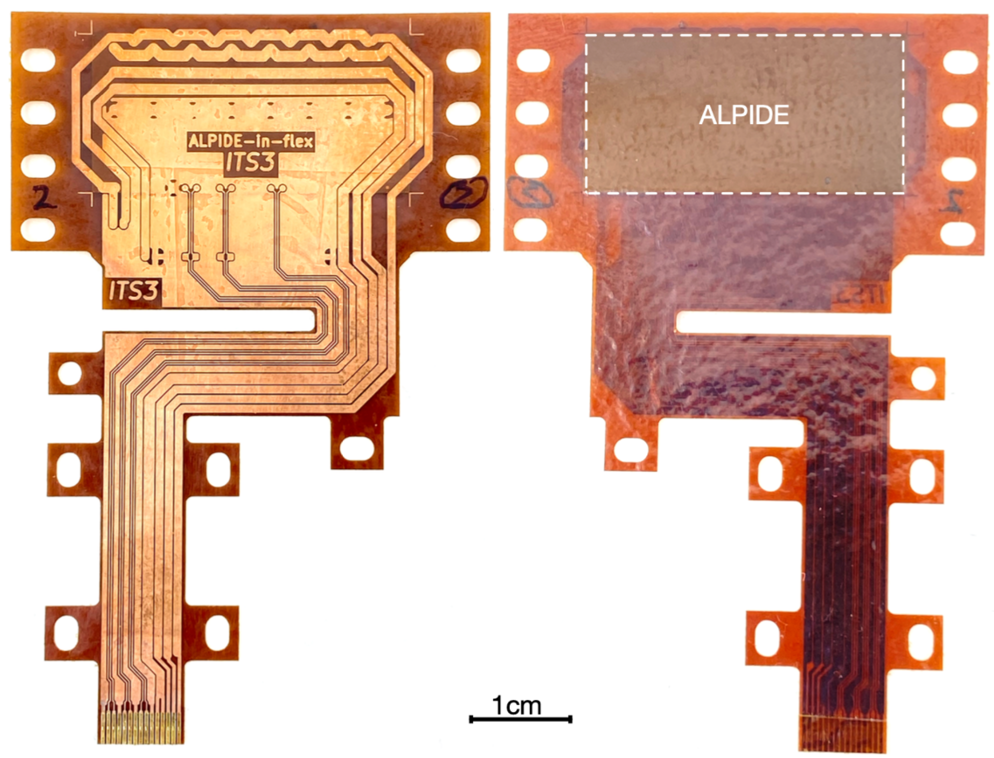
Detector integration: a truly cylindrical detector

R&D activities - Embedded MAPS

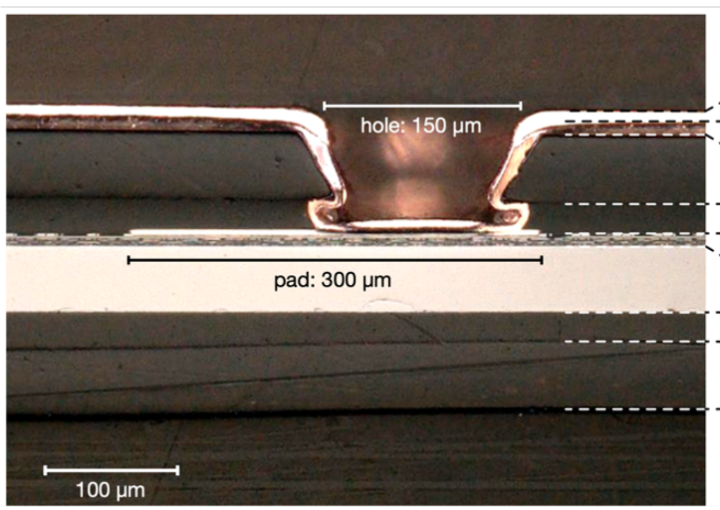
Assembly process



arXiv:2205.12669v1



Cross-section through one interconnection



part	thickness	radiation length
Cu plating	13 µm	(0.06%)
Cu gladding	5 µm	(0.07%)
Polyimide	45 µm	0.02%
glue	25 µm	0.01%
metal stack	10 µm	0.01%
silicon	45 µm	0.05%
glue	25 µm	0.01%
Polyimide	45 µm	0.02%
total:	**213 µm**	**0.11%** (+ 0.13% Cu)

Summary

- **ECFA Detector R&D Roadmap (10.17181/CERN.XDPL.W2EX)**

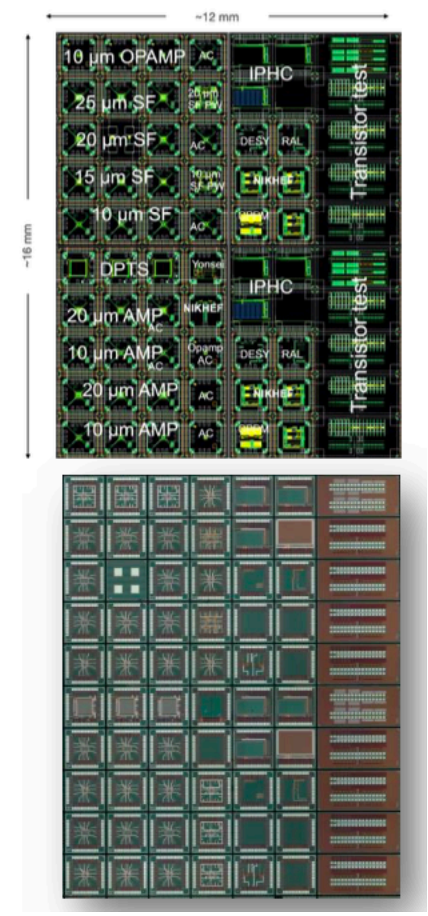
  Solid State Detectors Task Force identified essential Detector R&D themes

  1. Achieve full integration of sensing and microelectronics in monolithic CMOS pixel sensors
  2. Develop solid state sensors with 4D-capabilities for tracking and calorimetry
  3. Extend capabilities of solid state sensors to operate at extreme fluences
  4. Develop full 3D-interconnection technologies for solid state devices in particle physics

Backup

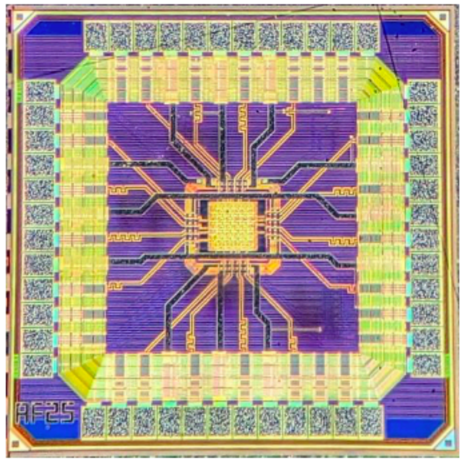
First test submission: MLR1

- Main goals:
  - Learn technology features
  - Characterize charge collection
  - Validate radiation tolerance
- Each reticle (12×16 mm^2):
  - 10 transistor test structures (3×1.5 mm^2)
  - 60 chips (1.5×1.5 mm^2)
    - Analogue blocks
    - Digital blocks
    - **Pixel prototype chips: APTS, CE65, DPTS**
- Submitted in December 2020
- Received diced chips in July 2021



APTS: Analogue Pixel Test Structure

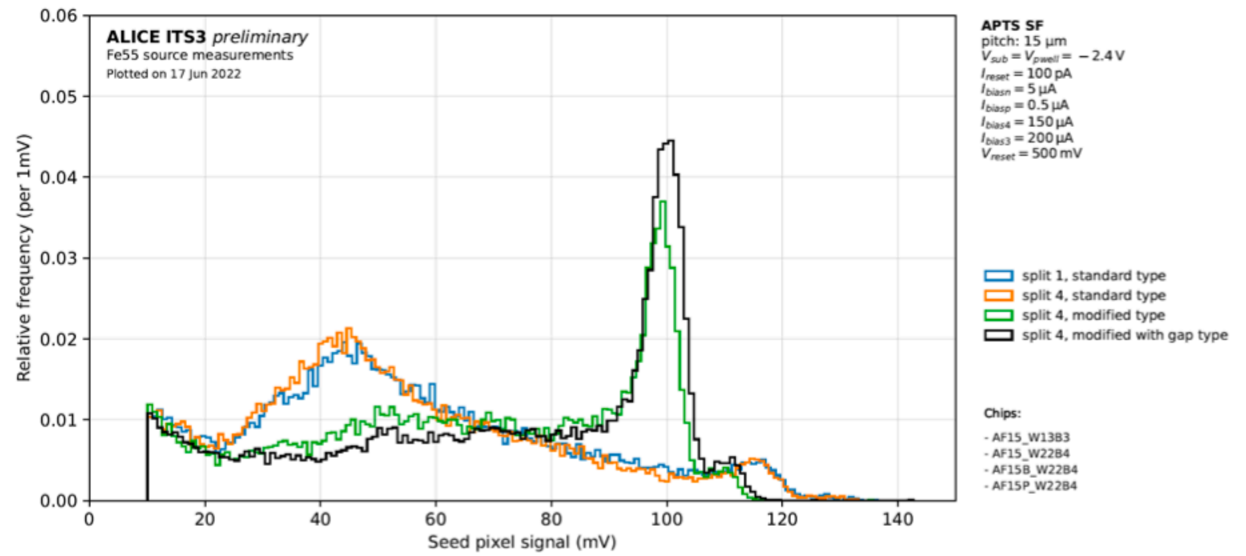
- 6×6 pixel matrix
- Direct analogue readout of central 4×4 submatrix
- Two types of output drivers:
  - Traditional source follower (APTS-SF)
  - Very fast OpAmp (APTS-OA)
- AC/DC coupling
- 4 pitches: 10, 15, 20, 25 µm
- 3 process variations
- Presented results with ^{55}Fe source



APTS-SF: Process modification reduces charge sharing

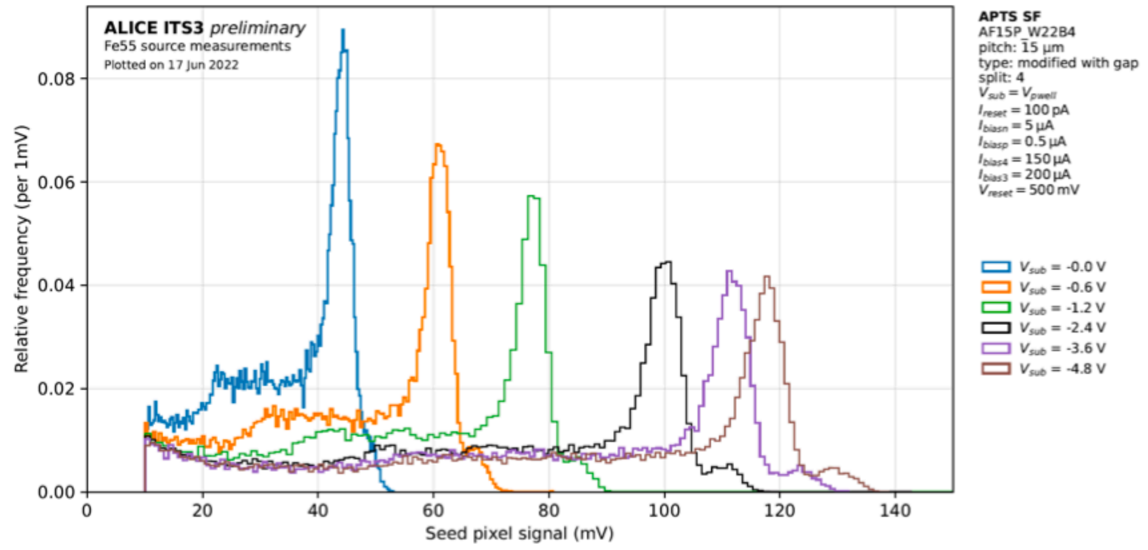
- In standard process seed pixel takes ~50% of charge
- In modified process most of the charge is collected in one pixel

Effect on efficiency and spatial resolution to be verified at beam test



APTS-SF:
Substrate bias amplifies the signal

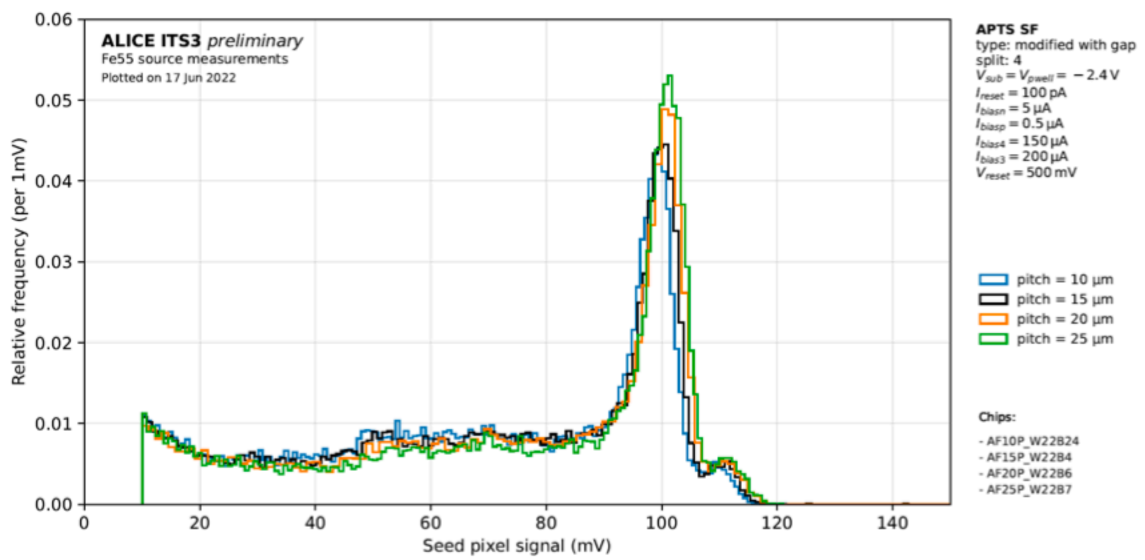
- Substrate bias lowers the node capacitance and increases signal amplitude
- Values as low as 2.2 fF were observed



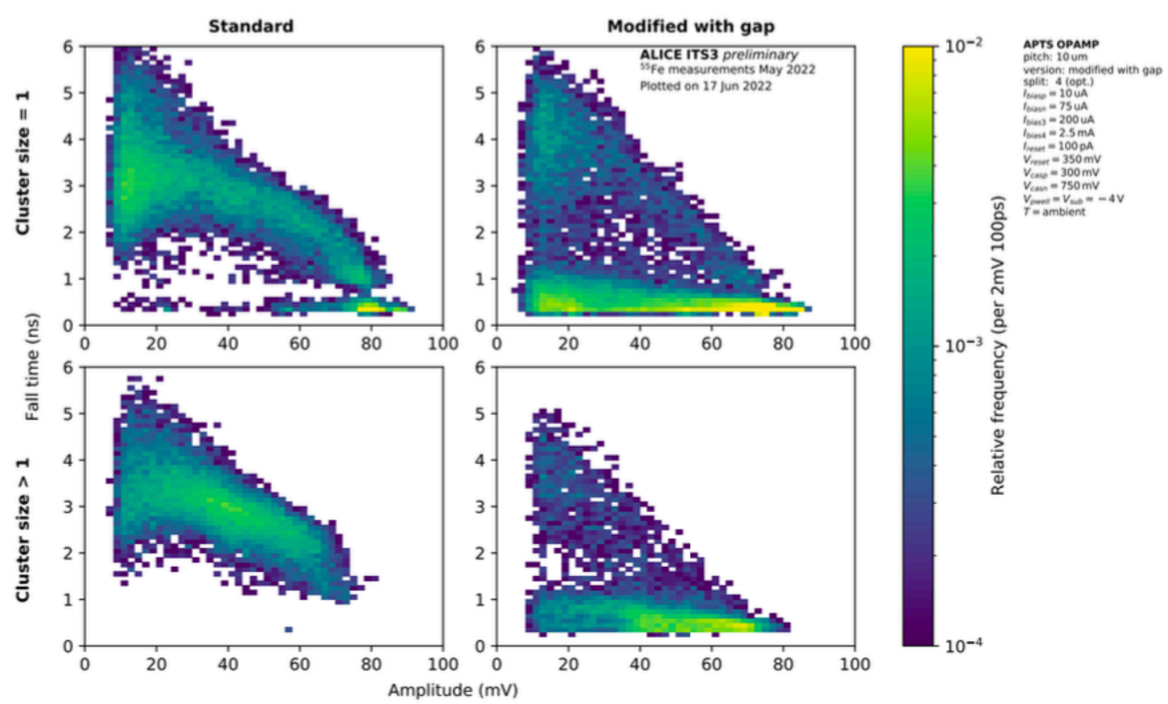
Backup

APTS-SF:
Charge collection vs. pixel pitch

- Charge collection doesn't seem to depend on pixel pitch
- Remarkable result to be confirmed by beam test
- If confirmed – another way to reduce power consumption



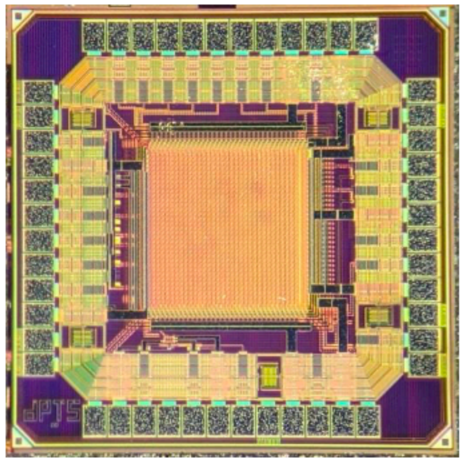
APTS-OA: Process modification reduces charge collection time



- Fast readout allows to estimate the charge collection time via signal fall time
- In modified process the charge is collected faster

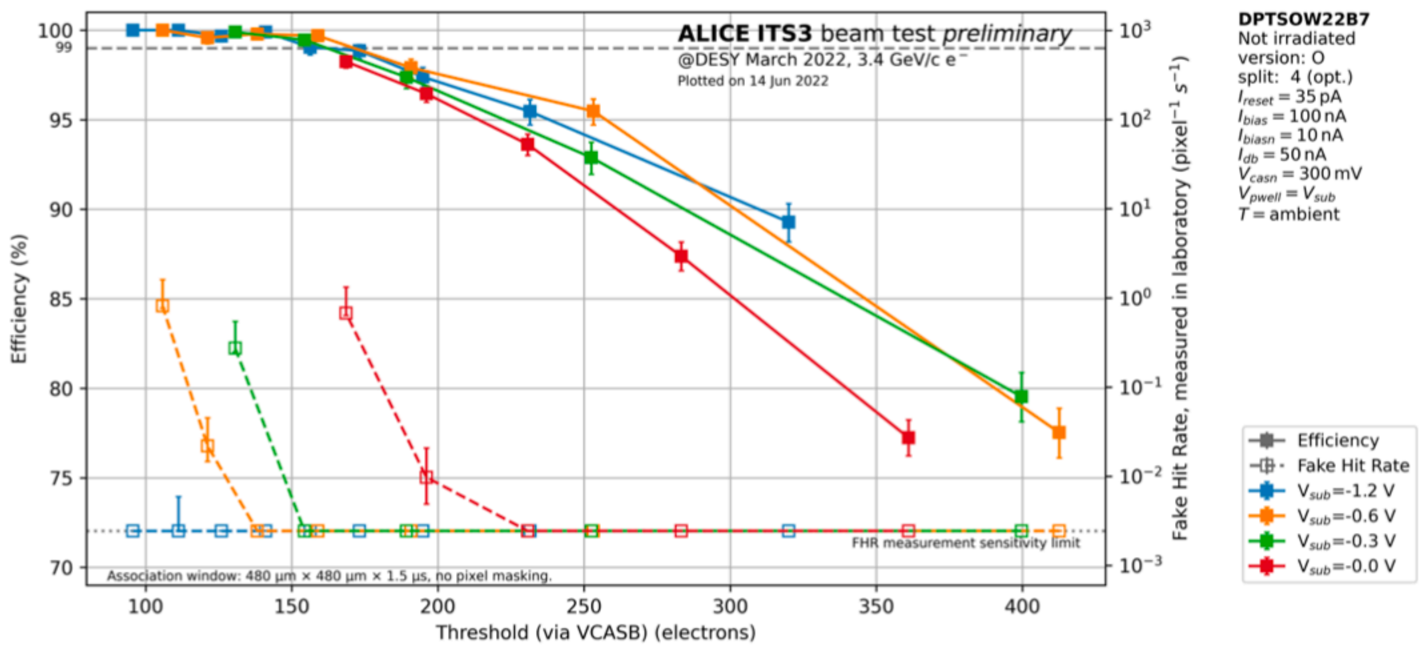
DPTS: Digital Pixel Test Structure

- 32×32 pixel matrix
- Asynchronous digital readout
- Time-over-Threshold information
- Pitch: 15×15 μm^2
- Only "modified with gap" process modification
- Tunable Power vs Time resolution



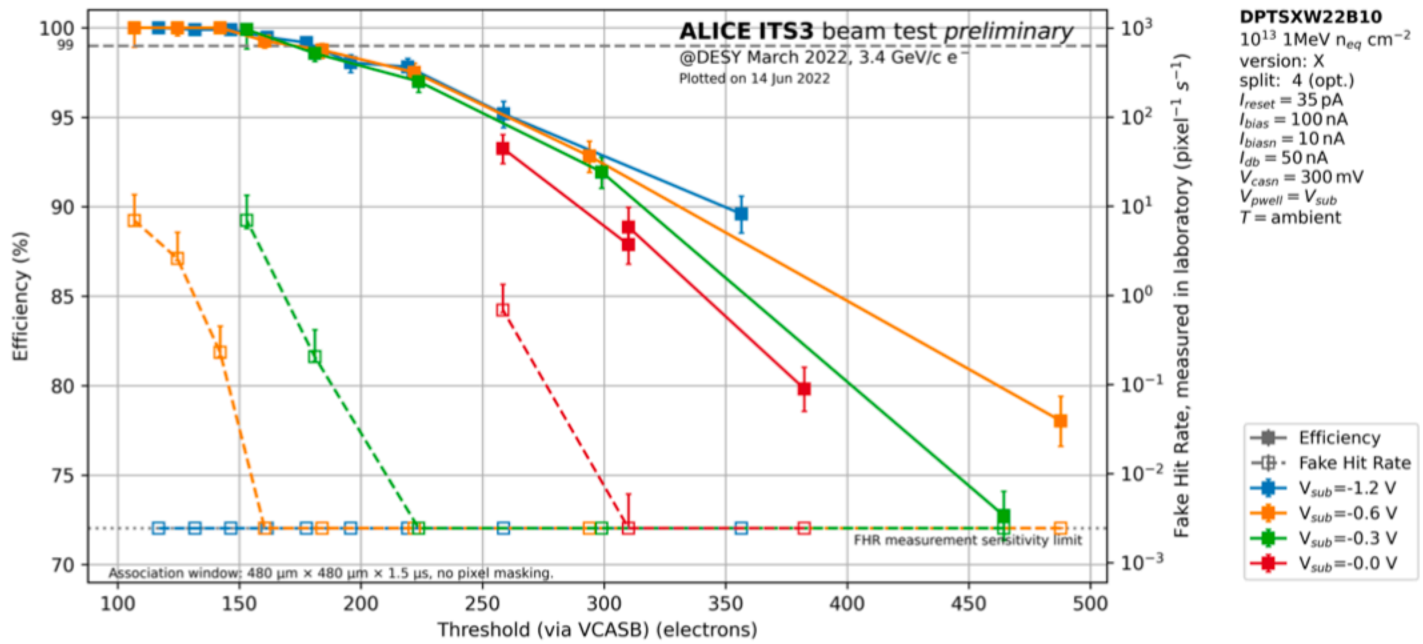
Backup

Non irradiated DPTS:
Excellent efficiency and low fake hit rate



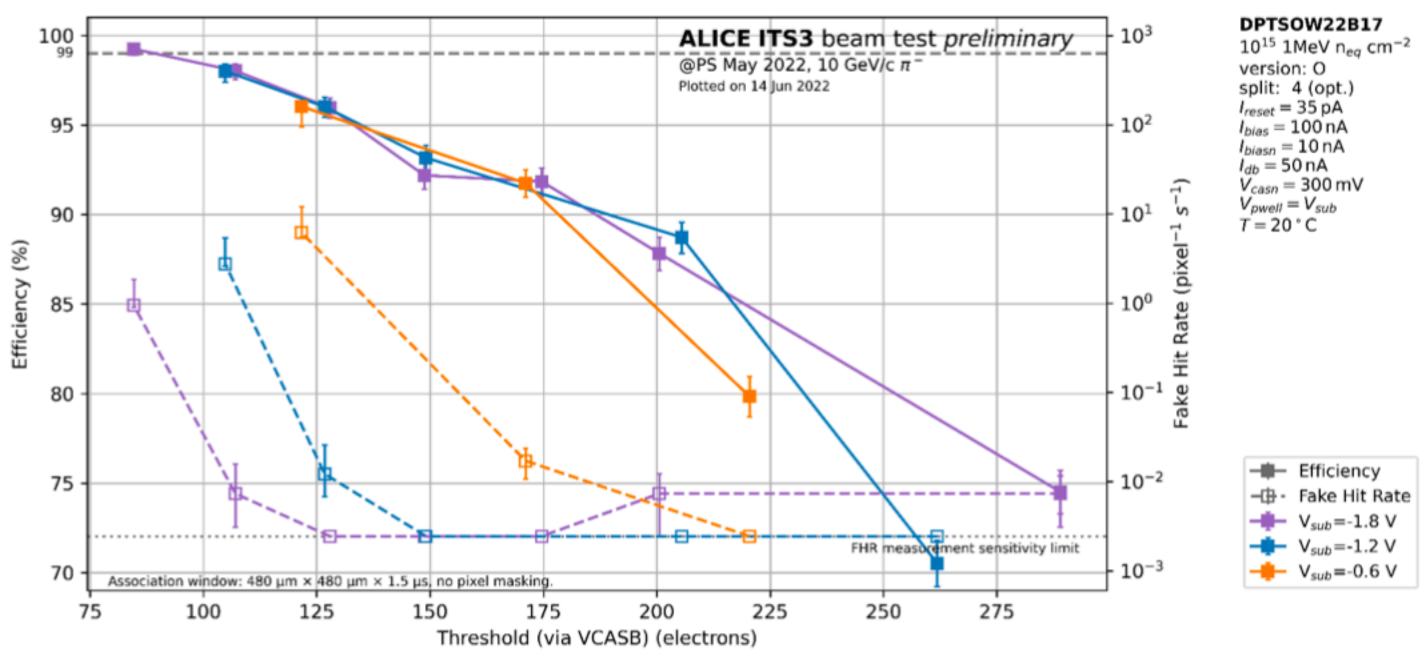
Backup

Irradiated DPTS (10^{13} n_{eq}): Larger fake hit rate, but has margin

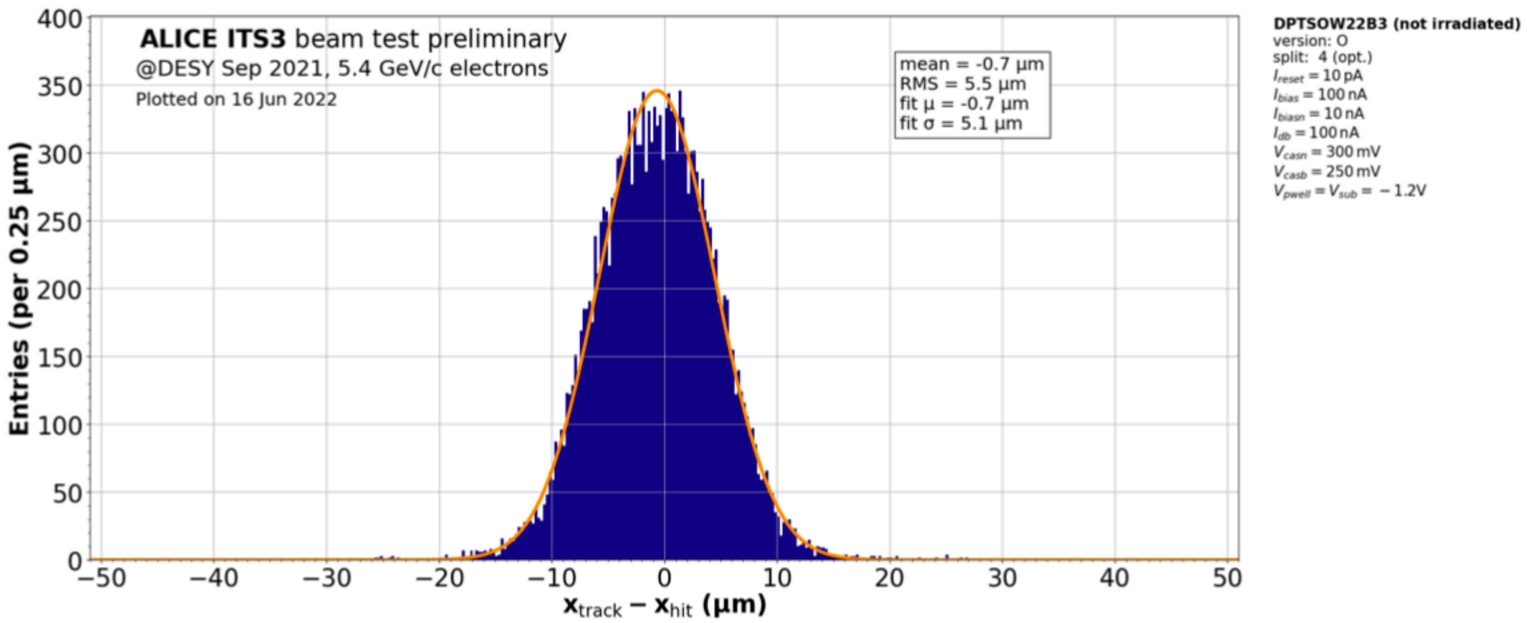


Backup

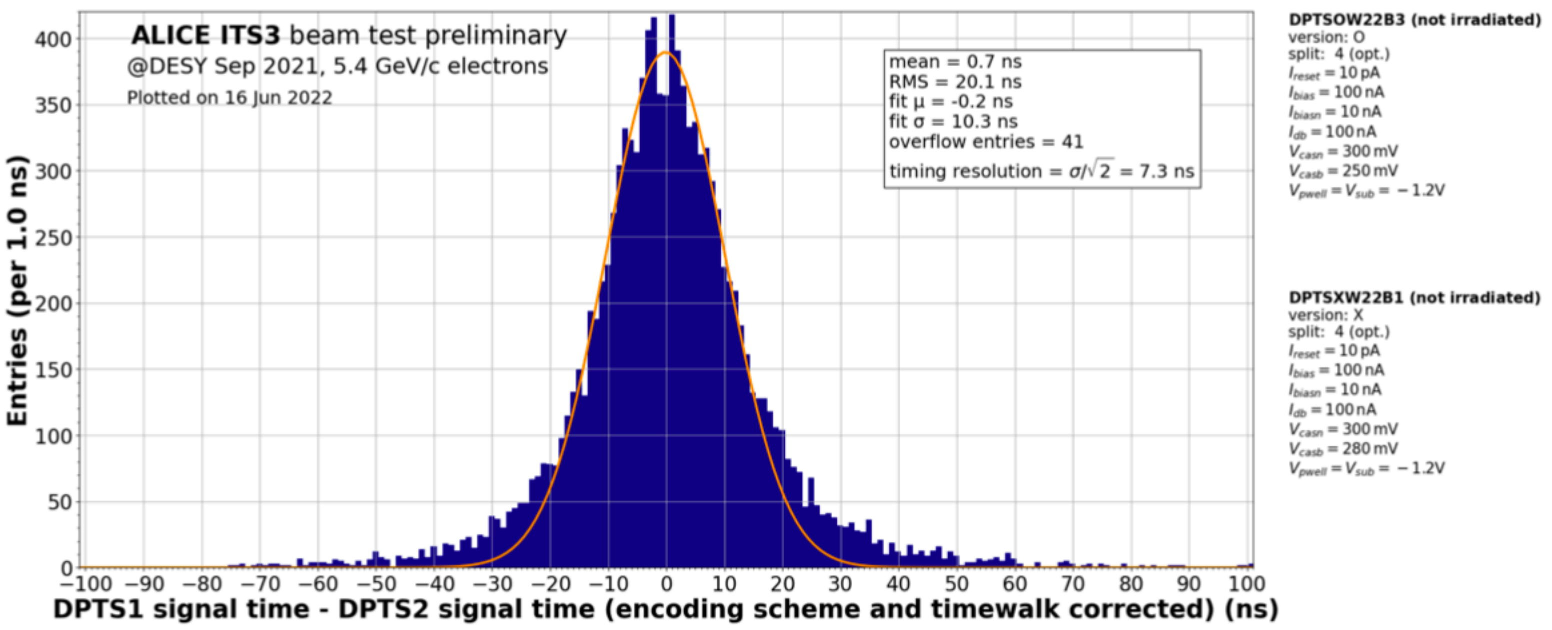
Irradiated DPTS (10^{15} n_{eq}):
Efficient at 20 °C with limited fake hit rate



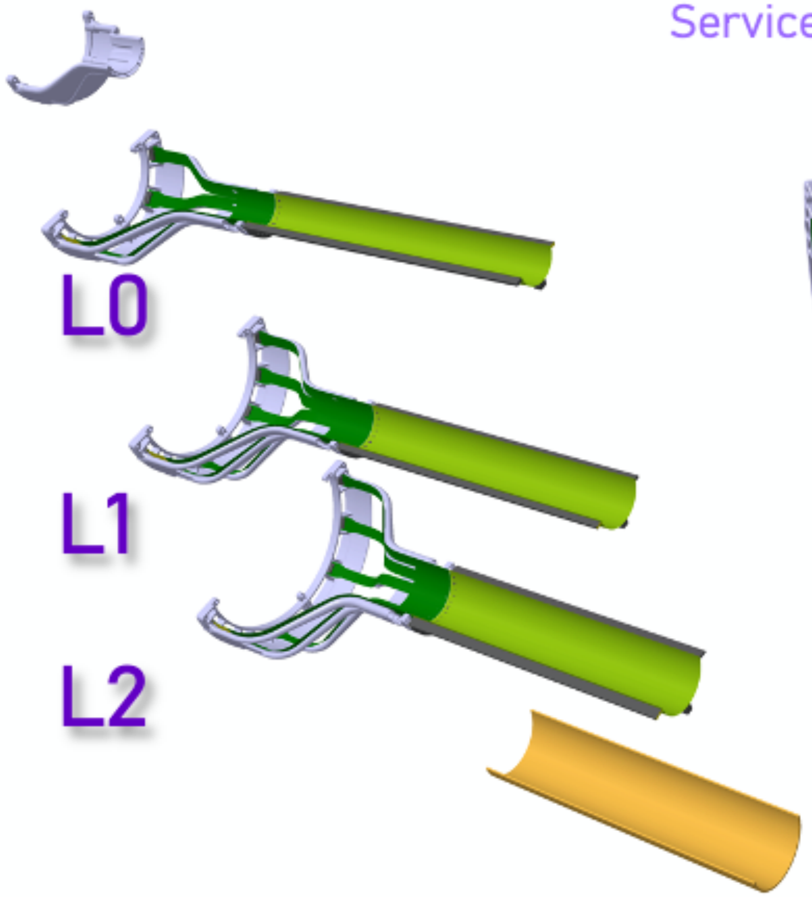
DPTS: Spatial resolution ~5 µm



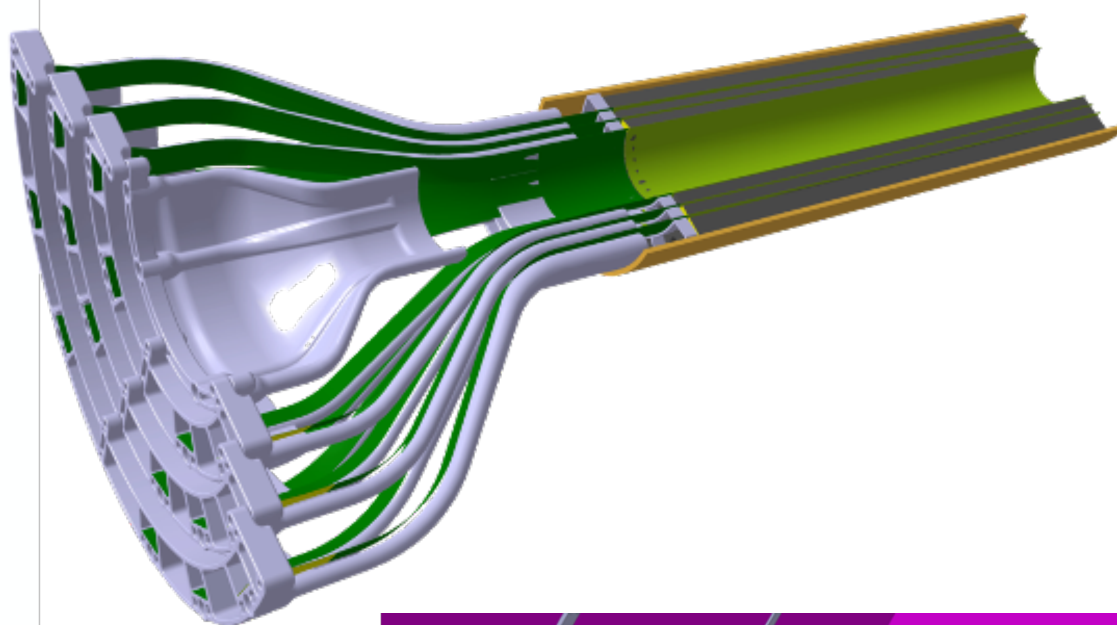
DPTS: Temporal resolution ~7 ns

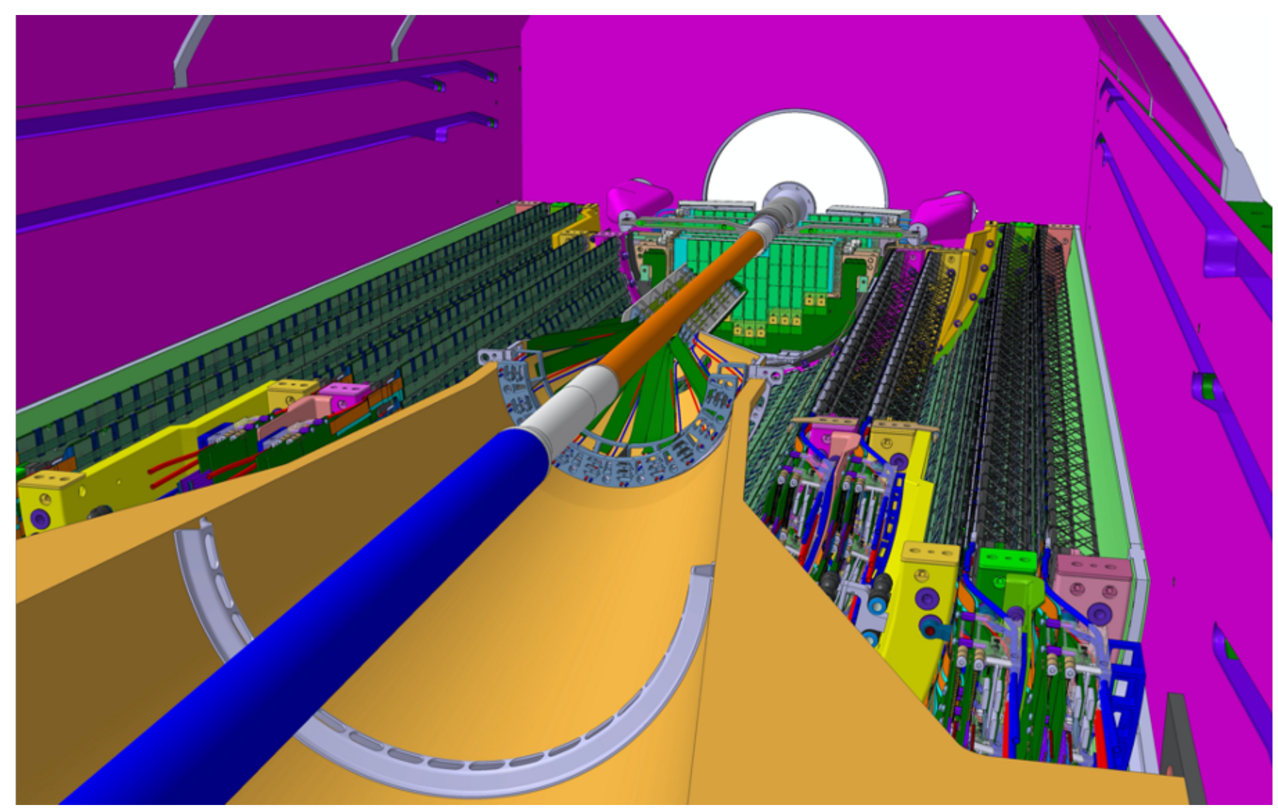


Backup

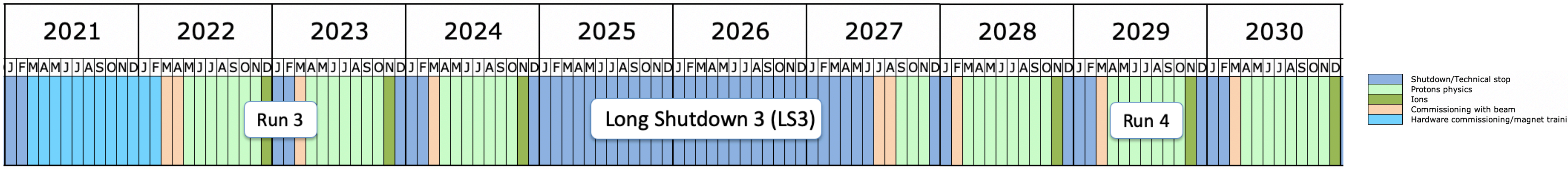


Service pigtail adds a challenge to the assembly sequence



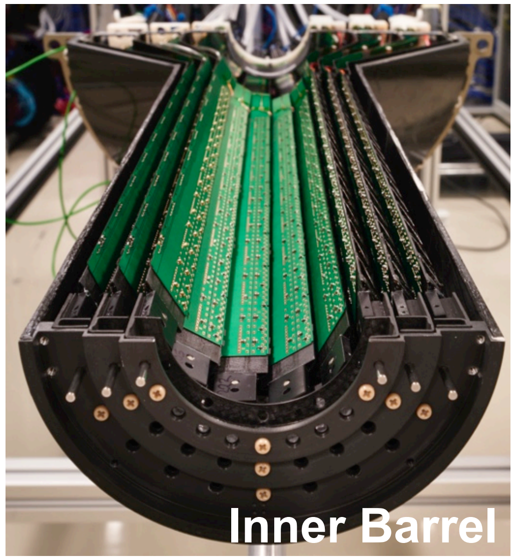


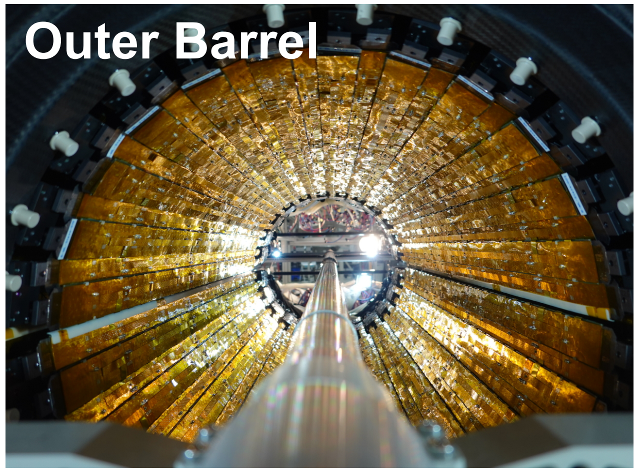
Backup



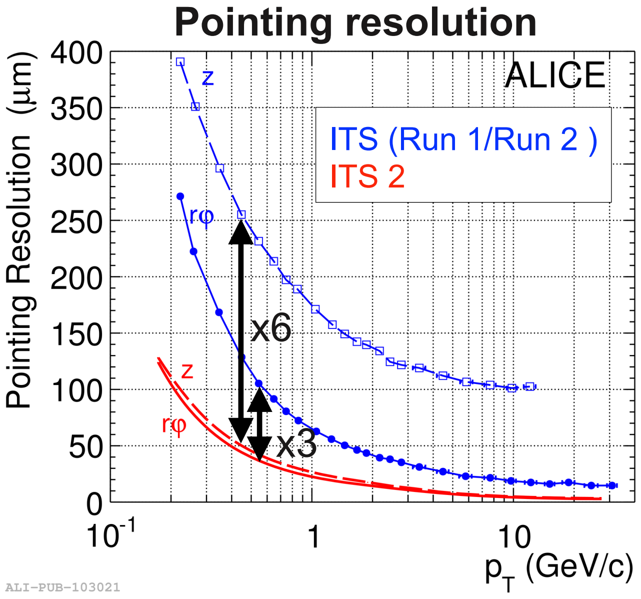
ALICE 2

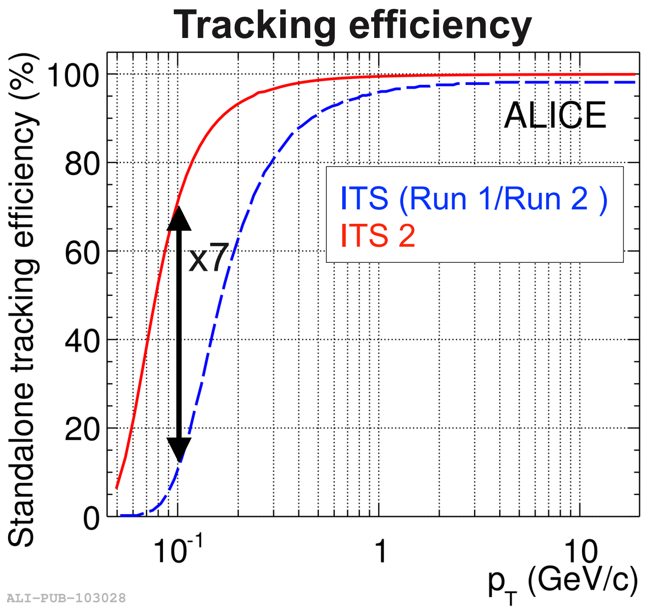
ITS2 for LHC Run 3





ITS2 installed and under commissioning

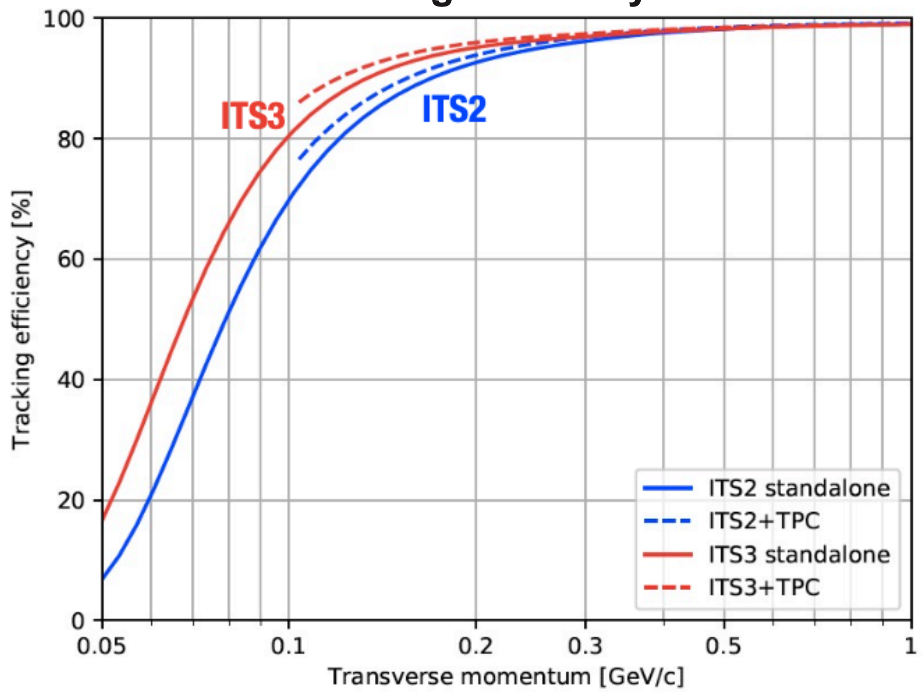




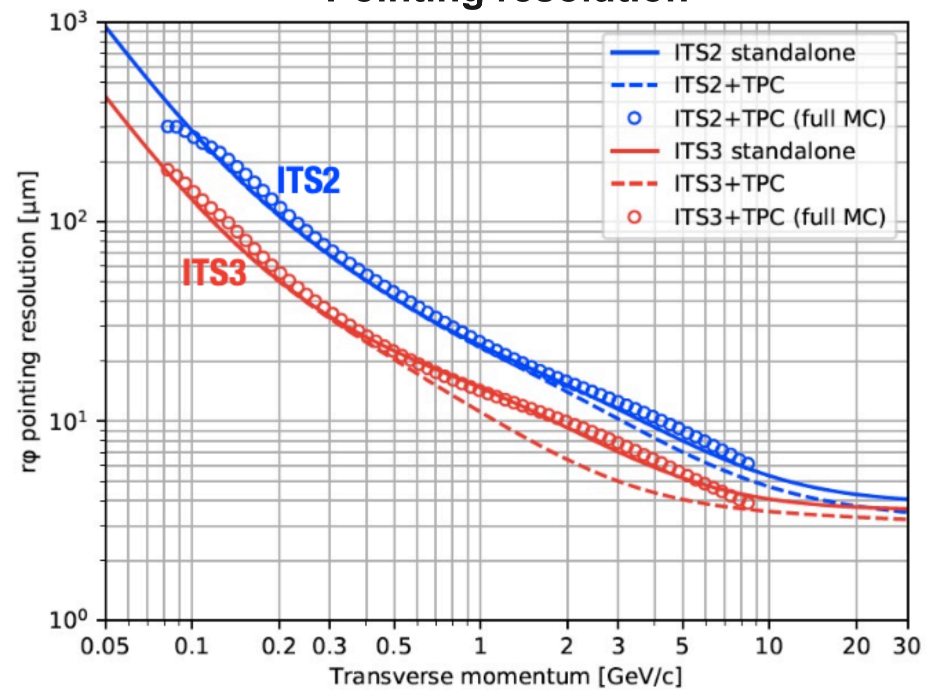
ITS2 will provide unprecedented performances
→ pointing resolution: 15 µm at p_T of 1 GeV/c
→ tracking efficiency: above 90% for p_T > 200 MeV/c

Backup

Tracking efficiency



Pointing resolution

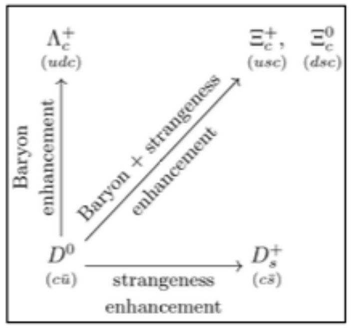


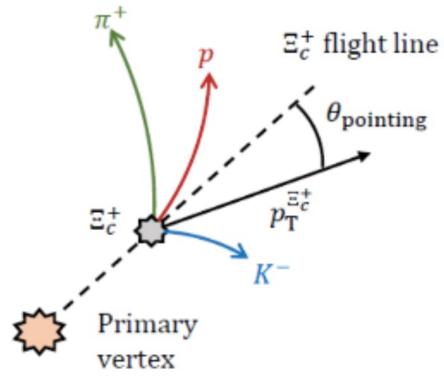
Improved pointing resolution and tracking efficiency for low momenta (×2 at all p_T)

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

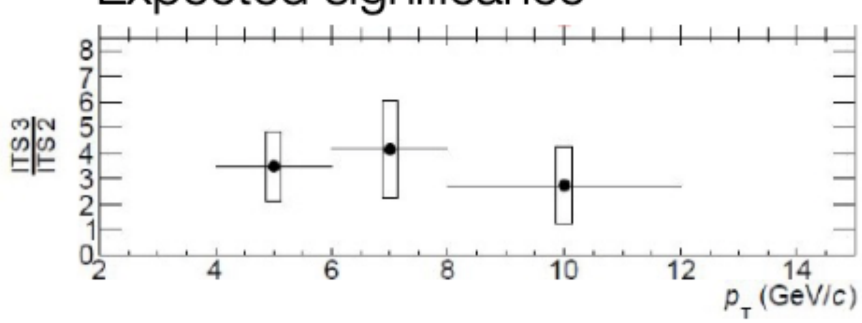
» Λ_C^+ and D_S^+ used to study baryon and strangeness enhancement (compared to D^0)

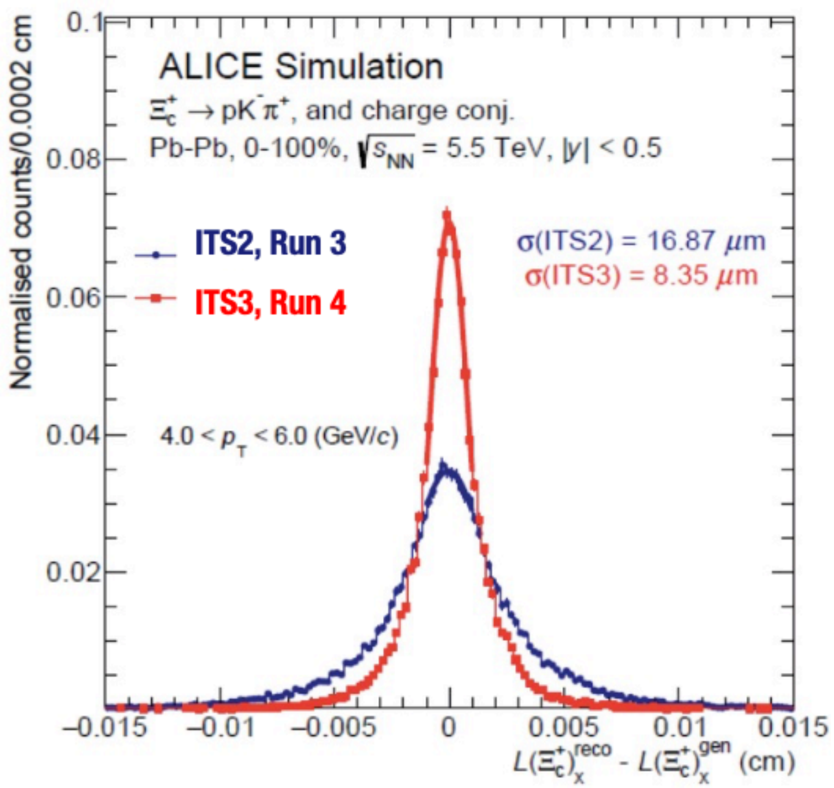
» Ξ_C might set very powerful constraints to test HF coalescence models

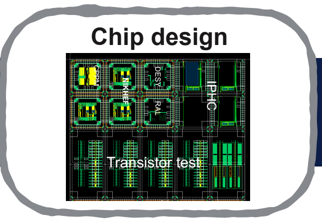




Expected significance

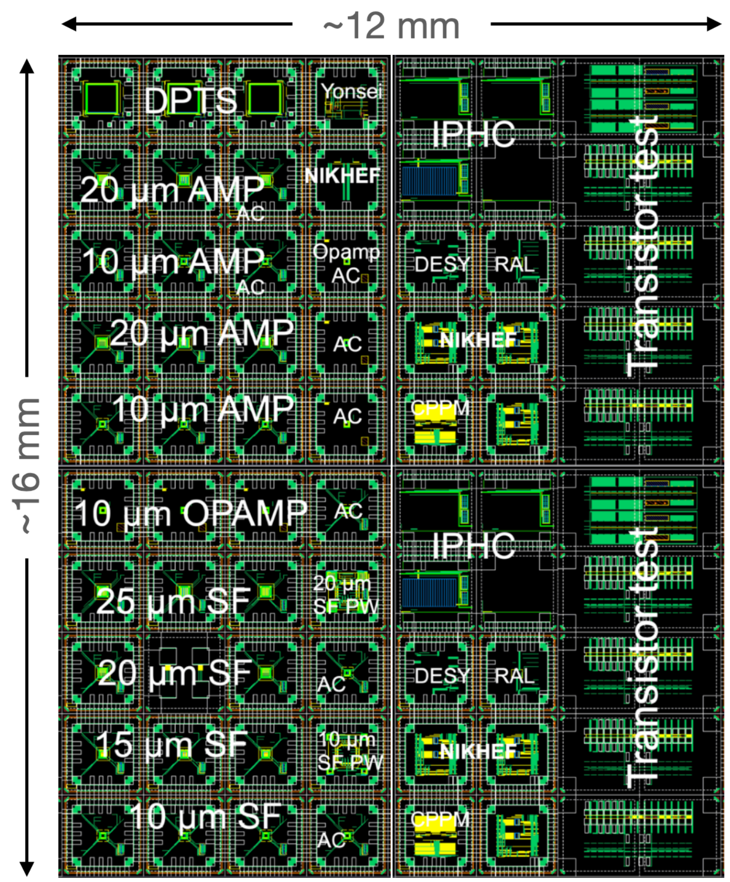






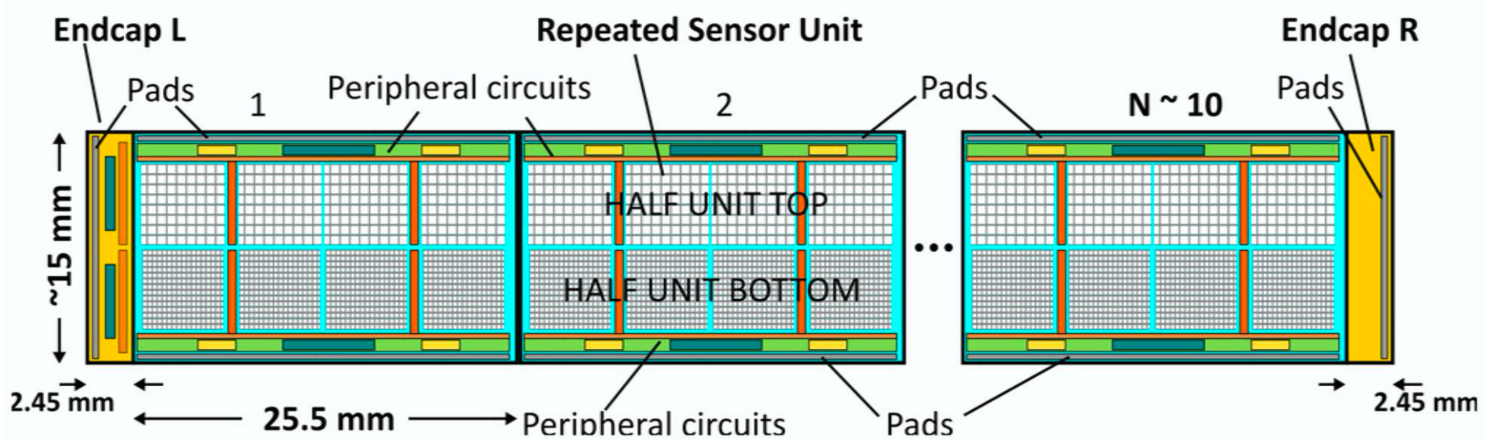
MLR1 SUBMISSION AND TEST + ER1

- » 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

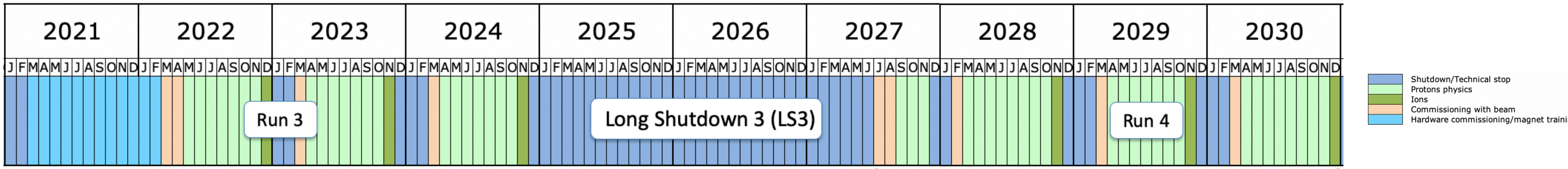


expect O(300) dies per wafer

- » 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

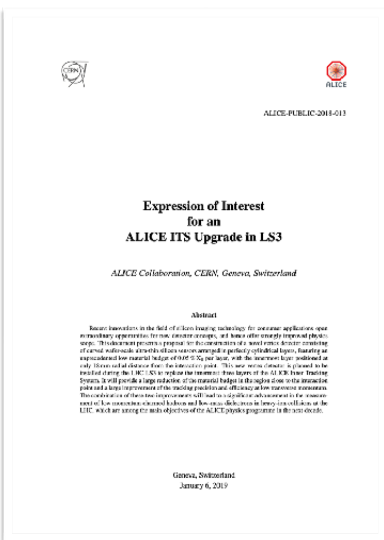


Backup



ALICE 2.1

Expression of Interest


ALICE-PUBLIC-2018-013
Expression of Interest
for an
ALICE ITS Upgrade in LS3
ALICE Collaboration, CERN, Geneva, Switzerland
Abstract
Geneva, Switzerland

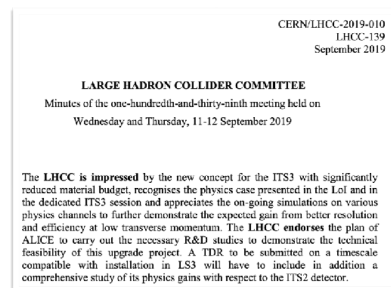
[ALICE-PUBLIC-2018-013]
https://cds.cern.ch/record/2644611

Letter of Intent


Letter of Intent
for an
ALICE ITS Upgrade in LS3
ALICE Collaboration, CERN, Geneva, Switzerland
Abstract
Geneva, Switzerland

[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.

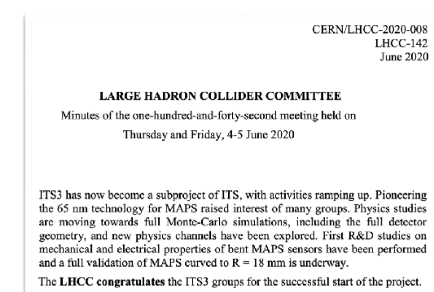
"The LHCC is **impressed** by the new concept for the ITS3…"

Project setup (spring 2020)

- Project leaders
- Work packages conveners
- Institutes joining

R&D kick-off (Dec 2019)

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."

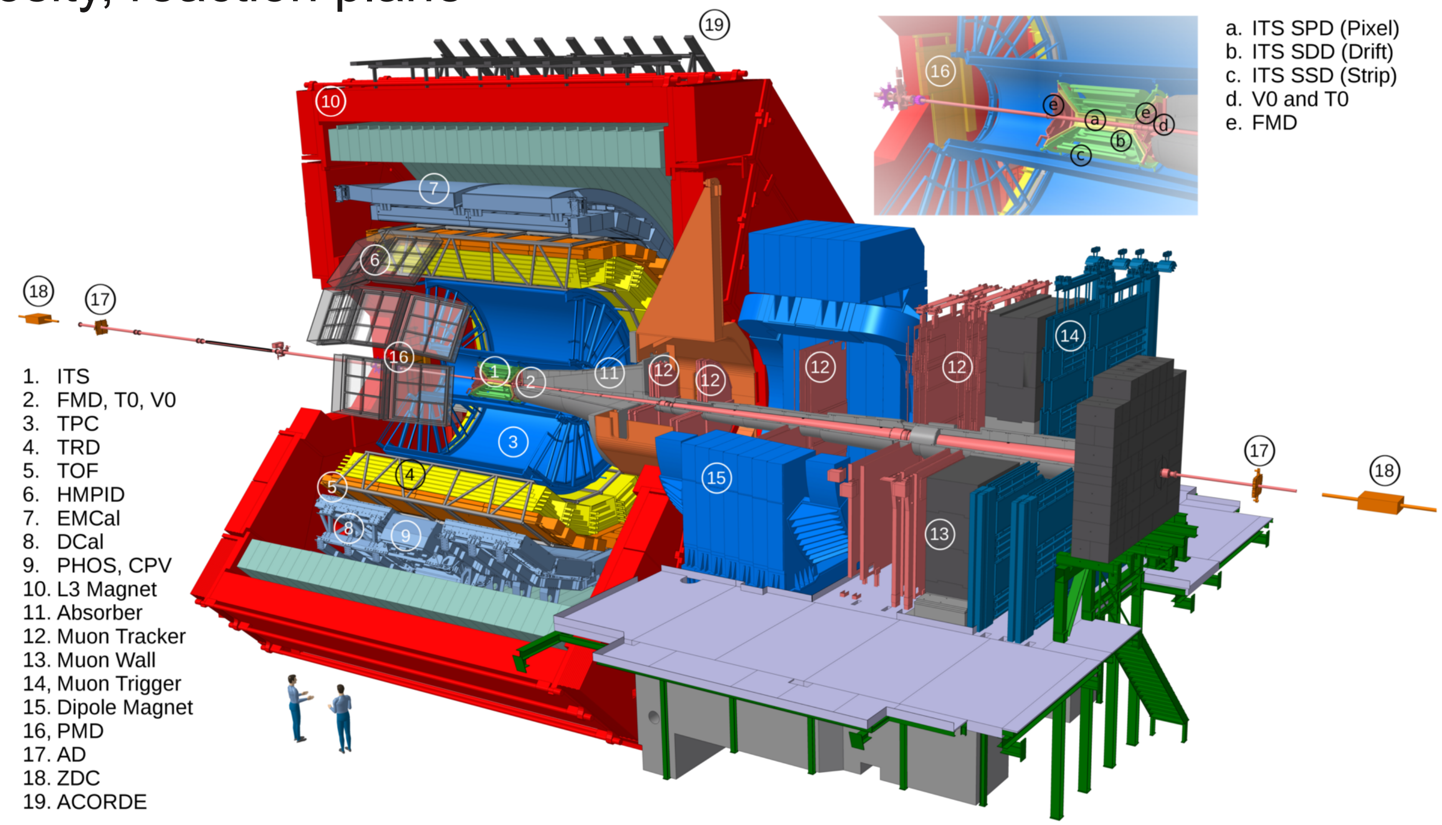
Oct 2018 — **Sep 2019** — **Sep 2019** — **Dec 2019** — **Spring 2020** — **Jun 2020**

Backup

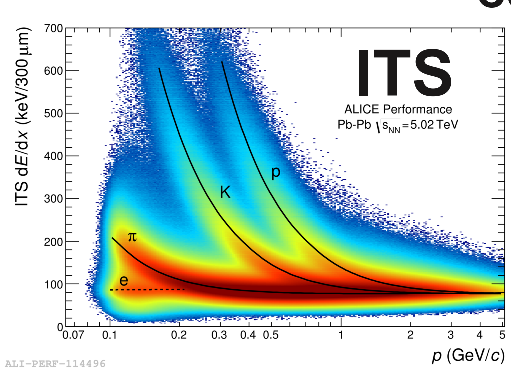
» Central barrel ($-0.9 < \eta < 0.9$)
» Muon spectrometer ($-4.0 < \eta < -2.5$)
» Forward detectors: trigger, centrality, luminosity, reaction plane

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

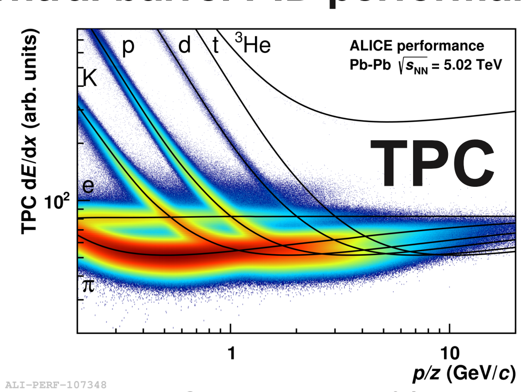
LHC Run 1 and Run 2 data taking		
Colliding System	**Year(s)**	**$\sqrt{s_{NN}}$ (TeV)**
Pb-Pb	2010-2011 2015-2018	2.76 5.02
Xe-Xe	2017	5,44
p-Pb	2013 2016	5.02 5.02, 8.16
pp	2009-2013 2015, 2017 2015-2018	0.9, 2.76, 7, 8 5.02 13



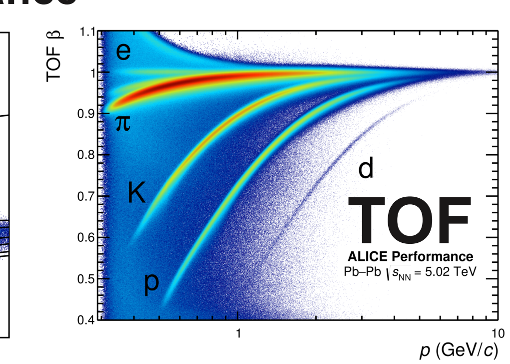
Central barrel PID performance



ITS $\sigma_{dE/dx}$ ~ 10-15%

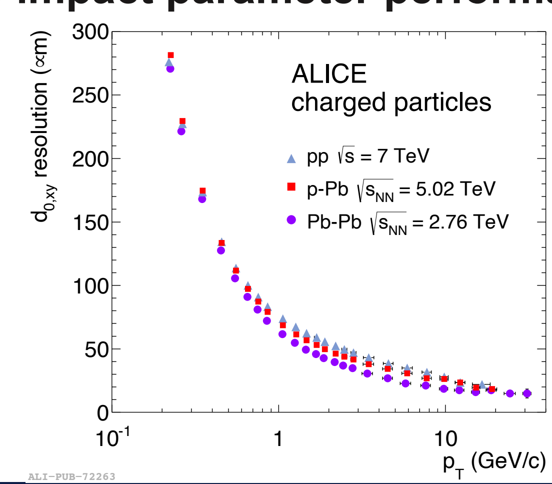


TPC $\sigma_{dE/dx}$ ~ 5%

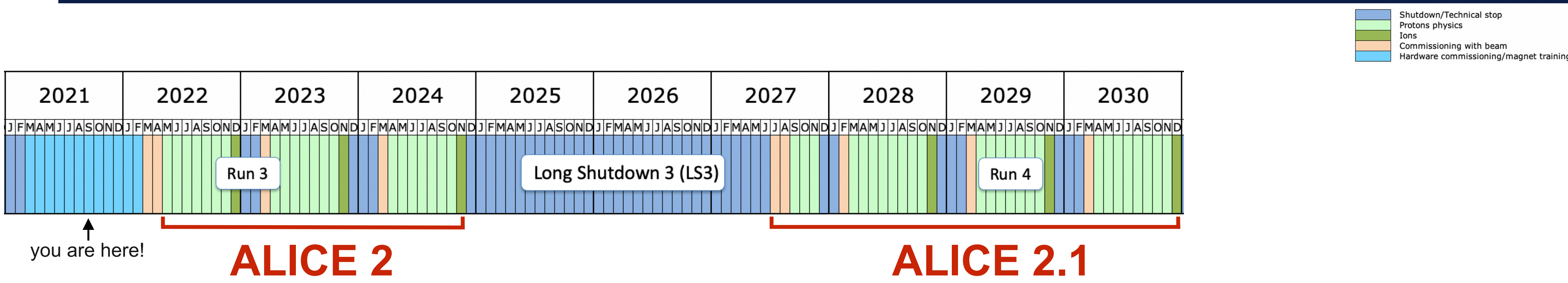


TOF $\sigma_{Time\ Of\ Flight}$ ~ 56 ps

ITS impact parameter performance



Backup



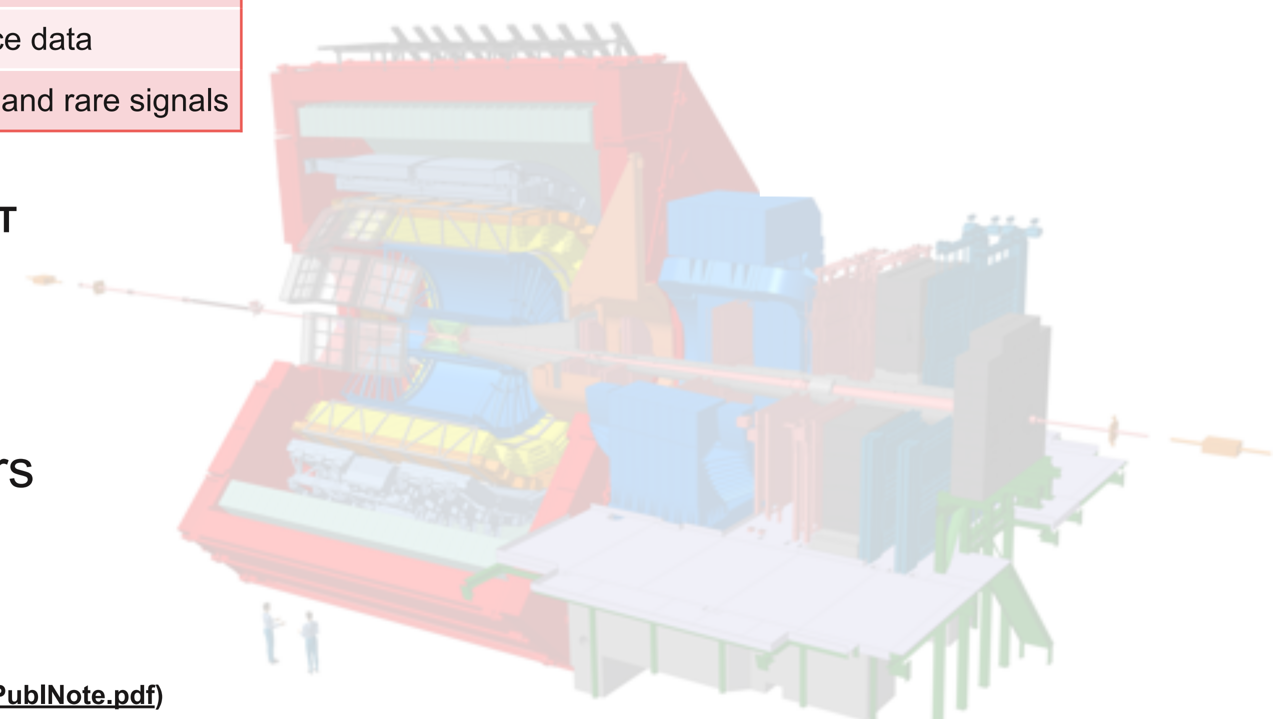
Data taking strategy

» **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

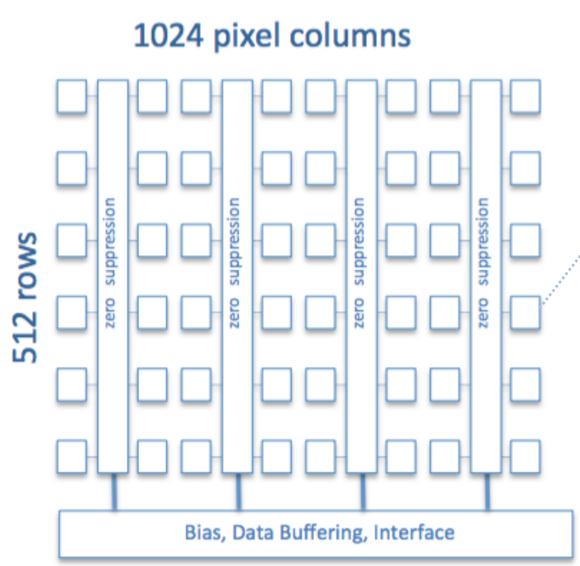
Backup

New Inner Tracking System (ITS 2)

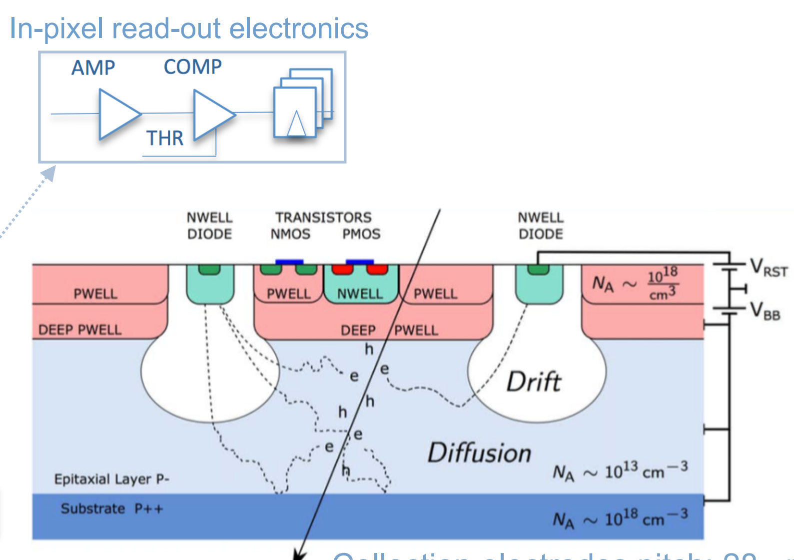
<u>Based on the ALPIDE Monolithic Active Pixel Sensor</u>

- » In-pixel amplification, shaping discrimination and Multiple-Event Buffers (MEB)
- » In-matrix data sparsification
- » High detection efficiency (>99%) and low fake-hit rate (<< 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

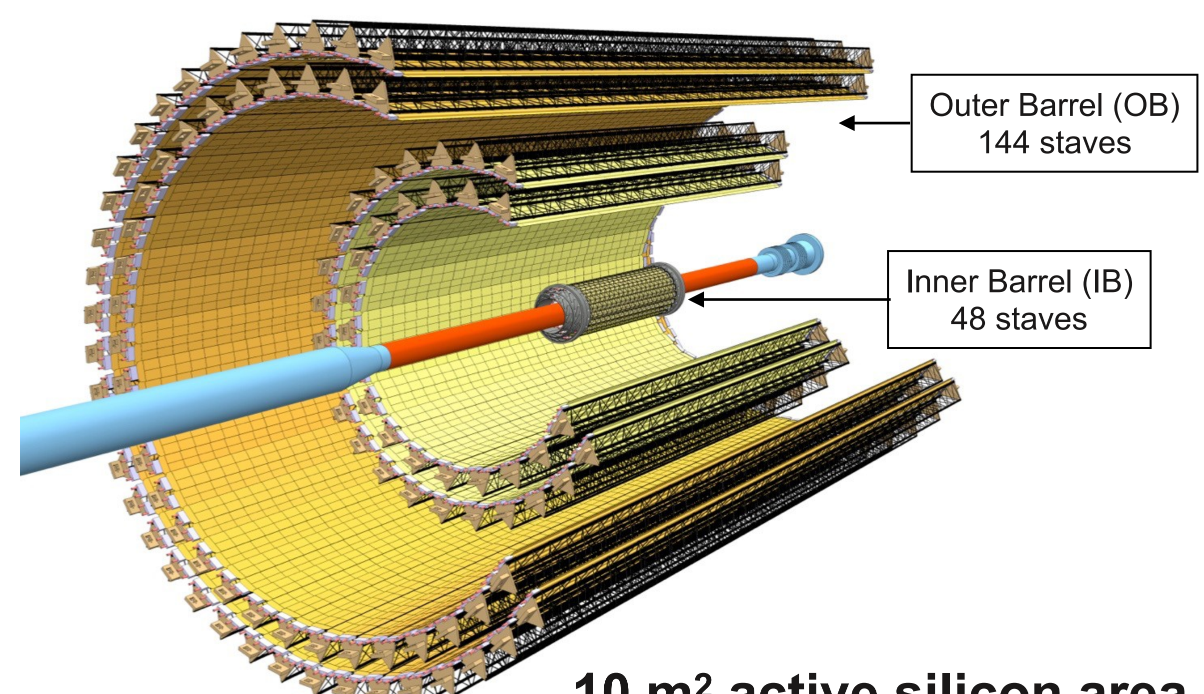
	ITS (Run 1/Run 2)	ITS 2
Number of layers	6 (pixel, drift, μstrip)	7 (MAPS)
Rapidity range	$\|\eta\| < 0.9$	$\|\eta\| < 1.3$
Material budget per layer	1.14% (SPD)	0.35% (IB)
Distance to interaction point	39 mm	22 mm
Pixel size	50 x 425 μm^2	29 x 27 μm^2
Spatial resolution	12 μm x 100 μm	5 μm x 5 μm
Max.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



Priority Encoder + Double Columns



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

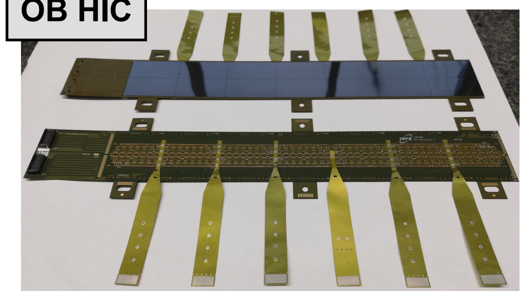
Dec '20

Installation in ALICE cavern

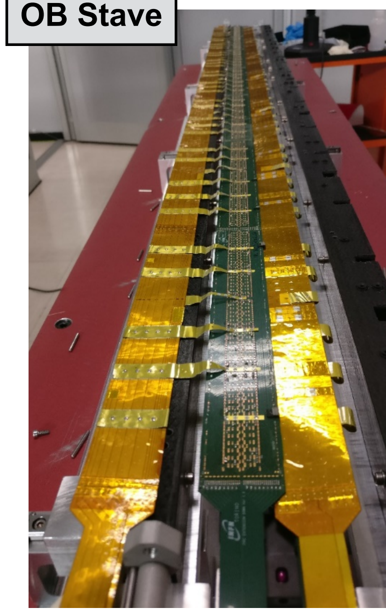
Mar '21

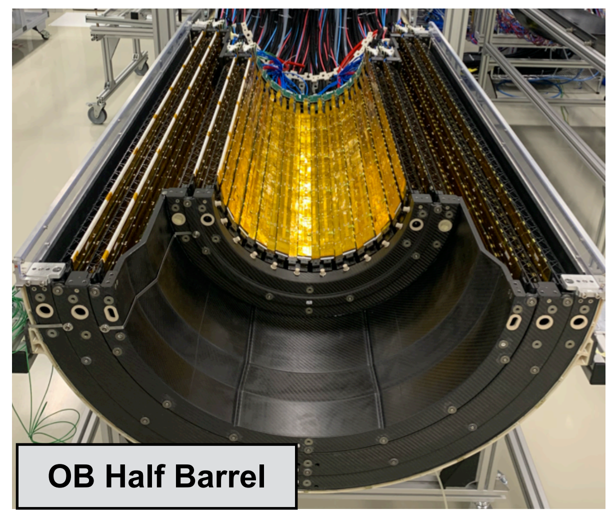
Global commissioning in ALICE

OB HIC

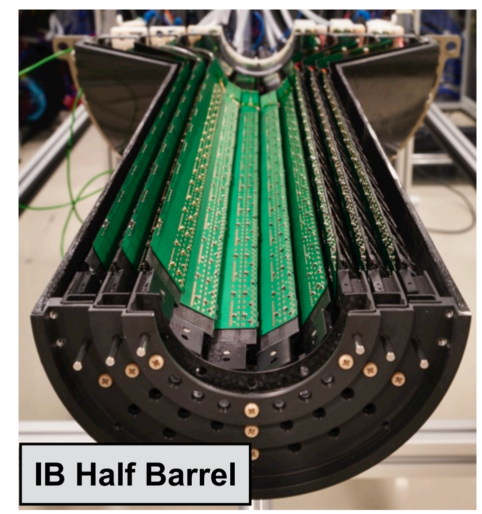


OB Stave



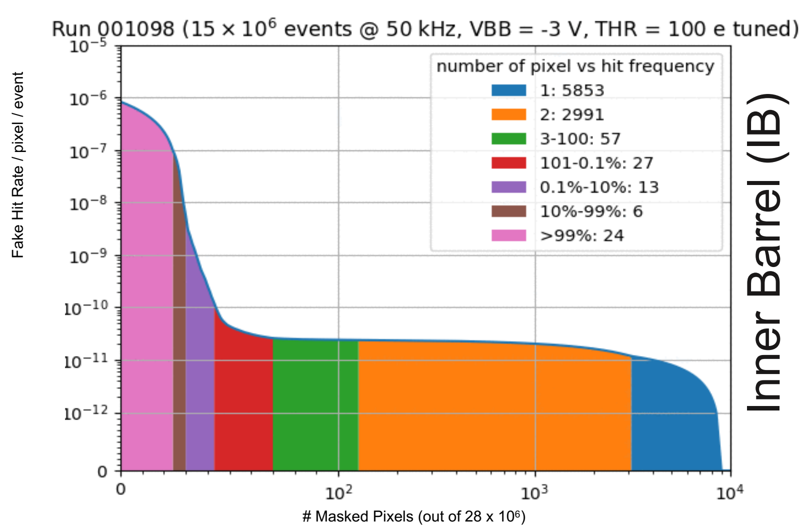


OB Half Barrel



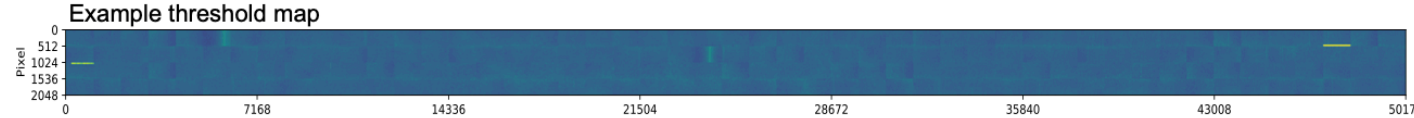
IB Half Barrel

Performance

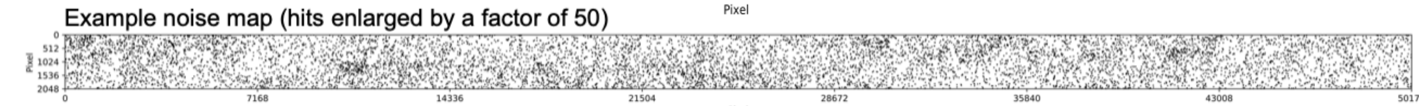


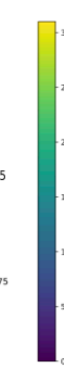
Inner Barrel (IB)

Example threshold map



Example noise map (hits enlarged by a factor of 50)



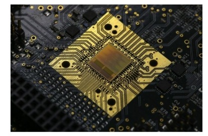


Outer Barrel (OB)

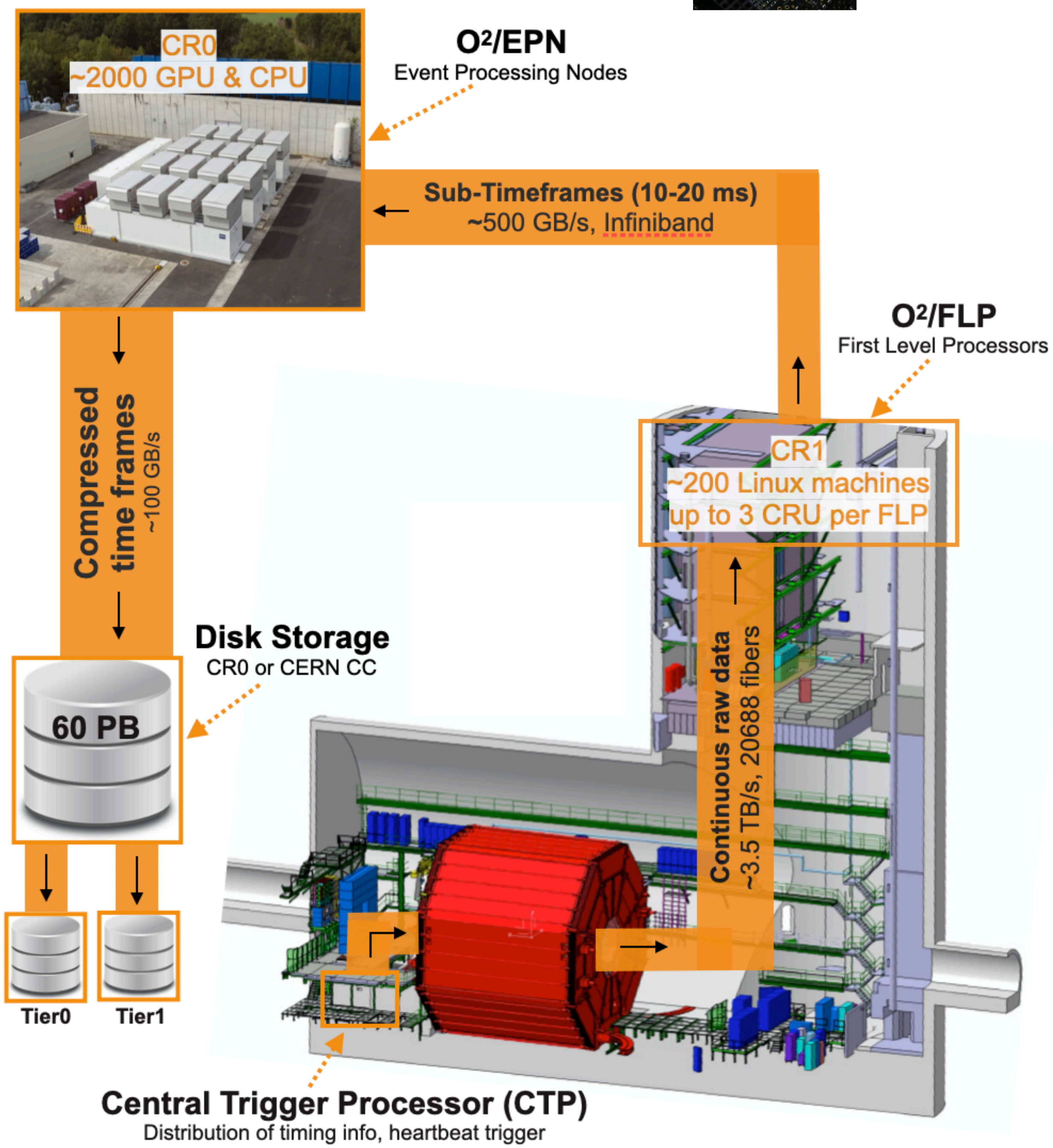
Fake-hit rate $< 10^{-9}$ /pixel/event masking less than 200 pixel/chip (average ~50 pixel/chip)
Threshold tuning to 100 e^- working to 2 e^- precision (on-chip spread: 20 e^-)

Backup

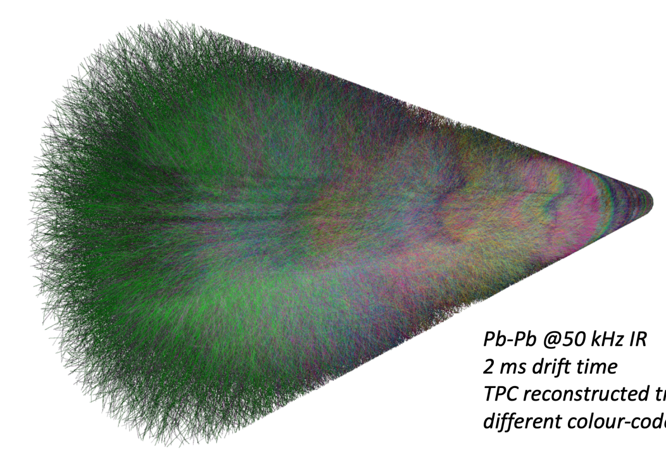
Integrated Online-Offline system (O²)



Readout upgrade for other detectors

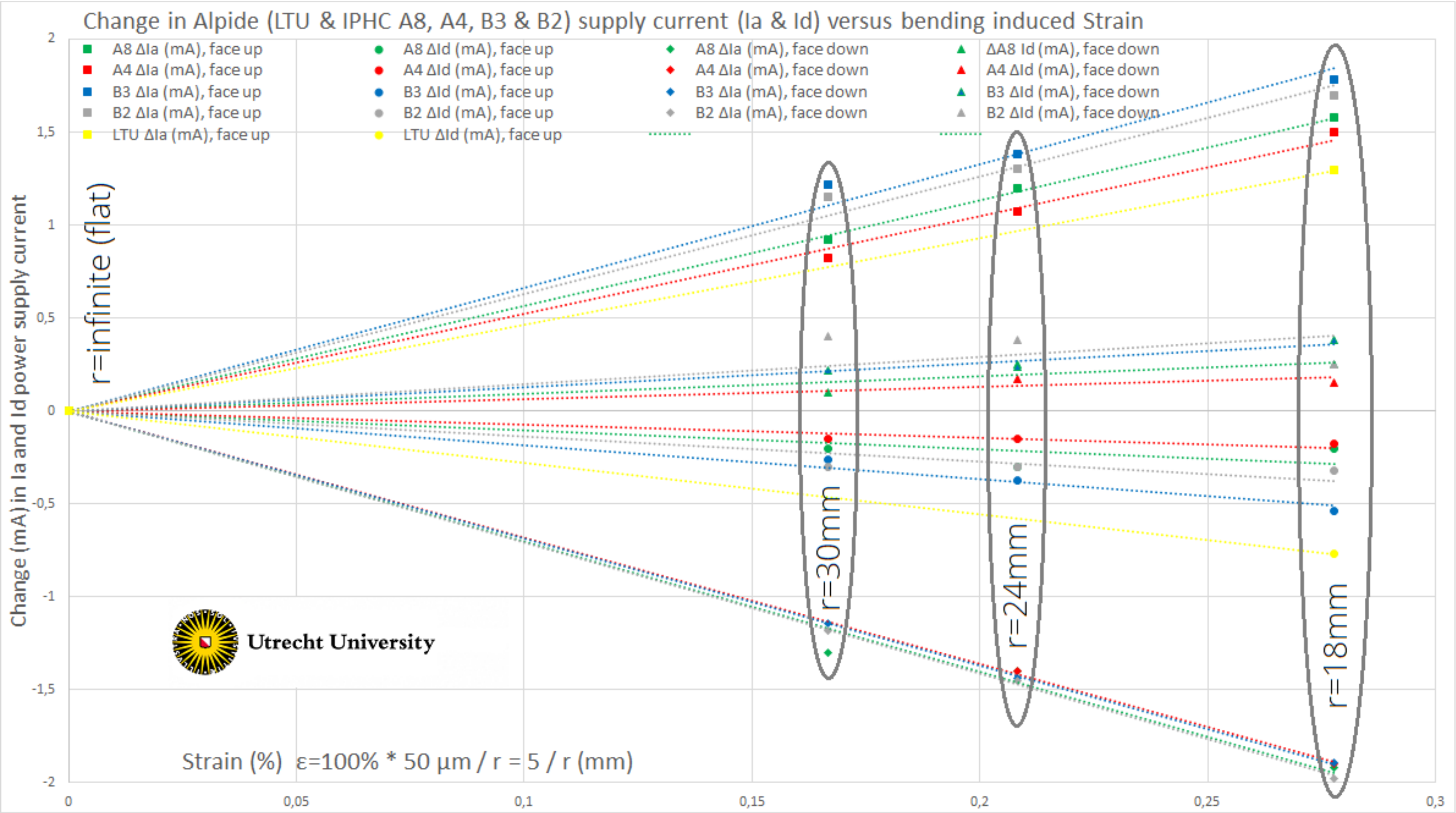


- **Continuous readout**
  - Upgrade of all detector readout boards
  - Heartbeat from CTP
  - Timeframe (instead of events)
- **Multi-step reconstruction chain**
  - Detector → FLP → EPN → Storage
- **Synchronous processing (EPN farm)**
  - Data volume reduction (factor 35)
  - Online calibration
  - Clusterization and tracking (using GPUs)
    → Compressed Time Frames (CTF)
- **Asynchronous processing (EPN farm/T0/T1)**
  - Final refined reconstruction
    → Analysis Object Data (AOD)



Pb-Pb @50 kHz IR
2 ms drift time
TPC reconstructed tracks from different colour-coded events

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
Change (mA) in Ia and Id power supply current
r=infinite (flat)
r=30mm
r=24mm
r=18mm
Utrecht University
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