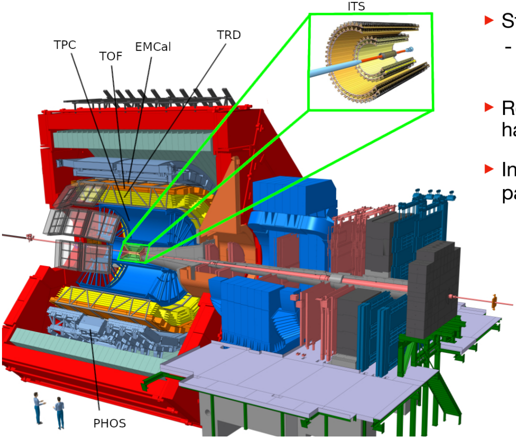
Assembly and operation of bent silicon pixel sensors towards the ALICE ITS3

Alperen YÜNCÜ

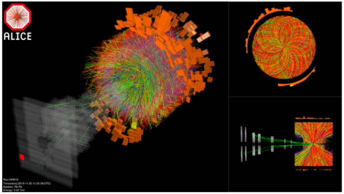
May 8, 2024

ALICE

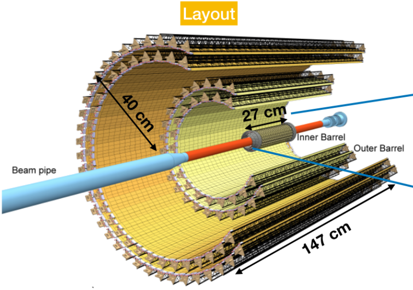
Detector and main goals

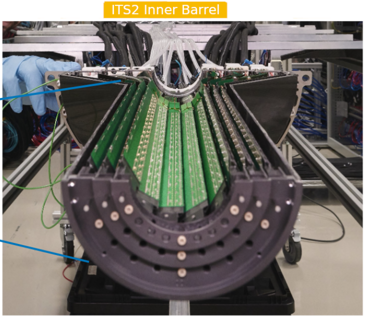


- Study of QGP in heavy-ion collisions at LHC
  - i.e. up to O(10k) particles to be tracked in a single event
- Reconstruction of charm and beauty hadrons
- Interest in low momentum (≲1 GeV/c) particle reconstruction



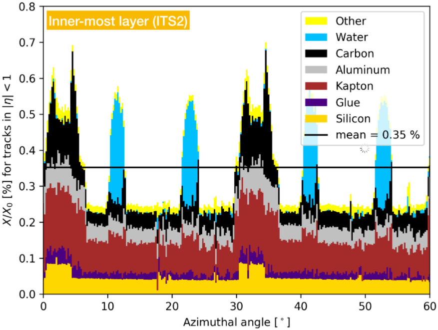
Current Inner Tracking System (ITS2)





- ITS2 is expected to perform according to specifications or even better
- The inner barrel is ultra-light ($0.35\%\,X_0$ per layer) but still most of the material comes from supports $\Longrightarrow$ further improvements seem possible
- Key questions:
  - Can we get closer to the interaction point?
  - Can we reduce the meterial budget even further?

Motivation for ITS3



- Observations:
  - $0.35\ \%$ X_0 per layer
  - Si makes only 1/7th of total material
  - Irregularities due to support/cooling

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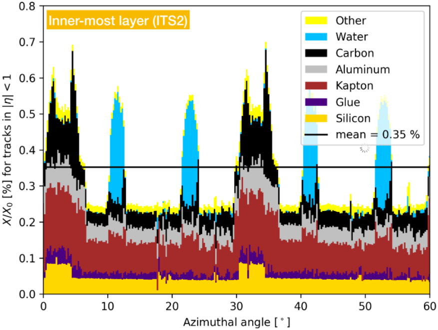

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  - Possible if power consumption stays below 20 mW/cm^2
  - Air cooling

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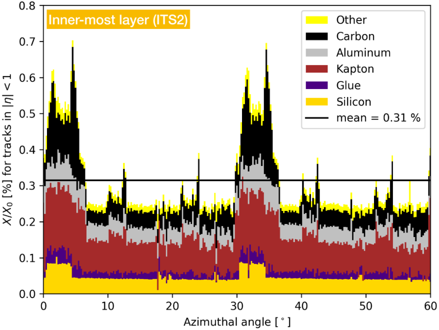

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  - $0.31\ \%$ X_0 per layer

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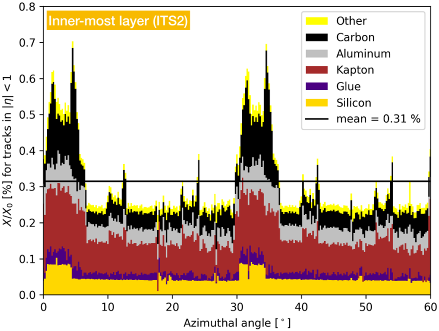

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- Removal of the circuit boards (power+data)
  - Possible if integrated on chip

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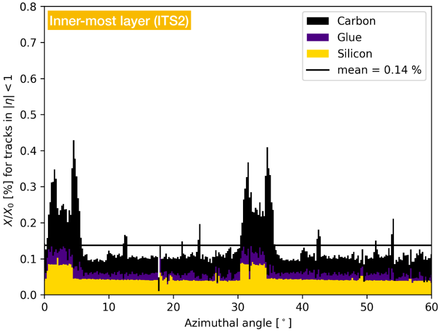

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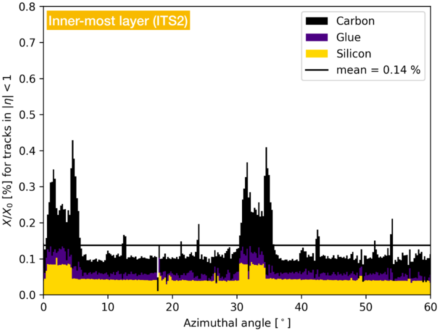
  - $0.14\ \%$ X_0 per layer

Motivation for ITS3



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- Removal of mechanical support
  - Benefit from increased stiffness by bending Si wafers into cylinderical shape

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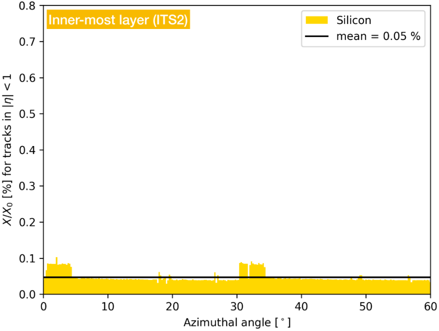

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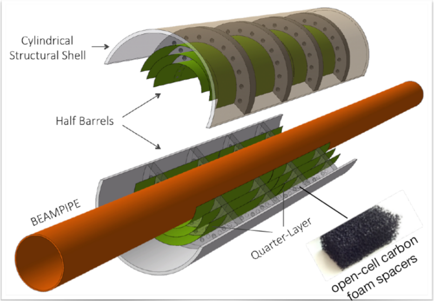
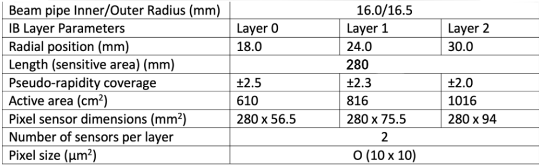
- Removal of mechanical support
  - Benefit from increased stiffness by bending Si wafers into cylinderical shape
  - $0.05\,\%$ X_0 per layer

ITS3 detector concept



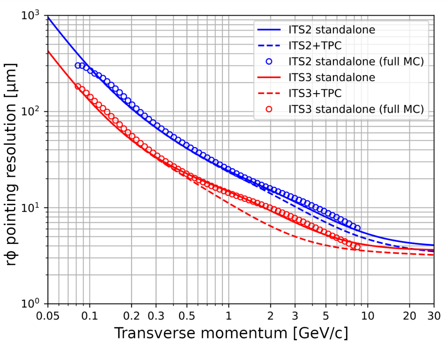


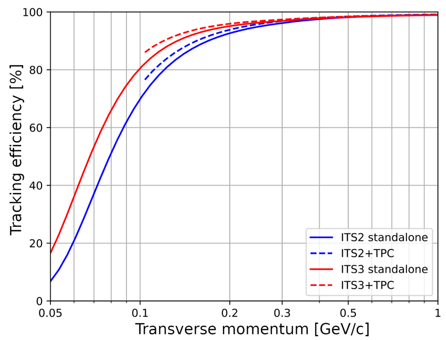
Beam pipe Inner/Outer Radius (mm)	16.0/16.5		
IB Layer Parameters	Layer 0	Layer 1	Layer 2
Radial position (mm)	18.0	24.0	30.0
Length (sensitive area) (mm)	280		
Pseudo-rapidity coverage	±2.5	±2.3	±2.0
Active area (cm²)	610	816	1016
Pixel sensor dimensions (mm²)	280 x 56.5	280 x 75.5	280 x 94
Number of sensors per layer	2		
Pixel size (µm²)	O (10 x 10)		

- Key ingredients:
  - 280 mm wafer-scale sensors, fabricated using stitching (Tower Partners Semiconductor (TPSCo) 65 nm CMOS Imaging Sensor (CIS) process)
  - Thinned down to 20-40 μm (0.02-0.04% X_0), making them flexible
  - Bent to the target radii
  - Mechanically held in place by carbon foam ribs
- Key benefits:
  - Extremely low material budget: 0.02-0.04% X_0 (beampipe: 500 μm Be: 0.14% X0)
  - Homogeneous material distribution: negligible systematic error from material distribution

THE WHOLE DETECTOR WILL COMPRISE SIX (!) SENSORS (CURRENT ITS IB: 432) AND BARELY ANYTHING ELSE

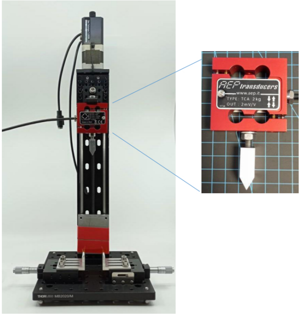
ITS3 performance



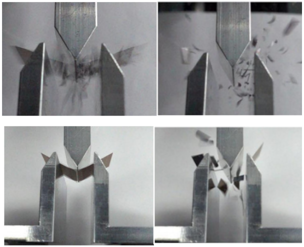


- Improvement on pointing resolution is factor of 2 over all momenta.
- Large improvement on tracking efficiency especially for low momenta.

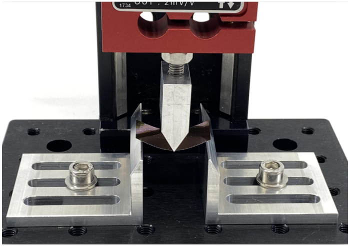
Bending Test

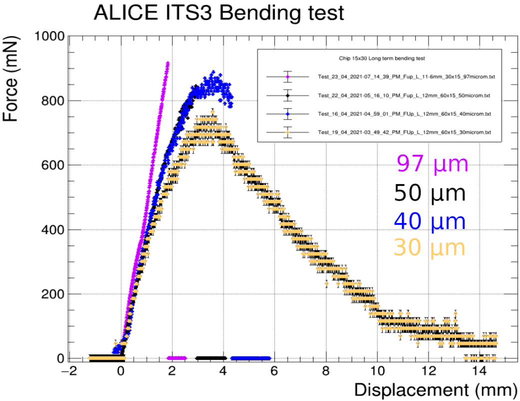


- Bending modulus
- Elastic - plastic region
- Breaking point
- Minimum radius

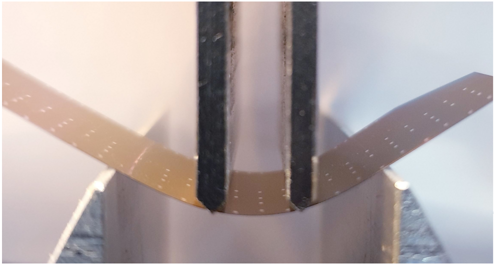


Bending Test (3-point test)

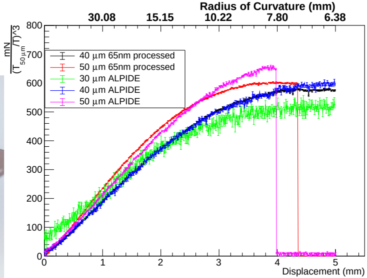


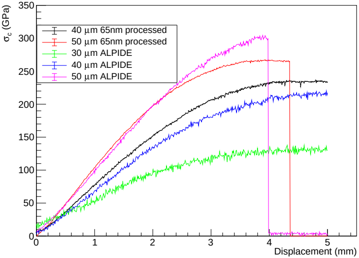


Bending Test (4-point test)

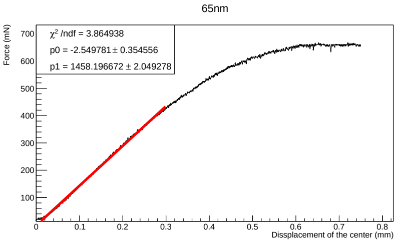


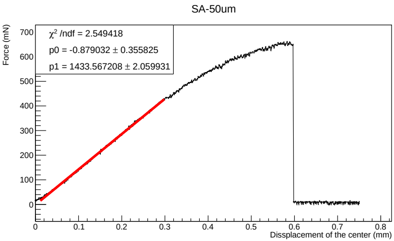
- 4-point test helps to have a more uniform curvature
- ..





Bending Test (4-point test)





Sensor	Young's Modulus (GPa)
65nm-40um	104 ± 63
65nm-50um	126 ± 76
SuperALPIDE-30um	89 ± 54
SuperALPIDE-40um	102 ± 62
SuperALPIDE-50um	117 ± 71
Single Crystal Silicon	130-185

Bending Tests

- Monolithic Active Pixel Sensors are quite flexible
  - already at thicknesses that are used for current detectors
- Bending force scales as (thickness)$^{-3}$
  - large benefit from thinner sensors
- Breakage at smaller radii for thinner chips
  - again benefit from thinner sensors

ITS3 TARGET RADIUS AND THICKNESS ARE VERY FEASIBLE

Bent ALPIDE

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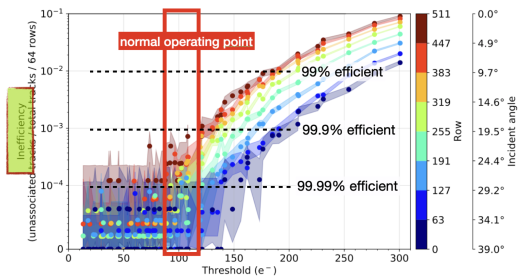
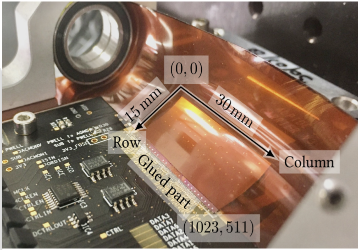
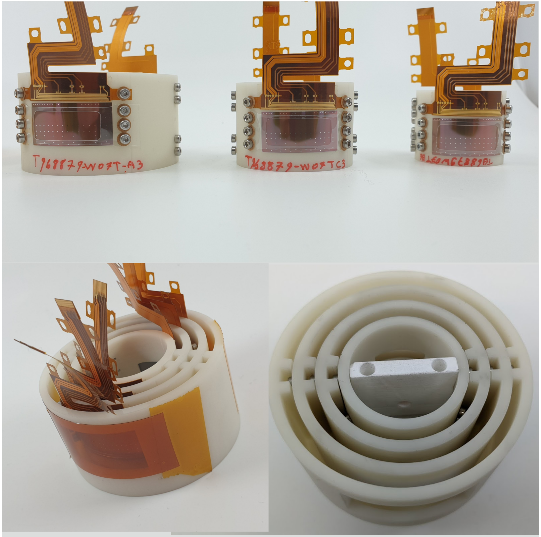


Fig. 10: Inefficiency as a function of threshold for different rows and incident angles with partially logarithmic scale (10^{-1} to 10^{-5}) to show fully efficient rows. Each data point corresponds to at least 8k tracks.



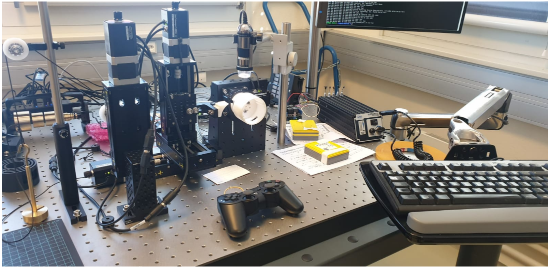
- Bent ALPIDE has high efficiency
- ASICs are functional in bent ALPIDE

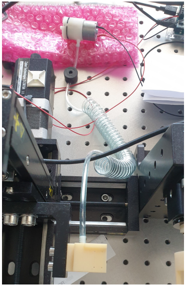
μITS3

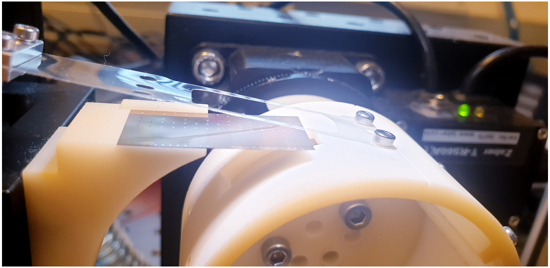


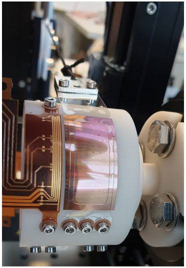
- μITS3 a mock-up of final ITS3
  - 6 ALPIDE bent to ITS3 target radii
  - Experience with handling thin, bent silicon was gained
- A Cu target is placed in the center, expect to see 120 GeV p-Cu collisions

μITS3 Preperation Setup

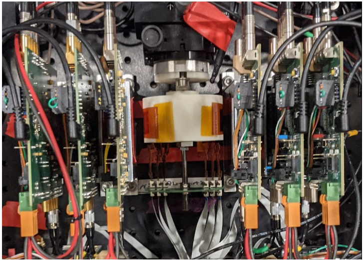




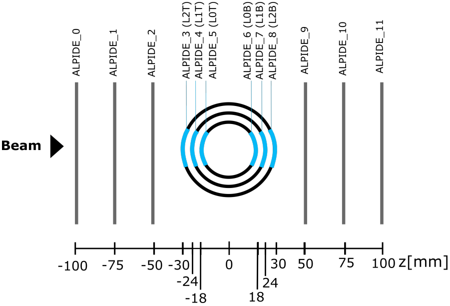


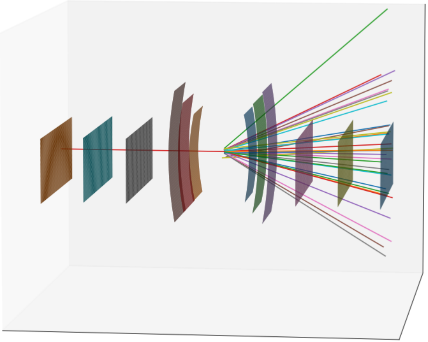


μITS3 in Testbeam

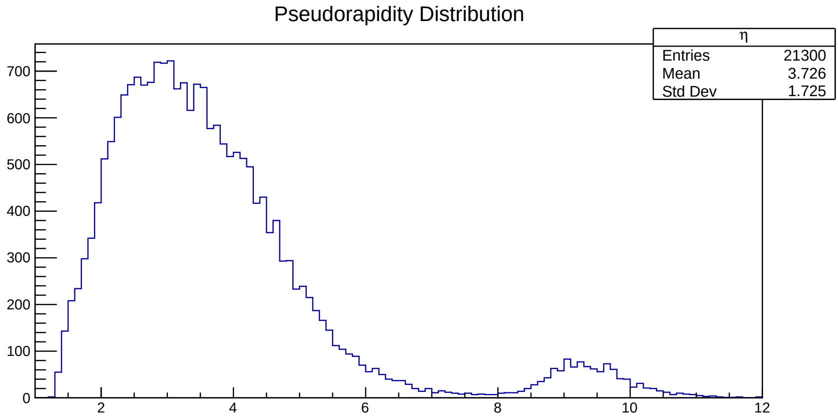


- The setup has tested in SPS
- 120 GeV hadron beam is used.

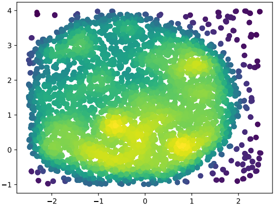




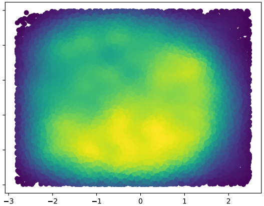
μITS3


Pseudorapidity Distribution
η
Entries 21300
Mean 3.726
Std Dev 1.725
0
100
200
300
400
500
600
700
2
4
6
8
10
12

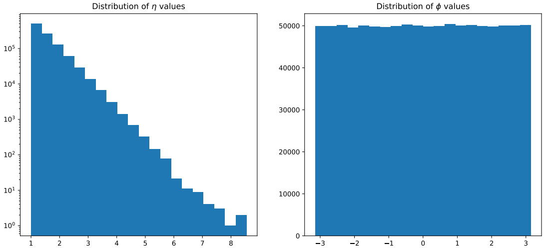
μITS3 acceptance



Vertex positions of real Data



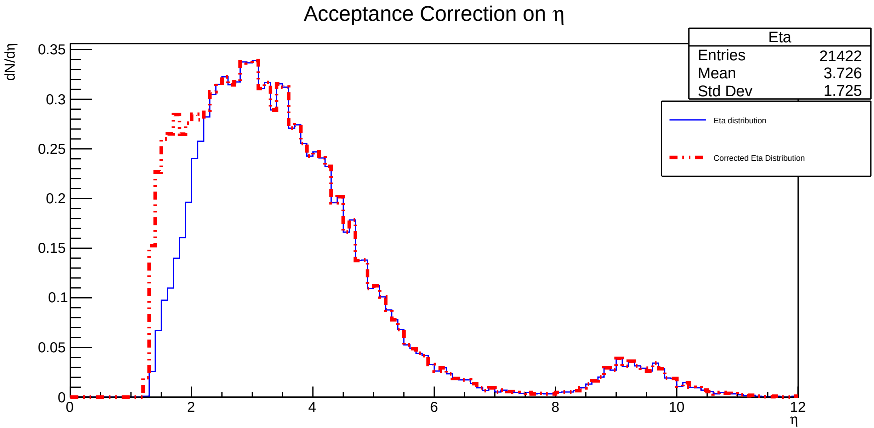
Generated vertex positions



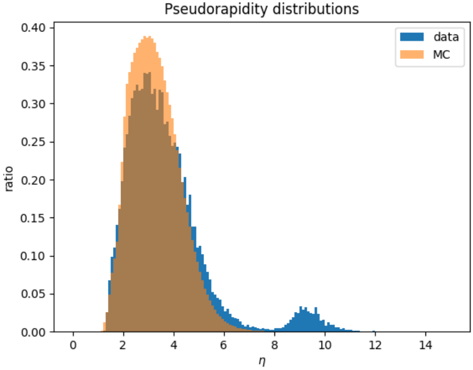
Generated tracks

- 10^6 Random tracks are created to check geometrical acceptance of the detector

μITS3 acceptance

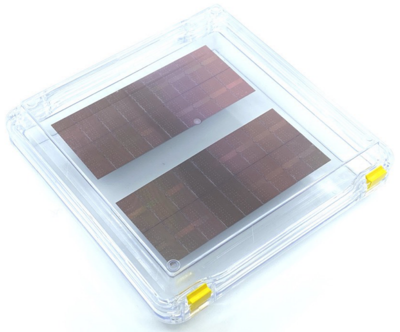


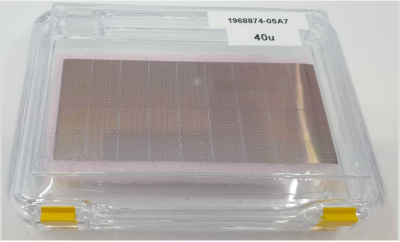
μITS3 comprasion with pythia



Pythia version	8.310
Number of events	99869
Collision Type	Fixed Target
Beam Energy	120 GeV
Beam particle	π^+
Target	Cu

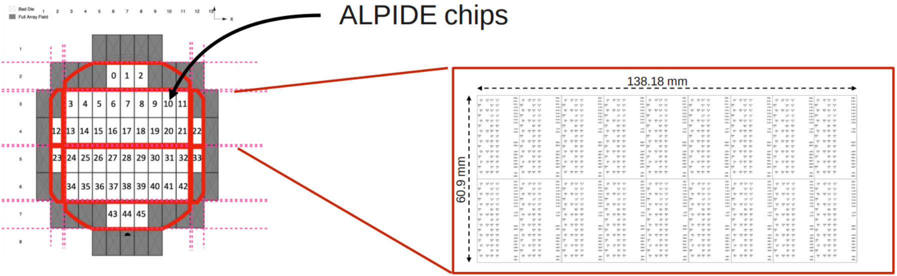
Super ALPIDE





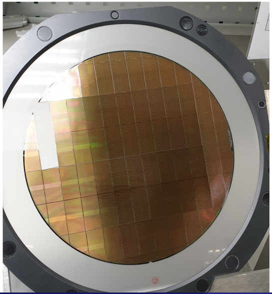
- To study the bending and interconnection of large pieces of processed chips, ”super-ALPIDE” is built.
- Comprises of **1 silicon piece cut** from an ALPIDE wafer size of $14\,\mathrm{cm} \times 6\,\mathrm{cm}$

Super ALPIDE



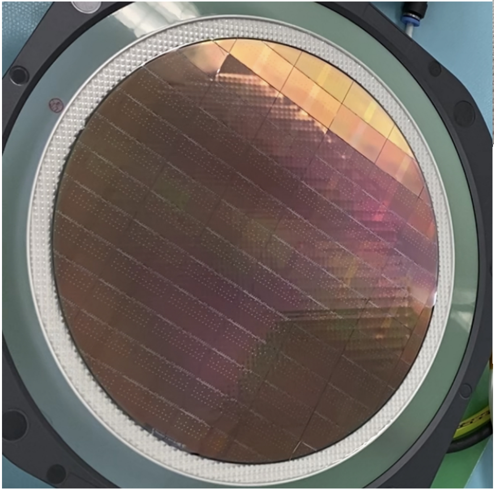
ALPIDE chips

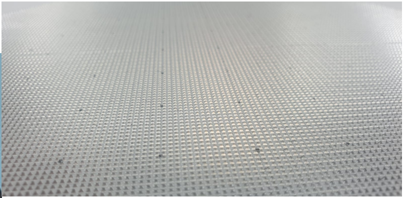
18 ALPIDE chips, covering about a half of an ITS3 half-Layer0



- Super-ALPIDEs are actually an array of ALPIDES.
- They consist 9×2 ALPIDE chips.

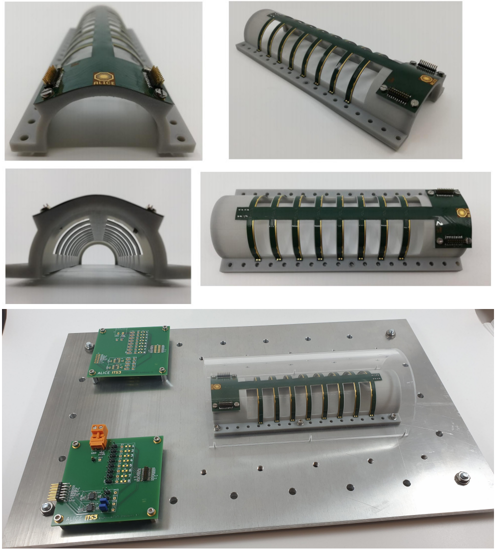
Picking up Super ALPIDE Chips





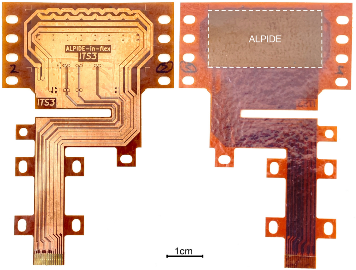
- Tested different methods how to pick large and very thinned chips
- Die-ejector with fine grid is the most efficient.

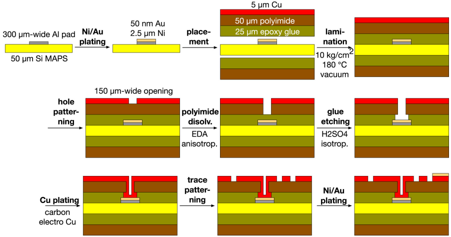
Exoskeleton



- 3-D printed.
- Designed to support super-ALPIDEs after bending.
- Windows to reach interconnection points at middle of super-ALPIDE

MAPS in Foil

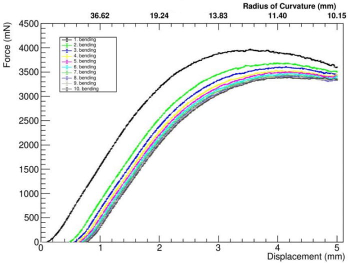


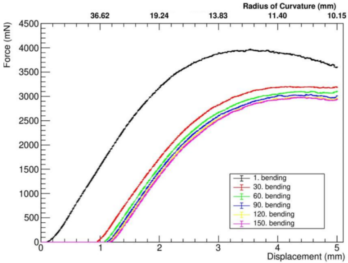


- A method to protect MAPS and its interconnection as part of R&D for bending thin slicon.
- MAPS are embeded in polyimide film with a copper layer for interconnections.
- For the first prototype ALPIDE sensors are used.
- Features:
  - Mechanical support
  - Mechanical protection
  - Electrical interconnection

doi.org/10.1016/j.nima.2021.166280

MAPS in Foil





- Mechanical and bending tests indicates polymide film successfully protects sensors from mechanical damages
- Unlike naked MAPS, bending proccess is not tottally irreversible

Summary

- Slicon is flexible enough to achieve targeted radii fot ITS3
- The effeciency of bent MAPS is close enough to flat ones
- Thanks to Super-ALPIDE study we have the know-how about how to deal with large and thin chips
- Further R&D for assembly and operation for bent MAPS are ongoing