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# Upgrade of the ALICE Inner Tracking System for LHC Run 4

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On behalf of the ALICE collaboration

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How can we further improve the ITS2 performance?

**Replacing the 3 innermost layers** with new ultra-light, truly cylindrical layers

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# ITS3 – lower material budget Lol: CERN-LHCC-2019-018

How can we further improve the ITS2 performance?

#### **Replacing the 3 innermost layers**



- **Circuit board**  $\rightarrow$  not required if integrated in circuit (stitching)
- Water cooling  $\rightarrow$  not required if power consumption < 20 mW/cm<sup>2</sup>
- Mechanical support  $\rightarrow$  not required if self supporting arched structure



#### Large improvement especially at low $p_T$

#### Improvement by a factor 2

 $\rightarrow$  boost of the ALICE core physics program, largely based on low momenta and secondary vertex reconstruction

ITS3 ALICE VERTEX, 2022, 25th October F.Carnesecchi,

# **ITS3: 6 truly cylindrical wafer-scale MAPS**

**Detector concept** 

#### From 432 to 6 bent sensors

- 300 mm wafer-scale MAPS sensors, fabricated using stitching
- **thinned down** to 20-40 µm, making them flexible
- **bent** to the target radii
  - (L<sub>0</sub> 23 mm  $\rightarrow$  18 mm, **closer** to the interaction point thanks to the new beampipe at 16 mm)
- mechanically held in place by carbon foam ribs

Beampipe inner/outer radius (mm)	16.0/16.5		
Layer parameters	Layer 0	Layer 1	Layer 2
Radial position (mm)	18	24	30
Length (sensitive area) (mm)	300		
Active area (cm <sup>2</sup> )	610	816	1016
Pixel sensors dimensions (mm <sup>2</sup> )	280 x 56.5	280 x 75.5	280 x 94
Number of sensors per layer	2		
Pixel size (µm²)	O(10x10)		



#### Key benefit:

- extremely **low material budget**: 0.02-0.04% X<sub>0</sub> (beampipe: 500 µm Be, 0.14% X<sub>0</sub>)
- homogeneous material distribution: negligible systematic error from material distribution



### **ITS3: 6 truly cylindrical wafer-scale MAPS**

#### **R&D** roadmap and challenges

#### Outline

Air for cooling Thermal test ongoing

#### Support with carbon foam ribs and handling ultra thin structures

Development of procedures to handle large thin chips and mechanical concept to hold thin sensors "without" material

Silicon flexibility and bending: ultra-thin, bent Monolithic Active Pixel Sensors Performance of bent silicon at different target radii: 18 mm, 24 mm, 30 mm

**Sensor design: 65 nm CIS process of TPSCo for tracking detectors** Charge collection efficiency, detection efficiency, radiation hardness

#### Stitching of wafer scale-chips

In chip power and signal distribution

# Cooling and support

#### Air for cooling and support with carbon foam ribs



Air cooling, Thermal and stability test ongoing:

- A set of bread board models based on heating elements are being developed
- Placed in a custom wind tunnel, thermal and mechanical properties are studied

Support and cooling optimization, maintaing the low material budget

• carbon foam as **spacers** 



ERG Carbon @Duocel  $\rho = 0.06 \text{ kg/dm}^3$  $K = 0.033 \text{ W/m} \cdot \text{K}$ 



ITS3



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# Silicon flexibility and bending

### Silicon flexibility and bending

ALICE

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#### 50 µm Dummy chip

Radius = 30 mm

Monolithic Active Pixel Sensors are flexible already at thicknesses that are used for ITS2

# Silicon flexibility and bending



Mechanical mockup of 3 truly cylindrical dummy layers Radii: 18 mm, 24 mm, 30 mm

Final aim  $\rightarrow$  turn these **dummy silicon** chips into a true single die monolithic pixel sensor

# Silicon flexibility and bending of ALPIDEs

Kapton, 100 µm

**Tension wire** 

ALIC

- Functional chips (ALPIDEs) are bent routinely
- Several ways were explored (bending before bonding, or vice versa, different jigs)
- The chips continue to work
  - (doi:10.1016/j.nima.2021.166280)

#### Jig radius = 18 mm

MNN Z9PEL COL

ALPIDE, 50 µm 2-1 Jogez

01092 ON J#S

### ALICE

ITS3

### Silicon flexibility and bending of ALPIDEs

- Full mock-up of the final ITS3, called "µITS3" :
  - 6 ALPIDE chips, bent to the target radii of ITS3 tested
- Beam test on µITS3:
  - uniform among different radii

"Beam test studies of bent MAPS for ALICE ITS3" L. Lautner, 25/10 11:05



#### $\mu ITS3:$ 6 ALPIDEs bent at 18 mm, 24 mm, 30 mm



# Sensor design

# Sensor design: MLR1

- Multi Layer Reticle 1

#### First submission in the Tower Partners Semiconductor (TPSCo) 65 nm technology

Received in 09/2021, 3 variants processes.

#### Verification of the technology for charge collection efficiency, detection efficiency, radiation hardness:

- larger wafers: 300 mm (instead of 200 mm), single "chip" is enough to equip an ITS3 half-layer
- smaller structure sizes to:
  - lower power consumption
  - increase spatial resolutions
  - increase in-pixel circuitry
  - increase yield



#### Charge sharing

**Charge Collection efficiency and speed** 



ITS3

### Sensor design: MLR1

#### **Multi Layer Reticle 1**

#### First submission in the TPSCo 65 nm technology

**APTS** – Analogue Pixel Test Structure



**matrix**: 6x6 pixels **readout**: direct **analogue readout of central 4x4 pitch**: 10, 15, 20, 25 μm **process**: all 3 variants **total**: 34 dies

#### **DPTS** – Digital Pixel Test Structure



**matrix**: 32x32 pixels **readout**: async. **digital with ToT pitch**: 15 μm **process**: 1 variant (modified with gap) **total**: 3 dies

1.5 mm

1.5 mm

Intensive characterization campaign performed:

- In the laboratory, also with **Fe-55 source**
- In a beam test setup



# Sensor design - APTS, process variants comparison

- Process modified with gap show a better charge collection (much smaller sharing peak)
  - indicates that the charge collection is very efficient
- Potentially better S/N also to higher thresholds



### Sensor design - APTS, pixel pitches comparison

#### **Process: modified with gap**

- Pixels of pitches of 10-25 µm show similar results
  - indicates that the charge collection is very efficient
- Allows to choose optimal pitch for the final sensor



Fe-55 results

### Sensor design – Beam test campaign

Received in 09/2021, since then several beam test performed:

- Sept 2021 (**DESY**): DPTS
- Oct-Nov 2021 (**PS, SPS**): APTS, DPTS
- Dec 2021 (**DESY**): DPTS
- March 2022 (DESY): DPTS
- April 2022 (**MAMI**): APTS
- June 2022 (**PS**): APTS
- July 2022 (**PS**): DPTS
- Aug and Oct 2022 (**PS, SPS**): APTS



### Sensor design - DPTS, efficiencies and fake hit rate

#### **Process: modified with gap**



With V<sub>bb</sub> applied **excellent detection efficiency** at acceptable fake hit rates and over large threshold

#### ALICE **Sensor design - DPTS, efficiencies and fake hit rate**

**Process: modified with gap** 

After irradiation 10<sup>13</sup> n<sub>eq</sub>/cm<sup>2</sup> at temperature ~ 30°



P. Becht. 25/10 15:20

slightly larger fake rates, but still largely operational



# Stitching – a wafer scale sensor





our target: ~280 x 94 mm

For such large area  $\rightarrow$  stitching needed: aim at a realization of **a true single wafer scale sensor** 



### Stitching – MOnolithic Stitched Sensor prototype

our target: ~280 x 94 mm → wafer scale sensor
→ stitching needed: a true single piece of silicon





### **Stitching – MOnolithic Stitched Sensor prototype**

Required dedicated design effort:

- understanding **stitching** rules to make a particle detector
- redundancy, fault tolerance

Crucial exercise to understand:

- yield
- uniformity

Engineering run to prototype under preparation:

expect sensors to test: mid 2023





### Conclusions

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**Upgrade of the ALICE Inner Tracking System, ITS3** Installation of new inner layers for LHC LS3 in 2026-2028

#### Aim at truly cylindrical wafer-scale MAPS sensors

Ultimate vertex detector

#### Silicon flexibility and bending proved

Full mock-up of the final ITS3 done, uniform performances among different radii

#### Sensor design validated

Improved charge collection efficiency with new design, 100% detection efficiency reached and radiation hardness higher than one needed from ALICE ( $10^{13} n_{eq}/cm^2$ )

#### Next step: stitching

First prototype to be received in 2023: fundamental for understanding the rules of stitching, yield and uniformity



