The Engineering, Production and Quality Assurance of the Inner Barrel Staves for the Upgrade of the ALICE Inner Tracking System.

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on behalf of the ALICE Collaboration

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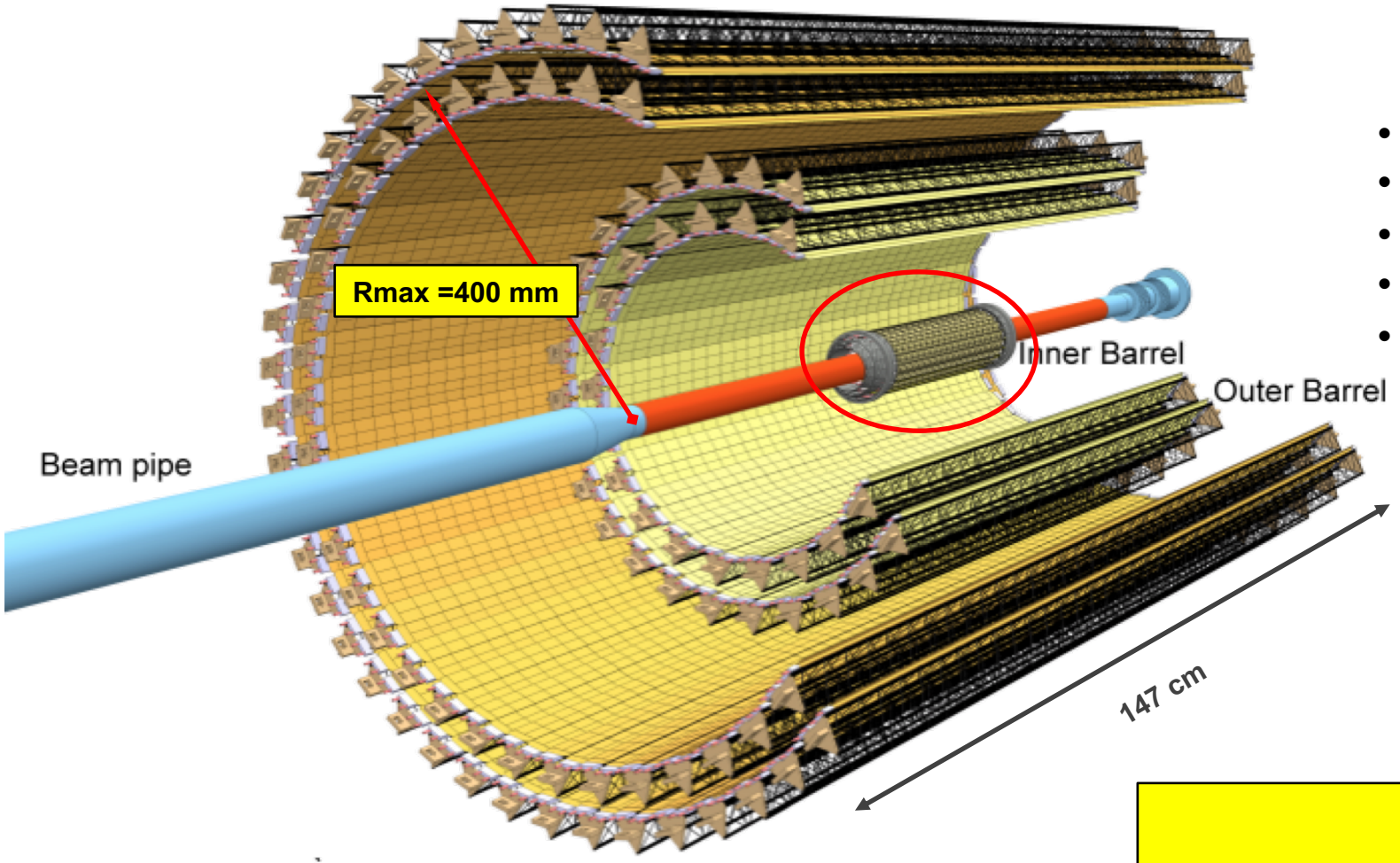
TWEPP 2019

Outline

- ALICE Inner Tracking System layout
- Manufacturing of:
    - Inner Barrel Flex Printed Circuit
    - Hybrid Integrate Circuit (HIC)
    - Stave
- Challenges
- Conclusion

Detector layout



Motivations and goals

- Close to Interaction point
- Small pixel (29 x 27 µm)
- Spatial resolution:~5 µm
- Low material budget : 0.38 %/X0
- Readout collision up to 100 kHz Pb-Pb and 400 kHz pp

10 m^2 active silicon area

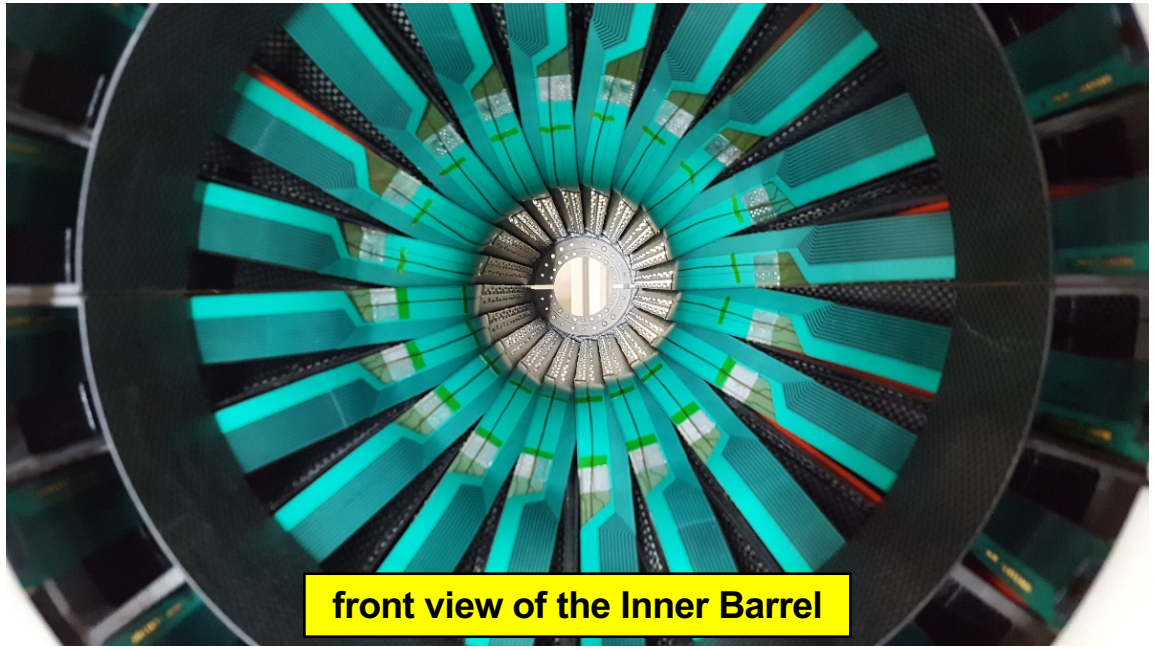
~ 24000 MAPS(Monolithic Active Pixel Sensor chips)

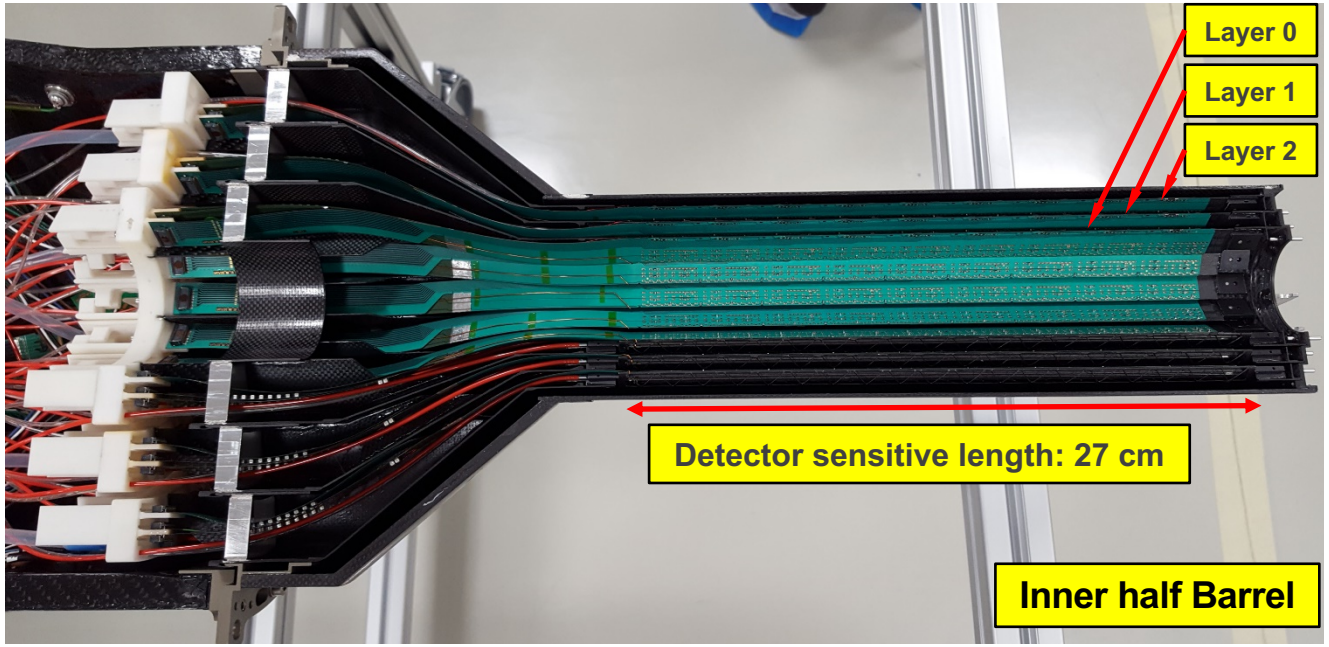
12.5 G-pixels

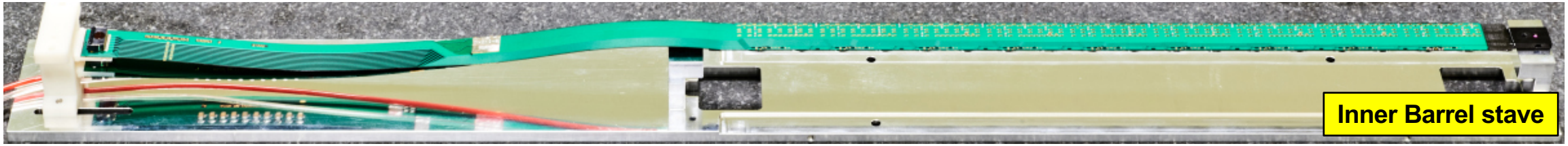
Inner Barrel (IB) layout

IB ITS upgrade in numbers (main components)

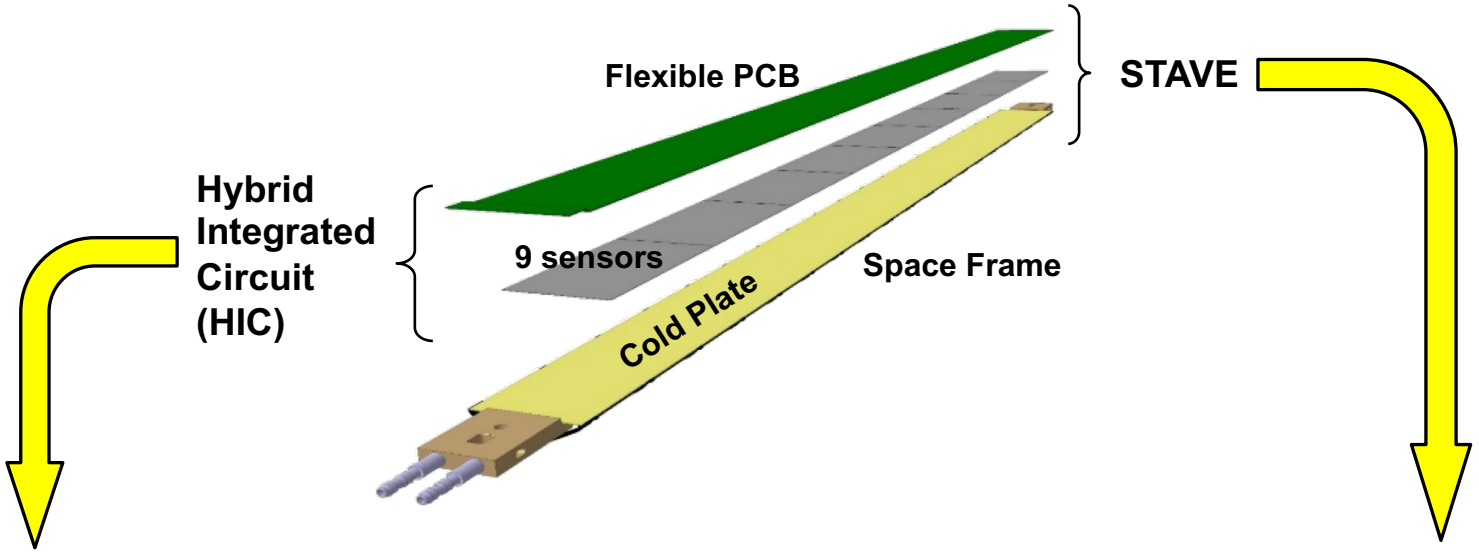
- IB staves: 48 (9 chips per Stave)
- Pixel sensor chip (ALPIDE 50 µm thick): 432

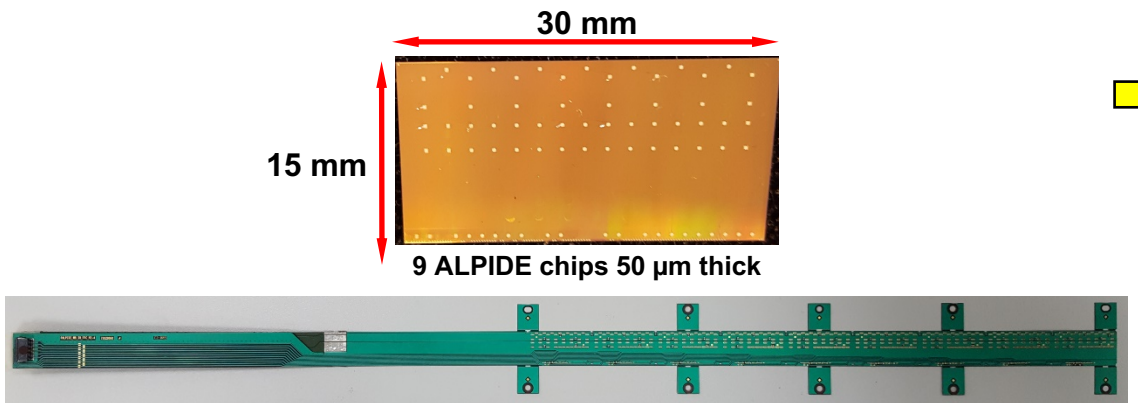


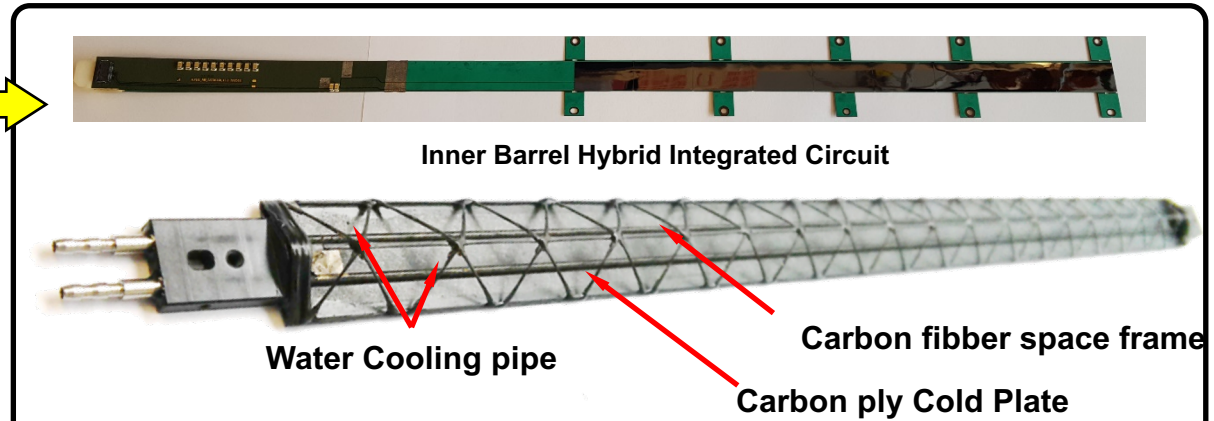




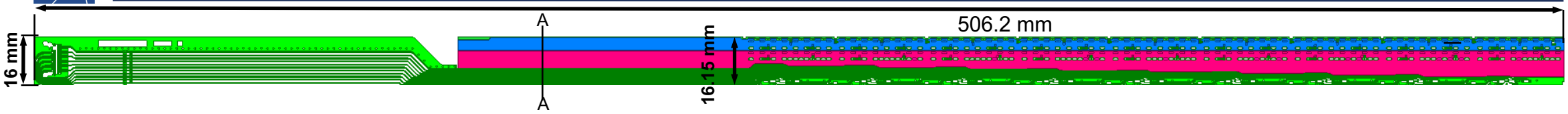
Inner Barrel STAVE layout and components



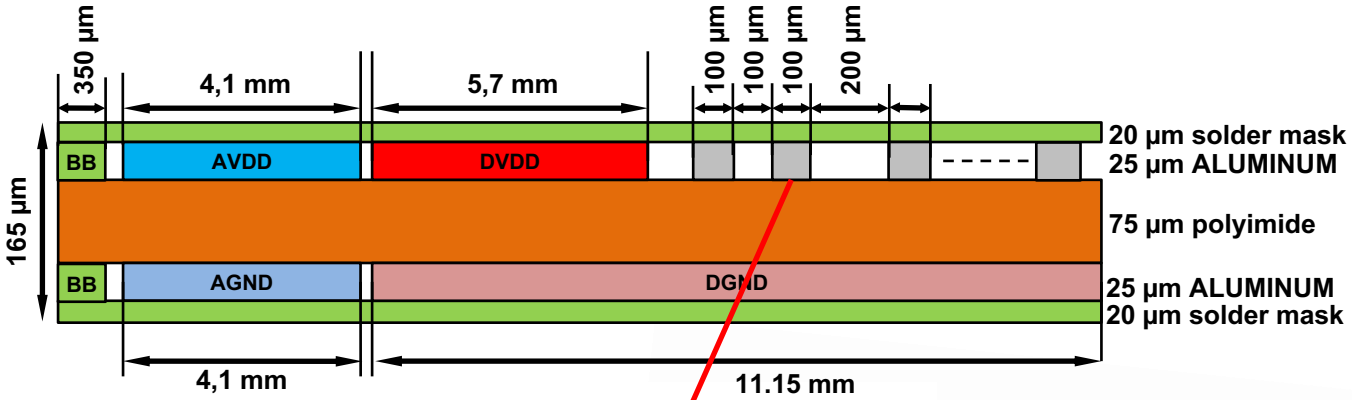




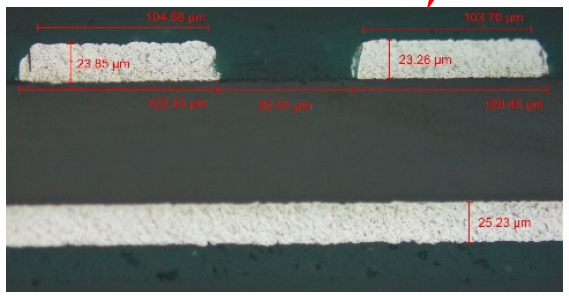
Inner Barrel Flex Printed Circuit



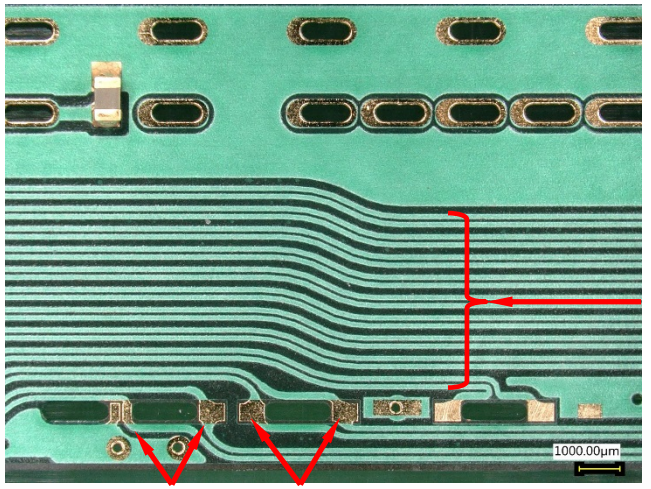
The 9 silicon chips are read out in parallel: each chip sends its data stream to the end of Stave, at 1.2Gb/s, via a dedicated differential pair, 100 µm wide. Two additional differential pairs distribute the clock and configuration signals at 40 MHz.

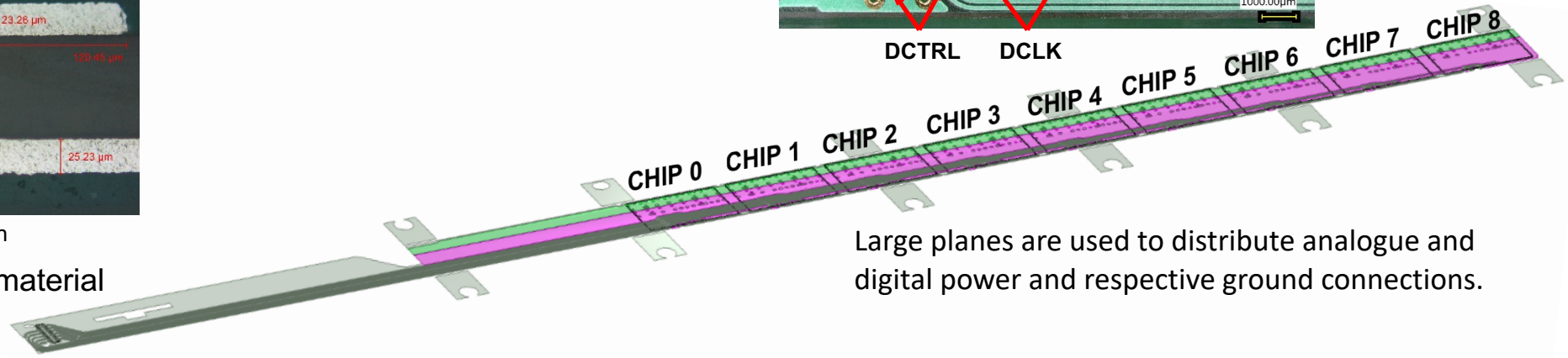


ITS FPC Layer stackup (A-A)



HSDATA cross section





Aluminum on polyimide to reduce the material budget

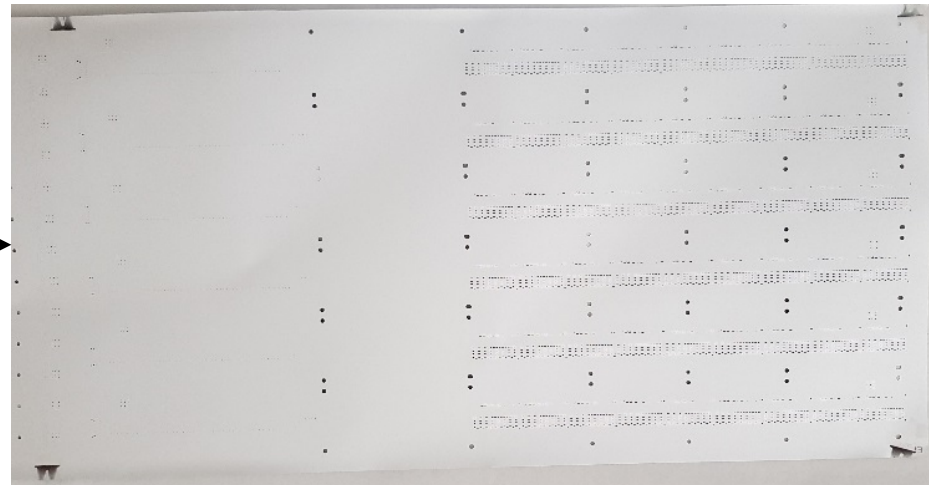
Large planes are used to distribute analogue and digital power and respective ground connections.

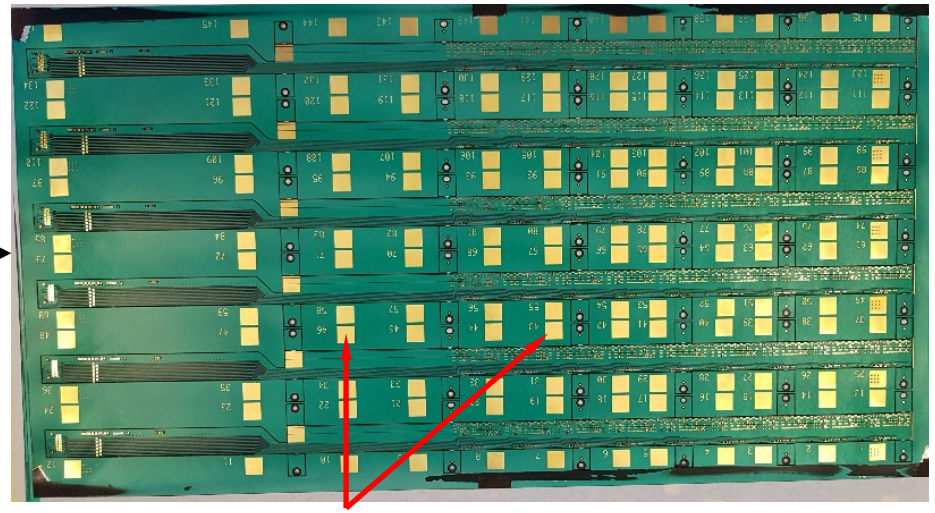
Inner Barrel Flex Printed Circuit manufacturing

Main production steps

1. Stabilization of polyimide heat treatment in vacuum @ 450°C for 2 h
2. Hole drilling by laser
3. FPC metrology (1)
4. Preparation for Al coating: Cleaning and polishing
5. Aluminum PVD coating
6. FPC metrology (2)
7. Photo-lithography, etching, coverlay, Ni/Au
8. Outline cutting by laser

The inner barrel FPCs are mostly manufactured at CERN PCB workshop.





Test coupons

- **8 batches of 24 IB FPCs, 192 FPCs in total**
- **8 batches delivered (85 % yield)**
  - **35 NOK, related to manufacture issues**
  - **8 NOK, related to damages during handling or SMD mounting**

Inner Barrel Flex Printed Circuit manufacturing

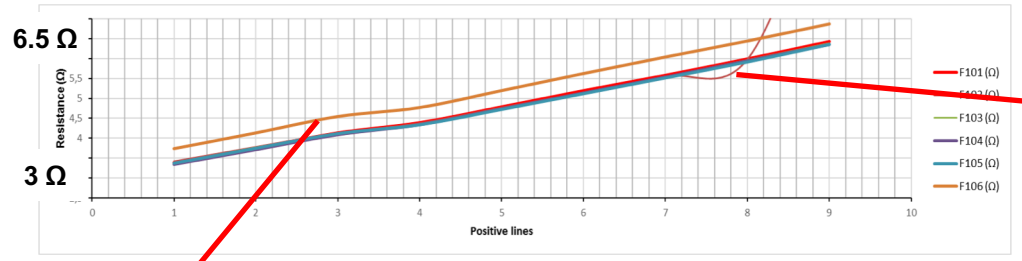
9 Electrical tests and metallographic analysis

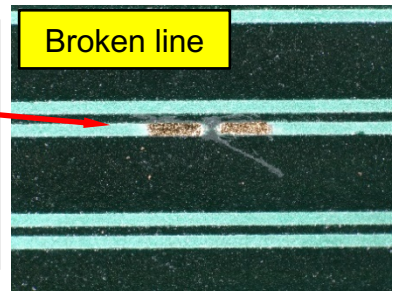
10 Passive components are assembled by hand

11 FPC metrology (3)

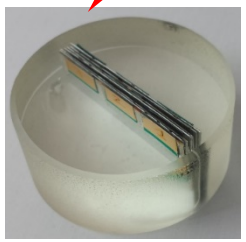
12 Cleaning and visual inspection

All the metrology is executed at CERN

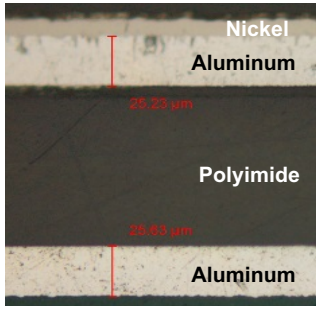


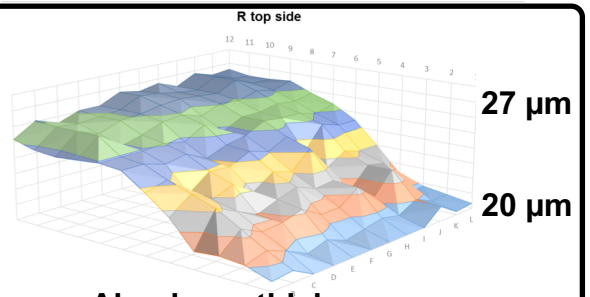


Resistance tracks measurements

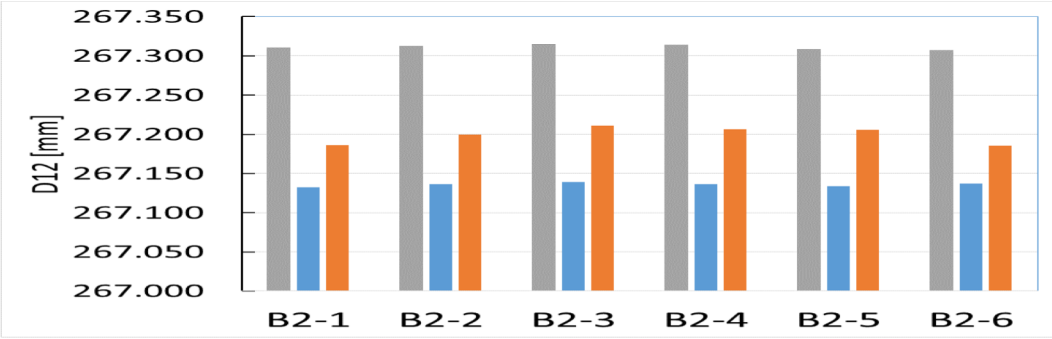


FPC coupons in resin for cross-section analysis





Aluminum thickness map



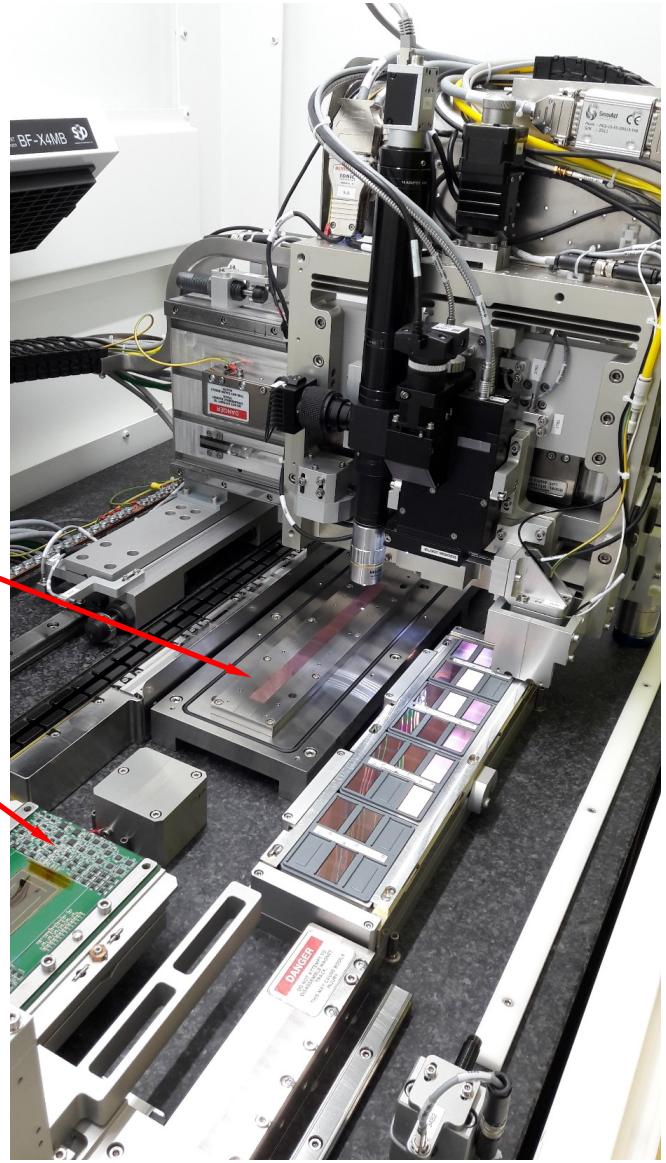
1 Laser drilling

2 PVD Alu

3 After SMD

Point to point opposite side hole distance. Tolerance 50 µm

ALICIA machine



Custom developed assembly and test machine for the ALICE ITS: This machine was designed and produced, with CERN specifications, by the IBS company based at Eindhoven, Netherlands.

- Electrical test with a probe card
- Automated pick and place of pixel chips (50 µm , 100 µm thick)
- Automated visual inspection and control of the chip
- Alignment of 1x9 or 2x7 pixel chips for HIC assembly (<5 µm alignment precision)

6 ALICIA machines were produced and installed in the ALICE ITS production centers.

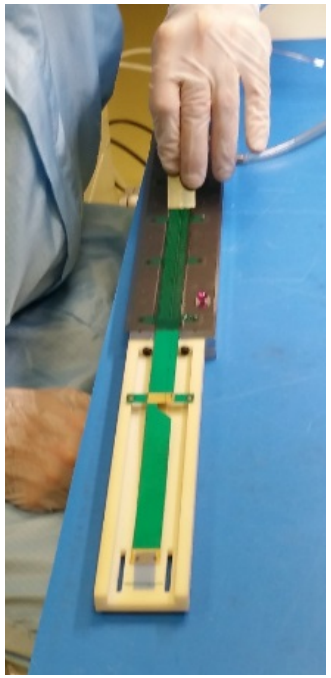
Manufacturing of Inner Barrel Hybrid Integrated Circuit

Components preparation

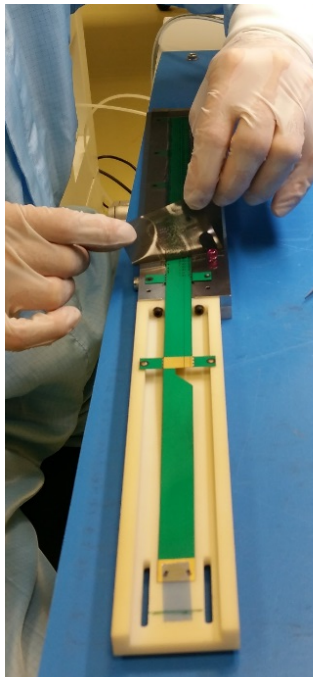
- Chips: visual inspection, selected “GOLD” (less than 50 dead pixels over 500 000) from electrical test.
- FPC: electrical characterisation, metrology, cleaning, visual inspection
- Gluing mask : visual inspection and cleaning

1. Chip alignment (5 µm accuracy) and edge inspection in ALICIA
2. Glue prepared in a planetary mixer 30 min before applying
3. Glue distribution on FPC using 90 µm thick gluing mask
4. Overlap FPC on chips in ALICIA using 50 µm shimming and 12 h curing
5. Removal from ALICIA and visual inspection

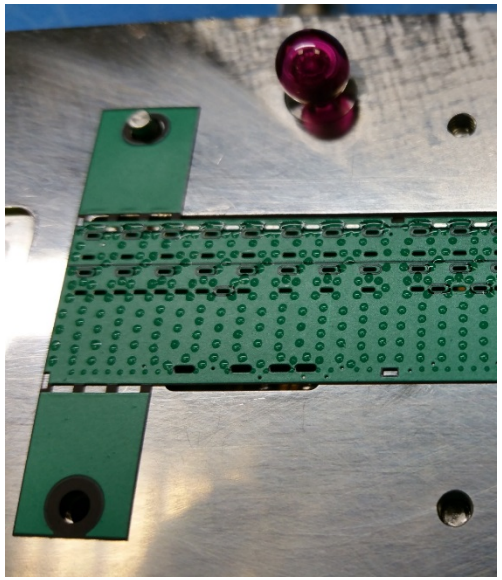
Glue spreading



Gluing mask removal



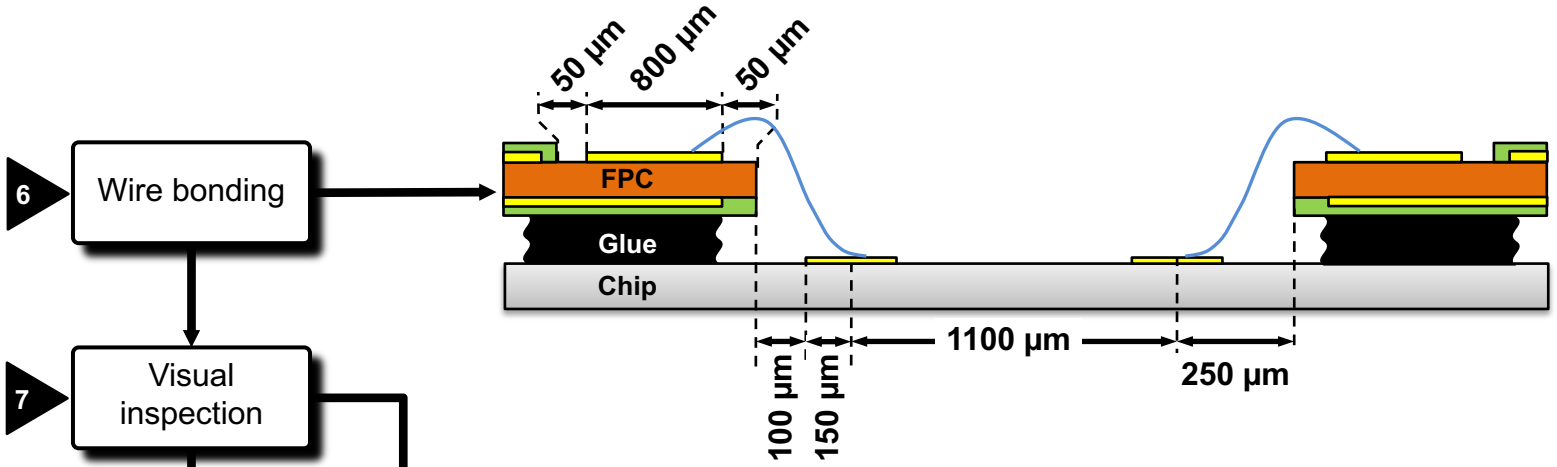
Glue droplets



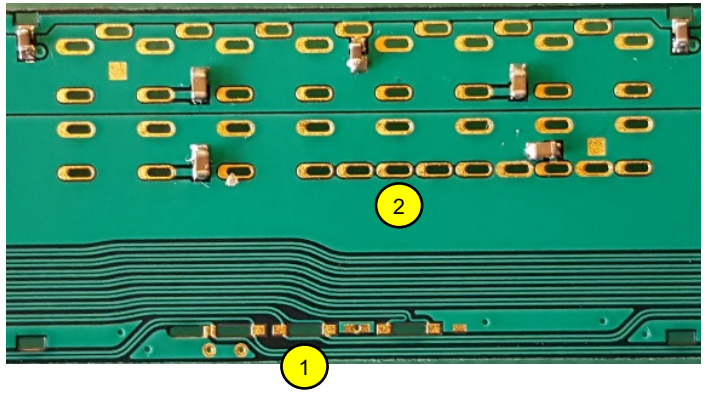
Overlap FPC on chips

Wire bonding through via

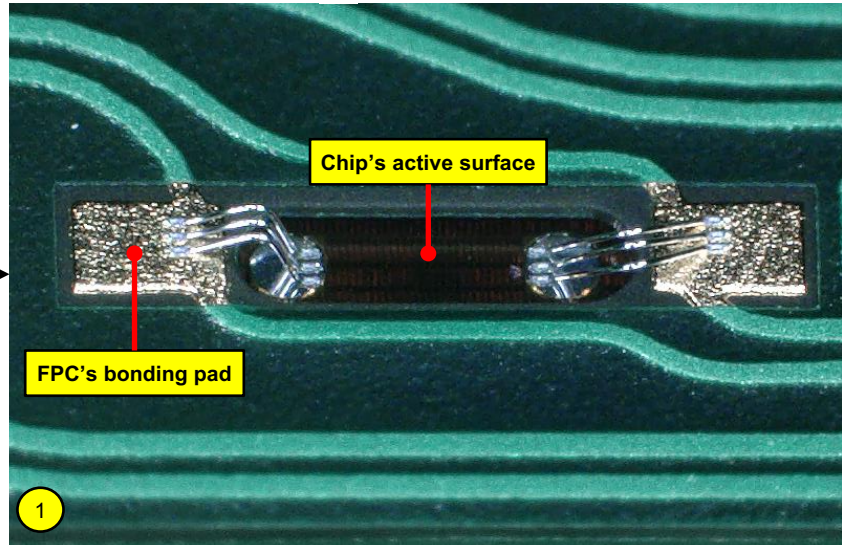
Schematic view of the FPC-Chip interconnection by wire bonding technique



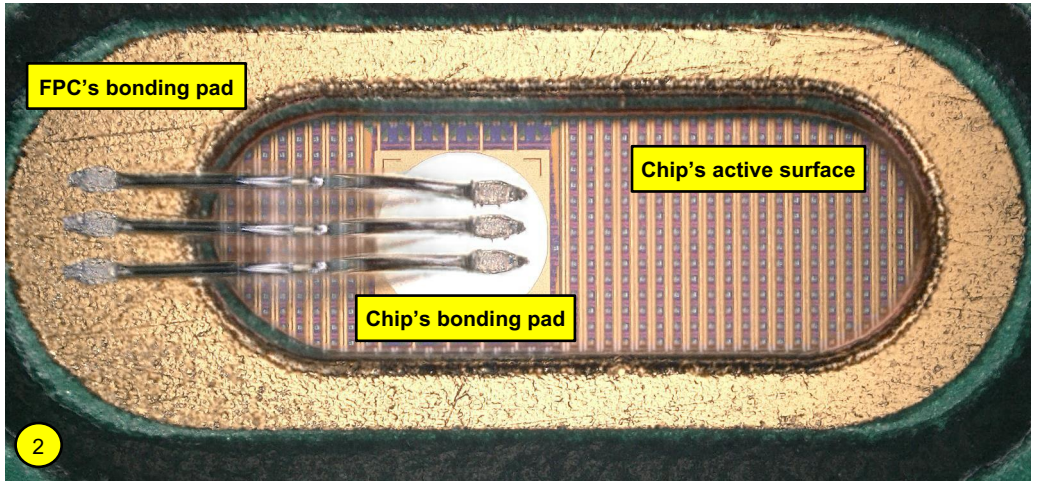
Wire bonding FPC layout



All the wire bonding is executed at CERN

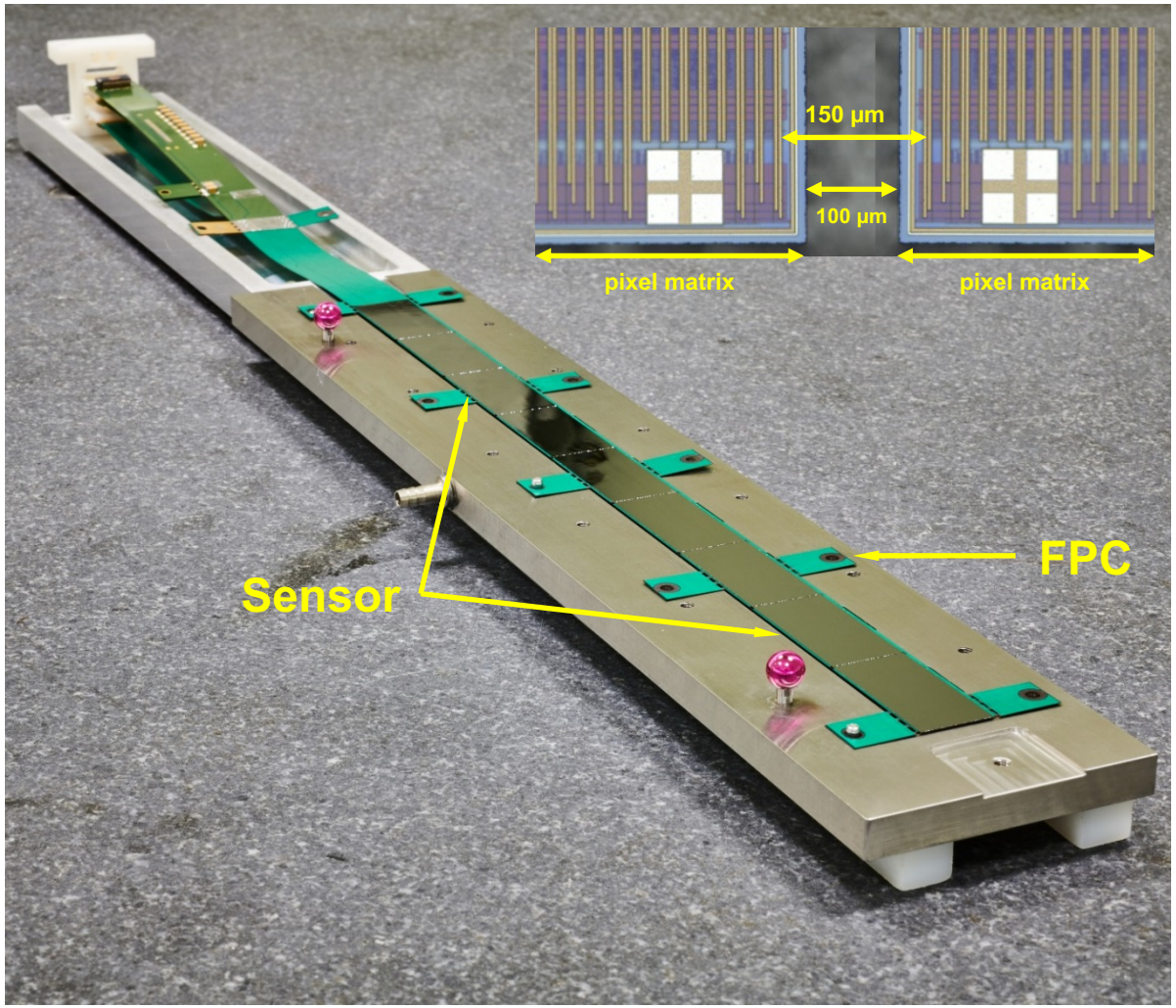


Signal connection

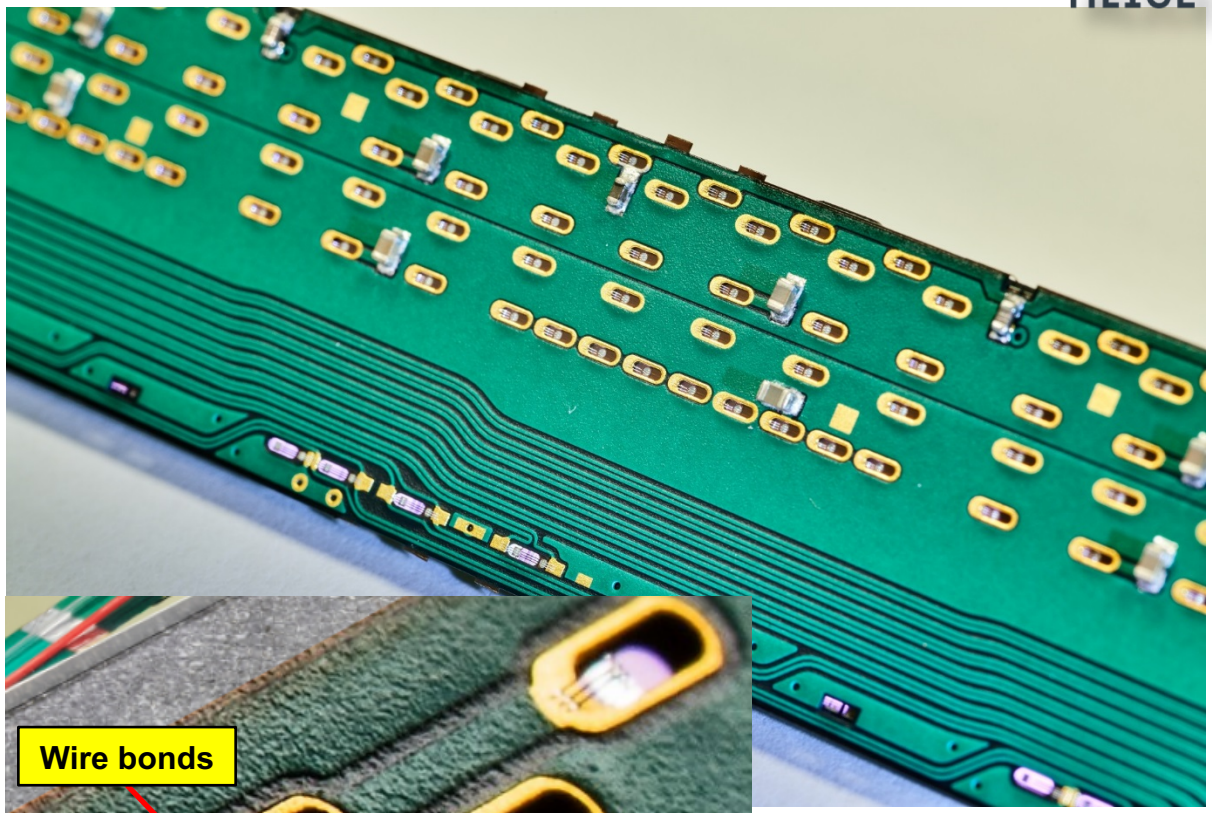


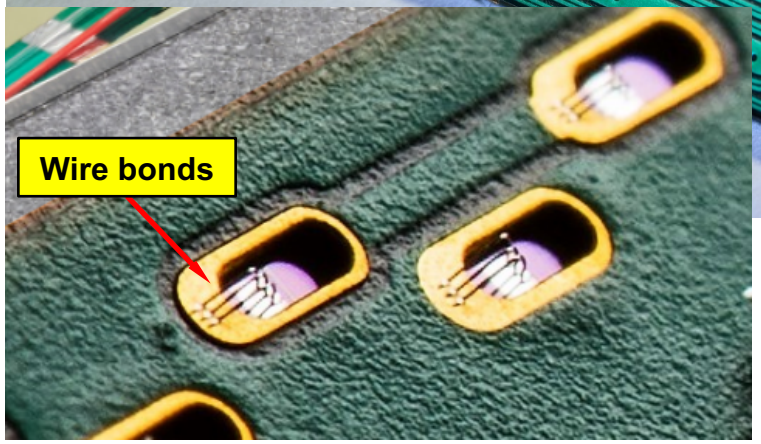
Power connection

IB HIC assembly procedure



After chip gluing



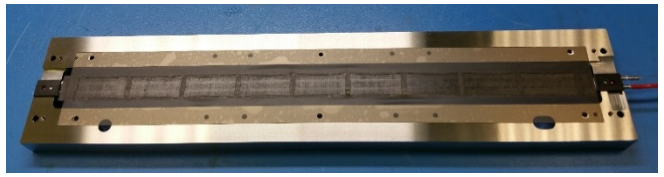


After chip wire bonding

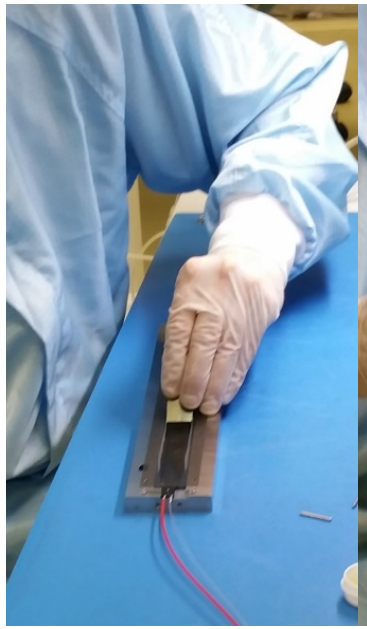
IB STAVE assembly procedure

1. Glue prepared in a planetary mixer 30 min before applying
2. Distribution of the glue Gluing of the HIC over the cold plate
3. Visual inspection
4. Power test and R/O test
5. Stave metrology

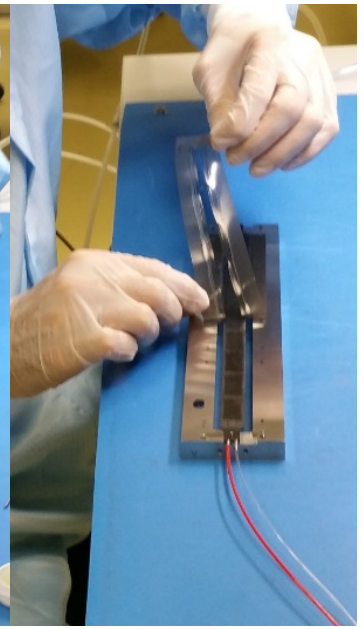
Gluing mask application



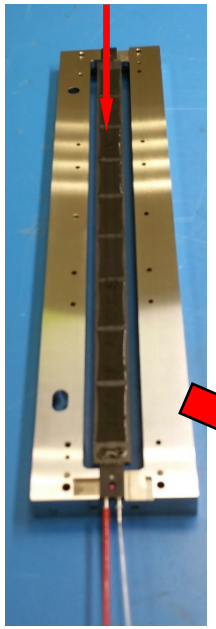
Araldite spreading

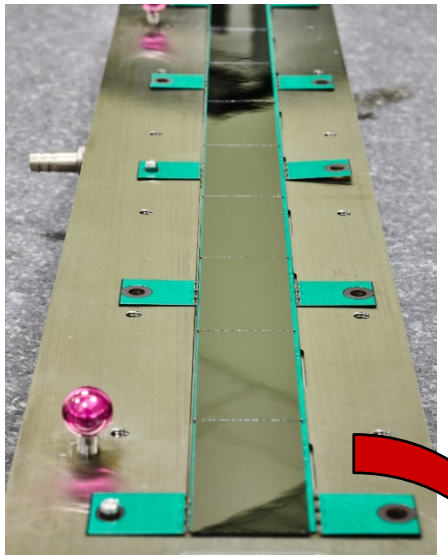


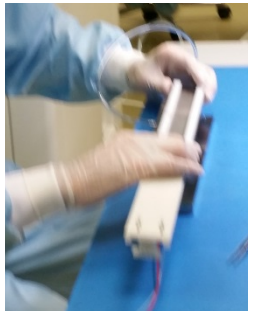
Gluing mask removal



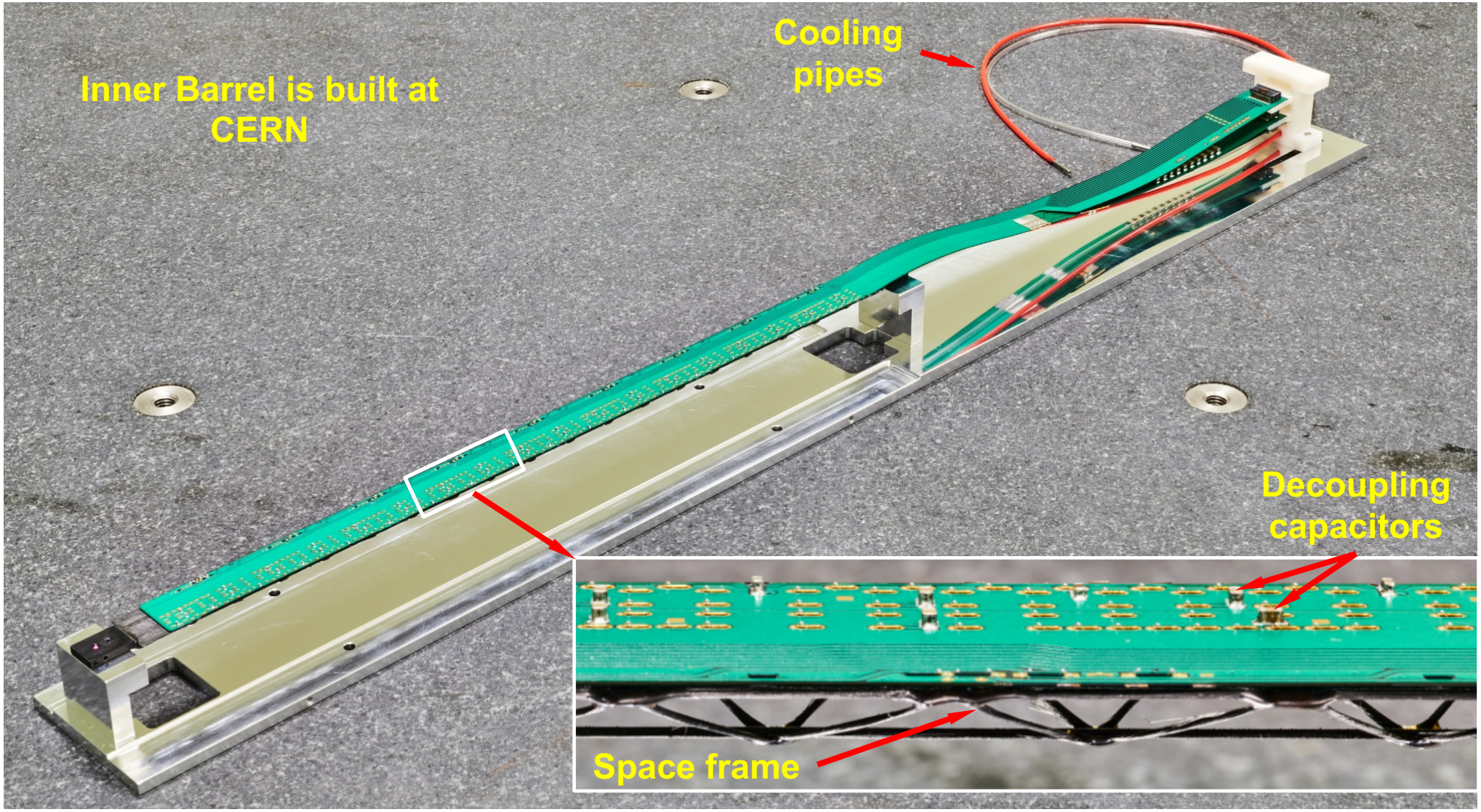
Space frame





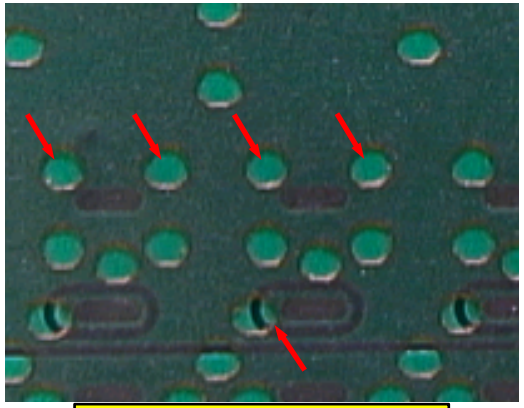


IB STAVE assembly procedure

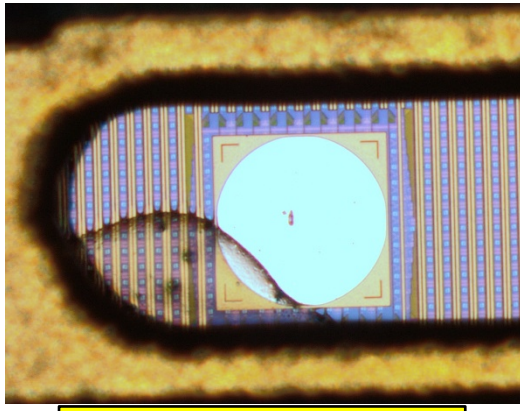


Challenges

- Gluing mask alignment and glue seepage



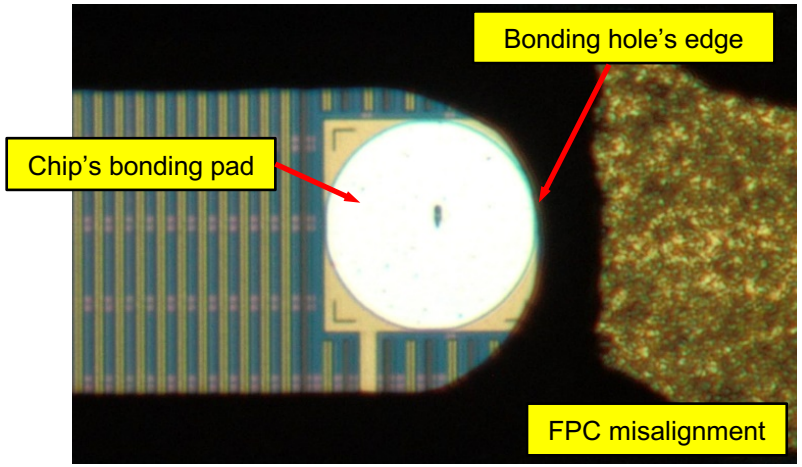
Gluing mask misalignment



Bonding pad covered by glue

- **Solutions:**
  - Improvement of the glue mask design
    - Hole diameter 600 µm
    - Thickness 90 µm
  - Using vacuum jig to align the glue mask
  - Glue mask manufacturing improvement
  - Start polymerization of the glue before applying it

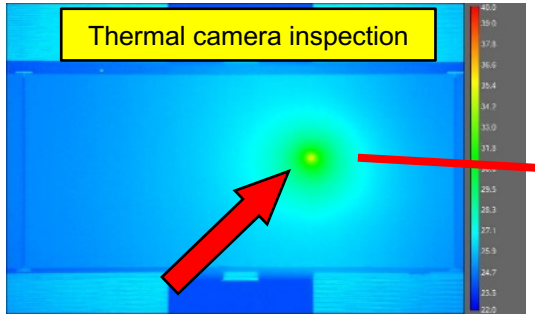
- FPC dimensional stability

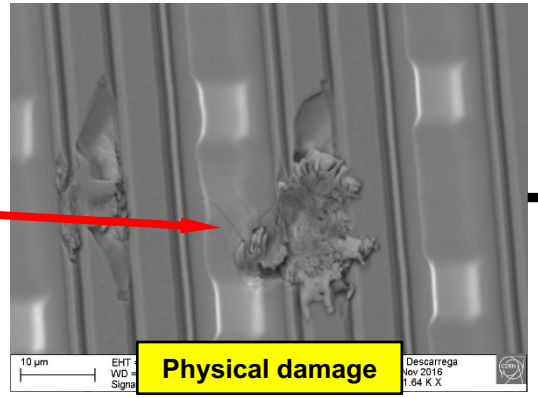


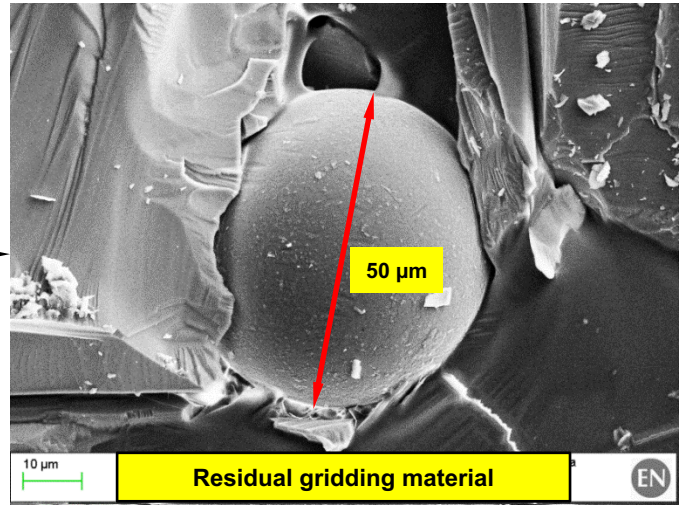
- **Solutions:**
  - Thermal treatment to stabilize the polyimide foil
  - Redesign the FPC layout with an expansion coefficient
  - Assembling the passive components by hand to prevent thermal stress.

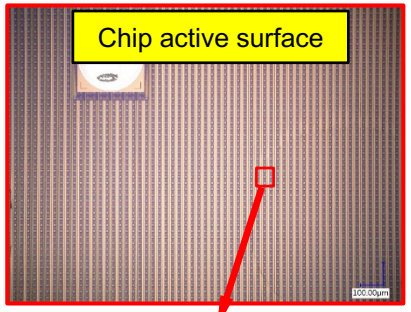
Challenges

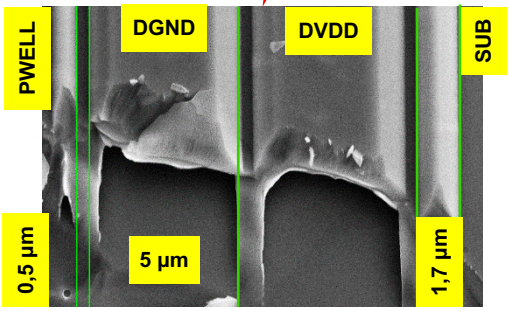
- Prevent hard particle contamination



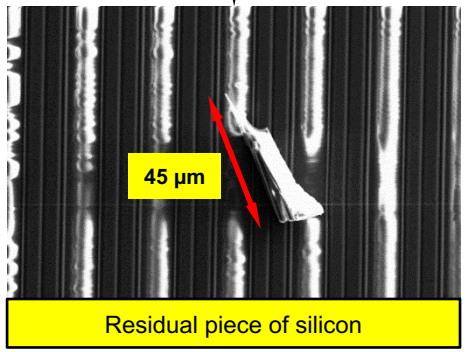


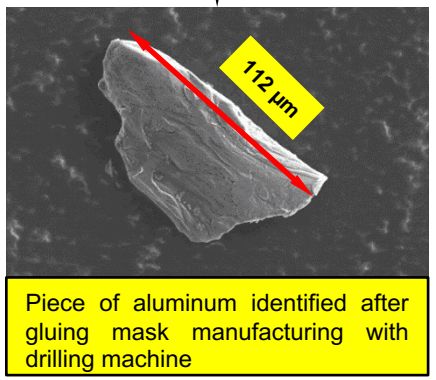




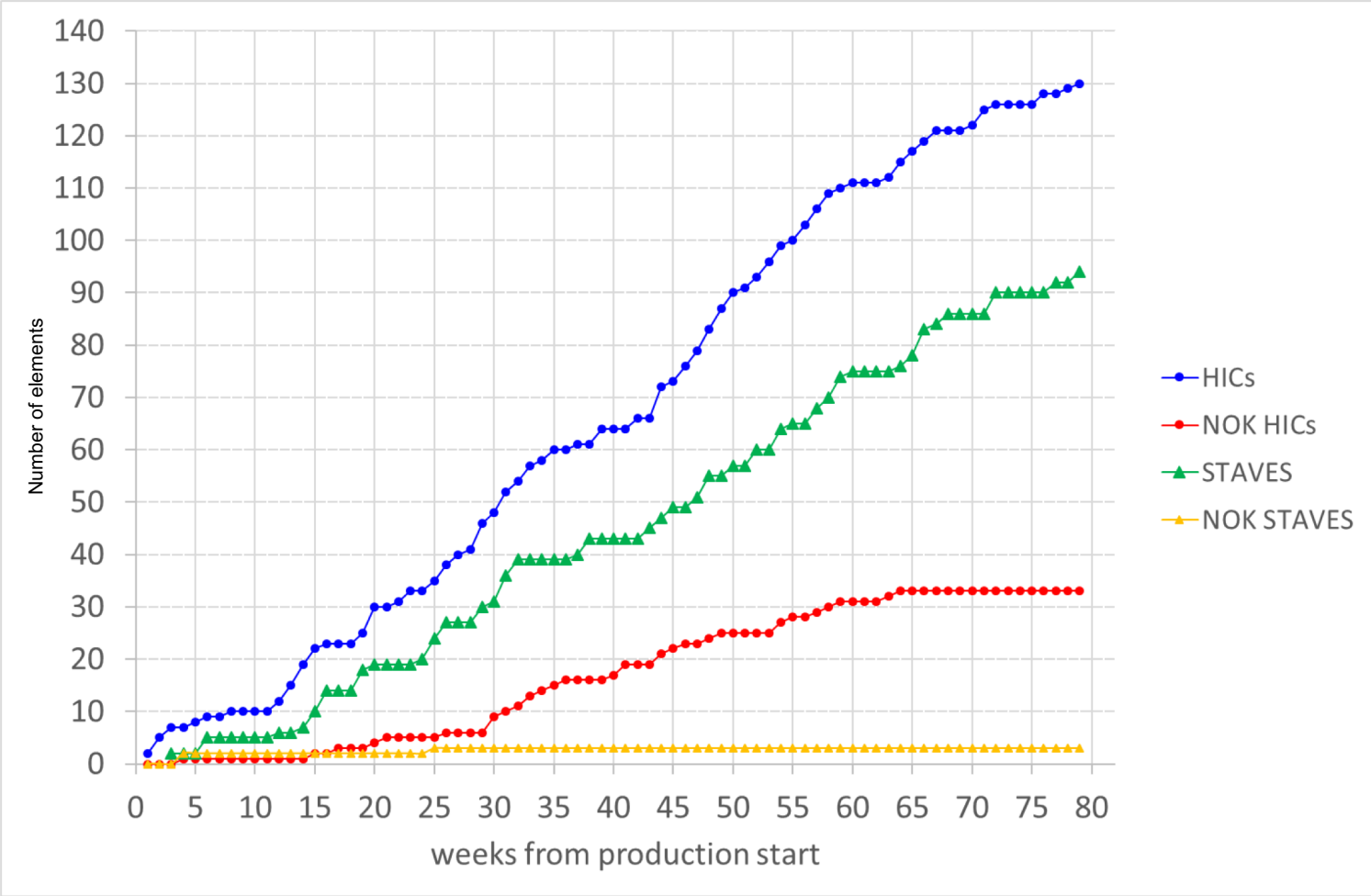


- **Solutions:**
  - Visual inspection steps added
  - Cleaning procedure improvement
  - Glue mask manufacturing improvement
  - Glue replacement, without filler particles
  - Glue layer thickness optimization





Inner Barrel staves



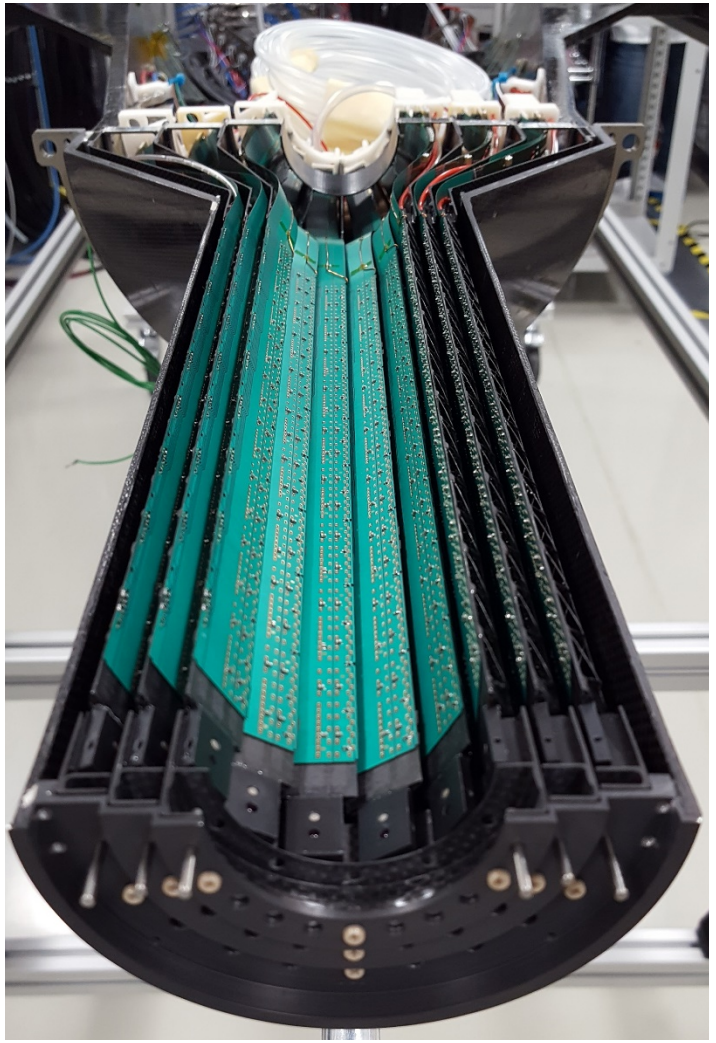
- 130 HICs were constructed
- 27 HICs were discarded mostly due to electrical problems
- 96 staves were constructed
- 1 Inner Barrel was assembled with 48 Staves

Conclusion

- ALICE ITS Inner Barrel was constructed
  - ✓ With low material, 0.38 %/X0
  - ✓ Conductive layer from aluminum
  - ✓ Signal lines routed without vias
  - ✓ Wire bonding through FPC

- Lessons learned
  - ✓ Intensive quality assurance
  - ✓ Importance of the metrology
  - ✓ Electrical tests
  - ✓ Cross section analysis
  - ✓ Prevention of contamination
  - ✓ Long training and specialize team

- Commissioning started and will be completed by April 2020, installation in the cavern in summer 2020



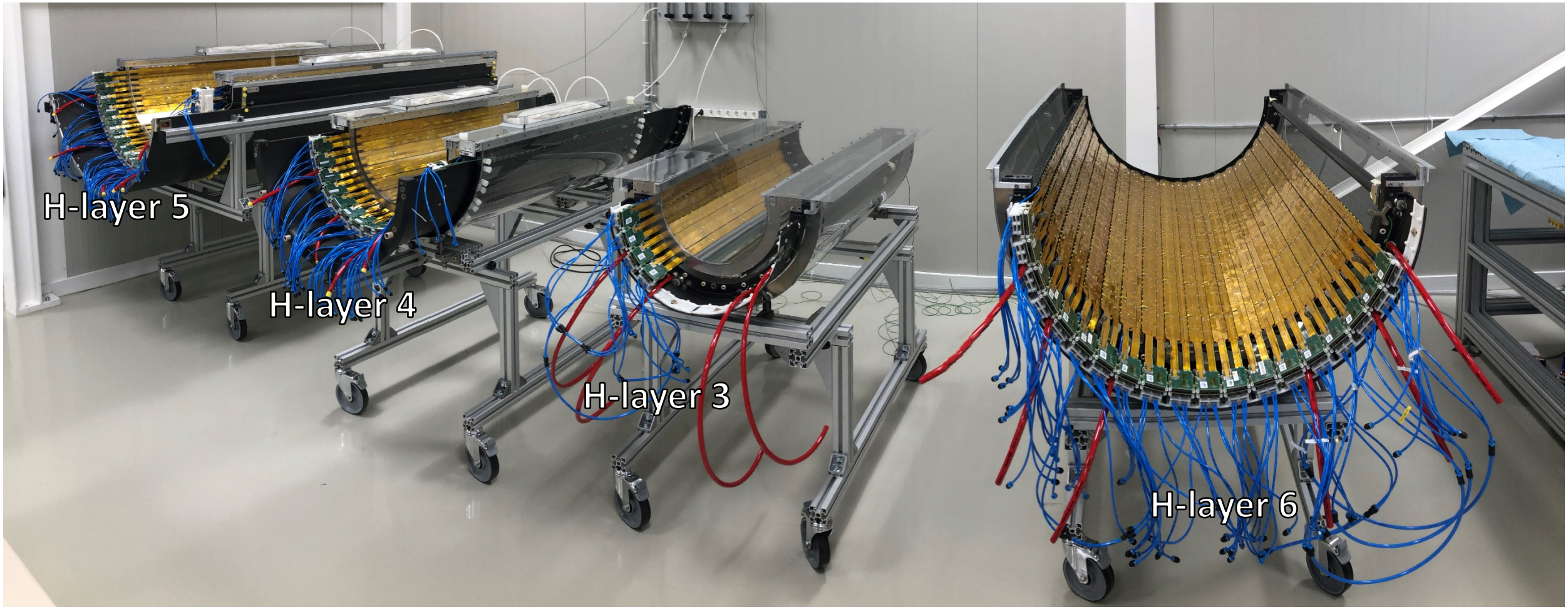
Inner half Barrel

Thank you for your attention!

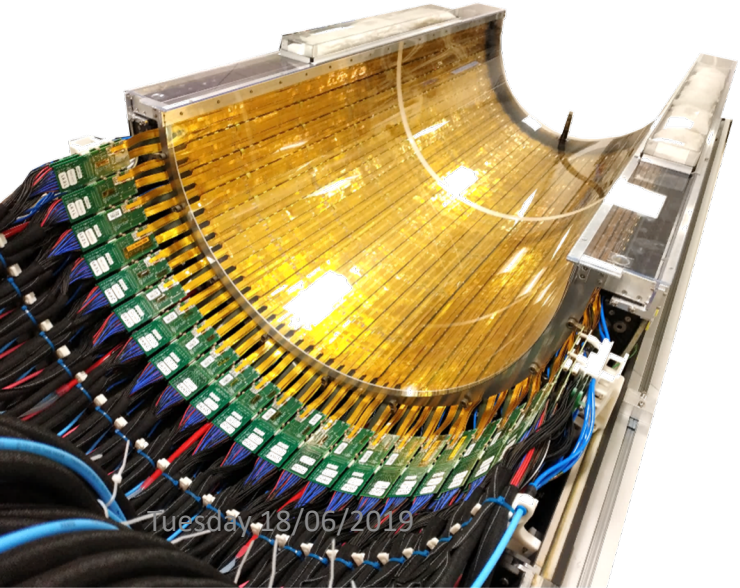
Backup slides

Stave integration: **OB layers**

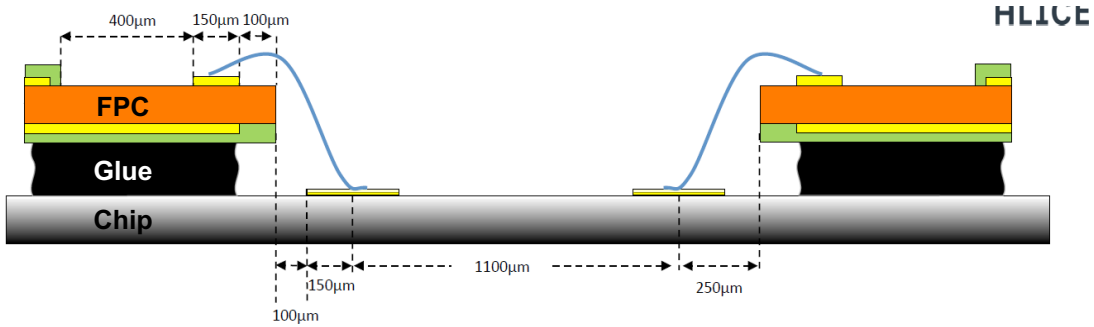
Half-barrel completed

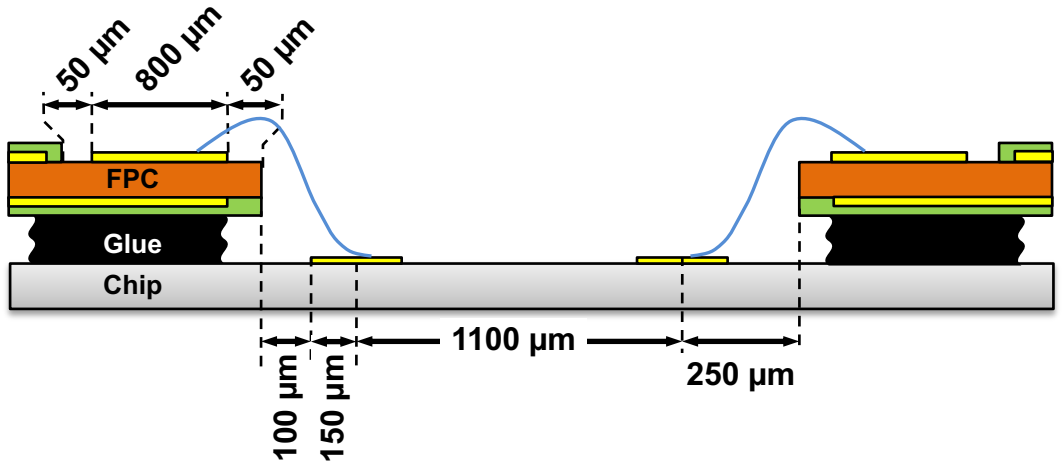


Stave integration: **Layers commissioning**



- **Layer 6** and **Layer 2** being commissioned with final electronics and cooling


400µm
150µm
100µm
FPC
Glue
Chip
1100µm
150µm
100µm
250µm


50 µm
800 µm
50 µm
FPC
Glue
Chip
1100 µm
100 µm
150 µm
250 µm