Assembly and characterization of 3D pixel modules for the ATLAS ITk detector

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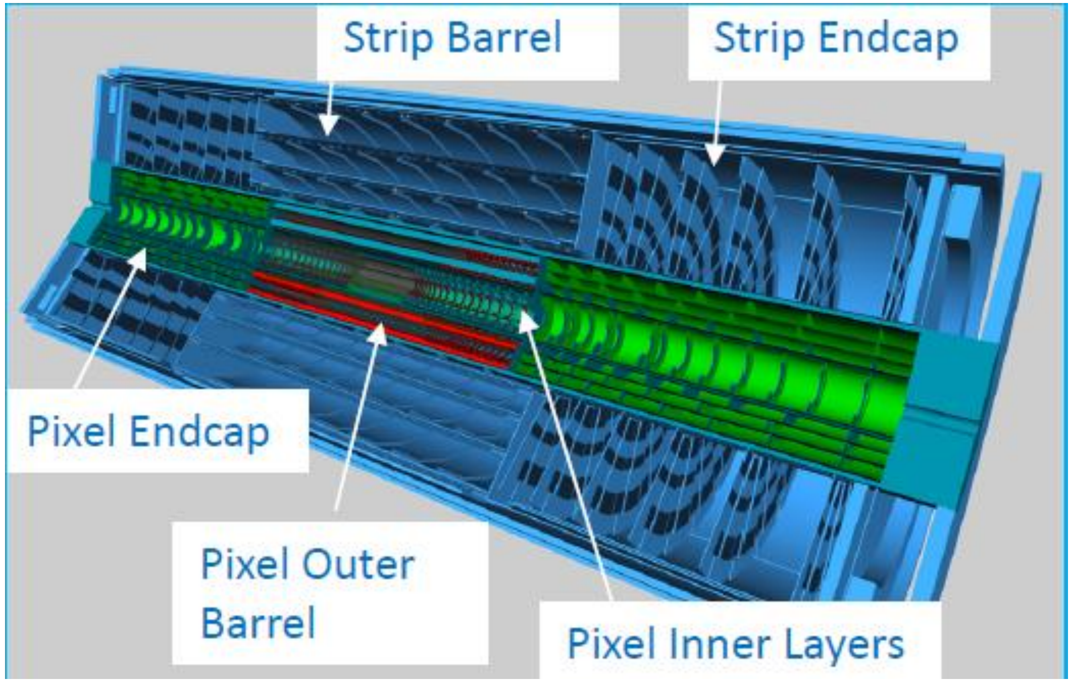
Institut de Física d'Altes Energies

CENTRO NACIONAL DE MICROELECTRONICA

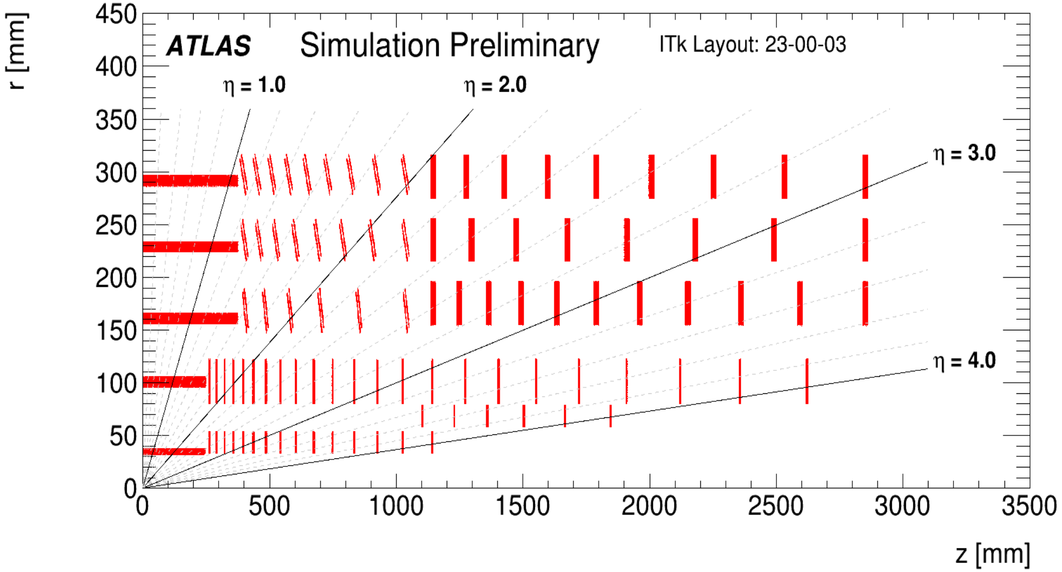
Motivation

The LHC next upgrade is the High-Luminosity LHC (HL-LHC) planned to start operation in 2029.



Challenges:

- **Radiation hardness**
    - The radiation fluence is larger close to the interaction point (between 1 and 2E16neq/cm^2)
- **Space constraints**
    - Limited space for detector modules, electrical services and cooling system results in very stringent mechanical constraints.

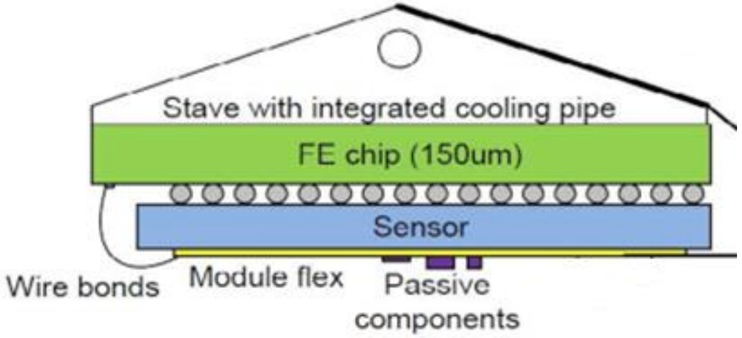


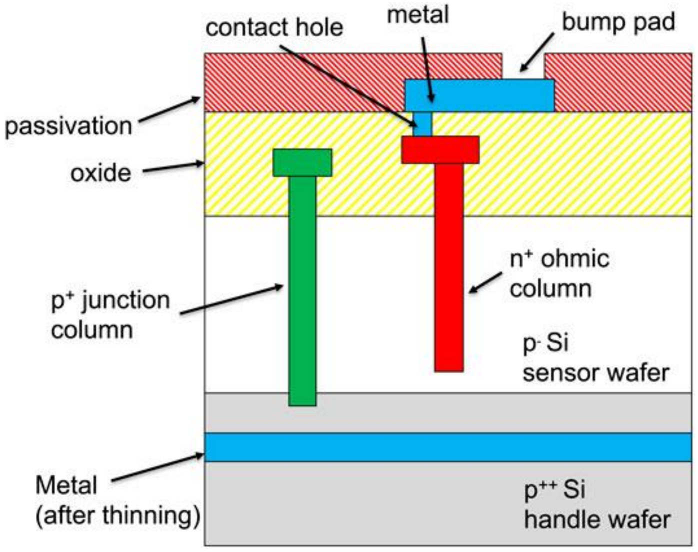
This presentation is divided in:

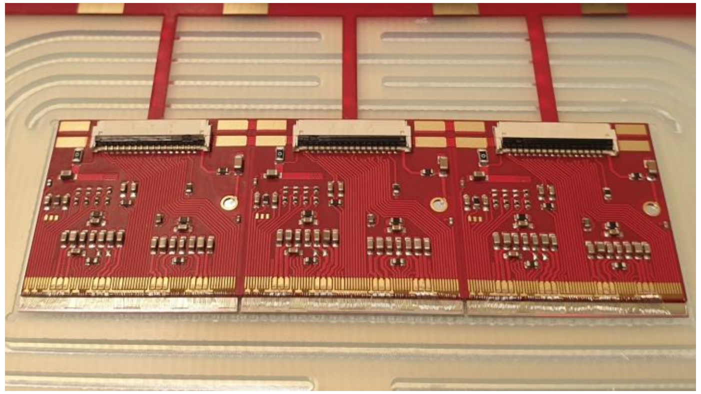
- Module assembly for ATLAS ITk Pixel detector in the layer L0.
- Sensor Quality Assurance

ITk Pixel Triplet Module

- **The Front-End (FE) chip**
  - 50x50 μm^2 pixel size
  - Dimensions: 20.3x21.2 mm^2, 150 µm thickness.
- **Sensors**
  - 3D silicon pixel sensors (50x50 μm^2 1E and 25x100 μm^2 1E cells).
  - 150µm active thickness with 250-270 µm total thickness.
  - Single side and SiSi technology
  - Sensor Fabrication sites:
    - FBK (Trento-Italy); SINTEF (Norway); CNM (Barcelona-Spain)
- **A set of 3 bare-modules attached together in a flex form a Module.**
  - One flex handles communication for 3 chips reducing the number of cables.
- **Finally, modules are attached to a mechanical support for cooling with CO2.**



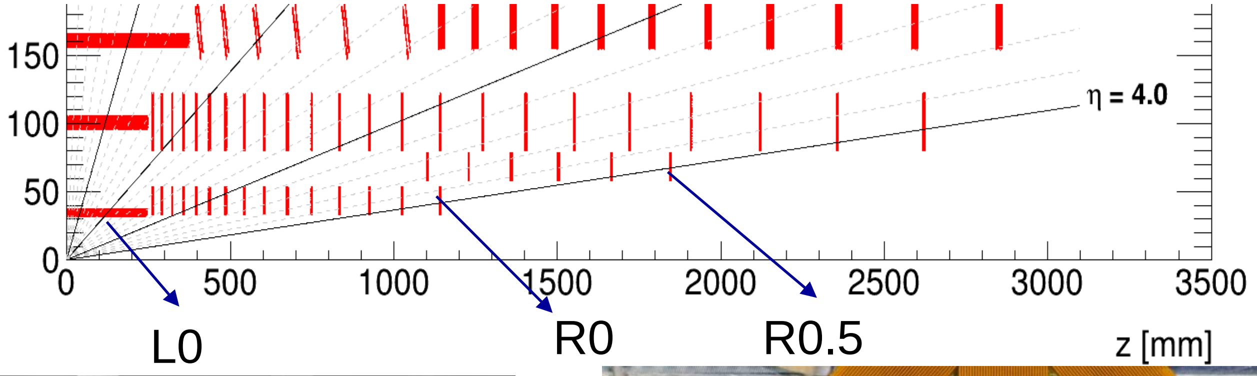


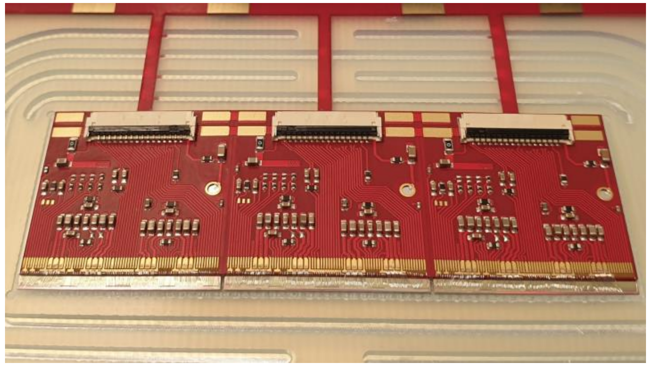


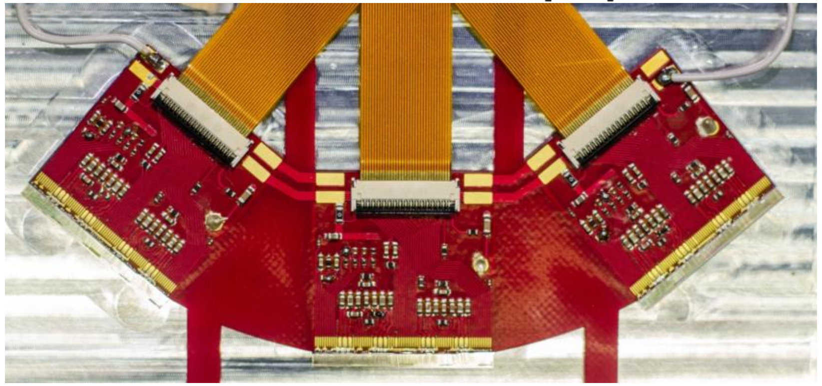
Module assembly

Assembly sides

- **Norwegian cluster**
  - Oslo; Bergen
  - Ring triplets R0 (End cap)
- **Italian Cluster**
  - Genova; Milan; Trento; Bologna
  - Rings triplets R0.5 (End cap)
- **Spain**
  - IFAE, Barcelona
  - Linear Triplet L0 (barrel)







For ATLAS ITk in the layer L0, it is necessary to assembly a total of 141 (96 + spares) functional linear triplet modules:

- **Developing the process and methodology of assembly**
- **Testing electrical performance.**

RD53A → ITkPixV1 → ITkPixV2

RD53A
- Prototypes
- 4 modules
- DONE

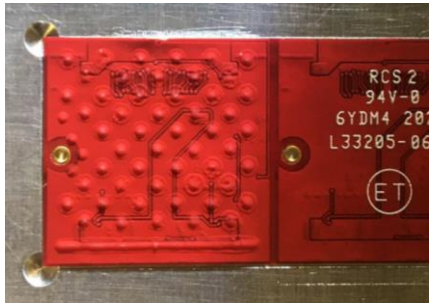
ITkPixV1
- Pre-production
- 18 modules
- IN PROGRESS

ITkPixV2
- Production
- 141 modules

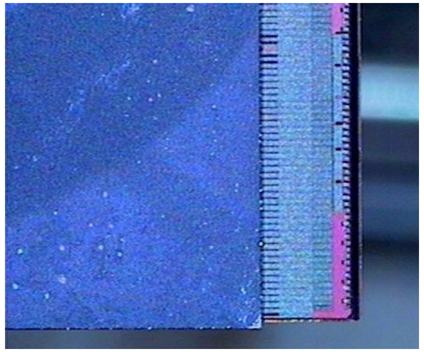
Assembly process

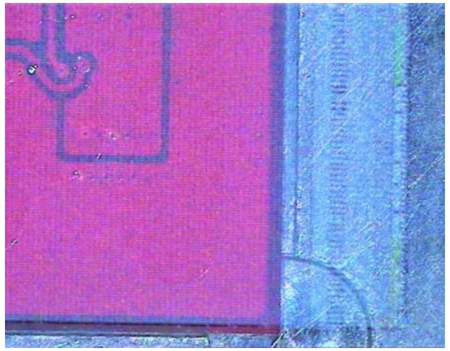
Applying the adhesive → Alignment → Adhesive Curing → Wire bonding

Applying the adhesive: Adhesive is prepared and applied on the flex.

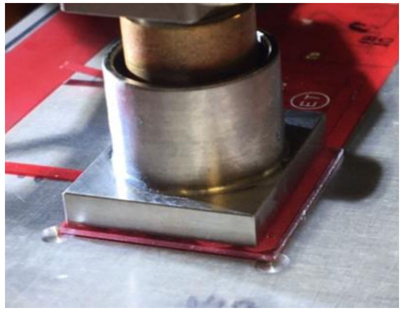


Alignment: The chip is aligned with respect the flex in the correct position.

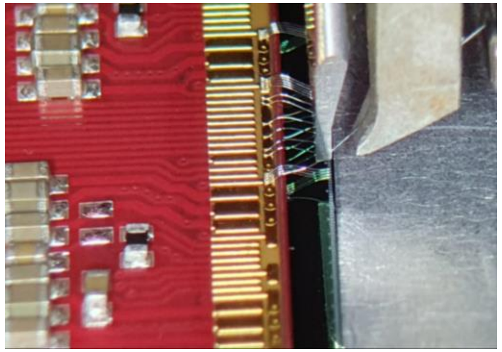




Adhesive Curing: The chip is placed on the top of the flex, and it is necessary to wait until the adhesive is cured.



Wire bonding: The connection between the chip and the flex is done by a wire-bonding process.



<u>Assembly process achieved a 5μm precision in position.</u>

Mechanical tests

Modules that don't match mechanical specifications can not be loaded in the final detector.

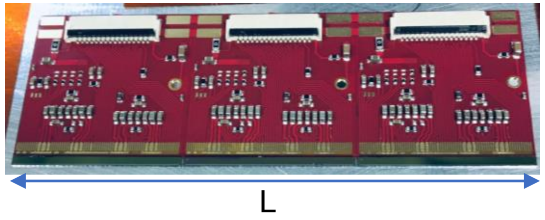
Dimensions

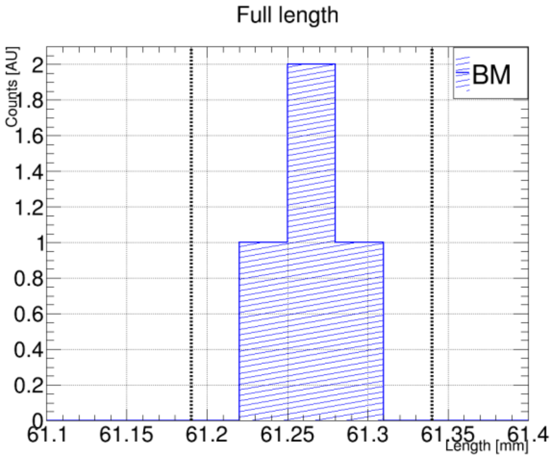
- Full length (L)
- Rotation

Glue

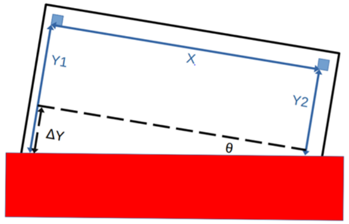
- Amount of glue
- Glue coverage

Between 61.26 +/- 0.075 mm

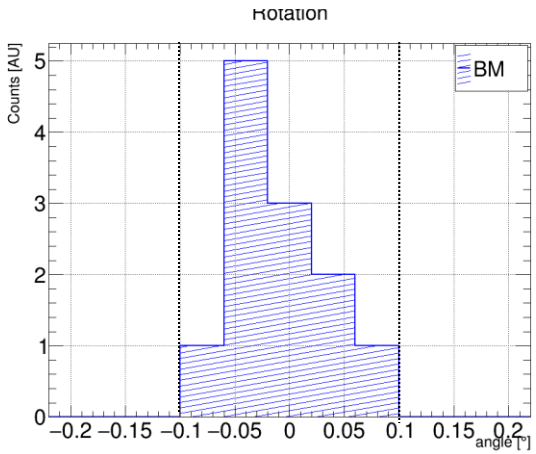




Value should be smaller than 0.1 degrees.

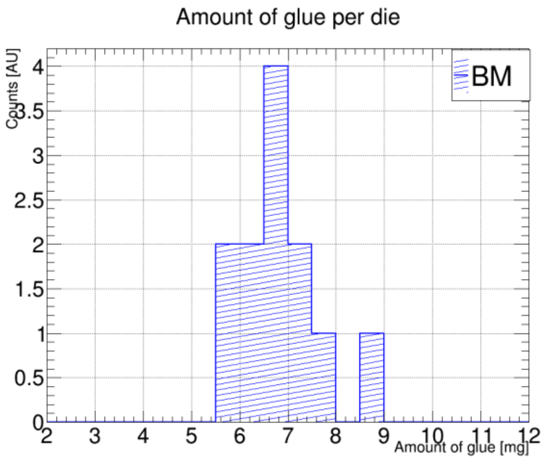


θ=arc tan(ΔY/X)

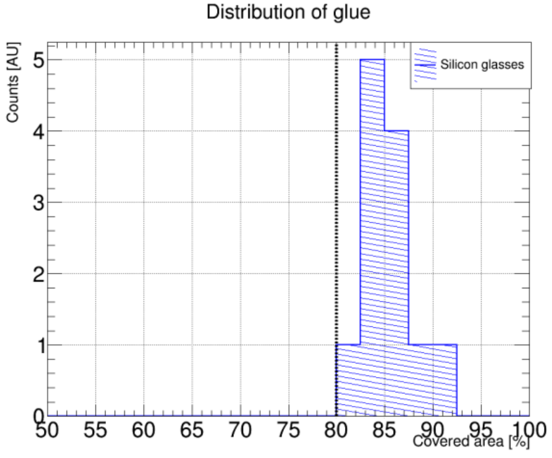


Amount of glue was measured weighing the components before and after assembly.

- Glue cover more than the 80% of the area.
- Did not see glue seepage.



Glue coverage was measure using a program that identify the background. Higher than 80% of the area.



Electrical test

Readout system YARR:

- Communication with the module
- Configure chip parameters
  - Threshold
  - Voltage/current regulators

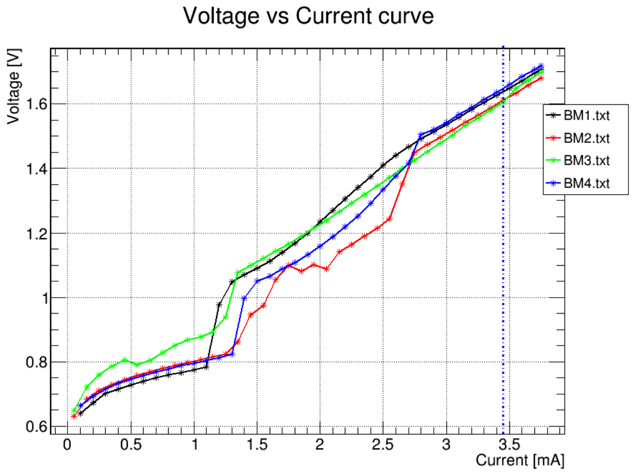
During the module production, these tests will be used to discard malfunctioning modules.

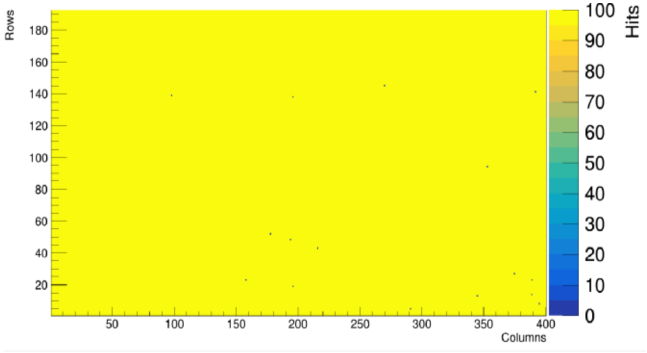
Establish communication

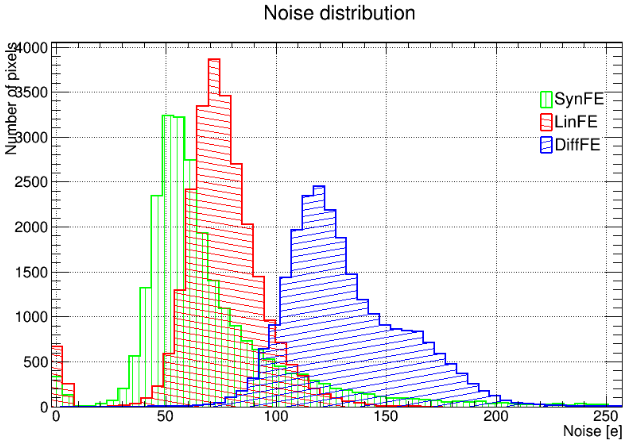
The VI of the chip is measured and an injection test is performed.
The operational current of these modules is 3.45 A.
At these value, the voltage should be 1.6 V

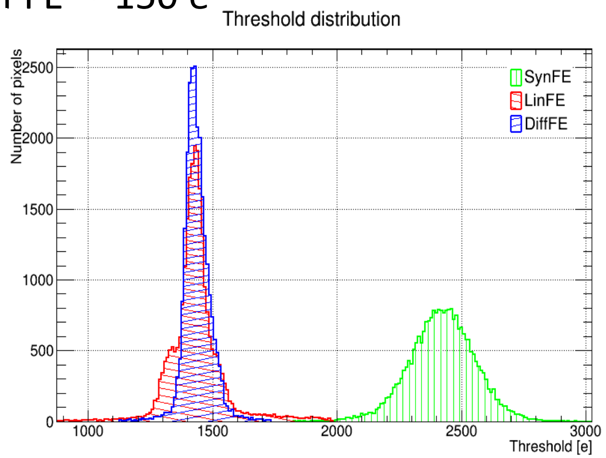
Threshold and noise scans

The threshold of each pixel is tuned
(RD53A chip has 3 different Fes)
Typical value of the noise ~ 80 e
For Diff FE ~ 150 e



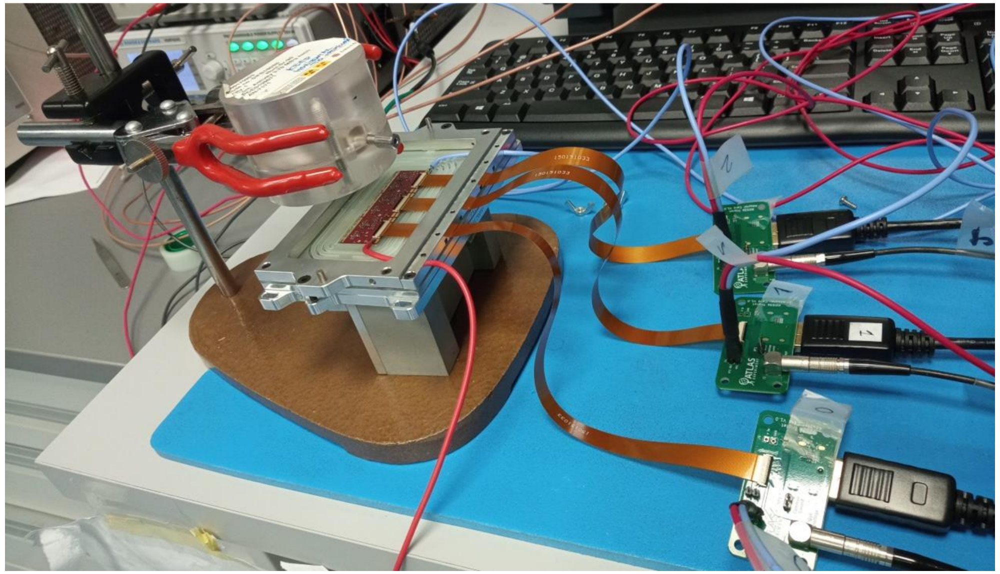






Electrical tests were performed at room temperature (20°C) and at low temperature (-25°C)

Electrical test - Source scan

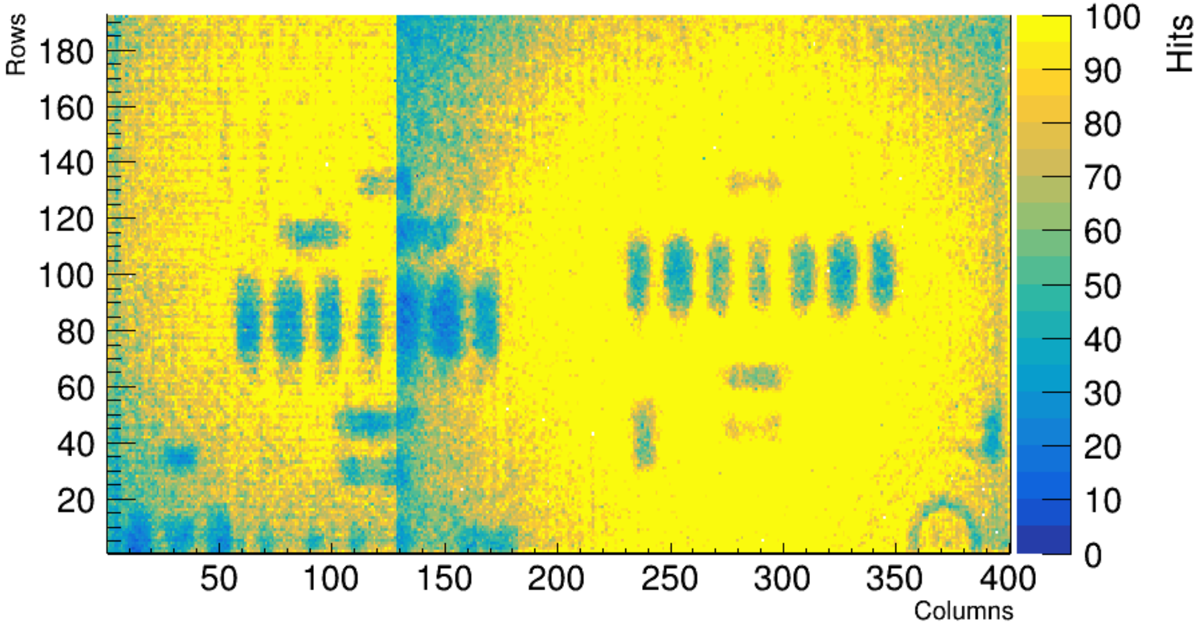


The final test to study the performance of the triplet is the Source scan.

In this test we use a ^{90}Sr radioactive source to measure the signal on each pixel to checked if there are not responding pixels due to a bad bump-bonding connection.

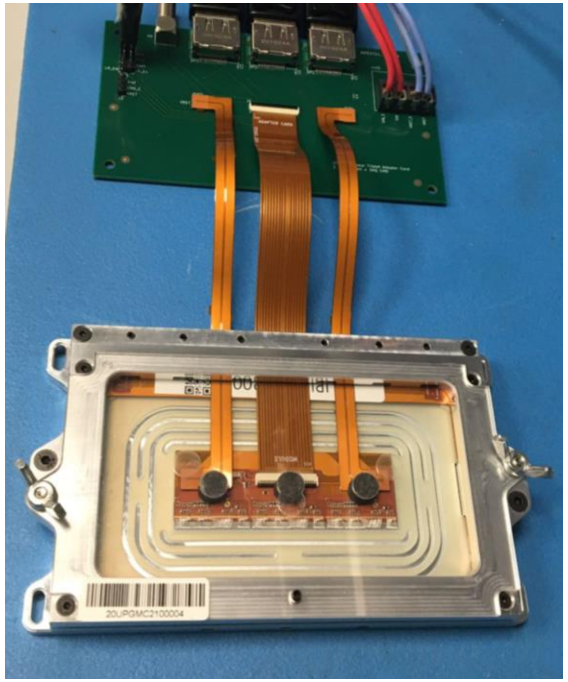
It can be seen that all the pixels respond.

So, there are no damage in the structure of the detector.



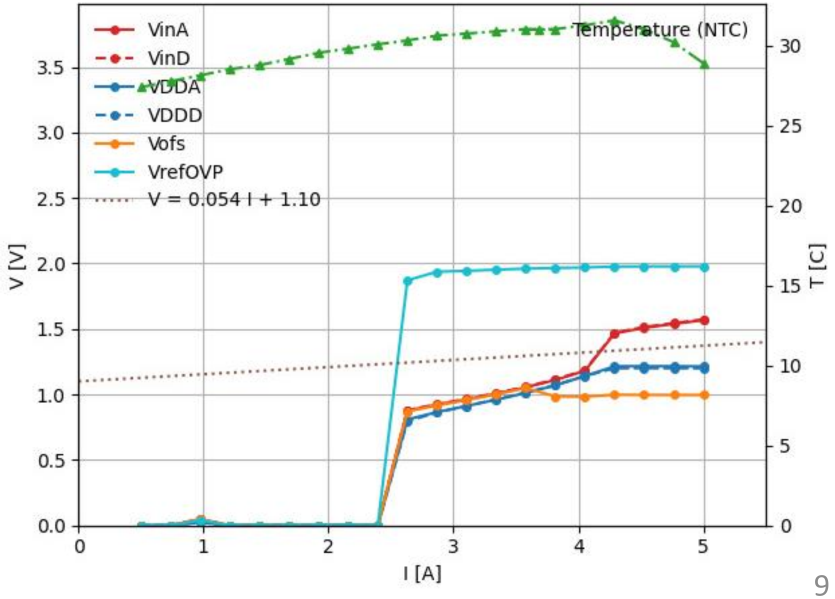
Preliminary electrical test – ITkPixV1.1 triplet modules

Preliminary electrical studies were performed using a linear triplet assembled with ITkPixV1.1 chips.



<u>Electrical test (using YARR system)</u>

- Communicate with the chip
- Focus on measuring internal voltages (probing).
  - E.g., VinD, VinA, VDDD, VDDA.
  - These value is accessible through a multiplexer (MUX)
  - MUX registers controlled by the readout system.



Sensor Quality Assurance (QA)

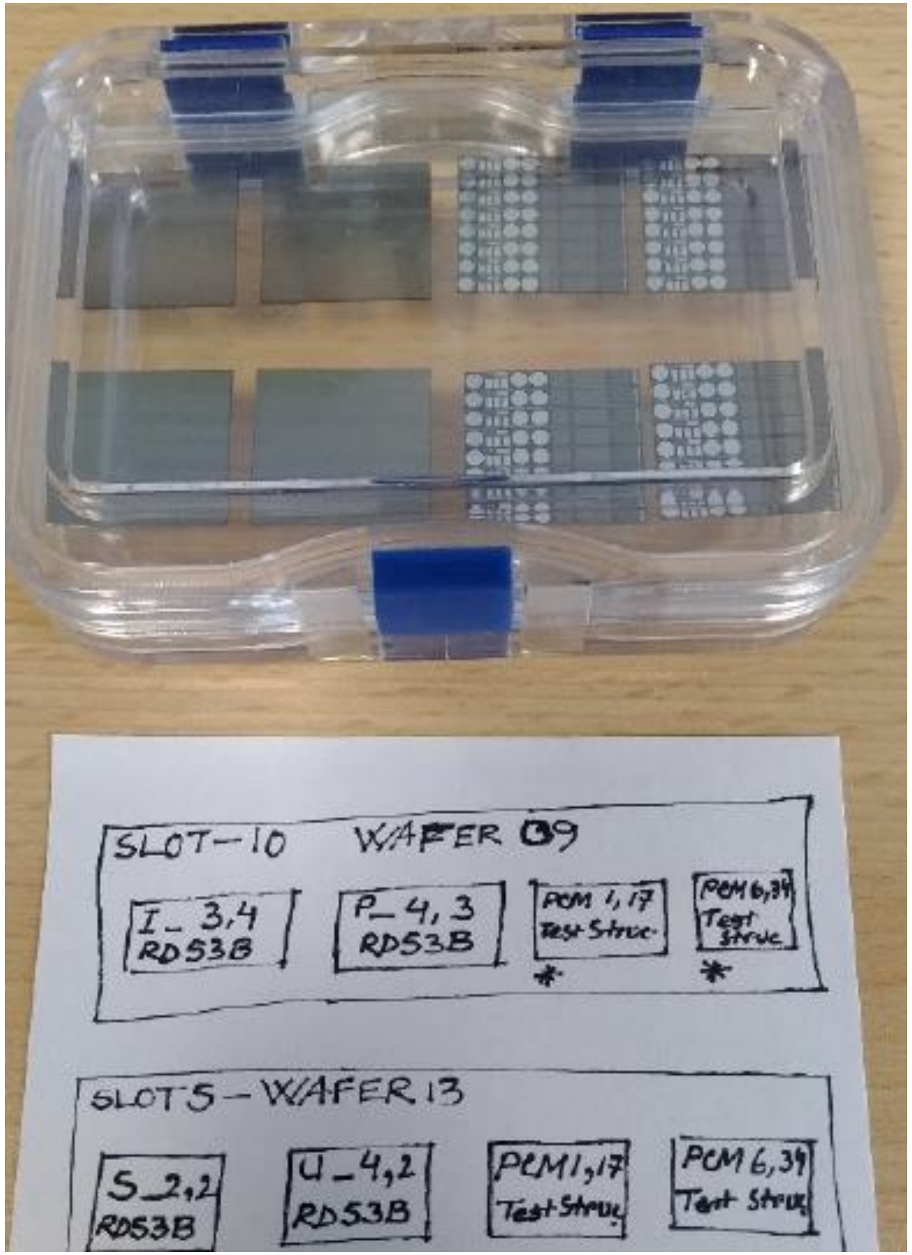
Two groups of RD53B 50x50μm^2 3D sensors and diodes from FBK were tested at CNM after irradiation.

The irradiation was done in CYRIC at Japan

- 70MeV proton beam.
- Uniformly irradiated.
- The modules are kept cold during irradiation.

QA/QC requirements for sensors after irradiation during operation:

- Power consumption at -25°C: < 40 mW/cm²
- Maximum current at -25°C < 0.20 mA/cm²
- Maximum operation voltaje < 250V
- Hit efficiency > 97%



Irradiated samples

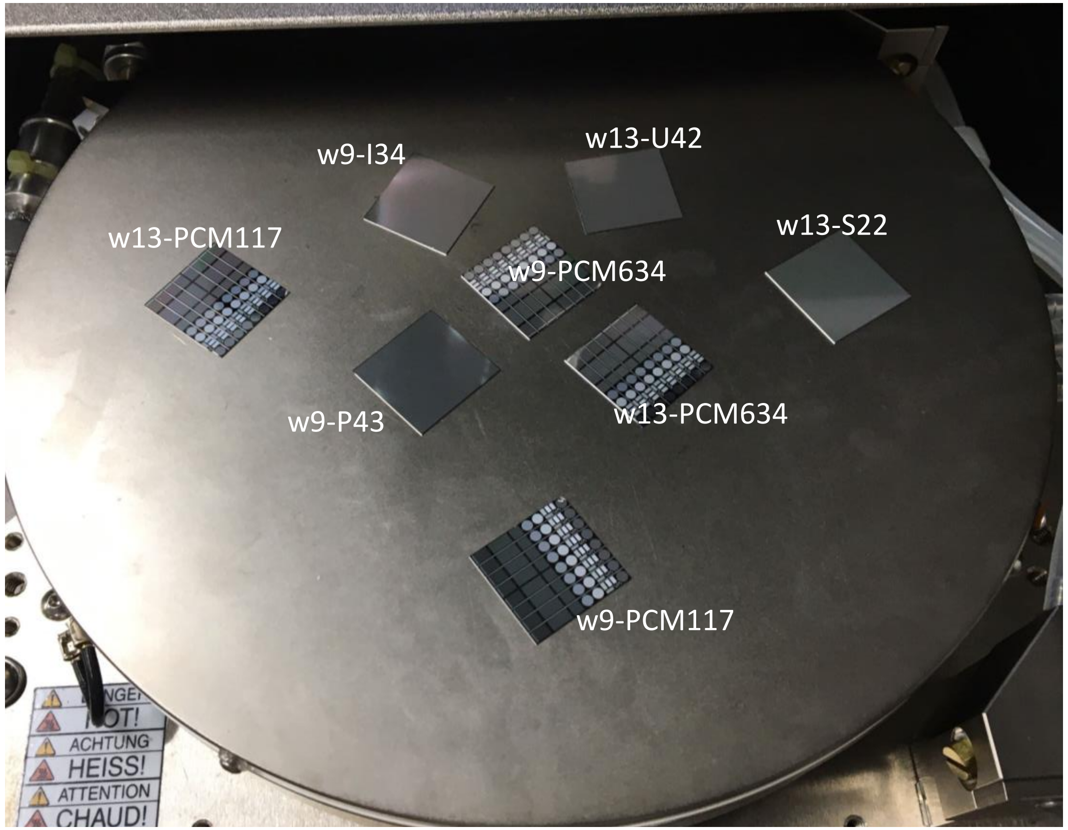
FBK sensors and diodes were measured in a probe station at CNM:

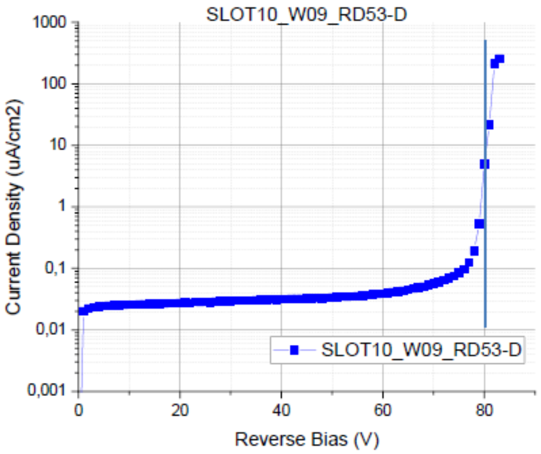
- Measurement temperature: -25ºC
- N2 was flushed to reduce the humidity inside de chamber.

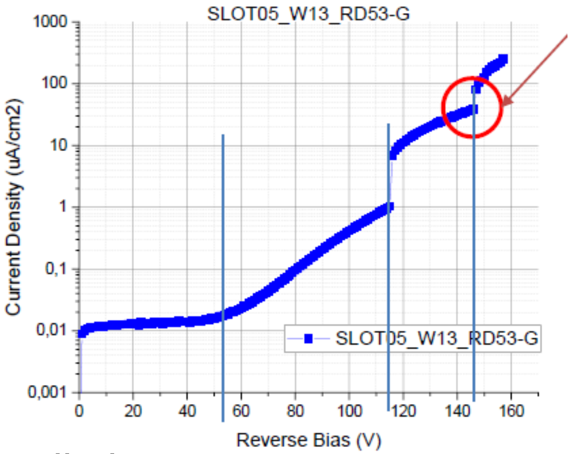
Measurements were carried out from 0V to 250V. Compliance level for diodes was 100µA while for sensors was 500µA.

Irradiated at	Sensor	Diodes
1e16neq/cm^2	w9-I34	w9-PCM117
	w13-S22	w13-PCM117
1.7e16neq/cm^2	w9-P43	w9-PCM634
	w13-U42	w13-PCM634

These sensors were also measured at Trento before irradiation (see D M S Sultan IWORID 2022 "**Quality Control (QC) of FBK 3D Si Sensors from the ATLAS ITk Preproduction**")

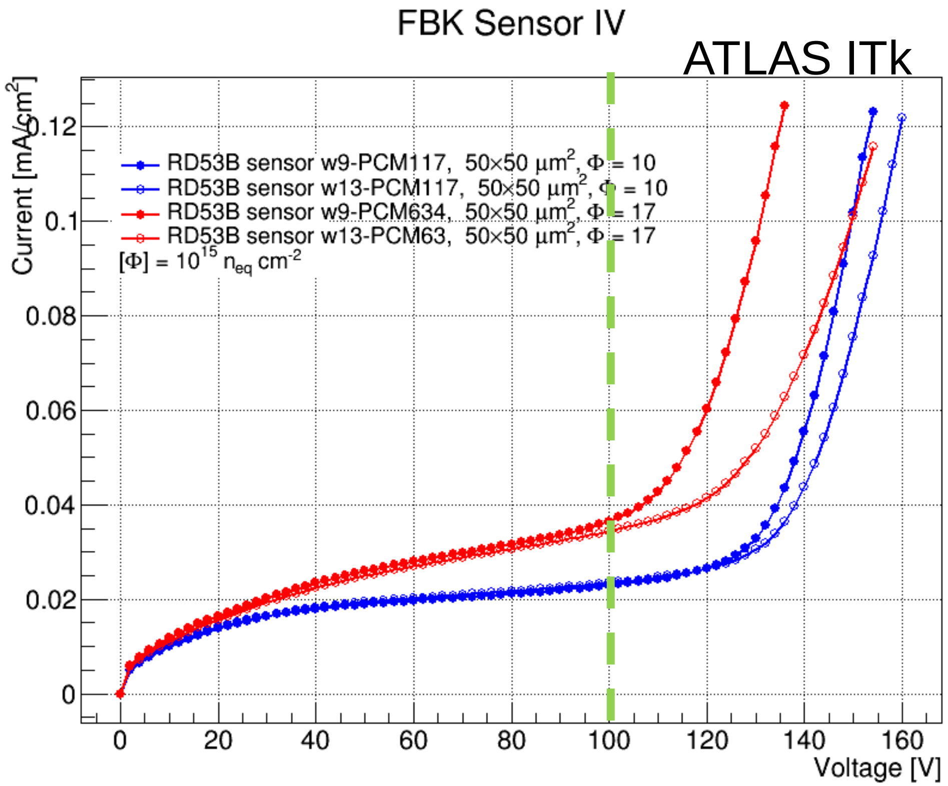


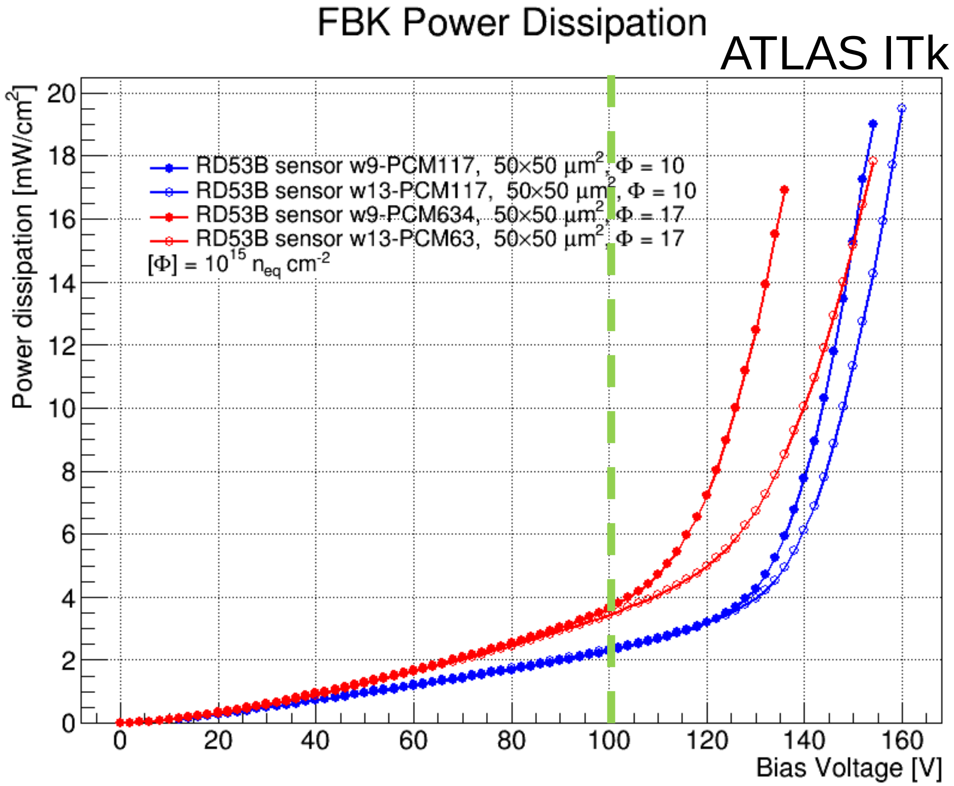




Measurements at CNM before irradiation

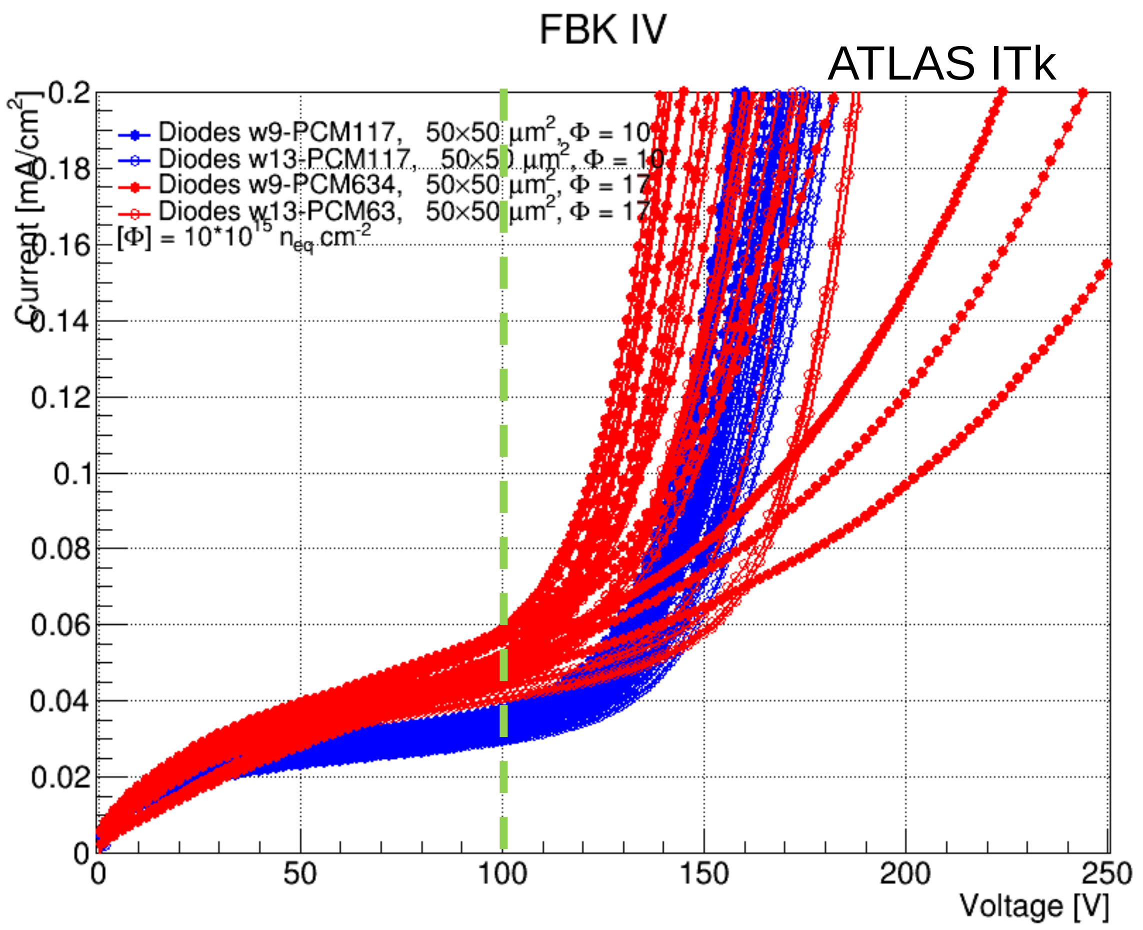
IV and Power dissipation measurements - sensors

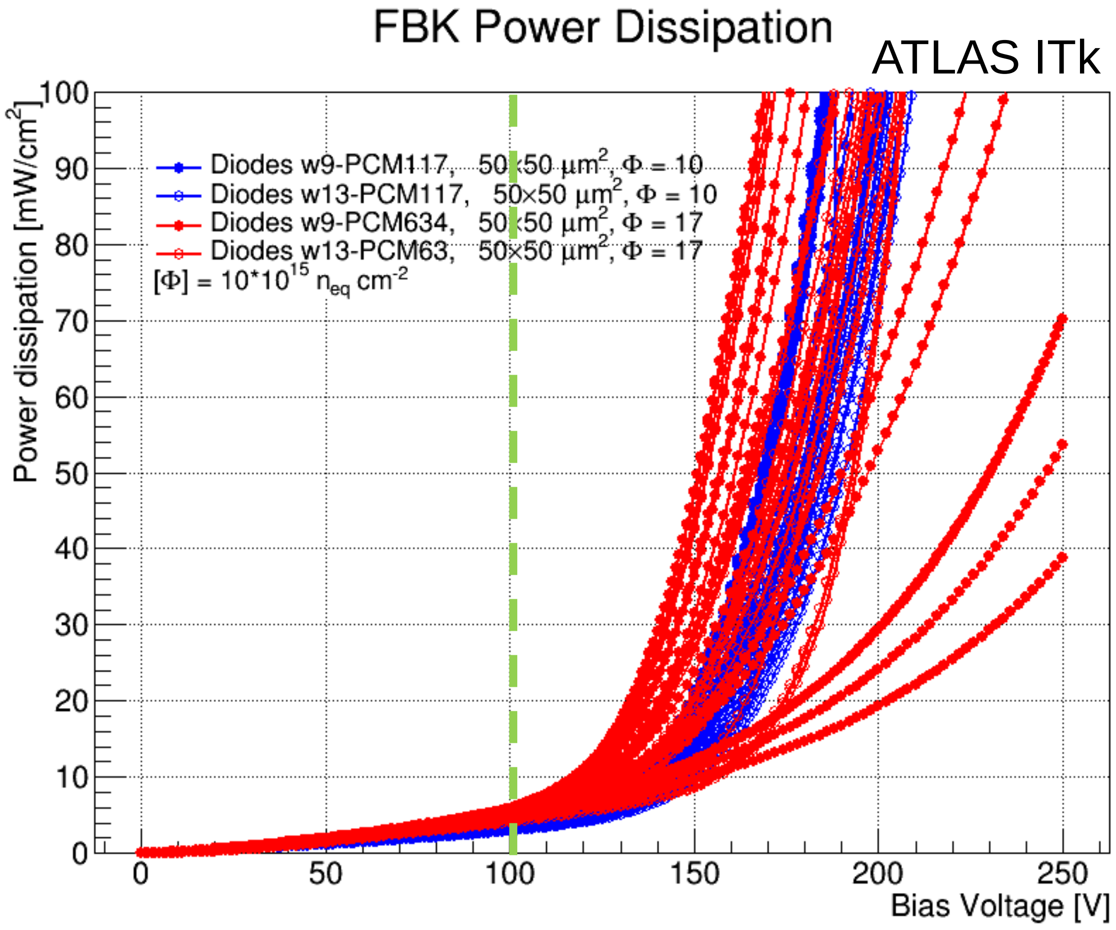




- Sensors are up to specifications.
- Efficiency >97% between 100 – 150V (see presentation of Simone Ravera link in this conference)

IV and Power dissipation measurements - diodes





- Similar results are obtained on large number of diodes
- All showing a breakdown larger than 100V

Conclusion

- The ITk Pixel detector will include about 100 linear triplet modules in its innermost layer.
- First prototype modules (RD53A) assembled meet all the ATLAS ITk specifications related to
  - Assembly process and electrical performance
- We are currently working on the next step of the site assembly qualification process, which is the production of ITkPixV1.1 triplet modules.
- As part of the Quality Assurance procedures for the ITk pixel sensor production
  - Two groups of RD53B 50x50μm^2 3D sensors and diodes from FBK irradiated at CYRIC in Japan were tested at CNM.
  - IV and Power dissipation are within specifications
  - Sensor production order will be issued soon.

Thank you for you attention

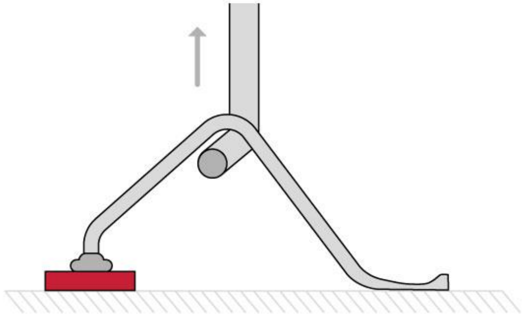
Backup slides

Mechanical tests

Wire bonding pull test

If wires are weak, they can break during shipping or loading in the mechanical support.

Pull test values should be higher than 5g.



Mean value for triplets is 6.1g.

Flatness

Flatness measurements are performed to check the height alignment among de chips in a single module.

The height between 2 points in the module should be lower than 50um.