Silicon Sensor Module Assembly at TIFR for the CMS Experiments

Kameswara Rao, Gagan Mohanty, Irfan Mirza,
Lokesh Bhatt, Mukund Shelke,Prashant,
Simon Periera, Sukant Mayekar, Thomas

(on behalf of the CMS HGCAL collaboration)
Dept of High Energy Physics
TIFR, Mumbai

DAE-BRNS High Energy Physics Symposium
BHU, Varanasi
December 19-23,2024

LHC Upgrade to High Luminosity LHC

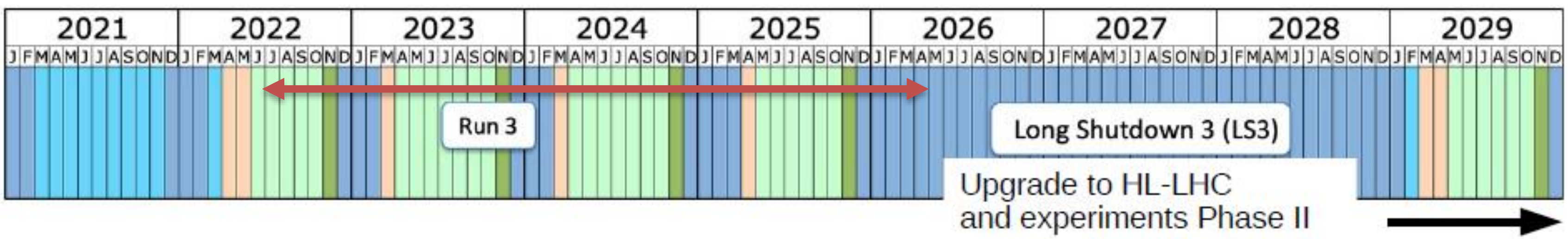
Instantaneous Luminosity: 2.5 x 10^{34} $s^{-1}cm^{-2}$ -> 5 – 7.5 x 10^{34} s^{-1} cm^{-2}

Pile-up events: O (80) -> O(140-200)

Radiation background 10^{14} n_{eq}/cm^{2} → 1 – 1.5 x 10^{16} $n_{eq}cm^{-2}$

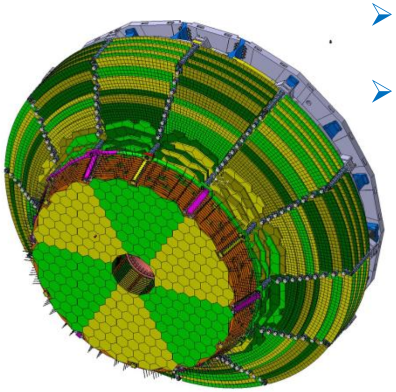
[Shilpi Jain's Talk]

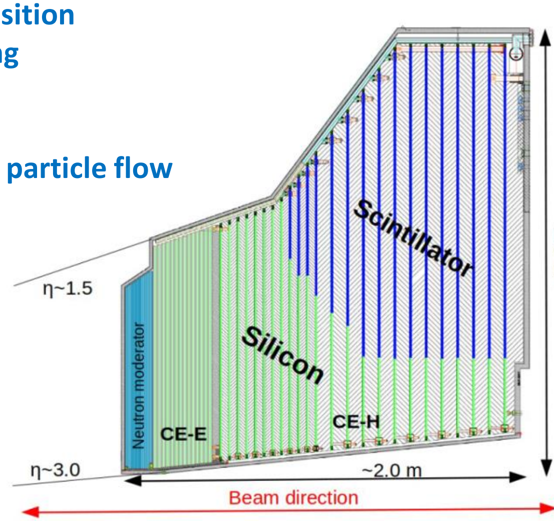
More radiation, more pileup, higher density of tracks, more data…..
CMS detector will be upgraded to cope up with new the challenges



Calorimetry

- **Replacement of the endcap calorimeters with a high-granularity calorimeter (HGCAL)**
  - ➢ **Measure energy and position**
  - ➢ **Precise hit/cluster timing**
  - ➢ **Radiation tolerant**
  - ➢ **Enhanced capability for particle flow reconstruction**
  - ➢ **Operation at -35°C**



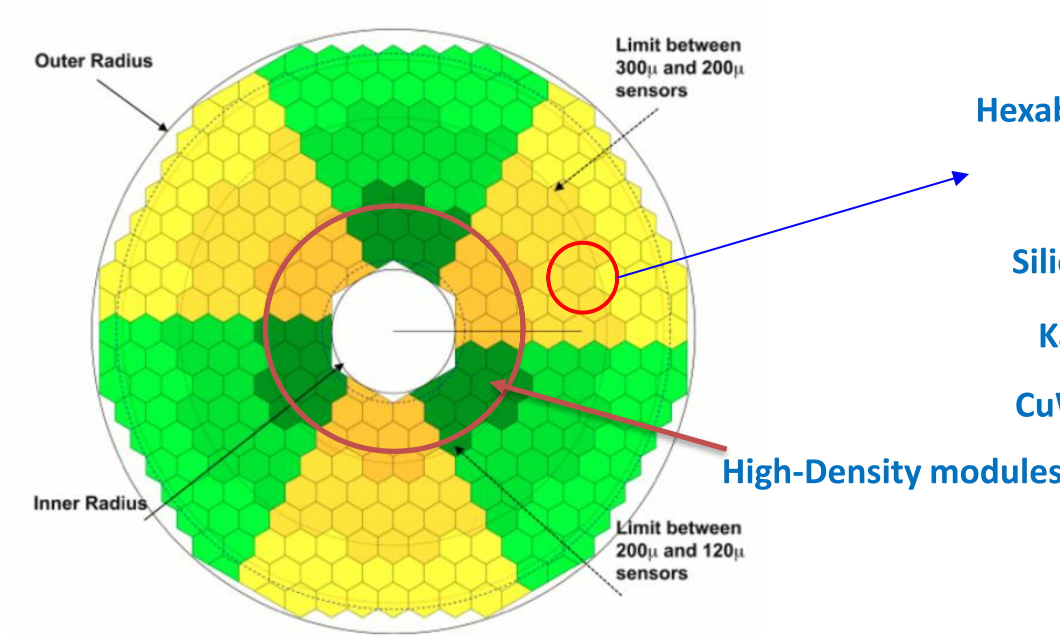


CE-E (Electromagnetic)
Active: Silicon
Passive: Cu, CuW, Pb absorbers
13 double-sided layers (full silicon)

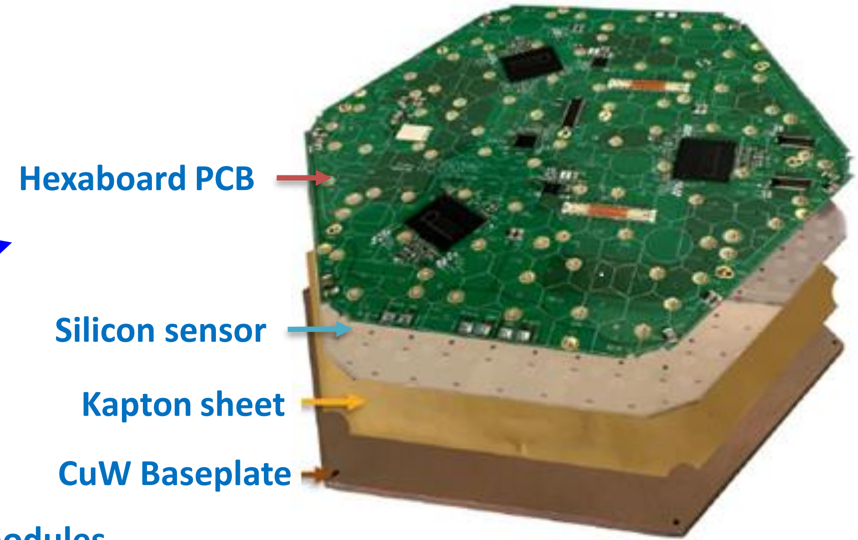
CE-H (Hadronic)
Active: Silicon + Scintillator / Silicon-photomultiplier
Passive: Steel absorbers
21 Si layers (full + mixed)

One of the Silicon Layers

HGCAL structure (silicon detector module)



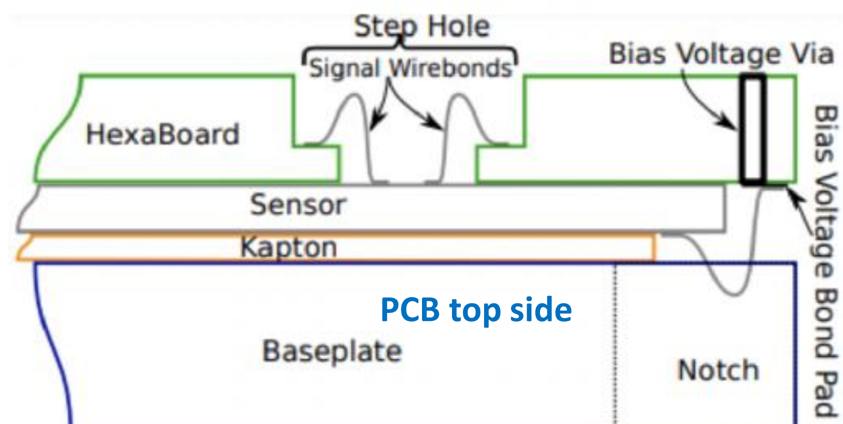
A complete Si layer



Stack up of an HGCAL Module

Silicon sensor

8” Low-Density sensor
192 cells with ~1.26 Sq. cm size
300µm & 200µm active thickness



Side view of the module

Technical Requirements of HGCAL Silicon Sensors

Planar p-type DC-coupled sensor pads

- simplifies production technology; p-type more radiation tolerant than n-type

Hexagonal sensor geometry preferred to square

- makes most efficient use of circular wafer area

8” wafers preferable to 6”

- reduces number of sensors produced & assembled into modules
- Cost per area is cheaper and simplifies the module mechanics

300μm, 200μm and 120μm active sensor thicknesses

- match sensor thickness (and granularity) to radiation field for optimal performance

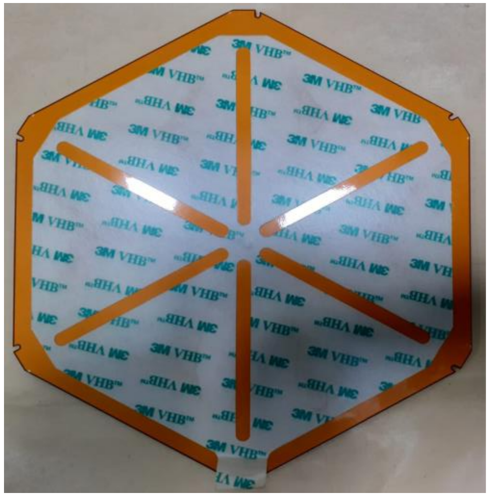
Simple, rugged module design & automated module assembly

- provide high volume, high throughput, reproducible module production & handling
- ~4.5K silicon-based HGCAL modules to be assembled in India for a total requirement of ~30K modules with ~15 modules per day capacity

We are assembling low density HGCAL modules at TIFR

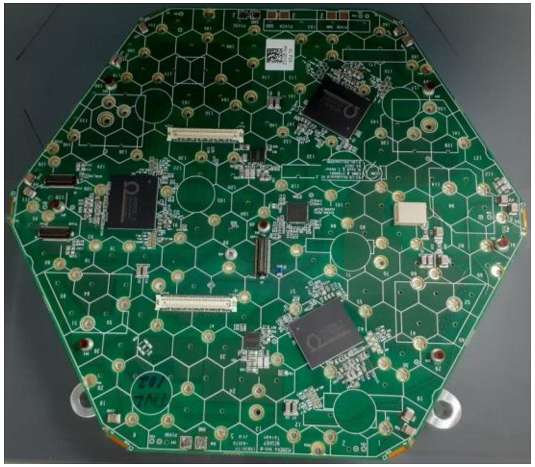
HGCAL Module Components and Key Assembly Steps

Module components:



CuW baseplate with transfer tape

Low-density (LD) silicon sensor

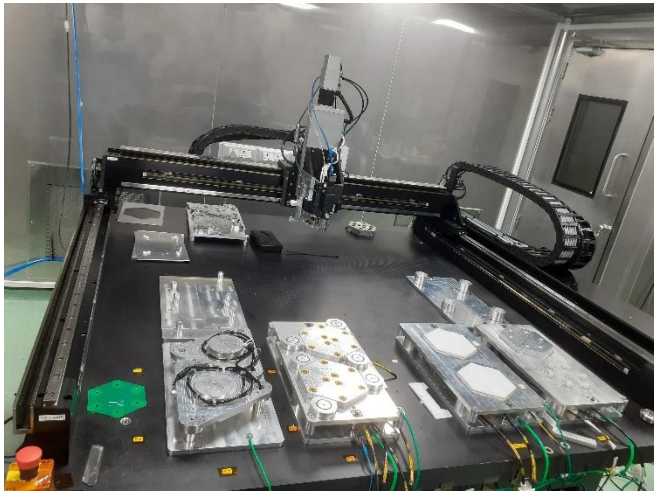


PCB top side

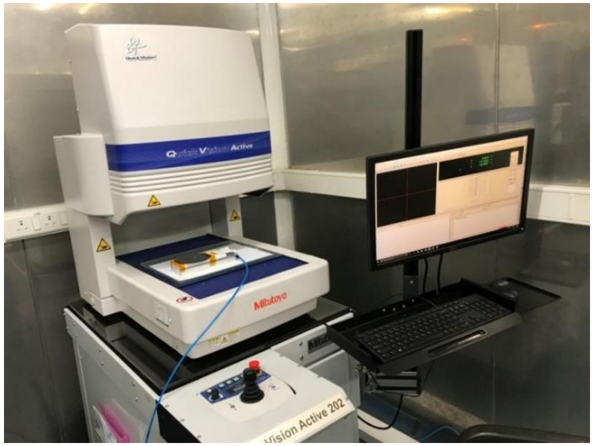
Key steps involved:

- Gluing on Baseplate + Placing of sensor + gluing on sensor + placing of PCB
- Fiducial measurements
- Wire-bonding
- Pull testing
- Visual inspection
- Electrical testing
- Encapsulation

Instruments needed for Module Assembly

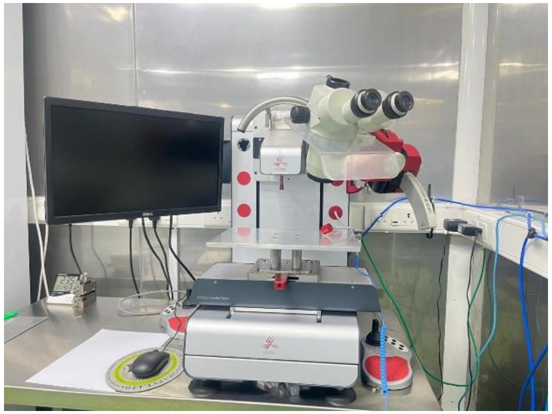


Aerotech Gantry
Working area: 1250mm x 1250mm x 100mm

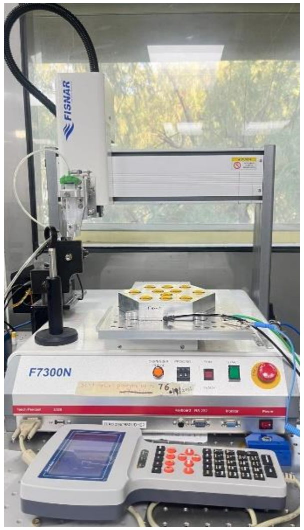


Coordinate Measuring Machine
Mitutoyo Vision Active 202
Working area: 250x200x150mm

Wirebonder
Delvotec 6400 – used for Belle II SVD
Working area: 150 x 200, 25mm in Z
Suitable for up to 6" wafers



Wire Pull Tester
XYZTEC condor sigma lite

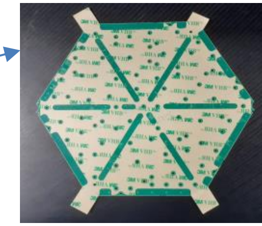


Fisnar F7300N mini gantry

- Leica M80 Microscope(90X)
- Motic Microscope (100X)
- Mushashi SM-300SX-3A mini gantry
- Dry cabinet (15% RH)
- Storage units
- Optical table (180x90cm)
- Around 700 Sq ft of clean room area

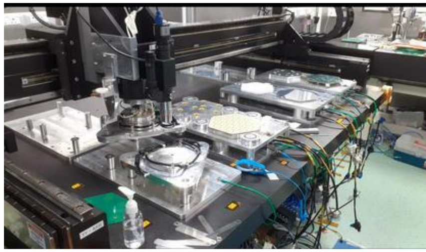
Flow chart of HGCAL Module assembly

1. Visual inspection, flatness ,thickness of components
2. Electrical QC on hexaboard
3. Attach transfer tape on hexaboard



Double sided tape

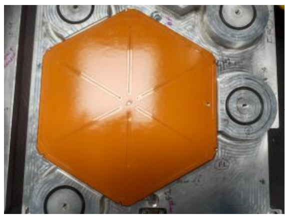
4. Electrical QC on hexaboard
5. Place baseplate on full module assembly tray, sensor on sensor tray, PCB on PCB tray



6. Run the Labview program which will hold the baseplate and sensor with vacuum on its trays

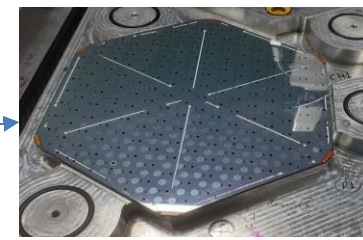
Hybrid model: tape + glue for faster production of modules

7. Remove transfer tape on baseplate and dispense glue on it

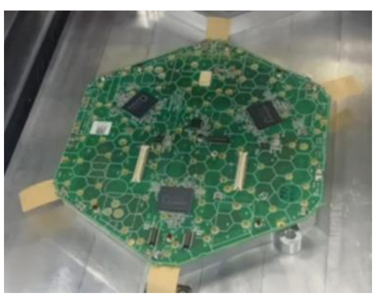


8. Pickup the sensor with sensor PUT and place it on the baseplate, keep it for 20min for curing purpose, measure Δx ,Δy, rotation of sensor using CMM
9. Dispense the glue on the sensor

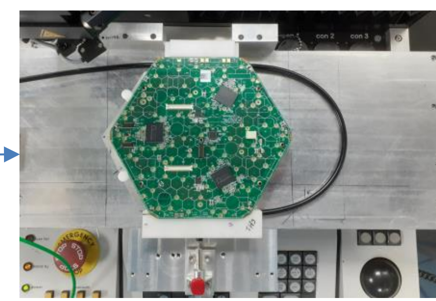
Glue : Araldite 2011



10. Pickup the PCB with PCB PUT and remove its 3M tape cover and place it on the sensor and keep it for 20min, measure Δx, Δy, rotation of PCB using CMM



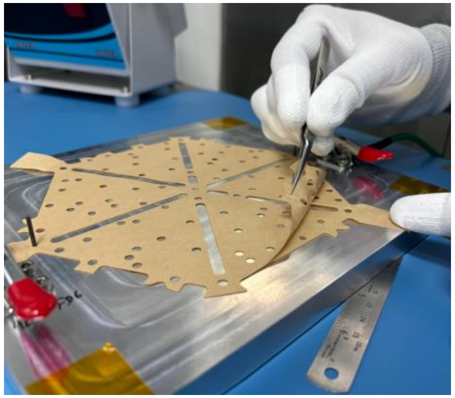
11. Electrical QC on PCB of assembled board
12. Backside bonding followed by encapsulation on assembled module
13. Frontside bonding followed by IV,QC test on assembled module



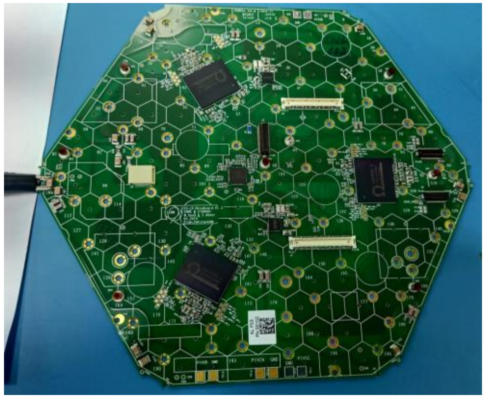
14. Encapsulation and thermal cycling followed by Electrical QC
15. Module placement on a carrier box and storage in a dry cabinet
16. Data entry in database
17. Module shipment (in batches) to CERN

Transfer tape attachment to Hexaboard

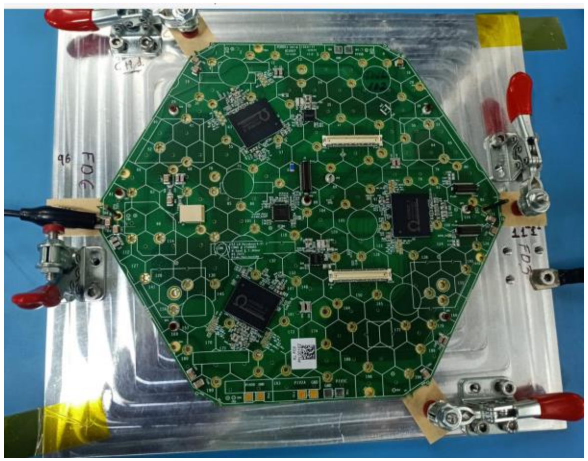
- Align transfer tape on the jig (3M-VHB double sided tape F9469PC)
- Remove parchment paper
- Hold the capacitor with crocodile clip which has to be connected to ground to avoid ESD damage to readout chips
- Place the Hexaboard on the transfer tape
- Perform QC on the Hexaboard with tape



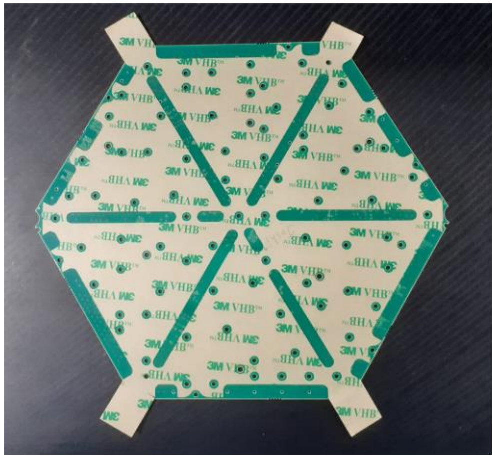
Removing parchment paper



Holding the capacitor with Crocodile clip



Placing the Hexaboard on tape

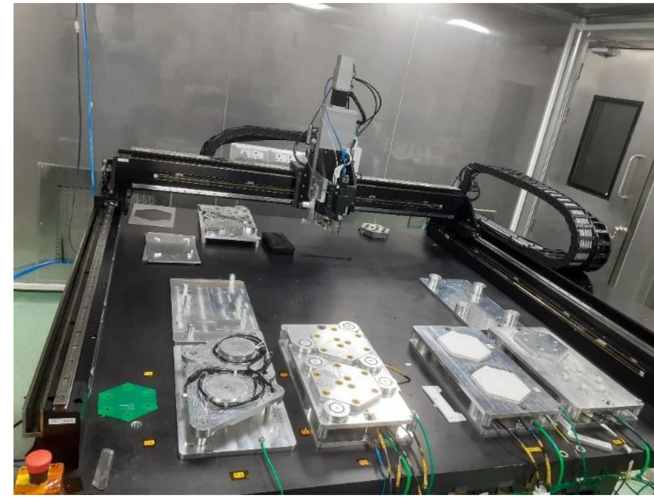


Hexaboard bottom side

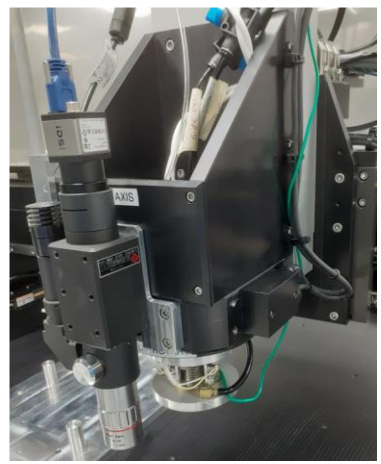
Aerotech Gantry setup

- Axis movement : X, Y, Z and Rotation
- Runs on Labview software
- Setup done for camera, syringe for dispensing glue and movement of gantry head in all directions
- Manifold setup for vacuum ON/OFF with the feedback system to NI products
- One of the vacuum holes on the gantry head will be used to pick up the sensor or Hexaboard pickup tool
- Second vacuum hole will be used to hold the sensor or Hexaboard
- Measure fiducials on the assembly tray
- Measure the two circle fiducials on the sensor left and right sides
- Program will calculate the Δx, Δy, rotation of the sensor and accordingly adjust while placing it on the baseplate
- Measure the fiducials on the Hexaboard
- Program will calculate the Δx, Δy, rotation of the Hexaboard with respect to the baseplate and accordingly adjust while placing them
- All fixtures are connected with vacuum and ground connections

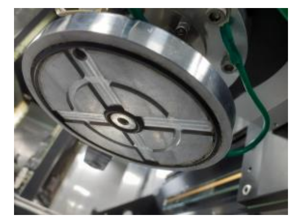
Desktop with Control units



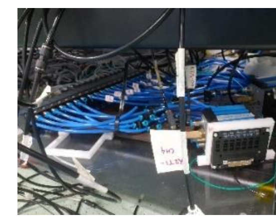
Aerotech Gantry



Gantry head with syringe and Camera setup

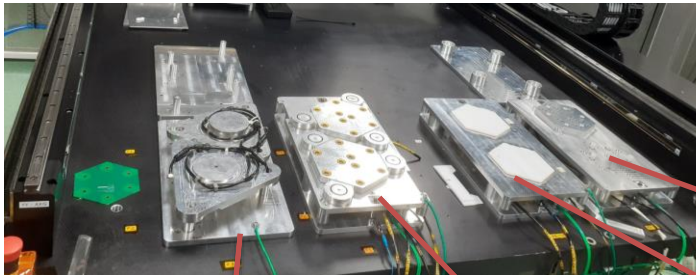


Gantry head with vacuum holes

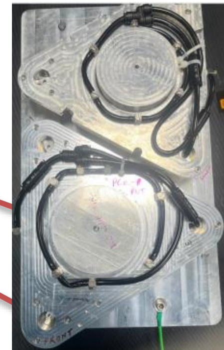


Manifold system for Vacuum ON/OFF

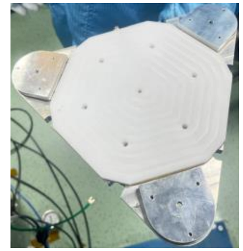
Details of jigs on the Gantry



Gantry with suitable jigs

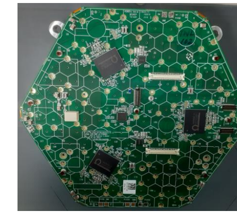


Sensor and PCB PUT



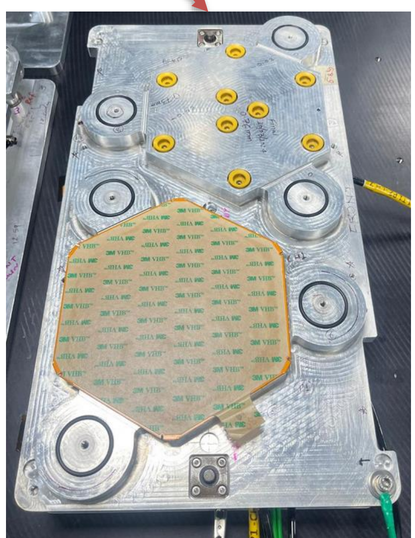
Sensor PUT

PCB Pickup tool

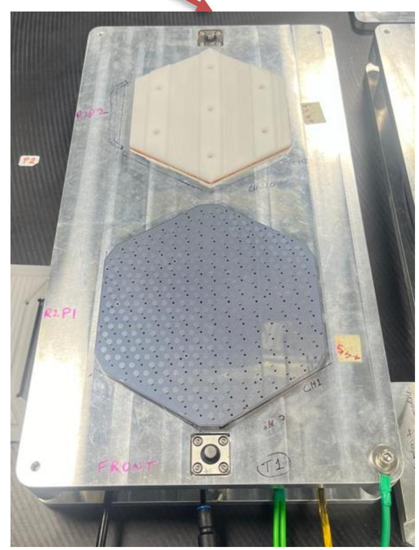


Hexaboard with components

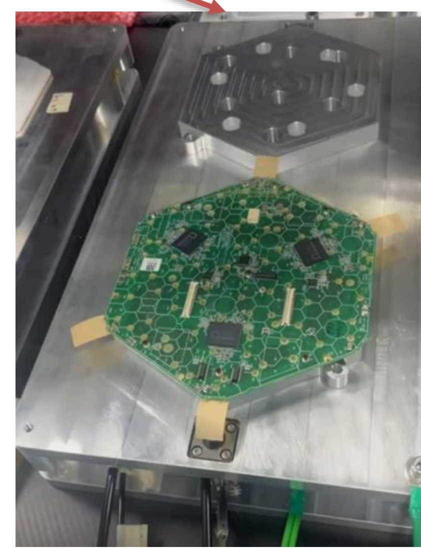
PUT holder



Full module assembly tray



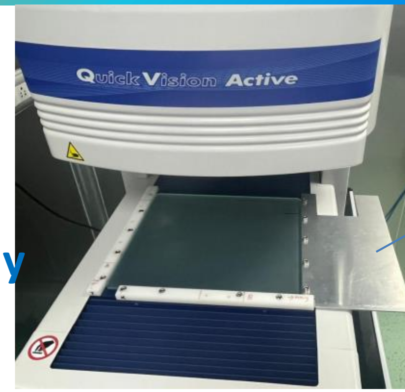
Sensor Tray



Hexaboard Tray

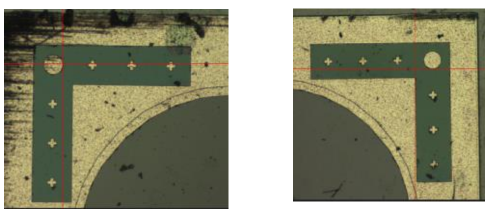
Mitutoyo Vision Measuring Machine

- Resolution: 0.1µm
- Full module assembly tray is 460x255x29mm
- Additional support attached on machine to accommodate the full module assembly tray
- During assembly we need to move the assembly tray to Vision measuring machine
- Measure fiducials on the assembly tray
- Measure the circle and Plus fiducials on the sensor left and right side
- Measure the FD3 and FD6 fiducials on the Hexaboard
- We calculate the Δx, Δy, rotation of sensor and Hexaboard with respect to baseplate

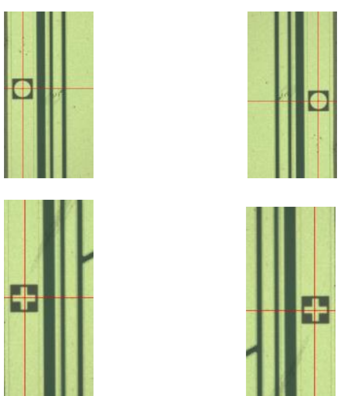


Additional support

Full module assembly tray

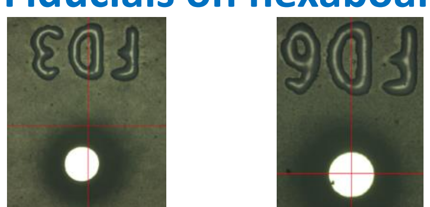


Fiducials on assembly tray



Fiducials on sensor

Fiducials on hexaboard

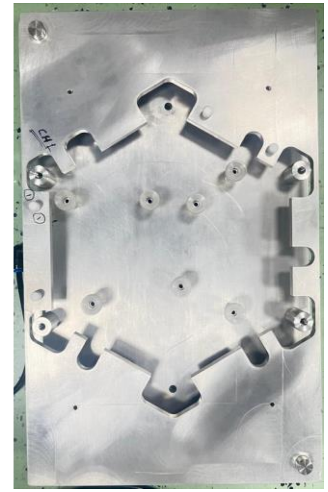


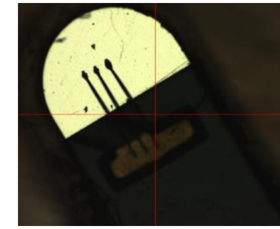
measuring fiducials on Hexaboard

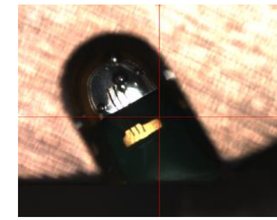
Delvotec 6400 wirebonder

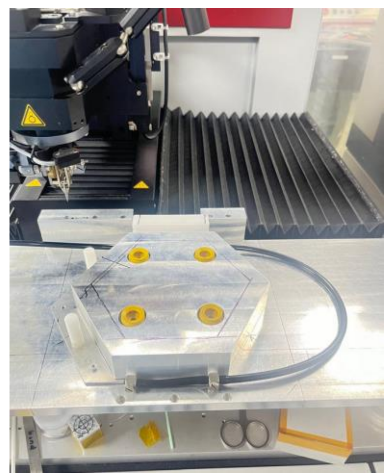
- Wedge bonding with 25µm Al. wire
- Suitable for 6” wafers
- Produced suitable jigs for frontside and backside bonding
- Performed backside bonding followed by encapsulation with Sylgard 186
- Performed frontside bonding with two operations
- Horizontal distance between bond 1(PCB) and bond 2(sensor) is 1mm
- Gap between adjacent bonds is 125µm
- Number of wirebonds:
  192 cells x 3 wirebonds/cell = 576 on step holes plus some additional bonds

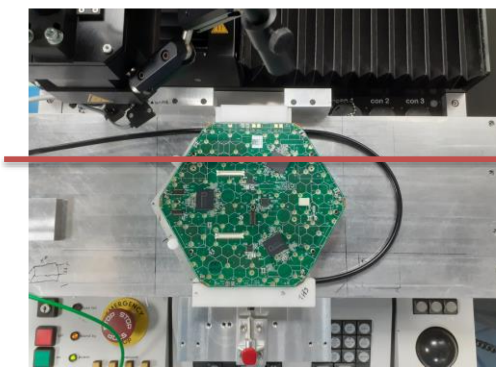

Wirebonder

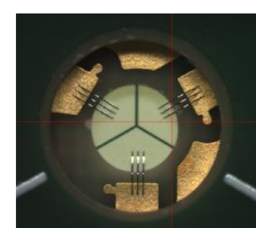

Backside bonding jig


backside bonds

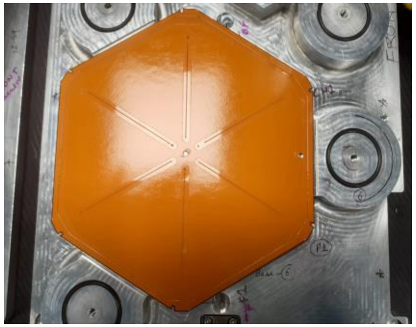

encapsulation of backside bonds


Frontside bonding jig

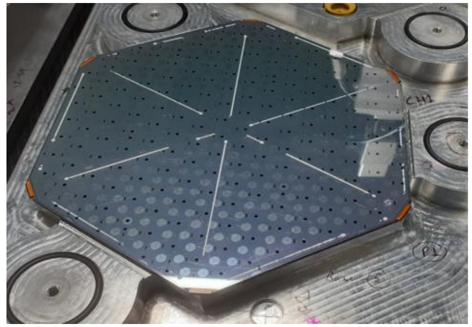

live module frontside bonding


One of the step hole bonding

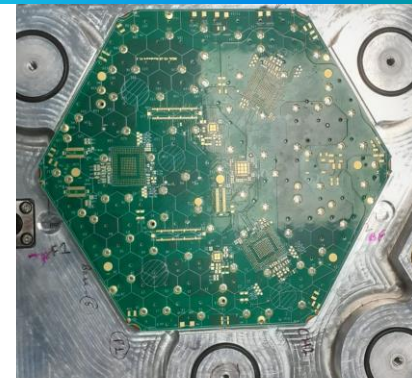
Prototype module assembly – 2 Modules



CuW baseplate
with tape and glue

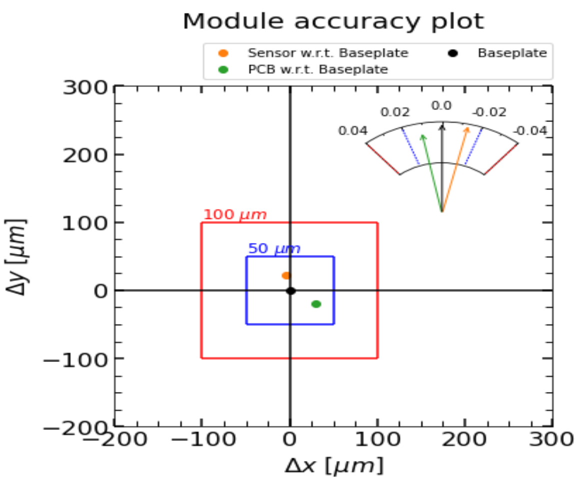


Sensor with glue pattern

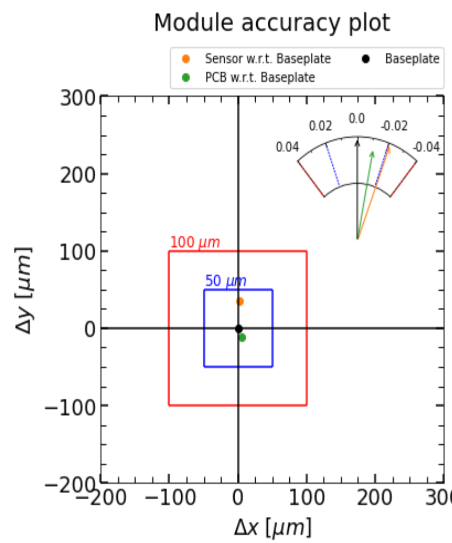


LD-V3 unpopulated hexaboard

1st Module



2nd Module



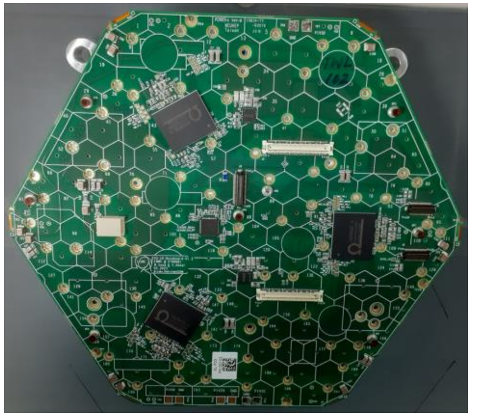
Target Δx, Δy : 50µm
Acceptable is 100µm

Rotation accuracy:
Target is +/- 0.02 deg
Acceptable is +/-0.04 deg

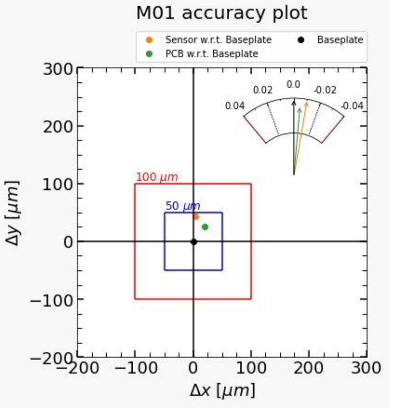
Conclusion: Alignment is very good, optimized the glue spread which makes us to go for live module

Live Module - 1

- Recently we assembled one live module
- All procedures followed
- Very good results of Δx, Δy, rotation of sensor and Hexaboard with respect to baseplate
- Backside bonding and encapsulation done
- Frontside wirebonding completed
- Frontside encapsulation jig is ready
- Need to perform frontside encapsulation with Fisner F7300N mini gantry

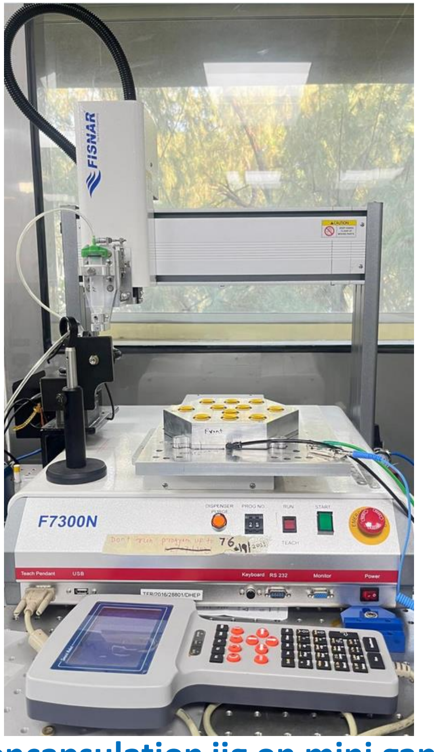


Topside of live module



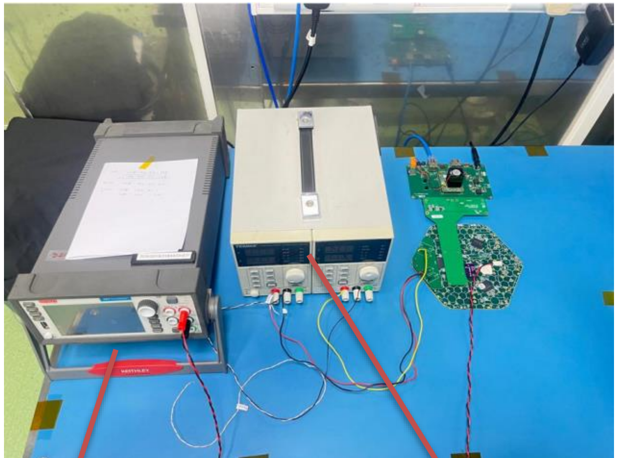
Placement plot

Video of Gantry operation if time permits
(2 Minutes video)



encapsulation jig on mini gantry

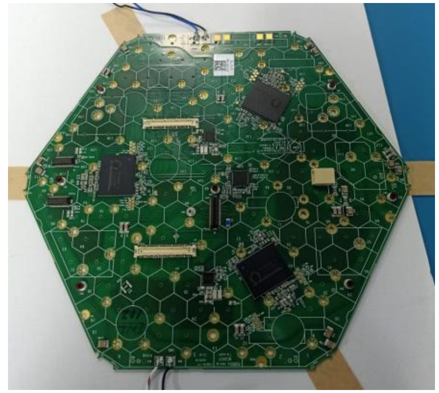
Electrical QC test setup



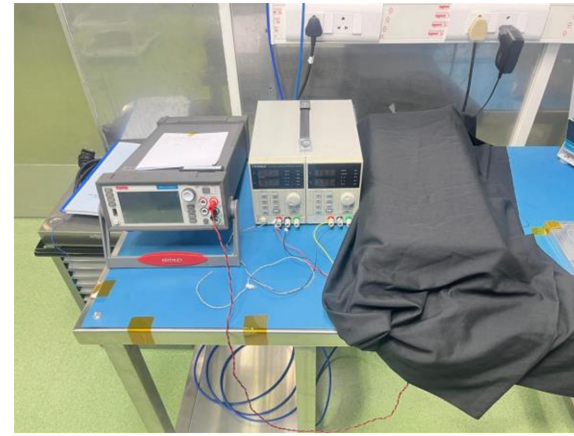
QC test setup

HV source unit

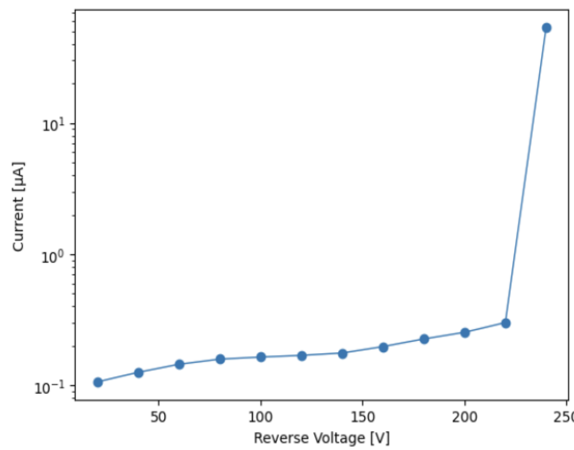
LV source unit



Hexaboard



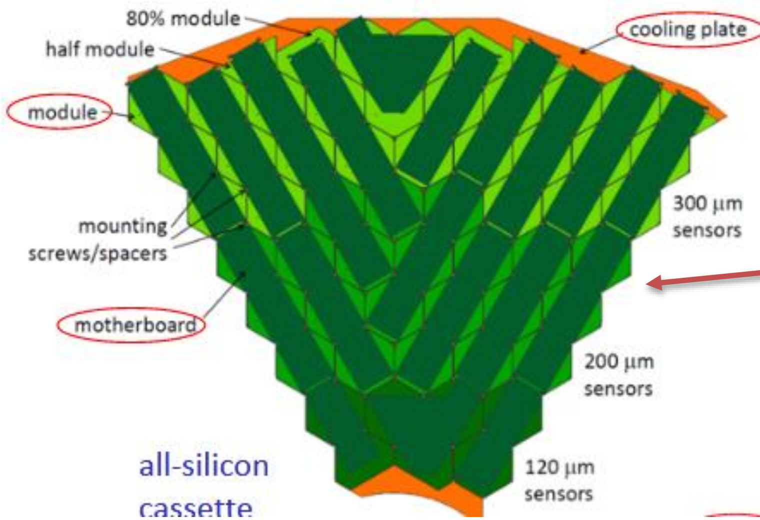
IV test



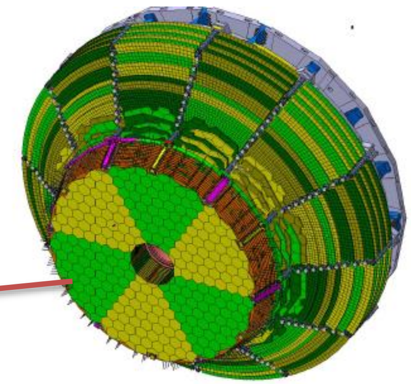
IV curve (current limit = 100 Microamperes)

- This may not be the early breakdown as evident from similar studies at other module assembly centers
- We are in process of retesting the module with higher current limit

Main Gantry and HGCAL modules in Cassette



HGCAL module in Cassette



Values for both endcaps

Silicon

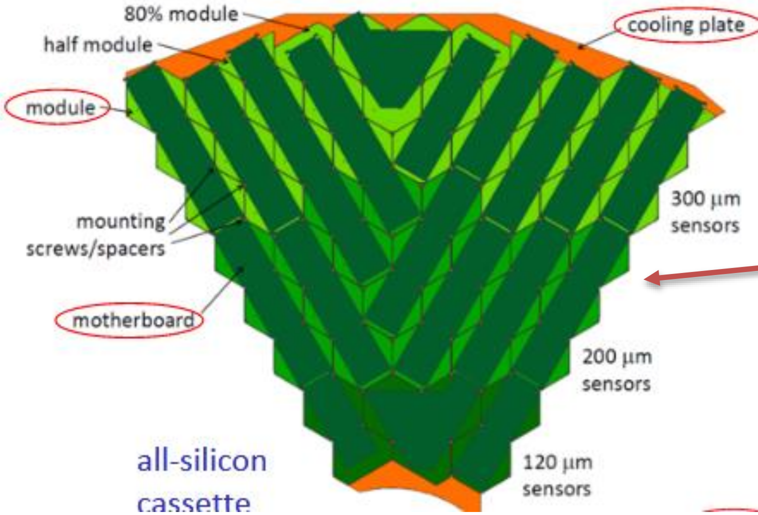
- 620 m^2 of silicon
- 6M channels

TIFR suppose to deliver ~ 4.5K low density HGCAL modules with 200µm and 300 µm sensor

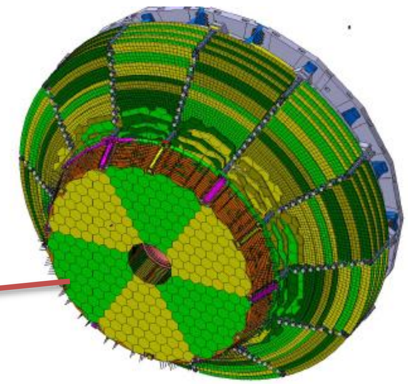
Summary

- Producing a large number of modules and validating them are big challenge
- Most of the operations are optimized
- Most of the equipment are in hand and planning to procure wirebonder suitable for 8” wafer
- We build two mechanical modules followed by one live module produced
- Planning to produce more live modules
- Rampup of fixtures are under progress

Main Gantry and HGCAL modules in Cassette



HGCAL module in Cassette



Values for both endcaps

Silicon

- **620 m^2 of silicon**
- **6M channels**

TIFR suppose to deliver ~ 4.5K low density HGCAL modules with 200µm and 300 µm sensor