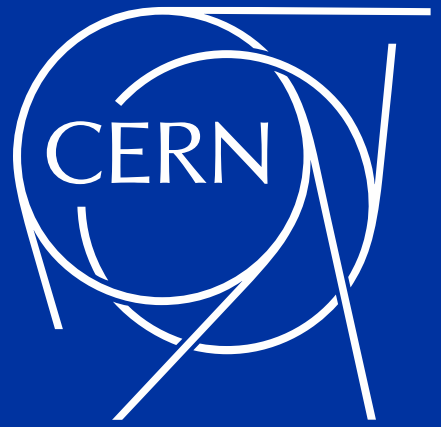




# A High-Granularity Timing Detector for the ATLAS Phase-II upgrade

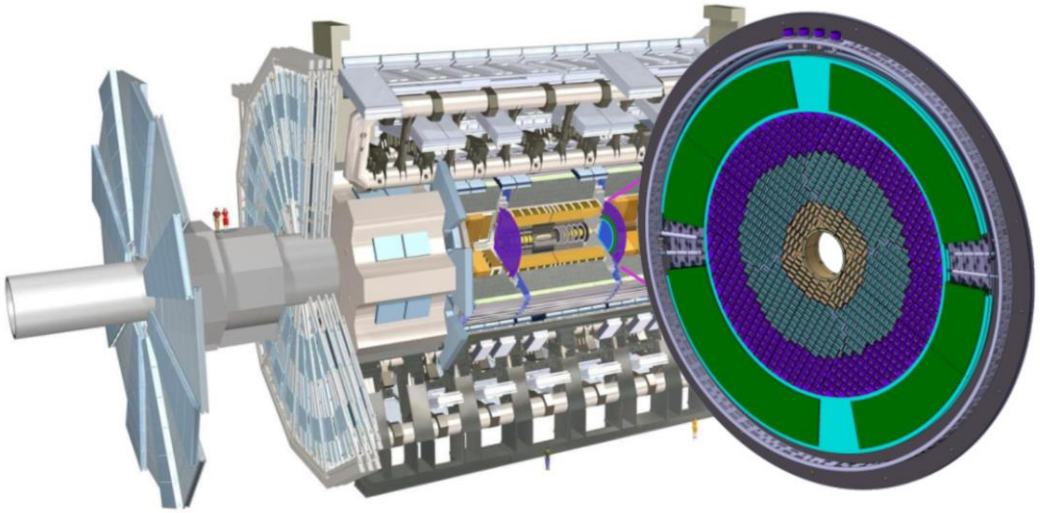
## PIXEL 2022 conference

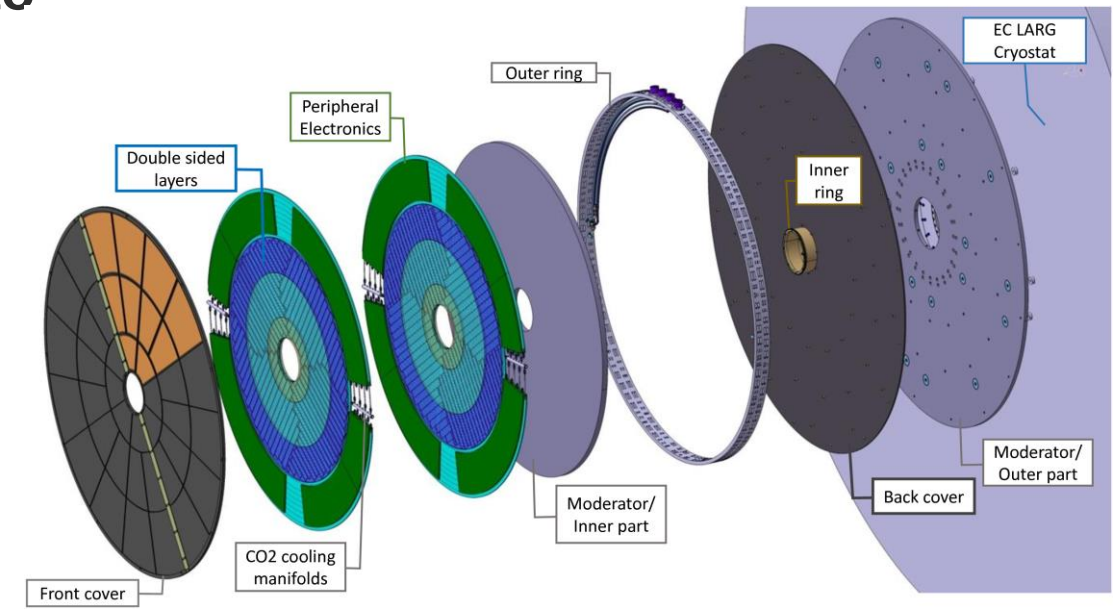
Afonso Ferreira on behalf of the HGTD group

12/12/2022

# High Granularity Timing Detector

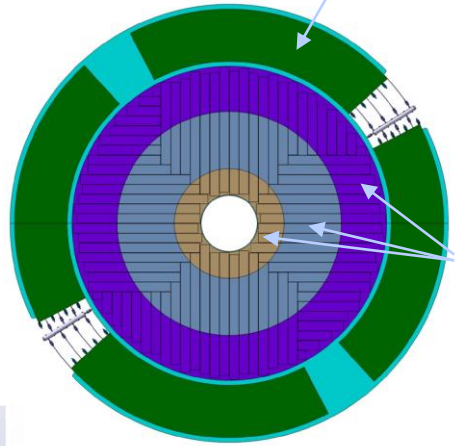
- ❖ **Detector designed to provide precise timing information to minimize pile-up in the High Luminosity LHC**
- ❖ **Also provides bunch-by-bunch luminosity information**
- **Per track timing resolution of 30 ps - 50 ps up to a fluence 2.5e15 $n_{eq}/cm^2$**
- **Covers forward regions 2.4 ≤ |η| < 4.0**
- **2 disks with double-sided layers mounted on cooling plates**
  - Located in endcaps region
  - Each layer composed of 3 rings with modules using silicon sensors

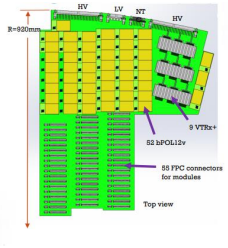




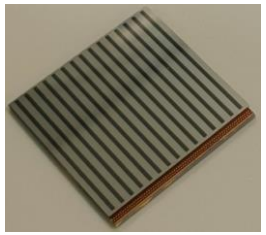
# HGTD Basic functionality overview

- **Charged particles detected by Low Gain Avalanche Detectors (LGADs)**
- **LGAD signals are registered by frontend ASIC ALTIROC**
  - Timing and hit information
- **Data transferred through module flex up to the peripheral electronics**
- **Data of multiple ASICs is aggregated at the peripheral electronics and sent to the off detector servers**

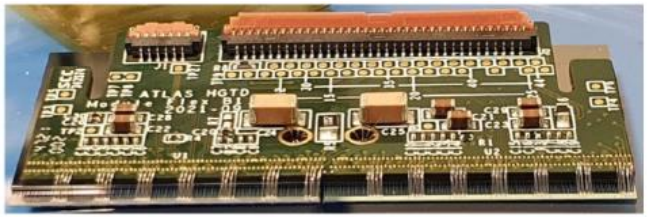


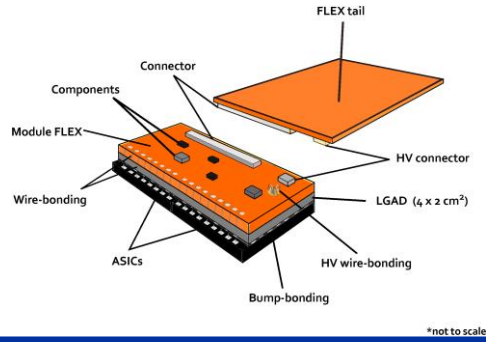
LGAD Sensors → 15x15 Sensor bump-bonding → ALTIROC ASIC → Wire-bonding → Module Flex → Flex-tail → Peripheral Electronics → Optical-links → Backend Servers

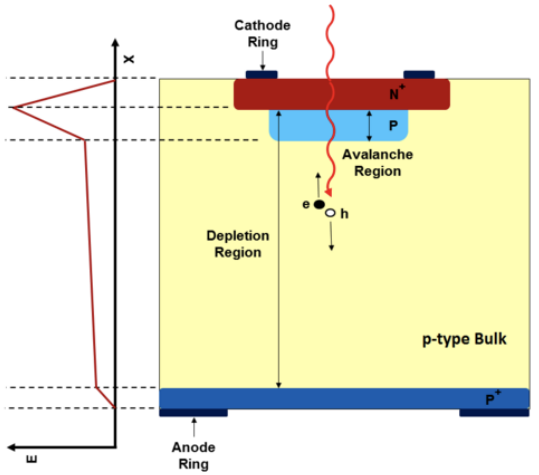
Bare Modules/hybrid



Full module



# LGAD Sensor technology

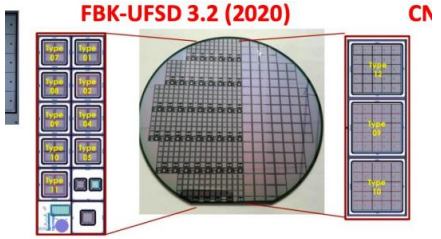


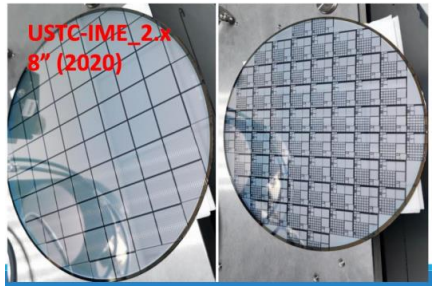

- **LGADs are segmented planar silicon detectors with inner gain provided by a multiplication layer**
  - Avalanche in multiplication layer triggered by charged particles
  - ***Fast Timing*** → internal gain and thin active layer provide a good rise time
  - ***High Radiation hardness*** → *highly doped multiplication layer maintains performance up to high radiation levels*

- **Each HGTD LGAD is 1.3 x 1.3 $mm^2$**
- **Full-sized sensor composed of 15x15 pads**

Various prototypes from multiple vendors tested in the R&D phase

- IHEP-IME, USTC-IME, FBK, HPK, CNM

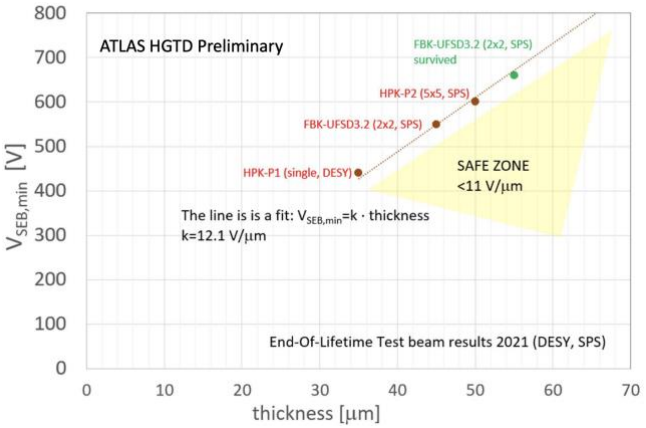


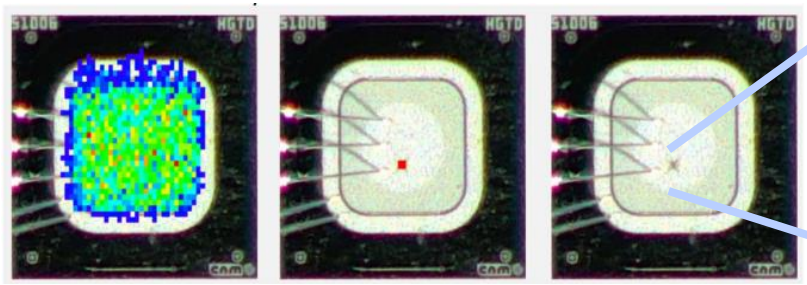



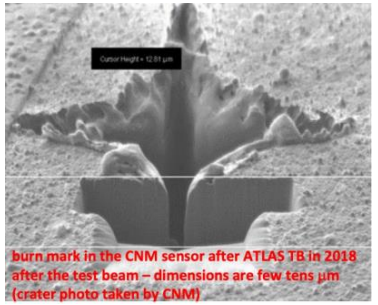
# Single Event Burnout

At 2021 test beams we identified an upper limit for the operational bias voltage due to **Single Event Burnout (SEB)**.

- Most likely cause is a collapse of the electrical field
- The *thickness* and *bias voltage* are crucial parameters to determine a safe operating voltage
- After dedicated test beam camping a safe zone was determined: **< 11 V/µm**
- **Sensors are 50 µm thick so max voltage is 550 V**



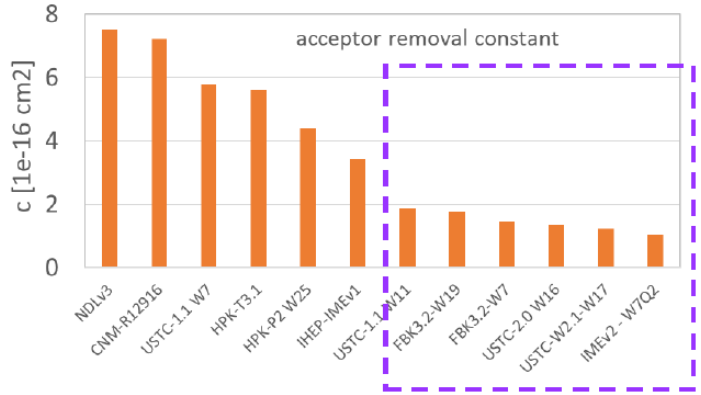






*Large current in small region created a fat crater*

In 2022-2021 R&D focused on identifying sensor capable of operating in the safe zone at high irradiation levels

Sensors with carbon enriched gain layers identified as best candidates




- Multiple runs from various providers using carbon based gain layer (FBK, USTC-IME and IHEP-IME,)

# HGTD Sensor Testbeam tests

SEB only visible at test beams (DESY, SPS)

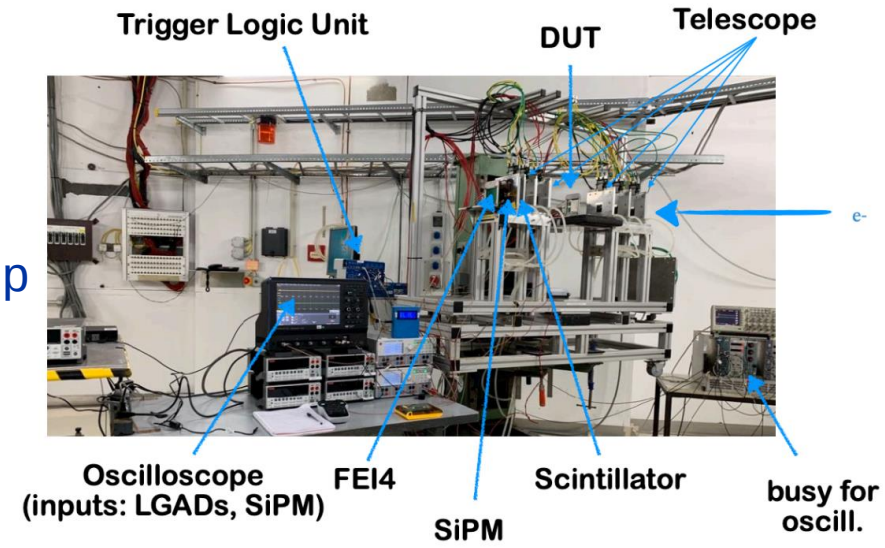
- 64 sensors tested across DESY and SPS

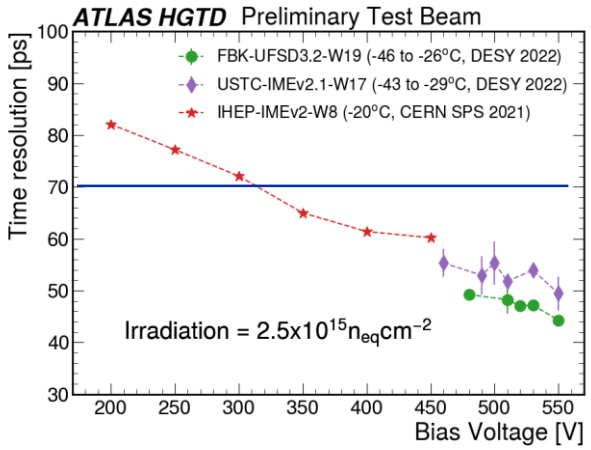
**All carbon enriched gain layer sensors achieve our requirements  safely below SEB threshold**

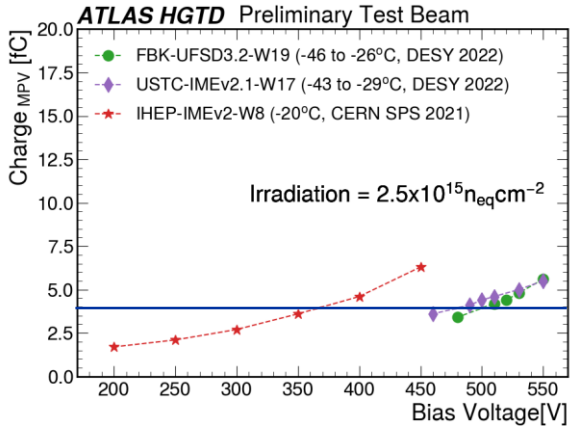
**At the highest fluence level 2.5e15 $n_{eq}/cm^2$**

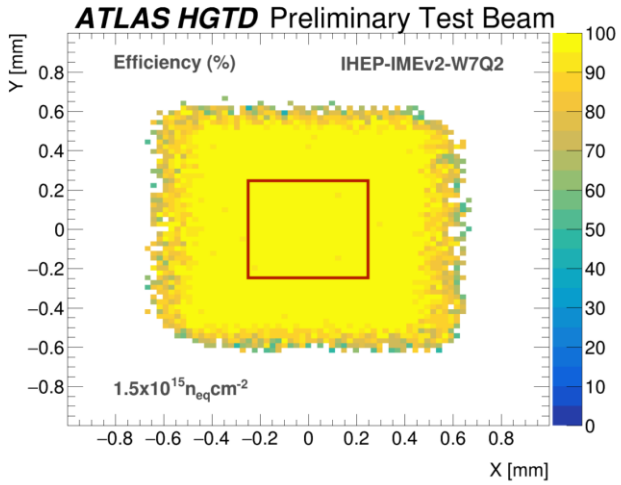
- ✓ **Time resolution < 70 ps**
- ✓ **Charge 4 fC**
- ✓ **High efficiency in active region of sensor**

DESY Setup



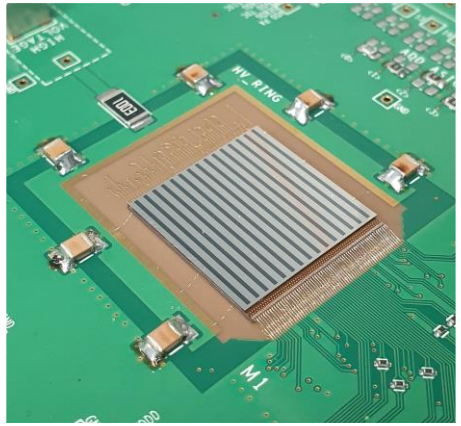



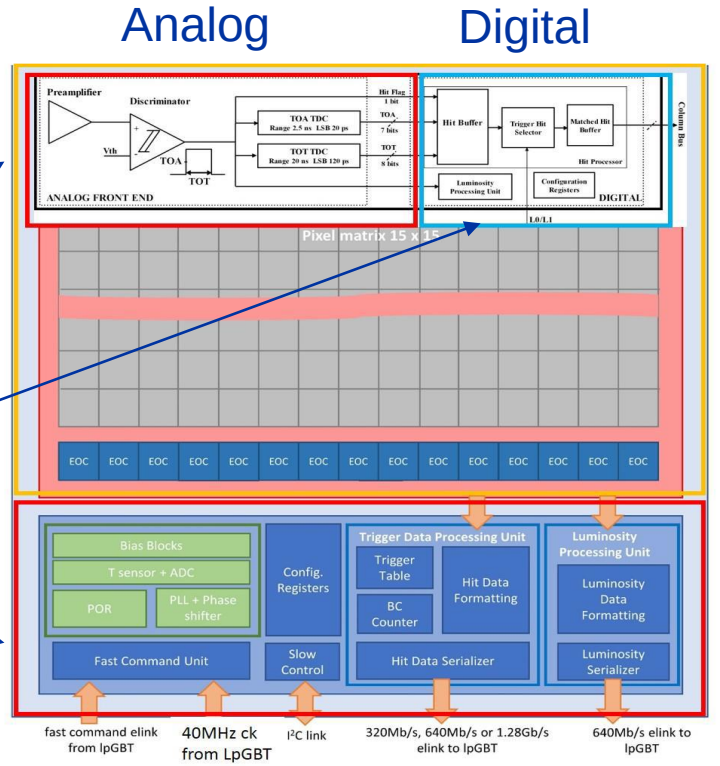



# ALTIROC – HGTD FRONTED ASIC

## ALTIROC is a fast timing ASIC

- 225 channels bump bonded to 15x15 full sensor
- A preamplifier and a discriminator to capture LGDAs signal
- 2 Vernier TDCs for timing data
  - Time of Arrival (TOA): 2.5 ns window with 20 ps resolution (7 bits)
  - Time over Threshold (TOT): 40 ns window with 40 ps resolution (9 bits)
- Timing data and hit flag stored in local registers
- Local data aggregated column wise and transmitted through e-links at L0/L1 trigger rate
- Multiple configurations and control options



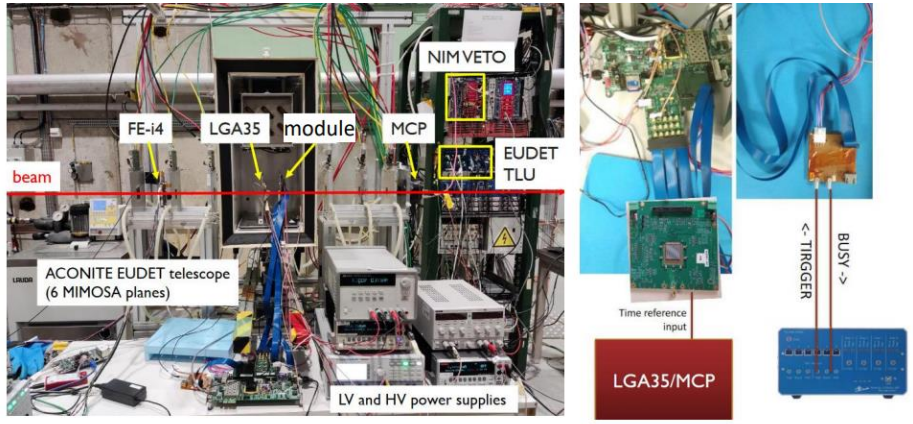



Control and Data transmission

- Timing requirements quite strict as
  - <70 ps jitter at 4 fC and <25 ps jitter at 10 fC
  - Minimum discriminator threshold 2 fC
- Most recent version of ASIC is **ALTIROC 2** with most of the final capabilities (not final version)
  - 225 channels for full size sensor
  - Includes voltage and transimpedance amplifiers
  - Digital memory for timing data
  - Data serializer for data transmission

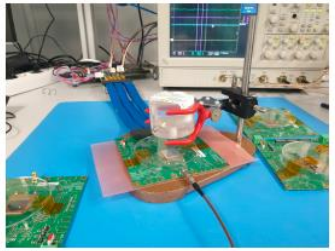
# ALTIROC 2 tests

SPS test-beam setup




**Ongoing tests on multiple characteristic of the ASIC at testbenches and test-beams (Vth, jitter, TOA, TOT…)**

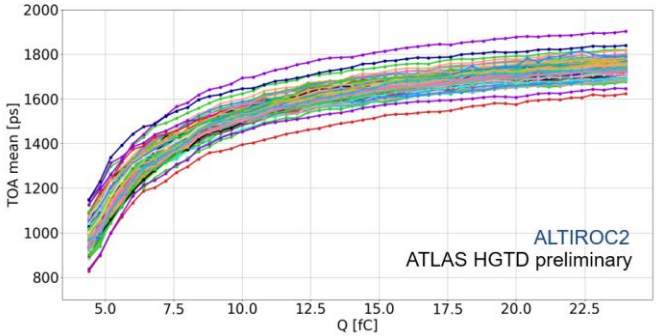
## Bare ALTIROC 2 tested

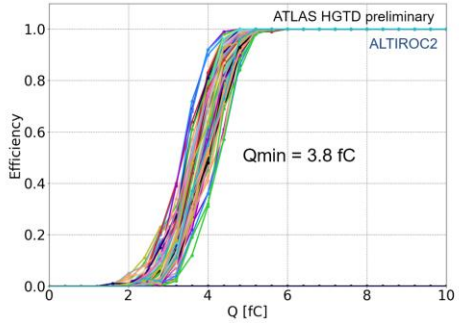


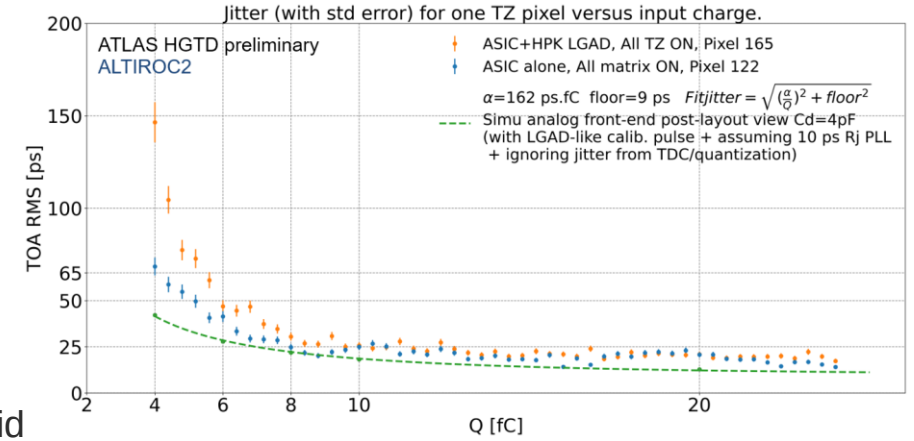
- ✓ All blocks are functional
- ✓ Main requirements are fulfilled

## ASIC + sensor (Hybrid) tests ongoing

- ❖ Successfully assembled multiple hybrids for testing
- ❖ Difference in TOA/TOT behavior at low charge under study
  - ➢ *Parasitic inductances between sensor/preamp are the likely cause*



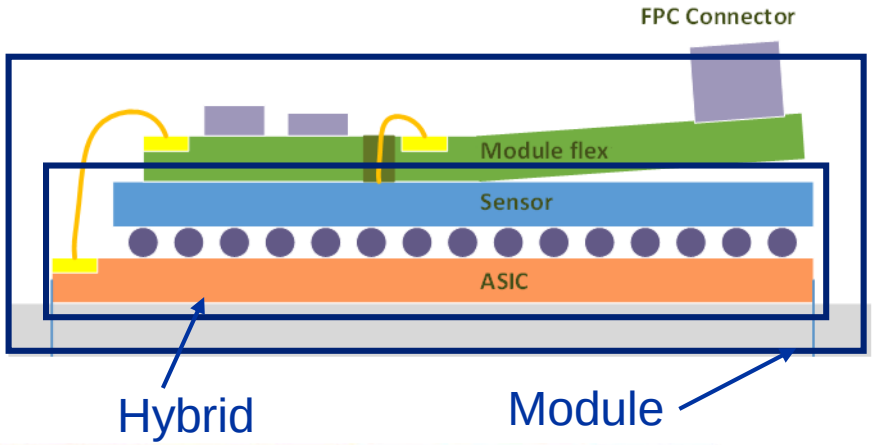



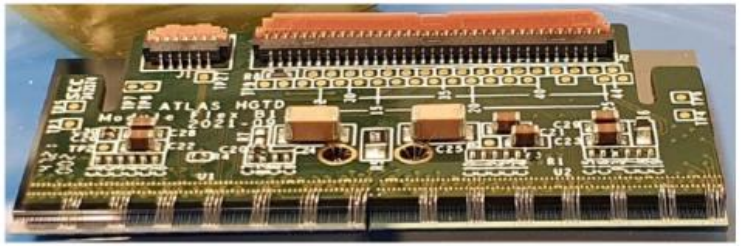



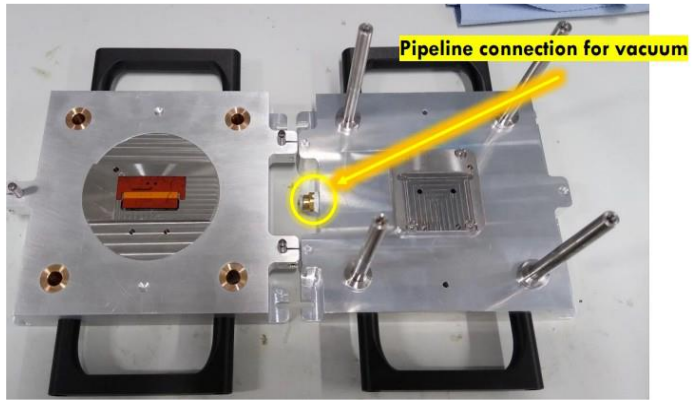

TOA and trigger efficiency of all channels with transimpedance amplifier on a Hybrid

# HGTD Module assembly

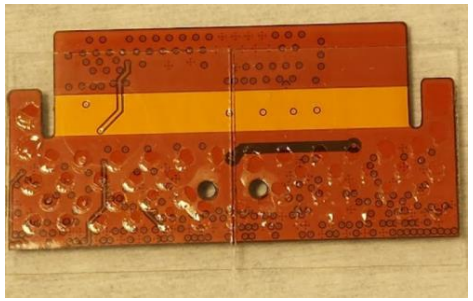
- HGTD modules are composed of a flexible PCB attached to 2 hybrids
  - 8032 modules to be assembled in 6 separate institutes
  - 2cm x 4cm dimension
  - Module flex glued on the surface of the LGAD sensor
  - Flex wirebonded to ASIC for readout and sensors for HV biasing
  - Ongoing test on reading out hybrid through the module flex
  - Assembled digital modules (flex + ASIC) for readout tests

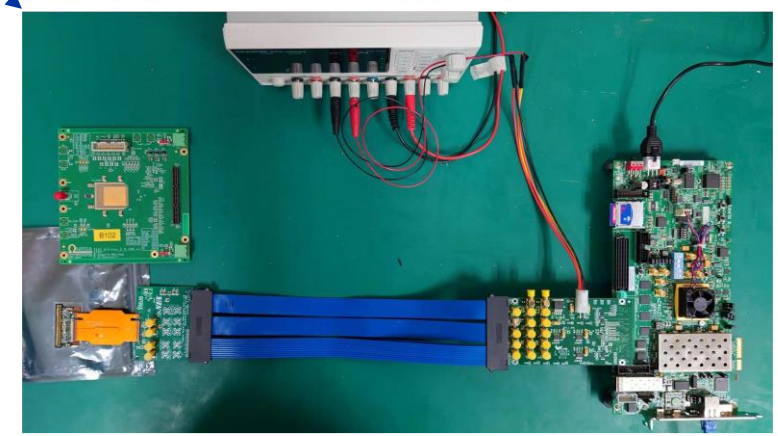




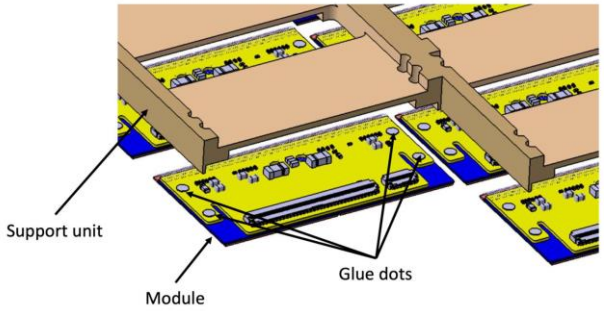
Jig for gluing Flex

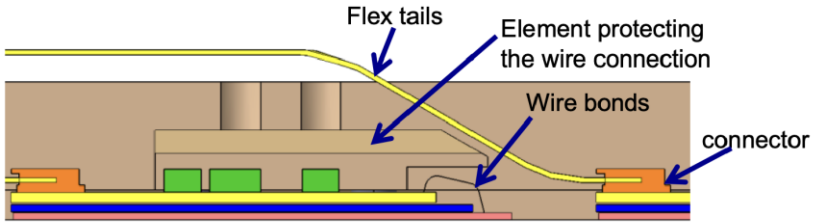

Glue deposition on flex test

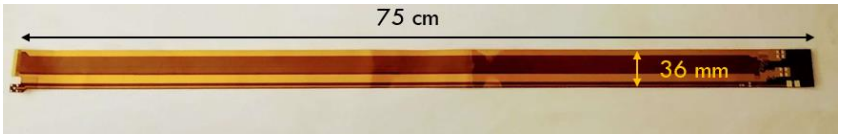


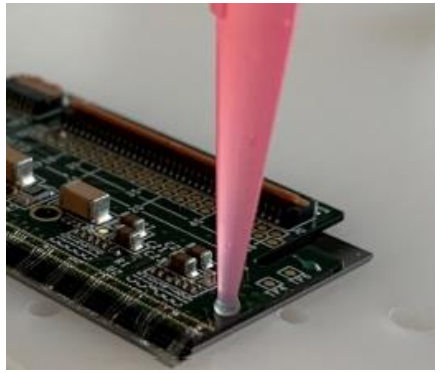
# HGTD detector unit and flex tail

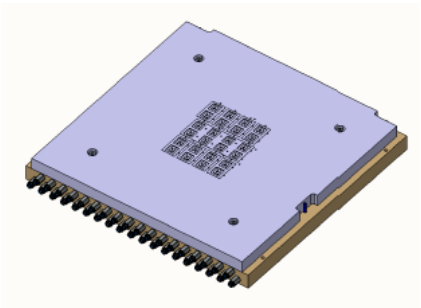
- **Modules are glued to detector units**
  - Detector units made out of PEEK
  - 13 unique detector units per side
- **Ongoing development of tooling for loading and manufacturing of detector units**
  - Vacuum plates hold modules for gluing
  - Glue placed on side of flex → exact amount and placement done by a machine
  - Detector unit aligned and placed on top

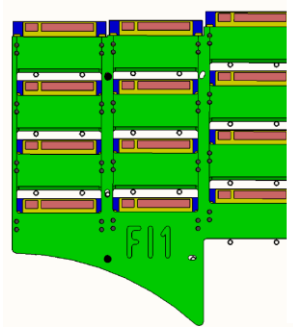


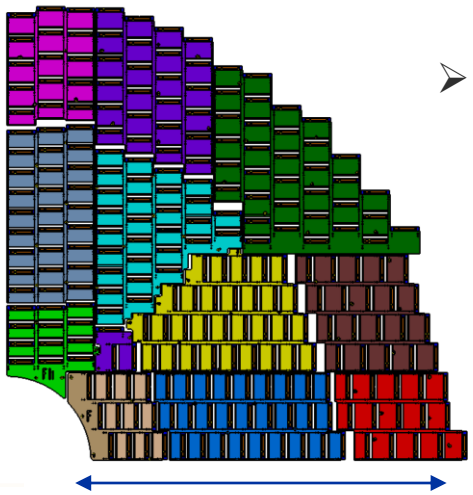





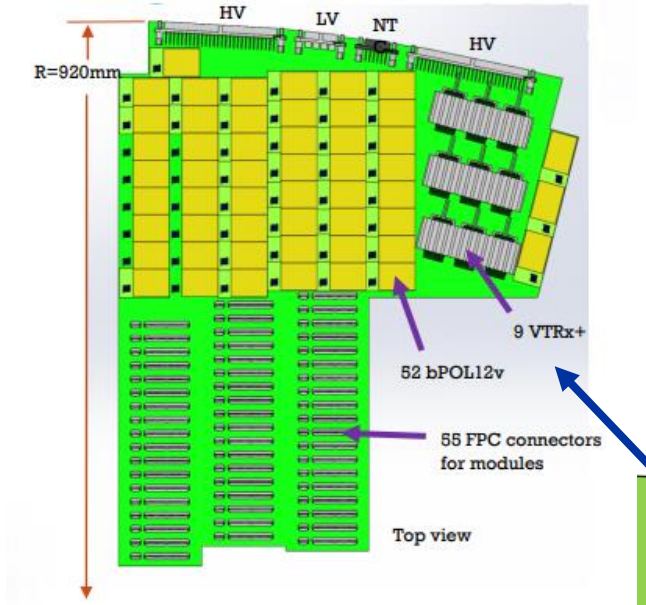


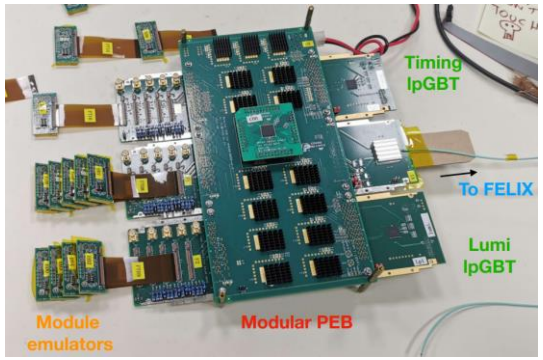



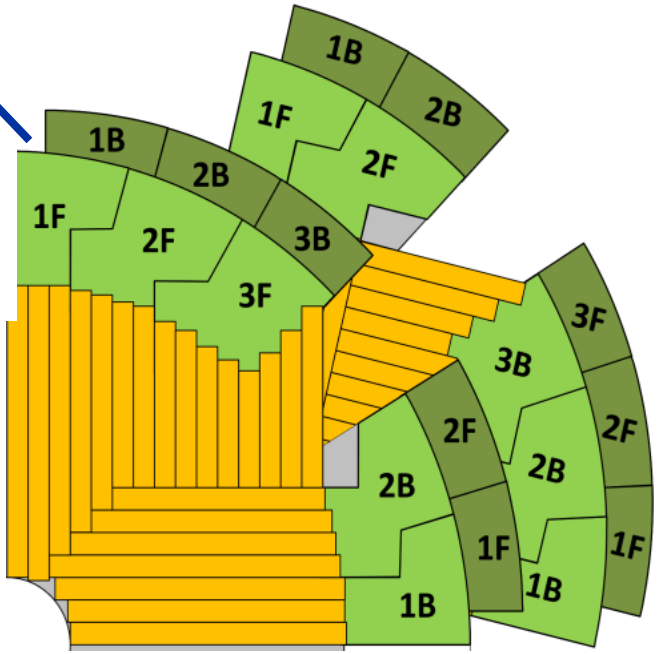

- **Flex tails connect peripheral electronics to modules**
  - Flex tail manufactured in different sizes
  - Tight thickness constraints → **4.2mm max thickness for a 19 flex stack**
  - Flex carries data as well as HV for biasing and LV power for ASIC

# HGTD Peripheral Electronics Boards (PEBs)

- Peripheral Electronic Boards are located outside the HGTD active region
  - 6 unique boards per quadrant
  - Data from ASIC aggregated at PEBs
  - Complex design due to density of components
- PEB 1F is the densest and connects to 55 modules
  - ✓ Schematic complete for an initial prototype
- Ongoing tests on individual components
  - Developed emulator board to test basic readout chain
  - Includes 2 LpGBTs, DC-DC converter, VTRX
  - Distributed among 4 institutes for testing

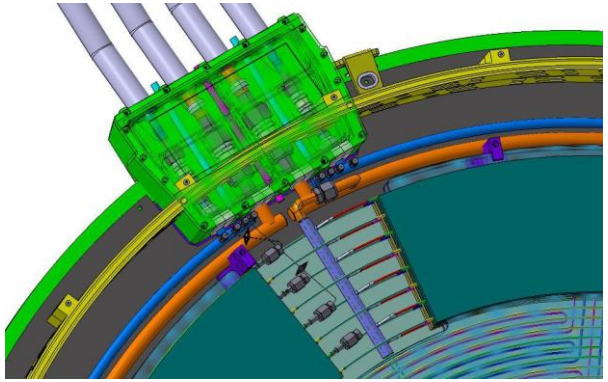


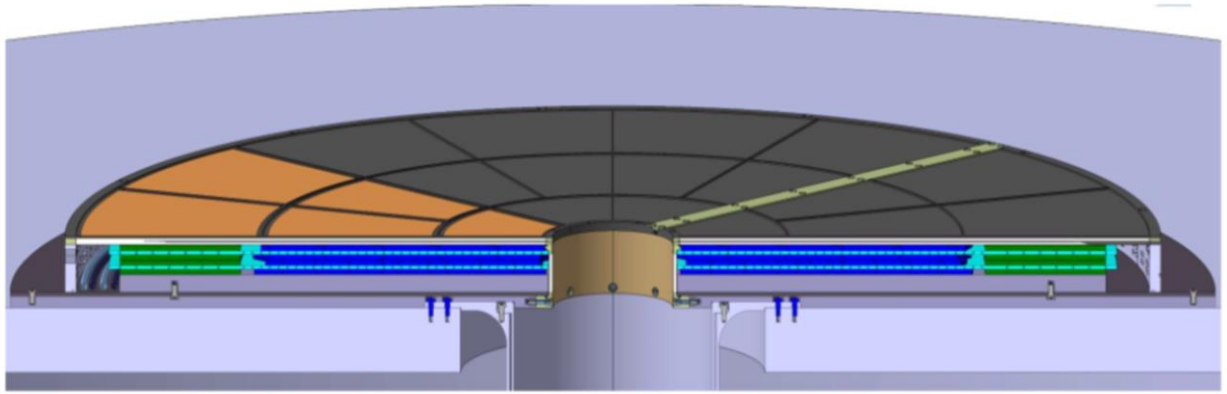



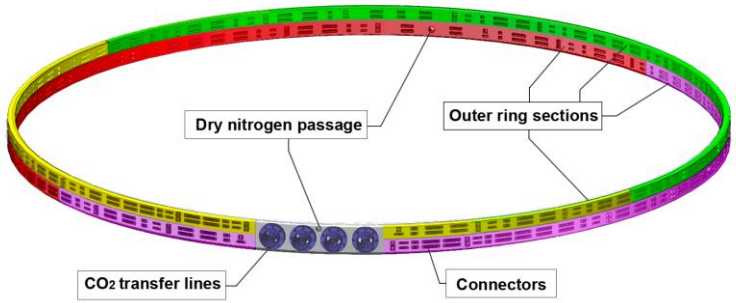



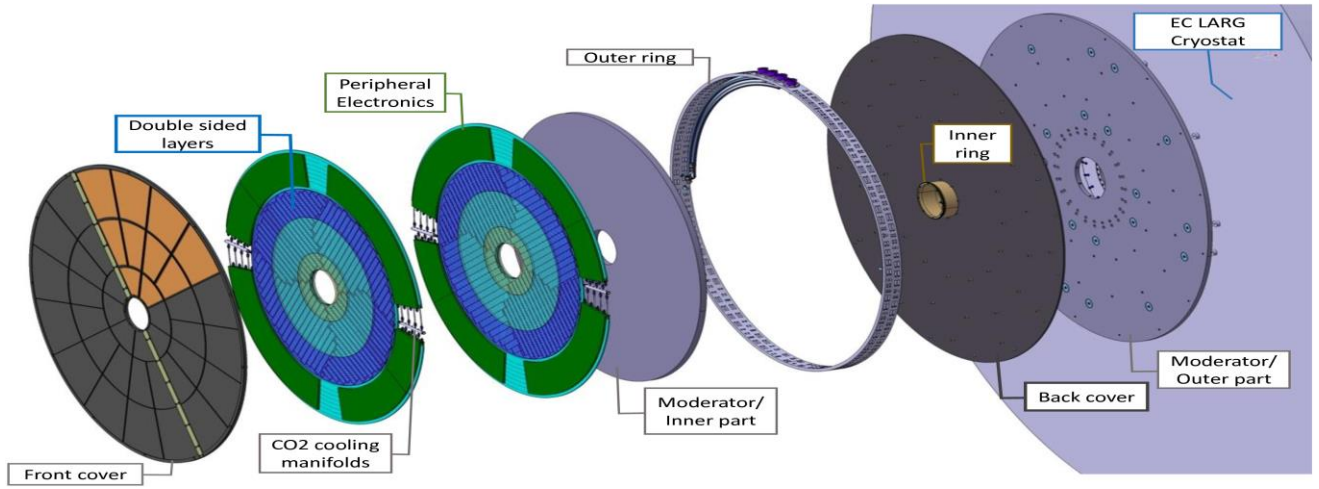
# HGTD Vessel and cooling

- **Sensors and ASIC need to be operated at -30°C**
  - Modules mounted on a cooling plate to maintain stable temperature
  - Cooling plate in-between two layers
  - Liquid CO2 cooling through serpentines inserted in plate
  - 8 serpentines per half disk
- **Cooling plate and inside of vessel attached to ground (Faraday cage)**
- **Feedthrough design ongoing**



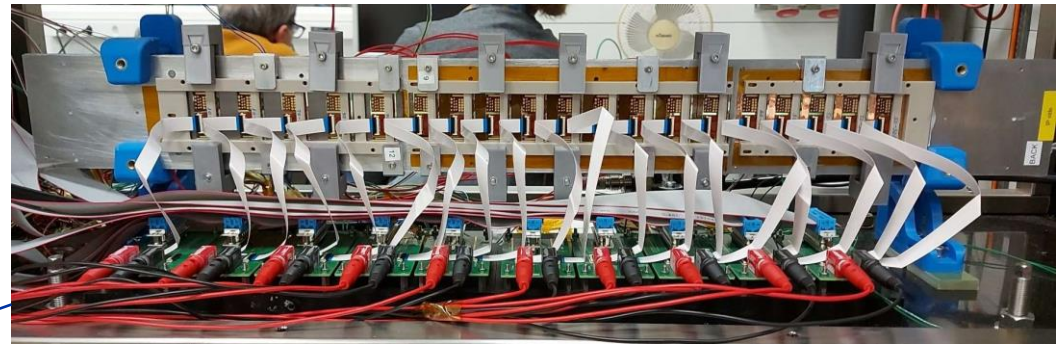




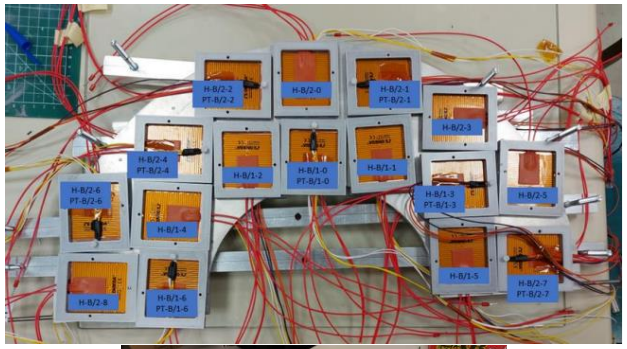
# HGTD demonstrator work

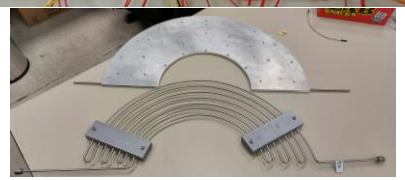
**Building a demonstrator at CERN to verify various parts of HGTD**

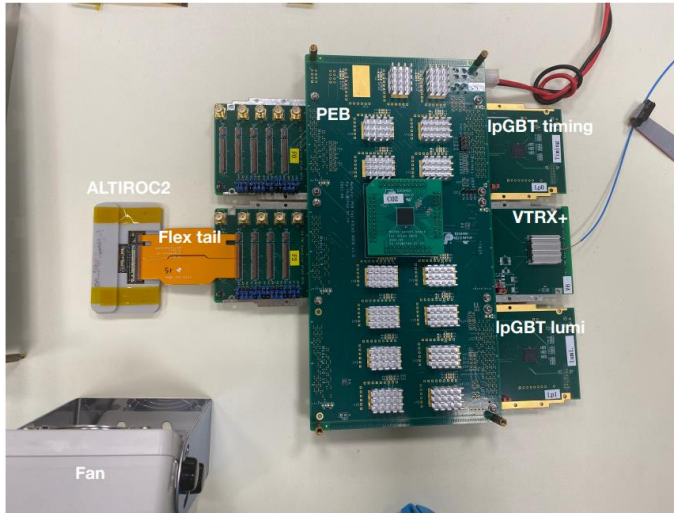


## Heater Demonstrator:

- ❖ Verify CO2 cooling capabilities as well as identify best thermal media between modules and cooling plate
- ❖ Module-sized silicon heaters on prototype support
- ✓ *Best thermal media → two graphite sheet layers with thermal grease in between*
- ❖ Heating test with Kapton heaters on plate with inner serpentine and capillary





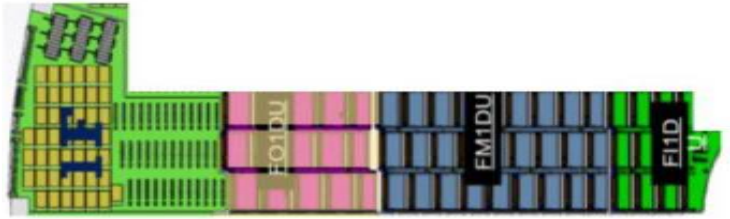



## DAQ demonstrator

- ❖ Successful communication link between server and multiple module emulators
- ❖ Ongoing tests on communication with ALTIROC 2 with module flex

## Full demonstrator

- ❖ Preparation for full demonstrator with 55 modules connected to prototype PEB



# Summary

- **Good progress with LGAD R&D**
  - Carbon enriched sensors satisfy requirements up to 2.5e15 $n_{eq}/cm^2$
- **ALTIROC 2 produced and tested**
  - ASIC alone fulfills requirements
- **Produced hybrids and modules with full size sensors**
  - Ongoing tests in test-benches and test-beams
- **Ongoing work on loading modules on to support units in preparation of full demonstrator tests**
- **Developing DAQ readout chain digital modules**

# Thank you