High Granularity Timing Detector

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on behalf of the HGTD group

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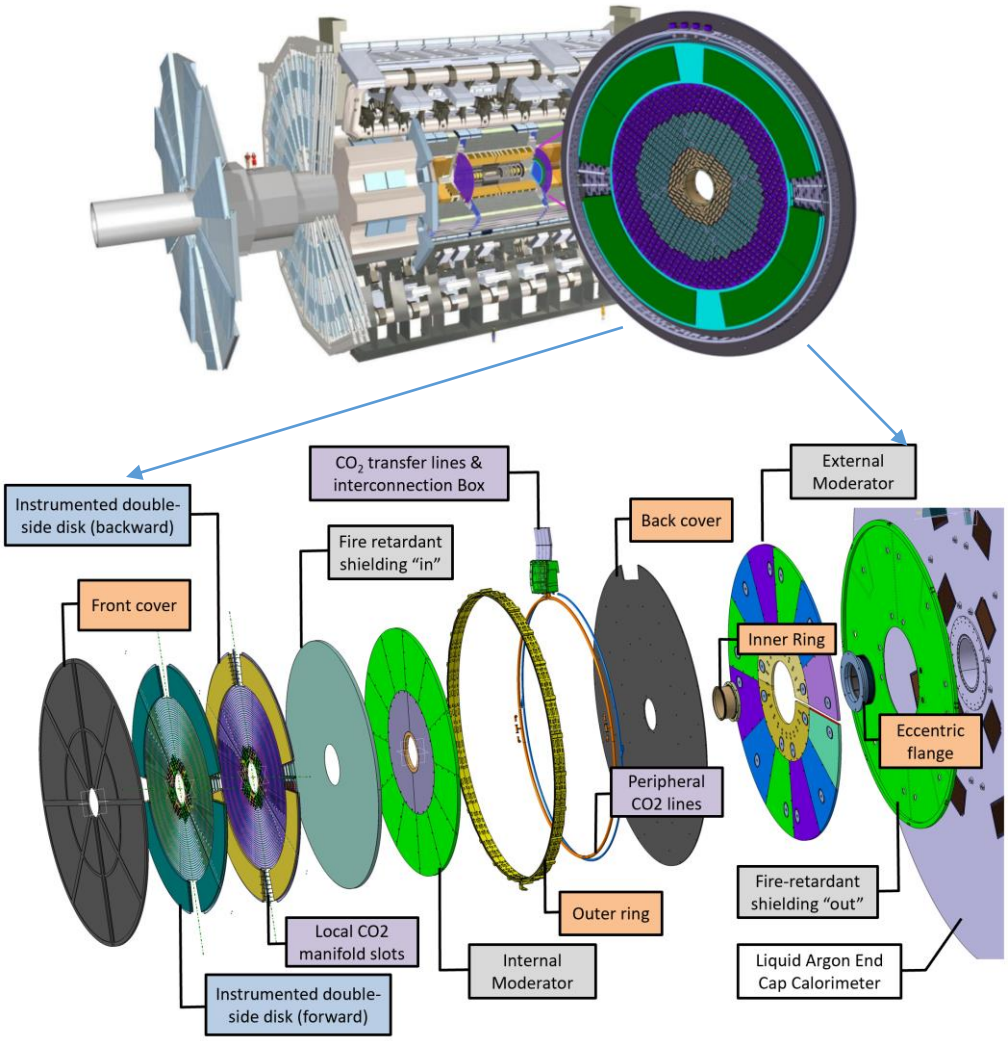
Introduction to HGTD(High Granularity Timing Detector)

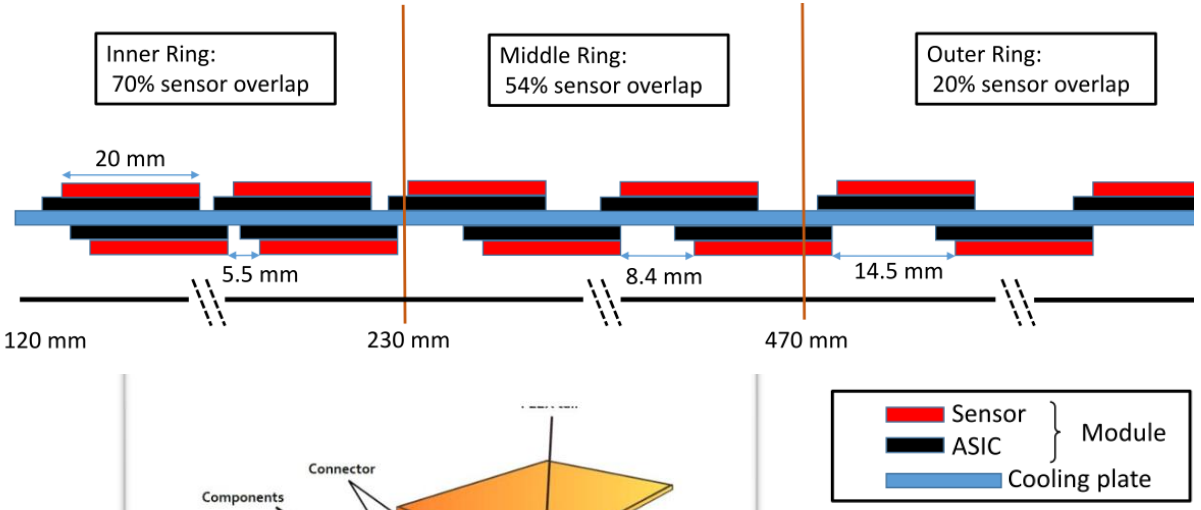
- Pixel detector with coarse spatial resolution but precise timing
  - Pileup rejection
    - Time resolution per track (hit): 30-50 ps
    - 35-70 ps/hit resolution
  - Luminosity measurement
    - Count number of hits at 40 MHz (bunch by bunch)
    - Goal for HL-LHC: 1% luminosity uncertainty
- Two end-caps
  - $z \approx \pm 3.5$ m from the nominal interaction point.
  - $110 < r < 1000$ mm
  - Active detector region: $2.4 < |\eta| < 4.0$
- Each end-cap
  - Two instrumented disks, rotated by 15°

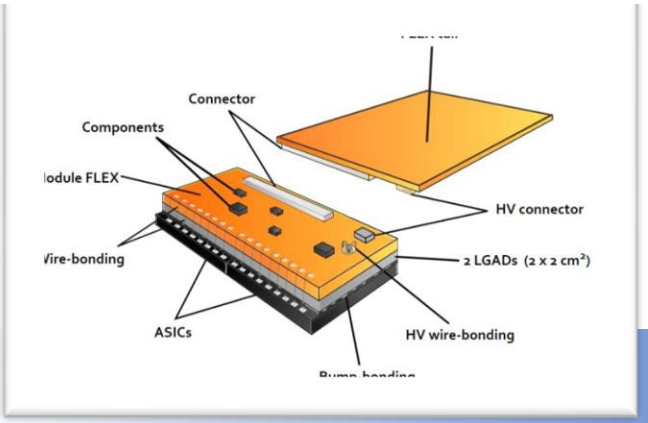


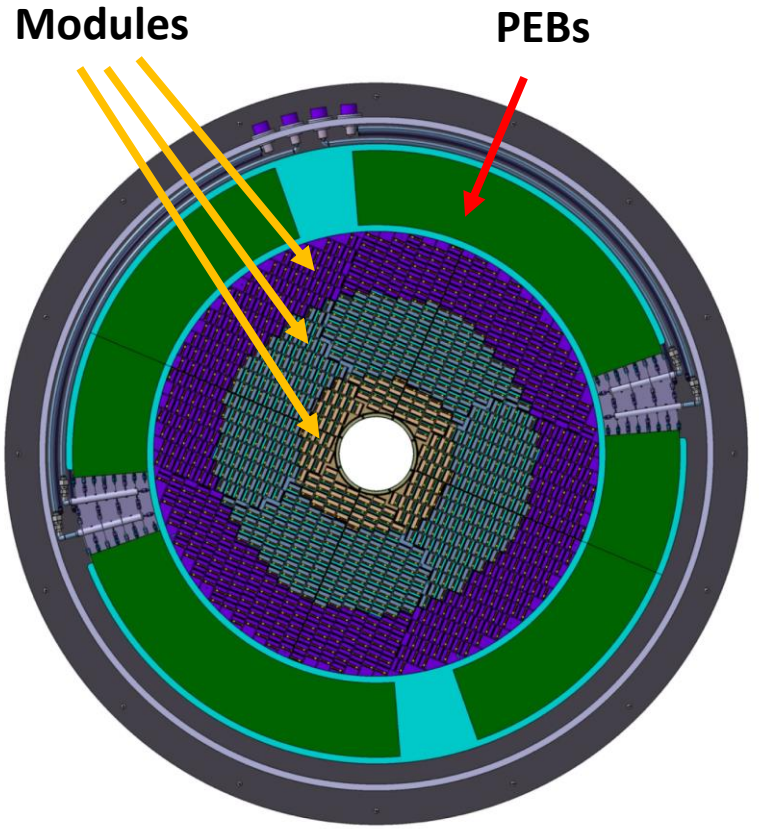
Instrumented Disk

4 Disks:

- Double-sided layers mounted on a cooling plate
- 3 ring layout
- module
  - consist of two hybrids(2 sensors+ 2 ASICs)
  - 2 x 4cm^2, 15x30 channels
- **8032 modules**
  - ~3.6 million 1.3×1.3 mm^2 pixels
  - 6.1 m^2 active area

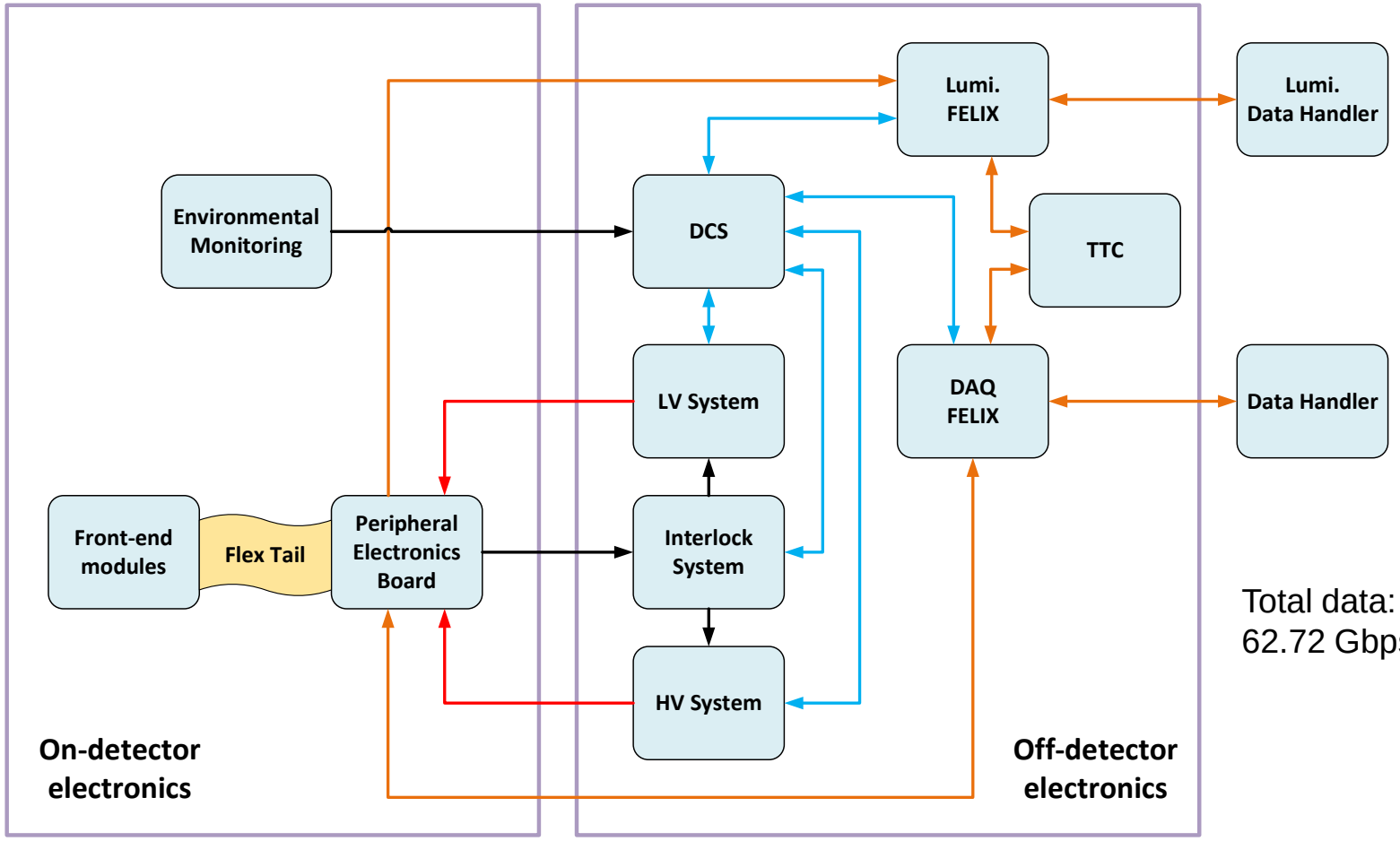






- Connected via flex tails, arranged in rows, to the Peripheral Electronics Boards (PEB) @ 660 < r < 920 mm

HGTD Electronics

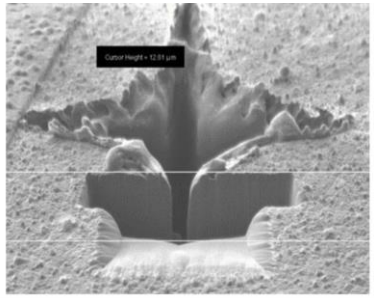


Total data: Up to 10 Tbps
62.72 Gbps per PEB

High irradiation environment
0.4T ~ 1.5T

Low irradiation environment
<0.4T

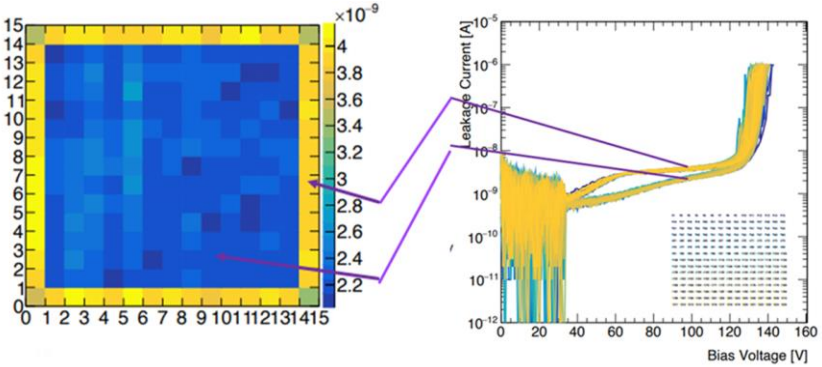
Sensor:
LGAD(Low-Gain Avalanche Detectors)

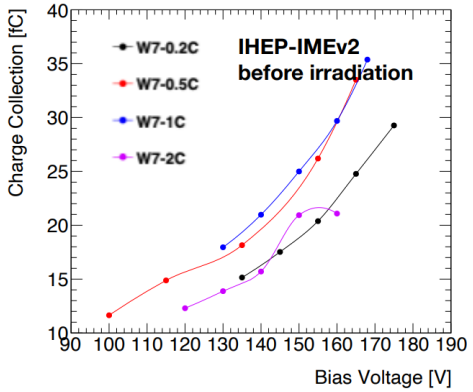


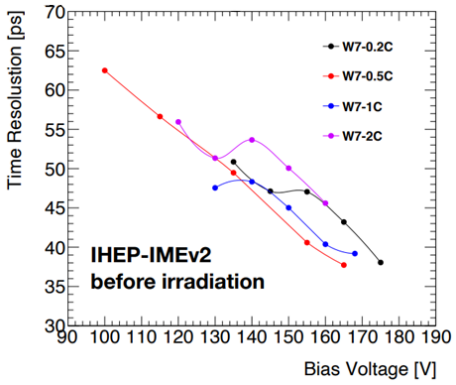
burn mark in the CNM sensor after ATLAS TB in 2018 after the test beam –dimensions are few tens mm (crater photo taken by CNM)

- "Single event burnout" effects observed in LGADs irradiated to the highest fluences
  - Studies, fabrication and test sensors with carbon enriched gain layers
  - Operate at lower bias voltages

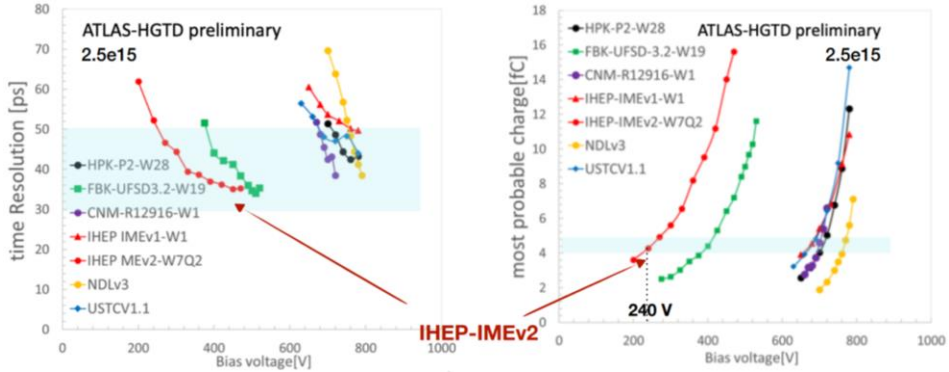
- First efficiency measurements in the test beam with ASIC and full size detectors FBK4.0. Sensors perform as expected.
- Contributions:
  - IHEP-IME(78%)/USTC-IME(10%): Pre-production started at Feb. 2023 and on-schedule, first batch be delivered at July.
  - CNM(12%) : Wafer testing started at May 2023







- Before-irradiation performance
  - Collected charge > 30fC
  - Time resolution < 40ps

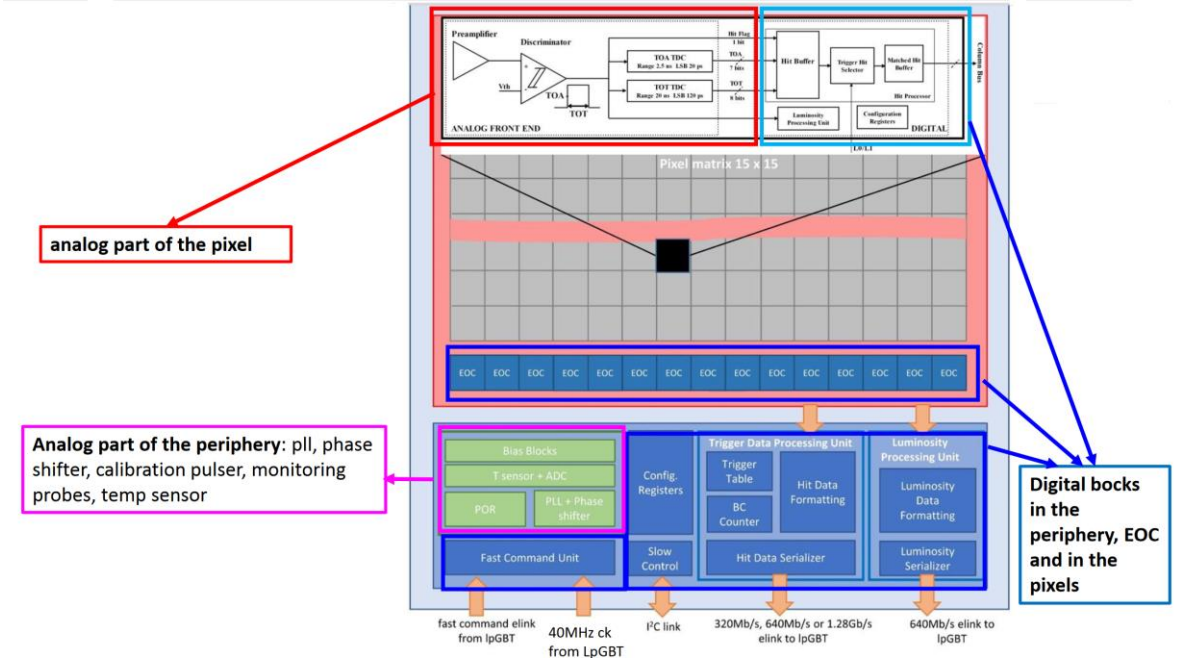


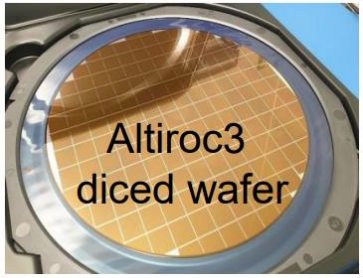
- Post-irradiation performance
  - Voltage for 4fC < 400V
  - Time resolution < 50ps

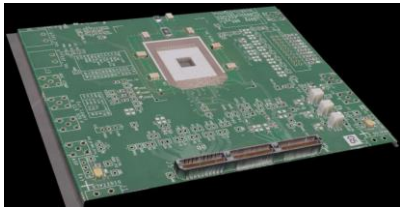
ASIC: ALTIROC (ATLAS LGAD Timing Integrated Read-Out Chips)

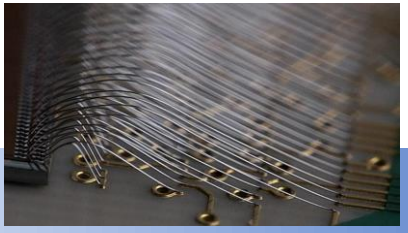
Full size ASIC (15x15 pixel matrix), 12-inch wafer, TSMC 130nm

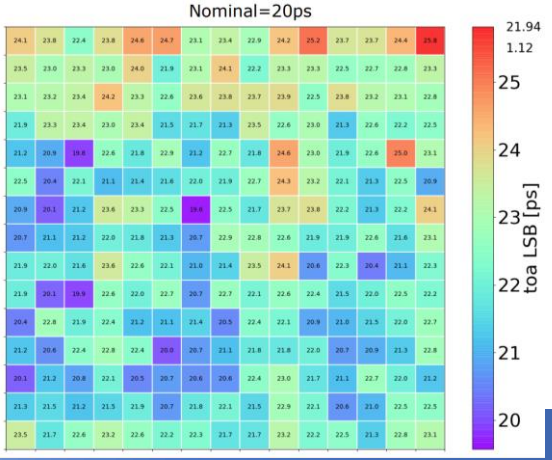
- ALTIROC2
  - Submitted in May 2021, delivered to CERN in Sept. 2021
  - Setups available at different institutes (OMEGA, IJCLAB, IFAE, LPC, IHEP, USTC), will perform tests on ASIC and ASIC + Sensor
- ALTIROC3
  - Fabrication started around Dec. 2022, wafers be shipped to IMEC by Feb., 2023.
  - ALTIROC3 tests already started 25th April— first tests look promising
  - Check of I2C communication, bias voltages, some DACs, clocks and analog signals on scope
  - Full chain for one pixel (timing data path) functional
  - Vth distribution much more uniform than ALTIROC2

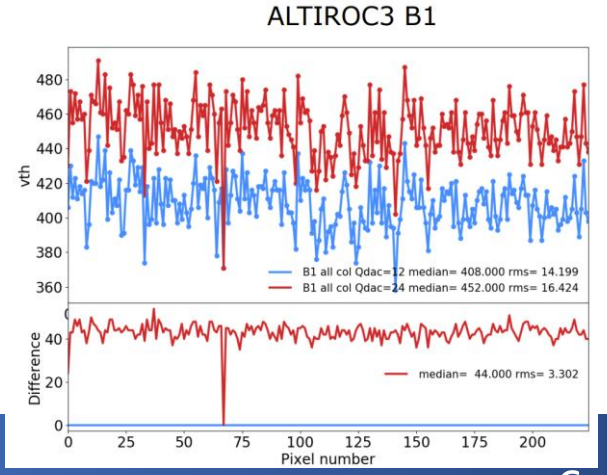












Modules and Detector Units

Module contains 2 ASICs, 2 Sensors & module flex

- **Hybridization:**

About ~110 hybrids have been produced successful. Well developed and studied HGTD hybridization process , results meet the specifications (X-ray tests, shear tests)

Thermal cycling suggest possible failures at temperature range limit. Mitigations being considered: More bumps on ground ring; parylene coating; different CTE materials for Module Flex

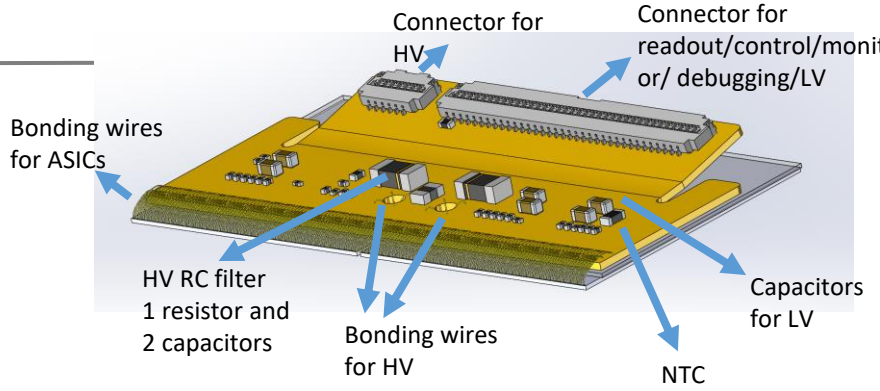
- **Module flex:**

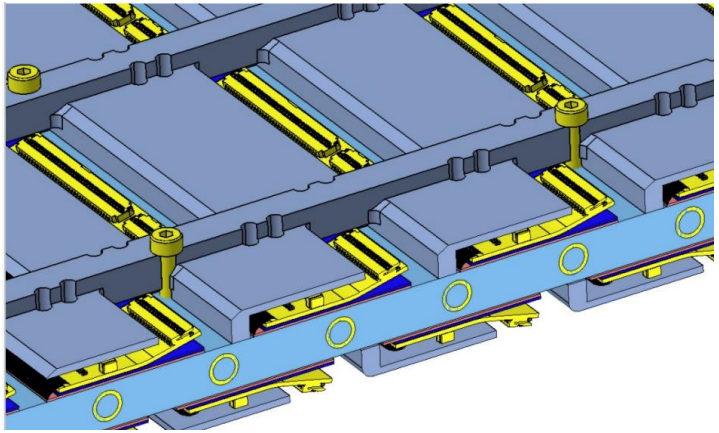
Finished the selection and evaluation of components. Early prototype has been successfully produced, key parameters meet HGTD requirements. Lower CTE module flex being fabricated, will be delivered next week.

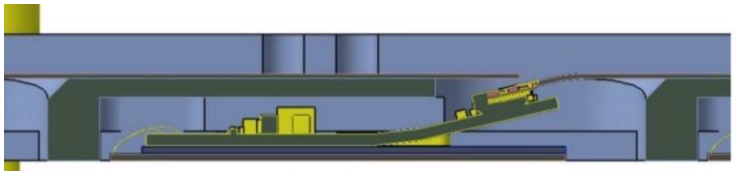
- **Module assembly:**

Two method developed: Jigs tools and pick-and-place machine, test system for full module has been developed

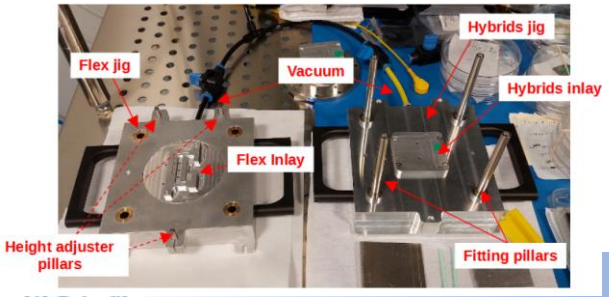
Certification for assembly ongoing with the production of demonstrator modules



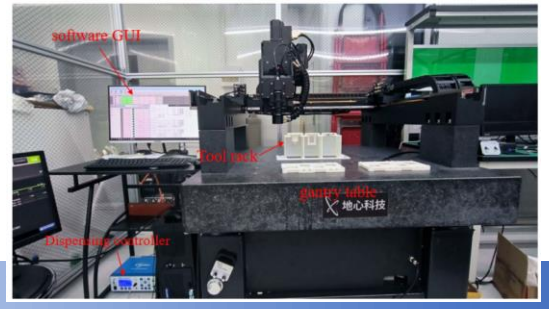




Loading modules on support units



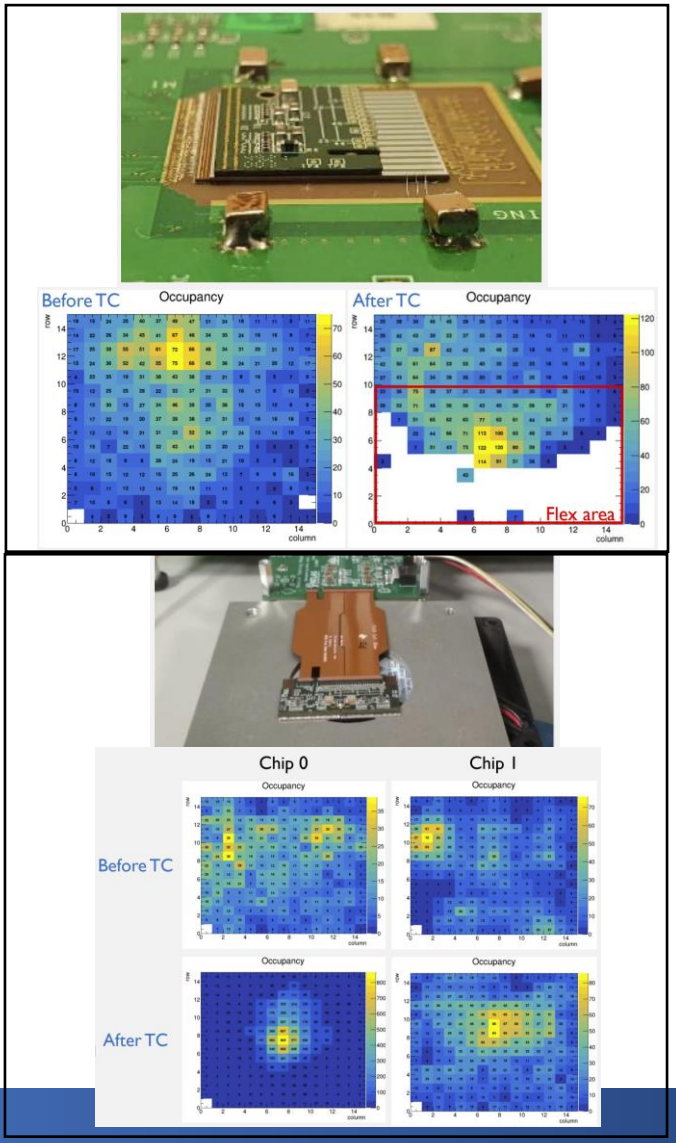
Jigs tools



Gantry

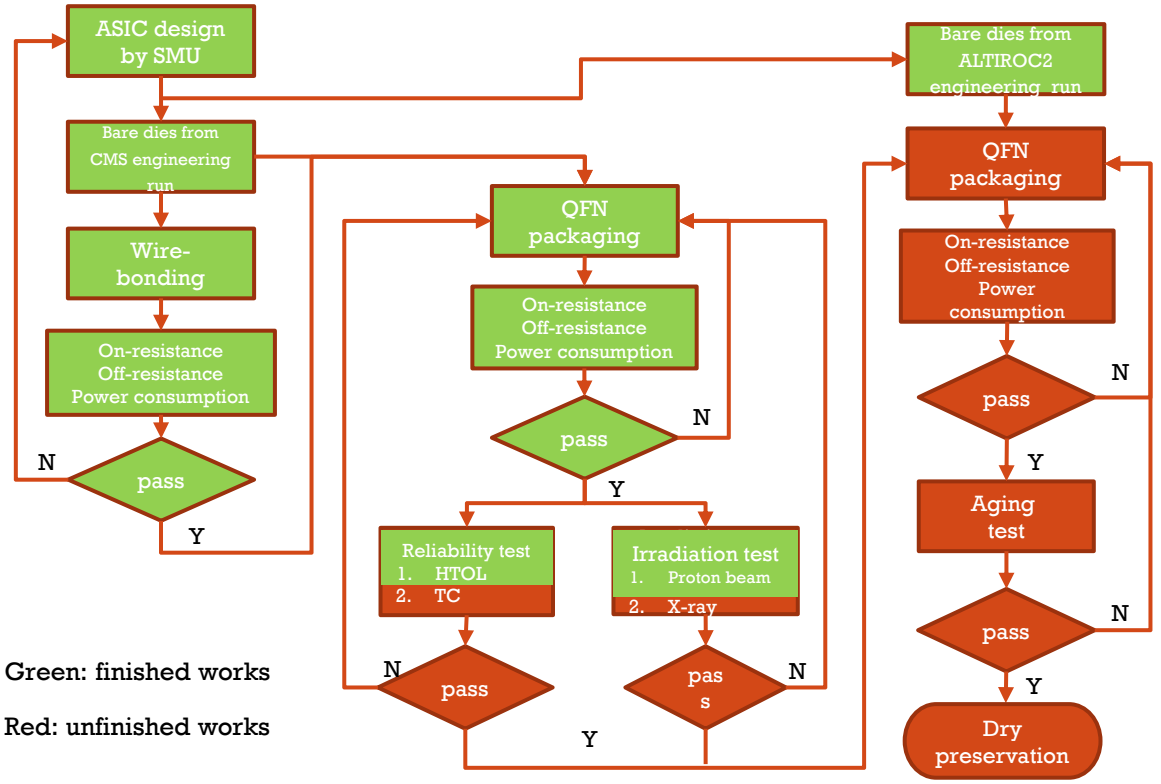
Module - Bump Disconnection during Thermal Cycles

- First observed at IFAE in preparation for the PDR, Also observed at IHEP (less dramatic) and more recently at IJCLab
- On different devices:
  - Hybrids mounted on PCBs with flex on top
    - Thickness of sensor
      - At IFAE: 200-250 um vs at IHEP 700 um
      - Thickness could explain larger effect seen at IFAE
  - On module flex with restricted range (-30C to +40C) no disconnection
    - But would expect failures as in the nominal range (-45C to +40C)
- CTE mismatch between silicon, PCB and glue?
- Further studies of the issue:
  - Continue thermal cycling studies in different labs of PCB+hybrid+flex
  - Study thermal cycling effects on full module (module flex) [mid Feb]
  - Study effect of glue (PCB+hybrid+glue) [end of Feb]
- Possible mitigations:
  - Parylene coating (initially of PCB+hybrid+flex)
  - Flex redesign/material change with low-CTE
  - Different glues, less glue/gluing pattern
  - Larger bump bonds (initial study of 80 → 100 um diameter ball didn't work)
  - Larger pads to accommodate larger bump ball also possible (sensor and ASIC pad design change)
  - More (mechanical) bumps (potential detrimental effect on ALTIROC performance)



Peripheral Electronics Board – MUX64

- A 64:1 multiplexer is developed to handle all voltages to be measured by one ADC channel
- Reliability Test
  - High Temperature Operating Life (HTOL)
    - 32 samples, 85 ˚C, 16days, All passed HTOL
  - Temperature Cycle (TC)
    - 32 samples, -40 ˚C to 85 ˚C
    - 4 batches launched, more than 100 cycles per batch
      - Connectivity issues, but can recover to normal after tests
      - New test boards under production, and testing is expected to complete in two months
- Irradiation Test
  - Proton beam
    - Beam energy: 80 MeV, Spot size: $20 \times 20 mm^2$
      - Thanks to CSNS APEP
    - Measured injection rate: $1.89 \times 10^9\ pps/cm^2$
    - 2 samples passed test
  - X-ray
    - Instrument model: MultiRad160
    - TID dose rate: up to 5 Gray/s
    - 2 samples passed test, 3 pcs under annealing

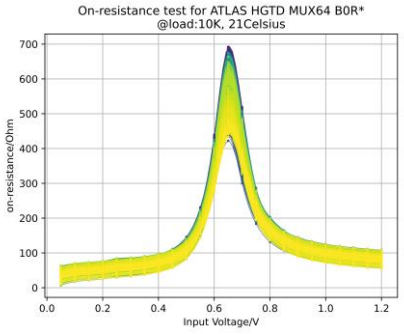


- Green: finished works
- Red: unfinished works

	Requirement	Tested
Si 1MeV n_{eq} fluence	2.5 x 10^{15} n_{eq}/cm^2	3.21 × 10^{15} n_{eq}/cm^2
TID	0.5 M Gy	0.75 M Gy

Bare dies

QFN88 with serial number



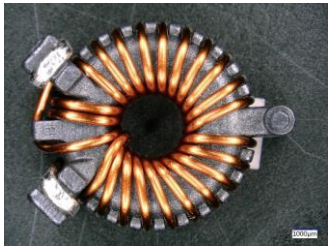
On-resistance test for 170 pcs

Open cavity package for irradiation tests

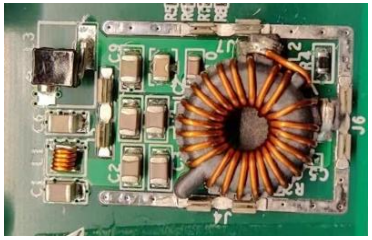
QFN88 socket adapter board

Peripheral Electronics Board – DC/DC converter

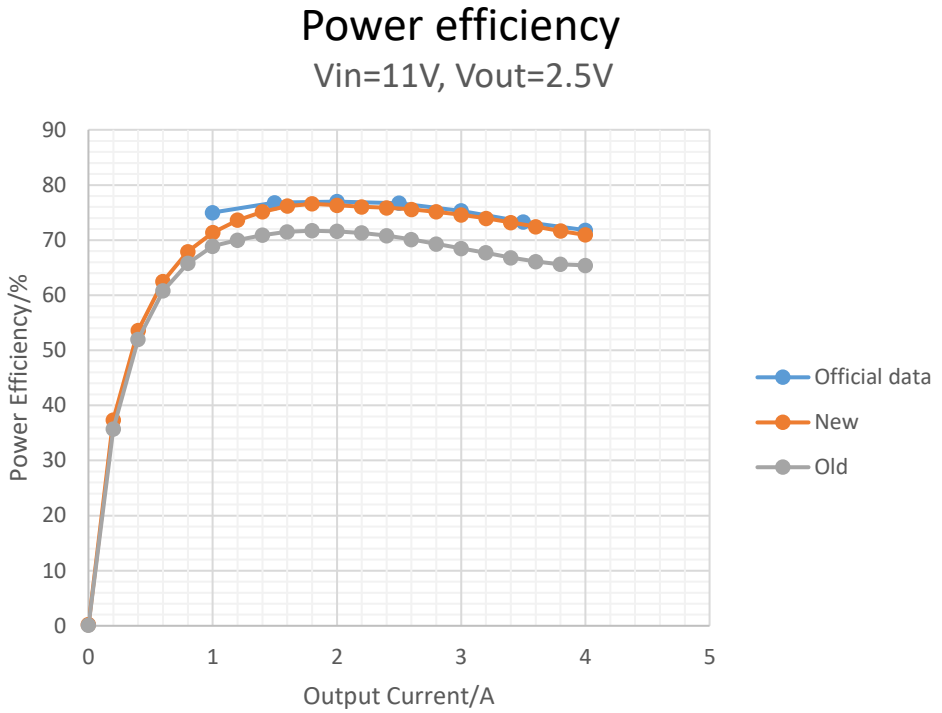
- HGTD requires a low profile inductor (Height < 5 mm)
  - Old coil from ITk, reviewers suggested a new coil from CMS during PEB PDR.
  - Power efficiency has been improved by 4%~7%



Old design with bPOL12v



New design with bPOL12v

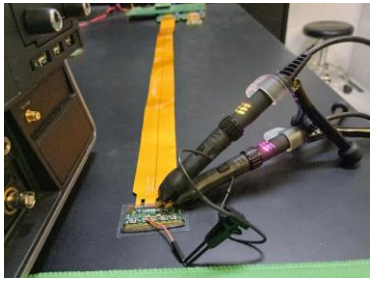


- 160 pcs of new inductor for PEB 1F prototype ordered through CERN procurement office

Peripheral Electronics Board – lpGBT & VTRx+

- Modular PEB, minimum system for full chain readout
  - Support up to 14 modules with two lpGBTs and one VTRx+
  - 2 x 10 Gbps uplinks
  - One carrier board with multiple mezzanine cards
- Elink Skew and Jitter
  - 40MHz for ALTIROC2, 320MHz for ALTIROC3
  - Jitter < 9 ps
- Elink BER test
  - Down link @ 320 Mbps, BERT < 10^{-12}
    Up link @ 1.28 Gbps, BERT < 5 x 10^{-13}

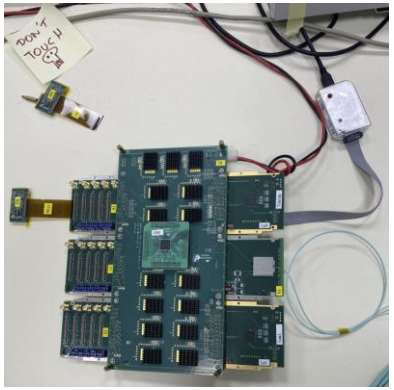
FELIX and modular PEB	Jitter (ps)		Duty		Skew between clk and fast-cmd (ns)	
ECLK	40MHz	320MHz	40MHz	320MHz	40MHz	320MHz
Test points on PEB (without flex tail)	5.256	6.473	50.20%	50.95%	1.353	1.446
Test points on bare module flex with 70 cm flex tail (without ALTIROC)	7.314	7.586	50.19%	50.90%	1.498	1.489
Test points on digital module with 70 cm flex tail (with ALTIROC)	8.052	7.863	50.19%	50.88%	1.550	1.548



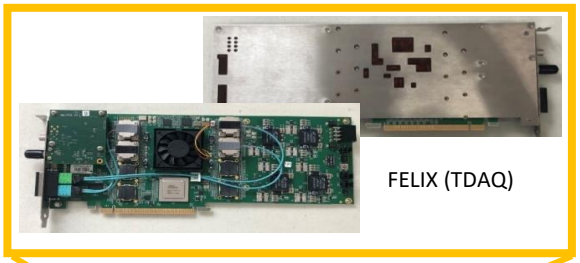
Elink skew and jitter tests

Uplink Eye Diagram tests

- Complete the prototype demonstration system
  - from the front-end modules to back-end TDAQ system
- Delivered to CERN, Nikhef and KTH

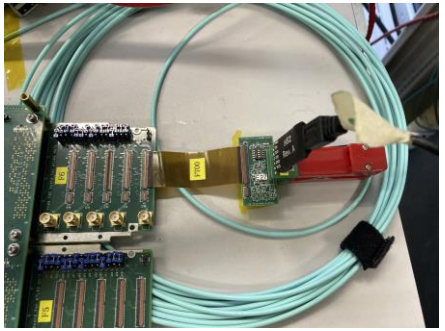


@CERN

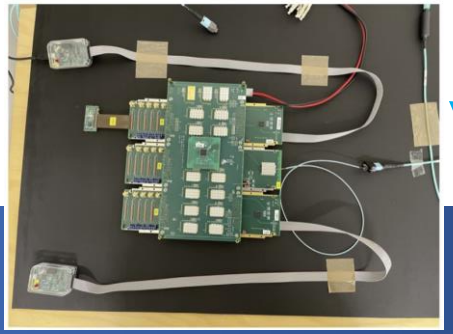


FELIX (TDAQ)

FELIX Server



@Nikhef

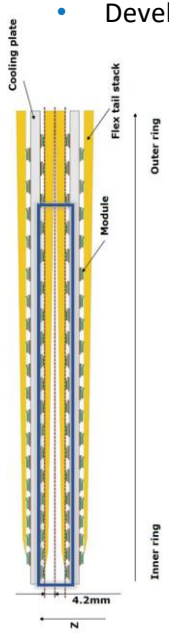


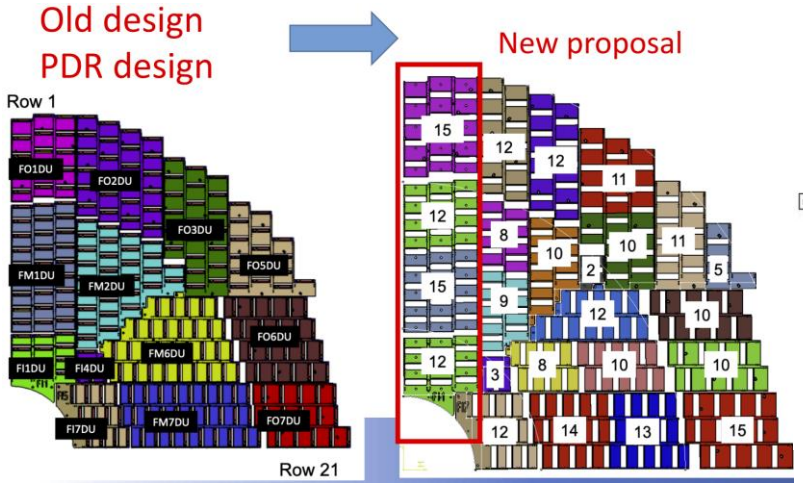
@KTH

Progresses in Other Activities

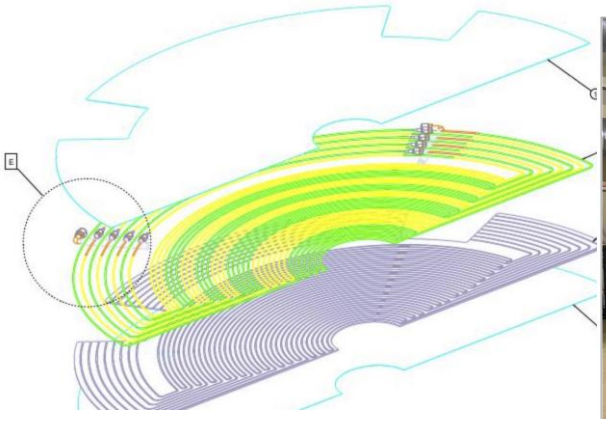
- Modules and Detector Units
  - 54 working modules for demonstrator is proceeding by All 6 sites according to their MoU responsibilities
  - Support units reduced in size to facilitate loading and assembly
  - Mockup test for flex tail integration started
  - Low CTE flexes are in production
- Luminosity, DAQ and Controls
  - Progresses on ELMB and OPC server for DCS
  - Developments on Lumi. & DAQ
- Mechanics
  - Update the design and thermal simulation of CO2 cooling
  - Prototype prod & assembly for demonstrator ongoing
- Services, assembly and installation
  - Installation procedure refinement
  - Clean room layout defined
- Simulation Performance
  - Continuous improvements of detector description to latest designs (step files)
- TestBeam
  - Beam requests confirmed for 2023
  - Paper: Sensor performance ready for submission, LGAD End-of-Life under HGTD review

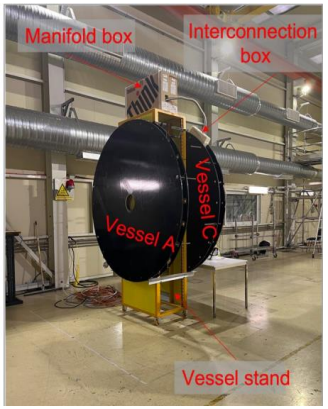
flex tail integration test





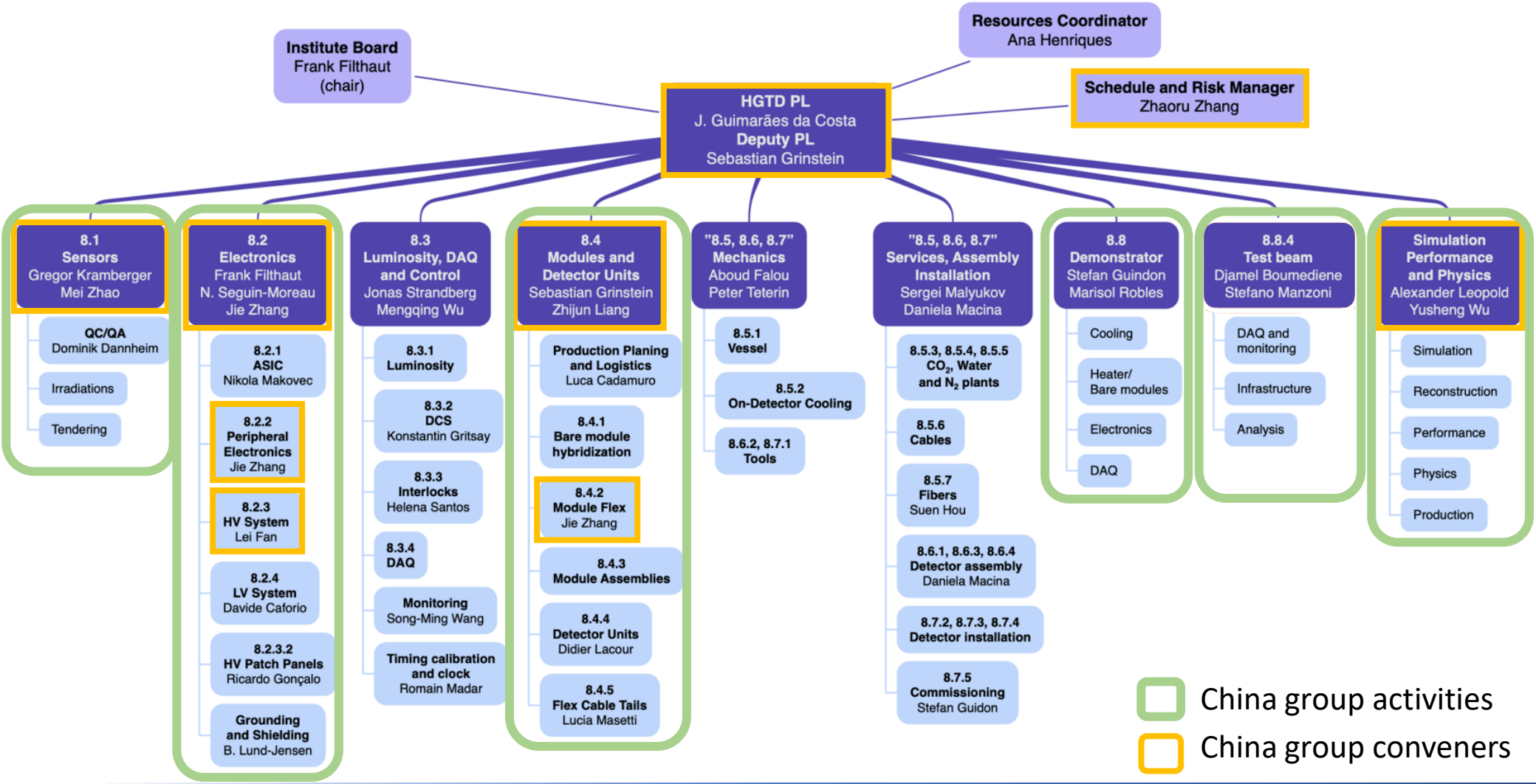
Support units reduced in size





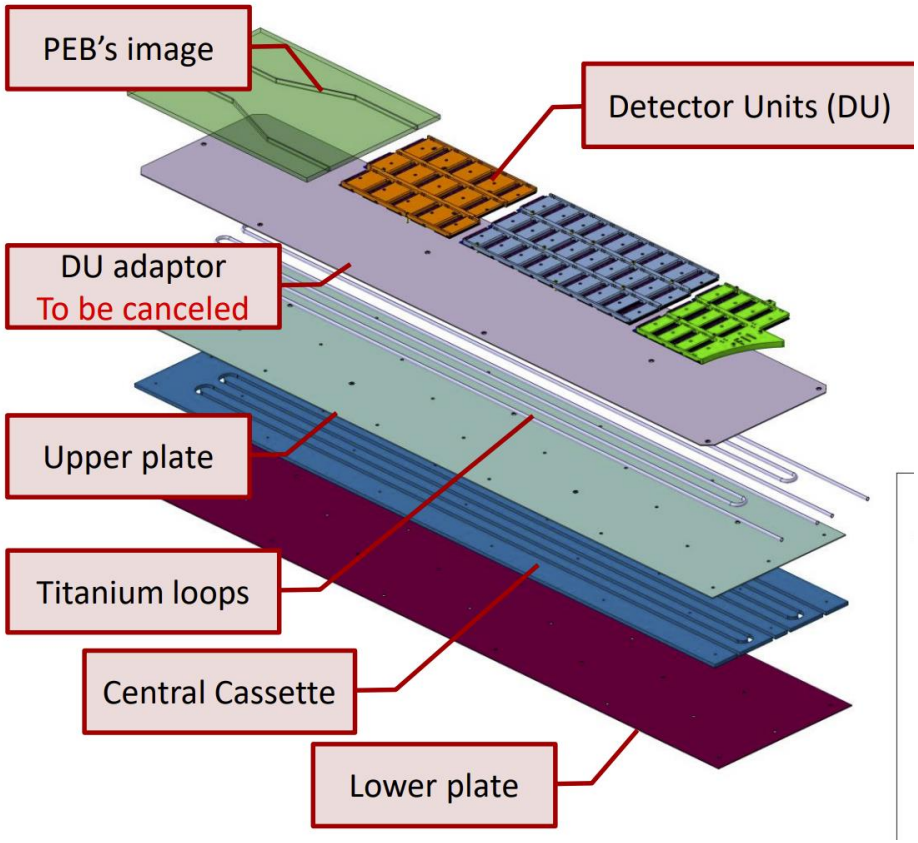
Cooling plate assembly design

HGTD Organization Chart



Conclusion and Outlook

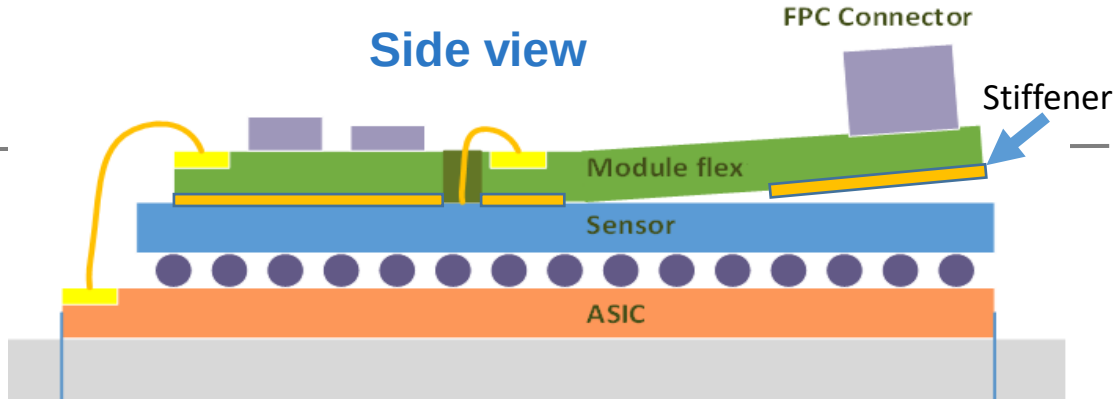
- Focus on the full demonstrator this year
  - Electronics : 54 modules mounted on 4 support units + flex tails + PEB 1F + LV + HV
  - Cooling plate prototype
  - Detector assembly
  - TDAQ + Lumi. DAQ + DCS
- Most tasks are moving or have moved towards the FDR phase
  - LV FDR passed in Jan.
  - HV FDR schedule in Aug.
  - Flex tail FDR schedule in May
  - Cables and connectors PDR + FDR schedule in Jun.
  - Module flex FDR schedule in Aug.
  - Hybridization FDR schedule in Oct.
  - ASIC FDR schedule in Sep.
  - PEB FDR schedule in Oct.



Preliminary scheme for demonstrator
(Titanium loop between Upper plate and lower plate)

Thanks to your attention

CTE analysis



From top to bottom

Item	Marerial	CTE	Mismatch for L = 20 mm, δT = 70 K
Flex PCB	PI	14~19 ppm/K	15.7~22.7 um
Low CTE PCB	?	5~9 ppm/K	3.1~8.7 um
Glue	?	~85 ppm/k	115.1 um
Sensor, ASIC	Silicon	~2.8 ppm/K	0
Thermal grease or others	?	?	?
Cooling plate	Aluminum	~13.1ppm/K	14.4 um

ref: https://www.engineeringtoolbox.com/thermal-expansion-metals-d_859.html)