ATLAS High Granularity Timing Detector: mechanics, services, integration and assembly

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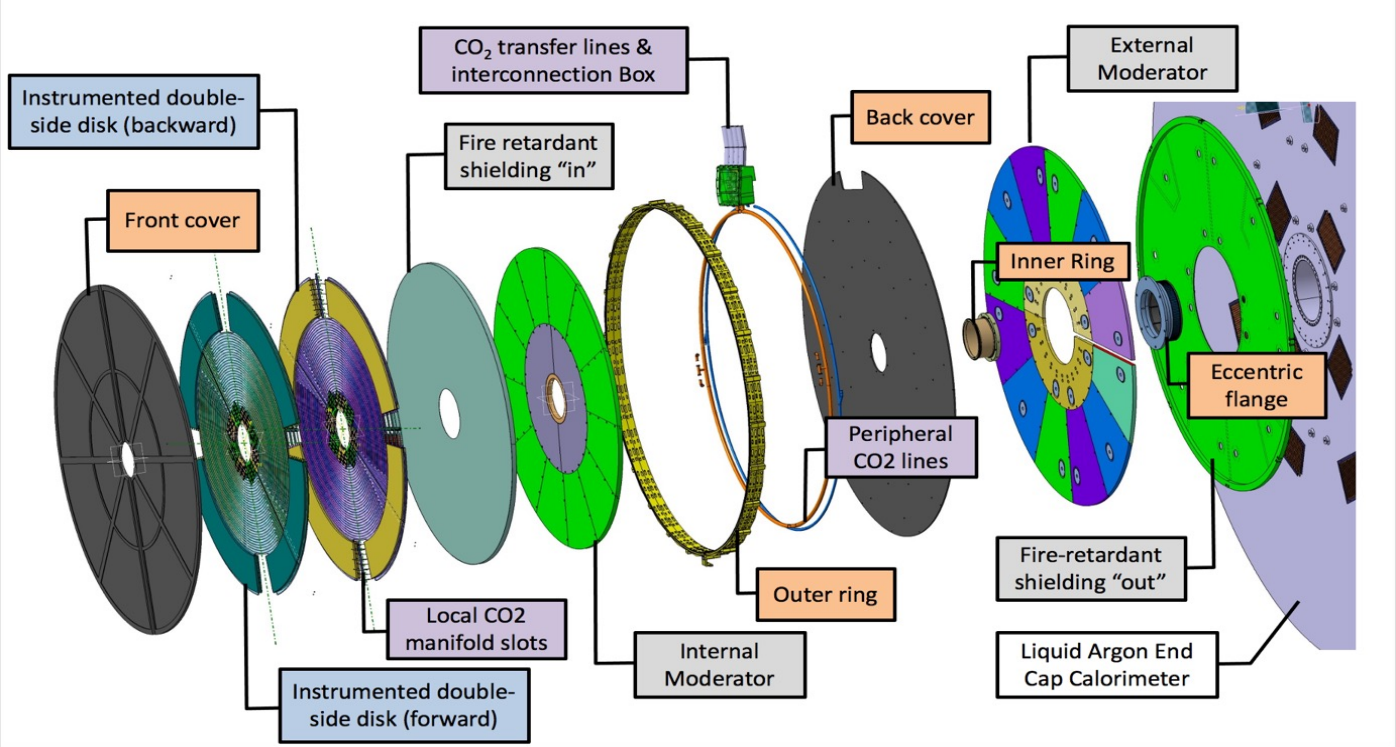
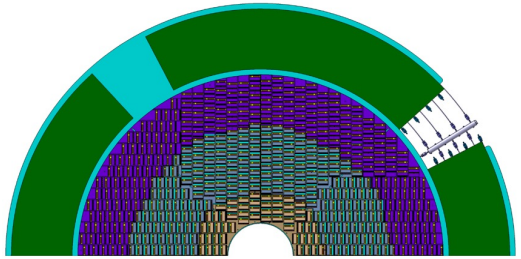
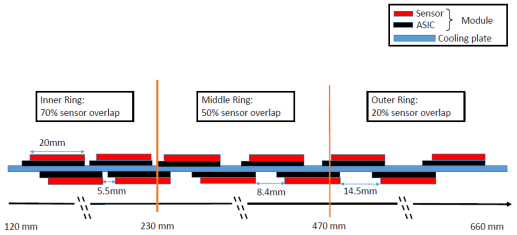
HGTD mechanics overview



HGTD end cap components

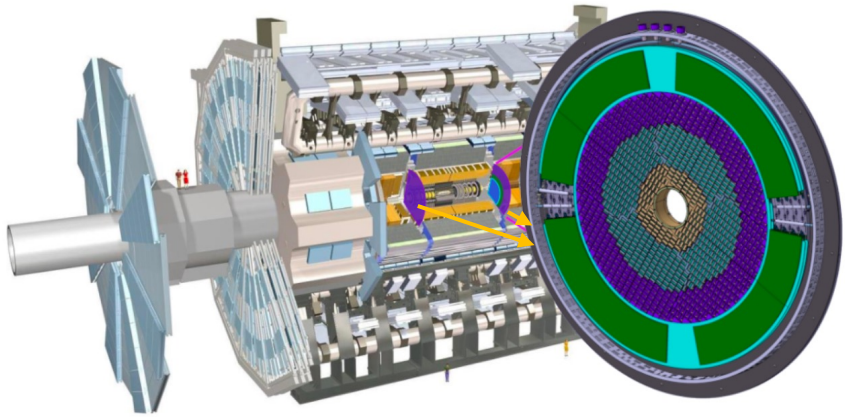


Instrumented double sided half-disk.
Flex tails are not shown on top of modules.



Sensors layout on both sides of half-disk

HGTD will provide:
Timing information for charged particles with a targeted
per-hit resolution of **35-70 ps** over full lifetime
per track resolution of **30-50ps**
Luminosity measurement by reading hit counts at 40 MHz
at reduced range

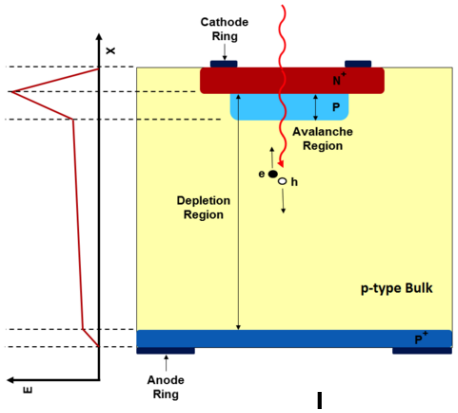


HGTD includes 2 identical detectors to be installed on each of two calorimeter end-caps at ± 3.5 m from IP.

Each of these detectors comprises two disks instrumented on both sides, encapsulated in a hermetic CO_2-cooled vessel.

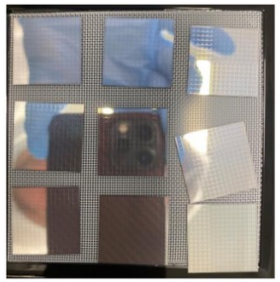
Pseudo-rapidity coverage: $2.4 < |\eta| < 4.0$
Active area: $120 \text{ mm} < r < 640 \text{ mm}$
Envelope: $110 \text{ mm} < r < 1050 \text{ mm}$,
125 mm along beam line

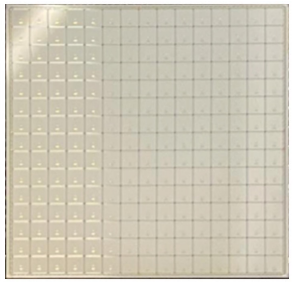
HGTD module overview and assembly



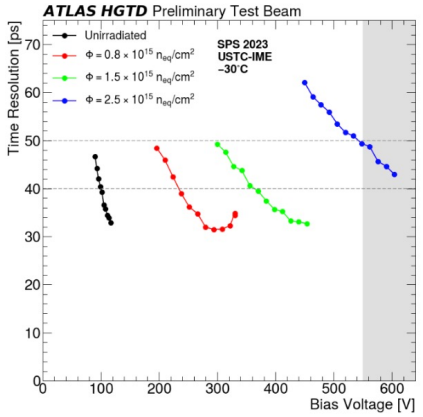
Sensor used in HGTD: Low Gain Avalanche Detector (**LGAD**):
N-on-P silicon sensor with additional p-type gain layer, gain of **10-20**
Active thickness of **50 µm**
Total sensor thickness of **775 µm**
Each sensor comprises **15x15** pads of **1.3x1.3 mm²**
Sensor size: **2x2 cm²**
Total in HGTD are used **16 K** sensors
3.6 M channels

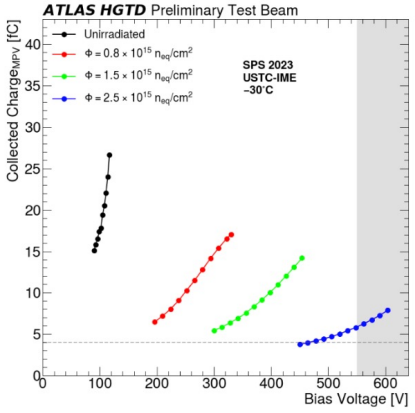
Performance of sensors will be degraded by radiation. This will require replacing the sensors in inner ring at each long LHC shutdown (LS), in middle ring at every second LS.

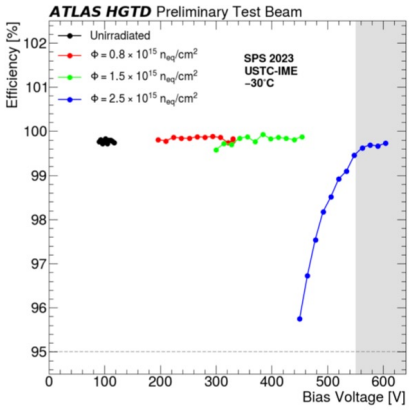




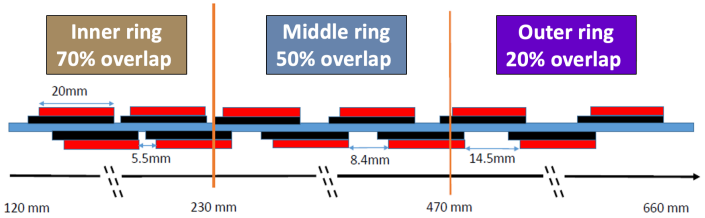
Basic requirements at beginning/(end) of operation:
- withstand fluence of 2.5 x 10^{15} n_{eq}/cm^2 (TID of 2 MGy)
- time resolution <40 ps (< 50 ps)
- collected charge of >10fC (> 4 fC)
- efficiencies of 97% (95%)



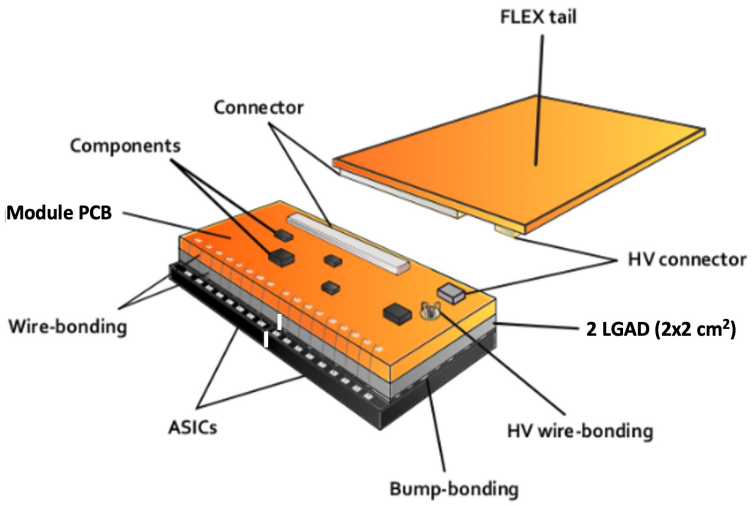


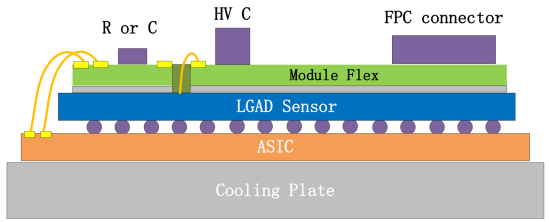


Sensors will be produced by IHEP-IME and USTC-IME. Pre-production done, full QA/QC deployed, so far is within specifications



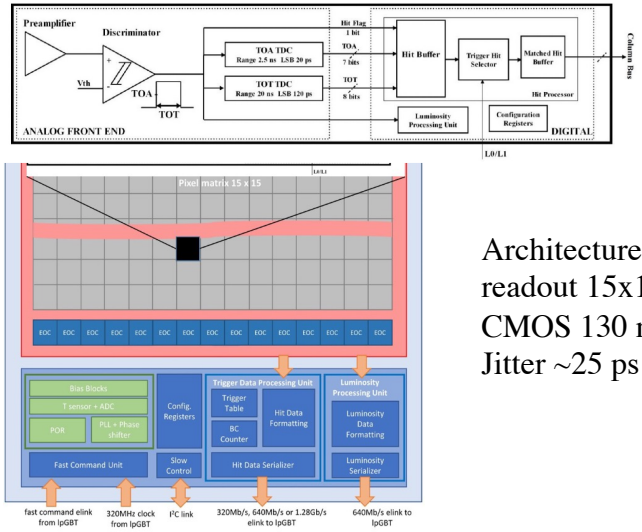
HGTD module overview





Flex tail

- HGTD counts 8032 detector modules
- The module is composed of 2 hybrids, each consisting of LGAD sensor bump bonded to ASIC ALTIROC, glued together on module PCB.
- LGAD sensor comprises 15x15 sensitive pixels, each connected to one of ASIC ALTIROC readout channels. Hybrid dimensions are ~2x2 cm^2, module size is ~2x4 cm^2.
- Module PCB is connected to ASICs by wire bonds on one side, and connected to peripheral electronics boards via flexible PCB, so called flex tails.

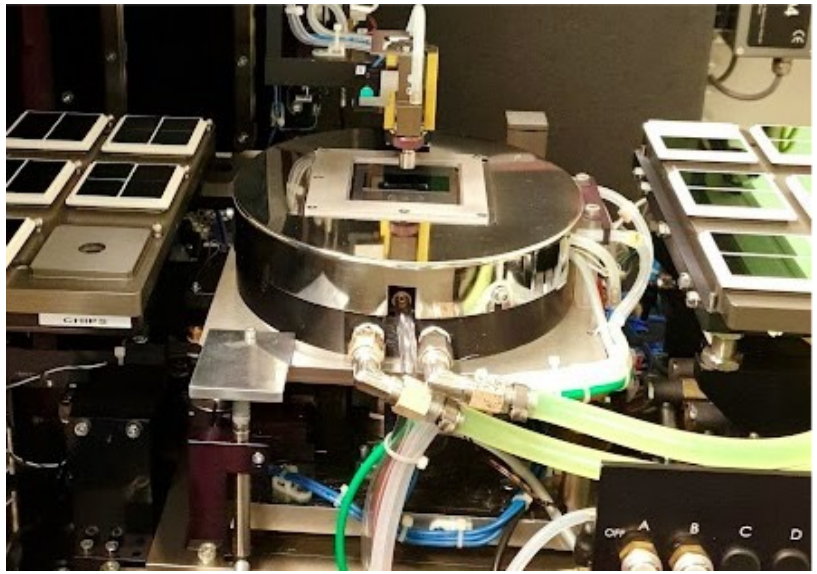


Architecture of the ALTIROC ASIC
readout 15x15 pads, 2x2 cm^2,
CMOS 130 nm,
Jitter ~25 ps

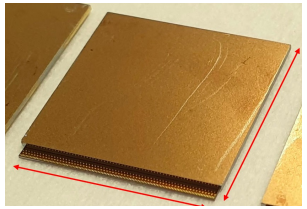
HGTD module assembly

LGAD

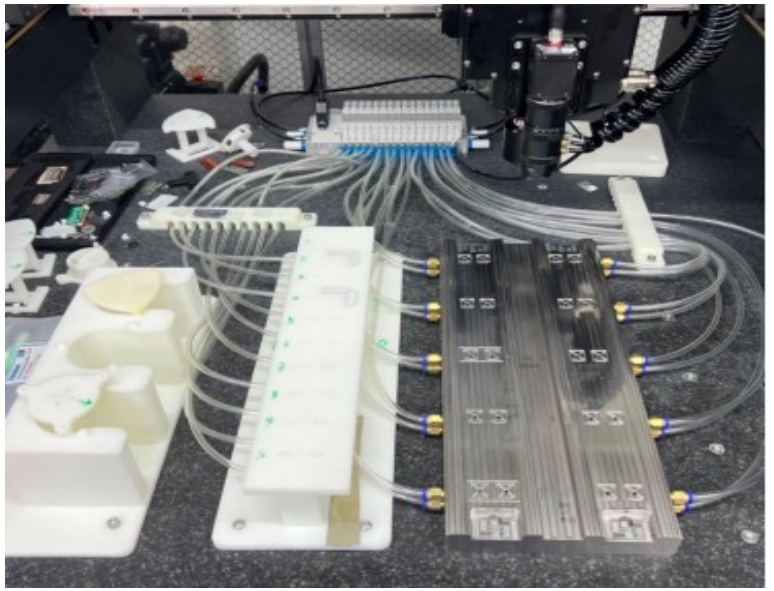
ALTIROC ASIC



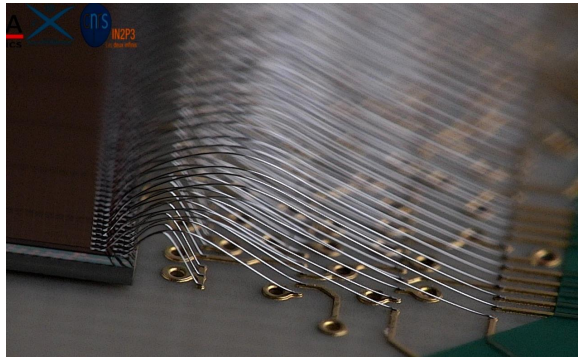
Bump bonding with 100 µm balls



Assembled hybrid undergo X-ray control



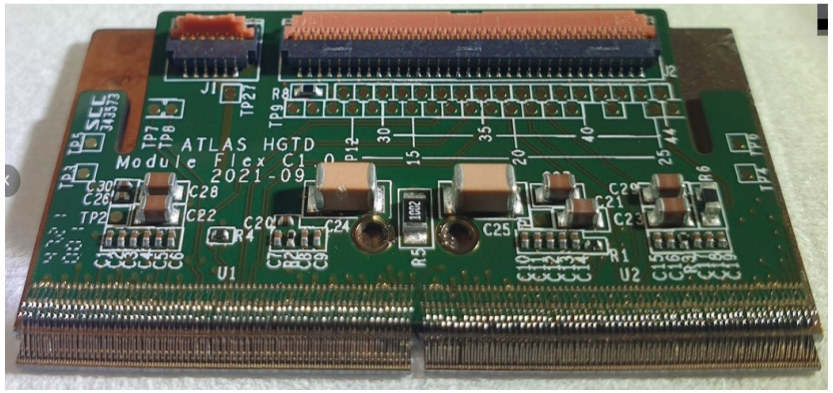
Module assembly:
gluing 2 hybrids to module PCB



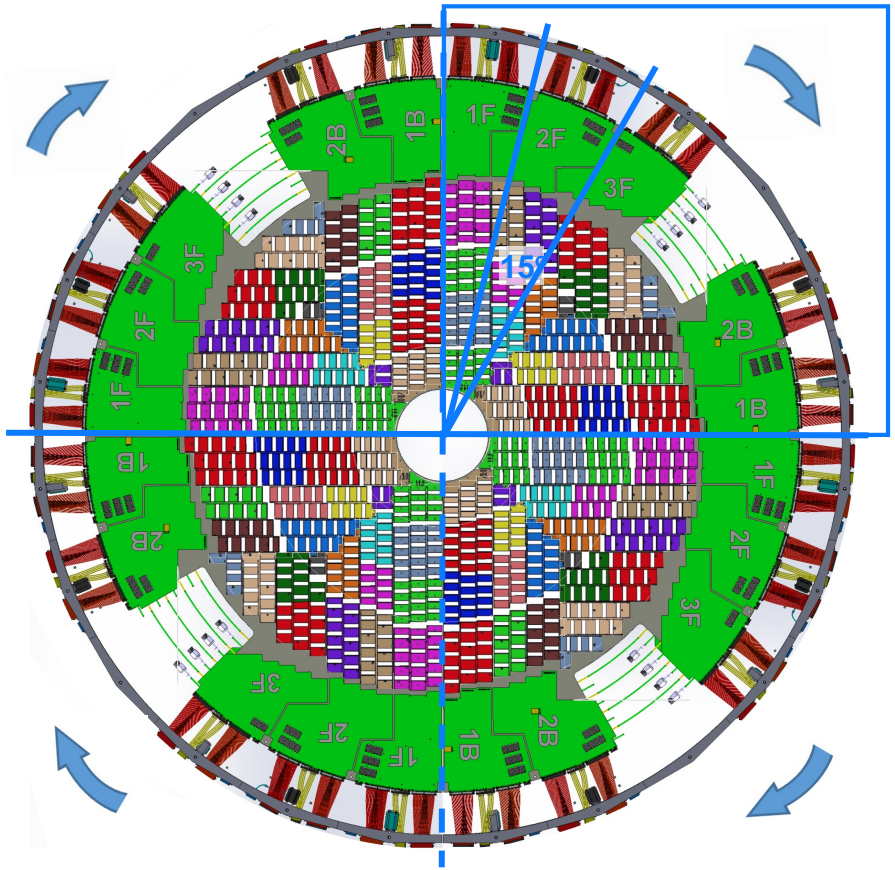
Wire bonding

Module test

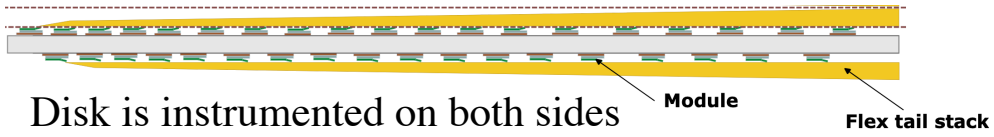
Assembled module



Instrumented disks layout



Front side if instrumented disk
(flex tails are not shown)

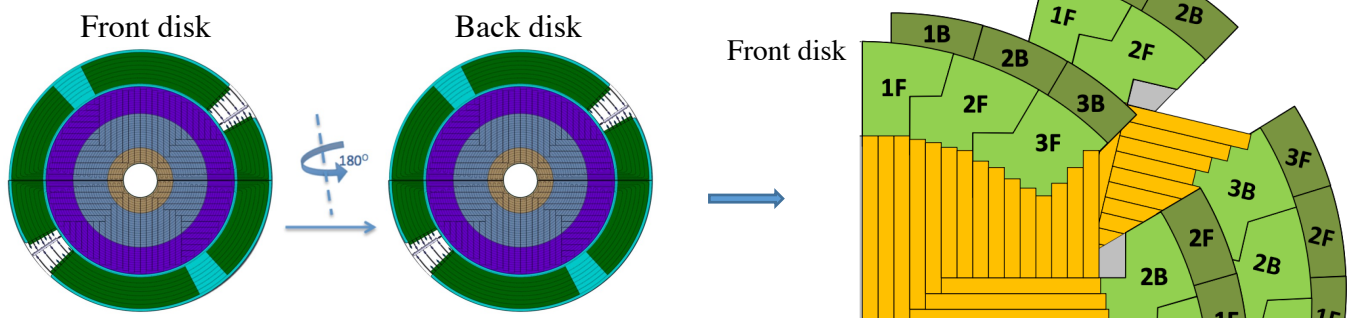


Disk is instrumented on both sides

Design of HGTD detector is optimized to maximize number of identical components:

- all disks are instrumented equally, composed of 2 identical half-disks
- all quadrants of disk are identical
- only 6 different types of PEBs are used
- positions connectors on PEB and on 15° section of outer ring are the same for each PEB
- all pigtails and fanouts of the same type are identical
- number of identical flex tails is maximized.

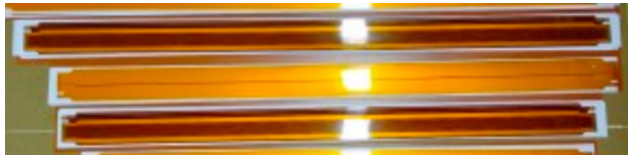
➢ **It is sufficient to consider only one quadrant of the instrumented disk**
➢ **It is sufficient to define the arrangement and lengths of PEB services only in one of the 15º sections.**



Rear disc is turned face-back to create a 15º angle between rows of modules on the discs

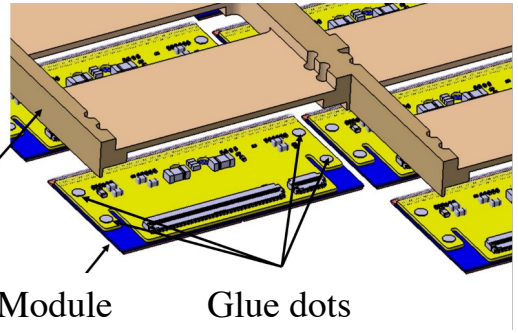
Loading modules

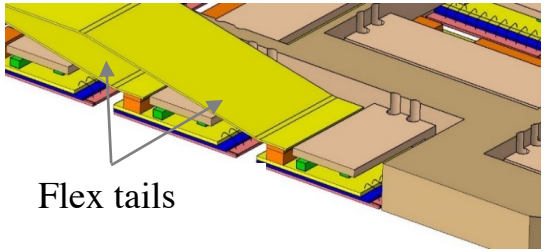
- HGTD modules will be installed on both sides of CO2 cooling support via a thermal interface layer
- Before installation, modules will be loaded onto support units made of PEEK.
- Assembled detector units are screwed onto cooling disk
- Modules are connected to Peripheral Electronic Boards (PEB) via flex PCB (flex tails)



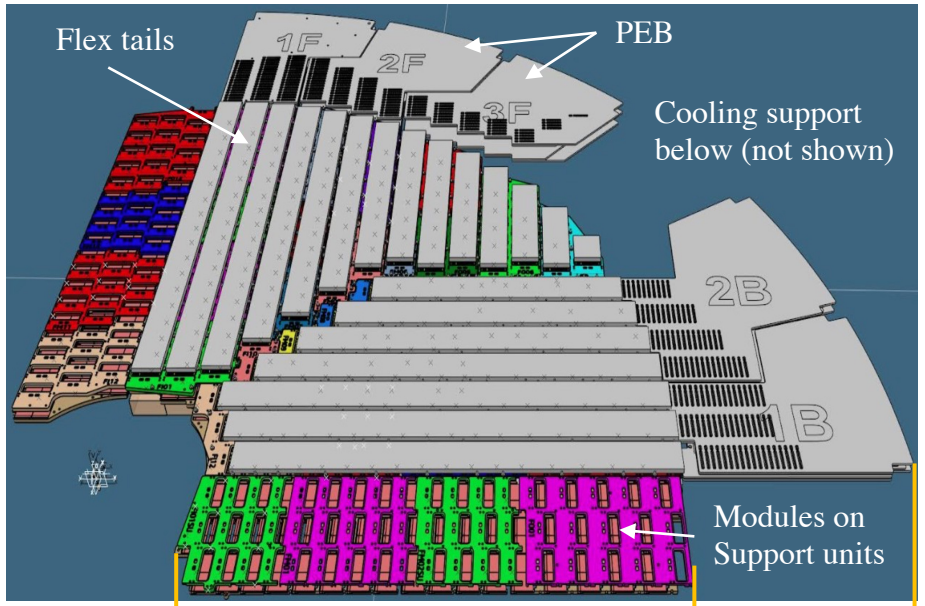
Flex tails

48 types of supports will be used
768 supports in total for HGTD
24 supports per quadrant on each side

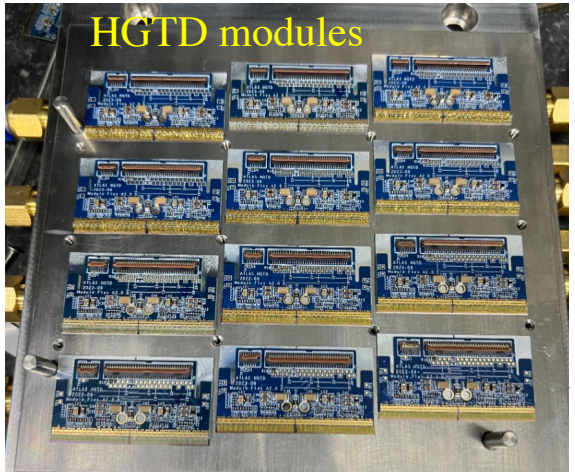


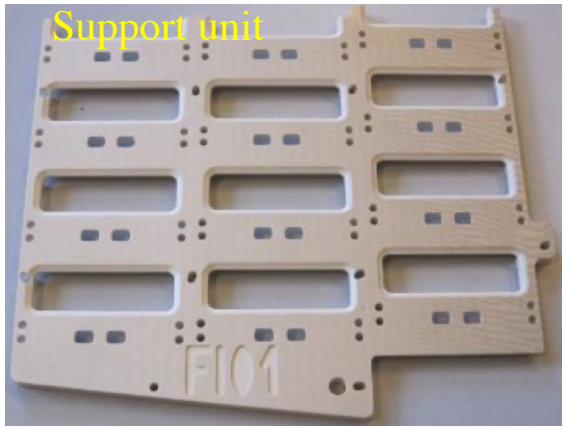


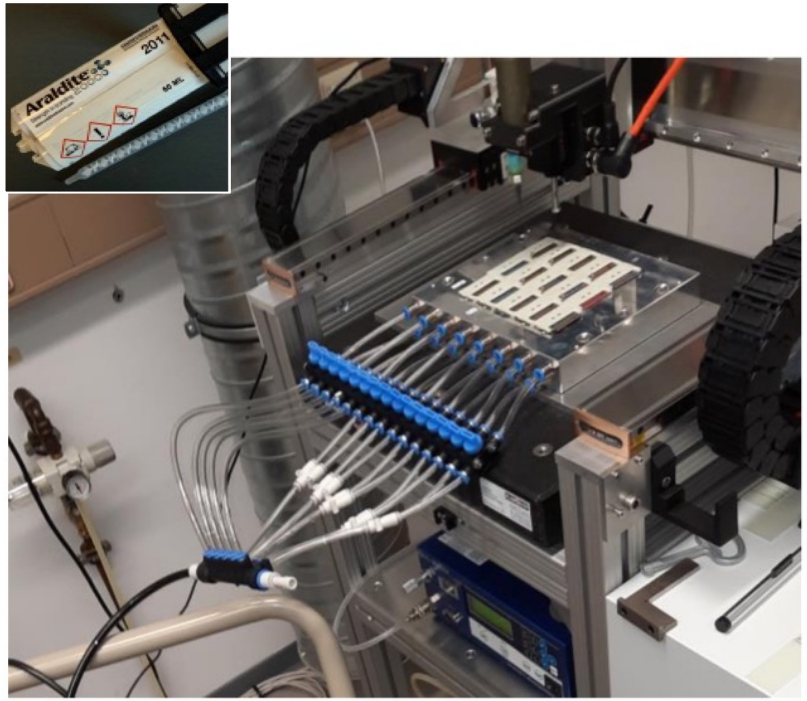
Support units on one quadrant



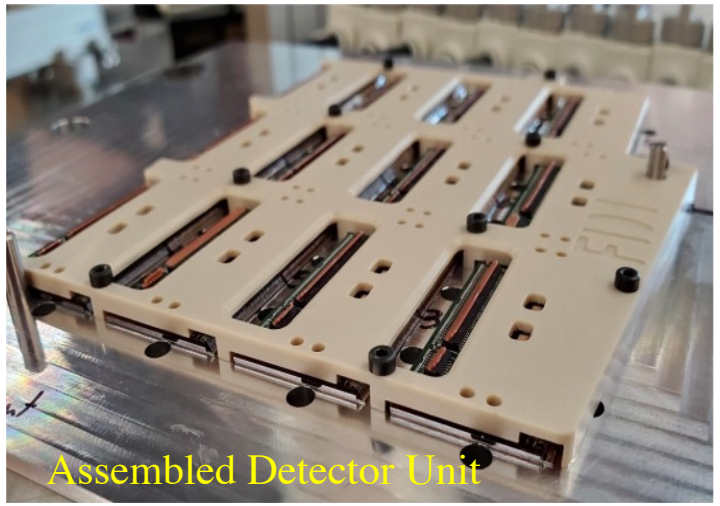
Module loading on support units

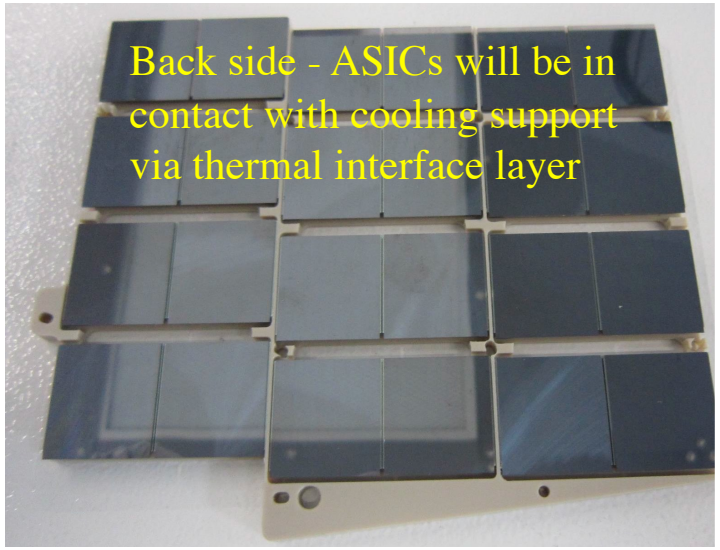






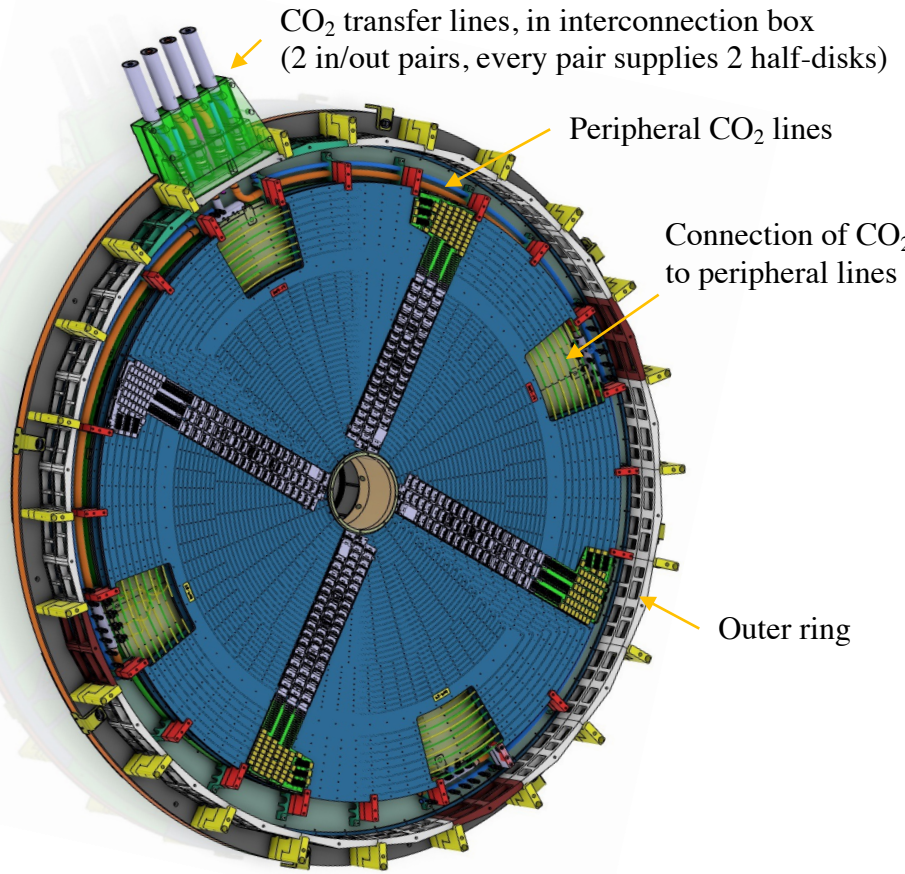
Assembly tooling:
Modules held in place by vacuum,
glue deposited on the modules,
support unit placed on top

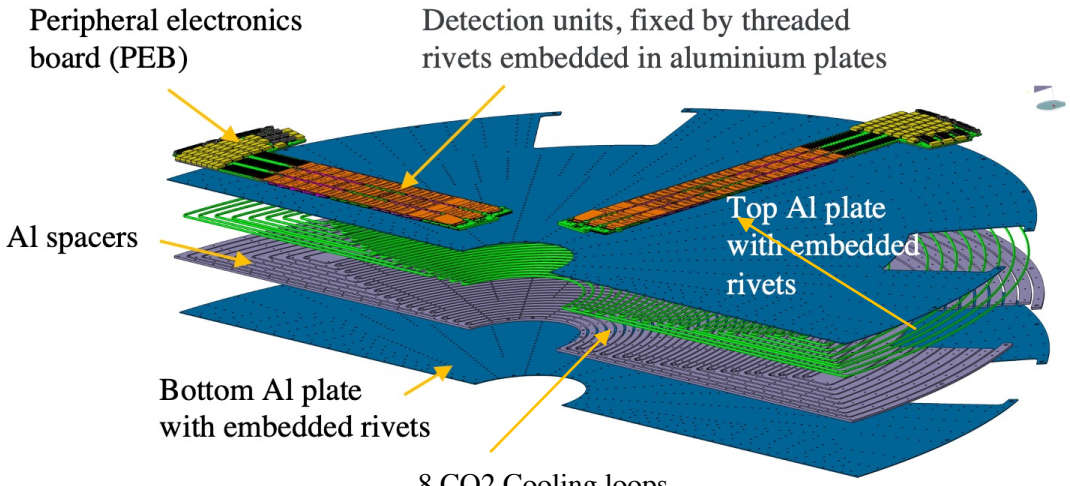


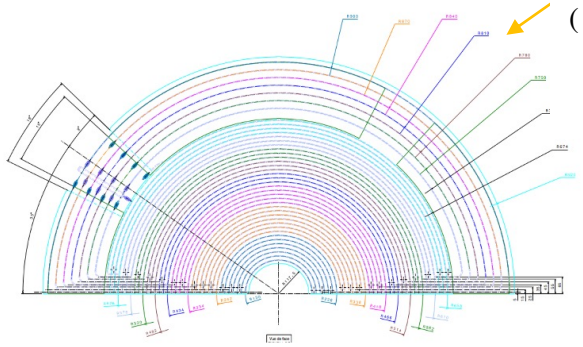


CO2 cooling services inside vessel

- HGTD will be cooled using 2-phase evaporative CO_2 cooling system
- Nominal temperature of CO_2 in vessel ~ -35 ºC, LGAD sensors at ~ -30 ºC
- Inner volume of the vessel will be flashed with dry nitrogen gas, keeping due point at -55 ºC.
- Heaters will be used on vessel covers and on outer ring to prevent condensation



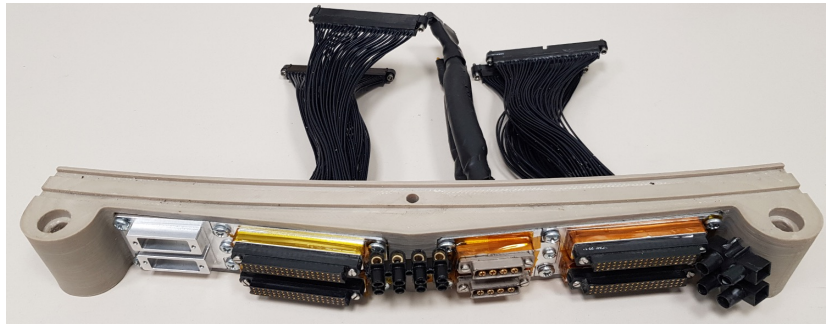




4 cooling supports per vessel

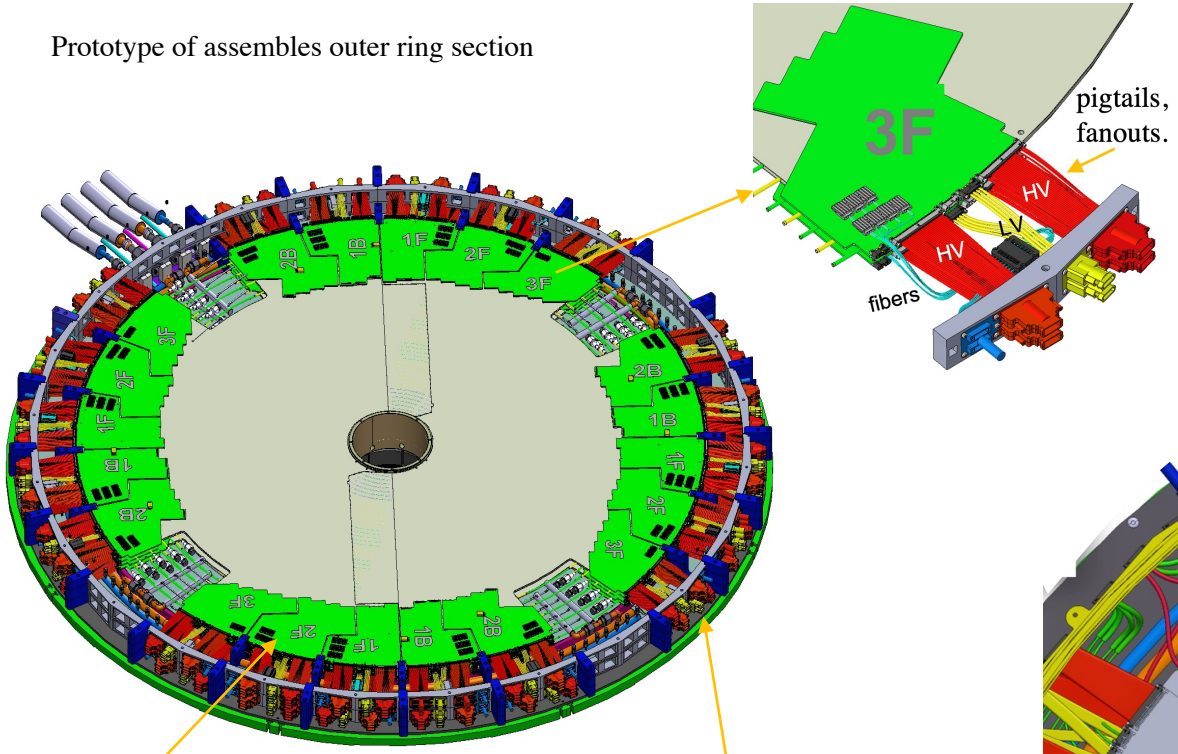
Services inside vessel

- ~300 cables and 40 optical cables connected to each vessel at outer ring
- 281 pigtails + 80 optical fanouts per vessel interconnect PEBs with cables
- HV, LV, NTC pigtails all are identical, fanouts are the same length
- Vessel is made as a Faraday cage



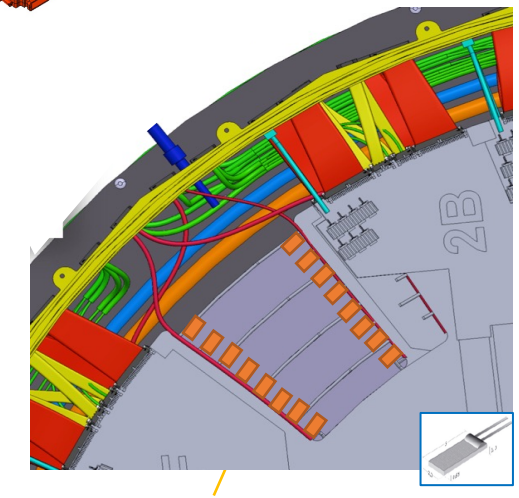
All sections of outer ring will be pre-assembled with services. First prototype shown in picture.

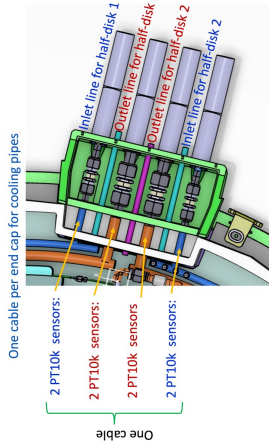
Prototype of assembles outer ring section



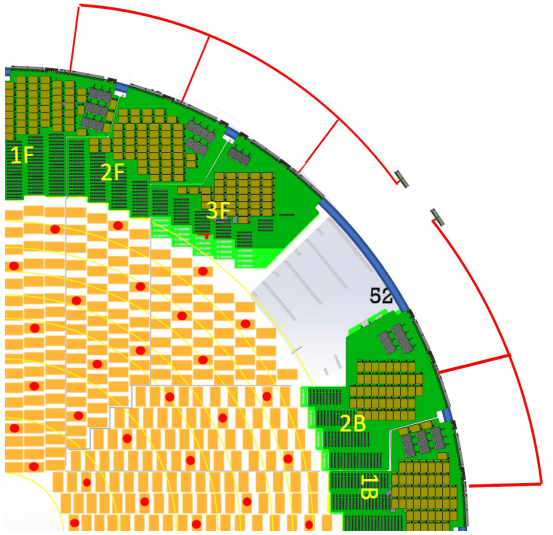
Peripheral electronics

All cables and fibers connected to outer ring.





PT10k on cooling loops of half-disk

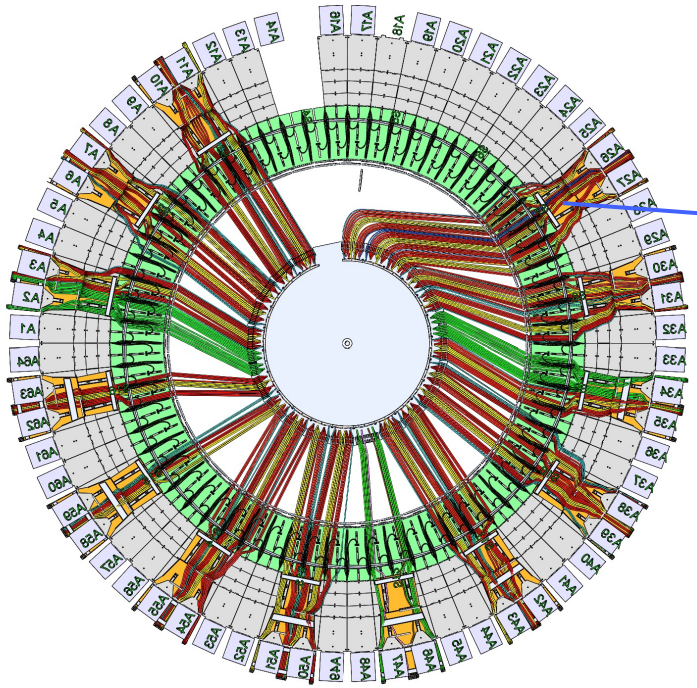


NTC sensors on modules

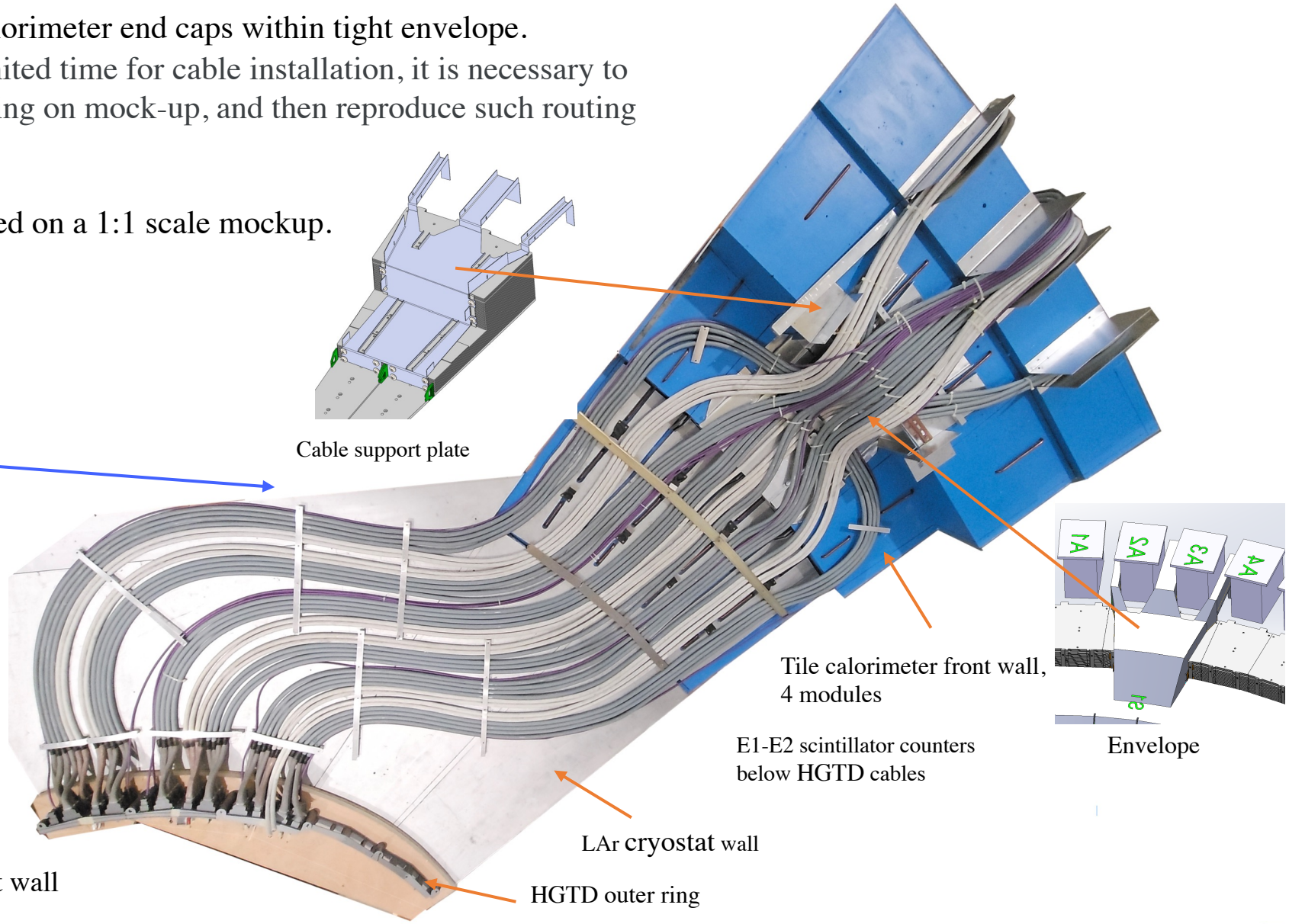
Cable routing on front wall of calorimeter end cap

- ~ 340 cables to be installed on calorimeter end caps within tight envelope.
- Given difficult conditions and limited time for cable installation, it is necessary to perform and document cable routing on mock-up, and then reproduce such routing when installing cables in ATLAS.

Most populated bundle was installed on a 1:1 scale mockup.

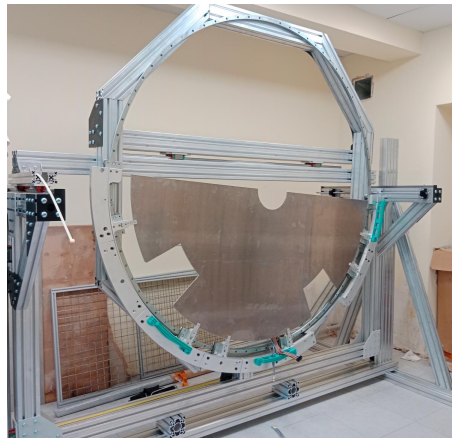


Routing of HGTD cables on calorimeter front wall



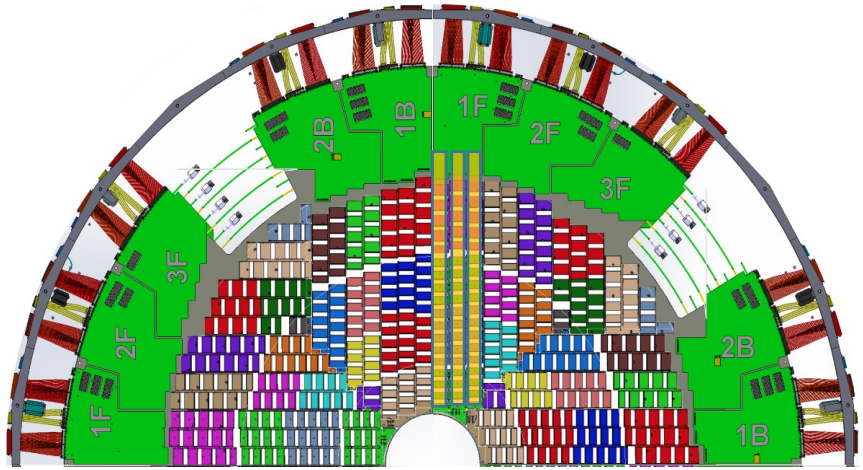
Half-disks instrumentation and integration into vessel

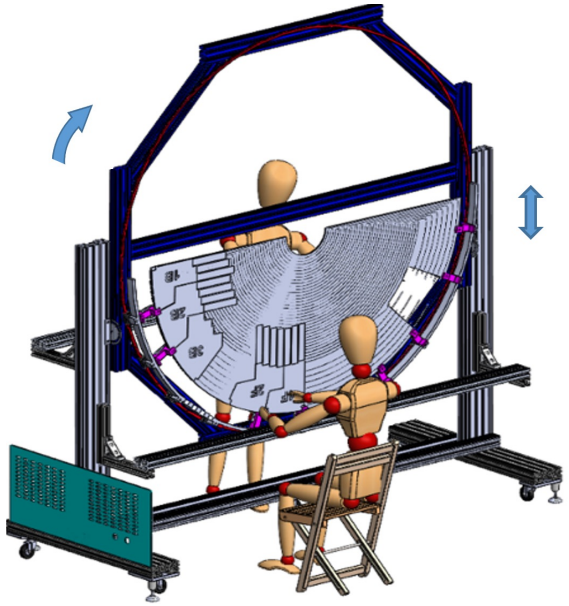
- Dedicated tool for half-disks assembly, the assembly stand, will be used
- Integration stand - for integration of instrumented disks into vessel
- Small CO2 cooling station will be used during final tests in vessel
- Half-disc assembled with all services and outer ring section
- All possible tests will be performed during assembly and integration
- Assembled half-disk will be transferred to vessel without disconnection of services
- Completely assembled and tested HGTD end cap will go for installation in ATLAS



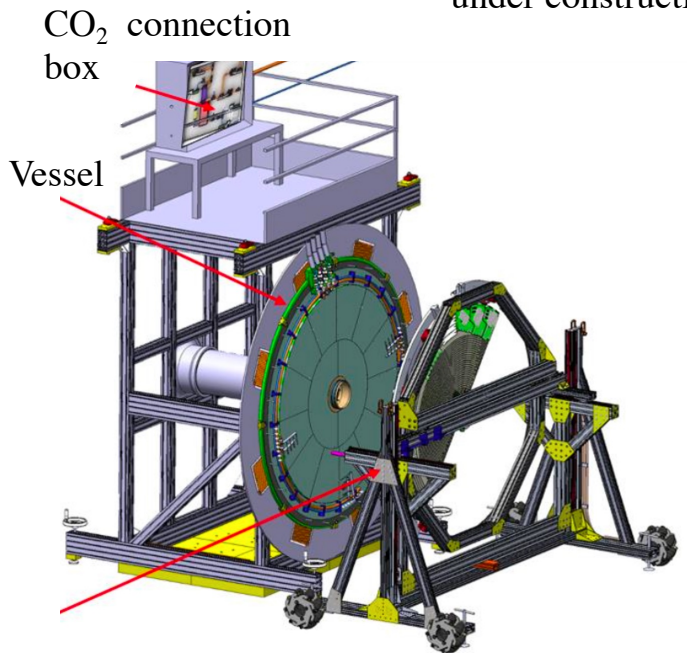
Assembly stand prototype under construction

8 instrumented half-disks for both HGTD endcaps





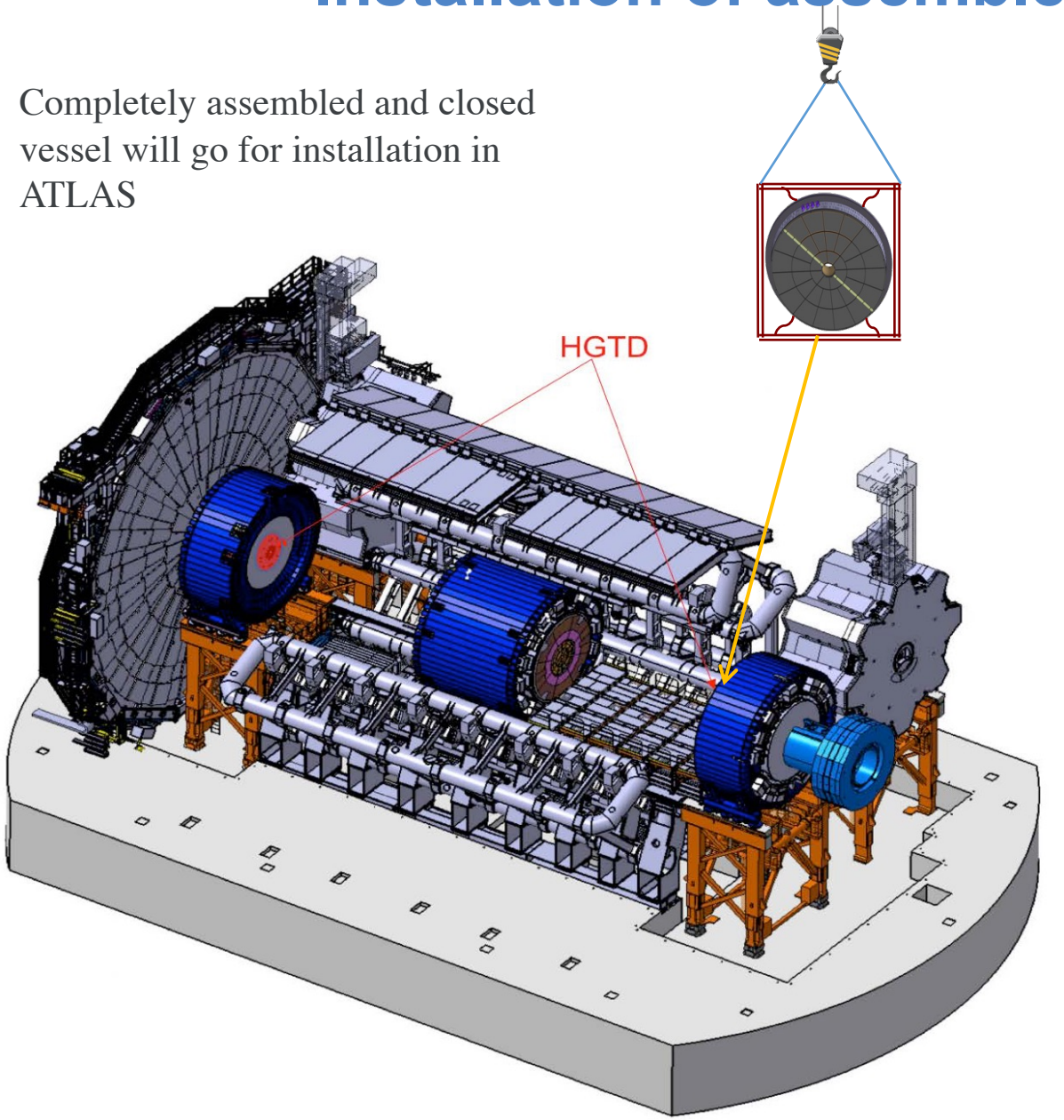
Assembly stand will allow vertical movement and rotation of half disk.



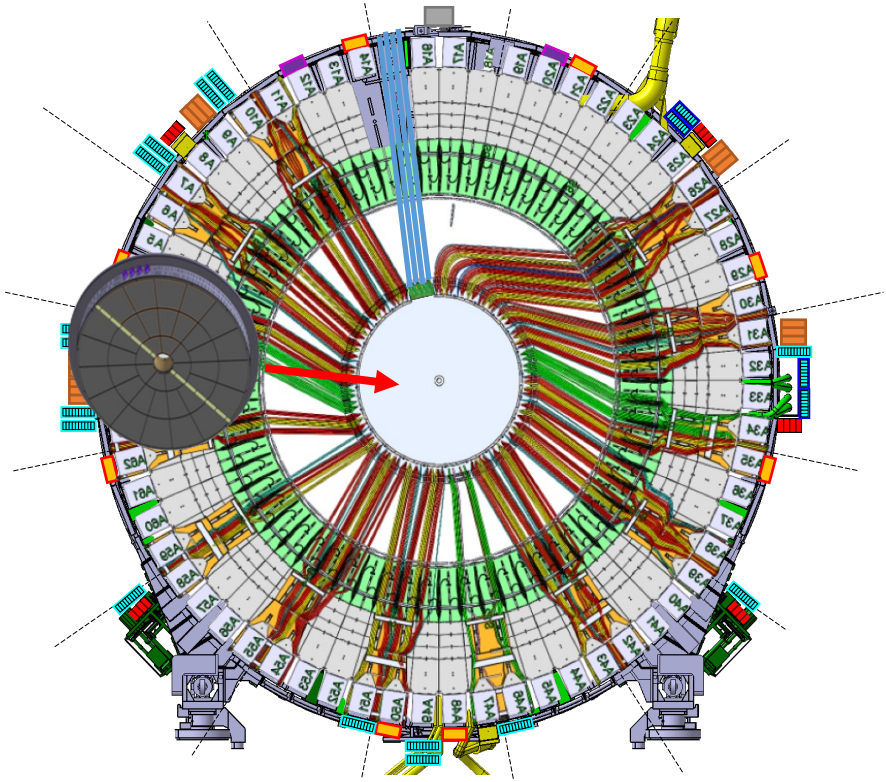
Assembly stand in front of integration stand

Installation of assembled detector in LS3

Completely assembled and closed vessel will go for installation in ATLAS



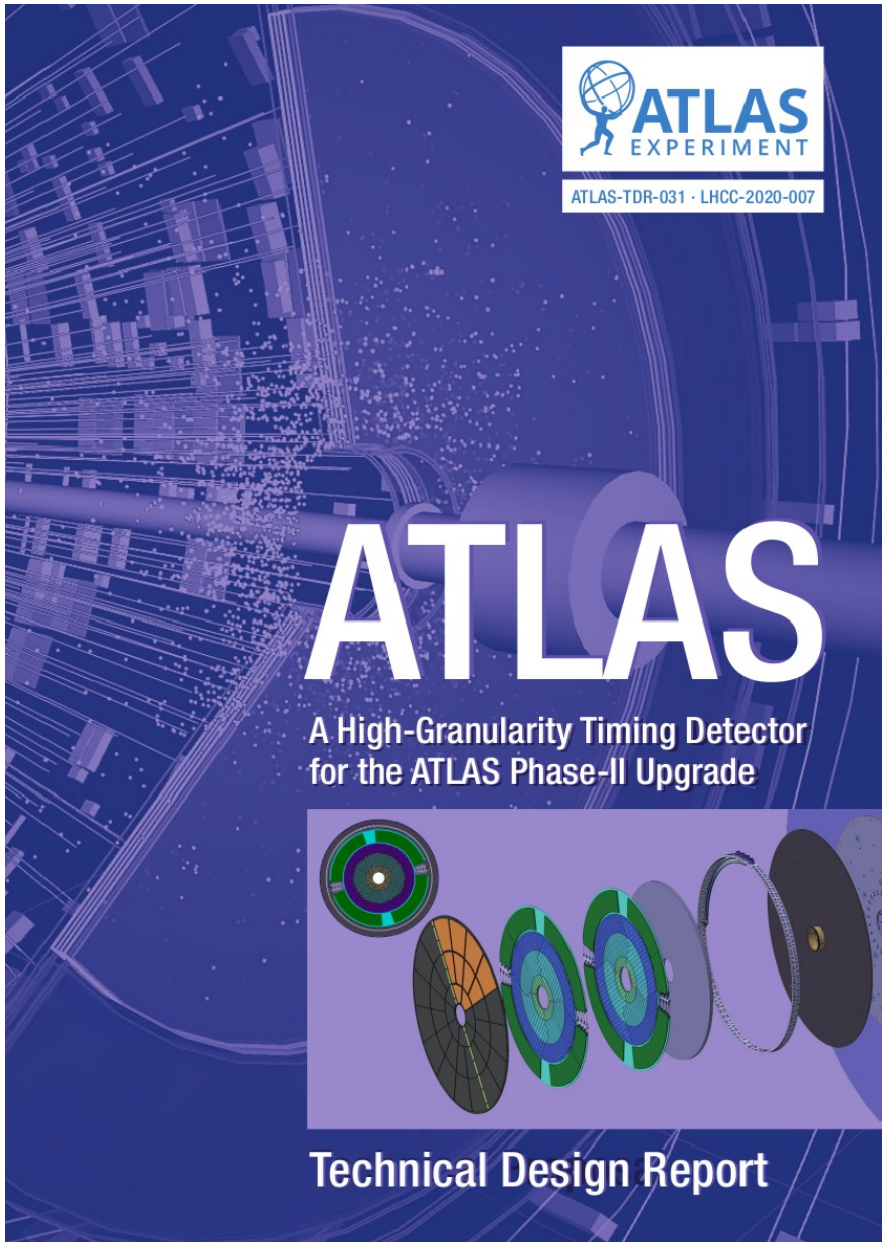
After fixing HGTD on calorimeter, all services, preliminary installed, will be connected to the vessel



Summary

- HGTD will provide precision timing information for charged particles in the forward region of ATLAS along with luminosity measurements during full life of HL-LHC
- LGAD sensors and front-end ASICs ALTIROC meet requirements up to fluence of 2.5 x 10^{15} n_{eq}/cm^2
- HGTD design is progressing well, detector subsystems nearing Final Design and Production Readiness Reviews. PRR for sensors passed in July 2024.
- The workload is evolving towards testing of mechanics, services, cooling, back-end electronics, preparing for detector assembly. Test beam activity are ongoing.
- Tests of the HGTD demonstrator built around the 1F PEB are in progress.
- Slowly moving towards mass production and construction of HGTD

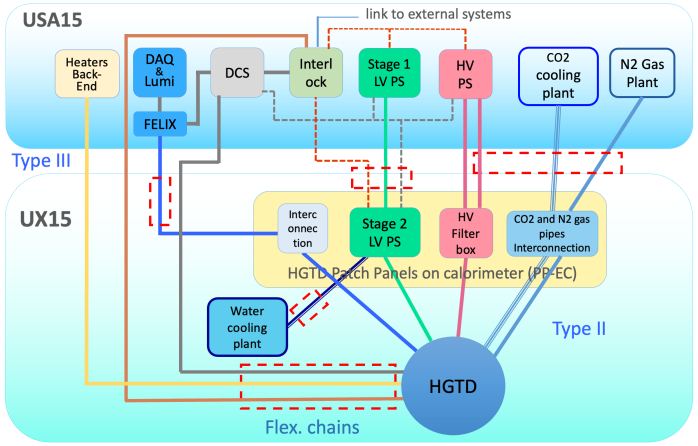
Backup slides



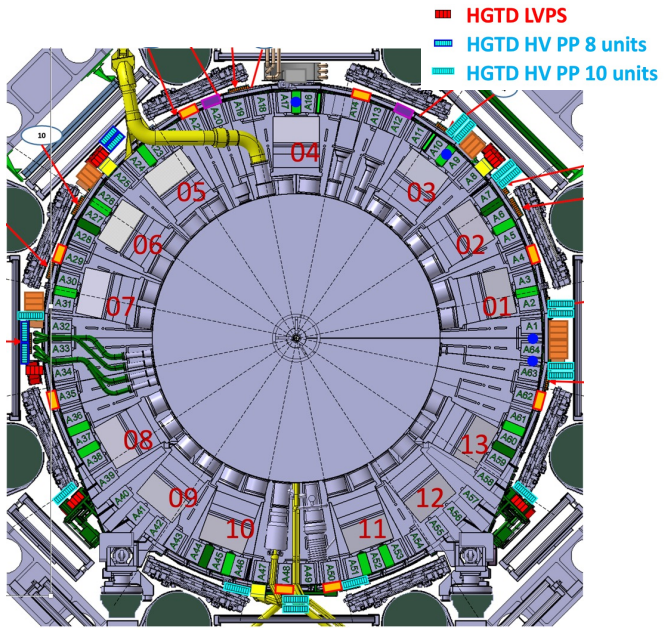
High Granularity Timing Detector TDR specification

Pseudo-rapidity coverage	$2.4 < \|\eta\| < 4.0$
Thickness in z	75 mm (+50 mm moderator)
Position of active layers in z	±3.5 m
Weight per end-cap	350 kg
Radial extension:	
Total	110 mm $< r <$ 1000 mm
Active area	120 mm $< r <$ 640 mm
Pad size	1.3 mm × 1.3 mm
Active sensor thickness	50 µm
Number of channels	3.6 M
Active area	6.4 m^2
Module size	30 x 15 pads (4 cm × 2 cm)
Modules	8032
Collected charge per hit	> 4.0 fC
Average number of hits per track	
$2.4 < \|\eta\| < 2.7$ (640 mm $> r >$ 470 mm)	≈2.0
$2.7 < \|\eta\| < 3.5$ (470 mm $> r >$ 230 mm)	≈2.4
$3.5 < \|\eta\| < 4.0$ (230 mm $> r >$ 120 mm)	≈2.6
Average time resolution per hit (start and end of operational lifetime)	
$2.4 < \|\eta\| < 4.0$	≈ 35 ps (start), ≈ 70 ps (end)
Average time resolution per track (start and end of operational lifetime)	≈ 30 ps (start), ≈ 50 ps (end)

HGTD services overview

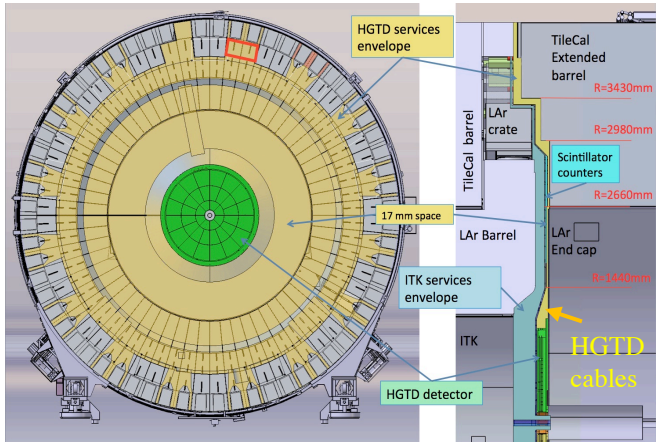


Overall HGTD service layout

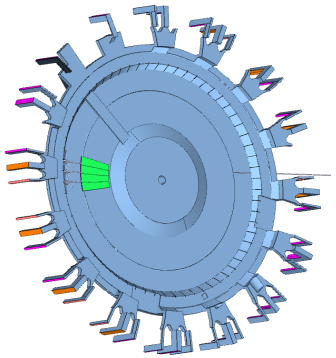


HGTD LV PS and HV filter boxes on calorimeter end cap (PP-EC)

- 300V to 10V DC-DC converters, 20 units grouped in 5 mini-crates
- 160 HV filter boxes grouped in several places on calorimeter surface
- CO2 cooling, Nitrogen gas and water cooling flexible chains on top of calorimeter end cap

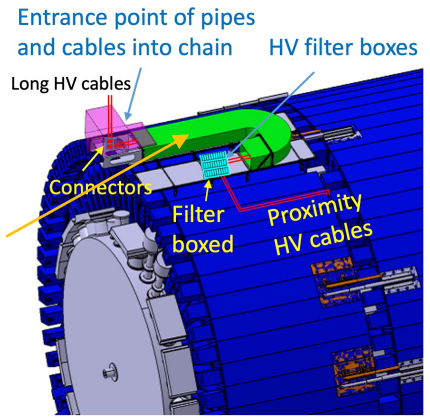


Envelope for HGTD services



3d model of envelope

HGTD will replace MBTS detector in ATLAS, taking its space in the gap between calorimeters barrel and and cap. HGTD services must fit into available space, which is very tight in beam direction.



Flexible chains on top of calorimeter end cap

HGTD back-end electronics is located in USA15 service cavern.

All cables and fibers, except HV cables, are routed though various flexible chains.

CO2, N_2 gas and water pipes, as well as part of HV cables installed in short flex chains.

Stage 2 LV PS and HV filter boxes are located on calorimeter end cap surface on HO side (PP-EC area). LV PS are accessible in run configuration.