ATLAS & CMS TIMING DETECTORS

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Institute of High Energy Physics

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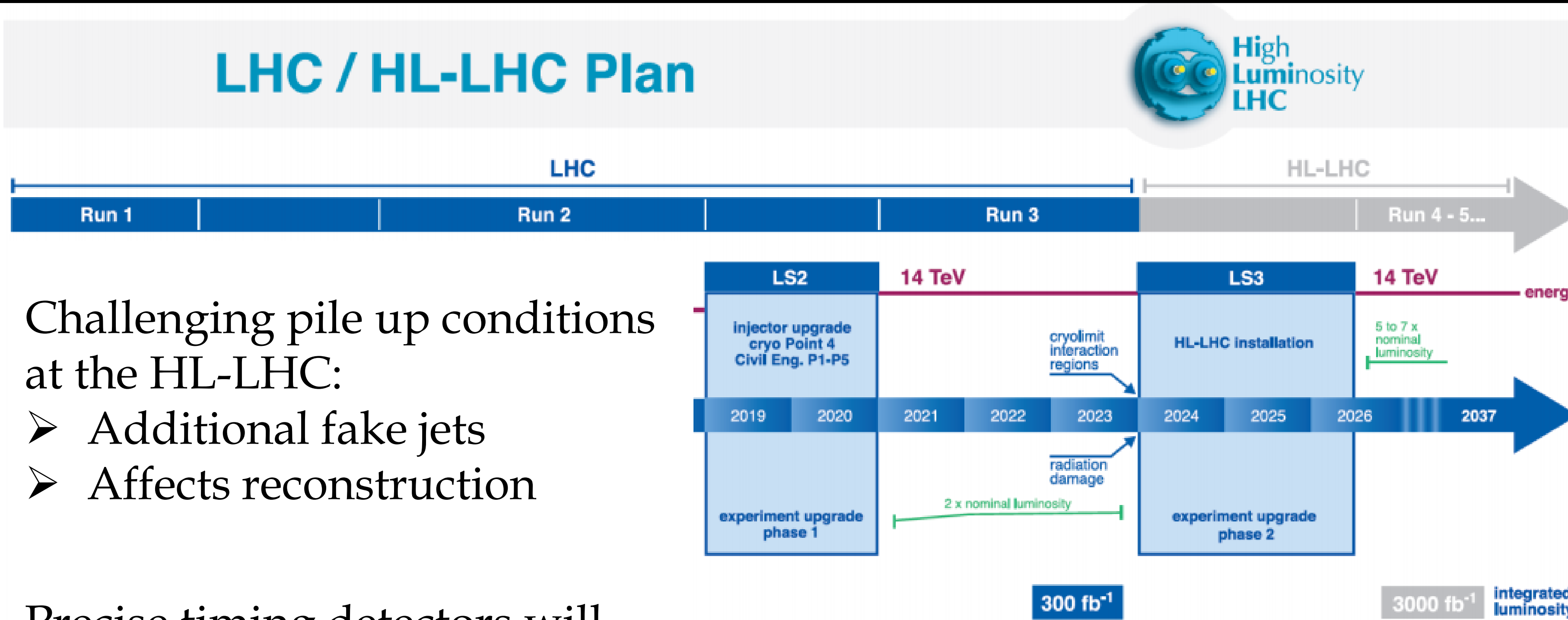
Institute of High Energy Physics
Chinese Academy of Sciences

HL-LHC

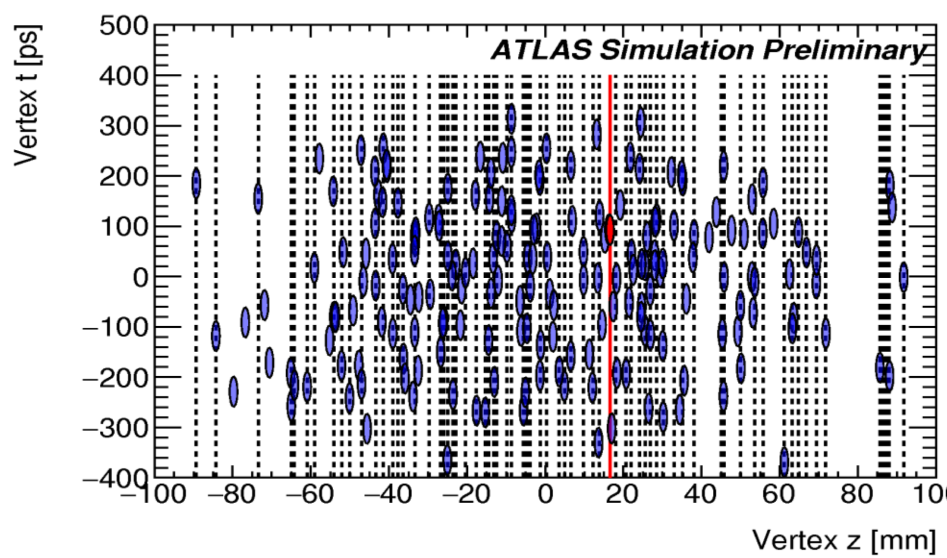


Challenging pile up conditions at the HL-LHC:

- Additional fake jets
- Affects reconstruction

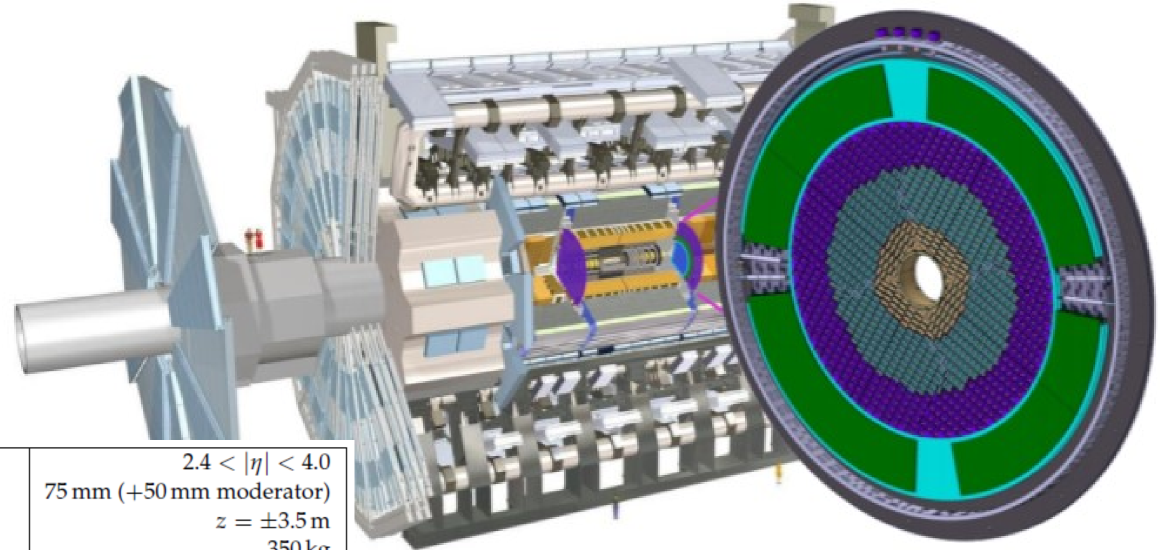
Precise timing detectors will provide time resolution:

- Resolve dense interaction environment with precision timing
- Improve track-to-vertex association

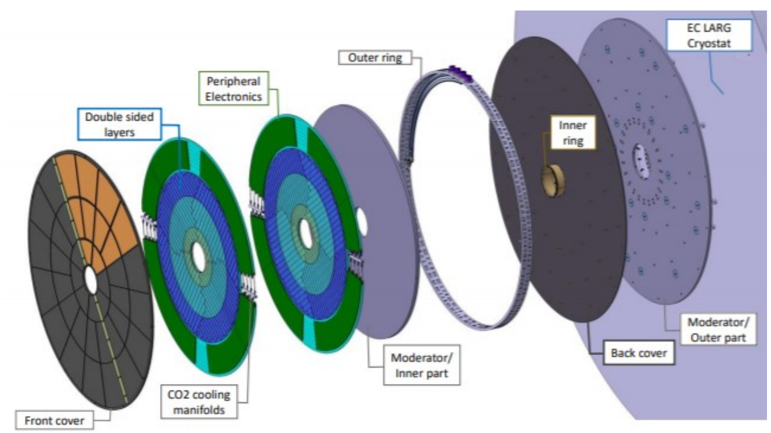


ATLAS: High Granularity Timing Detector (HGTD):

- Sensor: Large Gain Avalanche Detector (LGAD)
- ~35 (start) ~70 ps timing resolution
- ~ 2.5 x 10^{15} n_{eq}/cm^2 radiation tolerance



Pseudo-rapidity coverage	$2.4 < \lvert\eta\rvert < 4.0$
Thickness in z	75 mm (+50 mm moderator)
Position of active layers in z	$z = \pm 3.5$ 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	
$2.4 < \lvert\eta\rvert < 2.7$ (640 mm $> r >$ 470 mm)	≈2.1
$2.7 < \lvert\eta\rvert < 3.5$ (470 mm $> r >$ 230 mm)	≈2.5
$3.5 < \lvert\eta\rvert < 4.0$ (230 mm $> r >$ 120 mm)	≈2.7
Average time resolution per hit (start and end of operational lifetime)	
$2.4 < \lvert\eta\rvert < 4.0$	≈ 35 ps (start) ≈ 70 ps (end)
Average time resolution per track (start and end of operational lifetime)	≈ 30 ps (start) ≈ 50 ps (end)



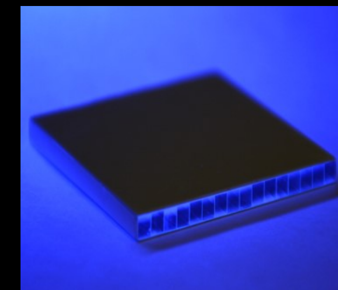
CMS PRECISION TIMING STRATEGY

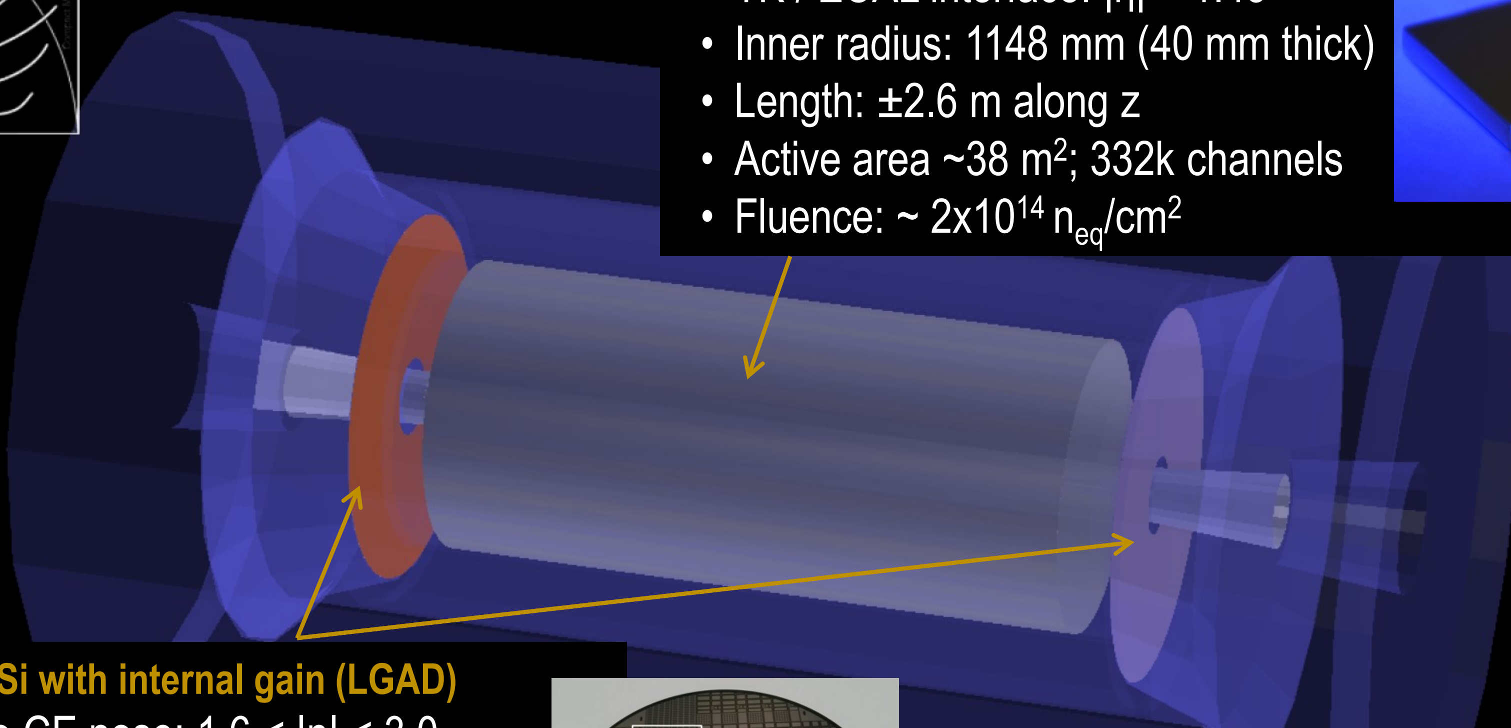
CMS: MIP Timing Detector (MTD)

Barrel Timing Layer (BTL)

Barrel: LYSO bars + SiPM readout

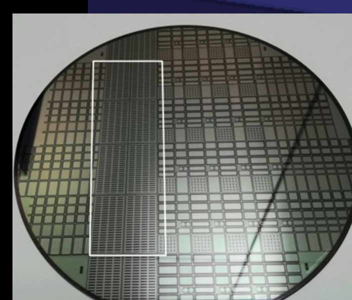
- TK / ECAL interface: $|\eta| < 1.45$
- Inner radius: 1148 mm (40 mm thick)
- Length: ±2.6 m along z
- Active area ~38 m^2; 332k channels
- Fluence: ~ 2×10^{14} n_{eq}/cm^2





Endcaps: Si with internal gain (LGAD)

- On the CE nose: $1.6 < |\eta| < 3.0$
- Radius: 315 < R < 1200 mm
- Position in z: ±3.0 m (45 mm thick)
- Active area ~14 m^2; ~8.5M channels
- Fluence: up to 2×10^{15} n_{eq}/cm^2

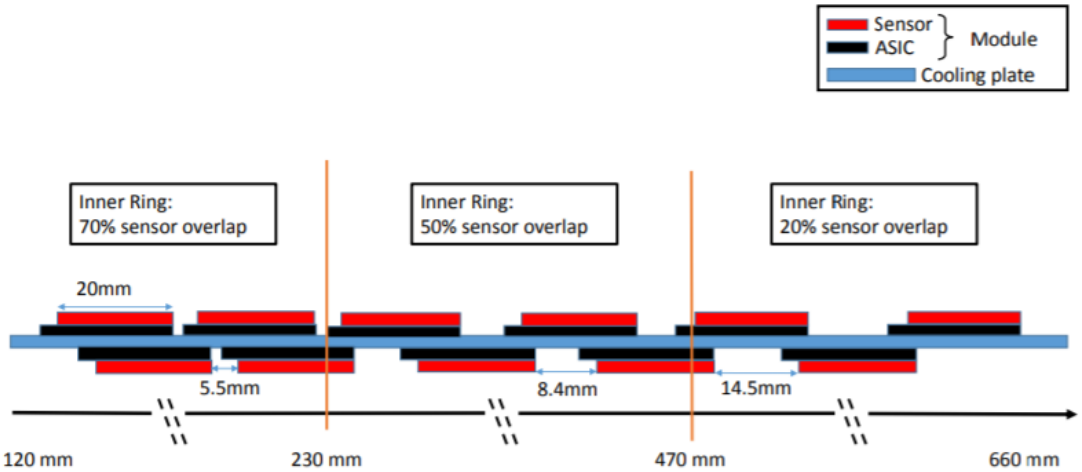


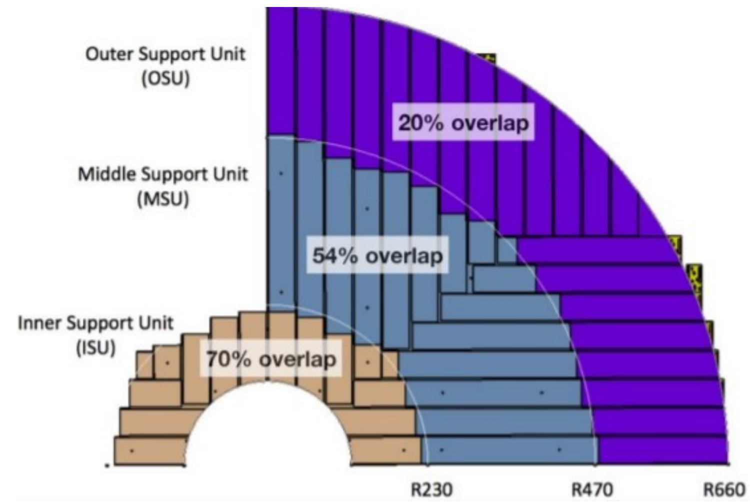
MIP sensitivity with time resolution of 30 ps at HL-LHC start and <60 ps at 3 ab-1

Endcap Timing Layer (ETL)

ATLAS HGTD LAYOUT

- Three rings layout optimised for timing performance and cost
- Module overlap has been optimised for uniformity
- Disk rotation in opposite direction (15-20) to avoid gaps and maximize the hit efficiency
- Each cooling/support disk is separated in two half circular disks
- Support unit made of carbon fibre ensures exact module position and alignment of x and y readout row





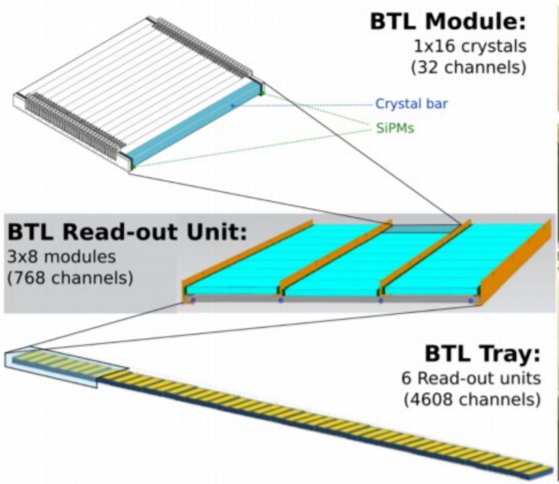
CMS MTD LAYOUT

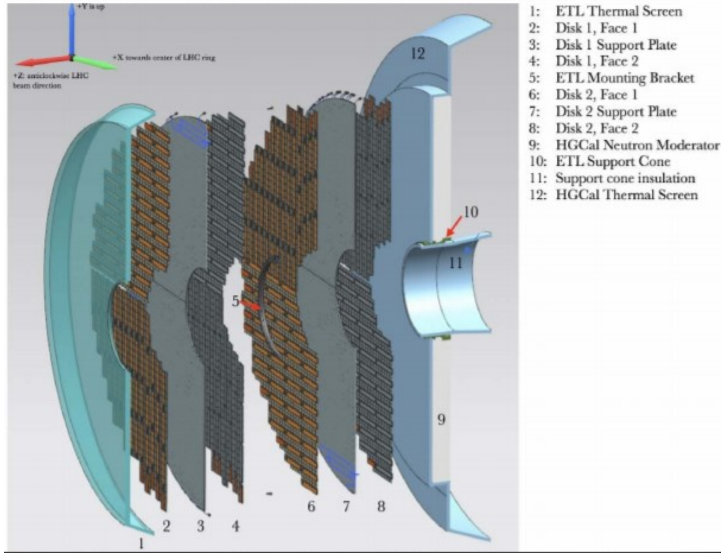
BTL layout:

- Detector mounted on the inner surface of the Tracker Support Tube share services and schedule with tracker
- Single layer, 40 mm thick, segmented into 72 trays
- Each tray consists of 6 Readout Units with 24 modules each

ETL layout:

- Double mounted on the endcap calorimeter.
- Sensor modules on two sides of support disk.
- Services run across modules in service channels to periphery.
- Separate cold volume.

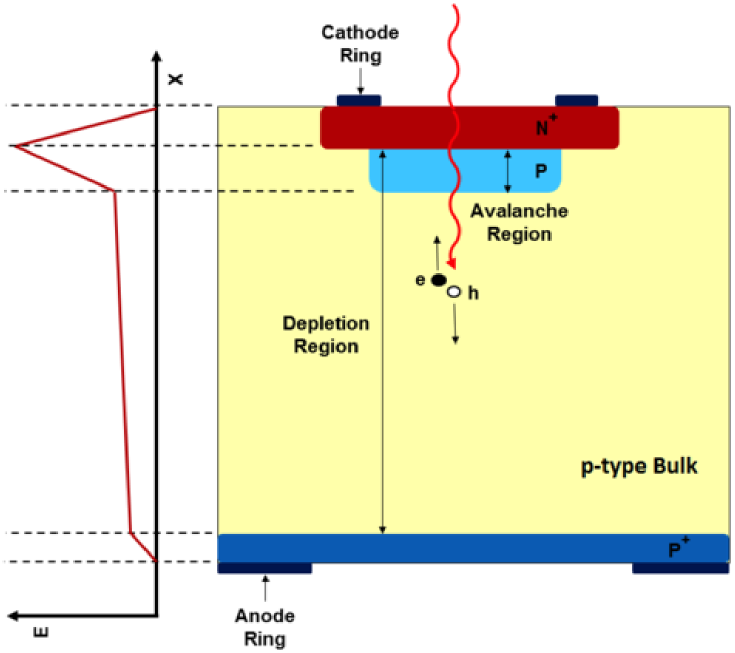


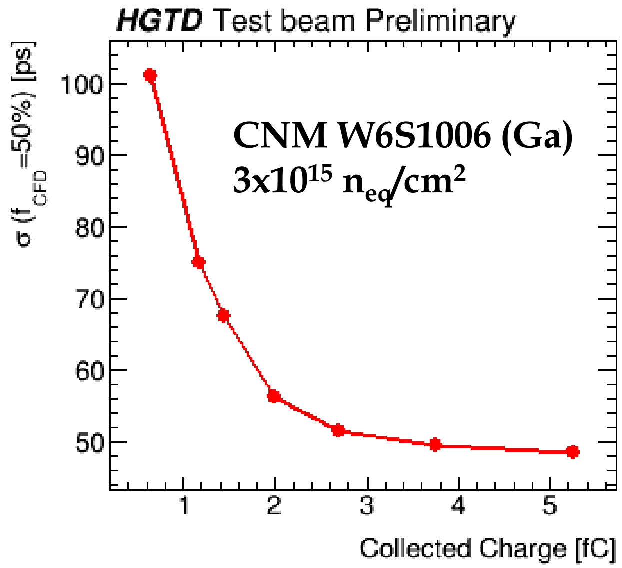


SENSORS

LGAD sensors:

- Baseline sensor technology for ATLAS HGTD and CMS ETL.
- n-p silicon planar detector + multiplication layer that amplifies the signal
- High E field
- Moderate internal gain (10-50)
- Excellent time resolution ~30 ps before irradiation
- New doping materials, substrates and new geometries being studied.
- Prototypes tested from CNM, HPK, BNL, FBK

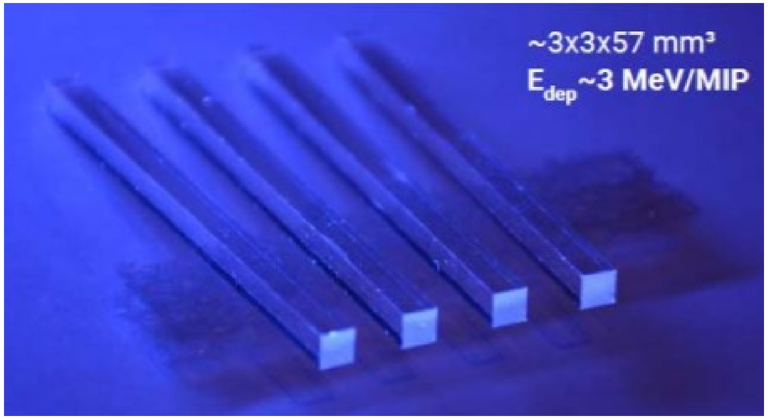




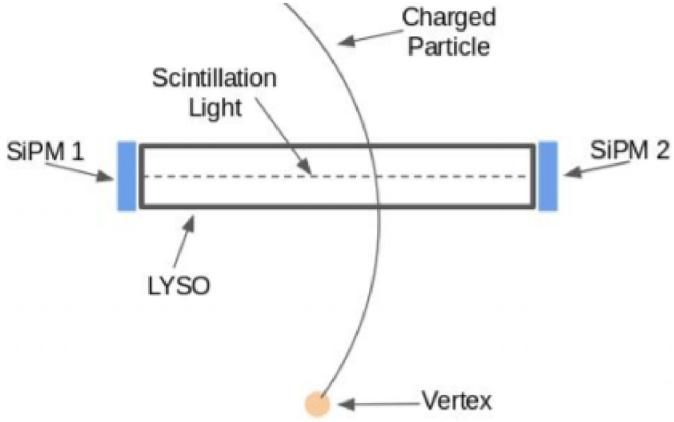
SENSORS

CMS BTL:

- Cerium doped Lutetium based scintillation crystals (LYSO):
  - Excellent radiation tolerance
  - Density (7.1 g/cm3), bright (40k ph/MeV)
  - Fast rise time O(100ps), decay time ~40 ns
- Silicon Photomultipliers as photo-sensors:
  - Compact, insensitive to magnetic fields, fast
  - Optimal SiPM cell size : 15 mμ
  - High dynamic range, rad tolerant
  - Photo Detection efficiency : 20-40%



3x3x57mm LYSO crystal bars with two 3x3mm SiPMs glued at each end



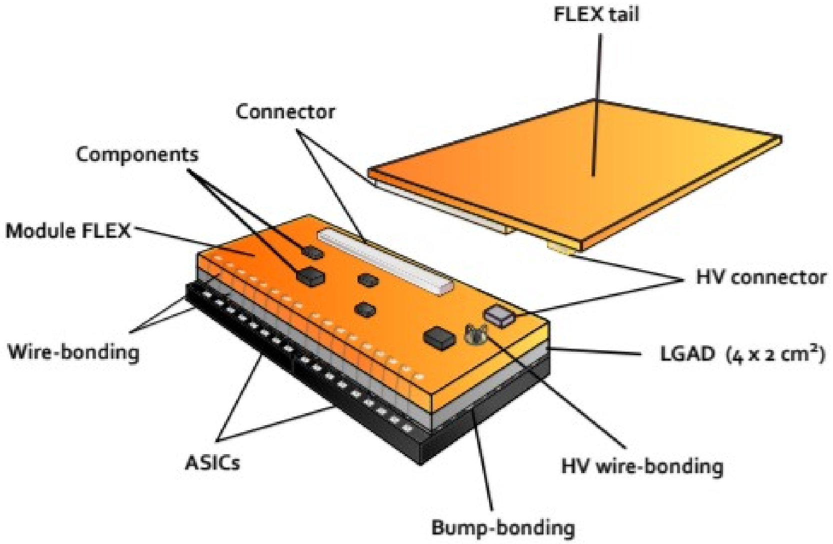
HGTD MODULE

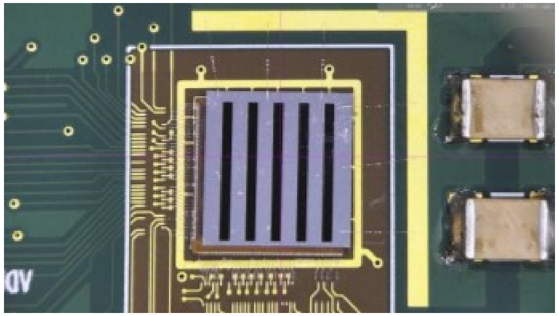
Flexible printed circuit board:

- Bare module glued to small flex
- Routing all connections between ASIC and peripheral on-detector electronic
- Signal lines wire bonded to two ASIC
- 2 layer design with 220 μm thickness

ALTIROC front-end ASIC:

- Radiation hardness ~2 MGy
- Target time resolution ~25 ps
- Latency up to 35 μs @ 1 MHz trigger
- Low power dissipation
- 15x15 channels (pixels)
- I²C link for slow control
- PLL and phase shifter
- Time over threshold (ToT) and Time of Arrival (ToA) information
- Bunch-by-bunch luminosity data in a separate stream





5x5 LGAD sensor bump-bonded to ALTIROC1

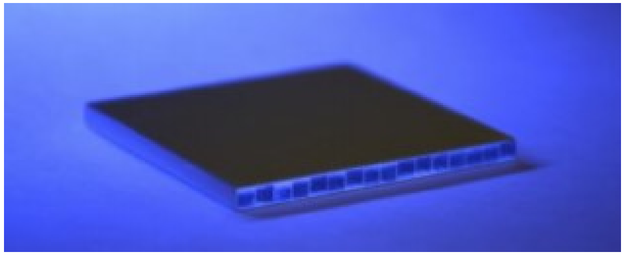
CMS BTL AND ETL MODULES

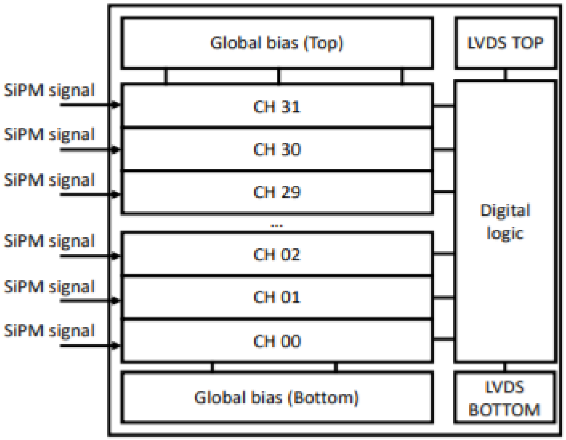
BTL module:

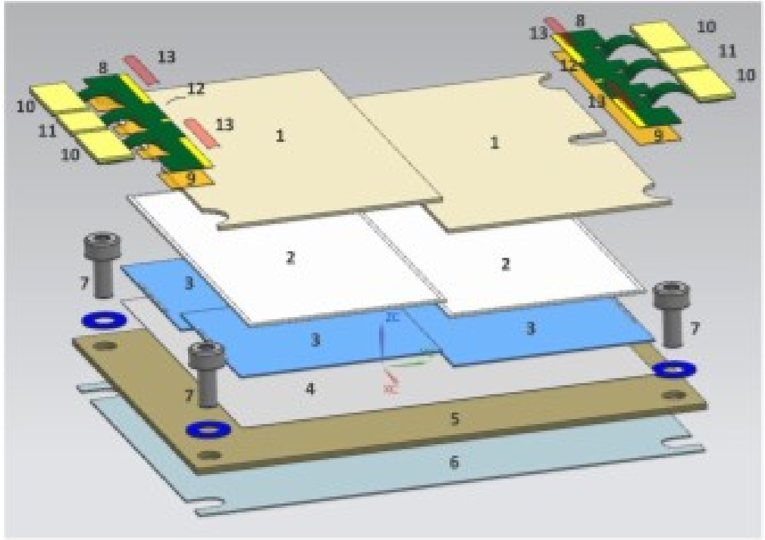
- ➢ 16 LYSO bars + 2 SiPM arrays
- ➢ TOFHIR front end ASICs
  - 32 channels
  - Time-to-digital converters ~25 ps
  - Charge-to-digital converters

ETL module:

- ➢ Bare modules laminated to an AlN substrate
- ➢ Flex lines wire bonded to the ASICs
- ➢ ETROC front-end ASIC
  - 16×16 channels (pixels)
  - 65 nm technology
  - ASIC contribution to time resolution < 40ps





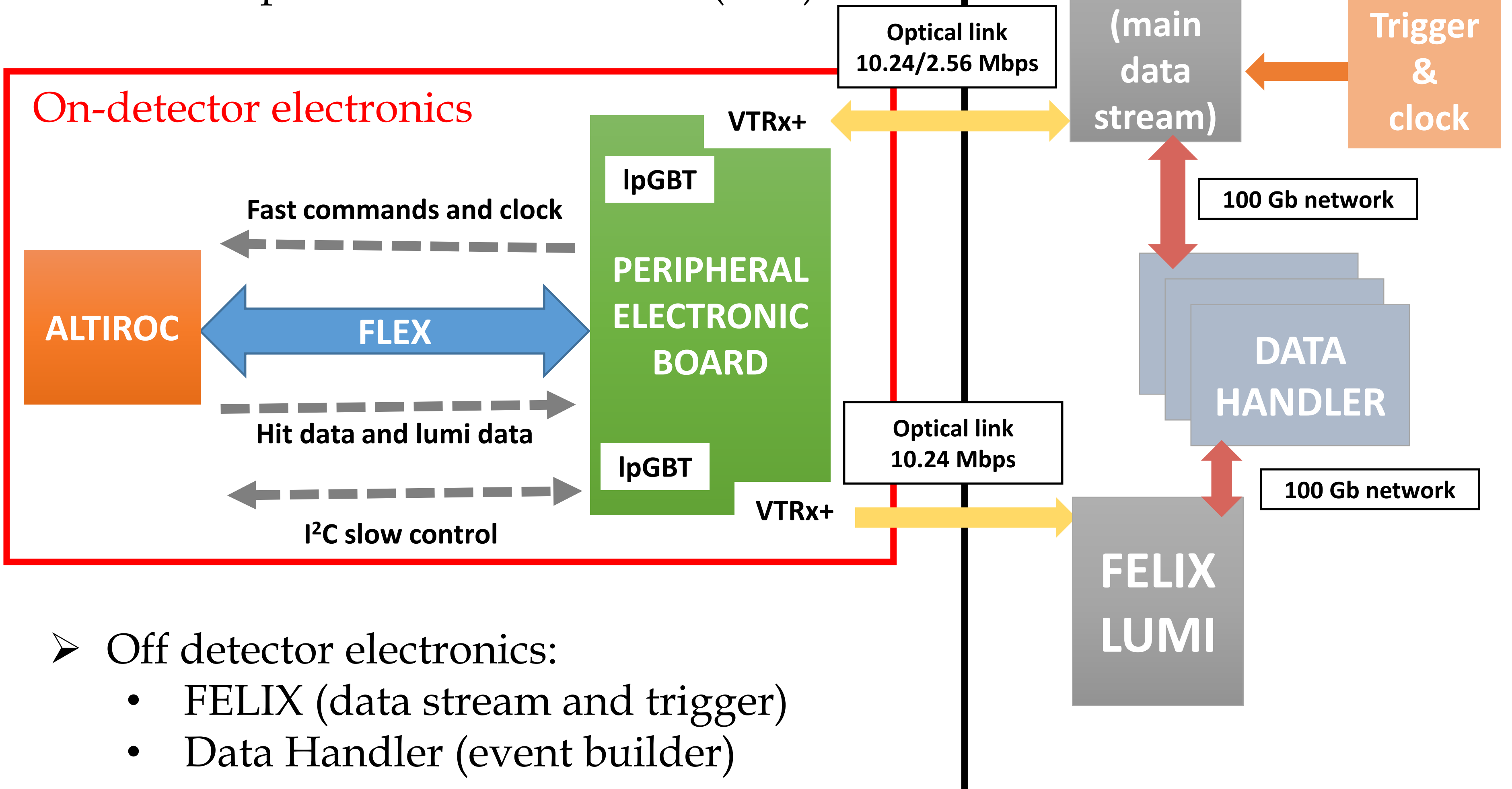


1: AlN module cover
2: LGAD sensor
3: ETL ASIC
4: Mounting film
5: AlN carrier
6: Mounting film
7: Mounting screw
8: Front-end hybrid
9: Adhesive film
10: Readout connector
11: High voltage connector
12: LGAD bias voltage wirebond
13: ETROC wirebonds

ATLAS HGTD READOUT CHAIN

HGTD readout system:

- On detector electronics:
  - Front-end ASIC (ALTIROC)
  - Peripheral electronic board (PEB)

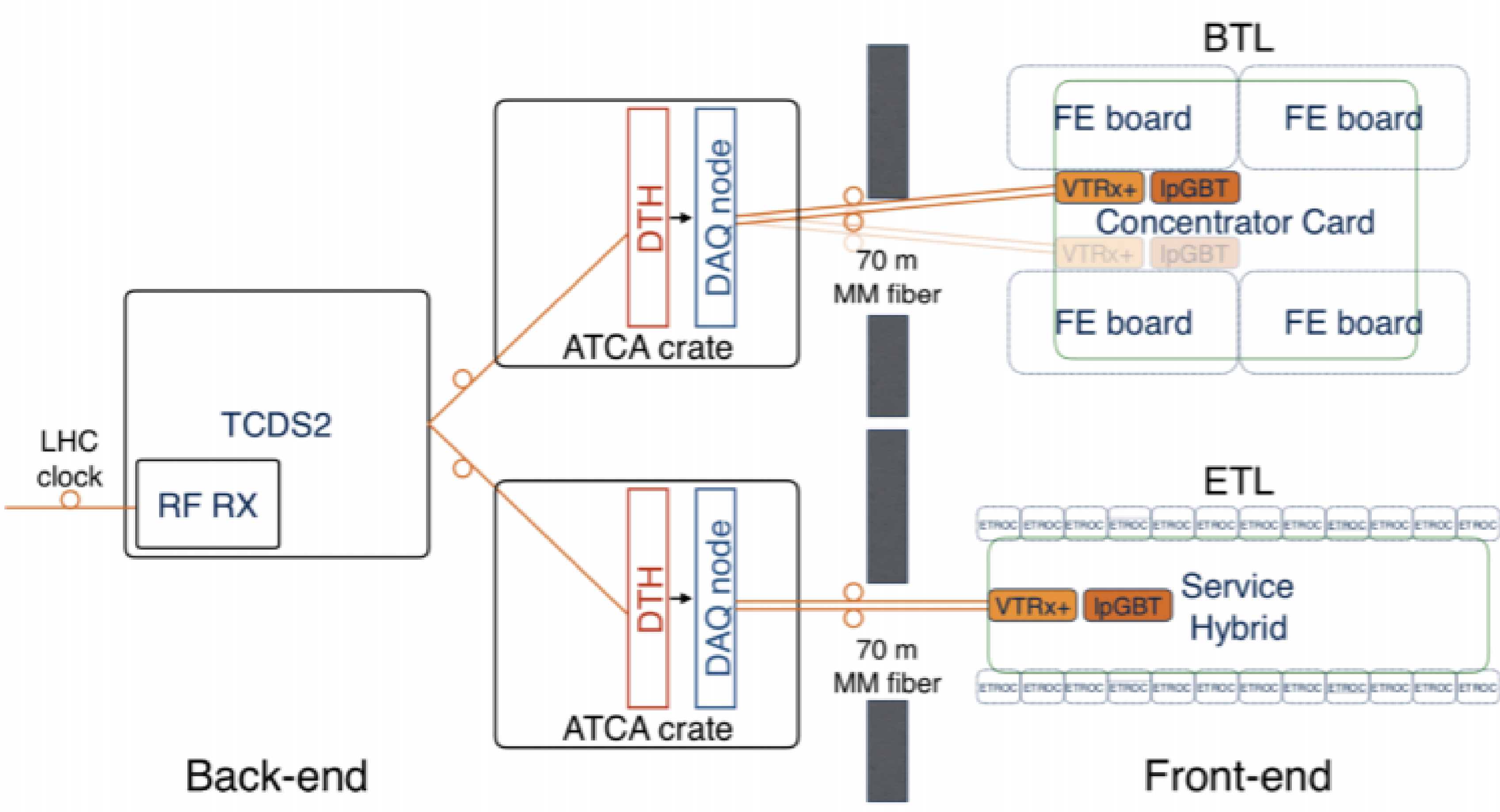


- Off detector electronics:
  - FELIX (data stream and trigger)
  - Data Handler (event builder)

CMS MTD READOUT CHAIN

Off-detector electronics:
- DAQ node boards
- DTH board (timing)

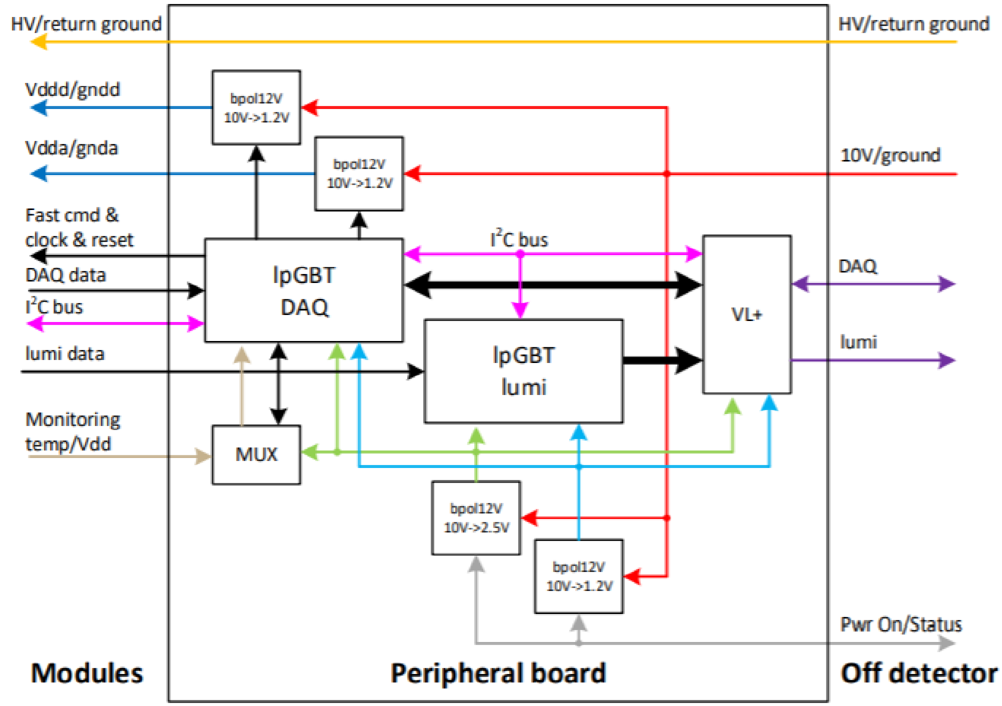
On-detector electronics
- BTL: Concentrator card
- ETL: Hybrid boards

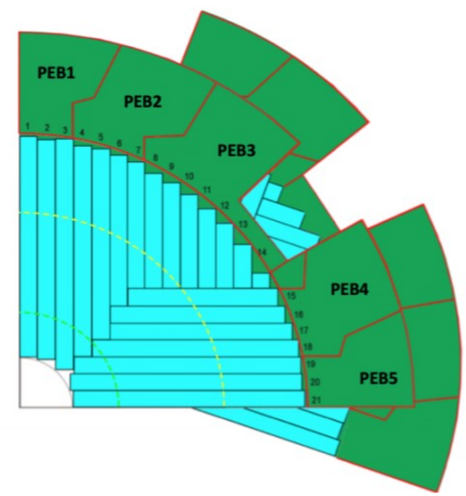


ATLAS HGTD ON-DETECTOR ELECTRONICS

Peripheral electronic board:

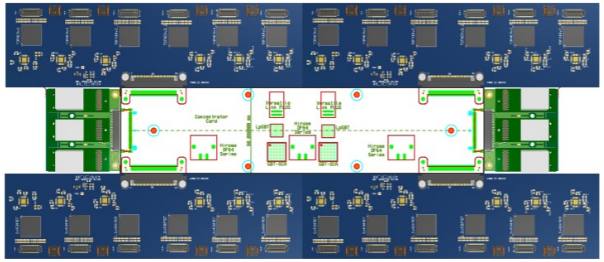
- bpool12VDC-DC converter
- Low power GigaBit Transciver (lpGBT)
- LV and HV services
- I²C bus for slow control and module configuration
- Versatile link Plus (VTRx+): 2.56 and 10.24 Gbps (down/up-link)
- E-link speed 320, 640 and 1280 Mbps (up-link) and and 320 Mbps (down-link)



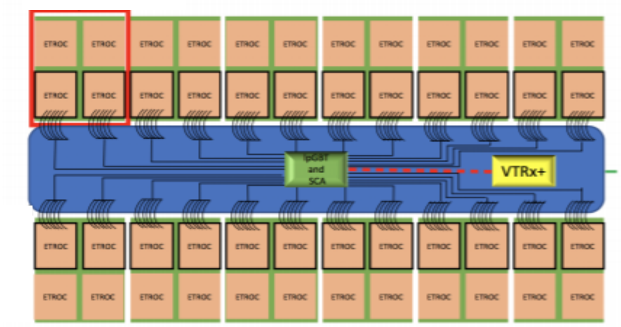


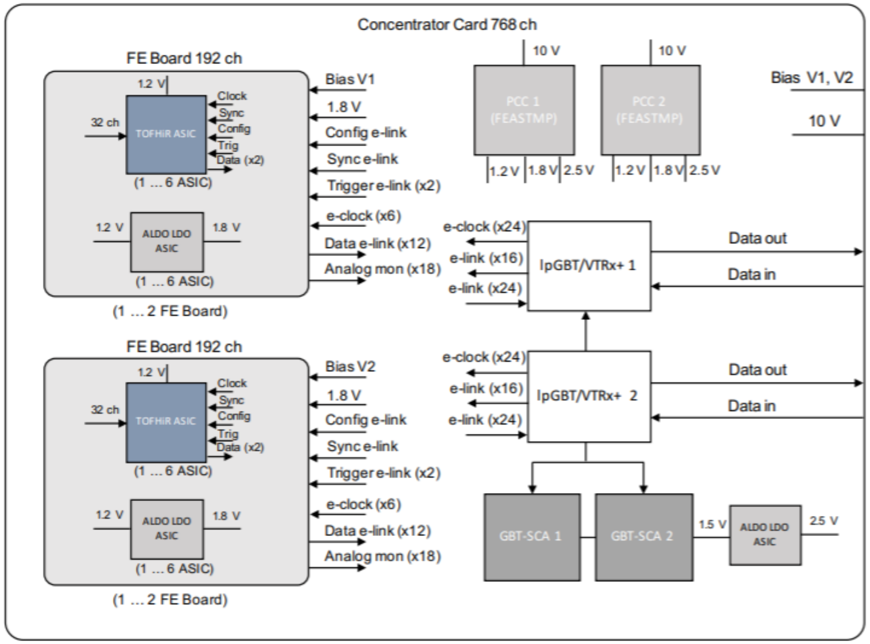
CMS MTD ON-DETECTOR ELECTRONICS

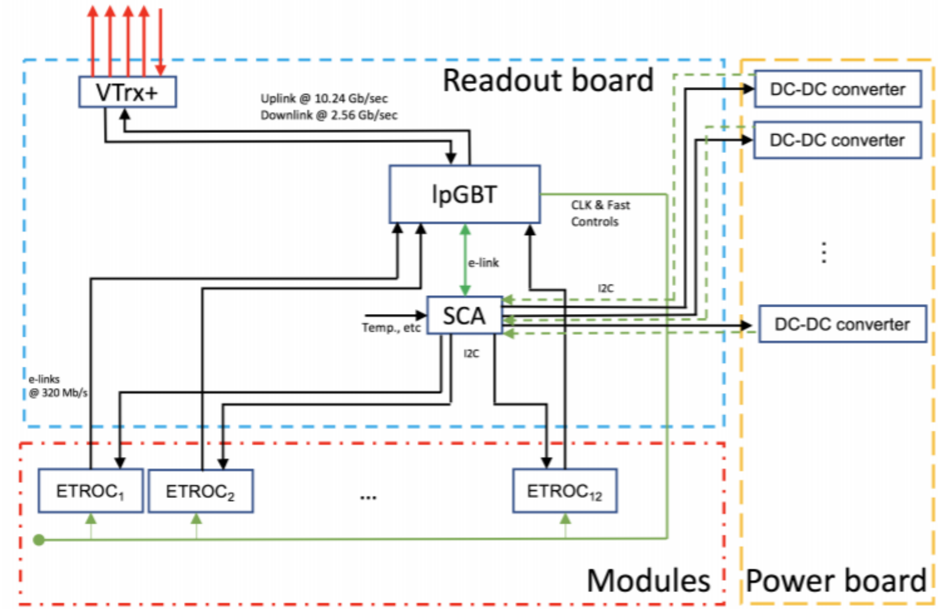
BTL concentrator card:
- Power Control Converter (DC-DC) cards
- GBT-SCA chip for slow control
- lpGBT
- VTRx+



ETL hybrid boards:
- DC-DC converter
- SCA chip for slow control
- lpGBT
- VTRx+



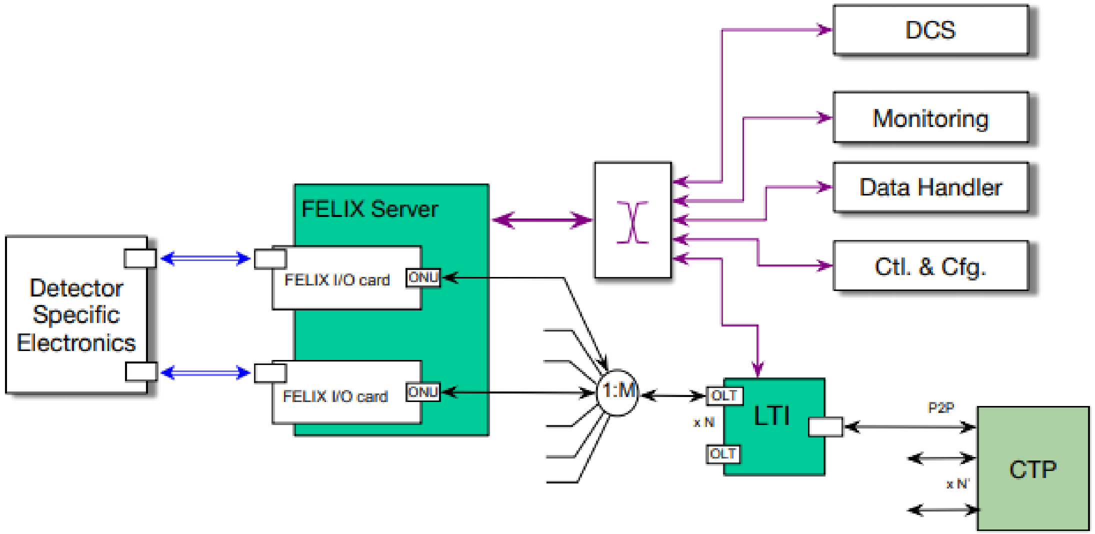


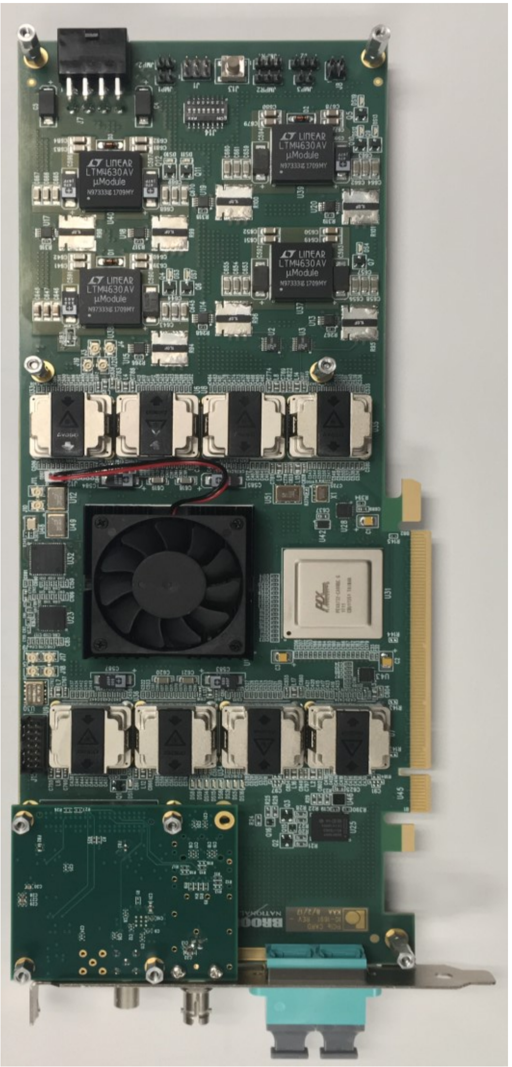


ATLAS HGTD OFF-DETECTOR BACKEND

The FELIX (Front End LInk Exchange) board will be common to all ATLAS phase-II detectors and it will interface with most of the ATLAS systems:

- Data Handler → Event builder
- Detector Control System (DCS): LV current, temperature,…
- Timing, trigger and control
- On-line monitoring

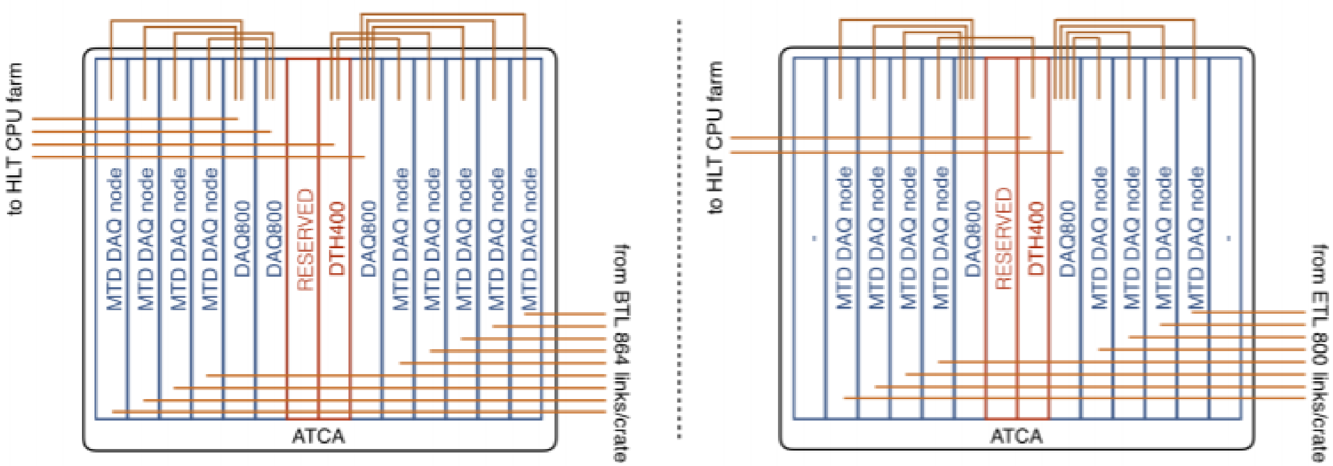


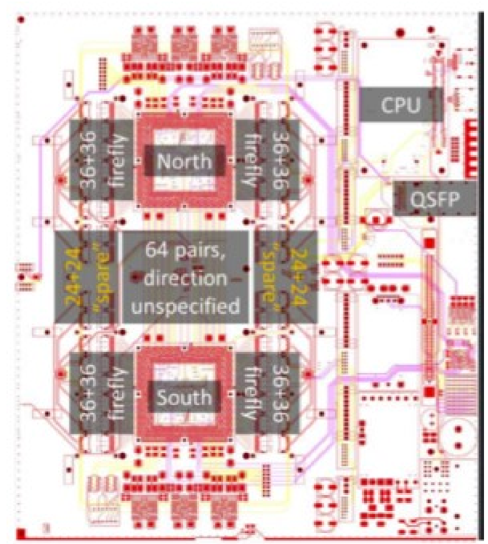


CMS MTD OFF-DETECTOR BACKEND

Based on advanced telecommunications architecture (ATCA) with centrally defined CMS specifications:

- The interface to the central Timing and Control and DAQ systems is provided by the data trigger hub (DTH400) and additional data bandwidth to the DAQ system is provided by a DAQ800 board.
- Unpacking and processing of the data received from the front-end will be accomplished by the MTD back-end (Serenity) boards positioned in node slot

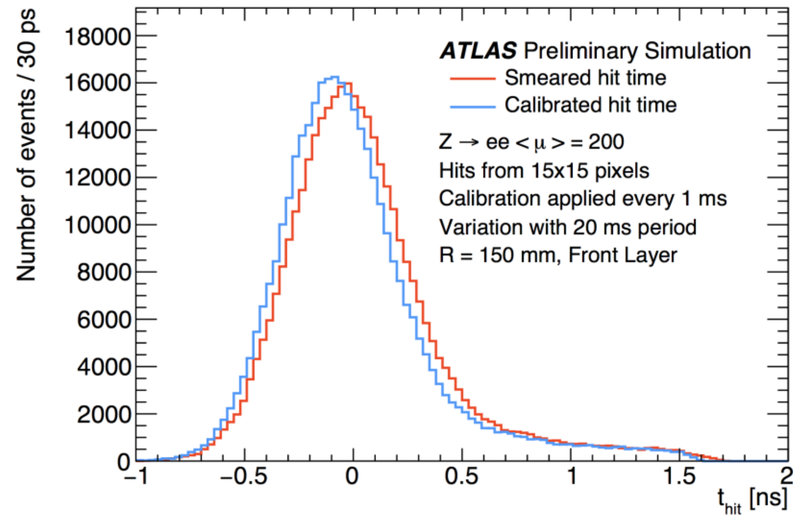


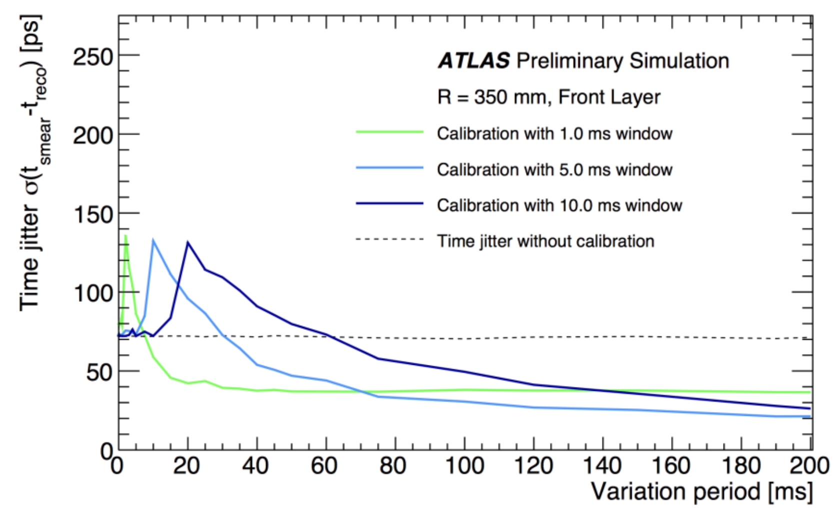


Serenity board

ATLAS HGTD TIMING CALIBRATION

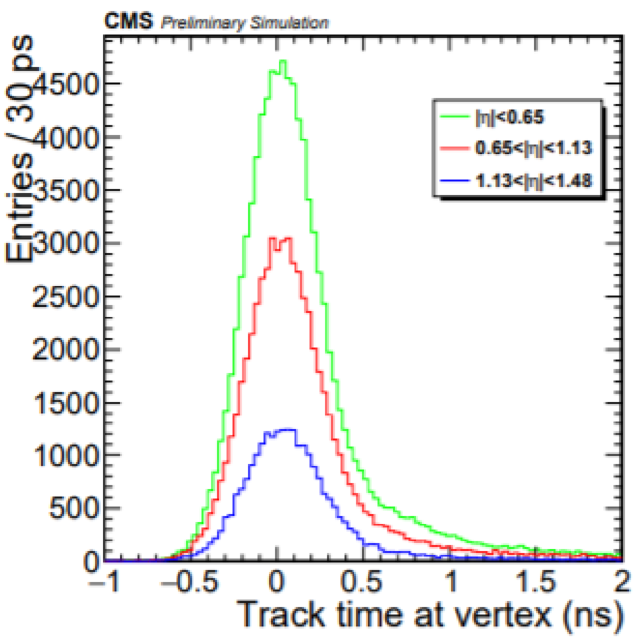
- Static and dynamic contributions to the clock can affect the time resolution of the detector:
  - Static: time-of-flight, non-uniform clock propagation paths within an ASIC.
  - Dynamic: high-frequency jitter, noise in the flex cables, and low frequency day/night temperature changes
- On-line measurement of the average hit time per ASIC at a high trigger rate in the back-end electronics to take into account dynamic contributions.
- The hit time will be averaged during ~20 ms and later on the correction will be applied offline.

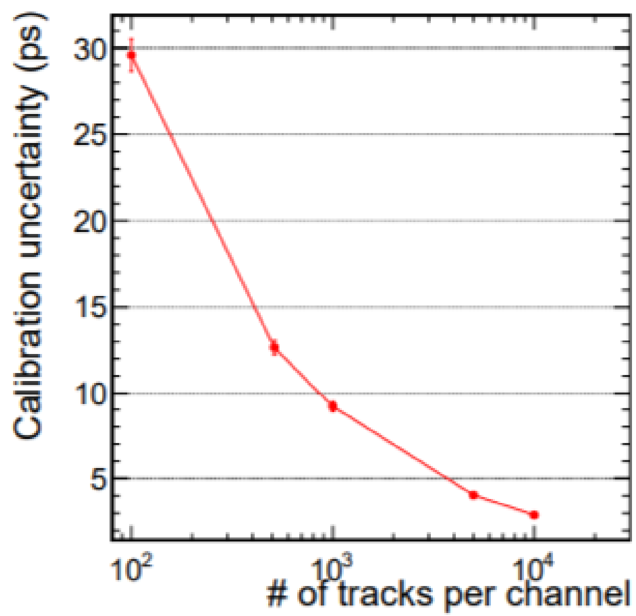




CMS MTD TIMING CALIBRATION

- The time offsets of the MTD channels can be inter-calibrated using all the tracks collected by the CMS high level trigger.
- At 1 kHz high level trigger rate, 1000-10000 tracks per channel (BTL) will be collected in around 20 or 200 s, providing the possibility of frequent and granular calibrations.
- These calibration constants can be made available for the prompt reconstruction of the events and thus applied offline.





CONCLUSIONS

- ATLAS and CMS upgrade for HL-LHC foresees novel precision timing detectors with target 30-50 ps time resolution per track.
- Novel LGAD sensors are the baseline technology for ATLAS HGTD and CMS ETL while LYSO and SiPM is the baseline technology for CMS BTL.
- On-detector electronics will be based on common lpGBT and VTRx+ electronics for phase-II upgrade. Dedicated front-end ASICs ALTIROC (HGTD), ETROC (ETL) and TOFHIR (BTL) are under development.
- Off-detector back-end will be based on common FELIX boards for ATLAS HGTD while common (DTH and DAQ800) CMS boards and dedicated DAQ nodes will be used for MTD.
- CMS MTD Technical Design Report was recently (2019) approved.
- ATLAS HGTD Technical Design Report is currently under the approval process.

Thank You