# Status and Perspectives for ATLAS HL-LHC Upgrade Program

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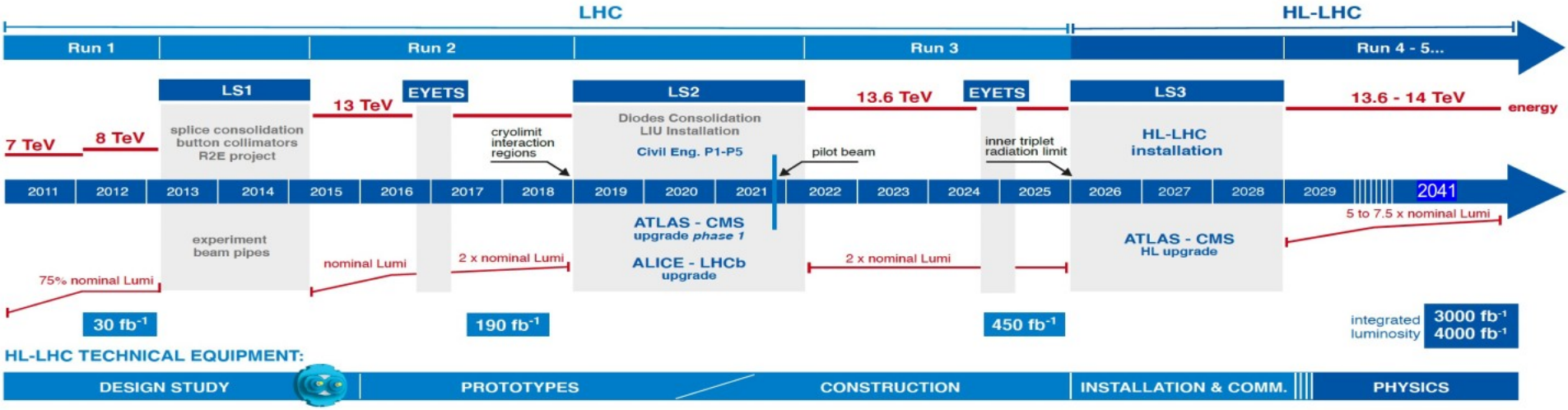
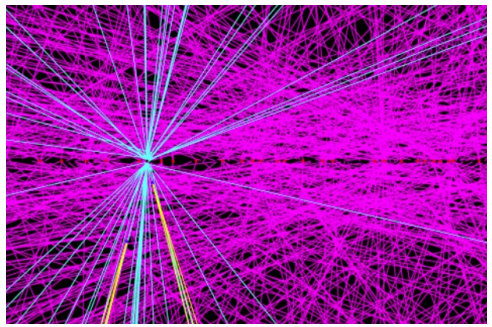
On behalf of the **ATLAS Collaboration**

# The High Luminosity LHC



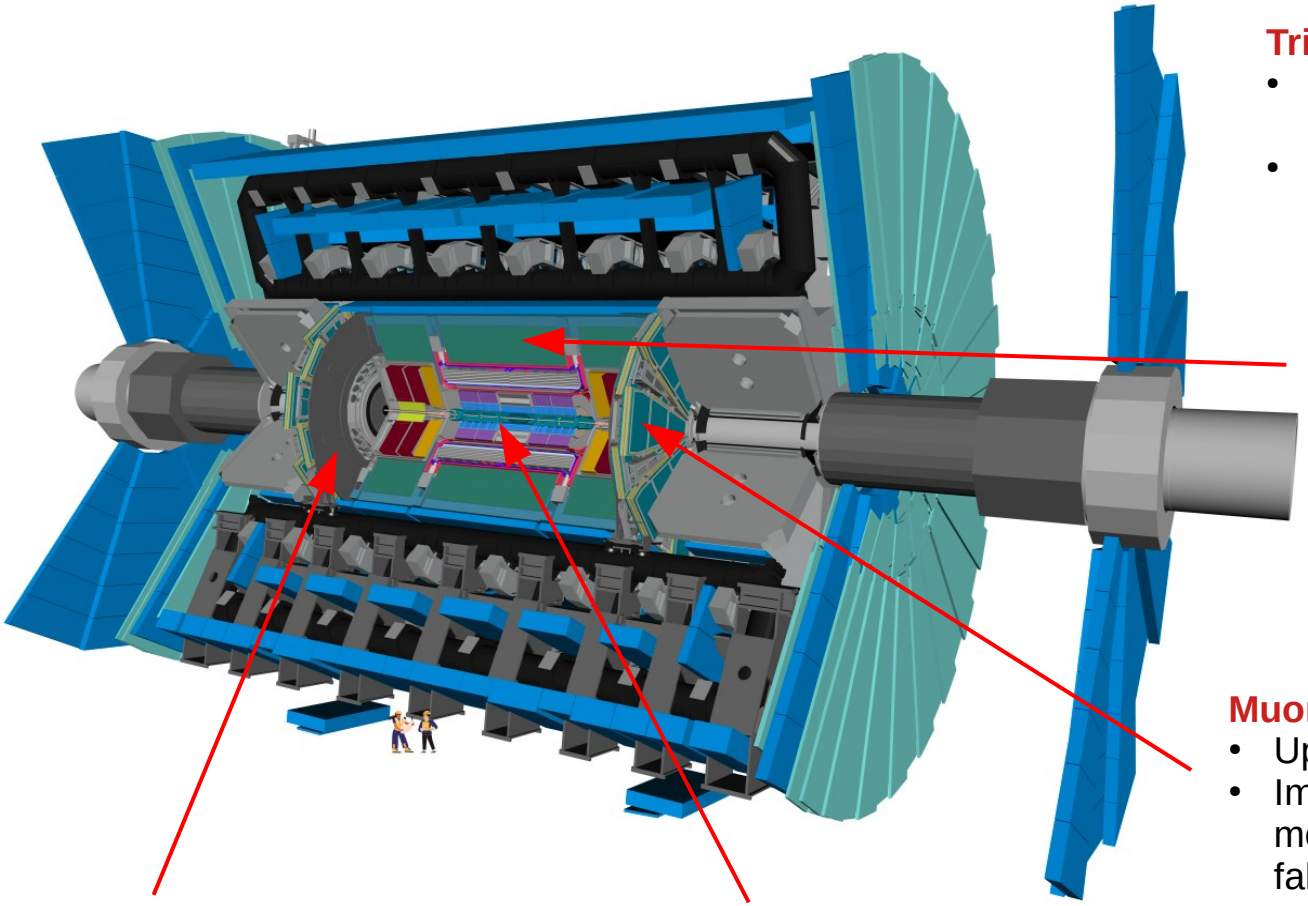

- LHC and its experiments have produced many results (see talks in this and future sessions)
- LHC accelerator periodically upgraded to keep exploring the energy frontier...
- The “HL-LHC” period will start in ~2029 with ~5 times the nominal luminosity
- This will increase the pile up from current μ~50 to μ=200
- Need to **upgrade ATLAS experiment** to deal with more radiation damage, more “messy” events...

LHC event

HL-LHC simulation

# ATLAS Upgrade Overview



**Trigger and DAQ Upgrade**
- Single level Trigger with 1MHz output (x 10 current)
- Improved system with faster FPGAs

**Calorimeter Electronics**
- On-detector electronics upgrades of LAr and Tile Calorimeters
- Provide 40 MHz readout for triggering

**Muon Detector**
- Upgrade of inner barrel chambers
- Improve trigger efficiency and momentum resolution, and reduced fakes

**High Granularity Timing Detector**
- Precision track timing (30 ps)
- Improve pile-up rejection in the forward region

**New Inner Tracker (ITk)**
- All silicon with 9 layers up to |η|=4
- Less material finer segmentation
- Improve vertexing, tracking, b-tagging

*See talk of C. Luci on phase-I Upgrades*

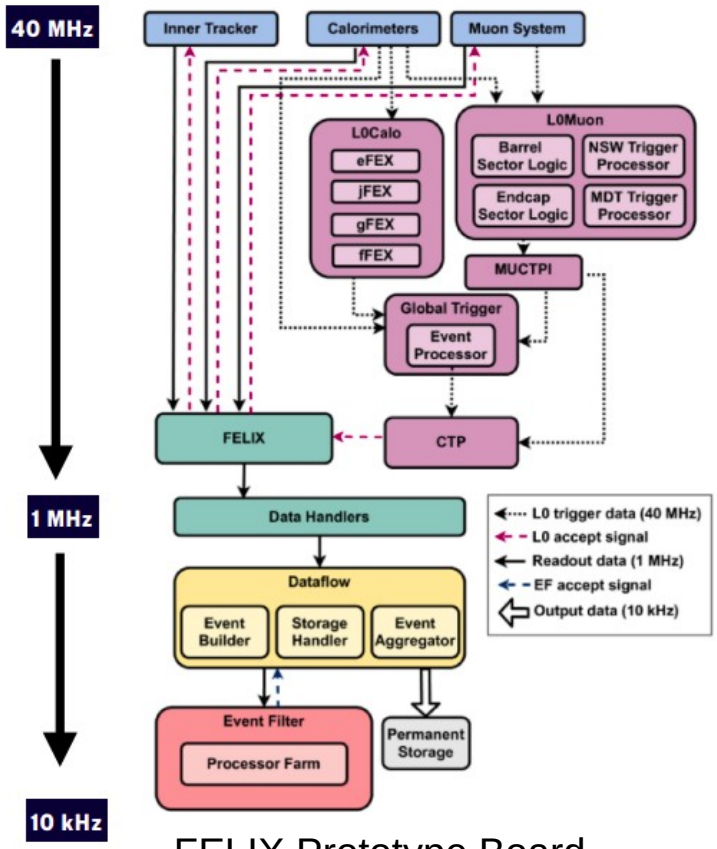
# Trigger and DAQ Upgrade

**Trigger:**

- Trigger data input at 40 MHz
- Level-0: Rate 1 MHz, latency 10 μs
- Software based Event Filter: Rate 10 kHz
- Exploits full detector granularity and extended tracking range, improves muon trigger efficiency
- For the Event Filter use COTS hardware, either pure software solution, or GPU or FPGA card acceleration (under evaluation).

**DAQ:**

- Unified backend electronics based on custom PCIe FPGA cards (FELIX) instead of VME-based readout boards




FELIX Prototype Board


https://doi.org/10.1016/j.nima.2022.167994

# Calorimeter Electronics


Continuous readout at 40 MHz:
New on-detector and off-detector electronics

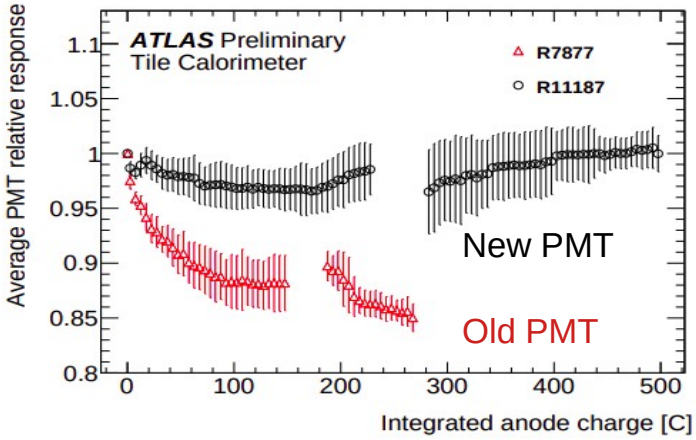
*See A. Gavriliuk talk in this conference*

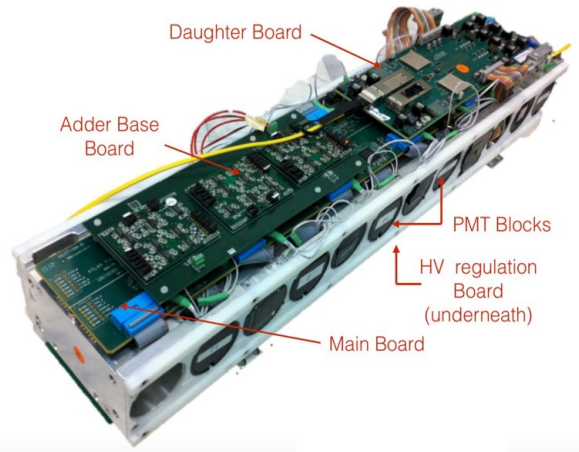
## Liquid Argon Calorimeter (LAr)

- Total bandwidth of 345 Tbps
- New high precision front-end electronics with a 16-bit dynamic range and 0.1% linearity
- ATCA boards for waveform feature extraction (E, time)
- New ASICS (ADC, calibration DAC & pulser)

## Tile Calorimeter:

- Replacement of the most exposed PMTs (about 10%).
- Replacement of passive PMT HV-dividers by active dividers for better response stability.
- On-detector electronics at advanced stage, production ongoing
- Phase-2 demonstrator installed (July 2019) in ATLAS and is taking data during Run 3



# Muon System

## Upgrade readout/trigger electronics

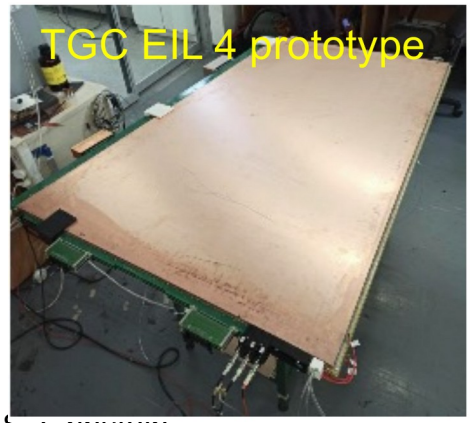
- all hit data is sent off detector to trigger logic boards with L0 trigger rate of 1 MHz

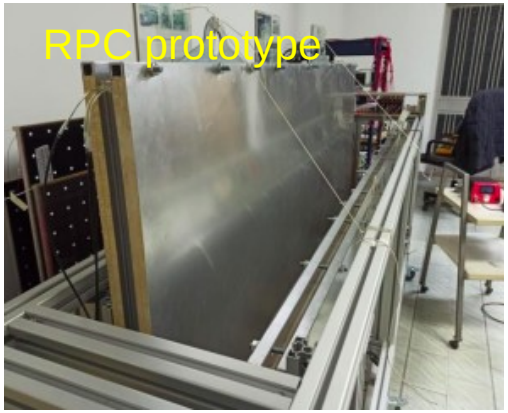
## Addition layers of sMDT, RPC, and TGC

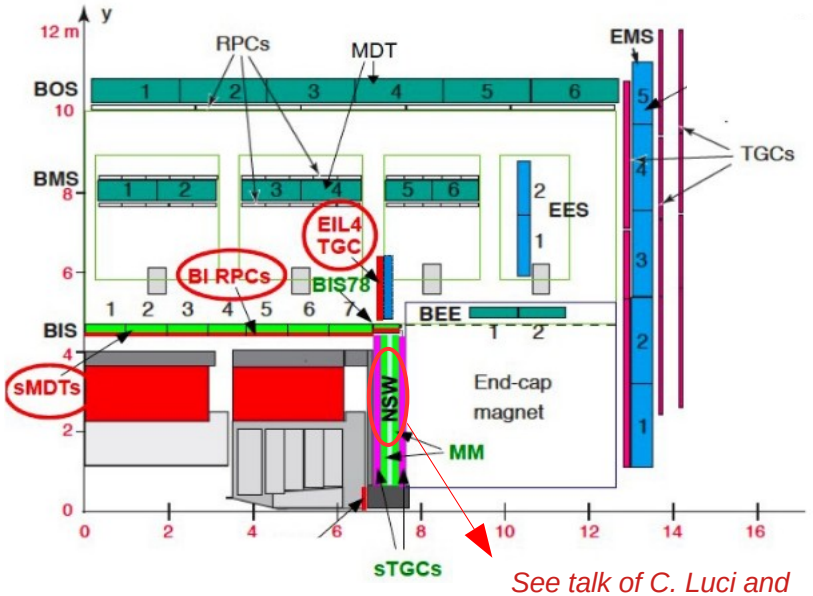
- Improve coverage, trigger uniformity & momentum resolution, reduce fake rates

## Current status

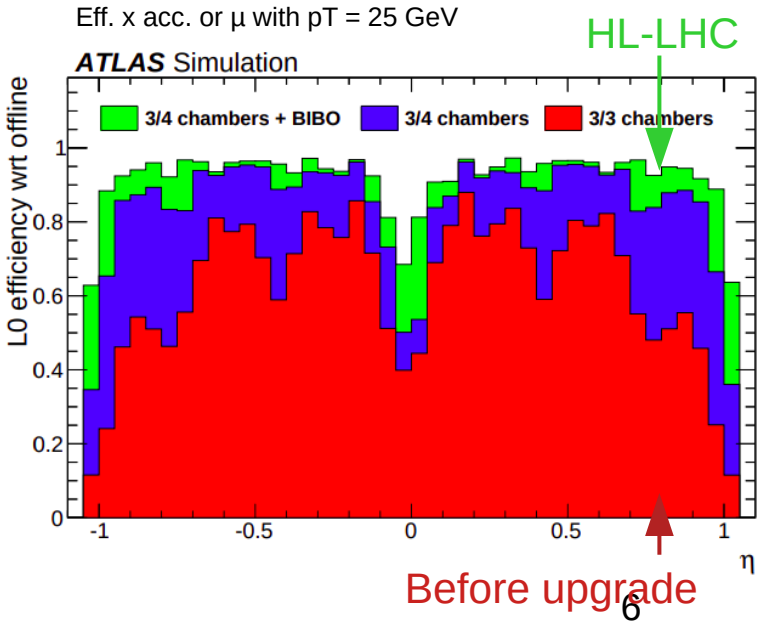
- sMDT: chambers in production, electronics pre-production
- RPC: FE prototypes submitted, prototype chamber nearly complete
- TGC: Triplet prototype completed, FE ASIC production complete



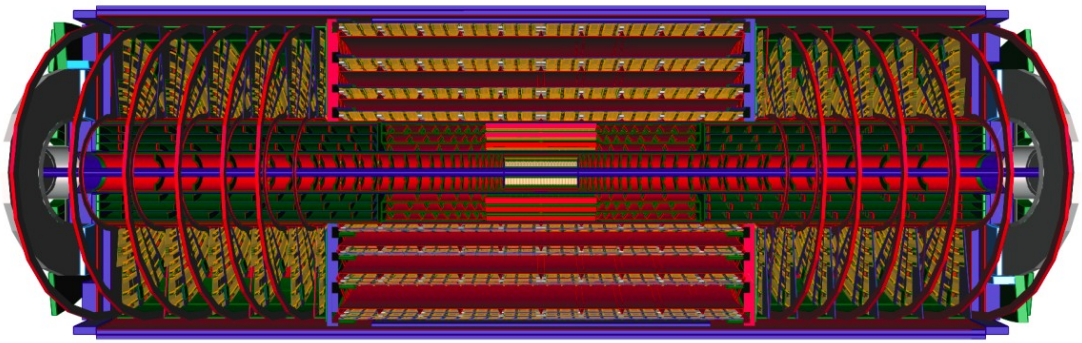



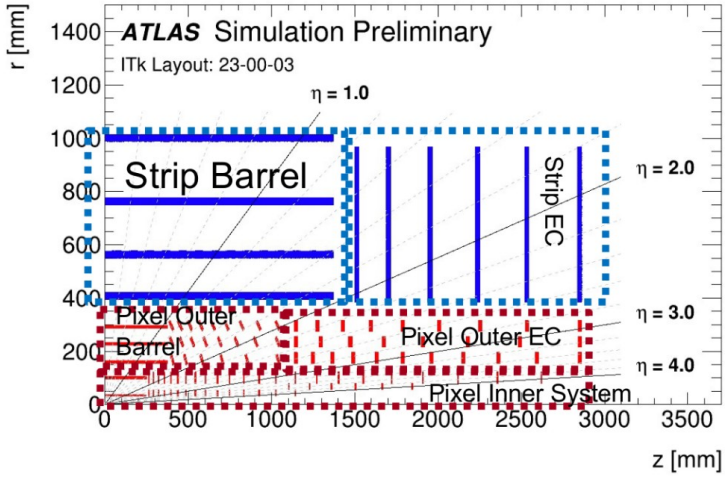




*See talk of C. Luci and S. Kabana*

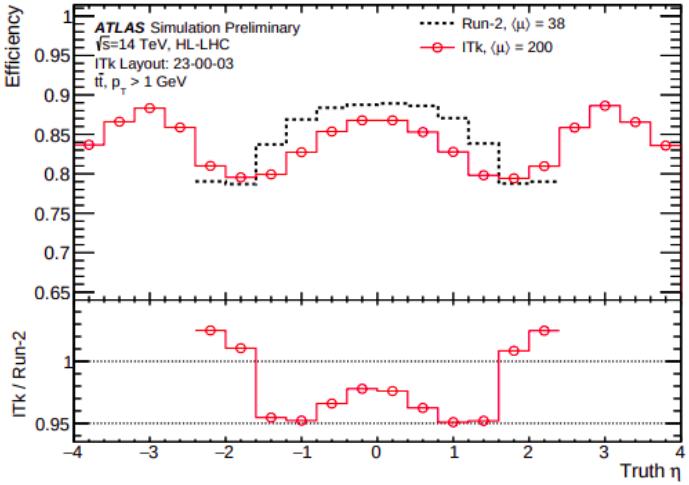


# Inner Tracker (ITk)






- Complete replacement of the current Inner Detector (Pixel, SCT, TRT) with **Silicon**-only system
- Pixel (Inner system, outer barrel, outer endcap, 13 $m^2$) and Strip detector (barrel, endcaps, 168 $m^2$)
- Eta coverage increases **from 2.5 to 4**
- Reduced material and finer segmentation
- At least 9 silicon hits per track
- Radiation tolerant up to **1E16 neq/cm²** (inner Pixel)




ATL-PHYS-PUB-2021-024

# ITk Pixel Detector

**General features:**

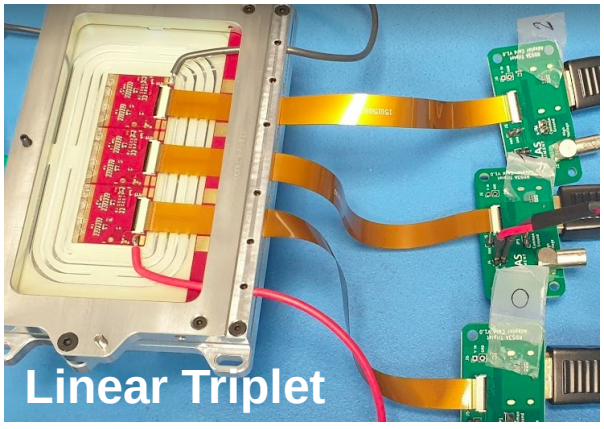
- Organized as three systems (inner, outer, outer endcaps)
- Five barrel-layers
- More than 5,000 M pixels, ~10 k modules
- Inner system replaceable (radiation damage)
- Serial powering
- Carbon fiber supports, thermal demonstrators

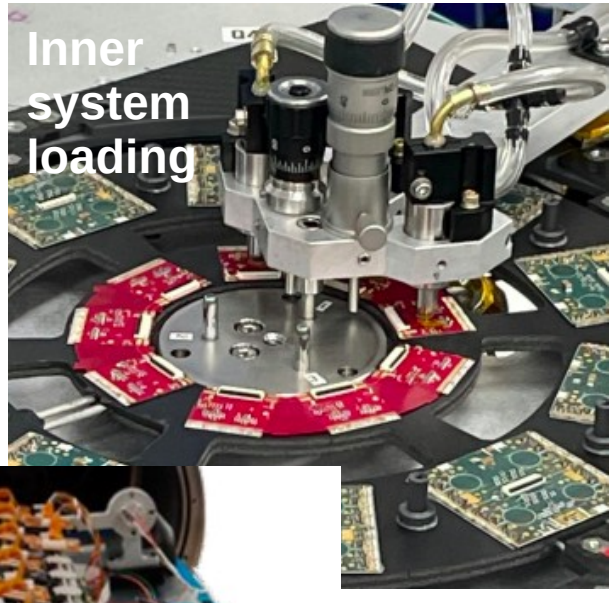
**Sensors:**

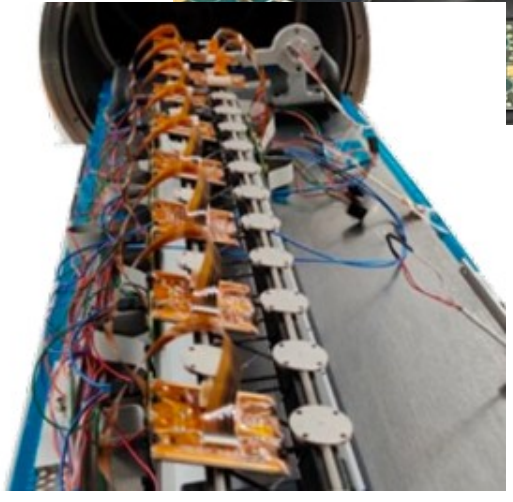
- Pixel sizes 25 x 100 $\mu m^2$ (innermost barrel) and 50 x 50 $\mu m^2$ (everywhere else)
- 3D sensors in innermost barrel/disks and planar sensors in the other layers
- 3 or 4 FE chips/module

**Production status:**

- All sensors are in pre-production
- Hybridization pre-production modules started
- ITkPixV2 readout chip has been submitted



Thermal studies

# ITk Strip Detector

## General features:

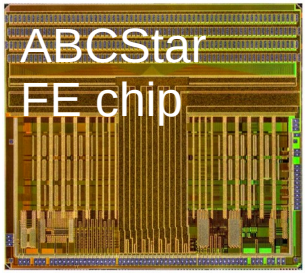
- Four-layer barrel and two six-disk endcaps
- Angular coverage of $|\eta| < 2.7$
- 18 k modules

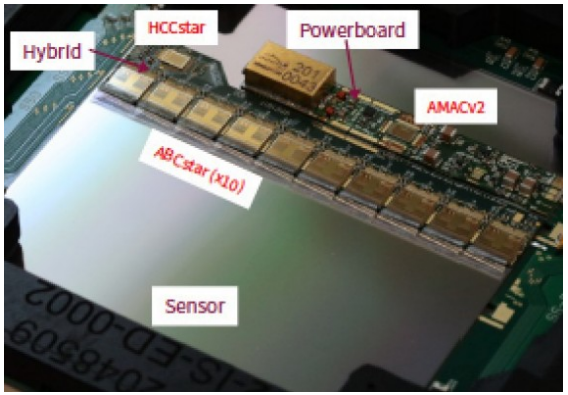
## Sensors/ASICs:

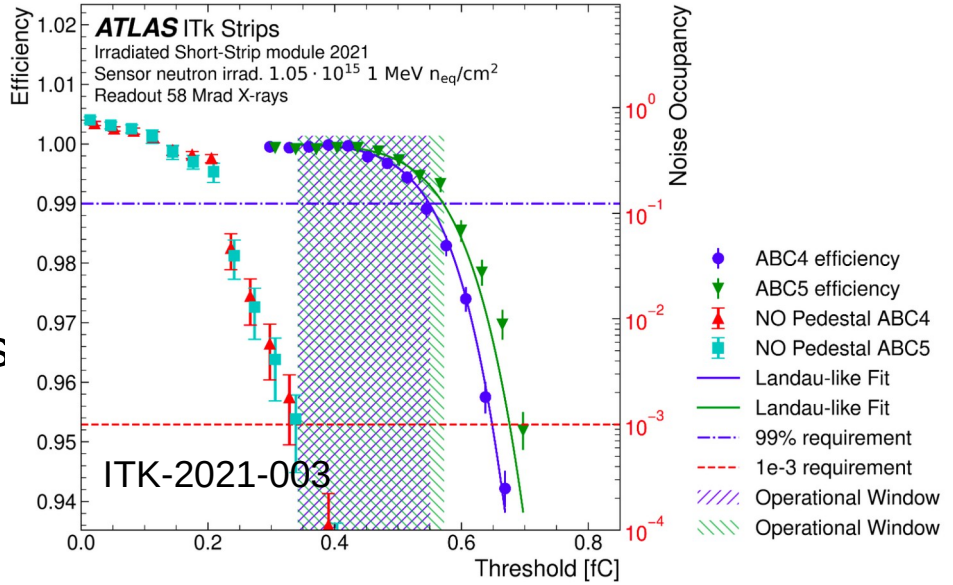
- Strip width ~75 μm
- ~60 M channels
- ABCStar, HCCStar and AMAC chips
- Radiation: 1.6E15 neq/cm$^2$

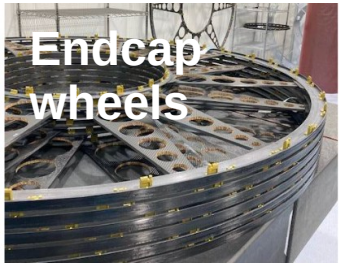
## Production status:

- Sensors: In production.
- ASICs in production
- Hybrids and modules in pre-production
- Mechanics in production



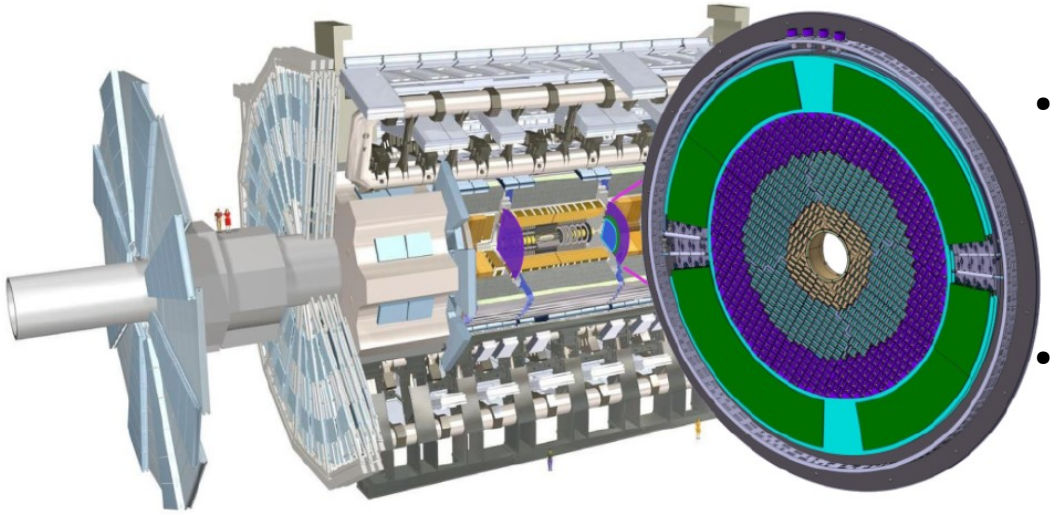





~62 cm

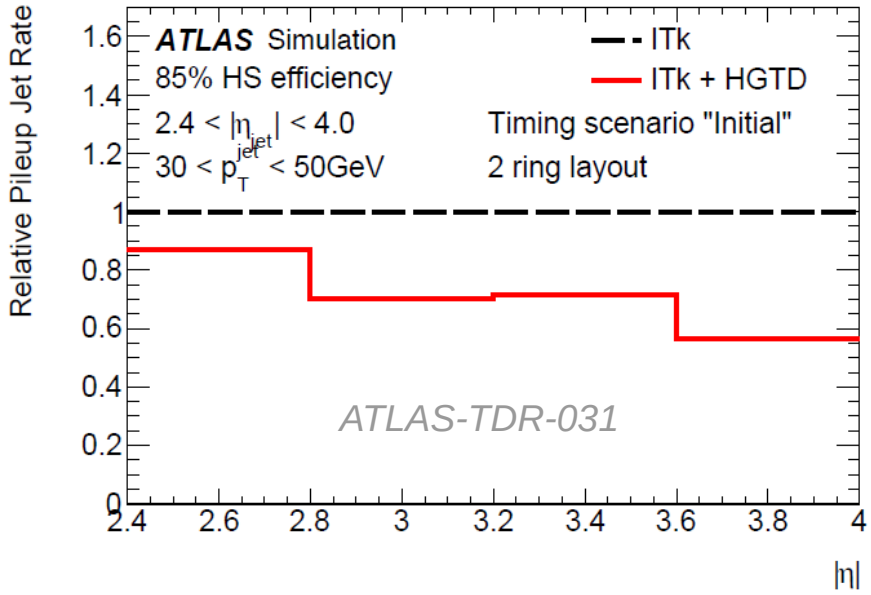
# High Granularity Timing Detector



- HGTD designed to improve ATLAS performance in the forward region in view of increased pile up in the HL-LHC
- Also provides luminosity information

Target time resolution:
**30-50 ps/track** up to 4000/fb

- Located between barrel and end-cap calorimeters (|z|=3.5 m)
- Silicon detector modules mounted on disks
- Two sensor layers/disk
- Two disks/side (total 4 layers/side)
- Active area: 12 cm < r < 64 cm
  - **2.4 <|η|< 4.0**
- Disk replacement plan to maintain 2.5E15 neq/cm2 level



# High Granularity Timing Detector

## Sensor:

- 15x15 array with pad size: 1.3 x 1.3 $mm^2$
- Single-event burnout (SEB) was observed on LGAD sensors during beam tests
- Mitigated by carbon-infused sensors (can be operated at decreased high voltage)

## ASIC:

- First full size ALTIROC2 prototype very successful, not fully rad hard
- ALTIROC3 wafers recently received

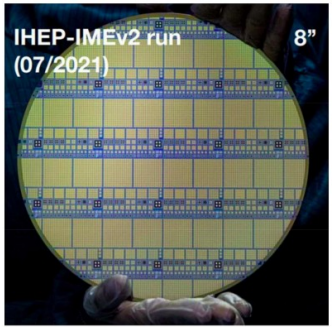
## Modules:

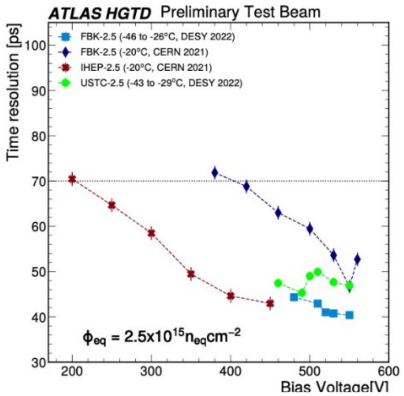
- Modules (2 ALTIROCs bump bonded to 2 LGAD sensors) have been demonstrated to work

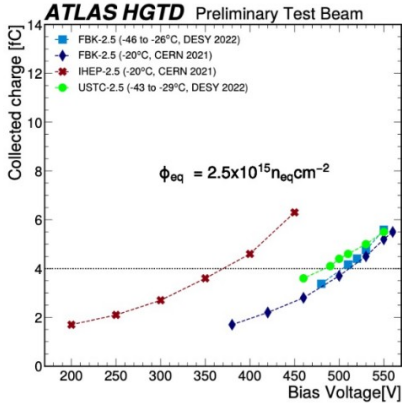
## System tests:

- Thermal demonstrator
- Electrical demonstrator on-going

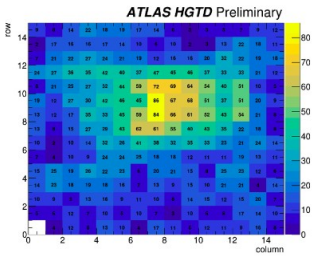
*See S. Ridouani more detailed talk this afternoon*

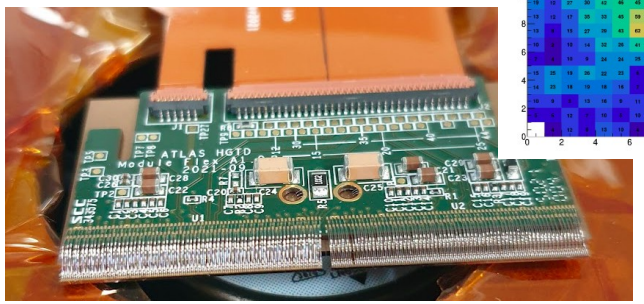




*HGTDPublicPlots*



# Summary and Conclusions

- ATLAS detector currently undergoing mayor upgrade to optimize the experiment for HL-LHC data taking period
  - Objective is to maintain or improve physics performance in view of more demanding environment
- Trigger system upgrade: 100 kHz to 1 MHz
- Most detector electronics (DAQ and trigger systems) will be upgraded to cope with the luminosity increased and increased trigger/readout rate
- Muon detector upgrade (sMDT, TGC, RPC) to improve coverage and triggering
- An all-new silicon tracker (ITk) with 5 layer pixel and 4 layer strips which improves tracking up to $|\eta|<4$
- The High Granularity Timing Detector (HGTD) based on LGADs will help to reduce pile-up effect in the forward region with timing measurements

*Many interesting results in this conference and looking forward to physics with the high luminosity LHC!*

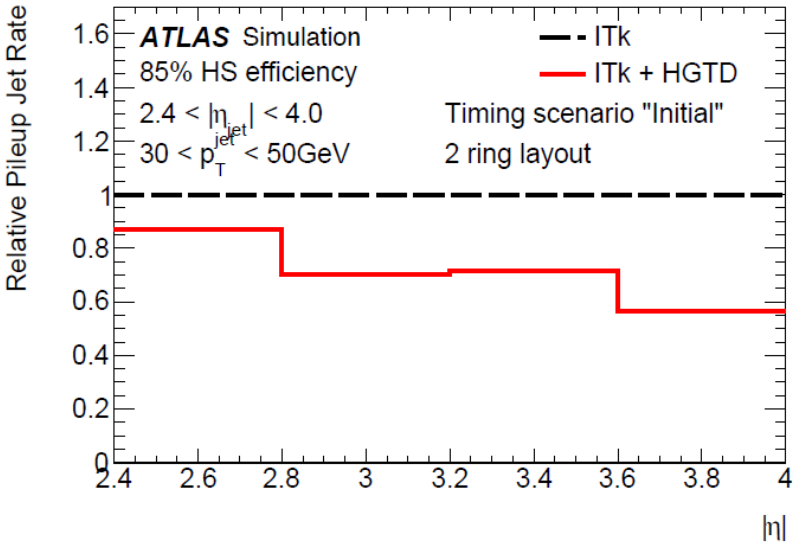
# Back Up Slides

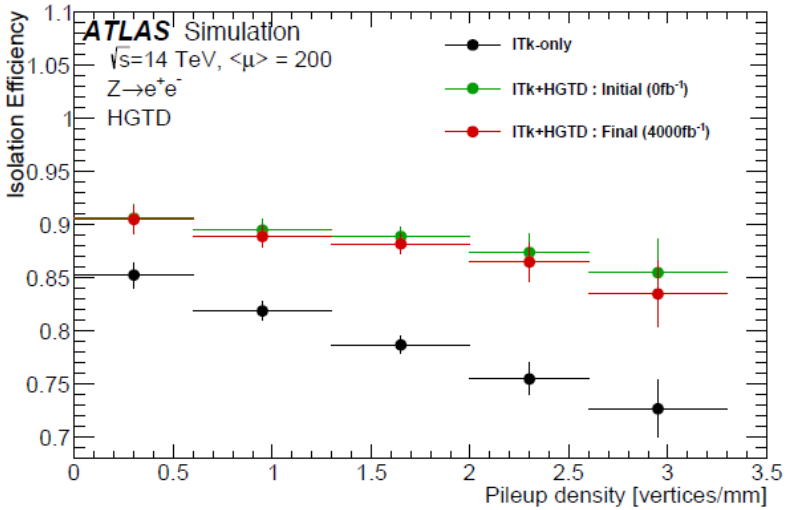
# Impact of HGTD

Example, two “straight forward” improvements with HGTD

## Pile up rejection

- PU jets identified by looking at the tracks associated to a jet
- HGTD can help identifying PU tracks, specially at large η




## Electron isolation efficiency

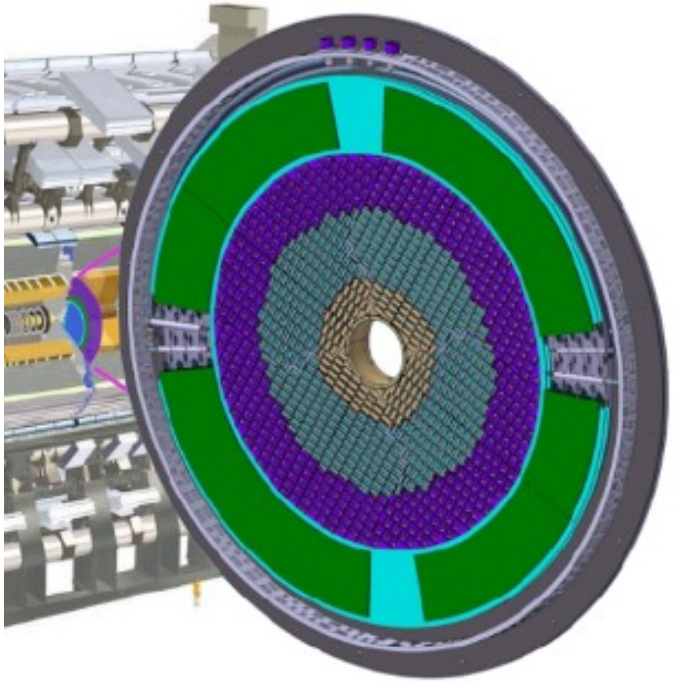
- PU tracks can cause electrons to fail isolation requirements
- HGTD can help maintain high efficiency, specially at high pile up

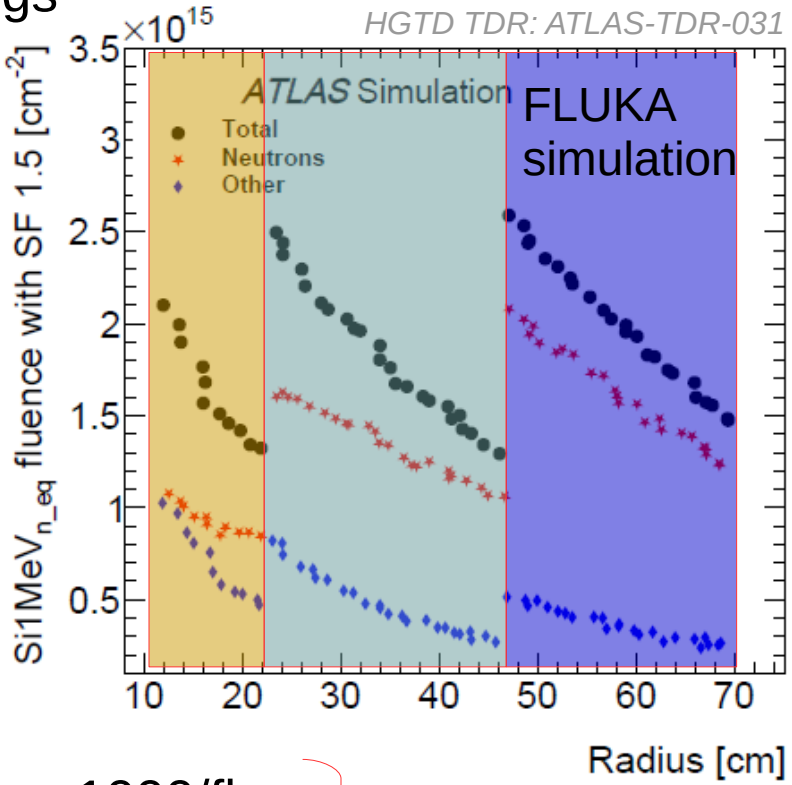


*Material from HGTD TDR ATLAS-TDR-031*

# HGTD Radiation Hardness

- The strategy to cope with the high radiation environment is to segment the detector into replaceable rings






- Inner ring (12-23 cm) replaced every 1000/fb
- Middle ring (23-47 cm) replaced every 2000/fb
- Outer ring (47-64 cm) never replaced

Maximum fluence:
**2.5E15 1MeV $n_{eq}$/cm²**
and 2MGy at the end of HL-LHC (4000/fb)