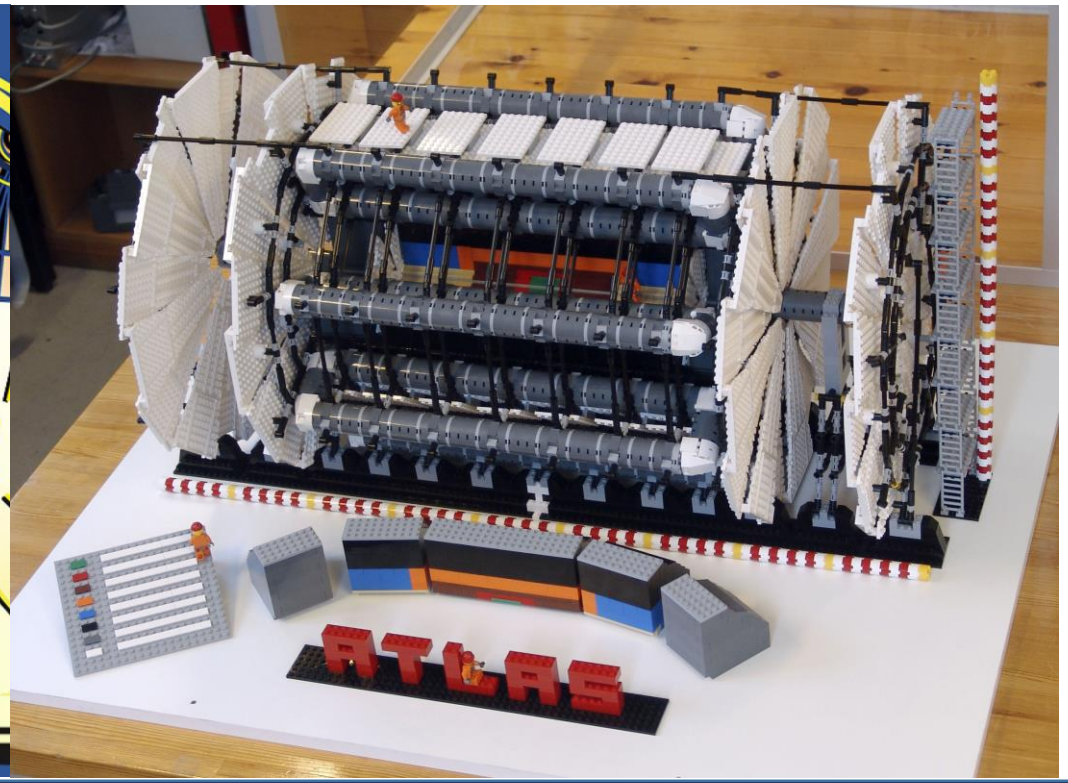
Status and progress on the ATLAS Phase-II detector upgrades

Oleg Solovyanov on behalf of the ATLAS collaboration



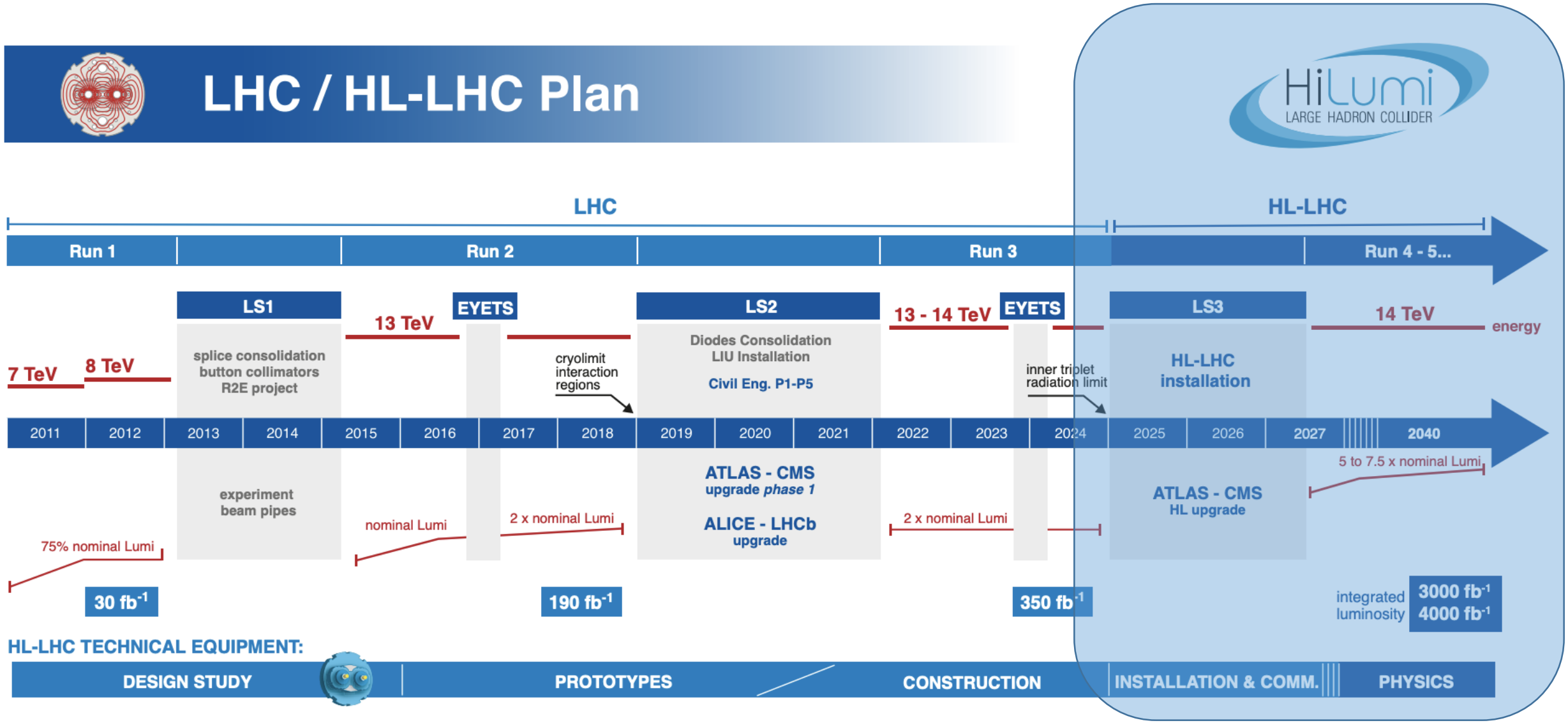
ATLAS Phase II upgrade talks and posters at this conference

- Physics motivations and detector upgrades for the new era of the ATLAS experiment – *Marisilvia Donadelli*
- Upgrades for ATLAS – Richard Teuscher
- Status and progress on the ATLAS Phase-II detector upgrades – Oleg Solovyanov (this talk)
- Performance of the Tile Calorimeter Demonstrator system for the ATLAS Phase-II Upgrade - Edward Khomotso Nkadimeng
- Upgrade of ATLAS Hadronic Tile Calorimeter for the High Luminosity LHC - Ryan Peter Mckenzie
- A High-Granularity Timing Detector for the ATLAS Phase-II upgrade - Asmaa Aboulhorma
- Development of the ATLAS Liquid Argon Calorimeter Readout Electronics for the HL-LHC - Mesut Unal

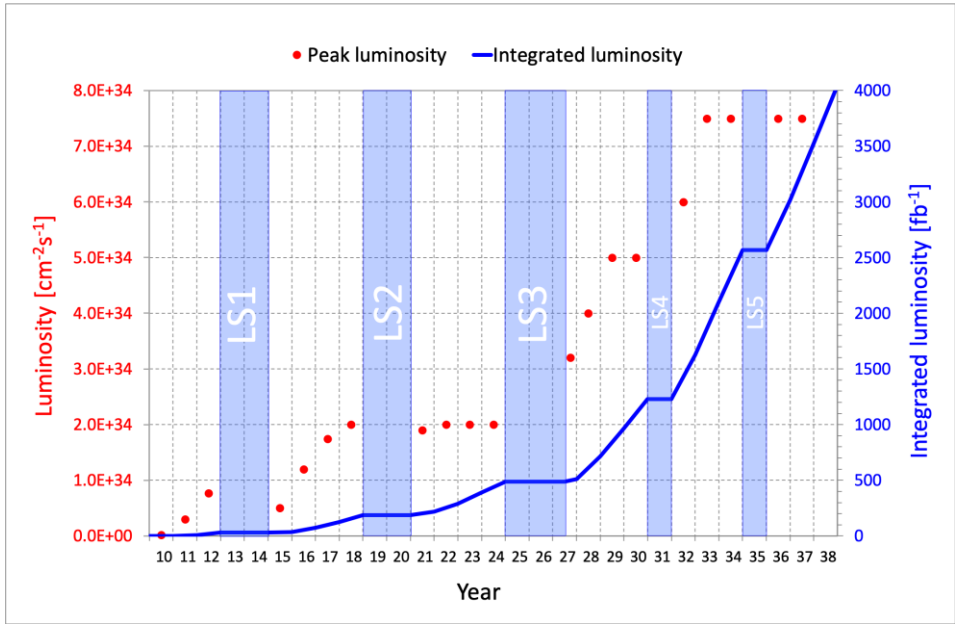
Outline

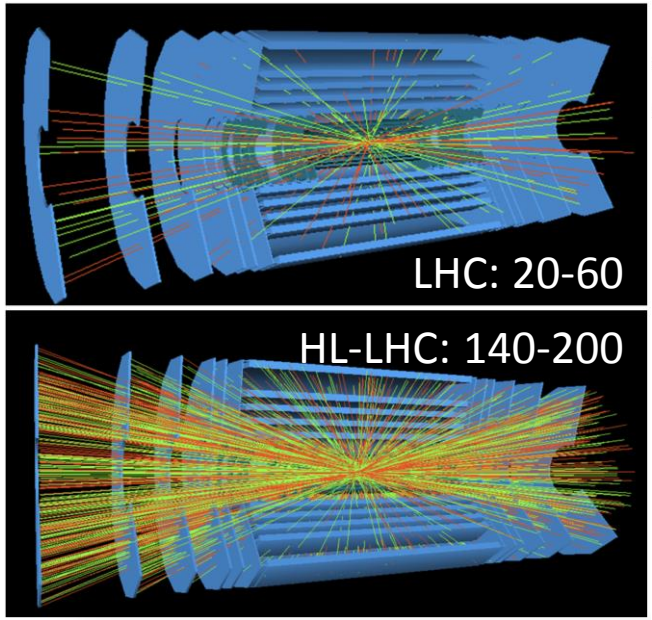
- HL-LHC
- ATLAS Phase-II detector upgrades
  - ATLAS detector overview
  - Inner Tracker (ITk Pixel, Strip)
  - Calorimetry (LAr, Tile)
  - Muon Spectrometer (MDT, RPC, TGC)
  - Forward detectors (HGTD, etc.)
  - Trigger and DAQ (TDAQ)
- Summary

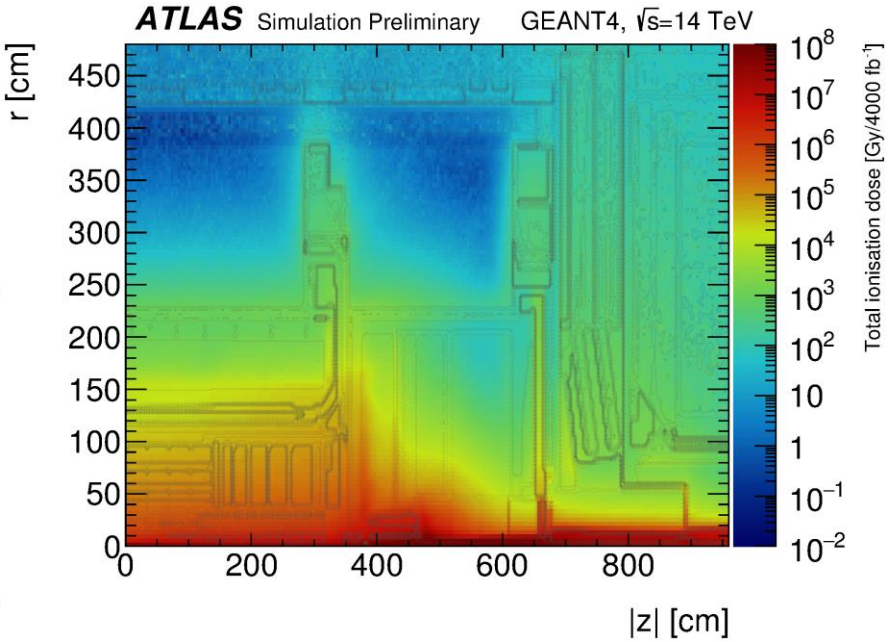
HL-LHC timeline



HL-LHC challenges for detectors



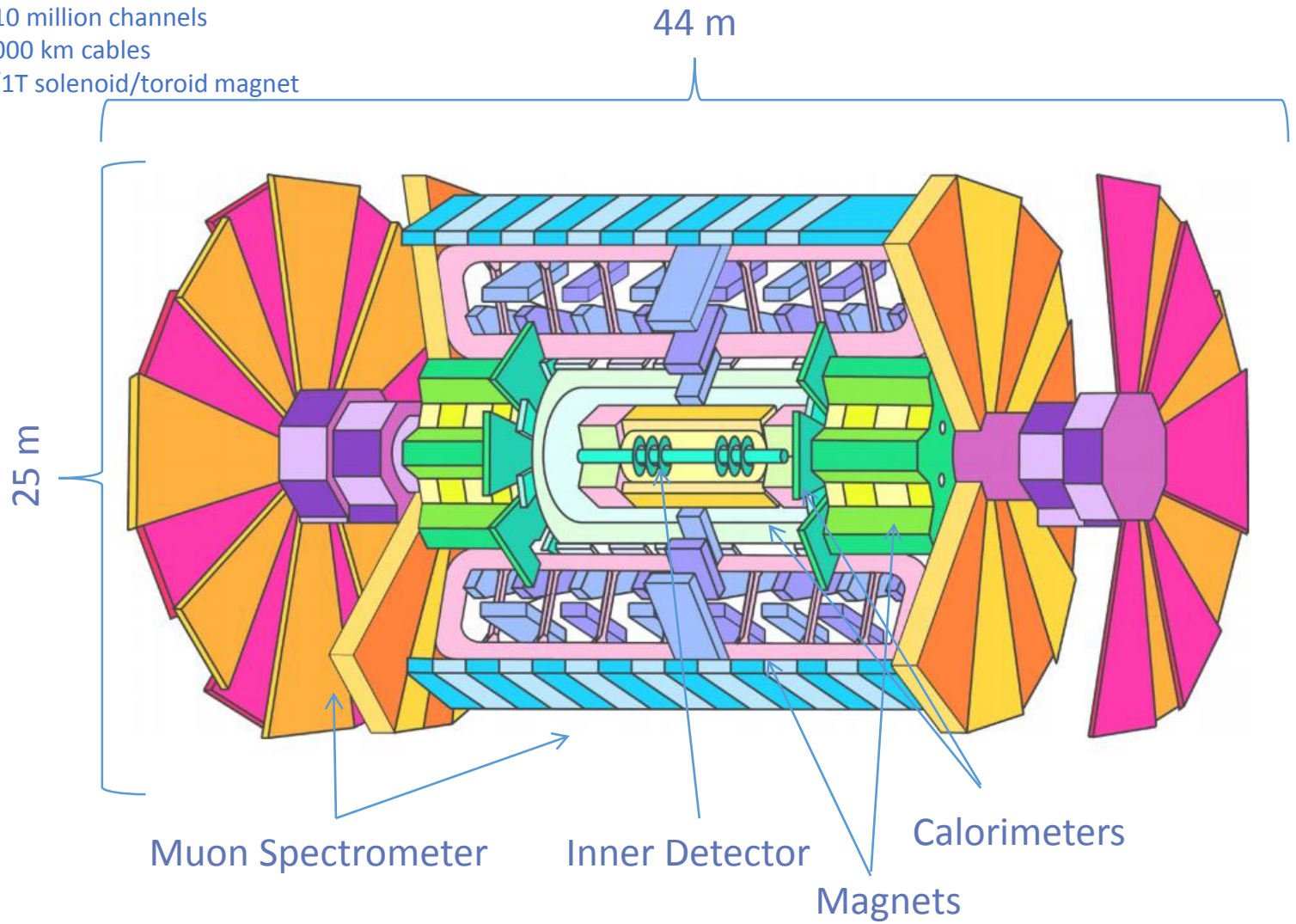




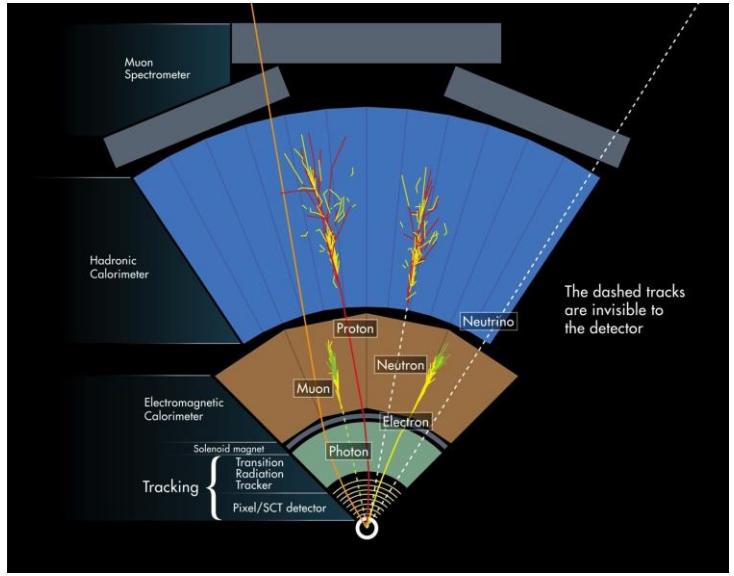
- The HL-LHC programs challenges the detector and detector electronics
  - High luminosity – from $2x10^{34}$ $cm^{-2}s^{-1}$ up to $7.5x10^{34}$ $cm^{-2}s^{-1}$, high trigger rates from 100 kHz L1 to 1 MHz in ATLAS
  - High pile-up conditions – from $<\mu>=20$ of LHC design up to $<\mu>=200$ for HL-LHC, large detector occupancies
  - Increased radiation doses – about 20x increase up to a few MGy TID for 4000 fb^{-1}
  - Long term operation – 15 additional years on top of the original 15 (was designed for 10)
- Detector upgrades are underway to provide new detectors and electronics to ensure the high efficiency and high quality data taking in HL-LHC era

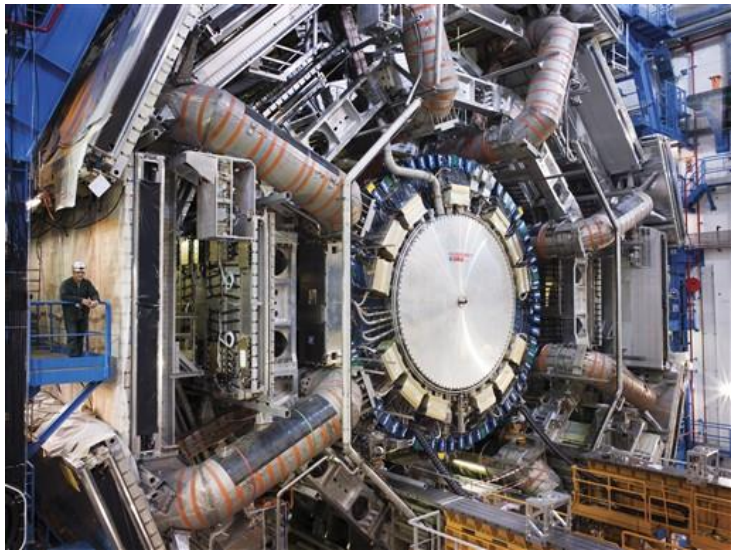
ATLAS detector overview

~7000 tons
~110 million channels
~3000 km cables
2T/1T solenoid/toroid magnet



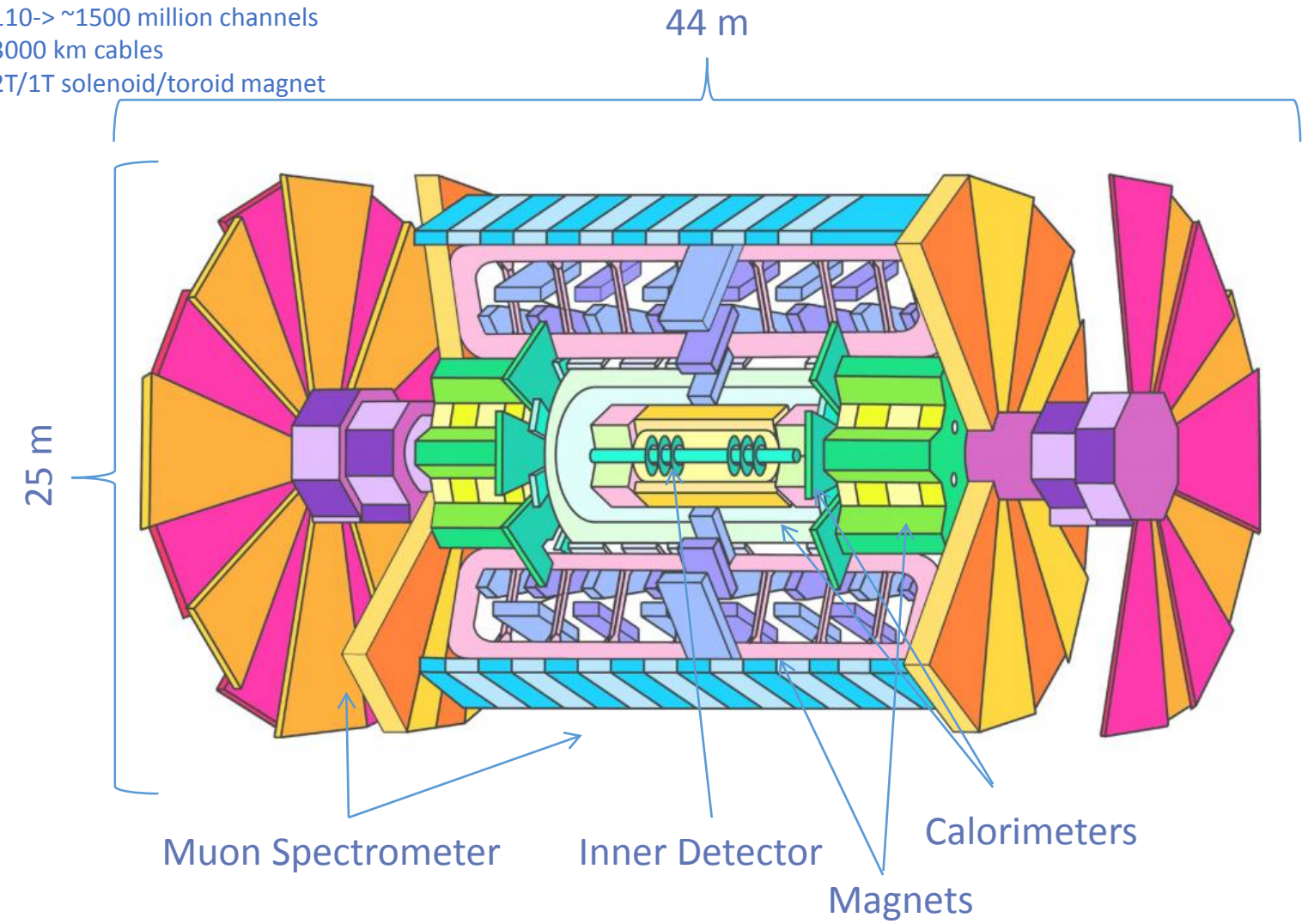
ATLAS Colouring Book





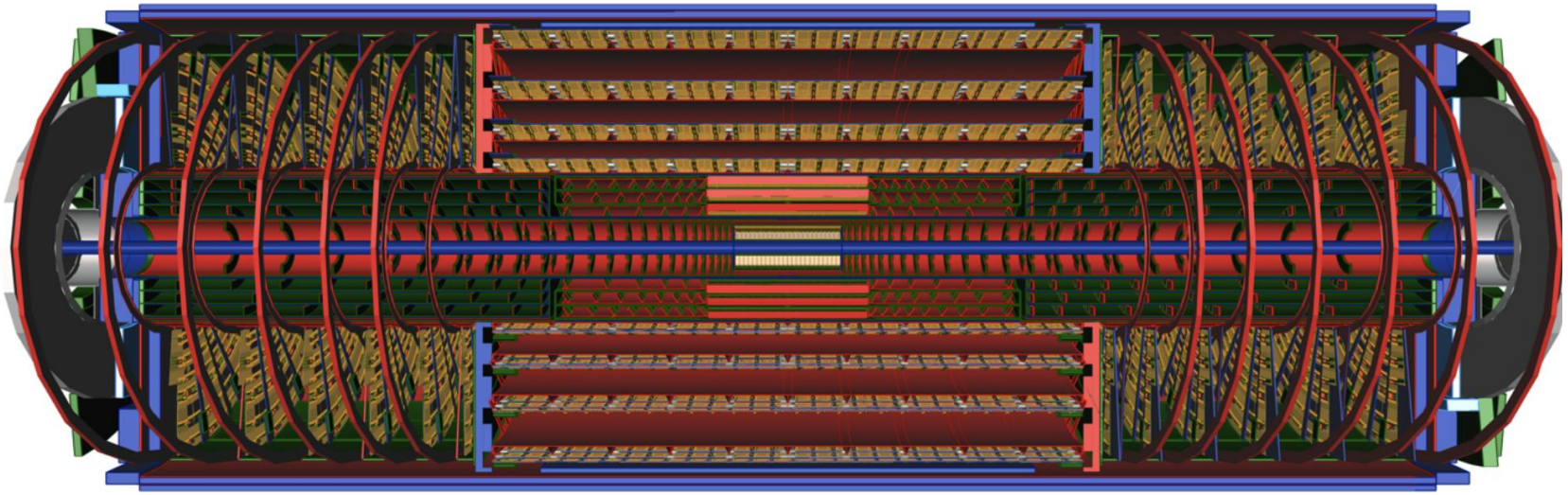
ATLAS detector Phase-II upgrades

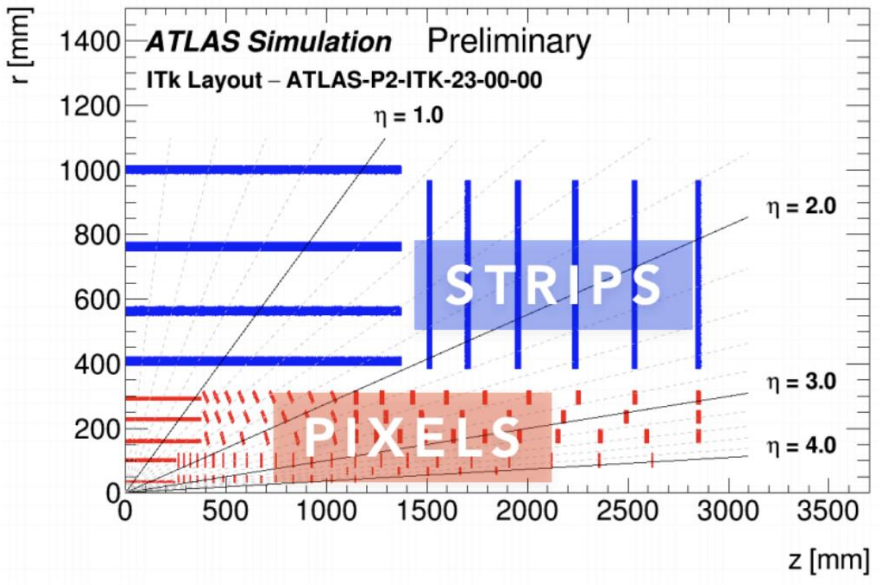
~7000 tons
~110-> ~1500 million channels
~3000 km cables
~2T/1T solenoid/toroid magnet



System	Phase-II upgrades
Tracker	Completely new Inner Tracker (ITk), comprised of Pixel and Strip sub-detectors
Calorimetry	Front-end and back-end electronics replacement for 40MHz continuous readout
Muons	New muon chambers and upgraded electronics for continuous readout
Forward	New luminosity and timing detector (HGTD), upgrades for other detectors

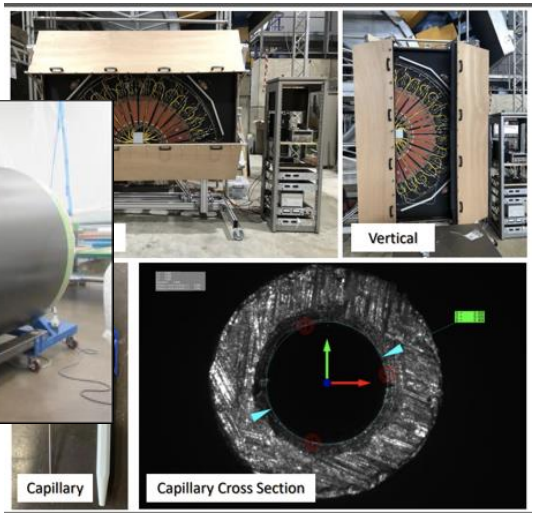
Inner tracker (ITk)





- Completely new all-silicon inner tracker with increased acceptance from $|\eta|<2.5$ (ID) to $|\eta|<4$ (ITk) and increased pile-up rejection
- Inner part made from 5 barrel layers and end-cap rings of pixel detectors, outer part made from 4 barrel layers and 6 end-cap disks of strip detectors
- Tracking performance comparable or better than before at much higher pile-up conditions
- Advanced progress in common mechanics and cooling

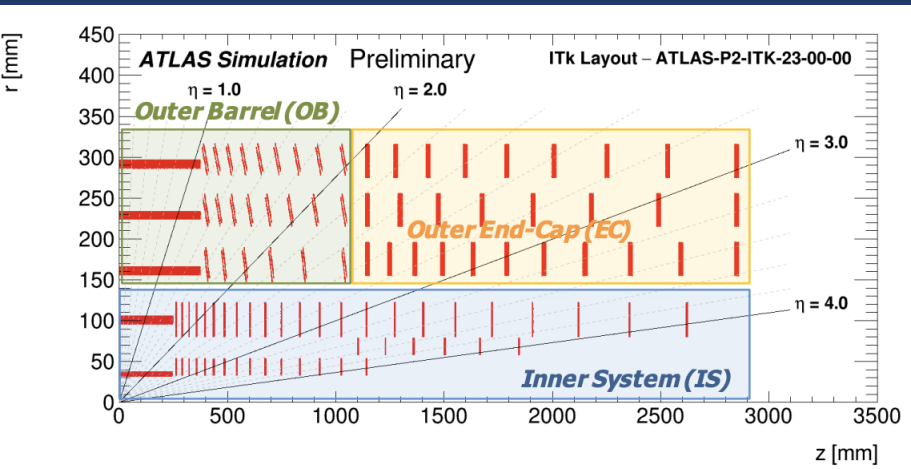
Outer cylinder

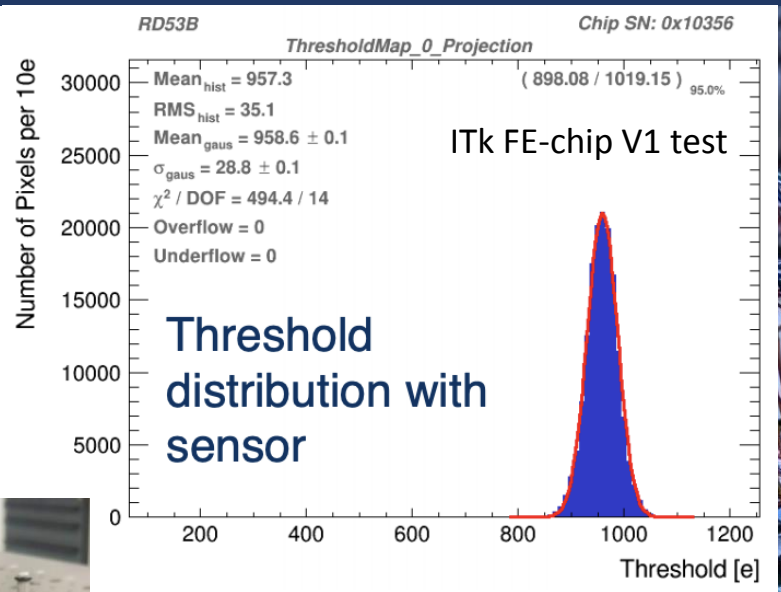


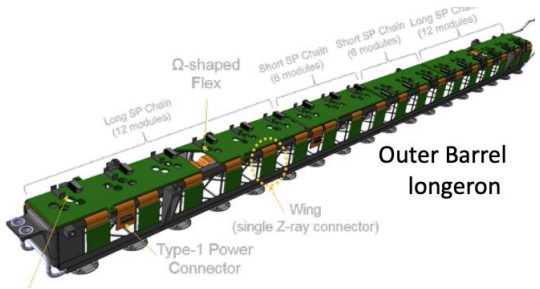
Cooling mock-ups and tests

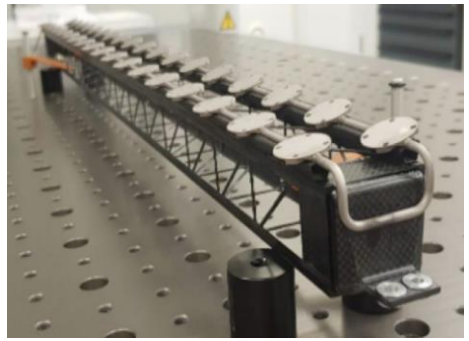
Inner tracker (ITk) Pixel

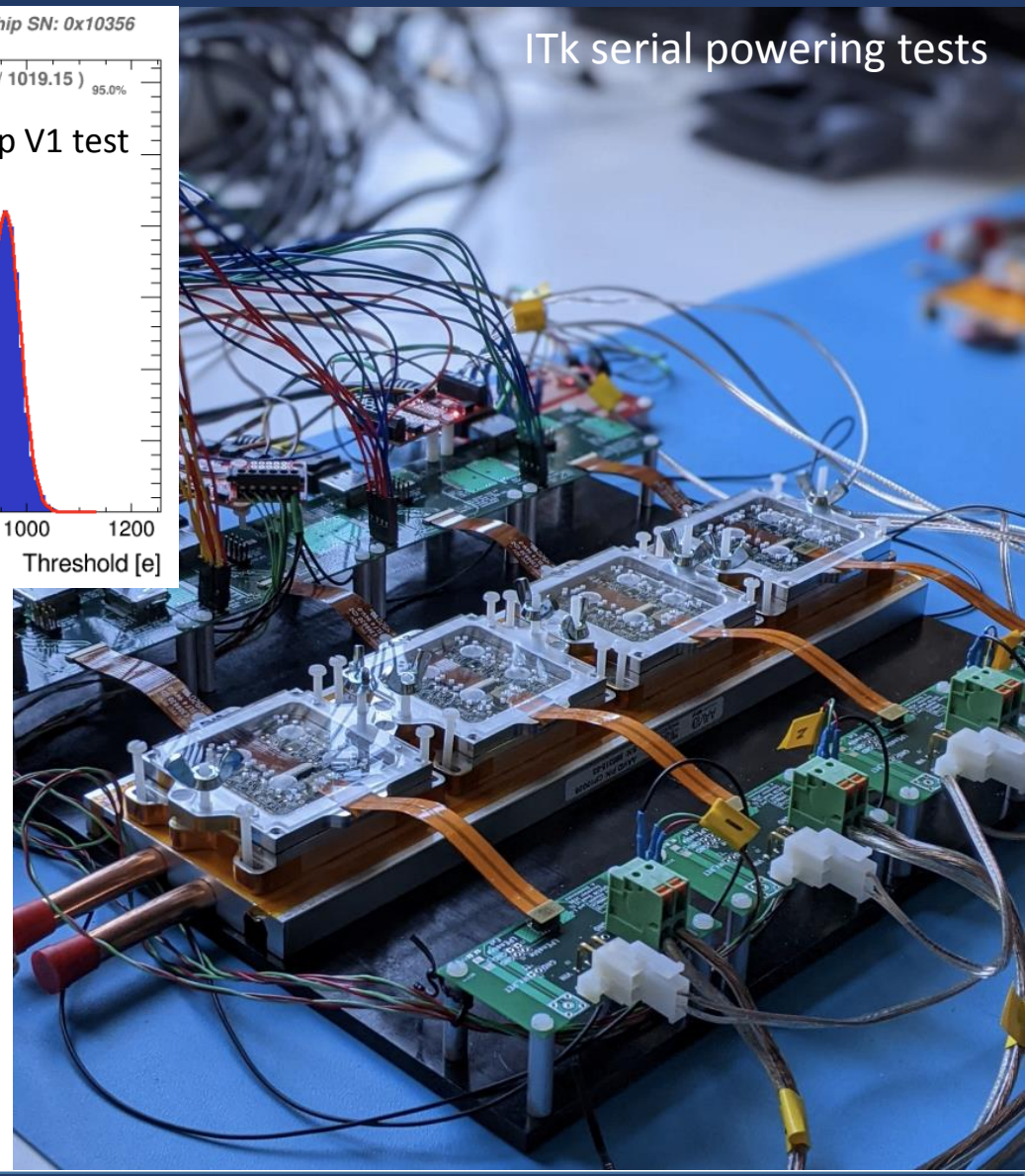
~13 m2 of silicon (1.2 m2 ID)
~9400 modules (200 ID)
~1400 Mpx (92 Mpx ID)







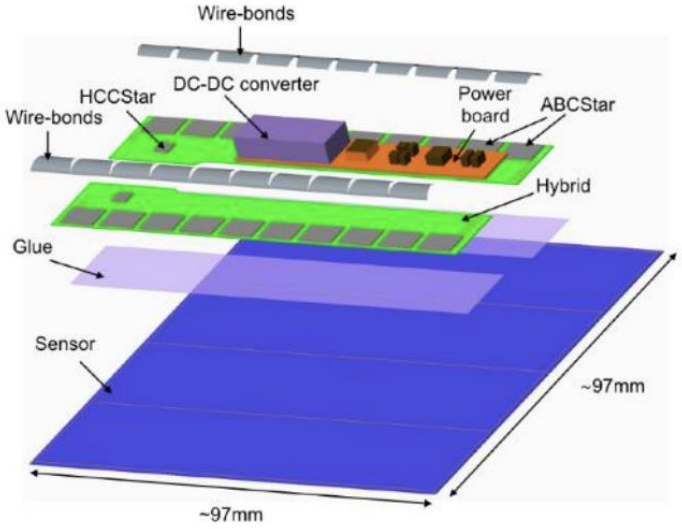




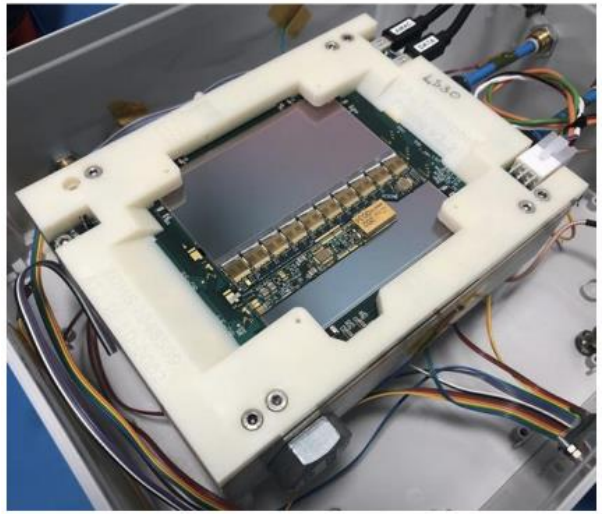
- A lot of progress despite COVID-19
- ITk FE-chip V1 works well, sensor modules expected soon
- Successful serial powering tests
- Moving into pre-production for sensors, FE-chip and hybridization

Inner tracker (ITk) Strip

~165 m2 of silicon (61 m2 ID)
~18 k modules (4 k ID)
~60 Mch (6 Mch ID)

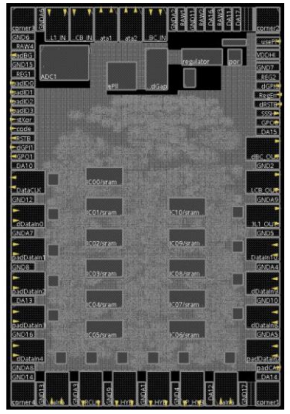


Barrel module with pre-production components

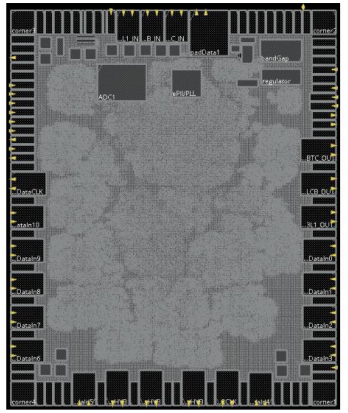


- Advancing well despite COVID-19
- Significant progress in integration
- First production sensor delivery expected soon
- System tests, including test beams, on-going
- Entering pre-production stage
- Production database crucial

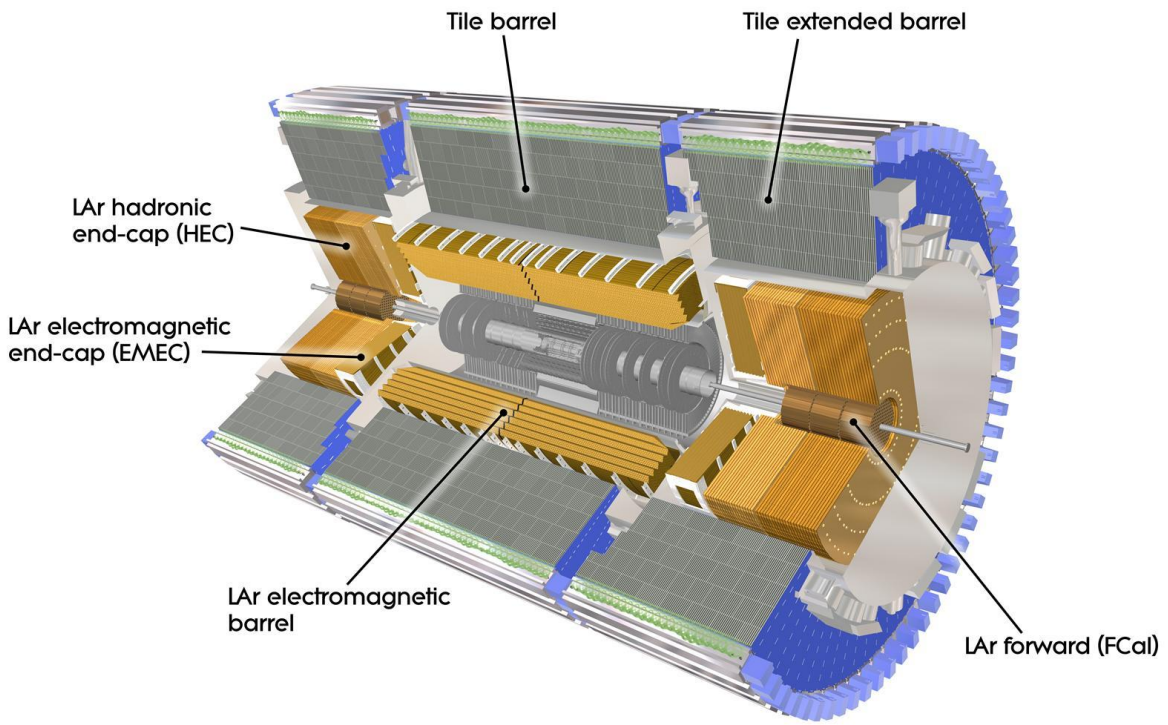
HCCStarV0

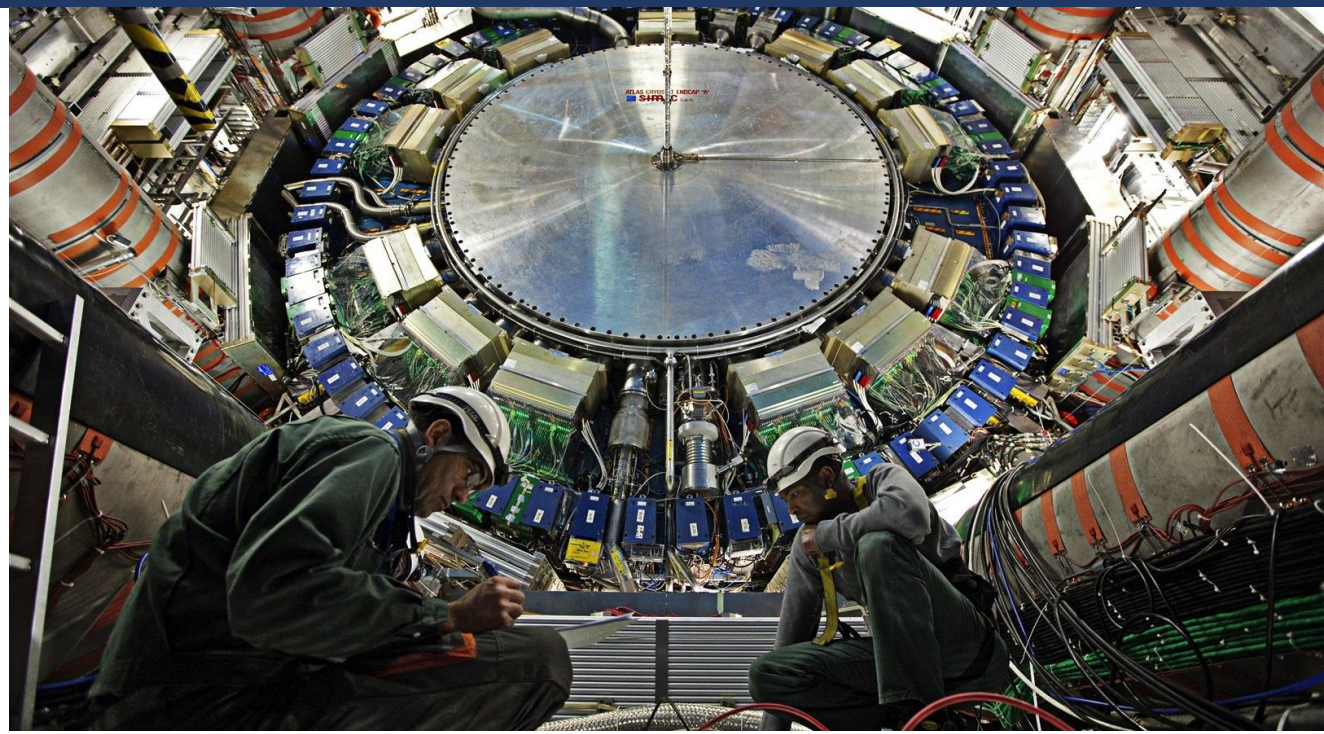


HCCStarV1



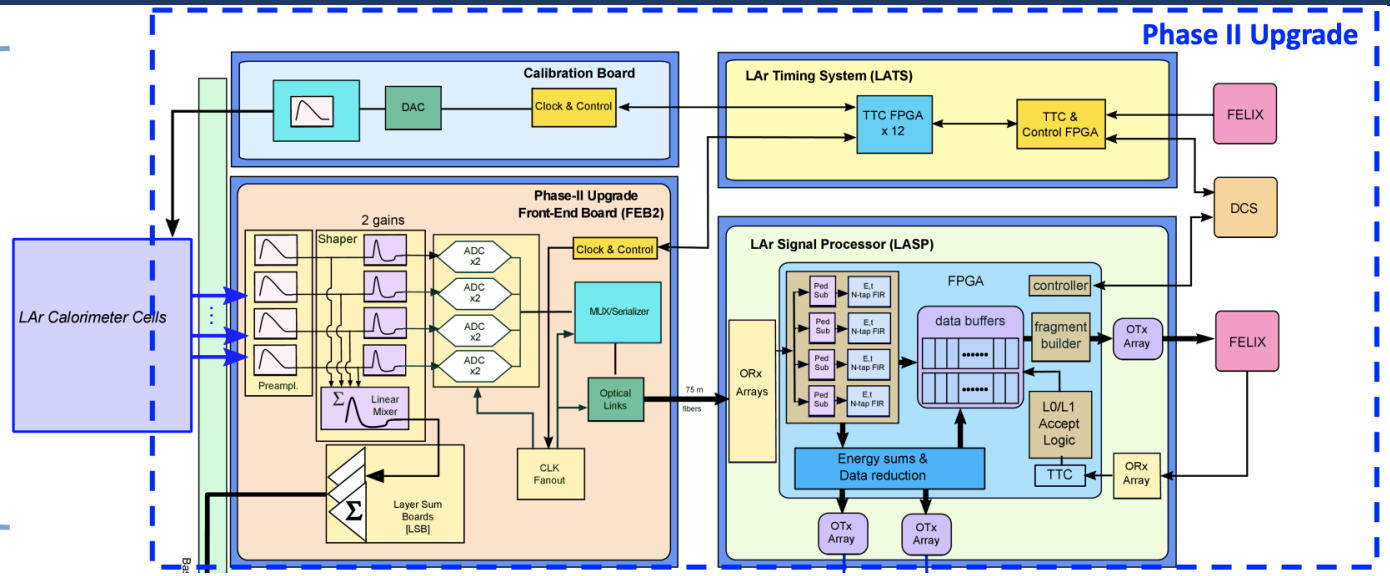
Calorimetry

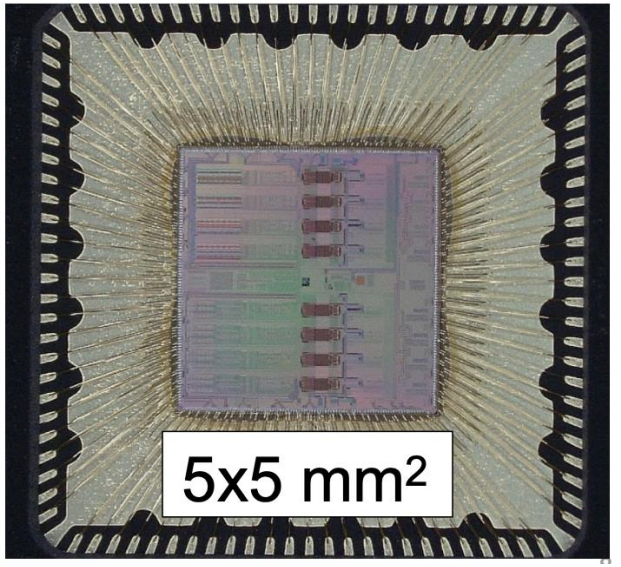




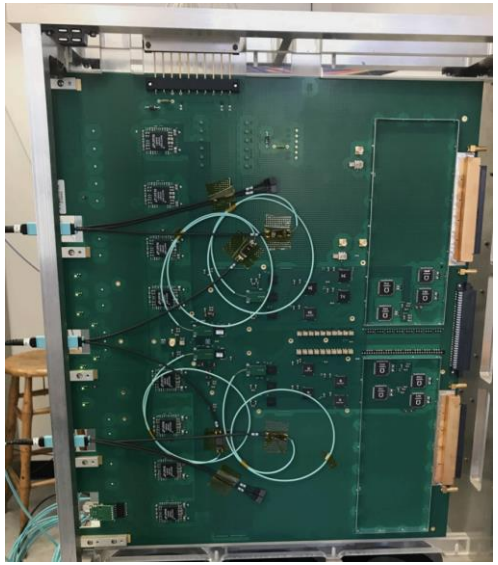
- Complete replacement of the front-end electronics to meet new radiation, trigger and readout performance criteria
- ASIC development, complex FPGA firmware, high-speed optical links
- New back-end electronics, new power supplies

Electromagnetic calorimeter (LAr)



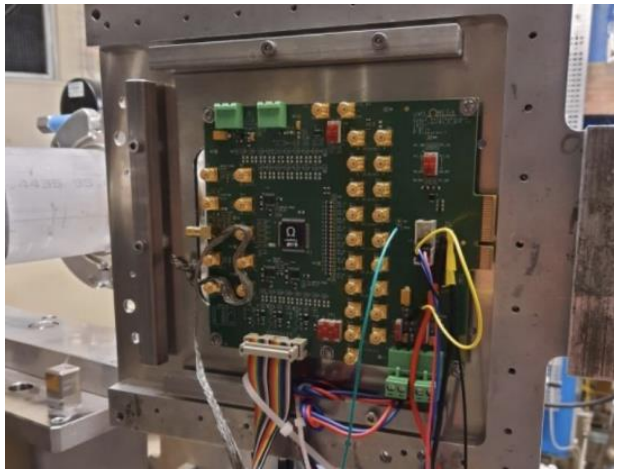


COLUTAv3 ADC ASIC

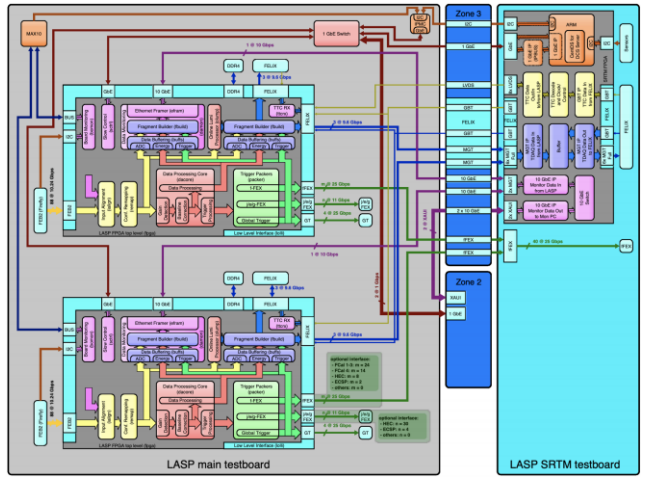


FEB2 slice test-board

- New front-end and back-end electronics
- 40 MHz continuous readout
- Improved radiation hardness
- New LV power supplies
- Major technical progress in all areas
- One full cycle for all ASICs
- Large firmware effort to take into account

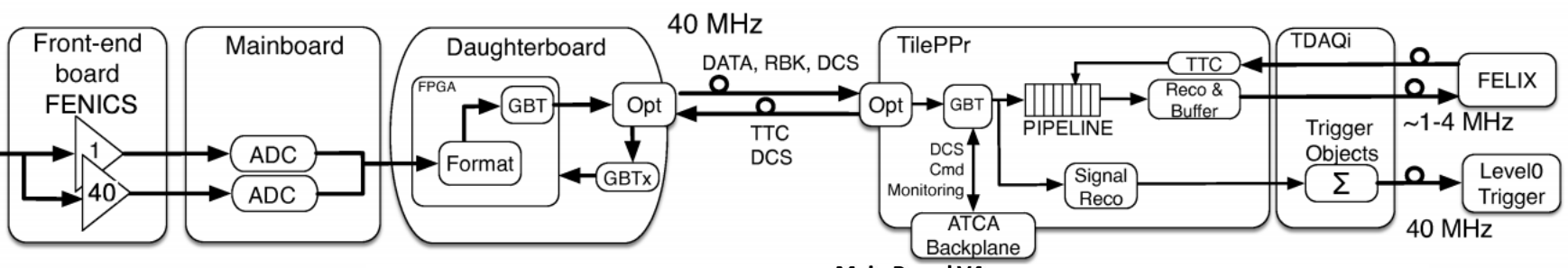


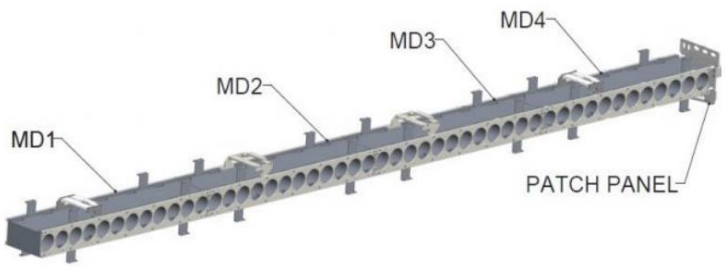
Irradiation test of the LAUROC2 ASIC

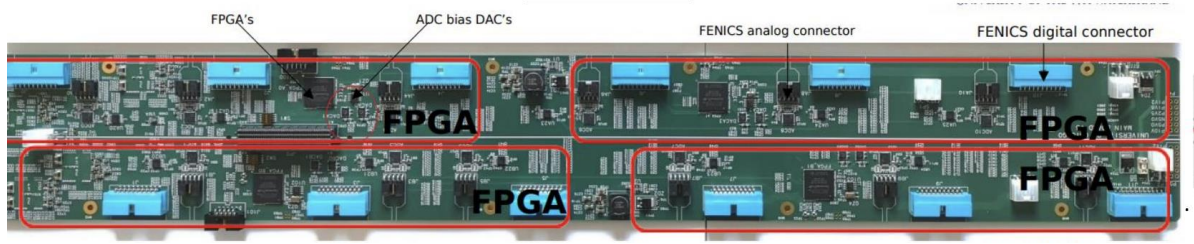


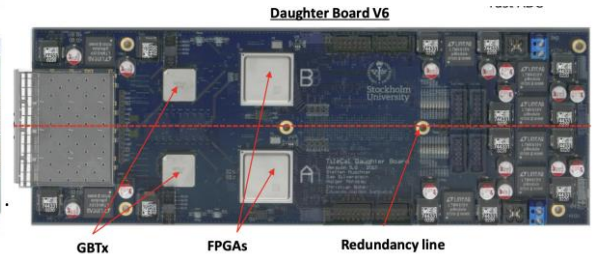
Back-end firmware scheme

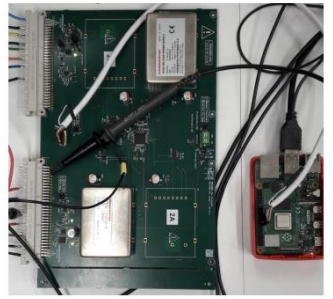
Hadron calorimeter (Tile)

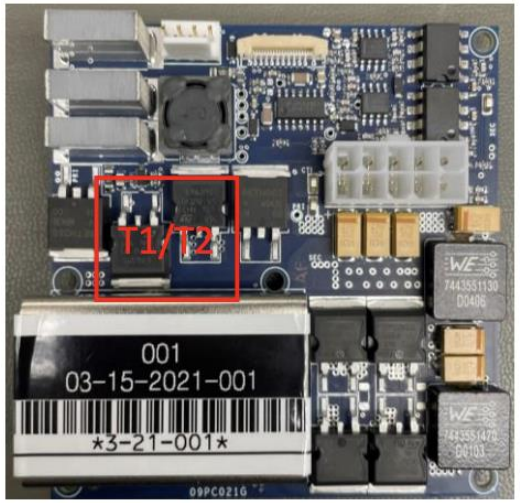












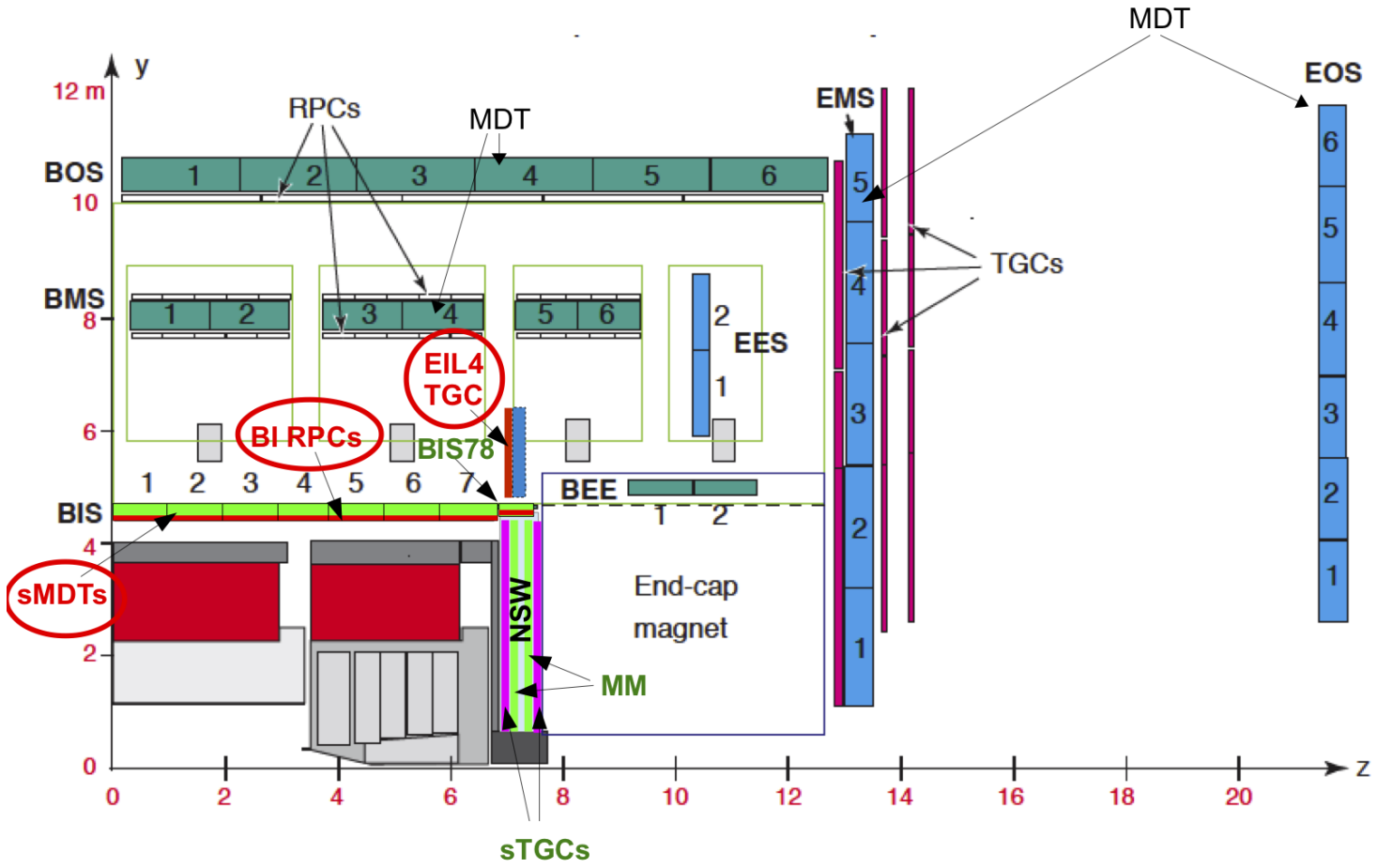
LV power supply brick

HV system

- New front-end and back-end electronics
- 40 MHz continuous read-out
- Improved radiation hardness and redundancy
- New mechanical supports for front-end electronics
- New power supplies for HV and LV
- Project well on track
- Entering production phase in many areas

Muon spectrometer

- Upgrade of several types of muon chambers
  - BI RPC+sMDT
  - EIL TGC
  - NSW sTGC
- Upgrade of readout electronics
- Upgrade of power systems
- Important progress despite challenges and COVID-19
- Most of the projects in prototyping phase
- Some chambers (sMDT) and ASICs (TGC) already in production



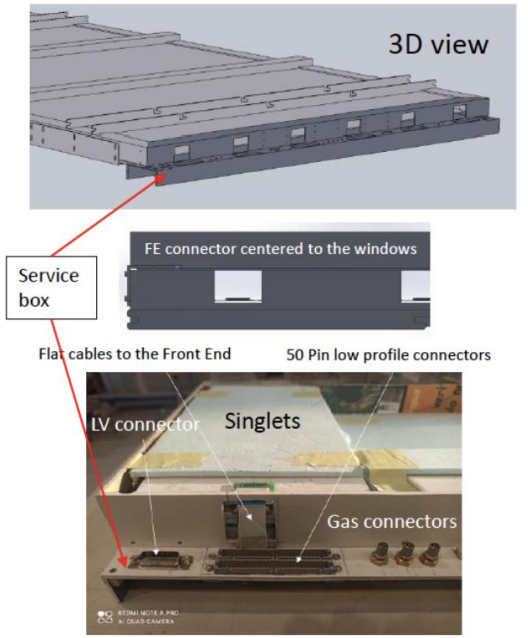
MDT – Muon Drift Chambers, **RPC** – Resistive Plate Chambers, **TGC** – Thin Gap Chambers

Muon spectrometer chambers

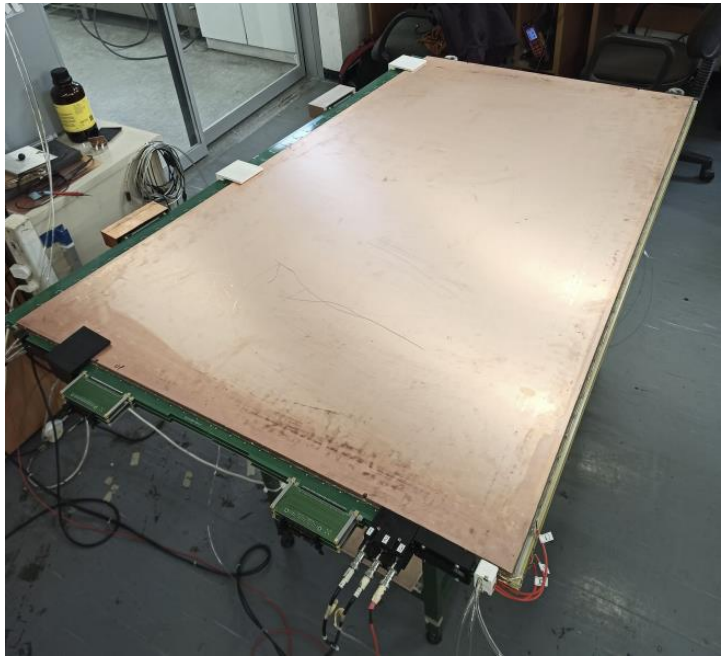
- sMDT
  - Production underway at two sites
  - High precision and performance of the first chambers
  - New electronics allows for better performance than legacy
- RPC
  - Prototypes are being constructed
  - Mechanics design progressing well
- TGC
  - First prototype has been built
  - Tests ongoing, new prototypes to follow

New sMDT chamber tubes

Drift tubes production



RPC chamber design mock-up

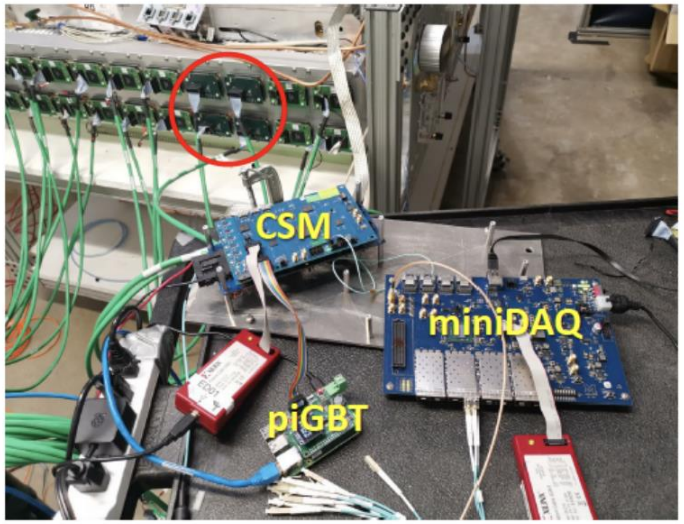


TGC EIL-4 chamber first prototype

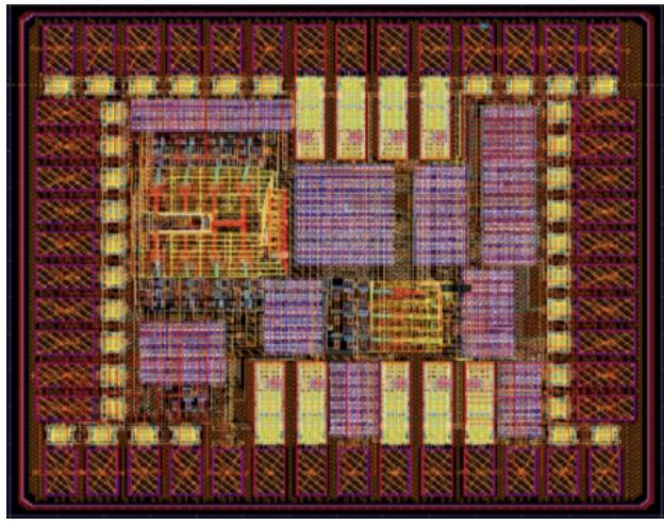
Muon spectrometer electronics

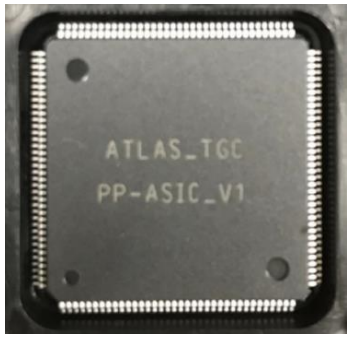
- MDT
  - Some ASICs are already produced
  - Prototypes are being tested with real chambers
- RPC
  - Front-end ASIC pre-prototype just received
  - Firmware development for read-out board
- TGC
  - ASIC production completed
  - Several prototype boards
  - Joint integration test passed

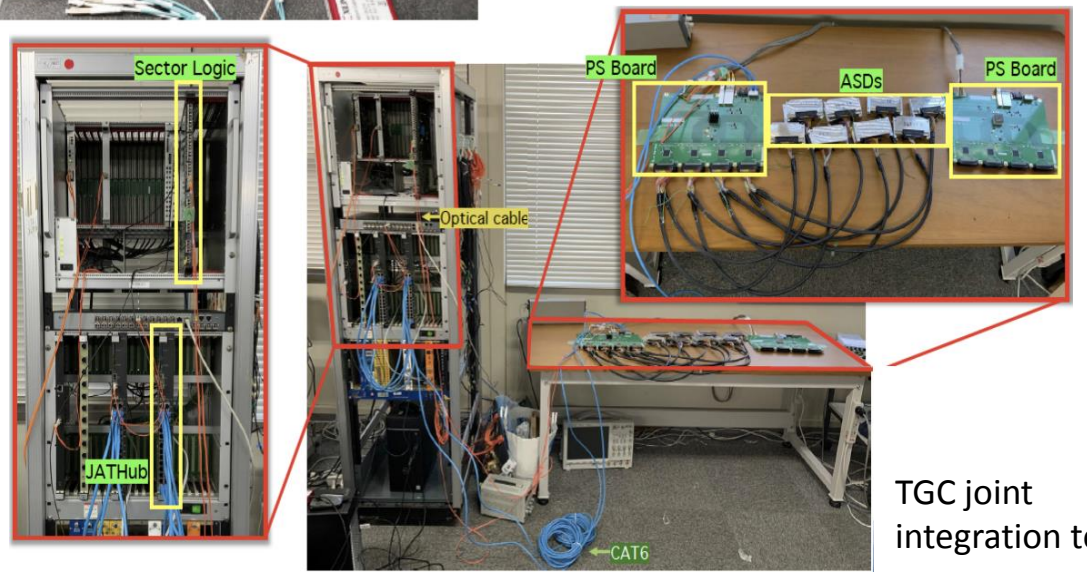
Cosmic ray test stations at Michigan



RPC FE ASIC pre-prototype

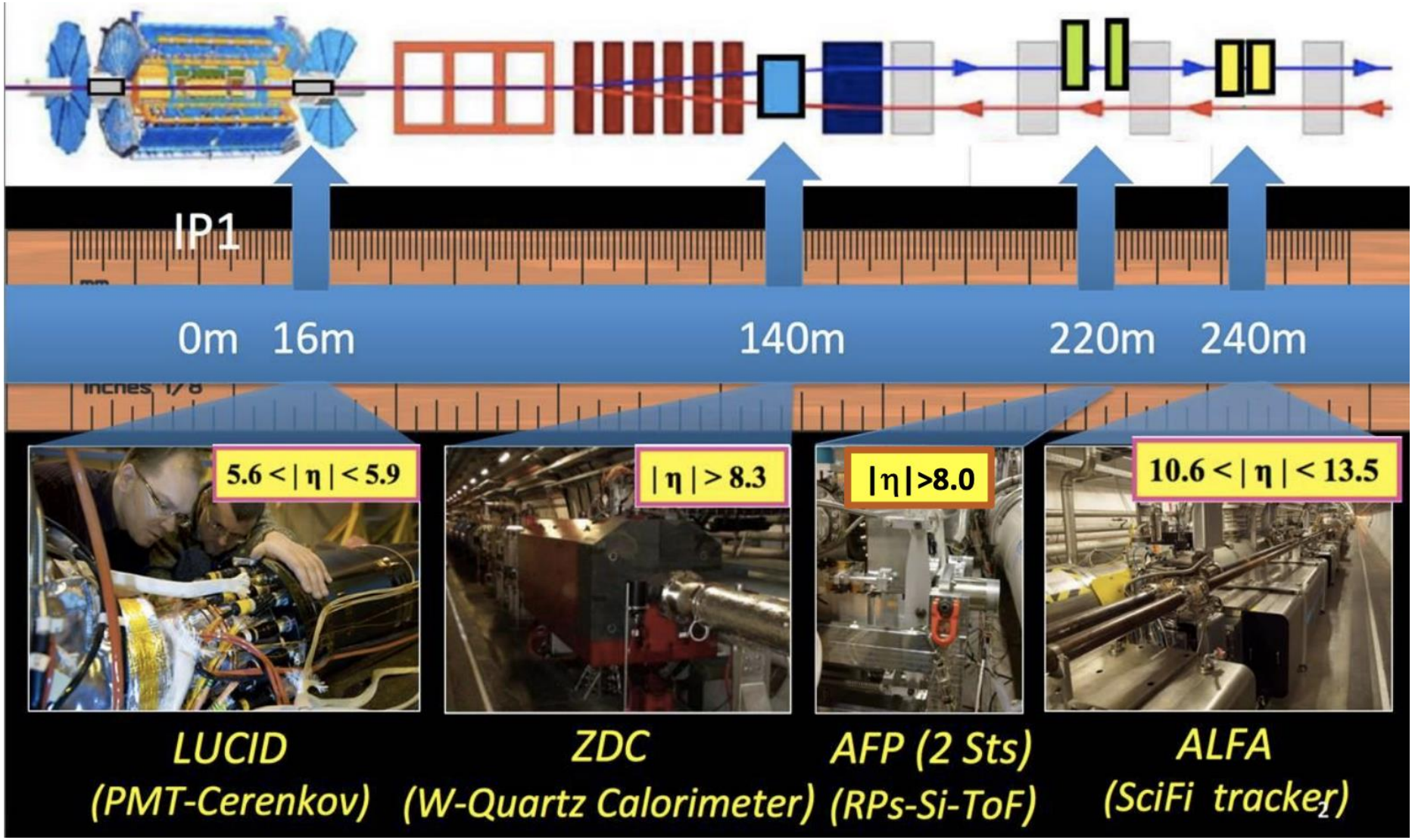






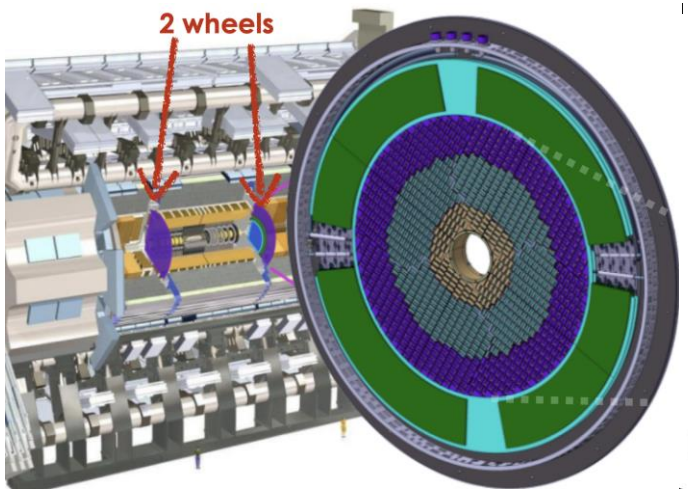
TGC joint integration test

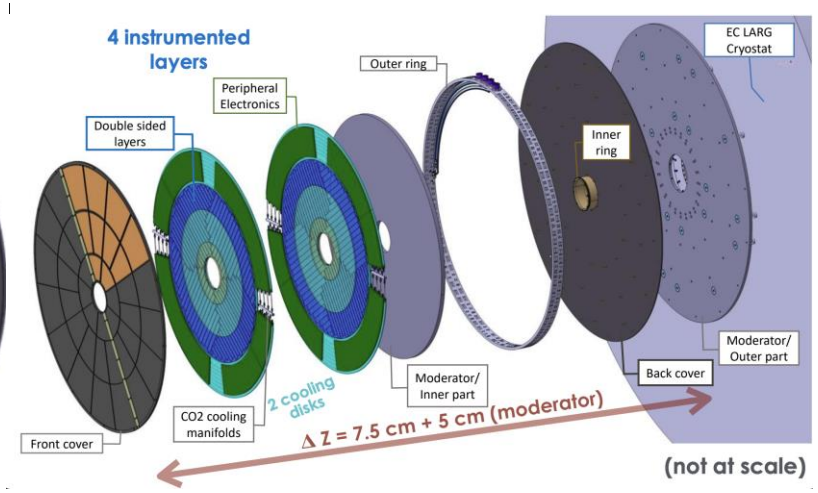
Forward detectors



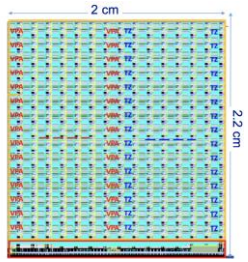
- HL-LHC program requires stable and precise luminosity measurement
- Rich forward physics and Heavy Ion physics program
- New luminosity and timing detector – HGTD
- Upgrade of luminometers and forward detectors
  - Beam Conditions Monitor (BCM')
  - Luminosity Cherenkov Integrating Detector (LUCID3)
  - Pixel luminosity rings (PLR)
  - Zero Degree Calorimeter (ZDC')

High-granularity timing detector (HGTD)

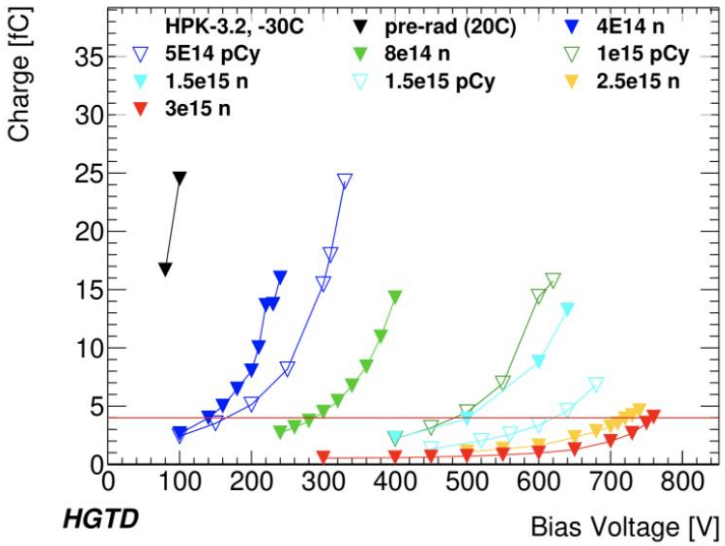




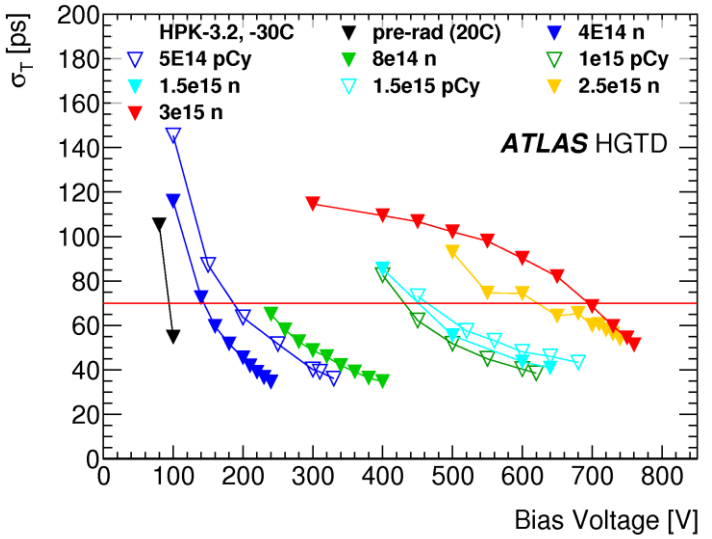
15x15 LGAD



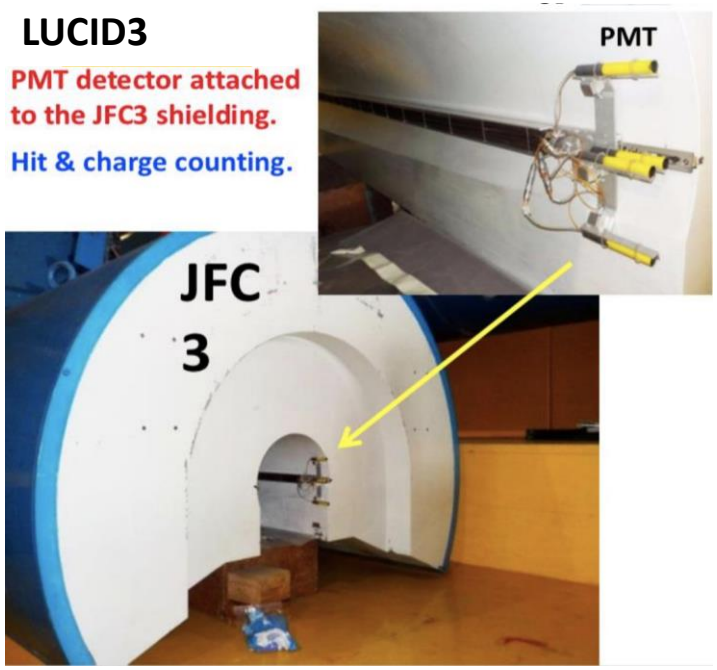
ALTIROC2

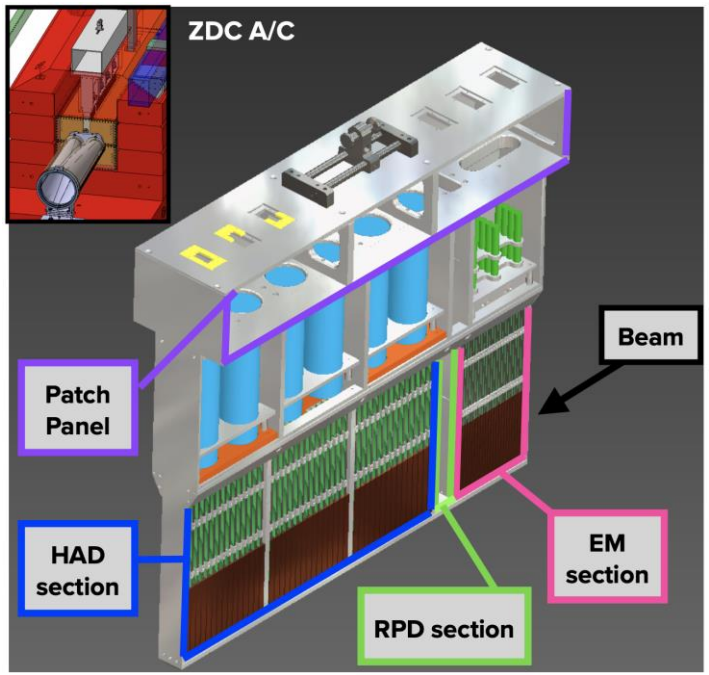


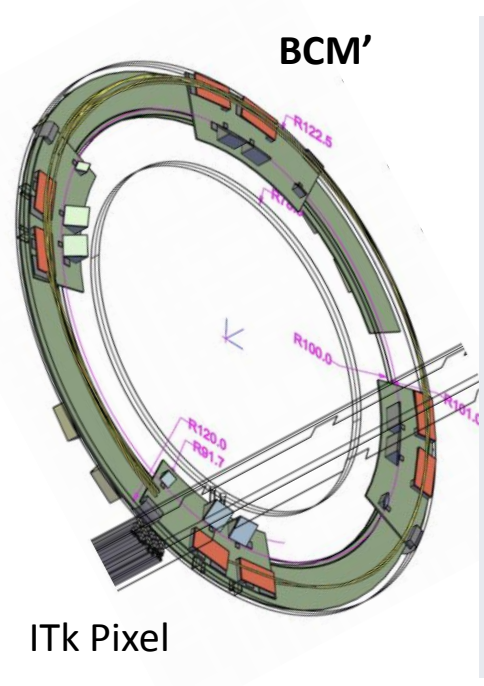
- Fine timing (<70ps/hit) to disentangle events in large pile-up conditions
- Precision luminosity measurement bunch-by-bunch
- Four layers of silicon detector modules, covering 2.4<|η|<4.0, 3.6 Mpix
- Low gain avalanche detector (LGAD) technology sensors will be bump-bonded to read-out ASIC
- Many vendors satisfy charge collection and timing requirements after irradiation
- Read-out ASIC v1 (ALTIROC1) shows good performance, full-size ASIC v2 (ALTIROC2) being submitted
- Mechanics and cooling (CO2@-30C) – design and verification in progress

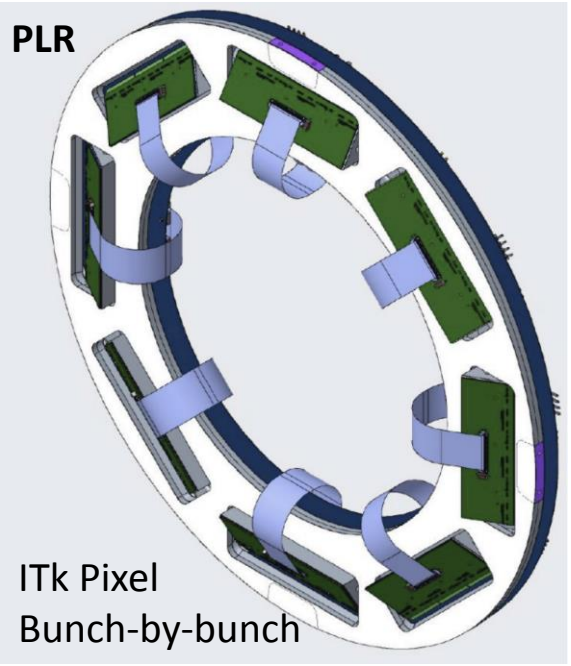


Other forward detectors upgrade





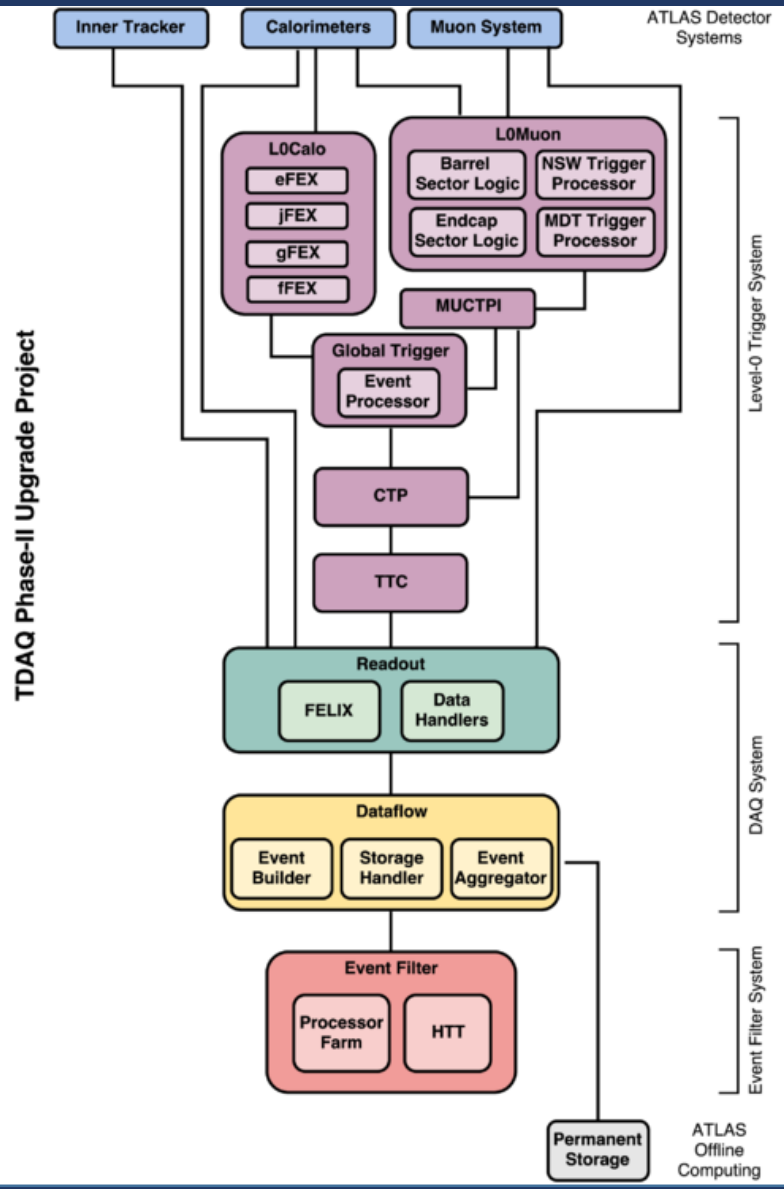


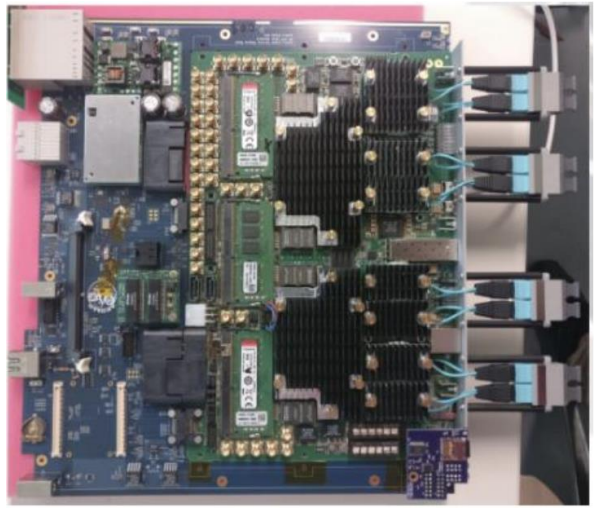


- Apart from the new HGTD, existing forward detectors will undergo upgrades to withstand HL-LHC conditions and provide forward physics and luminosity measurements
- Luminosity Cherenkov Integrating Detector (LUCID3), Zero Degree Calorimeter (ZDC'), Beam Conditions Monitor (BCM'), Pixel Luminosity Ring (PLR)
- Some projects still in initial design phase, but looking forward!

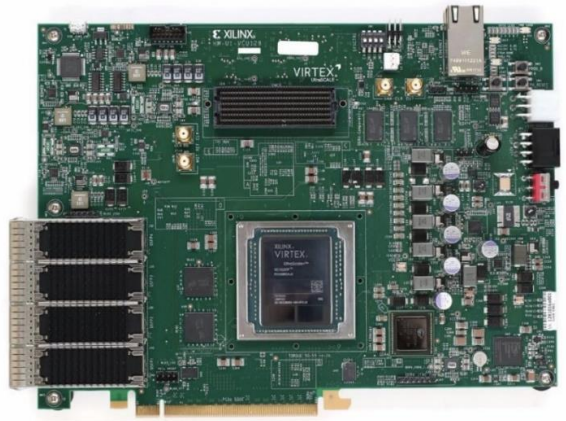
Trigger and DAQ (TDAQ)

- Moved to single-level HW trigger at 1 MHz
- Detector read-out with 10us latency at 5.2 TB/s based on FELIX
- 10-25 Gb/s optical link speeds
- Using ATCA standard
- Bi-directional TTC
- Increased usage of SoC
- Container-based farm
- Good progress in many areas
- Soon to decide on HW vs SW tracking in Event Filter
- Trying Kubernetes for farm orchestration
- Looking for RDMA networking





L0 muon trigger board prototype



FELIX Phase-II test-board

Summary

- The HL-LHC programs challenges the detector and detector electronics in many aspects, including high radiation doses and high pile-up
- Upgrades are underway to provide new detectors and read-out electronics to ensure the high efficiency and high quality data taking in HL-LHC era
- Outstanding work of all teams and projects despite pandemic difficulties
- Many projects entering pre-production or production phase
- New electronics with FPGAs requires large software effort
- Early integration and vertical slice tests are crucial for success
- Still many things to be done, and thanks to strong and motivated teams it will be possible