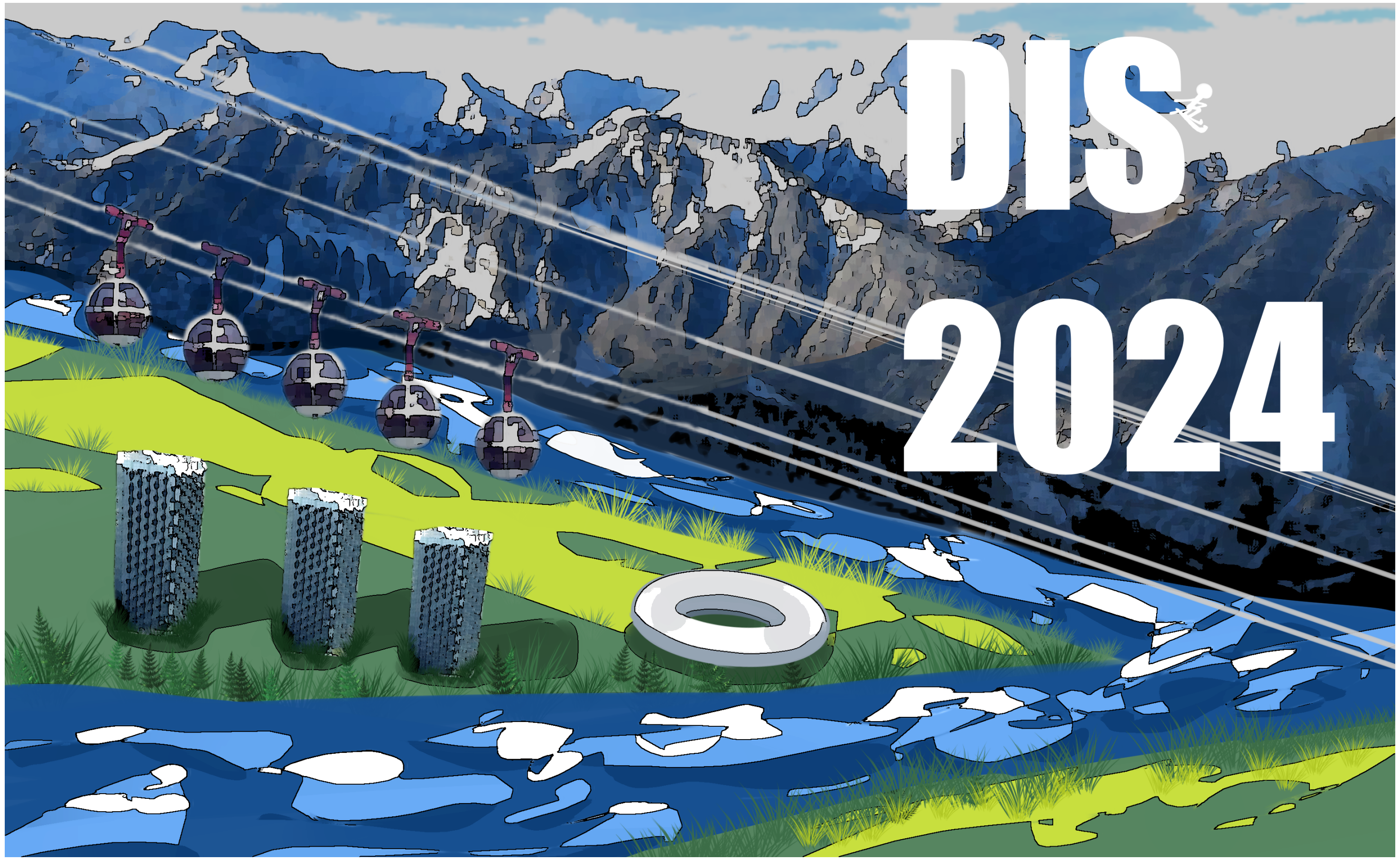


ATLAS Upgrades for High Luminosity LHC

Oleg Solovyanov on behalf of the ATLAS collaboration

Particules pLasmas Univers applicationS
Laboratoire de Physique de Clermont

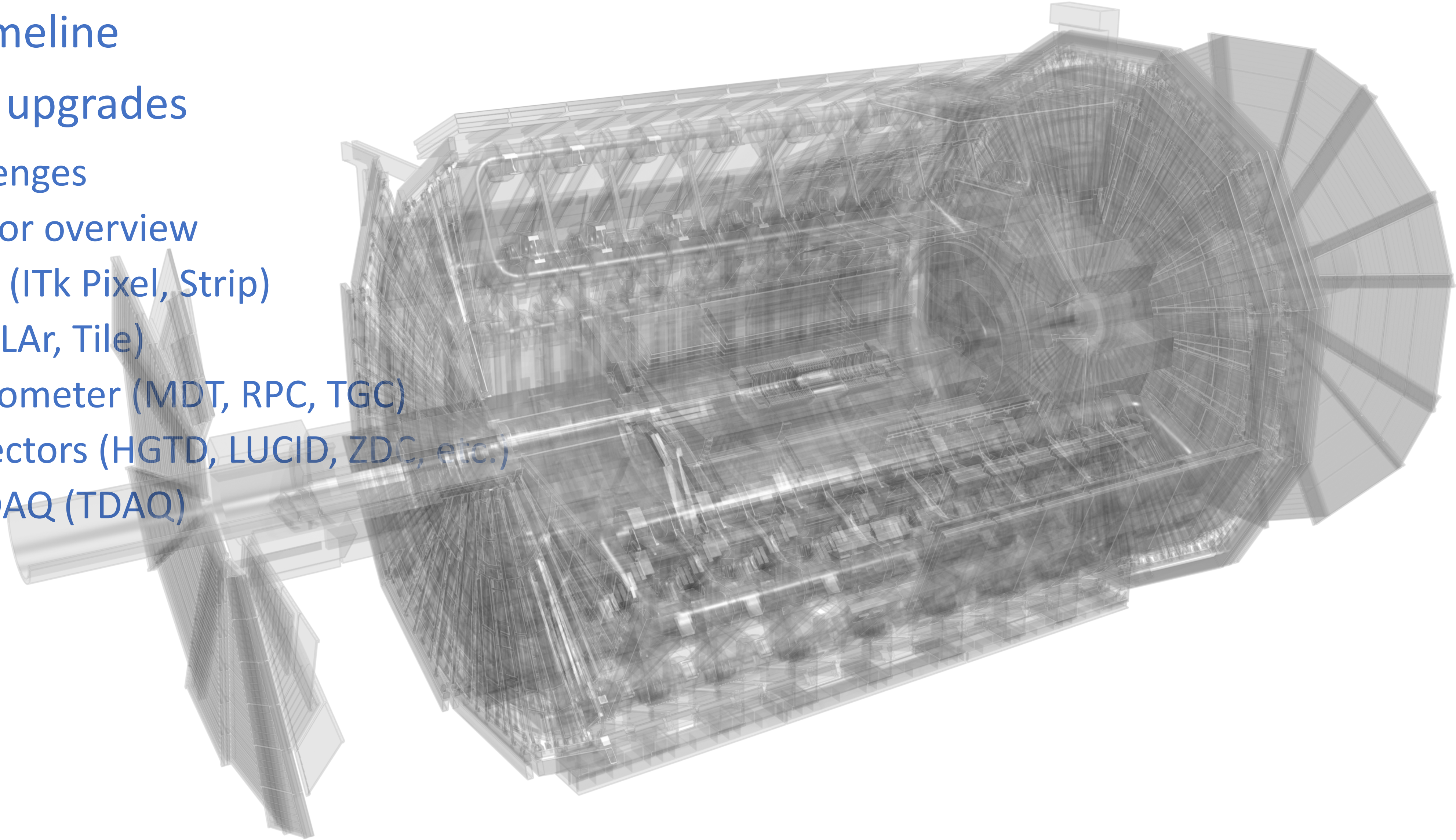
Université Clermont Auvergne

ATLAS Upgrade talks at this conference (WG6)

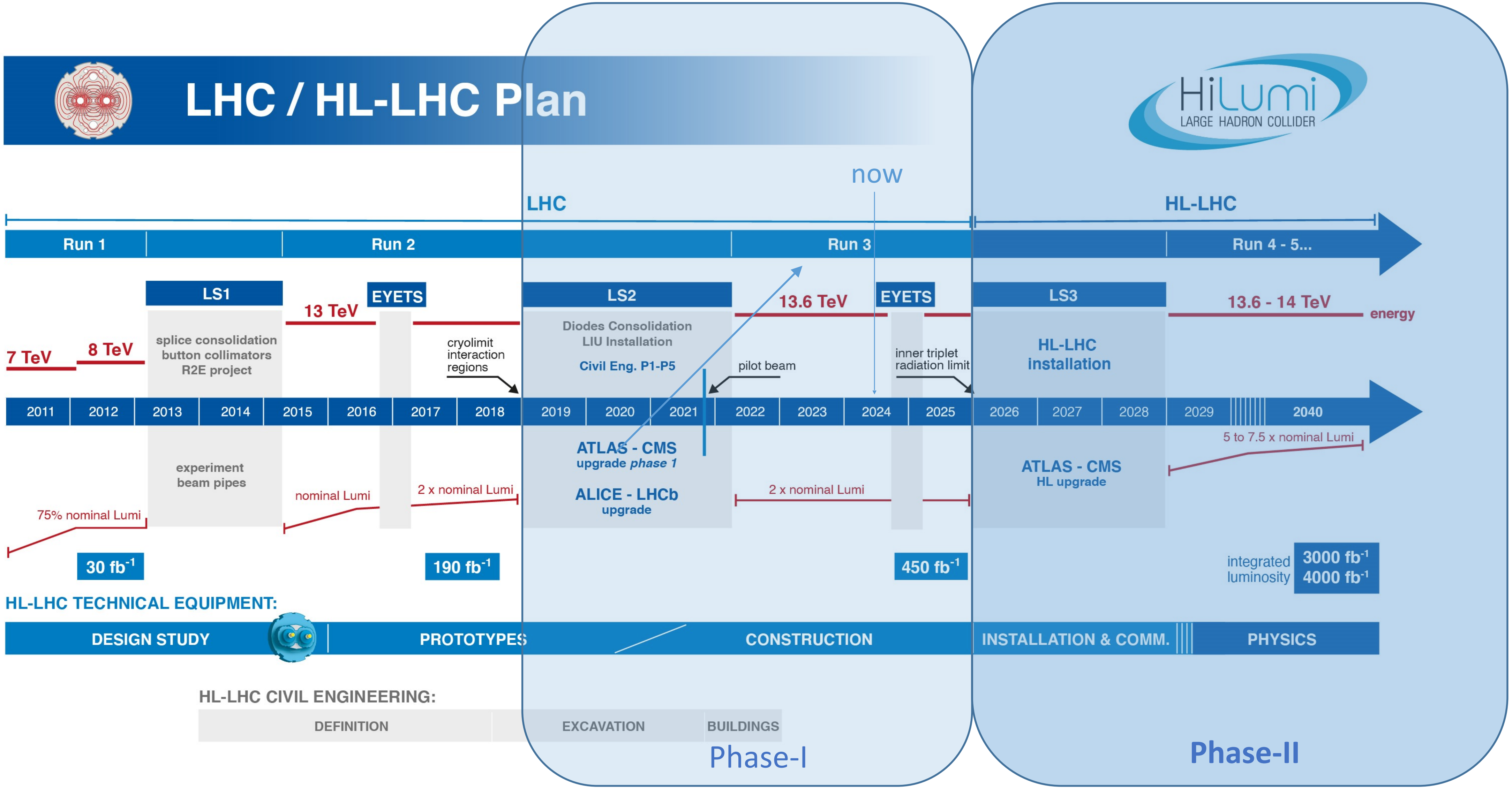
- ATLAS upgrades for High Luminosity LHC - *Oleg Solovyanov*
- Expected performance of the ATLAS ITk detector for HL-LHC – *Yassine El Ghazali*
- ATLAS ITk Pixel Detector Overview - *Ali Skaf*
- The ATLAS ITk Strip Detector System for the Phase-II LHC Upgrade - *Elizaveta Sitnikova*
- Development of the ATLAS Liquid Argon Calorimeter Readout Electronics for the HL-LHC - *Elena Mazzeo Milano*
- Technical challenges and performance of the new ATLAS LAr Calorimeter Trigger - *Emilien Chapon*
- Upgrade of ATLAS Hadronic Tile Calorimeter for the High Luminosity LHC - *Oleg Solovyanov*
- Upgraded Lucid and Zero Degree Calorimeter Detectors for ATLAS at the High Luminosity LHC - *Antonio Sbrizzi*

Outline

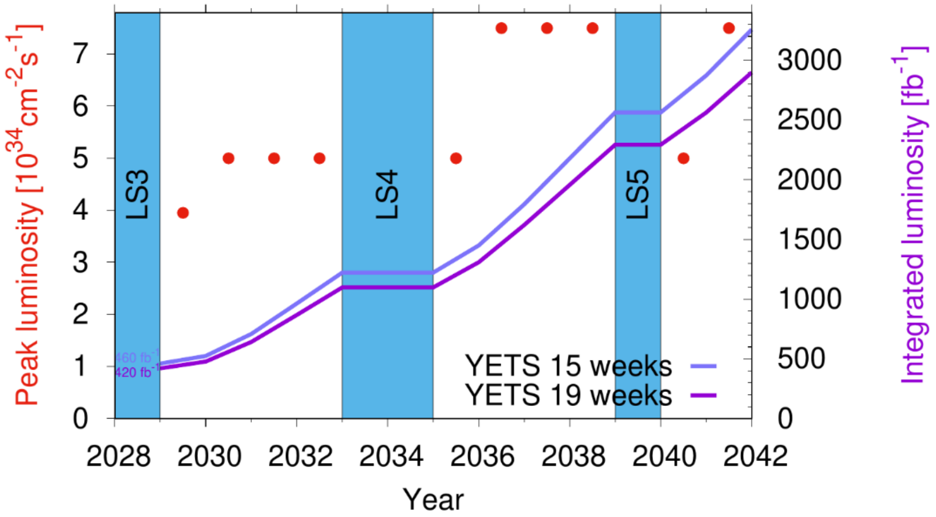
- LHC/HL-LHC timeline
- ATLAS Phase-II upgrades
  - HL-LHC challenges
  - ATLAS detector overview
  - Inner Tracker (ITk Pixel, Strip)
  - Calorimetry (LAr, Tile)
  - Muon Spectrometer (MDT, RPC, TGC)
  - Forward detectors (HGTD, LUCID, ZDC, etc.)
  - Trigger and DAQ (TDAQ)
- Summary

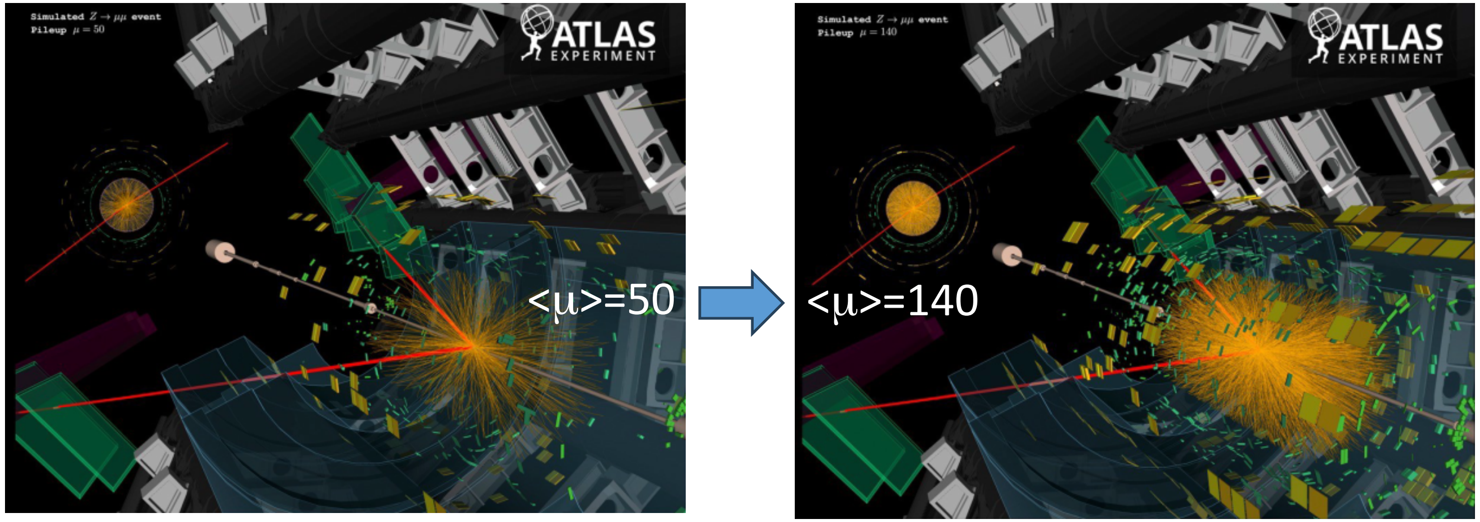


HL-LHC timeline



HL-LHC challenges for detectors

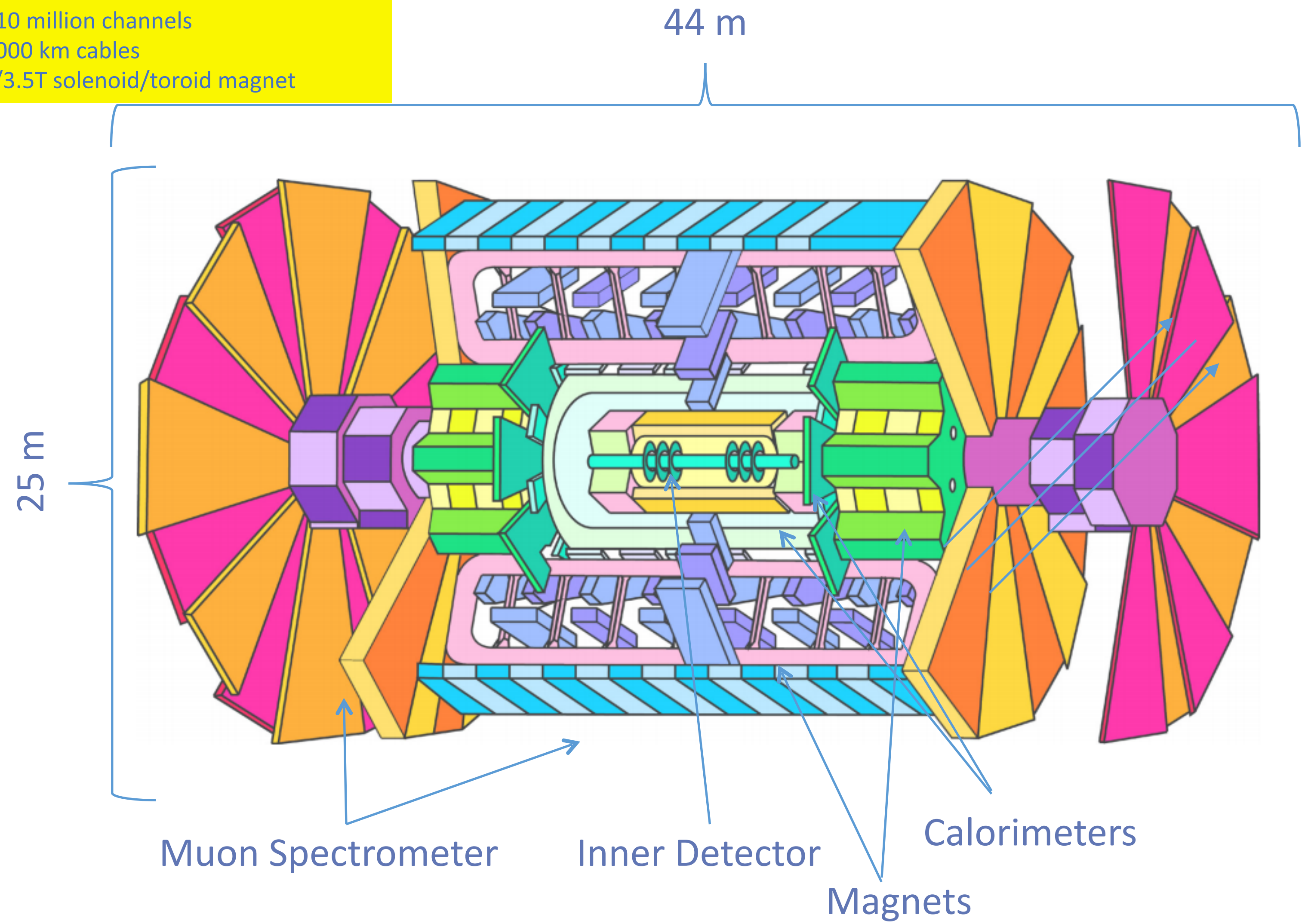




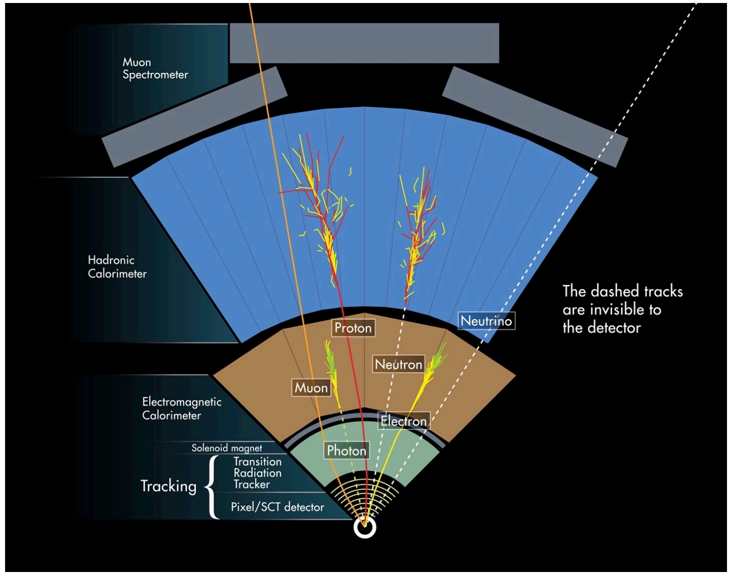
- The HL-LHC programs challenges the detector and detector electronics
  - Higher luminosity – from $2x10^{34}$ cm^{-2}s^{-1} up to $7.5x10^{34}$ cm^{-2}s^{-1}, higher L1 trigger rates from 100 kHz to 1 MHz
  - Higher pile-up conditions – from <μ>=20 of LHC design up to <μ>=200 for HL-LHC, large detector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

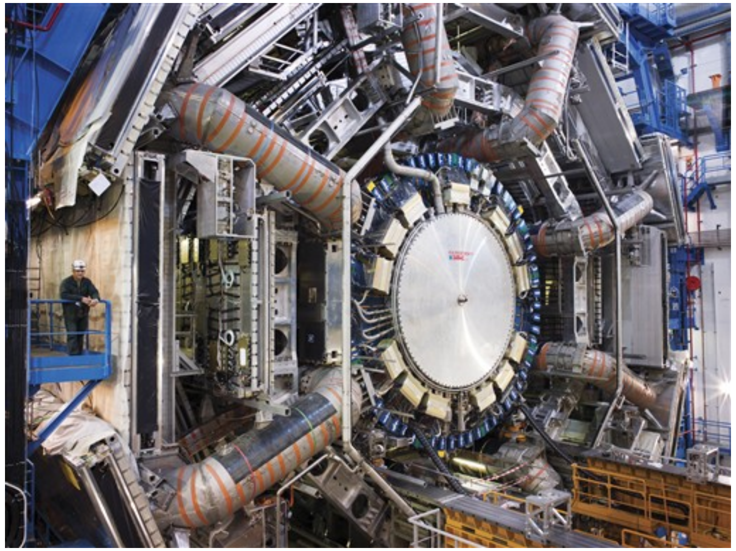
ATLAS detector overview

~7000 tons
~110 million channels
~3000 km cables
2T/3.5T solenoid/toroid magnet



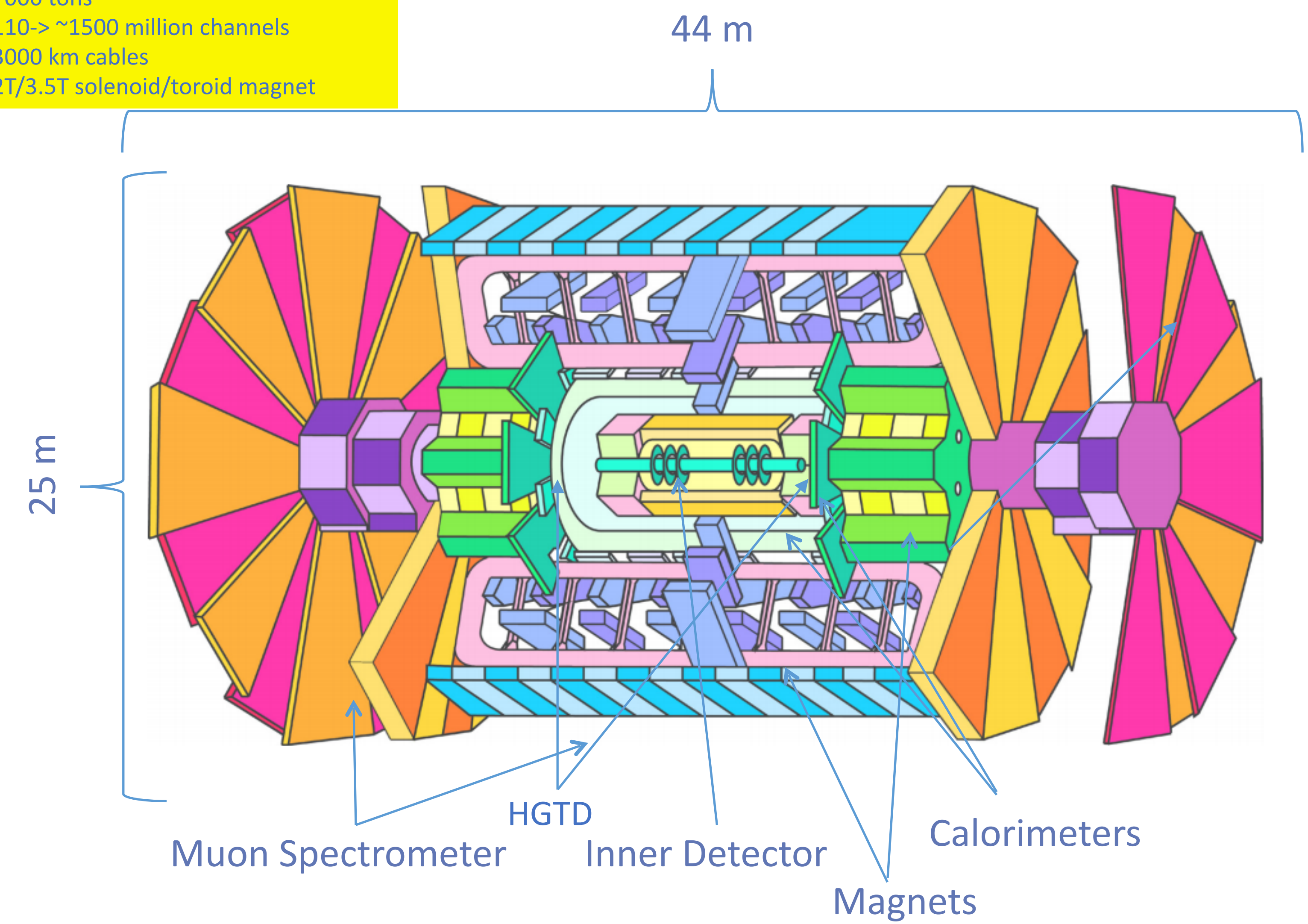
ATLAS Colouring Book





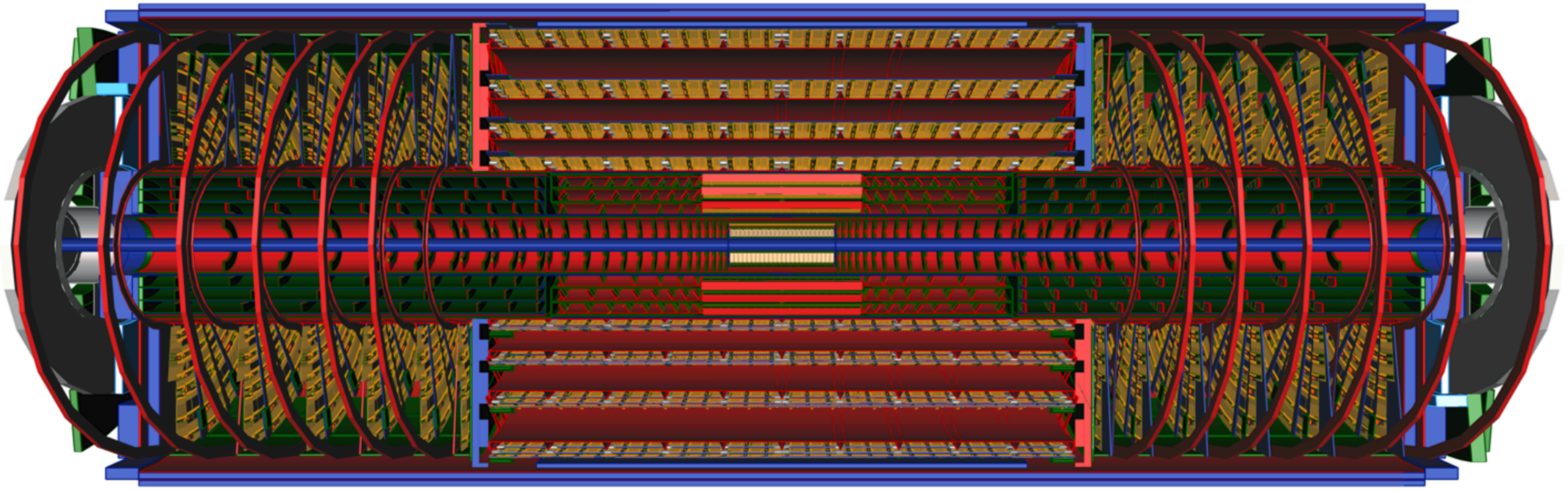
ATLAS detector Phase-II upgrades

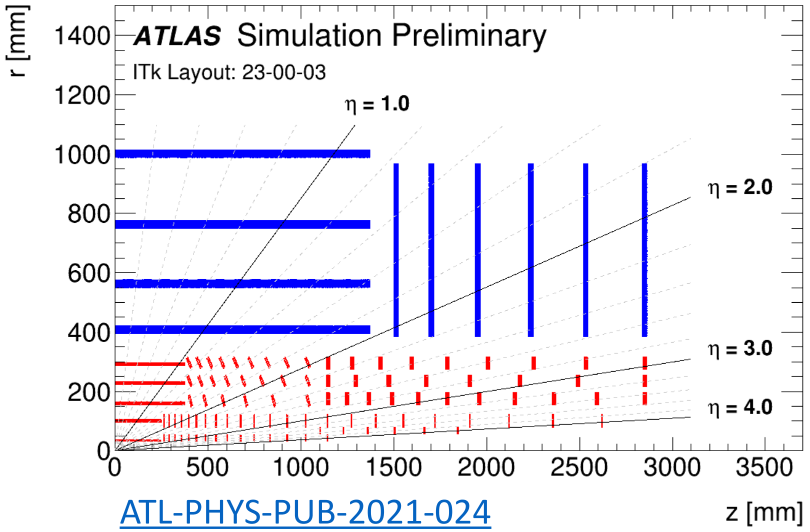
~7000 tons
~110-> ~1500 million channels
~3000 km cables
~2T/3.5T solenoid/toroid magnet



System	Phase-II upgrades
Tracker	Completely new Inner Tracker (ITk), comprised of Pixel and Strip sub-detectors
Calorimetry	On- and off-detector 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
Trigger & DAQ	New architecture, electronics and software

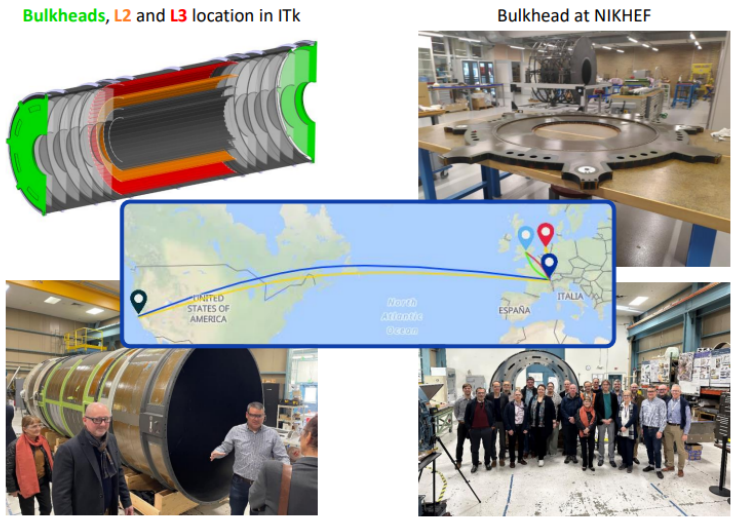
Inner tracker (ITk)





ATL-PHYS-PUB-2021-024

- Completely new all-silicon inner tracker with increased acceptance from |η|<2.5 (ID) to |η|<4 (ITk), reduced material budget 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
  - 165 m^2 of silicon strip and 13 m^2 of silicon pixels
- Tracking performance comparable or better than before at much higher pile-up conditions
  - ≥ 13 hits/track in the barrel and ≥ 9 hits / track in the forward region
- At the advanced stages for common mechanics and cooling

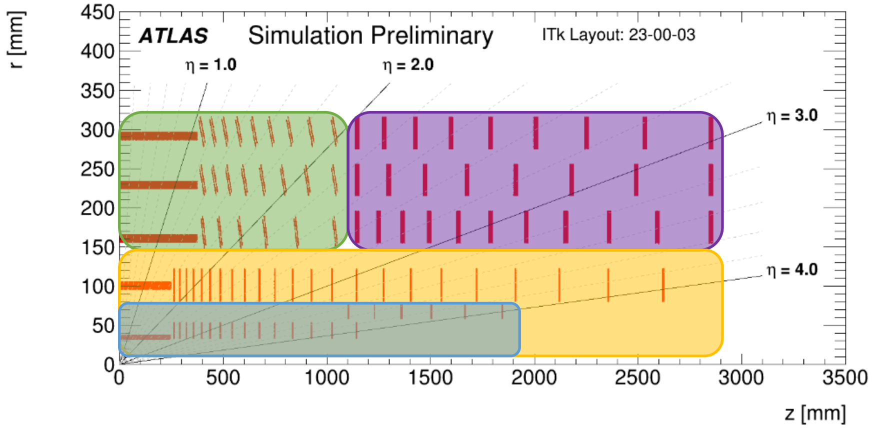


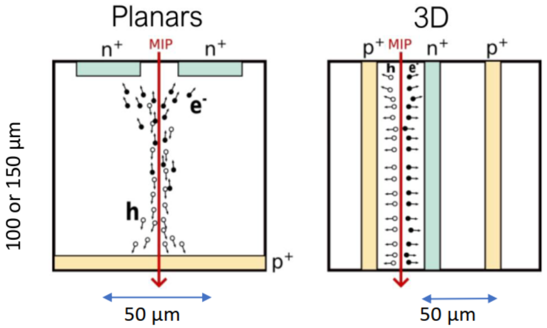
OC barrel and forward assembled and surveyed in LBNL

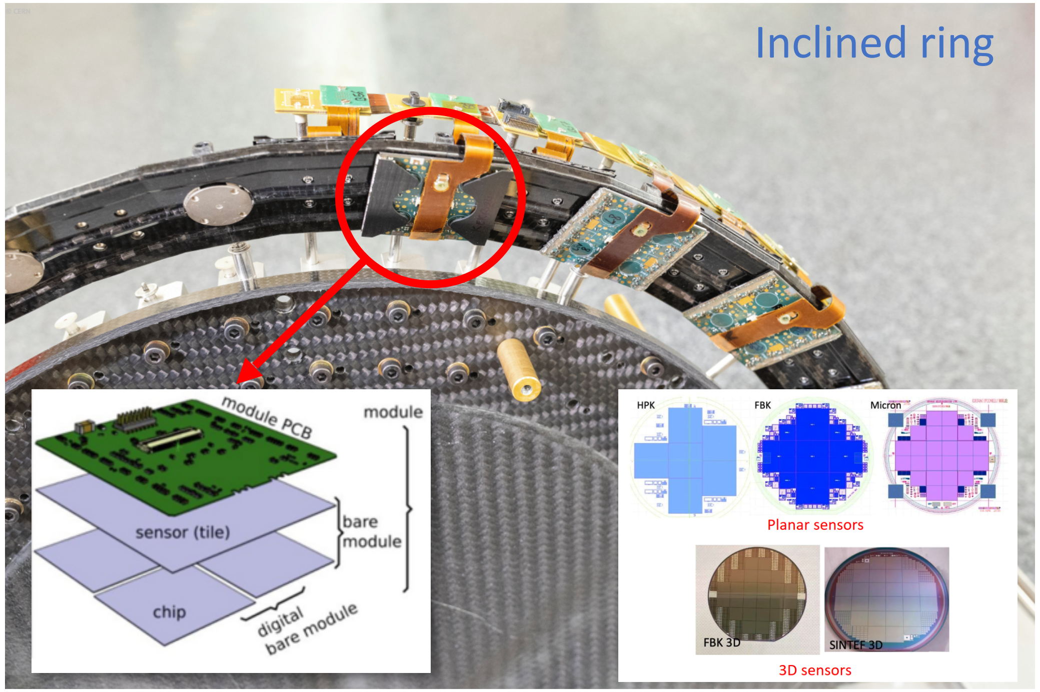
Visit at LBNL in December 2023

Inner tracker (ITk) Pixel

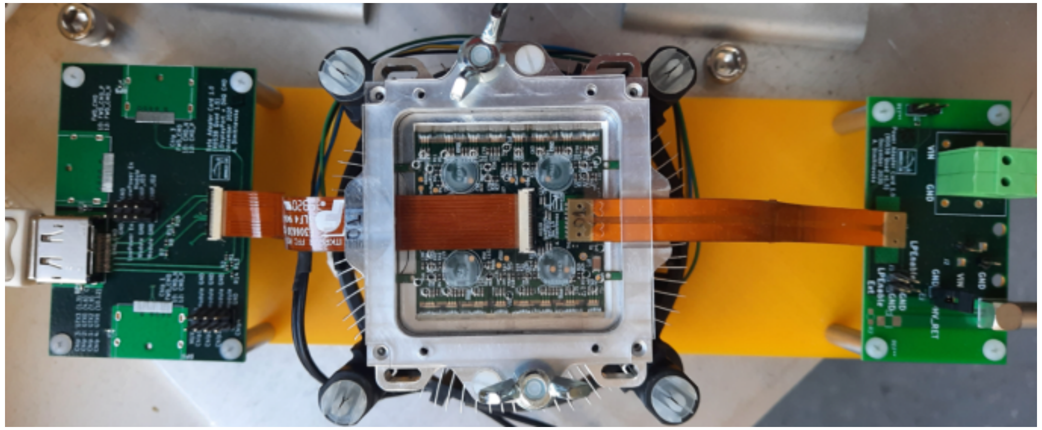
~13 m2 of silicon (1.2 m2 ID)
~9000 modules (200 ID)
~1400 Mpx (92 Mpx ID)





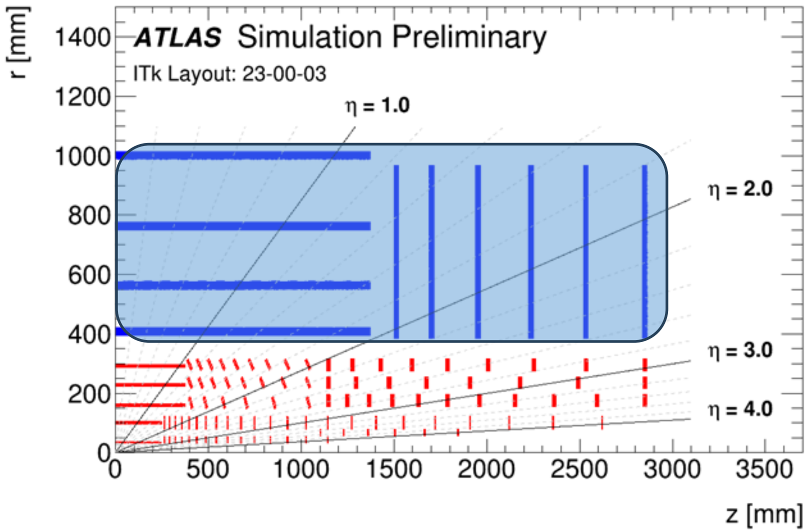


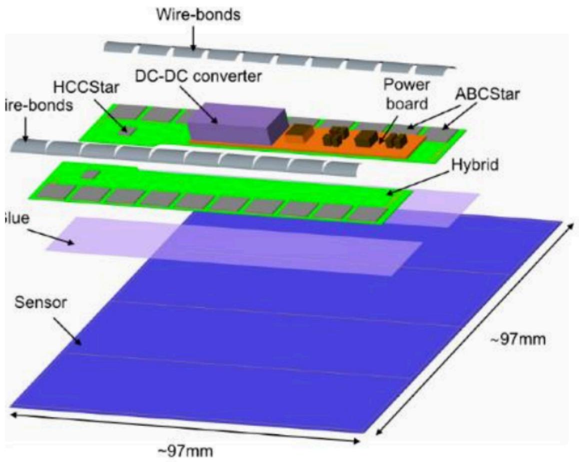
- Silicon sensors with 50x50 and 25x100 µm pixel size of small 100-150 µm thickness
- Sensor production is in progress
- ASIC production has been started
- Module production starts this year (2024)
- Many tests with pre-production items are ongoing

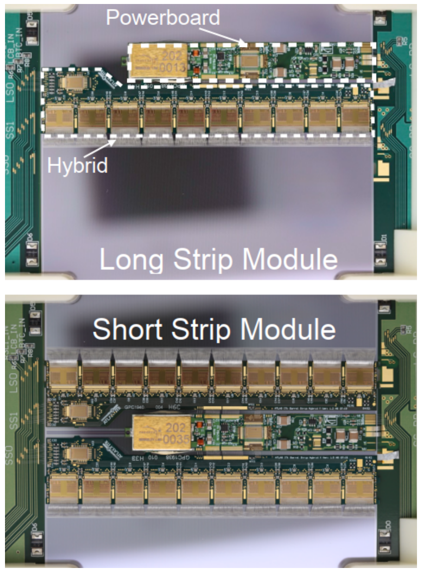


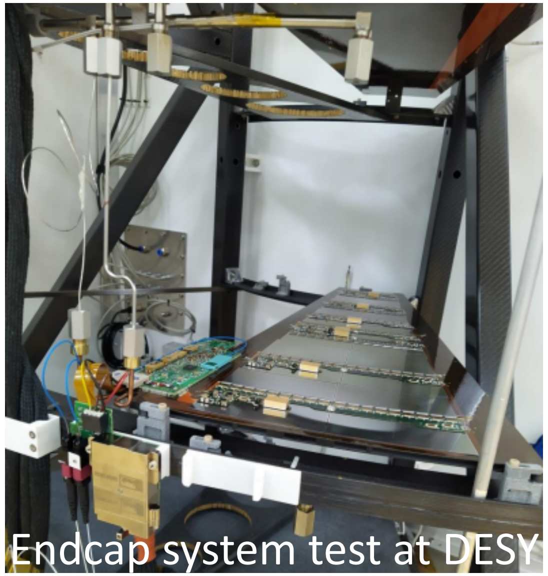
Inner tracker (ITk) Strip

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

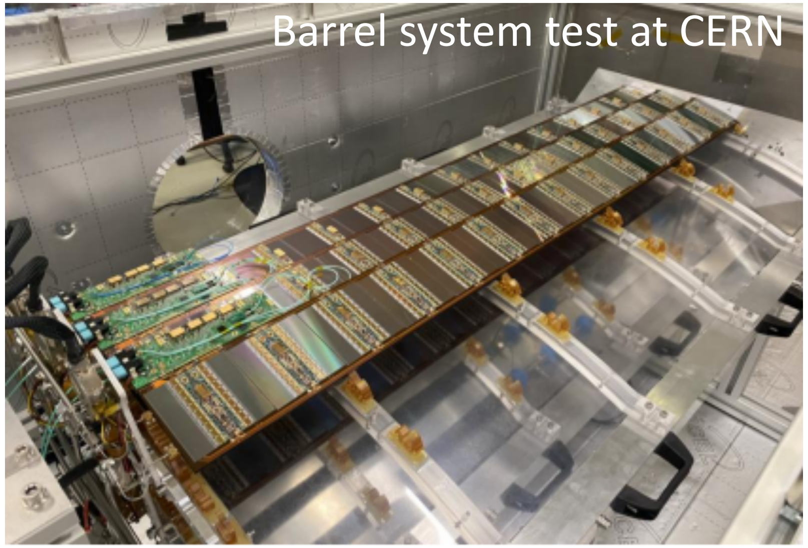




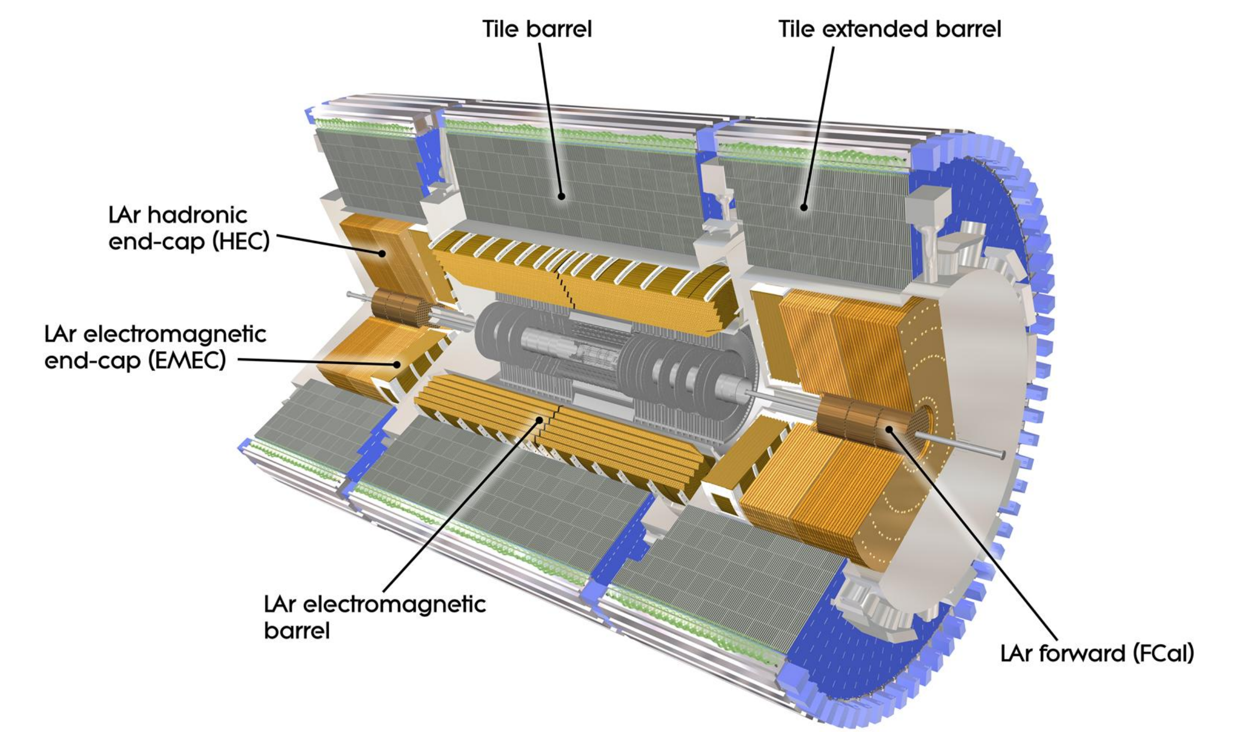


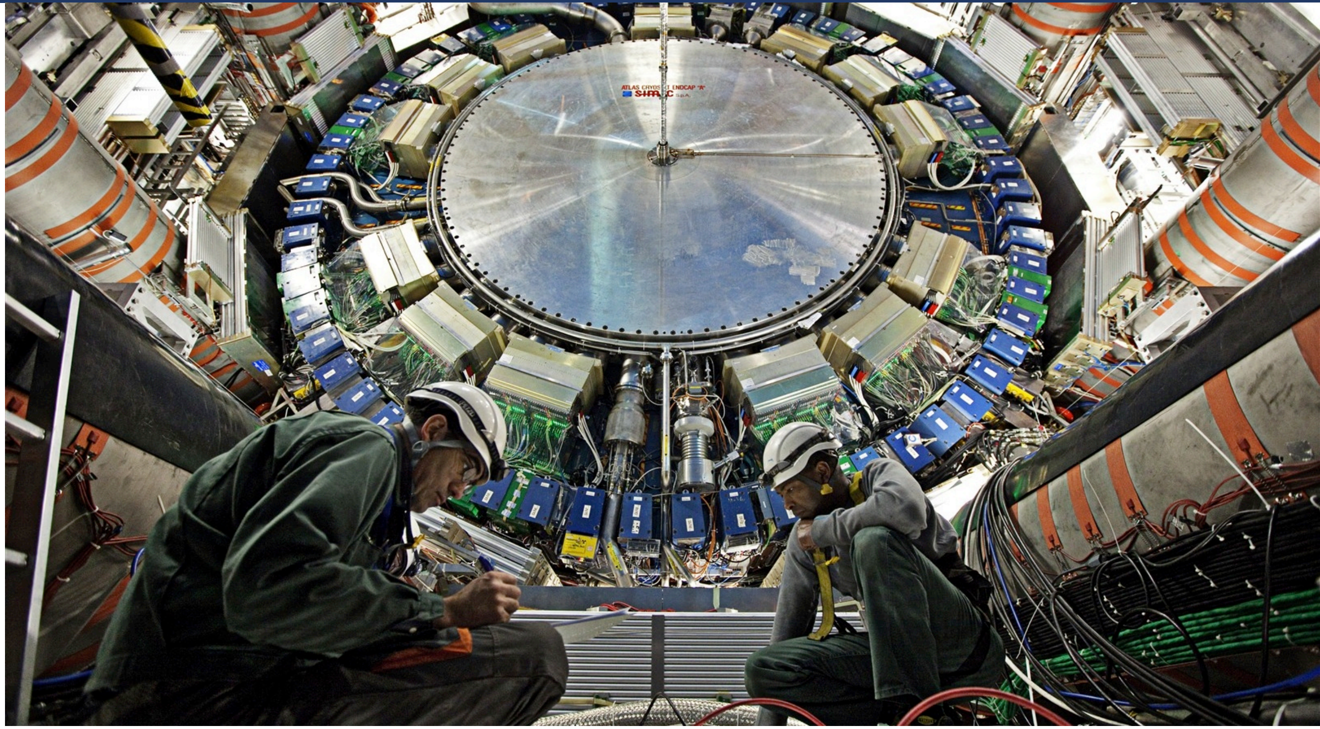


- Silicon strip sensors with 70-80 μm pitch
- Sensor and ASIC production is well underway
- Mechanical sub-structures in pre-production
- Many system tests are ongoing



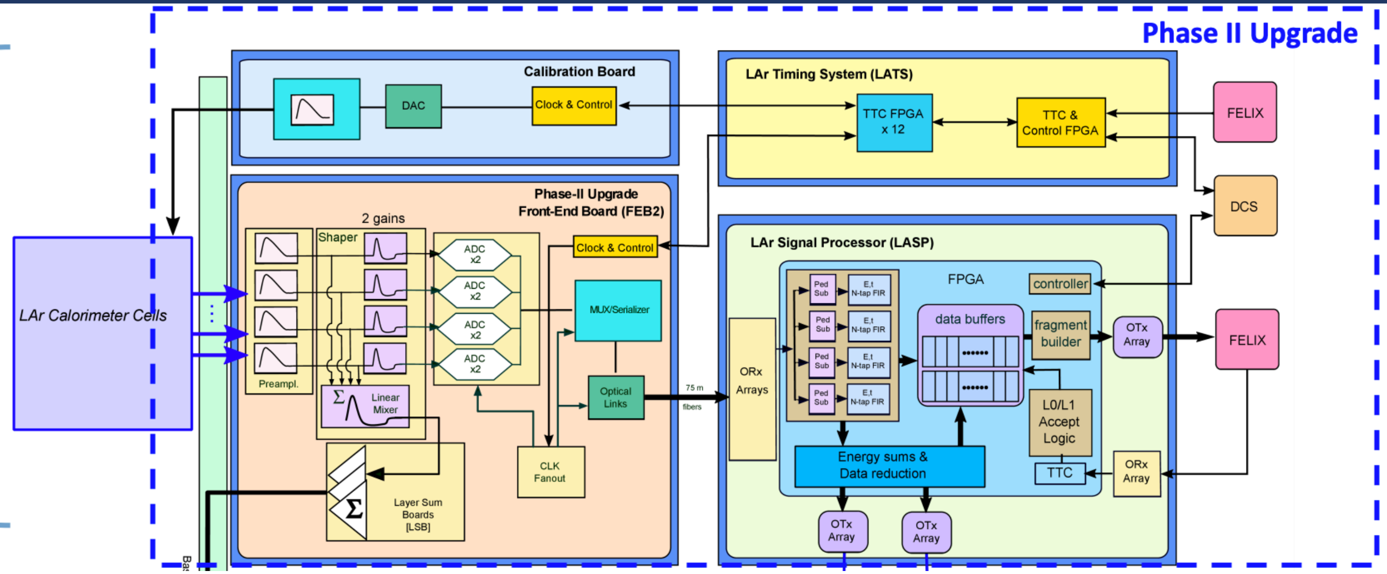
Calorimetry

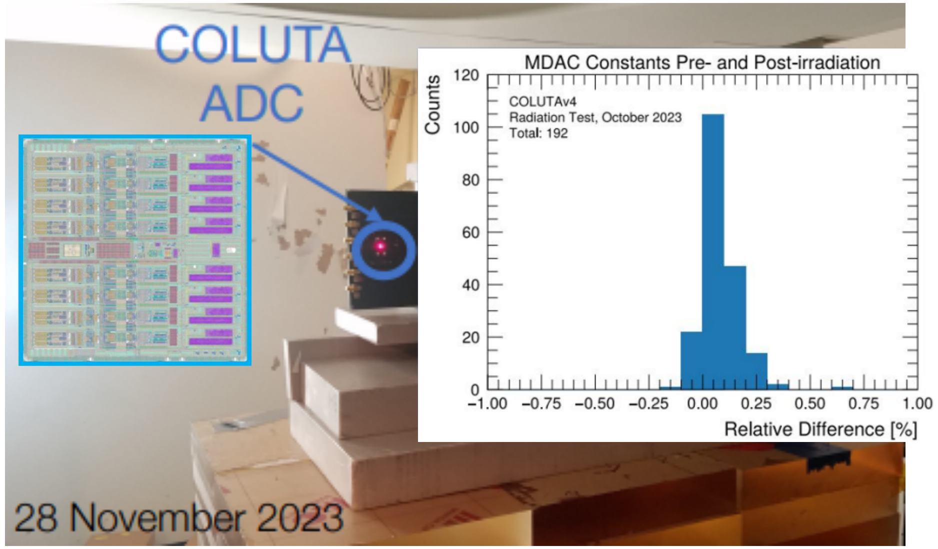




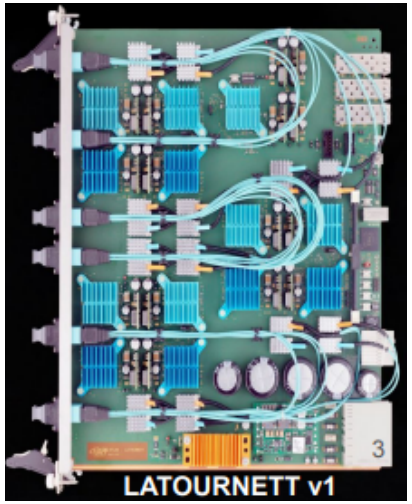
- Complete replacement of the on-detector electronics to meet new radiation, trigger and readout performance criteria
- ASIC development, complex FPGA firmware, high-speed optical links
- New off-detector electronics, new power supplies

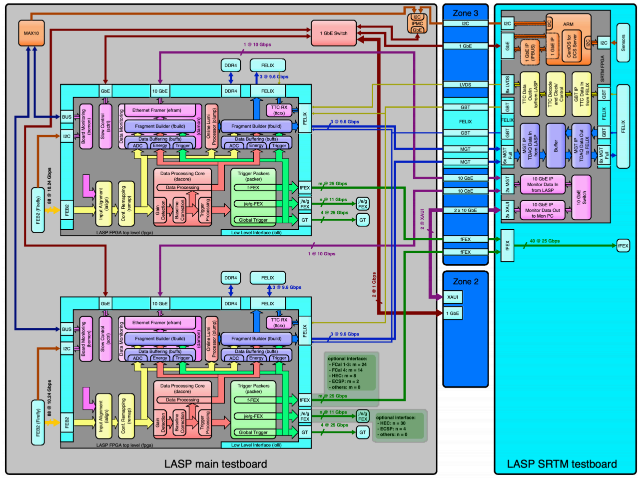
Electromagnetic calorimeter (LAr)





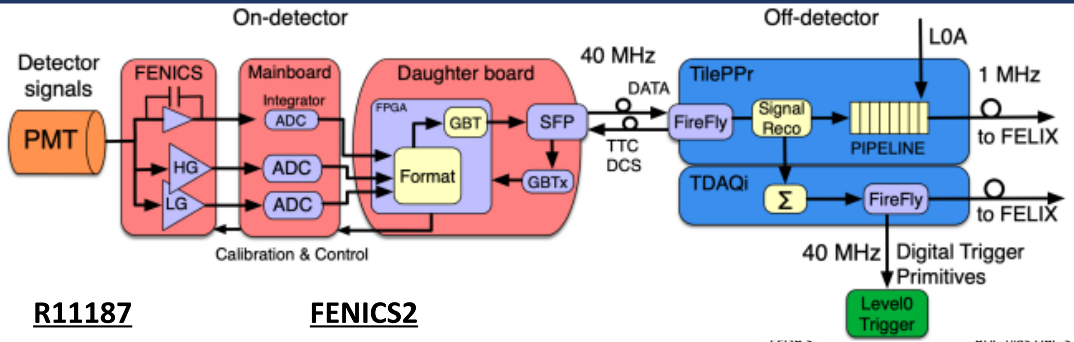
- New on- and off-detector electronics
- 40 MHz continuous readout
- Pre-production ASICs available
- Irradiation tests ongoing
- Preparation for slice-tests
- Large firmware effort

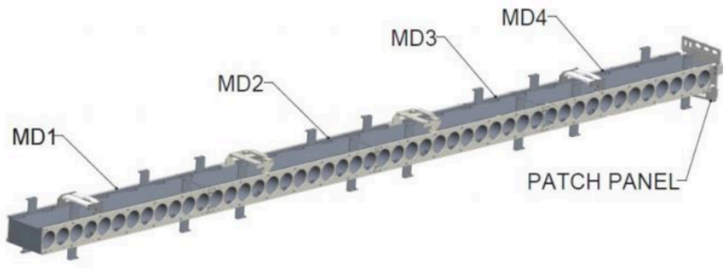


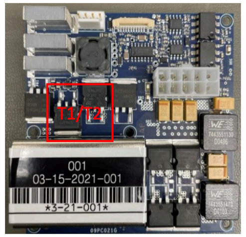


Back-end firmware scheme

Hadron calorimeter (Tile)



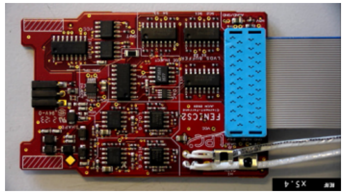




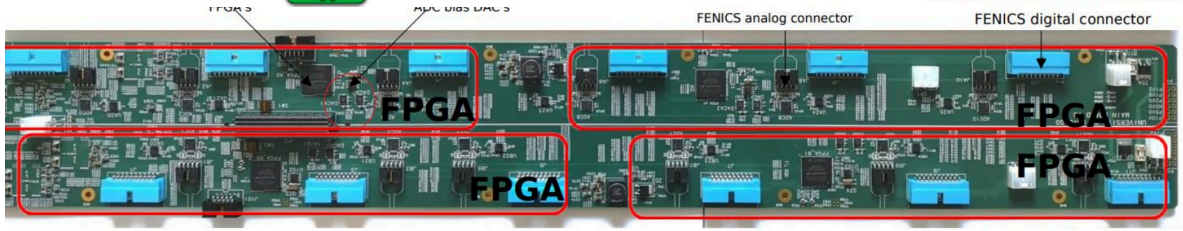
Power brick

R11187

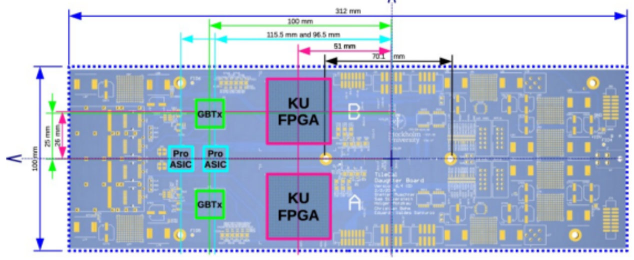
FENICS2



Main Board V4



DB6v4



- New on- and off-detector 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
- Production phase in many areas, some already completed and delivered

PPR (CPM + Carrier)

TDAQi in operation

Muon spectrometer

- Upgrade of several types of muon chambers
  - Barrel Inner (BI) RPC+sMDT
  - End-Cap Inner Layer (EIL) TGC
- Upgrade of readout electronics
- Upgrade of power systems
- Most of the projects in production phase
- Some chambers and ASICs already fully produced

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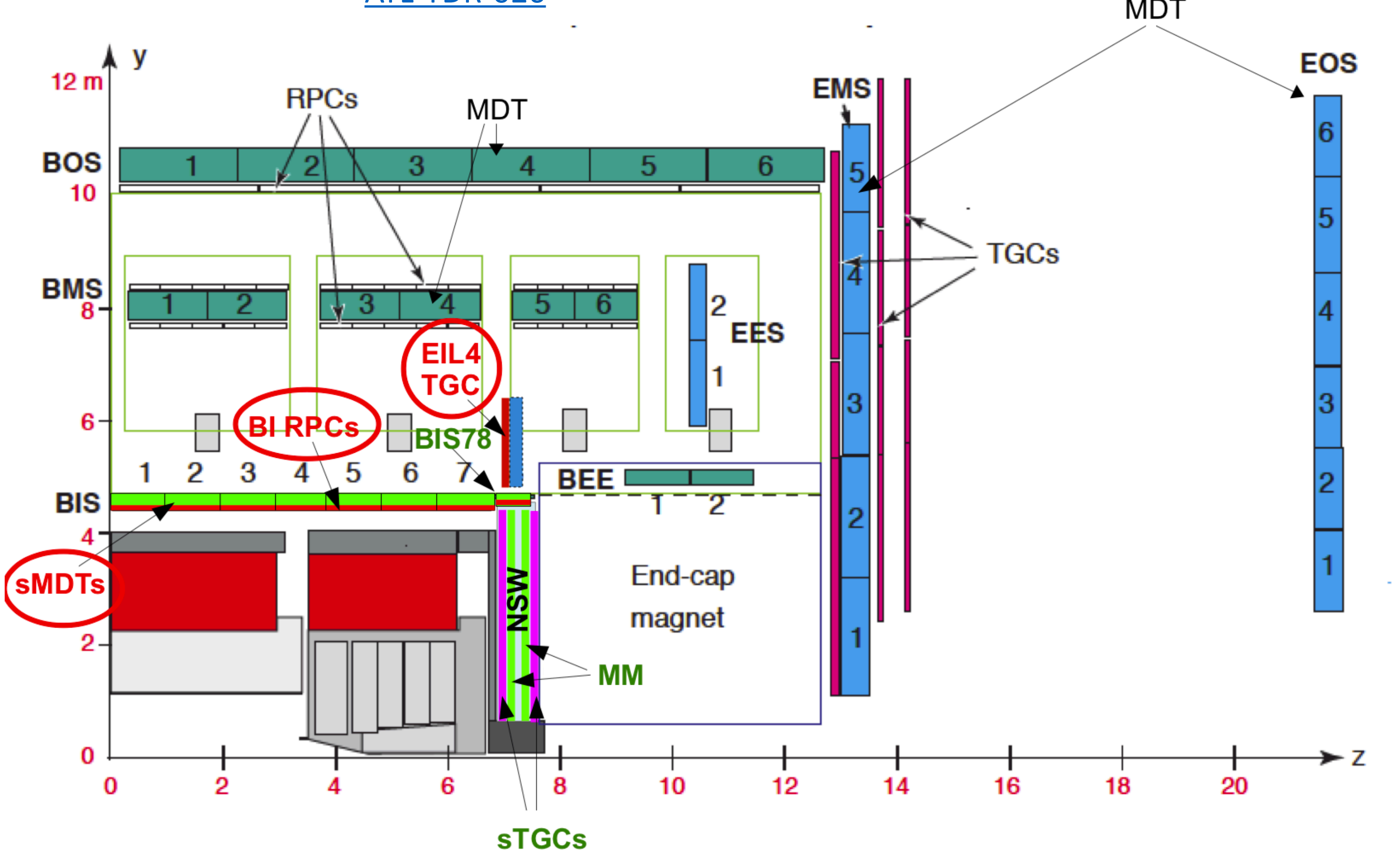
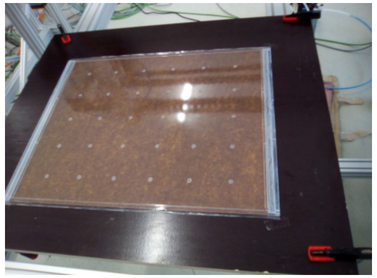


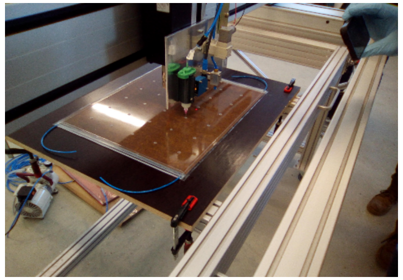
MDT – Muon Drift Chambers, **RPC** – Resistive Plate Chambers, **TGC** – Thin Gap Chambers

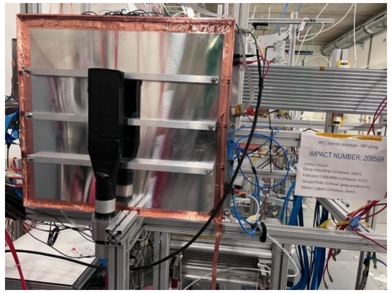
Muon spectrometer chambers

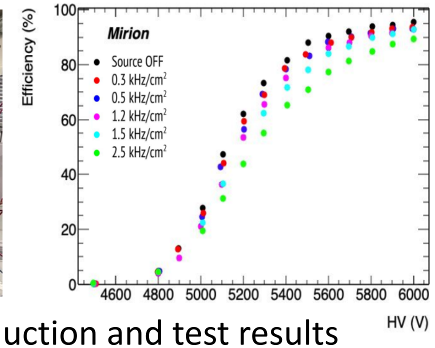
- sMDT
  - Production complete
  - High precision and performance
- RPC
  - Mechanics design validated
  - Production is about to start
- TGC
  - Production started
  - Several chambers already done

New sMDT chamber tubes and test of chambers after production

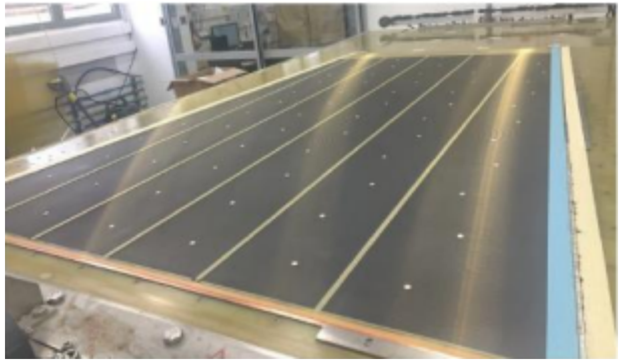








RPC chamber pre-production and test results

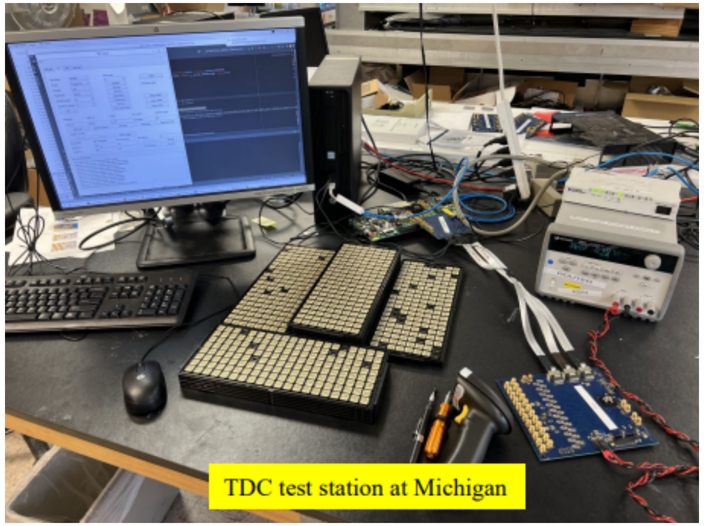


TGC EIL-4 chamber production

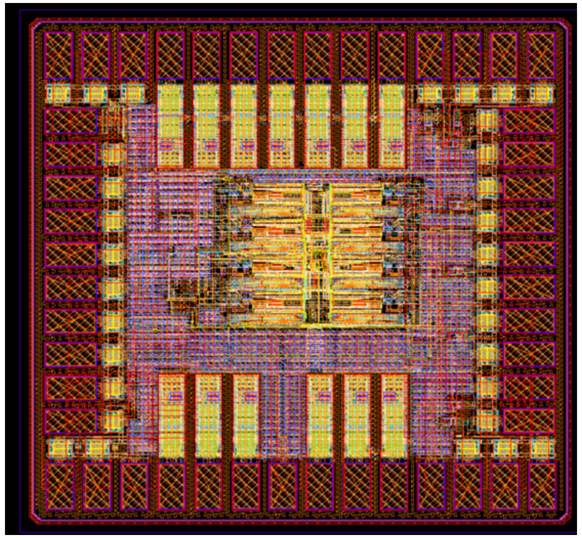
Muon spectrometer electronics

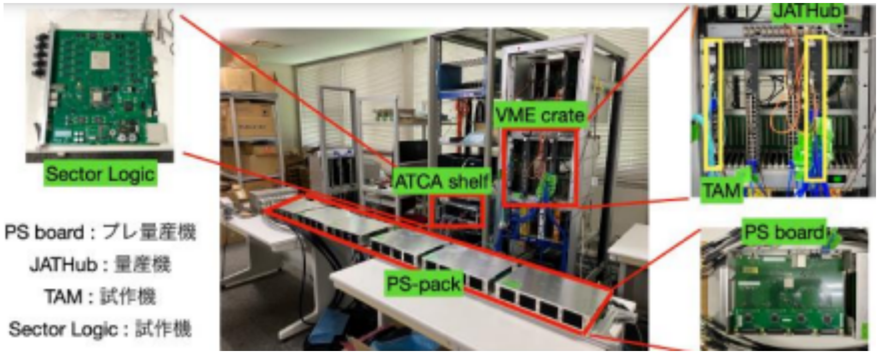
- MDT
  - ASICs are fully produced
  - Pre-production boards are being validated
- RPC
  - Moving towards production
  - ASICs submitted for production
  - Full validation of readout chain
- TGC
  - ASIC production completed
  - Moving towards board production

MDT TDC ASIC tests



RPC FE ASIC prototype

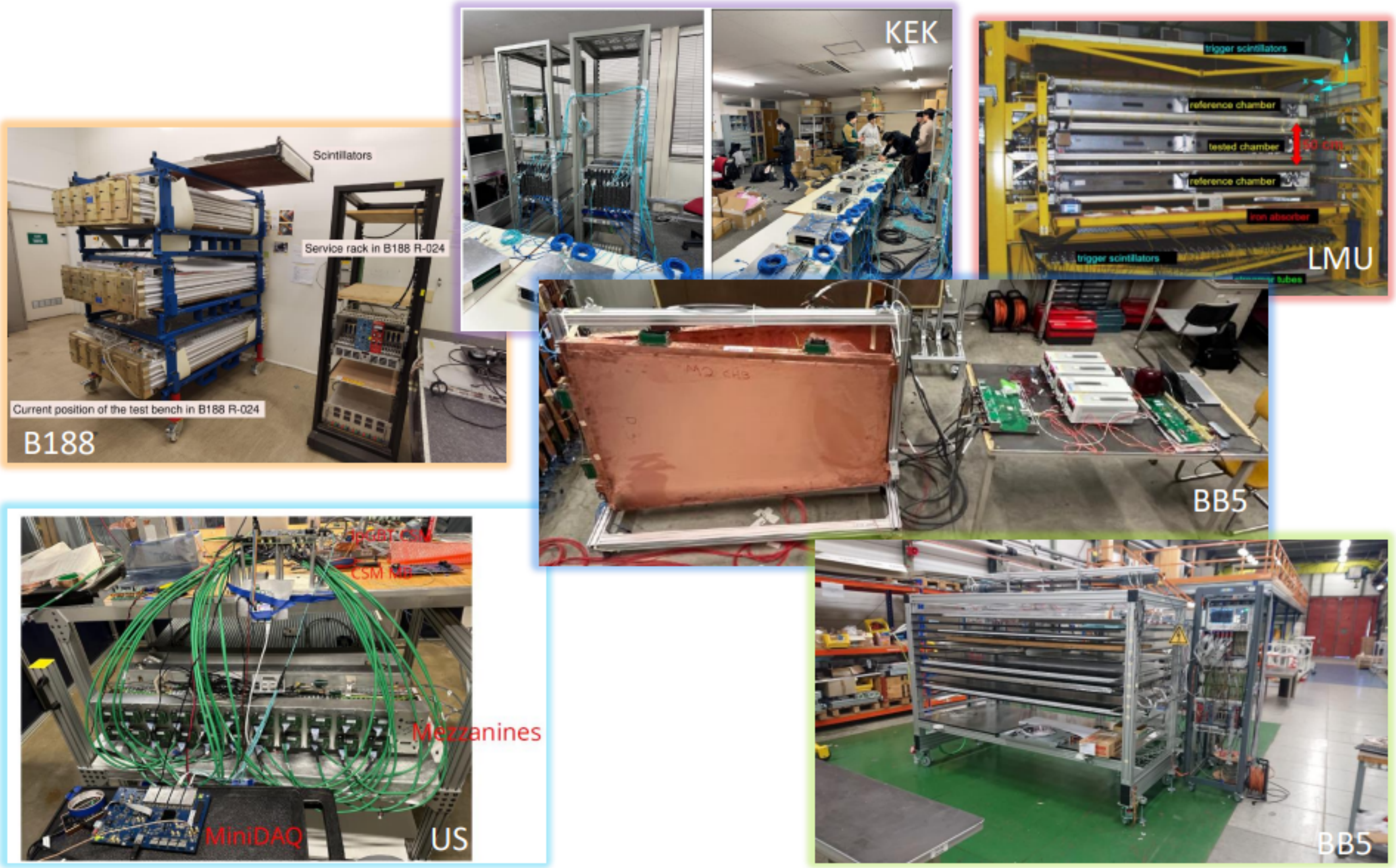




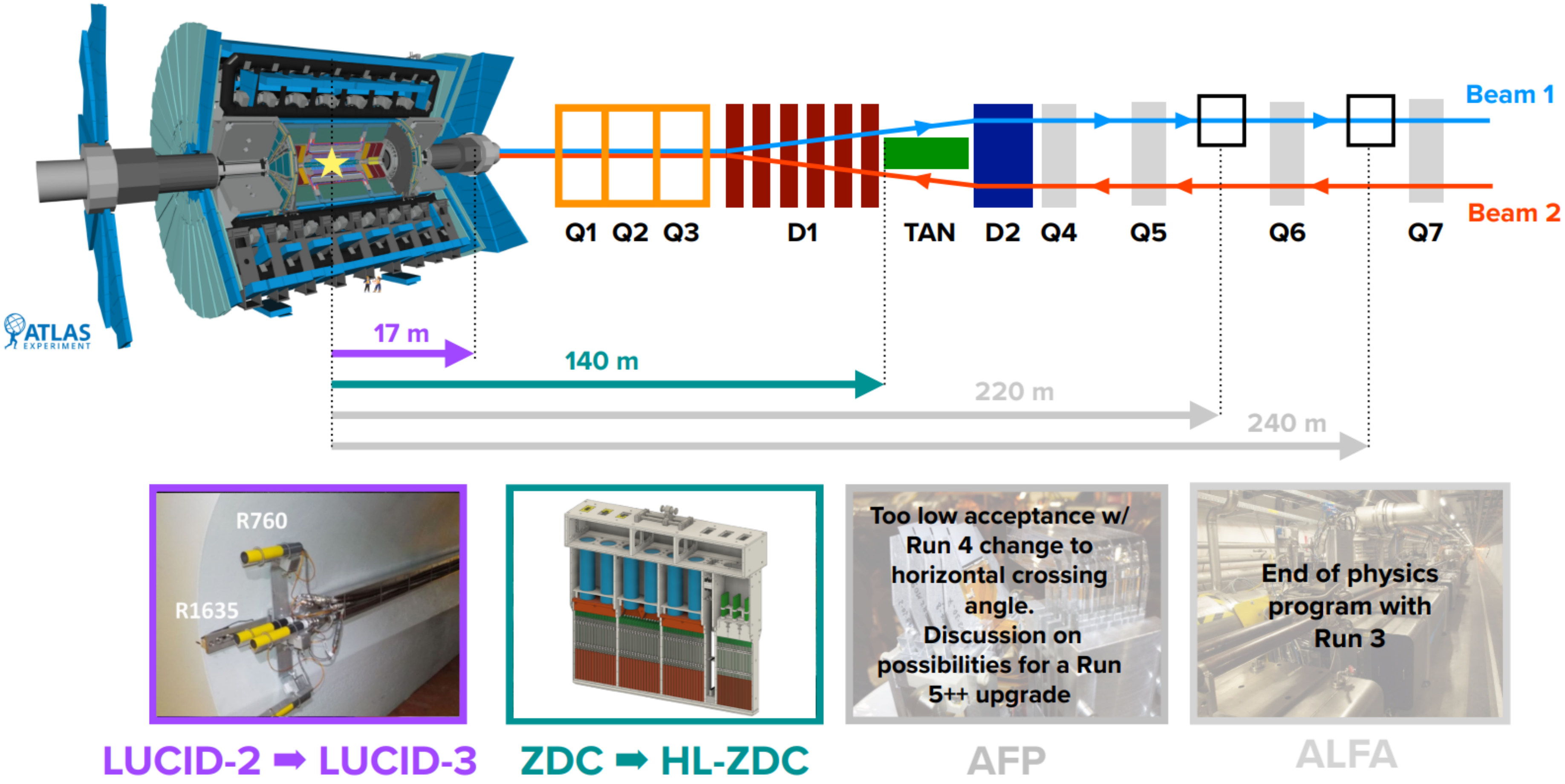
TGC joint integration test

Muon spectrometer integration tests

- Complex multi-component project
- Requires multiple test and integration facilities
- Underway at multiple cites

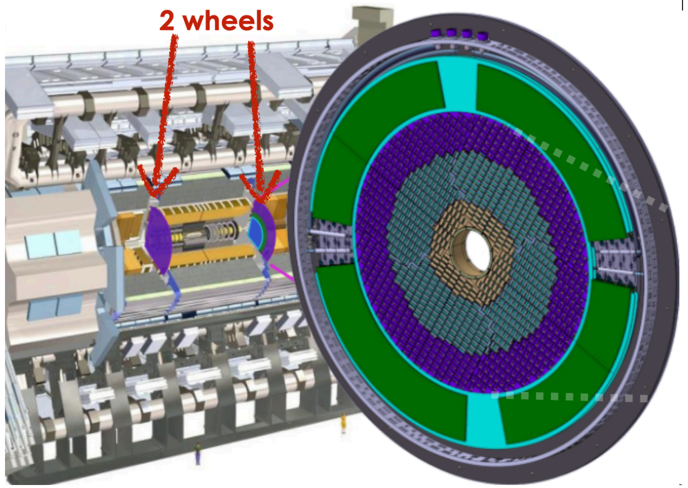


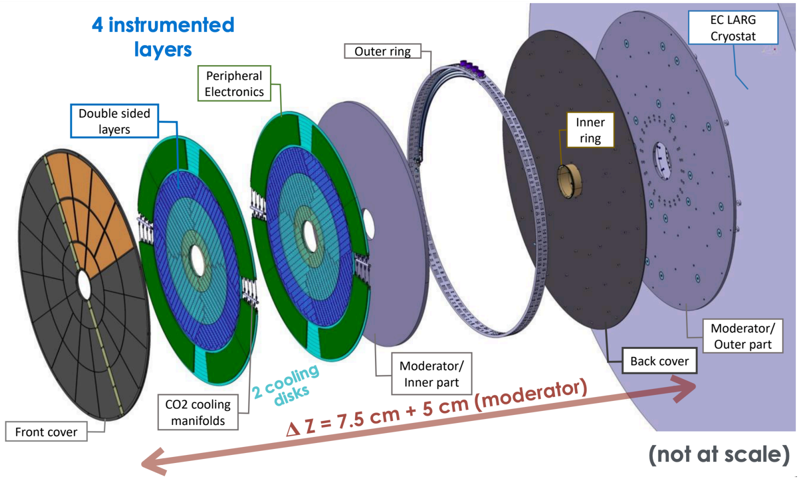
Forward and luminosity detectors

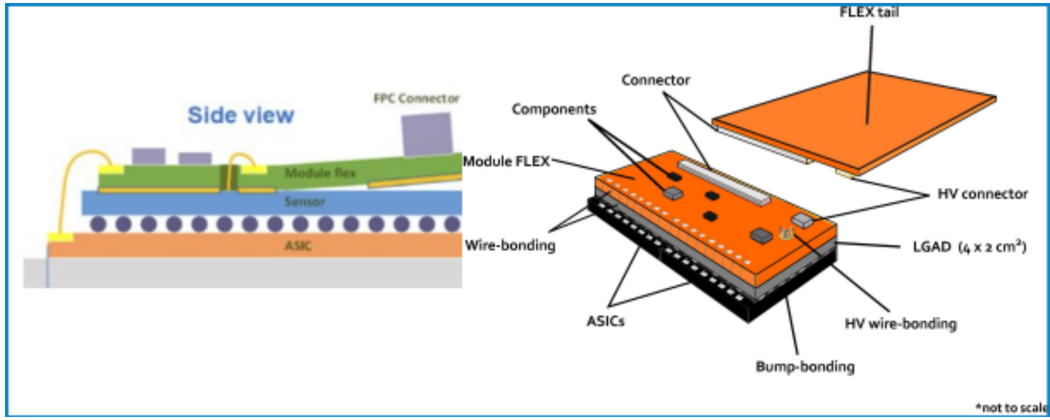


- HL-LHC program requires stable and precise luminosity measurement
- Rich forward physics and Heavy Ion physics program
- New luminosity and timing detector – HGTD
- Upgrade of luminometers and forward detectors
  - Beam Conditions Monitor (BCM')
  - Luminosity Cherenkov Integrating Detector (LUCID3)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

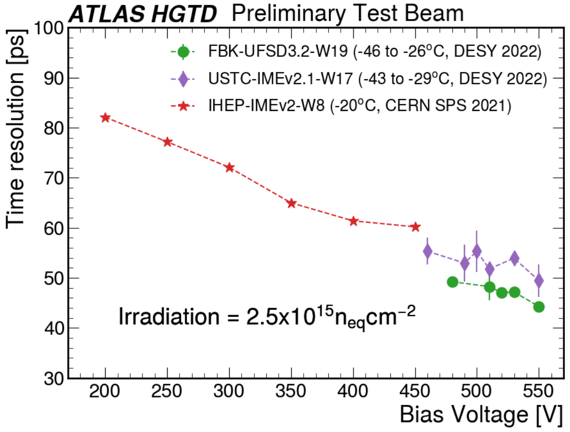
High-granularity timing detector (HGTD)







- Fine timing (30-50ps/track) 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, bump-bonded to read-out ASIC. Pre-production complete, performance matches design requirements.
- Read-out ASIC (ALTIROC3) shows good performance, pre-production version (ALTIROC-A) to be submitted soon
- Mechanics and cooling design progress



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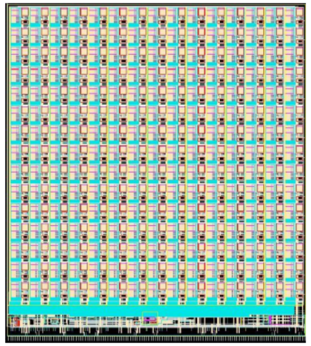
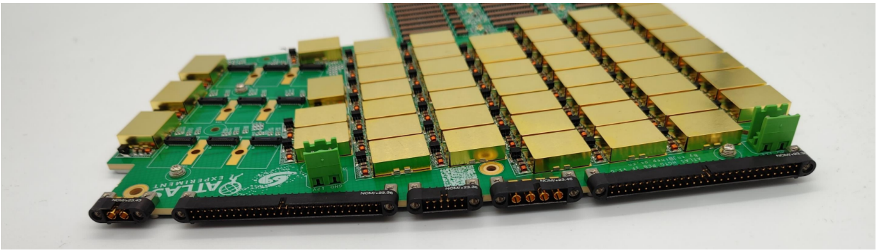
LGAD sensor

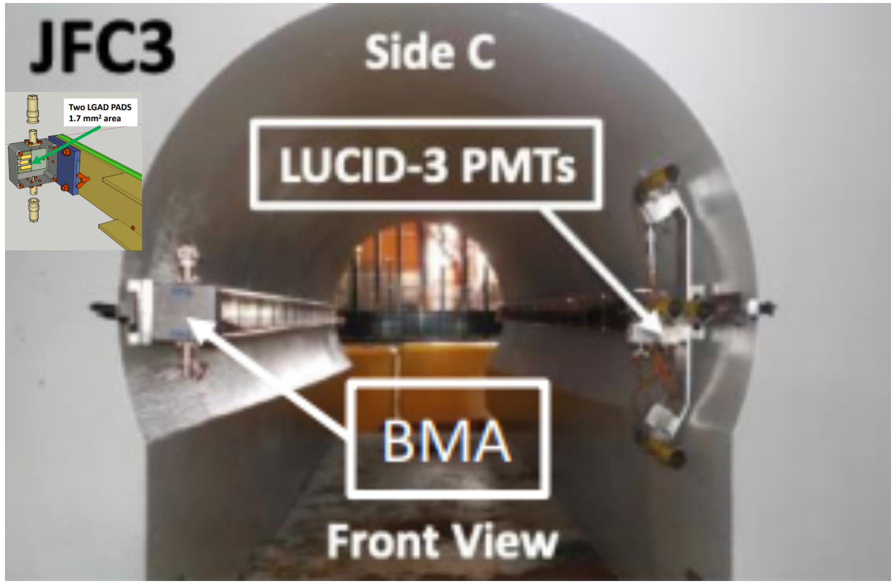


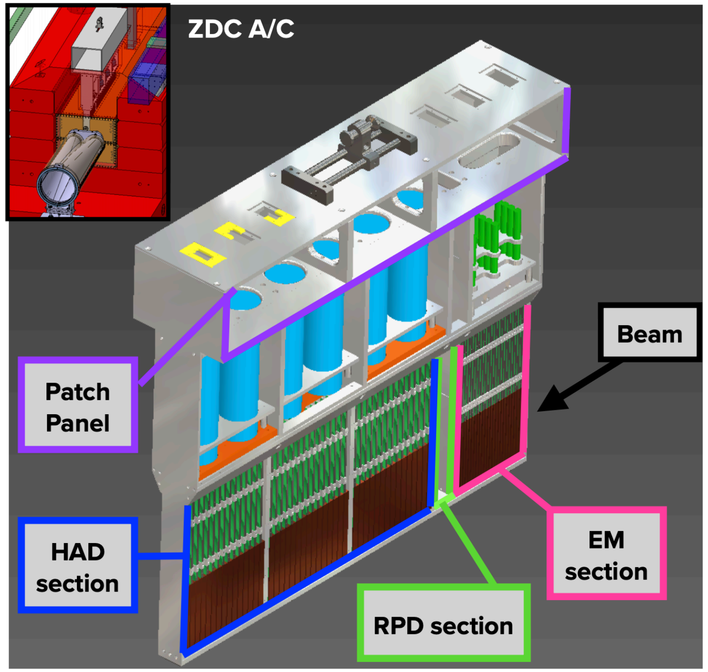
ALTIROC-A

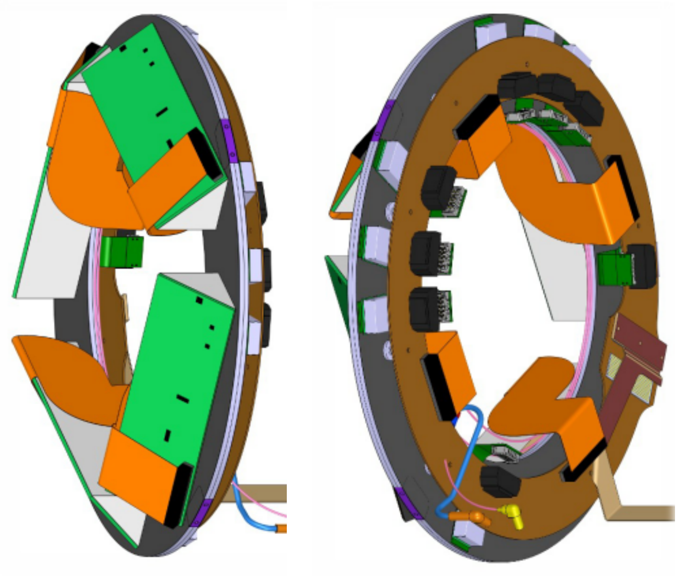


Full size Peripheral Electronics Board (PEB) prototype

Other forward detectors upgrade





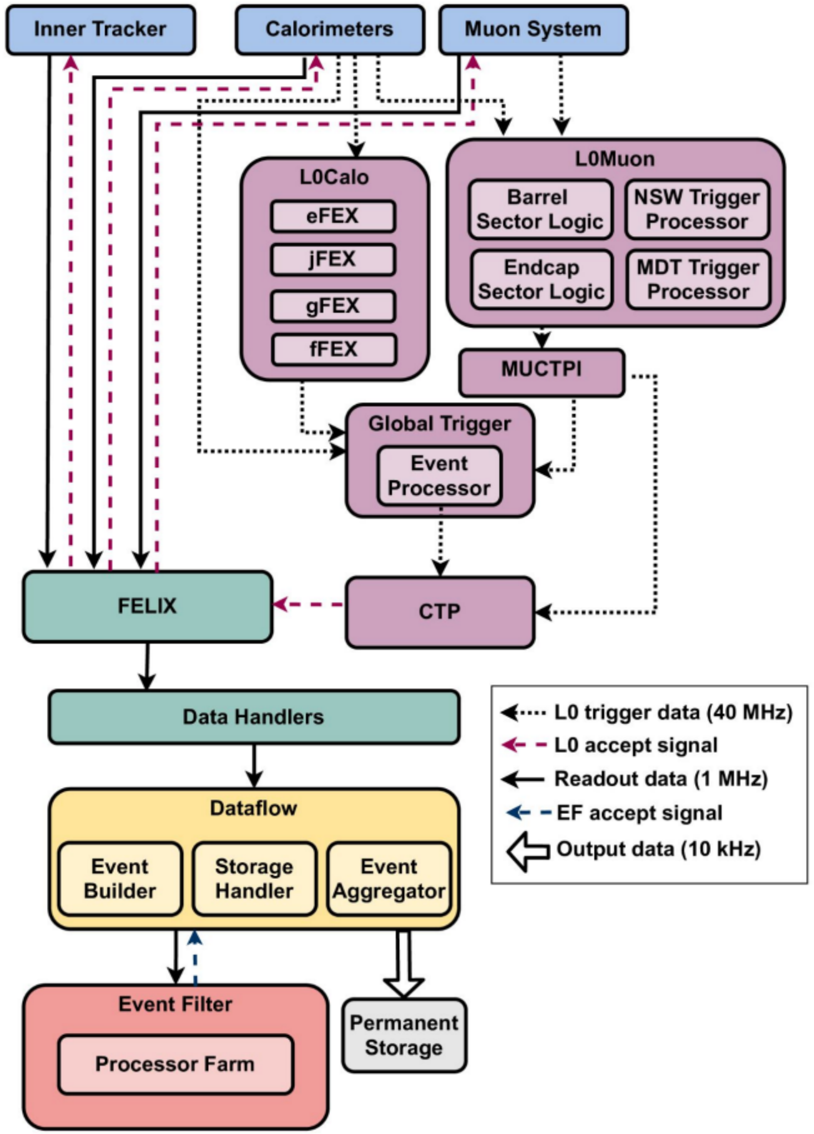


BCM' ring new design

- Apart from the new detector (HGTD), existing forward detectors will undergo upgrades to withstand HL-LHC conditions and provide forward physics and luminosity measurements
- Luminosity Cherenkov Integrating Detector (LUCID3), High-Lumi Zero Degree Calorimeter (HL-ZDC), Beam Conditions Monitor (BCM')

Trigger and DAQ (TDAQ)

- Moved to single-level HW trigger at 1 MHz
- Detector read-out with 10us latency at 5 TB/s based on FELIX
- 2.5-25 Gb/s optical link speeds
- Using ATCA standard
- Bi-directional TTC
- Increased usage of SoC
- Container-based farm
- Kubernetes (k8s) for farm orchestration
- Accelerators (GPU), Machine Learning (ML) and Neural Networks (NN) for online reconstruction



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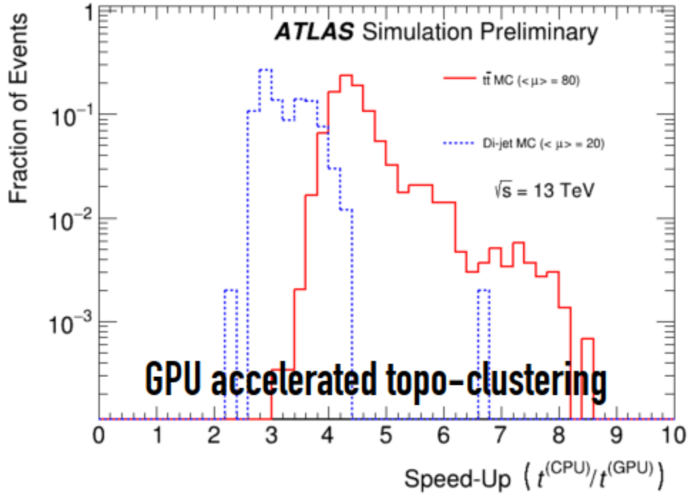
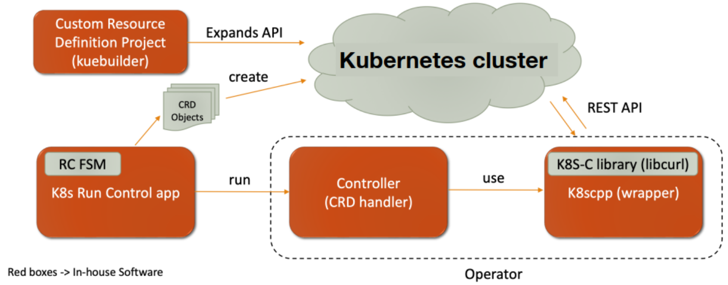




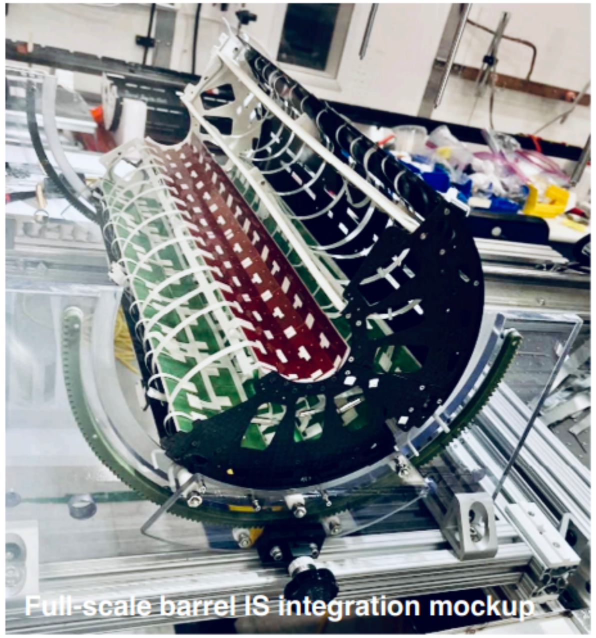

FLX-182
DAQ (FELIX) Phase-II prototype board

Summary

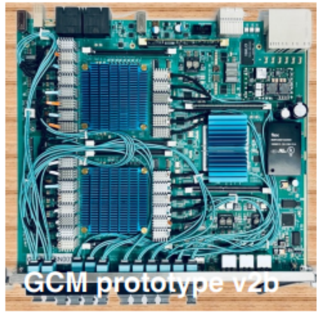
- The HL-LHC programs challenges the detector and detector electronics in many aspects, including high radiation doses and high pile-up
- Upgrades are underway to provide new detectors and read-out electronics to ensure the high efficiency and high-quality data taking in HL-LHC era
- Many projects entering pre-production or production phase
- Some components already produced and delivered to CERN
- New electronics with large FPGAs requires significant firmware effort
- Early integration and vertical slice tests are crucial for success
- Ambitious and extremely complex project with more that 800 FTE/year (full-time equivalent effort)
- Moving forward thanks to a very dedicated community

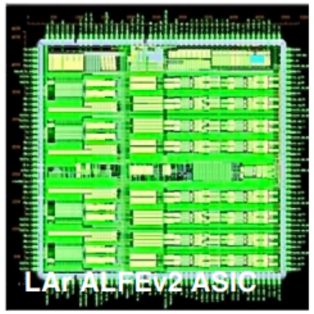
Thanks!

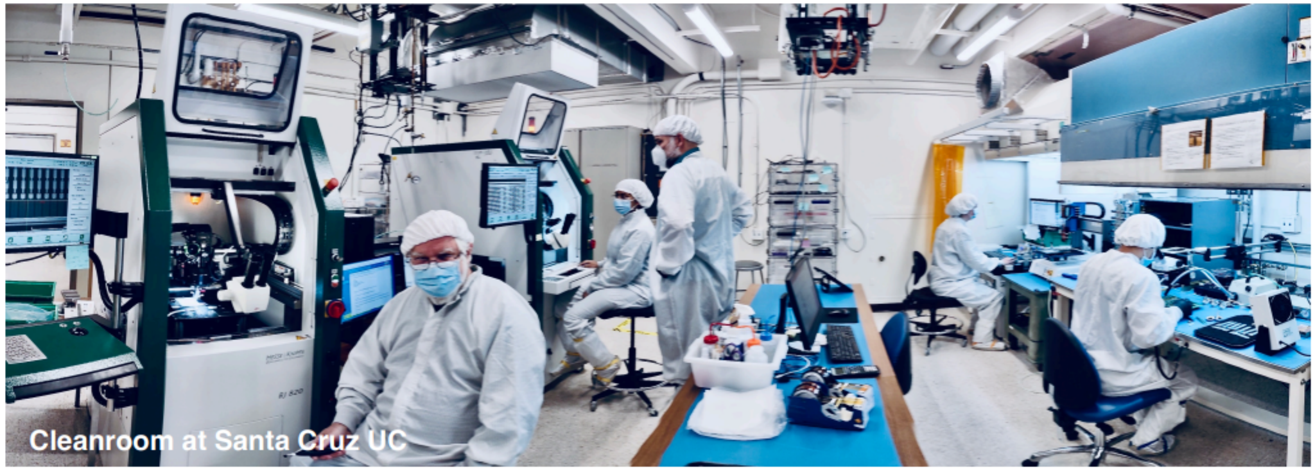

SR1 ITk surface assembly cleanroom at CERN

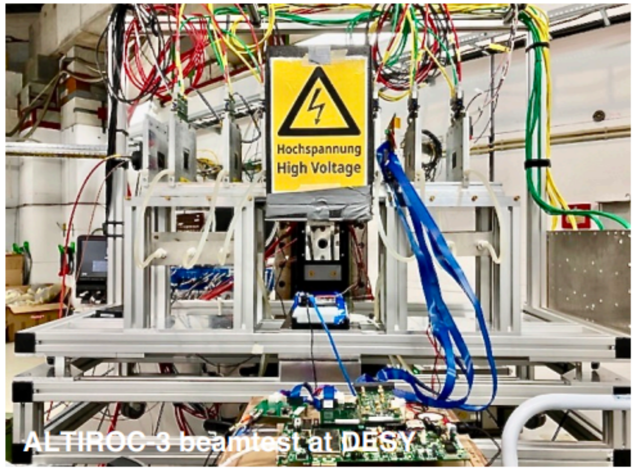

Full-scale barrel IS integration mockup


sMDT chambers at CERN (BB5)

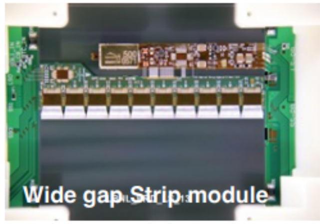

GCM prototype v2b

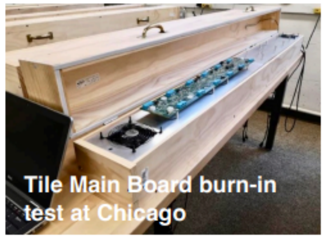

LAr ALFEv2 ASIC


Cleanroom at Santa Cruz UC



ALTIROC-3 beamtest at DESY


Wide gap Strip module


Tile Main Board burn-in test at Chicago