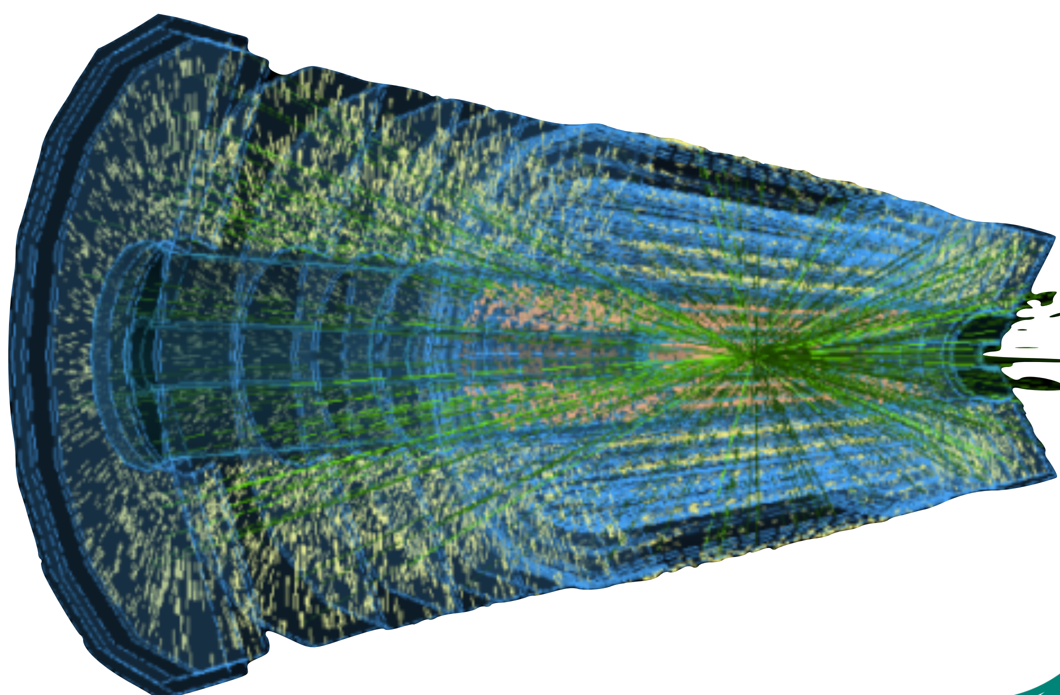
ATLAS detector upgrades

MPI Annual Project Review
15 December 2014

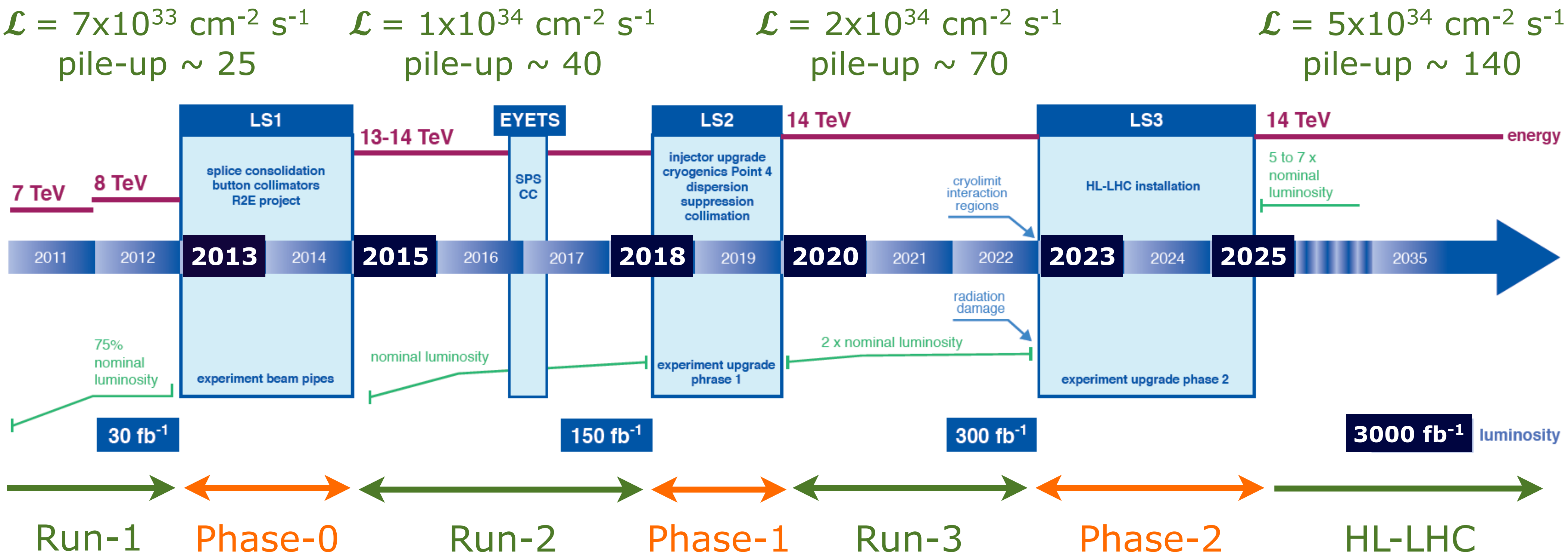
Tayfun Ince
on behalf of the MPI ATLAS group

Outline:

- LHC plans
- Why upgrade?
- Muon spectrometer
- Calorimeter
- Inner tracker
- Summary



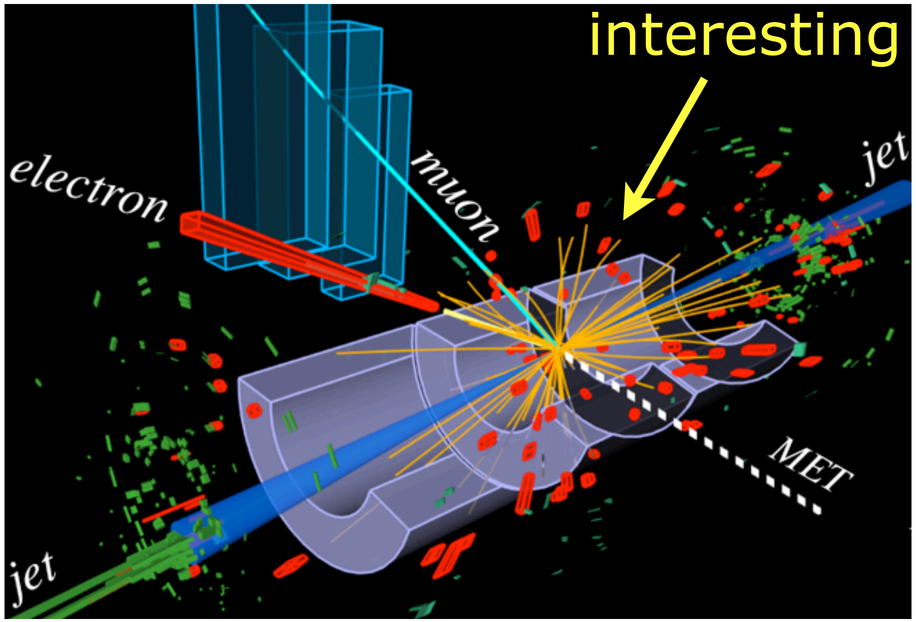
LHC plans

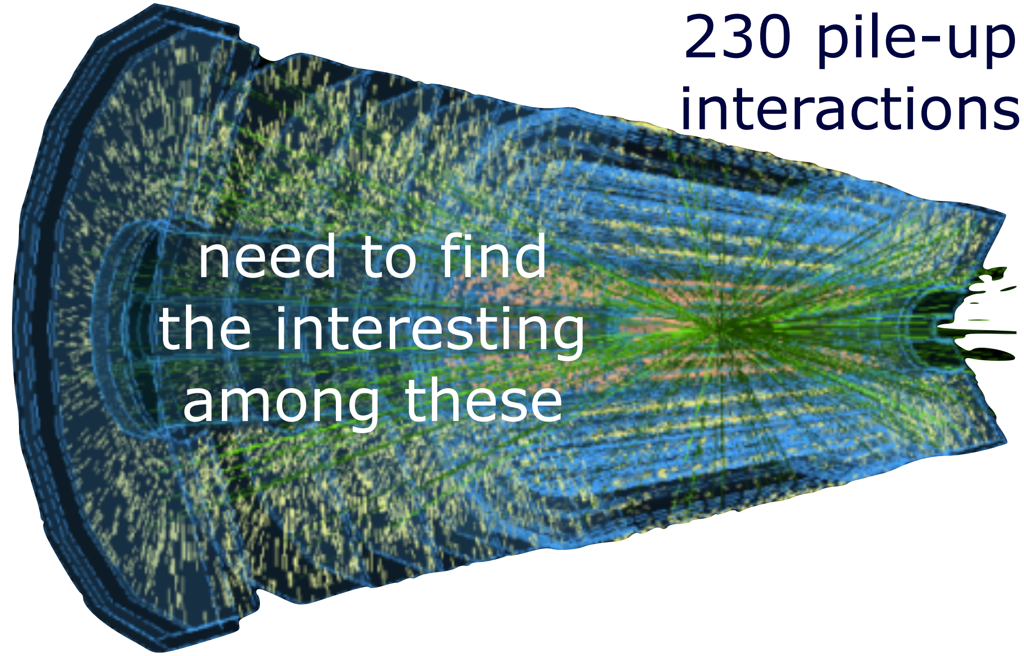


- LHC designed originally for
  - $\mathcal{L} = 1 \times 10^{34}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$
  - Pile-up ~ 22
- LS1: long shutdown-1
- Pile-up: superposition of interactions from the same or near-by bunch crossings

discovery of rare physics
requires high luminosity
and sufficient collision energies

Why do detectors need upgrade?





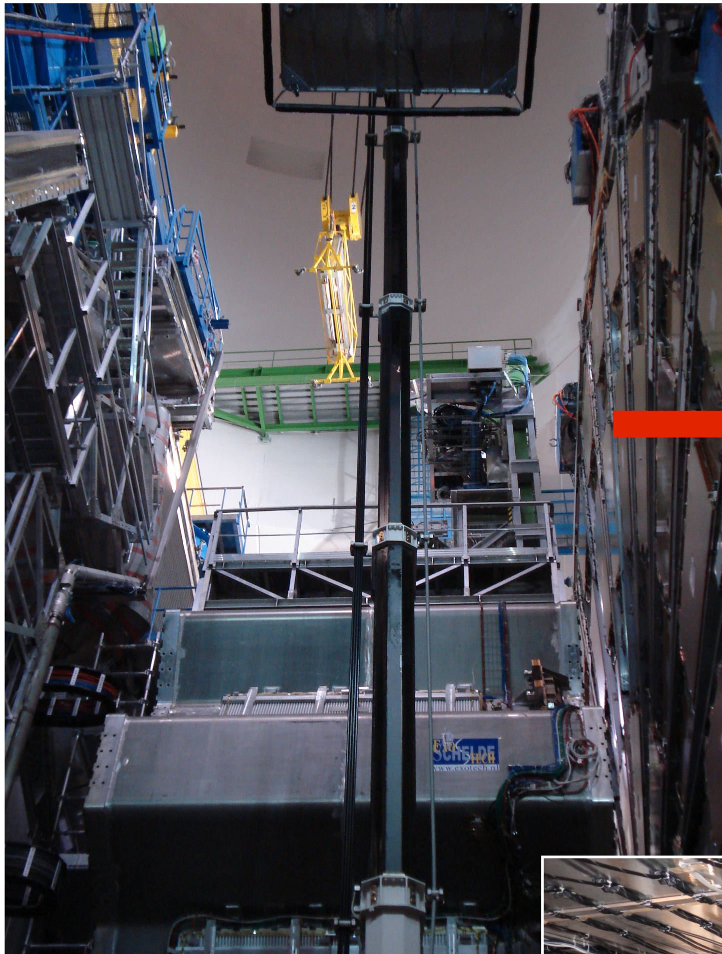
- When LHC surpasses design luminosity and pile-up by factors higher, detectors need to be ready for the challenge of
  - withstanding more radiation damage
  - measuring and identifying more particles and vertices
  - more accurate trigger decisions for the interesting physics
  - keeping more data in buffers until trigger arrives
  - sending more data for each trigger
- And the reason of natural aging may cause replacement of parts

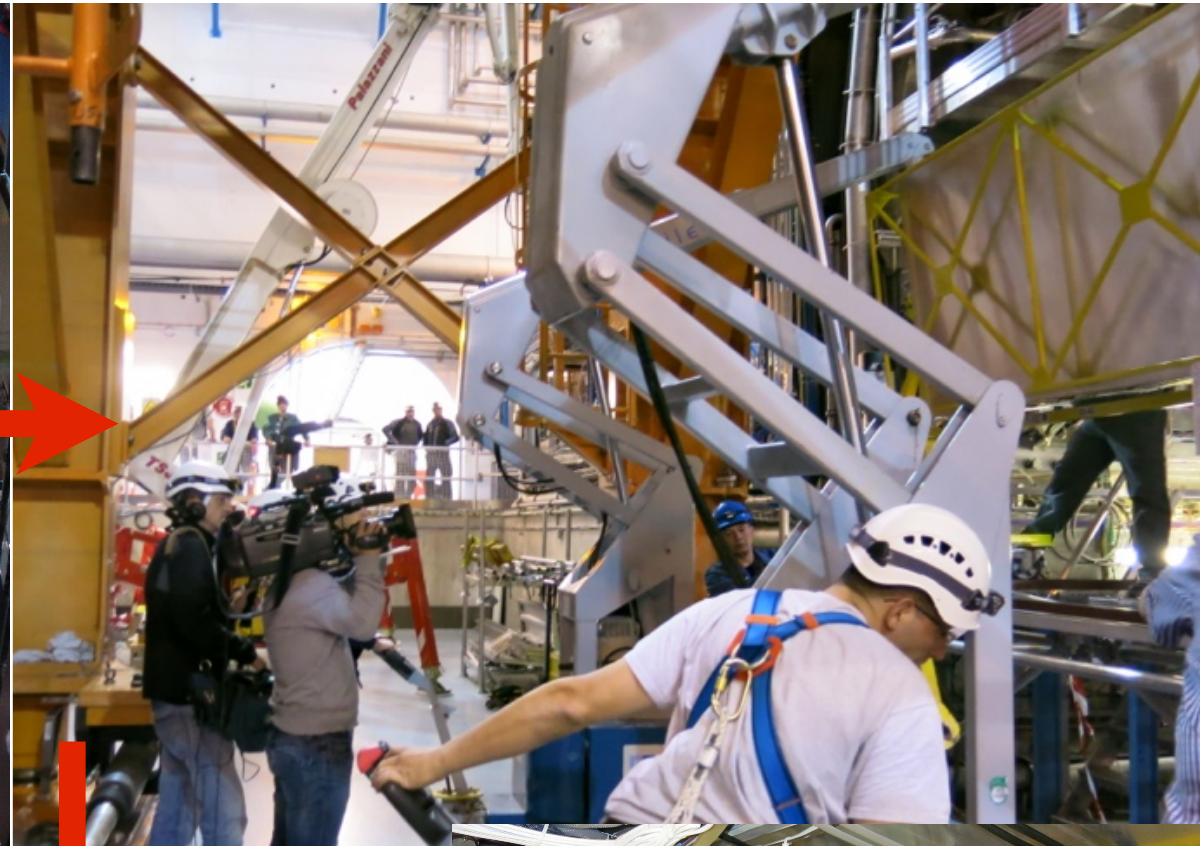
Muon system phase-0 upgrades (2014)

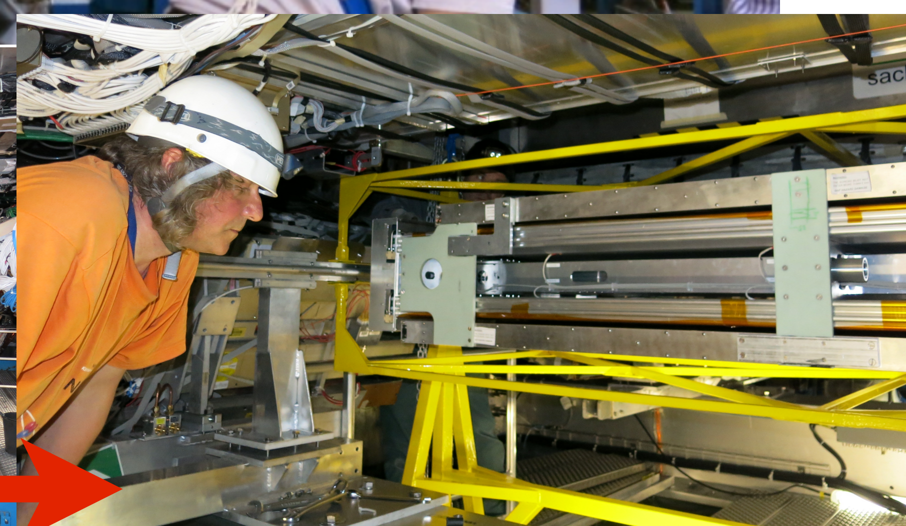
New small-diameter drift tube (sMDT) chambers

- sMDT chambers, with half the drift tube diameter of the present MDTs, are a development of MPP
- Ideal to improve the acceptance of the muon spectrometer
- 10x higher rate capability, than MDTs, for HL-LHC
- Two new sMDT chambers for ATLAS constructed and installed in 2014
- The most precise drift tube chambers ever built (10 µm sense wire positioning accuracy) and much shorter construction time than MDTs

sMDT chamber installation in April 2014







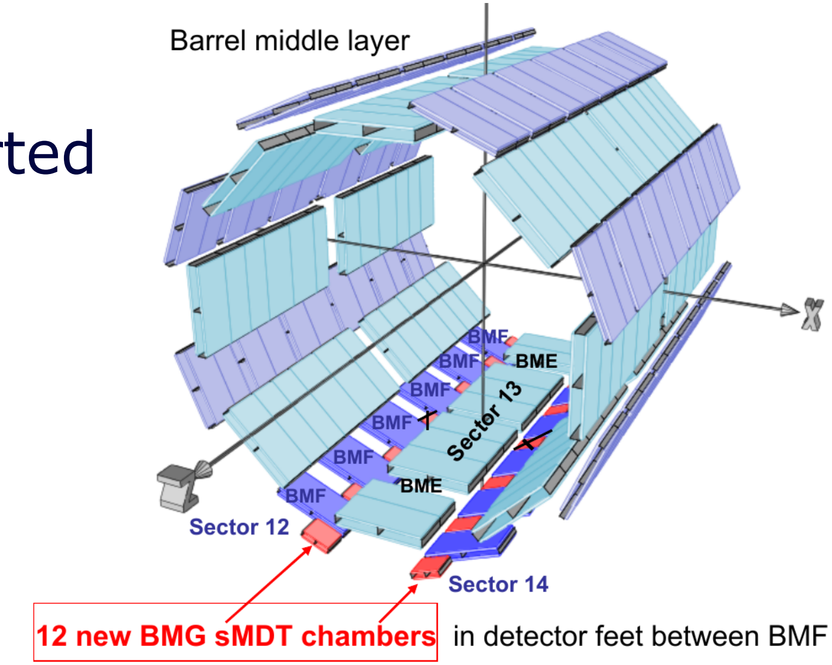
documented by Deutsche Welle and broadcast worldwide

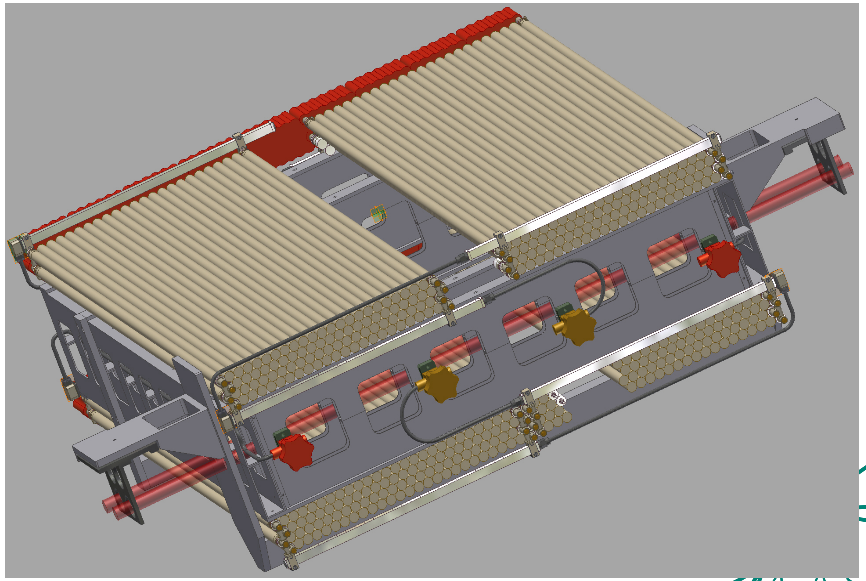
Muon system phase-1 upgrades (2017-19)

sMDT chamber construction for 2017

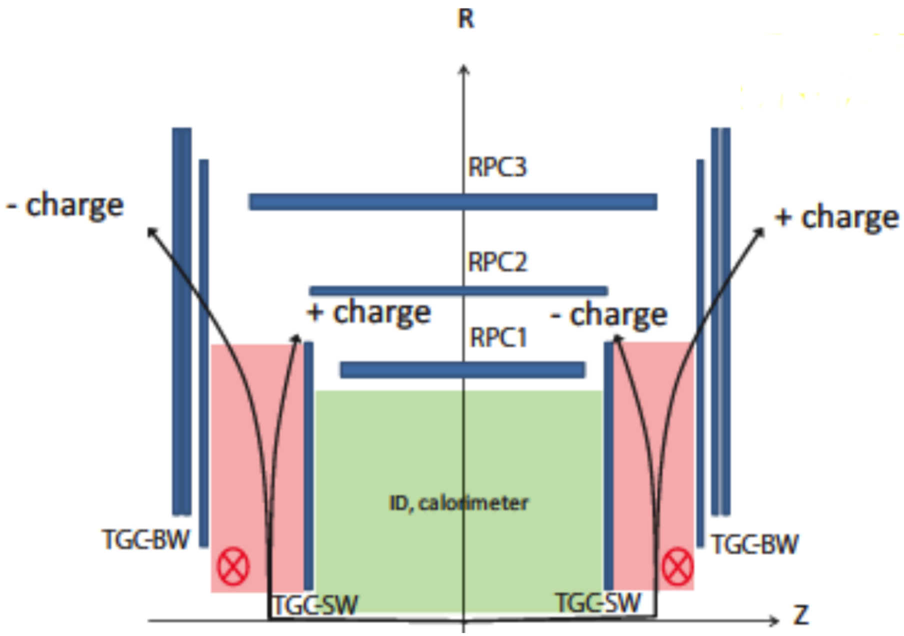
- 12 sMDT chambers for installation in winter shutdown 2016/17 in the ATLAS feet sectors
- Design completed and production started

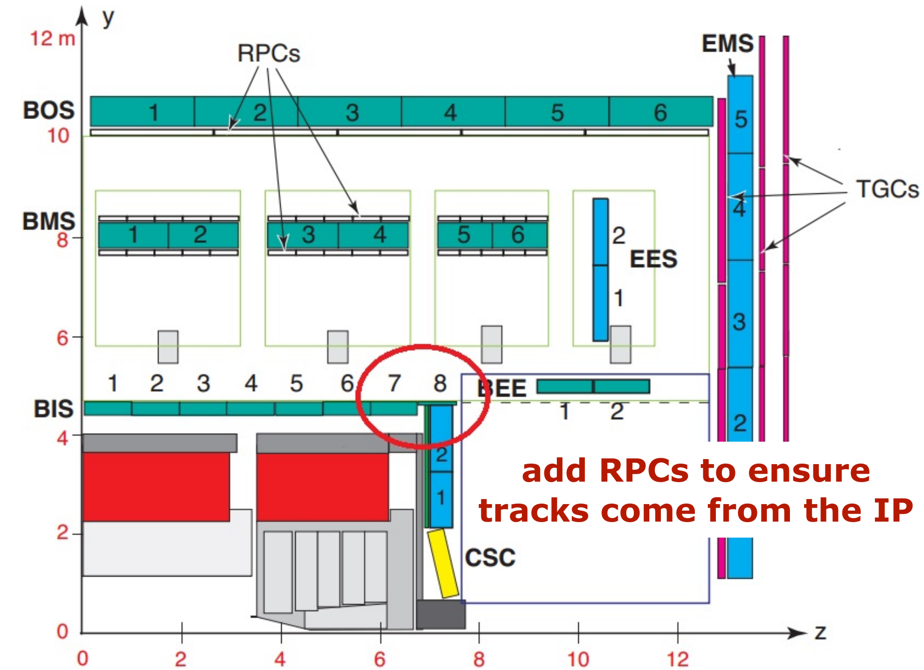
excellent work of
IHEP Protvino technicians
assembling drift tubes at MPP



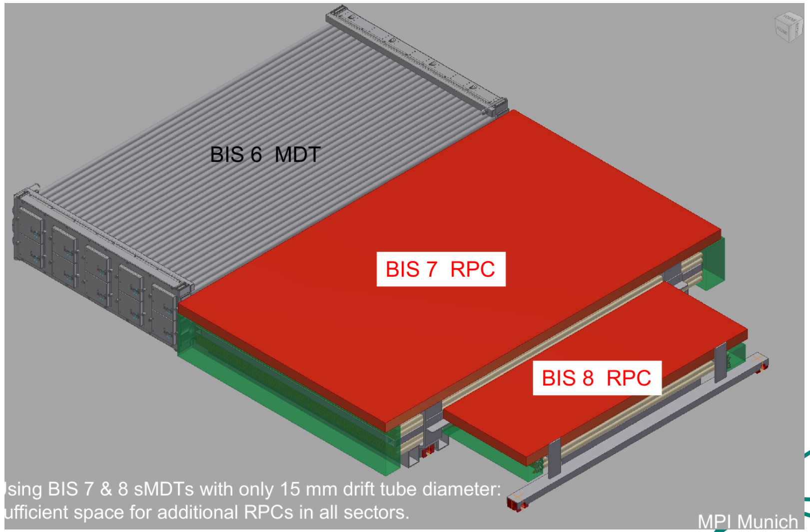


BIS-7/8 project





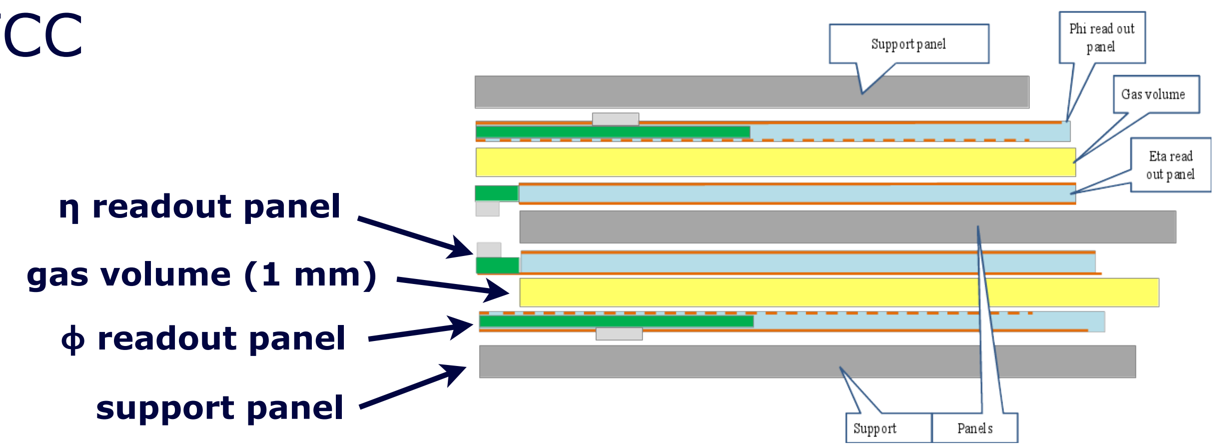
- Suppress fake high-p_T muon triggers
- Due to space constraints a hybrid of sMDT chambers and new thin-gap resistive plate trigger chambers (RPCs) have to replace the existing MDTs
- Production of 16 integrated sMDT-RPC chambers at MPP to be installed in LS2 (2018-19)



Strengths of new thin-gap RPCs

- Improvements to present RPCs
  - 10x higher rate capability
  - 10x higher spatial resolution (~1 mm)
  - 10x higher time resolution (~100 ps)
  - Time of flight measurement at trigger level allows for a slow-particle trigger at HL-LHC

- Candidate technology for future detectors
  - Detector for particle flow calorimeters (ILC)
  - Trigger chamber for muon systems at ILC or FCC
  - Hybrid of a thin RPC and an sMDT chamber is a self-triggering high precision muon chamber suitable for experiments at the ILC or FCC

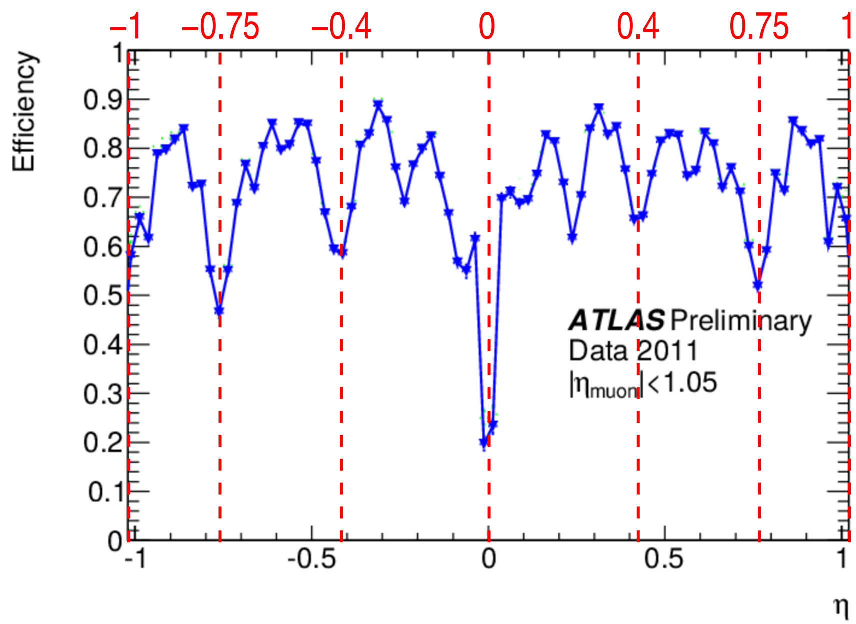


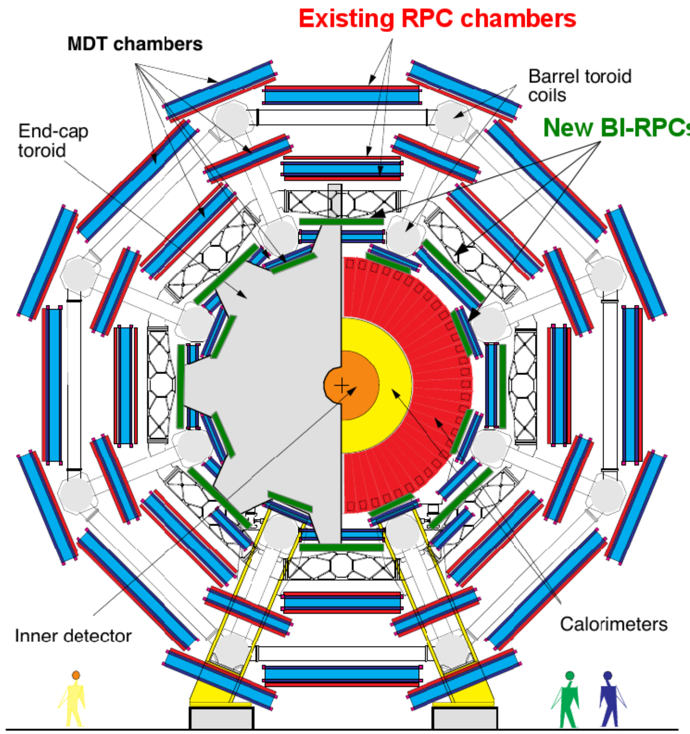
Muon system phase-2 upgrades (2023-25)

MPP coordinates muon system phase-2 upgrades

BI RPC project

- Installation of new thin-gap RPCs in the barrel inner layer (BI) to close acceptance gaps



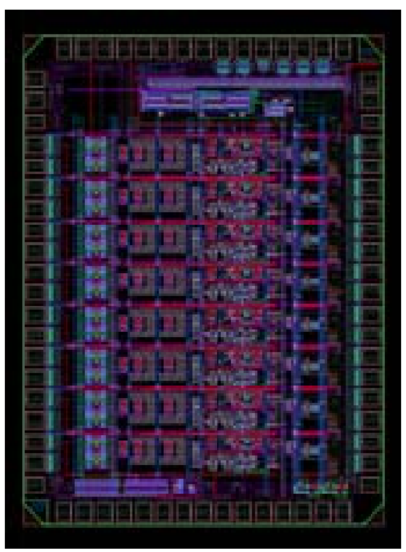


- Requirements of the BI RPC project
  - Replacement of the existing MDT chambers with sMDT chambers to free space for thin-gap RPCs
  - Development of thin-gap RPCs that can fit into the freed space
  - Pilot project: BIS-7/8 upgrade
  - Design of sMDT and new thin RPC chambers by MPP
  - Production of sMDT chambers by MPP

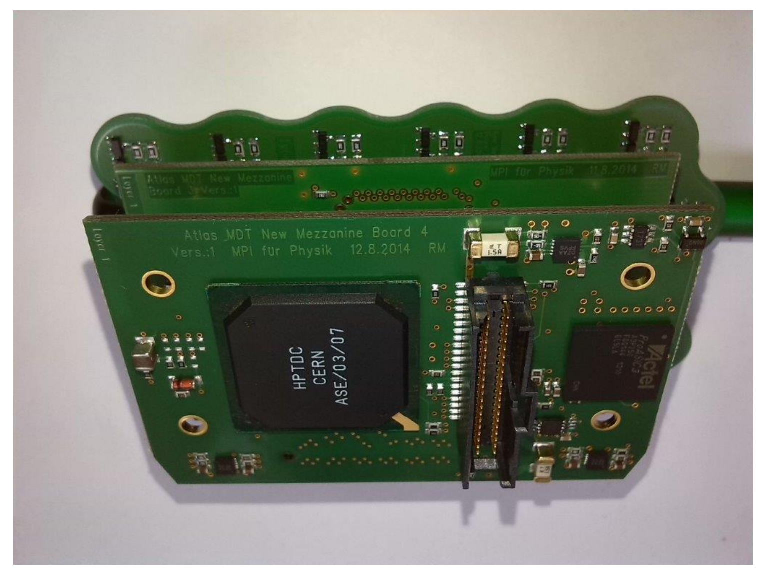
Development of new MDT front-end electronics

- To exploit the physics potential of the HL-LHC one has to cope with ~10x higher level-0/1 trigger rates than at the LHC
- This requires new front-end electronics for all muon chambers
- Development at MPP:
  - New Amplifier Shaper Discriminator (ASD) chip
  - New Time-to-Digital-Converter (TDC) chip with a new additional fast chain for the muon trigger

Prototype with 8 channels on 0.8 mm x 1.1 mm



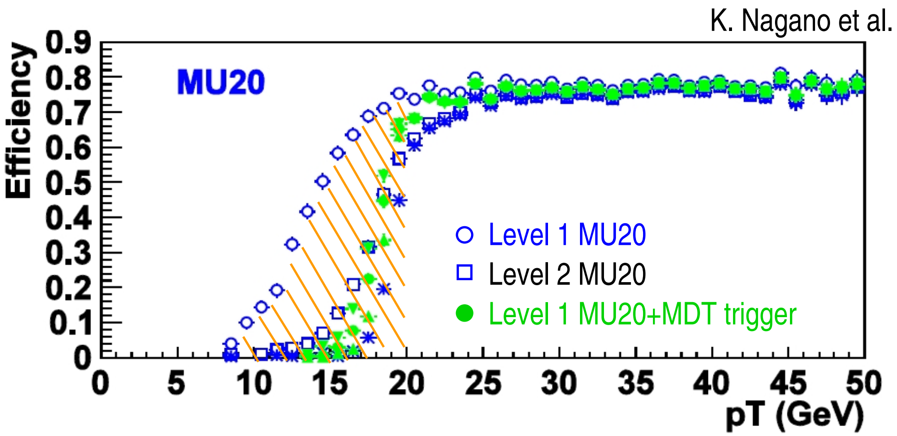
ASD chip in IBM 130 nm technology

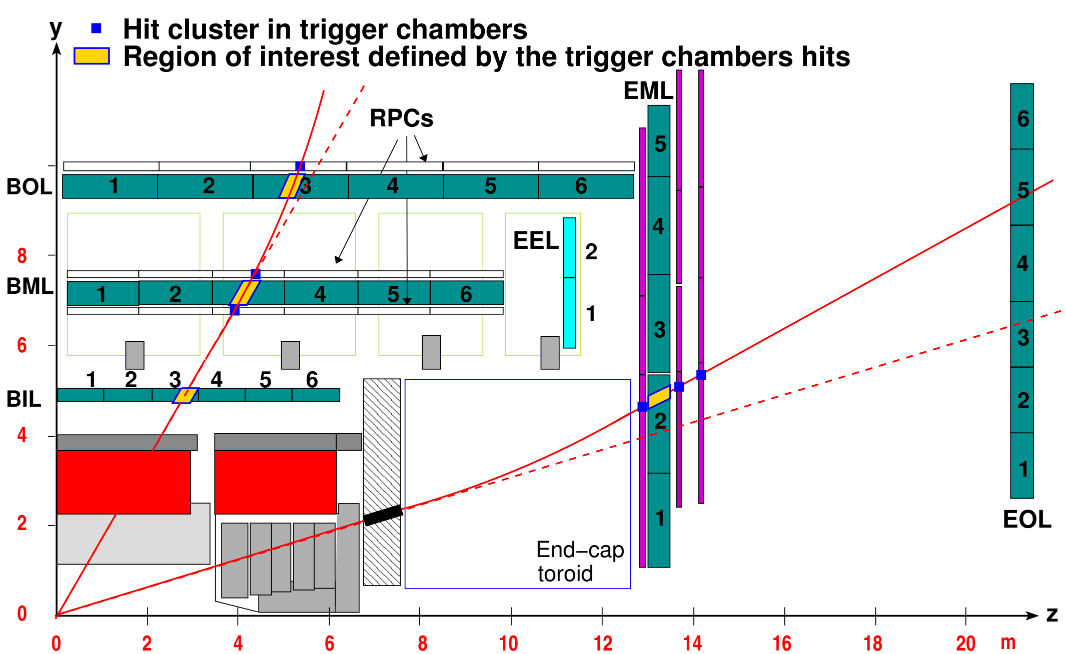


Prototype on–chamber read–out board with ASD and TDC chip

MDT level-1 trigger concept

- Sharpen the trigger threshold by using MDT hits (~0.1 mm resolution) in the regions of trigger chamber hits (~10 mm resolution) for a precise momentum measurement
- Level-1 MDT trigger requires a new fast MDT chamber read-out chain and a fast MDT track reconstruction





- MPP is developing
  - the new trigger concept
  - fast read-out hardware
  - fast track reconstruction algorithm
  - high-rate test of a trigger demonstrator

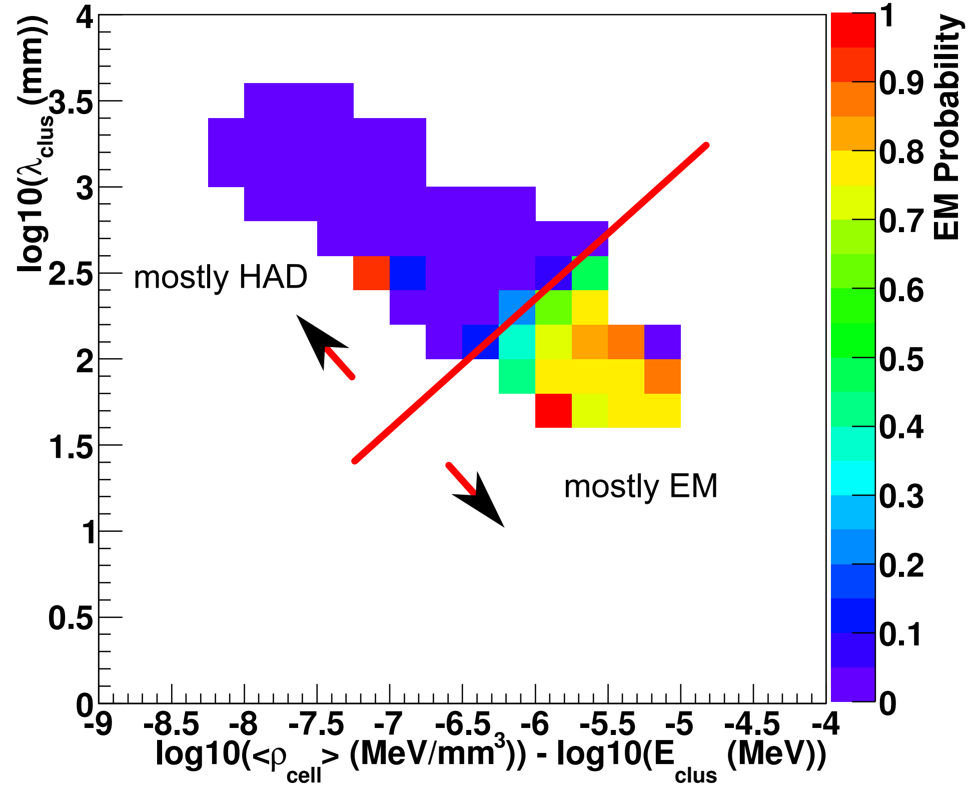
Calorimeter phase-0 upgrades (2014)

Pile-up suppression in jet energy calibration (I)

- ATLAS LAr calorimeters are non-compensating (e/h ~ 1.3) in that response to electrons and hadrons are not the same

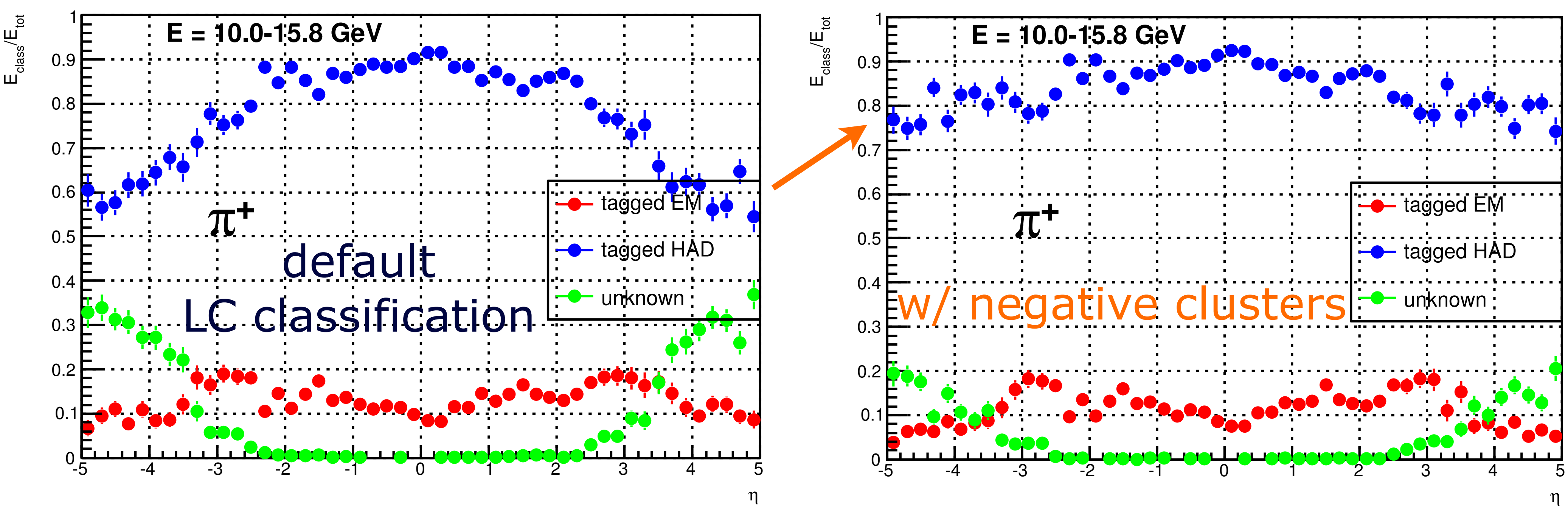
- Local hadron calibration (LC):
  - classify clusters as EM or hadronic based on shower properties and energy density of cells;
  - apply cell level corrections for non-compensation;
  - apply cluster level corrections for leakage and dead material;
  - finally apply jet level corrections for non-detectable losses

ATLAS standard method developed and maintained by MPP



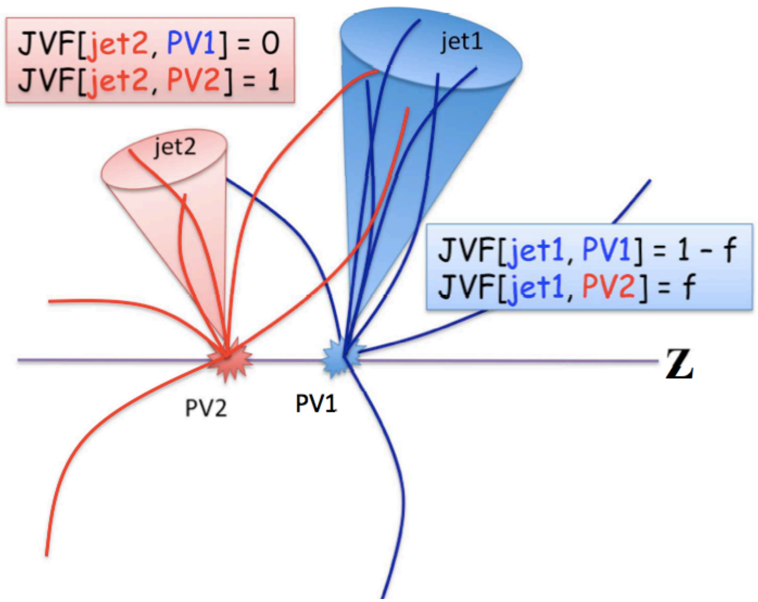
Pile-up suppression in jet energy calibration (II)

- LC applied only to positive clusters in Run-1
- High pile-up causes negative and positive energy clusters
- Developed a scheme to treat negative energy clusters in LC as well to have them help cancel pile-up naturally
- Classification improves linearity in single pion reconstruction



Pile-up suppression in jet reconstruction

- Jet Vertex Fraction (JVF): a discriminant measuring probability of a jet coming from a particular vertex
- Similar to JVF, define a Cluster Vertex Fraction (CVF) to reduce the contamination of signal jets by clusters from pile-up



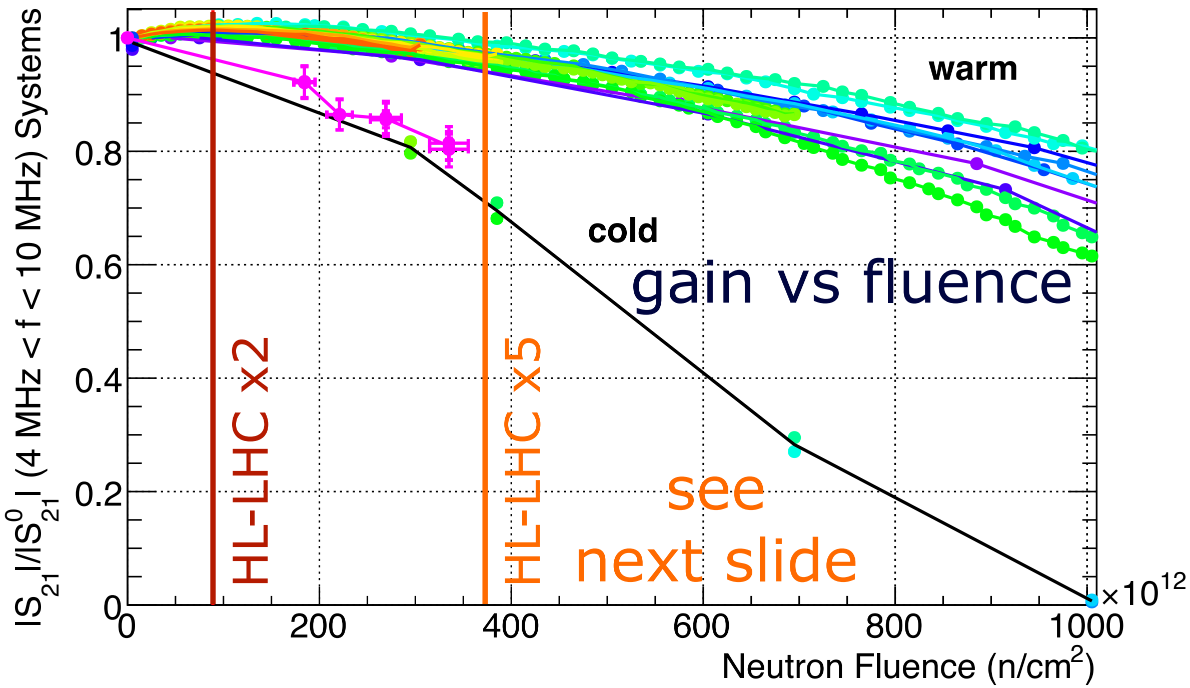
$$CVF\left(cluster_i, vertex_j\right) = \frac{\sum_k p_T\left(trk_k^{cluster_i}, vtx_j\right)}{\sum_n \sum_l p_T\left(trk_l^{cluster_i}, vtx_n\right)}$$

- (Internal) plots show that by applying a cut on the CVF
  - the jet energy scale at constituent level (LC scale) stays fairly constant with increasing pile-up
  - the amount of fake jets from pile-up is greatly reduced

Calorimeter phase-2 upgrades (2023-25)

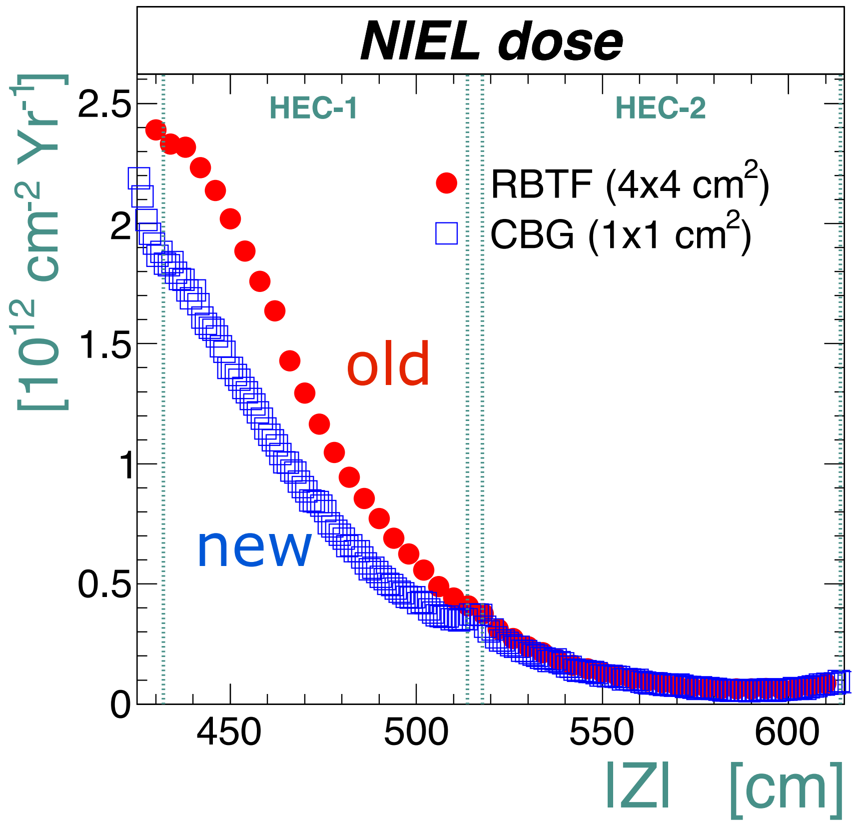
Qualification of HEC cold electronics for HL-LHC

- Hadronic endcap calorimeter (HEC) readout electronics, BB96 GaAs ASICs originally built by MPP for LHC design conditions, put through extensive irradiation program and accelerated aging tests, in close collaboration with the electronics department
- Si-based (nMOS and pMOS) alternative technologies also tested
- GaAs sufficiently radiation hard for HL-LHC conditions
- No significant performance degradation in the aging tests



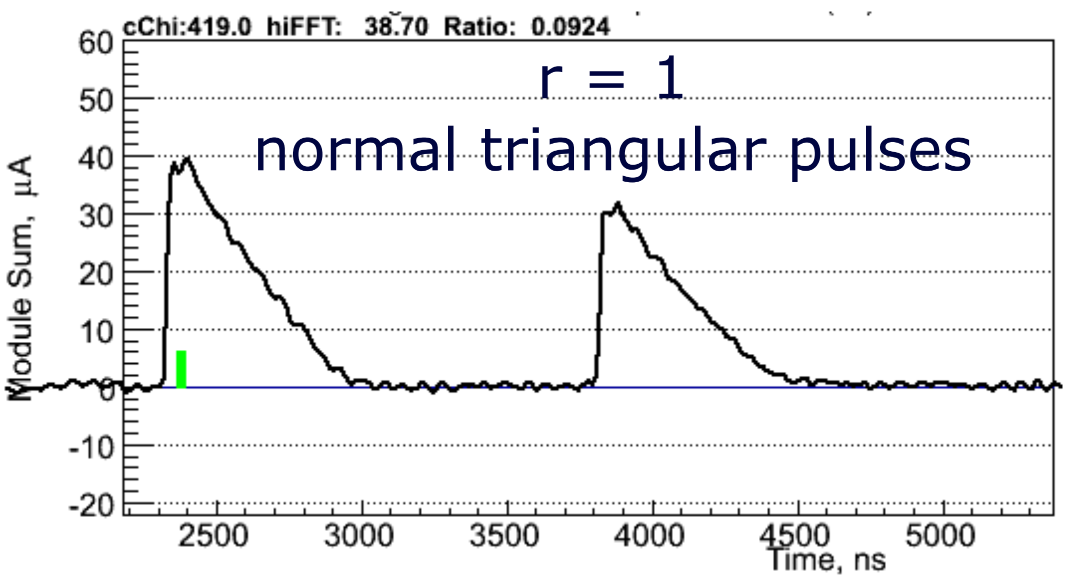
Radiation levels near the HEC cold electronics

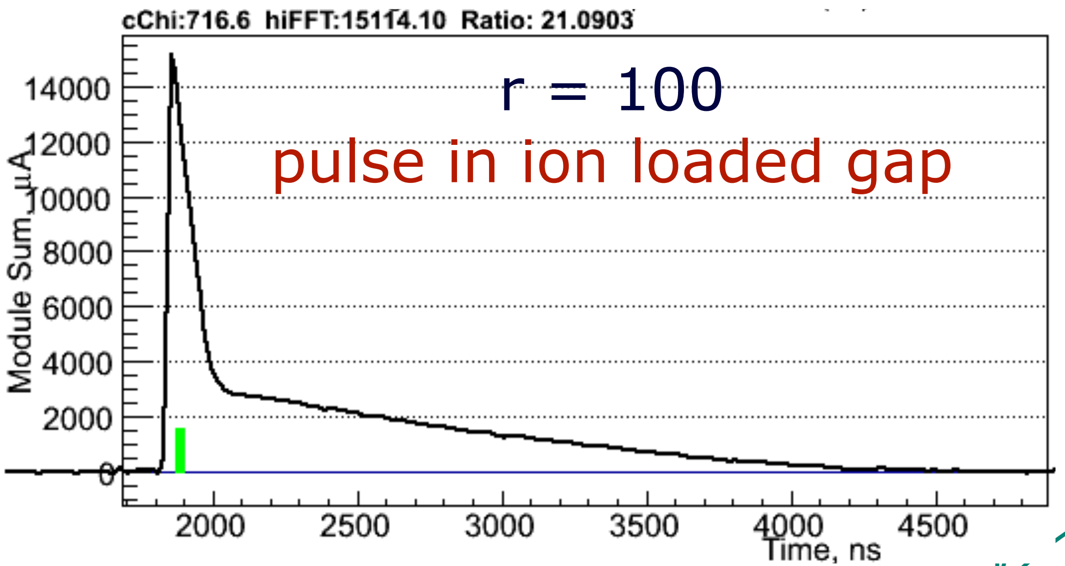
- MPP estimated radiation levels in the region with HEC cold electronics (204 < R < 205 cm, 432.1 < |Z| < 613.9 cm) in HL-LHC conditions, based on simulations of the ATLAS detector
- Updated simulations give 30% lower expected NIEL dose at the highest fluence region
- Thanks to the data from the ATLAS radiation detectors after 3 years of operation, safety factor of 5 lowered to 2 with the gained confidence in the simulations



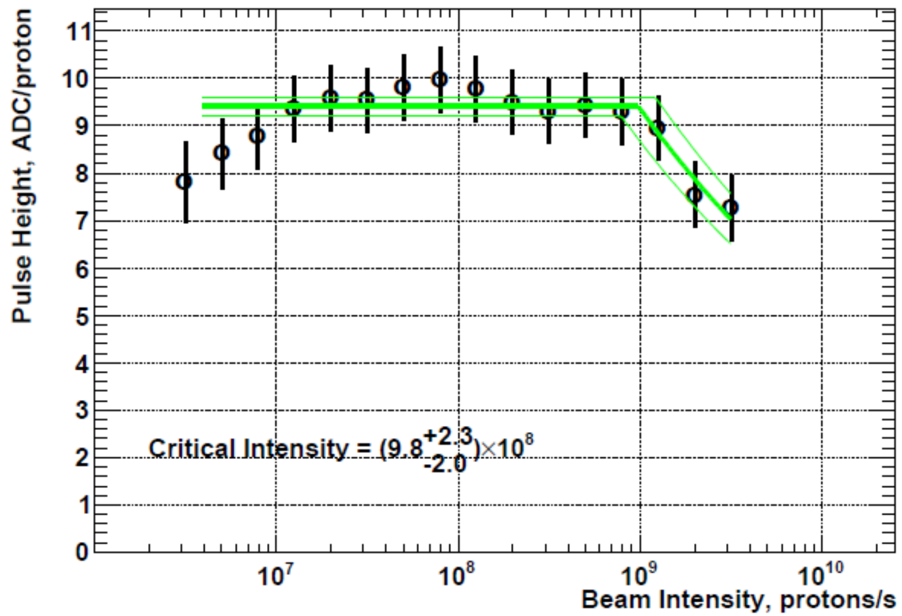
HiLum experiment (I)

- Studying limitations on the operation of the endcap calorimeters (FCAL, EMEC, HEC) for HL-LHC
- Test beam of 50 GeV protons from IHEP U70 accelerator
- LAr ionization pulse shape distorted in an ion loaded gap; unpredictable and therefore, impossible to determine proper calibration
- Results show EMEC and HEC will be fine in HL-LHC conditions



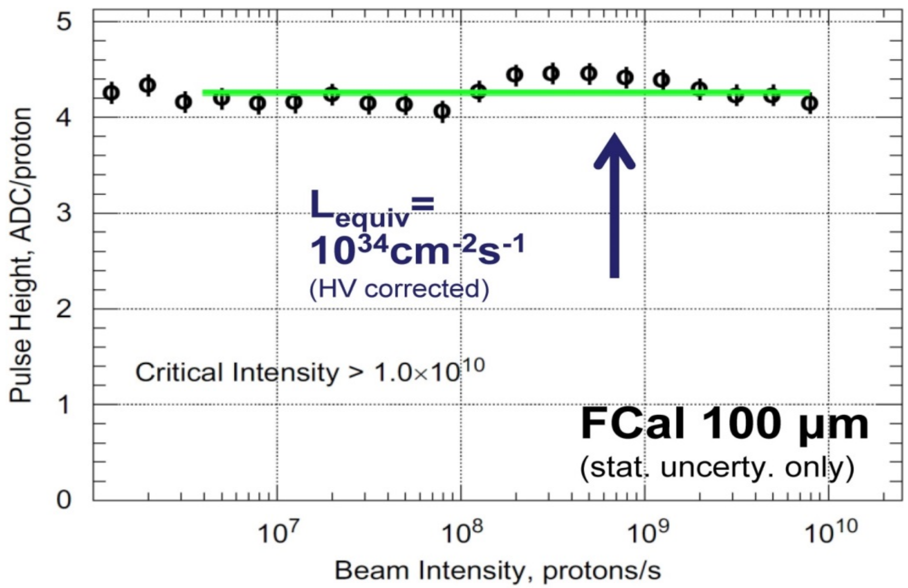


HiLum experiment (II)



NIM A 669 (2012) 47

present FCal
with 269 μm gaps
suffers degradation
at HL-LHC conditions



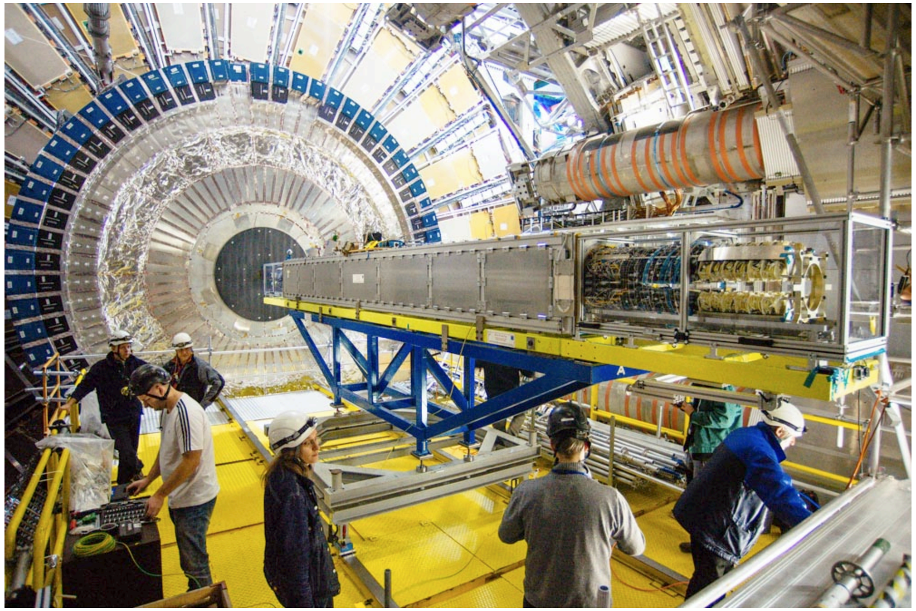
sFCal for HL-LHC
119 μm gaps

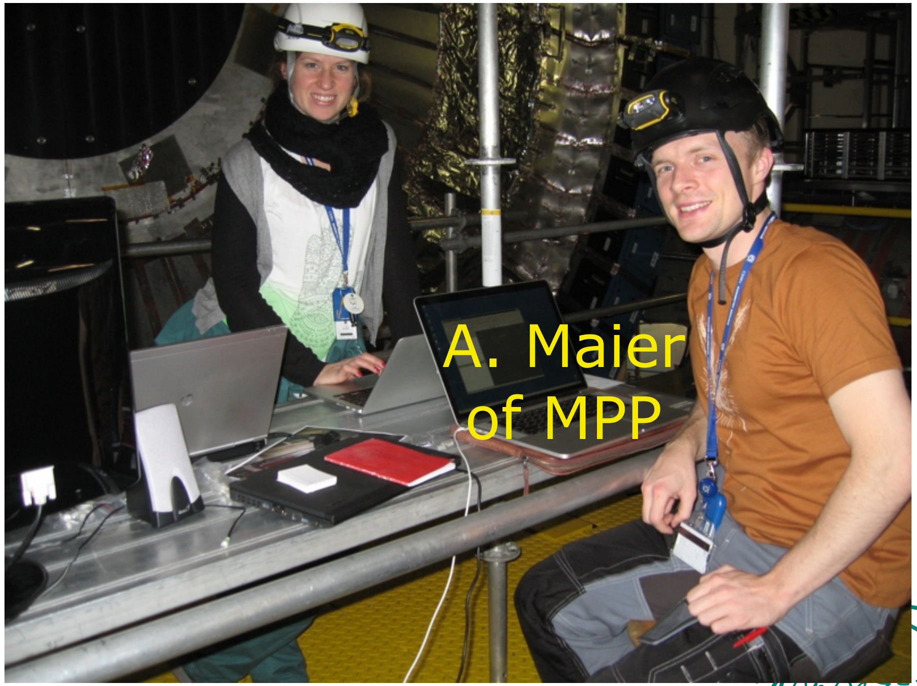
- MPP joined the forward calorimeter (sFCal) upgrade program

Inner tracker phase-0 upgrades (2014)

Pixel refurbishment

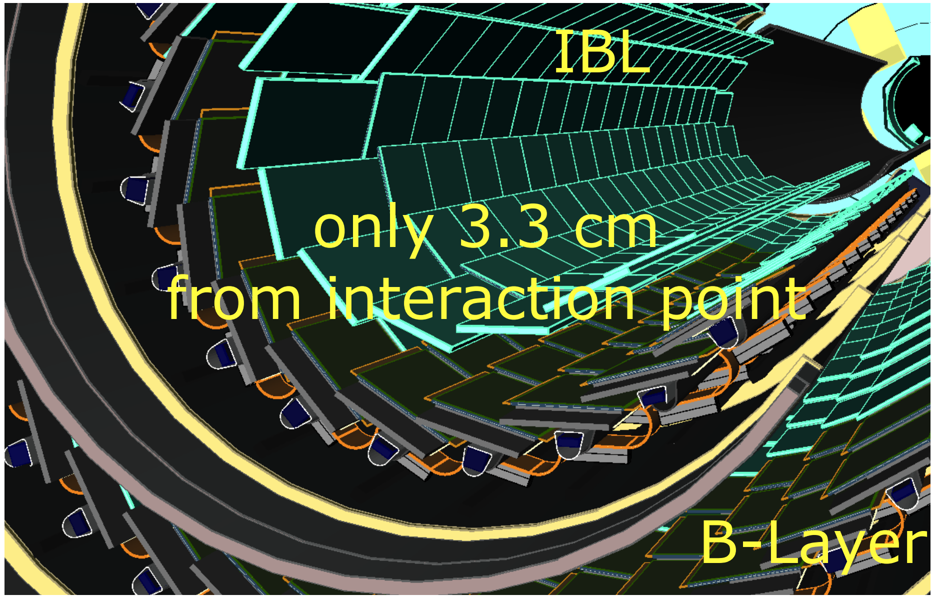
- Pixel services replaced on-surface and transported back to cavern in December 2013
- Layer-1 readout speed doubled and optical components moved outside detector volume for potential future repairs
- Re-connection in the cavern completed in April 2014
- 98.1% (95% end of Run-1) of the detector operational
- MPP coordinated connection to the new services and testing, and study & repair of the inactive modules from Run-1





Insertable B-Layer

- The major ATLAS phase-0 upgrade
- New inner-most pixel layer with finer granularity, higher rate capability and higher radiation tolerance
- Improves tracking, vertexing and b-hadron identification



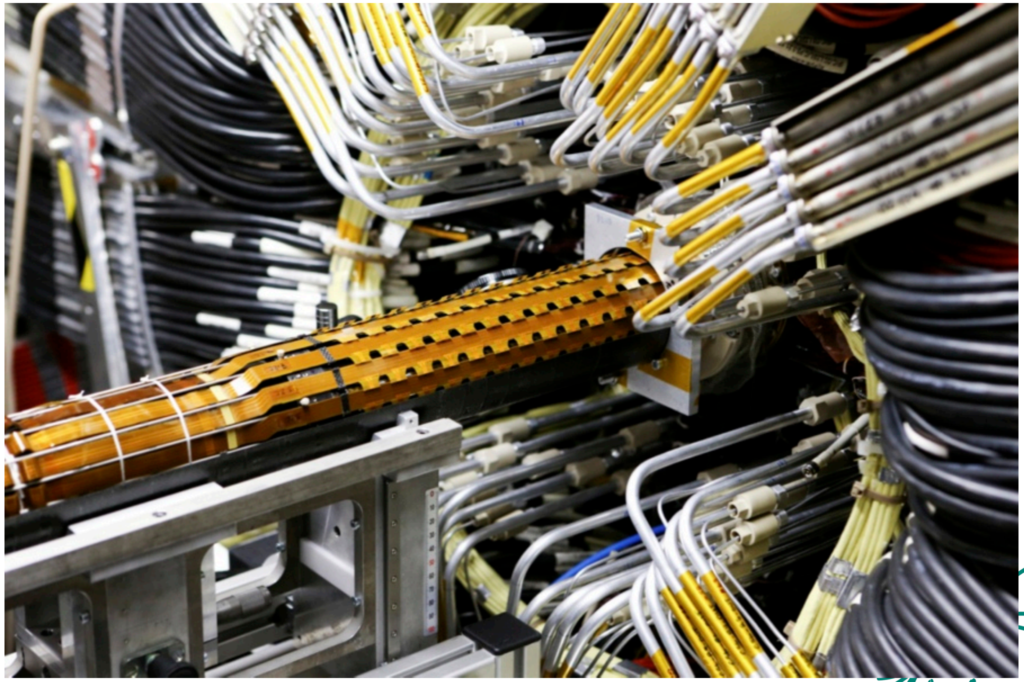
- Made of 14 staves (structures holding the detector modules)
- Defect pixels only ~0.1%
- MPP coordinated the IBL stave quality assurance on all aspects from defining the test program to the testing and the selection of the 14 IBL staves

IBL installation

last stave integrated around the new beam pipe end of March 2014

transported to the cavern in May 2014

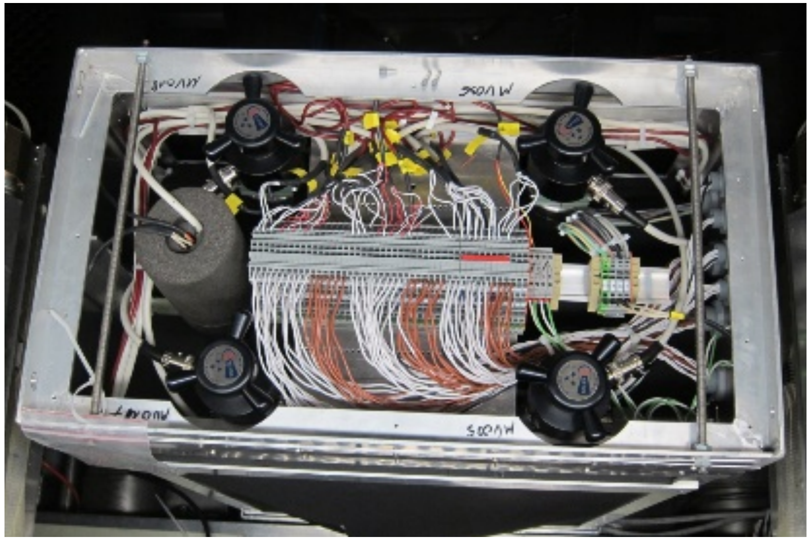
installation completed end of June 2014



IBL CO_2 cooling system

- Fully commissioned
- Operation at -35 ℃ up to 3 kW load demonstrated
- Safe operation assured during beam pipe bake-out at 230 ℃
- Junction and manifold boxes built by MPP
- Joint in-house collaboration with Belle
- Continue the involvement in the development of CO_2 cooling for the phase-2 tracker

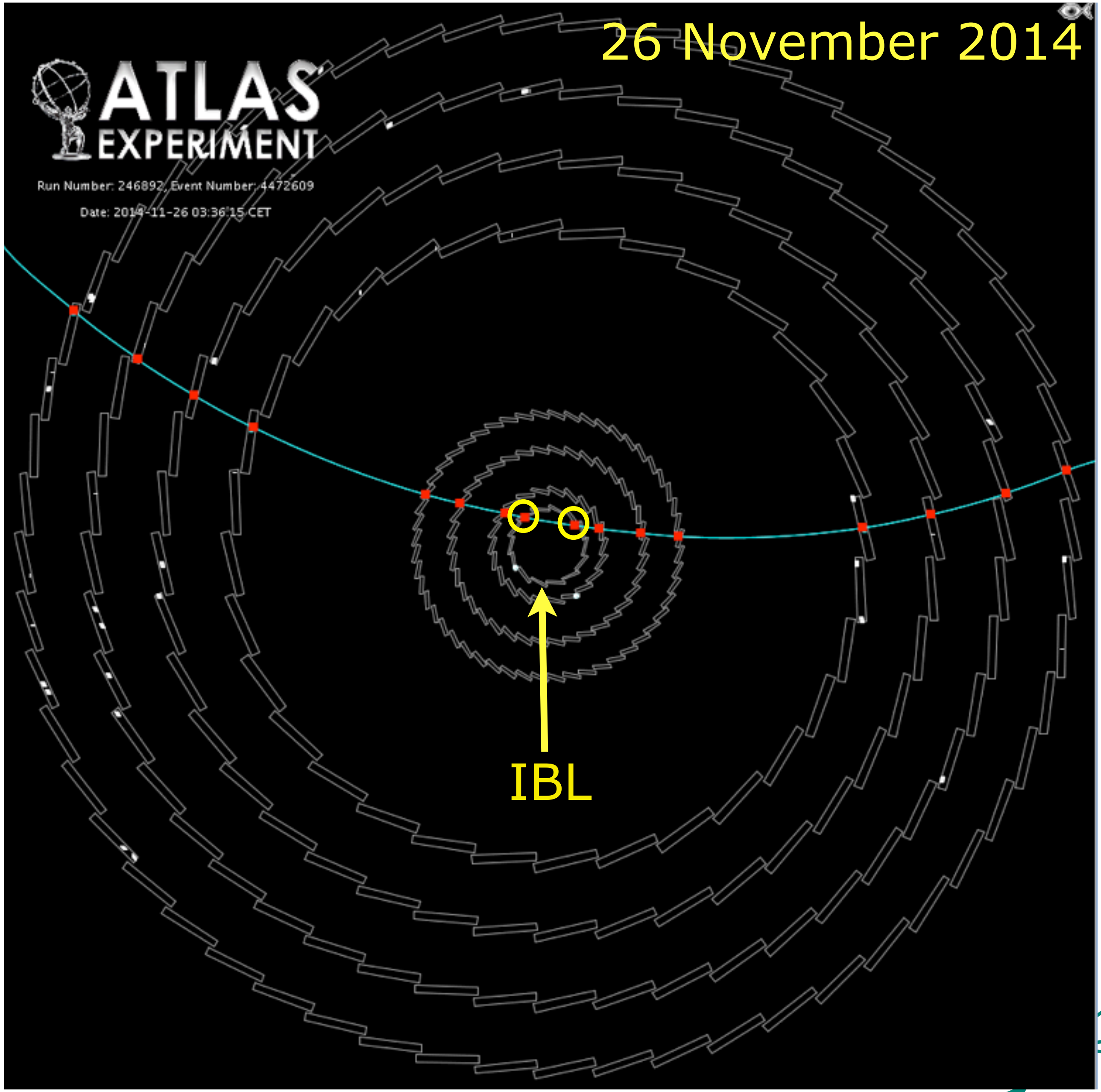
junction box



manifold box

IBL in action

a cosmic ray passing through the IBL in the presence of a solenoidal magnetic field

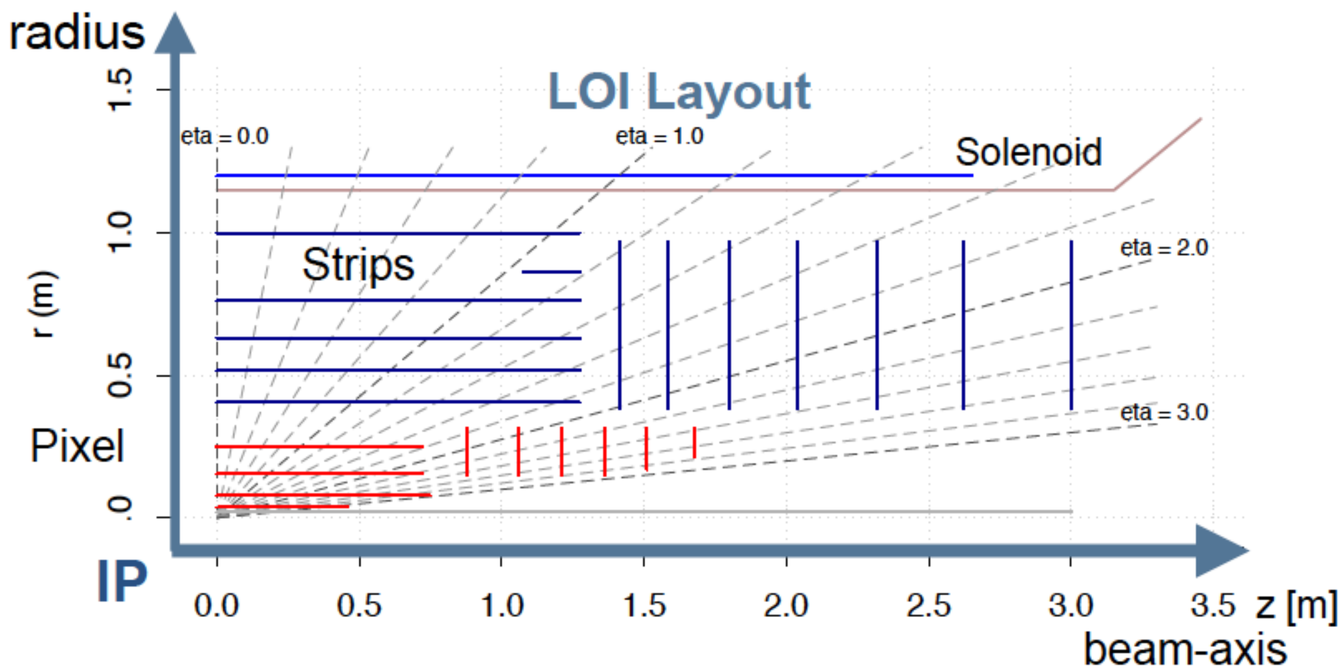


MPP coordinates preparation of the 4-layer pixel system for optimum physics performance in Run-2 and beyond

Inner tracker phase-2 upgrades (2023-25)

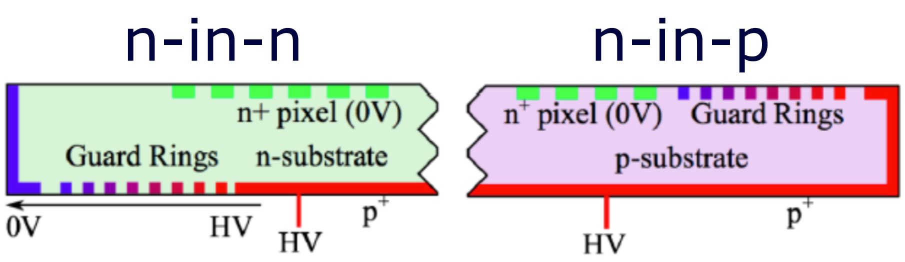
New tracker (ITK) for HL-LHC

- ITK requirements imposed by HL-LHC conditions:
  - thinner sensors for more radiation tolerance
  - finer granularity for improved pattern recognition
  - minimum inactive area to get very close to the interaction point without tilting the modules for improved vertex reconstruction
  - faster readout electronics with larger hit buffers
  - reduced material to minimize nuclear interactions, photon conversions, Bremsstrahlung…

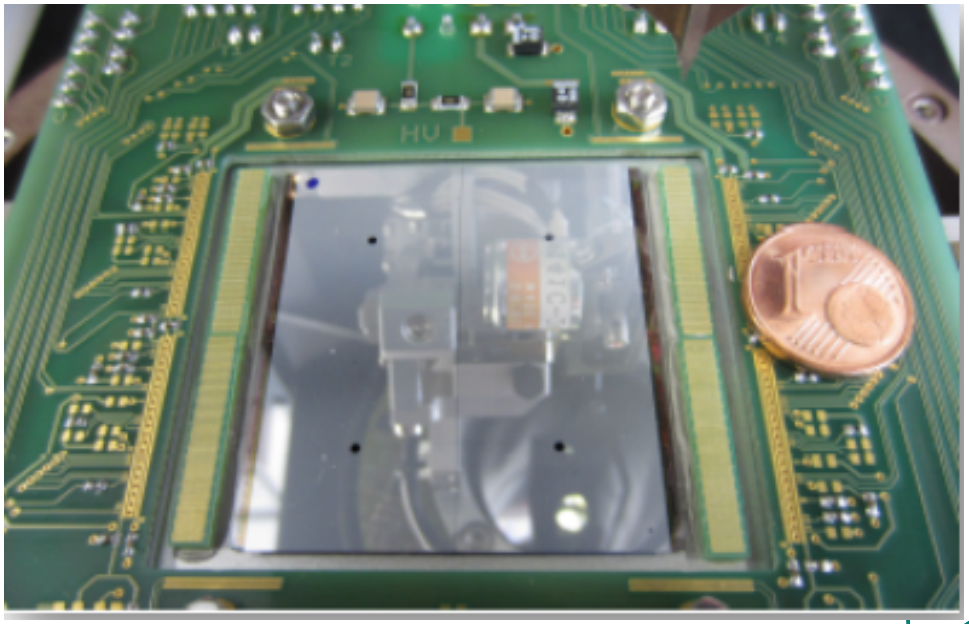


Development of n-in-p pixel sensors for ITK

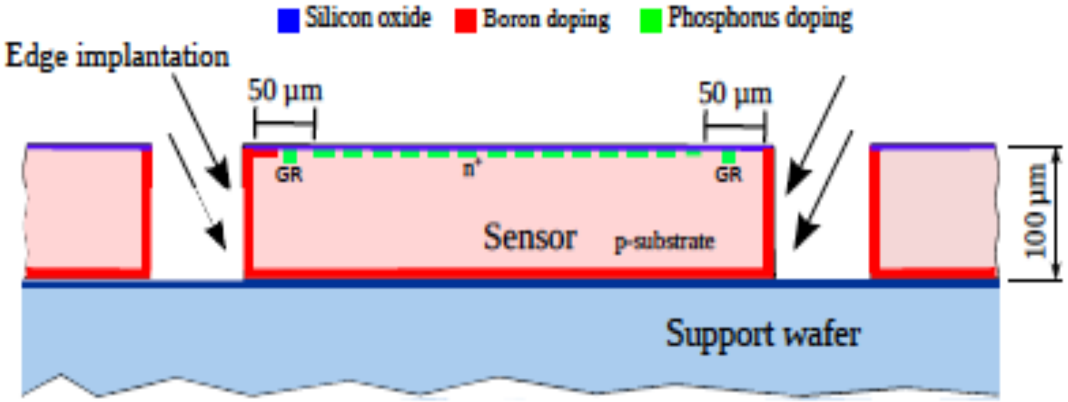
- Need to demonstrate feasibility of building 8 m^2 (2 m^2 current coverage) of pixel modules with 150 μm thick sensors
- n-in-p are cost effective to cover large areas thanks to the single side processing
- Successful beam tests with prototype sensors of thicknesses as low as 75 μm, irradiated to HL-LHC conditions
- MPP coordinates ITK planar sensor development activities

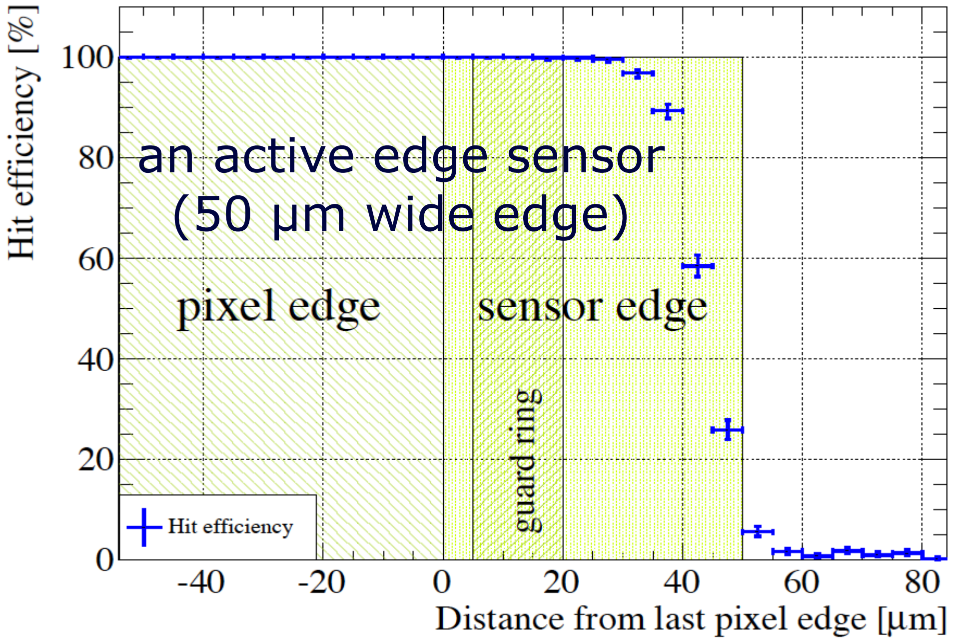


prototype module 4x4 cm^2



Active edge thin pixel sensors for ITK





- Pixel b-layer and IBL modules, with 1 mm and 250 µm inactive edges, tilted for overlap to avoid efficiency loss
- Active edge sensor allows the inner-most layers to be placed closer to the beam-line by avoiding the need for tilting
- Achieved preserving maximum efficiency as near as 25 µm to the edge with a prototype sensor

Summary

- MPP has continued to lead the upgrade activities in all three major sub-systems of the ATLAS detector
  - Muon spectrometers:
    - Two new sMDTs installed in April; building 12 more for 2017
    - New thin RPCs for HL-LHC to close muon acceptance gaps
    - New MDT readout electronics and trigger concept for HL-LHC
  - Calorimeters:
    - New jet measurement techniques for pile-up suppression
    - MPP built HEC cold electronics even qualified for HL-LHC
    - Beam test of endcap calorimeters in HL-LHC like conditions
    - Joined sFCal upgrade R&D program
  - Inner trackers:
    - Pixel refurbishment and reconnection completed in April
    - IBL construction and installation completed in June
    - IBL cooling system junction and manifold boxes built by MPP
    - Development of thin active edge n-in-p pixel sensors for the new tracker ITK for HL-LHC

Questions?