

ATLAS Detector Operation and Upgrades



ATLAS Projects and Personnel 2021

Team leader: S. Bethke

Muon Detector

Seniors:

H. Kroha (PL)

O. Kortner

R. Richter (retired)

Postdocs:

M. Holzbock,

P. Rieck (left)

E. Voevodina

PhD students:

D. Buchin,

S. Maschek

D. Prelicpean (CERN)

M. Rendel

Master students:

G. Eberwein (left)

S. Grewe (now PhD)

D. Prelicpean (CERN, now PhD)

Bachelor students: 10

Engineers:

S. Abovyan, V. Danielyan,

D. Soyk, J. Zimmermann

Technicians:

T. Brunner, J. Haas, L. Schafroth,

3 technicians from IHEP Protvino

Calorimeter

Seniors:

S. Menke (PL)

T. Barillari (deputy team leader)

A. Kiryunin

P. Schacht (retired)

Postdocs:

T. McCarthy (left)

M. Spalla

PhD students:

N. Wenke

Engineers:

U. Leis (50%)

Muon Trigger

Seniors:

S. Kortner (PL, W2 group)

Postdocs:

D. Cieri,

D. Duda

V. Walbrecht (left)

PhD students:

S. Grewe,

A. Hoenle (left)

A. Reed

Inner Tracker

Seniors:

R. Nisius (PL)

Postdocs:

F. Guescini

J. Jiménez Peña

M. Şahinsoy Karacasu

PhD students

Š. Hadžić

Computing

Seniors:

S. Kluth (PL)

A. Verbytskyi

S. Stonjek

S. Tafula (MPCDF)

C. Delle Fratte (MPCDF)

Postdocs:

D. Britzger

PhD students

F. Klimpel (CERN)

Master students:

J. Hessler

S. Hill

MPP ATLAS Operation and Coordination Tasks

Muon Detector & Trigger

Detector operation:

D. Cieri:

Muon efficiency measurement coordinator (institute commitment),
MDT trigger firmware coordinator,
Trigger SW depository manager

E. Voevodina:

MDT chamber operation group member

Physics:

S. Kortner:

Global EFT interpretation coordinator

P. Rieck:

Jets + Dark Matter coordinator

D. Duda:

Di-boson, multi-lepton & extra dimension searches coordinator

M. Holzbock:

Missing energy & pile-up tagging coordinator

Upgrade:

H. Kroha:

sMDT chamber upgrade coordinator,
Muon Upgrade Steering Group member

P. Rieck, M. Rendel:

sMDT construction QA/QC coordinators

O. Kortner:

MDT front-end board coordinator,
MDT trigger co-coordinator

R. Richter:

MDT ASD chip coordinator

D. Soyk:

RPC mechanics project engineer

Calorimeter

Detector operation:

S. Menke :

LAr Calorimeter Steering Group member,
Radiation Task Force member,
calorimeter reconstruction and calibration software

T. Barillari:

Operation task sharing panel member,
HEC LV power supply coordinator

A. Kiryunin:

HEC simulation

P. Schacht:

HEC high-lumi test coordinator

M. Spalla:

Jet definitions and MC calib.convenor,
Calorimeter reconstruction software

N. Wenke:

Particle flow calibration

Upgrade:

S. Menke :

Phase-2 LAr calorimeter upgrade co-coordinator

T. Barillari:

HEC LV power supply coordinator

Inner Tracker

Detector operation:

J. Jiménez Peña:

Inner tracker alignment coordinator

Physics:

J. Jiménez Peña:

Top properties and mass coordinator

Upgrade:

F. Guescini:

Pixel detector testbeam coordinator

Computing

Detector operation:

Operation of Tier-2 computing facility Garching

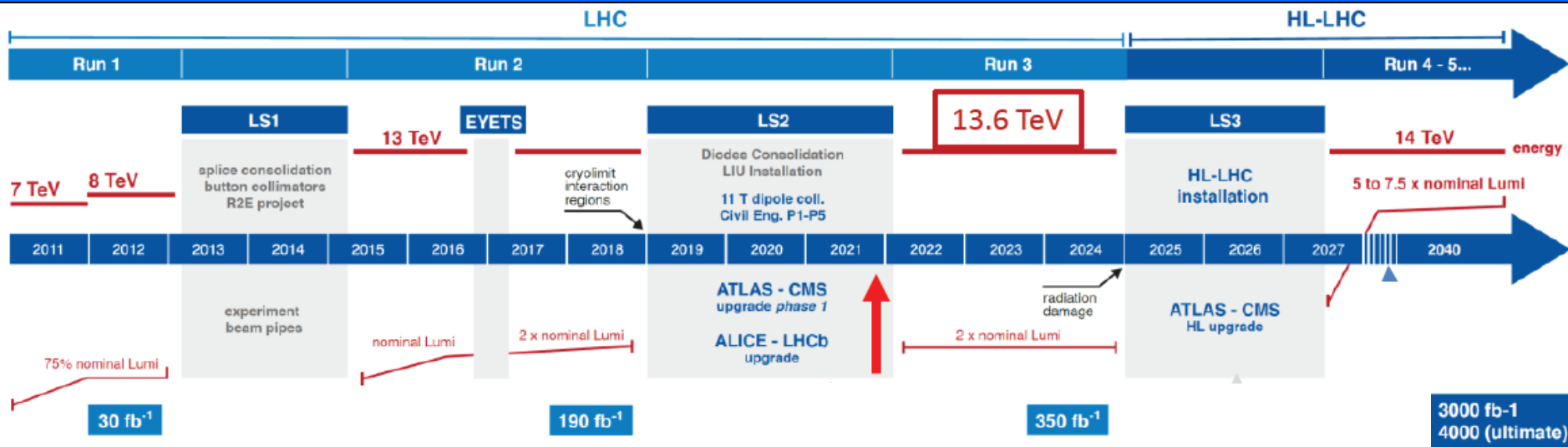
S. Stonjek:

Central software reviewer

A. Verbystkyi:

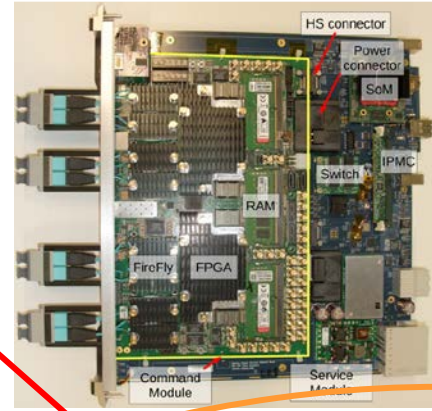
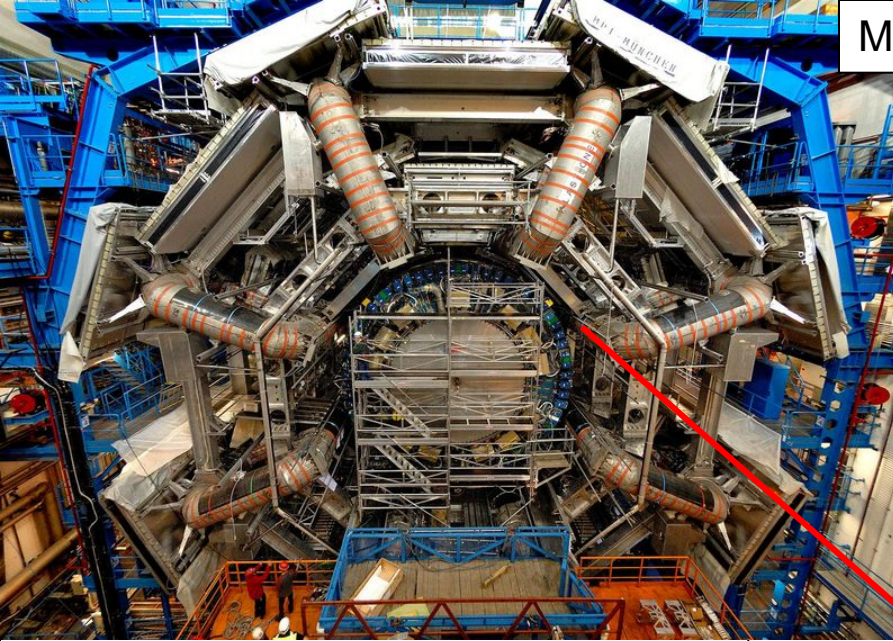
Monte Carlo generation software maintenance

LHC Schedule



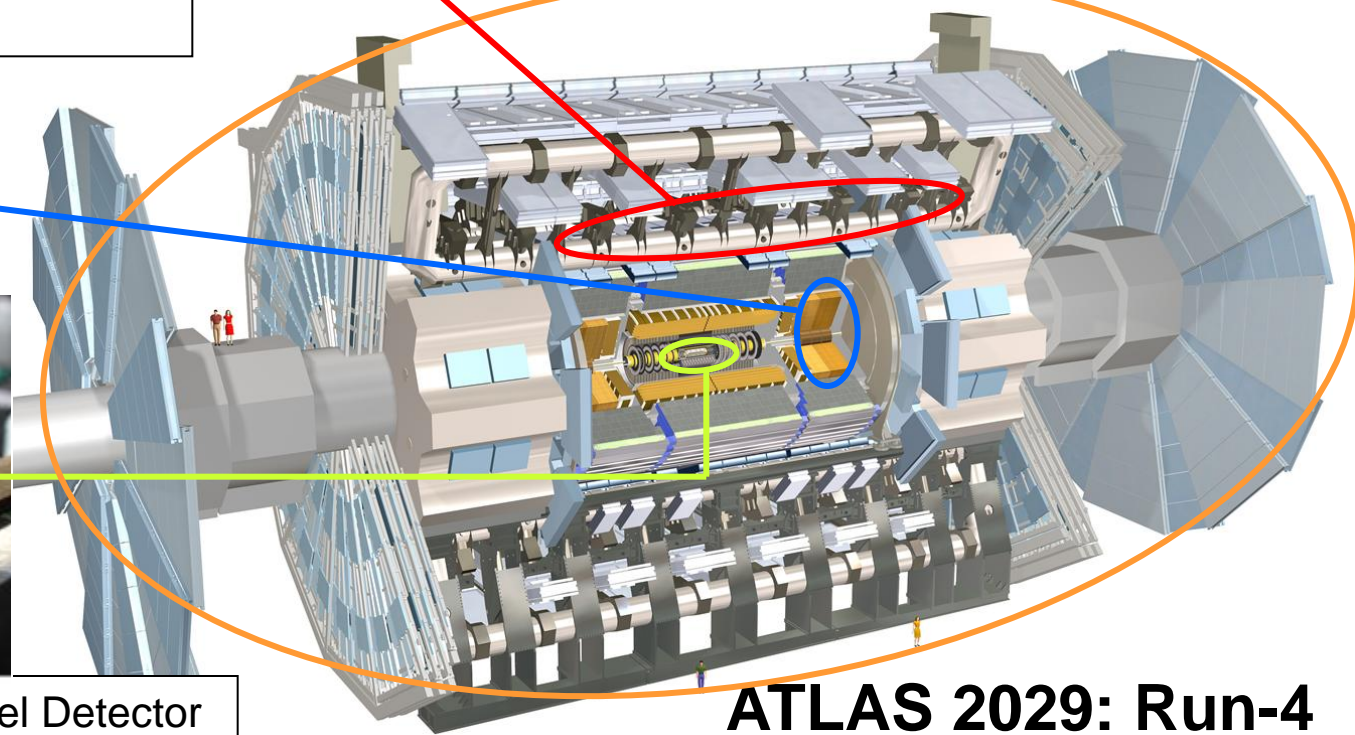
- **ATLAS Phase-1 upgrade** in Long Shutdown 2 almost completed.
Installation of new **BIS78 sMDT + RPC chambers built at MPP**.
Restart of data taking in Run-3 in April 2022 with **13.6 TeV collision energy**.
- Plan to extend Run-3 to 4 years and Long Shutdown 3 by 6 months, i.e. LS 3 from 2026 to end of 2028. Minimum extensions, necessary to allow for the construction of the new inner tracker for HL-LHC.
- **Challenging operating conditions at HL-LHC:**
7.5 x nominal LHC luminosity of $1 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ over more than 10 years of operation (4000 fb⁻¹ total), i.e. 7.5 x higher radiation damage, background counting rates, trigger rates and event pile-up (200 pp interactions per bunch crossing).
- **ATLAS Phase-2 Upgrades for HL-LHC:**
 - Replacement of the inner tracker by all-silicon strip and **pixel detector**.
 - New silicon pixel timing detector.
 - **New inner barrel muon tracking and trigger detectors sMDT+ RPC**.
 - New trigger/DAQ system at 1- 4 MHz, including SW inner tracker trigger and **first HW muon track trigger**.
 - **New readout and trigger electronics for all detector systems**.

MDT chamber RO electronics, Muon trigger processors



Muon Spectrometer & Muon Trigger:
sMDT + RPC chambers

Hadronic Endcap Calorimeter (HEC)
Low Voltage Power Supplies



All-Silicon Inner Tracker: Pixel Detector

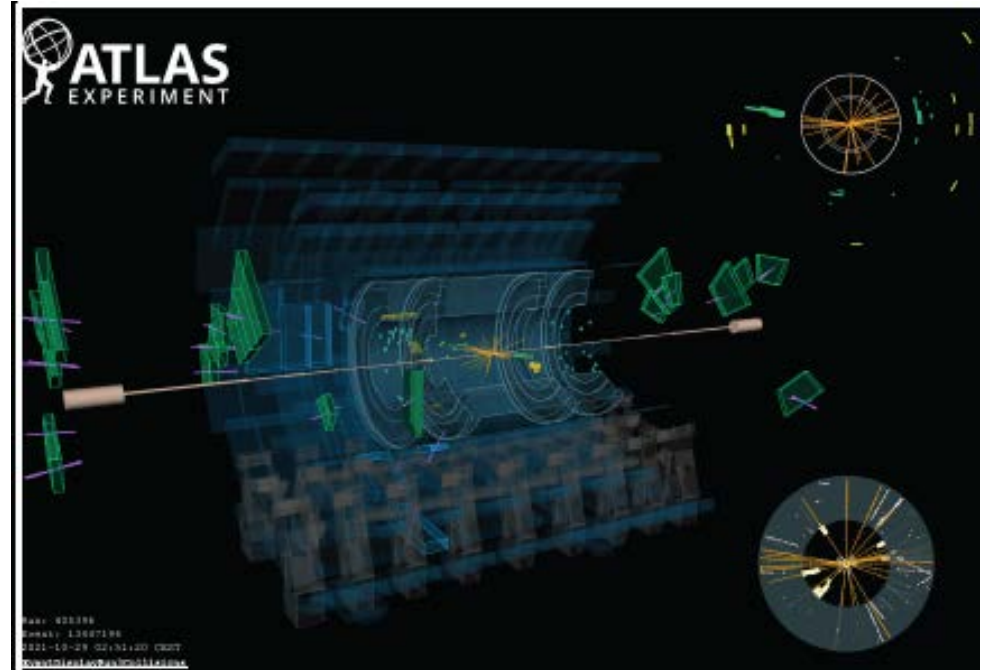
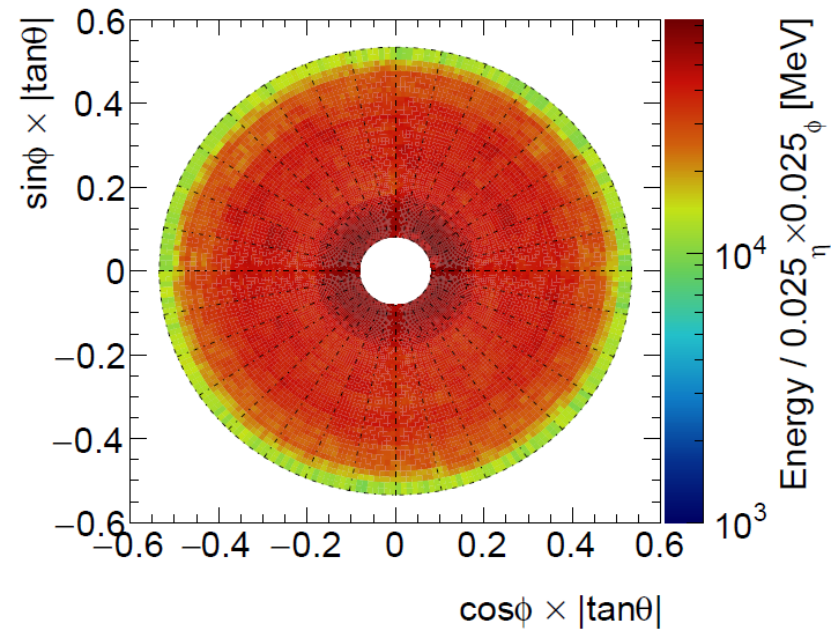
ATLAS 2029: Run-4

LHC Pilot Run October 2021

Proton beams colliding with collimators:
beam splash events

40 hours pp collision data taking at 900 GeV

ATLAS Preliminary LAr Endcap C
Run 405495 Event 50896
Date: 29 Oct 2021 21:51:01 CEST



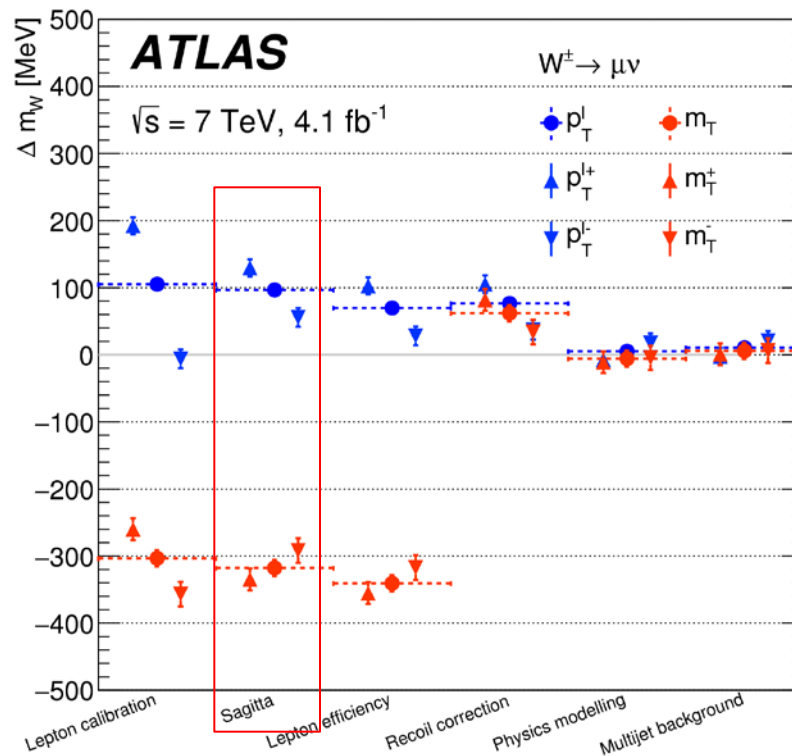
All detector parts working.

Alignment Corrections for the Inner Tracker

Alignment (track sagitta) corrections for the Inner Tracker (using $J/\psi \rightarrow \mu\mu$ decays) coordinated by MPP.

Further significant improvements of the alignment precision achieved this year.

Important ingredient for example for the ATLAS precision W mass measurement with **small systematic uncertainty** due to the absolute track sagitta measurement:



$$m_W = 80370 \pm 19 \text{ MeV}$$

Radiation Predictions for HL-LHC

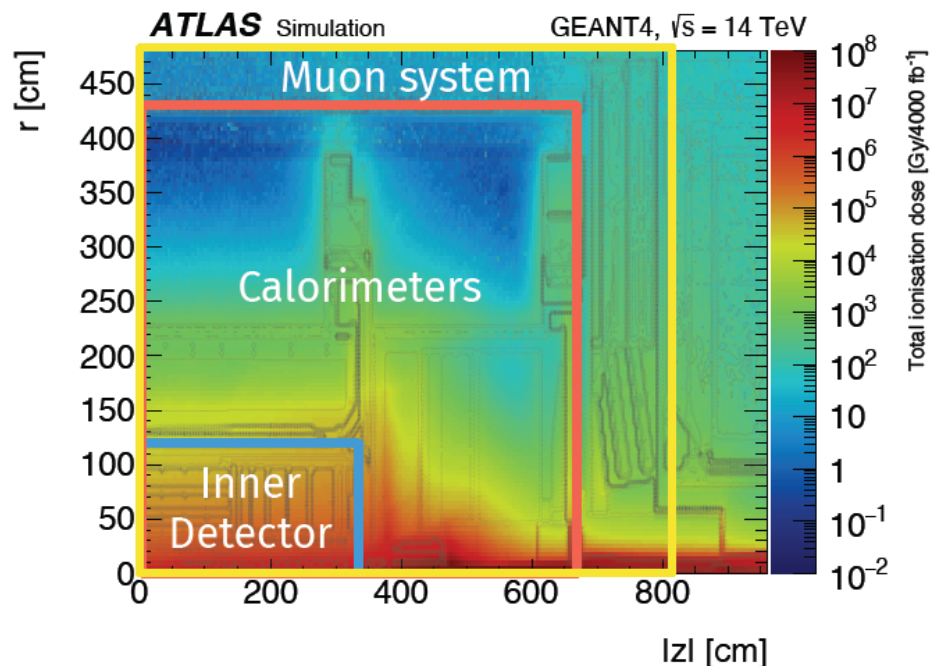
Proton, neutron and γ radiation induced by secondary interactions of particles from pp collisions in the detectors, shielding and cavern walls.

10 x higher radiation hardness requirements for detectors, readout electronics, even power supplies at HL-LHC.

Calorimeters survive, including HEC cold electronics. Inner Tracker has to be replaced. Inner layers of the Muon Spectrometer have to be upgraded and all Calo and Muon electronics to be replaced.

Modern 65 nm CMOS ASIC chips sufficiently radiation hard (RD53 collaboration).

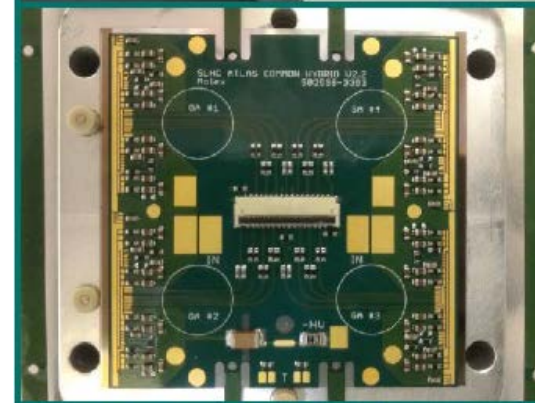
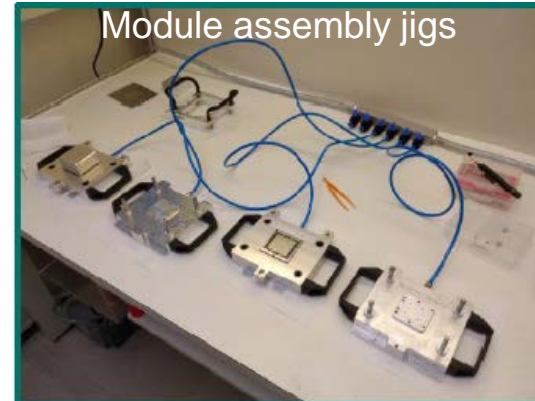
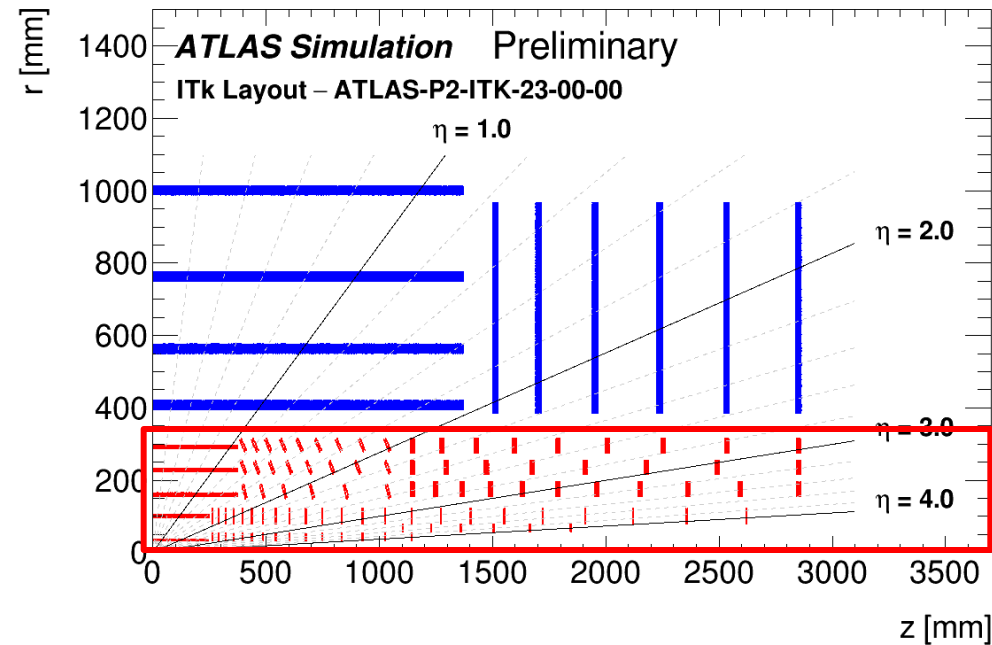
New radiation hard 3D and planar silicon (pixel) sensor technologies developed within the RD50 collaboration.



Pixel Detector Module Production

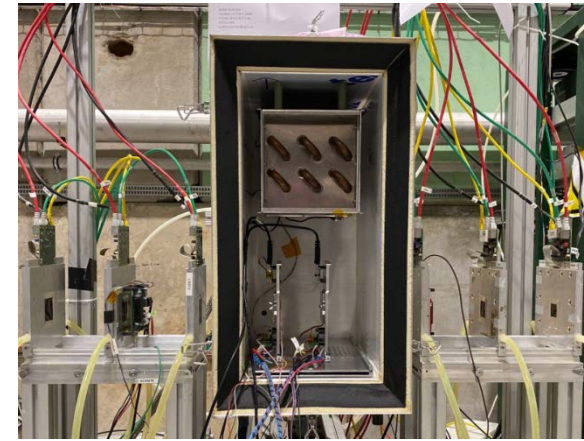
Long-time participation in radiation hard planar silicon pixel sensor development together with the MPG Semiconductor Lab within the RD50 collaboration.

The production of around 150 pixel sensor modules for the 1st sensor layer of the **Pixel Detector** in the years 2022 – 2025 is under preparation: MPP is qualified as production site.



Pixel Detector Operation

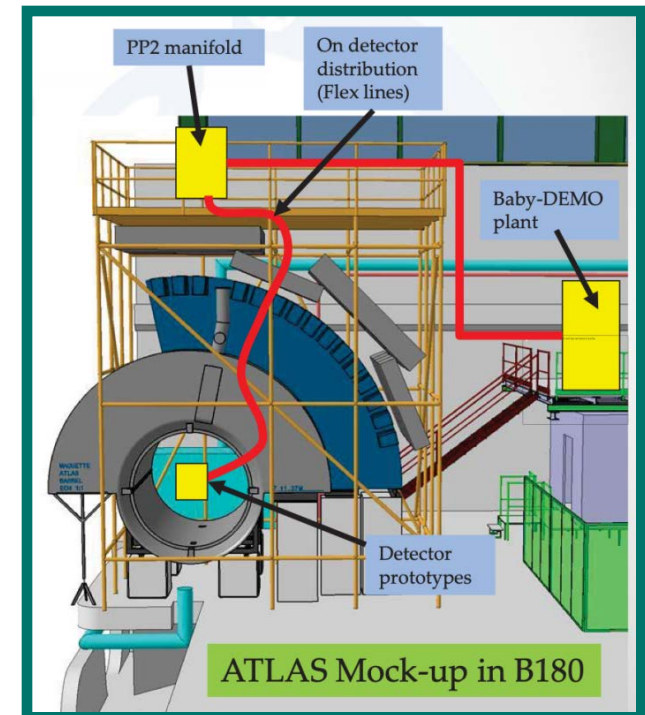
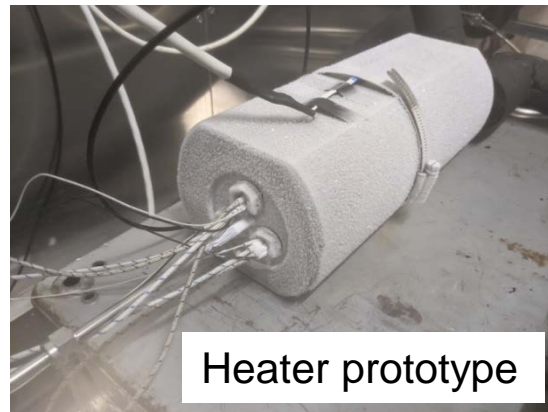
Testbeam measurements of pixel sensor modules at DESY to qualify sensors and produces coordinated by MPP.



Silicon sensors + electronics have to be cooled to $-35\text{ }^{\circ}\text{C}$ at all times to keep the radiation damage under control.

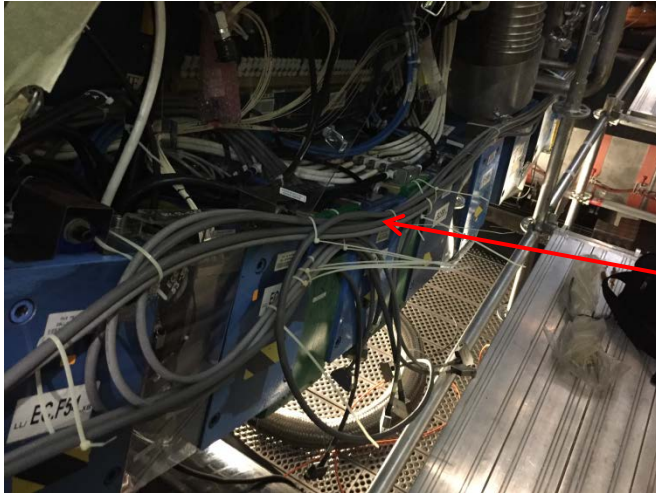
MPP contributes to the CO_2 cooling system of the ATLAS inner tracker with the design of flexible cooling pipes, distribution boxes and heaters.

Successfully tested in the cooling system mock-up at CERN.



Lar Calorimeter Electronics

The Lar calorimeter upgrade for HL-LHC (readout and trigger electronics, DAQ system) is being co-coordinated by us.



12 new radiation hard low-voltage power supplies to be constructed for the HEC readout electronics.

Radiation hard voltage regulators and FPGAs found.

16 m long supply cables to the detector validated.



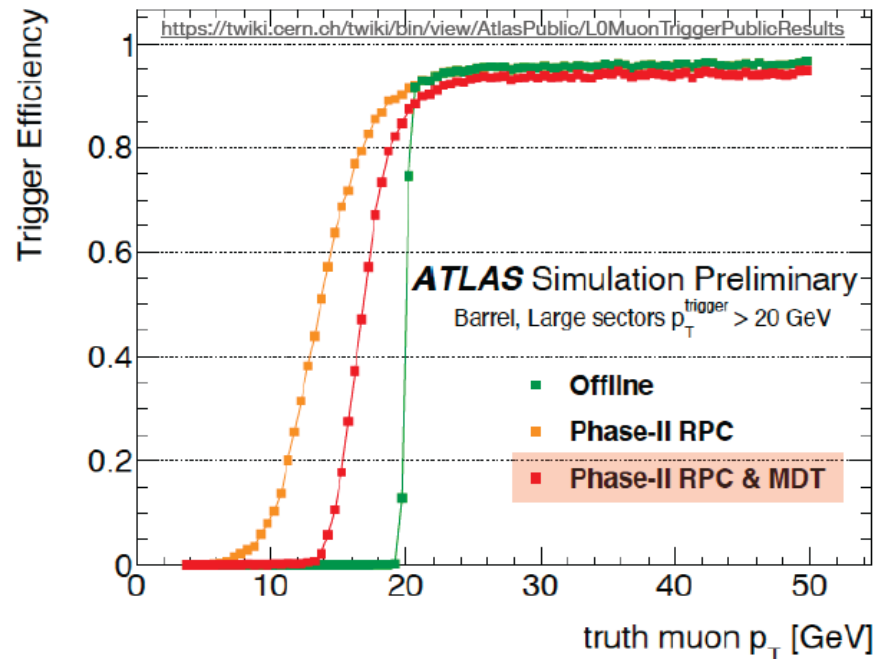
Boxes with externally accessible power boards and cooling system developed and tested.

Muon Spectrometer Upgrade Program

Requirements for the upgrade of the Muon Spectrometer for HL-LHC:

- (1) 96 new sMDT chambers in the barrel inner layer increasing the rate capability by a factor of 10.
- (2) Limited lifetime and efficiency loss of the RPC trigger chambers in the barrel:
272 additional thin-gap RPC chambers in the barrel inner layer.
8 new sMDT + RPC chambers already installed in the present shutdown for Run-3.
- (3) Use of the precision tracking chambers MDT and sMDT in the first level muon trigger increasing the trigger momentum resolution and selectivity by an order of magnitude.
- (4) The one order of magnitude higher first-level trigger rate and latency requires replacement of the present MDT front-end electronics (like for the other ATLAS subdetectors).

All muon system upgrade projects have been proposed and are carried out under the leadership of the MPP group.



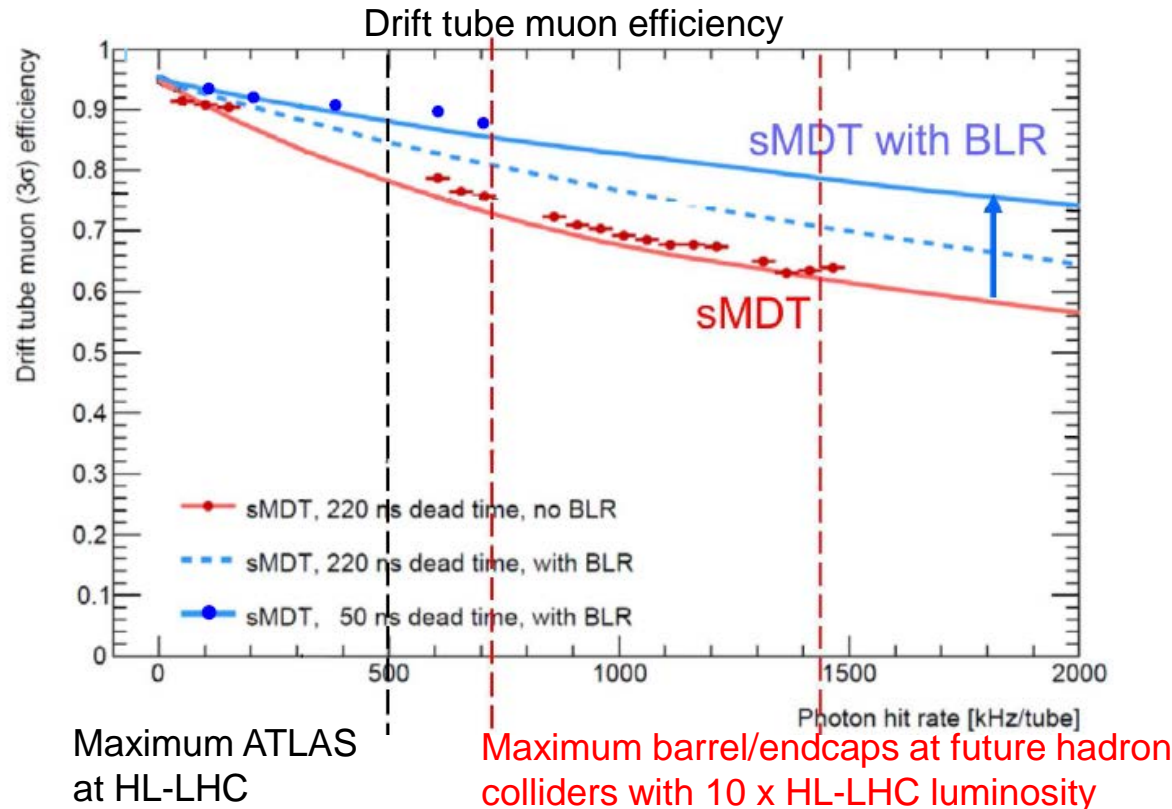
sMDT Chamber Background Rate Capability

10 times higher rate capability of sMDTs with 15 mm tube diameter (MDTs 30 mm \varnothing) due to the lower occupancy and strongly suppressed effects of space charge from background radiation.

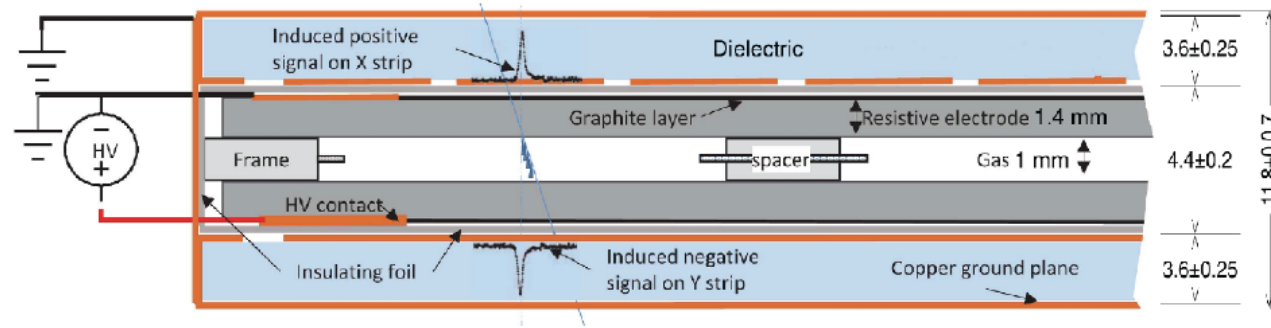
Readout electronics has become the limiting factor due of signal pile-up at high counting rates.

Active baseline restoration (BLR) techniques showed promising results in high-rate tests at the CERN Gamma Irradiation Facility.

Now implementation in an improved readout ASIC chip in 65 nm CMOS technology for upgrades in high-rate regions of the muon spectrometer and future colliders.



Thin-Gap RPC Trigger Chamber Design and Production



Thin-gap RPC design completed:

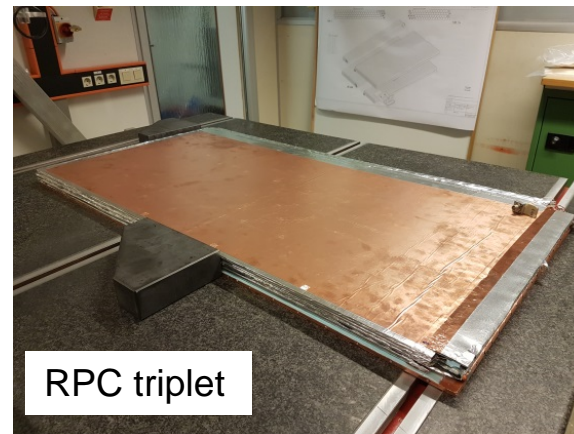
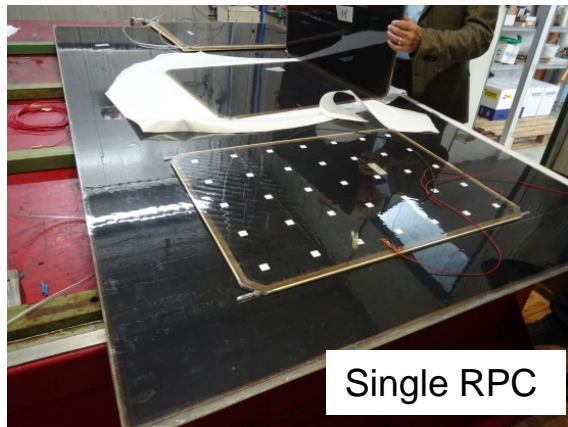
10 x improved lifetime and rate capability, sub-ns time resolution

RPC construction procedures have been established at MPP.

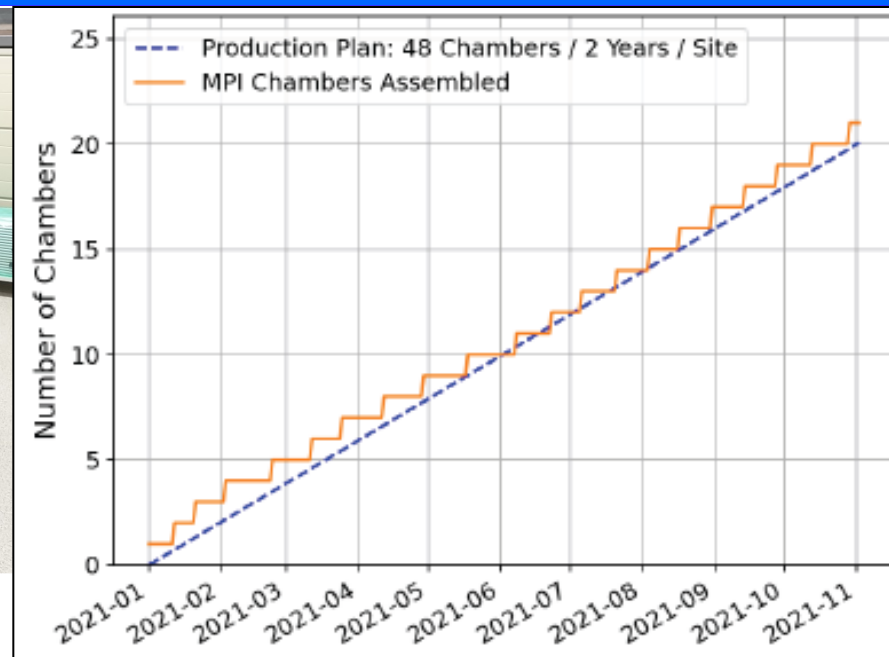
Reliable and sustainable industrialized mass production is required for ATLAS and many other applications.

Technology transfer to several companies in progress for the mass production for the ATLAS upgrade in 2022–2024.

RPC triplets needed for the ATLAS upgrade: assembly in the support frames designed by MPP in the new building in Garching in 2023–24.



sMDT Chamber Production



Serial production of 48 BIS 1-6 sMDT chambers at MPP until middle of 2023.

The other 48 at University of Michigan. Successful technology transfer in 2020-2021.

Production start in January 2021 as planned with a steady rate of 2 chambers per month in spite of Corona restrictions. 24th chamber completed in December 2021.

The only Phase-2 upgrade project in production and on schedule in ATLAS, (together with the MDT front-end electronics designed by MPP).

SMDT Chamber Production

Drift tube insertion in precision assembly jig



Automated glue dispenser

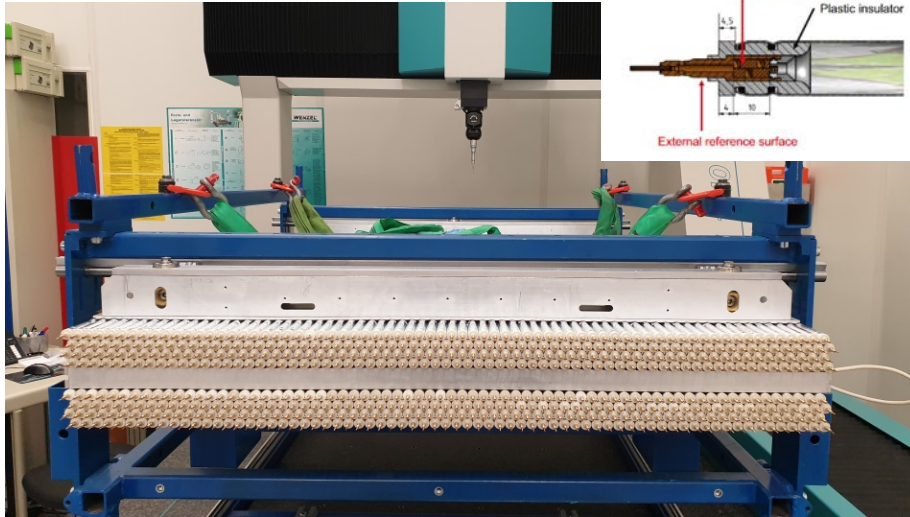


sMDT Chamber Production



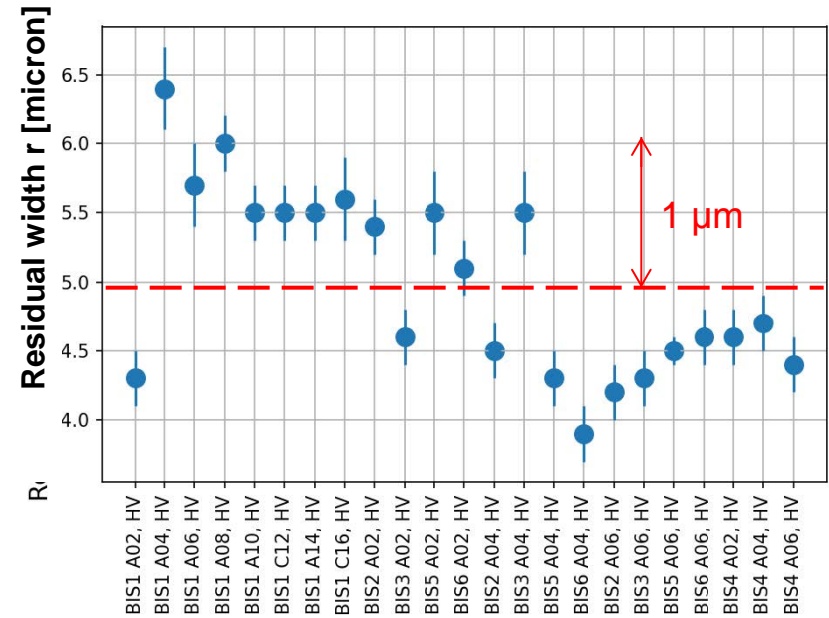
Chamber Precision

Sense wire position measurement with automated coordinate measuring machine:

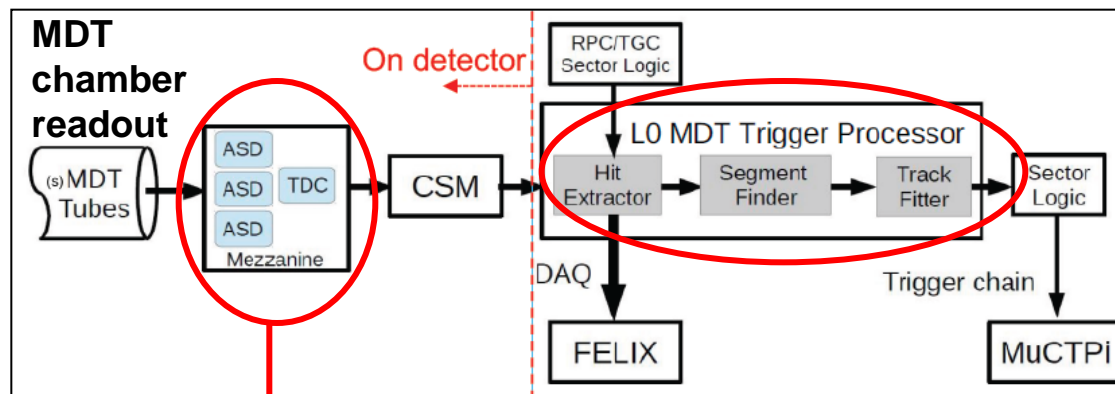


Wire positioning accuracy:

5 μm wire pos. accuracy achieved in serial production
(world record, requirement 20 μm)



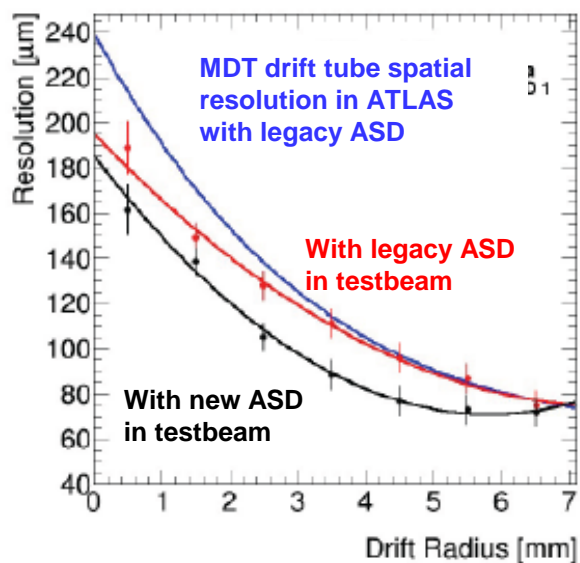
New (s)MDT Readout Electronics



Readout boards for all (s)MDT chamber types and the new ASD and TDC chips designed by MPP.

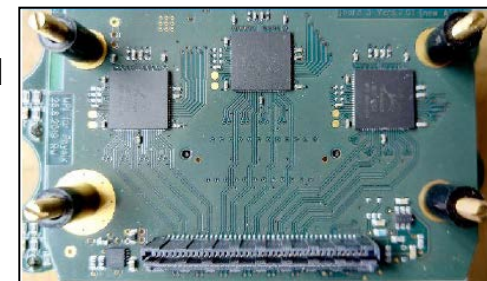
ASD chips produced already in 2019. TDC chip and readout board production in 2022- 2023.

Whole on-detector readout chain validated in the CERN Gamma Irradiation Facility in Nov. 2021.



Significantly improved noise performance of the new ASD chip compared to the legacy chip.

ASD board



TDC board



MDT-Based Muon Track Trigger

First-level track trigger for the first time in ATLAS.

Concept developed at MPP, including:

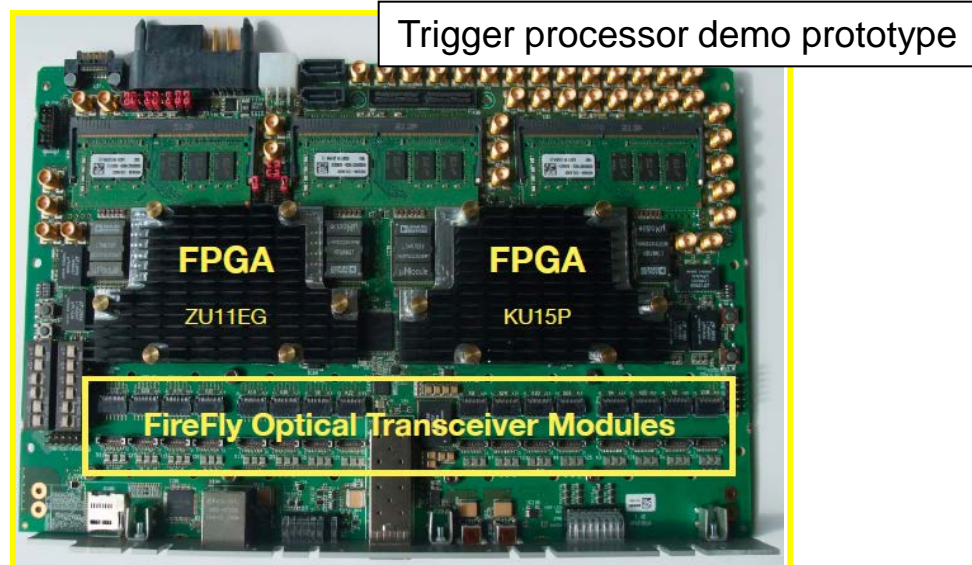
- efficient algorithm for pattern recognition and track/momentum reconstruction at the high γ background rates at HL-LHC and
- the firmware implementation on FPGA processors allowing for a **trigger decisions within only 1 μ s.**

MPP responsible for design and production of the 64 trigger processors.

First demonstrator prototype produced and tested this year.

Final prototype design completed (FPGAs, cooling). External fabrication until end of next year.

Serial production 2023 – 25.



Technical Personell on the Project 2021

Muon Detector and Trigger

sMDT construction mechanics:

A. Wimmer

T. Brunner (ATLAS)

L. Fink

L. Schafroth (75% ATLAS)

E. Töpfer

P. Vanoni

3 technicians from IHEP Protvino (ATLAS)

sMDT construction electronics:

S. Schmidl

V. Grüniger

J. Haas (75% ATLAS)

Mechanical engineering:

A. Eiterer (HoD)

sMDT chambers

K. Liebicher

G. Obermüller (20%)

S. Podkladkin (retired)

M. Stadler

J. Zimmermann (ATLAS)

RPC chambers

P. Maly

D. Soyk (ATLAS)

S. Vogt

Electronics engineering:

MDT ASICs, RO boards, trigger

M. Fras

S. Abovyan (ATLAS)

V. Danielyan (ATLAS)

R. Maier

Y. Zhao

Electronics production:

R. Maier

E. Linnhard

Calorimeter

Electronics engineering:

HEC LV power supplies

J. Habring

Electronics assembly:

HEC LV power supplies

A. Fischer

Mechanical engineering:

HEC LV power supplies

S. Vogt

Inner Tracker

Pixel module assembly :

E. Töpfer

Module wire bonding:

Q. Fischl

C. Schlammer

Mechanical engineering:

Pixel module assembly,
CO₂ cooling system

S. Vogt

Thank you very much for the excellent support!

Summary

- Enormous progress in the design and construction of our contributions to the ATLAS upgrade under Corona restrictions with the outstanding support by the technical departments.
- Decisive technology developments at this institute.
- Still huge work ahead at MPP and at CERN until far into Run-4:
 - Completion of the sMDT and RPC and the pixel module construction.
 - In between: Moving of the construction facilities to the new building in Garching.
 - Completion of the muon trigger processor and firmware development.
 - Installation and commissioning of the 96 new muon chambers within only one year in 2026 – 27.
 - Installation and commissioning of the readout and trigger electronics for the MDT chambers in ATLAS.
 - Construction and installation of the new rad. hard HEC LV power supplies.