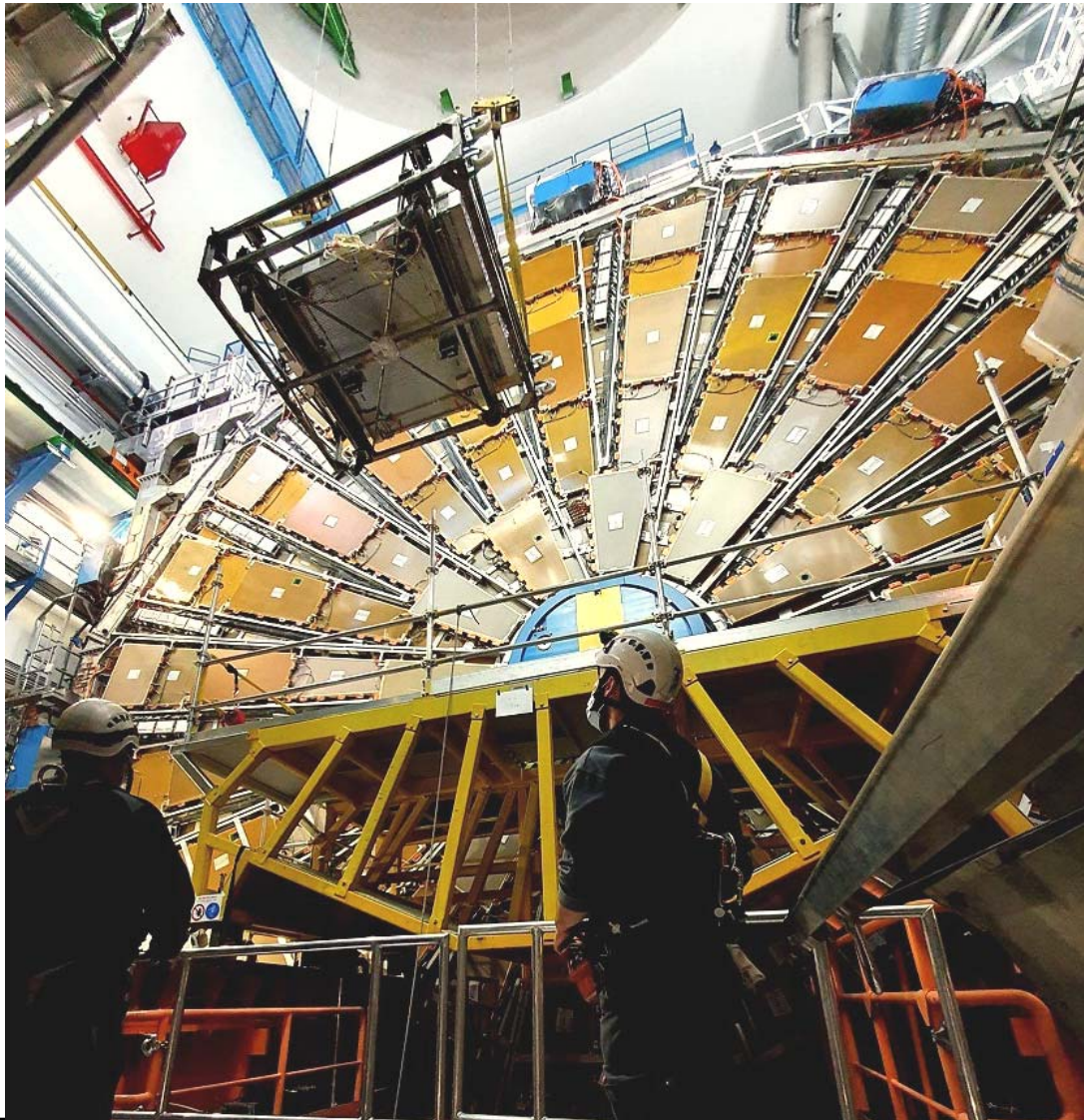
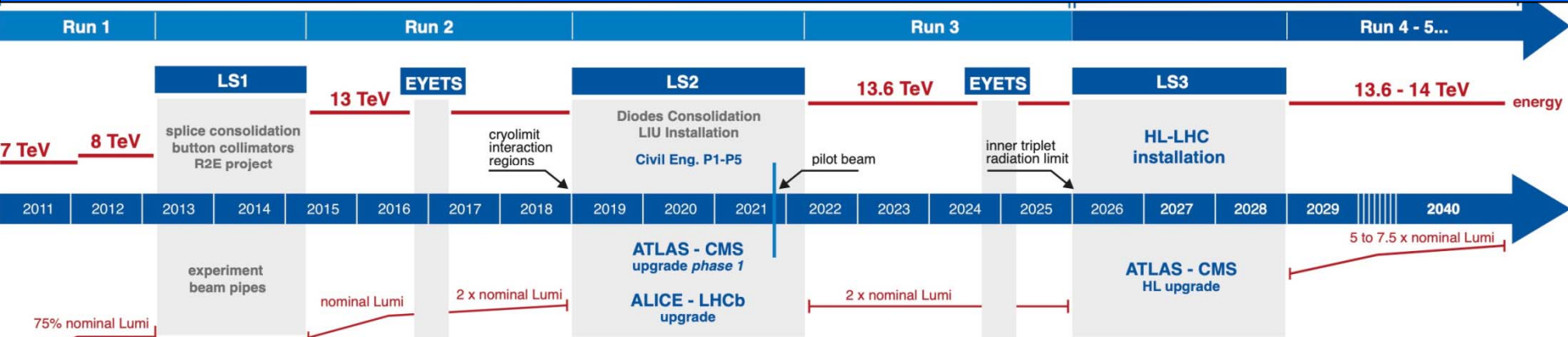


ATLAS Muon Spectrometer Upgrades



On behalf of
the MDT and
Minerva groups

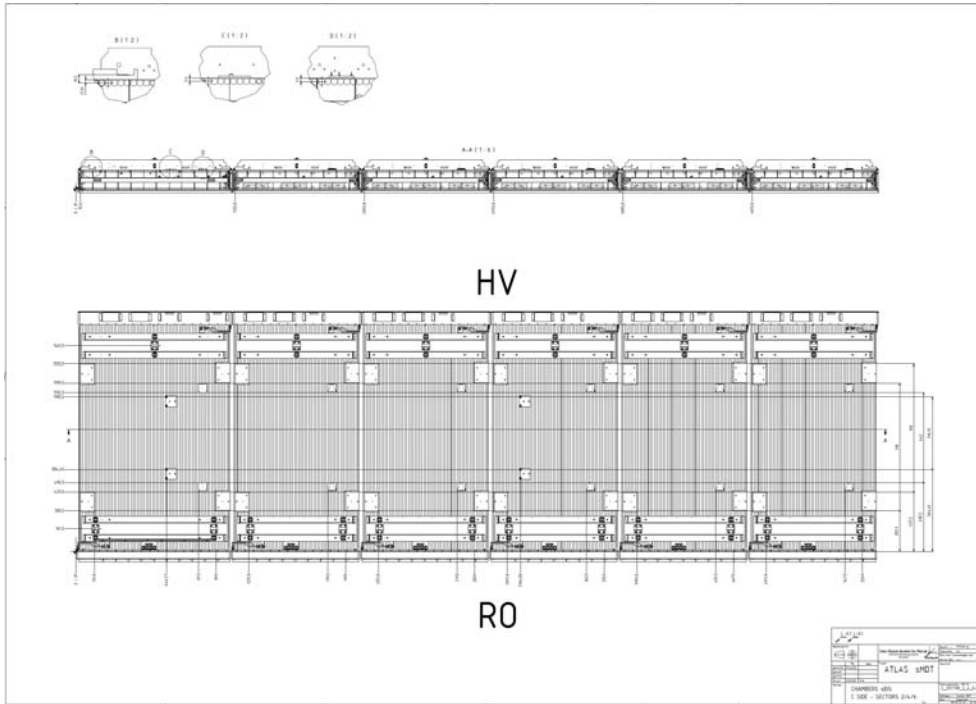
ATLAS Muon Upgrades



- **Phase- 0 and 1 Muon System upgrades** in LS1 (BME), EYETS (BMG) and LS2 (BIS78), proposed and developed by MPP, completed. Chambers installed and in operation. Initiative, R&D and design for New Small Wheels upgrade.
- **Phase-2 Muon System upgrades** in LS3, proposed, developed and coord. up to TDR by MPP:
 - 96 new BIS sMDT detectors (design MPP, construction MPP & Michigan 50:50).
Coordination MPP.
 - 275 new BIS and BIL RPC chambers (gas gap design and construction MPP & INFN 50:50).
BIS coordination MPP.
 - First-level hardware muon track trigger based on (s)MDT precision tracking chambers (trigger processor hard- and firmware design MPP, production MPP & Boston & Japan).
Co-coordination MPP.
 - New (s)MDT chamber front-end boards (design MPP, production and test LMU & Würzburg).
Coordination MPP, 16.000 pcs. (3.000 pcs.)
 - New ASD ASICs (design MPP, production MPP & LMU, 80.000 pcs.)
Coordination MPP.
 - New TDC ASICs (design and production MPP & Michigan 50:50, 20.000 pcs.)

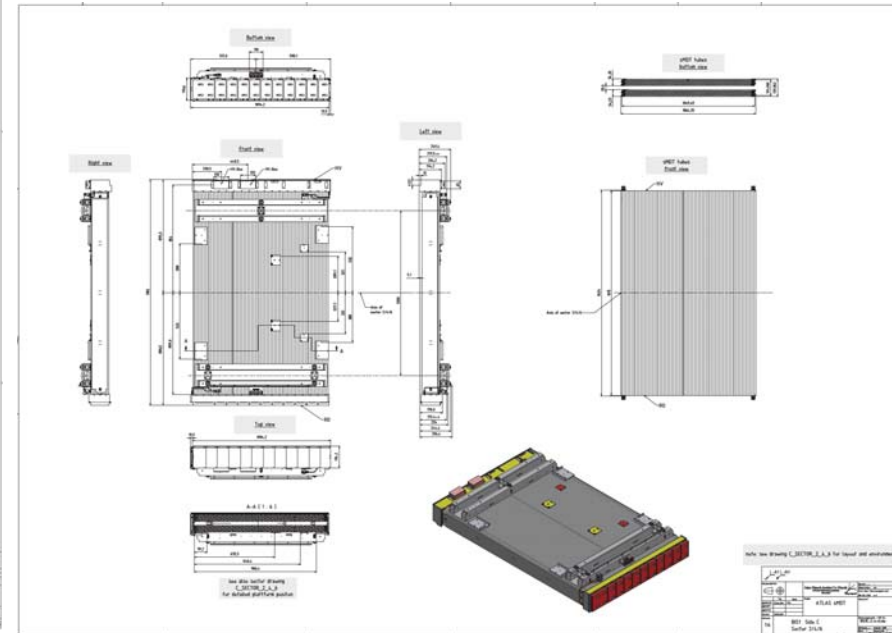
BIS Layer Design: sMDT

Layout of new BIS layer:



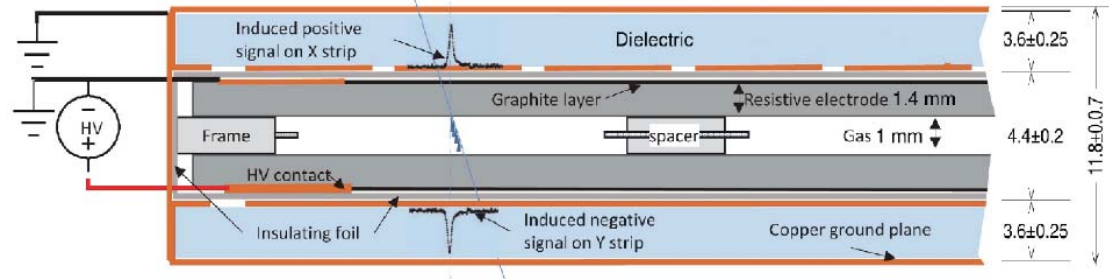
Design of sMDT chambers:

10 different types with different services and alignment connections

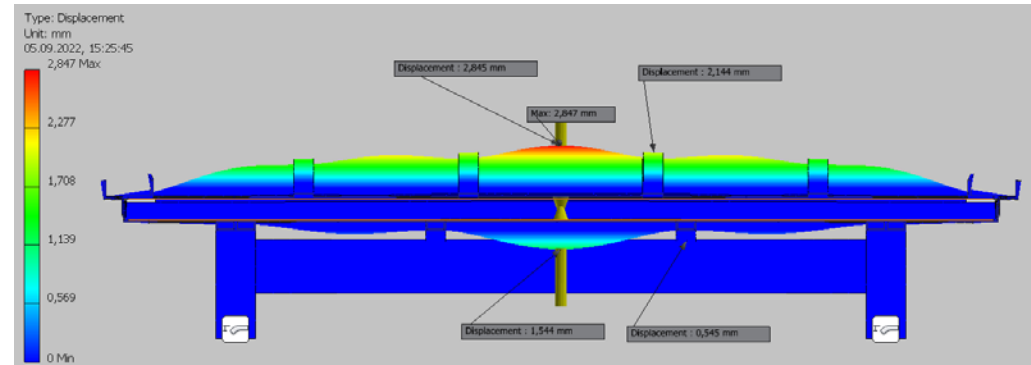
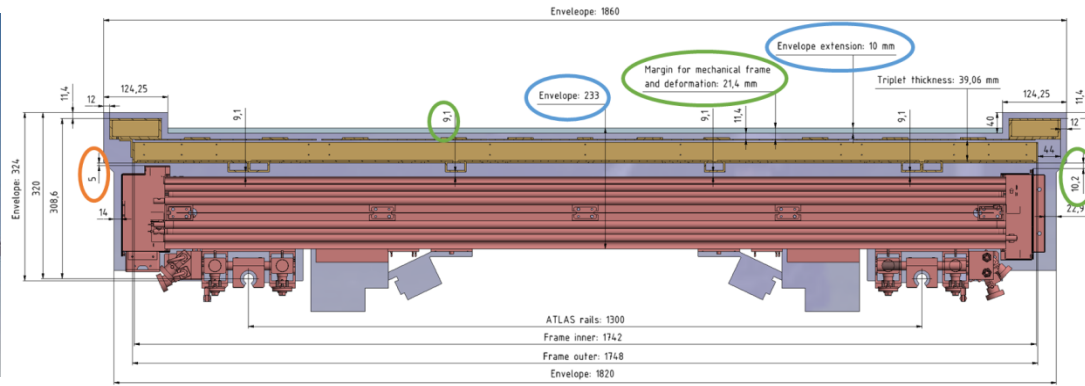
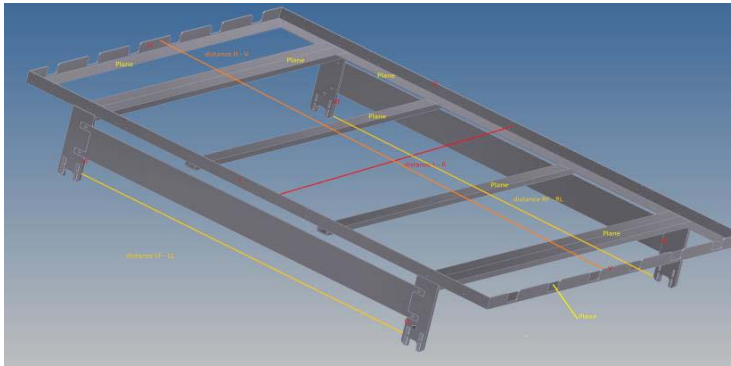


BIS Layer Design: RPC

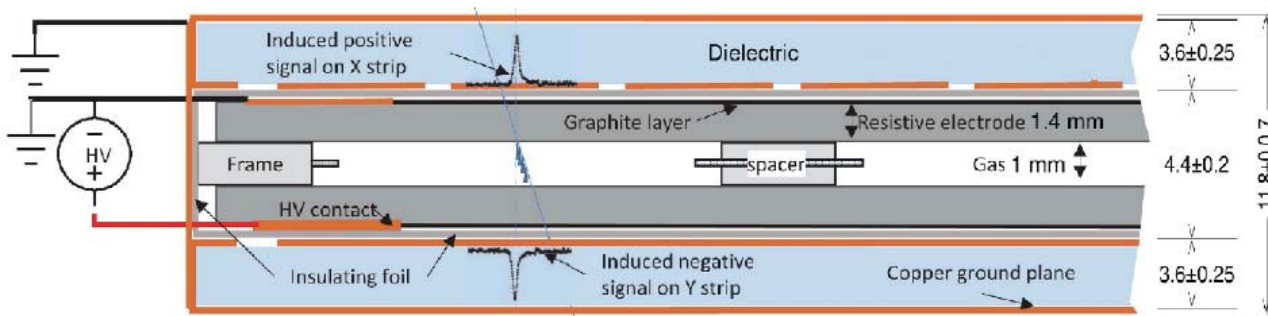
Design of RPC gas gaps:



Design of support frames for RPC triplets. Integration of sMDT and RPC chambers:



Thin-Gap RPC Trigger Chamber Design and Production



Thin-gap RPC design completed:
10 x improved lifetime and rate capability,
sub-ns time resolution

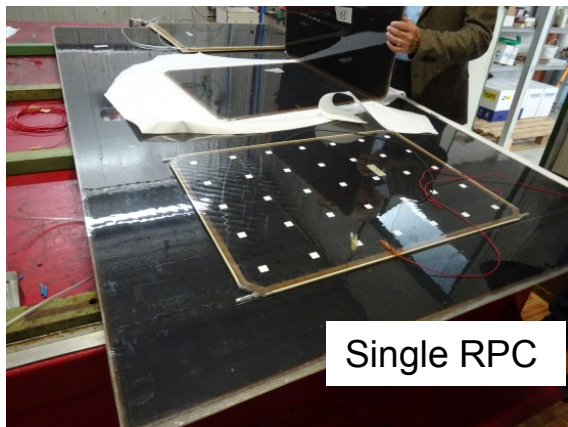
Reliable and sustainable industrialized mass production is required for ATLAS (and many other applications).

RPC construction procedures established at MPP in 2021/22.

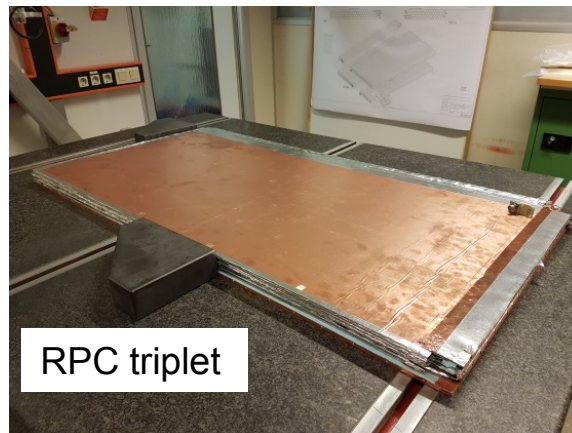
Successful Technology transfer to two German companies for the mass production for the ATLAS upgrade in 2022–2024.

Gas gap prototype construction and qualification under irradiation at GIF in 2023.

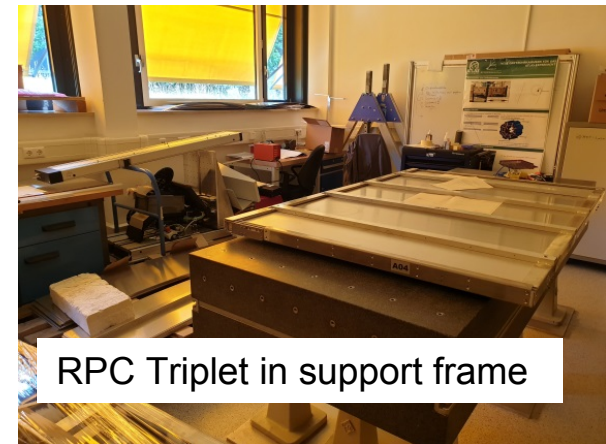
Gas gap production in 2024 -25.



Single RPC

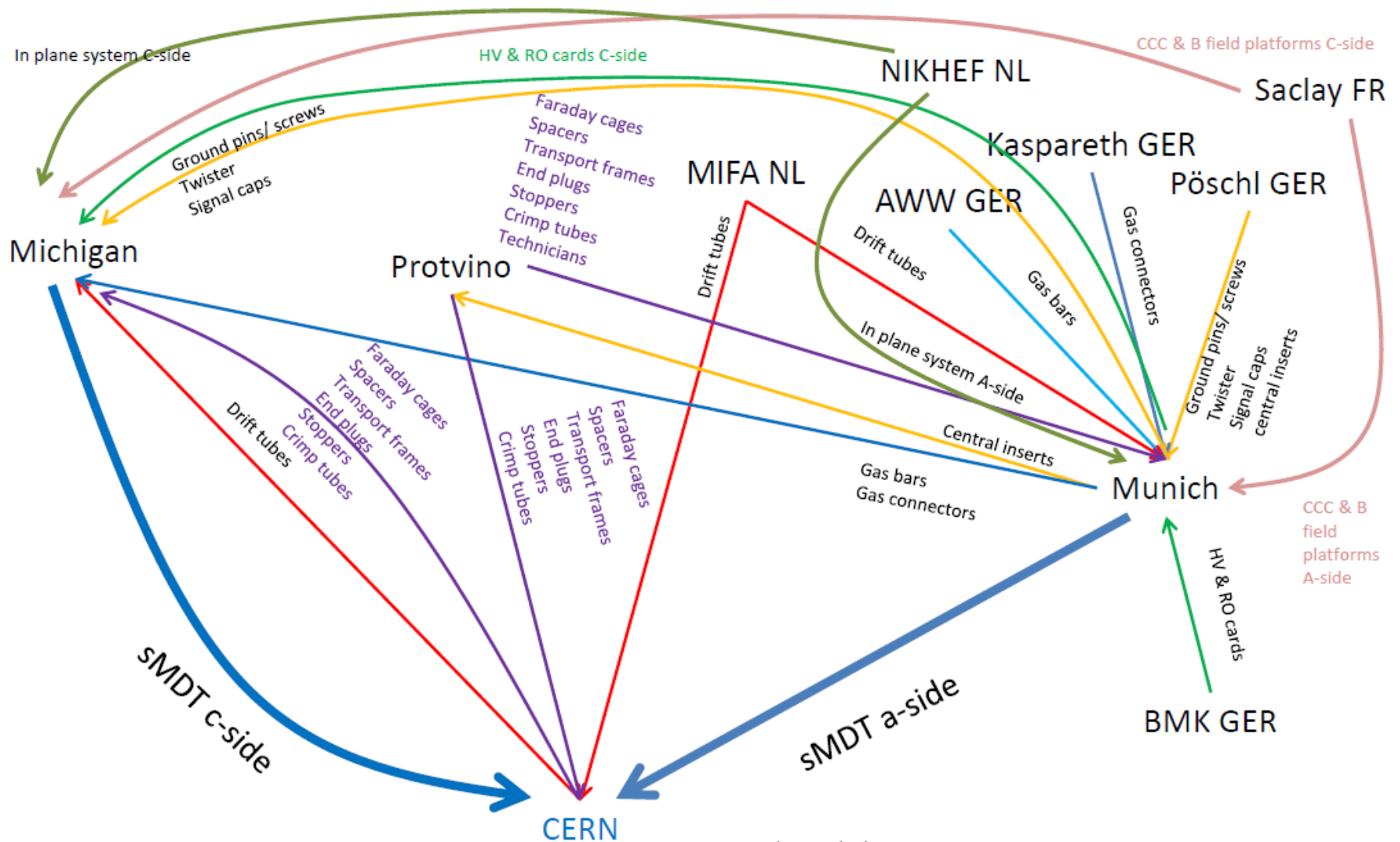


RPC triplet



RPC Triplet in support frame

sMMDT Production Logistics



Organised by MPP.

Early procurement essential for timely completion of sMMDTs ahead of ATLAS schedule.

IHEP Protvino sMDT In-kind Contributions

Injection molded
drift tube endplugs



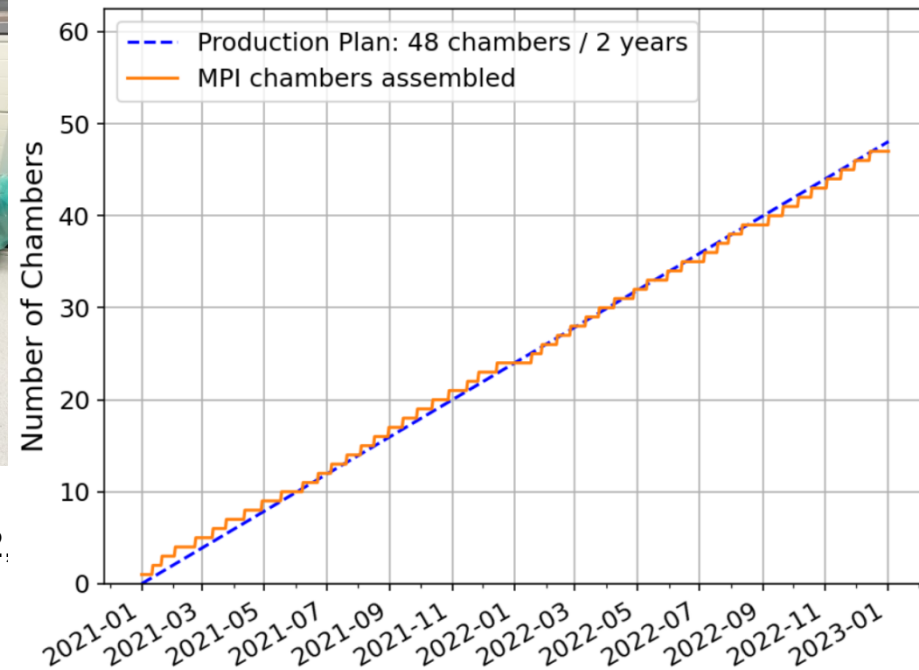
Chamber rail supports



sMDT transport and
storage frames



sMDT Chamber Production



Semi-automated drift tube assembly and test:
by technicians from IHEP Protvino June 2016 – Feb. 2022,
by temporarily hired personnel Feb.-Dec. 2022.

Serial production of 48 BIS 1-6 sMDT chambers at MPP Jan. 2021 – Jan. 2023
at a steady rate of 2 chambers per month as planned.

The other 48 chambers produced at University of Michigan March 2021 – Oct. 2023.
Successful technology transfer in 2020-2021.

The only Phase-2 upgrade project in production and on (ahead of) 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 Production Quality Monitoring



push new code to repo



Base Image: centos7, ROOT



Final image: adding frontend code, mostly python



CERN Openshift

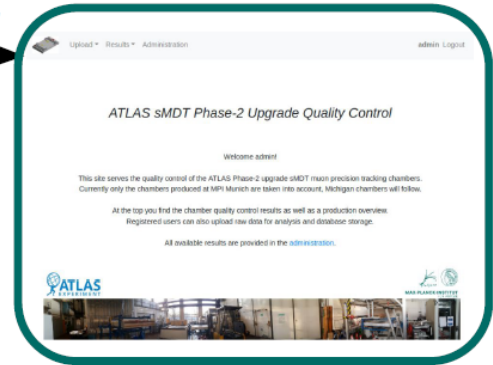
Image update, triggered by repo push



Data taking in lab



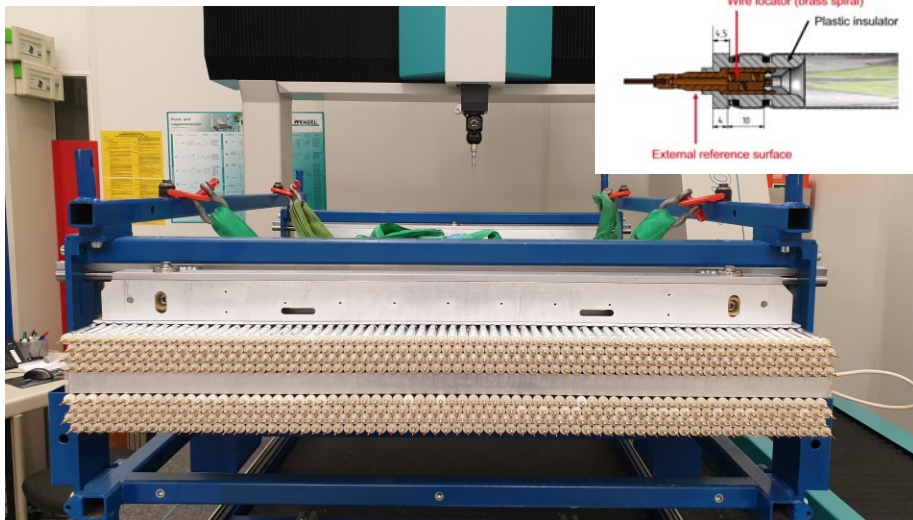
Deployment



Frontend

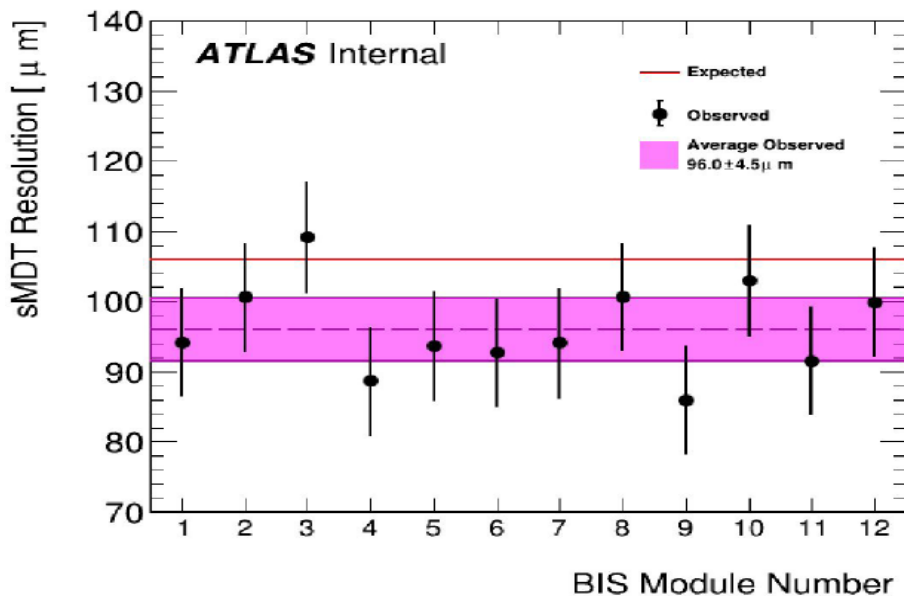
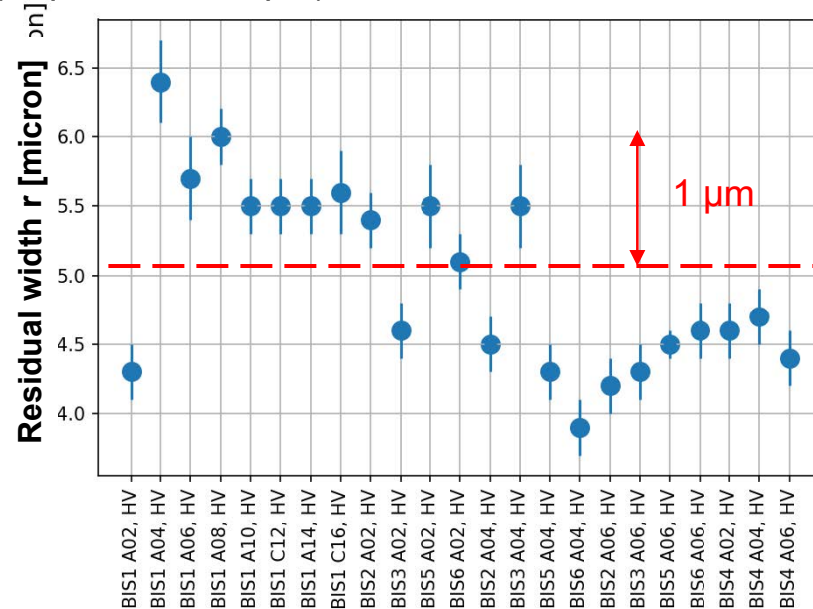
Chamber Precision and Performance

Sense wire position measurement with automated coordinate measuring machine:



Wire positioning accuracy:

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



Spatial DT resolution of serial prod. chambers

with legacy electronics

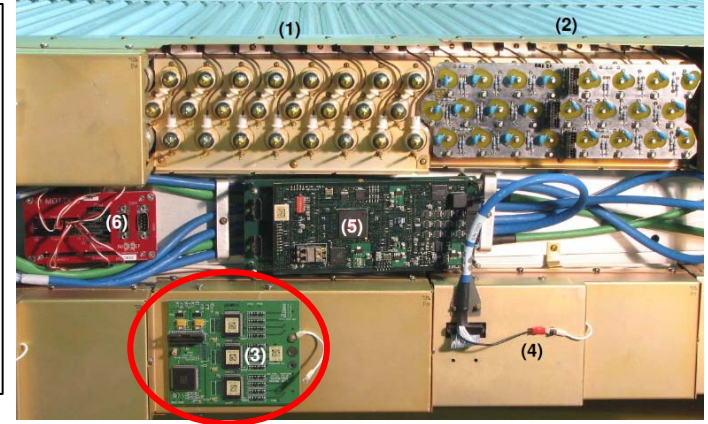
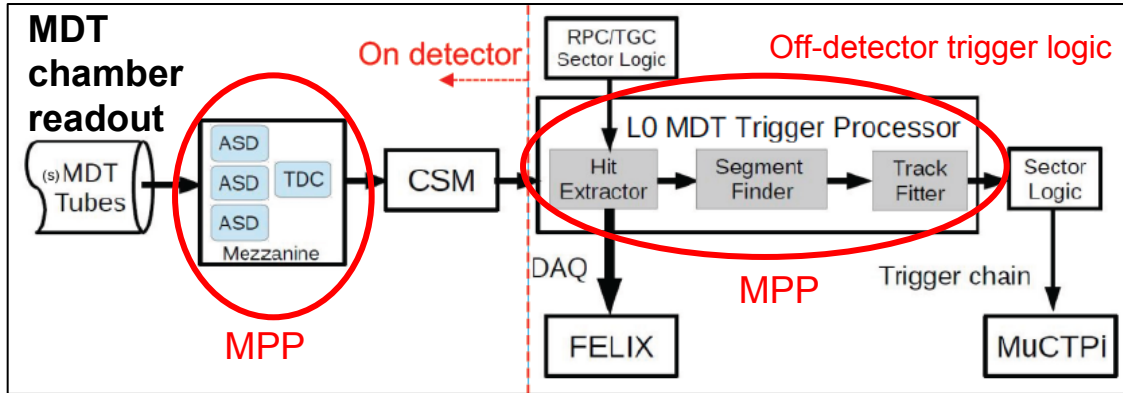
with new ASD for Phase 2

Chamber Storage and Test at CERN BB5 Hall

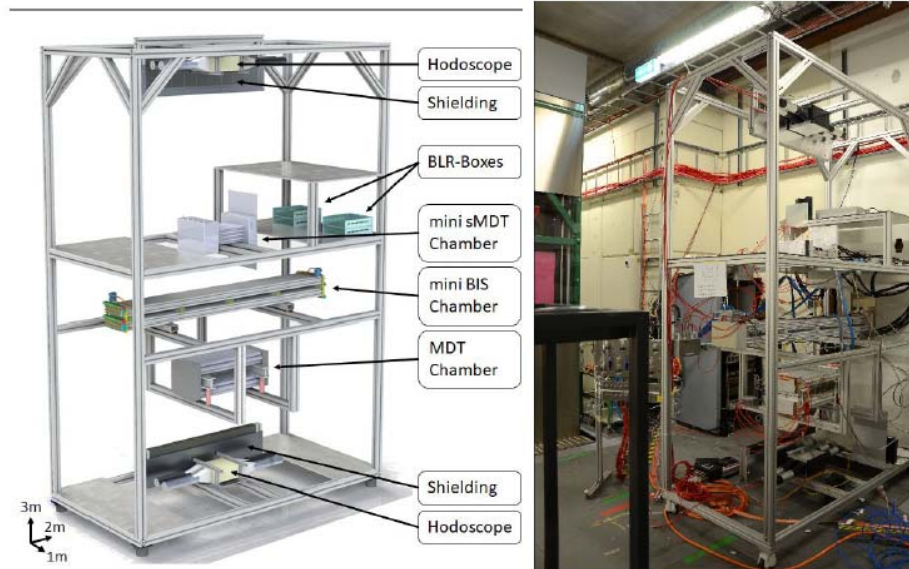


New (s)MDT Readout Electronics

To cope with 10 x higher 1st level trigger rates and latency and continuous MDT readout for the new MDT track trigger.

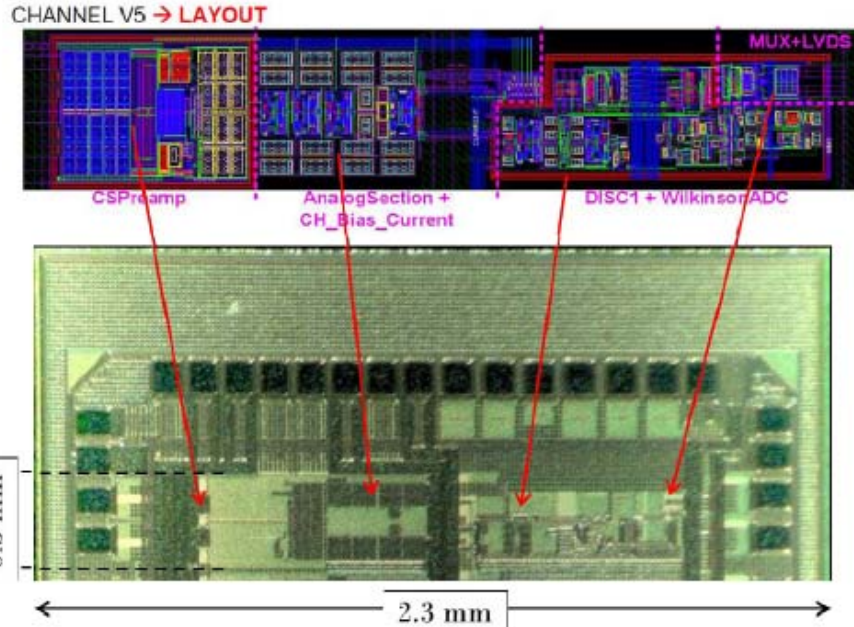


Full on-detector readout chain validated in the CERN GIF in Nov. 2021 with pre-production chips:



MDT ASD ASIC Development

ASD ASIC in Global Foundry 130 nm CMOS technology:

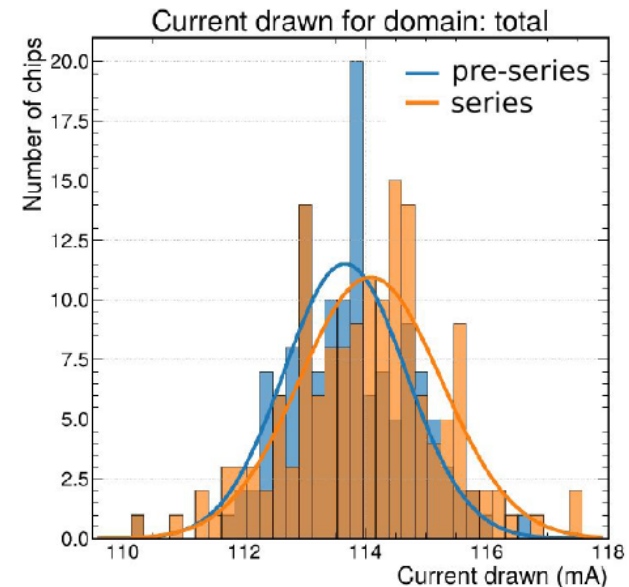


Arrival of 80k chips at MPP:



Pre-series production in 2019.
Delivery of packaged series chips in January 2021.

Excellent performance , 92% yield.

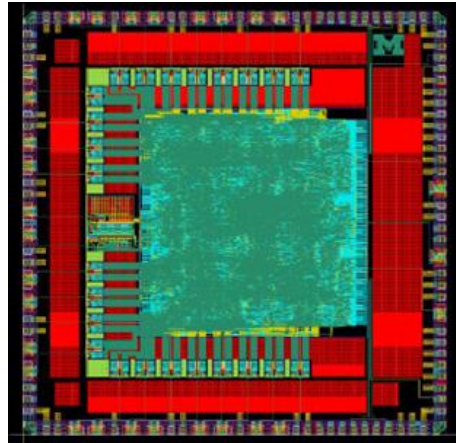


Further development in progress:

Updated version in sustainable TSMC 65 nm CMOS technology

- with reduced power consumption
- still faster shaping for pile-up reduction
- active baseline restoration functionality

TDC ASIC and MDT Front-end Boards



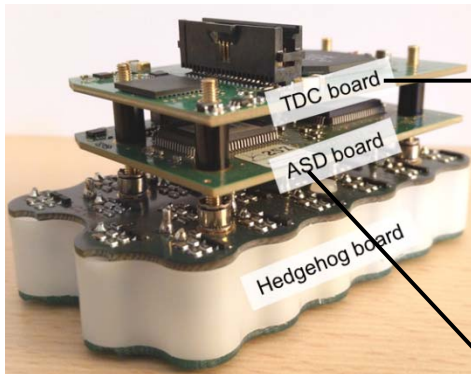
TDC ASIC in TSMC 130 nm CMOS technology.

Pre-production in 2021.

Serial production of 20k chips in 2022.

Design of (s)MDT front-end (mezzanine) cards ready (freelancing engineers from Yerevan).

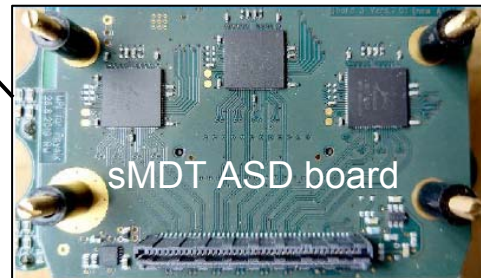
Production start in fall 2023 after delivery of rad. hard low-voltage regulators (LDOs); neutron and proton irradiation test campaign and selection in 2021.



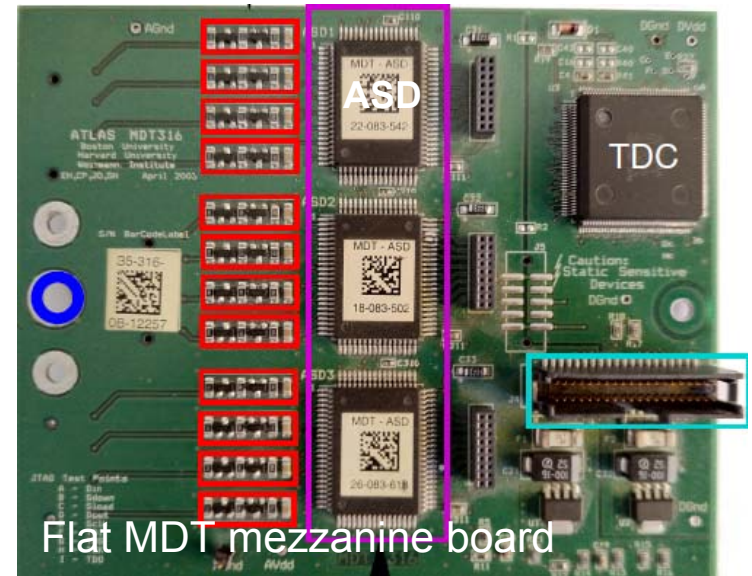
Stacked sMDT FEE card



sMDT TDC board



sMDT ASD board

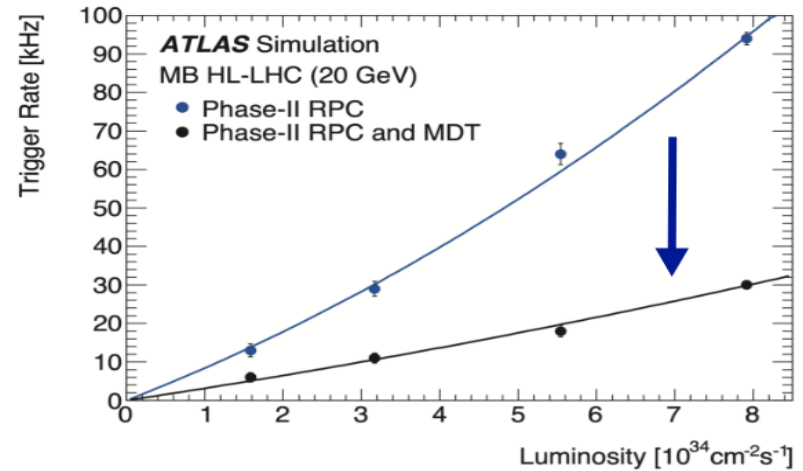
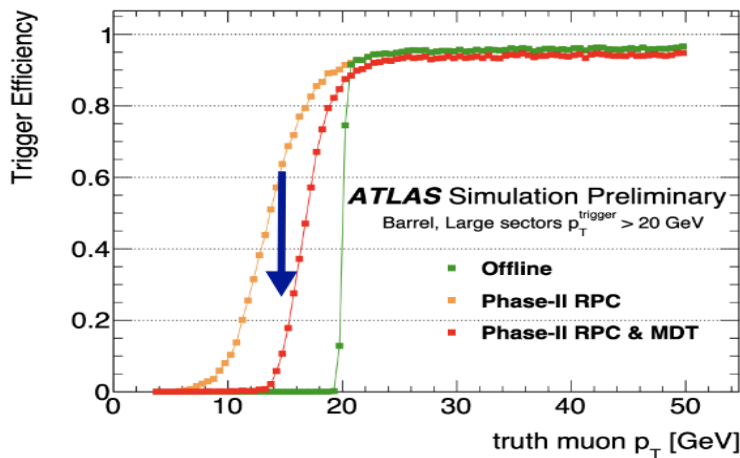


Flat MDT mezzanine board

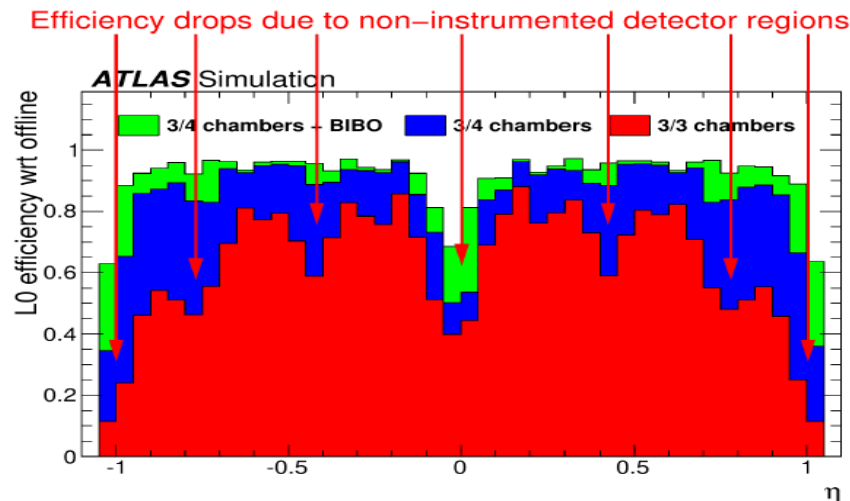
New MDT Based Muon Track Trigger

MPP concept:

Improvement of momentum resolution and selectivity of the 1st level muon trigger by almost an order of magnitude by making use of the high spatial resolution of the (s)MDT chambers with continuous readout in order to suppress the overwhelming trigger rate from low-momentum muons.



In addition, closing of trigger acceptance gaps in the barrel and backup for legacy RPCs & TGCs:



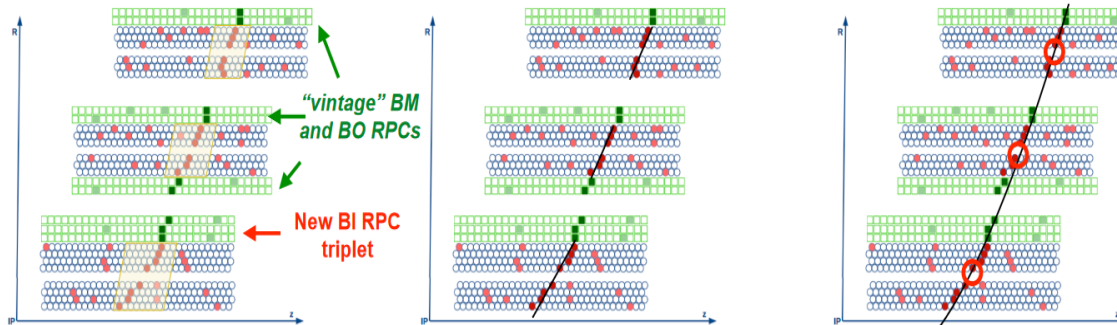
MDT Trigger Algorithm

Implemented on FPGAs, performs pattern recognition, track fitting and transverse momentum determination within 1 μ s. Compact solution developed by MPP. Coordinated by MPP.

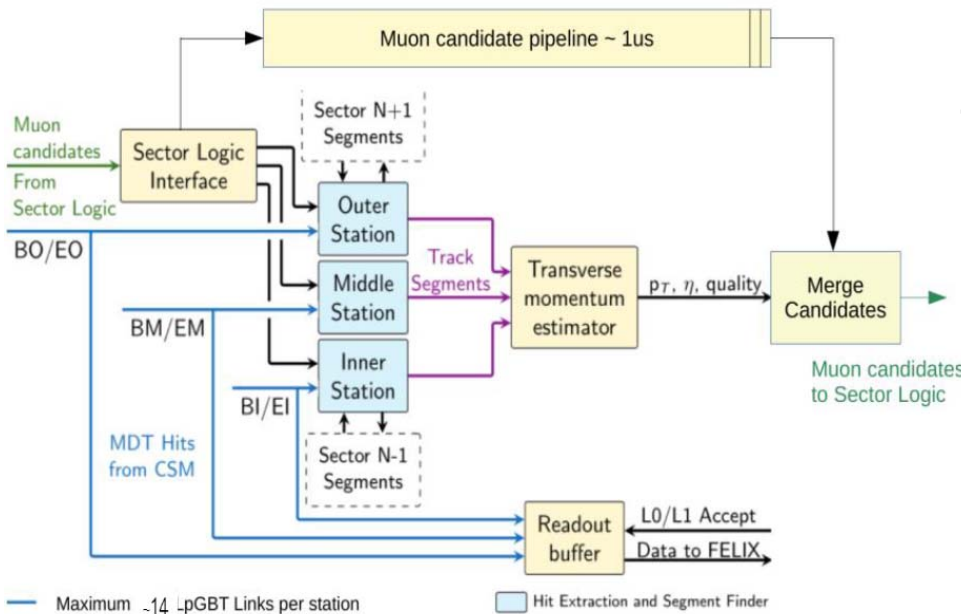
Hit extraction: match MDT hits with candidates from SL, provide calibrated hit positions

Segment finding: fit straight track segments in each station

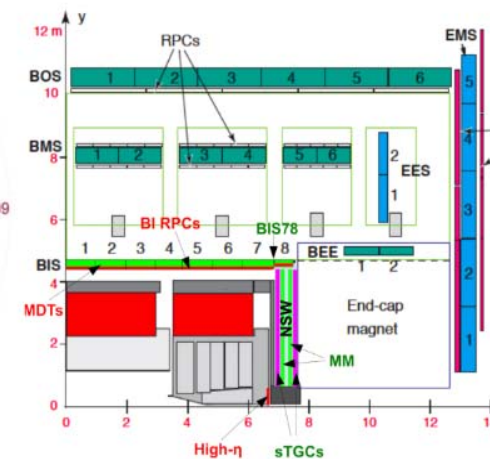
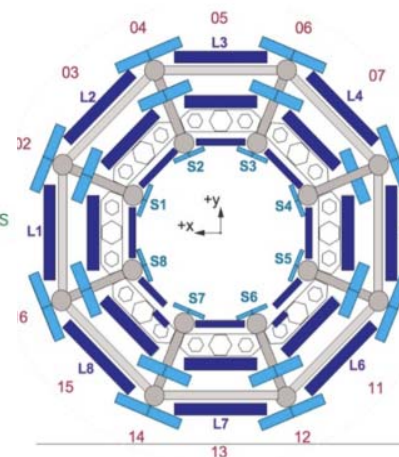
p_T estimation: derive momentum estimate from group of segments



Seeds and BCID from RPC/TGC hits via the Sector Logic (SL).

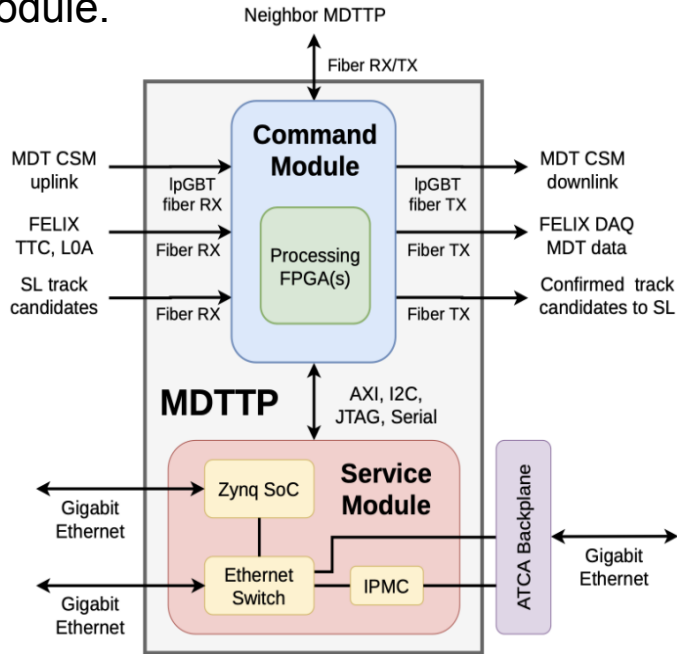


Performed in parallel in 16 ϕ sectors with 4 η sectors each covering barrel and endcaps :

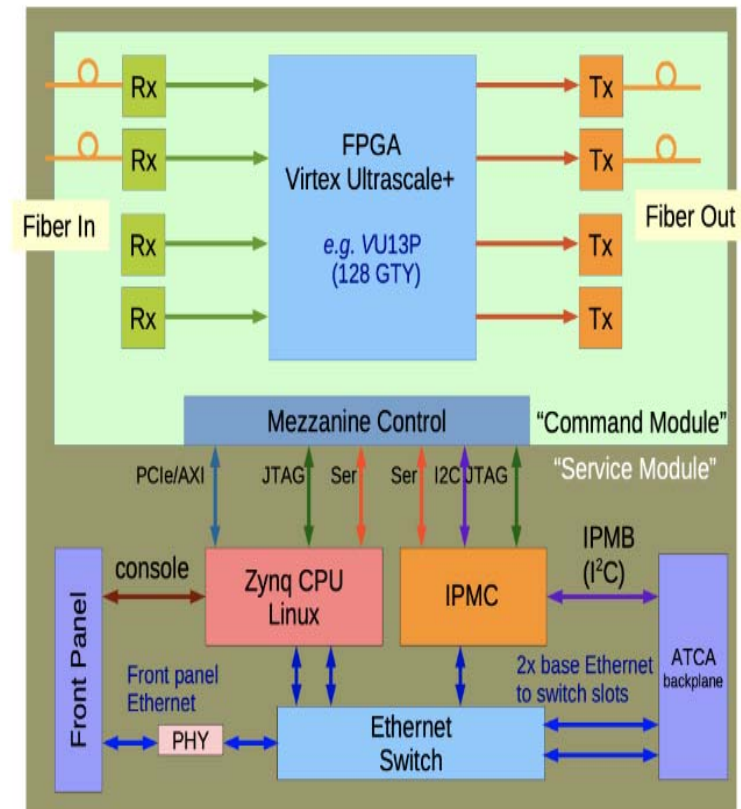


MDT Trigger Processor Hardware

64 ATCA trigger processor blades, consisting of a Service Module carrying the Command Module.



The Command Module carries the FPGA and a large number of 10 Gbps optical transceivers (MPP design, in cooperation with company)

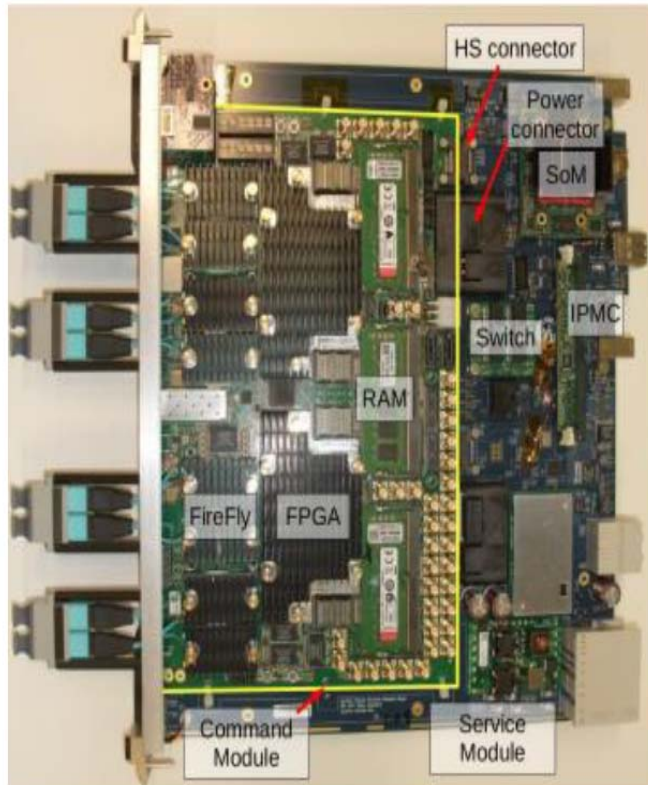


Service module



Command Module Status

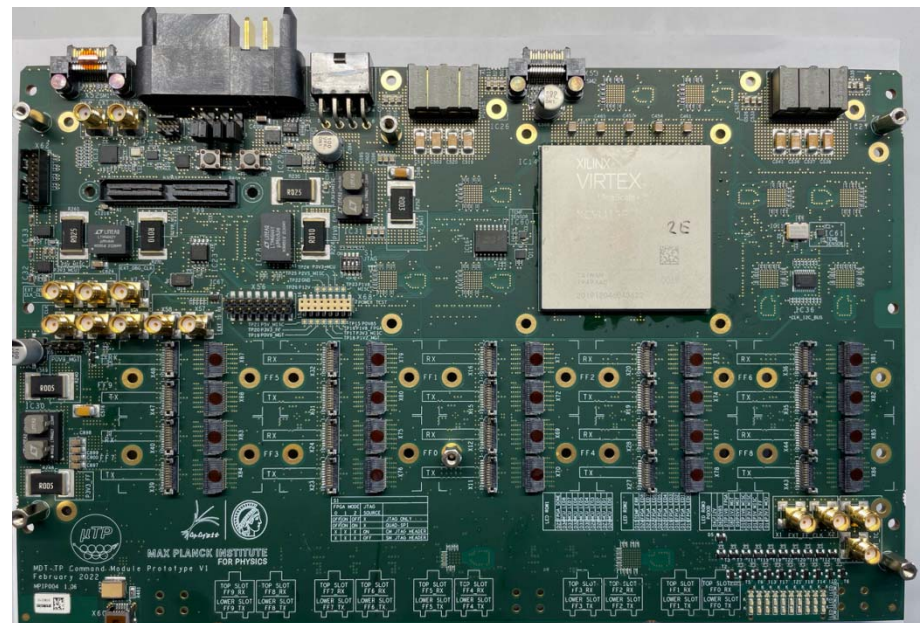
First demonstrator modules produced and tested in 2020-21. Proof of trigger algorithm implementation and latency on FPGA.



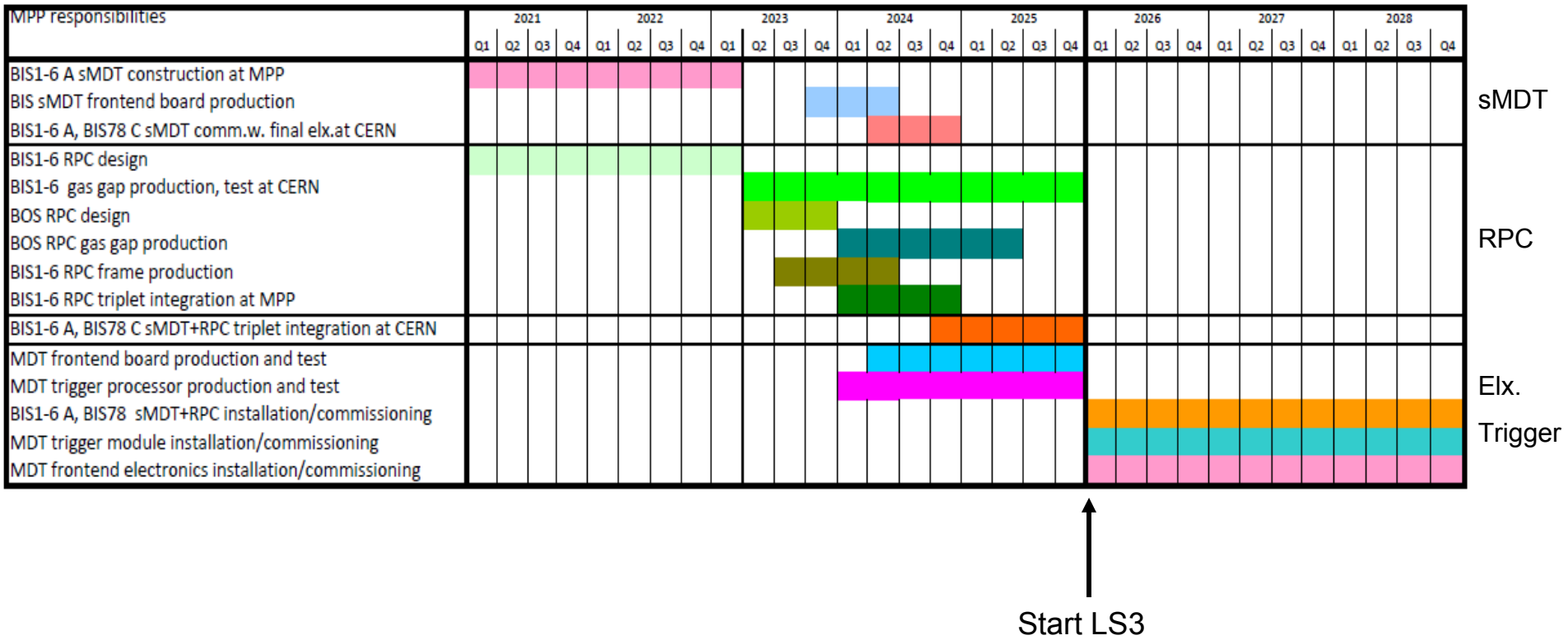
Final prototype designed and produced 2021-22. Validation in 2023.

Production and test in 2024-2025.

Needed for the commissioning of the new muon chambers and electronics in ATLAS.



Schedule Overview



Start LS3