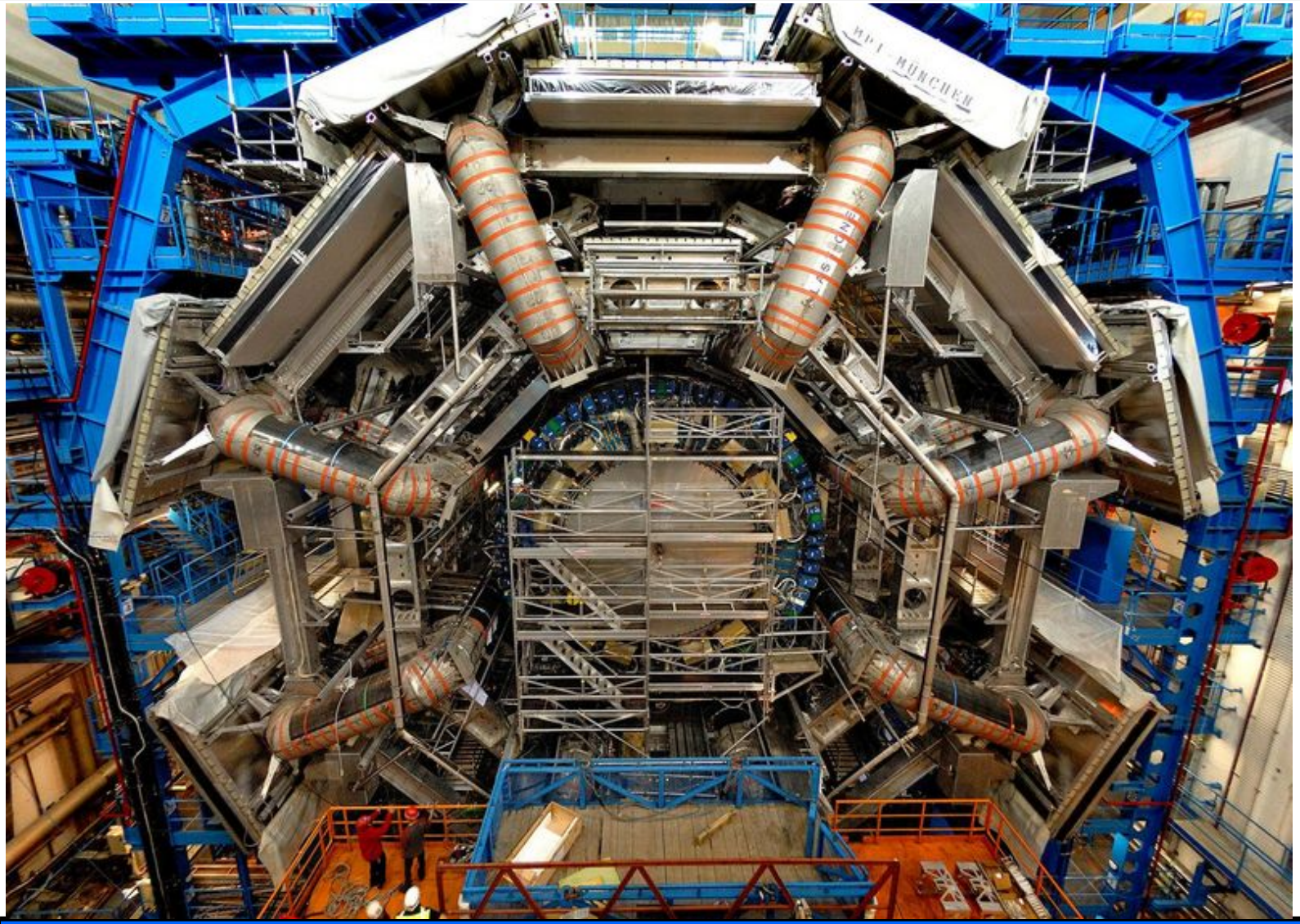
MPP and the ATLAS Muon Spectrometer



On behalf of
the MDT and
Minerva groups

ATLAS Muon Spectrometer Concept

Role of MPP:

Concept of muon spectrometer with air-core toroid (one option in LoI).

Development of High-Pressure Drift Tube (HPDT) chambers as precision muon tracking detectors in a fierce competition with two other proposed technologies by NIKHEF (Honeycomb strip ch.) and CERN (Jet Cell ch.).

Leadership in the design of the final solution, the Monitored Drift Tube (MDT) chambers.
Proved to be reliable and robust high-precision tracking solution over large areas.
No aging since start of operation at LHC. Promise for future collider experiments.

First MDT chamber prototypes: demonstration of the required 20 μm sense wire positioning accuracy.

Construction of 100 BOS MDT chambers. Coordination of the world-wide construction effort.

Development of the projective optical alignment system with 30 μm precision over distances of > 10 meters. In particular, concept of the endcap alignment system with alignment bars.

Demonstration of the alignment concepts in the UA1 hall and H1 beam line at CERN (DATCHA installation).

Challenge: Unprecedentedly high background rates in the muon spectrometer at the LHC.

High rate performance tests and validation of MDT chambers in the CERN GIF facility by MPP.

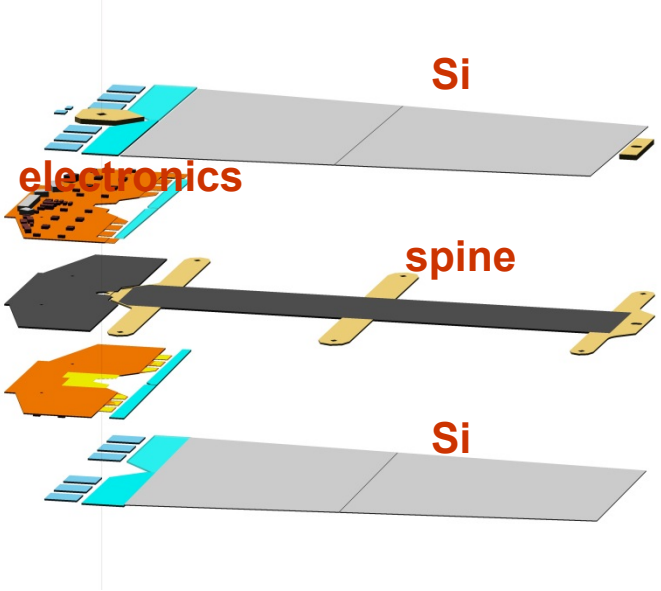
Intial high competition with other ATLAS construction projects at MPP.

Semiconductor Central Tracker SCT

Experience of the MPP/MPE semi-conductor lab (HLL) in (double-sided) silicon sensor development and production for the ALEPH vertex detector (G. Lutz).

Strong proponent of double-sided p-in-n silicon strip sensor technology with sufficient radiation hardness and significant cost saving.

Design and in-kind delivery of 3000 (1/3) of the silicon strip sensors for endcap wheels from CIS foundry in Erfurt, Germany (partner of HLL) 2000-2002.



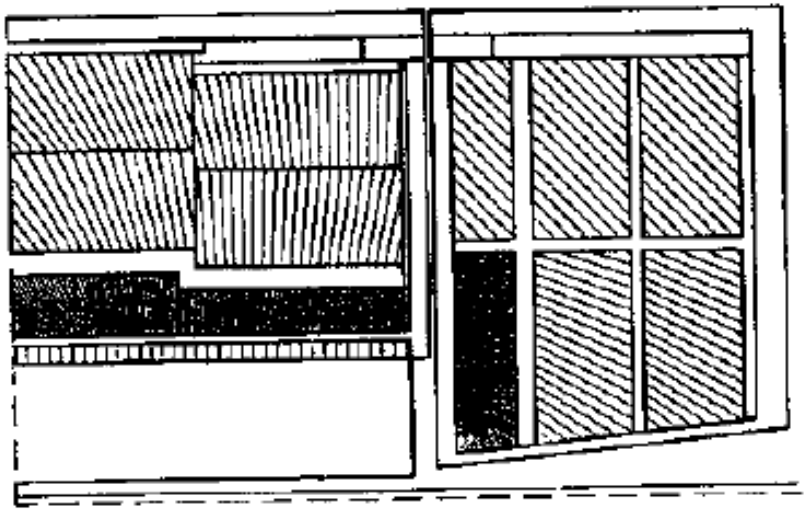
Assembly of 400 (10%) of endcap sensor modules in 2002-2004.

Design of ATLAS pixel sensors at HLL.

Liquid Argon Calorimeter

Experience in LAr calorimetry from the CELLO and H1 experiments (H. Oberlack, P. Schacht).

Proposal of Thin-Gap Turbine (TGT) em and had. LAr calorimeter with cold electronics in competition with the Accordion Calorimeter concept (LoI).



TGT: Absorber plates at constant 45^0 angle w.r.t. the particle direction.

One HEC wheel.

$\Rightarrow$ Participation in HEC LAr calorimeter. Construction of one of four wheels.

Design and production of HEC cold frontend electronics. Inaccessible in the HEC cryostat. Proved to be sufficiently radiation hard also for HL-LHC.

Coordination of the LAr Calorimeter System until the start of data taking (H. Oberlack).

ATLAS Muon Spectrometer Project MPP 1992-2020: Muon Personnel

Directors: F. Dydak, U. Stierlin, V. Soergel, S. Bethke

ATLAS LoI 1992 (30 years anniversary): W. Blum, H. Kroha

1990s: Concept and design:

Seniors: W. Blum, H. Dietl, T. Ferbel (Humboldt Fellow), C. Gruhn, H. Kroha, A. Manz, R. Richter

Postdocs: F. Bauer, U. Bratzler, H. Breuker, A. Ostapchuk, T. Lagouri, S. Schael, M. Treichel

Engineering team: K. Ackermann, B. Dulny, K. Fritsch, T. Haubold, S. Podkladkin, S. Vogt, M. Zinsmeister

5 Diplomas

2000s: MDT construction and installation, data analysis preparation and first physics:

Seniors: S. Kortner, O. Kortner, H. Kroha, A. Manz, R. Richter

Postdocs: N. Benekos, J. Dubbert, A. D'Orazio, F. Legger, J. von Loeben, S. Mohrdieck, S. Kotov, I. Potrap, D. Rebuzzi, V. Zhuravlov, X. Zhu

Engineering team: T. Haubold, S. Podkladkin, M. Stadler, S. Vogt, H. Wetteskind, J. Zimmer

7 PhDs, 8 Diplomas

2010s: Physics and upgrades:

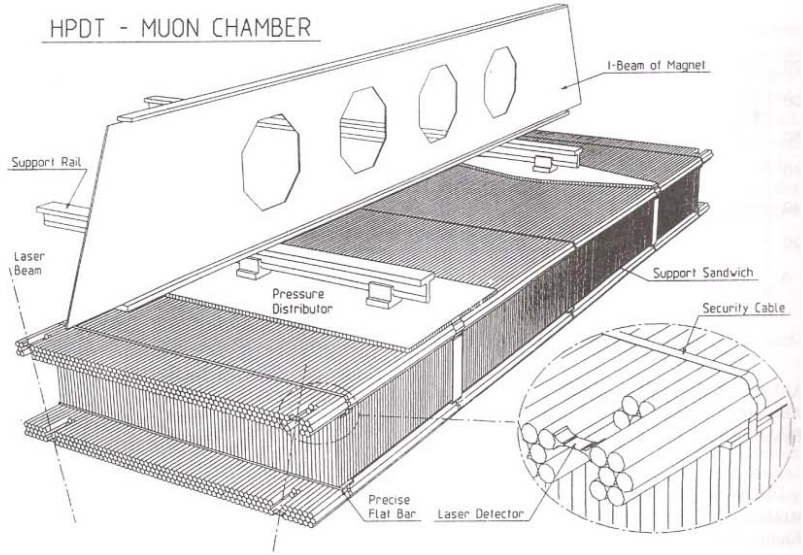
Seniors: S. Kortner, O, Kortner, H. Kroha, R. Richter

Postdocs: D. Cieri, D. Duda, M. Flowerdew, C. Giuliani, M. Holzbock, F. Müller, S. Nowak, P. Rieck, E. Sandstroem, F. Sforza, E. Takasugi, E. Voevodina, V. Walbrecht, J. Yuan, Z. Zinonos

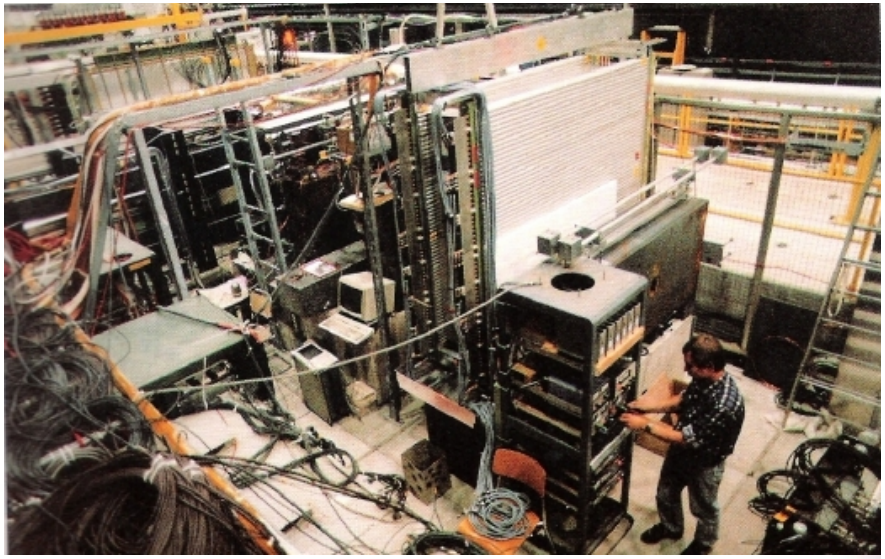
Engineering team: Electronics: S. Abovyan, V. Danielyan, M. Fras, B. Weber, Y. Zhou
Mechanics: M. Lippert, P. Maly, S. Podkladkin, D. Soyk, S. Vogt, J. Zimmermann

21 PhDs, 25 Masters, 79 Bachelors

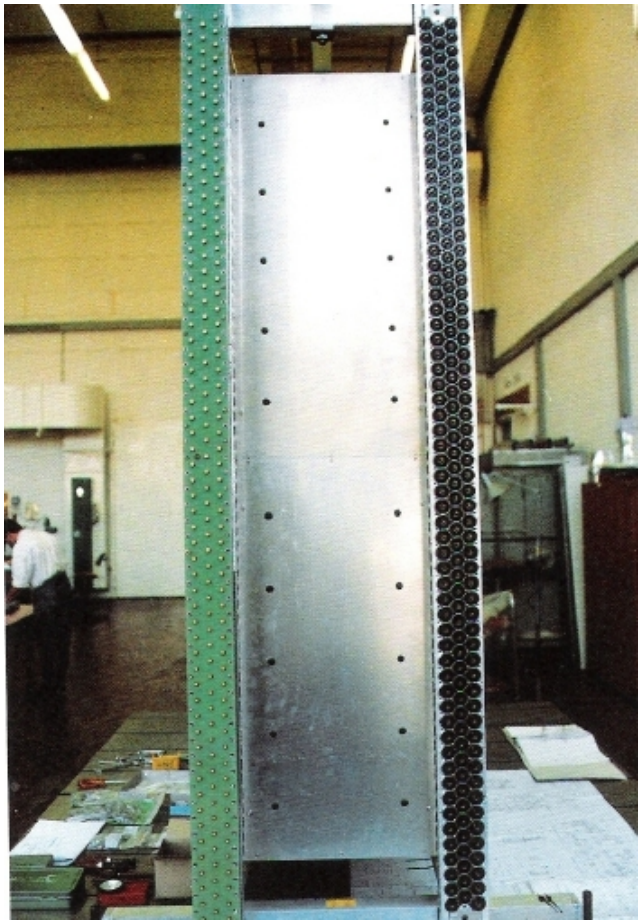
Drift Tube Chamber Development



MPP HPDT chamber design 1992/93 (LoI)

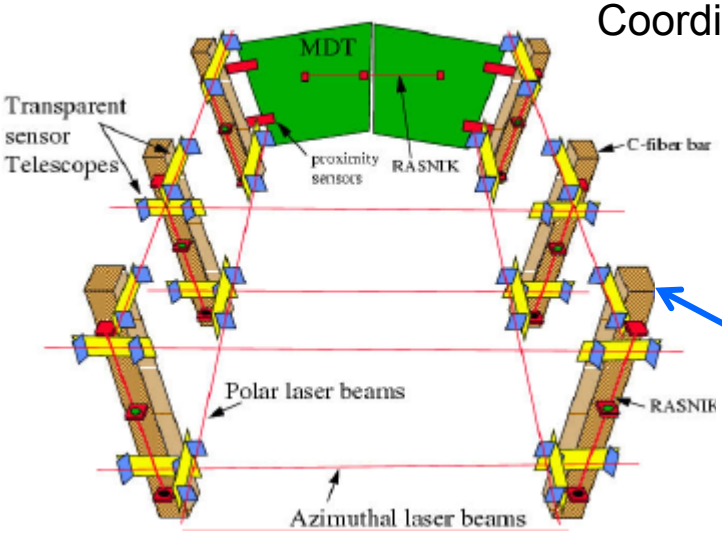


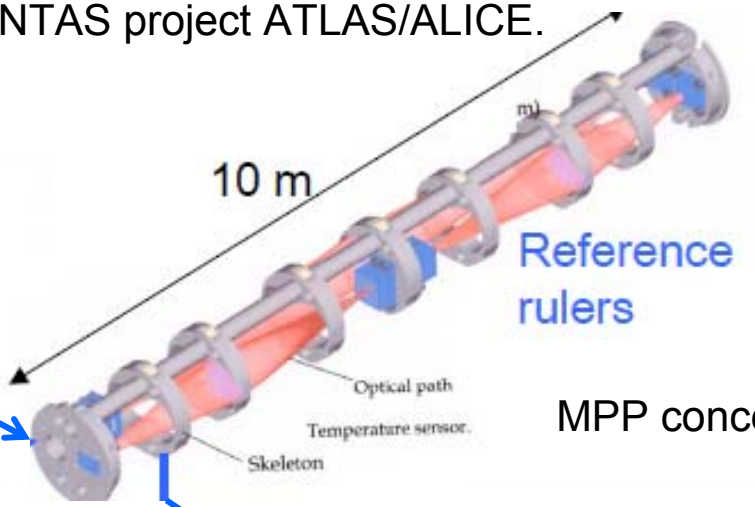
April 1993: First HPDT chamber prototype in the CERN muon beam



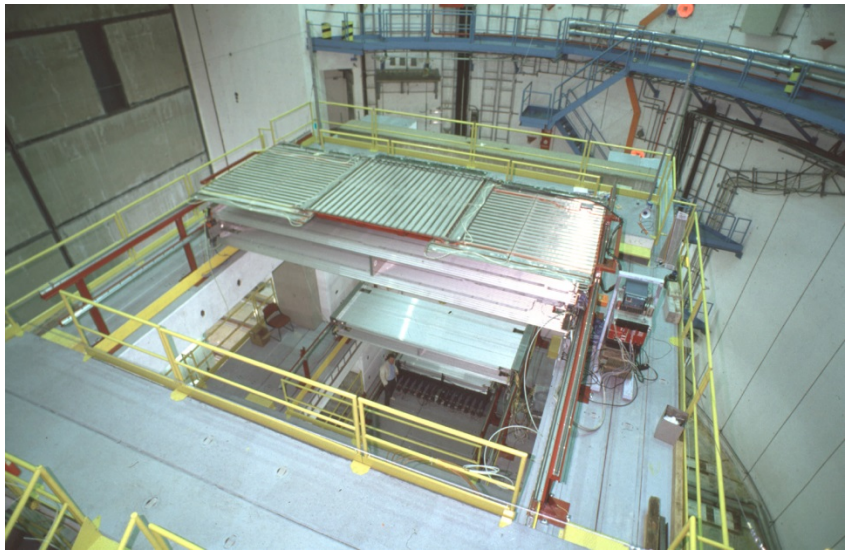
Optical Alignment Monitoring System Development

Demonstration of the projective alignment concept with 30 μm absolute precision.
Coordination of INTAS project ATLAS/ALICE.





MPP concept



1996-2000: DATCHA muon barrel alignment teststand in the UA1 pit operated by MPP

2000-2005: DATCHA muon system and alignment teststand in the SPS H1 muon beam

Timeline of the ATLAS Muon Spectrometer

Mar. 92 Expressions of Interest for ASCOT and EAGLE.

Oct. 92 ATLAS Letter of Intent

May 93 Decision for Air Core Toroid. First high-pressure drift-tube detectors tested.

Jan. 94 Decision for MDT chambers.

Dec. 94 Approval of LHC in 2 stages (2004 and 2008).

Dec. 94 ATLAS Technical Proposal.

June 96 First MDT ch. in test beam.

Dec. 96 Approval of LHC in 1 stage (2005).

Mar. 97 MDT chamber construction technique and optical align-ment concept decided.

May 97 ATLAS Muon Spectrometer Technical Design Report.

Feb. 98 First MDT prototype ch., demo of TDR design.

June 99 Production Readiness Review.

May 00- -Oct. 05 Drift tube production at JINR, Dubna.

July 00 Prod. site review MPI/LMU.

Aug. 00 Module 0 chamber.

July 01 10% of chamber construction.

Nov. 02 50% of chamber construction.

July 03 70% of chamber construction ("standard chambers").

Dec. 03 85% of chamber construction.

Feb. 05 Installation of first 4 chambers

Dec. 05 Chamber construction complete (incl. chambers w. cutouts).

Feb. 06 All chambers at CERN.

July 05- -May 06 Integration of MDT with RPC. trigger chambers at CERN.

Feb. 06- -June 06 Installation of remaining 84 chambers in ATLAS.

Collaborations

Established german ATLAS muon collaboration together with Freiburg and LMU and BMBF funding of MDT construction.

MPP BOS MDT drift tube and chamber testing at LMU Garching.

EU ISTC and INTAS projects for funding of MDT construction at JINR Dubna and IHEP Protvino.

Drift tube production for BOS MDT chambers at JINR Dubna:
Funding of a clean room and installation of an automated assembly station.

Dubna 1999

Dubna February 2000

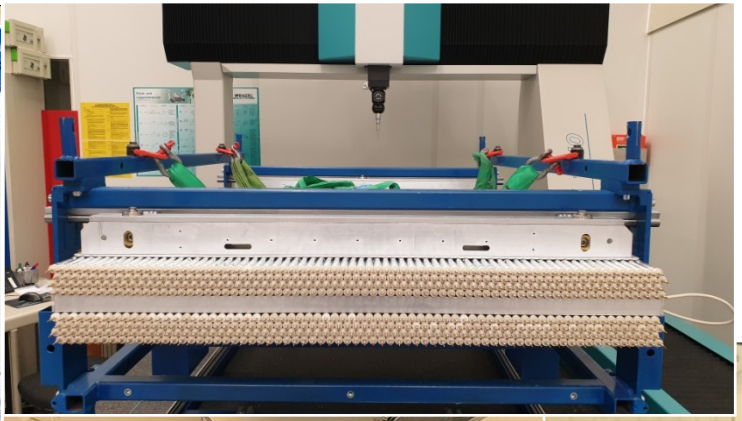
New Large Detector Construction Infrastructure at MPP

Large clean rooms in the old and the new experimental halls.

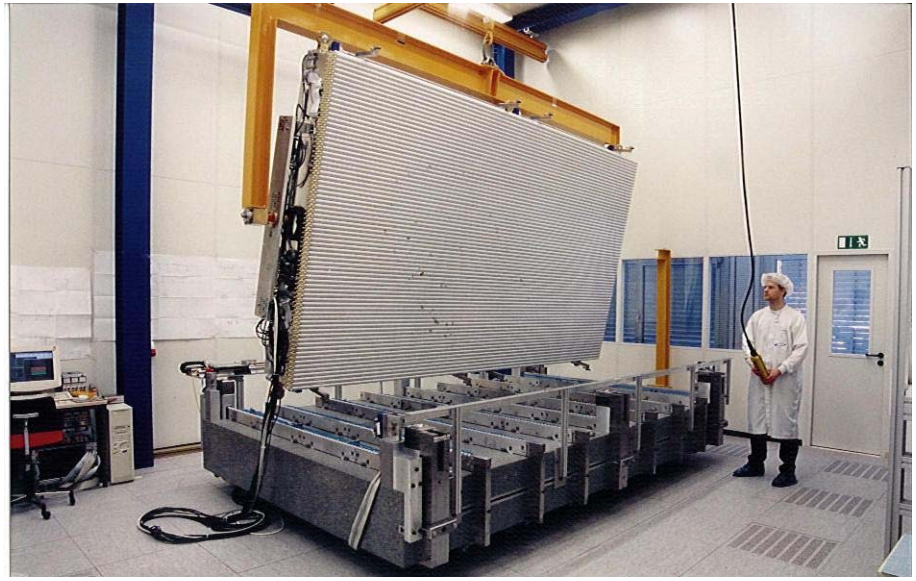
Large Coordinate Measurement Machine and big granite tables in the new hall.

15 mostly temporary mechanical and electronics technicians for MDT construction and installation.

University educated engineering team for complex design tasks and integration in ATLAS detector and mandatory FEM calculations.



BOS MDT Chamber Prototypes and Production



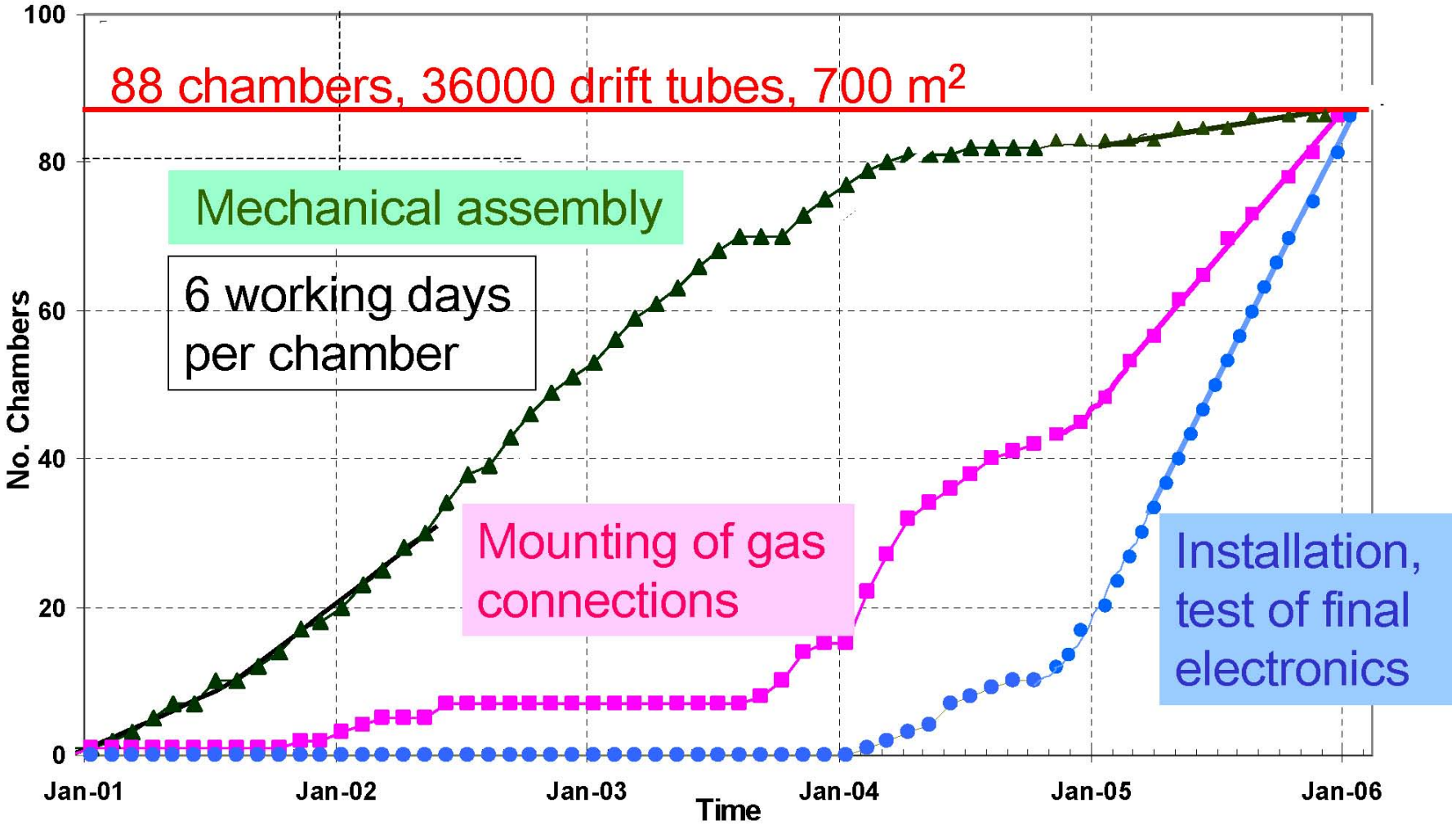
February 1998: First MDT chamber prototype in the new clean room

August 2000: First BOS MDT chamber

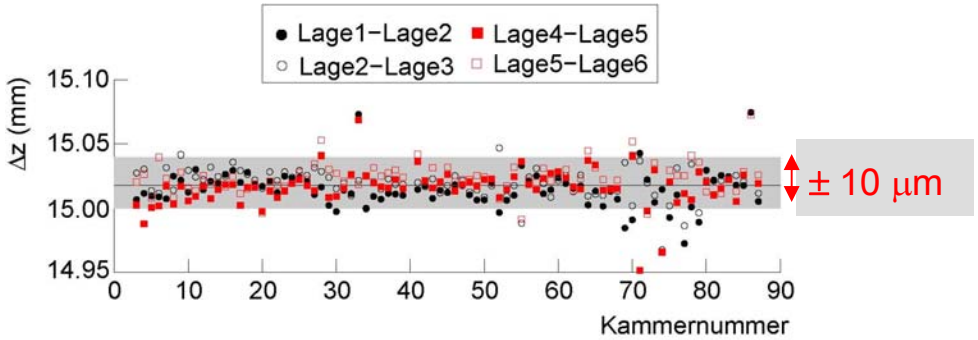
August 1998: First MDT chamber in the muon beam

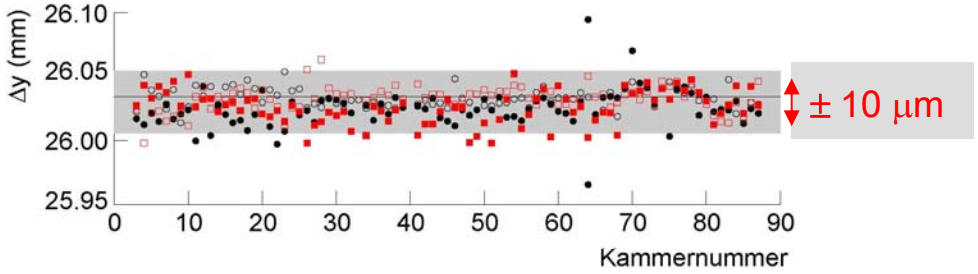
July 2001: 10 of 100 BOS MDT chamber produced

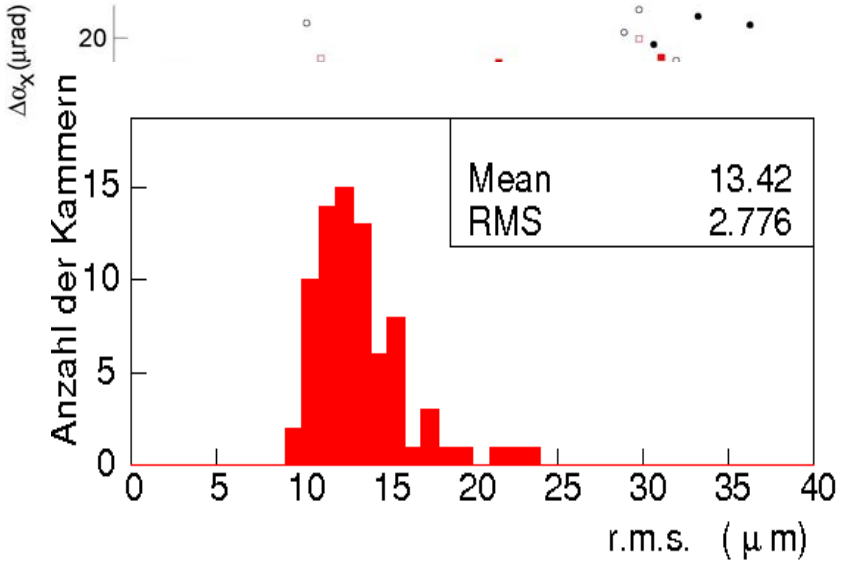
BOS MDT Chamber Construction and Installation 2000-2005



Chamber Precision and Quality







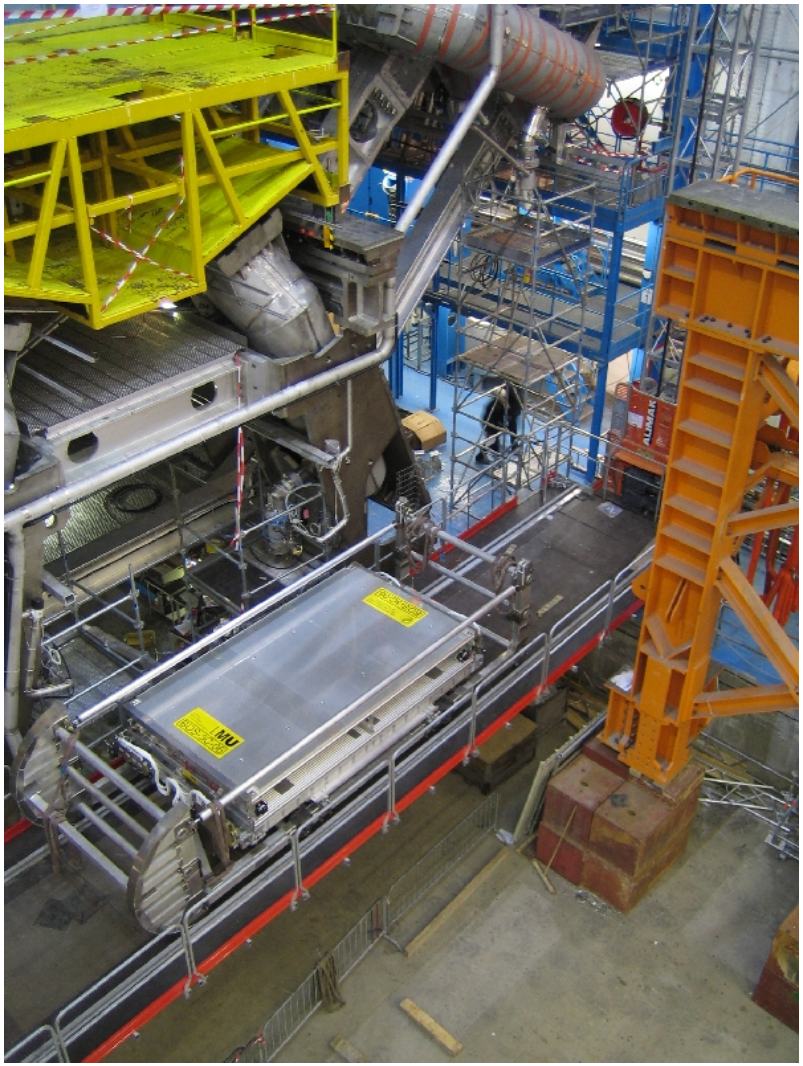
Chamber test at storage hall north of Munich

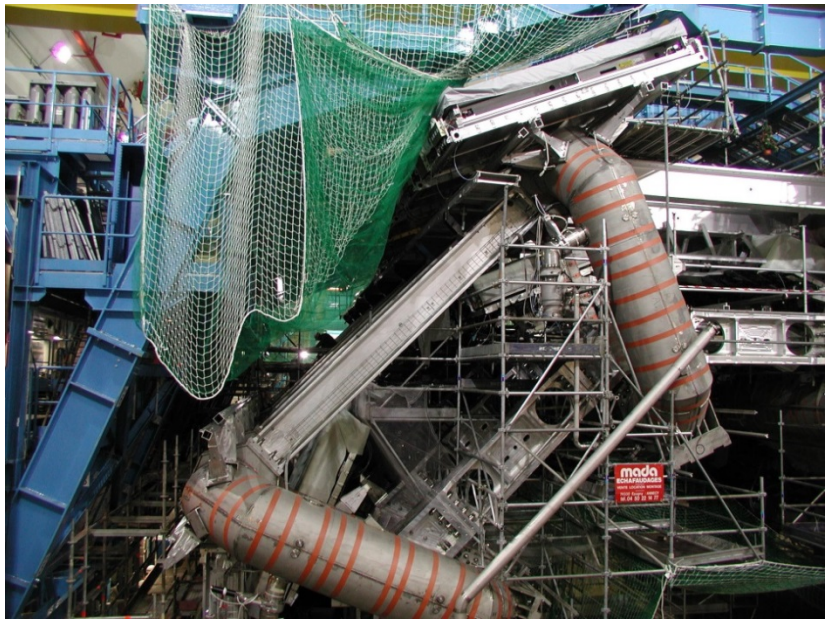
Komponente	Anzahl	In München	Am CERN	Prozent
Undichte O-Ringe	289712	0	0	0
Abgehängte Rohre	36192	18	1	0.05
Gerissene Drähte	36192	11	3	0.04
Frontend-Elx Karten	4876	50	40	1.85
HV Verteiler-Boxen	88	0	3	3.41
DCS Boxen	88	0	4	4.55
T-Sensor	1584	2	3	0.32
Alignment-Sensorkomp.	1056	0	3	0.28
B-Feld Sensor	176	0	1	0.57

MDT-RPC Integration at CERN

MDT Chamber Installation

MDT chamber commissioning
coordination MPP

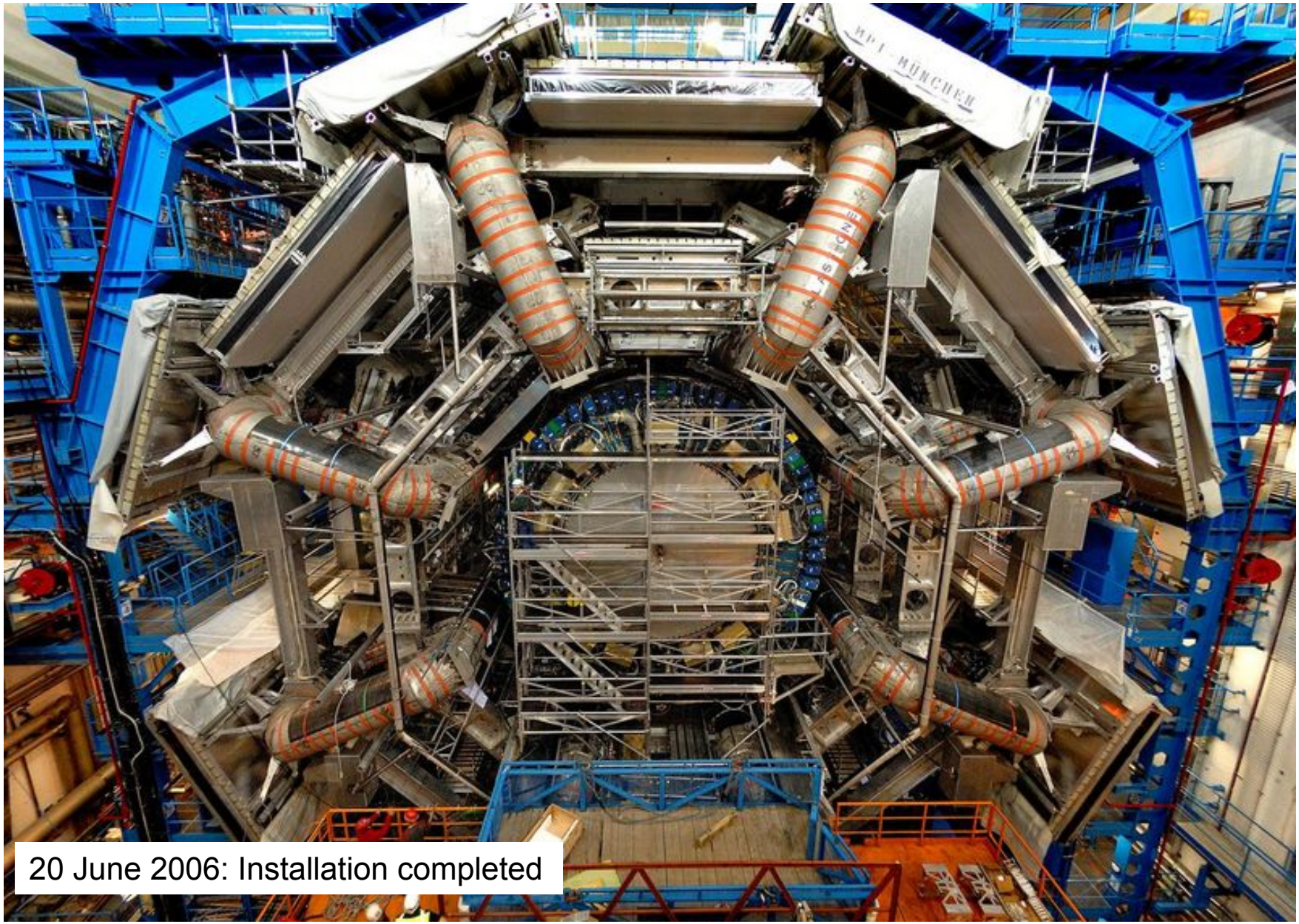




MDT Chamber Installation

February 2005: Feet sector installation

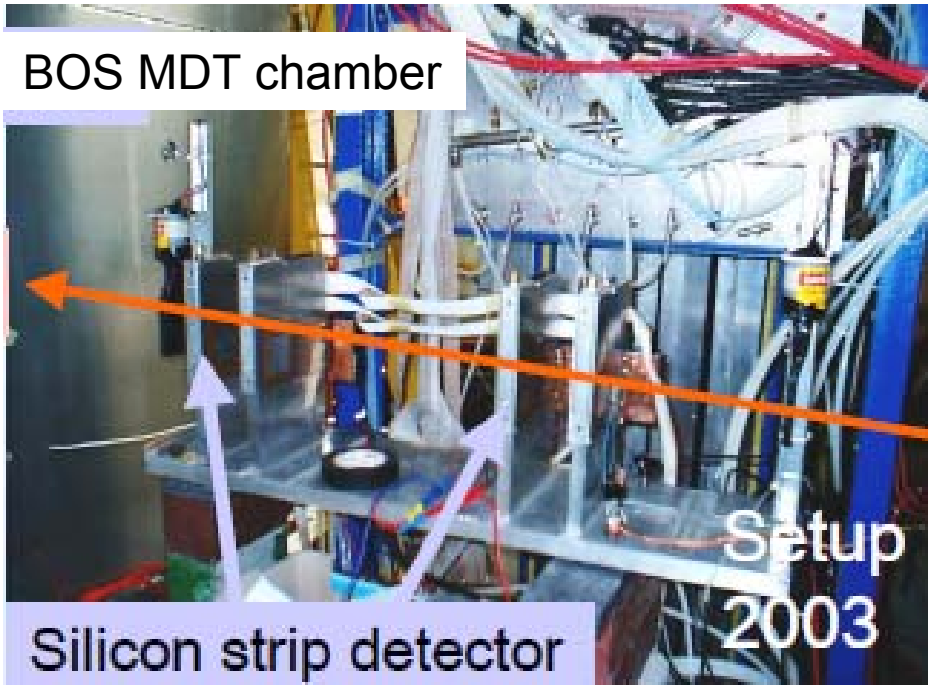
BOS MDT Chamber Installation

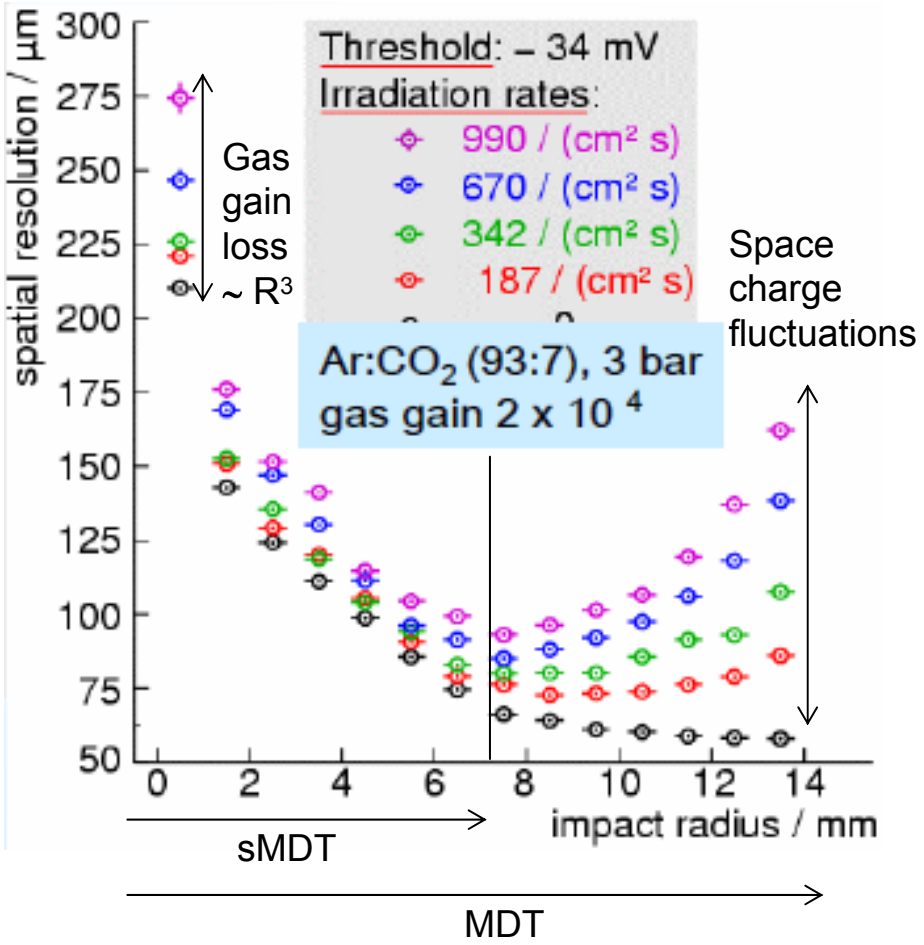


20 June 2006: Installation completed

High Background Rate Tests of MDT Chambers 2002-2004

⇒ Standard MDT performance reference. Basis for muon detetor upgrade planning.





ATLAS Muon System Upgrade R&D for HL-LHC Since 2008

MPP muon system upgrade concepts for HL-LHC (2008):

- Background rate of neutrons and γs in ATLAS muon spectrometer proportional to inst. luminosity.

  Limitation of the rate capability of MDT in Small Wheels and barrel inner layer.

  ⇒ Development sMDT chambers with 10 x higher rate capability

  ⇒ Proposal of New Small Wheels equipped with sMDT chambers for Phase 1 upgrade

  ⇒ Proposal of integrated sMDT + RPC chambers for the barrel inner layer for Phase 2. Improves also acceptance and robustness of the barrel muon trigger system.

- Excessive 1st level trigger rate from low-p_T muons due to limited spatial resolution of the muon trigger chambers.

  ⇒ Make use of the high spatial resolution of the MDT chambers in a MDT-based 1st level muon track trigger with new triggerless MDT readout and fast FPGA based trigger processors to achieve 10 x better p_T selectivity.

  Improves also acceptance and robustness of the barrel muon trigger system.

- New continuous MDT readout and 10 x higher 1st level trigger rate and latency require new MDT readout electronics.

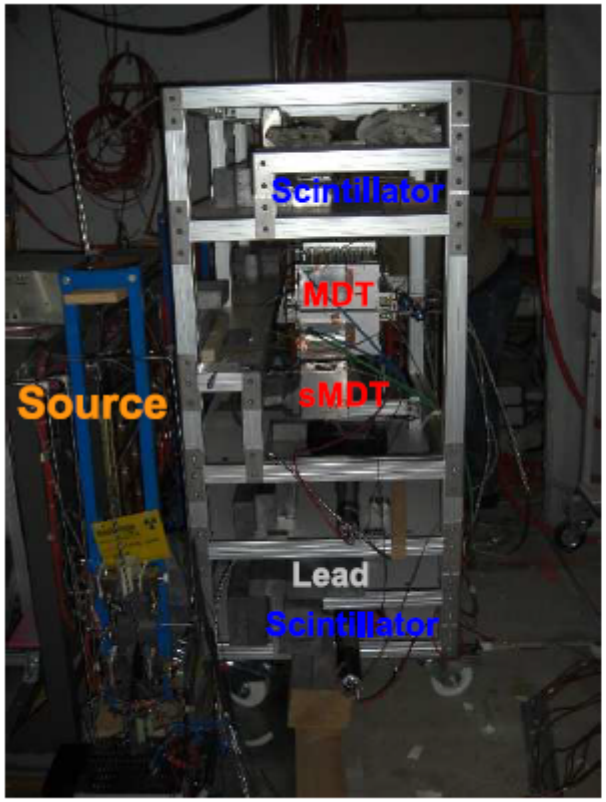
  ⇒ Development of new ASD and TDC frontend ASICs.

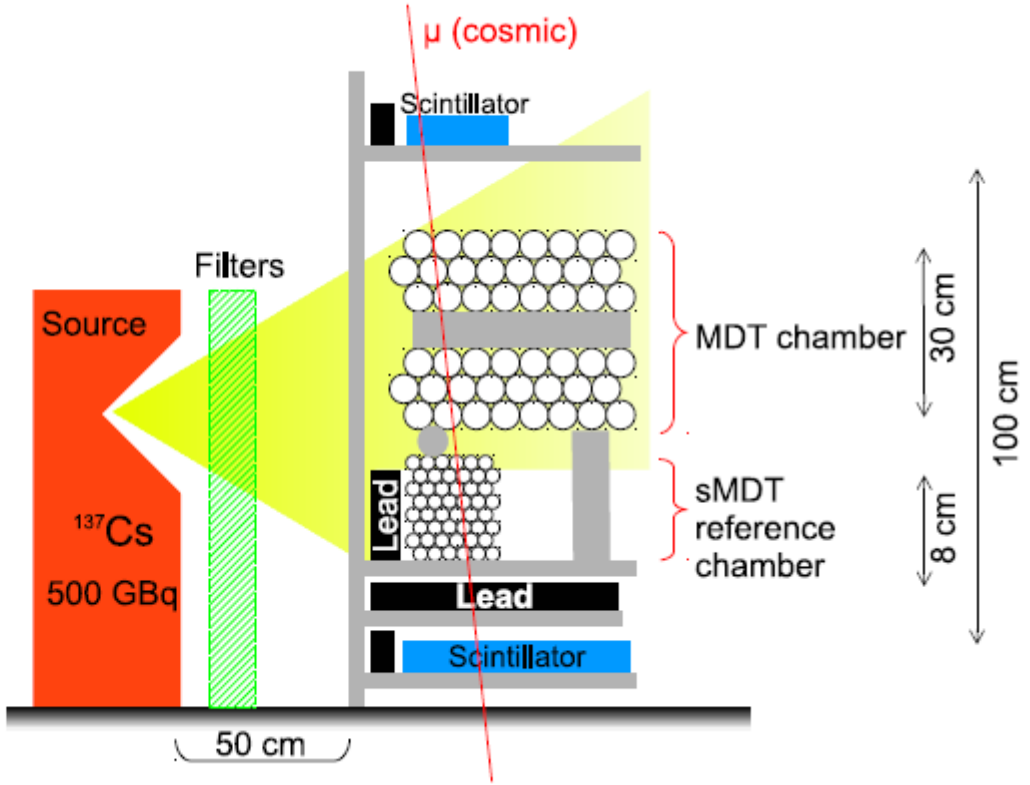
  Establish chip design capability at MPP (since 2010).

Concept of MDT Based 1st Level Muon Track Trigger

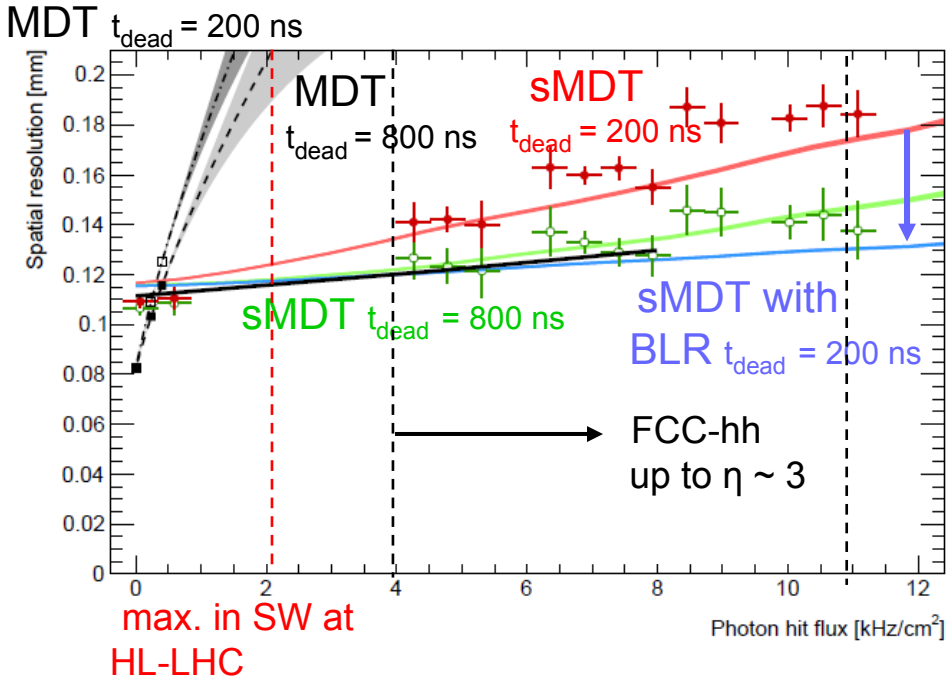
MPP proposal: ATLAS Phase 2 Letter of Intent 2012, TDR 2017.

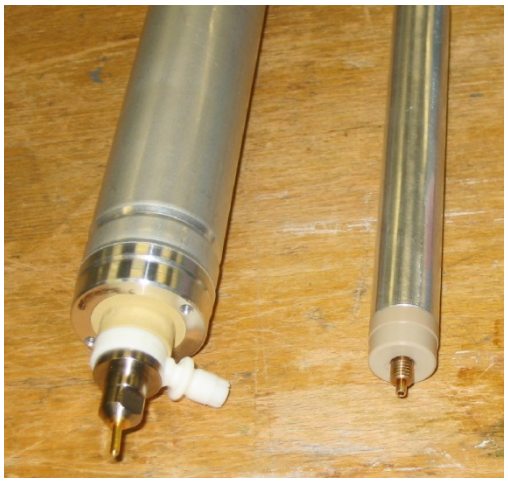
Hardware and Firmware demonstration under irradiation background in GIF
(S. Nowak PhD thesis 2015).





High-Rate Performance MDT vs. sMDT





15 mm ∅ sMDT tubes
instead of 30 mm ∅ MDTs

High rate studies in GIF of MDT chambers since 2002 and of sMDT chambers since 2008 (with legacy electronics).
More than sufficient for NSW at HL-LHC.

Rate capabilty of sMDTs limited by RO electronics due to signal pile-up.

⇒ New Phase 2 MDT ASD chip with faster shaping and reduced noise, less sensitive to signal pile-up.

⇒ Eventually suppression of pile-up effects by active baseline restoration circuit. Under evelopment.

Sufficient for high-precision muon system and trigger at FCC-hh up to η ~ 3.

Implementation in modern chip technologies is a challenging novelty!

sMDT Chamber Development for ATLAS

New drift tube assembly facility at MPP

Full-scale 2 x 8 layer sMDT prototype chamber for the NSW inner radius 2010.

sMDT chambers:

New simpler, less expensive, more robust drift tube design.

Enabling faster, more precise chamber construction.

Better than 5 µm sense wire pos. accuracy achieved.

Optimised for large-scale chamber productions like for NSW, Phase 2 BIS, FCC-hh…

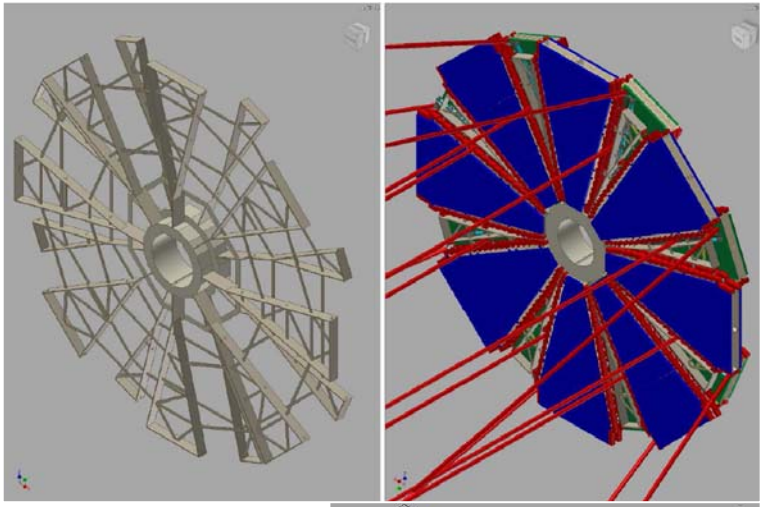
Allowing complicated shapes like BMG, BIS78 chambers…

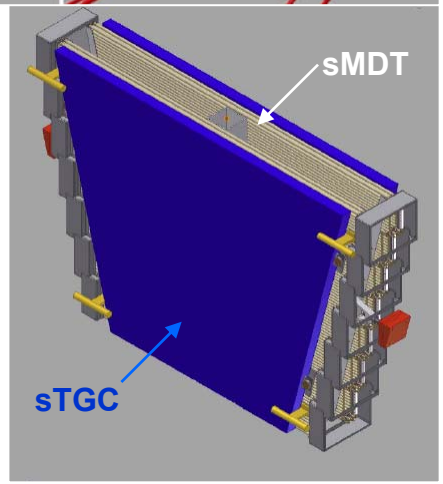
NSW Upgrade Proposal and Design Studies

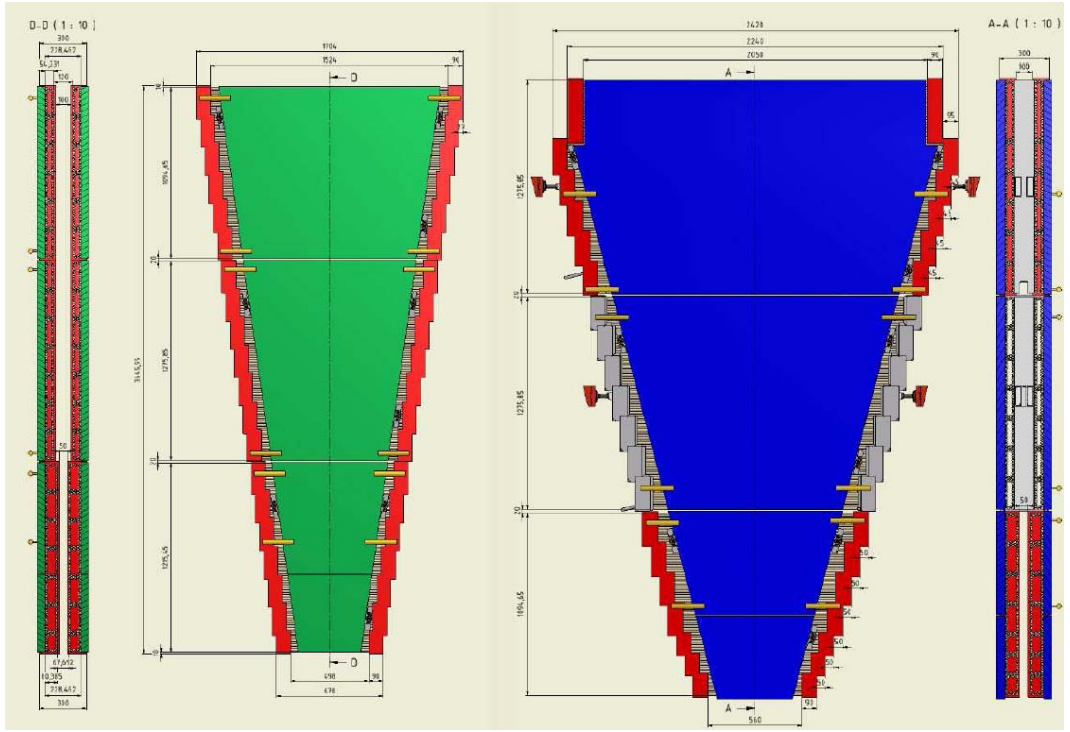
Demonstration of required sMDT rate capability.

Engineering study of NSWs with integrated sMDT and sTGC detectors including proven optical alignment system.

⇒ One of two options in the NSW Technical Proposal 2013.



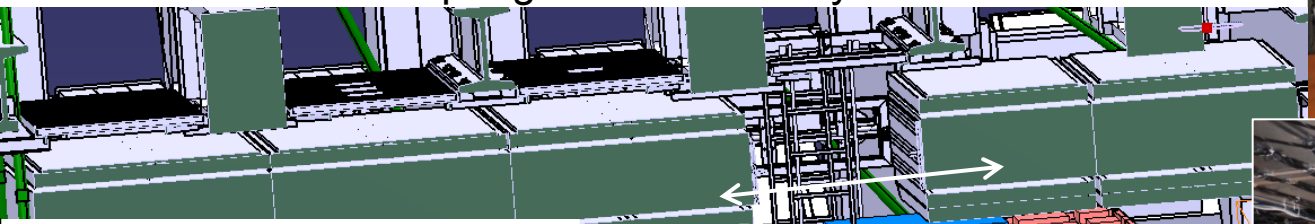


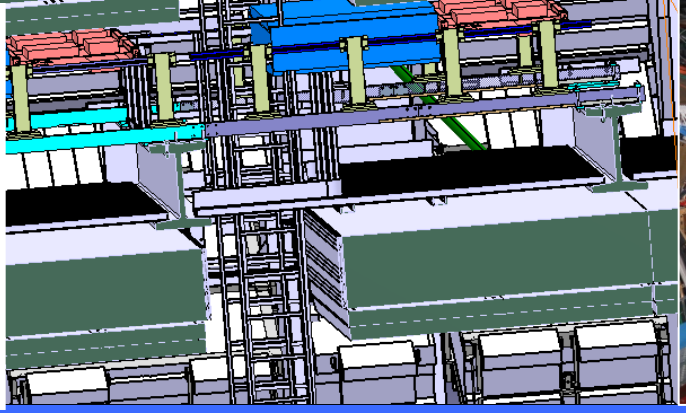


BME sMDT Chamber Construction 2013

Integration with RPCs at CERN.
Improved muon momentum resolution in the access shaft region.

Installation in LS1 in spring 2014. Filmed by Deutsche Welle TV.

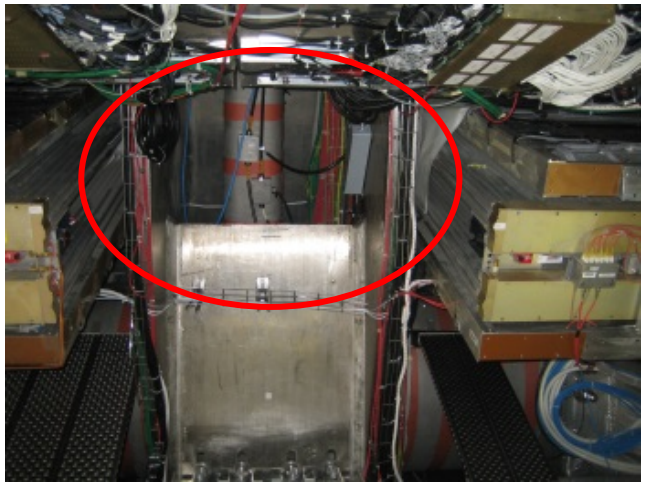


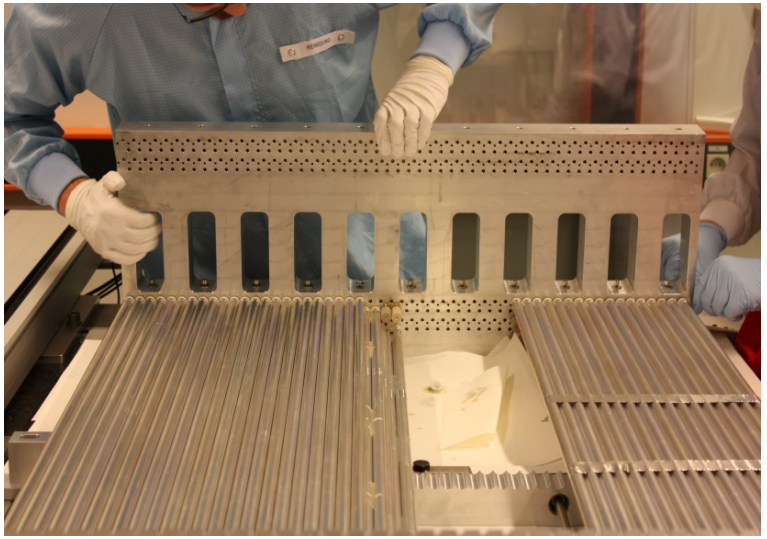


BMG sMDT Chamber Construction 2015-17

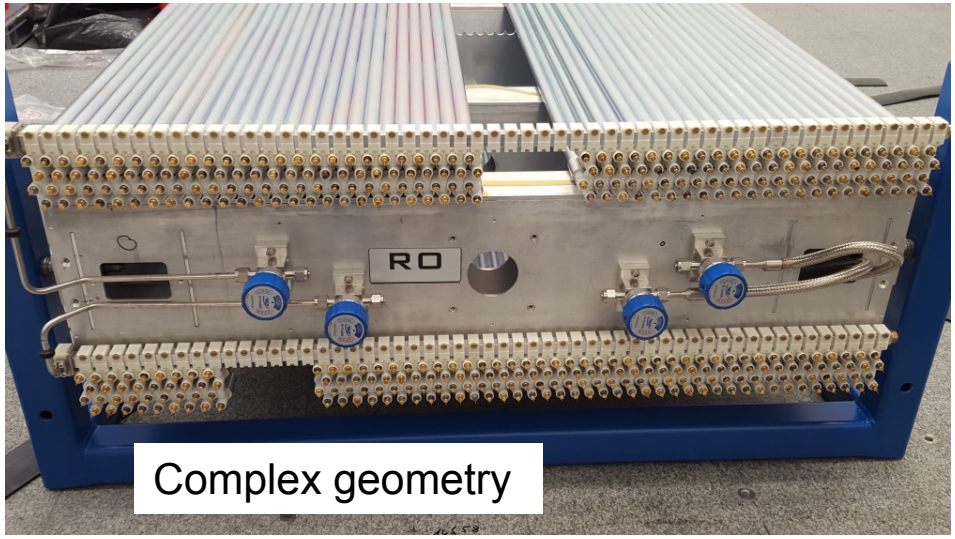
12 BMG sMDT chambers to fill the acceptance gaps in the detector feet in barrel sectors 12 and 14.

Installation in the EYETS 2016/17.

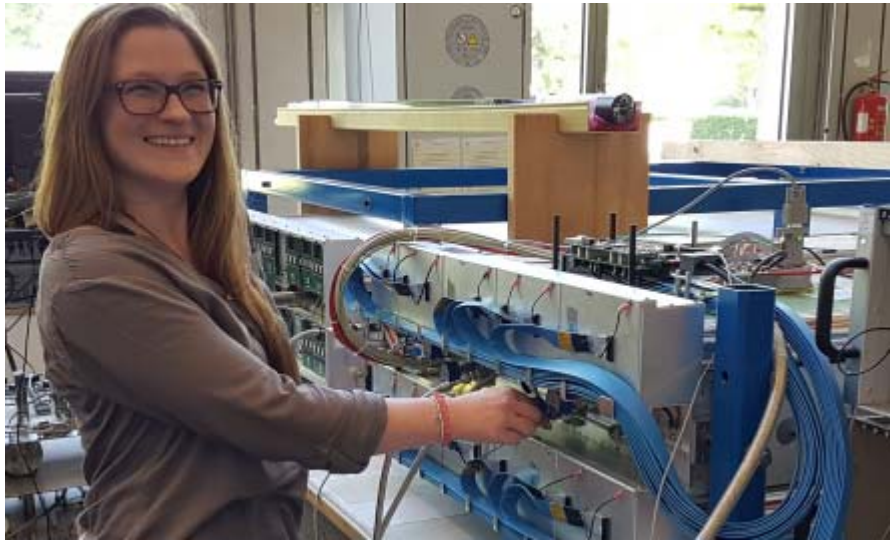




Assembly with high spacer: model for FCC-hh precision muon tracking and trigger chambers.



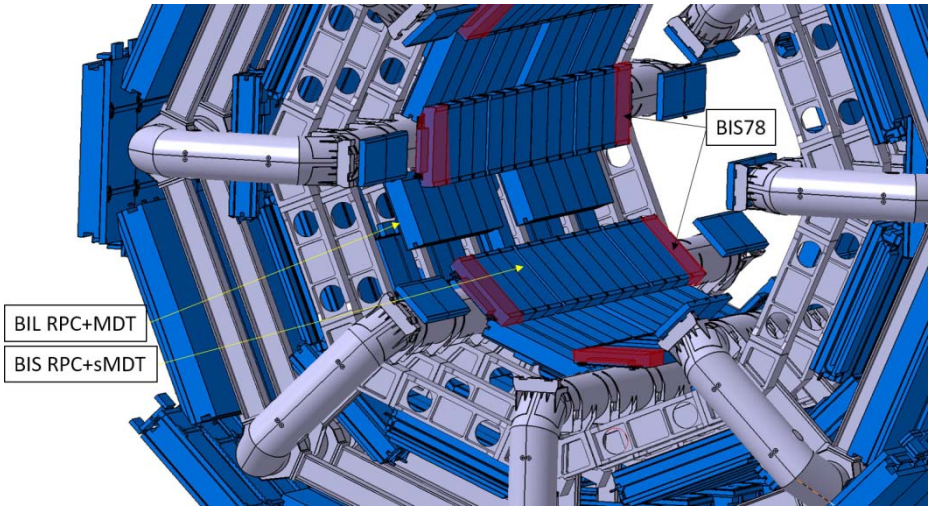
Complex geometry

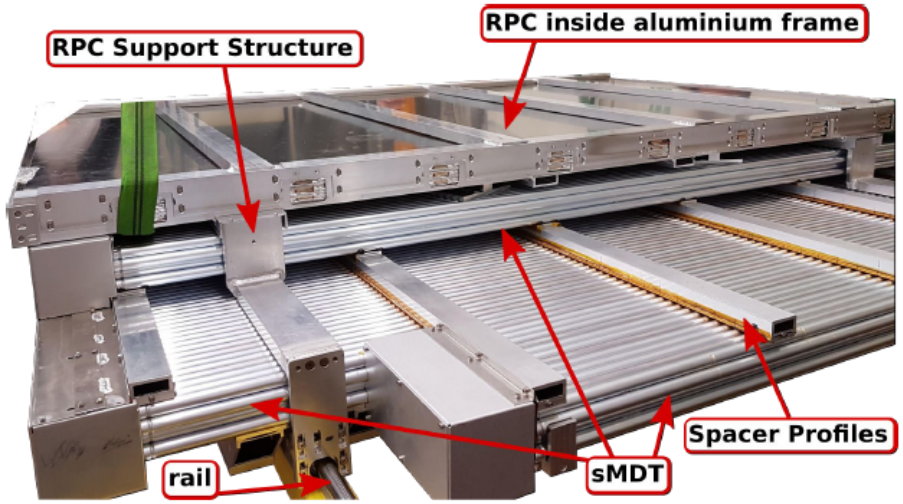


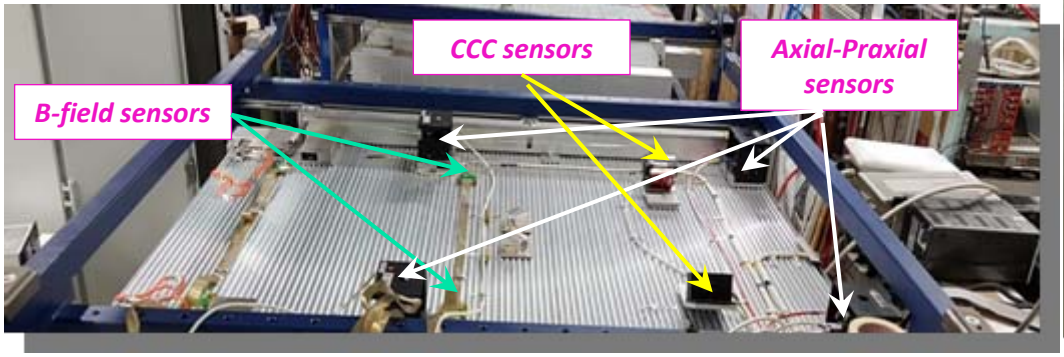
BIS78 sMDT Chamber Construction 2017-19

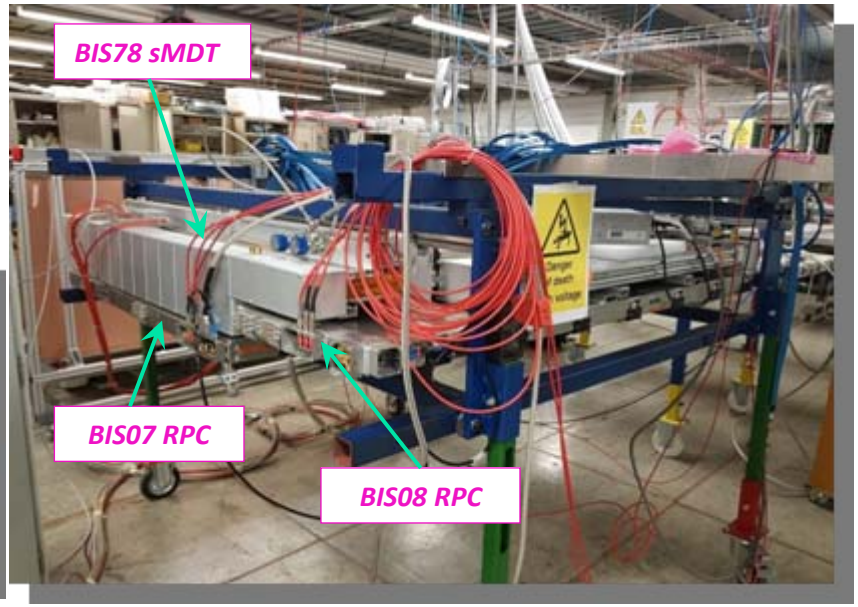
16 BIS78 sMDT +RPC chambers as Phase 1 pilot project for Phase 2 BIS layer replacement.
Complement to NSW in the barrel/EC transition region.

Complex chamber shapes, all different,
overlap with NSWs,
integrated with thin-gap RPC triplets,
engineering MPP ATLAS:









BIS78 Chamber Installation 2020