Quality Control in the Construction of new small-diameter Muon Drift Tube (sMDT) Chambers for the ATLAS Muon Spectrometer at the HL-LHC

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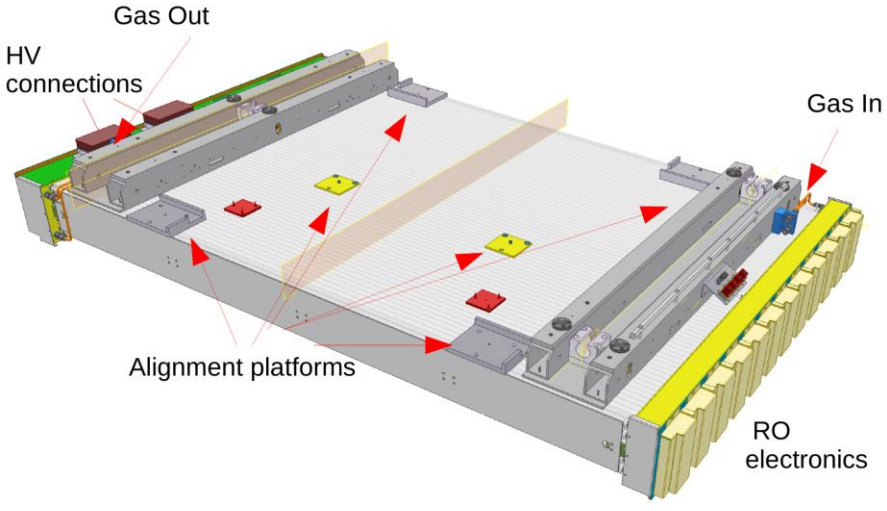
Overview

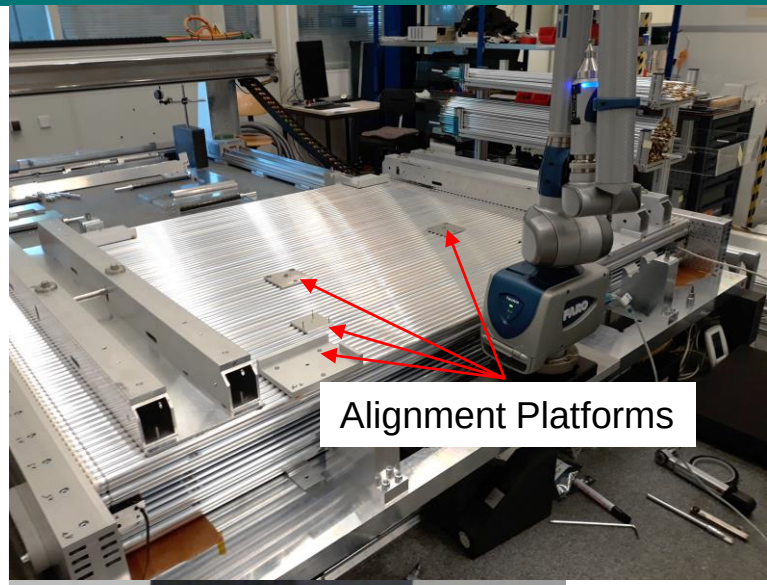
- Installation of 96 sMDT chambers + thin-gap RPCs in 2027-28 during the ATLAS detector upgrade for the High-Luminosity LHC in the small barrel sectors
- Goal: increase the trigger acceptance, rate capability, efficiency and selectivity
- sMDTs half the diameter of previous MDTs (30 mm → 15 mm)
- 464 (BIS2-6) up to 560 (BIS1) sMDTs make up a chamber

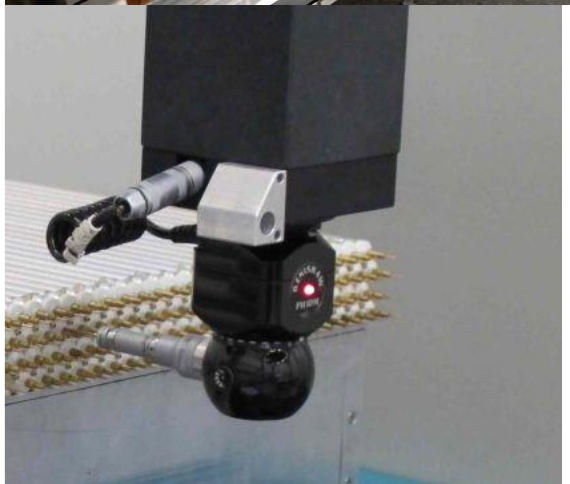


- Operated with Ar:CO2 (93:7) gas mixture at 3 bar absolute pressure and 2730 V operating voltage to provide a single tube resolution of 100 microns
- 48 chambers built at MPI Munich, 48 chambers built at University of Michigan
- Start of series production at MPI: December 2020

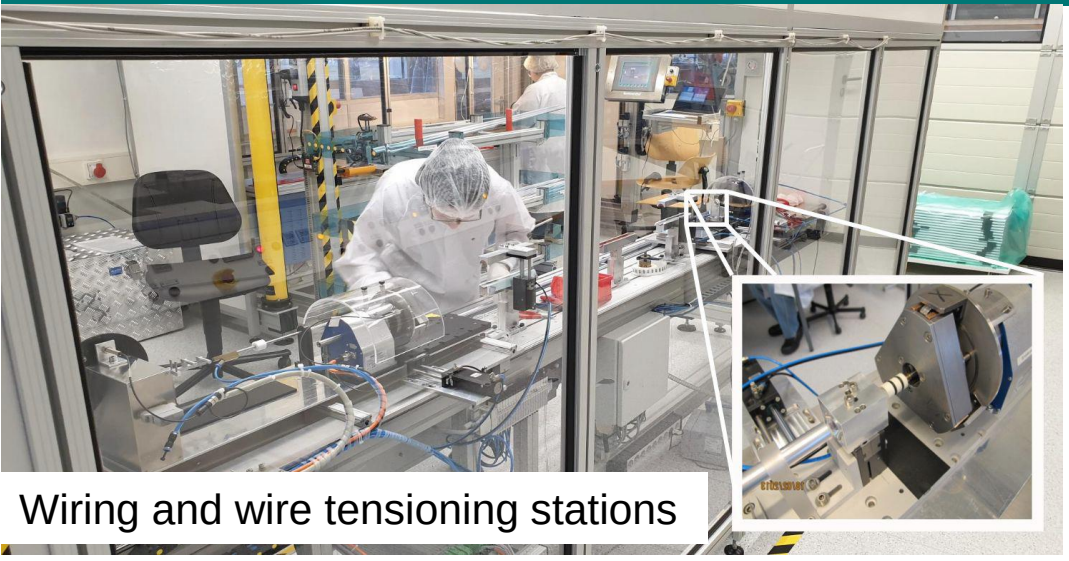
Quality Control Motivation

- High mechanical precision, high reliability and lifetime over >15 years of ATLAS operation at HL-LHC
- Stringent quality control and documentation of all components and at all steps of the chamber construction:
  - Tube production
  - Chamber and alignment sensor platform gluing
  - Wire position measurements
  - Gas system installation
  - Electronics installation
  - Cosmic ray tests





Tube Production



Wiring and wire tensioning stations

Gas tightness and dark current tests

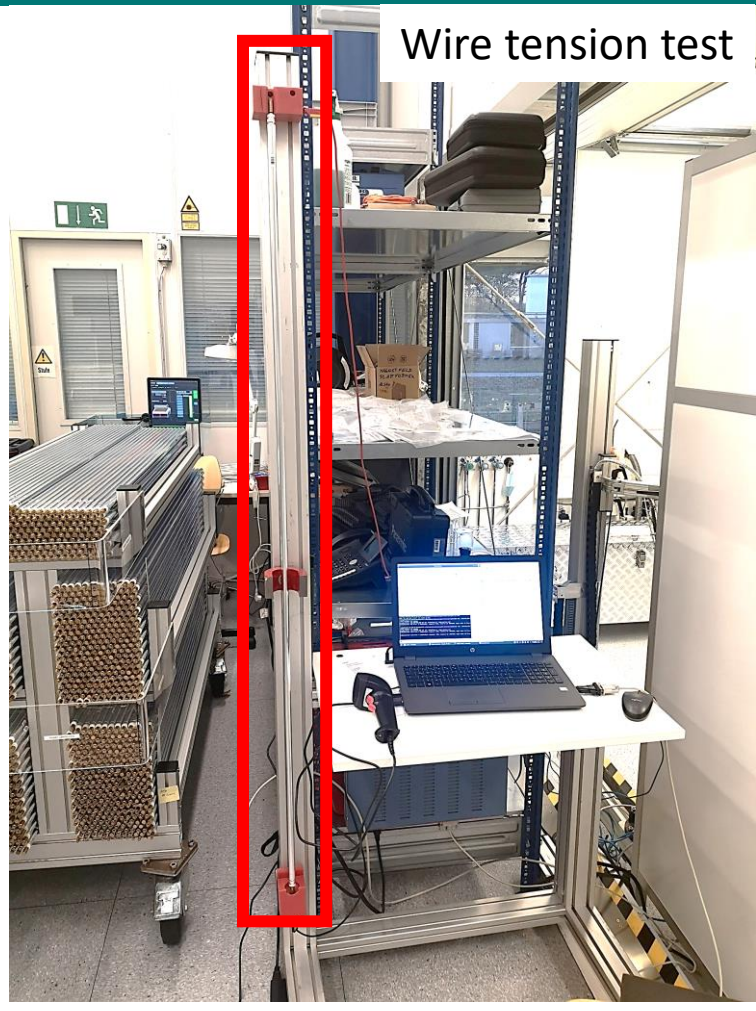
- Drift tube production under class 1000 clean room conditions to avoid any contamination
- Automated assembly to avoid direct contact with wire by hand
- ≥ 60 tubes produced and tested per day

Drift Tube QC:

- Gas leakage rate
  - Tube filled with Ar:He (95:5) gas mixture at 3 bar overpressure in evacuated cylinder
  - detecting leaking He, translate to leaking Ar
- Dark current
  - Dark current tested with nominal $ArCO_2$ gas mixture at 3015 V

Drift Tube QC

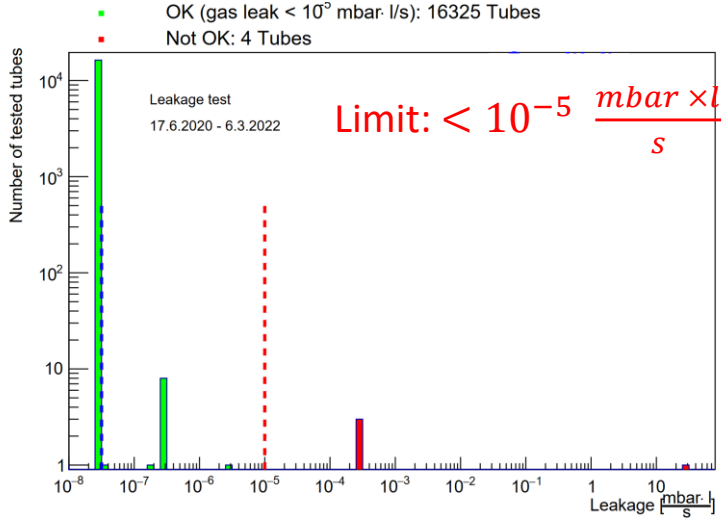
- Tube length
  - Selection into 3 length categories
  - Important for gas system installation
- Wire tension
  - Assure knowledge of wire position over whole tube length
  - 2 measurements with 2 weeks delay → make sure wires don’t slip out of the crimps
- Production failure rate ~1 %

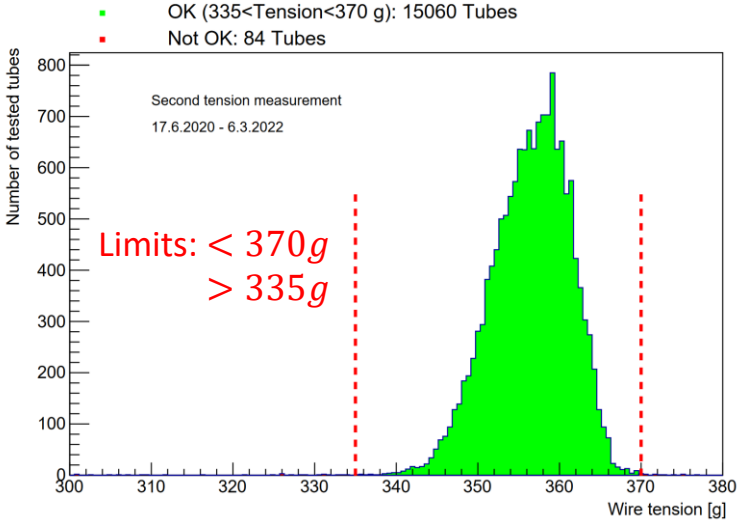


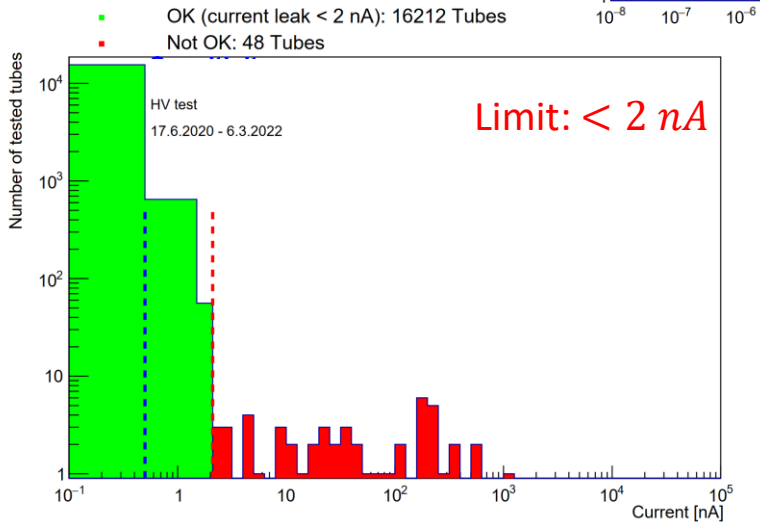
Drift Tube QC

Tube certification:

- Each tube labeled and identified with a bar code in the QC database including its location in the chamber
- Tubes checked to be "good" according to the database before gluing them in the chamber

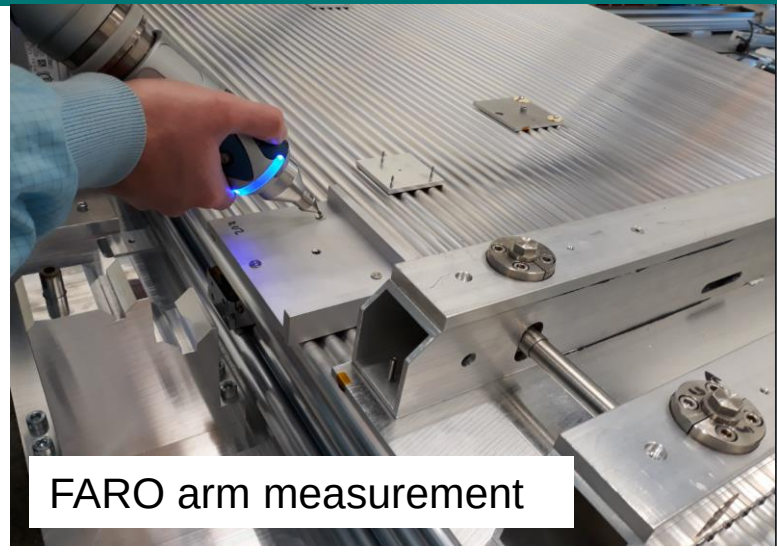




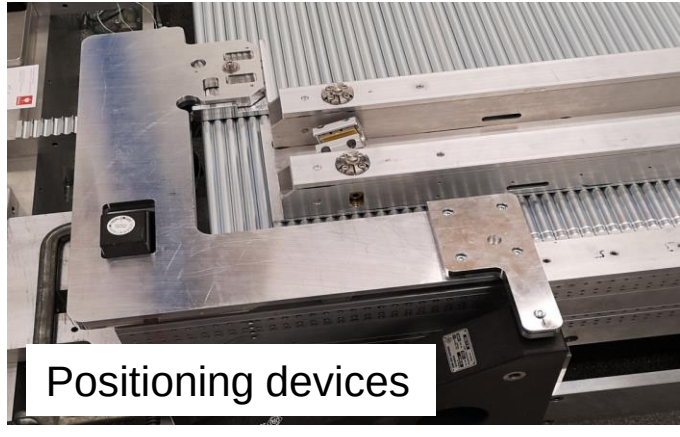


Alignment Platforms

- Chamber and platform gluing in temperature-controlled class 1000 clean room
- Platforms for mounting of optical sensors of the global chamber alignment monitoring system
- 3D electro-mechanical feeler (FARO arm) measures platform positions in each direction
- Positions relative to the sense wire grid must be known with at least 30 µm precision
- FARO arm measurement achieves 10 µm precision



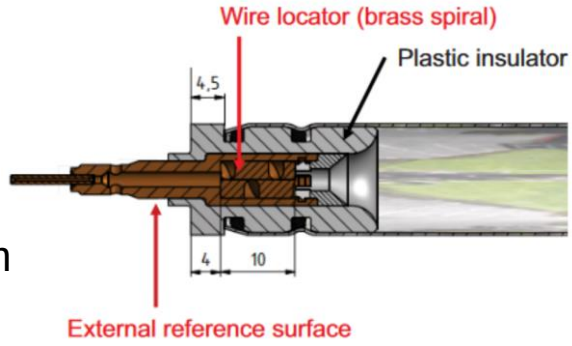
FARO arm measurement

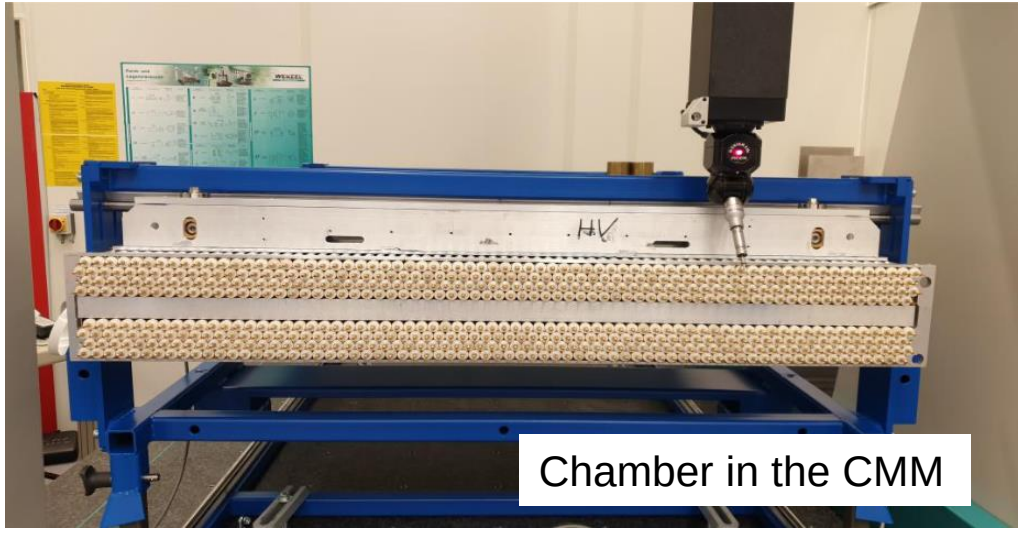


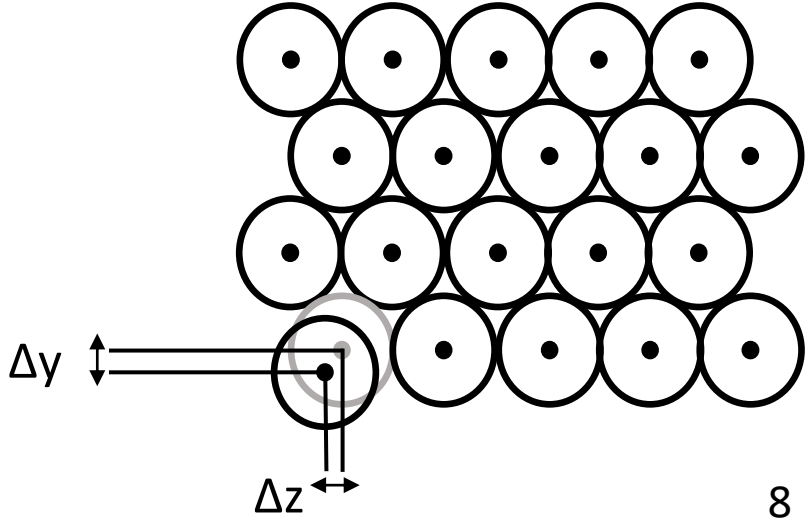
Positioning devices

Wire Position Measurements

- Automated Coordinate Measurement Machine (CMM) used to measure position of each endplug
- Derive wire position accuracy w.r.t. fitted sense wire grid
- 10 µm of precision achieved, 20 µm required to achieve desired momentum resolution
- Monitor further important quantities: layer distances, gravitational sag, torsion

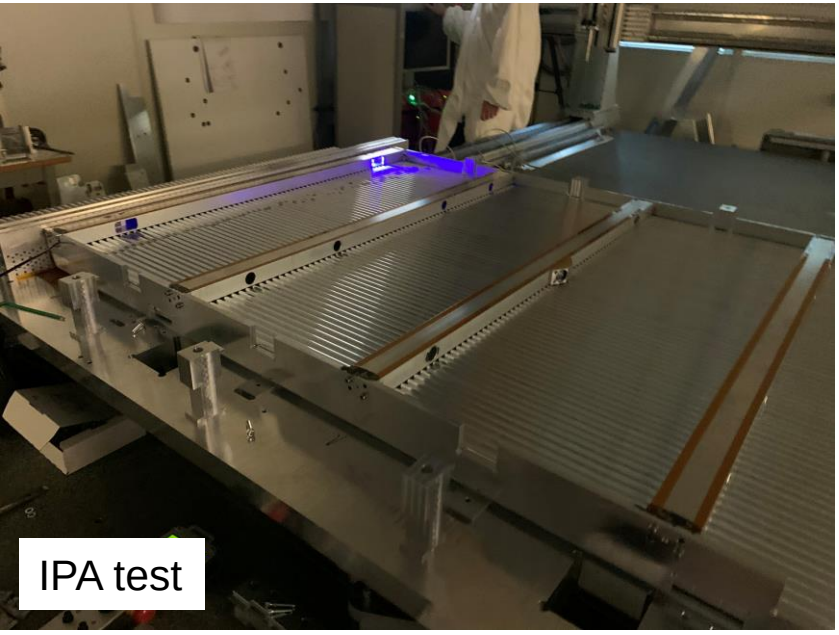



Chamber in the CMM



In-Plane Alignment System and Torsion

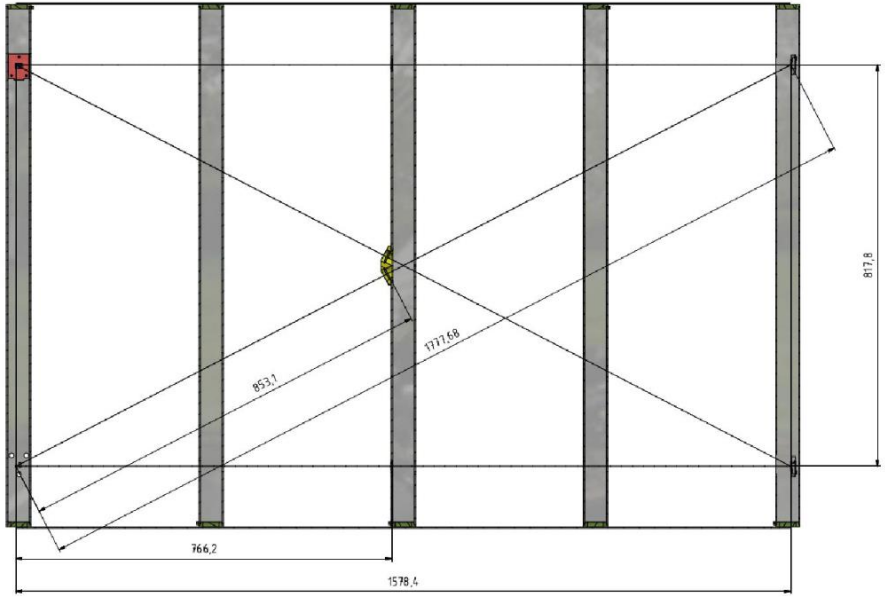
- In-Plane Alignment System (IPA) situated in the spacer between the multilayers
- Responsible for the monitoring of unstable chamber torsion outside CMM
- Validate IPA configuration by comparing CMM and IPA torsion results



2 CCD Cameras

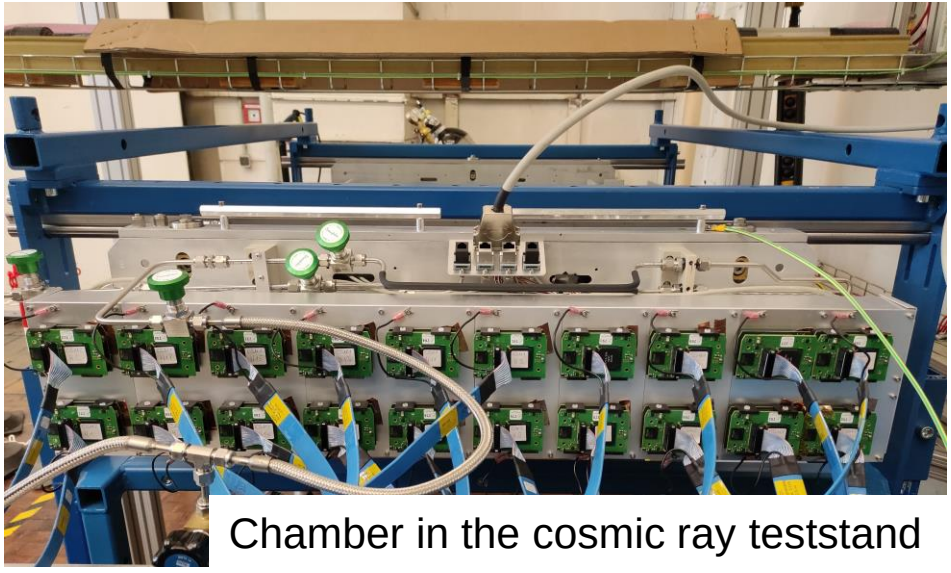
4 lenses

2 LEDs projecting chessboard-like patterns



Gas System and Readout Electronics

- Measurement of the Ar gas leak rate via pressure drop over 24 hours with corrections for temperature variations
- Leak rate limit: $2n_{tubes} \times 10^{-8} \frac{bar \times l}{s}$ i.e. pressure drop below 6.7 mbar in 24 h



Chamber in the cosmic ray teststand

Gas system installation

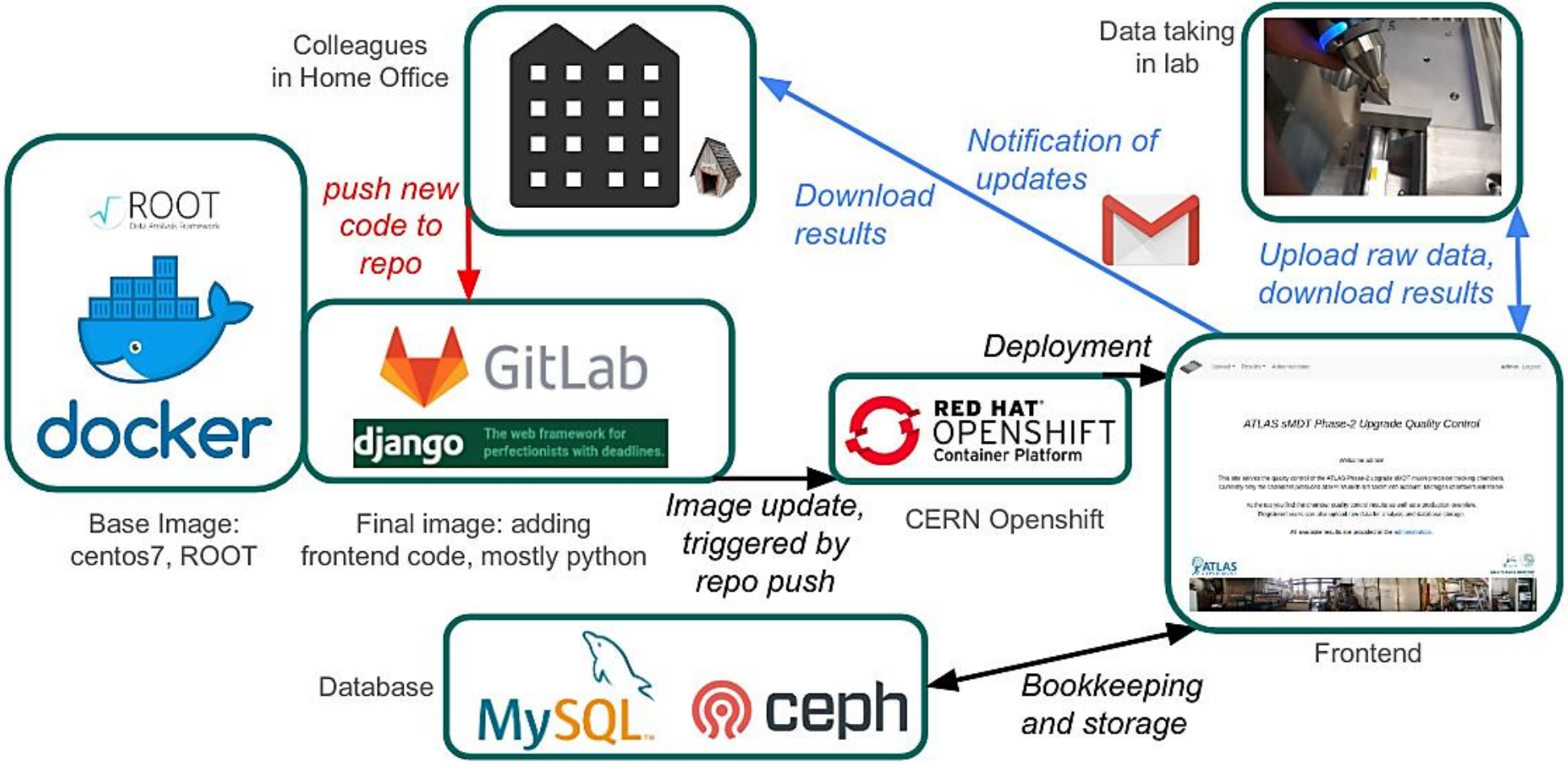
- Electronics mounting and cabling → identifier for each electronics card
- Cosmic ray teststand with muon tracking for efficiency and resolution measurement

Quality monitoring

- Common QC database for the two production sites at MPI Munich and Michigan, hosted at CERN
- Web-frontend, upload raw data from QC measurements
- Automated analysis of platform position, CMM wire position, torsion and pressure drop measurements
- Mechanical and electronics performance posted on webpage in real time
- Automatic email notification of experts about new results

  → fast feedback for the chamber construction
- Storage of data about each individual drift tube and chamber production steps

How it works

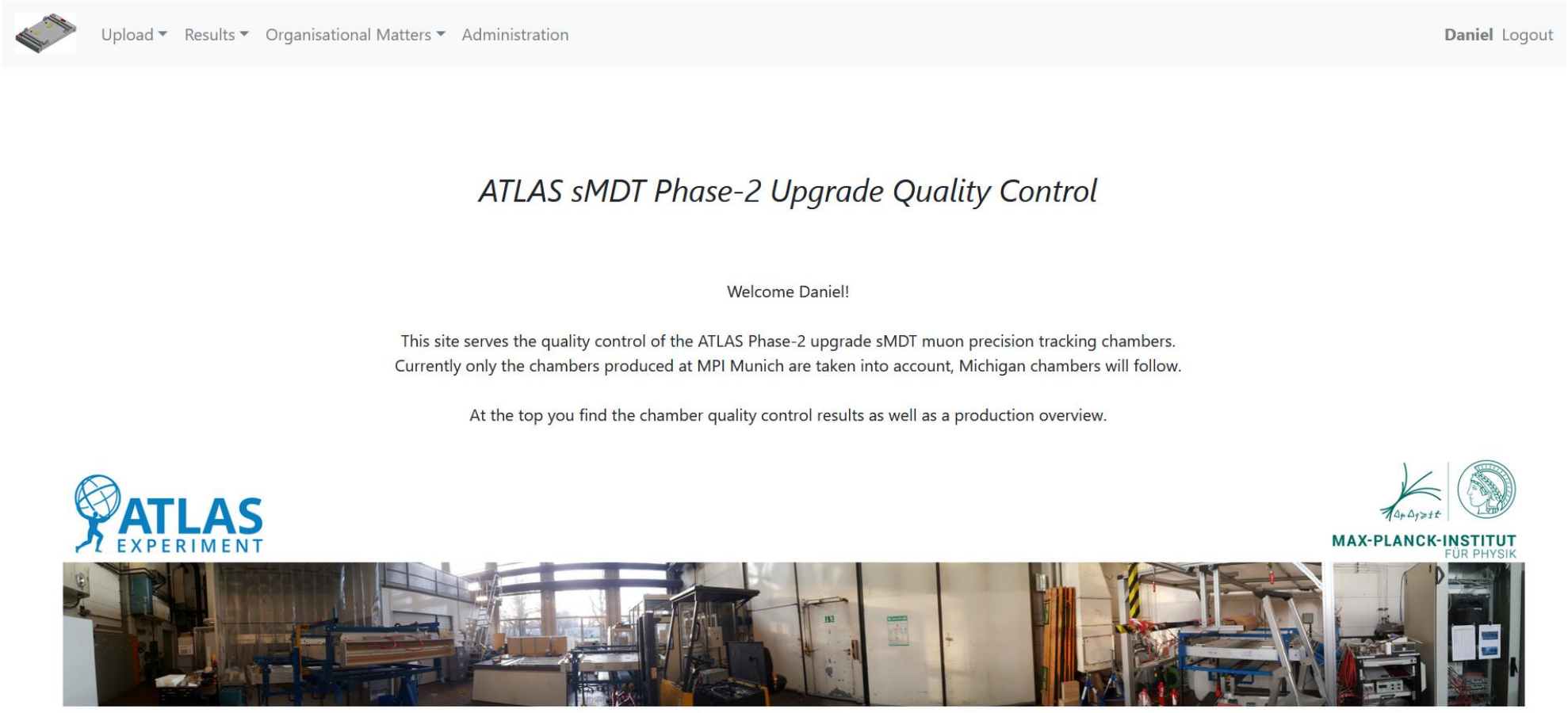

Colleagues
in Home Office
Data taking
in lab
Notification of
updates
Download
results
push new
code to
repo
Upload raw data,
download results
ROOT
docker
GitLab
django
The web framework for
perfectionists with deadlines.
Deployment
RED HAT
OPENSHIFT
Container Platform
ATLAS sMDT Phase-2 Upgrade Quality Control
Base Image:
centos7, ROOT
Final image: adding
frontend code, mostly python
Image update,
triggered by
repo push
CERN Openshift
Frontend
Database
MySQL
ceph
Bookkeeping
and storage

Summary

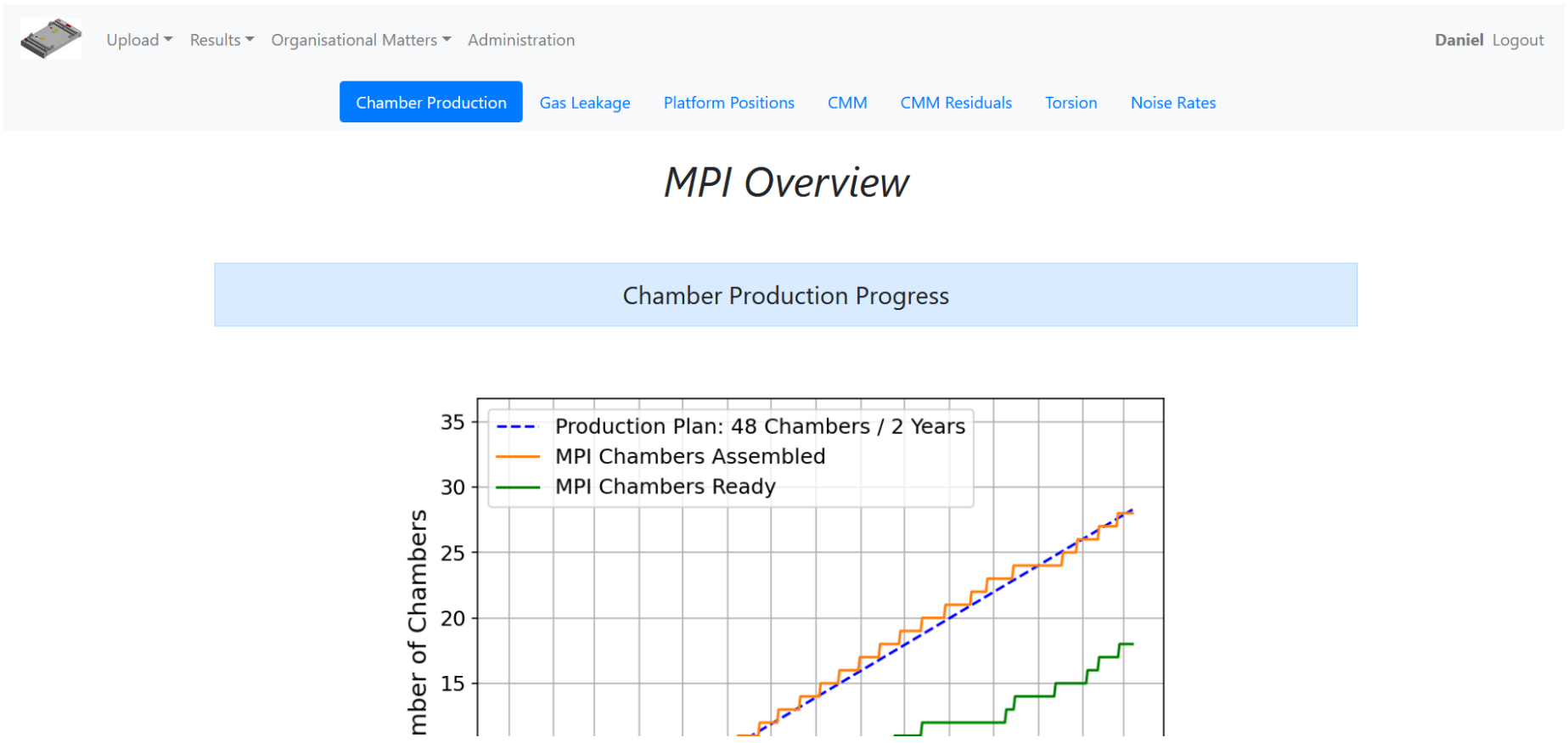
- Stringent and exhaustive QC program essential part of series production of new sMDT chambers for the ATLAS phase-2 upgrade
- Tube production with a very low failure rate, multiple tests before certification
- Validation of chamber quality in every step of production
- Database with web-frontend to assure fast tracking of the quality measurements
- Completion of a chamber every 2 weeks
- 29 of 48 chambers already constructed and certified at MPI, 15 of 48 at Michigan, 23 chambers at CERN already
- QC continues at CERN!

BACKUP

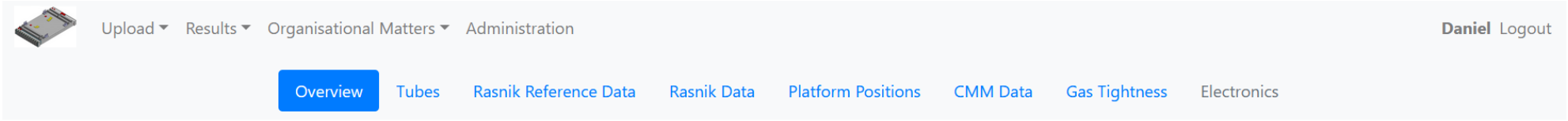
QA/QC Webpage



Production Overview



Camber Overview



Measurement Results

MPI Module 25: BIS3 A08

RO Axial-Praxial 1

Coordinate	Distance	Distance Stat. Error	Distance Nominal	Offset to Nominal
x	424.026	0.005	424.000	0.026
y	19.409	0.007	19.500	-0.091
z	90.482	0.005	90.450	0.032

HV Axial-Praxial 1

Coordinate	Distance	Distance Stat. Error	Distance Nominal	Offset to Nominal
x	1333.976	0.005	1334.000	-0.024
y	19.453	0.009	19.500	-0.047
z	90.488	0.009	90.450	0.038