Overview of ATLAS Muon Spectrometer Alignment

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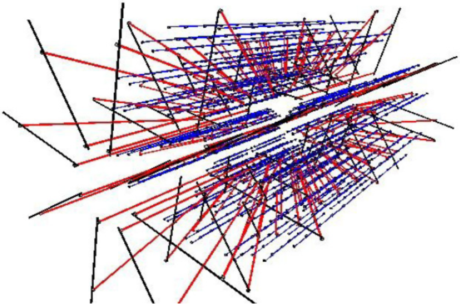
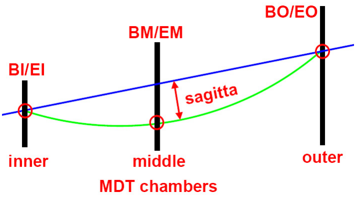
& others . . .



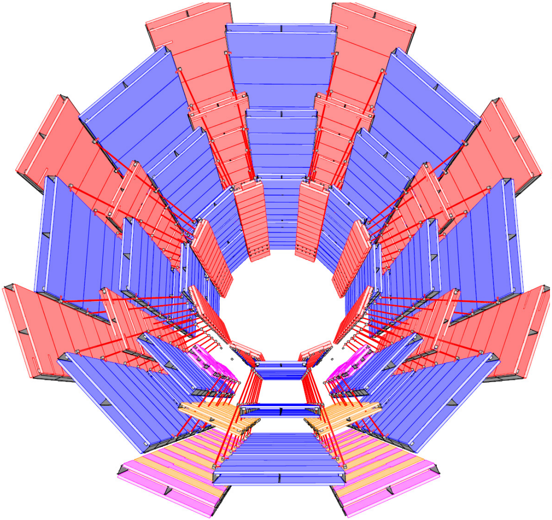
Outlook for ATLAS Muon Spectrometer alignment

- momentum measurement design goal:
  $\delta p_t/p_t = 10\%$ for 1 TeV muons $\Rightarrow$
  sagitta of 500 μm measured with 50 μm accuracy
- muon chambers ($\sim$ 1200 in total) are high-precision objects by construction: sense wires are placed with 20 μm precision during chamber assembly
- single muon chamber spatial resolution is $\sim$ 40μm
  $\Rightarrow$ muon chambers must be aligned to 30 μm accuracy in order to provide the required momentum resolution

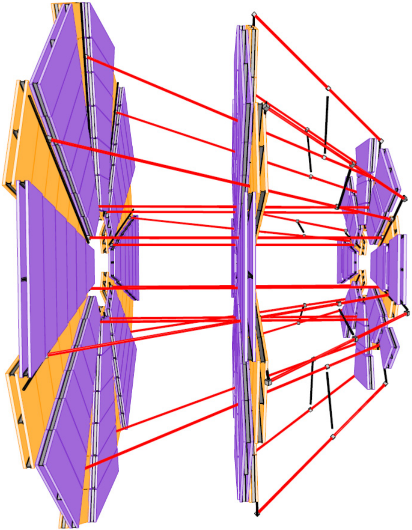


- in the first order, only the relative alignment of triplets of chambers traversed by the same muon track is important
- in the barrel region 3-point straightness monitors (RASNIKs) installed on the inner/middle/outer chambers form such projective lines pointing to the interaction region
- in the endcap regions projective lines are impossible because the cryostats of endcap toroid magnets block the interaction region $\Rightarrow$ the endcap alignment relies on high precision reference rulers – alignment bars which form alignment grid for the endcaps

Layout of ATLAS Muon Spectrometer

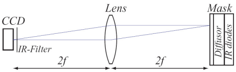


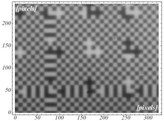
Barrel



Endcap C

Optical alignment sensors



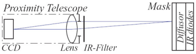


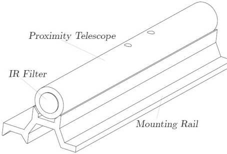
RASNIK straightness monitor

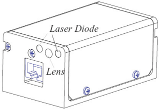
- 3-point imaging system
- typical accuracy of 1 μm in transverse plane
- operational distance is limited by air turbulence along the optical path (a few meters)
- few tens of μm accuracy in axial direction

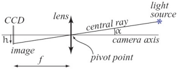
Proximity monitor

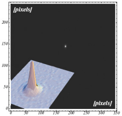
- RASNIK-based – CCD and lens combined into one unit (telescope)
- transverse coordinate accuracy is 1 μm
- magnification resolution is $5 \cdot 10^{-5}$







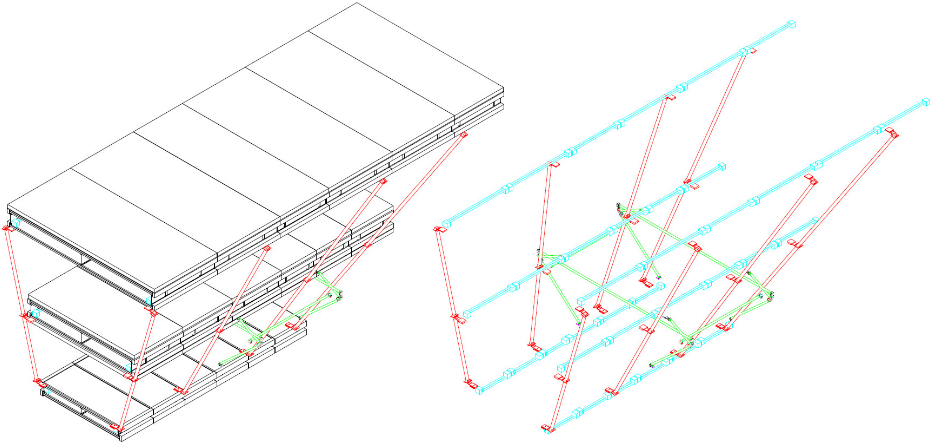




BCAM angle monitor

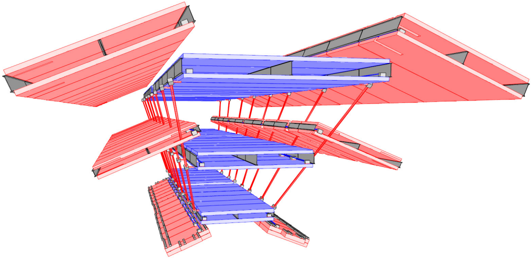
- angular resolution is 5 μrad over dynamic range of 40 mrad
- needs two light sources to measure axial displacements
- works over any distance without adjusting

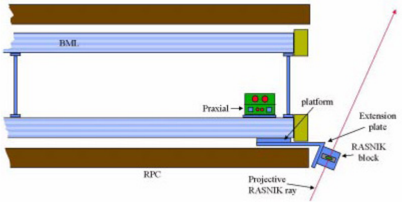
Subsystems of barrel optical alignment



- Projective system (red)
- Axial/Praxial system (cyan)
- Reference system (green)
- Small-to-large chamber connections
- Inplane system (MDT)
- BIL-BIR connections

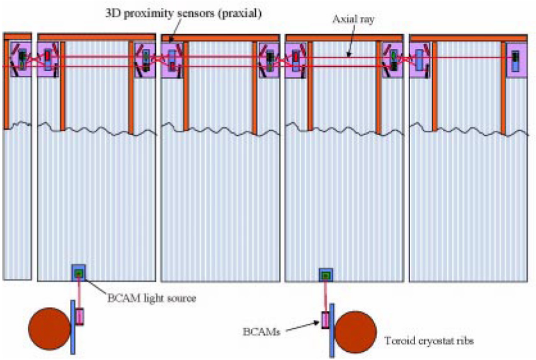
Barrel projective system

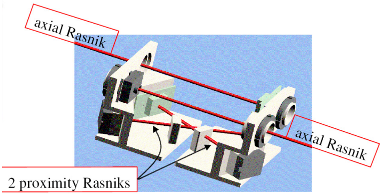




- provides correction to track sagitta measurement with required 30μm precision
- 2 $\times$ 4 projective lines per half sector of large chambers (2 $\times$ 3 in rail sectors)
- barrel small chambers have to be aligned with respect to large chambers by using muon tracks in the overlap regions
- RASNIK elements are mounted on extension plates which, in turn, are mounted via 3-ball system on platforms precisely glued on tube multilayers

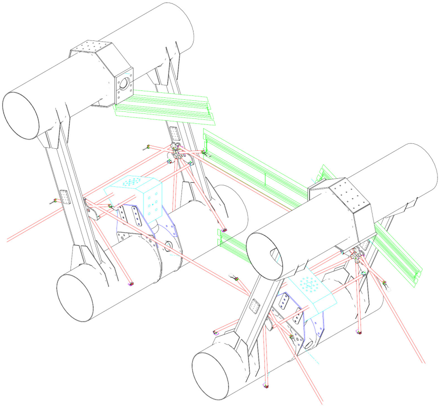
Barrel axial and praxial systems

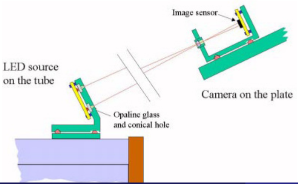




- combines MDT chambers within one sector into a single "rigid" layer which allows to decrease the required number of projective line
- consists of axial and proximity (praxial) subsystems with RASNIK sensors
- axial system measures relative position of the neighboring chamber praxial platform on the far side
- proximity system measures relative position and orientation of two neighboring praxial platforms
- has resolutions better than 10 μm on translations and 30 μrad on rotations
- elements of the both subsystems are mounted on the same platform: four praxial platforms are glued at the four corners of all MDT chambers

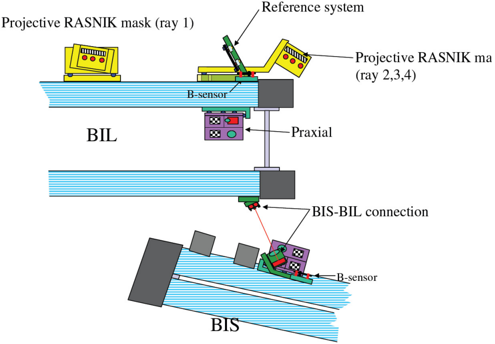
Barrel reference system

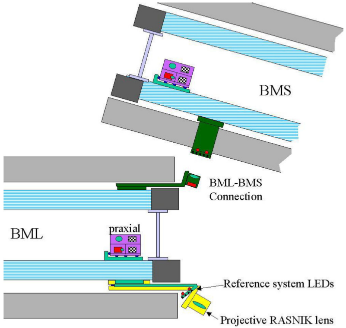




- forms a reference frame for the barrel muon chambers with a precision of $\sim$ 400 μm on translations and $\sim$ 500 μrad on rotations
- below 1 mm precision is needed by pattern recognition of muon reconstruction and by magnetic field service
- also allows for second order corrections to sagitta measurements
- plates of the reference system are mounted on the toroid cryostat ribs
- active elements are BCAMs mounted on these plates pointing to LED sources placed on muon chambers or on other plates

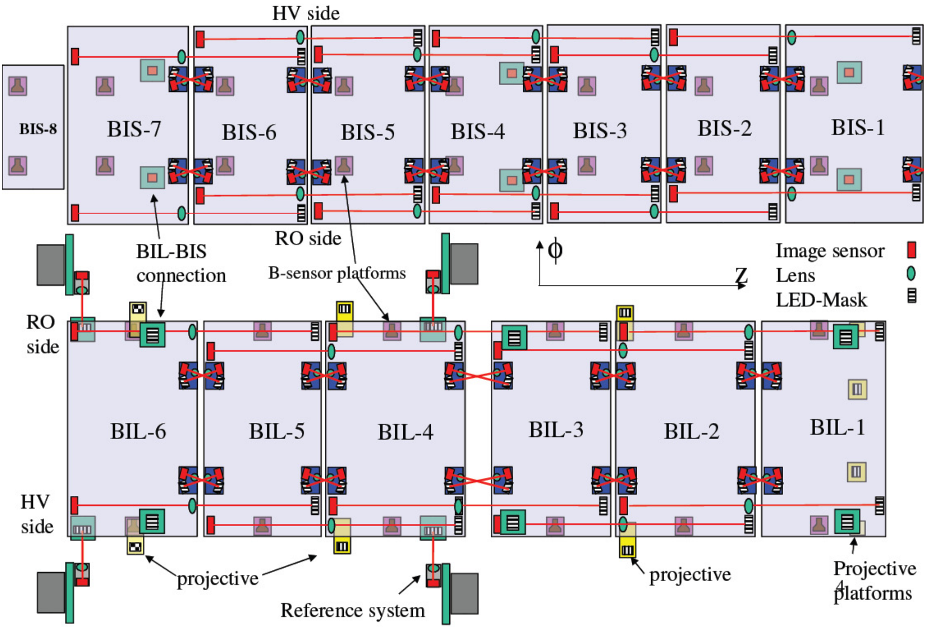
Barrel small-to-large chamber connections



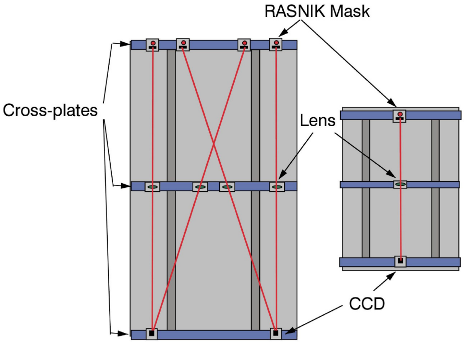


- small-to-large chamber optical connections are part of the reference system
- BCAMs are mounted on large chambers with LED sources placed on adjacent small chambers (reverse setup for inner stations)

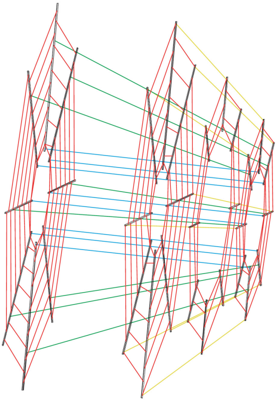
Overall scheme of barrel optical alignment for a standard sector



- monitors chamber deformations (“M” in MDT) which are described by 8 parameters and result primarily in modification of the wire layout
- based on 4 RASNIK sensors (except BIS chambers which have only 1 sensor)
- calibrated directly during chamber assembly
- determines wire displacements with $\sim$ 10 μm accuracy



Layout of endcap optical alignment

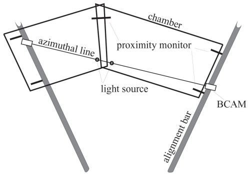


Endcap reference grid

- alignment bars (black) are instrumented with internal RASNIKs and T-sensors and their shape is determined by calculations
- polar bar-to-bar BCAM lines (green, blue and yellow) form a quasi-projective layout of light rays
- azimuthal bar-to-bar BCAM lines (red) control relative positions of bars within one layer of endcap muon stations

Endcap chamber-to-bar alignment

- pairs of adjacent small and large chambers form logical units
- two proximity sensors on “bar-sides” of each chamber measure displacements with respect to alignment bars
- connection between a small and a large chamber maintained by one proximity sensor and one azimuthal BCAM pair (needed to control out-of-plane movements in the overlap region)



Endcap alignment bars

The bar consists of an aluminum tube:

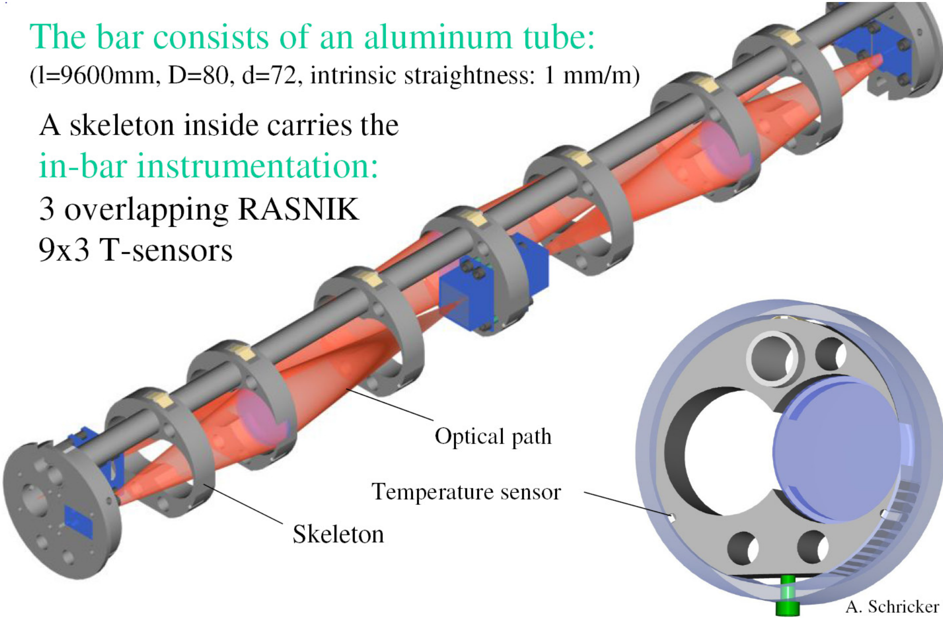
(l=9600mm, D=80, d=72, intrinsic straightness: 1 mm/m)

A skeleton inside carries the

in-bar instrumentation:

3 overlapping RASNIK

9x3 T-sensors



Optical alignment software

Two optical alignment reconstruction programs are available:

- ASAP (ATLAS Spectrometer Alignment Program) mostly used in barrel
- ARAMyS (Alignment Reconstruction for the ATLAS Muon Spectrometer) used in endcaps

ASAP/ARAMyS inputs

- nominal detector description
- results of geometry survey
- sensor calibration constants
- optical sensors readout (provided by optical alignment DAQ)
- temperature sensors readout (provided by DCS)
- alignment bar shape functions (ARAMyS)

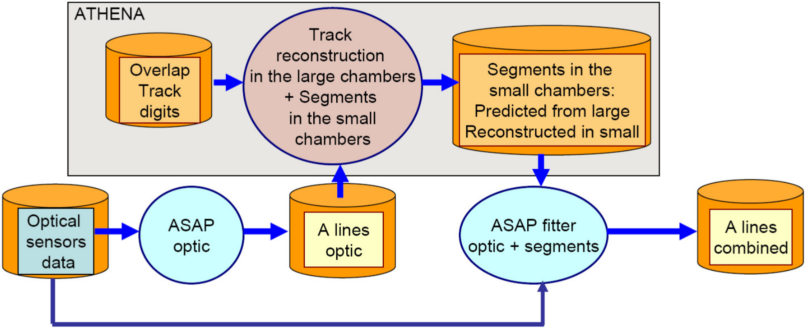
Reconstruction output

- corrected detector description (ASAP)
- global positions of optical sensors (ARAMyS)

Both programs were intensively used in alignment tests in H8

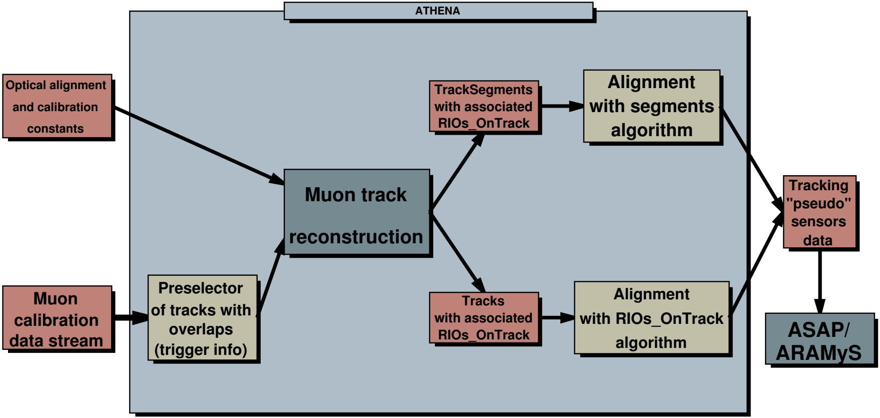
Tasks for track based alignment

- Many muon chambers don't have projective optical alignment sensors – no correction to sagitta measurement
  - small barrel chambers
  - BEE chambers
  - BIS8 chambers
  - barrel-to-endcap connection
- Tracks passing through overlaps between these chambers and optically aligned chambers must be used to obtain their relative positions



ATHENA track based alignment package

The package is being developed by MPI MDT group



- based on Common Tracking EDM (uses its data objects and tools) to be independent of particular muon reconstruction algorithm (Muonboy or MOORe)
- have two modes: “alignment with RIO_OnTrack” which is a universal algorithm and “alignment with segments” which has specific use cases (runs with magnetic field off and “very misaligned detector” scenario at start-up)

Alignment system tests and installation status

Optical alignment tests

- relative concept
  - follow variations of sagitta corrections from some moment at which sagitta corrections are known (e.g. straight tracks from special runs with magnetic field switched off)
  - sensor positioning accuracies and many calibration parameters cancel out
  - successfully tested in H8 with one octant setup of barrel and endcap chambers with the achieved resolution on sagitta correction of 10 μm for barrel and 16 μm for endcap
- absolute concept
  - provide sagitta corrections at any time without external references
  - difficult to achieve the required sagitta resolution due to large uncertainties from sensor positioning
  - tests in H8 gave precision on the order of 400 μm for absolute chamber positions

ATLAS muon optical alignment installation (status of 15.05.2006)

- Barrel projective system in sector 13 partly installed, 5 out of 12 alignment rays had clashes with cable trays/cryogenic line/floor bars
- BMS/BMF axial/praxial/inplane system installed and validated
- BOS/BOF/BOG axial/praxial/inplane system installed but some minor realignments needed
- barrel reference system installed and was used during toroid release but not retested since