Implementation of Chamber Misalignments in the ATLAS Muon Spectrometer Description

M.Bianco[1 2] I.Borjanovic[1], G.Cataldi[1], G.Chiodini[1], R.Crupi[1,2], E.Gorini[1,2], F.Grancagnolo[1], S.Grancagnolo[1,2], A.Guida[1,2], R.Perrino[1], M.Primavera[1], G.Siragusa[1,2], S.Spagnolo[1,2], A.Ventura[1,2] and the ATLAS Collaboration [1]

[1]Istituto Nazionale di Fisica Nucleare, sezione di Lecce, Italy

[2]Dipartimento di Fisica, Università del Salento, Italy

The Atlas Muon Spectrometer (MS) [2] is designed to reach a very high transverse momentum resolution for muons in a $\mathrm{p_T}$ range extending from 6 GeV up to 1 Tev and pseudo-rapidity below 2.7 thanks to an air-core toroidal magnetic field. Typically a muon track crosses three measurement stations separated by about 5 m, each providing a measurement of the corresponding super-point with precision of 50 μm. The system consists of about 1700 stations, with individual mechanical supports, organized in Large and Small sectors around the eight toroid coils, and made of four detector technologies: Monitored Drift Tubes (MDT) and Cathode Strip Chambers (CSC) (at $2 \leq |\eta| \leq 2.7$) for precision tracking in the bending plane $(\mathrm{R-z})$ and Resistive Plate Chambers (RPC) at $|\eta| \leq 1$ and Thin Gap Chambers (TGC) at $|\eta| \geq 1$ for triggering and coarse tracking in the transverse plane. The most demanding design goal is an overall uncertainty of 50 μm on the sagitta of a muon with $\mathrm{p_T} \geq 1$ TeV, which must be achieved within the following constraints: single MDT resolution of 80 μm, uncertainty from MDT auto-calibration below 30 μm, wire position known within 20 μm, chamber positions determined within 30(40) μm in the barrel (end-caps). MDT chambers ($\sim$ 1200) are made of two arrays of staggered aluminium drift tubes, $1-6$ m long, 3 cm diameter, 400 μm thin Al wall, leading to a global thermal expansion coefficient of 25 μm/m/°C. In order to meet the design performance of the MS, the absolute alignment of more than 1000 MDT chambers, along with their deformations induced by temperature gradients and mechanical stress, have to be known and appropriately handled by the Detector Description Software at run-time.

For each station, 3 angles, 3 shifts and 8 deformation parameters (tube plane twist, sagging or elongation of the support plates separating the two multi-layers), will be provided by a sophisticated optical alignment system [3], based on laser beams and CCD cameras, in addition to offline alignment procedures. Moreover, they will be stored in a Condition Database, implemented in Oracle, using the COOL LCG API, with an appropriate Interval of Validity for use in reconstruction applications.

The software (`MuonGeoModel`) describing the ATLAS MS geometry of active and inert materials is based on a package used ATLAS wide `GeoModel`[4] for the construction of a transient description of the ATLAS detector which can be easily translated into a `GEANT4` representation. The MS layout is represented as a hierarchy of volumes of a given material, provided with identification tags and relative transforms. Volumes corresponding to Detector Elements hold cached absolute transforms. Moreover, some transforms are alignable, i.e. they consist of a nominal and a Δ transform, the latter allowing to be updated at run-time. At any update, all cached full transforms beneath the aligned node in the tree are automatically re-calculated. Moreover, a set of classes, representing the `Readout Geometry`, accessed via a Detector Manager, and linked to nodes corresponding to Detector Elements, provide information with the readout granularity: i.e. strip position, read-out side, etc.

In the ATLAS Computing System Commissioning, aiming at the production of the ultimate physics and performance studies before LCH collisions, summarized in [5], most data samples have been simulated and successfully reconstructed with a MS layout described by a set of primary numbers stored in the static geometry database which include some realism: broken cylindrical symmetry and random misplacements of all MDT chambers (rms of shift and tilt parameter distributions are 1 mm and 1 mrad).

More recently, in the context of the Condition Data Challenge, the data describing the chamber random misalignments have been stored in the Condition Database. Software tools for accessing them, on the basis of their Interval of Validity, have been developed. Finally, the ability of `MuonGeoModel` to represent the correct MS geometry by initializing the geometry representation with primary numbers corresponding to the nominal layout and updating such transient model afterwords with alignment data extracted from the Condition Database has been demonstrated in the Full Dress Rehersal (FDR) in the summer 2008. The Atlas FDR is a data challange aimed at simulating the full data processing chain from the sub-farm output (SFO) output disk at point-1 up to Tier-2 AOD (Analysis Object Data) distribution and analysis; the input data samples have been produced in raw format and coherent, in composition, with realistic trigger menus and instantaneous luminosity according to the early expectations for the 2008 runs (10^{31} and 10^{32}). The data transferred at Tier-0 undergo a first round of reconstruction with preliminary calibration constants and, after the constants are refined (in one day time), the bulk processing of all physics data samples is done. The track based monitoring of the Muon Spectrometer was able to show a large improvement of the average χ^2 of the tracks after the application of run-time changing optical alignment constants fead to `MuonGeoModel` according to their interval of validity.

Despite the good performance and accuracy of the optical alignment system, some elements of the Spectrometer are not optically linked (e.g. small chamber towers in barrel). Therefore, track-based alignment is used to achieve the alignment requirements. Straight tracks, recorded with magnetic field off, are used to cross-check the absolute alignment of the chambers, and to help establish an “initial” geometry without field. Cosmic tracks recorded in ATLAS are being used for this purpose. From first studies performed on these data sets, track residuals in the top-most sector of the Spectrometer are shown in Fig.1. The width and offset of the residuals distribution are clearly reduced when using rough optical alignment corrections, which corresponds here to a relative position of the middle chamber compared to the outer and inner ones of 500 μm. The improvement is even larger with track-based alignment corrections. More refined use of cosmics and optical data will allow to come closer to the precision requirements. Tracks going though overlap regions between small and large chambers will serve as “virtual sensors” connecting the chambers whose position is precisely known to Studies performed on simulations have shown the validity of the method, which should allow to reach the required precision throughout the Spectrometer.

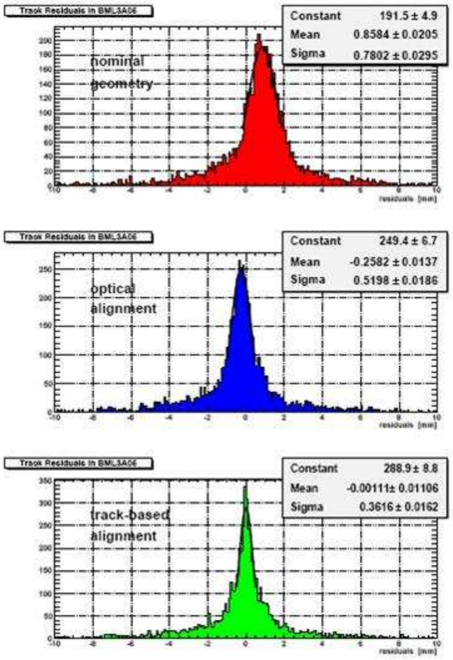

Figure 1. Track residuals (distance of the hits from a straight track) in cosmic rays events without any alignment corrections (top); with rough alignment corrections from the optical alignment system (middle); with alignment constant derived from track based alignemnt procedures (bottom).

`GeoModel` does not provide any built-in ability to handle deformations. Moreover, memory saving mechanisms, like parametrization and volume sharing, exploit symmetry and regularity. Therefore, MDT deformations are not simulated in `GEANT4` due to memory restrictions and system complexity. However, most of them can be described at the level of `Readout Geometry` with tubes shifted and tilted with respect to their nominal location in the multilayer[1]. A first implementation of MDT deformations, based on such concept, is in place and exhibit the expected functionality. In order to validate the description of deformation effects on simulated data, the following approach is under test: particles are simulated in `GEANT4` in the nominal geometry, then in the digitization procedure, the local hit position is transformed to the global frame and then relocated back into the sensitive volume by using the `MuonGeoModel` interfaces which account for deformations; the corrected hit is finally digitized.

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[1] Bent tubes and wire sagging are handled with other mechanisms and tools outside the scope of `MuonGeoModel`.

REFERENCES

1. ATLAS Collaboration is made of about 2500 Physicists coming from 167 Institutions of the following countries: Argentina, Armenia, Australia, Austria, Azerbaijan, Belarus, Brazil, Canada, Chile, China, Colombia, Czech Republic, Denmark, France, Georgia, Germany, Greece, Israel, Italy, Japan, Morocco, Netherlands, Norway, Poland, Portugal, Romania, Russia, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Taiwan, Turkey, UK, USA, CERN, JINR.
2. ATLAS Collaboration, *ATLAS Muon Spectrometer Technical Design Report*, CERN/LHCC/97-22 31 May, 1997.
3. C. Amelung, *The alignment system of the ATLAS muon spectrometer*, Eur.Phys. J. **C33**, 2004, 999-1001.
4. J.Boudreau at al. *ATLAS detector simulation : status and outlook*, CERN-ATL-SOFT-PUB-2005-004 19 Dec, 2005.
5. The ATLAS Collaboration (G. Aad et al.) *Expected Performance of the ATLAS Experiment - Detector, Trigger and Physics*, arXiv:0901.0512, Jan. 2009.