View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by CERN Document Server

Streamlined Calibration of the ATLAS Muon Spectrometer Precision Chambers

Daniel S. Levin*
for the ATLAS Muon Collaboration
*Department of Physics, University of Michigan

ATL-MUON-PROC-2009-010
25 November 2009

***Abstract*—The ATLAS Muon Spectrometer is comprised of 1150 optically Monitored Drifttube Chambers (MDTs) containing 354,000 aluminum drift tubes. The chambers are configured in barrel and endcap regions. The momentum resolution required for the LHC physics reach (dp/p = 3% and 10% at 100 GeV and at 1 TeV respectively) demands rigorous MDT drift tube calibration with frequent updates. These calibrations (RT functions) convert the measured drift times to drift radii and are a critical component to the spectrometer performance. They are sensitive to the MDT gas composition: Ar 93%, CO_2 7% at 3 bar, flowing through the detector at arate of 100,000 l hr^{-1}. We report on the generation and application of Universal RT calibrations derived from an inline gas system monitor chamber. Results from ATLAS cosmic ray commissioning data are included. These Universal RTs are intended for muon track reconstuction in the LHC startup phase.**

I. INTRODUCTION

THis paper reports on the production of drift-time to drift-radius *RT functions* derived from the ATLAS muon spectrometer Gas Monitoring Chamber (GMC), their use in the spectrometer cosmic ray commissionioning runs and the anticipated application in muon track recontruction during the intial phase of LHC beam collisions. The ATLAS muon spectrometer[1] is a cylindrical detector 45 m long and 22 m diameter and comprises 1150 *Monitored Drift Tube* (MDT) chambers in a toroidal, air-core, 0.6 T magnetic field. Calibration of these chambers is an ambitious undertaking involving the combined efforts of three *Tier-2* calibration centers[2] which have been established to process data from a dedicated calibration data stream. During normal LHC running these centers are expected to produce sets of calibration constants with a 24 hour latency. However, this calibration processing is resource intensive and requires adequate hit statisitcs (several thousand tracks per chamber) for optimal performance. An alternative, streamlined calibration source is offered by the GMC. This choice is especially appropriate during the inital low luminosity LHC phase when muon event rates are expected to be low.

The GMC performs two tasks: First, it continuously analyzes the MDT gas drift spectra and provides hourly updates of gas quality[3]; Secondly, it generates twelve times daily a *Universal* RT (URT) calibration function corresponding to a standard temperature and pressure of 20°C and 3000 mbar. This URT function represents a calibration anchor for the MDT gas at any time[4]. With appropriate compensation for the local spectrometer chamber temperature and pressure, and where appropriate, for the magnetic field, the compensated URT can serve as an effective calibration and can be used directly for the track reconstruction. As these URT functions are produced as a byproduct of the normal gas monitoring task, they convey a convenient calibration source whose production requires minimal computational resources.

II. DRIFT TIME

The spectrometer's *precision* coordinate is transverse to the tube direction (the tube laying within the chamber plane) and is determined by the radial distance to the anode wire of a charged particle track passing through a drift tube. Ionization electrons accelerate towards the wire, initiating an avalanche and yielding a signal. The drift time is defined as the time of arrival at the wire of the first drift electrons along a trajectory corresponding to the distance of closest approach to the passing ionizing particle. This drift time is the primary measured physical quantity in the MDT system. Part of deposited charge is also read out, but not considered further here. Technically, the readout time is the discriminator threshold crossing time of the anode signal collected by chamber mounted front-end readout electronics[5][6]. The drift time is this threshold crossing relative to that of a zero impact parameter track, one passing at the wire. The drift time of track passing a the wire is called a *T0* and represents a timing offset. Generally each tube or electronics channel is characterized by a specific T0, which is a function of the aggregate cable delays and particle times of flight.

A. Drift time calibration

The *drift radius* is computed from the drift time by means of a time-to-space function, commonly referred to as an RT function. The RT function is expressed as a lookup table specifying the drift radii corresponding to drift times. To achieve optimal resolution over the entire spectrometer the RT functions must be tuned to local chamber conditions: gas composition, temperature, pressure, magnetic field and high voltage. Ideally the RT function is determined for a region over which conditions are homogeneous. The variation of drift times due to changes in these parameters are estimated from Garfield simulations[7] and are validated by measurement[8][9]. In ATLAS, the local chamber environmental conditions are measured from embedded sensors. Therefore changes in the drift spectra, after accounting for perturbations in temperature and pressure are attributable to variations in the gas composition. Other factors such as the magnetic field strength and applied high voltage are tightly constrained and do not exhibit significant temporal variations.

The calibration of the drift tubes is done with autocalibration algorithms which operate, as noted above, on groups of chambers for which the environmental conditions are homogeneous. In practice these regions generally correspond to a single chamber or chamber multilayer. The frequency at which calibrations should be updated can be guided by the output from gas monitorig. In this way determination of the overall health of the MDT gas mixture is a central component to this calibration program.

III. THE MONITOR CHAMBER

The GMC[10] utilizes the same type of 3.0 cm outer diameter drift tubes employed in the spectrometer. 96 tubes are glued into a pair of three-layer *multilayer* arrays with overall dimensions 50 cm wide × 70 cm length × 21 cm deep. While much smaller than ATLAS muon spectrometer chambers, the chamber construction mirrors that of conventional chambers. The drift tubes were manufactured and assembled into a chamber at the University of Michigan using the same tooling used to produce the ATLAS Endcap tubes and chambers of the MDT system.

The GMC is thermally insulated with temperatures varying by approximately 1°C. Multiple temperature sensors provide precise thermal monitoring with 0.1°C preciosn, used to correct the measured drift times to those of a 20°C equivalent gas. Similarly, pressure sensors placed at the output and input gas ports enable gas pressure measurements with a relative precision of 1 mbar. With thermal and pressure variations removed, any change in the measured drift spectra or RT functions are characterstic of the drift gas composition.

Spectrometer gas monitoring is achieved by strategic placement of the GMC in the ATLAS gas facility, a surface building located 100 m above and 50 m dispalced from the detector cavern. The GMC samples gas from the MDT *supply* and *return* gas trunk lines at the beginning and end of a 300 m round trip to the subterranean gas manifolds feeding the spectrometer. The MDT gas system supplies and exhausts all chambers in parallel,therefore the gas in the two monitor partitions is representative of the gas in all chambers in the spectrometer. The GMC supply and return lines are connected through flow controllers to two independent gas paritiions. The GMC acquires cosmic ray muon data from a scintillator trigger at 15 Hz. Every hour ~ 50000 tracks are collected during which time the GMC gas volume has been mostly flushed. Because of this high volume replacement rate the hourly measurements of drift time accurately reflect the actual MDT gas that flows into the spectrometer.

The analysis of the drift spectra are expressed as a set of fit parameters characaterized by the gas conditions under well-controlled conditions of temperature, pressure. In particular, the maximum drift time as derived from the drift time spectrum (referred to here on as $T_{max}(spectrum)$) is a single parameter representing the average electron drift velocity across the tube radius. After the effects of temperature and pressure are compensated, $T_{max}(spectrum)$ is very sensitive to the gas composition. An addition of 100 ppm of water vapor for example increases the T_{max} by $\sim$ 7 ns. An observed variation in T_{max} signals a change in composition and issues an alarm for recalibration. The GMC runs independently and acquires data asyncronously from ATLAS and produces output rapidly and continuously: Drift time measurements are generated hourly and RT functions are computed bi-hourly.

IV. MEASUREMENT OF MAXIMUM DRIFT TIME

The $T_{max}(spectrum)$ is determined by fitting the rising and trailing edges of the drift spectra (Figure 1). These fits use modified Fermi-Dirac functions of the form: $f(t) = \frac{A+D\times t}{(1+e^{(B-t)/C})}$ The 50% point of the rise/fall is B, C is the rise/fall time and D allows for a small slope before the tail of the distribution. For fits to the rising edge D is set to zero. Operationally, the difference of the parameters corresponding to the 50% rise/fall defines $T_{max}(spectrum)$: $T_{max}(spectrum) = B_{trailing} - B_{rising}$ When all 48 tubes from one chamber partition are combined into a single spectrum, about 150,000 histogram entries per partition are accumulated per hour. The resultant statistical error on a single $T_{max}(spectrum)$ measurement is 0.6 ns.

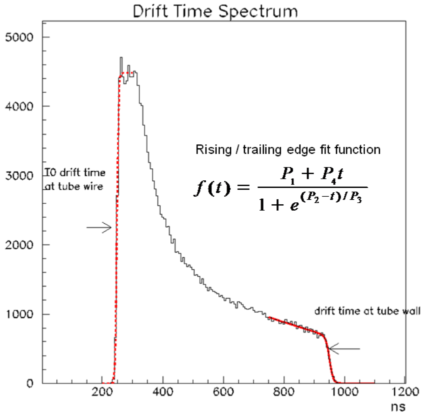

Fig. 1. Drift time spectrum showing the fit to rising edge and tail, corresponindg to tracks oassing at the wire and tube wall repectively.

A. Drift time monitoring results for 2009

The GMC has been in nearly continuous operation since September, 2007. Over more than a two years, a reliable image of the MDT gas system performance has been established. Figure 2 reports the gas system performance for a 3 month period. Several features are evident. The $T_{max}(spectrum)$ is observed to vary on any time scale from one day to over a month. The variations are due primarly to the change in water vapor in the gas mixture. There are two sources of the water vapor. The first is due to ambient humidity of the cavern air. Although the MDT system is nominally leak tight, external water vapor can slowly permeate into the gas system via the plastic endplugs used in the drift tubes, via small leaks and via the numerous O-ring seals in each tube. Secondly, water vapor is injected up to a level of 1000 ppm to preserve endplug integrity. Variation due to water vapor fraction can be as large as a few ns on daily scale to tens of ns over a week or more.

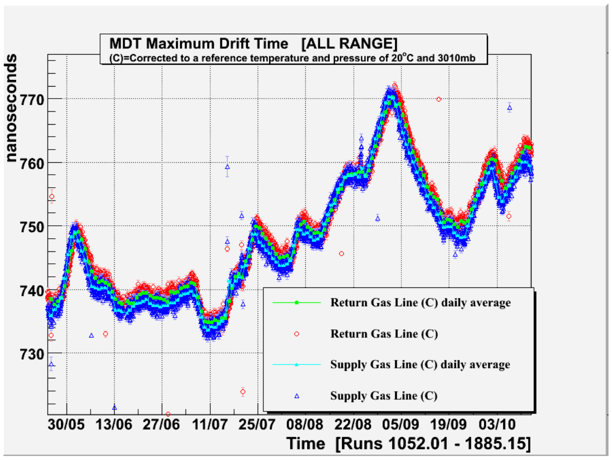

Fig. 2. Trend of maximum drift time from May to October 2009.

V. GENERATION OF RT FUNCTIONS

RT functions are the transfer functions relating the drift radius R to the drift time T via the electron drift velocity: $v_{drift} = dR/dT$. They are determined from an iterative *autcalibration* algorithm. The algorithm commences with an ensemble of about two hours data, yielding 90000 tracks. The average track residuals from this collection are determined at each of 100 radial bins spanning from the tube wire to tube wall. These residuals are then used to correct an initial *estimated* RT to produce the next generation. This procedure is repeated until no further convergence. Convergence is measured as a change in the T_{max}, the drift time at a radius equal to the tube inner diameter.

Autocalibration takes as a starting point an approximation of the desired RT function. This initial function can be an RT determined under different gas condtions or can be derived directly from the the integral of the drift spectrum dN/dT, and assuming a uniform flux, dN/dR=constant: $dR/dT = dR/dN \times dN/dT$. In normal running mode the *starter* RT is simply the previously computed RT from an earlier dataset. An example of an RT from an MDT chamber is shown in Figure 3. Such functions are output every two hours from the gas monitor. A composite daily function is compiled at mightnight each day and is comprised of the average of the previous 12 RTs generated during the previous 24 hours.

1) Self-Test of RT Generation: For each RT function computed from gas monitor data, a $T_{max}(RT)$ is defined as the drift corresponding to the tube radius. This RT derived maximum drift time is expected to track the $T_{max}(spectrum)$. Figure 4 reports the difference: $T_{max}(RT) - T_{max}(spectrum)$ over four months. Aside from an offset, the result of different operational definitions of the maximum drift time, the $T_{max}(RT)$ tracks the $T_{max}(spectrum)$ quite well.

A. Temperature Corrections

The URT described above represents the nominal calibration for standard temperature and pressure. While the actual MDT gas pressure is regulated to be within a few mbar of 3000 mbar, many MDT chambers have temperatures that deviate from 20°C. Figure 5 shows the distribution of temperatures through the muon spectrometer. Each measurement is an average of several onboard sensors. The vertical gradient is nearly 7°C over 22 m. These temperature variations introduce a timing correction which has been calculated using Garfield[7], and is shown in Figure 6. This curve is computed for a 1.2°C increase. It is scaled by the measured deviation of the chamber temperature from 20°C, then applied bin by bin to the RT function to obtain the chamber specific RT.

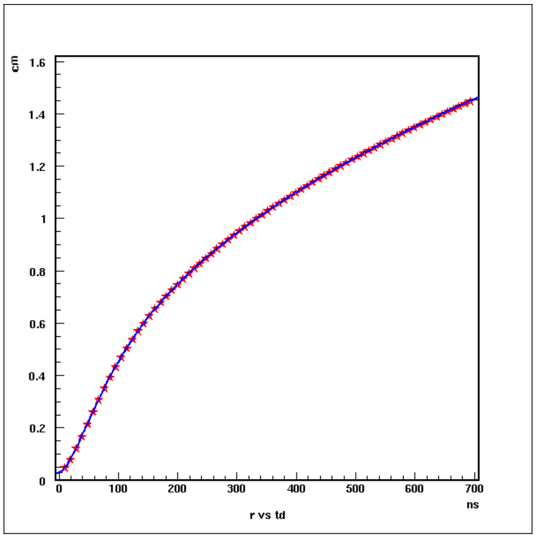

Fig. 3. Example of RT function obtained from the gas monitor for 93% Ar, 7% CO2, 3 bar and 20°C

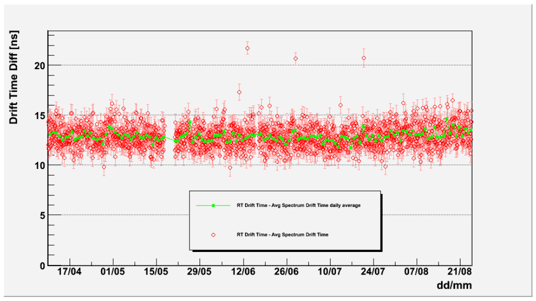

Fig. 4. Difference of $T_{max}(RT) - T_{max}(spectrum)$ over 4 month interval. The small green data points are the daily average.

Figure 7 which shows the residual distribution as a function of drift radius for two RTs: One is the Universal RT,the second after it has been corrected to the measured MDT chamber average temperature of 24°C. The temperature corrected RTs yield residuals which are quite flat across the tube radius, and whose mean values fall mostly within a 20 micron error tolerance for the MDT calibration error budget.

VI. RESULTS: APPLICATION OF URTS TO ATLAS COSMIC RAY COMMISSIONING DATA

An effective test gas monitor generated URT functions is established by the quality of track segment recontruction in a

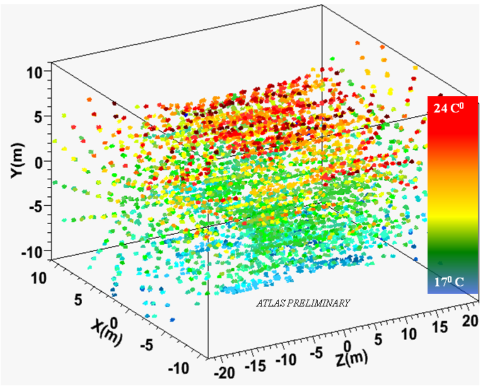

Fig. 5. Distribution of temperatures through the muon Spectrometer. The vertical gradient is nearly 7°C over 22 m.

Fig. 6. Garfield calculation of the change in drift time as a function of drift radius for a 1.2°C shift from 20°C

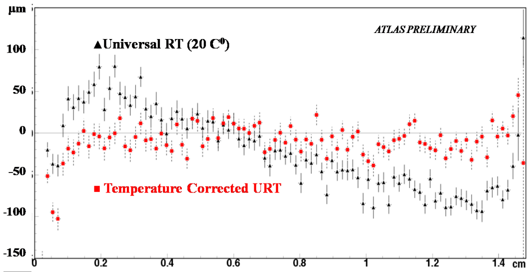

Fig. 7. Application of a temperature corrected RT to cosmic ray commissioning data: This plot shows hit residuals as a function of drift radius for a chamber at 24°C using the universal RT without (black) and with (red) the temperature compensation to the drift time.

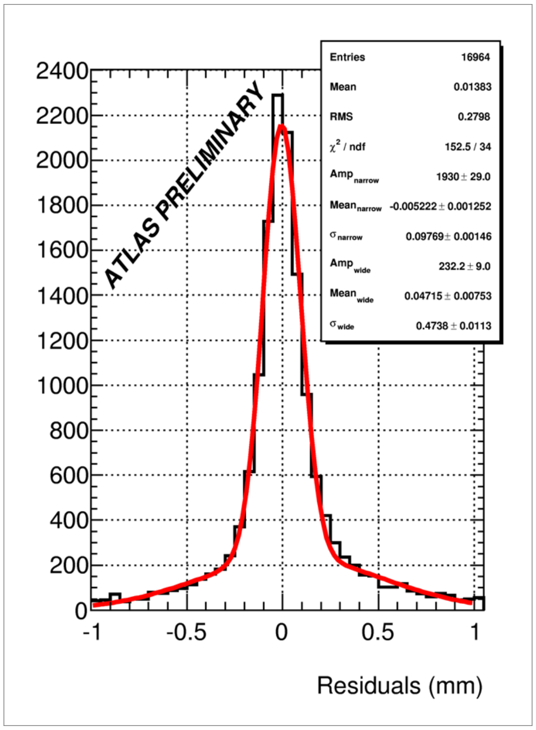

Fig. 8. Hit residual distribution for a single endcap chamber. Distributions like these for all chambers are fit with a double Gaussian function having narrow and wide components. The narrow one is a proxy for the intrinsic single hit resolution. In this example, the narrow gaussian width is 98 μm.

large ensemble of MDT chambers. the preferred metric for this test is the *residuals*. This residual is defined as the radial distance of a given tube hit from the best fit track segment where the tested hit is excluded from the fit. The hit residual serves as a conservative proxy of the tube resolution. The residual width is the convolution of the intrinsic resolution and the fit extraploation/interpolation error. The residual distribution is fit with a *double Gaussian* function. The double Gaussian fit yields a *narrow* fit component which reflects the intinsic tube resolution away from the wire and a *wide* fit component sensitive to near wire tracks and delta rays. This paper uses the narrow Gaussian component as a proxy measure of the resolution.

An example of the hit residual distribtion for a single endcap chamber is shown in Figure 8 and in Figure 9. The 98 micron width of the narrow Gaussian is compariable to results obtaned with direct autocalibration produced RT using the chamber data. Other factors discussed below, specific to the cosmic ray commissioning data, contribute to resolution smearing. The result in Figure 8 indicates that the chamber is calibrated to near the design resolution.

An important test of the URT is its application to all of the spectrometer MDT chambers. The performance of a large ensemble of spectrometer chambers is extracted from fits similar to Figure 8. A single overnight cosmic ray run from the Fall of 2008 was analyzed. Muon events are triggered by the resistive plate chambers (RPCs)[1] in the barrel region. The acceptance of the RPCs in these cosmic ray runs also covers many endcap MDT chambers. Chambers having more than 2000 segment hits were fit with double gaussians, and the width and means of the narrow Gaussian wrere extracted. These results are shown in the histograms: Figure 10 and in Figure 11. The 4 micron means of the residuals are very close to zero and within an 20 μm error tolerance. The peak of the distribution of residual widths is at 107 μm and about 90% of chambers have widths under 140 μm. We note that additional sources of uncertainty associated with cosmic ray runs reported below limit the minimum resolution obtainable.

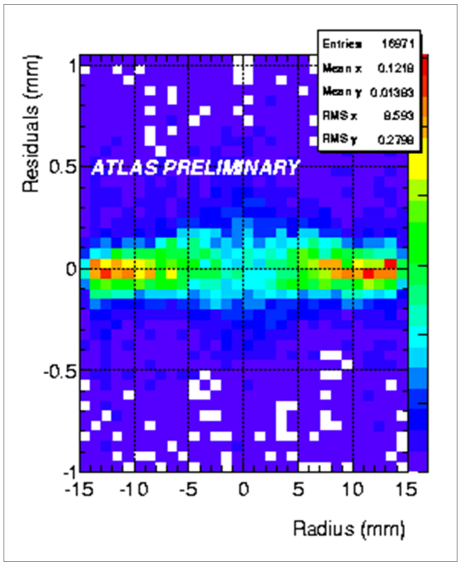

Fig. 9. Hit residual distribution as a function of drift radius for a single endcap chamber.

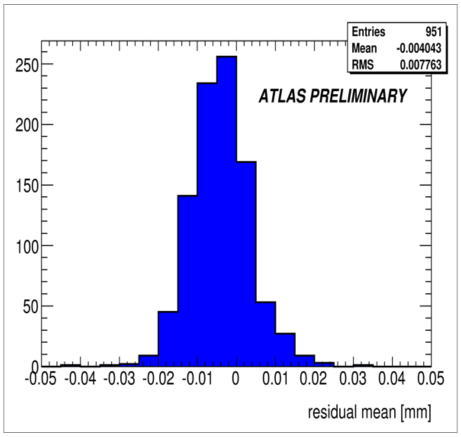

Fig. 10. Distribution of narrow Gaussian mean values of individual chamber hit residual distributions.

A. *Contributing factors to resdial width broadening*

Three factors unrelated to the accuracy of the RT function combine to broaden the residual distributions reported here. The first is a 25 ns trigger timing jitter characteristic of all cosmic ray commissioing data. This jitter directly degrades the T0 drift time pedestal offset. It is partially removed by a T0 tuning algorithm, but the resultant timing jitter is estimated to be 2 ns. Secondly, cosmic tracks are not contrained to pass through the beam interaction point and in many chambers can have different hardware trigger pathways. This distorts the rising edge of many chamber drift spectra and renders the associated T0, which is determined from a rising edge fit, very uncertain. Lack of a well-fit T0 in these cases signifiacntly degrades the resolution. Thirdly, in all instances presented here, for lack of a sufficient number of tracks, a single uniform T0 is obtained for an entire chamber and not separately for each tube. In summary, uncertainties in the tube-specific T0s are estimated to exist at the 3 ns level or larger. On average this results in $\sim$ 60 micron resolution smearing. Added in quadrature with the 80 micron intrinsic resolution yields approximately 100 μm.

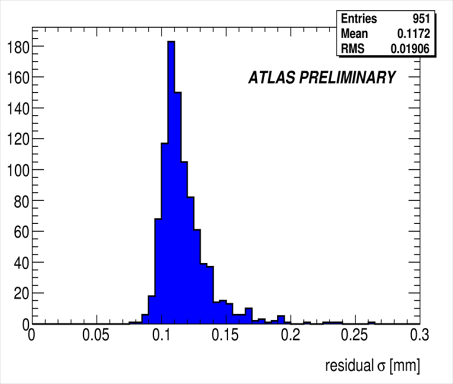

Fig. 11. Distribution of narrow Gaussian widths of individual chamber hit residual distributions.

VII. CONCLUSION

This report describes a streamlined daily production of RT functions which will provide an initial calibration source for the ATLAS muon spectrometer precision chambers. These functions are generated daily with temperature corrections specific to each chamber. Cosmic ray commissioning data suggest that nearly all chambers using these RT functions exhibit residial distributions centered within 4 μm of zero, with residual widths of 100 μm, consistent with or approaching design expectations.

REFERENCES

[1] The ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*,JINST 3 S08003 (2008)

[2] F. Petrucci, *Calibration Software for the ATLAS Monitored Drift Tube Chambers*,NSS/MIC 2005 , San Juan, El Conquistador Resort, Pue rto Rico , 23 - 29 Oct 2005 - pages 153-157 Geneva: CERN, 2004

[3] N. Amram et al *Long Term Monitoring of the MDT Gas Performance*, IEEE-NSS Dresden, Germany N53-3 October 2008

[4] D.S. Levin for the ATLAS Muon Collaboration *Calibration of the ATLAS Muon Precision Chambers with a Universal Time-to-Space Function* IEEE-NSS Dresden, Germany N30-192 October 2008

[5] E. Hazen *et al*., *Production Testing of the ATLAS MDT Front-End Electronics* 9th Workshop on Electronics for LHC Experiments, Amsterdam, The Netherlands, 29 Sep - 3 Oct 2003, pp.297-301

[6] Y. Arai*et al*., *ATLAS Muon Drift Tube Electronics* JINST 3 P09001 (2008)

[7] R. Veenhof *GARFIELD* CERN Program Library, W5050; Geneva: CERN

[8] M. Cirilli *Drift Properties of Monitored Drift Tubes Chambers of the ATLAS Muon Spectrometer* IEEE Transactions on Nuclear Science, Vol 51, No. 5, October 2004

[9] F. Cerutti et al *Study of the MDT Drift Properties Under Different Gas Conditions* ATL-MUON-PUB-2006-004; Geneva : CERN, 03 Feb 2003

[10] D. S. Levin et al *Drift Time Spectrum and Gas Monitoring in the ATLAS Muon Spectrometer Precision Chambers*, Nuclear Inst. and Methods in Physics Research **A** Vol 588/3 pp 347-358