The offline Data Quality Monitoring system of the ATLAS Muon Spectrometer

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Abstract. The ATLAS detector has been designed to exploit the full discovery potential of the LHC proton-proton collider at CERN. Its Muon Spectrometer (MS) has been optimized to measure final state muons from those interactions with good momentum resolution in a wide momentum range. In order to ensure that the hardware, DAQ and reconstruction software of the ATLAS MS is functioning properly, Data Quality Monitoring (DQM) tools have been developed both for the online and the offline environment. The offline DQM is performed on histograms of interesting quantities, which are filled during data processing with the ATLAS software framework at the CERN Tier0 facility. Then those histograms can be displayed and browsed by shifters and experts. They are also given as input to the Data Quality Monitoring Framework (DQMF) application, which performs the actual data quality assessment and sets status flags. The offline muon DQM structure and content, as well as the corresponding tools developed, are presented, with examples from the cosmic ray data collected for the MS Barrel during the commissioning phase.

1. Introduction

The ATLAS Muon Spectrometer (figure 1) has been designed to provide standalone measurement of the muon momentum up to a few TeV with a precision of less than 10%, and to trigger on single muons with transverse momentum down to a few GeV. A more detailed description of the ATLAS MS and its expected performance can be found in [1], [2] and [3].

The muon momentum is determined by its curvature in a toroidal magnetic field of typical value between 2 and 8 Tm, which runs in the \( \phi \) direction. The muon curvature in \( \eta \) is measured by three precision chambers positioned along its trajectory (Inner, Middle and Outer stations). Each station is expected to provide a measurement of the muon trajectory in the precision plane with an accuracy of the order of 50\(\mu m\). For most of the acceptance, the precision chambers consist of Monitored Drift Tubes (MDT). In the end-cap inner region, for \( |\eta| > 2.5 \), Cathode Strip Chambers (CSC) are used, since they are able to cope with higher background rates.

The trigger chambers are based on two different technologies: the Resistive Plate Chambers (RPC) are covering the barrel region while the Thin Gap Chambers (TGC) are used in the higher background environment of the end-cap region. Two RPC chambers are attached to each of the middle barrel MDT chambers providing the low-\( p_T \) trigger information. The high-\( p_T \) trigger is provided by RPC modules installed on the outer barrel chambers combined with the middle chambers signals. The RPC are also used to provide the coordinate along the MDT tubes that cannot be measured by the MDT chambers.
Similarly in the end-cap, two TGC doublets and one triplet are installed close to the middle station and provide the low- and high-pT trigger signals. The TGC are also measuring the coordinate of the muons in the direction parallel to the MDT wires. For this purpose, some TGC chambers are also installed close to the inner MDT to improve the measurement accuracy of this coordinate.

In order to ensure that the hardware, DAQ and reconstruction of the MS is functioning properly, Data Quality Monitoring tools have been developed both for the online and the offline environment. The offline DQM is performed within hours of the run, at the same time with a first data processing. The tools used for this offline quality assessment are presented. For more information on the whole ATLAS detector offline DQM, see [4].

The ATLAS MS is currently fully installed and operational in the experimental pit of the LHC tunnel crossing Point 1, 100m underground (figure 2). In the 2008 fall period, the detector has been operated for several months, collecting data from cosmic muons that reached it through the two elevator shafts. Data from this period have been extensively used to develop and test the DQM tools, as well as debug the detector and the reconstruction. The examples shown here are from a stable run of this period with the magnetic field off.

2. The flow of the offline Data Quality Monitoring

The offline DQM is run at the same time with the full reconstruction on the “express stream”, which contains about 10% of the data. This fast processing is done at CERN Tier0 machines within hours of the run, and signals the quality of the run for full processing.

The monitoring follows the flow of the reconstruction chain (see figure 3):

- Raw data monitoring is performed when the raw byte stream data are converted to hit information (Low level).
- Segment monitoring is performed when track segments are reconstructed from trigger and precision hits, using pattern finding algorithms. Track monitoring is performed when muon tracks are reconstructed in the whole MS (Mid level).
Physics monitoring is performed when physics objects are formed using combined information from different subdetectors (High level).

The outcome of this process is a ROOT file with histograms, which in turn are fed into the Data Quality Monitoring Framework [5]. The DQMF is an application designed to check histograms in an automated way and report results and summaries, both in the online and the offline environment. Its functions are

![Figure 3. Schematic diagram of the flow of the offline muon DQM, with respect to the data processing.](image)

![Figure 4. Example of the DQMF web display interface. The user can choose the subsystem/monitoring group of interest, then navigate down the tree to the monitoring histograms they want to check. The quality status of each monitoring group and histogram is shown by color in the tree and the histogram view. By clicking on individual histograms, more information is displayed, such as mean/RMS, the algorithm used to produce the quality flag and the reference histogram used for the comparison if this was the check performed.](image)
• Navigation through the histogram tree and plotting in a user-friendly way.
• Automatic web display. An example of the web display interface is shown in figure 4.
• Performance of various checks on the histograms, using simple (eg. mean and RMS) or more sophisticated algorithms (eg. comparison with reference histograms). Those checks use thresholds to set alarm levels (GREEN, YELLOW or RED) on the quality of the data, and propagate these quality flags to more global levels (eg. chamber→sector→Barrel side A/C→whole MS→detector).
• Storage of data quality flags and other quantities of interest in a database for later use.

3. Raw data monitoring
At this “low level” monitoring, hit related quantities are monitored, in order to check the condition of chambers, verify it against the online monitoring results, and test the readout and decoding chain from online to offline. Such quantities are

• Hit multiplicities and noise levels, noisy and dead channels (see figure 5).
• Spacial and time correlations of the trigger and precision chambers (see figure 6).
• Charge (ADC) and time (TDC) spectra, and especially \(t_0\) and \(t_{\text{max}}\) stability (see figure 7).

The \(t_0\) and \(t_{\text{max}}\) are defined from fits of the leading and trailing edge of the spectrum, and depend on the trigger timing and gas conditions respectively.

![Figure 5. x-y map of the MDT hit occupancy for the endcaps, reflecting the geometry of the detector.](image)

![Figure 6. Spacial hit correlation for a given Barrel sector: MDT wire vs RPC strip z position.](image)

![Figure 7. Typical MDT time spectrum.](image)

4. Segment and track monitoring
At this “mid level” monitoring, there is access to reconstructed quantities, which are checked in order to test the reconstruction chain for the two algorithms used. The segments are confined to one station, therefore they are used to monitor the reconstruction efficiency per chamber and verify the calibration. The tracks, spanning the whole MS, are also used for verification of the alignment and magnetic field mapping. Such quantities monitored are

• Segment and track multiplicity, hit on segment/track multiplicity (see figures 8, 9 for the segments and 12 for the tracks).
• Fit quality and parameters (see figure 13 for an example of track reconstruction quality).
• Hit residuals, pulls, local spacial distributions (see figure 10, 11 for the segments and 14 for the tracks).
• Chamber and tube efficiencies.
• Track \(p_T\) and charge ratio.
5. Physics monitoring

At this “high level” monitoring, physics quantities are checked in order to test the overall MS and detector performance, software chain and longterm stability, as well as the robustness of the calibration, alignment and magnetic field mapping. Such quantities are
- Reconstructed particle mass peaks, for the momentum scale and resolution (see figure 15).
- $p_T$ and charge asymmetry distributions.
- Well-known particle production cross-sections.
- Muon trigger and reconstruction efficiencies.

The efficiencies are measured with the "Tag-and-probe" method [6]: A “tag” muon is selected with strict quality requirements. Then a loose “probe” muon is chosen (usually just an Inner Detector track), according to the requirement that it gives the Z boson mass together with the tag muon. Finally the probe muon is matched with a MS track or an object that passes the trigger whose efficiency is being measured. A schematic of the method is shown in figure 16.

![Figure 15. Invariant di-muon mass in simulated data, where the Z boson mass peak is obvious.](image1)

![Figure 16. Schematic of the “tag-and-probe” method. The decay of Z bosons into two muons is exploited by knowing the region of the detector that the second muon is expected to be, after tagging the first one.](image2)

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