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Calibration and Performance of the precision chambers of the ATLAS muon spectrometer.

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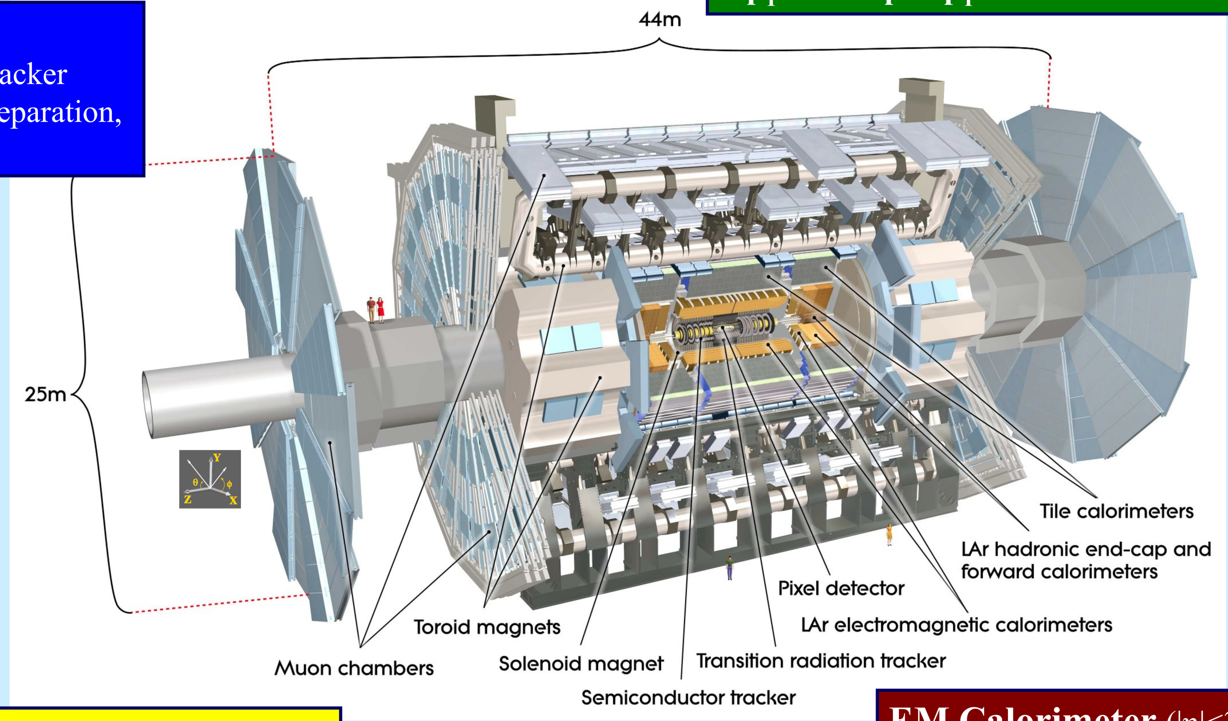
The ATLAS Detector

Muon Spectrometer ($|\eta|<2.7$)
air core toroid magnets with gas chambers,
provides μ trigger and standalone momentum measurement,
$\sigma/p_T<10\%$ up to $p_T\sim1$TeV

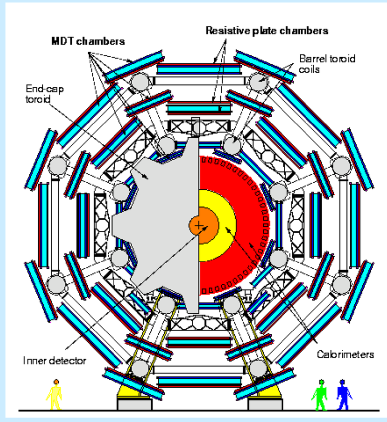
Inner Detector ($|\eta|<2.5$, B=2T)
Si pixels, Si strips, Transition Radiation tracker
provides precise tracking, vertexing, e/π separation,
$\sigma/p_T<3.8\cdot10^{-4}p_T(\mathrm{GeV})\oplus0.015$

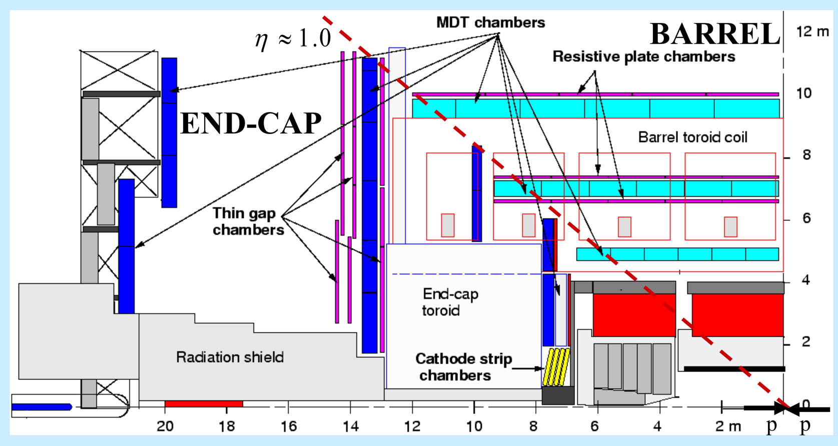


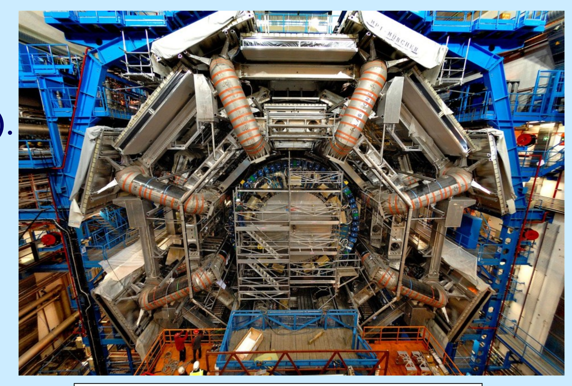
Hadronic Calorimeter
Scint/Fe tiles ($|\eta|<3.2$) and W(Cu)/LAr (fwd region $|\eta|<4.9$)
provides trigger, jet measurement, E_T^{miss}
$\sigma/E\sim50\%/\sqrt{E(\mathrm{GeV})}\oplus0.03$

EM Calorimeter ($|\eta|<3.2$)
Pb-LAr accordion structure, longitudinal segmentation
provides e/γ trigger, identification, measurement
$\sigma/E\sim10\%/\sqrt{E(\mathrm{GeV})}\oplus0.007$

The Muon Spectrometer







Toroidal magnetic field
bending power 2-6Tm (Barrel) 4-8Tm (End-Caps).
Standalone p_T measurement
provided by 3 radial muon stations:

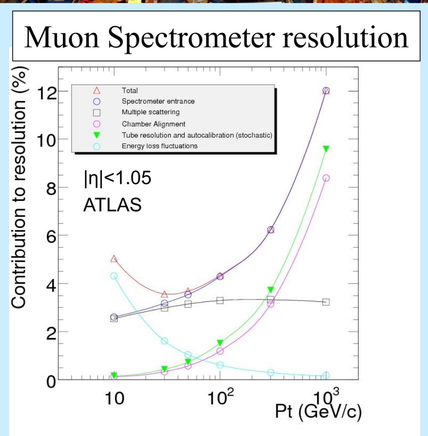
Muon Trigger Chambers

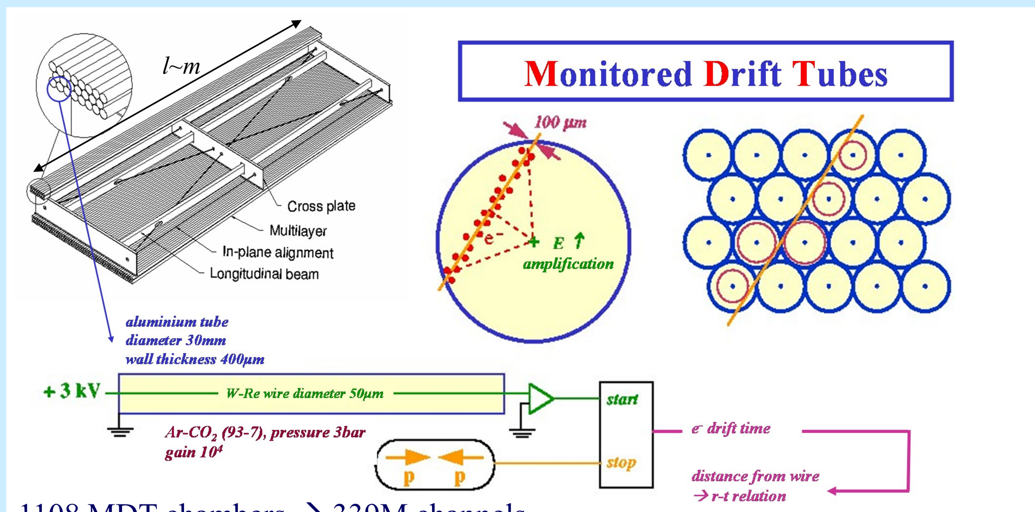
- **Resistive Plate Chambers** (Barrel) time resolution of 1.5ns.
- **Thin Gap Chambers** (End-Cap) time resolution of 1.5ns.

Muon Precision Chambers

- **Monitored Drift Tube Chambers** ($|\eta|<2.7$) chamber spatial resolution of 35μm.
- **Cathode Strip Chambers** (only the inner layer in $2.0<|\eta|<2.7$) chamber spatial resolution of 50μm.

Muon Spectrometer resolution





1108 MDT chambers → 339M channels

The MDT Calibration

To ensure a **80μm resolution on single hit**, continuous MDT calibration is necessary to keep all effects (i.e. gas mixture, temperature, magnetic field) under control. It consists of:

- computation of single tube drift time offset t_0,
- determination of the **r-t relation** of each chamber,

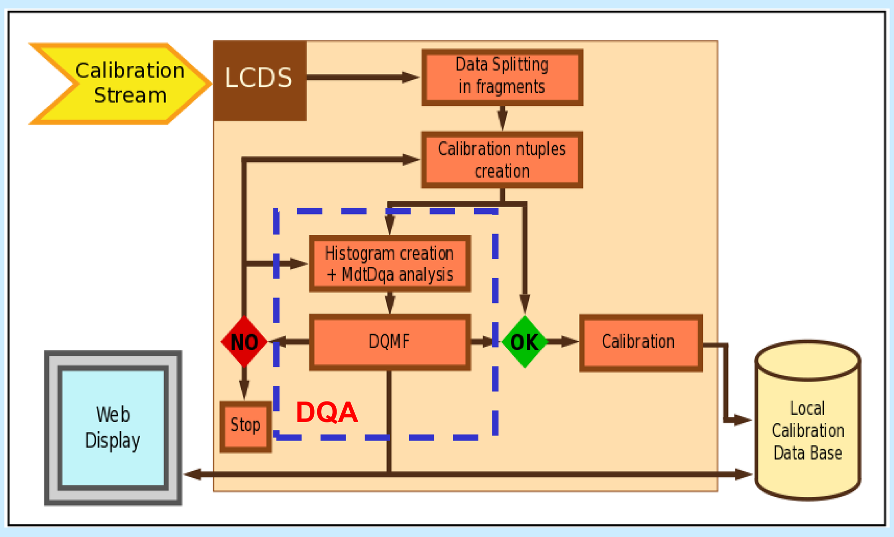
and requires $\sim2\cdot10^8$ muon tracks over the entire spectrometer in less than week!

This statistics is not achievable using the standard ATLAS Data Flow (muon rate on tape ~50Hz)

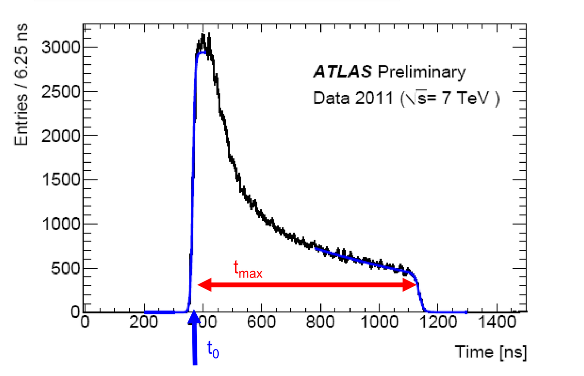
→ Need a dedicated Stream of muon data:

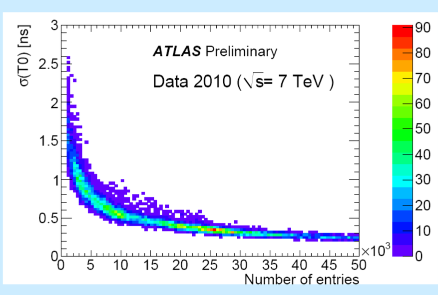
THE MUON CALIBRATION STREAM

- Muons are extracted from the second level trigger, requiring a track in the MDTs pointing to the vertex (10kHz muon rate in 2010 obtained with an instantaneous luminosity of $\sim10^{32}cm^{-2}s^{-1}$)
- Data are streamlined and processed in 3 Calibration Centres
  - Ann Arbor, Munich, Rome;
  - ~400 CPUs each.
- ~1 day latency for the full chain:
  - data extraction and splitting to ~200 calibration ntuples (LCDS tool),
  - assessment of the data quality (DQA),
  - calibration computation.
- Update of the MDT calibration constants in the Condition database at CERN, when significant variations are observed.



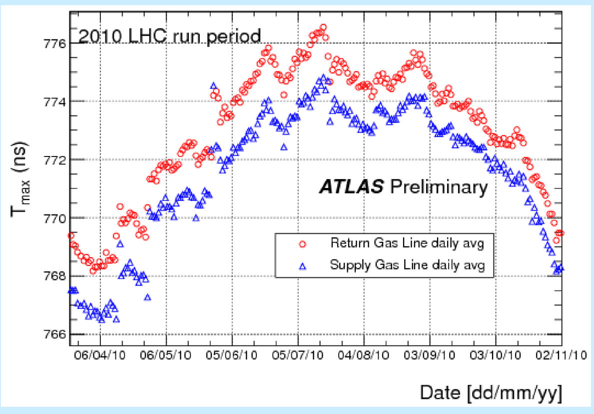
MDT Drift Time Spectrum



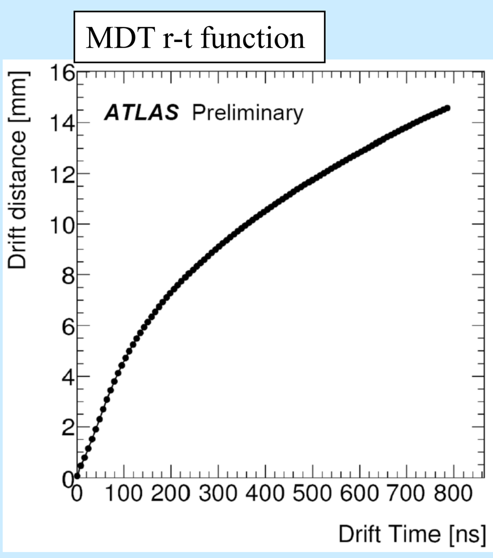


Statistical uncertainty on the determination of the drift time offset (t_0) as a function of the number of entries in the spectrum; well **below 1ns** for a number of entries larger than few thousand.

Trend of the daily averaged maximum drift time (t_{max}) for first year LHC running 2010. Each data point is the average of 24 hourly measurements, done by a dedicated MDT chamber (not belonging to the detector) sampling the main MDT gas supply/return trunk lines of the Muon Spectrometer.



MDT r-t function



Data Quality Assessment with 2010 data

The data quality assessment at the Calibration Centers takes advantage of the large statistics of muon tracks from the Calibration Stream to monitor the MDT performances looking at each detector level, from macro-regions (Barrel/End-Cap regions, sectors) down to chambers and individual drift tubes. Also the muon track reconstruction is monitored, providing high level quality assessment on current reconstruction with latest calibration constants.

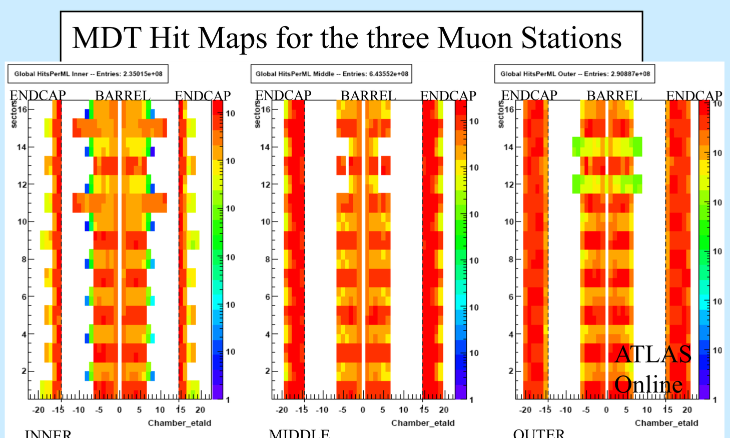
A dedicated tool (the ATLAS Data Quality Monitoring Framework) checks the MDT histograms in an automated way, assigns quality flags and reports results and alarms. The histograms are stored with a tree architecture, reproducing the Muon Spectrometer structure.

MDT Histogram Tree

Flags of histograms are combined and propagated along the folder tree, up to the top level, in order to alert the shifter in case of anomaly. A weight is assigned to each element, according to its relevance for the data quality report.

The global flag (ALLMDTs) is computed from the hit maps, according to the ATLAS rule:
Green → Detector ON > 90%
Red → Detector ON < 90%

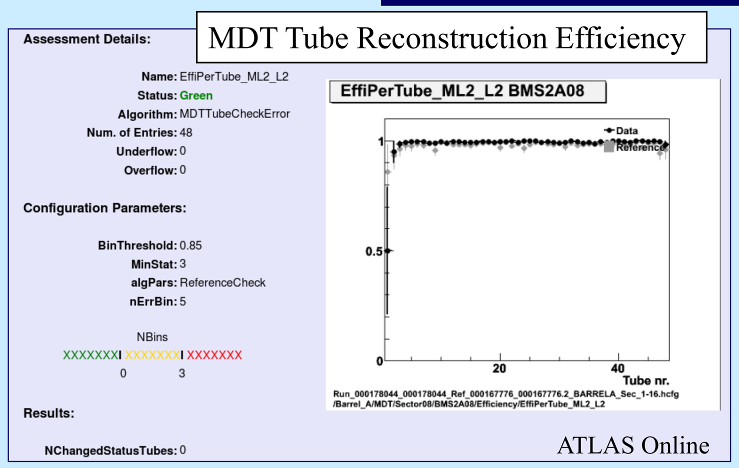
MDT Hit Maps for the three Muon Stations



MDT chamber hit map distribution in the calibration stream during a LHC run 2010.

Examples of data quality checks at the Calibration Centers

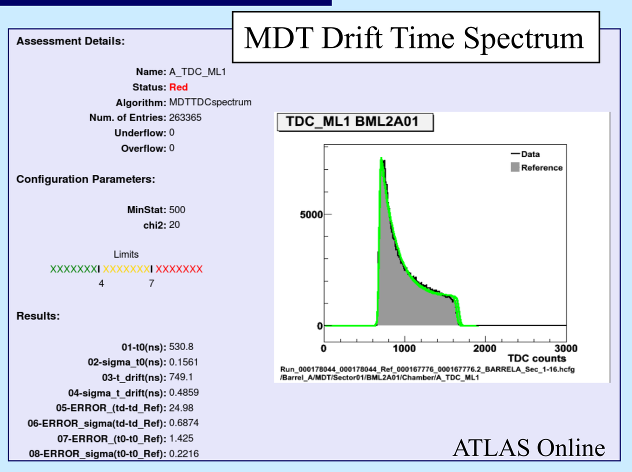
MDT Tube Reconstruction Efficiency



Check of reconstruction efficiency in a drift tube layer: the efficiencies are stable and reproducible.

Comparison	
Data:	March 2011
Reference:	October 2010

MDT Drift Time Spectrum

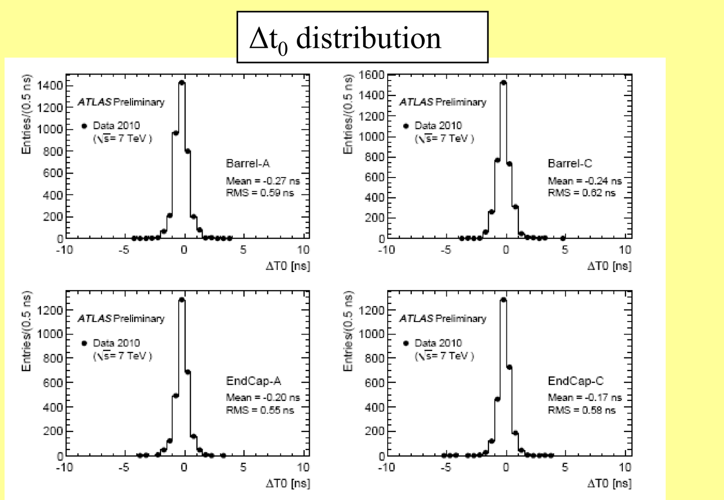


Alarm correctly reported due to a drift time spectrum modification with a t_{max} difference of 25ns, compatible with a known sizeable change in the gas mixture.

The MDT calibration with 2010 data

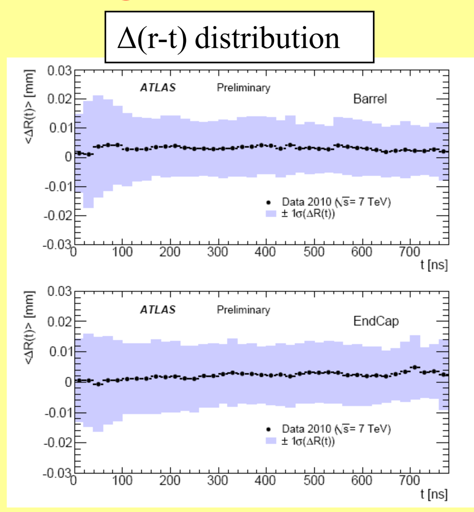
Short-term reproducibility and stability of t_0 and r-t, comparing results obtained in different high statistics runs taken few days apart (October 2010), measured using muon calibration stream data.

Δt_0 distribution



The t_0s were obtained with a fit to the drift time spectrum of all the tubes in the same front-end electronics card (group of 24 drift tubes). The means show a very small overall shift of **-0.2ns** and the RMSs are all compatible with the statistics uncertainty of each measurement. The distributions show very good short-term reproducibility and stability of the t_0s for all the MDT chambers of the Muon Spectrometer.

Δ(r-t) distribution

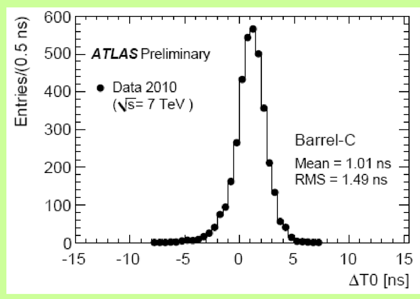


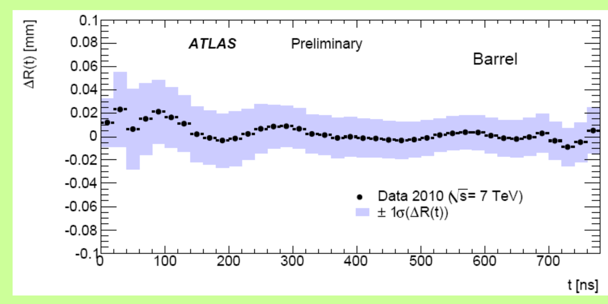
The r-ts are evaluated per chamber for each run. In each time bin, the distribution of the differences between the two r-ts is fit with a gauss function, the resulted means are reported (black dots). The colored bands represent the ±1σ (width of the gaussians in that bin) regions. The bands show the spread of the r-ts differences around the mean value. The stability of the r-t determination is **within ±10μm** all over the detector, ensuring a good short-term reproducibility.

Estimate of the systematics in the t_0 and r-t determination, comparing results obtained using different muon samples: calibration stream muons and muons selected and reconstructed offline with p_T >4GeV (both Inner Detector and Muon Spectrometer), for the same collision data.

Δt_0 distribution

The distribution shows an estimate of the systematics due to muon selection in the t_0 determination for the Barrel-C. Similar results are obtained for the other regions: the RMS differences are **between 1.4 and 1.7ns** and an overall difference of about **1ns** is observed.





Δ(r-t) distribution

The plot shows the systematics due to muon selection for the Barrel. The black dots are the means resulted fitting with a gauss function the r-t difference in that bin. The differences are well **below 30μm** for most of the tube radii all over the detector.
The colored bands are the ±1σ regions and represent the spread of the r-ts differences around the mean value.

Di-muon Spectrum

As overall figure of the good performance of the muon detectors, this plot shows the invariant mass of couple of opposite sign muons, reconstructed combining Inner Detector and Muon Spectrometer measurements.
Only events with at least one muon of p_T>15GeV are selected.

→All expected resonances are observed!