Muon detector spatial alignment for the Upgrade

Stefania Vecchi - INFN Ferrara

Tracking&Alignment meeting, November, 16^{th} 2017

Why muon alignment is important in the current LHCb: a reminder

Spatial alignment of the Muon stations is needed to ensure:

- high L0 muon trigger efficiency (trigger towers need to be aligned)
- charge symmetry of the muon trigger (L0 trigger p_{T} computation relies on M1-M2 actual positions)
- less/negligible impact on the muon-ID and HLT performances due to the robustness of the algorithms (see 9)

Performance of the LHCb muon system, J. Instrum. 8 (2013) P02022

> The spatial alignment of the muon detector must guarantee the design performance of trigger and offline muon identification. As explained in section 2, the L0MU trigger requires hits in all the 5 stations aligned on a muon track-segment having a p_T above a given threshold. Offline muon identification is more flexible in the reconstruction of the muon track-segment but requires the matching with a track reconstructed in the tracking system through the whole spectrometer.
>
> The alignment accuracy needed in the system is driven by the trigger requirements in the stations M1, M2 and M3. For these three stations the FOI of the hit search window in the non-bending vertical coordinate, is defined by 1 pad only. As a consequence, a relative y misalignment between the stations would directly contribute to trigger inefficiency ($\sim$2% for 1mm misalignment). In the bending coordinate x, the FOIs are composed of several pads and the main effect of a misalignment is a bias in the p_T calculation, at the percent level for 1mm misalignment. However the bias can be removed if the trigger algorithms are suitably corrected using the true x positions. The alignment of stations M4 and M5 is less important because in their case the y FOI is as large as 3 pads and their hits are not used to calculate p_T. The detector mechanics was designed with the aim of reaching a precision of the order of 1 mm in x and y directions. The alignment requirements along z are much less demanding due to the forward geometry of the experiment.

Why muon alignment is important in the current LHCb: a reminder

L0Muon trigger towers are defined "hardware"

- towers point to the interaction point (IP) both in x and y
  - projectivity wrt IP has been maintained despite the impossibility of perfectly closure of M half stations
- size of FOI in y is 1 pad dimension (M1R1: 2.5cm)
- size of FOI in x is tuneable ± 6 pad (± 4 in Run2) dimension (M1R1: 1.0cm)

$\rightarrow$ a misalignment would cause a loss of trigger efficiency

The L0Muon trigger selects the two muons with the highest p_{T} for each quadrant of the muon detector, then a minimum p_{T} is required.

p_{T} computation:

- is determined from the (x, z) direction of hits in M1 and M2, assuming the muon coming from IP
- using look-up tables (LUT)

$\rightarrow$ a misalignment not included in the LUT would cause a bias in the p_{T} computation (charge dependent)

Nucl.Instrum.Meth.A579:989-1004,2007

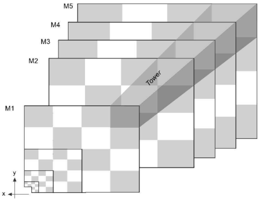

Fig. 5. A quadrant of the muon detector with its 48 towers pointing toward the interaction point.

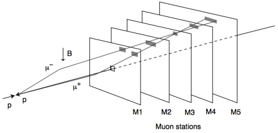

Fig. 4. Track finding by the Level-0 muon trigger. In the example shown, μ^+ and μ^- cross the same pad in M3. Grey areas illustrate the field of interests used by the algorithm for station M1, M2, M4 and M5.

Current muon alignment strategy

Muon alignment runs online, automatically, at the beginning of each fill since start of Run2:

- needs 500k "selected muon tracks"
- needs the tracking to be aligned (relative alignment)
- usually converges in 3 max iterations (takes $\sim$15 min to run in the online farm)
- Sends a warning message to the expert in case a displacement ($> 1mm$) is detected so that actions can be taken (check / update LHCBCOND)

First data taken at the beginning of a run period are the most important:

- provide the reference Muon alignment $\rightarrow$ stored in the LHCBCOND ($\rightarrow$ online=offline)
- often trigger a "mechanical" adjustment of one muon half station, to guarantee efficient L0 performance (trigger towers)
- provide inputs to produce LUT for L0-muon trigger ($\rightarrow$ correct p_{T} computation, minimize asymmetries)

Then run the muon alignment regularly to monitor the stability of the alignment at each run

LHCb Upgrade: changes concerning the Muon dedector

The main changes that concern the Muon detector and its alignment are:

- M1 station will be removed
- More shielding will be added (inner calo)
- Read-out will be changed (40MHz)
- LHCb readout @ 40 MHz → L0 hardware trigger will be removed → Event reconstruction& (software) trigger @ 40 MHz
  - triggering on muons will rely on muonID-like algorithms implemented on the farm → robustness against misalignments
- the need of muon alignment weakens considerably

Nevertheless the software alignment remains the most reliable tool we have to measure the actual positions of the muon detector, so we surely need it also in the Upgrade. We foresee to implement the same functionalities we have in the current configuration.

Current software for Muon alignment ...

- Strategy: align muon half stations (T_x, T_y) wrt the tracking stations (assumed aligned).
- Use muon tracks reconstructed as *BestMuonTracks* $\equiv$ *Long tracks*+*Muon segment* with additional requirements:
  - events pass the selection of *Hlt1DiMuonHighMassDecision*
  - Muon track segment reconstructed (at least 4 stations hit)
  - good Matching to the Long track (ghostProb$<$0.7, $p > 6$ GeV)
  - selected not too busy events (Velo hits $<$ 4000, OT hits $<$ 8000)
  - in Calo acceptance

Relevant code:

- AlignmentOnline/AlignOnline/python/AlignmentConfigurations/MuonAlignment.py
- Alignment/TAlignment/python/TAlignment/TrackSelections.py (BestMuonTracks)

Current software for Muon alignment ... and needs for updates

tool	project	explanation
BestMuonTracks	Alignment/TAlignment	best muon track selection
MakeMuonTracks	Alignment/AlignTrTools	
MuonNNetRec	Rec/Muon/MuonTrackRec	muon segment (stand-alone)
MuonHitDecode	Rec/Muon/MuonTrackRec	decoding
MuonClusterRec	Rec/Muon/MuonTrackRec	clustering
MuonPadRec	Rec/Muon/MuonTrackRec	decoding
ConfiguredForwardStraightLineEventFitter	Rec/Tr/TrackFitter	fit of the Muon track segment
MeasProvider	Rec/Tr/TrackTools	special measurement for clusters (MuonProvider.clusterize=True)
TrackFilterAlg	Alignment/TAlignment	further selection
TrackMuonMatching	Alignment/AlignTrTools	matching with the Long track
ConfiguredEventFitter	Rec/Tr/TrackFitter	Fit Best/TMuon tracks for alignment
MeasProvider	Rec/Tr/TrackTools	special measurement for clusters (MuonProvider.clusterize=True)

Don't foresee major changes in the muon-track selection, except for the obvious ones: geometry (no M1), decoding (change of readout electronics), and due to the new framework.

Conclusions

The changes to the triggering of the events expected for the Upgrade make the muon alignment not so crucial (as it is now, for the L0-muon trigger), nevertheless, since it is the most reliable tool we have to measure the actual positions of the muon detector, we think it is a good idea to port the current code in the upgrade framework.

- Minor changes expected, mainly due to the new decoding needed (new readout electronics).

When: after the new decoding is in place.
Extra: might be useful to perform some studies to measure the robustness of muon-ID to misalignments

Muon ID and Muon @ HLT

Muon triggers in the High Level Trigger of LHCb, LHCb-PUB-2011-017

5.1 Muon reconstruction in HLT1

A fast muon identification is performed to validate the Velo tracks as muon candidates. A combination of the low occupancy of the muon stations, the fact that the LHCb magnet does not bend tracks in the vertical plane and the requirement that a particle must have

at least 6 GeV of momentum to pass all muon stations provide the starting point for early selection of muon candidates from available Velo tracks. An algorithm has been designed to search for muon hits which match a Velo track. As a first step, a search window is defined in the M3 station, the centre of which is determined by extrapolating the Velo track to M3. Due to the large amounts of material present before and between the muon stations, multiple scattering might cause a muon track to deviate from the track obtained by extrapolating the VELO track in a straight line. The vertical size of the search window is chosen to be 20 cm, which is optimized empirically. For the horizontal size the maximum possible deflection of a 6 GeV track is calculated for a positive and negative particle. Any hits found inside the search window are combined with the Velo track to form candidate tracks for a search for additional muon hits in stations M2, M4 and M5. A candidate track is created by extrapolating the Velo track to the focal plane of the magnet and from that point on continuing to the position of the seed hit. By extrapolating the candidate track and using a fixed search window size, additional hits are searched for in M2, M4 and M5. To optimise the efficiency of the search, a candidate track is provisionally accepted if it contains at least one hit in addition to the seed hit. As the final step of the algorithm, a linear χ^2 fit in the horizontal plane is performed and this χ^2 is required to be less than 25. As soon as a single candidate is found, the algorithm stops and the Velo track is accepted.