Muon detector spatial alignment with 2016 collision data

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Why muon alignment is important: 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 expected on the muon-ID and HLT performances (see 13)

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: 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

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

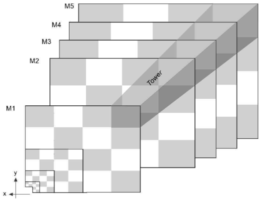


Fig. 5. A quadrant of the muon detector with its 48 towers pointing toward the interaction point.

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)

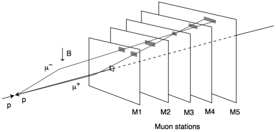


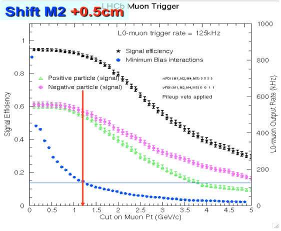
Fig. 4. Track finding by the Level-0 muon trigger. In the example shown, μ^+ and μ^- cross the same pad in M3. Grey areas illustrate the field of interests used by the algorithm for station M1, M2, M4 and M5.

Why muon alignment is important: former studies

Charge asymmetry introduced if misalignments (in M1 or M2) are not accounted in the LUT.

W.Baldini&S.Vecchi LHCb week June 2006

simulation of misaligned scenarios



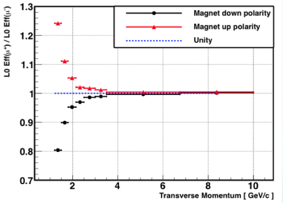
2011 data, LUT correspond to "ideal detector geometry", not true positions (didn't consider opening and staggered chambers in z).

- measured up to ∼5% charge asymmetry for L0Muon TOS
- affected ΔA_{CP} measurement from SL B decays

→ Early 2012: new LUT J.Cogan produced based on measured muon alignment

- restores symmetry to ∼% level

A.Webber LHCb week Feb 2012



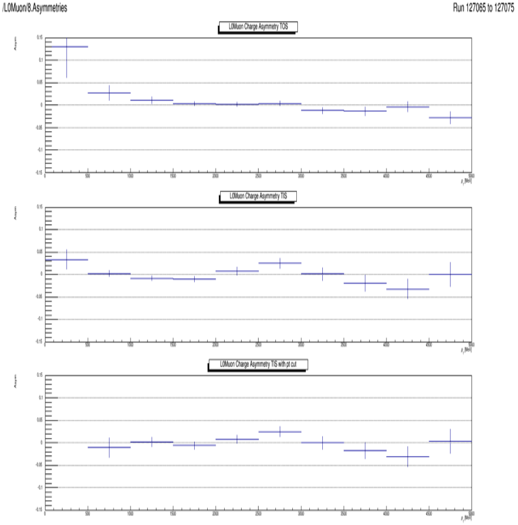
Why muon alignment is important: now is monitored online

Since 2012 new LUT are produced with measured Muon alignment positions at the beginning of the data taking (and updated if needed during the run).

L0Muon asymmetry was monitored online in 2012 (not in 2015, due to incompatibility with updates in HLT).

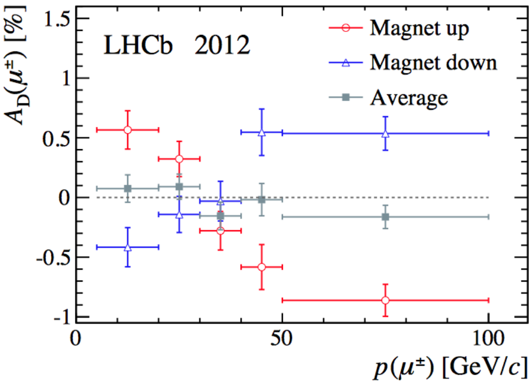
Should be part of the DQ plots when the next release will be put in production.

J. Cogan 2012 data – fill 3025



Much smaller asymmetries since 2012

Jacco de Vries, A&S week, Jan 2015[a]



- Asymmetry for (L0Muon + Hlt1TrackMuon + IsMuon + PIDmu>0)

[a] NB: residual asymmetries due to the Muon detector geometry can still be present (see Alessia Satta's presentation, A&S week, Jan 2015)

“Hardware” muon alignment

During the the winter shutdown the muon halves have been opened to access the detector. After their closure a survey measurement has been performed. Values in 1-2 mm compatible with 2012 survey.
The DDDB (containing the reference survey positions) has not been udpated wrt 2012.

	DDDB: deviations wrt ideal “closed” geometry						ideal projective offset “open”
Station	Tx [mm]	Ty [mm]	Tz [mm]	Tx [mm]	Ty [mm]	Tz [mm]	Tx [mm]
M1	–2.9–3.2	–1.3	4.1	5.0+1.3	–0.6	6.9	±6.11
M2	–8.2	–0.72	–9.4	7.0	0.96	–7.5	±7.70
M3	–9.4	–1.5	–5.2	8.1	0.55	–0.2	±8.31
M4	–11.4	–1.7	–12.4	14.5–4.0	1.31	–6.6	±8.91
M5	–11.5	0.21	–4.3	11.1	0.23	2.3	±9.52
	C-side			A-side			

Online muon alignment

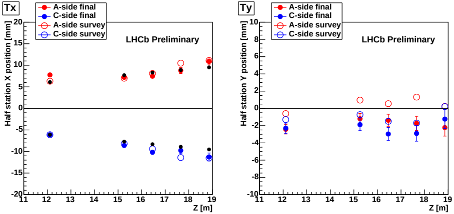
Muon alignment runs online, automatically, at the beginning of each fill since start of Run2:

- needs 500k "selected muon tracks"
  - events pass the selection of *Hlt1DiMuonHighMassDecision*
  - Muon track segment reconstructed (at least 4 stations hit) "as usual"
  - good Matching to the Long tracks (ghostProb$<$0.7, $p > 6$ GeV)
  - selected not too busy events (Velo hits < 4000, OT hits < 8000)
- 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 alignment on 2016 collision data needed to set the reference Muon alignment.

1. runs 173905-174056 (fills 4905 and 4911): 303k events, 288k muon tracks
2. runs 174362-174380 (after M1A adjustment): 500k events, 440k muon tracks

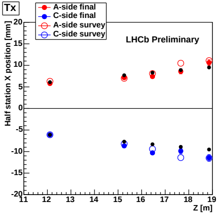
Results (1) runs 173905-174056

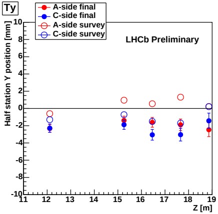


deviation	wrt DDDB				wrt projective (individual M2 positions as pivot)			
Station	Tx [mm]	Ty [mm]	Tx [mm]	Ty [mm]	Tx [mm]	Ty [mm]	Tx [mm]	Ty [mm]
M1	1.47± 0.24	-1.82±0.55	0.023±0.26	-0.99±0.59	2.05±0.30	-1.47±0.73	0.70±0.32	-0.80±0.79
M2	0.21±0.21	-2.15±0.61	0.40±0.24	-1.16±0.66	–	–	–	–
M3	-0.63±0.32	-1.92±0.70	0.79±0.36	-1.47±0.76	-0.30±0.39	-0.09±0.96	-0.91±0.44	-0.94±1.05
M4	-1.7±0.69	-3.04±0.82	-1.64±0.75	-1.20±0.90	0.45±0.73	-0.35±1.08	0.20±0.80	-0.72±1.18
M5	-0.17±0.84	-2.46±0.98	-0.23±0.93	-1.45±1.09	2.02±0.88	-0.75±1.24	-0.64±0.98	1.09±1.34
[a]	A-side		C-side		A-side		C-side	

- A and C sides are reasonable well "centred" around the beam-pipe
- M1A projectivity is off by 2mm (away from the beam) → moved on 13th May (https://lblogbook.cern.ch/Shift/92605)
- absolute Y positions looks ALL more negative than in past years (Muon collapsing? or Tracking alignment on Y still not optimal ?)
- 13th May:Julien Cogan produced a LUT for the L0 Muon trigger with actual position + manual displacement on M1A (https://lblogbook.cern.ch/Shift/92641)

Results (2) 174362-174380 (after M1A adjustment)



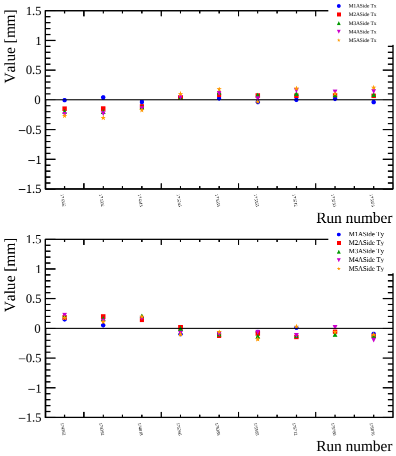


deviation	wrt DDDB				wrt projective (individual M2 positions as pivot)			
Station	Tx [mm]	Ty [mm]	Tx [mm]	Ty [mm]	Tx [mm]	Ty [mm]	Tx [mm]	Ty [mm]
M1	-0.50±0.20	-1.73±0.44	0.01±0.22	-0.99±0.49	0.12±0.24	-1.22±0.59	0.77±0.27	-0.79±0.65
M2	0.15±0.18	-2.35±0.50	0.48±0.29	-1.16±0.54	–	–	–	–
M3	-0.69±0.26	-2.16±0.57	0.90±0.29	-1.55±0.62	-0.30±0.32	-0.11±0.78	-0.94±0.36	-1.02±0.85
M4	-1.90±0.56	-3.21±0.67	-1.53±0.62	-1.34±0.74	0.32±0.60	-0.29±0.88	0.18±0.66	-0.86±0.97
M5	-0.48±0.69	-2.70±0.80	-0.03±0.76	-1.64±0.89	1.78±0.72	-0.75±1.01	-0.74±0.80	0.90±1.11
	A-side		C-side		A-side		C-side	

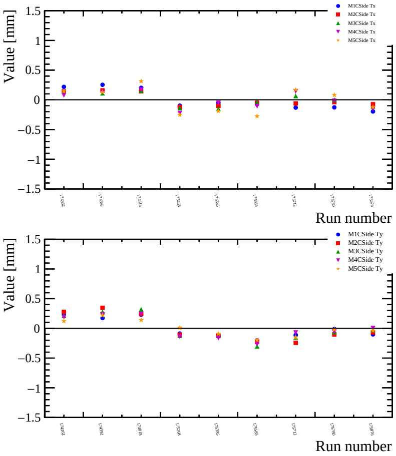
- M1A projectivity is now good
- M3C projectivity is not excellent, but more complicated to adjust and less critical (provided LUT have the right positions)
- 14th May: Julien Cogan produced an updated version of LUT for the L0 Muon trigger with measured positions (https://lblogbook.cern.ch/Shift/92772) – only minor changes
- released LHCBCOND to update the offline database (tag: cond-20160517)

stability of muon alignment

each run we run the muon alignment to check the stability of the alignment wrt cond-20160517 positions: results far below 1mm "warning" threshold



A-side



C-side

Conclusions

Performed the muon station alignment with 2016 collision data

- "mechanical" movement of M1A of $\sim$2 mm (13th May) suggested by results
- good symmetry of the two halves and projectivity
- M3C x-z projectivity is not excellent, but more complicated to adjust and less critical (provided LUT have the right positions)
- LHCBCOND and LUT for L0Muon trigger released (cond-20160517)
- monitor the stability of the alignment at each run

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.