

Effects of muon alignment on tracking efficiencies

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20th November 2025



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Strategy for tracking efficiency determination:

- Tag-and-probe method with $J/\psi \rightarrow \mu^+ \mu^-$
- Combine efficiencies of two methods:
 - VeloMuon: SciFi efficiency
 - Downstream: Velo efficiency
- Cross check with MuonUT method
 - Today I will show the effect of alignment on this method

Tag-and-probe method

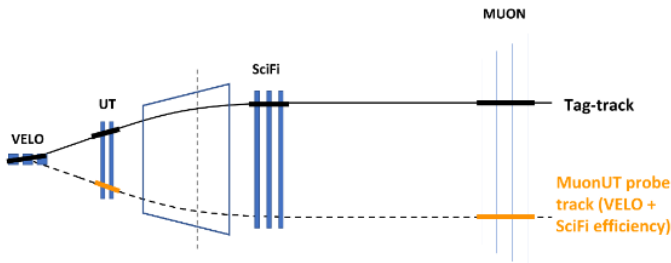


Figure from [Rowina's thesis](#)

- Fully reconstruct one muon from $J/\psi \rightarrow \mu^+ \mu^-$
- Partially reconstruct the other muon
- Match hits in specific sub-detector with partially reconstructed track

$$\epsilon_{\text{track}} = \frac{N_{\text{matched}}}{N_{\text{matched}} + N_{\text{failed}}}$$

The MuonUT method

- ① Get hits from Muon system
- ② Reconstruct standalone muon track
 - Four muon hits (M2, M3, M4, M5)
 - Fit straight line in YZ and XZ planes
 - Calculate p_x kick from knowledge of magnet centre z_{magnet} , assuming track originated from the origin
- ③ Extrapolate track to UT and add UT hits

What is the issue?

- Huge difference in the number of μ^+ and μ^- candidates for 2024
 - Only in data, not MC
- Behaviour swaps between magnet polarities
- What is the cause?
 - 1 Fewer tracks reconstructed on the C-side, compared to A-side
 - 2 Kinematic distributions, such as p_T and $J/\psi \chi_{\text{vtx}}^2$, are shifted \implies Effectively tighter cuts in trigger selection

How large is the issue? A factor two!

Sample	Magnet polarity	μ^+	μ^-	Ratio $+/-$
2024 block 1	Up	1126660	2046110	0.55
2024 block 5	Up	2739920	5832372	0.47
2024 block 6	Down	5036676	2322011	2.17
2024 block 7	Down	2430038	1155671	2.10
2024 block 8	Up	702585	1443764	0.49

What about 2025?

- No asymmetry in μ^+ and μ^- candidates in 2025 data
- Kinematic distributions look much more symmetric in 2025

Main changes in 2025 data taking (by Michel de Cian):

- Use muon clusters instead of muon hits
- Constrain $y = (0 \pm 20)$ mm at $z = 0$ in linear fit in the YZ plane

Additionally: Muon alignment updated in September 2025, which affects Sprucing25c3/4 (see details [here](#))

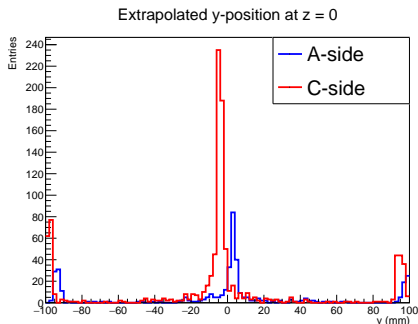
My hypothesis: Muon system misalignment in y

- Mis-aligned Muon system could bias the extrapolation to the UT
- UT hits might not be correctly added, or track quality might be worse
- Effect not seen in VeloMuon or Downstream methods because tracking detectors place stronger constraints on the particle trajectory
- y -constraint added by Michel counteracts misalignment in 2025 data
- How to prove this hypothesis?

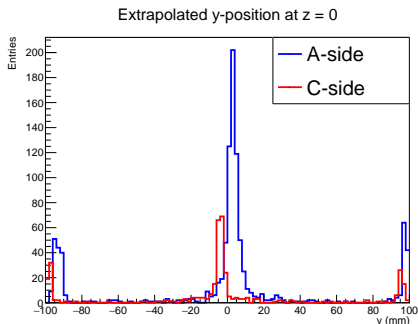
Strategy for analysing 2025 data:

- 1 Tuple VeloMuon events that also passed MuonUT trigger line
 - Unbiased sample of muons to study alignment with
- 2 For the same events, create new tuple with muon tracks
 - Rerun standalone muon track reconstruction without y -constraint
- 3 Match muon tracks to VeloMuon probe tracks using LHCbIDs
- 4 Study y -position of muon tracks, extrapolated back to the origin

Sprucing25c3 MagUp alignment



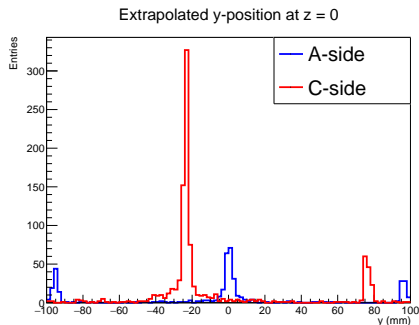
(a) Positive muons



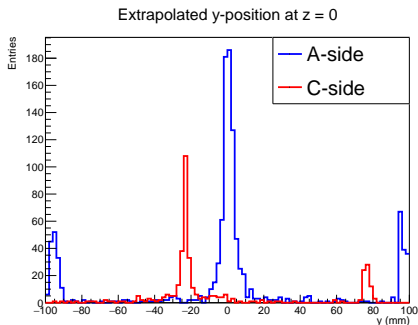
(b) Negative muons

- μ^+ (μ^-) mostly hit the C-side (A-side) due to magnetic field
- Minor residual mis-alignment, but this is probably very close to the position resolution of the Muon system anyway

Sprucing25c1 MagUp alignment



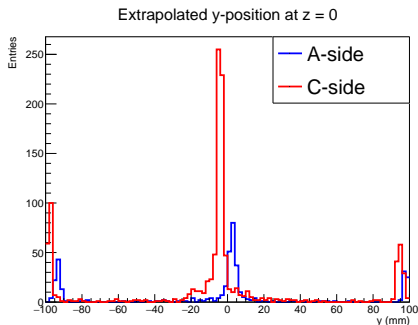
(a) Positive muons



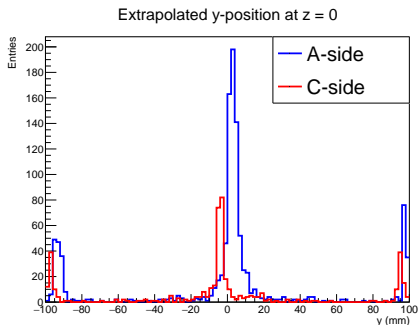
(b) Negative muons

- Huge (~ 25 mm) bias on the y -position of the muons going through the C-side of the muon system
- The only change in Sprucing25c3 was the muon alignment

Sprucing25c1 MagUp alignment



(a) Positive muons



(b) Negative muons

- Reconstructing Sprucing25c1 with newest muon alignment: No bias!
- Somehow, a 5 mm misalignment in M3 can cause a 25 mm bias in y at the origin (maybe level-arm effect?)

To get an unbiased quantification of the effect on the trigger selection:

- Re-run trigger line selection in Moore in Sprucing25c1 data
 - ① With nominal settings
 - ② Without y -constraint
 - ③ Without y -constraint and with new alignment
- 2025 data does not have the charge asymmetry, so this should be unbiased evidence for my hypothesis

Retention when running MuonUT trigger line in Moore
over 50×10^3 events from Sprucing25c1

y-constraint	Alignment	μ^+	μ^-	Ratio $+/-$
Yes	Old	388	416	0.93
No	Old	80	199	0.40
No	New	184	208	0.88

- Studied impact of muon alignment on the MuonUT method by rerunning reconstruction on 2024 data without y -constraint
- Muon standalone tracks have a large mis-alignment on the C-side before September 2025
- Confirmed this by running Moore with/without alignment
- What next?
 - ① It would be useful to include the misalignment in MC, as this is a significant effect
 - ② The effect seems to be affect failed and matched samples in the same way, so tracking efficiencies should not be affected

Thanks for listening!