

Effects of muon alignment on tracking efficiencies

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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

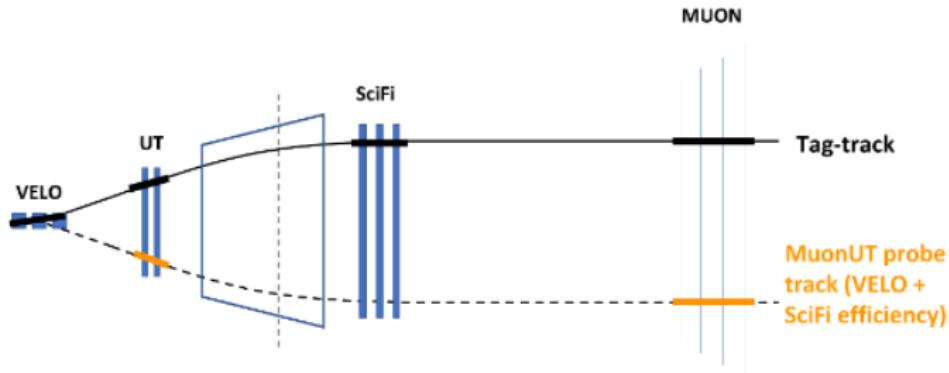


Figure from Rowina's thesis

- 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

Charge asymmetry in MuonUT tuples

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

Charge asymmetry in MuonUT tuples

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 $y = (0 \pm 20) \text{ mm}$ 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

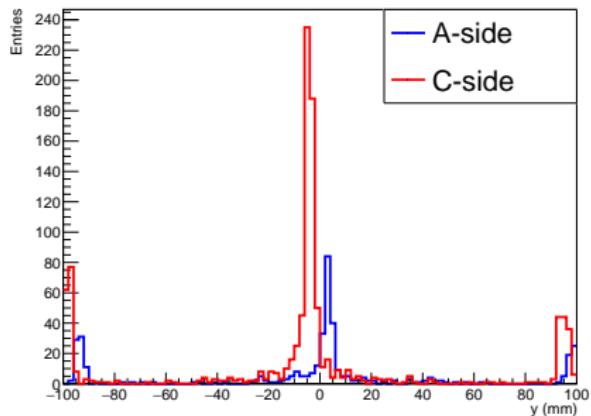
- Mis-aligned Muon system could bias the extrapolation to the UT
- UT hits might not be correctly added, or track quality might be worse
- Effect not seen in VeloMuon or Downstream methods because tracking detectors place stronger constraints on the particle trajectory
- y -constraint added by Michel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

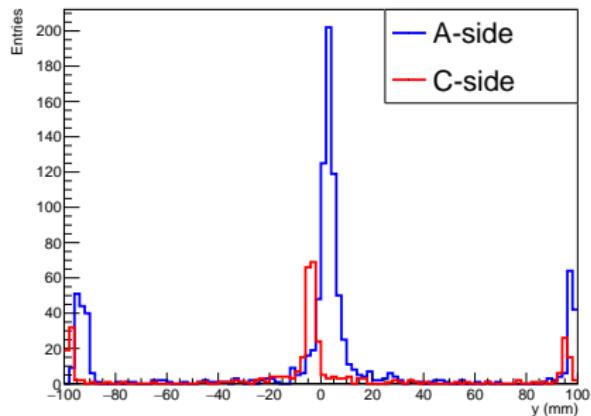
Sprucing25c3 MagUp alignment

Extrapolated y-position at z = 0



(a) Positive muons

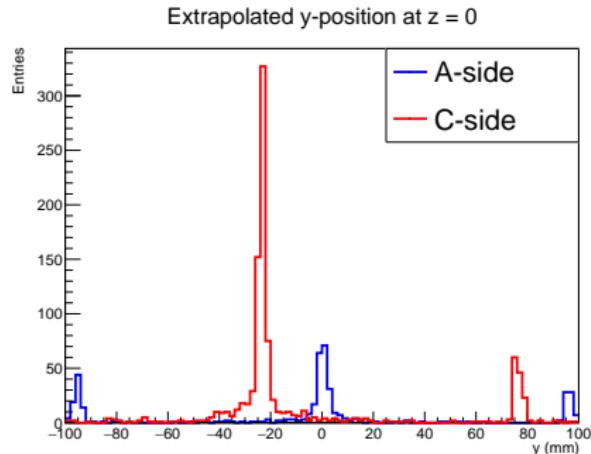
Extrapolated y-position at z = 0



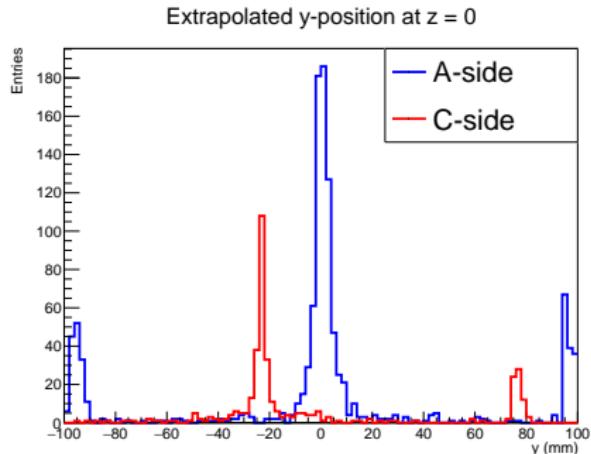
(b) Negative muons

- 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

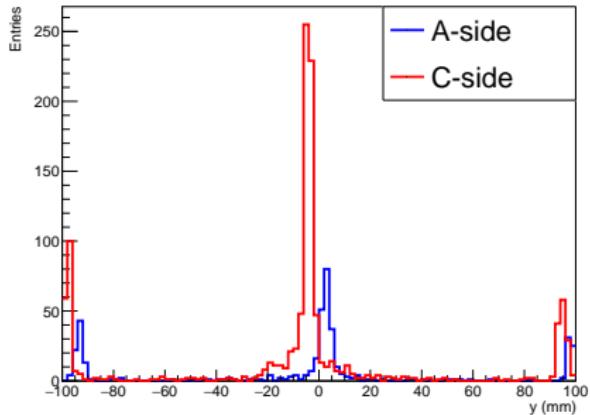


(b) Negative muons

- 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

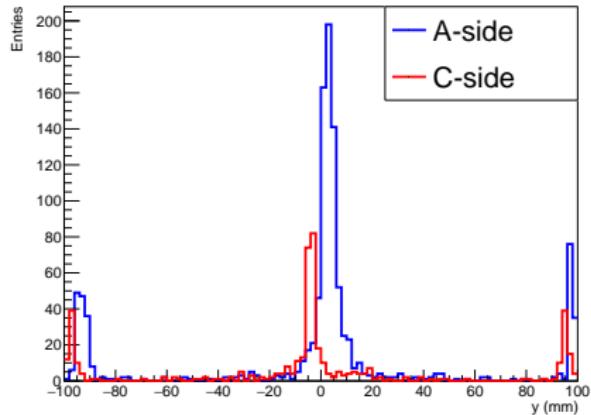
Sprucing25c1 MagUp alignment

Extrapolated y-position at $z = 0$



(a) Positive muons

Extrapolated y-position at $z = 0$



(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?)

Effect on trigger selection

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

Effect on trigger selection

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

Summary

- 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!