Effects of muon alignment on tracking efficiencies

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Introduction

Strategy for tracking efficiency determination:

- Tag-and-probe method with $J/\psi \to \mu^+\mu^-$
- 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

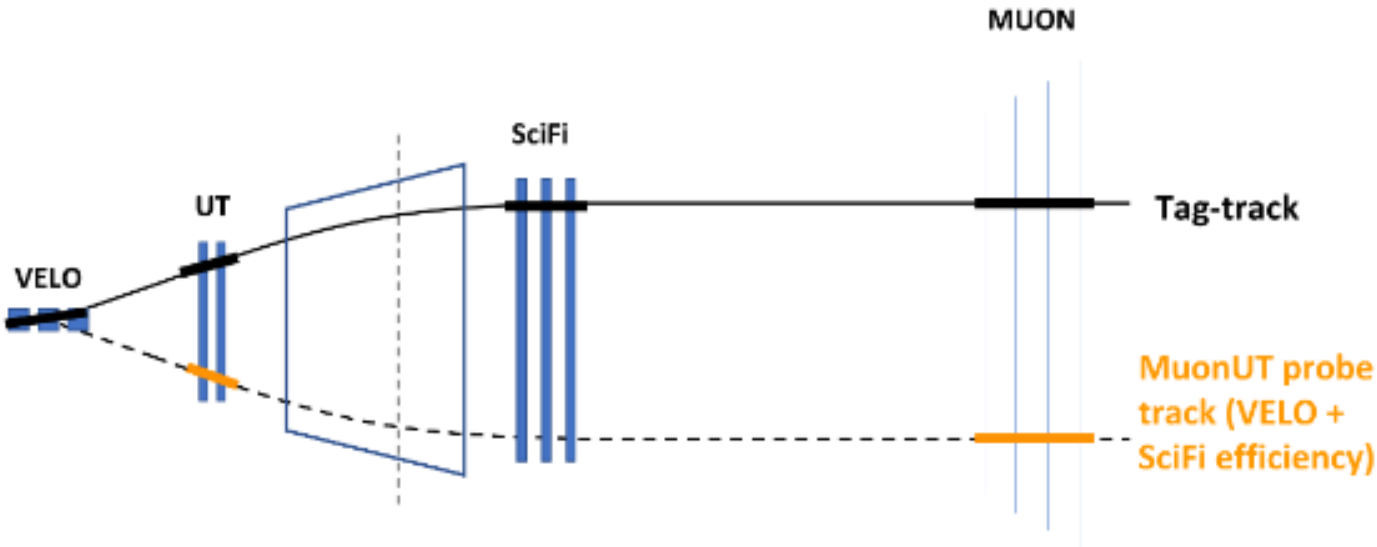


Figure from Rowina's thesis

- Fully reconstruct one muon from $J/\psi \to \mu^+\mu^-$
- 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/ψ χ^2_{vtx}, are shifted $\Longrightarrow$ 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

Charge asymmetry in MuonUT tuples

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)

Muon alignment

My hypothesis:
Muon system misalignment in y

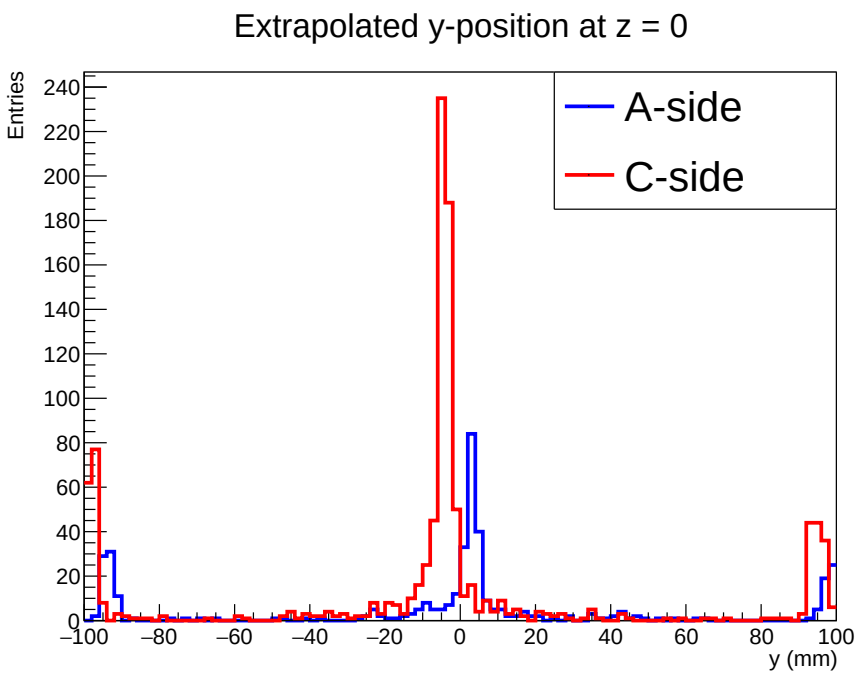
- Mis-aligned Muon system could bias the extrapolation to the UT
- Results in worse track quality $\implies$ Worse J/ψ χ^2_{vtx}, etc
- Effect not seen in VeloMuon or Downstream methods because tracking detectors place stronger constraints on the particle trajectory
- y-constraint added by Michel counteracts misalignment in 2025 data
- How to prove this hypothesis?

Study of 2025 data

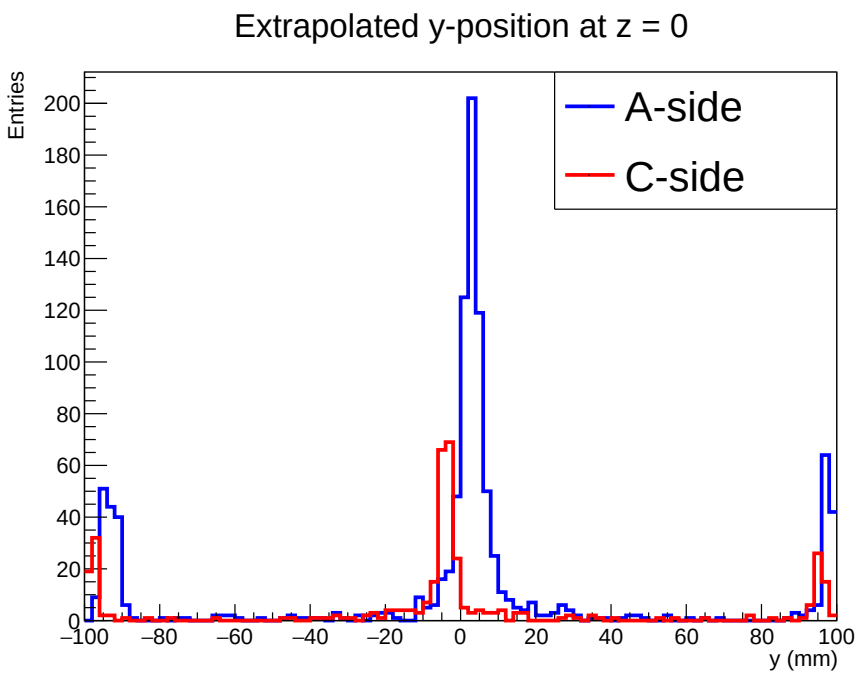
Strategy for analysing 2025 data:

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



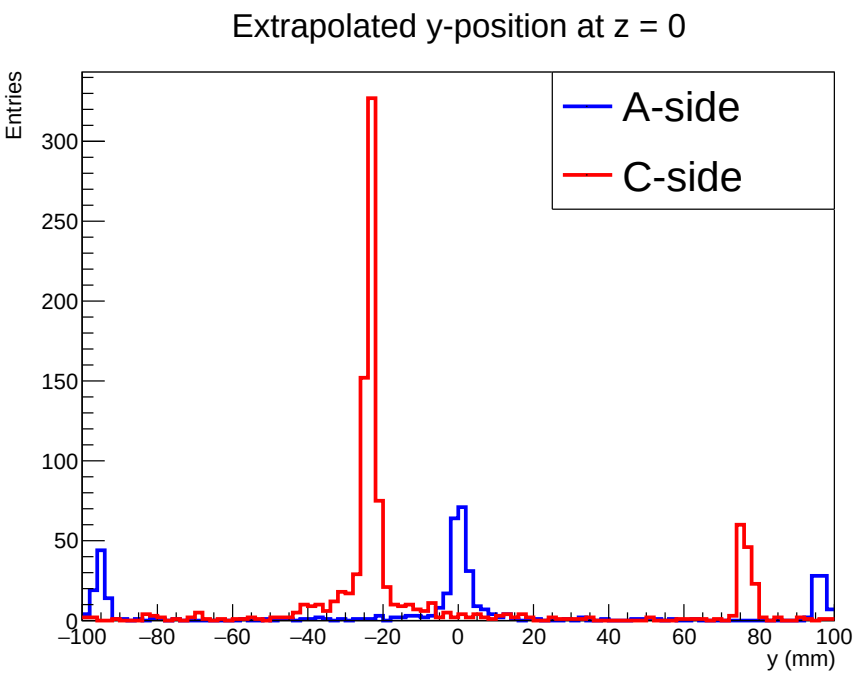
(a) Positive muons



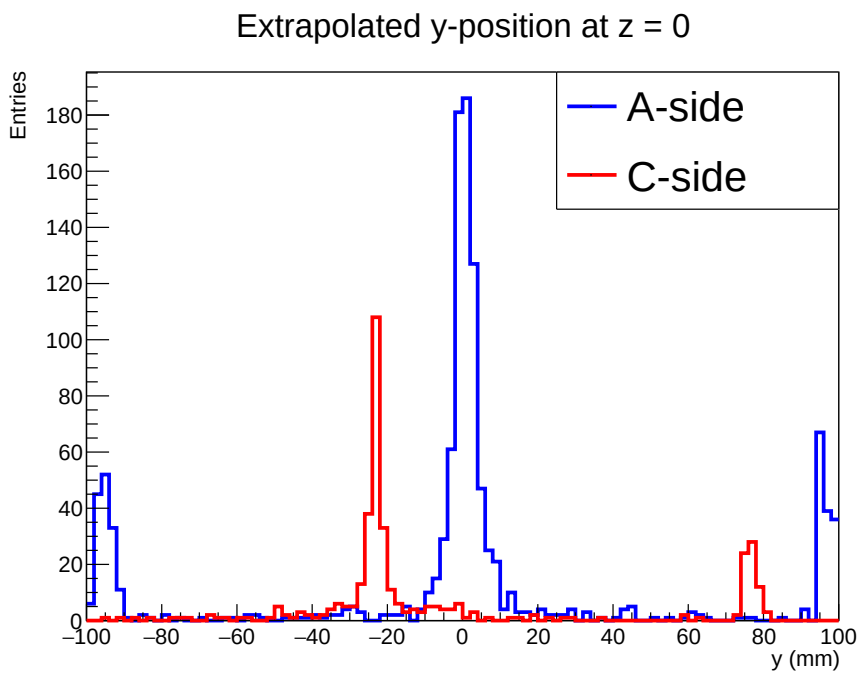
(b) Negative muons

- 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



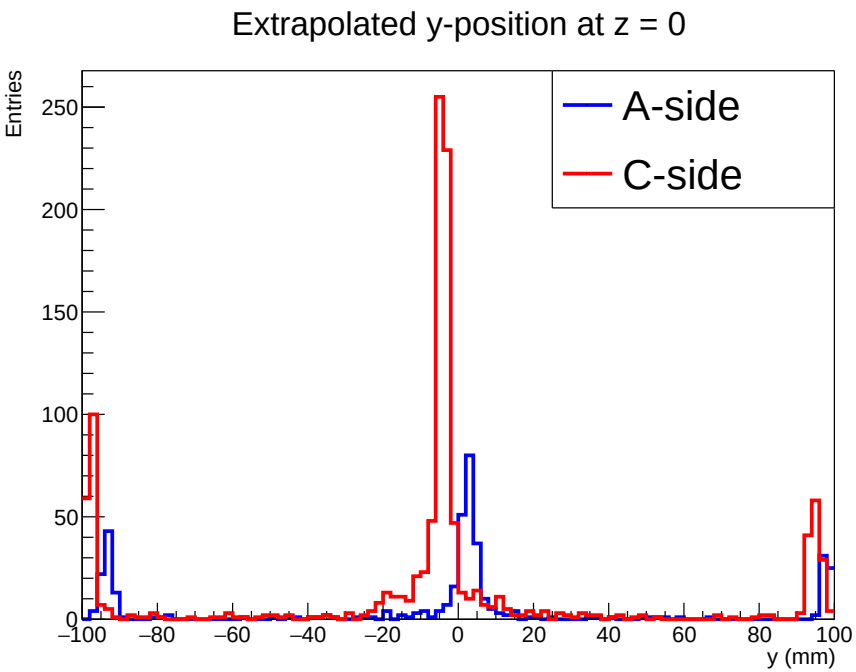
(a) Positive muons



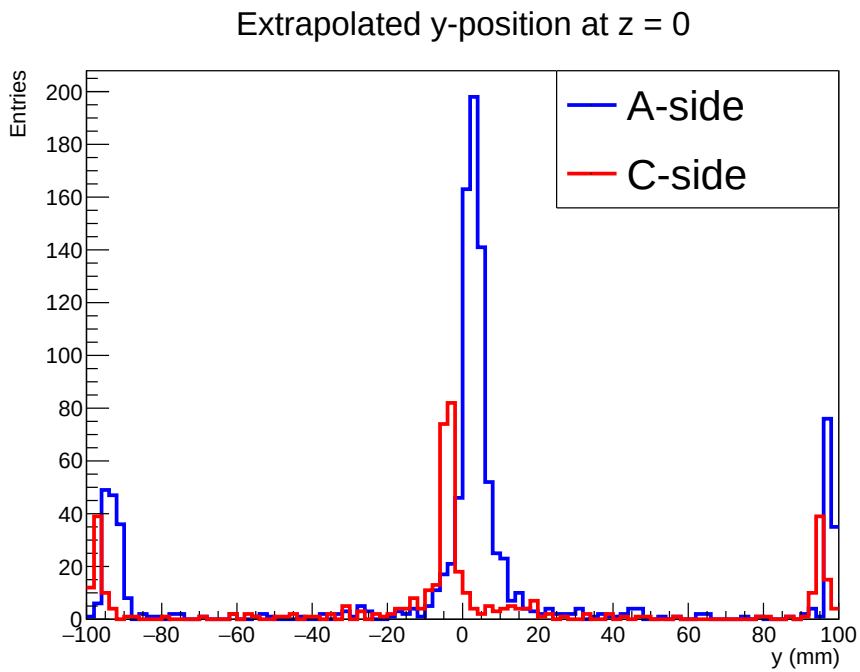
(b) Negative muons

- Huge ($\sim 25\,\text{mm}$) 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?)

Effect on trigger selection

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

- Re-run reconstruction and trigger selection on Sprucing25c1 TurCal data (which have rawbanks saved)
  - This sample does not have a charge asymmetry, so the results should be unbiased, even though it has undergone a trigger selection
- Re-run trigger line selection in Moore:
  1. With nominal settings
  2. Without y-constraint
  3. Without y-constraint and with new alignment
  4. With y-constraint and with new alignment

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	459 ± 21	416 ± 20	1.10 ± 0.07
No	Old	80 ± 9	199 ± 14	0.40 ± 0.05
No	New	184 ± 14	208 ± 14	0.88 ± 0.09
Yes	New	516 ± 23	456 ± 21	1.13 ± 0.07

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!