Effects of muon alignment in MuonUT method

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Introduction

Recap from last time:

- I've looked at discrepancies in tracking efficiencies
- Previous presentations: Fit bias
  - Reduced significantly with different parameterisation
  - Still see discrepancies at low η
- Today: Study large charge asymmetry in MuonUT method

Tag-and-probe method

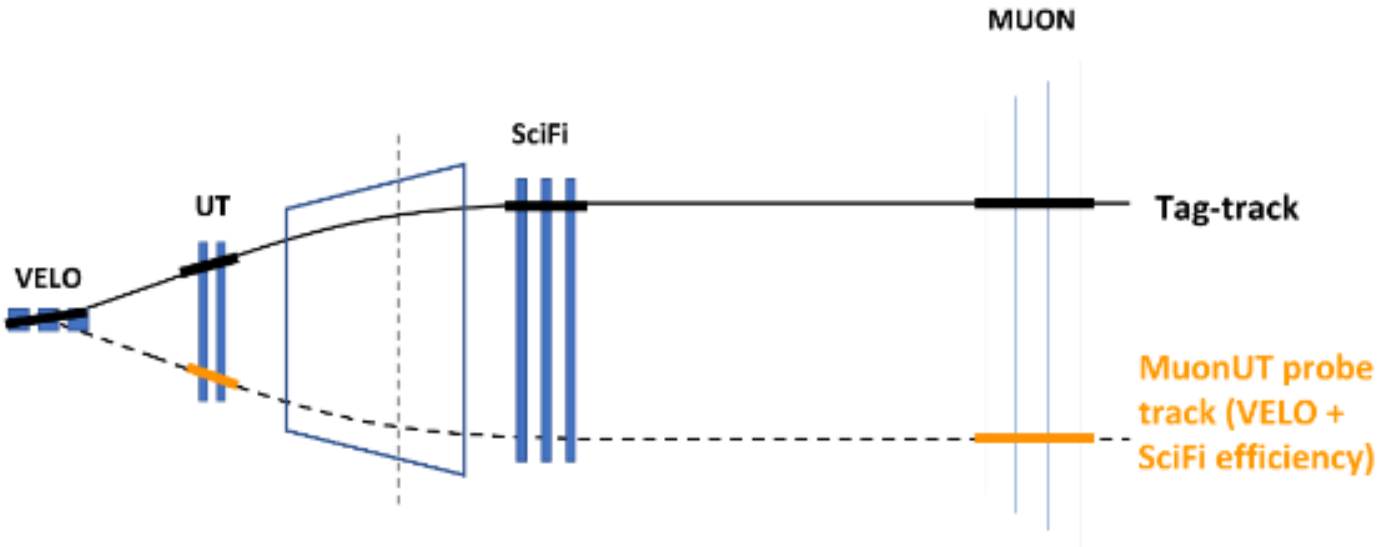


Figure from Rowina's thesis

- 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

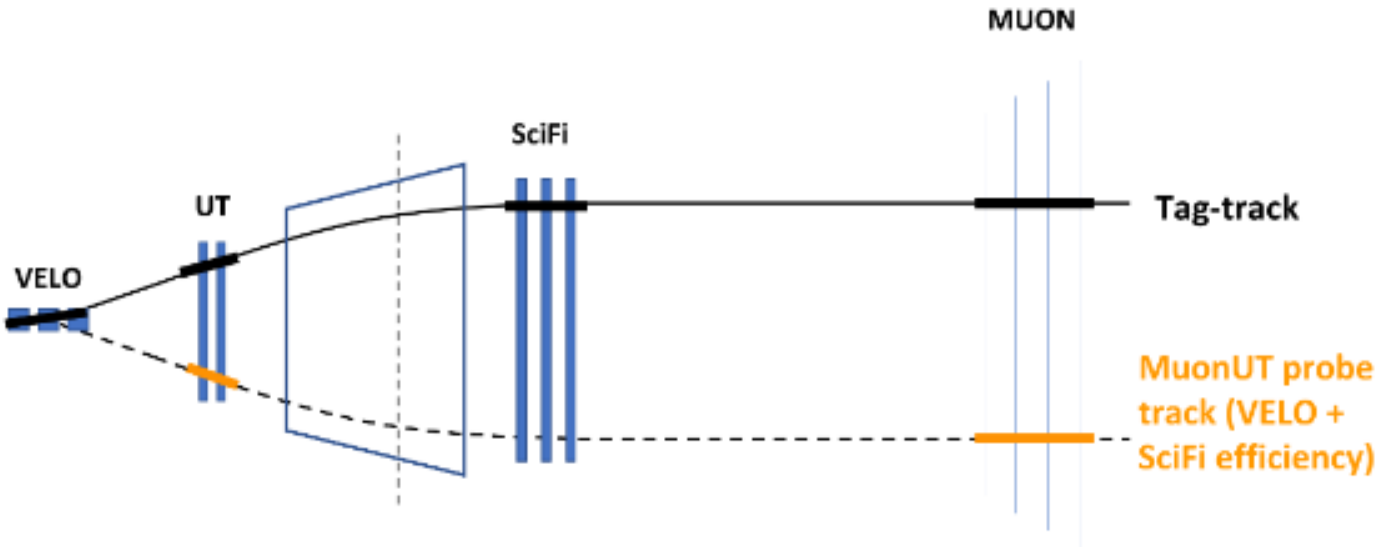


Figure from Rowina's thesis

- The MuonUT method is used to cross check the long track efficiency
- Reconstruct probe using Muon and UT hits $\Longrightarrow$
- Sensitive to VELO and SciFi efficiency

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

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):

- 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 (Sprucing25c3) (see here)

Muon alignment

My working assumption for the last few months:
Muon system misalignment in y

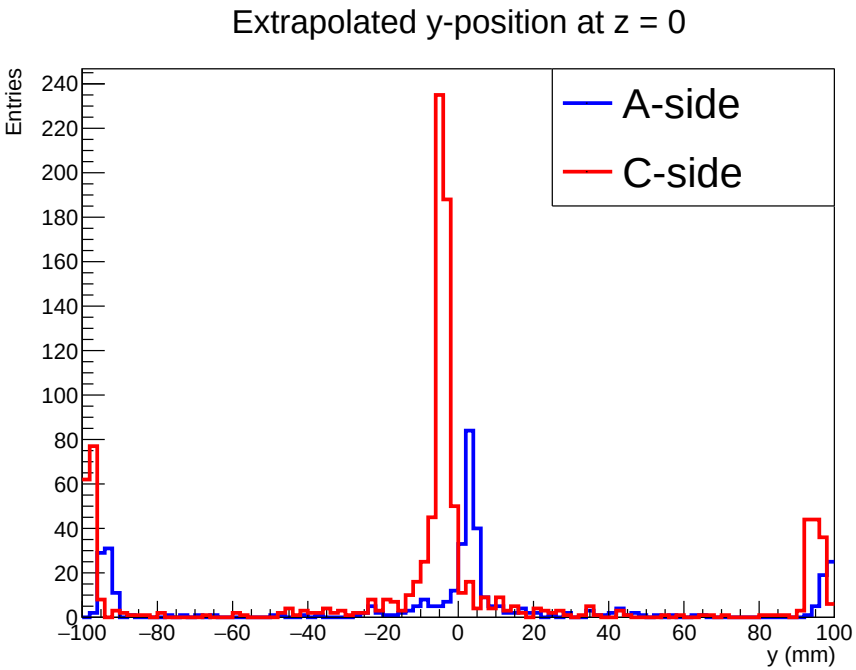
- Mis-aligned Muon system could bias the extrapolation to the UT
- UT hits might be be correctly added, or track quality might be worse
- Effect not seen in VeloMuon or downstream because hits from tracking detectors place stronger constraints on particle trajectory
- y-constraint added by Michel counteracts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

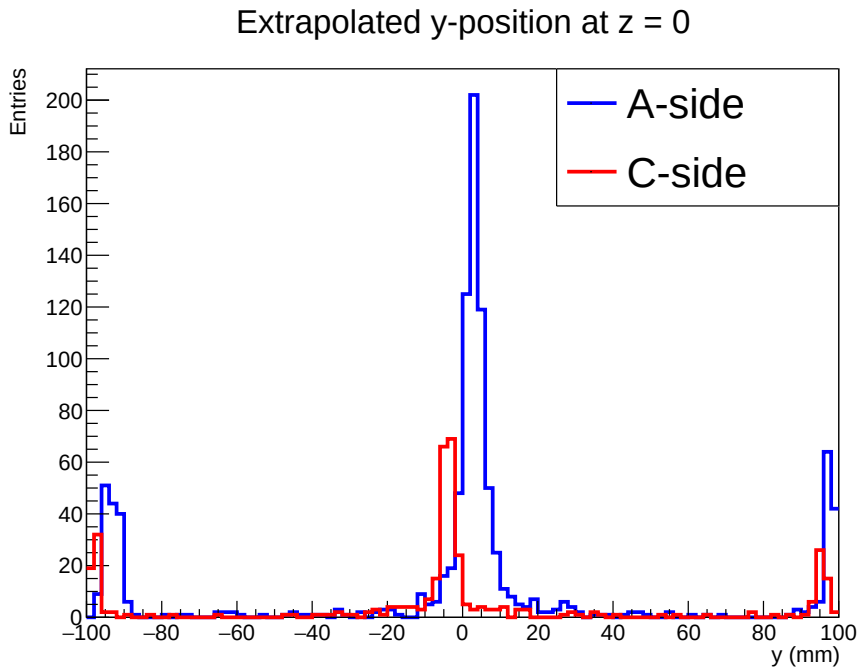
Study of 2025 data

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
   - Small issue: A small number of events with multiple muon track candidates with exactly the same LHCbIDs...?
   - For now keep these, but I'm really scratching my head over this
4. Study y-position of muon tracks, extrapolated back to the origin

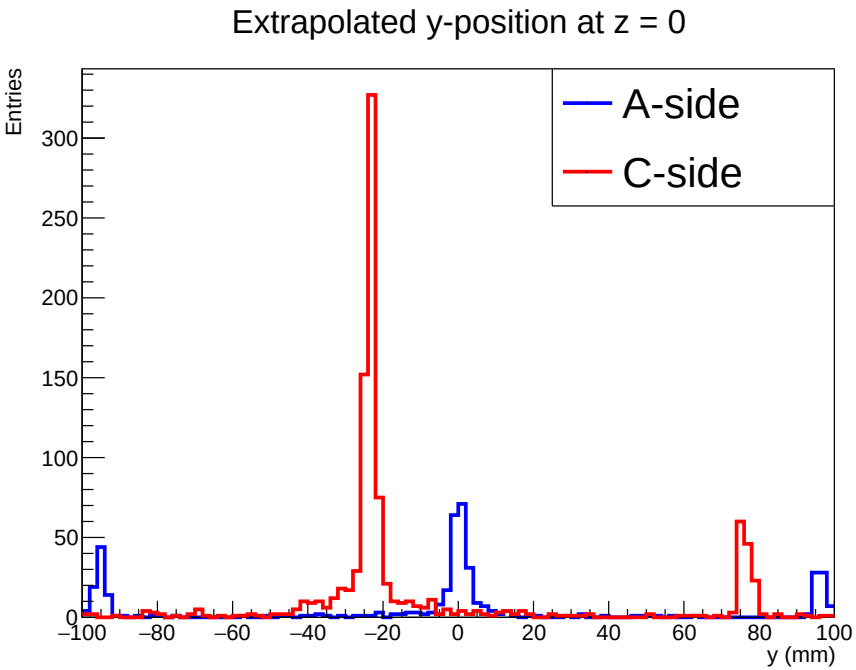
Sprucing25c3 MagUp alignment

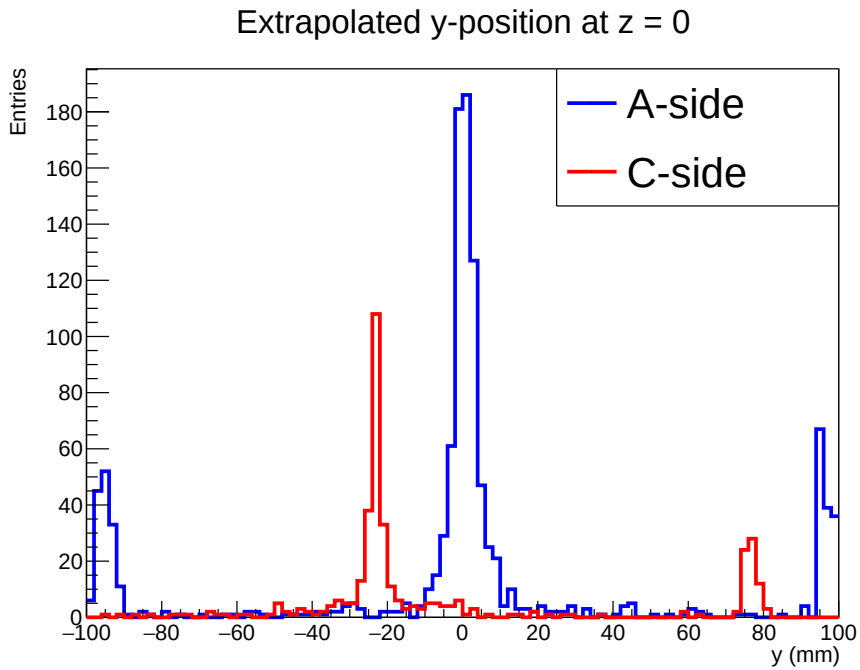




- μ^+ μ^- mostly hit the C-side (A-side) due to magnetic field
- Minor residual mis-alignment, but this is probably very close to the position resolution of the Muon system

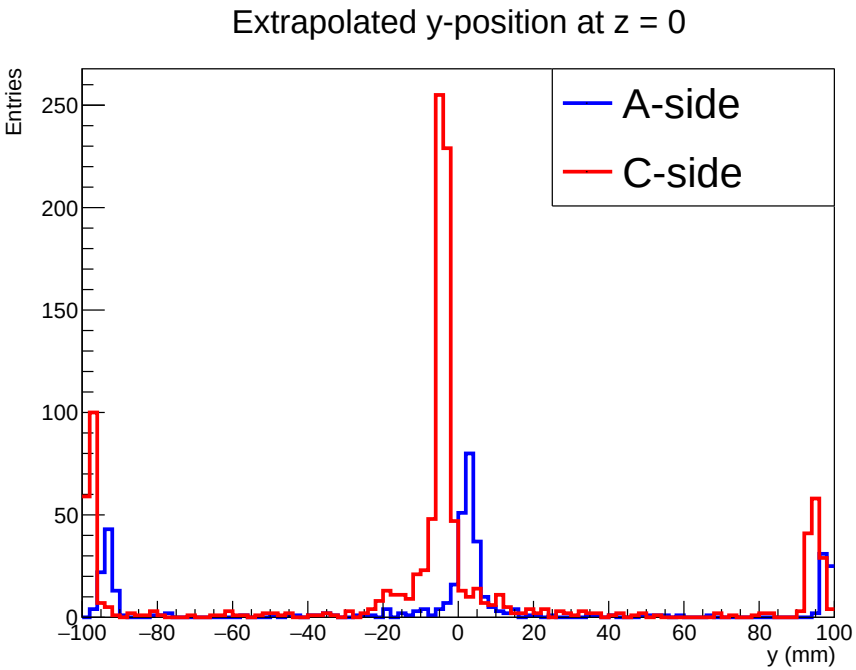
Sprucing25c1 MagUp alignment

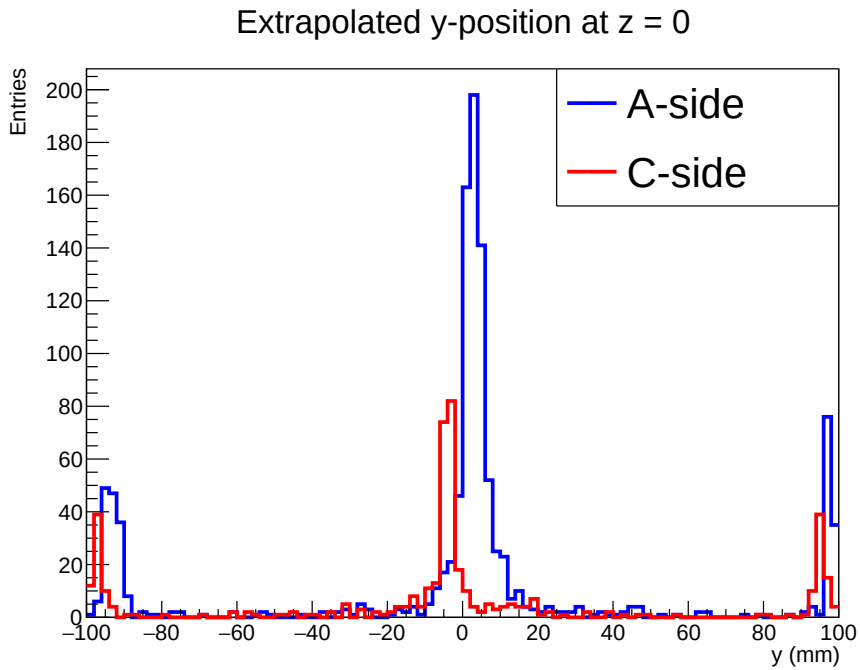




- Huge ($\sim 25\,\text{mm}$) mis-alignment on the C-side
- Have checked with Chenxu Yu, the only change in Sprucing25c3 was the muon alignment

Sprucing25c1 MagUp alignment





- Reconstructing Sprucing25c1 with newest muon alignment: No bias!
- However, I don't fully understand how a 5 mm misalignment in M3 can cause a 25 mm bias in y at the origin

Summary and next steps

- 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
- Clear evidence that something is going on, but it's difficult to quantify charge asymmetry because 2025 data doesn't have this "feature"
- Next steps:
  1. Rerun MuonUT trigger lines in Moore, without y-constraint, using old and new alignment
  2. Decide whether or not this affect matched and failed samples identically

Thanks for listening!