

# 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

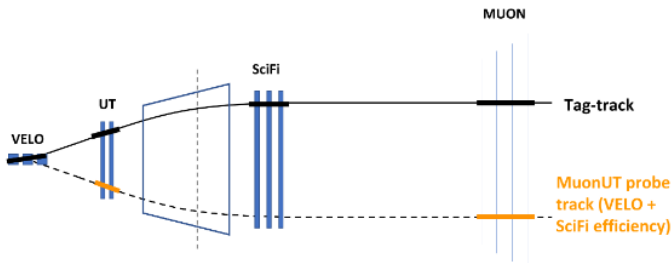


Figure from [Rowina's thesis](#)

- 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  $z_{\text{magnet}}$ , 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  $\mu^+$  and  $\mu^-$  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	$\mu^+$	$\mu^-$	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  $\mu^+$  and  $\mu^-$  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 $y$

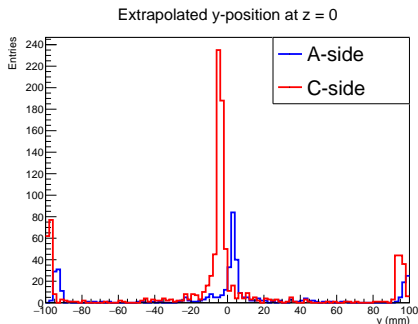
- Mis-aligned Muon system could bias the extrapolation to the UT
- Results in worse track quality  $\implies$  Worse  $J/\psi$   $\chi^2_{\text{vtx}}$ , etc
- Effect not seen in VeloMuon or Downstream methods because tracking detectors place stronger constraints on the particle trajectory
- $y$ -constraint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



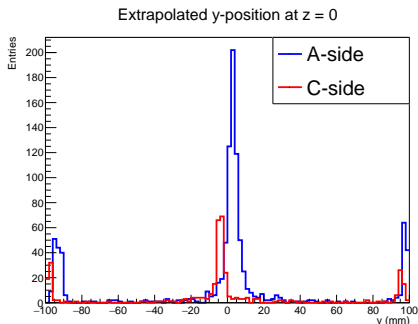
## Strategy for analysing 2025 data:

- 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



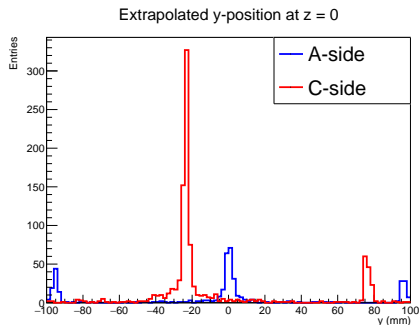
(a) Positive muons



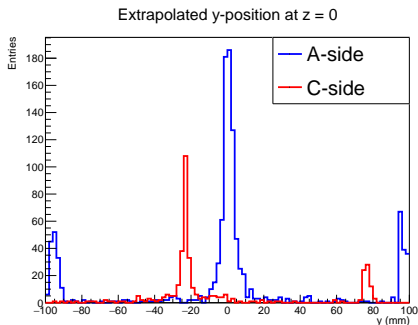
(b) Negative muons

- $\mu^+$  ( $\mu^-$ ) 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



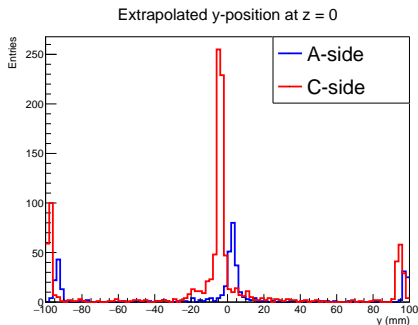
(a) Positive muons



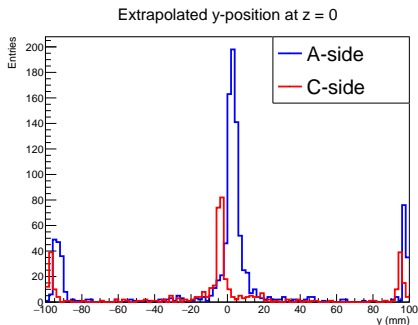
(b) Negative muons

- Huge ( $\sim 25$  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 lever-arm effect?)

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

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

y-constraint	Alignment	$\mu^+$	$\mu^-$	Ratio $+/-$
Yes	Old	$459 \pm 21$	$416 \pm 20$	$1.10 \pm 0.07$
No	Old	$80 \pm 9$	$199 \pm 14$	$0.40 \pm 0.05$
No	New	$184 \pm 14$	$208 \pm 14$	$0.88 \pm 0.09$
Yes	New	$516 \pm 23$	$456 \pm 21$	$1.13 \pm 0.07$

- 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!