Effects of muon alignment in MuonUT method and HLT1 trigger efficiencies

Martin Tat

Heidelberg University

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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 $\implies$ 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

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 $y = (0 \pm 20)\,\mathrm{mm}$ at $z = 0$ in linear fit in the YZ plane

Additionally: Muon alignment updated in September 2025 (Sprucing25c3) (see here)

Muon alignment

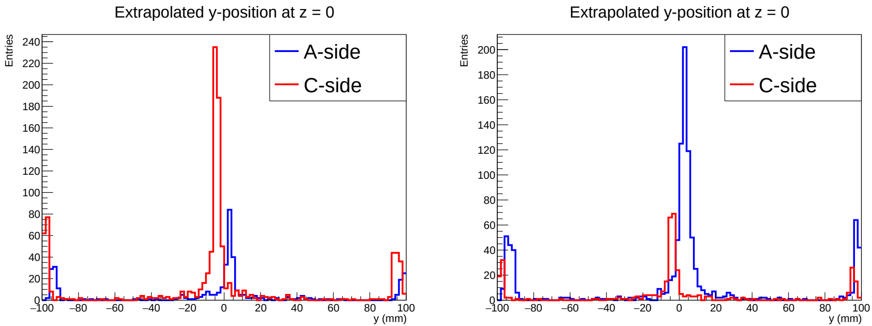
My working assumption for the last few months:
Muon system misalignment in y

- 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?

Strategy for analysing 2025 data:

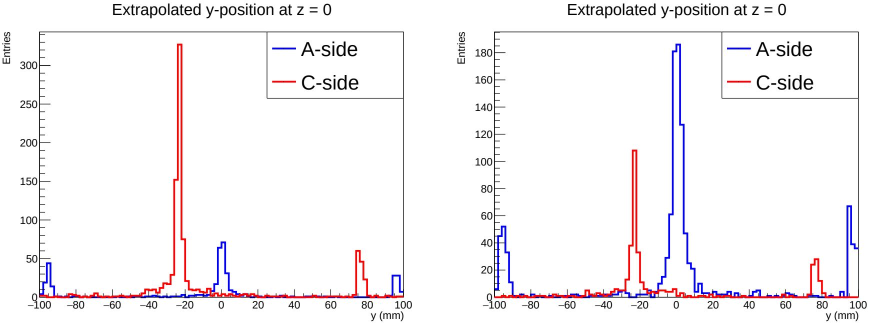
1. Tuple VeloMuon events that also passed MuonUT trigger line
   - Unbiased sample of muons to study alignment with
2. For the same events, create new tuple with muon tracks
   - Rerun standalone muon track reconstruction without y-constraint
3. Match muon tracks to VeloMuon probe tracks using LHCbIDs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

Spurcing25c3 MagUp alignment



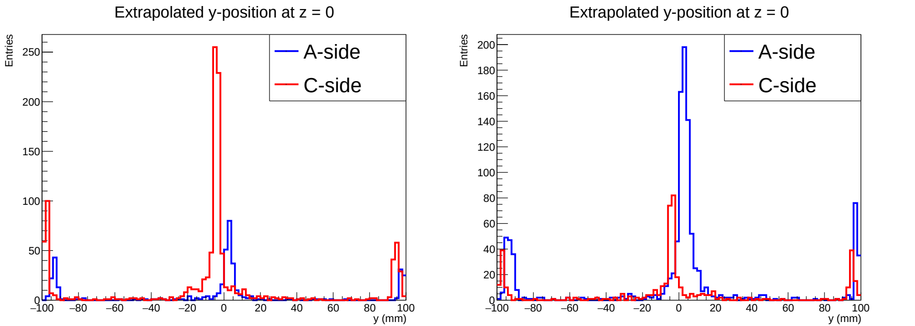
- μ^+ μ^- mostly hit the C-side (A-side) due to magnetic field
- Minor residual mis-alignment, but this is probably very close to the position resolution of the Muon system

Sprucing25c1 MagUp alignment



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

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 on MuonUT charge asymmetry

- 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
- Next steps:
  1. Decide whether or not this affect matched and failed samples identically

HLT1 trigger efficiencies

- The most urgent issue currently is the significantly larger SciFi (VeloMuon) efficiencies for blocks 7/8, compared to blocks 5/6
  - Seen in fits performed by Rowina
  - Reproduced in TrackCalib2 by Rowina
- I have tried to understand differences in the data samples
  - For now look at positive muons in blocks 5 and 8
  - Main difference: $\mu = 4.4$ vs $\mu = 5.3$
  - HLT1 trigger thresholds have also changed

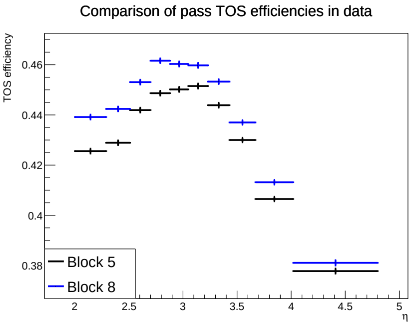
HLT1 trigger efficiencies

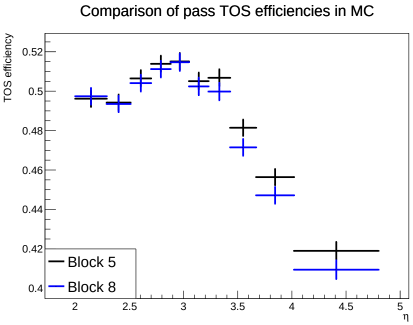
- Integrated luminosity:
  - Block 5: $1.16\,\text{fb}^{-1}$
  - Block 8: $0.44\,\text{fb}^{-1}$
- Candidates per luminosity:
  - Block 5: 13.3×10^6 per fb^{-1}
  - Block 8: 9.7×10^6 per fb^{-1}
- Signal candidates per luminosity (by sideband subtraction):
  - Block 5: 4.2×10^6 per fb^{-1}
  - Block 8: 4.1×10^6 per fb^{-1}
- Background candidates per luminosity (from sidebands):
  - Block 5: 3.1×10^6 per fb^{-1}
  - Block 8: 1.9×10^6 per fb^{-1}

HLT1 trigger efficiencies

- To understand differences, check trends in TOS trigger efficiencies
- TOS selection:
  - `Hlt1TrackMVA` or
  - `Hlt1TrackMuonMVA`
- TOS selection:
  - `Hlt1TrackMVA` or
  - `Hlt1TrackMuonMVA` or
  - `Hlt1TwoTrackMVA`
- Things I've looked at:
  - Difference between blocks 5 and 8
  - Difference between pass and fail samples
  - Difference between data and MC

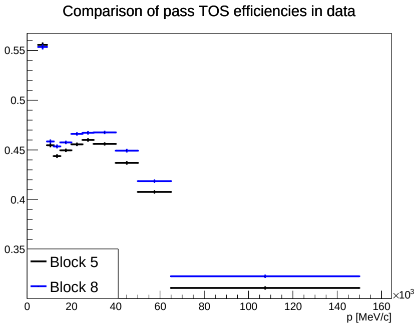
HLT1 TOS efficiency comparison between blocks

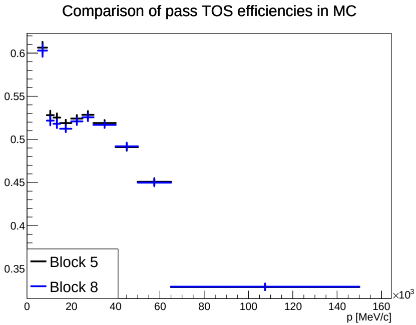




Comparison between blocks 5 and 8, in bins of η, for matched candidates

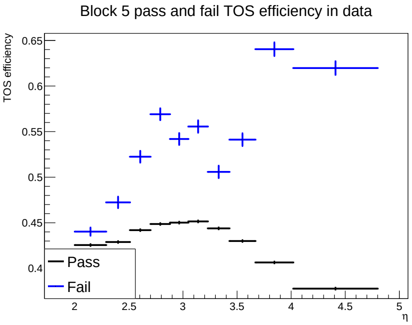
HLT1 TOS efficiency comparison between blocks

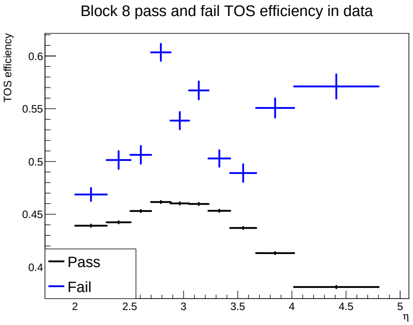




Comparison between blocks 5 and 8, in bins of p, for matched candidates

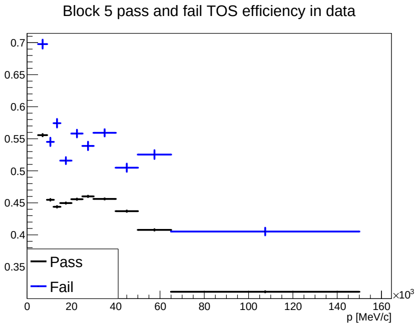
HLT1 TOS efficiency in matched and failed samples

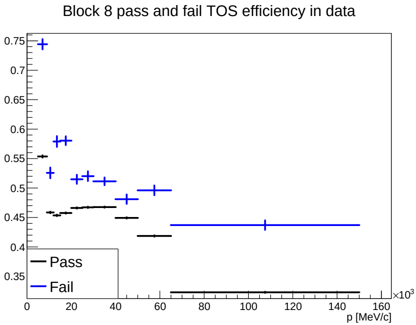




Comparison between matched and failed candidates, in bins of η, for data

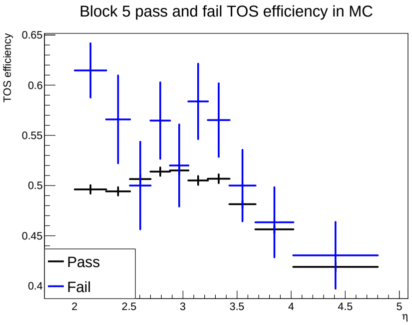
HLT1 TOS efficiency in matched and failed samples

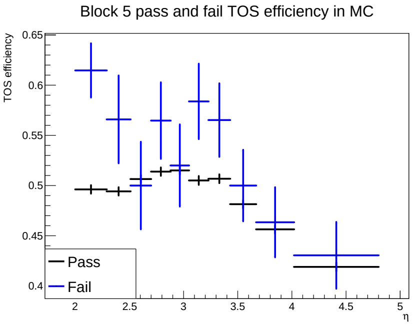




Comparison between matched and failed candidates, in bins of p, for data

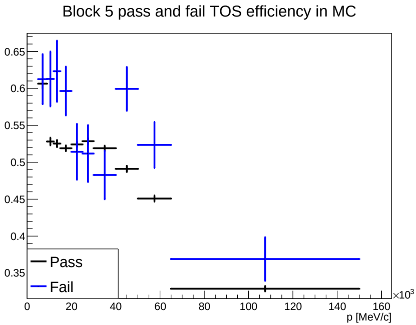
HLT1 TOS efficiency in matched and failed samples

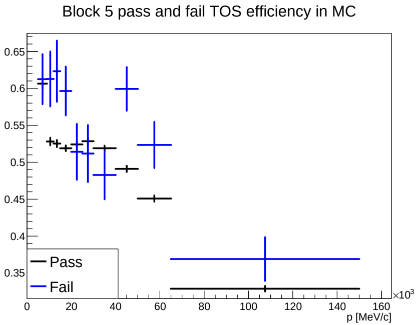




Comparison between matched and failed candidates, in bins of η, for MC

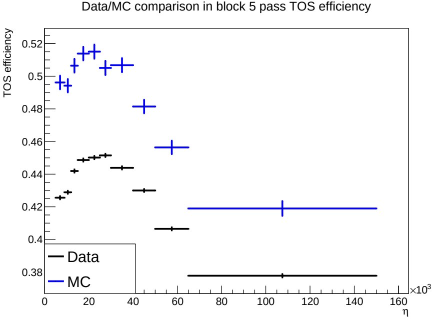
HLT1 TOS efficiency in matched and failed samples





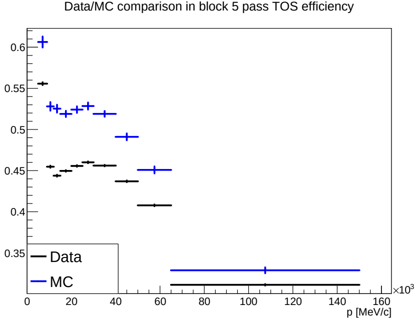
Comparison between matched and failed candidates, in bins of p, for MC

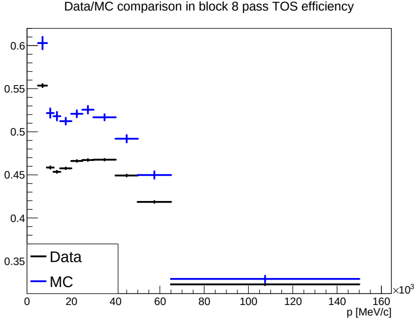
HLT1 TOS efficiency comparison between data and MC



Comparison between data and MC, in bins of η, for blocks 5 and 8

HLT1 TOS efficiency comparison between data and MC





Comparison between data and MC, in bins of p, for blocks 5 and 8

Summary on HLT1 TOS efficiencies

- Observe a significantly larger HLT1 TOS efficiency on matched sample in block 8
  - Only in data
  - Could be due to changes to HLT1
  - Could this affect tracking efficiencies?
- See some differences in TOS efficiencies between matched and failed samples
  - Is this expected?
- MC generally has a higher efficiency for matched sample, but statistics insufficient in failed sample to draw any conclusion
- Is there anything suspicious here that should be looked into in more detail?