Multiple Coulomb scattering for exiting μ tracks

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Amir Gruber | Tel Aviv University | MicroBooNE

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Key points

- We're interested in reconstructing momentum for exiting tracks
- Multiple Coulomb scattering based measurements get $\sim 10\%$ bias for certain p ranges
- We tried applying the standard MCS calculation algorithm to segments of tracks in a way that will minimize bias
- Unfortunately,
  - Minimized bias leads to too large resolution
  - "Tuned" results did not result in true optimization as a function p_{True}
- We observed some interesting properties of MCS calculation-based momentum reconstruction

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Measuring p_μ using Multiple Coulomb scattering

- While muons traverse a medium, they are scattered off nuclei
- Standard deviation of a muon's scattering angle given a muon's momentum p can be derived using a tuned Highland formula:

$$\sigma_0^{RMS} = \sqrt{\left(\frac{\kappa(p)}{p\beta c}\right)^2 + (\sigma_0^{res})^2}$$

Where $\kappa(p)$ is a tuning function for Highland's formula (see MCS paper for details)

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Measuring p_μ using Multiple Coulomb scattering

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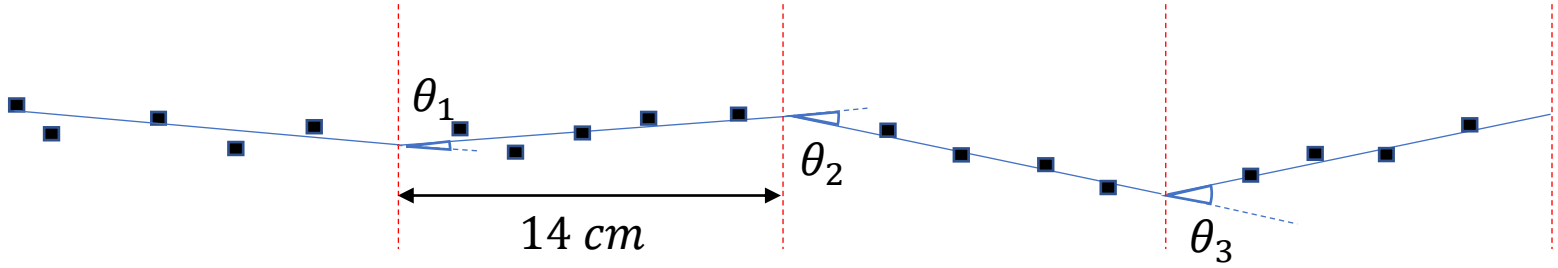

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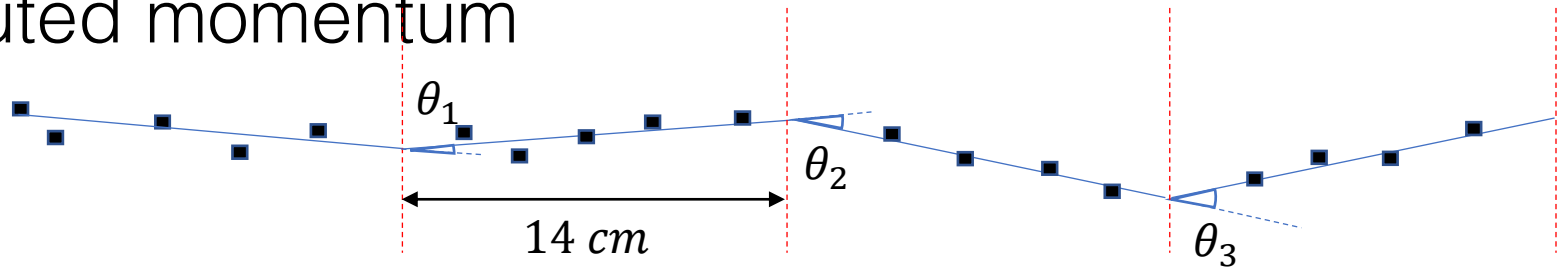
Measuring p_μ using Multiple Coulomb scattering

- Reconstructed tracks are divided to segments of constant length ($14\ cm$, Ar interaction length)
- Scattering angles between consecutive segments are measured
- Likelihood that the particle has a specific momentum is calculated for a range of momenta
- Momentum with maximum likelihood is chosen to be the MCS-computed momentum



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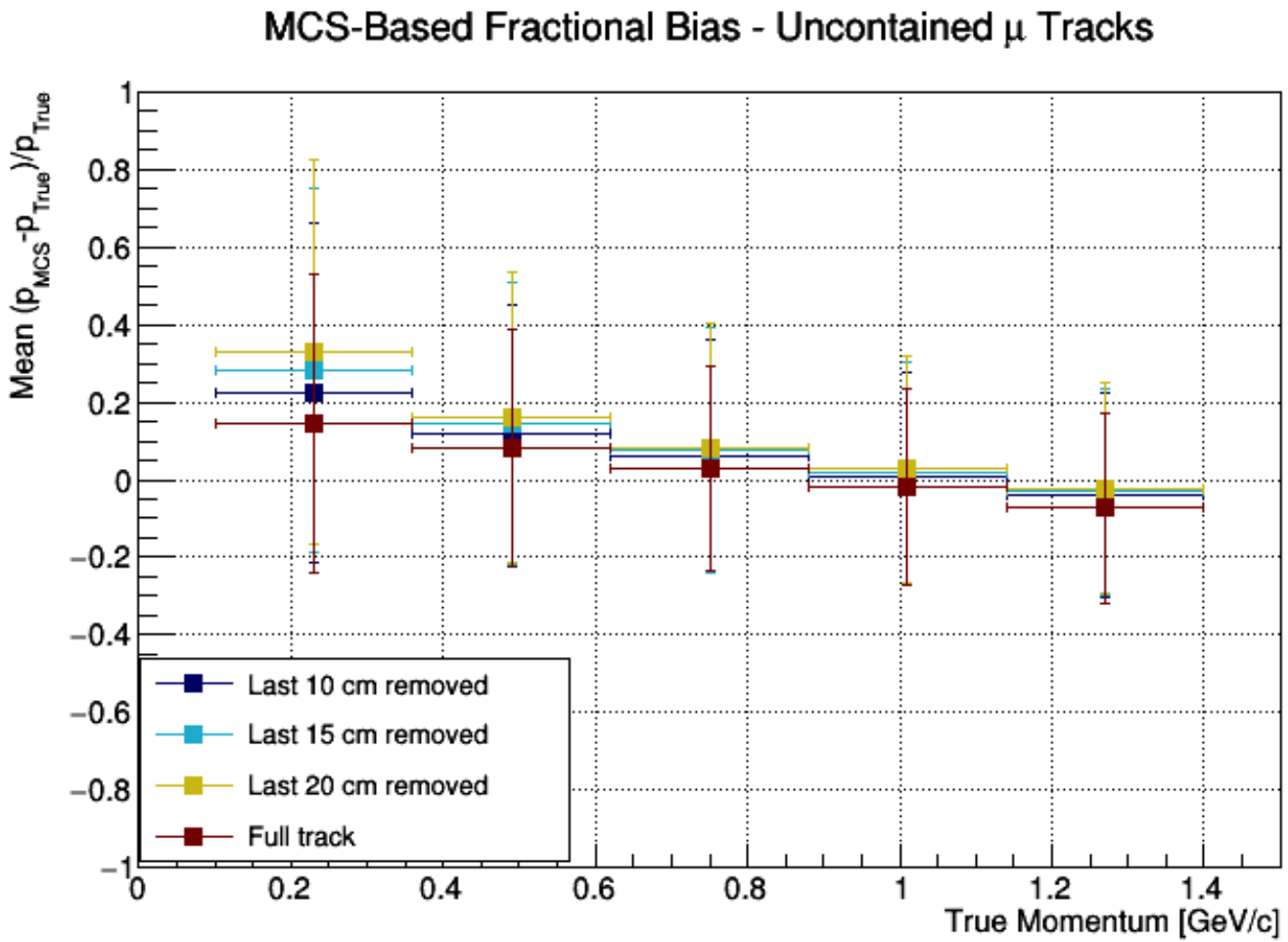
Event selection

- Based on ν CC inclusive filter
- |PDG ID| = 13, ν PDG ID = 14
- Forward going tracks
- p_{MCS} at $0 - 10\ GeV/c$
- Effective track $> 20\ cm$ (Part of track used for p_{MCS} calculation)
- ν and daughters' start contained
- ν score > 40
- IsMuonCandidate:
  - fGeneration = 2
  - μ cut track score > 0.85
  - Vertex distance < 5 cm
  - $\chi^2_\mu < 30, \chi^2_p > 60$
  - $\frac{\chi^2_p}{\chi^2_\mu} > 7$

Removing constant part of tracks



In order to minimize $\frac{p_{MCS}-p_{True}}{p_{True}}$ (fractional bias), we removed the last segments of tracks before applying the standard MCS calculation to the shortened tracks

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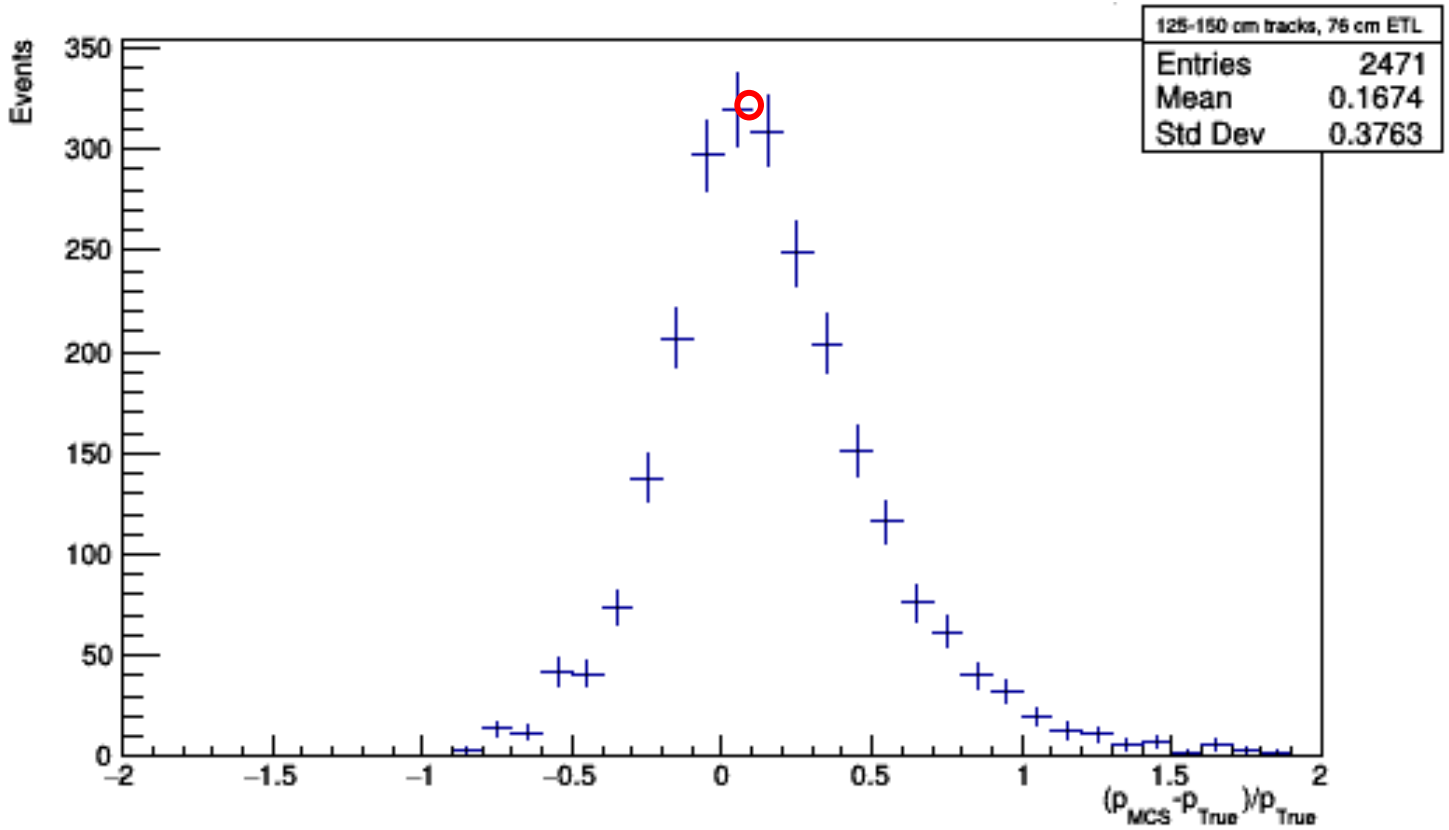
MCS calculation by effective track length variation

- Momentum was reconstructed by taking first part of tracks with varying length – effective track lengths of 50 to 250 cm
- After reconstruction, for each track length range we chose the effective track length that had minimal absolute mean bias in that range



$125 - 150\ cm$ tracks, $76\ cm$ effective track length

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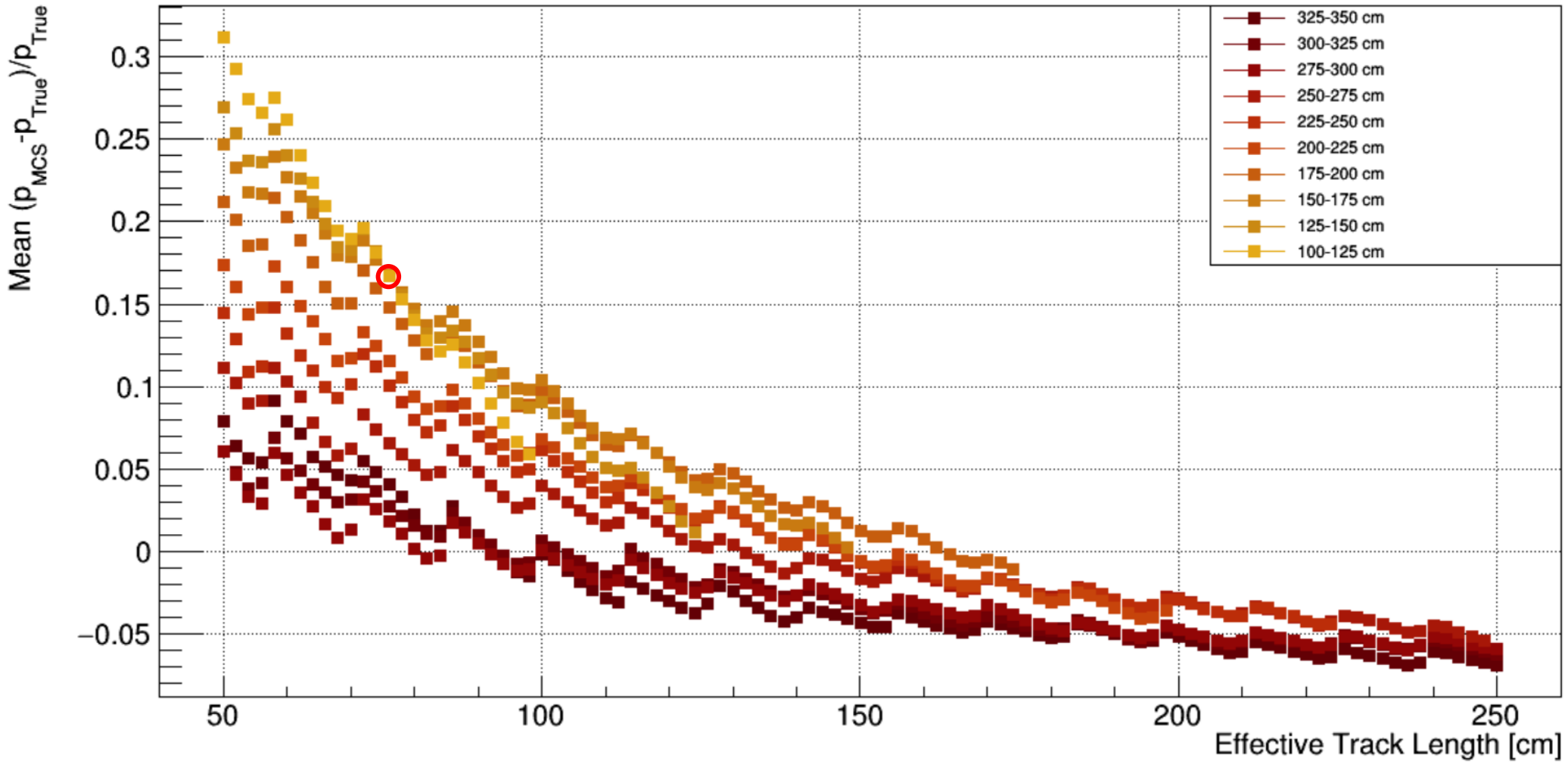
Bias by effective track length for different length ranges



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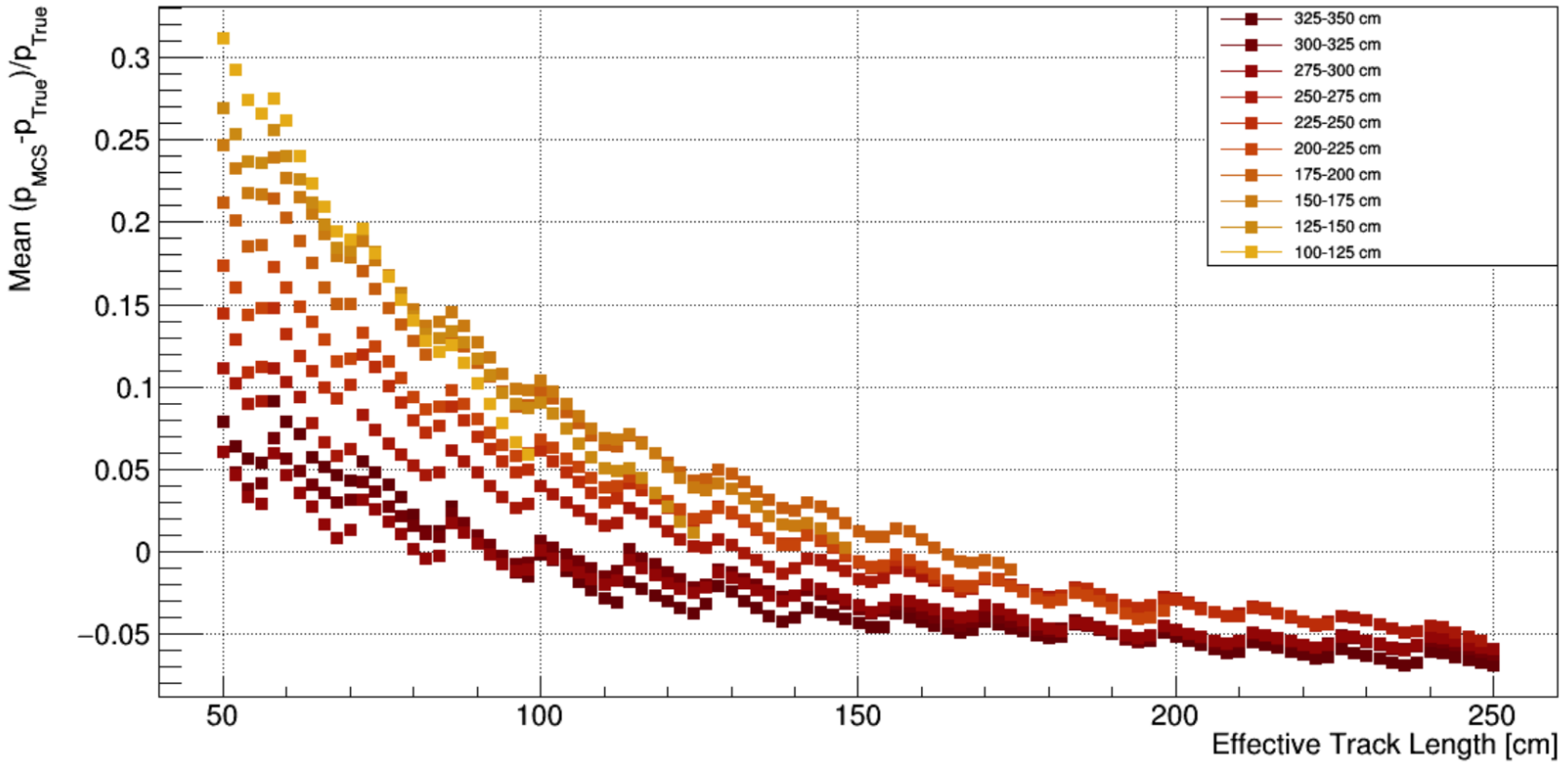
Bias by effective track length for different length ranges

- Decreasing monotonic trends as a function of:
  - Effective track length
  - Reconstructed track length
- Bias converges (but not to zero)
- "Bumps" occur every $14\ cm$ – maximal segment length in the MCS algorithm



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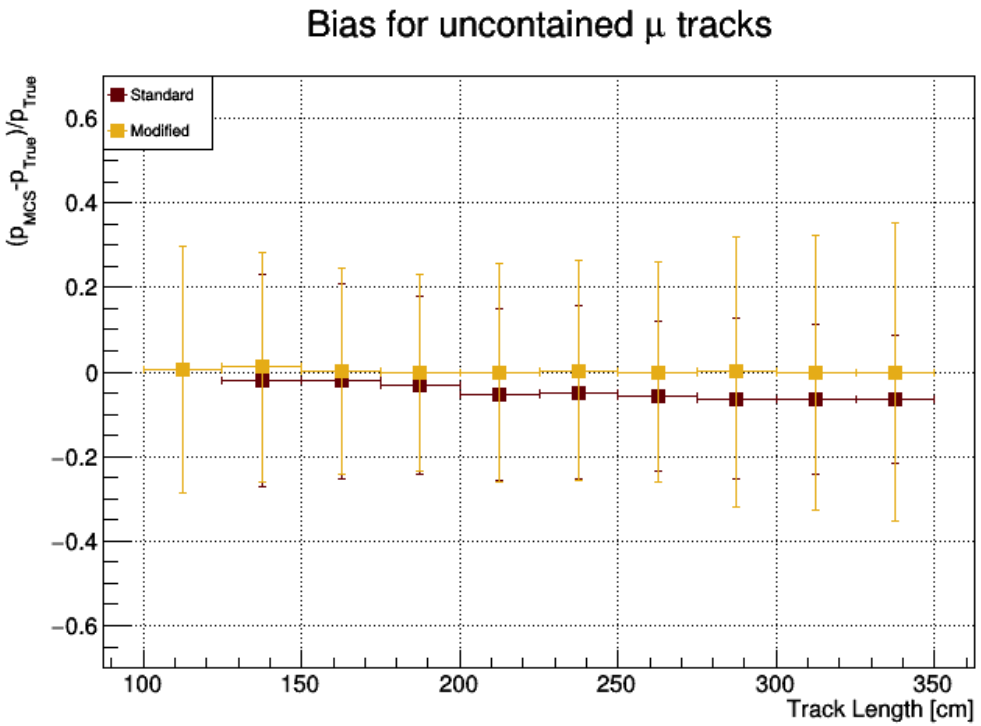
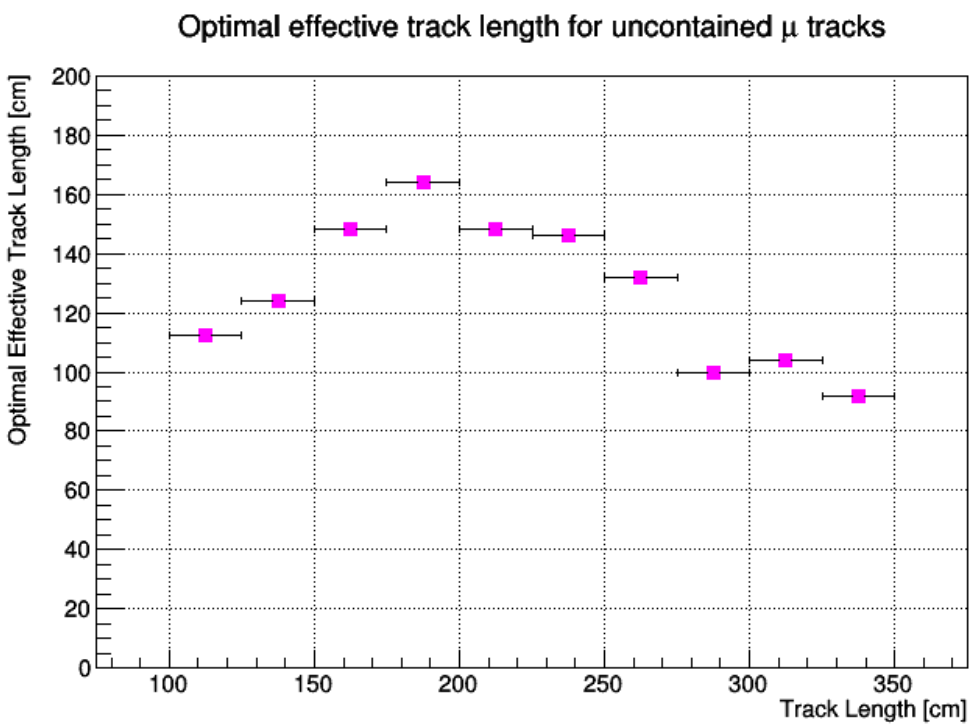
Results as a function of reconstructed track length $(100 - 350\ cm)$





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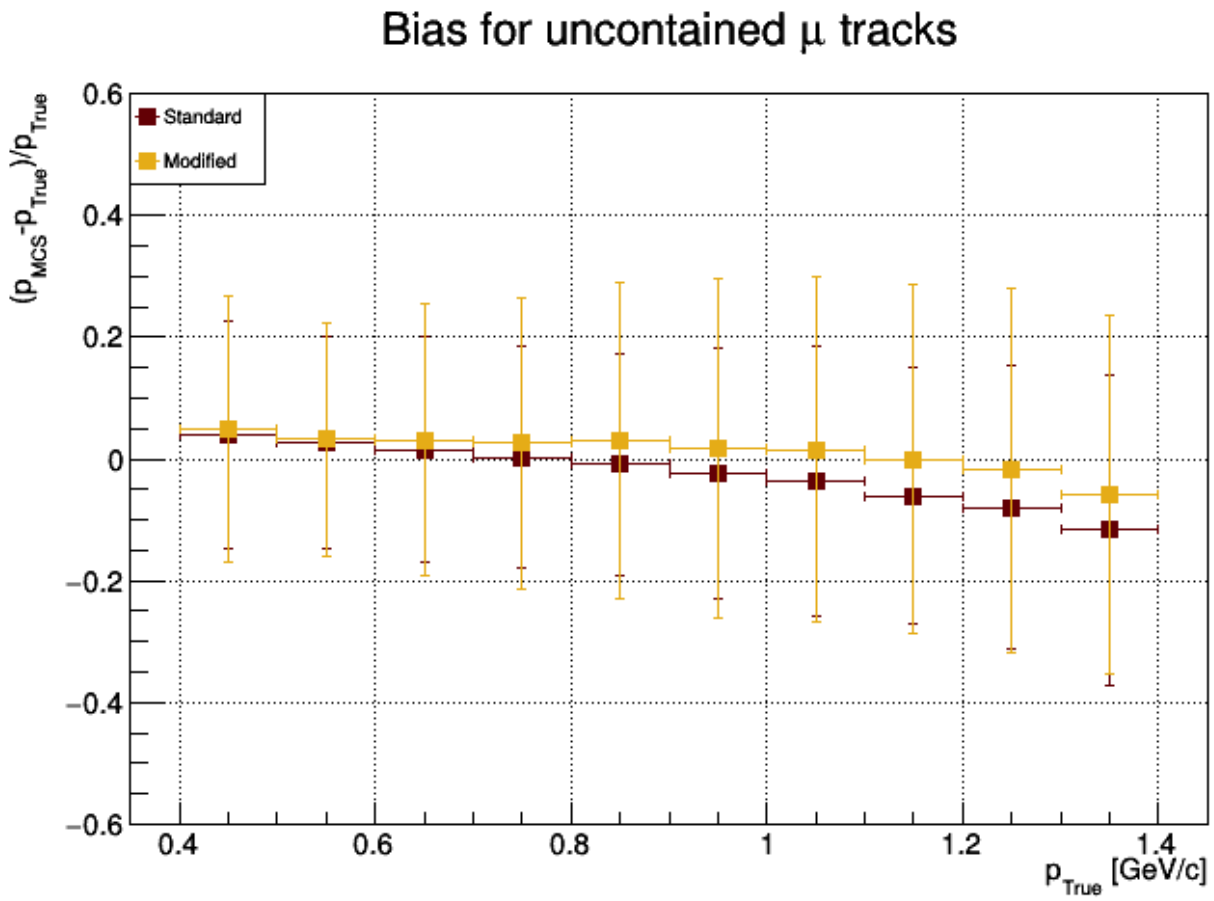
Modified calculation by true momentum



Plotted values are for tracks with $100 - 350\ cm$ reconstructed length

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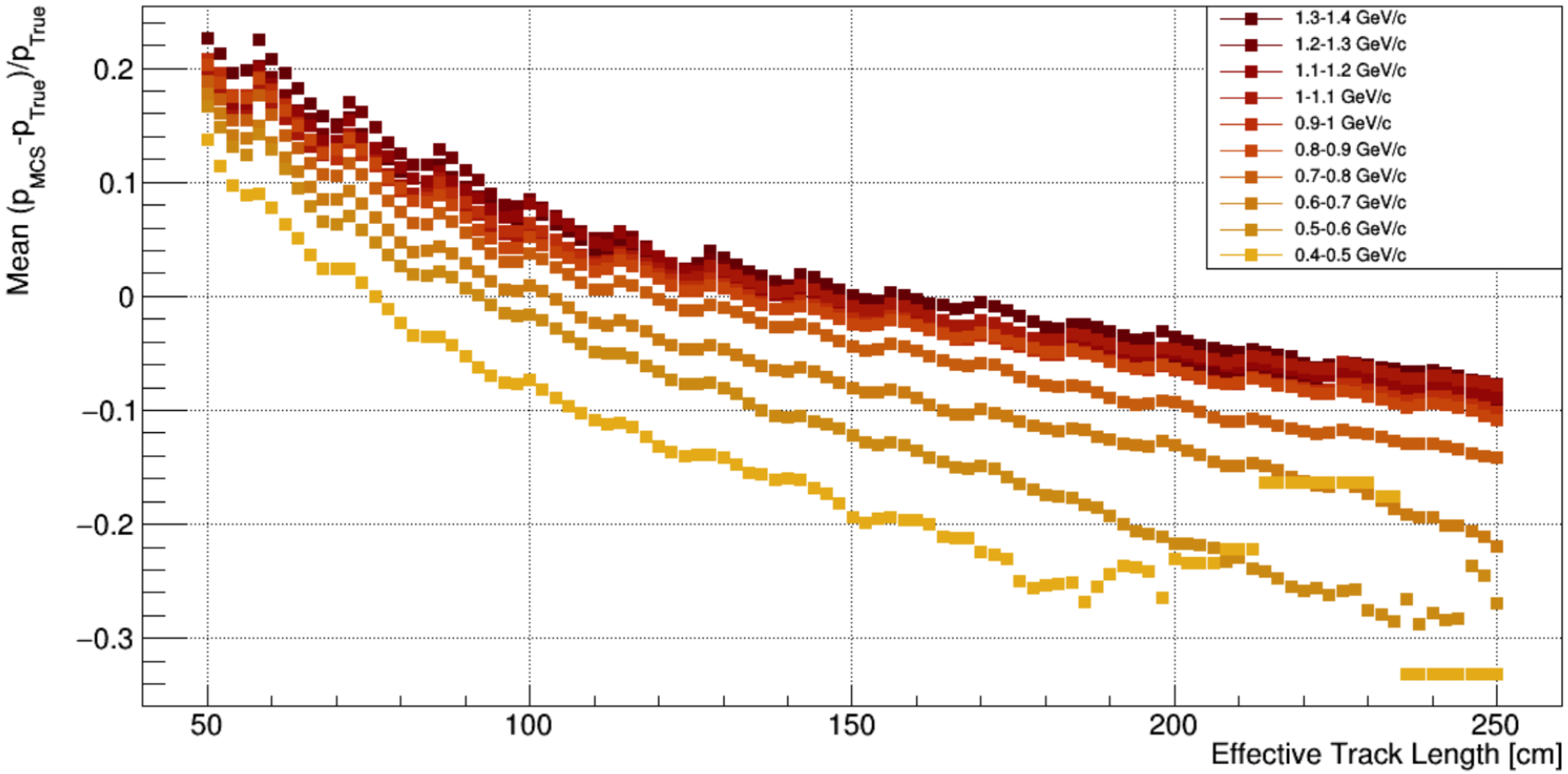
Bias by effective track length for different p_μ ranges



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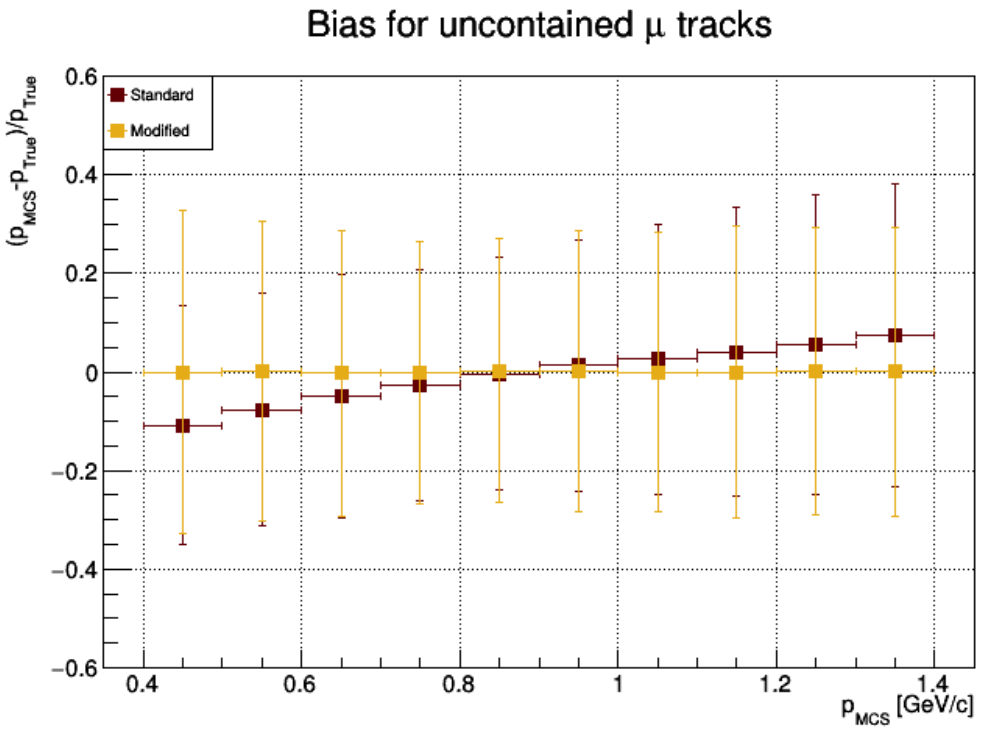
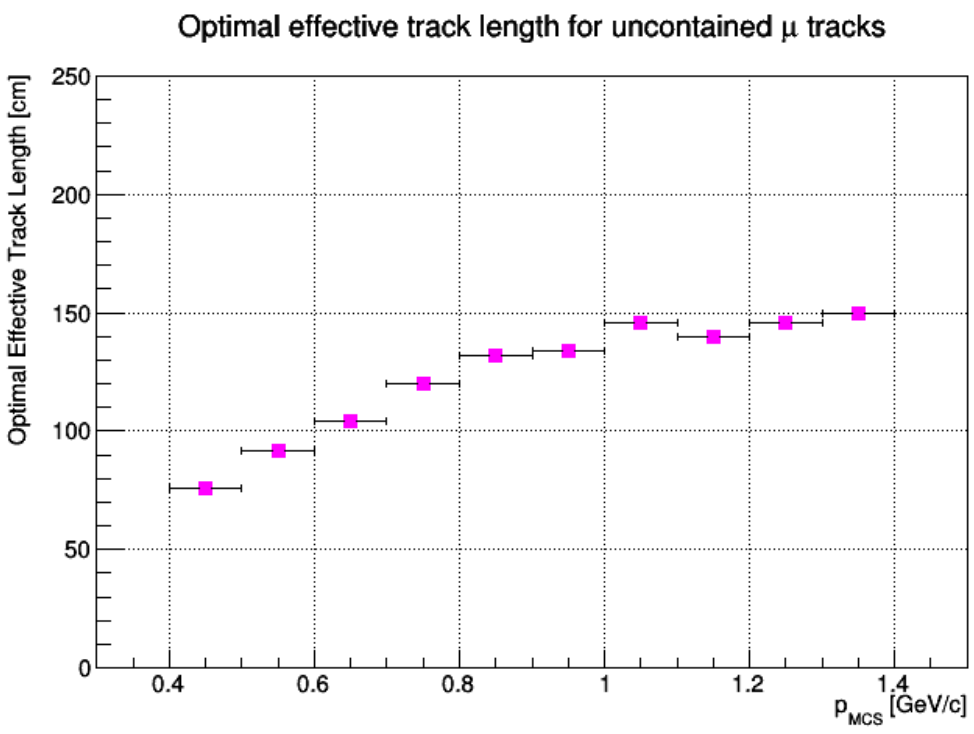
Results as a function of MCS momentum $(0.4 - 1.4\ GeV/c)$





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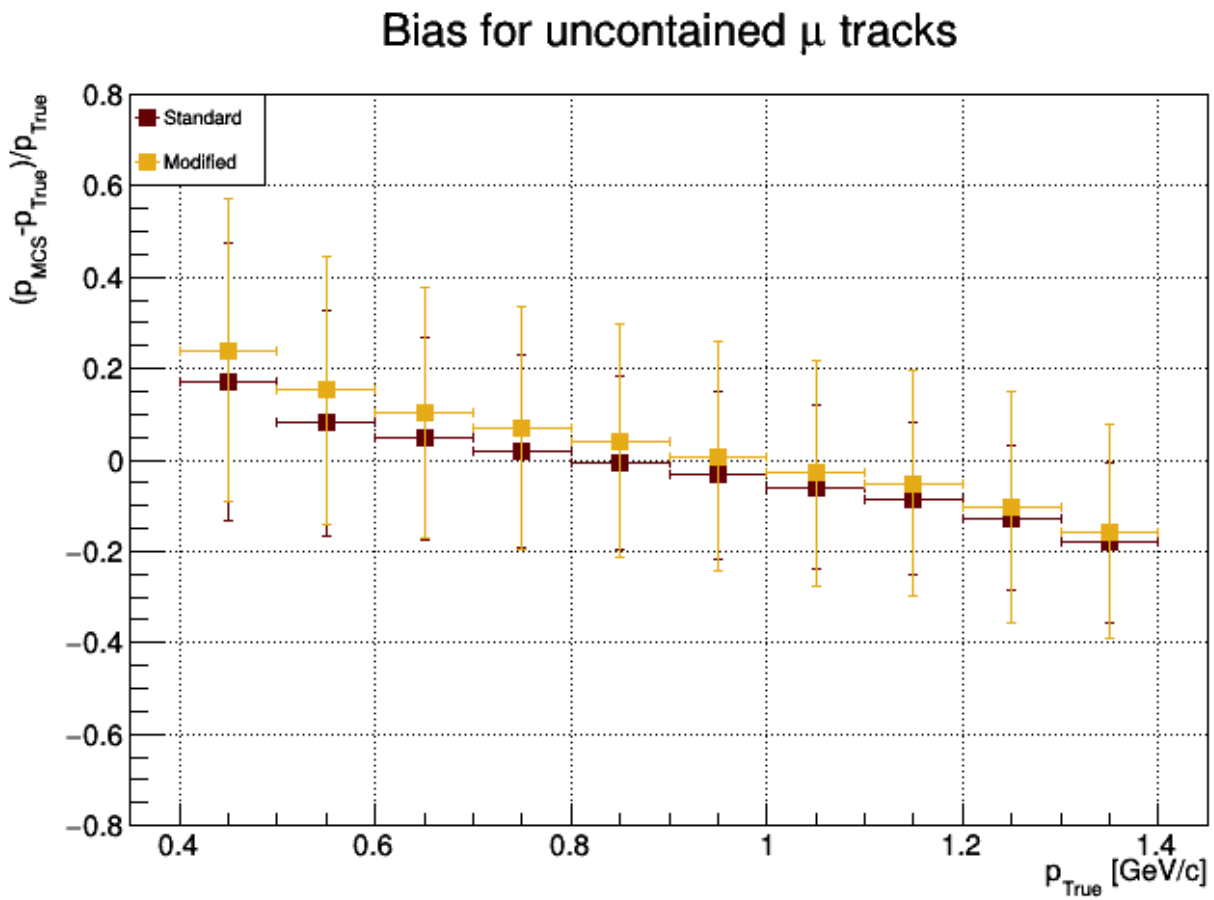
Modified calculation (by p_{MCS} binning) by true momentum



Plotted values are for tracks with $0.4 - 1.4\ GeV/c$ p_{MCS}

Summary & Conclusions

- We tried using a modified p_{MCS} calculation to minimize fractional bias
- The bias was minimized at the expense of resolution (that's expected)
- Tuned results by track length, p_{MCS} did not result in better results as a function of p_{True}
- We observe significant monotonic trends in bias as a function of:
  - Effective track length
  - Full reconstructed length
  - Reconstructed p_{MCS}

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Other ideas

- Ideas we explored:
  - Removing ends of tracks where space charge effects are dominant (accounting for parts within the fiducial volume)
  - Varying the MCS segments length (not just $14\ cm$)
  - Adding $\frac{dE}{dx}$ info to the calculation
- Other suggestions?