Optimizing the Tracker (and Related Elements) for Improved Mu2e-II Sensitivity

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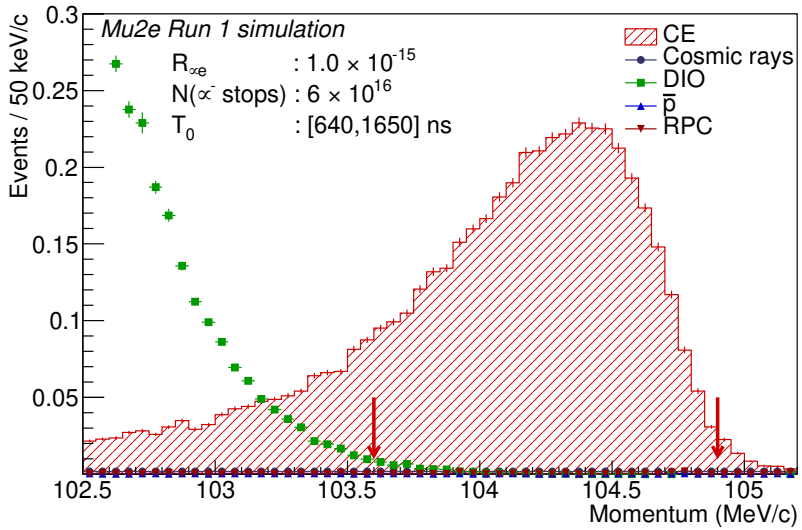
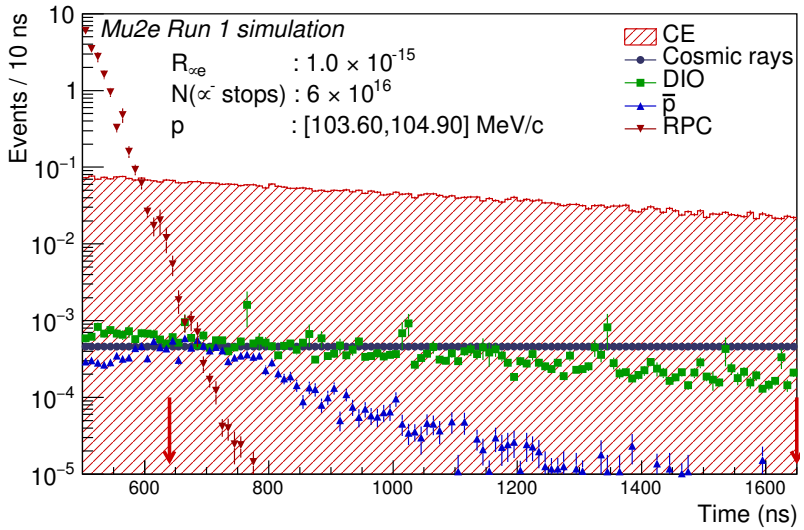
Mu2e Sensitivity (SU2020 Paper)





Channel	Mu2e Run I
SES	2.4×10^{-16}
Cosmic rays	0.046 ± 0.010 (stat) ± 0.009 (syst)
DIO	0.038 ± 0.002 (stat) $^{+0.025}_{-0.015}$ (syst)
Antiprotons	0.010 ± 0.003 (stat) ± 0.010 (syst)
RPC in-time	0.010 ± 0.002 (stat) $^{+0.001}_{-0.003}$ (syst)
RPC out-of-time ($\zeta = 10^{-10}$)	$(1.2 \pm 0.1$ (stat) $^{+0.1}_{-0.3}$ (syst)$) \times 10^{-3}$
RMC	$< 2.4 \times 10^{-3}$
Decays in flight	$< 2 \times 10^{-3}$
Beam electrons	$< 1 \times 10^{-3}$
Total	0.105 ± 0.032

- Decay In Orbit (DIO) and Cosmic Rays contribute ~equally to the background
- Sensitivity optimization requires N_{bkg} <<1

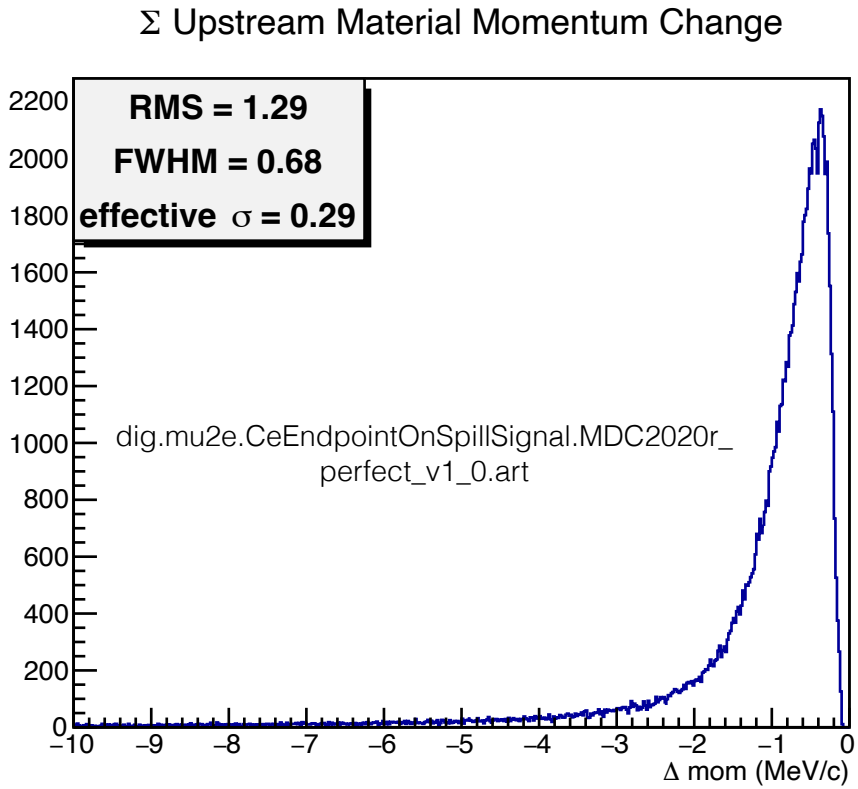
10X Improved Sensitivity Goal for Mu2e-II

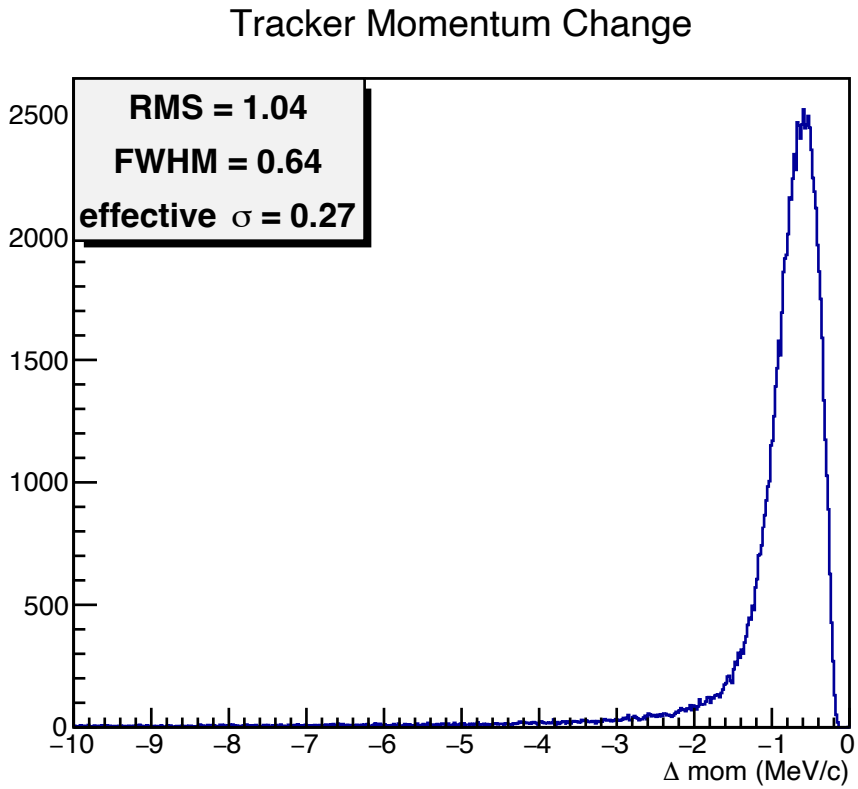
- Requires 10X stopped muons (assuming $N_{bkg}<<1$)
  - Assume 3X from increased rate, 3X from increased duty factor
- The DIO background scales with the muon stops
  - Will increase by 10X
  - To keep $N_{bkg}<<1$ the DIO rejection must be improved by a factor of ~5
  - **The track momentum resolution must be improved**
- The cosmic ray background scales with livetime
  - Will increase by 3X
  - Cosmic rays will no longer be the dominant background
  - Some rejection improvement will be needed to keep $N_{bkg}<<1$ (X2?)
  - Tracker/tracking improvements could help
    - Improved momentum resolution ⇒ smaller selection window
    - Improved upstream track finding ⇒ better reflection background rejection
    - Other track⇔CRV correlations might also be helpful

Tracker Momentum Resolution

- The Mu2e DIO background comes roughly equally from (Gaussian) core and high-side momentum resolution tails
- The resolution core is dominated by material effects:
  - Energy loss in upstream passive material
    - Stopping Target and Proton Absorber (IPA)
  - Multiple scattering in the straw walls
  - ⇒ **Improving the core resolution requires reducing or mitigating the effect of materials**
- The high-side tails are caused by reconstruction effects:
  - LR ambiguity mis-assignment
  - Non-Gaussian time-to-distance response
  - ⇒ **Reducing the high-side tails requires improving the reconstruction algorithms and/or the data they are fed**
    - General tracking resolution improvements will also help

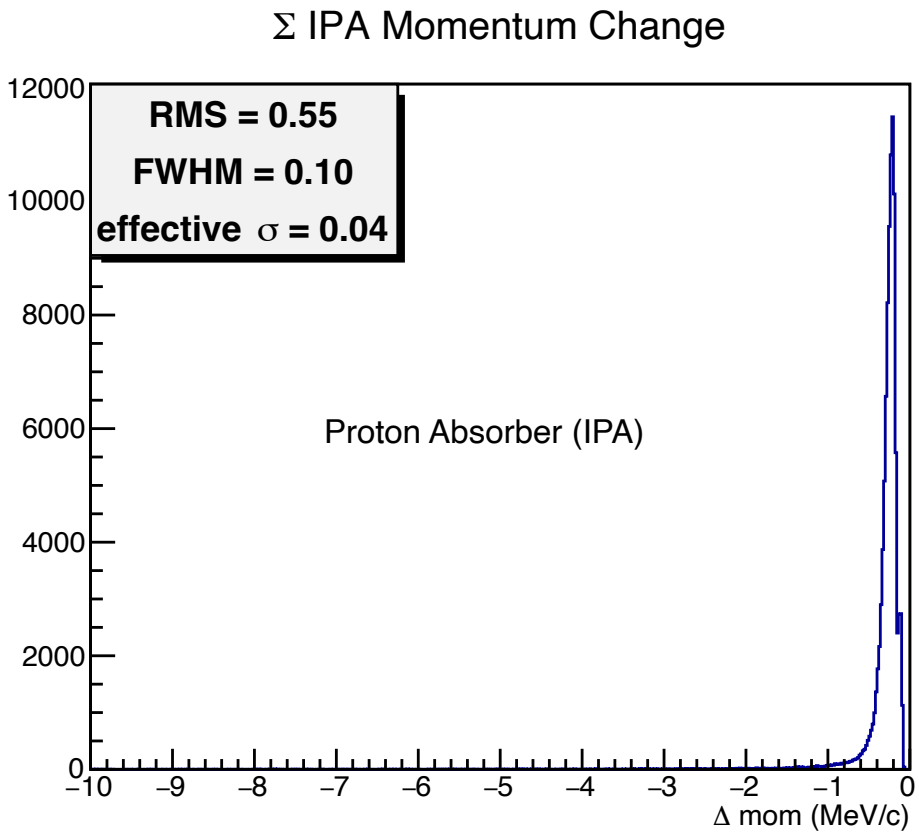
Material Impacts

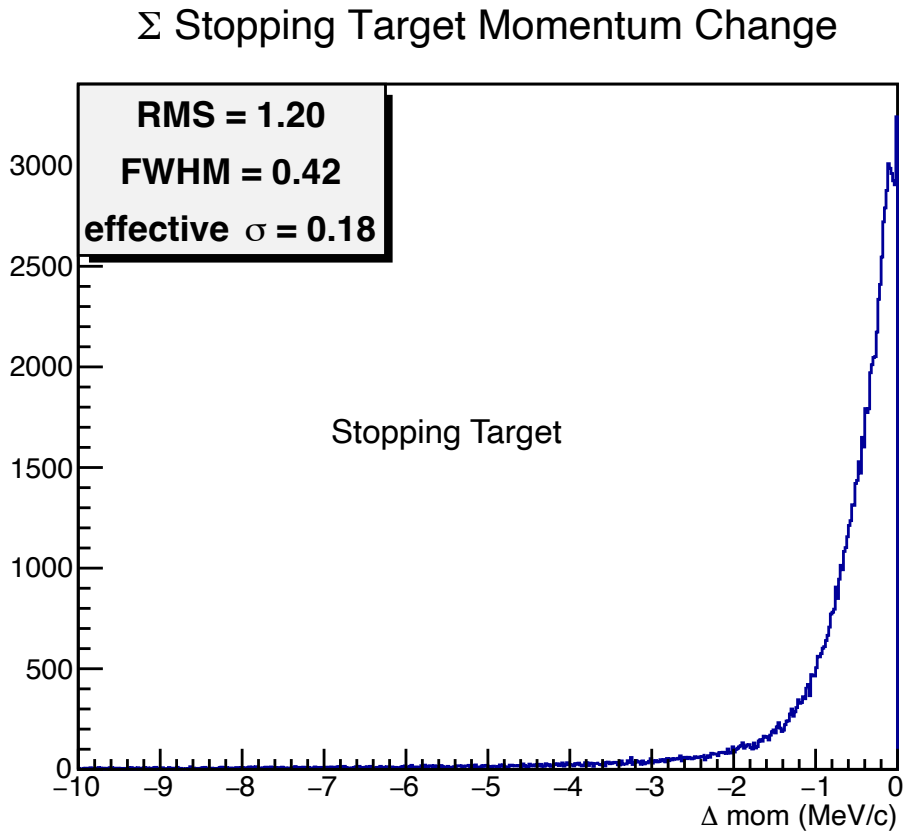




- Plots are from the detailed G4-based Mu2e simulation of Conversion electrons (Ce)
- Δmom = MC true change in the Ce momentum getting to (going through) the tracker
  - The core peak width defines the momentum resolution
  - Negative tails cause efficiency loss
    - minor impact on sensitivity
  - The mean value is mostly irrelevant (can be calibrated out)
- The Upstream material impact is roughly equal to the tracker material impact
  - Naively, both must be reduced to improve the resolution

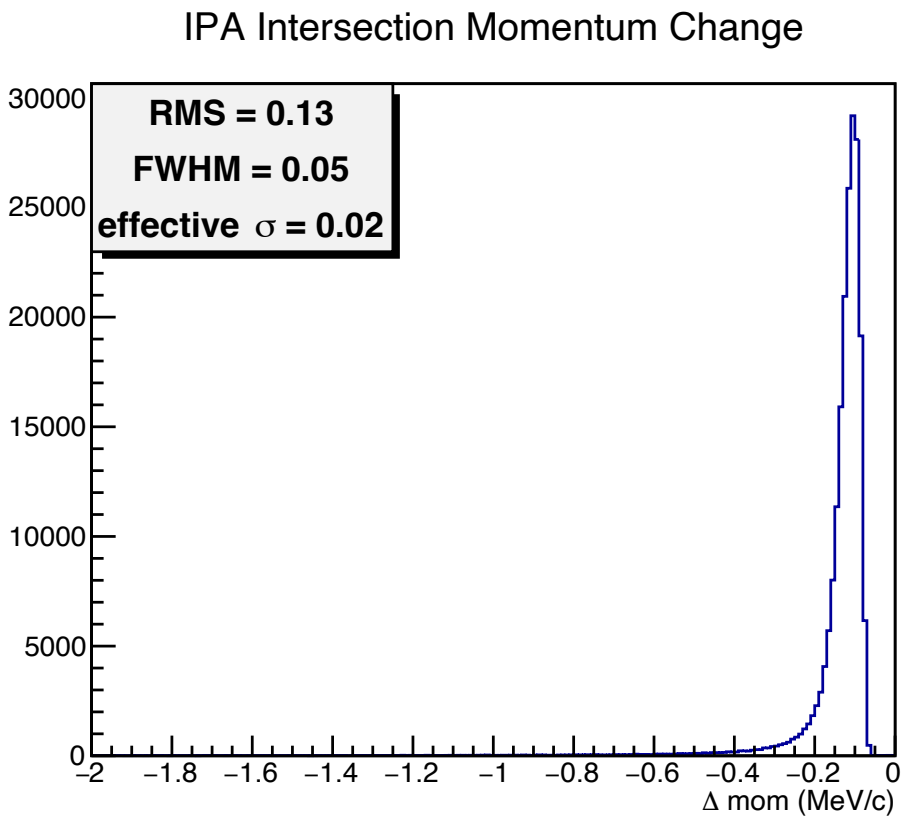
Upstream Material Impact

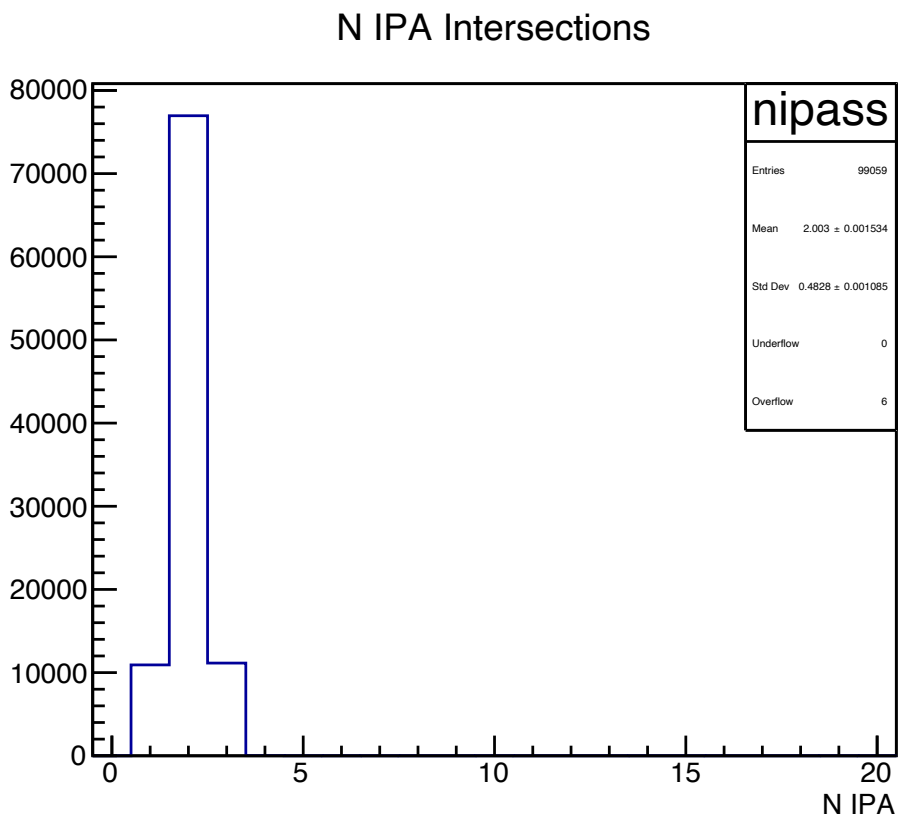




- The upstream material resolution is dominated by the stopping target
- The muon stopping rate is proportional to the target mass
  - We cannot improve the sensitivity by simply reducing the mass

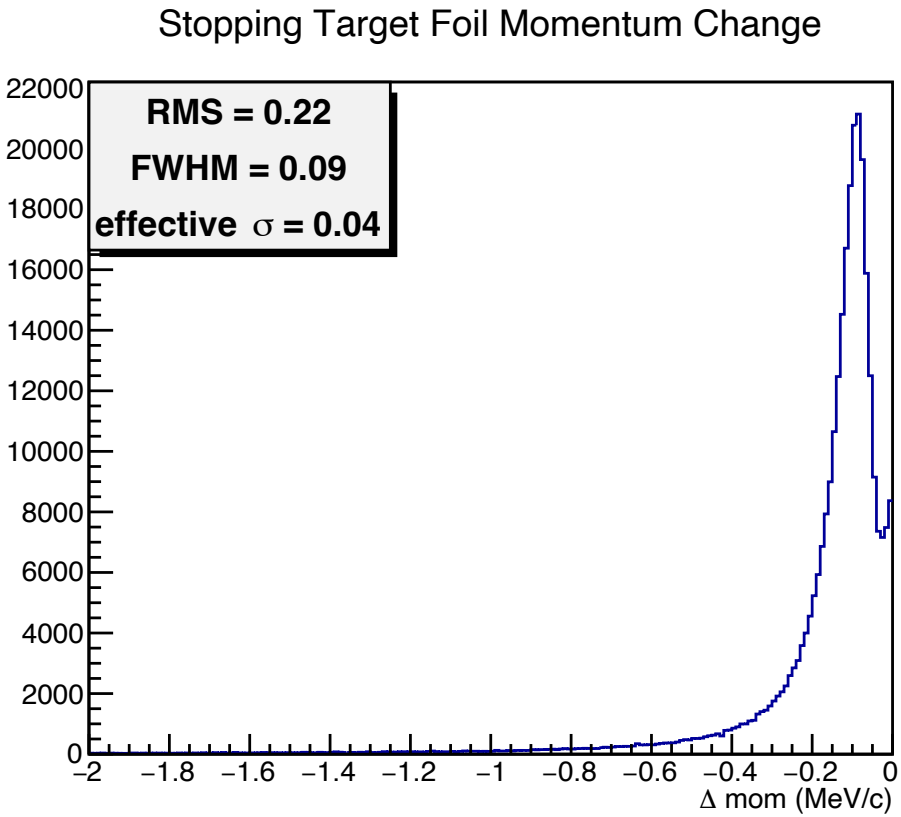
IPA Material Impact

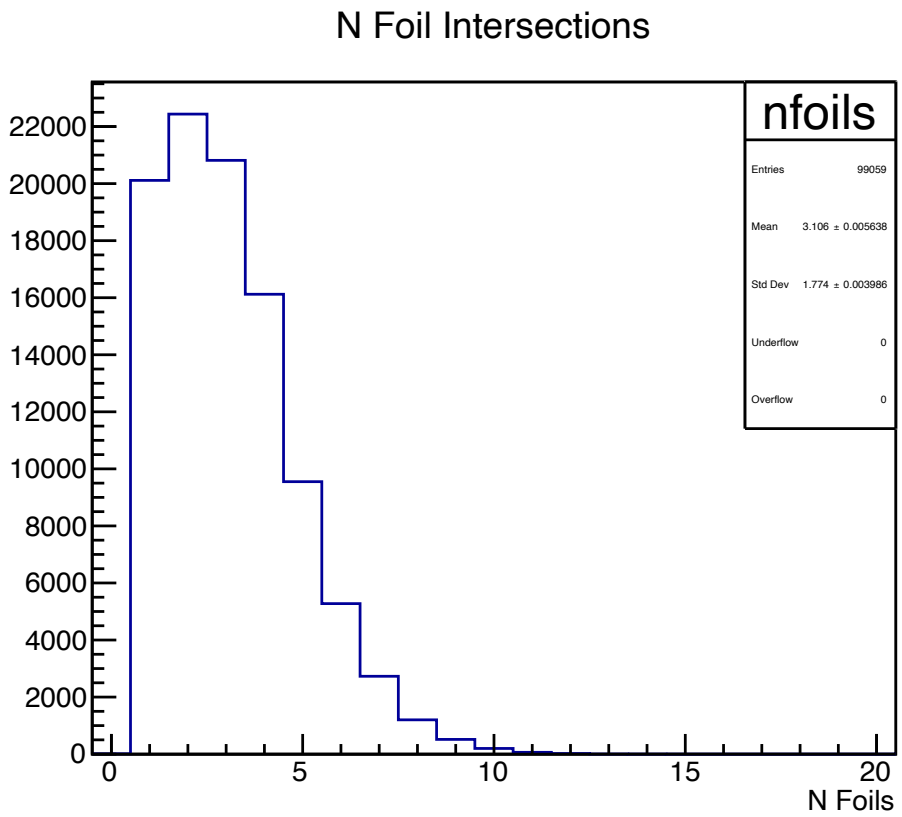




- Conversion electrons cross the IPA 2 ± 0.5 times
  - Each intersection contributes a small amount to the resolution
- The net impact is small since the number of intersections is ~constant

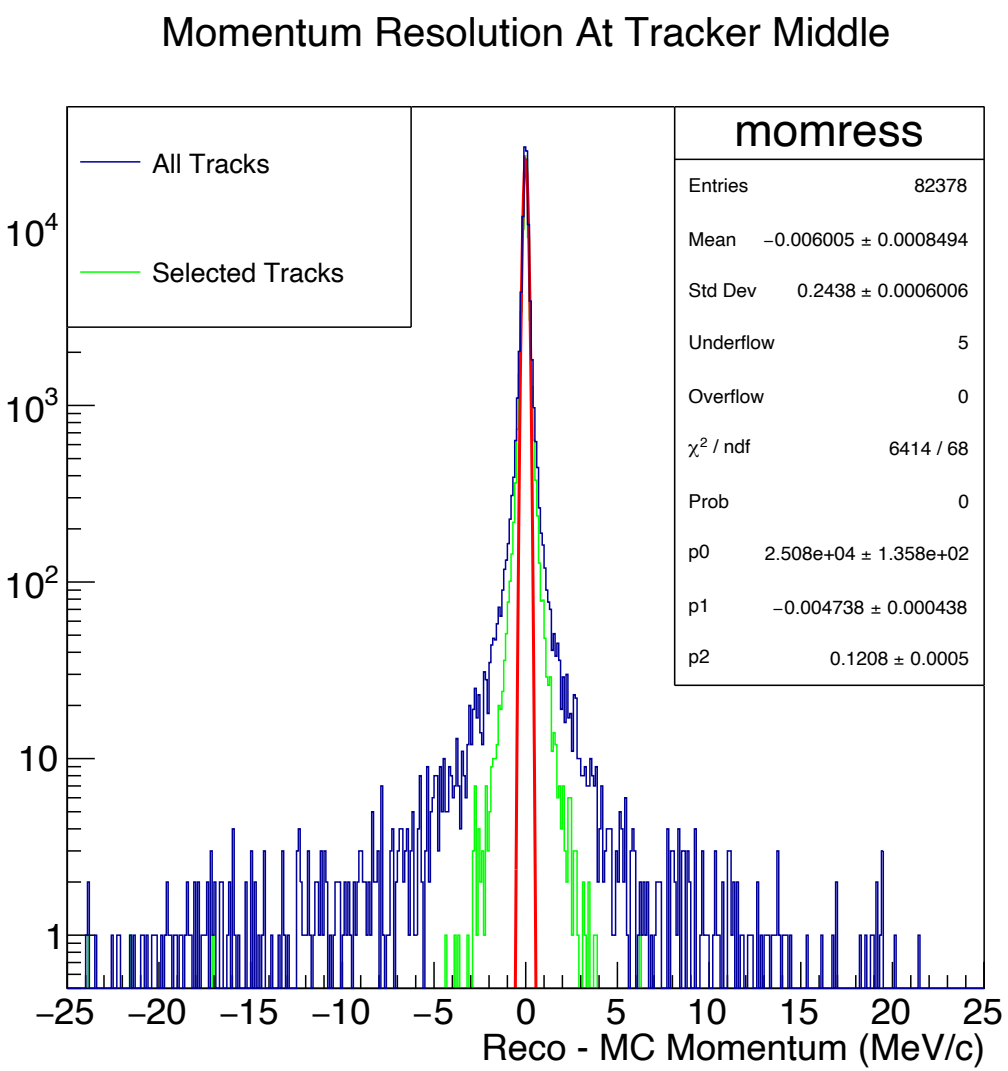
Target Material Impact





- Conversion electrons intersect 3.1 ± 1.8 target foils
  - Each foil intersection contributes a modest amount to the resolution
- **The target resolution is dominated by the variation in the number of crossings**
  - Variation in the crossing angle (material path) also contributes

Momentum Reconstruction Resolution



- The core resolution (120 KeV/c) is less than expected (270 KeV/c)
  - The fit corrects for energy loss in each straw crossing
    - Using the predicted trajectory
  - This removes the (dominant) resolution contribution due to **variation in the amount of material intersected**
- The resolution tails can be greatly reduced by fit quality cuts
  - RMS after selection is ~2X core resolution

How to Improve the Sensitivity (Tracker)

- Mitigate the target energy loss impact
  - **Predict the target material (number and paths of foil intersections) using the track fit**
  - **Optimize the target geometry for predicting the target energy loss**
  - Investigate how to improve the # of μ-stops/gm
    - Can the muon beam be optimized?
  - Actively count the target intersections
    - NB: the target foil energy deposition is not intrinsically useful as E_{ce} > critical energy
- Reduce the reconstruction artifacts causing high-side tails
  - **Improve the hit information quality and quantity**
  - Improve the drift calibration (T2D)
  - Improve the pattern recognition algorithm (LR ambiguity assignment)
  - Improve the track selection algorithms
- Reduce the tracker (straw) mass
  - Reduced mass will improve the fit quality and extrapolation accuracy
- Mitigate the IPA energy loss impact
  - Predict the material path using the track fit

Backup

Upstream Materials

Stopping Target (37 Al foils)

Proton Absorber (HDPE cylinder)

Other Tracker Requirements

- Must be buildable and operable
- Acceptable radiation damage to wires
  - Increase C/cm tolerance or reduce charge load
- Acceptable radiation damage to electronics
  - Increase rad hardness or reduce (photon) fluence
- Acceptable pileup
  - Increase TDAQ pileup tolerance or reduce pileup rate