Comparison of muon trajectory reconstruction methods with detailed track simulations for track reconstruction optimization

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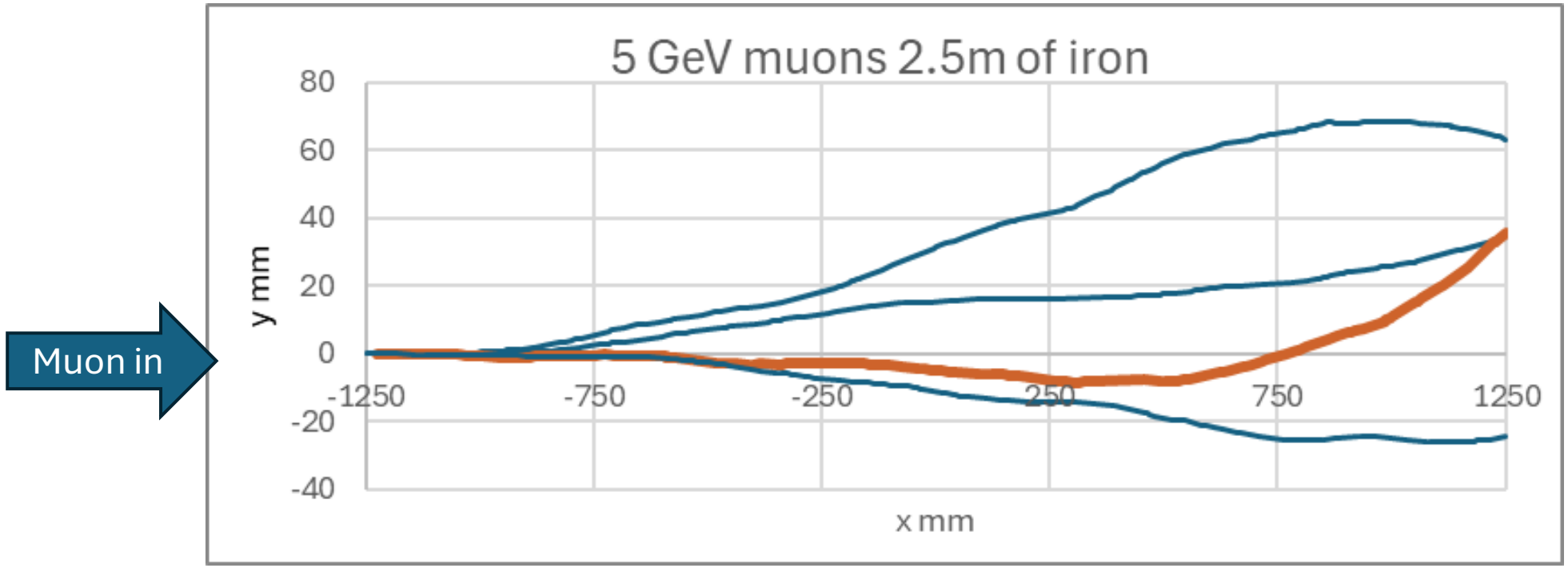
The problem

Trying to reconstruct entire muon path with minimal information

- Entrance position and angle
- Exit position and angle (extract total scatter angle)



Simulation study using Geant4 and MC-10 cask test bed with Giant Muon Tracker (GMT) array

GMT array

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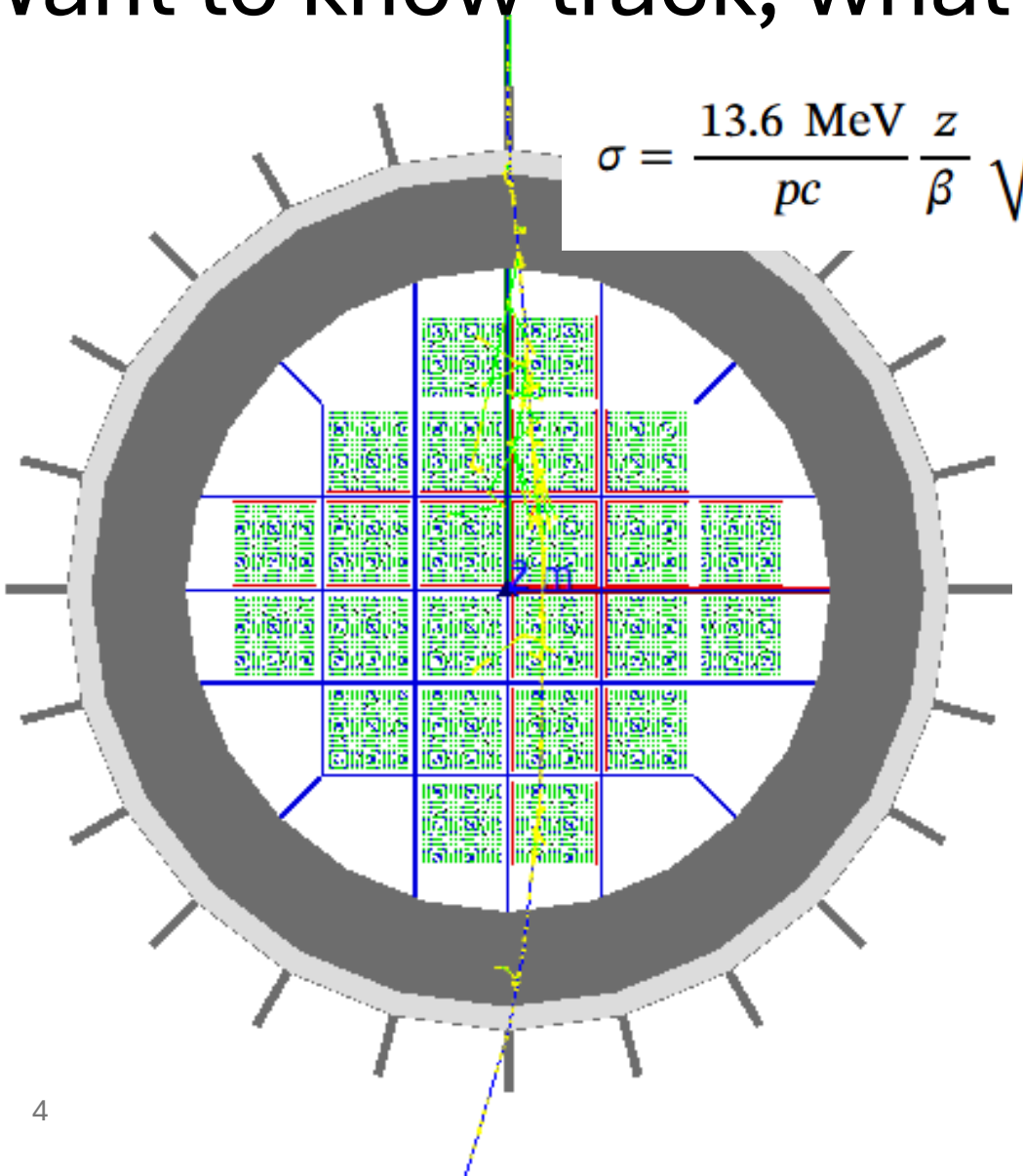
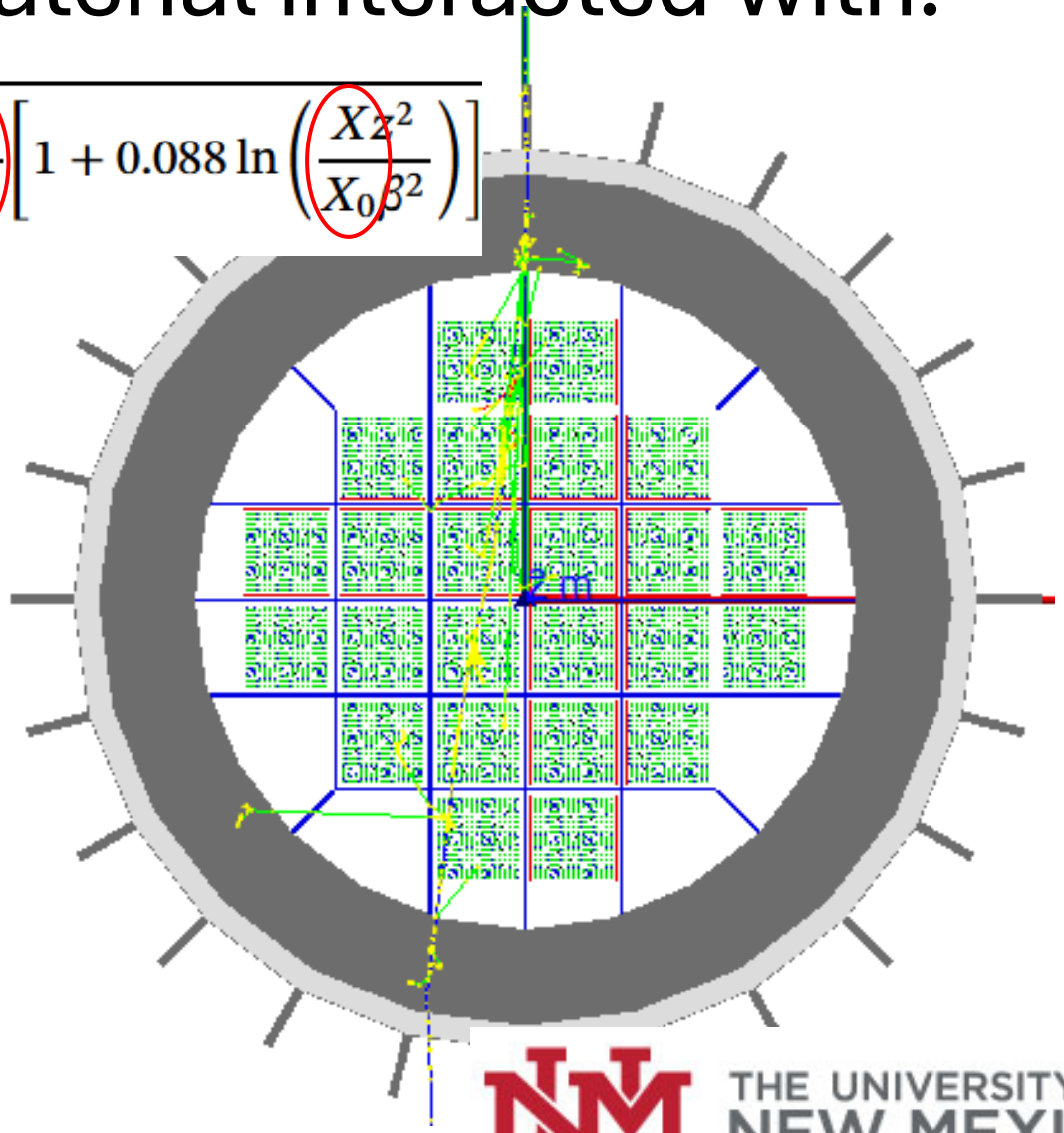
Simulation in spent nuclear fuel (SNF) cask
Want to know track, what material interacted with.

$$\sigma = \frac{13.6\ \text{MeV}}{pc}\frac{z}{\beta}\sqrt{\frac{X}{X_0}\left[1 + 0.088\ln\left(\frac{Xz^2}{X_0\beta^2}\right)\right]}$$





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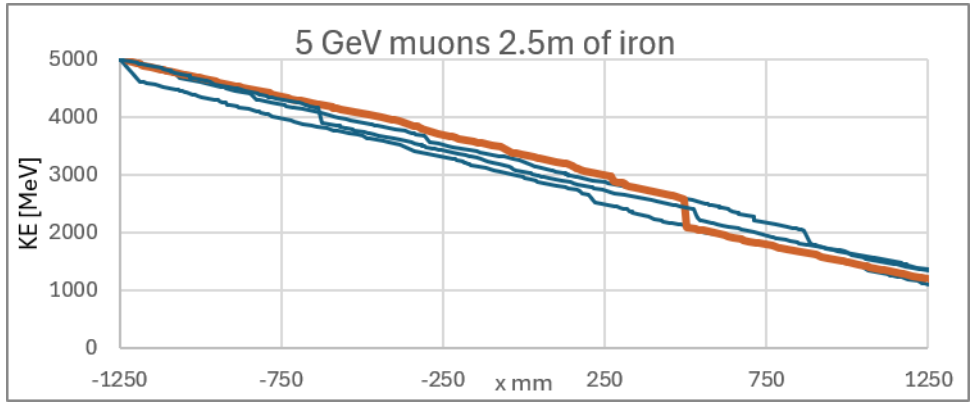
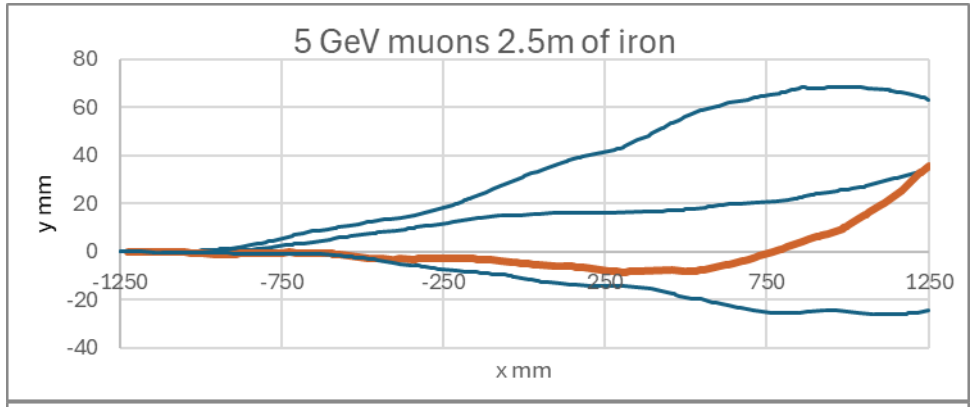
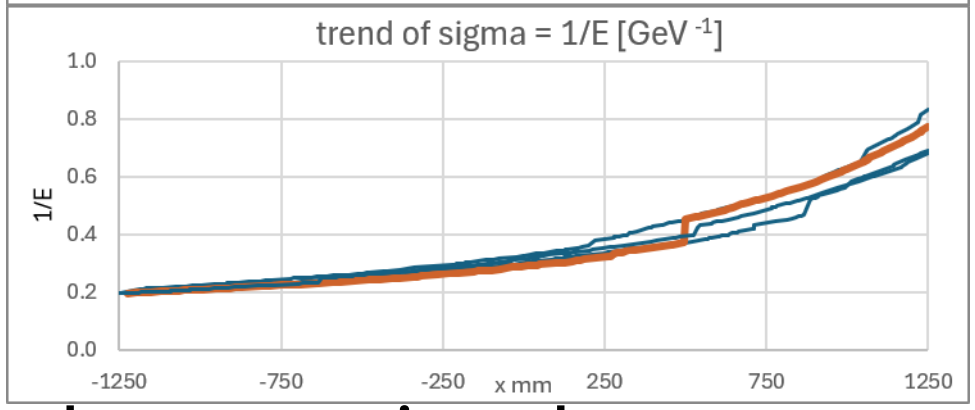
More scatter per cm with lower kinetic energy – as muon slows

$$\sigma = \frac{13.6\ \text{MeV}}{pc}\frac{z}{\beta}\sqrt{\frac{X}{X_0}\left[1 + 0.088\ln\left(\frac{Xz^2}{X_0\beta^2}\right)\right]}$$

Straighter at higher energies, more curved at lower energies (more angle deflections)



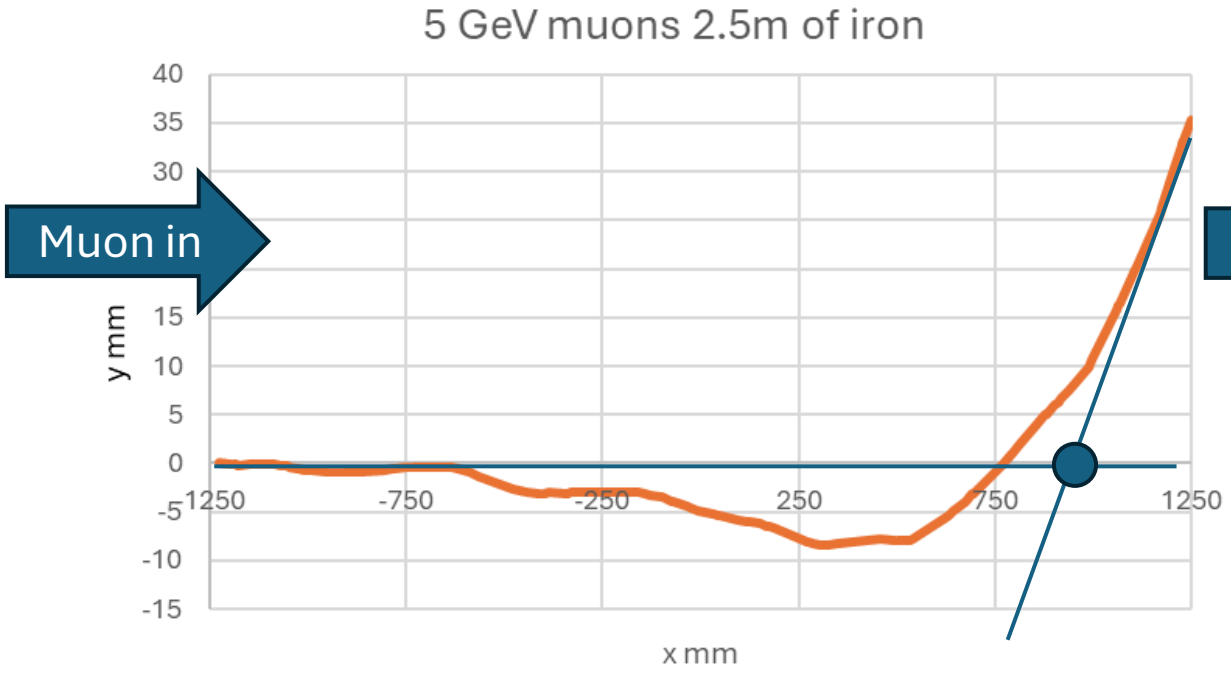


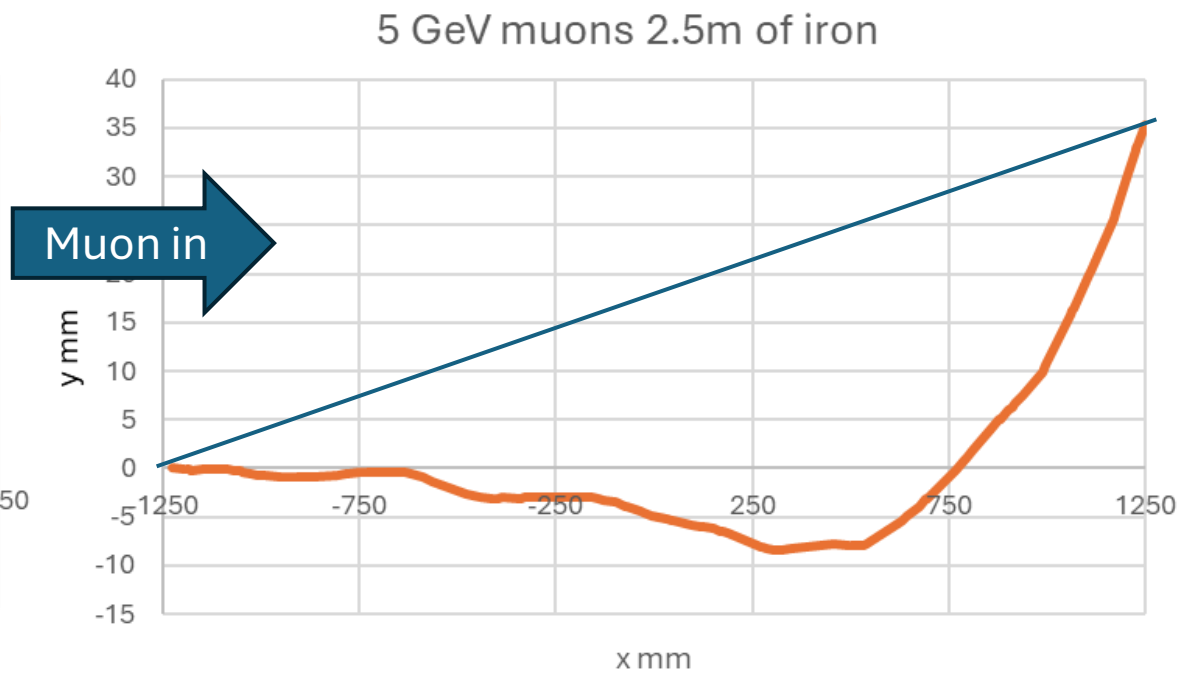


Nearly constant rate of energy loss
$\beta \sim 1$ and $(pc) \sim E\ (=KE + mc^2)$

Realistically we don't know the energies, but can predict general behavior. Need approach based on knowns.

Known = entrance/exit positions and angles
Different approaches to reconstructing track





Using entrance/exit position and angles.
Point of closest approach (POCA)
Just gives one point.

Using entrance/exit positions.
Straight line between entrance and exit points
Can do much better.

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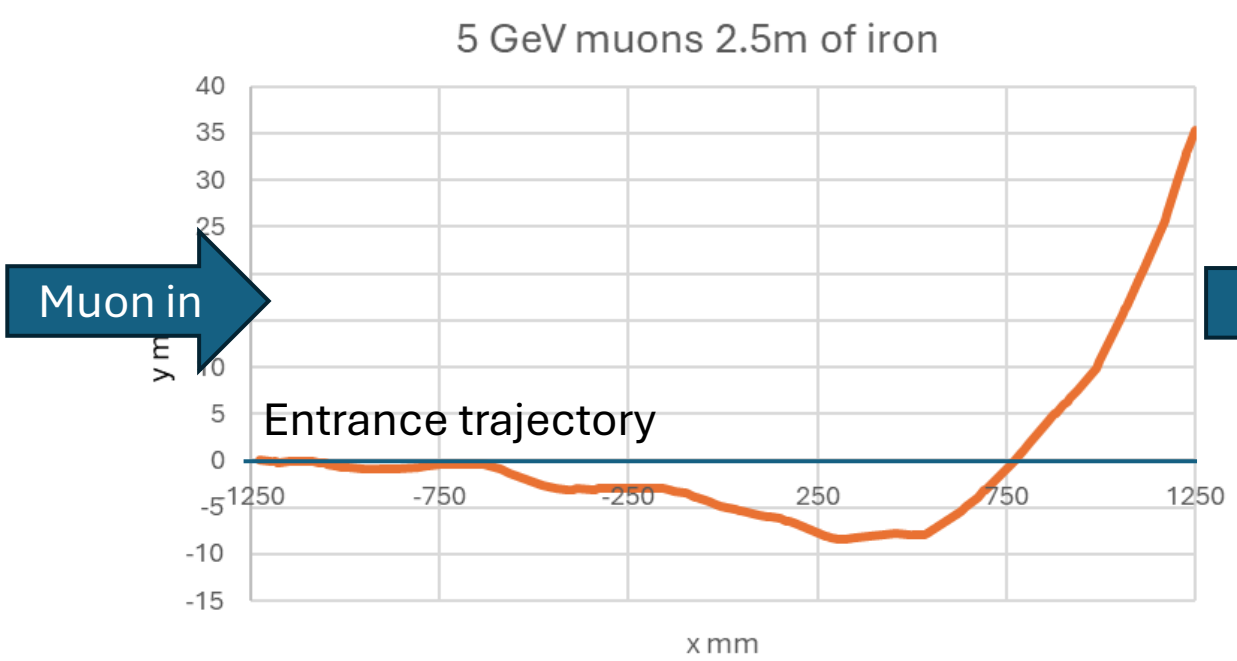
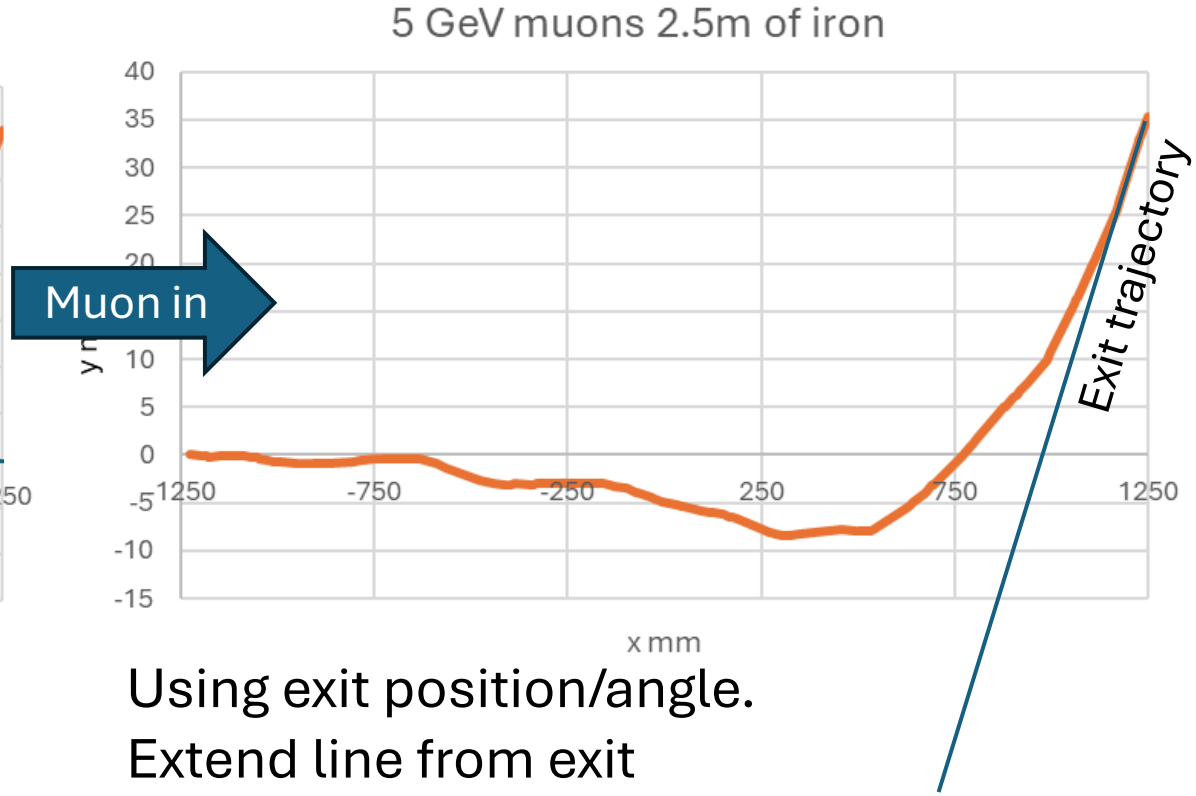
Known = entrance/exit positions and angles
Different approaches to reconstructing track



Using entrance position/angle.
Extend line from entrance
Good near entrance, worse further in



Using exit position/angle.
Extend line from exit
Good near the exit side… but
Residual gets big **very quickly**

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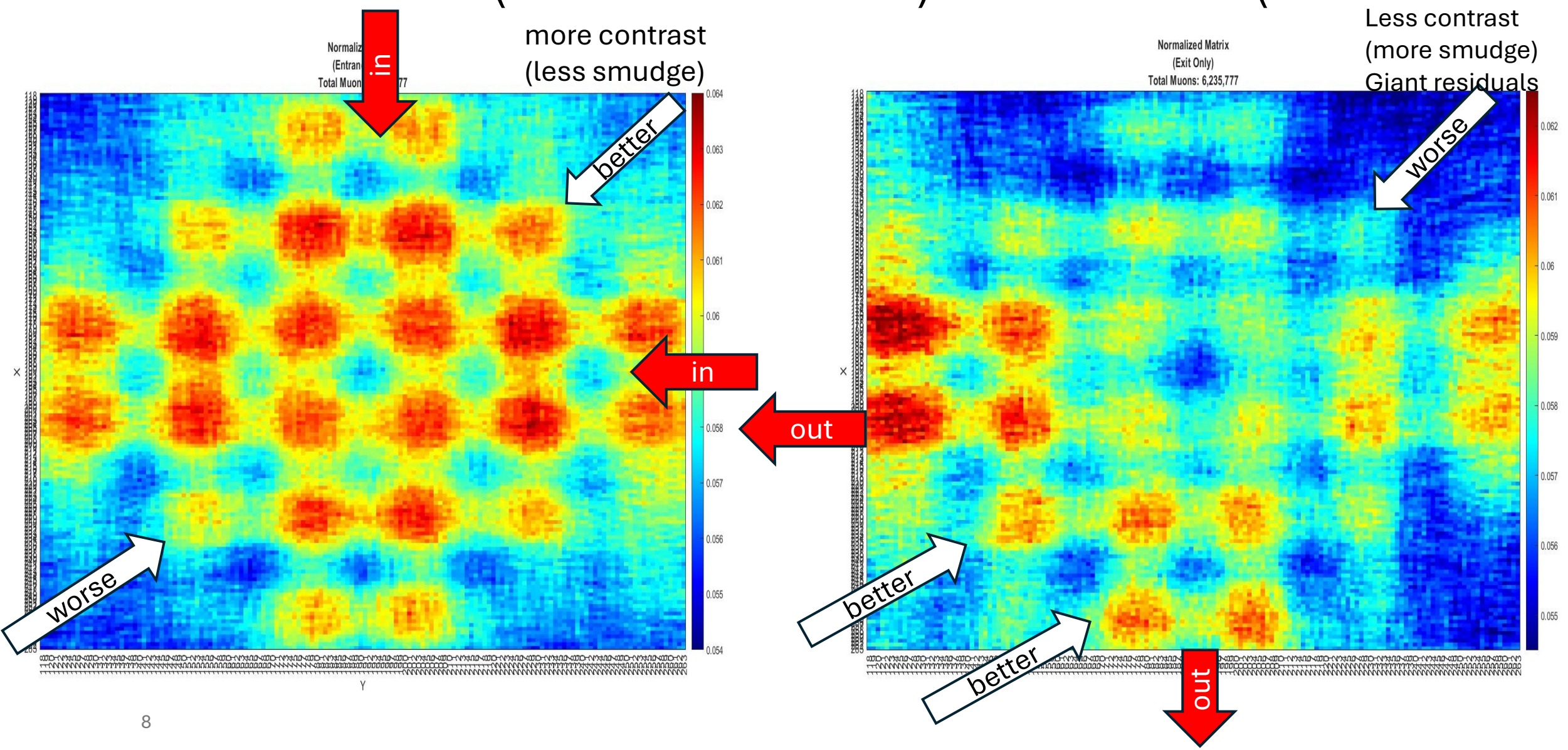
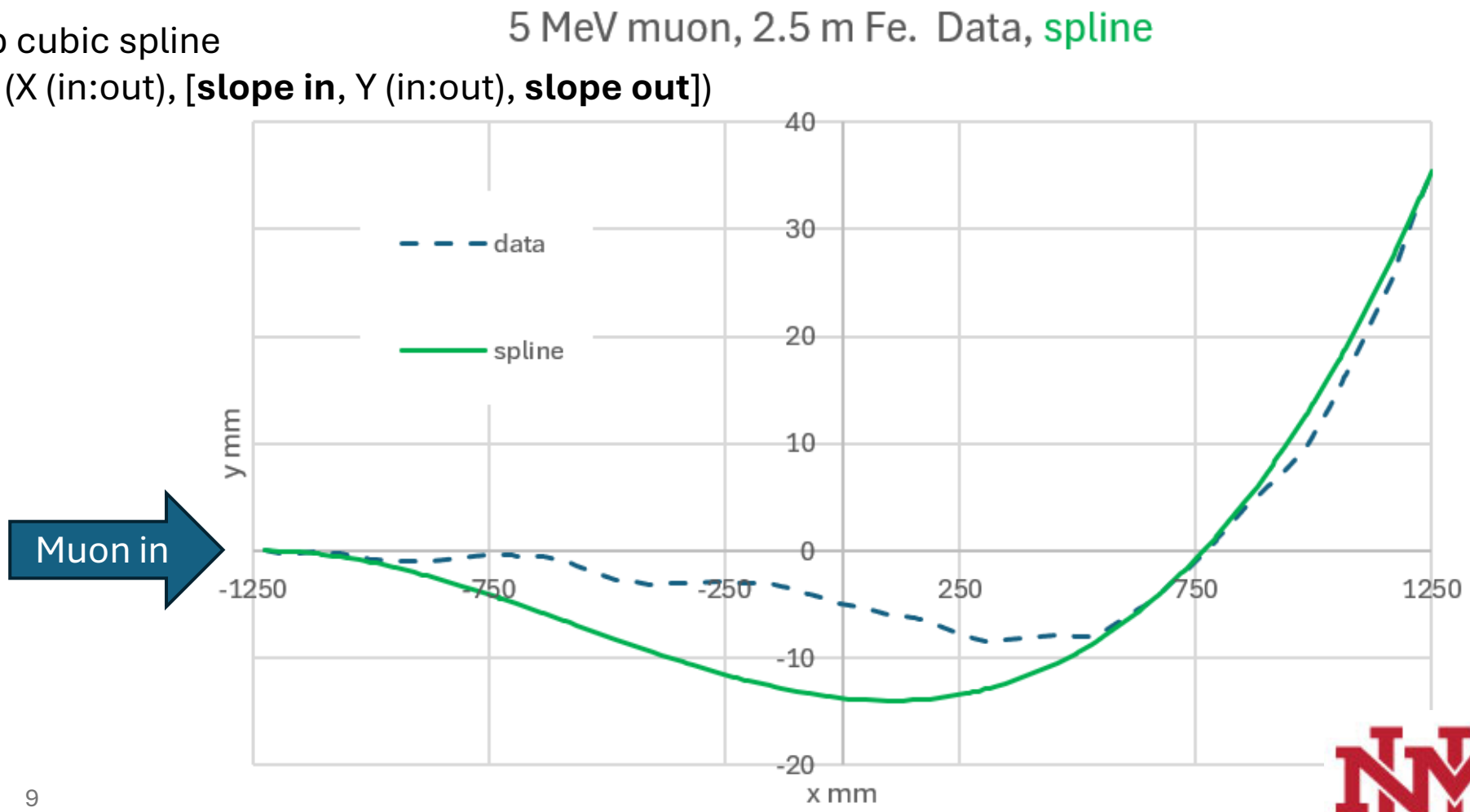
Straight line reconstruction in cask

from entrance detector (better near entrance) or exit detector (better near exit)



So combine entrance and exit information using spline that follows entrance and exit positions/angles. (can be better near center)

Matlab cubic spline
Spline (X (in:out), [**slope in**, Y (in:out), **slope out**])



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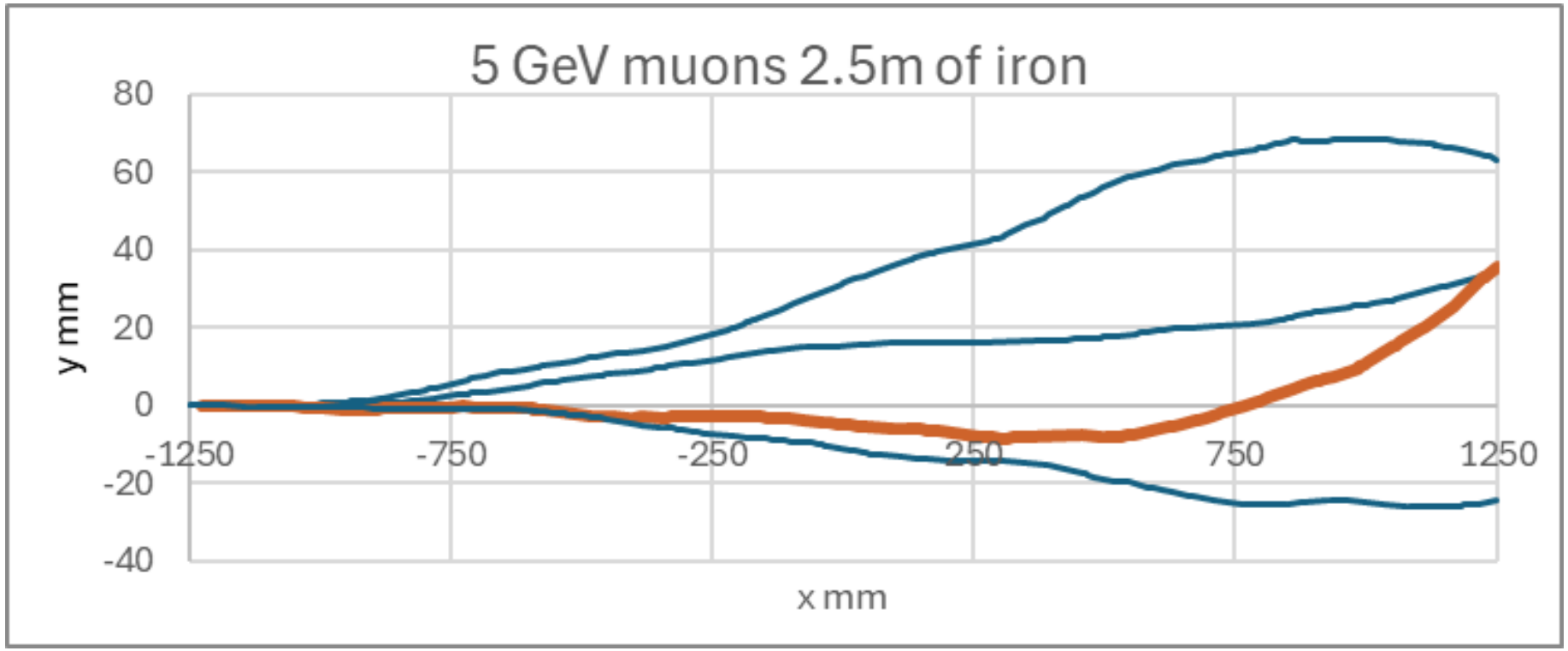
Reminder, more curved near the end.
More line like at the beginning, more spline like at the end.
Let's use that physics.



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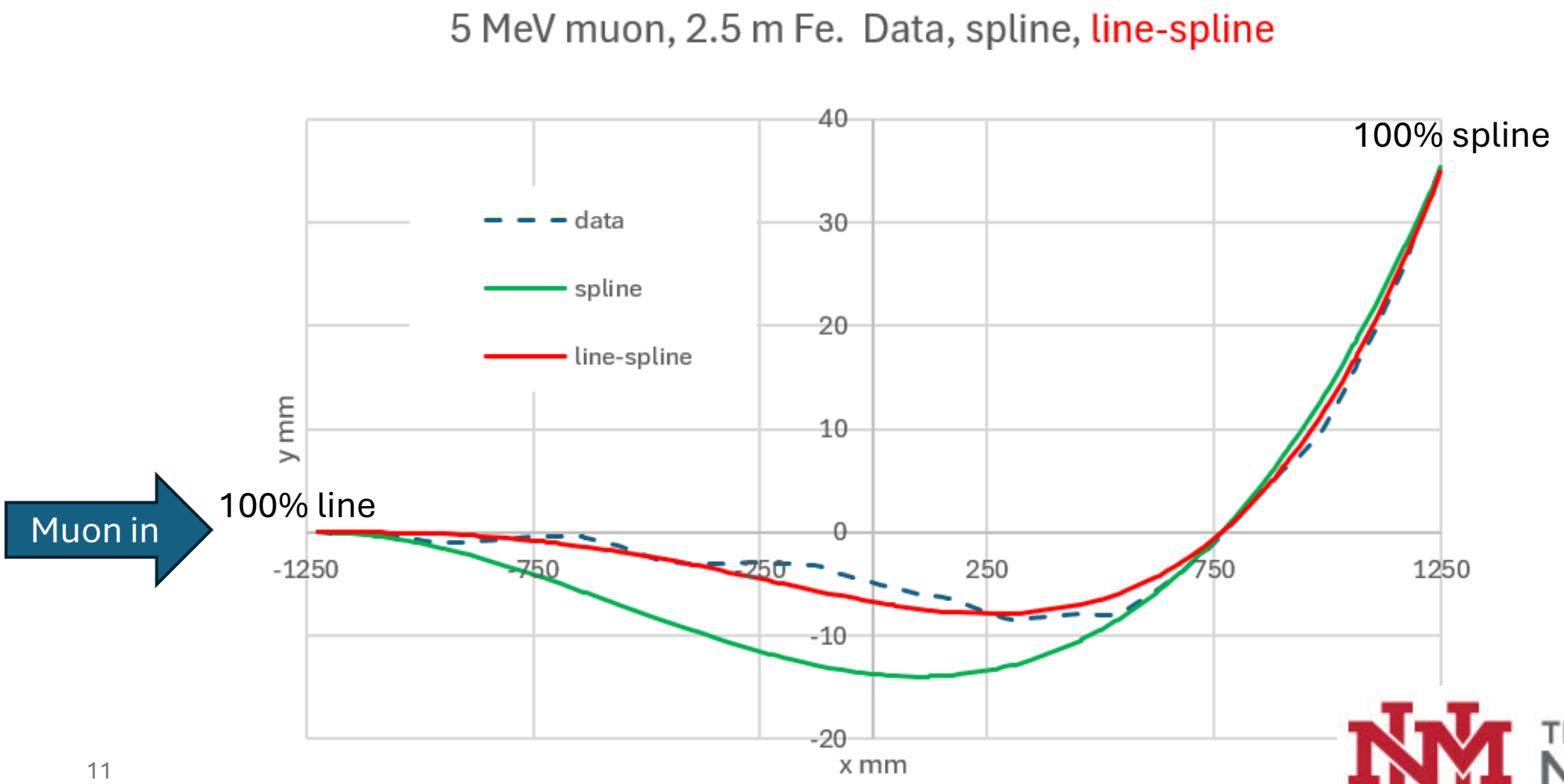
Straighten entrance by weighting with line "line-spline"

(line function)*(distance weight) + (spline function)*(1-distance weight)



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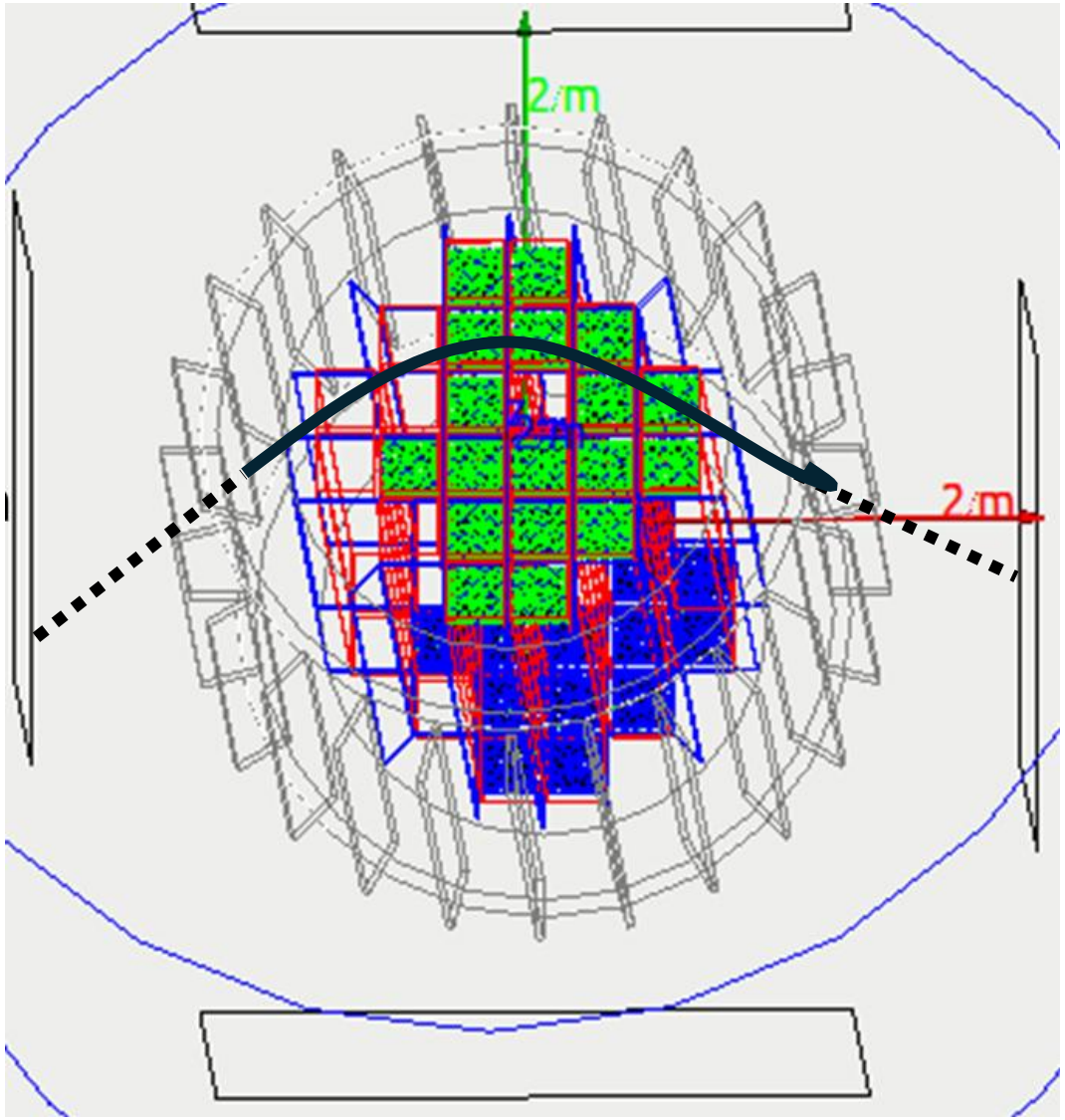
Also, use knowledge of environment.

Assume straight line in air between detector and cask, approximate scatter (spline, etc) happening only inside of cask



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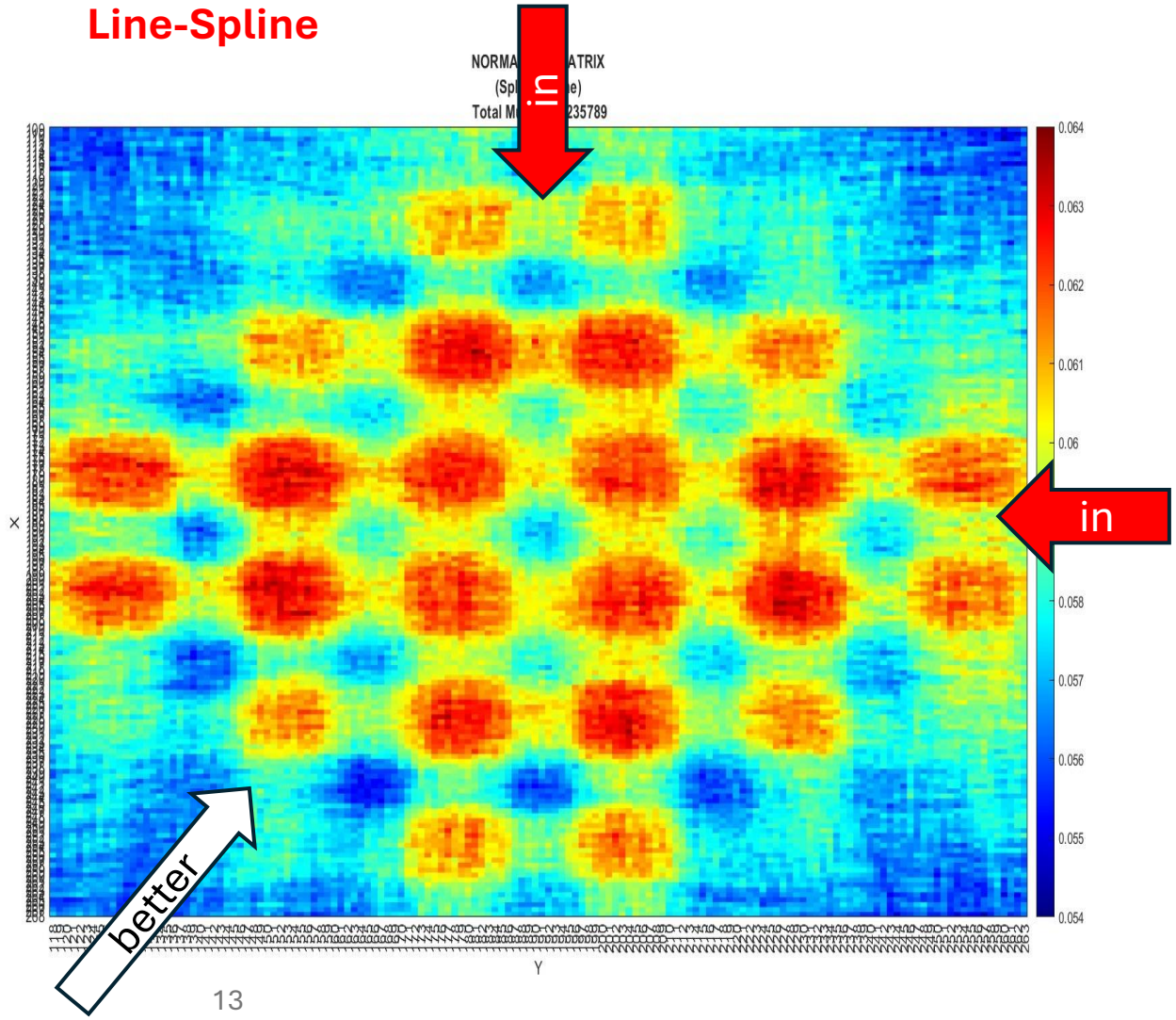
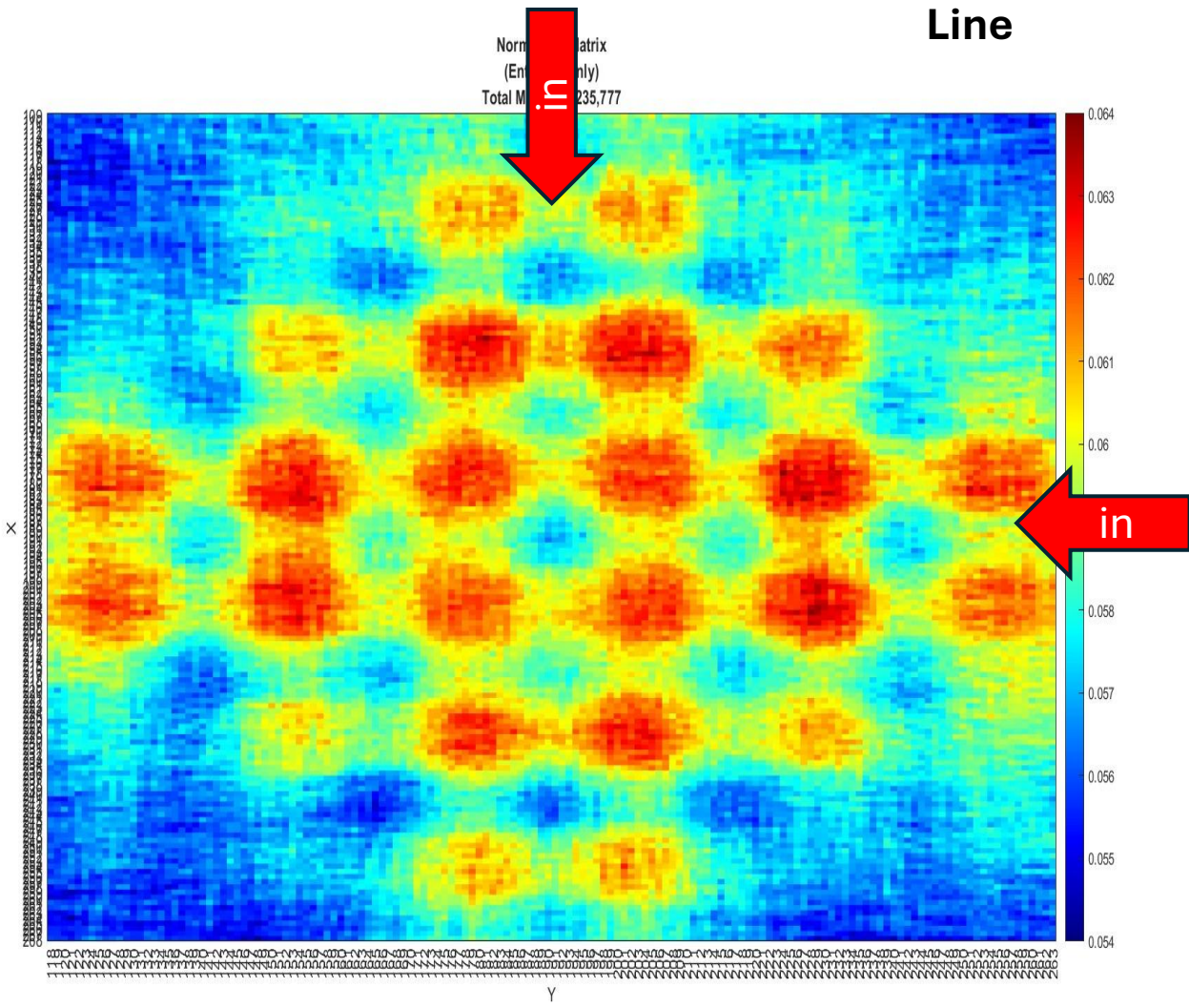
Line-Spline vs Line from entrance.

Line-Spline



Line

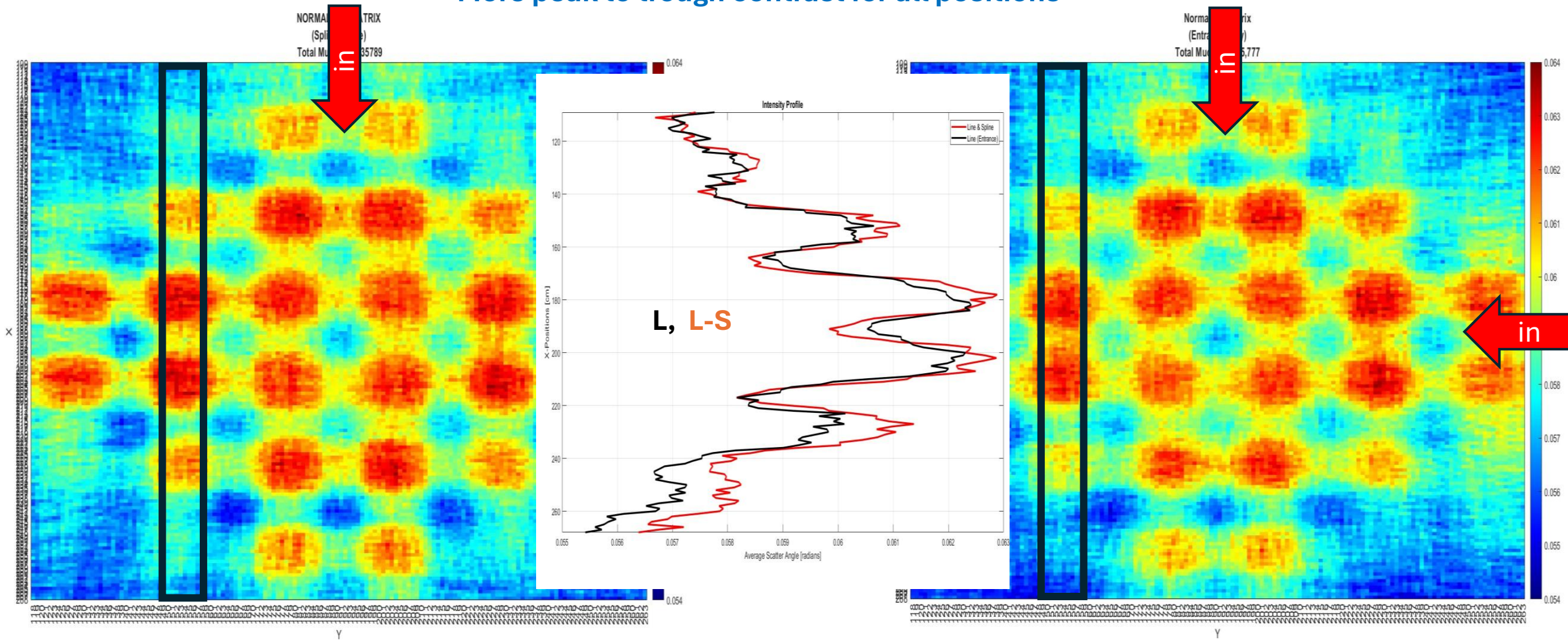


Line-Spline vs Line from entrance. Intensity profile.

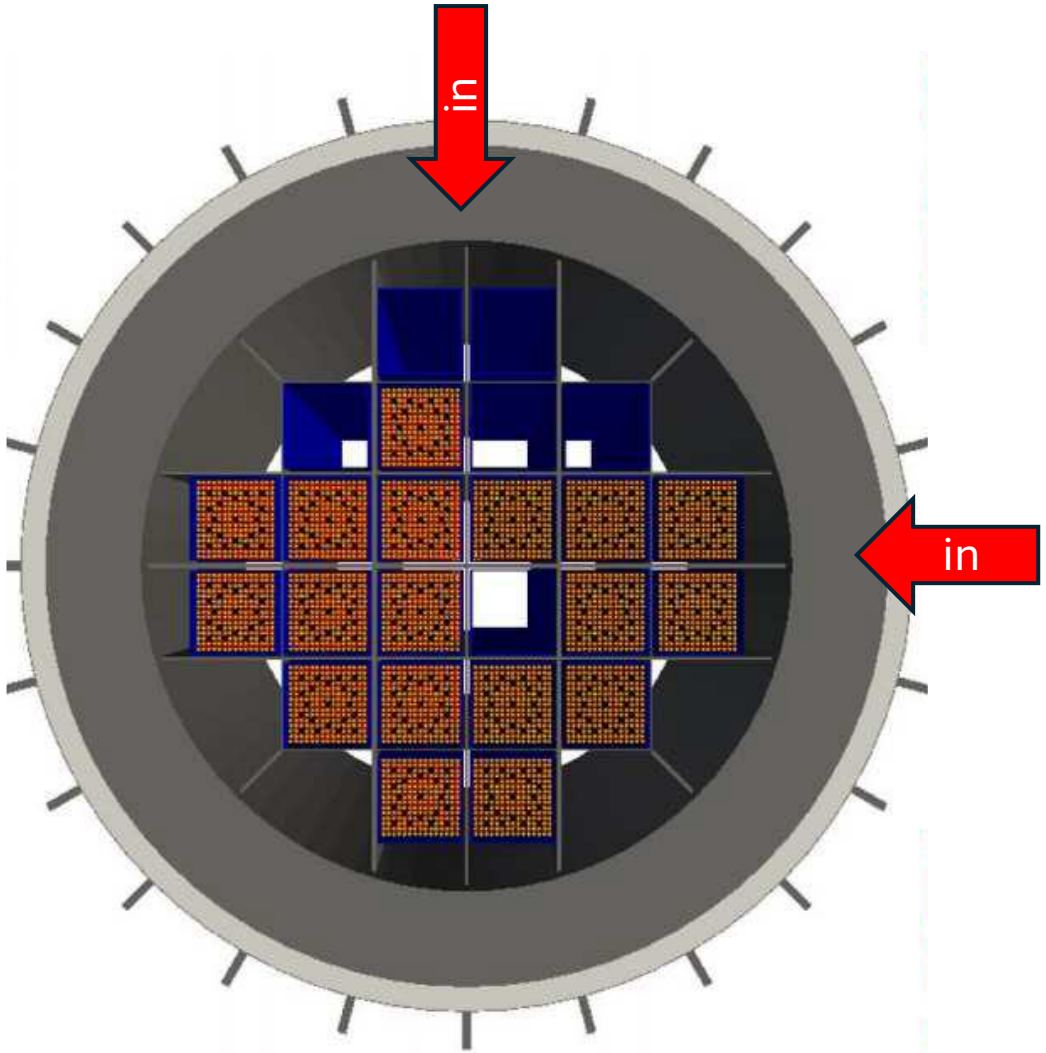
Greater intensity for bundles at exit side (bottom, left)
More peak to trough contrast for all positions

Line-Spline

Line



Experimental Work: Imaging partially filled MC-10 cask at INL with GMT array



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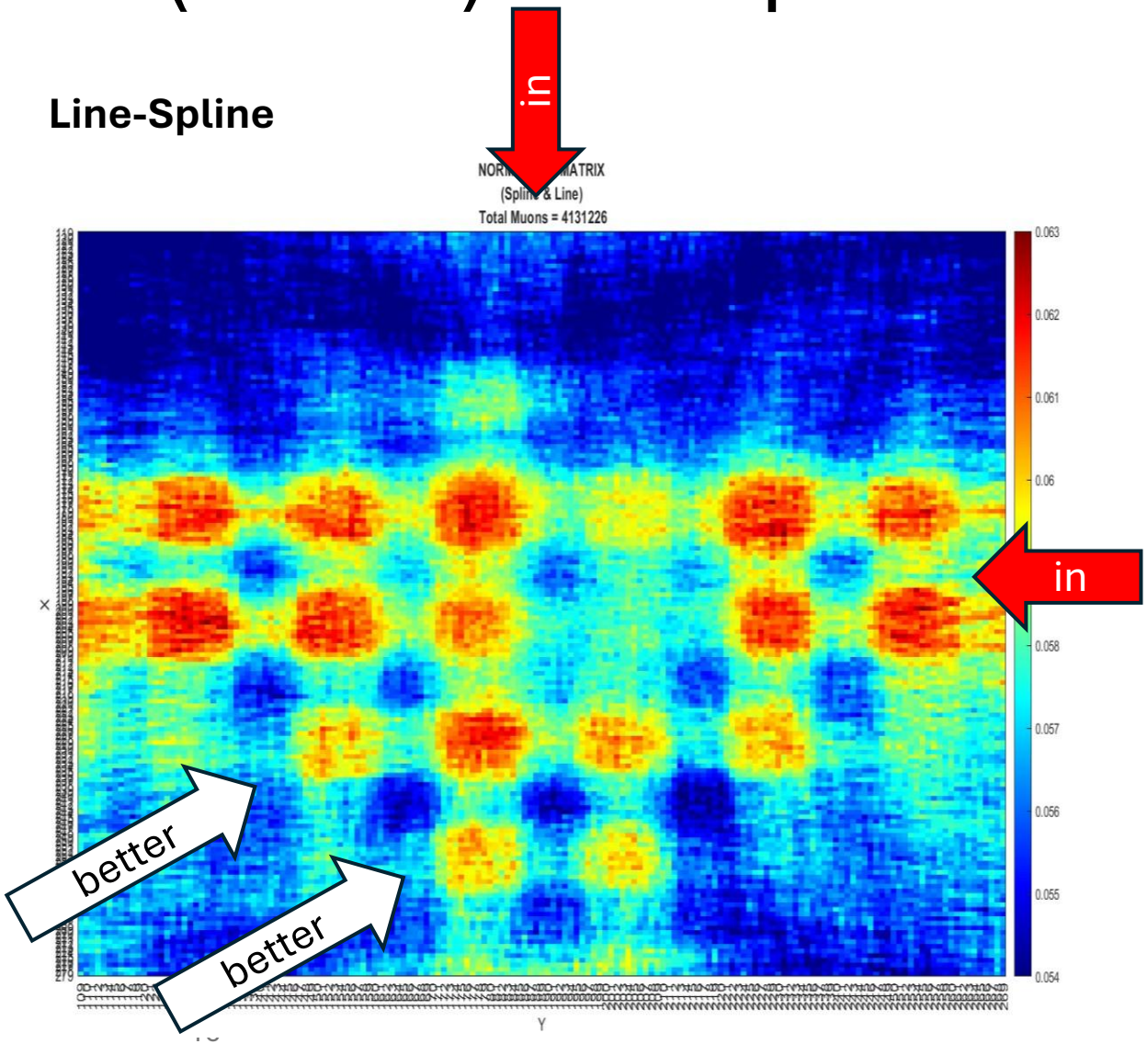
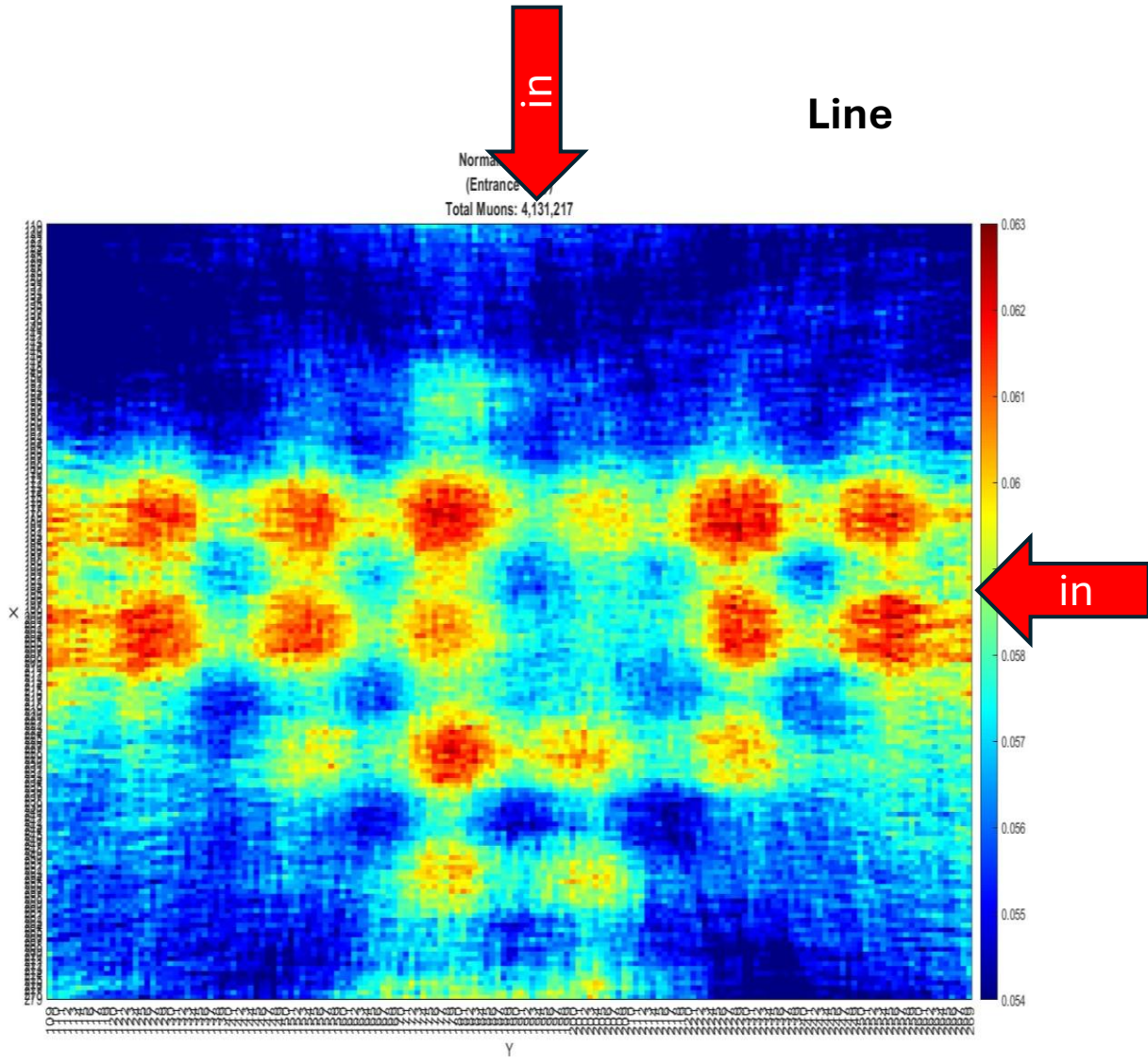
(MC-10) Line-Spline vs Line from entrance.

Line-Spline



Line



Conclusion

Used entrance/exit positions/angles AND physics informed curvature to reconstruct muon tracks – no knowledge of E needed

Line-Spline technique

- Great fit against Geant4 simulations of tracks
- Improves image reconstructions from simulated data

Working on application to experimental data