Approximately Optimizing ND-GAr-Lite Scintillator Spacing

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ND-GAr(-Lite) Meeting
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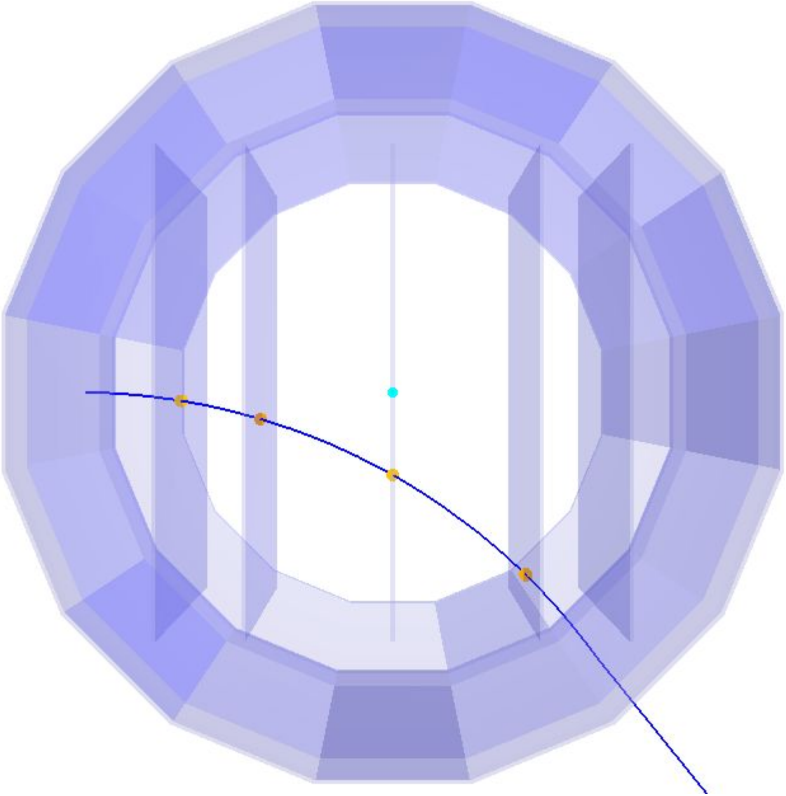
ND-GAr-Lite Nominal Design

Currently the ND-GAr-Lite reconstruction requires three hit scintillator planes for a track to be reconstructed.

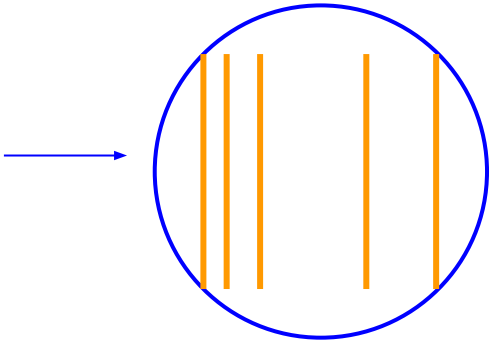
The base design has planes at the following positions z = {-240, -150, 0, 150, 240} cm, where 0 is the center.

Low momentum muons will bend enough to fall short of hitting the third plane and not qualify for reconstruction.



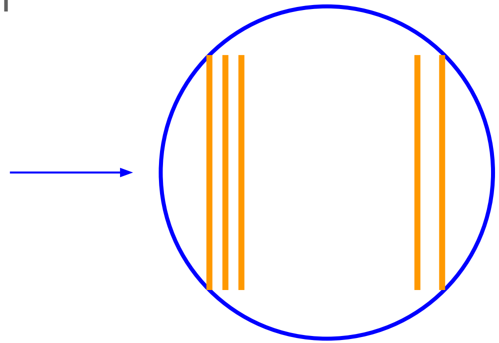
How to improve? Efficiency vs. Resolution

Increase efficiency/acceptance for low momentum muons by adjusting the scintillator plane spacing -- closer planes at the upstream end.



Adjusting the plane spacing will affect the momentum resolution, primarily by changing the lever arm available for measuring a track.

Some spacing configurations can make the efficiency or resolution better/worse for particular momentum ranges.



Method

Using the true trajectory information for a sample of muons that reach ND-GAr from ND-LAr.

- For each MC trial, estimate the efficiency and momentum resolution for a proposed plane spacing using the muon sample.
- The proposed plane spacing fixes the first plane and places the other four planes randomly within ND-GAr-Lite.
- Efficiency is estimated by how many tracks “hit” three or more scintillator planes.
- Momentum resolution is estimated using the Gluckstern formula.

Repeat many times and build an efficiency vs. resolution graph.

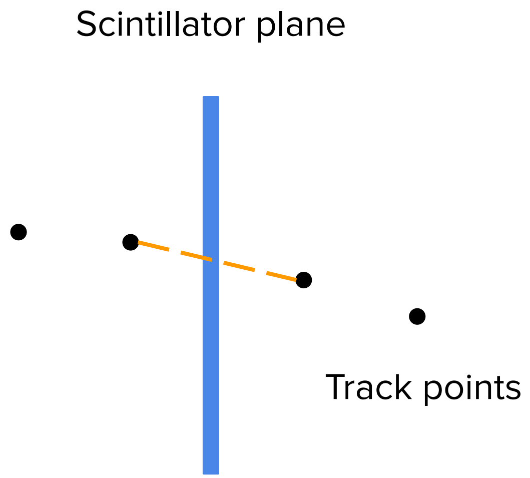
Intersecting Planes

Given a 3D line and a 2D plane, calculate the point where the line intersects the plane (if at all).

Find the true muon trajectory points in front and behind the first scintillator plane.

Draw a vector between them and calculate the intersection with the (infinite) scintillator plane.

Check if intersection falls within the scintillator boundary, and register a “hit” if true.



Gluckstern Approximation

Using the Gluckstern formula to approximate the transverse momentum resolution due to measurement errors.

$$p_T = \sqrt{p_y^2 + p_z^2}$$

$$\frac{\delta p_T}{p_T} = \sqrt{\frac{720}{N+4}} \left(\frac{\sigma \, p_T}{0.3 B L^2} \right)$$

Where **N** is the number of planes hit, **sigma** is the position resolution (3 mm), **B** is the magnetic field (0.5 T), and **L** is the distance between the first and last measurement point (the lever arm).

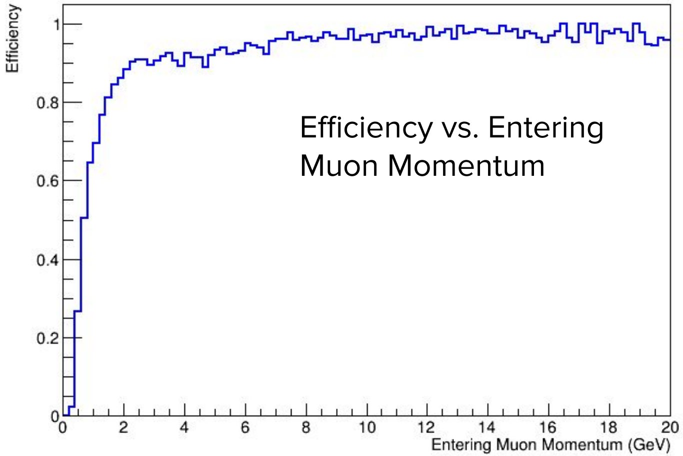
There is no multiple scattering contribution at the moment; unsure what to use for the scattering length (X0) and material thickness (and the proportionality constants in front).

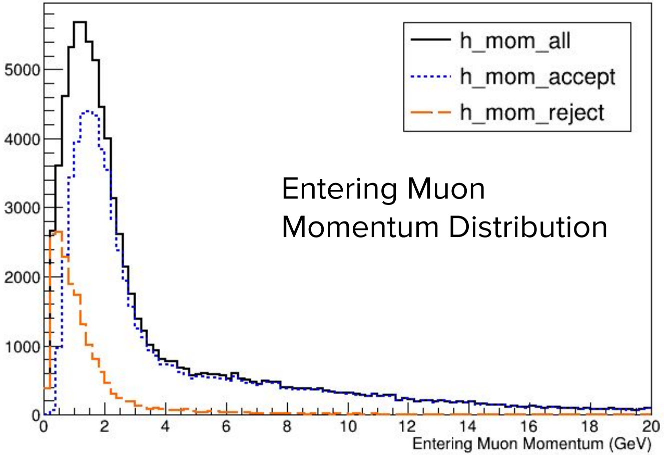
Nominal Configuration

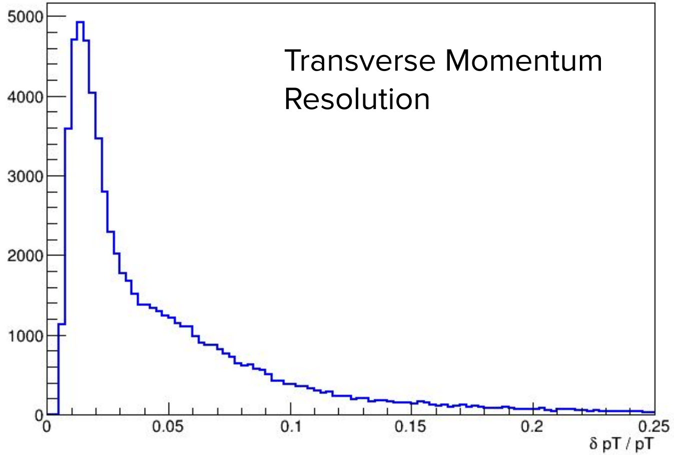
Performance metrics for the nominal configuration with planes at z = {-240, -150, 0, 150, 240}.

Efficiency as expected drops off sharply at around 1-2 GeV momentum (total efficiency about 79.2%).

Resolution distribution peak is about 1.5%, but with a fairly large tail (average is about 5.3%).







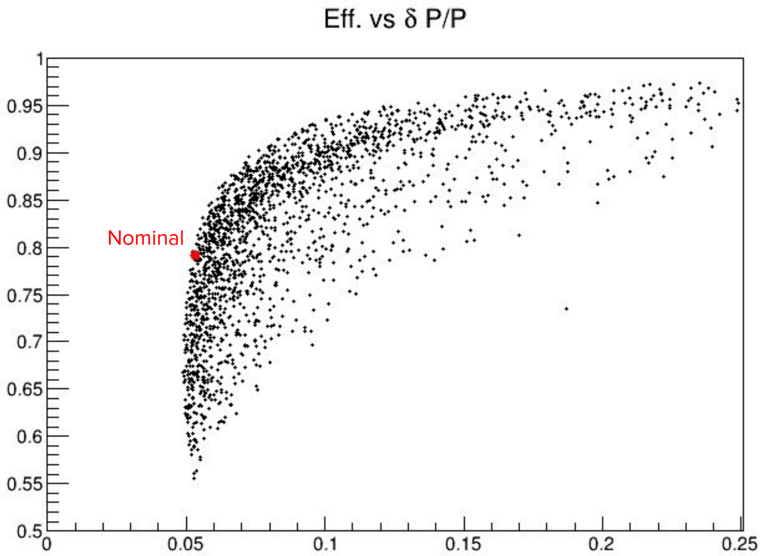
Efficiency vs. Resolution

Results from 2000 proposed scintillator plane arrangements.

Plotting the total efficiency and average momentum resolution for all "reconstructed" tracks.

These metrics are flawed due to the unequal or skewed underlying distributions.

Still gives a useful look at overall behavior of the plane spacing.

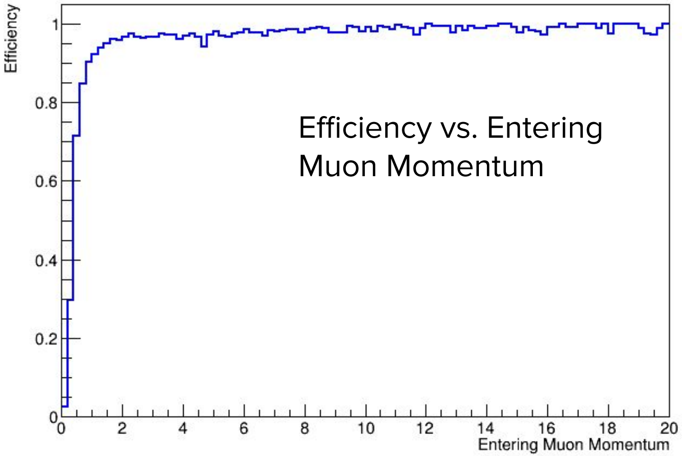


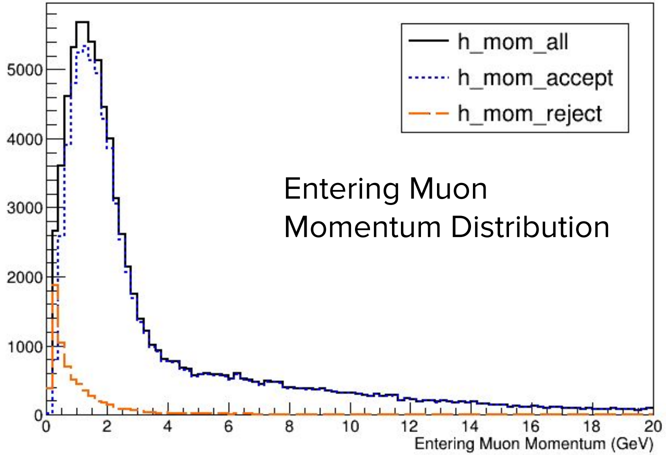
Random Proposed Solution

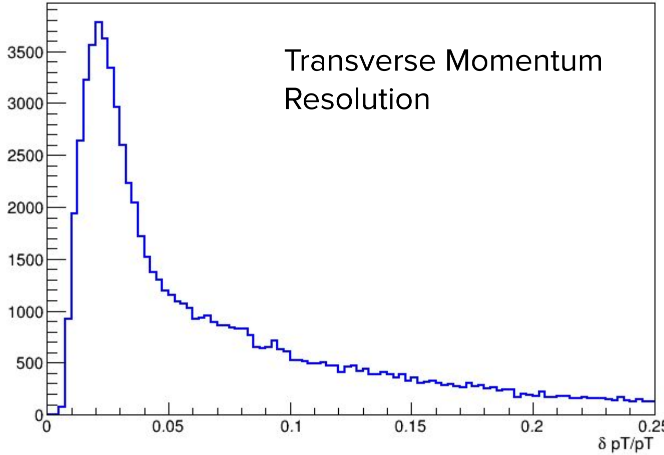
Performance metrics for a single MC configuration with planes at z = {-240, -215, -132, -16, 135}.

Efficiency is much better -- total efficiency about 92.1%.

Resolution distribution peak is about 2.1%, but with a fairly large tail (average is about 10%).







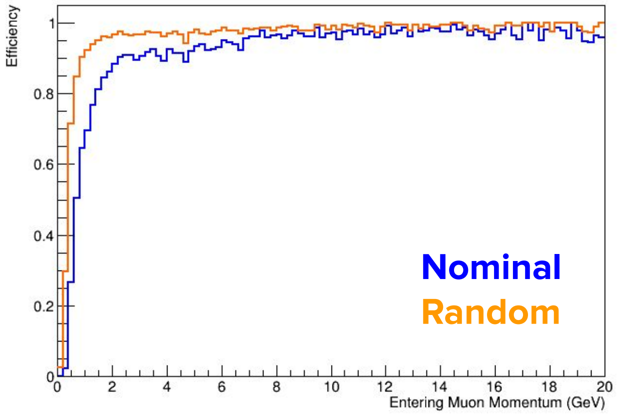
Summary

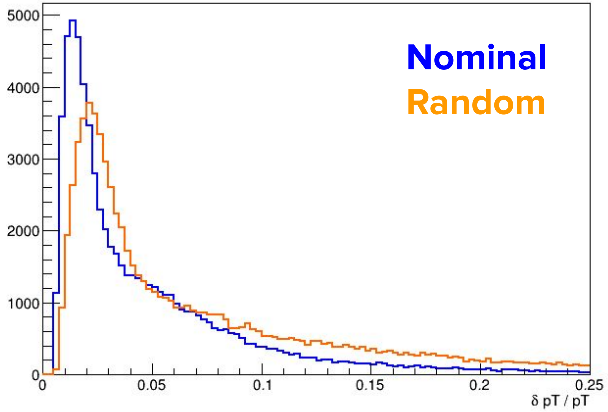
Built a tool to simulate different scintillator plane spacings for an approximate optimization.

Simple total efficiency vs average estimated momentum resolution more or less behaves as expected.

Suggestions on how to improve the optimization?

Particularly related to estimating the momentum resolution and how to deal with the skewed distribution.



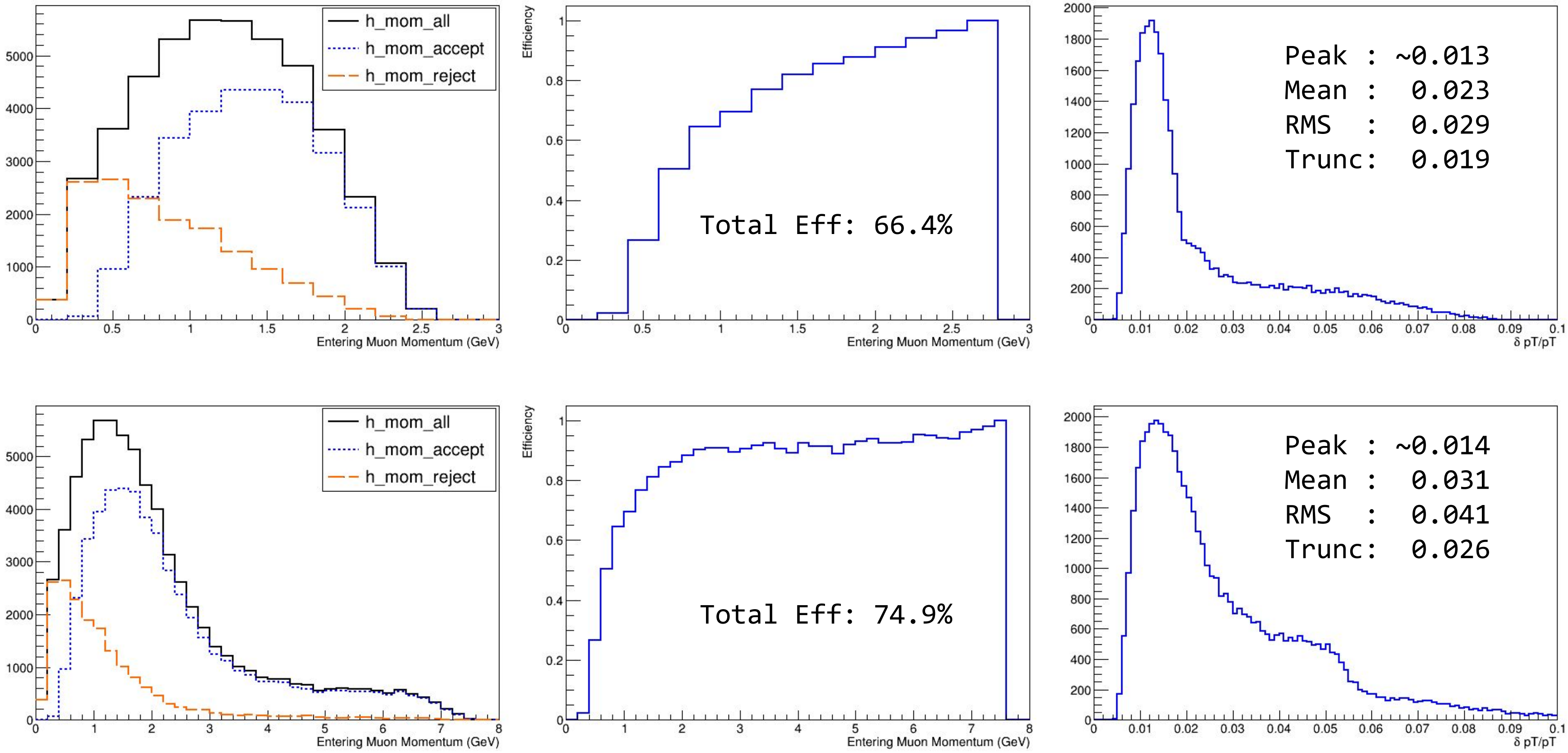


2021/02/26 Update

Comments Received

A list of comments and suggestions received during/after the Monday meeting:

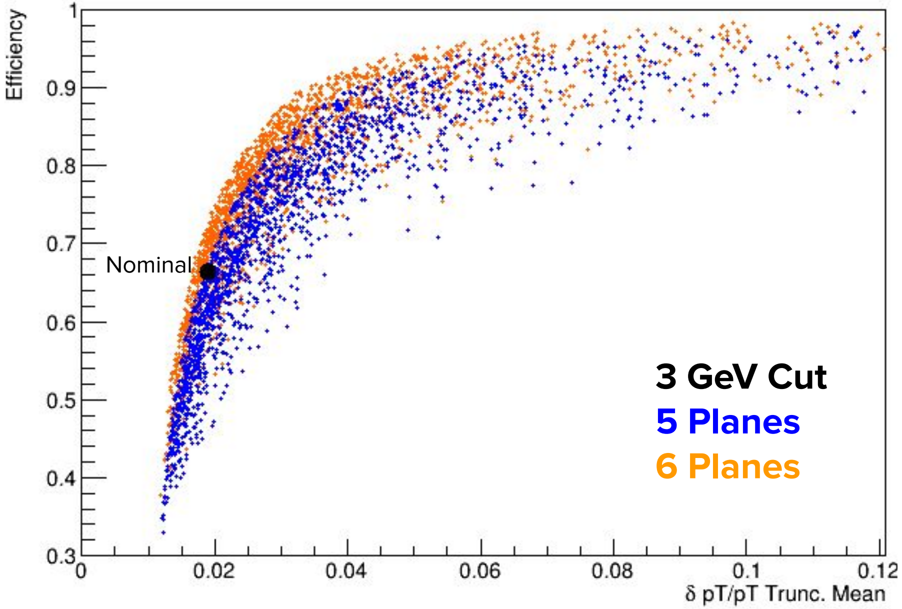
- Limit momentum range of muon sample, for example 3 or 8 GeV or less
- Use a truncated mean as for the momentum resolution as a metric
- Add an additional (6th) scintillator plane
- Extend the vertical plane area to the edges of the cylinder
- Adjust vertical position (y-axis) of scintillator planes
- For low momentum tracks, the momentum resolution may be driven by the LAr rather than the GAr.
- Use improved value for scintillator position resolution
- Improve estimation of momentum resolution (e.g. adding multiple scattering to Gluckstern)
- Possibly prioritize efficiency over momentum resolution

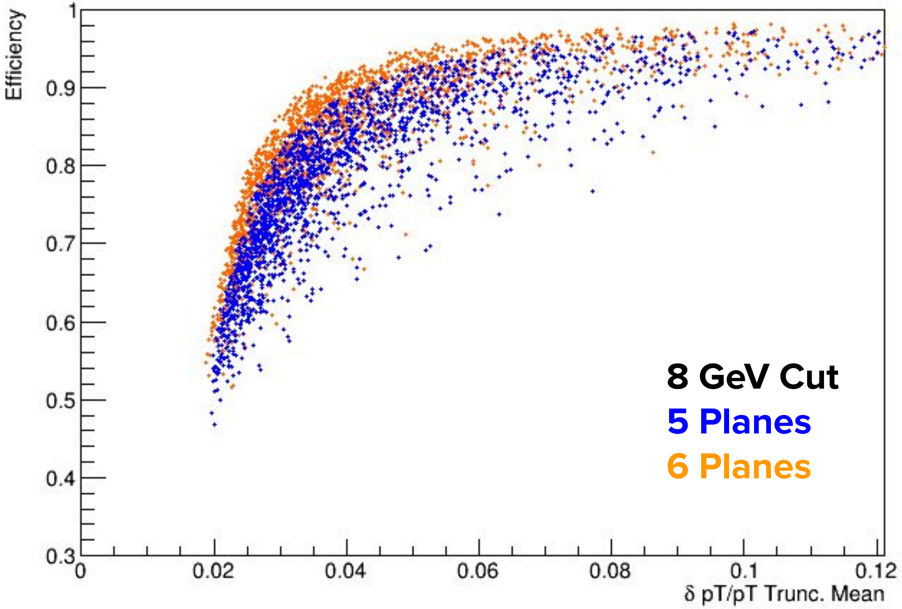


Previous Plots Remixed

The nominal configuration plots redone using a truncated mean and limiting muon sample to an upper limit on momentum at production of 3 or 8 GeV.

These plots and numbers are for establishing a baseline to compare with.





- Total efficiency versus the truncated mean of estimated momentum resolution for 2000 trials.
- Upper momentum limit/cut of 3 GeV (left) and 8 GeV (right).
- On average adding a sixth plane improves total efficiency 5 to 6 percentage points for a given resolution. This improvement is reduced at very low or very high efficiency regions.

Efficiency vs. Resolution & 5 vs. 6 Planes

Summary (again)

Updated code to include cuts on muon momentum and truncated mean calculation.

Truncated mean still not perfect estimator, but better than simple average

Six planes performs better than five planes (as expected).

Possible extensions: changing plane size/height, estimating LAr Δp contribution

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Efficiency & Plane Z-Positions
Nominal 74.9% : (-240, -150, 0, 150, 240)
RNG 5 Planes 90.5% : (-240, -215, -132, -16, 135)
RNG 6 Planes 95.8% : (-240, -218, -186, -36, 36, 135)
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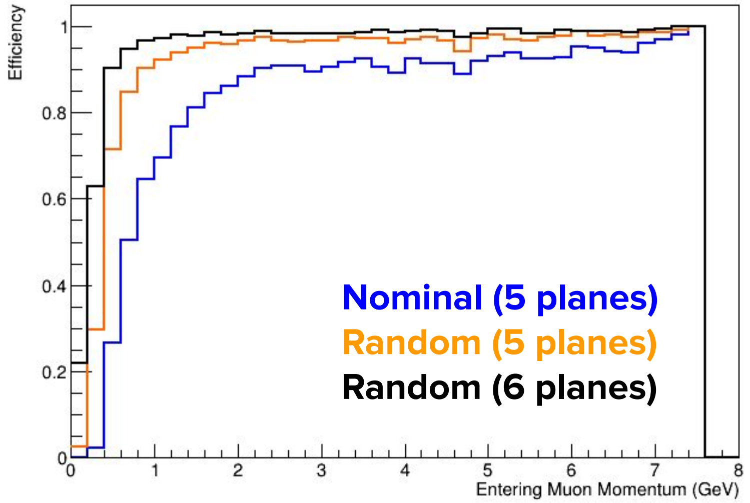

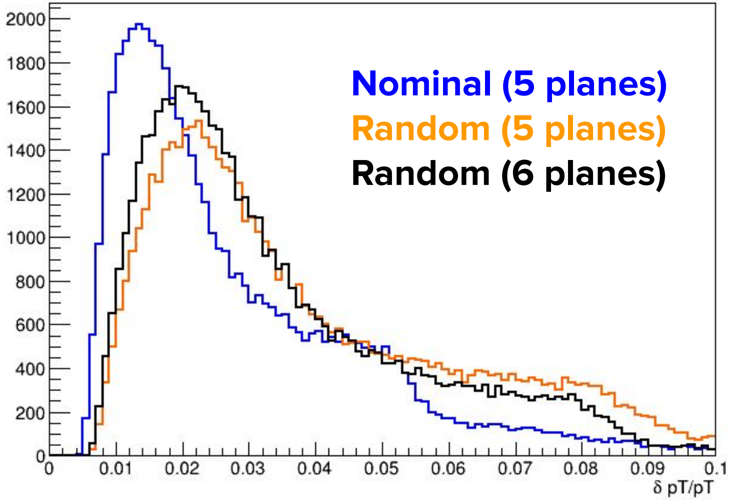

Tables of Numbers

Nominal		Random 5 Plane		Random 6 Plane	
Eff :	0.749	Eff :	0.905	Eff :	0.958
Peak :	~0.014	Peak :	~0.022	Peak :	~0.020
Mean :	0.031	Mean :	0.067	Mean :	0.171
RMS :	0.041	RMS :	0.119	RMS :	0.454
Trunc:	0.026	Trunc:	0.046	Trunc:	0.069