Muon EDM Measurements at Liverpool

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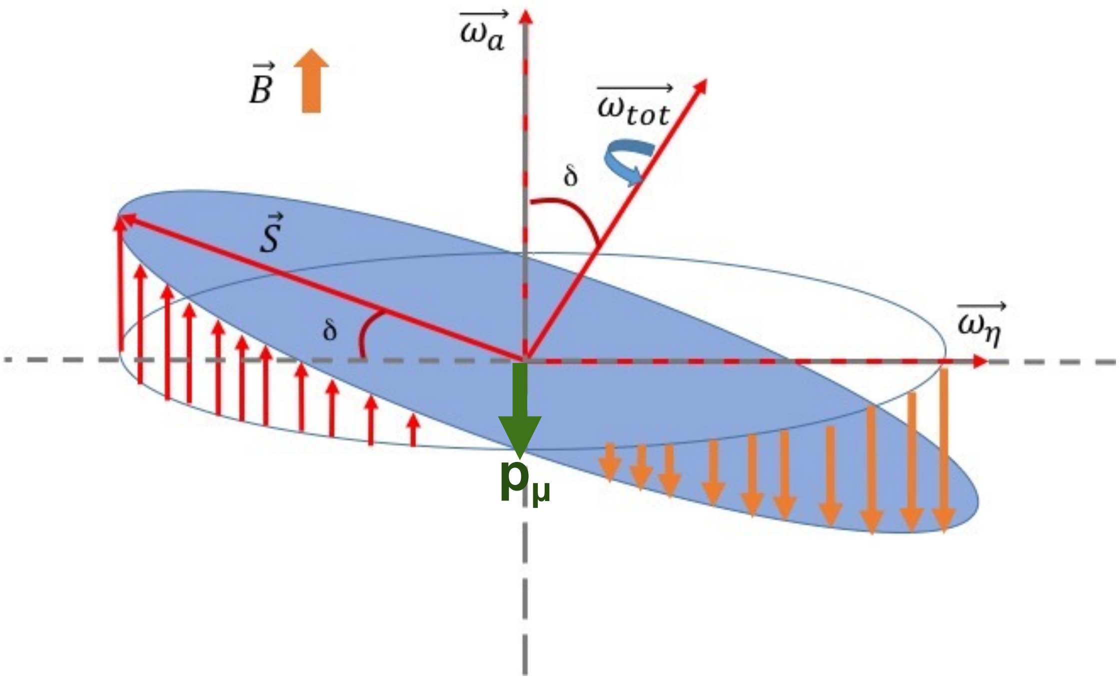
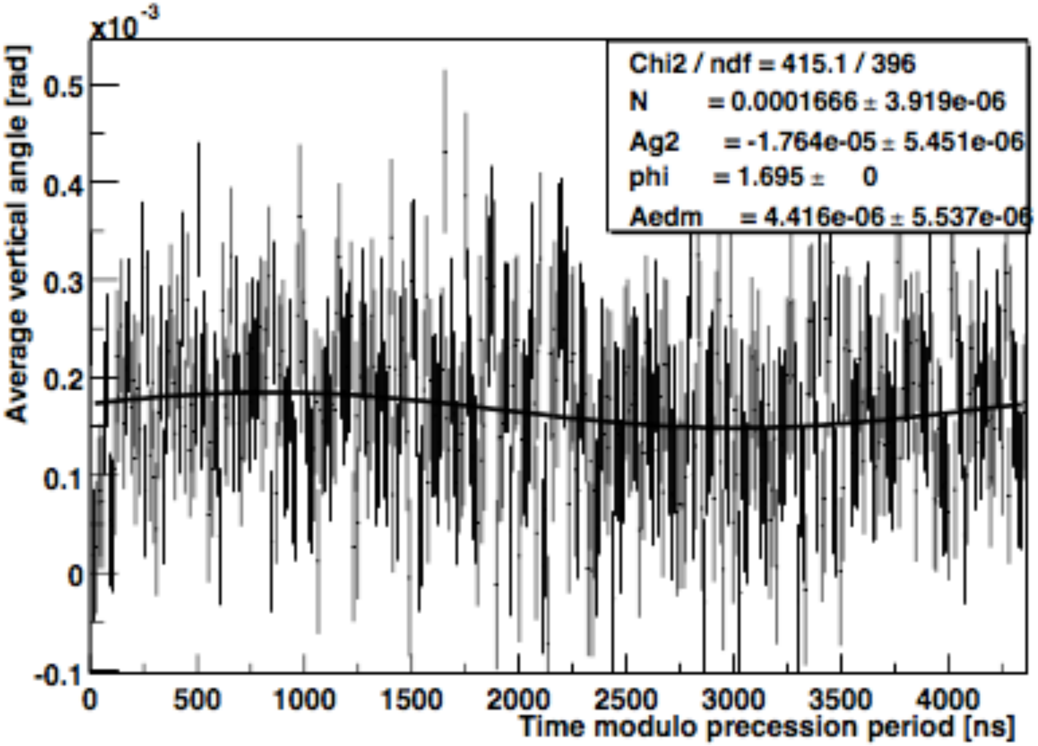
Muon EDM at FNAL



A permanent muon EDM tilts the precession plane
Causes an oscillation in the vertical angle of positrons out of phase with g-2
The precession frequency also increases

Vertical Angle - Tracker

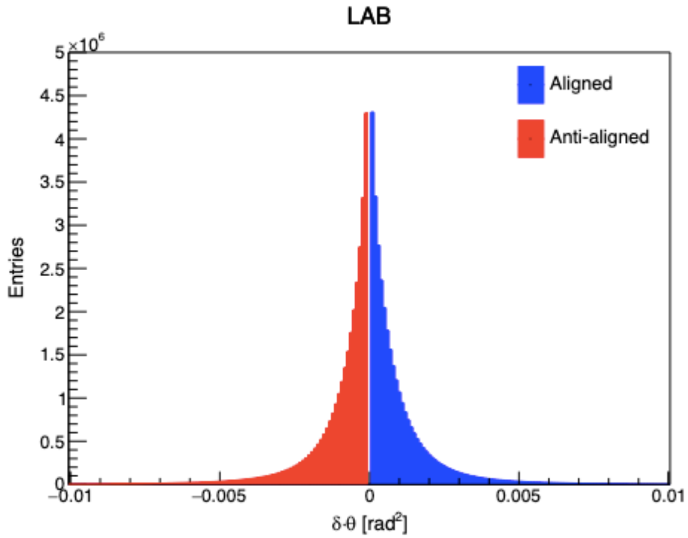
- Can also look directly at vertical position and angle measurement
- Angular measurement less dependent on detector misalignment

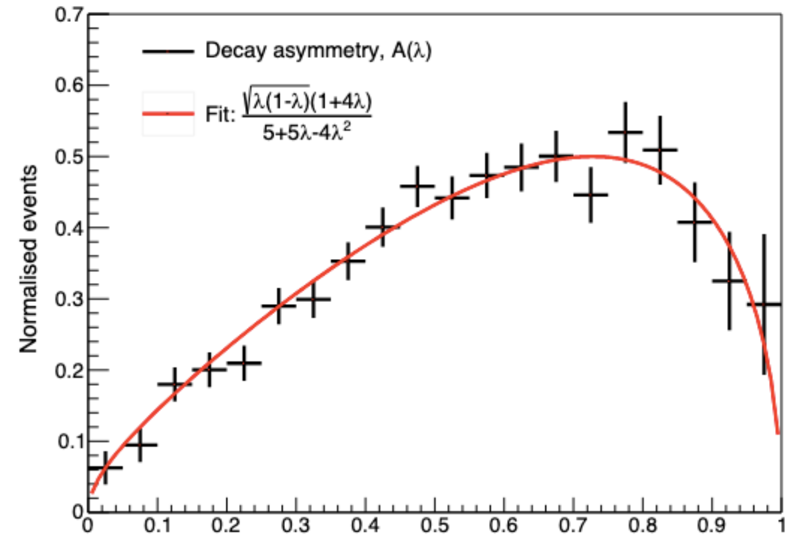


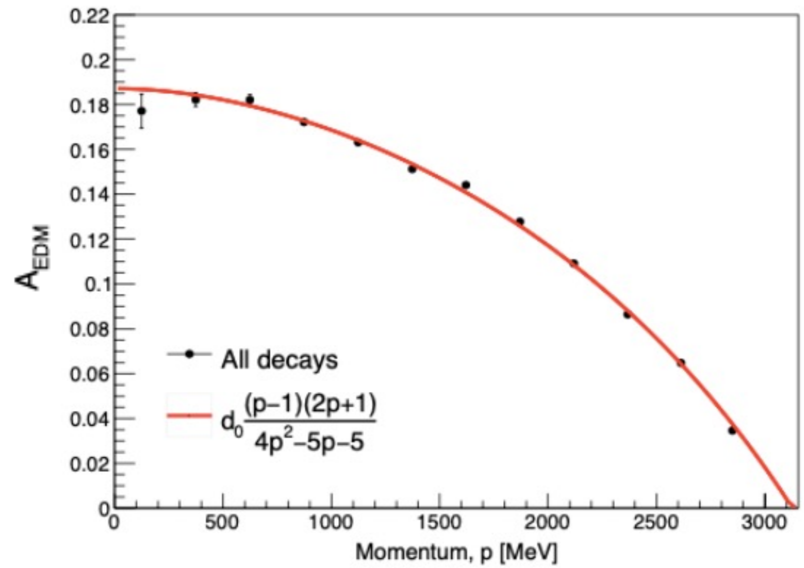
- Get phase and period from ω_a fit
- Fold data over at precession period
- Directly look for sinusoidal* oscillation out of phase with ω_a

*actually not sinusoidal!

What Do We Gain From the Trackers?

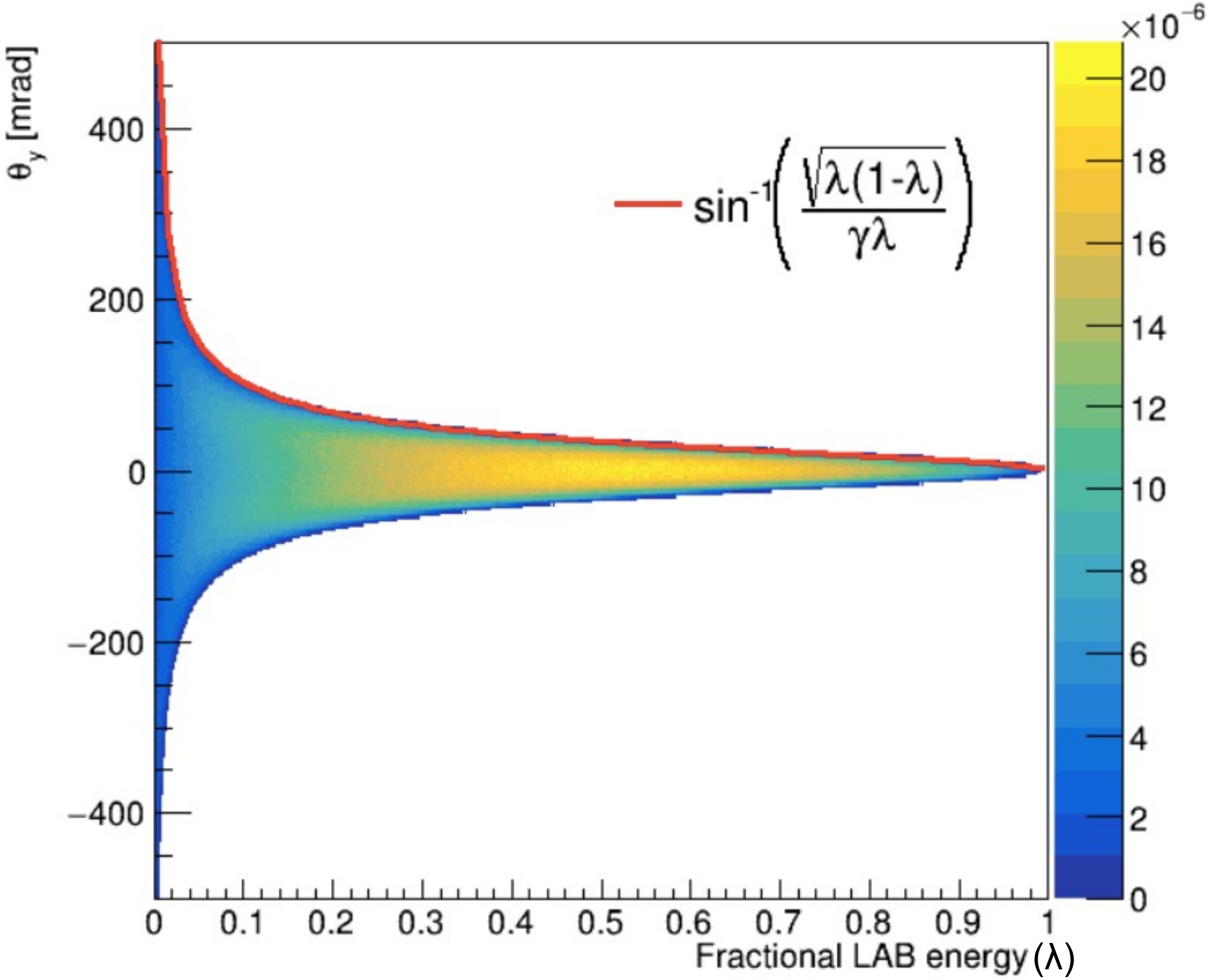


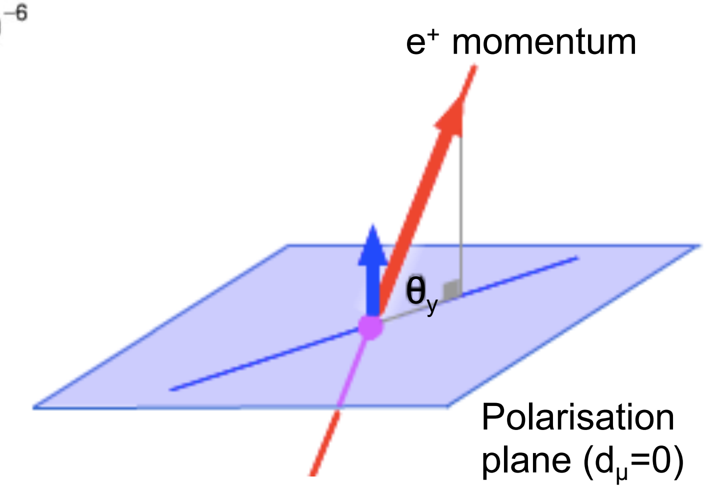




- The momentum measurement means we can focus on the most important positrons
- The vertical angle measurement is less sensitive to mis-alignment
- Can it also be used to re-weight?

Vertical Angle in LAB Frame





$$\sin\bar{\theta}_y = \frac{\sqrt{\bar{\lambda}(\tilde{y}-\bar{\lambda})}}{\gamma\bar{\lambda}}\sin\tilde{\phi}$$

Where *y* is fraction energy in rest frame

Vertical Angle Expression

Derived an expression, assuming β=1, m_e=0 and no betatron oscillations, for the time dependent probability of decay in terms of λ, θ_y

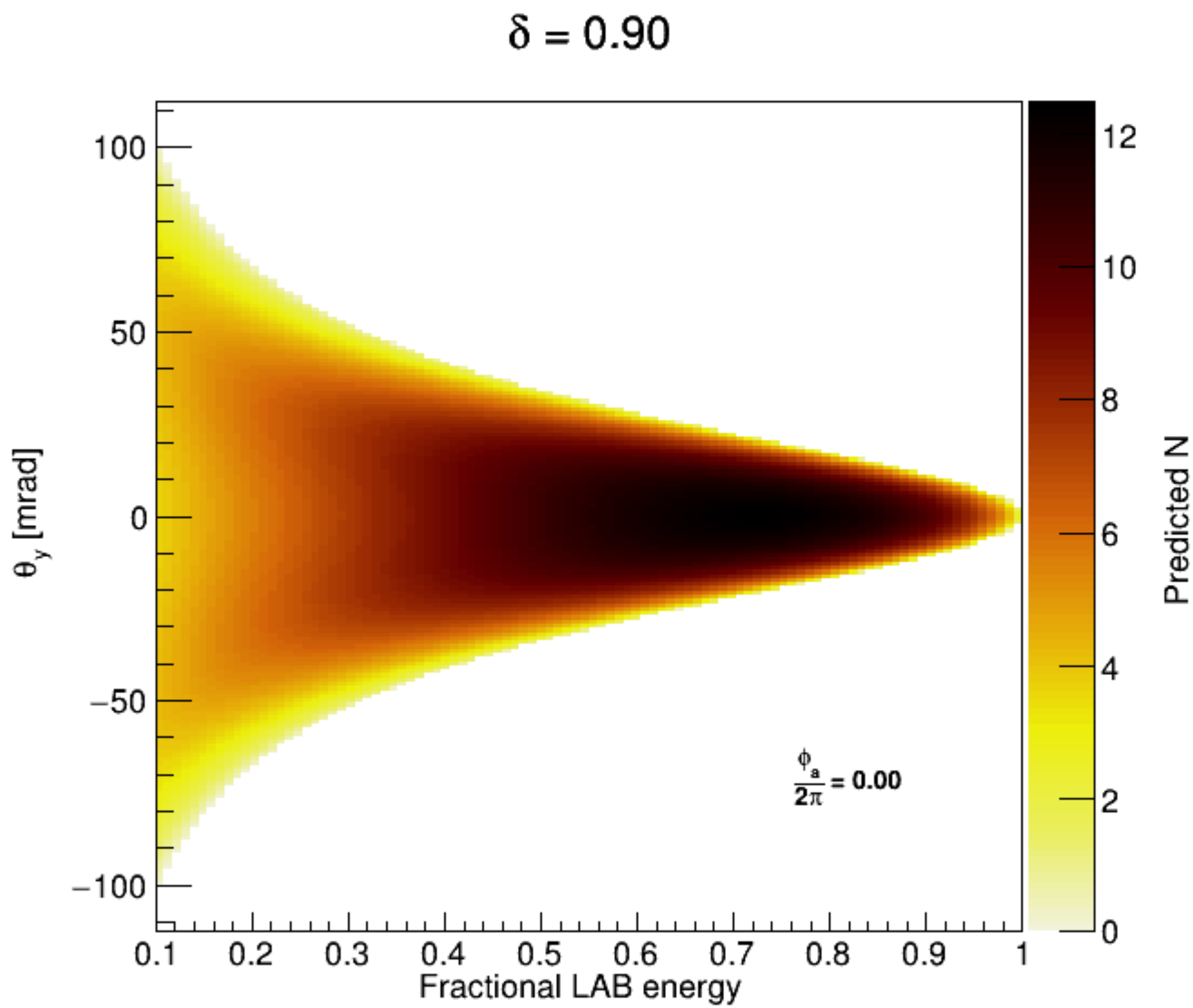
$$P(\bar{\lambda},\bar{\theta_y}) = \frac{2\gamma}{15\pi}\sqrt{\bar{\lambda}(1-\bar{\lambda}C)}\left(22C\bar{\lambda}-16C^2\bar{\lambda}^2+9\right) + \frac{4\gamma^2\bar{\lambda}\ \sin\bar{\theta_y}\ \sin\delta\ \sin\omega t}{3\pi}\sqrt{\bar{\lambda}(1-\bar{\lambda}C)}(4C\bar{\lambda}-1) + \frac{2\gamma\ \cos\omega t\ \sqrt{\bar{\lambda}(1-\bar{\lambda}C)}}{15\pi}(-16C^2\bar{\lambda}^2+40C\bar{\lambda}^2-10\bar{\lambda}+2C\bar{\lambda}-1)$$

$$C = 1+\gamma^2\sin^2\bar{\theta}_y$$

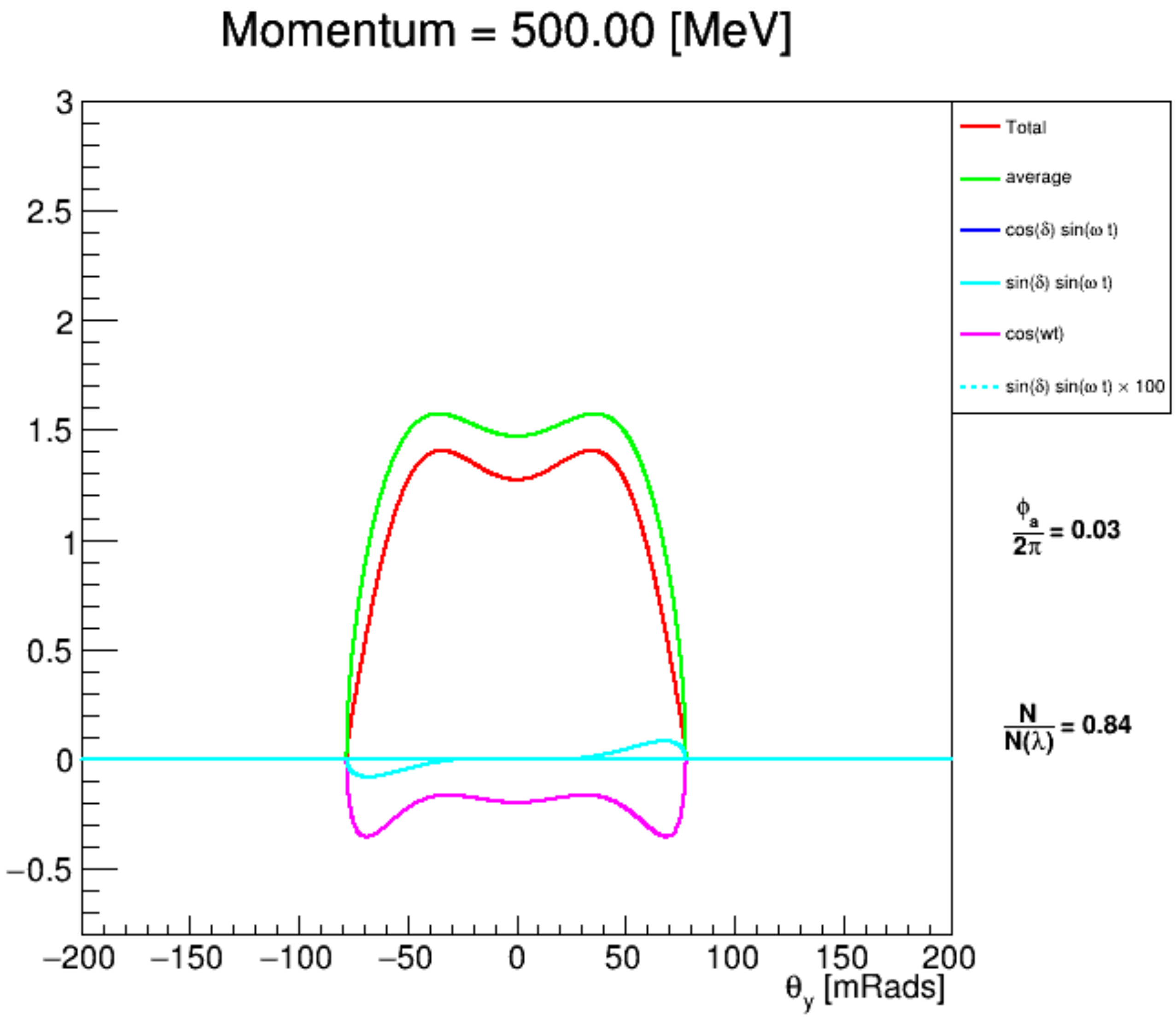
- Good assumptions for the g-2 experiment!

- 1st term is time independent, and gives the average
- **2nd term depends on the tilt (EDM),** and oscillates out of phase with g-2
- 3rd term is the g-2 oscillation, independent of EDM

Total N(λ, θ_y, t)



Visualising the oscillation



Fermilab muon EDM – Projected Sensitivity

- Run 1 tracker analysis limit (for no signal):

  $|d_\mu| < 2.0 \times 10^{-19}$ ***e.cm (95%)***

- We expect a fully systematically limited calorimeter measurement:

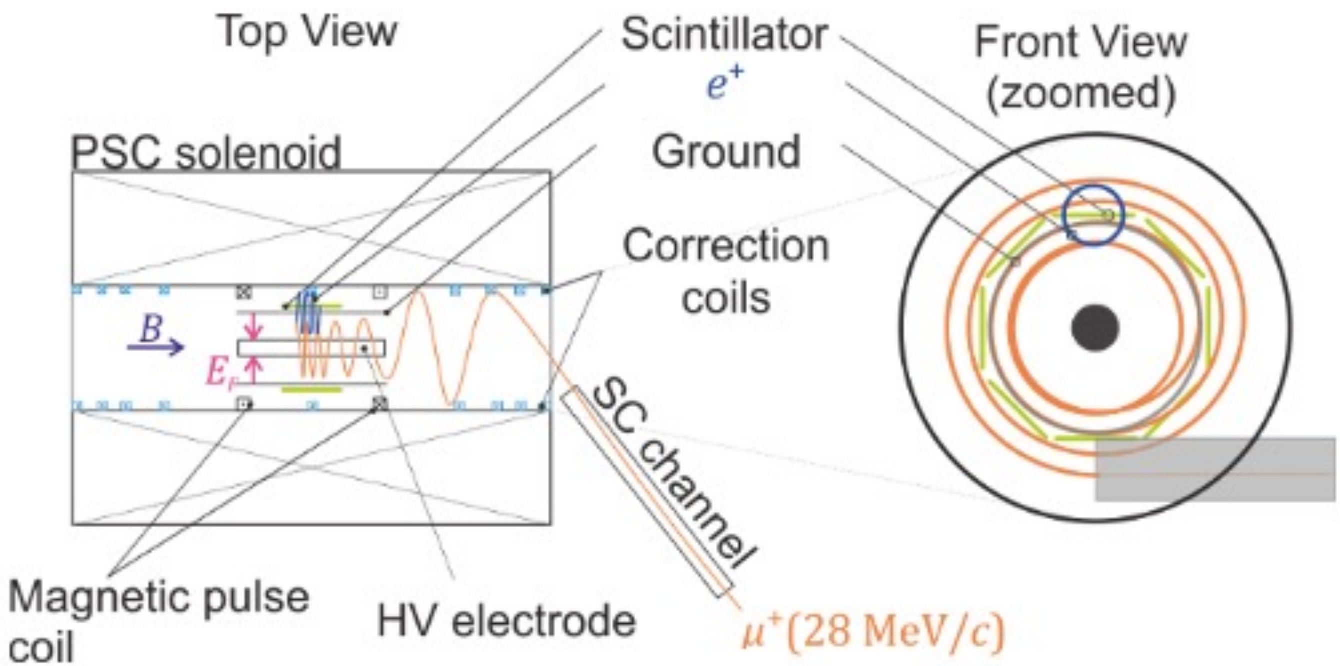
  $|d_\mu| < 2.0 \times 10^{-19}$ ***e.cm (95%)***

- Using all data up to and including run 5 and 6, with current tracking, limit will approximately be

  $|d_\mu| < 0.3 \times 10^{-19}$ ***e.cm (95%)***

- Potential optimising of tracking + reprocessing and vertical angle reweighting to squeeze these limits further

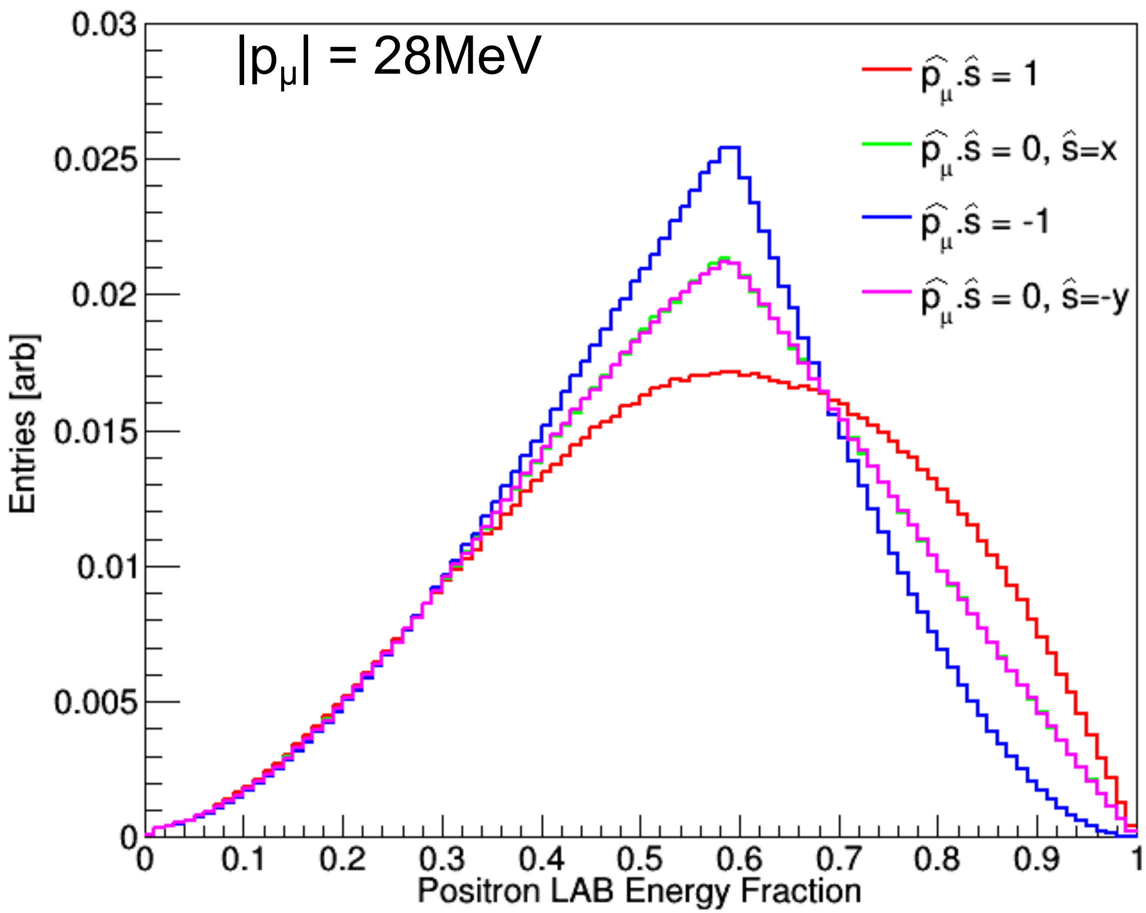
Straw tracker @ PSI



- Originally about 100mm of longitudinal space for tracker
- The closeness of the layers to the storage region determines minimum momentum acceptance
- Possibility of inner and outer layers and more…

g-2 oscillation – Phase I

For Phase I (p = 28MeV) maximum energy is ~68.65 MeV

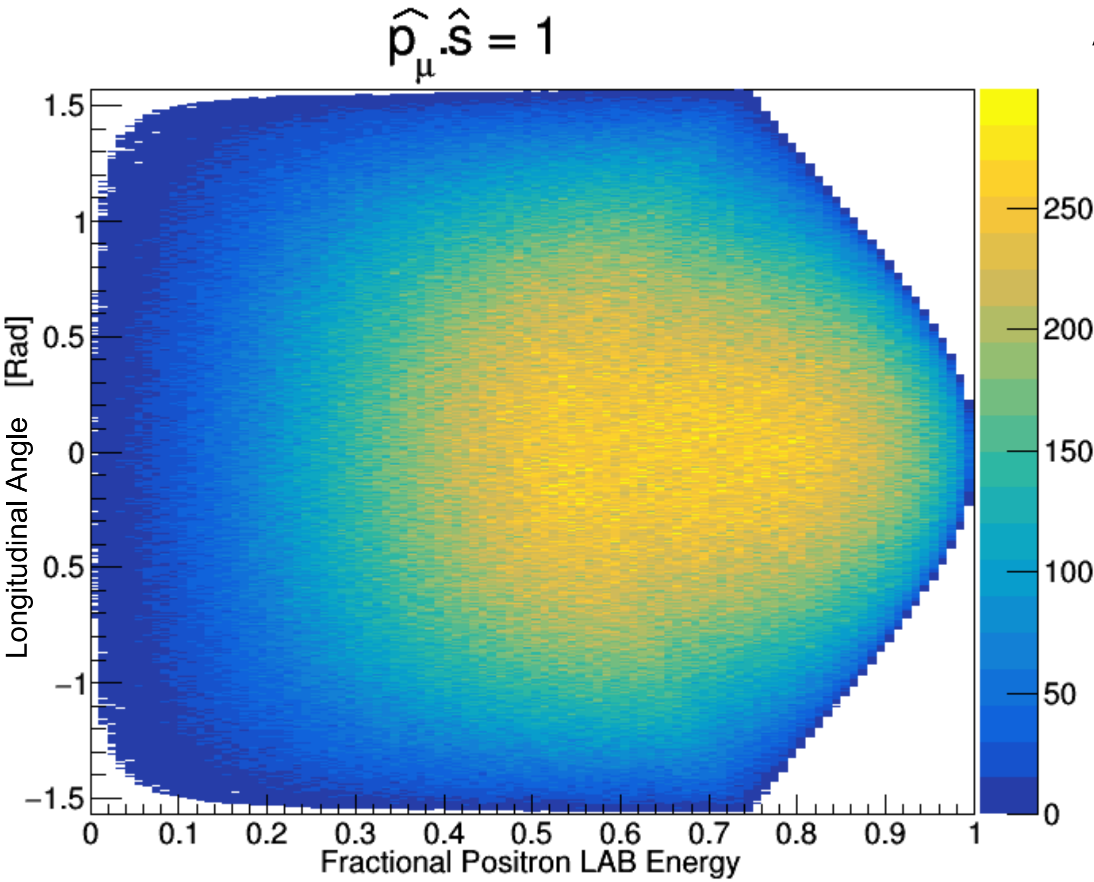


- LAB frame e^+ Momentum distribution depends on polarisation orientation
- For frozen spin method and no EDM this will have no time dependence
- Acceptance will typically cut off low momentum, so will see oscillation in detected number of e^+

Longitudinal Angle – Phase I

$\lambda=1 \rightarrow |p|\approx 68MeV$

$|p_\mu| = 28MeV$



- Rotating the polarization vector (s) w.r.t the momentum vector changes longitudinal angle and momentum distribution
- For g-2 precession in transverse plane average decay angle is unaffected

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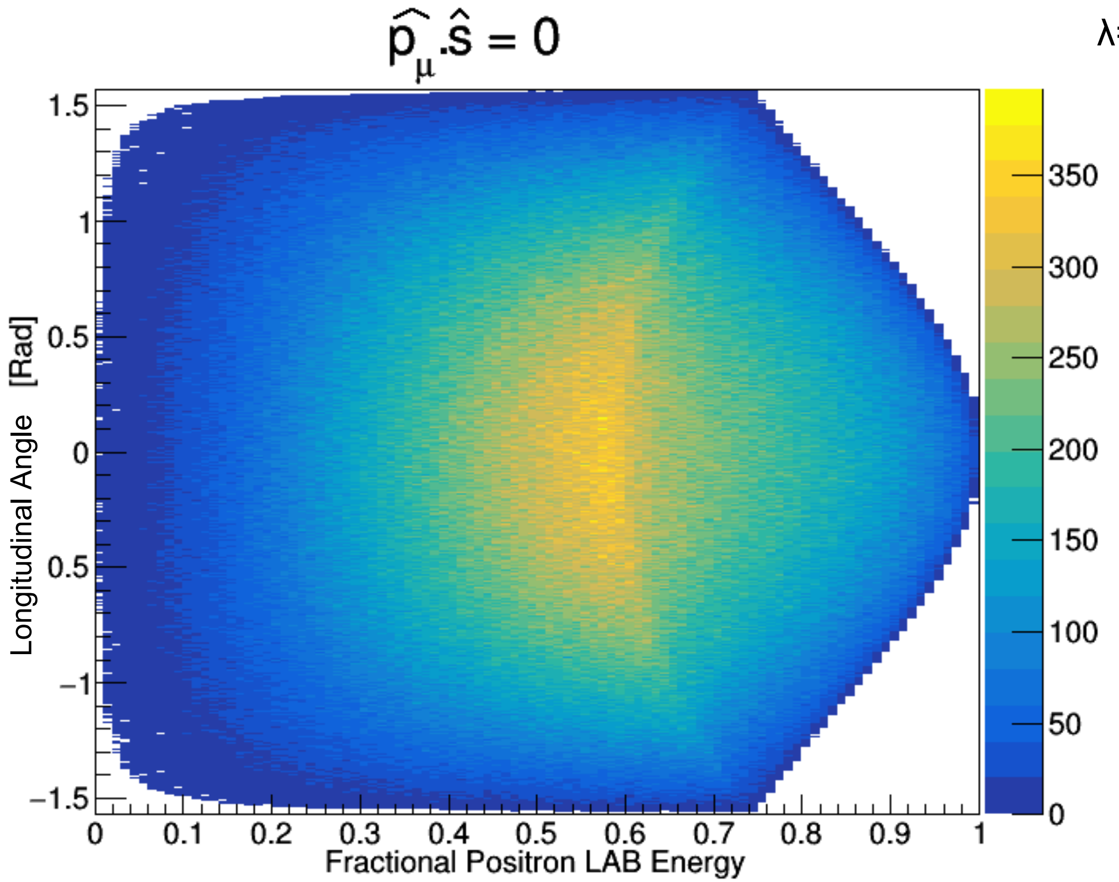

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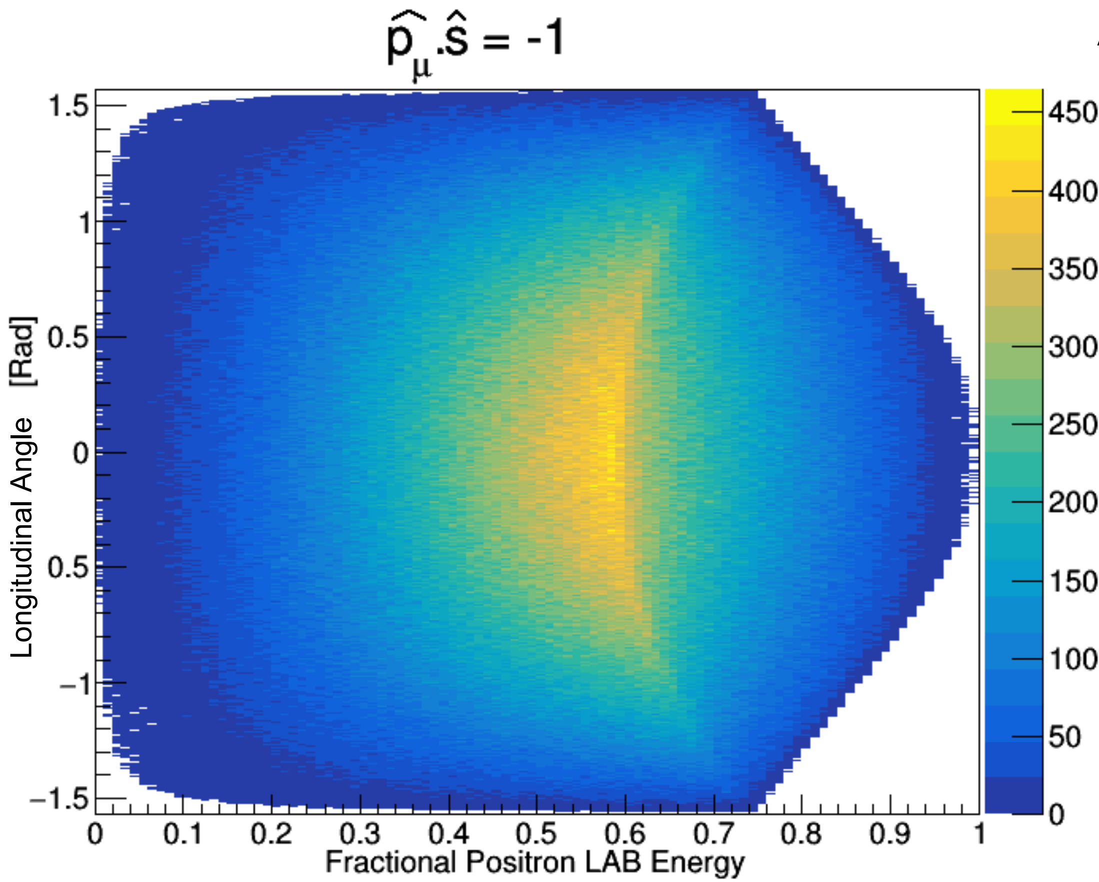

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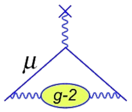
Acceptance



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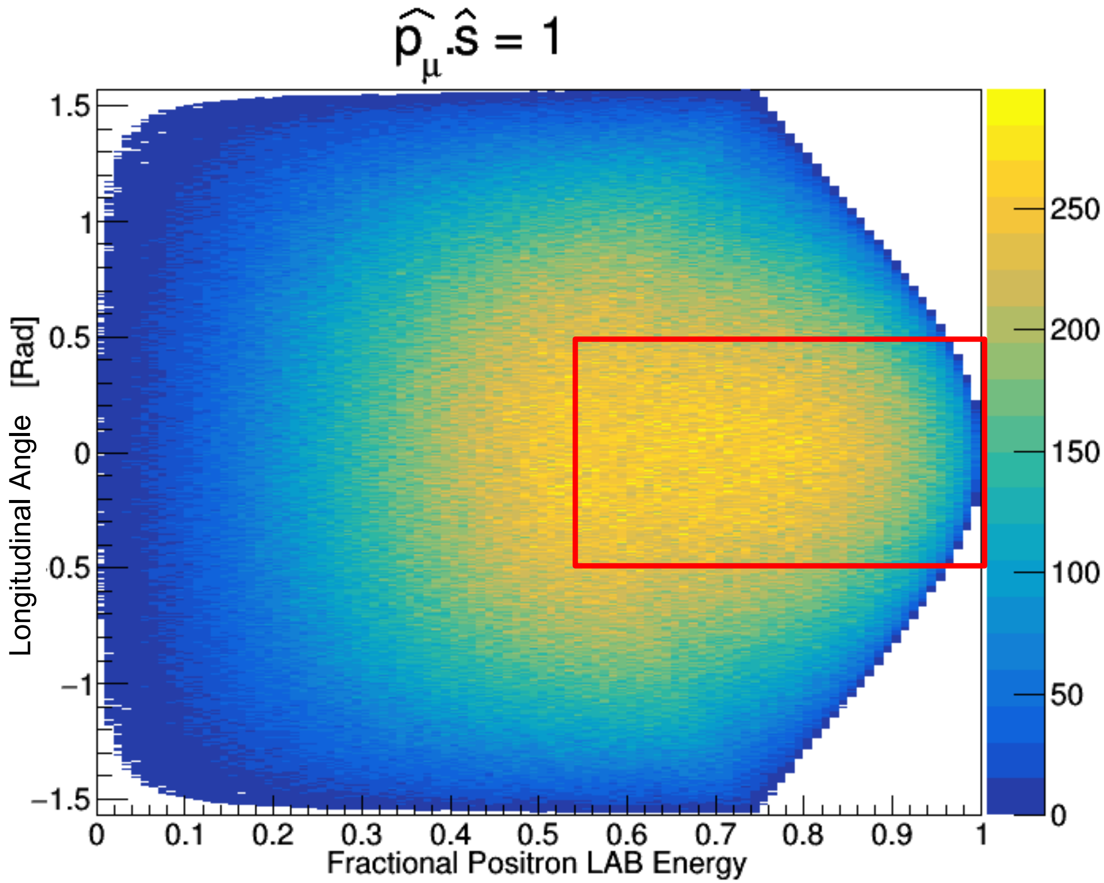


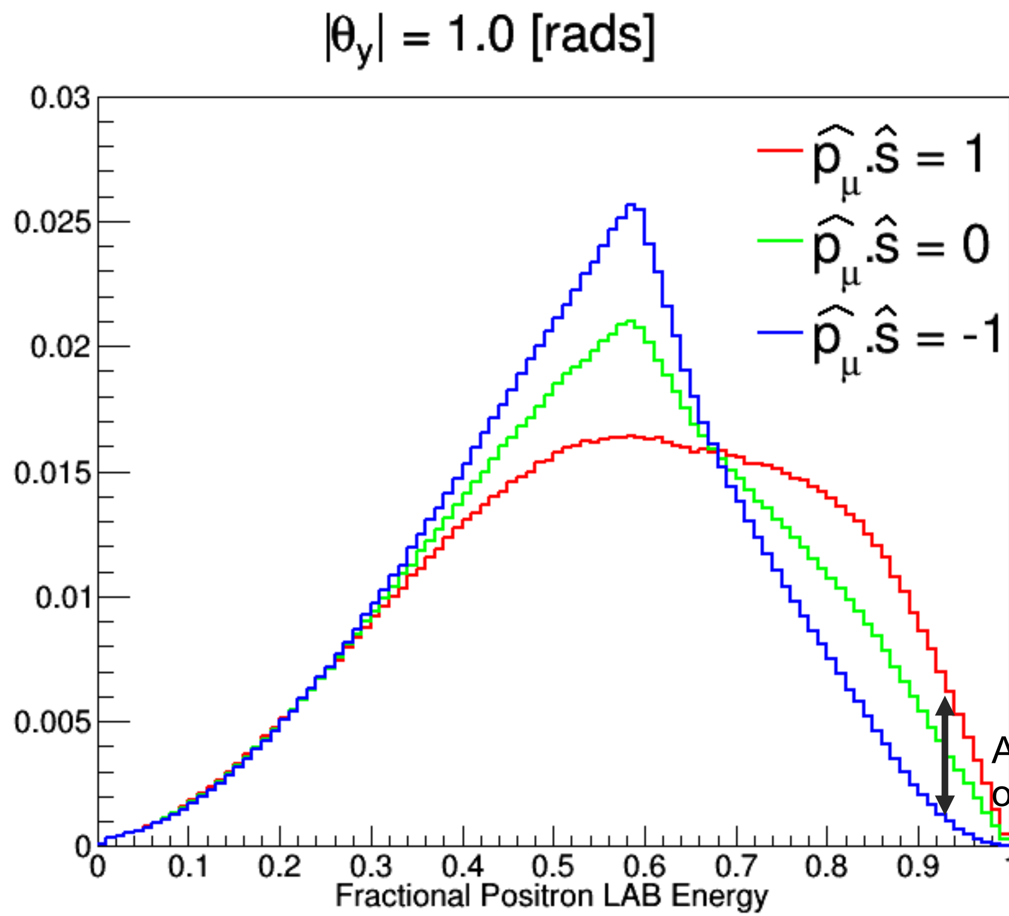
- Acceptance selects a region of this space
- Shown here is a min. momentum of 41MeV, $|\theta_y|=0.5$

Effect of Acceptance – Phase I

$\lambda=1 \rightarrow |p| \approx 68$MeV

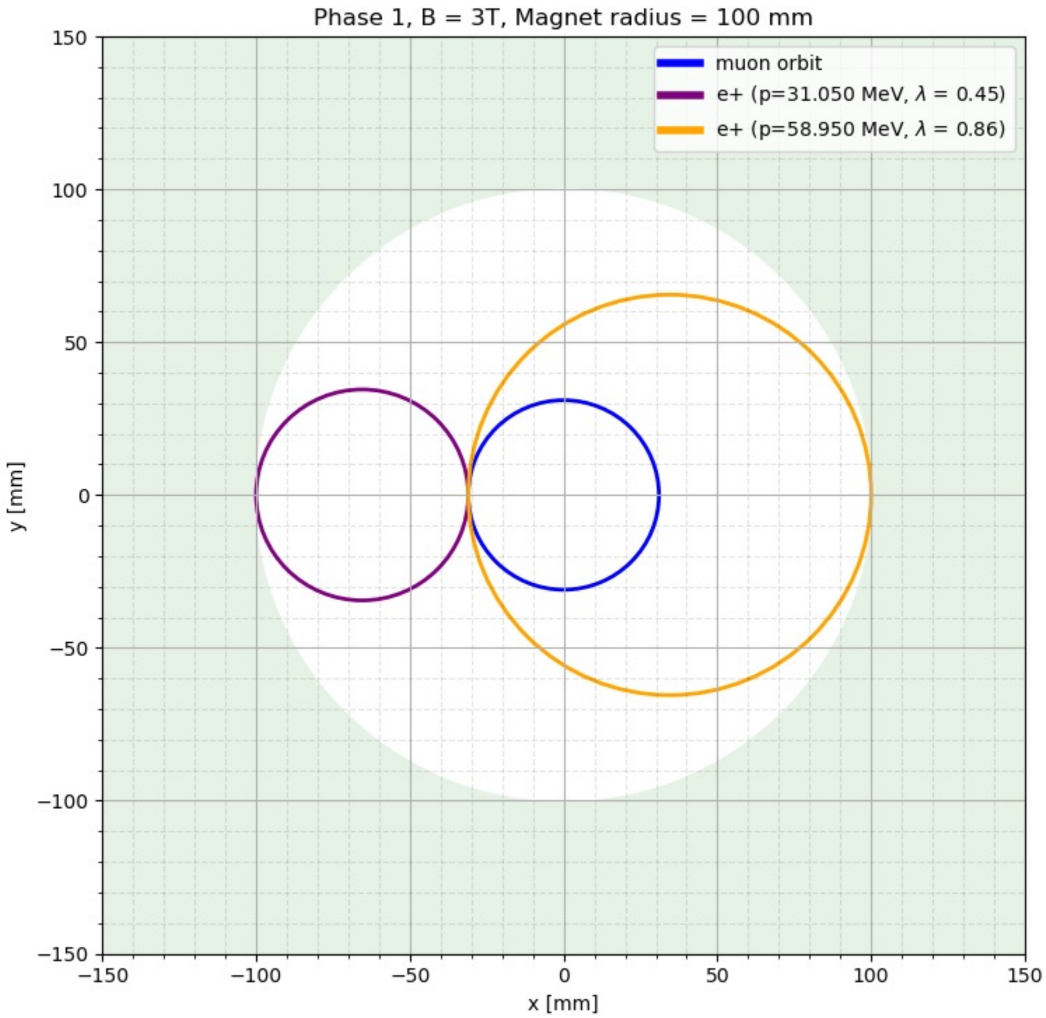
Apply a simple absolute cut on the longitudinal angle as proxy for acceptance…

$|p_\mu| = 28$MeV



Amplitude of oscillation at this λ

Momentum Acceptance



A simplified version of the momentum acceptance

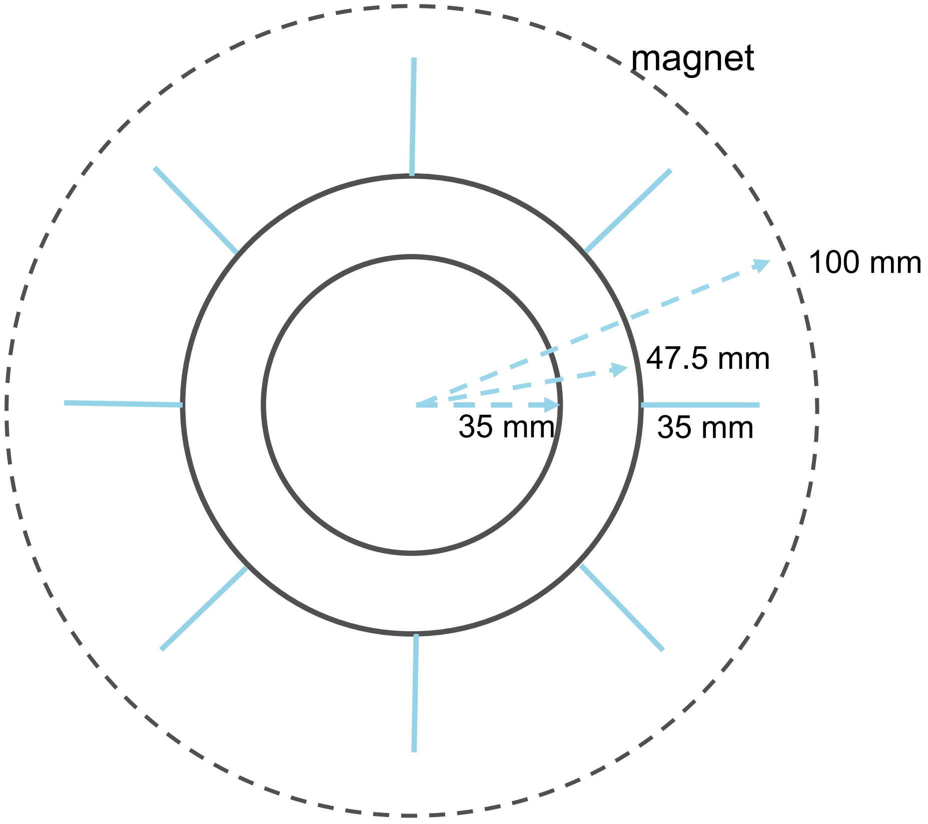
Here the magnet bore is 100mm radius, and the muon orbit is at r=30mm

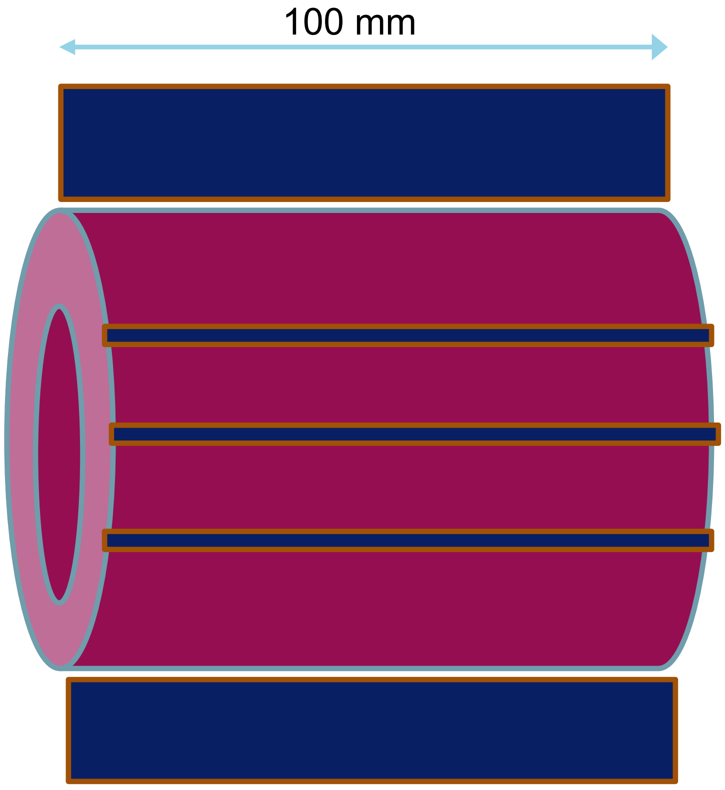
Any positron above 59 MeV will hit the magnet, regardless of decay direction

For (31 < p < 59) MeV positrons it depends on the decay direction

Including ‘Petals’

Two layers + petals: In this round of simulation we used 8 ‘petal’ layers, 100mm long





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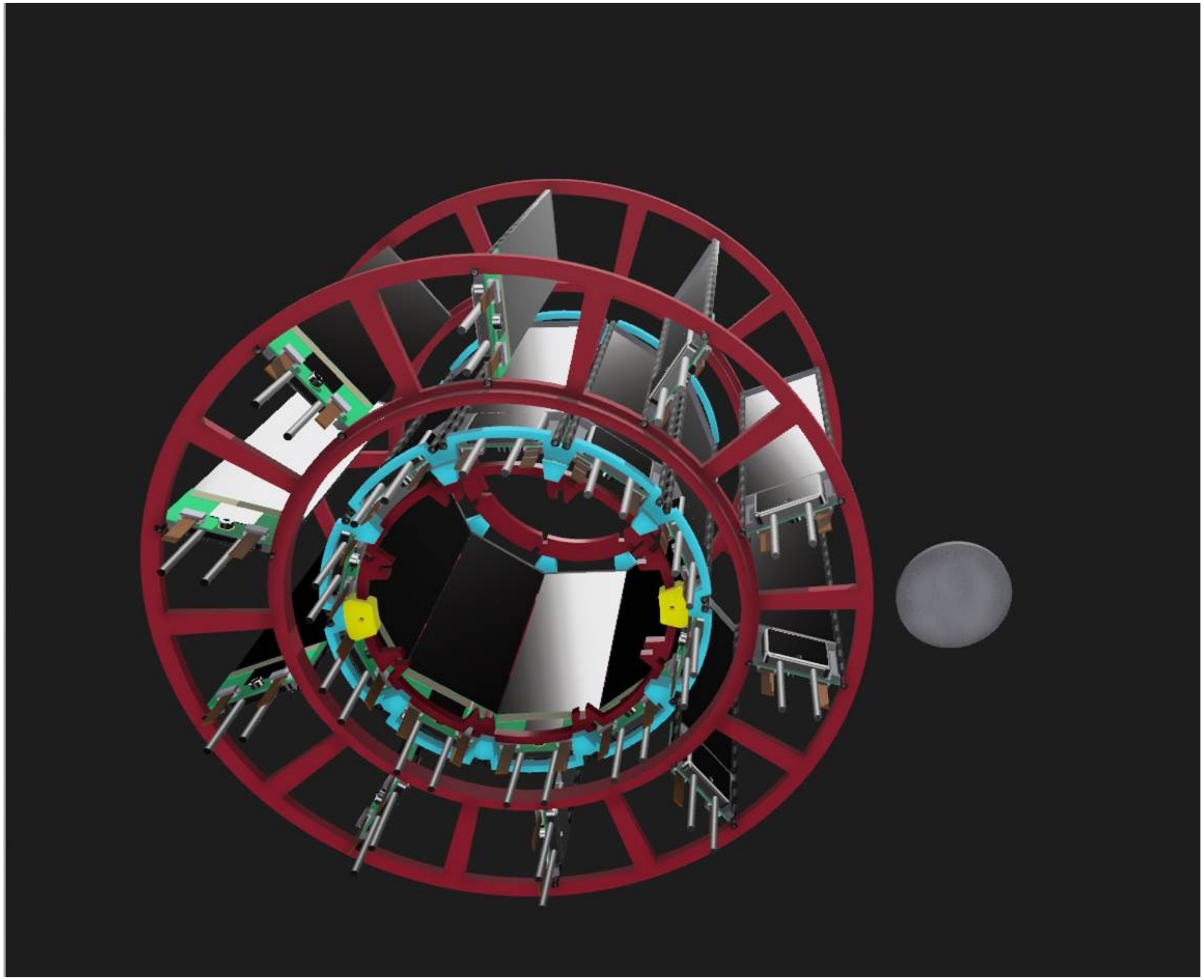
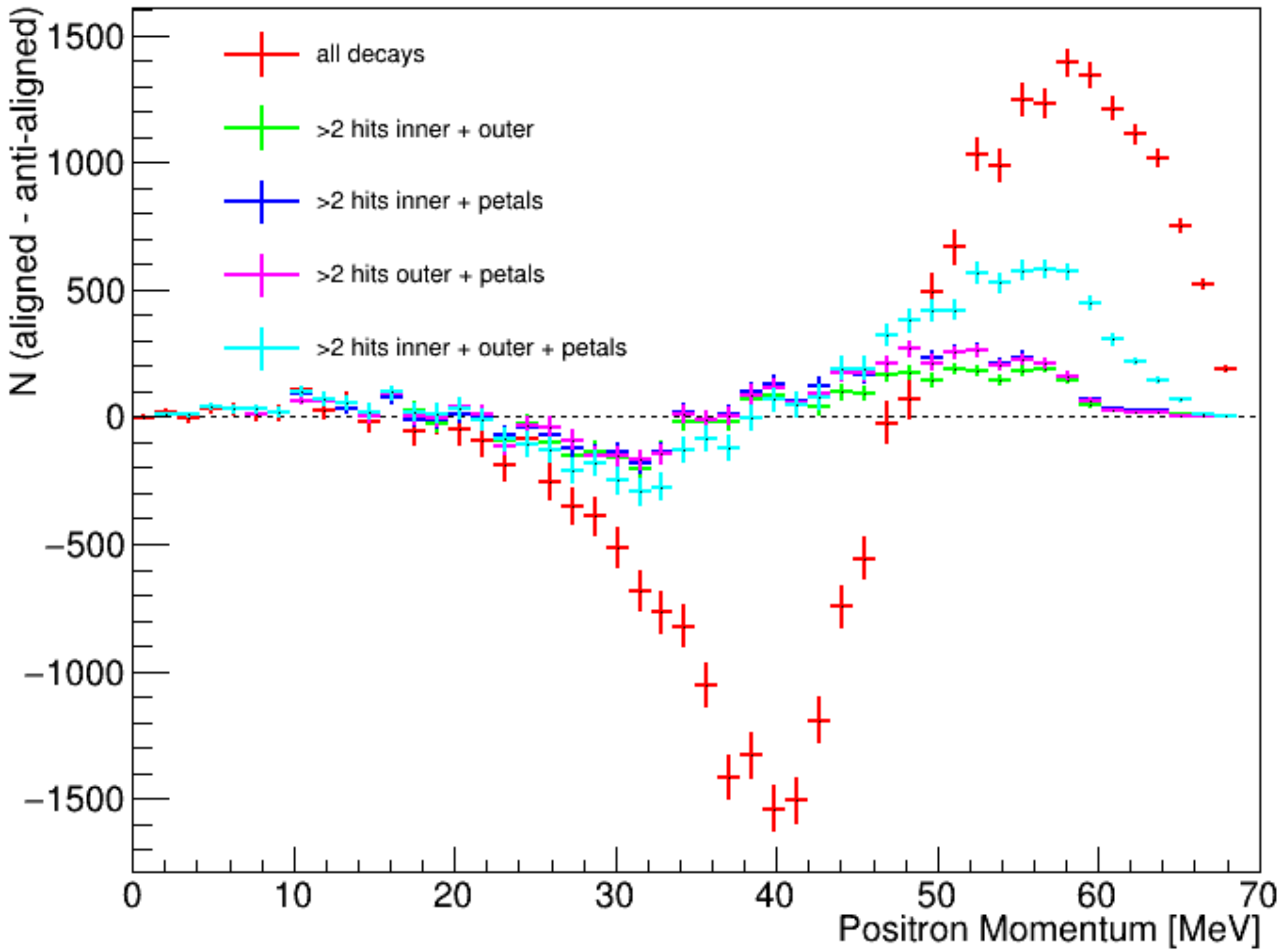


Including Petals – g-2 sensitivity (nhits >= 3)

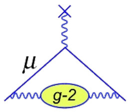


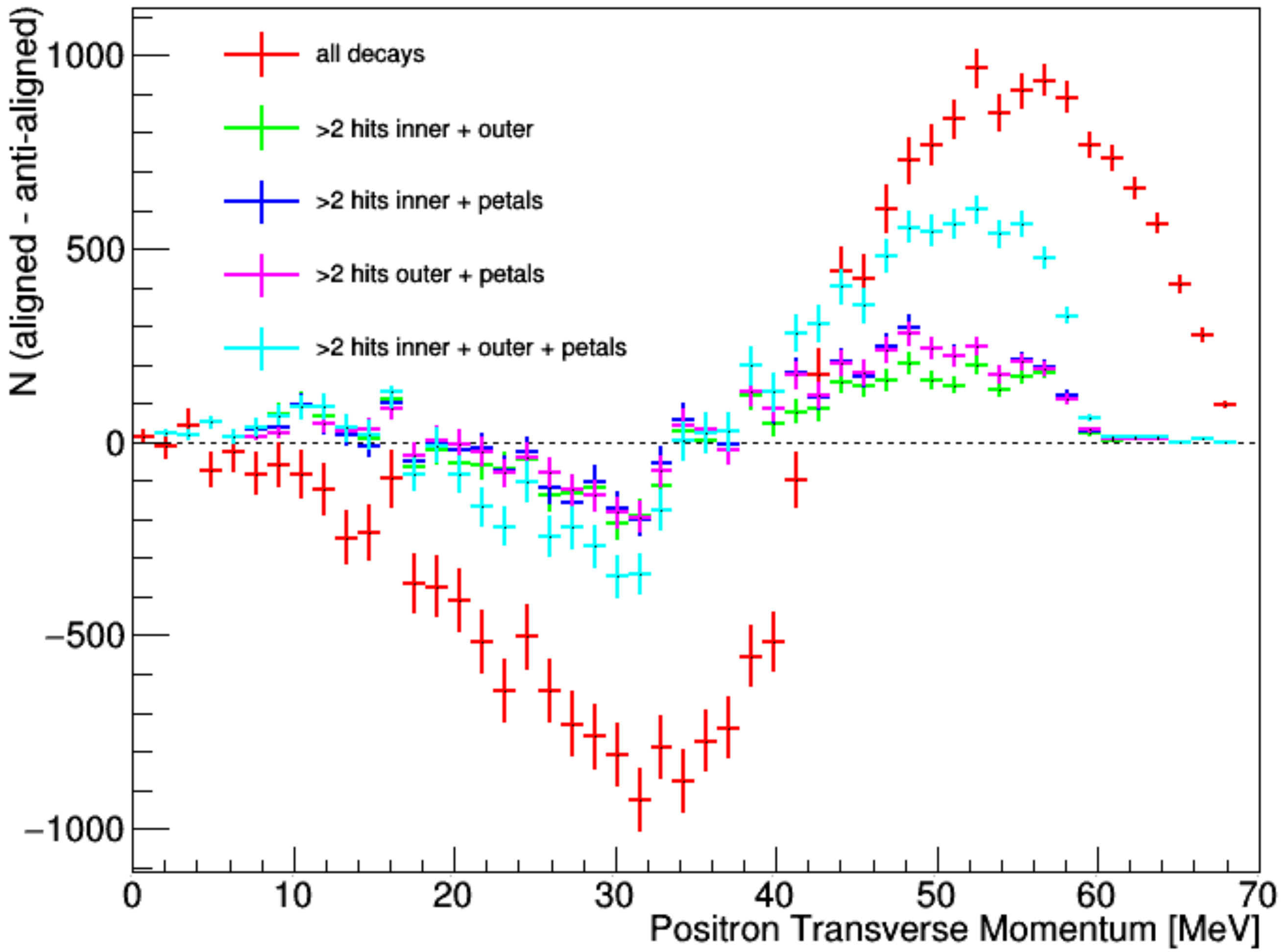
Restores sensitivity (somewhat) with extra 'petal' layers

To get momentum would need to get longitudinal measurement

Strip detector can only measure transverse momentum…

Including Petals – g-2 sensitivity (nhits >= 3)

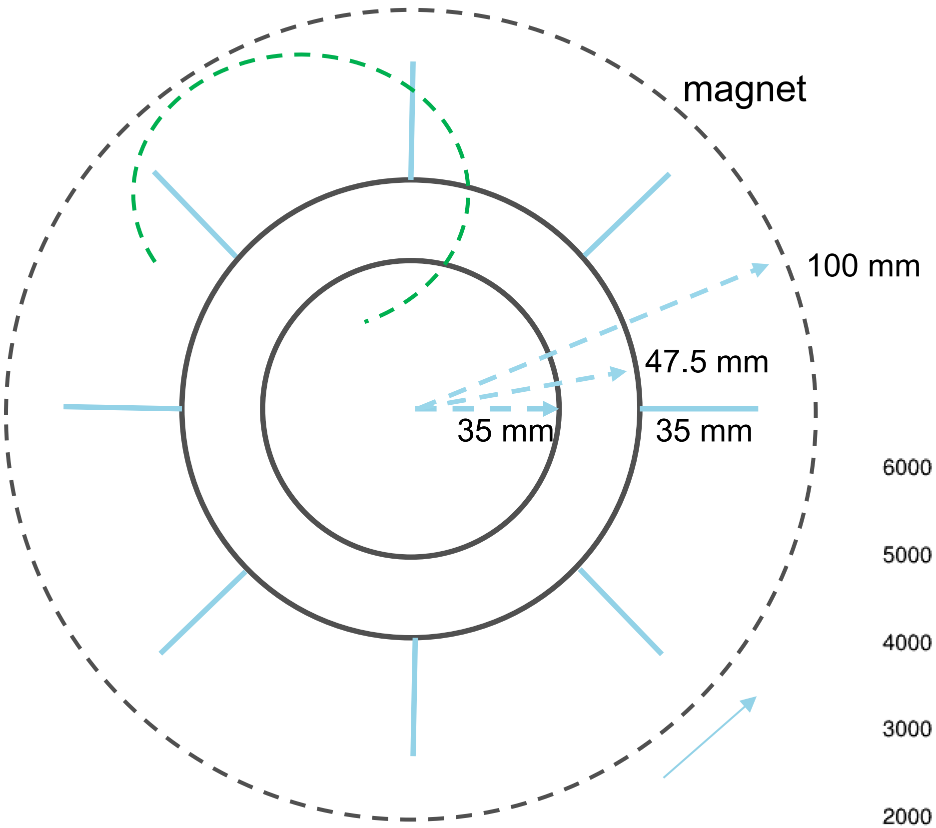




Still good sensitivity using transverse momentum only

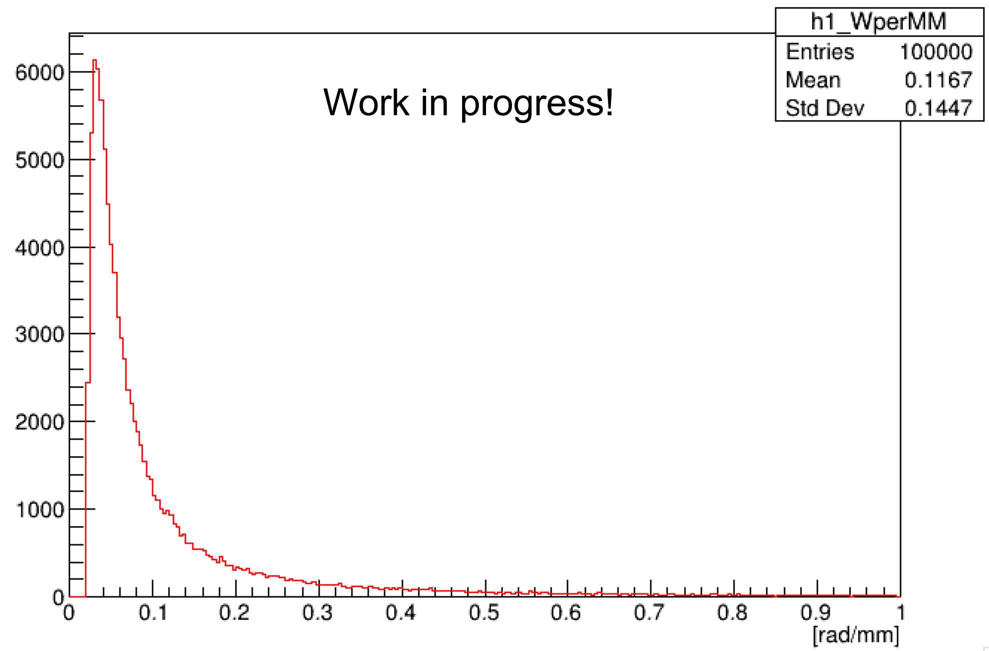
How much would increasing longitudinal dimension help?

Increasing longitudinal dimension



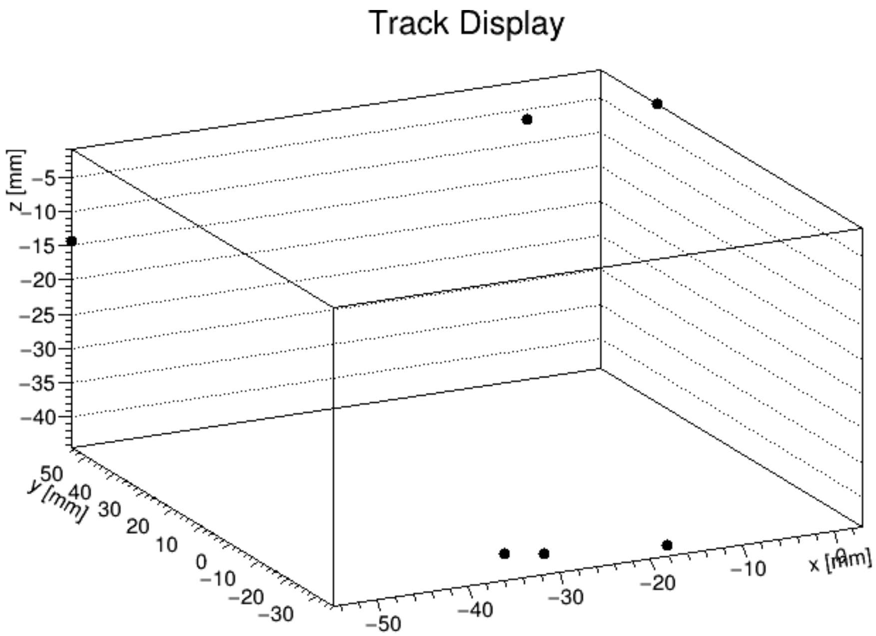
Simulation has 100mm length in longitudinal direction

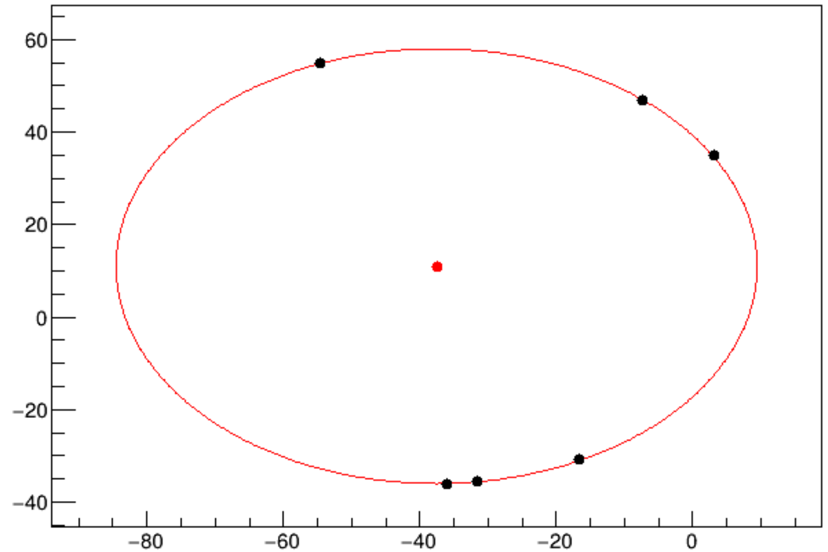
We want to know how much bend there is per mm of longitudinal travel – only depends on decay kinematics



Can use this to estimate how many more hits we would get, or how many petal layers are required

Track Fitting





- We have the track fitting underway, which is required for resolution studies
- Can then investigate the impact of multiple scattering on g-2 determination
- Want to add scintillating detectors into the same simulation!

Conclusions

EDM At FNAL

- EDM analysis well established at FNAL
- Squeezing as many tracks out of the data as possible, as sensitivity is likely to be statistically limited
- Possibility to increase sensitivity to an EDM by reweighting based on momentum and vertical angle

EDM At PSI

- Tracker used in phase-I to confirm frozen spin method, by checking g-2 oscillation is frozen out
- Optimising the detector position/orientation for this purpose
- Track fitting is now in place so resolution studies can begin, and we want to add in Scintillating detectors
- Currently not considering the beam oscillations – how will they impact the acceptance?