Searching for a muon EDM with the g-2 experiment

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Outline

- EDM Physics overview
  - EDM Physics - background
  - Motivations for EDM searches
  - Current limits on EDMs of fundamental particles
- μEDM and the g-2 experiment
  - Experimental technique
  - Reducing the upper limit – improvements from E821

EDM Physics

Magnetic dipole moment

$$\vec{\mu} = g\frac{Qe}{2m_\mu}\vec{s}$$

Electric dipole moment

$$\vec{d}_\mu = \eta\frac{Qe}{2m_\mu c}\vec{s}$$

EDM Physics

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Hamiltonian for a fermion in B and E field

$$\hat{H} = -\vec{\mu}\cdot\vec{B} - \vec{d}\cdot\vec{E}$$

Transformation Properties

	$\vec{B}$	$\vec{E}$	$\vec{\mu}$	$\vec{d}$
C	-	-	-	-
P	+	-	+	+
T	-	+	-	-

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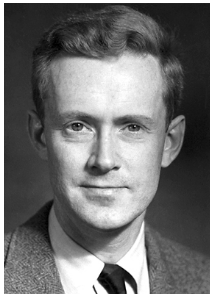

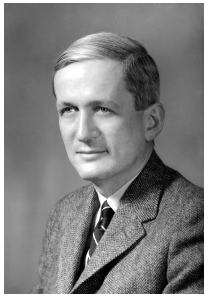

That's fine!*

*E.M Purcell and N.F Ramsey, Phys. Rev. **78**,807 (1950)

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C	-	-	-	-
P	+	-	+	+
T	-	+	-	-
CP	-	+	-	-
CPT	+	+	+	+

If CPT valid → EDM would violate CP

Current upper limits on EDMs

- Upper limits for e^- and μ are much higher than their SM predictions
- Some SUSY models predict μEDM ~ 10^{-24} e.cm

Particle	EDM Upper Limit (e.cm)	SM value (e.cm)
p	7.9×10^{-25} [1]	
n	2.9×10^{-26} [2]	$\sim 10^{-32}$
^{199}Hg	3.1×10^{-29} [1]	
e^-	1.6×10^{-27} [3]	$< 10^{-41}$
μ	1.8×10^{-19} [4]	$< 10^{-38}$

[1] PRL **102**, 101601 (2009)
[2] PRL **97**, 131801 (2006)
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Expected sensitivity of new g-2 experiment:
$\sim 10^{-21}$ e.cm

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Experimental Technique

g-2 frequency is given by:

$$\vec{\omega}_a = -\frac{Qe}{m_\mu}\left[a_\mu \vec{B} - \left(a_\mu - \frac{1}{\gamma^2 - 1}\right)\frac{\vec{\beta} \times \vec{E}}{c}\right]$$

$$\vec{\mu} = g\frac{Qe}{2m_\mu}\vec{s}$$

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Dependence on E field cancelled out by choosing $\gamma = 29.3$

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EDM adds a term to this expression:

$$\vec{\omega} = \vec{\omega}_a + \vec{\omega}_{EDM}$$

$$\vec{\omega}_{EDM} = -\frac{e\eta}{2m_\mu c}\left(\vec{\beta} \times \vec{B}\right)$$

$$\vec{\mu} = g\frac{Qe}{2m_\mu}\vec{s}$$

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A non-0 EDM would increase the measured precession frequency

→ Introduces systematic error on g-2 measurement

$$\vec{\mu} = g\frac{Qe}{2m_\mu}\vec{s}$$

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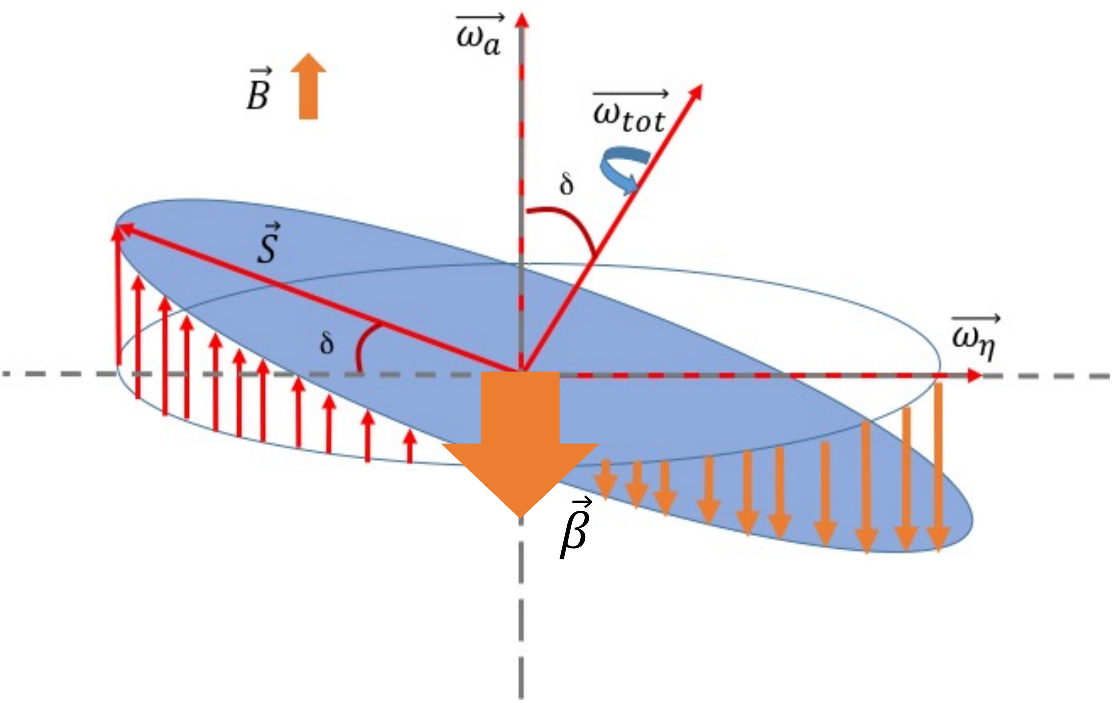
Precession Plane Tilt

μEDM tilts the precession plane of the muons by an angle δ



EDM tilts the muon precession plane towards the centre of the g-2 storage ring by

$$\delta = \tan^{-1}\left(\frac{\eta\beta}{2a_\mu}\right)$$

$$\vec{\omega} = \vec{\omega}_a + \vec{\omega}_{EDM}$$

$$\vec{\omega}_{EDM} = -\frac{e\eta}{2m_\mu c}\left(\vec{\beta}\times\vec{B}\right)$$

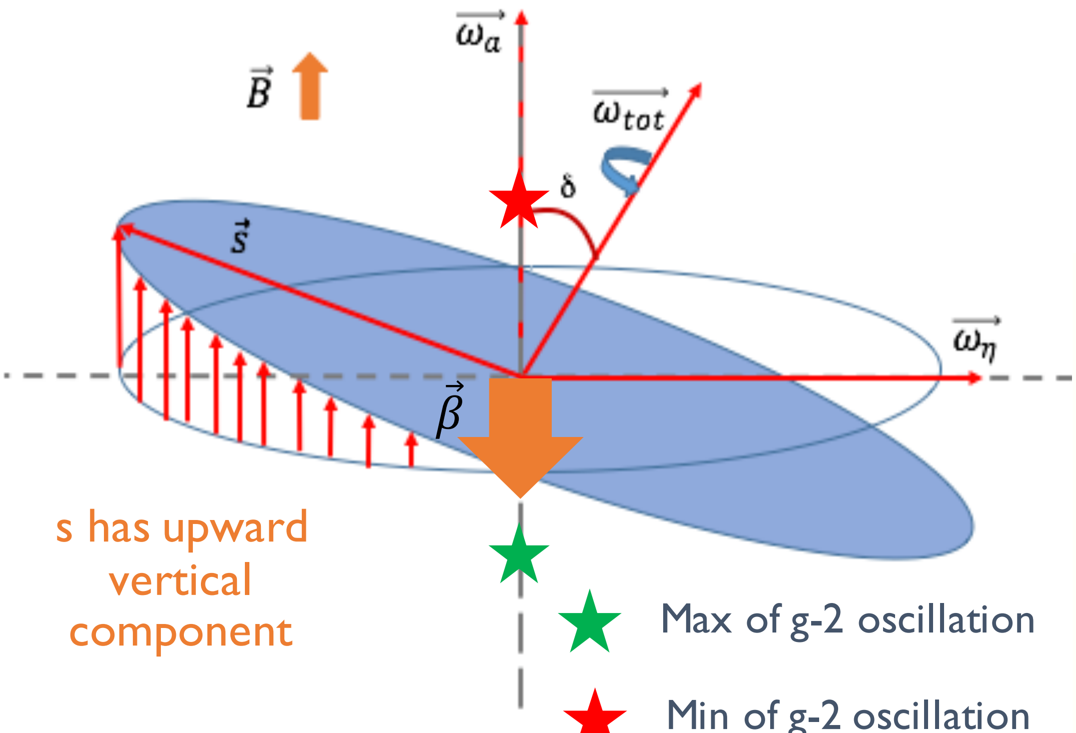
Measured angle is reduced due to Lorentz contraction:

$$\delta' = \tan^{-1}\left(\frac{\tan\delta}{\gamma}\right)$$

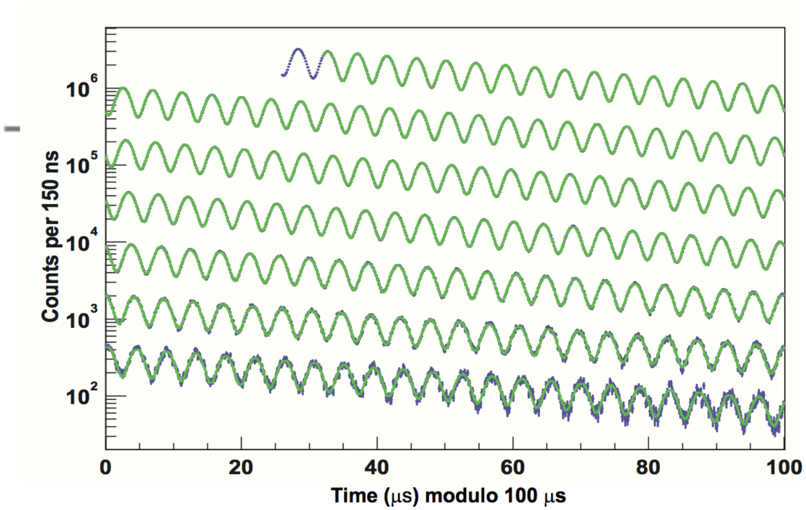
Phase Difference

Precession plane tilt causes an oscillation in the angle at which the decay e+ are emitted

e+ preferentially emitted in direction of muon spin



Decay angle oscillation is at the same frequency as ω_{total}, but 90° out of phase



g-2 oscillation is at a maximum when spin is aligned with momentum

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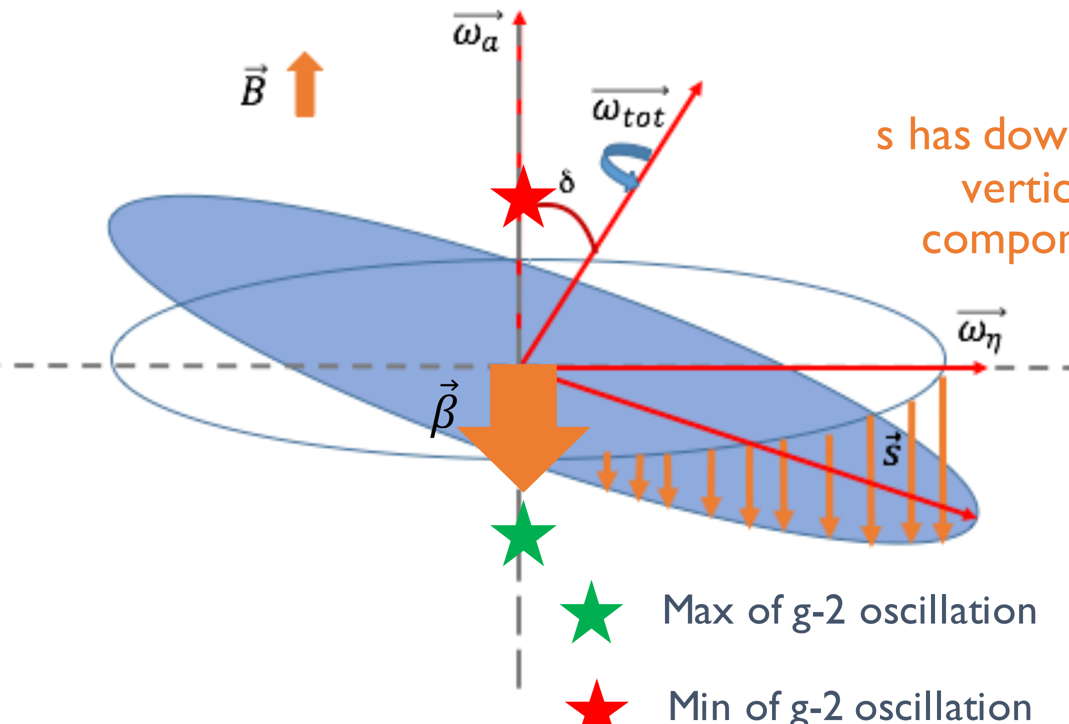
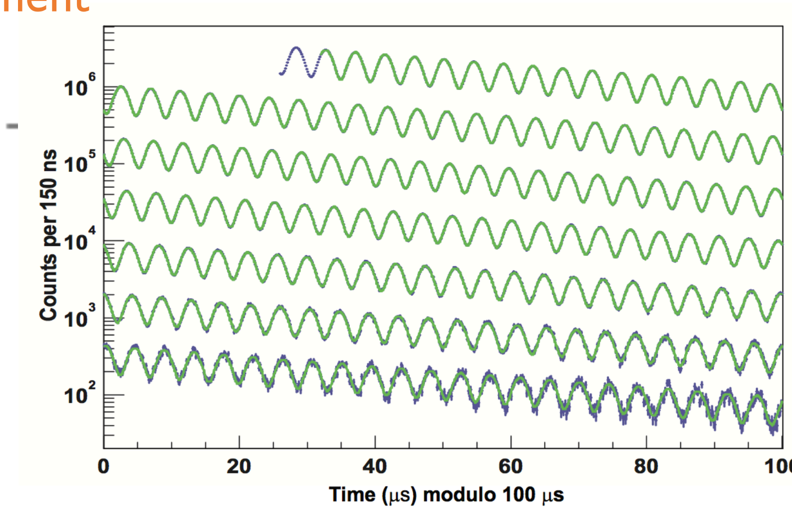


g-2 oscillation is at a maximum when spin is aligned with momentum

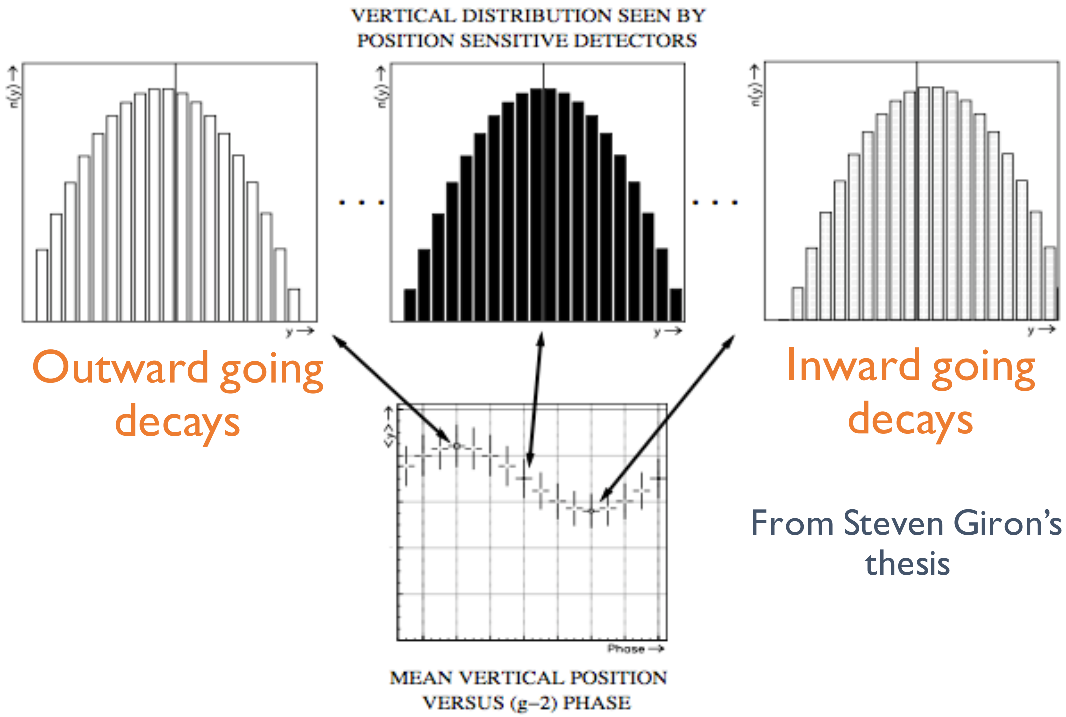
Decay angle oscillation is at the same frequency as ω_{total}, but 90° out of phase

s has downward vertical component



Vertical Position Oscillations

- Oscillation in the e+ vertical decay angle leads to an oscillation in the average vertical position on the calorimeters
- This analysis method was dominated by systematics in E821 – very sensitive to detector misalignment effects



From Steven Giron's thesis

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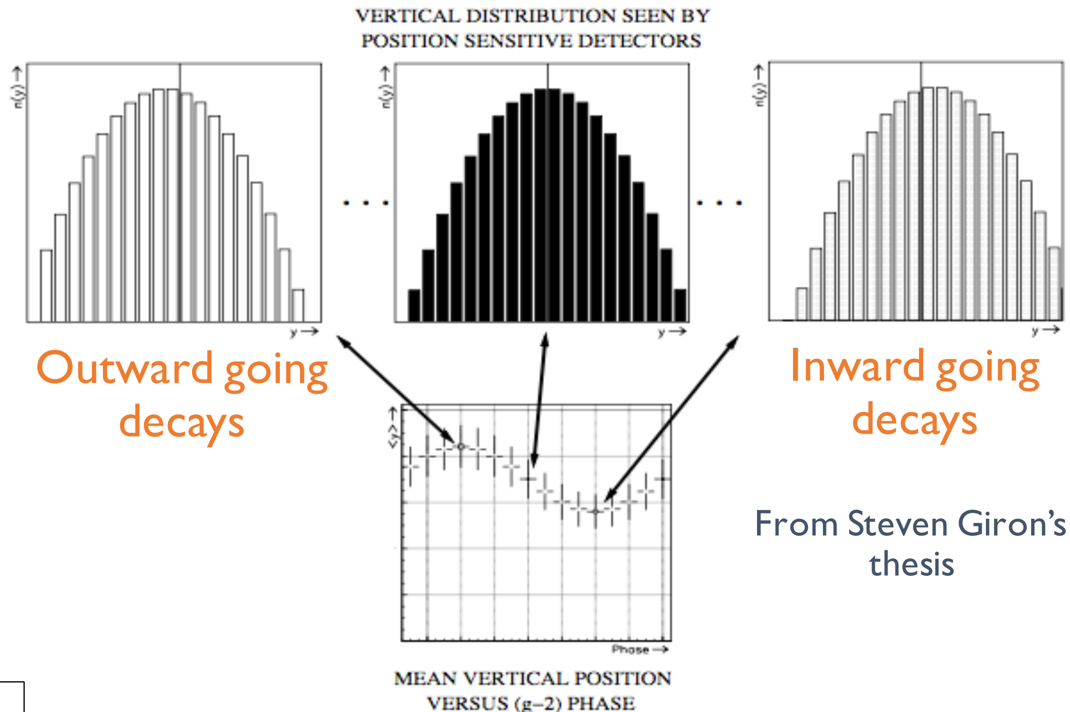

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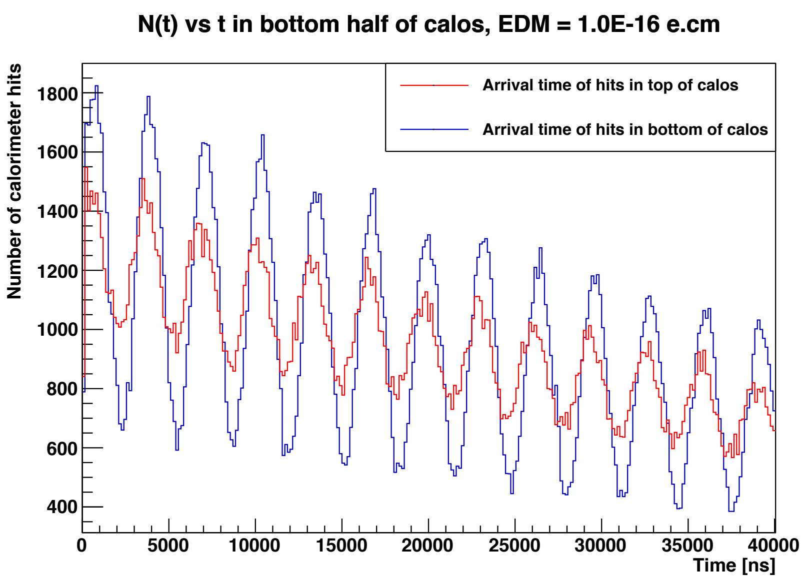
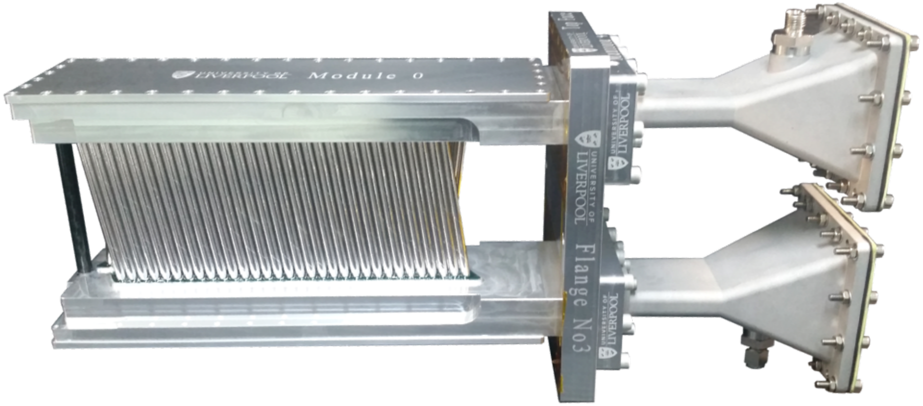


- See a difference in the amplitude of oscillation in N(t) in the hits arriving in the top and bottom halves of the calorimeters

→ Inward decays are more concentrated/less spread out

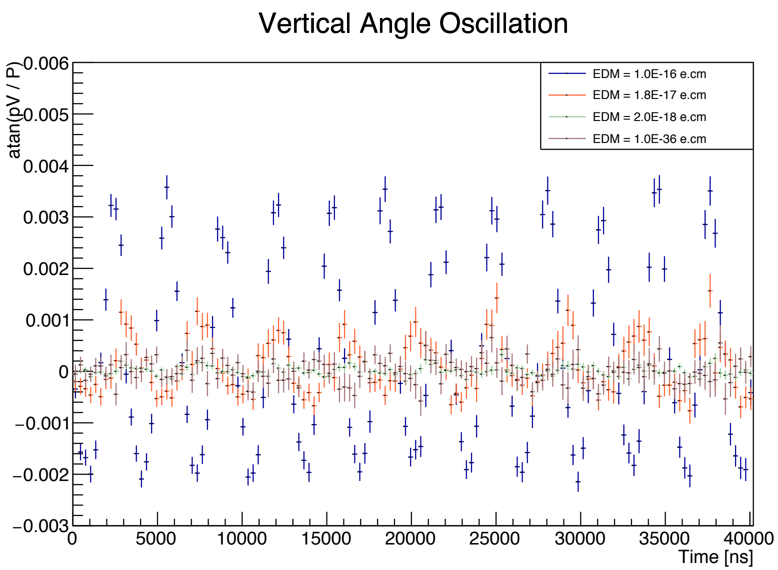
Vertical Angle Oscillations

- Alternative analysis method: measure the vertical angle oscillations directly using tracking detectors
- Reconstruct the vertical angle of the positron at decay point



→ Can track e+ through magnetic field, so effect of radial field on path of e+ has no effect

Target: $d_\mu < |{\sim}10^{-21}|$ e.cm



→ Detector misalignment has much less effect on this measurement – statistics dominated

→ E989 has more sophisticated tracking and much higher statistics – best chance of reducing μEDM limit using this analysis method

Conclusions

- Primary μEDM signal is a vertical oscillation in positron decay angle caused by a tilt in the muon precession plane
- Vertical oscillation in e+ decay angle leads to measurable oscillation in vertical position of arrival at calorimeters
  → Detector misalignment has significant effect on this method
- Direct measurement of e+ decay angle using much improved tracking detector system
  →Much less dependent on detector misalignment – statistics dominated
- Muon g-2 experiment aims to place new upper limit on μEDM of ~10^{-21} e.cm