Measuring the muon electric dipole moment at the Fermilab Muon g-2 experiment

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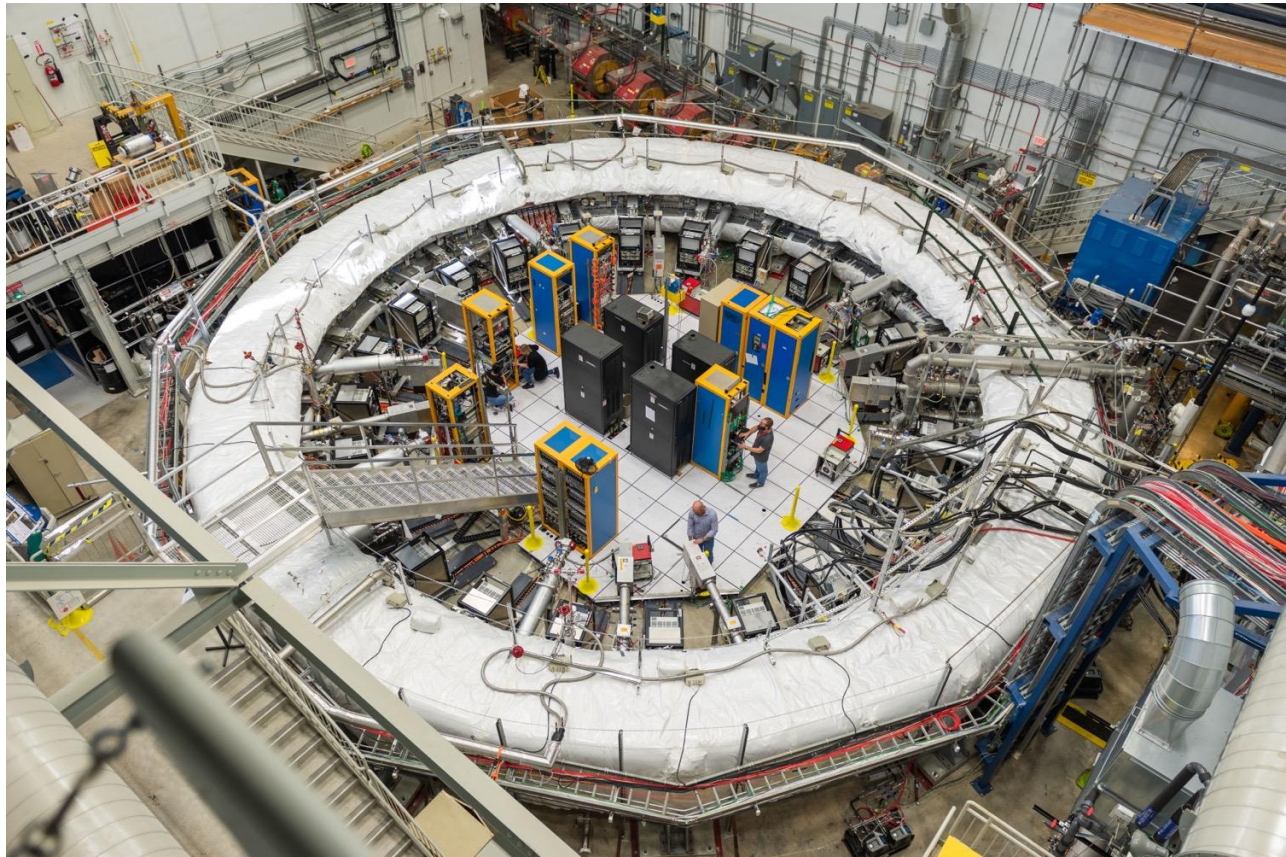


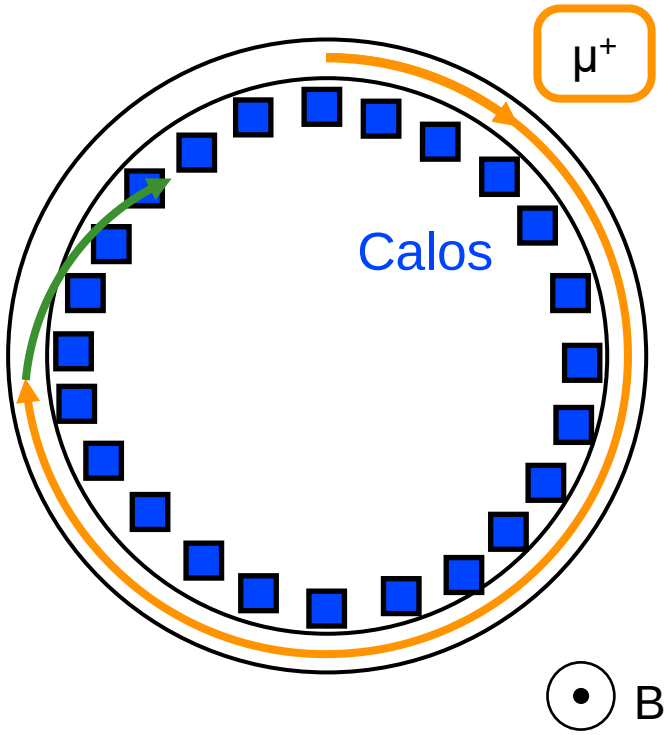
Fermilab Muon g-2

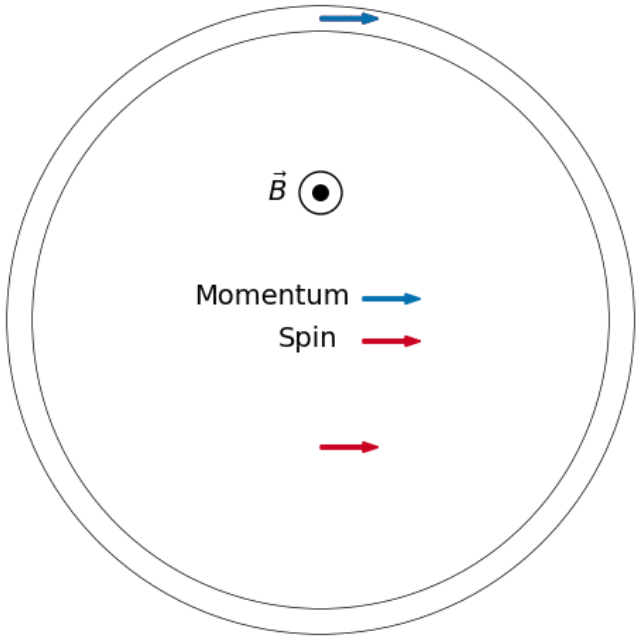
- Measuring the muon anomalous magnetic moment.

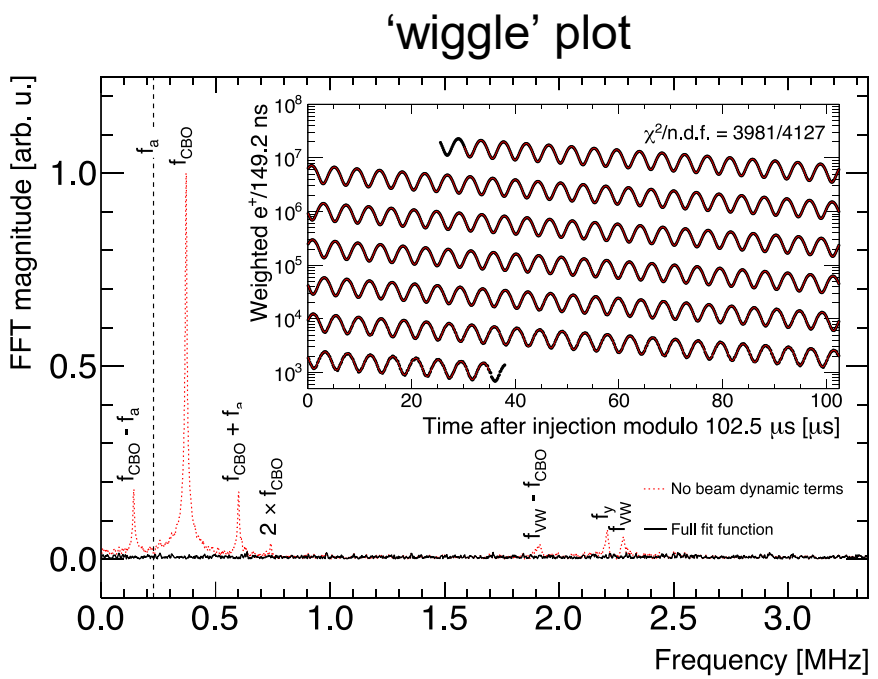
$$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$$

Latest result measured the muon anomalous magnetic moment to 0.20ppm Phys. Rev. Lett. **131,** 161802 (2023)

- High energy positrons favourably decay along spin vector.







Electric dipole moments (EDMs)

- Classically, charged point-like particles have zero EDM.

- A small EDM arises due to quantum fluctuations polarising the vacuum around the particle $\boldsymbol{\mathcal{O}(10^{-36})}$ **e cm for muons.**

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

CP even CP odd

$$\vec{d} = \eta \frac{q}{2m} \vec{s}$$

Magnetic moment!

$$\vec{\mu} = g \frac{q}{2m} \vec{s}$$

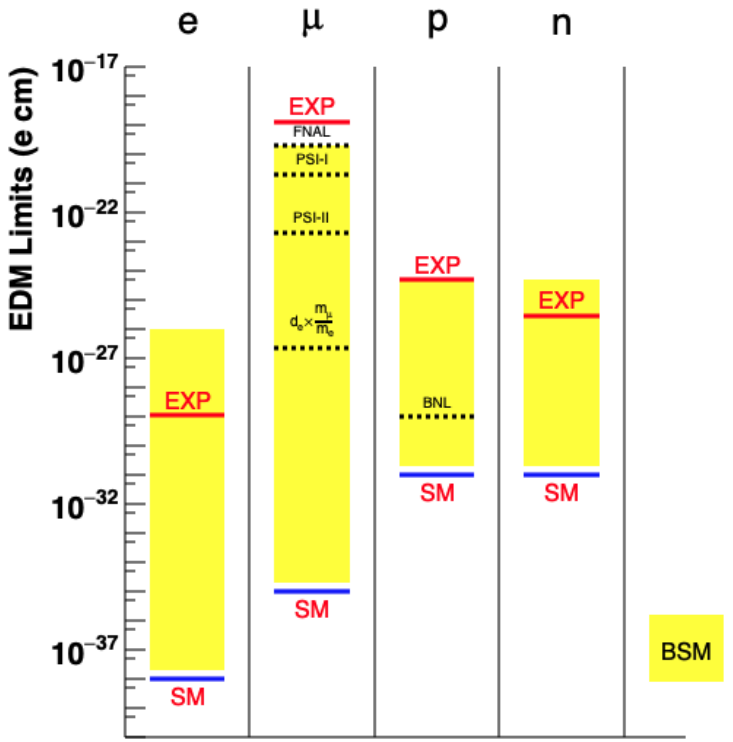
- A measurement of non-zero EDM would **violate CP symmetry**.

Muon EDM

- The **current best limit** was set at BNL: $|\boldsymbol{d_\mu}| < \mathbf{1.8 \times 10^{-19} e \cdot cm}$.*

- Many orders of magnitude above SM predictions.

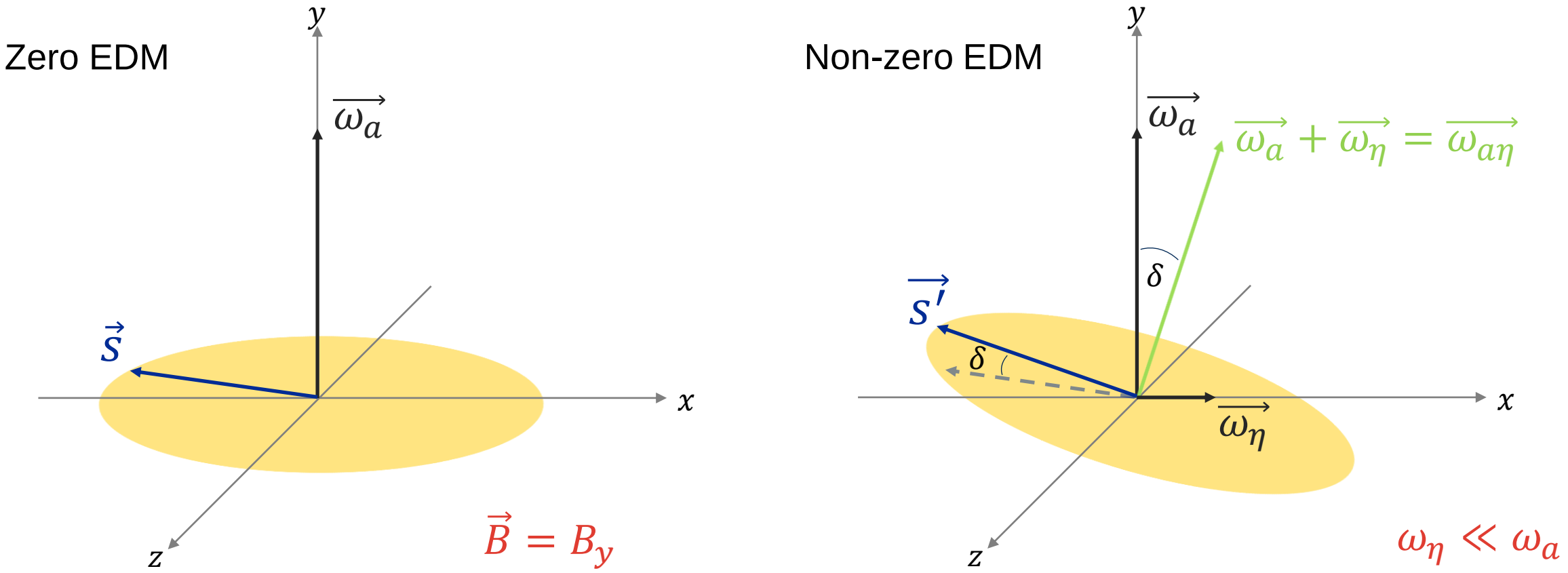
- Improving on this will help to **constrain BSM theories.**



Plot: Mark Lancaster

*Phys. Rev. D **80**, 052008

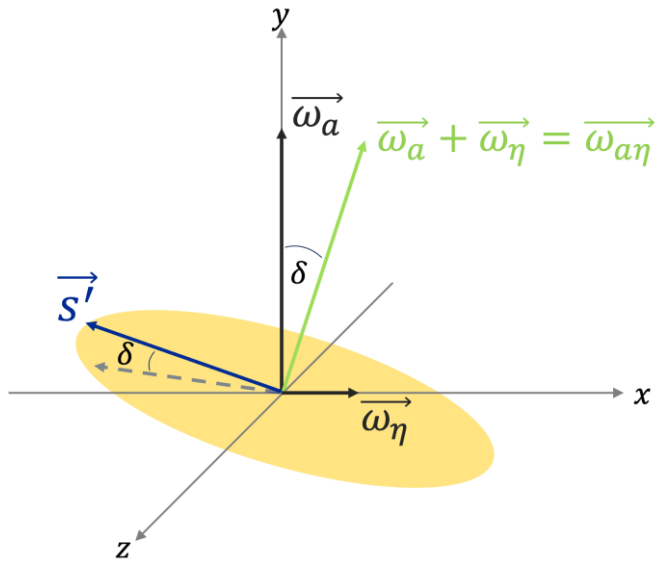
Measuring the muon EDM



- **Lorentz transformation** of the B field in the laboratory frame to the muon rest frame introduces an electric field.
- This produces a torque, **tilting the spin precession plane**.

Measuring the muon EDM

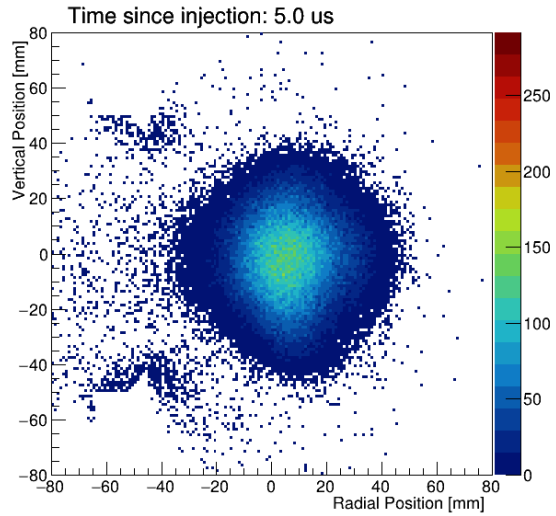
- The **average vertical decay angle will oscillate π out of phase with the g-2 oscillation.**
  - Measure the angle the decay positron makes with the horizontal.
  - Fit this oscillation to extract the tilt angle.

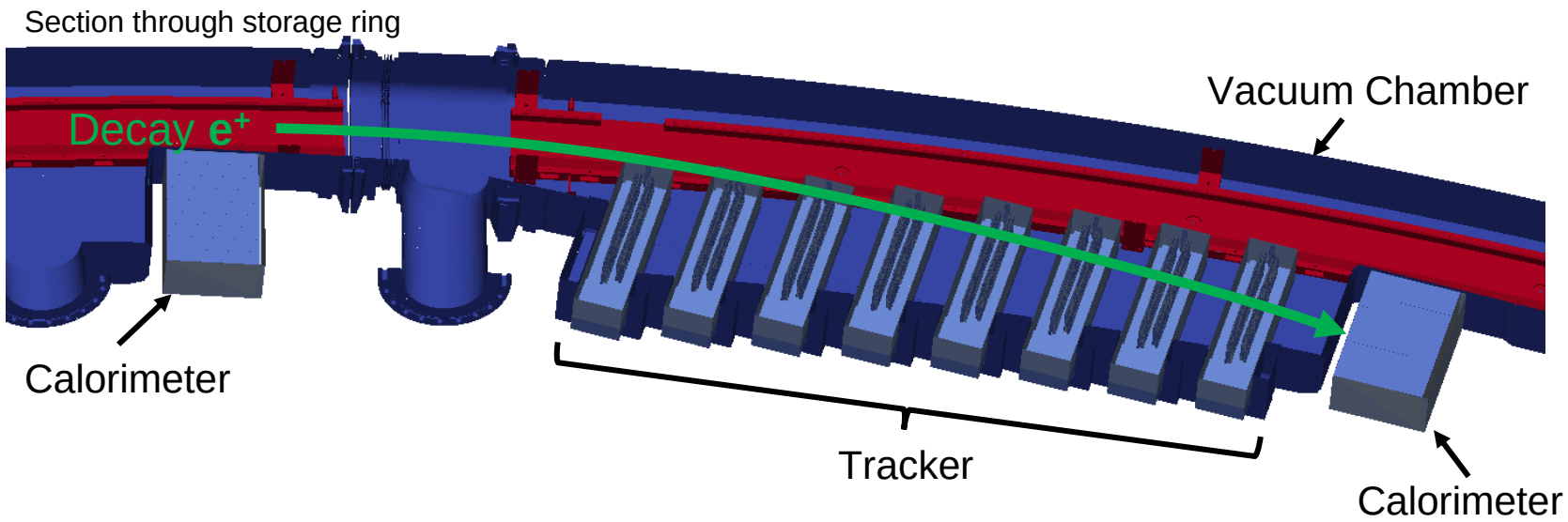


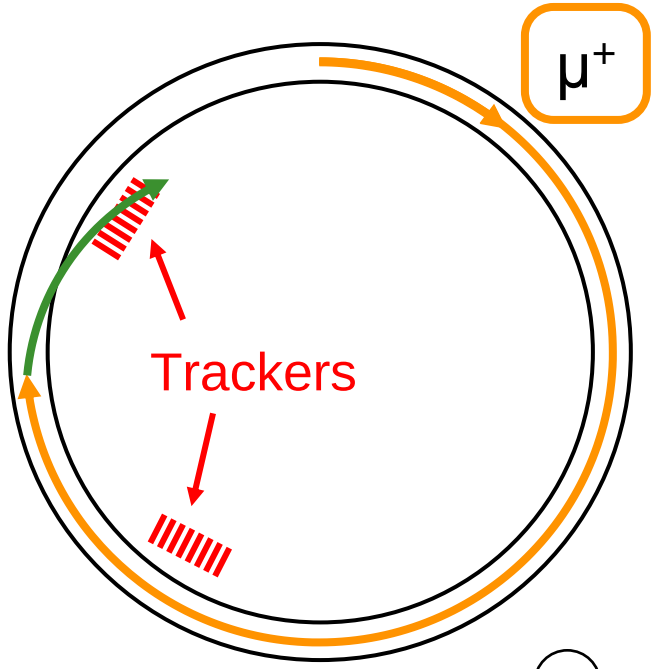
Straw trackers

- Two straw tracker stations around the ring.
- **Extrapolate backwards to the positron decay position**.

Beam oscillations → systematics & corrections.
Vertical decay angle → EDM.







Analysis

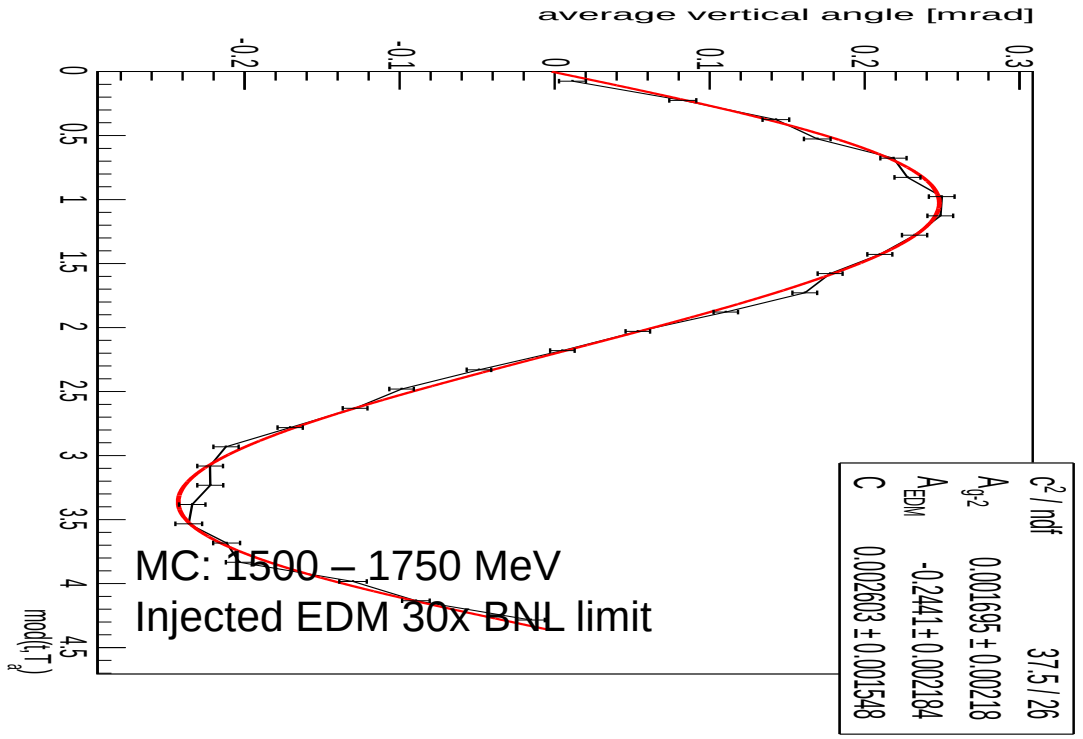
- Use a **momentum binned analysis** for positrons between 1000 – 2500 MeV.
  - Improves the accuracy of the acceptance correction.

- Plot average vertical decay angle $\langle \theta_y \rangle$ vs. time modulo the g-2 period $\mathrm{T_a}$.
  - Minimise beam oscillations, maximise oscillations with $T = T_a$.

Out of phase with the g-2 oscillation

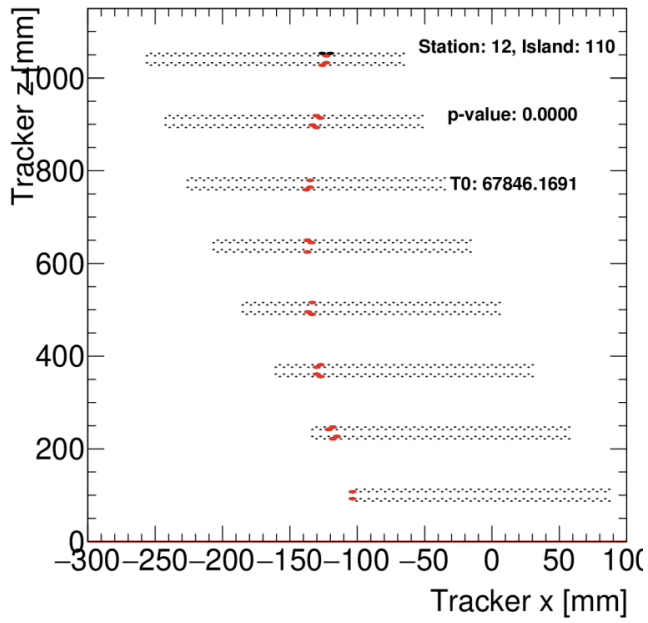
$$\frac{A_{g-2}\cos(\omega_a t + \phi_a) + A_{EDM}\sin(\omega_a t + \phi_a)}{1 + A_N \cos(\omega_a t + \phi_a)} + \mathrm{C}$$

From momentum binned tracker wiggle plot



Tracking optimisation

- Result from BNL was statistically limited.
- **Aim to improve the limit by an order of magnitude.**
- To help achieve this **we have been optimising the tracking to increase the statistics for EDM analysis**.
  - Previously, optimised to study beam oscillations using high quality tracks.

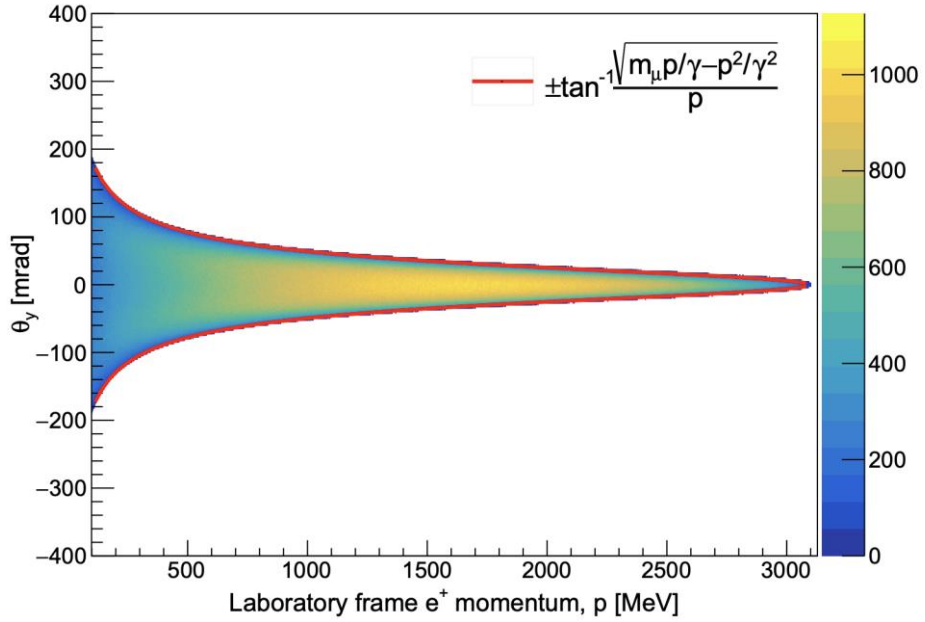


- Managed **to increase the number of tracks by 2.7x for Run-2/3**
  - Removing bad hits after fitting and fill-time dependent measures.

Systematics

- A **radial magnetic field would also induce a tilt in the spin precession plane**.
  - Measure this directly with a hall probe and using the surface coils.
  - Correct for any tilt from radial field.

- **Tracker acceptance**.
  - The trackers do not see all the decay positrons with same efficiency.
  - Use simulation to determine the impact of this **momentum dependent affect**.



Summary

- Experimental limits on EDMs are well above SM predictions.

- Muon g-2 will also measure the **muon EDM** with the aim of **improving the limit by an order of magnitude** with analysis of Run-1 and Run-2/3 data well underway.

- New techniques **increased the number of tracks by 2.7 times for Run-2/3**, which will be be crucial in achieving this goal.

Muon g-2 collaboration meeting, Liverpool 2023

Thanks for listening!