A search for the muon electric dipole moment in the Fermilab Muon g-2 experiment
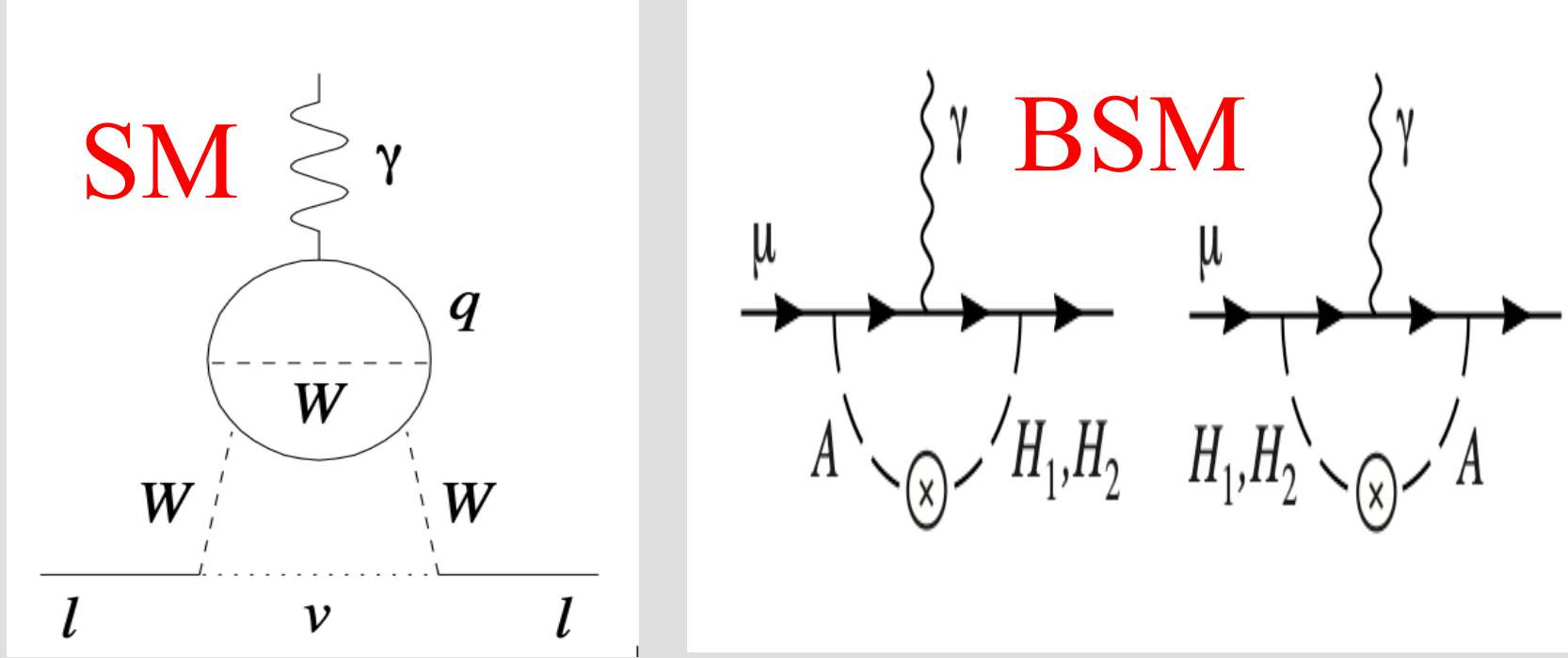
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1. Muon Electric Dipole Moment

In QFT, the electric dipole moment (EDM), an analogy with the magnetic dipole moment $\vec{\mu} = g\frac{e}{2mc}\vec{s}$, is given by:

$$\vec{d} = \eta \frac{e}{2mc}\vec{s}$$

$d_\mu \sim 10^{-42}$ e cm (SM Prediction) [1]

$d_\mu \sim 10^{-21} - 10^{-27}$ e cm (BSM Prediction)

Contributing processes to a lepton EDM are at the 3-loop level in the Standard Model and in Beyond Standard Model Physics (e.g. Higgs Doublet, SUSY) [2]

2. Current Research Status

There are direct and indirect limits on the muon EDM:

Direct limits:

$$|d_\mu| \leq 1.8 \times 10^{-19} \text{ e cm}$$

Based on the BNL Muon g-2 experiment[3]

Indirect limit:
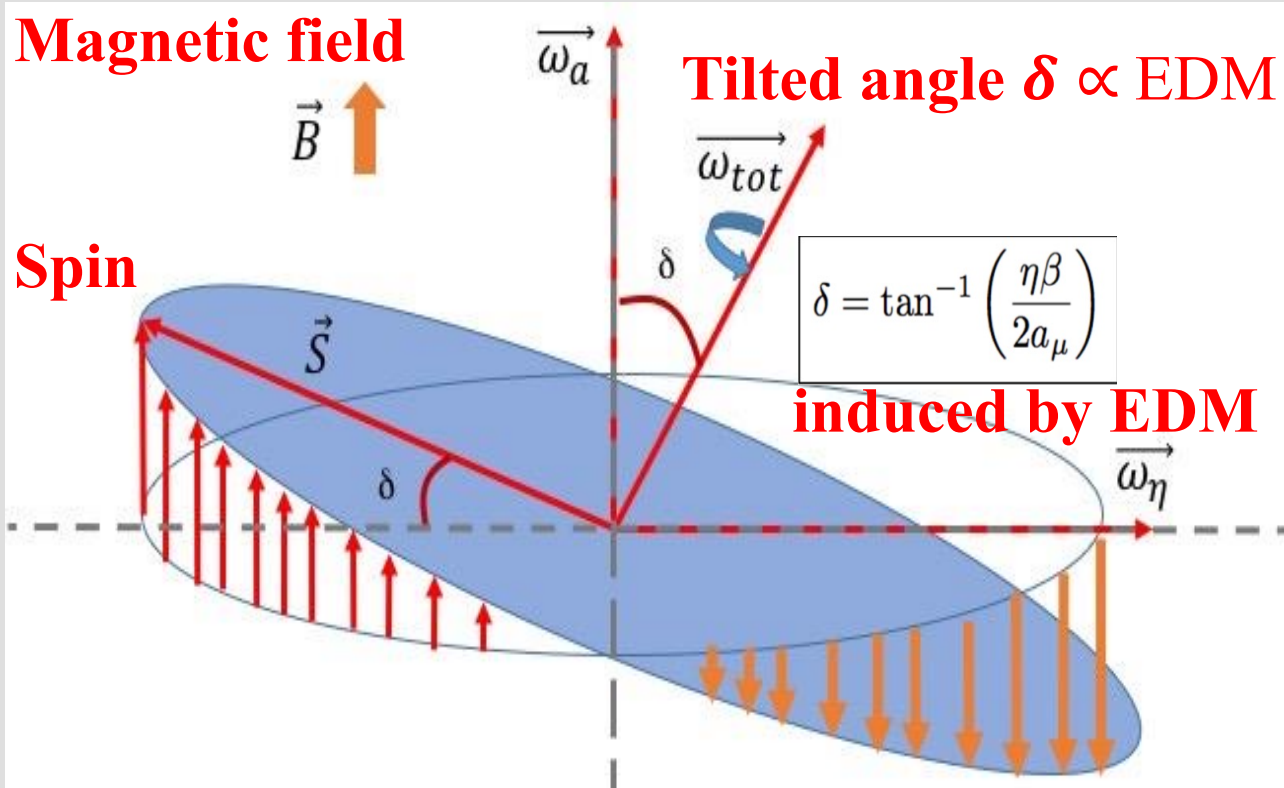
$$|d_\mu| \leq 1.9 \times 10^{-20} \text{ e cm}$$

Based on the d_{Hg}, d_{thO} EDM[4]

$$|d_\mu| = \frac{m_\mu}{m_e}|d_e| \leq 2.3 \times 10^{-27} \text{ e cm}$$

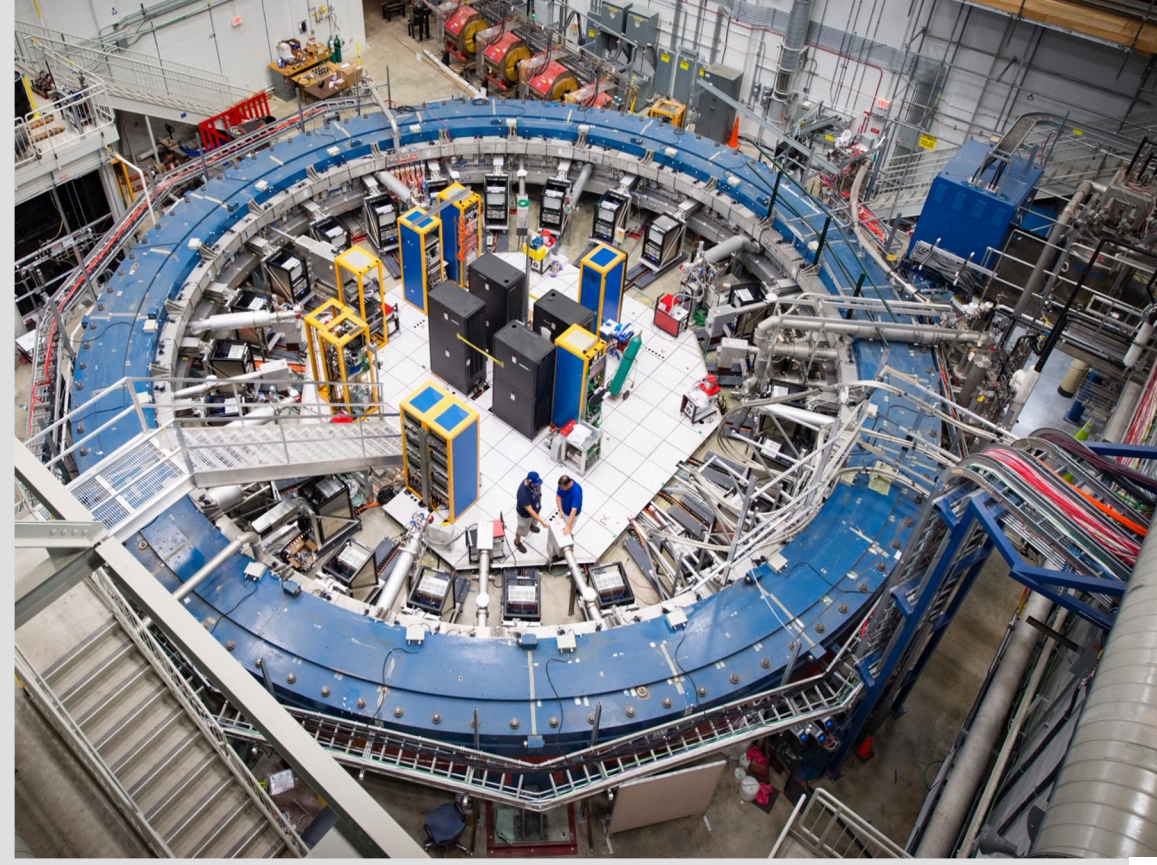Minimal flavor violation

Any detected signal is a strong hint of new physics.

3. EDM Measurement in The Fermilab Muon g-2 Experiment

Magnetic field $\vec{B}$

Spin $\vec{S}$

$\vec{\omega}_a$

Tilted angle $\delta \propto$ EDM

$\vec{\omega}_{tot}$

$\delta = \tan^{-1}\left(\frac{\eta\beta}{2a_\mu}\right)$
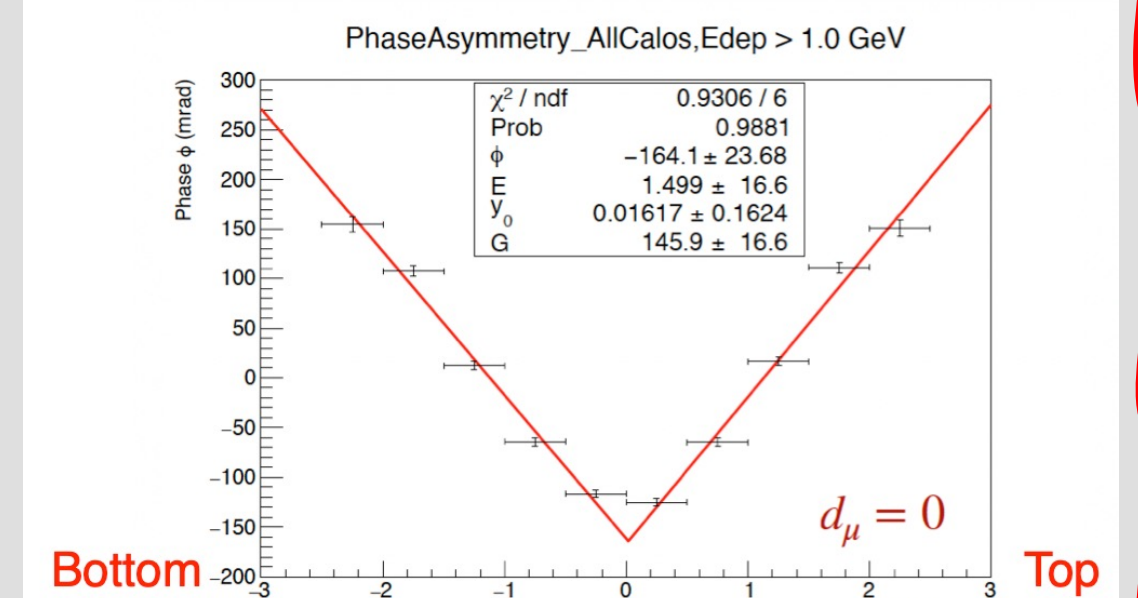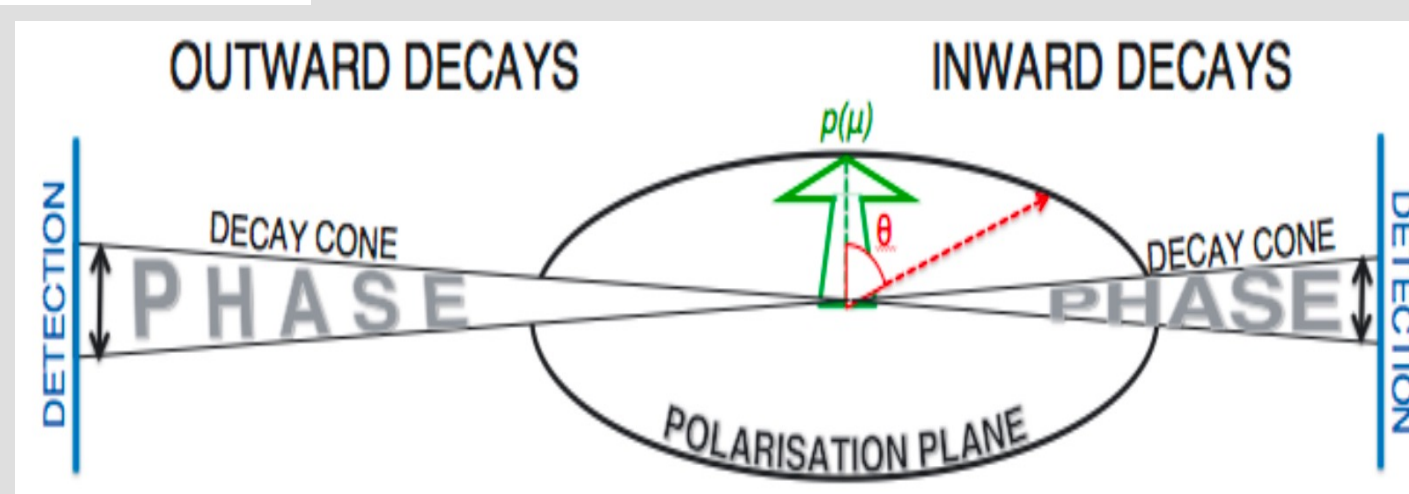
induced by EDM $\vec{\omega}_\eta$

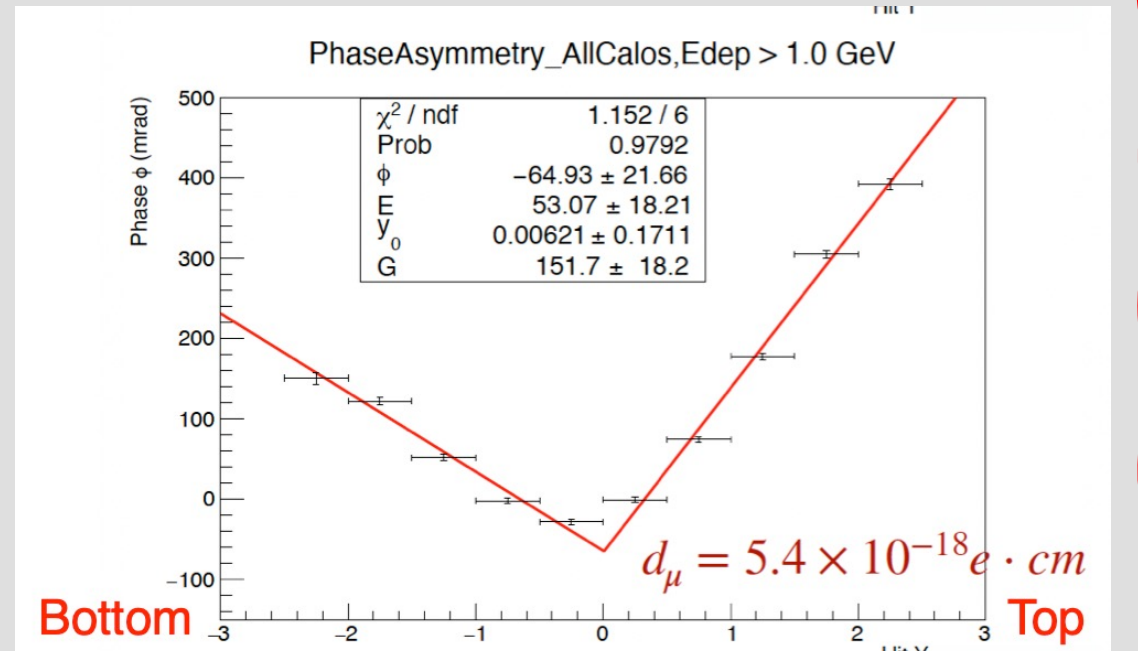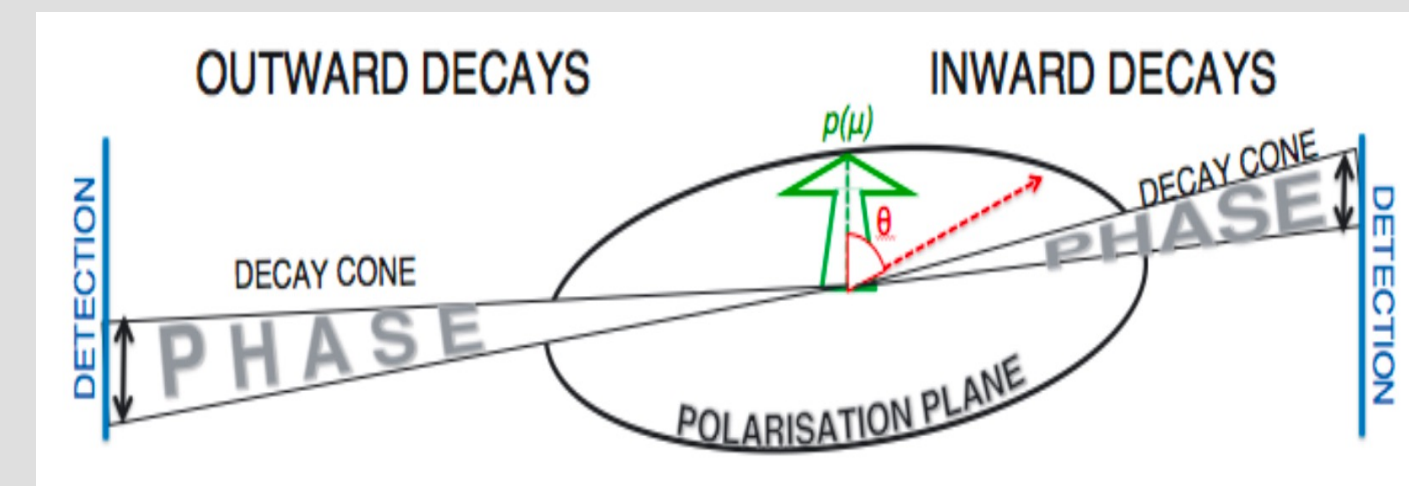The precession plane tilted when EDM existed

The phase asymmetry will be evidence of EDM's existence

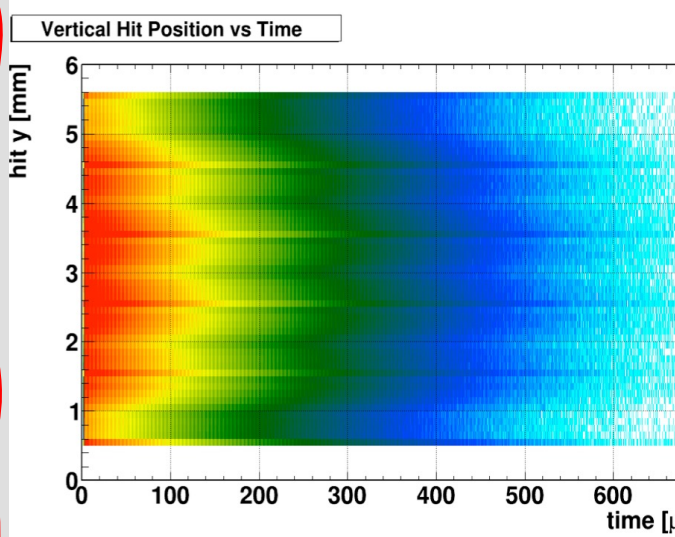For EDM = 0, the phase vs vertical hit position is symmetric

$d_\mu = 0$

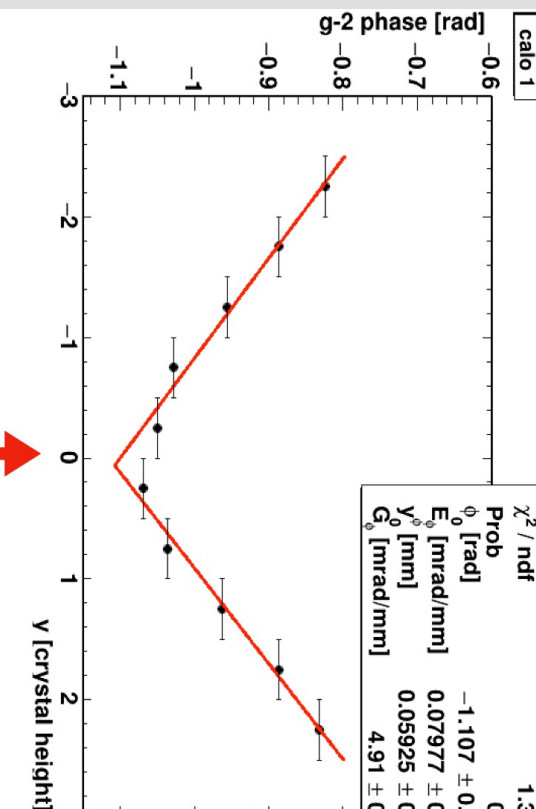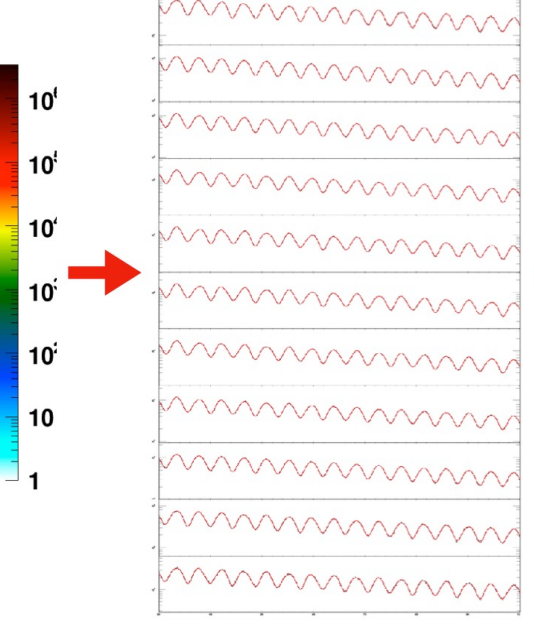For EDM ≠ 0, the phase vs vertical hit position is asymmetric as the precession plane is tilted.

$d_\mu = 5.4 \times 10^{-18} e \cdot cm$

4. Calorimeter Phase Method Analysis

Reconstruct the vertical hit versus time

Time spectrum for 10 vertical bins

Fit phase vs vertical hit with ϕ_y
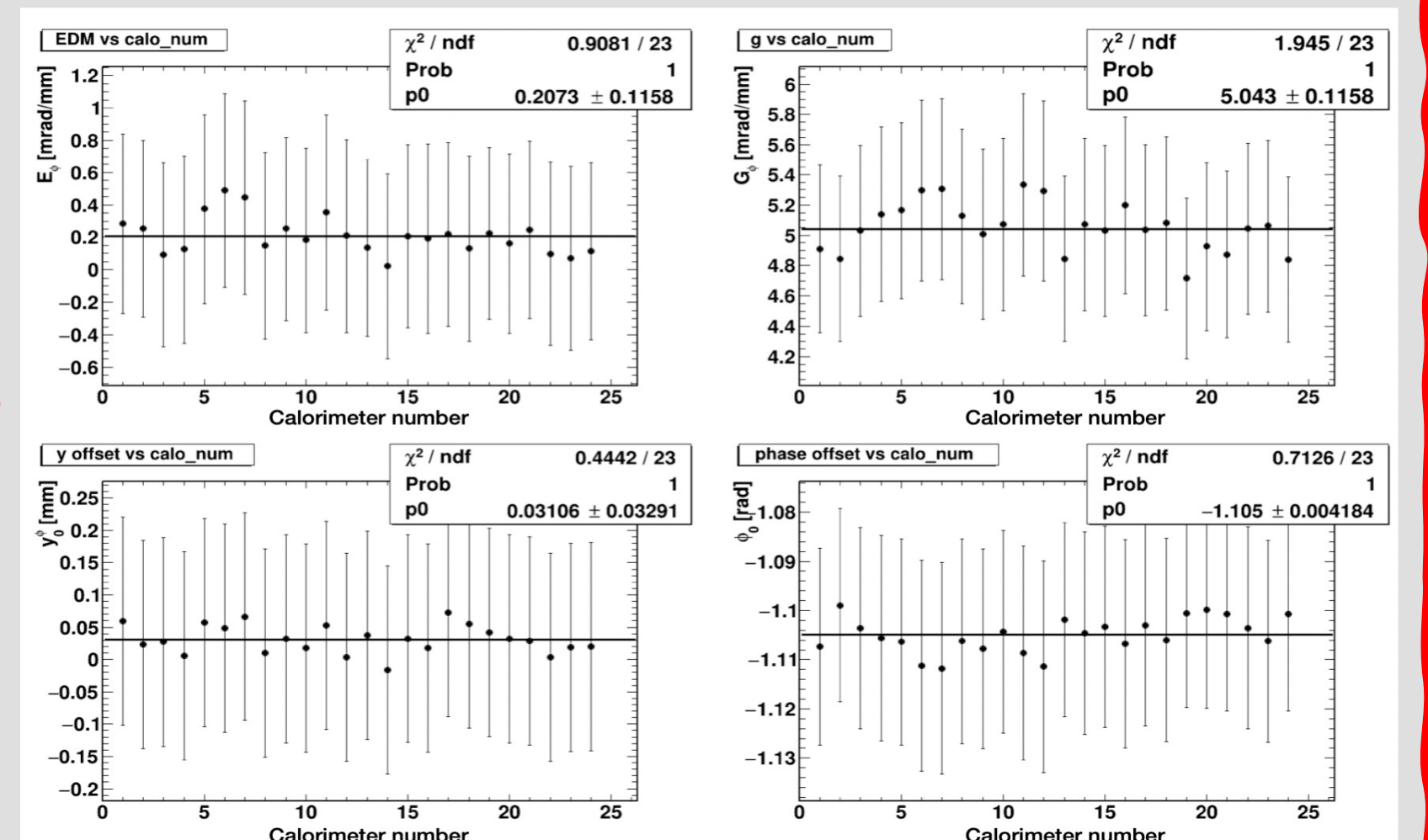
$$\phi(y) = \phi_0 + E_\phi(y - y_0^\phi) + |G_\phi(y - y_0^\phi)|$$

overall detector phase offset — a quantity proportional to the muon EDM — vertical detector offset — phase changes not related to EDM

1. Muon EDM is a sensitive probe to BSM physics;
2. A more sensitive search for muon EDM is currently underway at Fermilab Muon g-2

5. Run2 Preliminary Analysis

Reference:
1. Phys. Rev. D 89 (2014) 056006
2. HEP - Ph (1997) 9707544
3. Phys. Rev. D 80 (2009) 052008
4. Phys. Rev. Lett 128 (2022) 131803