

Search for a permanent muon electric dipole moment at the Fermilab Muon g-2 experiment

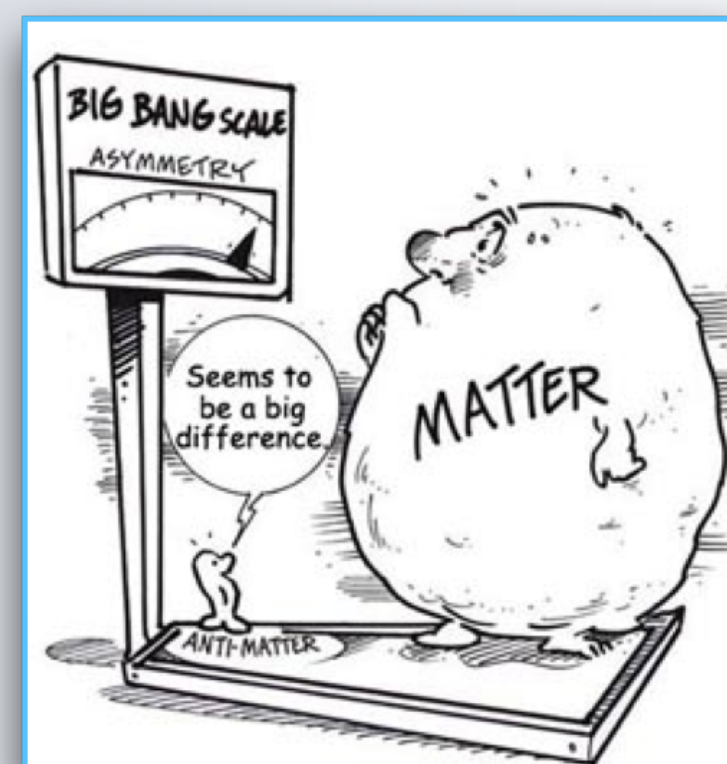
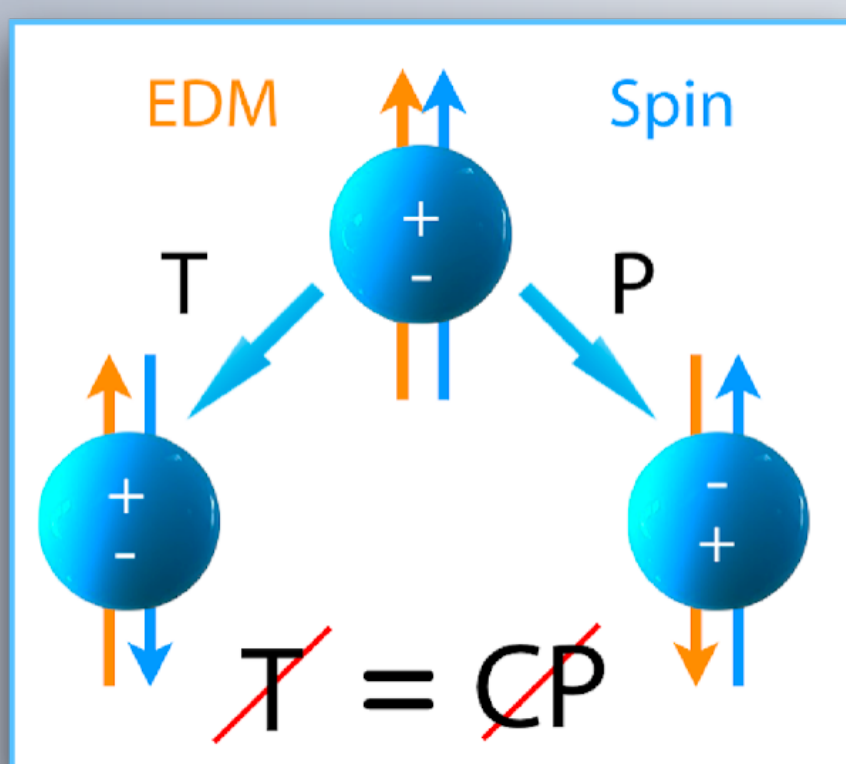
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ABSTRACT

- The presence of a permanent electric dipole moment (EDM) in any elementary particle implies Charge-Parity (CP) symmetry violation and thus could help explain the matter-antimatter asymmetry observed in our universe.
- Within the context of the Standard Model (SM), EDMs of SM particles are extremely small. However, in many beyond SM (BSM) theories, EDMs could be within experimental reach in the near future.
- Recently, the muon EDM is of particular interest due to the tensions in the anomalous magnetic moment of the muon and the electron, and hints of lepton flavor universality violation (LFUV) in B-meson decays.
- In some of the BSM theories with LFUV, the muon EDM could be as large as $1e-22$ e cm. Moreover, the 23 orders of magnitude difference between the current experimental limit ($1e-19$ e cm) and the SM prediction ($1e-42$ e cm) means muon EDM is one of the least tested areas of the SM and **any detected signal is a strong hint of new physics**.
- In this poster, we will present how the Muon g-2 experiment at Fermilab can perform a more sensitive muon EDM search ($10^{-21} e \cdot cm$).

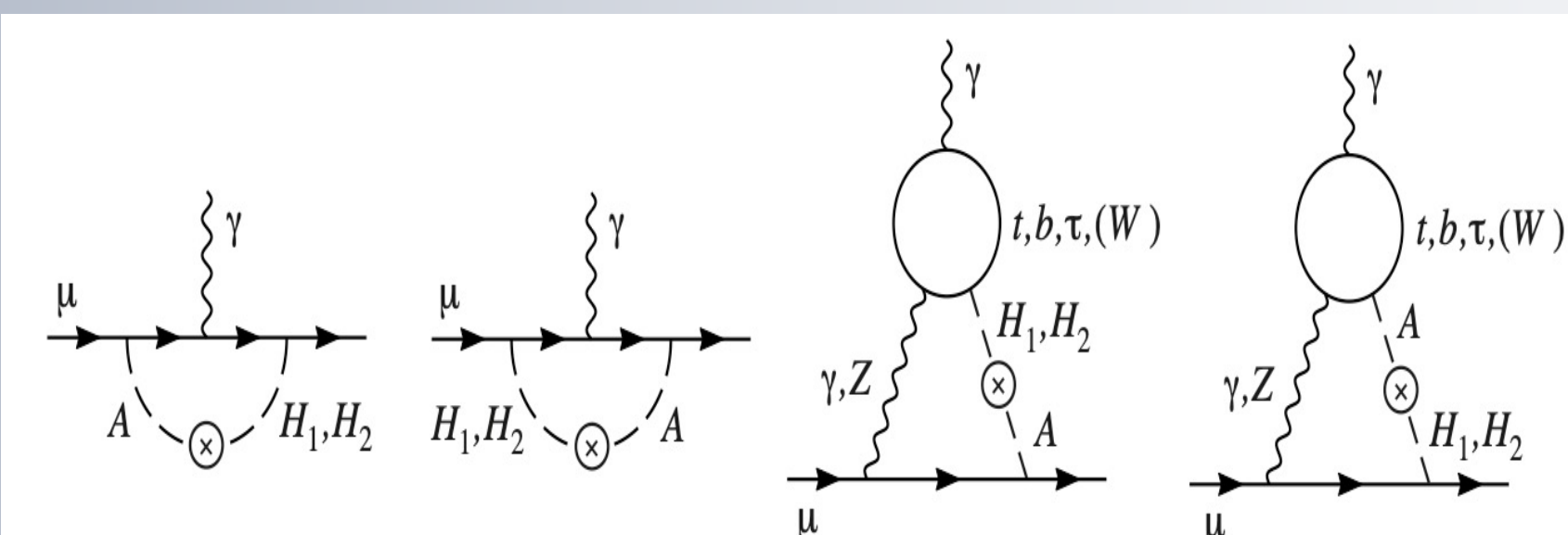
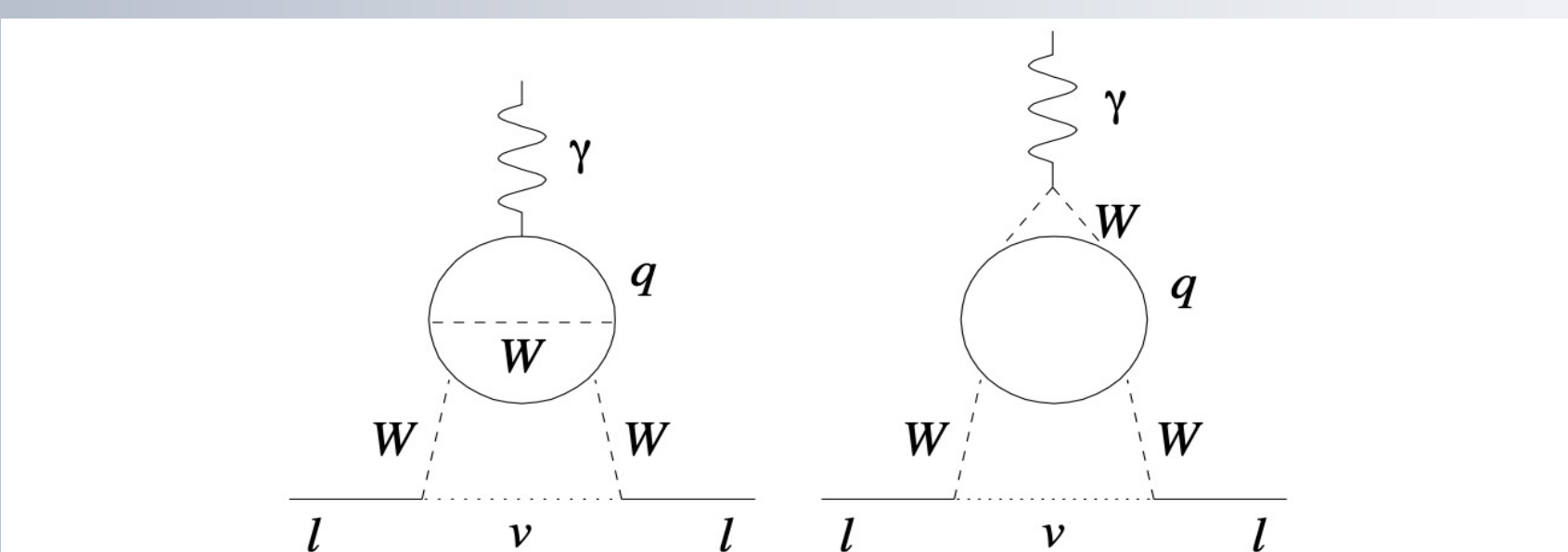


WHAT IS EDM

The electric dipole moment, analogy with magnetic dipole moment $\vec{\mu} = g \frac{e}{2mc} \vec{s}$, is given by:

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

Contributing processes to a lepton EDM at the 3-loop level in Standard Model and in Beyond Standard Model (Higgs Doublet)



The best limit on the muon EDM is provided by the BNL muon g-2 collaboration[1]:

$$d_\mu = (0.0 \pm 0.9) \times 10^{-19} e \text{ cm}$$

$$|d_\mu| < 1.8 \times 10^{-19} e \text{ cm (95% C.L.)}$$

$$|d_\mu| < 1.9 \times 10^{-20} e \text{ cm}$$

(Based on d_{Hg} and d_{ThO} EDM)

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Particle	System	EDM Limit ($e \cdot \text{cm}$)	SM ($e \cdot \text{cm}$)
e	ThO molecule	1.1×10^{-29} (90% C.L.)	$O(10^{-44})$
μ	Muon storage ring	1.8×10^{-19} (95% C.L.)	$O(10^{-42})$
τ	$e^+e^- \rightarrow \tau^+\tau^-$	$-2.2 < \text{Re}(d_\tau) < 4.5 \times 10^{-17}$ $-2.5 < \text{Im}(d_\tau) < 0.8 \times 10^{-17}$	$O(10^{-41})$
n	Neutron storage cell	1.8×10^{-26} (95% C.L.)	$O(10^{-32})$
^{199}Hg	Mercury cell	7.4×10^{-30} (95% C.L.)	$O(10^{-36})$

Current limits and Standard Model prediction for $|d|$ of other particles[2,3,4]:

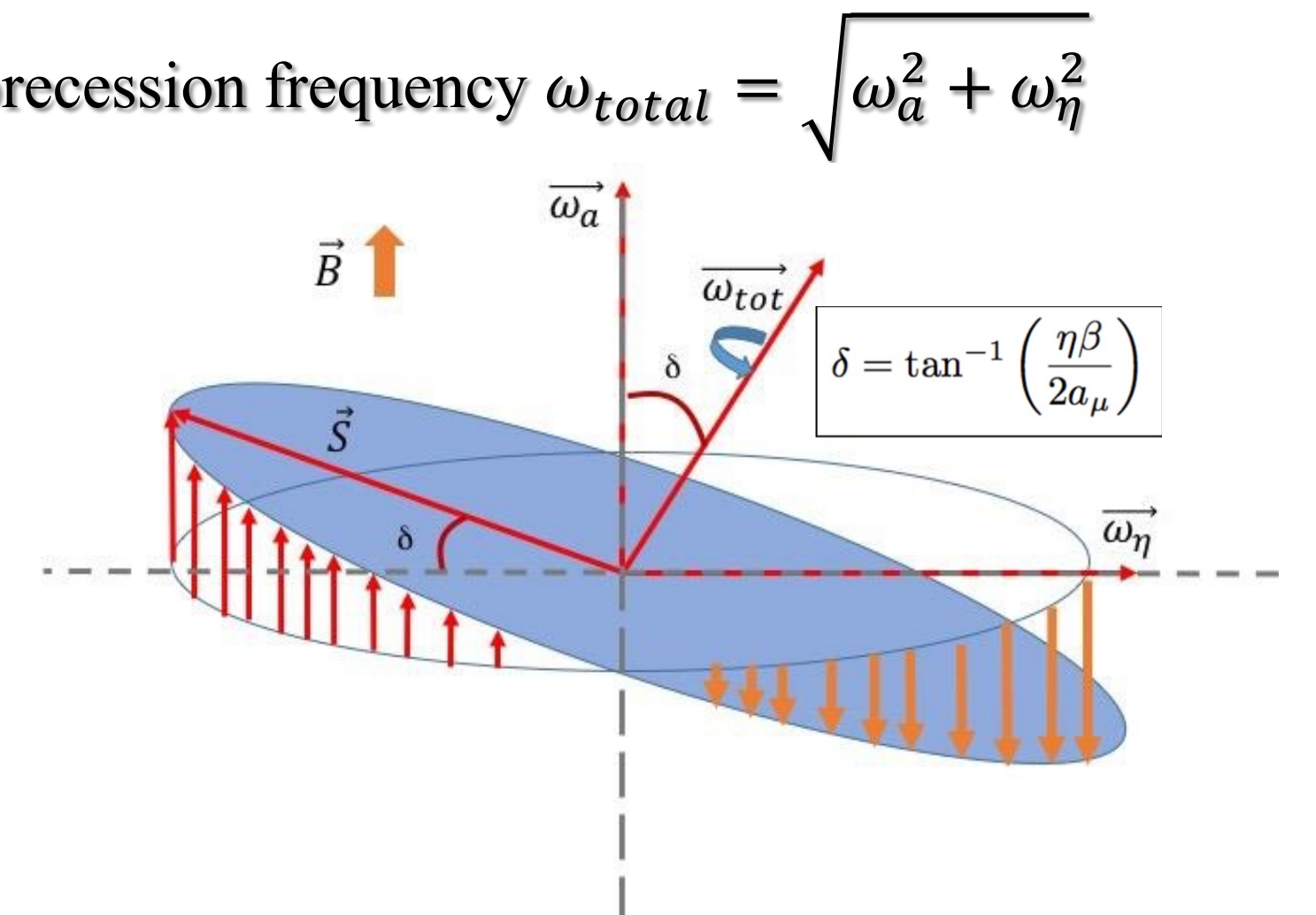
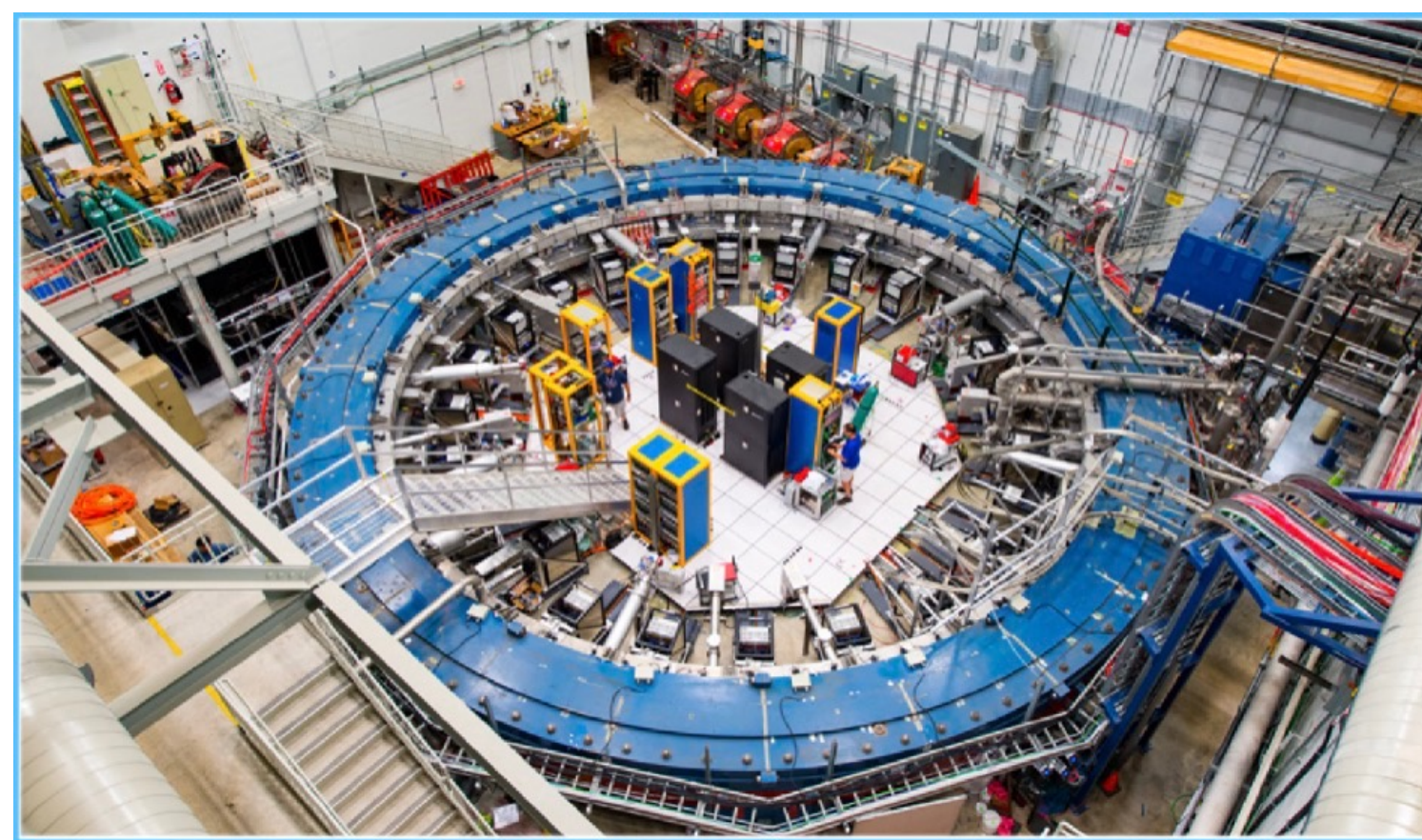
EDM MEASUREMENT AT FNAL

EDM in a storage ring

In the presence of electric and magnetic fields, the Hamilton is: $\mathcal{H} = -\vec{\mu} \cdot \vec{B} - \vec{d} \cdot \vec{E}$;

Extra oscillation – tilts precession plane towards the center of the ring;

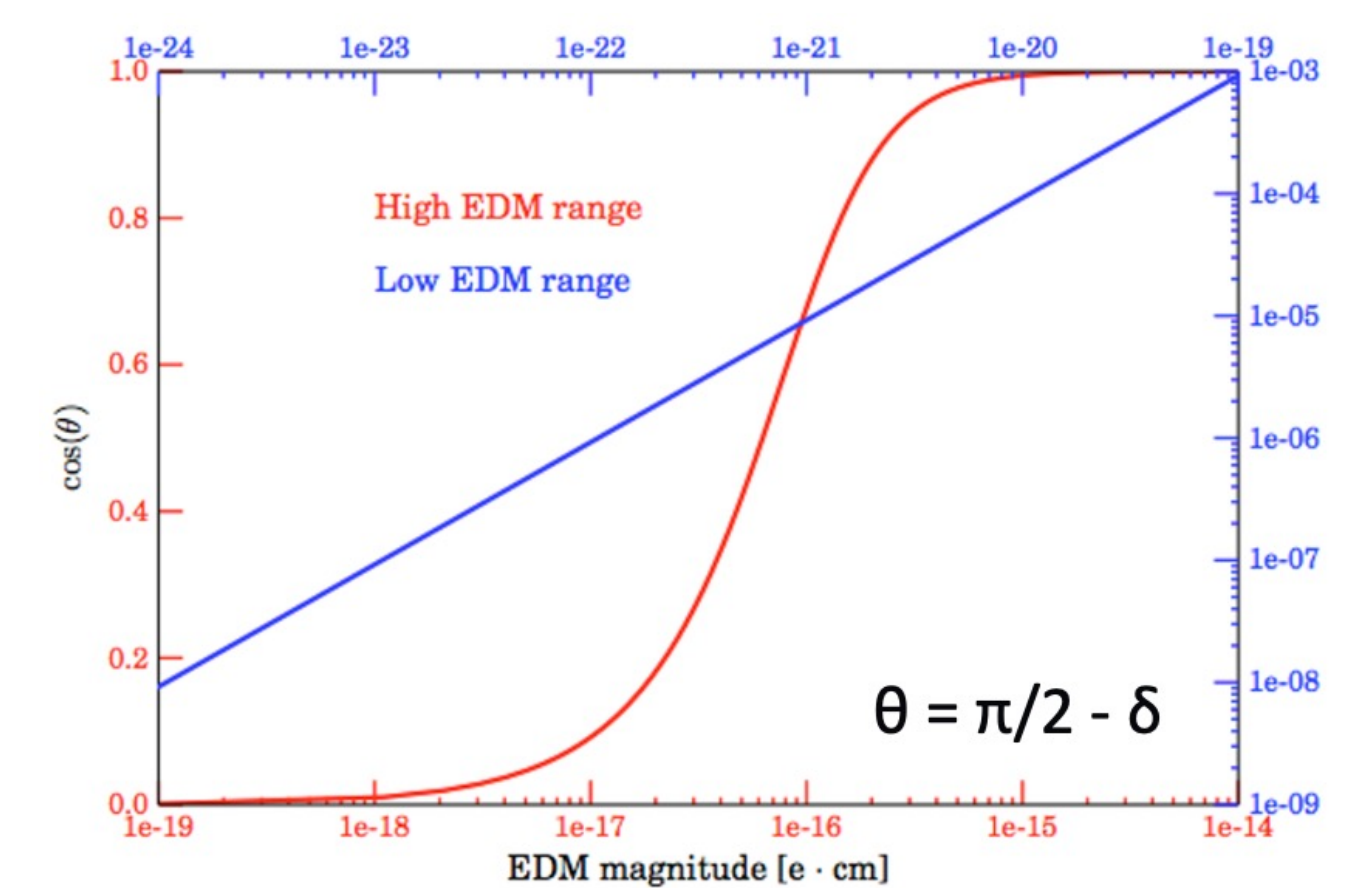
Oscillation is $\pi/2$ out of phase with the a_μ oscillation, and increase muon precession frequency $\omega_{total} = \sqrt{\omega_a^2 + \omega_\eta^2}$



Measuring the EDM

Tilt δ is proportional to the EDM magnitude:

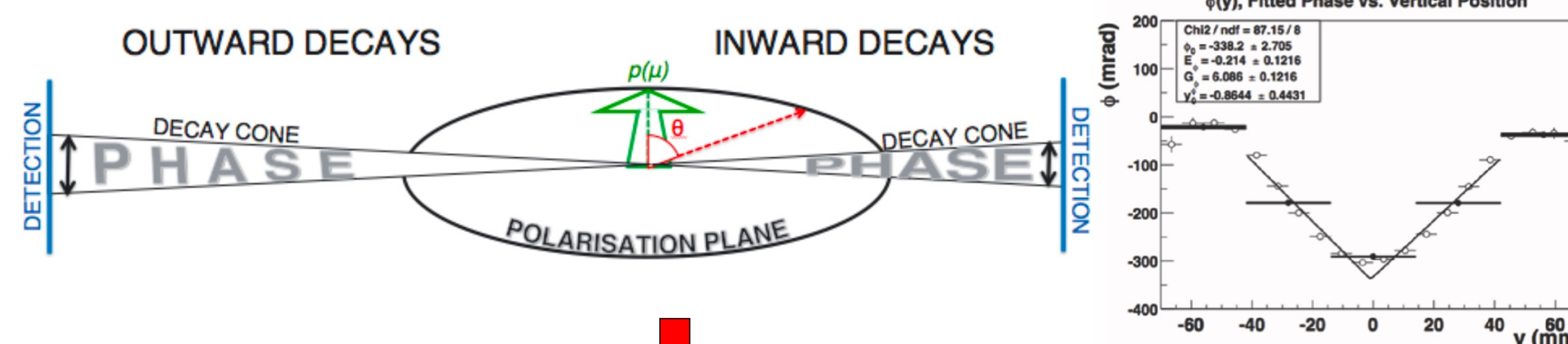
- For large EDM, look for an increase in precession frequency.
 - For EDM smaller than that, two possible methods:
- (1) Phase Asymmetry Method,
 - (2) Vertical position/angle variation



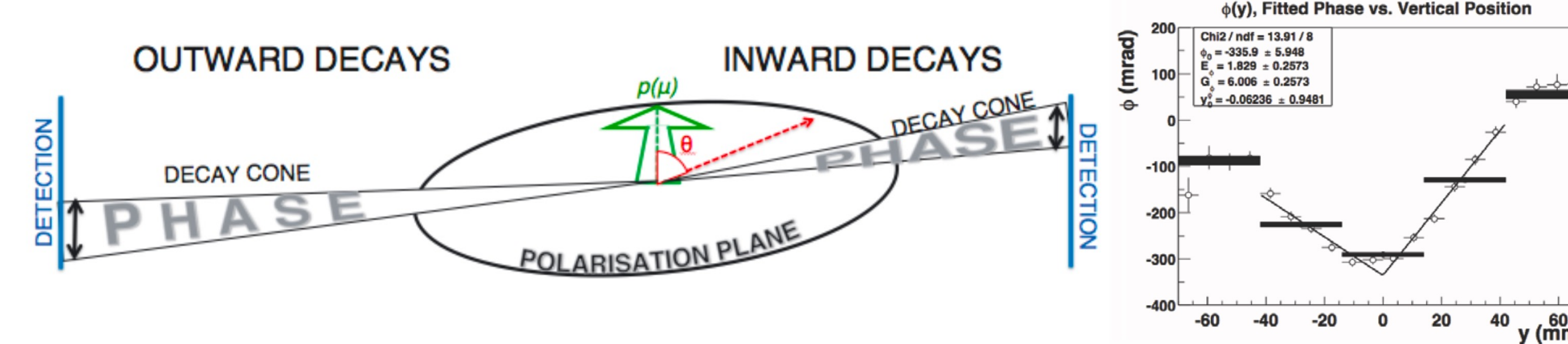
1、Phase Asymmetry Method

Inward decays travel a shorter distance than outward decays;

With no EDM, detection is symmetrical as the polarization plane is flat



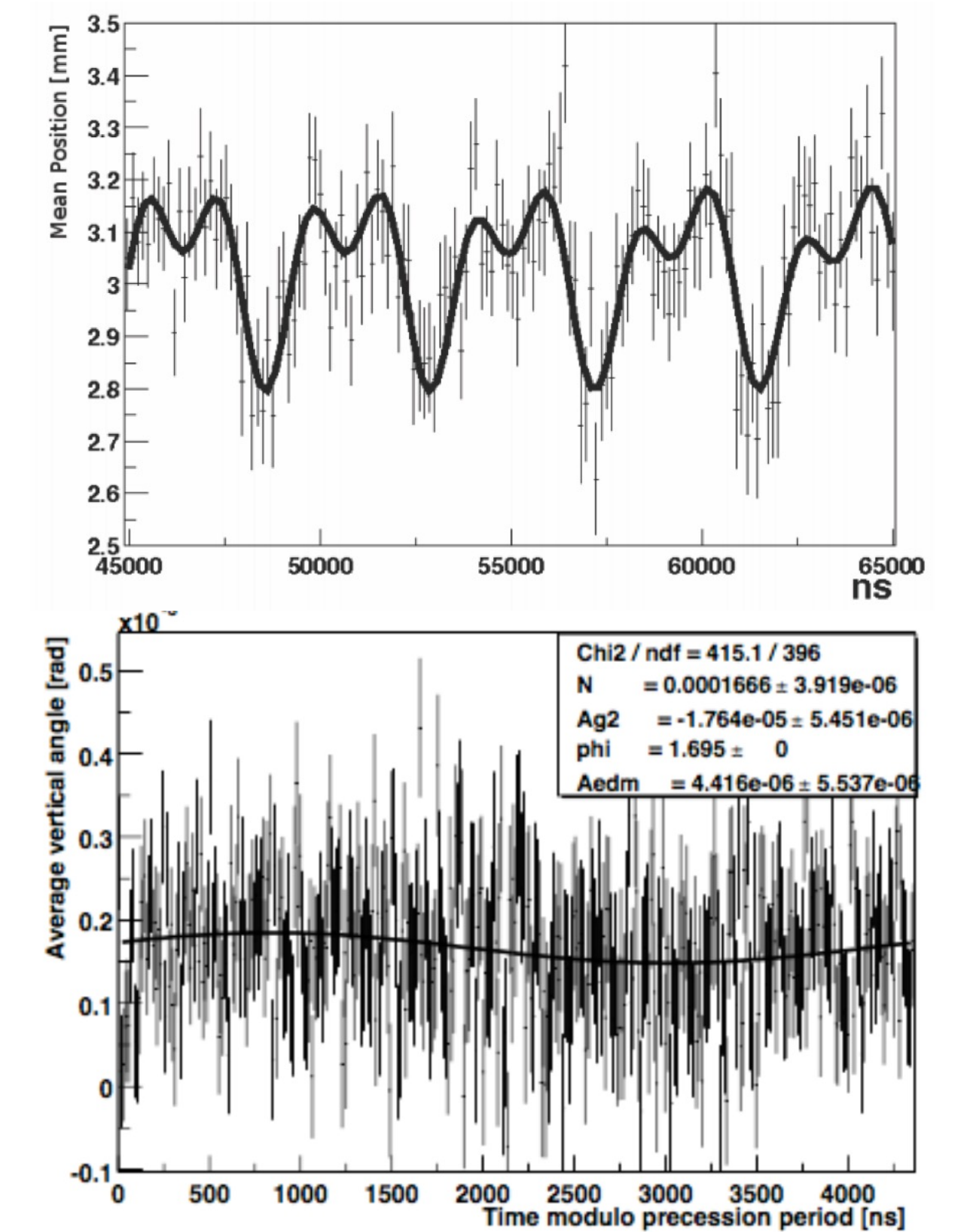
With an EDM, precession plane is tilted, so we see an asymmetry



Method is systematically limited – detector alignment dominant uncertainty

2、Vertical position/angle variation

Measure vertical angle variation (trackers) or vertical position variation (calorimeters) as a function of the time, and fit;



BNL tracker analysis statistically limited, and Calorimeter analysis systematically limited;

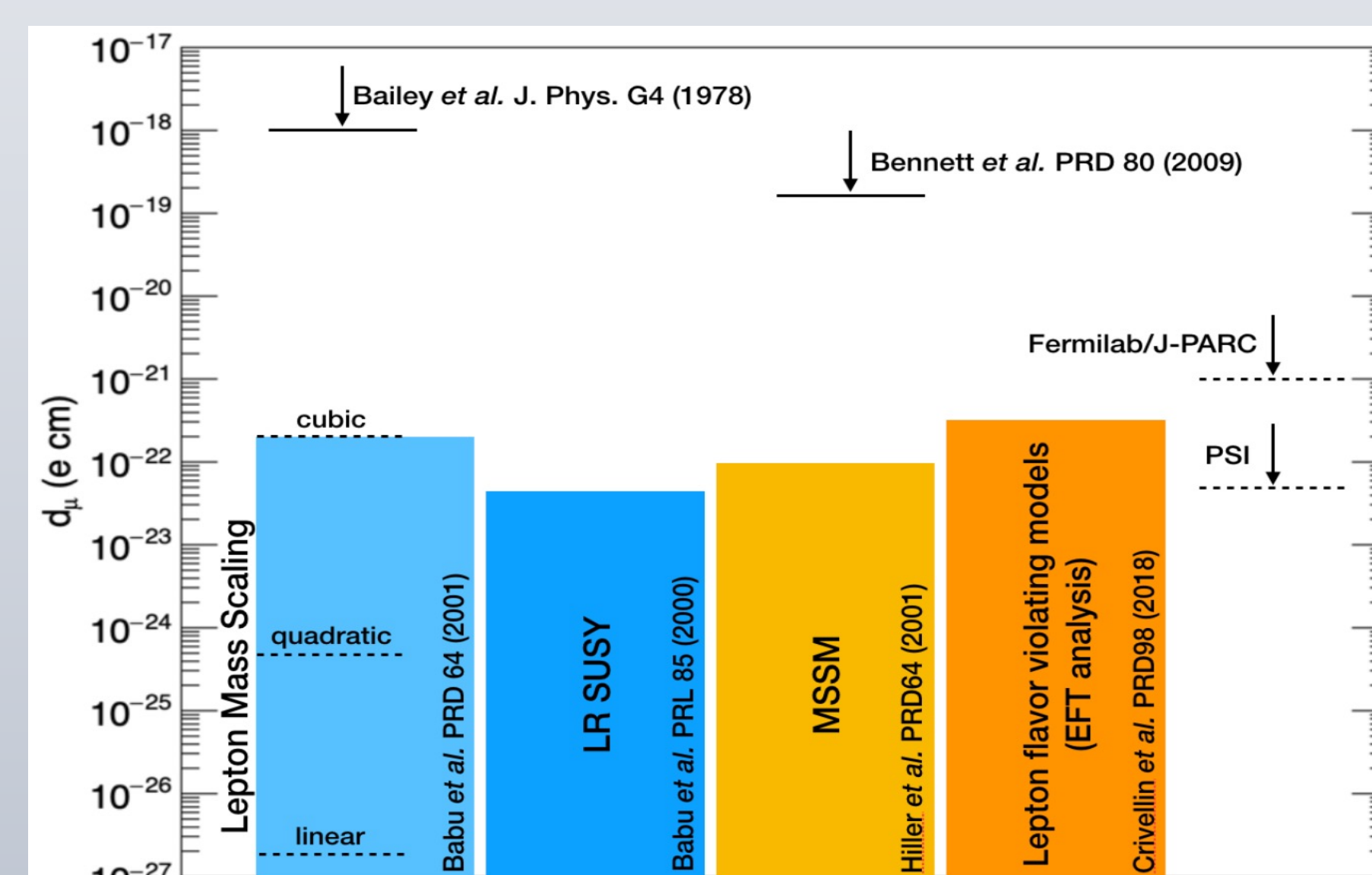
We have improved trackers + higher statistical data able improve here the most compared to BNL[7]

OTHER EXPERIMENTS

To date

Three possible experiments have been either proposed or implemented so far in which one can search for an EDM:

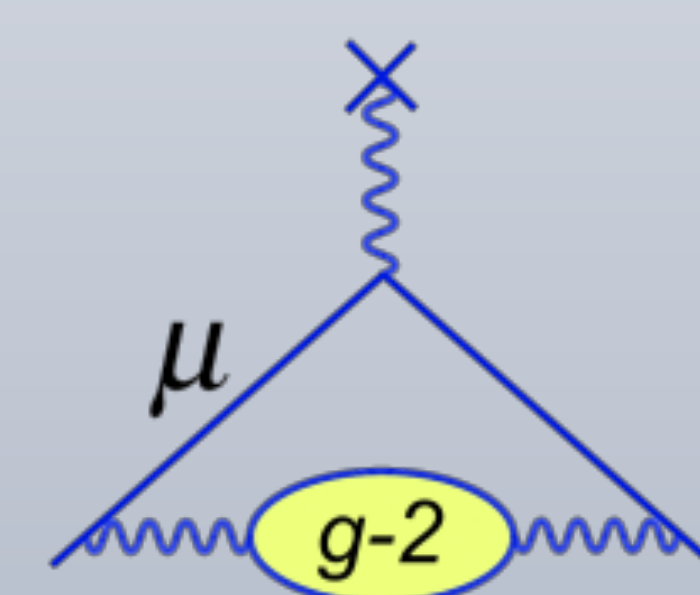
- BNL, FNAL, J-PARC (Japan)[5];
- PSI (Switzerland): frozen-spin technique[6];



Predictions of the muon EDM from various BSM models, and projected sensitivity of recent experiments

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A non-zero EDM would provide indirect evidence of BSM physics!
An EDM limit would serve as a constraint on BSM physics!