Future Heavy Lepton EDM Measurements

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Outline

- Brief EDM description
- How to measure EDMs in a storage ring
- Experimental prospects
  - Running with ring as is, add detectors
  - Modifying rings
  - Dedicated experiment

- Tau EDMs
  - How to do it
  - Prospects?

Brief EDM description

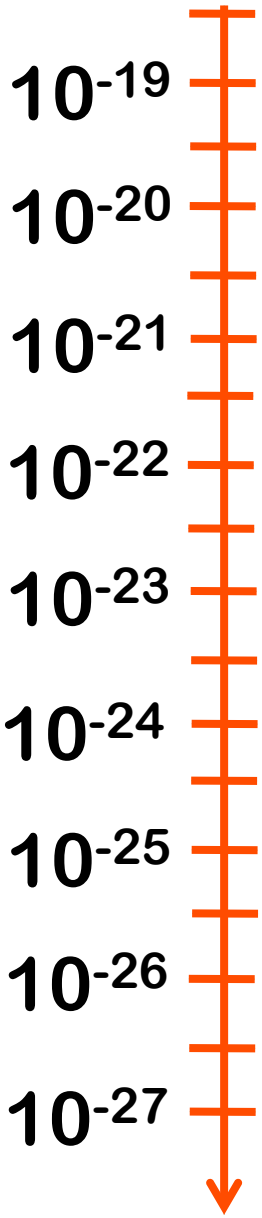
- What is an EDM
  - Separation of charge
- Why do we care about them
  - Could explain the g-2 anomaly
  - Offers explanation for CP violation
- Current status of EDMs
  - $|d_e| \leq 0.14 \times 10^{-26}$ e cm (arXiv:1301.1681, 2013)
  - $|d_\mu| < 1.9 \times 10^{-19}$ e cm (arXiv:0811.1207v2, 2009)
  - $|d_\tau| \sim 10^{-17}$ e cm (arXiv:0210066, 2002)

g = 2 (+ correction terms)
η = 0 (+ tiny corrections from CP violating terms)

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

$$\mu = \frac{g}{2}\frac{e\hbar}{2m} \qquad d = \frac{\eta}{2}\frac{e\hbar}{2mc}$$

Muon EDM milestones



$|d_\mu| < 1.8 \times 10^{-19}$ e-cm @ 95%

$|d_\mu| \sim 3 \times 10^{-22}$ e-cm

** Probes imaginary part of anomaly*

$|d_\mu| < 10^{-23}$ e-cm: $(m_\mu / m_e)^2$

$|d_\mu| < 10^{-25}$ e-cm: (m_μ / m_e)

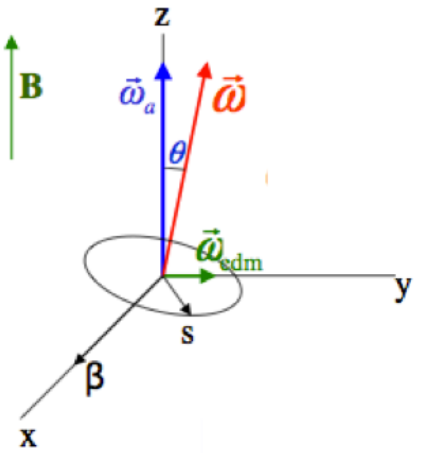
* $d_\mu^{\rm NP} = {\rm Im} D \qquad a_\mu^{\rm NP} \frac{e}{2m_\mu} = {\rm Re} D \qquad D = |D| \exp(i\phi_{\rm CP})$

EDMs and g-2

- Experimentally, EDMs and the g-2 precession frequency are intertwined

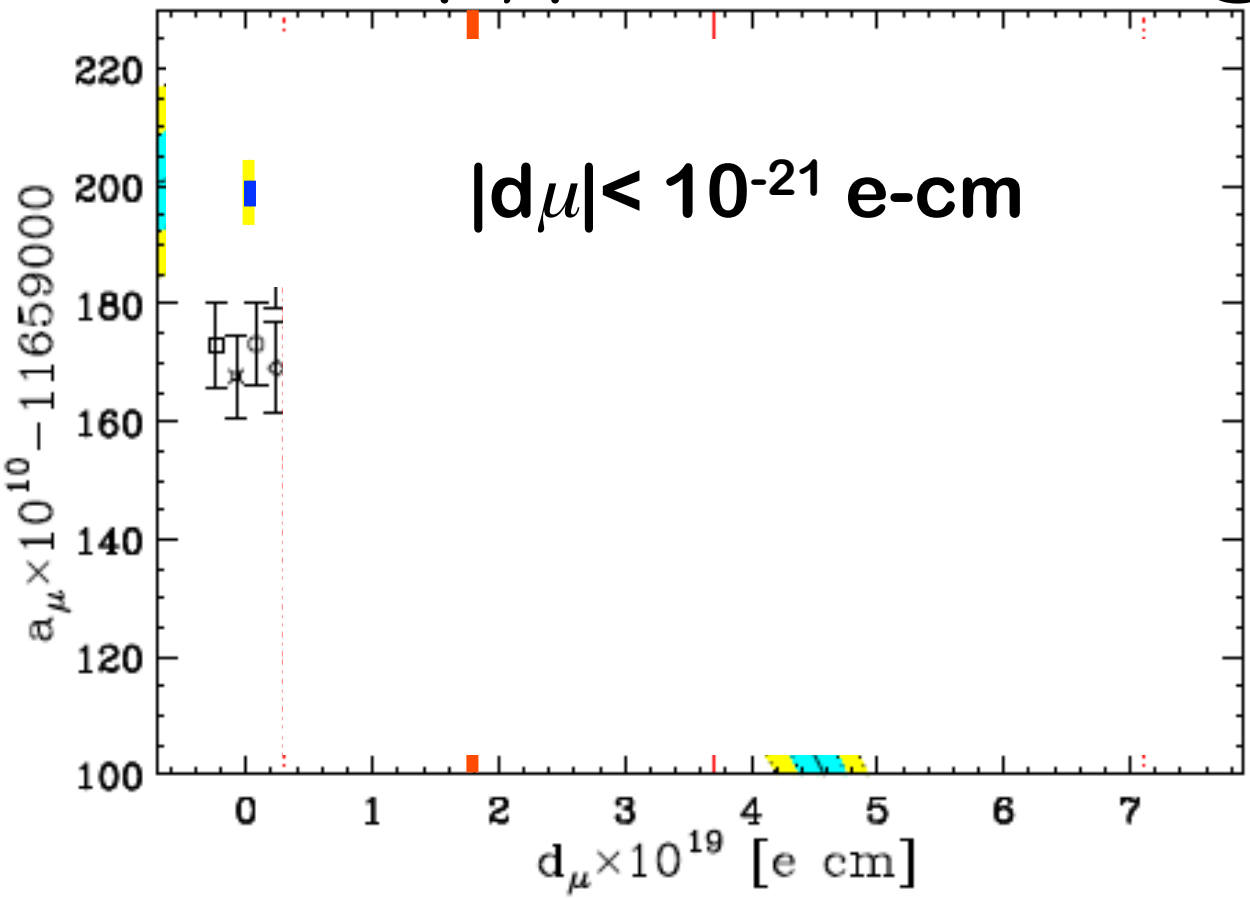
$$\vec{\omega} = -\frac{e}{m}\left\{a\vec{B} + \left(\frac{1}{1-\gamma^2} - a\right)\frac{\vec{\beta}\times\vec{E}}{c} + \frac{\eta}{2}\left(\frac{\vec{E}}{c} + \vec{\beta}\times\vec{B}\right)\right\}$$

- g-2 causes a rotation in the horizontal plane
- EDMs cause a vertical oscillation
- g-2 precession will swamp EDM
  - Can mitigate this with more tracking stations
  - New method: Radial electric field



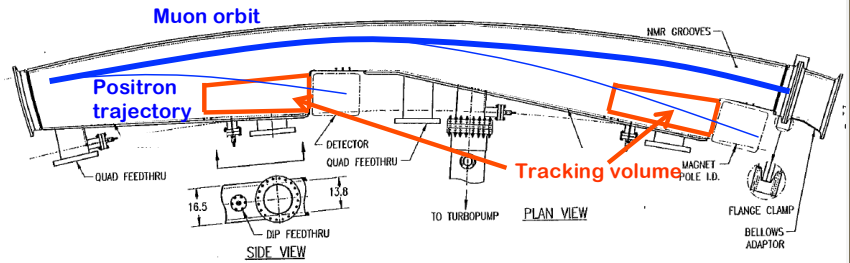
Relationship between g-2 and EDMs

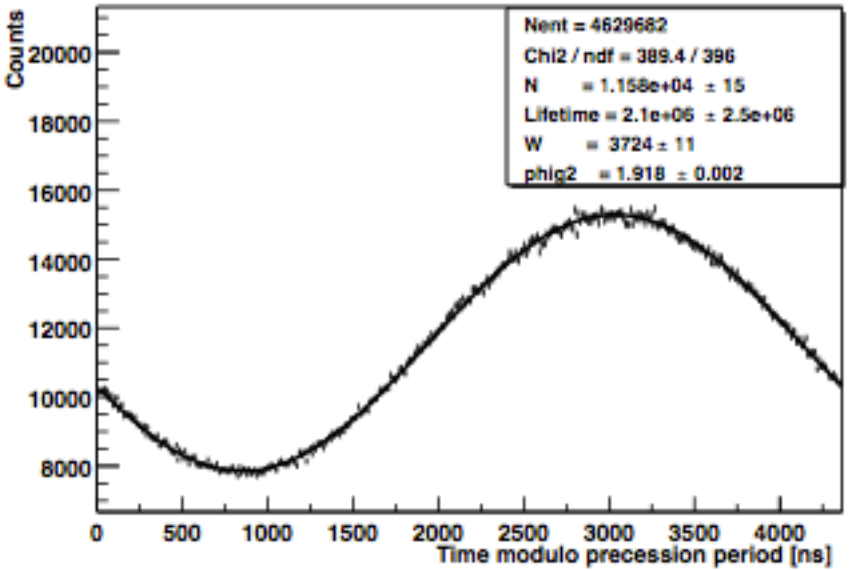
$|d\mu| < 1.8 \times 10^{-19}$ e-cm @ 95%

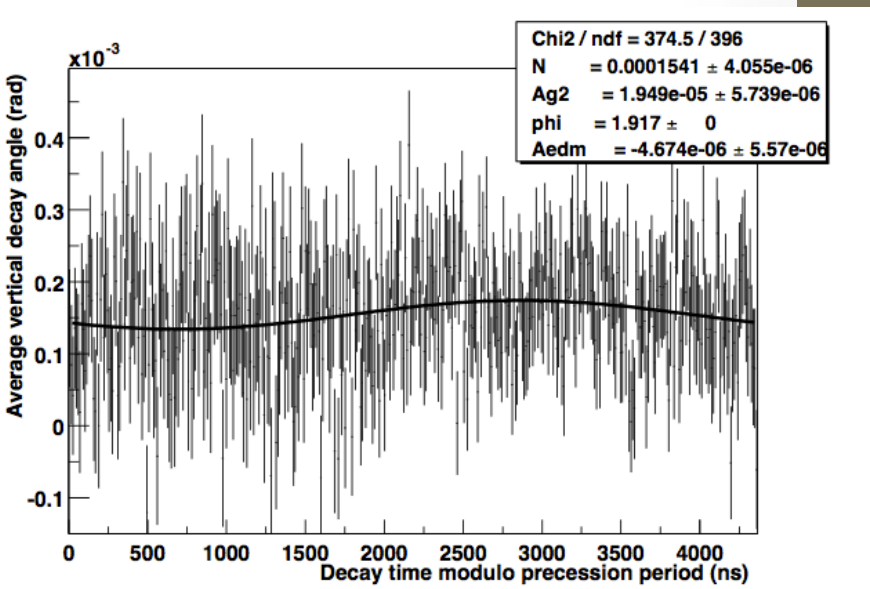


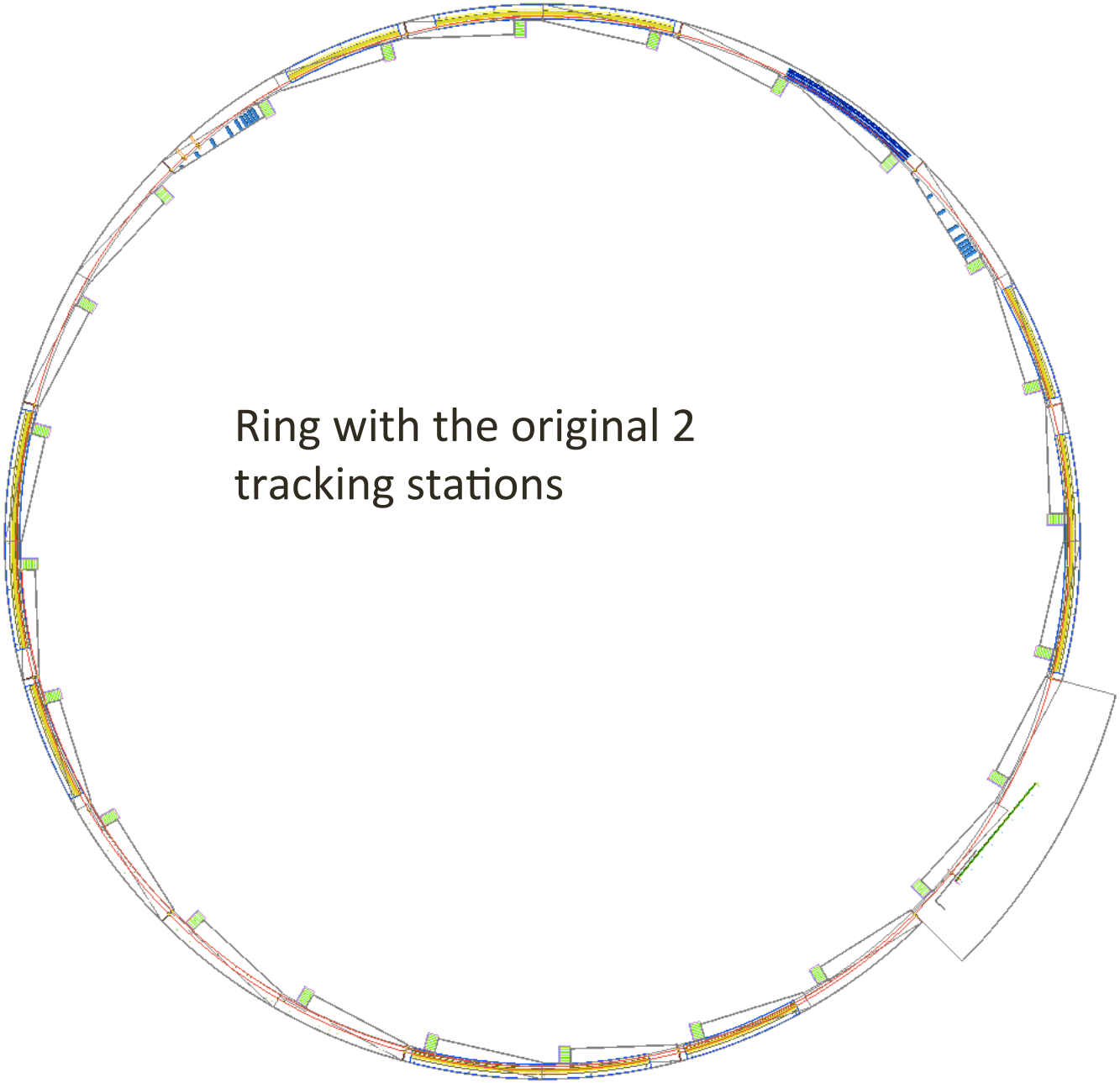
Parasitic EDM

- Will see an asymmetry in the up-down positron count
- First calculate phase and frequency from position sensitive detectors





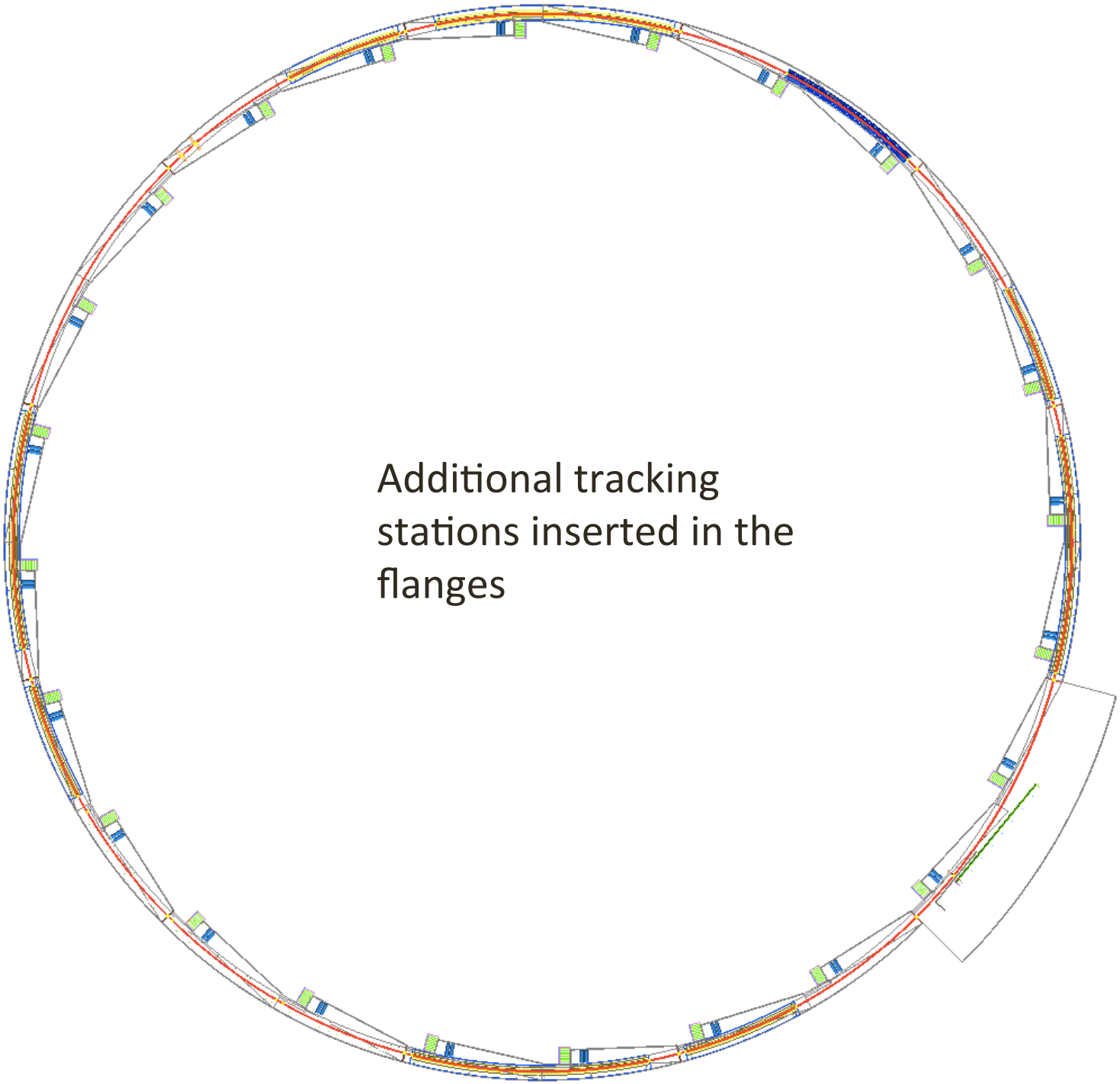




Ring with the original 2 tracking stations

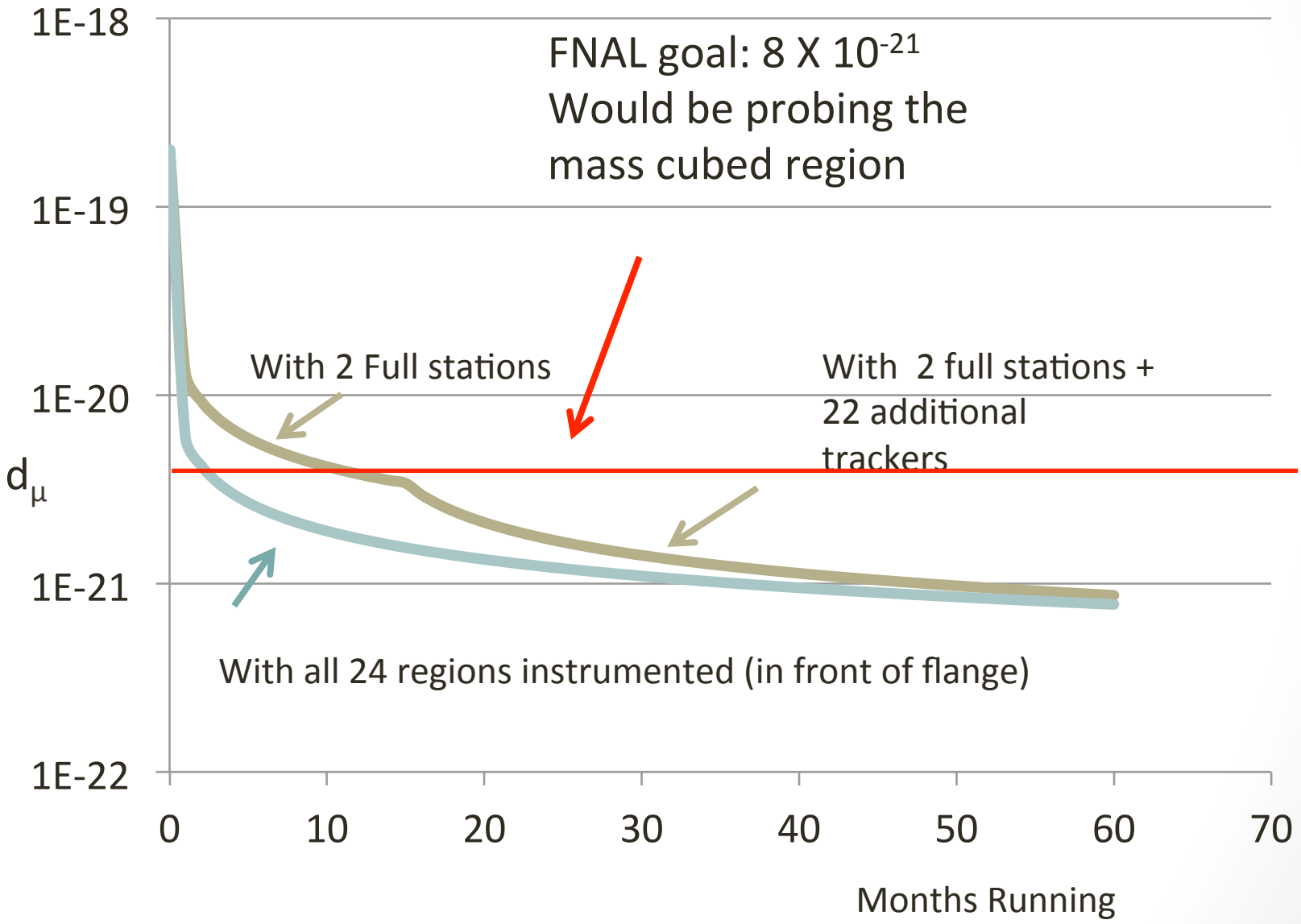
Beyond Parasitic Measurement

- Instrument all 24 scallop regions with trackers
  - Add horizontal straws in all scallop regions
  - Increases track count to
- Could run opportunistically with mu2e
  - Change the magnets using automated controls
  - Disconnect/reconnect devices in 2 places
  - Would take about 8 hours



Additional tracking stations inserted in the flanges

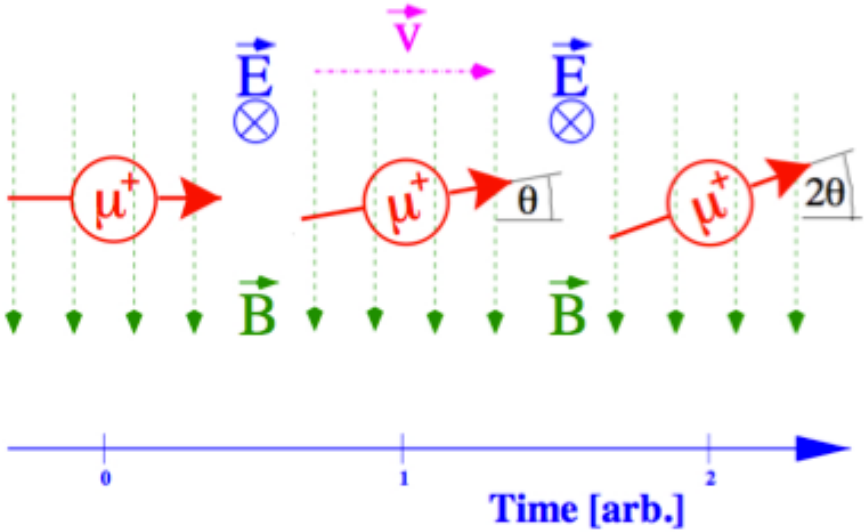
What will we see with longer running?



Dedicated EDM experiment

- Concept: Remove the g-2 precession by applying a radial E field
  - Cancel the first 2 terms

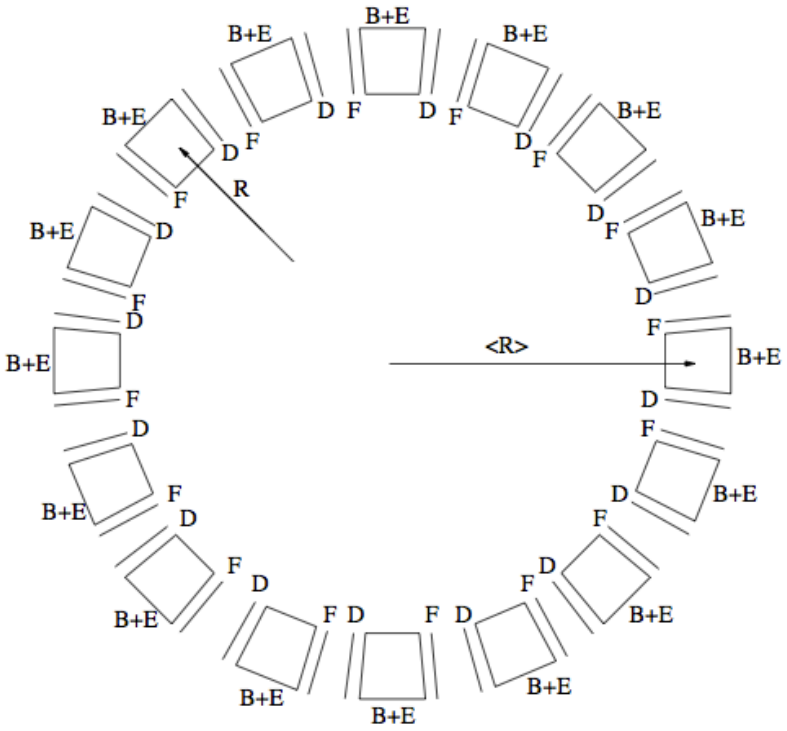
$$\vec{\omega} = -\frac{e}{m}\left\{ a\vec{B} + \left(\frac{1}{1-\gamma^2} - a\right)\frac{\vec{\beta}\times\vec{E}}{c} + \frac{\eta}{2}\left(\frac{\vec{E}}{c} + \vec{\beta}\times\vec{B}\right)\right\}$$



As time increases, the precession becomes more pronounced

J-PARC

- J-PARC Parameters
  - R ≈ 6.5m
  - γτ = 11 μs
  - β = 0.978
  - Polarization is 50%
  - B = 0.25 T



- Sensitivity

$$\sigma_\eta = \frac{\sqrt{2}}{\gamma\tau(e/m)\beta BAP\sqrt{N}}$$

- $d_\mu < 10^{-24}$ e cm $\sigma_\eta = 4 \times 10^{-3}/\sqrt{N}\,;\, N = 4 \times 10^{16}$ $\sigma_\eta = 2 \times 10^{-11}$

*http://www.bnl.gov/edm/papers/jparc_loi_030109.ps

PSI

- PSI Parameters
  - R ≈ 0.5 m
  - $\gamma\tau$ = 3.5 μs
  - β = 0.76
  - Polarization is 90%
  - B = 1.0 T
- PSI Sensitivity

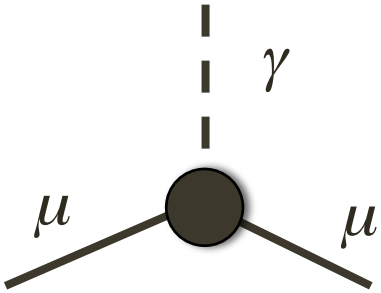
- $d_\mu < 10^{-23}$ e cm

*arXiv:0606034v3

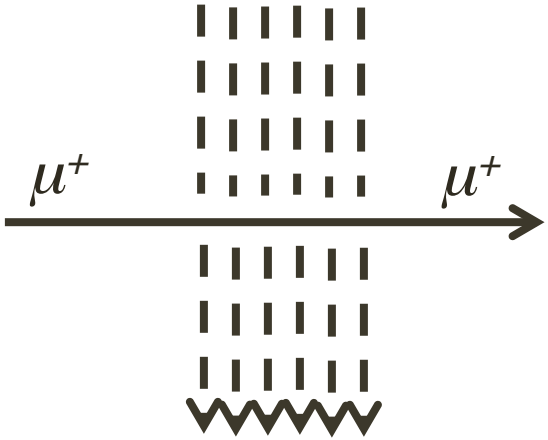
$$\sigma_\eta = \frac{\sqrt{2}ac\gamma}{\tau(e/m)EAP\sqrt{N}}$$

$\sigma_\eta = 2.4 \times 10^{-3}/\sqrt{N}$; $N = 4 \times 10^{12}$ $\sigma_\eta = 10^{-9}$

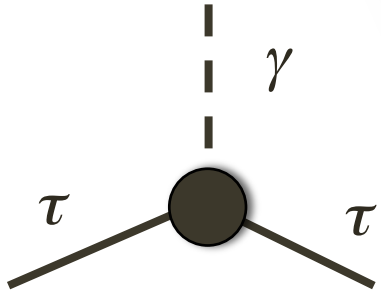
Tau EDM



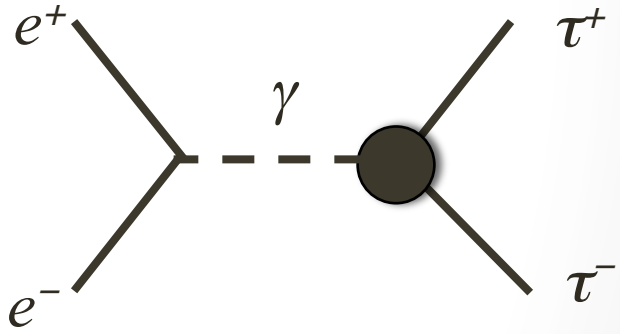
Look for spin precession in E field



Long life = good.
Plenty of time to see slow precession



Look for T-odd observables
τ pair production



short life = good.
both decay and can reconstruct triple product correlations

Tau EDM

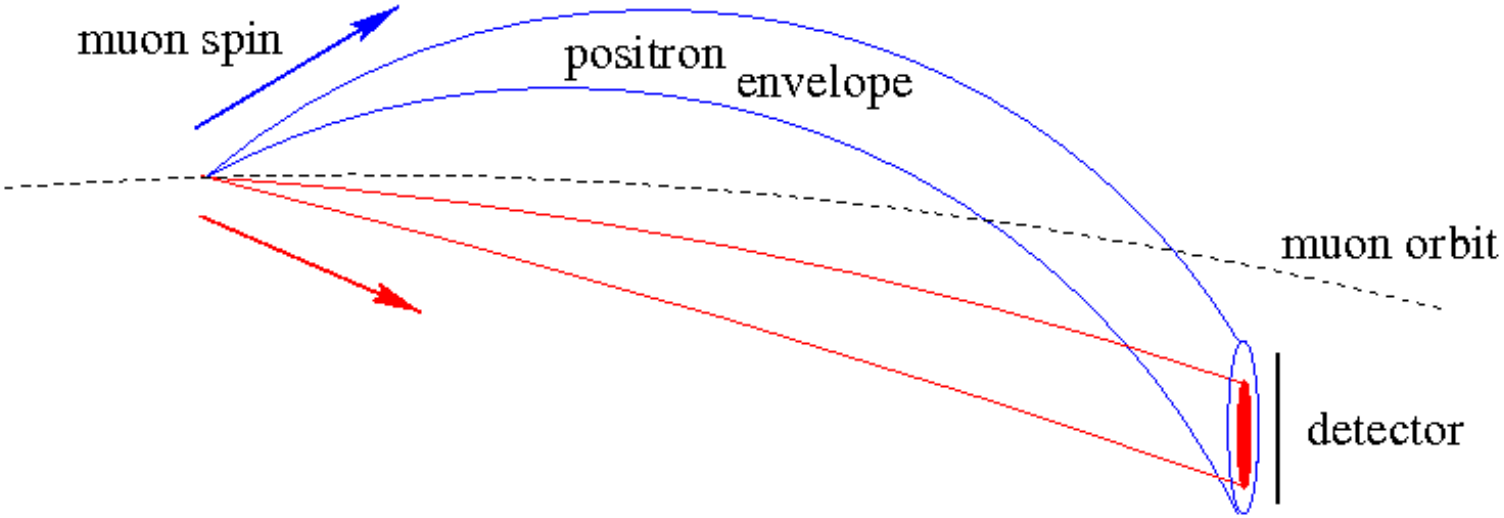
- Best result from Belle (30 fb^{-1})
  - $(-2.2 < Re(d_\tau) < 4.5) \times 10^{-17}$ e cm
    - CP odd, T odd
  - $(-2.5 < Im(d_\tau) < 0.8) \times 10^{-17}$ e cm
    - CP odd, T even
- Projections from Belle II:
  - 10^{-19} w/ 50 ab^{-1}
  - Factor of 3 gain with polarized beam

Conclusions

- Prospects for muon EDM:
- Longer parasitic run with the g-2 experiment
  - Add more trackers
  - Relatively easy to do
  - Goal is to get to 10^{-21} e cm
- 2 proposals for dedicated storage ring experiments
  - J-PARC and PSI
  - Bring us down to 10^{-24} e cm
  - Not so easy to do
- Tau EDMs
  - Definitely worth working on!

Backups

Systematics



- EDM asymmetry is 90 degrees out of phase with g-2 asymmetry
  - When decay points into the ring versus out of the ring
  - Large flight length difference
  - Beam spread means higher acceptance for muons that point in
  - Need to define specs on knowledge of alignment and acceptance to get to the second order of magnitude