Muon decoherence with the Fermilab muon g-2 experiment

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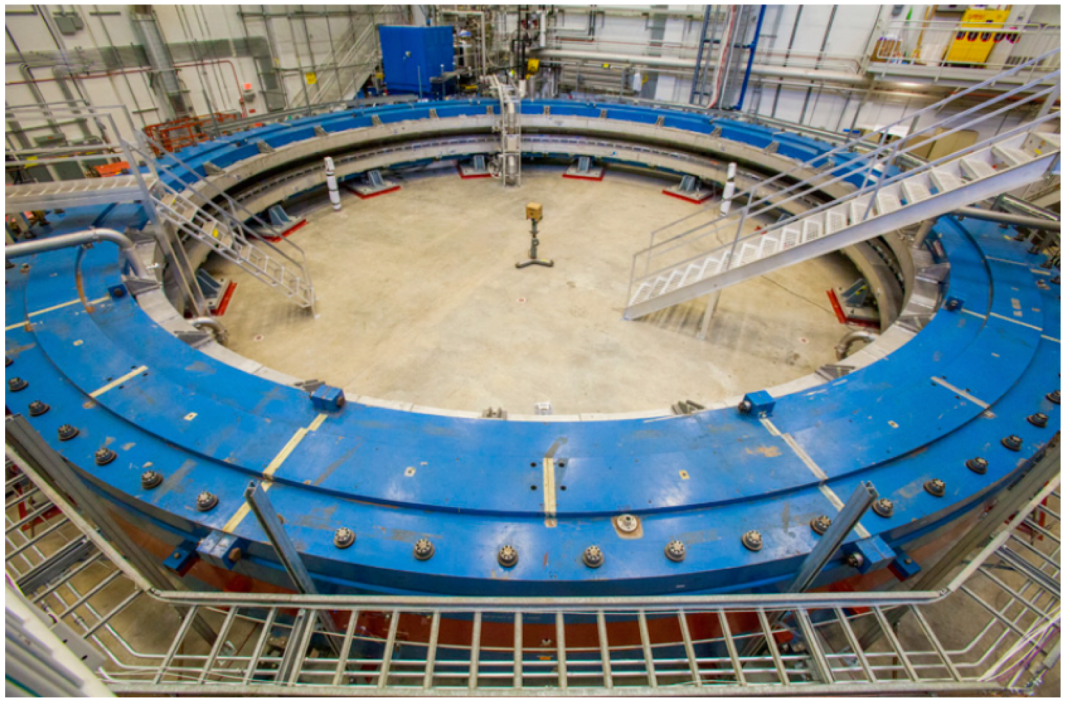
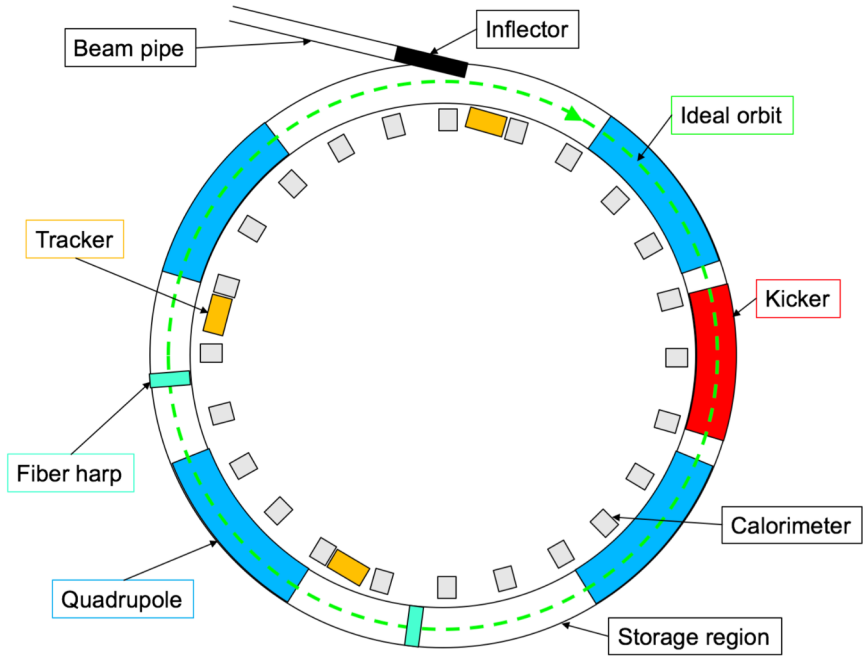
Fermilab muon g-2 experiment

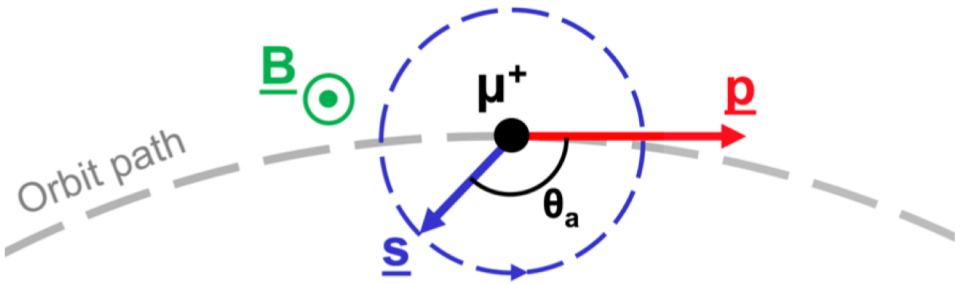
- Measures anomalous magnetic moment of the muon
  - e.g. precession of muon spin in magnetic field resulting from loop Feynman diagrams
- Inject ~3 GeV μ^+ into a 14 m magnetic storage ring
  - μ^+ spins precess in B field → produces sinusoidal modulation in decay e^+ energy
  - Extreme precision: 140 ppb (most precise high energy physics measurement ever)

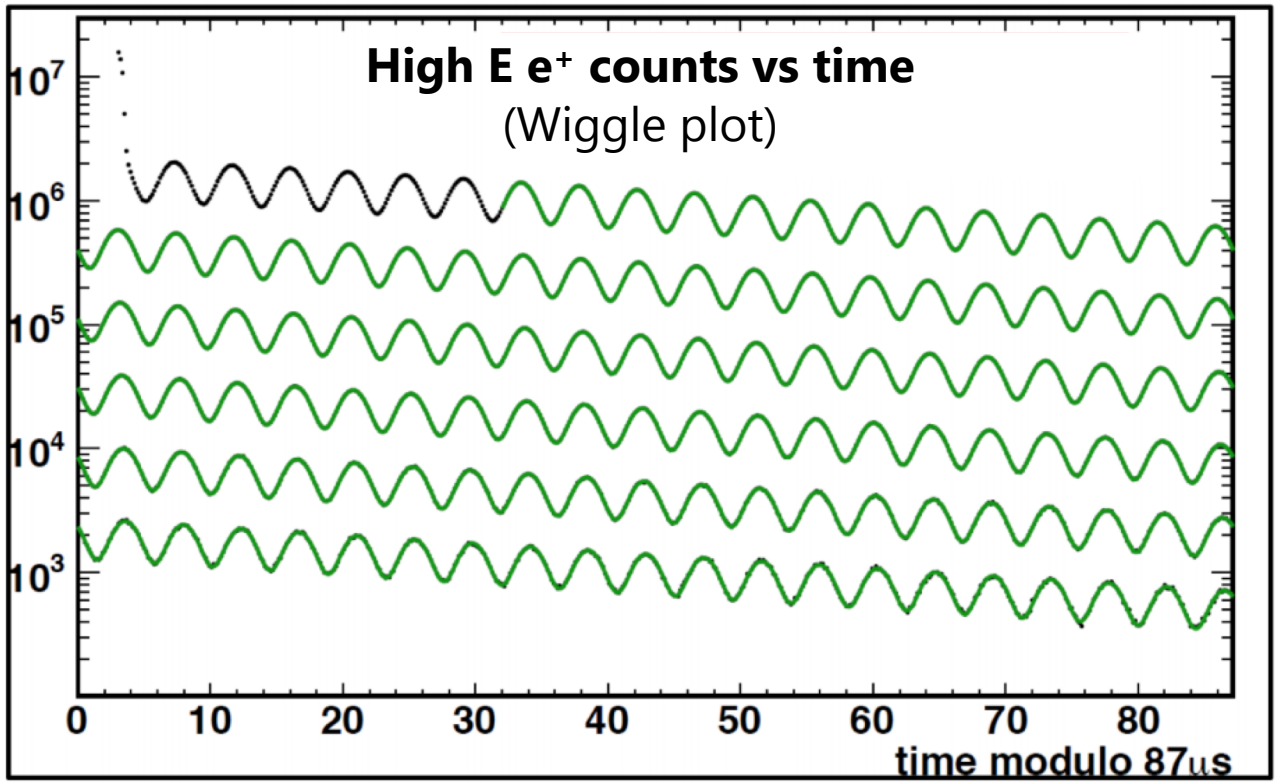




Measurement principle

- μ^+ orbit in ring whilst spins precess
- Alignment of spin and momentum vectors varies with time
  - Decay e^+ emitted preferentially aligned with spin vector
  - Decay e^+ energy maximal when they align (Lorentz boost)



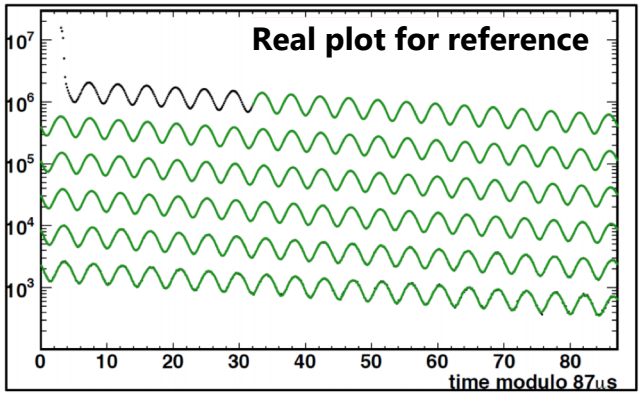


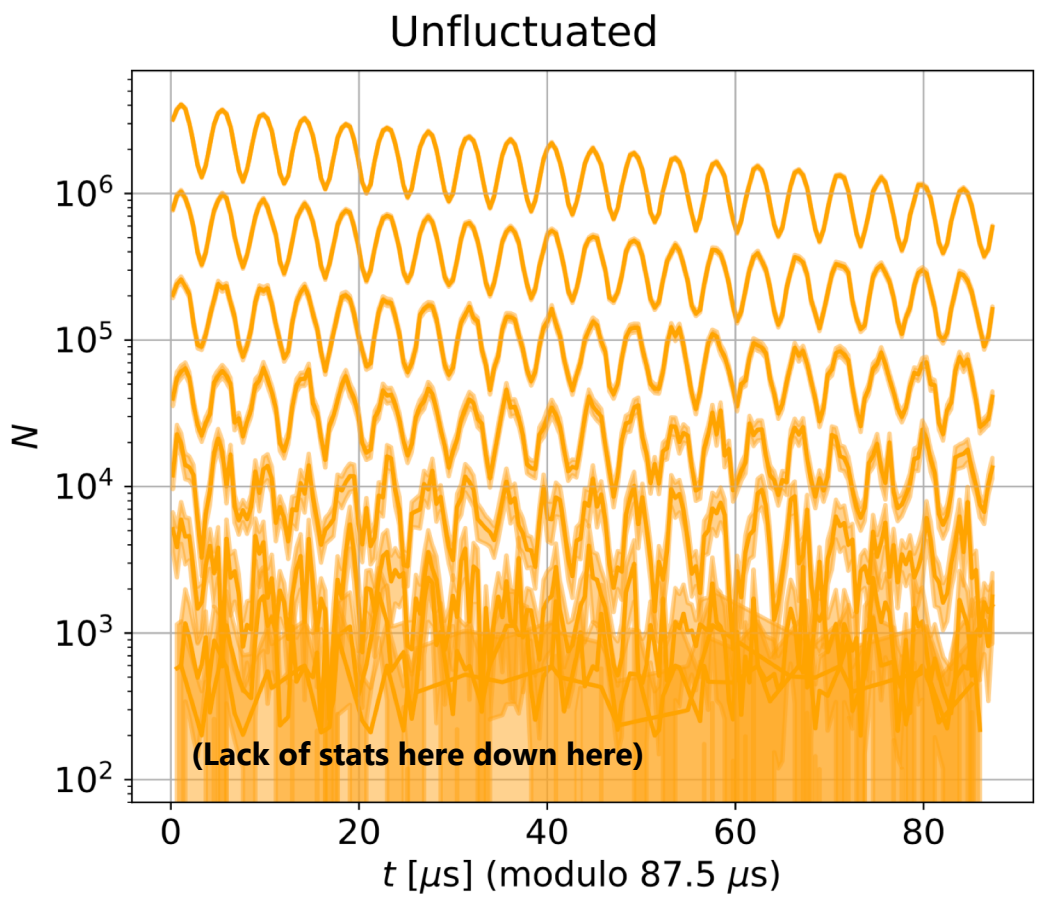
Decoherence

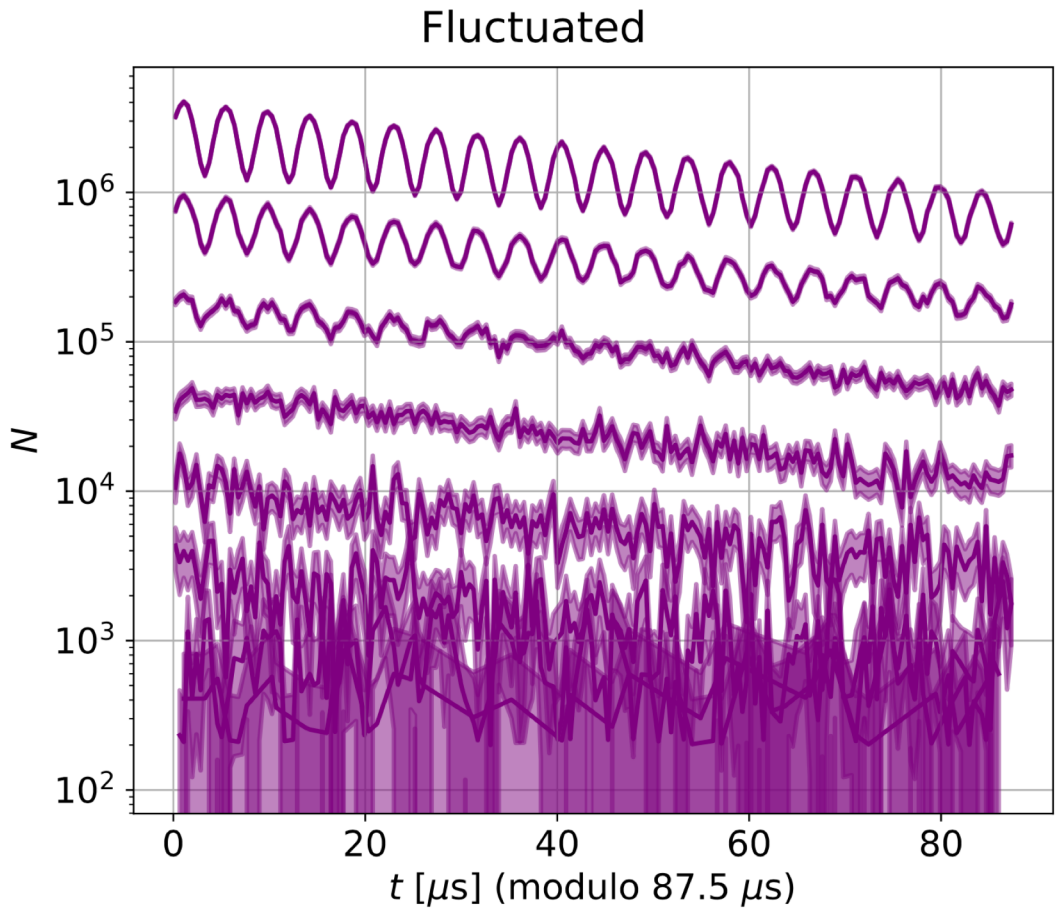
- Measures sinusoidally varying decay positron counts
  - Frequency is the difference between the spin precession and orbital frequencies
- Lightcone fluctuations (e.g. from fluctuating space-time) would cause stochastic variations in orbital frequency
  - The sinusoidal behaviour would damp over time (decoherence)
- This is a brand new quantum decoherence measurement channel
  - Complimentary to my atmospheric neutrino search

Injecting signal with toy MC

- Inject orbit fluctuation into g-2 toy
- See damping over distance in wiggle plot as expected







Analytic treatment

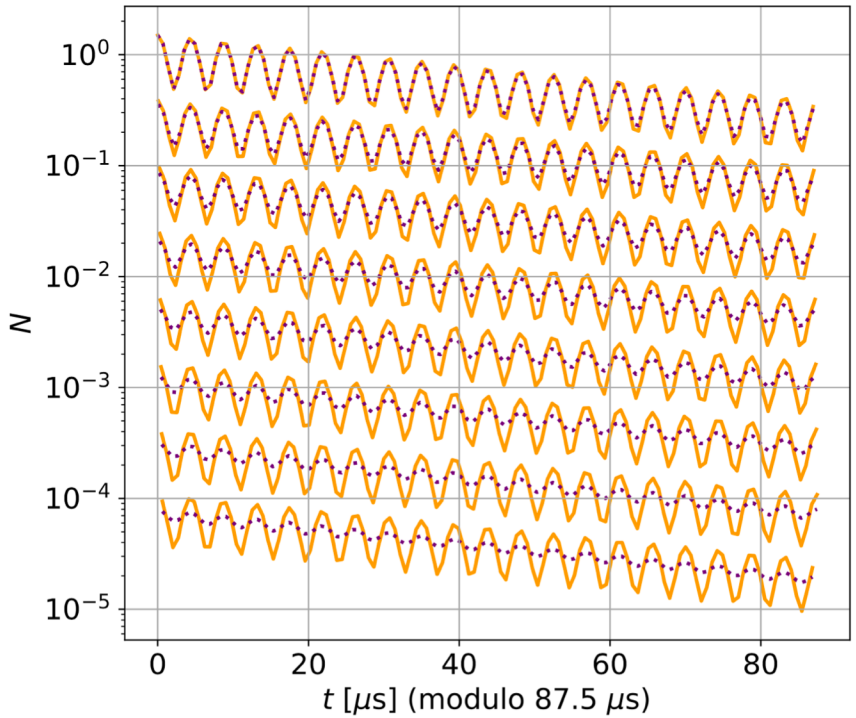
- Define an analytic treatment of the effect:
  - Γ defines damping strength (comparable formalism to neutrino decoherence)

Muon g-2

$$N(t) = e^{-t/\tau}\left(1 + Ae^{-\Gamma t}\cos(\omega_a t + \phi)\right)$$

Neutrino oscillations

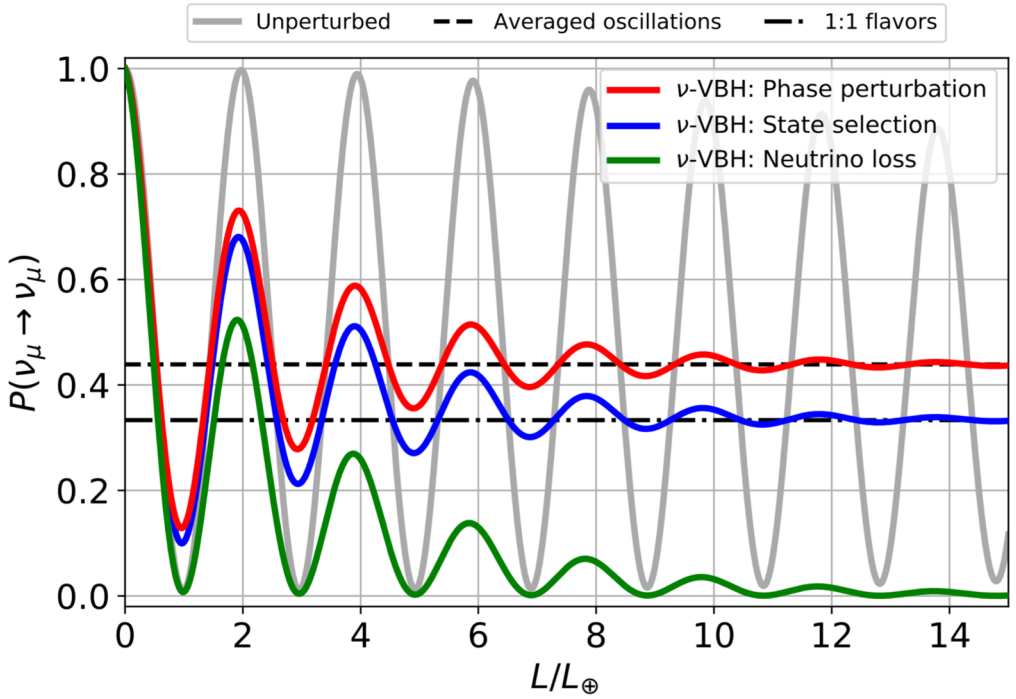
$$\mathcal{P}^{(2\nu)}_{\mu\mu} = 1 - \frac{1}{2}\sin^2 2\theta_{23} \cdot \left[1 - e^{-\Gamma_{32} L} \cdot \cos\left(\frac{\Delta m^2_{32}}{2E_\nu} L\right)\right]$$



Coherence length sensitivity

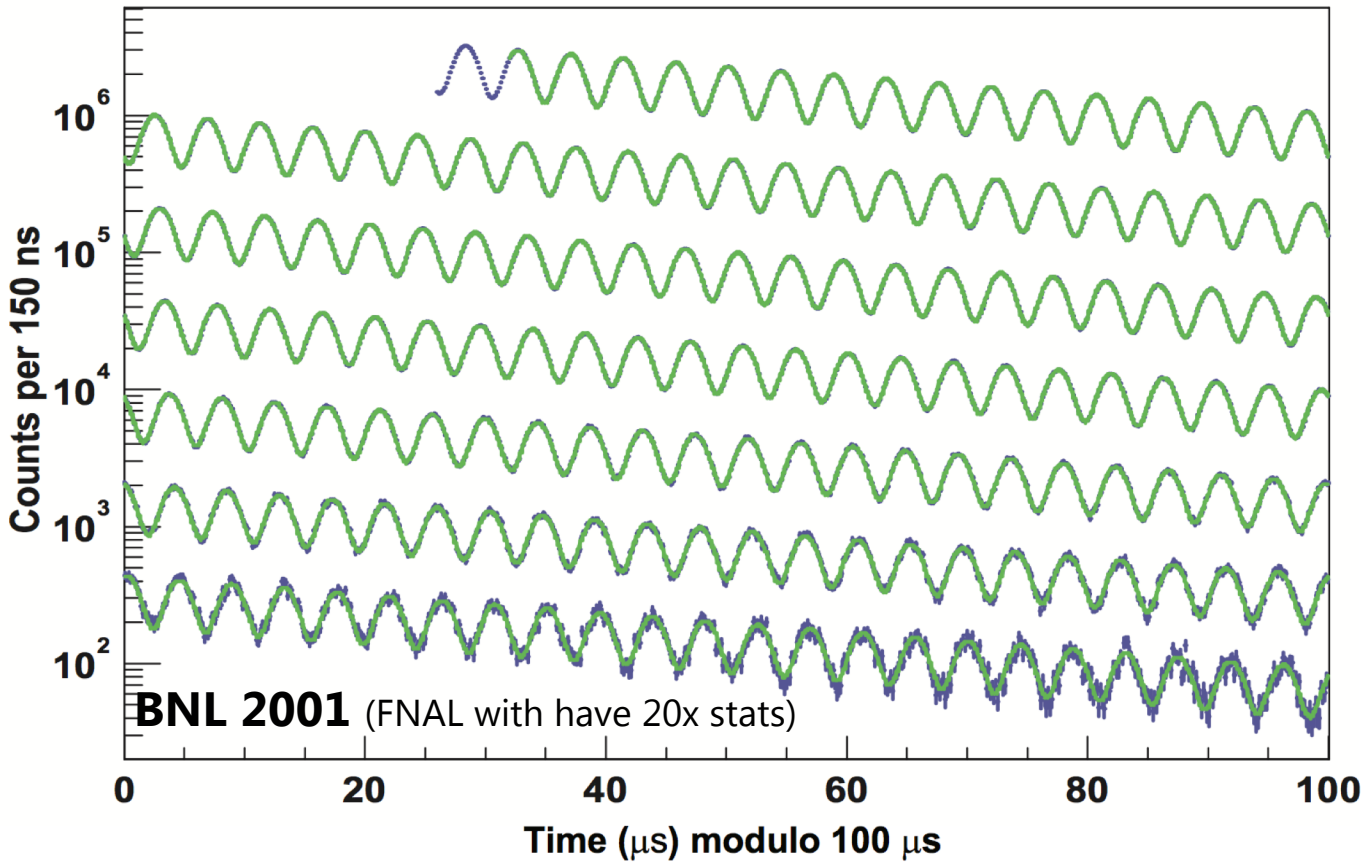
- How does the sensitivity of this measurement compare to IceCube atmospheric neutrinos?

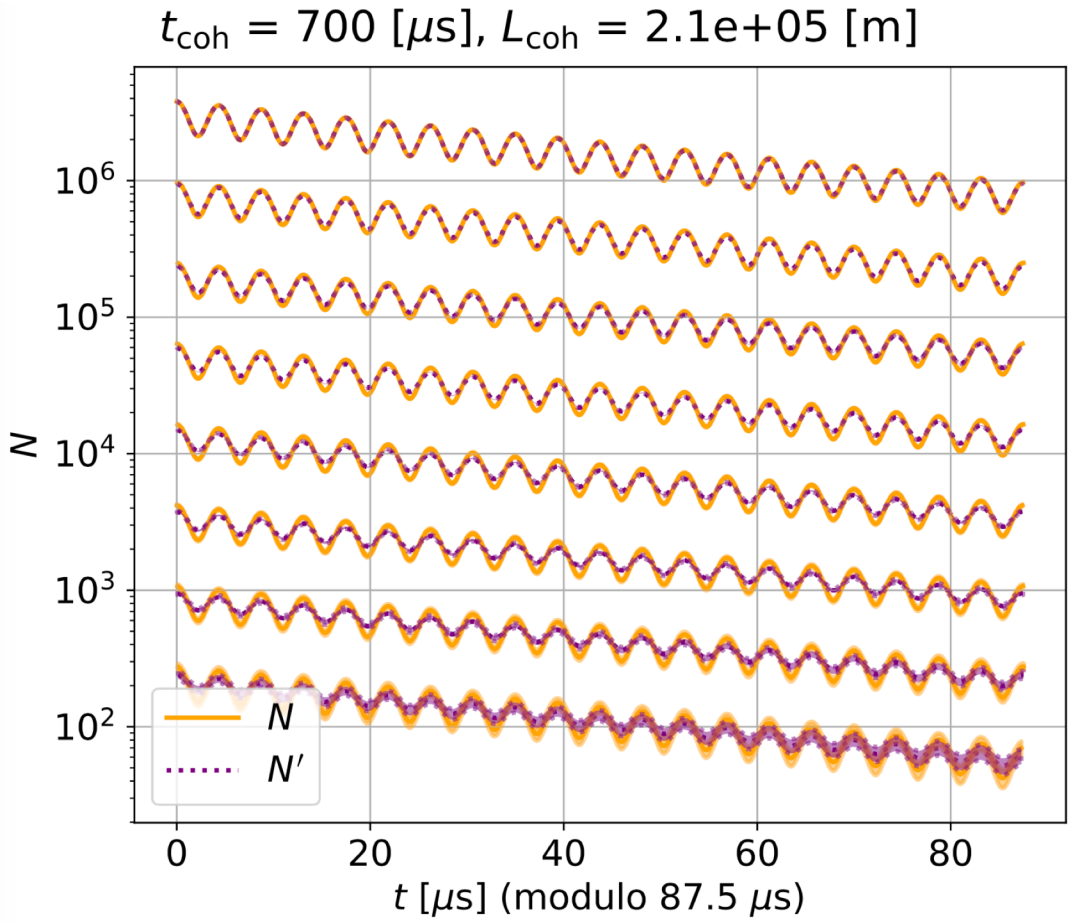
	Max distance	Energy	Precision
IceCube	12,700 km	5 GeV – 100 TeV	Low
Muon g-2	200 km	3 GeV	Very high



Estimating sensitivity

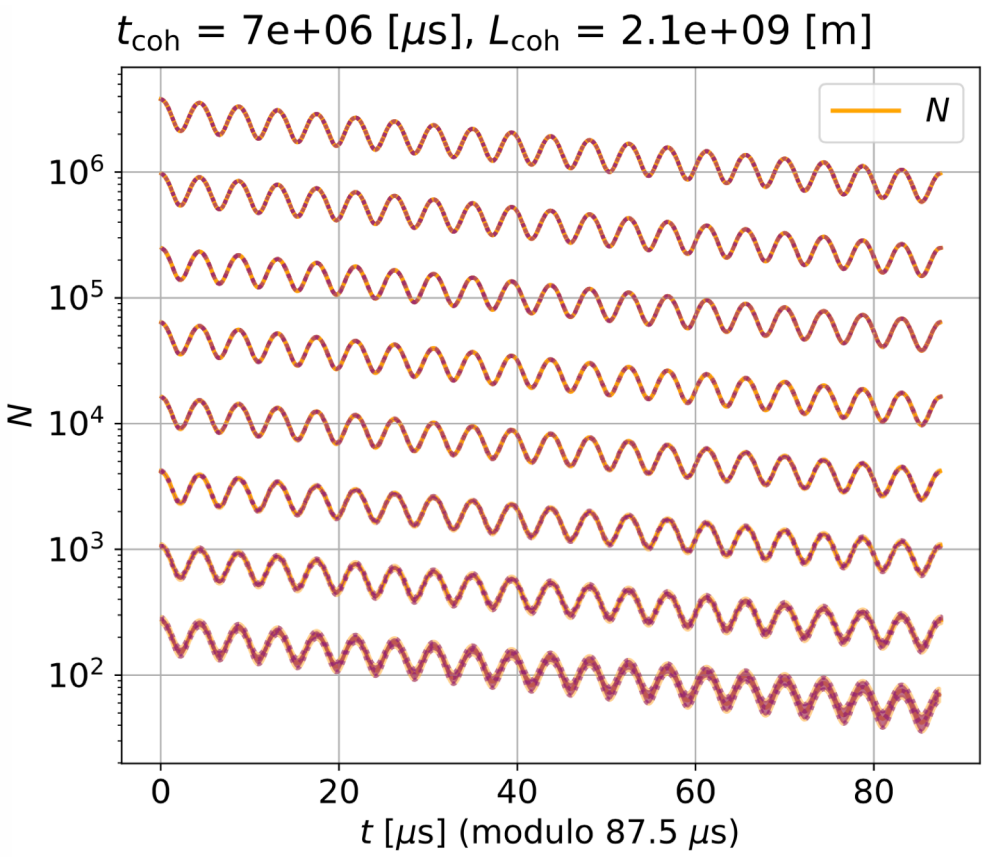
- Generate wiggle plot with realistic stats using my analytic form
- Inject signal and compare results to null hypothesis

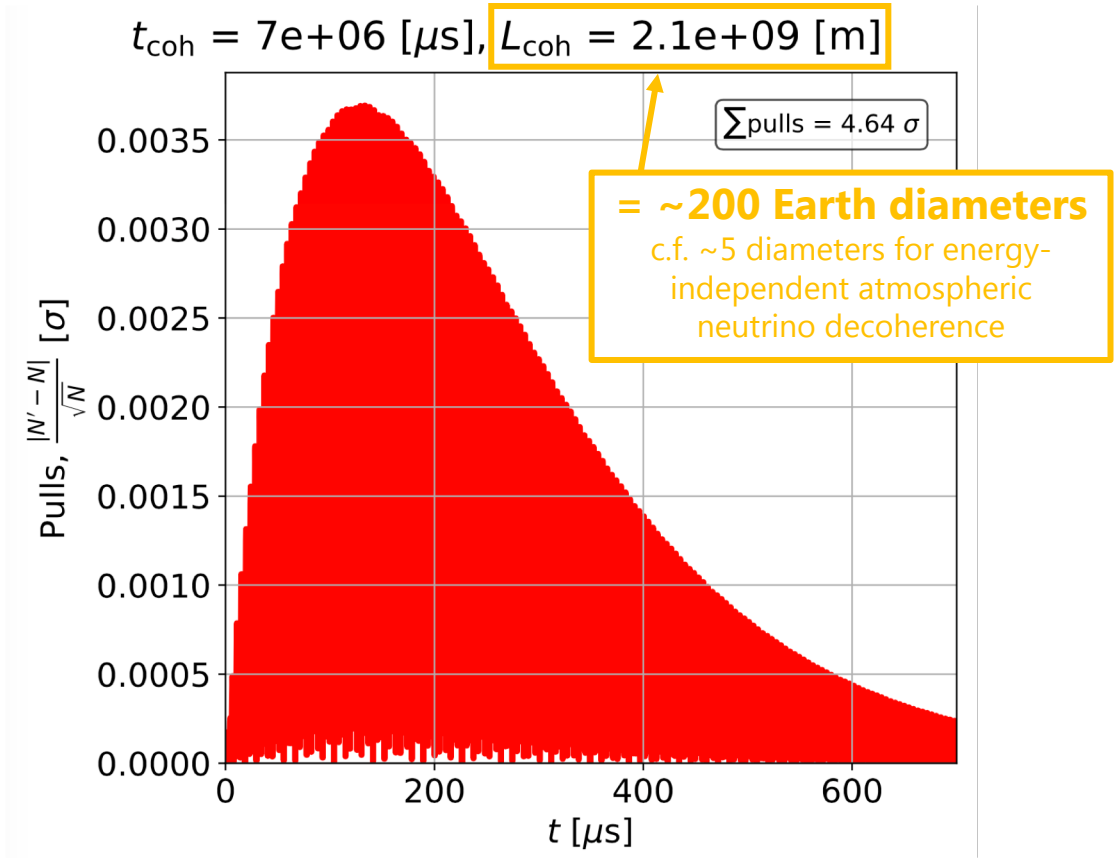




Estimating sensitivity

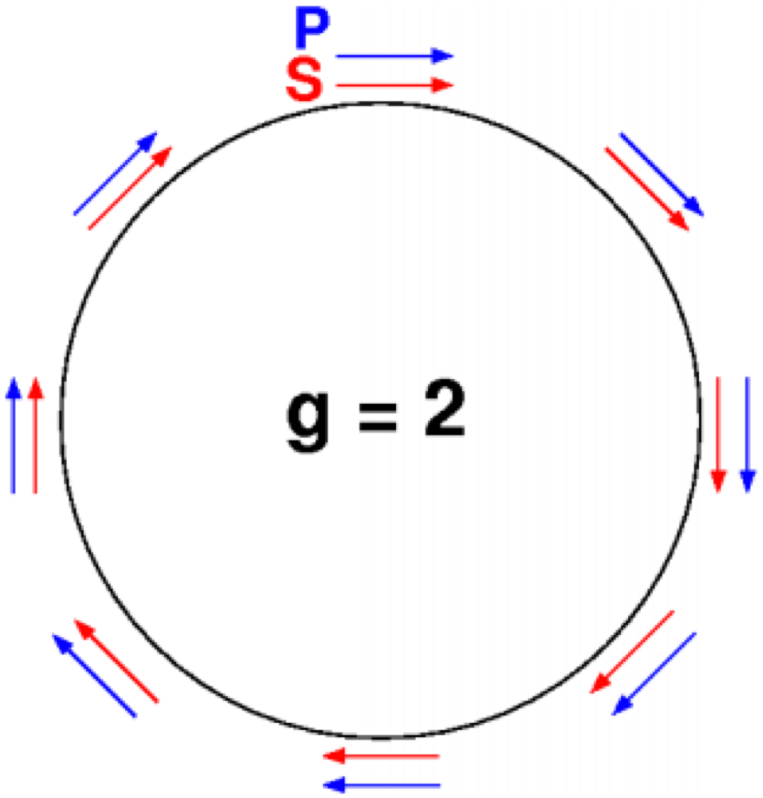
- Statistical precision is massive, so even slight effects can be detected
- Naive estimate of ~5σ discovery threshold (stats uncertainty only)…

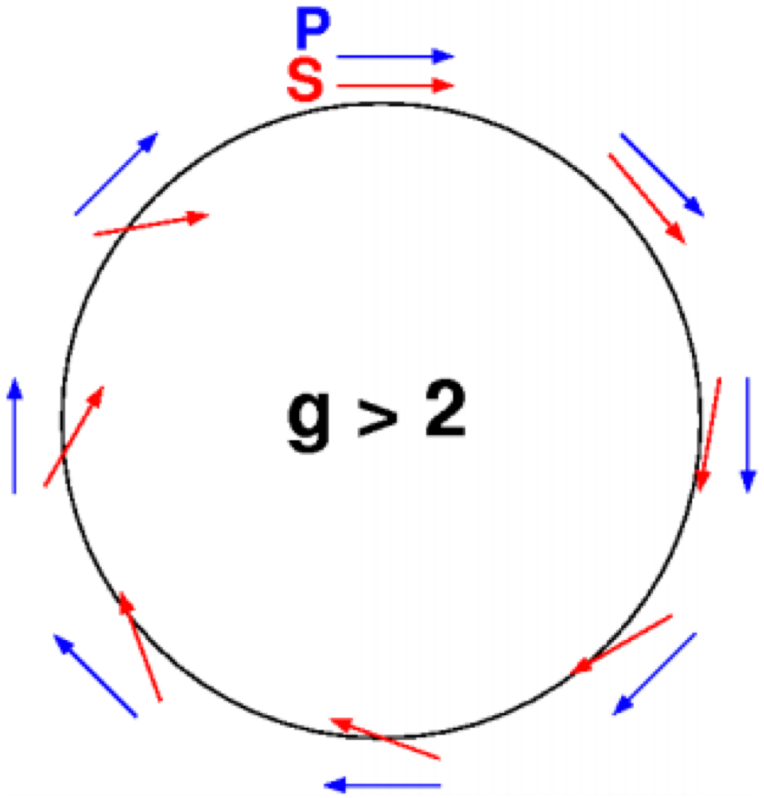




Backup

Dependence of frequency on g-factor





Damping in toy MC

- Decay exponential removed for testing of coherence length calculation…