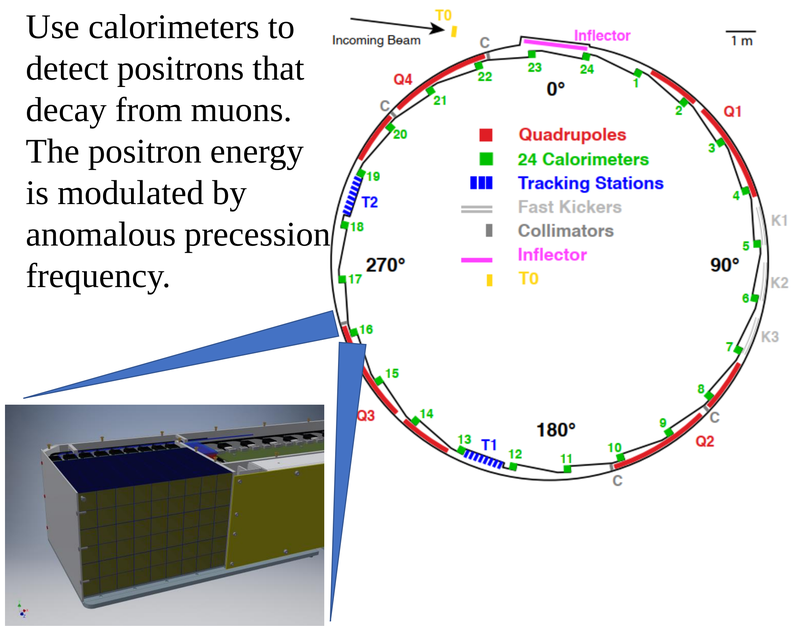
Muon Lifetime Measurement with Muon g-2 Experiment at Fermilab

Zejia Lu
Shanghai Jiao Tong University

Muon g-2 Experiment

- Use calorimeters to detect positrons that decay from muons. The positron energy is modulated by anomalous precession frequency.



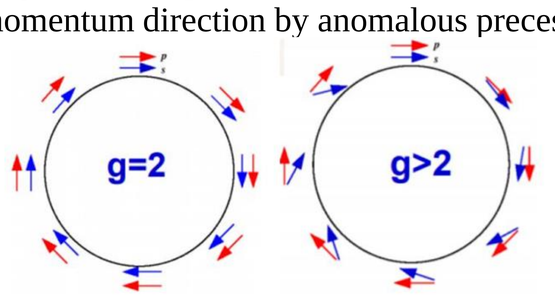
- Muons' momentum and spin both rotate in the horizontal plane of the storage ring.

$$\vec{\omega}_c = -\frac{q\vec{B}}{m\gamma}$$

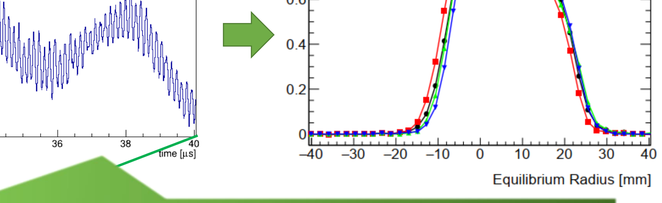
$$\vec{\omega}_s = -g\frac{q\vec{B}}{2m} - (1-\gamma)\frac{q\vec{B}}{m\gamma}$$

$$\vec{\omega}_a = \vec{\omega}_s - \vec{\omega}_c = -(\frac{g-2}{2})\frac{q\vec{B}}{m}$$

- When $g > 2$, the spin direction of muons overtakes the momentum direction by anomalous precession.



- The energy distribution of decayed positrons depends on the angle between muon momentum and muon spin direction.

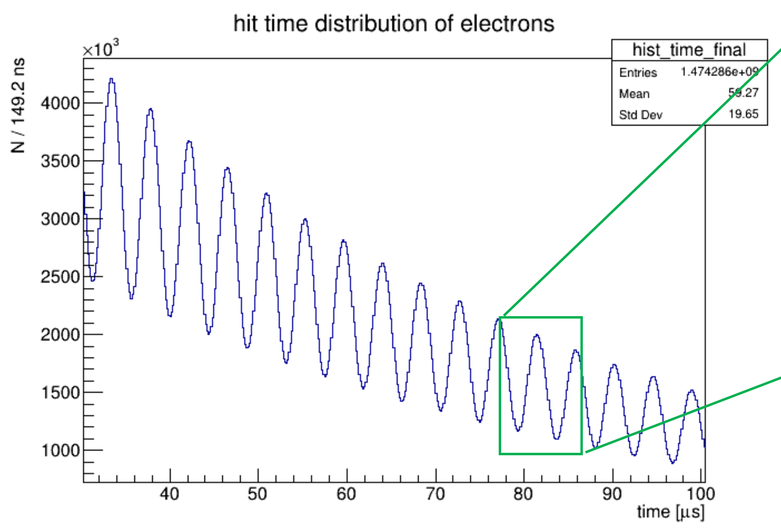


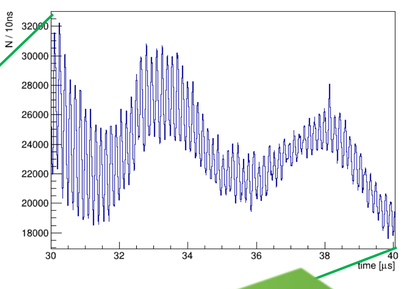
Muon Lifetime Measurement

- The time spectrum of high-energy positrons is modulated by wiggle + exponential decay

$$Ne^{-\frac{t}{\gamma\tau}}[1 + A\cos(\omega t + \phi)]$$

- Muons rotates in the storage ring with energy ~3.1 GeV.
- Muon lifetime is Lorentz boosted.

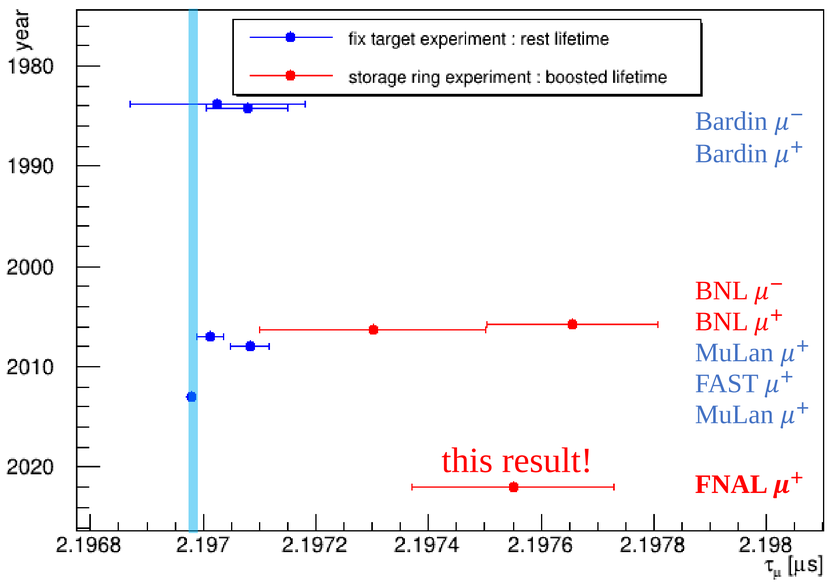




- **Fast Rotation Effect**: Muons rotate with high cyclotron frequency in the storage ring.
- Derive boosted factor γ from $\omega_{cyclotron}$.

$$\omega_{cyclotron} = 2\pi R/\beta c$$
$$R = p/qB$$
$$\tau_{rest} = \tau_{boosted}/\gamma$$

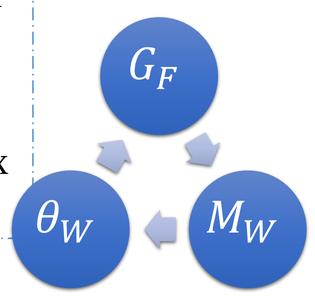
Experimental Results Comparison



- The preliminary result of muon lifetime measurement with Run-1 dataset is

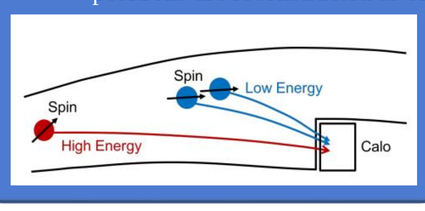
$$\tau_{\mu^+} = 2.19755 \pm 0.00018\ \mu s$$

- An independent measurement of muon lifetime other than fix target experiments. Measure Fermi constant G_F independently to better understand weak interaction.
- ~3σ discrepency between the storage ring and fix target experiment results. Further study ongoing.

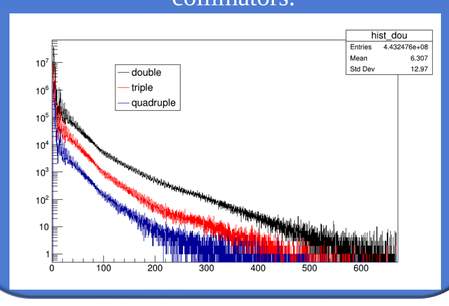


Systematics Uncertainties

pileup Pileup happens when two or more positrons are reconstructed as one.



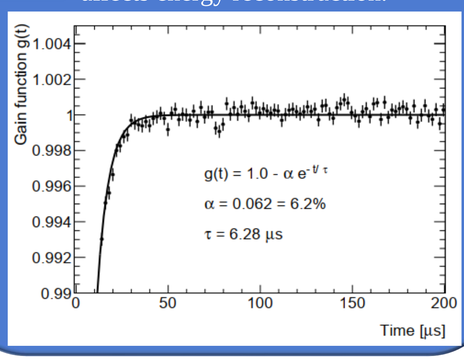
lost muon Lost muons hit on collimators.



Sub dataset		Run-1a	Run-1b	Run-1c	Run-1d
fast rotation analysis uncertainty on γ (Fourier Method)[1]		150*	150	150	150
statistics from τ		46	37	30	29
systematics	time randomization	2	1	1	1
	gain	69	66	73	17
	pileup	6	9	8	3
	lost muon	3	2	1	1
	beam oscillation	2	1	3	3
total		173	168	168	155

* Uncertainties in ppm.

gain Gain recovery from injection flash affects energy reconstruction.



[1] Physical Review Accelerators and Beams 24.4 (2021): 044002.