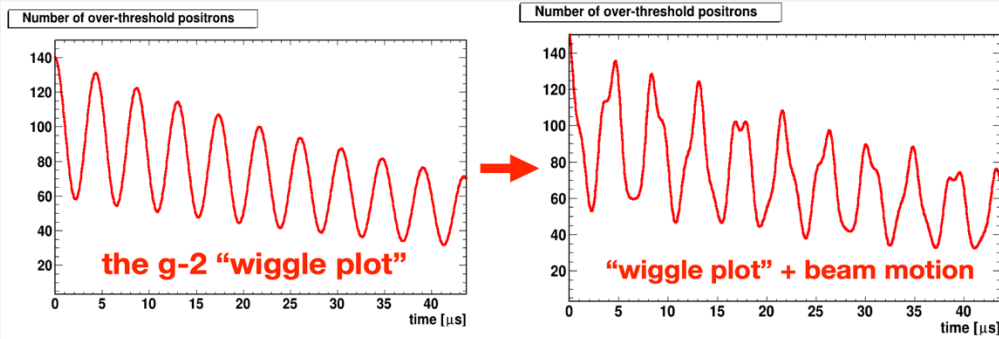
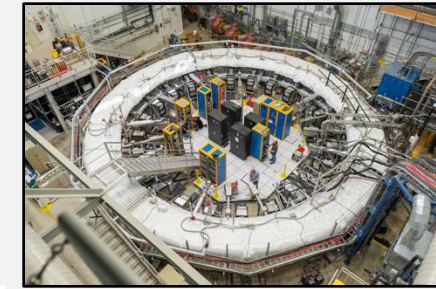


The coupling between betatron oscillation and detector acceptance

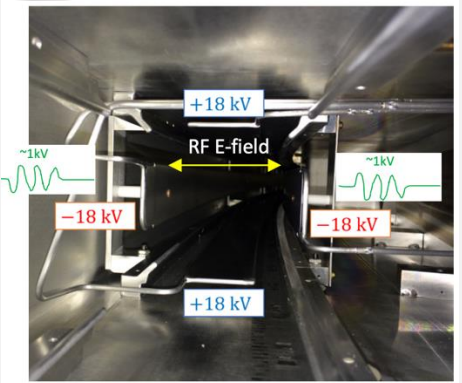


Major systematics source for ω_a

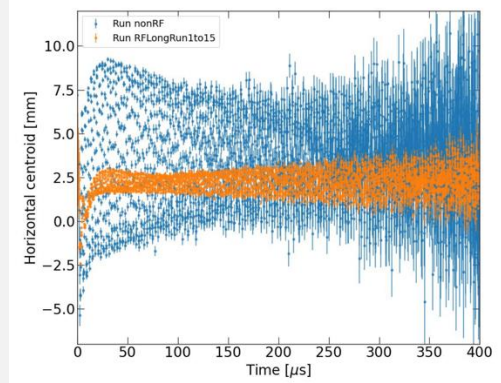
Systematic uncertainty	Run-2 (ppb)	Run-3a (ppb)	Run-3b (ppb)	Run-2/3 (ppb)
CBO handling	22	18	28	21
Pileup corrections	9	6	7	7
Gain corrections	5	4	5	5
Residual slow effect	5	14	10	10
Other systematics	2	5	3	4
Total	25	24	31	25



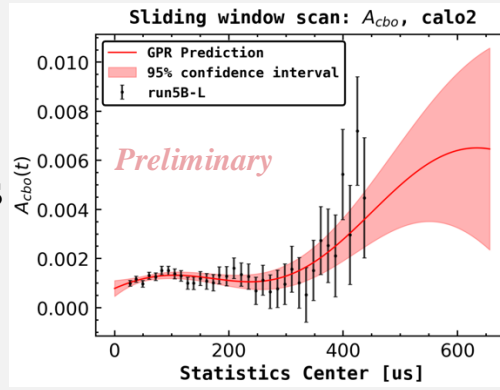
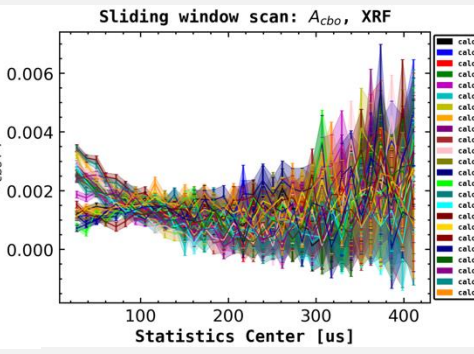
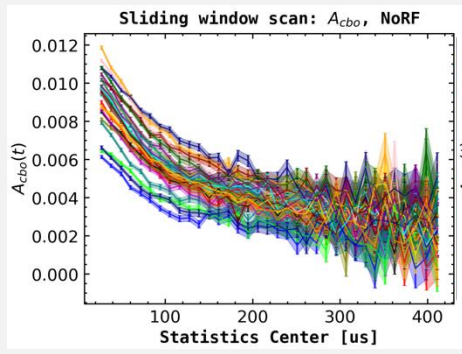
Electrostatic Quadrupole + RF



CBO seen by tracker



CBO modeling becomes more difficult



CBO modeling in the anomalous precession frequency analysis for Fermilab Muon g-2 experiment

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Physics and Measurements of Muon g-2

- A thin particle has a magnetic dipole moment of $\vec{\mu} = \mu_B \vec{\sigma}$ with $\mu_B = \frac{e\hbar}{2m_e}$. In addition to the effects from QED, slow-drift and focusing effects modify the factor away from 2. It has become customary to measure the discrepancy $a_\mu - 2$. We will measure the anomalous magnetic moment of muon, $a_\mu = \frac{e\hbar}{2m_\mu} (g - 2)$, in an unprecedented precision of 50 ppb.
- We achieved our stated goal in August 2023, compatible with the Run-1 and Run-2 (E821) result, reaching the 1σ level.
- Fermilab E989 Measurement Principle
 - We measure muon spin precession frequency ω_p .
 - We measure muon anomalous precession frequency ω_a .
 - We use a proton Larmor frequency as a reference of B field.
- Wobble plot
- Beam motion

Beam Dynamics and Systematics

- The betatron oscillations enter the data through coupling between detector acceptance and the muon decay position.
- We will measure the anomalous magnetic moment of muon, a_μ , in an unprecedented precision of 50 ppb.
- The systematic of a_μ is 10 ppb, in which the contribution from different betatron oscillation (CBO) individually contributed to 10 ppb.
- Modeling CBO in a better way will reduce the uncertainty.

CBO Amplitudes Suppressed in Run-5/6

- We applied a radio-frequency (RF) electric field to the quadrupole plates to further suppress the CBO amplitude during Run-5/6 data taking.

CBO modeling in Run-4/5/6 Data Analysis

- Extracting CBO Amplitude Over Time Using Calorimeter Data
 - We use our single plot into small time windows, such that the CBO amplitude could be sufficiently regarded as constant, namely using a sliding window approach.
 - We use the time window width: $\Delta t = \frac{1}{\omega_a} \sqrt{1 + \frac{1}{\omega_a^2} \frac{d\omega_a}{dt}}$.
- Unusual CBO Shapes in Some Calorimeters for Run-5/6 Data
 - The CBO amplitudes are small and unstable.
 - The shape cannot be described by the exponential function.
 - Interpolation methods are limited to the finite data range from the sliding window compared to 700 μs wobble plot.
- Gaussian Process Regression Method
 - GPR is a non-parametric machine learning technique.
 - We can benefit of a generalization of the Gaussian probability distribution to infinitely many variables.
 - We propose using GPR to model the CBO amplitudes and make predictions where the sliding window data are not available.
- Systematics Evaluation
 - The systematic is from the way to model the CBO, that is the GPR template shape for the GPR method modeling.
 - We randomize the sliding window data, reproduce GPR template and then evaluate the systematic error in the nominal result.

Conclusion

- The CBO effect is reduced by a factor of 15 for Run-5/6 datasets by introducing the RF electric field, but making CBO modeling more difficult.
- The CBO effect can be described by sliding window method.
- We propose to model the CBO by a machine learning GPR method and present the preliminary CBO systematic values, which are below 10 ppb.

References

Acknowledgements

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- This poster will be showing
 - Brief introduction of Fermilab Muon g-2 experiment
 - Beam dynamics effect in the anomalous precession frequency analysis
 - A machine-learning method, Gaussian Process Regression (GPR), to model CBO
 - Preliminary result for Run-4/5/6 data