Muon Anomalous Frequency Analysis in the Muon g-2 Experiment at Fermilab

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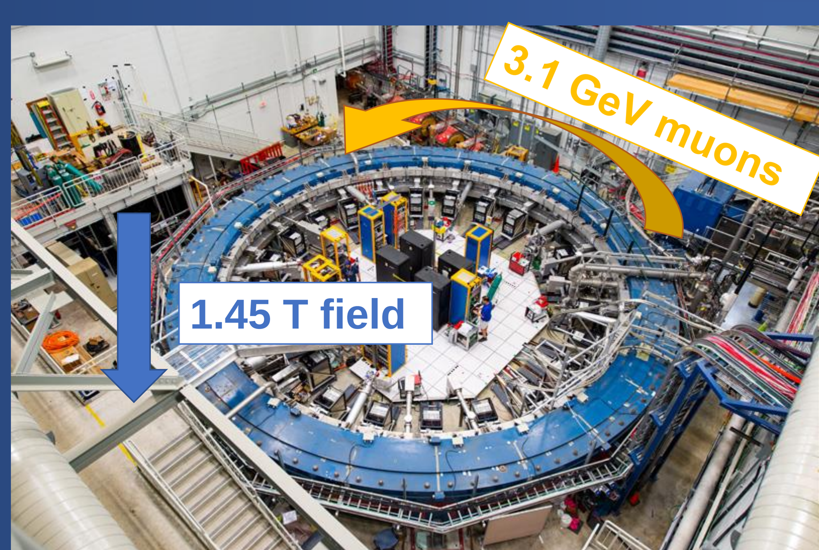
Anomalous Frequency (ω_a) Analysis

- **Measuring muon anomalous magnetic moment $a_\mu = \frac{g_\mu - 2}{2}$**

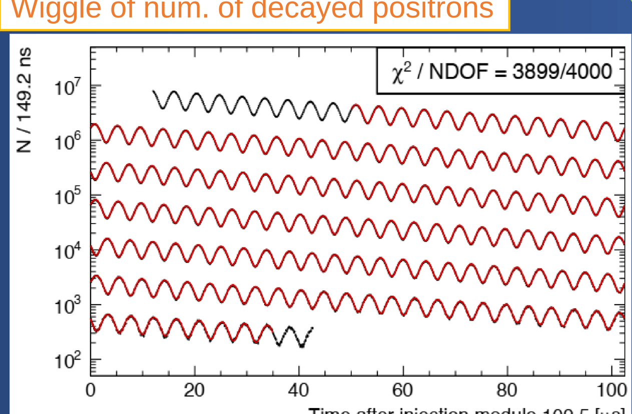


Polarized muon bunches are injected into storage ring with an uniform magnetic field. Because g>2, muons' spin will precess, the precess frequency is called anomalous frequency (ω_a).

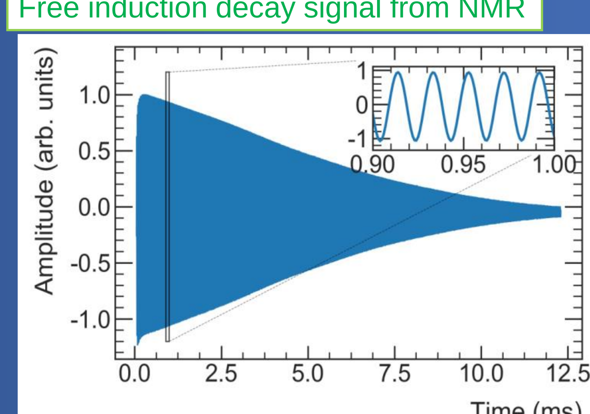
$$a_\mu = \frac{m_\mu}{q}\frac{\omega_a}{B} = \frac{\omega_a}{\tilde{\omega}'_p(T_r)} \frac{\mu'_p(T_r)}{\mu_e(H)} \frac{\mu_e(H)}{\mu_e} \frac{m_\mu}{m_e} \frac{g_e}{2}$$

Constraints from other experiments

Wiggle of num. of decayed positrons



Free induction decay signal from NMR



- **ω_a analysis workflow**

Positron clusters reconstruction → Pileup correction → ω_a fitting → Systematics uncertainties evaluation

- **ω_a fitting function**

$$\begin{aligned} f(t) = Ne^{-t/\tau} \cdot [1 - A \cdot A_{CBO}(t) \cos(\omega_a t + \phi \cdot \phi_{CBO}(t))] \\ \cdot [1 - k_{loss} I(t)] \\ \cdot [1 - e^{-t/\tau_{VO}} (A_{VO,c} \cos \omega_{VO} t + A_{VO,s} \sin \omega_{VO} t)] \\ \cdot [1 - e^{-2t/\tau_{CBO}} (A_{2CBO,c} \cos 2\omega_{CBO} t + A_{2CBO,s} \sin \omega_{2CBO,s} t)] \\ \cdot [1 - e^{-t/\tau_{CBO}} (A_{CBO,c} \cos \omega_{CBO} t + A_{CBO,s} \sin \omega_{CBO} t) \\ - e^{-t/\tau_{VW}} (A_{VW,c} \cos \omega_{VW} t + A_{VW,s} \sin \omega_{VW} t) \\ + e^{-t/\tau_{CBO} - t/\tau_{VW}} (A_{CBO+VW,c} \cos(\omega_{CBO} + \omega_{VW}) t \\ + A_{CBO+VW,s} \sin(\omega_{CBO} + \omega_{VW}) t) \\ + e^{-t/\tau_{CBO} - t/\tau_{VW}} (A_{CBO-VW,c} \cos(\omega_{CBO} - \omega_{VW}) t \\ + A_{CBO-VW,s} \sin(\omega_{CBO} - \omega_{VW}) t)] \end{aligned}$$

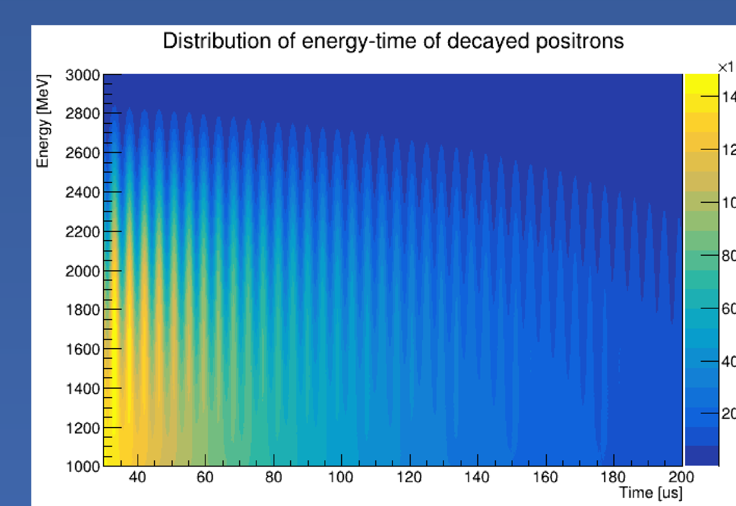
Exponential decay + wiggle (asymmetric and phase modulated by coherent betatron oscillation)

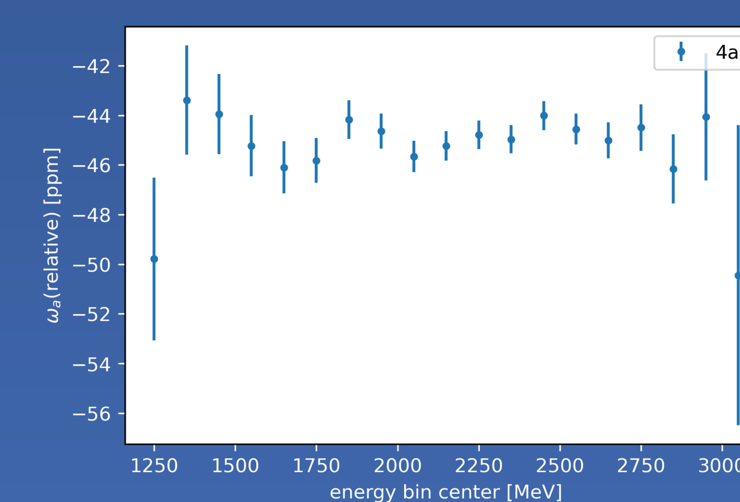
Lost muon correction

Beam oscillation corrections
3 types of oscillation mode: horizonal position (CBO), vertical position (VO), vertical width (VW)

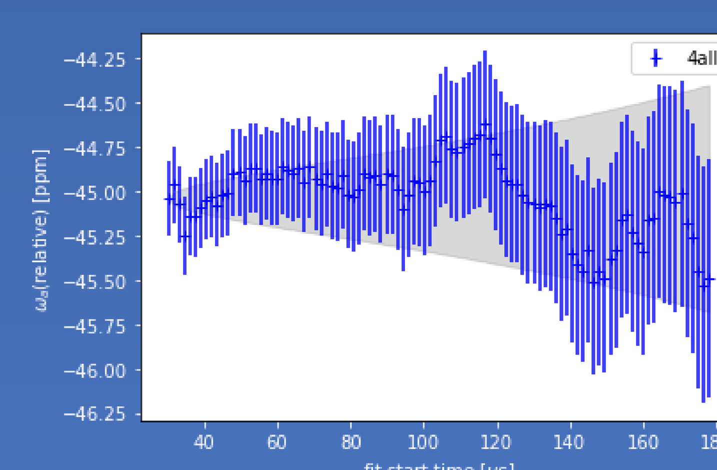
Consistency Check

- **Energy binned scan**



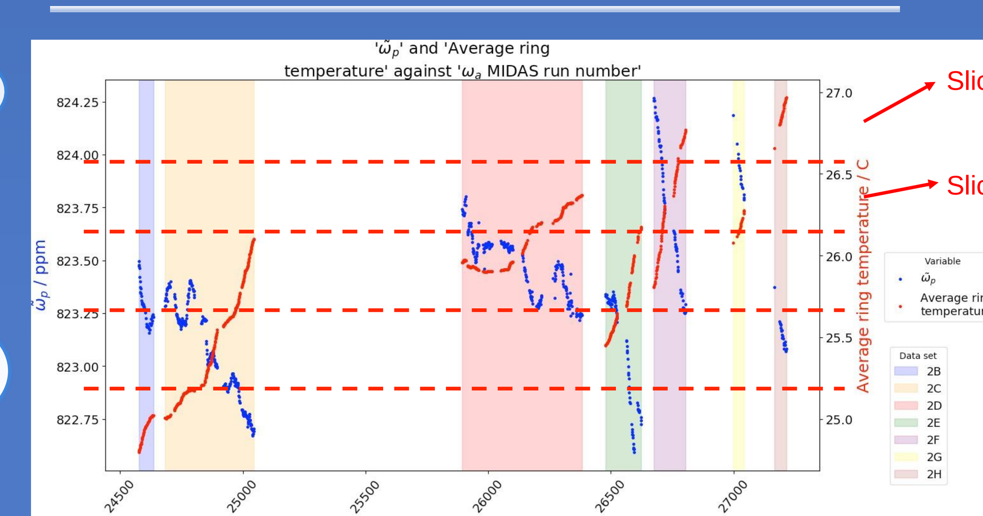


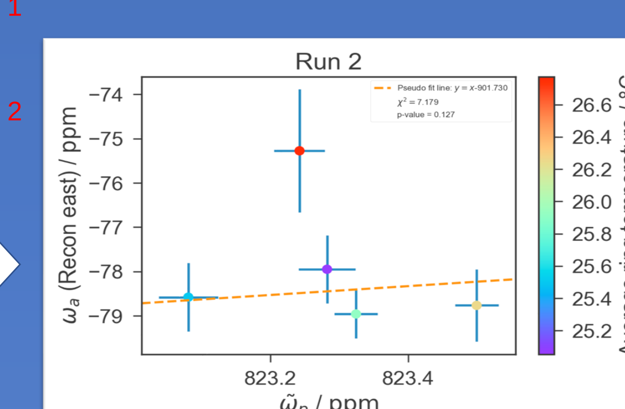
- **Fit start time scan**



- The fitted values of ω_a are consistent in different energy bins.
- With fit start time changing, the ω_a varies within the statistic uncertainty.
- These results show the consistency in ω_a data.

- **External variable consistency check**

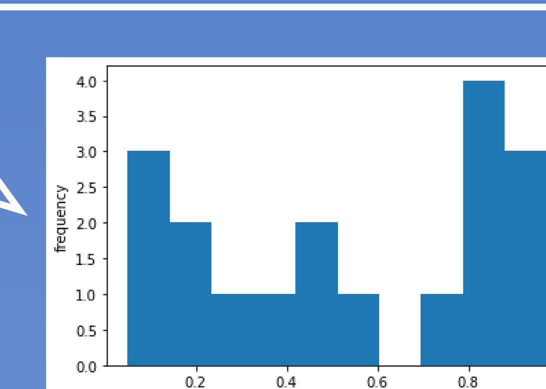




The muons data is divided into different runs, each with a measured ω_p (B field) value and external variables such as ring temperature, magnet current…

Runs are sliced into different datasets according to external variable. Consistency of ω_a / ω_p verse external variable can be checked.

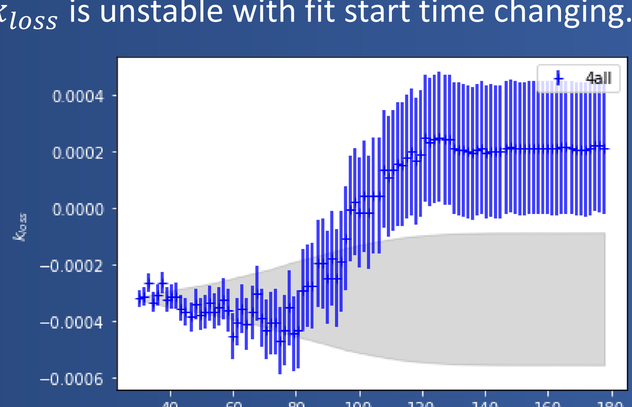
With different external variables checked, the overall p-values are consistent.



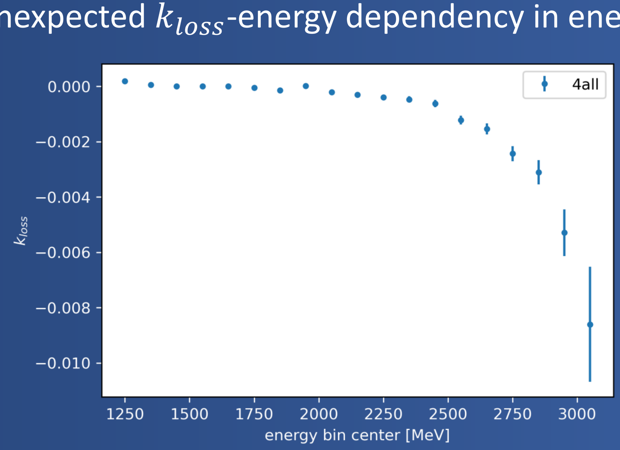
Residual Slow Effect

- **Evidence of residual slow effect**

- Since Run-3, the lost muon rate parameter k_{loss} fitting result is negative (which is unphysical, means muons are 'gained' instead of 'lost').
- k_{loss} is unstable with fit start time changing.

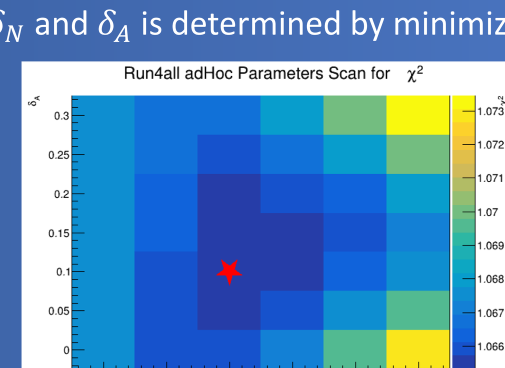


- Unexpected k_{loss}-energy dependency in energy bin scan.

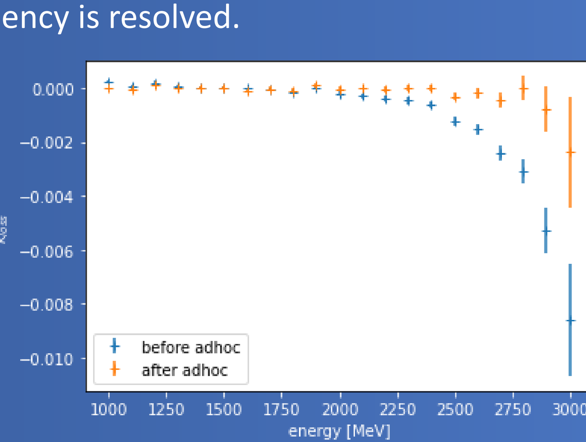


- **Correction of residual slow effect**

- An ad-hoc gain correction on cluster energy is used to correct the residual slow effect:
$$G_{ad-hoc} = 1 + \delta_N \times 10^{-3} \cdot e^{-t/\tau} \cdot [1 + \delta_A \cos(\omega_a t + \phi)]$$
- Parameter δ_N and δ_A is determined by minimizing the fitting χ^2.



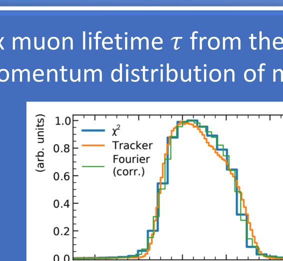
- With the ad-hoc gain correction, the k_{loss}-energy dependency is resolved.



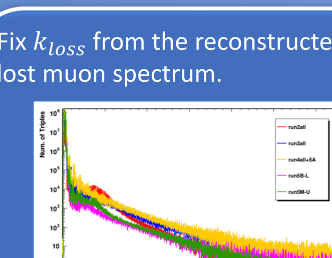
- **Source of residual slow effect**

- Diagnose the source of residual slow effect :
Isolate the residual slow term by fixing long-term parameters in the fitting :

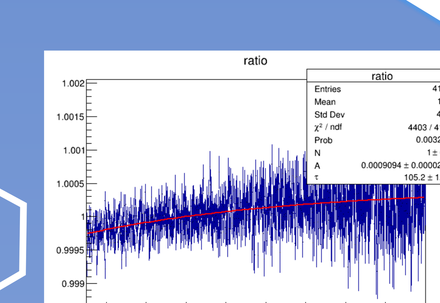
Fix muon lifetime τ from the momentum distribution of muons.



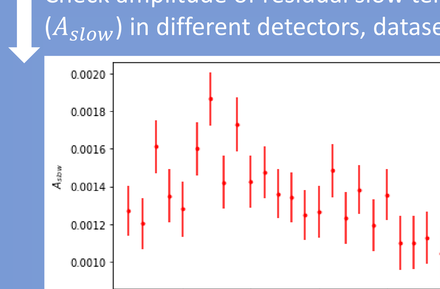
Fix k_{loss} from the reconstructed lost muon spectrum.



Residual slow term isolated from residual

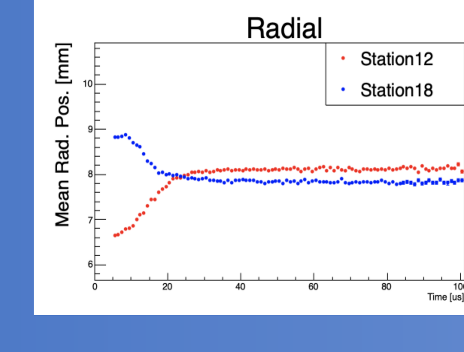


Check amplitude of residual slow term (A_{slow}) in different detectors, datasets…



- Beam-dynamic induced slow effect

➢ Beam dynamic effects (drift of beam mean positron, width, beam oscillation decoherent) may induce detector acceptance corrections which are energy dependent.
➢ Study ongoing to further investigate the correlation between acceptance corrections and residual slow effect (A_{slow}).



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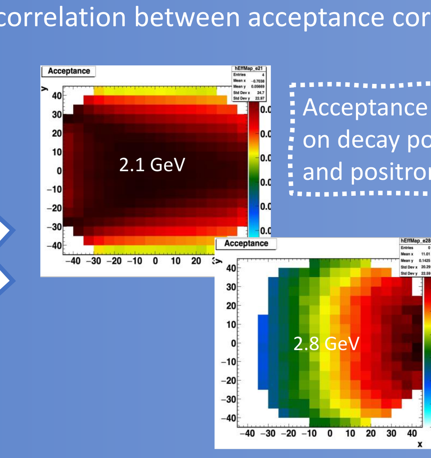

Acceptance depends on decay position and positron energy

⇒ $N_{slow}(E, t)$