Final report

Eddy currents analysis in the Muon g-2 experiment

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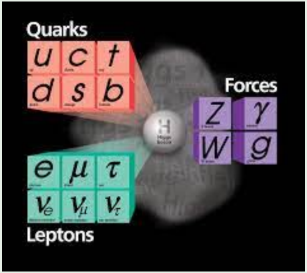
A brief introduction on the Muon g-2 experiment

What g actually is

- $\vec{\mu}_l = g \frac{e_l}{2m_l} \vec{S}$
- Quantity of interest: $a_l = \frac{g-2}{2}$

What l stands for



Why Muons?

- More massive than electrons
- More long-lived than Tauons

What is the reason why we are really interested in g-factor?

- It is possible to perform a very precise comparison between Theory and Experiments
- It could led us to New physics beyond the Standard Model

Theory and Experiment: A phenomenological Journey

First Theoretical approach

- Dirac equation Prediction(1928): $a_l = 0$

First experimental discrepancy

- Kusch & Foley(1948): a_e=0.00119(5)

Standard Model Improvements

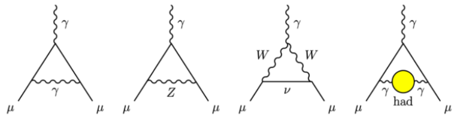


Figure: The lowest Feymann Diagram order for each interaction

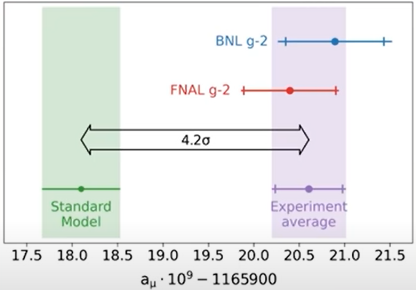
- New approach in the studying of particle physics
- Virtual particles as mediators for interactions
- Possibility to explore further orders beyond Dirac tree level term
- First order correction(Schwinger(1947)): $a_l = \frac{\alpha}{2\pi}$

Question: Is this theory in agreement with the experiments ?

Muon g-2: The state of art

Comparison between latest achievements

	Theoretical prediction	BNL result	RUN 1 result
a_μ^{SM}	116591810 x 10^{-11}	11659208 x 10^{-10}	116592061 x 10^{-11}
δ_{a_μ}	370 ppb	540 ppb	465 ppb



FNAL Goal

- confirm BNL results
- Increase the statistic
- Achieve a precision of 140 ppb
- Overcome 5σ limit

FNAL Muon g-2 Experiment

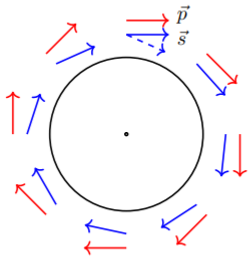


Figure: Anomalous precession frequency

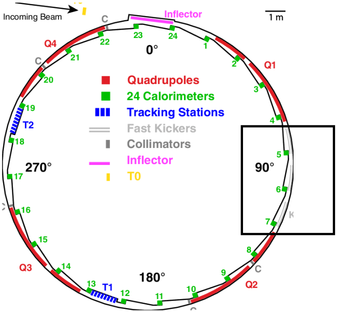
Quantity of interest

- $\vec{\omega}_a$: the difference between momentum and spin angular frequency
- Main goal is to measure $\vec{\omega}_a = \frac{q}{m}\left[a_\mu \vec{B} - a_\mu \left(\frac{\gamma}{\gamma+1}\right)(\vec{\beta}\cdot\vec{B})\vec{\beta} - \left(a_\mu - \frac{1}{\gamma^2-1}\right)\frac{\vec{\beta}\times\vec{E}}{c}\right]$

My task

- Measure eddy currents contribution on the ω_a fit with Faraday rotation effect
- Reduce the errors on RUN 1 eddy currents contribution (-27(37) ppb)

Schematic of the Muon g-2 storage ring



- Storage ring is composed by a lot of components and each of them has its role
- In this presentation we are interested in **Fast Kickers**.

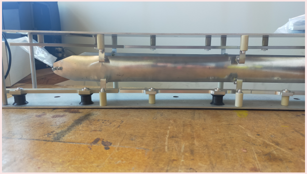
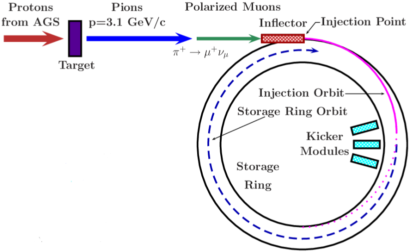


Figure: Kicker in MC-1 mezzanine

Kickers role and the reason why we are interested in them

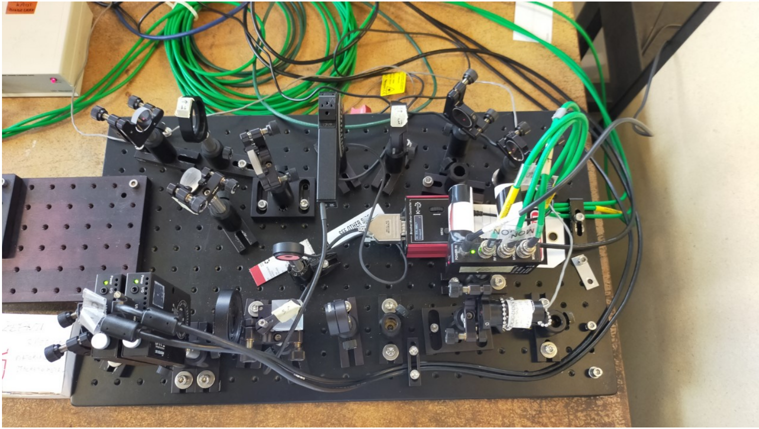
The issue in a nutshell

- We need a system of kickers in order to place the muons in the correct orbit.
- This is achieved thanks to a ~ 4 kA current along aluminium plates lasting only 120 ns
- However this produces eddy currents hence a small spurious magnetic field.
- The goal of the project is to measure magnetic field due to eddy currents.



INFN Breadbord

Eddy currents effect is measured with a Magnetometer

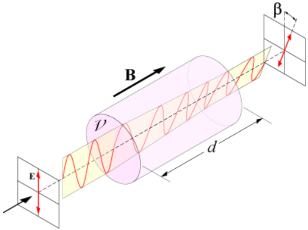


The Faraday effect

We set this breadboard in order to measure magnetic field inside a crystal.

Faraday effect equation:

$$\theta = BVd$$



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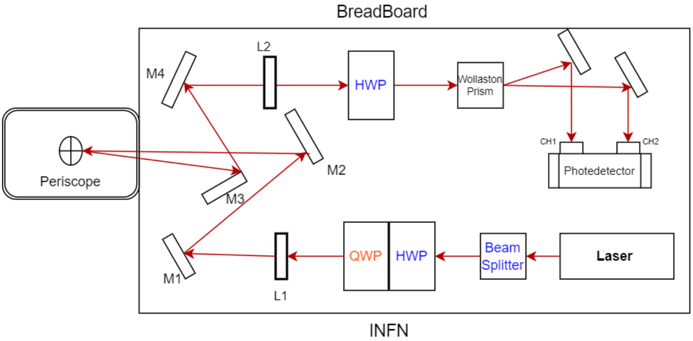
where

- θ is the angle between in and out polarization
- B is the magnetic field inside the crystal
- V is the Verdet constant
- d is the distance travelled by laser beam

We choose d such that for B $=$ 1.45 T (field in the ring), $\theta = 2\pi n$ in order to avoid a further rotation. We set n=4.

Measuring Magnetic field: Breadboard in a nutshell

The principle of the measurement is to send a laser light through a Verdet crystal made of Terbium Gallium Garnet(TGG) in order to study Faraday rotation.



Two different periscopes: We want analyze both in order to make a comparison.

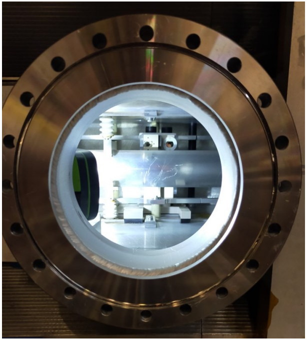


Figure: Periscope mounted in the ring

A brief description of the components

- Plastic Bridge: to reduce vibrations effect due to kicks
- Unlensed Periscope
- Lensed periscope: to avoid symmetry axis distortion between laser beam and crystal during kicks
- Teflon Bar: to give stability
- Kapton tape: to fix trolley line

Into the ring: Preparation for acquisition

After testing the breadboard,we move it in the ring

Figure: Breadboard in the ring

Preliminary steps:

- Mount periscopes and the Breadboard
- Laser alignment
- Turn on magnetic field at 1.45 T
- Turn on the kicker 3 at 42 kV
- HWP & QWP scan in order to find the best angle

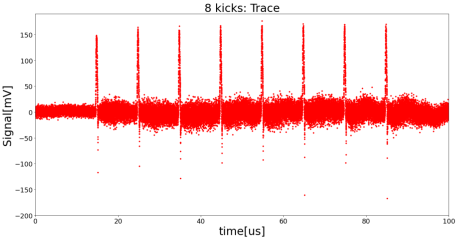
The goal of the project

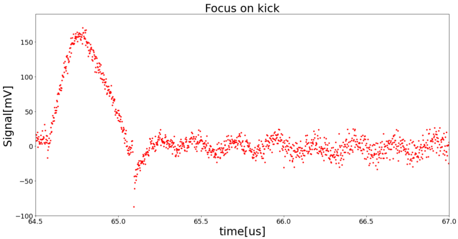
Experimental setup

- Two 8 kicks' groups separated by 300 ms
- Kicks separated by 10 ms
- One kick for each muons bunch

Analysis

- Average over very long Data acquisitions
- Rebinning by 10
- Exponential fit at the end of each kick



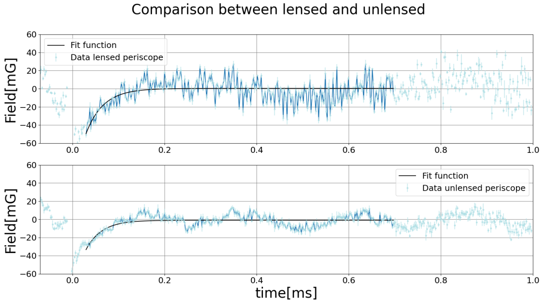


First attempt: Fitting data

Fit function and interval

- Analysis strategy similar to Run-1
- Fit function: a + $B_{EC} \cdot e^{-\frac{(t-0.03)}{\tau}}$
- Fit interval: between 30μs and 700μs after the kick (like ω_a fit)

- Signal/noise for Unlensed periscope : ~ 27
- Signal/noise for Lensed periscope : ~ 7



Correction required

- Remove baseline oscillation in order to get same baseline for each kick
- Remove mechanical oscillation

First correction: Remove the baseline oscillation

What we noticed

- Baseline is not the same for each kick
- It needs to be adjusted before doing average and comparing kicks

What we did

- Remove points from signal regions (kicks)
- Sinusoidal fit over the 100ms-trace
- Subtract point by point the oscillation ($\sim$ 20 Hz) from original data

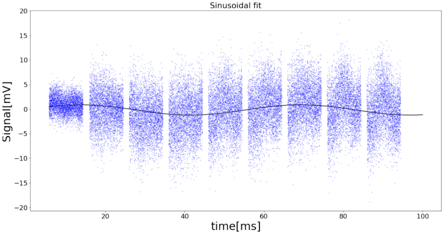


Figure: Unlensed periscope

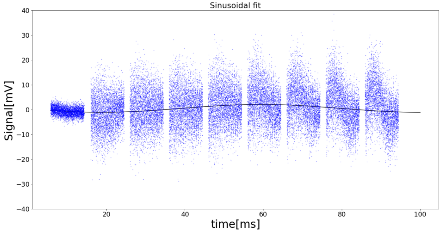


Figure: Lensed periscope

Second correction: Remove mechanical vibrations

What we noticed

- After each kick we see oscillations
- More visible thanks to FFT of exponential fit residuals
- These are due to mechanical vibrations of the periscope

What we did

- Sinusoidal fit between 0.1 and 1 ms after each kick
- Fit function describes mechanical oscillation for each kick ($\sim$ 4.5 kHz)
- Subtract point by point the oscillation from each kick

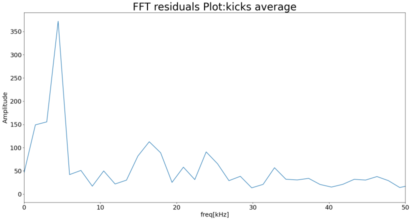


Figure: FFT example plot

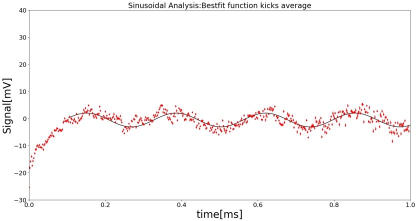


Figure: Unlensed periscope example plot

Second attempt: fitting Data

Repeat same steps as the first attempt

Fit function: $a + B_{EC} \cdot e^{-\frac{(t-0.03)}{\tau}}$

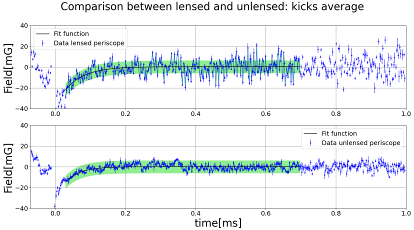


Figure: kicks' average

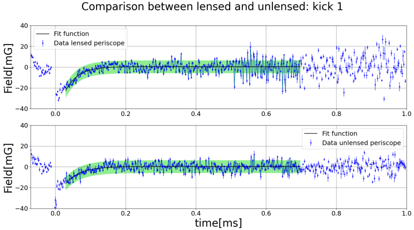
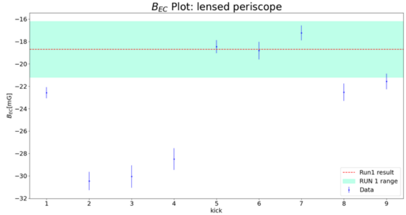


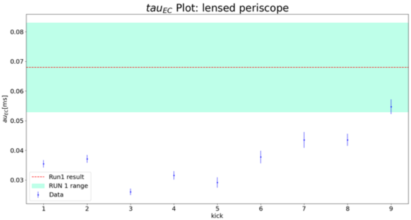
Figure: First kick

- The green shaded band represents the associated uncertainty in RUN1 ($\sim$ 6 mG)
- Great consistency!

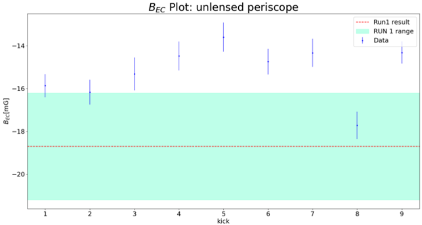
Comparison with RUN 1

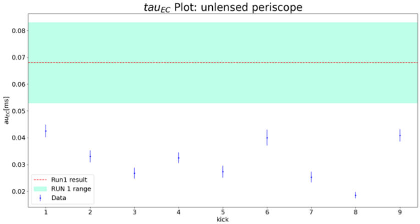
Lensed periscope





Unlensed periscope

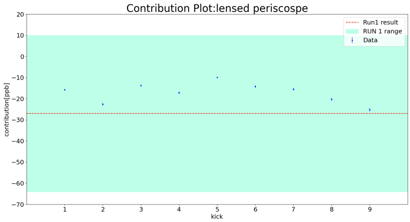


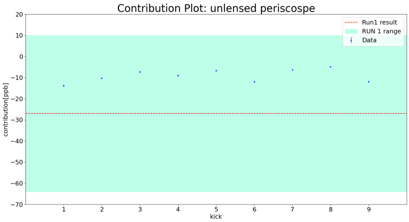


Contribution to omega A

Contribution Calculus

- We want to consider the contribution of eddy currents upon the ω_a fit.
- Function: $\frac{\Delta\omega_a}{\omega_a} \simeq \frac{B_{EC}}{B_{tot}} \times 8.5\% \times 0.94 \times \left(\frac{\tau_k}{\tau_k+\gamma\tau_\mu}\right)^2$
- We have not yet estimate systematic uncertainties





What's next?

A further improvements in Data analysis considering:

- A more complex fit function
- Study of the systematic uncertainties

Improvements in Hardware

- New Breadboard system is being tested in laboratory

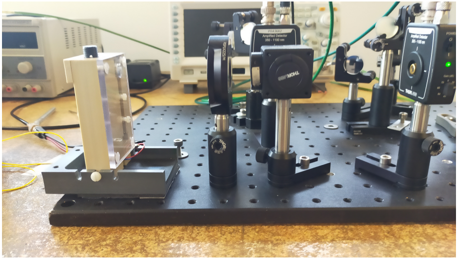


Figure: New periscope project

- I would like to extend my sincere thanks to Hogan Nguyen, Marco Incagli, Paolo Girotti, Anna Driutti and Antonio Gioiosa for their assistance at every stage of the research project.

Thank you for your attention