Midterm report: Eddy currents analysis in the Muon g-2 experiment

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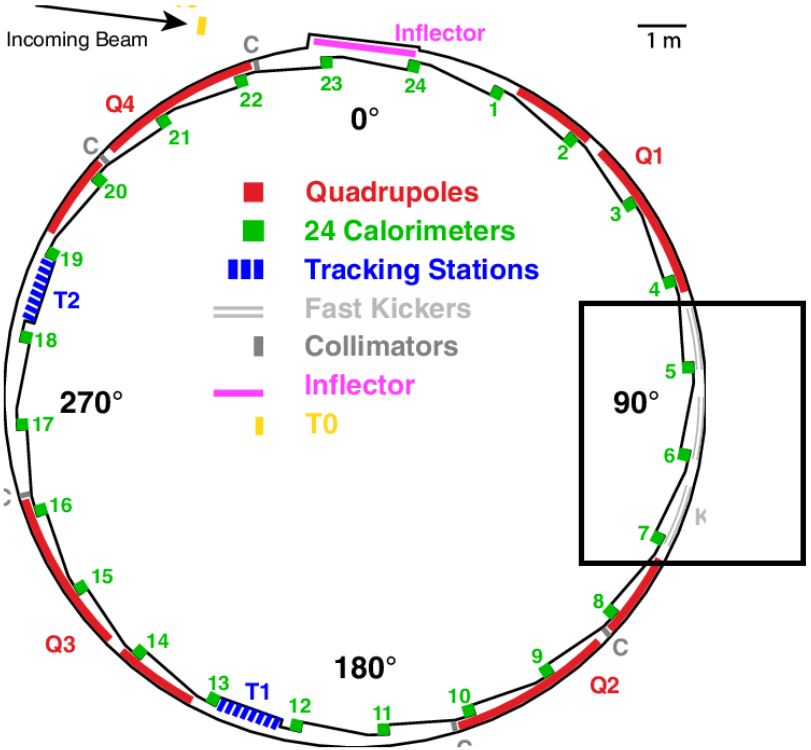
Fermilab

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**.

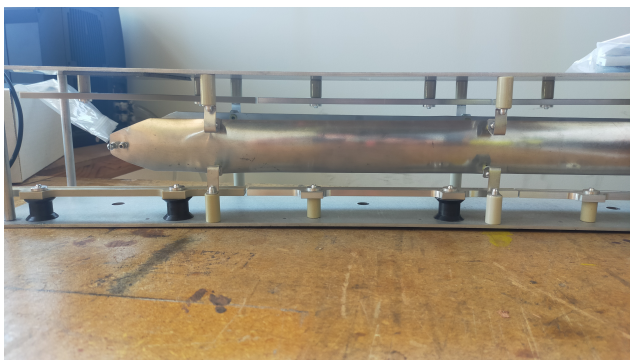
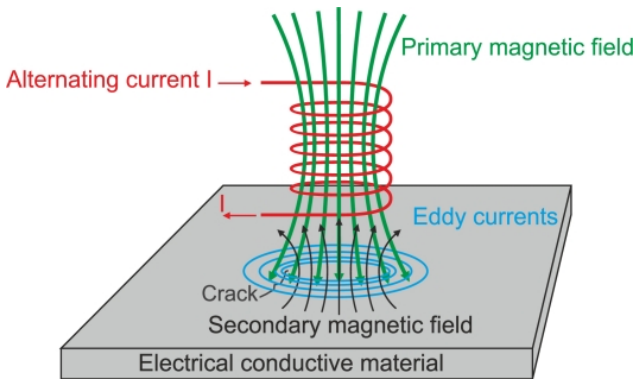


Figure: Kicker in MC-1 mezzanine

Kickers role and the reason why we are interested in them

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



How do Eddy currents affect final results ?

Eddy currents contribute in RUN 1

A general overview:

- Defining $\vec{\omega}_a$ as the difference between momentum and spin angular frequency
- Main goal is to measure $\vec{\omega}_a = \frac{q}{m}\left[a_\mu \vec{B} - a_\mu \left(\frac{\gamma}{\gamma+1}\right)(\vec{\beta}\cdot\vec{B})\vec{\beta}\right]$
- Where we have defined $a_\mu = \frac{g-2}{2}$, being g the g-factor of muons.

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

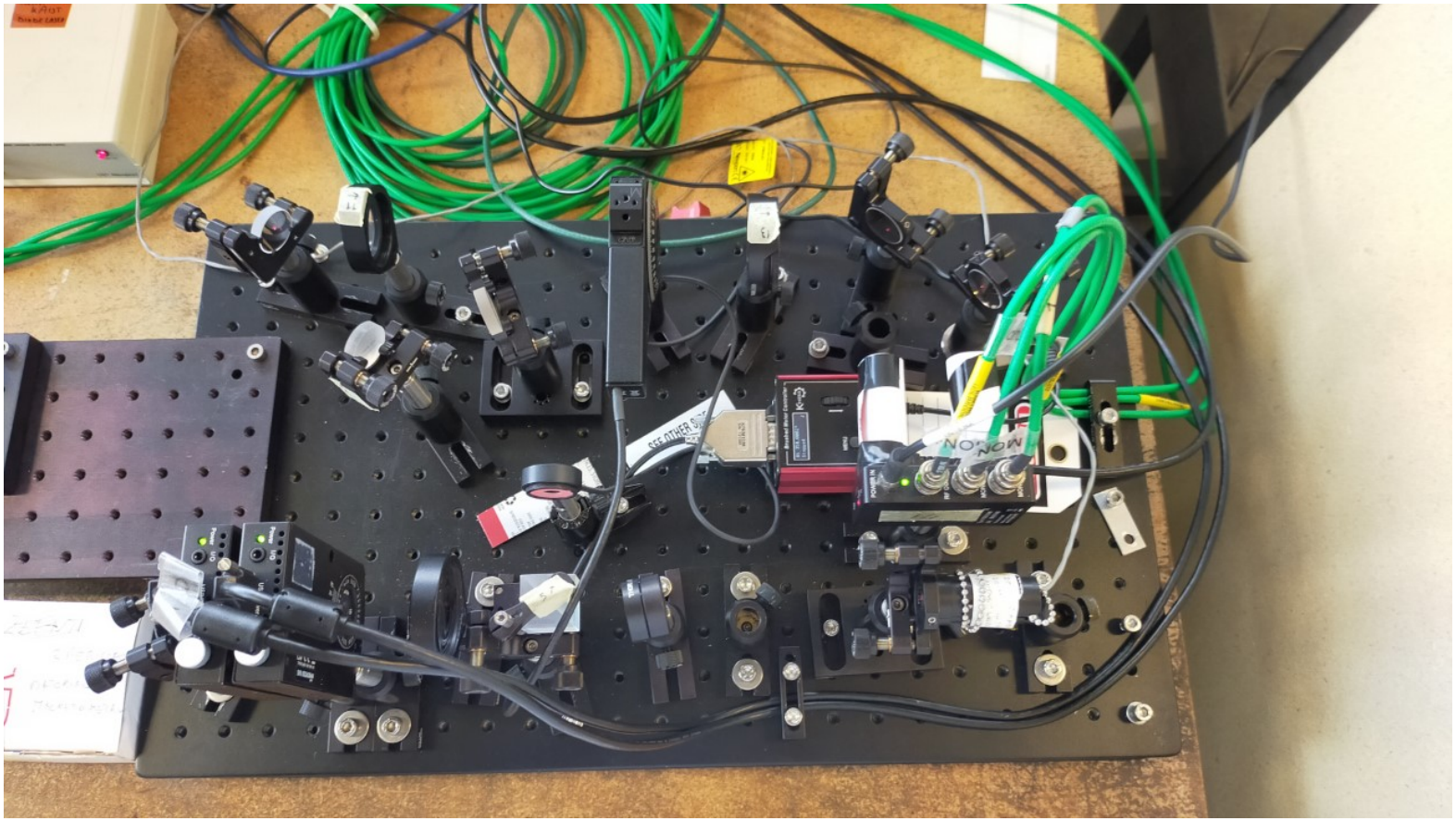
FNAL goal: Achieve a precision of 140 ppb.

Eddy currents contribute in RUN 1: $\frac{\Delta\omega_a}{\omega_a} \approx -27(37)$ ppb

Our team works in order to reduce the error of the eddy currents contribute.

INFN Breadbord

Eddy currents effect is measured with a Magnetometer



Goal of the project

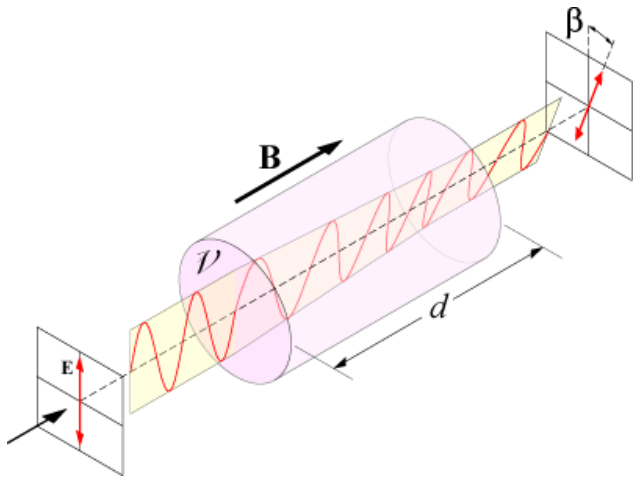
We set this breadbord in order to measure magnetic field inside a crystal. How can we deal with that?

- Faraday effect equation:

$$\theta = BVd$$

where:

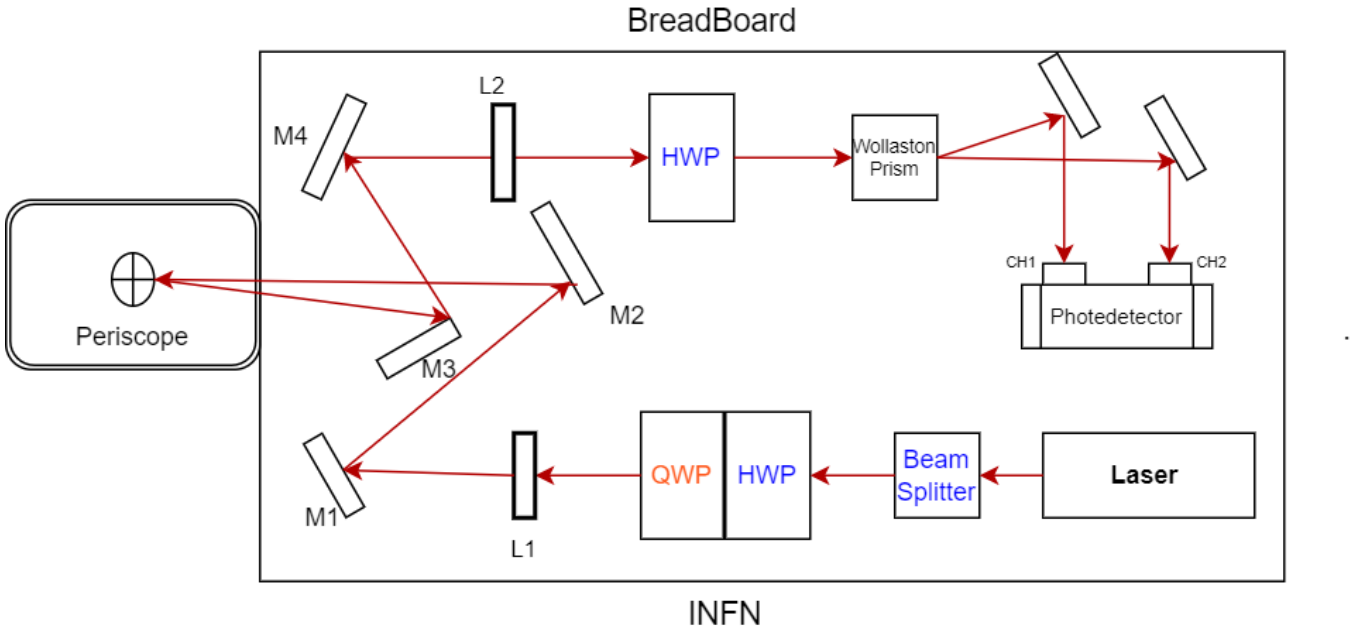
- θ is the angle between in and out polarization
- B is the magnetic field inside the crystal
- V is the Verdet constant
- d is the distance travelled by laser beam



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.



- Beam splitter is used to improve laser beam signal
- First HWP is used to set the angle maximizing the signal.
- QWP is used to study the noise
- Polarized laser light hits the crystal and changes its polarization.
- Wollaston prism splits laser light in two beams with a defined angles.
- Photodetector collects signals and gives first beam, second beam and the difference output intensities.

Preliminary test

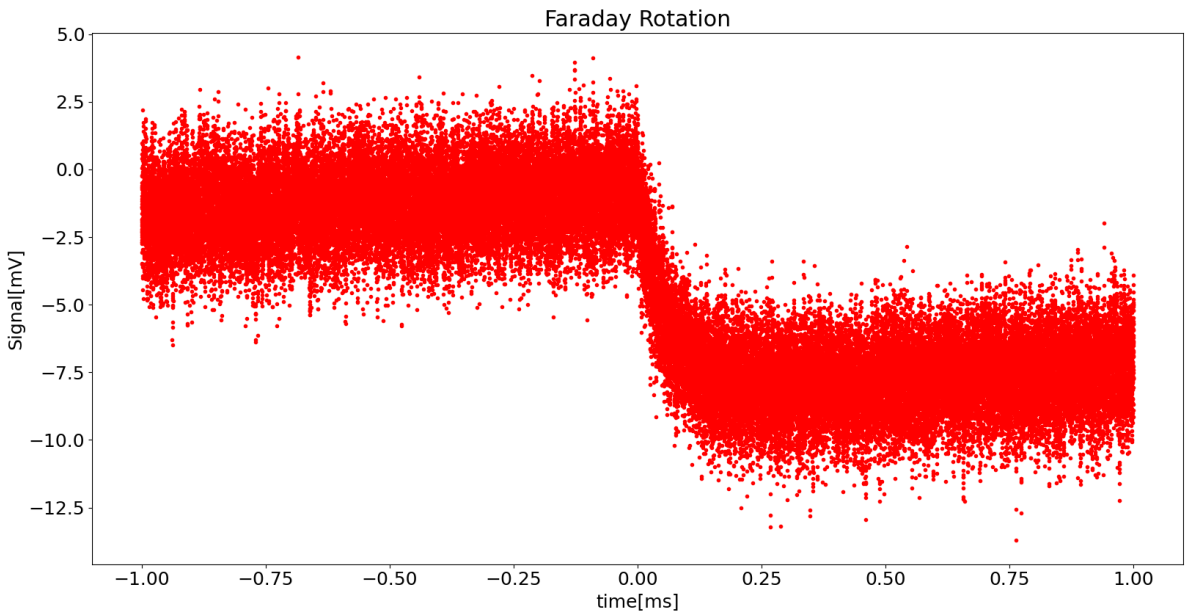
Real experiment

- 8 bunches, one every 10 ms
- 300 ms pause
- other 8 bunches, one every 10 ms

Laboratory test

- We simulated kicker magnetic field using a coil and setting the following parameters:

WF	Ampl	Period	P.Width
Pulse	1 Vpp	10 ms	1 ms



- A-B channel[mV] vs time[ms]
- $B = 0 \Longrightarrow$ signal~0
- $B \neq 0 \Longrightarrow$ Light polarization changes $\Longrightarrow$ signal $\neq 0$

Steps required before starting Acquisition

Different types of frameworks

Mezzanine test	Ring no field	Ring with field
Magnetic field simulated by a coil	Kicker set at ~42 kV (as in RUN 2-3) and Magnetic field off	Kicker set at ~ 42 kV (as in RUN 2-3) and Magnetic field on

Steps required

Laser alignment	HWP scan	QWP scan
Setting mirrors in order to get a correct trajectory of the laser beam	Setting the initial HWP angle that maximize signal	Setting the QWP angle that maximize signal

Mezzanine test:HWP scan & QWP scan

- Studying the difference between up and down signals during Faraday rotation in order to get the best angles

HWP scan

- Remove QWP polarizer
- Scan over the initial HWP angles
- Find angle that maximize signal and signal over noise
- Repeat a more carefully survey around a peak
- Choose best angle: in our case 28.5°!

QWP scan

- Set HWP best angle
- Repeat same steps as HWP scan
- Choose best angle: 36.5°

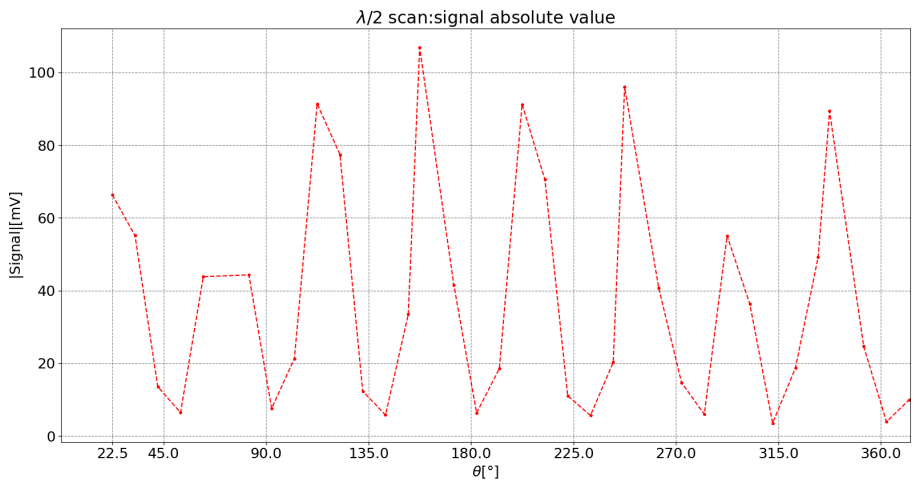


Figure: $\lambda/2$ scan: Absolute value[mV] vs angle[°]

Into the ring: Magnetic field off

We move the board in the ring

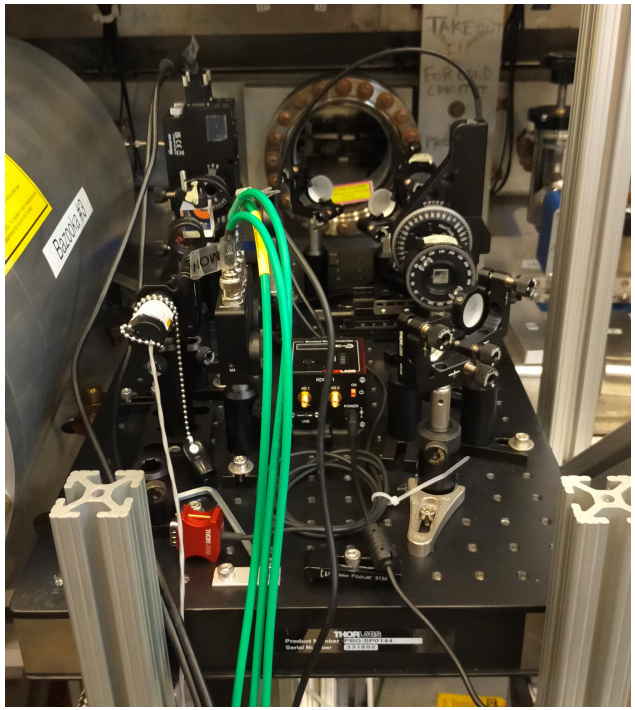


Figure: Breadboard in the ring

Preliminary steps:

- Mount new periscope
- Laser alignment
- Turn on the kicker 3 at 42 kV
- HWP scan
- QWP scan

We perform analysis with a periscope without lens.
Future task: Repeating same steps for a periscope with lens in order to make a comparison.

Periscope: new improvements

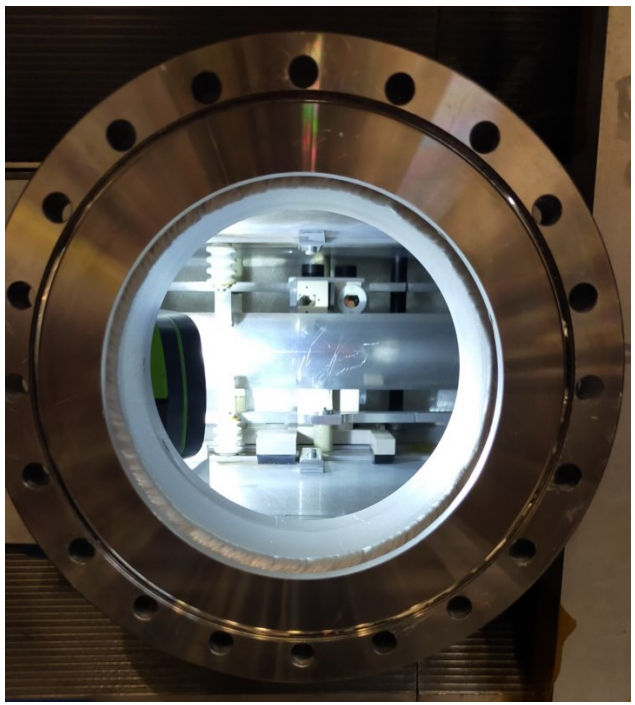
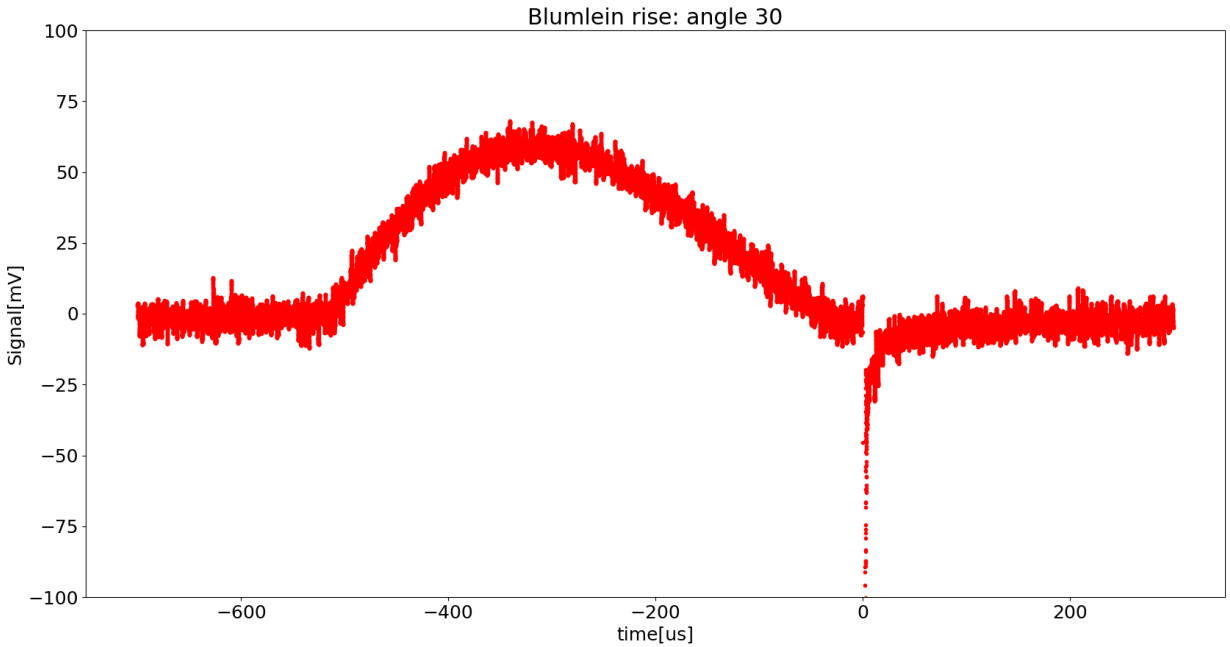


Figure: Periscope mounted in the ring

A brief description of the new components

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

Blumlein rise and analysis method

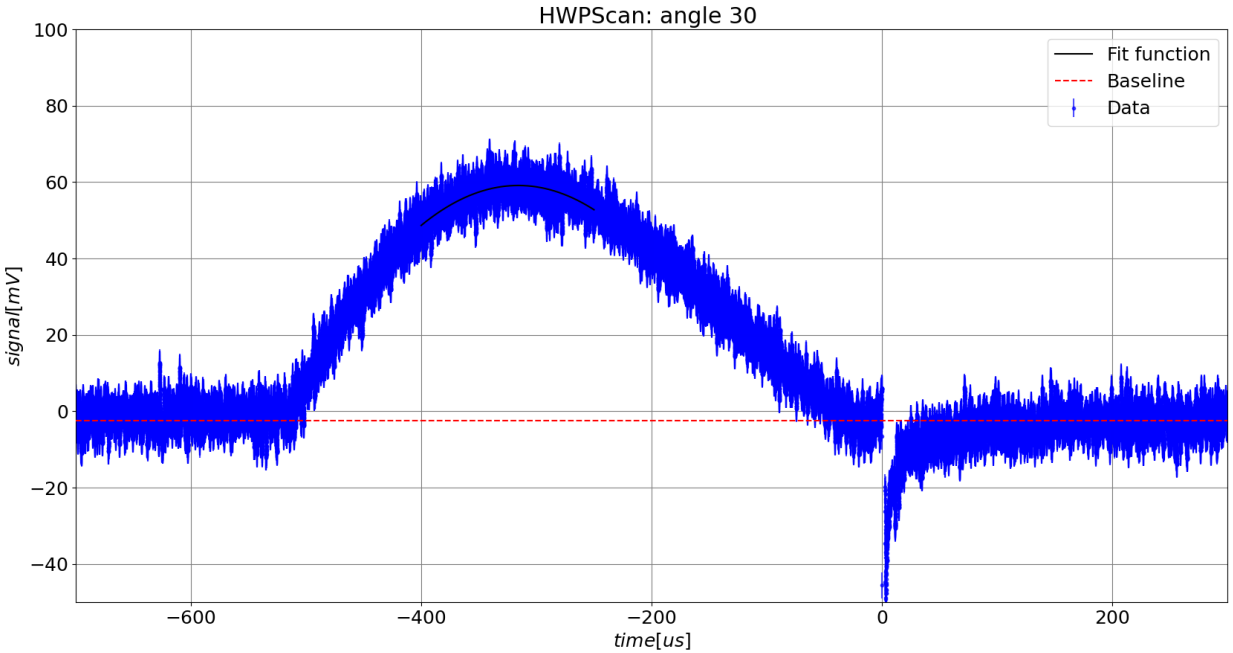


- Different waveform compared to mezzanine
- New analysis method required for Wave Plates scan

Method used to get peak and baseline for each angle:

- Baseline: taking first 10% and last 20% and doing average and std
- Peak: Parabolic fit around the peak (30-45%) in order to get it
- Amplitude : Difference between the peak and the baseline

HWP & QWP scan

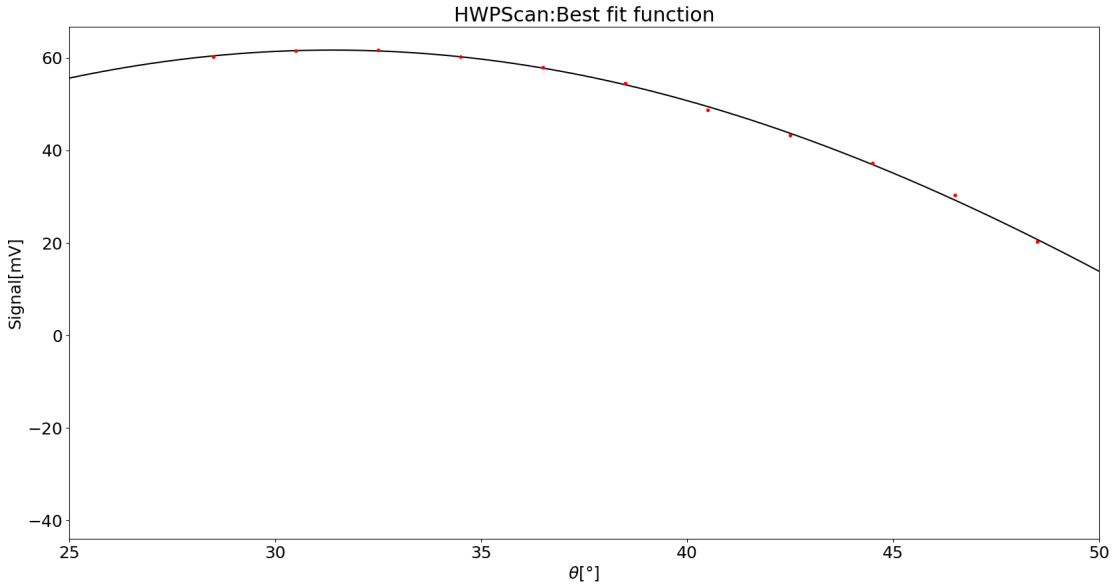


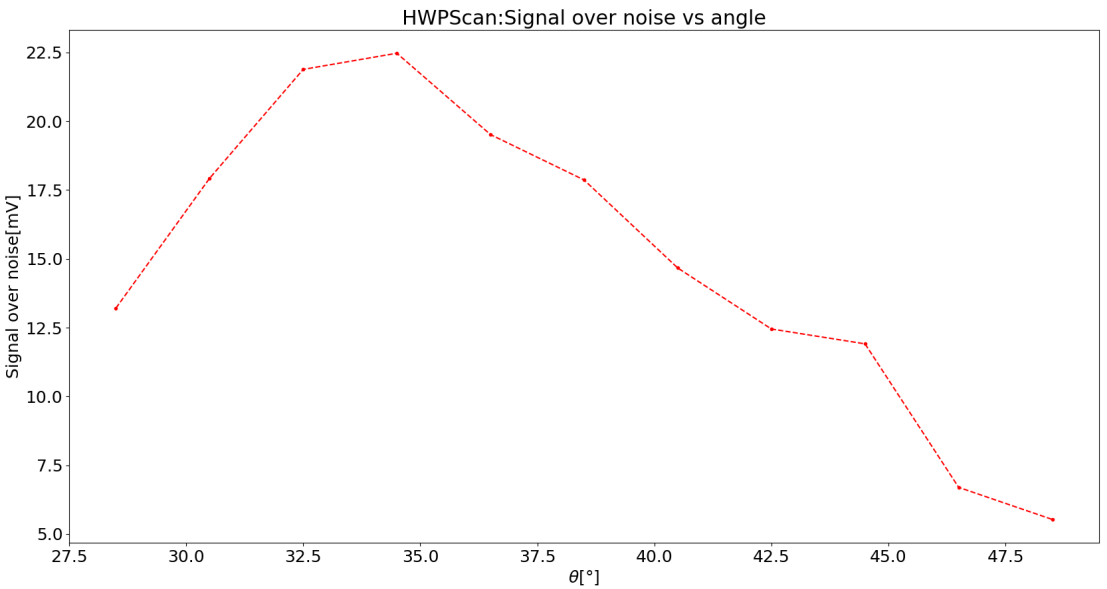
- Data Plot
- baseline
- Fit function for peaks

Angle analysis to get best value

- Sinusoidal Fit between angles and amplitudes
- Plot Signal over noise vs angle
- Choosing best angles both for HWP and QWP

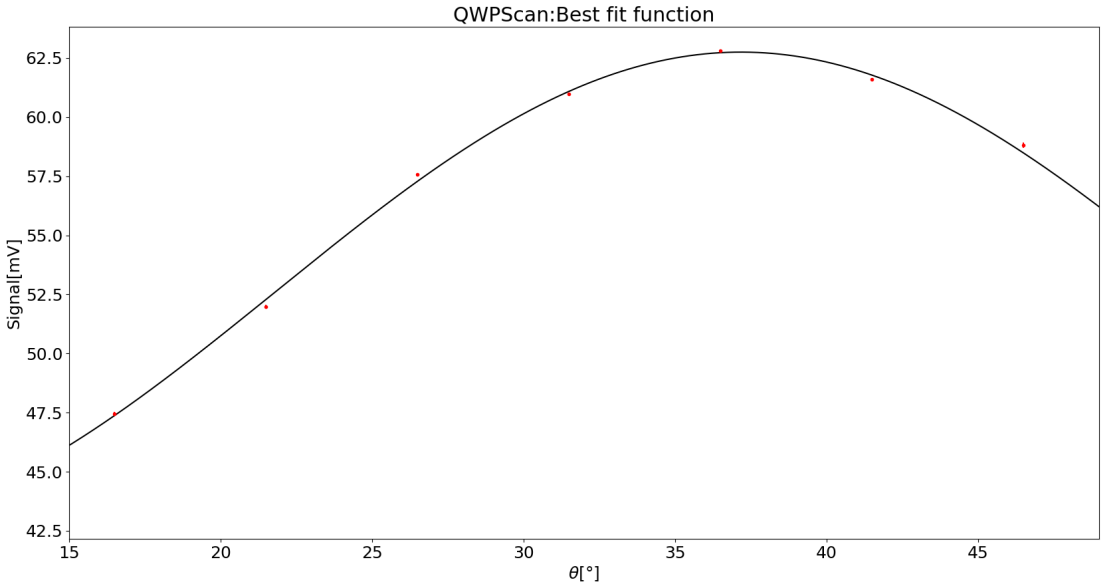
HWP:Angles vs signal Plots and Fits

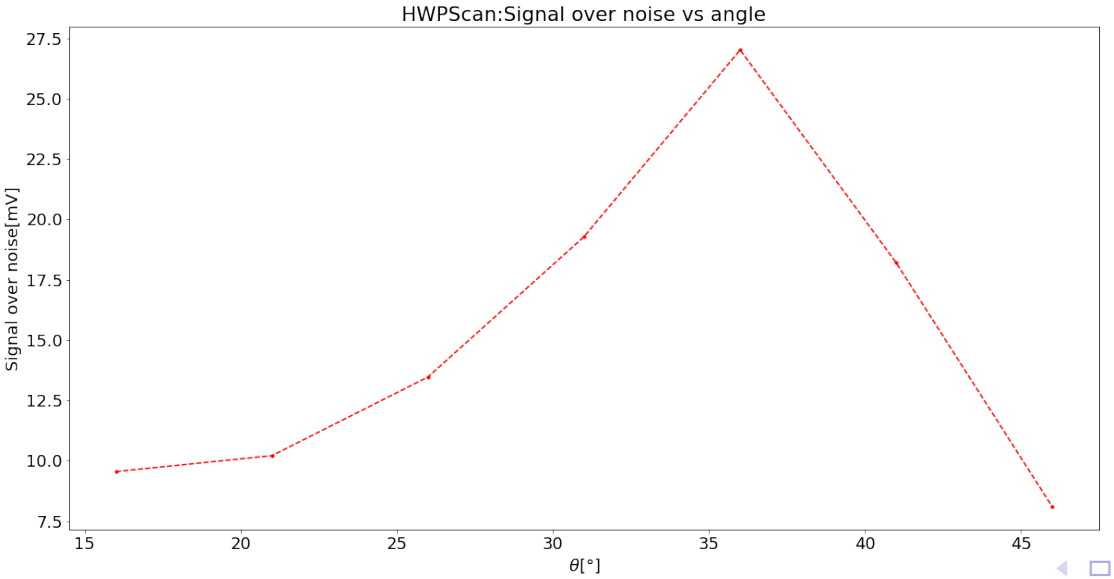




- Starting from the results of mezzanine analysis
- Analysis around the peak
- Best angle choosen: 31.5°

QWP:Angles vs signal Plots and Fits





- Starting from the results of mezzanine analysis
- Analysis around the peak
- Best angle chosen: 36.5°

A long acquisition: Looking for Eddy currents

Collected about 30k wave forms and perform an average over Data

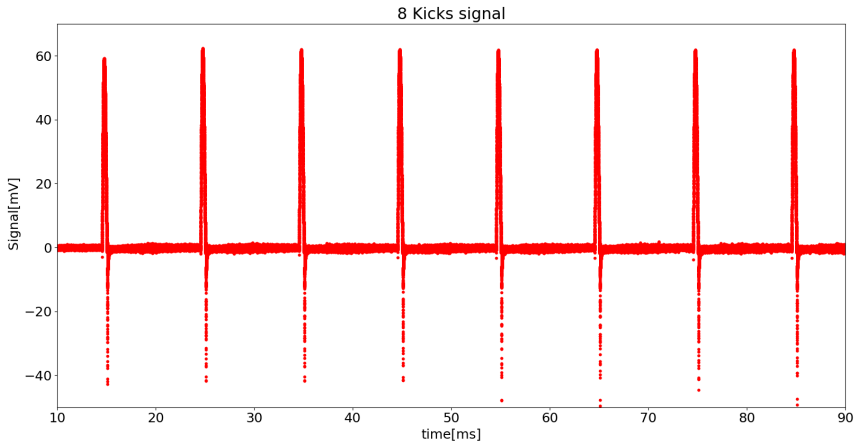


Figure: 8 Kicks:signal[mV] vs angle[°]

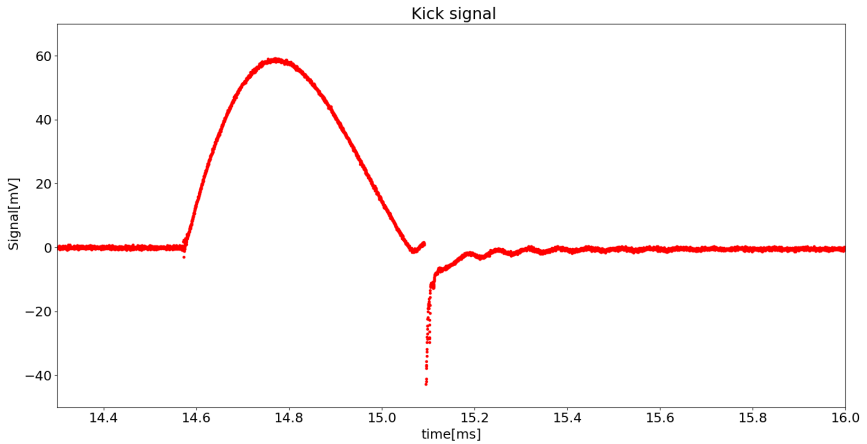


Figure: Focus on the first kick

We are able to see Blumlein rise and fall

We saw a new detail

Zooming on the end of the fall...

Eddy currents

Got eddy currents!

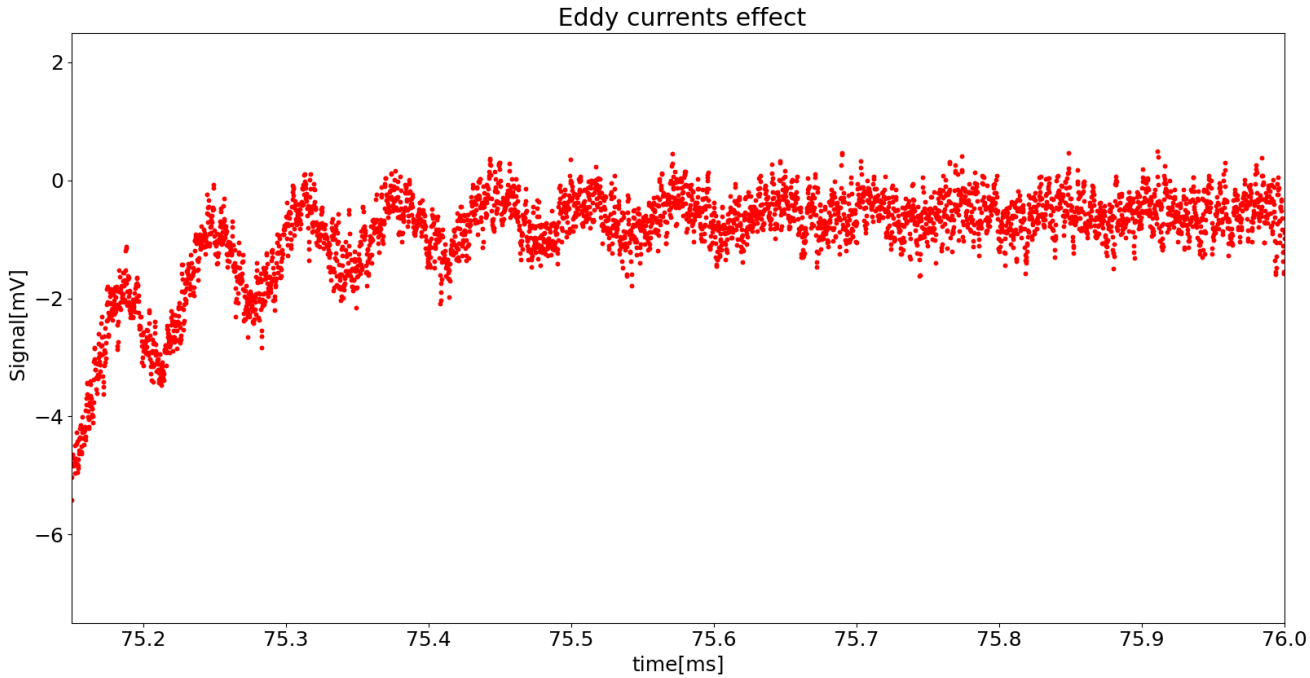


Figure: Eddy Currents effect at the end of the falling

Magnet on and final steps

- **Repeat same steps as magnetic field off framework**
- **Study calibration between angles and magnetic field ramp up**

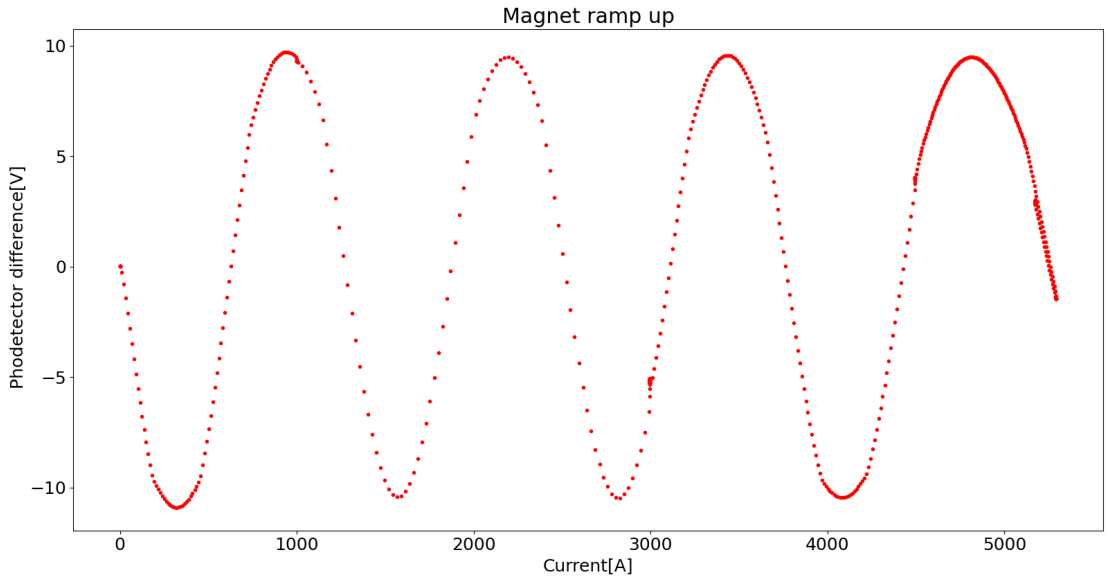


Figure: Signal[V] vs current[A]

- **This is another way to see Faraday effect!**

Description

- Current increases with time
- Magnetic field increases with current
- Light polarization inside crystal changes
- Relationship between Magnetic field (I) and angle

Tasks for the future

Preliminary steps

- HWP scan
- QWP scan

Data analysis

- Studying noise contribute
- Performing long acquisition
- Analyzing eddy currents contribute

THANKS FOR YOUR ATTENTION!