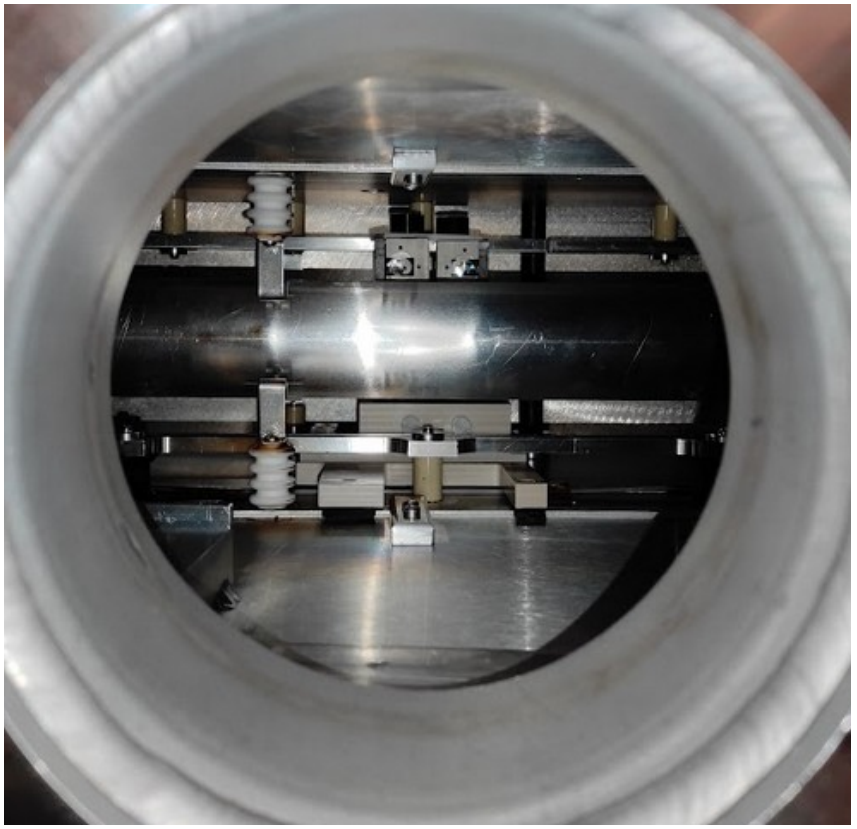


INFN Magnetometer

Riunione referee g-2
27 Jun 2024

P. Girotti
on behalf of the g-2 Italian collaboration

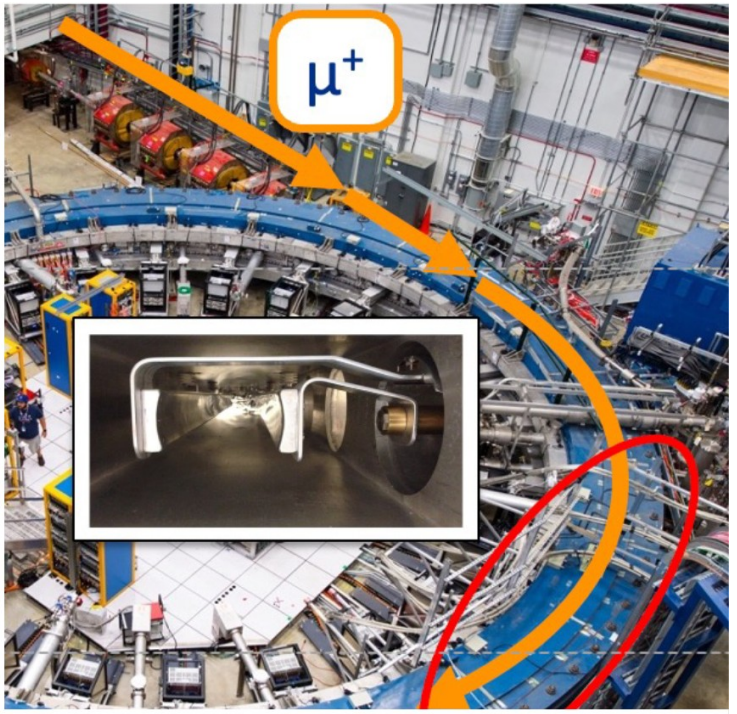
Overview

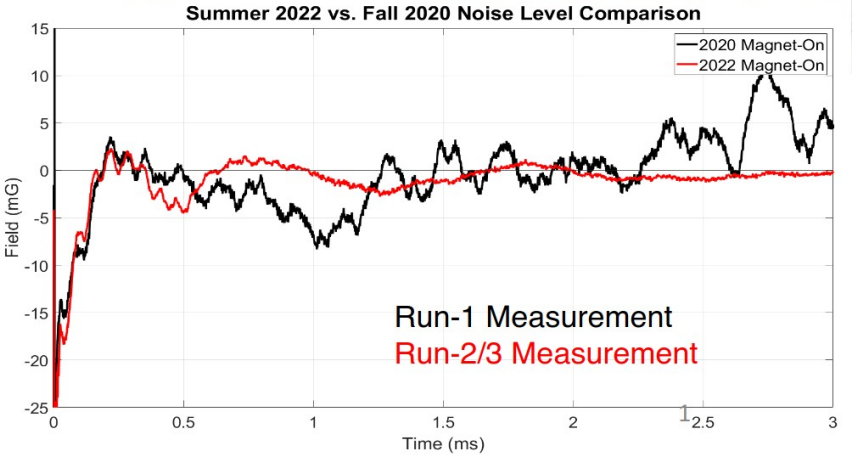
- Fast Kicker magnets move the beam to center right after injection (kicker pulses ~250 Gauss)
- Kicker creates eddy currents in the nearby metal during the pulses ⇒ **transient magnetic field**
  (mGauss effect to be accounted in the B field measurement)

$$\frac{\omega_a}{\omega_p} = \frac{\omega_a^m}{\omega_p^m} \frac{1 + C_e + C_p + C_{pa} + C_{dd} + C_{ml}}{1 + B_k + B_q}$$

Measured Values

Systematics	Description	Run-1 [ppb]	Run-2/3 [ppb]
B_q	Vibrations caused by Quadrupole pulsing. Better mapping in azimuth in Run-2/3	92	20
B_k	Kicker-induced Eddy currents. Improved magnetometer measurements thanks to more stable setup that greatly reduced vibrations	37	13
Trolley calibration, tracking, muon weighting	Improvements in analysis and more trolley measurements. Stabilized temperature in the hall to reduce diurnal variations in the field	56	46

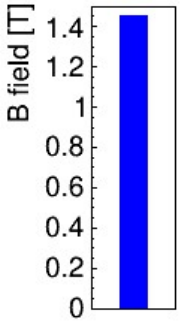


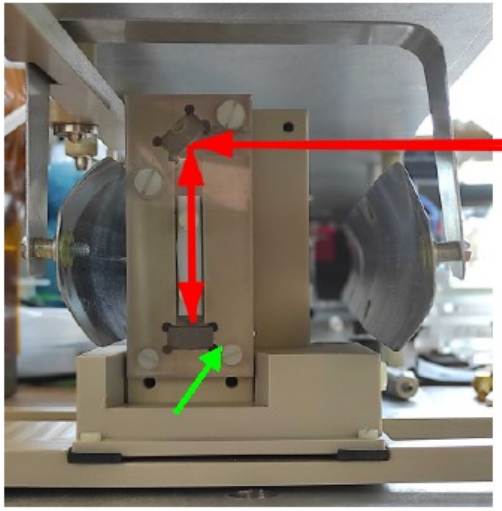


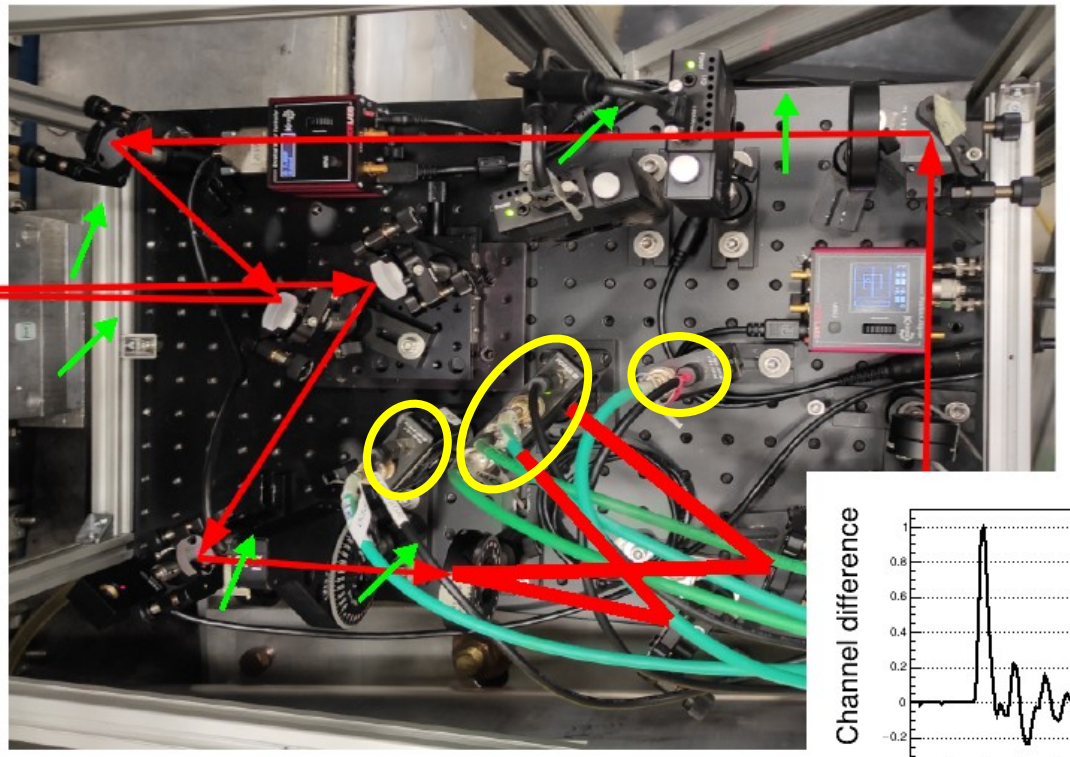
INFN Magnetometer

- Primary goal: measure ~**10^{-7} T** transients with ~**µs** sampling
- Secondary goal: measure ~**10^{-2} T** kick shape with ~**ns** sampling

Two periscopes with
32 mm TGG crystals
at magic radius and +17.5 mm

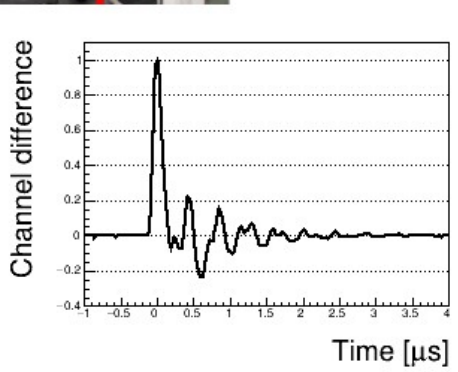






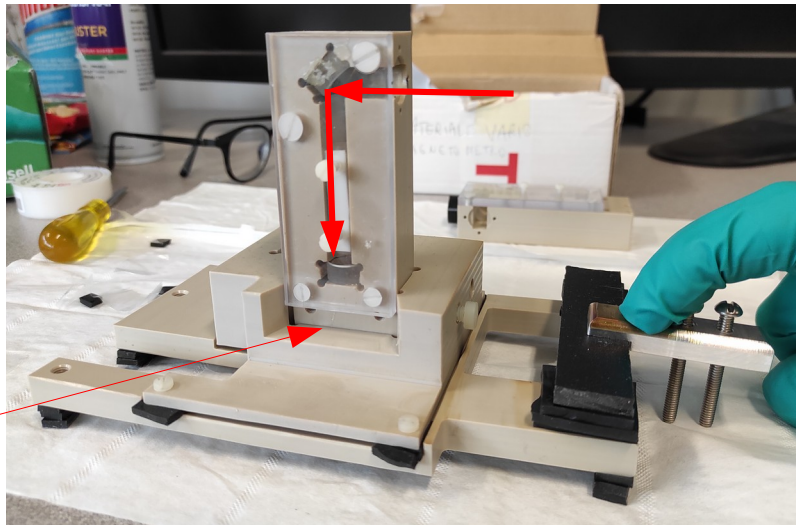
HWPin: 22.5°

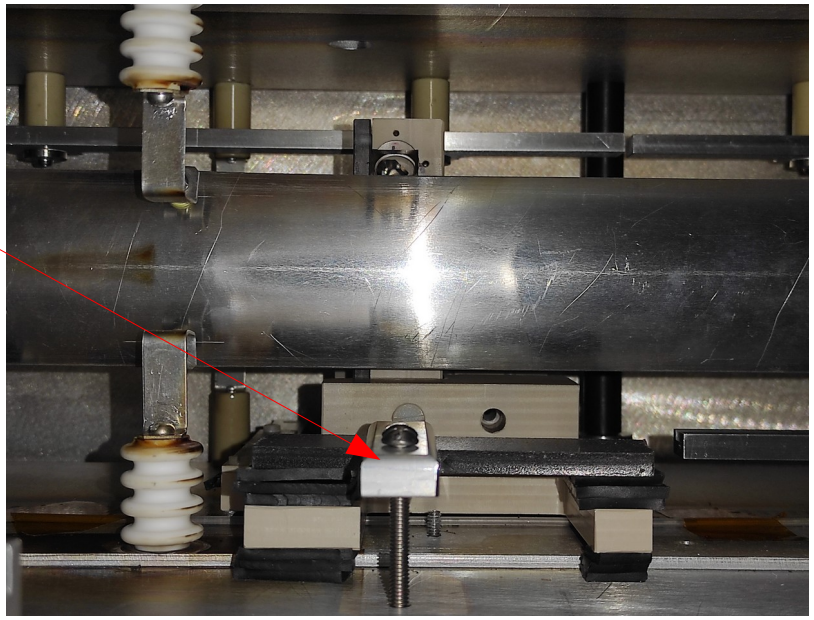
HWPout: 33.2°

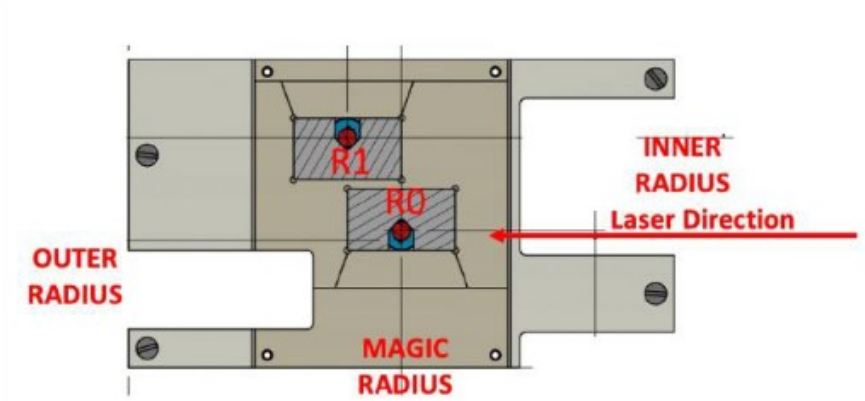


Periscopes

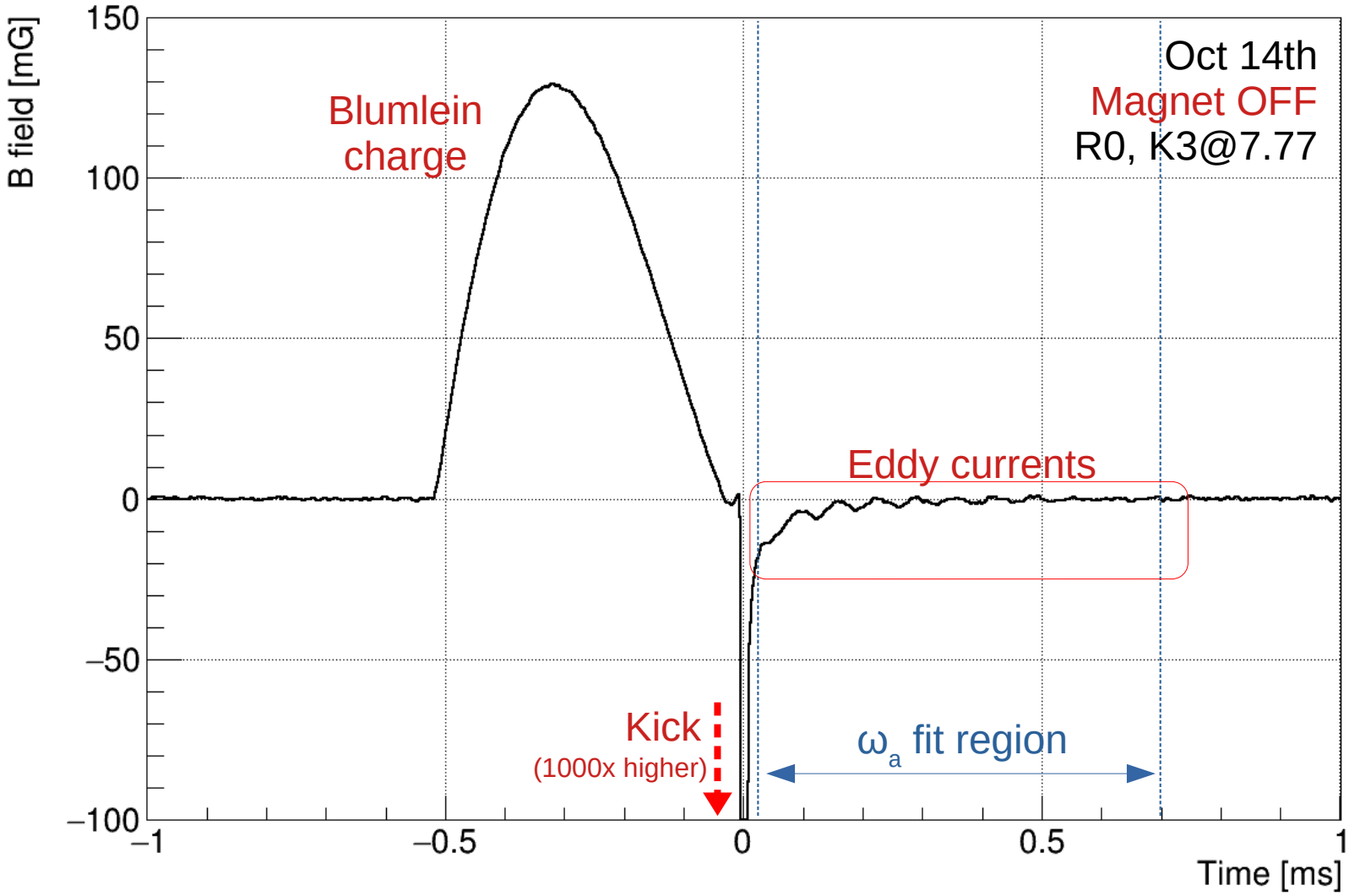
- Two periscopes at two radii
  - R0 (magic radius)
  - R1 = R0 + 17.5 mm
- New bridge design wrt 2022 with added rigidity
- Kicker cage clamp repurposed to hold the bridge since Oct 17





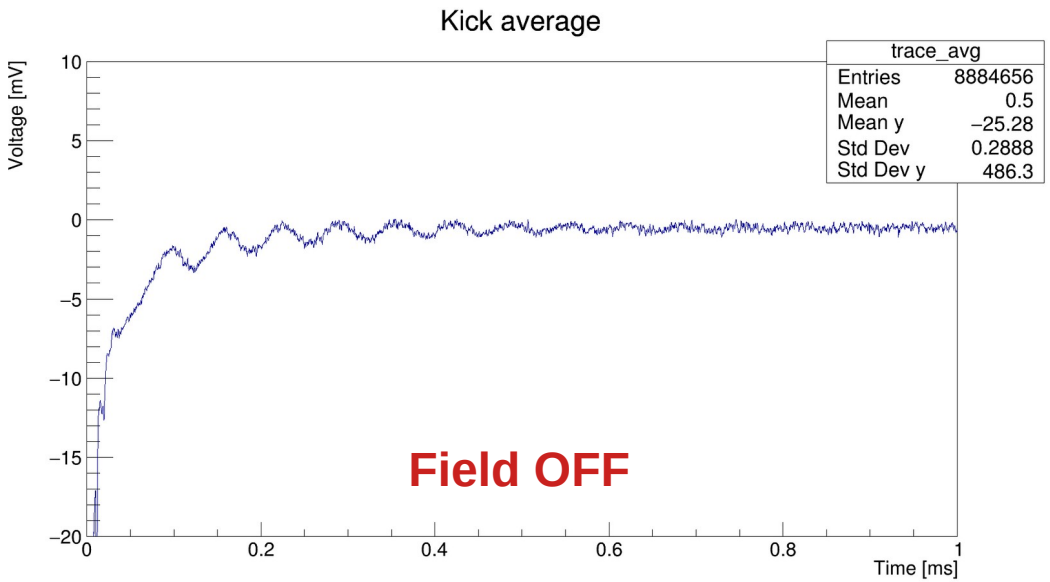


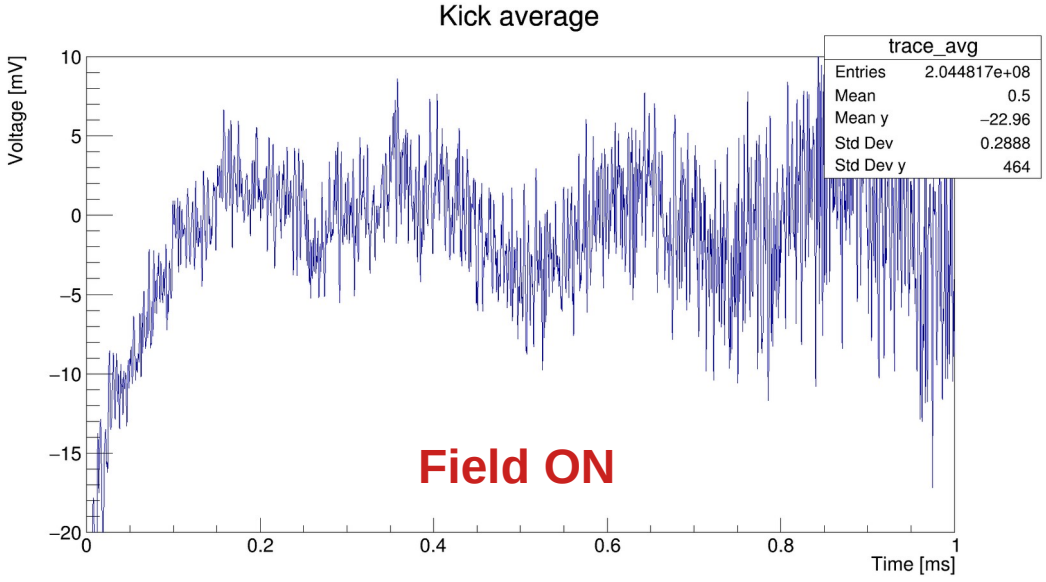
Transient anatomy



2023/2024 goals

- Eddy currents transients measured in 2022 during summer shutdown after Run-5
- High oscillation noise observed in the data with magnet on
- 2023/24 campaign goals:
  - Determine (and remove) this noise
  - Measure kick and transient at different radii





Post Run-6 campaigns

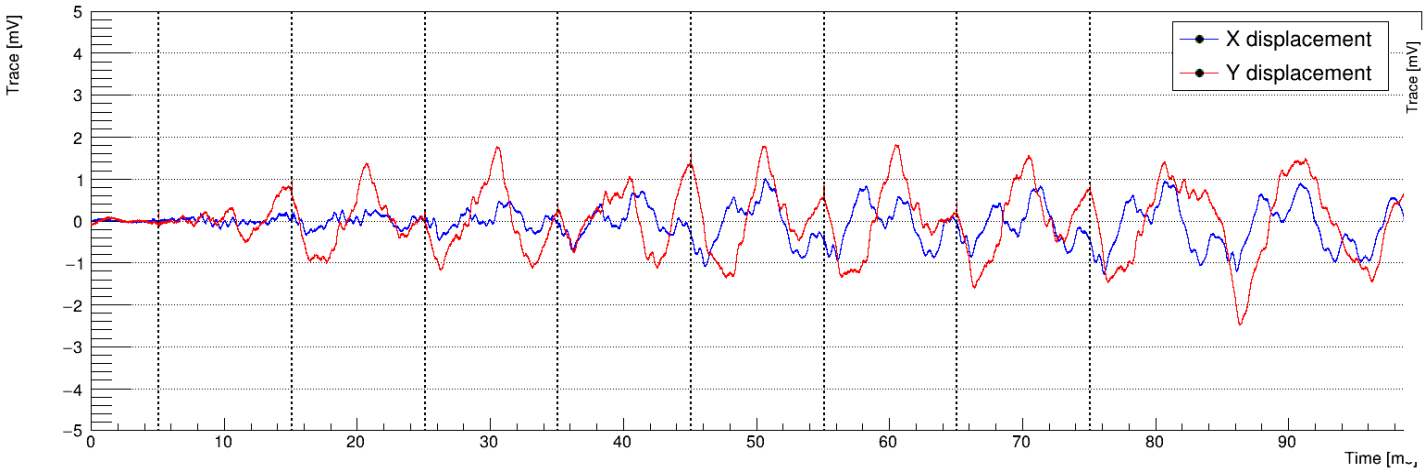
August 2023:
- Commissioning of new periscopes design
- First kick measurements at R0 and R1 with no field

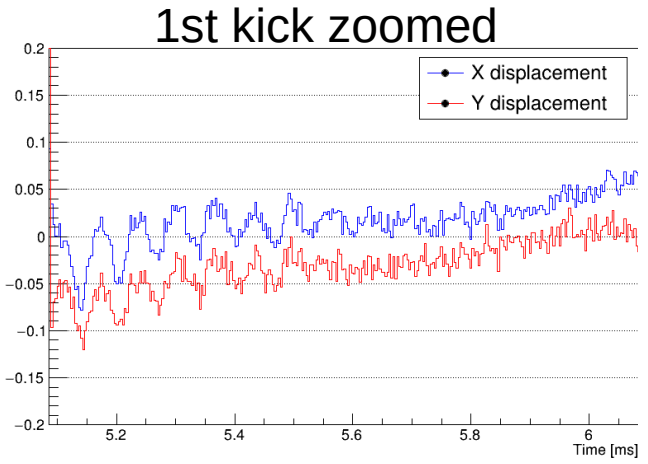
October 2023:
- **550+ hours** of acquisition with/without field
- Many configurations tested here:
  - Free-standing and clamped periscope bridge
  - Various magnet and kicker setpoints
  - Fast kick shape measurements
  - Vibration measurements (quadrant photodiode)

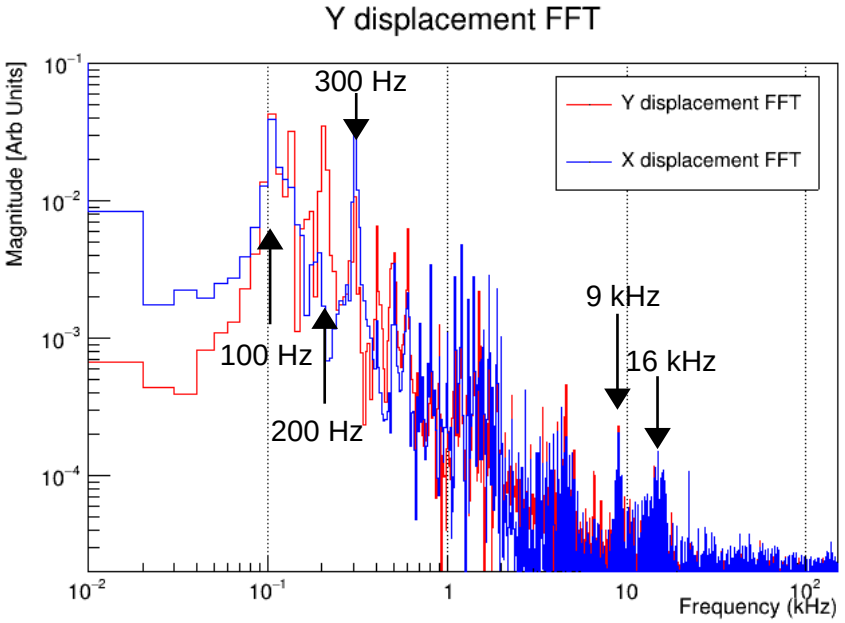
December 2023:
- HWPout symmetry test
- Full 16-kicks train measurement

January 2024:
- **230+ hours** of eddy currents measurements
- Measurement at various magnet setpoints
- Vibration suppression studies with Quarter WavePlate
- Best campaign for transient determination at R0

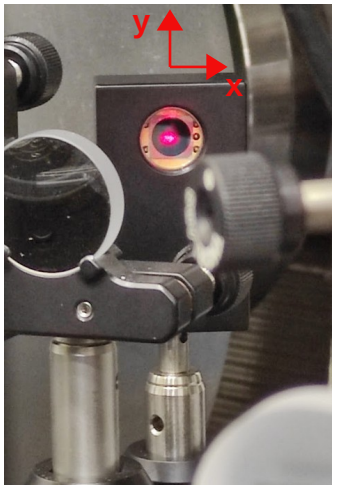
Vibration analysis



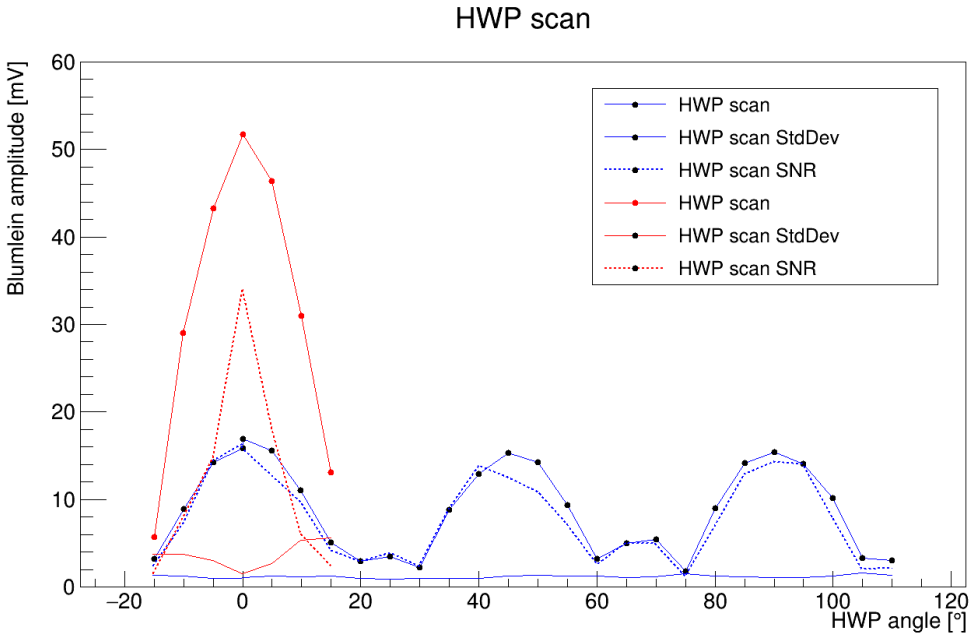




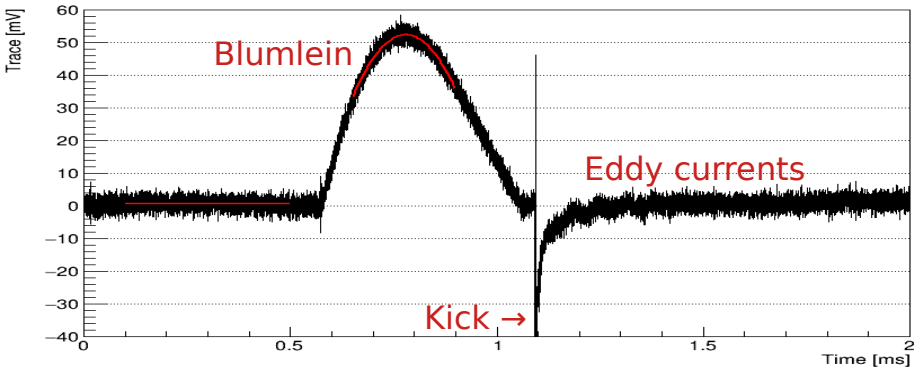
- Quadrant photodiode measures x,y oscillations of the laser beam after exiting the periscopes
- Low frequencies (100, 200, 300 Hz) evident and correlated with kicks
- 17 kHz visible too in the first 1 ms after the first kick



Data calibration

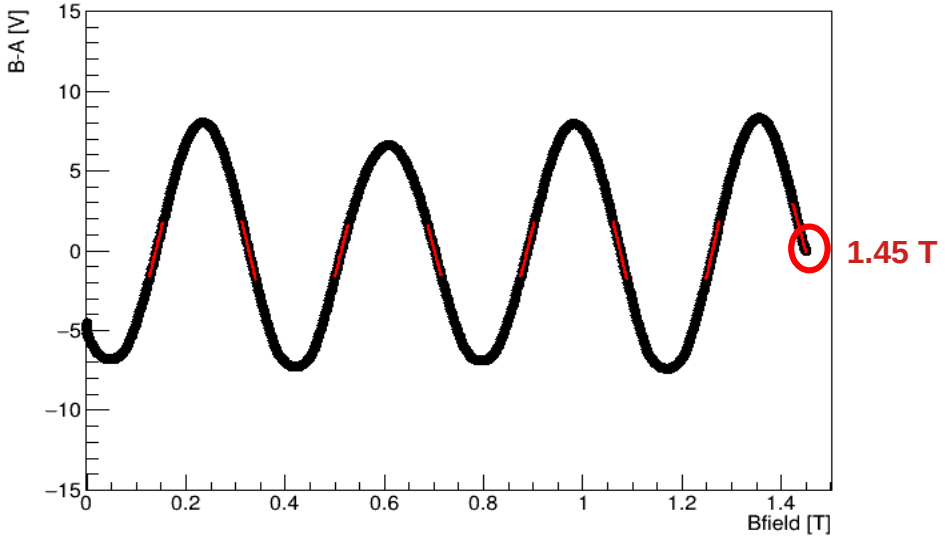


Half-wave plates scanned to find maximum sensitivity polarization angle
Blumlein peak amplitude used as metric

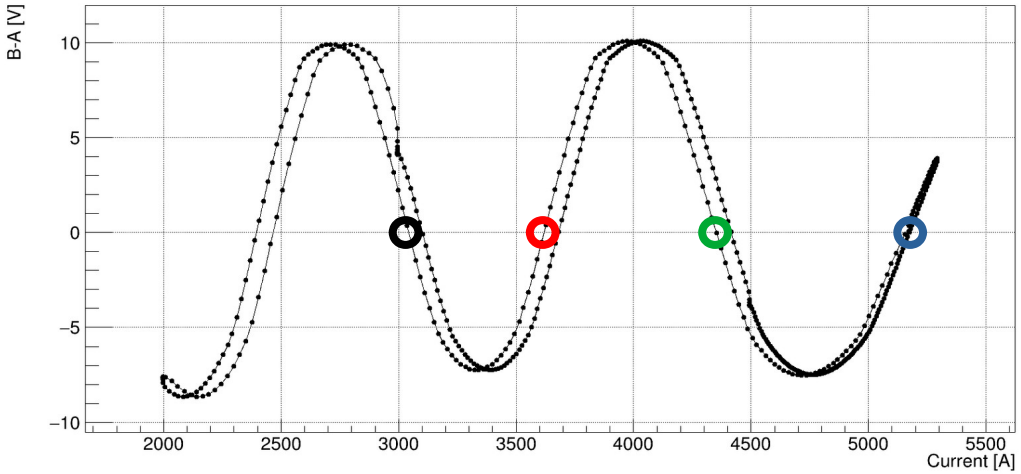


Magnet ramp-up and ramp-downs measured with fixed waveplates to measure absolute calibration

mV → mG

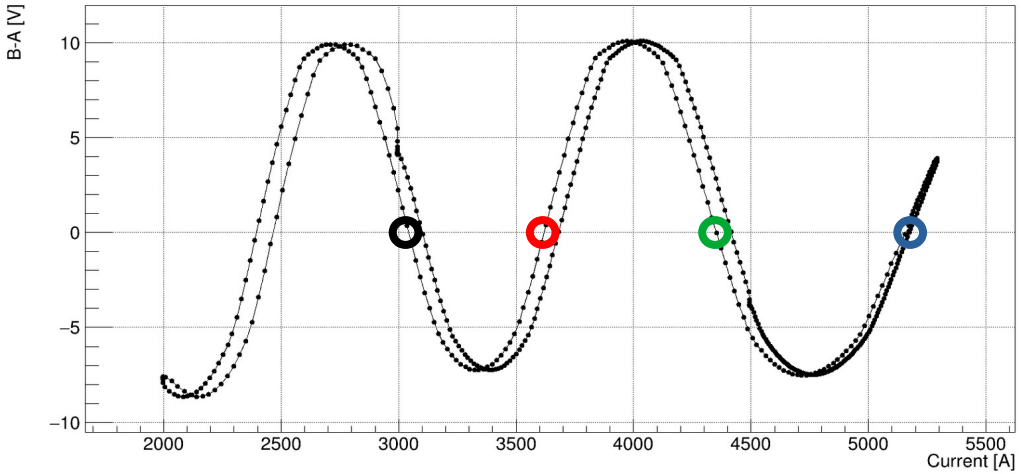


Magnet scan



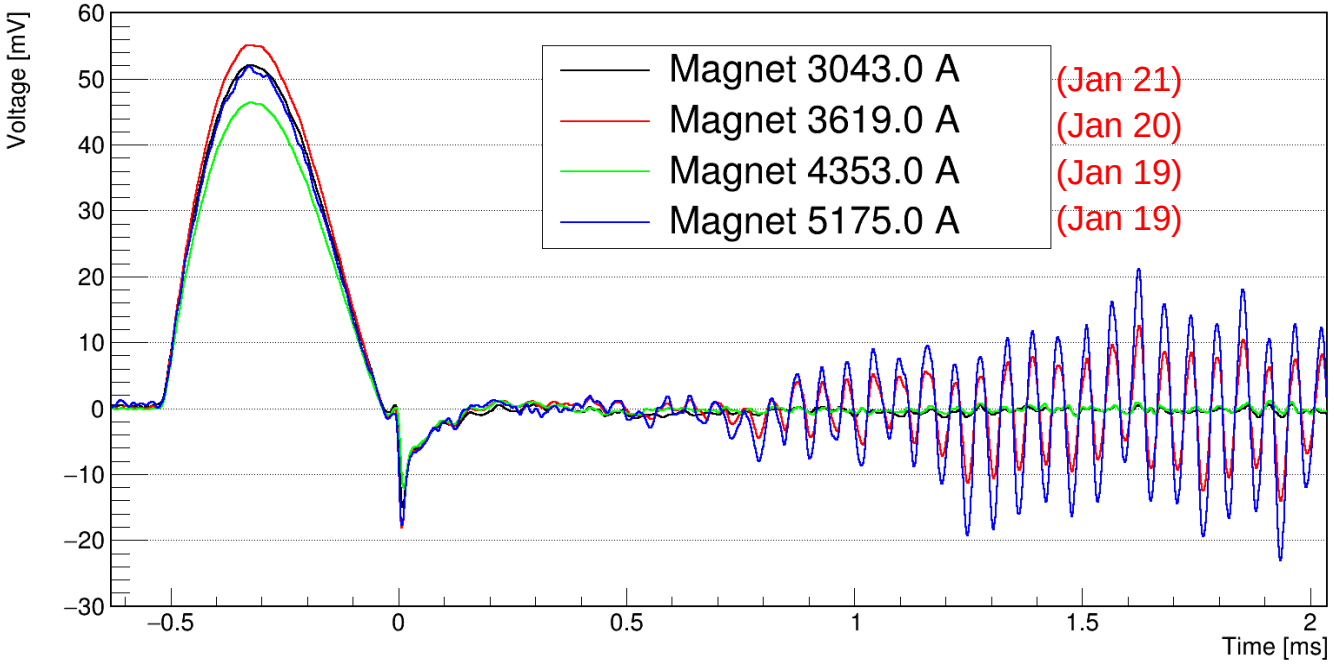
- Magnet strength values corresponding to the nodes of descending ramp measurements
- [3043, 3619, 4353, 5173] A
- Faraday rotation angles: [2.5π, 3π, 3.5π, 4π]

Magnet scan



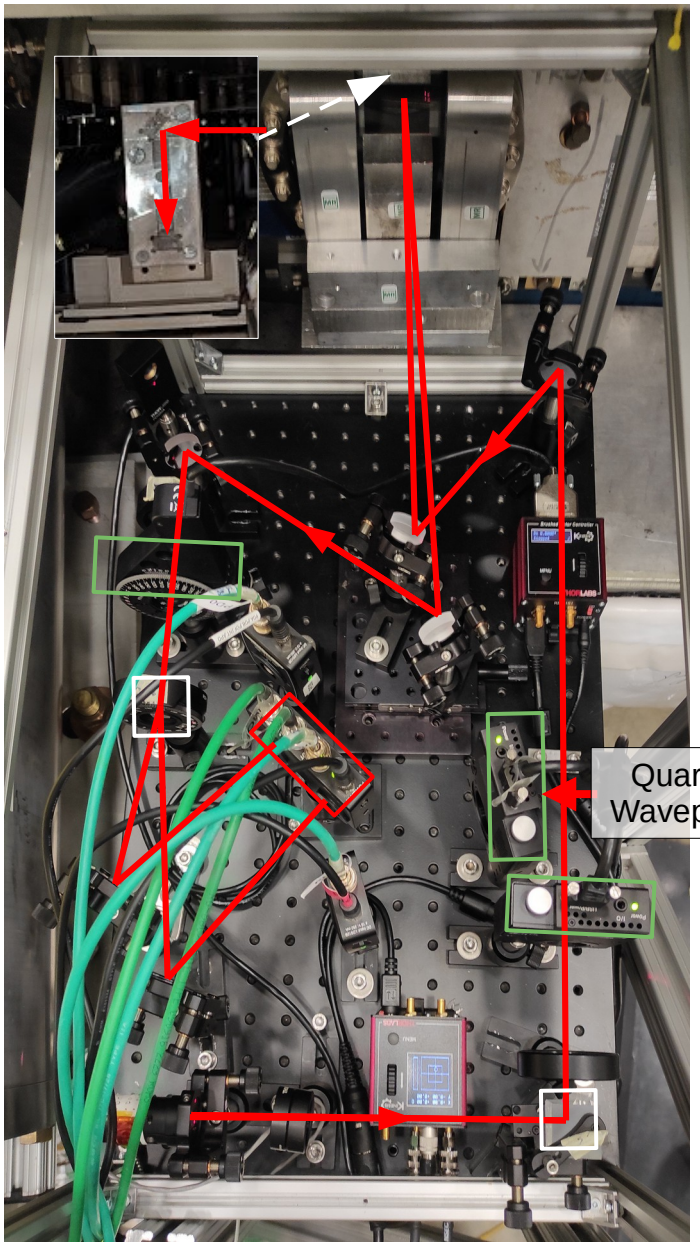
- Magnet strength values corresponding to the nodes of descending ramp measurements
- [3043, 3619, 4353, 5173] A
- Faraday rotation angles: [2.5π, 3π, 3.5π, 4π]

- Vibrations suppressed for the nodes with negative slope! (2.5π, 3.5π)
- Physical reason not understood yet



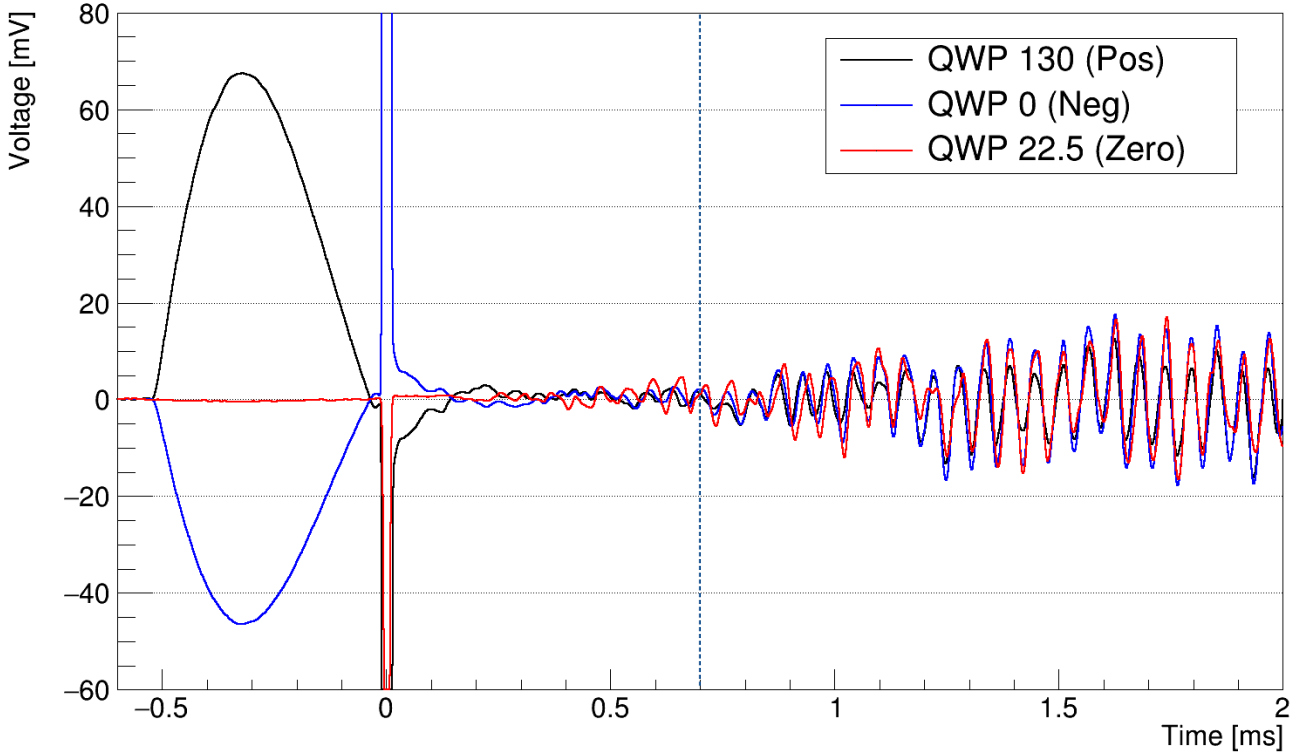
Quarter WavePlate

- Quarter WavePlate inserted on Jan 23rd
  - Last 6 days of acquisition
  - 100% remote, eventually proven to be the best quality data
- 45° incident linearly polarized light becomes circularly polarized
  - No Faraday effect
- Goal is to measure effects not depending on the kicker magnetic field



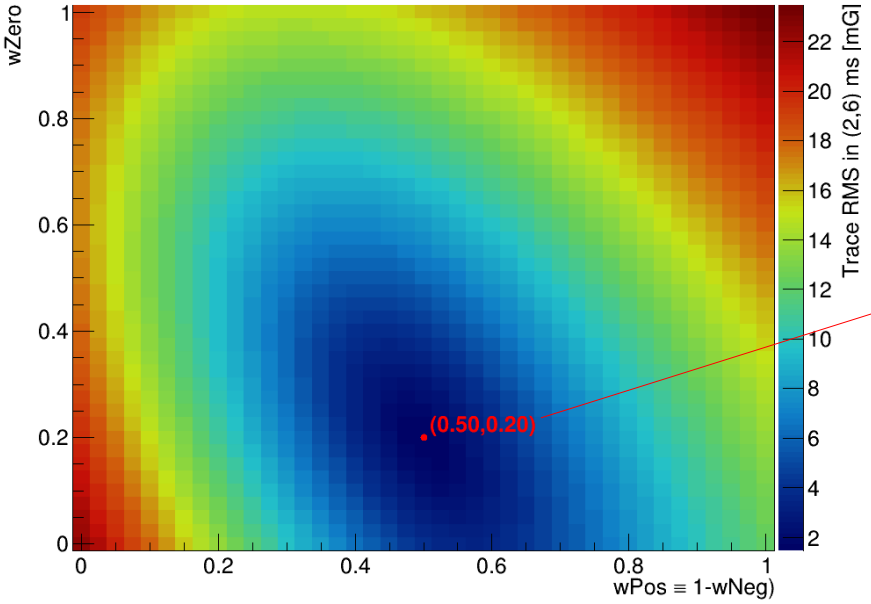
Vibration subtraction

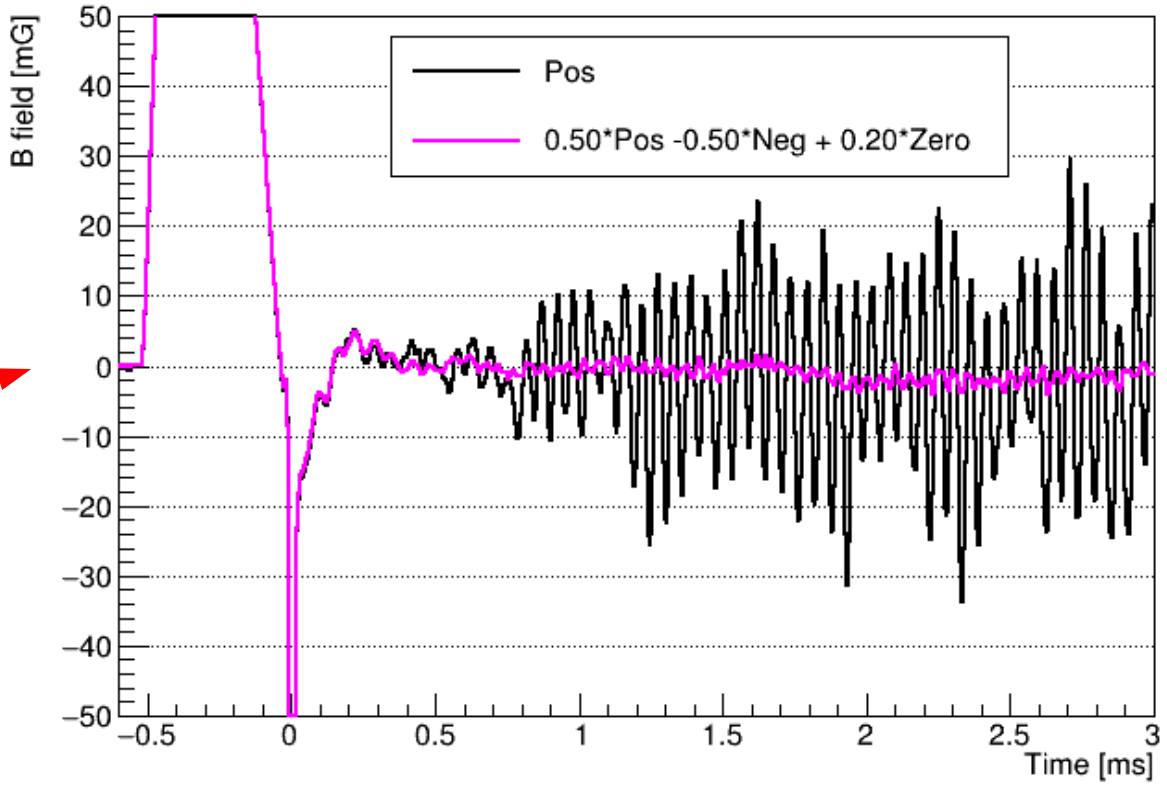
- Three significant acquisitions
- QWP 22.5°: zero blumlein and transient → oscillations are not field **transients**
- Sign, phase, amplitude of oscillation in the three cases is very similar – but not exactly equal. Can we cancel them out?



Minimization scan

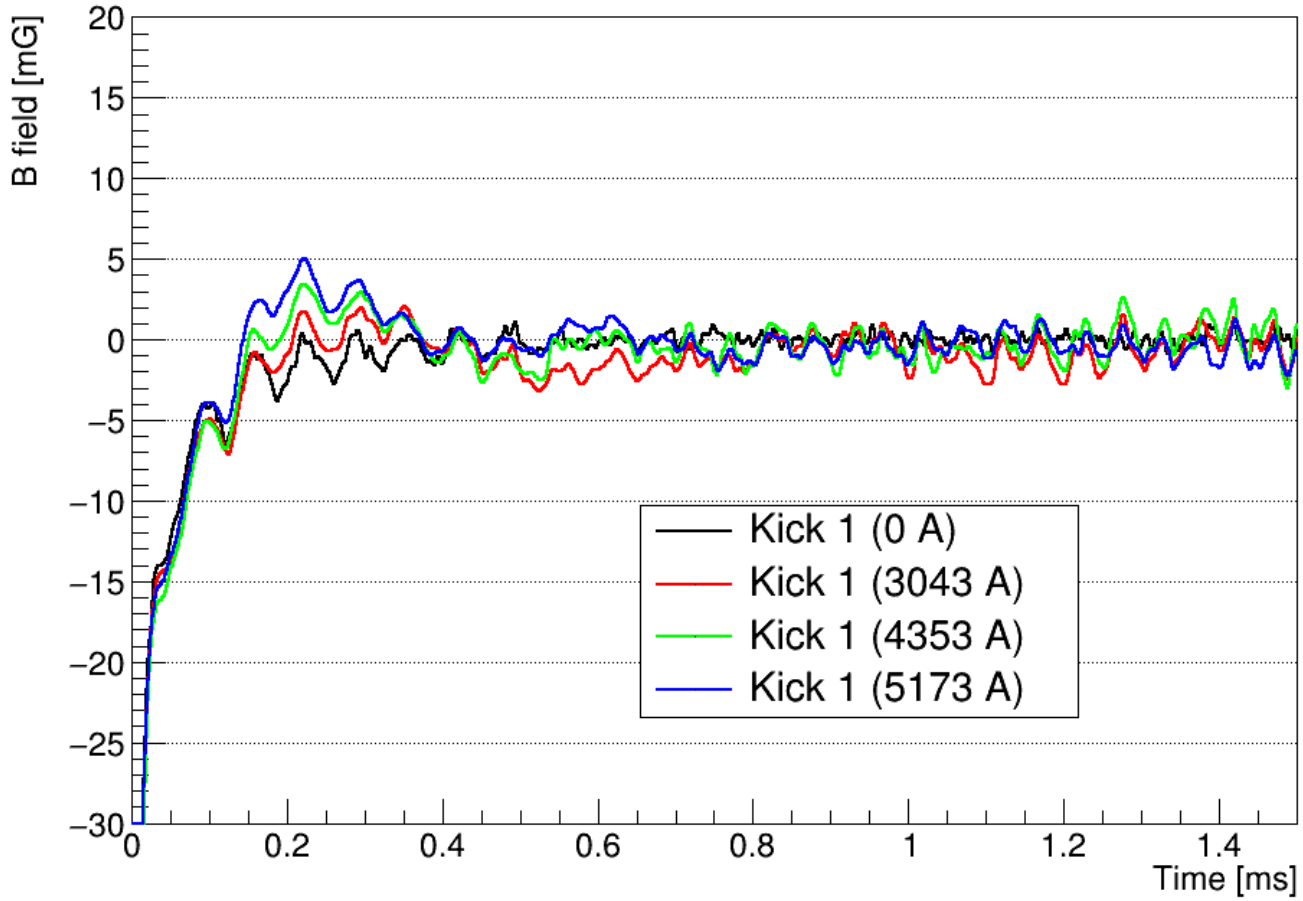
- Finding the best combination of P, N, Z with a minimization scan
- wPos*Pos + wNeg*Neg + wZero*Zero
- Vibration quantified as trace RMS in [2,6] ms range
- Success!





Magnet strength

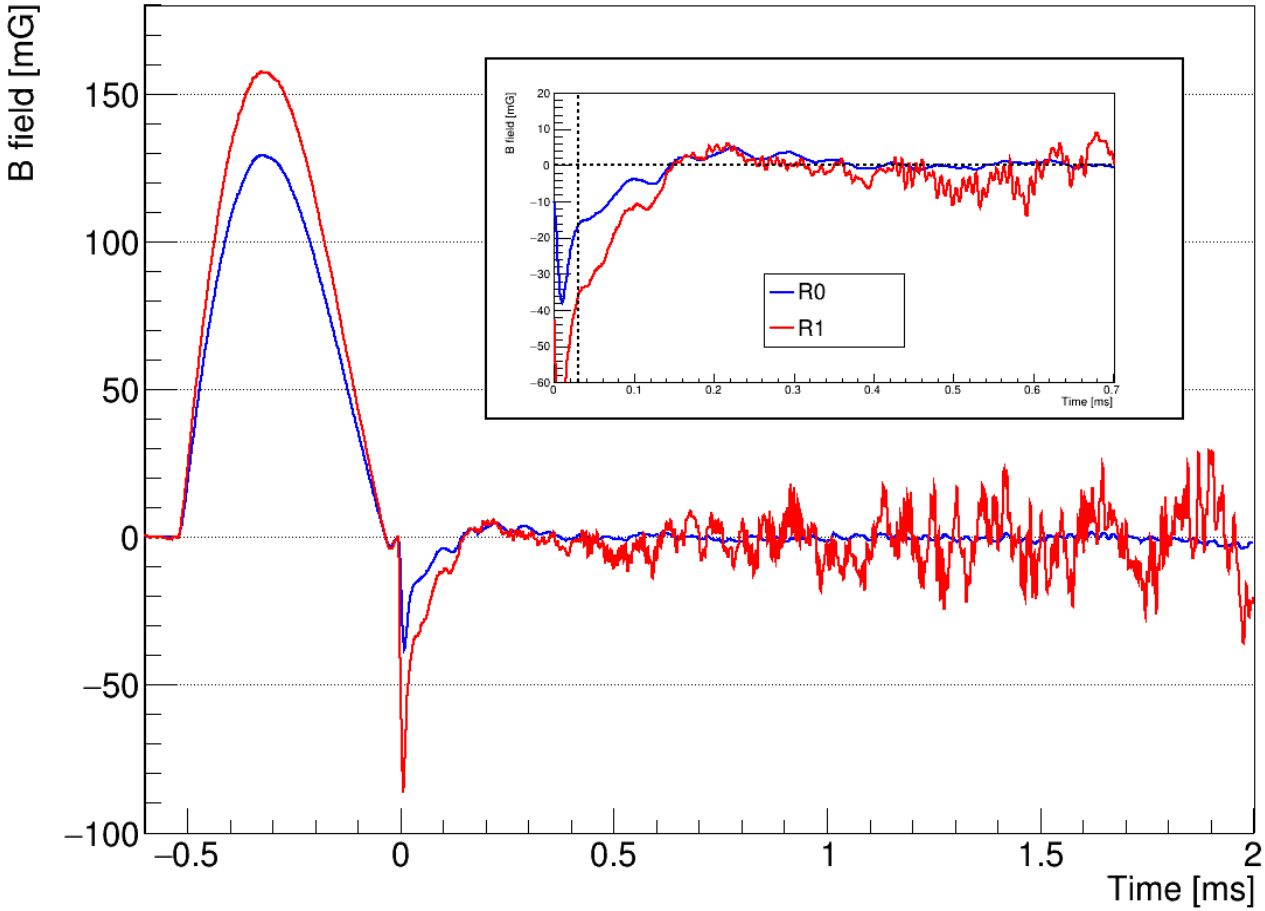
- Back to magnet strength comparison → with calibration and no vibrations
- Full current (blue) treated with vibration subtraction with QWP
- “Overshoot” at ~0.2 ms correlated with magnet current

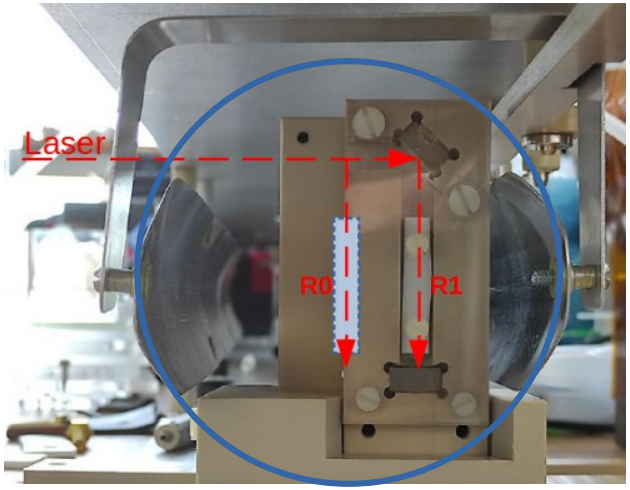


Oct 14
Jan 21
Jan 19
Jan 25-28

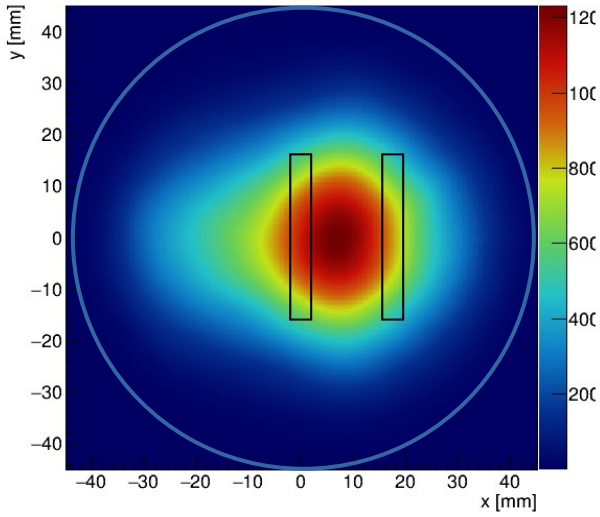
Radial dependence

- R0 is at magic radius, R1 is +17.5 mm
- Blumlein amplitude higher at R1 → +22%
- Eddy currents transient higher at R1 → ~2x @30 μs



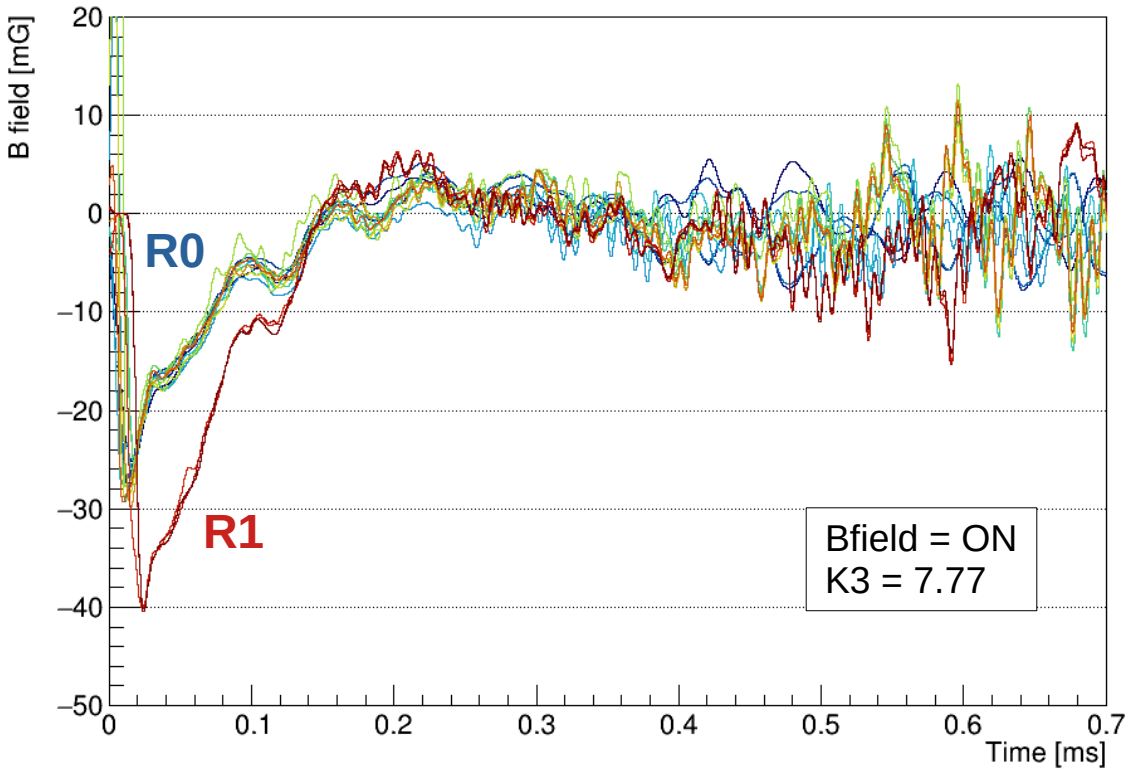


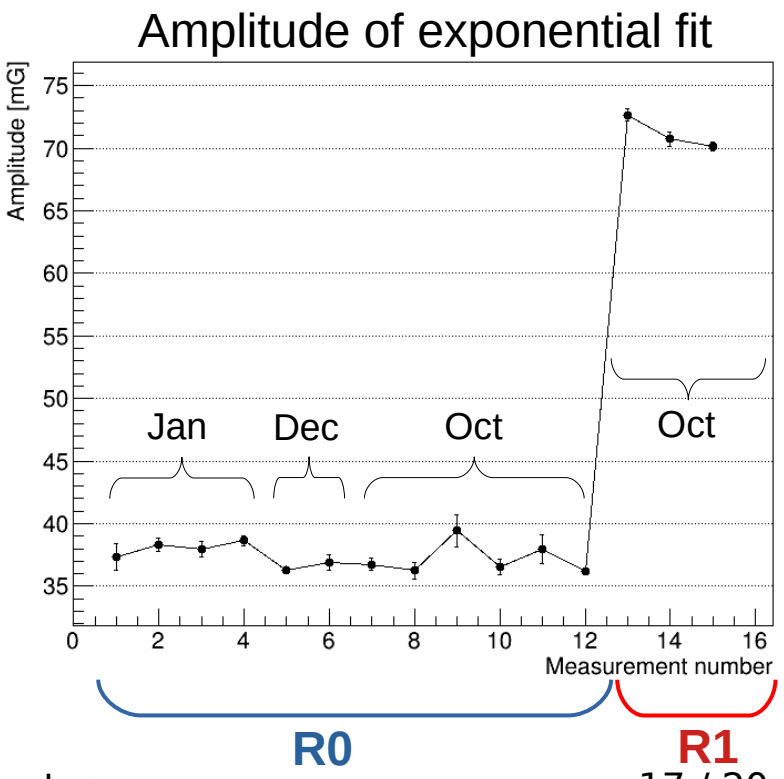
Beam distribution Run3b



System reliability

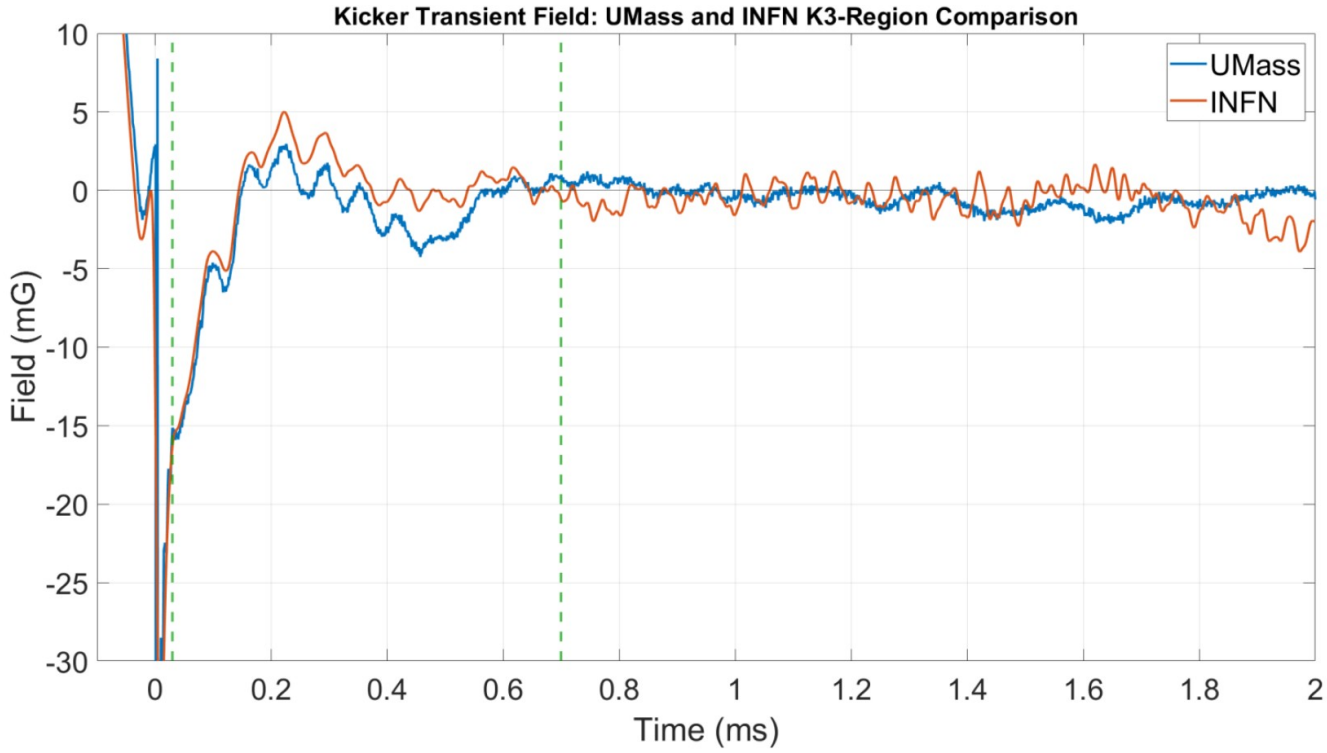
- Blumlein used for relative calibration
- R0 measurements spanning Oct, Dec, and Jan campaigns
- Very consistent results – especially in the [0,300] μs region





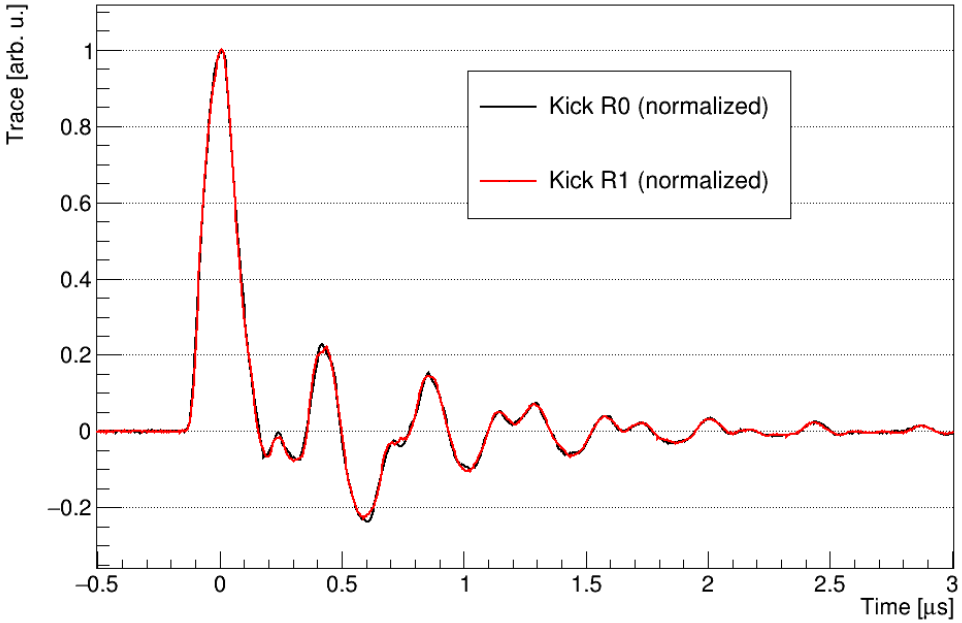
Comparison with UMass fiber magnetometer

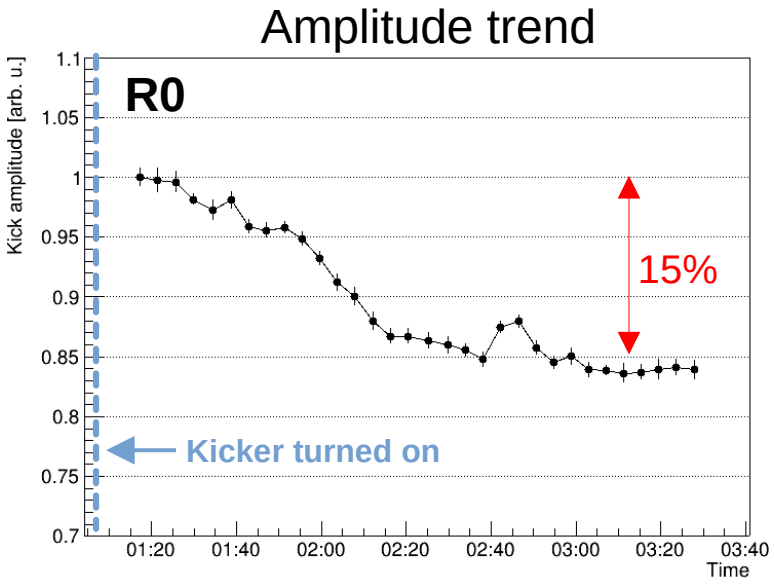
- First comparison during April collaboration meeting
- Measurement at the same kicker 3 region
- Good agreement at nominal radius



Kick shape

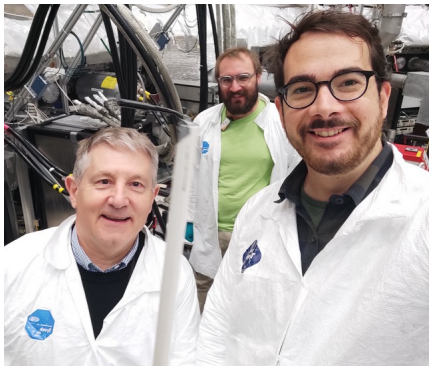
- R0 and R1 with magnet ON measured in Oct 8-9
- Measurement configuration didn’t allow for laser stability normalization
- This limits absolute calibration precision to ~15%
- Kick **shape** is very consistent between R0 & R1
- Data now used in the gm2ringsim simulation





Conclusions

- Overall, very successful 2023/2024 magnetometer campaigns with a lot of good quality data
- Many periscope design improvements but didn’t remove oscillations
- Magnet scan + QWP studies have shed light on this puzzle → successful vibration cancellation
- Both kick and transient data show higher effects at outer radius (+22% kick, +90% transient at +17.5 mm)
- Good agreement with Umass team, although radial dependence is under investigation
- Analysis toward completion, currently doing:
  - Calculation of Bk term
  - Systematic uncertainties determination
  - Writing technical paper



Thank you for your attention!