PSI Center for Neutron and Muon Sciences

ETH zürich

Kicker System for Muon Storage Tests in 2025

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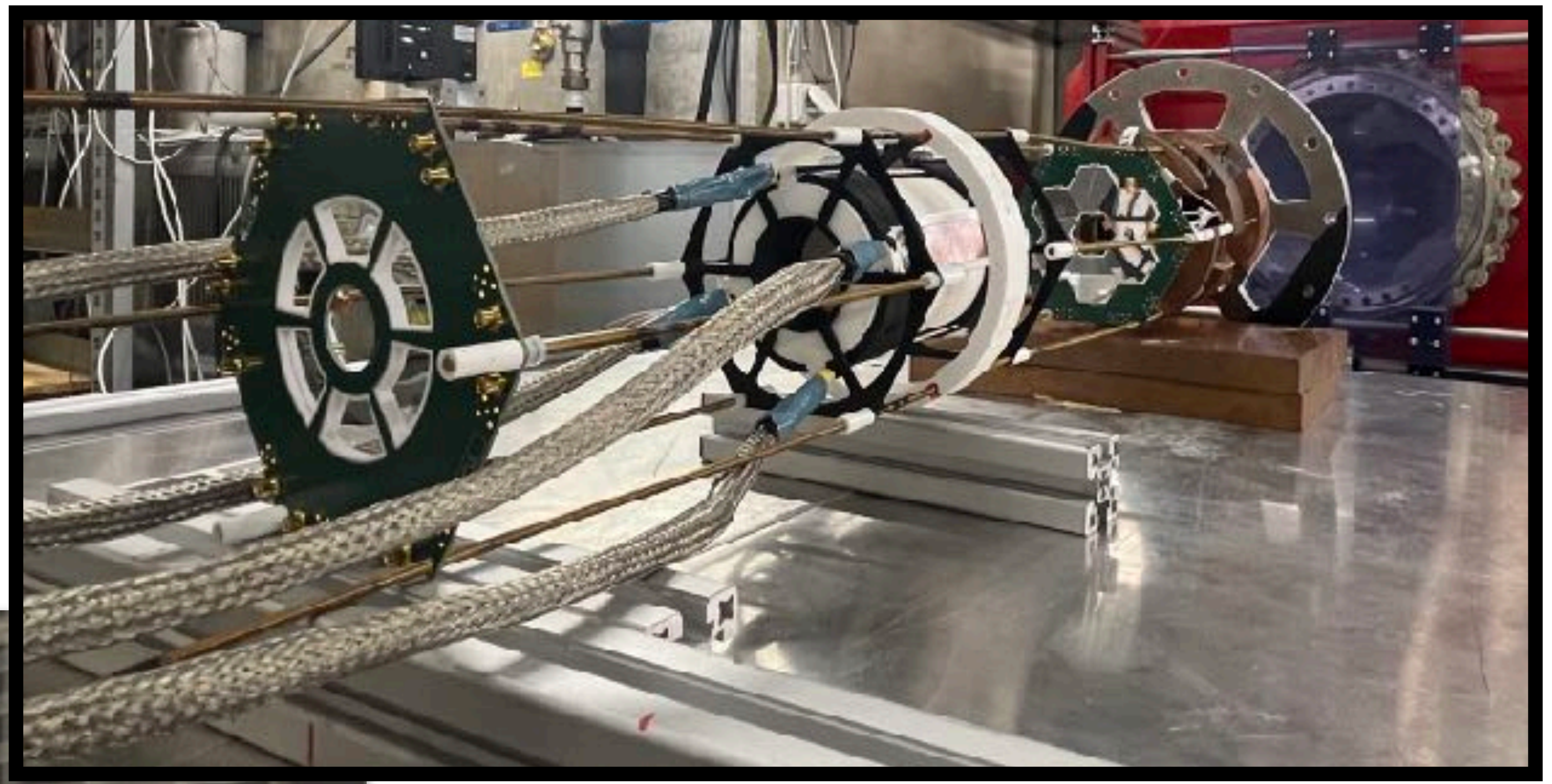
BVR56 - muEDM Review
Presented on behalf of the muEDM Collaboration

Kicker Coil

A pulsed radial magnetic field of ~1mT will be generated by the kicker coil over the storage region to trap muons inside the weakly focusing field.
As their transit time is ~100ns, the inductance of the coil must be minimised to permit the necessary high currents >100A.



Sept. beamtime established that a grounded braid around each of the coaxial cables significantly shields the detectors from the kicker pulse.

Support structure prototype implemented for Sept. beamtime, with work ongoing to optimise for minimum thickness.

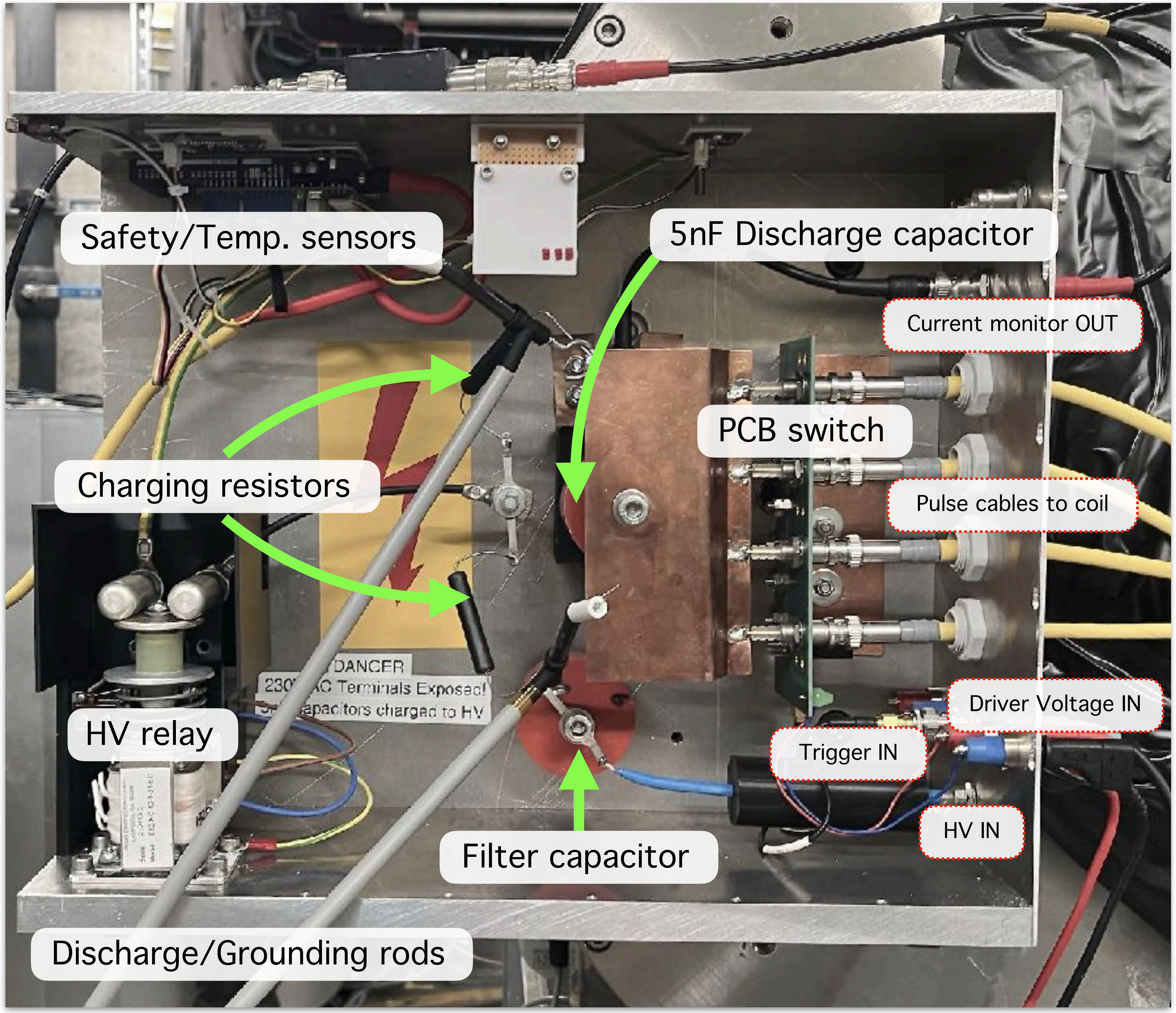
Central and outer conductors of the coaxial cables are both used to transmit current.

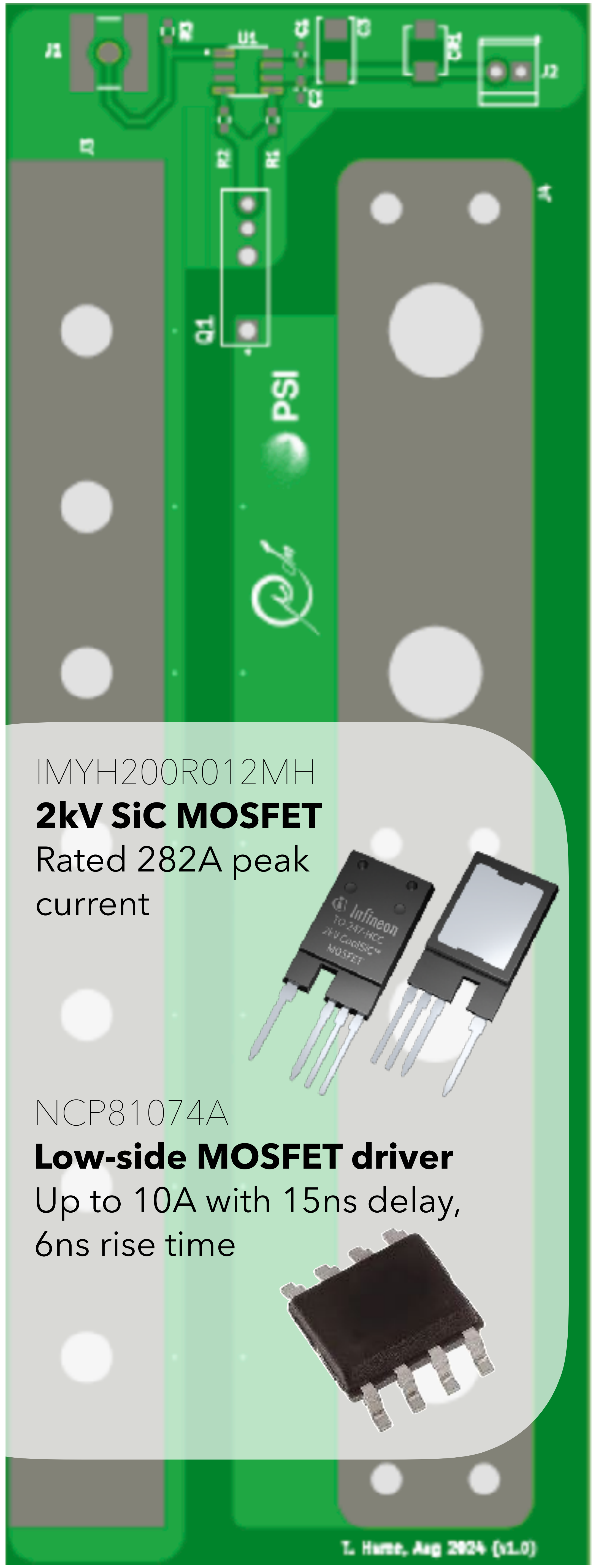
Pulse Generator Design (Sept. 2024)

A pulse generator was developed at PSI for the Sept. 2024 testbeam.

The pulse was generated by discharge of a 5nF capacitor over the kicker coil with a low-side switch.

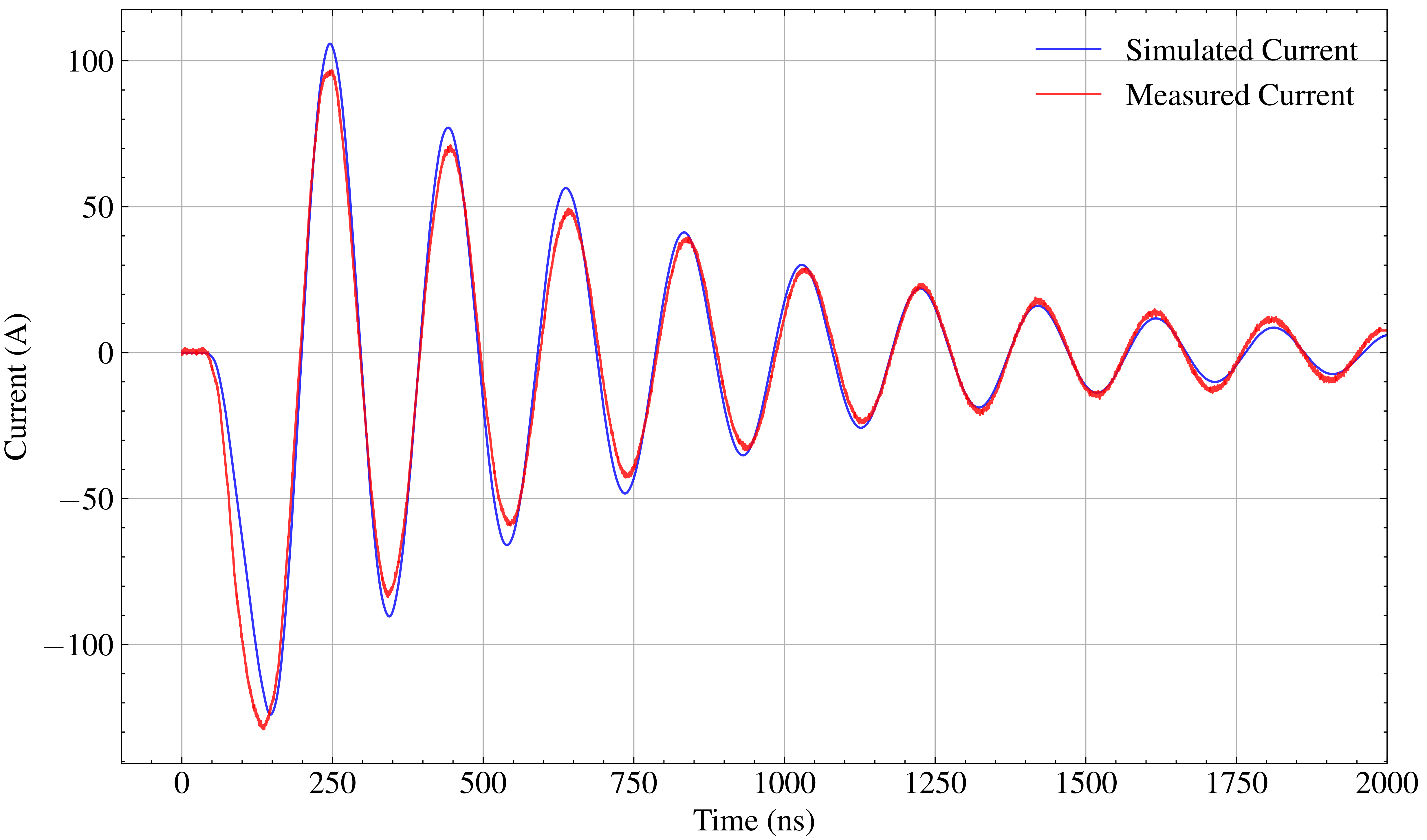
- Operating voltage 1.5kV
- Peak current 32A/quadrant
- Osc. frequency 6MHz
- Osc. damped τ ~ 500ns



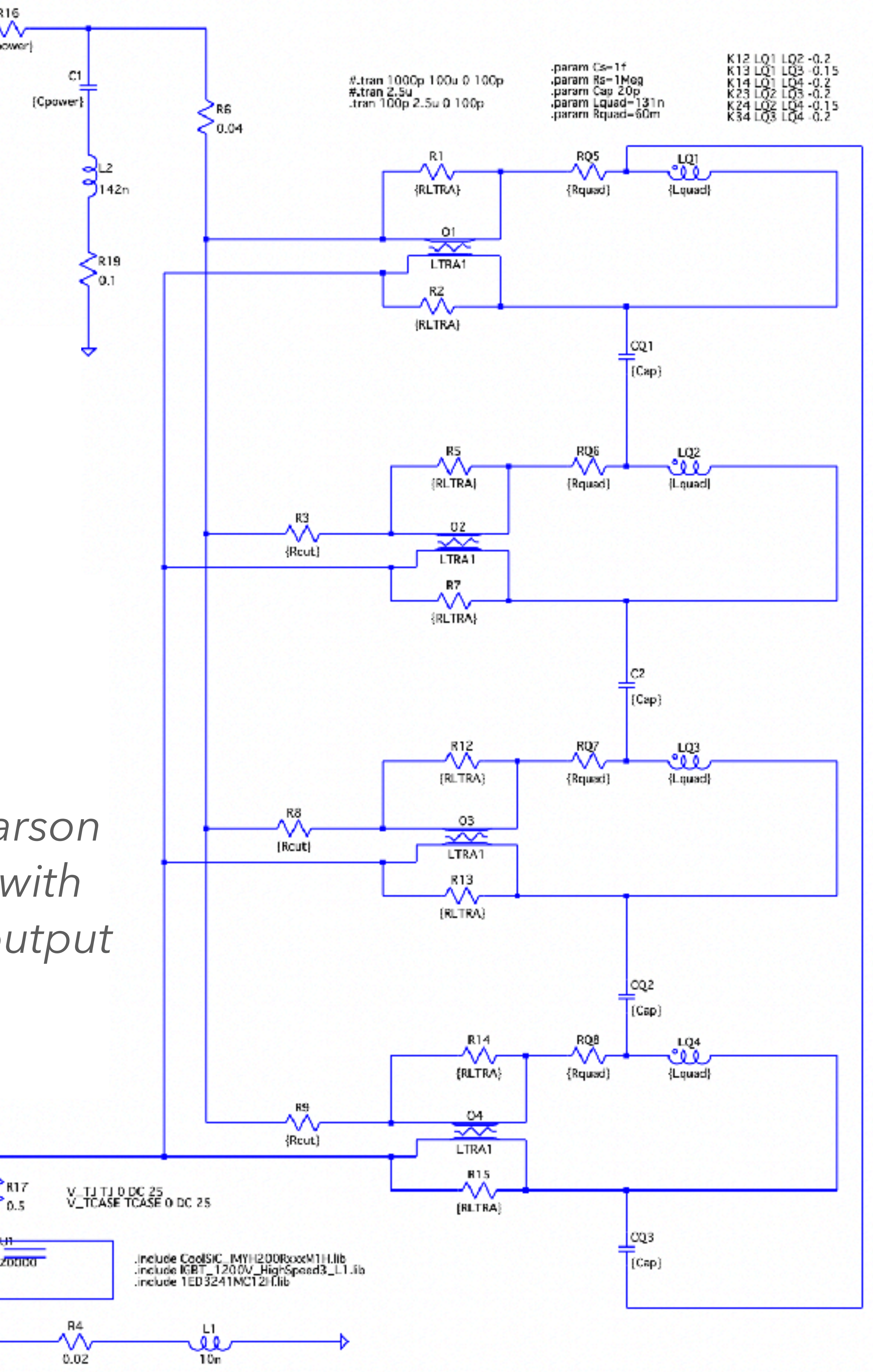


Optimised Simulations

A simulation of the pulser used in Sept. 2024 (5nF discharge into all four coil quadrants in parallel with single low-side switch) is well matched by simulation incorporating estimates of stray components and deriving gate-source voltage from measurements.



Current measured using Pearson wideband current monitor with -3dB at 20MHz and 0.1V/A output



Adaptation for damped pulse

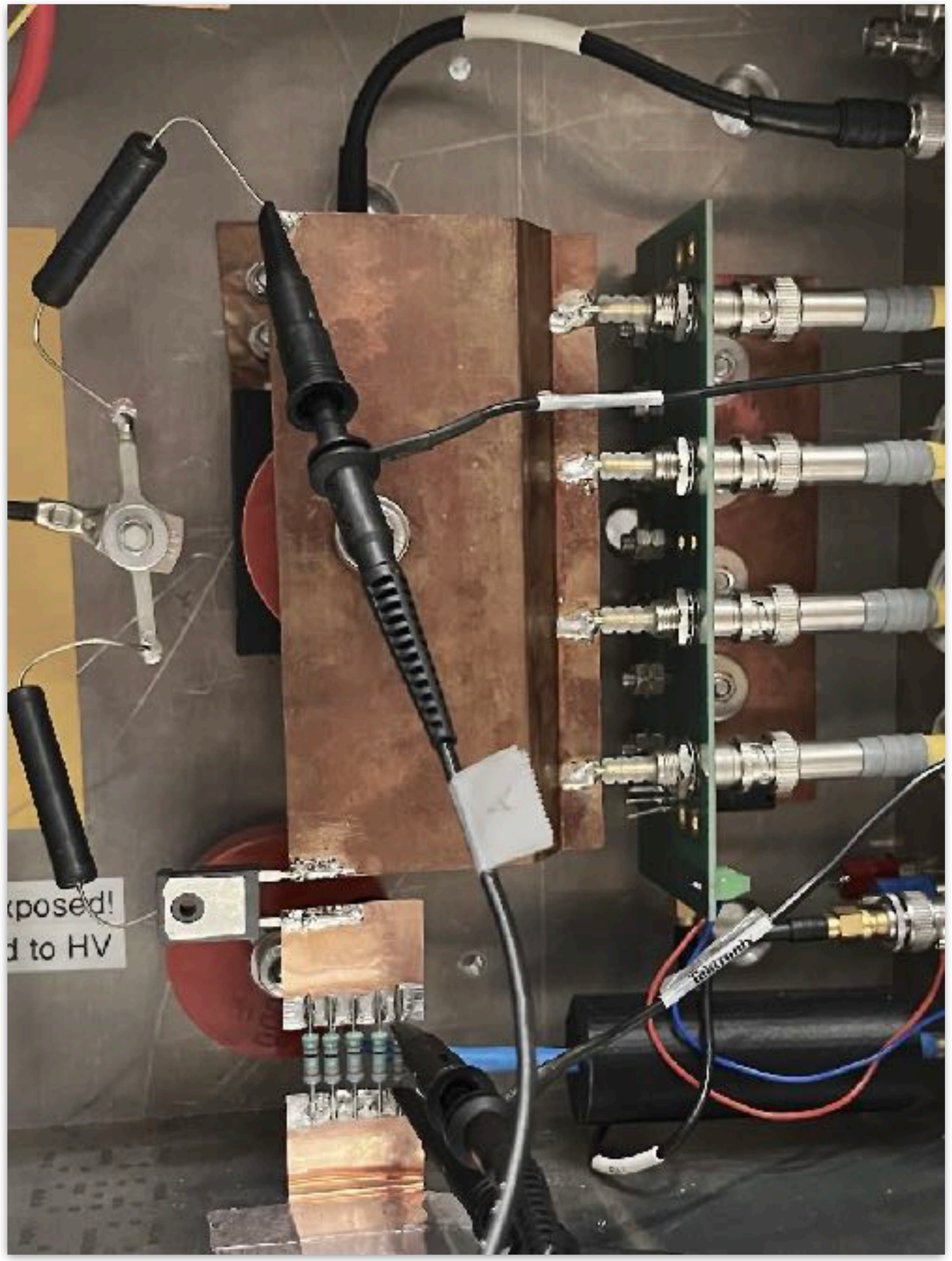
GC50MPS33H

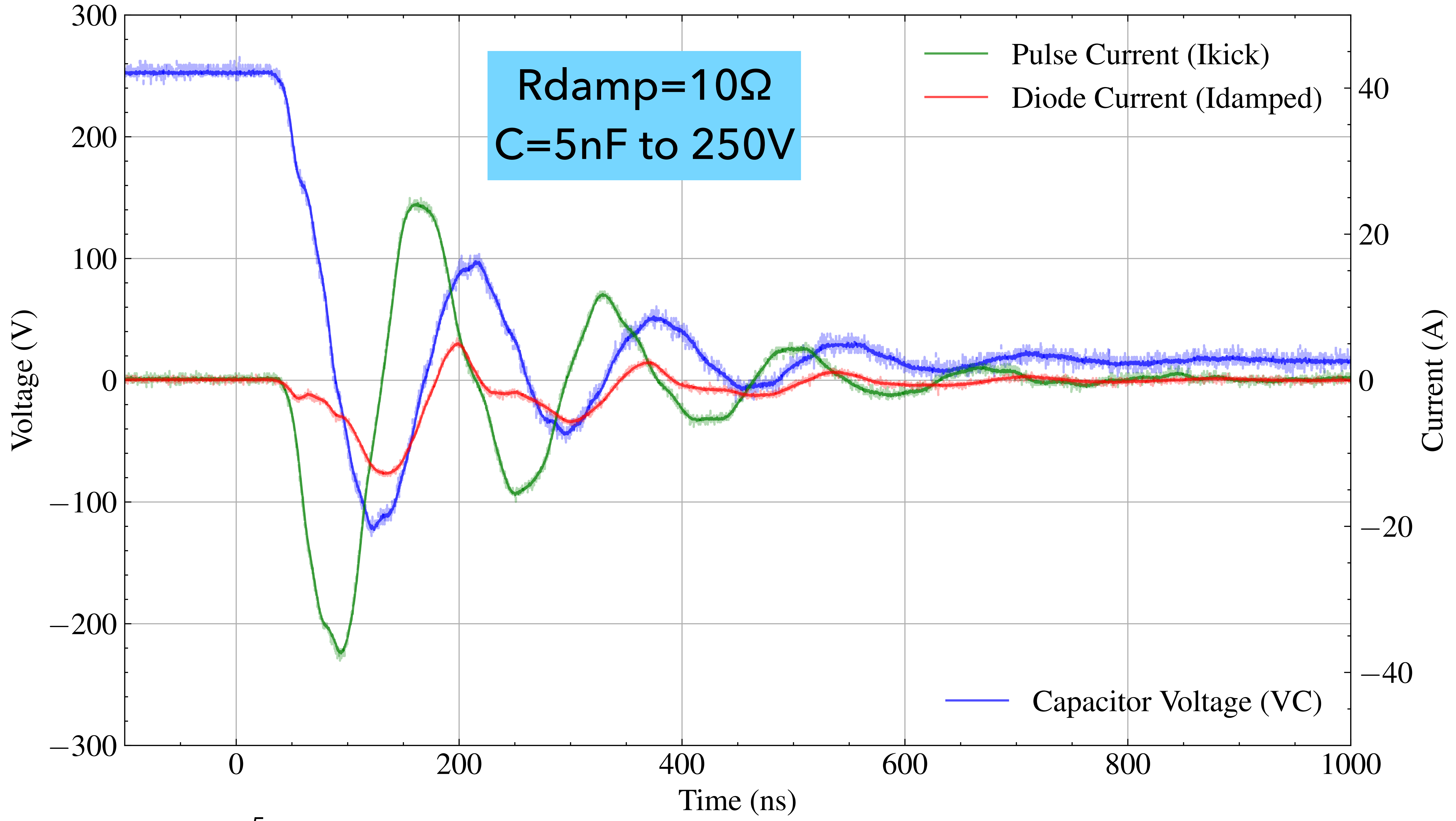
3.3kV 40A SiC Schottky diode

SiC offers:

- low capacitive charge for fast switching
- low reverse recovery current for speed & heat efficiency

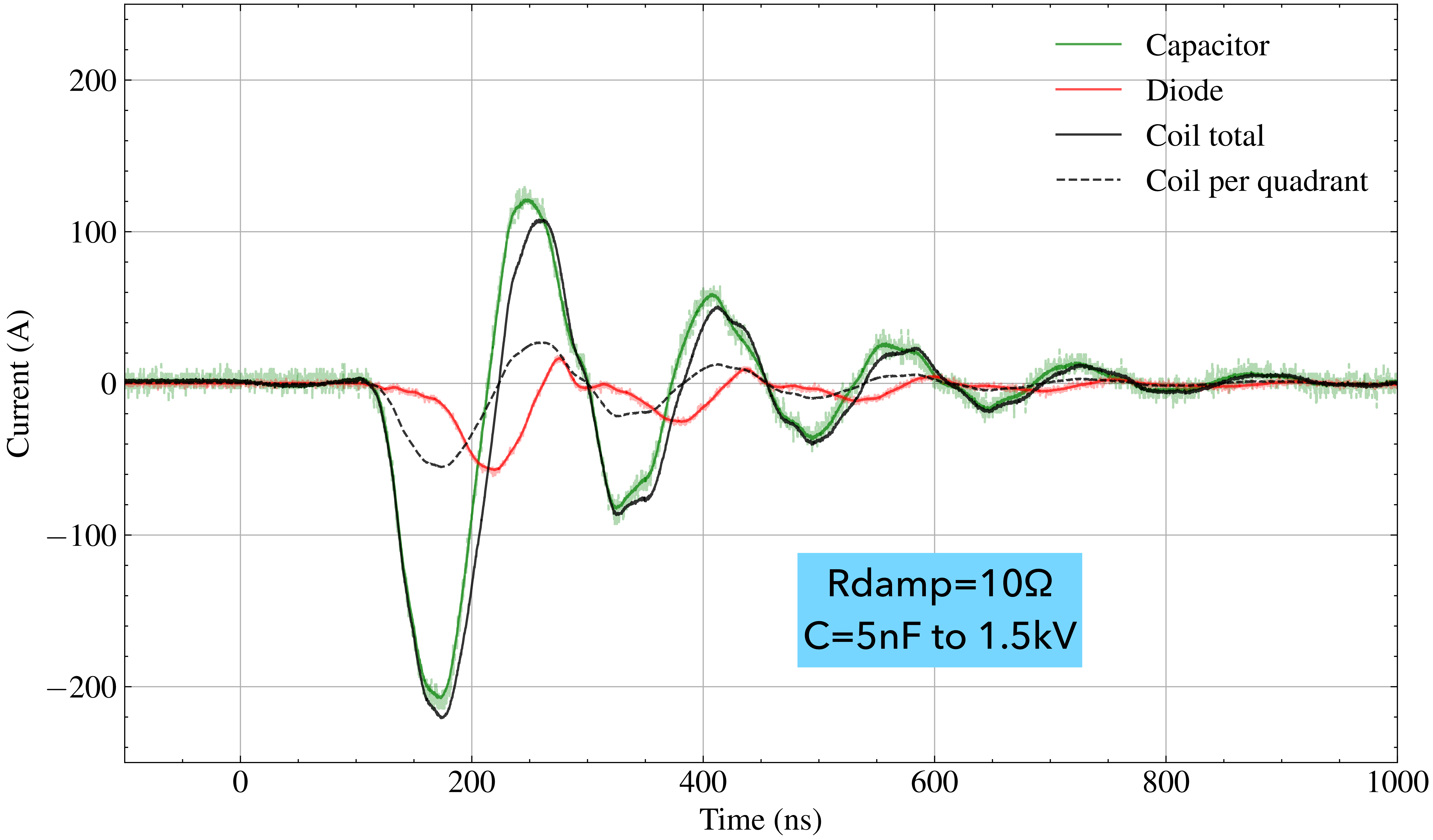
Additional damping will generate a pulse shape suitable for muon storage tests in 2025, where oscillations close to the frequency of the longitudinal betatron oscillation are permissible.

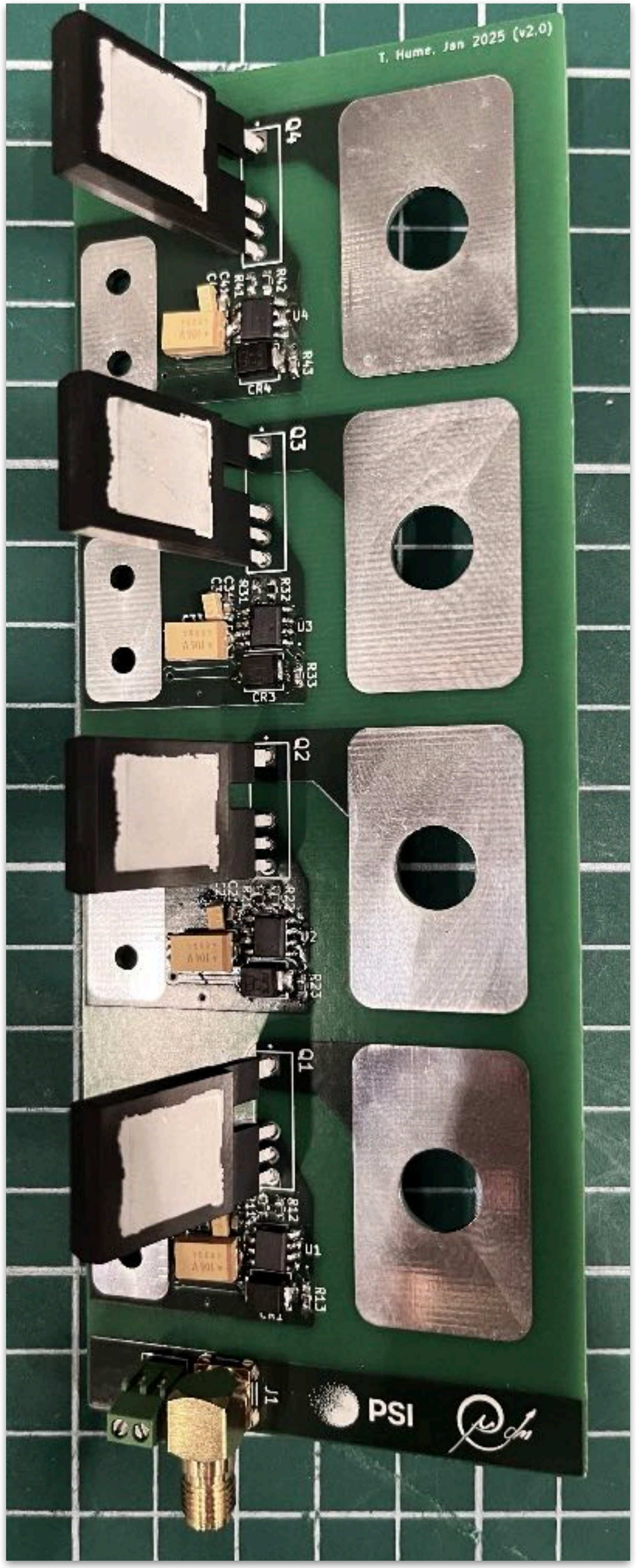




Improving peak current

An updated system was tested in Jan. 2025, demonstrating that >50A per quadrant can be achieved by switching each quadrant in parallel, avoiding saturation of the SiC MOSFET.





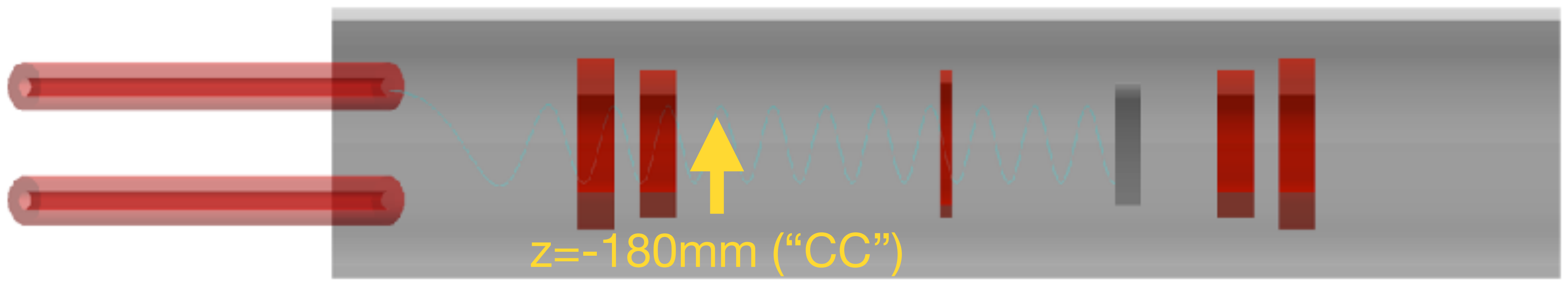
Acceptance Map

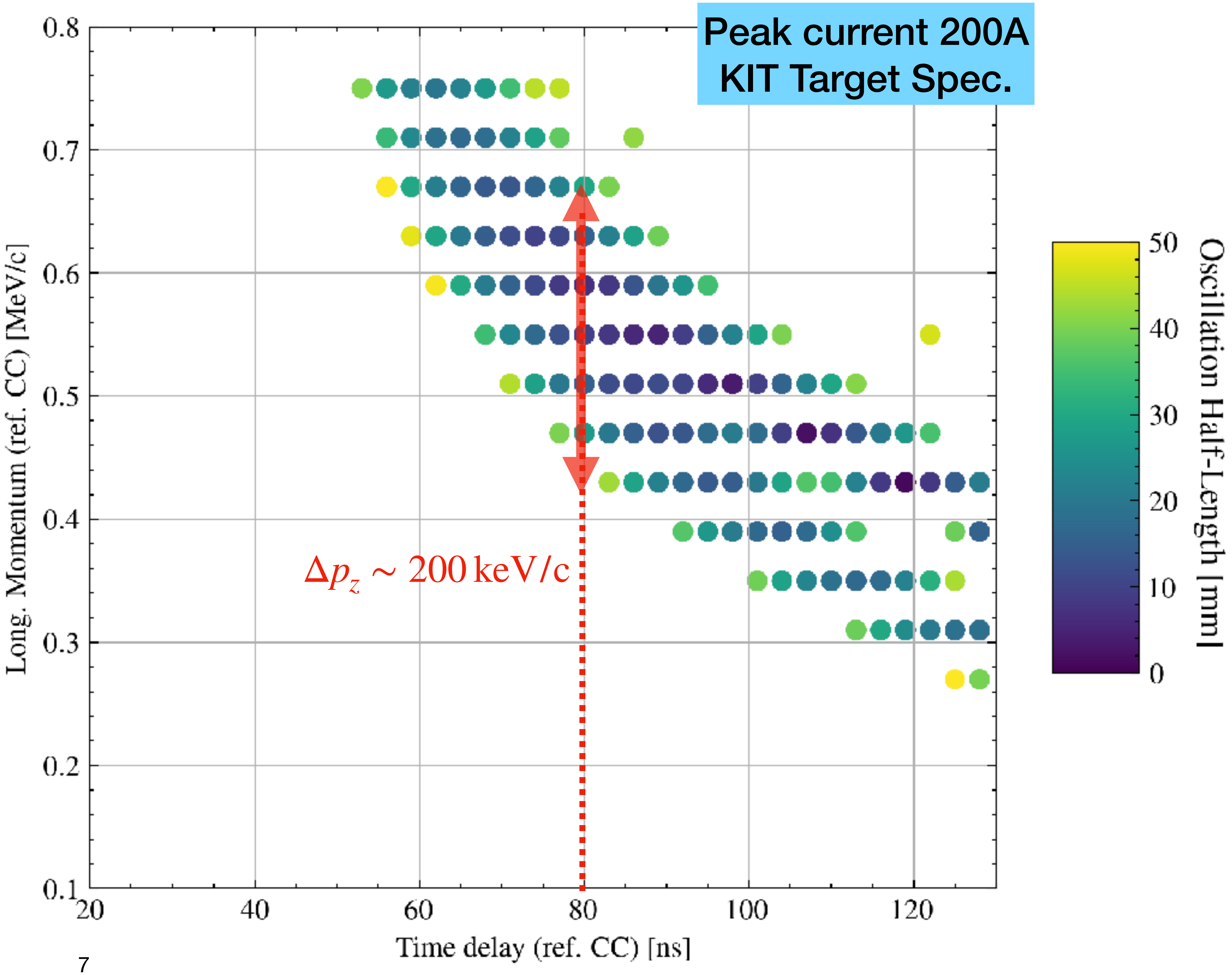
Muons injected near the exit of the correction coils (CC) are plotted on the acceptance map if they are stored for given input parameters:

- longitudinal momentum
- time delay

The colour indicates the half-length of the oscillation in the weakly-focusing field.

The time of the pulse must be fixed, therefore must be chosen for maximum acceptance of the momentum distribution.





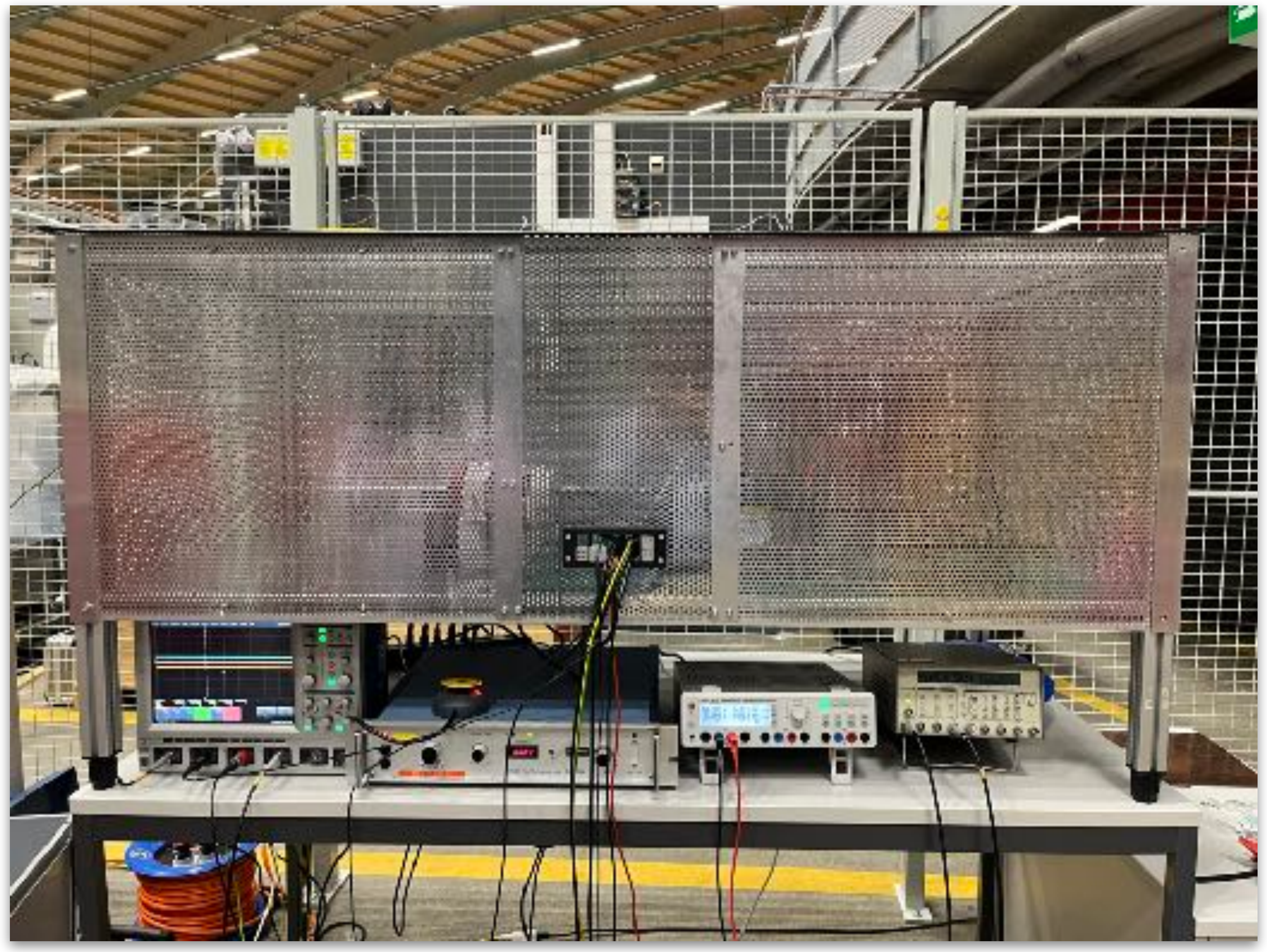
Expected efficiency

For a total time delay (inc. offset to ref. CC z=-180mm) in the range 100-140ns we can expect ~0.4% efficiency from injected to stored muons for the proposed KIT system. With its current performance (Jan. 2025) we can expect ~0.1% efficiency from the PSI system in development for testbeams.

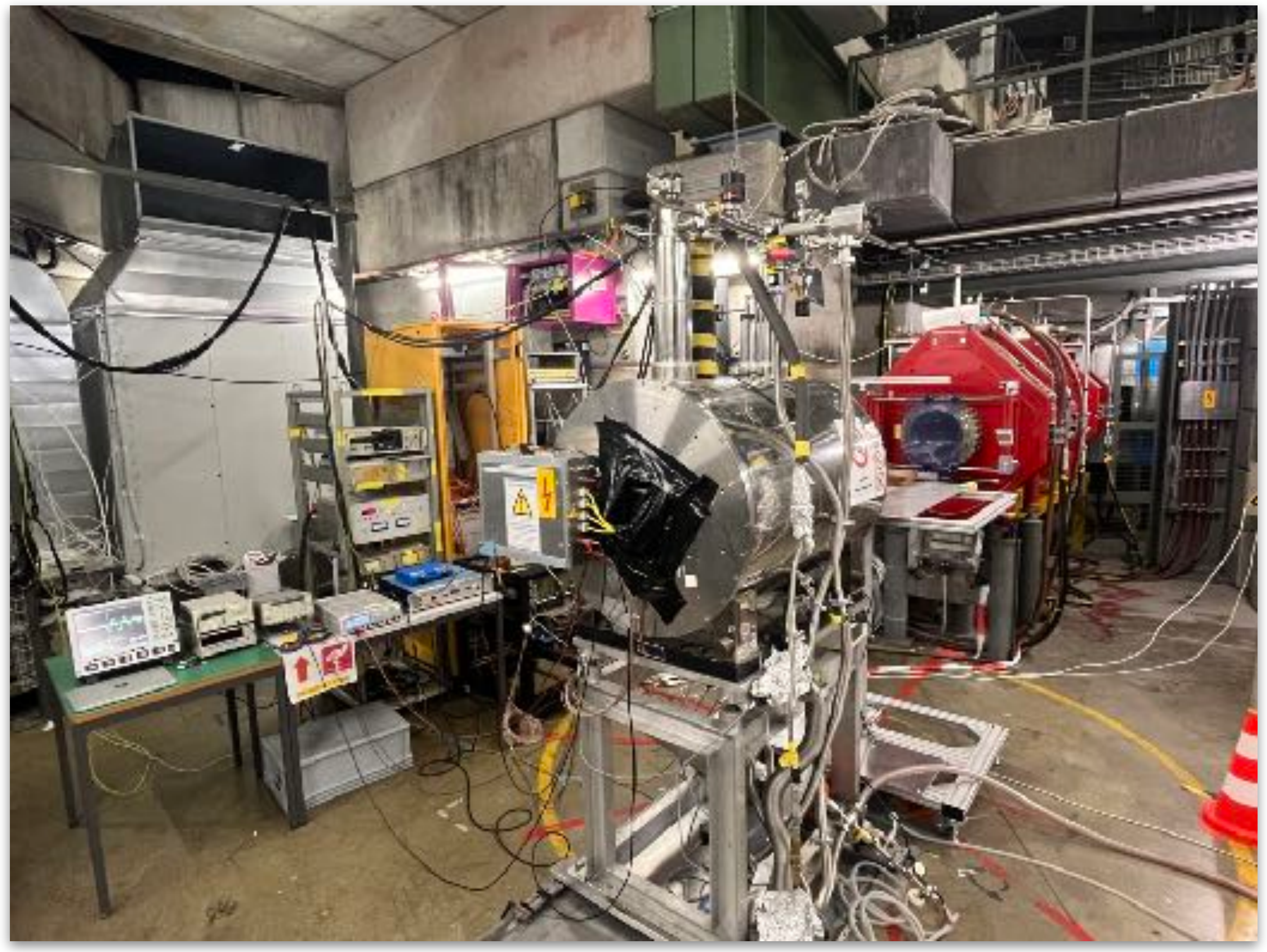
Requirement	KIT Target Specs	PSI Development Pulser	PSI Status	Comment on PSI System
Peak Amplitude	200A × 4 circuits	50-100A x 4 circuits	📈	Parallel MOSFETs avoiding saturation already provide sufficient current for storage tests. Further optimisation to capture higher momenta will be pursued in high-side upgrade.
FWHM	33ns to 66ns	Matched to longitudinal betatron oscillation frequency 7MHz	✅	Diode performance demonstrated. Damping resistance can be adjusted for optimal performance.
Latency	<60ns	Measured 40ns to leading edge	✅	Sufficient to trigger from entrance detector TTL signal. Expect <20ns additional delay in high-side configuration.
Recovery time	20μs	40us to full recharge with 5nF	✅	A filtering capacitor guarantees 3 close events, although average repetition rate limited as below.
Repetition rate	2000/s	Constrained by heat dissipation and the driving voltage supply. Target: 500Hz	⚠️	System currently limited to 200Hz V=1.5kV by heat dissipation in MOSFET, could improve with heat-sink. Also limited by voltage supply frequency response.
After-pulse oscillations	<10A for $t-t_0<150s$	N/A Instead, implement weakly damped pulse to exploit successive kicking in phase with longitudinal betatron oscillation	🤝	Sufficient for storage demonstration; KIT will improve efficiency and suppress systematics for EDM measurement. Aim for handover to KIT system in 2026.
Vacuum compatibility	Grounded coil with coaxial connection via vacuum feedthrough	Sept. 2024: in air, low-side switch Testbeam 2025: in vac, high-side switch	🛠️	Upgrade to a high-side switch by isolating the gate driver on the PCB using a capacitive isolator and bootstrap capacitor to supply charge to the MOSFET.

Conclusions

- Kicker coil driven with fast, short, high-current pulse, placing demanding requirements on the pulsed power electronics.
- Successful implementation of a testbeam pulse generator developed at PSI for systematic effects measurement on PiE1 Sept. 2024:
    - Current up to 32A per quadrant, sufficient as proxy for after-pulse oscillations (up to 10A)
- With the upgrades outlined, the PSI system will have the performance to permit our first demonstration of muon storage in 2025, a key milestone in the muon EDM search at PSI.
    - Today, current up to 55A per quadrant, sufficient for muon storage at a quarter of efficiency goal.
    - Conversion to high-side switch chosen as solution for in-vacuum operation.

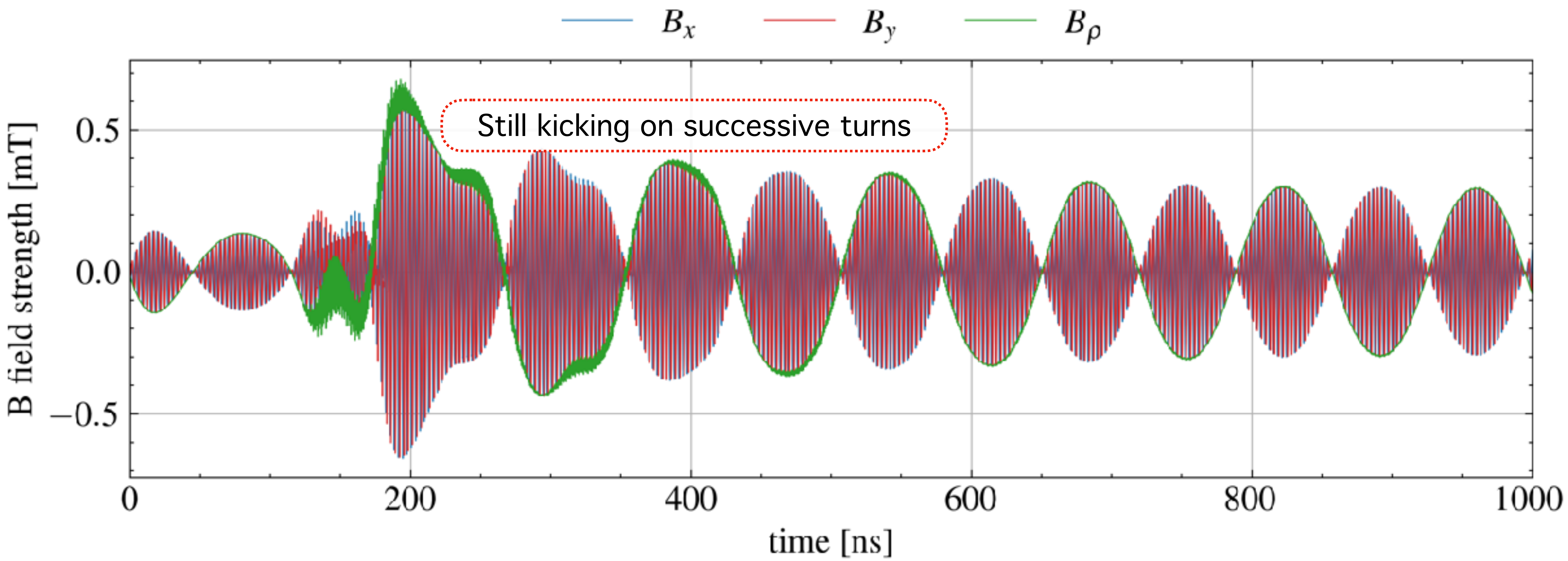


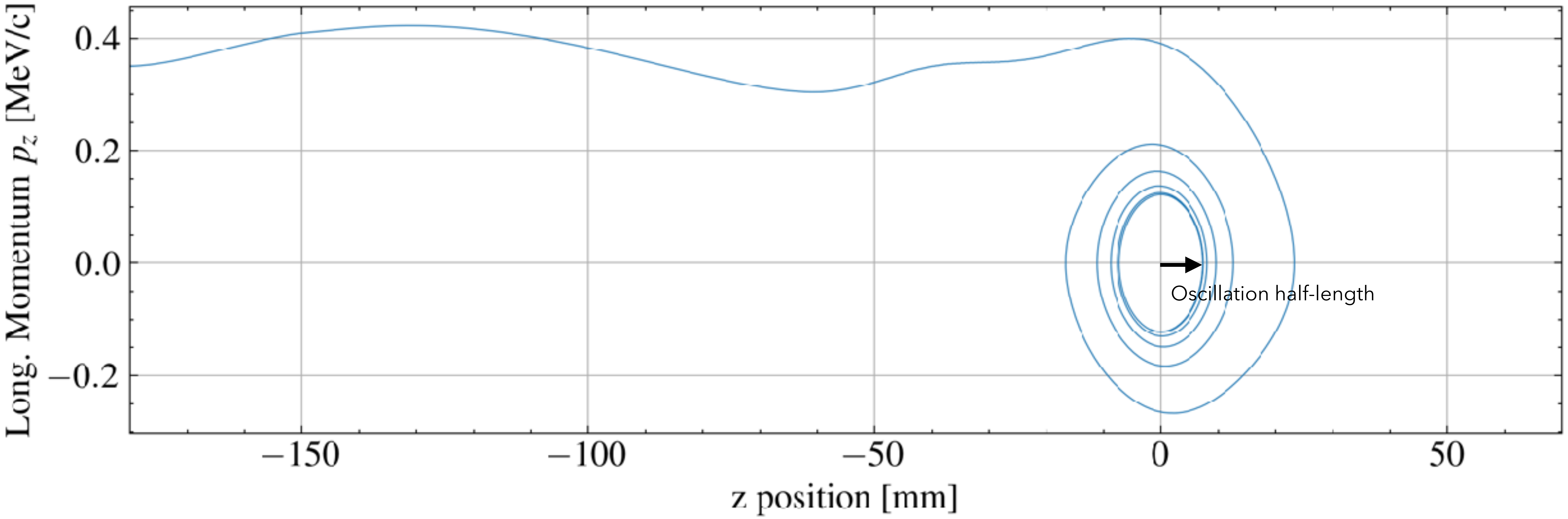
Thanks to the guidance of M. Paraliev (Pulsed Magnets, PSI), laboratory support of M. Pedrozzi (RF, PSI) and equipment support of S. Mair (Electronics & Control Systems, PSI).



Matching with betatron oscillation

The pulse width can be matched to the 7MHz longitudinal betatron oscillation in the weakly focusing storage field.





When the muon turns around, the pulse has opposite sign to further reduce the longitudinal momentum remaining during storage.