Fast pulsed magnet development at DESY

The machine injection kicker & septum laboratory

Gregor Loisch on behalf of the DESY kicker magnet group

PSI GFA Accelerator Seminar
Villigen, 27.07.2023

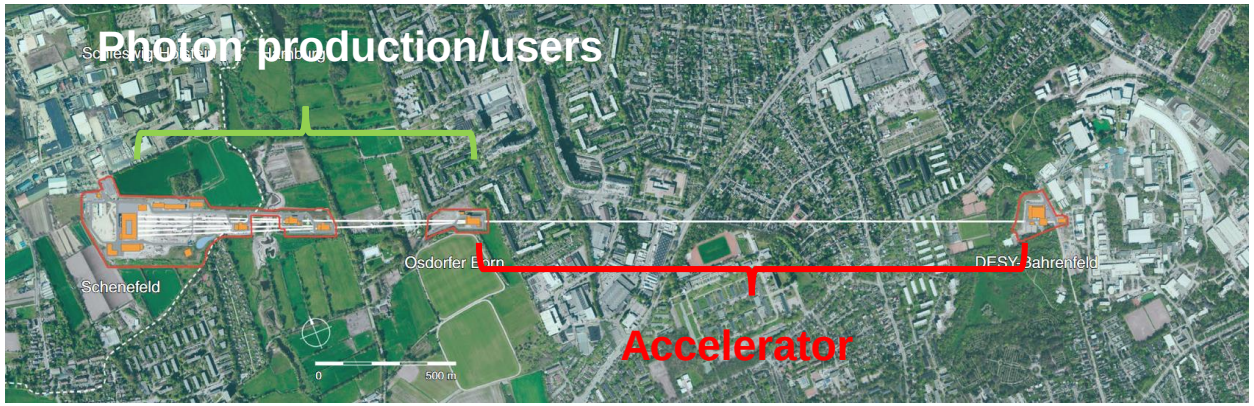
HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

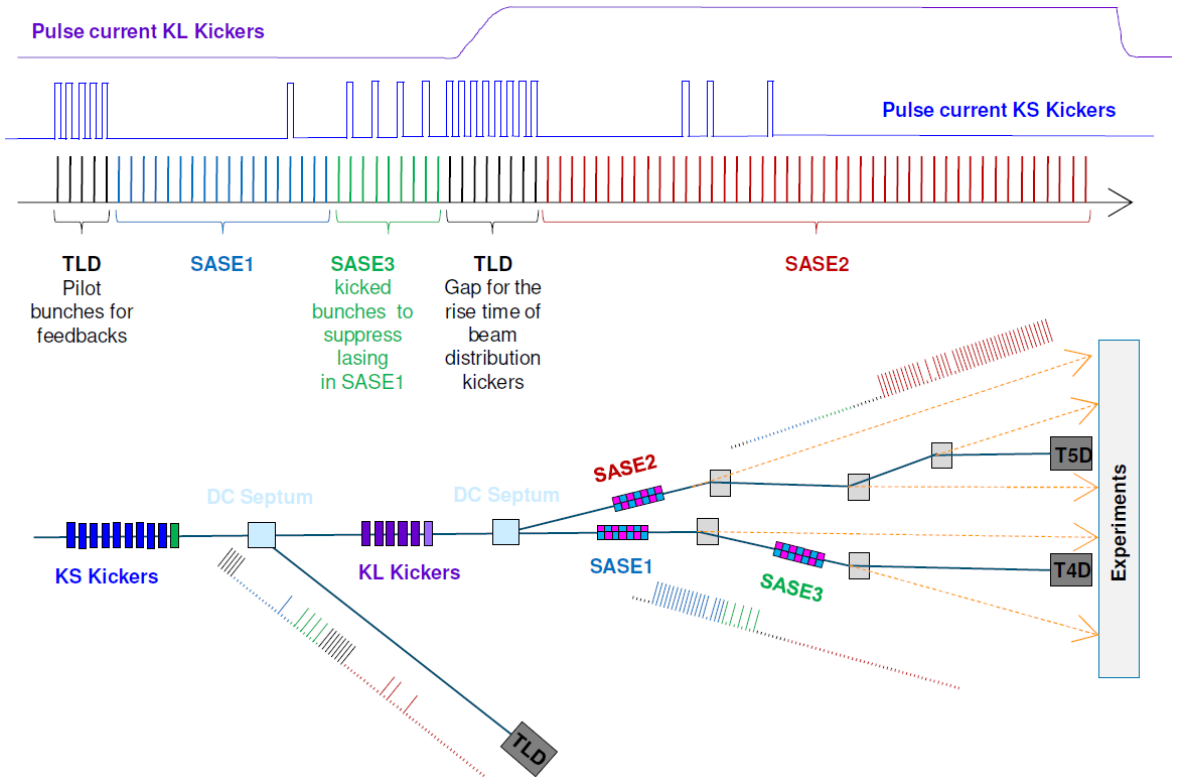
DESY.

Pulsed power at DESY

The kicker & septa magnets laboratory

- Currently operating 102 pulsed power systems for kicker magnets
- Kicker & septa laboratory has 12 members
  - Head of group (Frank Obier)
  - 2 development engineers
  - 1 physicist
  - 8 technicians
- Various tasks
  - Development of new systems
  - Series production for e.g. new beamlines
  - Integration into accelerator control system
  - Maintenance of existing hardware
  - Participation in accelerator operation

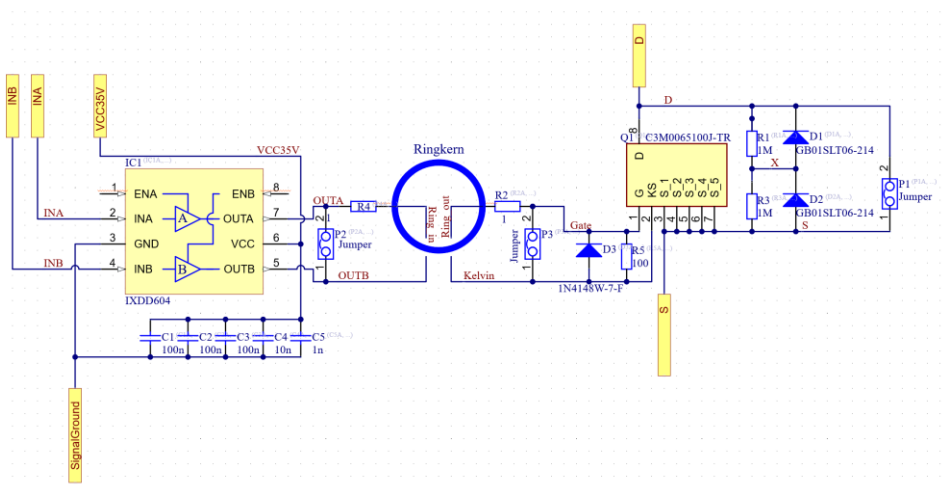


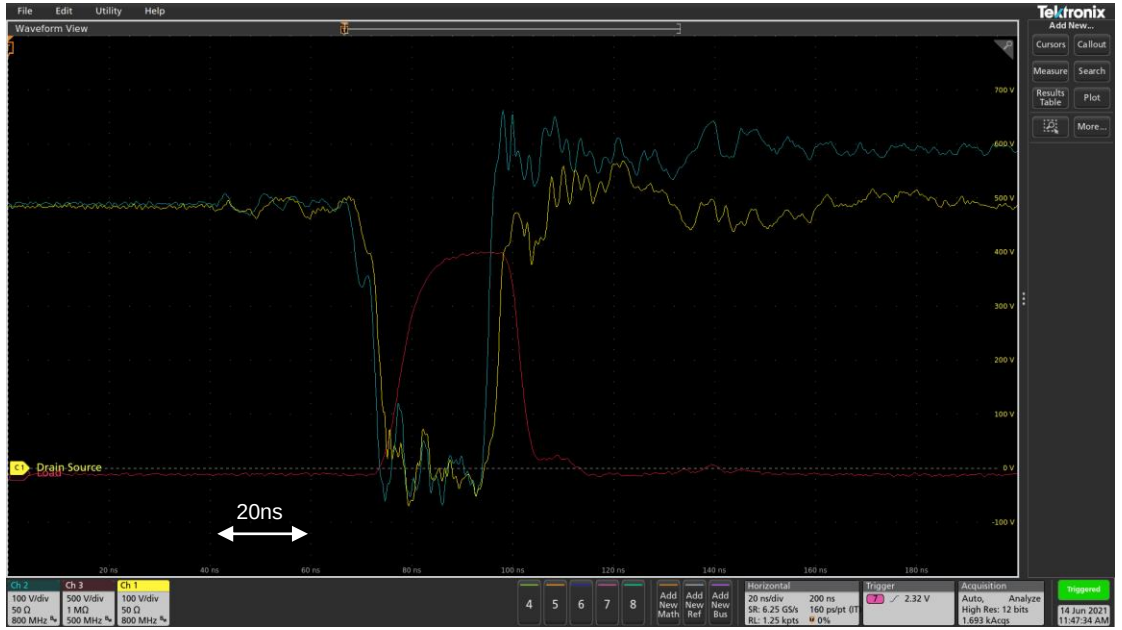


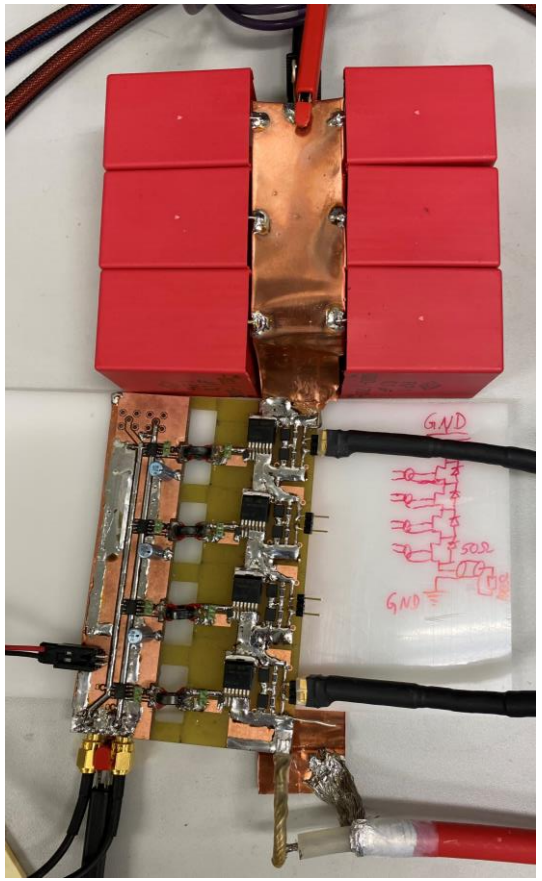
Pulsed power development projects

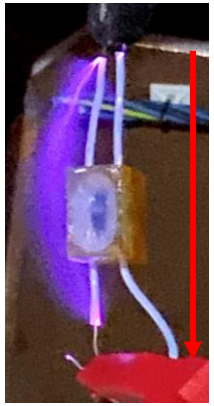
MHz Bunch selection for European XFEL

- Distribute 10Hz trains of ~2400 bunches @4.5MHz rep. rate
- 10x 2m stripline kickers
- Currently using 5kV commercial pulser system
- Developing upgrade for 8kV into 50Ω striplines
- Si MOsFETs w/ Si drivers
- Initially faced issues with arcing in 1:1 trigger transformer







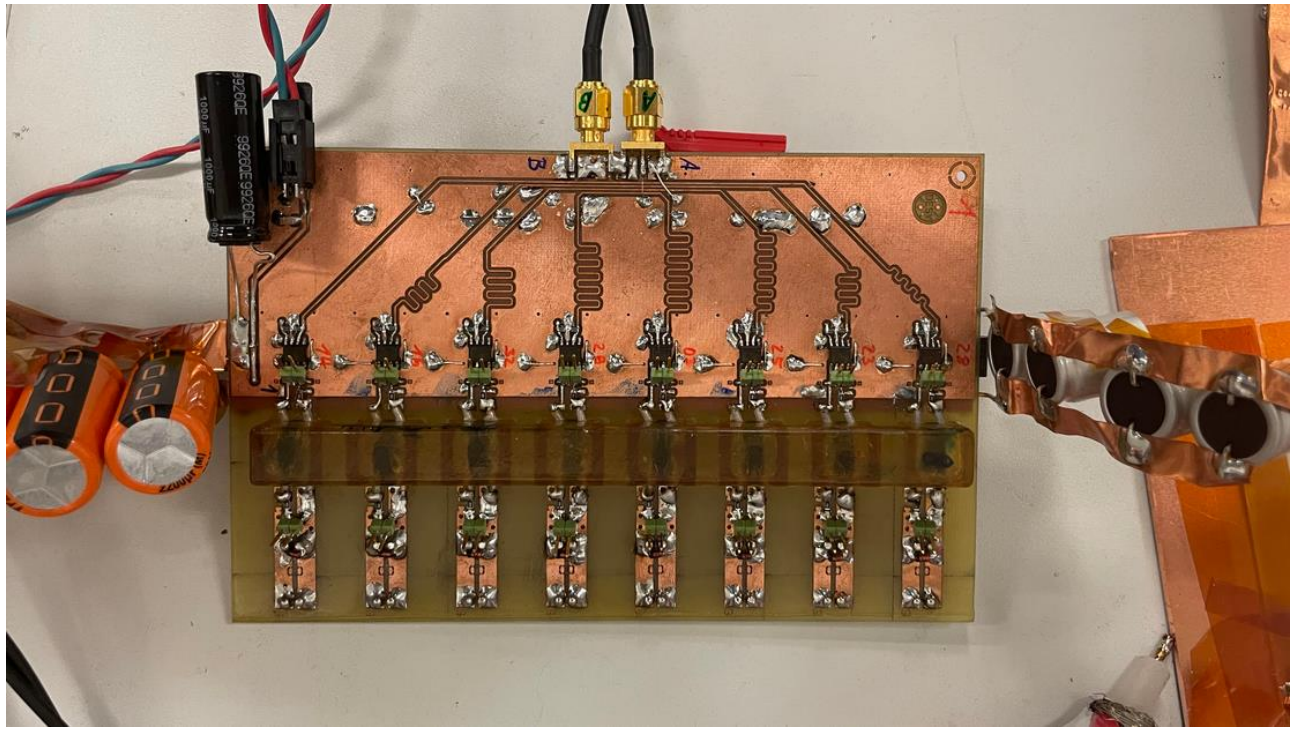


20kV

Pulsed power development projects

MHz Bunch selection for European XFEL

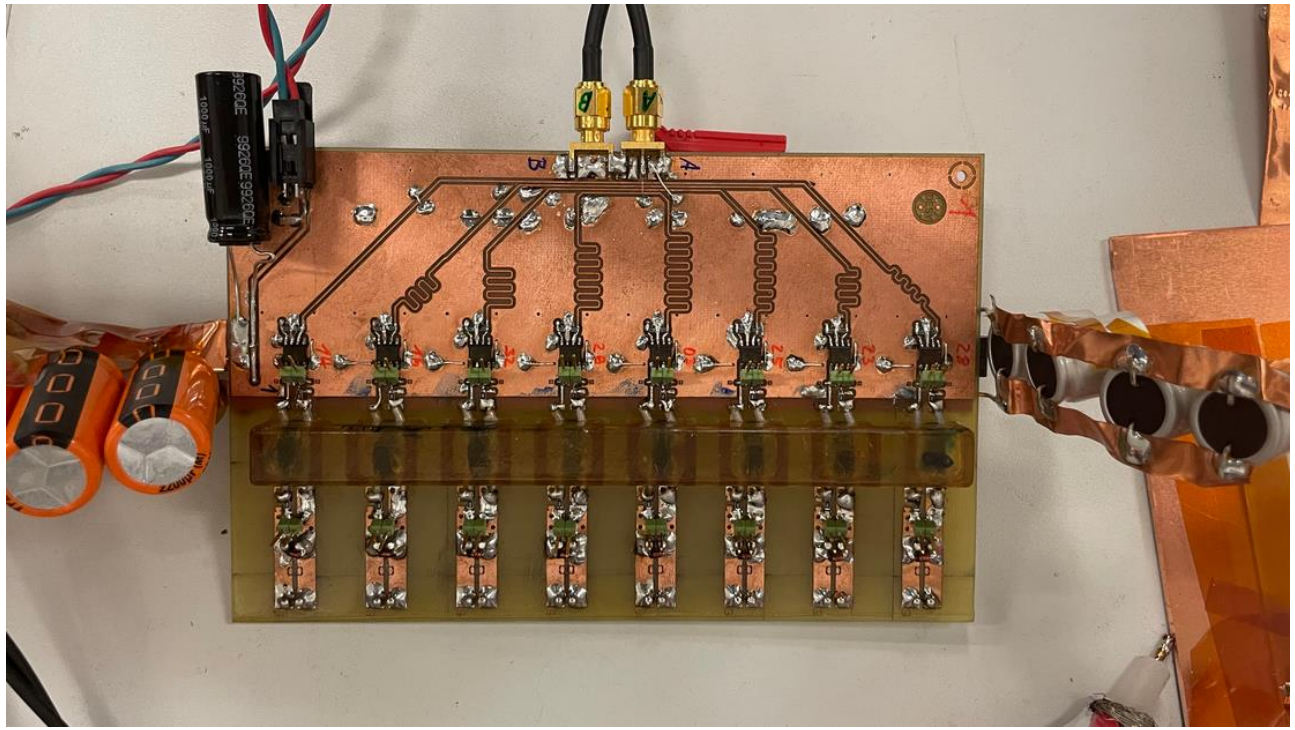
- A lot of time invested into finding proper ferrite core material
  - Various materials slowing down pulses too much
  - Partially large variations in different badges
  - → selection of parts
- Pre-selection of switches & drivers due to variation within badges
- Currently in final development stage



Pulsed power development projects

MHz Bunch selection for European XFEL

- Mid-term future:
  - CW upgrade for CW Eu XFEL operation
- Currently favoured layout: parallel stages w/ reduced repetition rate
- Recently faced heatload problems:
  - Nearly whole bunch train was kicked into dump
  - → 23,000 pulses /sec
  - Overheating of load resistors
  - Upgrade required for CW

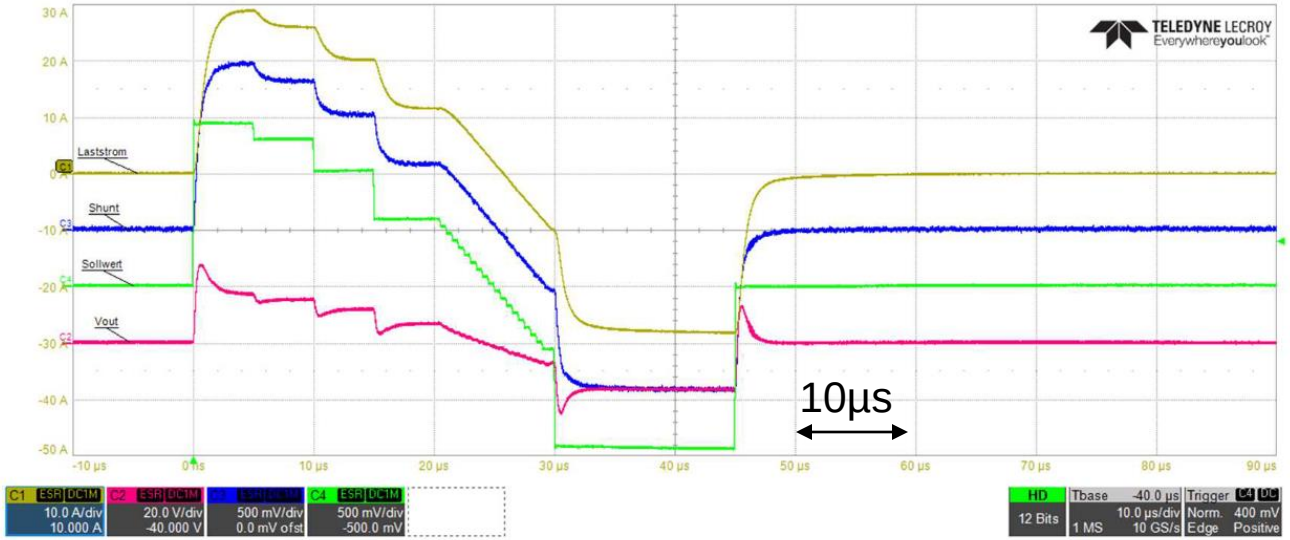


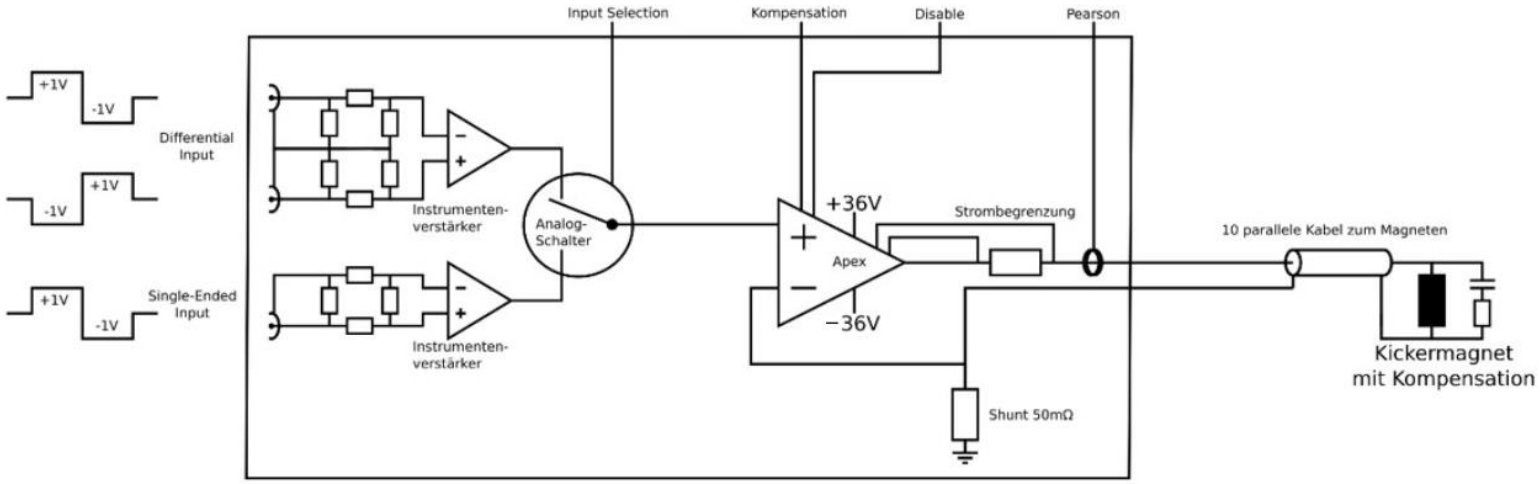
Pulsed power development projects

Beam position feedback kickers

- Inductive kicker for correcting bunch positions in linacs
- Using operational amplifier to amplify external signal within -100A …100A
- ~Slow but sufficient for drifts along a bunch train
- Easy to integrate into accelerator control system
- New setup for flexible bunch distribution in radiobiology at PITZ facility

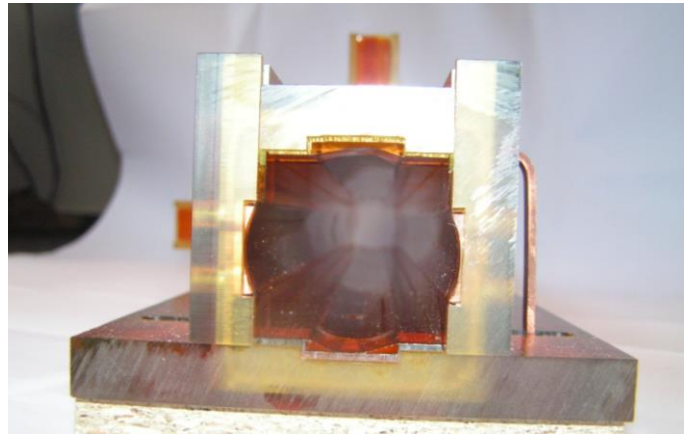
Test of Apex-amplifier w/ 1µH load



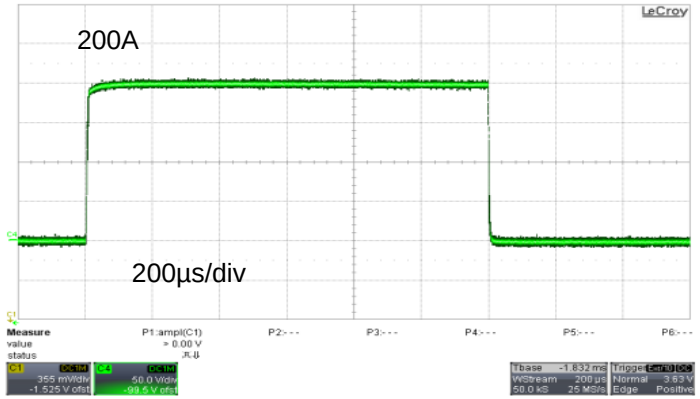


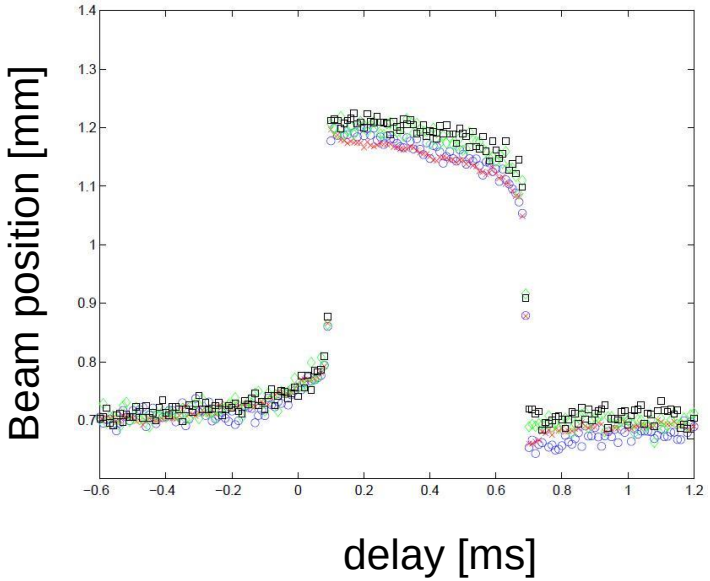
Pulsed power development projects

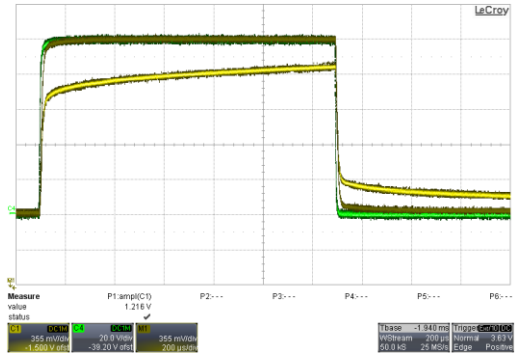
Skin effect mitigation in bulk Cu conductors



- For ~1ms square pulse kick, a Cu plate conductor was used
- Current rectangular, deflection showing significant slope → measured in B-field and reproduced in simulation
- → skin depth in conductor changing along rect. pulse
- Replacement w/ non-insulated Cu mesh/braid
- Field change during pulse mitigated ~completely



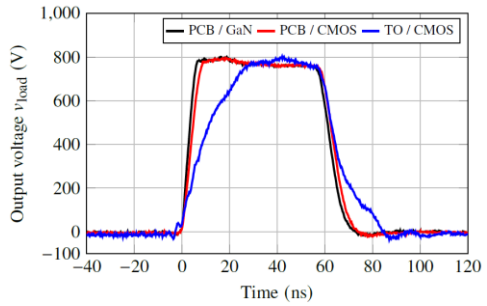


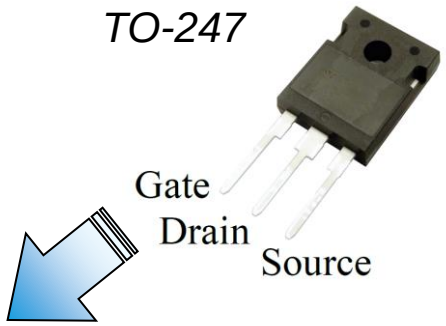


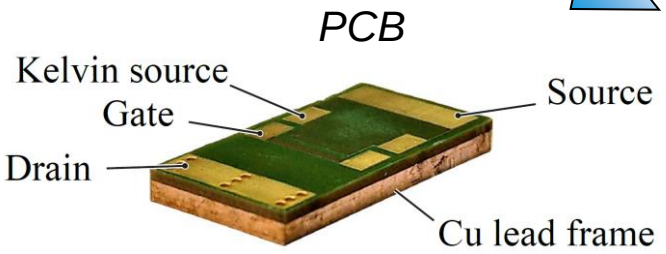
Pulsed power development projects

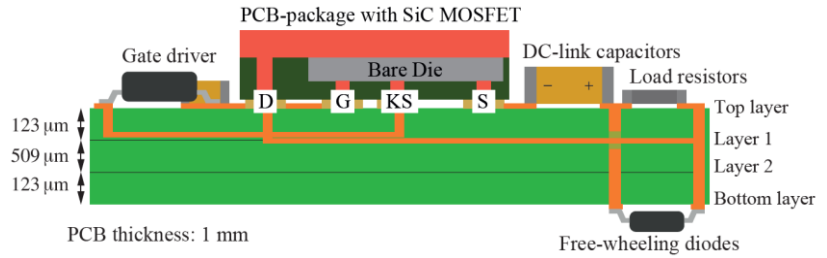
(Really) fast injection kickers for PETRA IV

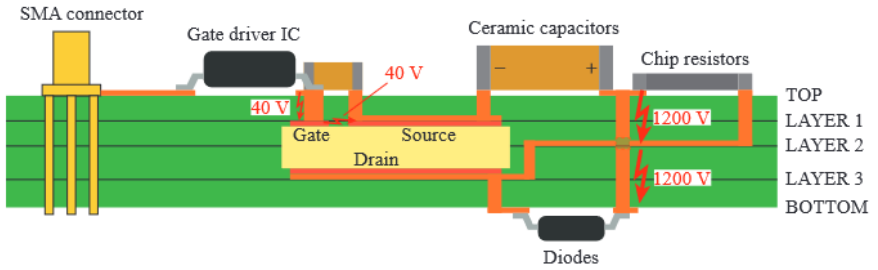
- Initiated research project with ETH Zurich
  → investigate capabilities of available switches
- Group of J. Biela
- SiC MOsFET switches with minimised inductances (<~1nH) and GaN driver (e.g. 3D-printed board)
- Fastest possible switching of single stage
- Stacking of stages in
  - Marx-topology
  - Inductive adder topology
- → fastest possible switching in “classic“ topology!?











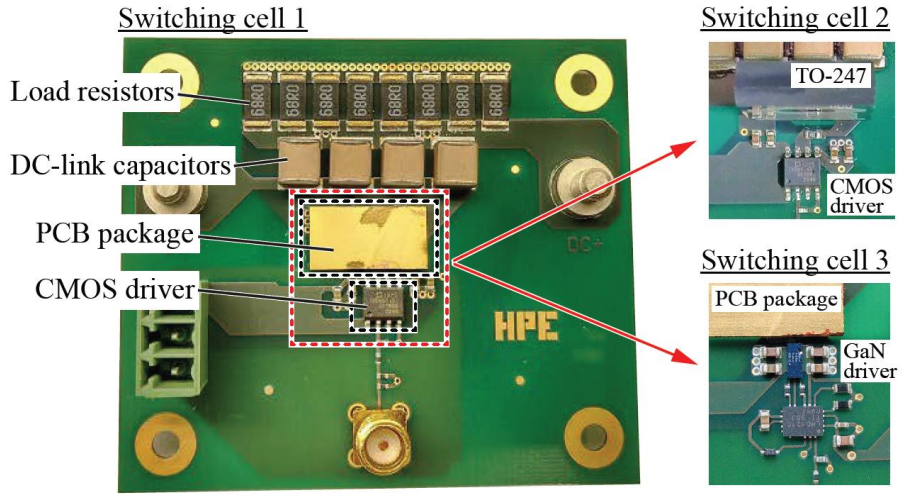
R. Risch, J. Biela – Solid-State Marx Generator vs. Linear Transformer Driver: Comparison of Parasitics and Pulse Waveforms for Nanosecond Pulsers – PPC2021
R. Risch, J. Biela – Influence of Power Semiconductor Device Variations on Nanosecond Pulses in a Solid-State Marx Generator – EPE2022
R. Risch, J. Biela – PCB-Embedded Packaging for Ultra-Fast Switching of SiC MOSFETs – CIPS22

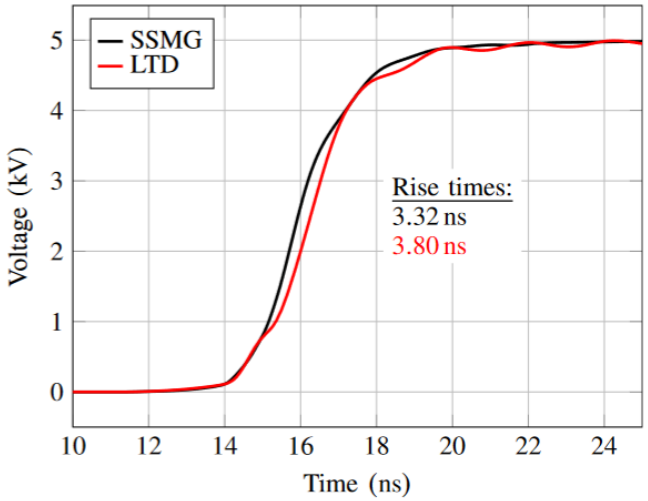
Pulsed power development projects

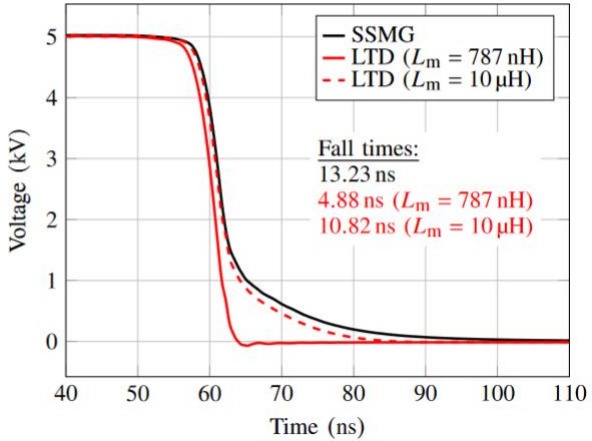
(Really) fast injection kickers for PETRA IV

- Single-stage switch-on times:
  - ~3.4 ns (450V, 400A)
  - ~4.5 ns (800V, 94A)
- Currently assemblying 5kV generator prototype
- Simulation of LTD & Marx performed
  - Marx-generator slightly faster turn-on
  - LTD faster turn-off
- Results for further speed-up by gate-boosting pending

→ Available switches too slow for this application!







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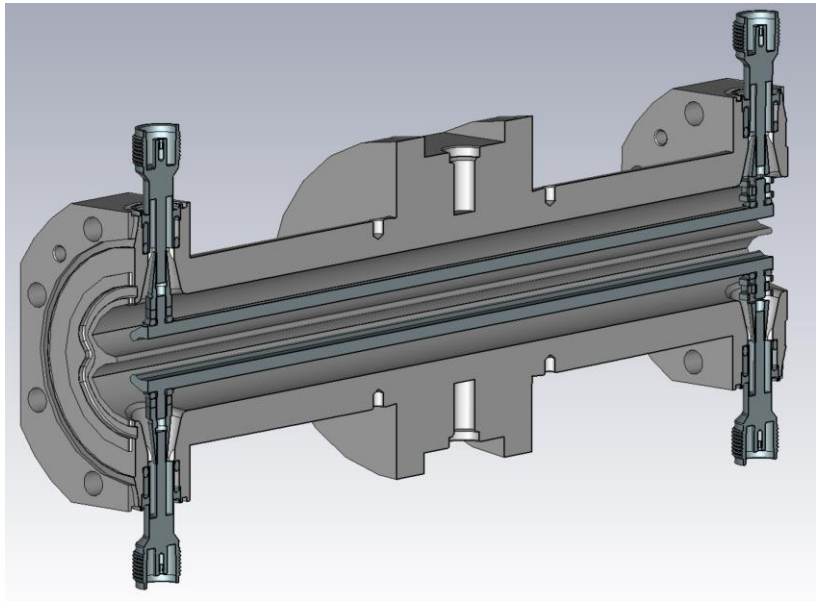
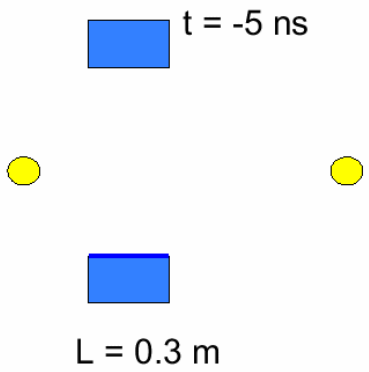
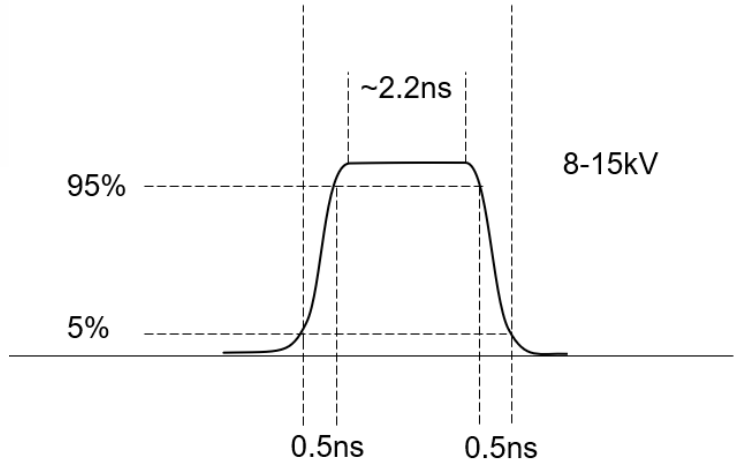
Pulsed power development projects

(Really) fast injection kickers for PETRA IV

- PETRA IV: upgrade to existing PETRA III facility
- Much smaller beam size → more sensitive to beam disturbance
- Deflection of only one bunch at injection!
- Bunch separation (2-4) ns
- HV pulses with tight requirements:
  - 8-15 kV
  - ~2-3ns length
  - Timing jitter <50ps
  - Amplitude jitter <1%
- Baseline option: commercial pulsers using DSRDs

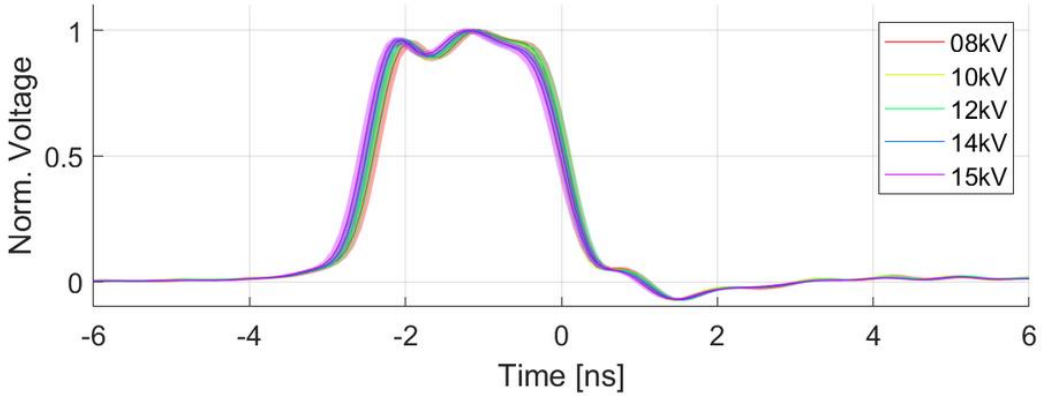




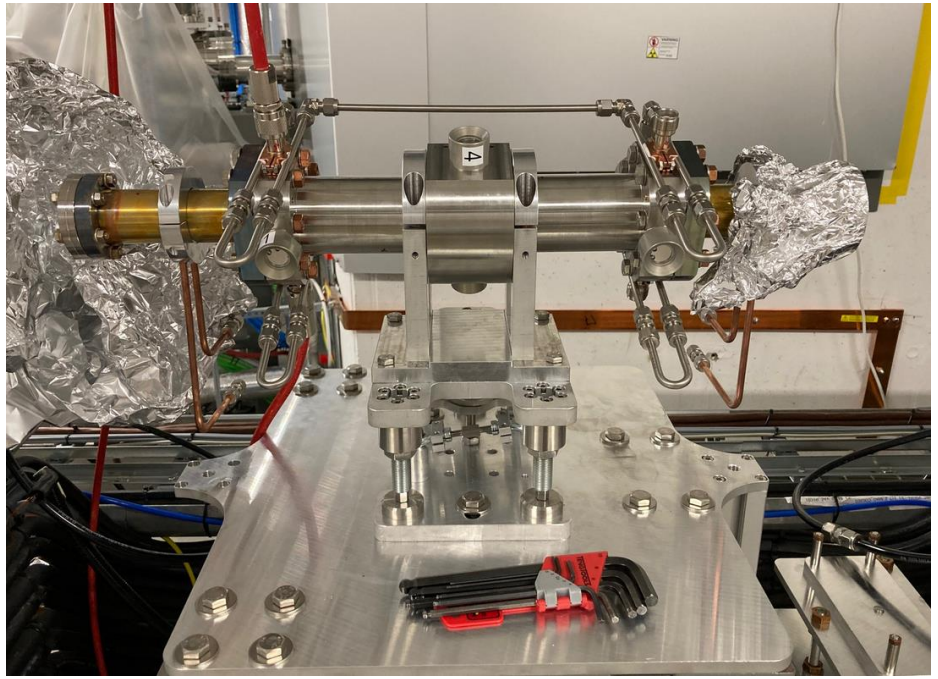


Pulsed power development projects

(Really) fast injection kickers for PETRA IV



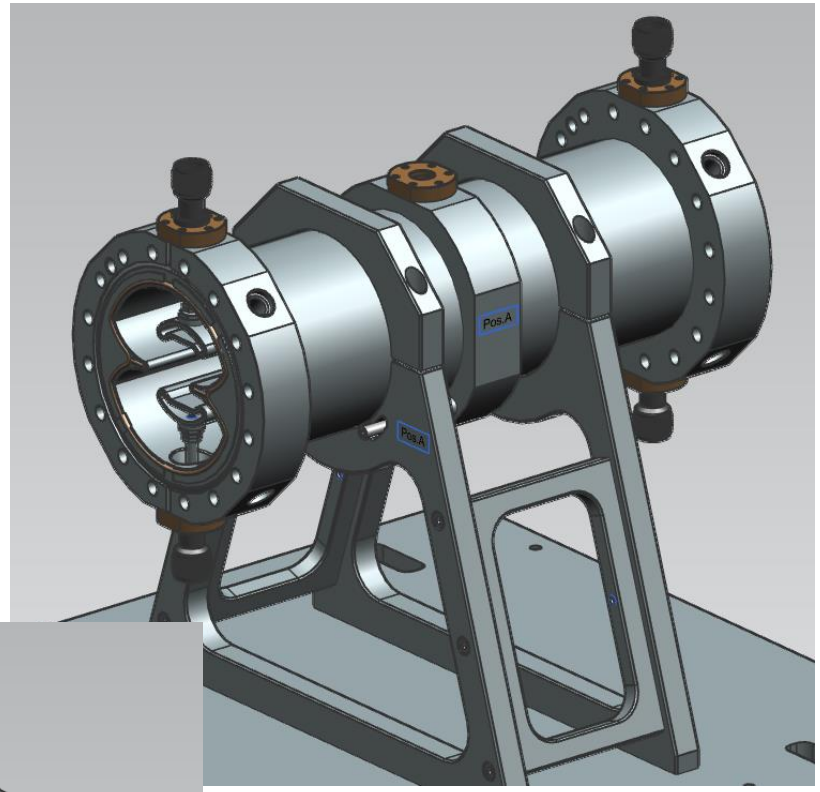
- Prototype currently installed at MAX IV 3 GeV ring
- 1 week beamtime to measure wakefield heatload & kick performance in mid-August
- Detailed studies of kicker performance at DESY‘s ARES linac in autumn
- Final kicker prototype next year
- Development of HV load resistors ongoing
- Pulser solution currently open
  - Commercial pulsers may not be available
  - Conventional pulse circuits too slow
  - Planning to start new development (collaboration w/ PSI!)

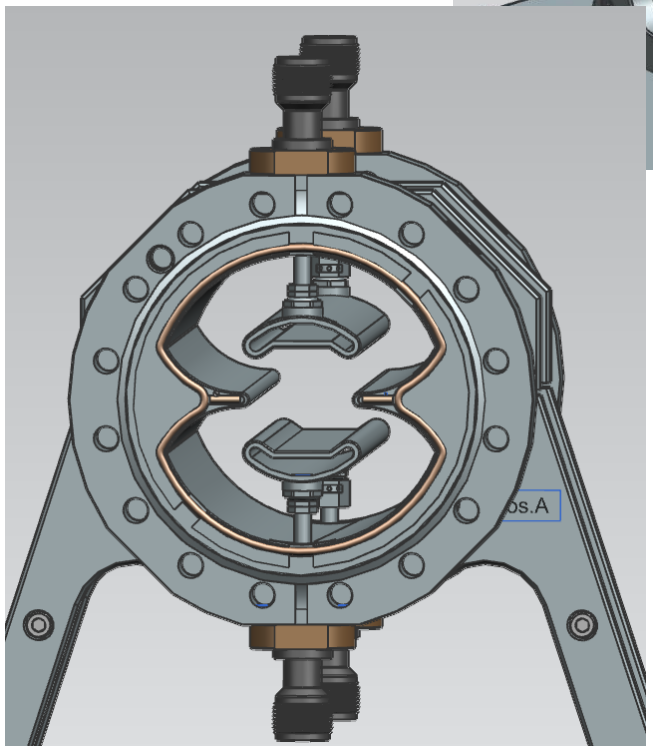


PETRA IV feedback kickers

Derivative of injection kicker design

- PETRA IV will need 8 – 16 fast orbit feedback kickers
- Planning to re-use design of injection kicker
- Scaled 14mm → 32mm aperture
- Hollow electrodes for weight reduction
- Simulations show good mechanical stability
- Waiting for successful injection kicker tests at MAX IV
- 1st prototype in 2024

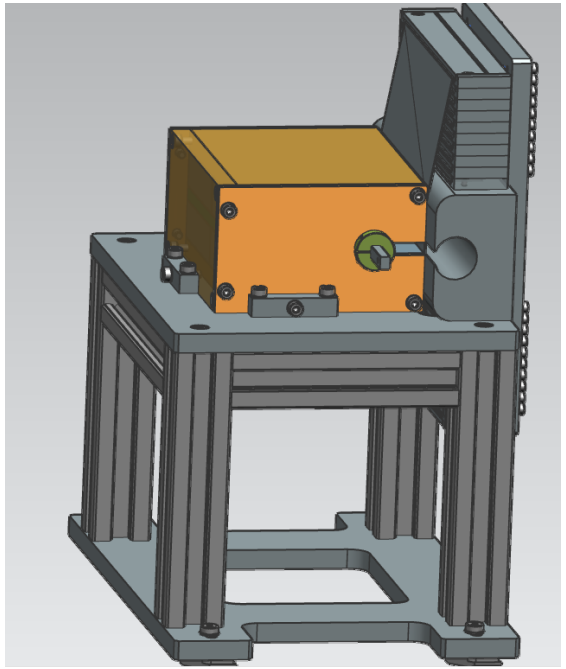


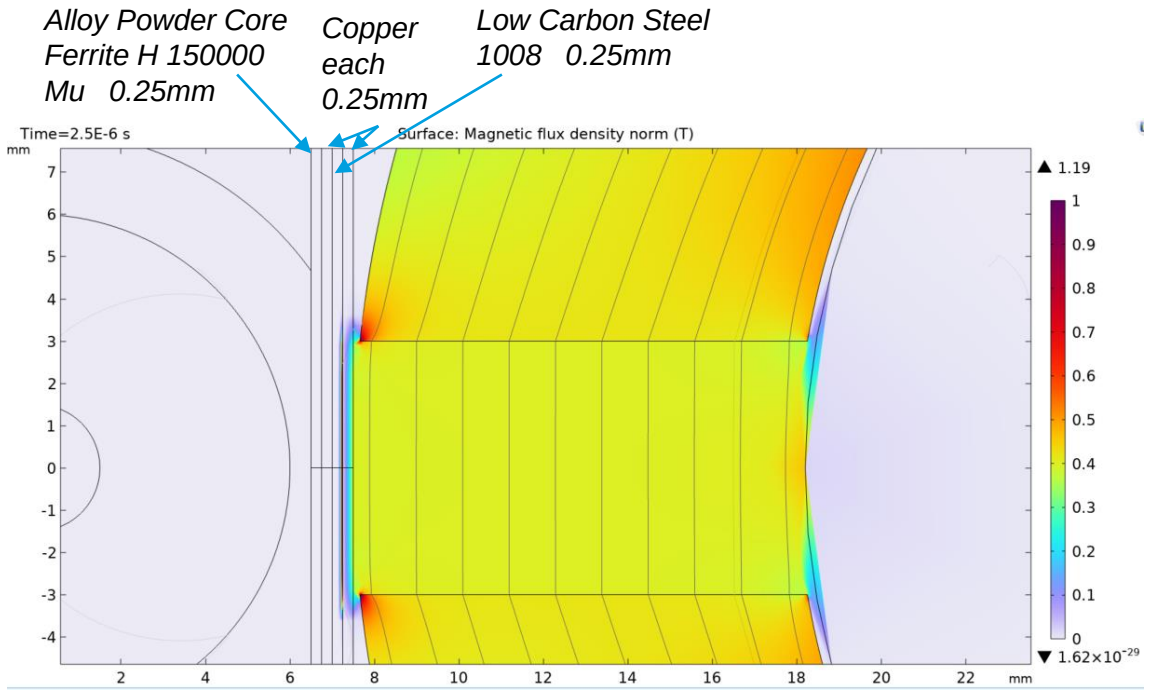


PETRA IV injection septum

Septum w/ 1mm blade

- PETRA IV requires septum w/ 1mm blade thickness
- Requirements very similar to PSI SLS2.0 septum
- Development currently ongoing
- Test setup of blade material being manufactured
  - Holder for easy assembly of different blades
  - Cu, Fe and Mumetal foils/sheets stacked for 1mm thickness
- Simulation studies w/ CST & Comsol ongoing
- Benchmark experiments in autumn
- 1st septum prototype in 2024

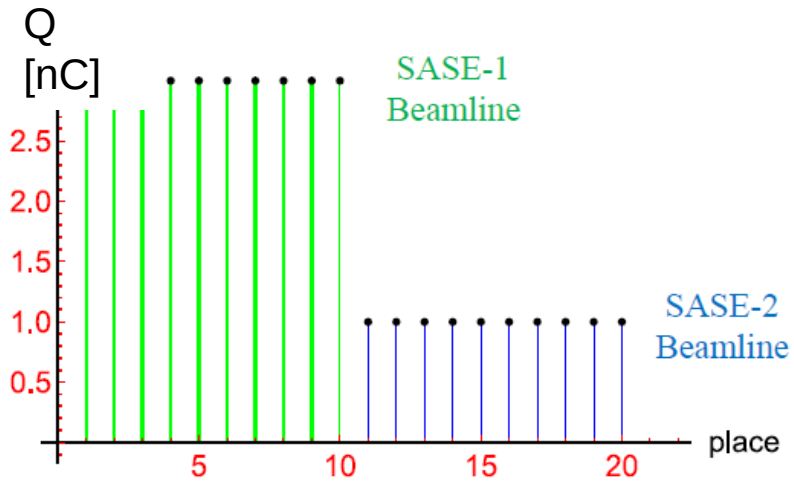


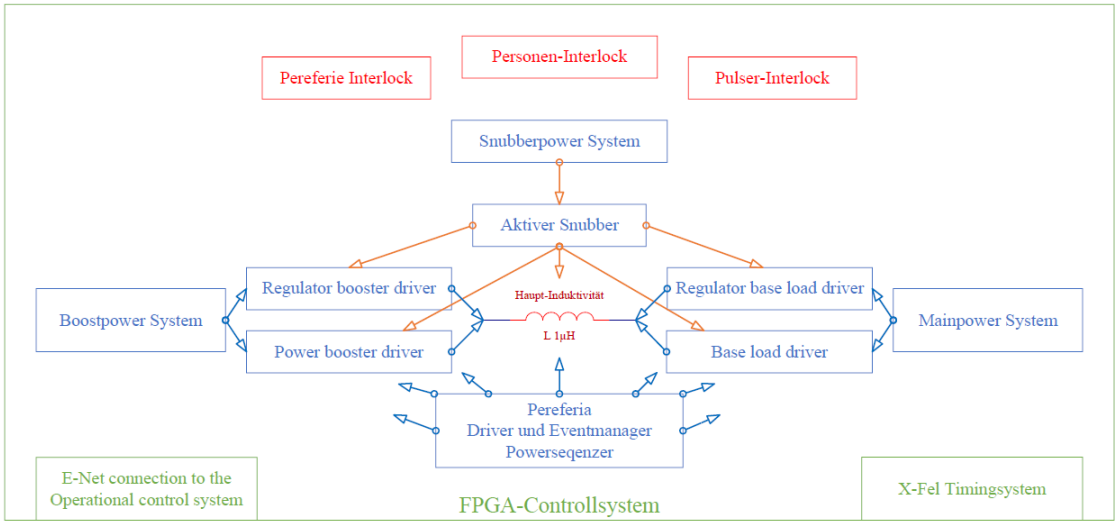


2.5kA solenoid pulser

Feedback solenoid for EuXFEL photoinjector gun

- EuXFEL beamlines demand different bunches
- Gun solenoid focus/emittance compensation varies w/ charge
- → pulsed correction solenoid will be installed
- Flexible pulse parameters requested
  - 2.5kA max. current w/ pulse modulation
  - Pulse width <2ms
  - Rise time <10µs, Fall time <4µs
  - Pulse-to-pulse stability 0.1%
- Main control via Xilinx Kintex-7 FPGA
- Staged setup: HV pulse front driver stage + base load driver stage

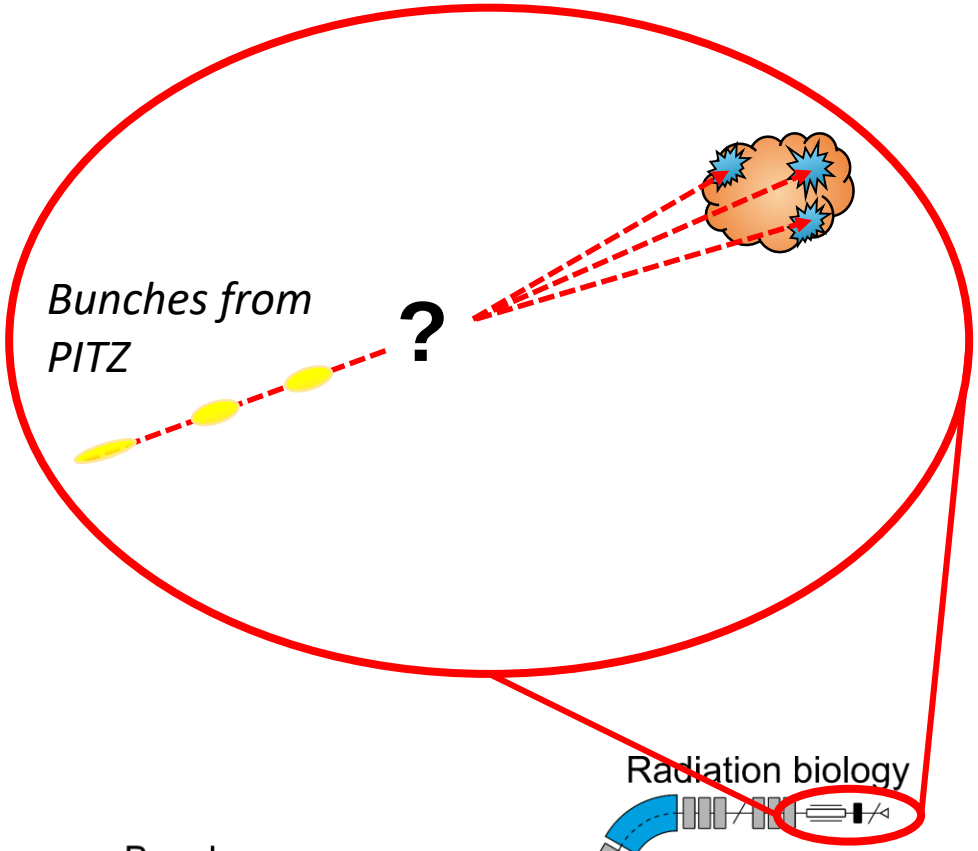


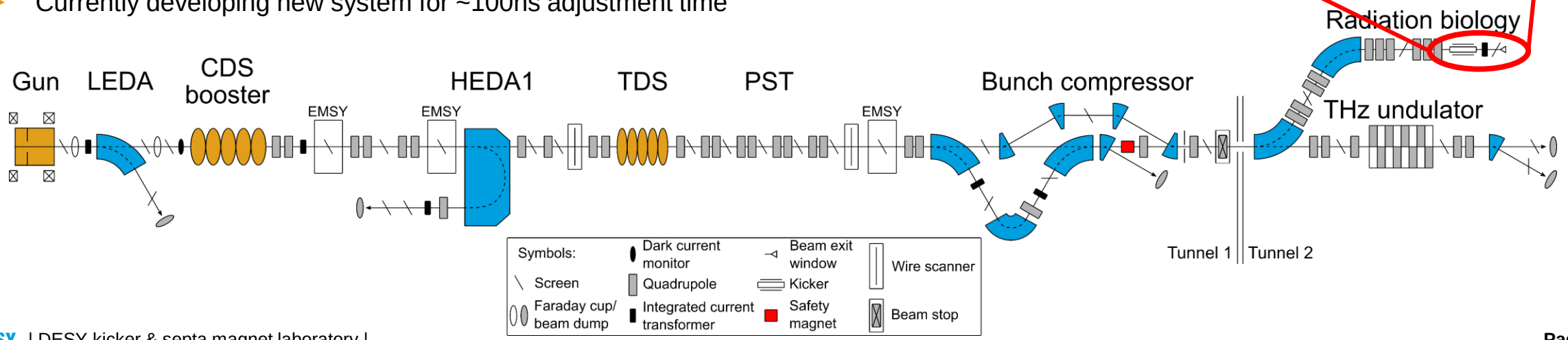


Bunch distribution kicker for VHEE FLASH radiotherapy

Feedback solenoid for EuXFEL photoinjector gun

- Radiobiology beamline currently being set up at PITZ facility (DESY Zeuthen)
- Main goal: investigate electron radiotherapy w/ FLASH effect
  - Radiation of tumors in < ~100ms reduces healthy tissue damage
  - Radio treatment has to happen in 1 bunch train
  - Still under investigation, first clinical trials ambiguous
- Request for kicker system for scanning of sample/tumor
- Feedback kicker for first tests (~10µs adjustment time..)
- Currently developing new system for ~100ns adjustment time





Thank you for your attention!

Contact

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