PULPOKS

PULsed POwer for Kicker Systems workshop 2023

A 2.5kA modulator for the European XFEL injector

Joachim Kahl

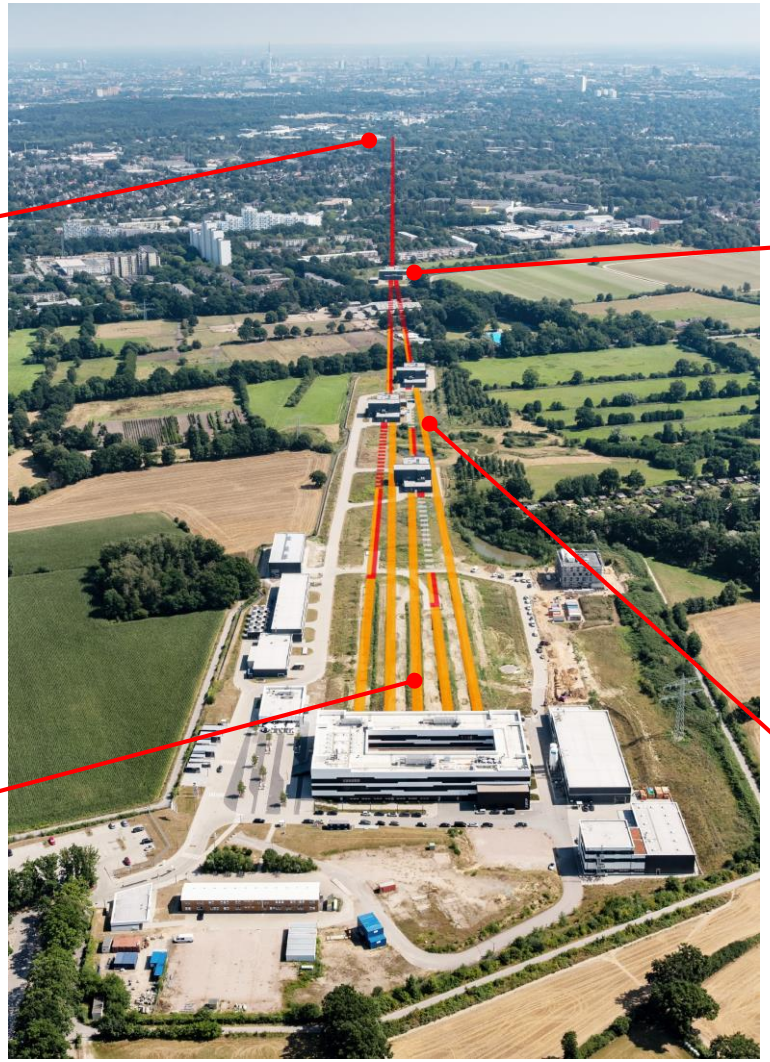
DESY Hamburg, 24.–26. April 2023

HELMHOLTZ

DESY.

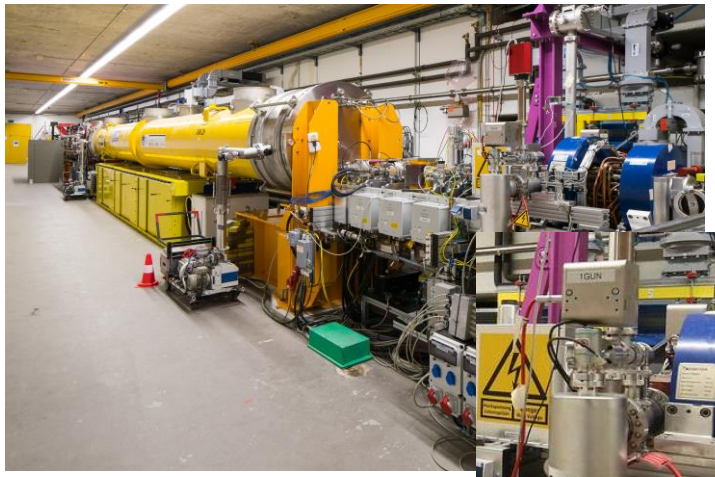
European XFEL - X-ray Free Electron Laser in Hamburg

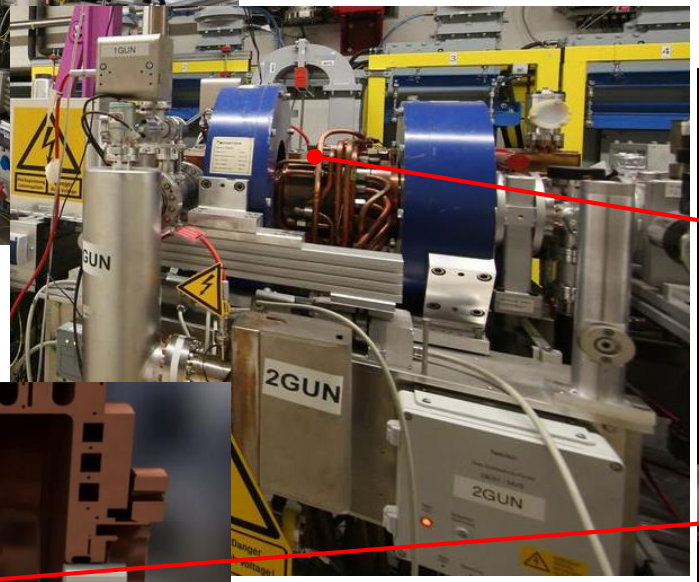
Eu. XFEL site overview

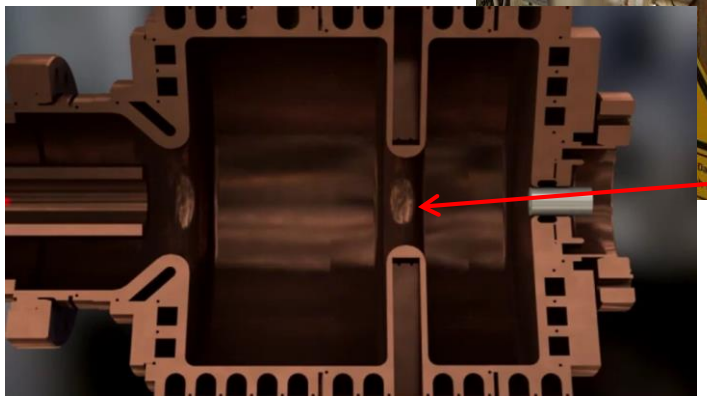


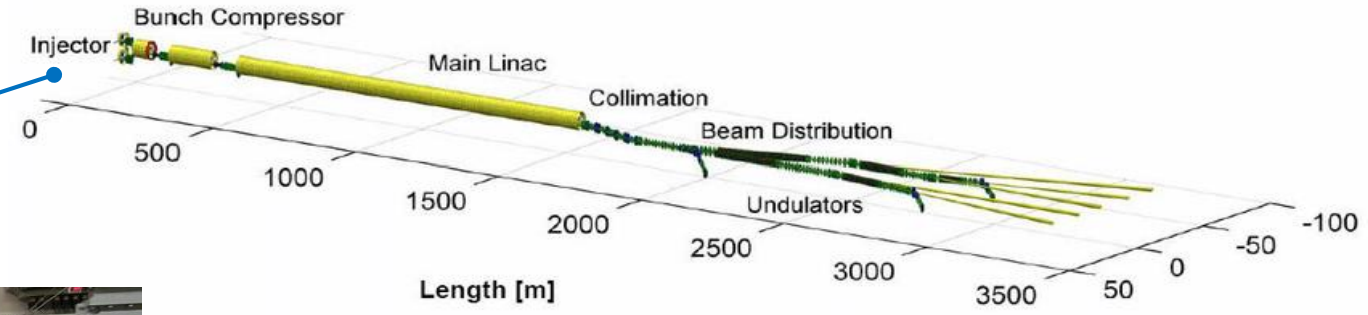
European XFEL - X-ray Free Electron Laser in Hamburg

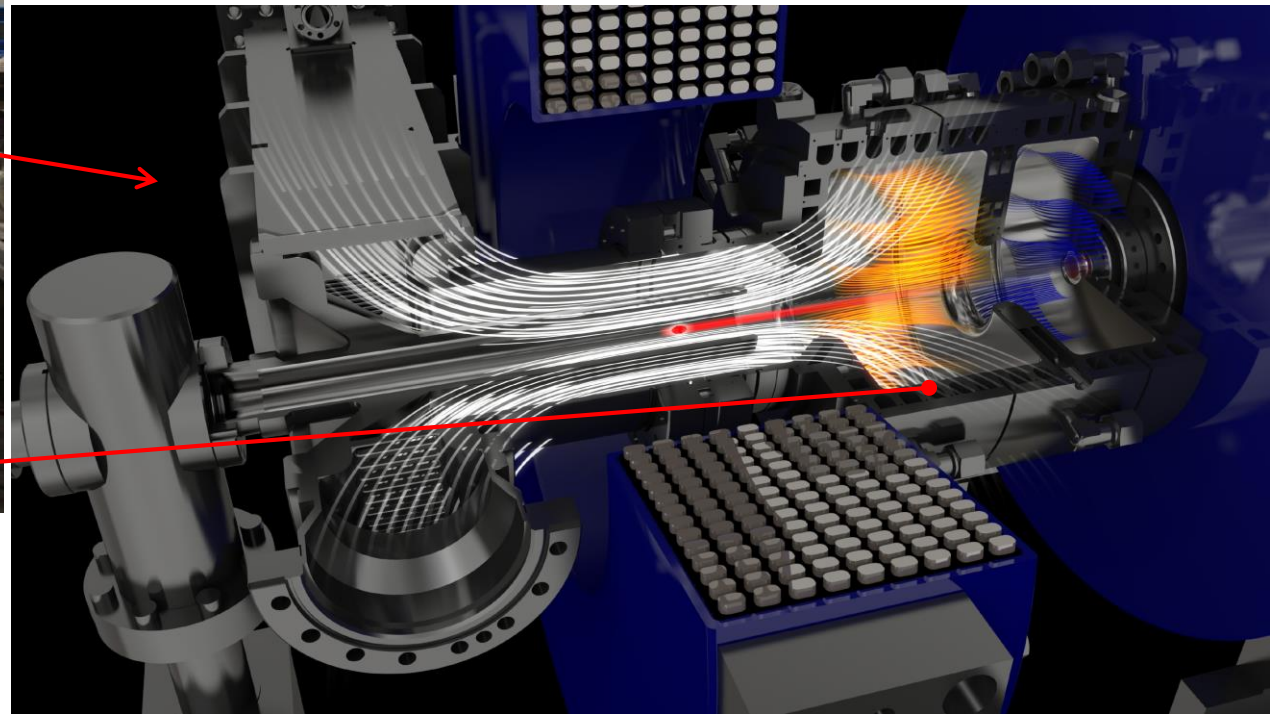
The electron source





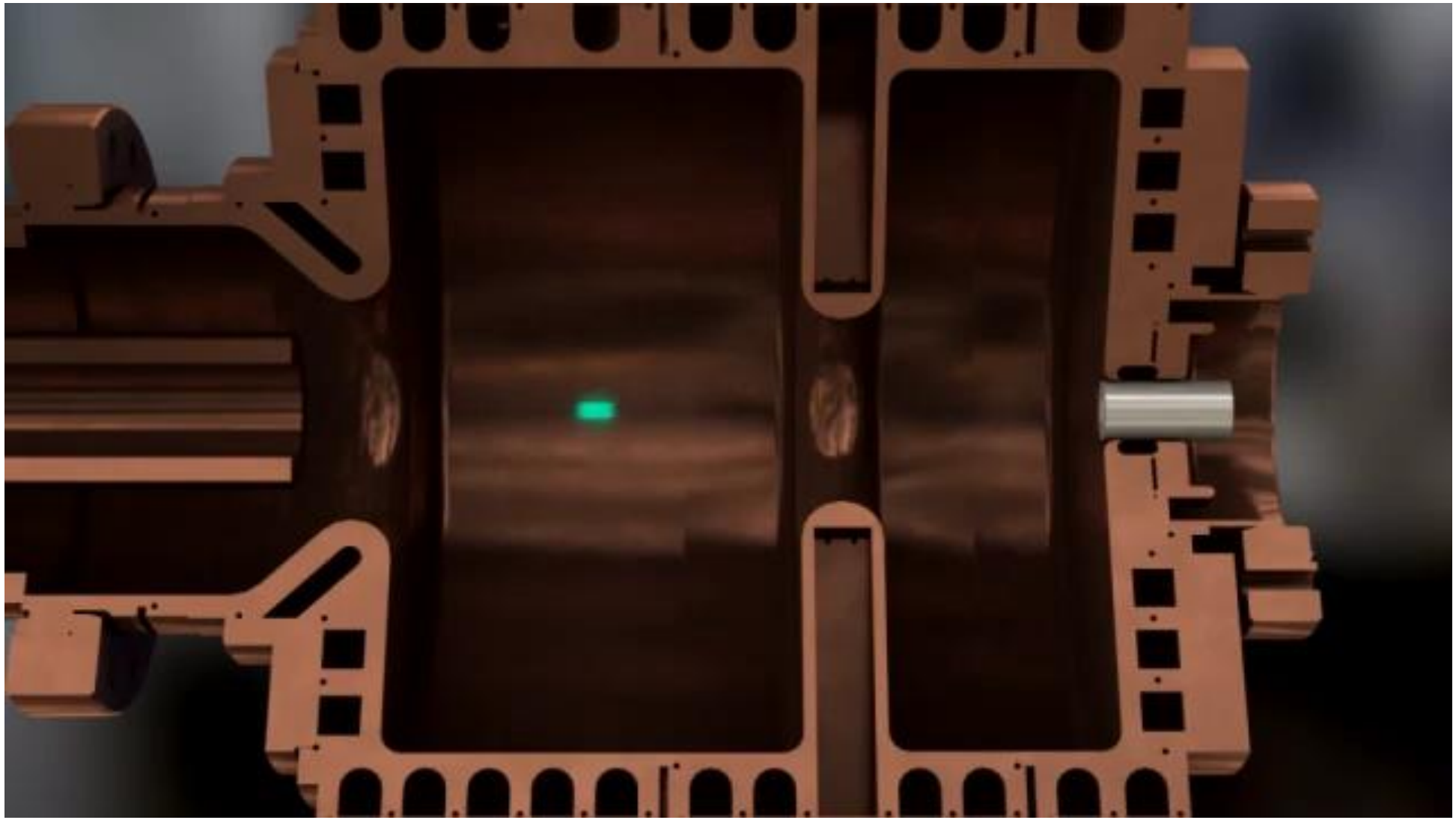






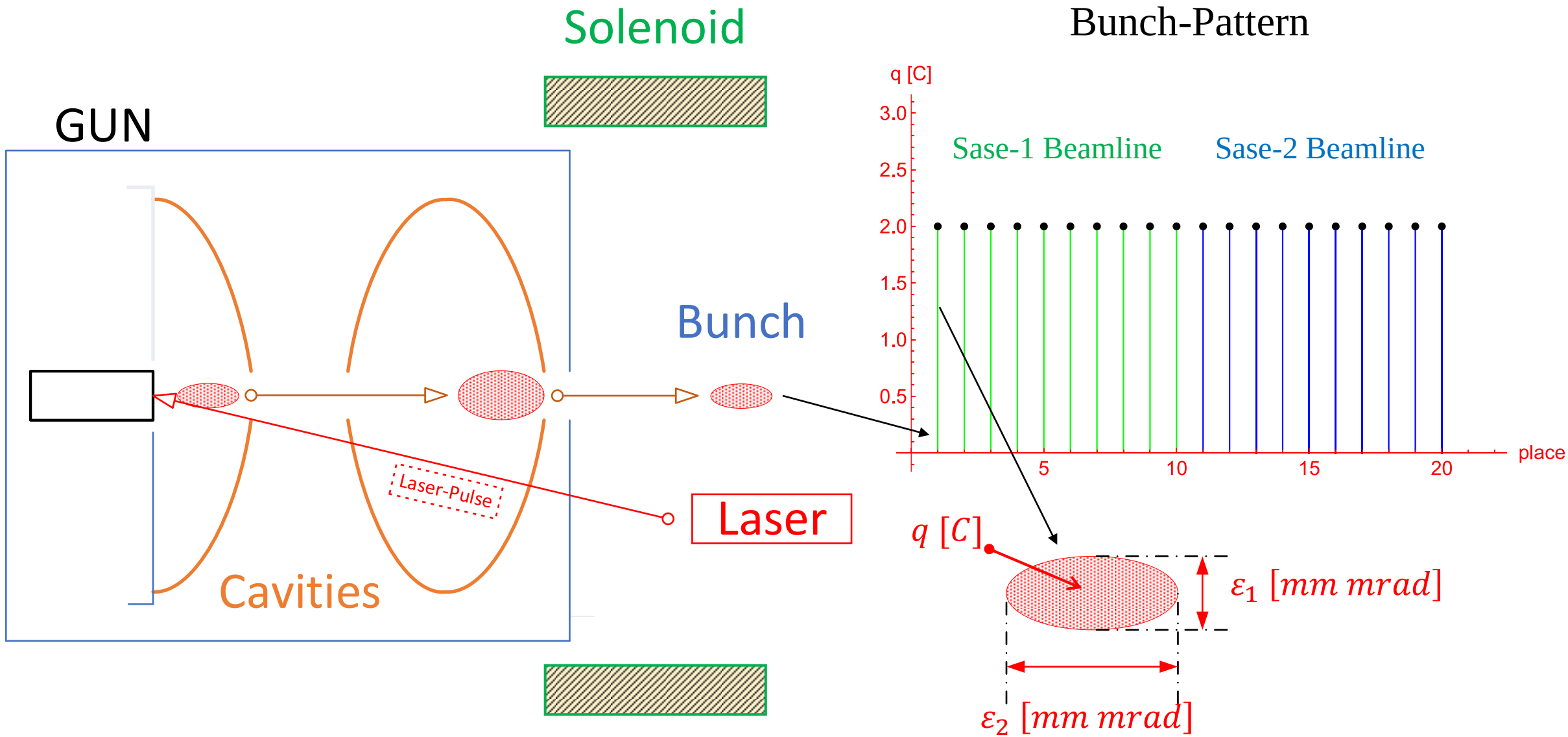
European X-FEL Gun

Eu. XFEL gun working principle



European X-FEL Gun / Solenoid

Gun solenoids role for beam emittance



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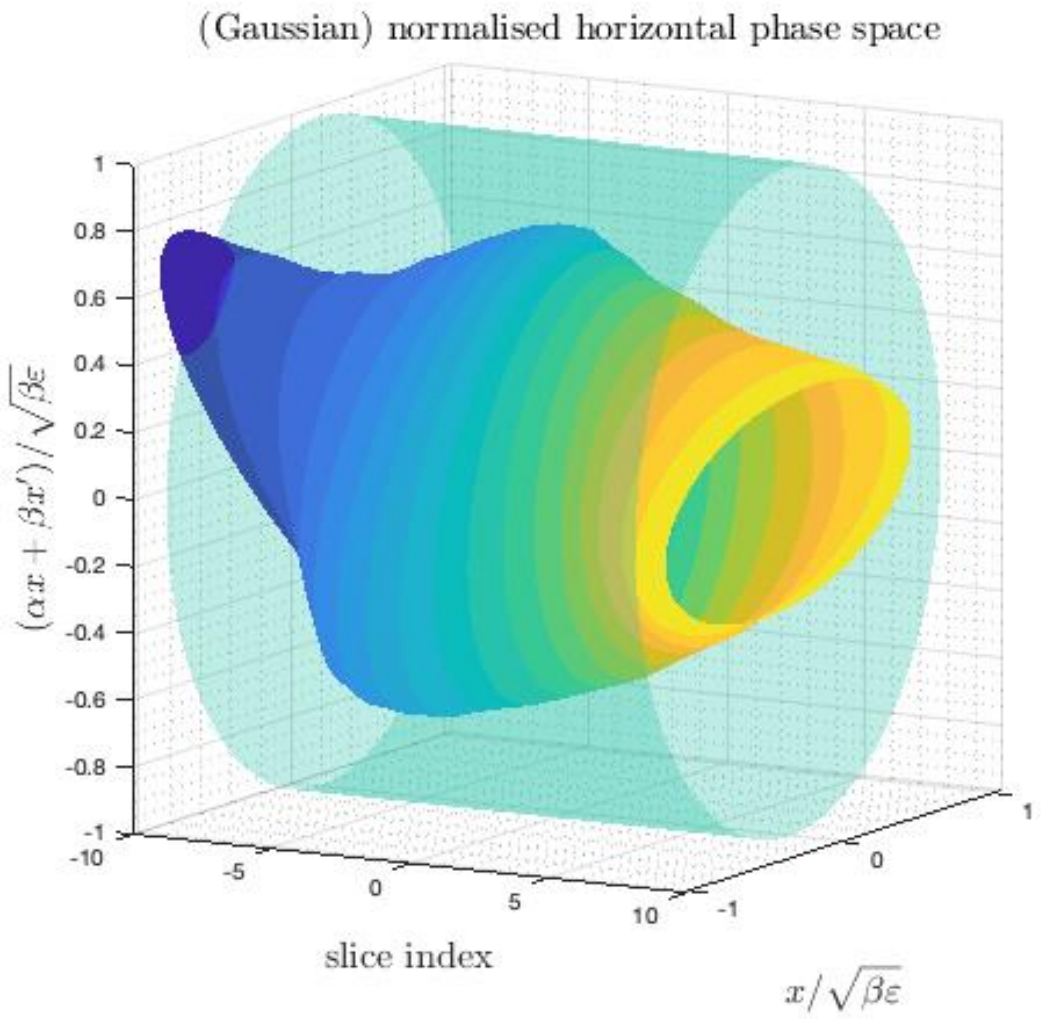
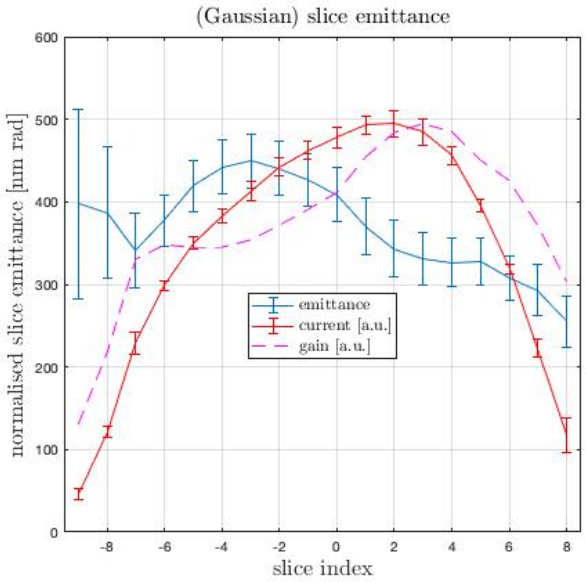
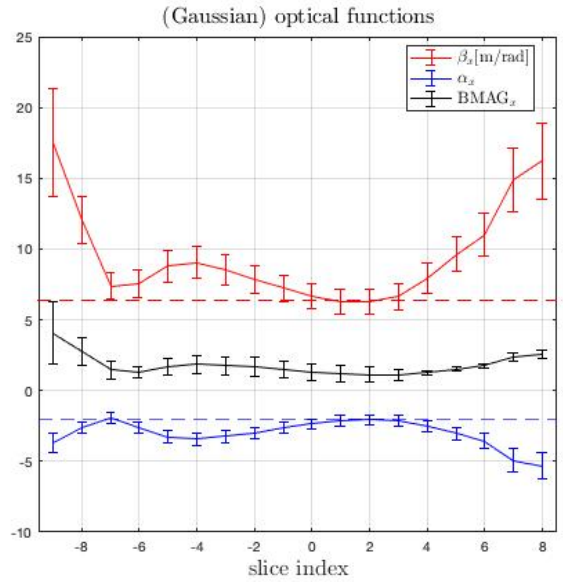
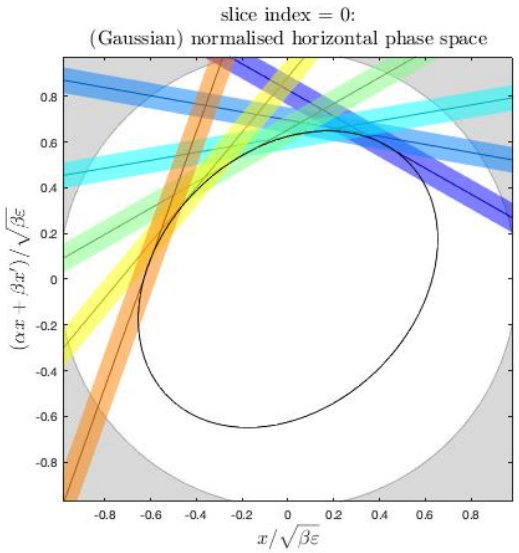




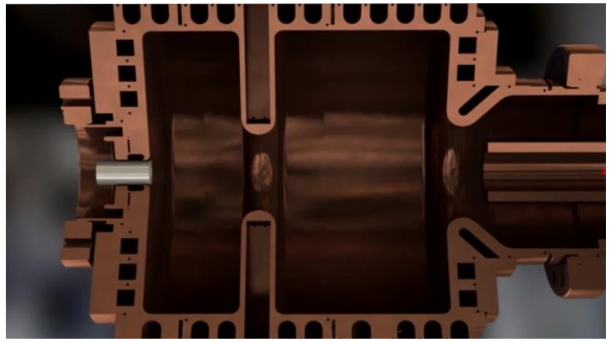


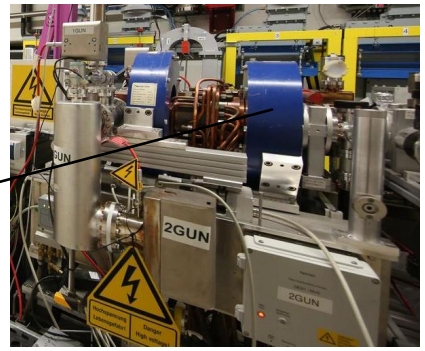


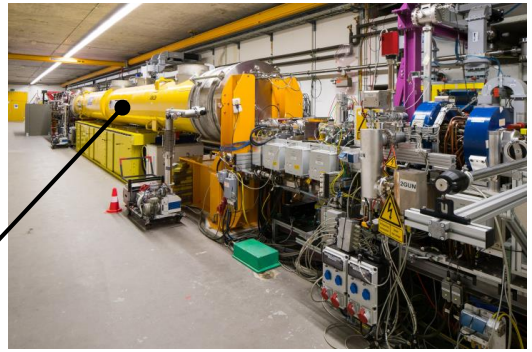
European X-FEL Gun / Solenoid

Space charge & beam dynamics

Main solenoid current
DC < 400 A



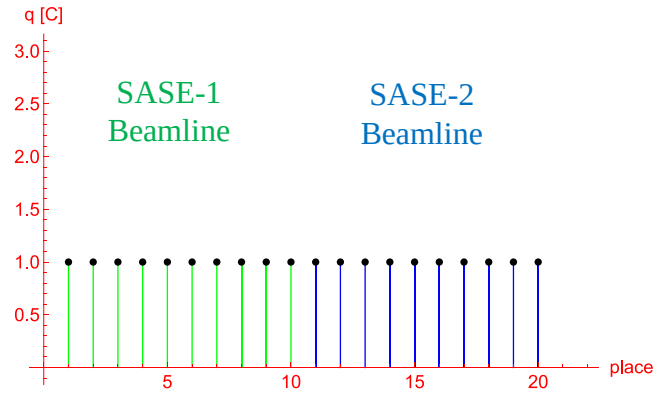




A1 – Cavity Modul

$\varepsilon_1\ [mm\ mrad]$

$q\ [C]$



s $[mm]$

European X-FEL Gun / Solenoid

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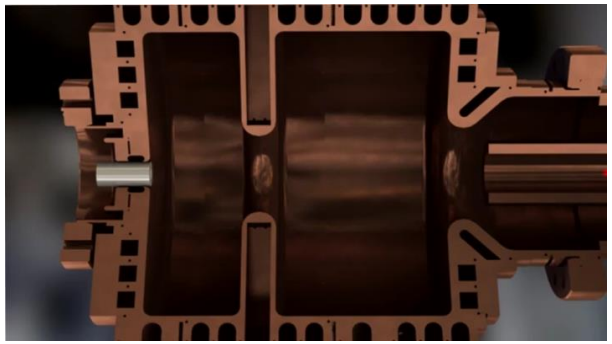
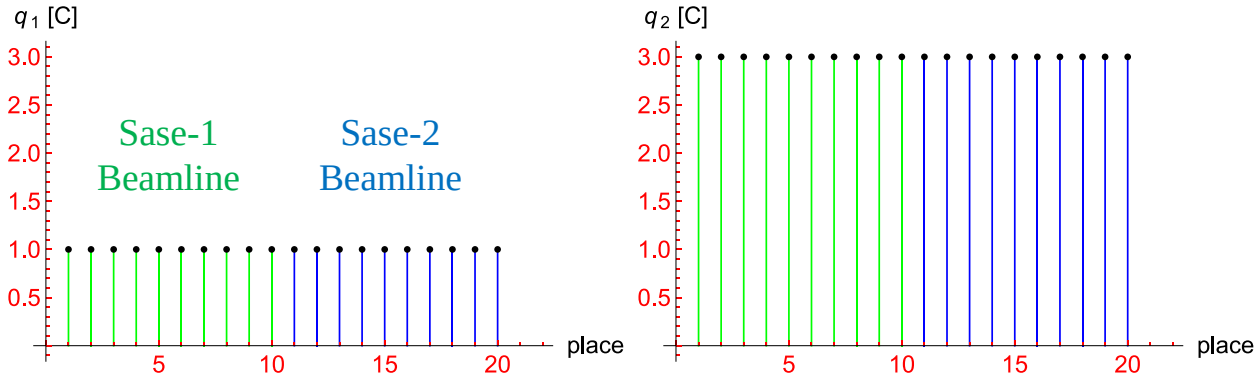
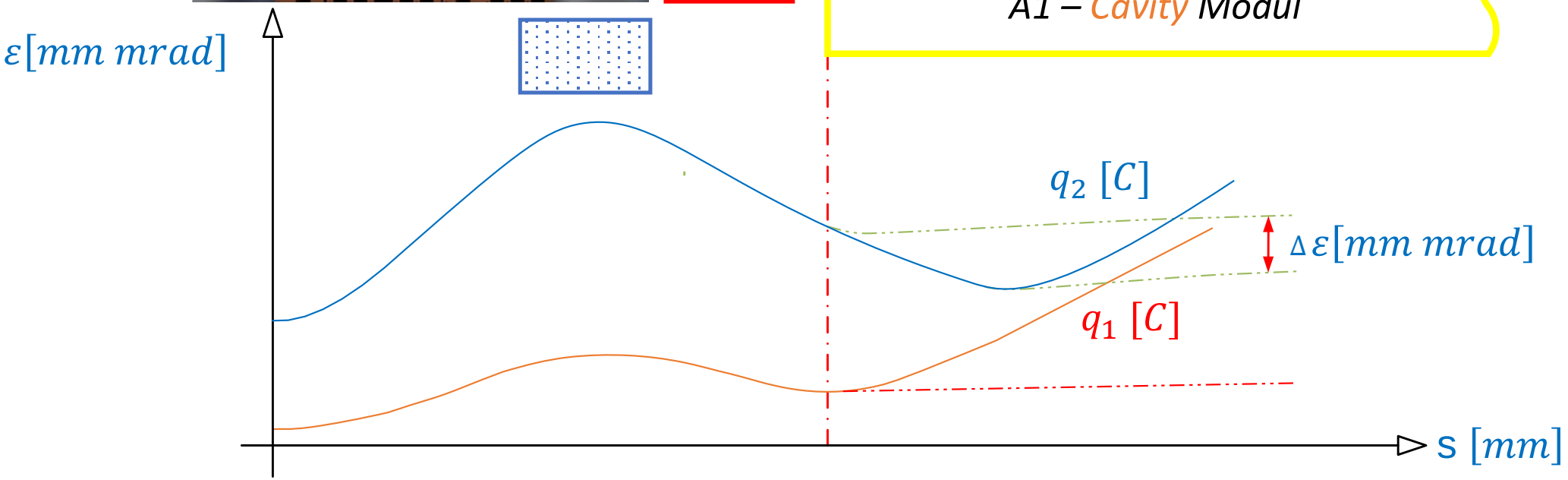




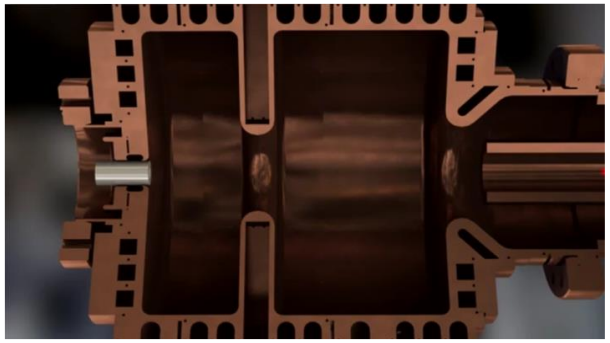
A1 – Cavity Modul

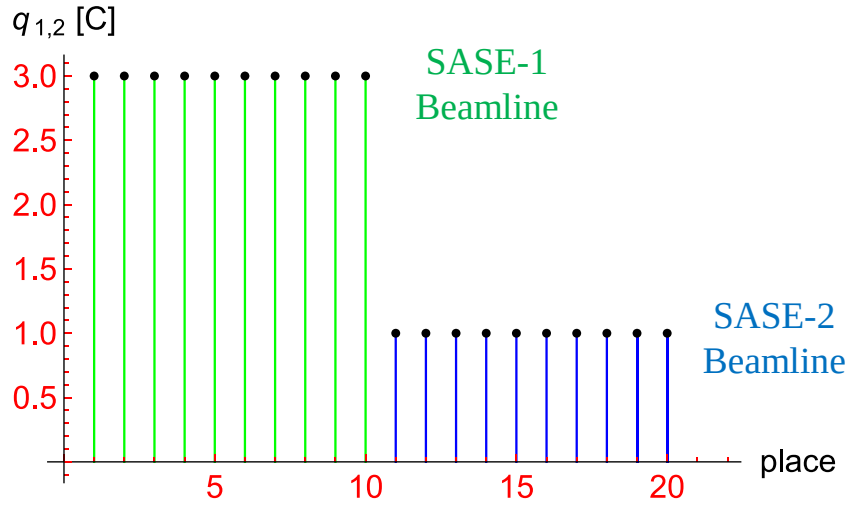


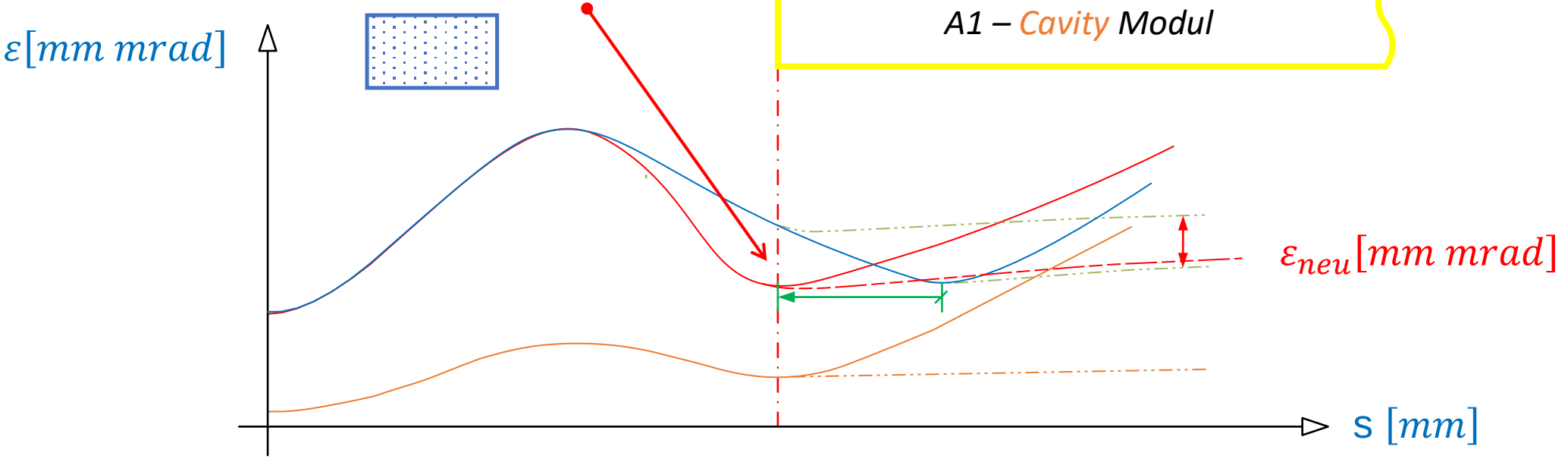
European X-FEL Gun / Solenoid

Space charge & beam dynamics

Main solenoid current
DC < 400 A

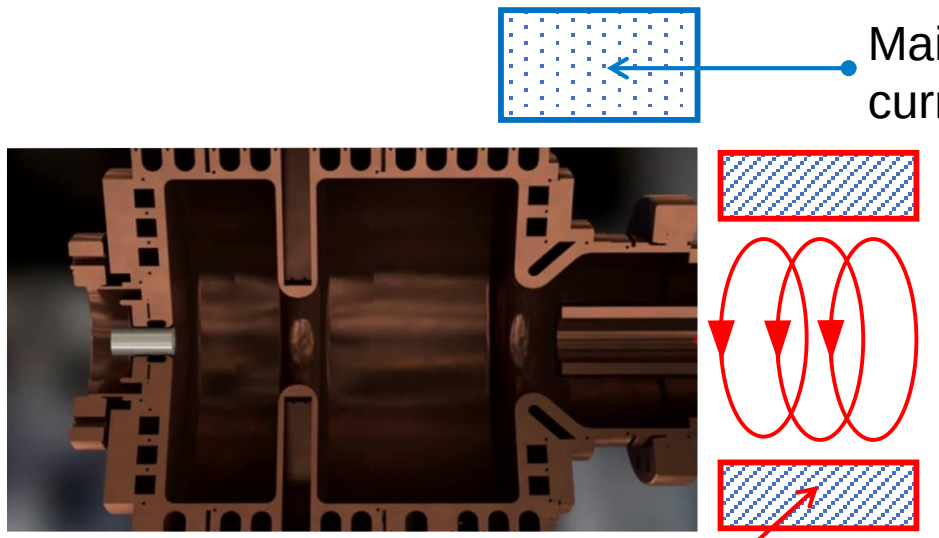


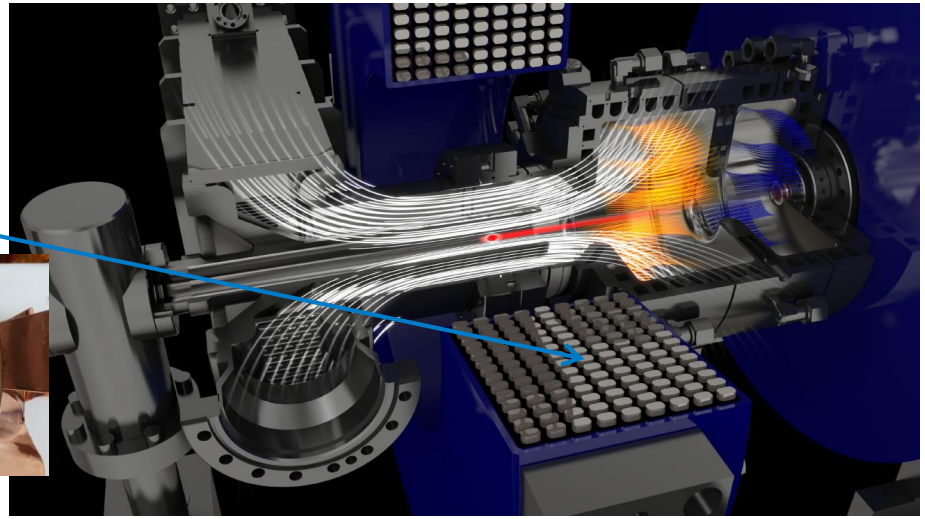




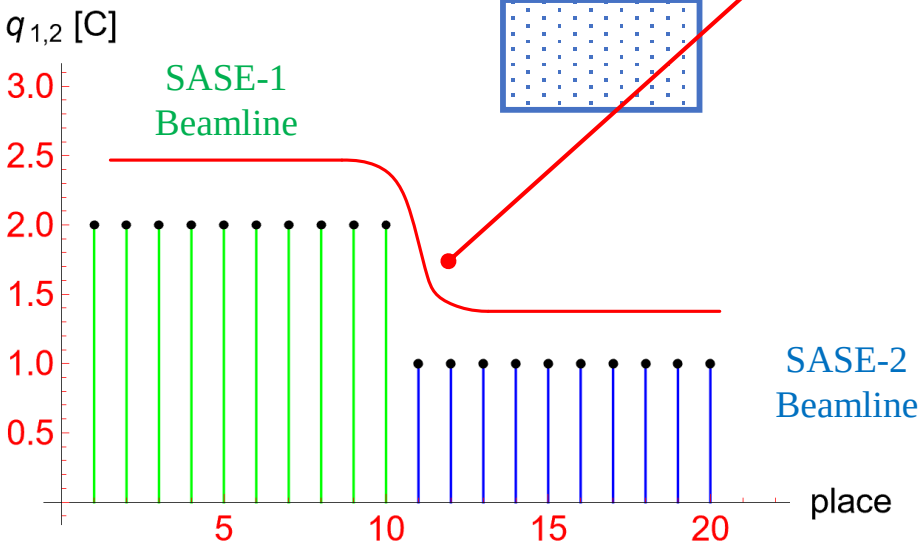
European X-FEL Solenoid 2.5kA Modulator

Modulator parameters





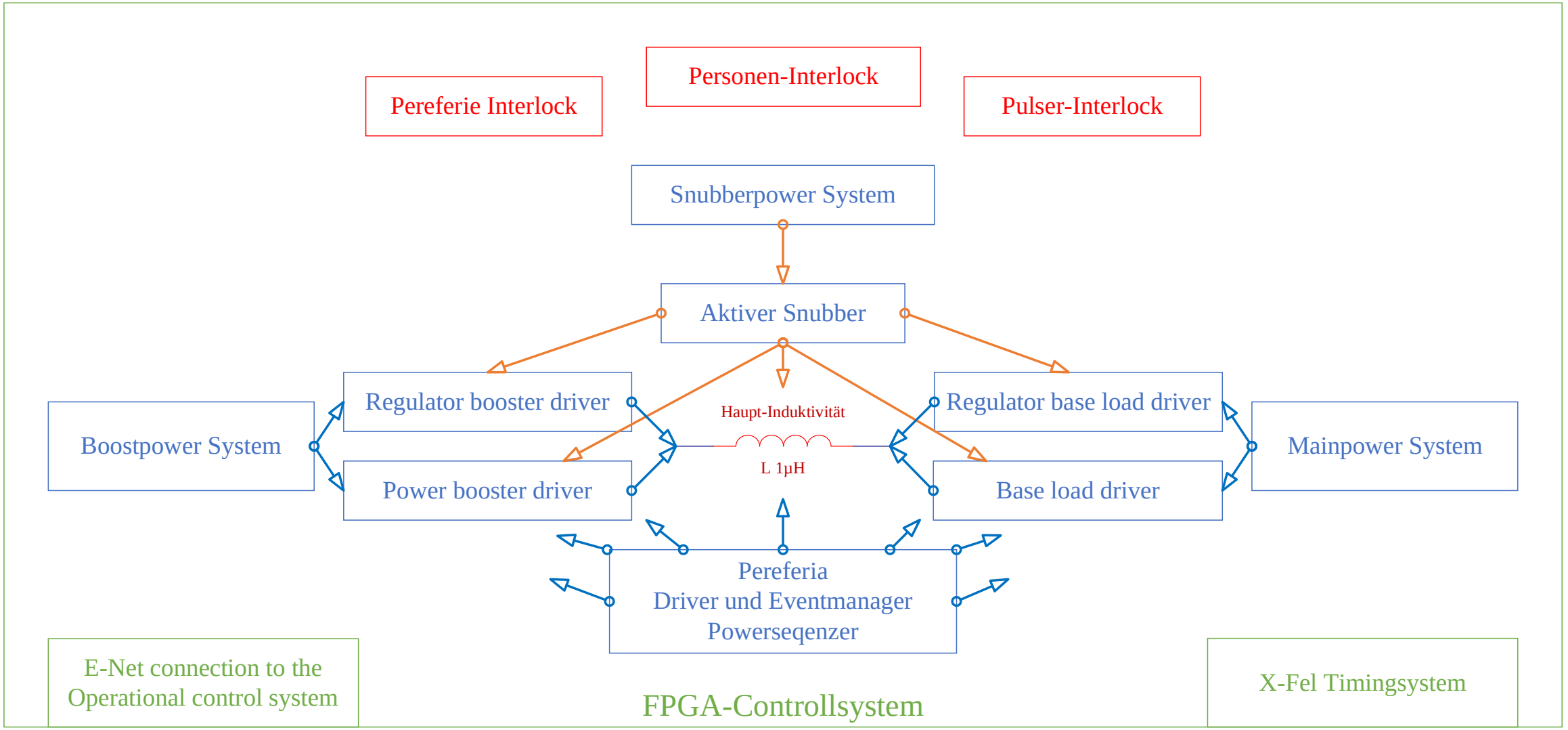
Main solenoid
current DC < 400A



- **Solenoid Modulator**
- Current 0..2500A
- Pulse modulation possible yes
- Pulse to pulse regulation yes
- Pulse width 0..2ms
- Rise Time < 10µs
- Fall Time 2µs .. 4µs
- Pulse to pulse stability $\geq 1 * 10^{-3}$

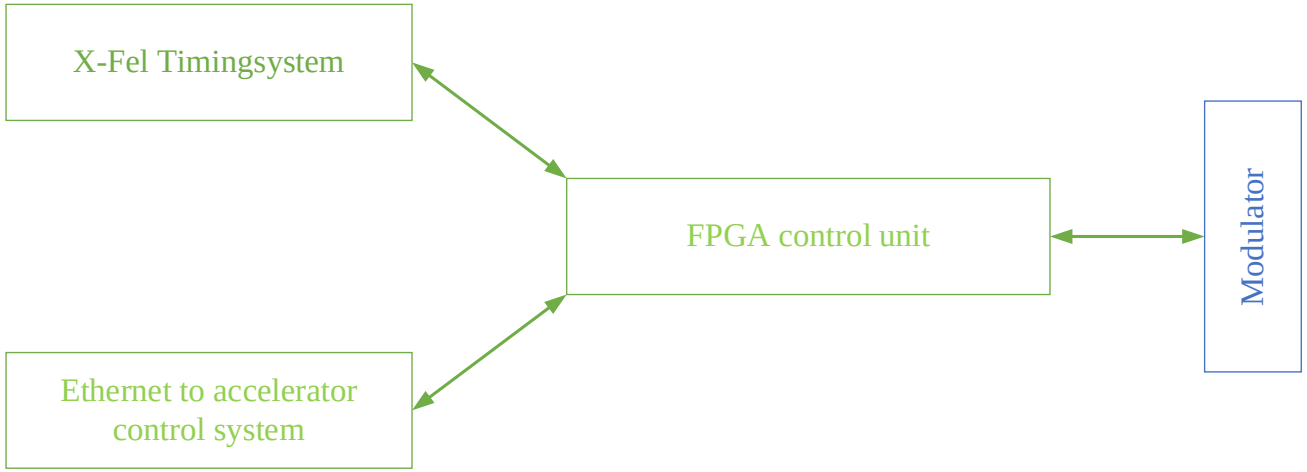
European X-FEL Solenoid 2.5kA Modulator

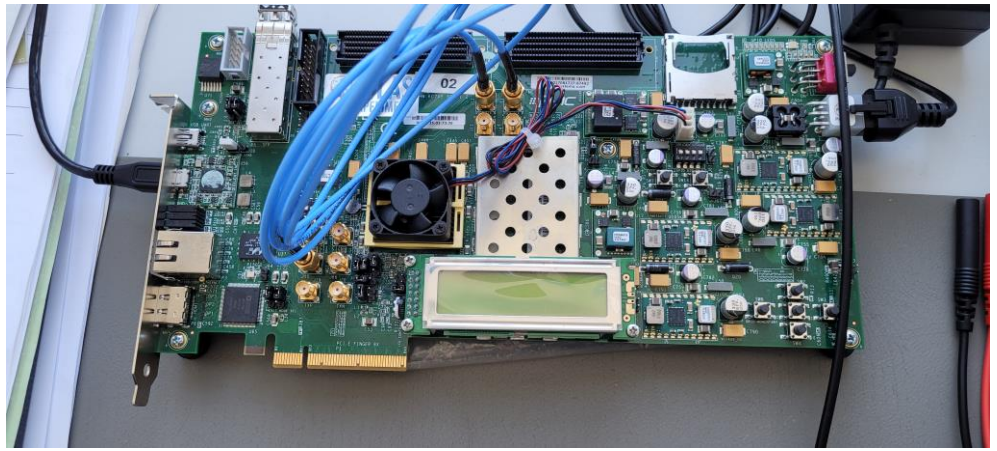
Schematic flow chart

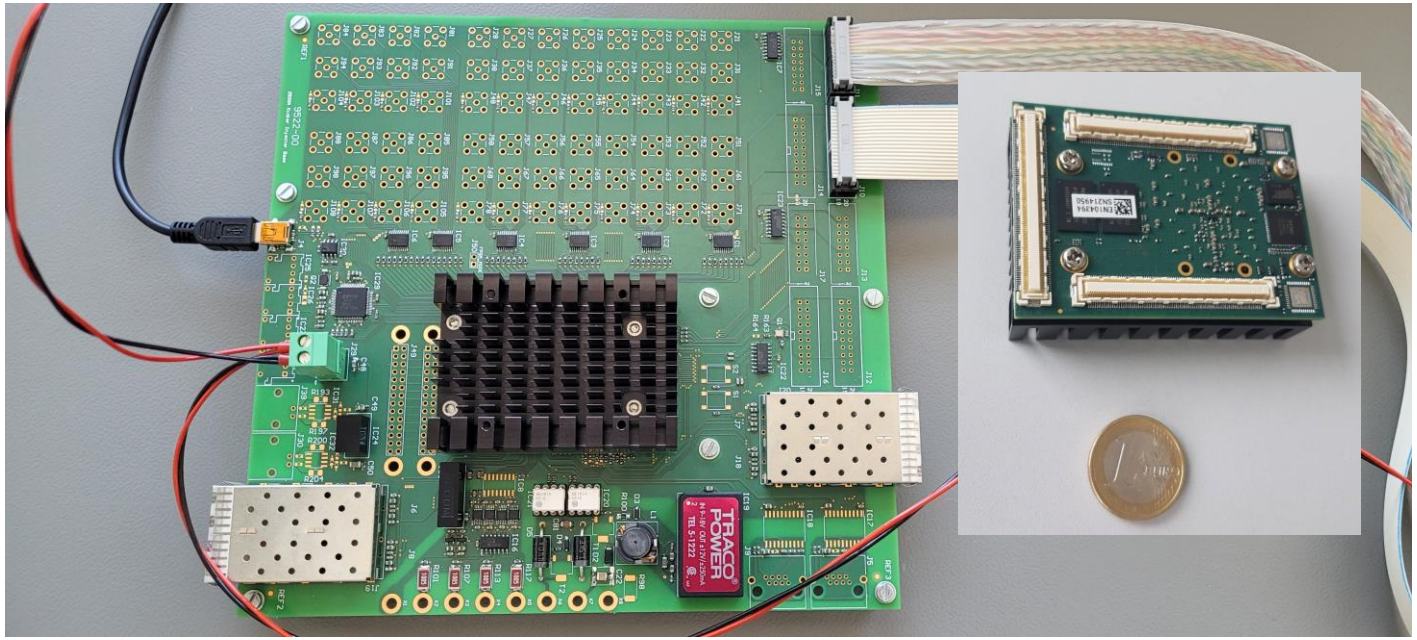


European X-FEL Solenoid 2.5kA Modulator

Modulator 2.5kA FPGA-Control unit





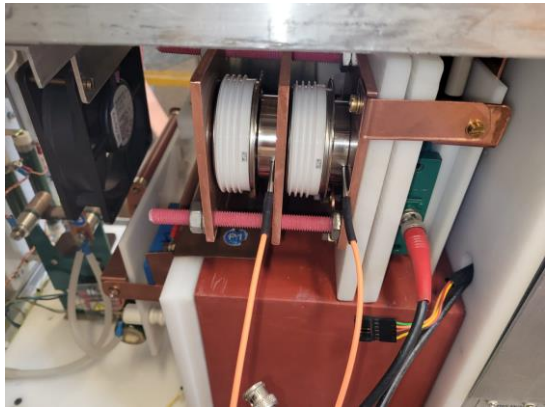


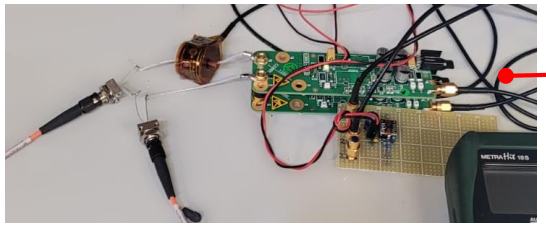
"Mercury KX2" FPGA module by Enclustra on main board

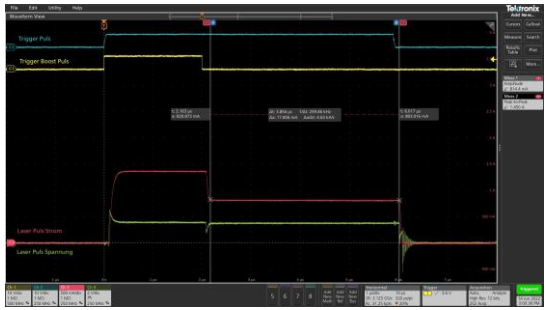
FPGA Type: Xilinx Kintex-7

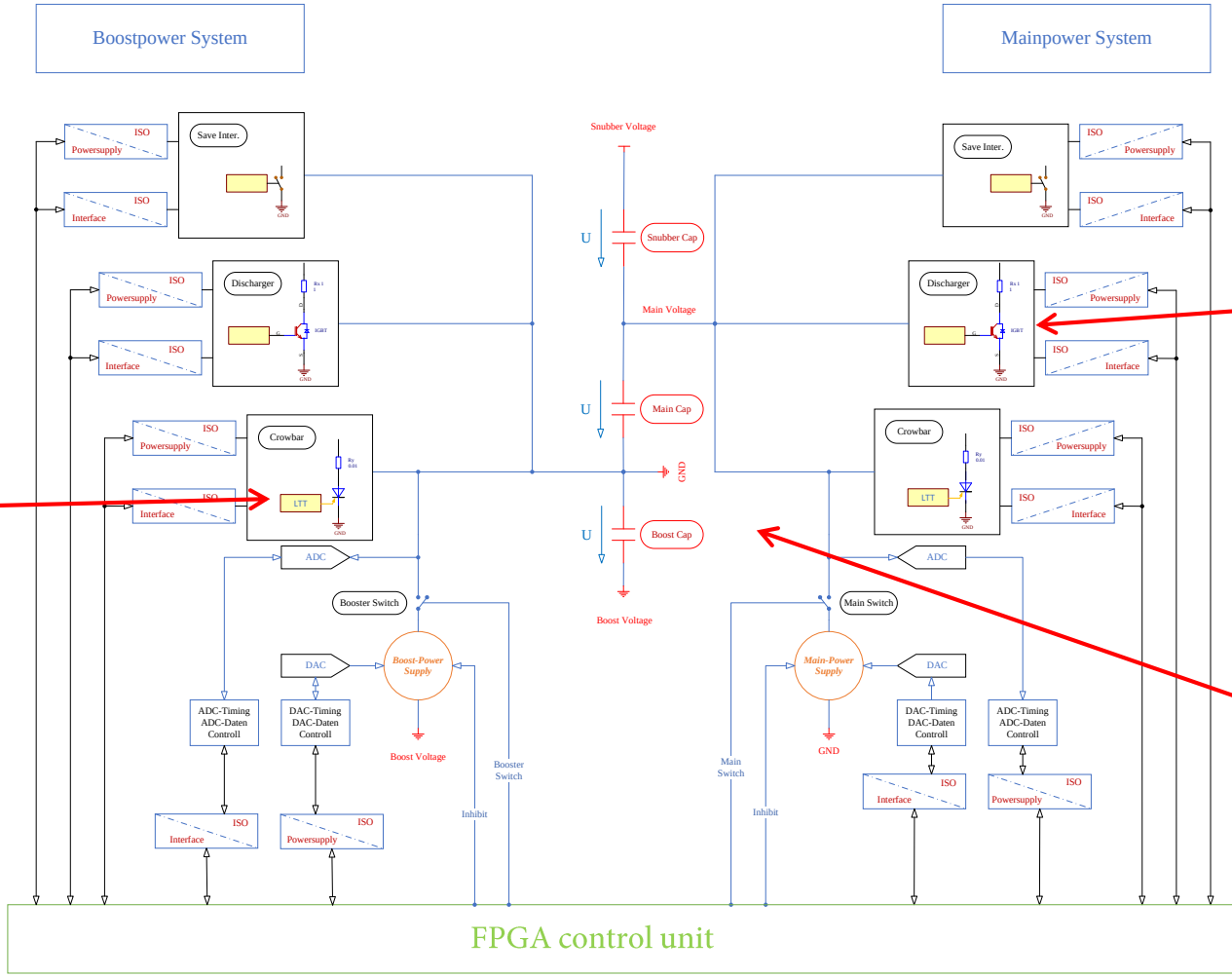
European X-FEL Solenoid Modulator 2.5kA

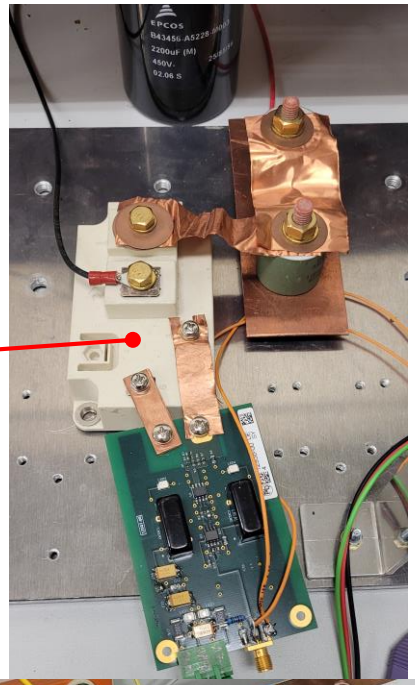
Modulator 2.5kA Boost-power / Main power

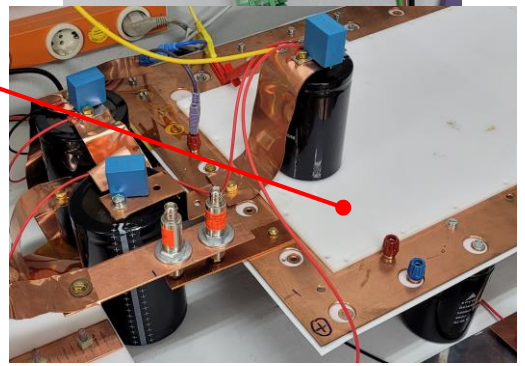






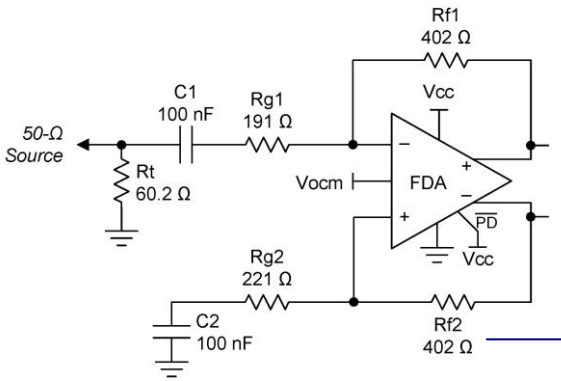


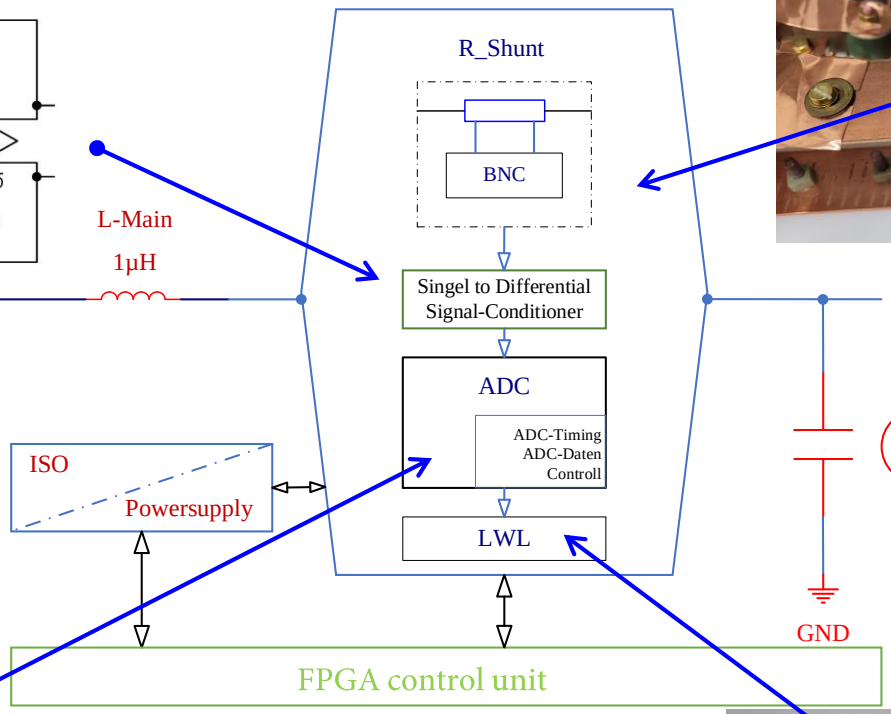


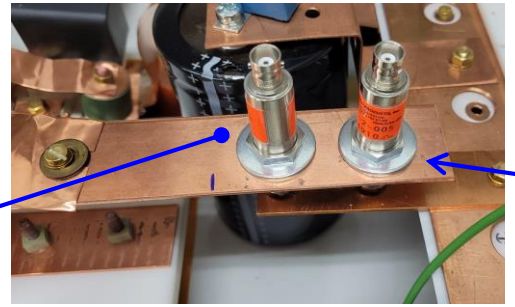


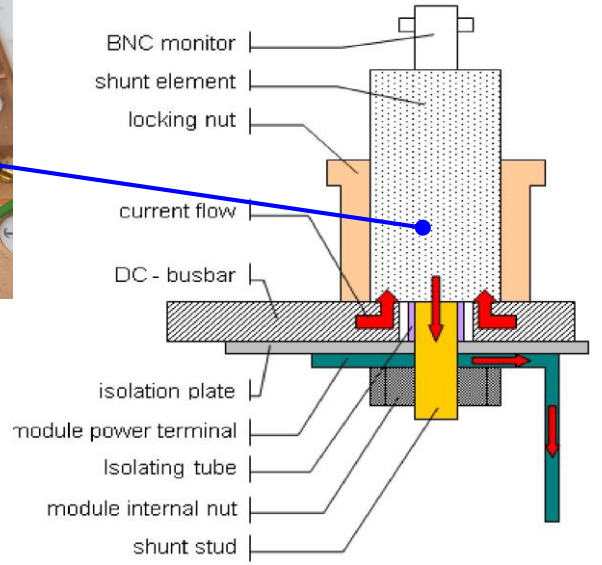
European X-FEL Solenoid 2.5kA Modulator

Modulator 2.5kA current monitoring



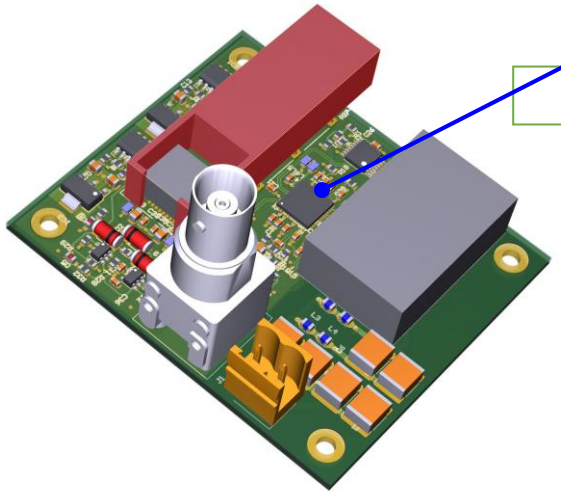






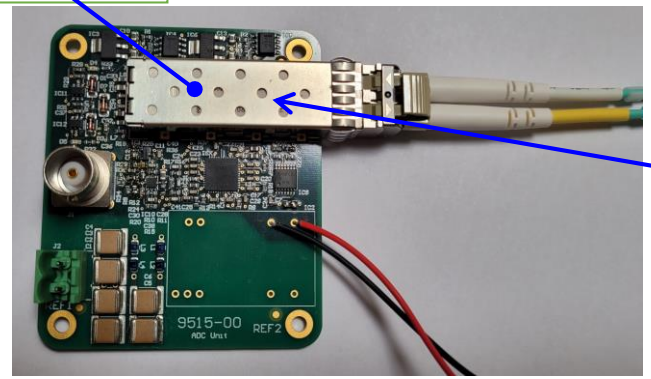
THS4541IRUNT

- Negative Rail Input
- Rail-to-Rail Output, Precision
- 850-MHz
- Fully Differential Amplifier

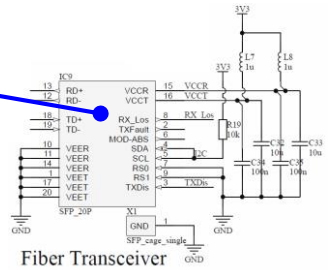


Analog-to-Digital Converters

- ADC32J4x
- Dual-Channel
- 14-Bit
- 50-MSPS to 160-MSPS

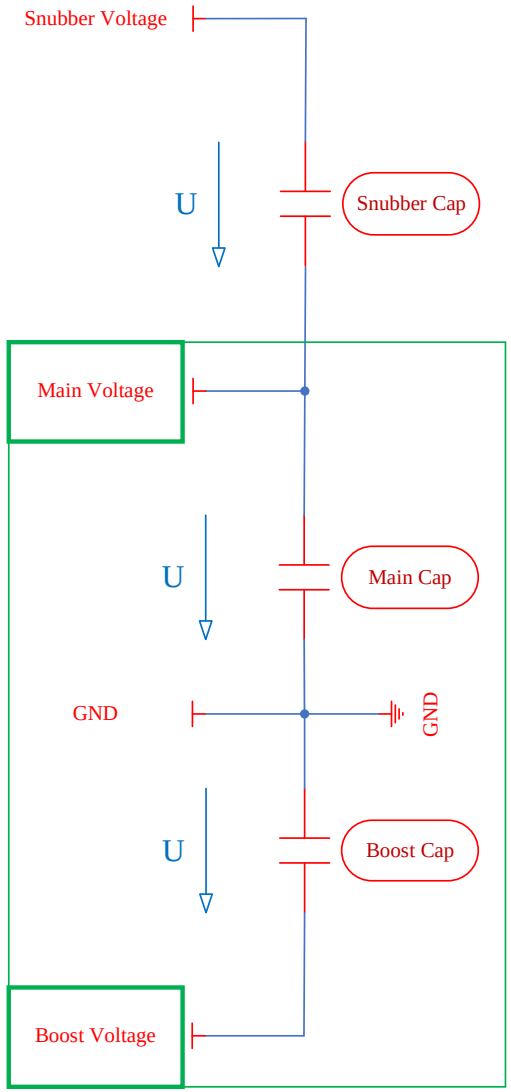


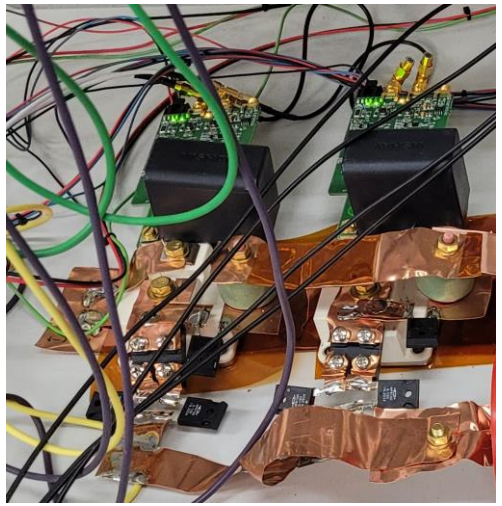
A Series - SBNC Series		
Resistance	Ω	0,005
Bandpass	MHz	200
Risetime	nsec	2
Emax	Joules	15



European X-FEL Solenoid 2.5kA Modulator

Modulator 2.5kA power booster driver





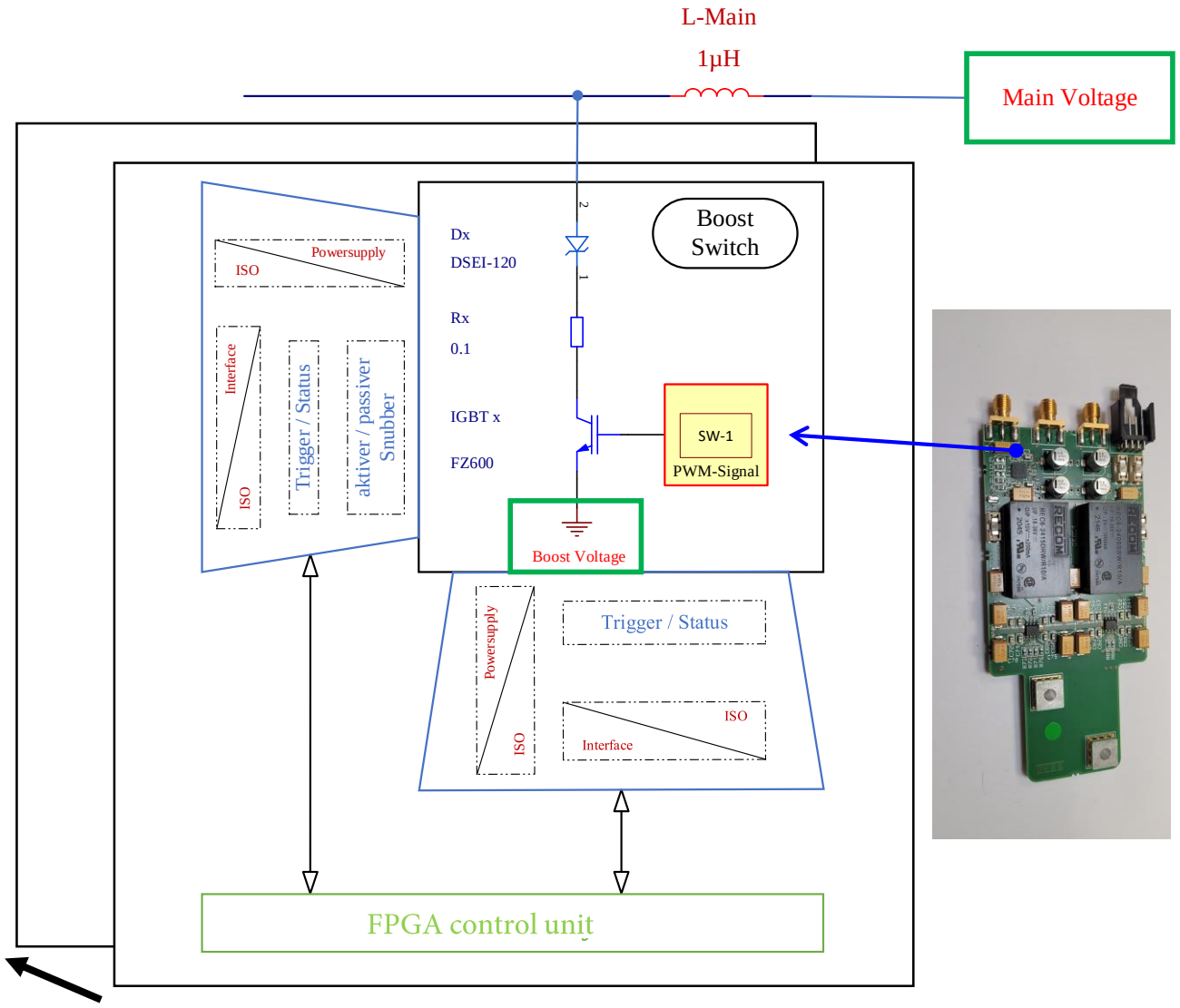
here only 2 elements in the test setup

ideal

$$U_L = -L\frac{d\,i(t)}{dt}$$

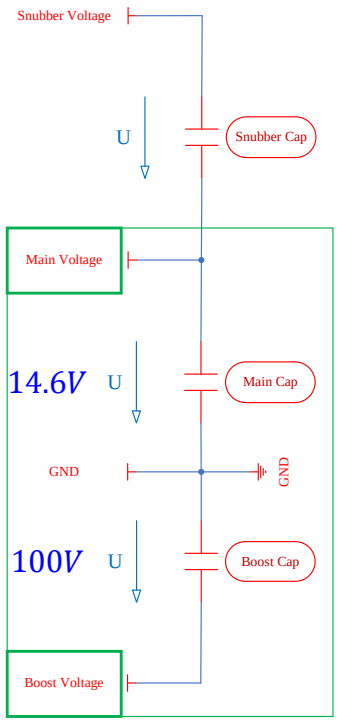
$$U_L = \left|-1\mu H\,\frac{2500A}{10\mu s}\right| = 250V$$

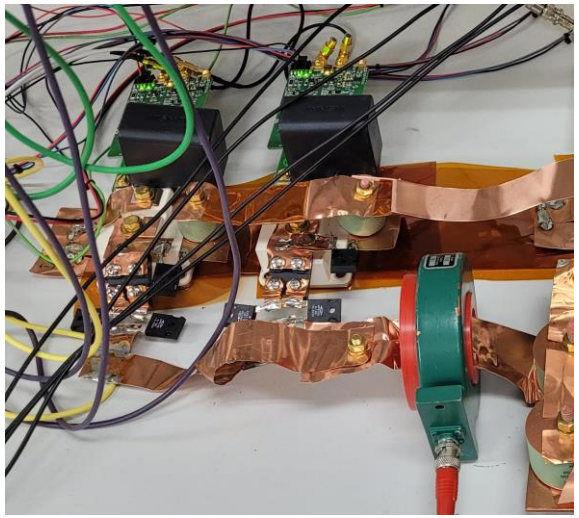
There are 8 elements in the modulator

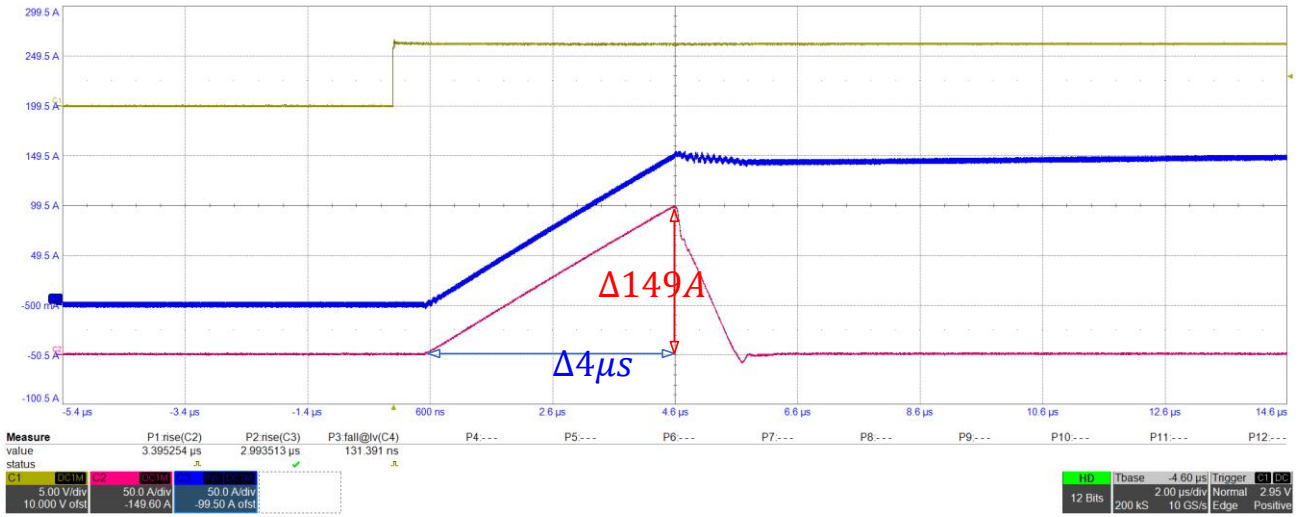


European X-FEL Solenoid 2.5kA Modulator

Modulator 2.5kA power booster driver







Inductance estimate

$$U_L = -L\frac{d\,i(t)}{dt}$$

$$L = \frac{|U_L| \times dt}{d\,i(t)}$$

$$L \approx \frac{|100V + 14.6V| \times 4\mu s}{149A} \approx 3.07\mu H$$

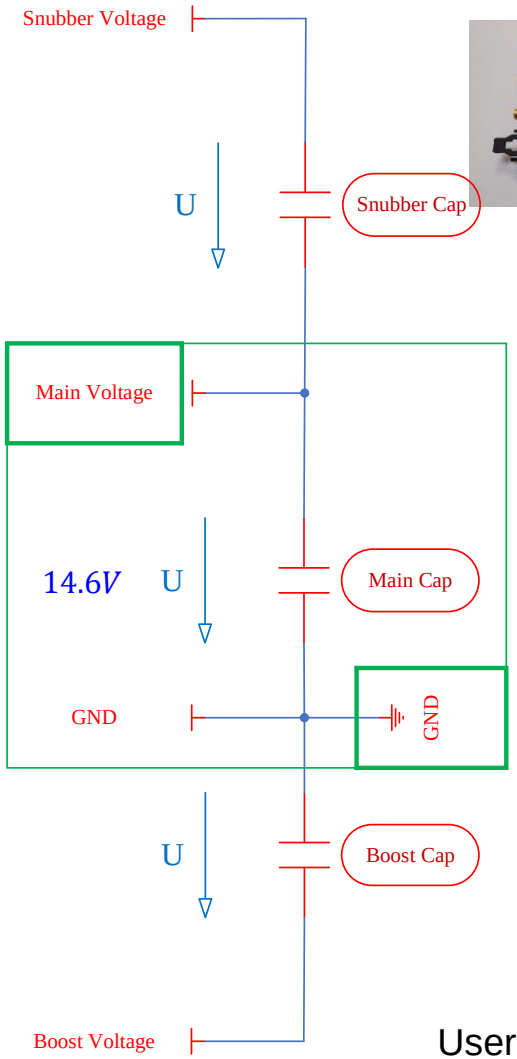
Load voltage (incl. realistic inductance)

$$U_L = -L\frac{d\,i(t)}{dt}$$

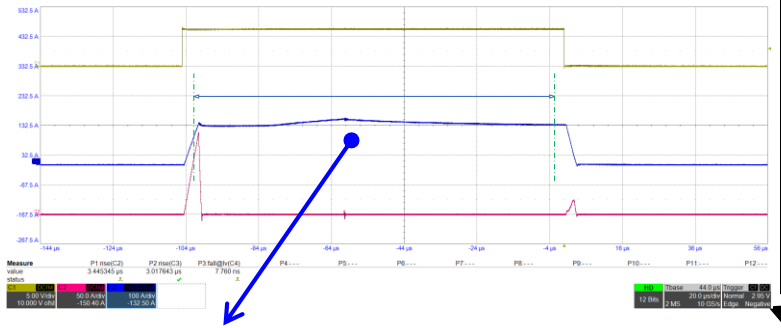
$$U_L = \left|3.07\mu H\,\frac{2500A}{10\mu s}\right| = 767.5V$$

European X-FEL Solenoid 2.5kA Modulator

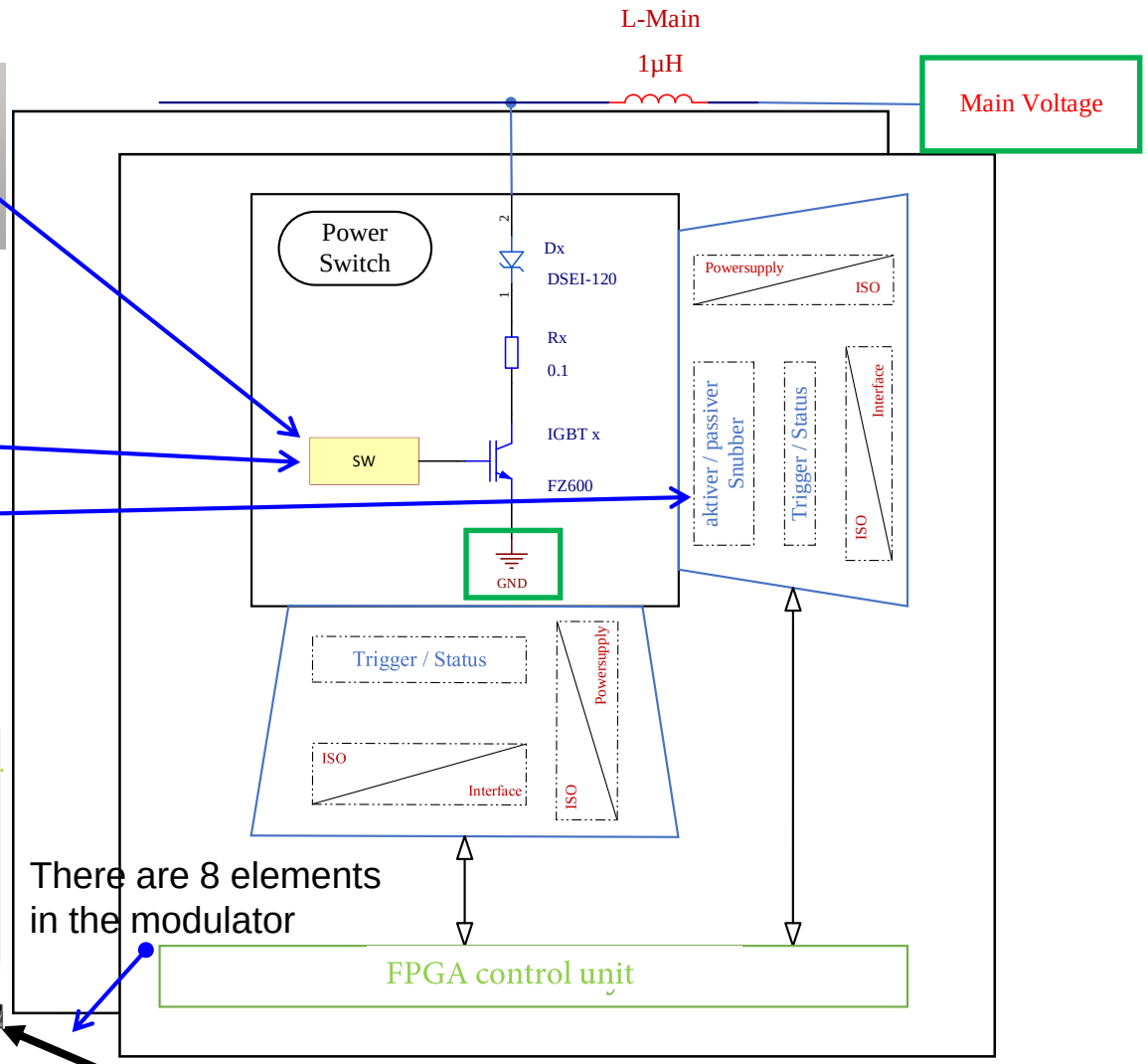
Modulator 2.5kA base load driver



only 3 elements in the test setup



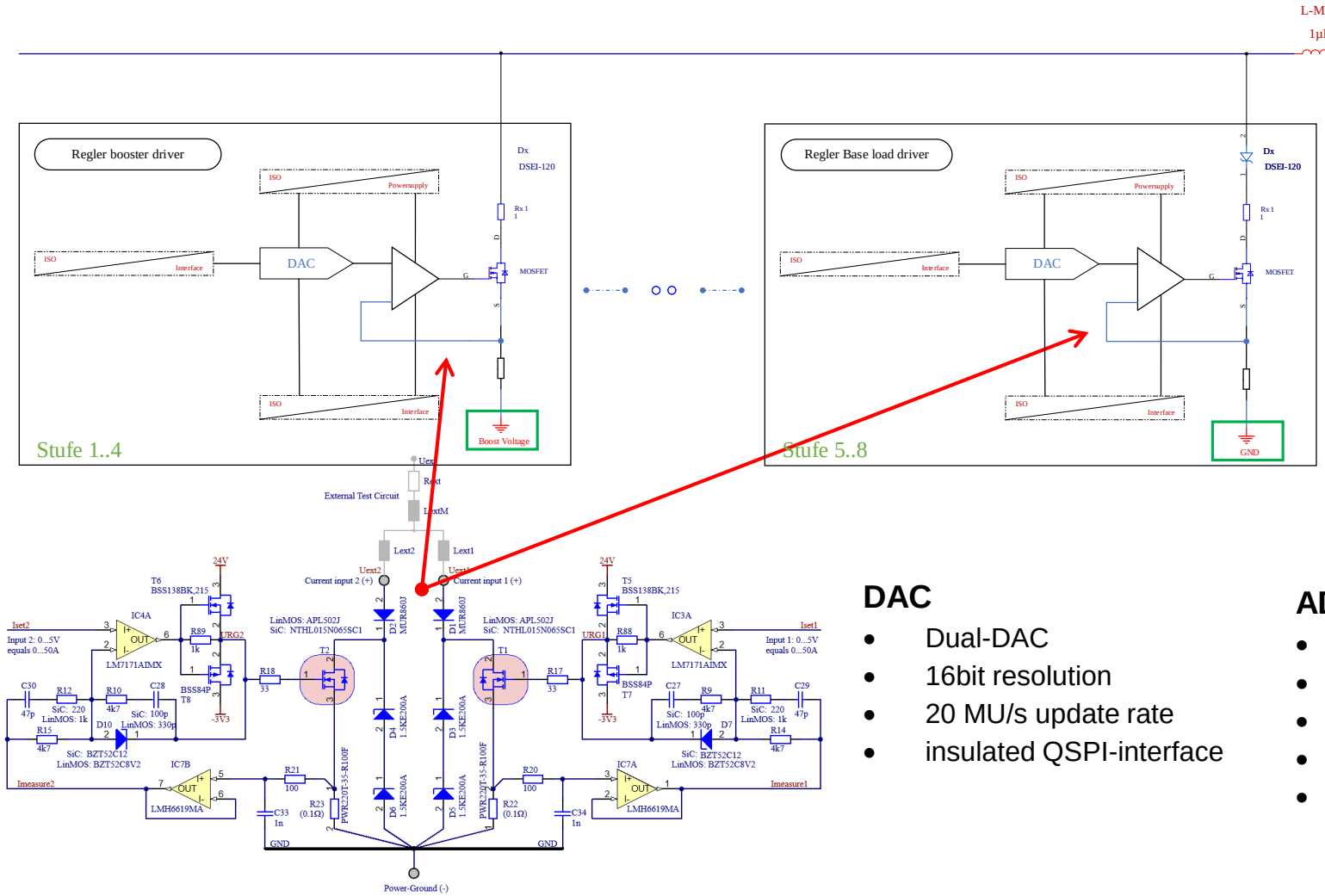
User puls with Modulating

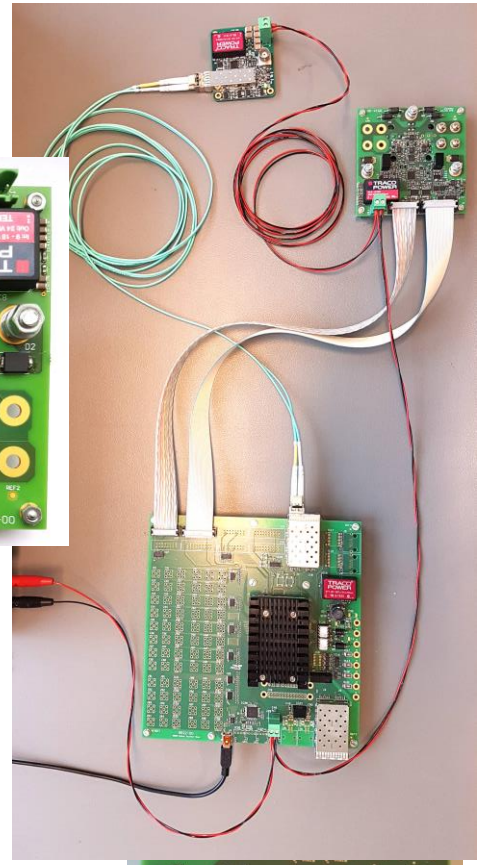


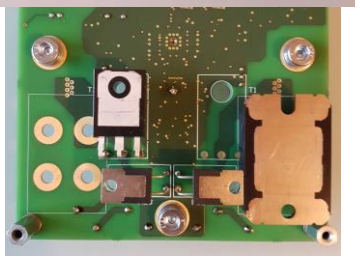
There are 8 elements in the modulator

European X-FEL Solenoid 2.5kA Modulator

Modulator 2.5kA modulation booster / modulation base driver







DAC

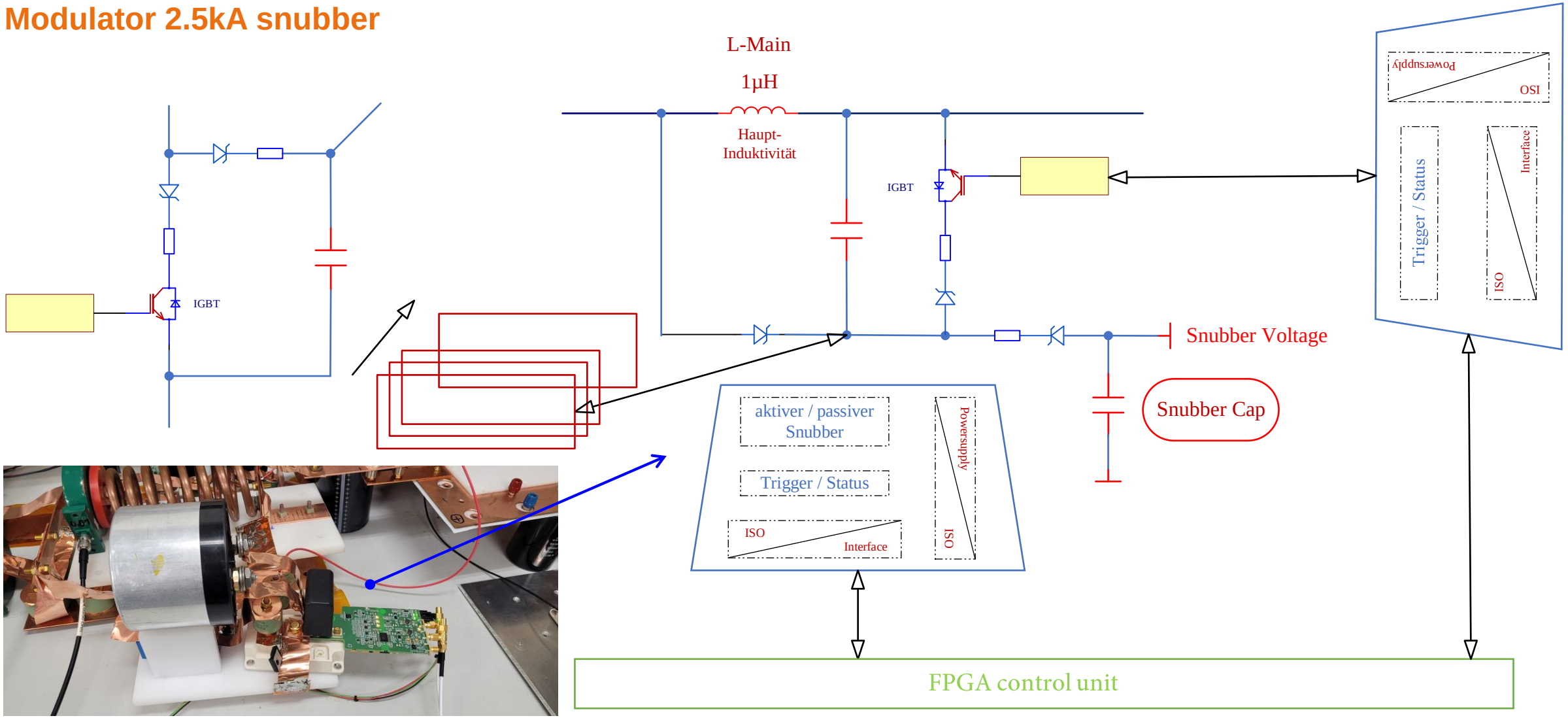
- Dual-DAC
- 16bit resolution
- 20 MU/s update rate
- insulated QSPI-interface

ADC

- Integrated Dual-ADC
- 14bit current monitoring
- 50 MS/s sampling rate
- Insulated LVDS interface
- 2 GBit JESD204B links

European X-FEL Solenoid 2.5kA Modulator

Modulator 2.5kA snubber



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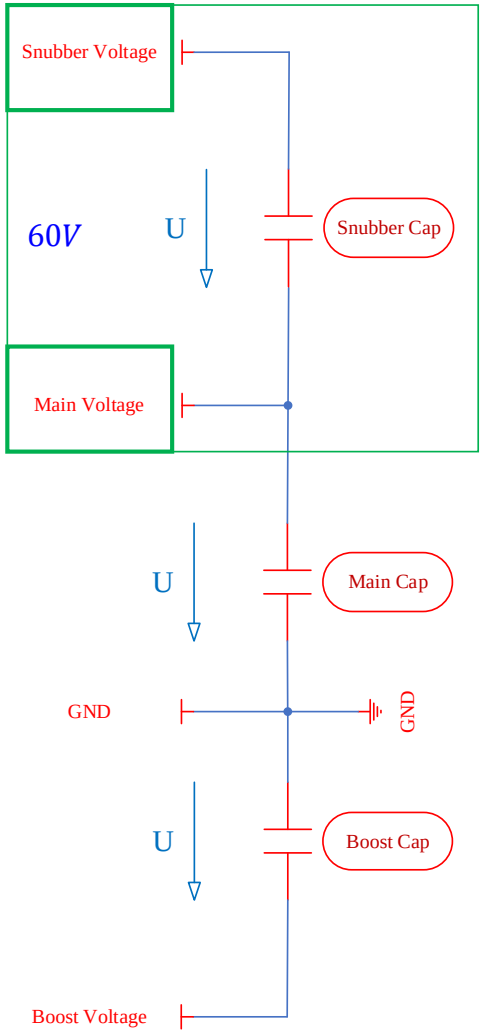
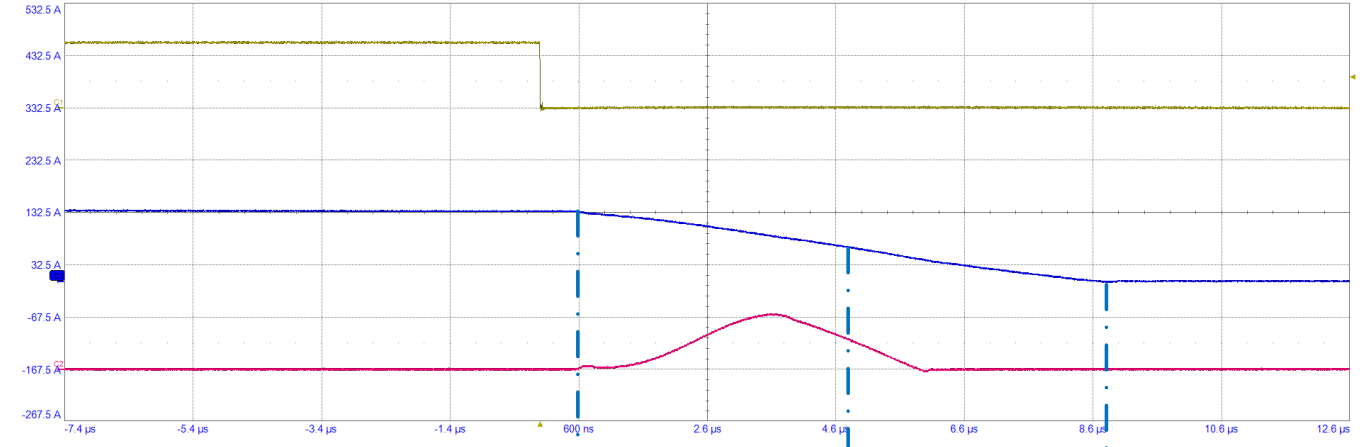
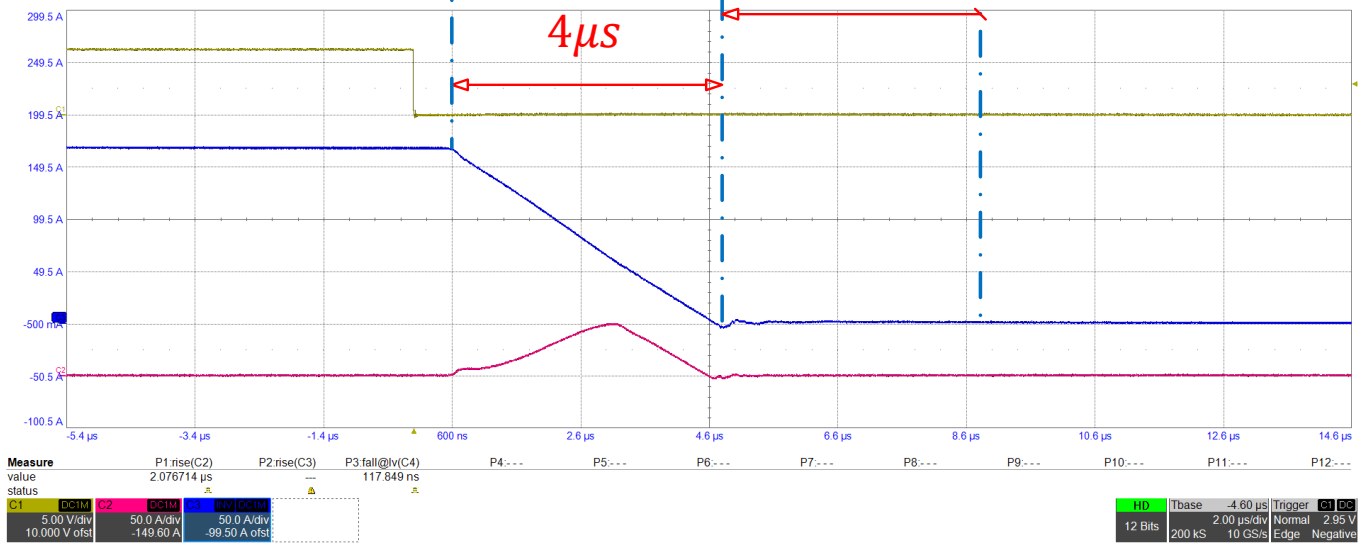


increasing the snubber voltage → switch off time reduced from 8µs to 4µs





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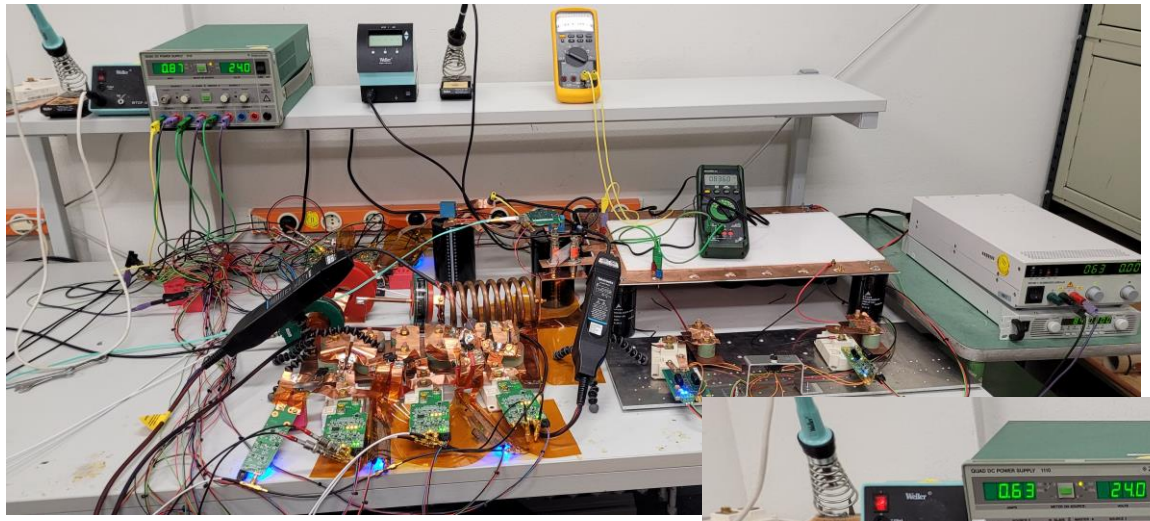
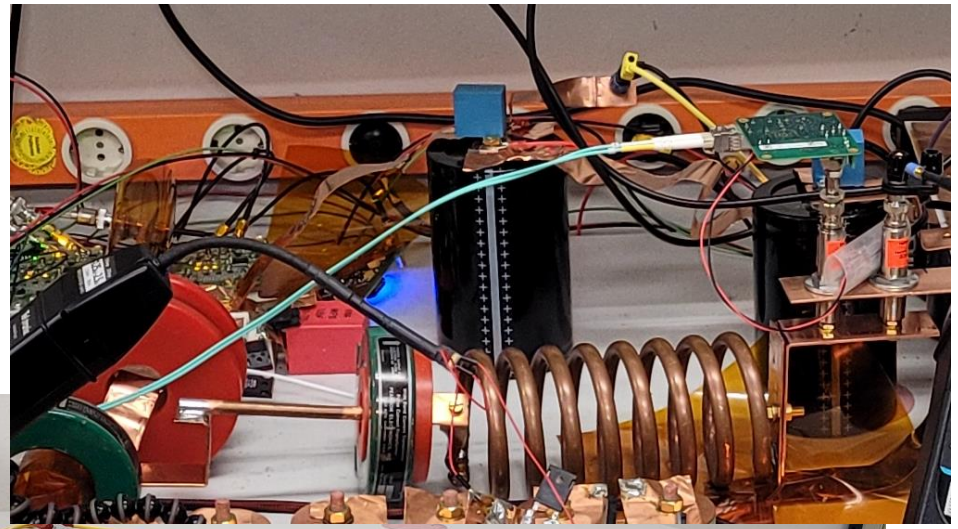
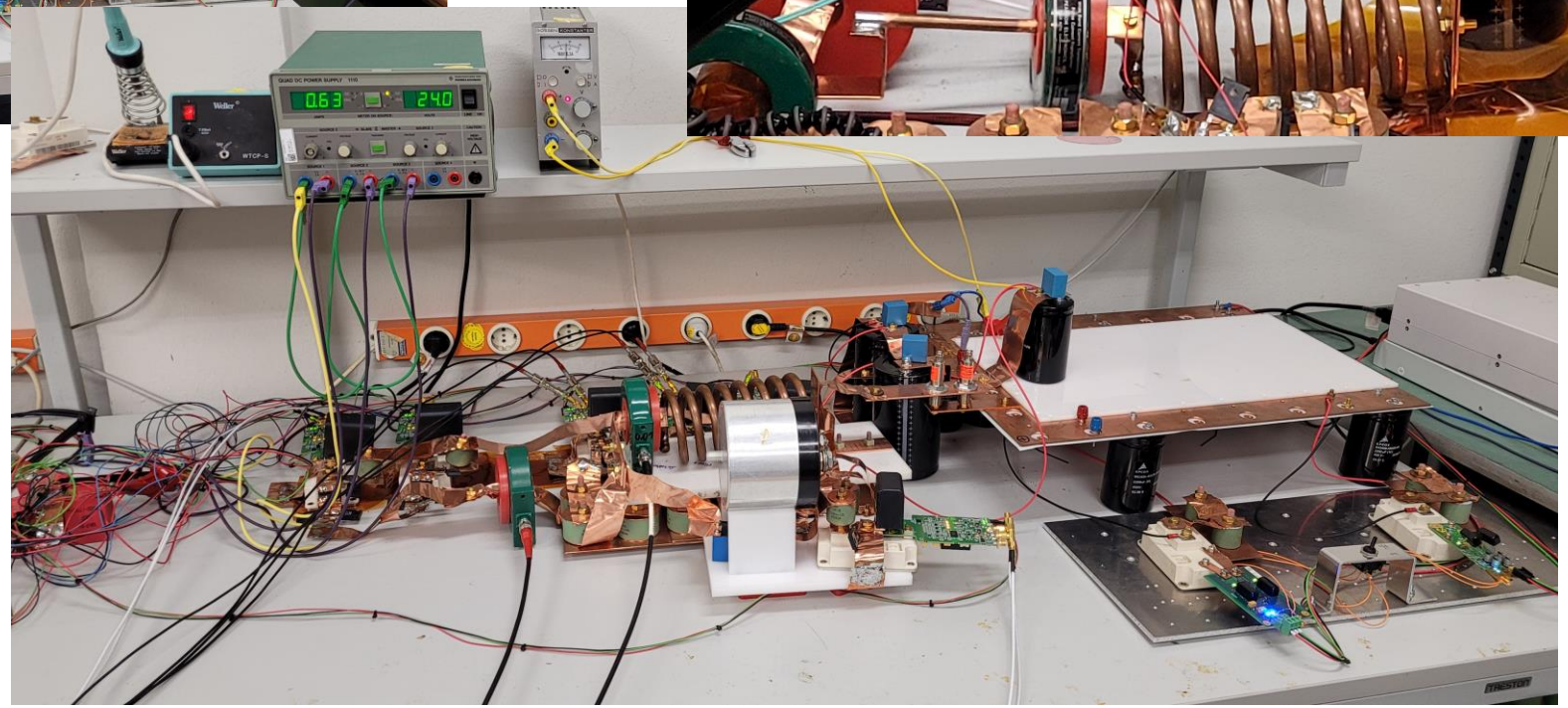
Test setup w/o modulation stage and control unit

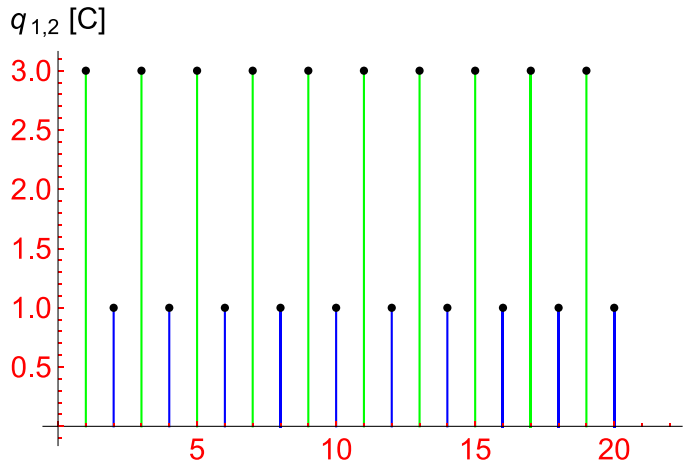






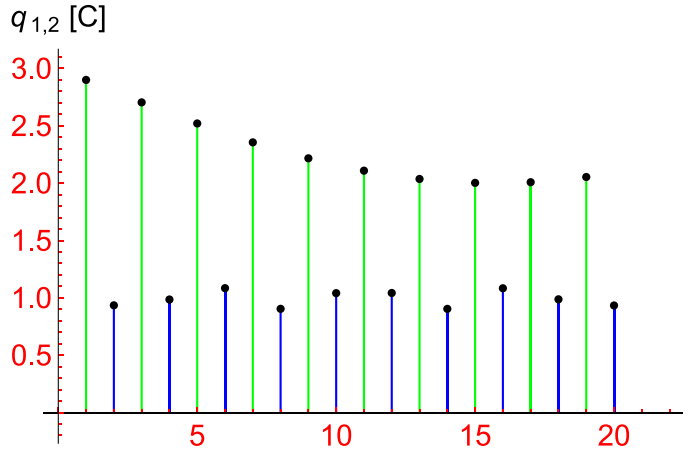
Summary

- Mechanical integration in EuXFEL injector critical (space constraints)
- Reduction of parasitic inductances and main inductance to ~1μH
- New possible bunch patterns, e.g. due to machine upgrades
  - ➢ Interleaving
  - ➢ Modulated charge patterns
  - ➢ CW use of the machine
- Limitations of existing components → new bunch patterns would require complete redesign



SASE-1 Beamline

SASE-2 Beamline



SASE-1 Beamline

SASE-2 Beamline

Thank you!