Machine Protection for Single-Pass FELs

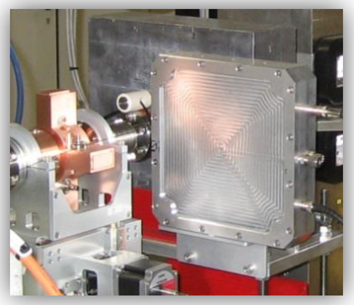
Lars Fröhlich

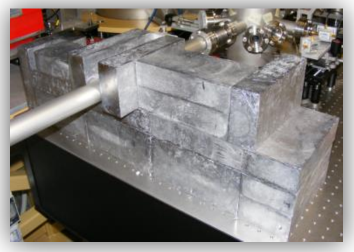
FEL 2012, Nara, Japan — August 26–31, 2012

What is Machine Protection?

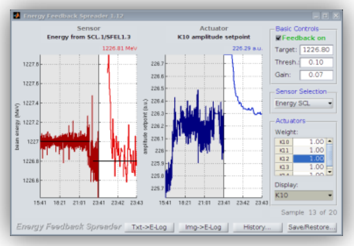
Machine protection is the sum of all measures that protect an accelerator and its infrastructure from the beam.

- Machine Protection System
  - Interlock on components (magnets, screens, ...)
  - Monitoring of the beam (beam loss monitors, charge monitors, BPMs, ...)
  - Mitigation (inform the operator, reduce repetition rate, fire abort kickers, stop beam production, ...)





- Collimators, absorbers
- Shielding



- Physics (matching, collective effects, ...)
- Robust systems+software (feedbacks, LLRF, controls, ...)
- Safe procedures (switch on, change beam energy, ramp to full power, ...)

Average Electron Beam Powers

Photo: Michael J. Linden

Normal conducting

• FERMI@Elettra	1.3 GeV	10-50 Hz	7-60 W
• SACLA	7 GeV	10-60 Hz	18-140 W
• LCLS	15 GeV	120 Hz	8-440 W

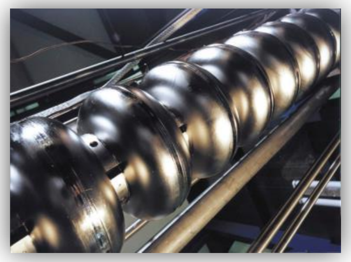
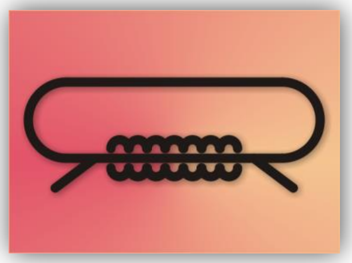


Photo: DESY

Superconducting

• FLASH	1.3 GeV	1-3 MHz pulsed	10 W - 22 kW
• European XFEL	17.5 GeV	4.5 MHz pulsed	>500 kW
• Berkeley NGLS	2 GeV	1 MHz CW	600 kW



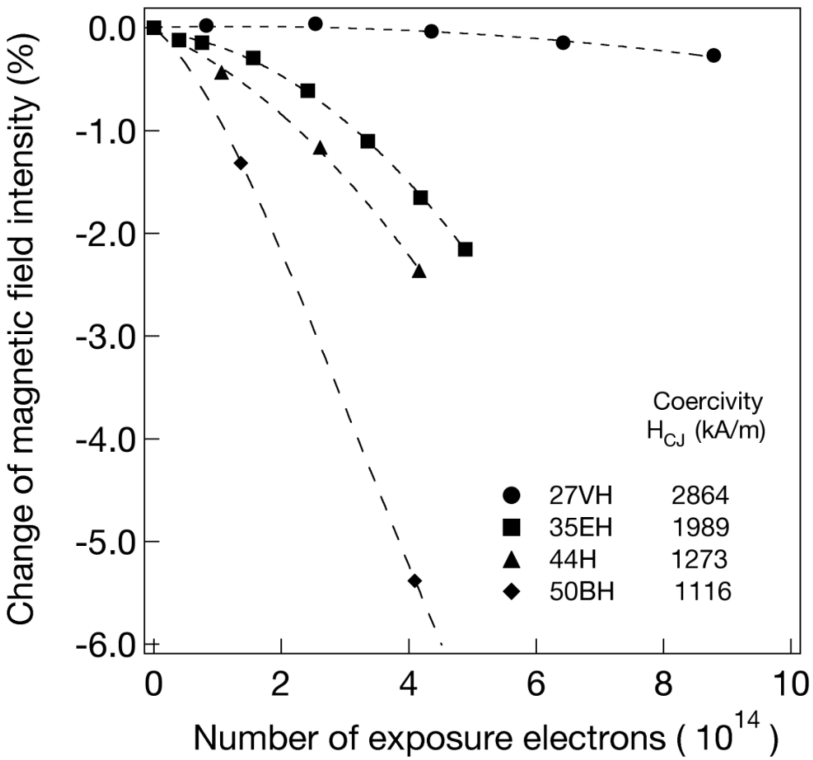
Energy recovery linacs

• NovoFEL	12 MeV	5.6-22 MHz CW	15-60 kW
• Jlab FEL	200 MeV	75 MHz CW	>1 MW
• Future ERLs	5 GeV	1.3 GHz CW	500 MW

Hazards

Local loss power (W)	Effects
100 – 1000	Thermal/mechanical damage
10 – 100	Mechanical failure of flange connections
1 – 100	Activation of components
1 – 100	Radiation damage to electronics, optical components, &c.
1 – 10	Excessive cryogenic load, quenches
0.01 – 0.1	Demagnetization of permanent magnets

Demagnetization of Permanent Magnets

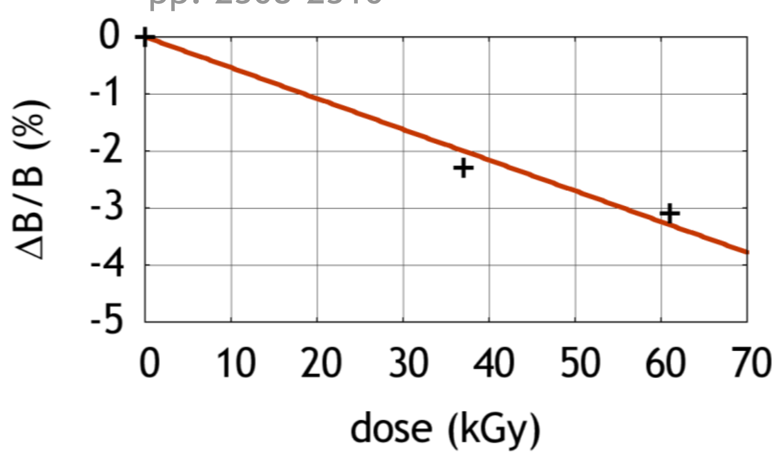


($Nd_2Fe_{14}B$ magnets, 2 GeV electrons)

Teruhiko Bizen – “Brief Review of the Approaches to Elucidate the Mechanism of the Radiation-induced Demagnetization” (ERL workshop 2011, Tsukuba, Japan)

- FELs rely on precision magnetic fields
- Permanent magnets lose magnetic field under irradiation with high energy electron beams
- Various magnetic materials behave differently

Skupin et al., “Undulator demagnetization due to radiation losses at FLASH”, Proc. EPAC 2008, pp. 2308–2310

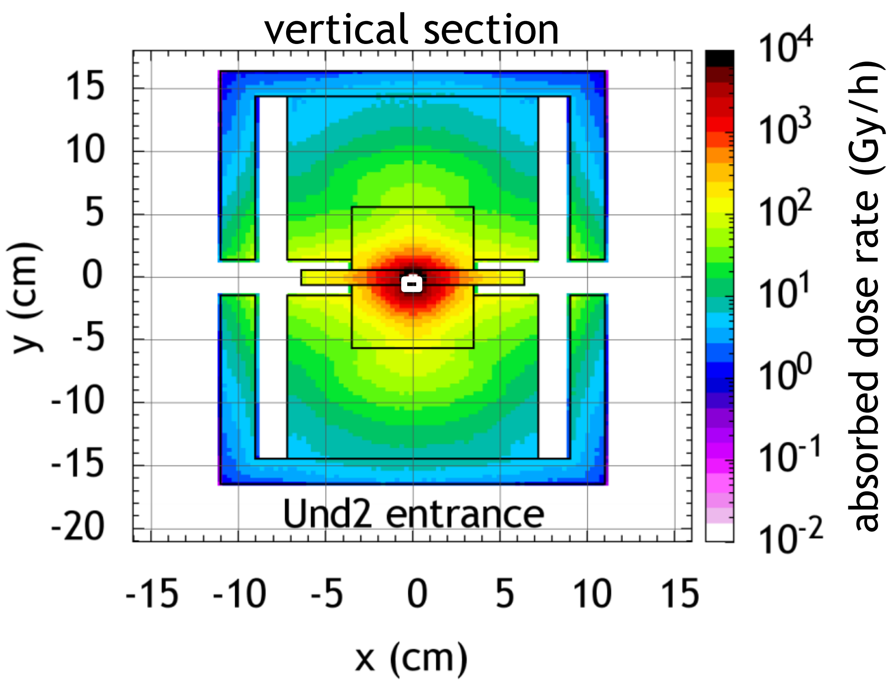


Demagnetization of Permanent Magnets

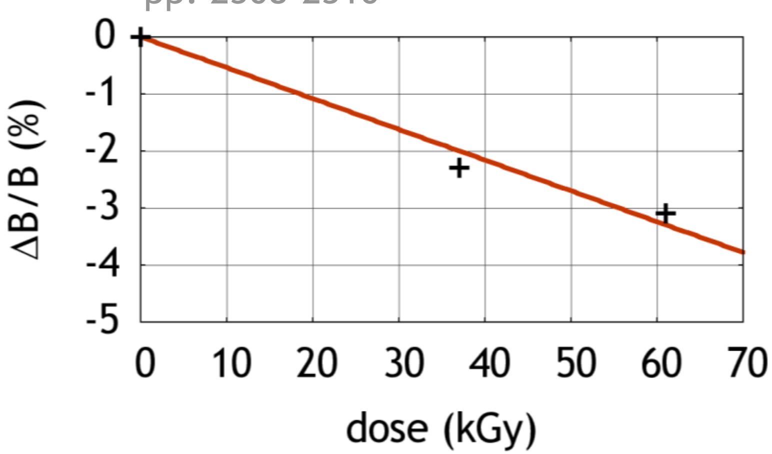
Can demagnetization be compensated by undulator tuning (opening gaps)?

- FELs rely on precision magnetic fields
- Permanent magnets lose magnetic field under irradiation with high energy electron beams
- Various magnetic materials behave differently

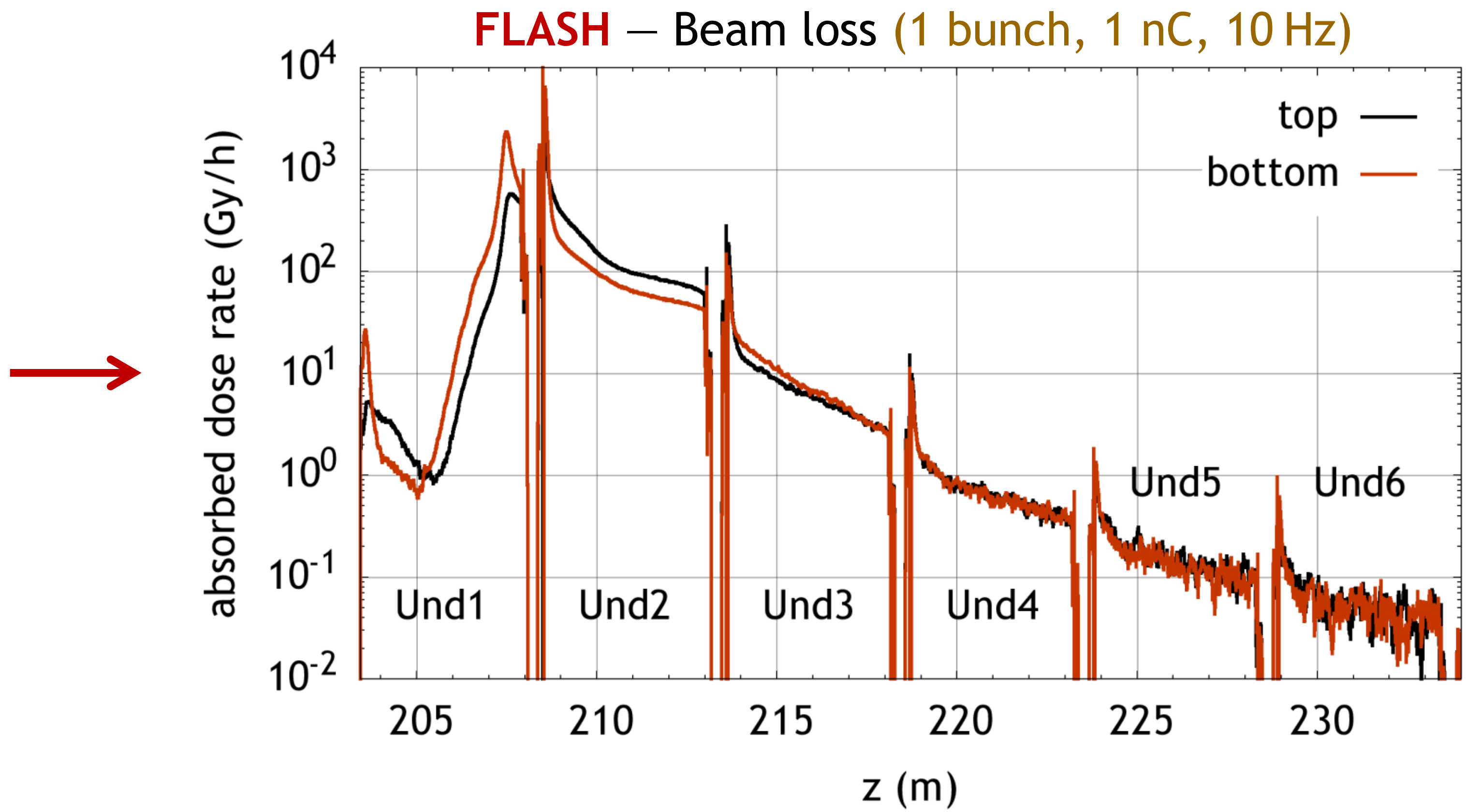
FLUKA beam loss simulation
(FLASH, 1 bunch, 10 Hz)



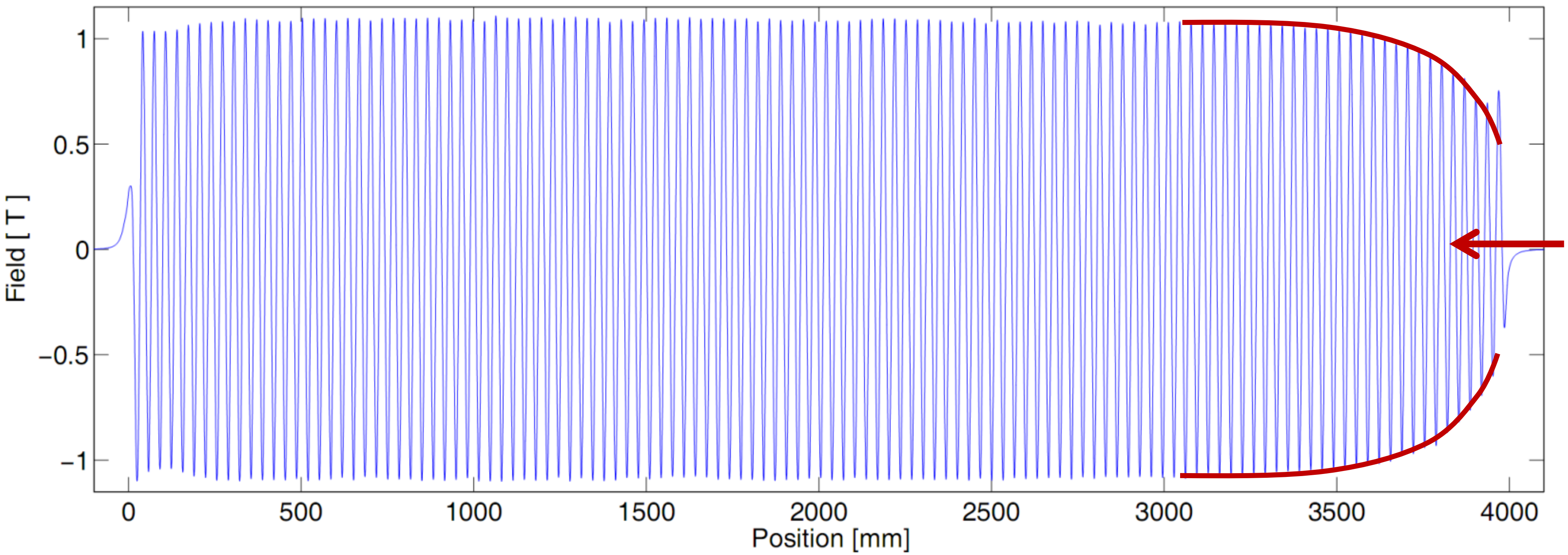
Skupin et al., “Undulator demagnetization due to radiation losses at FLASH”, Proc. EPAC 2008, pp. 2308–2310



Dose Deposition in Undulators

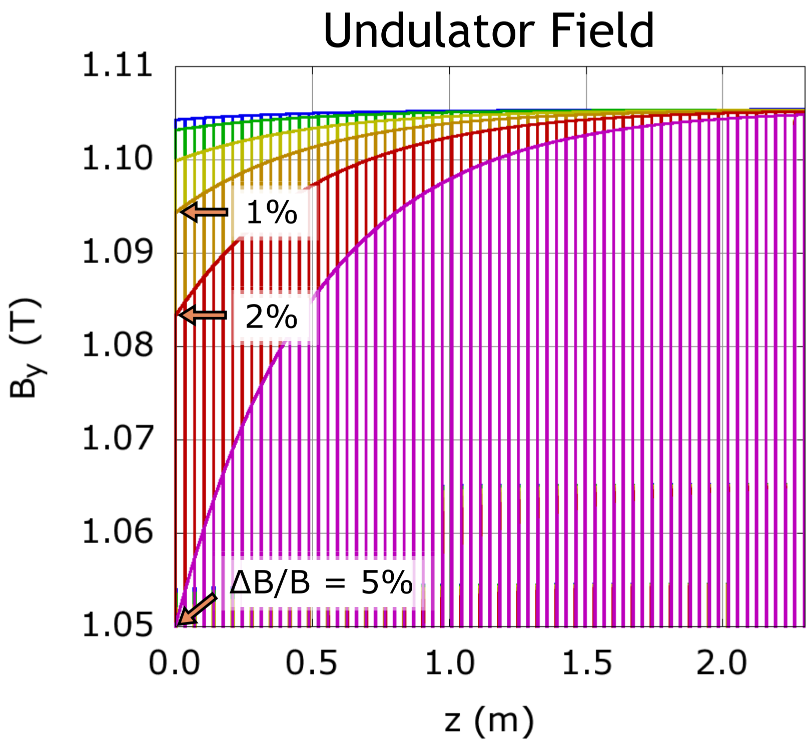


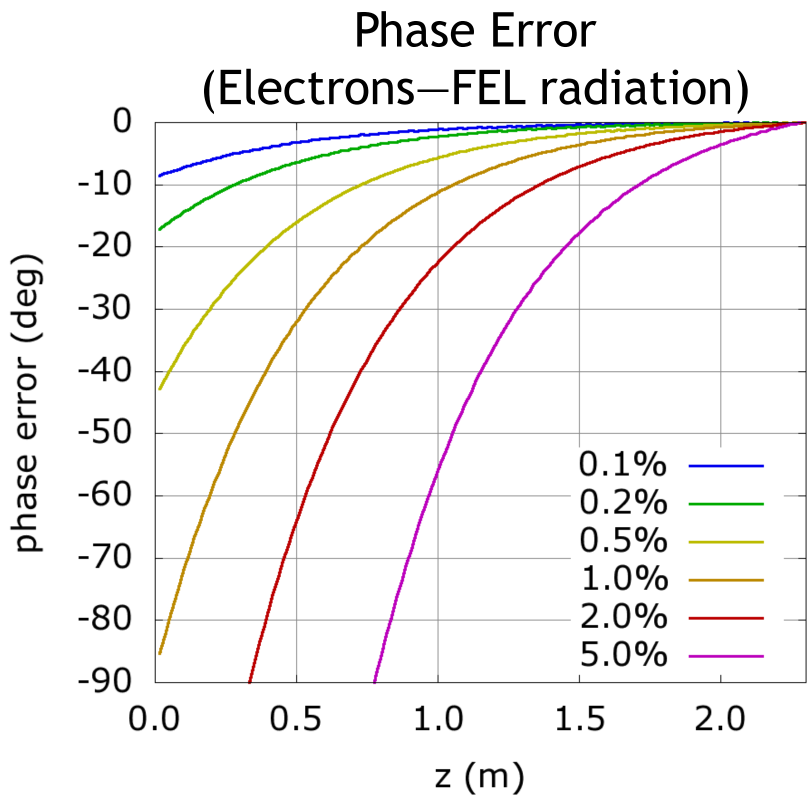
Field Loss of a PETRA-II Undulator



P. Vagin et al., "Commissioning experience with insertion devices at PETRA III", SR2010, Novosibirsk, Russia.

Demagnetization and Phase Error





Example: FERMI@Elettra FEL-2, second stage radiator

66 periods of 3.48 cm

Conclusion

- Machine protection should not be just a system of interlocks
- Superconducting FELs can transport dangerously powerful beams
- Permanent magnet undulators need protection