RADIATION DETECTION.

Radiation Safety and Dose Monitoring in Plasma Accelerators

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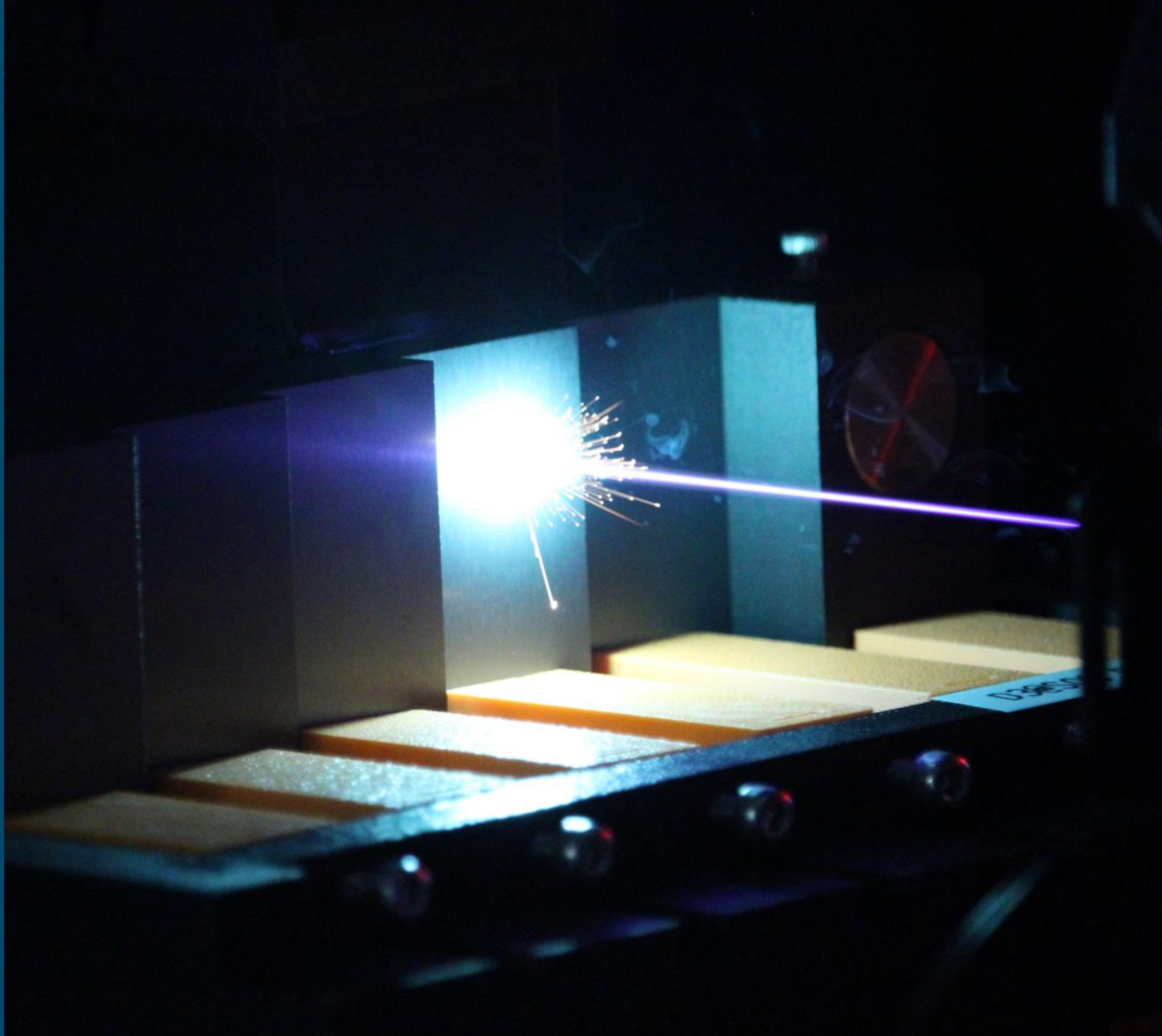
for the radiation protection group D3 of
Deutsches Elektronen-Synchrotron DESY

22. September 2025

HELMHOLTZ



Material burn-through at European XFEL

Why radiation generation matters

Considerations for transitioning plasma accelerators to applications.

Plasma accelerators are linear accelerators

Electron losses at PETRA III: 10^{15} electrons/year

Electron production at FLASH: 10^{15} electrons/s

Why radiation generation matters

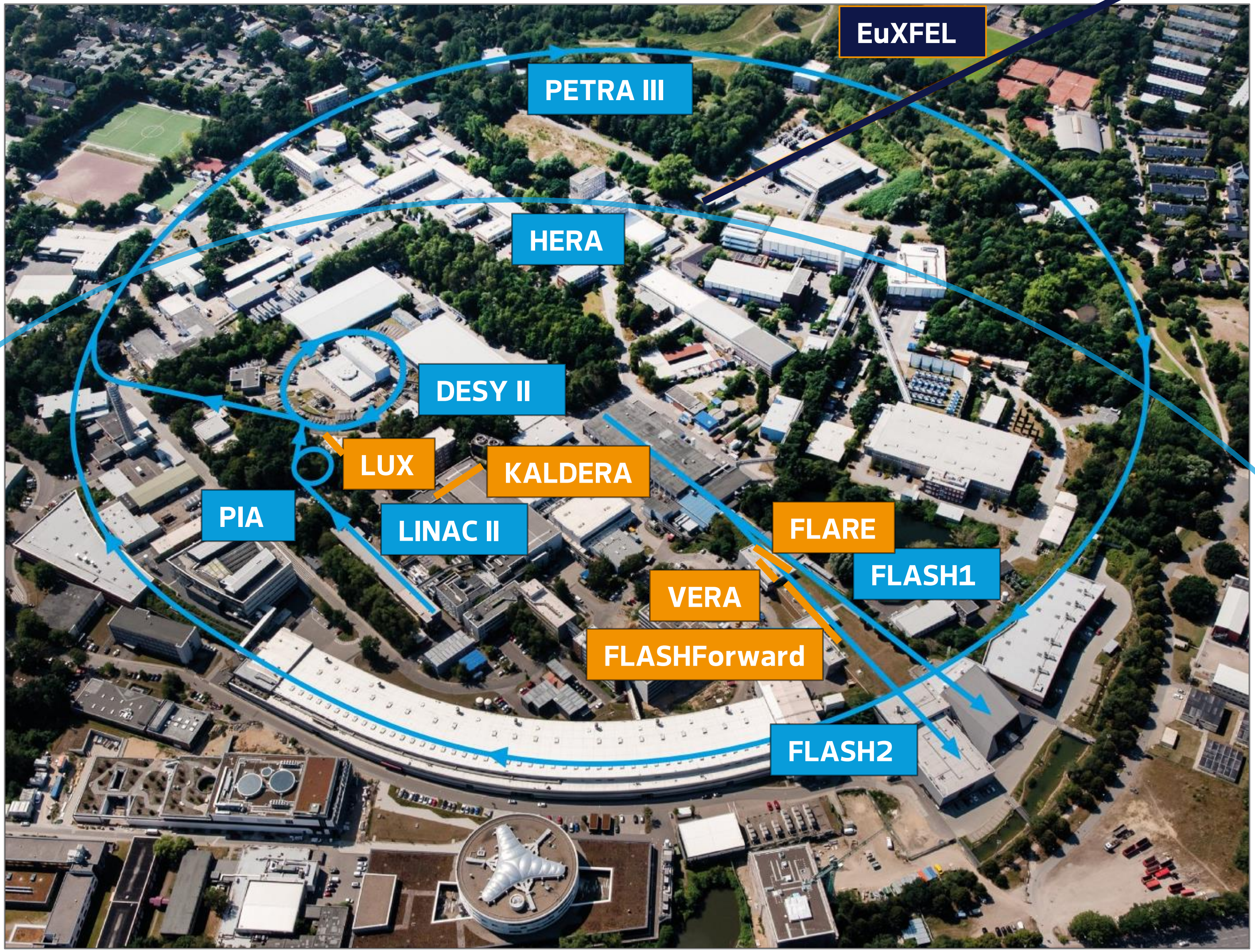
Considerations for transitioning plasma accelerators to applications.

- How is radiation monitoring done at DESY?
- How does radiation generation differ at plasma accelerators?
- What do we need to consider for plasma accelerators to transition to real world applications?

Deutsches Elektronen-Synchrotron DESY

Large campus with many accelerators installed

- Many different types of accelerators with energies ranging from few MeV to multiple GeV.
- User facilities: synchrotrons and FELs
- Several laser-plasma accelerators and a beamdriven accelerator
- Comparison of conventional and plasma accelerators highlight differences and let us look into the future



European XFEL

Detector development at DESY

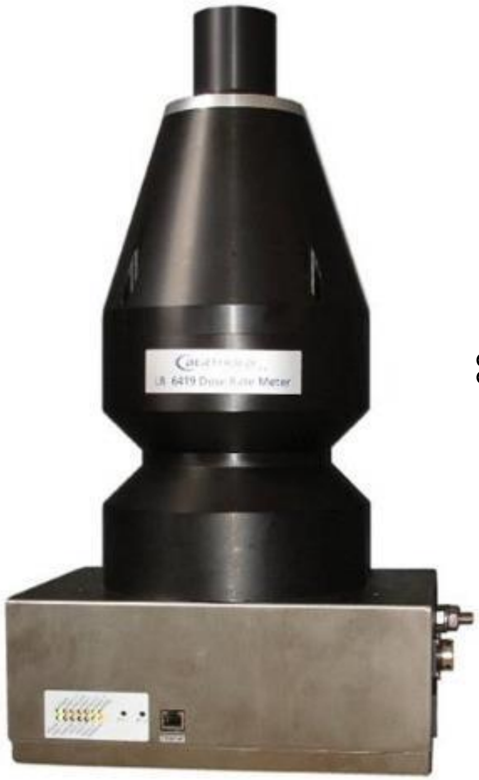
Detector design for dose monitoring at particle accelerators and advanced light sources

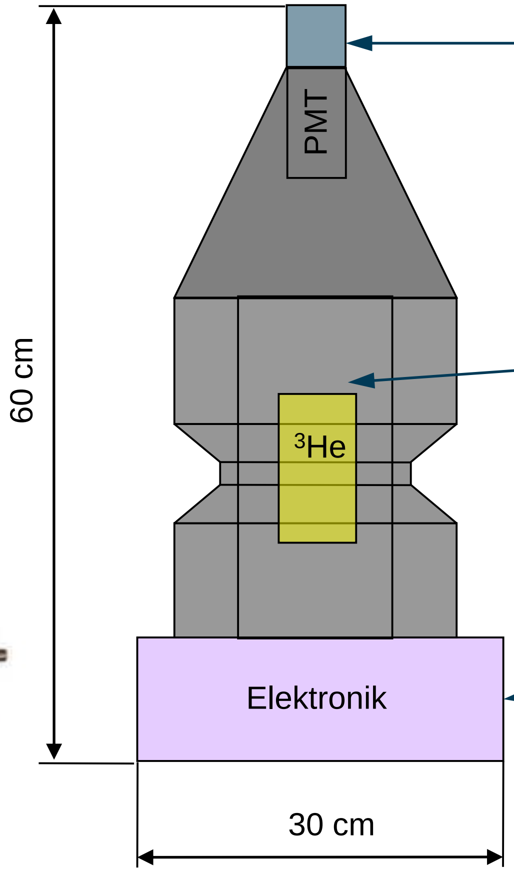
PANDORA
Combined photon and neutron detector for pulsed radiation fields

BTM
Burn-through detector system for indirect measurement of radiation

The PANDORA detector

Simultaneous detection of photon and neutron flux





Scintillator with photomultiplier
- measurement of photons
- measurement of high-energy neutrons

Moderator with **^{3}He-Counter**
- measurement of low-energy neutrons

Electronic Boards
- Electronics boards: power supply, 250 MHz ADC, interlock integration, etc.

VERA

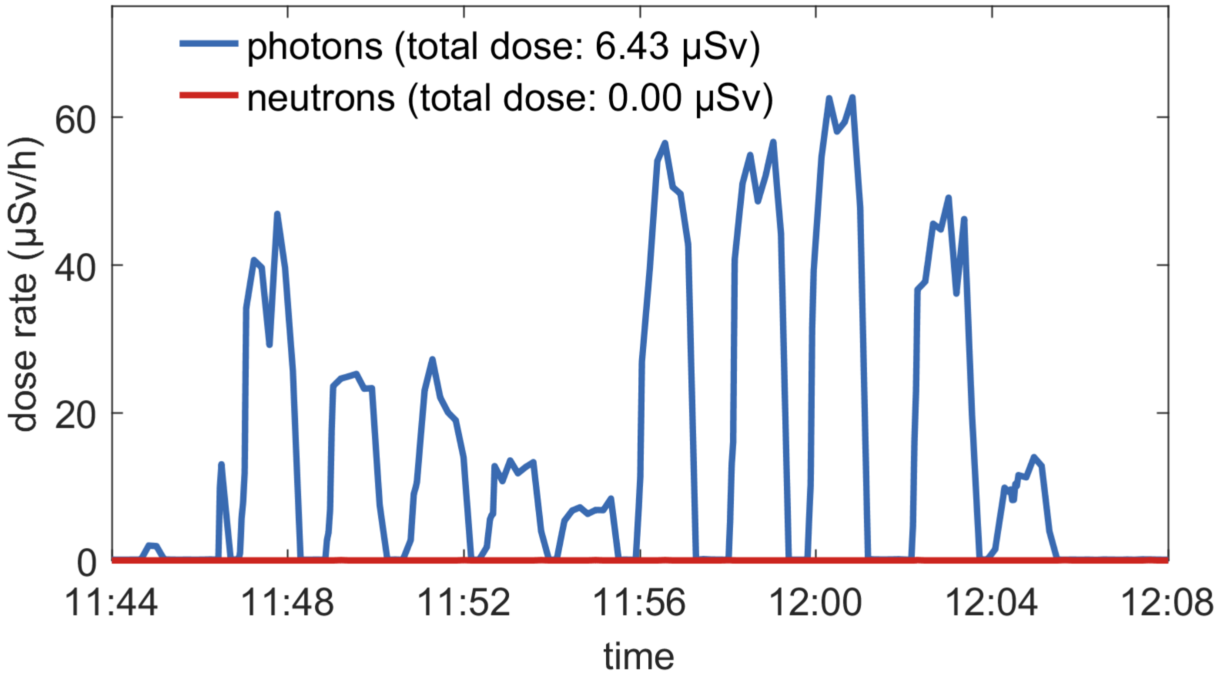
Laser-plasma acceleration at high repetition rates

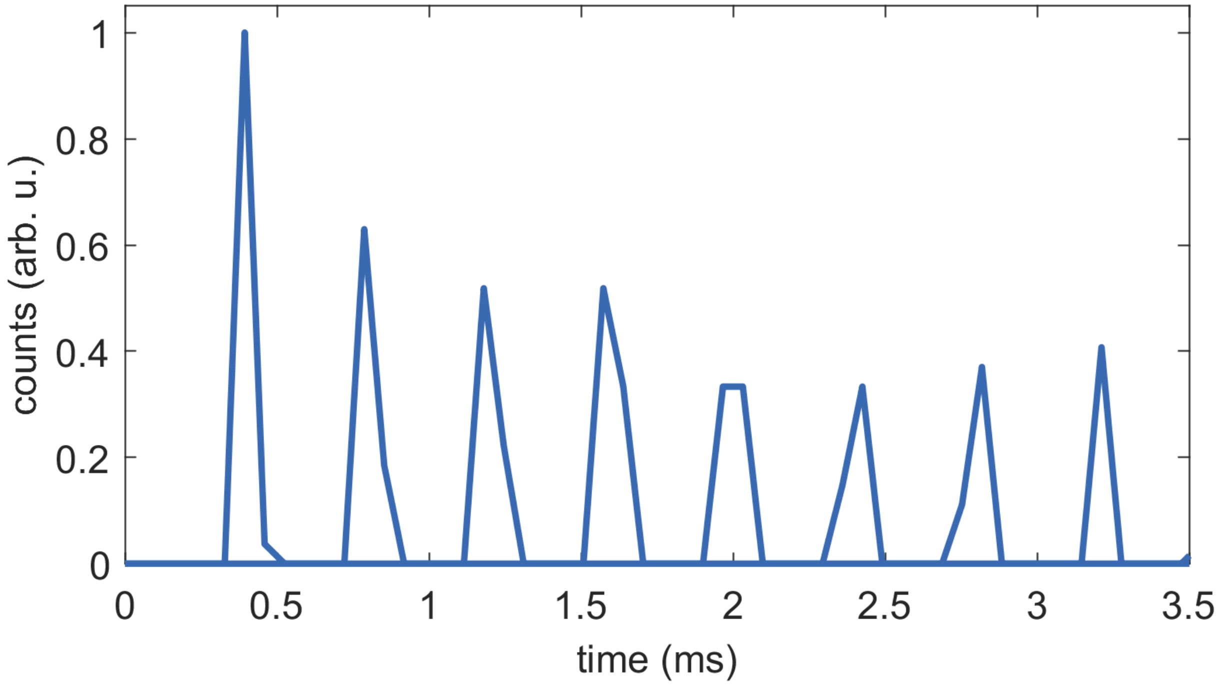
- Electron energies of less than 10 MeV
- Acceleration at high repetition rate
- Post compression of industrial laser using MPC

B. Farace
Breaking new ground:
first electron acceleration
with an industrial Yb:YAG
laser at 2.5 kHz,
Mon. 19:00, Postersession

The PANDORA detector

Dose measurements at VERA with high repetition rates and low electron energies





KALDERA

Laser-plasma acceleration at high average power

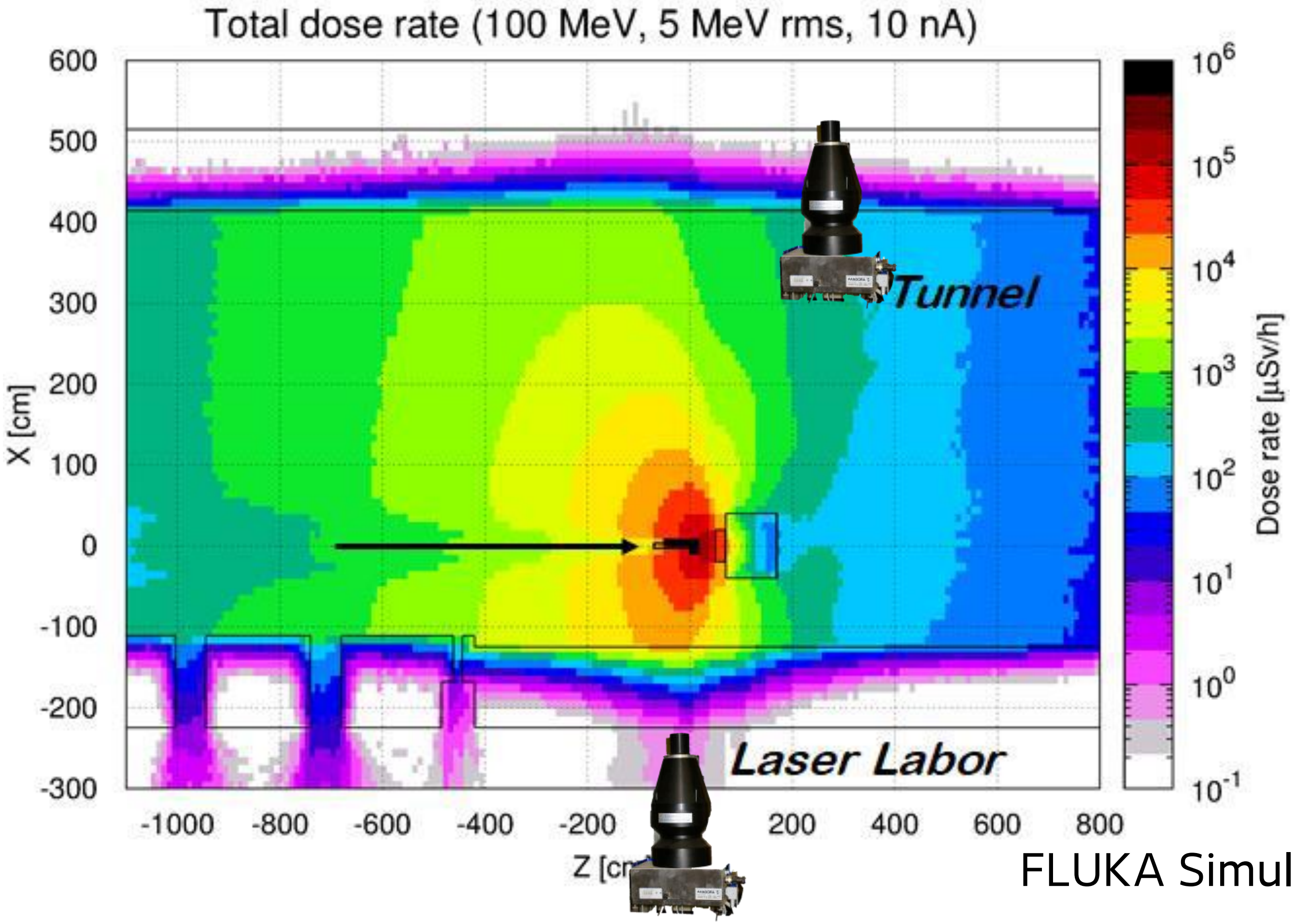
- Electron energies of >100 MeV
- Acceleration at repetition rate of 100 Hz (1 kHz in the future), high charges and high energies
- Accelerator in old DORIS storage ring

M. Kirchen
First Electron Beams from the High-Average-Power Laser-Plasma Accelerator KALDERA
Mon. 17:00, PS3

KALDERA commissioning

FLUKA simulations to estimate dose in operation and active monitoring system

Simulation for 1W beampower at KALDERA (100 MeV, 100 pC, 100 Hz)



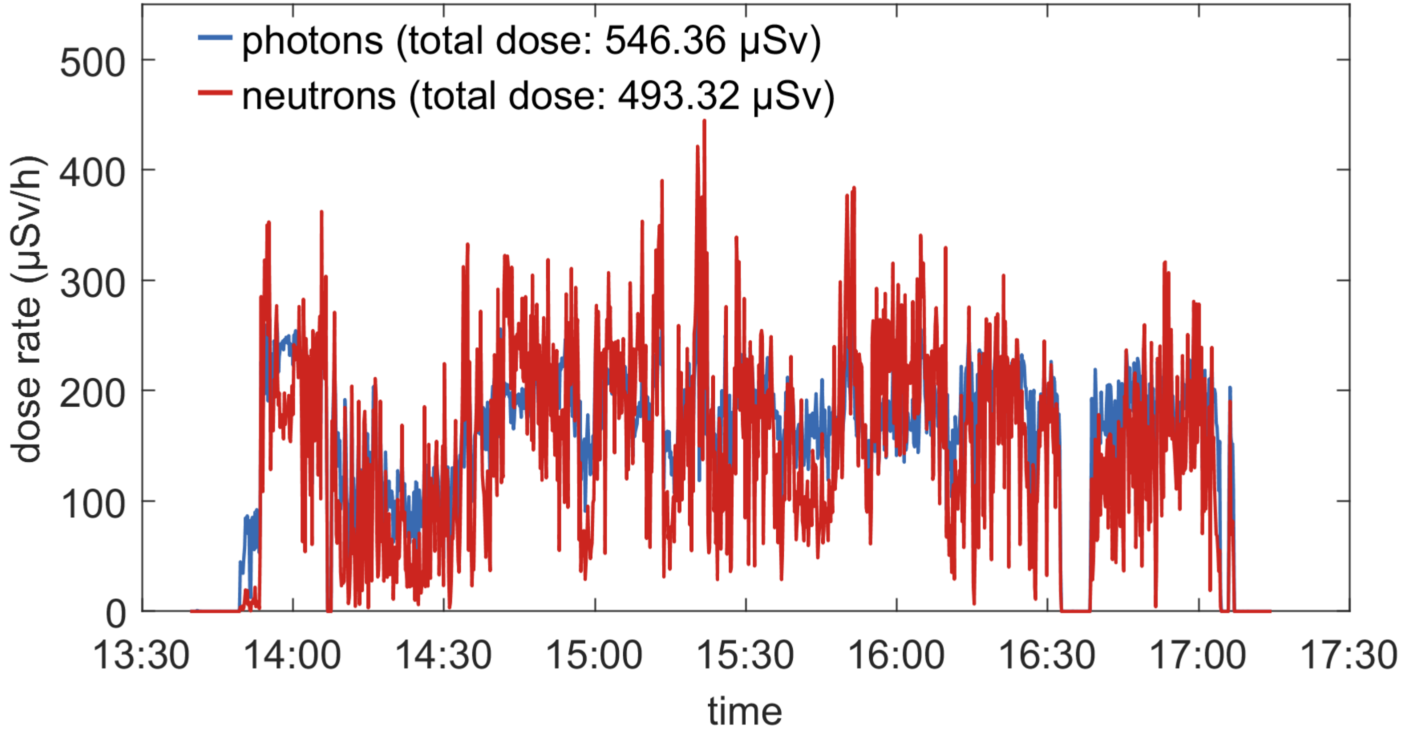
FLUKA Simulations by T. Liang

KALDERA commissioning

Comparison of measured and simulated doses: Detected doses higher than expected

Assumed beampower in simulations: 1W
Beam power during operation roughly 0.3 W

KL 4: (FLUKA: 300-400 µSv/h)

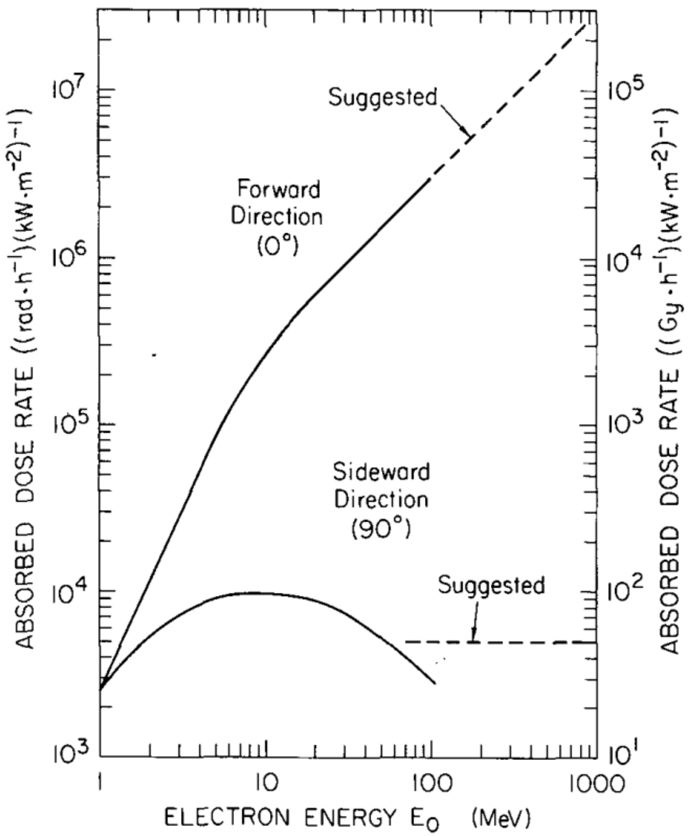


Dose calculations for accelerators

Unwanted electrons in plasma accelerators need to be considered for dose production

- Simulation assume perfect capture in dump
- Low energy electrons can be produced at large angles and not reach diagnostics, but contribute to dose production
- Low energy electrons have very significant contribution to dose in transverse geometries
- Contribution of electrons that are heated in the plasma source (see poster)

Bremsstrahlung of electrons colliding with high-Z target

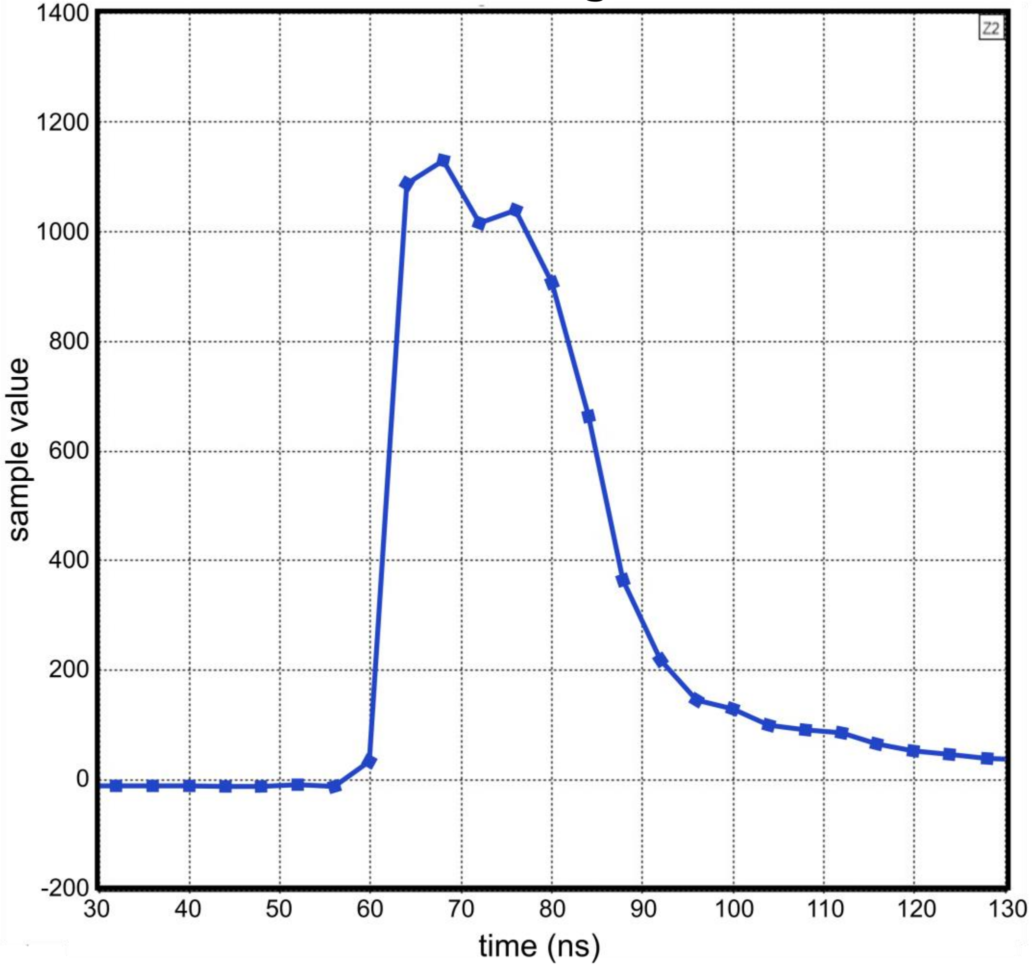


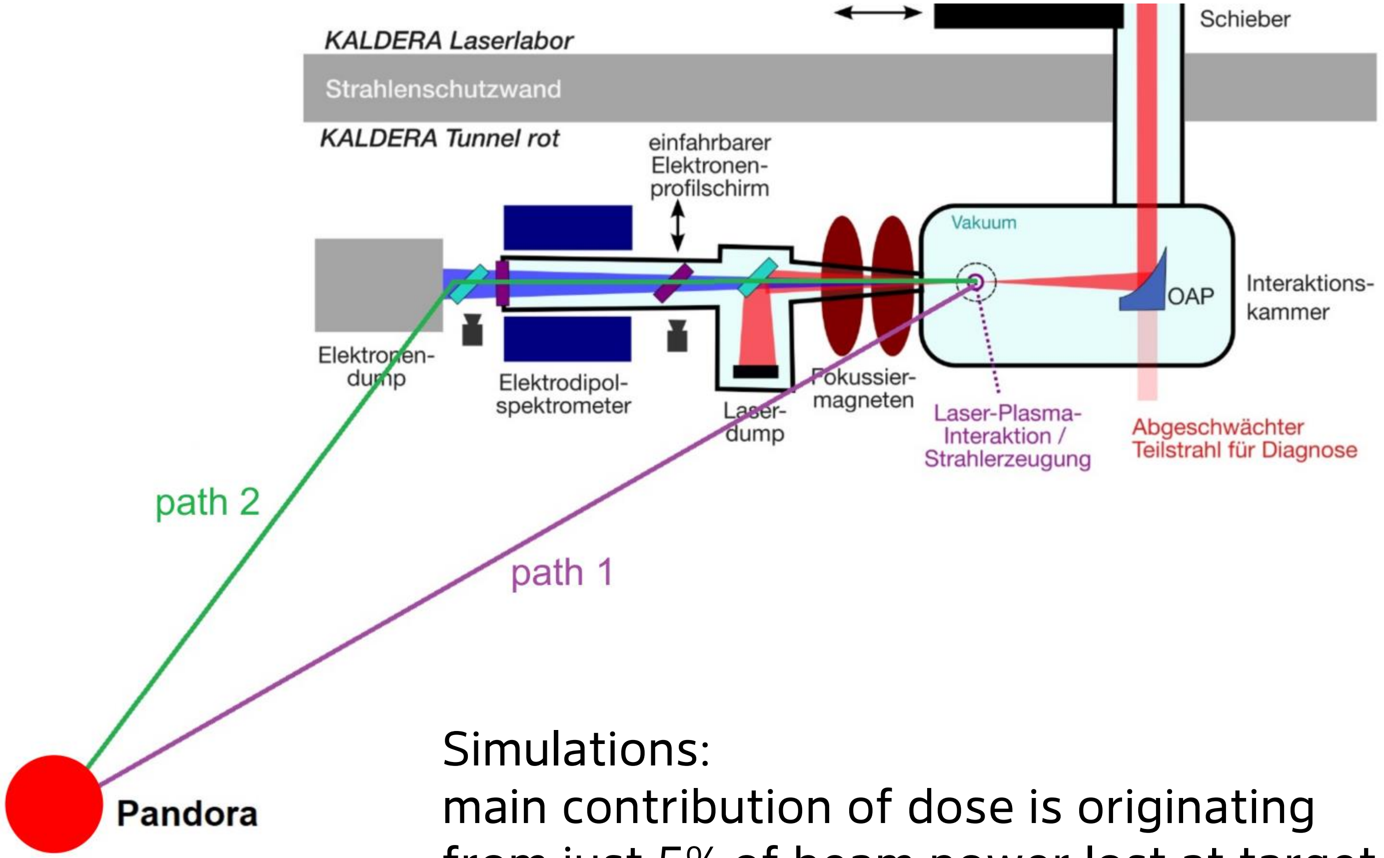
Swanson, TRS 188, IAEA, 1979
Radiological Safety Aspects of the Operation of Electron Linear Accelerators

ADC to detect sources of radiation generation

Possible to distinguish different radiation sources using high speed ADC

scintillator signal





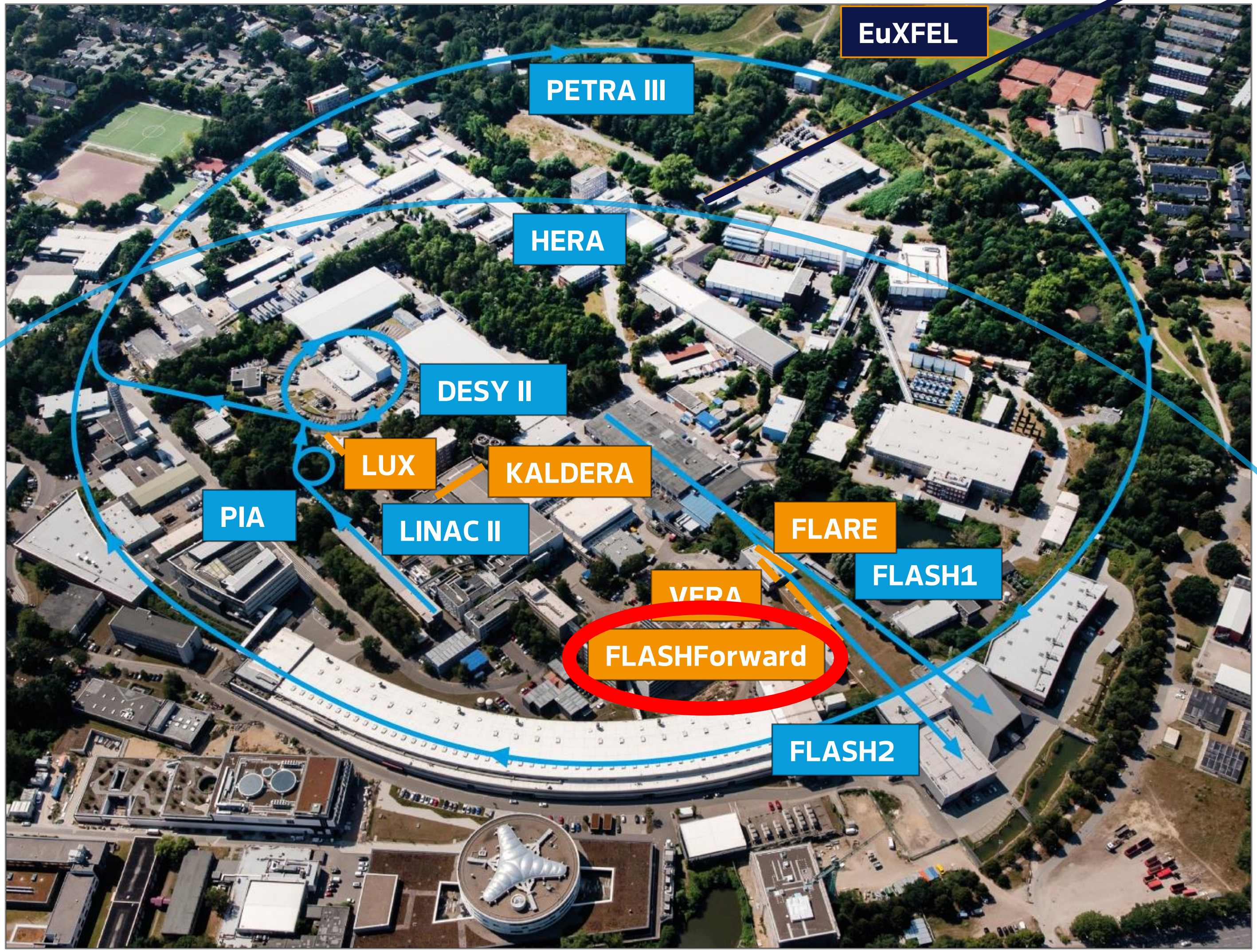
Simulations:
main contribution of dose is originating from just 5% of beam power lost at target

FLASHForward

Beam-driven plasma acceleration at the FLASH FEL

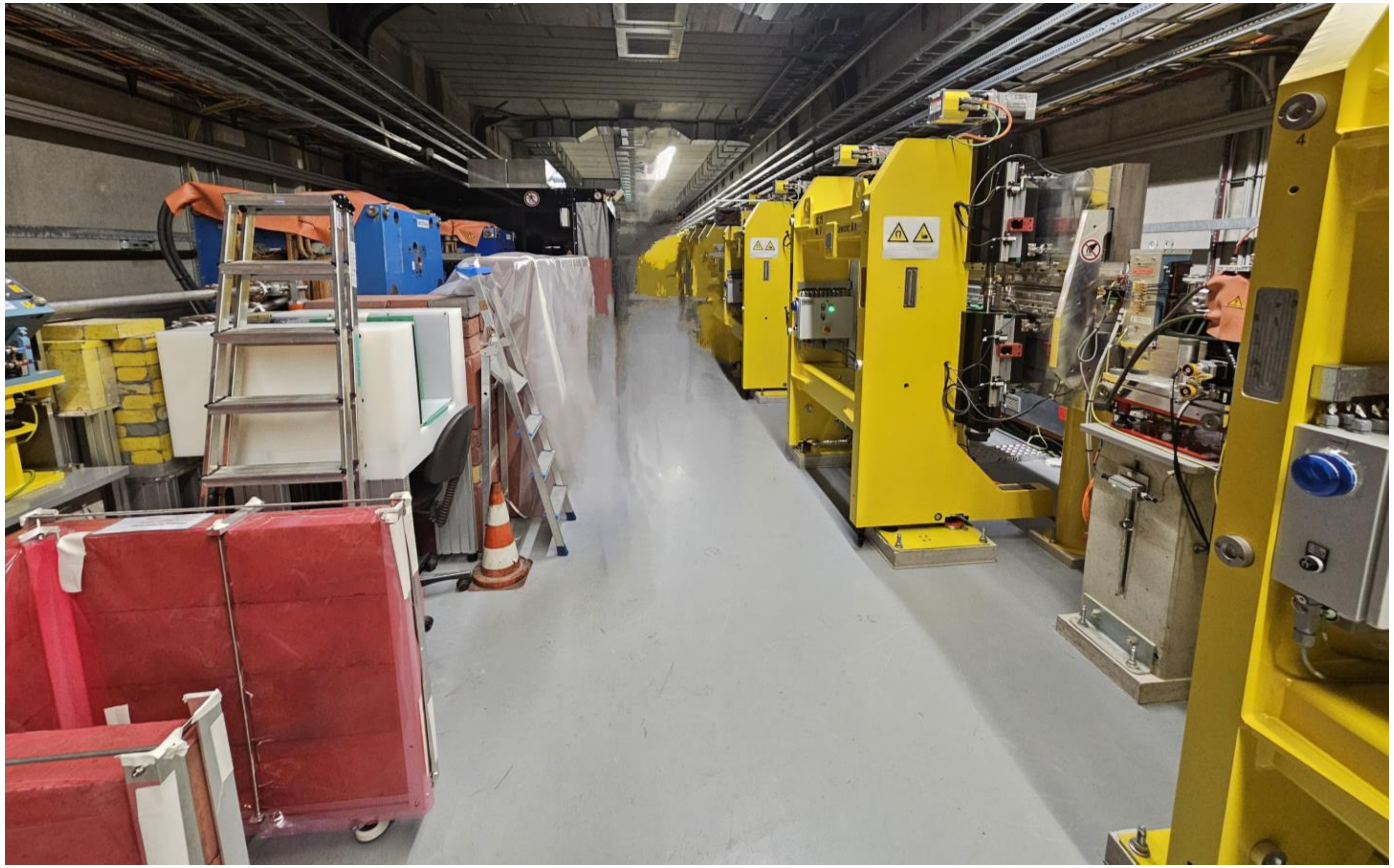
- Increase energy of FLASH (up to 2.5 GeV)
- Acceleration at very high repetition rates utilizing FLASH micro-bunch structure
- Beamline located next to FLASH2 FEL-beamline

J. Wood
Latest Results from the FLASHForward Experiment
Wed. 16:40, PS1



Dose production in beam-driven accelerators

Controlled driver dumping required in order to minimize dose production for beam-driven accelerators

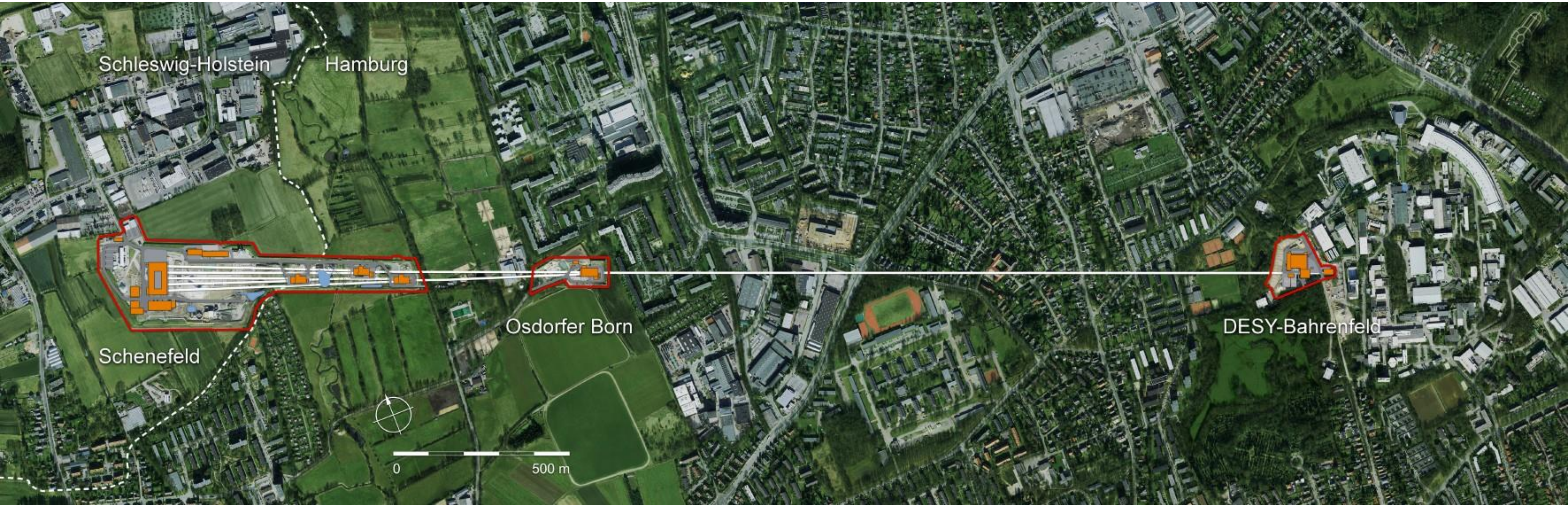


- FLASH accelerator with beam powers of up to 100 kW
- FLASHForward currently limited to 20 W due to undulators next to it.
- Already at these powers vacuum pumps break due to radiation
- Controlled dumping of used driver bunch extremely challenging
- Advanced and more shielding required as average power increases

European XFEL

Largest X-ray FEL in the world

Electron energies of up to 16 GeV, 3.4 km long accelerator, ultra bright x-ray flashes



Non-linear(?) radiation protection

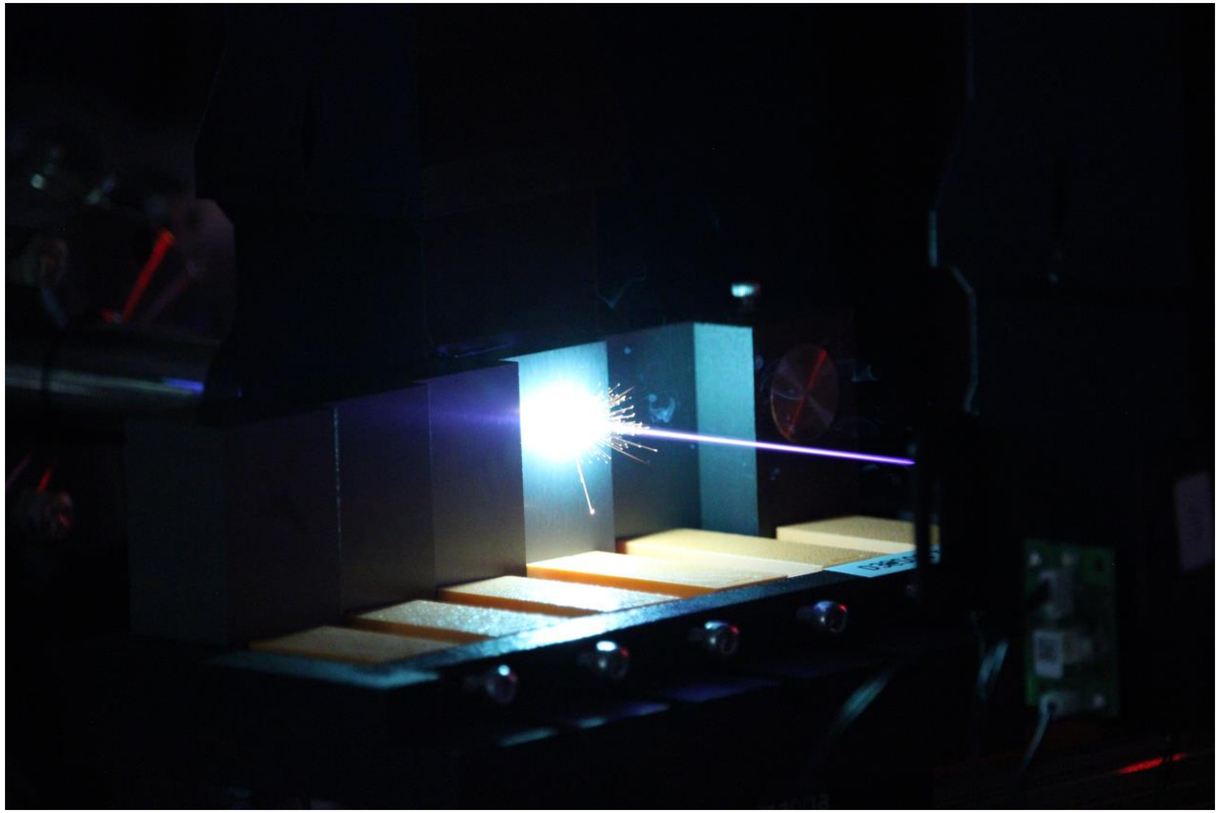
Ultra-high brilliance changes requirements for radiation protection

- Copper block with 150 mm length in 9.3 keV EuXFEL x-ray beam
- X-ray transmission is roughly 10% for 12 μm of copper
- For 150 mm this means the transmission is 10^{-10000}

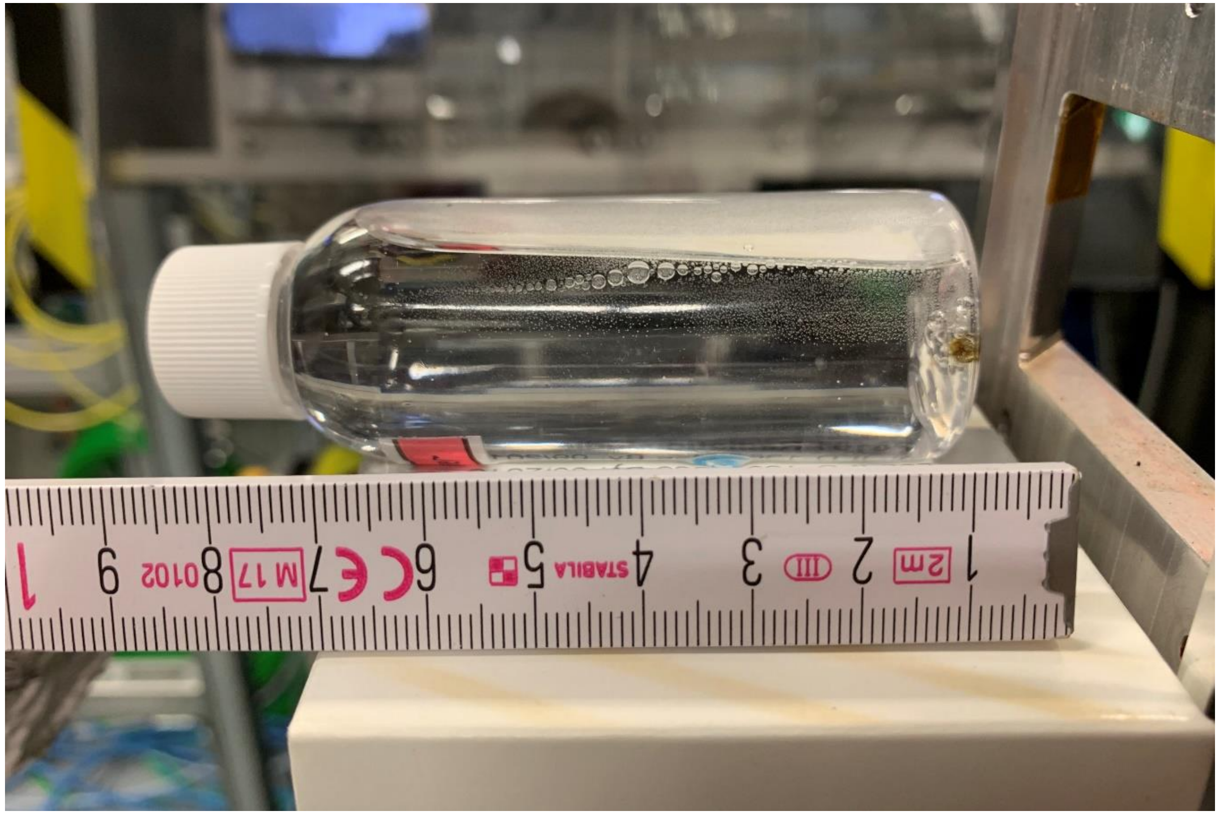
Reality: Burn through the block in 4 s

Non-linear(?) radiation protection

Ultra-high brilliance changes requirements for radiation protection



Burn through tests in B4C and air



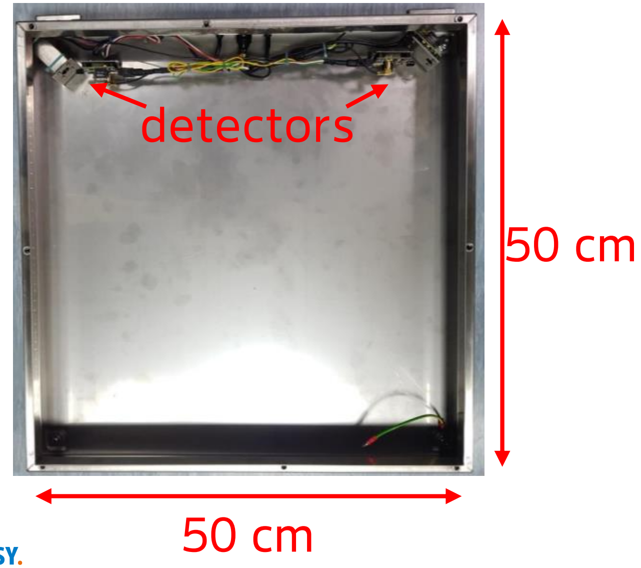
X-ray beam in water

Shielding of high flux x-rays not possible!

Burn-through monitor system

Active x-ray detection system for ultra-high brilliance x-ray beams

European XFEL

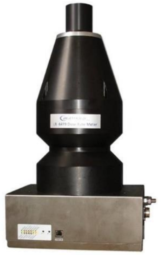


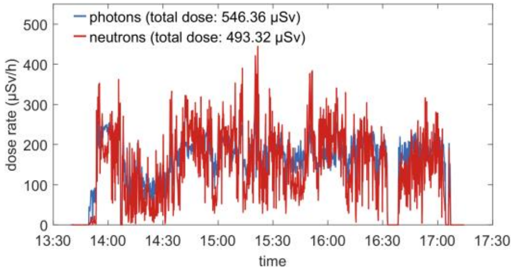
- Indirect measurement of radiation
- Monitoring of air-fluorescence in arbitrary volumes
- Detectors acts directly on radiation interlock: if light is detected the EuXFEL turns off
- Detection system with continuous self-testing

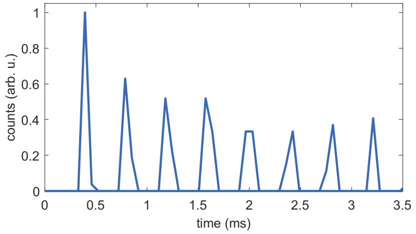
Summary and outlook

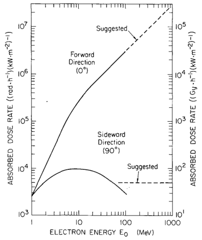
Radiation safety and dose monitoring in plasma accelerators

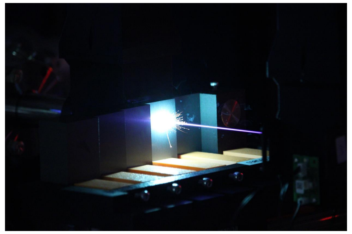
- PANDORA offers great utility for dose monitoring in plasma accelerators. Upgraded detector currently being developed. Community input welcome!
- Independent measurements of photons and neutrons enable additional information on electron generation.
- Use of ADC enables time-resolved measurements of radiation fields.
- Low-energy electrons and used drive beams need to be considered, especially at high repetition rates and powers.
- At high x-ray intensities radiation shielding does no longer work as expected.
- Indirect detection system for safe operation of next generation of light sources developed at DESY.











Thank you

Find me at my Poster on Wednesday

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