Radiation Safety Challenges and Detector Solutions for Plasma Accelerators

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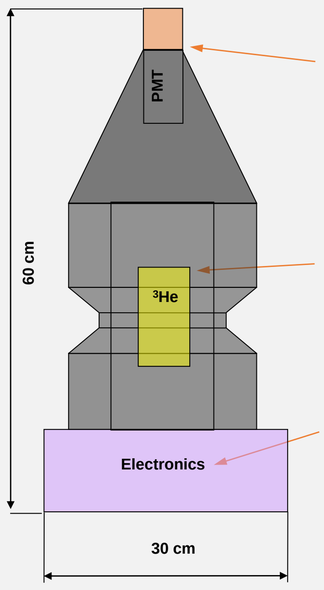
The PANDORA detector[1]



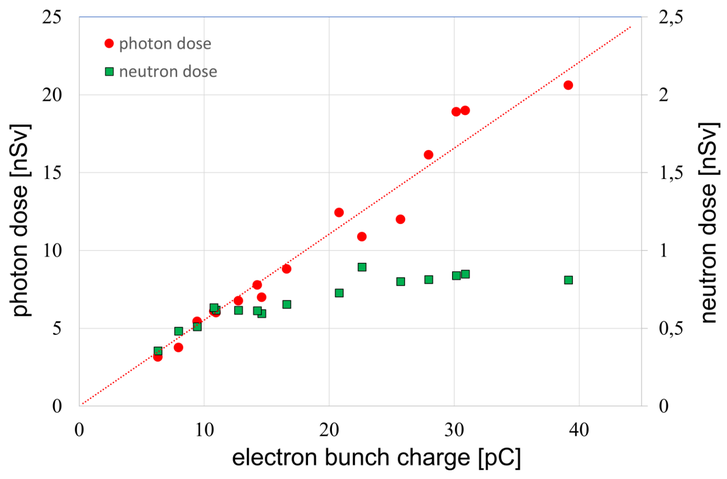
Scintillator with photomultiplier
- measurement of photons
- measurement of high-energy neutrons

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

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

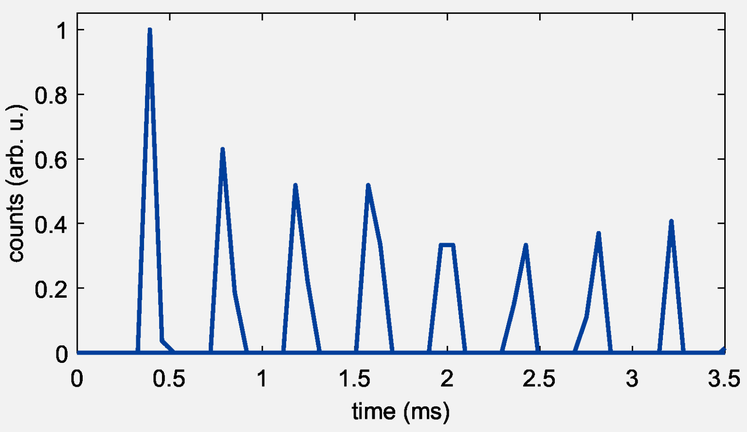
Neutron and photon measurements

- Experiments at FLARE with ~50 MeV electrons using ionization injection [2].
- Charge increased by increasing laser power.
- PANDORA enables indirect charge measurements and indicates low vs. high energy.

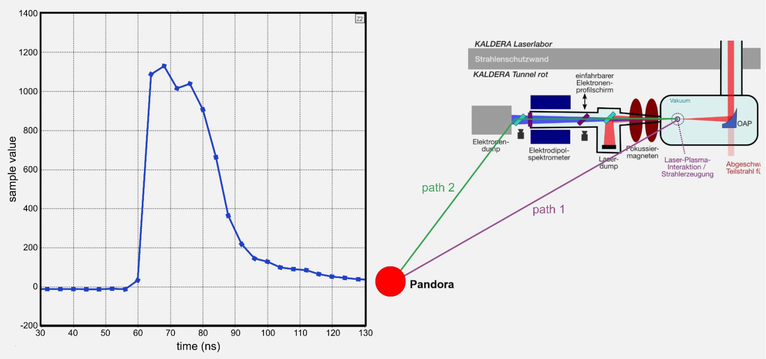


ADC for time resolved radiation measurements

- Independent measurement of repetition rate of 2.5 kHz at VERA.



- Measurement of different radiation sources at KALDERA with resolution of few ns (2-3 m)

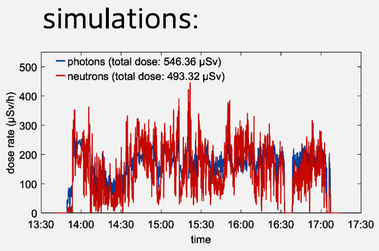


Radiation generation in plasma accelerators

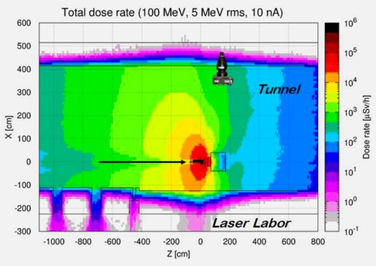
- Plasma accelerators are linear colliders, not synchrotrons.
- Linear colliders generate orders of magnitude more charge, thus radiation is more critical:
  - PETRA III has a loss of 10^{15} electrons per year
  - FLASH produces up to 10^{15} electrons per second
- Unique plasma-accelerator properties further complicate radiation generation.

Generation of unwanted charge

- KALDERA: Comparison of measurements and simulations:

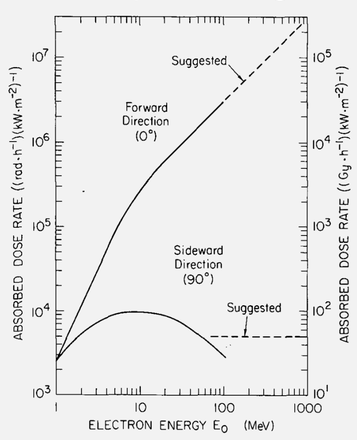


Measurement: 500 µSv/h at 0.3 W

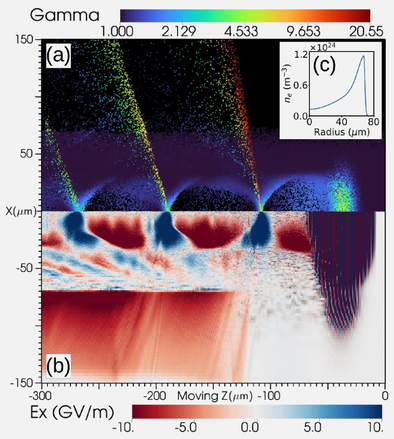


Simulation: 400 µSv/h at 1.0 W

- Possible reasons for dose-rate differences:
  - Simulations assume perfect electron capture in the dump.
  - Low-energy electrons created at large angles stay undetected, but create dose.
  - Dose contribution of not carefully dumped electrons can be orders of magnitude higher.
  - Electrons may be heated or emitted radially from the plasma target.



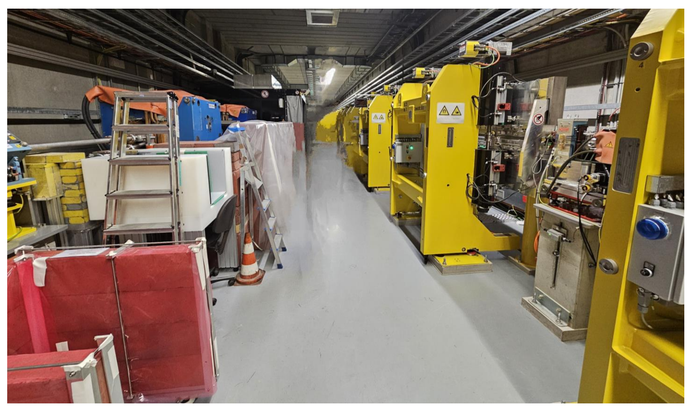
bremsstrahlung from electrons [3]



radial emission of electrons [4]

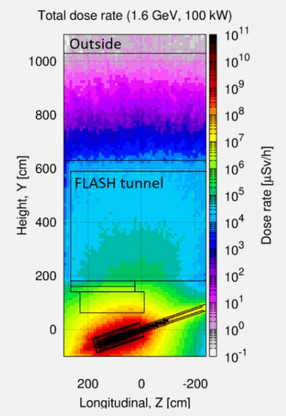
Driver dumping in beam-driven accelerators

- Used drive bunches typically have a large energy spread: transport is challenging.
- FLASHForward currently limited to 20 W due to fear of radiation damage at undulators next to it.
- At these powers electronic devices keep failing.
- FLASH2 has allowance to run with up to 100 kW.



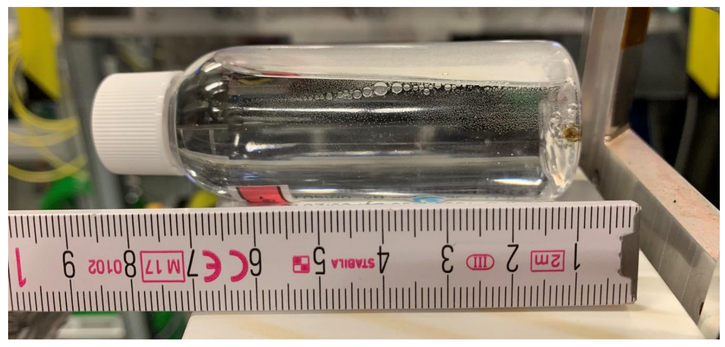
High-power plasma accelerators

- Require controlled dumping of all electrons.
- Require dumps placed safely away from electronics and magnetic structures (e.g. undulators).
- require critical dumping and shielding, sometimes at the cost of compactness.



Radiation physics at high x-ray flux

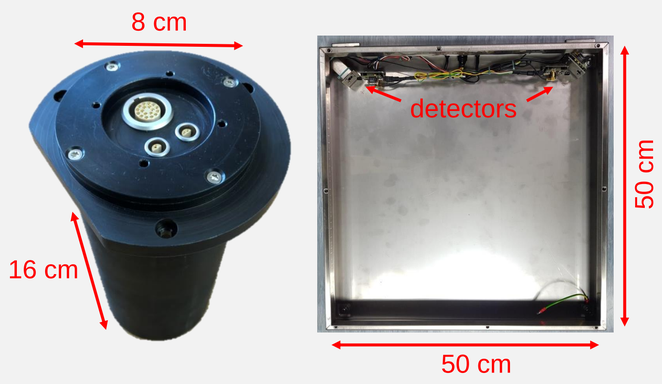
- Shielding experiments using 150 mm copper block.
- XFEL beam with energy of 9.3 keV sent on block.
- Beam should be attenuated by factor 10^{10000}.
- Instead: Burn through of copper block in 4 s.
- Similar effects in other materials.



Shielding of high flux x-rays not possible!

Burn-through monitor system

- Indirect detection of radiation from air fluorescence
- Detector system acting on accelerator operation
- Continuous self-testing of entire detector system
- Easily customizable to match monitored volume



Summary

- The PANDORA detector is well suited for radiation measurements at plasma accelerators. Community input for further improvements is welcome.
- Low-energy electrons or used driver bunches can cause significant doses if not dumped carefully.
- At high average powers, all radiation poses risks to nearby electronics and magnetic structures.
- At very high fluxes, x-rays cannot be fully shielded. A burn-through monitoring system was developed to ensure safe operation with such beams.

References

[1] A Klett et al., Radiat. Meas. 45, 10, 1242-1244, 2010
[2] S Bohlen et al., Phys. Rev. Accel. Beams 25, 031301, 2022
[3] WP Swanson, TRS 188, IAEA, 1979
[4] T Garett et al., arXiv:2506.21503v2, 2025

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