Superradiant THz radiation generation (STERN)
Toward first light (uPdate)

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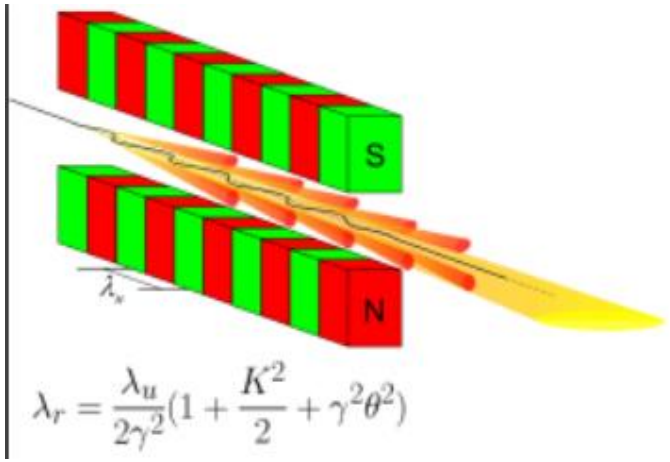
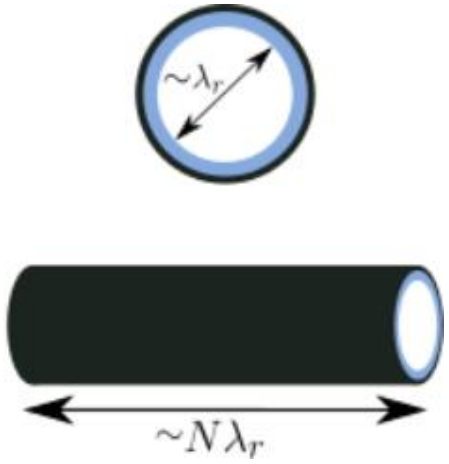
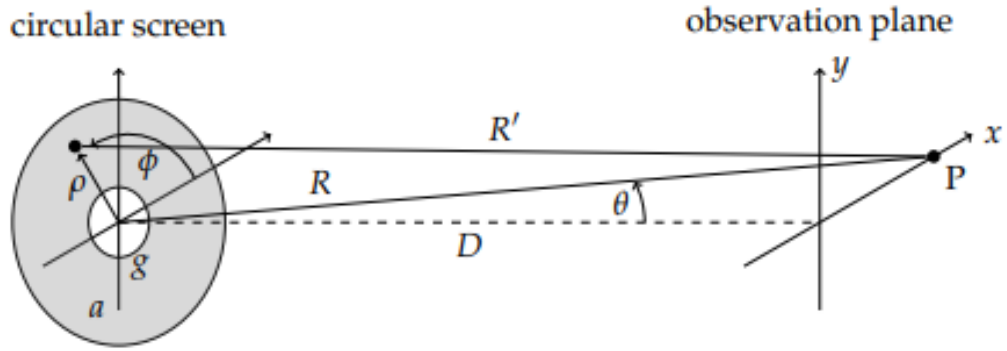
Overview

- Users want a THz (1-30 THz) pump source for XFEL
  - Should provide broadband (hammer) high gradient pulses single cycle pulses
  - Should also provide tunable multicycle THz with ~ 5-20% BW (i.e. 5 – 20 cycles)
- STERN using diffraction radiation for single cycle pulses, and wakefields in waveguides for narrowband pulses
- Undulator approach could work in eventual CW upgrade

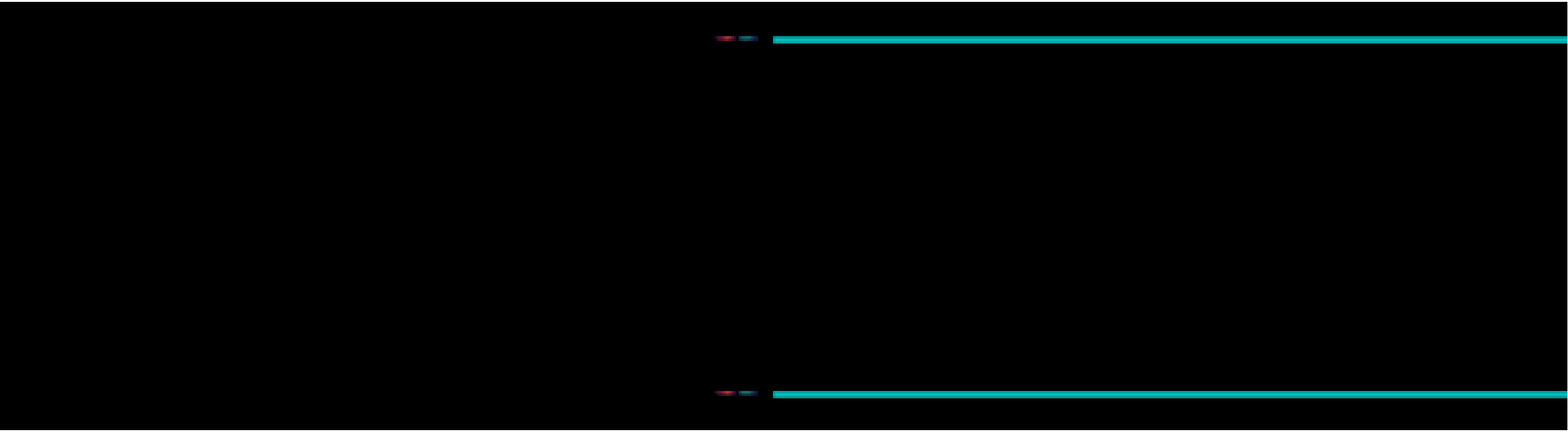






Overview

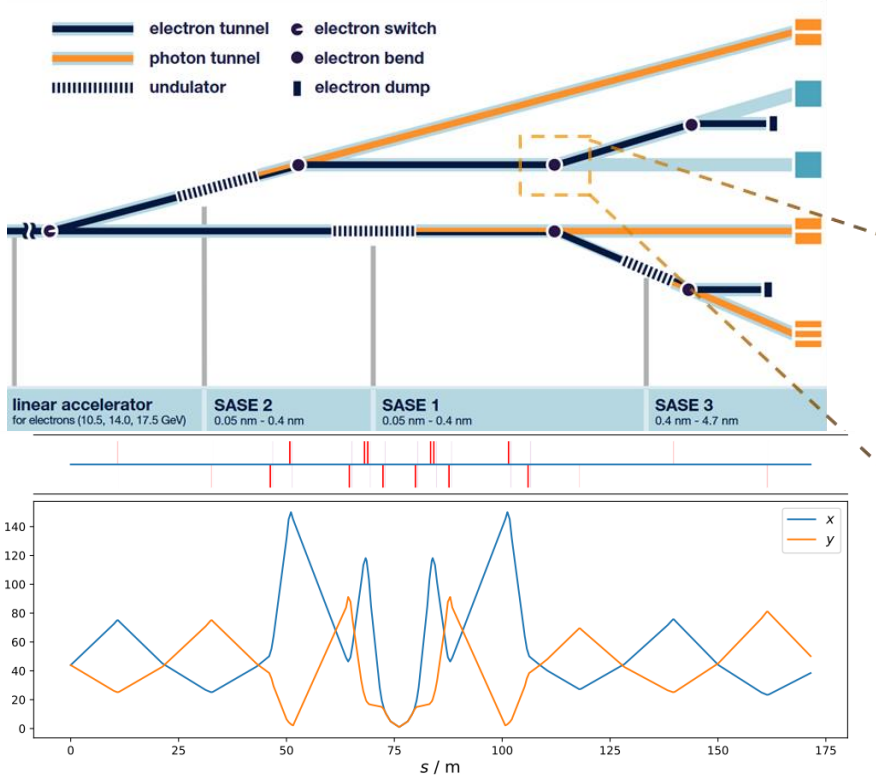
- Waveguides ‘stitch’ a pulse together based on difference between group velocity and beam velocity
- Has been achieved in various types of structures at different labs, e.g. FACET noticing Joule level THz wakes.

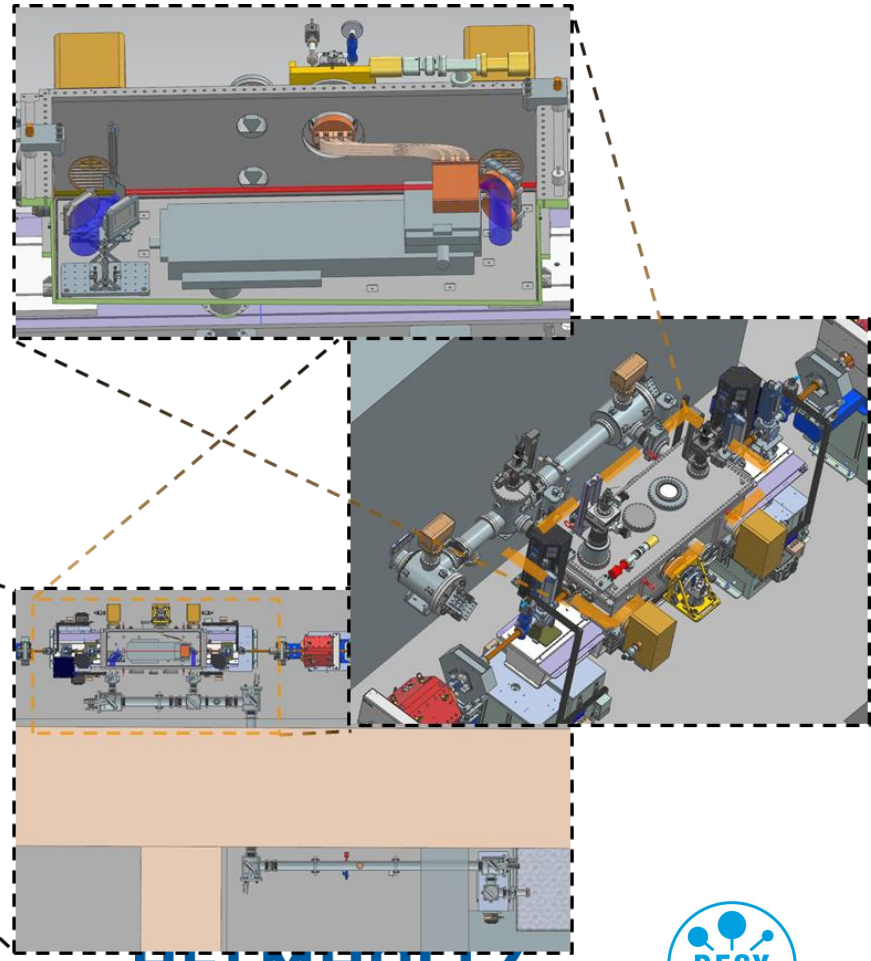


Achievements in the past 2 years

- The last two years have prepared for the design of our experimental area which needs to be installed in the long 2025 shutdown (which is now)!

- Most notable efforts have been design and procurement of:
  - Chamber design
  - THz transport
  - Lab design
  - Waveguides



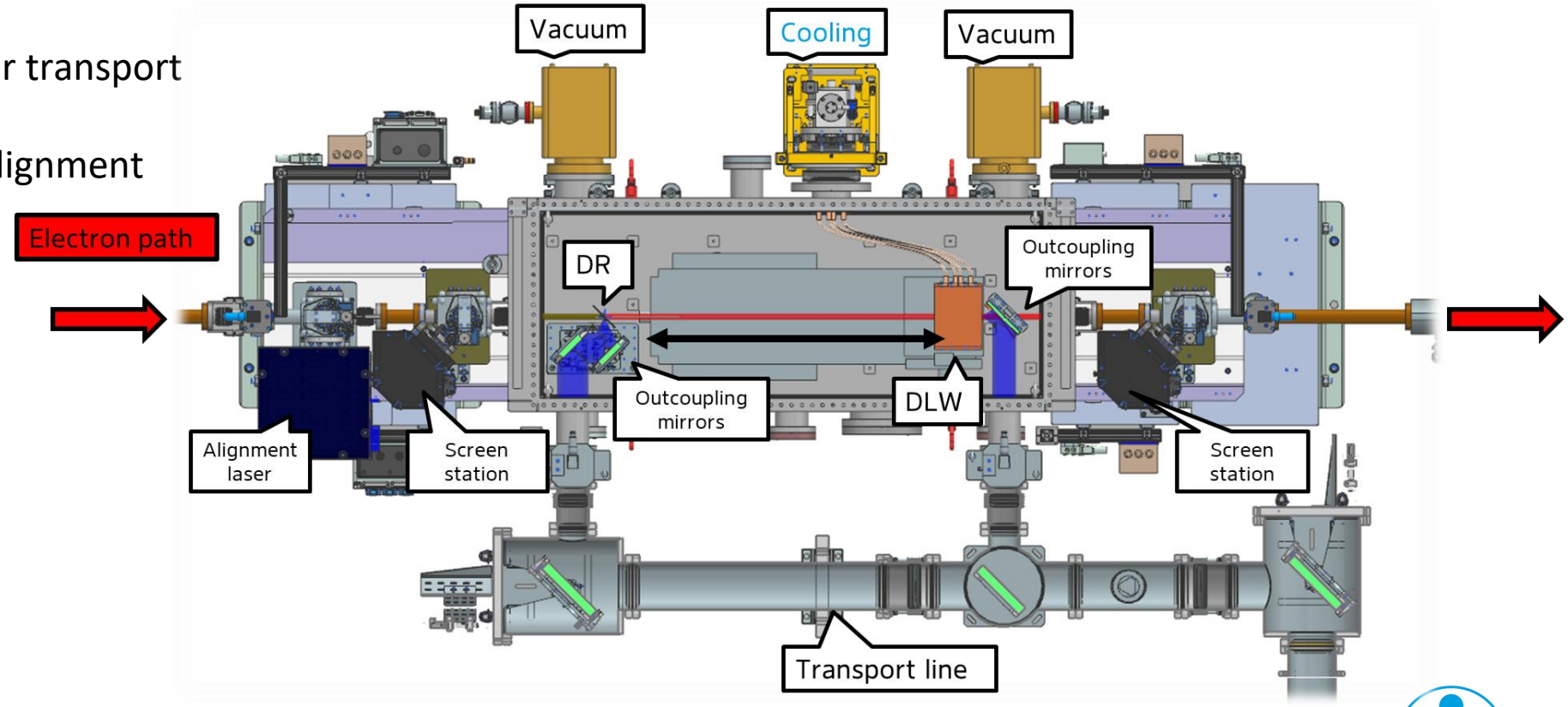


At 16 GeV, $\gamma = 32000$,

$$\sigma_r = \sqrt{\frac{\epsilon_n \beta}{\gamma}} = 3\ \mu m.$$

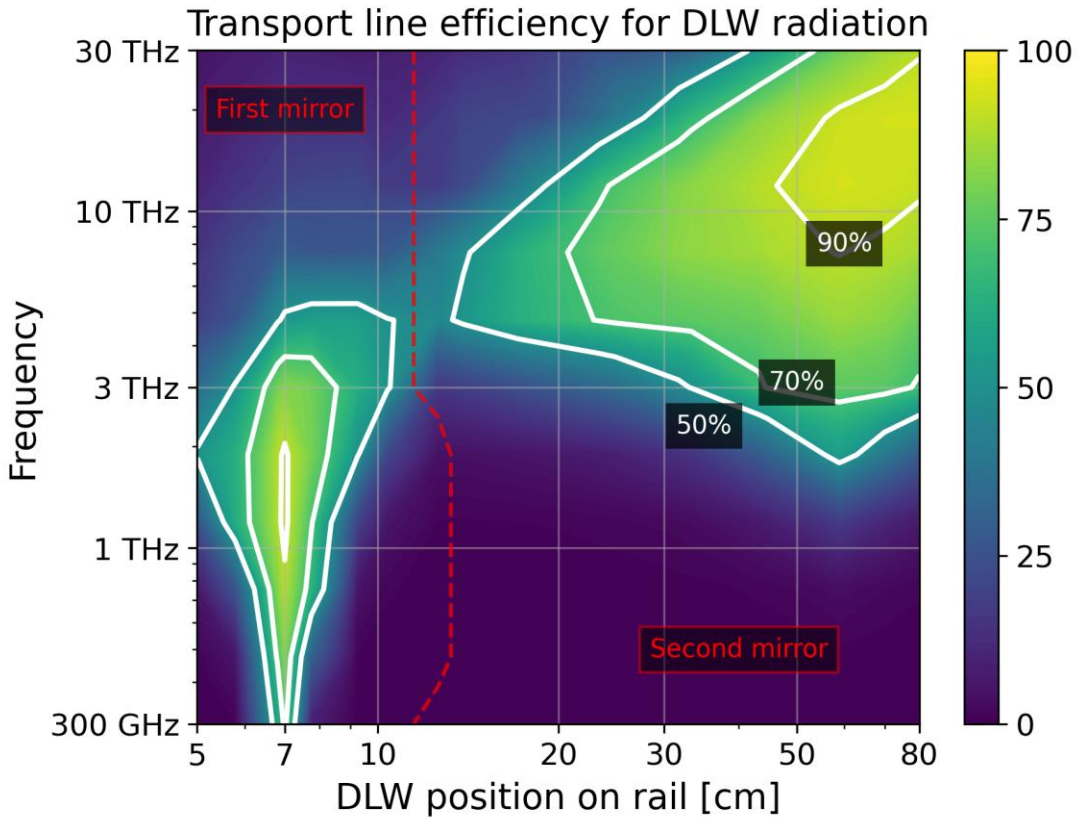
Main chamber

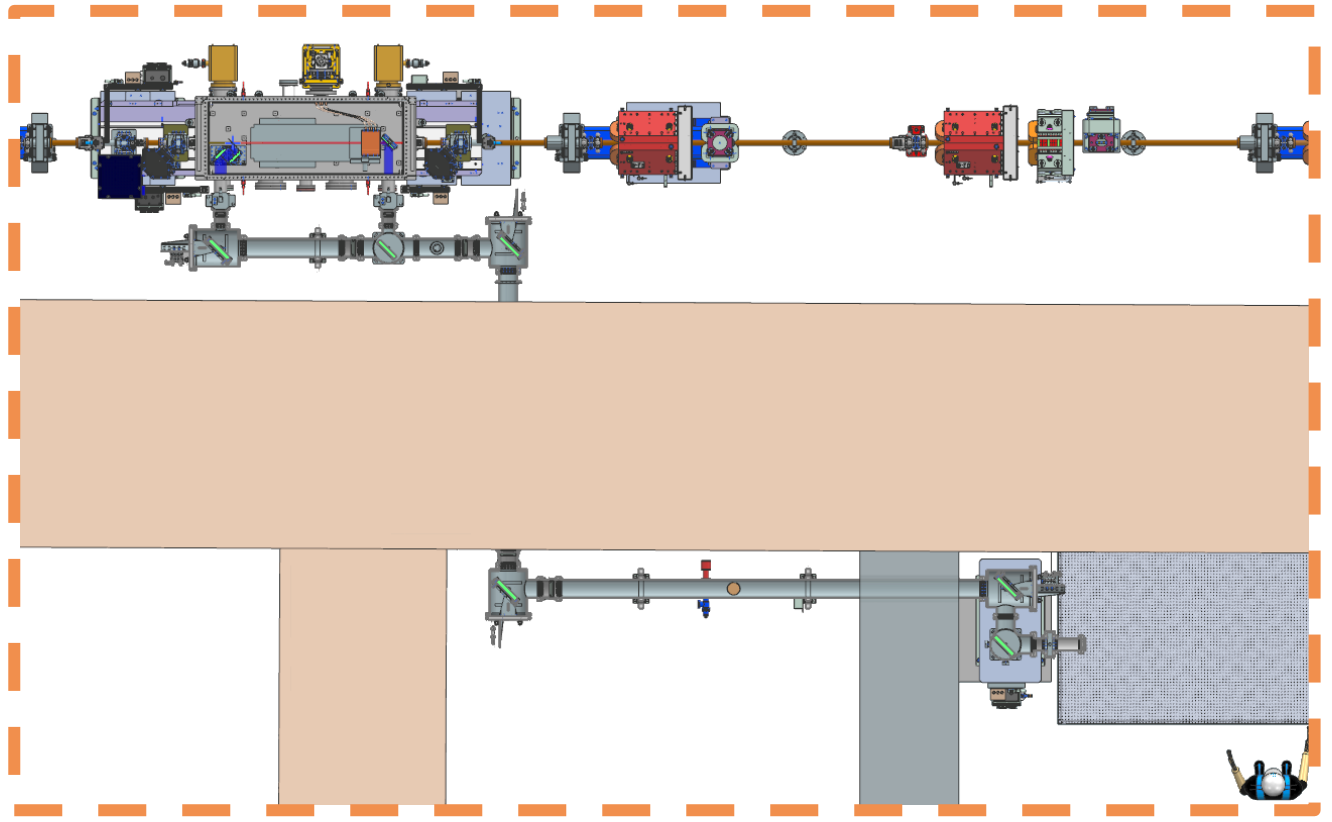
- 5D positioning system from Suna, similar design in use at PETRA, capable of 1 um positioning.
- Cryo for waveguide cooling (losses+tunability) anticipate 70 k
- Rail to improve coupling for transport
- Mirror chamber for laser alignment



THz transport

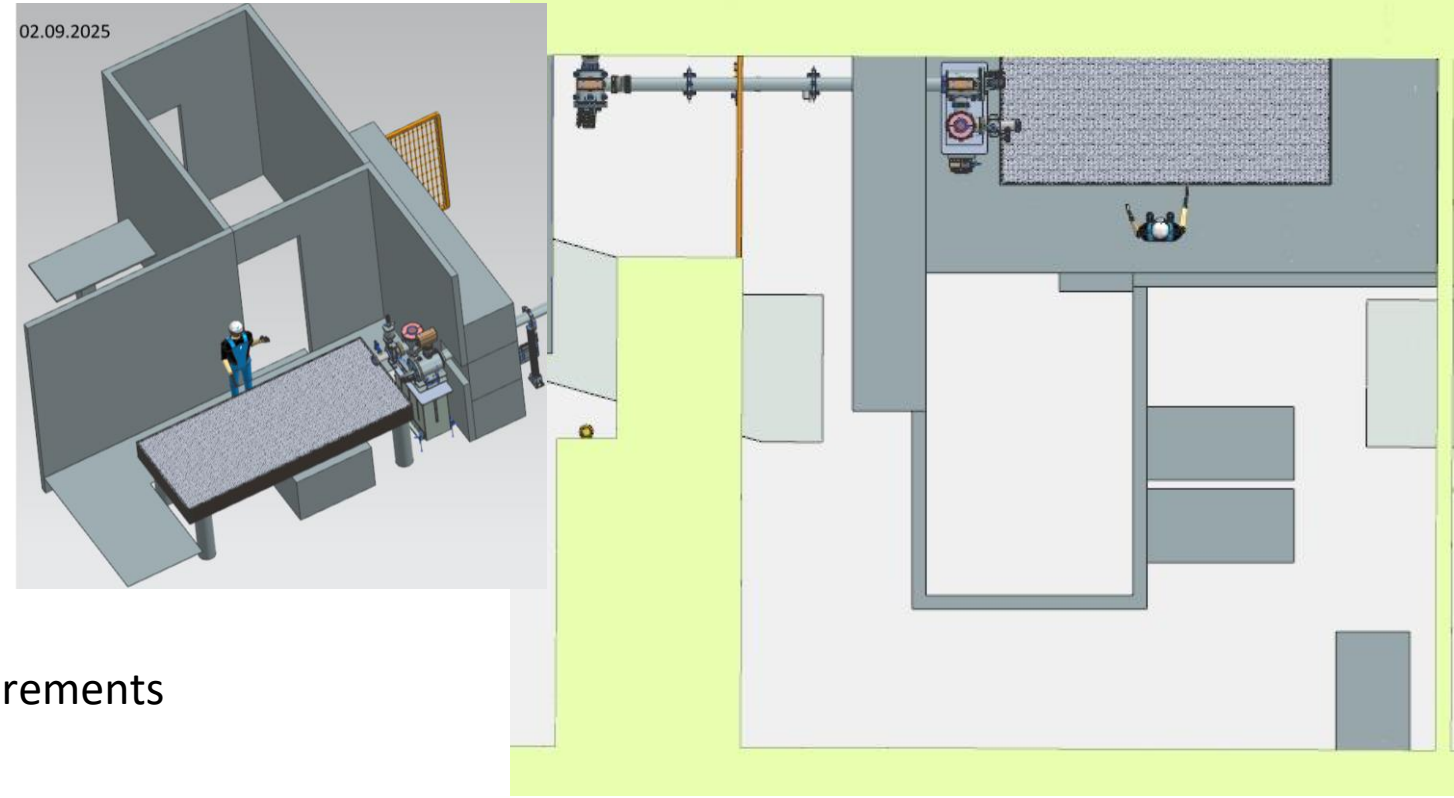
- Design of rail system, two holey mirrors and beamline required significant simulation and optimizations
  - Accomplished with ocelot with support from Sergey





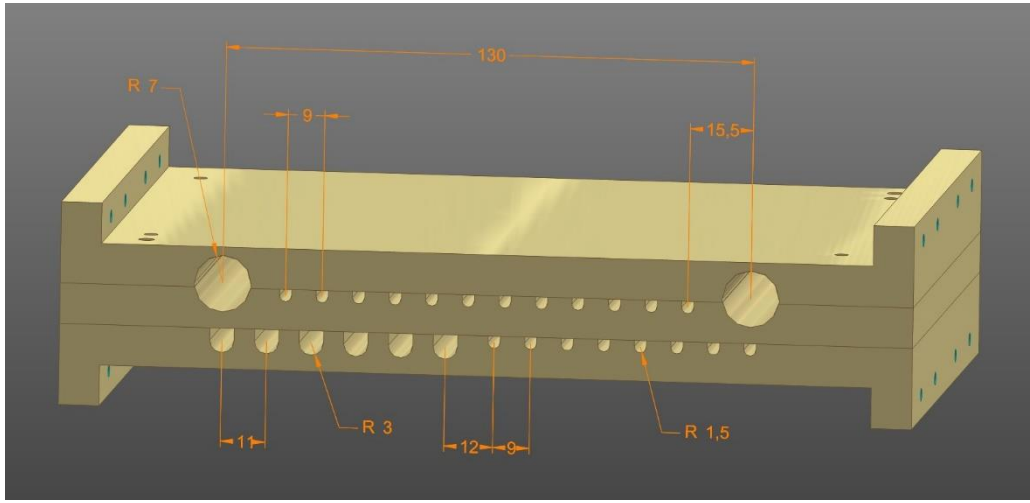
Lab layout

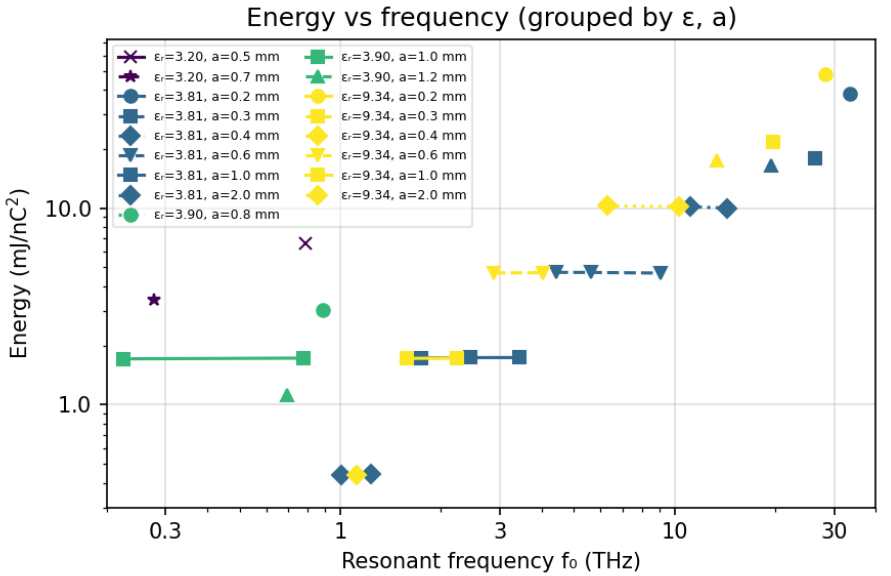
- Lab design complete procurement ongoing.
  - False floor to avoid a 1.44 m beam height.
  - Accessible during machine operation
  - New wall has installed
- Planned THz diagnostics include
  - THz camera
  - Pyrometer
  - Autocorrelator for spectral content measurements
  - Calibrated CRISP-like spectrometer
  - Single shot EOS



Waveguides

- Significant room for R&D in this sector, we have many ideas, great opportunity for publications
- For sub-THz, quartz tubes provide robust and low loss solutions
- For higher frequencies ALD coated copper tubes are very promising for their thin layers
- Other options being investigated (tapered, fibers, corrugated etc.)





Deviations from plan

- Currently deviating due to lack of THz source to characterize our tubes.
  - REGAE laser has died where Juna built her setup.
  - T. Feurer THz source in Bern died
  - THz source at XFEL has died (Ilie Radu)
  - We think it is now essential to invest in a long term system (Pharos) for these measurements.

Timeline of this R&D activity

Proposed Date	Milestone Description	Updated Date
Date / Period	Milestone Description	New Date/ Period
24H2	Completion of THz beamline design and initialization of procurement	24H2
24H2	Tests of ALD waveguides	24H2
25H1	Lab development and procurement	25H2
25H2	Installation of STERN	25H2
26H1	Detection of first THz	26H1
26H2	Characterization complete of first structures and TR	26H2
26H2	Beginning of laser-upgrade diagnostics	26H2
27H1	First (S)EOS detection	27H1
27H1	Iris-line Demo development/ procurement	27H1
27H2	Spectral down selection / filtering demonstration	27H2

Risks to R&D Project

- Adequate characterization of the waveguides have proven to be problematic.
- Delivery of mirrors for beamline (November)
- Chamber build up issues (electronics, movement problems, delivery times etc)

Outlook / Summary

- On track for producing first THz in STERN next year
- Waveguide development underway to produce narrowband high energy pulses at tunable frequencies
- Working with XFEL now to hire postdoc for THz transport prototype
- Upcoming two years will determine how to handle extension, or reality of becoming a standard source for users.

Publications

- K. Peetermans, A. Bacci, A. Grigoryan, B. Grigoryan, F. Lemery, K. Flöttmann, M. Rossetti Conti, M. Ivanyan — "*Simulation and optimization of a sub-THz Cherenkov FEL at AREAL*", DOI:10.18429/JACoW-IPAC25-MOPB105

- K. Peetermans, F. Lemery, M. Krasilnikov, X. Li — "*Optimizing Cherenkov waveguide seeding for THz SASE FELs towards stable, few-cycle pulses*", DOI:10.18429/JACoW-IPAC25-MOPB106

- K. Peetermans, F. Giesteira, F. Lemery, J. Wernsmann, K. Flöttmann, L. Müller, T. Wohlenberg, V. Kalender — "*Courant–Snyder formalism for modeling, optimizing and simulating broadband THz radiation transport*", DOI:10.18429/JACoW-IPAC25-TUPM031

- K. Peetermans, I. Zagorodnov, F. Lemery — "*Cherenkov waveguide design for THz production at the EuXFEL*", DOI:10.18429/JACoW-IPAC25-TUPM032

- J. Wernsmann, K. Floettmann, B. Steffen, and F. Lemery.
  Design, fabrication, and characterization of 3D-printed photonic crystals for THz filtering applications in particle accelerators.
  In: Proceedings of the 16th International Particle Accelerator Conference (IPAC 2025), Taipeh (Taiwan), 1–6 June 2025, pp. 2520–2522, 2025.

- J. Wernsmann, F. Amorim Goncalves Giesteira, and F. Lemery.
  Development and Laboratory Validation of a Precise Alignment Setup for Electron Beam-Based THz Radiation Generation at European XFEL.
  In: Proceedings of the 16th International Particle Accelerator Conference (IPAC 2025), Taipeh (Taiwan), 1–6 June 2025, pp. 2325–2525, 2025.

- TDR coming soon

Thanks

Karel Peetermans, Juna Wernsmann, Winni Decking, Klaus Floettmann, Nina Golubeva, Nils Lockmann, Bernd Steffen, Marie Kristin Czwalinna, Martin Dohlus, Igor Zagorodnov, Jonah Richards, Torsten Wohlenberg, Lukas Mueller, Daniel Thoden, Lucy Müller, Riko Wichmann, Stuart Walker, Marc Guetg, Shan Liu, Sergey Tomin, Weilun Qin, Tianyun Long, Serge Bielawski, Mikhail Krasilnikov, Gianluca Geloni, Dirk Lipka, Artem Novokshonov, Gero Kube, Ingmar Hartl, Evgeny Negodin, Matthias Scholz