Beam losses and radiation studies for advanced operation schemes at the European XFEL

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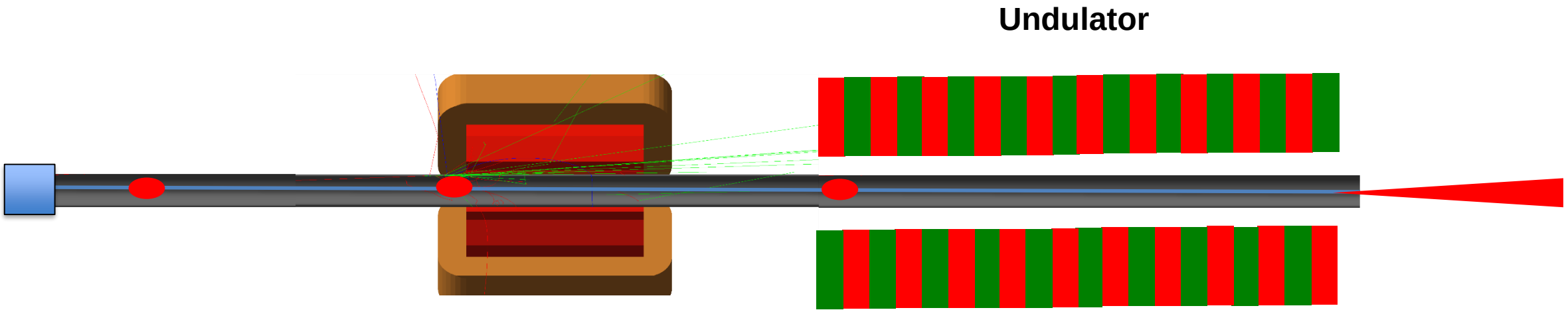
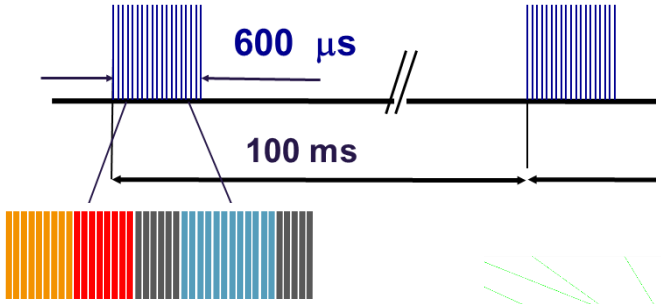
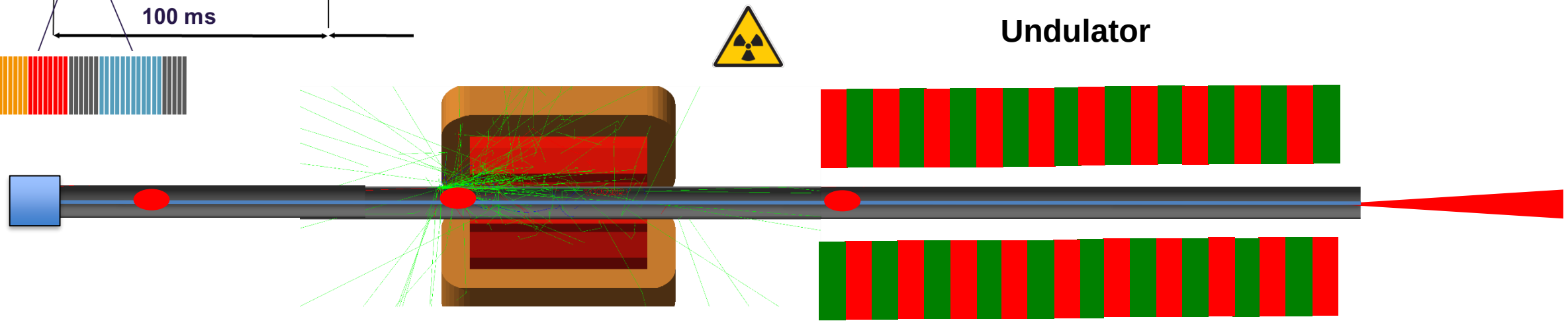
DESY-STFC-XFEL collaboration meeting
Hamburg
05.12.2024

Why do we care about beam losses and radiation?



Why do we care about beam losses and radiation?

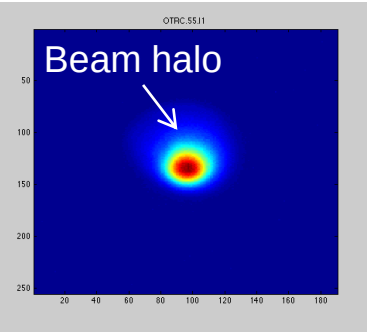




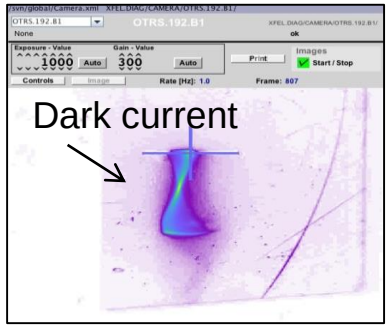
MHz repetition rate
>500 kW of beam power

Sources of beam losses and radiation

- **Beam halo/tail:** off-position/angle and off-energy particles (>±3σ)
  - **Dark current (DC):** from gun cathode (due to field emission) and cavities
  - **Optics related**: mismatch, coupling, dispersion, non-linearities etc.
  - **Physical processes**: collective effects (space charge, wake field), beam gas scattering, intra-beam scattering, beam gas bremsstrahlung etc.
- **Synchrotron radiation** generated by the undulator



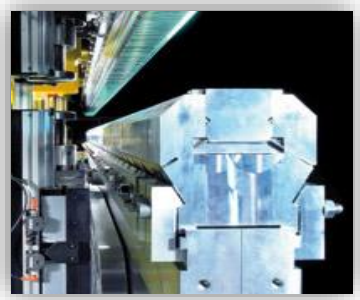
Beam spot of the halo on injector screen



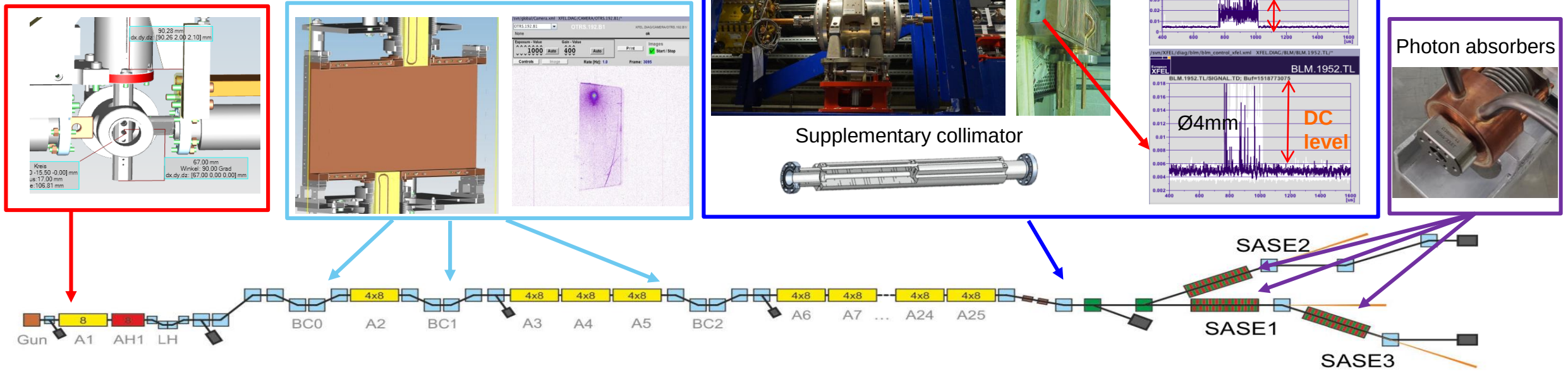
Dark current measured in bunch compressor section

Potential problems caused by beam losses and radiation

- **demagnetization of undulators**
- **radiation damages of other components** (electronics, vacuum chamber etc.)

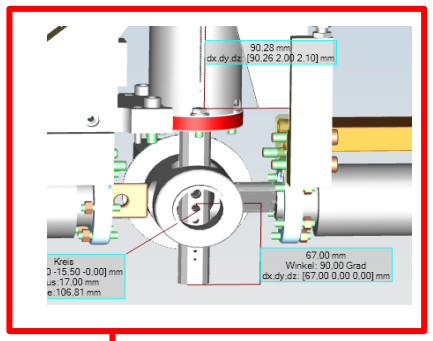


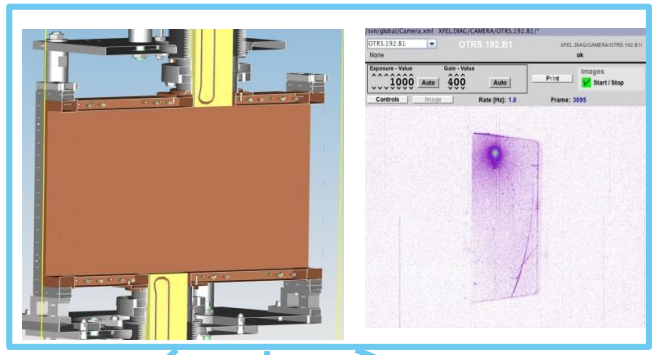
Collimators installed at Eu-XFEL



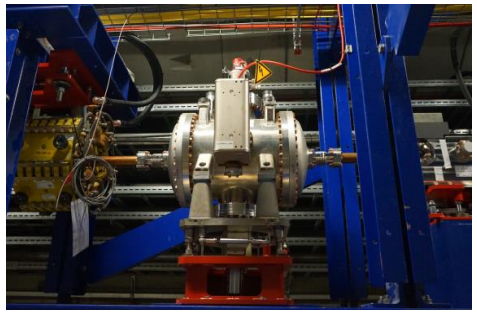
Location	Geometry	Material	Thickness/length	Number	Main collimation target
Gun	plate with Ø 2-8 mm holes	Cu	11 mm	1	DC
	plate with Ø 8 mm hole	Cu	11 mm	1	DC and secondary particles
Bunch compressors	upper and lower bars	Cu	35 mm/75 mm	3	DC, energy halo
CL section	Ø 4,6,8,20 mm holes	Ti alloy+Al+Cu	0.5 m	4	DC, betatron and energy halo
	Ø10 mm holes	Al	1 m	3	secondary particles
Undulator	9 x 8 mm elliptical holes	Cu	3 mm	Nr. of cells	synchrotron radiation

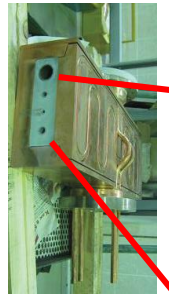
Collimators installed at Eu-XFEL

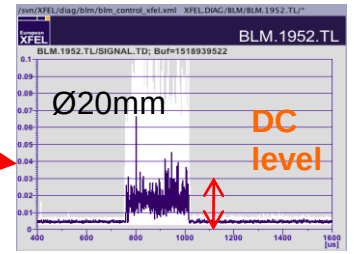


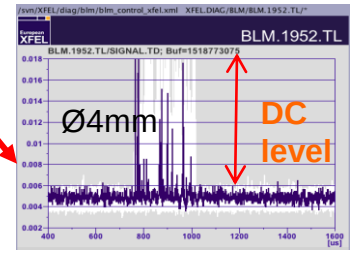


Main collimator

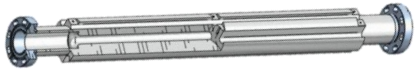




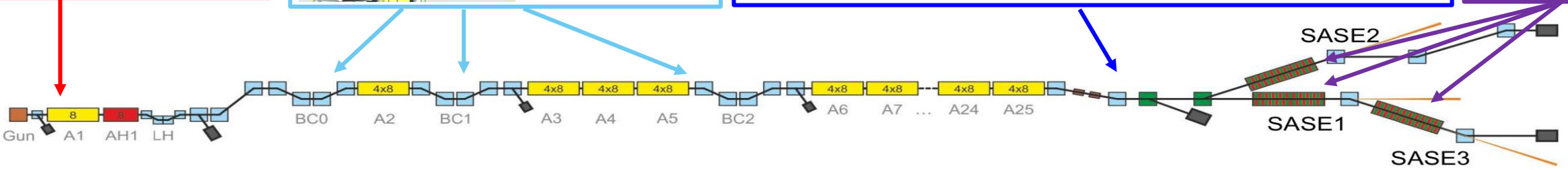


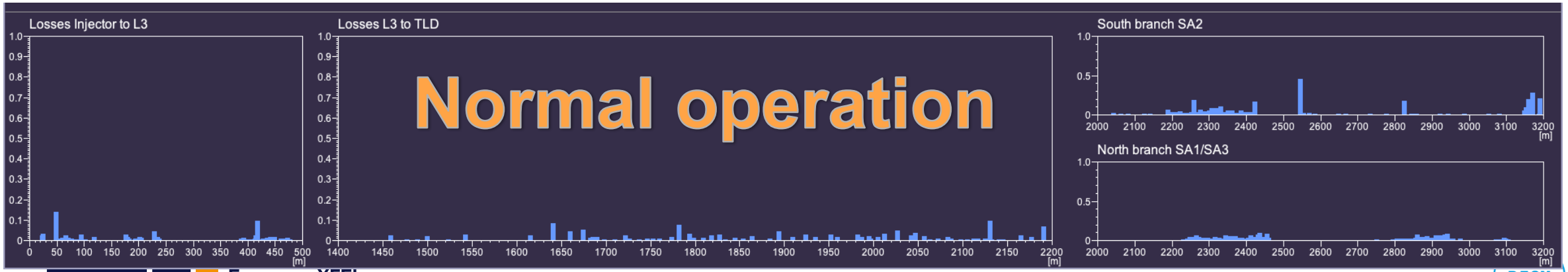


Supplementary collimator



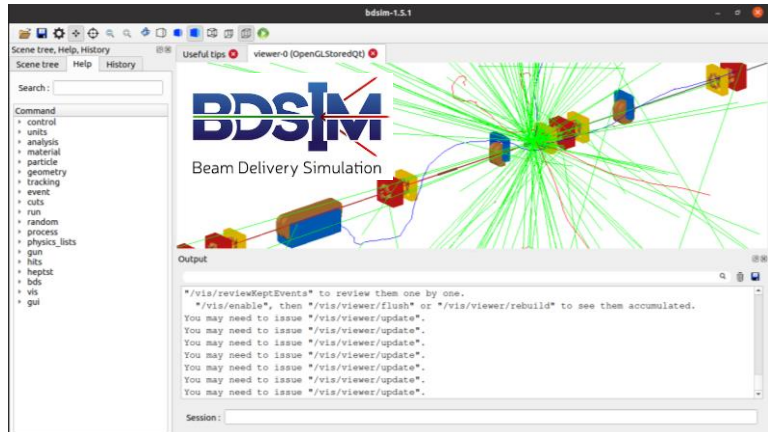
Photon absorbers





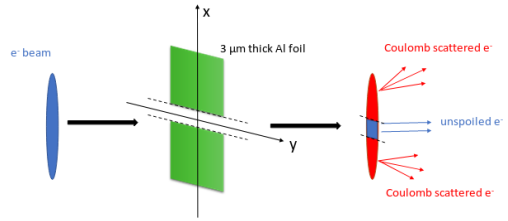
Normal operation

Advanced operation modes (with small apertures)

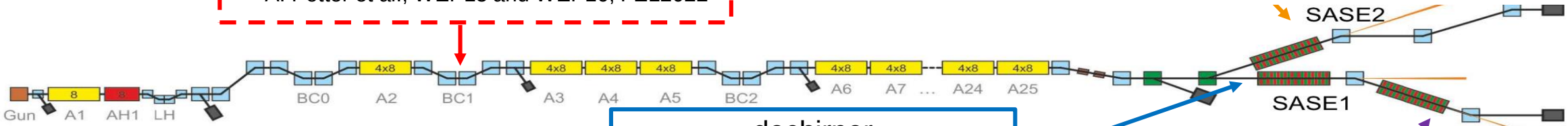


L. Nevay, S. Boogert et al., *Computer Physics Communications* 252 (2020): 107200

slotted foil (180 um gap)

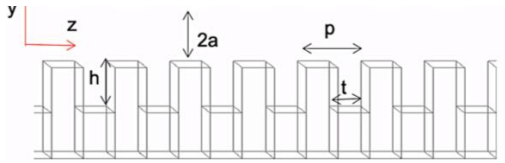


A. Potter et al., WEP15 and WEP16, FEL2022



- Short pulse generation
- Fresh slice application
- Higher photon energy
- Polarization control
- THz generation
- …

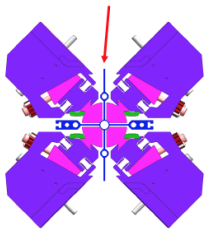
dechirper
(0.5 mm to beam core)



JunjieGuo et al., NIMA 1034 (2022): 166780

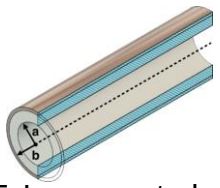
Apple-X undulator

Vacuum chamber diameter: external / internal 11 / 9.4 mm, wall thickness: 0.8 mm.



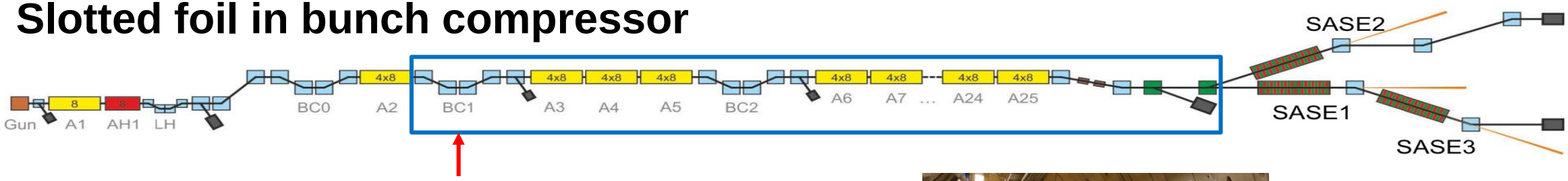
A. Potter et al., TH3D, FLS2023

STERN
(r=1-2 mm)

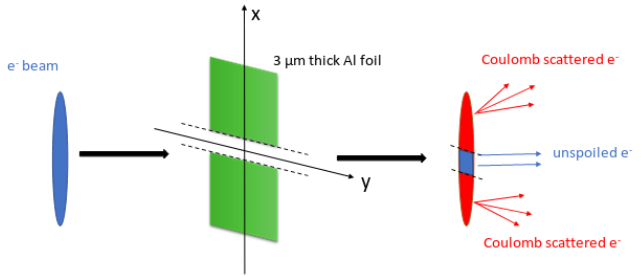


F. Lemery et al.

Slotted foil in bunch compressor

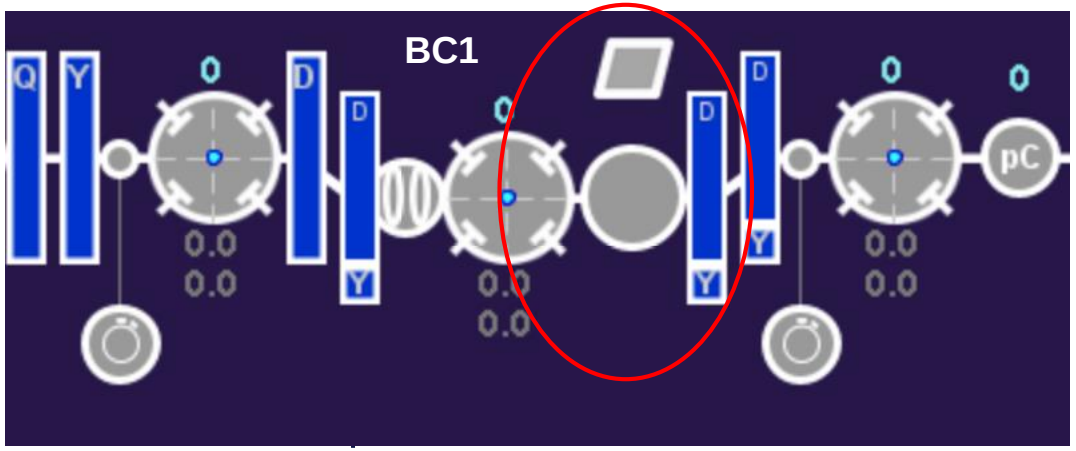


slotted foil (180 um gap)



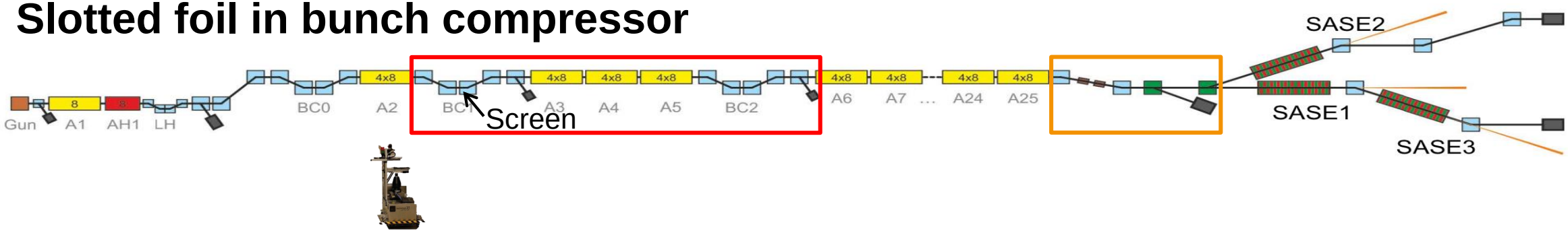
A. Potter et al., WEP15 and WEP16, FEL2022

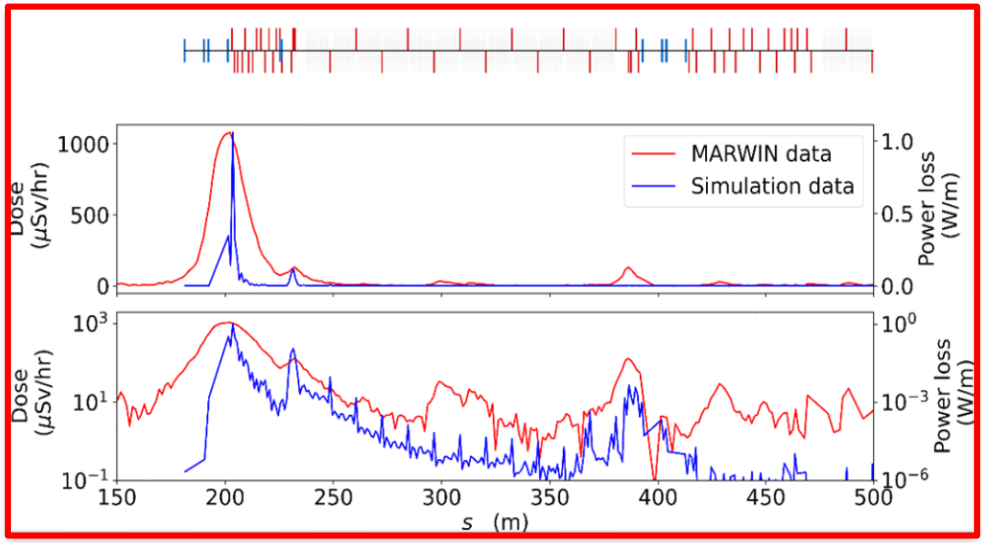
Dehne, Andre, et al. proceeding of ICALEPCS'17 (pp. 76-80).

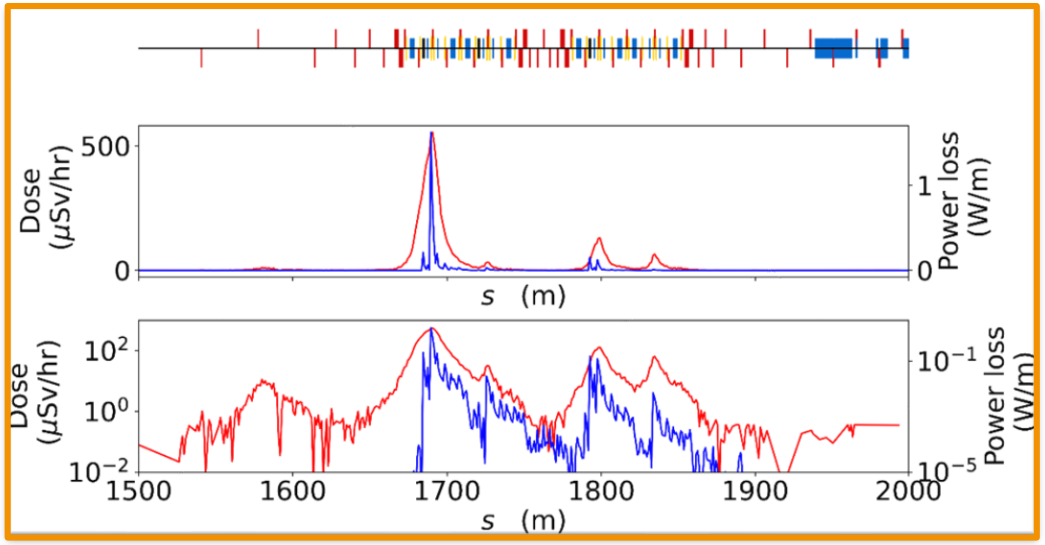


- Radiation scan using Marwin performed with a screen inserted in BC1 and compared with simulation

Slotted foil in bunch compressor

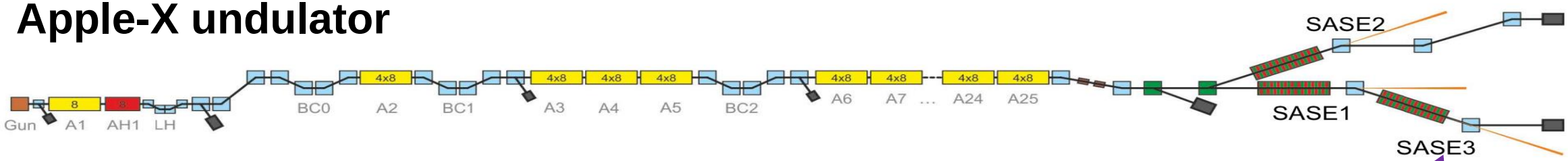




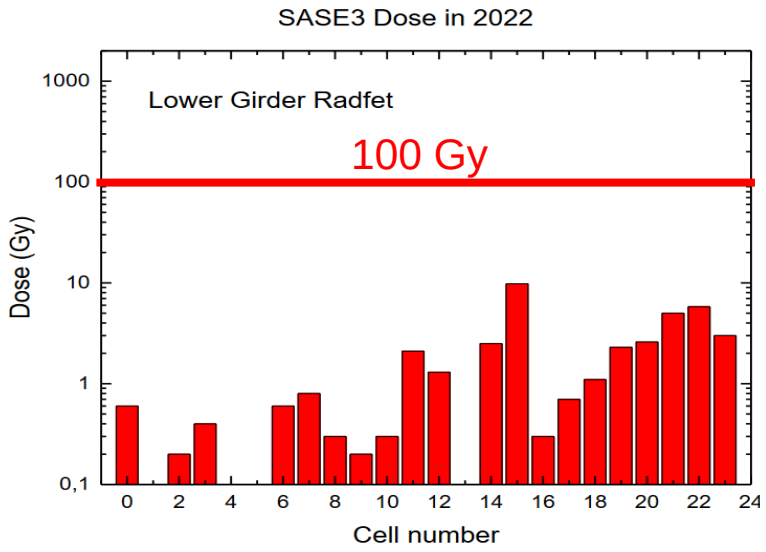


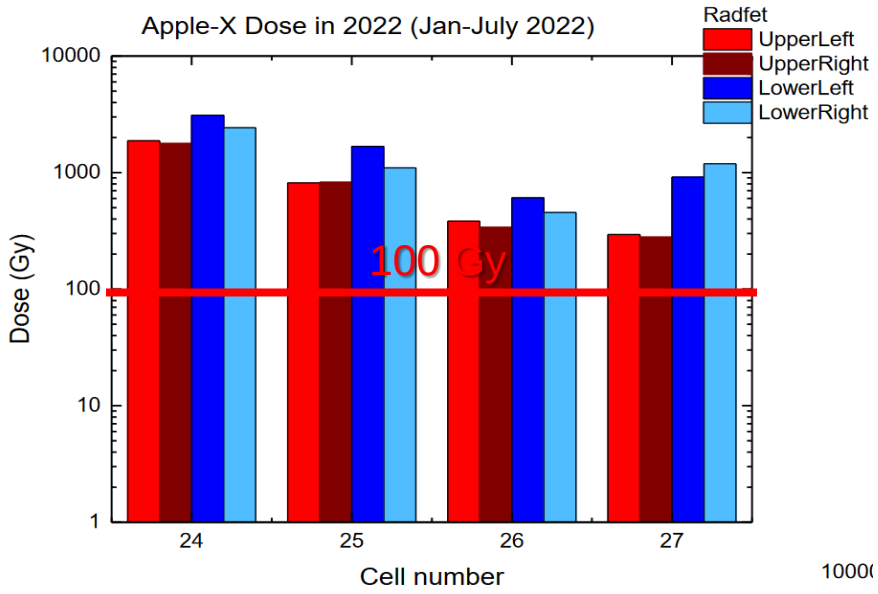
- **Nice agreement** between simulation and measurements
  - Negligible losses in the linac
  - Losses near bunch compressor and in the collimation section acceptable for **up to 1000 bunches/train**, can also be controlled by extra shielding of the components

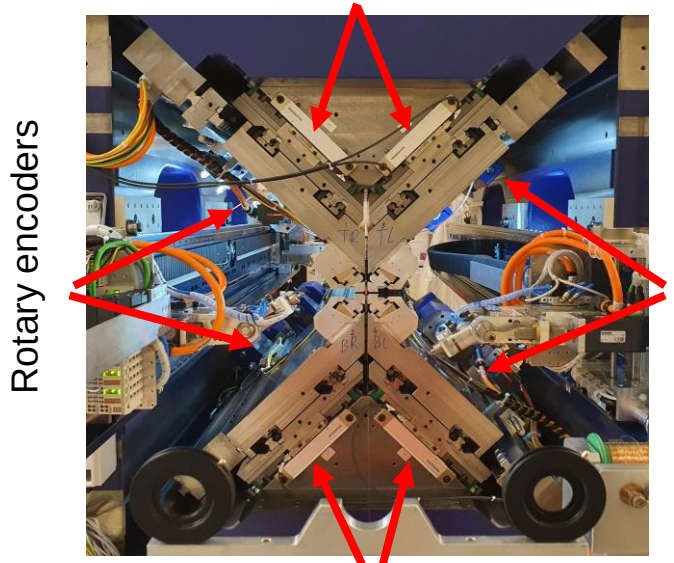
Apple-X undulator



Vacuum chamber diameter: external / internal 11 / 9.4 mm, wall thickness: 0.8 mm.





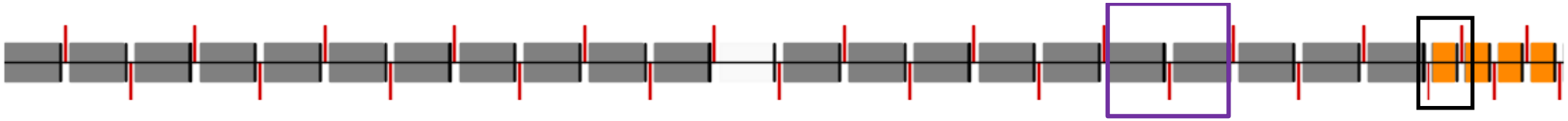


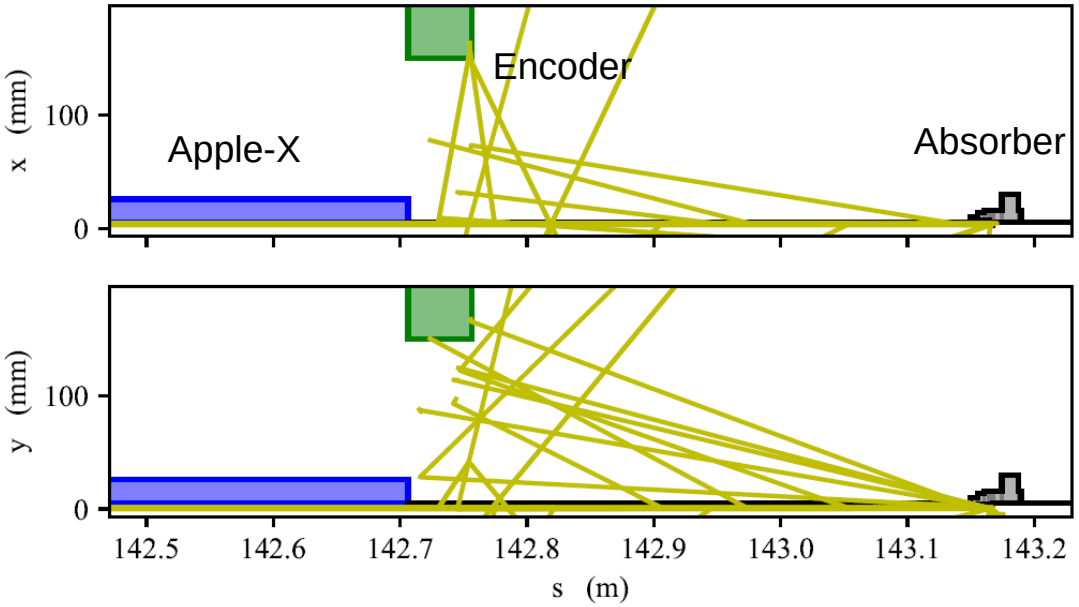
- **Installed in winter 2021, first lasing - April 5. 2022**
- Motor encoder damaged due to radiation on the Apple-X undulators
- Radiation level in the afterburner area is **>100 times higher** than in the planar undulator

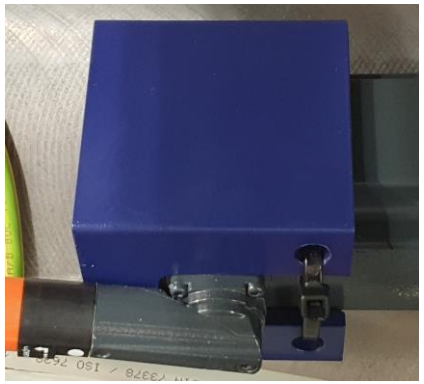
S. Karabekyan et al., TUPAB122, IPAC'21

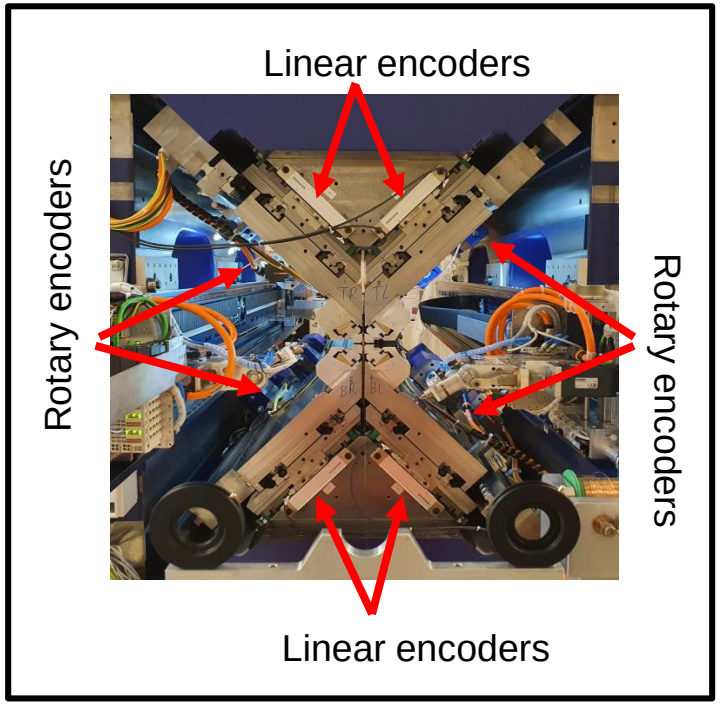
Apple-X undulator: simulation results

cell19 & cell20

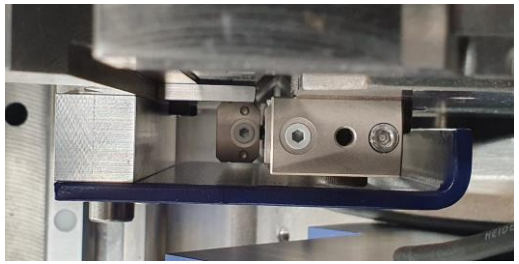








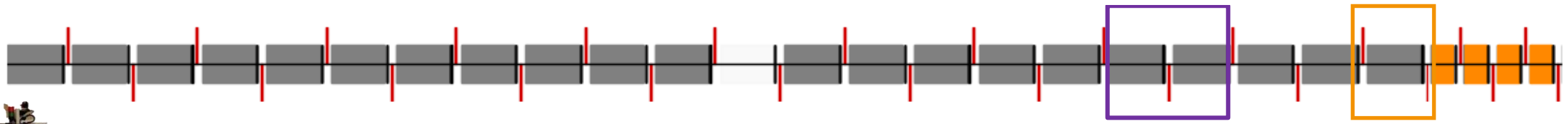
- Back-scattered particles are the main cause of the radiation
- Lead shielding added to protect encoders

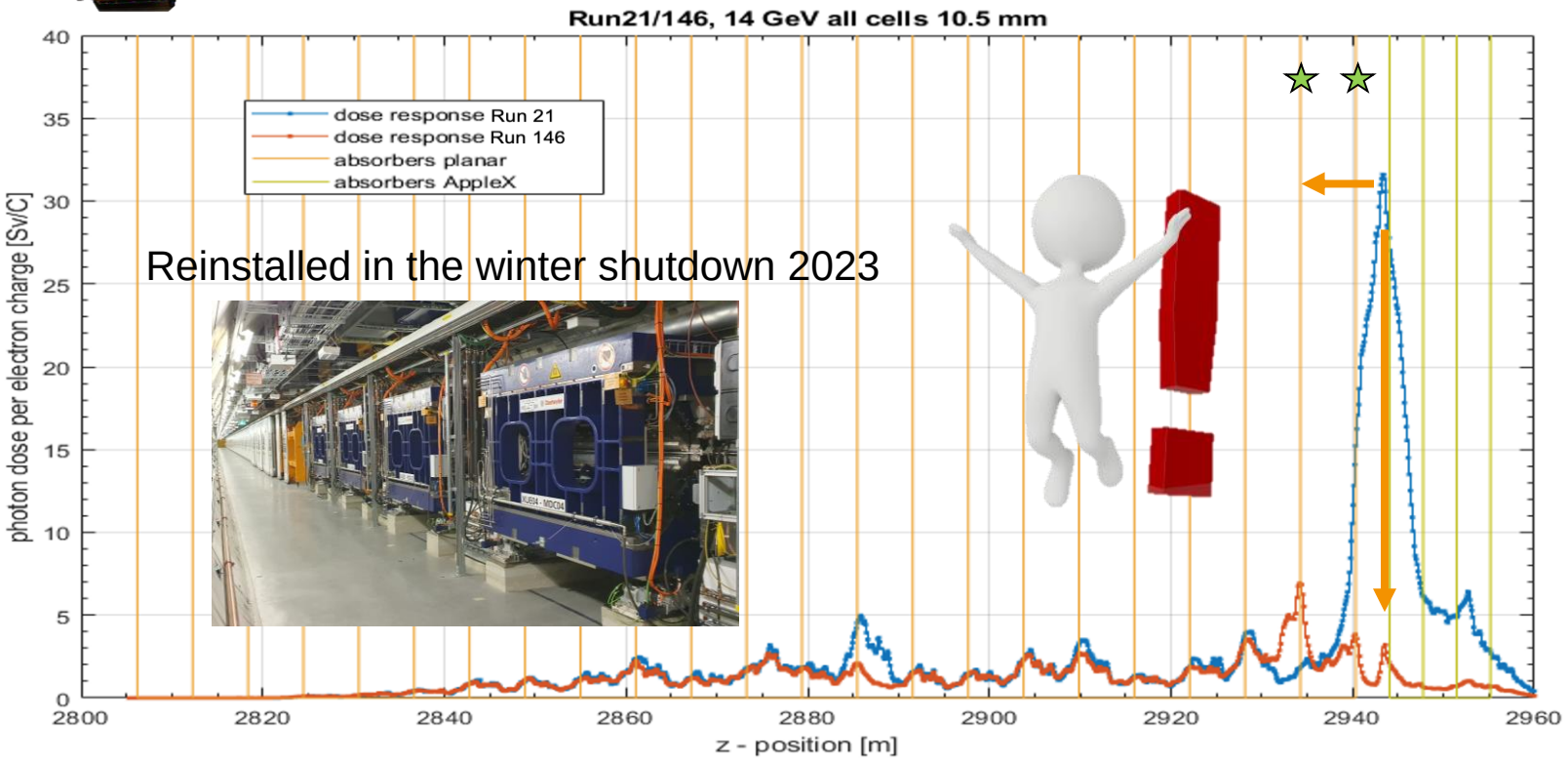


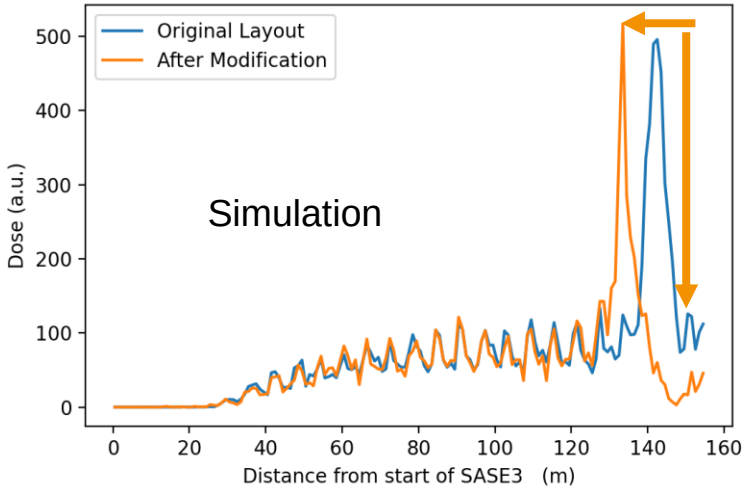
Courtesy of Suren Karabekyan

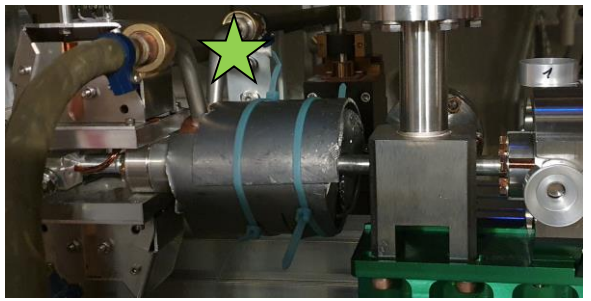
Apple-X undulator: next steps

cell19 & cell20



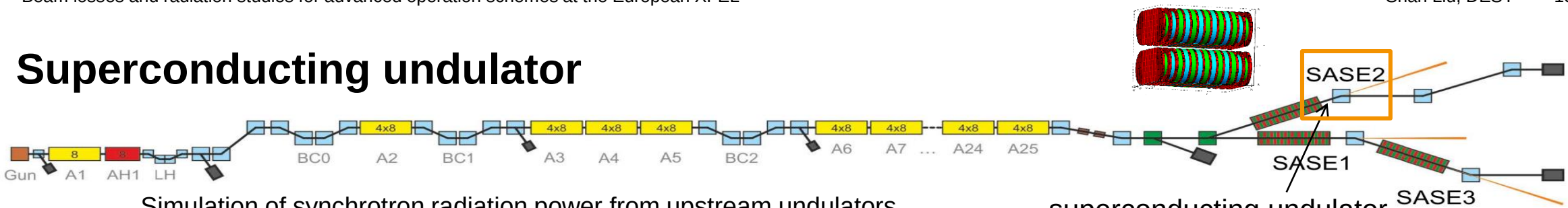






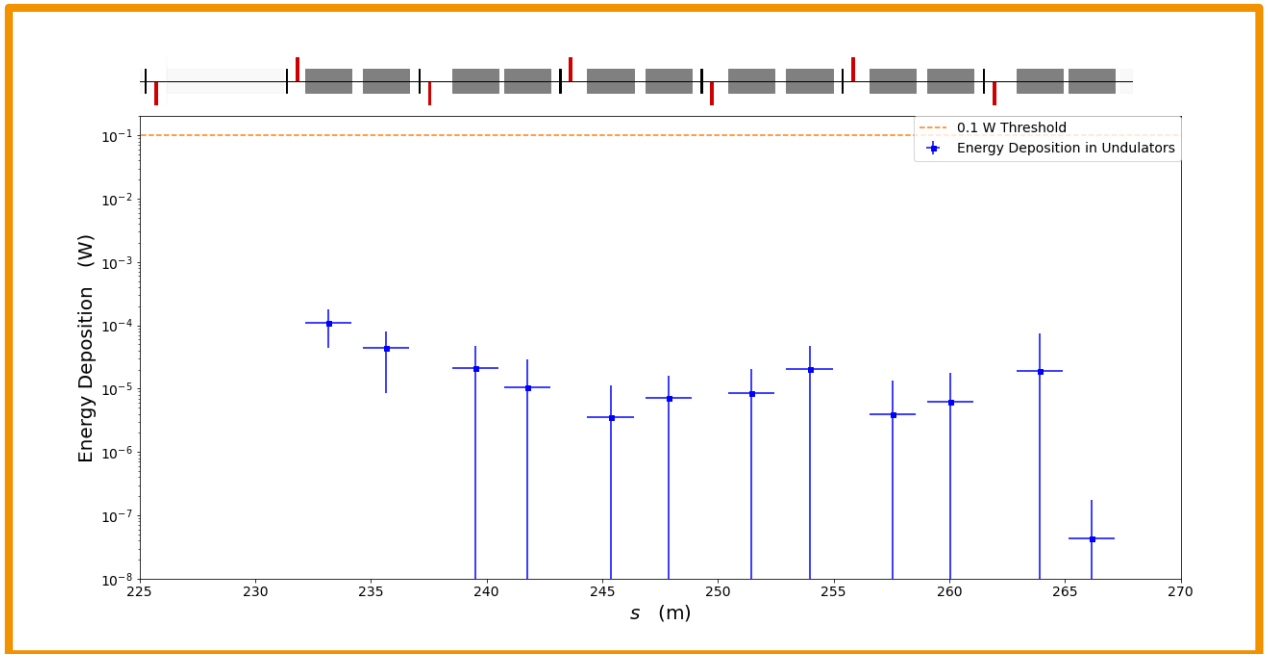
3 to 6 mm Lead shield added

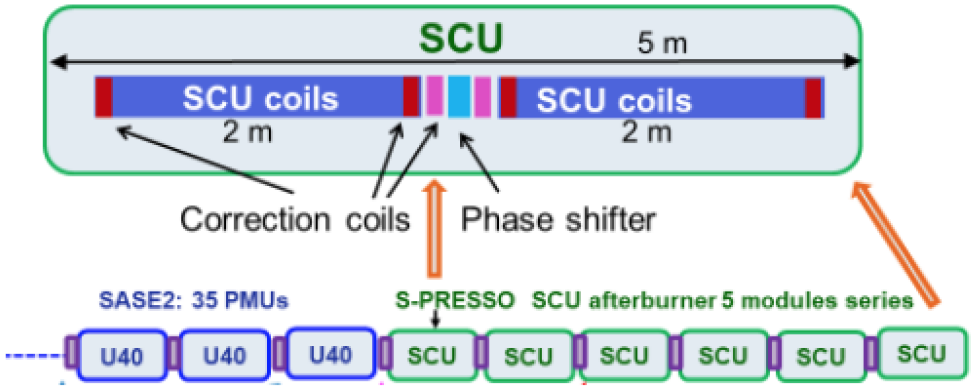
Superconducting undulator

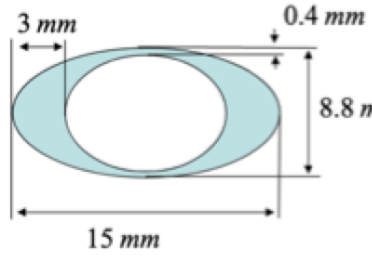


Simulation of synchrotron radiation power from upstream undulators

superconducting undulator
(5 mm aperture)

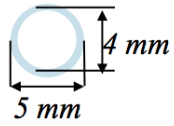






Cross Section

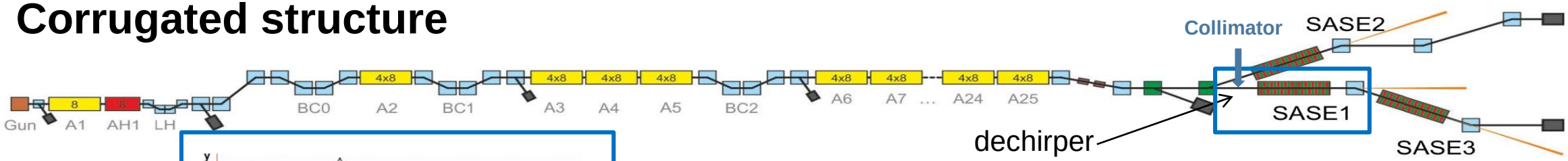
Standard undulator vacuum chamber and SR absorber



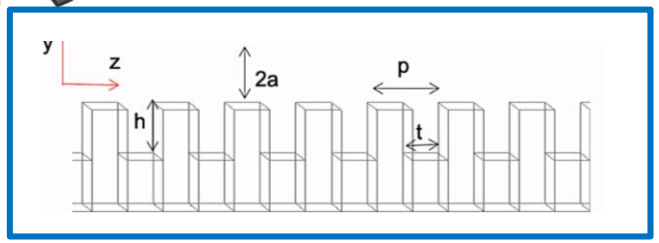
SCU vacuum and SR absorber

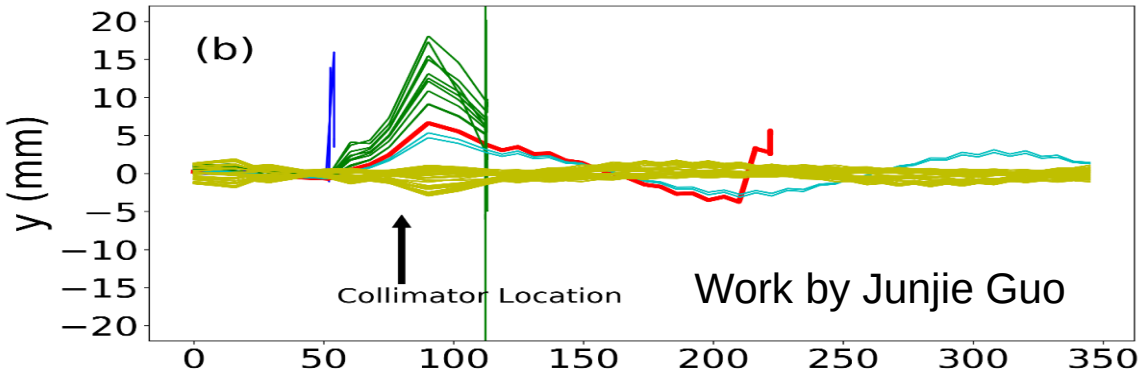
- Power calculated for worst case scenario: 1 nC beam with 27000 bunches/second
- All absorber apertures before the final U40 are 8mm and all absorber apertures after the final U40 are 4mm, **SR caused heat load acceptable with 4mm aperture absorber** -> beam halo study to be continued

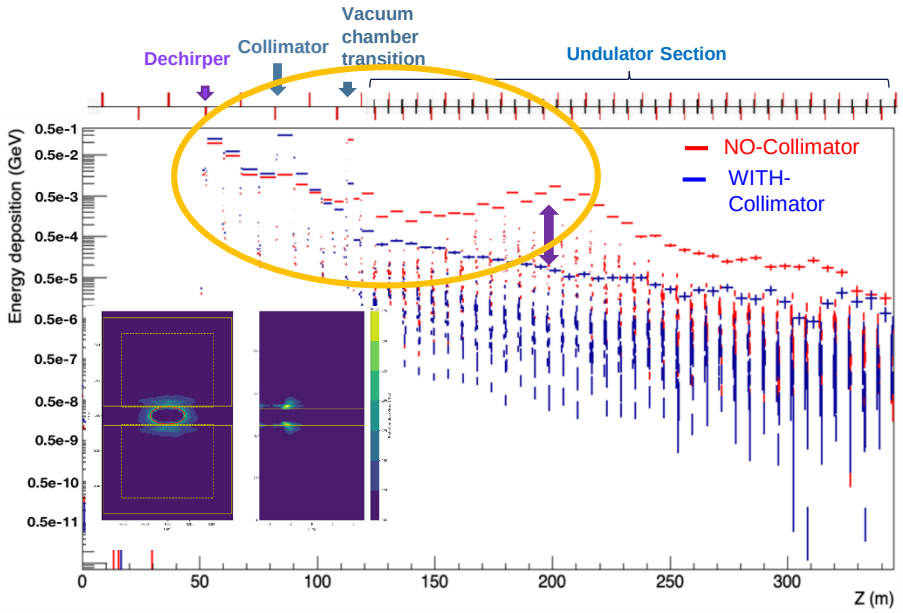
Corrugated structure

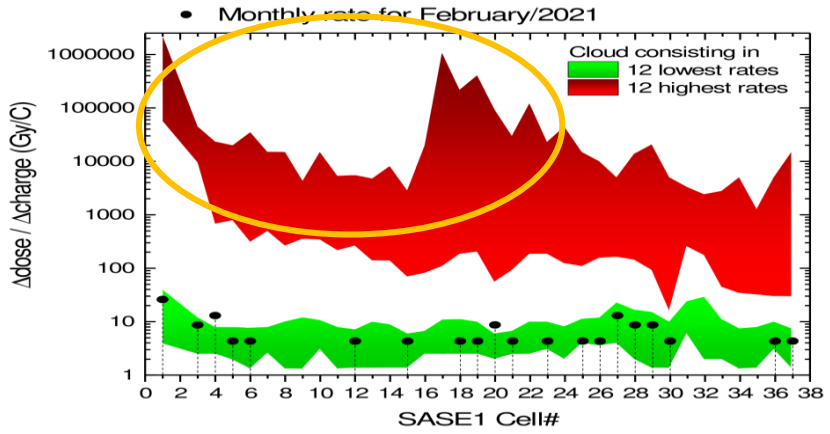


(0.5 mm to beam core)





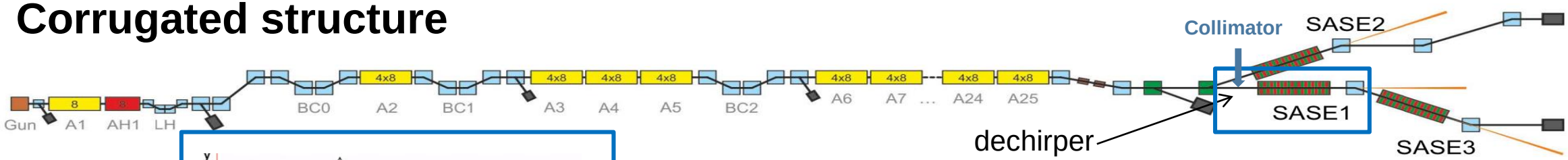


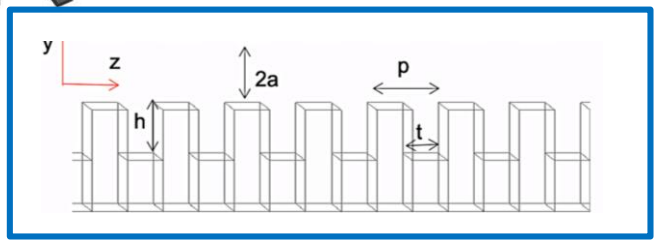


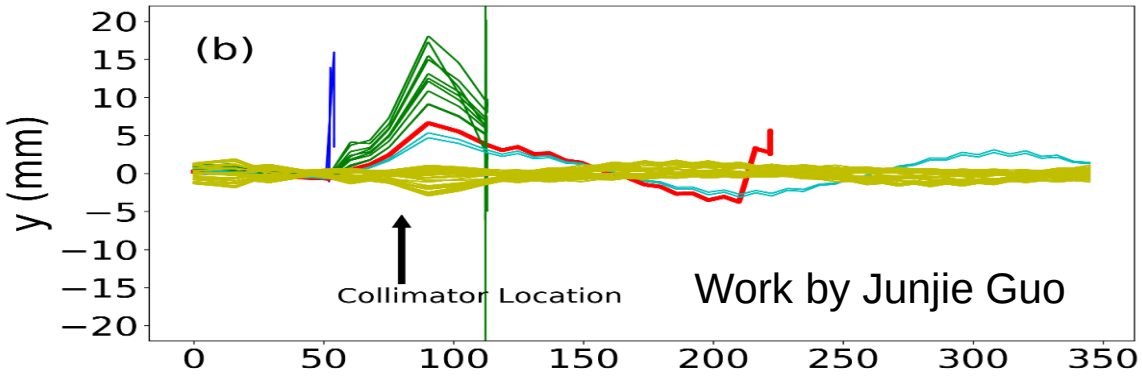
- 13 mGy/hr w/o and 2.5 mGy/hr with extra collimator
  -> 2191 hrs/year operation possible

Guo, Junjie, et al. NIMA 1034 (2022): 166780

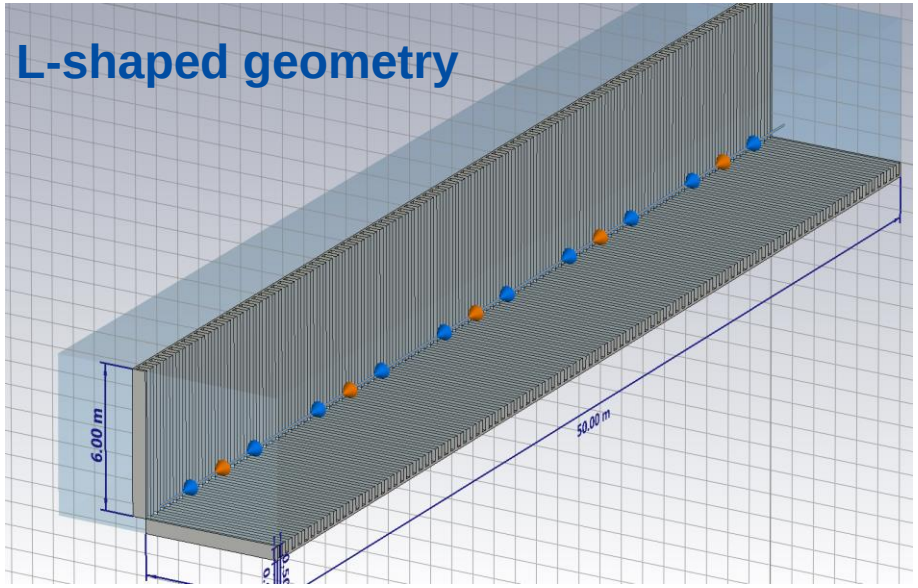
Corrugated structure



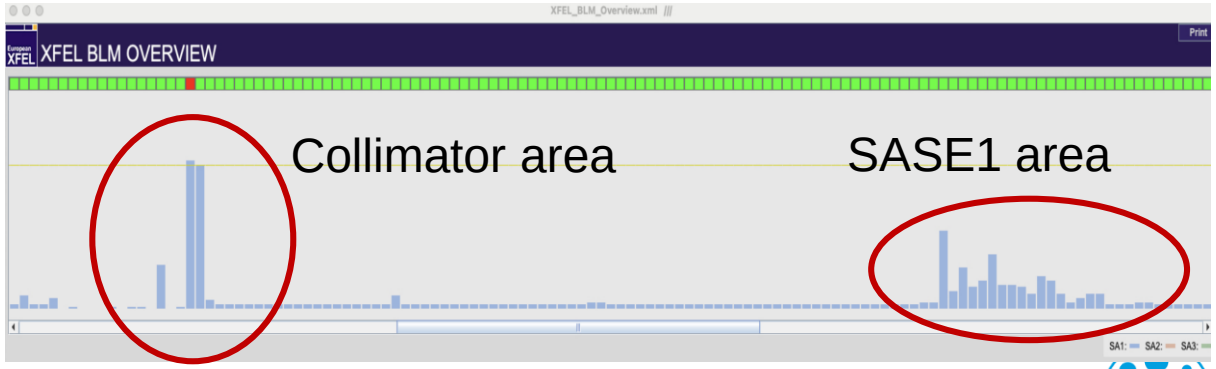




L-shaped geometry

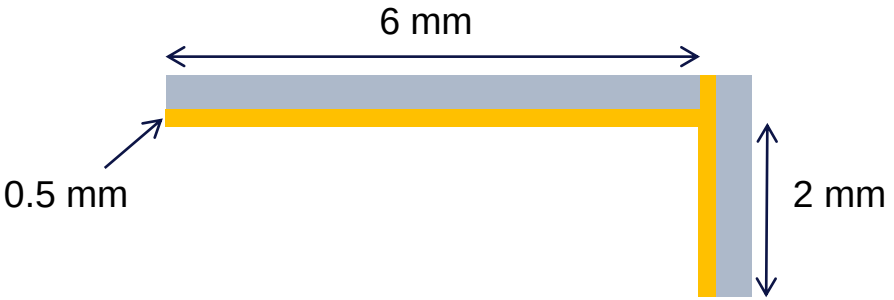


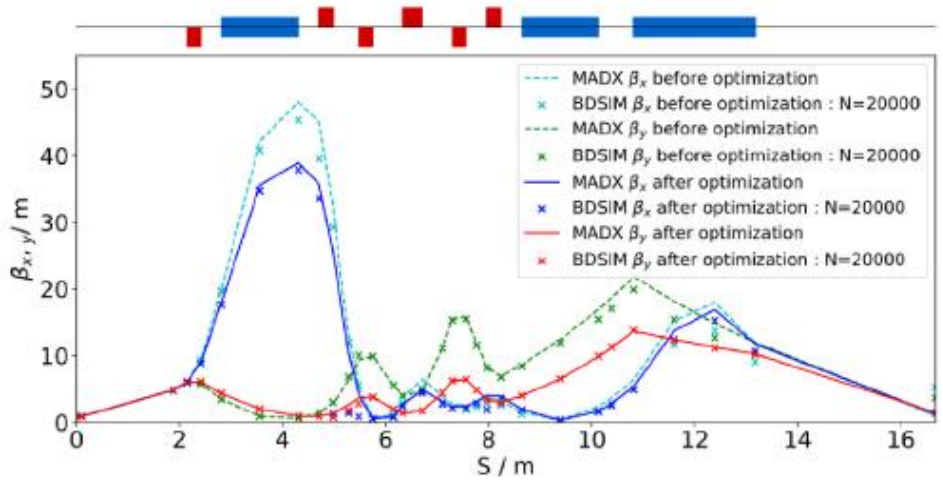
Loss pattern at high rep. rate

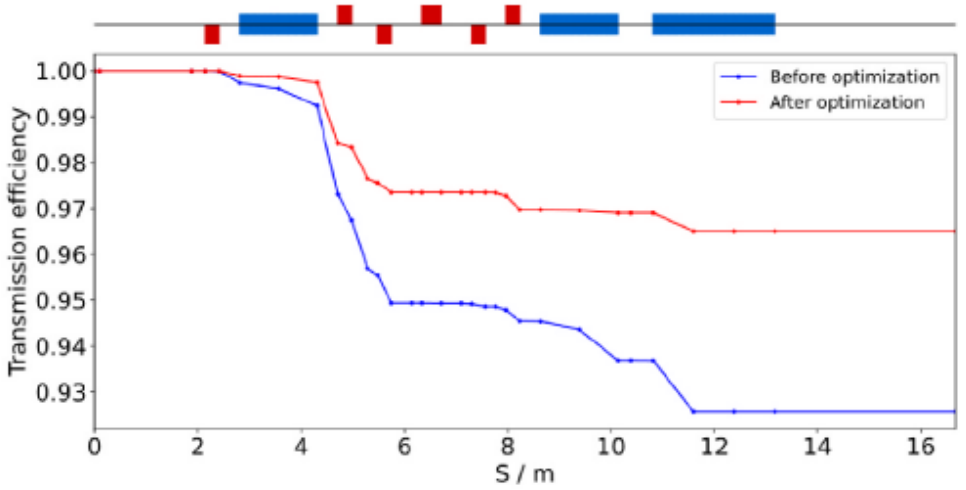


Plan for future work (for Jiacheng Wu)

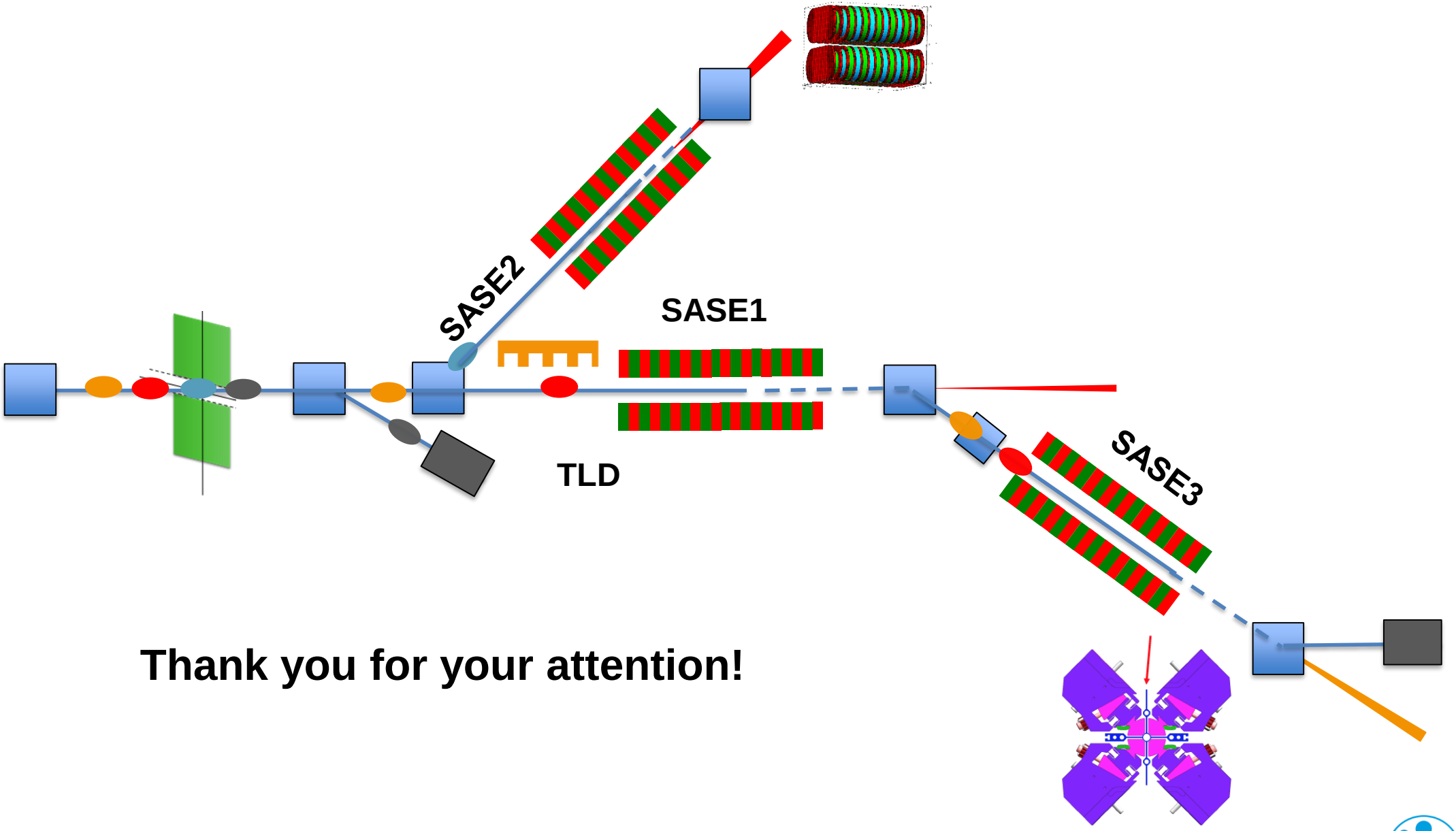
- Change dechirper to L-shape in BDSIM
- Add one more collimator and optimize the design of the collimator to minimize losses
- Possible use of machine learning in combination with BDSIM







Chen, Yu, et al. "Start-to-end modeling and transmission efficiency optimization for a cyclotron-based proton therapy beamline." *Nuclear Engineering and Technology* (2024).



Thank you for your attention!