Smart*Light: A new type of X-ray source for materials characterization

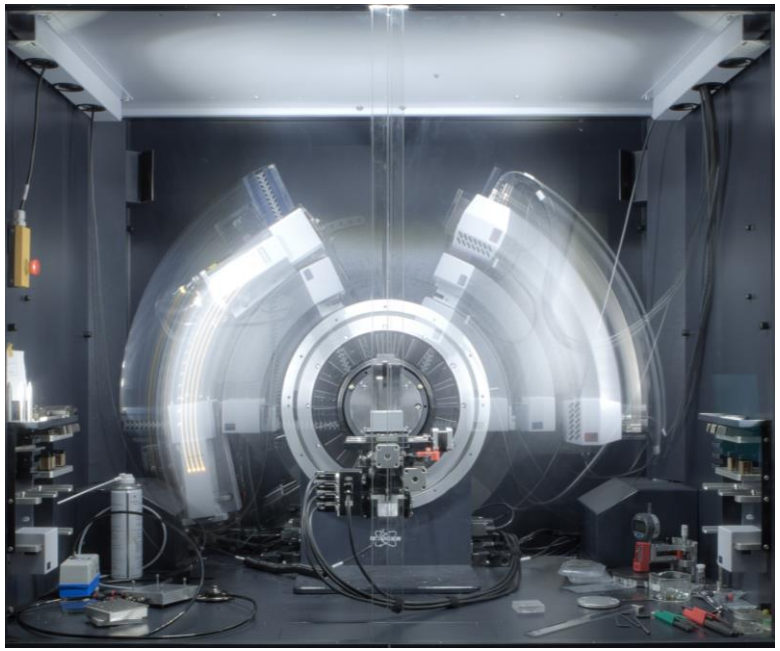
Compact accelerator-based soft and hard X-ray source

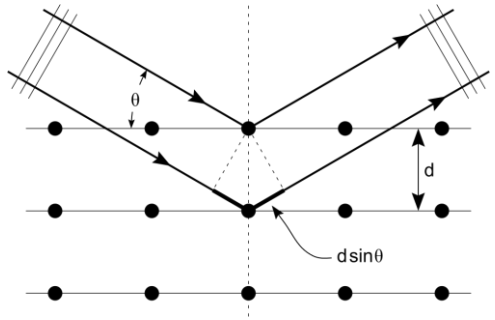
Dr. Gesa Welker and ir. Daniel Nijhof

Department of Applied Physics

Example: X-ray diffraction

2D





3D

Example: X-ray diffraction

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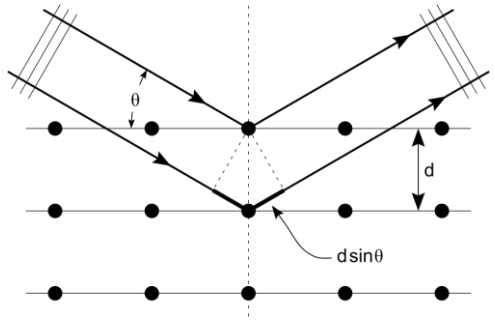
3D



Example: X-ray diffraction

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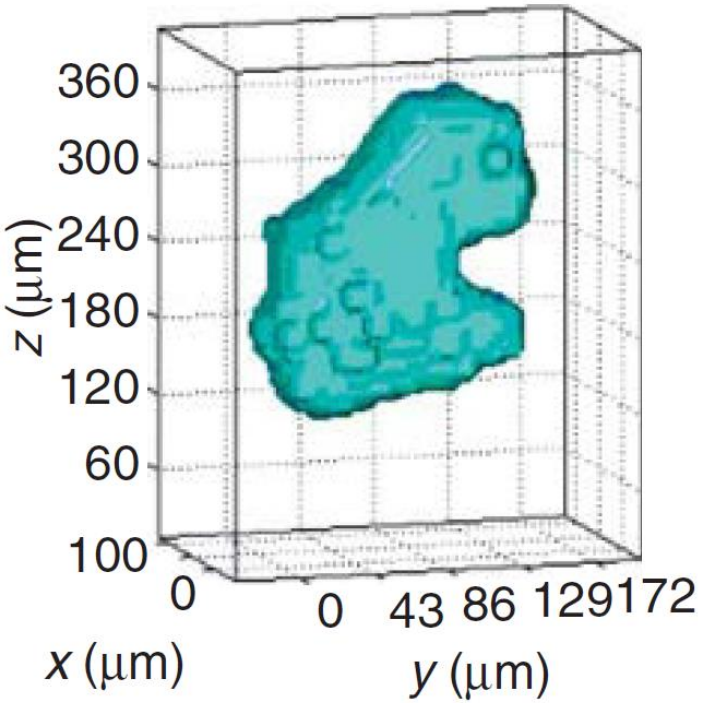
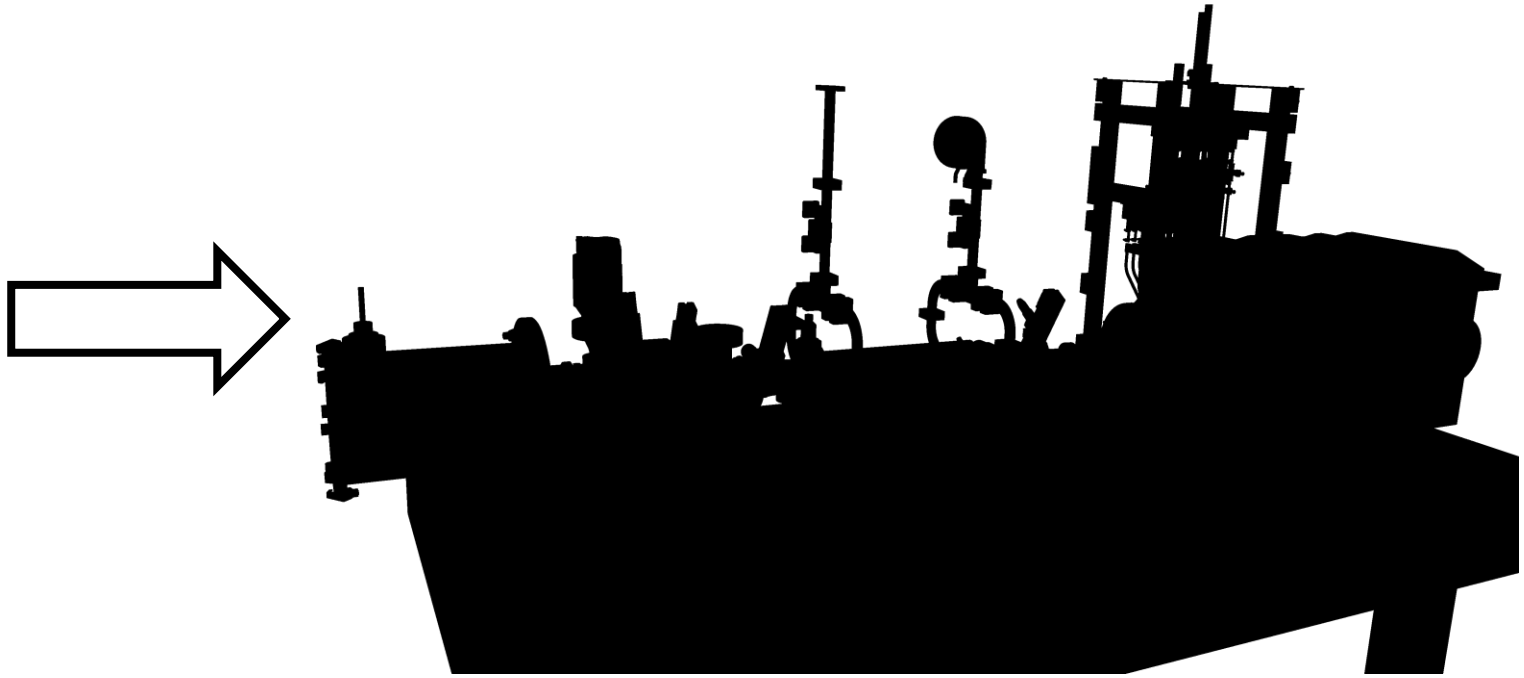


Figure taken from D. J. Jensen et al. "3DXRD Characterization and Modeling of Solid-State Transformation Processes". *MRS Bulletin* **33**, 621–629 (2008).


Diamond light source (United Kingdom)

European Synchrotron Radiation Facility (ESRF, France)



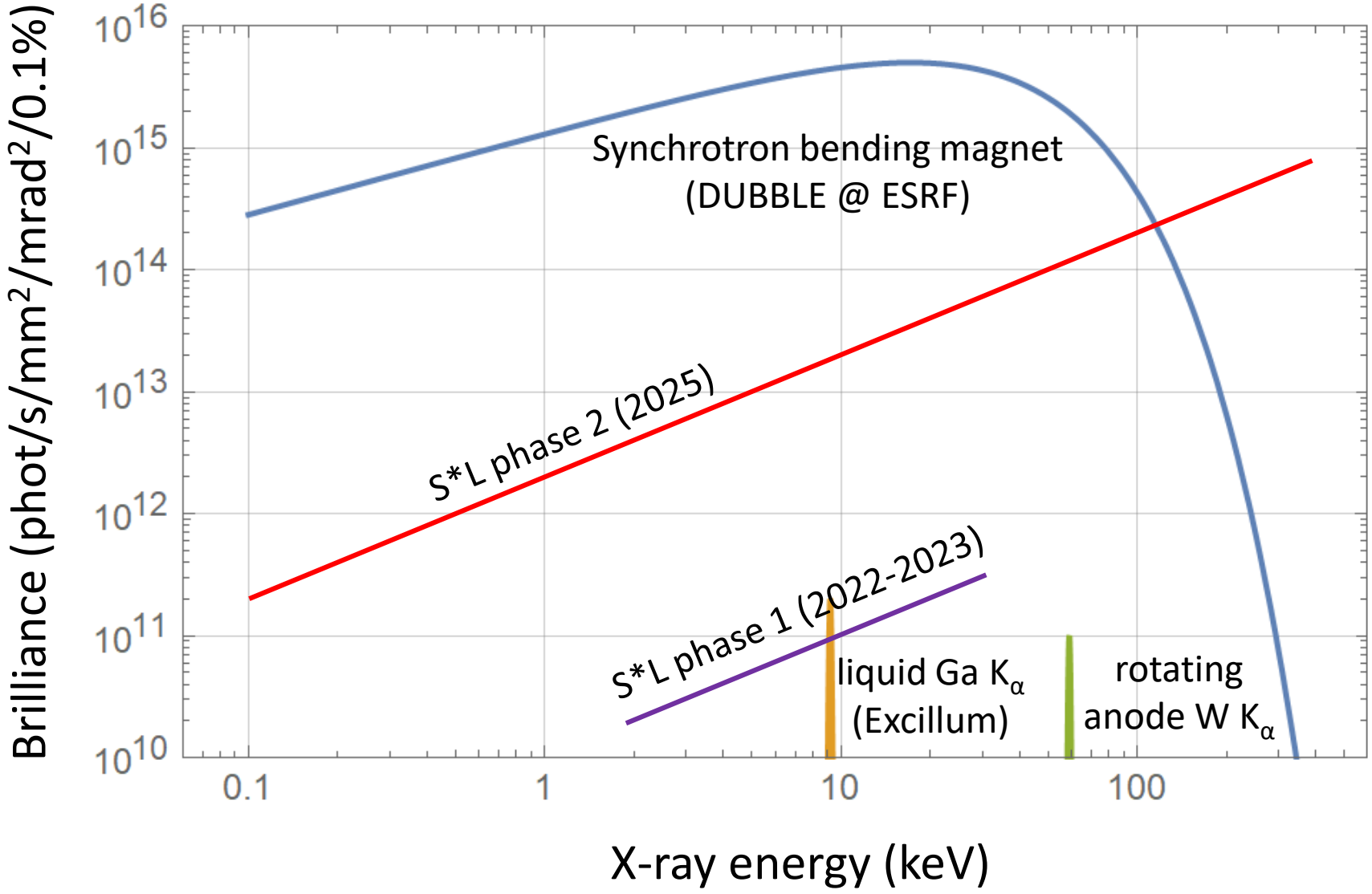
Synchrotrons

- ‘Brilliant’ X-rays
- (very) large facility
- Scarce beam time

Smart*Light

- Less brilliant X-rays
- Compact facility
- Affordability

Brilliance (Intensity & directionality & monochromaticity)



X-ray generation by Inverse Compton Scattering (ICS): what happens physically

$$\lambda_X = \lambda_0 \frac{1-\beta\cos\theta}{1+\beta}, \quad \beta = \frac{v_z}{c}$$

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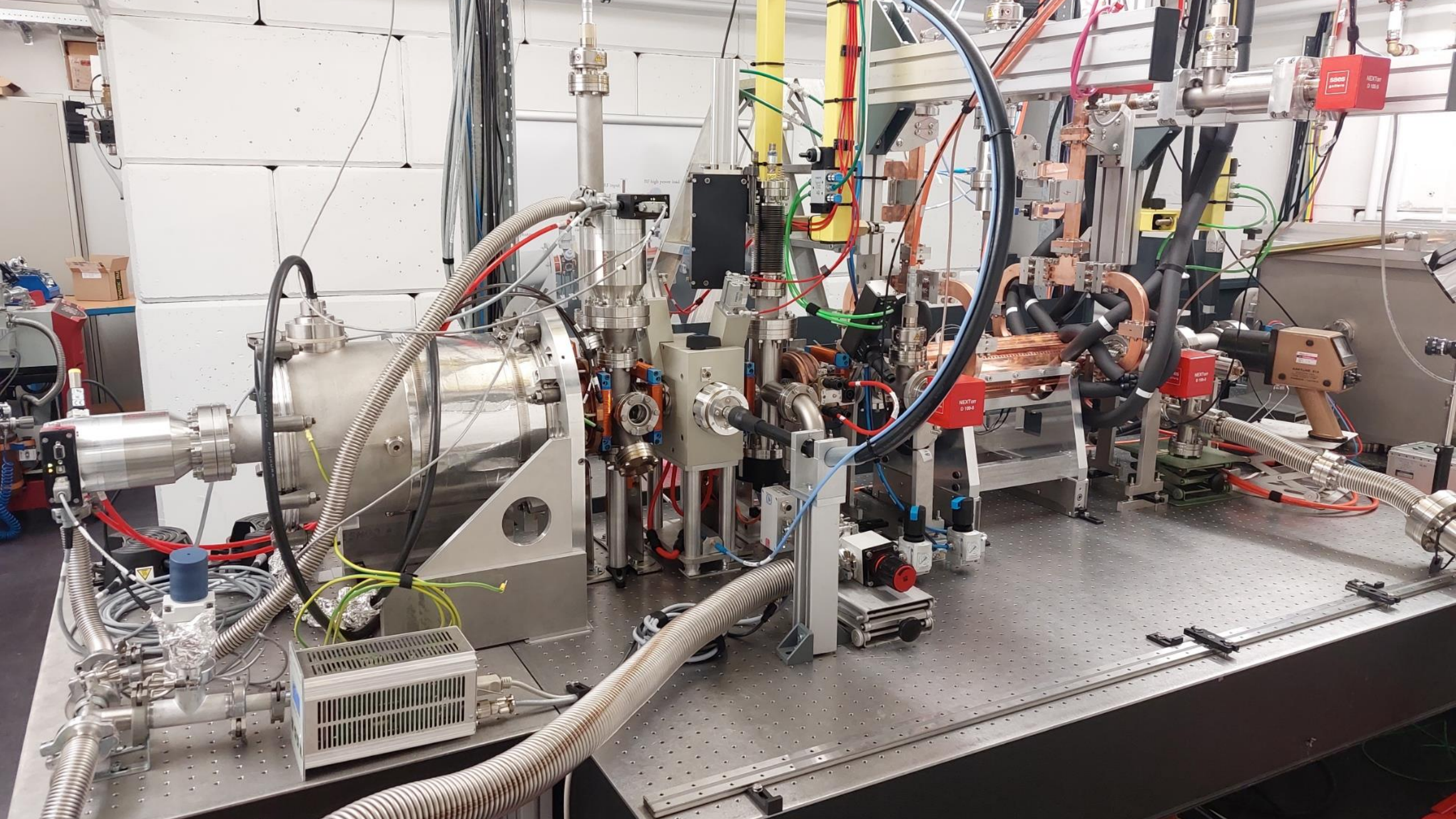
$$\lambda_X = \lambda_0 \frac{1-\beta\cos\theta}{1+\beta}, \qquad \beta = \frac{v_z}{c}$$

(double) Doppler shift

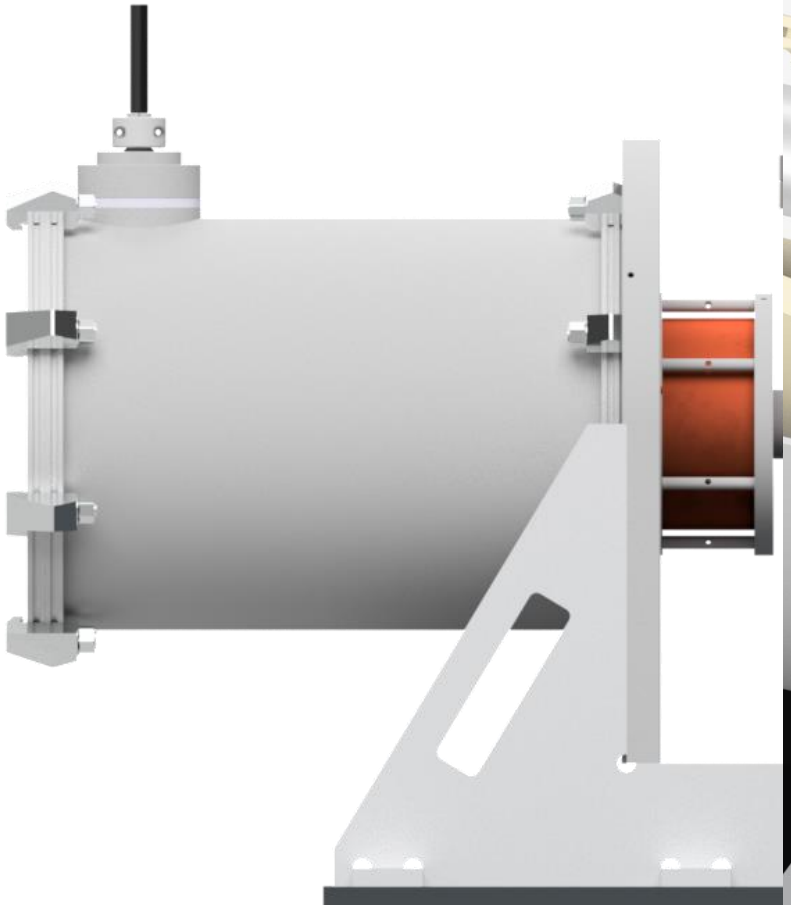
Courtesy of ir. Brian Schaap

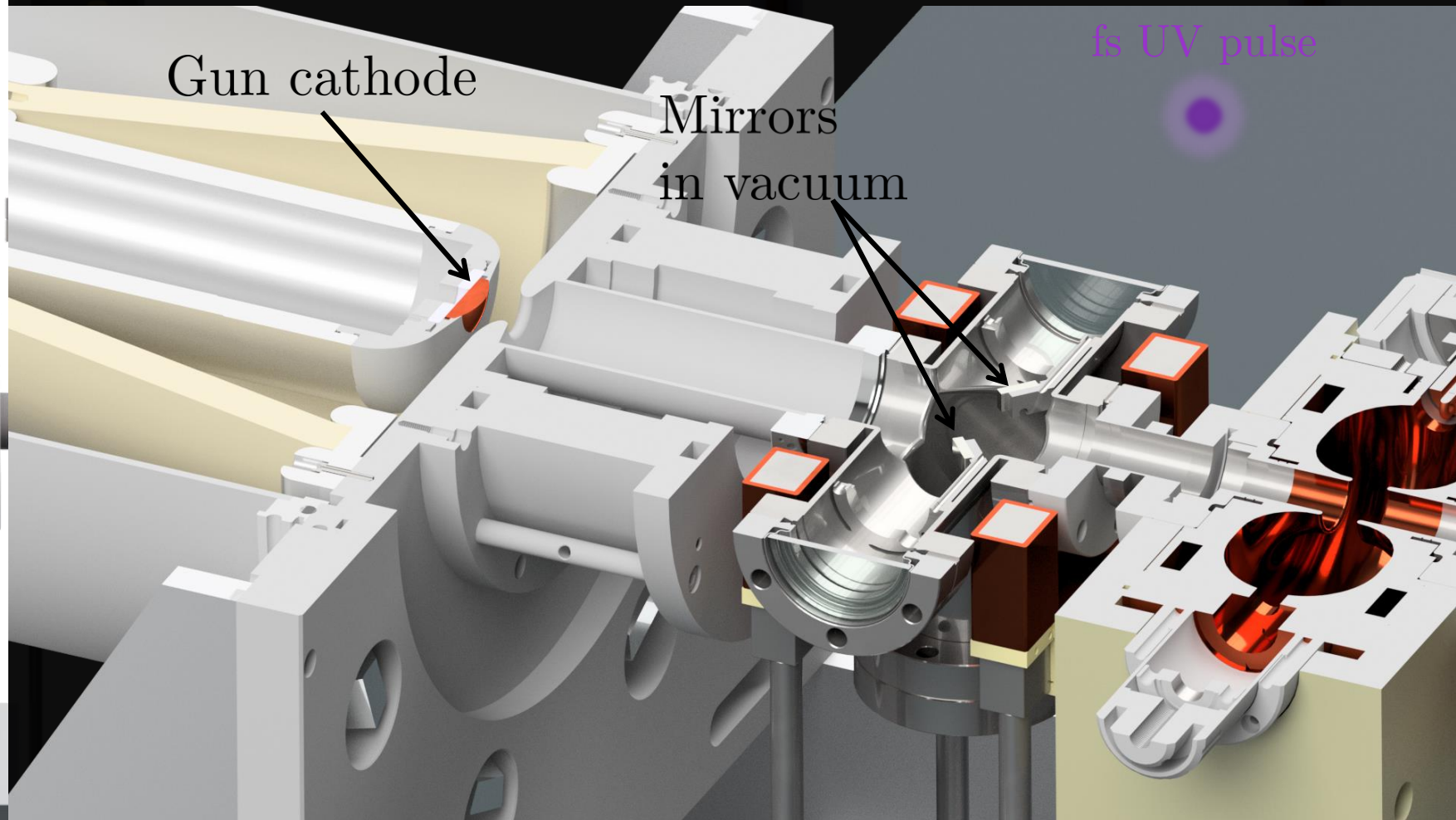
X-ray generation by Inverse Compton Scattering (ICS): what happens practically



100 kV DC photogun

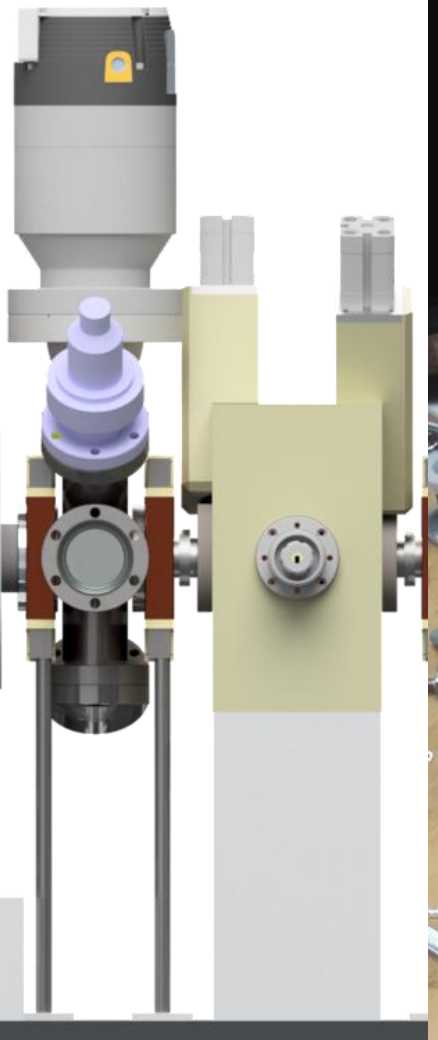
- 10 pC bunches (62 million electrons)

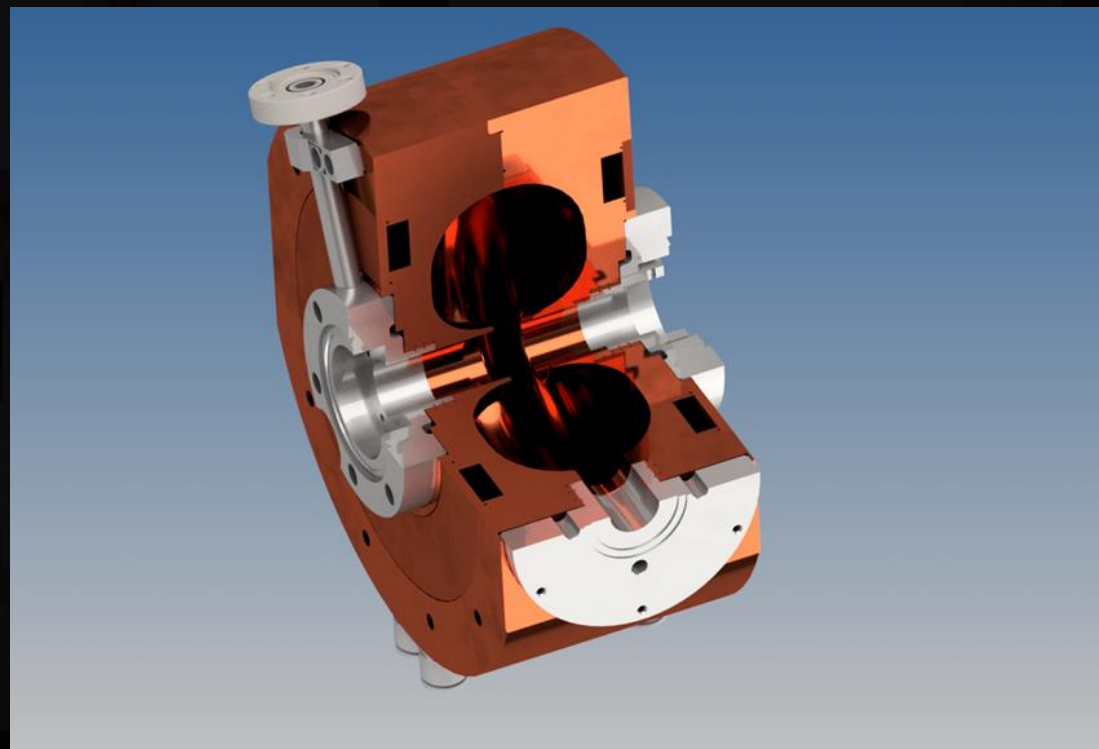


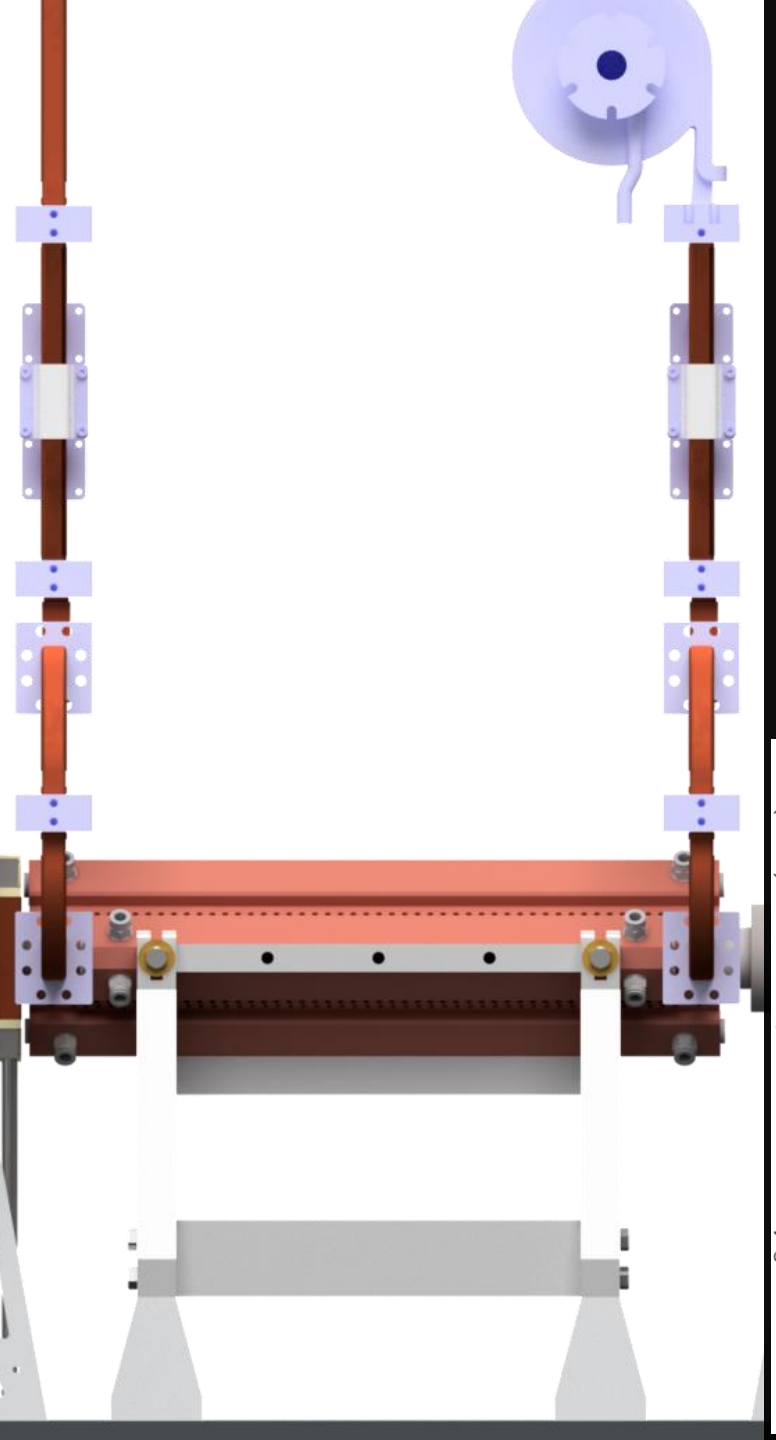


1.5 GHz bunching cavity

- Longitudinally focusses bunches in accelerator
- Bunch compression up to ∼1 ps

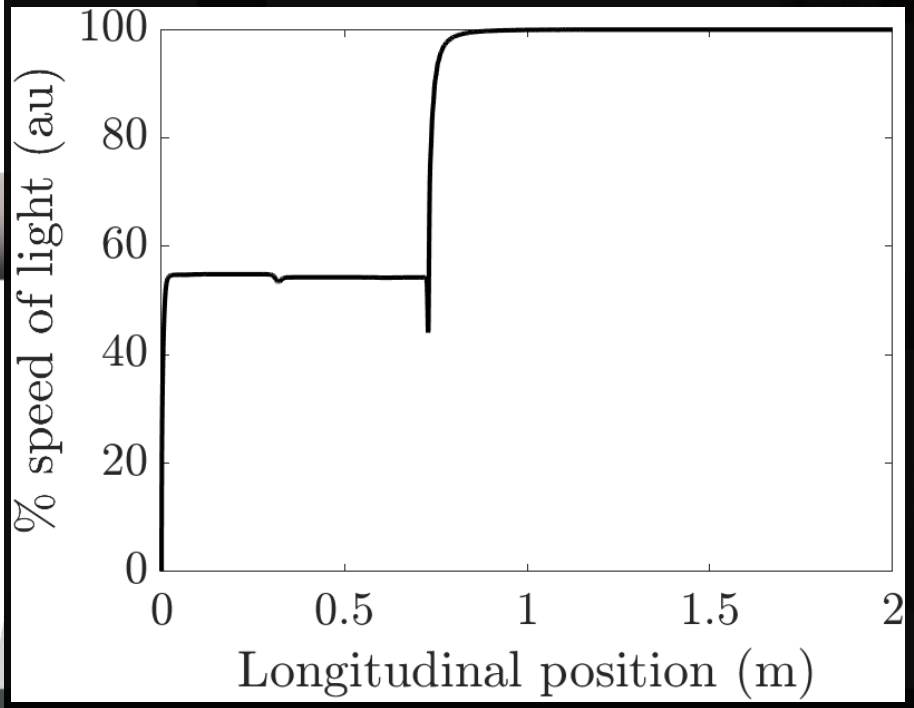


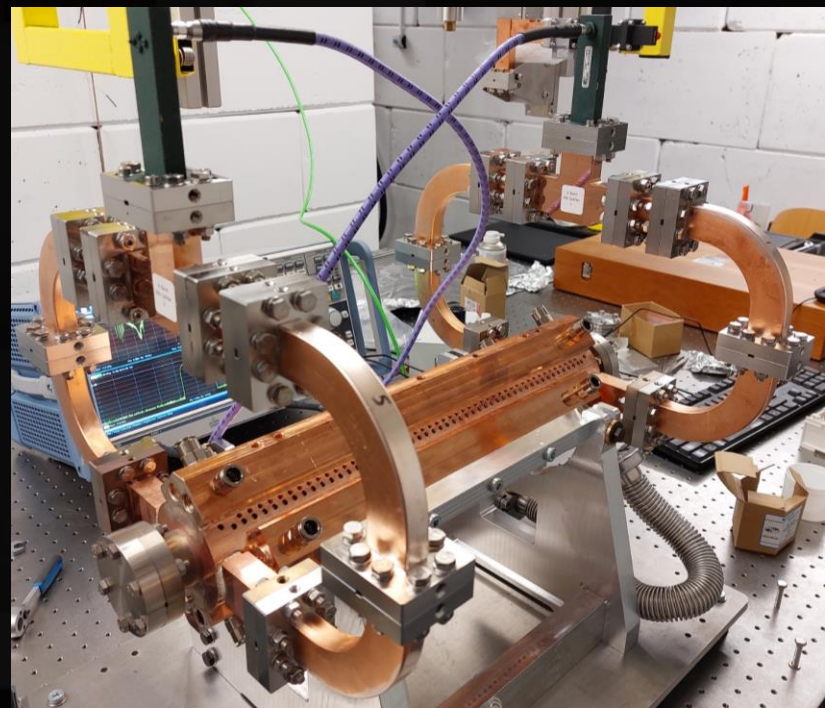




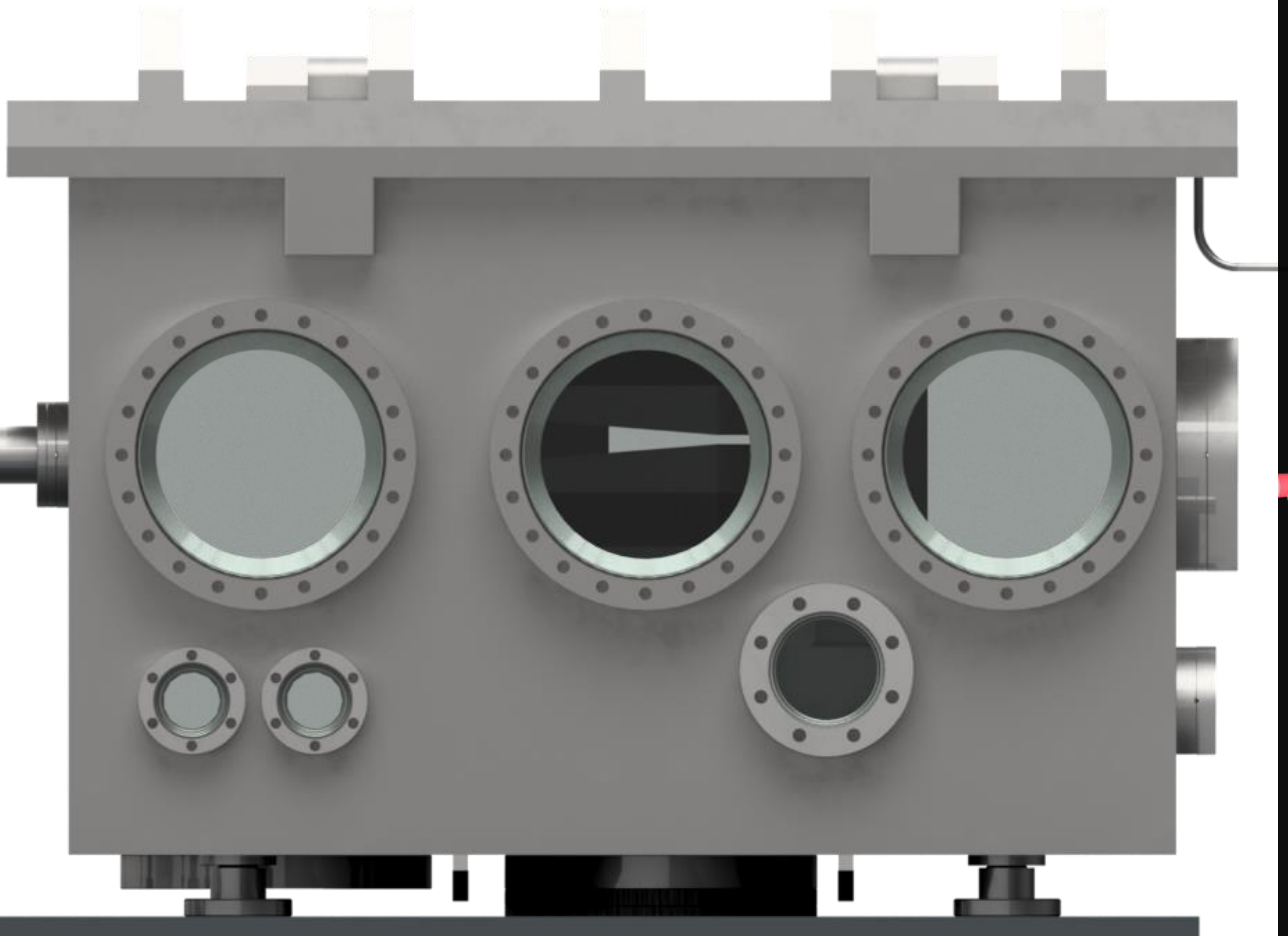
X-band accelerator

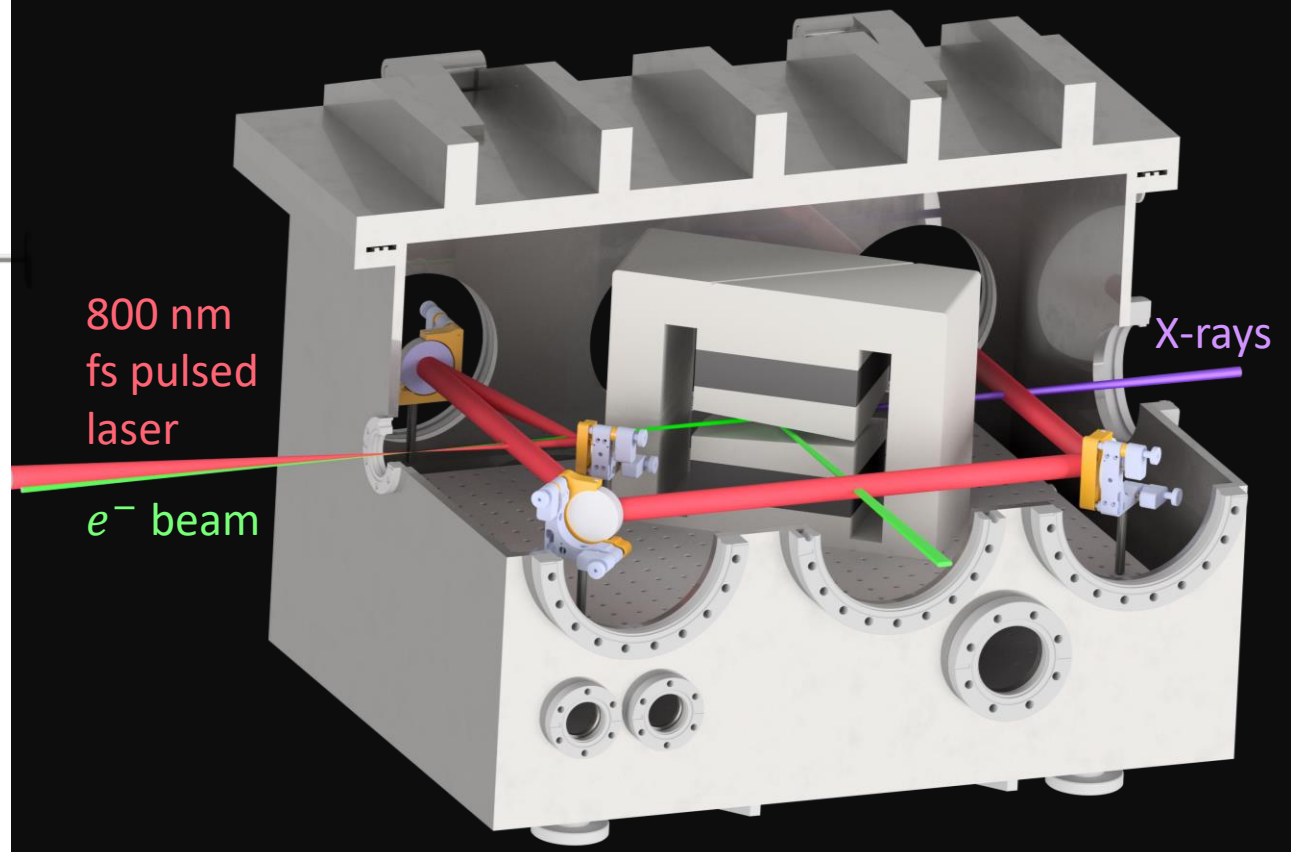
- 50-cell structure @ 11.9942 GHz
- >100 MV/m accelerating gradients
- $0.55c \rightarrow 0.9976c$ (14.5 MeV)

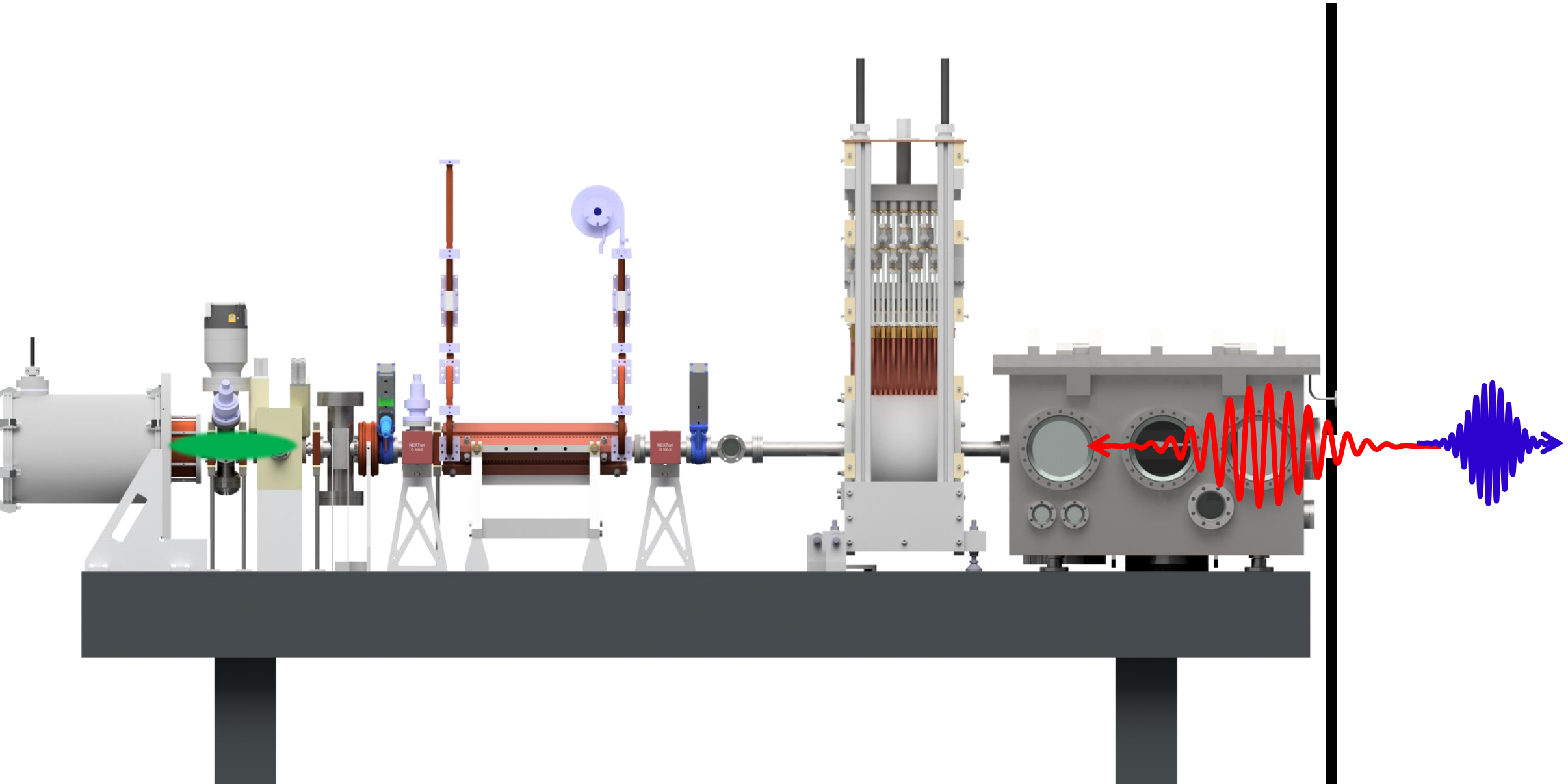




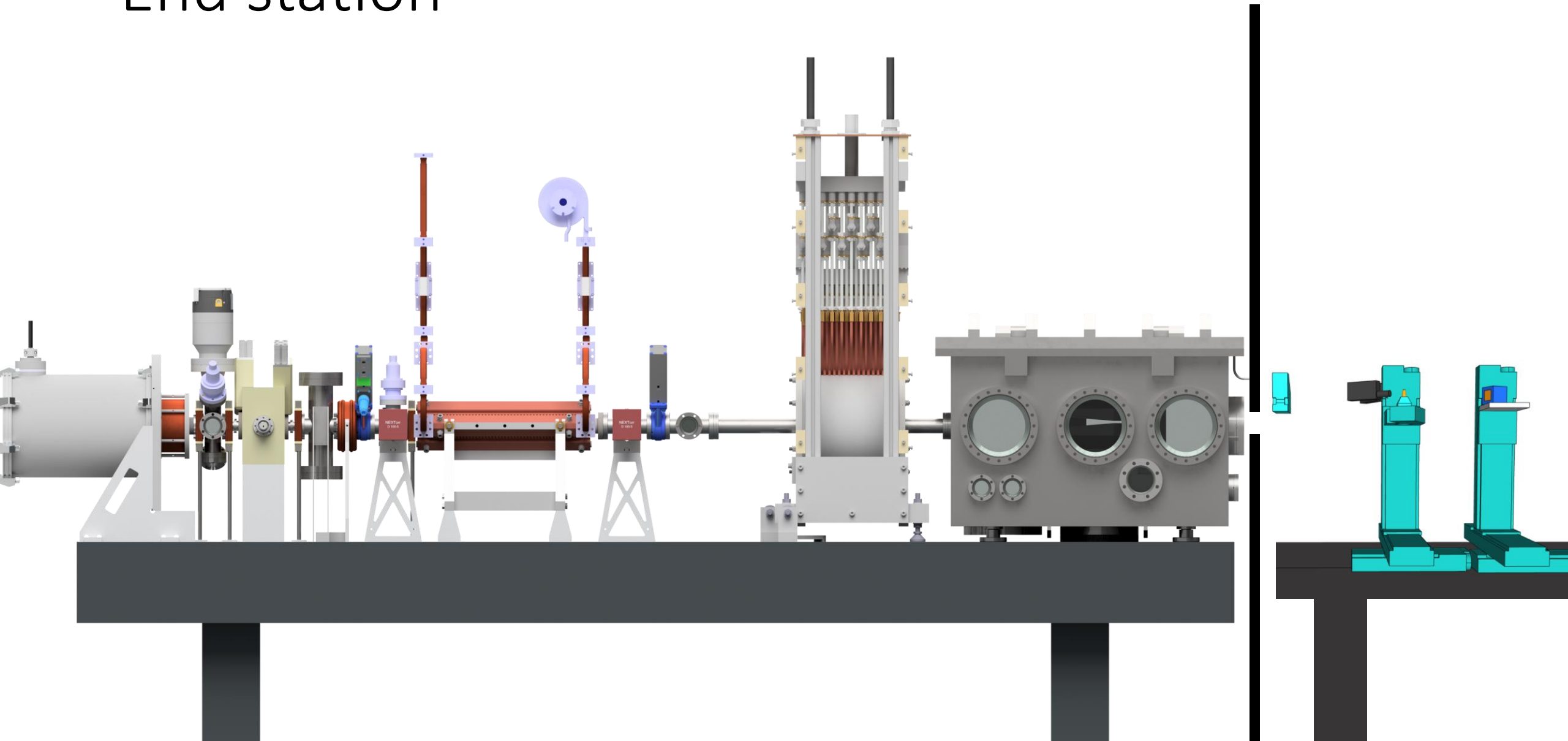
Interaction chamber







End station



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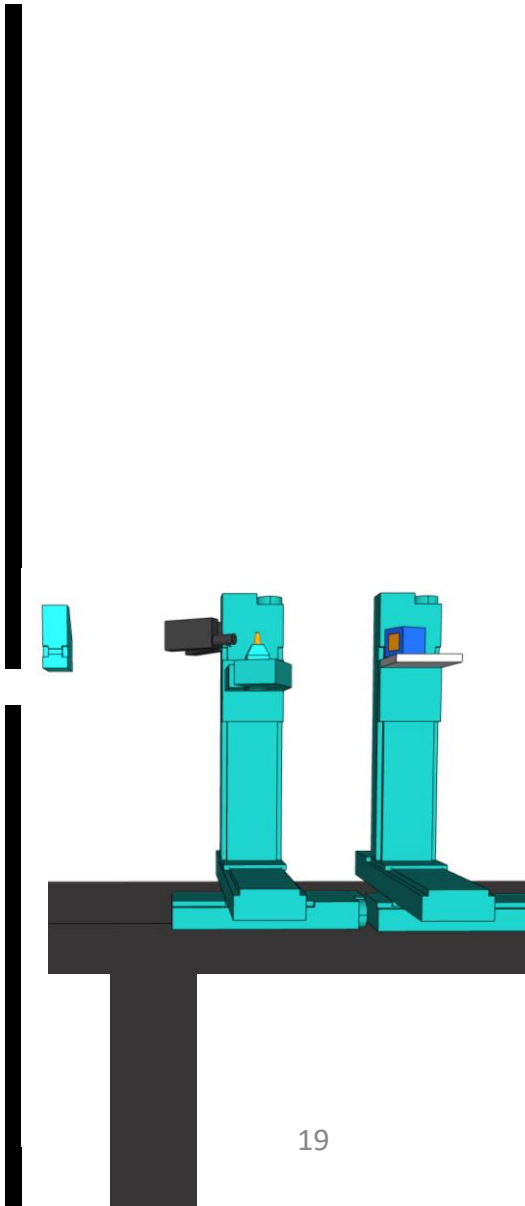

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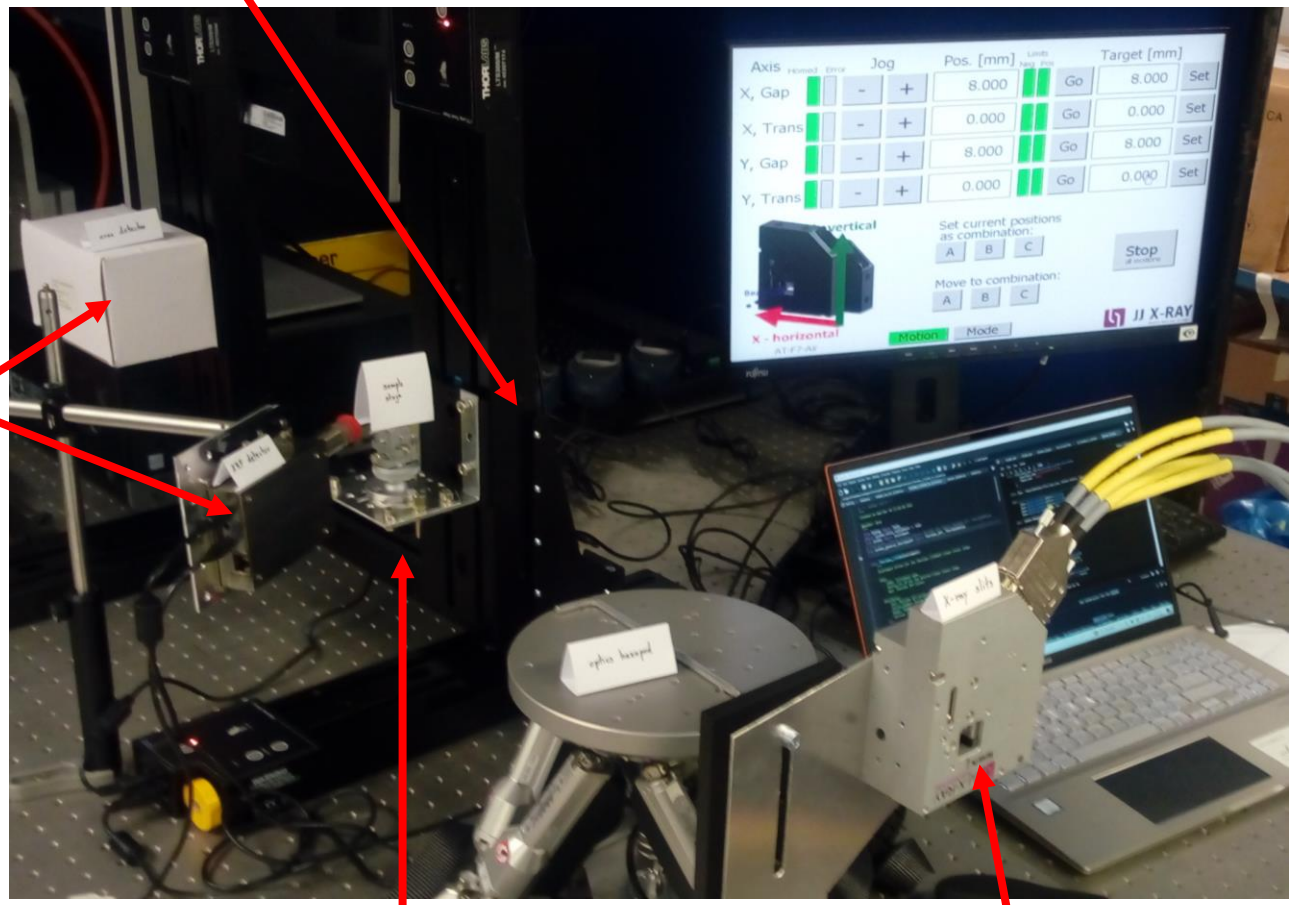

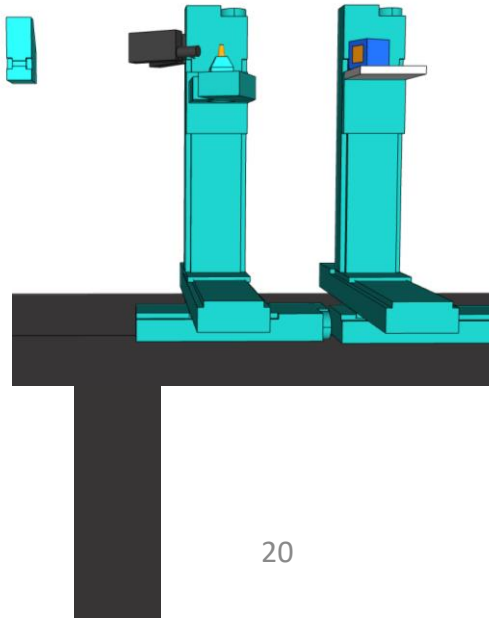

Controlled with QCoDes Python software framework

https://qcodes.github.io/Qcodes/

Advantages of Smart*Light X-rays

High intensity + directionality

Monochromatic

Tuneable

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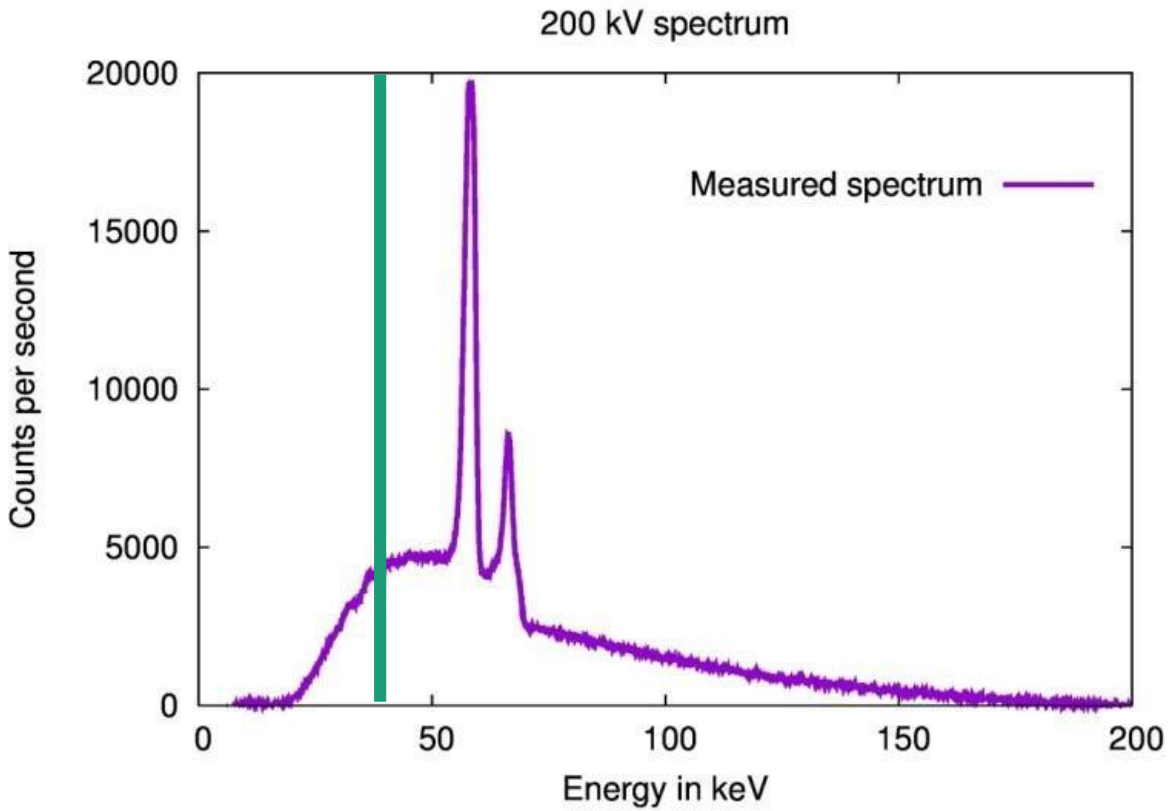

Image taken from Tisseur et al. Conventional x-ray radiography versus image plates: a simulation and experimental performance comparison. (2015) https://www.researchgate.net/publication/286897188

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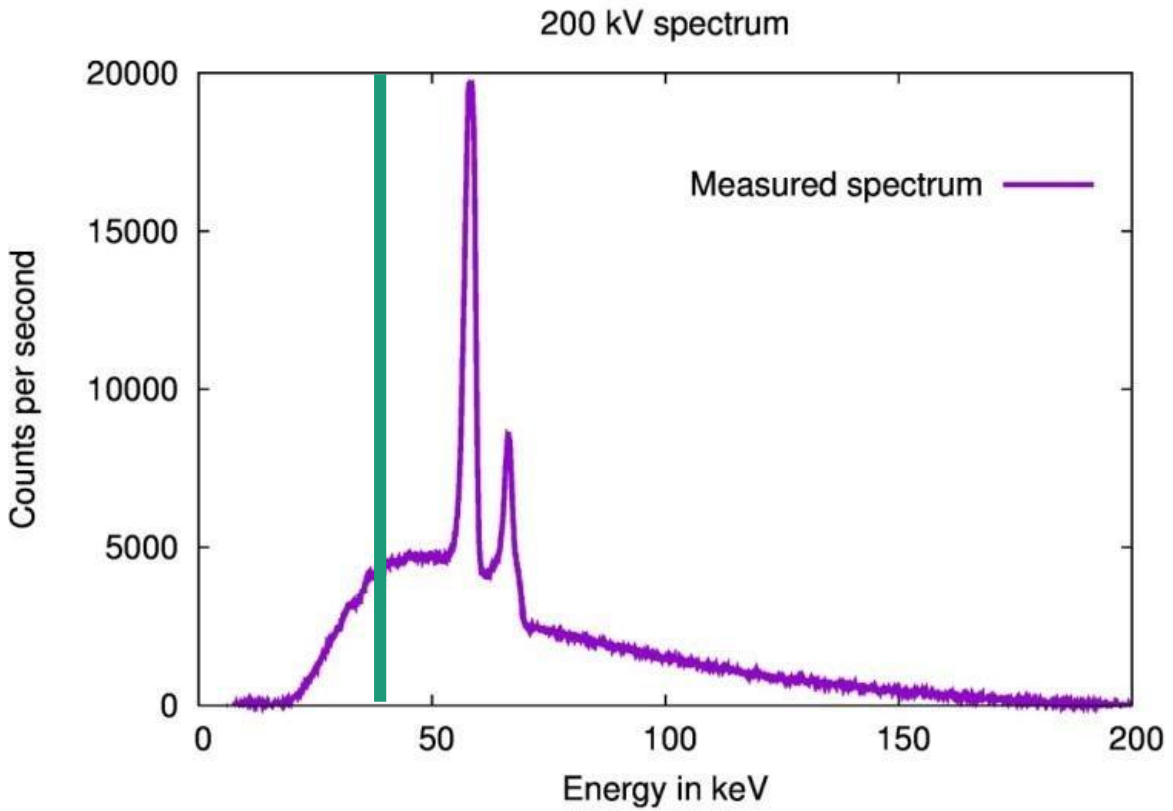

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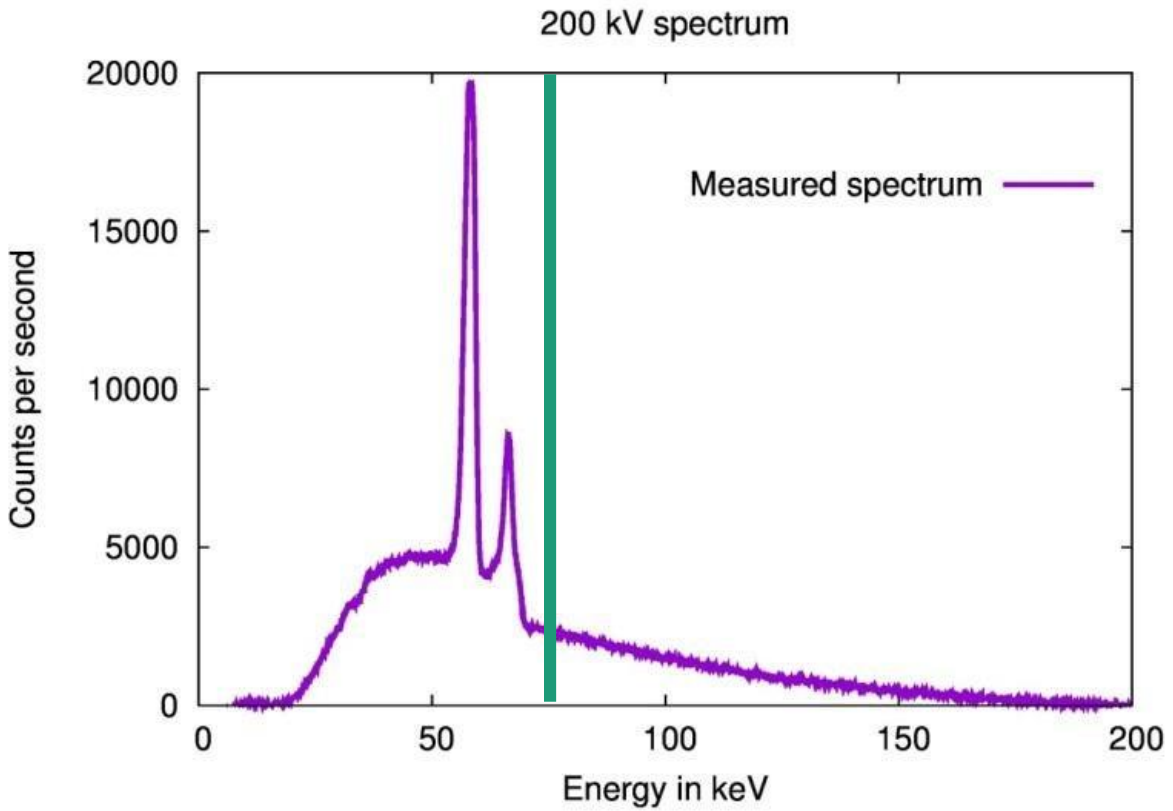

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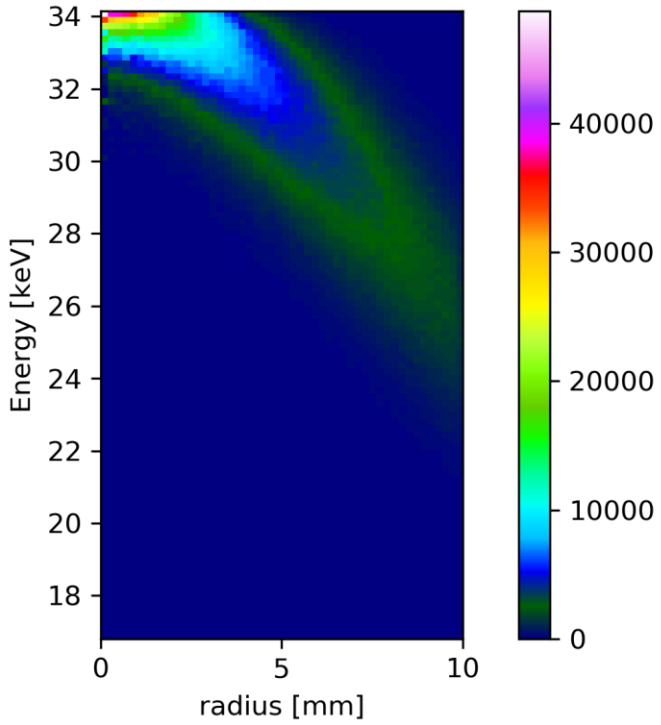
Beam characterization

Fluorescence screen

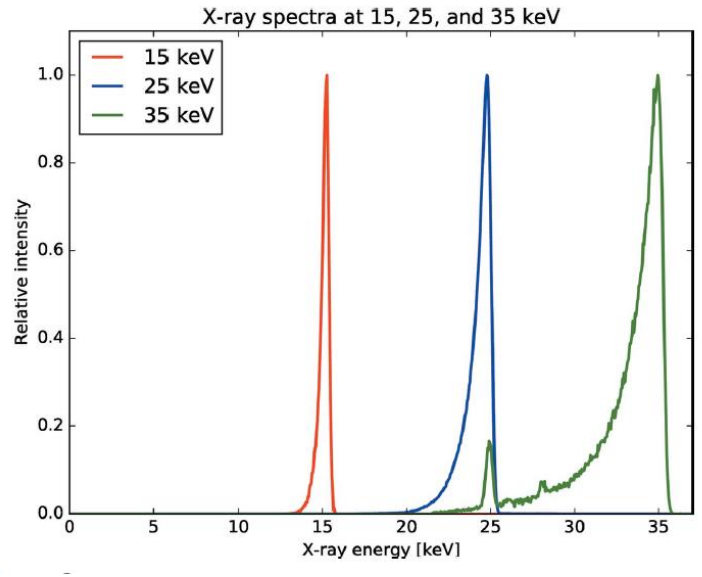
Beam characterization

Fluorescence screen

Spatial distribution



Energy spectrum



Spectrum taken from:
Eggl et al.
J. Synchrotron Rad. 23, 1137-1142 (2016)

Measurement methods

XRR

X-ray radiography

XRF

X-ray fluorescence

K-edge imaging

Measure above / below absorption edge

Phase-contrast XRR

XRD

X-ray diffraction

SAXS

Small-angle X-ray scattering

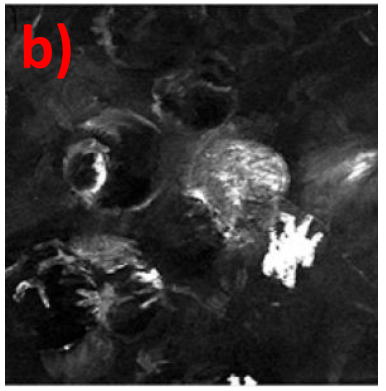
X-ray fluorescence of paint layers

Vincent van Gogh: “Flower Still Life with Meadow Flowers and Roses”, Kröller–Müller Museum, Otterlo, rotated for illustration

b) Hg fluorescence signal

c) Zn fluorescence signal

d) Zn fluorescence measured from the back



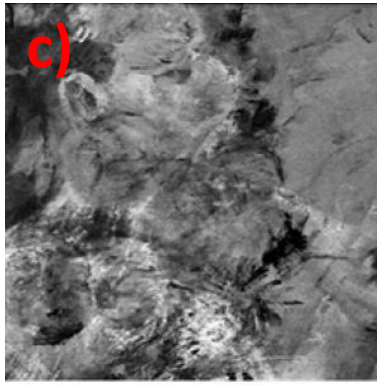


Figure taken from M. Alfeld and J. A. C. Broekaert: “Mobile depth profiling and sub-surface imaging techniques for historical paintings – a review”, Spectrochimica Acta Part B 88, 211- 230 (2013)

Thank you!

Jom Luiten

Peter Mutsaers

Harry van Doorn

Hein van den Heuvel

Samu Oosterink

Matthias Alfeld

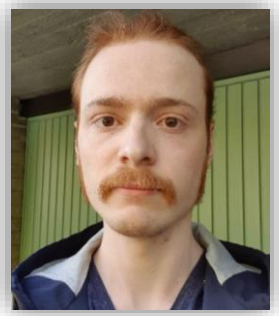
Joris Dik

Bram Klein

Eddy Rietman

Rick van den Berg

Ids van Elk



Victor Schmeetz

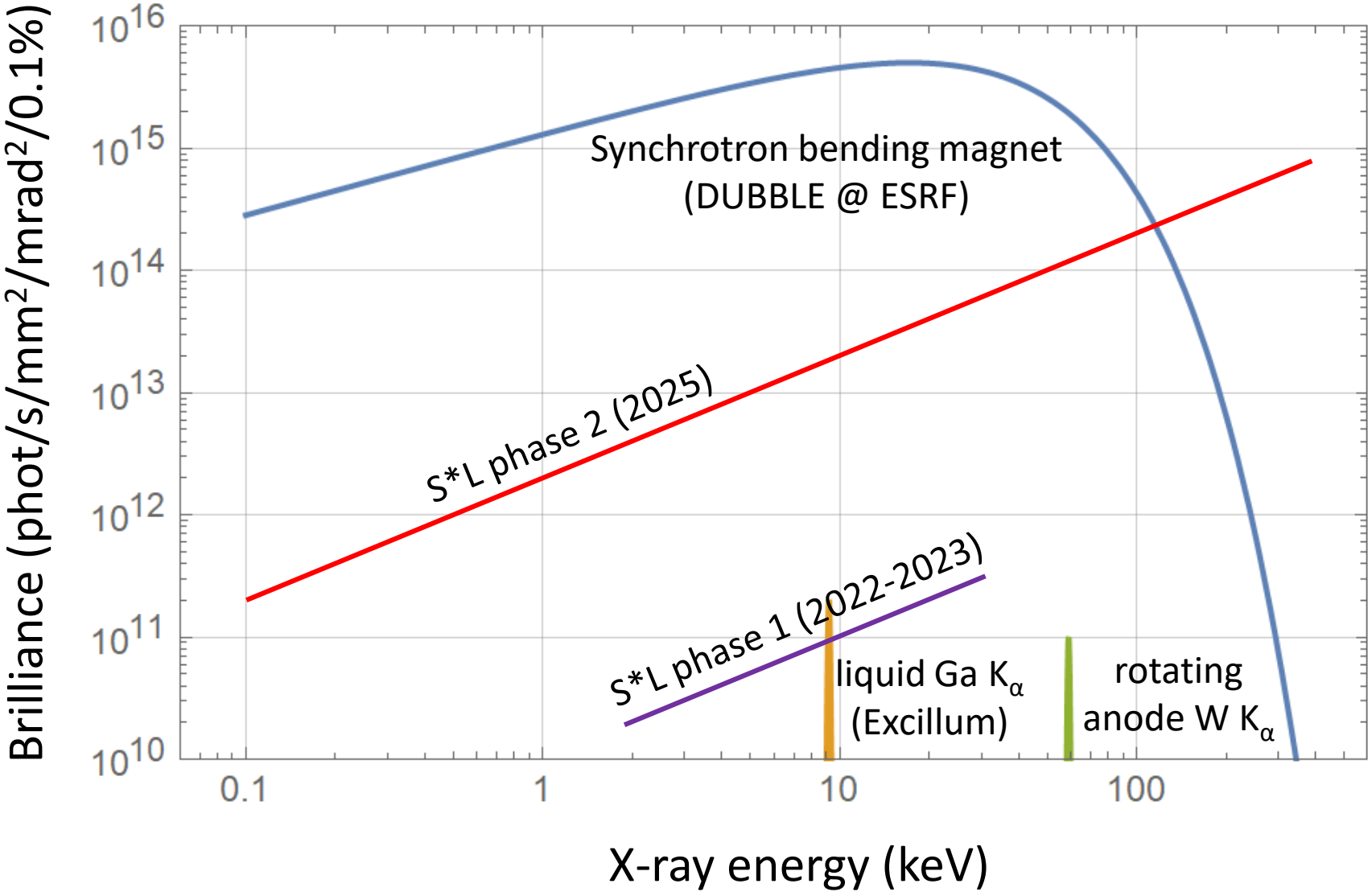
Luís de Almeida Nieto

Hessel Castricum

Honourable mentions: Xavier Stragier, Tom Lucas, Marco van der Sluis, Maurits Kok

Backup slides

Brilliance (Intensity & directionality & monochromaticity)



Interaction laser wavelength (nm)	Klystron power (MW)	X-ray energy (keV)
800	6	5
800	24	20
400	6	10
400	24	40

1.5 GHz bunching cavity

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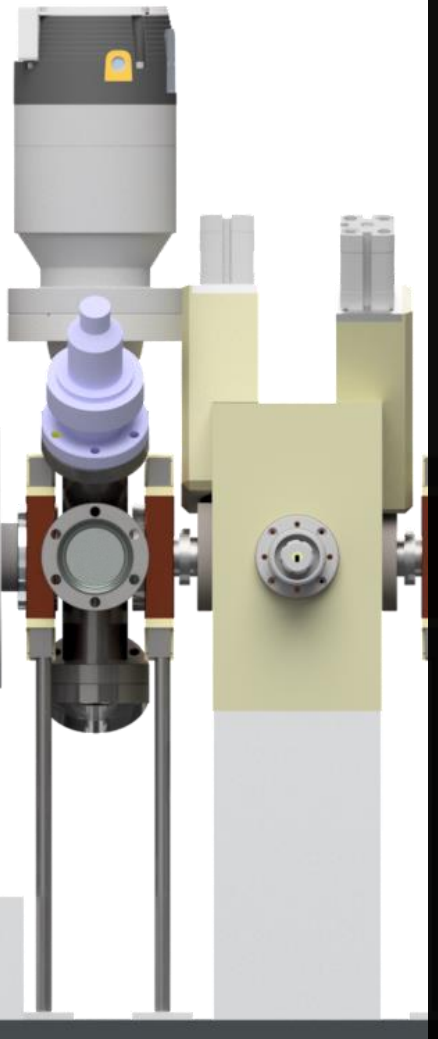
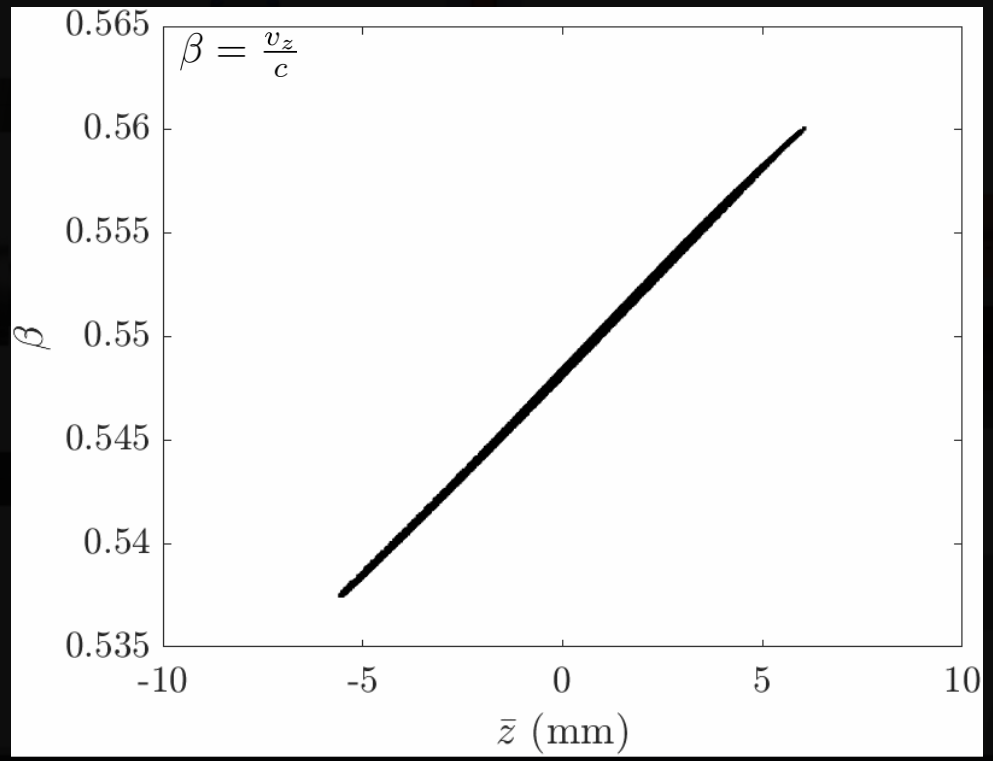
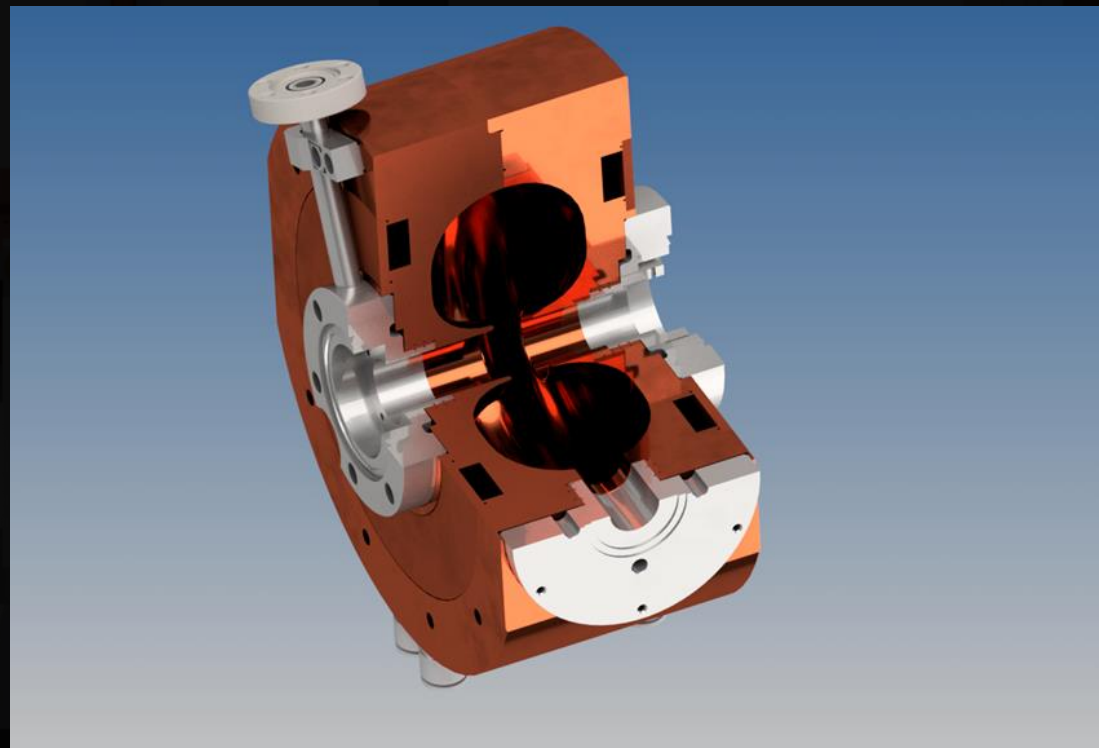
- Bunch compression up to ∼1 ps







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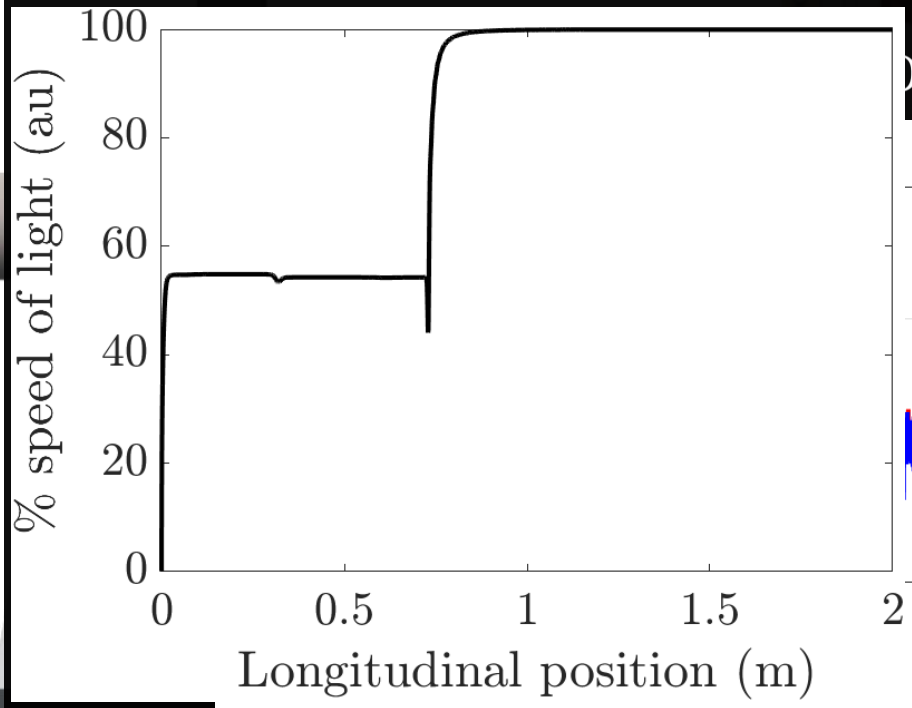

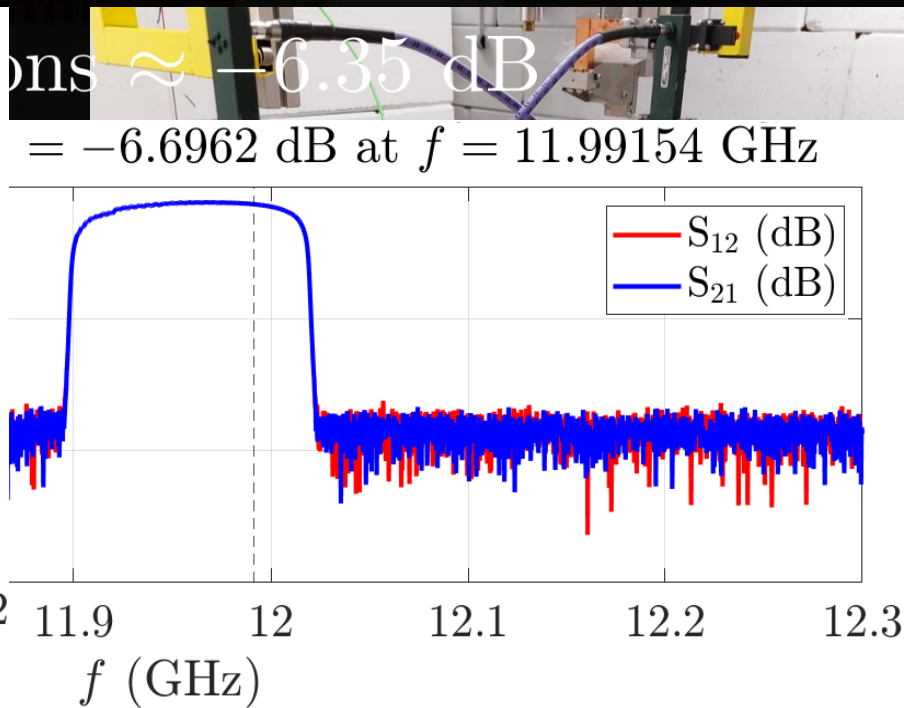

X-band accelerator