

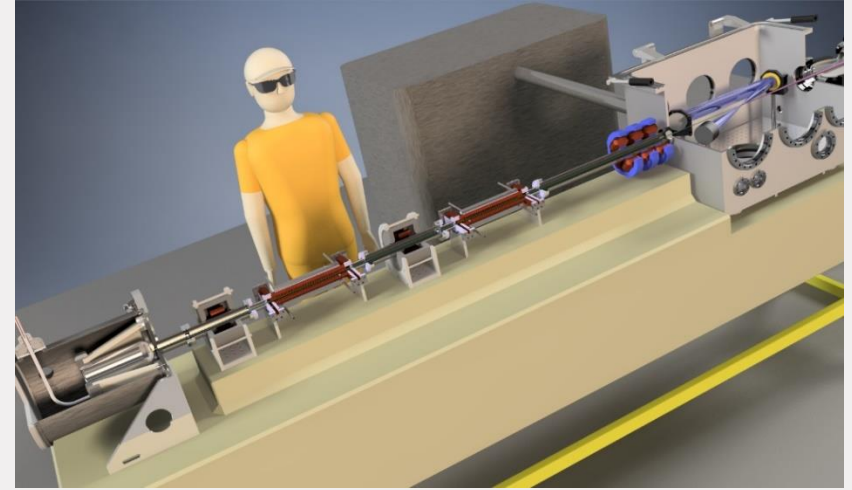


## Smart\*Light: a compact hard X-ray ICS source based on X-band acceleration

**XLS complementary use and opportunities, 9 November 2021**

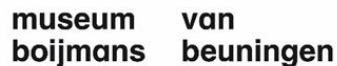
Peter Mutsaers, Tom Lucas, Xavier Stragier, Wiebe Toonen, Rick van den Berg, Ali Rajabi, Linda Stoel, Joos Schoonwater, Aimée Jacobs, Daniel Nijhof, Tim de Raadt, Brian Schaap, Marco van der Sluis, Eddy Rietman, Harry van Doorn, Hein van den Heuvel, Frans van Setten, [Jom Luiten](#)

# Smart Light

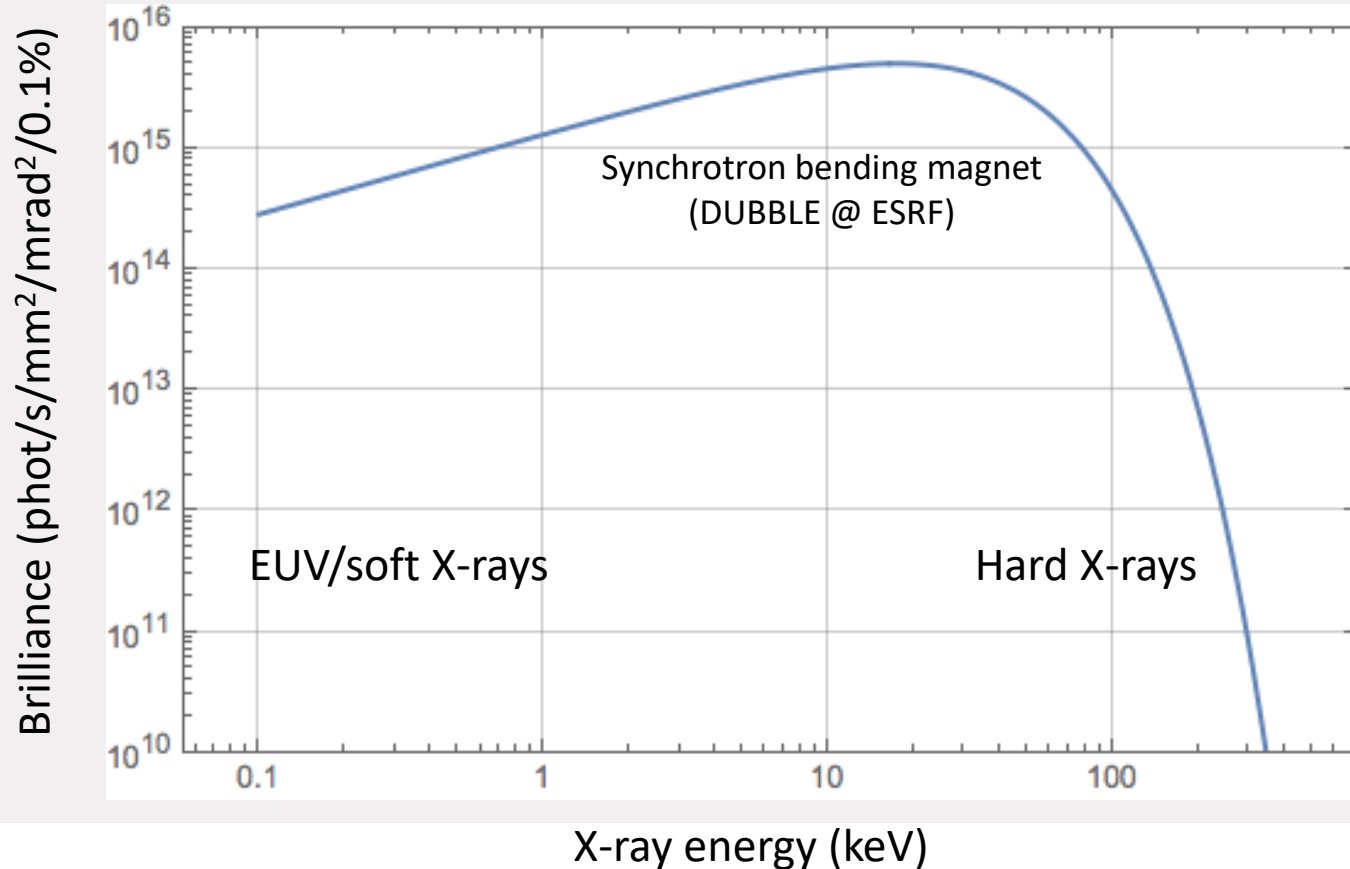


**Interreg**   
EUROPESE UNIE  
**Vlaanderen-Nederland**  
Europees Fonds voor Regionale Ontwikkeling



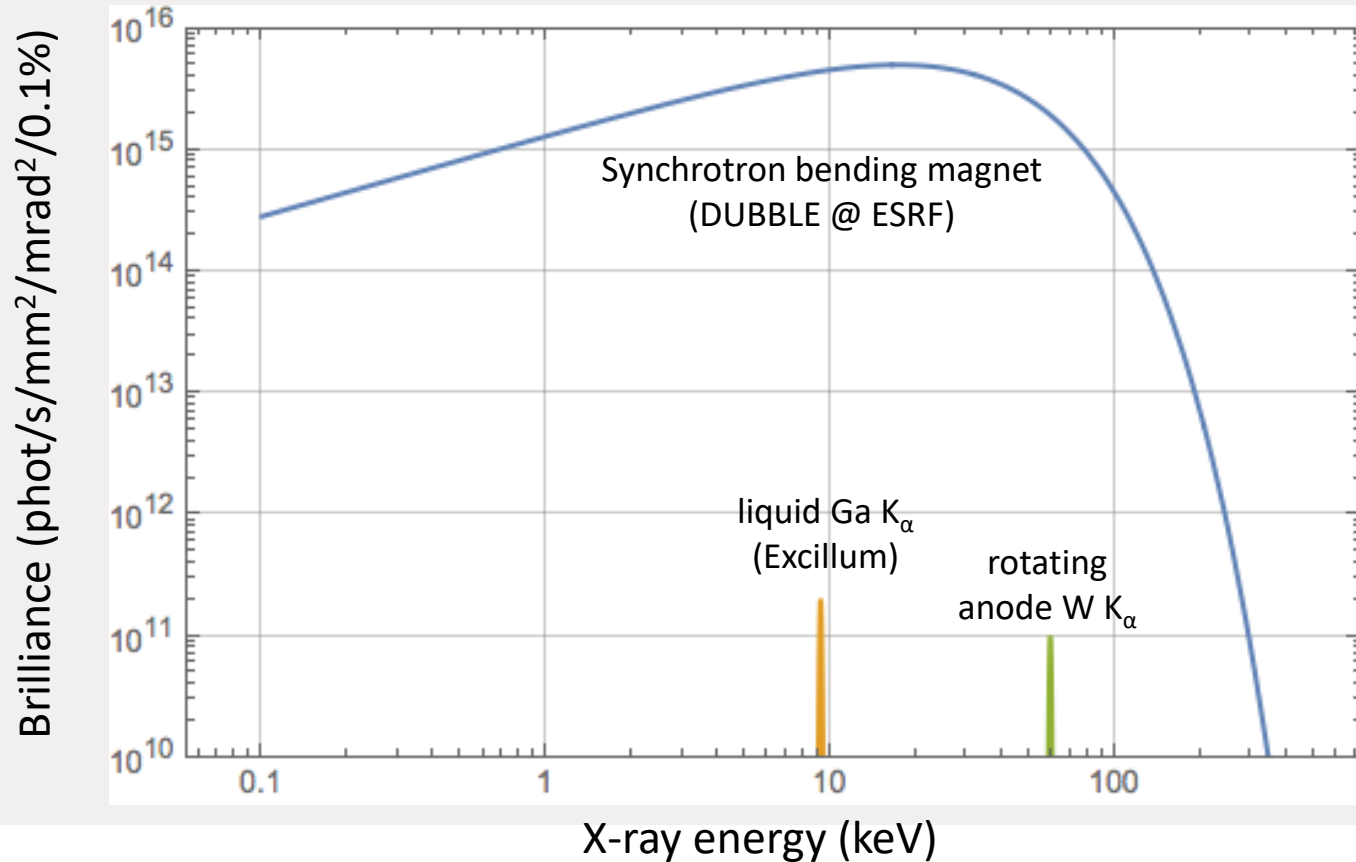


# Brilliance synchrotrons

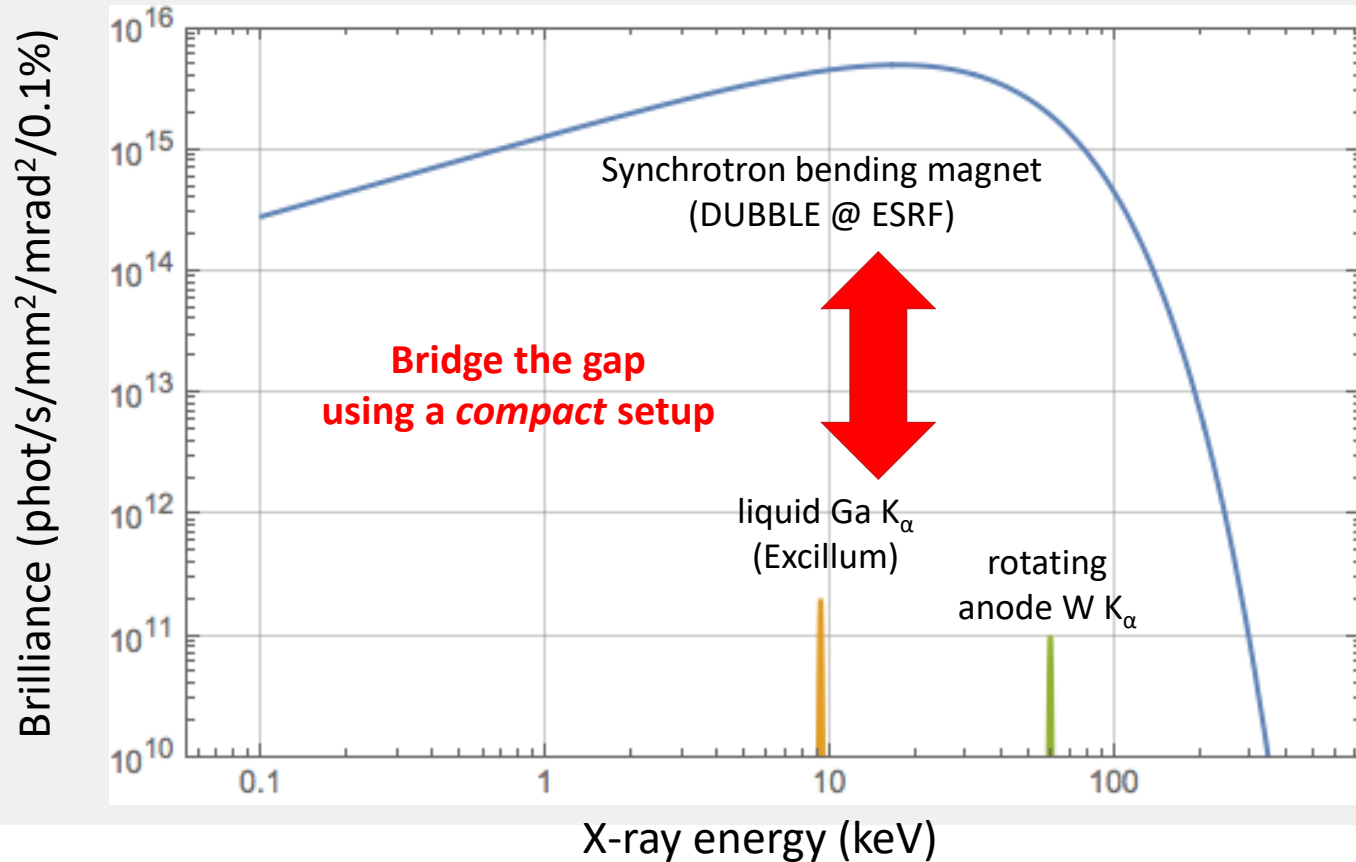




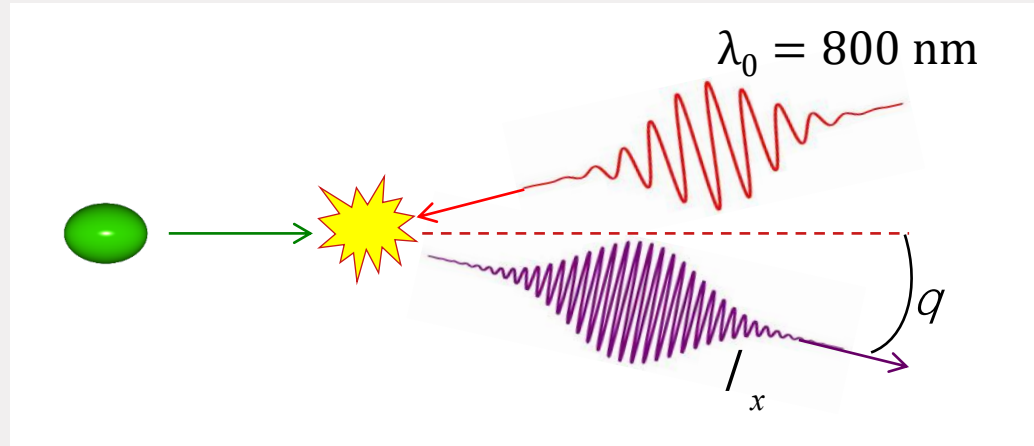
# Brilliance



# Brilliance



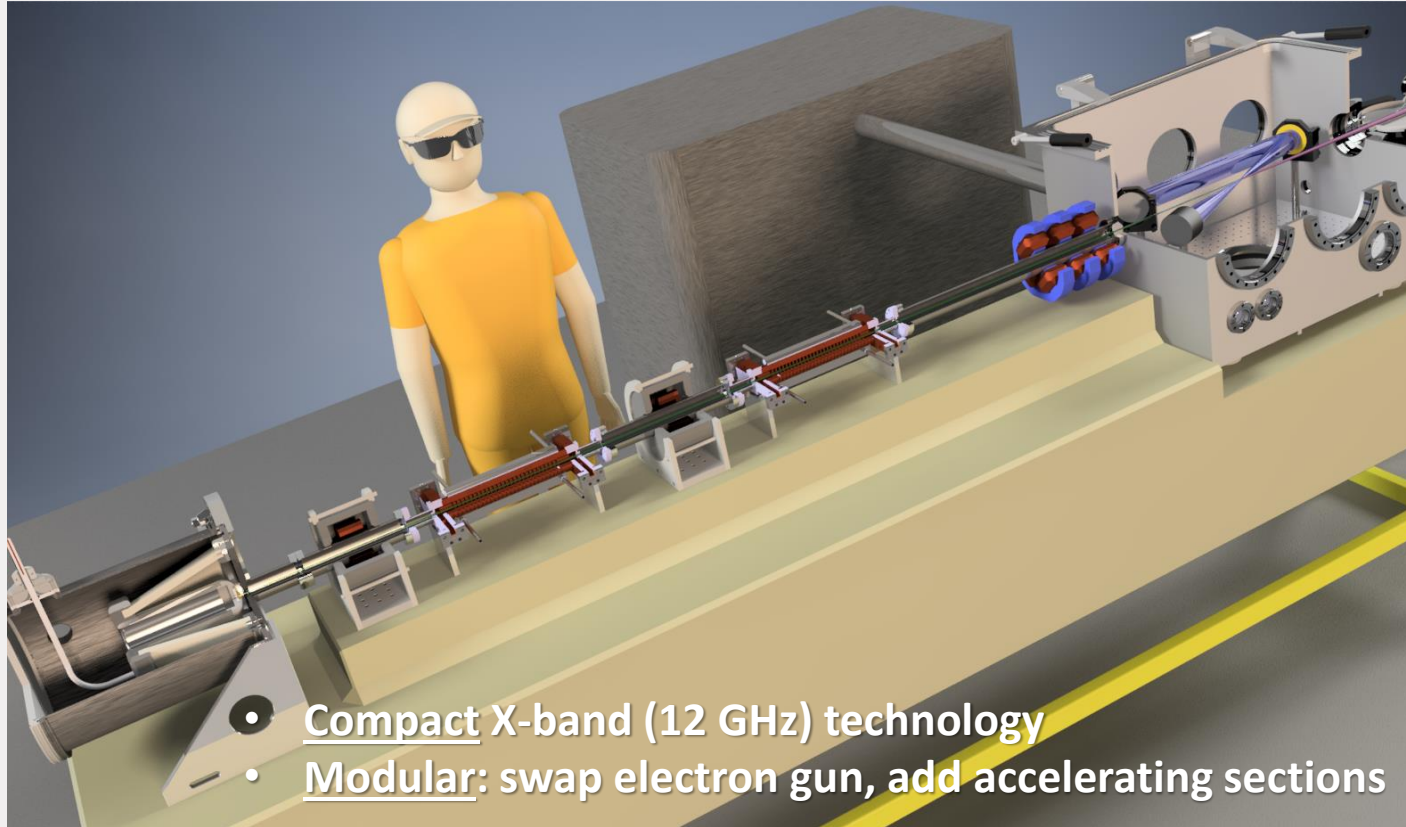
# X-ray generation by Inverse Compton Scattering



$$I_x = \frac{I_0}{4g^2} (1 + g^2 q^2)$$

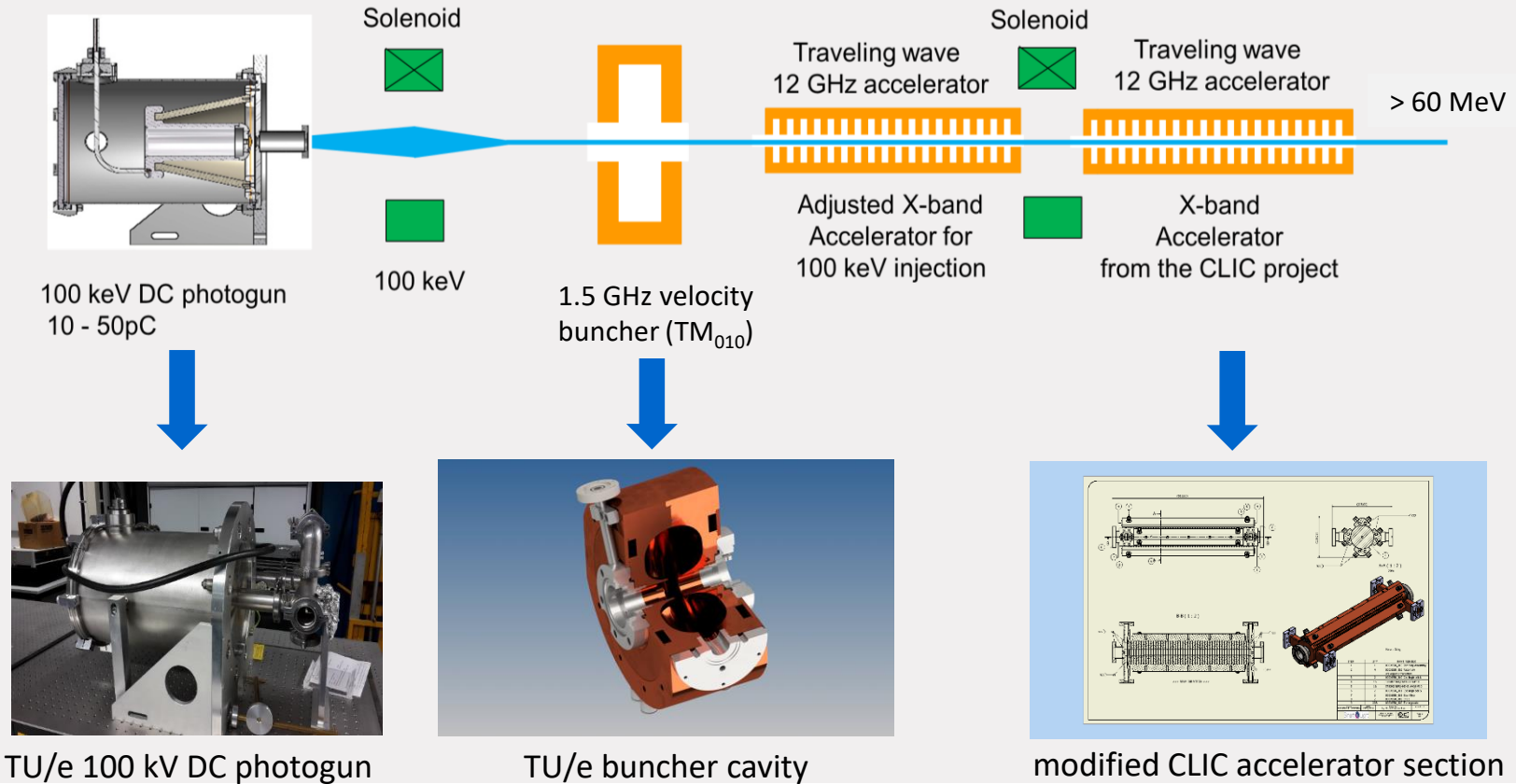
Electron energy	Lorentz factor	X-ray wavelength	X-ray energy	Half cone angle 1% energy spread
5 MeV	11	17 Å	0.73 keV	9.0 mrad
30 MeV	60	0.55 Å	23 keV	2.5 mrad
60 MeV	118	0.14 Å	89 keV	1.0 mrad

# Smart\*Light: a linear-accelerator-based ICS source

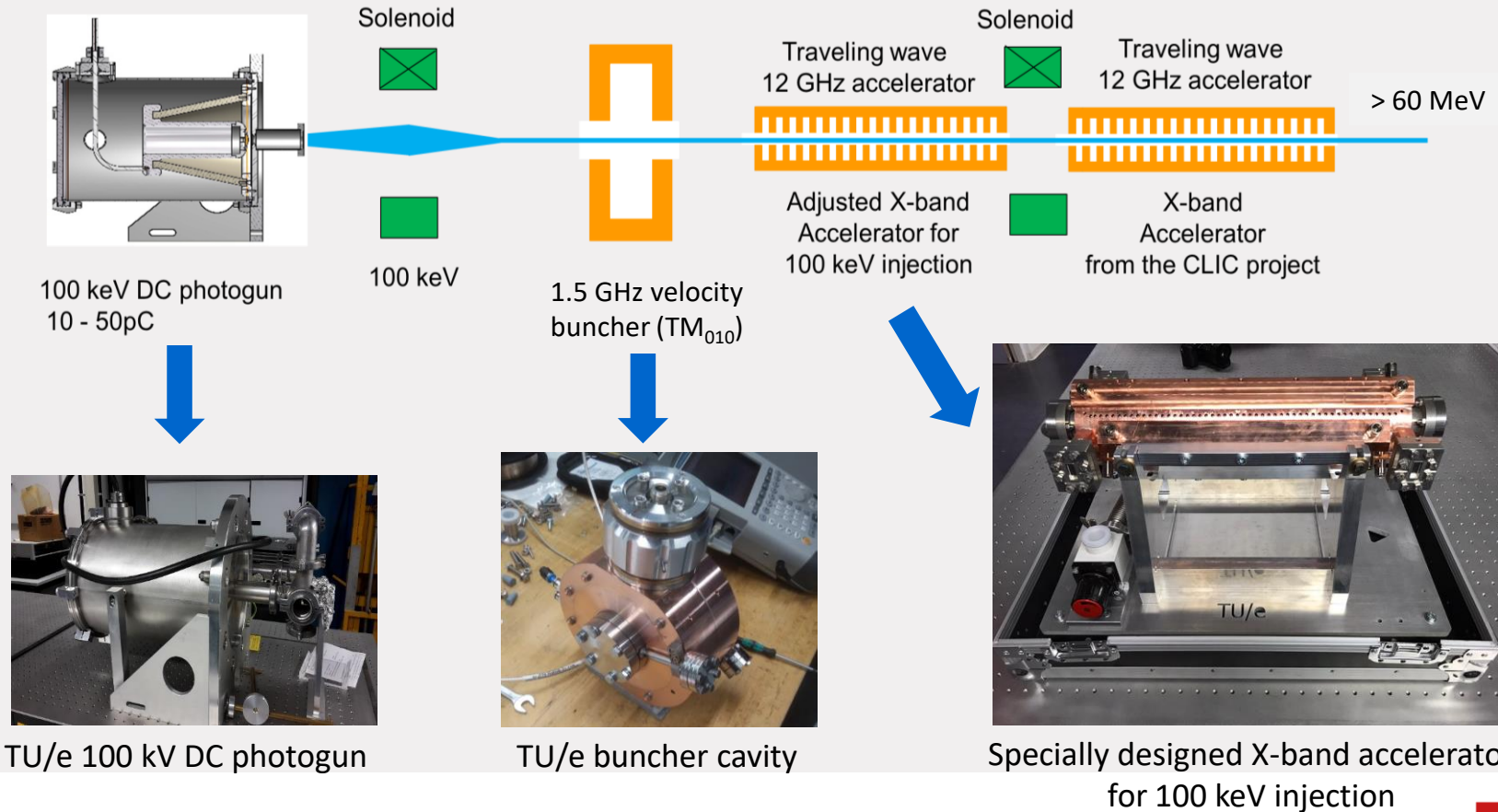




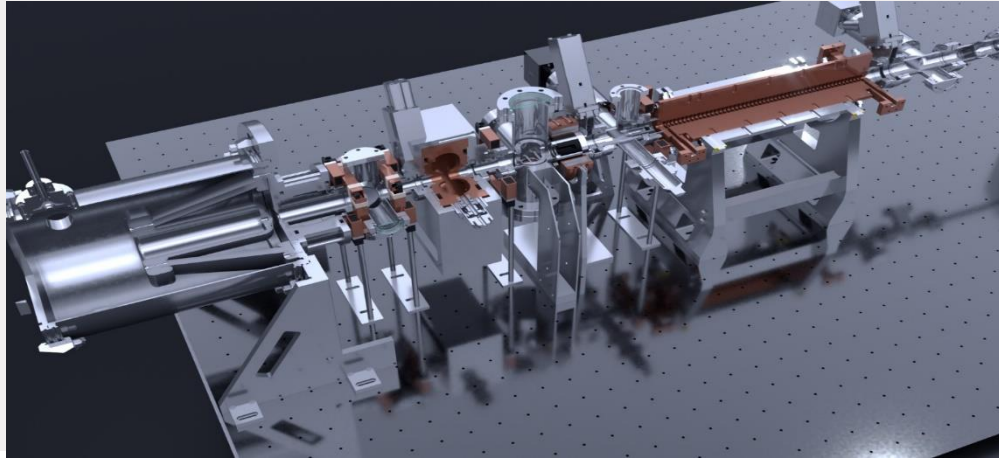
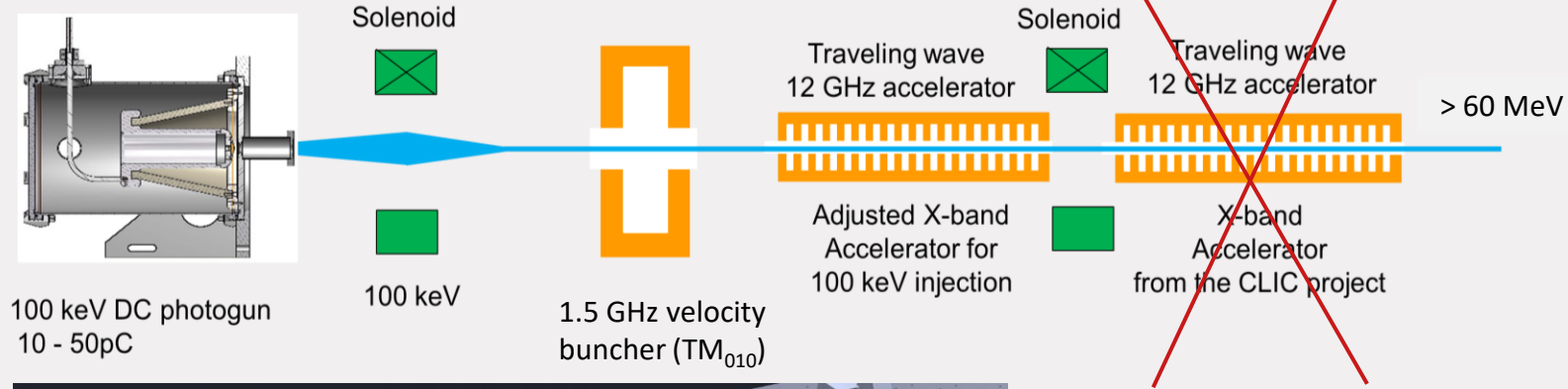
# Electron beam line components



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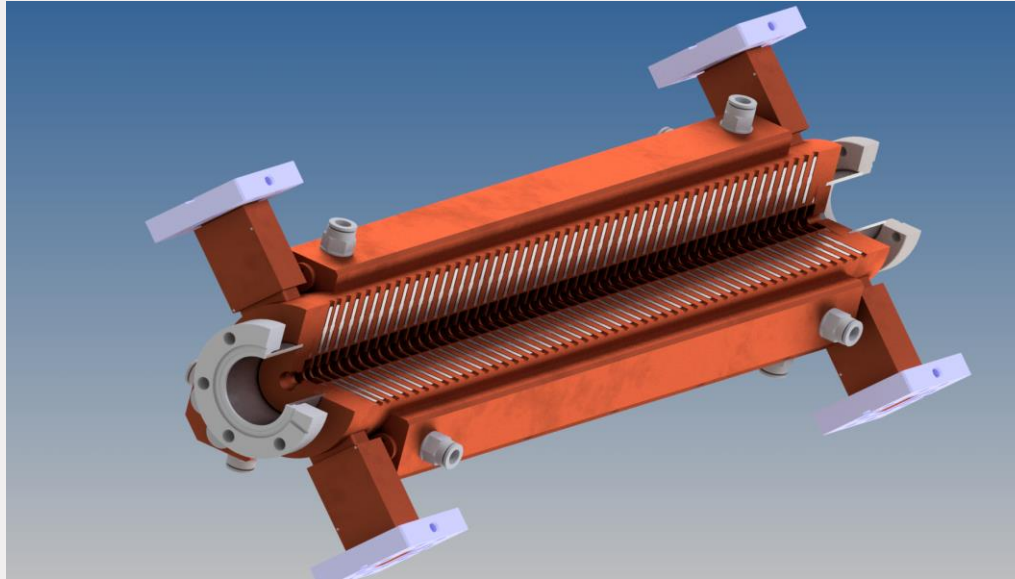
# Electron beam line components



**Smart\*Light phase 1:**  
a single X-band accelerator section

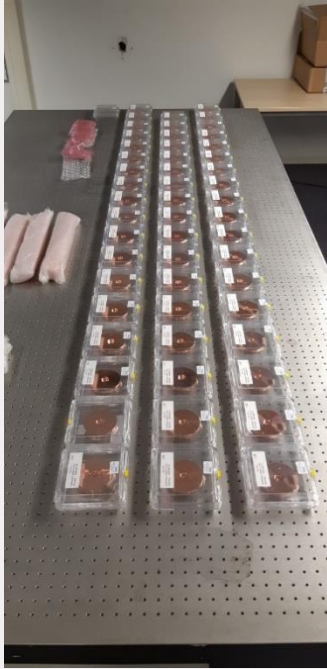
# TU/e design of 50-cell X-band accelerator

Design based on 24-Cell CLIC standard

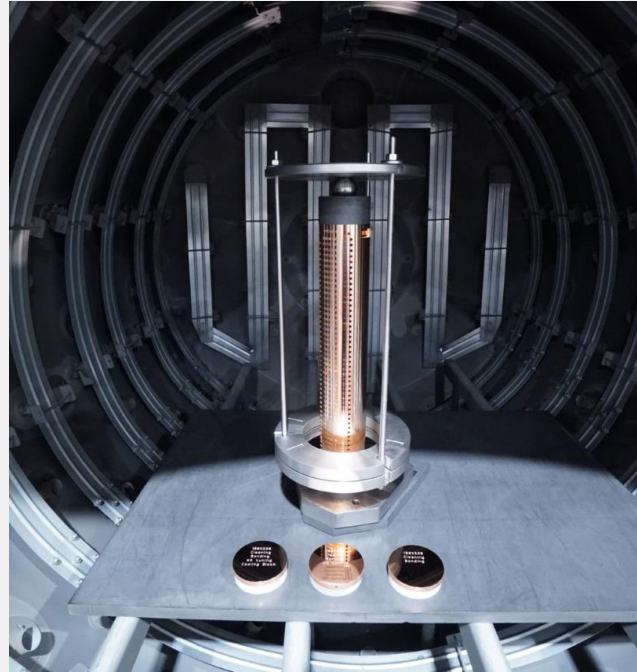


First few cells adjusted to allow injection at 100 keV;  
Acceleration to 30 MeV at 75 MV/m gradient.

# Fabrication 50-cell X-band accelerator



Fabricated by VDL

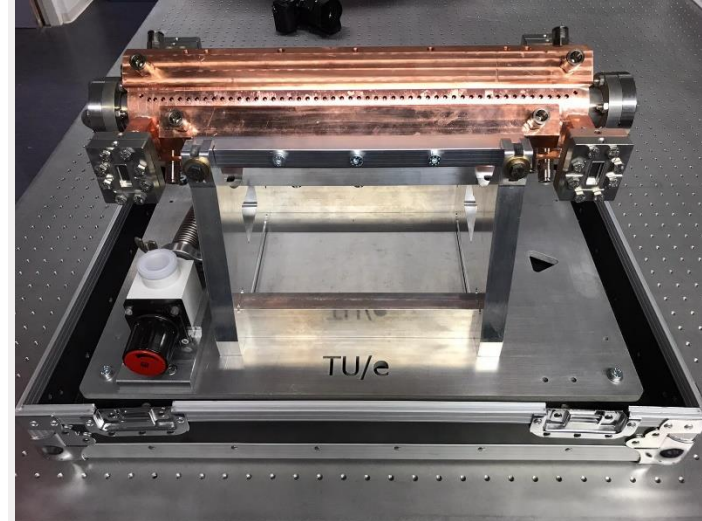
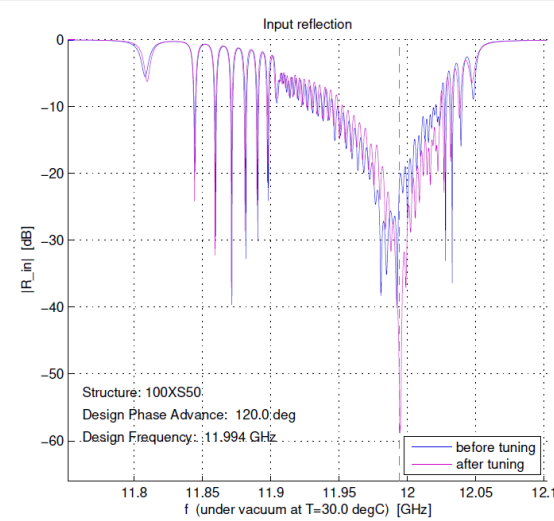
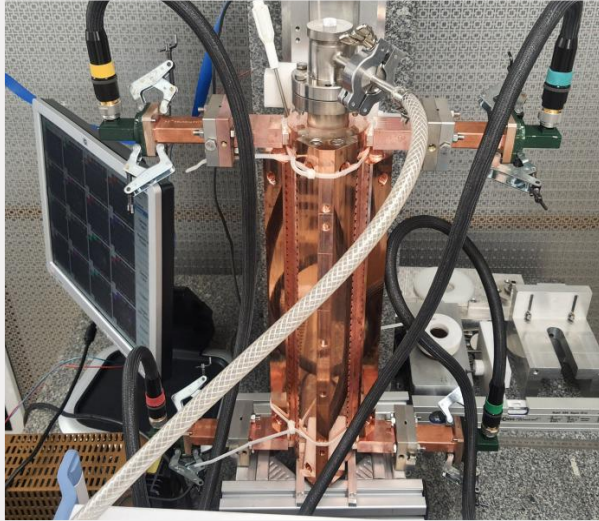


Bonding and Brazing by BodyCote



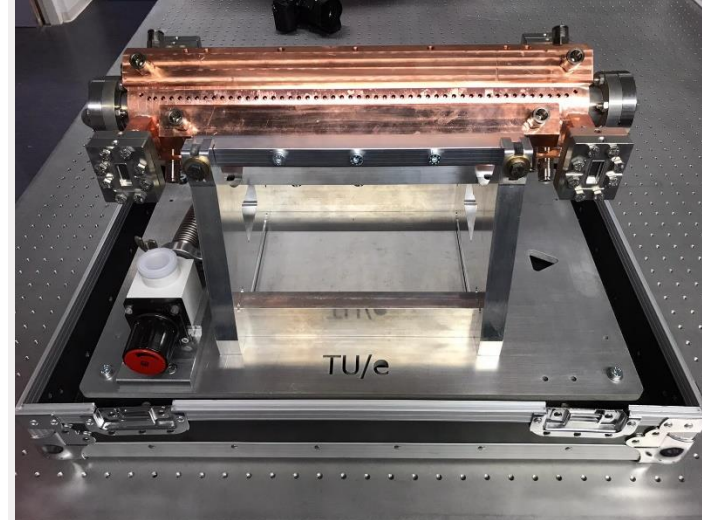
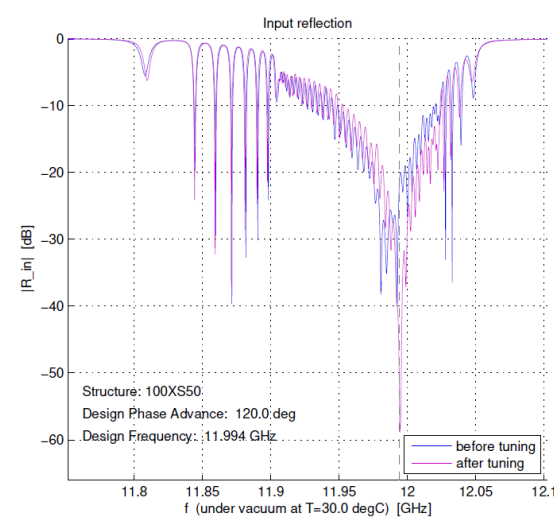
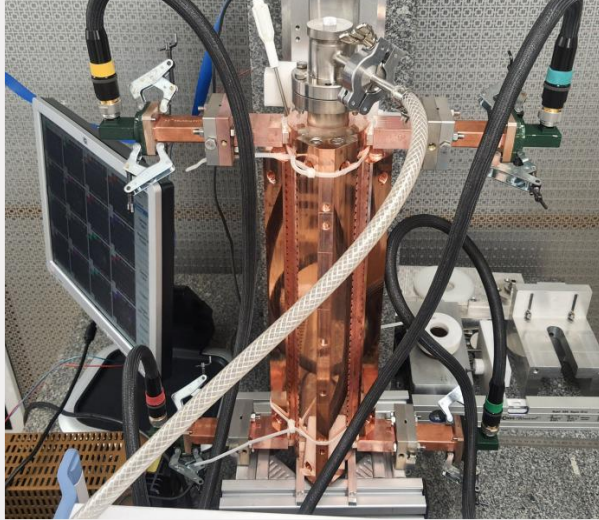


# Low Power Testing @ CERN



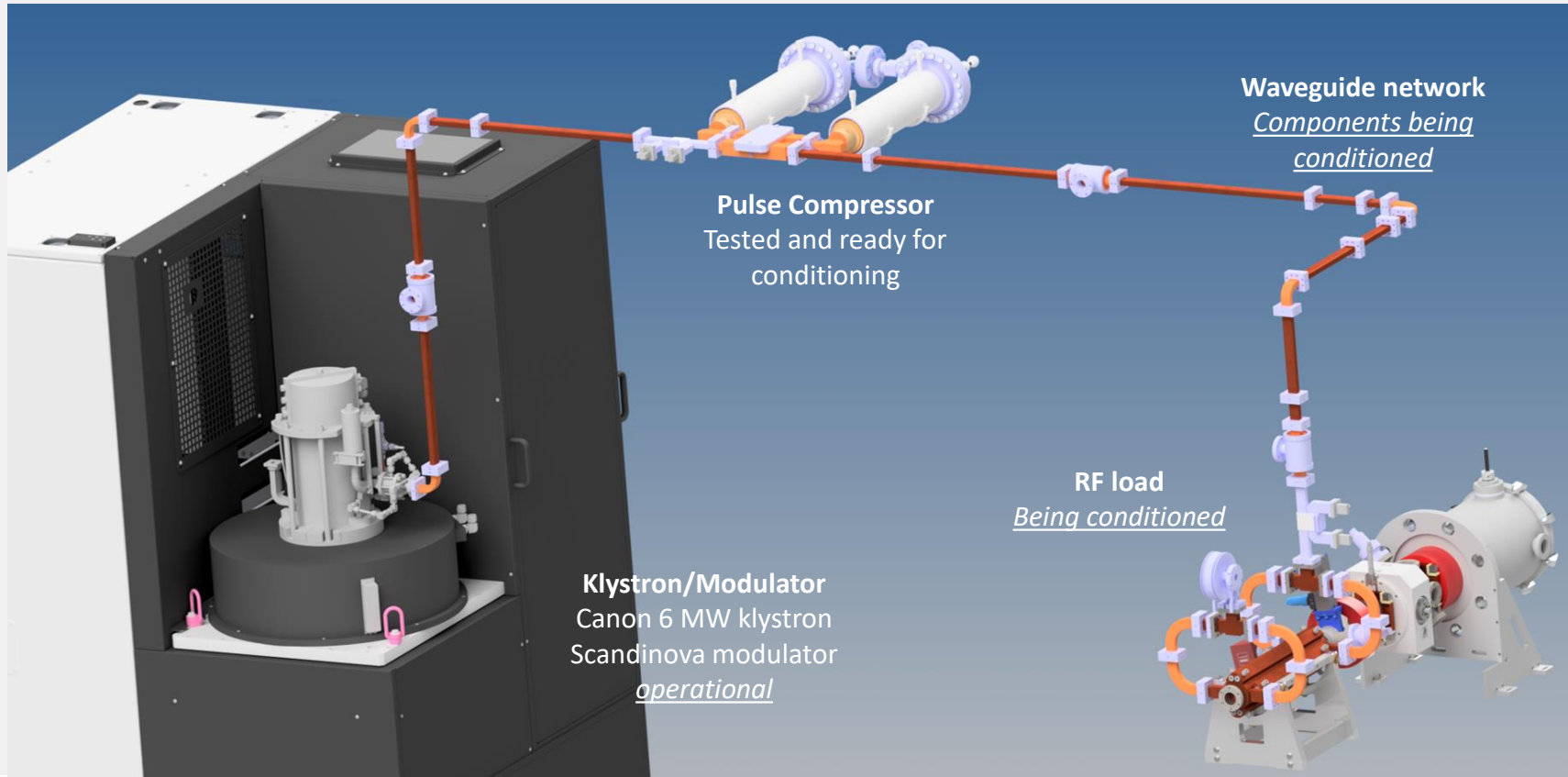
Performed by Hikmet Bursali and Rolf Wegner

# Low Power Testing @ CERN



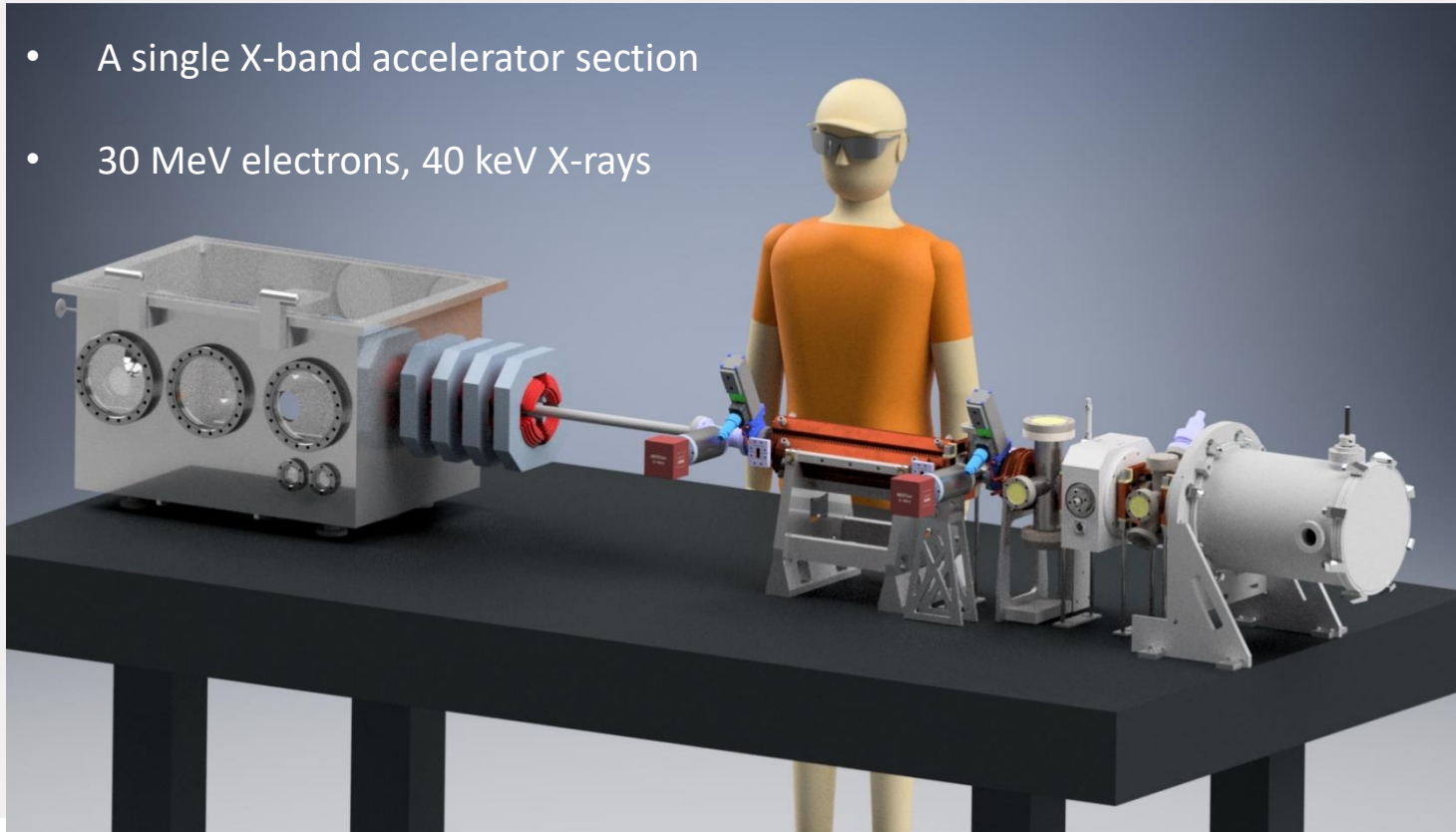
Ready for action @ TU/e!

# High Power 12 GHz RF System - status

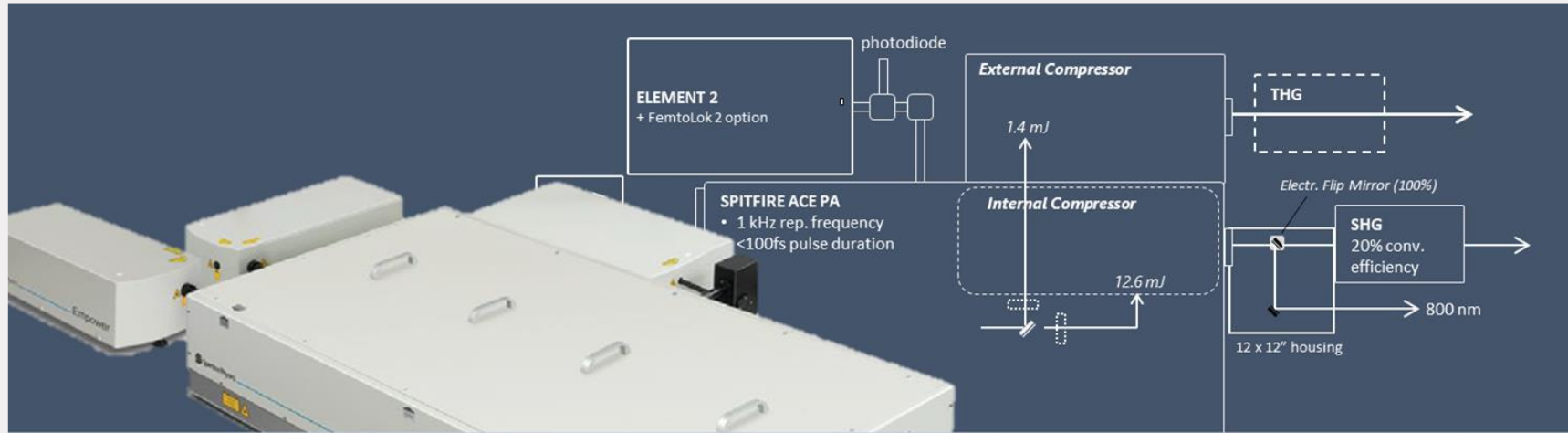


# Smart\*Light phase 1 in 2021

- A single X-band accelerator section
- 30 MeV electrons, 40 keV X-rays



# Laser System: Spectra Physics Spitfire



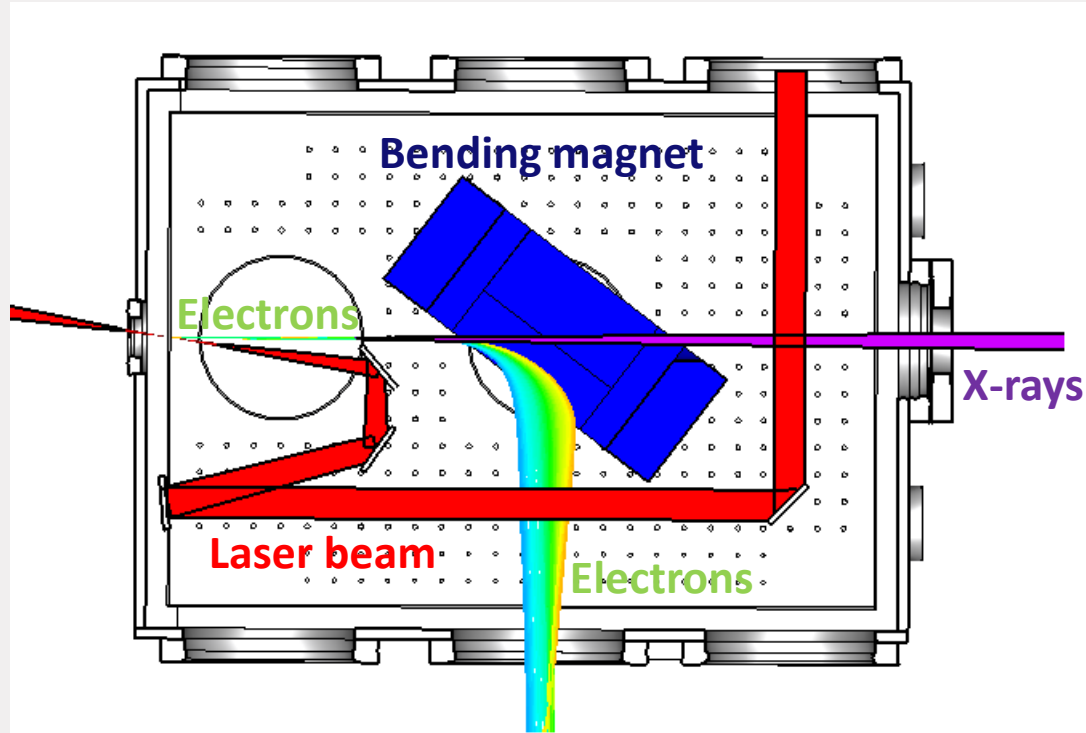
## Inverse Compton Scattering Interaction Laser

**Operational**

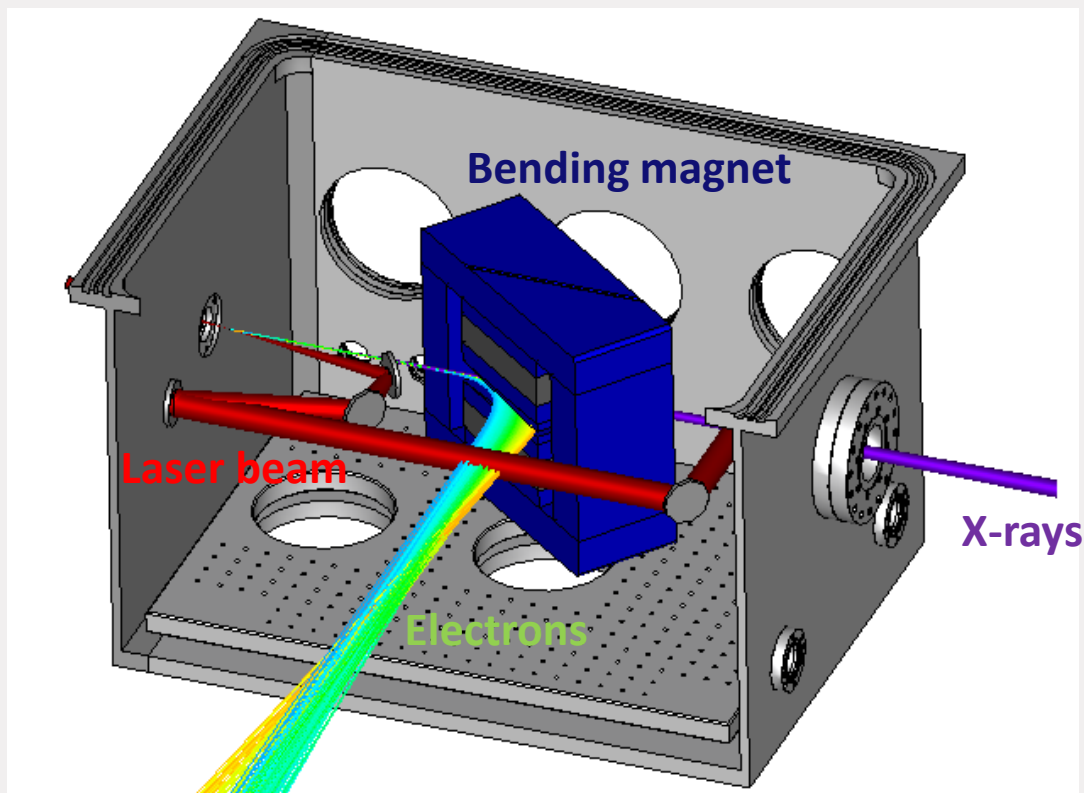
- 100 fs, 800 nm, 13 mJ, @ 1 kHz
- SHG: 400 nm, 3 mJ @ 1 kHz



# Interaction Chamber: where electrons meet laser pulses

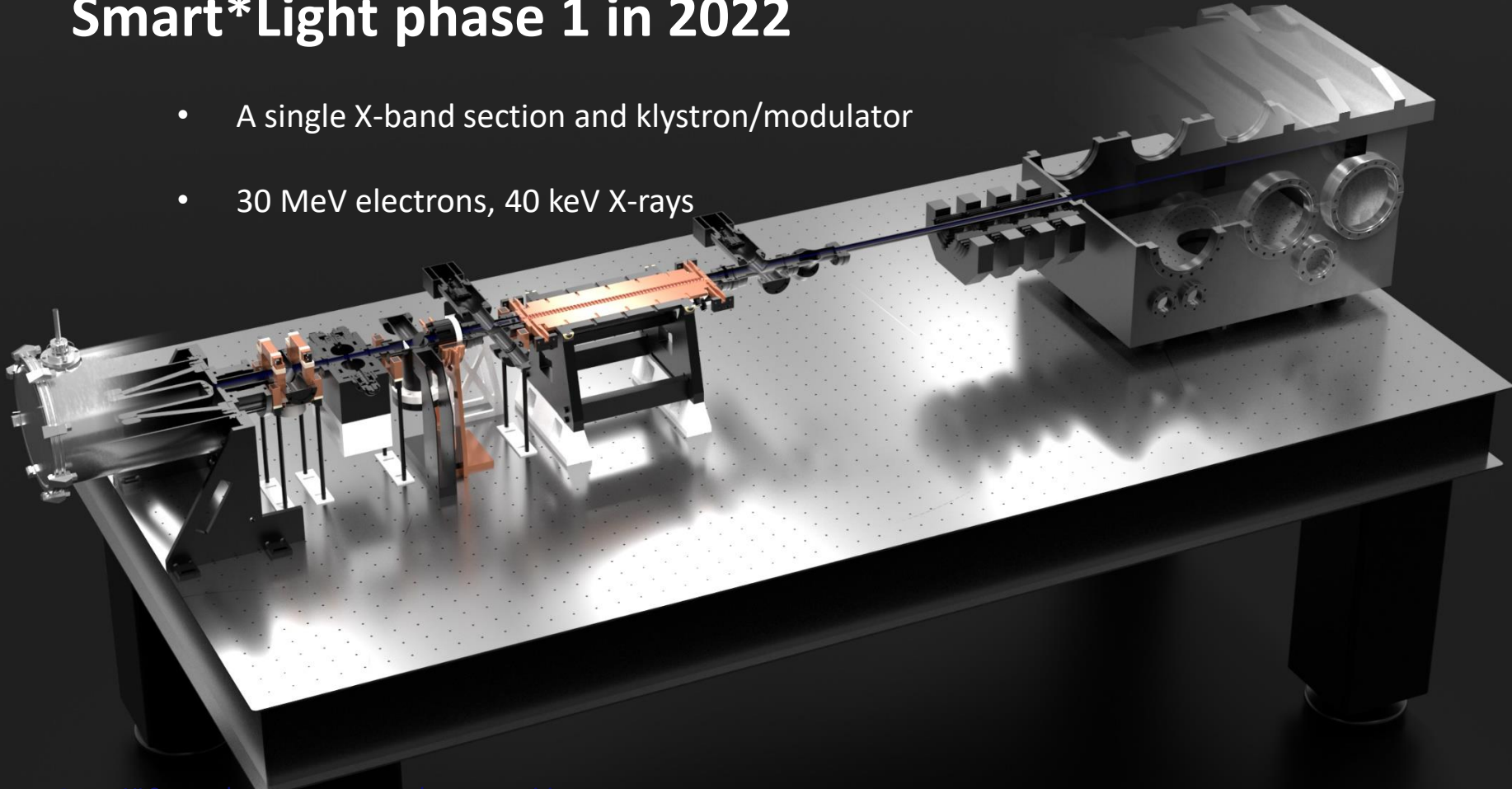


# Interaction Chamber: where electrons meet laser pulses

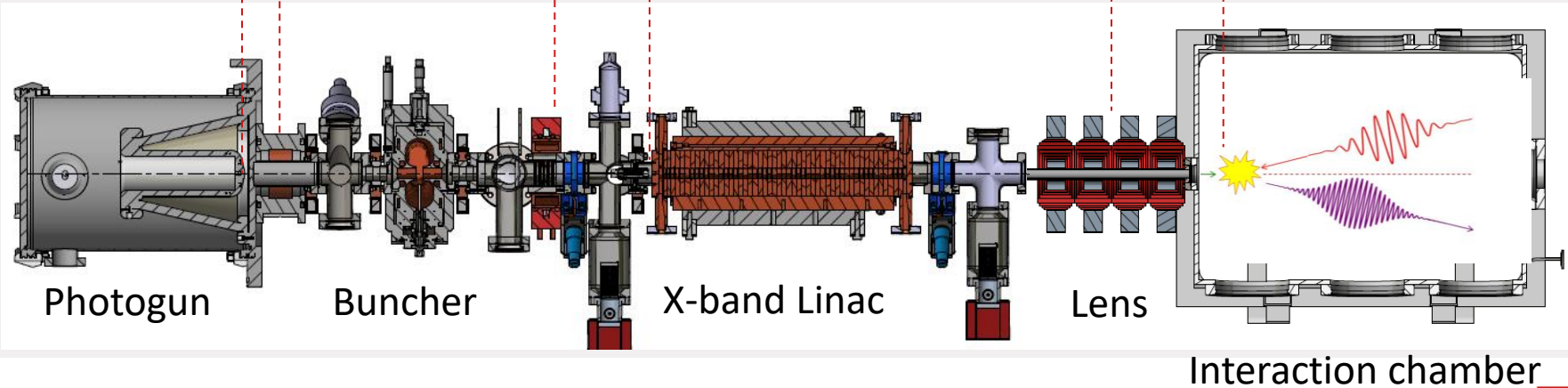
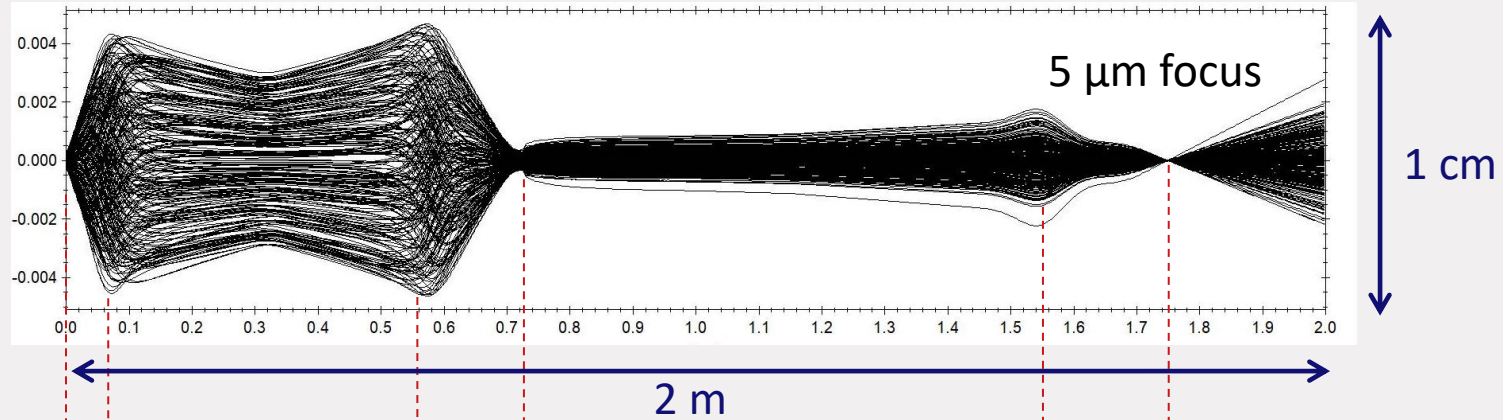


# Smart\*Light phase 1 in 2022

- A single X-band section and klystron/modulator
- 30 MeV electrons, 40 keV X-rays



# Electron paths through beamline

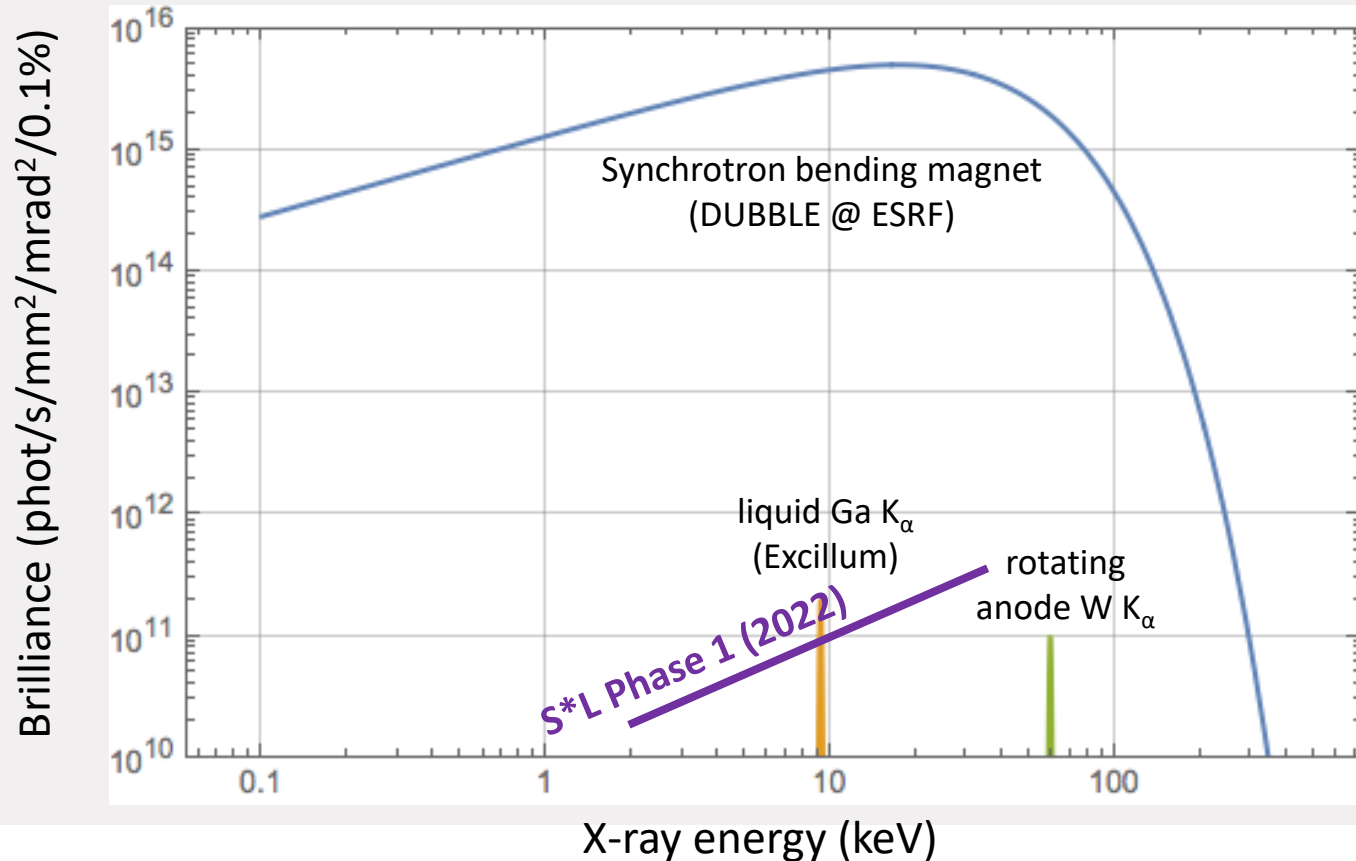


# Smart\*Light phase 1

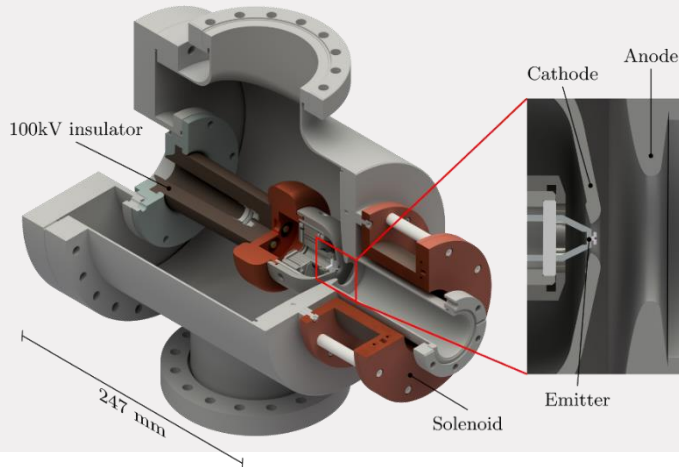
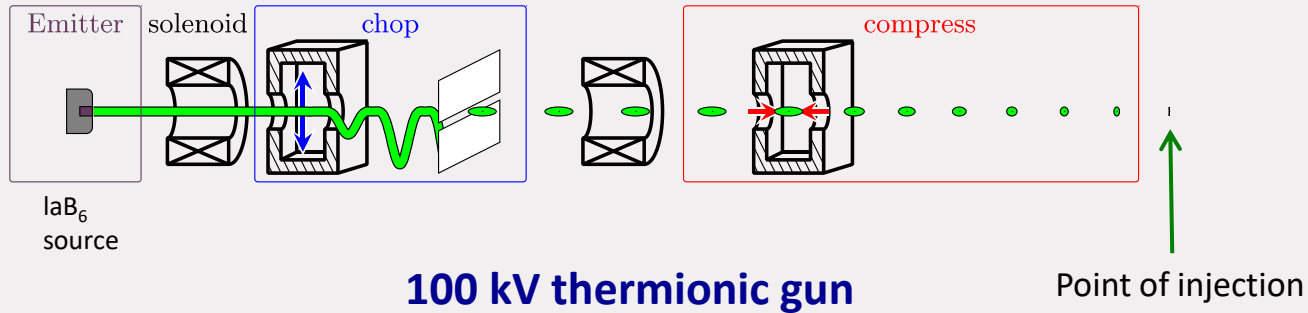
Electron bunch charge	50-100 pC
Electron bunch energy	up to 30 MeV
Normalized rms emittance	0.5 mm mrad
Electron beam radius (rms)	5 $\mu\text{m}$
Laser wavelength	400-800 nm
Laser pulse energy	6-12 mJ
Laser pulse length	100 fs
Laser beam waist	10 $\mu\text{m}$ (5 $\mu\text{m}$ rms radius)
Repetition rate	1 kHz



# Brilliance Smart\*Light phase 1



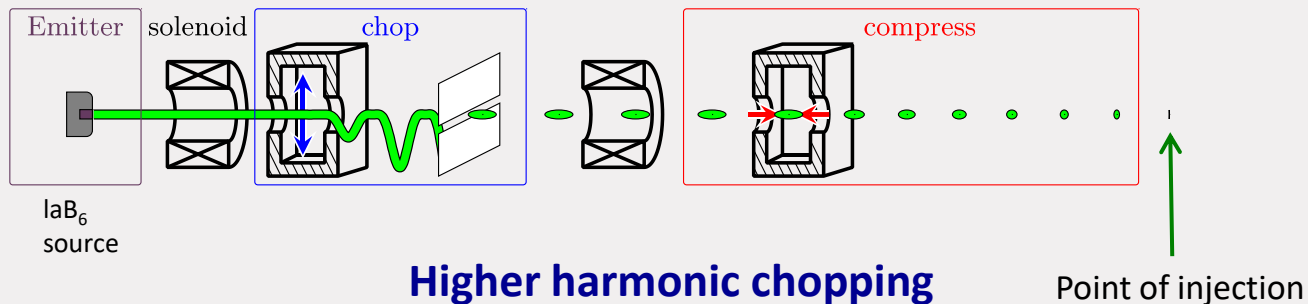
# Gun upgrade for 100-bunch burst mode



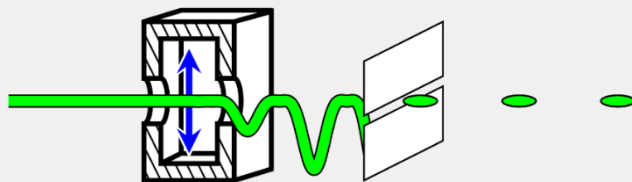
- 1 mm LaB<sub>6</sub> crystal @ 1760 K
- 10 MV/m cathode field strength
- 100 mA continuous current
- 70 nm rad thermal emittance

W.F. Toonen et al., PRAB **22**, 123401 (2019)  
W.F. Toonen et al., NIMA **1013**, 165678 (2021)  
A. Rajabi et al., NIMA **1019**, 165843 (2021)

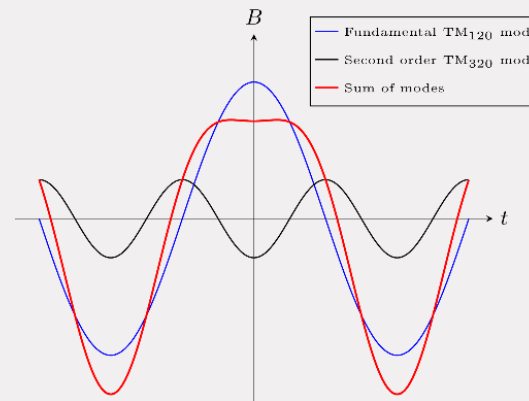
# Gun upgrade for 100-bunch burst mode



30% duty cycle: 70 pC/bunch @ 1.5 GHz

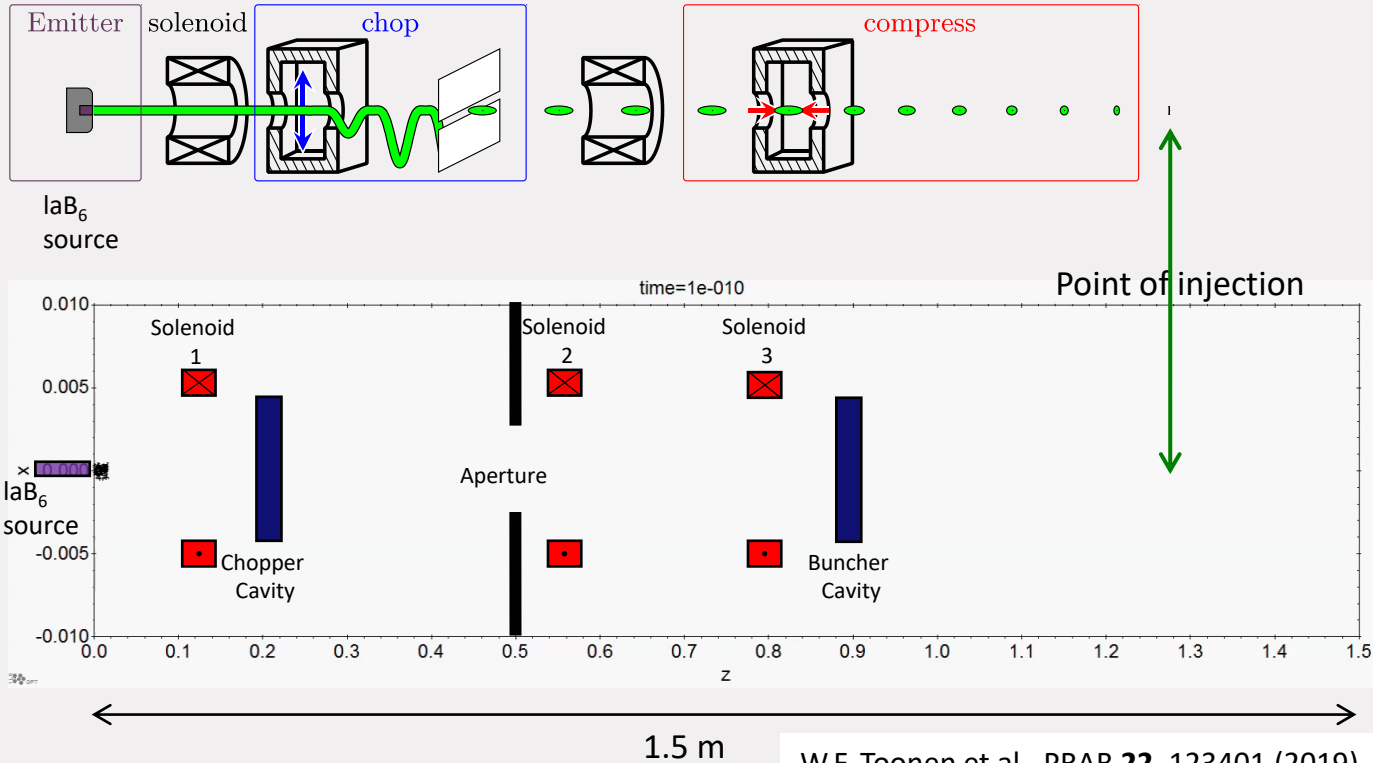


RF cavity:  
Fundamental (1.5 GHz) and  
second harmonic (3 GHz) mode



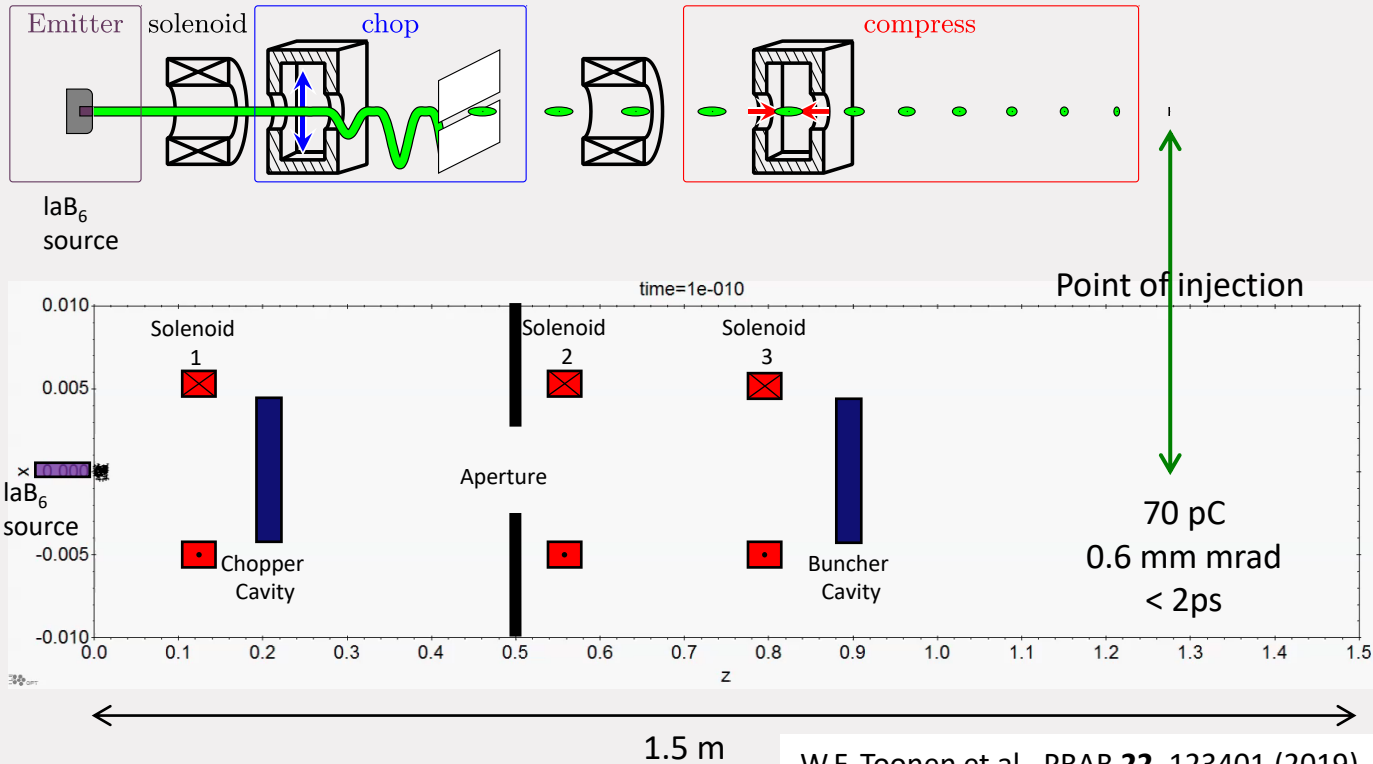
W.F. Toonen et al., PRAB **22**, 123401 (2019)  
W.F. Toonen et al., NIMA **1013**, 165678 (2021)  
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# Gun upgrade for 100-bunch burst mode



W.F. Toonen et al., PRAB **22**, 123401 (2019)  
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# Gun upgrade for 100-bunch burst mode

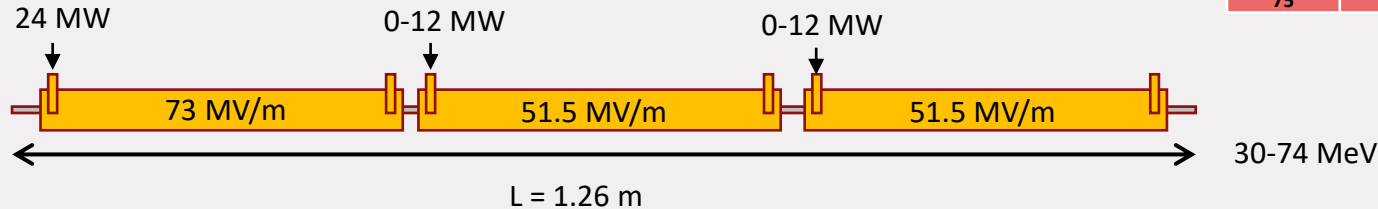
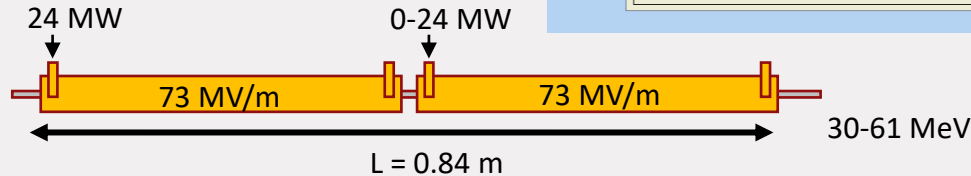
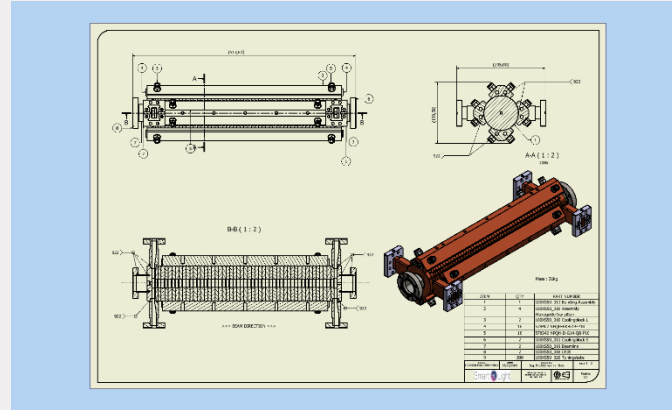


W.F. Toonen et al., PRAB **22**, 123401 (2019)  
 W.F. Toonen et al., NIMA **1013**, 165678 (2021)  
 A. Rajabi et al., NIMA **1019**, 165843 (2021)



# Upscaling to harder X-ray energies

Add 50-cell X-band sections; run with two klystrons.

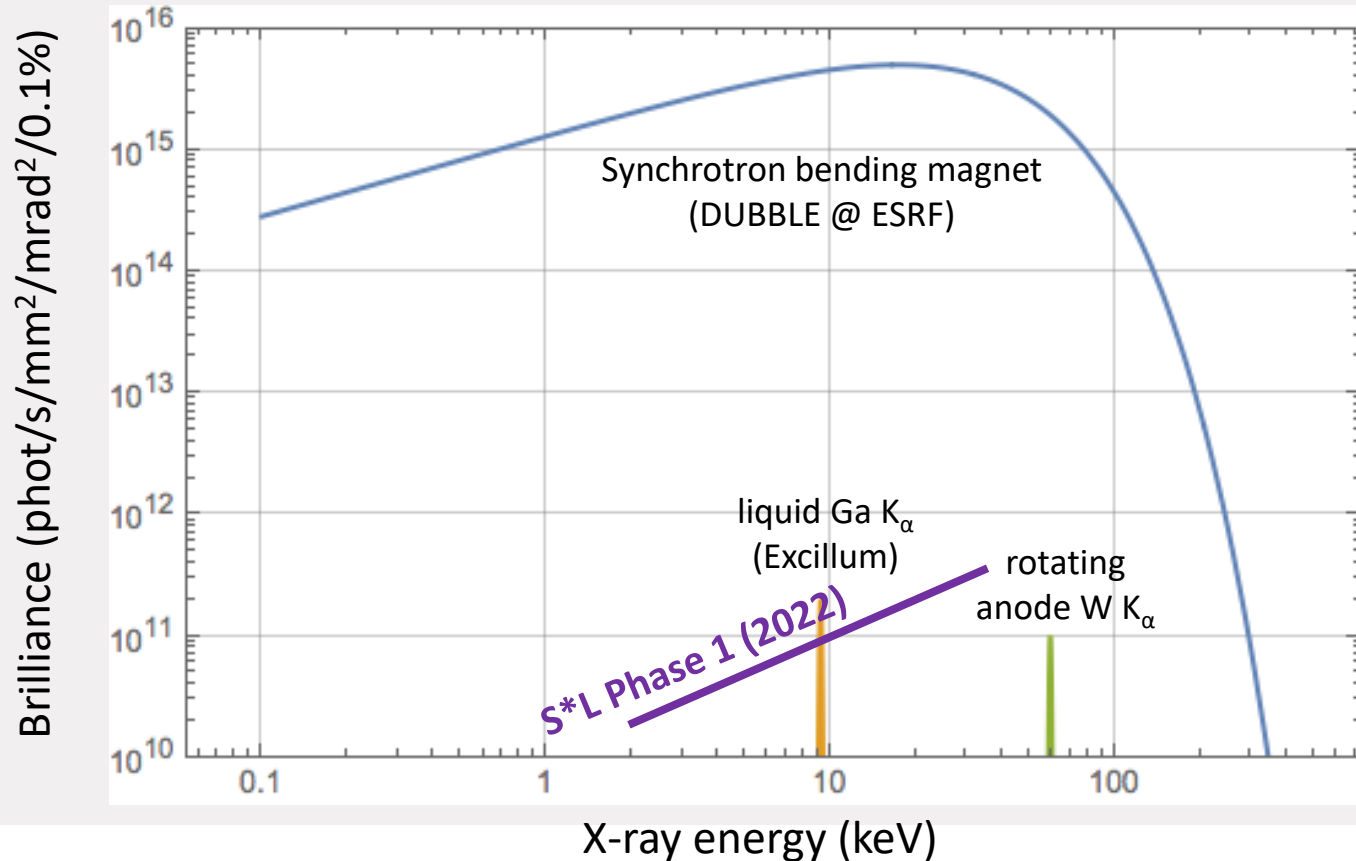


electron energy [MeV]	X-ray energy [keV] for a 515 nm laser
5	1,1
10	4,1
15	8,9
20	15,5
25	24,0
<b>30</b>	<b>34.3</b>
35	46,4
40	60,4
45	76,2
50	93,9
55	113,4
<b>60</b>	<b>134.8</b>
65	158,0
70	183,0
<b>75</b>	<b>209.9</b>

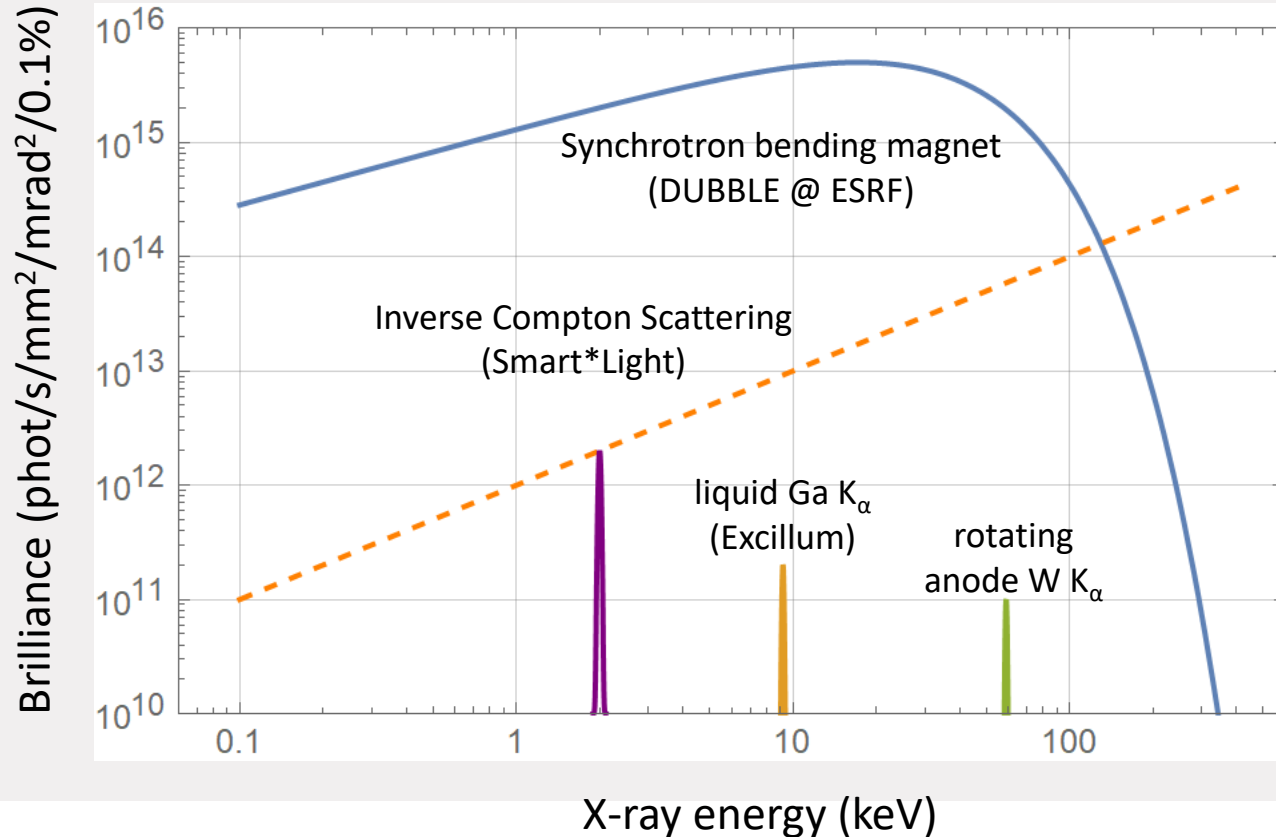
## Smart\*Light phase 2

Electron bunch charge	70 pC
Electron bunch energy	up to 60 MeV
Normalized rms emittance	0.6 mm mrad
Electron beam radius (rms)	5 $\mu\text{m}$
Laser wavelength	400-800 nm
Laser pulse energy	6-12 mJ
Laser pulse length	100 fs
Laser beam waist	10 $\mu\text{m}$ (5 $\mu\text{m}$ rms radius)
Repetition rate	> 100 kHz

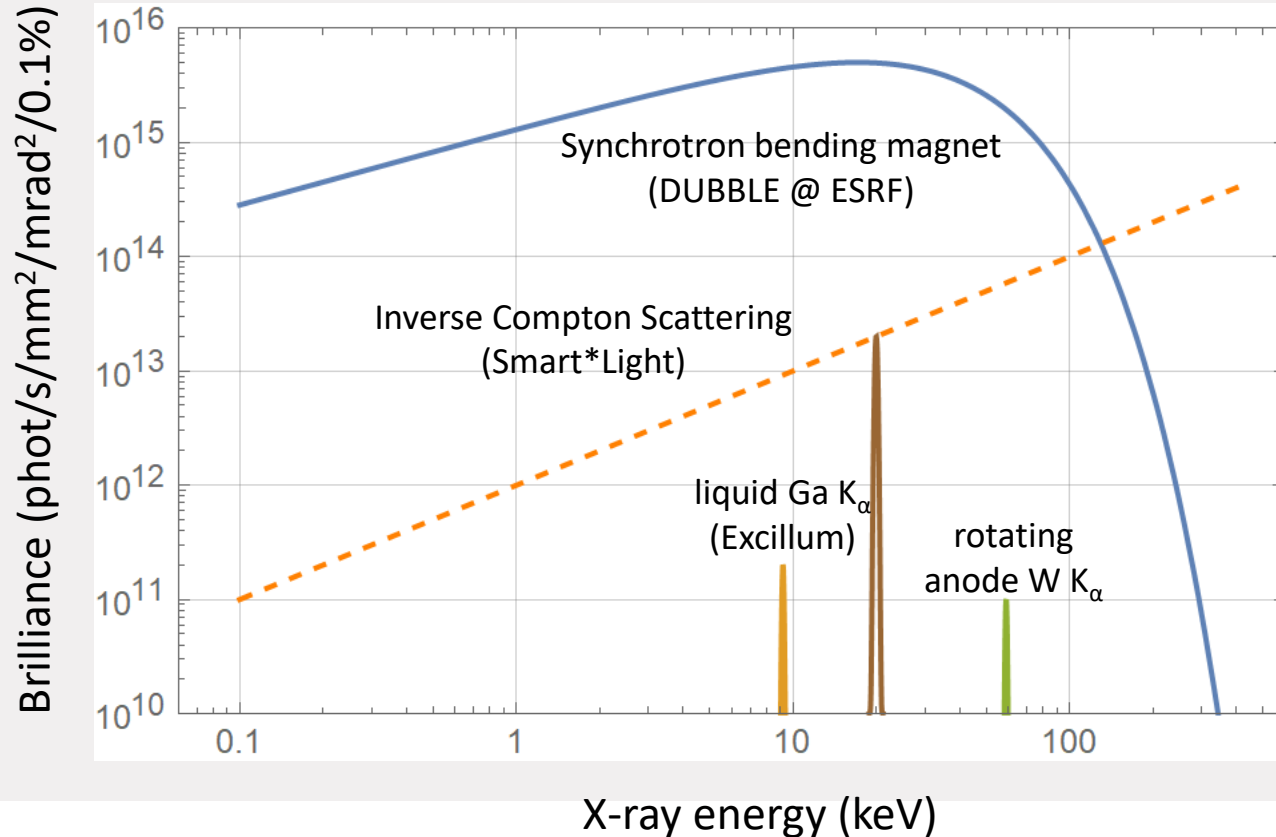
# Brilliance Smart\*Light phase 1



# Brilliance Smart\*Light phase 2

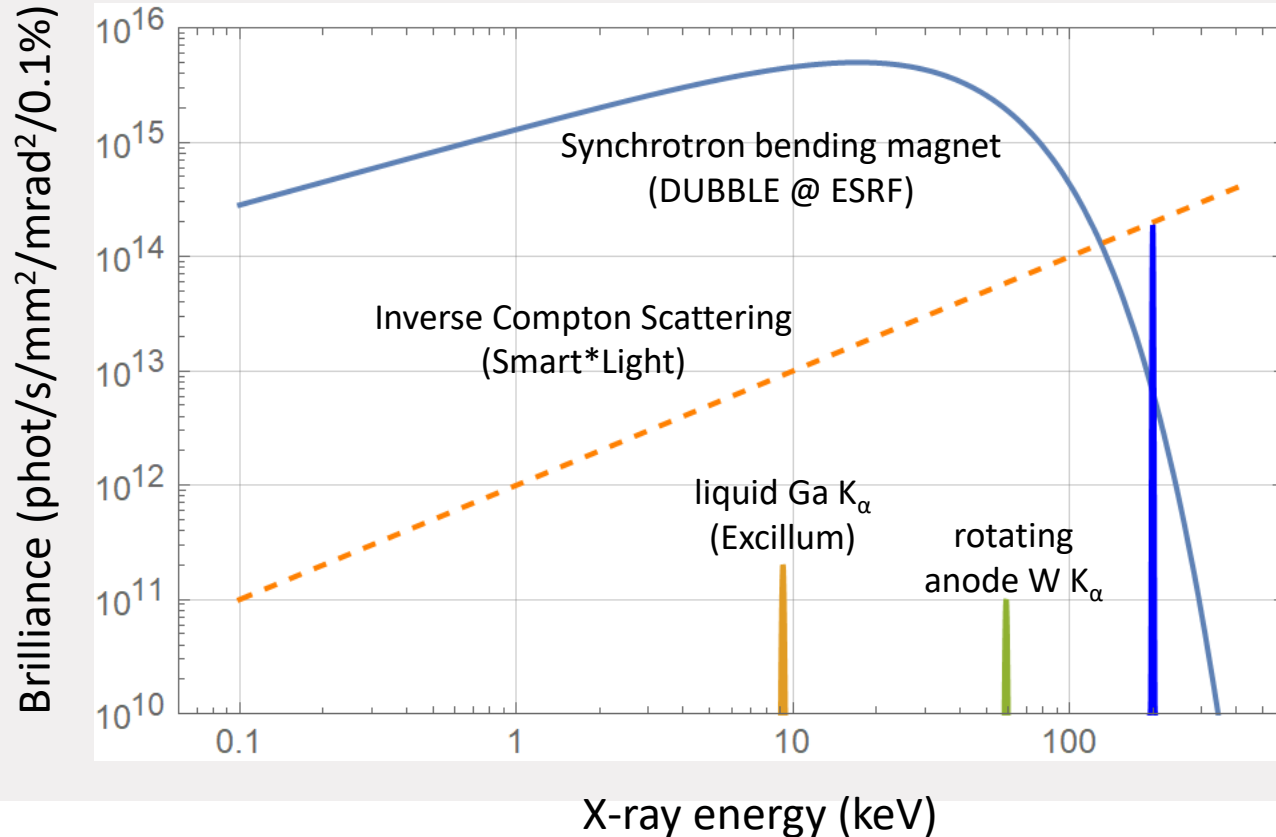


# Brilliance Smart\*Light phase 2

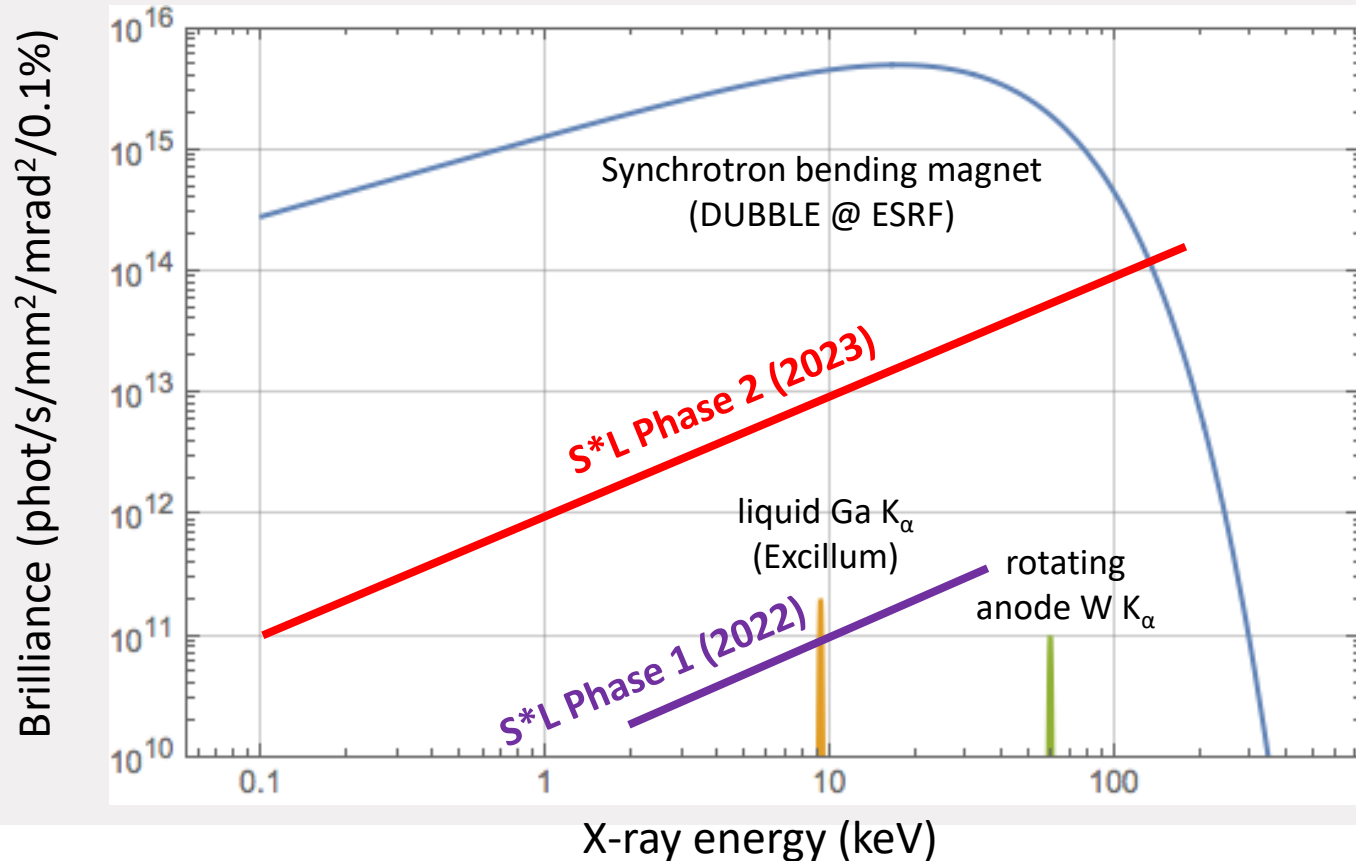




# Brilliance Smart\*Light phase 2

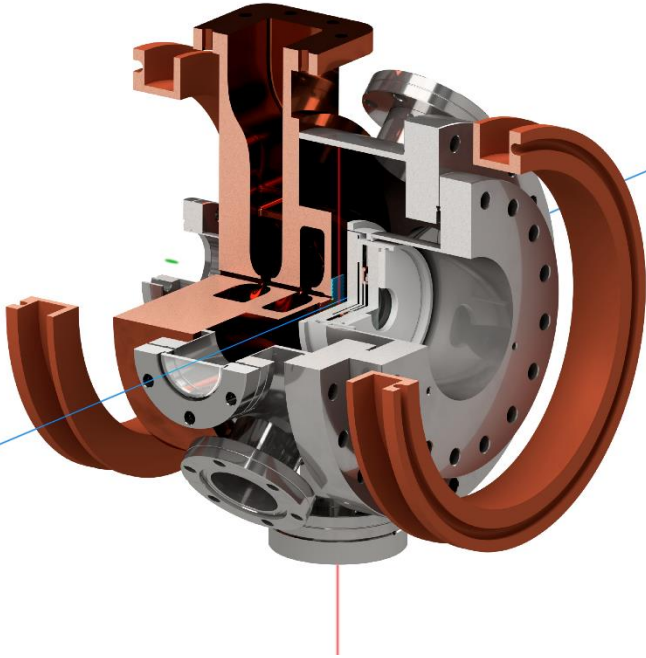


# Brilliance Smart\*Light



# Future: ultracold 100 keV DC-RF gun

- Ultracold source based on femtosecond photoionization of laser-cooled atoms
- Source temperature  $T_e = 10$  K, thermal emittance 1 nm rad, bunch charge up to 1 pC
- DC acceleration to 10 keV, RF acceleration to 100 keV, 1 kHz rep rate



CW operation of 3 GHz 2-cell  
standing wave RF accelerator:

$$Q_0 \approx 8900$$

$$E_0 \approx 10 \text{ MV/m}$$

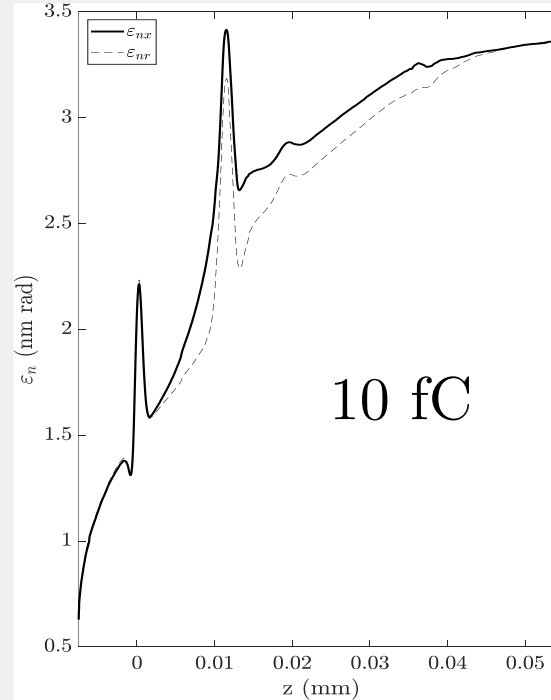
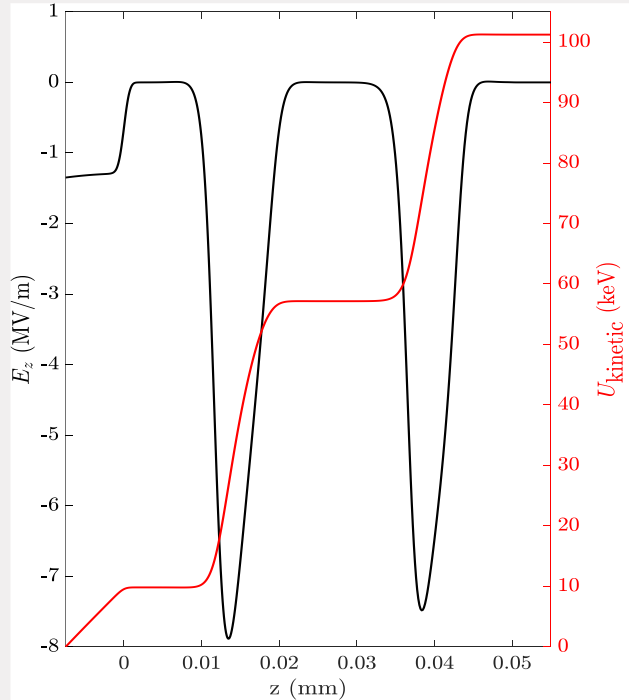
$$P_{\text{peak}} < 5 \text{ kW}$$

*Aim for high coherence at  
limited X-ray flux*

J.G.H. Franssen et al., PRAB **22**, 023401 (2019)

S.B. van der Geer et al., J. Phys. B **47**, 234009 (2014)

# Future: ultracold 100 keV DC-RF gun



J.G.H. Franssen et al., PRAB **22**, 023401 (2019)

S.B. van der Geer et al., J. Phys. B **47**, 234009 (2014)

# Summary

- Smart\*Light: Inverse Compton Scattering Source for tunable, monochromatic hard X-ray beams in a compact setup
- Achievable hard X-ray brilliance several orders of magnitude higher than current lab sources
- Achievable hard X-ray brilliance at high energies comparable to synchrotron bending magnet radiation (DUBBLE @ ESRF)
- Construction underway; first light in 2022, full performance in 2023.



# We are hiring!

## **Postdoc position (2 yrs.) for the development of an Inverse Compton Scattering X-ray source based on high gradient linear accelerator technology**

The Smart\*Light Project is a compact Inverse Compton Scattering (ICS) Hard X-ray source which is currently under development at Eindhoven University of Technology (TU/e). This compact ICS source will consist of an in-house built 100 keV DC photogun which will produce low emittance electron bunches to be injected into a novel 30 MeV X-band accelerating structure, designed specifically for the capture of 100 keV electrons. Completing this system is a state-of-the-art amplified femtosecond laser system and an interaction chamber for the generation of Hard X-rays. All parts have been built or purchased and are ready for integration. We are looking for an experienced accelerator physicist who will take charge of the conditioning of the X-band accelerator structure, and the subsequent generation and characterization of relativistic electron beams. Together with the rest of the TU/e Smart\*Light team, the candidate will subsequently produce the first X-rays, which will be applied to cultural heritage studies, in close collaboration with material scientists of the international Smart\*Light consortium. The position is available immediately.

For more information, please contact prof. Jom Luiten ([o.j.luiten@tue.nl](mailto:o.j.luiten@tue.nl)) or dr. Peter Mutsaers ([p.h.a.mutsaers@tue.nl](mailto:p.h.a.mutsaers@tue.nl)).

