Spectral characterization of hard X-ray from LWFA

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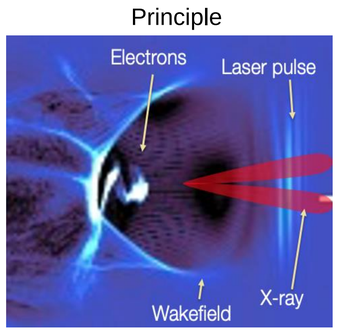
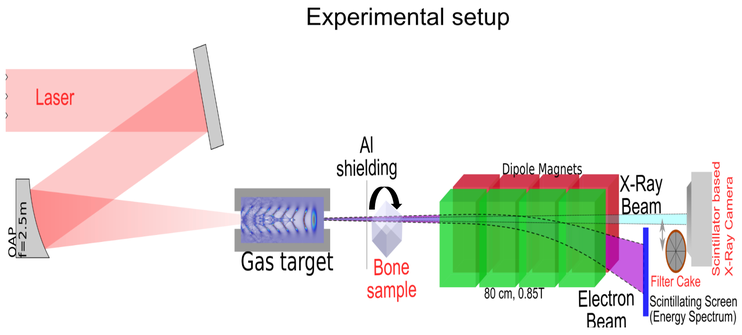
Betatron X-ray source

Principle



Betatron radiation: keV – 10‘s keV

Experimental setup



A high-intensity laser pulse drives a plasma wave, where high brilliance X-rays are produced by wiggling of trapped electrons in the strong radial fields of the plasma during their acceleration[2,3].

Any asymmetry in the plasma wave leads to net oscillation of the electron bunch population with the betatron frequency. Delivering a high photon flux from its intrinsic source size of some microns, this X-ray source is ideally suited for imaging applications like microtomographies[2,3].

$$\omega_c = \frac{3}{2} K \gamma^2 2\pi c/\lambda_u$$

$$\lambda_u(t) = \sqrt{2\gamma(t)}\lambda_p$$

Spectrum reconstruction method

Filter pack

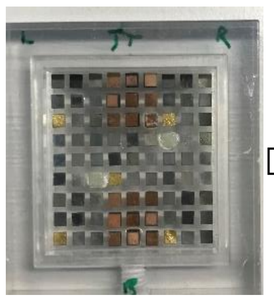
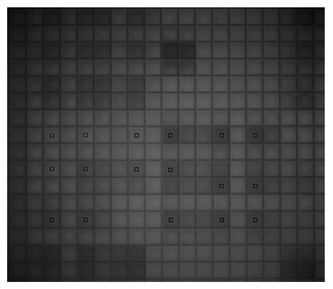
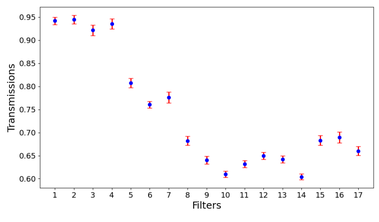


Image of the filter with our in house built detector



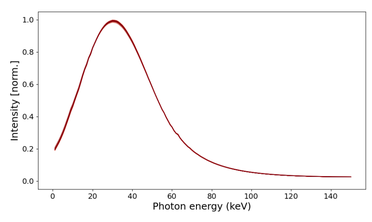
Transmissions through the metal filters contain information about the incoming spectrum.

Transmissions



Bayesian inference framework

Spectrum

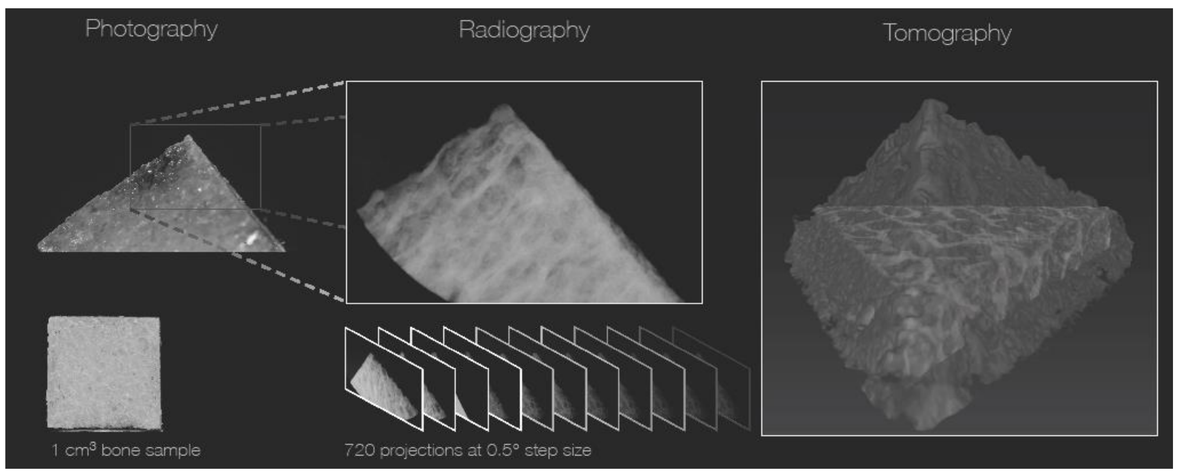


Spectrum reconstruction is an inverse problem that can be solved using suitable algorithms (gradient decent, EM, GP, etc.) Best results were achieved with PyMC GP algorithm [6].

Applications of LWFA X-ray sources

Quick tomographies of bone samples with Betatron source

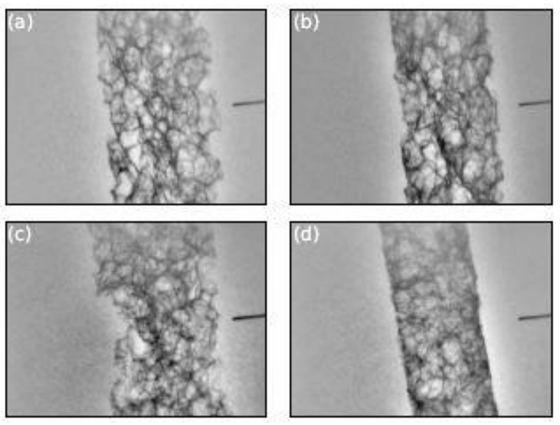
High brightness of LWFA driven betatron X-ray source is sufficient for *medical imaging*, demonstrated here with a tomography of a **human bone sample** (Typical betatron source here consists of 10^9 photons per shot).



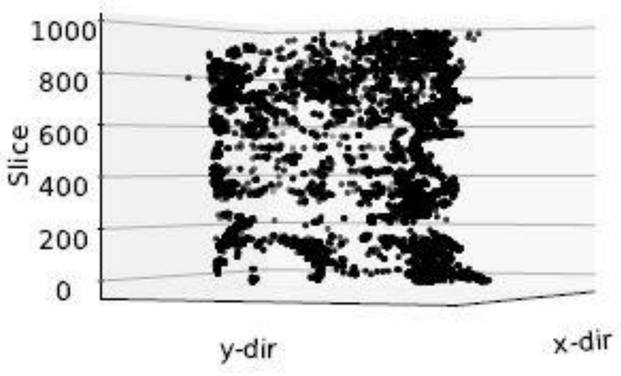
Tomography of a bone sample. Total data acquisition time: < 3 minutes[1].

Quick tomographies of thick samples with Compton source

Compton sources can provide quasi-monochromatic tunable high energy X-rays (10-100keV for a, <<1 from 30-90meV electrons) and can also be used in tomography applications.



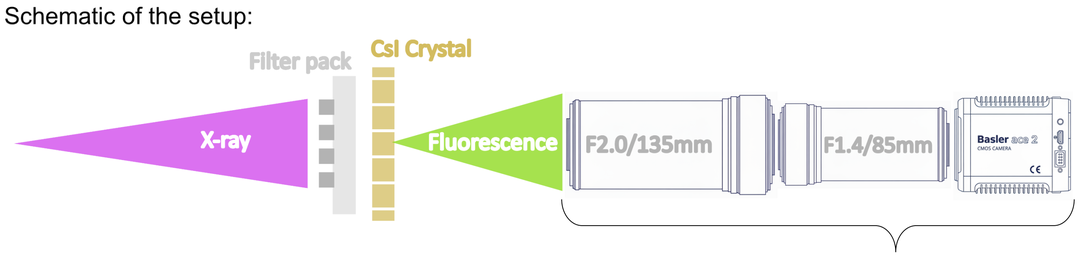
Projection data of a aluminium foam after averaging and background subtraction. The individual projections, such as shown in figure for rotation positions of 0 (panel a), 20 (b), 68 (c) and 121 (d)[4].



Stacking all slices to form a 3D reconstruction of the aluminium foam sample[4].

Verification of spectrum reconstruction using X-ray tube

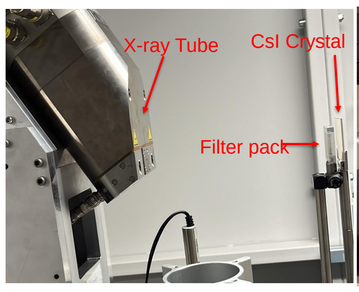
Schematic of the setup:

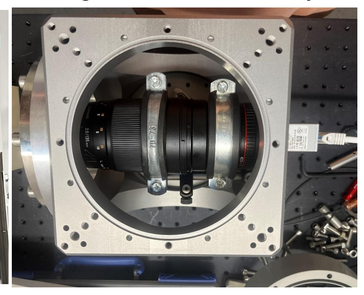


Fluorescence detection with high collection efficiency

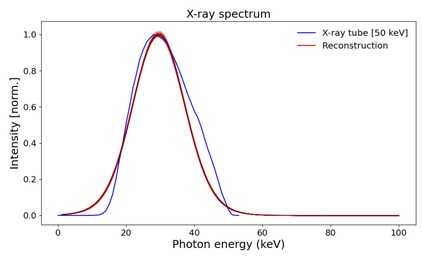
The transmission through the individual filter elements is measured using a pixelated scintillating CsI screen that is imaged using a CMOS camera. For spectrum reconstruction, Bayesian inference based on Gaussian processes was applied [6]. The reconstructed spectra agree reasonably well with the spectra of a tungsten source at different driving voltages.

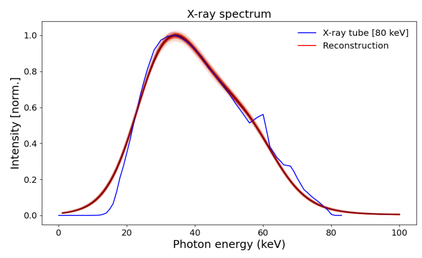
Setup for method verification





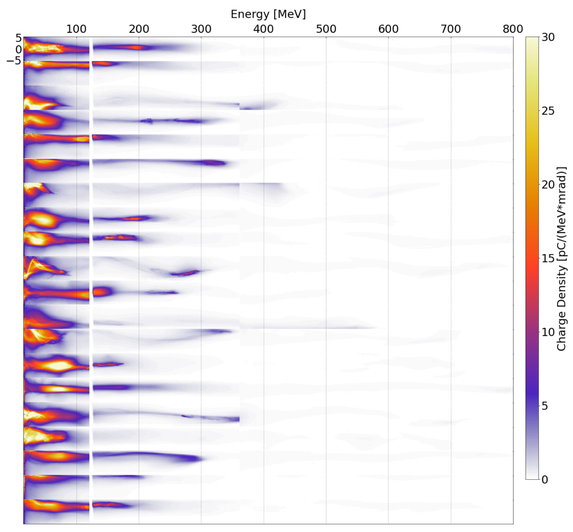
Results/Verification:

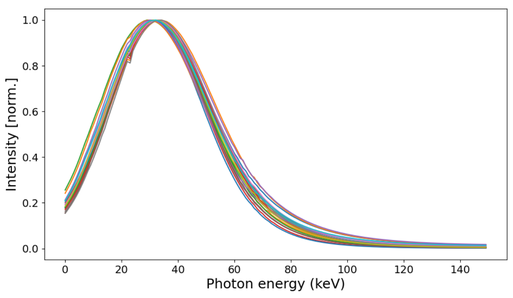




Preliminary results from LWFA experiments

Electron Spectra → Reconstructed X-ray Spectra





- Laser energy: 20.5 J (Before compression)
- Laser pulse length: 28 fs
- Slit nozzle length: 10 mm
- Gas: Hydrogen mixed with 4% nitrogen

Preliminary analysis shows strong correlation between the maximum electron energy and center-of-mass energy of the corresponding X-ray spectrum.

References

1. Döpp A. et al. Quick x-ray microtomography using a laser-driven betatron source, Optica 5, 199-203 (2018)
2. Götzfried J. et al. Research towards high-repetition rate laser-driven X-ray sources form imaging applications, Nuclear Inst. and Methods in Physics Research, A (2018)
3. Tajima, T. & Dawson, J. Laser Electron Accelerator. Physical Review Letters **43**, 267-270 (1979).
4. A. Schletter, Dissertation: Ultrafast Coherent X-ray Pulses: Laser-Based Sources and Applications (2024).
5. K. Ta Phuoc, S. Corde, C. Thaury, V. Malka, A. Tafzi, J. P. Goddet, R. C. Shah, S. Sebban & A. Rousse. Nature Photonics 6, 308–311 (2012)
6. PYMC https://www.pymc.io/