Experimental progress towards an all-optical Thomson source for X-ray flourescence imaging

Kristjan Põder§, Simon Bohlen§, Theresa Staufer‡, Martin Meisel§, Theresa Brümmer‡, Florian Grüner‡, Jens Osterhoff§

§Deutsches Elektronen Synchrotron DESY, Notkestr. 85, Hamburg, Germany
‡Universität Hamburg, Mittelweg 177, Hamburg, Germany

Contact: kristjan.poder@desy.de

X-Ray Flouresence Imaging (XFI)

Medical imaging techniques

	PET[1]	CT[2]	MRI[3]	XFI[4]
Temporal resolution	poor	high	high	high
Spatial resolution	poor (4-5mm)	high (1mm)	high (1mm)	high (< 1mm)
Sensitivity	high	low	low	high
Dose exposure	moderate to high	high	none	low

Unique advantages of XFI for medical imaging

- Low reabsorption in human tissue due to high working point of ~70 keV
- High sensitivity
- No gold in the human body – no false detection
- GNPs can be attached to several peptides and antibodies
- GNPs are stable: enabling the possibility for pharmacokinetics
- Spatial resolution only limited by x-ray beam diameter

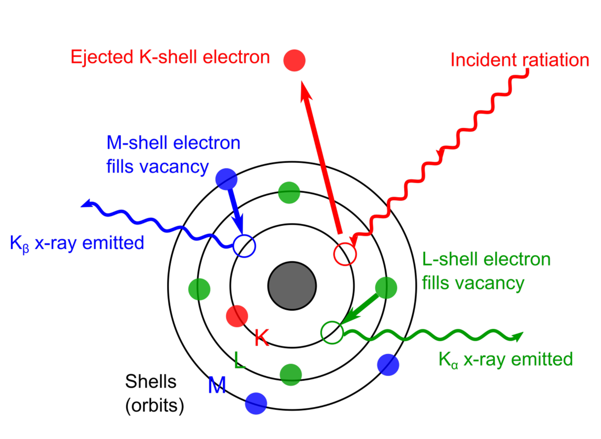

Figure 1: *X-Ray flourescence*

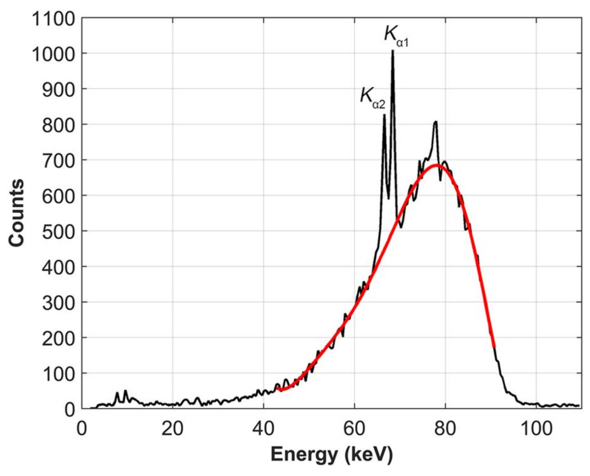

Figure 2: *X-ray tube spectrum with XFI signal [4]*

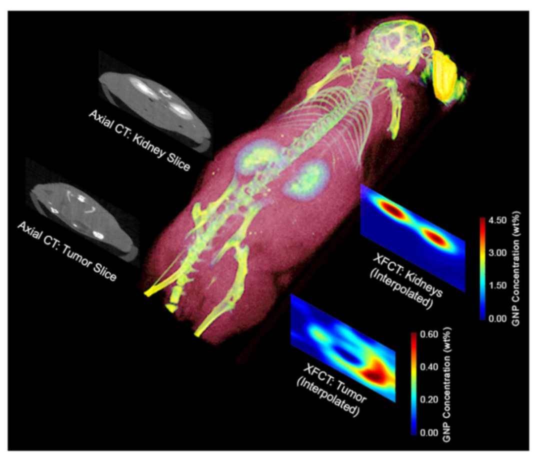

Figure 3: *XFI reconstruction [4]*

Thomson Scattering

Energy of Thomson scattered X-Ray is given by:

$$\omega_X = \frac{2\gamma^2 (1 - \beta \cos \alpha)}{1 + a_0^2/2 + \gamma^2\theta^2}\, \omega_L$$

XFI with GNPs requires source with:

- Low bandwidth ($< 15\,\%$)[5]: $\mathrm{BW} \simeq 2\sigma_\gamma$[6]
- Small source size and divergence: $\theta_S \sim \gamma^{-1}$
- Large flux and rep. rate: $N_X \propto Q N_{\mathrm{osc}} a_0^2 \sigma(\theta\mathrm{obs})$
- Compactness and low cost
- X-Ray energy $\hbar\omega_X \sim 90\,\mathrm{keV} \to \gamma \simeq 120$

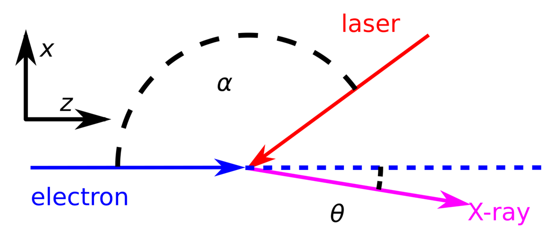

Figure 4: *Geometry of Thomson scattering*

While X-Ray tubes are cheap & compact and synchrotrons have desirable beam parameters, all-optical Thomson sources fulfill all criteria!

Experimental setup

Flexible setup to develop and demonstrate all-optical XFI X-Ray source

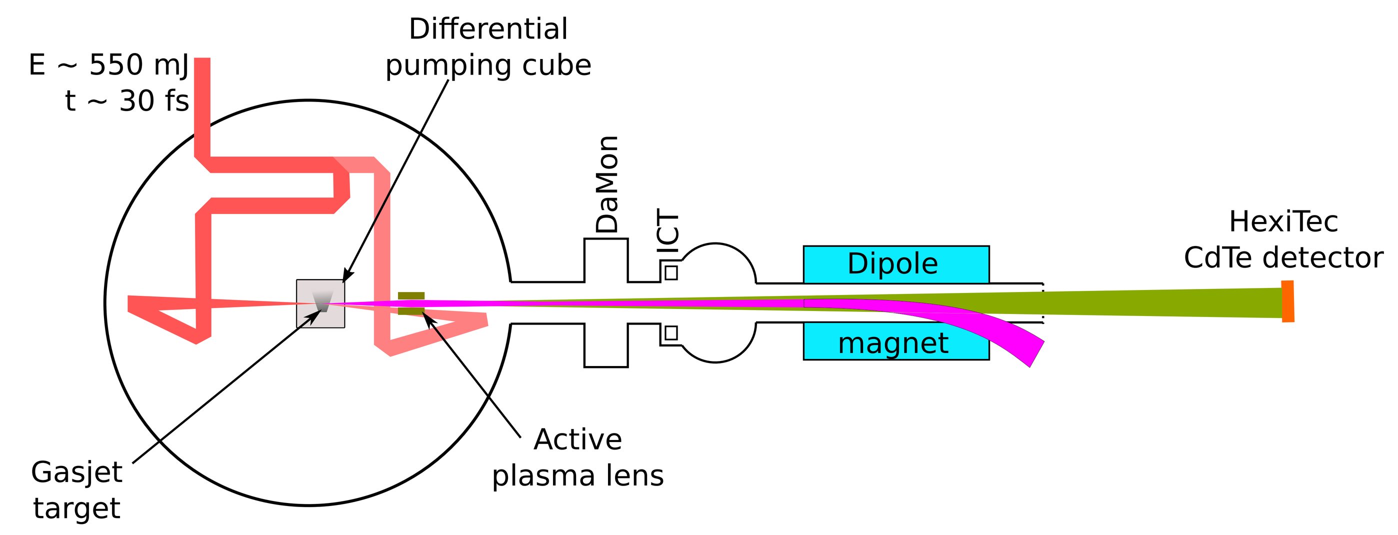

Figure 5: *Schematic layout of the experimental setup*

Stable electron beams

Stable ionisation injection beams from 1 % N_2 dopant

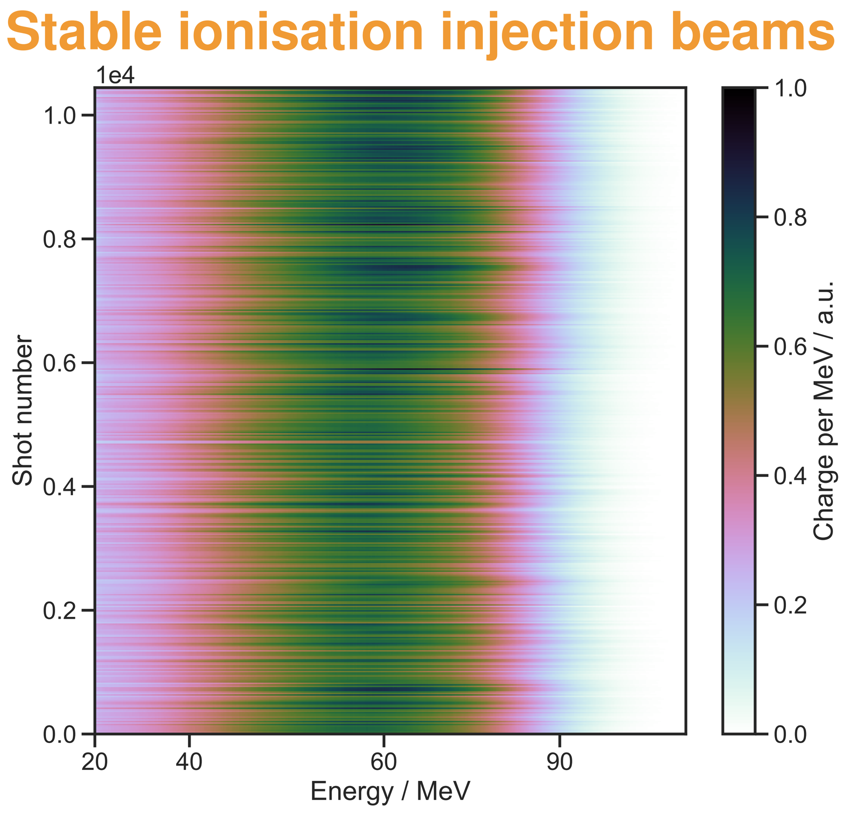

Figure 6: *Running average of 10^4 consecutive shots*

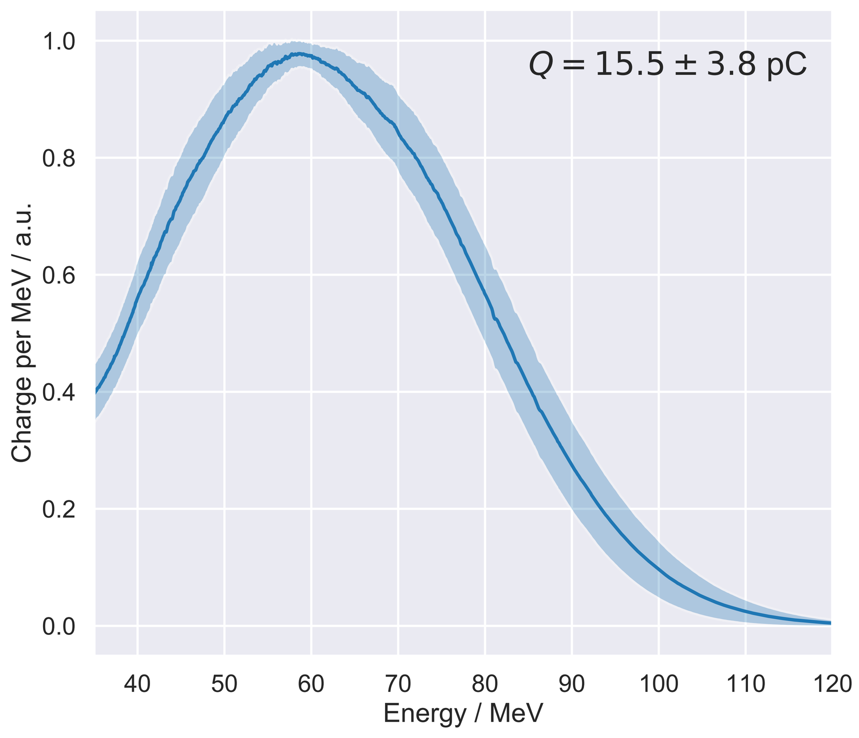

Figure 7: *Average spectrum of the shots, showing high stability*

Active plasma lenses

Compact, aberration-free, high gradient e-beam optics [7, 8, 9]

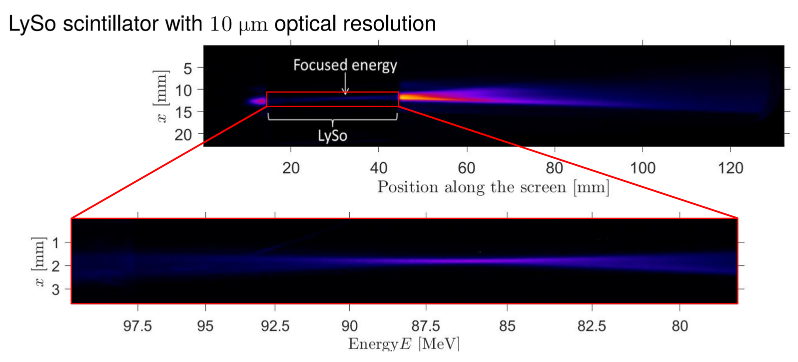

Figure 8: *"Butterfly" emittance measurement*

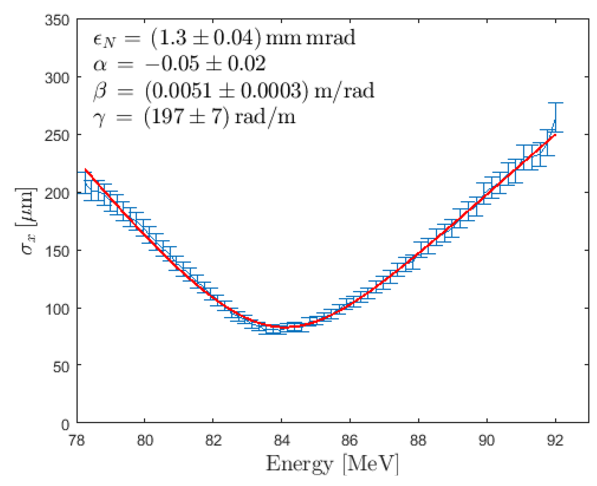

Figure 9: *Emittance extraction from "butterfly" measurement*

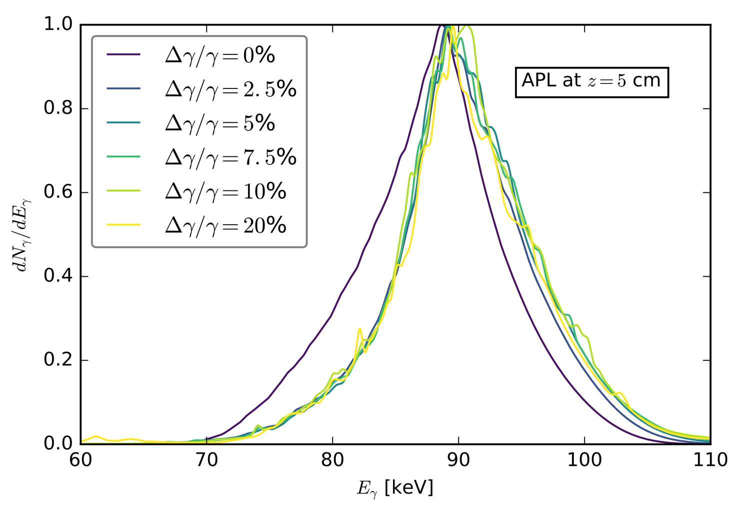

Figure 10: *APLs allow for spectral filtering of Thomson spectra*

Chromatic focussing effect can be used to spectrally filter X-Ray spectrum: relaxed requirements for electron beams!

Differential pumping

Enclosed differential pumping allows 10 Hz repetition rate

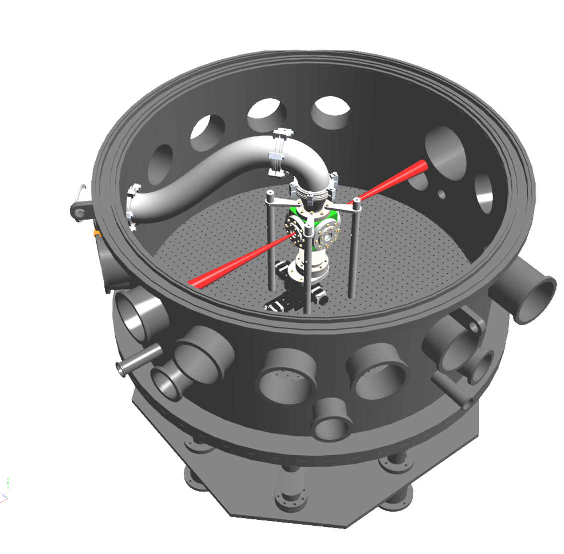

Figure 11: *CAD rendering of the differential pumping cube*

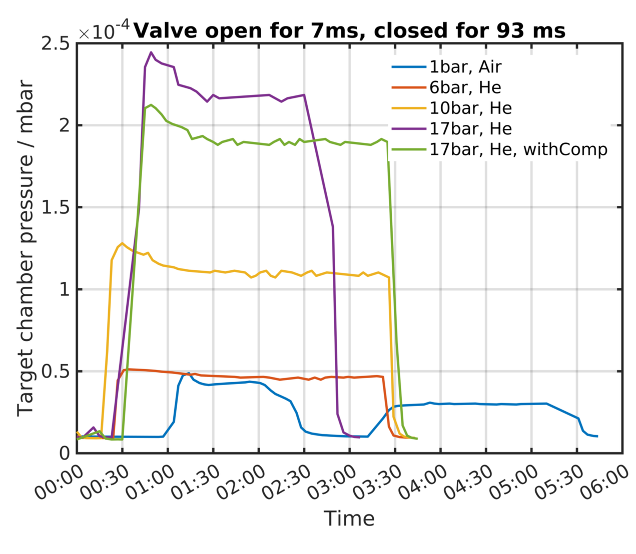

Figure 12: *Pressure in the chamber with the pumping cube*

- Cube with 2 mm holes, differentially pumped
- Surrounding vacuum pressure below 3×10^{-4} mbar with $10\,\mathrm{Hz}$ gas pulsing
- Allows for systematic studies of LWFA at 10 Hz
- Forms a robust and reliable 10 Hz electron beam source

First XFI measurements

Flourescence signal from Au and Gd measured

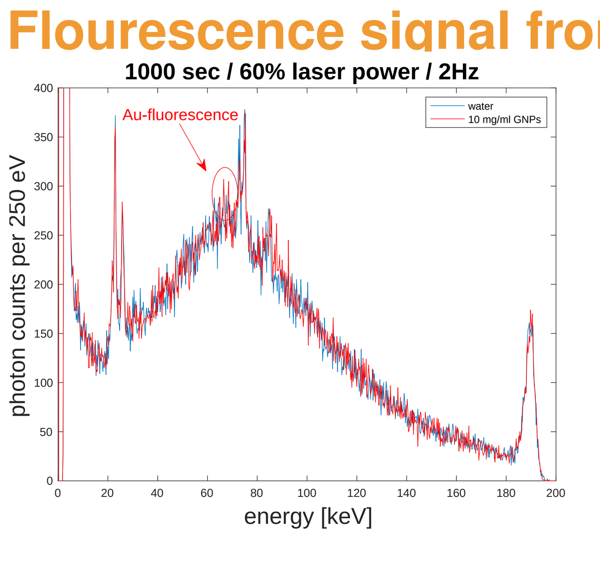

Figure 13: *XFI signal and background, showing clear signal*

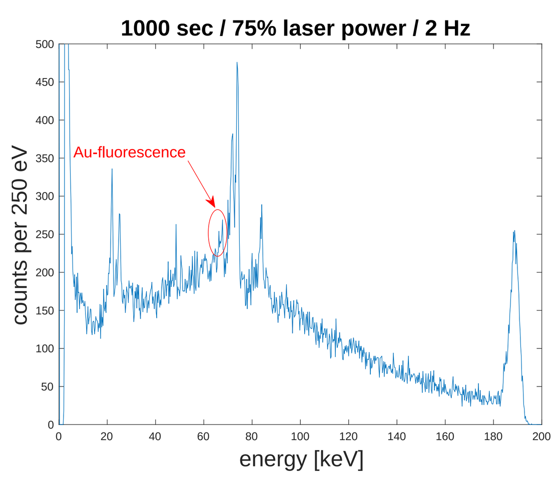

Figure 14: *XFI signal measured with 18 mg gold concentration*

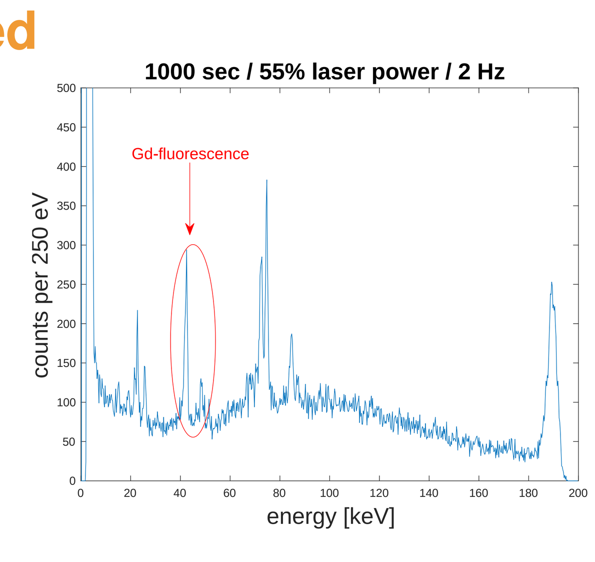

Figure 15: *XFI signal measured with 78 mg gadolinium concentration*

Using the Hexitec detector [10, 11]: 0.8 keV energy resolution, 80×80, $1 \times 0.25 \times 0.25$ mm pixels, kindly loaned from CLF.

Summary and future

Experimental campaign underway towards proof-of-principle XFI experiments

Milestones reached

- Differential pumping setup for 10 Hz gas-jet operation
- Stable, reliable electron beam source commissioned
- First XFI signal from all-optical X-Ray source measured
- Plasma lenses relax requirements on electron beam energy spread for XFI

Next steps:

- Installing and commissioning APL into Thomson source
- Demonstrate X-Ray spectrum filtering with APL
- Pushing for system-wide 10 Hz operation
- XFI measurements of medical samples

References

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PLASMED-X project

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES
Universität Hamburg
DESY.
Bundesministerium für Bildung und Forschung
HZDR Helmholtz Zentrum Dresden Rossendorf
KIT Karlsruher Institut für Technologie
Technische Universität Berlin
HelmholtzZentrum münchen Deutsches Forschungszentrum für Gesundheit und Umwelt