X-ray phase contrast imaging applied to laser driven shocks

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Summary

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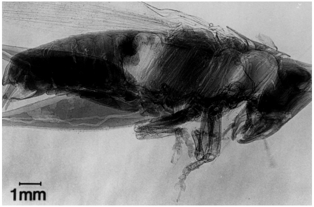
Refractive Index:

The refractive index is defined as:

$$n = 1 - \delta - i\beta$$

β: Absorption

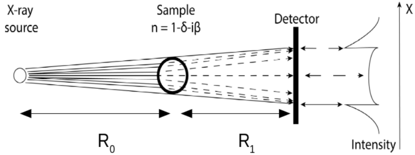


δ: Phase shifting

Absorption is sensitive to the density while phase-contrast is sensitive to the density variations.

F. Arfelli, et al.,Physics in Medicine & Biology 43, 28452852 (1998)

XPCI: propagation-based imaging (PBI)



$$I_{PBI} = M^{-2} I_0 T \left(\frac{\lambda d}{2\pi} \nabla_{\perp}^{2} \phi \right) \quad (1)$$

$$\phi = \frac{2\pi}{\lambda} \int \delta(z) dz, \delta \propto n_e \quad (2)$$

$$l_t \approx \frac{R_0 \lambda}{s} \quad (3)$$

T: transmission M: magnification λ: wavelength d: defocusing distance R_0: source-sample distance s: source size

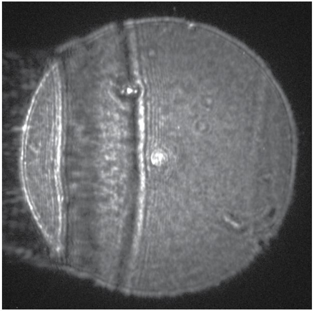
P.C. Diemoz, et al., Optic Express 20, 27902805 (2011)

Xizeng Wu and Hong Liu, Journal of X-Ray Science and Technology, 11, 3342 (2003)

XPCI for warm dense matter

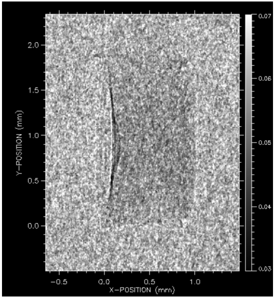
X-ray Phase-Contrast Imaging and application in HED physics
XPCI experiment at GSI
XPCI vs Absorption
Code development
Conclusion

Some experiments using XPCI to invetigate warm dense matter were performed at Linear Coherent Light Source (SLAC)[1]and at Trident laser facility[2]:



XFEL as backlighter

A. Schropp, et al., Scientific reports 5, 11089 (2015)



Laser as backlighter

J. Workman, et al., Review of scientific instruments 81, 10E520 (2010)

XPCI for large class laser facility

What we need:

- Bright laser-induced X-ray sources
- Carefully design of the experiment (development of the simulation tool to design and analysis)
- A proof of princile on medium laser facility

What we have done:

- Developed a specific code to compute XPCI (and absorption radiography)
- Designed a proof of principle experiment proposed, approved and perfomed at GSI in Germany
- Validated the code and the diagnostic technique

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Petawatt High-Energy Laser for Heavy Ion EXperiments (PHELiX):

PHELIX

Long Pulse:

$\tau \sim 1 - 10$ ns

E ~ 0.3 - 1 kJ

I ~ 10^{16} W/cm^2

Short Pulse:

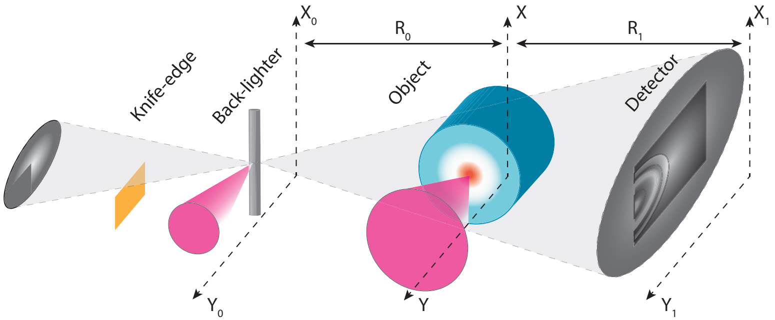
T ~ 0.5 - 20 ps

E ~ 200 J

I ~ 2 x 10^{21} W/cm^2

Combination of short and long pulse allows only 25 J per beam

Experimental setup



Short pulse:

- $\lambda[\mu\text{m}]$: 1
- E[J]: 25
- τ[ps]: 0.5
- *width*[μ]: 5

Source:

- R_0[cm]: 27
- R_1[cm]: 94
- $width_x[\mu\text{m}]$: 30
- $width_y[\mu\text{m}]$: 5

Long pulse:

- $\lambda[\mu\text{m}]$: 1
- E[J]: 25
- τ[ps]: 2000
- *width*[μ]: 50

Diagnostics

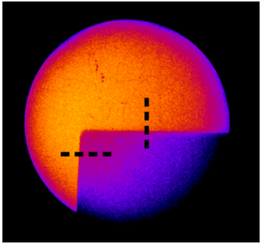
Primary diagnostics:

- X-ray phase-contrast imaging

Secondary diagnostics:

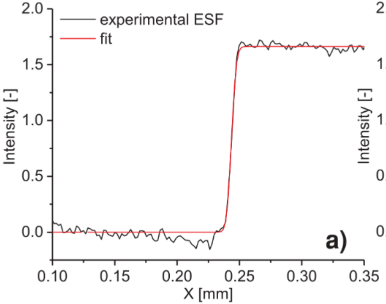
- Knife edge
- Bremsstrahlung cannon
- HOPG crystal spectrometer

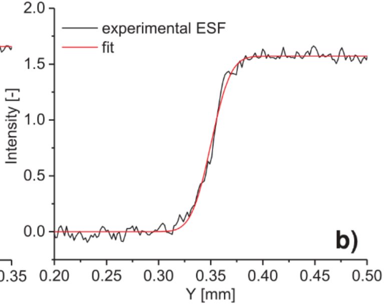
X-ray source



Source characteristics:

- Backlighter: Tungsten
- Horizontal dimension: 5 µm
- Vertical dimension: 30 µm
- Bremsstrahlung emission until 15 keV
- L-shell emission between 8 and 9 keV





Static object:

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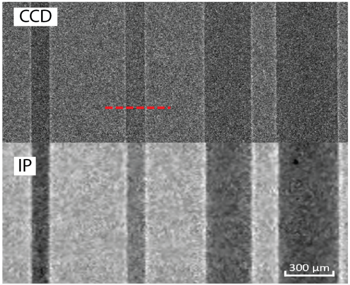
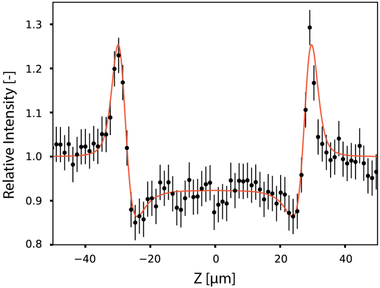
We performed a first test using a static object, a nylon wire:



a)

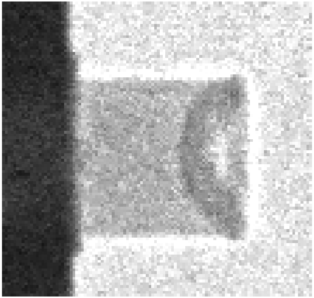


b)

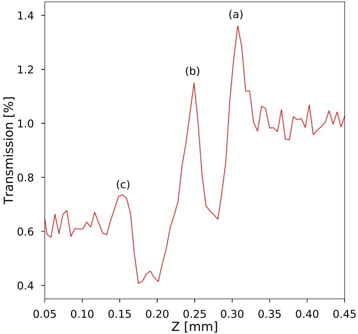
Good signal in a single shot.
Agreement between simulation and experimental data.

Shock-waves

Shock-wave generated at $5 \times 10^{14}\ Wcm^{-2}$
Delay between laser pulses 8 ns



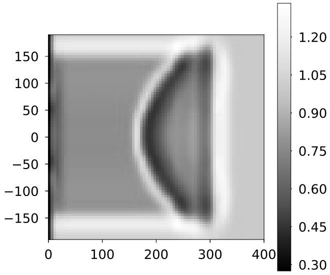
Experimental image



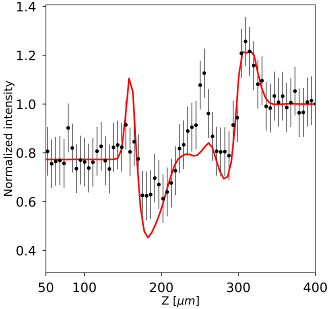
Experimental profile on axis

Simulation: nominal parameters (1)

Hydodynamic simulations at nominal parameters were performed using the code DUED.

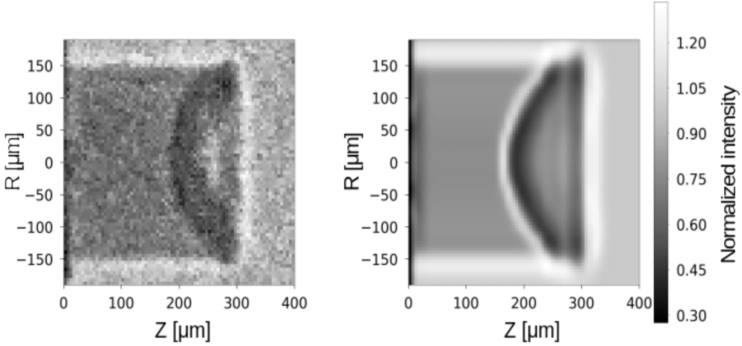


DUED simulation + phase-contrast module



Experimental profile on axis (black dots) and numerical profile (red line)

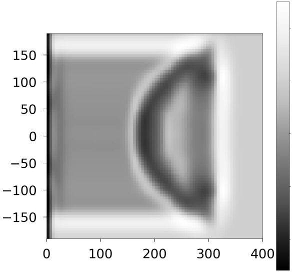
Simulation: nominal parameters (2)



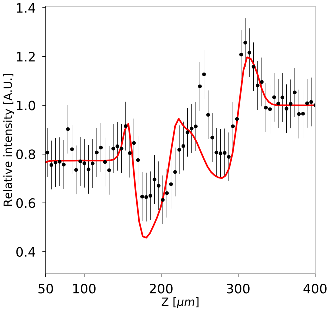
The experimental data are not well reproduced by the simulation.

Simulation: reduced focal spot (1)

Assuming he presence of spikes we tried a much smaller focal spot:

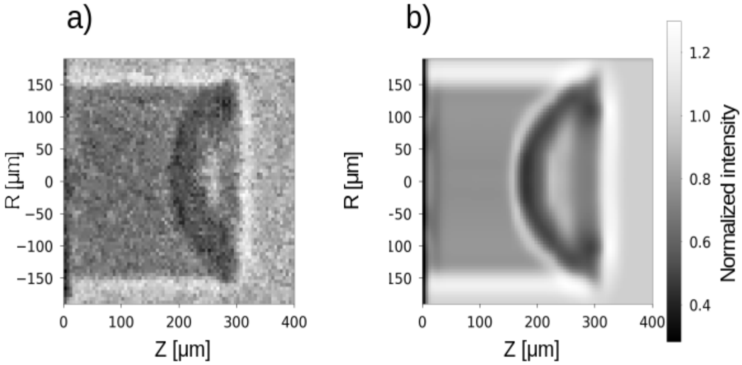


DUED simulation + phase-contrast module



Experimental profile on axis (black dots) and numerical profile (red line)

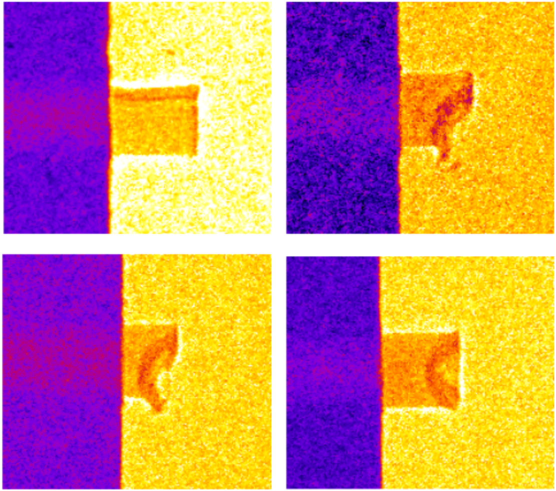
Simulation: reduced focal spot (2)



A better agreement, however a precise knowledge of the focal spot is required.

More shots

It is also interesting have a look on the 'failed' shots:



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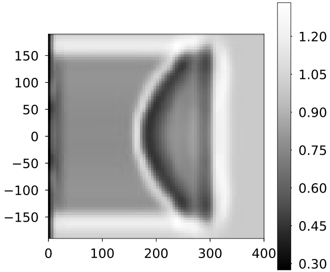
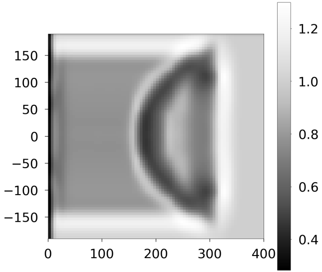
Absorption radiography vs XPCI (1)

Comparison between the numerical XPCI image with large and small focal spot.



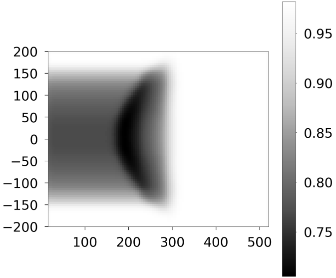
Large focal spot



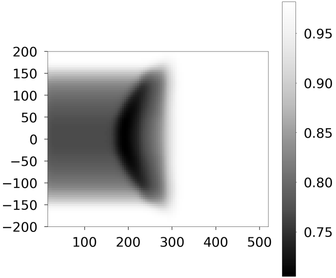
Small focal spot

Absorption radiography vs XPCI (2)

Comparison between the numerical absorption radiography image with large and small focal spot.



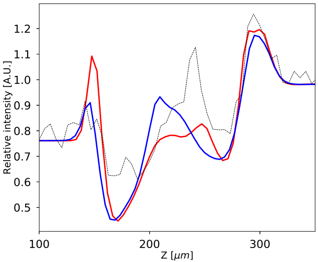
Large focal spot



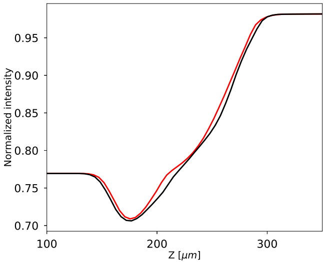
Small focal spot

Absorption radiography vs XPCI (3)

Comparison between the numerical intensity profiles on axis of numerical XPCI and absorption radiography.



XPCI



Absorption radiography

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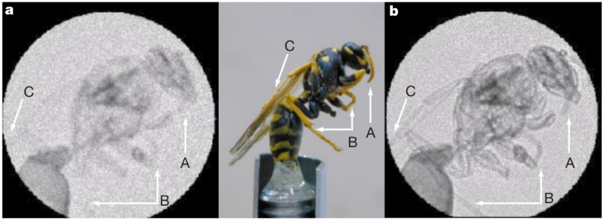
Developments

We are currently developing new functions:

- Inverting the XPCI intensity map to obtain directly a 2D density map
- Working in a full 3D space without any symmetry
- Working with neutrons



B. E. Allman, et al., Nature brief communications, 408, 158–159 (2000)

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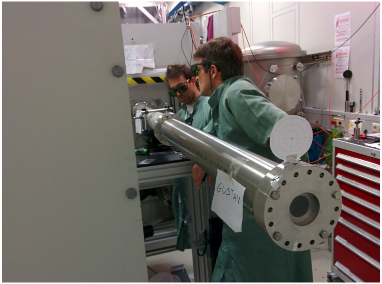
Conclusion

- We developed a code capable to predict XPCI starting from hydrosimulations
- We succeeded on a first proof-of-principle experiment to test XPCI using laser-produced X-ray source.
- We proved that XPCI can be successfully used in many of existing facilities where a short pulse is available.
- Due to its intrinsic sensitivity XPCI can be applied in different experiments. Different densities can be simultaneously probed

Thank you for the attention!



This work is available on arXiv:
https://arxiv.org/abs/1801.10049