Phase Contrast Imaging @ ATF

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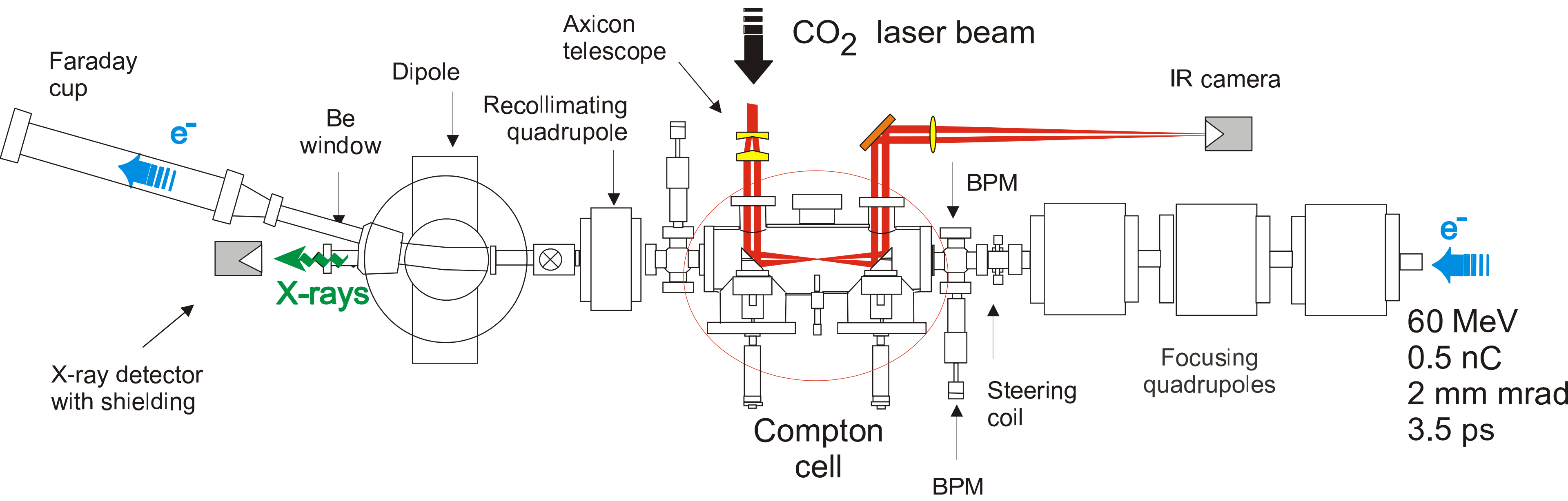
ATF Inverse Compton Source

BNL/INFN/UCLA collaboration goals:

- To study the fundamental physical property of the ICS x-ray beam
- Ultra-fast material probing
- To investigate the potential imaging applications of ICS x-ray source

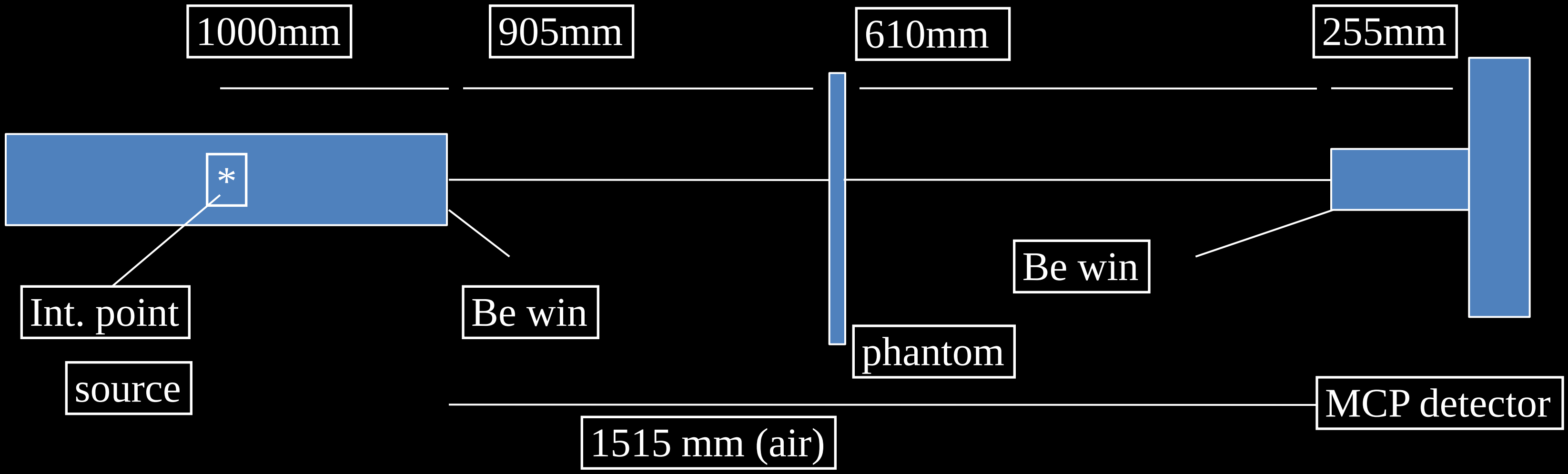
Layout of the ICS at BNL ATF



Slide from Vitaly talk at the Alghero workshop

MEASUREMENTS AT ATF

First run (December 2008)

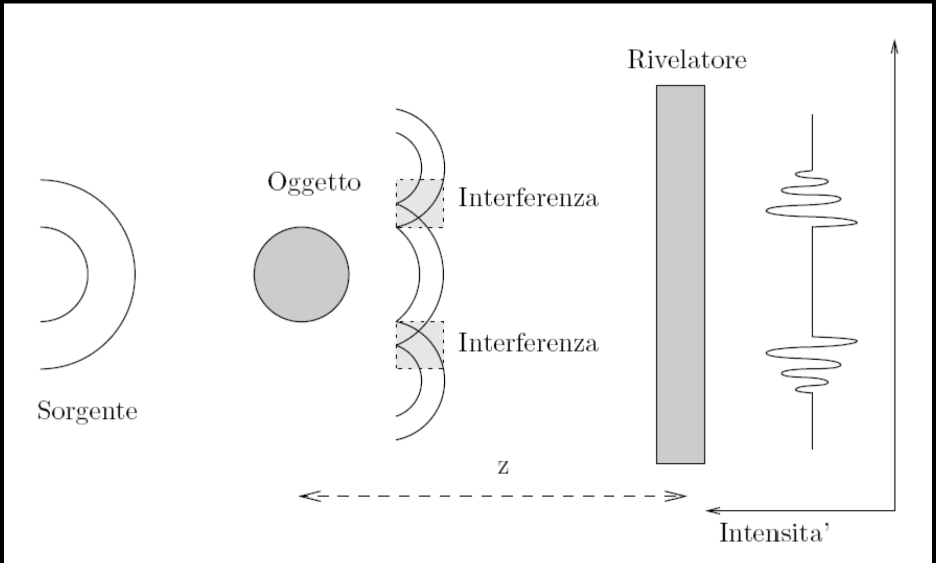


Past activities

- December 2008: first "preliminary" run
- March 2009: approval by the ATF Program Advisory Committee
- October 2009: run for phase contrast imaging (mean Energy = 10.8 keV)
- April 2010: data analysis completed
- September 2010 paper published by Applied Physics Letters

INLINE PHASE CONTRAST

Free space propagation (in-line) (Snigirev, 1995)



The shifted wave propagates in free space up to the detector.
During propagation, the wavefronts having different phase shift interfere.
This effect is more intense at the border of zones with different refraction index or different thickness

Partially (spatially) coherent beams

- For source-object and object-detector distances of the order of one meter the source size should be ~10 μm
- It can be observed also using polychromatic sources
- The acquisition of a single image is required

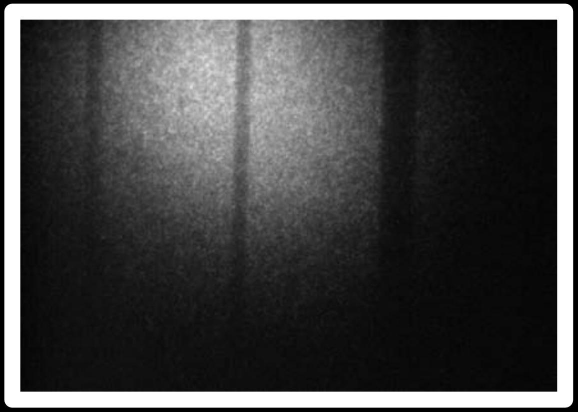
- The visible effect is an edge enhancement in the image

MEASUREMENTS AT ATF

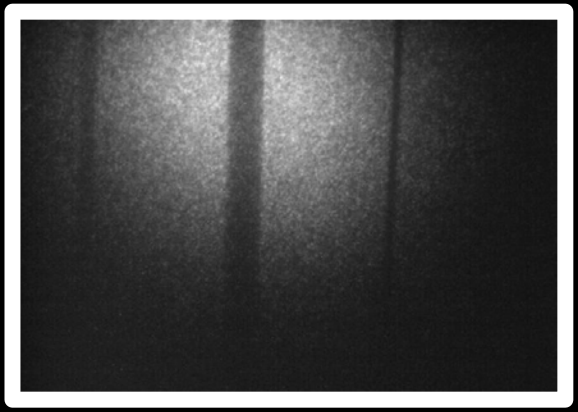
First run (December 2008)

- ICS source: 7 keV, $2*10^7$ photons per shot, shot duration 4 ps, spot size 50 micron, divergence 7-8 mrad
- Detector: MCP, pixel size 40 micron, PSF > 200 micron, efficiency ~1%
- Phantoms: Mo edge, plastic wires

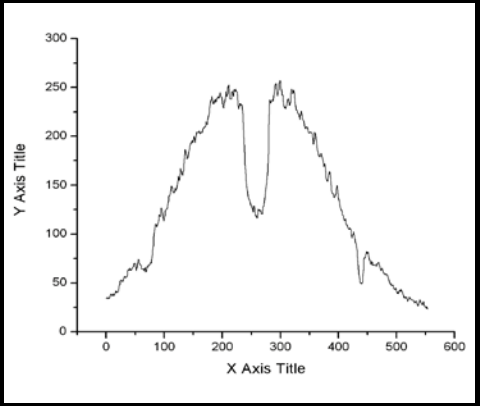
Single shot
PET wire, 500 micron of diameter



Average on 20 shots
PET wire, 500 micron of diameter



Average on 20 shots
PMMA wire, 1mm of diameter



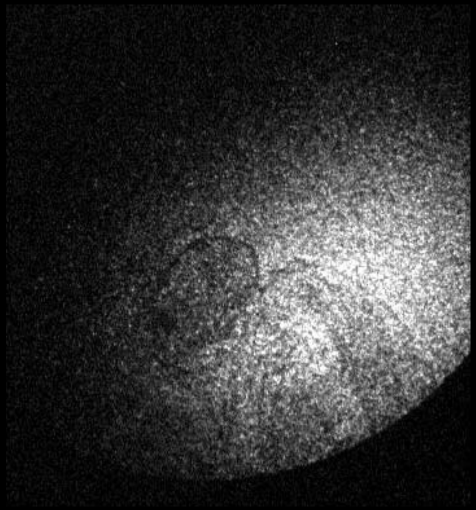
Profile of PMMA wire

We decided to increase beam energy and use a different detector

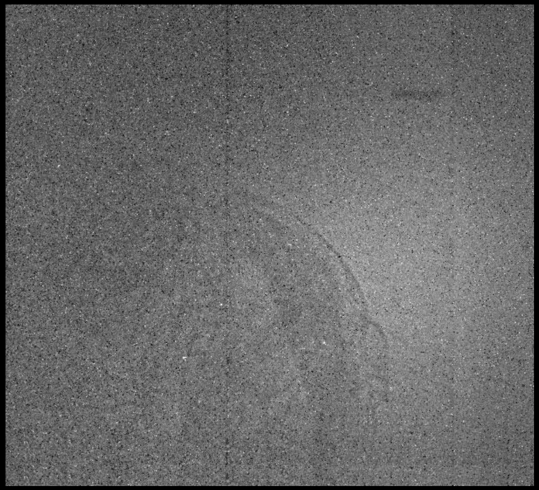
COMPARISON OF DETECTORS

Second run (October 2009)

Beam energy 11 keV



MCP detector



PPS CMOS
(Si direct detection)

APS CMOS +
CsI scintillator

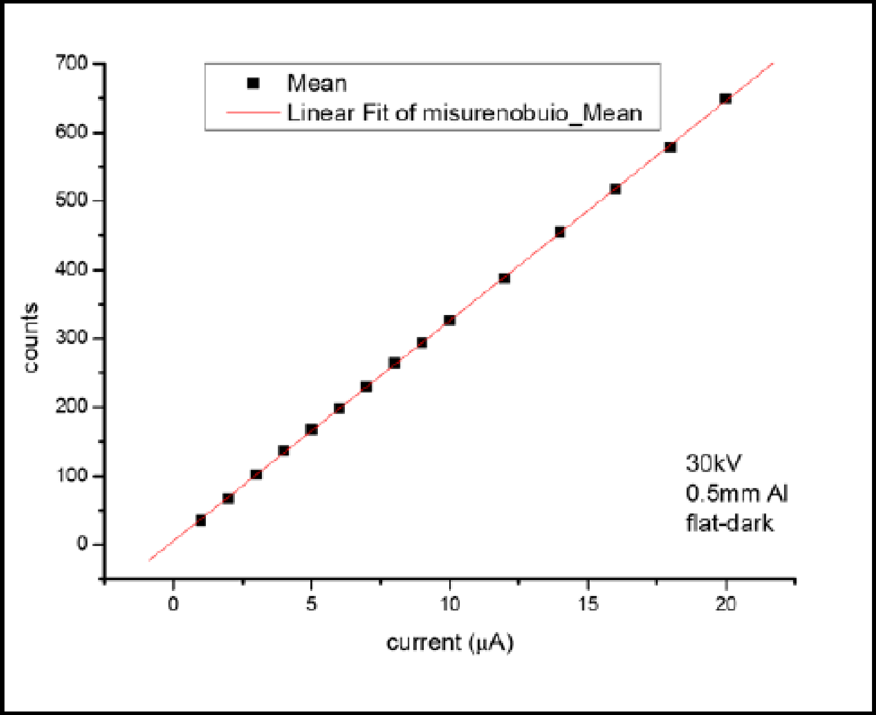
CMOS APS DETECTOR

The detector used is a flat panel (Hamamatsu C9728DK − 10) based on a CMOS sensor coupled to a scintillator (CsI).

- Active pixels readout
- Low noise: 80 electrons
- 1032 × 1032 pixels (50 μm pitch)
- High resolution
- 14-bit digital output

CHARACTERIZATION OF THE CMOS

Linearity



Linearity verified by means of an X-ray tube

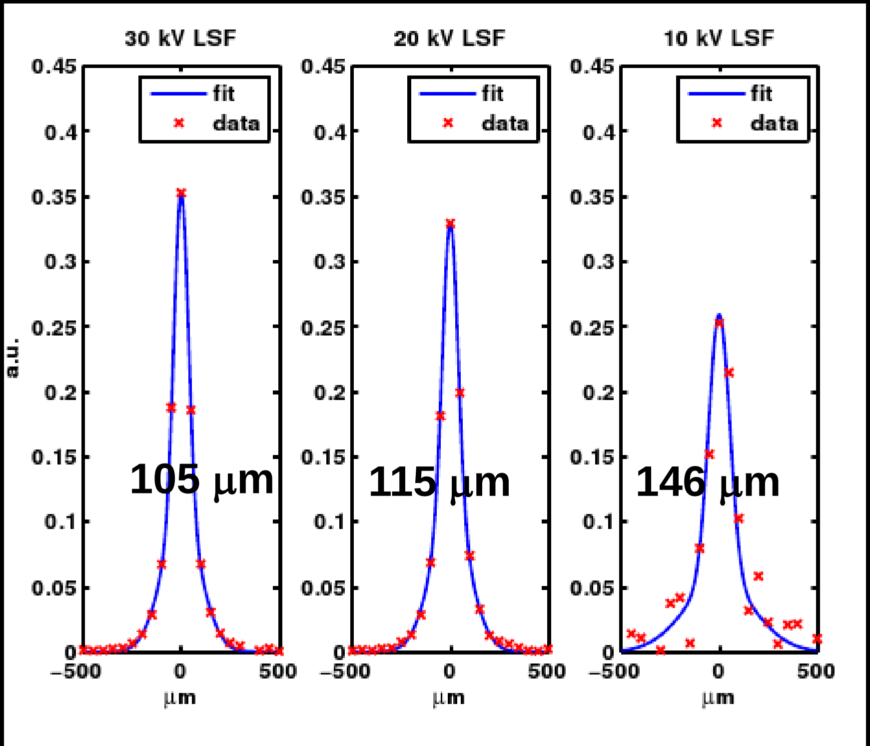
By varying the anodic current, uniformly exposed images have been acquired.

Average detector counts plotted against tube current

Procedure repeated for different spectral distributions of the x-rays

CHARACTERIZATION OF THE CMOS

Resolution Function
(quoting the FWHM)



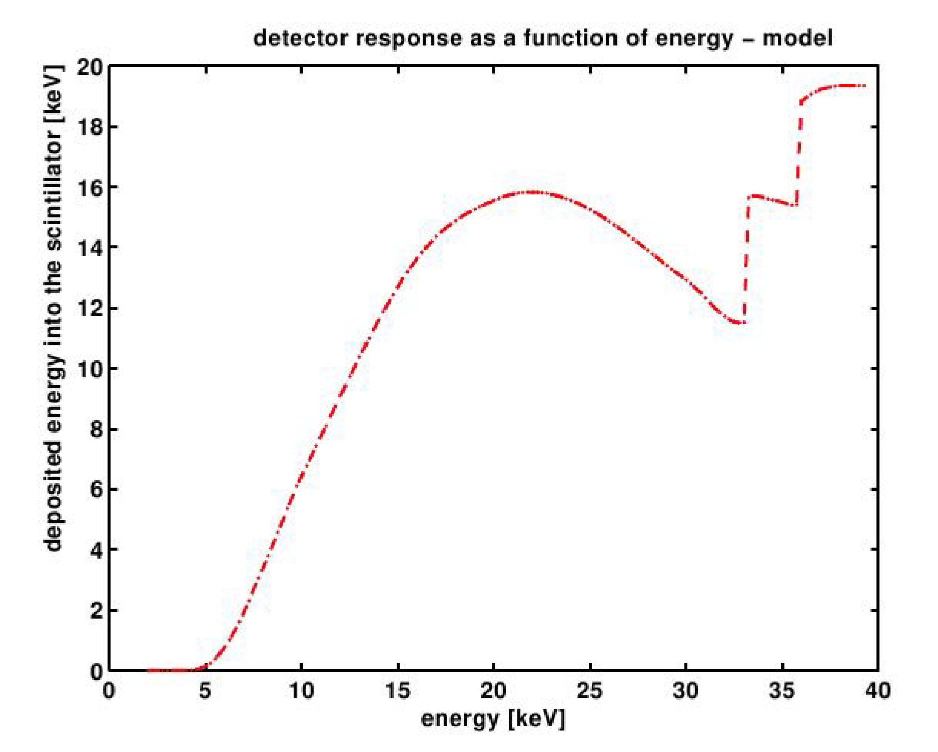
Resolution function measured by means of the Edge Response Function

Acquisition of images of a sharp W edge

The derivative of an image profile perpendicular to the edge is called Line Spread Function (LSF)

CHARACTERIZATION OF THE CMOS

Detector modeling



The detector response is modeled taking into account:

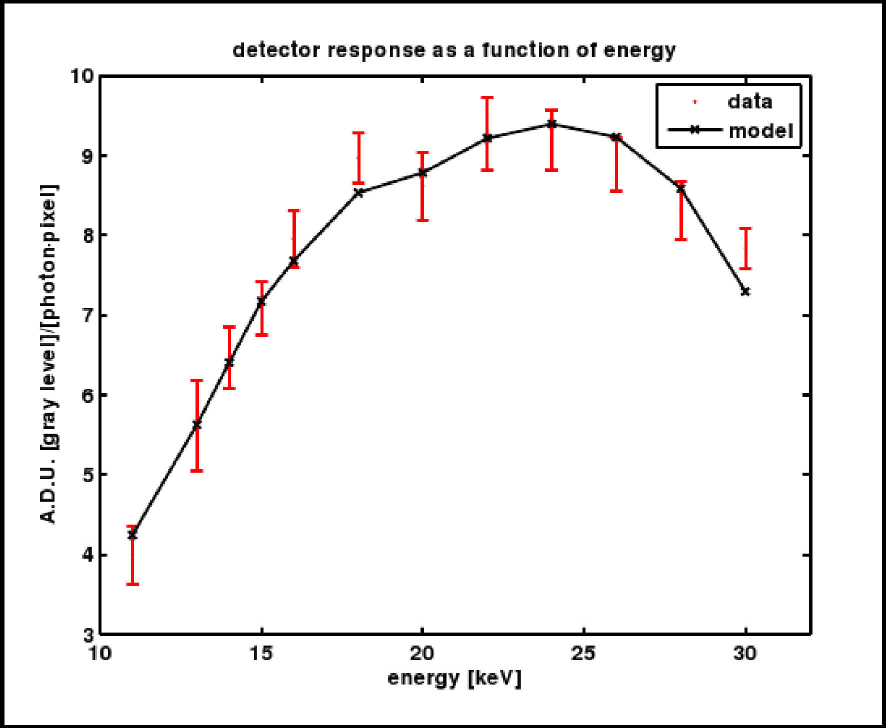
- the attenuation coefficient μ_{carb} of the graphite cover (of thickness Δ)
- the energy absorption coefficient μ_{en} of the τ-thick CsI scintillator
- the spectral distribution $\chi(E)$ of the x-rays (from experimental data or catalog)

a is a constant that relates the energy released in the CsI with the response of the detector

$$\mathcal{I} = a \int_0^\infty \mathcal{X}(E)(1 - e^{-\mu_{en}\tau})e^{-\mu_{carb}\Delta} dE$$

CHARACTERIZATION OF THE CMOS

Measurements at the Elettra (Trieste) synchrotron



Experimental check of the validity of the model

Experimental measurement of a

Linearity with monochromatic beams

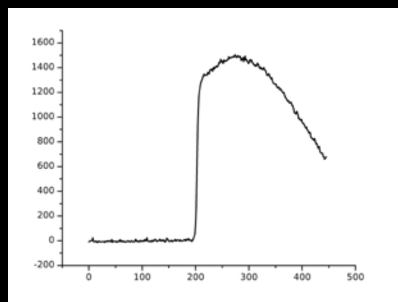
LSF as a function of x-ray energy (under investigation)

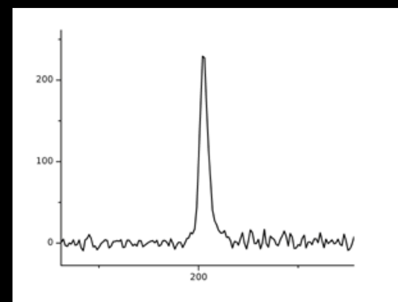
Noise as a function of x-ray energy and intensity (under investigation)

Edge Response Function at ATF

Second run (October 2009)

- Spot size





$$F_{img}^2 = F_{\det}^2 + (F_{sour} * M)^2$$

M=(z2-z1)/z1=2.1

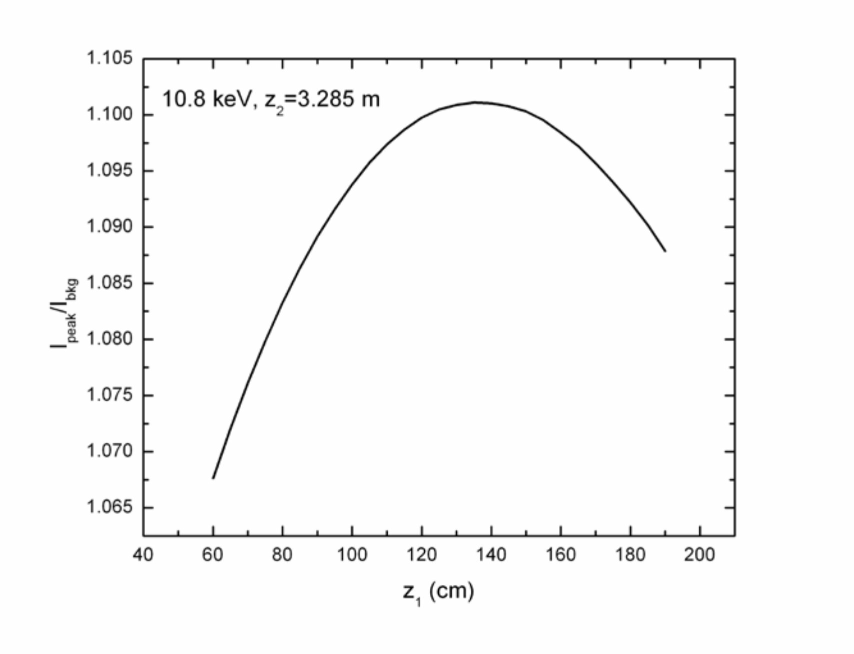
FWHM=90 μm

σ ~ 38 μm

- He Pipe added
- 10^7~10^8 ph/shot
- Energy 10.8 keV

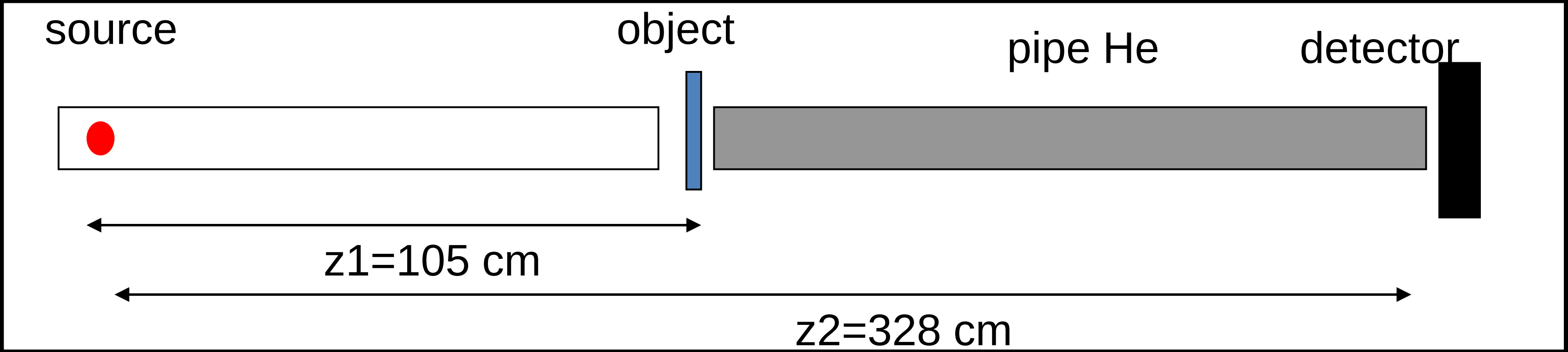
DEFINITION OF THE OPTIMAL CONFIGURATION

The optimal source-object distance (z1) was defined by means of simulations, searching for a maximum in the phase contrast signal.



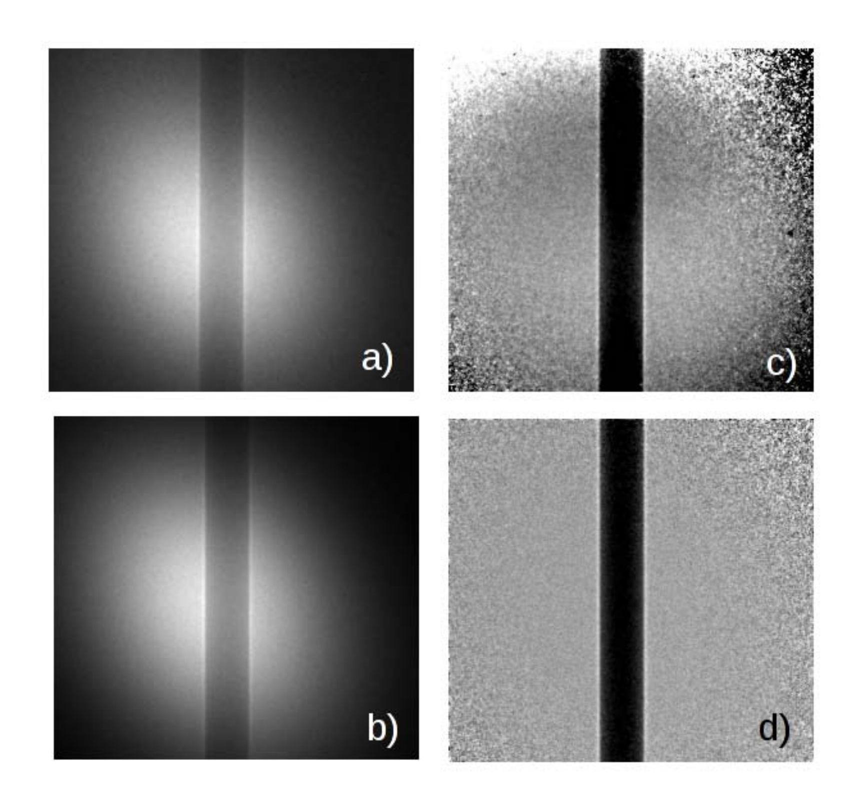
The simulation takes into account:

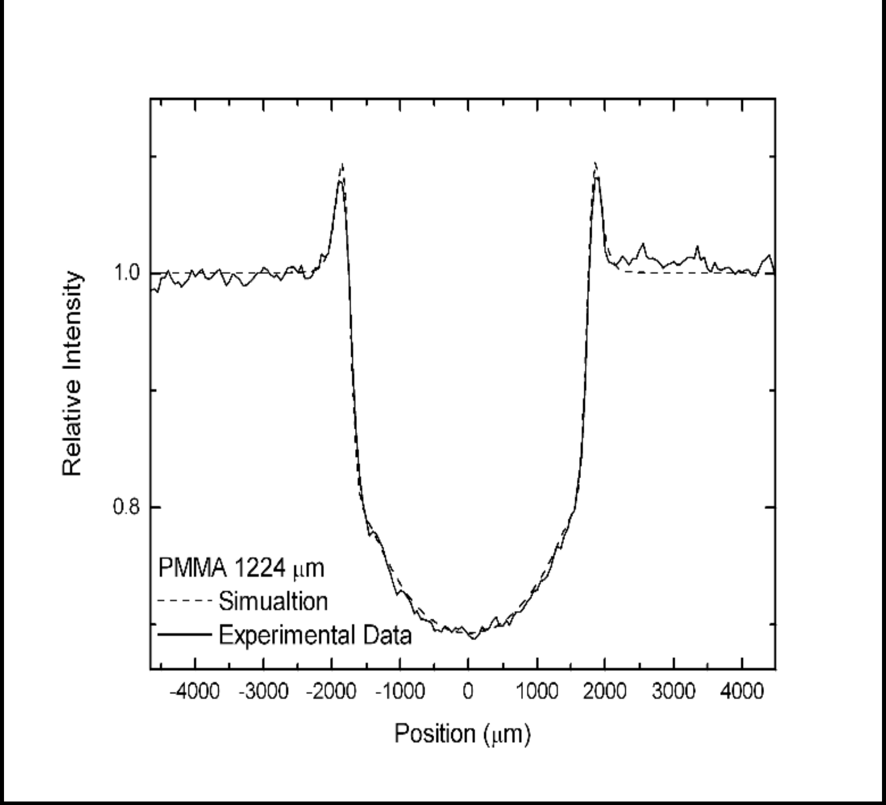
- LSF of the detector
- Source size
- Maximum source-detector distance
- Number of photons/shot



WIRE IMAGES

SINGLE SHOT IMAGES (pulse 4ps; Integration time 5 s) APL Vol. 97.Issue 13



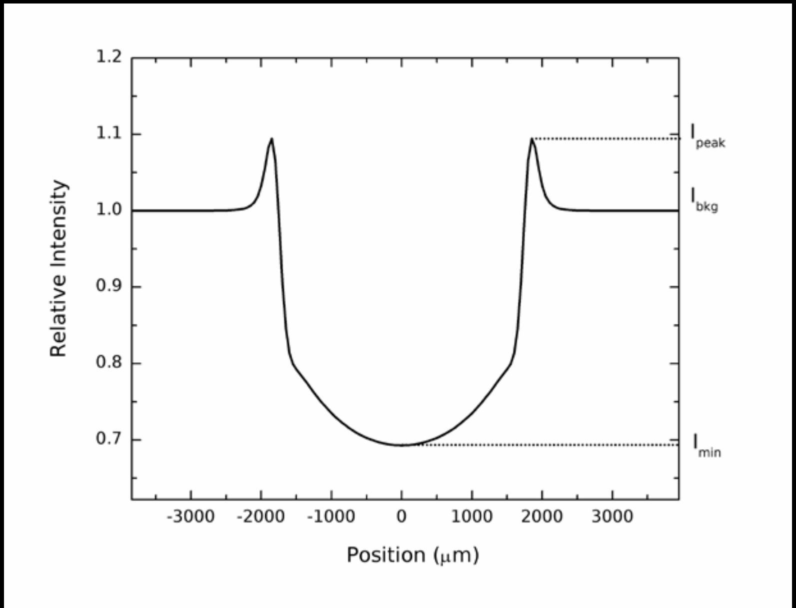


a)c) data, b) d) simulation;
a) b) raw data c) d) data normalized to intensity distribution (outside the wire)

Second run (October 2009)

COMPARISON WITH SIMULATIONS

Second run (October 2009)



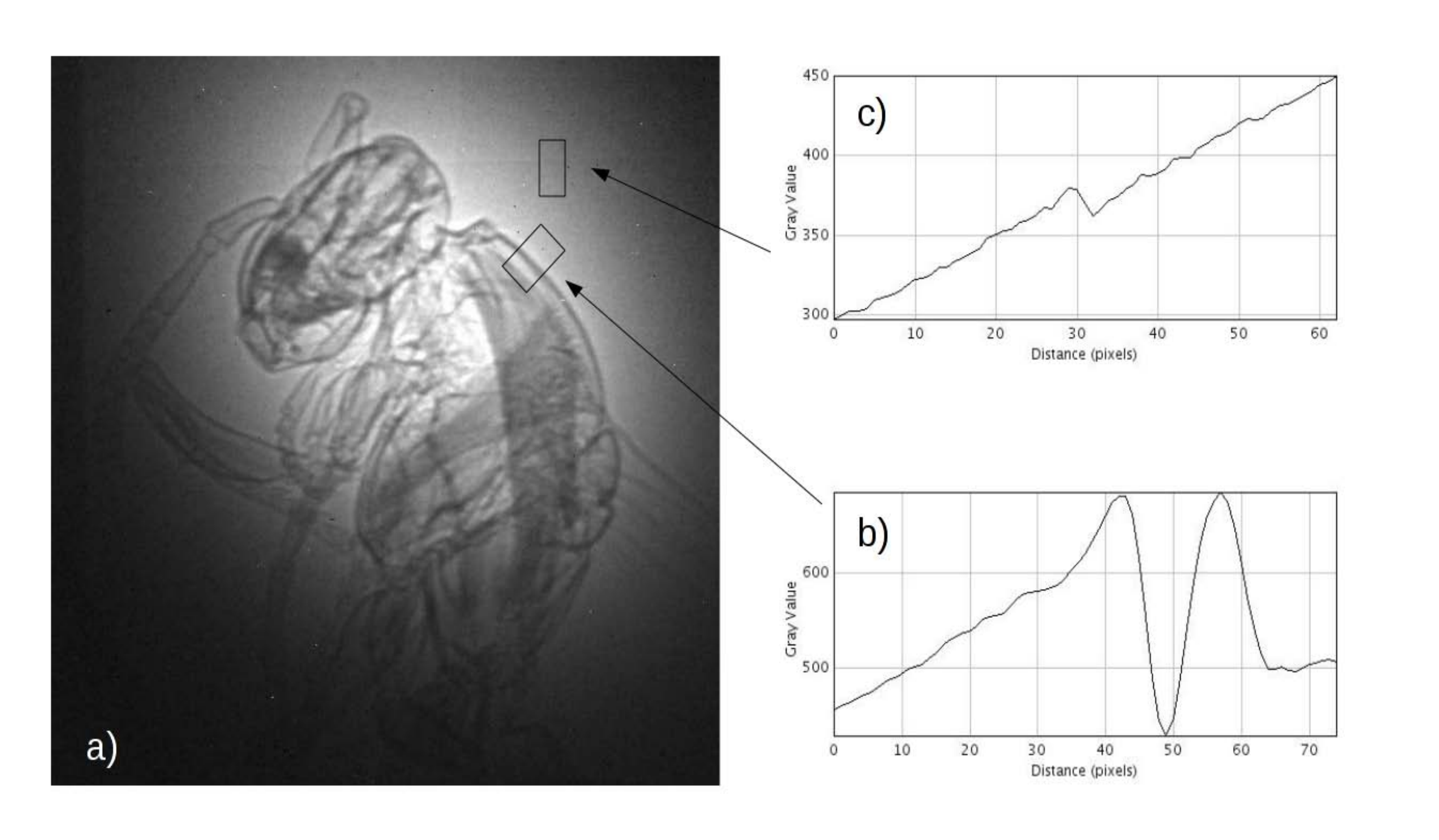
Errors on experimental data ~ 2%

	Experimental data		**Simulated data**	
	I_{peak}/I_{bkg}	I_{peak}/I_{min}	I_{peak}/I_{bkg}	I_{peak}/I_{min}
PET 107 μm	1.03	1.13	1.04	1.15
Nylon 170 μm	1.04	1.14	1.04	1.13
PET 520 μm	1.06	1.34	1.08	1.33
Nylon 535 μm	1.06	1.25	1.07	1.22
PMMA 1124 μm	1.08	1.57	1.09	1.58

IMAGE OF A BIOLOGICAL SAMPLE

SINGLE SHOT IMAGES

Second run (October 2009)



COMPETITORS

In-line phase-contrast imaging of a biological specimen using a compact laser-Compton scattering-based x-ray source

H. Ikeura-Sekiguchi,[1,a] R. Kuroda,[1] M. Yasumoto,[1] H. Toyokawa,[1] M. Koike,[1] K. Yamada,[1] F. Sakai,[2] K. Mori,[3] K. Maruyama,[3,b] H. Oka,[4] and T. Kimata[4]
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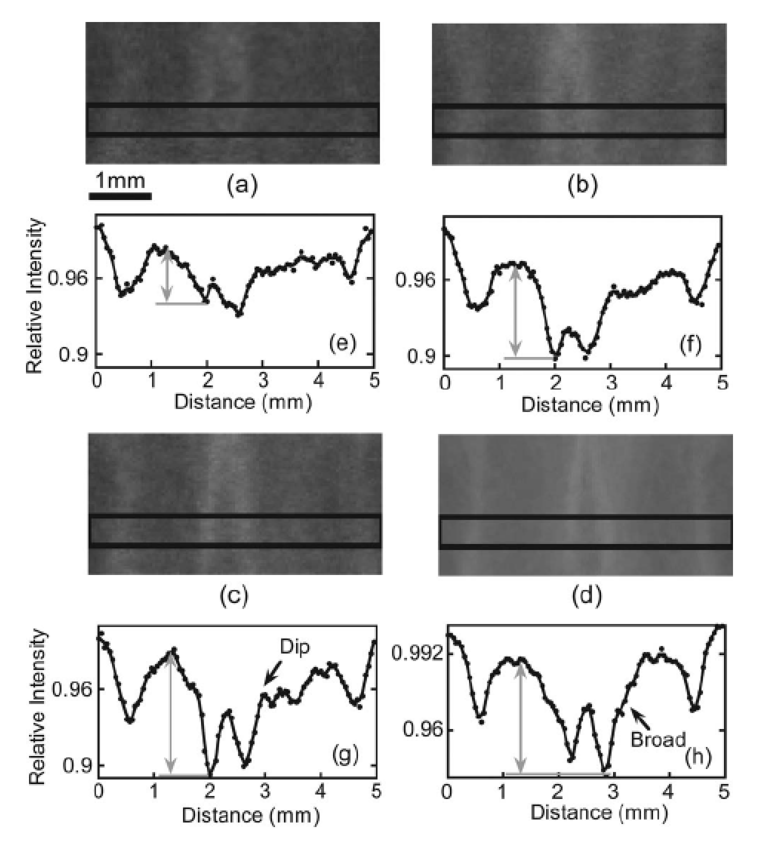
All data were measured using the x-ray energy of 30 keV with **18 000 shots** of pulsed x rays. The total integrated exposure time was **54 ns** and the total elapsed time was **1800 s**.



COMPETITORS

Journal of
Synchrotron
Radiation
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Hard X-ray phase-contrast imaging with the Compact Light Source based on inverse Compton X-rays

Received 6 September 2008
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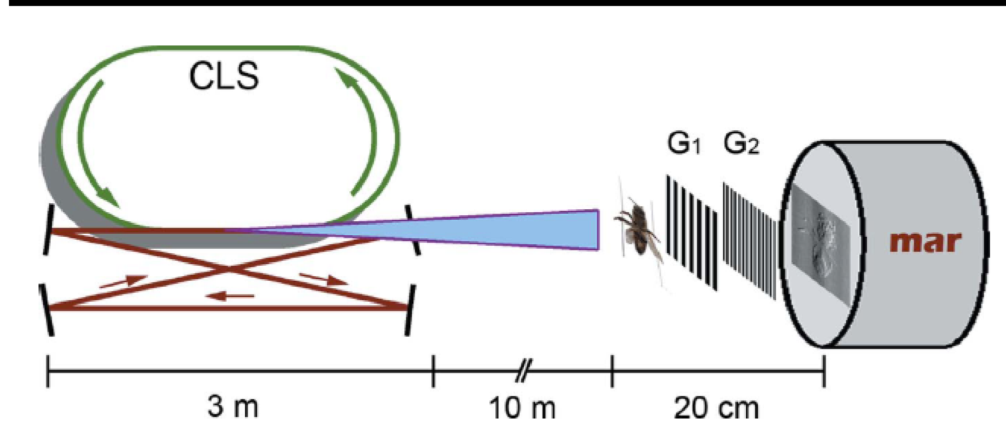
Martin Bech,[a*] Oliver Bunk,[b] Christian David,[b] Ronald Ruth,[c,d] Jeff Rifkin,[c] Rod Loewen,[c] Robert Feidenhans'l[a] and Franz Pfeiffer[b,e*]

Each image was recorded with an exposure time of 100 s, hence the total exposure time was 900 s per data set.



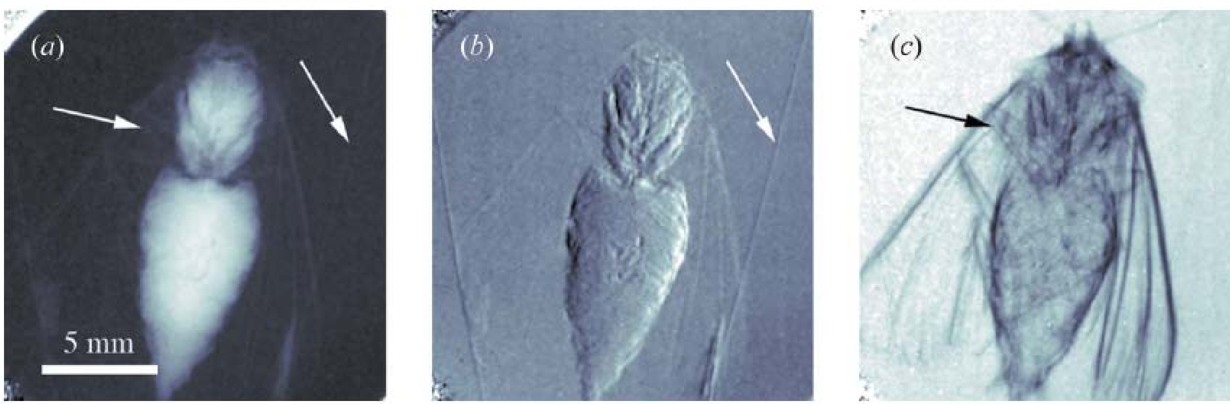


Figure 3
Three types of image contrast of a moth after data processing. (*a*) Standard absorption-contrast image. (*b*) Differential phase-contrast image. (*c*) Dark-field image. All three images are obtained from the same data set. Arrows indicate regions where the phase-contrast and dark-field images reveal details not visible on the standard X-ray image.

CONCLUSIONS ON SINGLE-SHOT PHC IMAGING

- We have investigated the feasibility of single-shot inline phase contrast imaging with the ATF ICS X-ray source.

- The PhC in the images is clearly visible.

- The experimental data are in agreement with simulations within the experimental errors.

- Images on a biological sample were obtained, showing the potential imaging applications of this state-of-the-art ICS source and opening a new frontier for a time-resolved imaging on a very short time scale