First OMEGA Laser Facility User's Group Workshop

29 April to 1 May 2009, Rochester, New York

Poster Session I – 1:30 pm-3:45 pm Wednesday 4/29/2009

HIPER DIAGNOSTICS DEVELOPMENT: A NOVEL, SPECTRALLY RESOLVED X-RAY IMAGING TECHNIQUE

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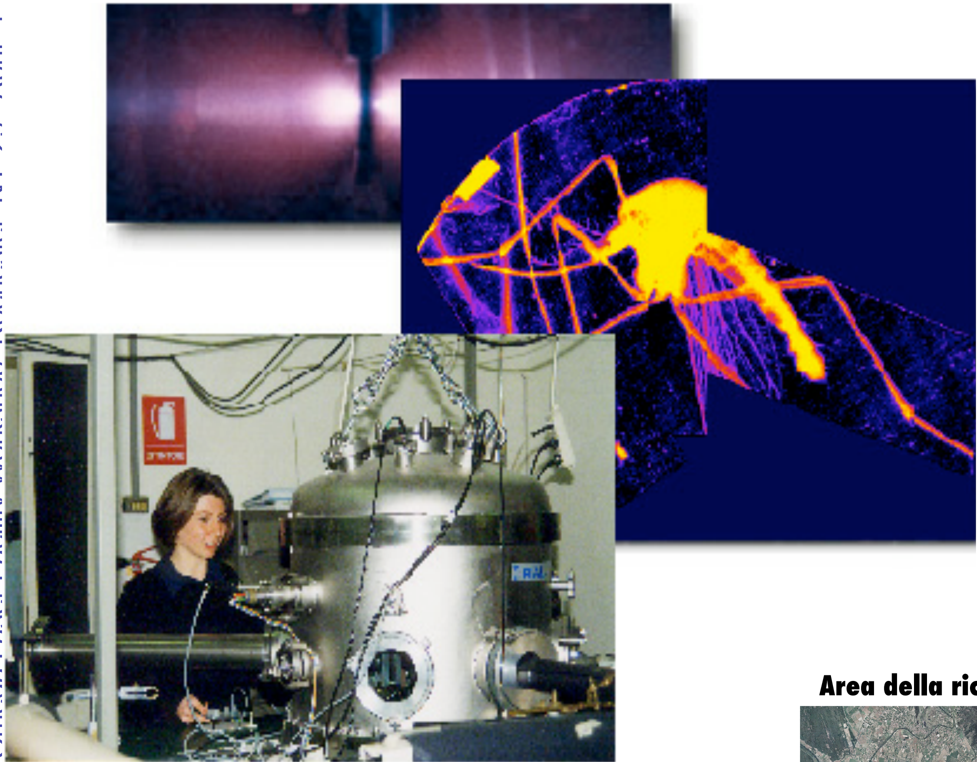
c) *Univ. Milano Bicocca, Milano, Italy*
d) IOQ, Univ. Jena, Germany
e) *PALS Laser Centre, Chech Republic*

The ILIL GROUP in Pisa



People

- **Antonio GIULIETTI** (CNR)*
- **Leonida A. GIZZI** (CNR)*
- **Danilo GIULIETTI** (Univ. Pisa & CNR)*
- **Paolo TOMASSINI** (INFN & CNR)
- **Luca LABATE** (CNR)*
- **Carlo A. CECCHETTI** (CNR)
- **Petra KOESTER** (CNR & Univ. of Pisa)
- **Tadzio LEVATO** (CNR & Univ. of Pisa)
- **Andrea GAMUCCI** (CNR & Univ. of Pisa)
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Contents

- Why studying fast electron propagation
- X-ray spectroscopy study: preplasma effect;
- X-ray single-photon detection;
- Monochromatic X-ray imaging: a new technique;
- Latest experimental results;
- Perspectives & Conclusions

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Studying fast electron transport

- The Fast ignition approach to Inertial Fusion Energy requires high current, fast electron beams to propagate efficiently in high solid density collisional plasmas;
- Transient magnetic fields and neutralising plasma return current occur;
- Return current will give rise to resistive thermal heating that will modify the spectral features of X-ray fluorescence;
- Knowledge is needed on the state of the material in which f.e. propagation occurs;
- X-ray spectroscopy if the principal tool for accomplishing this task;

The HiPER project

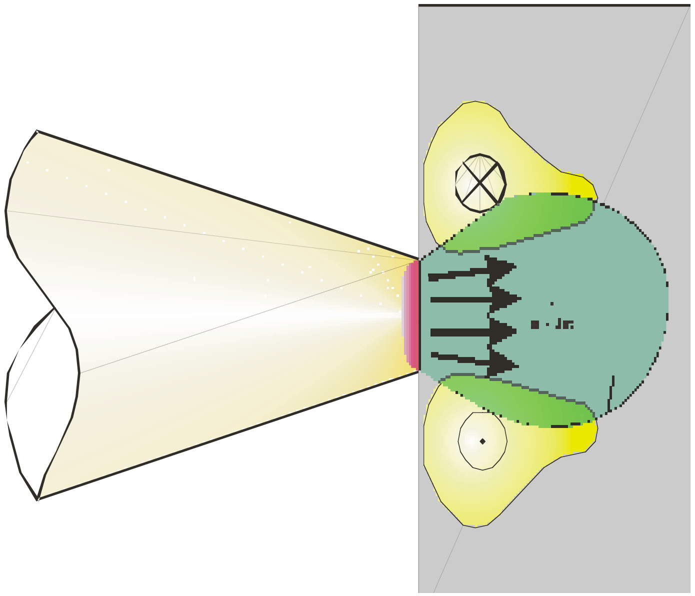
The HiPER project, now well into its preparatory phase, the EU as a European research infrastructures

http://www.hiper-laser.org/

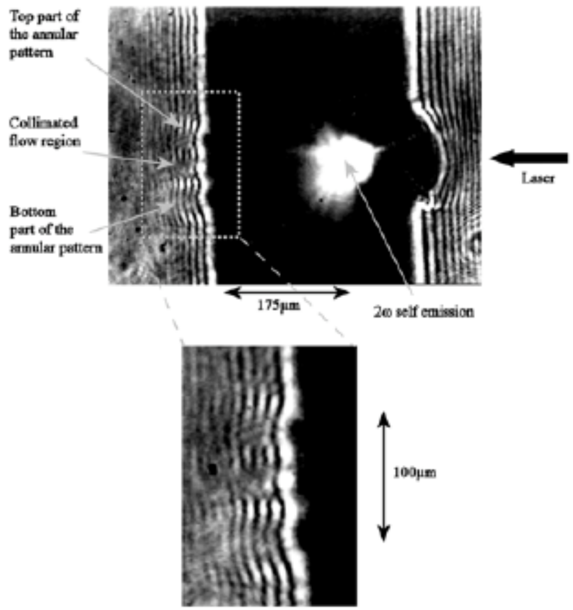
Scenario and motivation

basic ultraintense interactions and fast ignitor physics

- plasmas produced by laser intensities well above 10^{18} W/cm^2
- expected current of several MA



Application in fusion research (fast ignitor)



J.S.Green et al., et al., (2005)

Need to investigate PROPAGATION AND ENERGY DEPOSITION of fast electron beam inside the material

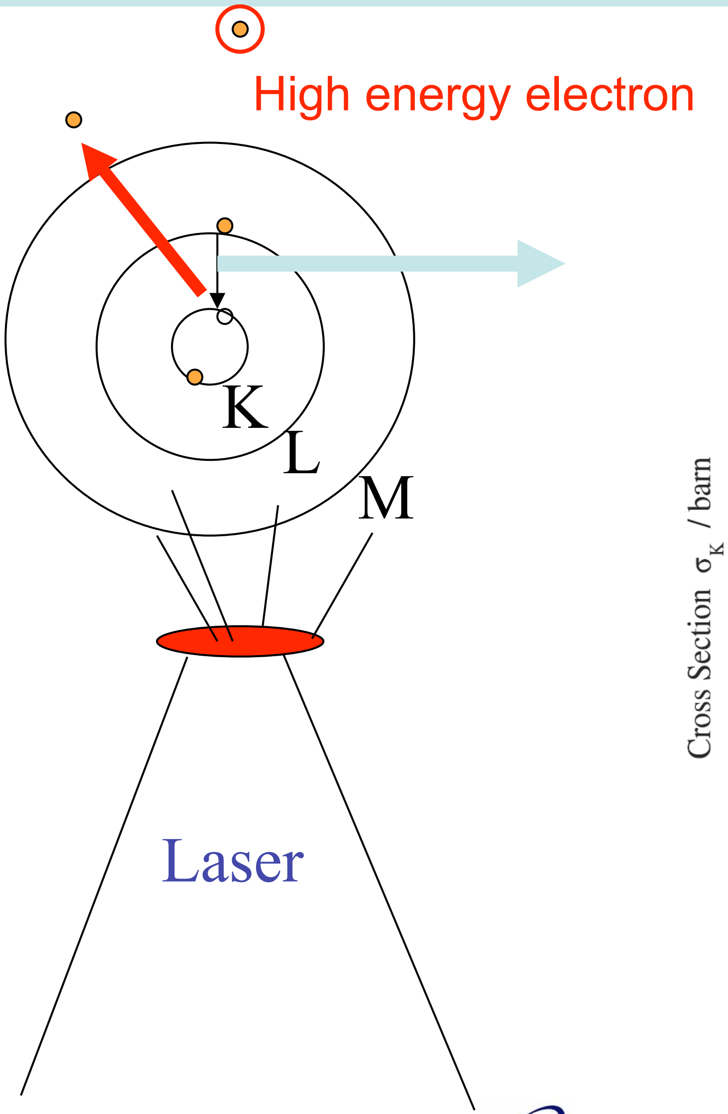
How to investigate f.e. transport

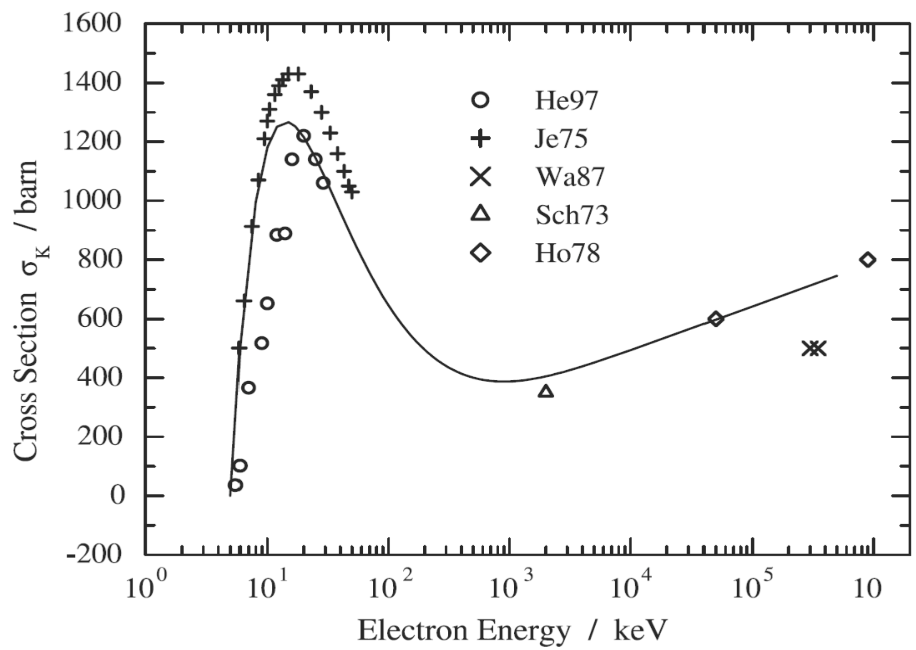
- Knowledge is needed on the applicability of X-ray techniques to f.e. transport studies in extreme conditions (diagnostic development);
- Foil targets can be used to investigate f.e. transport in solids and plasmas through detection of K-α emission;
- X-ray spectroscopy of shifted K-α components can be used to infer the electron temperature of the bulk target and to speculate on the role of refluxing of the fast electron beam at the target rear side;
- transport also plays a role in X-ray yield optimisation studies of laser driven X-ray sources;

Our experimental method

- We use intense and ultraintense laser-foil interaction;
- Optical scattering is used to monitor interaction regime;
- Electron propagation is studied through X-ray fluorescence emission;
- Imaging of X-ray emission is resolved in energy;
- Multi-layer targets are used to follow f.e. propagation;
- Forward-escaping fast electrons are detected and measured (spectrum and angular distribution);

Kα radiation mechanism

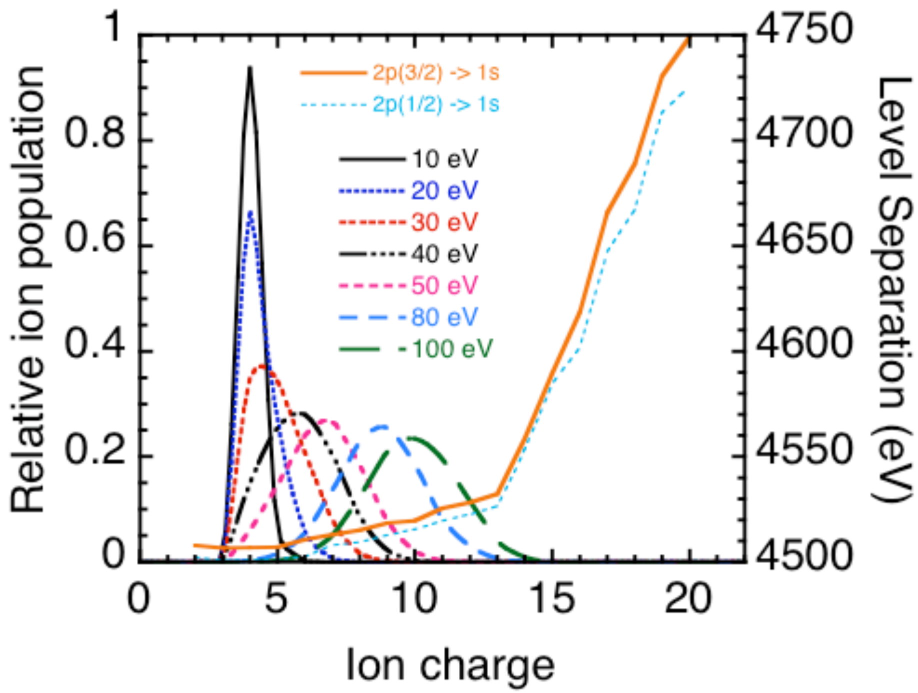




Ewald Europhys Lett Vol.60

CALCULATED ION POPULATION VS. TEMPERATURE

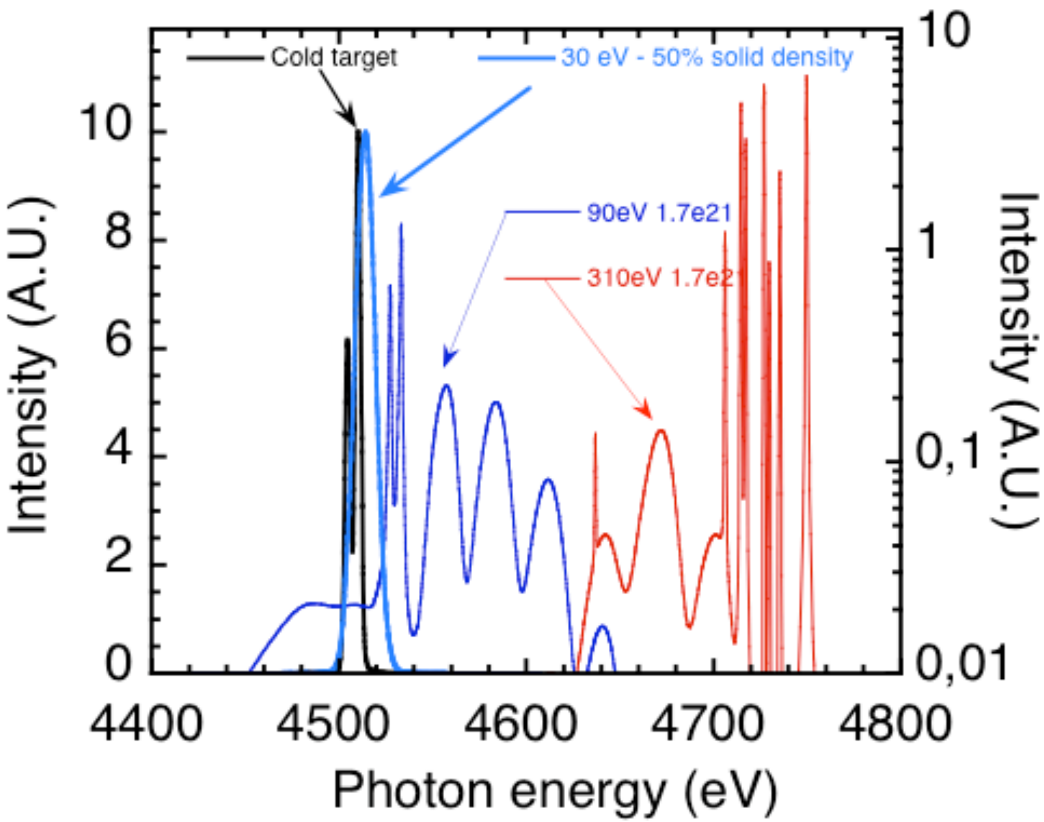
calculated ion population vs. temperature in Ti



Fast electron energy deposition gives rise to local heating in the target substrate. Heating will generate weakly ionised (warm) dense matter.

E. Martinolli et al., PRE, 73(4):046402, Apr 2006.

CALCULATED SPECTRA FROM Ti



Spectra calculated using the kinetic code flychk* for a cold/warm target and for a hot, critical density plasma. K-shell emission components fall in the 4.5 - 4.8 keV range

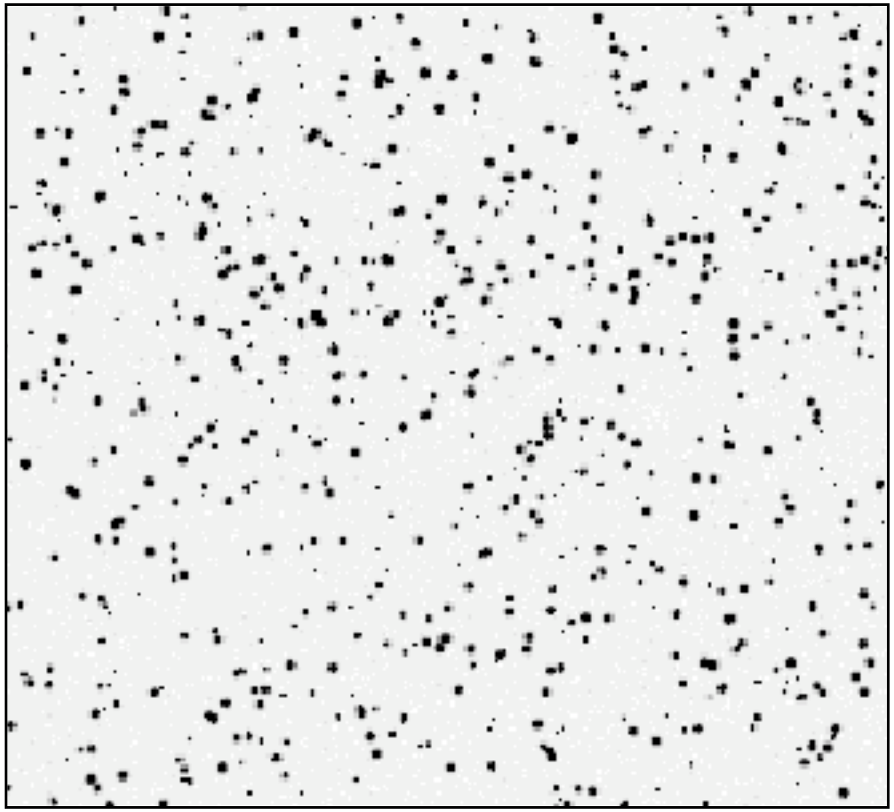
*H.-K. Chung et al., High Energy Density Physics, 1:3–12, 2005.

Space resolved measurements

- Energy resolved imaging is needed to identify regions of X.ray emission characterised by different physical conditions.
- Longitudinal propagation and energy deposition of fast electrons is usually studied by means of targets with a buried layer of a tracing element;
- Crystal imaging with toroidally bent crystals can be used to image out X-ray emission from the tracer layer at a given wavelength;
- Multi layer targets with multi-energy tracing element would provide a detailed f.e. propagation history;
- An extension of the standard pin-hole camera imaging has been used to achieve micrometer-resolution imaging with a few percent resolution in a wide spectral range above 1keV;
- The technique relies of the use of a low-noise CCD detector working in a low photon flux detection regime

Direct X-ray Spectroscopy

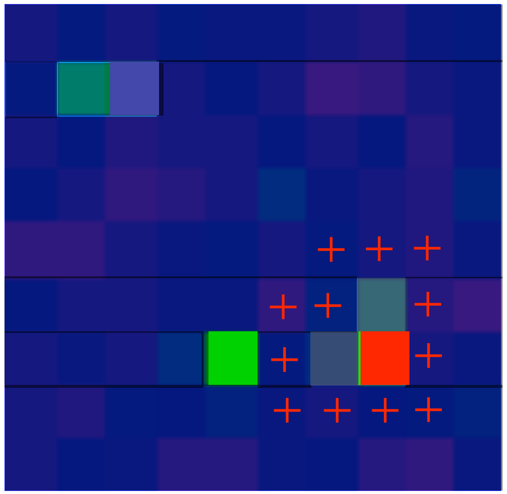
Spectral analysis of X-rays generated by femtosecond laser-plasma interactions is performed by using a low noise CCD array to measure the charge produced by each photon



The X-ray flux incident of the CCD array is controlled to ensure that the average number of photons per pixel is much less than one.

- **The image shows the result obtained with a Peltier cooled, 16 bits ccd array, after exposure to X-rays produced by a single femtosecond laser-target interaction event.**

Algorithm



Event identification

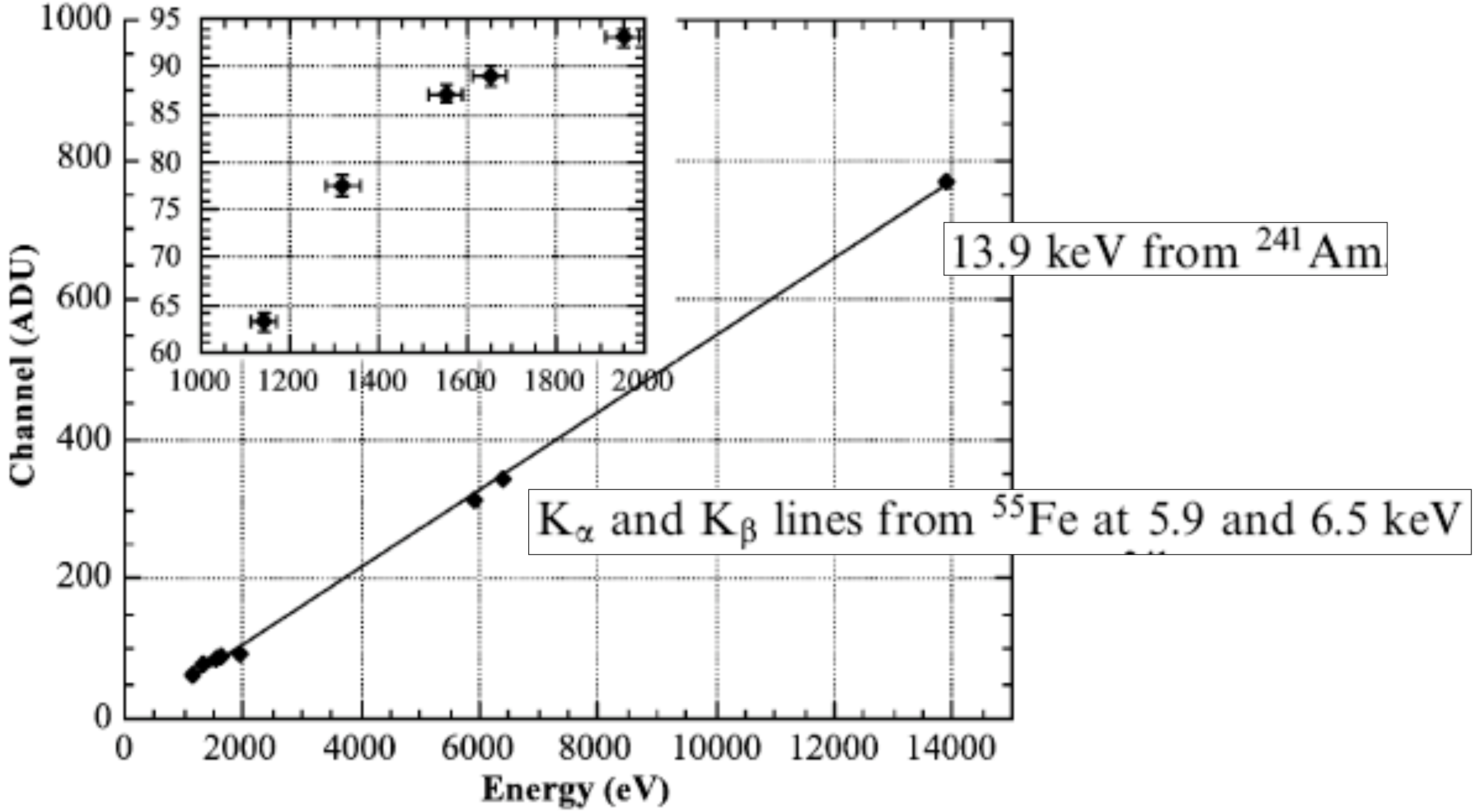
Subtraction of local background

Sum of charge over pixels of each event

Histogram of events for each class (one pixel, two pixels etc. …)

L. Labate et al., Nucl. Instr. and Meth. A. **495**, 148 (2002)

CCD Calibration curve for *SPS*

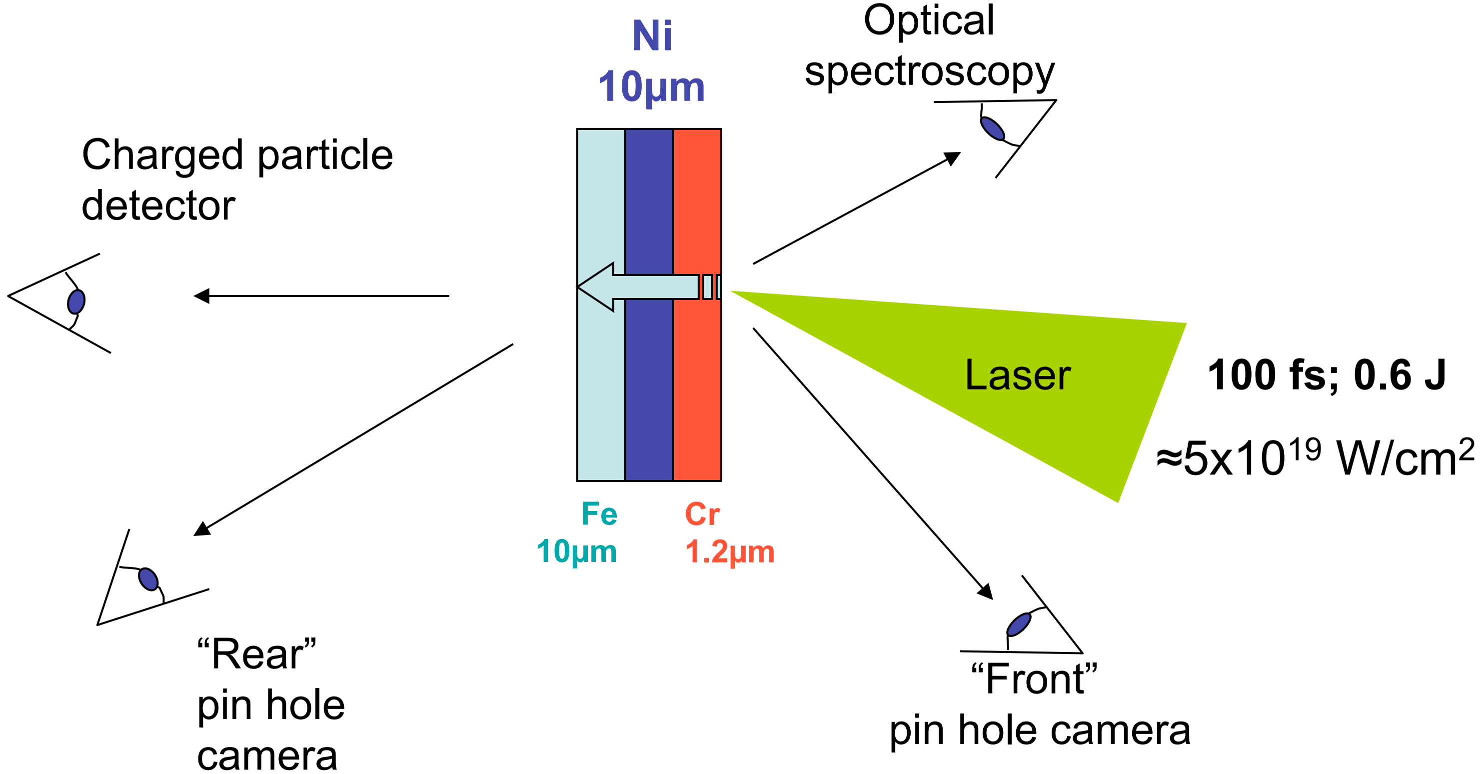


Calibration at higher (>2keV) energy was performed using radioactive sources

FAST ELECTRON PROPAGATION STUDIES AT IOQ

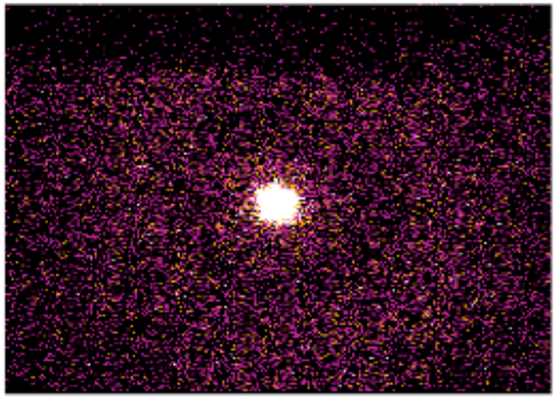
Experiment performed at the Jena (IOQ) laser facility within the LASERLAB access.

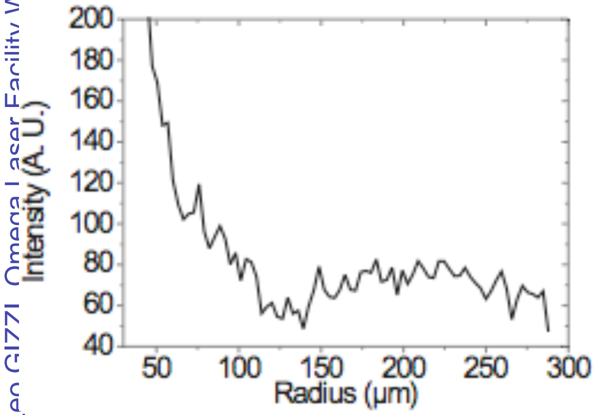
WE USE LARGE AREA, MULTI-LAYER METALLIC and METAL-INSULATOR TARGETS

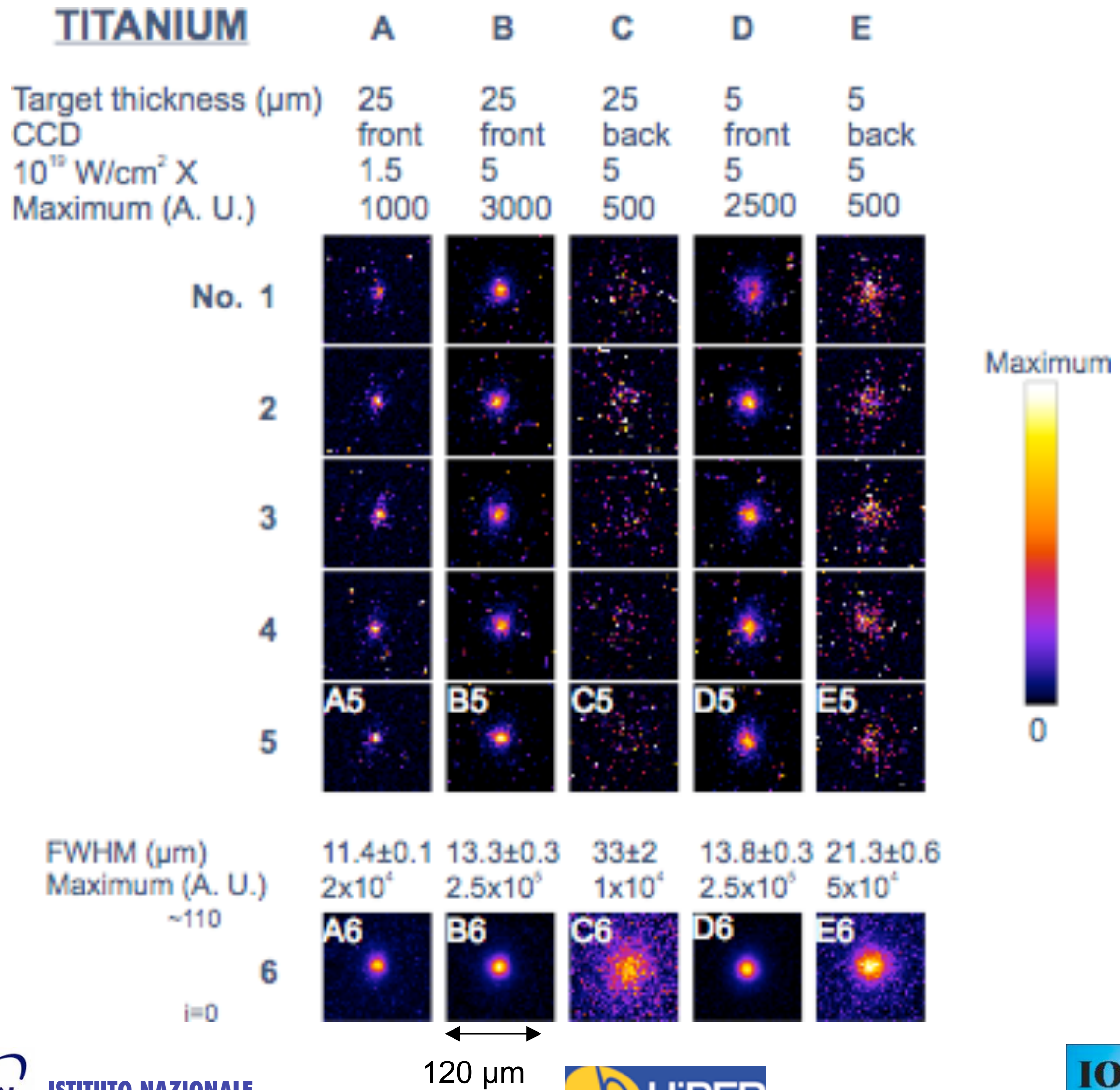


Conventional phc imaging - Ti foil

- X-ray imaging: M=11,
- spatial resolution 5 µm;

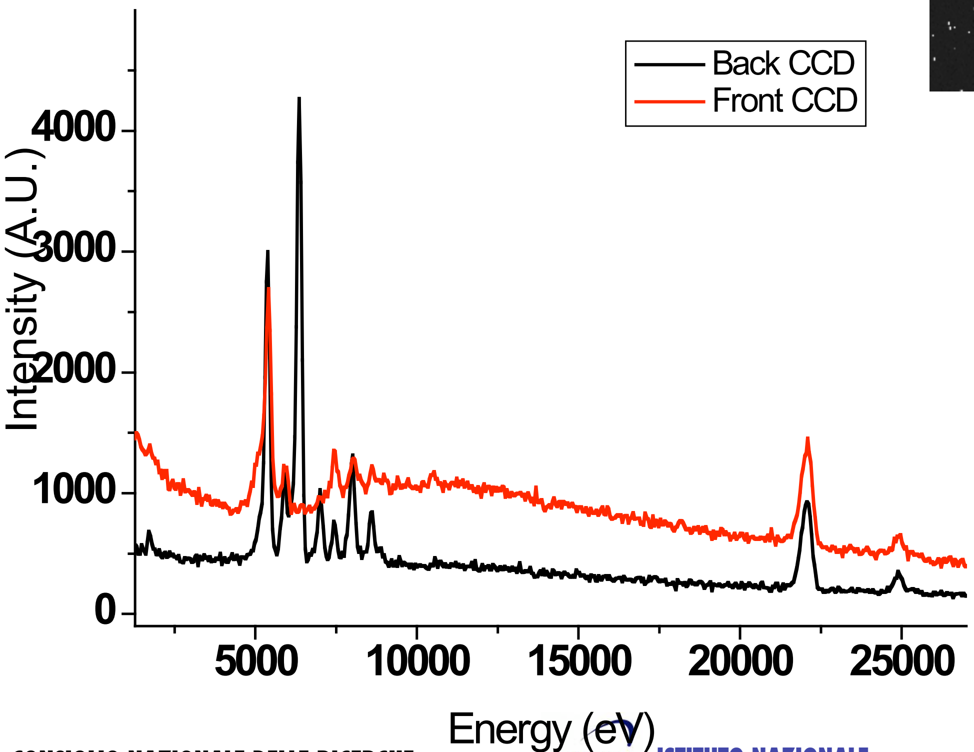


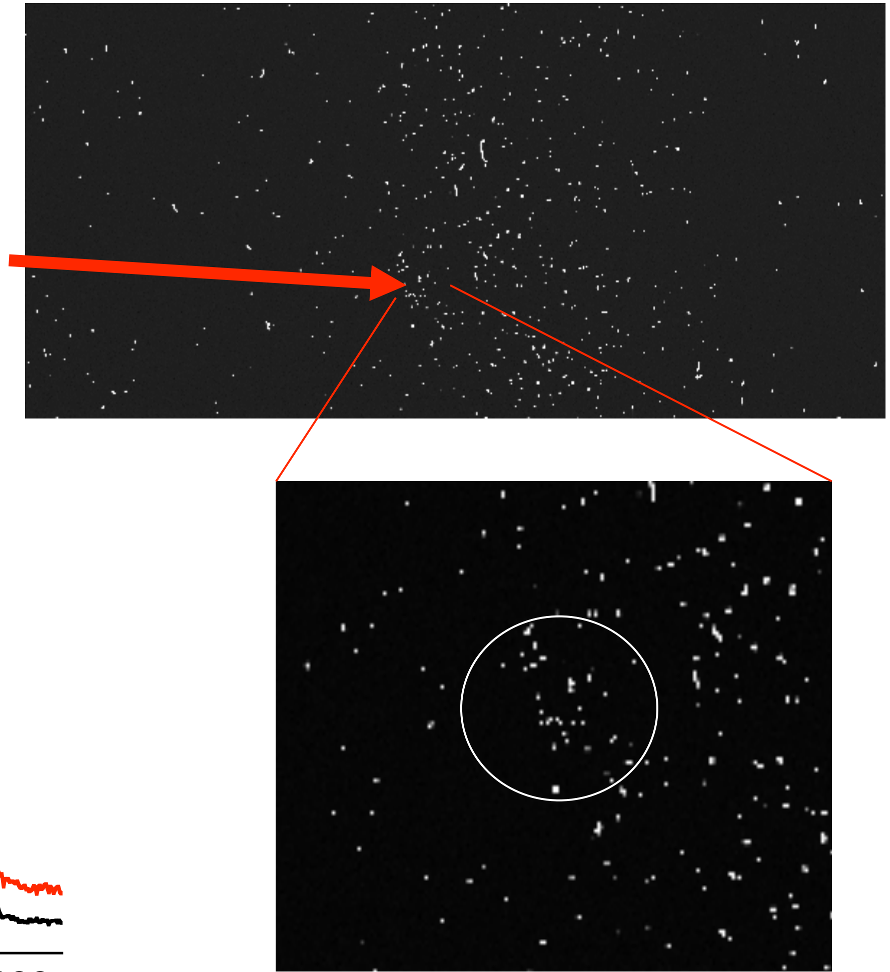




Low flux imaging

Signal must be single photon, to be able to use the CCD as a spectrometer. mylar foils were used to attenuate the signal





Leo GIZZI, Omega Laser Facility Workshop, Rochester, NY, 29th April, 1st May 2009.

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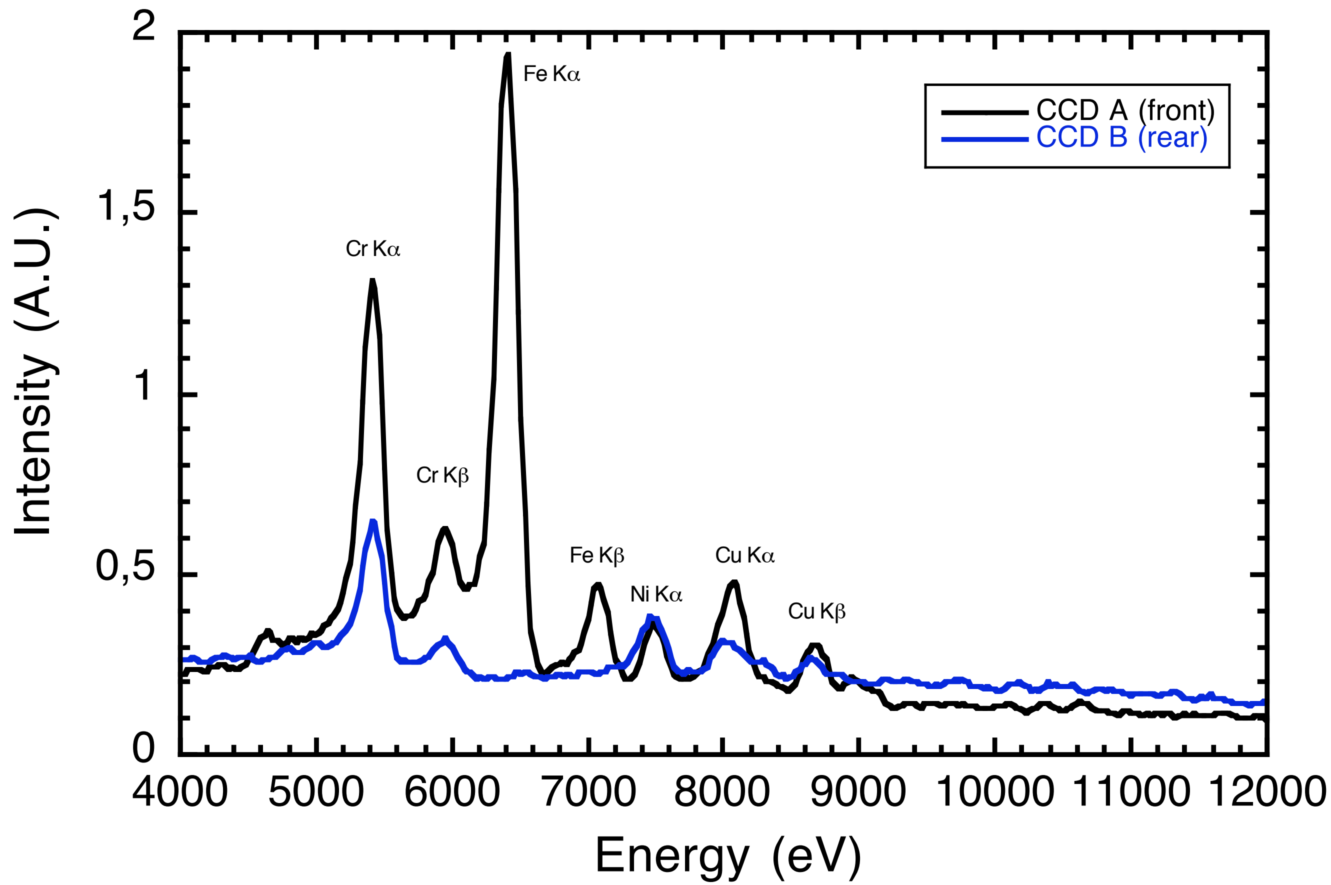
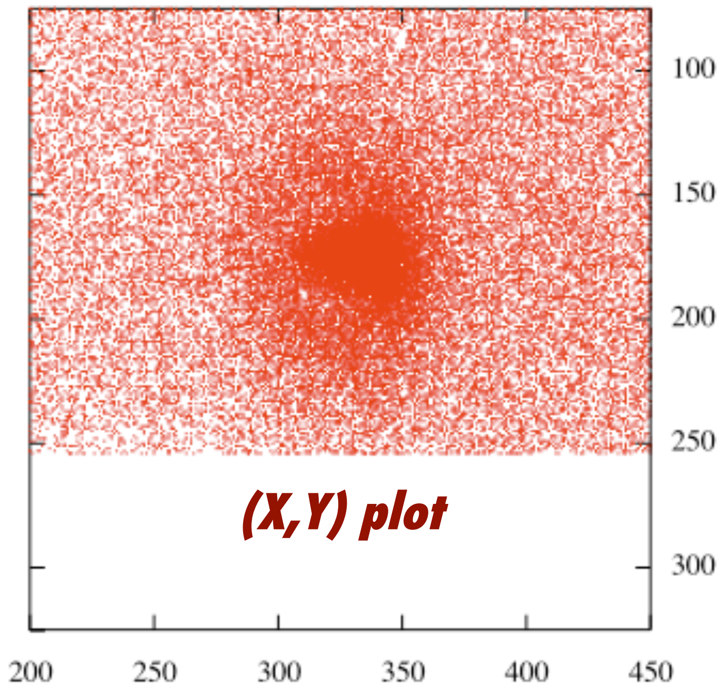
Front vs. Rear emission

Full spectrum taking all photons



Space/energy photon distribution!

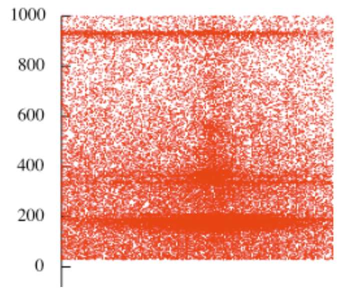
Energy resolved imaging



(X,Y) plot

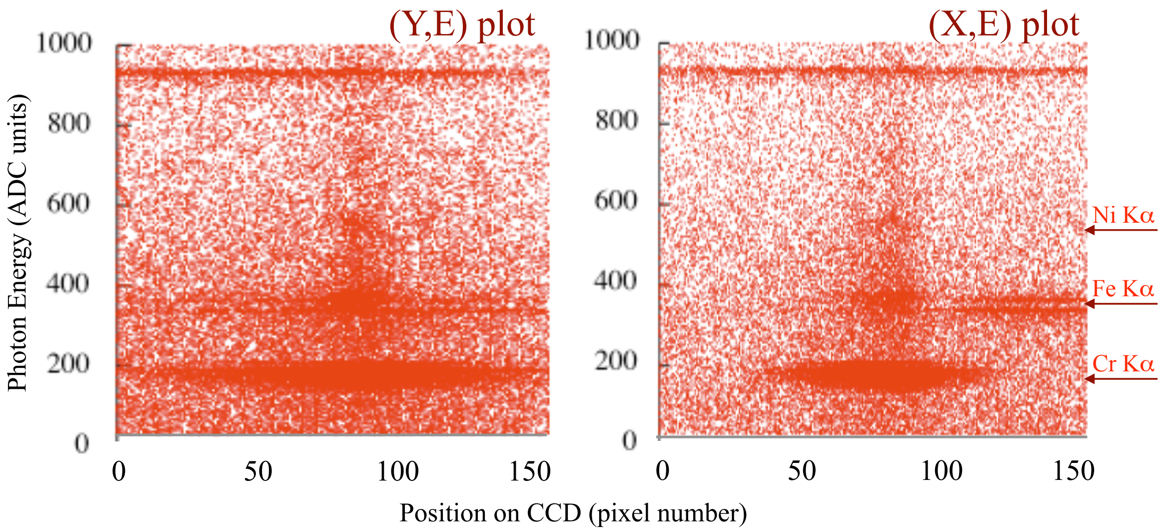
(X,E) plot

(Y,E) plot

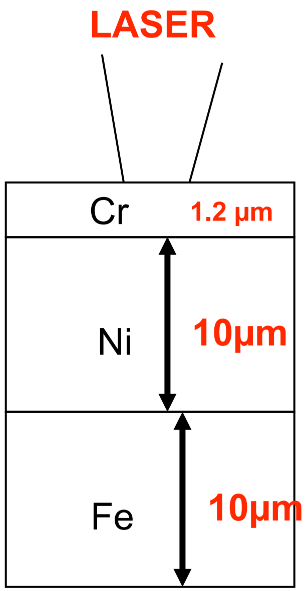


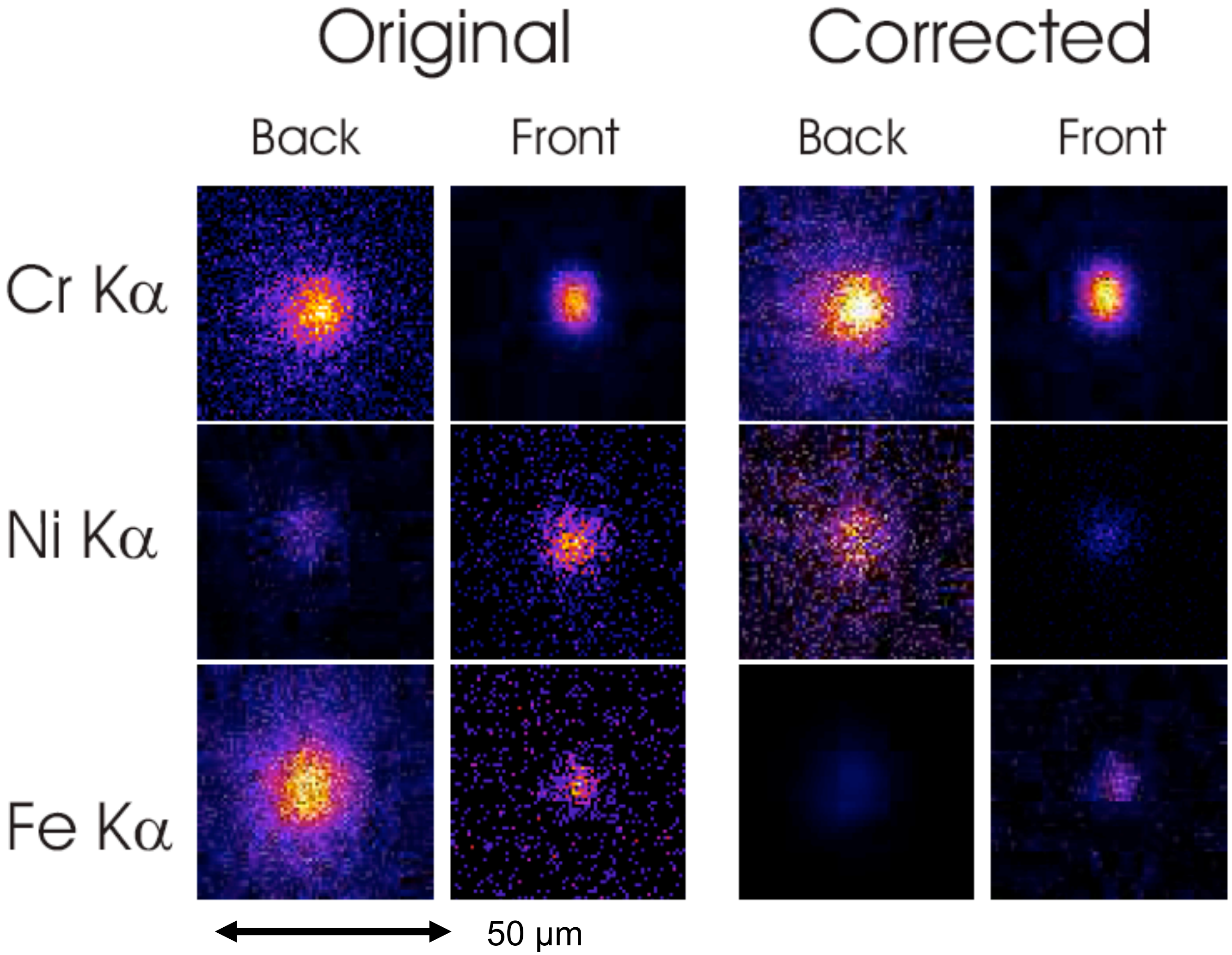
Space/energy photon distribution!

Energy resolved imaging

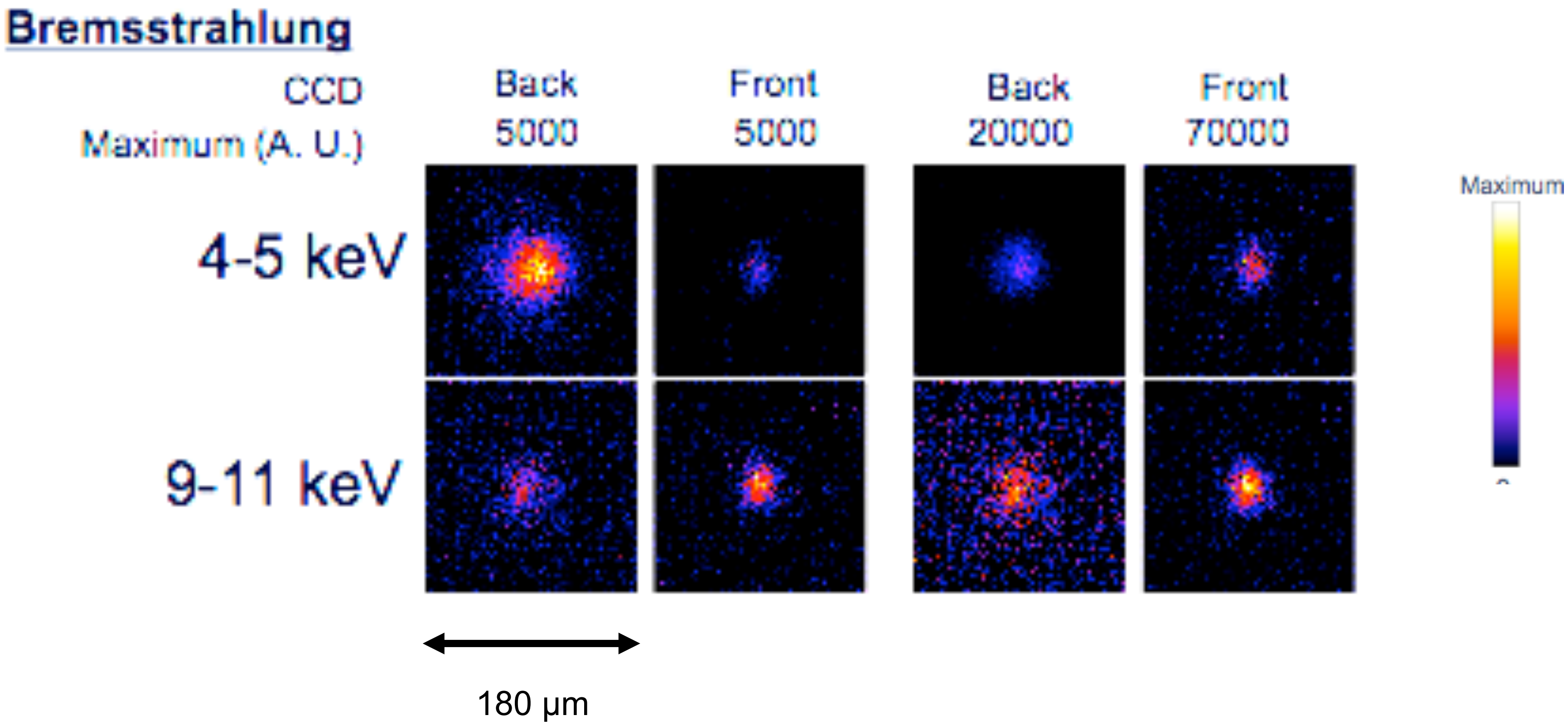


Imaging of front and rear side





Bremsstrahlung component

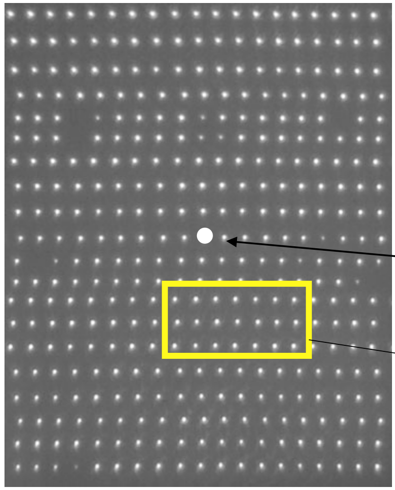


Extension to single shot measurement

- High energy laser experiments (e.g., RAL, OMEGA/EP, LULI) require single shot measurements;
- Our imaging technique requires >400 low flux images to collect a sufficient numcer of photons per spectral band to build up a full image;
- **Our approach is to use an array of closely spaced pin-holes and image out the source on a large area CCD array;**
- Custom array of pin-holes is needed due to the required diameter (<10μm), substrate thickness (>>10μm) and material. Also, geometry should be matched to achieve the required space resolution for a given source size and CCD specs.

First trial on custom pin-hole array
(laser drilling at ILIL)

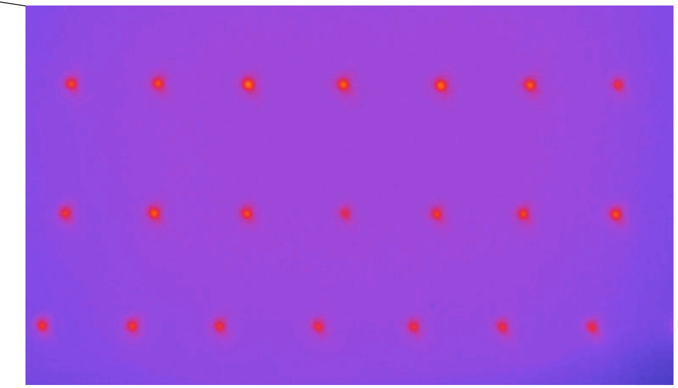
First 20X20 pin hole array sample made at ILIL on a 100µm thick substrate.



Alignment pin-hole

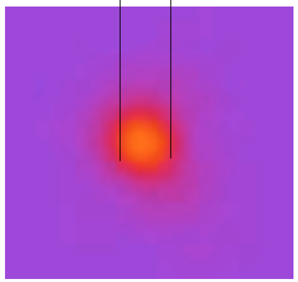
1mm

Optical microscopy image.



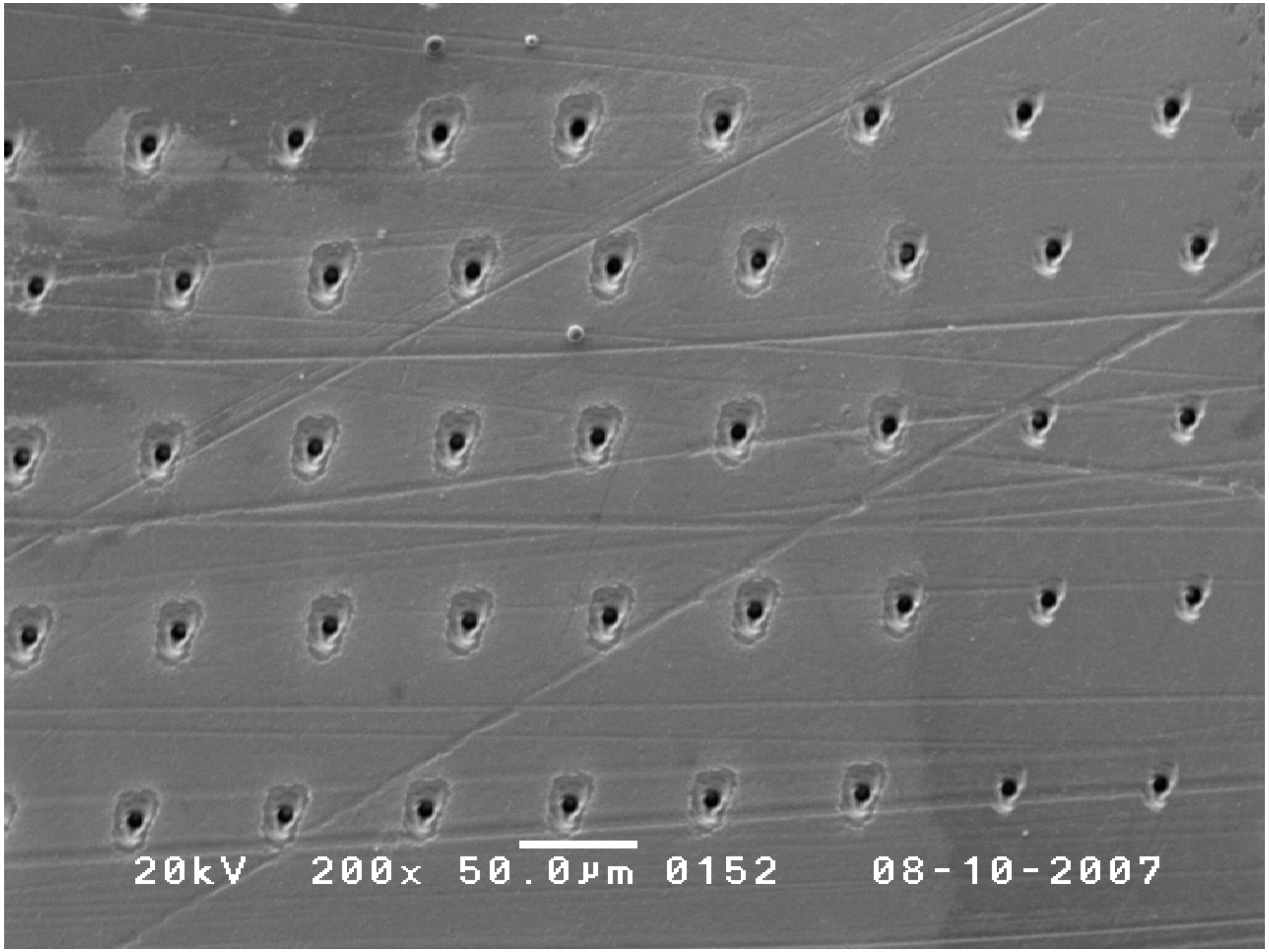
65µm

7µm FWHM



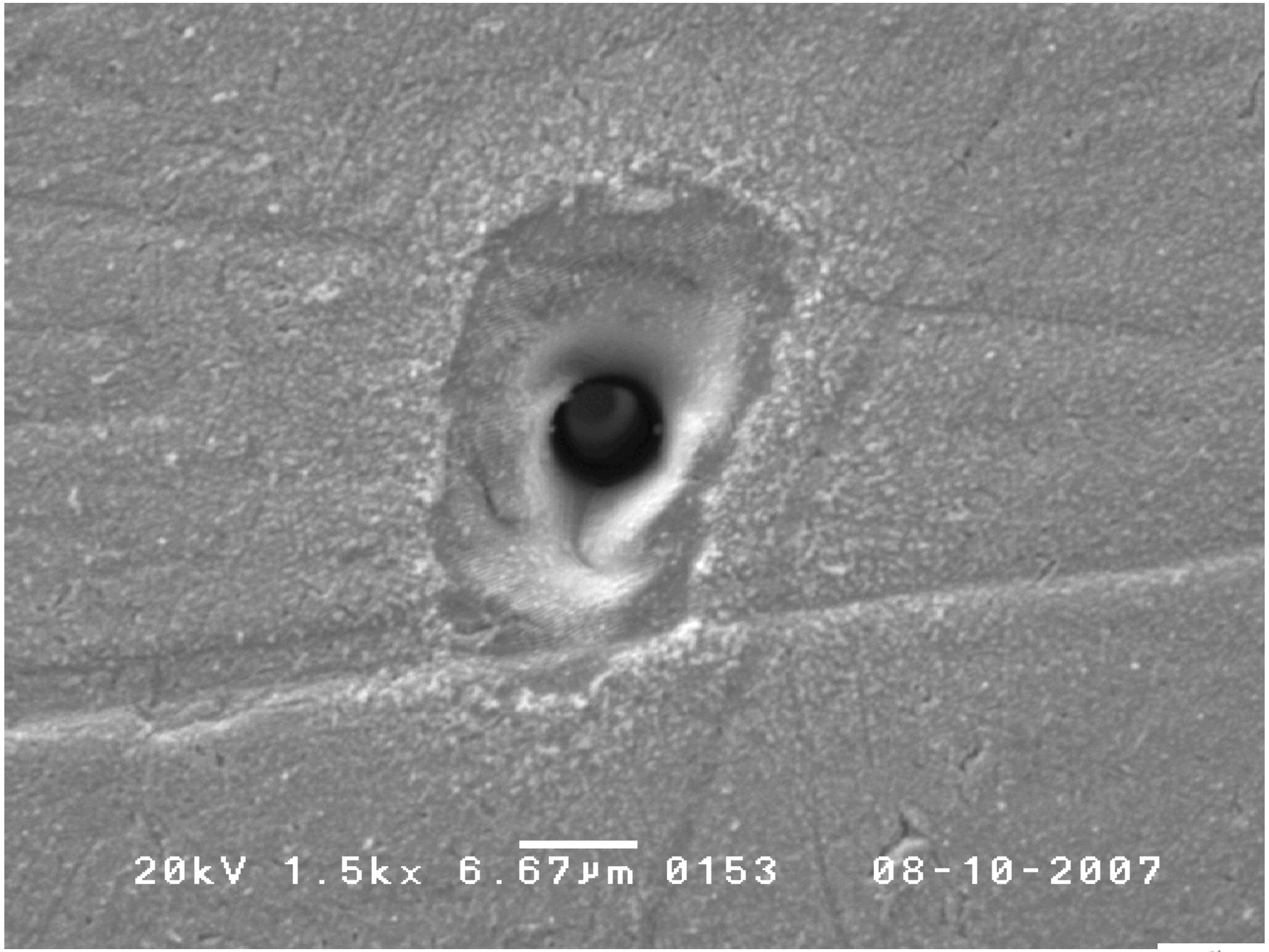
SEM images of custom made pin-hole array
(laser drilling at ILIL)

Front side - overview



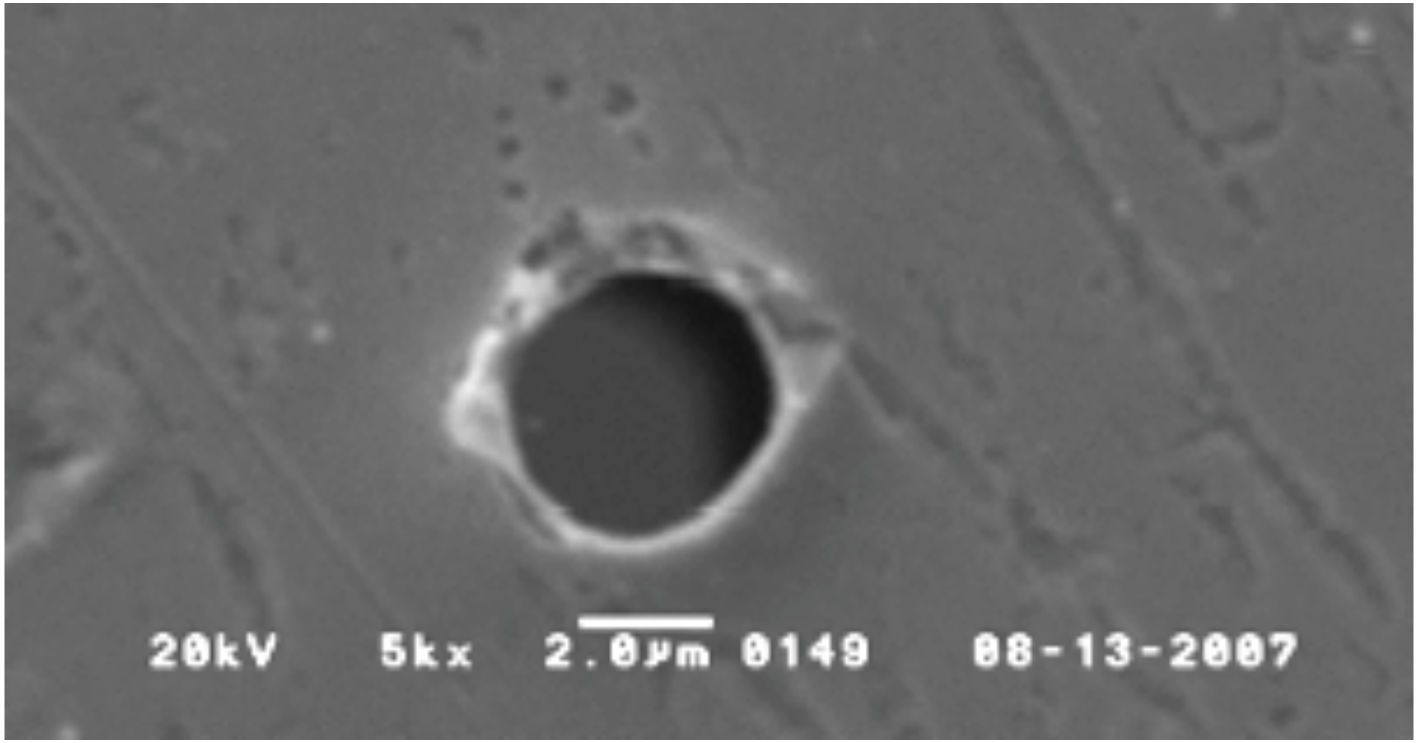
SEM images of custom made pin-hole array (laser drilling at ILIL)

Front side - single pin-hole



SEM images of custom made pin-hole array (laser drilling at ILIL)

rear side - single pin-hole



First single shot experiment

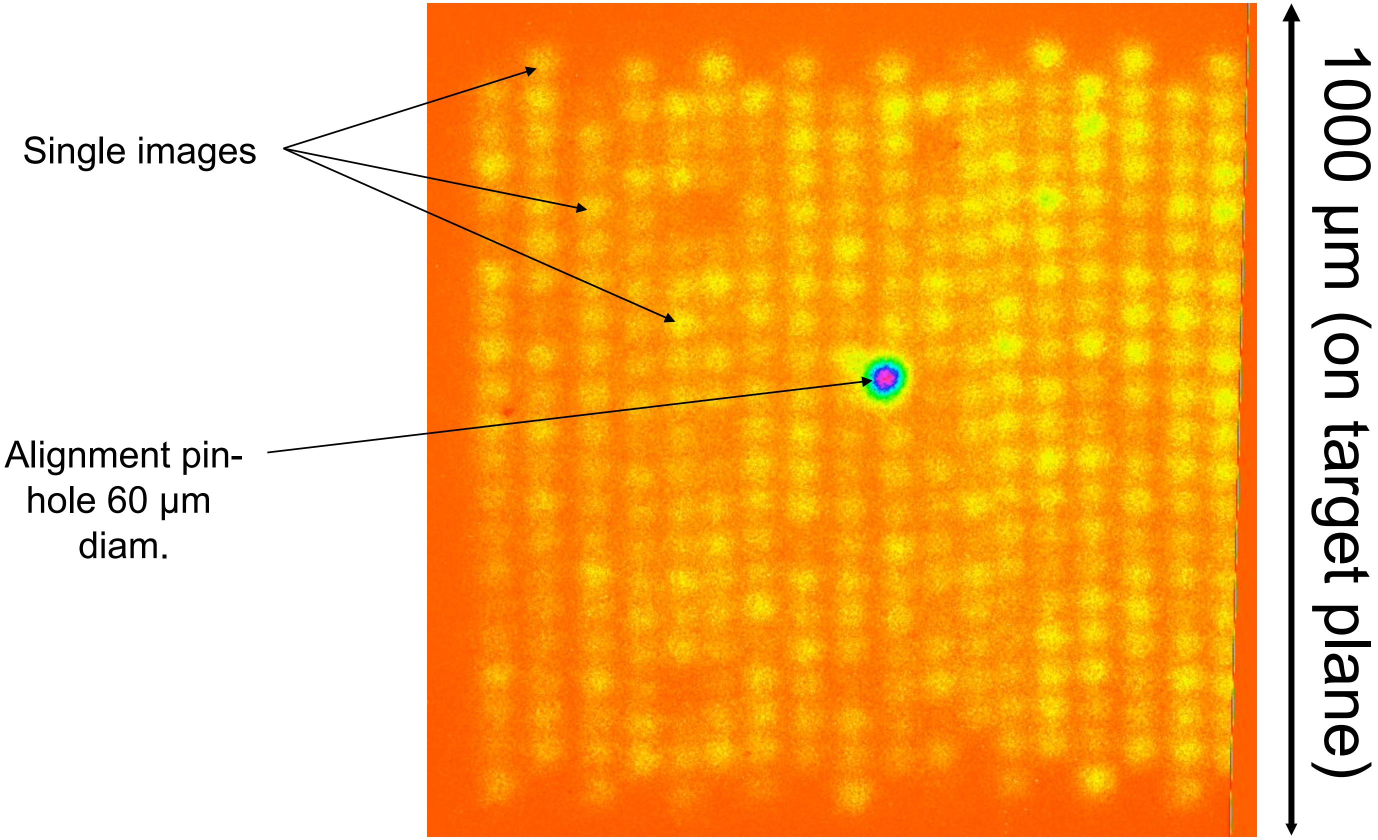
Single shot trial in progress at Prague PALS laser facility

General	Fundamental wavelength	1.315 Ì'm
	Pulse duration	300 to 400 ps
	Pulse contrast (prepulses & ASE)	~10^{-7}
	Repetition shot rate	25 min
	Output energy stability (over 10 shots)	< ą1.5 %
Main beam	Pulse energy at 400 ps	1 000 J
	Pulse power at 400 ps	3 TW
	Diameter	290 mm
	Conversion efficiency to 3 ω	55 %

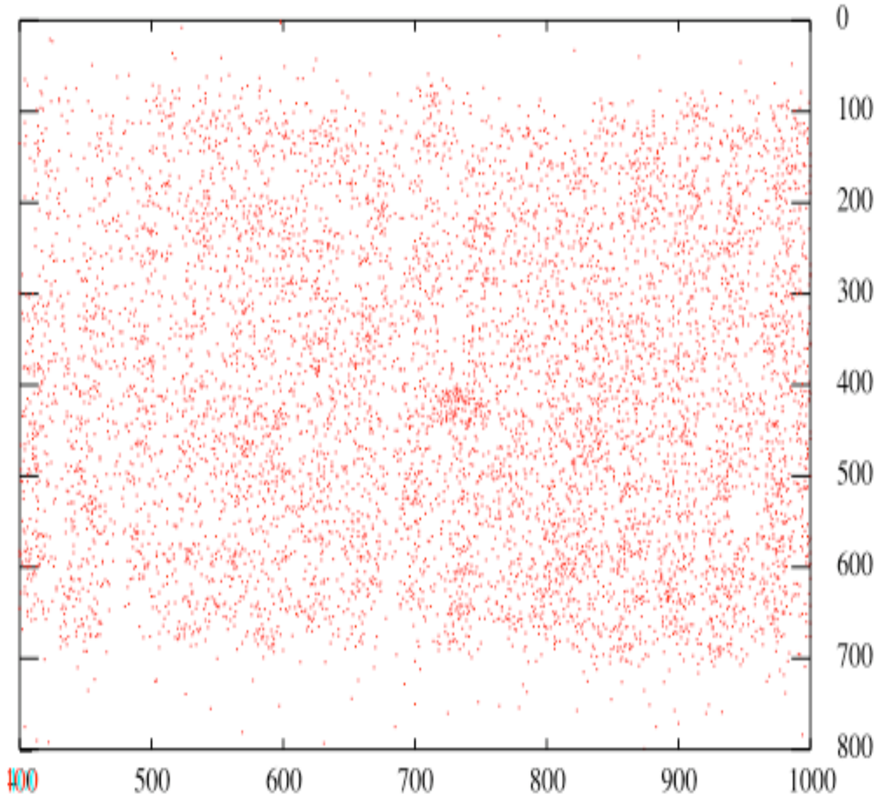
Target: thick Ti foil
Intensity: 10^{15} W/cm^2
Wavelength: 3w (438nm)
Pulselength: 200ps
Energy 60J
Spot size.: 100 μm^2, Target-PHA distance:12cm PHA-CCD distance: 60cm;
CCD array size: 1024x1024 pxls
Pixel size:13.5x13.5 μm^2.

First single shot array X-ray image

Images have been obtained at a range of intensity levels down to the single photon detection regime.

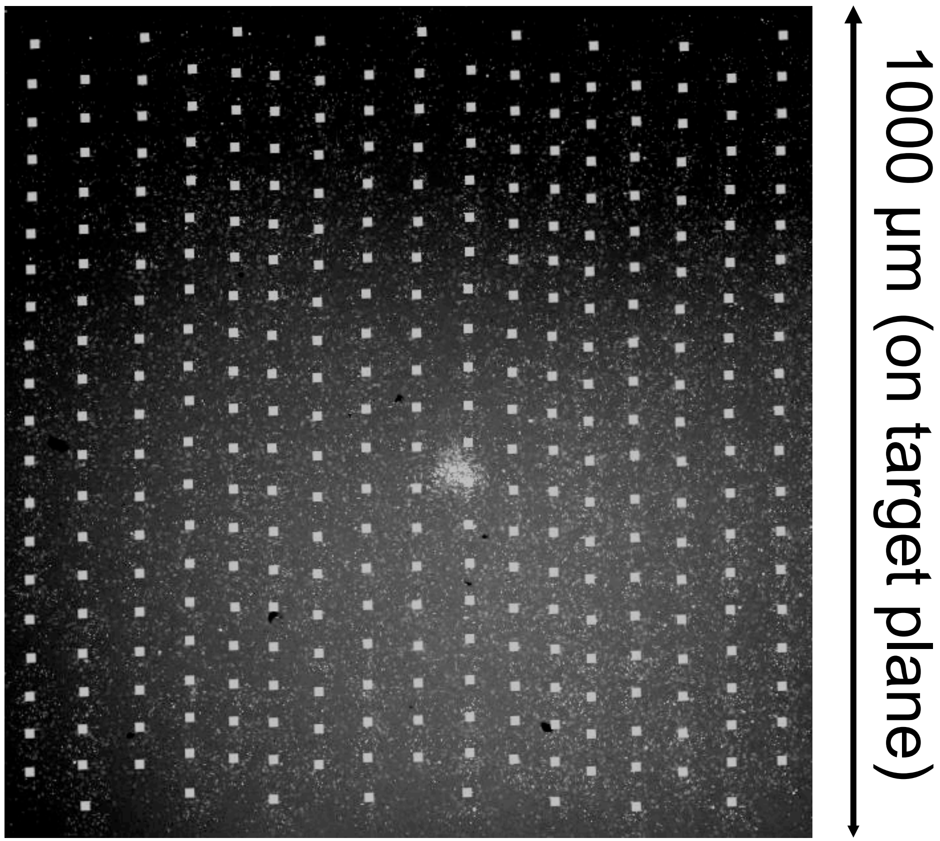


Identified photons (all energies)



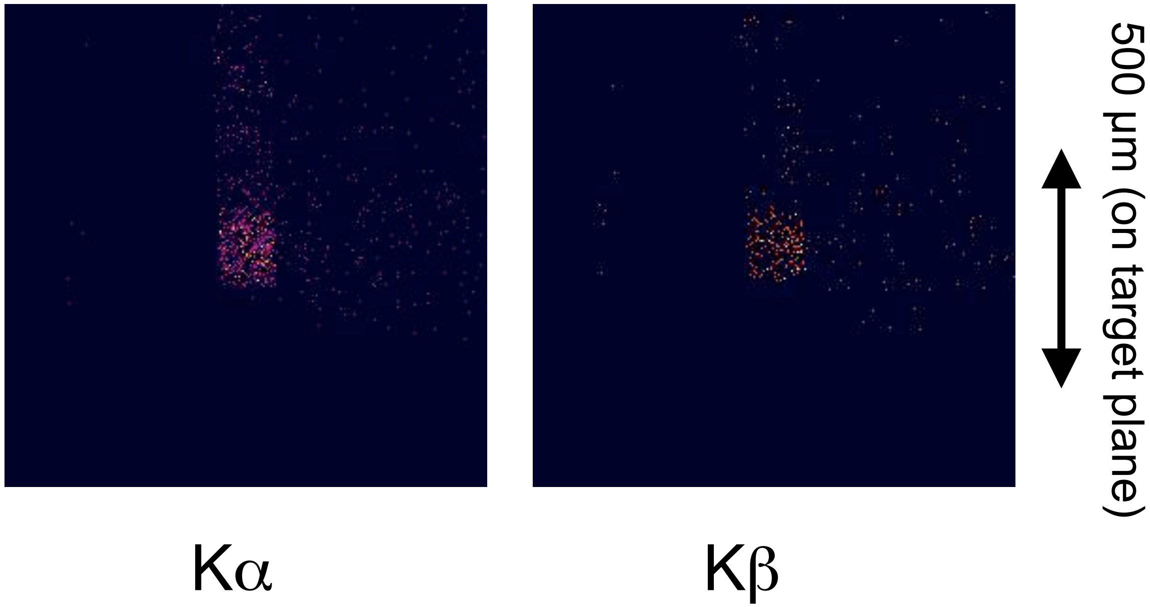
Collapsing all images to a single image

Individul images are superimposed taking into account the actual pin-hole array geometry



K-α and K-β images

Images at K-alpha and K-beta photon energy of Ti



Images were found to overlap due to the large source size (array designed for 10 μm sources)

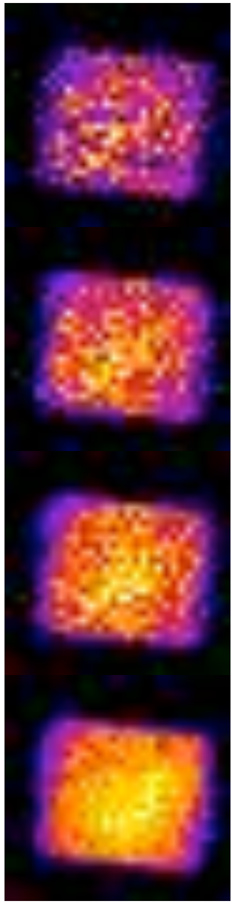
Edge clipping was implemented in the analysis to limit the effects of overlapping of images and mixing of photons at the edges

More accurate analysis is in progress …

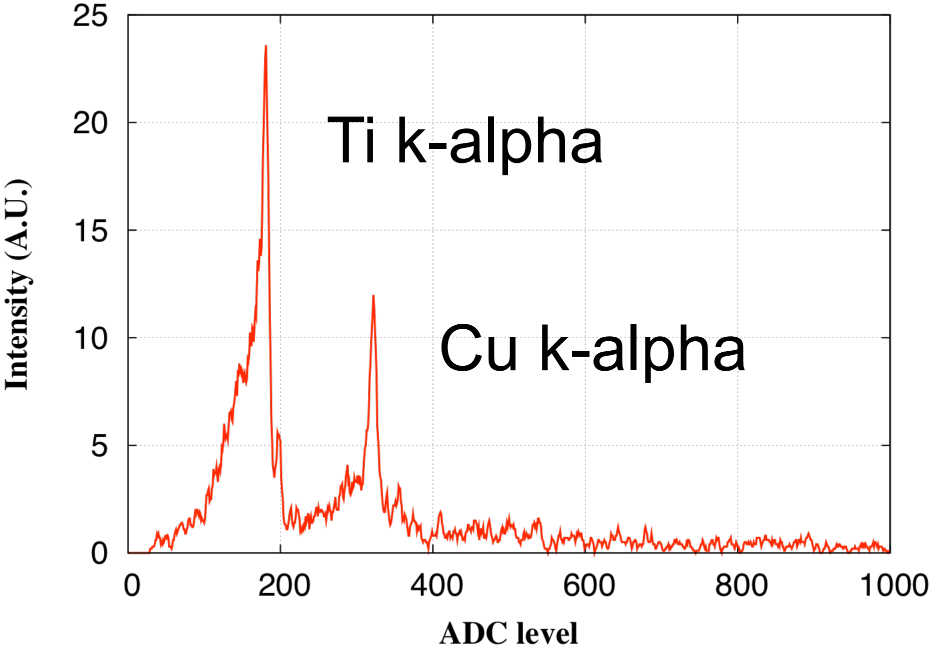
Statistics: how many images?

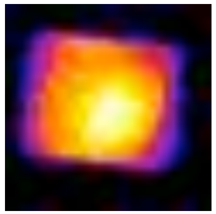
Ti-K-alpha

Increasing n. of combined images

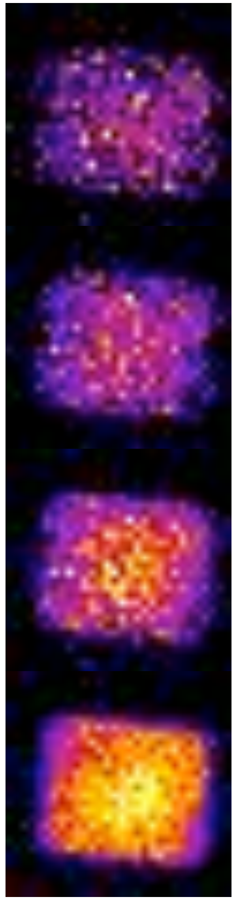


Cu(0.5micron)-plastic-Ti(0.5micron)
Shooting on Cu side





Cu K-alpha



CONCLUSIONS

•***EXTENSION OF THE SINGLE PHOTON DETECTION TECHNIQUE***

TO ENABLE µm-RESOLUTION, MONOCHROMATIC X-RAY IMAGING;

•***TECHNIQUE APPLIED TO DETECTION OF Ka EMISSION***

TO INVESTIGATE FAST ELECTRON PROPAGATION IN MULTI-LAYER TARGETS;

•***INTERACTION OF RELATIVISTIC PULSES WITH MULTI-LAYER METALLIC TARGETS show*** *collimated propagation of fast electrons inside the material;*

•*ANALYSIS OF DIFFERENT SPECTRAL COMPONENTS SHOWS EVIDENCE OF BREMSSTRAHLUNG EMISSION from fast electron propagation;*

•*ENERGY-RESOLVED, µm-resolution X-ray imaging extended to the* ***single-shot****, experiments.*

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•ANALYSIS OF DIFFERENT SPECTRAL COMPONENTS SHOWS EVIDENCE OF BREMSSTRAHLUNG EMISSION from fast electron propagation;

•MODELLING using a 3D hybrid code (PETRA) is in progress. Single layer calculations show significant consistency with experimental data. Multi-layer calculations are in progress.

•ENERGY-RESOLVED, μm-resolution X-ray imaging is being extended to the **single-shot**, high energy experimental regime.

Group Relevant publications

•L. Labate, T. Levato, M. Galimberti, A. Giulietti, D. Giulietti, M. Sanna, C. Traino, M. Lazzeri, L.A. Gizzi, A single-photon CCD-based setup for in situ measurement of the X-ray spectrum of mammographic units, Nucl. Instrum. Meth. Phys. Res. A **594**, 278-282 (2008).
•T. Levato, L. Labate, M. Galimberti, A. Giulietti, D. Giulietti, L.A. Gizzi, Detailed analysis of events from high-energy X-ray photons impinging on a two-phase front-illuminated CCD, Nucl. Instrum. Meth. Phys. Res. A **592**, 346-353 (2008).
•L. Labate, A. Giulietti, D. Giulietti, L.A. Gizzi, P. Köster, T. Levato, F. Zamponi, A. Lübcke, T. Kämpfer, I. Uschmann, E. Förster, A. Antonicci, D. Batani, B. Rus, Study of fast electron dynamics in solids using multispectral, monochromatic X-ray imaging, 35th EPS Plasma Physics Conference, 9-13 June 2008, Hersonissos, Crete, Greece;
•P. Köster, K. Akli, A. Antonicci, D. Batani, S. Baton, R.G. Evans, E. Förster, A. Giulietti, D. Giulietti, L.A. Gizzi, J.S. Green, T. Kämpfer, M. Koenig, L. Labate, K.L. Lancaster, T. Levato, A. Lübcke, A. Morace, P. Norreys, F. Perez, I. Uschmann, J. Waugh, N. Woolsey, F. Zamponi, Experimental investigation of fast electron transport through Kalpha imaging and spectroscopy in relativistic laser-solid interactions, 35th EPS Plasma Physics Conference, 9-13 June 2008, Hersonissos, Crete, Greece.
•L.A. Gizzi, A. Giulietti, D. Giulietti, P. Koester, L. Labate, T. Levato, F. Zamponi, A. Luebcke, T. Kaempfer, I. Uschmann, E. Foerster, A. Antonicci, D. Batani, Observation of electron transport dynamics in high intensity laser interactions using multi-energy monochromatic X-ray imaging, Plasma Phys. Controll. Fusion **49**, B221 (2007). doi: 10.1088/0741-3335/49/12B/S19
•L. Labate, A. Giulietti, D. Giulietti, P. Koester, T. Levato, L.A. Gizzi, F. Zamponi, A. Luebcke, T. Kaempfer, I. Uschmann, E. Foerster, Novel X-ray multi-spectral imaging of ultraintense laser plasmas by a single-photon CCD based pinhole camera, Rev. Sci. Instrum. **78**, 103506 (2007).
•L. Labate, A. Giulietti, D. Giulietti, P. Koester, T. Levato, L.A. Gizzi, F. Zamponi, A. Luebcke, T. Kaempfer, I. Uschmann, E. Foerster, A novel technique for X-ray multi-spectral imaging of ultraintense laser generated plasmas, ISUILS6 - International Symposium on Ultrafast Intense Laser Science, September 23-28, 2007, Tirrenia, Pisa, Italy.
•Leonida A. Gizzi, Observation of electron transport dynamics in high intensity laser interactions using monochromatic X-ray imaging, 34th EPS Conference on Plasma Physics, July 2-6, 2007, Warsaw, Poland, (tnvited talk).

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