SAND2007-1676C

Laser Generated
High Energy Density Physics

and the Status of the Z-Petawatt/ZR Projects at Sandia

Darmstadt, March 22, 2007

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Sandia National Laboratories

SNL Approval:
SAND 2007 ????

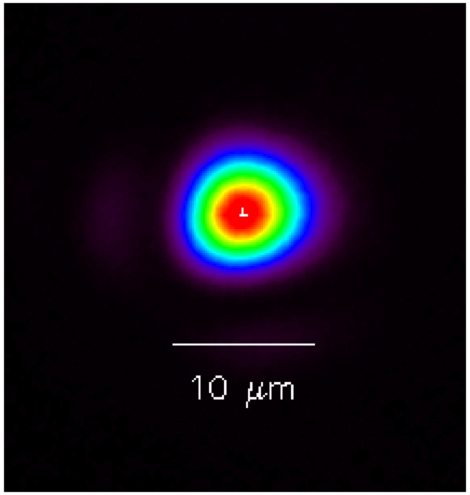
Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Z-Petawatt Motivation

Z-Beamlet / Z-Petawatt serve as supporting facilities for .
Main missions involve energetic radiation for diagnostic and interaction.
Mission fields and other fields of interest include to

- characterize the laser target; source definition
- increase the potential for backlighting:
  - * Temporal resolution
  - * Photon energy
  - * Intensity
- investigate the potential of particle beams for:
  - * Radiography/field mapping
  - * Interaction physics/fast ignition
- develop diagnostics/detectors/work procedures
- assess potential future hazards

Laser Performance



10 Hz OPCPA signal on target

FWHM x: 6.3 µm
FWHM y: 6.4 µm

Radius of disc which includes…

65.7% of total energy:	4.71 µm
81.1% of total energy:	7.55 µm
90.8% of total energy:	10.86 µm

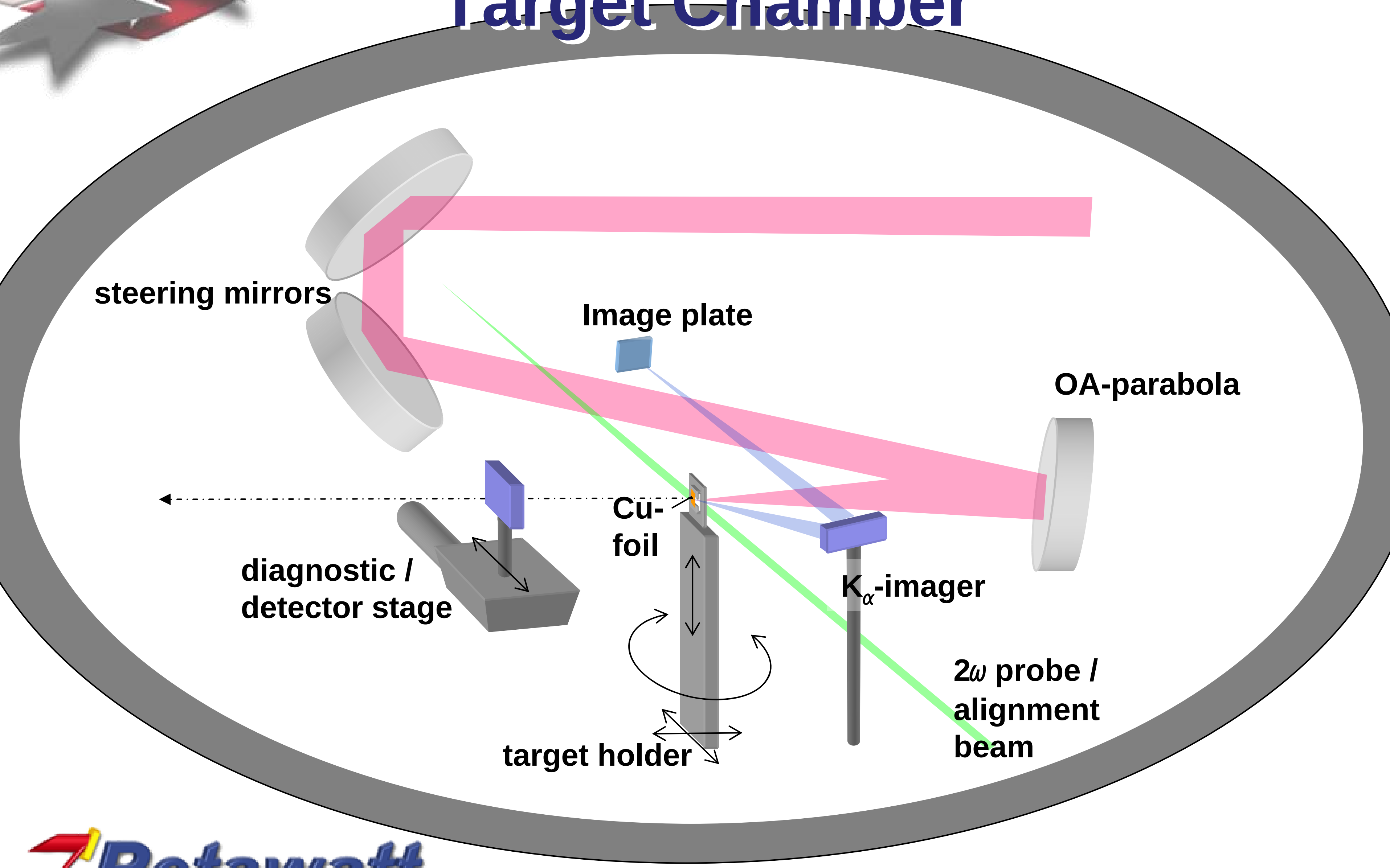
Strehl ratio: 0.58

Amplified energy: typ. 25 J, max. 33 J
Full pulse width: < 3 ps (BW limit ~450fs)
ASE prepulse better 10^{-6} @ < 1ns

Focus shape is approximately maintained for rod-shots.
Full system shot foci have not been measured yet.

Petawatt

Target Chamber



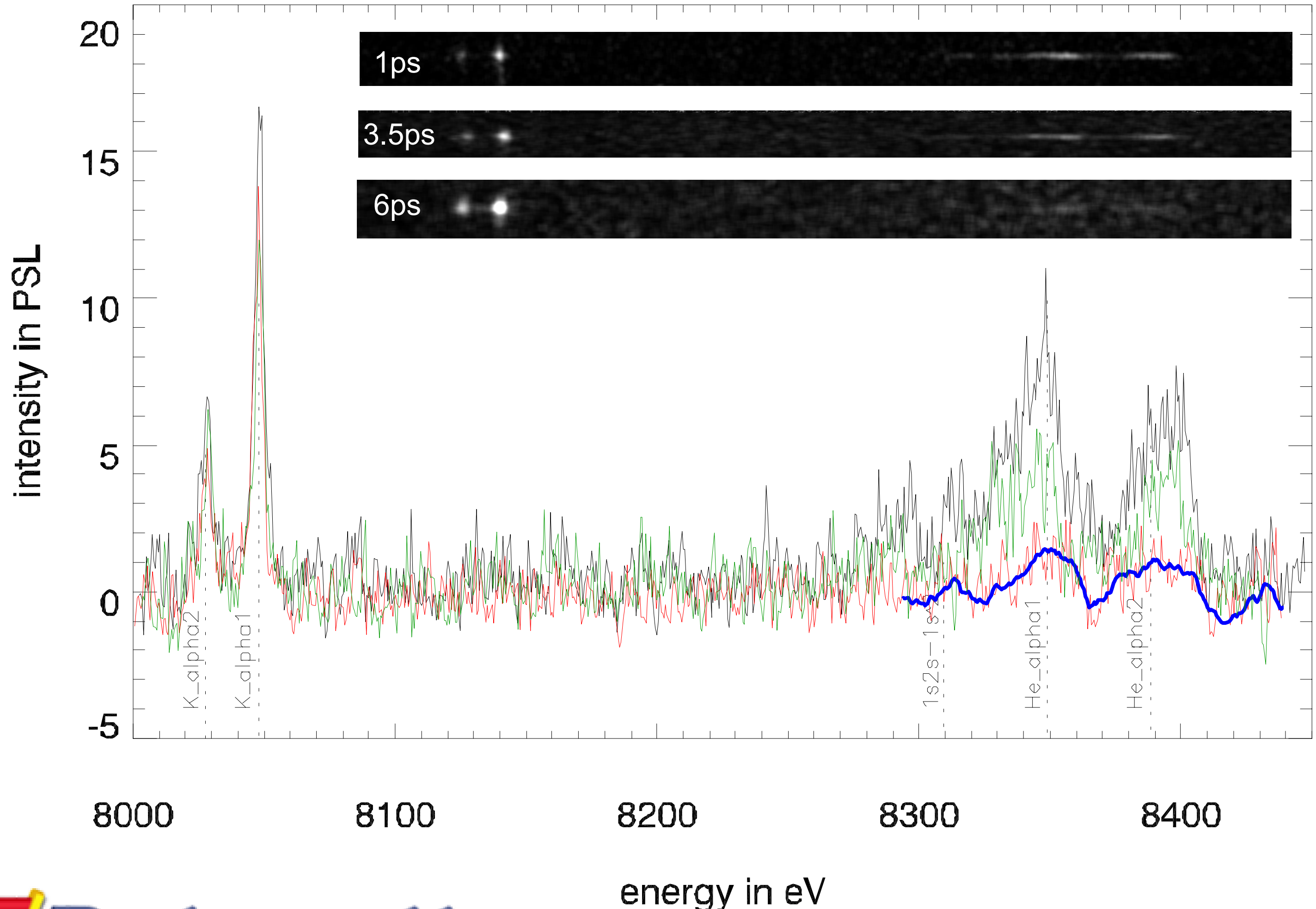
X-Ray Motivation

Providing X-rays for radiography on Z is the main mission of Z-Beamlet and will be the main mission of Z-Petawatt.
Primary importance is assigned to:

- **Efficiency of conversion into specific spectral lines (chromatic resolution)**
- **Brilliance/source size (spatial resolution)**
- **Benchmarking feasibility of crystal radiography for high energy x-rays.**

X-ray Spectra

Mica Crystal 2D-FSSR, 11th Order



δE/E < 5.5E-4

E/δE > 1820

t_{pulse}~ 1ps

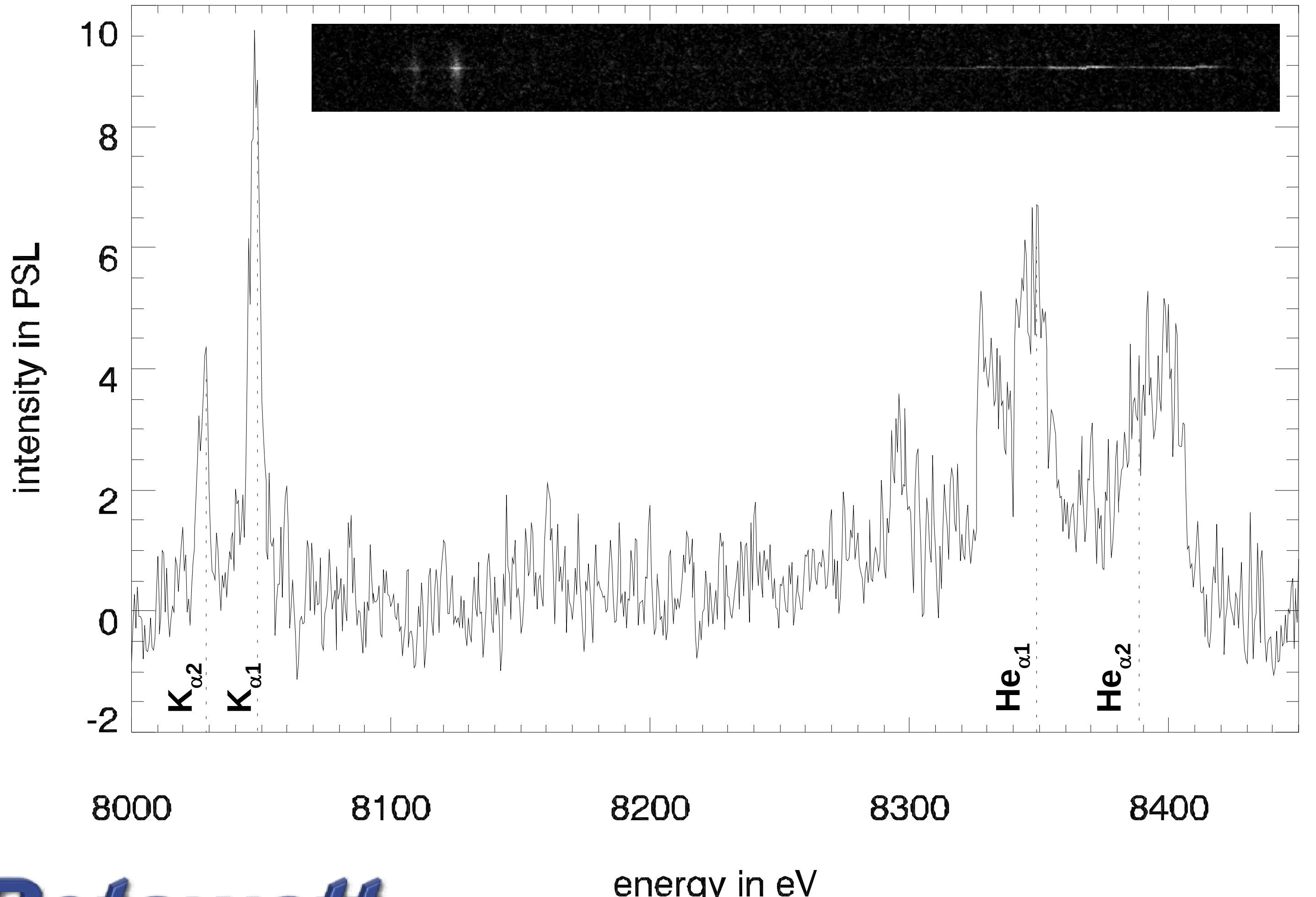
t_{pulse}~ 3.5ps

t_{pulse}~ 6ps

t_{pulse}~ 6ps (average 20)

X-ray Spectra

Mica Crystal 2D-FSSR, 11th Order

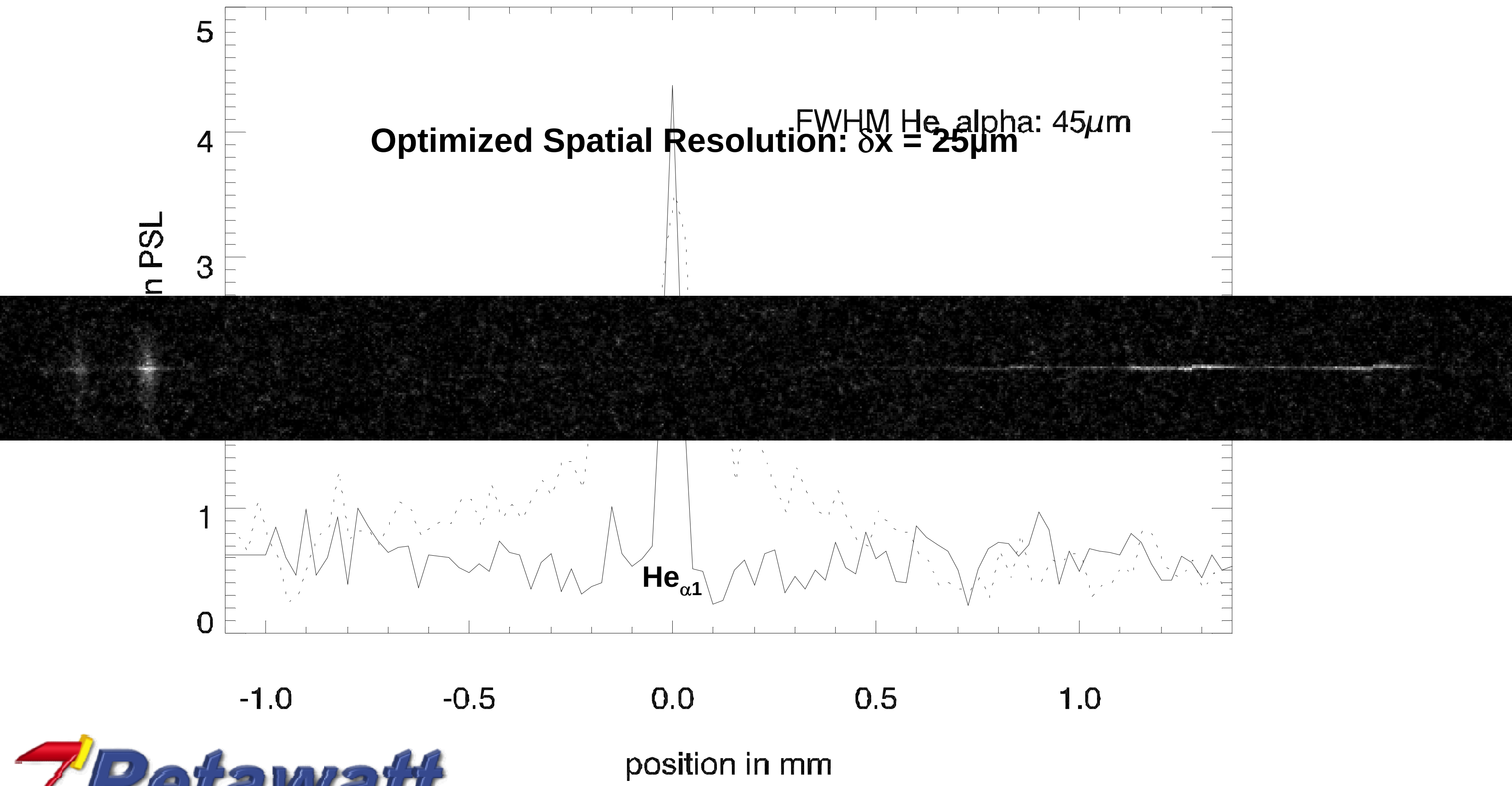


Optimized Spatial Resolution:

δx = 25µm

X-ray Spectra

Mica Crystal 2D-FSSR, 11th Order



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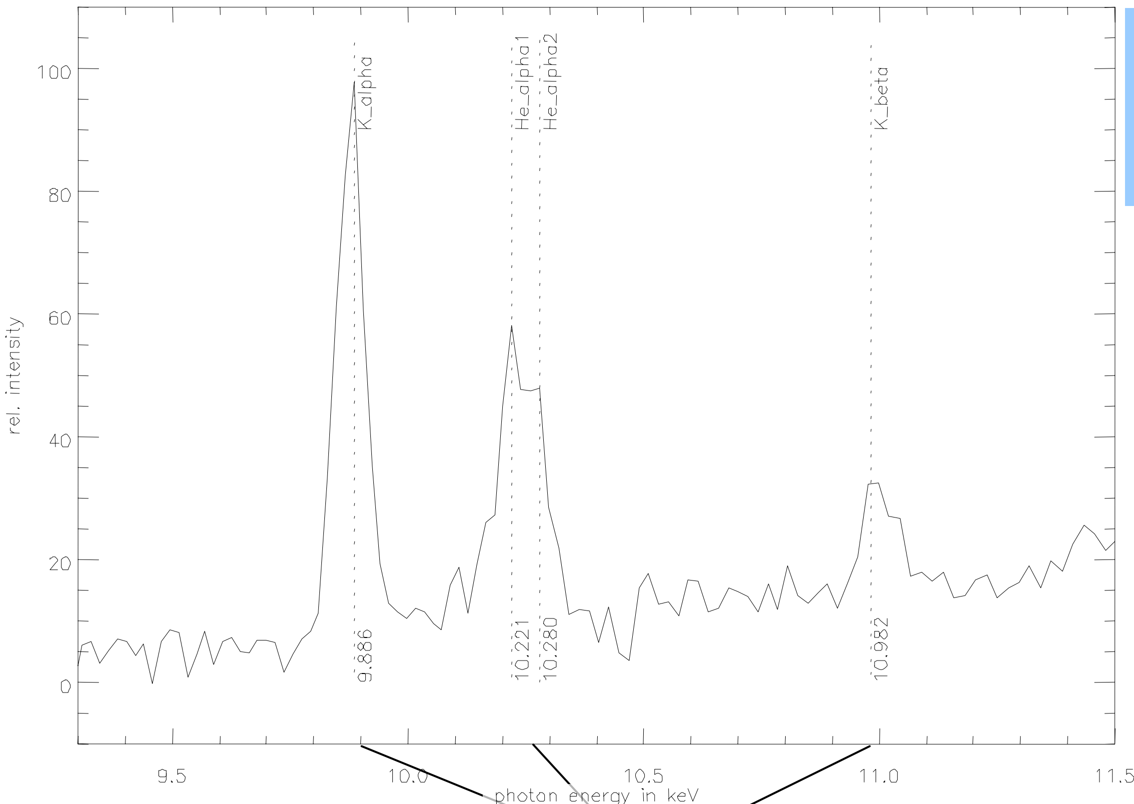
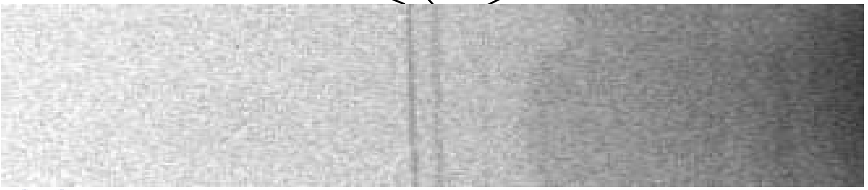
X-ray Spectroscopy

Germanium K_α- Spectra

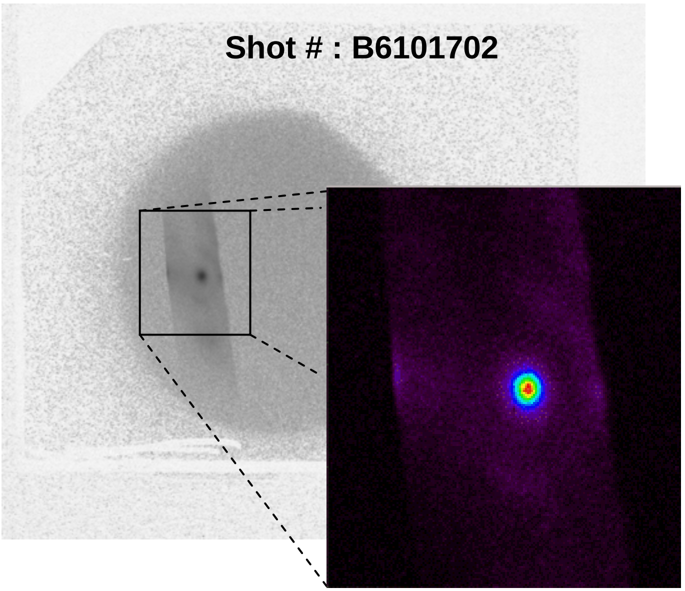


Shot # B6091101
0.5mm Ge
Front view, focused
27.7 J

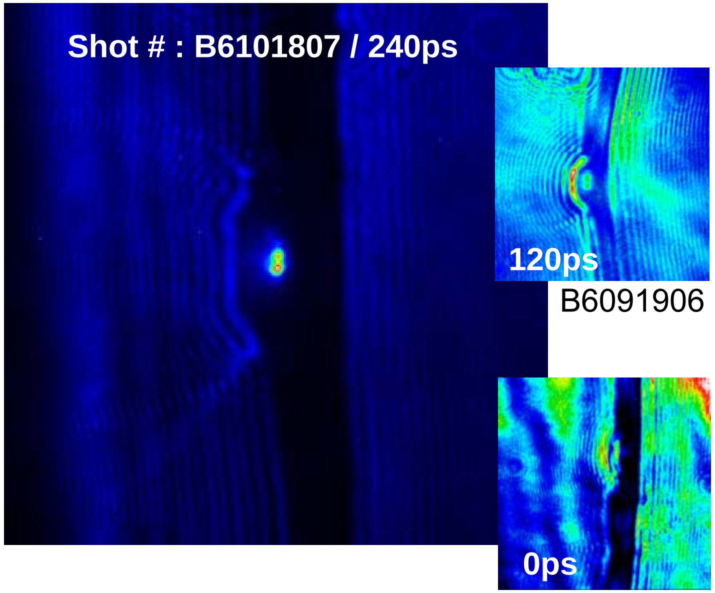


Target Diagnostic

(in collaboration with UCSD: Farhat Beg / Jim King)



•**Diagnostic: Spherically curved crystal; K_α X-ray imager**
•Target: 25 μm Cu foil
•Detector: Fujifilm BAS-SR image plate
•Laser energy: 20 J
•Spot diameter: FWHM~60 μm
•Magnification : 7.1x

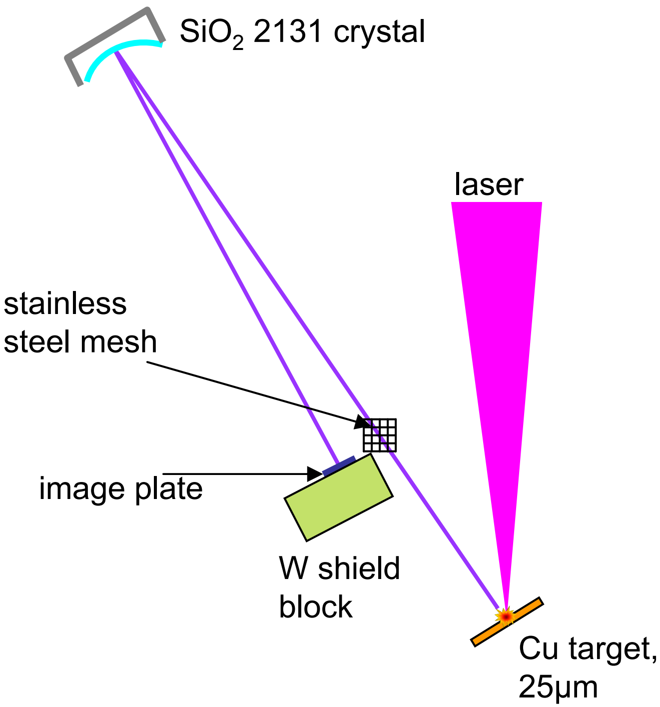


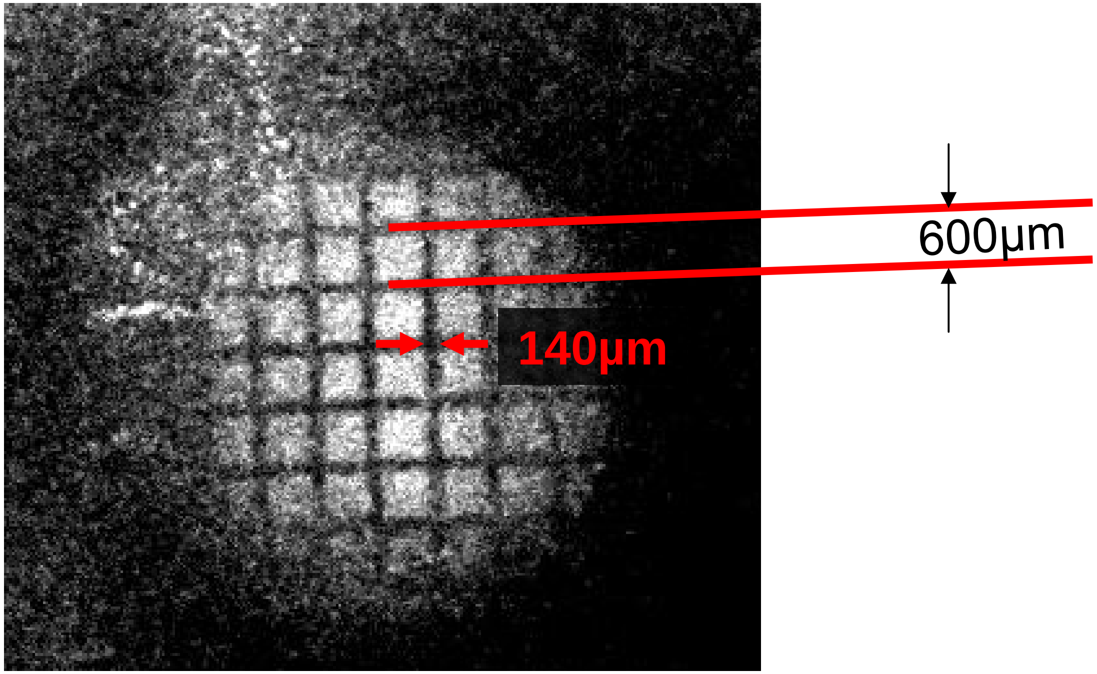
B6092003

•**Diagnostic: Shadowgraphy image / probe beam**
•Target: 25 μm Cu foil
•Detector: Roper internally cooled CCD
•Exposure time: ~300 fs
•Magnification: ~9

Cu K_α Radiography

1:1 Imaging at 8 keV





Ion Motivation

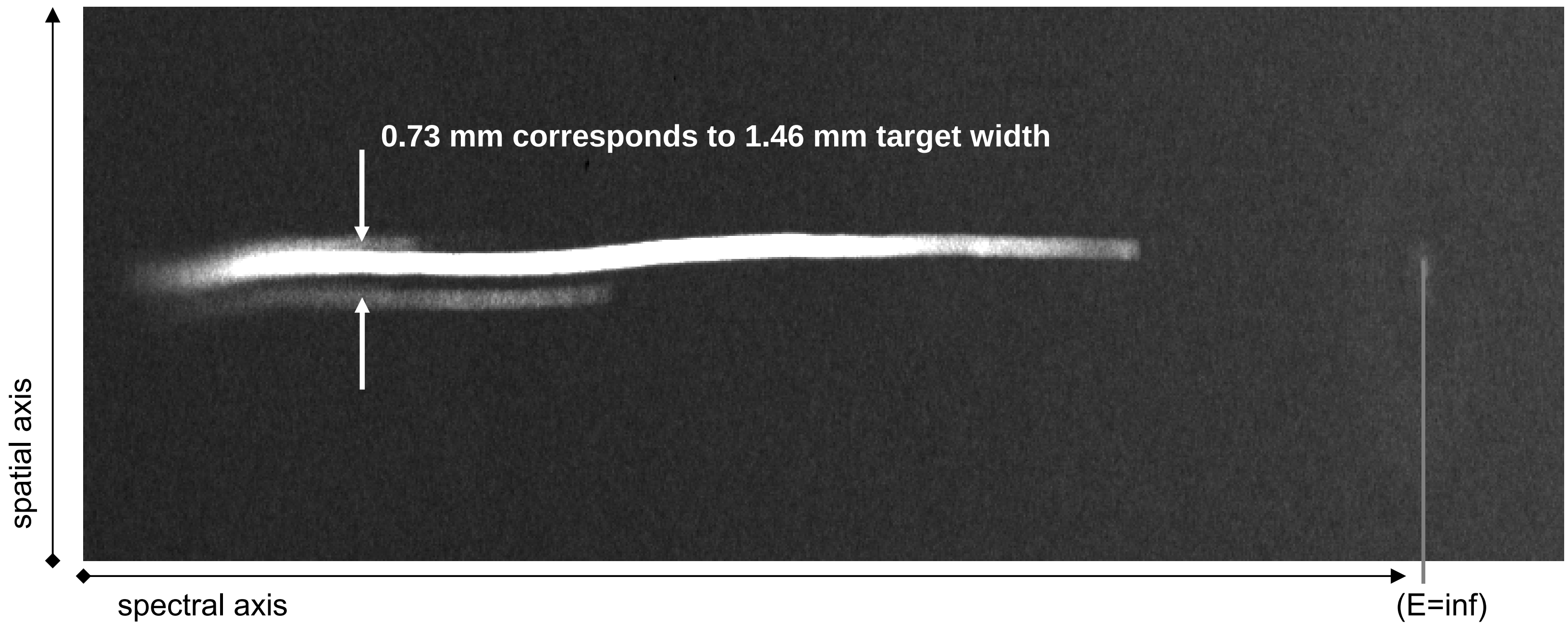
While of no immediate mission concern, laser generated ions are of high interest to our field due to the potential of a brilliant burst of charged particles for interaction with a primary target or as a diagnostic tool.
Many aspects of laser generated ions are still unclear.
Our main scientific focus includes:

- Emission characteristics
- Spectra
- Species
- Radiography concepts
- Fast ignition scenarios*

*(not yet experimentally addressed)

Ion Acceleration

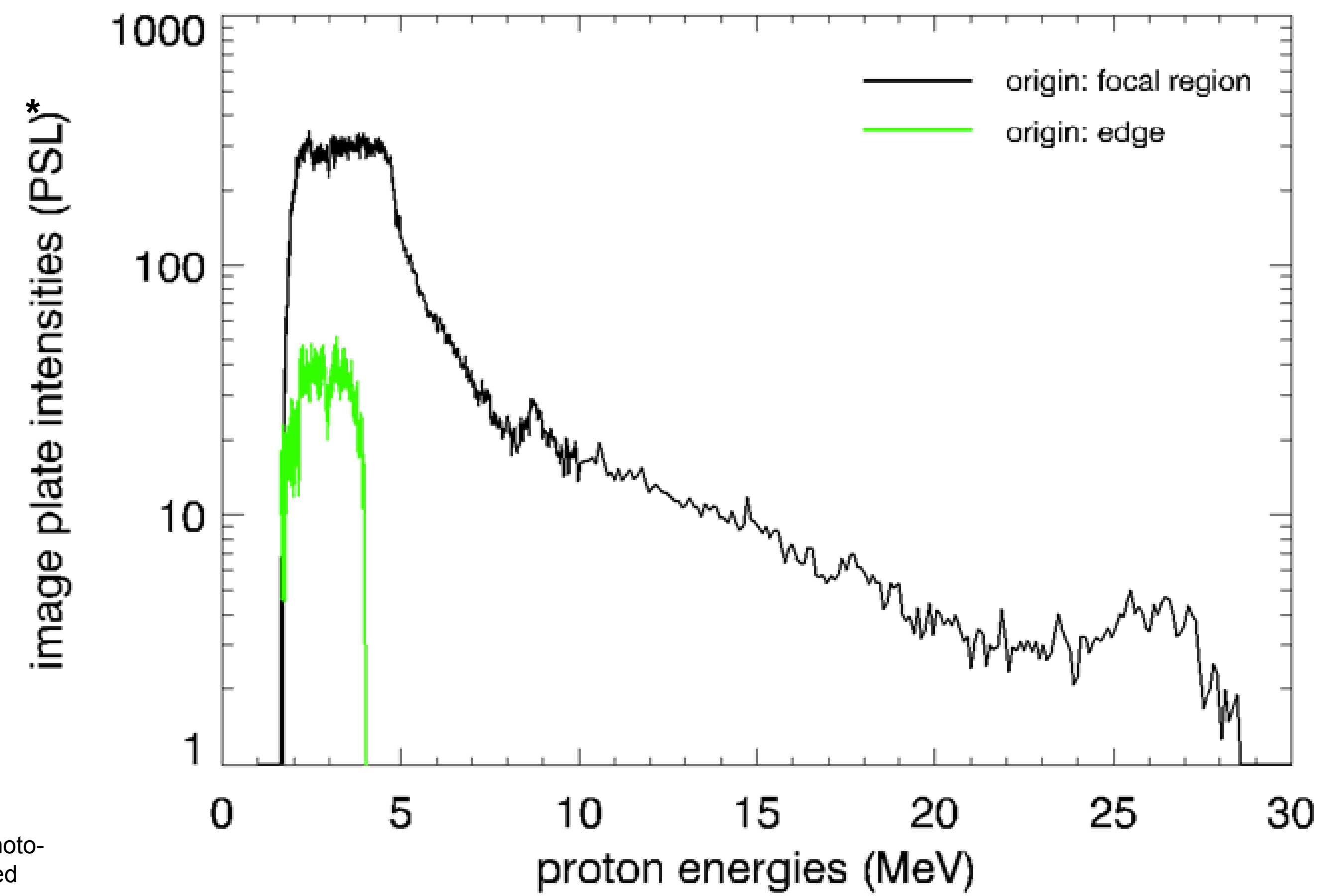
Proton Traces on B-Spectrometer



Low energy protons are emitted from the edges of the target foil and leave parallel ghost images on the image plate behind the Thomson parabola. Similar to X-ray emission, the intensity is substantial due to field enhancement at an edge. The entrance pinhole of the spectrometer projects a 1:2 demagnified 1D-image of the source.

Ion Acceleration

Proton Traces on B-Spectrometer

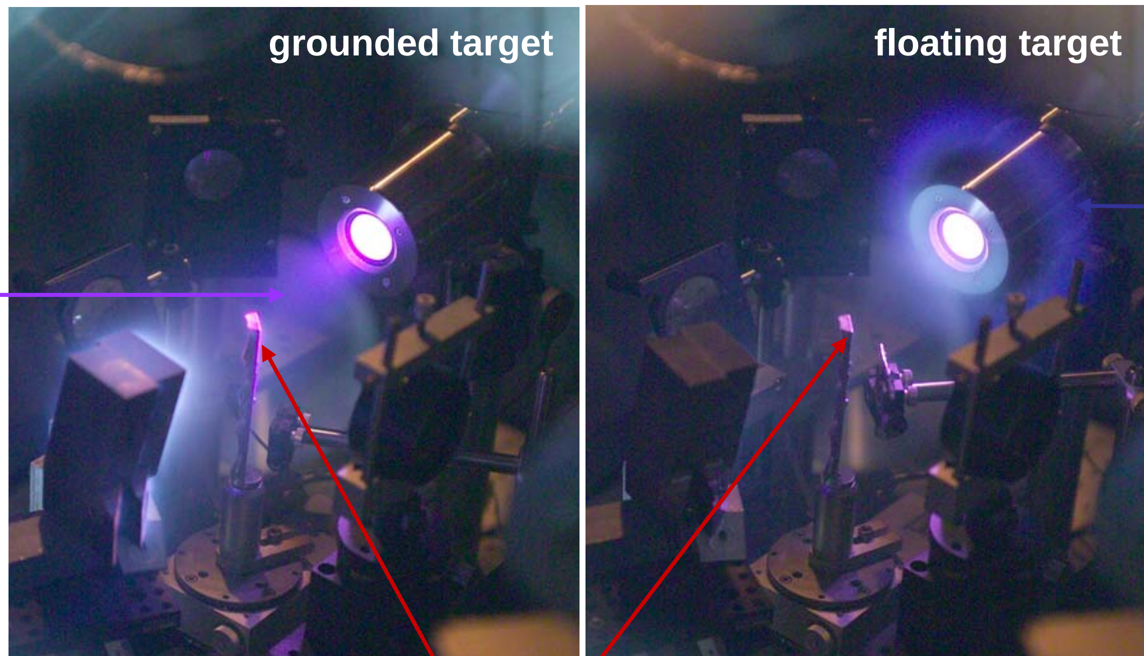


*PSL: photo-stimulated luminescence

Petawatt

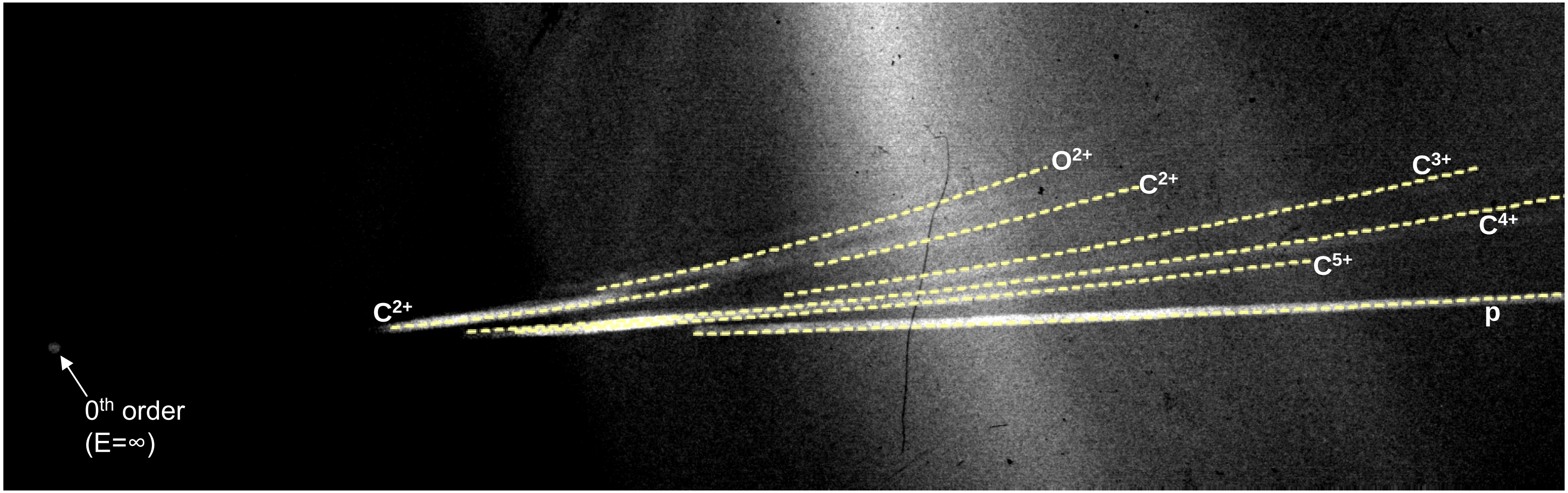
Ion Acceleration

Cleaned Targets for Controlled Contamination Layers: Electrostatic Charge of the Target



Ion Acceleration

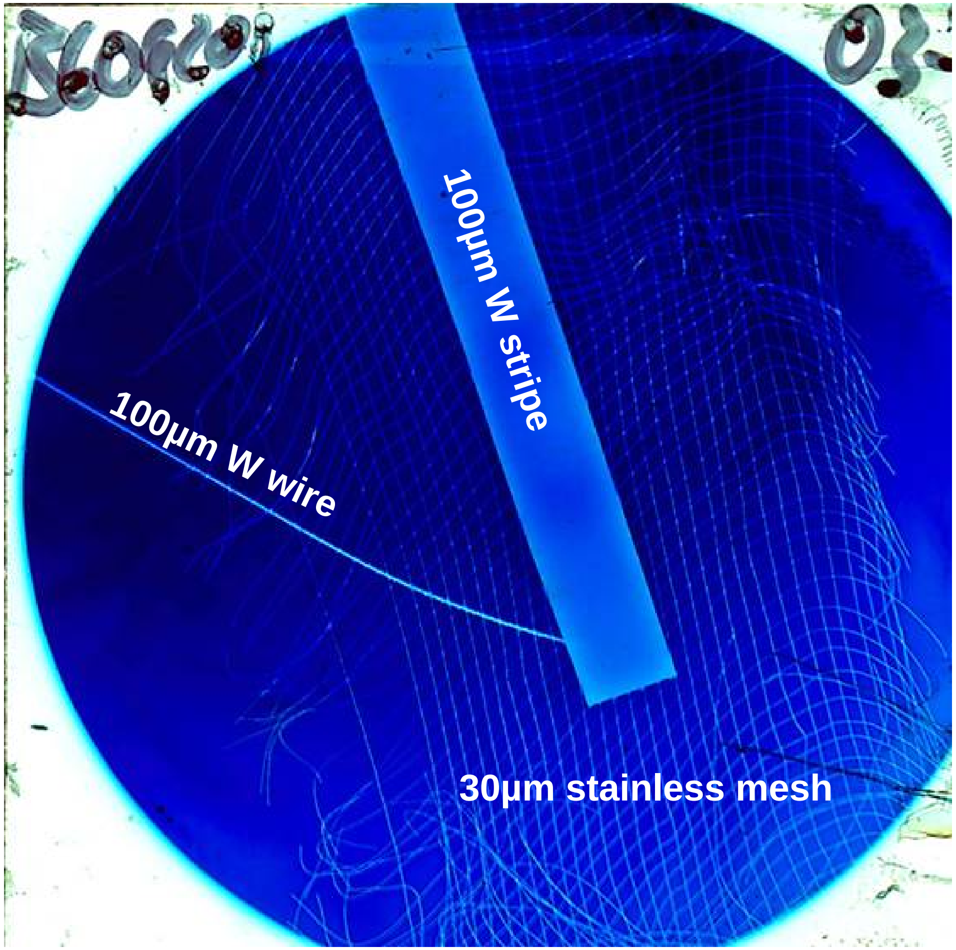
Cleaned Targets for Controlled Contamination Layers: Suppressing Protons and Enhancing Carbon



species	p	C^{5+}	C^{4+}	C^{3+}	C^{2+} (i)	C^{2+} (ii)	O^{2+}
E_{max}	7.7 MeV	30 MeV	24 MeV	4.4 MeV	9 MeV	1.8 MeV	2.6 MeV
E_{min}	<1 MeV	4.2 MeV	1 MeV	1.2 Mev	2.4 MeV	0.9 MeV	0.8 MeV

Proton Radiography

First Results

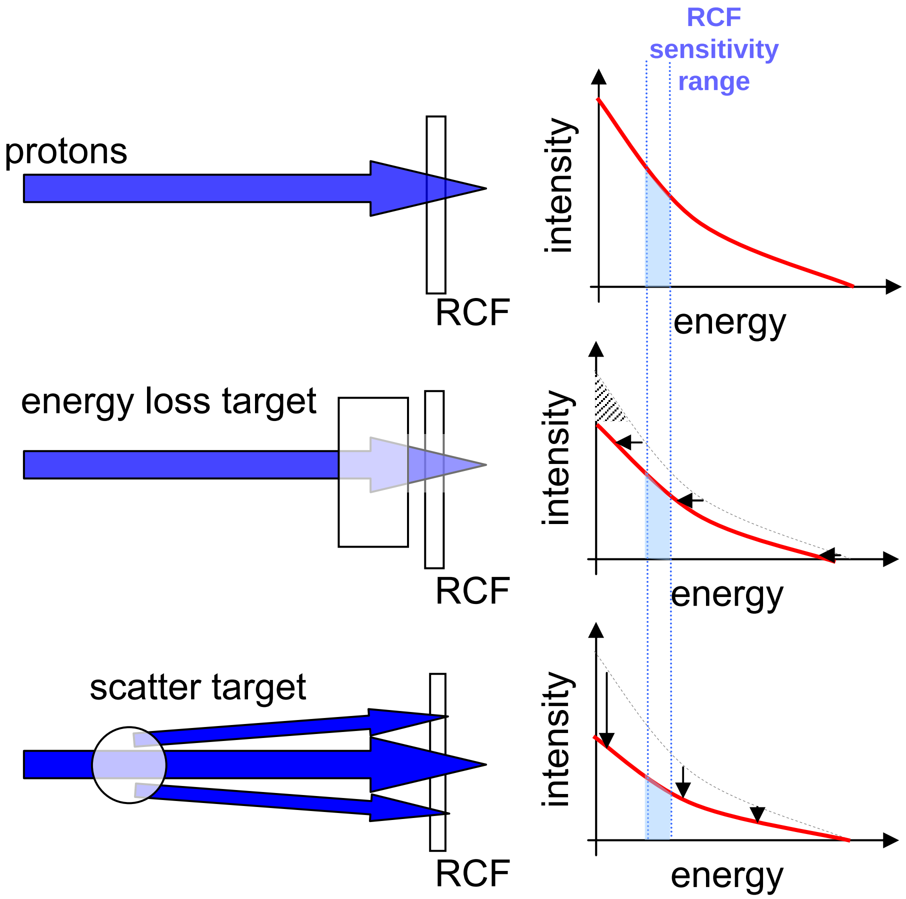


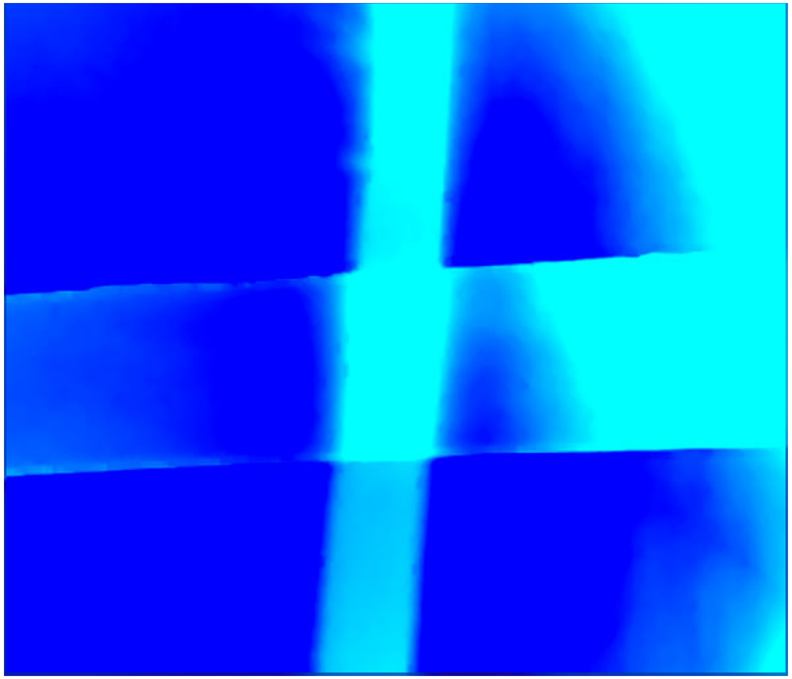
SHOT # B6092003

Petawatt

Proton Radiography

Scattering vs. Energy Loss



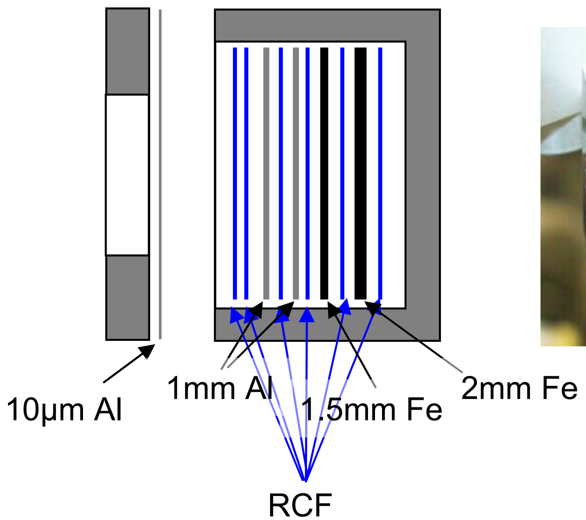


SHOT # B6090701 (5th layer)

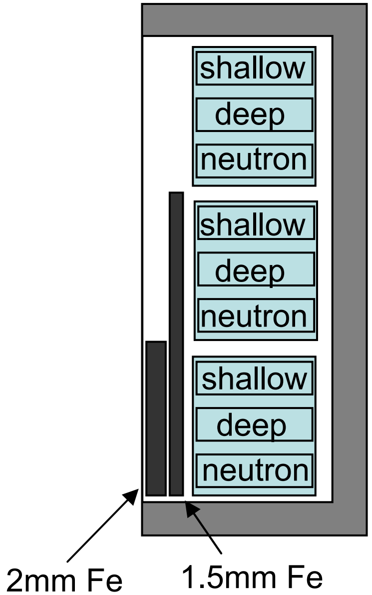
Radiation Hazard Assessment

One important concern is the timely assessment of hazards, namely of radiological hazards with ultra-intense high energy laser facilities. To address this question, we employ two different radiation detection systems:

SHEEBA: Spatial high energy electron beam analyzer
(based on Galimberti et al., Rev. Sci. Instr. 76, 053303, 2005)



TLD (thermoliminescend dosimeter) **'Tower'**



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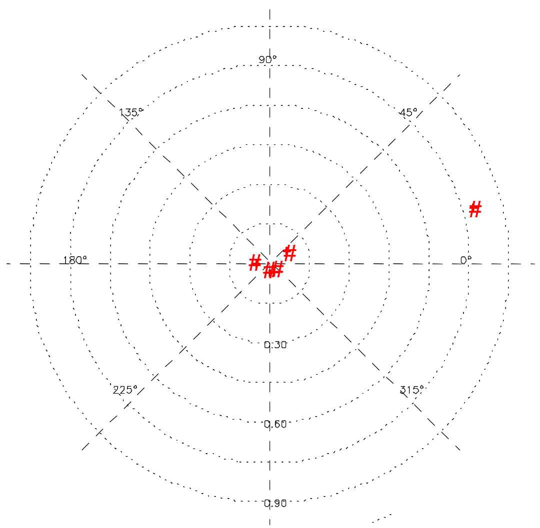
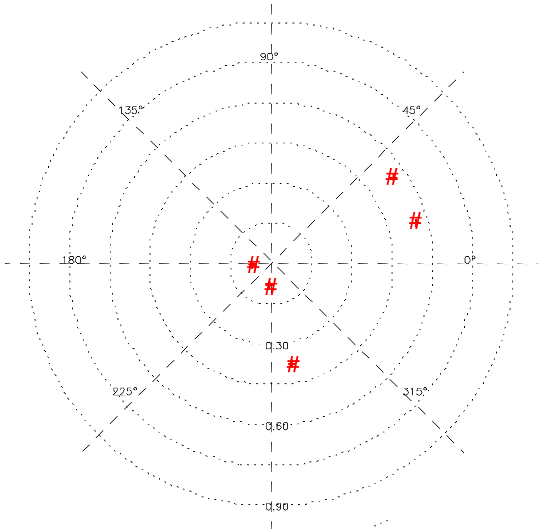
Radiological Measurements

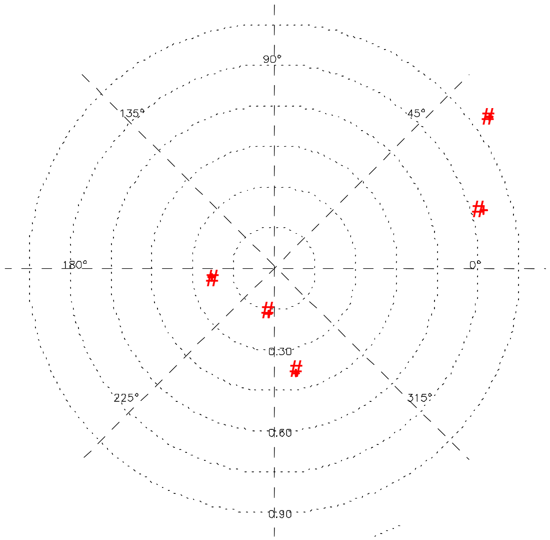
LULI, June 2006, TLD towers



Non shielded TLD, shallow
Max. dose = 65 rem / shot
Min. dose = 5.3 rem / shot



Shielded TLD (1.5mm steel), deep
Max. dose = 167 mrem / shot
Min. dose = 26 mrem / shot



Shielded TLD (3.5mm steel), deep
Max. dose = 22 mrem / shot
Min. dose = 10 mrem / shot

20 shots
Average laser energy = 13.4 J

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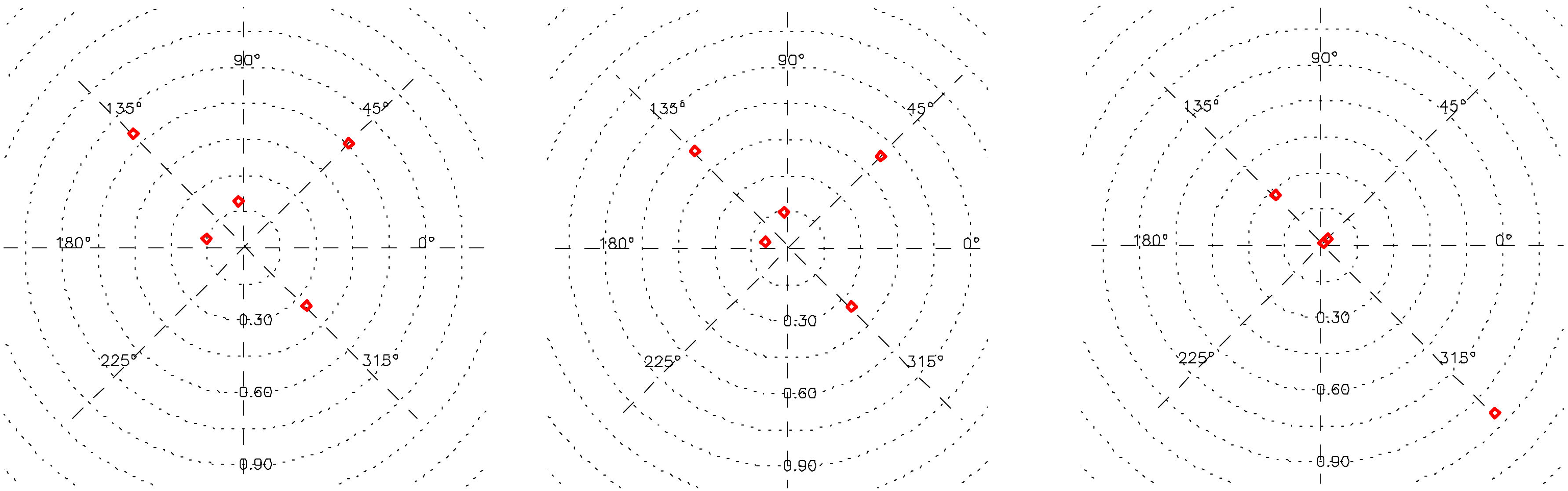
Radiological Measurements

LULI, June 2006, SHEEBA detectors



1st layer (+ 3µm Al)
Max. dose = 17 rem / shot
Min. dose = 3 rem / shot

2nd layer (+ 3 µm Al)
Max. dose = 17 rem / shot
Min. dose = 2 rem / shot

4th layer (+ 2mm Al)
Max. dose = 5 rem / shot
Min. dose = 0 rem / shot

53 shots
Average laser energy = 16.2 J

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Radiological Measurements

Comparison of TLD Measurements

SNL

shallow	deep	inside	outside	shield	distance [cm]	dose per shot [rem]
x		x		no	27	**161**
	x	x		no	14-41	**< 2**
x			x	glass	80	**0.21**
	x		x	glass	80	**0.11**
x			x	Al	80	**0.002**
	x		x	Al	80	**0.001**

LULI

shallow	deep	shield	distance [cm]	dose per shot [rem]
x		no	48	**66**
	x	no	30-48	**< 2**
x		1.5mm	30-48	**< 0.3**
	x	1.5mm	30-48	**< 0.15**
x		3.5mm	30-48	**<0.04**
	x	3.5mm	30-48	**<0.02**

Present Project Status
and
Expected performance

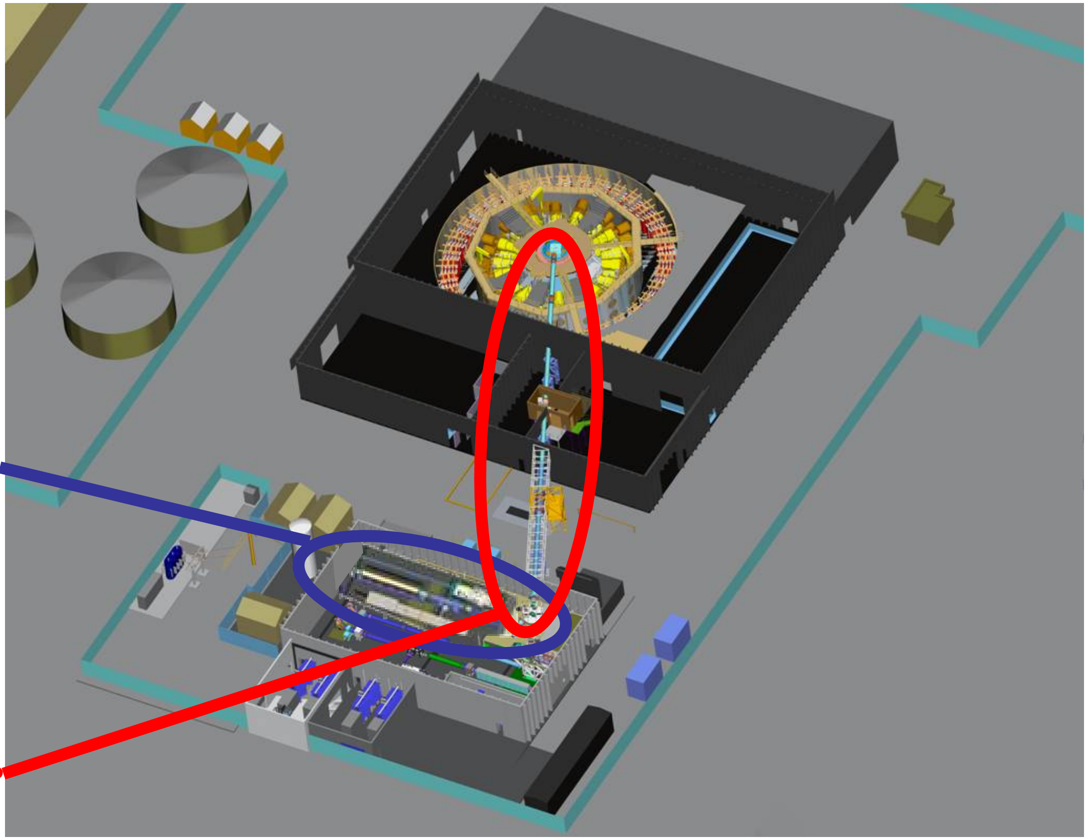
100TW and Z-Petawatt Parameters

Gold gratings:
0.4J/cm² (orth. σ)

t_{laser}=500fs
$\Delta\lambda$=4nm
ΔI_{max}=1:1.4

100TW Parameters:
FWHM: 15cm
A=176cm²
Max Energy: $(176cm^2 \cdot 0.4J/cm^2)/1.4=50J$
Max Peak Power: 100TW

ZPW Parameters:
FWHM: 43cm
A=1452cm²
Max E: $(1452cm^2 \cdot 0.4J/cm^2)/1.4=415J$
Max Peak Power: 0.83PW



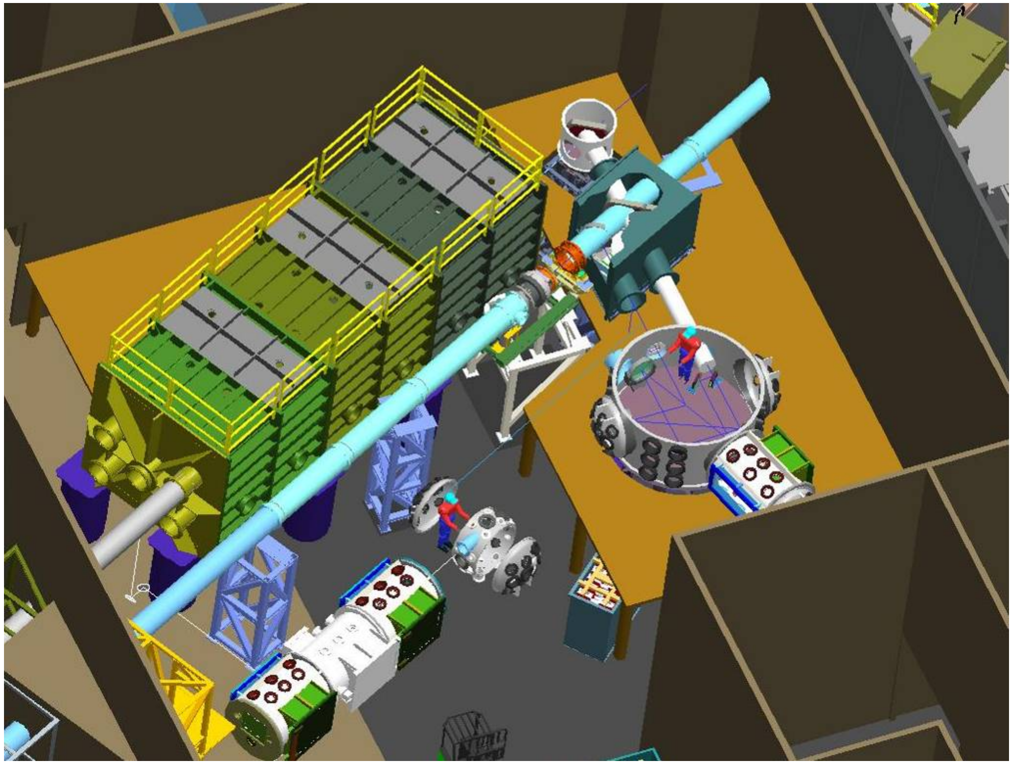
Z Petawatt

Z Petawatt

Expected Completion Date: September 2007

•Compressor Vessel:

- Two optical decks
- movable optical tables
- 13.56 × 4.36 × 4.36 m^3
- Weight 32.3 Tons
- 4600m^3/h roughing capacity
- 3× ISO-K 500 cryo pumps



Z Petawatt

Z-Petawatt

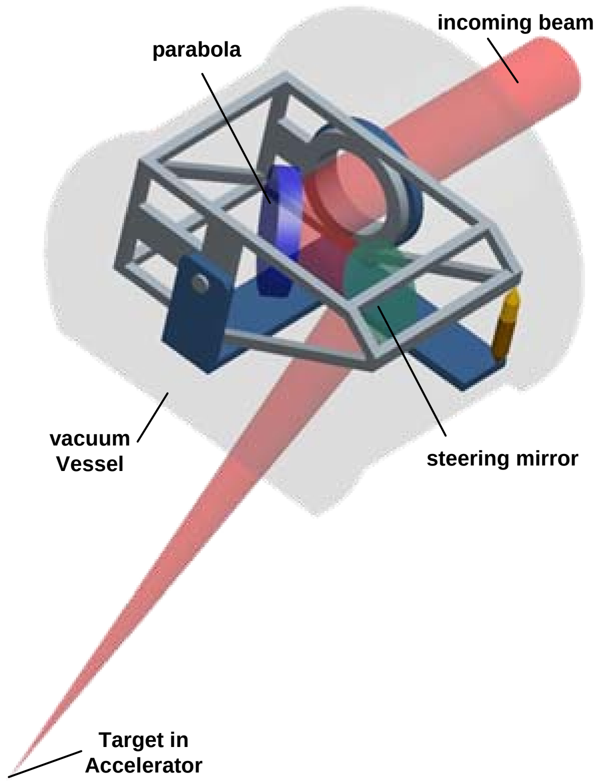
Expected Completion Date: September 2007

"Phase C" Petawatt compression bay and suggested HEDP laser target area.

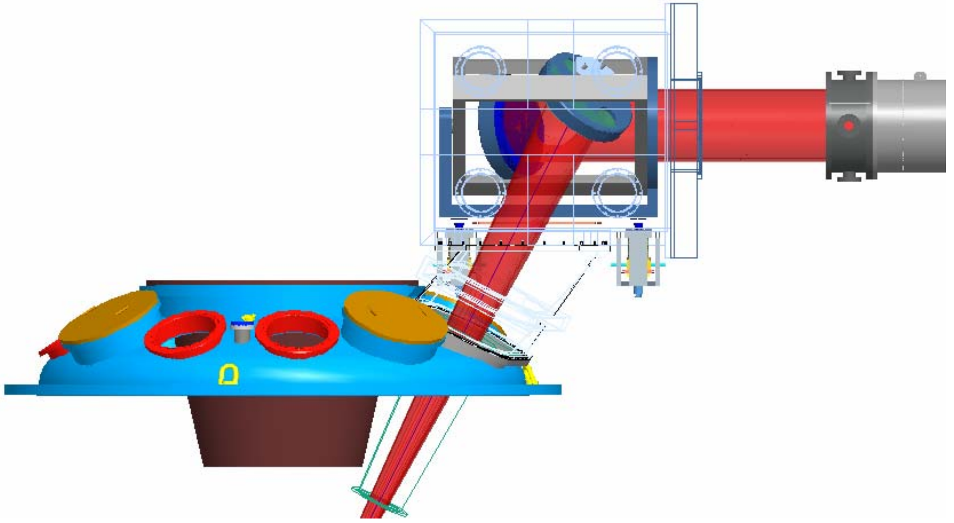
Phase C stages as switchyard for the injection of Z-Beamlet or Z-Petawatt into Z, too.

Z-Petawatt

Focusing Optics Assembly

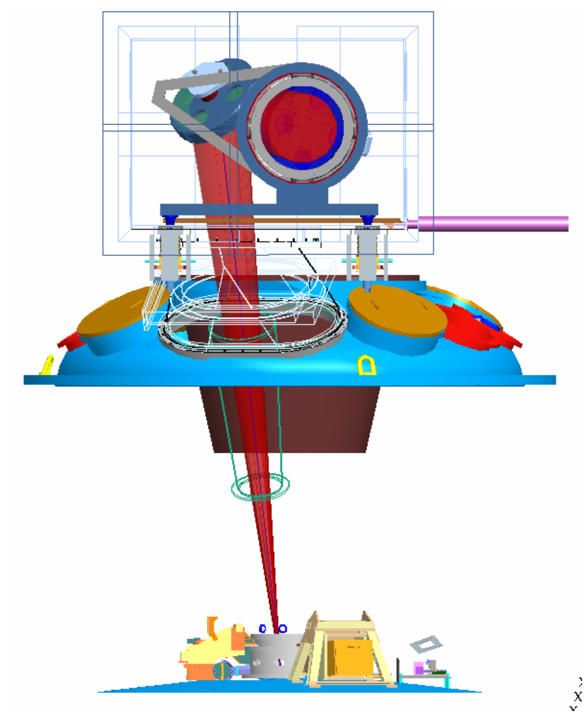


- The Final Optics Assembly (FOA) will have to transition to an all-reflective approach.
- The ZPW requirement for vacuum transport to target will use a vacuum vessel on the ZR lid (like the off-axis FOA currently).
- The flexible design will allow 1ω or 2ω

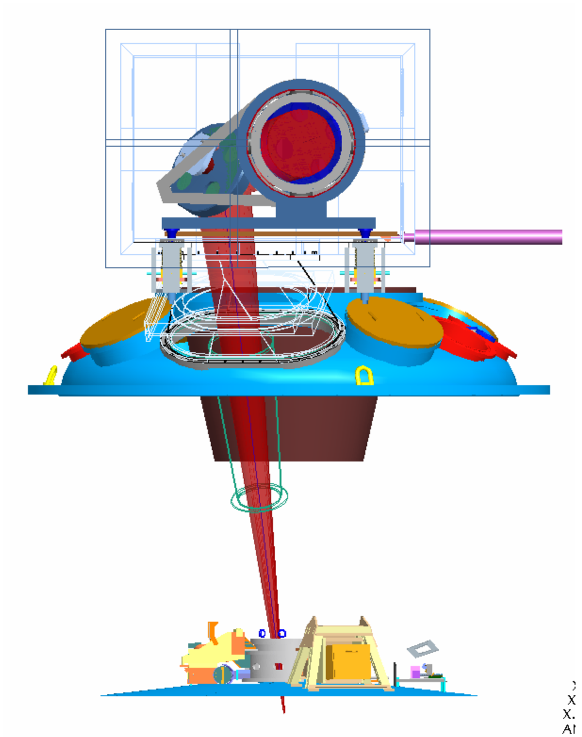


Focusing Optics Assembly

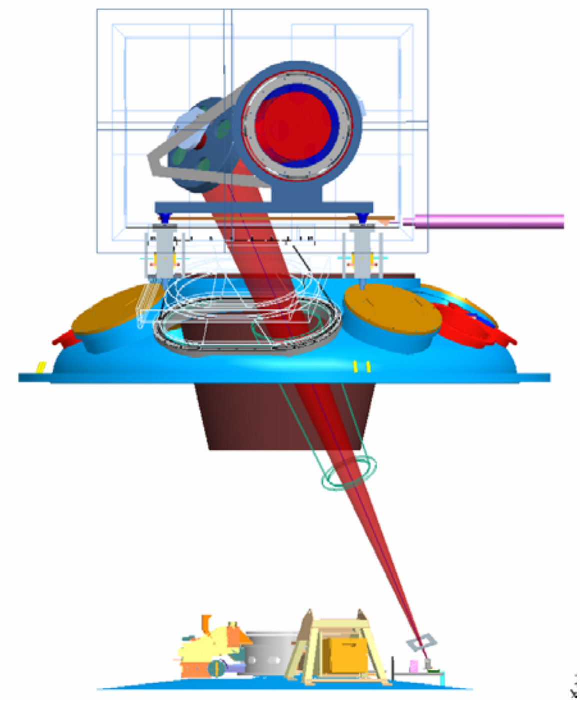
The new FOA will allow more pointing flexibility.



Crystal imaging



Defocus or fold horizontal



Point projection

…And anything in between!

Petawatt

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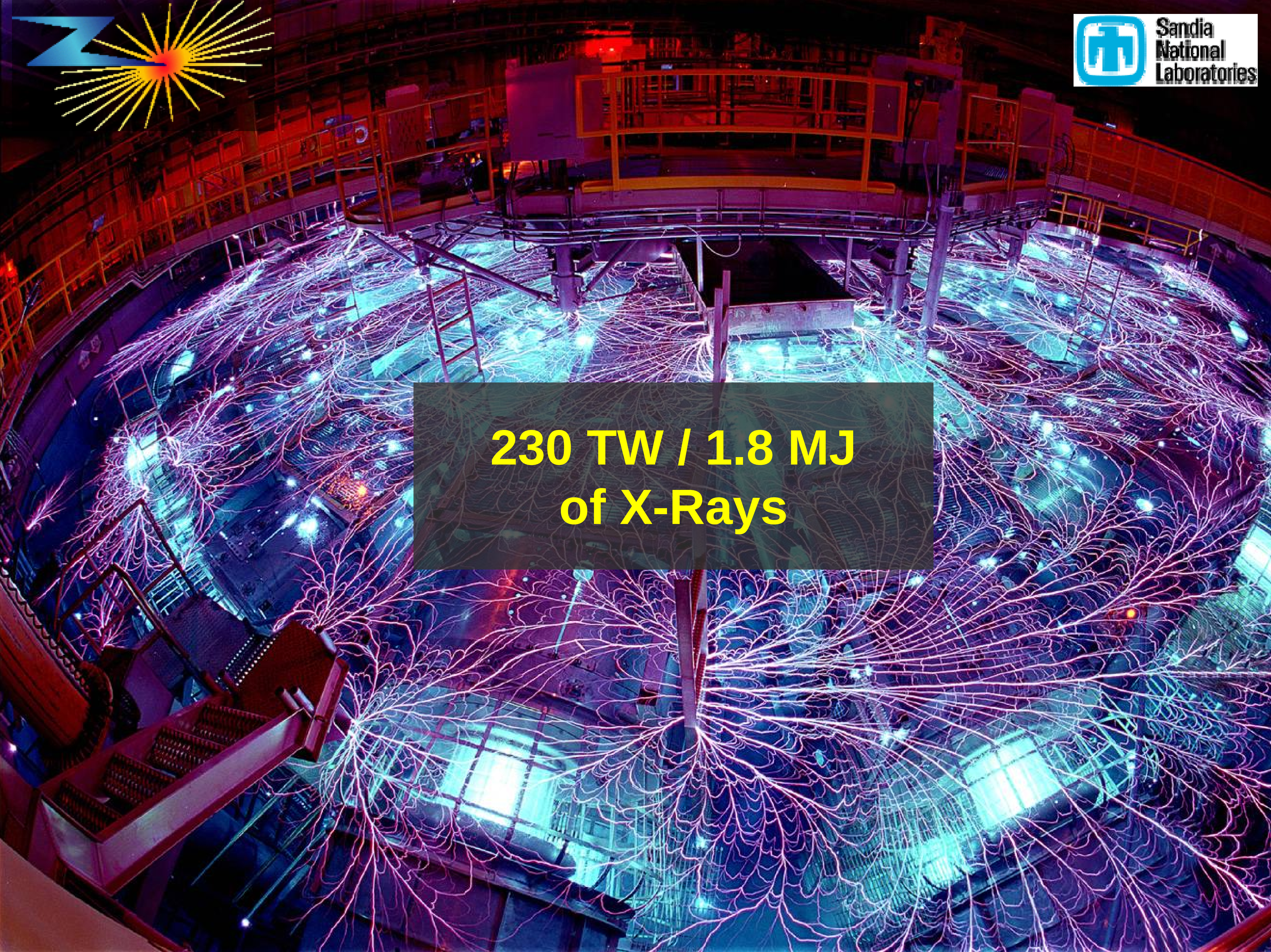
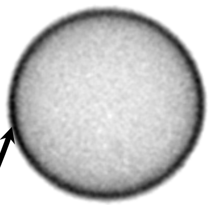
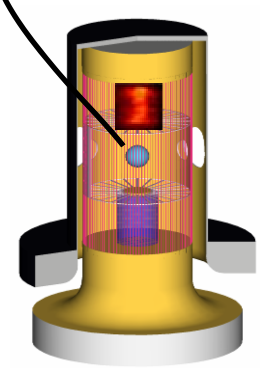

Sandia National Laboratories
230 TW / 1.8 MJ
of X-Rays

Compression on Z

ICF Spherical implosions



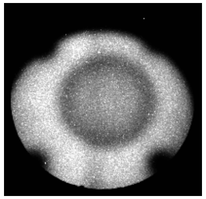
Pre-shot



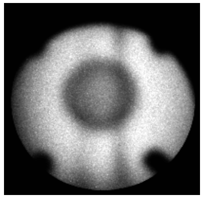
Double-Pinch

Hohlraum

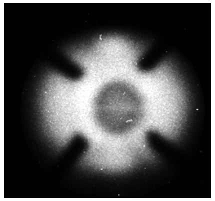
Z830



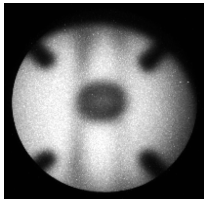
Z831



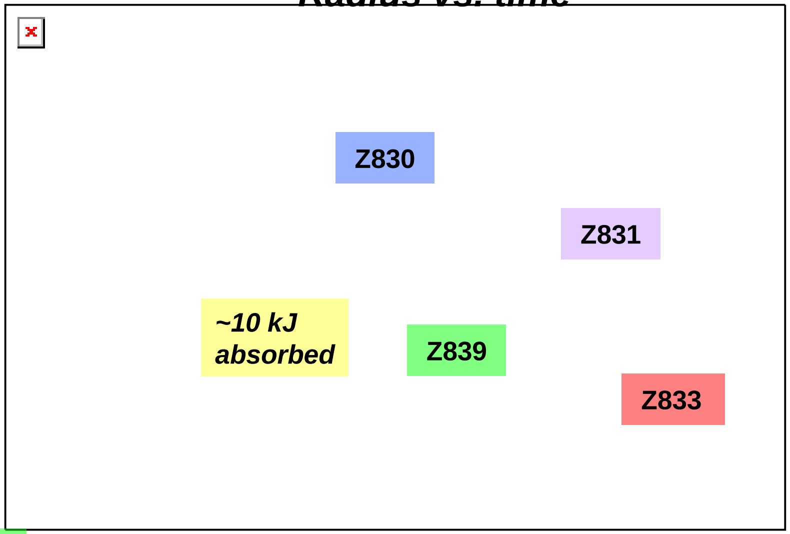
Z839



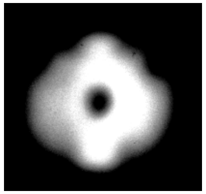
Z833



Radius vs. time



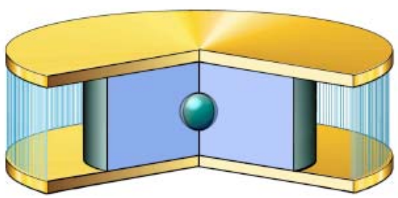
Peak density
~ 40 g/cc
CR > 14*



* up to 20 has been demostrated

Compression on Z

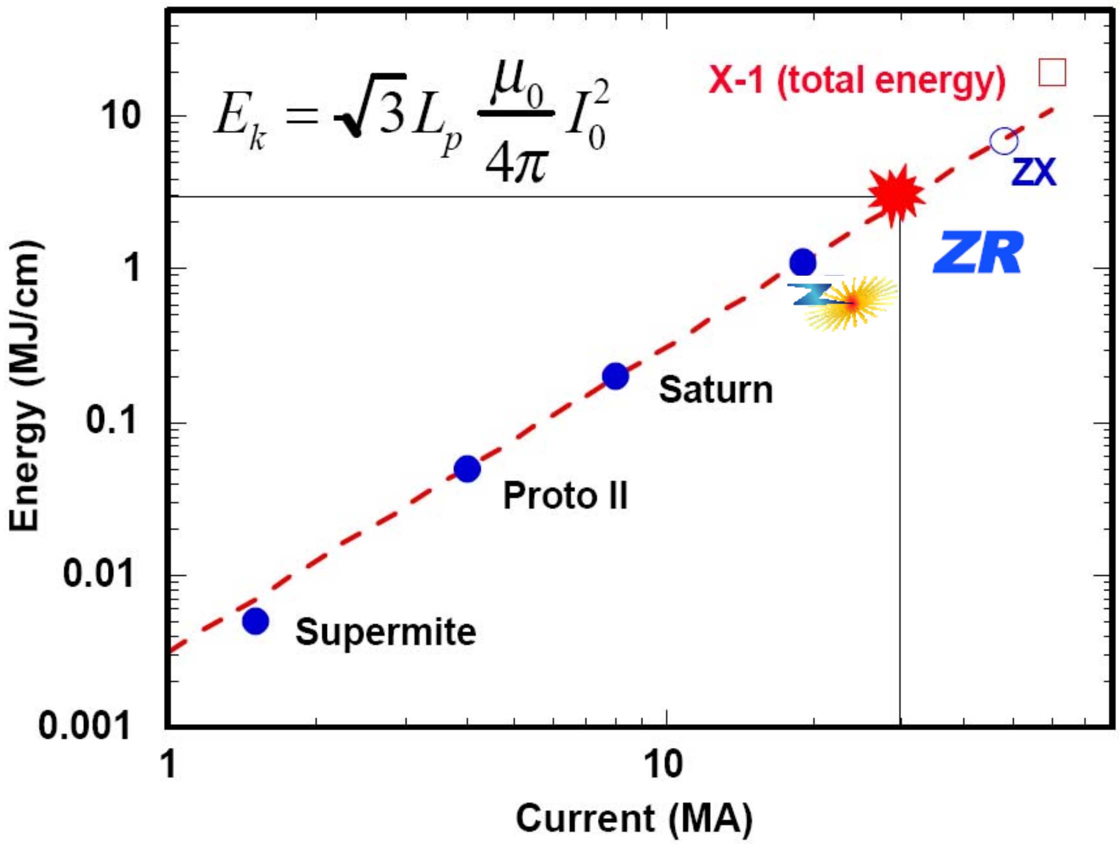
Dynamic Hohlraum



Demonstrated D-D neutrons

• **Maximum yield:**	**8×10^{10} neutrons**
• **Convergence ratio:**	**~ 10**
• **Hohlraum temperature:**	**~ 220 eV**
• **Absorbed X-ray energy:**	**~ 24 kJ**

Upgrading Z



The ZR upgrade:

ZR = Z Refurbishment

X-ray power: 350TW

X-ray energy: 3 MJ

Max. current: 30 MA

Conv. Ratio ~ 25

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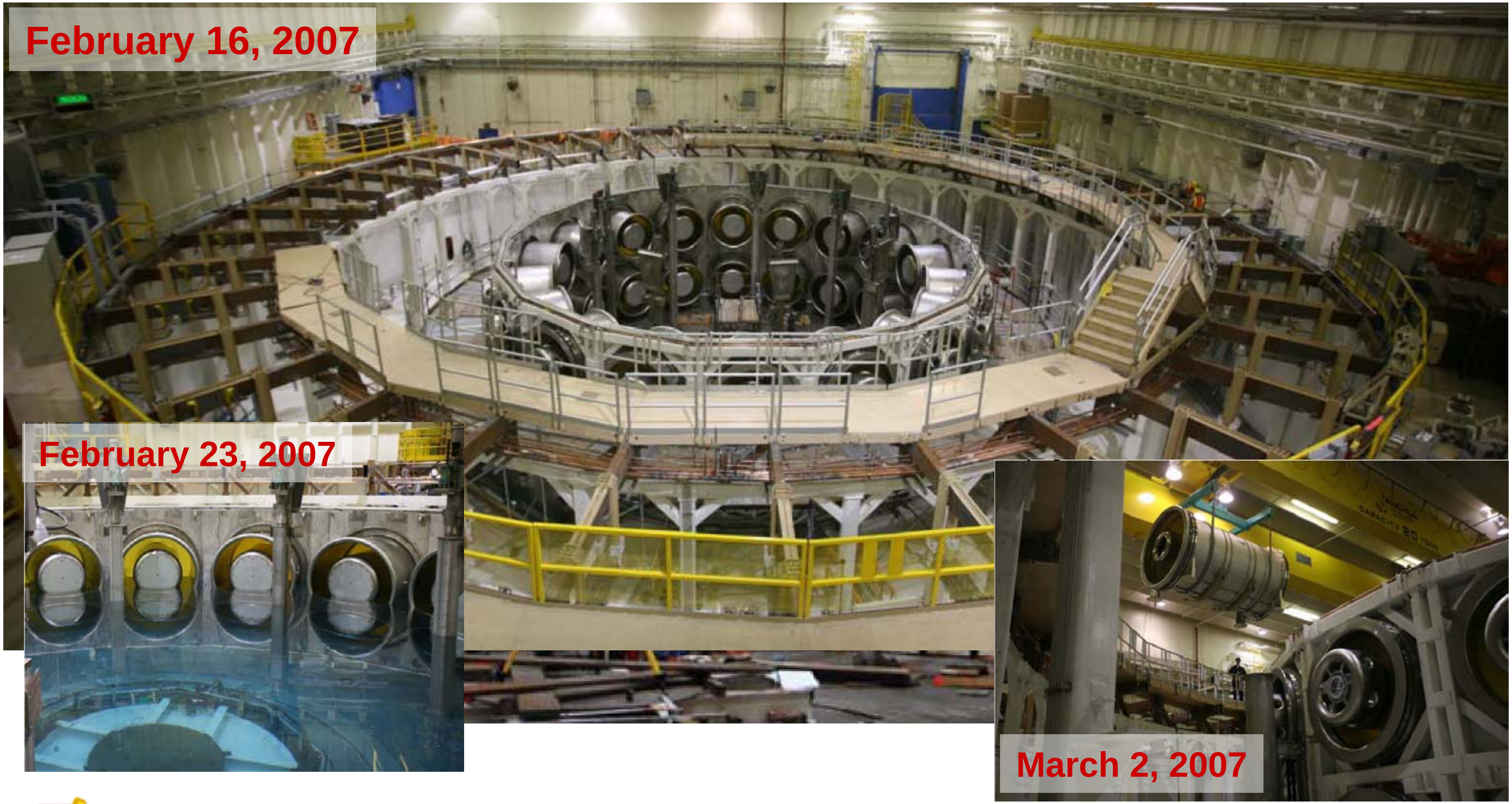
Z-Refurbishment

Expected Completion Date: August 2007



Z Petawatt

Timeline

front-end, 100TW subsystem
operational

PW compressor, cleanroom
completed

ZR and Z-PW
September 2007