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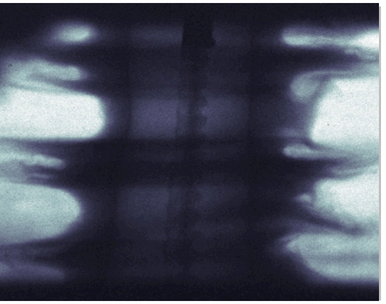

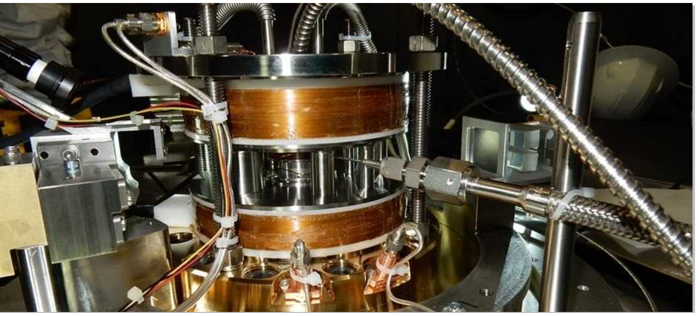

A 7.2 keV spherical crystal backlighter system for Sandia’s Z Pulsed Power Facility

Marius Schollmeier, P.F. Knapp, D.J. Ampleford, G.P. Loisel, G.K. Robertson, J.E. Shores, I.C. Smith, C.S. Speas, J.L. Porter, and R.D. McBride

DPP16 Meeting of The American Physical Society
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San Jose, California

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X-ray backlighter radiography with spherical crystals at Z

X-ray sources:
- Si He_α (1.865 keV) and/or
- Mn He_α (6.151 keV)

X-ray crystals:
- Qz (10$\bar{1}$1), ϑ_B = 83.9°
- Qz (22$\bar{4}$3), ϑ_B = 83.19°

Imaging parameters:
- FOV: 11.7 x 4 mm
- Magnification: 5.8
- Spatial resolution: 12 µm

Z-Beamlet laser (ZBL):
- 527 nm, 1 kJ, f/10 focusing
- two pulses, angularly multiplexed

Advantages:
- high sensitivity
- monochromatic
- <20 µm spatial resolution over large field-of-view (≈1 cm^2)
- no direct line-of-sight to object for debris and background mitigation

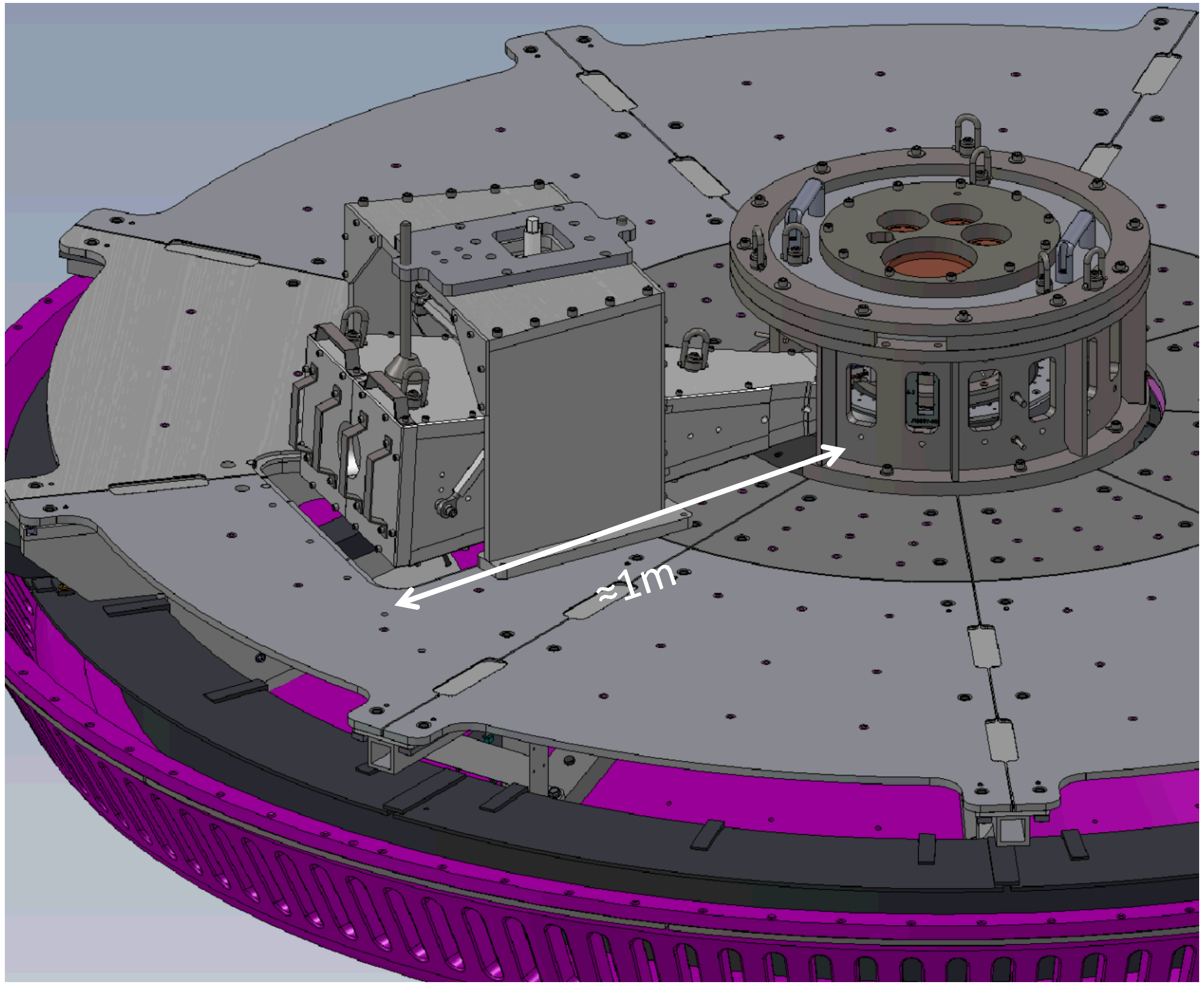
Limitations:
- Need to fulfill the Bragg condition:

$$E = m\, hc/(2d \sin \vartheta)$$

- Astigmatism due to off-normal incidence
- Source needs to emit suitable x-ray spectral line

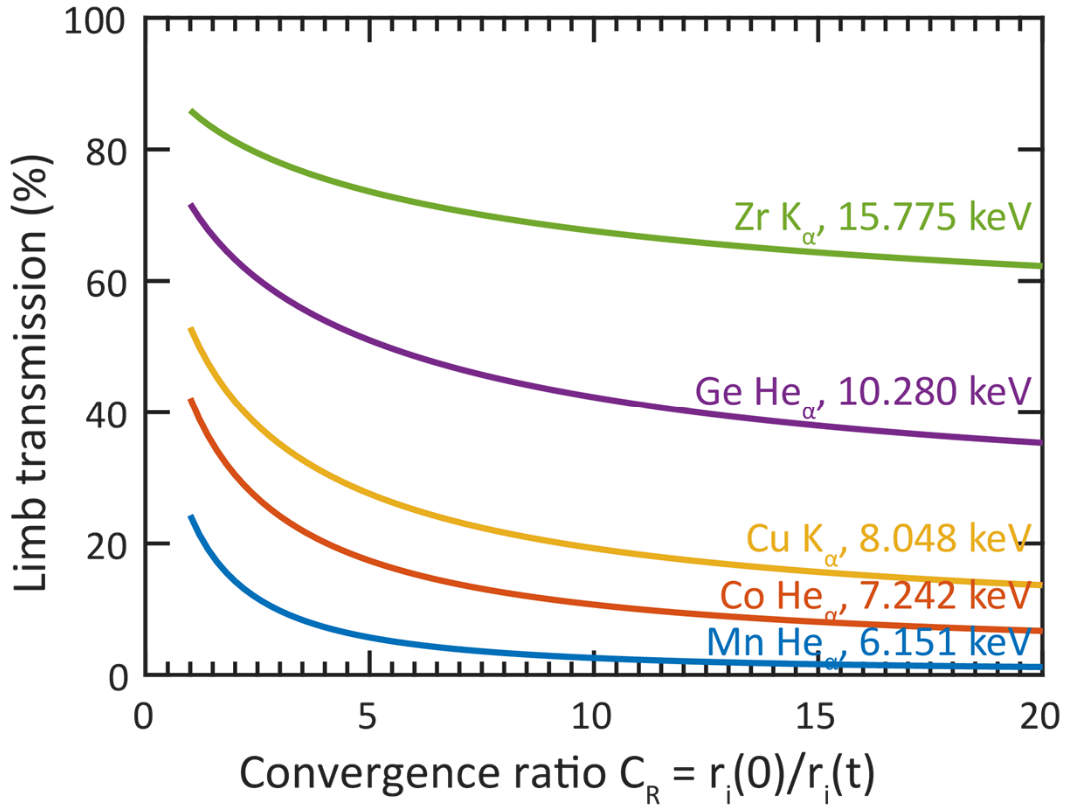
Z backlighter camera shielding

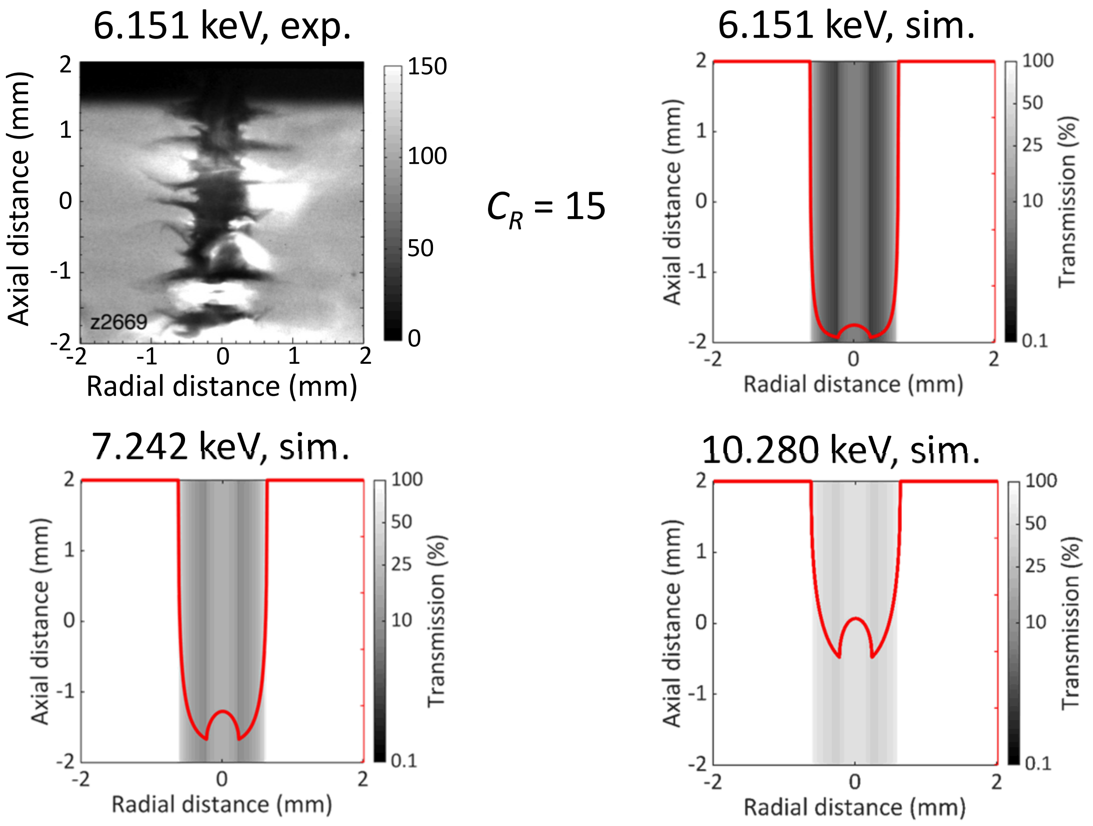
- Can accommodate two 75 mm image plates or two gated hCMOS cameras
- Material: 1” tungsten everywhere
  - Weight: 900 lb/400 kg
  - Cost: ≈$250k just in materials
- Position fixed due to cut-out in base plate and interference with other diagnostics
- Limits Bragg angles to $\vartheta_B = (83.5 \pm 1)°$



The majority of backlighting shots are for Magnetized Liner Inertial Fusion (MagLIF)*

- **In MagLIF, a D_2-filled, cm-scale, thick Be cylinder ('liner') is compressed by Z to achieve thermonuclear conditions**





*see e.g., invited talks by E.C. Harding (KI2.00002), Matthew Martin (NI2.00005), A.B. Sefkow (UI3.00006) at this conference

Systematic search for spectral line/crystal combinations*

Description	Quantity
Elements	Ne – Sn (Z = 10 – 50)
Spectral lines	He-like resonance and intercombination, $K_{\alpha1}$, $K_{\alpha2}$
Energy range	0.848 – 26.027 keV
Crystals	α-Quartz, Ge, Si, Mica, GaAs, InAs
Miller index ranges (*hkl*)	0 – 20 each
Possible combinations tested	9,112,824
Total number of matches with $R_{int} > 0$	37,265
Down-selection for Z application: 6 < E < 10 keV, ϑ = (83.5 ± 1)°	**15**

General search:

- **Use Python script to iterate through all combinations**
- **Call XOP [1] to calculate rocking curve and integrated reflectivity R_{int} for matches**
- **Sort by R_{int} for each element & x-ray energy**

*submitted for publication

[1] M. Sanchez del Rio and R.J. Dejus, Proc. of SPIE 8141, 814115 (2011)

Imaging crystals for the Z facility

index	element	x-ray energy [eV]	crystal	Miller indices (h k l)	ϑ_B [°]	R_{int} [µrad]	PSL* per 25 µm px
1	Si	1865	Quartz	(0 1 1)	83.9	421.17	143
2	**Si**	**1865**	**Quartz**	**(1 0 1)**	**83.9**	**185.40**	**63**
3	Cl	2789.8	Quartz	(1 1 1)	83.5	64.93	9.5
4	**Ar**	**3124**	**Ge**	**(2 2 0)**	**82.8**	**843.15**	**145**
5	Ca	3883	Quartz	(1 2 0)	83.1	11.25	1
6	Sc	4295	Quartz	(1 1 3)	83.5	52.98	3.2
7	**Mn**	**6151**	**Quartz**	**(2 2 3)**	**83.2**	**85.98**	**1.4**
8	**Co**	**7242**	**Ge**	**(3 3 5)**	**82.8**	**118.60**	**0.7**
9	**Ni**	**7766**	**Quartz**	**(2 4 0)**	**83.1**	**63.32**	**0.4**
10	**Zn**	**8999**	**InAs**	**(1 5 7)**	**83.6**	**69.50**	**0.2**
11	Zn	8950	Quartz	(2 1 7)	84.4	20.34	0.07
12	Ga	9628	Quartz	(1 6 0)	82.9	26.48	0.03
13	Ga	9575	Quartz	(4 3 3)	83.2	16.93	0.03
14	Ge	10280	Si	(8 4 0)	83.3	62.12	0.05
15	Ge	10221	Quartz	(3 0 8)	83.9	46.81	0.05

Astigmatism: 5-8 µm, including image plate resolution: 12-14 µm

red = already used combinations
blue = interesting combinations

*PSL = PhotoStimulated Luminescence;
calculated using Z-Beamlet parameters (527 nm, 1 kJ, 1 ns) and 6× magnification

Laser-only tests demonstrated feasibility of using Ge (335) for radiography

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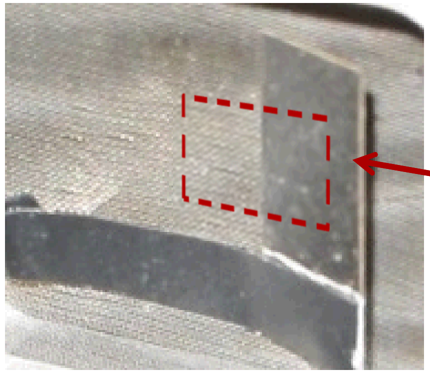
SXRY ray-tracing model:

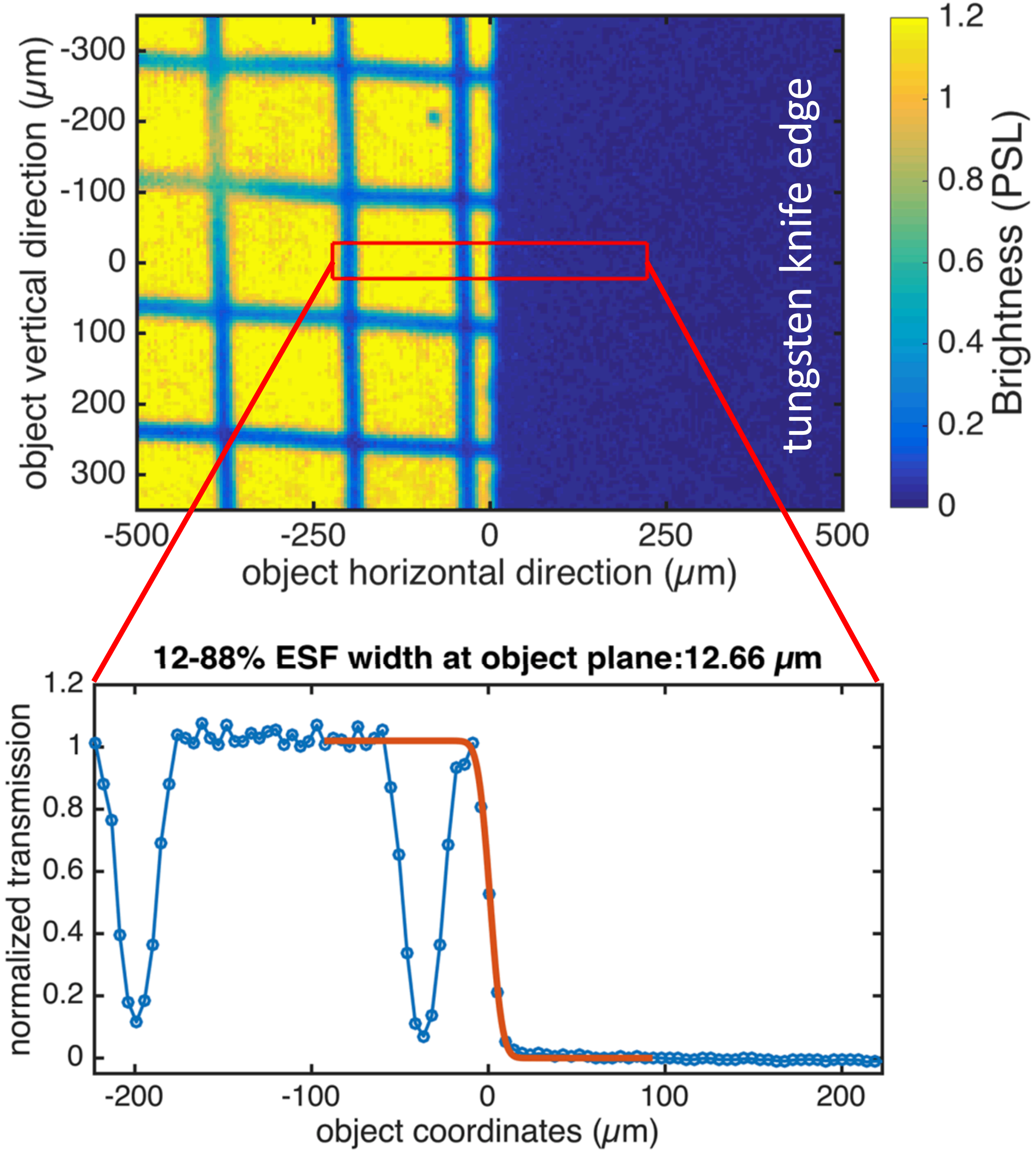
- **Meridional ESF: (12 ± 1) µm***
- **Sagittal ESF: (15 ± 2) µm***
- **Brightness: 750 phot./px**

Measurements:

- **Meridional ESF = (12.5 ± 0.5) µm**
- **Sagittal ESF = (16 ± 0.5) µm**
- **Brightness: 1500 phot./px**

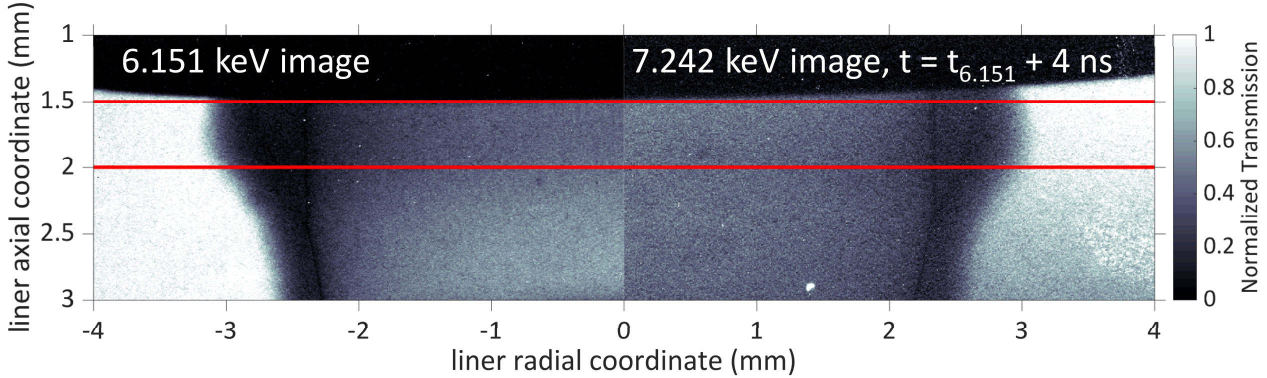


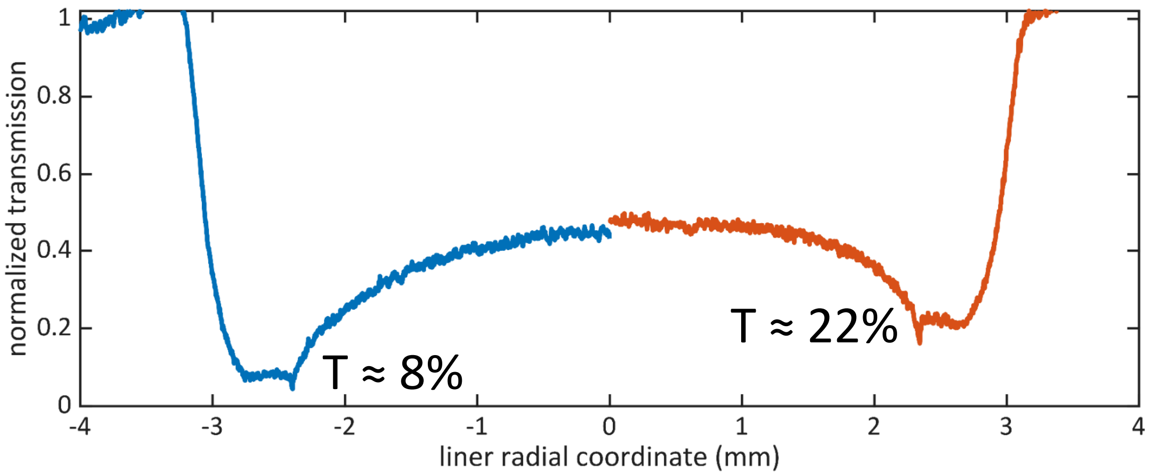
0.5 mm thick tungsten knife edge on 150 lpi mesh

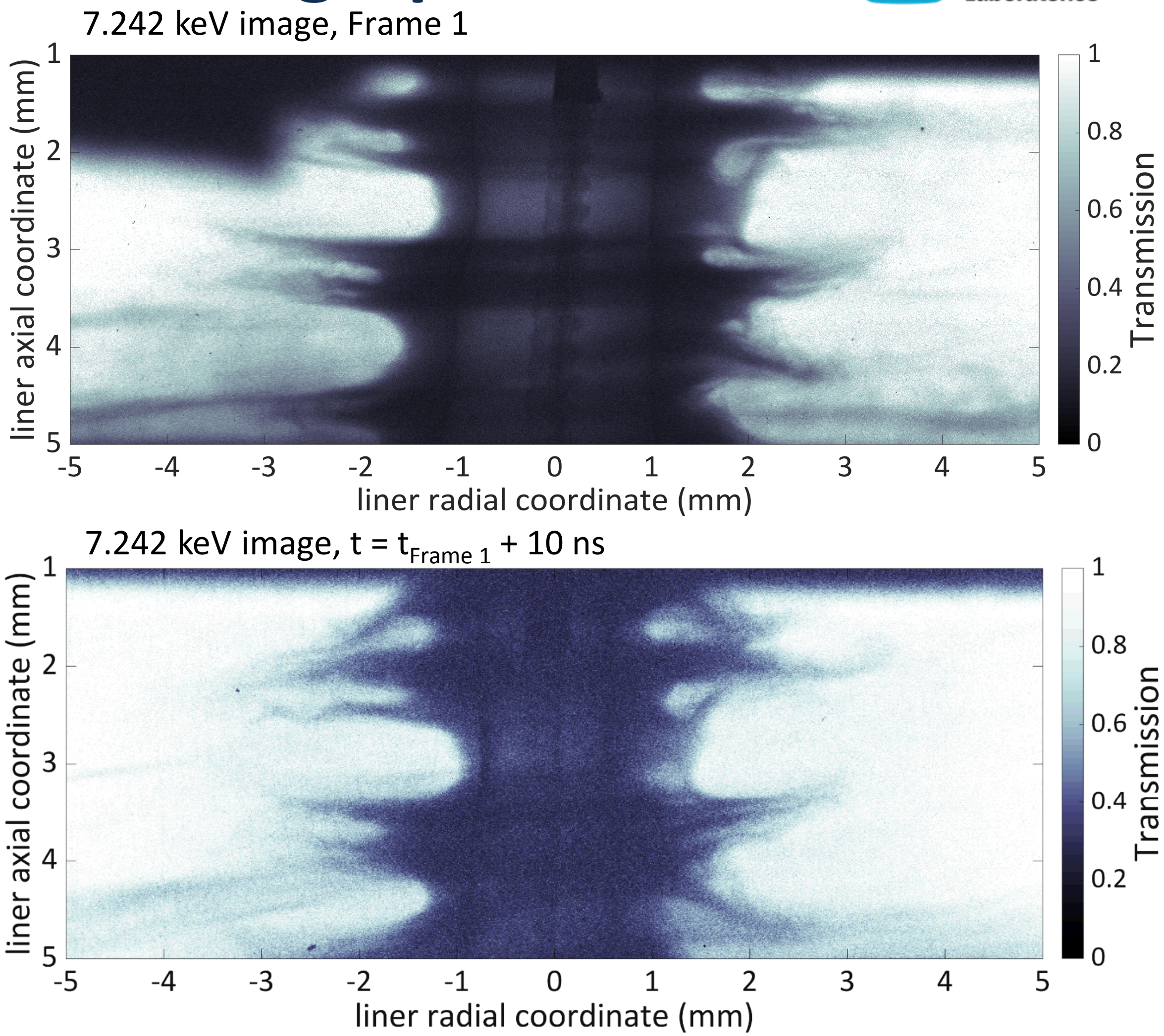


*Using 65 µm Gaussian PSF for detector; T. Ao et al., JQSRT 144, 92-107 (2014)

6.2 and 7.2 keV (two-color), two-frame radiographs







Z shot z2916, ‘Imp Thick-Ends’ campaign. ‘Thick-Ends’ liner design by Adam B. Sefkow, SNL and LLE

Z shot z2942, ‘Eddy’ campaign by Patrick F. Knapp and Matthew Martin, SNL

Summary and Outlook

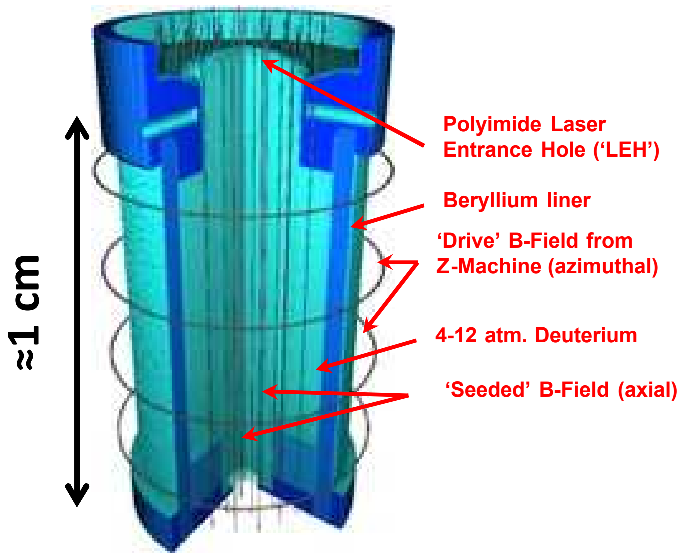
- A systematic evaluation was performed to find spectral-line and spherical-crystal matches suitable for high-resolution imaging at the Z Pulsed Power Facility

- A 7.2 keV backlighter system has been fielded at Z
  - Uses the 7.242 keV Co He-α resonance line and a Ge (335) crystal
  - Bragg angle close to 1.865 keV and 6.151 keV systems, facilitating two-color radiography
  - System still under development: 6 Z shots to date, 2 more scheduled for next week (12 images/crystals total)

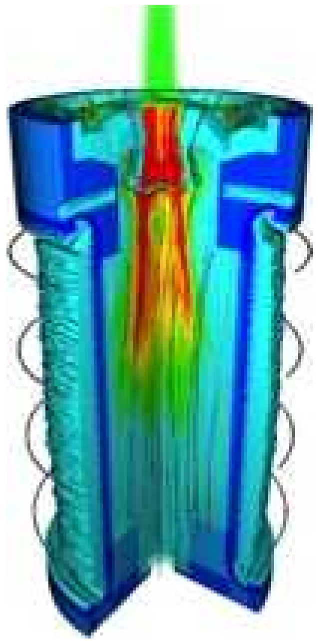
- Some future plans:
  - Confirm consistent performance of 7.2 keV system
  - Develop multi-frame, single line-of-sight backlighting at Z
  - Test higher-energy backlighter options

BACKUP SLIDES

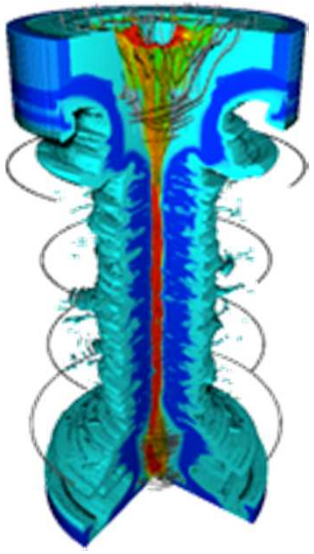
Magnetized Liner Inertial Fusion (MagLIF)*



Initialize axial magnetic field (B_0 = 10-30 T)



Laser heating of fuel (E_L = 2-4 kJ)

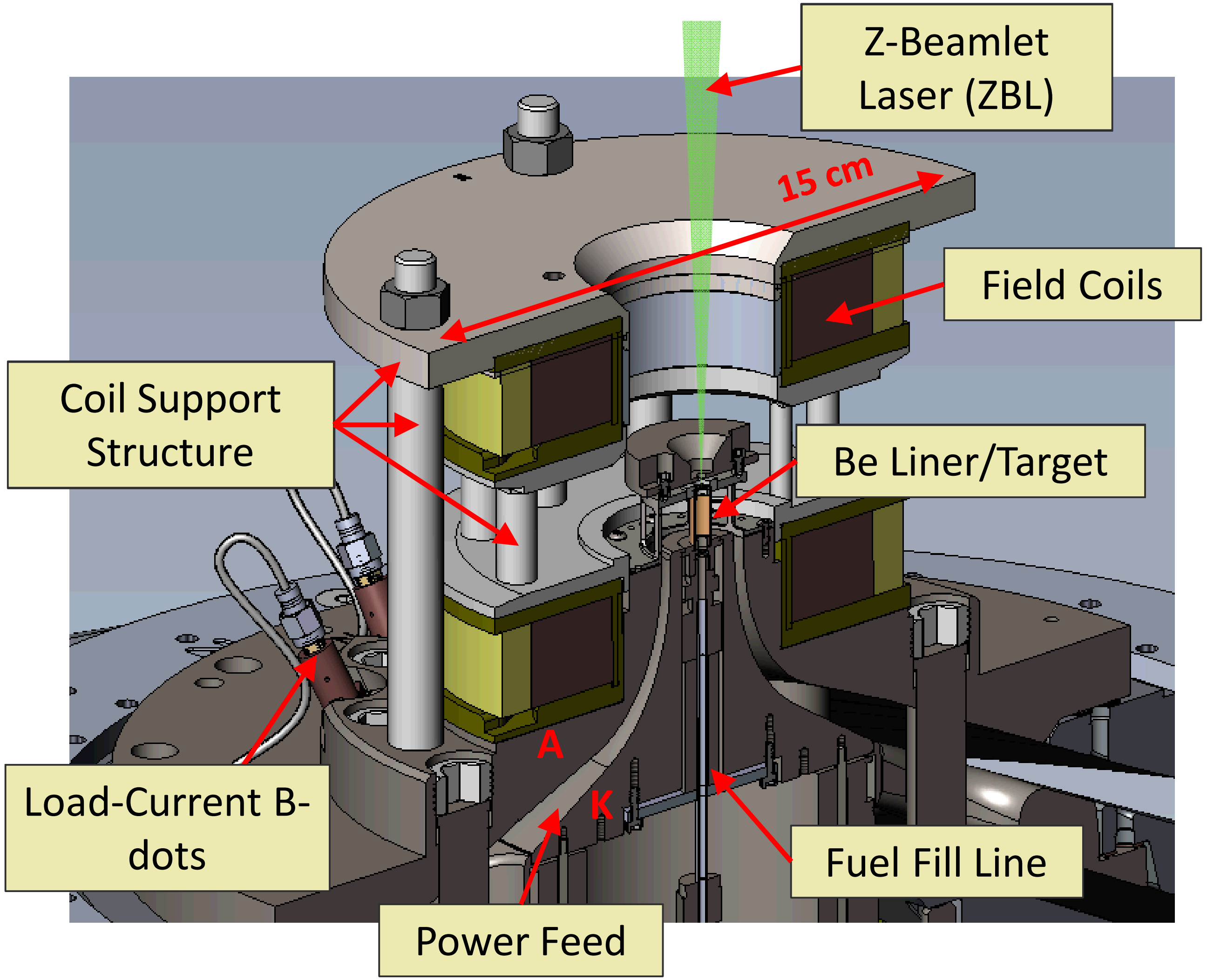


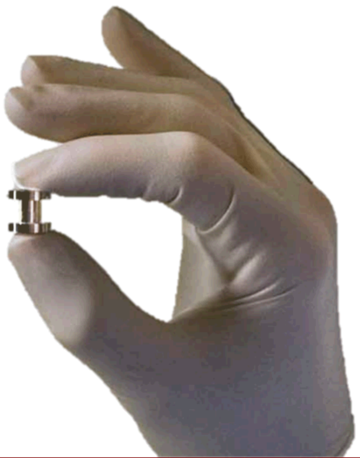
Magnetic compression of fuel

*S.A. Slutz et al.: Physics of Plasmas **17**, 056303 (2010); S.A. Slutz & R.A. Vesey, Phys. Rev. Lett (2012); A.B. Sefkow *et al.*, Phys. Plasmas (2014)

Anatomy of a Magnetized Liner Inertial Fusion (MagLIF)* target

- **Field Coils**: 10-30 T axial field w/ ≈3 ms rise time
- **ZBL**: 1-4 kJ, 2ω, 1-4 ns square pulse w/ adjustable prepulse
- **Power Feed**: Up to 24 MA (typical ≈18 MA) in 120 ns





*S.A. Slutz et al.: Physics of Plasmas **17**, 056303 (2010); S.A. Slutz & R.A. Vesey, Phys. Rev. Lett (2012); A.B. Sefkow *et al.*, Phys. Plasmas (2014)

Literature survey

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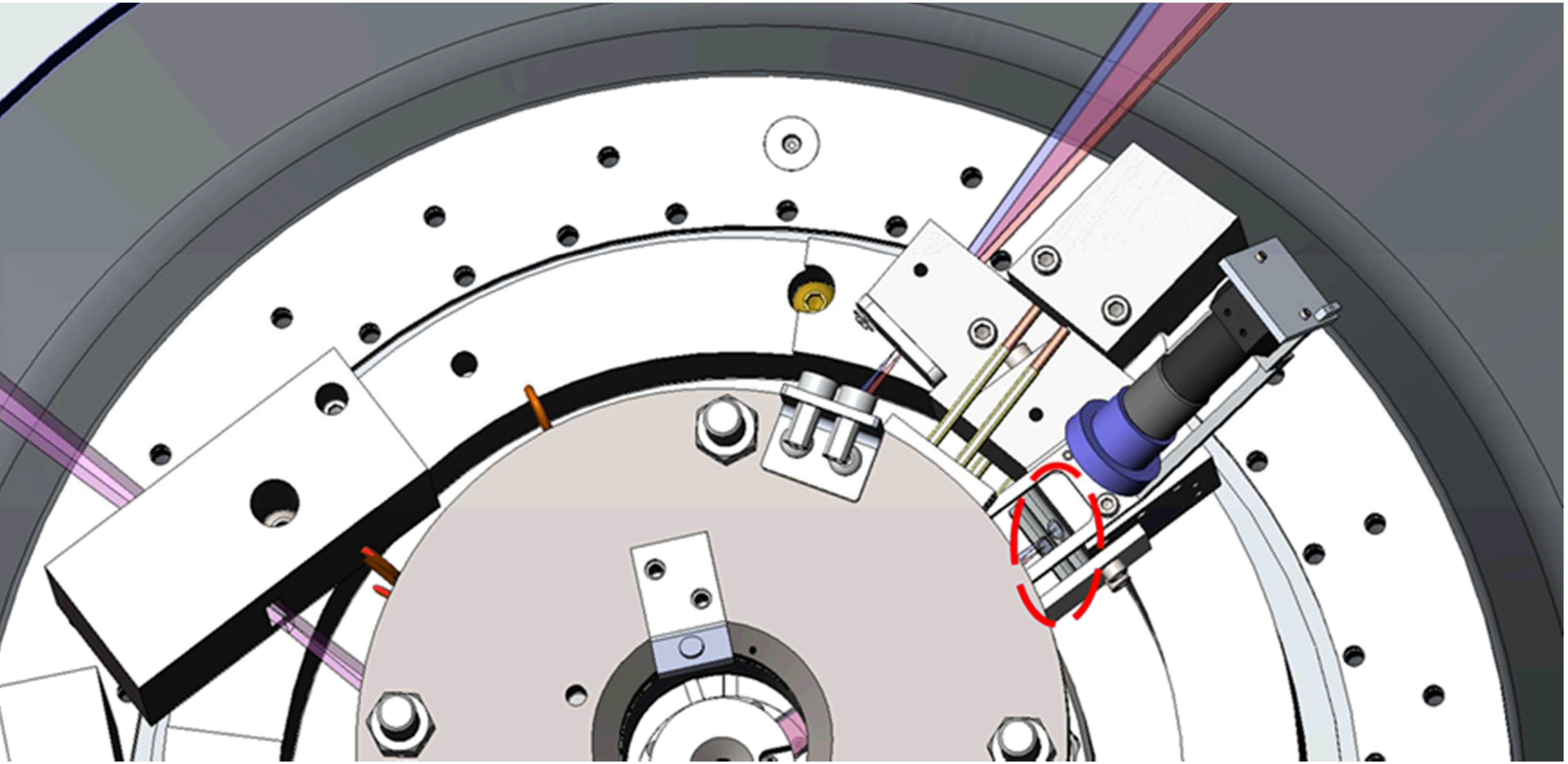
Spectral line	Energy [keV]	Crystal material	Miller indices hkl	$2d$ [Å]	ϑ [°]
Al He_β	1.468	Quartz	1 0 0	8.510	82.85
Mg Ly_α	1.473	Quartz	1 0 0	8.510	81.53
Al K_α	1.487	Quartz	1 0 0	8.510	78.39
Dy	1.494	Quartz	1 0 0	8.510	77.21
Si He_α	1.865	Quartz	1 0 1	6.687	83.80
Al H, He-like	1.927	Mica	0 0 6	6.647	75.25
Ar K_α	2.956	Quartz	2 0 0	4.255	80.00
Ar He_α	3.124	Ge	2 2 0	4.000	82.83
Ar He_α	3.140	Quartz	2 0 1	3.959	85.80
Ti K_α	4.505	Quartz	2 0 3	2.749	88.90
Sc Ly_α	4.542	Quartz	2 0 3	2.749	83.21
Mn He_α	6.151	Quartz	2 2 3	2.030	83.19
Ni He_α	7.806	Quartz	5 0 2	1.624	77.97
Cu K_α	8.048	Quartz	4 2 2	1.541	88.70
Ta L_α	8.141	Mica	0 0 26	1.534	83.17
Zr $K_{\alpha 2}$	15.691	Quartz	2 3 4	0.79126	86.98
Zr $K_{\alpha 1}$	15.775	Quartz	9 3 0	0.7868	87.34
Ru He_α	19.717	Ge	15 7 7	0.6296	87.15

Comparison to existing 6.151 keV system

	6.151 keV	7.242 keV
Crystal	Quartz (22$\underline{4}$3)	Ge (335)
Crystal size	28 × 10 mm	28 × 10 mm
Reflection order	1st	1st
Next possible higher order	2nd (12.302 keV)	3rd (21.726 keV)
X-ray source	Mn He y	Co He w
Bragg angle	83.19°	82.83°
Magnification	5.8	5.8
Crystal-to-Object distance	146.6 mm	146.55 mm
Crystal-to-Detector distance	850 mm	850 mm

Laser targets are in close proximity to magnetic field coils



Applied magnetic field affects Co x-ray source