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Multi-keV X-ray Yields from High-Z Gas Targets Fielded at the OMEGA Laser and the National Ignition Facility

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Disclaimer

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Presentation to
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The National Ignition Facility

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Summary

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We report on measurements and modeling of fluxes from X-ray source targets recently shot at the National Ignition Facility (NIF) and at the Omega laser. The targets were thin-walled pipes filled with mixtures of Xe and Ar gas at pressures of 1 to 1.5 atmospheres. The targets were irradiated with 3ω laser light, 20 kJ in 1 ns at Omega and 350 kJ in 5 ns at NIF. The emitted X-ray flux was monitored with multiple channels of X-ray-diode based DANTE instruments, and imaged with gated X-ray detectors. We compare predicted X-ray yields to measure yields. The current modeling appears to under-predict the yield of gas mixtures containing Ar at Omega.

High-efficiency cold X-ray sources have been validated experimentally

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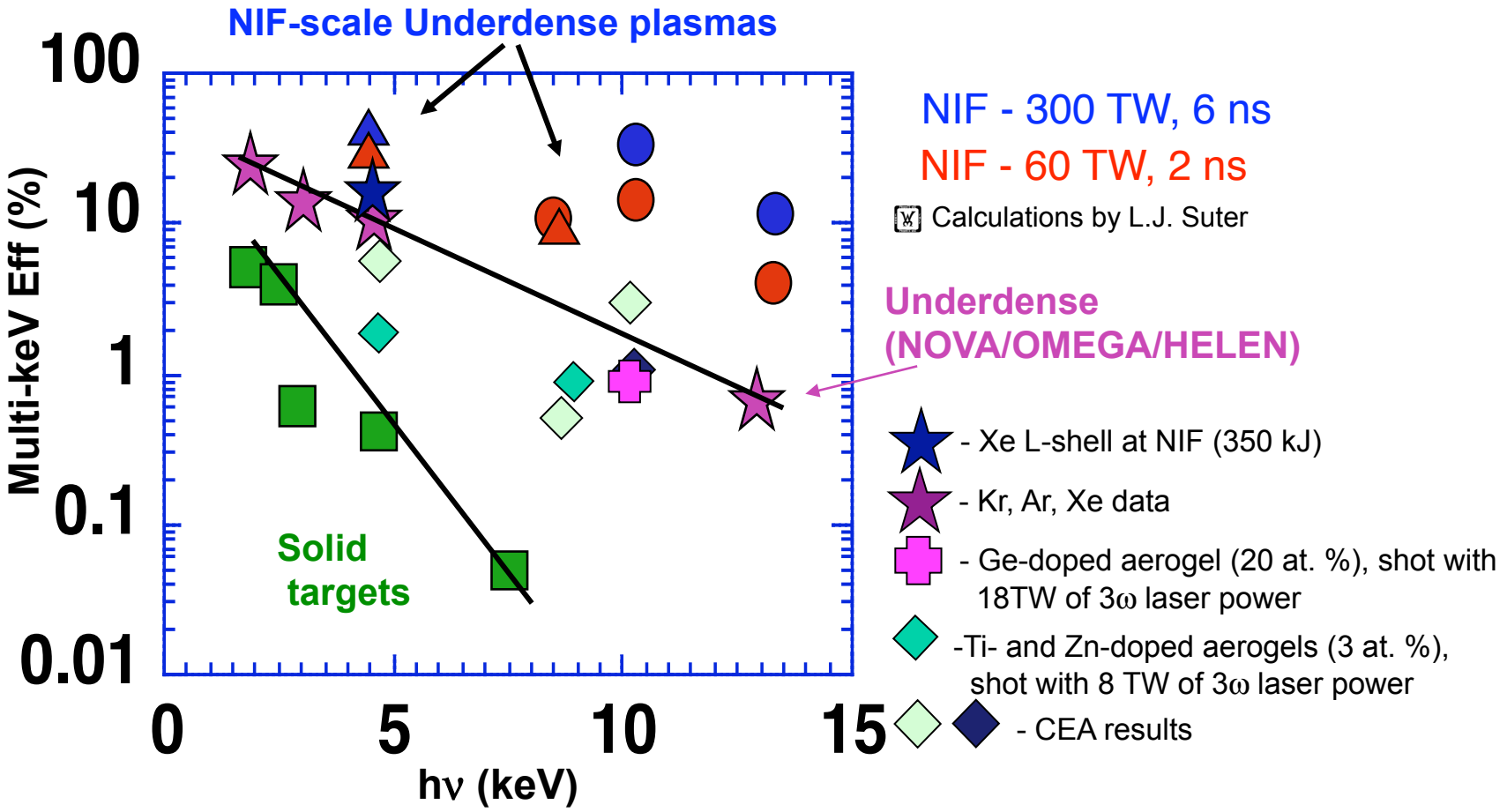

We are confident in the ability of our sources to scale to NIF

NIF Results

Physics of Plasmas, K. B. Fournier *et. al.*, "Multi-keV X-Ray Source Development Experiments on the National Ignition Facility", to appear (July 2010)

XRSA Campaign Purpose: Create Bright X-ray Source for High Energy Density Experiments

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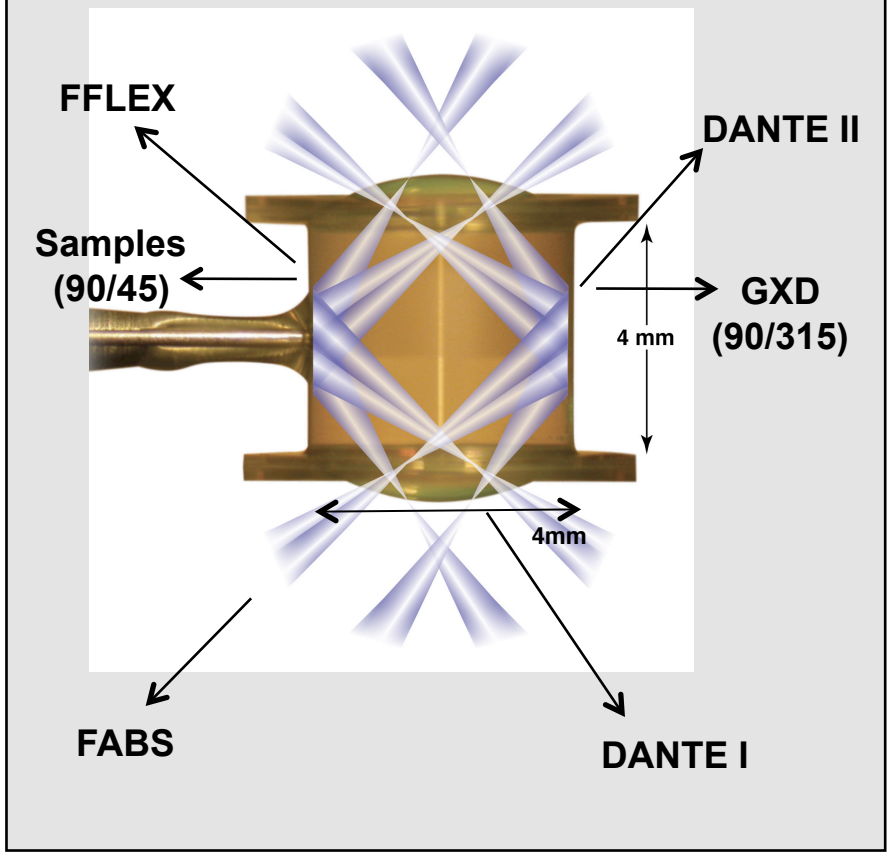
Thin plastic gas-filled hohlraums were heated with 112 - 132 beams (~350kJ)



- Beam configuration
  - 112-132 Beams
  - 5.2 ns square pulse
  - Total Energy: 350 kJ
  - Phase Plates
- Gas pipe targets
  - Target: 65:35 Ar:Xe @ 1.2 atm,
  - Non-Cryogenic
- Diagnostics (Primary)
  - DANTE I
  - DANTE II
  - XRSA cassette (90/45)

  (Secondary)
  - GXD (90/315)
  - FABS/NBI
  - FFLEX
  - EEMP
  - SXI U&L

Two-dimensional images show the supersonic, volumetric heating of the gas-pipe target

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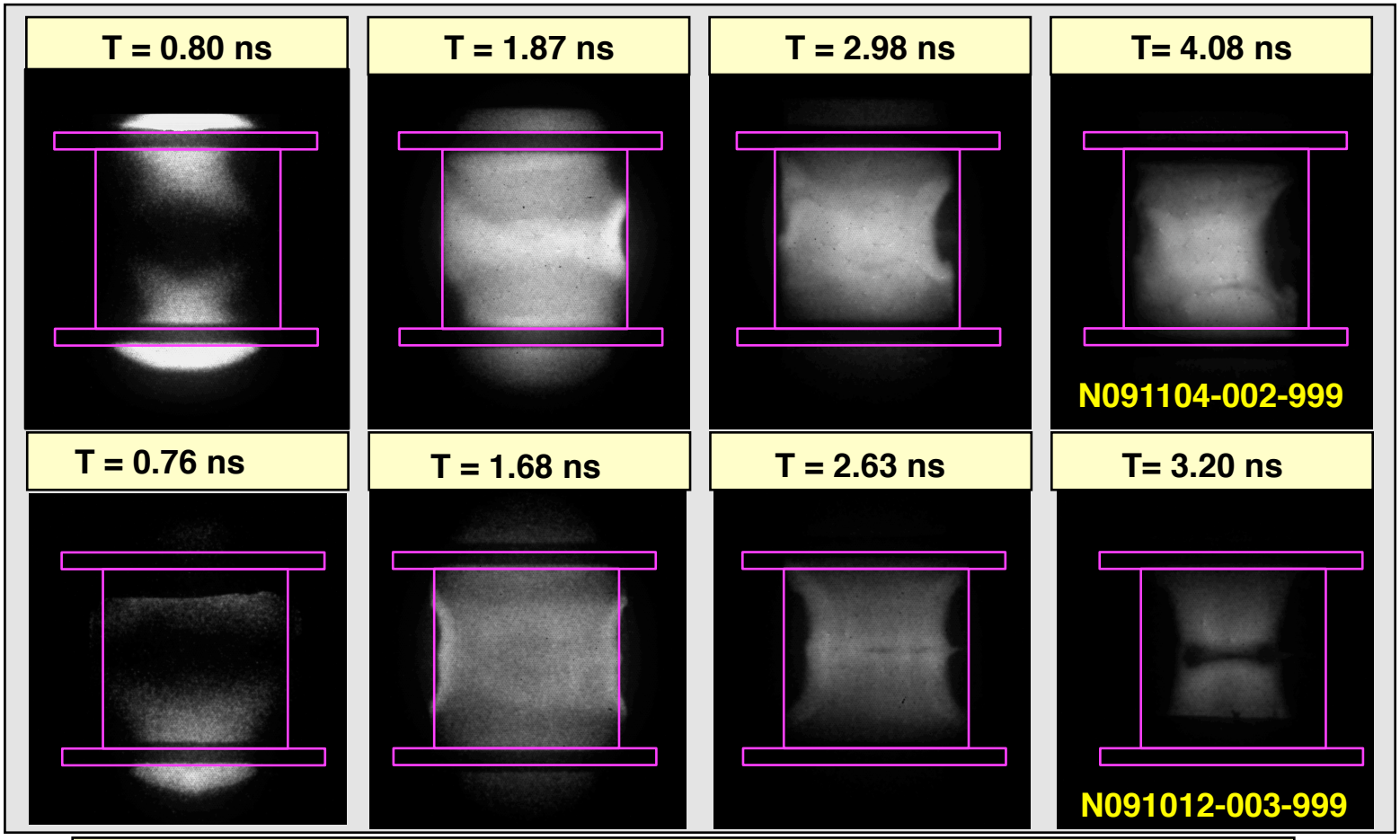
Filtered with 35 μm of Ti (hυ > 4 keV)



Supersonic, volumetric heating is the key to high laser-to-X-ray conversion

Measured yields over all energies demonstrated excellent reproducibility

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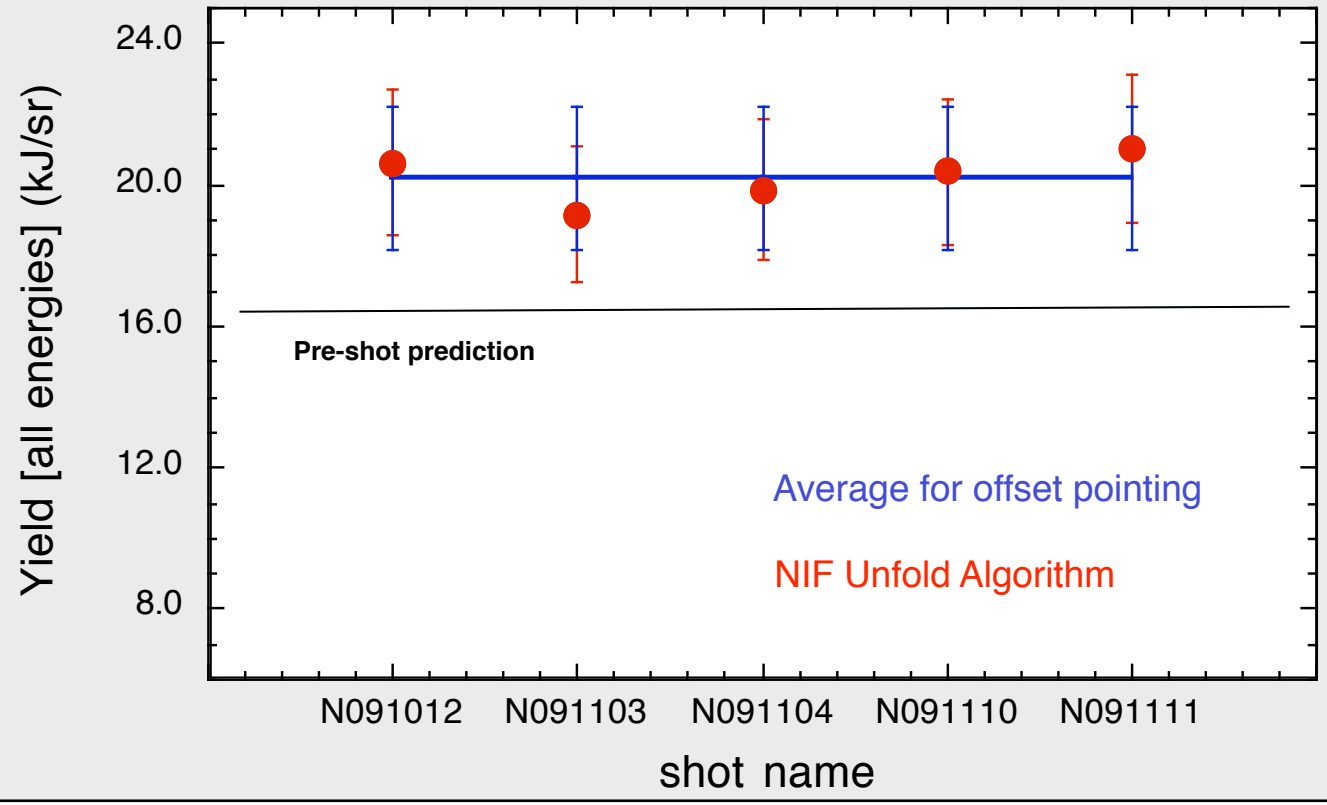
Summary of measured total X-ray yields from NIF targets and campaign requirements



Yield requirements are from a line-of-sight corrected LASNEX run

Measured X-ray spectra do not have the detail of theoretical predictions

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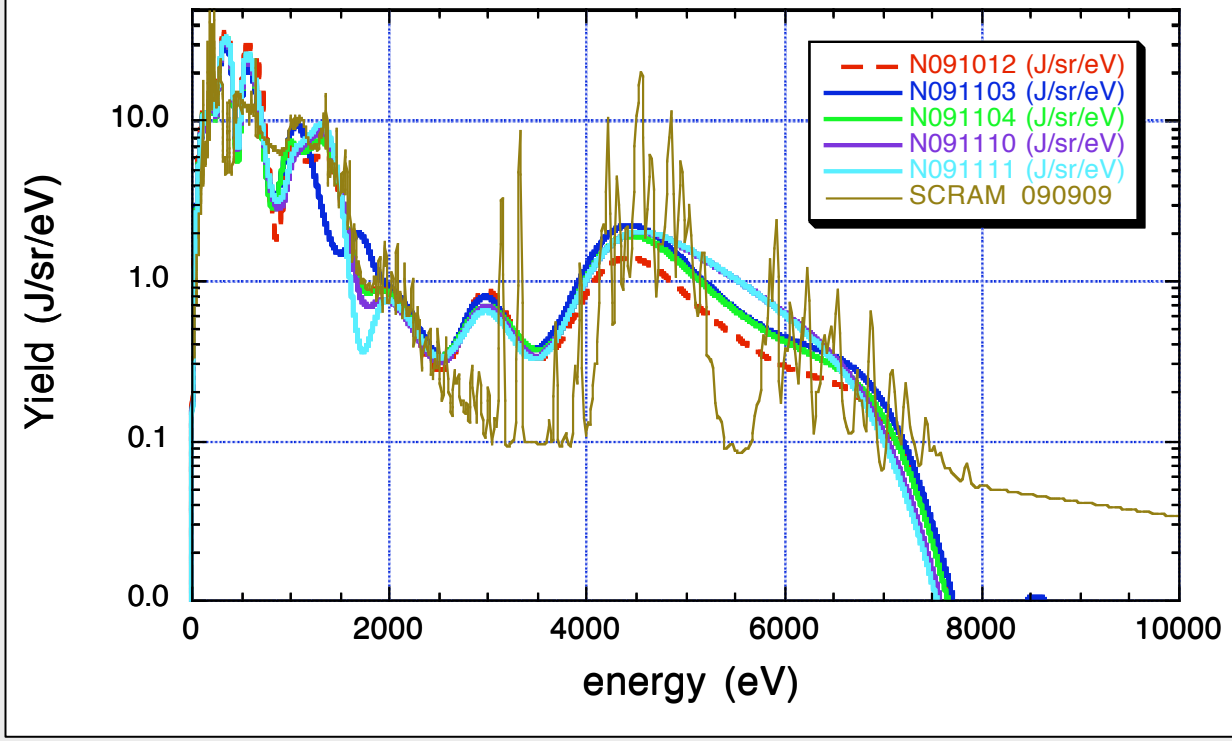
Dante-measured X-ray yields and theoretical spectrum



A high-energy-resolution spectrometer is essential to improving pre-shot output predictions and post-shot sample-response modeling

Integrated Spectral Yield Summary

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Yield (kJ/sr)	All energies	> 1.5 keV	> 3.0 keV
	MJM	MJM	MJM
N091012	20.65	3.61	2.43
N091103	19.16	4.87	3.55
N091104	19.85	4.37	3.17
N091110	20.36	4.81	3.68
N091111	21.00	4.63	3.66
AVERAGE*	20.17	4.77	3.63
LASNEX**	19.2	3.9	2.0

***N091103, N091110, N091111 only for the average**
**** As shot, for DANTE 1 at 37 degrees with respect to target axis**

Comparisons of unfolded DANTE spectra for all shots

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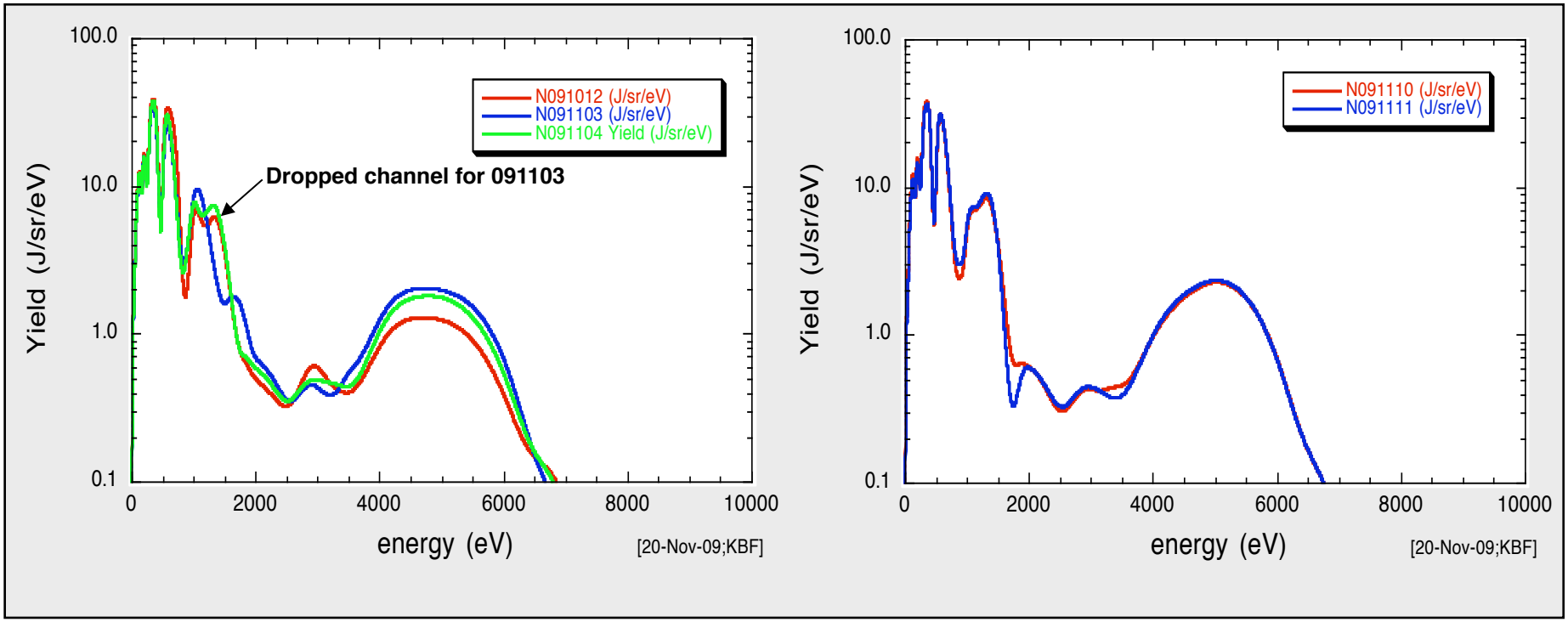
Excellent reproducibility in target output across the campaign



Consistent results for all shots, with small differences in spectral details

Observations on NIF source performance

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- We have used ≈ 1/5th of NIF's capability to heat a laser-driven plasma radiation source target.
  - We measured 12-15% laser-to-x-ray conversion for $h\nu > 3$ keV, and 65% laser-to-x-ray conversion for all x-ray energies.
- We can predict Ar K-shell ($h\nu \sim 3$ keV) and Xe L-shell ($h\nu \sim 4 – 7$ keV) emissivity from a high-temperature, non-LTE plasma with high accuracy, ≈ ±20%.
- We can predict the sub 1.5 keV target flux to ≈ ±10% with a non-LTE DCA simulation that has the correct view for the line of sight of the given diagnostic.
- Multi-keV flux follows laser power as designed, sub-keV emission lasts for ≈ 10 ns, as expected, multi-keV emission lasts only ~ 5 – 6 ns, consistent with laser pulse.

We are just beginning to optimize NIF's capabilities for X-ray source development

Omega Results

Targets are 1.8 x 1.8 mm Be cylinders with 75 micron thick walls

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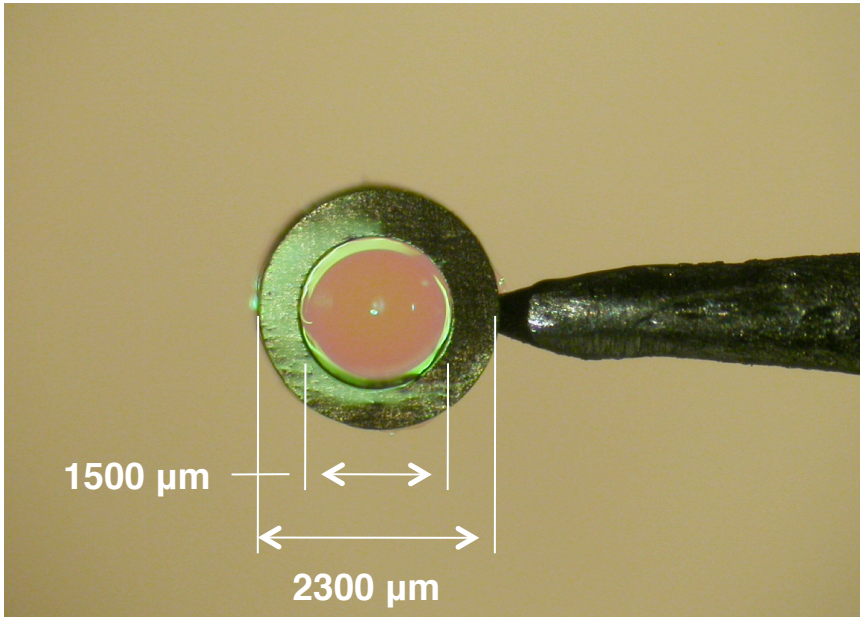

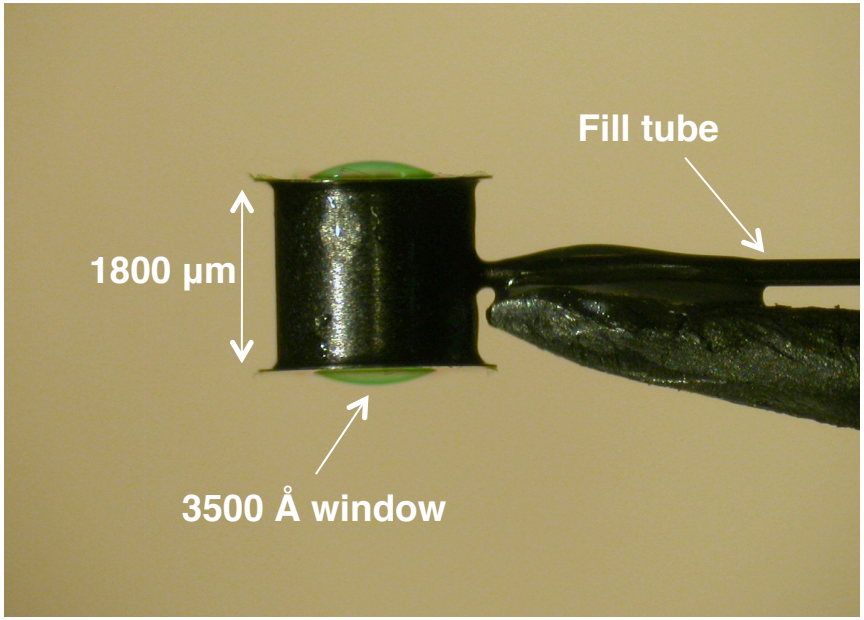

KBF–OBECAN–04

1.0 atm Ar - $n_e = 4.4\% n_{cr}$
1.5 atm Ar - $n_e = 6.6\% n_{cr}$
1.2 atm Xe - $n_e = 14.1\% n_{cr}$
1.2 atm Ar:Xe - $n_e = 9.7\% n_{cr}$

Preliminary Dante yield results and comparison to predicted conversion efficiencies (M/P ~ 1 - 2)

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Shot no.	Source	Shot-time pressure (atm)	Laser energy (kJ)	Yield (J/sr)	Conv. Efficiency (%/ sphere)	Predicted CE (%/ sphere)	M/P	Henway Ar K Emission (J/sr)
57690	Ar	1.04	19.238	511.8	33.4	16	2.1	42.329
57691	Ar	1.44	19.674	539.6	34.5	20	1.7	
57692	Ar	1.49	19.611	501.8	32.2	20	1.6	37.318
57693	Xe	1.17	19.443	608.0	39.3	40	1.0	2.772
57694	Xe:Ar (50:50)	1.19	19.500	580.5	37.4	33	1.1	8.484

- Note, yields are from DANTE unfolds on 4/22/10
- Yields, measured and predicted are *integrated over all energies*
- Note, simulation account for the specific Dante view factors at 37-degrees for our target on the P6-P7 axis

Predictions for target emission are substantially worse for targets containing Ar

FABS calorimetry shows that LPI beam-energy losses are small (< 10%), yielding good coupling

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Shot no.	Source	Shot-time pressure (atm)	Laser energy (kJ)	B25 Energy (J)	B25 SRS (J)	B25 SBS (J)	% total backscatter
57690	Ar	1.04	19.238	457.2	3.9	30.1	7.4
57691	Ar	1.44	19.674	468.9	6.5	35.8	9.0
57692	Ar	1.49	19.611	465.9	9.2	33.2	9.1
57693	Xe	1.17	19.443	459.5	5.3	23.2	6.2
57694	Xe:Ar (50:50)	1.19	19.500	460.9	6.1	32.2	8.3

- Note, SBS channel dominates these OMEGA LPI yields, which is the *opposite* of our measurements from Ar-Xe targets at NIF.

Dante-unfolds produce spectra for Ar, Xe and Ar-Xe targets

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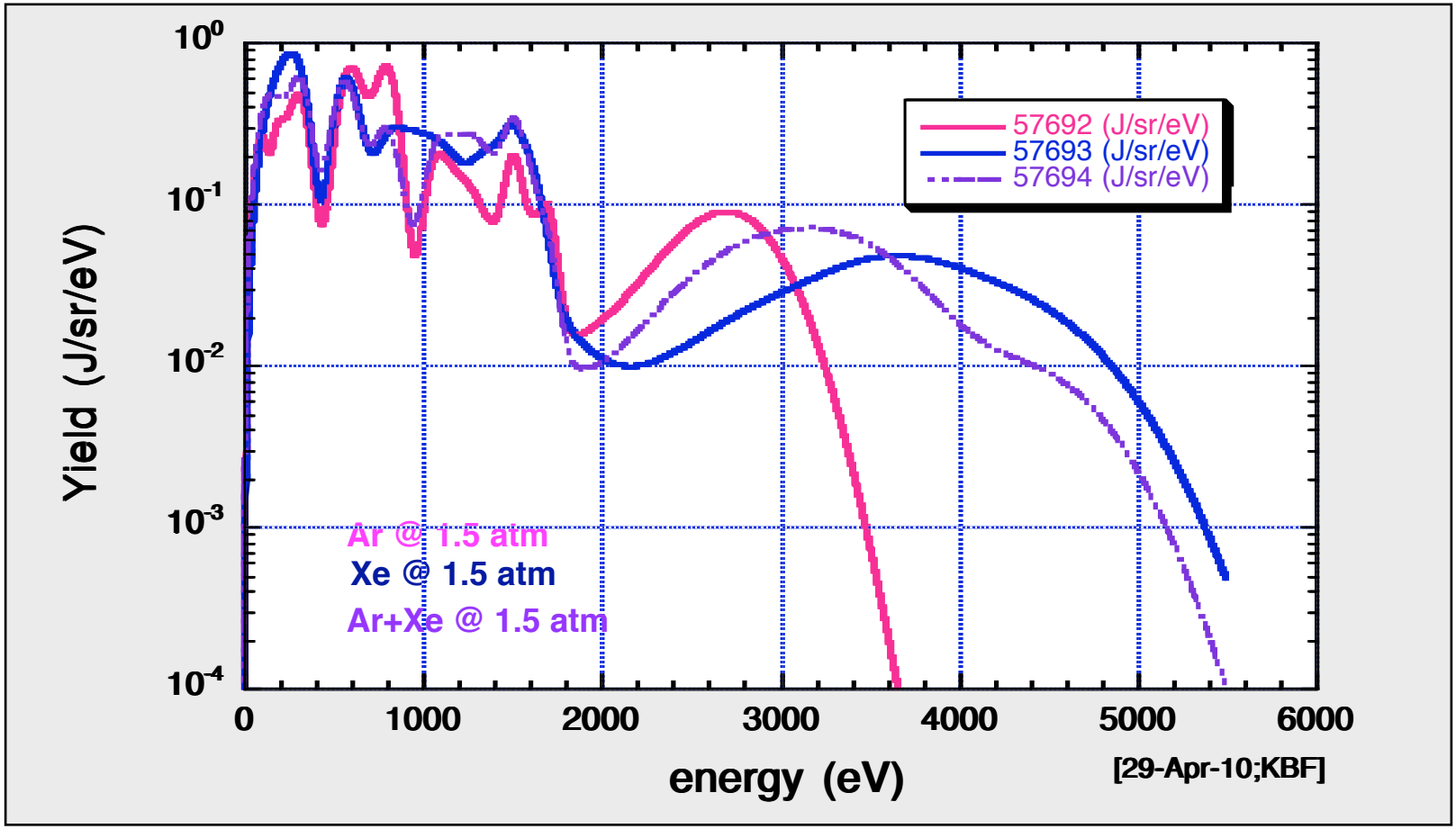

Preliminary Dante yield results and comparison to predicted conversion efficiencies (M/P ~ 1 - 2)

Shot no.	Source	Shot-time pressure (atm)	Laser energy (kJ)	Yield Total (J/sr)	Conv. Efficiency (%/ sphere)	Yield 0-2.5 keV (J/sr)	Yield 2.5-5.5 keV (J/sr)	Predicted CE (%/ sphere)	M/P
57690	Ar	1.04	19.238	511.8	33.4	470.0	41.8	16	2.1
57691	Ar	1.44	19.674	539.6	34.4	482.1	57.5	20	1.7
57692	Ar	1.49	19.611	501.8	32.1	455.6	46.2	20	1.6
57693	Xe	1.17	19.443	608.0	39.3	533.2	74.9	40	1.0
57694	Xe:Ar (50:50)	1.19	19.500	580.5	37.4	493.2	87.2	33	1.1

Shot no.	Source	Shot-time pressure (atm)	Laser energy (kJ)	Henway Ar K Emission (J/sr)	Conv. Efficiency (%/ sphere)
57690	Ar	1.04	19.2	35.8	2.3
57691	Ar	1.44	19.7	40.0	2.6
57692	Ar	1.49	19.6	31.5	2.0
57693	Xe	1.17	19.4	2.5	0.2
57694	Xe:Ar (50:50)	1.19	19.5	7.2	0.5

Ar K-shell yield is found by integrating from 3.0 to 3.6 keV

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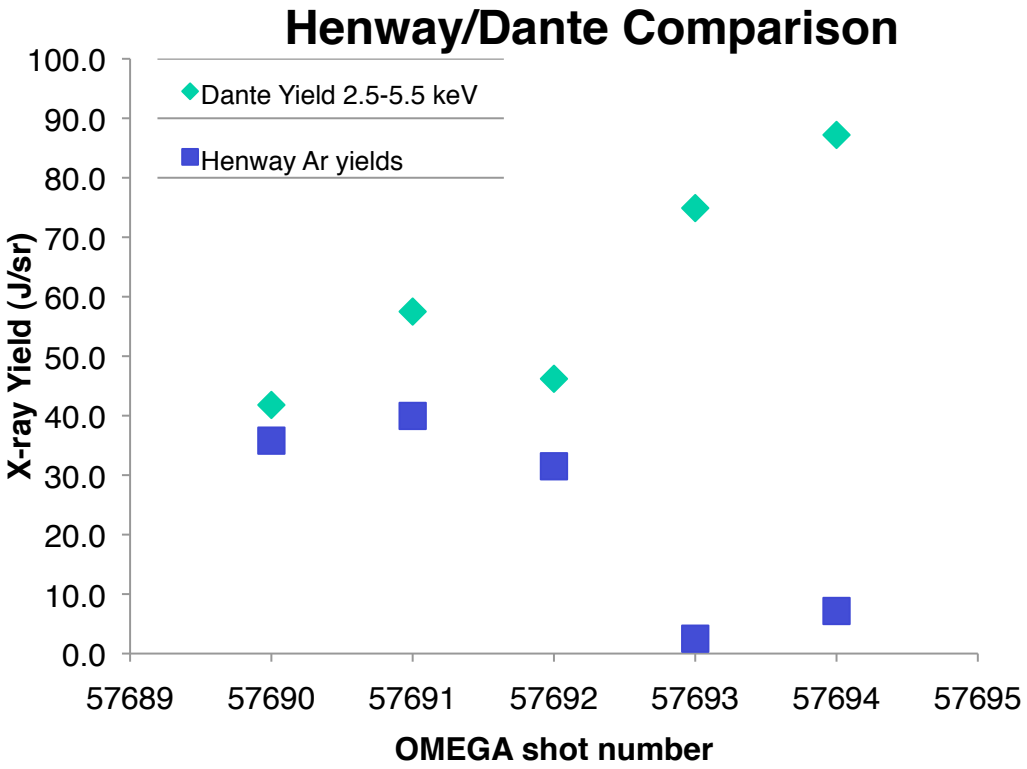

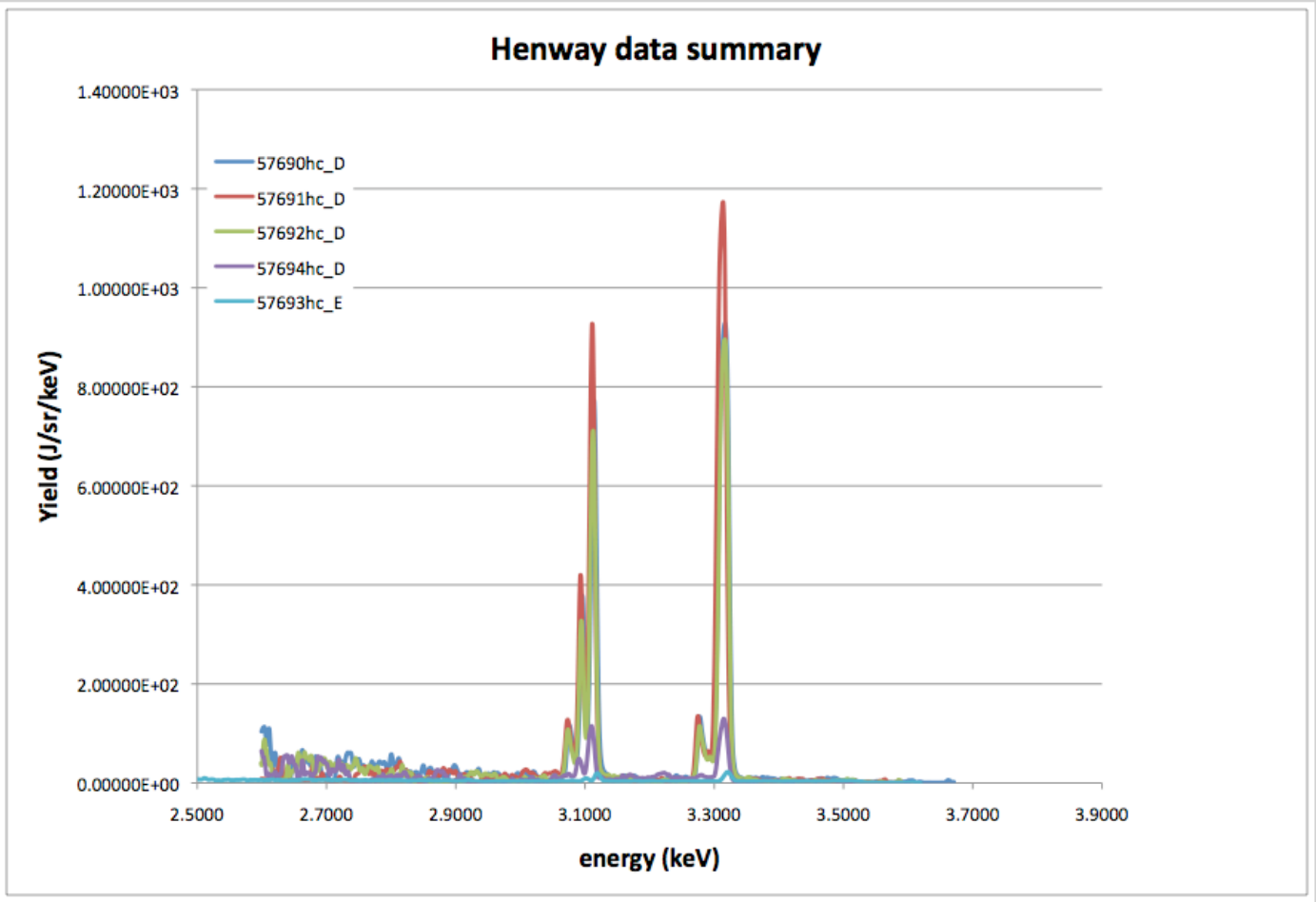
Henway data summary
1.40000E+03
1.20000E+03
1.00000E+03
8.00000E+02
6.00000E+02
4.00000E+02
2.00000E+02
0.00000E+00
Yield (J/sr/keV)
57690hc_D
57691hc_D
57692hc_D
57694hc_D
57693hc_E
2.5000
2.7000
2.9000
3.1000
3.3000
3.5000
3.7000
3.9000
energy (keV)

Dante-measured x-ray power waveforms show duration dependence on target element

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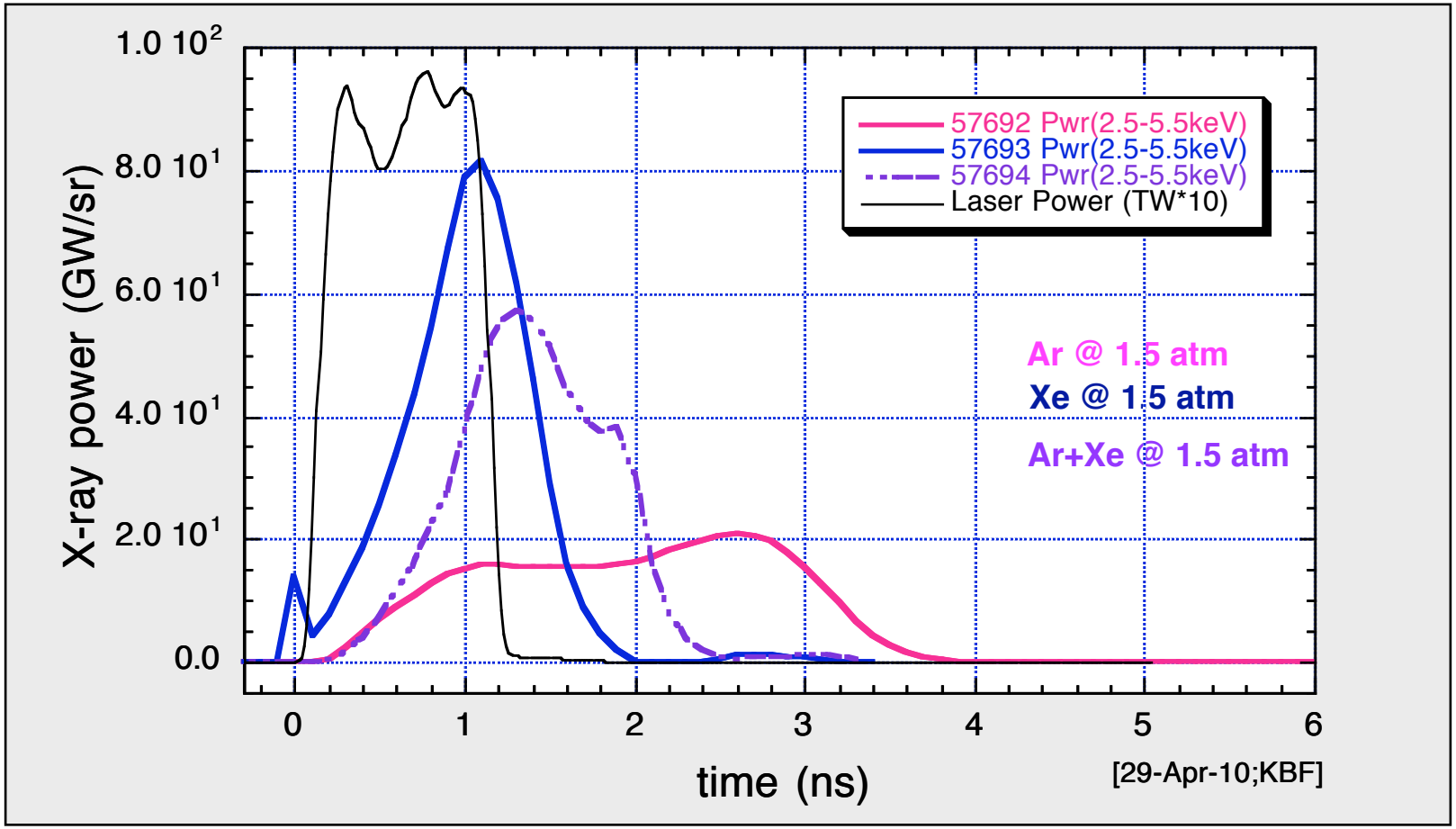

Differences between Xe and Ar emissions durations are being investigated

Comparison of static X-ray Pinhole Camera images for the three gas mixes

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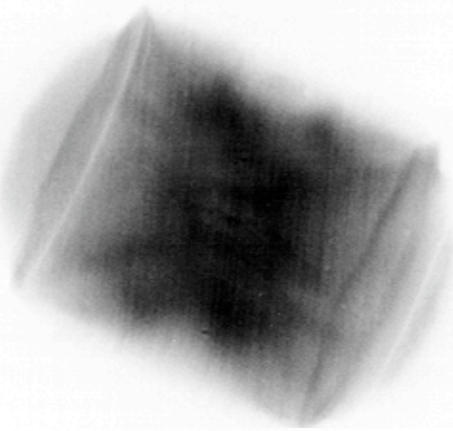
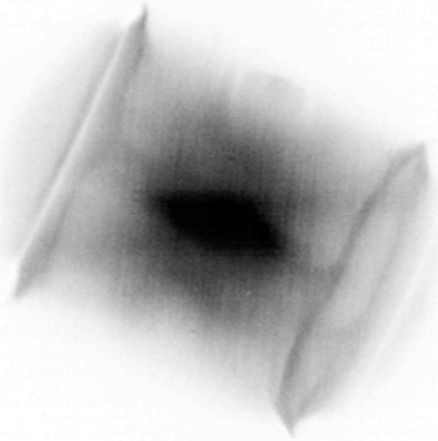
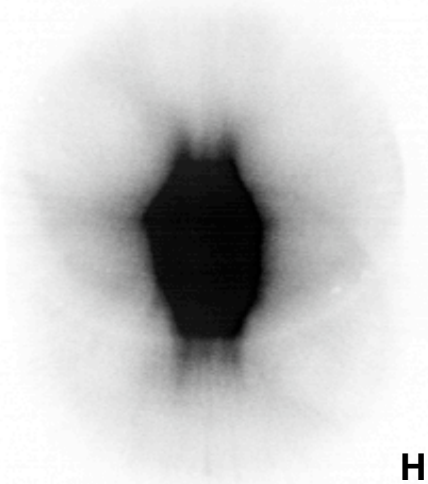
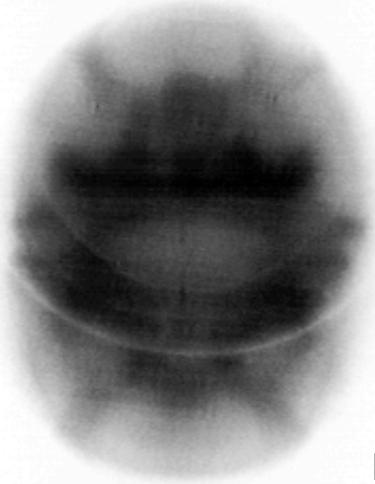
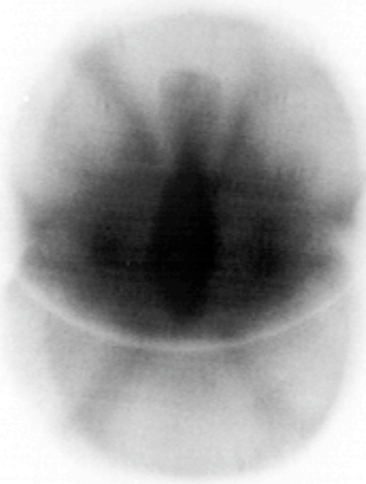
57692 1.5 atm Ar	57693 1.2 atm Xe	57694 1.2 atm Xe:Ar
		
H12	H12	H12
		
H13	H13	H13

Comparison of X-ray Framing Camera images for the three gas mixes near peak emission time

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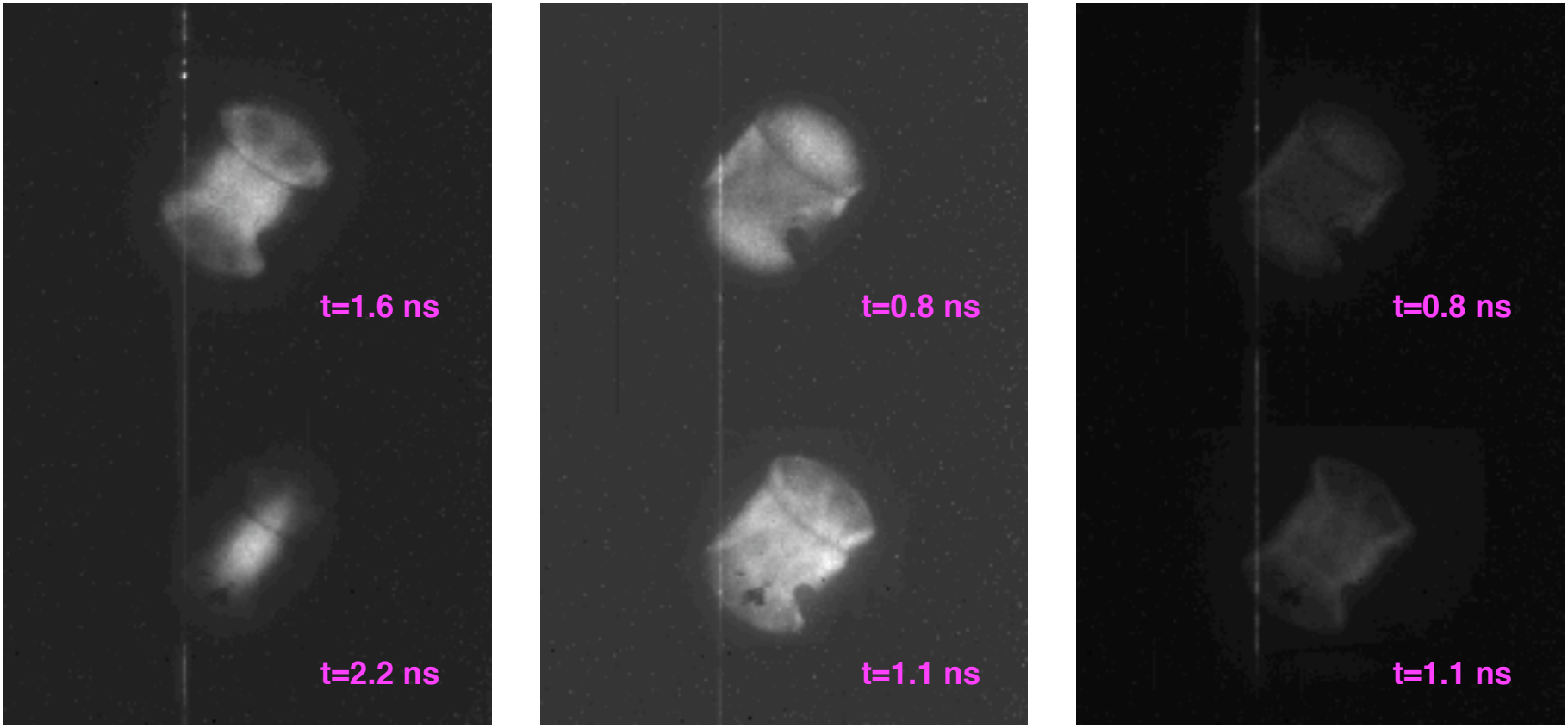
57692 1.5 atm Ar	57693 1.2 atm Xe	57694 1.2 atm Xe:Ar



XRFC4 in TIM1

H8 visible camera captures both SDC and XRSA cassettes during XRSD-10B shots