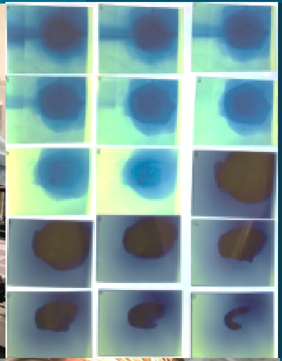
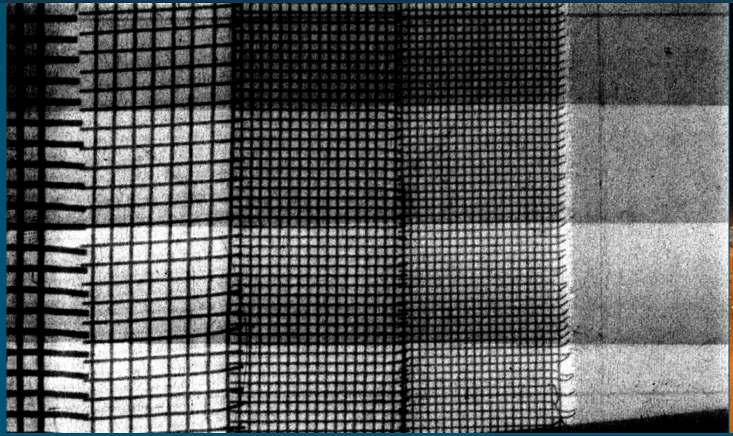
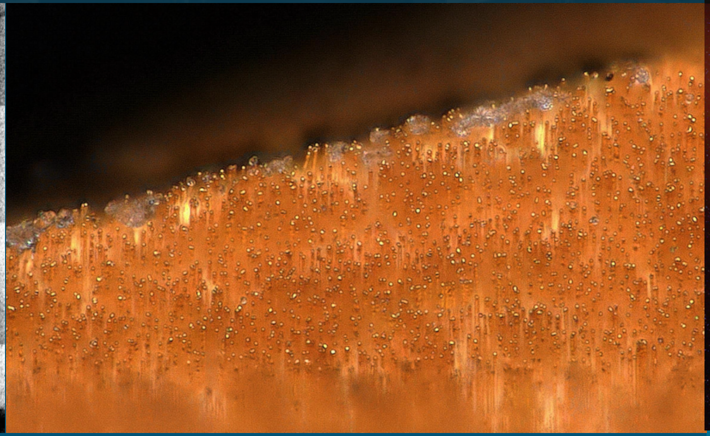
SAND2021-13786R

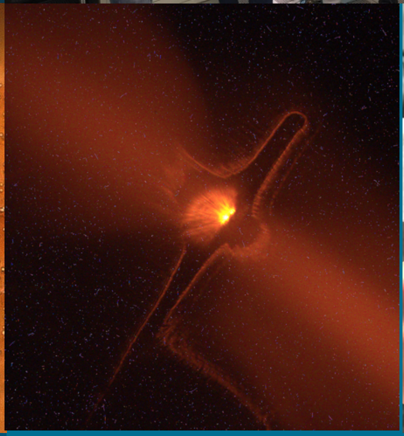
September 2021 Chama Campaign: TNSA and K_α x-ray radiography

10/13/2021









Benjamin Galloway

Patrick Rambo
Matthias Geissel
Quinn Looker
Tommy Ao

Mathieu Bailly-Grandvaux (UCSD/CMEC)
Joe Strehlow (UCSD/CMEC)
Farhat Beg (UCSD/CMEC)
Raspberry Simpson (MIT/SSGF)

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Outline

- Z-Petawatt in Chama
- Solid target interactions: TNSA and K_α x-rays
- Collaboration with UCSD
- Results from campaign

Z-Petawatt in Chama

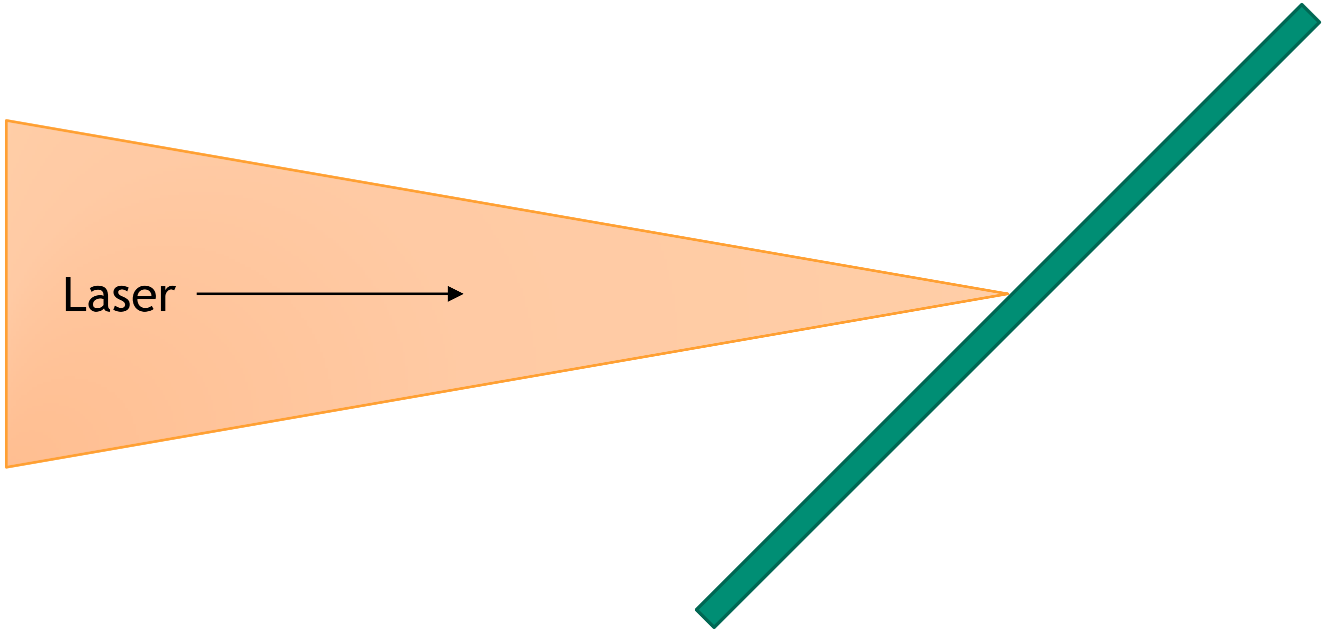
- The Z-Petawatt full-aperture upgrade was completed in FY20, with the first Chama target shot performed in September 2020.
- Commissioning and continuous improvements have been performed in tandem with Chama applications experiments:
  - ➢ LDRD (sacrificial mirrors)
  - ➢ Target Normal Sheath Acceleration (TNSA) & x -ray generation
- Part of commissioning involved benchmarking Z-Petawatt's capabilities against those of similar laser facilities.

	TITAN[†]	ARC[†]	ZPW
Maximum Intensity (W/cm^2)	10^{20}	10^{18}	~few 10^{19} (upgrade: 10^{20}-10^{21})
Focal Spot FWHM (µm)	10	50-80	20-50 (upgrade: 7-15)
Energy (J)	150	650	285 demonstrated (up to 420)
Pulse Length (ps)	0.6	10	~2 (upgrade: 0.6)
f/#	3	30-60	4-6
Shot Rate	~10x/day	~2x/day	~2x/day

"upgrade" refers to implementing a pre-corrector for chromatism in large lenses (planned for FY22)

[†]R. Simpson, "Scaling Studies of Laser-Driven Proton Acceleration in the Multi-ps Regime at the TITAN laser", NIF/JLF User Group Meeting, Feb. 4, 2021.

Solid target interactions: TNSA and K_α x-rays



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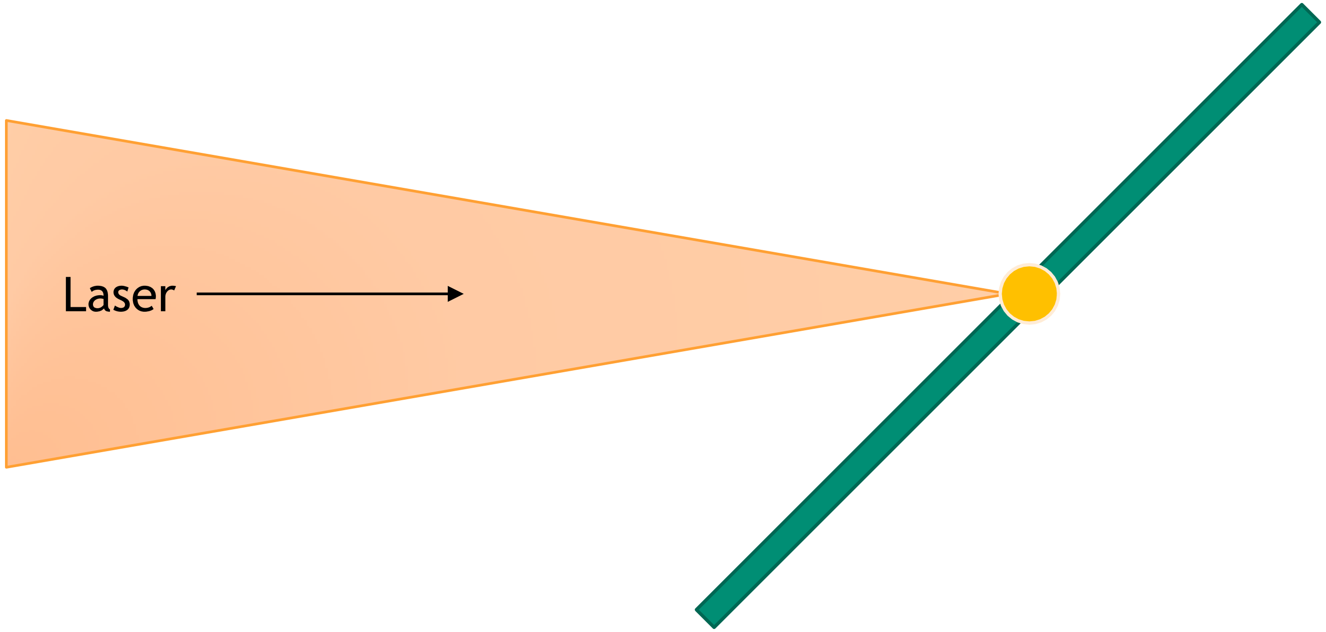

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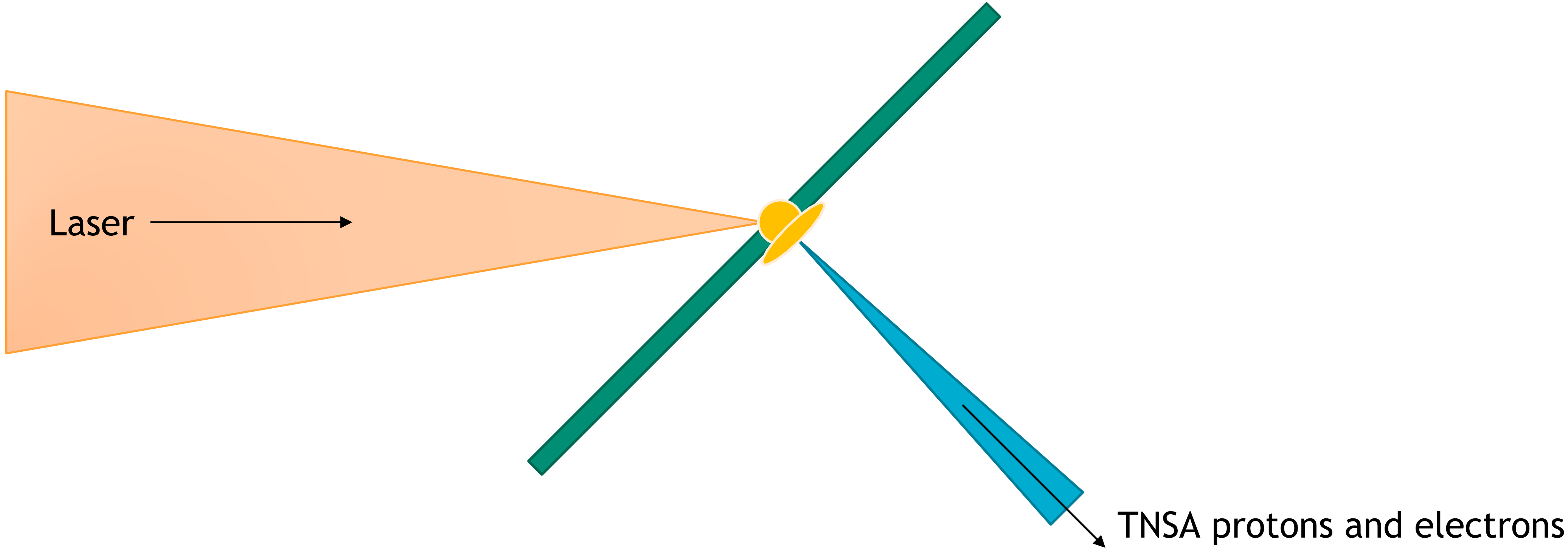

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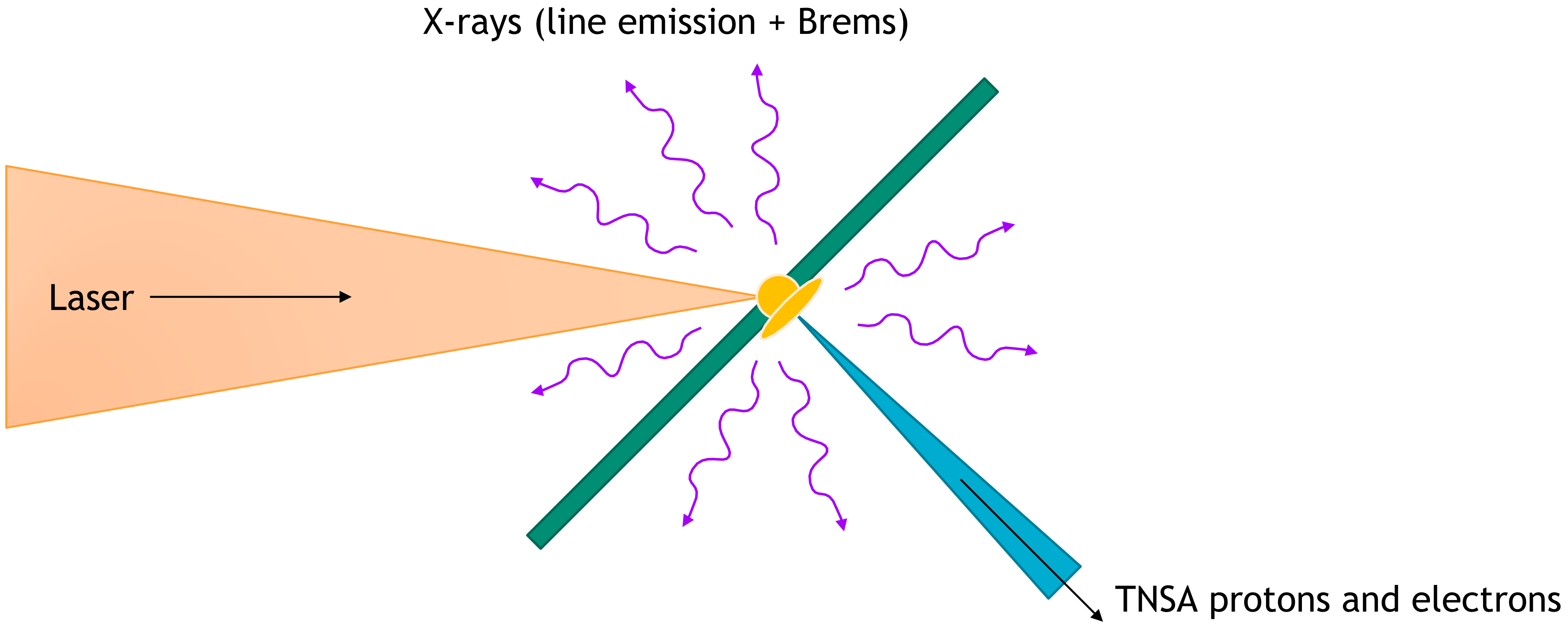

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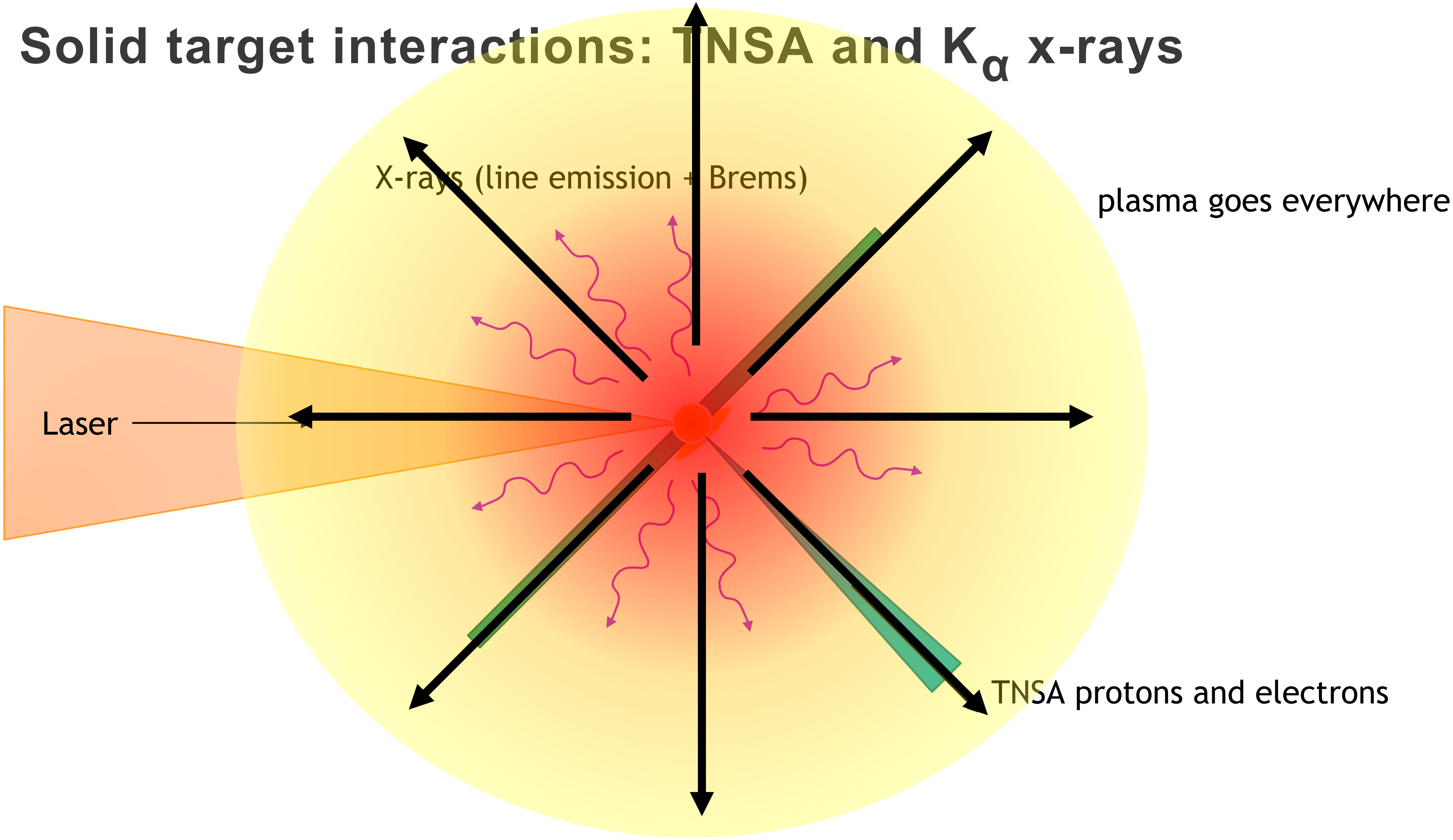
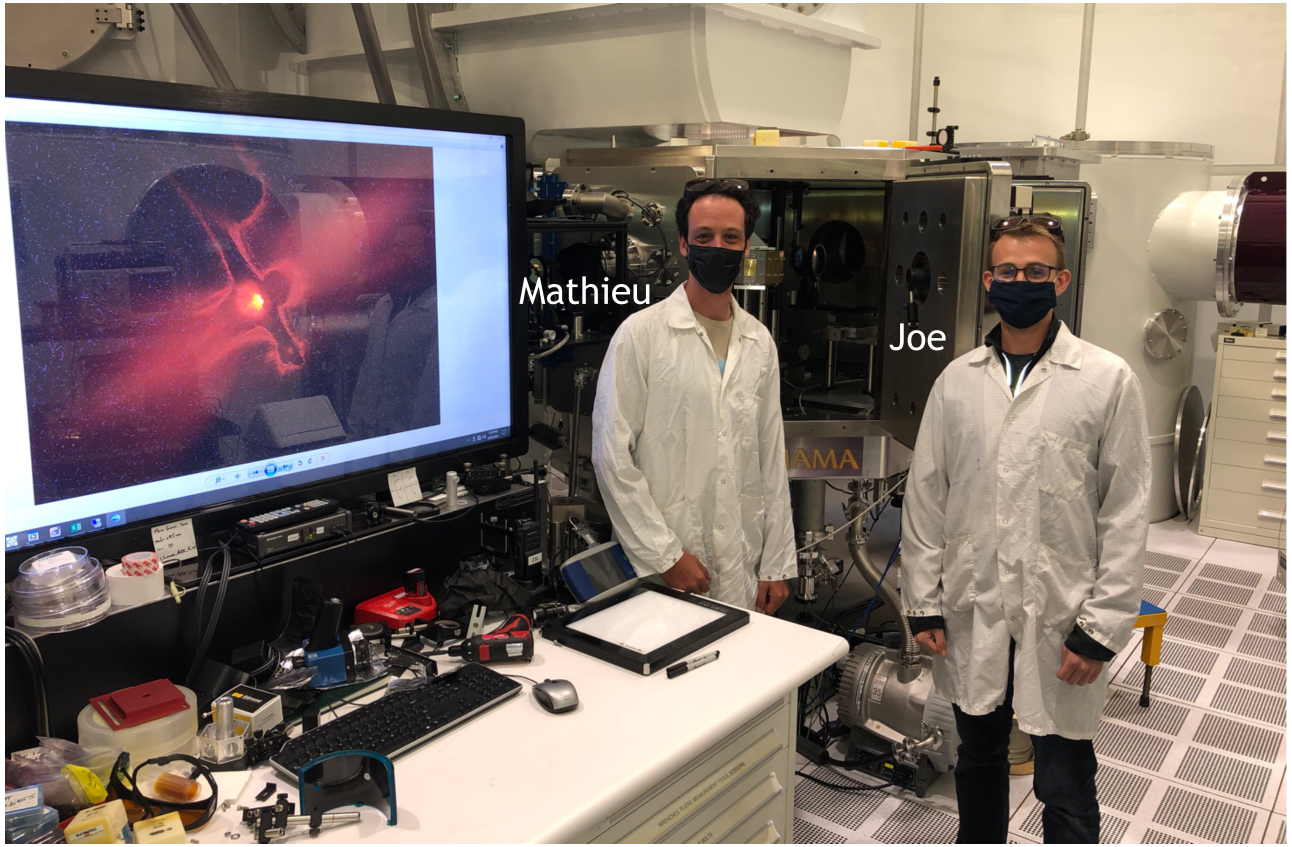


Collaboration with UCSD

- Joe Strehlow and Mathieu Bailly-Grandvaux visited from Farhat Beg's group at UCSD, supported by CMEC.
- They have strong experience performing TNSA experiments at user facilities with a variety of targets and laser drivers.
- The collaboration was immensely useful with regard to shot planning, setup, interpretations, and calibrated RCF analysis.



September 2021 Chama Campaign

Campaign goals:

1. Operations:
   a. Continue commissioning of Z-Petawatt in Chama
   b. Quantify on-target intensities achieved via TNSA protons
2. Radiography/diffraction:
   a. Evaluate K_α x-ray brightness and source size (while increasing x-ray energies, compare to Marius' previous results)
   b. Attempt radiography (use geometry relevant to Ultrafast X-ray Imagers (UXI)† on the Z-Machine)
   c. PACMAN ride-alongs to evaluate backgrounds levels
3. Collaboration:
   a. UCSD collaborators' primary interest was TNSA driven by different laser conditions
   b. Micro/nano-structured targets for enhanced energy coupling

Shot strategy to achieve campaign goals:

- Repeat Cu shots from prior Chama campaigns (reproducibility)
- Transition to higher Z targets (higher K_α x-ray energies), micro/nano-structured targets if there is time
- Implement diagnostics: RCF stack, CRITR, x-ray PHC, radiograph IP, Schlieren imaging, PACMAN

†L. Claus, Proc. SPIE **10390**,103900A

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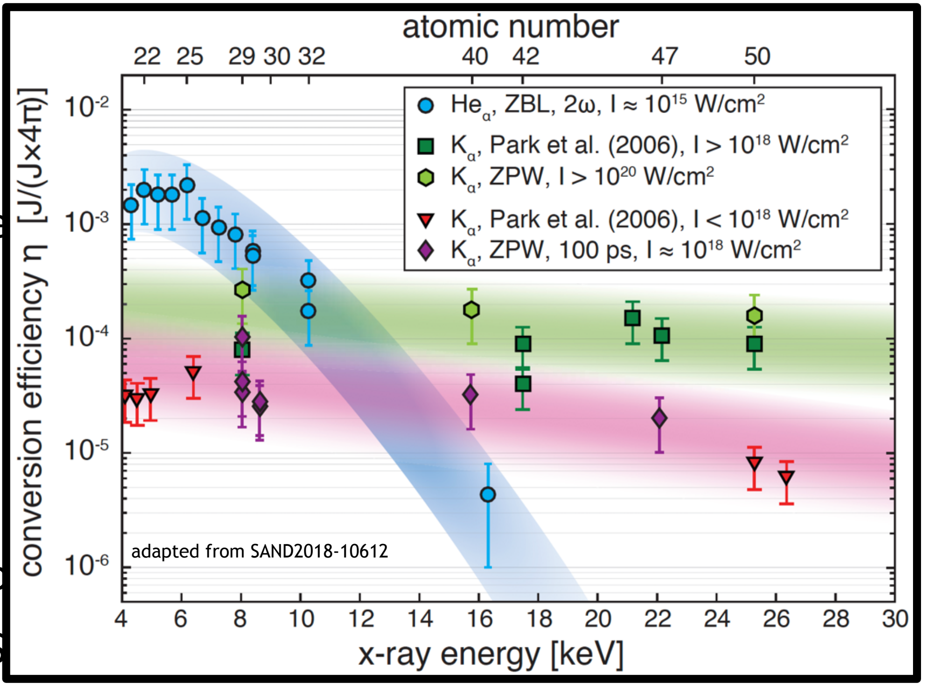
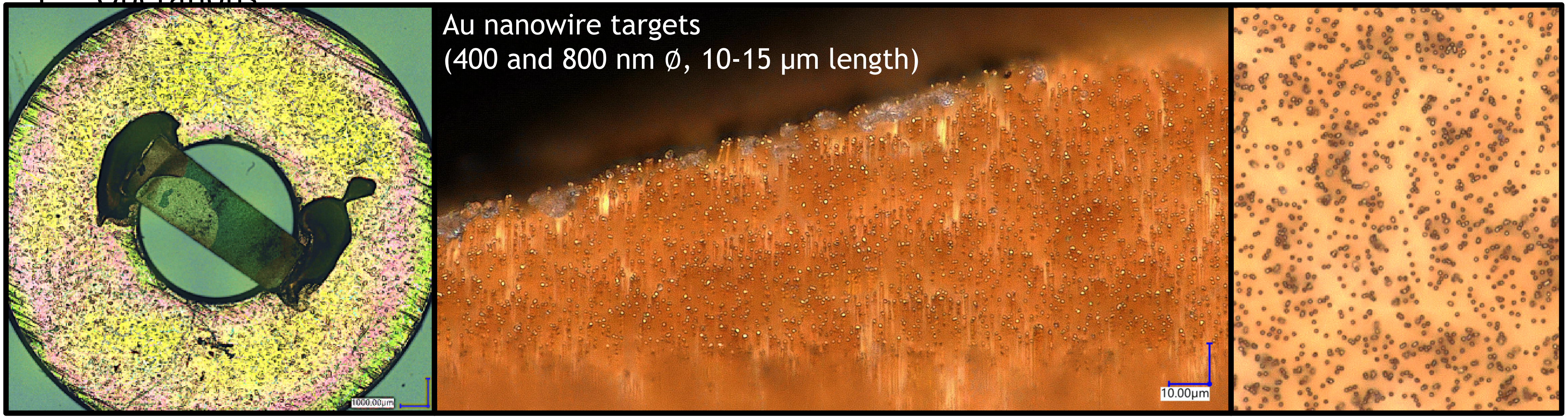


September 2021 Chama Campaign

Campaign goals:

Did not get around to shooting these

1. Operations:



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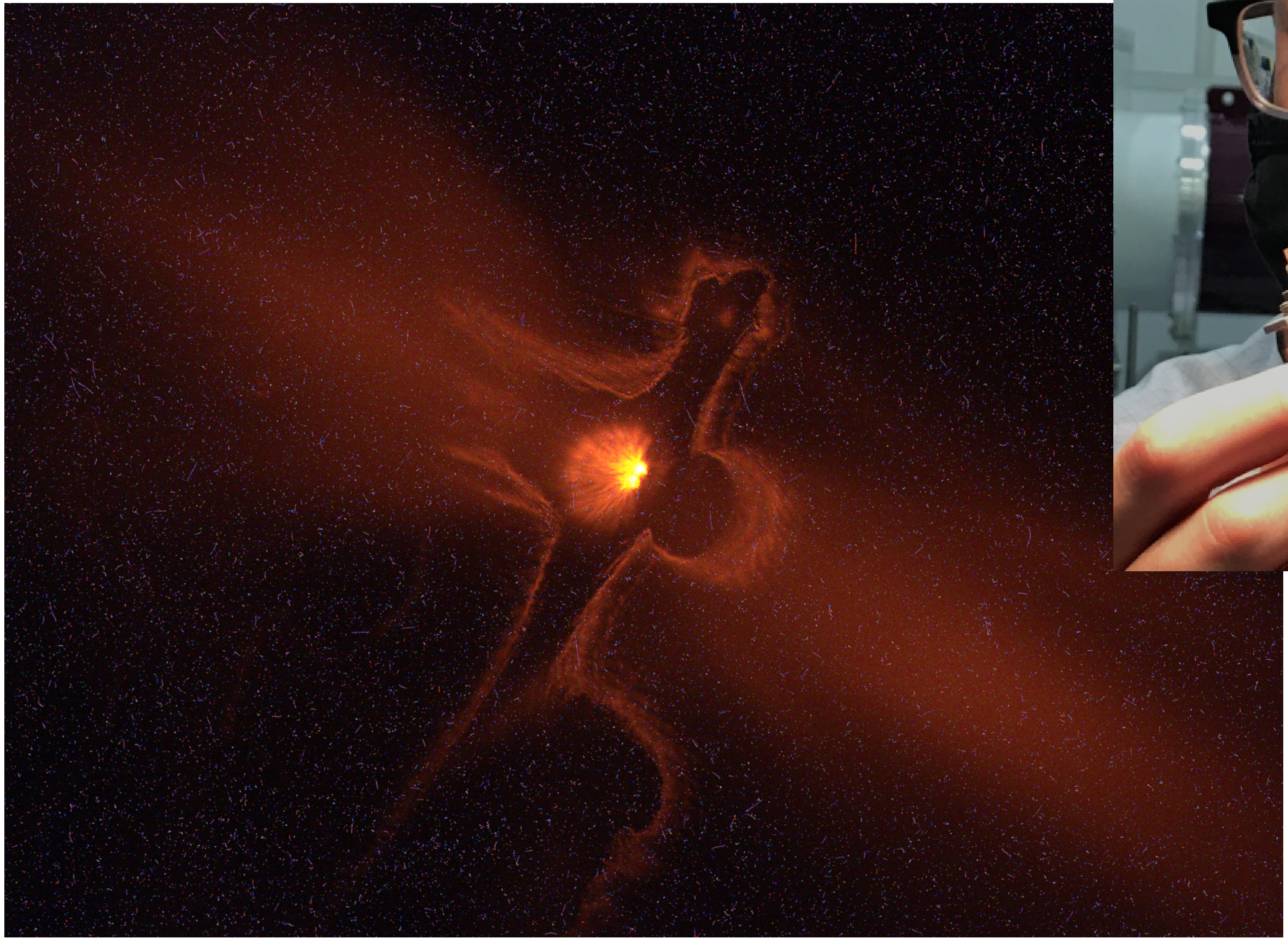
Results from campaign

13 shots performed:

Shot #	Target	Energy (J)	TNSA max E (MeV)	Experimental setup notes
B21091303	25µm Cu	228.6	28.8	➢ Baseline shot to repeat previous observations with Cu, 8.0 keV x-rays ➢ (note the CRITR zero-order block was not in position, Chama SE cam not triggering correctly)
B21091401	25µm Cu	217	26.6	➢ CRITR zero-order block placed in correct position ➢ (Chama SE cam still not triggering correctly)
B21091409	25µm Cu	243.7	0	➢ Chama gate valve was CLOSED, so shot into sapphire window ➢ (Chama SE cam triggers resolved)
B21092003	25µm Cu	218.7	35.4	➢ Repeat shot following Chama gate valve assessment/reinstallation ➢ Chama SE cam acquired backlit interaction
B21092209	25µm Zr	231.2	32.2	➢ Transitioned to Zr target, looking for 15.7 keV x-rays ➢ Chama SE cam converted to Schlieren imaging (same for all subsequent shots)
B21092303	25µm Zr	260.3	38	➢ Repeat shot for statistics
B21092309	25µm Mo	232.5	31.9	➢ Transitioned to Mo target, looking for 17.4 keV x-rays
B21092415	25µm Cu	254.3	40.8	➢ Added mesh and IP for 8 keV radiography: mesh array 26cm from TCC, IP 52cm from TCC (mag 2x), kapton on mesh array, 16-80um Al step wedge 5-layers
B21092710	25µm Cu	213.9	31.9	➢ Changed filtering/shielding for radiograph IP: 50-250um Al step wedge 5-layers, 20um Ni filter (square) added at 45 deg angle
B21092807	25µm Cu	216.6	29.8	➢ Changed radiograph magnification: mesh array 13cm from TCC, IP 52cm from TCC (mag 4x) ➢ Moved Ni filter to mesh plane: 20um strip placed at bottom of mesh array ➢ Added magnets to deflect electrons away from radiograph IP
B21092911	25µm Zr	234.6	29.8	➢ Transitioned to Zr target for 15.7 keV radiography ➢ Added 1cm polycarbonate before mesh to stop electrons (15.7 keV x-rays will transmit)
B21093006	25µm Zr	203.6	35	➢ Razor blade placed at bottom of mesh array for knife-edge measurement (could complement steel post edges)
B21093011	25µm Sn	229.5	23	➢ Transitioned to Sn target for 25 keV radiography

Results from campaign

Quick look at the Schlieren imaging diagnostic:



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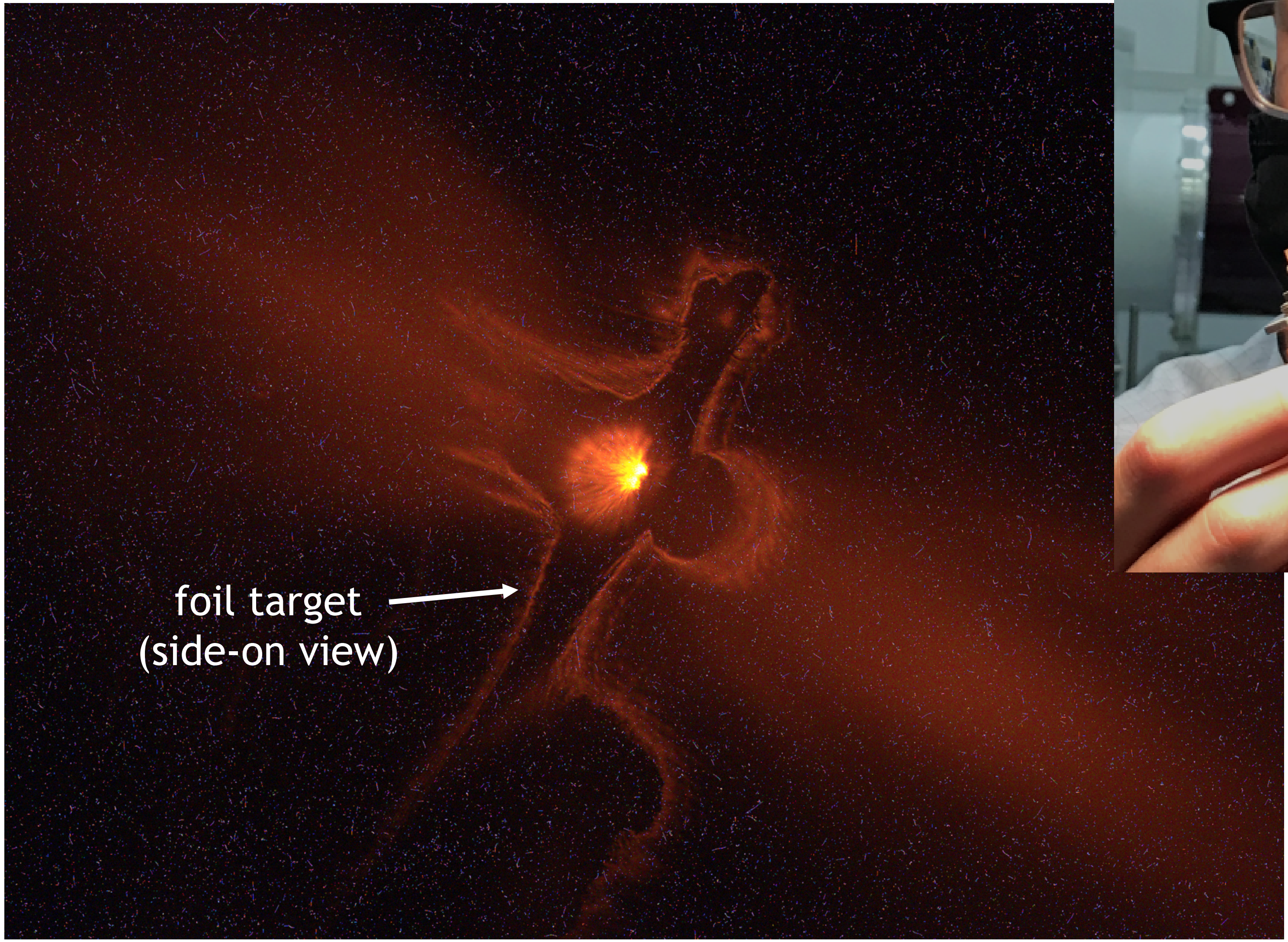

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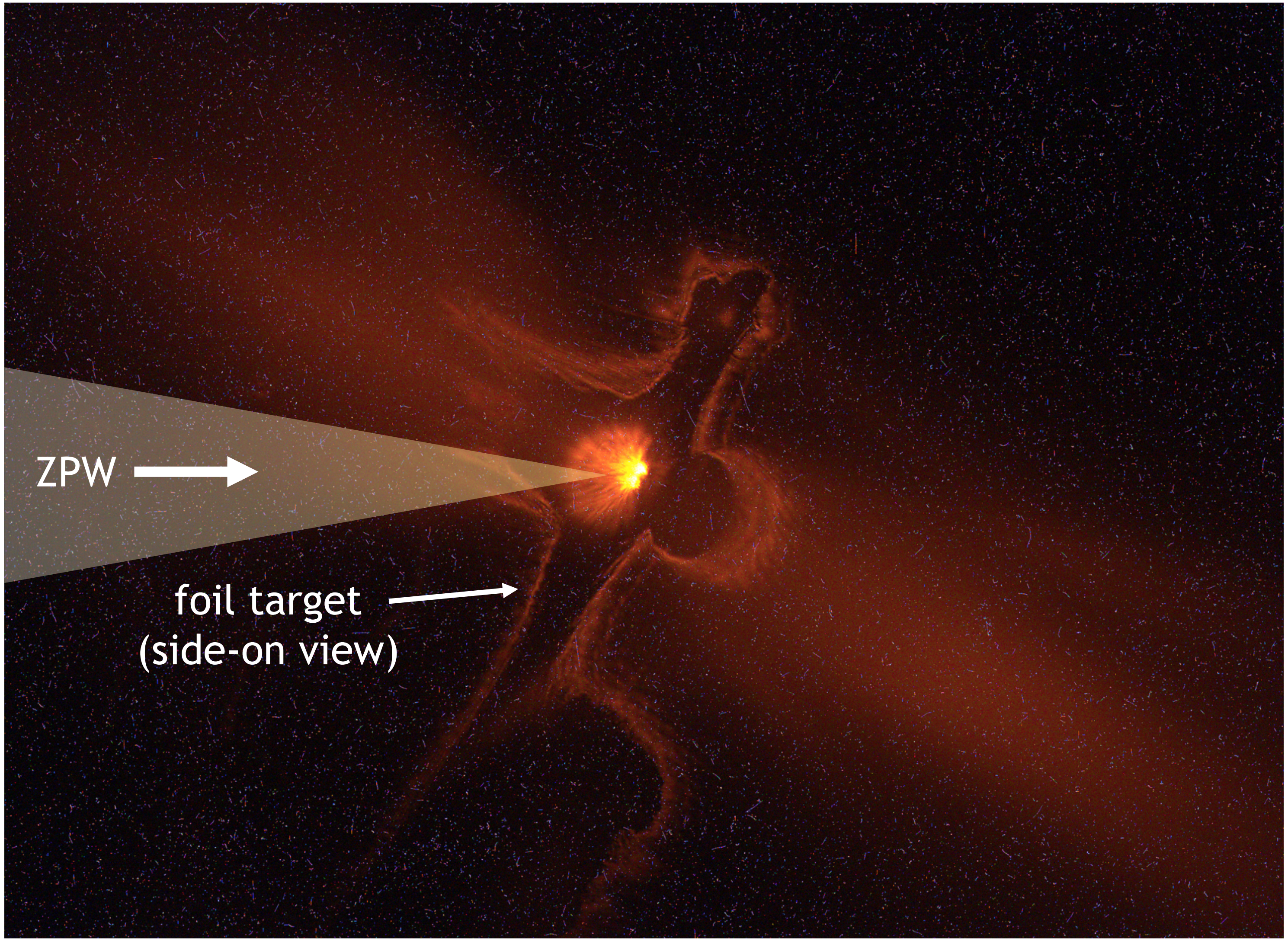

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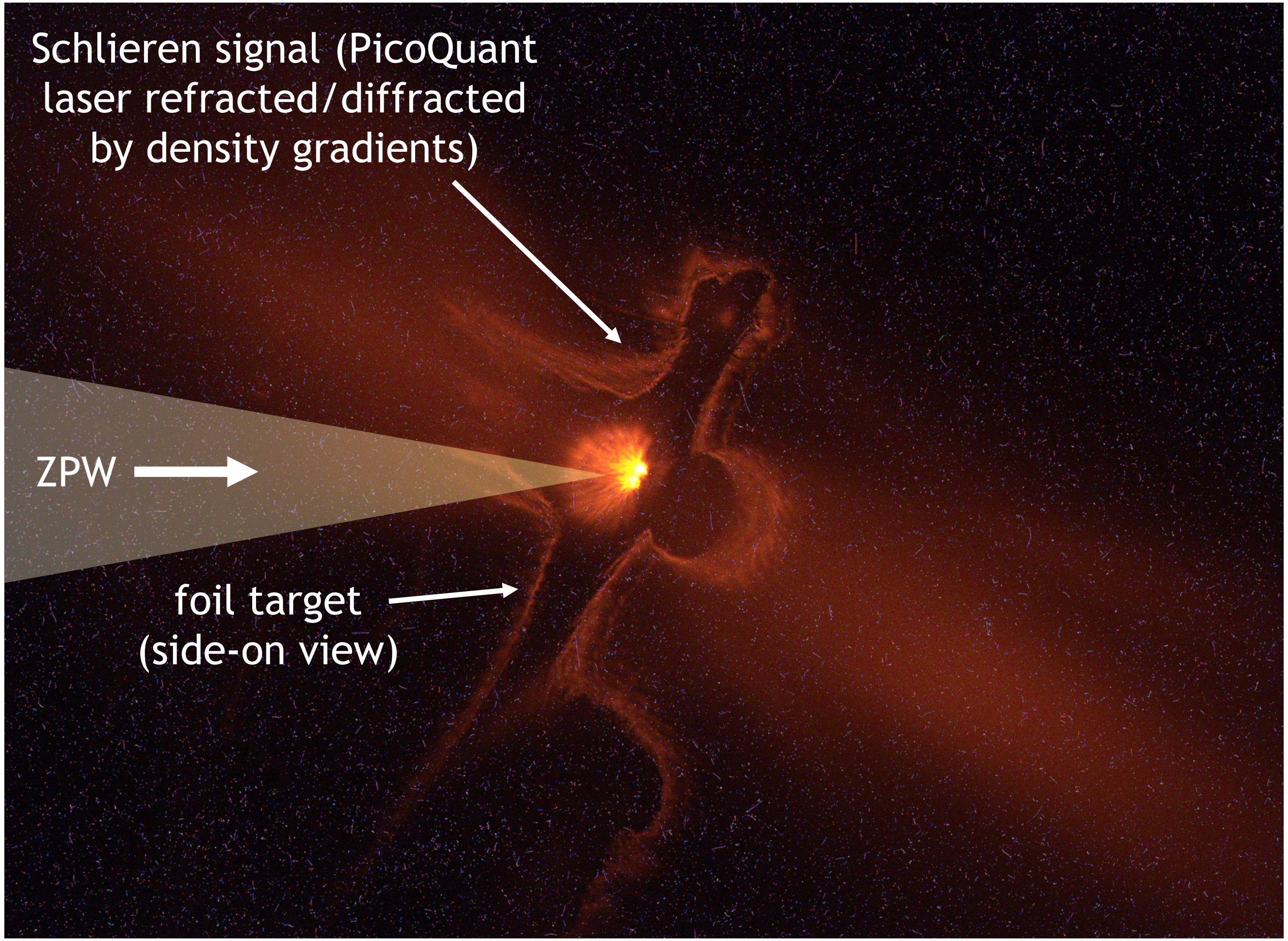

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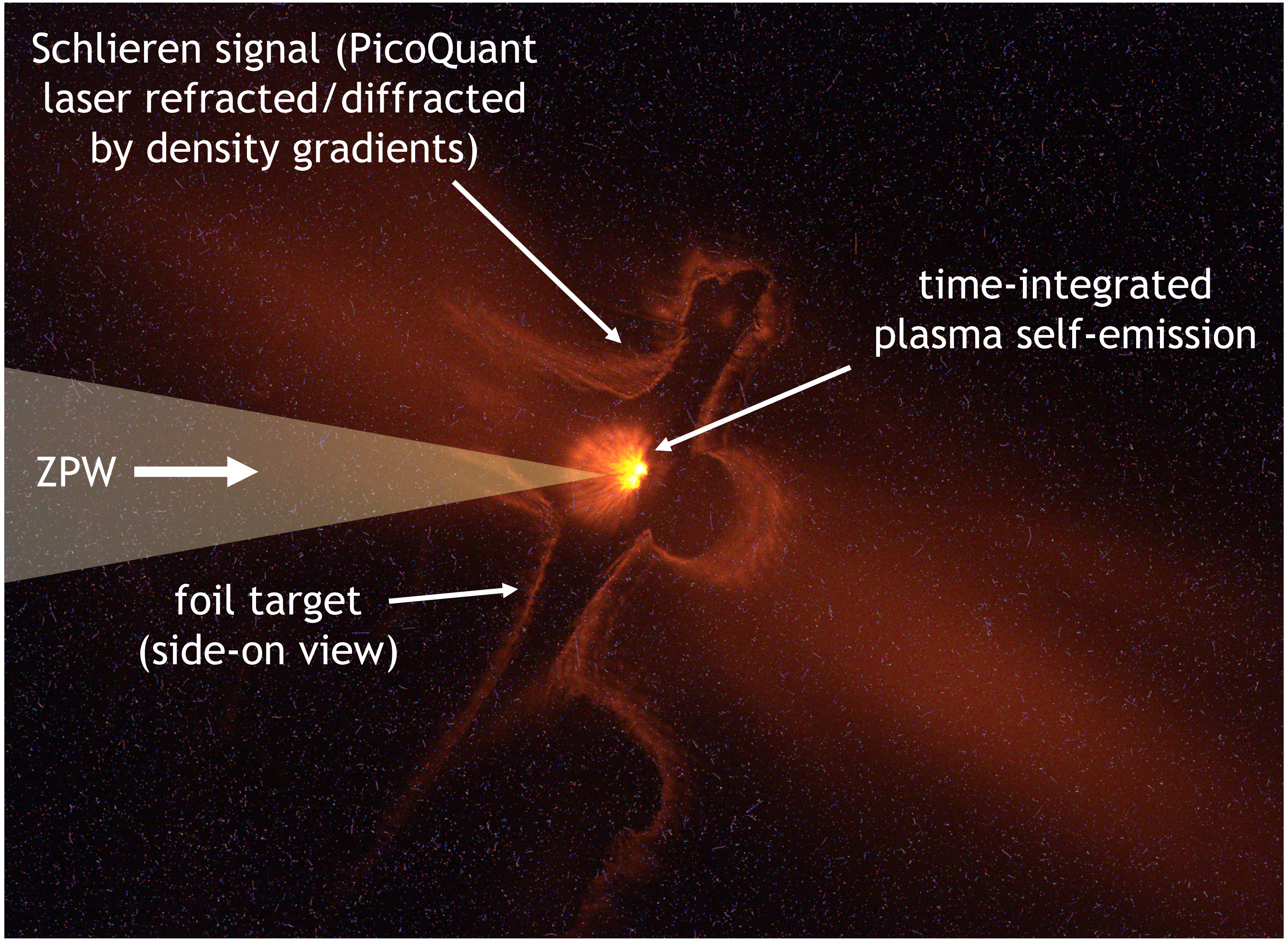

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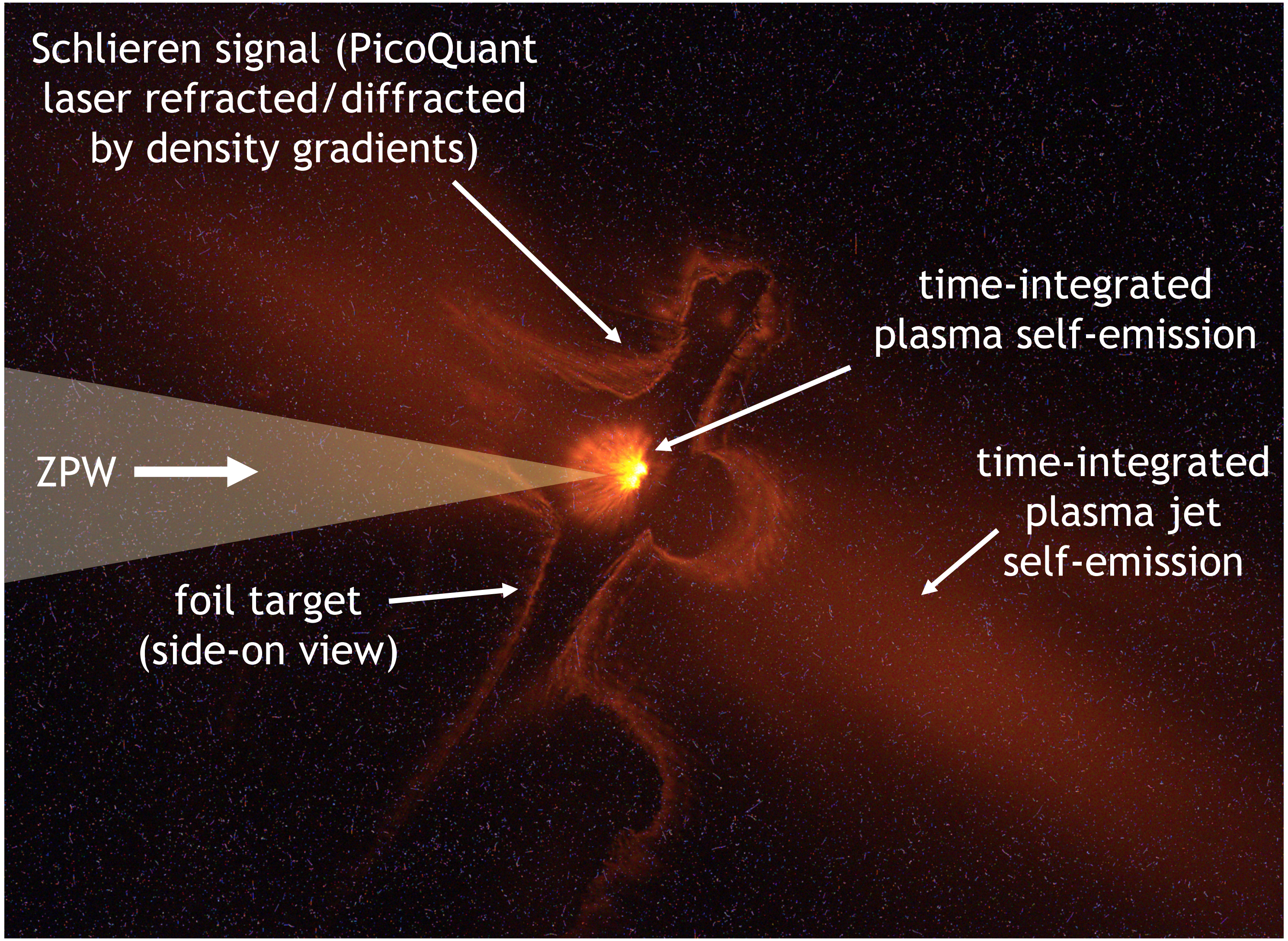

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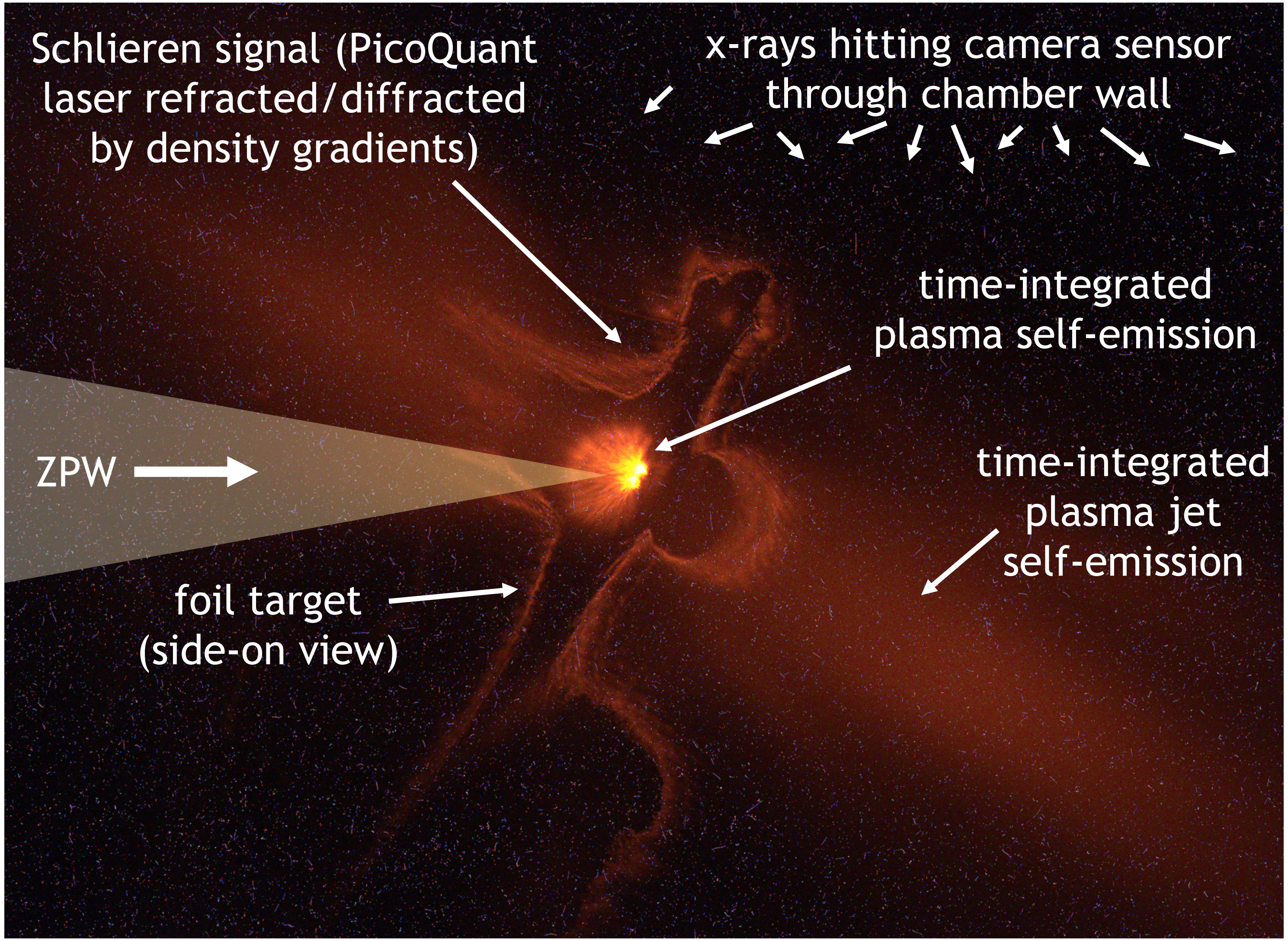

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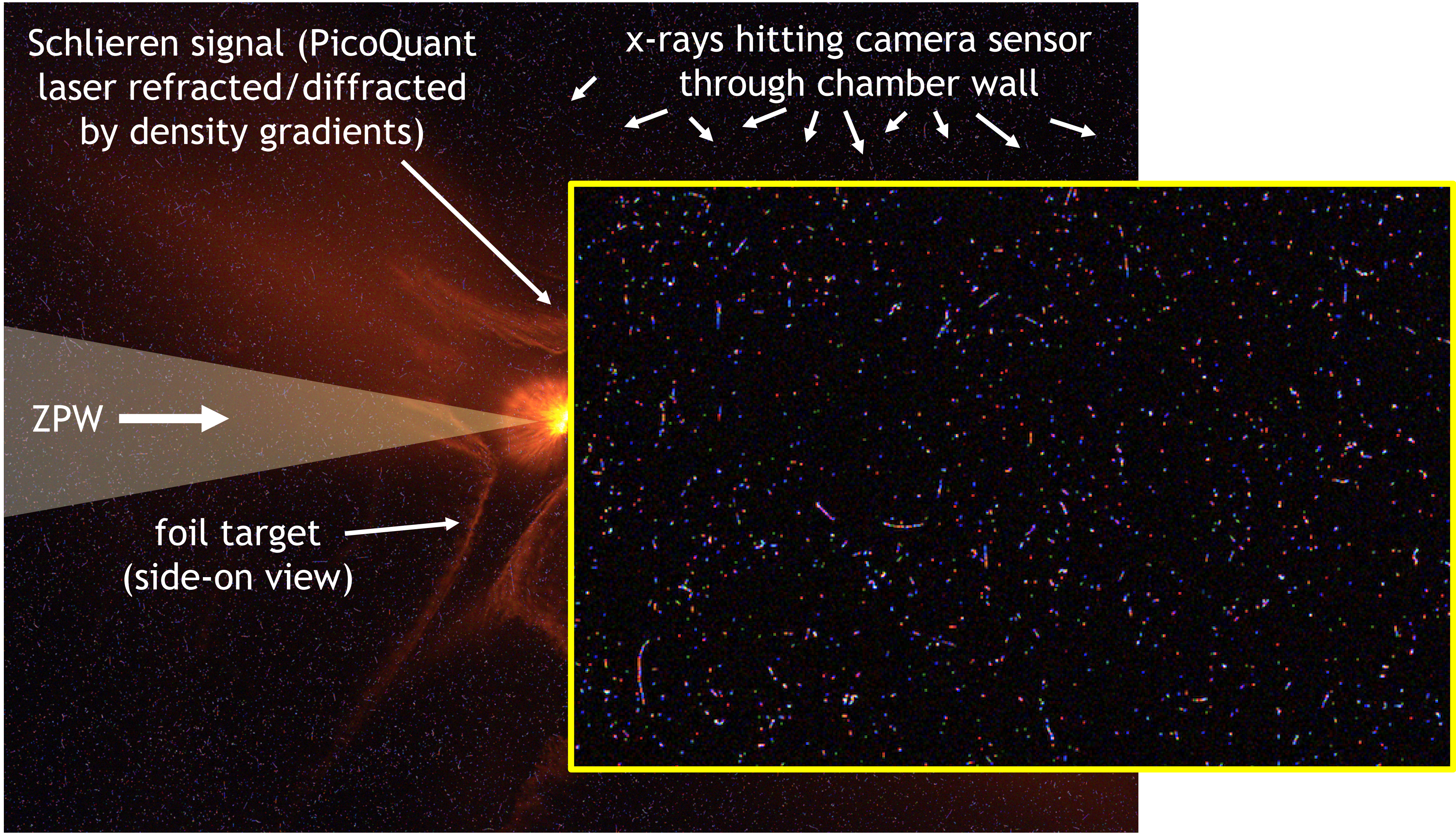
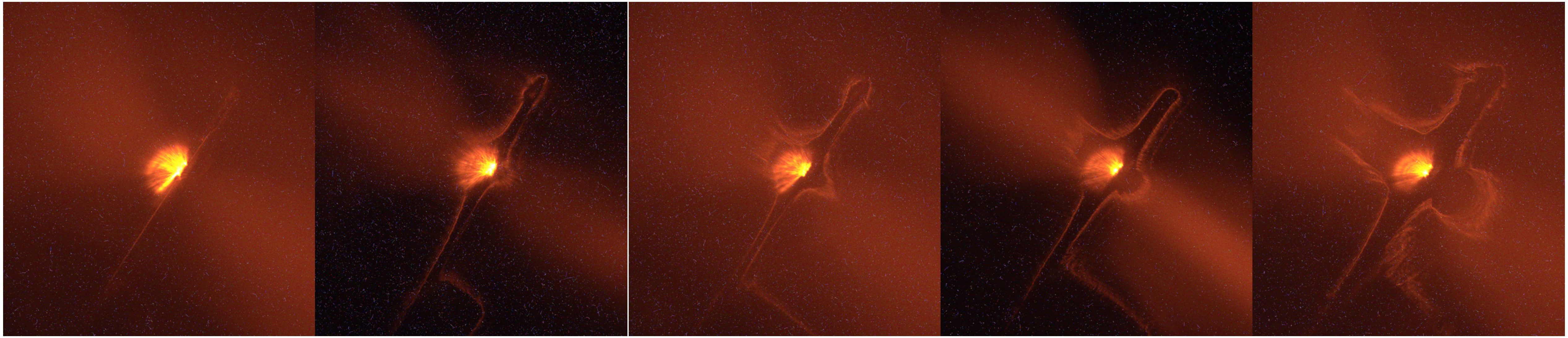


Results from campaign

Quick look at the Schlieren imaging diagnostic while varying timing (and material):

Zr | Cu | Zr | Sn | Zr



PQ arrives around -1ns

PQ arrives around +7ns

Exact timings are uncertain due to ZPW front-end timings not recorded on every shot

→ Room for improvement

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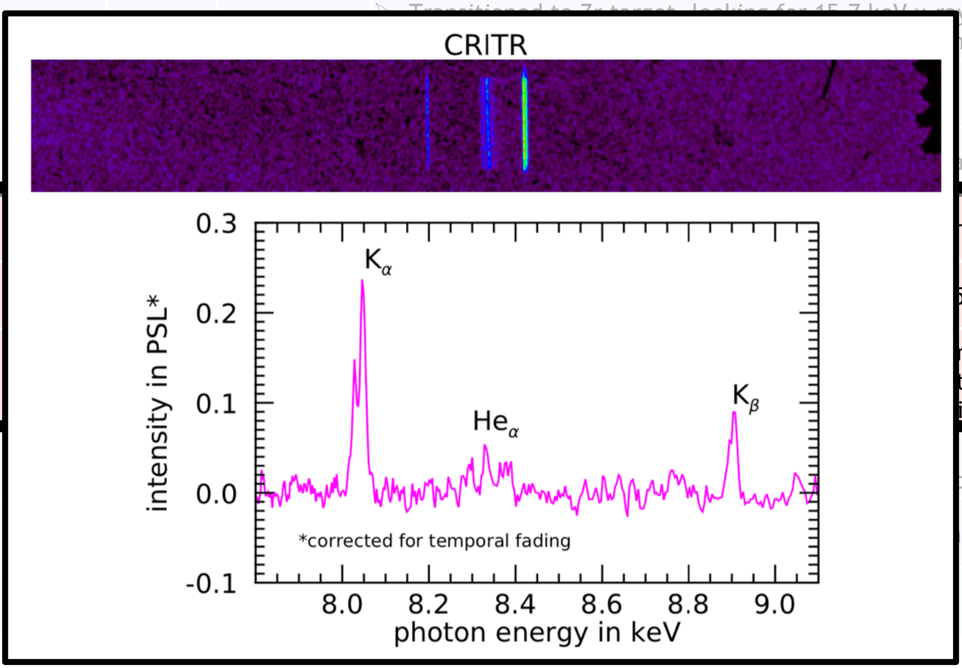

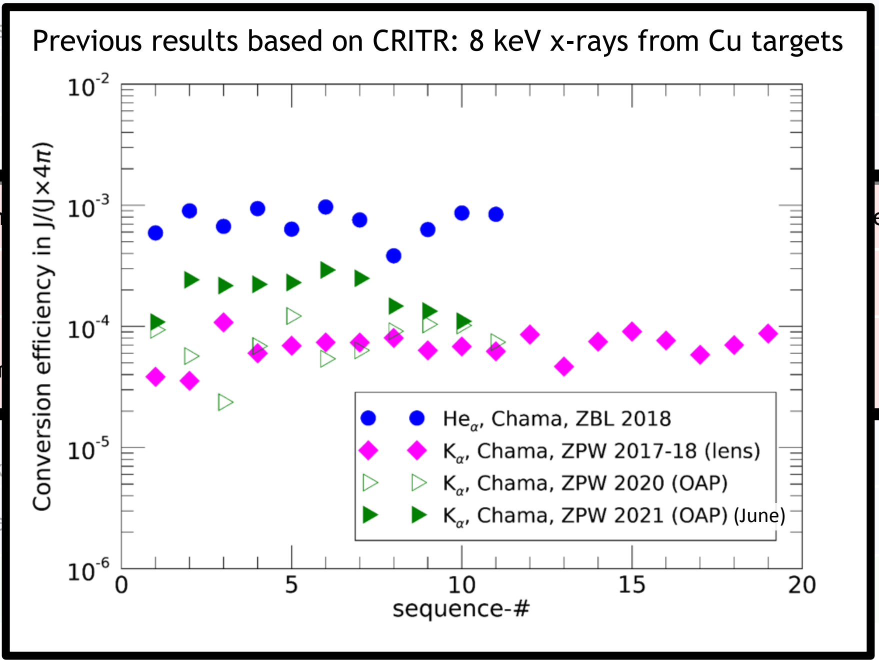

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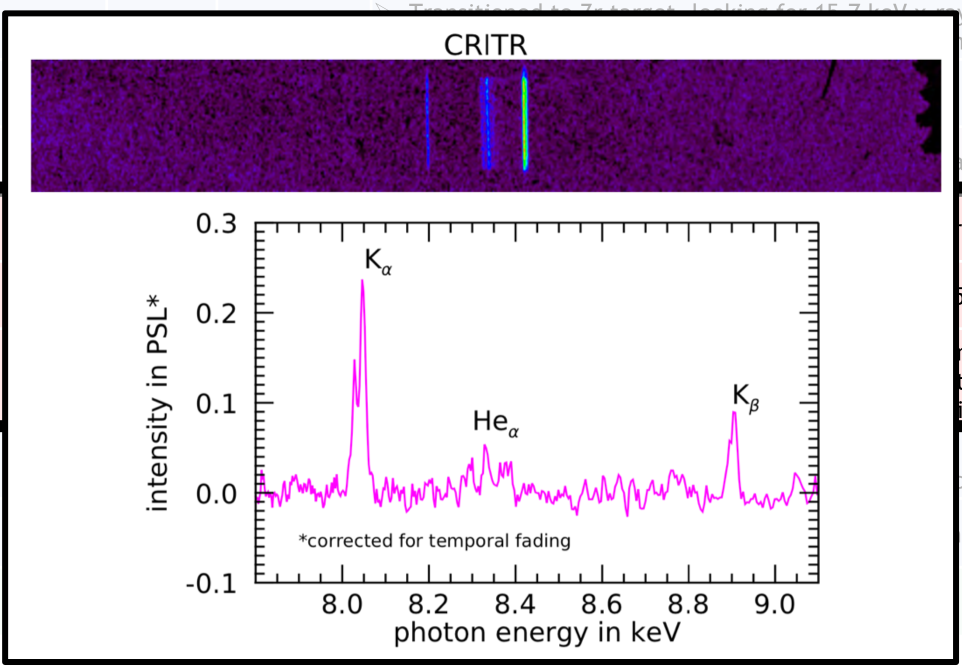

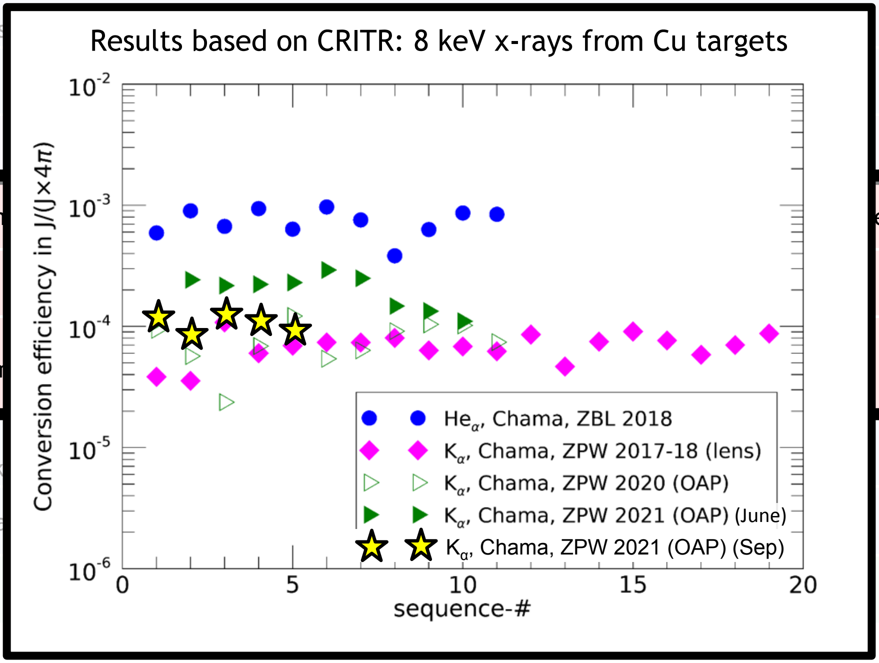

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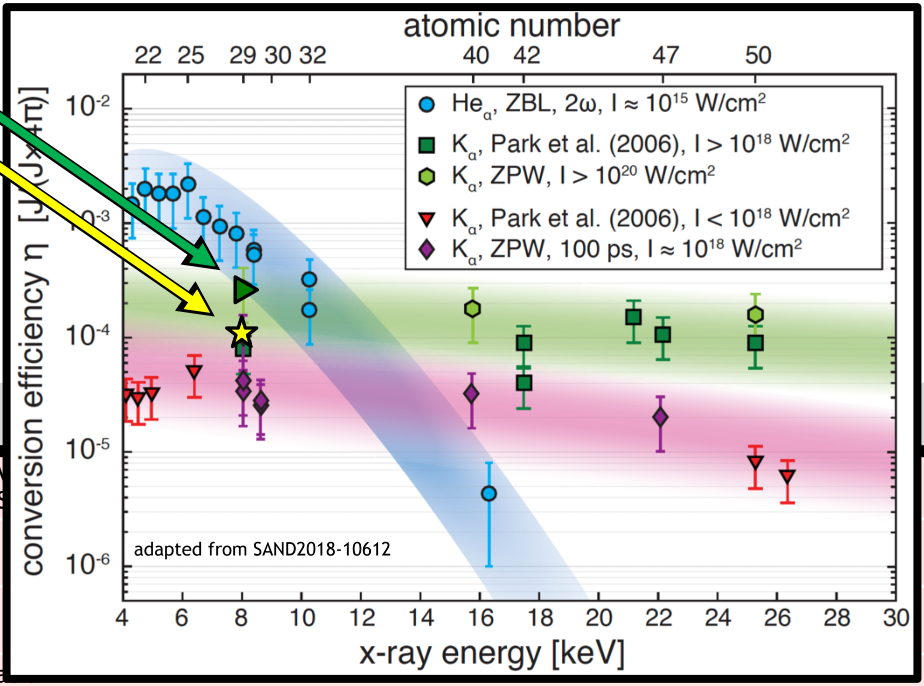

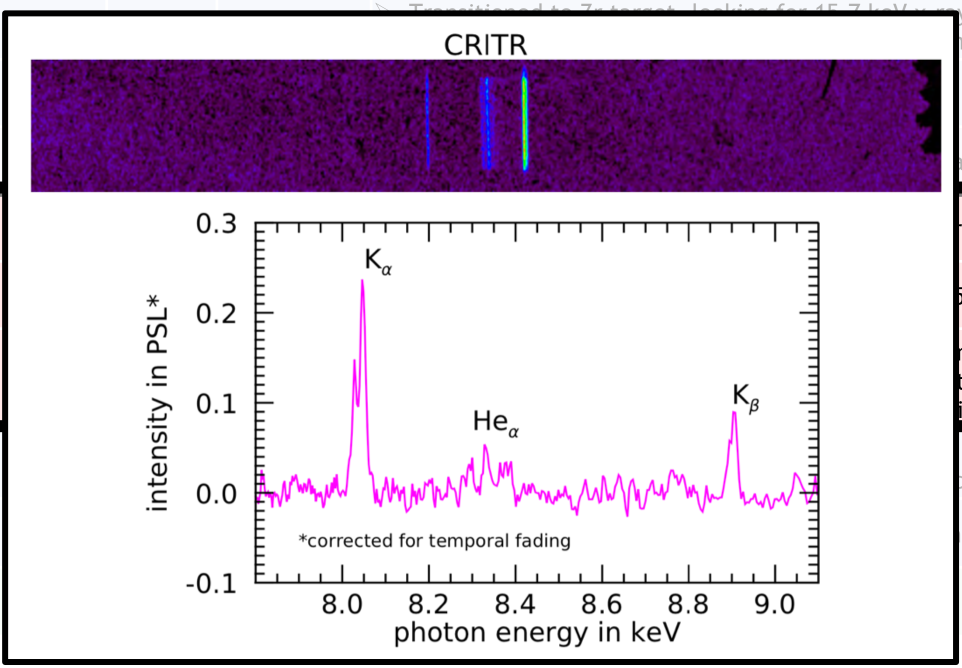

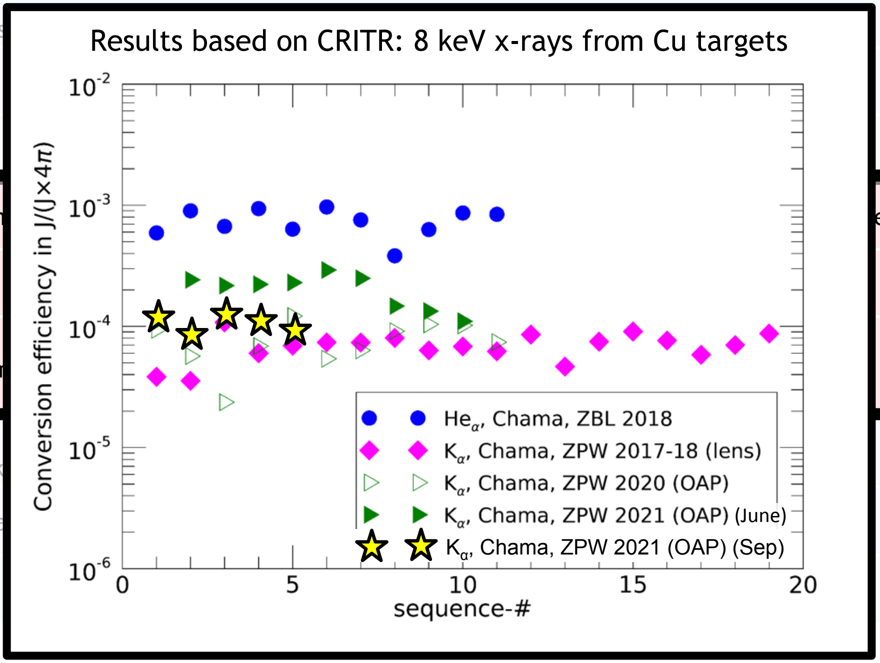

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B21092003	25µm Cu	218.7	35.4	➢ Repeat shot following Chama gate valve assessment/reinstallation ➢ Chama SE cam acquired backlit interaction
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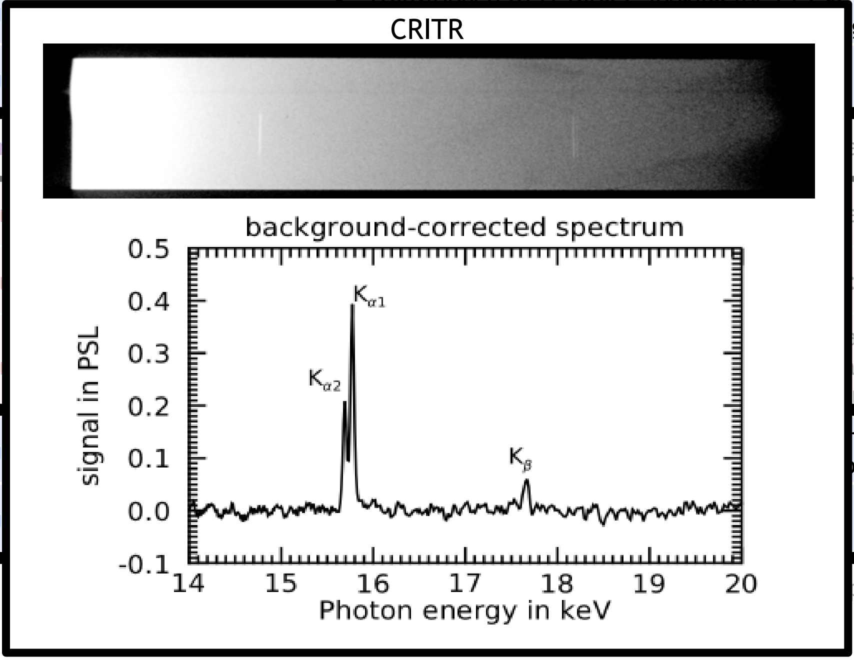
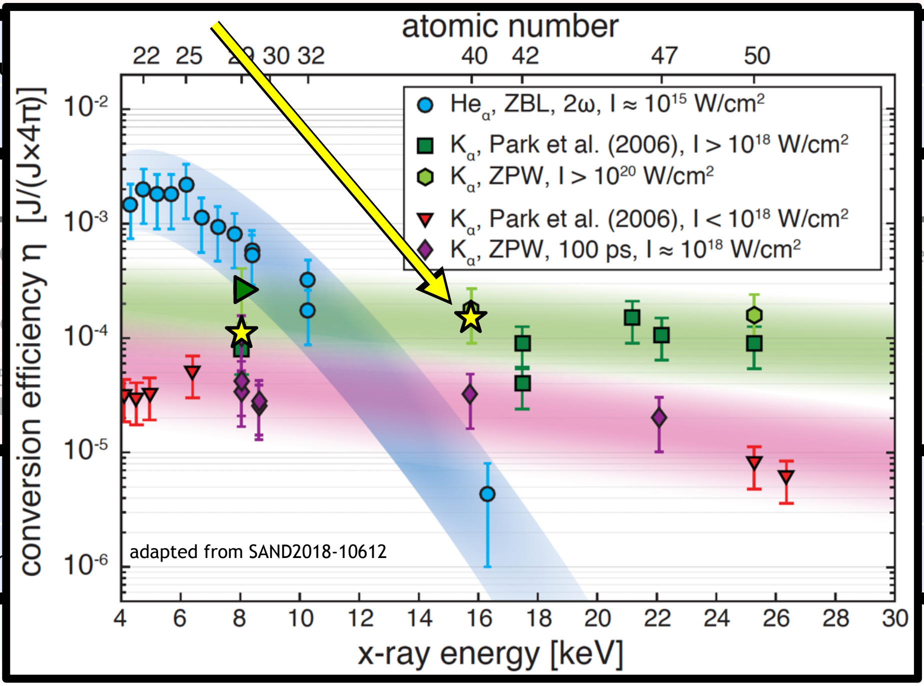
B21092303	25µm Zr	260.3	38	➢ Repeat shot for statistics
B21092309	25µm Mo	232.5	31.9	➢ Transitioned to Mo target, looking for 17.4 keV x-rays
B21092415	25µm Cu	254.3	40.8	➢ Added mesh and IP for 8 keV radiography: mesh array 26cm from TCC, IP 52cm from TCC (mag 2x), kapton on mesh array, 16-80um Al step wedge 5-layers
B21092710	25µm Cu	213.9	31.9	➢ Changed filtering/shielding for radiograph IP: 50-250um Al step wedge 5-layers, 20um Ni filter (square) added at 45 deg angle
B21092807	25µm Cu	216.6	29.8	➢ Changed radiograph magnification: mesh array 13cm from TCC, IP 52cm from TCC (mag 4x) ➢ Moved Ni filter to mesh plane: 20um strip placed at bottom of mesh array ➢ Added magnets to deflect electrons away from radiograph IP
B21092911	25µm Zr	234.6	29.8	➢ Transitioned to Zr target for 15.7 keV radiography ➢ Added 1cm polycarbonate before mesh to stop electrons (15.7 keV x-rays will transmit)
B21093006	25µm Zr	203.6	35	➢ Razor blade placed at bottom of mesh array for knife-edge measurement (could complement steel post edges)
B21093011	25µm Sn	229.5	23	➢ Transitioned to Sn target for 25 keV radiography

Results from campaign

Let's look at just the shots on Zr

Shot #	Target	Energy (J)	TNSA max E (MeV)	Experimental setup notes
B21091303	25μm Cu	228.6	28.8	➢ Baseline shot to repeat previous observations with Cu, 8.0 keV x-rays ➢ (note the CRITR zero-order block was not in position, Chama SE cam not triggering correctly)
B21091401	25μm Cu	217	26.6	➢ CRITR zero-order block placed in correct position ➢ (Chama SE cam still not triggering correctly)
B21091409	25μm Cu	243.7	0	➢ Chama gate valve was CLOSED, so shot into sapphire window ➢ (Chama SE cam triggers resolved)
B21092003	25μm Cu	218.7	35.4	➢ Repeat shot following Chama gate valve assessment/reinstallation ➢ Chama SE cam acquired backlit interaction
B21092209	25μ			➢ Transitioned to Zr target, looking for 15.7 keV x-rays g (same for all subseq
B21092303	25μ			
B21092309	25μ			eV x-rays
B21092415	25μ			esh array 26cm from T … rs
B21092710	25μ			50-250um Al step we
B21092807	25μ			ay 13cm from TCC, IP 5 ced at bottom of mesh m radiograph IP
B21092911	25μ			raphy p electrons (15.7 keV
B21093006	25μ			for knife-edge measur
B21093011	25μ			phy

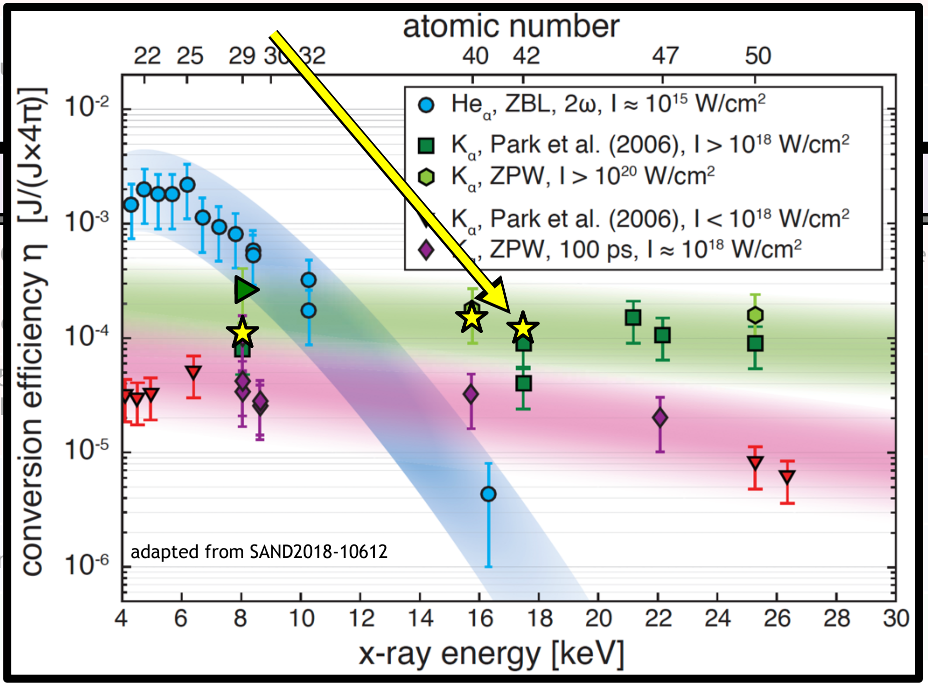




Results from campaign

How about that one Mo shot?

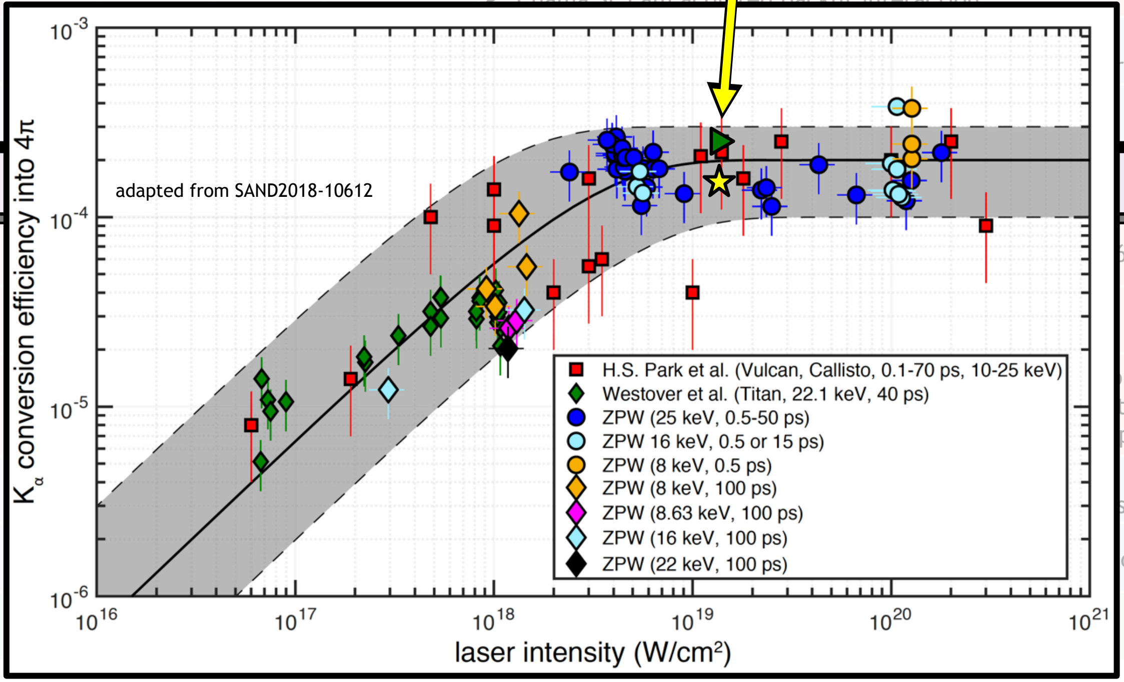
Shot #	Target	Energy (J)	TNSA max E (MeV)	Experimental setup notes
B21091303	25µm Cu	228.6	28.8	➢ Baseline shot to repeat previous observations with Cu, 8.0 keV x-rays ➢ (note the CRITR zero-order block was not in position, Chama SE cam not triggering correctly)
B21091401	25µm Cu	217	26.6	➢ CRITR zero-order block placed in correct position ➢ (Chama SE cam still not triggering correctly)
B21091409	25µm Cu	243.7	0	➢ Chama gate valve was CLOSED, so shot into sapphire window ➢ (Chama SE cam triggers resolved)
B21092003	25µm Cu	218.7	35.4	➢ Repeat shot following Chama gate valve assessment/reinstallation ➢ Chama SE cam acquired backlit interaction
B21092209	25µm Zr	231.2	32.2	➢ Transitioned to Zr target, looking for 15.7 keV x-rays ➢ Chama SE cam converted to Schlieren imaging (same for all subseq
B21092303	25µm Zr	260.3	38	➢ Repeat shot for statistics
B21092309	**25µm Mo**	**232.5**	**31.9**	➢ **Transitioned to Mo target, looking for 17.4 keV x-rays**
B21092415	25µm Cu	254.3	40.8	➢ Added mesh and IP for 8 keV radiography: mesh array 26cm from T … ers
B21092710	25µm Cu	213.9	31.9	➢ Changed filtering/shielding for radiograph IP: 50-250um Al step we
B21092807	25µm Cu	216.6	29.8	➢ Changed radiograph magnification: mesh array 13cm from TCC, IP ➢ Moved Ni filter to mesh plane: 20um strip placed at bottom of mes ➢ Added magnets to deflect electrons away from radiograph IP
B21092911	25µm Zr	234.6	29.8	➢ Transitioned to Zr target for 15.7 keV radiography ➢ Added 1cm polycarbonate before mesh to stop electrons (15.7 keV
B21093006	25µm Zr	203.6	35	➢ Razor blade placed at bottom of mesh array for knife-edge measur
B21093011	25µm Sn	229.5	23	➢ Transitioned to Sn target for 25 keV radiography

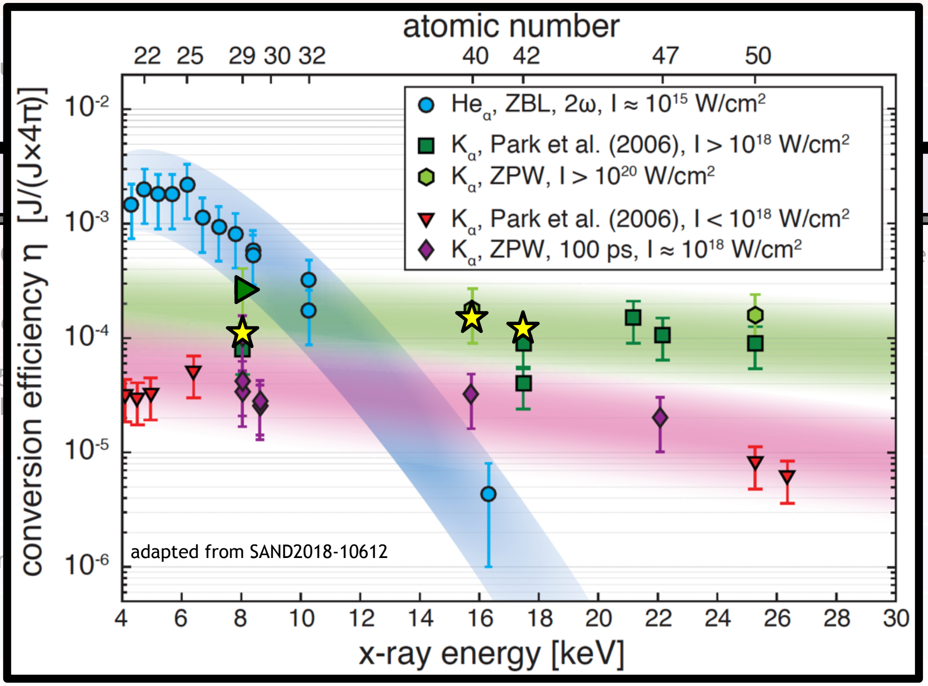


Results from campaign

Can we go further in conversion efficiency?

Shot #	Target	Energy (J)	TNSA max E (MeV)	Experimental setup notes
B21091303	25µm Cu	228.6	28.8	➢ Baseline shot to repeat previous observations with Cu, 8.0 keV x-rays ➢ (note the CRITR zero order block was not in position, Chama SE cam not triggering correctly)
B21091401	25µm Cu	217	26.6	➢ CRITR zero-order block placed in correct position ➢ (Chama SE cam still not triggering correctly)
B21091409	25µm Cu	243.7	0	➢ Chama gate valve was CLOSED, so shot into sapphire window ➢ (Chama SE cam triggers resolved)
B21092003	25µm Cu	218.7	35.4	➢ Repeat shot following Chama gate valve assessment/reinstallation ➢ Chama SE cam acquired backlit interaction
B21				all subseq
B21				
B21				
B21				5cm from T ... ers
B21				Al step we
B21				m TCC, IP 5 tom of mesh ph IP
B21				s (15.7 keV
B21				dge measur
B21				

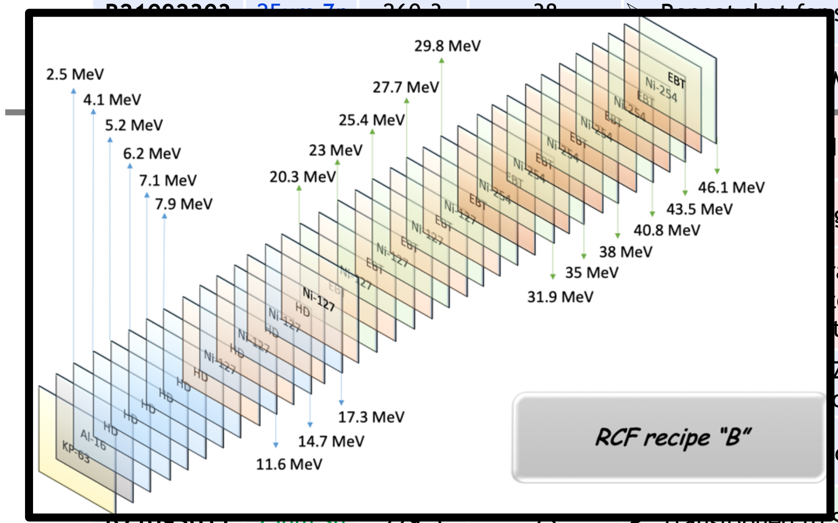


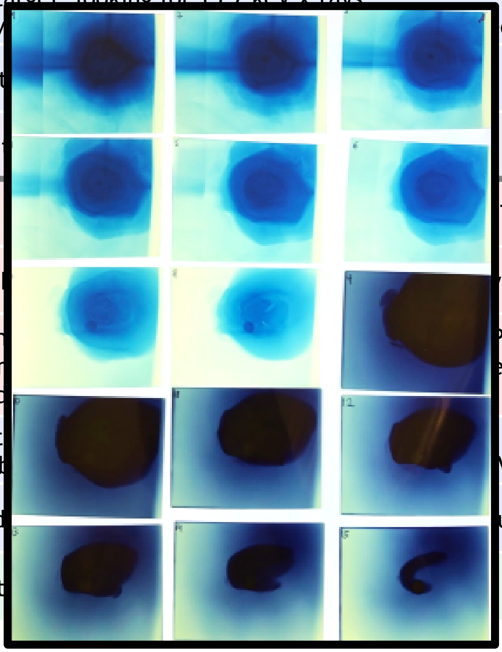


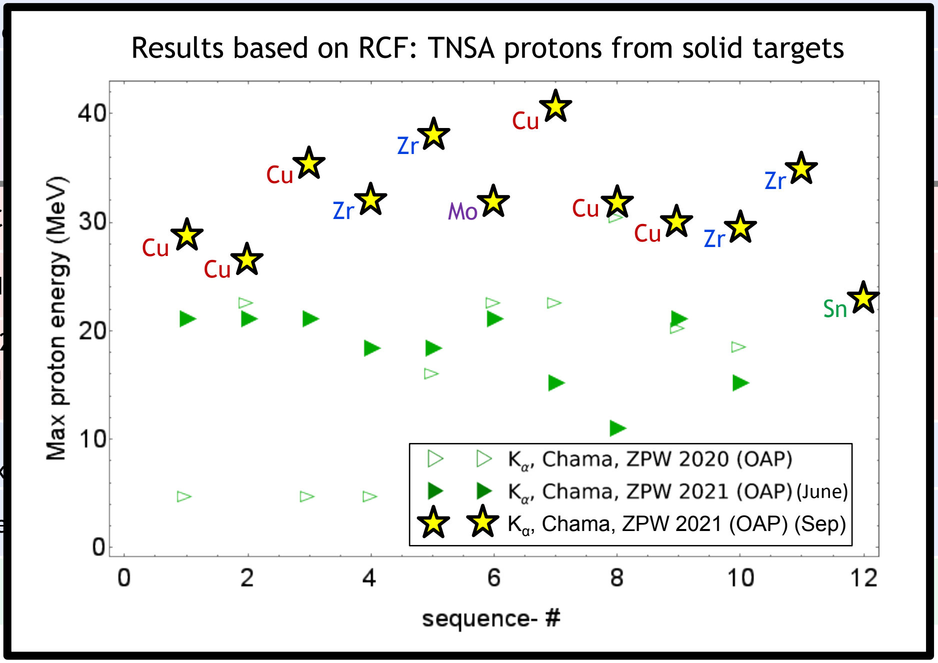
Results from campaign

How about the TNSA proton performance?

Shot #	Target	Energy (J)	TNSA max E (MeV)	Experimental setup notes
B21091303	25μm Cu	228.6	28.8	➢ Baseline shot to repeat previous observations with Cu, 8.0 keV x-rays ➢ (note the CRITR zero-order block was not in position, Chama SE cam not triggering correctly)
B21091401	25μm Cu	217	26.6	➢ CRITR zero-order block placed in correct position ➢ (Chama SE cam still not triggering correctly)
B21091409	25μm Cu	243.7	0	➢ Chama gate valve was CLOSED, so shot into sapphire window ➢ (Chama SE cam triggers resolved)
B21092003	25μm Cu	218.7	35.4	➢ Repeat shot following Chama gate valve assessment/reinstallation ➢ Chama SE cam acquired backlit interaction
B21092209	25μm Zr	231.2	32.2	➢ Transitioned to Zr target, looking for 15.7 keV x-rays ➢ Chama SE cam conv



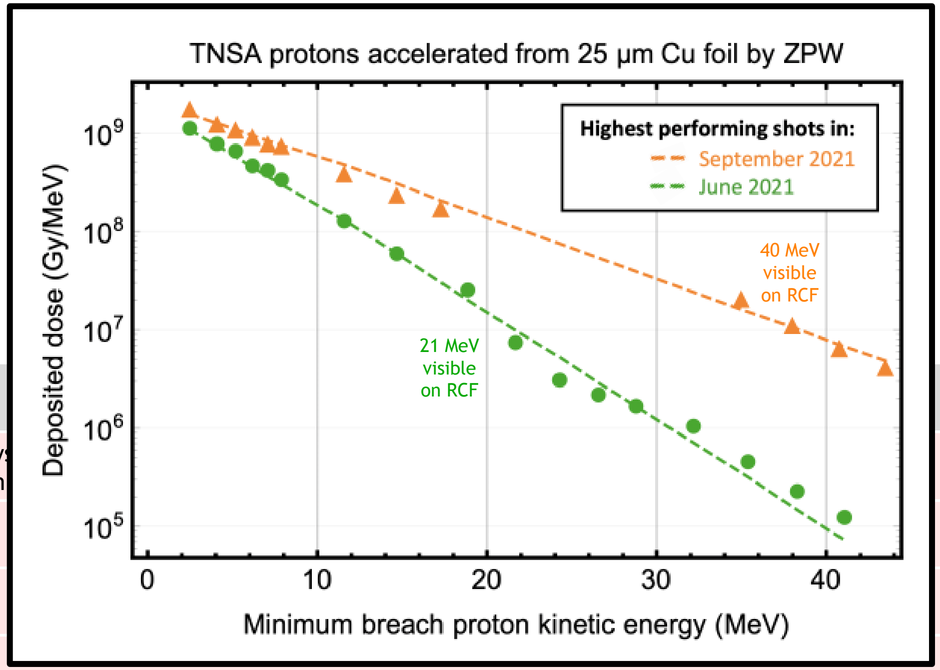


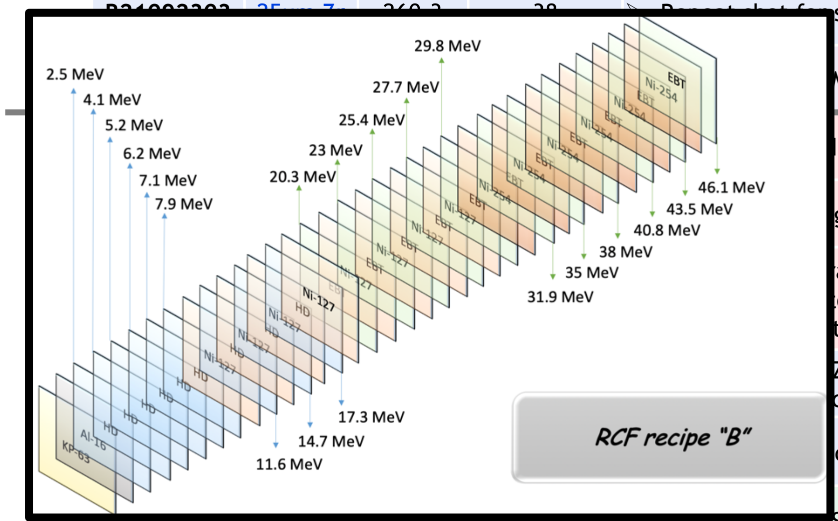


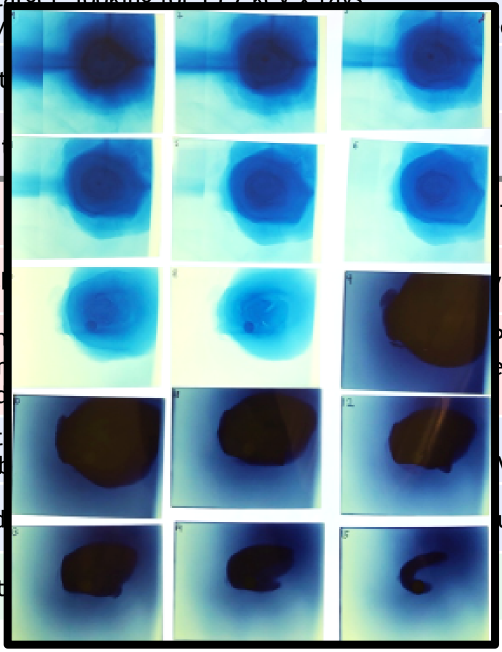
Results from campaign

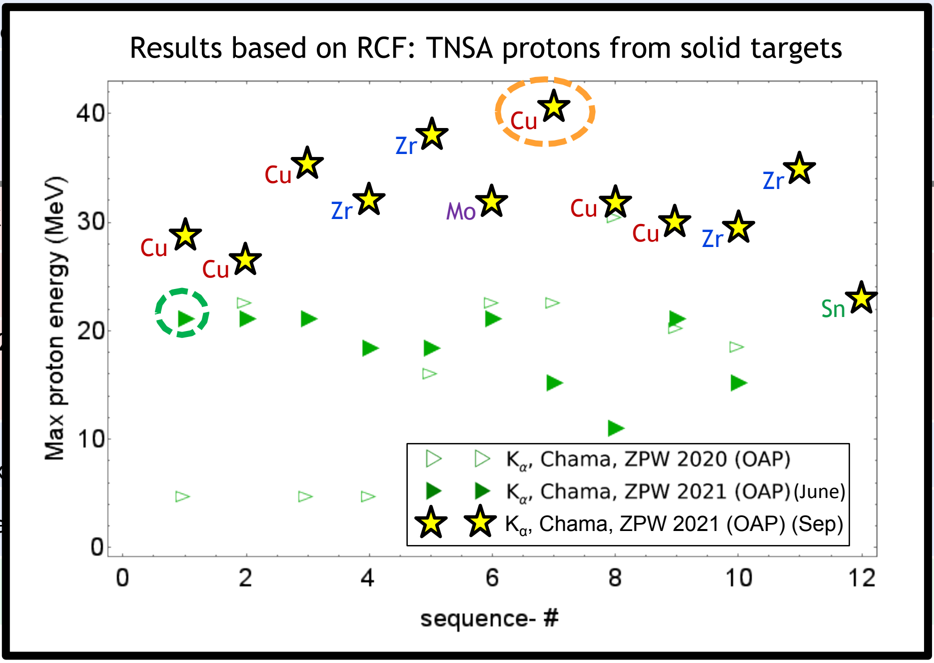
How about the TNSA proton performance?

Shot #	Target	Energy (J)	TNSA max E (MeV)	Experimental setup notes
B21091303	25µm Cu	228.6	28.8	➢ Baseline shot to repeat previous observations with Cu, 8.0 keV x-rays ➢ (note the CRITR zero-order block was not in position, Chama SE cam
B21091401	25µm Cu	217	26.6	➢ CRITR zero-order block placed in correct position ➢ (Chama SE cam still not triggering correctly)
B21091409	25µm Cu	243.7	0	➢ Chama gate valve was CLOSED, so shot into sapphire window ➢ (Chama SE cam triggers resolved)
B21092003	25µm Cu	218.7	35.4	➢ Repeat shot following Chama gate valve assessment/reinstallation ➢ Chama SE cam acquired backlit interaction
B21092209	25µm Zr	231.2	32.2	➢ Transitioned to Zr target, looking for 15.7 keV x-rays ➢ Chama SE cam conv

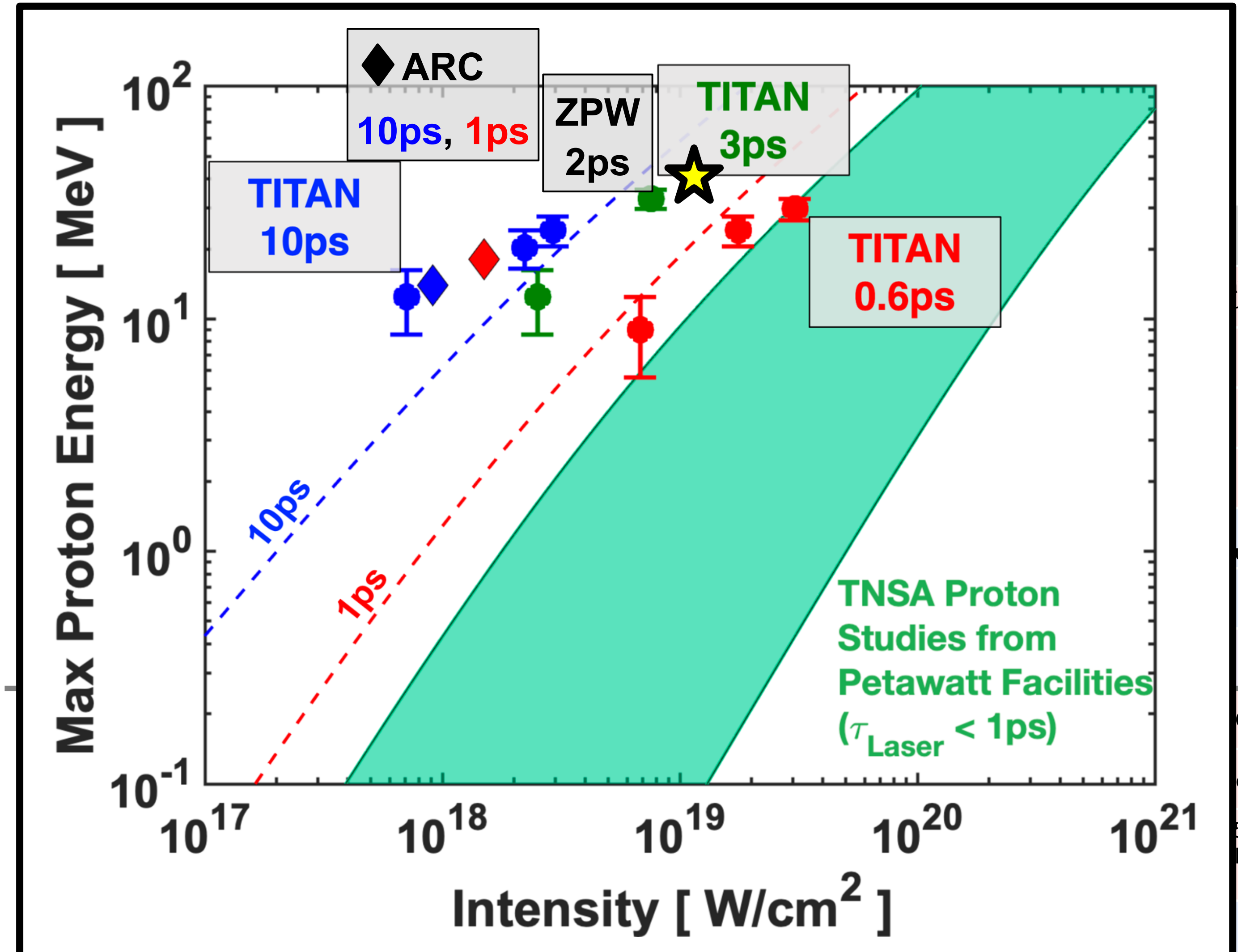




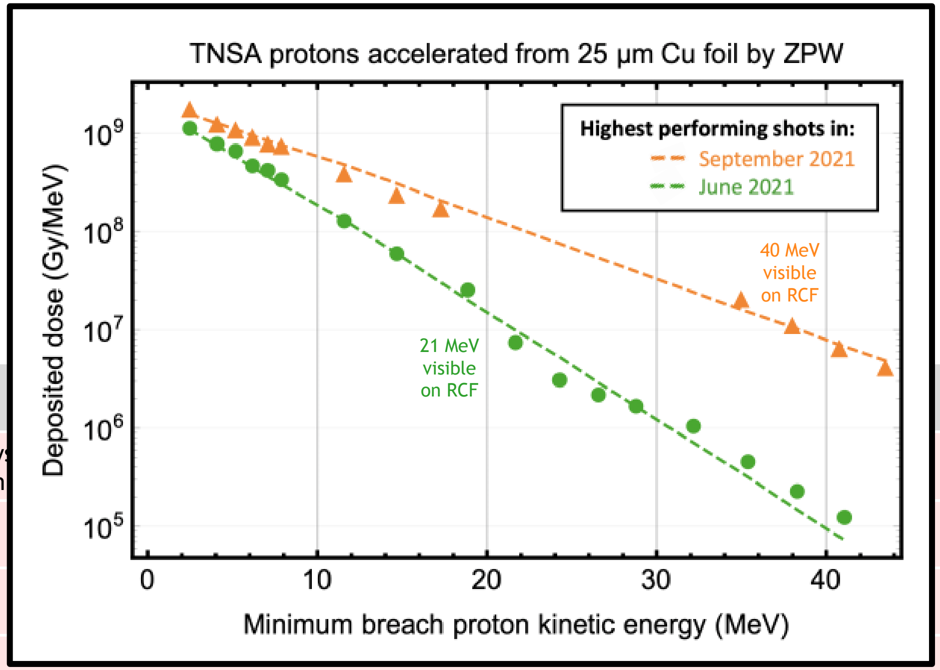


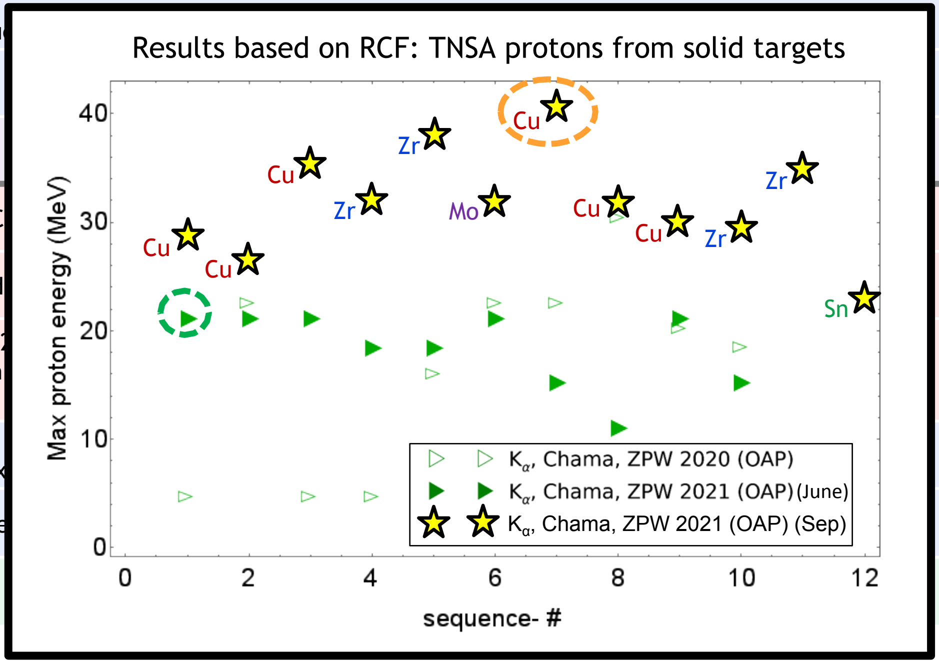


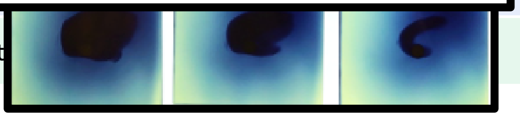
Results from campaign



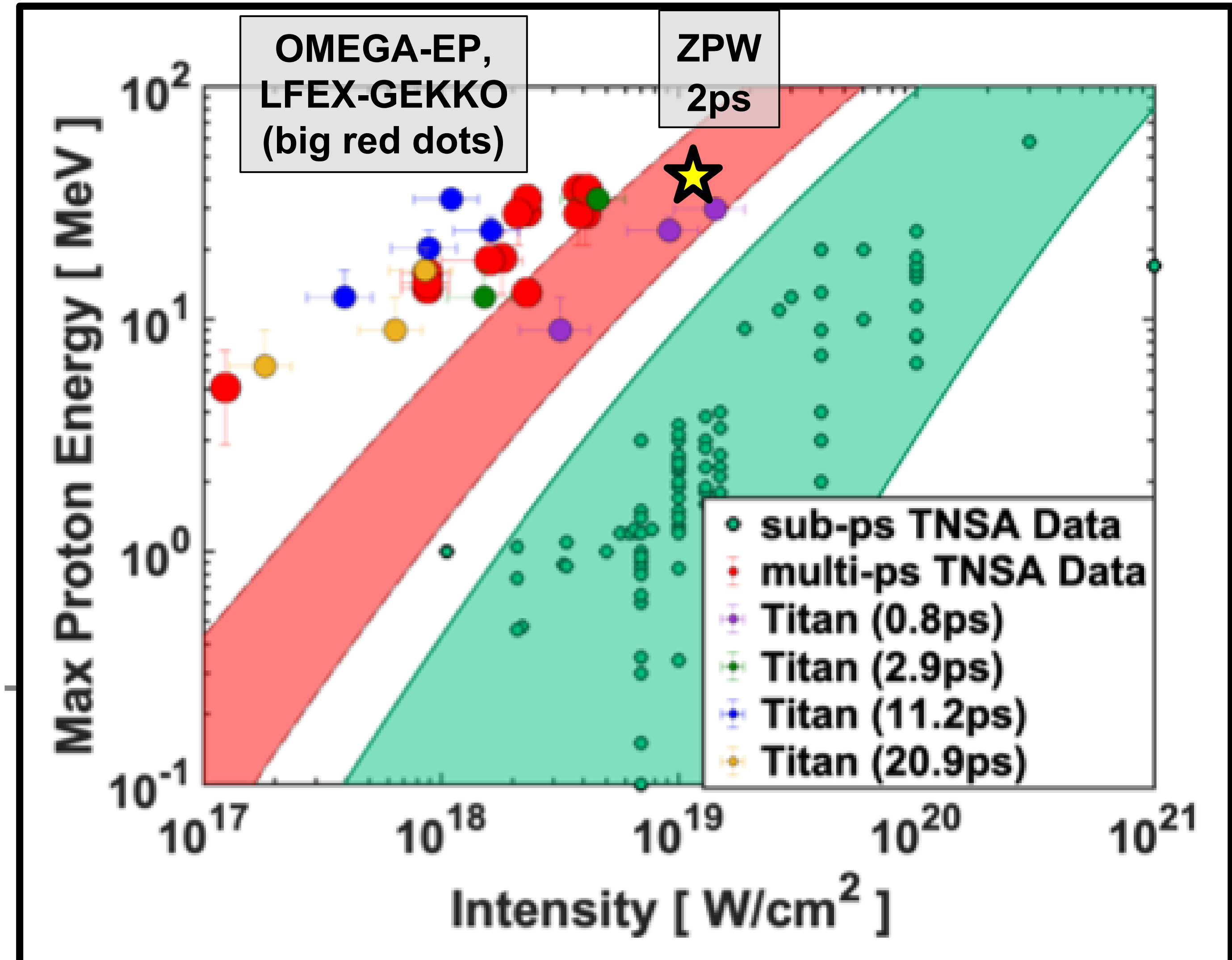
R. Simpson, "Scaling Studies of Laser-Driven Proton Acceleration in the Multi-ps Regime at the TITAN laser", NIF/JLF User Group Meeting, Feb. 4, 2021.



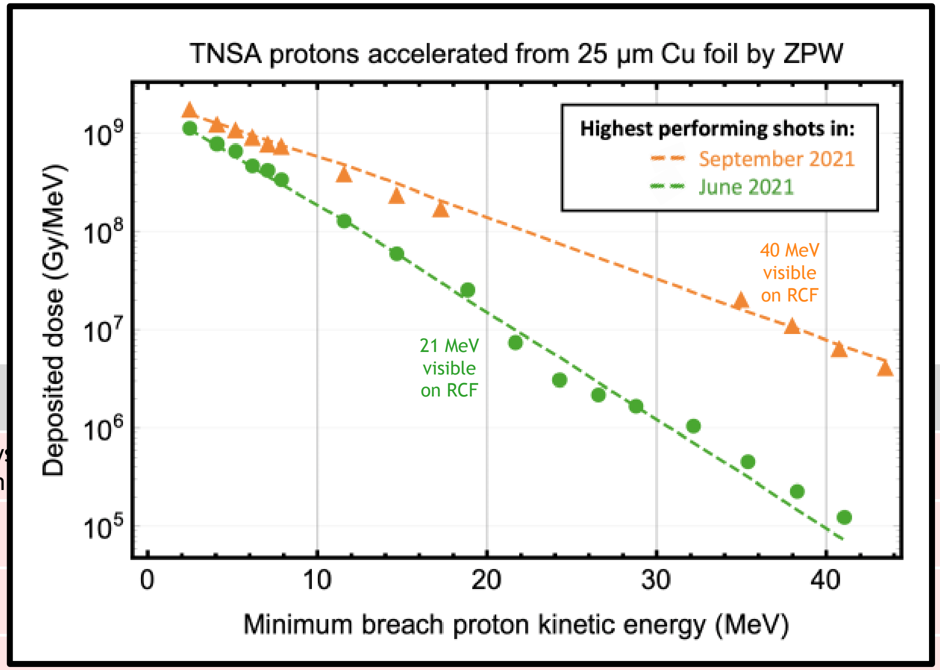


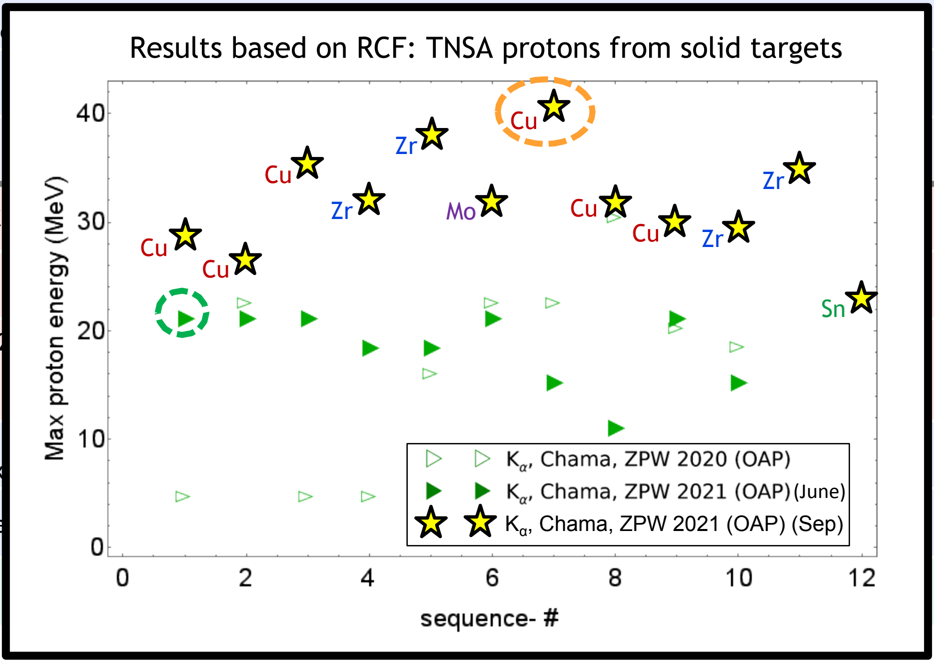


Results from campaign



The banded areas are the Fuchs model plotted from pulse durations of 30-700 fs (in green) and 1-10ps (in red)





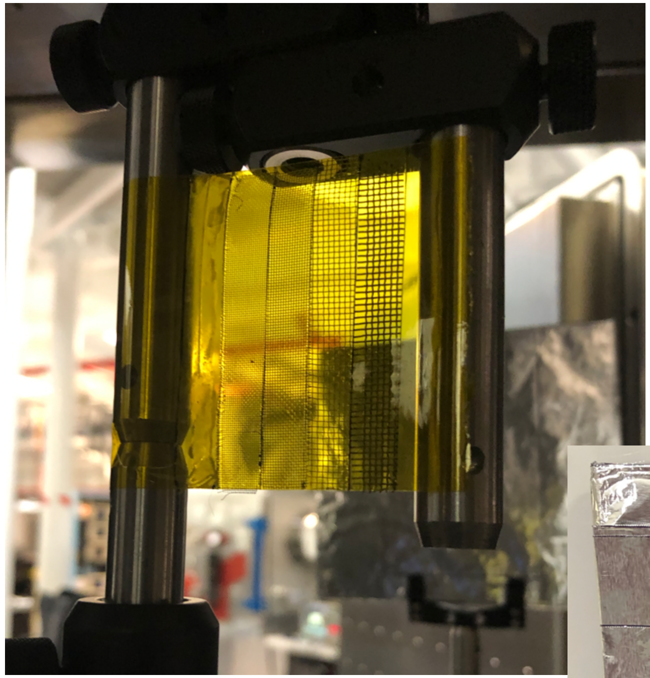
Results from campaign

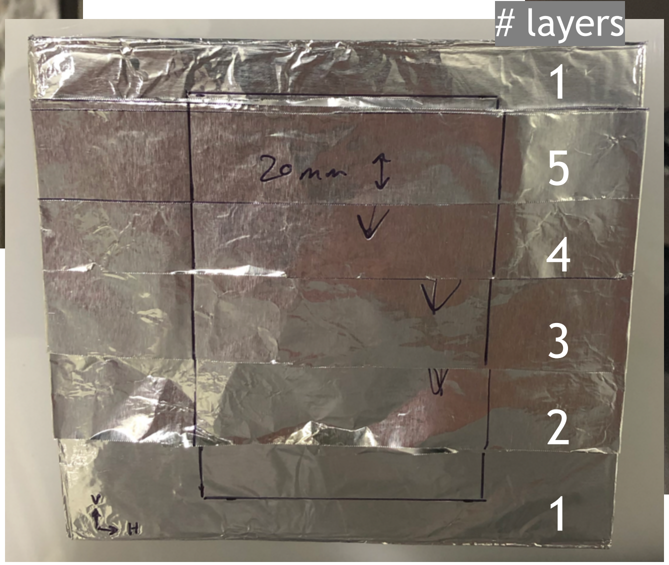
Second half of campaign added radiography of a mesh array

Shot #	Target	Energy (J)	TNSA max E (MeV)	Experimental setup notes
B21091303	25μm Cu	228.6	28.8	➢ Baseline shot to repeat previous observations with Cu, 8.0 keV x-rays ➢ (note the CRITR zero-order block was not in position, Chama SE cam not triggering correctly)
B21091401	25μm Cu	217	26.6	➢ CRITR zero-order block placed in correct position ➢ (Chama SE cam still not triggering correctly)
B21091409	25μm Cu	243.7	0	➢ Chama gate valve was CLOSED, so shot into sapphire window ➢ (Chama SE cam triggers resolved)
B21092003	25μm Cu	218.7	35.4	➢ Repeat shot following Chama gate valve assessment/reinstallation ➢ Chama SE cam acquired backlit interaction
B21092209	25μm Zr	231.2	32.2	➢ Transitioned to Zr target, looking for 15.7 keV x-rays ➢ Chama SE cam converted to Schlieren imaging (same for all subsequent shots)
B21092303	25μm Zr	260.3	38	➢ Repeat shot for statistics
B21092309	25μm Mo	232.5	31.9	➢ Transitioned to Mo target, looking for 17.4 keV x-rays
B21092415	25μm Cu	254.3	40.8	➢ Added mesh and IP for 8 keV radiography: mesh array 26cm from TCC, IP 52cm from TCC (mag 2x), kapton on mesh array, 16-80um Al step wedge 5-layers
B21092710	25μm Cu	213.9	31.9	➢ Changed filtering/shielding for radiograph IP: 50-250um Al step wedge 5-layers, 20um Ni filter (square) added at 45 deg angle
B21092807	25μm Cu	216.6	29.8	➢ Changed radiograph magnification: mesh array 13cm from TCC, IP 52cm from TCC (mag 4x) ➢ Moved Ni filter to mesh plane: 20um strip placed at bottom of mesh array ➢ Added magnets to deflect electrons away from radiograph IP
B21092911	25μm Zr	234.6	29.8	➢ Transitioned to Zr target for 15.7 keV radiography ➢ Added 1cm polycarbonate before mesh to stop electrons (15.7 keV x-rays will transmit)
B21093006	25μm Zr	203.6	35	➢ Razor blade placed at bottom of mesh array for knife-edge measurement (could complement steel post edges)
B21093011	25μm Sn	229.5	23	➢ Transitioned to Sn target for 25 keV radiography

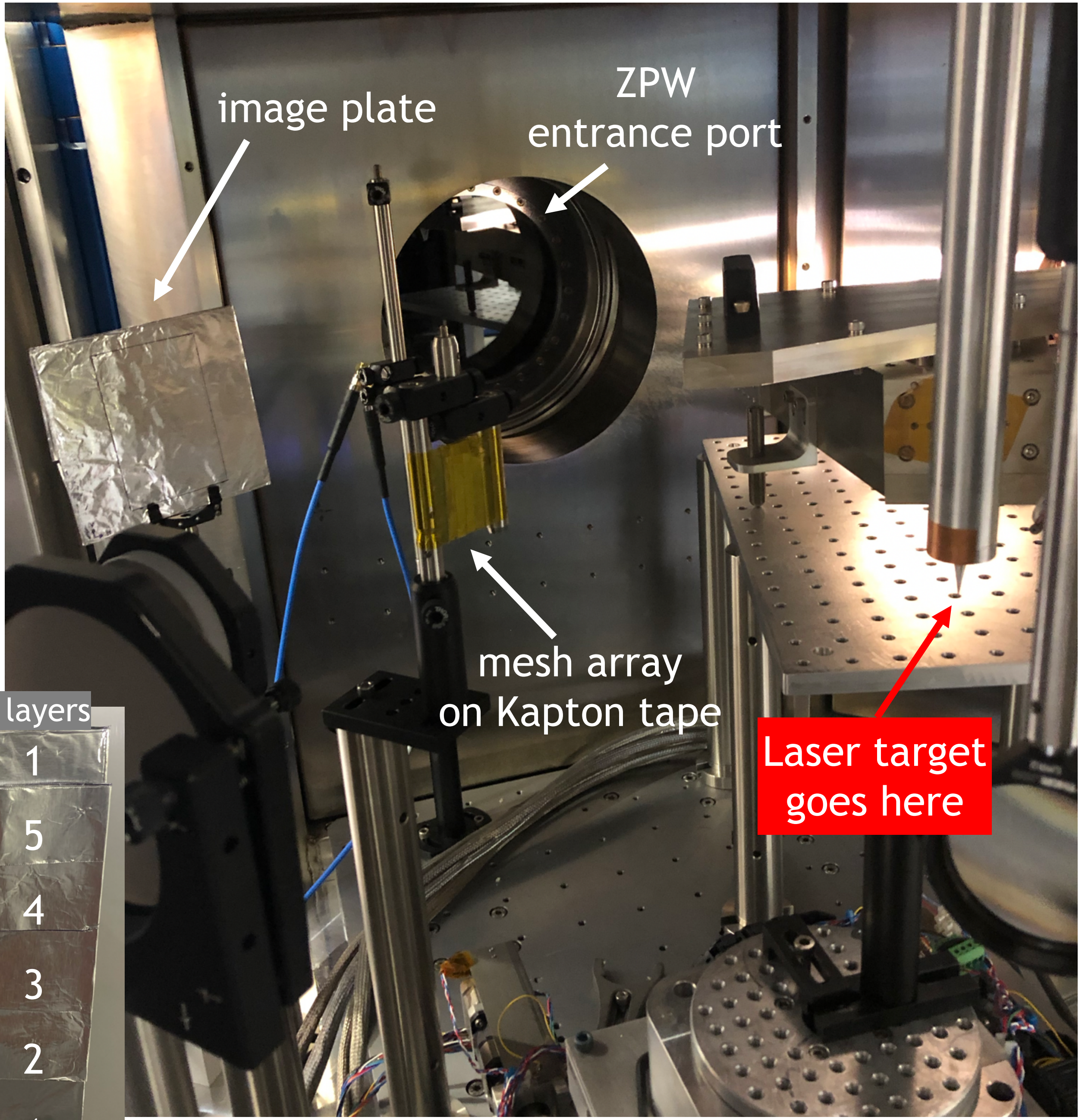
Results from campaign

Second half of campaign added radiography of a mesh array





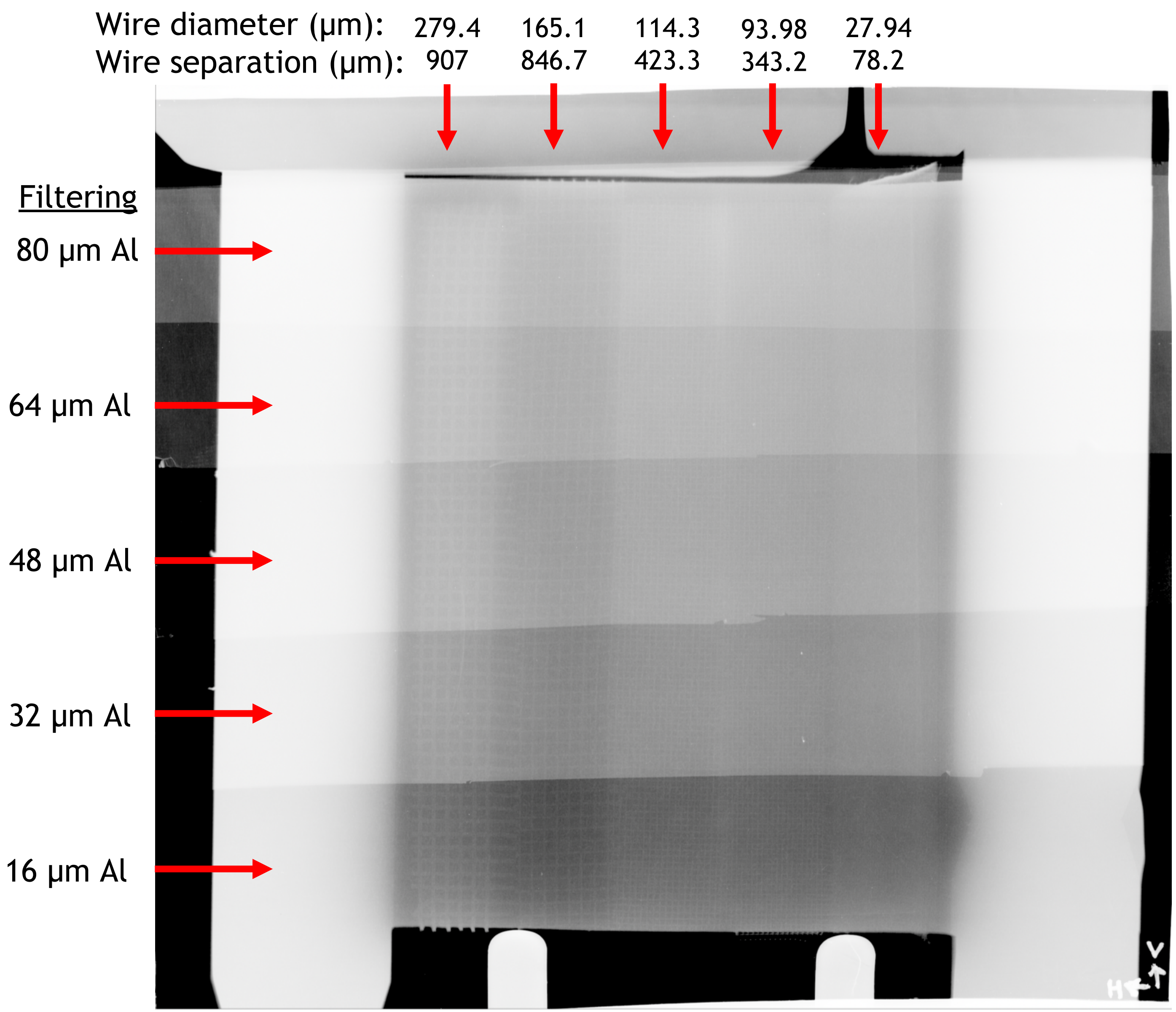
Al step wedge
16μm or 50μm steps



Results from campaign

First shot on Cu (8 keV)

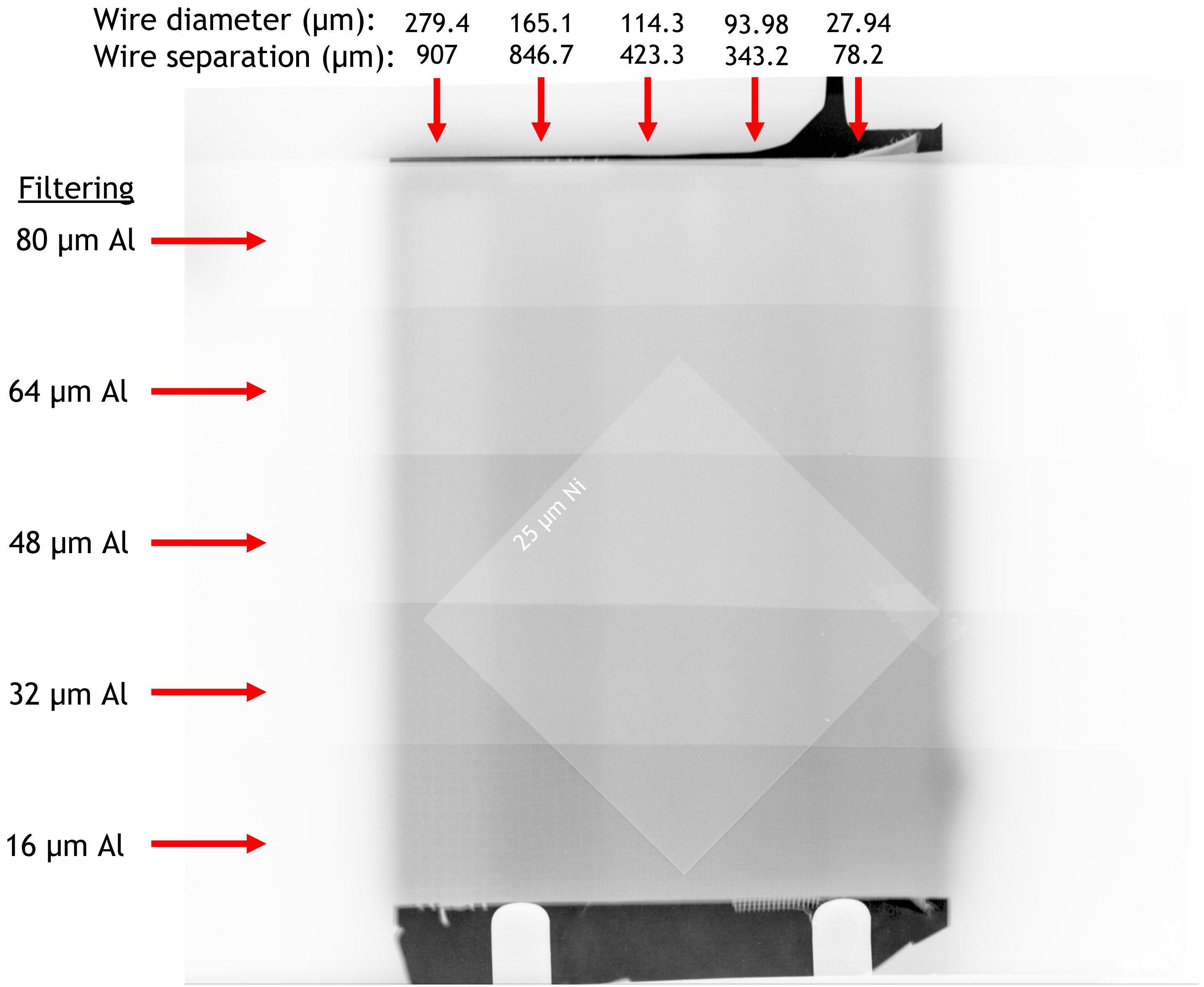
- 16µm Al steps
- Magnification of 2 (26cm-26cm)
- Lowest layer saturated until 7th scan
- Opacity contrast is fairly low, and is worse for thicker Al layers, suggests presence of background
- Fine mesh shows some periodicity (if you squint), so close to resolving ~78.2µm



Results from campaign

Second shot on Cu (8 keV)

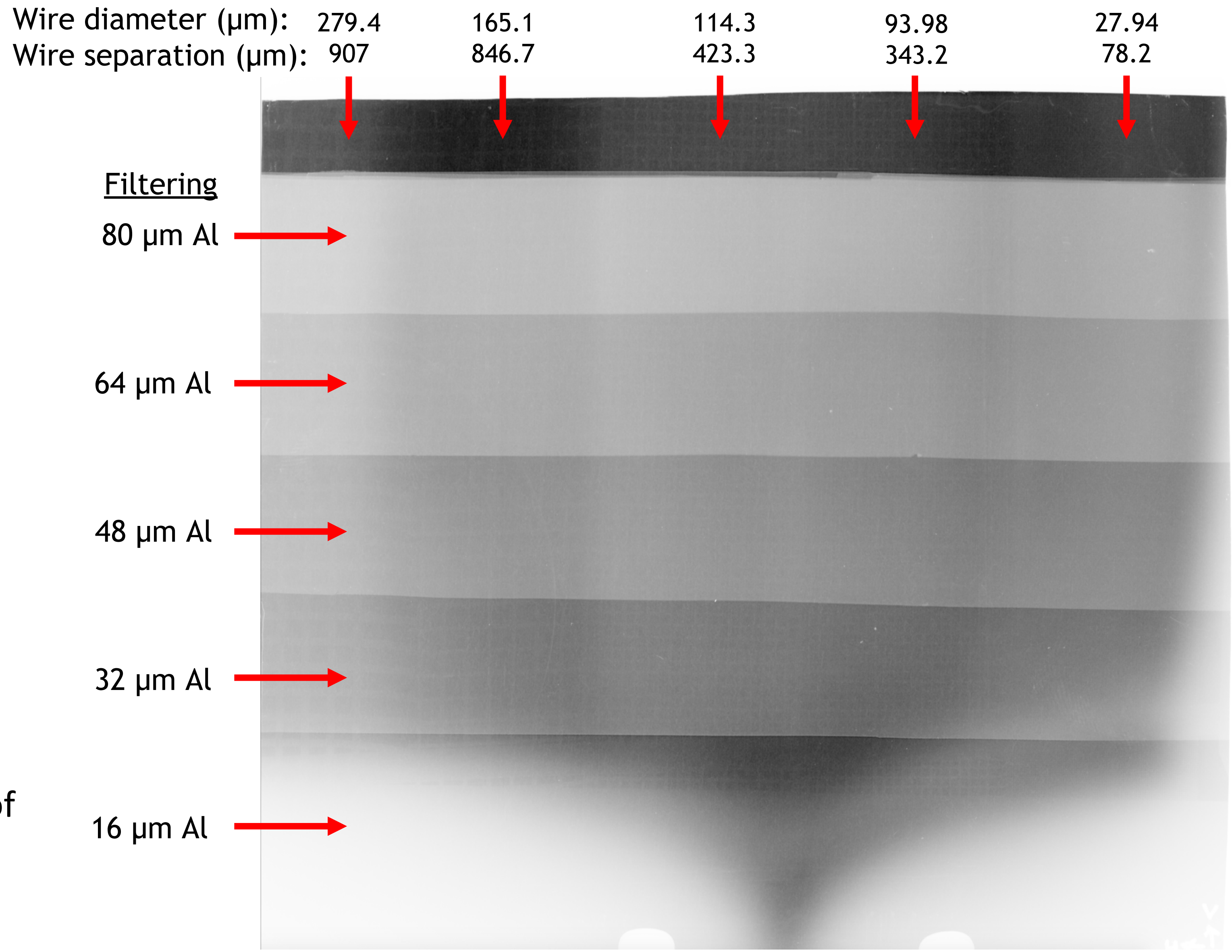
- 50µm Al steps, Ni filter added in front of image plate too
- Magnification of 2 (26cm-26cm)
- Lowest layer saturated until 7th scan
- No visible opacity contrast behind Ni layer, suggesting Ni itself is a source of background → electrons, fluorescence
- Some blurring or multi-exposure observed… electrons?



Results from campaign

Third shot on Cu (8 keV)

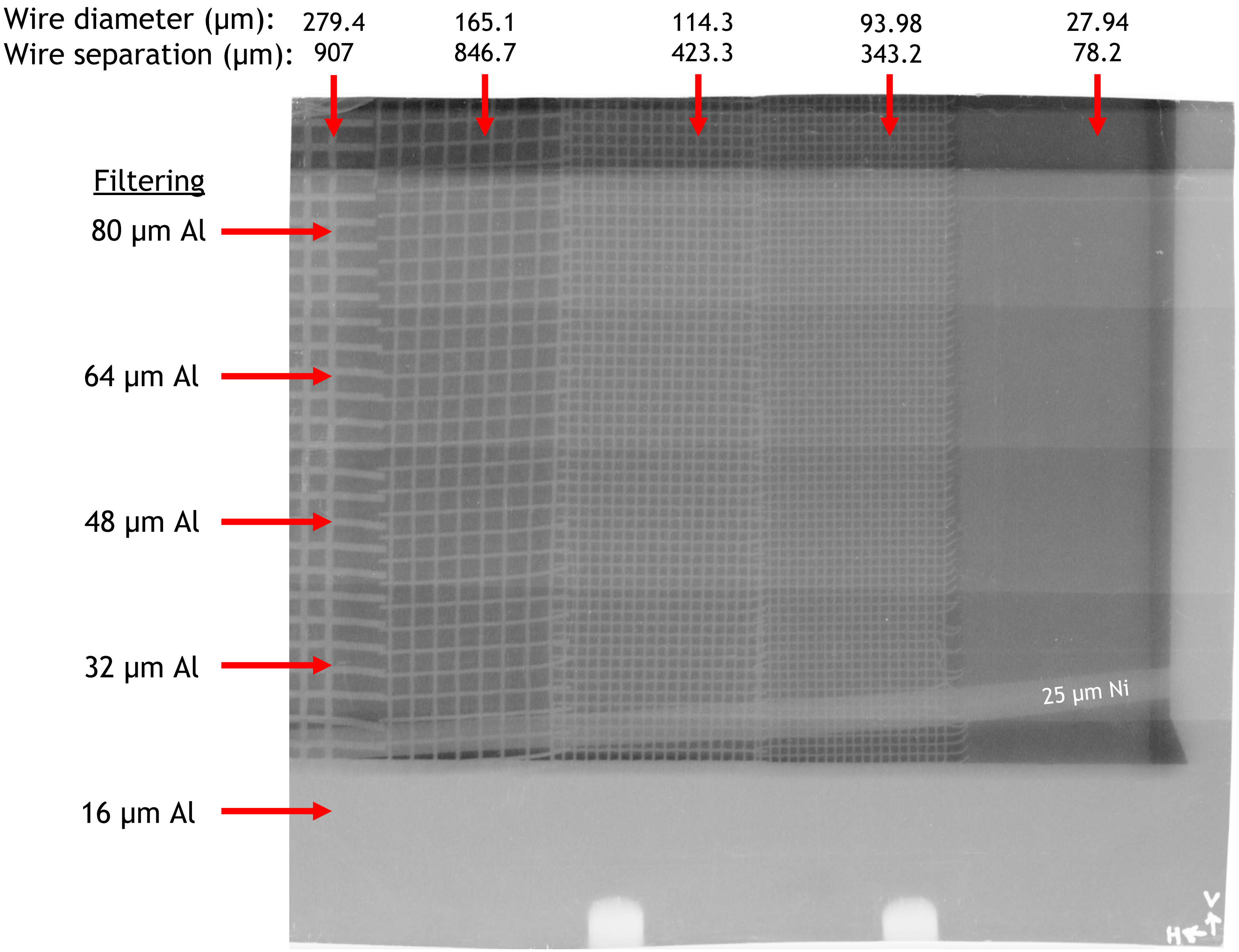
- 50µm Al steps, Ni filter moved to mesh plane as thin horizontal strip
- Magnification of 4 (13cm-39cm)
- Magnets added after mesh to deflect charged particles
- Required 4 scans for top layer (50µm Al)
- Noticeable difference in distribution of background. Electrons!



Results from campaign

First shot on Zr (15.7 keV)

- 50µm Al steps
- Magnification of 4 (13cm-39cm)
- 1cm of polycarbonate added in front of mesh to stop electrons (magnets still present)
- Required only 1 scan
- Background is essentially gone
- Can better discern fine mesh



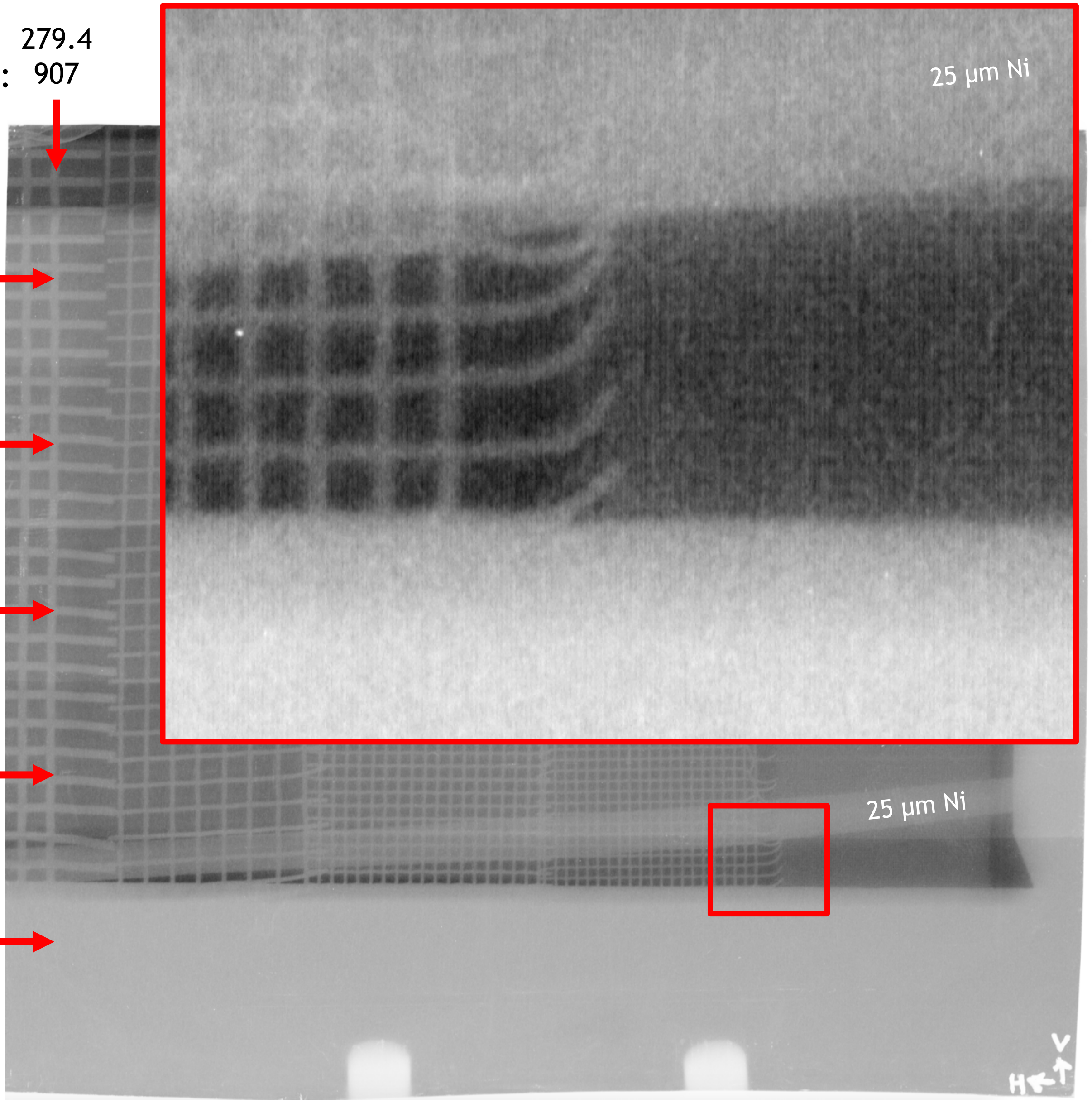
Results from campaign

First shot on Zr (15.7 keV)

- 50µm Al steps
- Magnification of 4 (13cm-39cm)
- 1cm of polycarbonate added in front of mesh to stop electrons (magnets still present)
- Required only 1 scan
- Background is essentially gone
- Can better discern fine mesh

Wire diameter (µm): 279.4
Wire separation (µm): 907

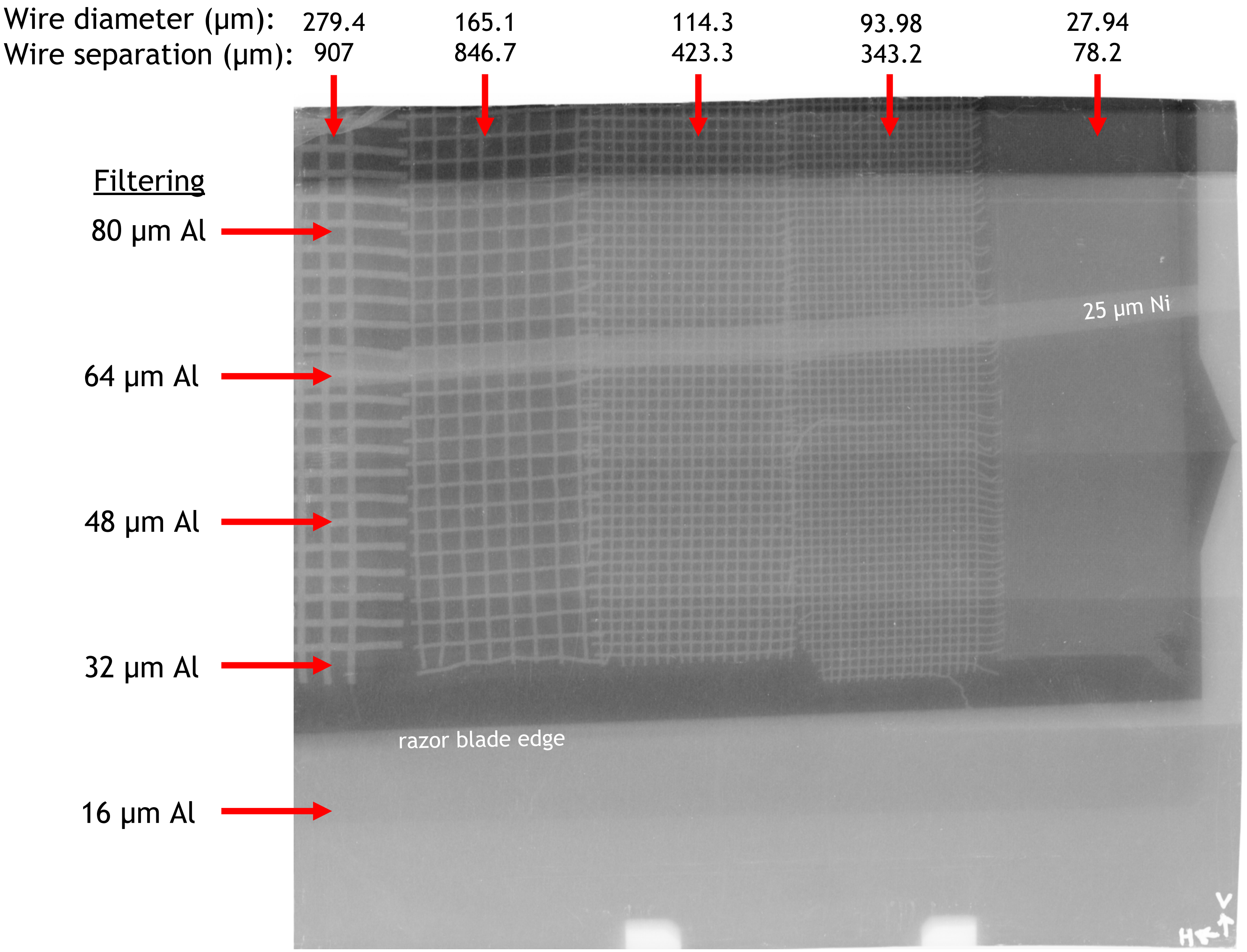
Filtering
80 µm Al
64 µm Al
48 µm Al
32 µm Al
16 µm Al



Results from campaign

Second shot on Zr (15.7 keV)

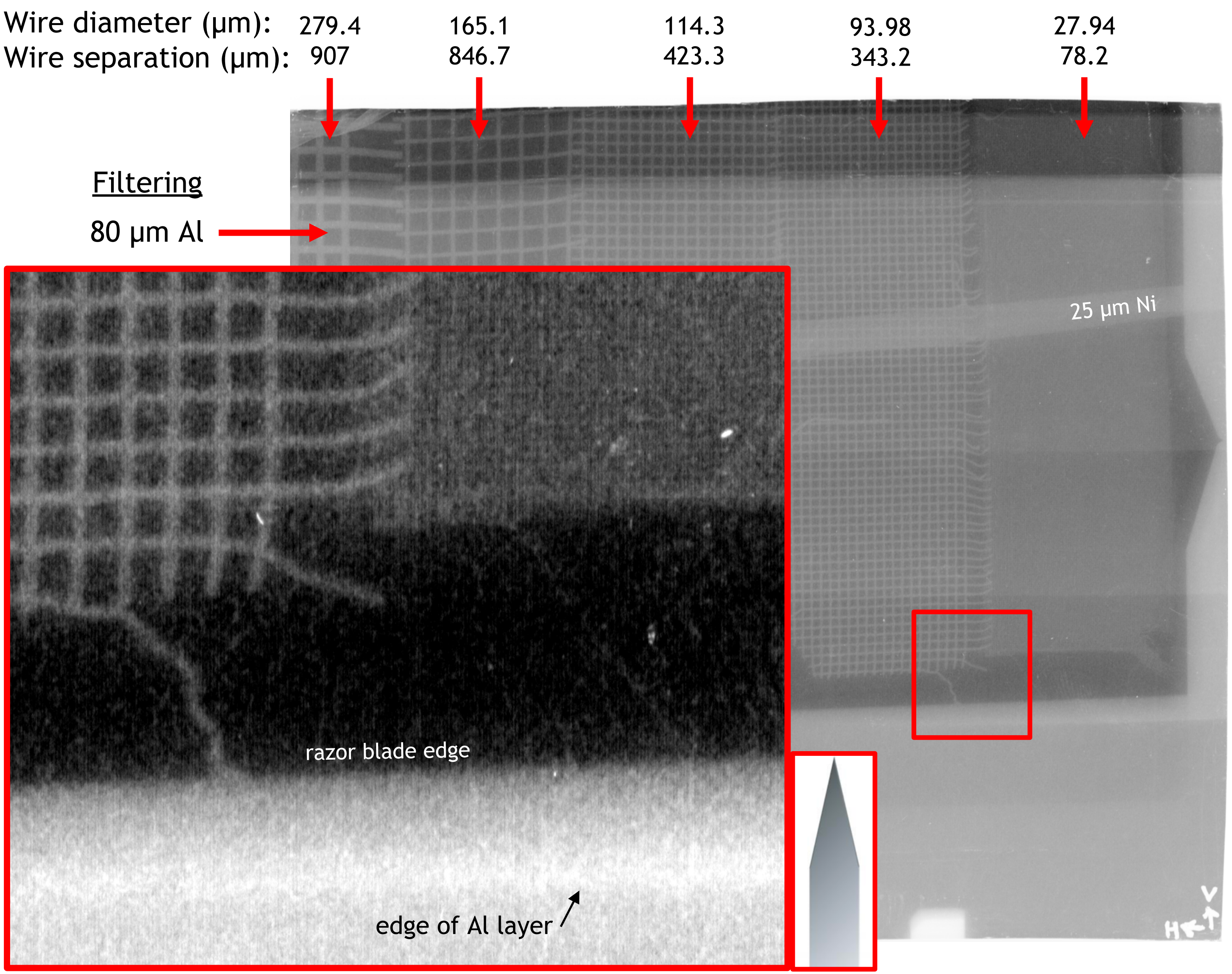
- 50µm Al steps
- Magnification of 4 (13cm-39cm)
- Razor blade placed at bottom (useful for knife edge measurement?)
- Required only 1 scan
- Background still gone
- Fine mesh still discernible



Results from campaign

Second shot on Zr (15.7 keV)

- 50µm Al steps
- Magnification of 4
  (13cm-39cm)
- Razor blade placed at bottom
  (useful for knife edge measurement?)
- Required only 1 scan
- Background still gone
- Fine mesh still discernible

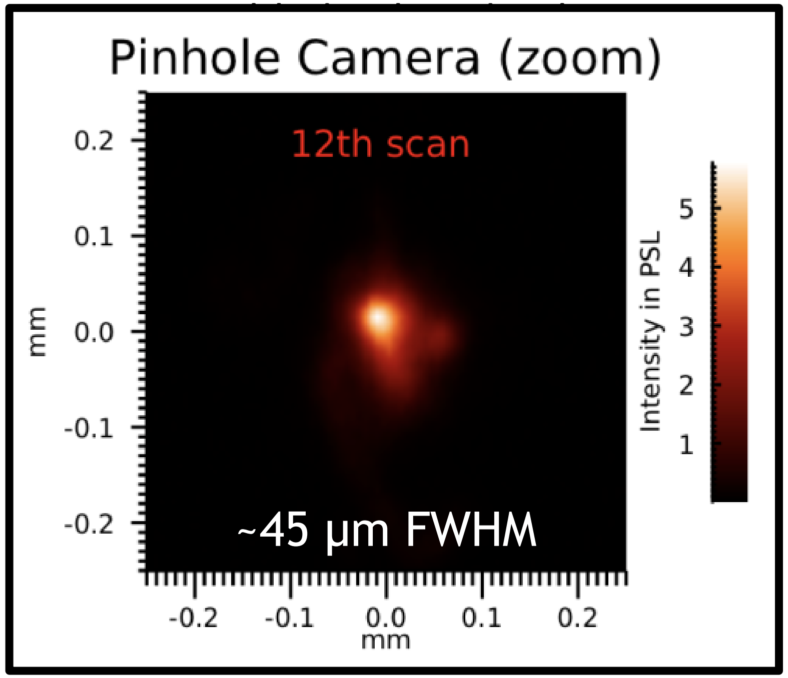


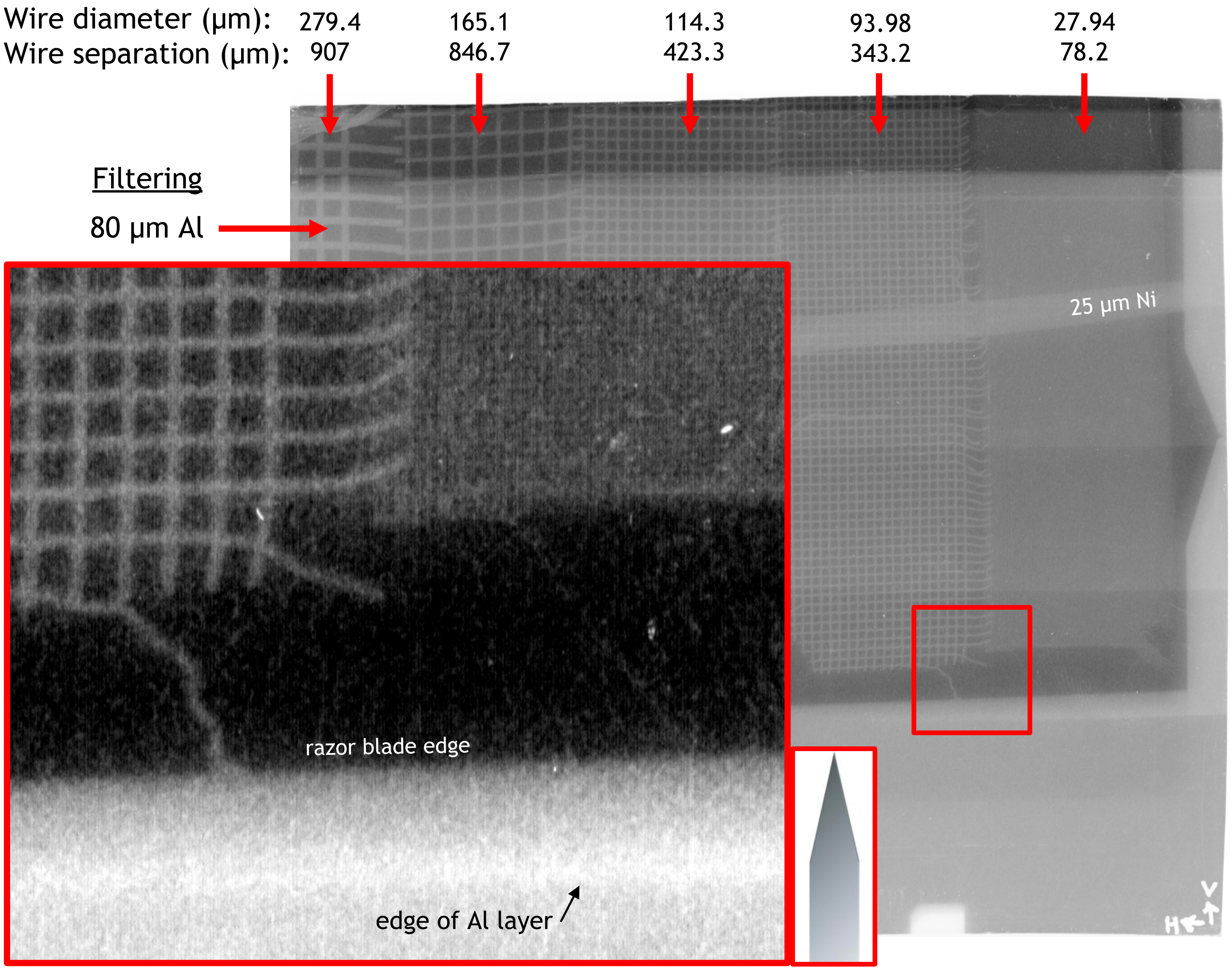
Results from campaign

Second shot on Zr (15.7 keV)

- 50µm Al steps
- Magnification of 4 (13cm-39cm)

nt?)

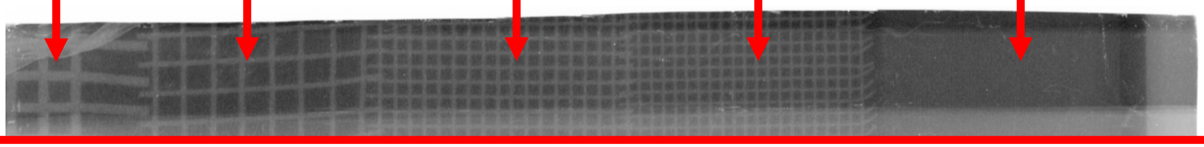


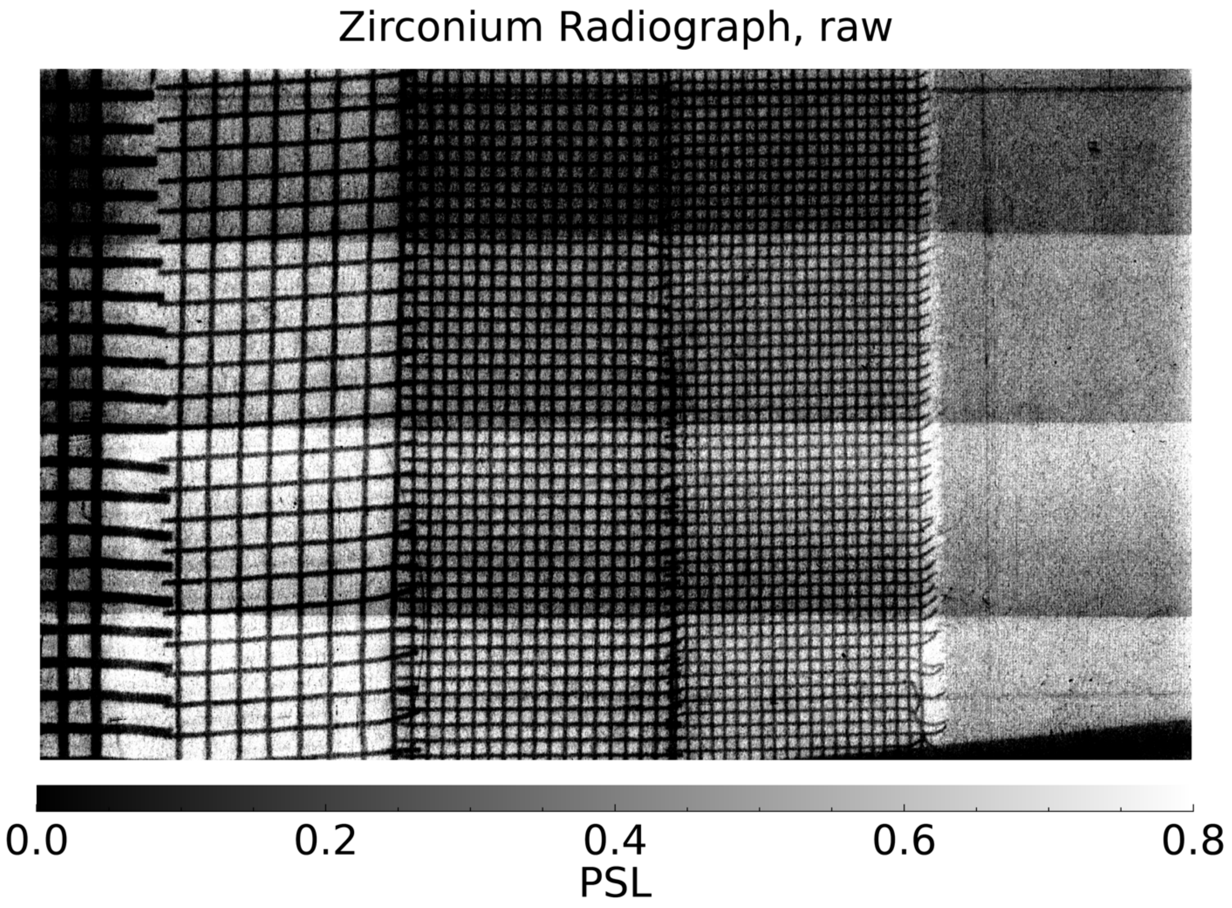


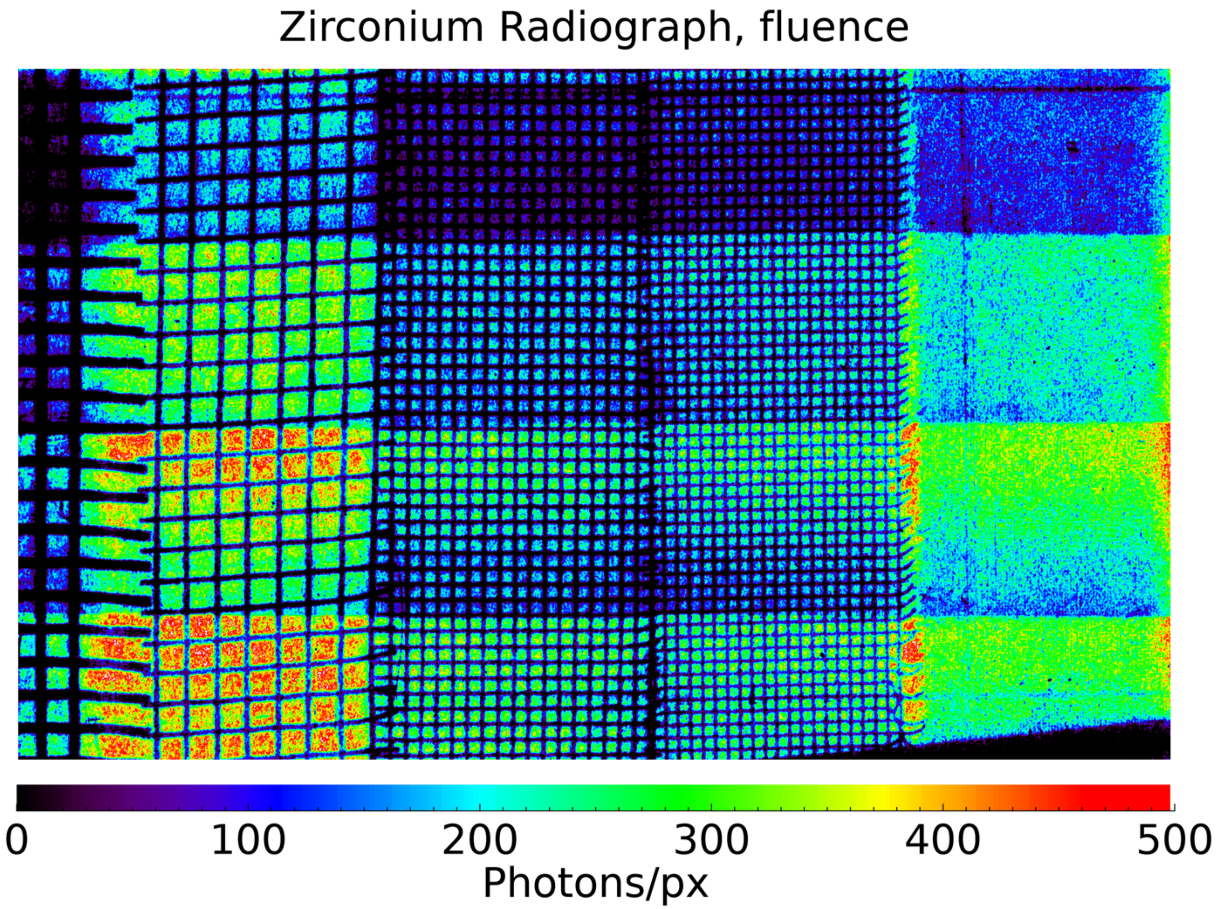
Results from campaign

Second shot on Zr (15.7 keV)

Wire diameter (μm):	279.4	165.1	114.3	93.98	27.94
Wire separation (μm):	907	846.7	423.3	343.2	78.2





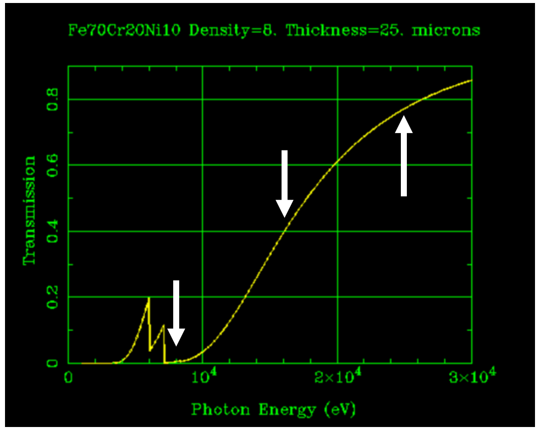


Assuming radiograph is only K_{α}, ~0.5 ph/μm^2

Results from campaign

Only shot on Sn (25 keV)

- 50µm Al steps
- Magnification of 4
  (13cm-39cm)
- Required only 1 scan
- Fine mesh not discernible
  (the opacity contrast at 25 keV is low)



Wire diameter (µm):	279.4	165.1	114.3	93.98	27.94
Wire separation (µm):	907	846.7	423.3	343.2	78.2

Filtering

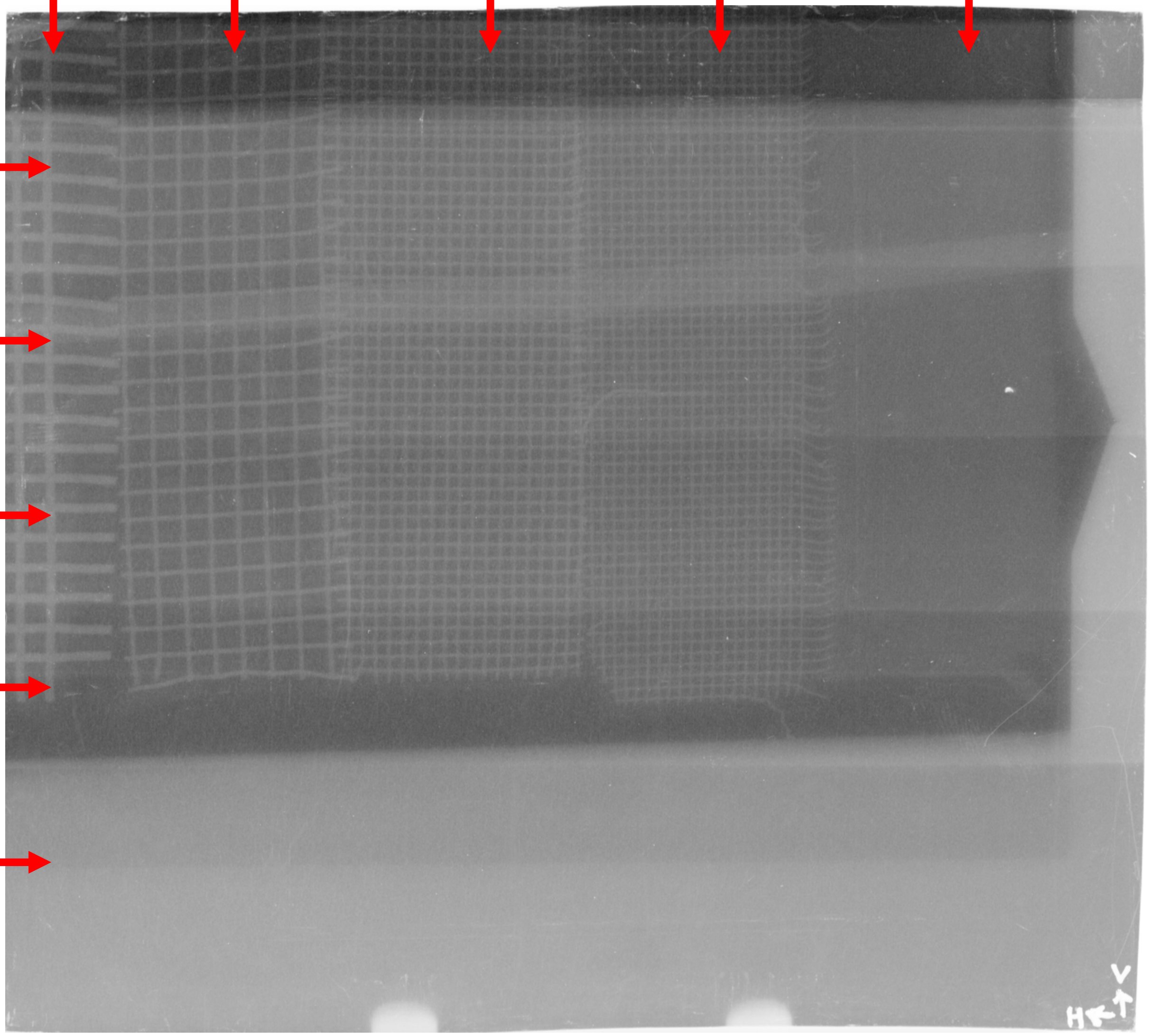
80 µm Al

64 µm Al

48 µm Al

32 µm Al

16 µm Al



B.L. Henke, E.M. Gullikson, and J.C. Davis. *X-ray interactions: photoabsorption, scattering, transmission, and reflection at E=50-30000 eV, Z=1-92*, Atomic Data and Nuclear Data Tables Vol. **54** (no.2), 181-342 (July 1993).

Summary

Successes:

1. Continued commissioning Z-Petawatt, including comparisons to previous TNSA/x-ray results. Results consistent with on-target intensities ≥10^{19} W/cm^2.
2. K_α x-ray conversion efficiencies are high and reproducible. Electrons can be stopped by 1 cm of polycarbonate while transmitting x-rays ≥16 keV. Lower energy x-rays more challenging.
3. TNSA protons observed at record levels with ZPW in Chama. Plenty of room to grow, considering the chromatic aberrations we know are present, as well as pulse duration and contrast optimizations left to perform.
4. Point-projection radiographs of meshes were successful with decent contrast, and source size is suspected to be fairly small (≤50 µm). Transition to UXI will help with spatial resolution.
5. The collaboration with UCSD is strong and was fruitful for this campaign. Compelling experiments for the future were proposed; planning and scheduling discussions to follow.
6. UCSD provided Sandia a method to extract absolutely calibrated proton spectra.
7. Working with Raspberry Simpson & Graeme Scott to compare TNSA data from TITAN for benchmarking.

Room for improvement:

1. Shot into the Chama gate valve, causing downtime and ~1% damage to Chama OAP. Led to process improvements to avoid repeats. Engineered controls are desired.
2. Didn’t get around to shooting Au nanowire targets, but can be left for future campaigns.

Summary

Next steps:

1. Perform pulse duration and contrast measurements of Z-Petawatt in the Chama chamber to better characterize the conditions of the interaction (intensity on target).
2. Analyze the through-focus spot size measurements recorded during this campaign to help with #1.
3. Perform follow-up campaigns to obtain more statistics and field new diagnostics:
   - ➢ More shots using higher Z materials; Investigate why we didn't see K_α lines from Sn with the CRITR.
   - ➢ Replace the radiograph image plates with UXI cameras† to enhance spatial resolution from the detector side, and possibly gate out background from secondary interactions; Try Si and GaAs sensors.
   - ➢ Perform pitcher-catcher experiments, using the proton beam to generate neutrons; Develop neutron diagnostics, such as the SiPM array using the PSEC4A 32-channel digitizer.
4. Continue collaborations with UCSD and Raspberry Simpson, possibly pursuing multi-beam experiments using ZPW, ZBL, and Chaco.
5. Determine if a conference proceeding or letter could be pursued with current data or soon to be acquired data from follow-up experiments.

†L. Claus, Proc. SPIE **10390**,103900A

Questions?