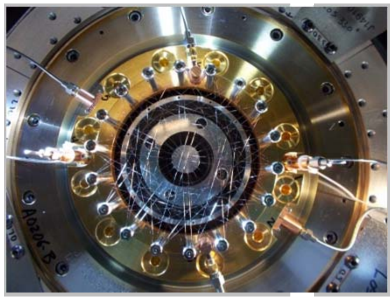
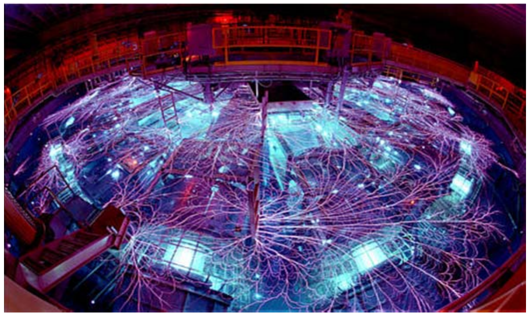
SAND2012-7254P





Ar gas puff shot summary

z2381-2382

(z2383 was Kr gas puff)

B. Jones, D. C. Lamppa, S. B. Hansen, D. J. Ampleford, T. Strizic, M. E. Cuneo, M. C. Jones *et al.*

Sandia National Laboratories

July 17-20, 2012

Exceptional service in the national interest

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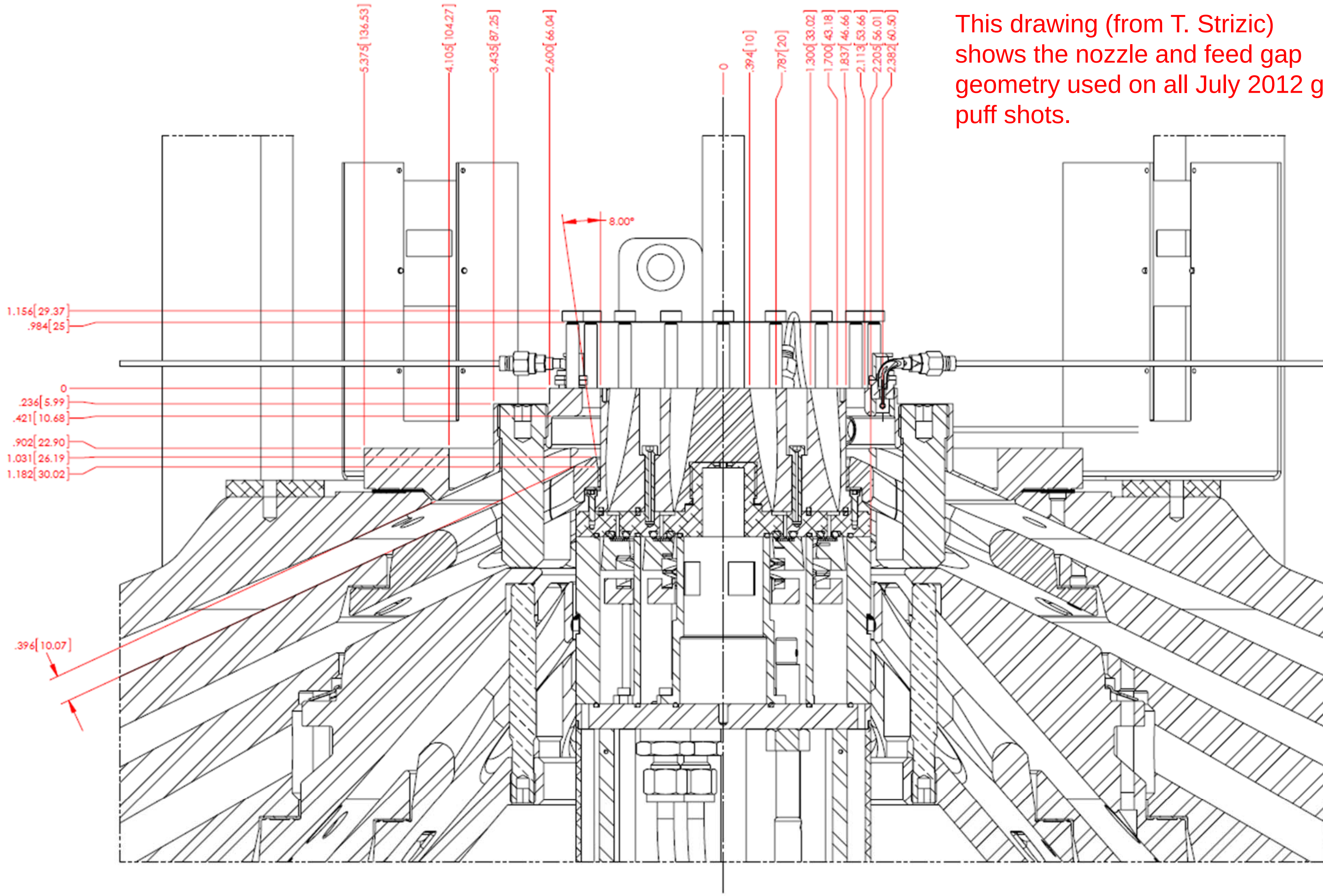
This drawing (from T. Strizic) shows the nozzle and feed gap geometry used on all July 2012 gas puff shots.



DETAIL D
SCALE 1 : 1

DRAWING NUMBER RorJ NUMBER			
DRAWING CLASSIFICATION UNCLASSIFIED			
SIZE C	CAGEC 14213	SCALE 1:24	
	ISSUE D	SHEET 2 OF 2	
STATUS SA-REL-7/3/12			

Z2381

70 kV Marx charge

A0206-A

7/17/2012

Shell-on-shell Ar gas puff

0.8 mg/cm total mass

~1:1.6 outer:inner mass ratio

25 mm pinch height

Nozzle J16469-003C-D, Config. #1

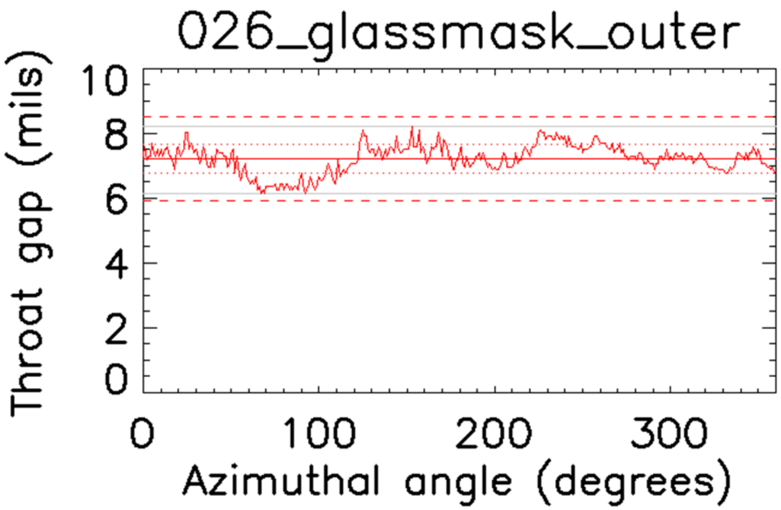
Interferometer: 40.90 psia middle, 15.30 psia outer plenum

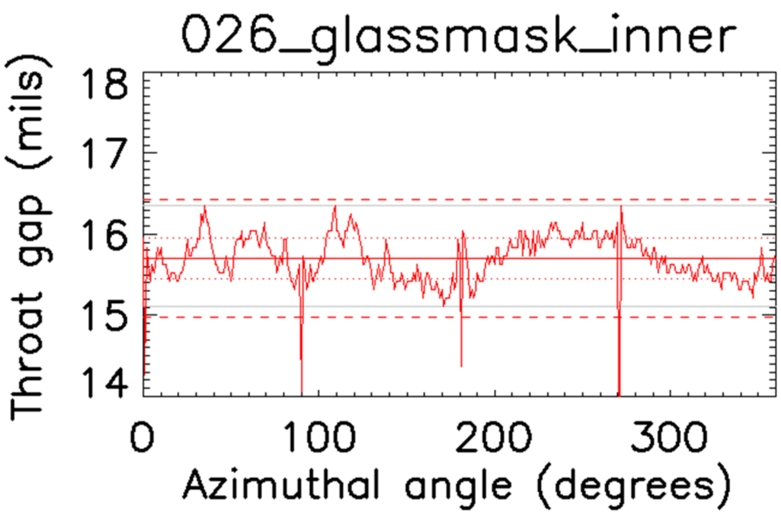
As-shot z2381: 41.1 psia middle, 15.2 psia outer plenum

Throat plate #26, Outer gap 7.22 mils ± 6.0%, Middle gap 15.70 mils ±1.6%

Z2381 nozzle J16469-003C-D throat plate details

- From “8cm Throat Plate Checkout Form” for nozzle D





Throat plate #	Outer gap width (mils)	Outer gap variability = σ/mean (%)	Outer gap variability =Δ/2/mean (%)	Inner gap width (mils)	Inner gap variability = σ/mean (%)	Inner gap variability =Δ/2/mean (%)
26	7.22193	6.051671	14.42365	15.7028	1.639051	3.980179

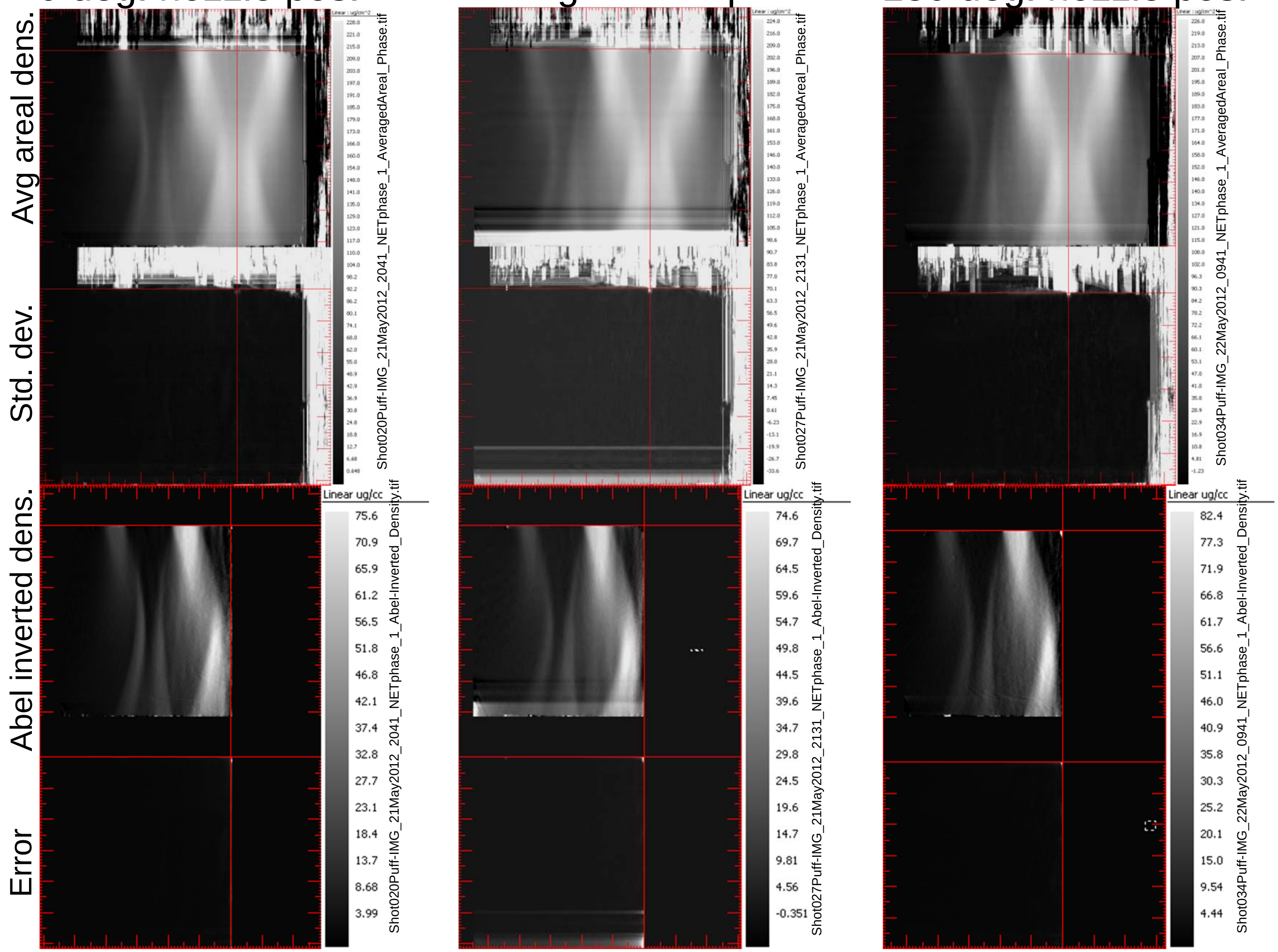
- Chris Jennings expressed interest in using throat plate characterizations as a basis for seeding 3D structure in MHD simulations
- These scans show structure in the gap that defines the gas flow at the base of the nozzle

Z2381, 70 kV,
Ar, 0.8 mg/cm
Nozzle D Config. # 1

A0206-A nozzle J16469-003C-D mass profiles

- For this nozzle we did shots at three different azimuthal rotations of the nozzle at SITF. We did not track throat plate orientation, so “0 deg.” does not correspond between last page and here. Lineouts and summary statistics from these interferometer datasets are on the next page.

Interf. shots 20-23 0 deg. nozzle pos. | Interf. shots 27-29 90 deg. nozzle pos. | Interf. shots 34-36 180 deg. nozzle pos.



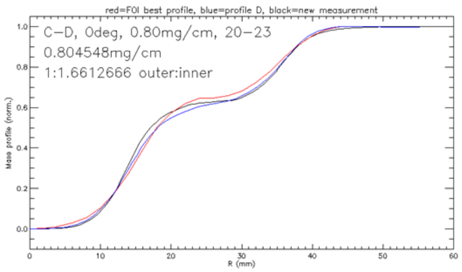
- Mass profile characterization with the SITF interferometer are available for all nozzles shot at Z. These can be the basis for initializing MHD implosion models.

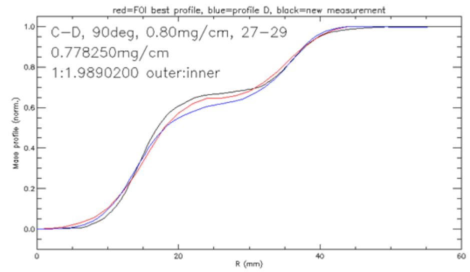
Z2381, 70 kV, Ar, 0.8 mg/cm Nozzle D Config. # 1

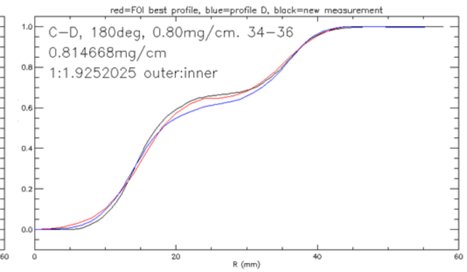
A0206-A nozzle D

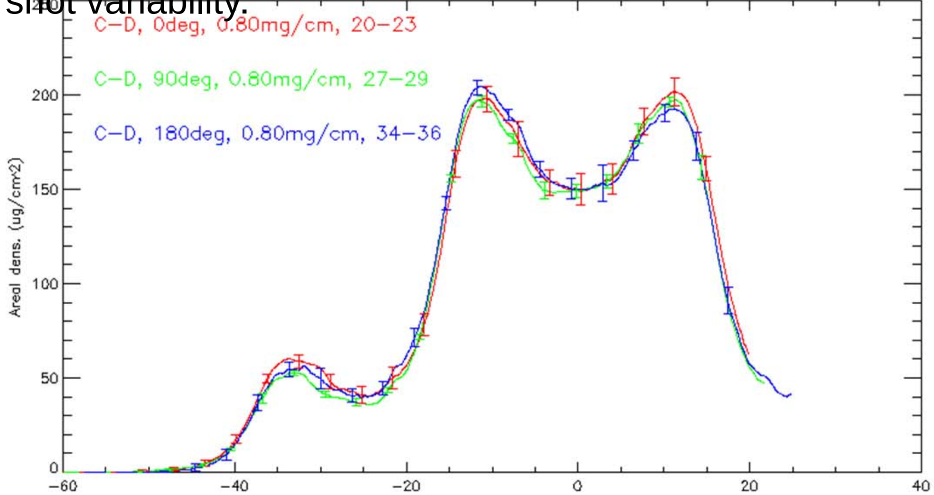
Nozzle	Orientat.	Target m	Shots	Cent.pin	Edge pin	Delta	Z noz.face	Face ang.	Fri.per.	Scale	Mtot	Ratio
C-D	0	0.8	20-23	765	1989	1224	370	1.5	40.9	1	804.548	1.661267
C-D	90	0.8	27-29	816	2042	1226	369	1.6	41.5	1	778.25	1.98902
C-D	180	0.8	34-36	870	2094	1224	409	1.7	41.9	1	814.668	1.925203

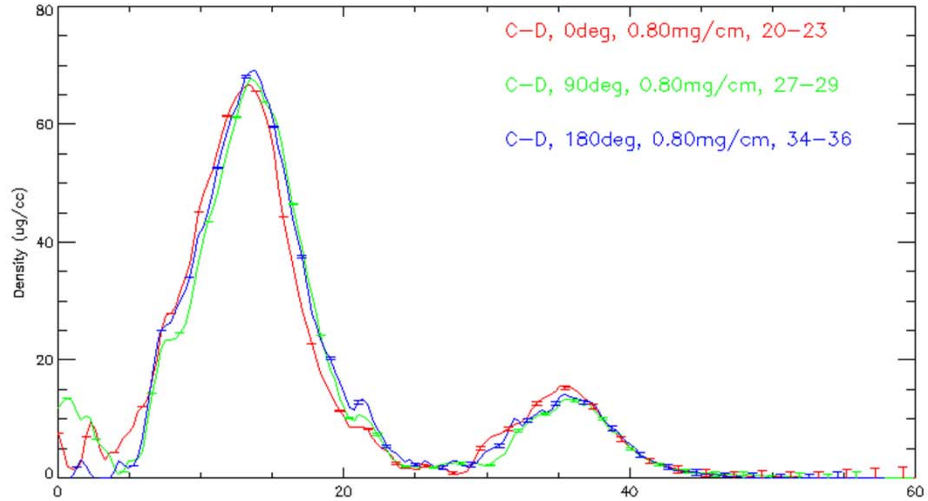
All plots are z=10-15mm lineouts. Areal density error bars are std dev of phase map avg so show shot-to-shot variability.

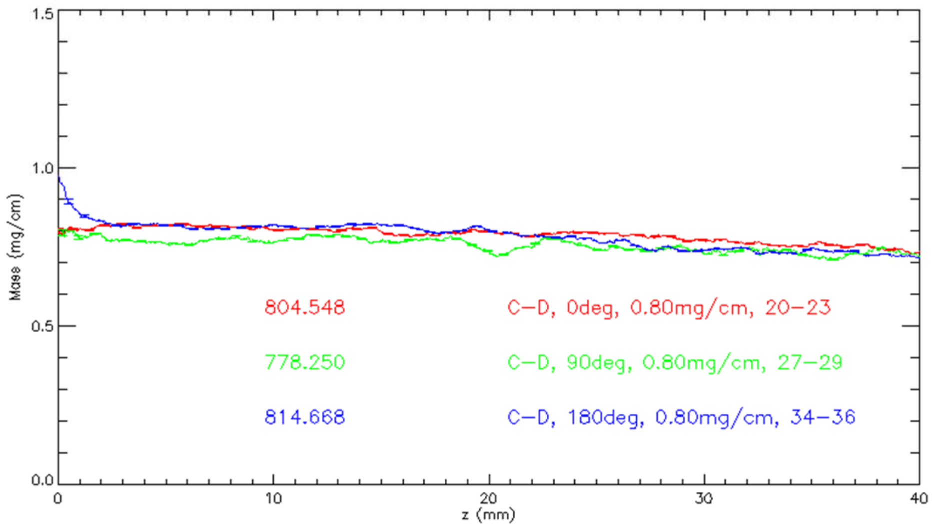


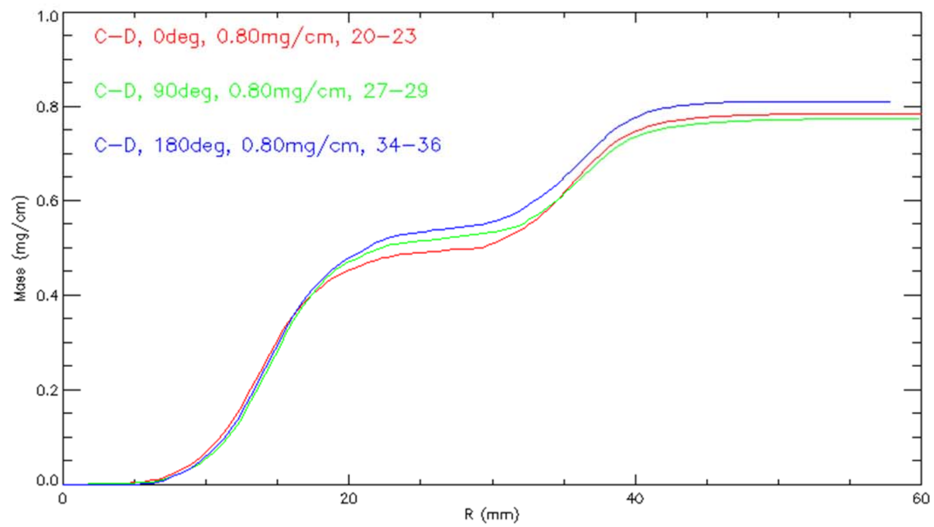




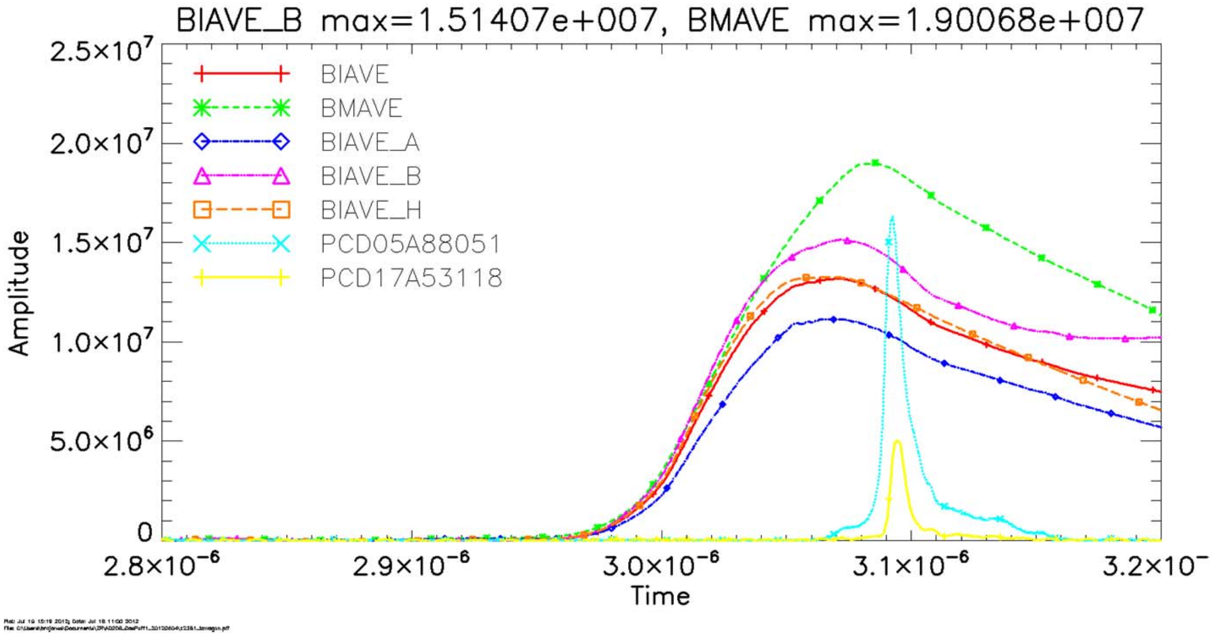


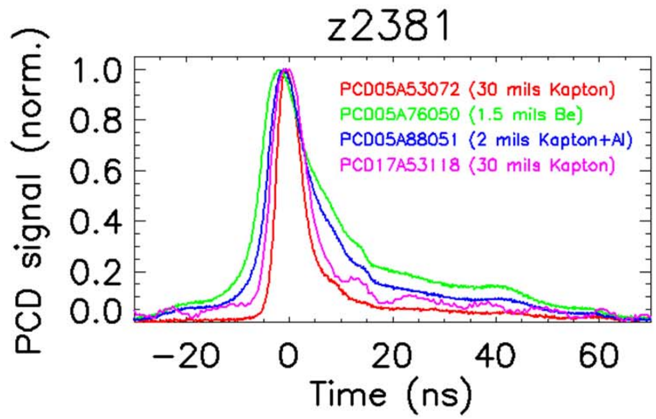


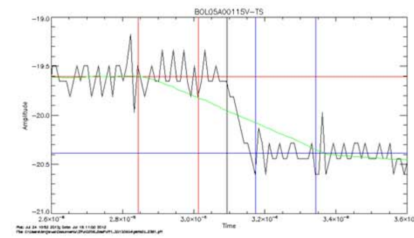


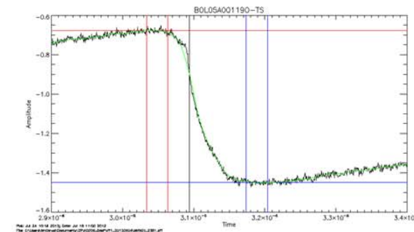


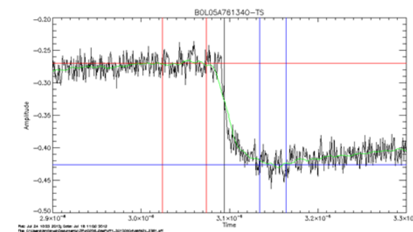
Z2381
70 kV

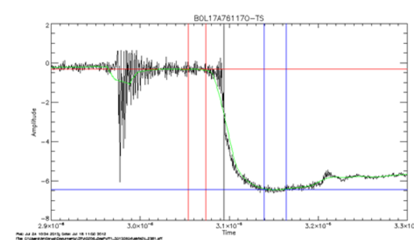








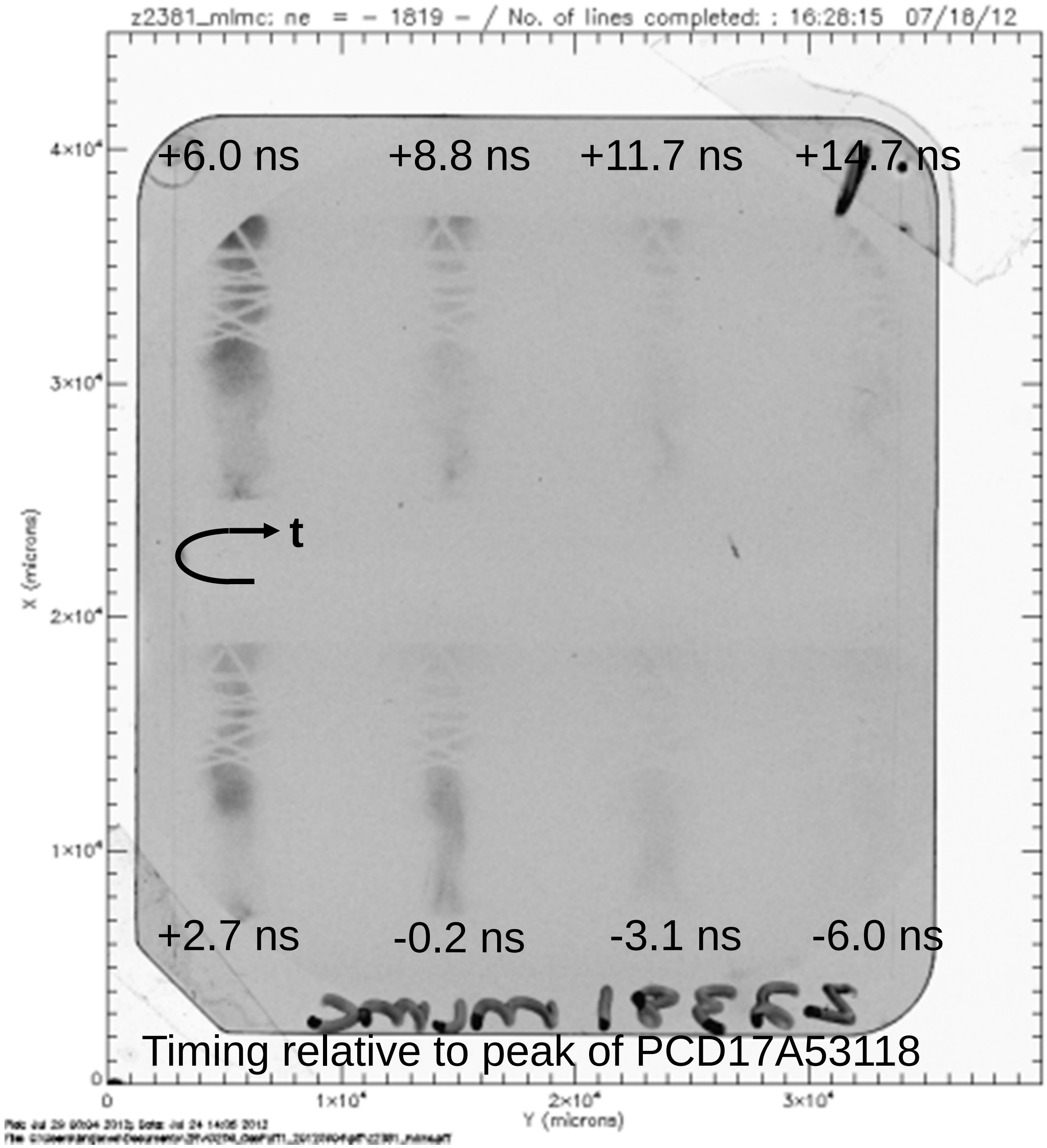




- BIAVE_B is the better B-dot design, expected to give best load current measurement (downside: it blocks a LOS)
- Gas puff shots showed significant convolute losses (compare BIAVE_B to BMAVE)
- PCD pulse widths ~10 ns (FWHM), though these were all through an aperture and not seeing full 25 mm pinch height. Zippered implosion could mean true pulse width is wider than measured
- This shot gave ~250 kJ, though yield diagnostics did not see entire pinch

Z2381 Ar K-shell gated pinhole camera shows zippered implosion

MLMC, 2 mils aluminized Kapton, Ar K-shell



- Cathode is at bottom of each frame, anode wire grid can be seen at the top of the images blocking the view of the pinch from the 13 degree angle of this instrument
- K-shell filtered gated pinhole camera showed a zippered implosion
- Due to zipper, true pulse width of K-shell radiation may have been more like 15 ns. I can attempt to reconstruct this from images, although anode wires will make it hard to be quantitative
- Pinhole images show brighter emission near the anode side on this shot, suggesting that the ~250 kJ K-shell yield inferred may be an underestimate
- The power/yield diagnostics had a 10 mm tall aperture just below the anode wires in this view; timing indicated makes sense

Z2382

80 kV Marx charge

A0206-B

7/19/2012

Shell-on-shell Ar gas puff

1.0 mg/cm total mass

~1:1.6 outer:inner mass ratio

25 mm pinch height

Nozzle J16469-003B-B, Config. #1

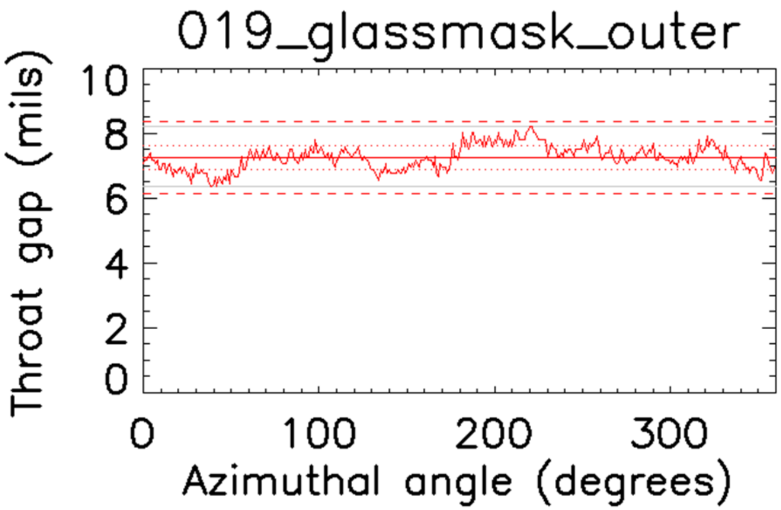
Interferometer: 47.96 psia middle, 22.68 psia outer plenum

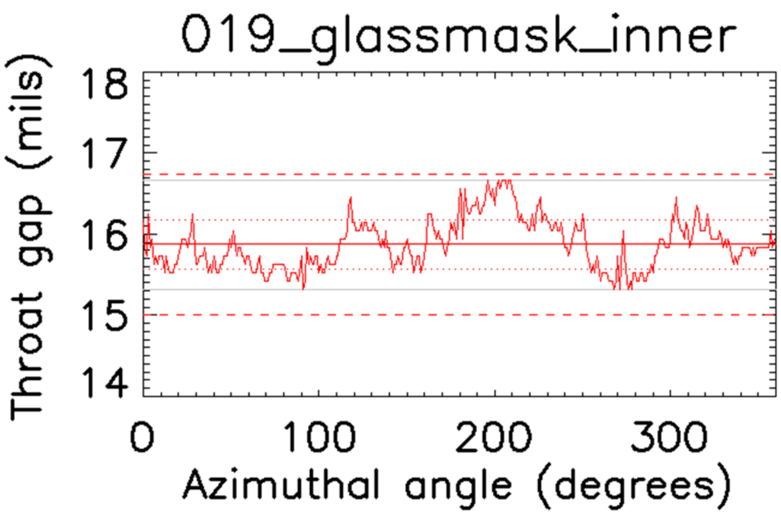
As-shot z2381: 48.2 psia middle, 22.8 psia outer plenum

Throat plate #19, Outer gap 7.26 mils ± 5.1%, Middle gap 15.88 mils ±4.3%

Z2382 nozzle J16469-003B-B throat plate details

- From “8cm Throat Plate Checkout Form” for nozzle B





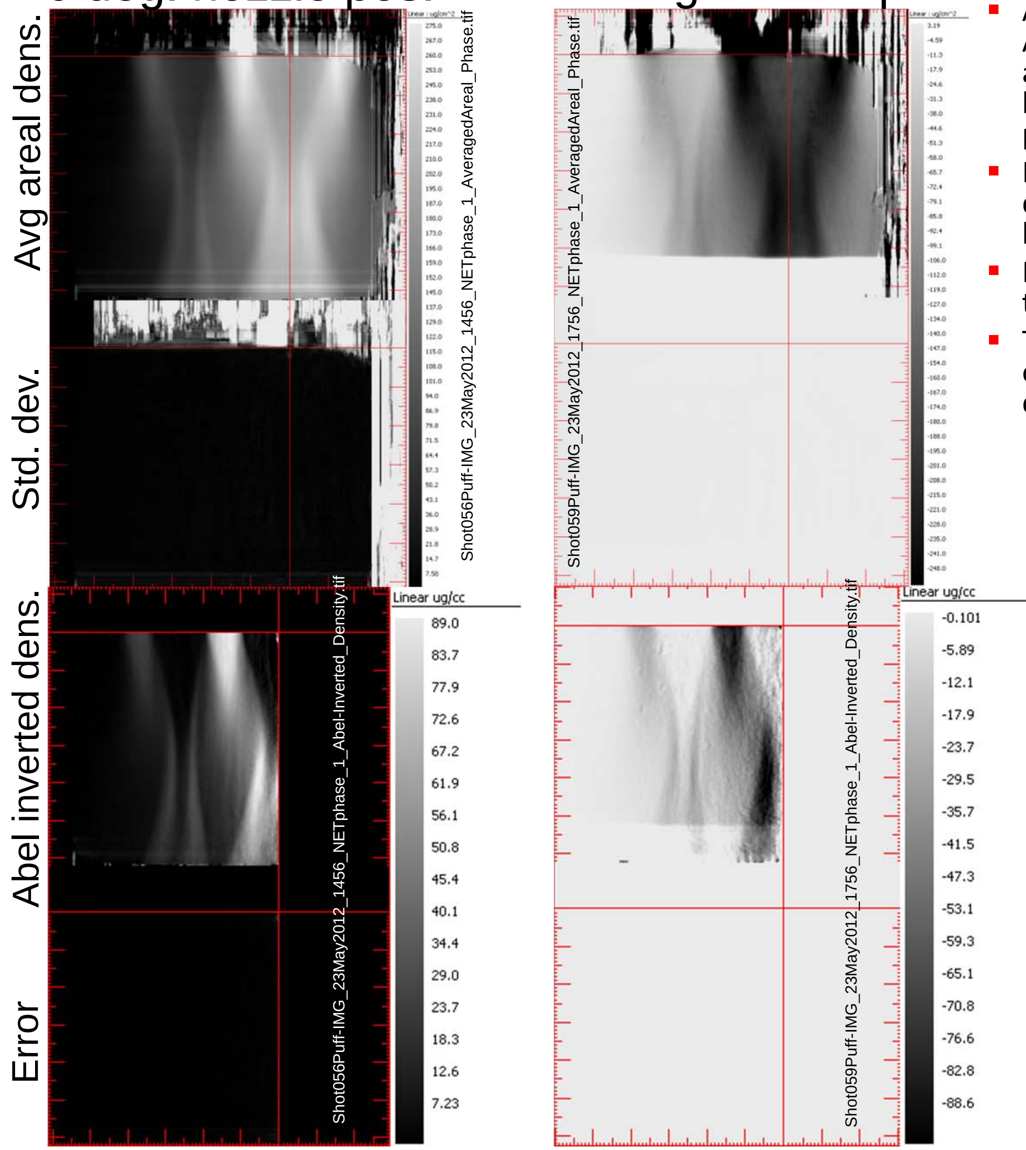
Throat plate #	Outer gap width (mils)	Outer gap variability = σ/mean (%)	Outer gap variability =Δ/2/mean (%)	Inner gap width (mils)	Inner gap variability = σ/mean (%)	Inner gap variability =Δ/2/mean (%)
19	7.25926	5.124862	12.91454	15.8759	1.93955	4.264868

Z2382, 80 kV
Ar, 1.0 mg/cm, 0/90 deg.
Nozzle B Config. #1

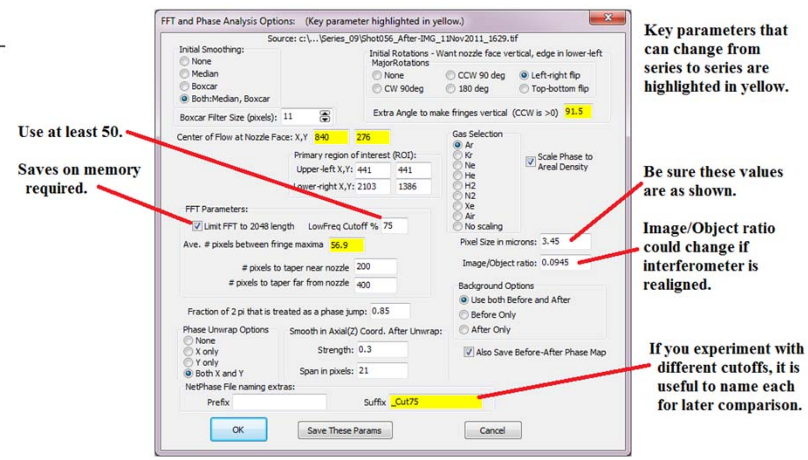
A0206-B nozzle J16469-003B-B mass profiles

Interf. shots 56-58
0 deg. nozzle pos.

Interf. shots 59-61
90 deg. nozzle pos.



- Note that nozzle B was shot at SITF and at Z at higher pulser charge voltage and coil current than was nozzle D on the prior shot; see "8cm Nozzle Configuration Sheet" for each and waveform pulser data
- We took SITF inteferometer data at two azimuthal positions for this nozzle (no correlation with throat plate orientation)
- Areal density maps are averages of the 3 shots indicated. Averaging improves signal-to-noise and provides some assessment of shot-to-shot variability (std. dev. map shown here for areal density and areal density error bars on next page are pixel-by-pixel standard deviation for the shot group)
- Phil Coleman's ImageViewer software used to unfold areal density fringes and to Abel invert. I used Phil's settings below, changing the yellow box inputs for each shot group
- Filenames of available unfold data are indicated in vertical text next to each image
- The 0 and 90 deg. images are inverted—this is just a sign error artifact of the analysis software. Need to check .txt data files and multiply by -1 if densities are negative

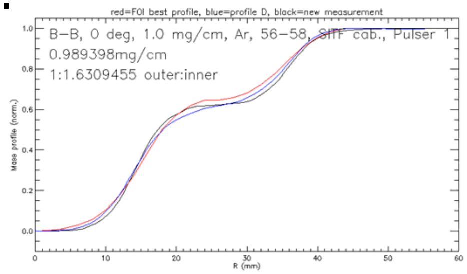


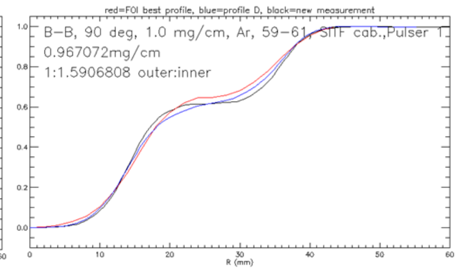
Z2382, 80 kV
Ar, 1.0 mg/cm, 0/90 deg.
Nozzle B Config. #1

A0206-B nozzle B

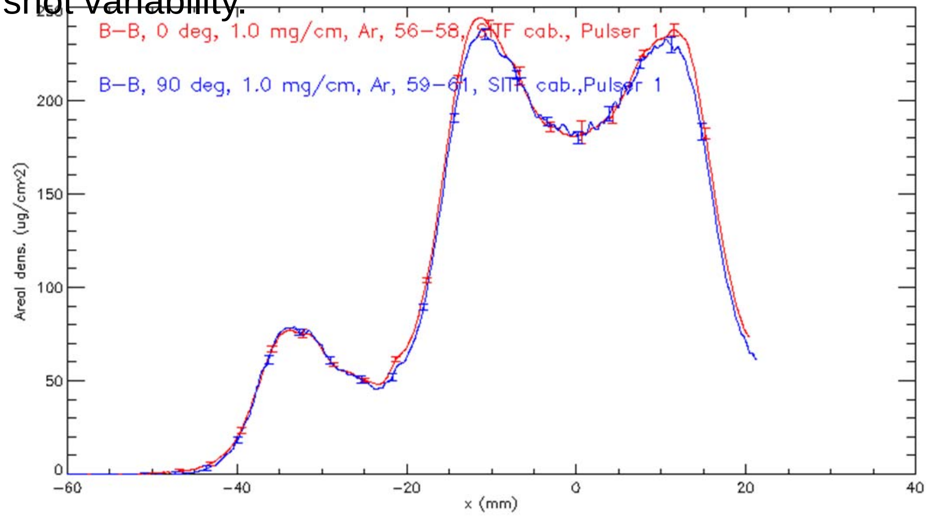
Nozzle	Orientat.	Target m	Shots	Cent.pin	Edge pin	Delta	Z noz.face	Face ang.	Fri.per.	Scale	Mtot	Ratio
B-B	0	1	56-58	772	1997	1225	346	1.6	39.1	1	989.398	1.630946
B-B	90	1	59-61	796	2022	1226	339	1.8	39.5	-1	967.072	1.590681

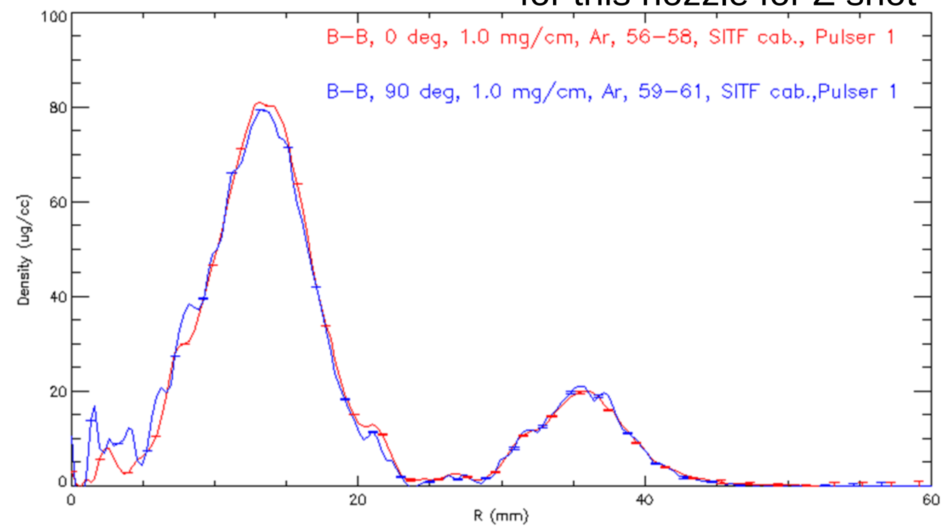
All plots are z=10-15mm lineouts. Areal density error bars are std dev of phase map avg so show shot-to-shot variability.

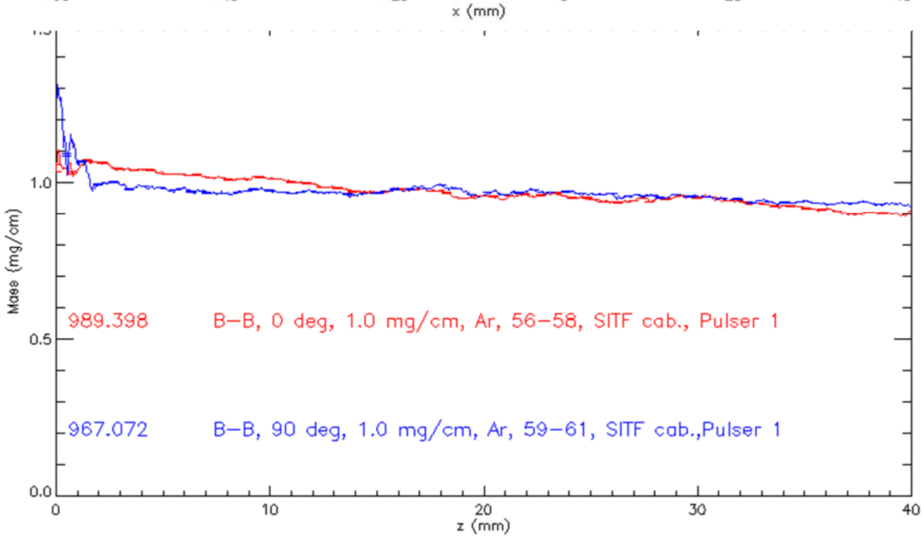


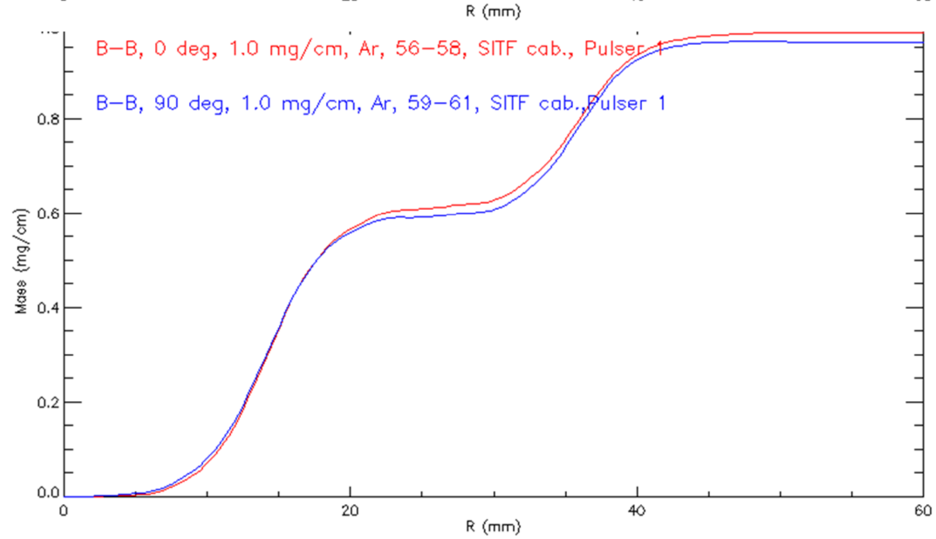


For plots on top row:
Red=best FOI profile per Ward's RMHD models
Blue=best 2D profile "D" per Ward/Chris/Eduardo
Black=measurements for this nozzle for Z shot

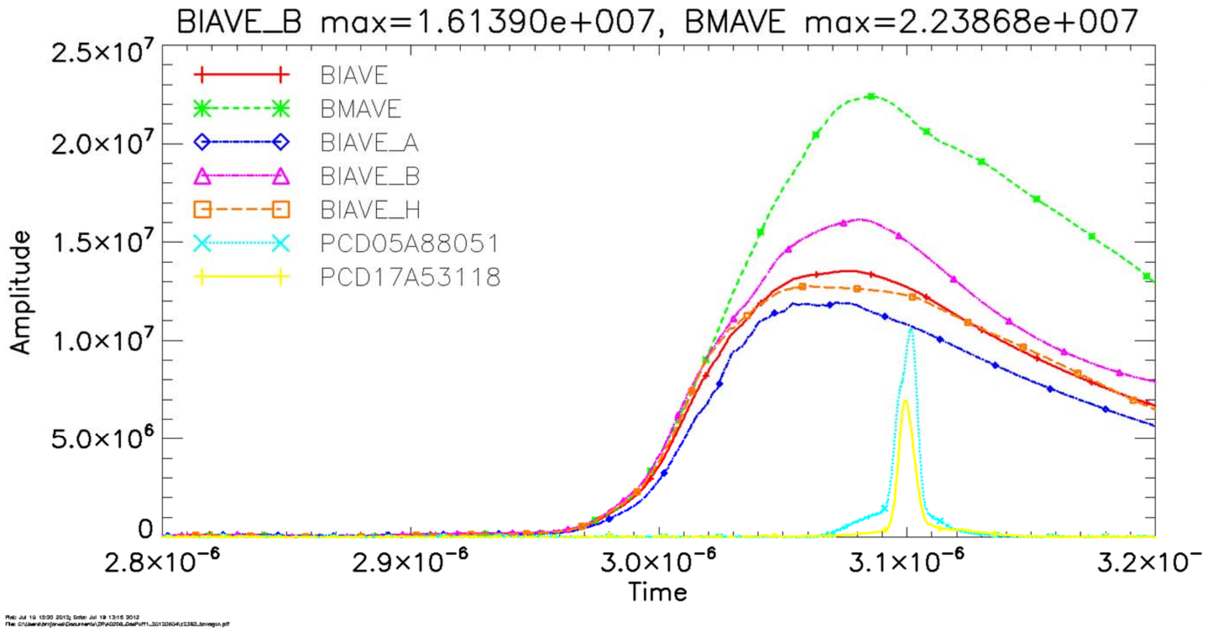


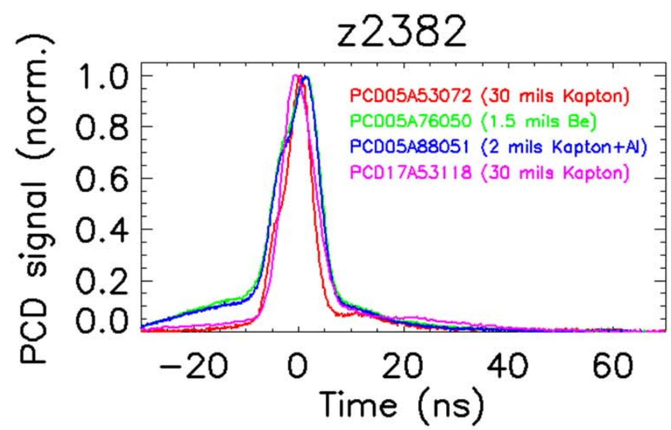


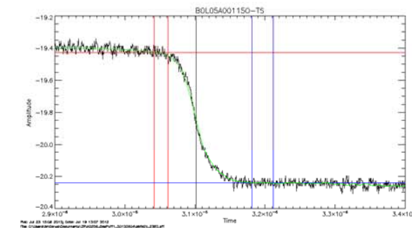


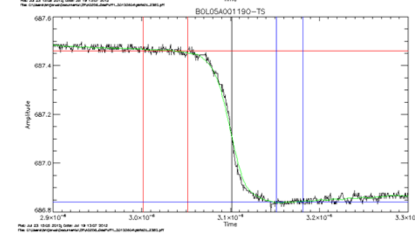


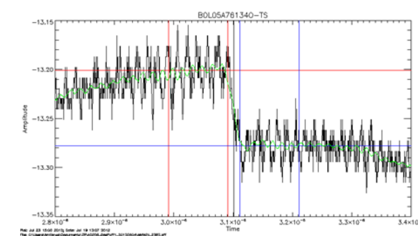
Z2382
80 kV

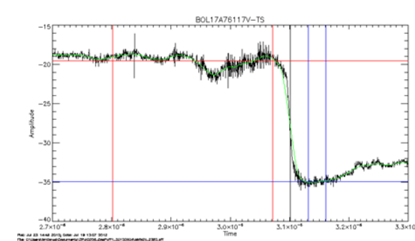






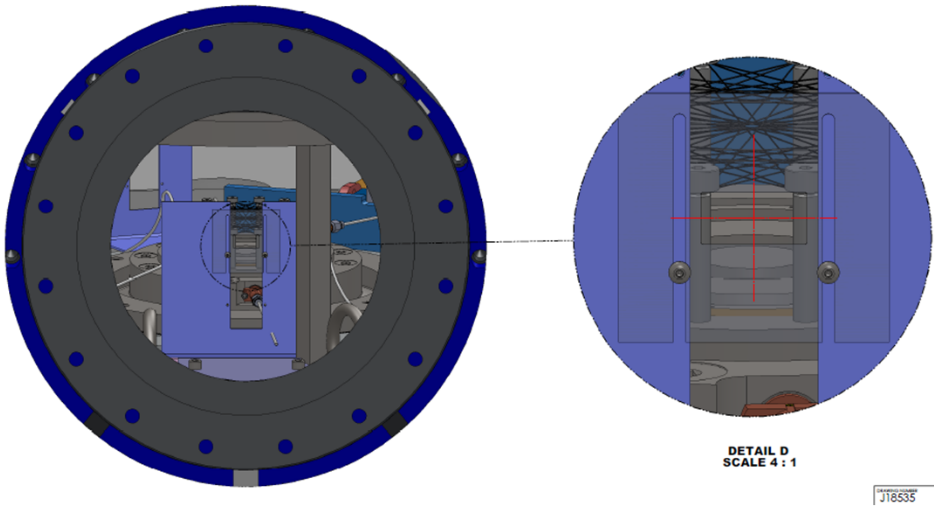


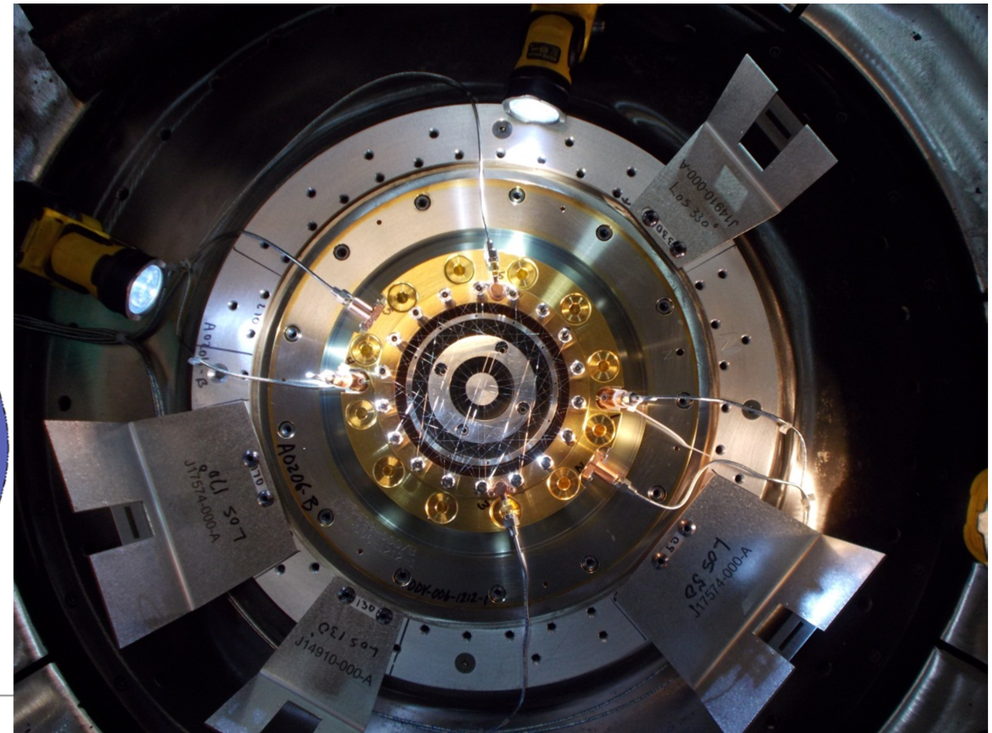


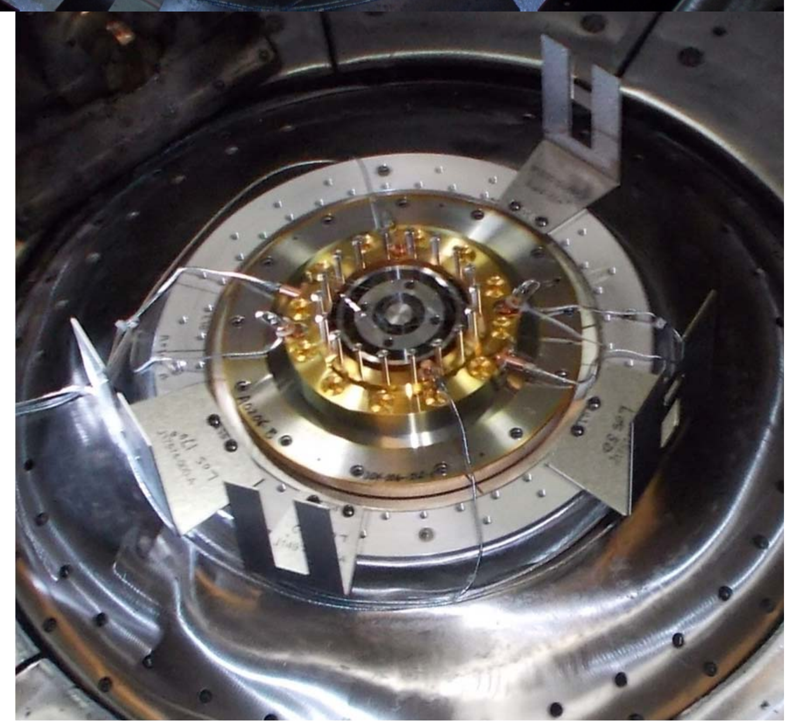


- This shot had lower signals on LOS 50 power/yield diagnostics than did z2381. LOS 170 showed higher signals. Stephanie's TIXTL processing also suggests that yield increased on z2382. We believe that the LOS 50 aperture was misaligned and will use LOS 170 bolometer/PCD data to evaluate yield on this shot.
- We still have caveat that the 10 mm aperture didn't see the entire pinch, which could affect the yield and pulse shape. The aperture misalignment from this shot further compromised the pulse shape.

Z2382
80 kV



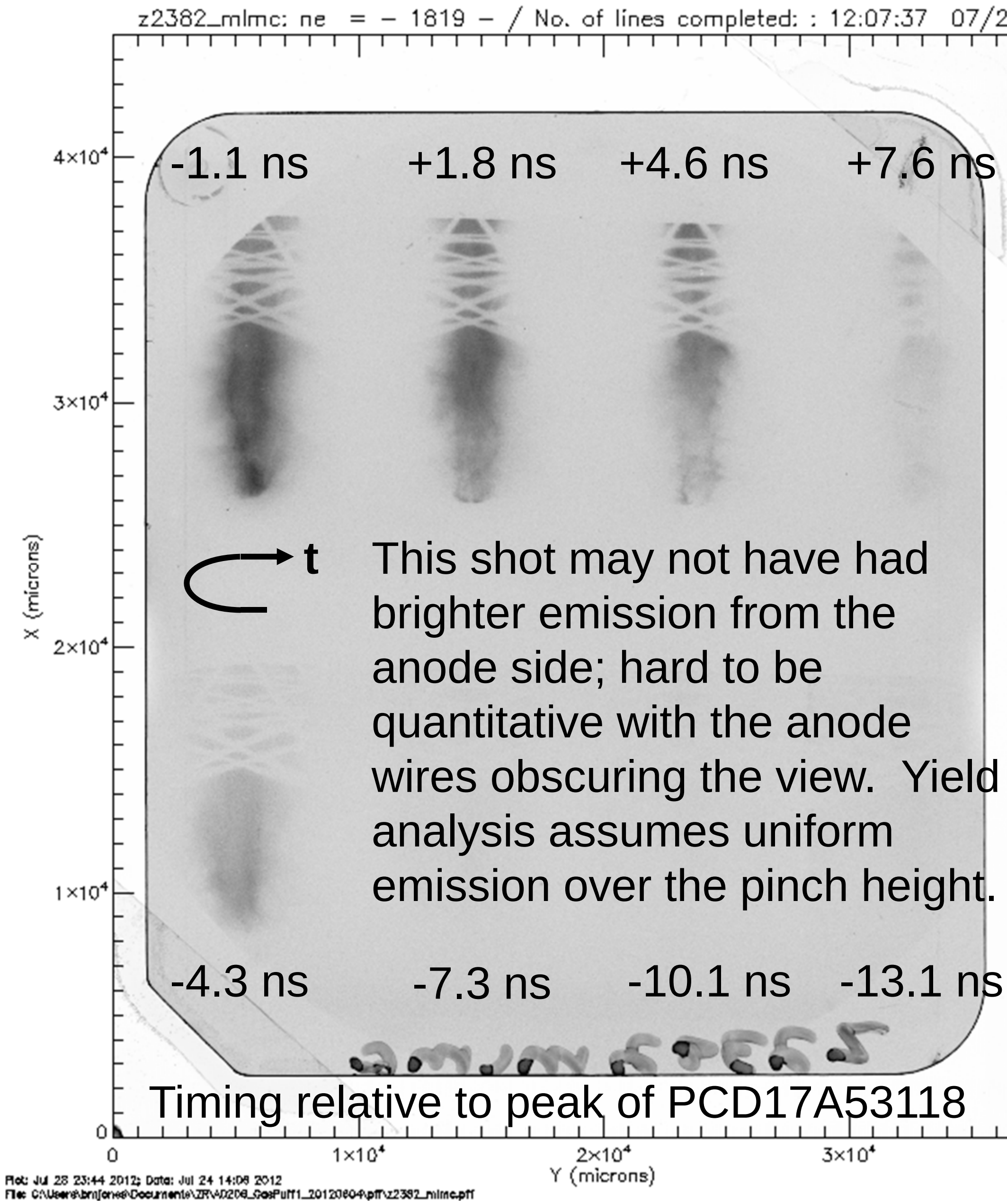




- CAD model views show how the aperture should have been aligned
- Photos show that LOS 50 aperture was lower than LOS 330 aperture. They should have been at the same height.

Z2382 MLM gated pinhole cameras show imploding shell with zipper

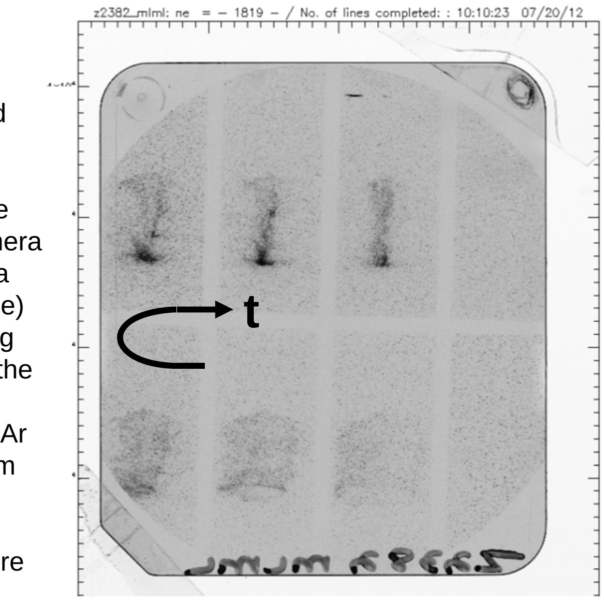
MLMC, 2 mils aluminized Kapton, Ar K-shell



This shot may not have had brighter emission from the anode side; hard to be quantitative with the anode wires obscuring the view. Yield analysis assumes uniform emission over the pinch height.

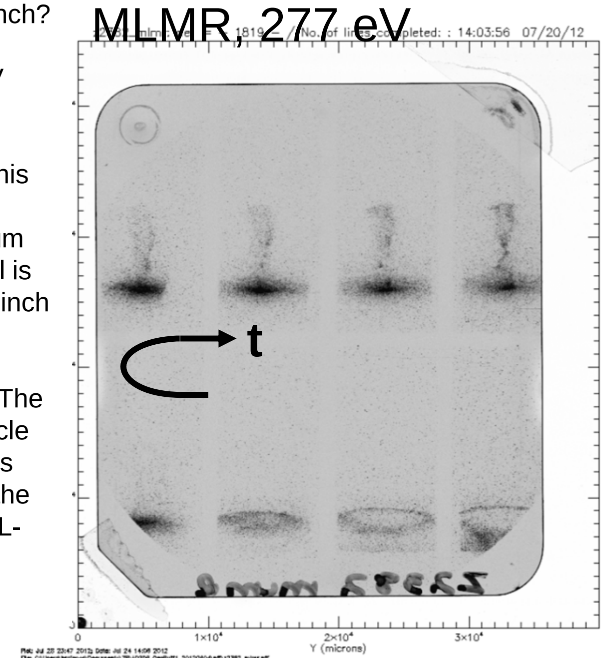
Timing relative to peak of PCD17A53118

MLML, 528 eV



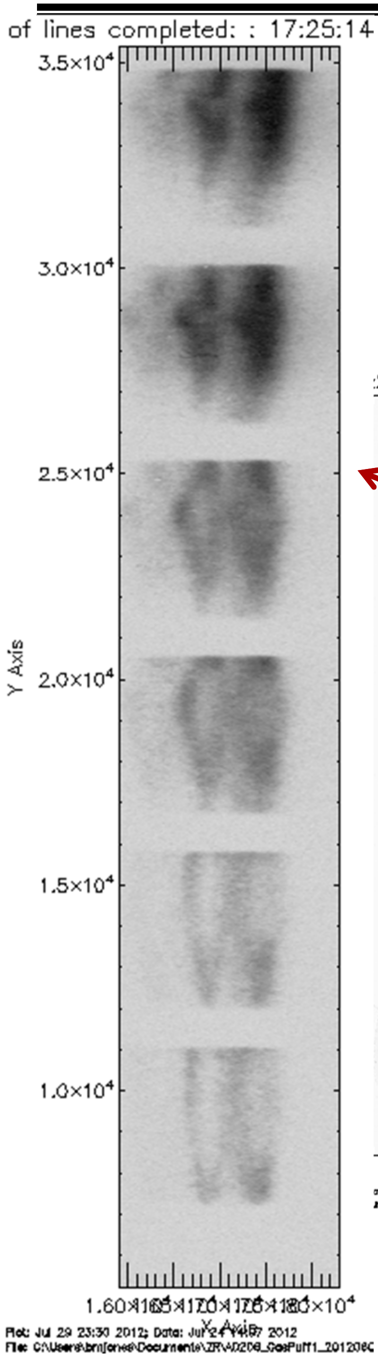
This shot had good mirrored pinhole camera data from MLML/MLMR. The MLML 528 eV camera (corresponding to a bright Ar L-shell line) shows an imploding shell that reaches the axis and then still looks hollow. The Ar K-shell images from MLMC also look hollow. Could this mean a cooler, more dense layer on the periphery of the pinch?

MLMR, 277 eV



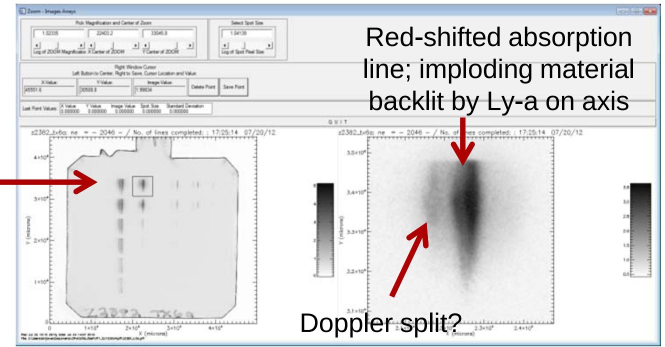
The MLMR 277 eV camera does not clearly show an imploding shell. This camera is likely looking at continuum emission, so signal is very low until the pinch stagnates at which point a hollow structure is seen. The bright emission circle from the cathode is probably SS from the electrode emitting L-shell lines that this mirror reflects.

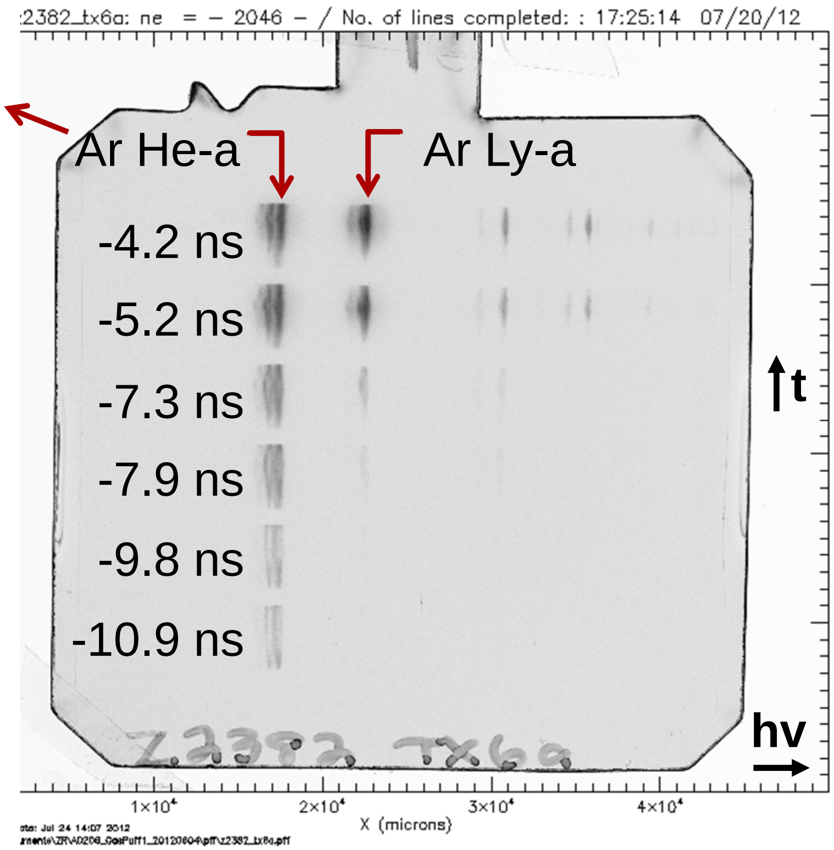
Z2382 TREX gated spectrometer shows Ar He-a turning on early, Ly-a is brightest later

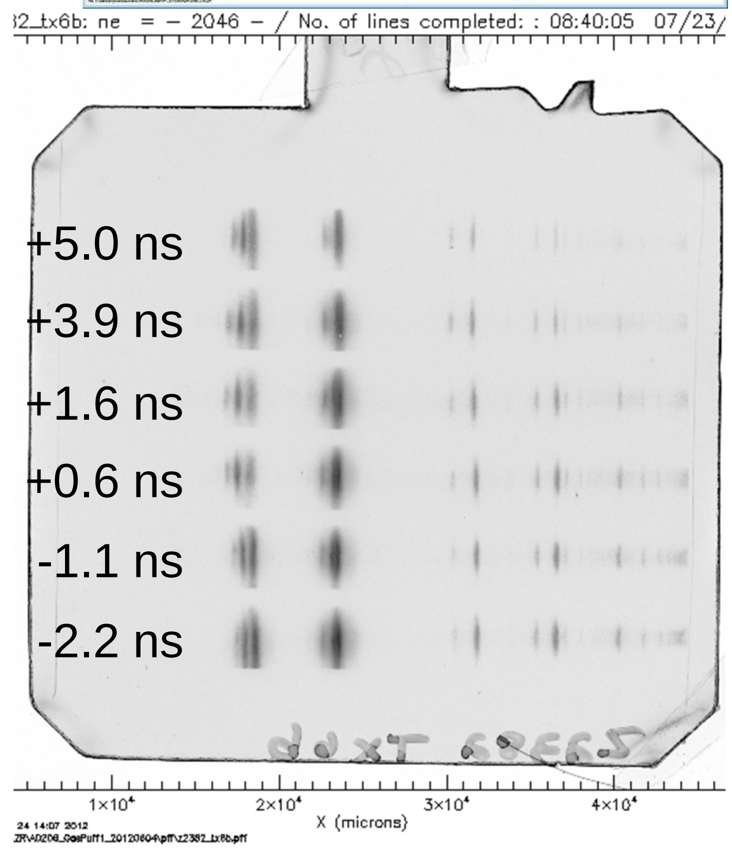


LOS 330 TREX 6A/6B, ellipse_t PET

- Early-time Doppler splitting in Ar He-a (maybe Ar Ly-a too) corresponding to times when MLML sees an imploding shell
- Quick Doppler velocity estimate from the splitting seen on the -10.9ns frame gives ~60 cm/us velocity
- Looks by eye like velocity is slightly accelerating (near axis)
- High n lines, satellites, and continuum turn on later in time
- May see Doppler-shifted absorption later in time



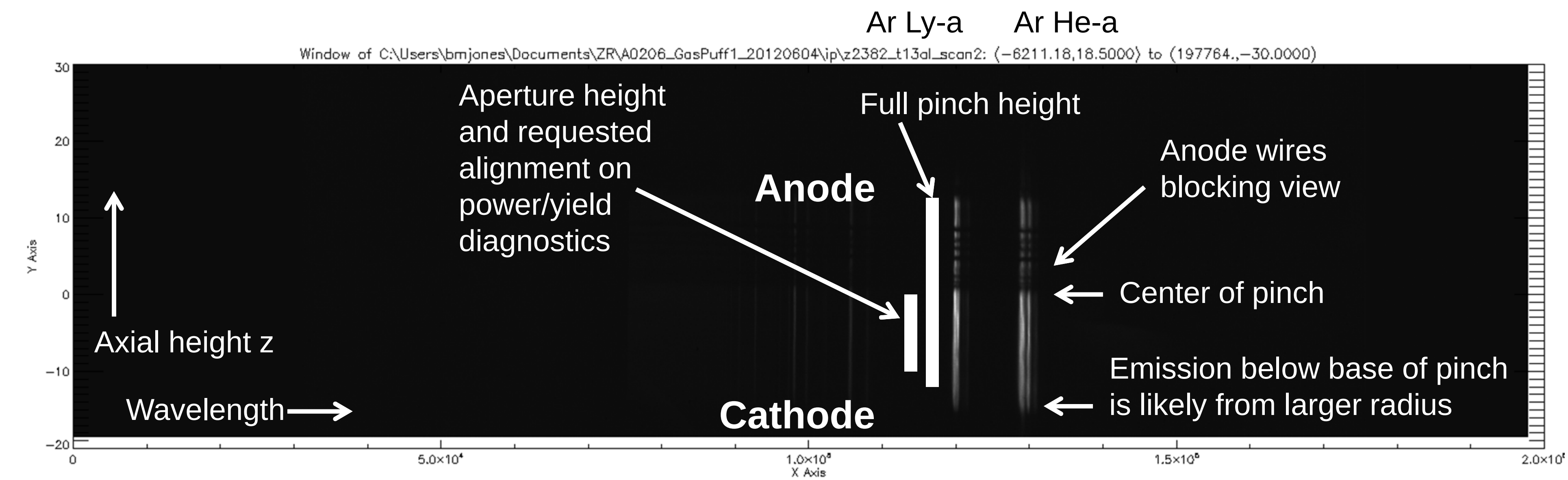




Timing relative to peak of PCD17A53118

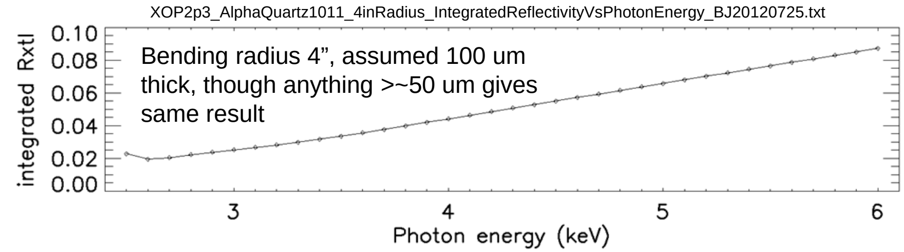
z2382 quartz TIXTL produced very clean Ar K-shell spectrum

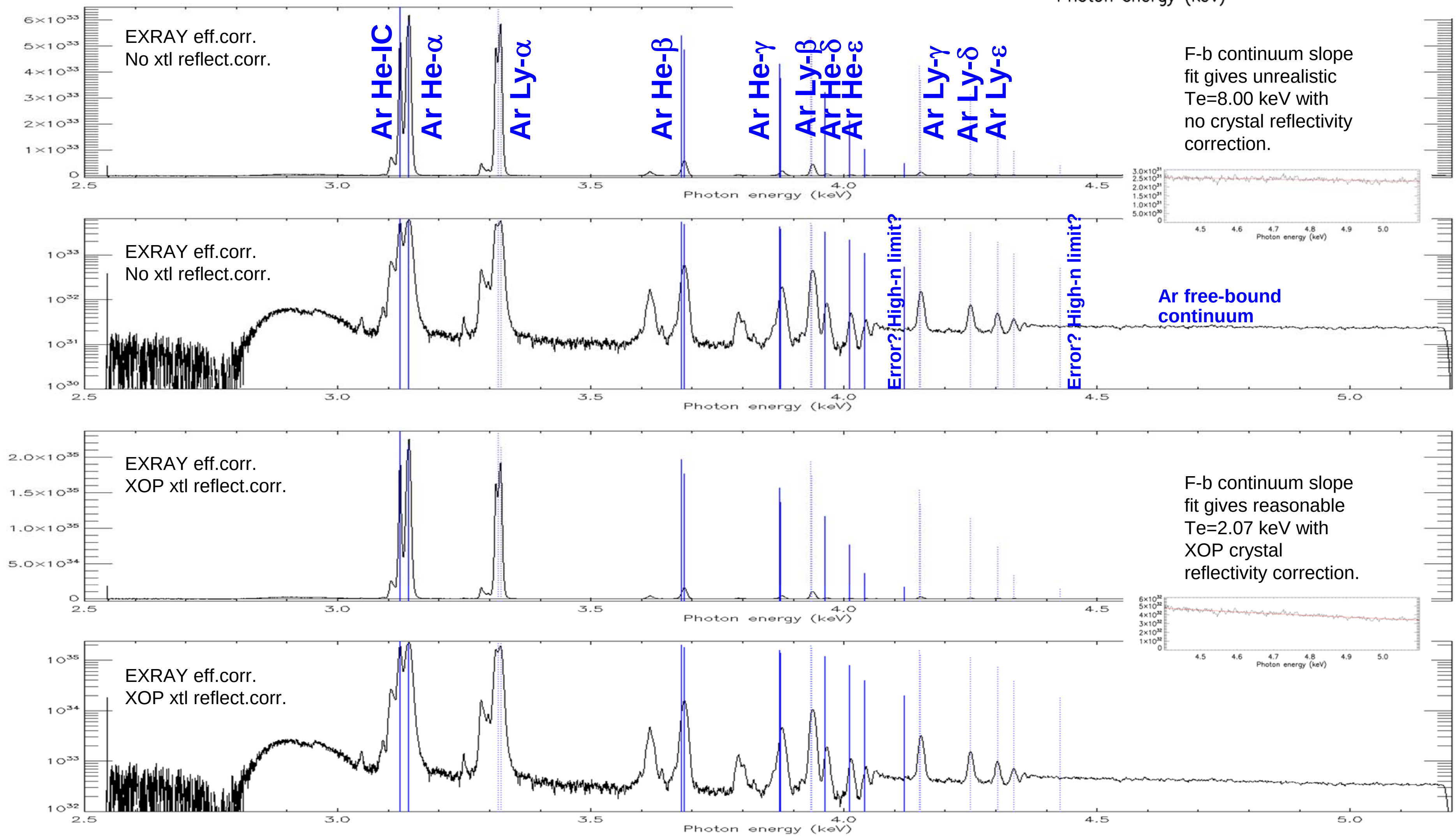
- Ar He-alpha and Ly-alpha lines are clearly the brightest spectral features
- Image plate used on TIXTLs, provides excellent dynamic range. Continuum and higher n lines are seen, as will be shown on following plots
- Alpha Quartz 1011 4” crystal provides ~3-5.5 keV coverage, good for the Ar K lines and part of the free-bound continuum
- We also used KAP 2” for coverage from 1-2 keV to 6-7 keV. The hope is to use this to measure any continuum emission at <3 keV. We are still processing these data.



Z2382 TIXTL Quartz 1011 integrated reflectivity model included from XOP code

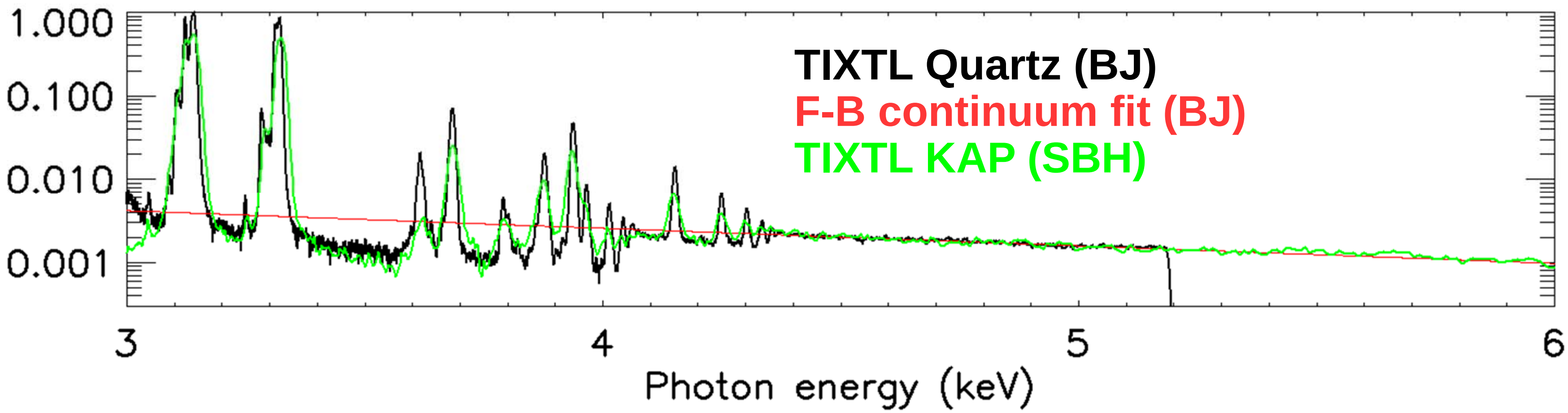
- Including a reflectivity model is necessary to infer a reasonable electron temperature from free-bound continuum slope, and to give consistent agreement with the LOS 170 30 mils Kapton PCD (sampling free-bound continuum region) after normalizing to LOS 170 bolo (constraining yield in K lines)

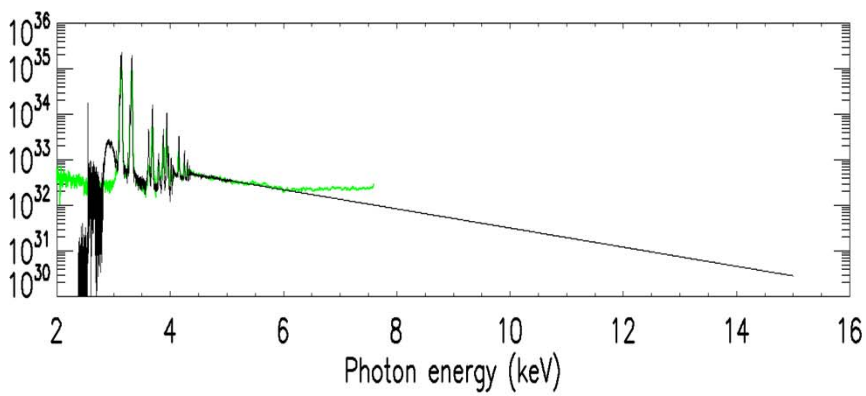


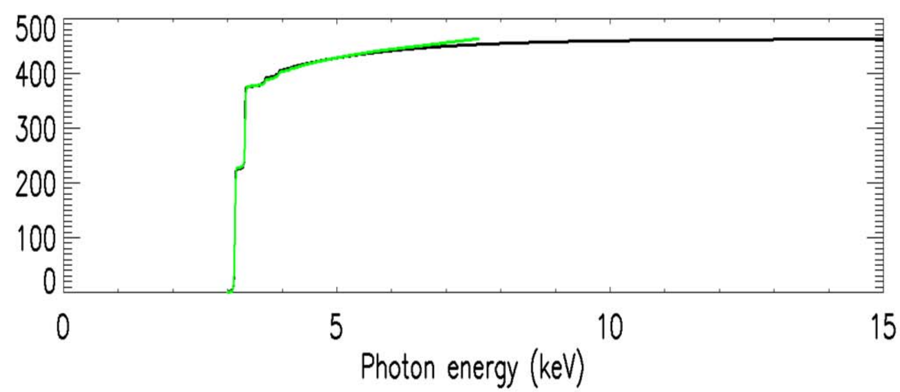


Z2382 Good agreement between processed Quartz (BJ) and KAP (SBH) TIXTL spectral shapes

- Quartz processed by Brent including XOP reflectivity model
- KAP processed by Stephanie
- With arb. scaling, they are overlaid and have the same free-bound continuum slope
- Free-bound continuum fit is used to extend the quartz data to higher photon energy
- With arb. scaling, the KAP and quartz TIXTLs show the same energy distribution in the Ar K lines and in the free-bound continuum up to ~6 keV (KAP data flattens out there and is no longer reasonable at higher energies)



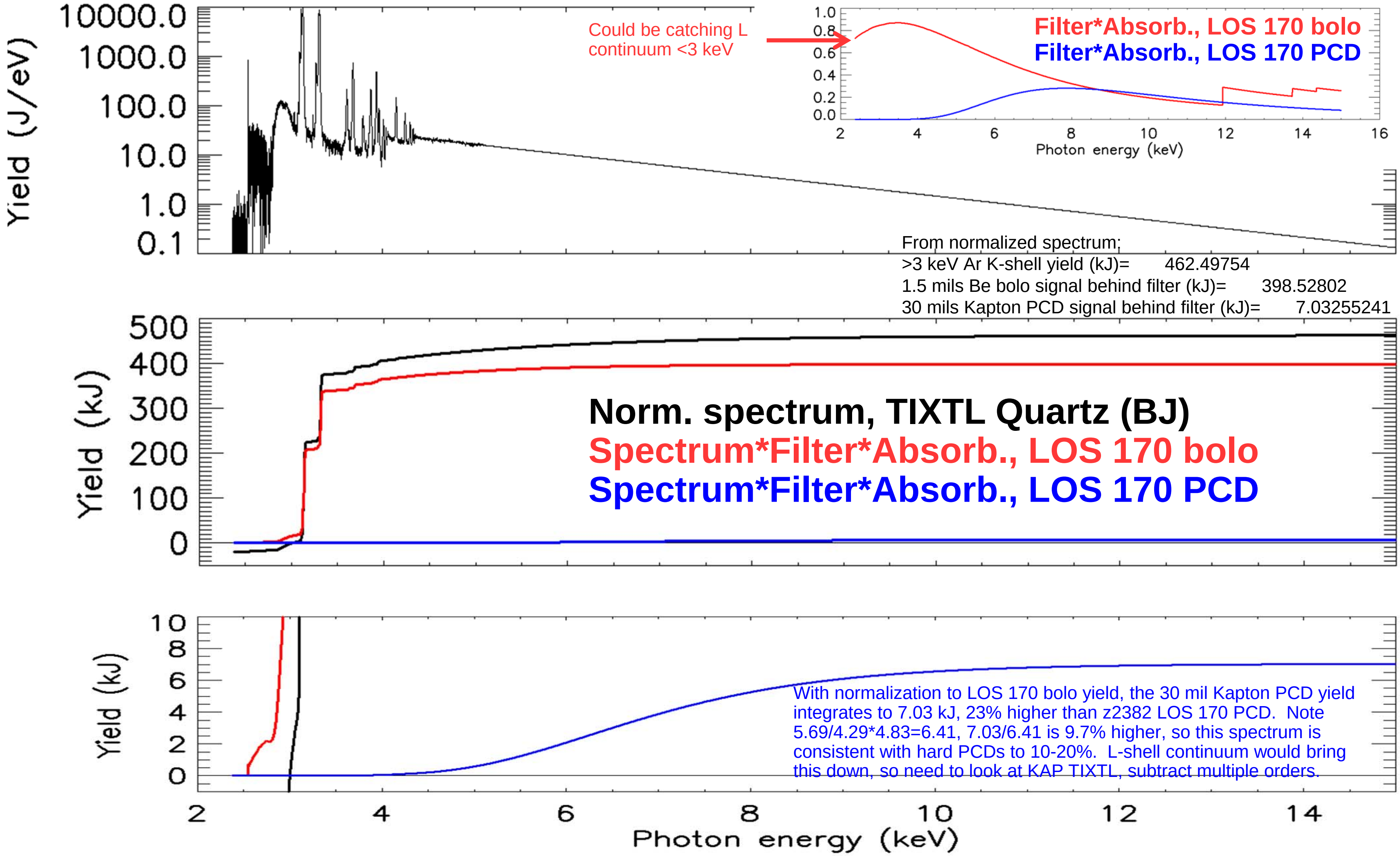




Z2382 Normalized TIXTL Quartz 1011 spectrum consistent with K bolo and harder PCD

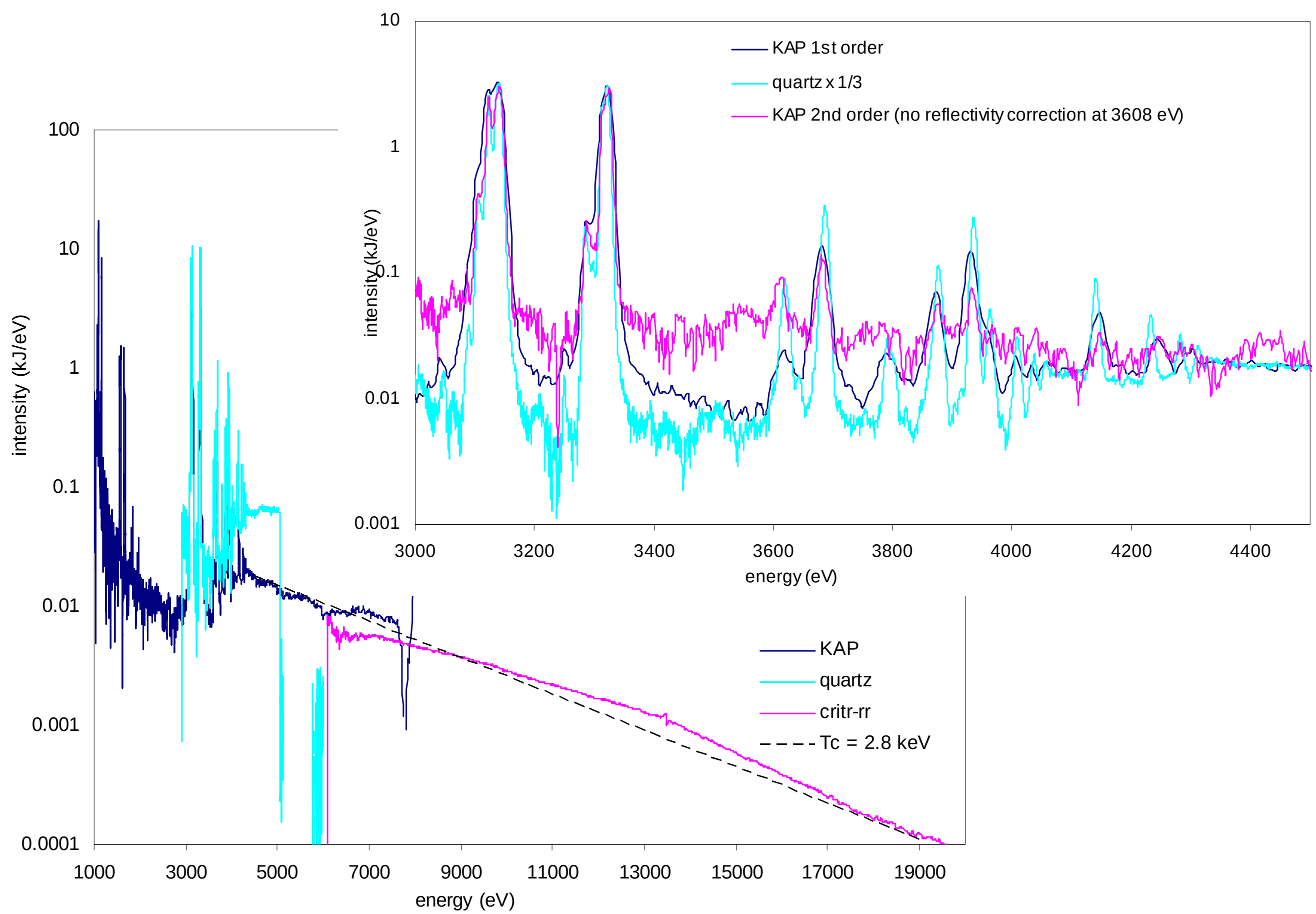
- Quartz TIXTL spectrum with f-b cont. extrapolation norm. to LOS 170 Au bolo (1.5 mils Be), which had 398.528 kJ 4pi/Lamb avg yield with filter trans=1.
- LOS 170 30mils Kapton filter #53 PCD check:

	4pi/Lamb. avg. yield with filter trans=1, all 30 mils Kapton		
Shot	PCD05A53072	PCD17A53118	PCD17A53121
Z2381	4.8278	4.28901	1.71756
Z2382	3.59139 (bad)	5.69365	2.39085



Z2382 CRITR spectral analysis from Stephanie

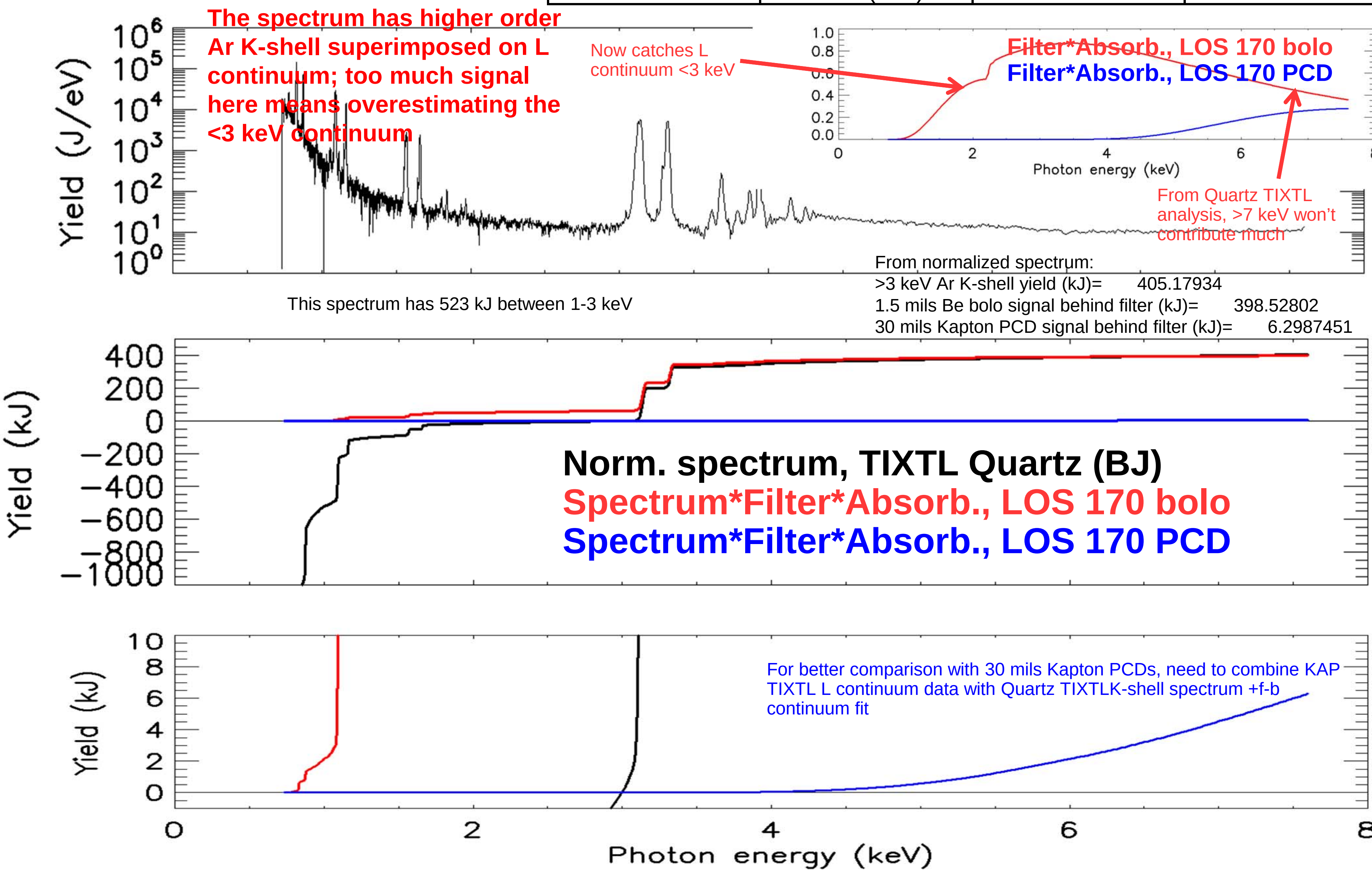
- Stephanie comments that CRITR gives Te=2.8 keV from the f-b continuum. She doesn't think that by eye the CRITR and KAP TIXTL continuum slope are that distinct\
- Top plot relates to how to subtract multiple orders from the KAP TIXTL spectrum so that we can include L continuum in the 1-3 keV range in the spectrum and in the normalization to yield diagnostic measurements



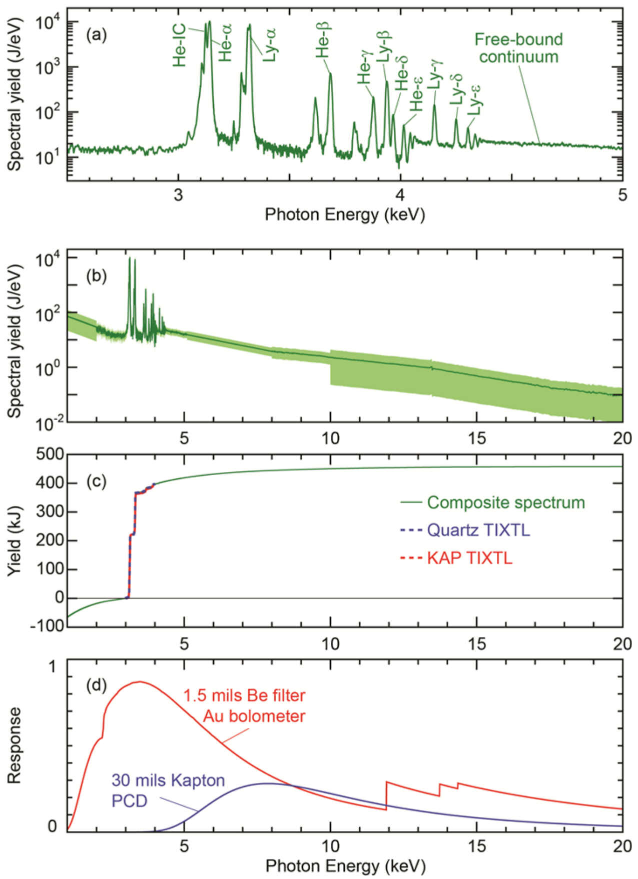
Z2382 >3 keV yield drops to 400 kJ using KAP spectrum, but this is underestimate

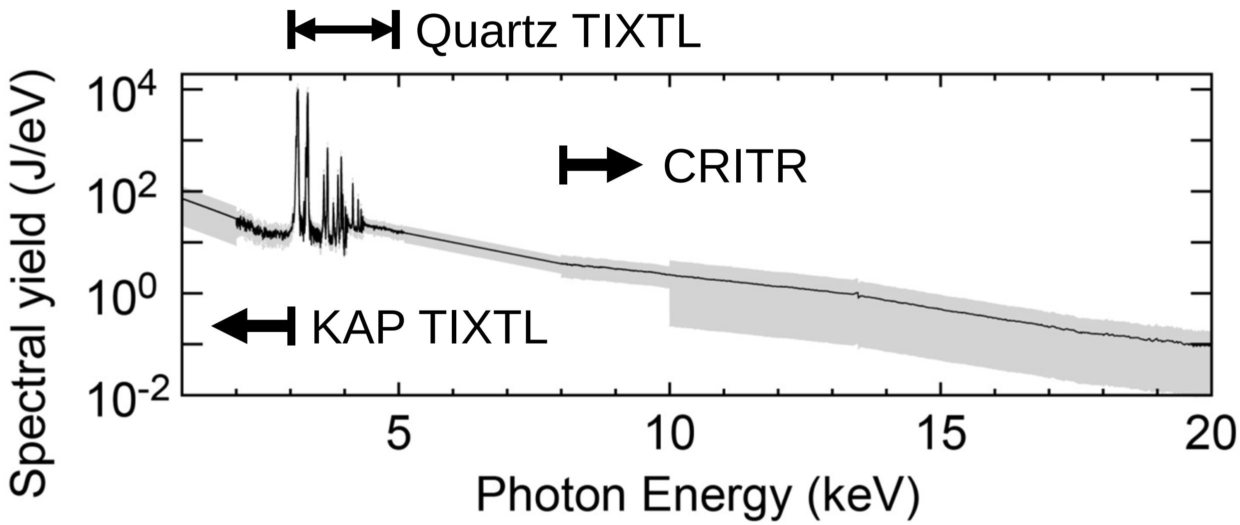
- KAP TIXTL spectrum per SBH analysis norm. to LOS 170 Au bolo (1.5 mils Be), which had 398.528 kJ 4pi/Lamb avg yield with filter trans=1.
- LOS 170 30mils Kapton filter #53 PCD check:

	4pi/Lamb. avg. yield with filter trans=1, all 30 mils Kapton		
Shot	PCD05A53072	PCD17A53118	PCD17A53121
Z2381	4.8278	4.28901	1.71756
Z2382	3.59139 (bad)	5.69365	2.39085



Composite spectrum from three different spectrometers is normalized to yield diagnostics





- Improved spectral characterization per Hansen/Ampleford Al spectra
- 450 kJ Ar K yield assumes axial uniformity; needs to be evaluated given zippering
- More discussion in milestone completion memo, and in pinhole image analysis below

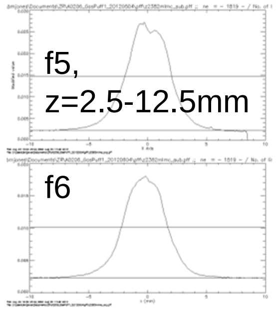
z2382 error accounting / weighted mean

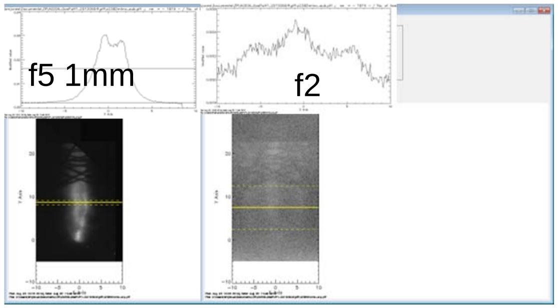
4pi/Lamb. avg. correction
Quartz TIXTL K spectrum

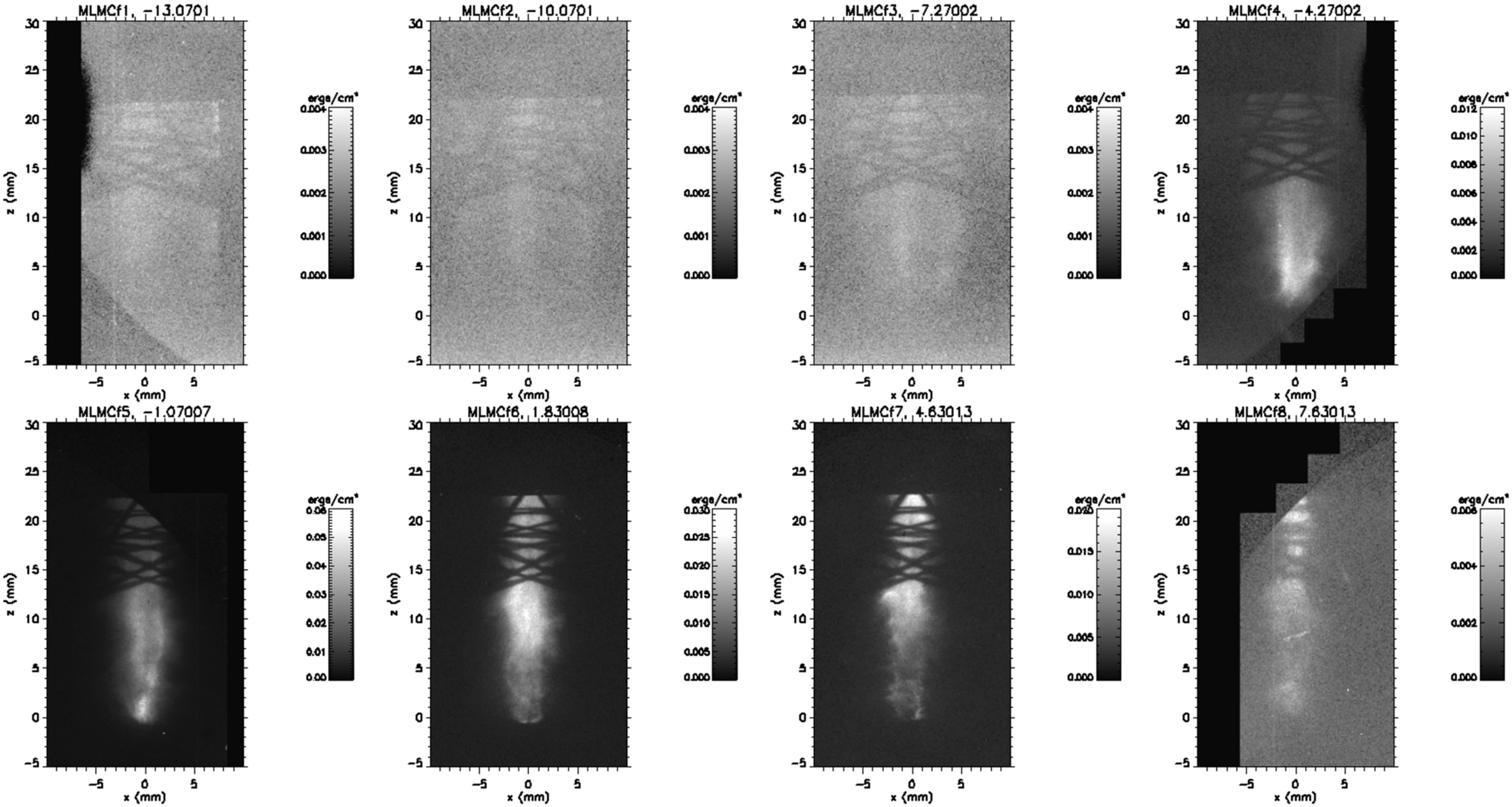
Error source	Error contribution (%)			
	LOS 50 PCDs w/ TIXTL FT and axial correct.	LOS 50 bolo w/ TIXTL FT and axial correct.	LOS 170 bolo (0º) w/ TIXTL filter trans	Calorim-eter w/ TIXTL filter trans
Au bolo cal standard (or calorim) absolute error (geometry, materials)	NA	NA	15	NA
Bolometer delta-V determination error	NA	NA	15	NA
Saturn PCD cal avg std dev (4 PCDs)	NA	NA	0	NA
PCD spread this shot (2 x 2 PCDs)	NA	NA	0	NA
TIXTL norm spread (LOS 170 bolo only)	NA	NA	0	NA
Length variation corr. error (not including)	NA	NA	0	NA
TIXTL high-hν cut-off variation (NA)	NA	NA	0	NA
TIXTL crystal reflectivity model var. (1 model)	NA	NA	0	NA
Lambertian/4π correction error	NA	NA	6	NA
Quadrature sum (net 1 sigma error) (%)	**NA**	**NA**	**22**	**NA**
K-shell yield defined as >3 keV (kJ)	**NA**	**NA**	**458**	**NA**
Weighted mean (LOS 170 bolo only)	**Call it 450 kJ ± 25% with caveats**			
	Not seeing full height (assuming uniform in z)			

Z2382 Process MLMC Ar K-shell pinhole camera, look at FWHM after converting to exposure

- Frame 5, closest to peak power: Lineout at z=7.5+/-5mm (LOS 170 aperture) gives FWHM=3.9713 mm.
- More localized 1mm lineout emphasizes pinch hollow profile, gives FWHM=4.061mm (but not that meaningful—could try Abel inversion)
- Frame 6: Lineout at z=7.5+/-5mm (LOS 170 aperture) gives FWHM=3.9305 mm.
- Early frames show imploding shell, but signal-to-noise is low. Column on axis could be time-integrated self-emission. Zipper is seen in shell.

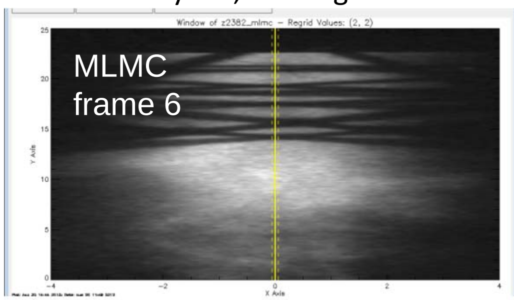




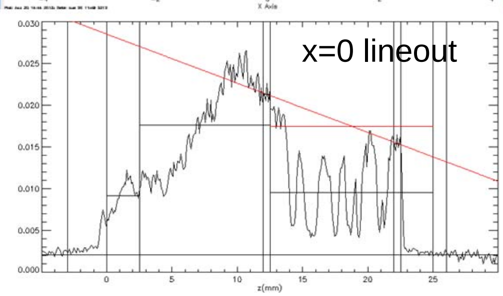


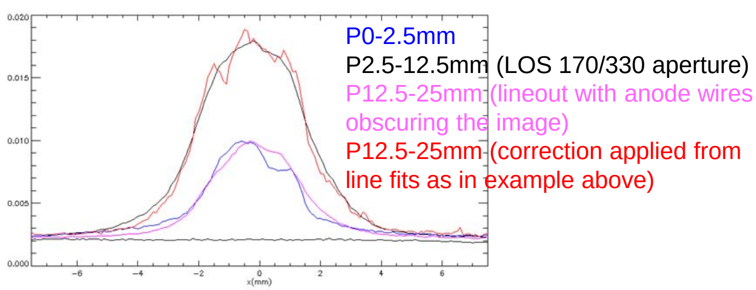
Z2382 Use MLMC to assess axial variation and pulse shape

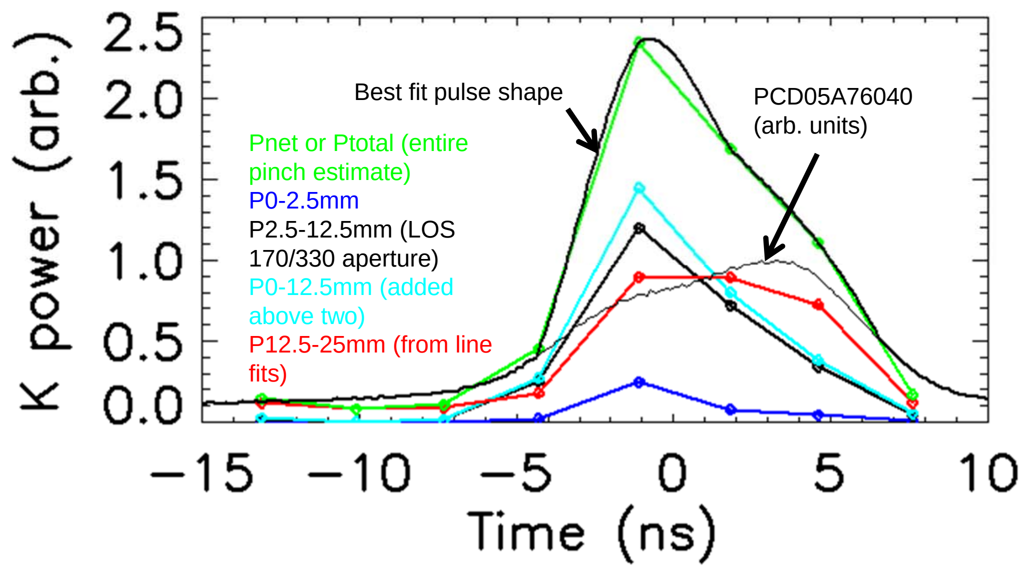
- For each frame, lineouts were taken at multiple vertical positions across the image (see frame 6, x=0 example below). A linear fit was performed between z=12 mm and z=22 mm regions unobscured by anode wires to estimate the emission from the top half of the pinch.
- The 'axial structure correction factor' was calculated for each frame as in the table. Omitting frame 2, which looks wacky, get 1.03921 correction factor when weighting by the total 'power' and averaging over frames. Omitting frames 1-3, which have low signal-to-noise, get 0.988328. This suggests that the yield was indeed close to 450 kJ, and that the dominant effect of the zipper is to broaden the pulse but not reduce the yield due to axial variations in this case.
- The 'total' column is the best estimate of the net K power from the entire pinch. This is plotted below, along with the power from different regions. Since LOS 50 diagnostics did not return data, I propose using this to estimate the net K power pulse shape.
- Best fit pulse shape uses PCD05A76040 for foot and tail rescaled to match MLMC foot, and uses spline fit to MLMC points for main pulse. This is saved as z2382_KPulseBestFit_MLMCpeak_PCD05A76040foottail_tnsreltpeak.ufo and gives 50 TW peak power when normalized to 450 kJ K yield, with significant error



Frame	Z=0-2.5mm	Z=2.5-12.5	Z=12.5-25mm	Total	Correction
1	0.00744649	0.0177738	0.118503	0.143723	3.2344909
2	0.00019937020	0.0011224622	0.079976130	0.081297962	28.971296
3	0.00035610041	0.014289590	0.092218344	0.10686403	2.9913814
4	0.019053683	0.25404361	0.17665753	0.44975482	0.70815372
5	0.24811670	1.1991908	0.89559443	2.3429019	0.78149430
6	0.078381945	0.71886338	0.89214331	1.6893886	0.94003321
7	0.043766787	0.33848485	0.72595897	1.1082106	1.3096132
8	0.0092225141	0.041883914	0.11759255	0.16869898	1.6111100

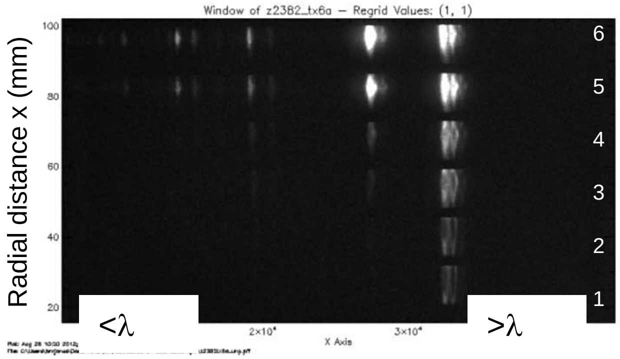


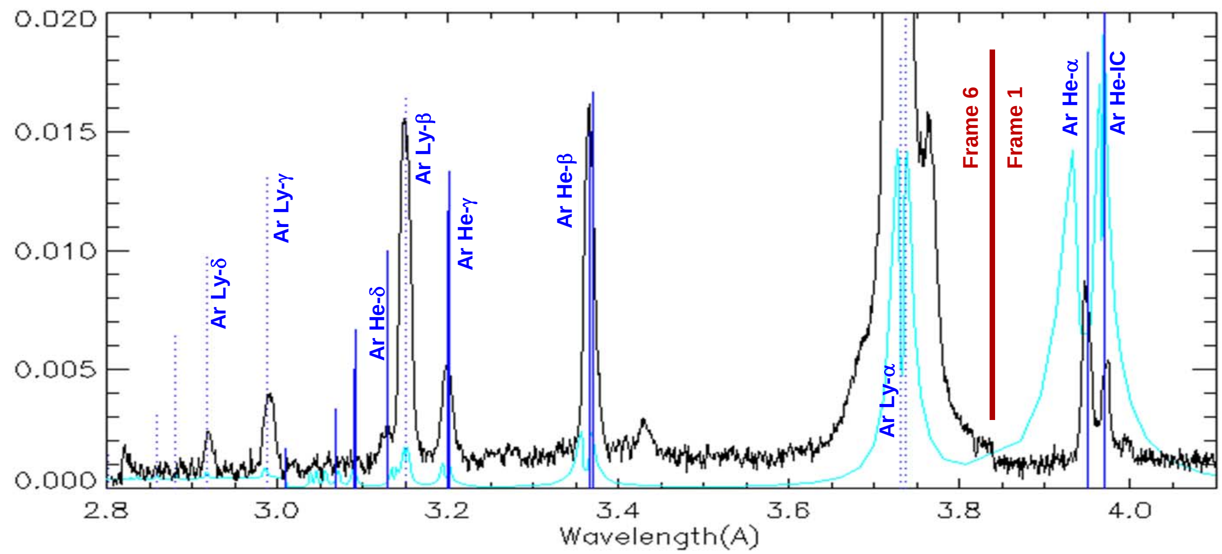




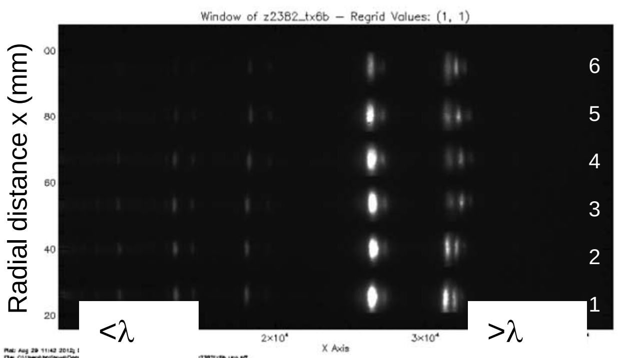
Z2382 TREX 6A/TREX 6B, ellipse_t PET, Ar K-shell time-gated spectra

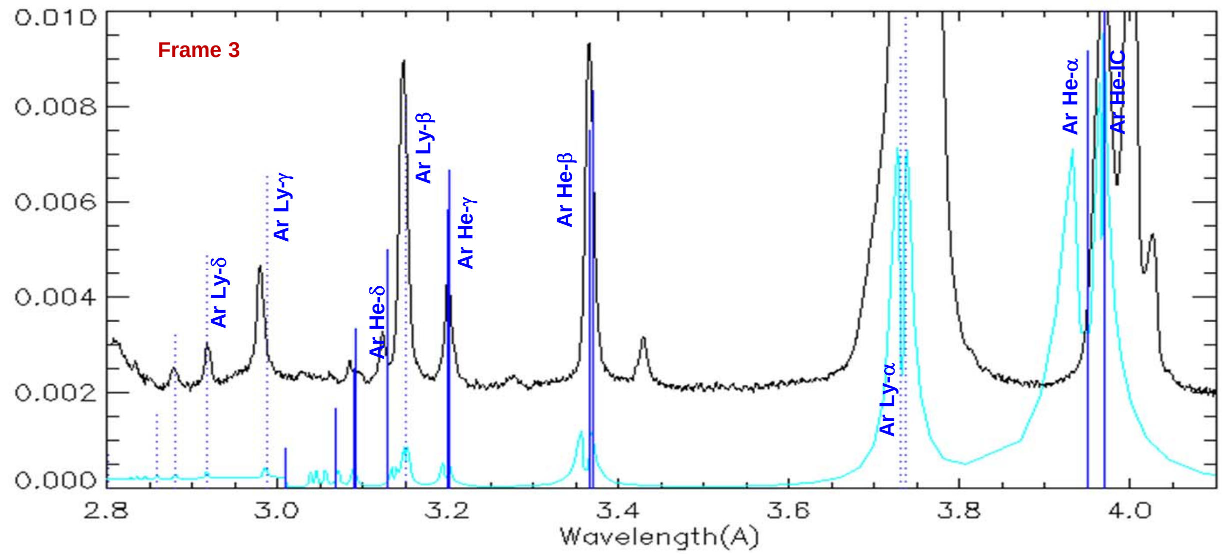
TREX 6A





TREX 6B





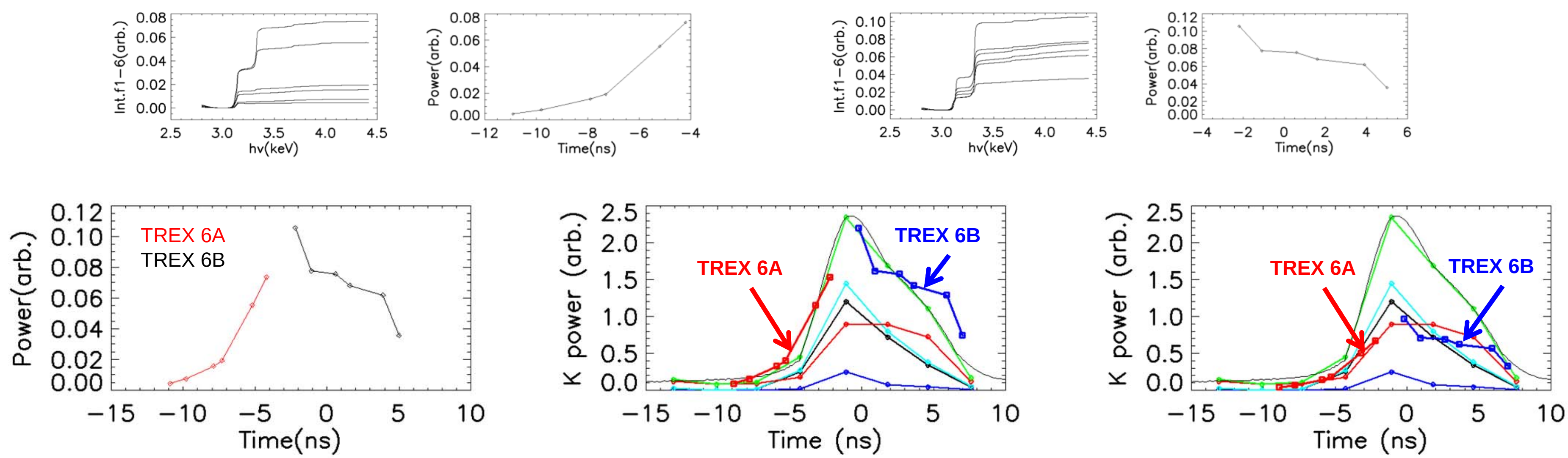
- I couldn't exactly match the positions of all the lines, which could indicate crystal artifacts or could possibly be physical due to Doppler/opacity effects shifting apparent line positions. I focused on matching high-n lines which should have lower opacity, or for early frames the outer edge of a Doppler split oval which should be at the correct reference wavelength. Note the wandering of the Ar He-a+IC in the later frames of TREX 6B. This will require further assessment.

Z2382 TREX 6A/B, construct effective K power pulse, compare to MLMC

- A lineout was taken across each frame, integrating over the radial spatial dimension
  - One can clearly see Ar He-a emission only at early time, with Ar Ly-a turning on before peak power and eventually becoming brighter than He-a
- These were then integrated to give 'effective K-shell power' pulse (bottom left plot)
  - TREX was looking through 10 mm tall aperture aligned similarly to LOS 170, but TREX is at 12 degrees, MLM at 13 degrees, so view will be slightly different
  - TREX spectral range capture Ar K lines, but not the free-bound continuum
  - As with the MLMC pulse shape, this assumes gain is identical between all MCP frames (and in this case cameras,) which may not be true
- I shifted TREX 'power pulse' by 2 ns to get reasonable agreement with the 'power pulse' constructed from MLMC Ar K pinhole images (green curve in middle bottom plot, or compare to 10 mm aperture view black curve at bottom right).
- I would say that the TREX and MLMC produce consistent pulse shapes, but FWHM of the MLMC/PCD combo pulse could be larger by ~25%, and there is at least a factor of 2 error in the amplitude of the foot and tail pulse from the PCD.

TREX 6A

TREX 6B



Z2382 Te from Ar K line ratios is less than inferred free-bound continuum slope

- Ar Ly-a/Ar He-a+IC line ratio is 0.666; Ar Ly-b/Ar He-b+IC line ratio is 0.625; using composite spectrum, Quartz TIXTL for these lines.
- Using 'best fit' pulse shape, peak K power was 50 TW. This could be 2x uncertain.
- Using Apruzese JQSRT 1997 contour plots at 3 mm diameter (closest to size from pinhole images; hollowness not accounted for)
- Suggests Te ~ 1 keV and ni of a ~3e20/cc. Significant caveats—pinch looks hollow so methodology may need to be revised, power level is uncertain 2x => 2x error in density, etc. It seems unlikely that 2 keV is feasible from line ratios as this would require much lower K power; even with 2x error in power, Te <1.3 keV from the contours given measured line ratios.
- The free-bound continuum could come from a hotter part of the plasma (Te=2-3 keV) than the bulk (hollow shell) that is emitting Ar K lines at closer to Te=1 keV. Could use CRITR-RR to infer Te at various radial positions—by eye it might have higher Te near center, and it certainly has the brightest continuum emission in the center rather than being hollow.