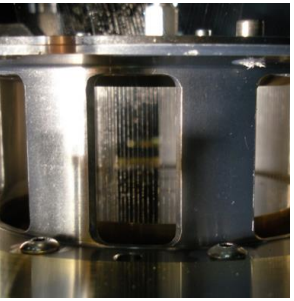
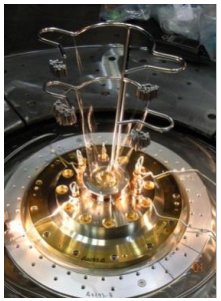
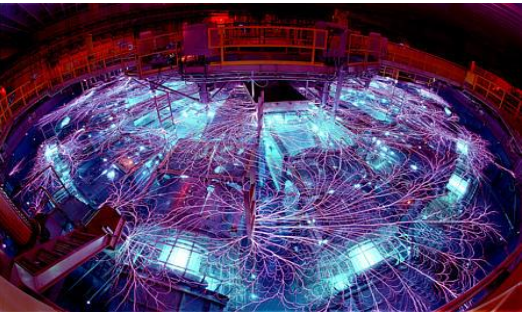
SAND2014-18254PE







20-100 keV crystal spectrometers on Z

David J. Ampleford, S.B. Hansen, C.A. Coverdale, P.F. Knapp, K.S. Blesener, V. Harper-Slaboszewicz, L.A. McPherson, B. Jones, D.B. Sinars, G.A. Rochau, M.E. Cuneo

Sandia National Laboratories

Work partially supported by Sandia LDRD projects 165733 & 173104

Sandia National Laboratories

Exceptional service in the national interest

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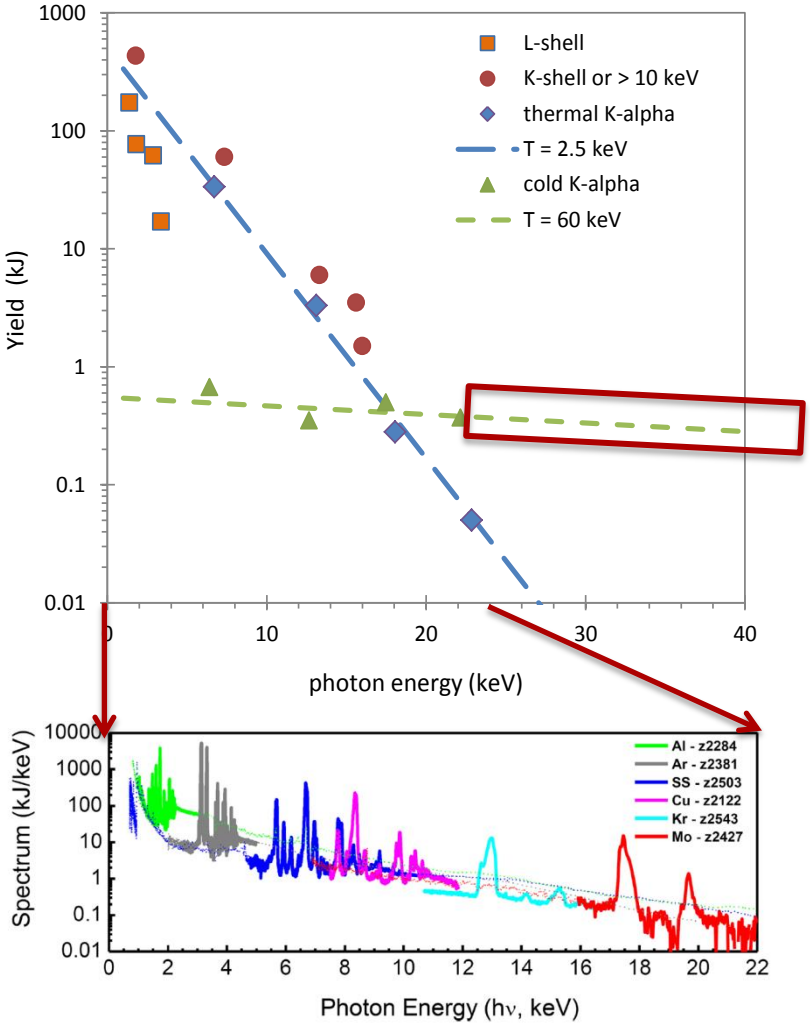
Overview / Goals

Need	Goals	Driver
Spectral Range	20-100 keV	Study K-shell radiators from Ag to Au and continuum beyond that
Spectral Resolution	λ / δλ ~200	Distinguish thermal from non-thermal lines. Distinguish lines from continuum
Resolving direction	Capable of radial or axial	Study structure in pinch in both directions
Field of View	≥ 2 cm in each direction	Collect all emission from 2 cm long pinch. Kα emission comes from large diameter
Spatial Resolution	0.5 mm	Resolve different radial extents of thermal and non-thermal lines
Sensitivity	10 J/cm/eV	Able to record 100 J in a line
Calibration	Need relative calibration	Absolute calibration of entire system would be very useful long term.

Emission from inner-shell ionization does not need the investment of ionization energy

- K-shell emission from thermal electrons
  - He-like and H-like lines
  - Need to ionize to the K-shell
  - Sharp drop with atomic number
  - Significant thermal radiative losses accompany the ionization
- K-shell emission from energetic electrons
  - Cold K-lines (Kα)
  - Need hot electrons/photons
  - Don't need to ionize bulk plasma
- Scaling previously explored with laser plasmas
  - H.-S. Park *et al.*, RSI 75, 4048(2004)



A range of x-ray diagnostics are available on Z tailored to different spectral regions

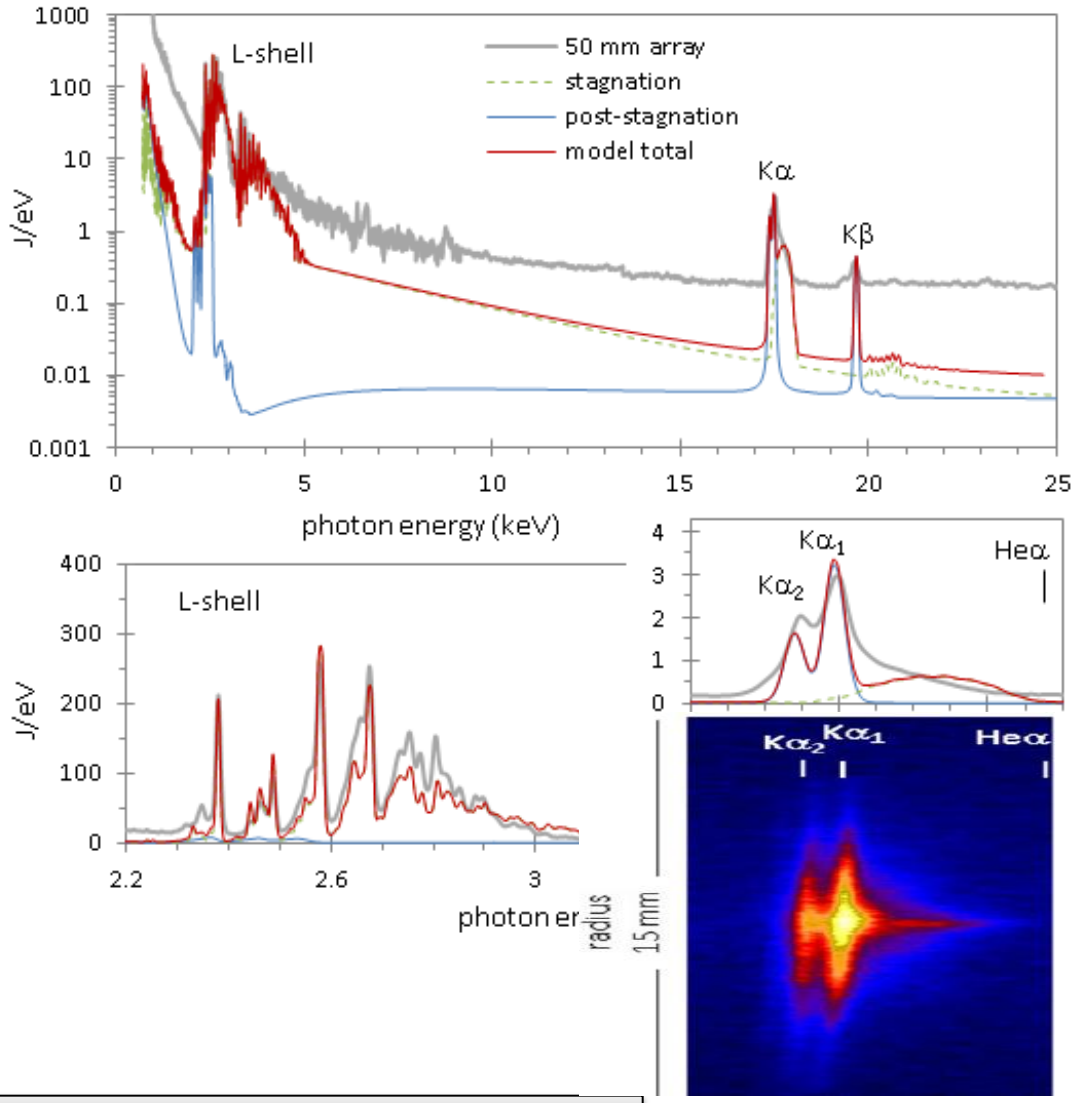
Instrument		1 keV				~1-20 keV				20-100 keV			
Name	Ref.	Fluence	Temporal	Spectral	Spatial	Fluence	Temporal	Spectral	Spatial	Fluence	Temporal	Spectral	Spatial
XRD	Chandler RSI												
TEP	Ives PRSTB												
MLM	Jones RSI												
Bolometer	Spielman RSI												
PCD	Spielman RSI									<30keV	<30keV		
Calorimeter	Pepping HEART												
PDI	Moore JRERE												
TIXTL	Nash RSI												
TREX	Lake RSI												
CRITR	Sinars RSI											Possible	
TiGHER	Knapp in progress											Possible <30 keV	
TLD	VHS HEART												
DAHX*	Moy SPIE												
TIPC*	McPherson HTPD												

Some Info. e.g. framed data, spectrum from filter unfold, 1D imaging

Good Info. e.g. continuous record, high resolution spectra, 2D imaging

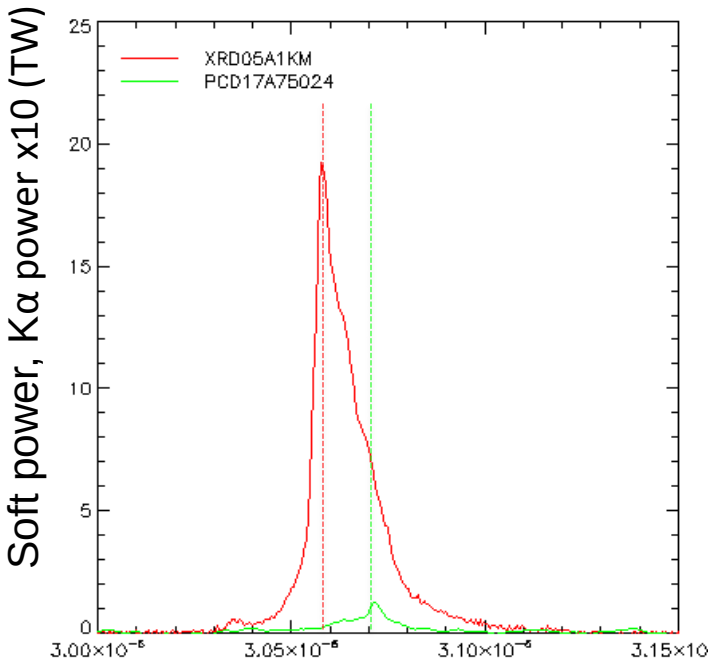
Spectral data provides insight into Mo emission at 17 keV - Similar with higher Z materials would be valuable

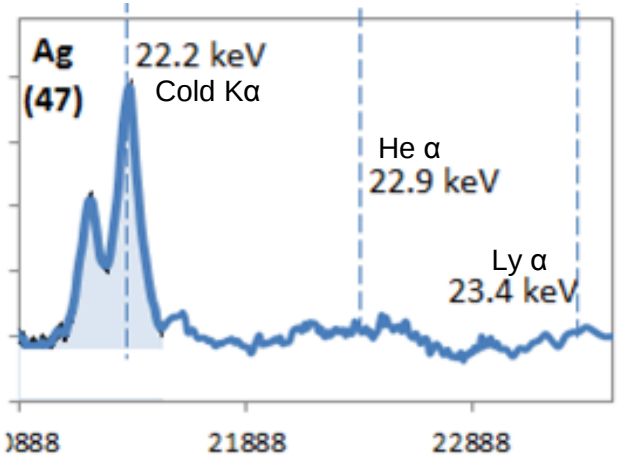
- CRITR spectrometer can provide radially resolved spectrum of Kα structure
- Different structures of L-shell Kα and cold Kα can be explained by
  - Hot core emitting some thermal K-shell and highly ionized L-shell
  - Followed by late-time 7mm cold plasma with hot electrons emitting cold Kα over 10s of ns



S.B. Hansen, D.J. Ampleford *et al.,* Physics of Plasmas **21**, 031202 (2014).

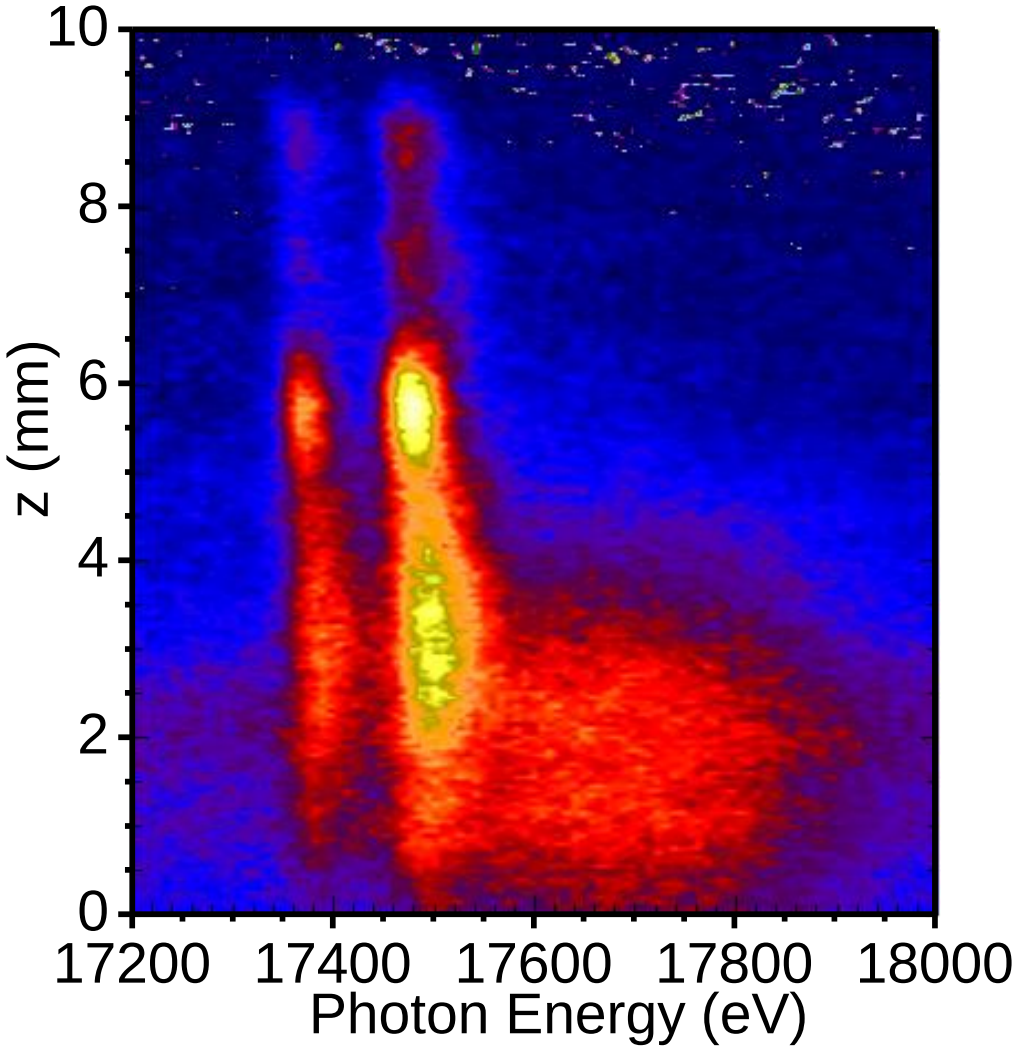
Initial experiments have demonstrated ability to emit Ag Kα

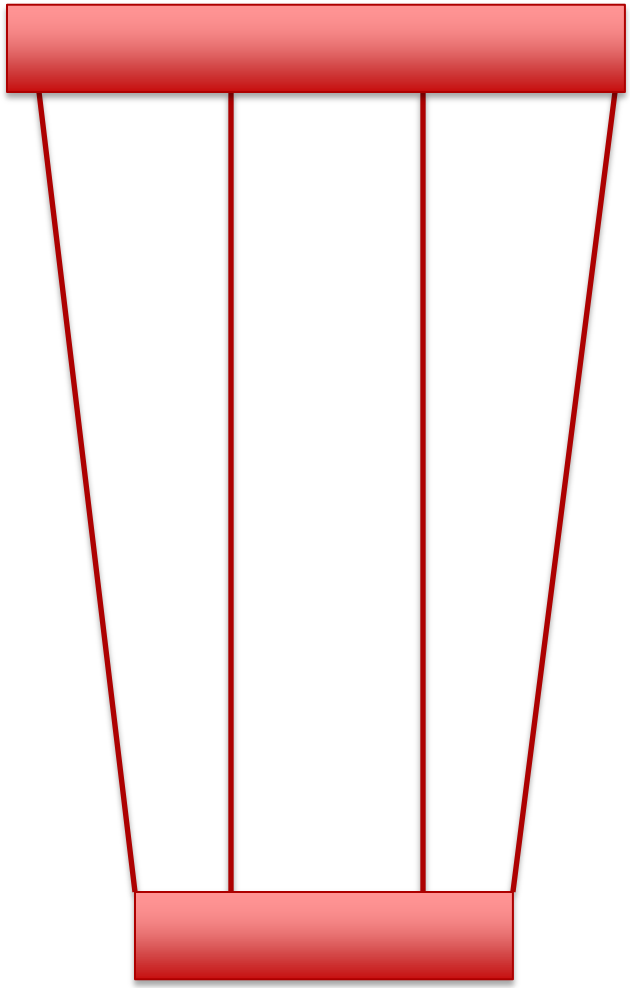




- Ag experiments on Z can generate Kα at 22keV
  - Kα emitted late in time
  - Ag Kα emitted from most of length of pinch
- No measureable Heα emission
- Dynamics appears very similar to Mo emission

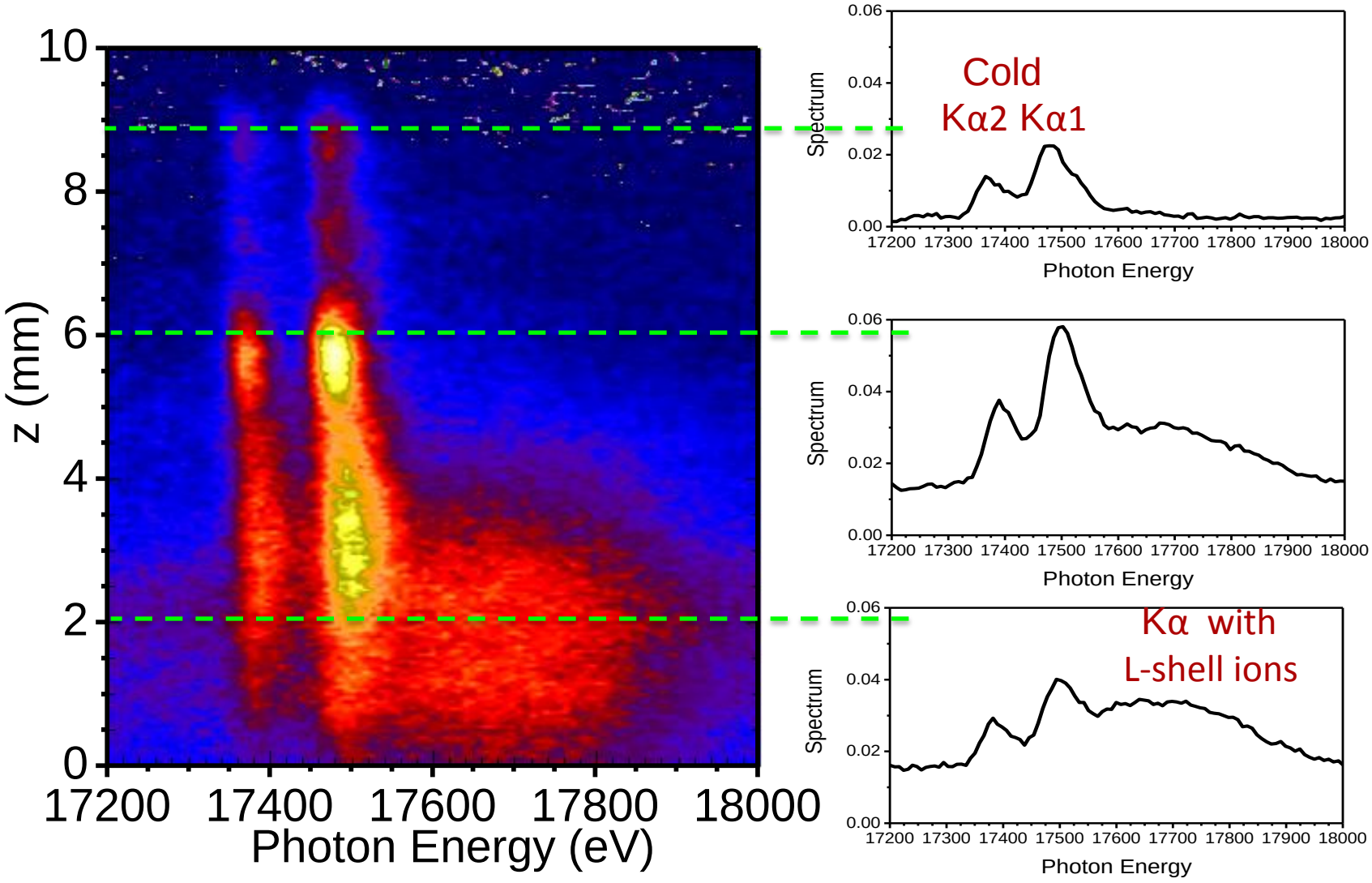
Experiments with conical pinch show need for spatial resolution to understand conditions



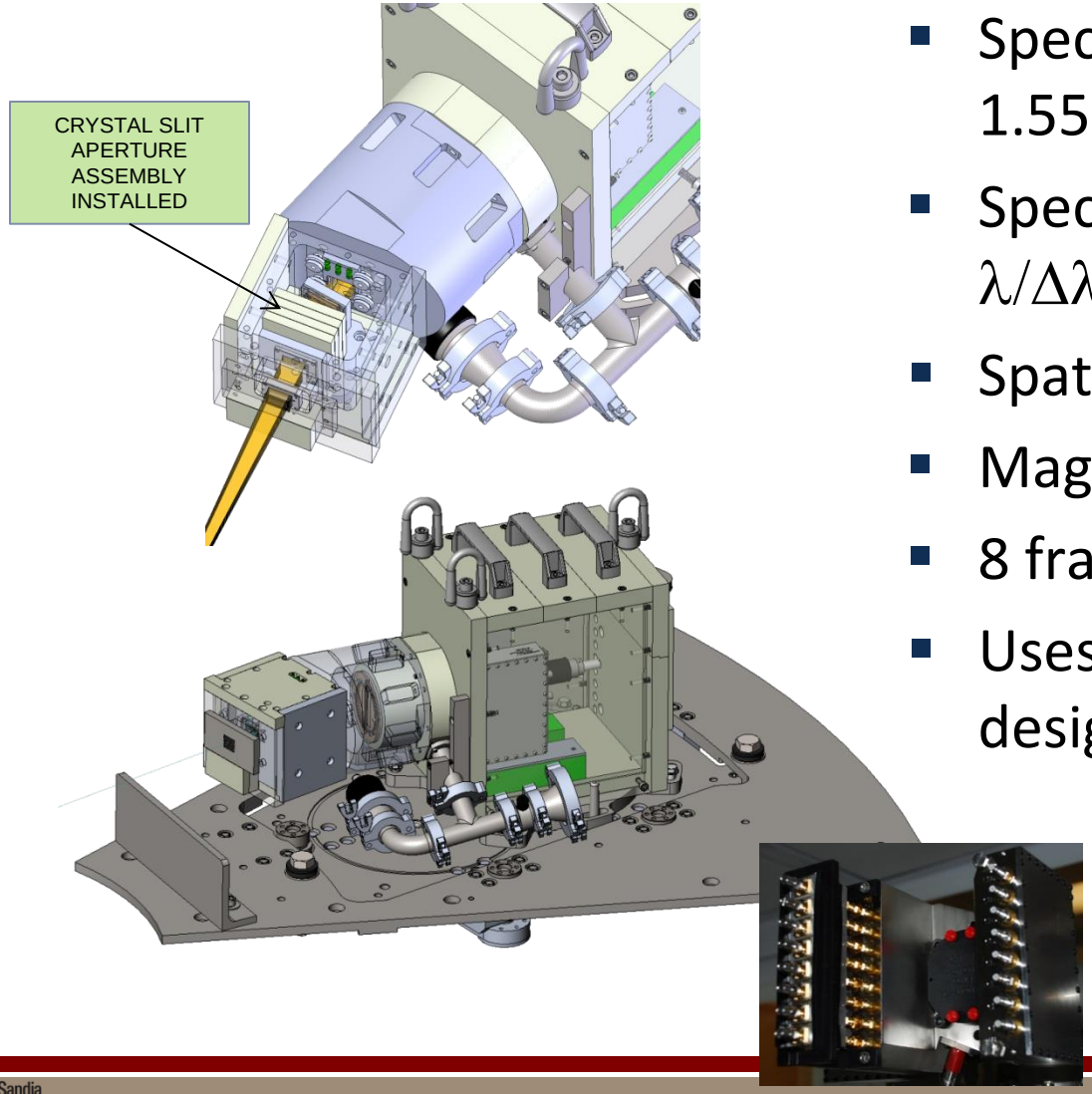


D.J. Ampleford *et* al., ICOPS 2014

Experiments with conical pinch show variation in conditions along pinch, with more L-shell states near cathode



Z is currently commissioning a time-resolved 8-25 keV spectrometer (TiGHER)

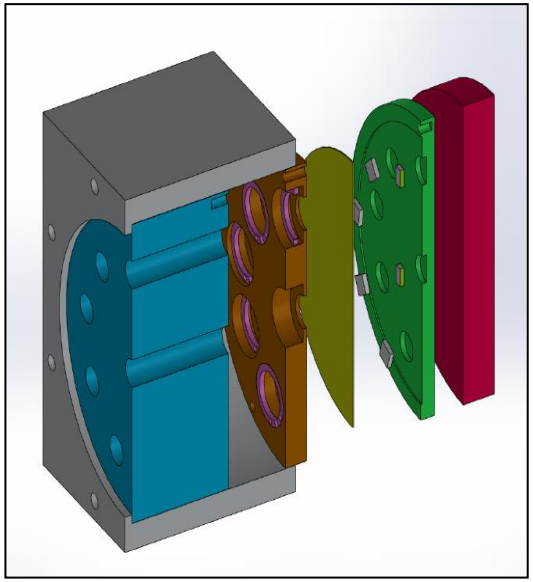


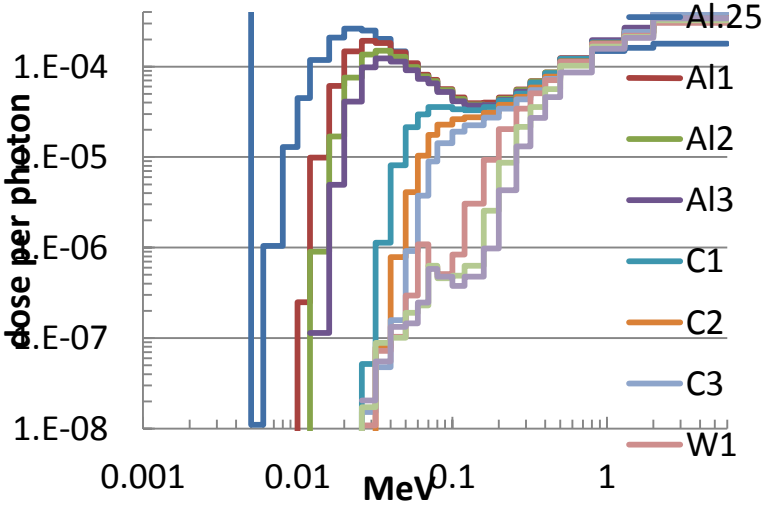
Spectrometer Specifications

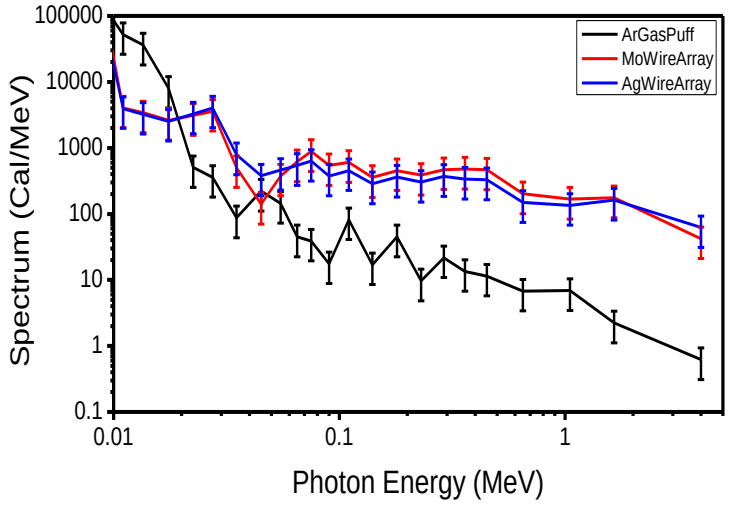
- Spectral range of 8-25 keV (0.5-1.55 Angstroms)
- Spectral Resolution $\lambda/\Delta\lambda$~700
- Spatial resolution ~100µm
- Magnification of 0.8 or 0.5x
- 8 frames, 250 ps gate width
- Uses existing NSTEC Gen-II MCP design

TLD stack for characterizing 10 keV-10 MeV

- Filtered TLDs are being fielded to characterize >10 keV spectrum
  - To date have been evaluating continuum from cold sources
  - Data suggested ~ 1kJ at > 50 keV for various sources
- Data shows change in spectrum for different loads
- Ross filter pairs will soon be explored
- Data being used to aid design of other instruments

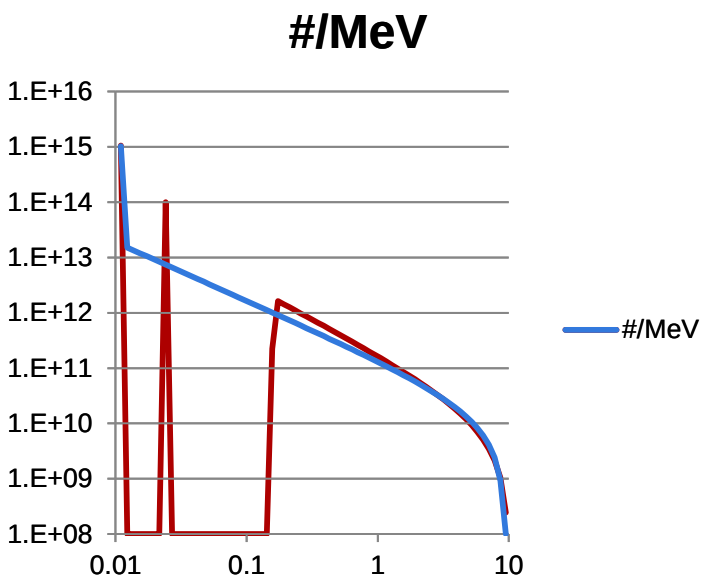






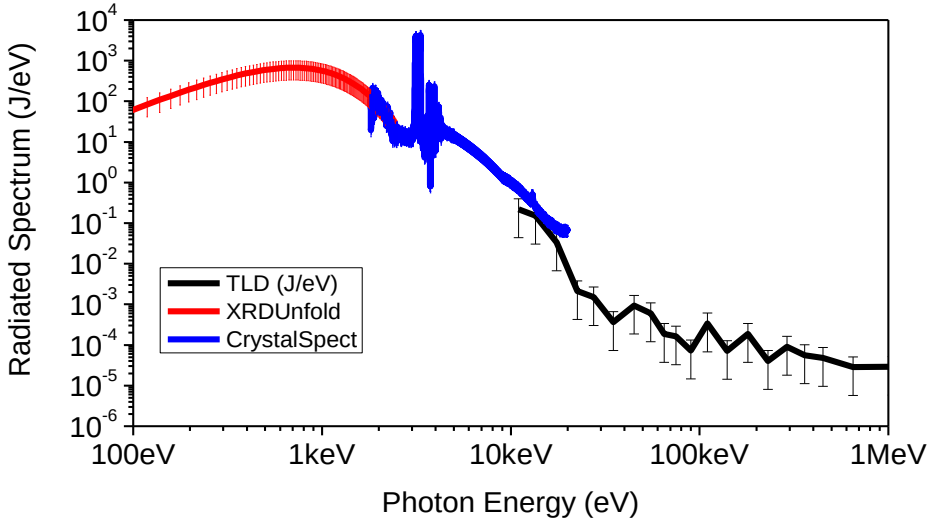
Filtered detectors can be ambiguous unless you have carefully chosen absorption edges

- Fits to TLD data on z2535
  - Assuming no silver line double brems unfold
  - Assuming silver line at 22 keV
- Both fit data within ~10% uncertainty

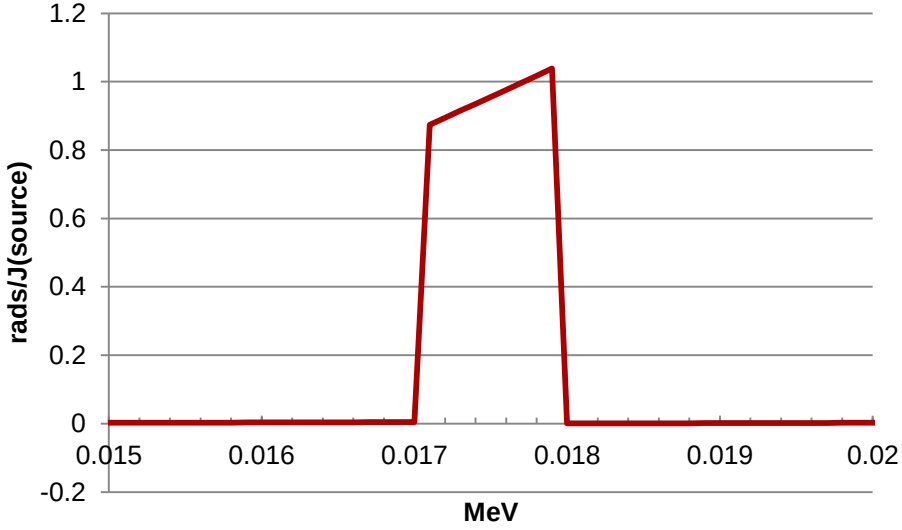


TLD detectors have been developed for Z to characterize high energy tail and enable diagnosis of >25 keV Kα sources

- Filter setup has been used to characterize high energy spectrum
  - Shown is for an Ar pinch
  - Spectrum for 10 keV to 1 MeV can be fit to filtered TLDs
  - Multiple diagnostics provide broadband characterization

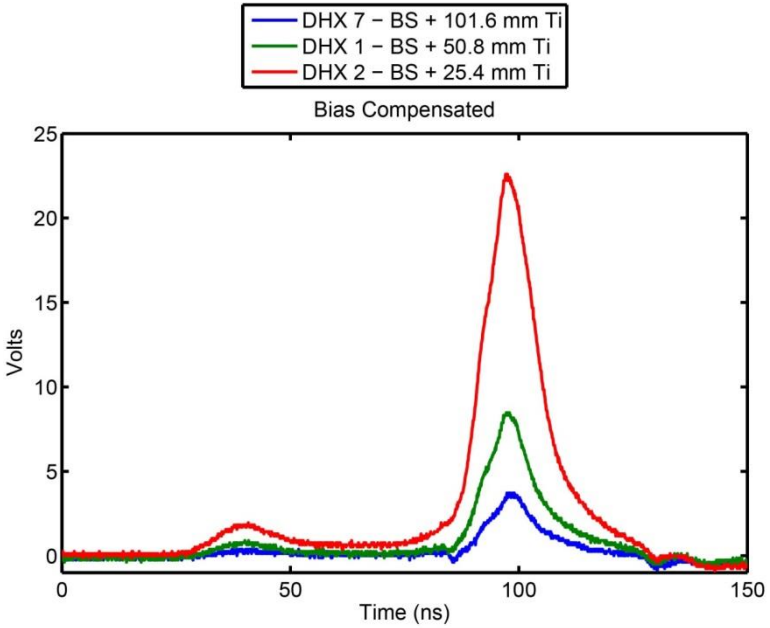


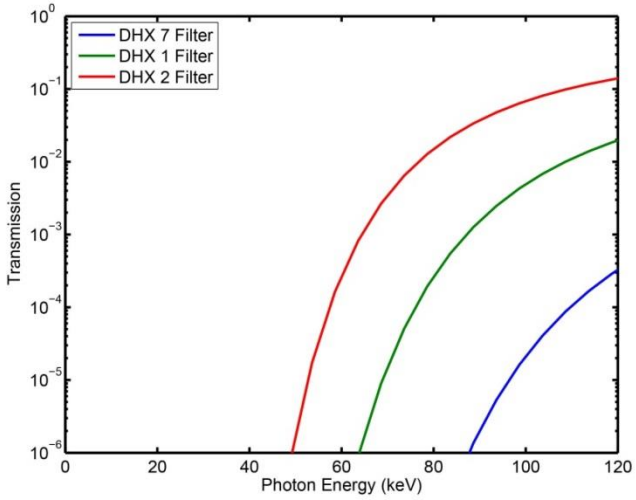
- Ross pair allows diagnosis of fluence/yield in a band
  - Dose Zr 484 ± 3.7% rads (3 TLDs)
  - Dose Y 289 ± 1.0% rads (3 TLDs)
  - Δdose 194 rads
  - Similar data for Ag
  - Should be able to diagnose W Kα

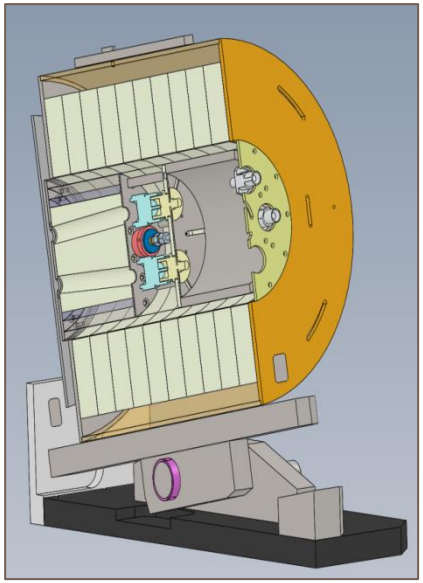


Differential Absorption Hard X-ray (DAHX) spectrometer will provide powers out to ~200keV

- Instrument previously fielded at Sandia by NSTec
- Recently fielded on few shots
- Calibrated power pulses at significantly higher energies than currently possible on Z
- Data shown is consistent with 160 keV Brems.

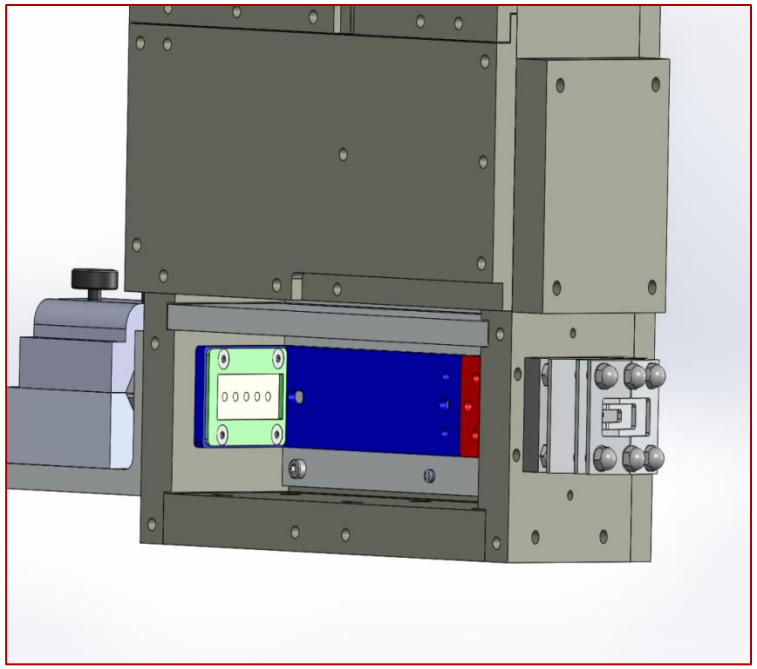


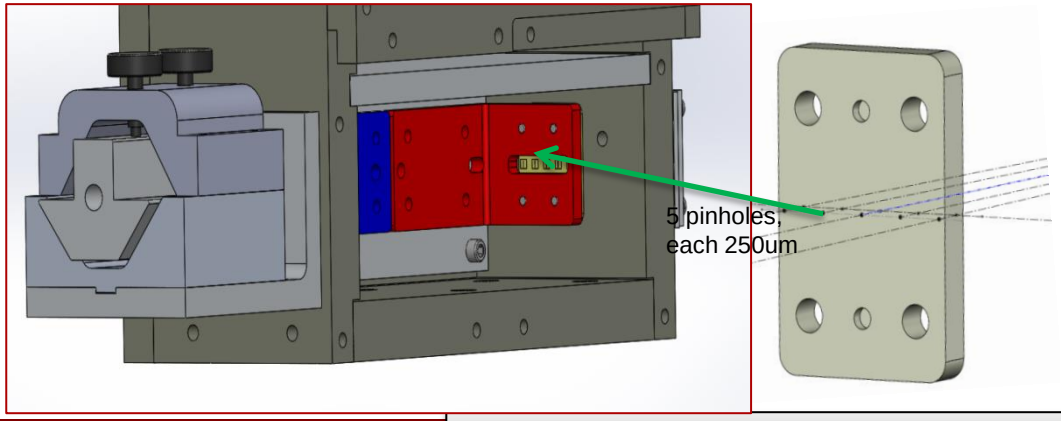




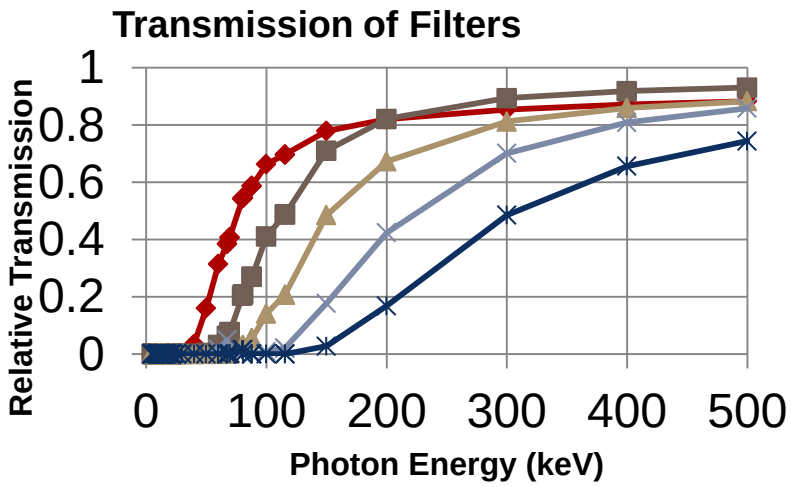
K. S. Blesener, *et al.,* High Temp. Plasma Diag., 2014
K. Moy, M.E. Cuneo *et al*., Proc. SPIE **6319**, 631901 (2006)

Time Integrated Pinhole Camera (TIPC) aims to provide information on spatial structure of > 20 keV emission





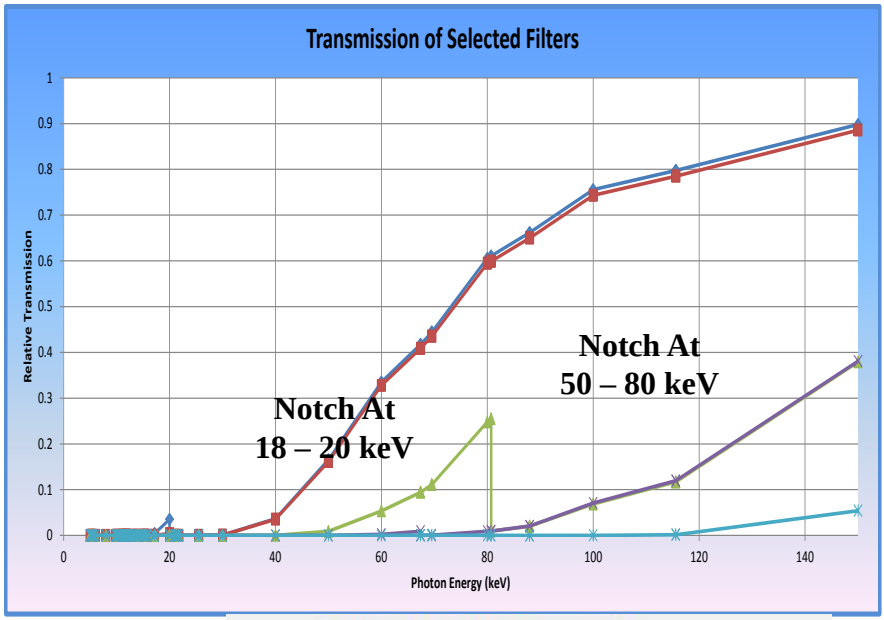
- Fielded in-chamber
- 5 filter cuts possible
  - Broad filters or Ross pairs
- Estimated resolution ~900 µm
  - 250 µm pinholes.
  - Conical or straight options
- Fielded on a few shots to date
  - Analysis underway

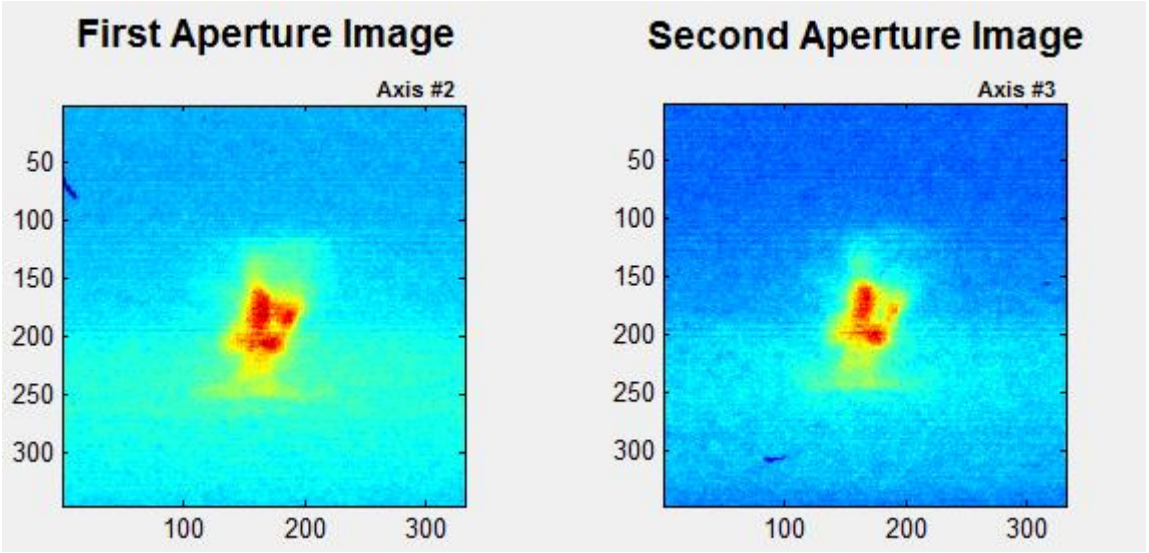


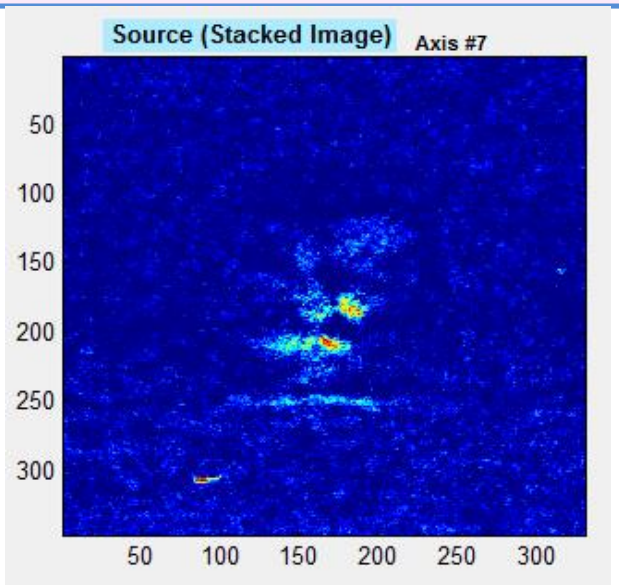
L.A. McPherson *et al.*, High Temp. Plasma Diagnostics 2014

Using notch filters have shown ability to get narrow band imaging with TIPC

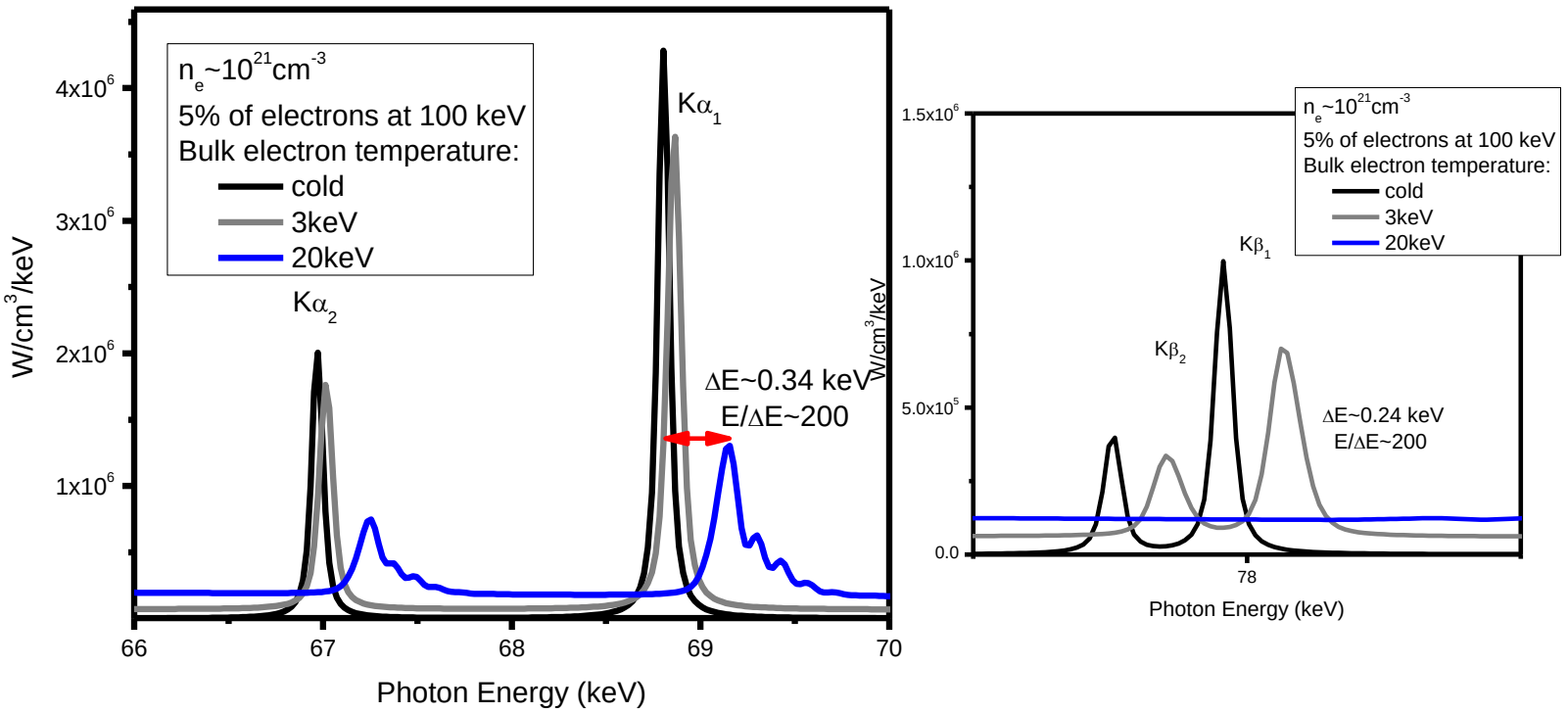
- Use Ross pair on Mo shot (z2657)
  - 250um Mo
  - 335um Ti + 125 umMo + 75um Ag
- See subtle differences in images
  - Subtraction shows band-pass image





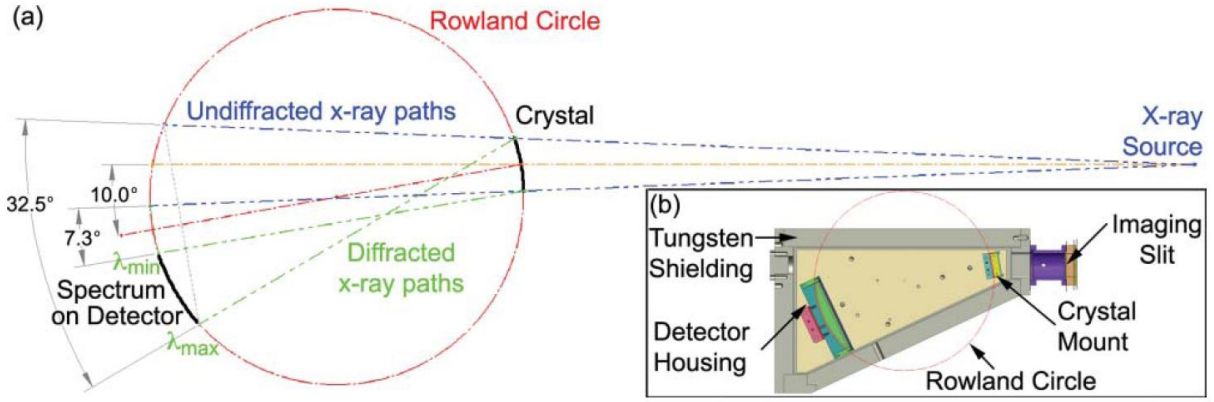


Simulated spectra help to motivate spectral requirements for a new instrument

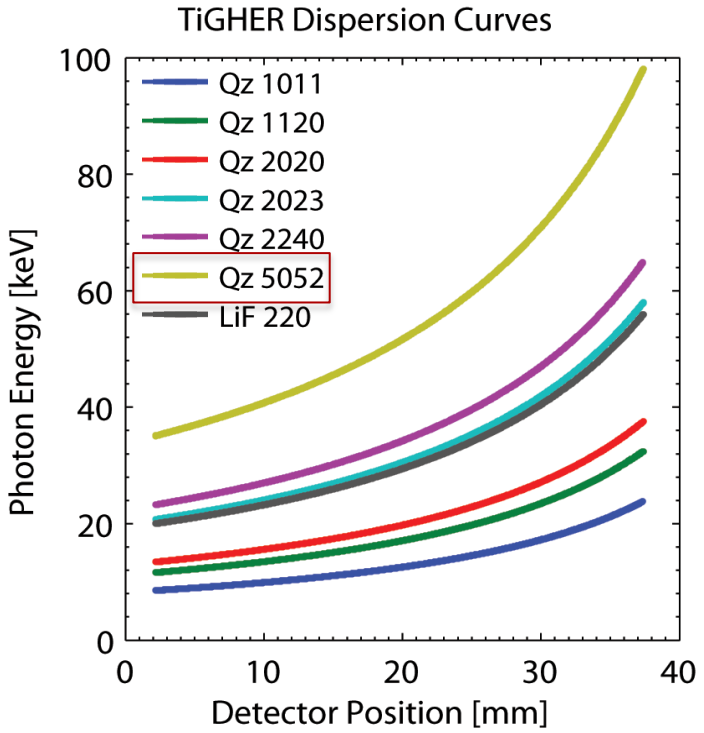


Simulated spectra from S.B. Hansen using SCRAM

Possible options: New crystals in existing instruments

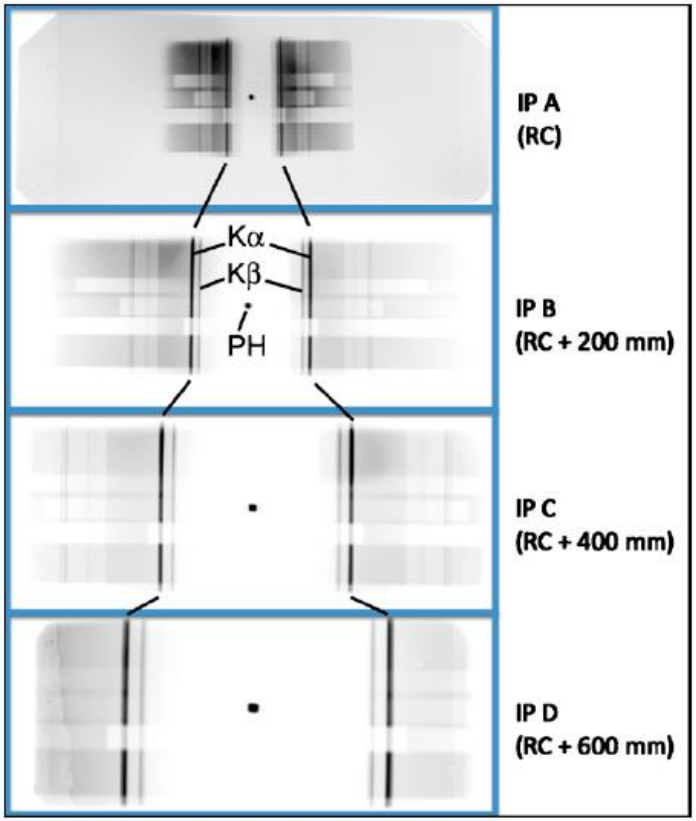


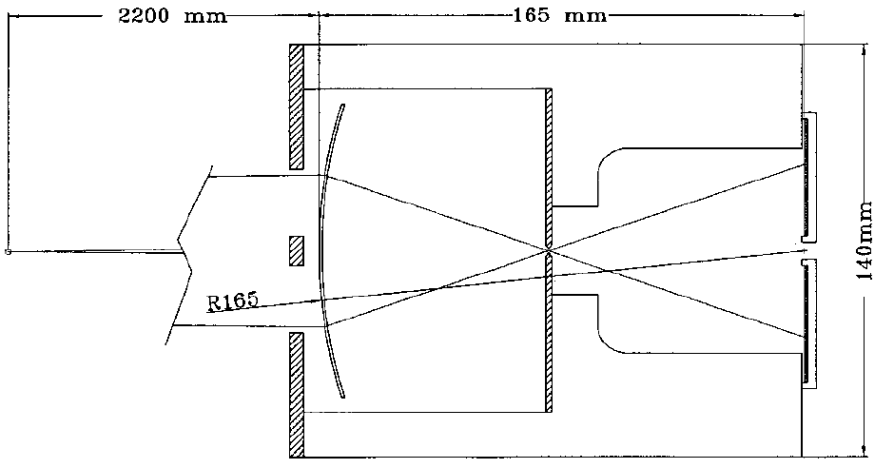
- Goal: 20-80 keV (0.155-0.62Å)
- To work in existing CRITR/TiGHER
  - Correct range given 2d & geometry
    - Plot shows dispersion for current geometry
  - Sufficient reflectivity
    - e.g. CXRO: Qz 5052-> .142-1.55 Å
    - Need absolute reflectivity

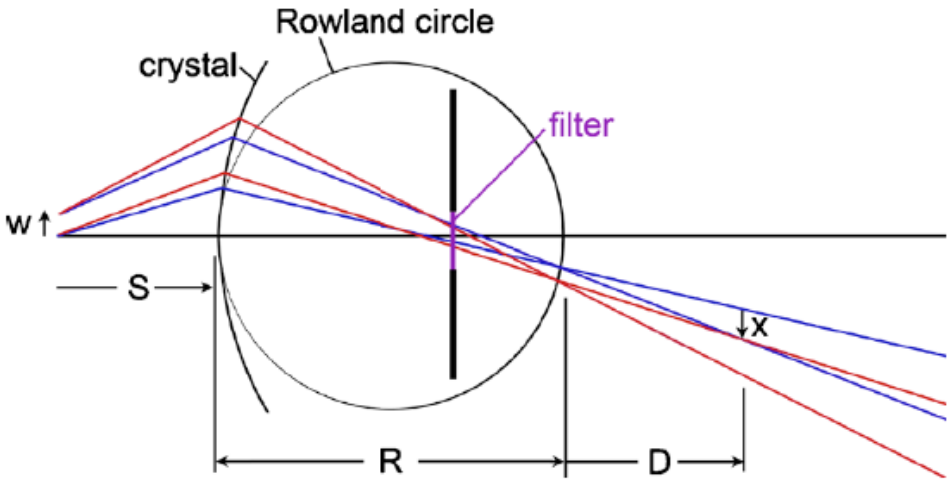


D.B. Sinars *et al.*, Rev. Sci. Instruments **82**, 063113 (2011)
Dispersion curves from P. Knapp

Possible options: Successful Cauchois spectrometers for these regions at other facilities







J.F. Seely *et al.*, Rev. Sci. Instruments **81** 10E301 (2010)
J.F. Seely *et al.*, Rev. Sci. Instruments **72** 2562 (2001)

Risks & Next steps

Risks

- Possible testing and calibration facilities
- Sensitivity/signal
- Unable to achieve resolution requirements
- Trade-offs between different requirements
  - Meeting sensitivity and resolution requirements

Next steps

- Field existing >20 keV in consistent way to provide cross-check
- Finalize requirements
- Quantitatively assess design options (e.g. reflectivities)

Overview / Goals

Need	Goals	Driver
Spectral Range	20-100 keV	Study K-shell radiators from Ag to Au and continuum beyond that
Spectral Resolution	λ / δλ ~200	Distinguish thermal from non-thermal lines. Distinguish lines from continuum
Resolving direction	Capable of radial or axial	Study structure in pinch in both directions
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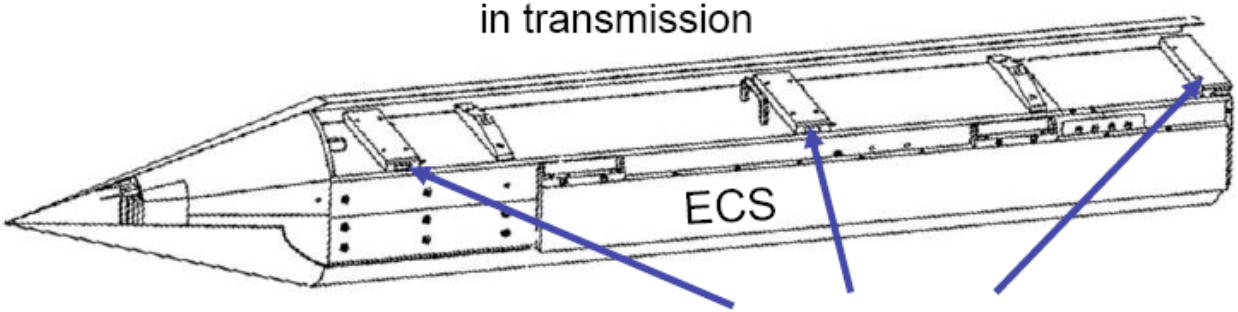
Spatial Resolution	0.5 mm	Resolve different radial extents of thermal and non-thermal lines
Sensitivity	10 J/cm/eV	Able to record 100 J in a line
Calibration	Need relative calibration	Absolute calibration of entire system would be very useful long term.

BACKUP

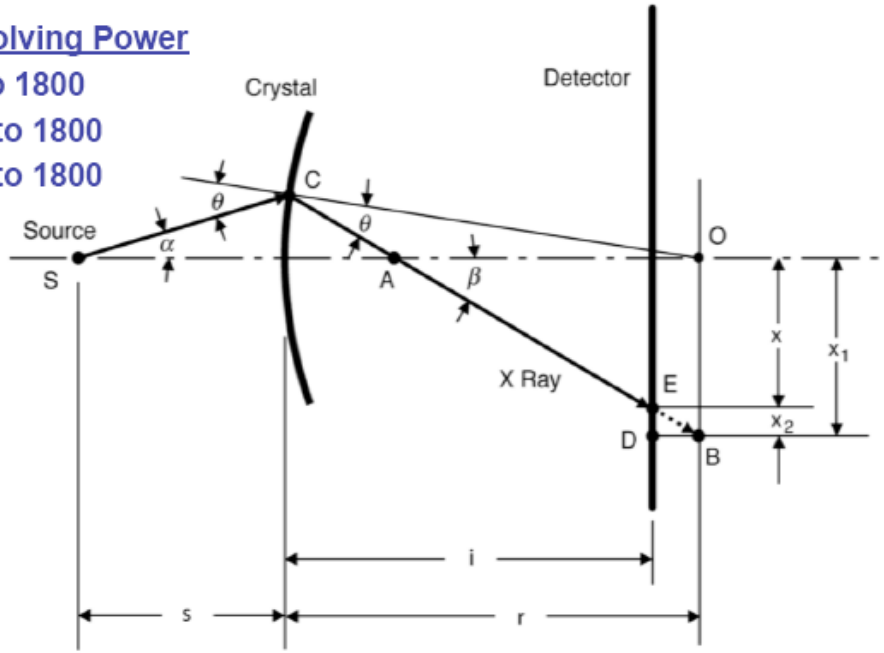
The EP Crystal Spectrometer (ECS)

TIM based x-ray spectrometer with cylindrically bent Quartz (10-11) crystal in transmission



Three detector positions:

Position	Distance	Energy Coverage	Resolving Power
1	0 mm	12 to 115 keV	60 to 1800
2	500 mm	24 to 115 keV	240 to 1800
3	1000 mm	42 to 115 keV	420 to 1800

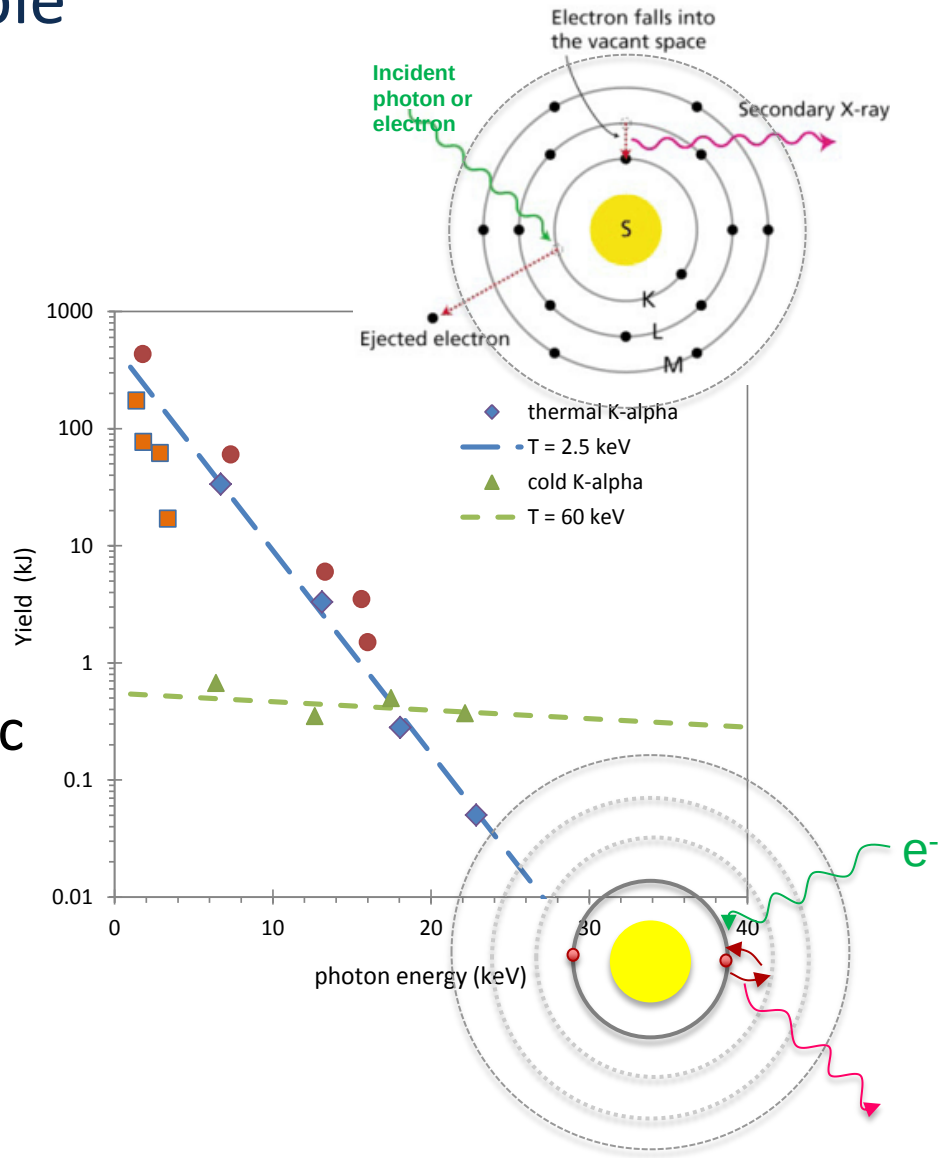


Qz (10-11) 2d 0.6684 nm
Bending radius 254 mm
Standoff 254 mm

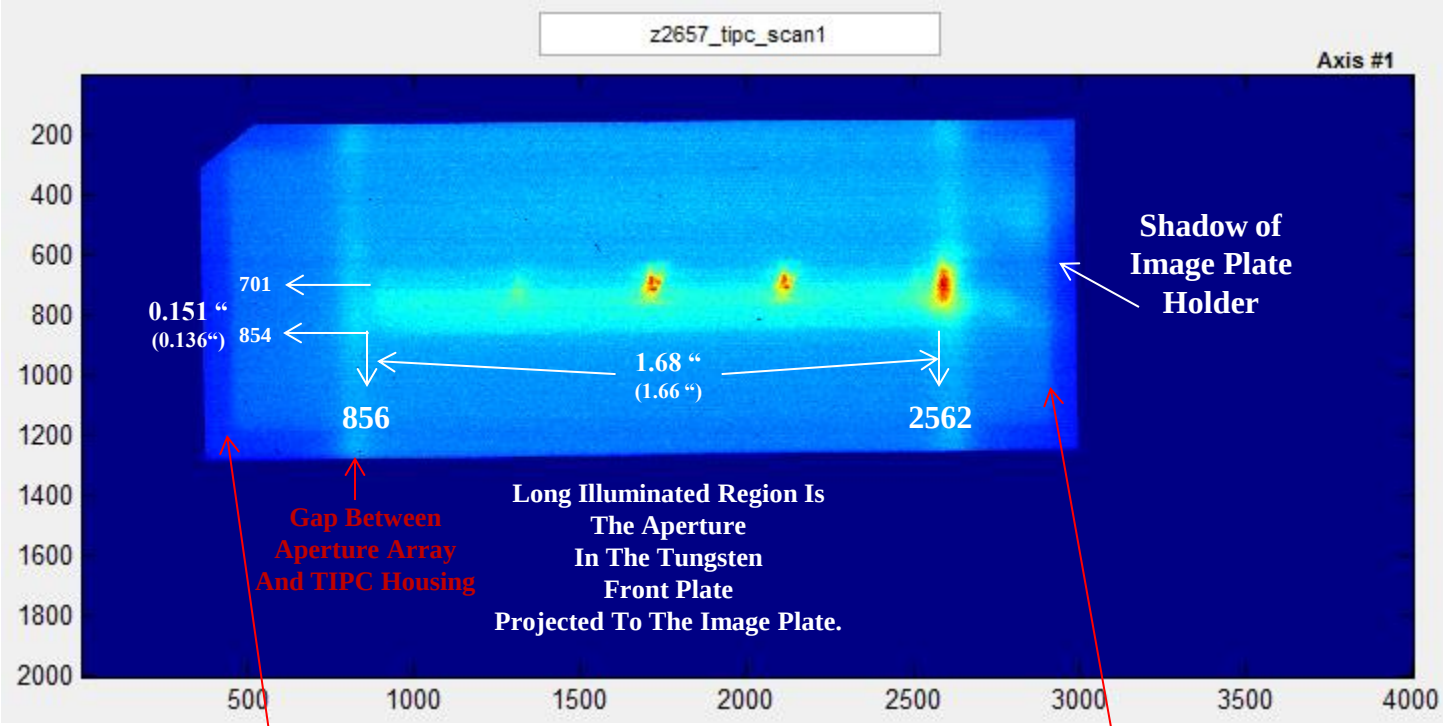
U. Felman, J.F. Seely *et al.* Omega Laser Facility User Group 2009

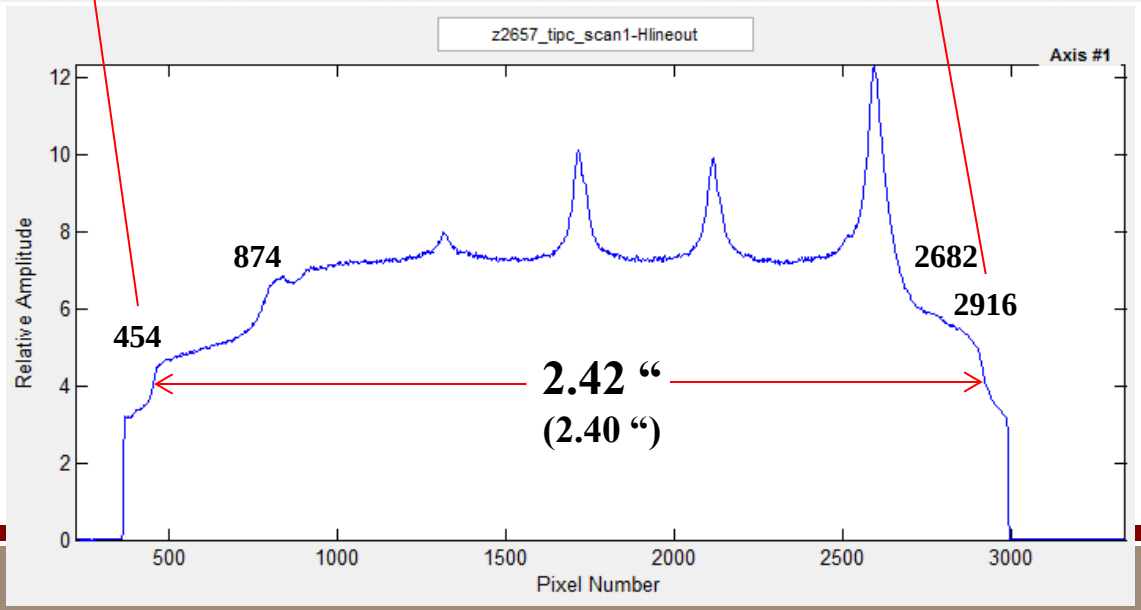
Inner shell scaling is favorable

- K-shell emission from thermal electrons
  - He-like and H-like lines
  - Need to ionize to the K-shell
  - Sharp drop with atomic number
- K-shell emission from energetic electrons
  - Cold K-lines (Kα)
  - Need hot electrons/photons
  - Don't need to ionize bulk plasma



Full Mo image





Combining data from spectral and absolute diagnostics provides additional confidence