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Sandia National Laboratories

The Differential Absorption Hard X-ray (DAHX) Spectrometer At The Z Facility*

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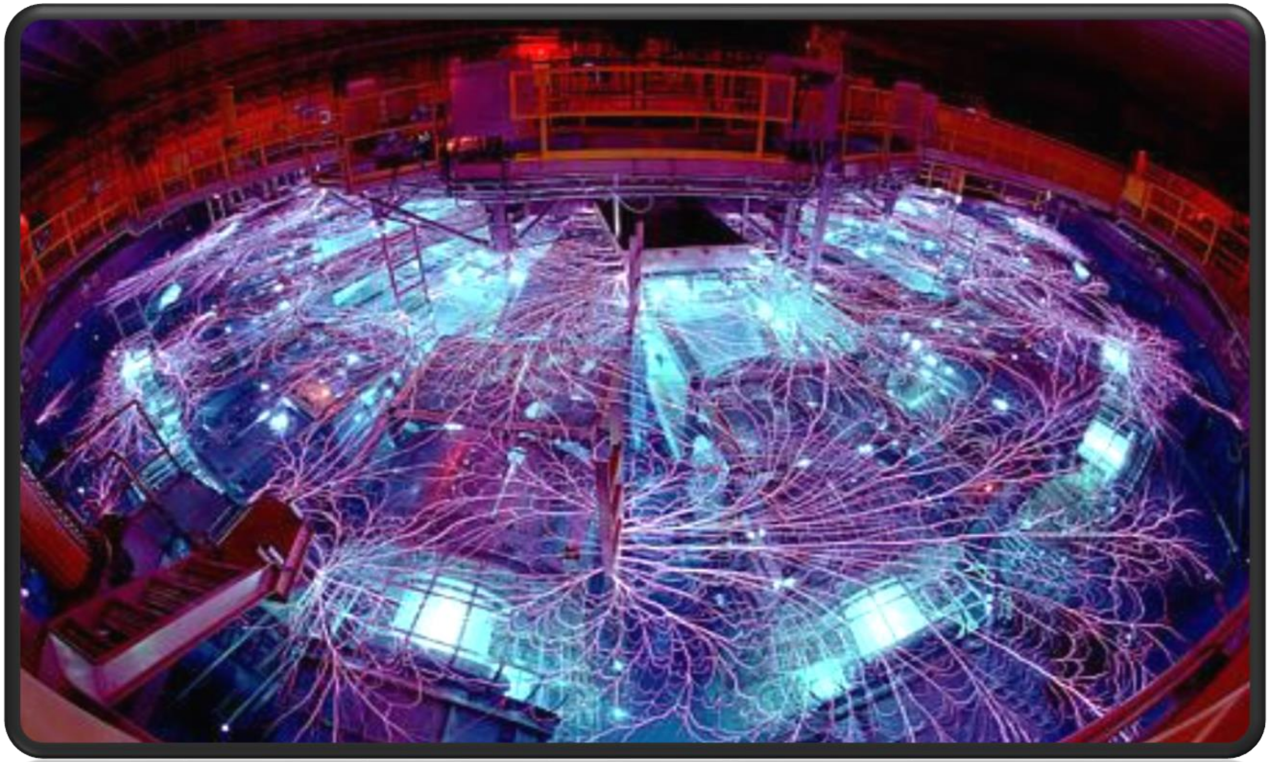
LDRD LABORATORY DIRECTED RESEARCH & DEVELOPMENT

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

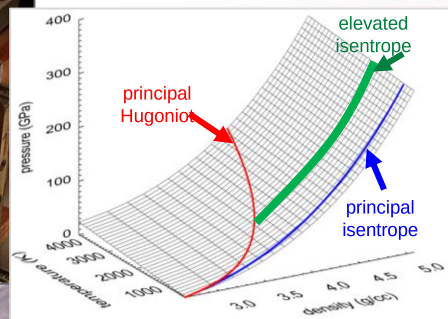
The Z accelerator is a pulsed power generator capable of delivering up to 26 MA in ~100 ns



Z produces extreme conditions in numerous ways

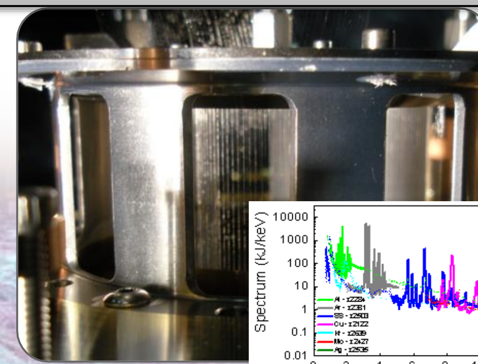
Dynamic Materials

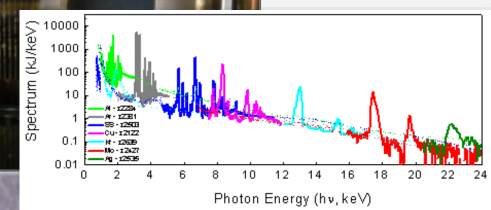
Compress materials to 10^7 Atm.



K-shell x-ray sources

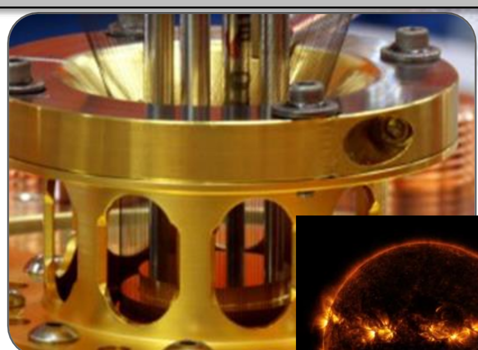
100's of kJ of multi-keV photons





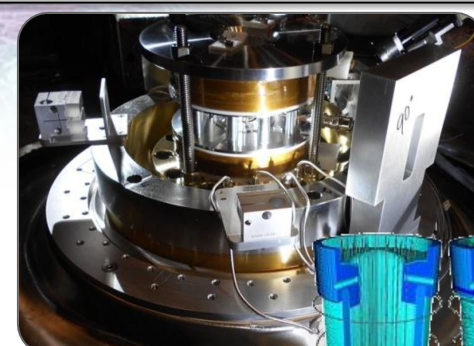
Stellar Opacities

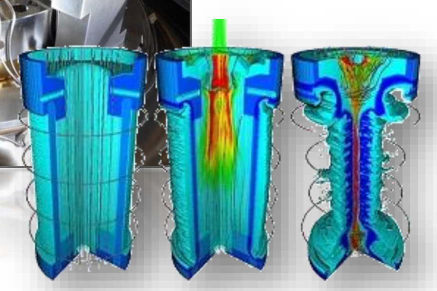
Temperature/density of convection zone



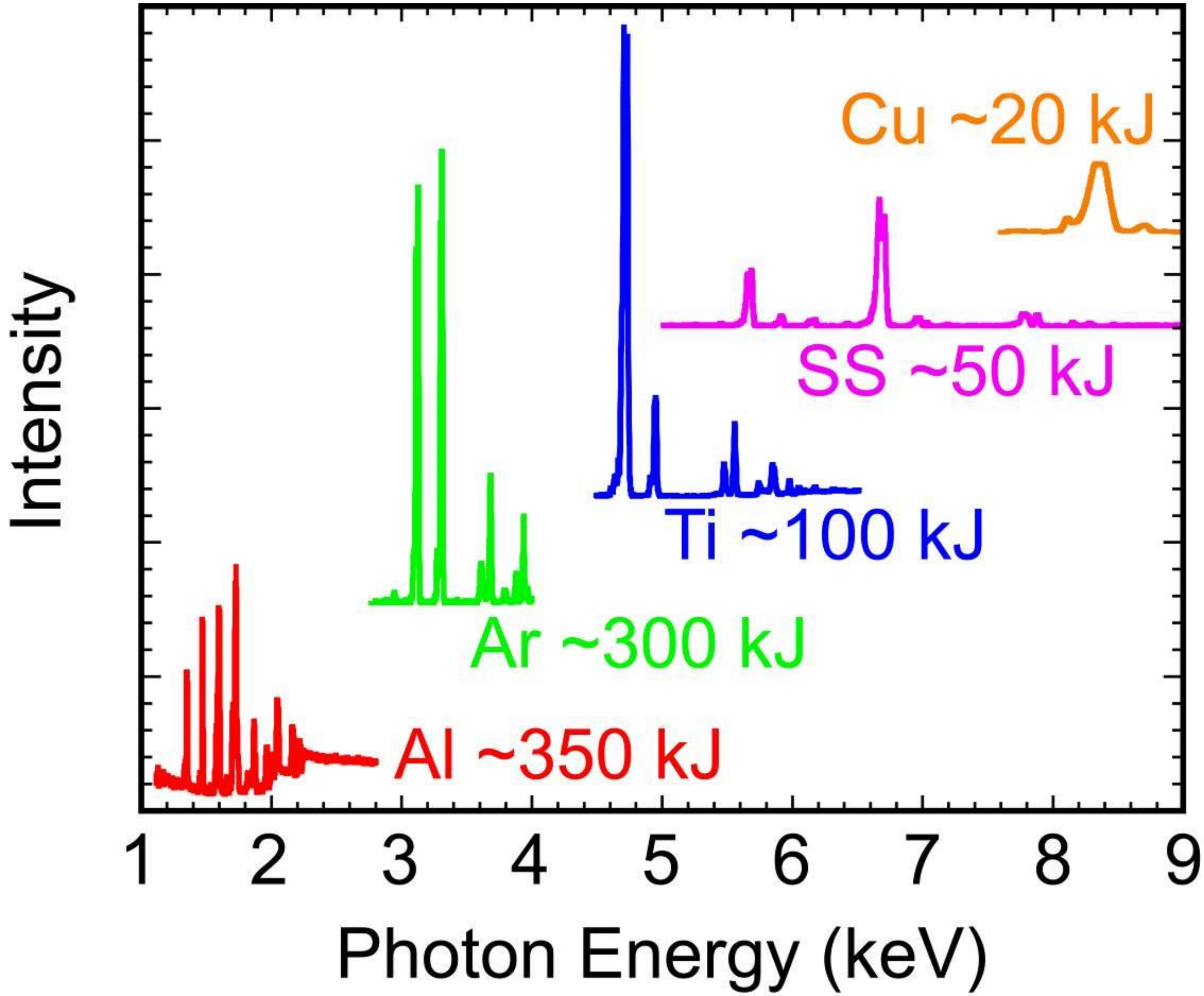
MagLIF Fusion Plasmas

DD fusion yields $>10^{12}$ neutrons



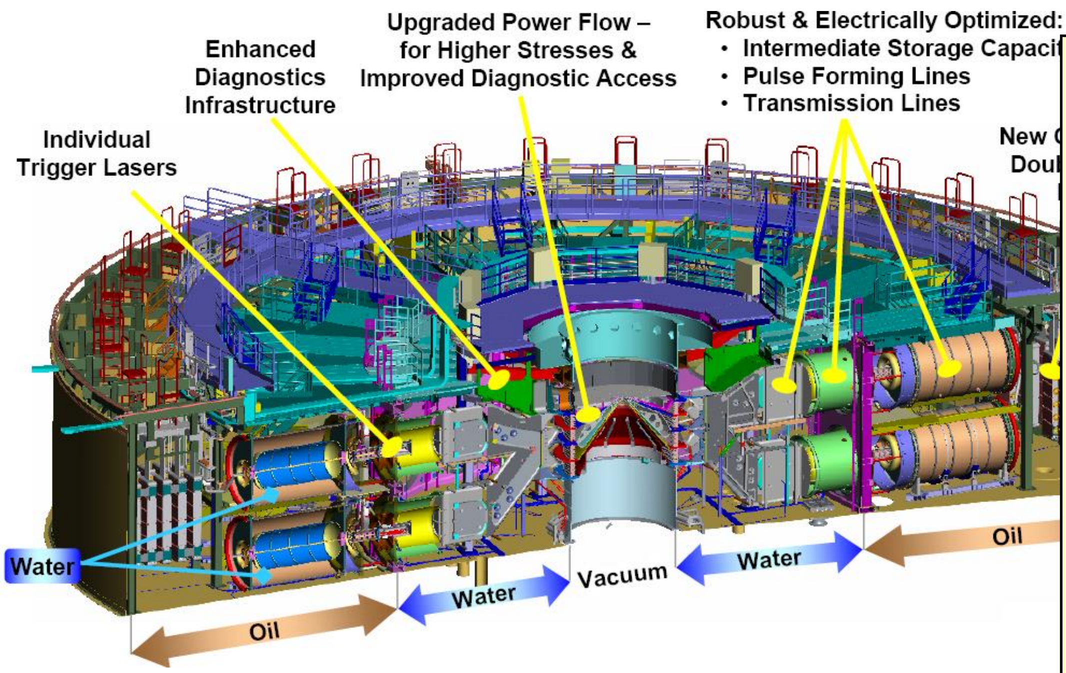


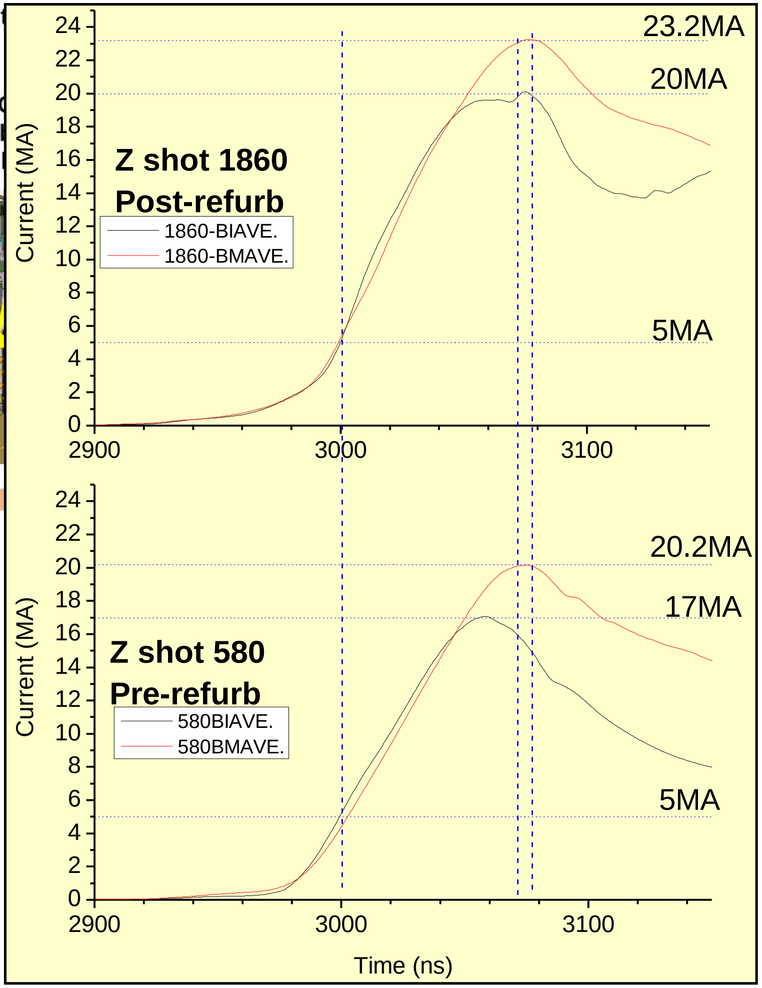
Prior to refurbishment, Z could drive K-shell emissions up to ~ 9 keV



- Drive thermal K-shell emissions
- Attempts made to overdrive Al and Ti sources to increase output at higher photon energies were marginally successful

Since 2008, refurbished Z has been available for experiments





For 65mm SS & Cu arrays ZR has achieved higher load currents than old Z (17%)

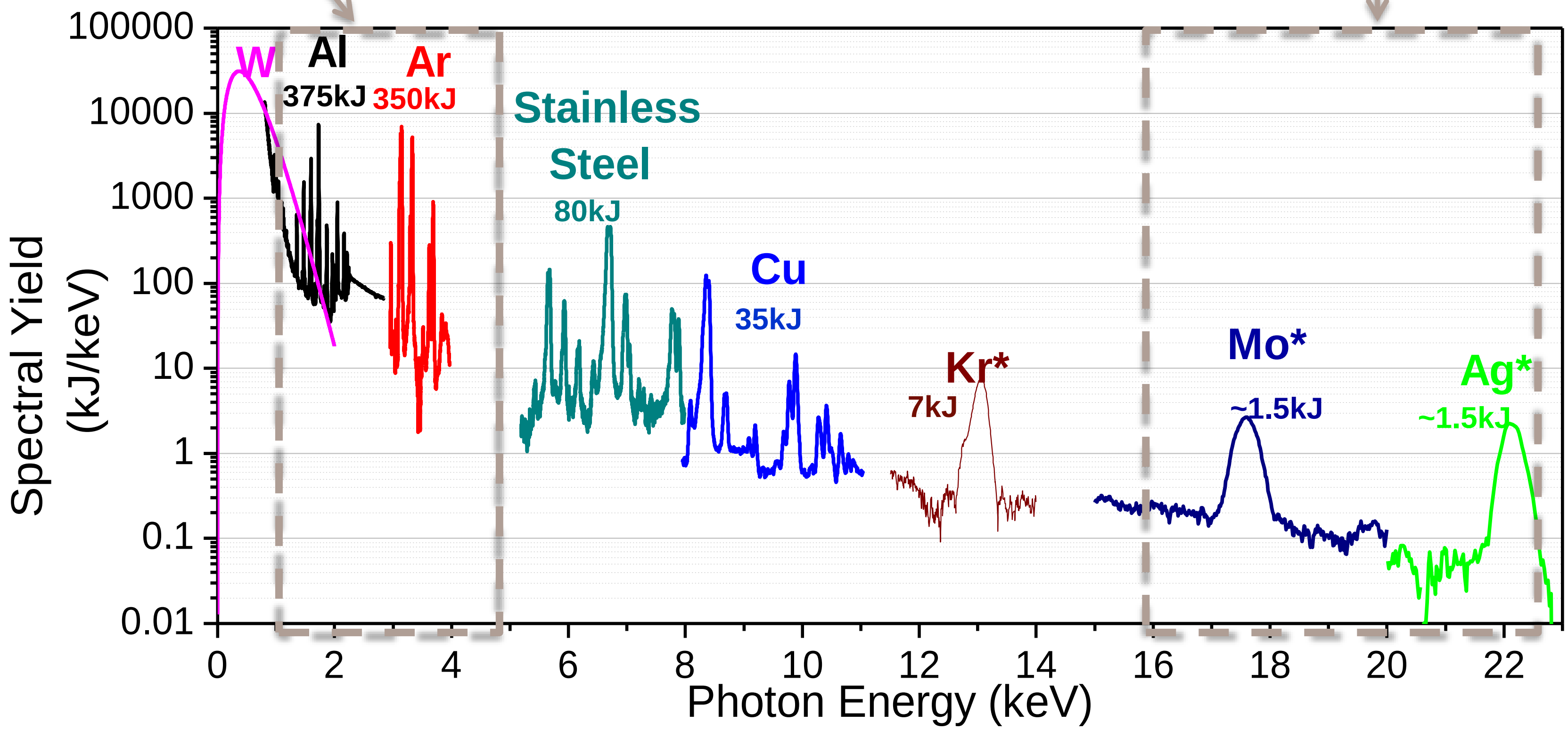
Current risetime is increased by ~10%

The energy available has enabled evaluation of higher photon energy thermal and non-thermal K-shell emissions

Z achieves very high yields – opacity can be a concern

Emission requires high temperatures and implosion velocities. Stability a concern.

Temperatures required too high – rely on inner shell ionization



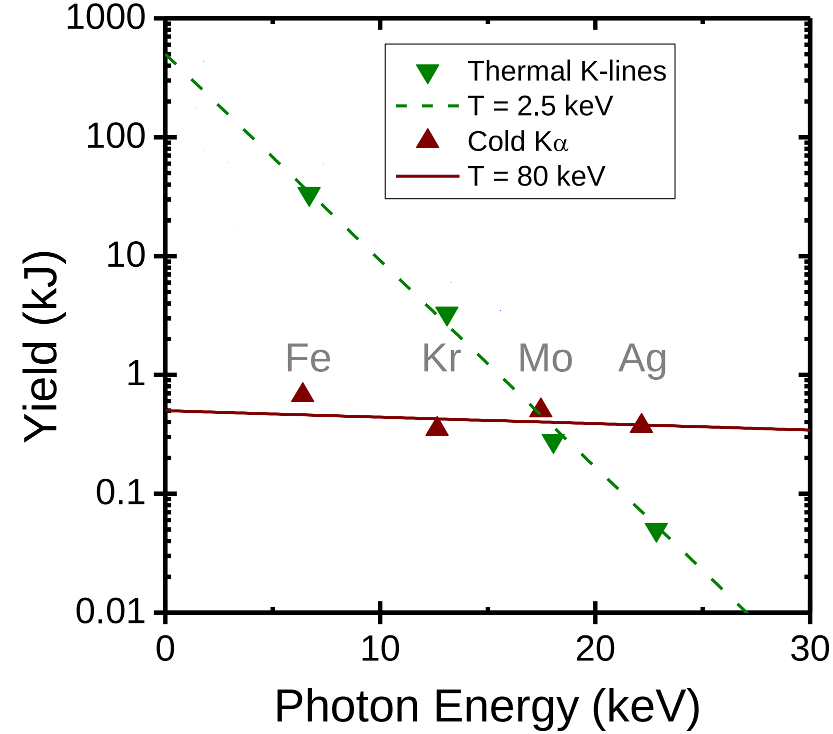
D.J. Ampleford *et al., APS DPP 2013*

D.J. Ampleford. B. Jones *et al.,* Phys Plasmas 21 056708 (2014)

Z diagnostics now extended to >20keV photons

Diagnosing the warm (20-100 keV) & hard (>100 keV) x-ray environment

- Yield, pulseshape, spectrum (line versus continuum)
  - TIPC, TLDs, DAHX, calorimeters, CRITR-X
- When is the warm and hard x-ray output?
  - DAHX
- Where are the warm and hard x-rays?
  - TIPC, TLDs

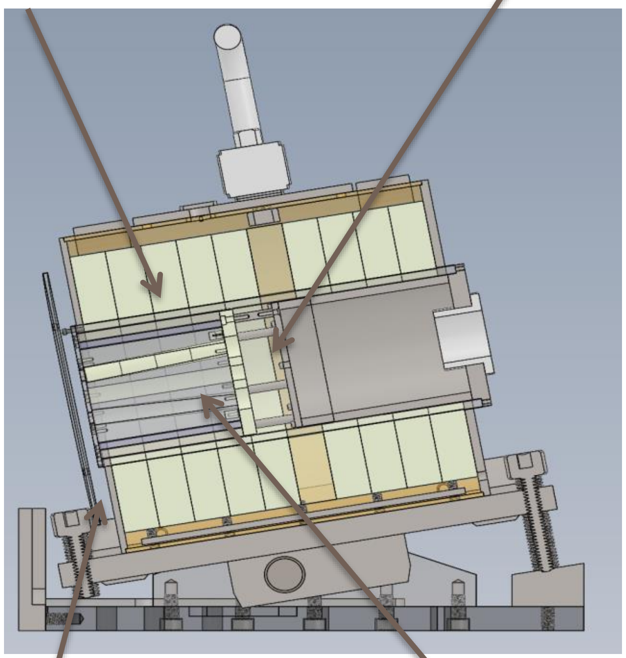


See D.J. Ampleford's talk: 6D-7

D.J. Ampleford *et. al.* ICMRE 2016

DAHX provides temporal and spectral information

DAHX = Differential Absorption Hard X-ray

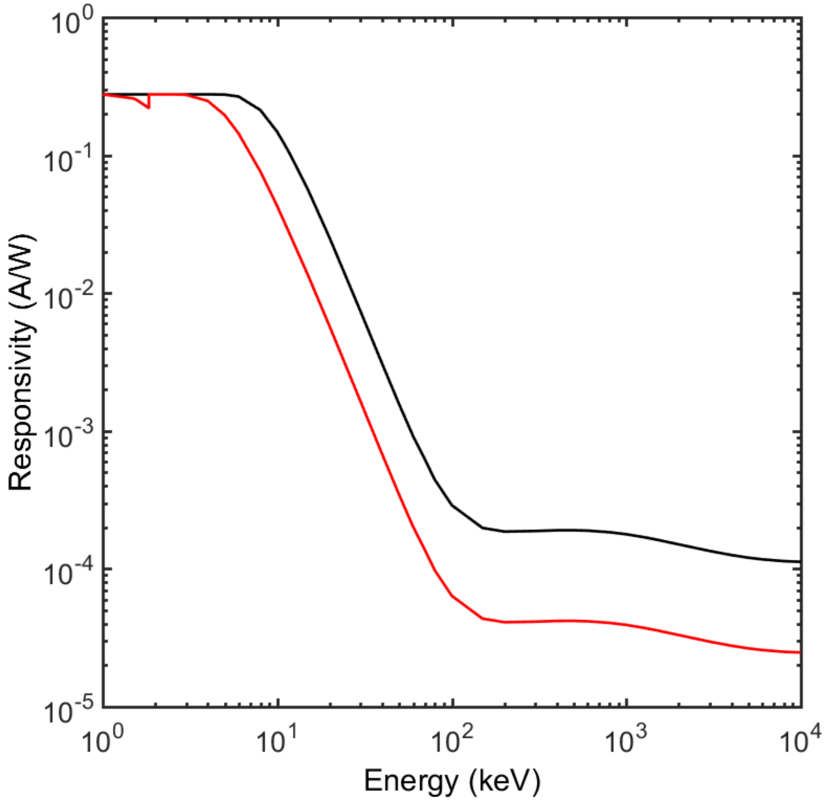


K. Moy *et. al.* Proc. of SPIE Vol. 6319 (2006).

- Diagnose 60-2500 keV x-rays with coarse spectral resolution
- 7 Si PIN diodes
- Highly collimated
- Temporal information in spectral bins
  - High time resolution ($\leq$ 1 ns)
- Correlate to soft x-ray emission temporally

Optodiode Si PIN Diodes

- AXUVHS5
  - 100 µm thick active layer
  - 1 mm^2 area
- AXUVHS11
  - 22 µm thick active layer
  - 0.28 mm^2 area



R(eV) = responsivity [A/W]
t = thickness [cm]
ρ = density [g/cm^3] (2.33)
A(eV) = mass energy attenuation [cm^2/g]

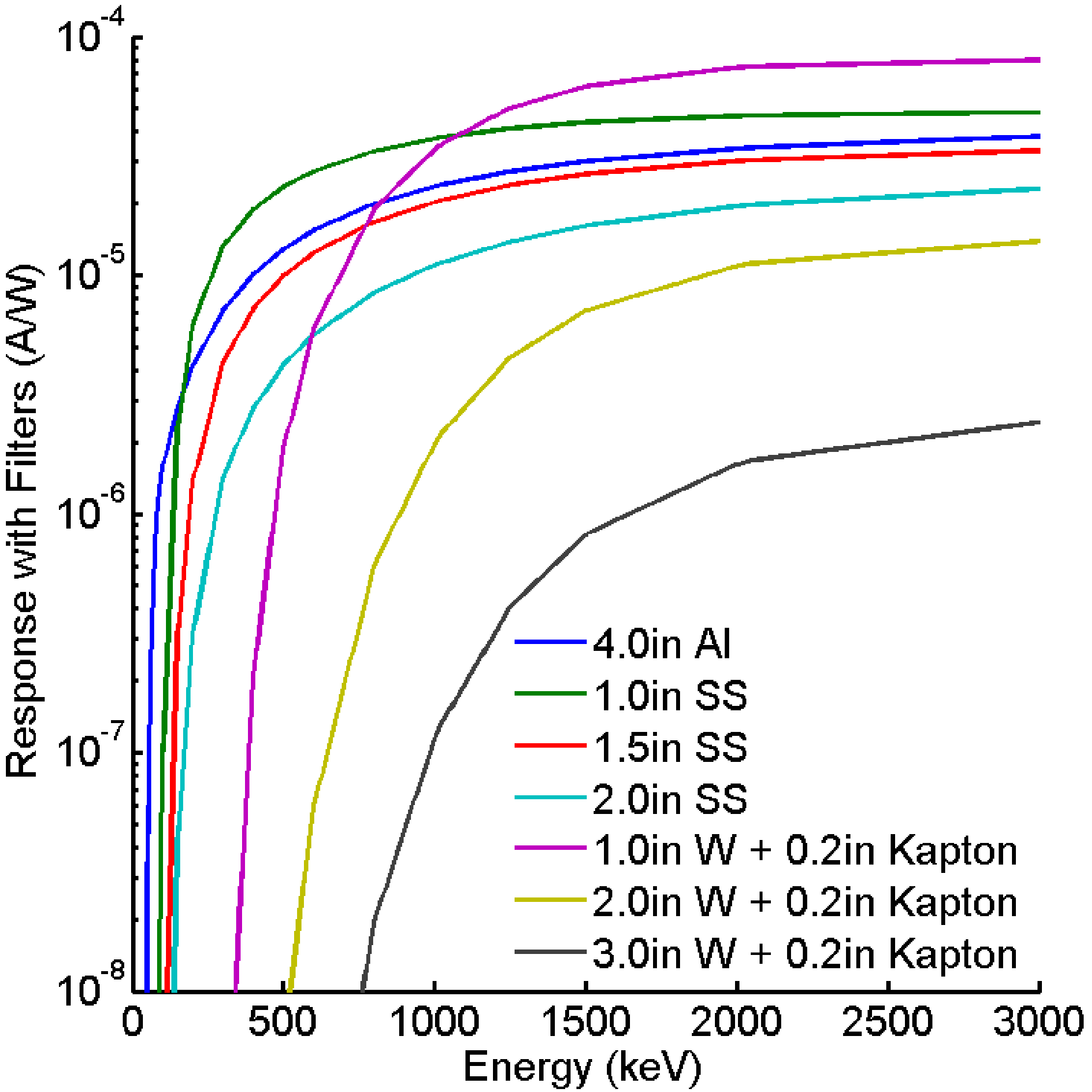
$$R(eV) = 0.265(1 - e^{-t\rho A})$$

Diode	rise-time (ps)	fall-time (ps)	sat. level (e$^-$/cm^2)	responsivity (A/W)
AXUVHS11	151±9.2	629±64	3×10^{12}	0.009636
AXUVHS5	247±23	2300	4×10^{12}	0.0080

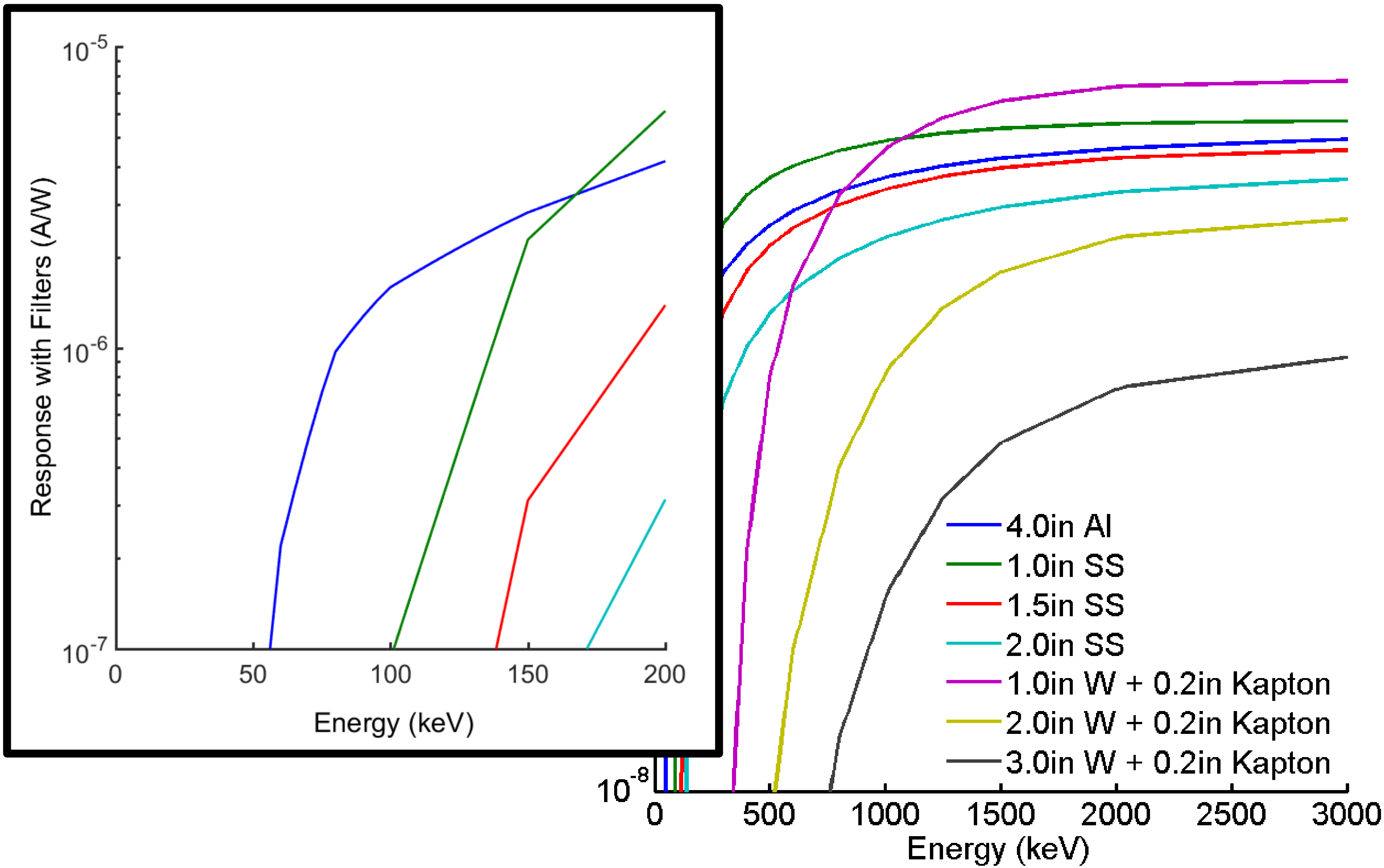
Measurements by J. Schwarz

Filter & Diode Folded Response

- ¼" Al 5083 Blast Shield
- HS11 22 µm
  - 4" Aluminum 5083
  - 1" Stainless Steel 304
  - 1.5" Stainless Steel 304
  - 2" Stainless Steel 304
- HS5 100 µm
  - 1" Tungsten
  - 2" Tungsten
  - 3" Tungsten
    - ASTM-B-77 Class 1, HD 17



Filter & Diode Folded Response



Data Unfold – An Underdetermined Problem

- Solving for source spectrum *S(t,E)* given:
  - The diode response $D_i(E)$
  - The filter transmission $F_i(E)$
  - The signal on the diode $M_i(t)$

$$M_i(t) = \int dE\, S(t,E) D_i(E)\, F_i(E) \qquad\qquad i = 1,2,\ldots,7$$

- *S(t,E)* needs to be constrained
  - Power Law

$$S(t,E) = A(t)\, E^{-k(t)}$$

  - Thermal Bremsstrahlung

$$S(t,E) = A(t) \exp \frac{-E}{T(t)}$$

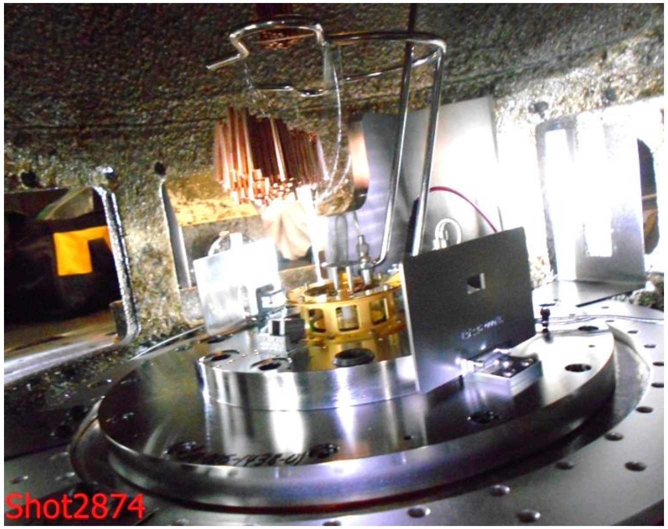
  - Attenuated Kramer's Law Bremsstrahlung

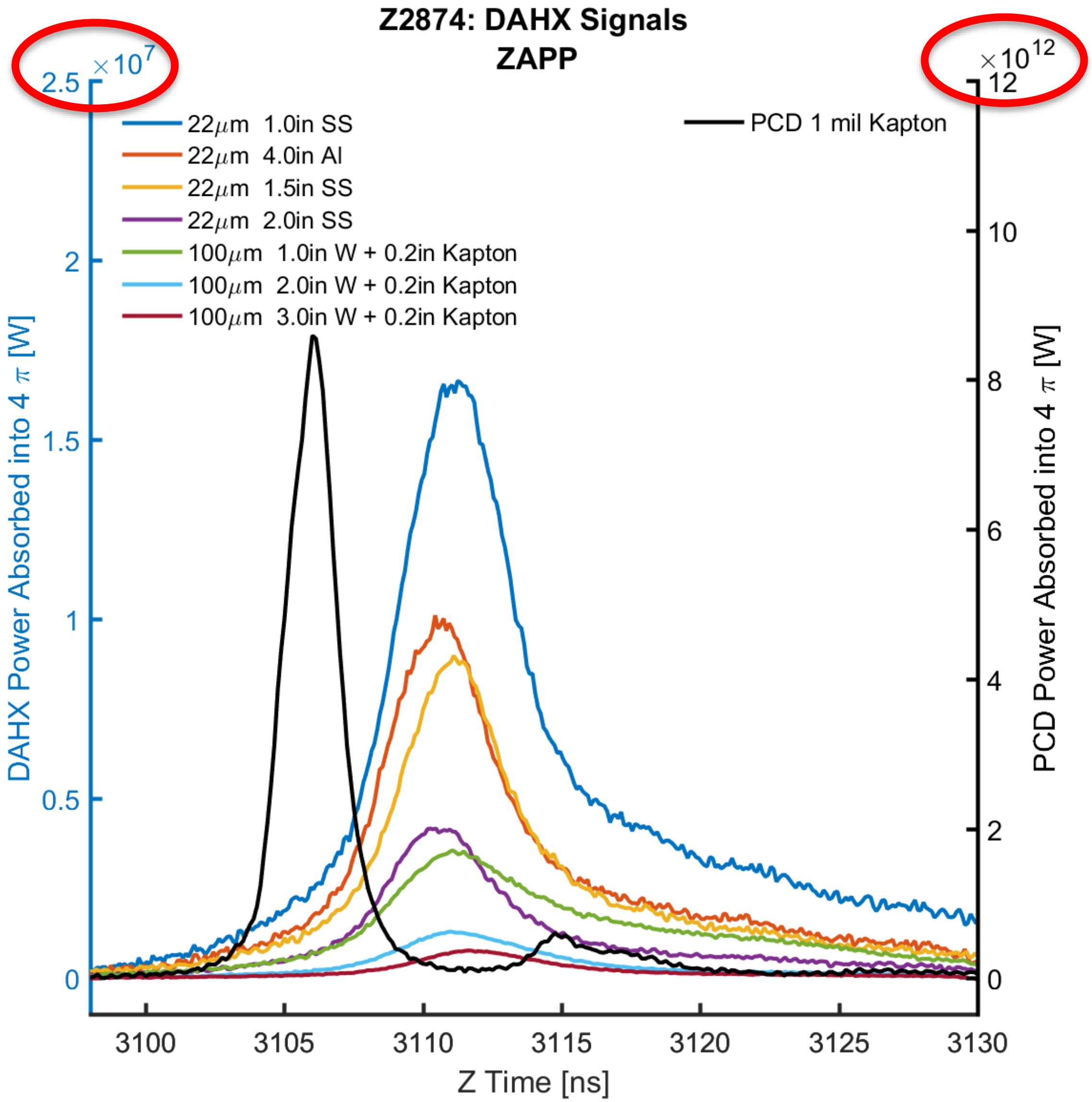
$$S(t,E) = A(t) \left[\frac{E_{max}(t)}{E} - 1\right]^r \exp -Q(t)\mu_A(E)$$

DAHX & PCD signals from W Wire Array used for Opacity Experiments (ZAPP)

Nested W Wire Array:

- 240/120 wires
- 11.4 micron wires
- 40/20 mm array diameter

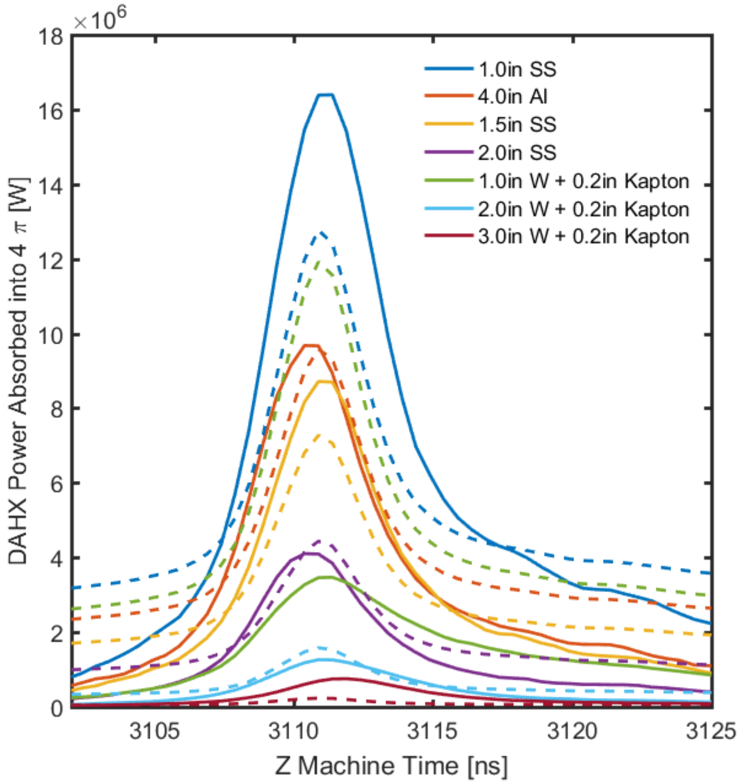




Thermal Bremsstrahlung V. Power Law Fits for Opacity W Wire Array z2874

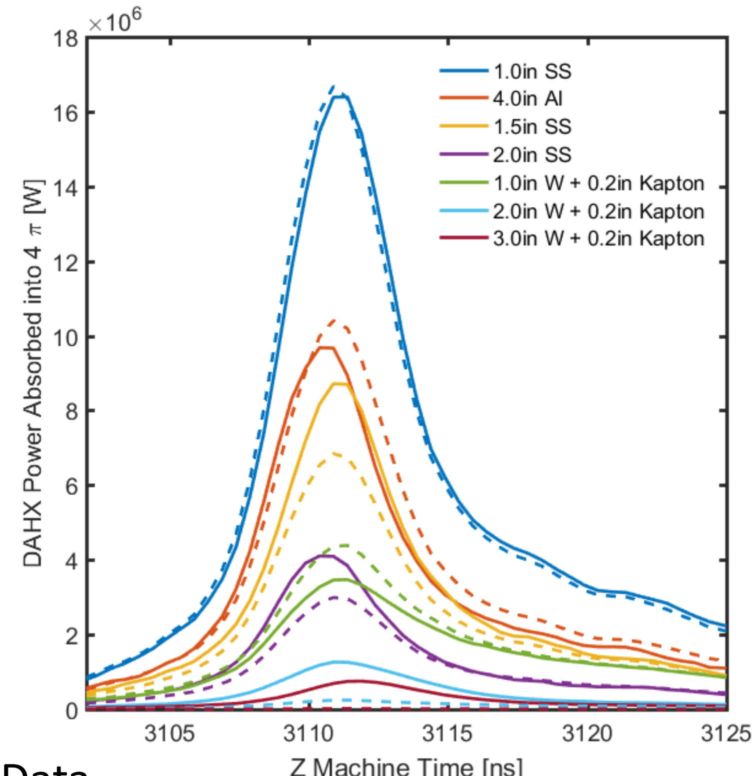
Power Law

$$S(t,E) = A(t)\, E^{-k(t)}$$



Bremsstrahlung

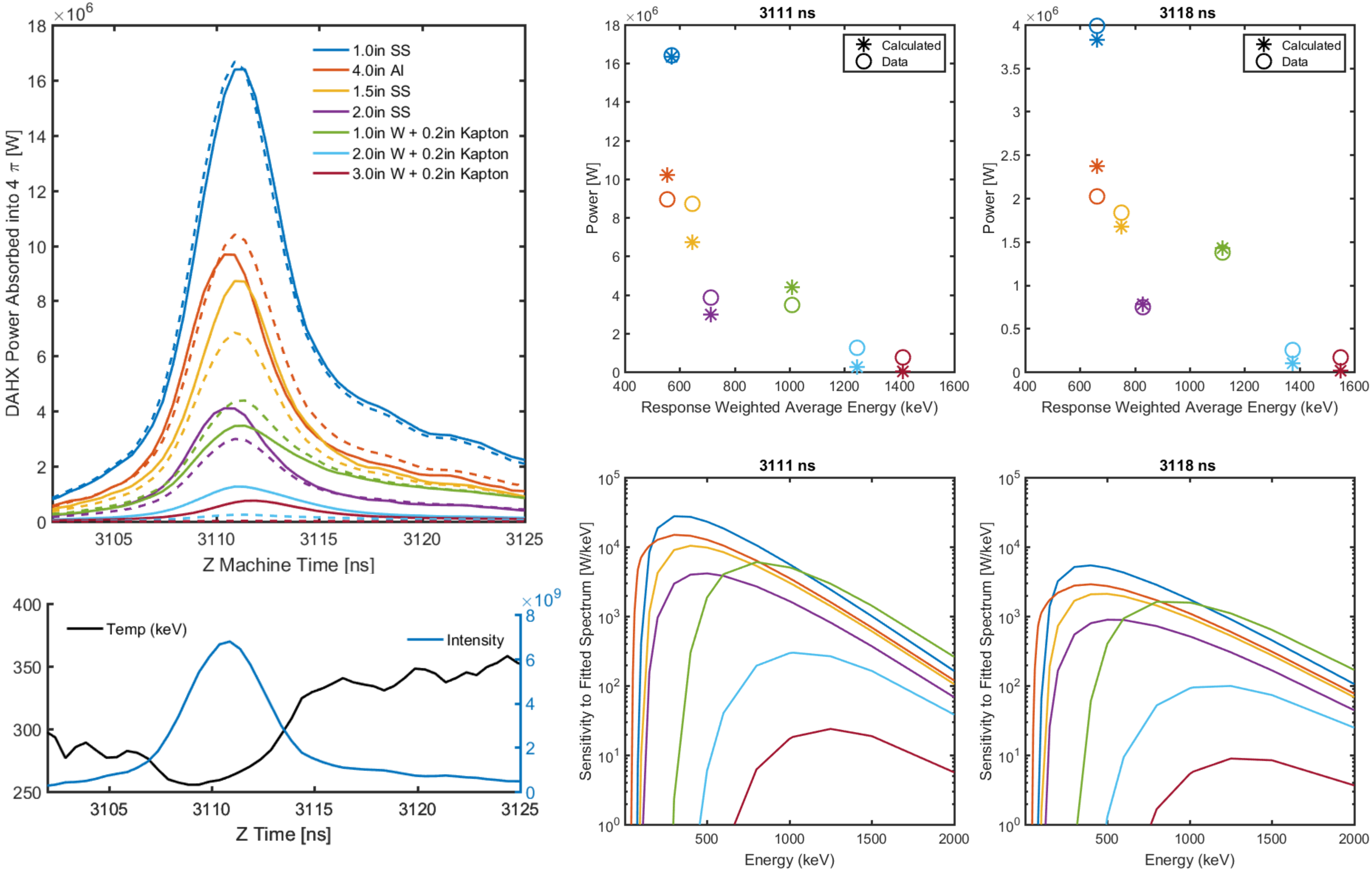
$$S(t,E) = A(t)\, \exp\frac{-E}{T(t)}$$



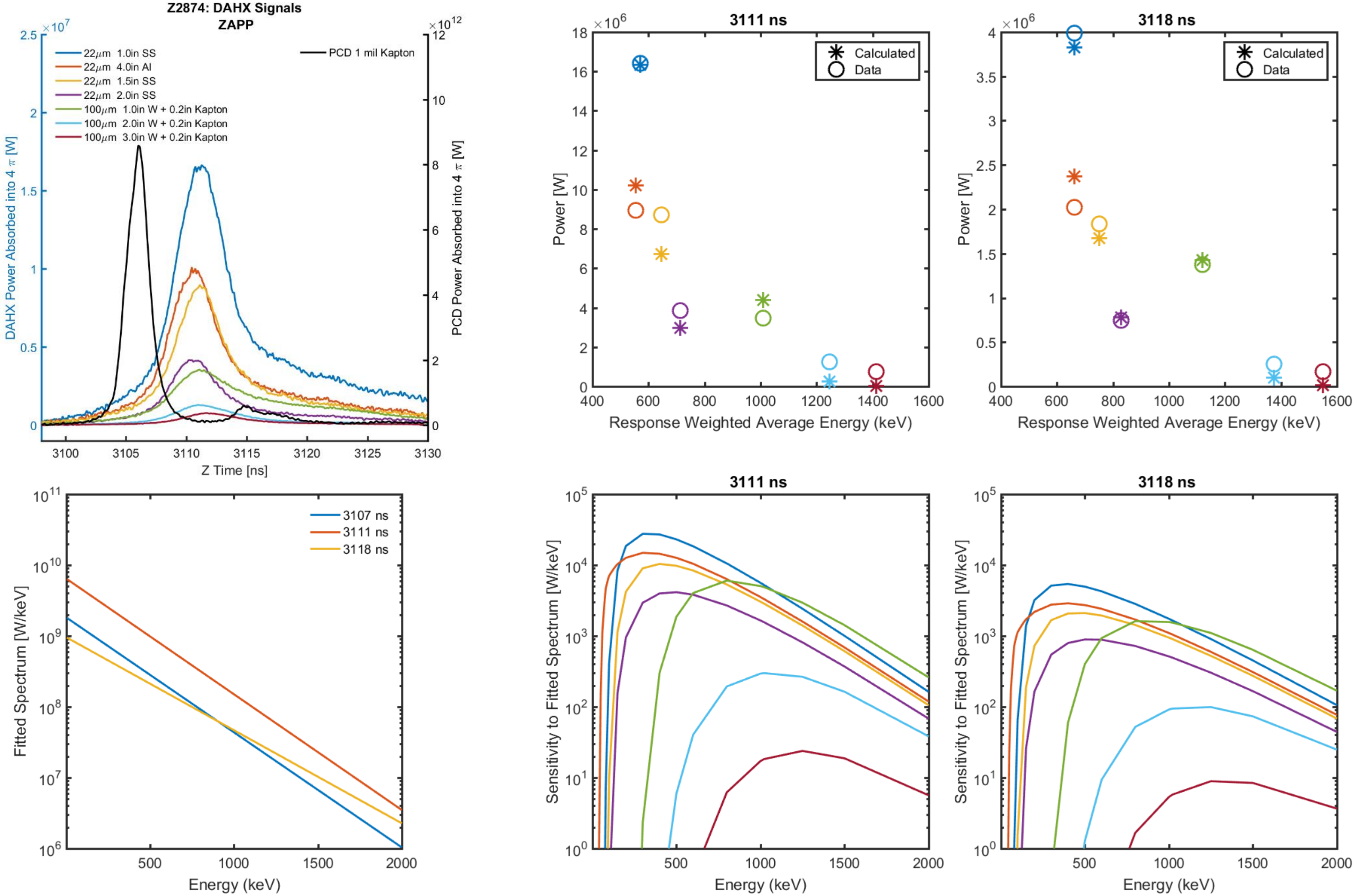
Solid = Data

Dashed = Fit

Thermal Brems. Fit to Opacity W Wire Array z2874



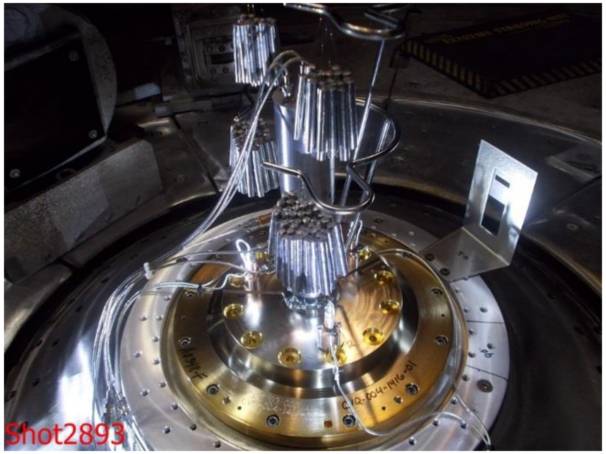
Thermal Brems. Fit to Opacity W Wire Array z2874



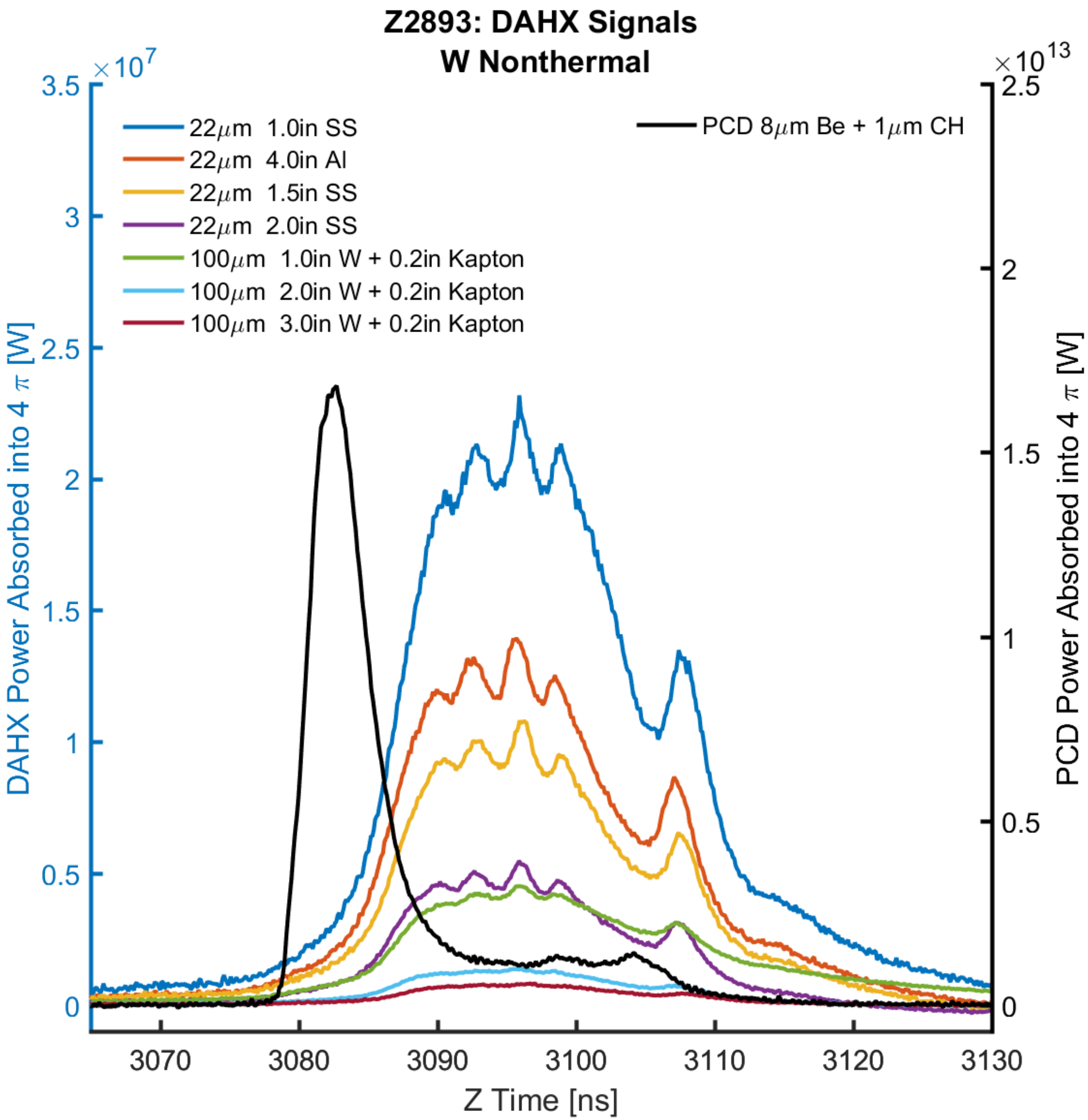
DAHX & PCD signals from W Nonthermal Wire Array

Nested W Wire Array:

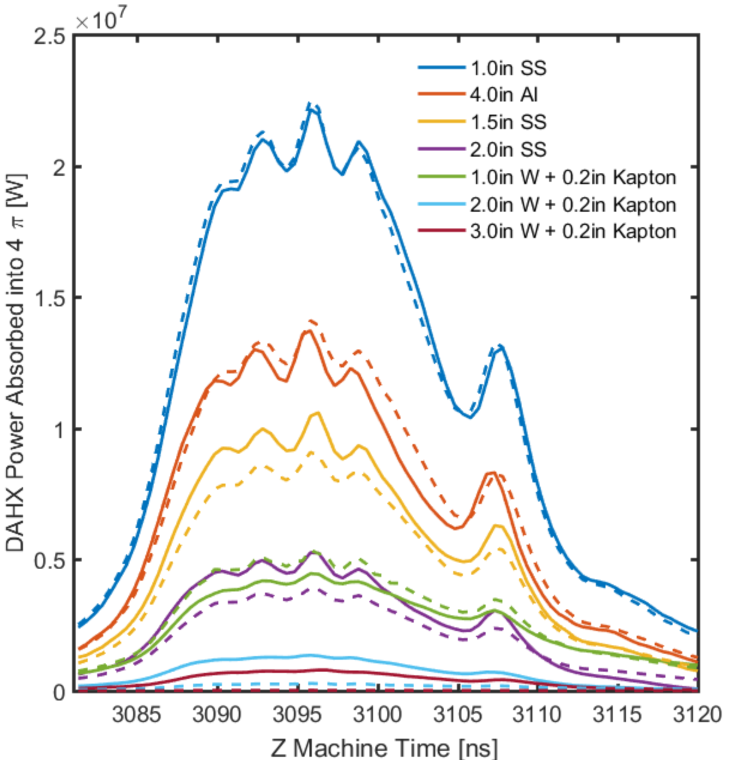
- 104/52 wires
- 20.7 micron wires
- 20/12 mm array diameter

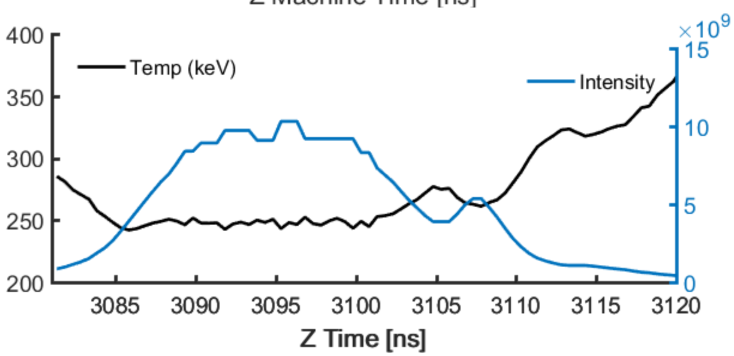


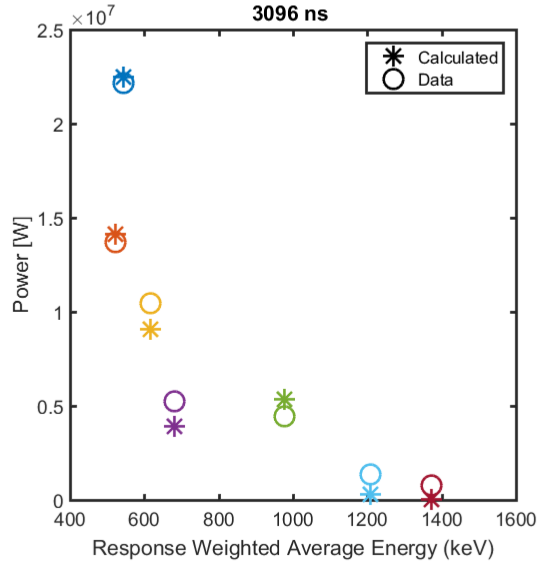
See D.J. Ampleford's talk: 6D-7

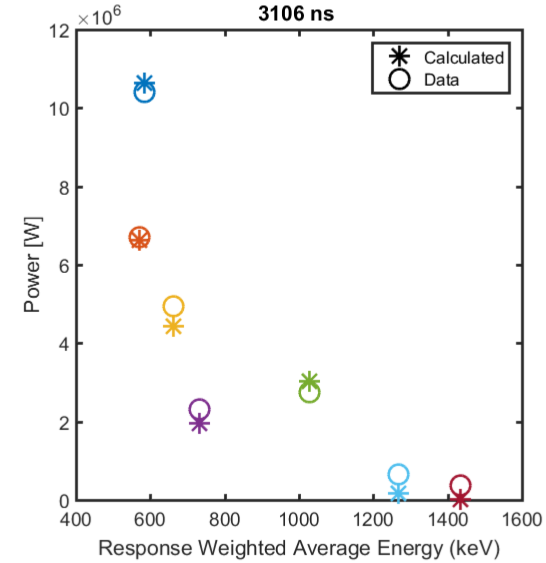


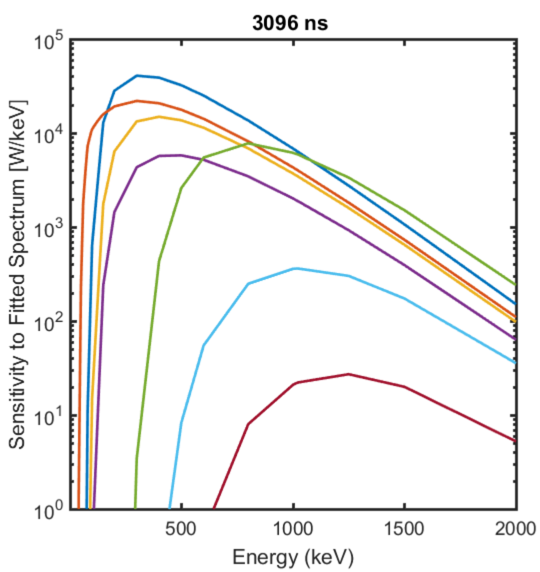
Thermal Brems. Fit to W Nonthermal Wire Array z2893

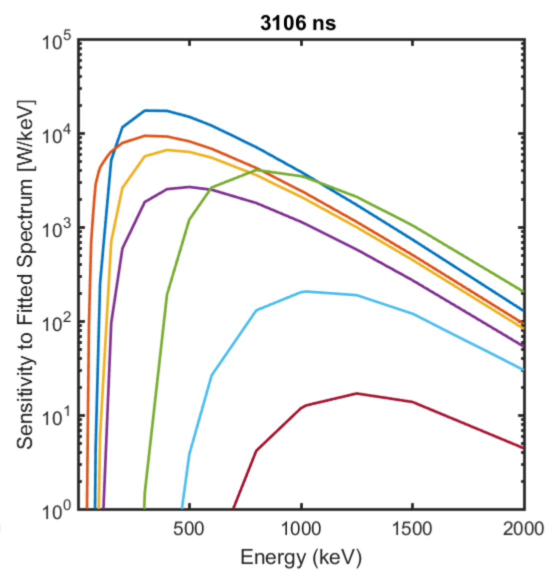




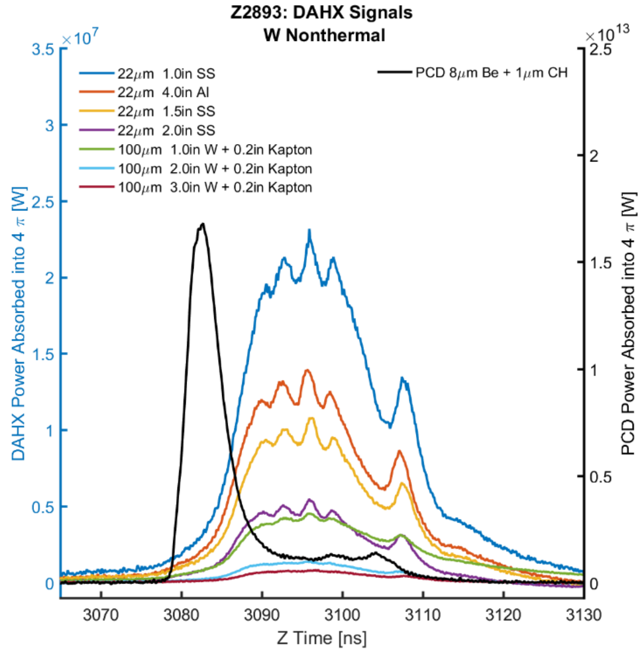


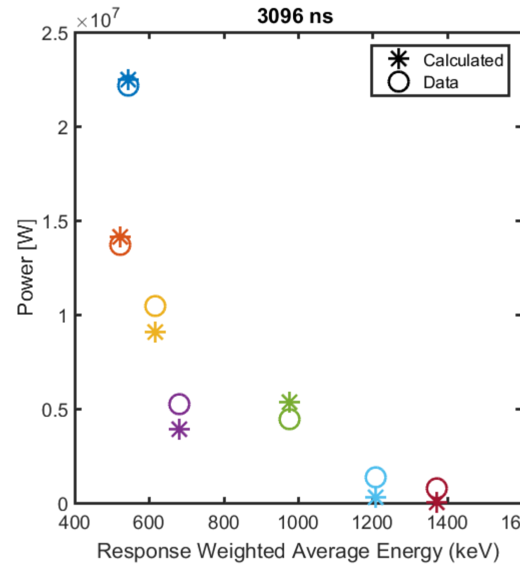


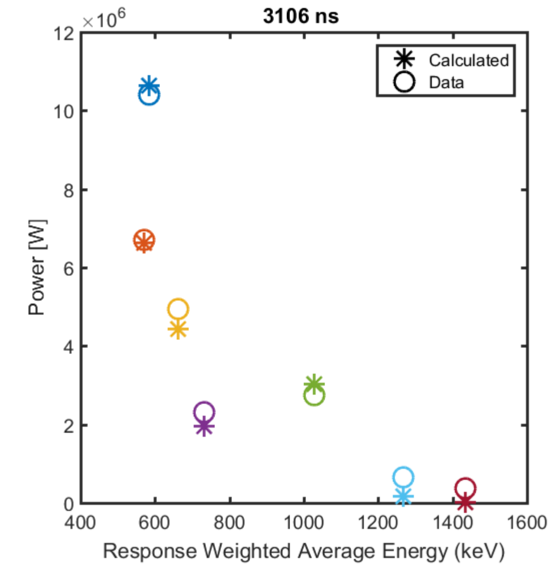


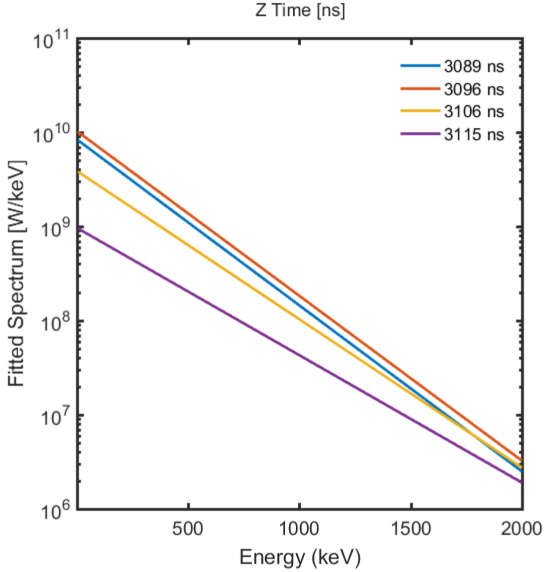


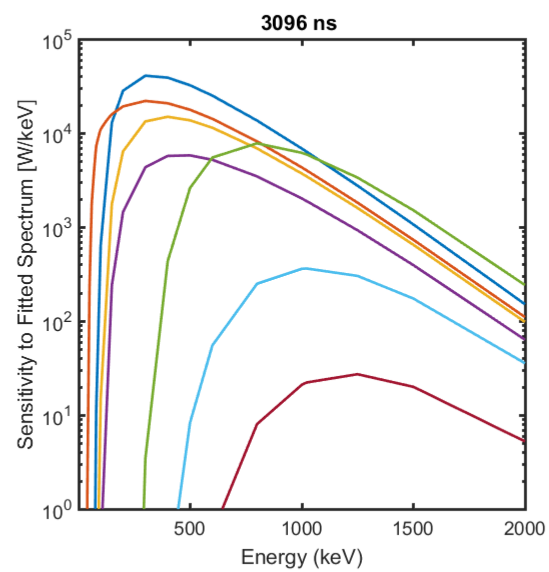
Thermal Brems. Fit to W Nonthermal Wire Array z2893

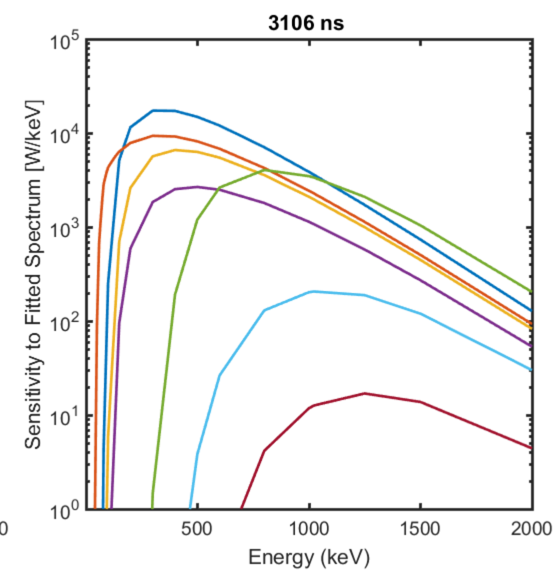




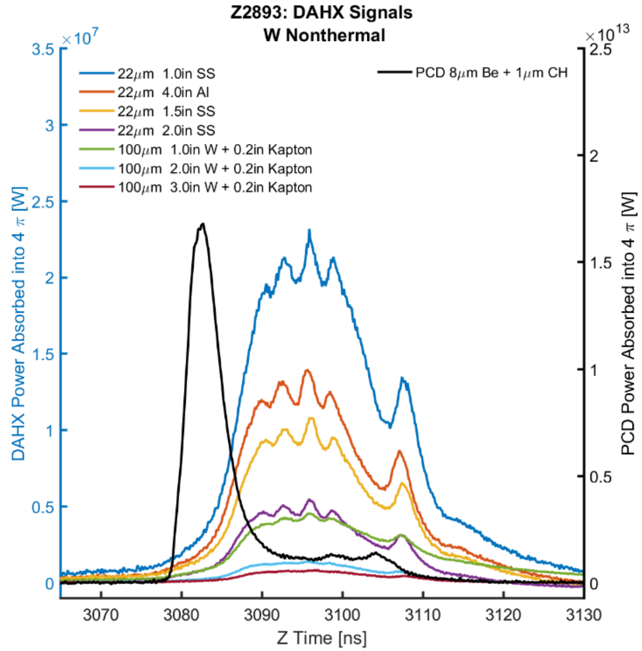


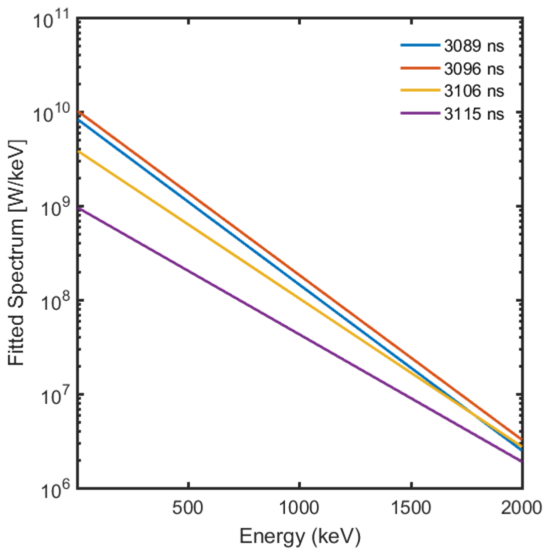


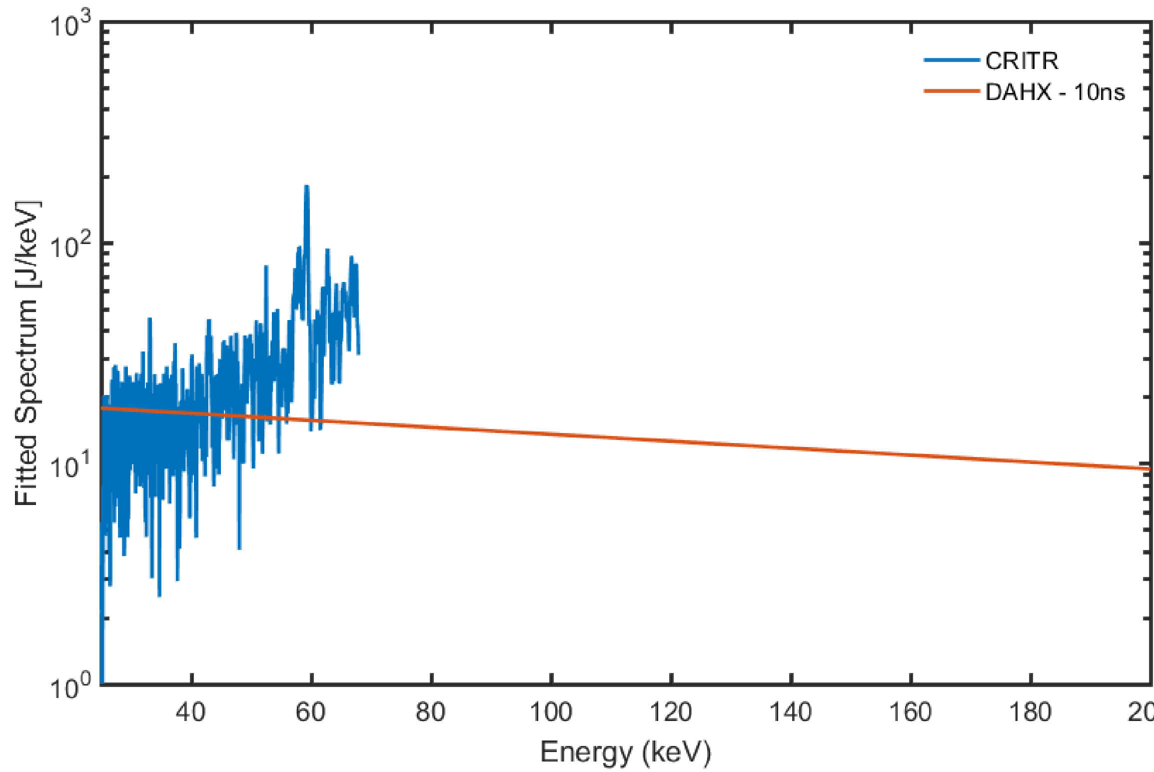




DAHX can be used to constrain high energy continuum

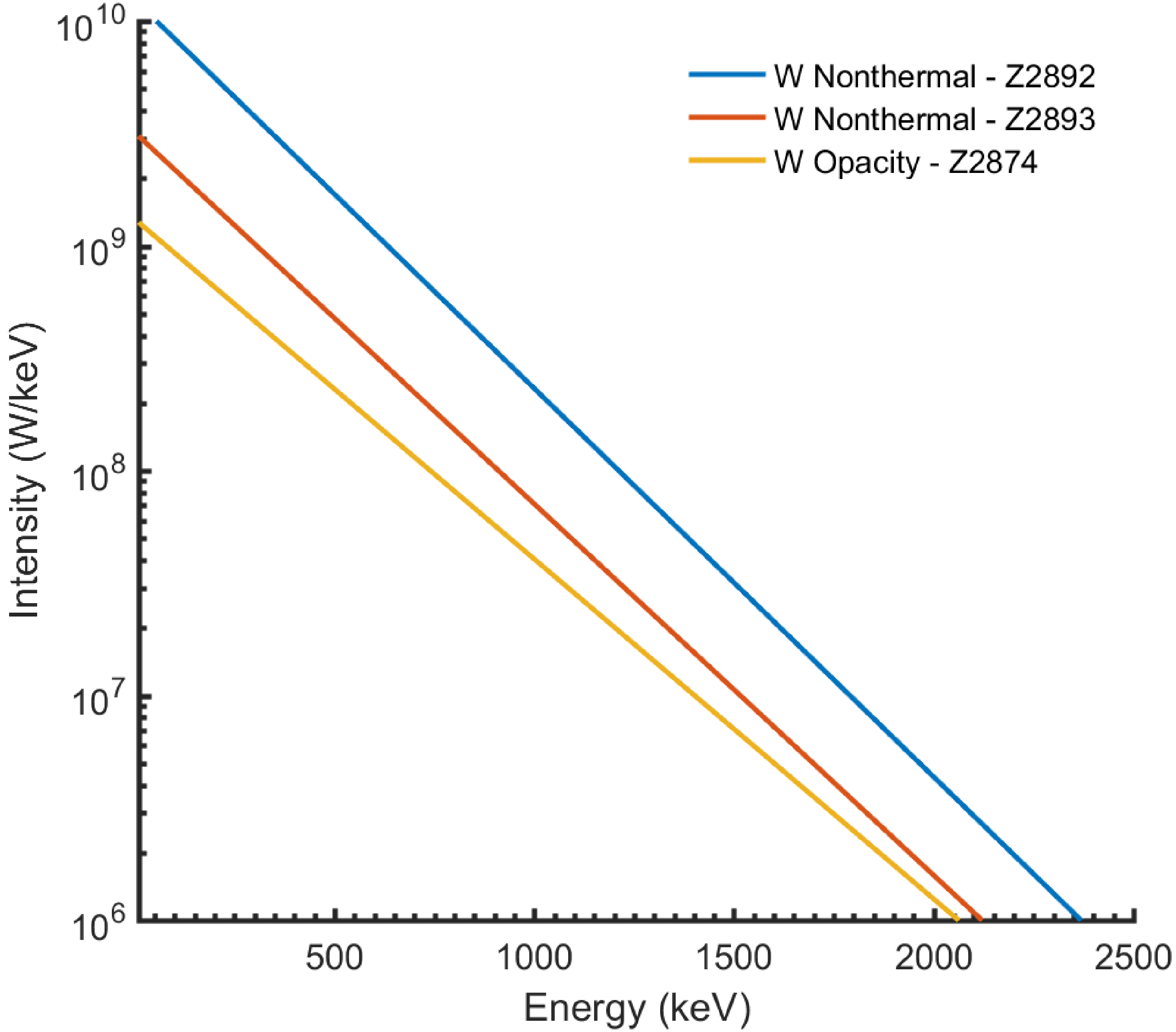






CRITR spectrum from G. Loisel

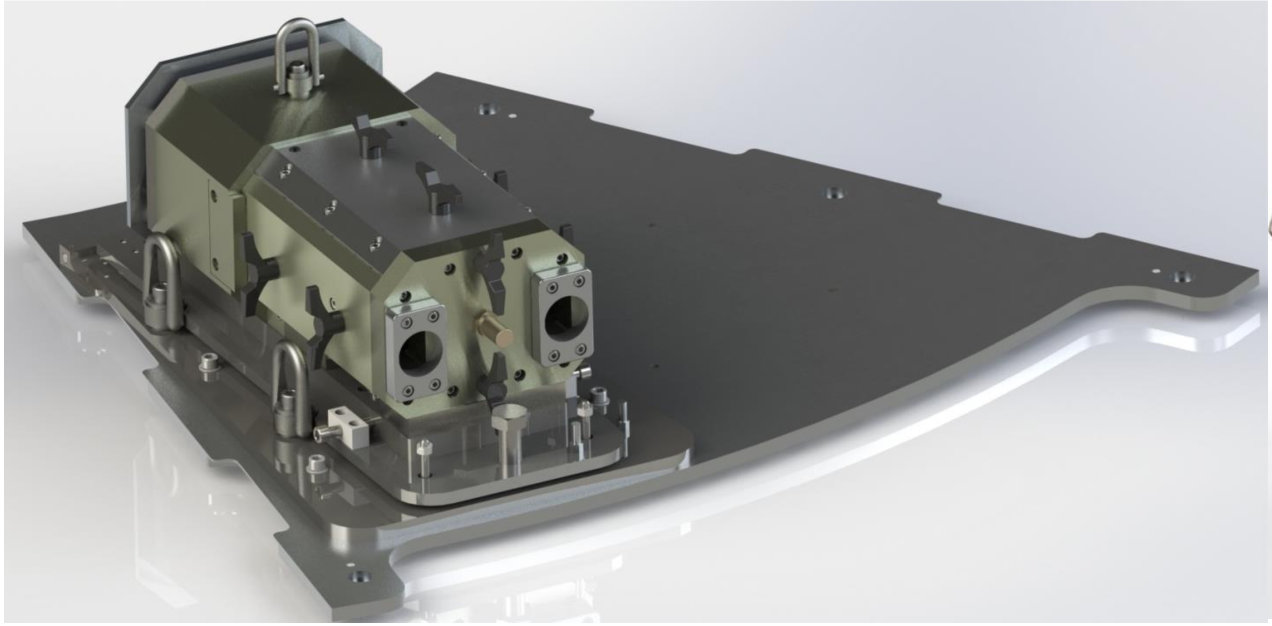
Opacity vs. Nonthermal – Time Integrated



WALLE

Wide-band Application Low-profile LOS Enclosure

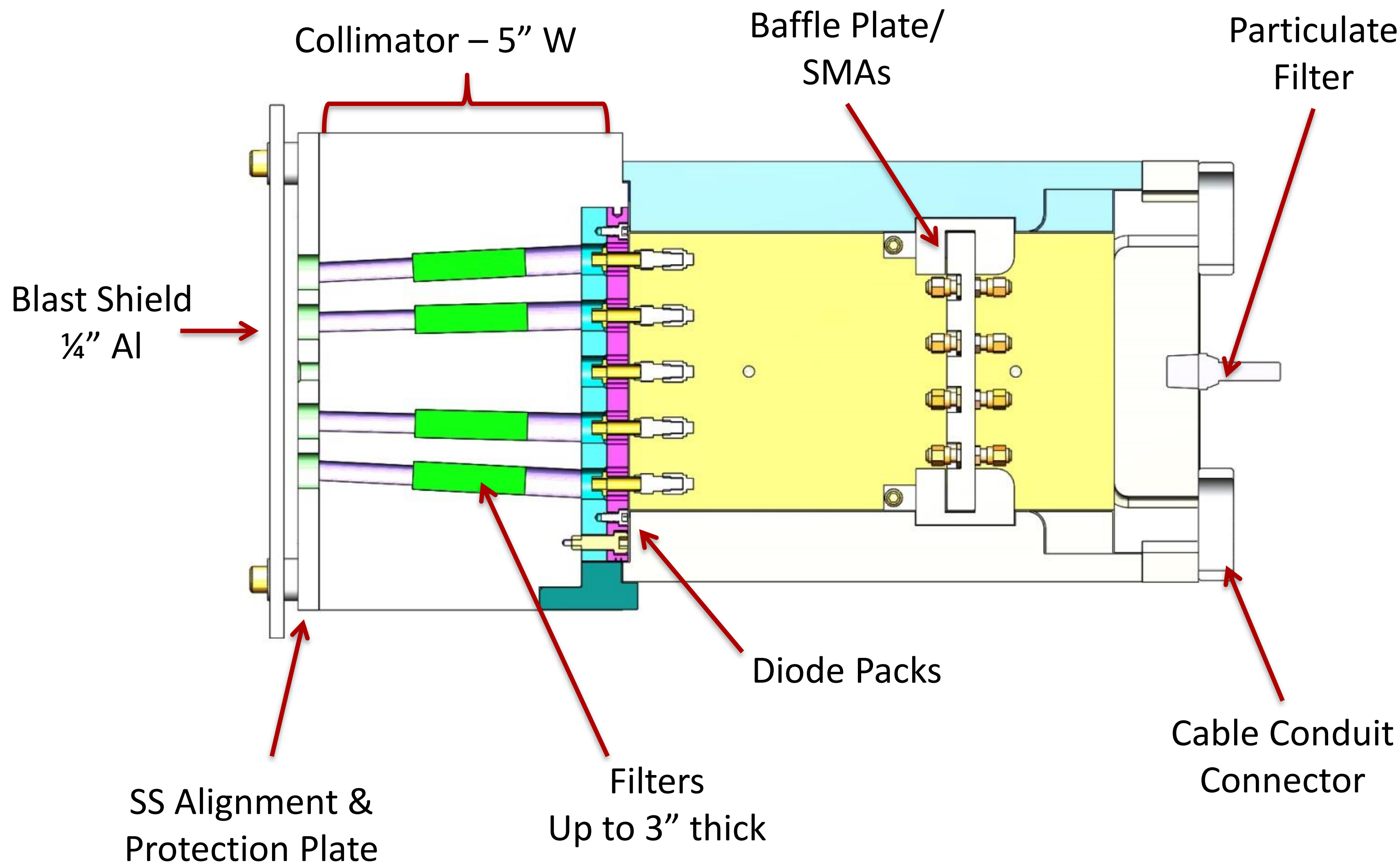
- Diagnose 40 – 3000 keV photons
- 15 Si Diodes that are farther away from load – 40”
- 20^{o} foot print
- Under 12 ^{o} view
- Maintain/Increase shielding



Preserves 12^o LOS View

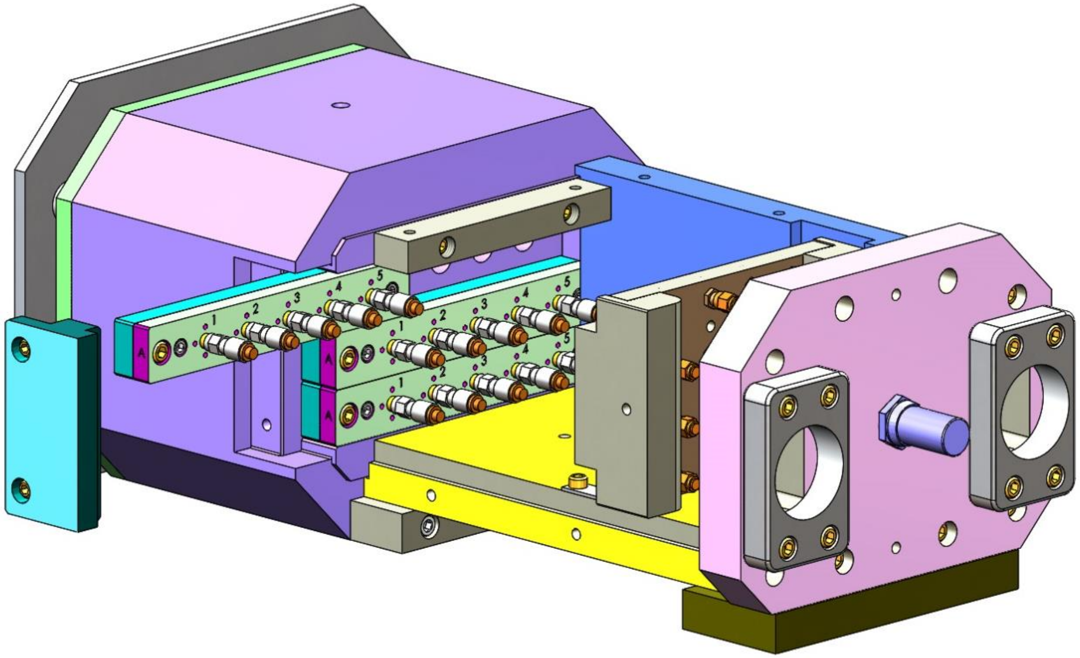
Envelope to maintain 12^o LOS views provided by Grafton Robertson

Interior – Top View

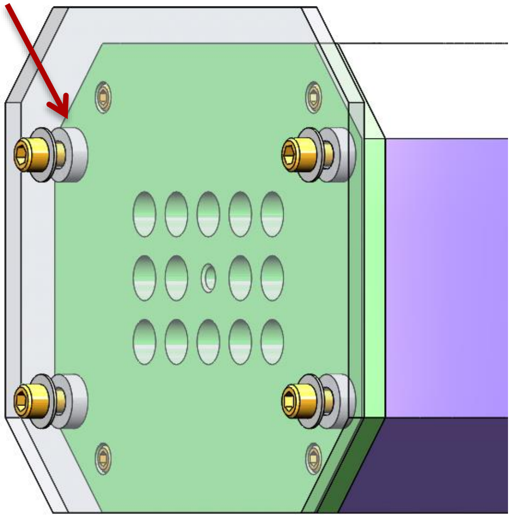


Diode Installation & Blast Shield

- Remove each diode pack separately
- Unique single side access for individual pack installation
- QMAs on diodes for easy cable detachment
- Jumper cables reduce strain on diodes
- Diode packs will be protected from to chamber debris
- Venting muffler reduces interior soot



- Four front bolts
- Four spacers for venting



WALLE Filter & Diode Folded Response

- ¼” Al 5083 Blast Shield
- HS11 22 µm
  - 2” Aluminum 5083
  - 3” Aluminum 5083
  - ½” Stainless Steel 304
  - 1” Stainless Steel 304
  - 1.5” Stainless Steel 304
  - 2” Stainless Steel 304
  - ½” Tungsten
- HS5 100 µm
  - 2” Stainless Steel 304
  - ½” Tungsten
  - 1” Tungsten
  - 1.5” Tungsten
  - 2” Tungsten
  - 2.5” Tungsten
  - 3” Tungsten
  - 5” Tungsten
    - ASTM-B-77 Class 1, HD 17

Questions?

Distributed TLDs demonstrate $1/r^2$ scaling of dose

TLDs stacks with identical filtering fielded in Z at various distances

- Needs clear line of sight to source
- Each container had 4 CaF2:Mn TLDs
- Equilibrated by 10 mils of Al
- Filtered by 1 cm stainless steel