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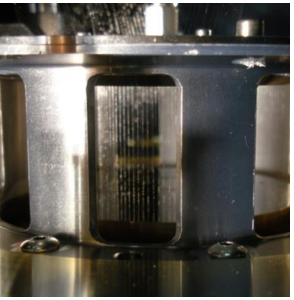

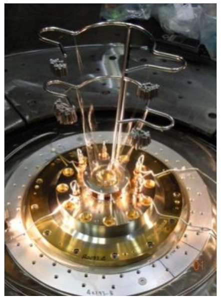

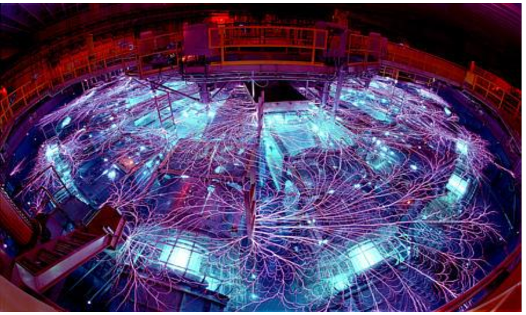

Scaling of non-thermal line emission on Z to hν ~ 22 keV

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ICOPS/Beams 2014
Washington, DC, May 2014

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Summary: Kα emission from inner-shell ionization enables z pinches on Z to emit at hν ~ 22 keV and likely even higher photon energies

- K-shell emission due to thermal electrons (Heα, Lyα) drops sharply with increasing atomic number / photon energy
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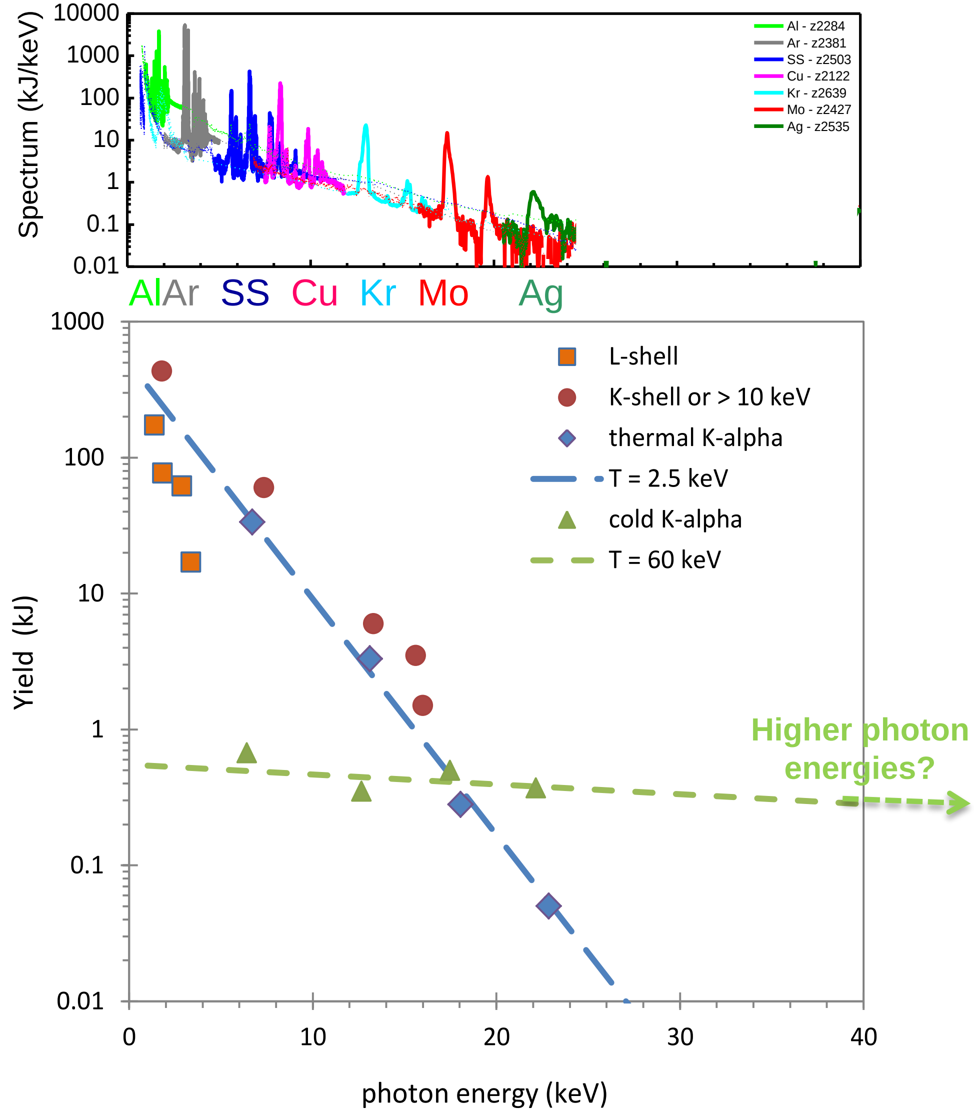
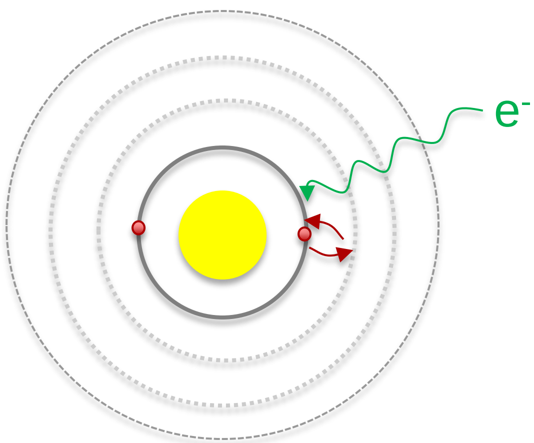
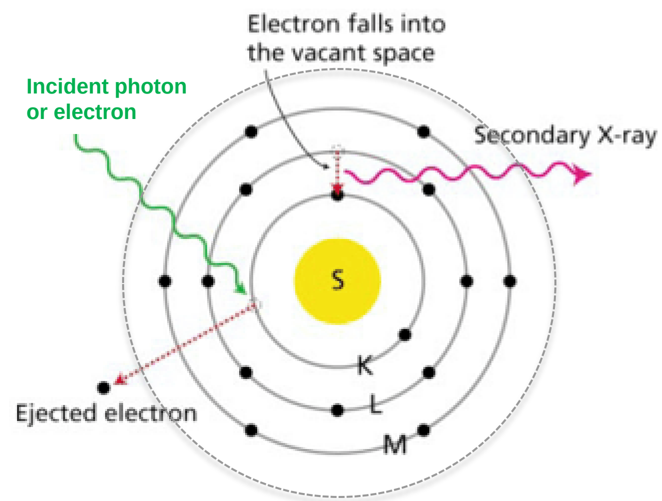


Emission from inner-shell ionization does not need the investment of ionization energy

- K-shell emission from thermal electrons
  - He-like and H-like lines
  - Need to ionize to the K-shell

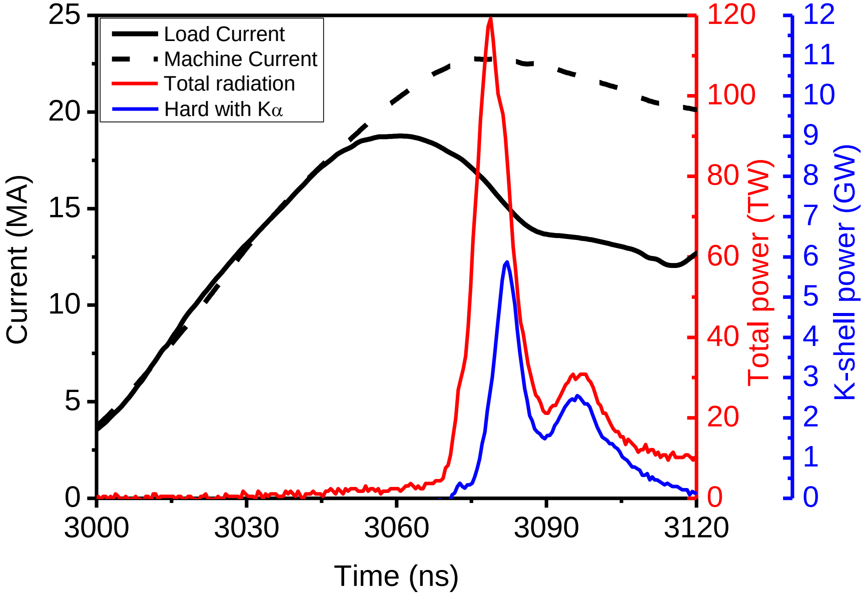


- K-shell emission from energetic electrons
  - Cold K-lines (Kα)
  - Need hot electrons/photons
  - Don't need to ionize bulk plasma



Data from Mo wire arrays indicates Kα emission comes late in time, and corresponds to high energy electron beams

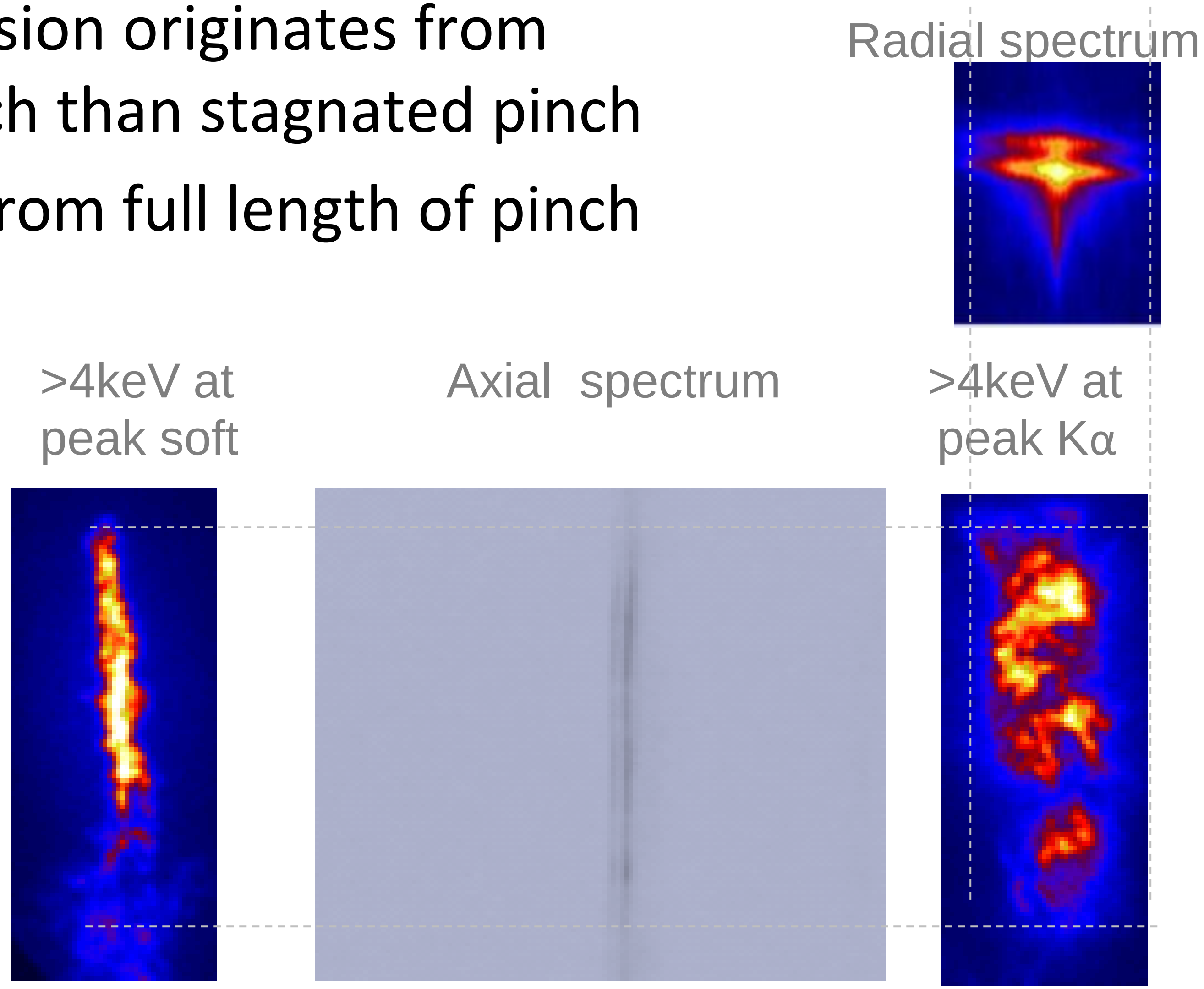
- PCD detectors indicate that hard (e.g. Kα) emission is late in the x-ray pulse
- Hard emission originates from broad area
  - Consistent with pinch disruption
- Initial Faraday cup data: Kα generation coincides with peak of electron beams



P.D. LePell *et al.*, Physics of Plasmas **12**, 032701 (2005); I. Shrestha *et al.*, HEDP 6, 113 (2010);
Recent work: S.B. Hansen, D.J. Ampleford *et al.*, Physics of Plasmas 21, 031202 (2014).

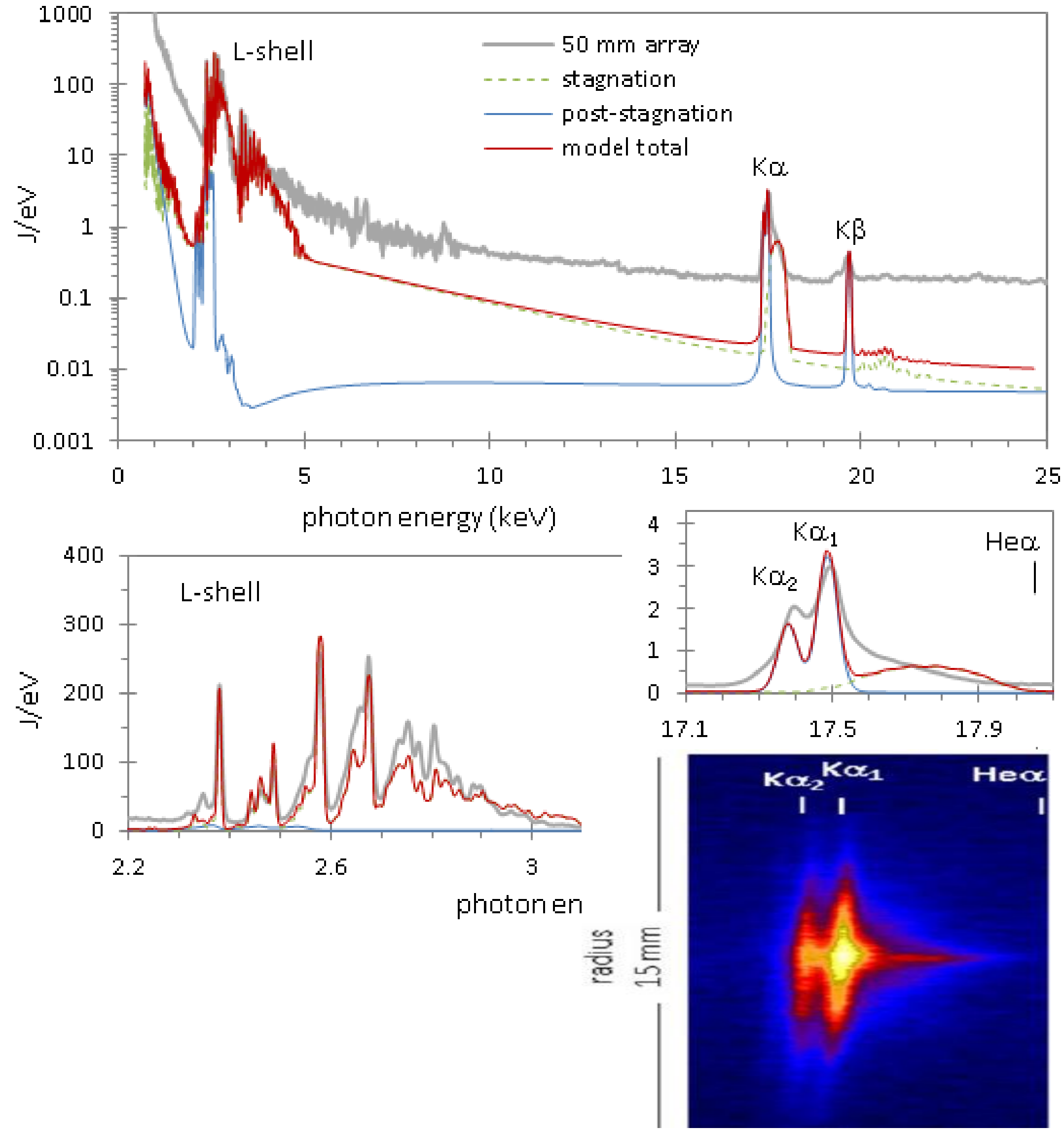
Spatially and spectrally resolved diagnostics indicate Kα emission originates from disrupted pinch

- Hard emission originates from larger pinch than stagnated pinch
- Emission from full length of pinch

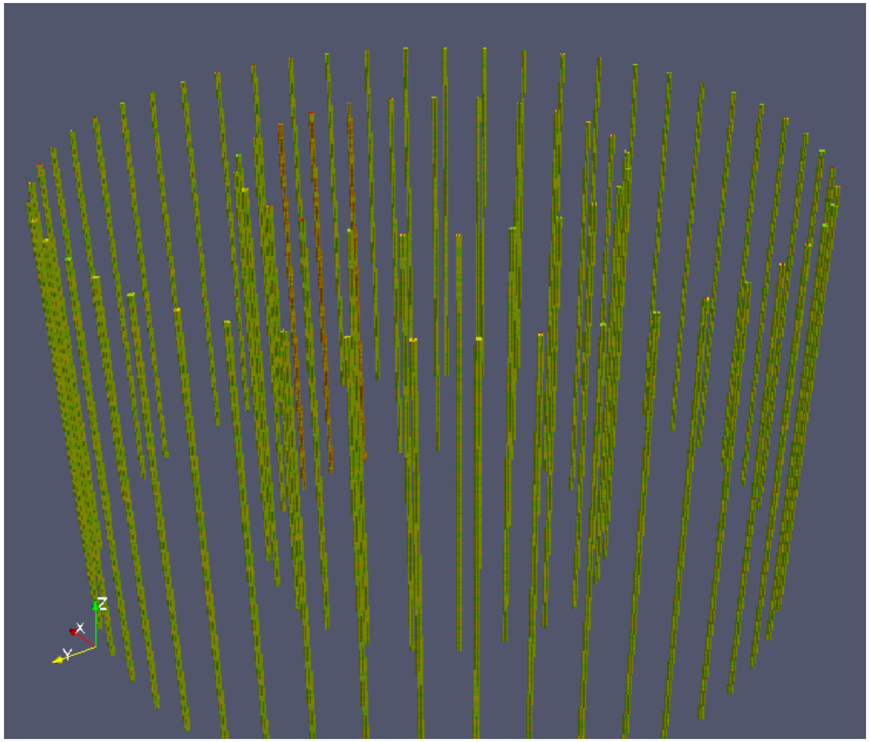


Modeling of 50mm-diameter Mo data consistent with multi-stage evolution

- Comparing SCRAM simulations to broadband spectra provides insight into plasma conditions present
  - Hot core (0.8mm diameter) emitting some thermal K-shell and highly ionized L-shell
  - Surrounded by cooler, larger plasma (12mm diameter) emitting Ne-like L-shell
  - Followed by late-time 7mm cold plasma with hot electrons emitting cold Kα over 10s of ns



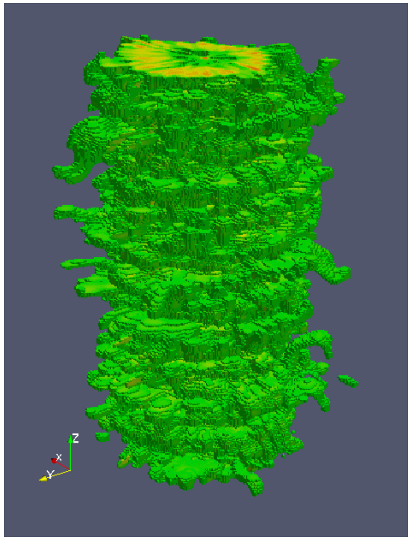
MHD + PiC simulations have been used to model the Kα generation

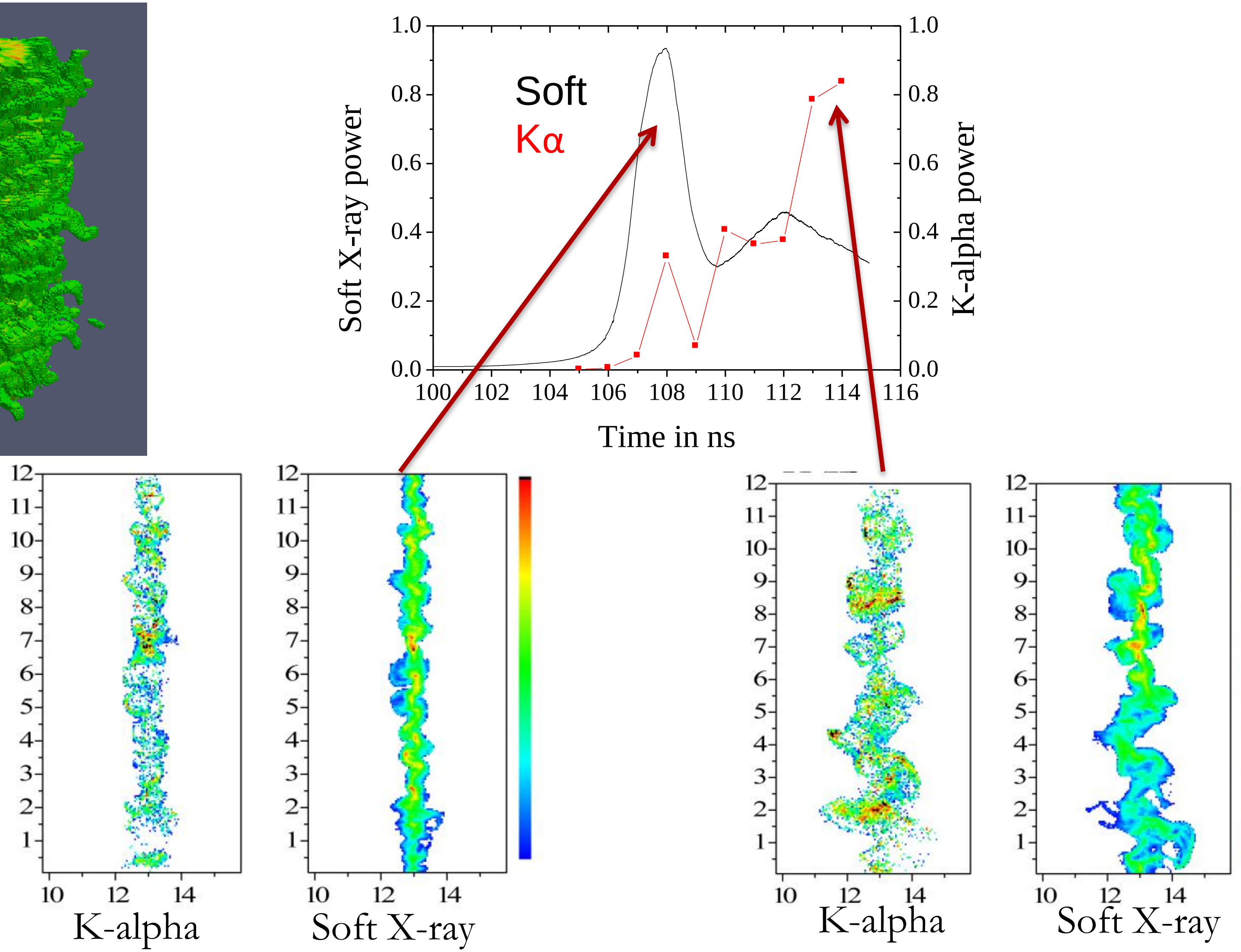


Colour – mass density, white fast elctron density

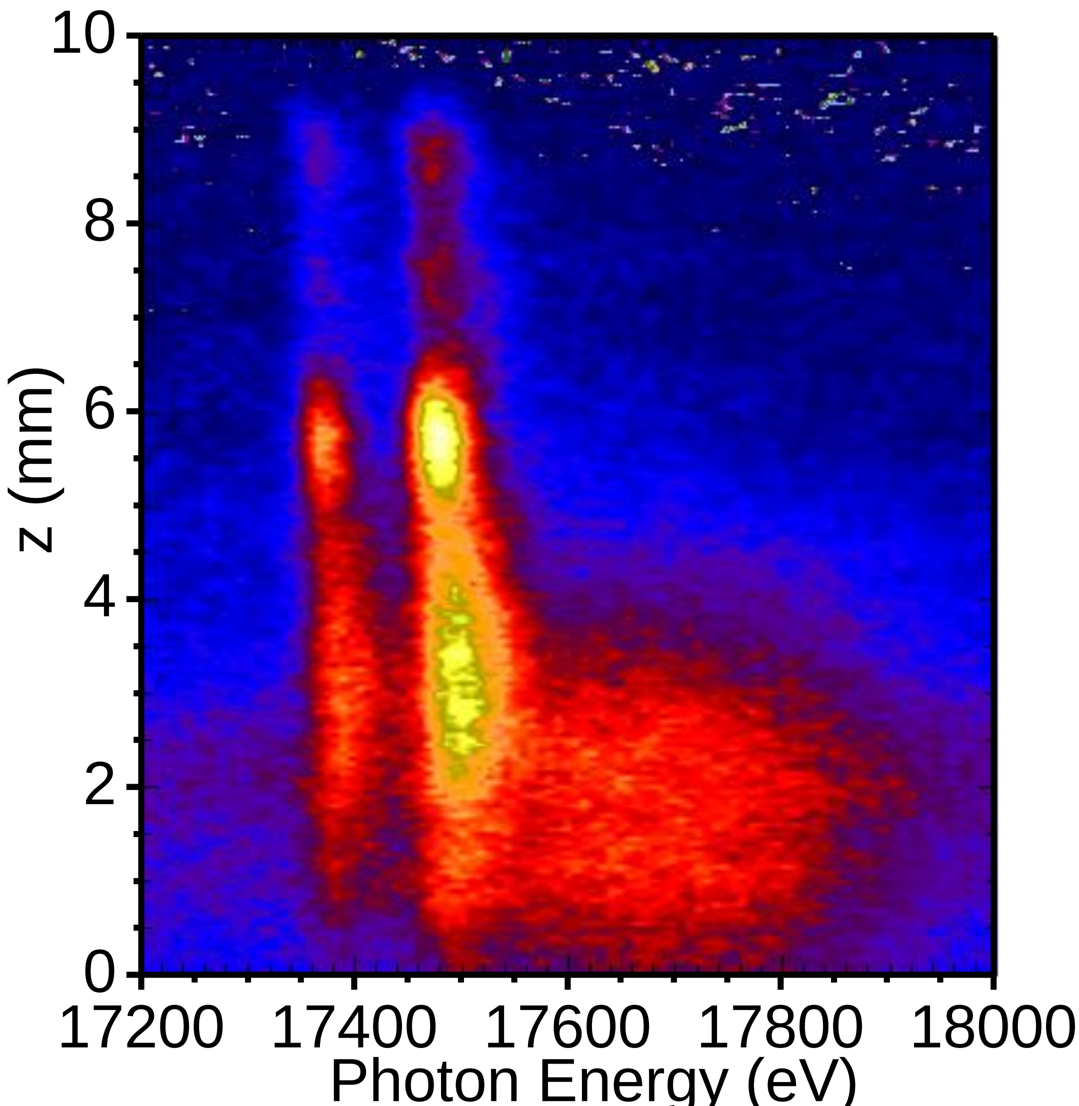
- Gorgon MHD run in tandem with 3D EM PiC code Melinda
- Electron runaway condition based on when $\underline{E}.\underline{B}/|B|$ exceeds the Dreicer field
- Fast electron trajectories are tracked in evolving E and B fields predicted by MHD model
- Kα prediction based on
  - $n_{fast}\, v_{fast}\, n_i\, \sigma\, E_{k\text{-}alpha}$

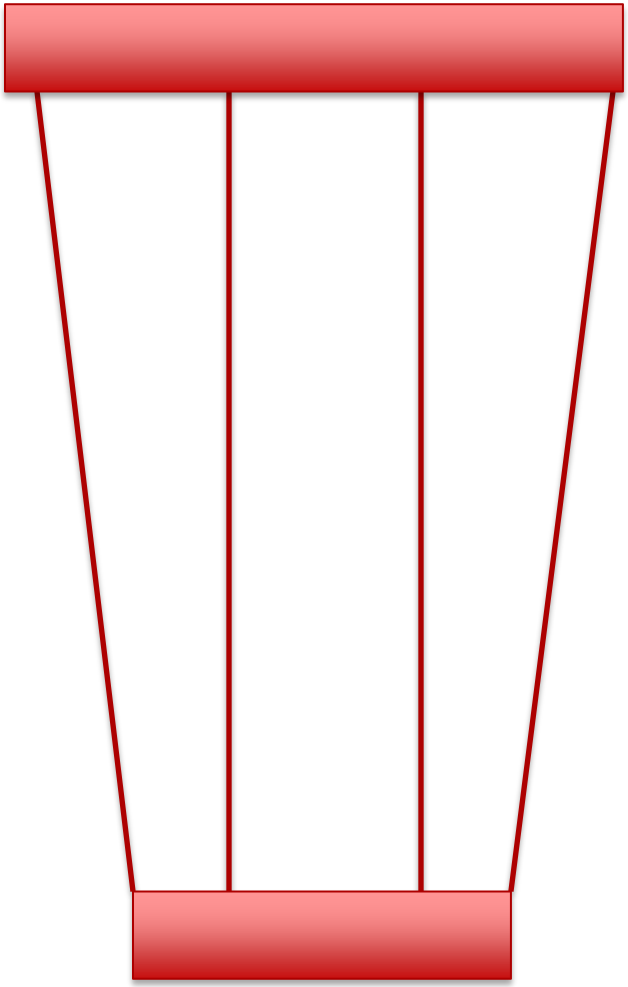
Predictions of K-alpha emission from runaway electrons show emission late in time





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





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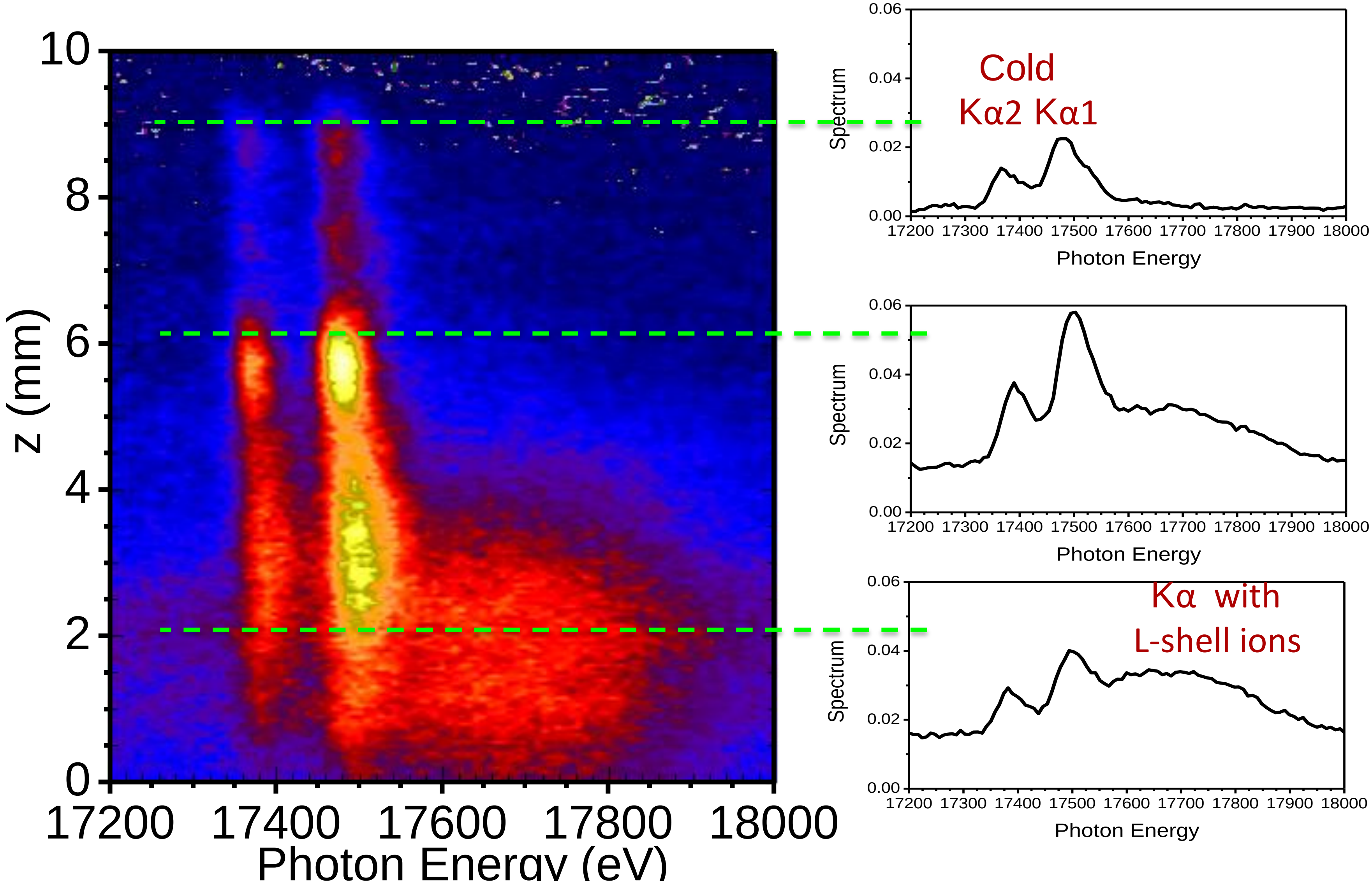
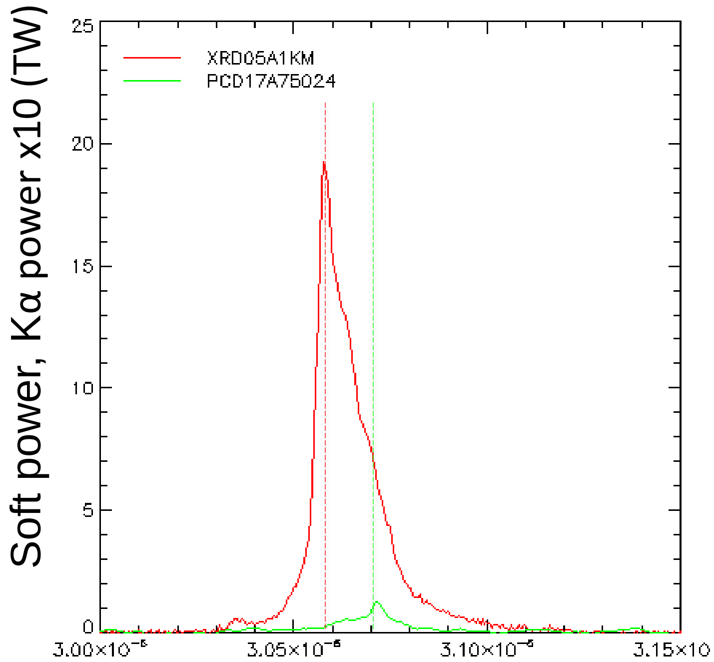
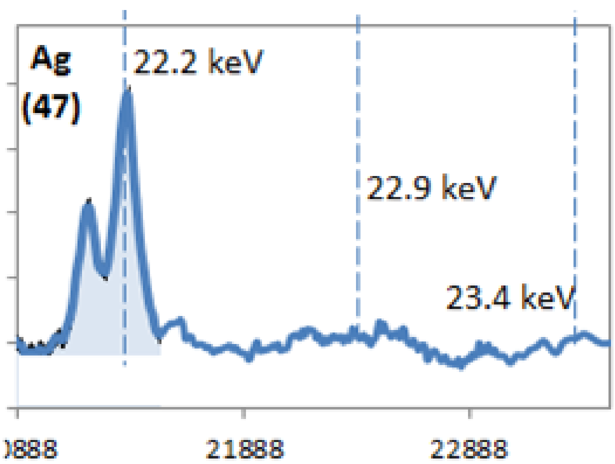


Initial experiments have demonstrated ability to emit Ag Kα

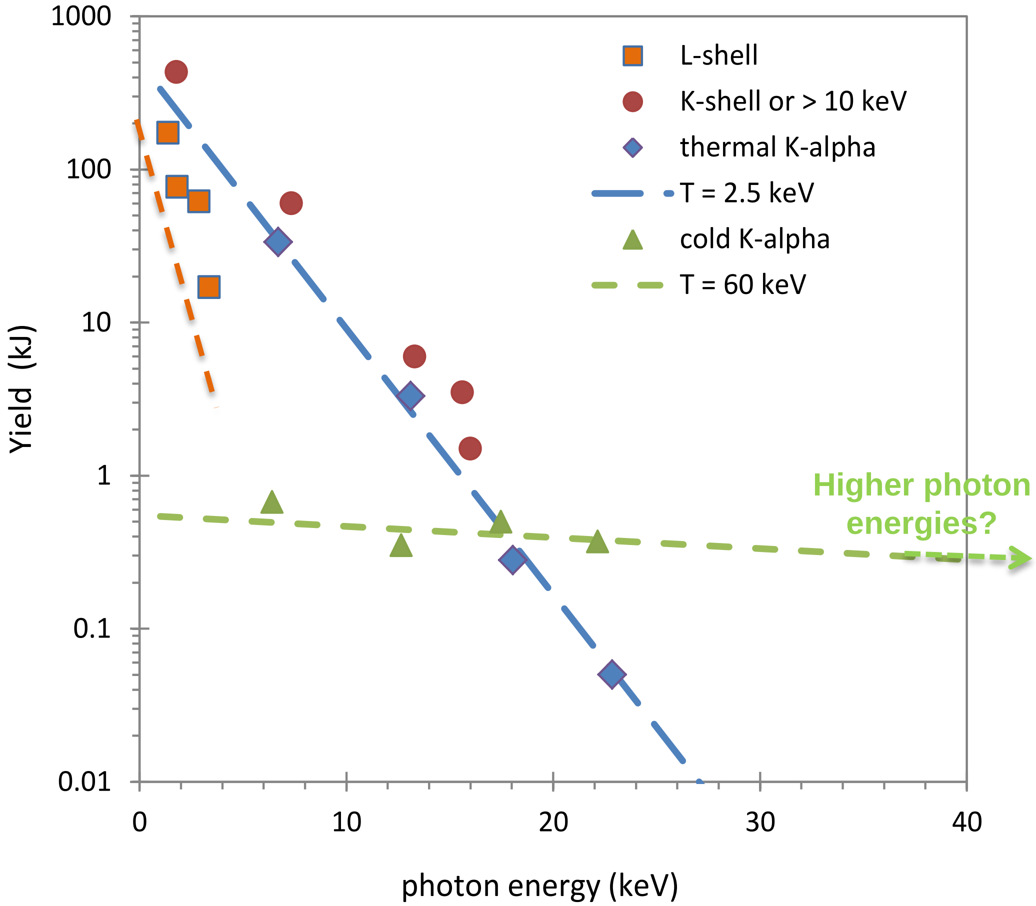




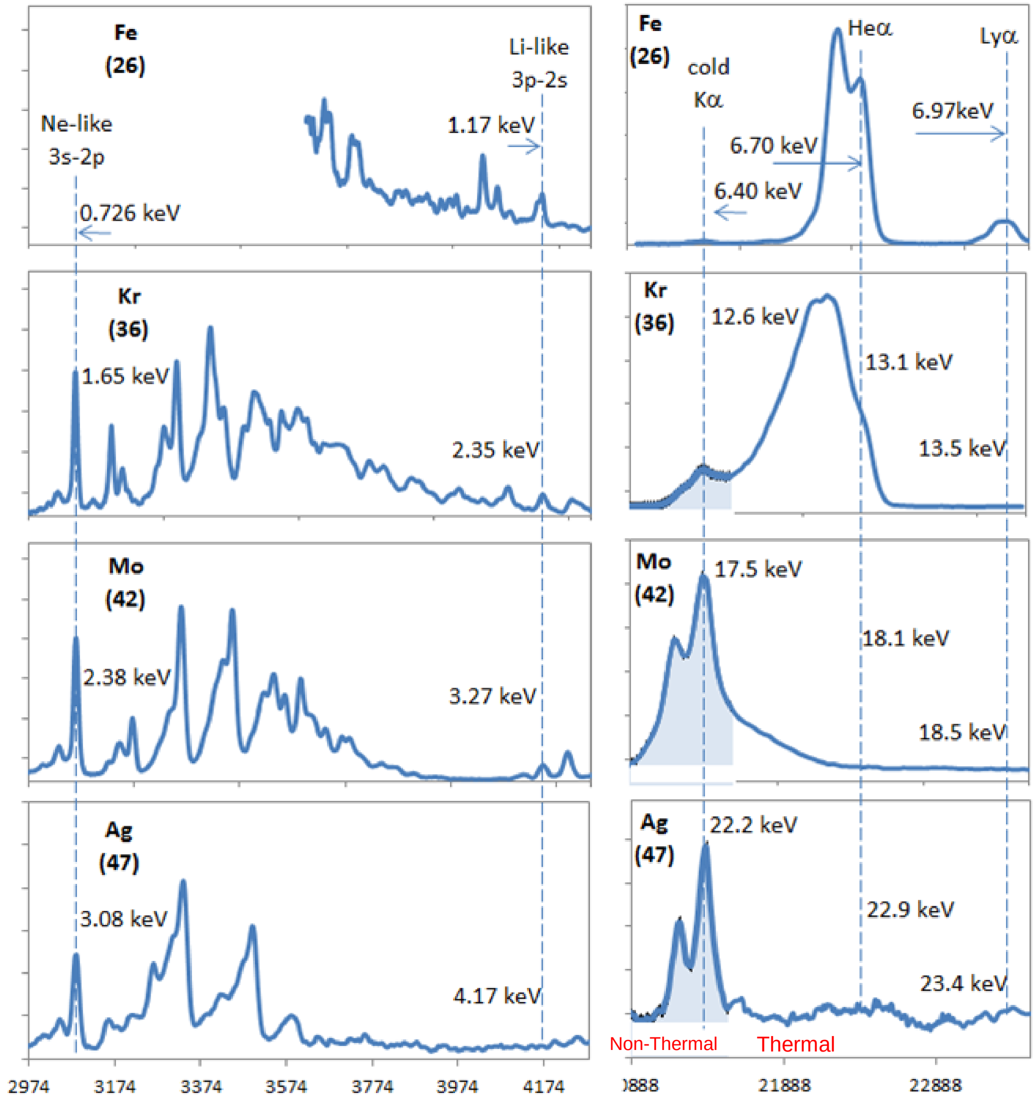
- Ag experiments on Z can generate Kα at 22keV
  - Kα emitted late in time
  - Ag Kα emitted from most of length of pinch
- No measureable Heα emission

Comparison of different materials demonstrates transition from efficient thermal K-shell generation to efficient non-thermal K-shell generation

- By comparing different material implosions can see trends in emission
  - L-shell drops precipitously with hν
  - Thermal K-shell drops fairly quickly
  - Cold Kα becomes much more efficient for >20keV emission



Comparison of spectra from different elements demonstrates transition from thermal to non-thermal emission



- Fe
  - Some Li-like L-shell
  - K-shell dominated by He-like, some H-like
- Kr
  - Li-like dropping
  - Cold Kα starts to show considerably
- Mo
  - Negligible Li-like
  - Cold Kα dominates K-shell emission
- Ag
  - No Li-like
  - No thermal K-shell, all Cold Kα

Various recent improvements at Z will enable experiments studying Kα emission

- Characterizing electron beams
  - Multi-energy bin Faraday cup
- Better characterization of spectra in 1-20 keV photon energy range
  - TiGHER spectrometer – time resolved spectra to ~20 keV
  - Higher spectral resolution at 17-22 keV on CRITR using 2^{nd} order
- Characterization of >25 keV photons (Coverdale ICOPS)
  - Spectral fits to filtered TLDs (V. Harper-Slaboszewicz)
  - Time resolved hard filtered SiD's (DAHX, K. Blesener)
  - Hard x-ray time integrated pinhole camera (TIPC, A. Mcpherson)
  - Investigating crystals for >25 keV spectrometers
  - Ross pairs on various diagnostics to provide narrow band measurements

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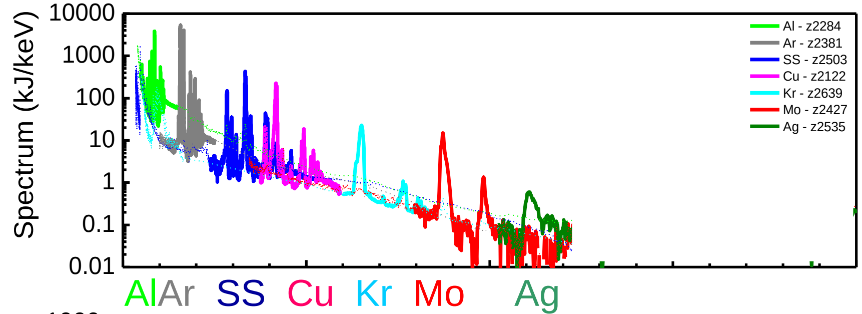

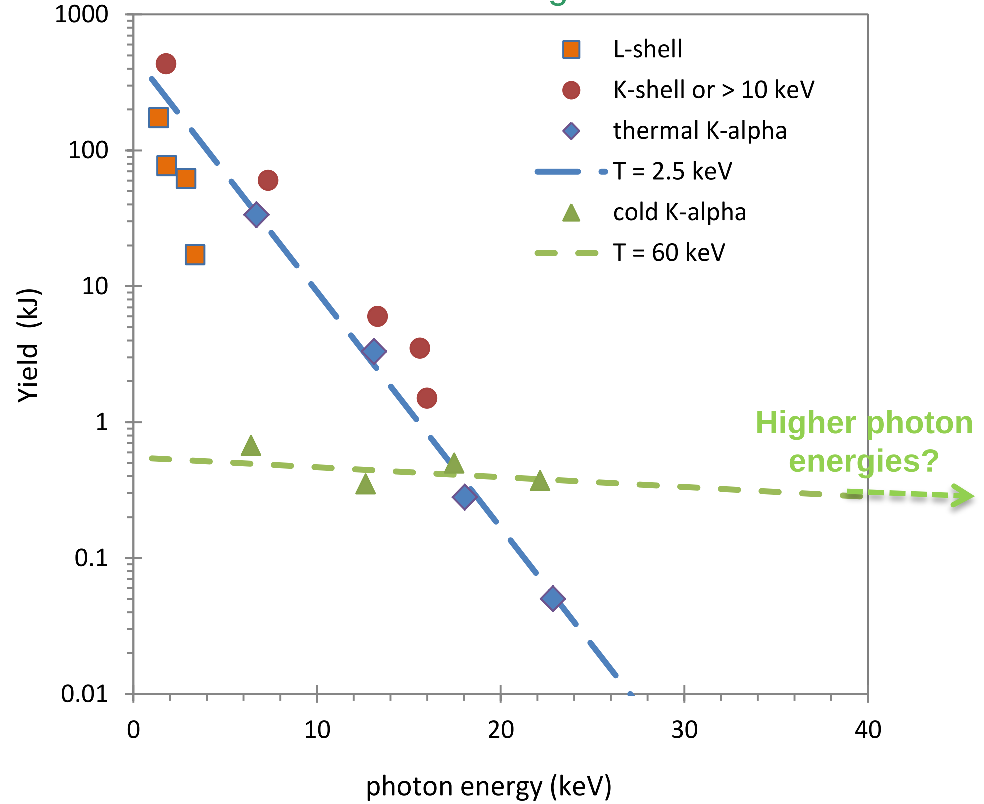

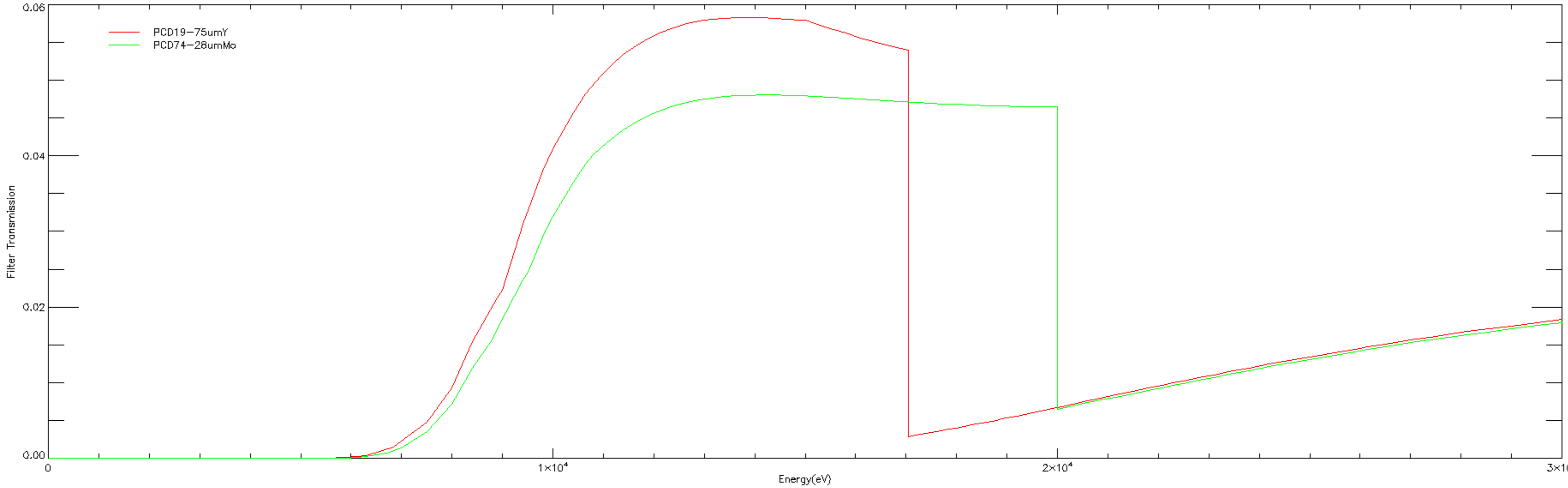
PCD19−75umY
PCD74−28umMo
Filter Transmission
Energy(eV)
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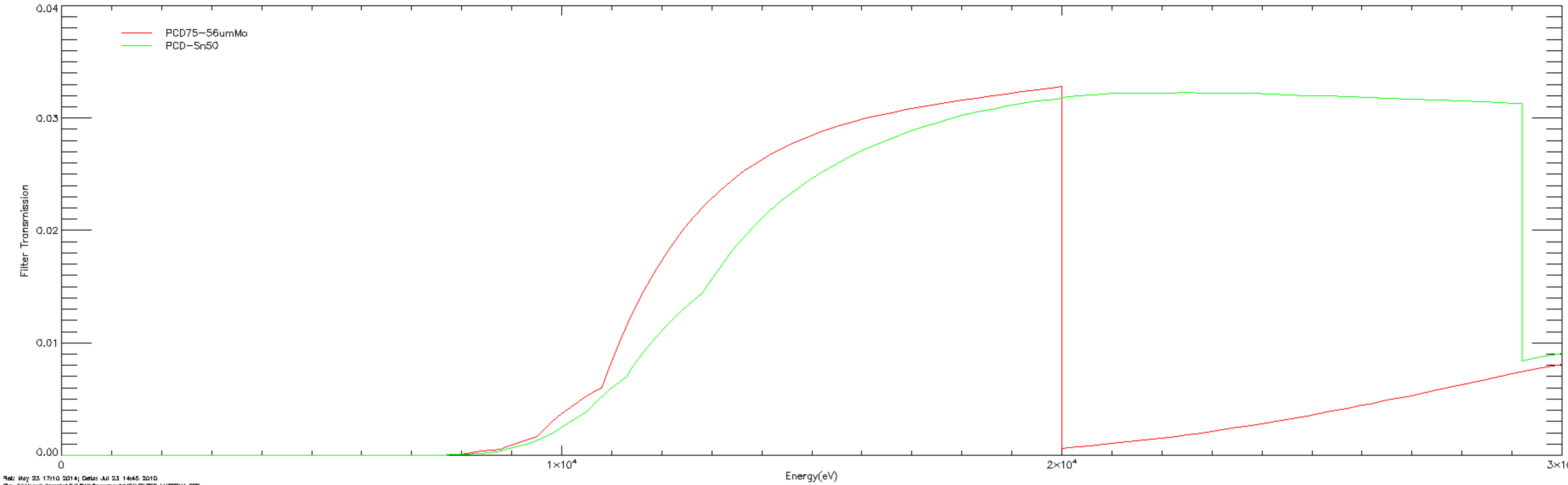
0.04
0.02
0.00
0
1×10⁴
2×10⁴
3×10⁴


PCD75−56umMo
PCD−Sn50
Filter Transmission
Energy(eV)
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0.03
0.02
0.01
0.00
0
1×10⁴
2×10⁴
3×10⁴