Time Resolved T_e from X-ray Streak Camera Measurements at the NIF

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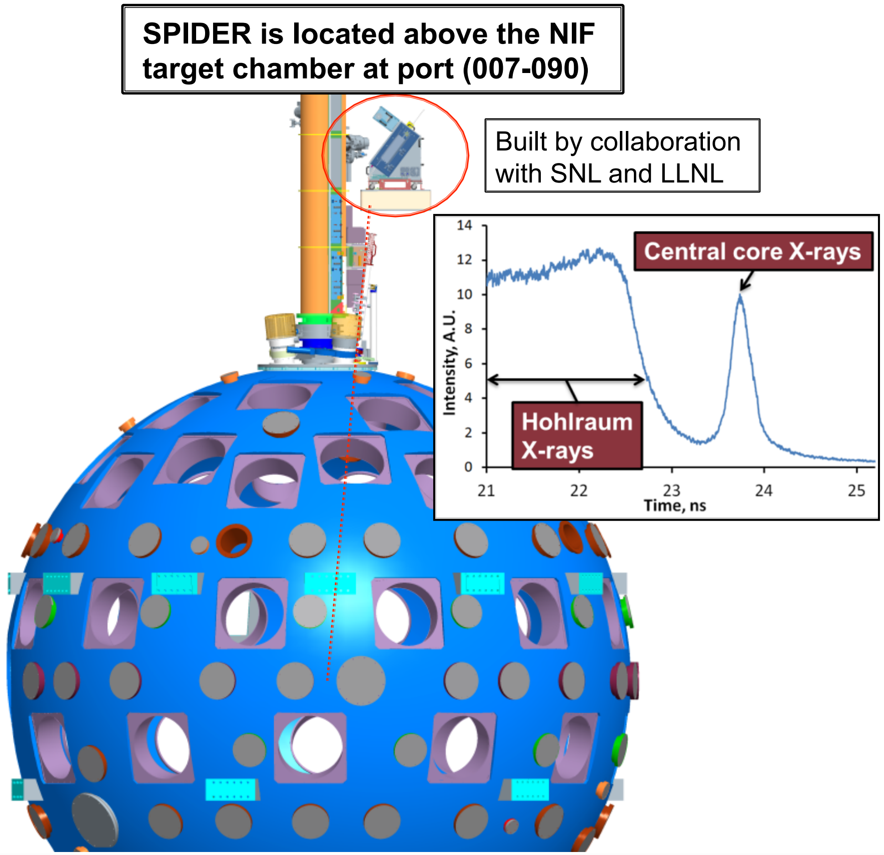
Outline

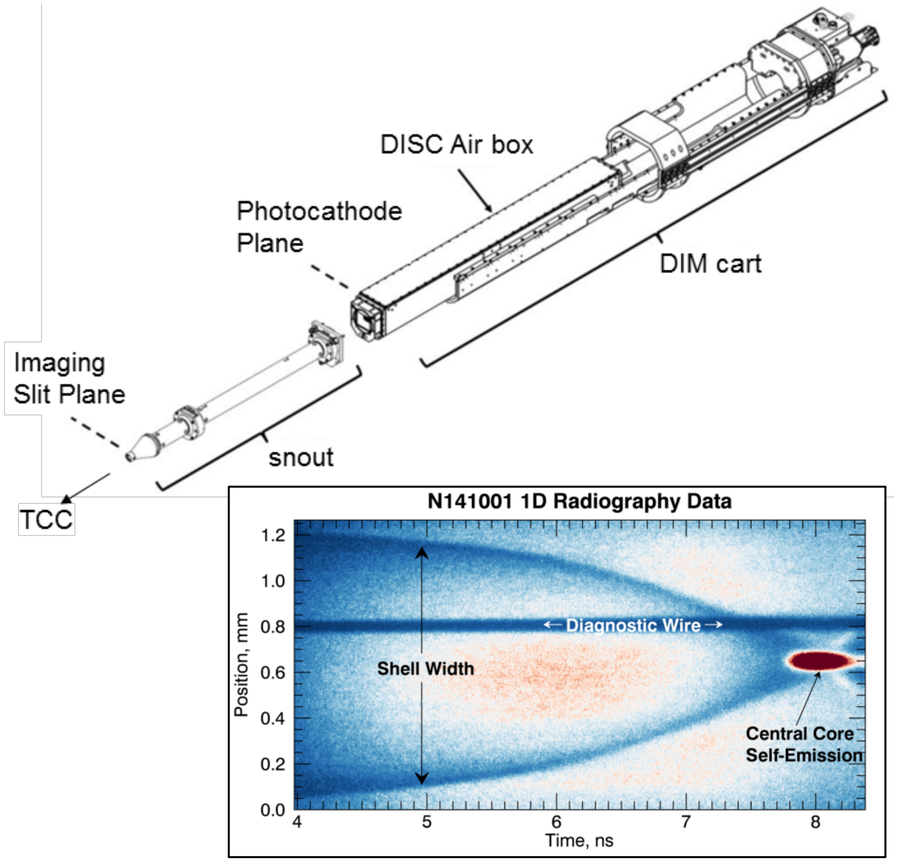
- X-ray Streak Cameras on NIF: SPIDER & DISC
  - This talk will show T_e using SPIDER; DISC will need to be adapted for T_e
- Method of inferring T_e using a hot spot model & filters
- T_e results using SPIDER from recent DT shots on NIF
- Opacity of fuel, ablator & plasma and uncertainty in filter thickness causes problems in calculating T_e
- Continuum Method of inferring T_e
- Future plan: Using DISC for inferring T_e using the Continuum

The two X-ray Streak Cameras on the NIF, SPIDER[1] & DISC[2], are utilized differently



SPIDER is located above the NIF target chamber at port (007-090)

Built by collaboration with SNL and LLNL



[1] Streaked Polar Instrumentation for Diagnosing Energetic Radiation

[2] DIM Imaging Streak Camera

[3] NIF X-Ray Spectrometer

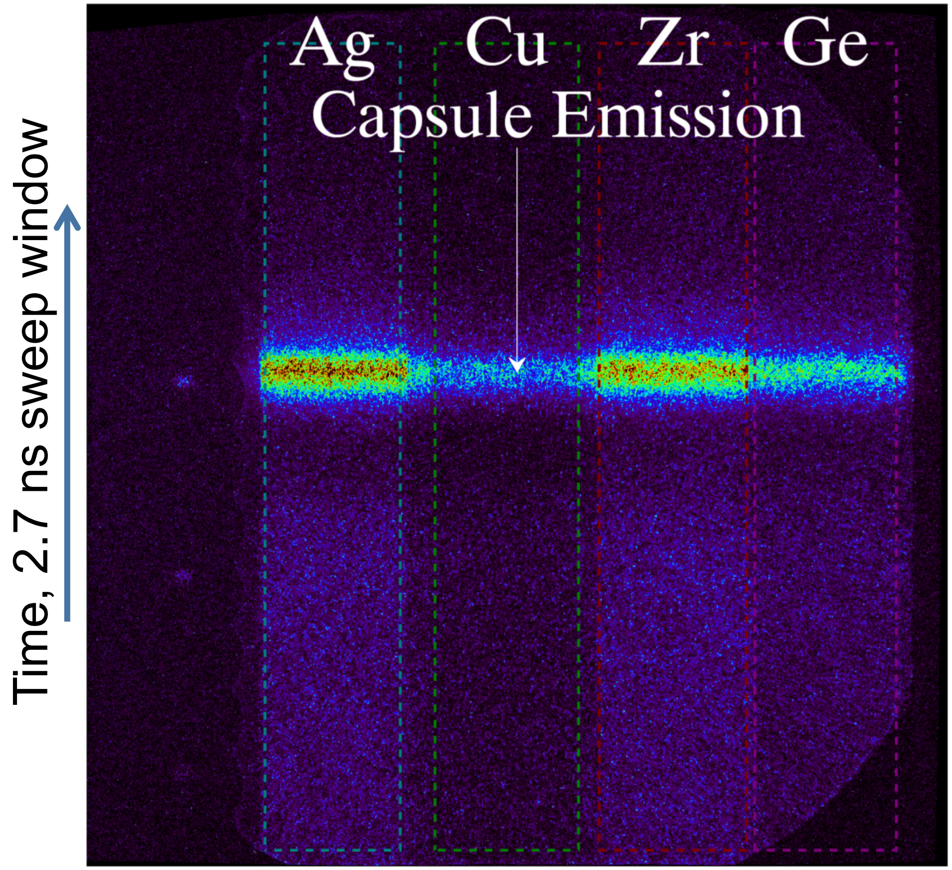
SPIDER is a fixed diagnostic that primarily measures bang time and burn widths from implosions, DISC is a DIM instrument used for 1D Radiography experiments and spectroscopy with NXS[3]

SPIDER is mostly a fixed diagnostic, whereas DISC can vary its recording parameters

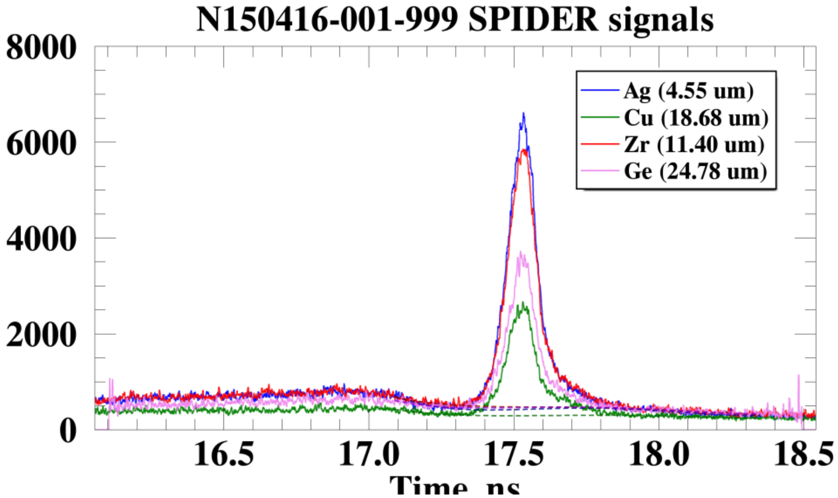
- Both SPIDER and DISC use an identical streak tube design
- Calibrated sweep windows: 3, 5, 10, 20 ns
- SPIDER temporal slit: 150 µm → 13 ps temporal resolution
- SPIDER photocathode: 1 µm CsI
- DISC temporal slit: 100 µm – 500 µm
- DISC photocathodes: 0.15, 0.2, 1 µm CsI & 30 nm Au

SPIDER uses a fixed slit, photocathode and standoff distance while DISC can change these as well as affix a snout for 1D imaging, spectroscopy, etc.; However, it must occupy a DIM

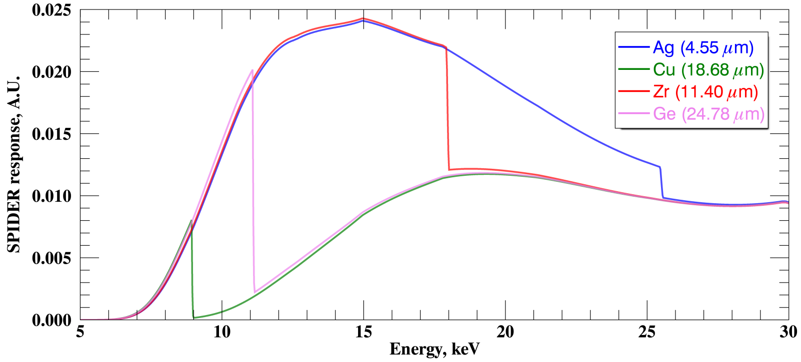
SPIDER uses sets of four filters as Ross pairs & to infer T_e



N150416:
DT 3-shock adiabat shaping, DU Hohl, 1.77MJ, 390TW, 1.6mg/cc
4He fill, 1xSi, T-1(175um) CH capsule, DI=6.9/6.2, mini-quench



Spectral response of SPIDER through the individual filters



T_e is inferred by comparing the measured signal to simulated signals using a model

Generalized Hot Spot Emission Model

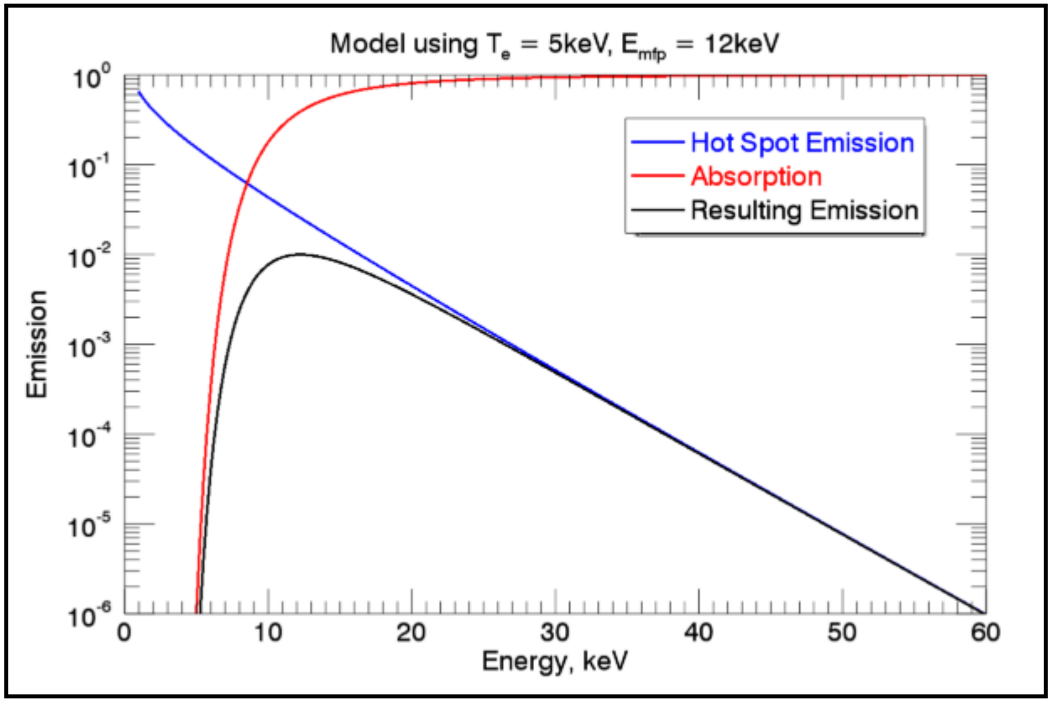
Hot spot model using fits to DCA* 100 Gbar tables (Patel):

$$f_H = 2.8/A_v^2 \; Z_H^2 \; \times 5.04E22\, e^{-hv/kTe} \; 1/(hv)^{0.39} \; 1/(kTe)^{0.15}$$

Bound-Free Absorption (Atzeni, Patel):

$$Absorption \sim e^{-(Emfp/hv)3}$$

$Emfp \sim (\rho L)^{1/3}$ is equivalent to the photon energy corresponding to a single mean free path through the shell

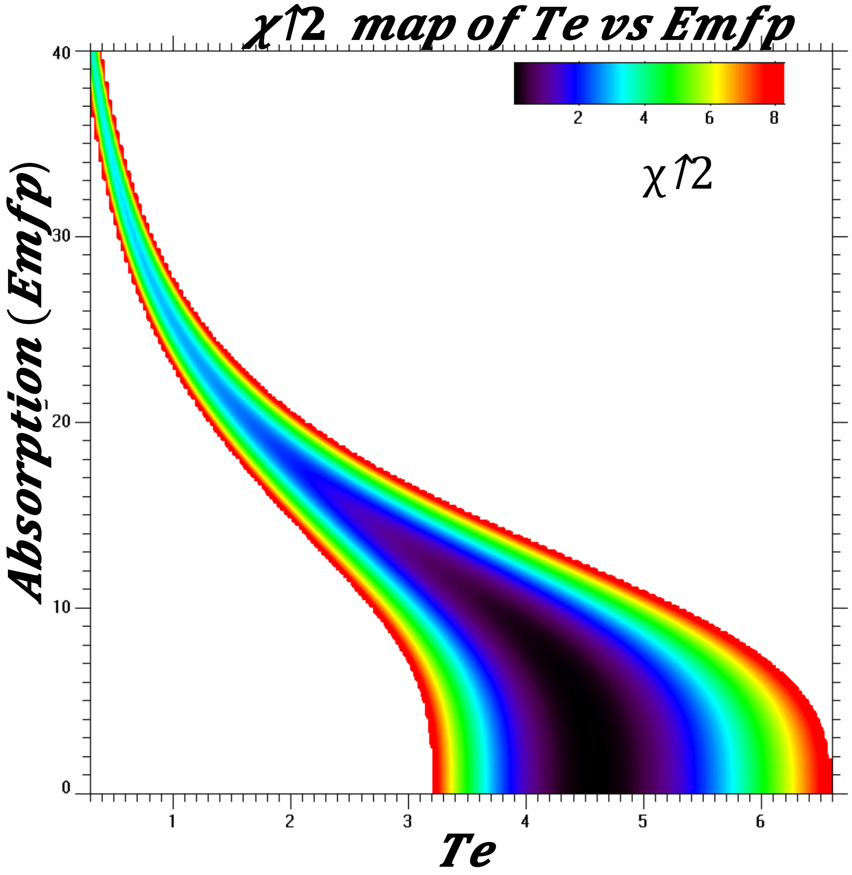


*Detailed Configuration Accounting, Opacity model in HYDRA

Absorption becomes insignificant above 20keV

T_e and Absorption are simultaneously solved by minimizing the $\chi\uparrow 2$ difference from measured signal

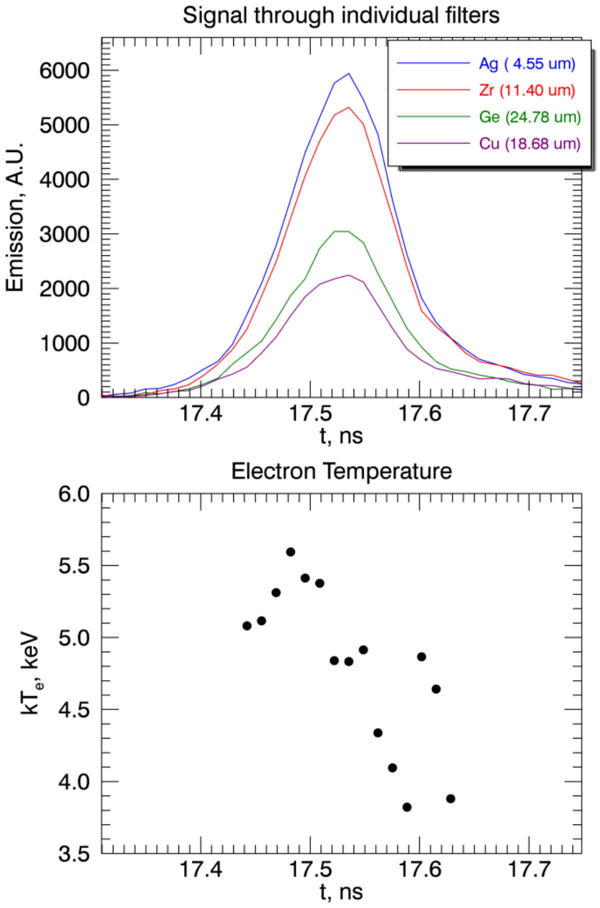
- Integrate the simulated signal over all energy for each filter
- Scan over a range of T_e and E_{mfp} until the squared difference between measured and simulated signal is minimized
- This analysis often results in no absorption



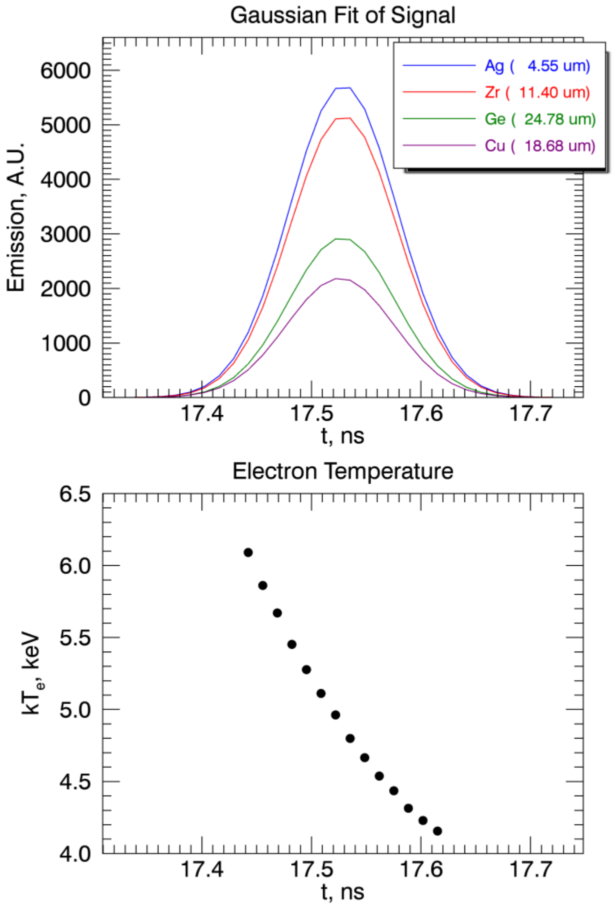
Least squares fit of T_e and E_{mfp} comparing measured signal to model is found for each time step

In this example, calculated T_e is close to T_{ion} measurement from N-TOF's of 5.3 keV

SPIDER Data
DT shot
N150416

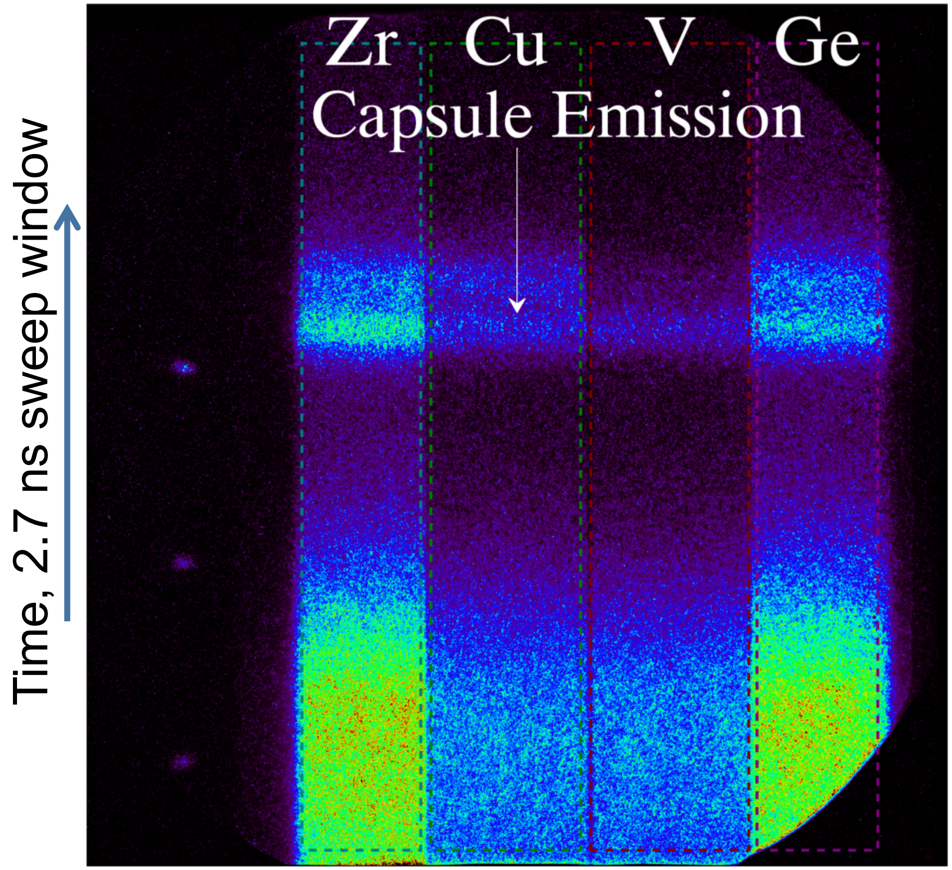


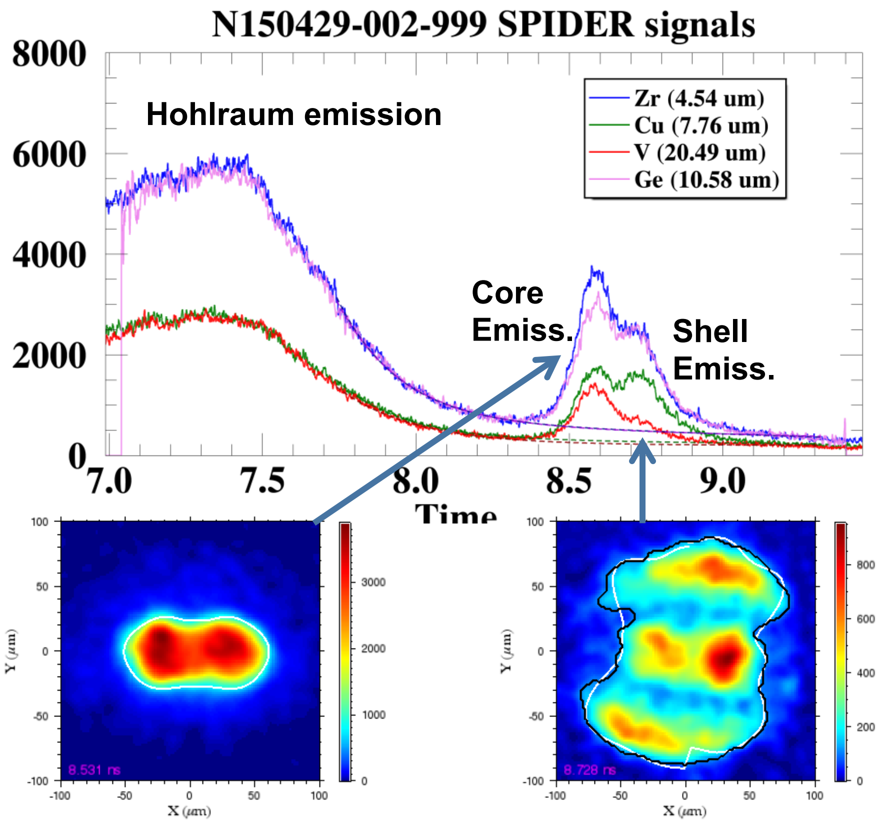
Fitting to Gaussian



Calculated zero optical depth; Gaussian fit of signal produces smooth T_e evolution

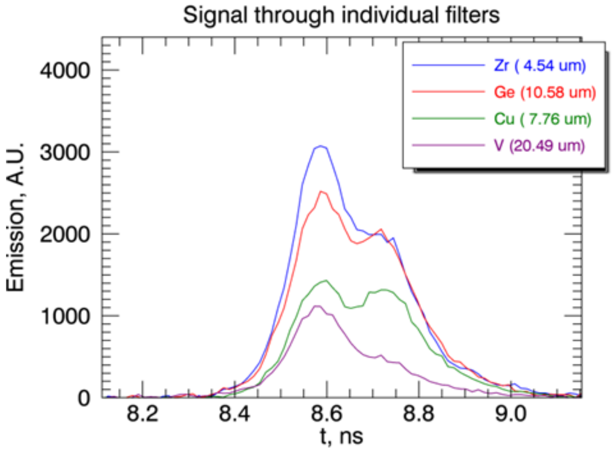
This HDC DT shot produced two x-ray peaks, the 1st from the core and the 2nd from the shell





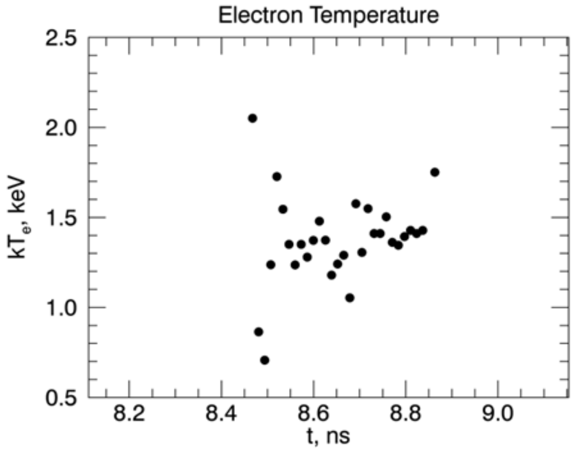
It is expected that the 2nd hump have a much lower temperature, since the carbon emission occurs in the colder shell region

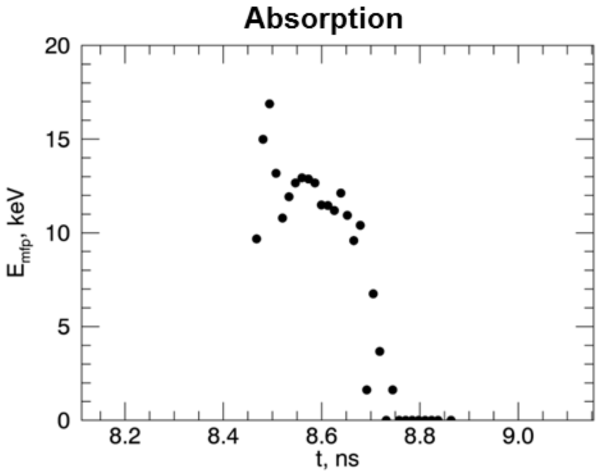
However, the analysis returns a low T_e throughout the emission and a jump in the optical depth



Jump in optical depth

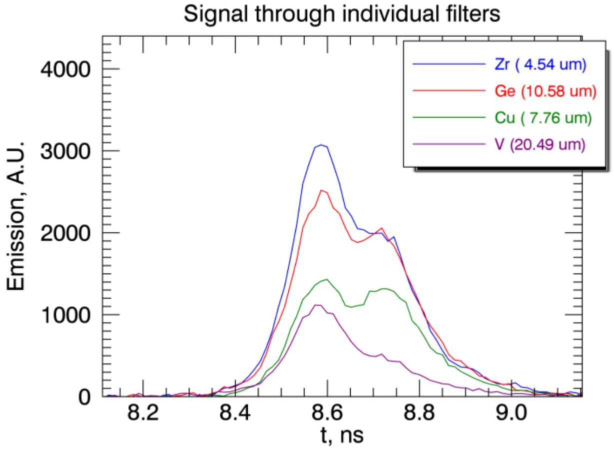
DT Tion
~ 3.8keV

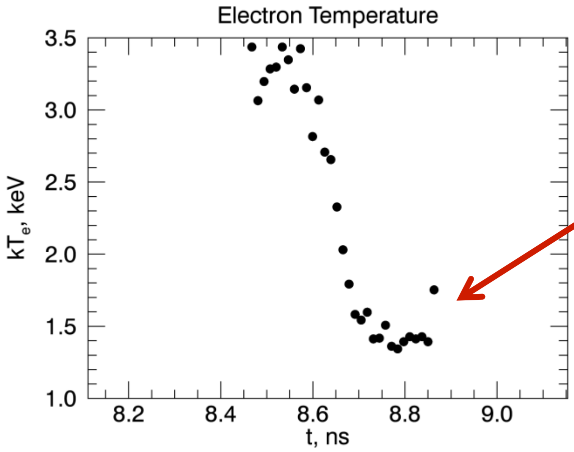




Fixing optical depth at 0, the calculated T_e is within range of T_{ion} and evolves as expected

DT Tion
~ 3.8keV

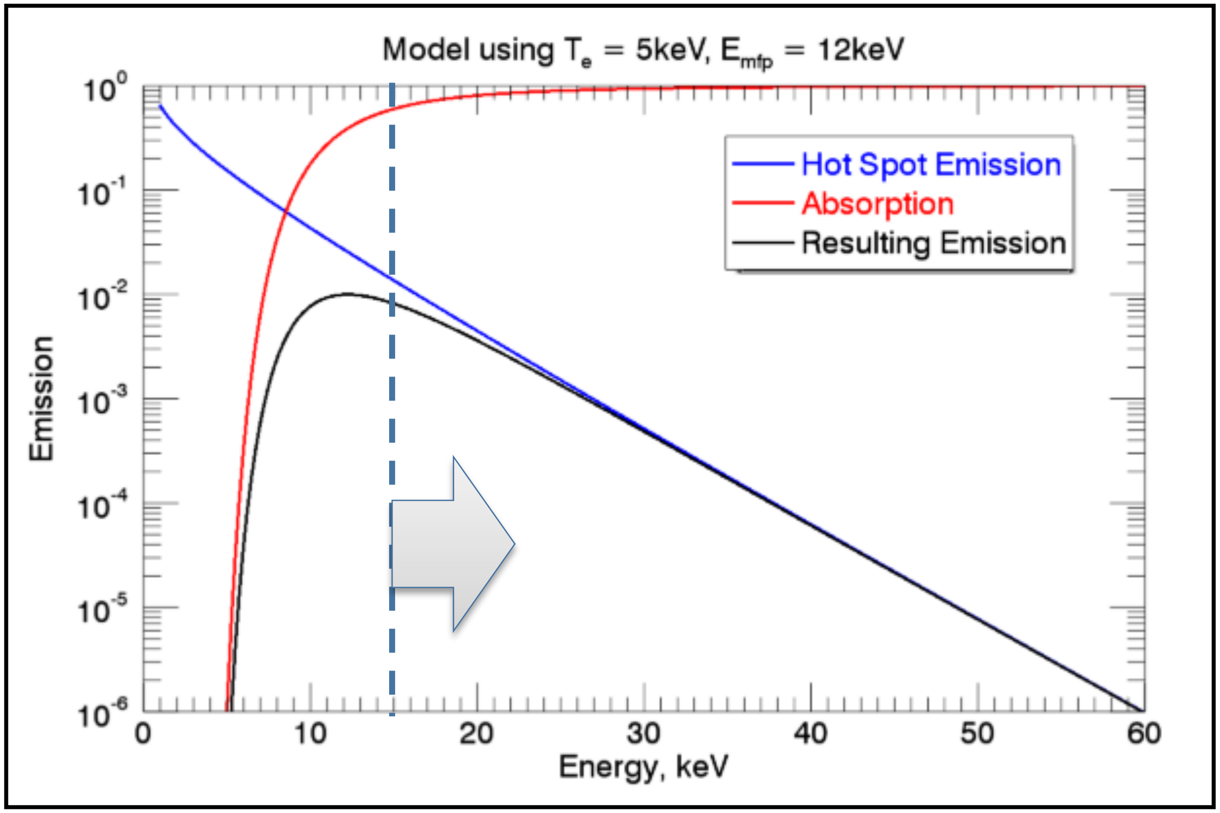




Sharp drop in Electron temperature with shell emission

Systematic issue: (1) Opacity model may not capture HDC/NVH well, (2) filter transmission not as assumed

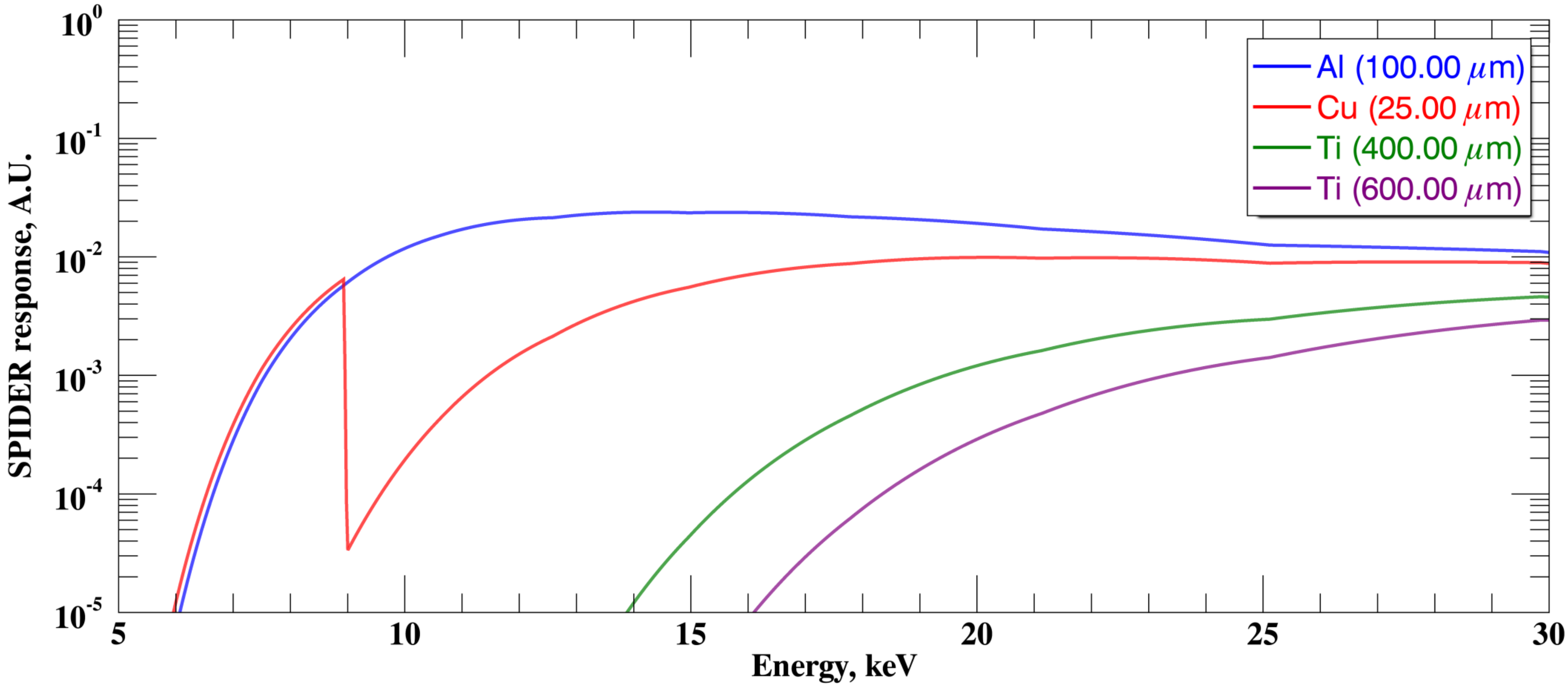
Opacity of fuel, ablator & plasma and uncertainty in filter thickness causes problems



Using thick filters that would sample the continuum region of the hot spot model would eliminate the reliance in opacity models and drastically reduce uncertainty in filter thickness

Continuum model requires two thick filters to solve for T_e; add'l filters for Opacity or Ross pairs

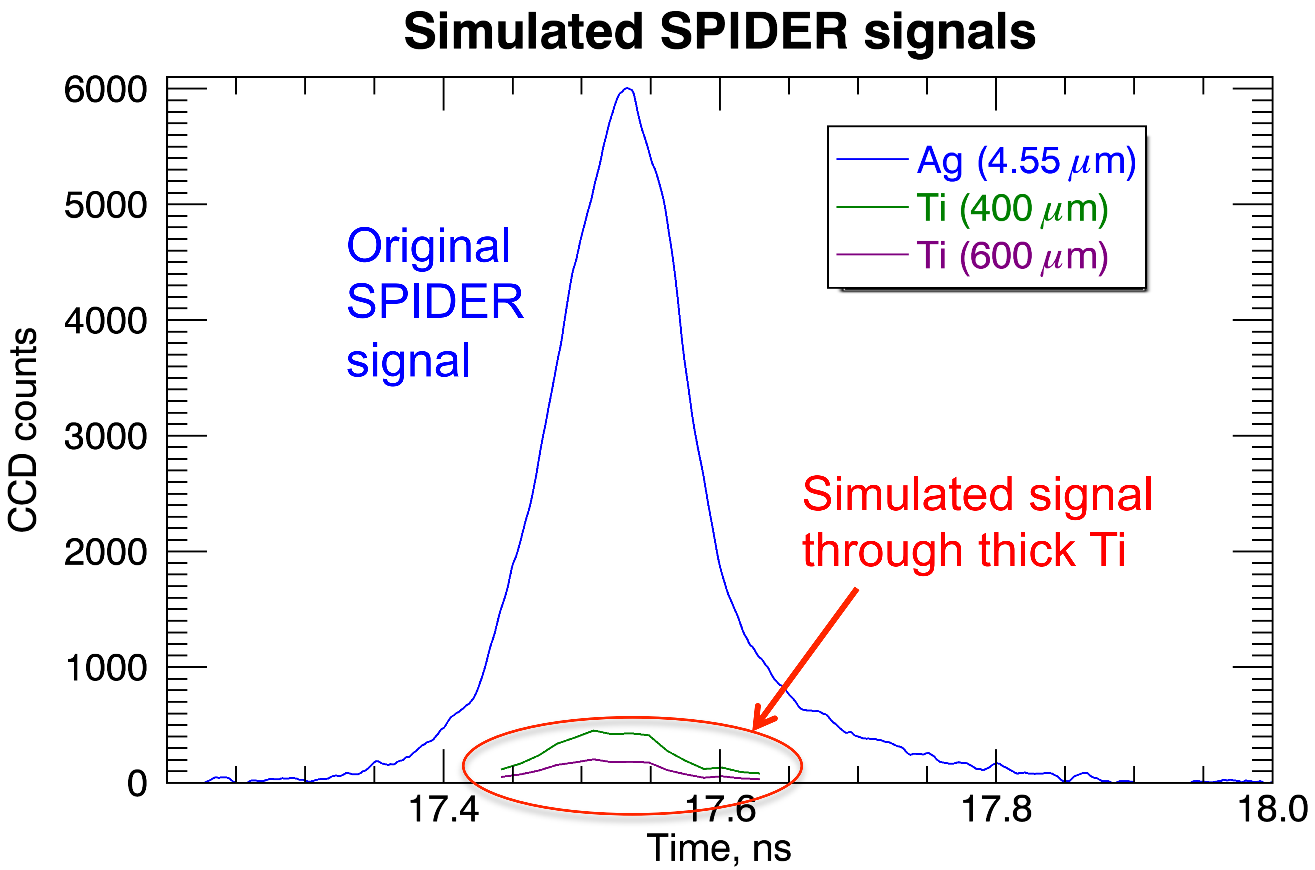
Spectral response using thicker filters



Titanium filters, 400 & 600 µm thickness are one choice that would focus on Continuum slope

Simulating the SPIDER signal through thick Ti gives low signal

Simulation based on the 1st results shown: N150416



SPIDER Signal through thick filters would be close to detector noise: unreliable T_e calculations

DISC would be better for inferring T_e using the continuum slope method

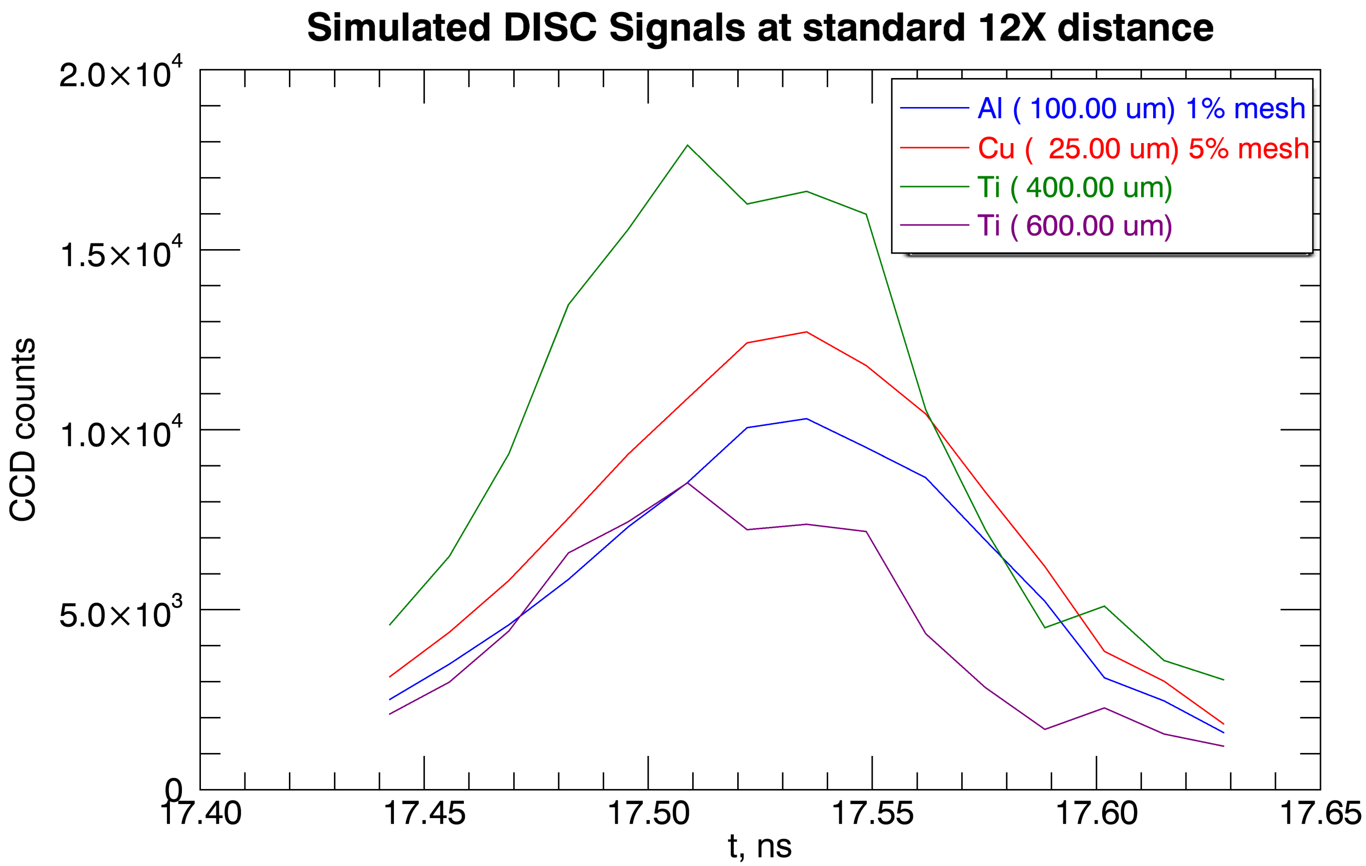
- DISC on a DIM can get ~7X closer to TCC for up to 50X more solid angle than SPIDER
- In order to optimize dynamic range of the streak camera with the other thinner filters, 1% Open Area ratio Gold Mesh (20 micron thick) would be used to reduce signal on thinner filters
- Currently, DISC can't operate in high neutron flux not only due to CCD, but also because the instrument contains components with EEPROM* and micro-controllers

*Electrically Erasable Programmable Read-Only Memory

NIF may build a DISC usable in a high neutron flux similar to the HGXD's

Simulated DISC signal through thick filters would give exceptional S/N

Simulation based on the 1st results shown: N150416



This signal level would theoretically result in good T_e calculations; Possible to use even thicker Ti

Summary

- T_e can be inferred by performing a least squares fit of x-ray signal through certain filters to signal derived from a generalized hot spot model
- The T_e results using data from SPIDER show reasonable time evolution and good agreement with T_{ion} but unrealistic absorption
- There is uncertainty in the opacity model & filter thicknesses
- The continuum slope method may be better for inferring T_e
- DISC would be ideal to record hard x-rays since it can be placed much closer to TCC and detect optimal signal levels using thick filters

NIF may build a DISC usable in a high neutron flux similar to the HGXD's

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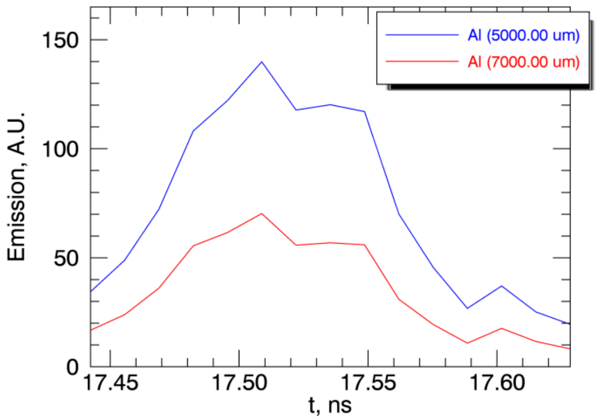
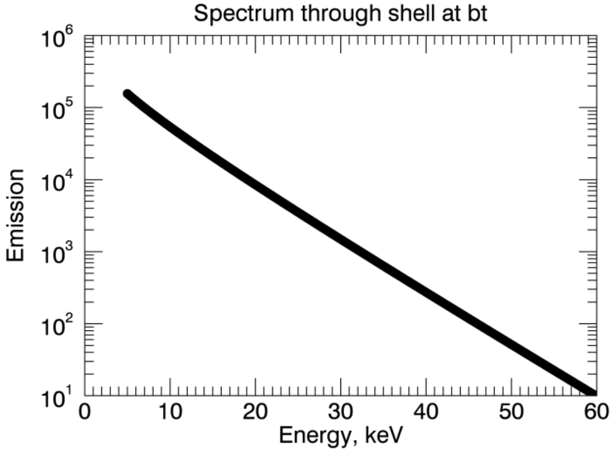
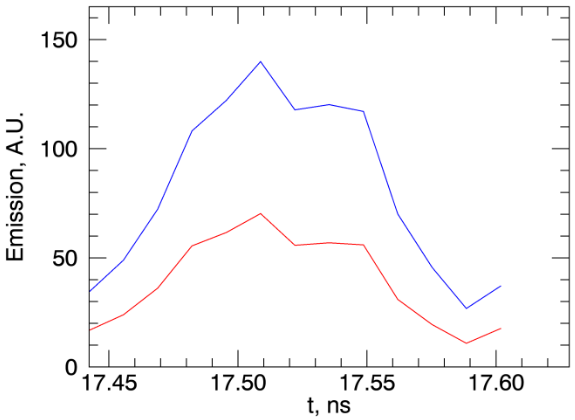
Calculated T_e using simulated signal gives similar values to thinner filter results



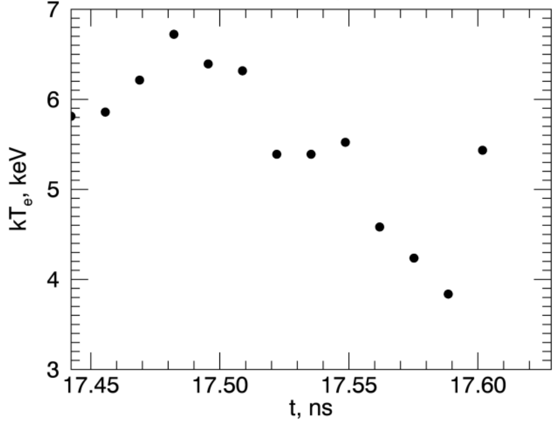
Signal through individual filters



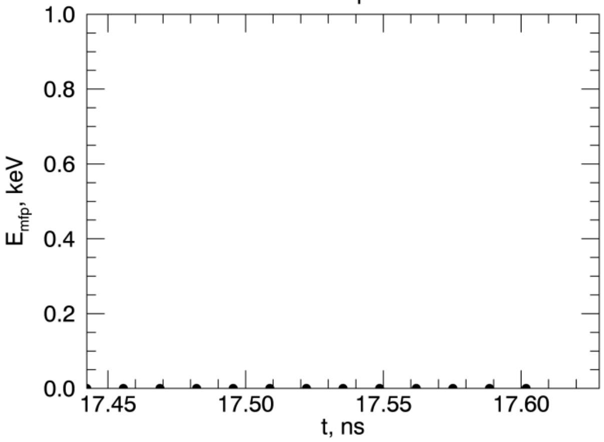
Spectrum through shell at bt



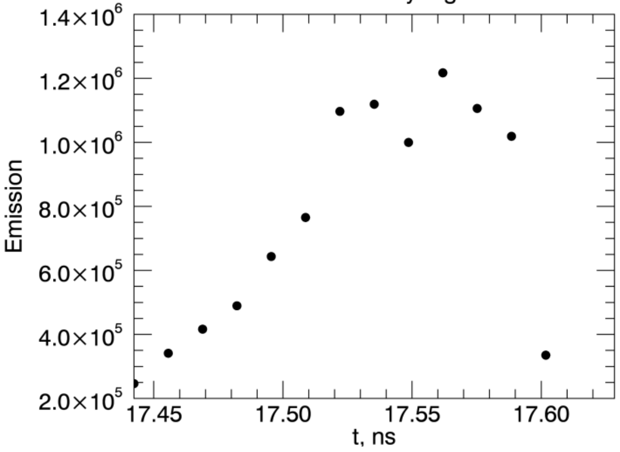
Reproduced Signal



Electron Temperature



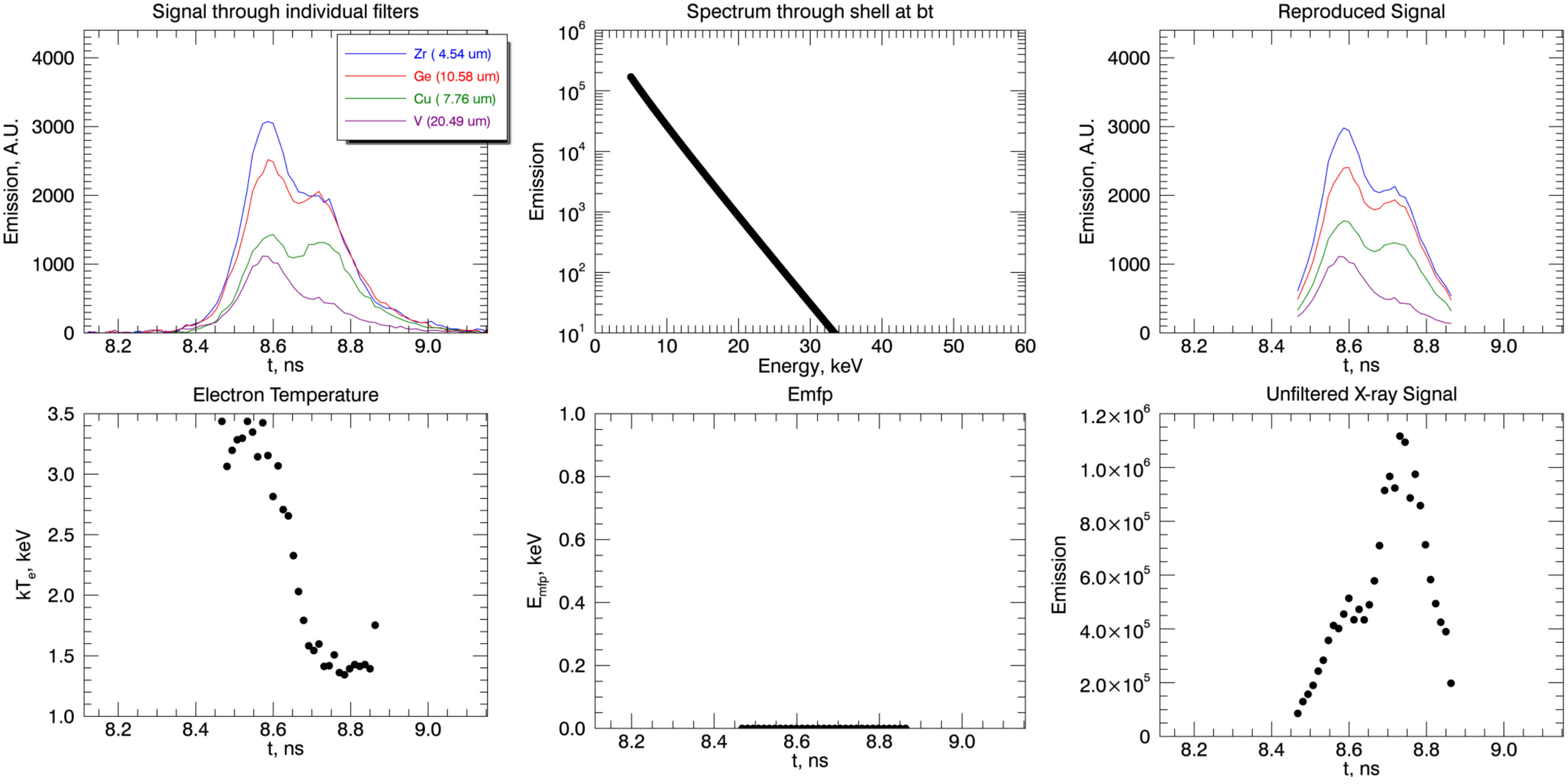
Emfp



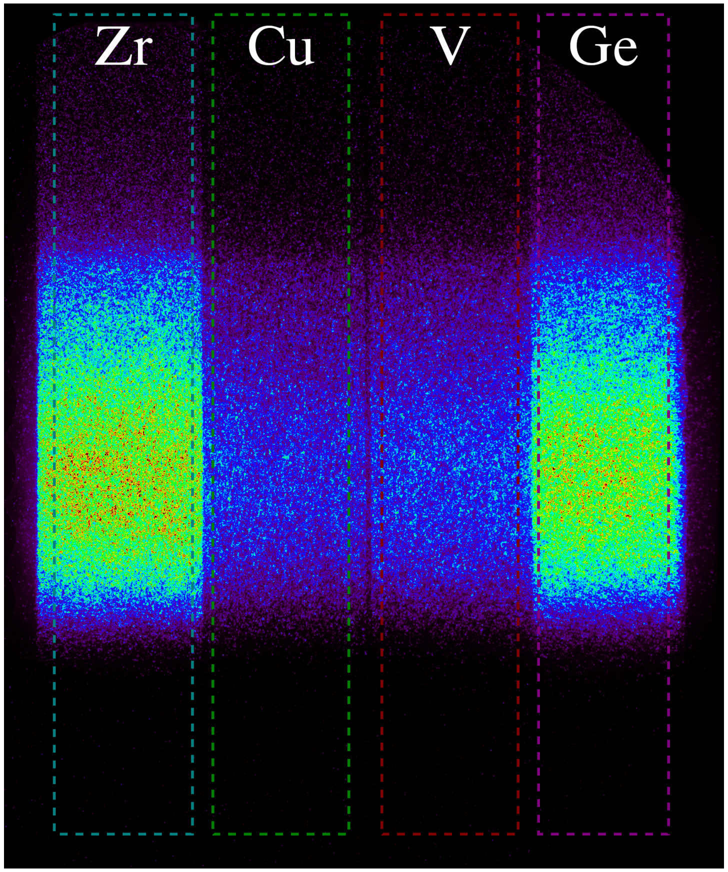
Unfiltered X-ray Signal

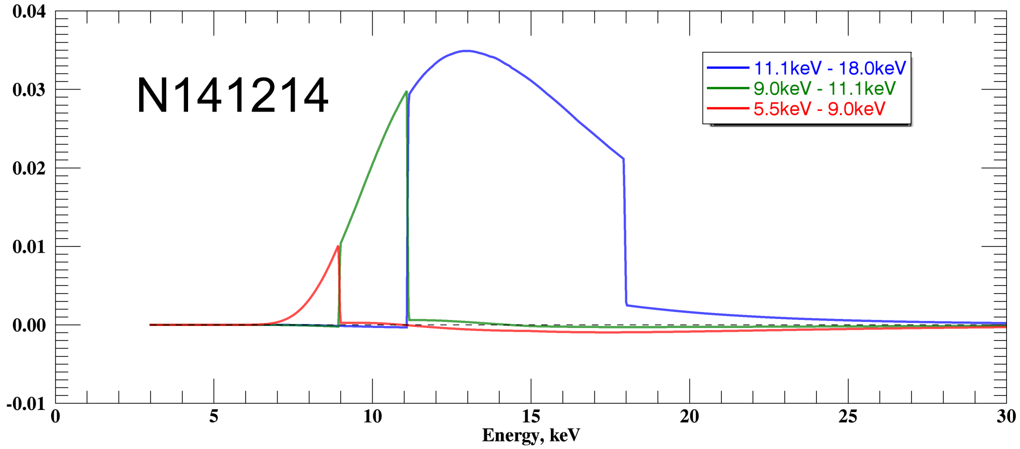
T_e decreases through emission

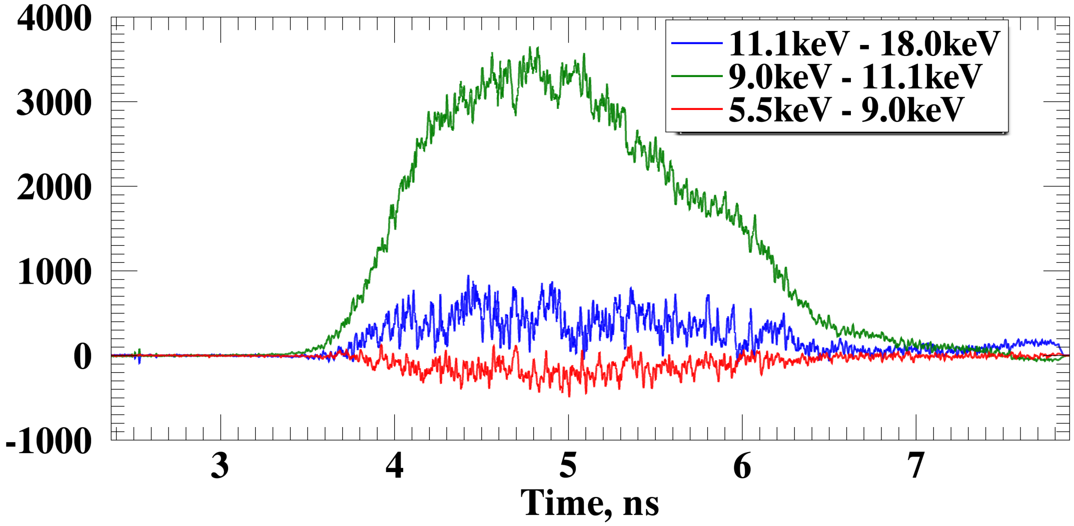
Fixing optical depth at 0, the calculated T_e is within range of T_{ion} and evolves as expected

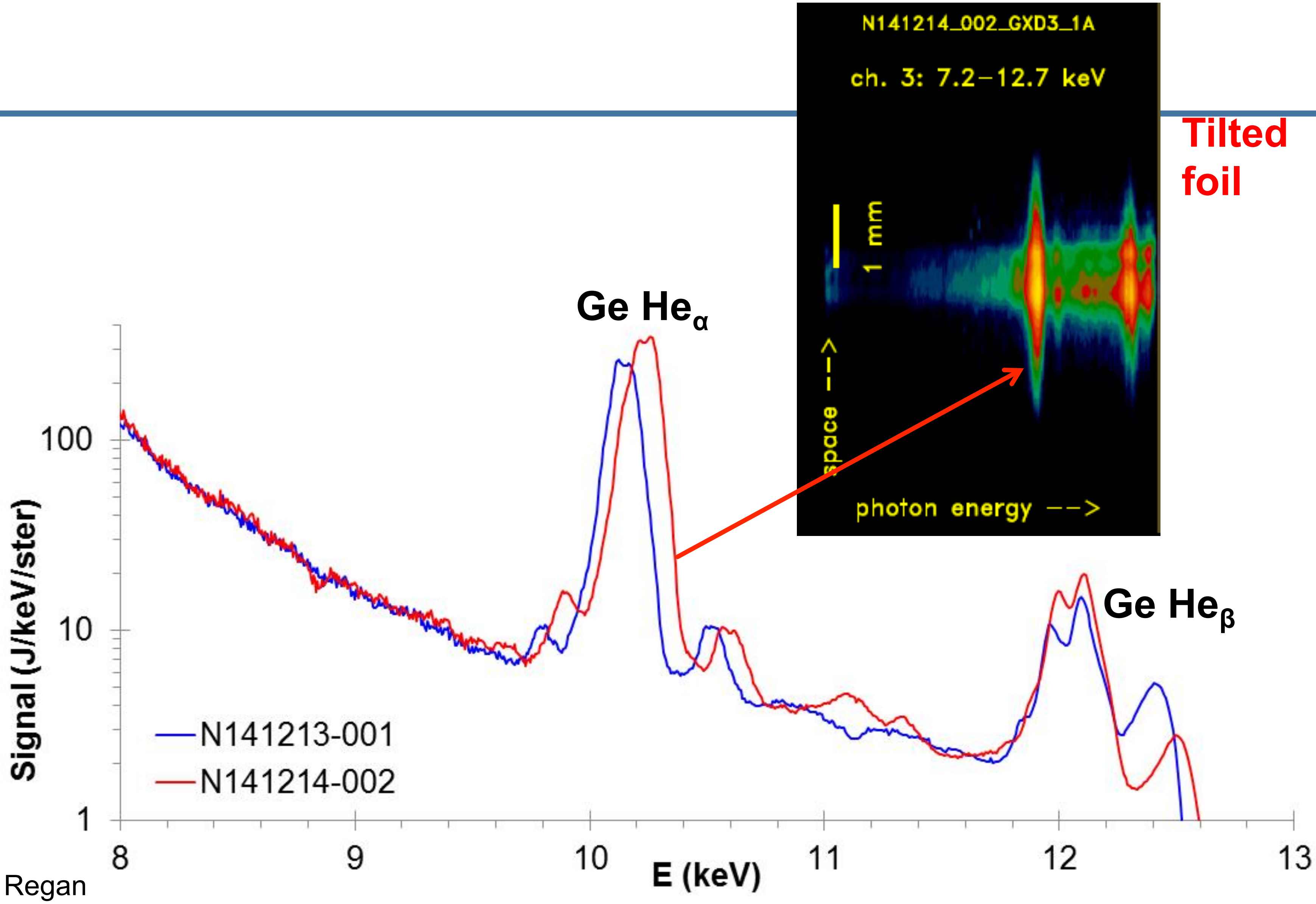


Ge transmission source shows negative Ross pair results even though model shows positive







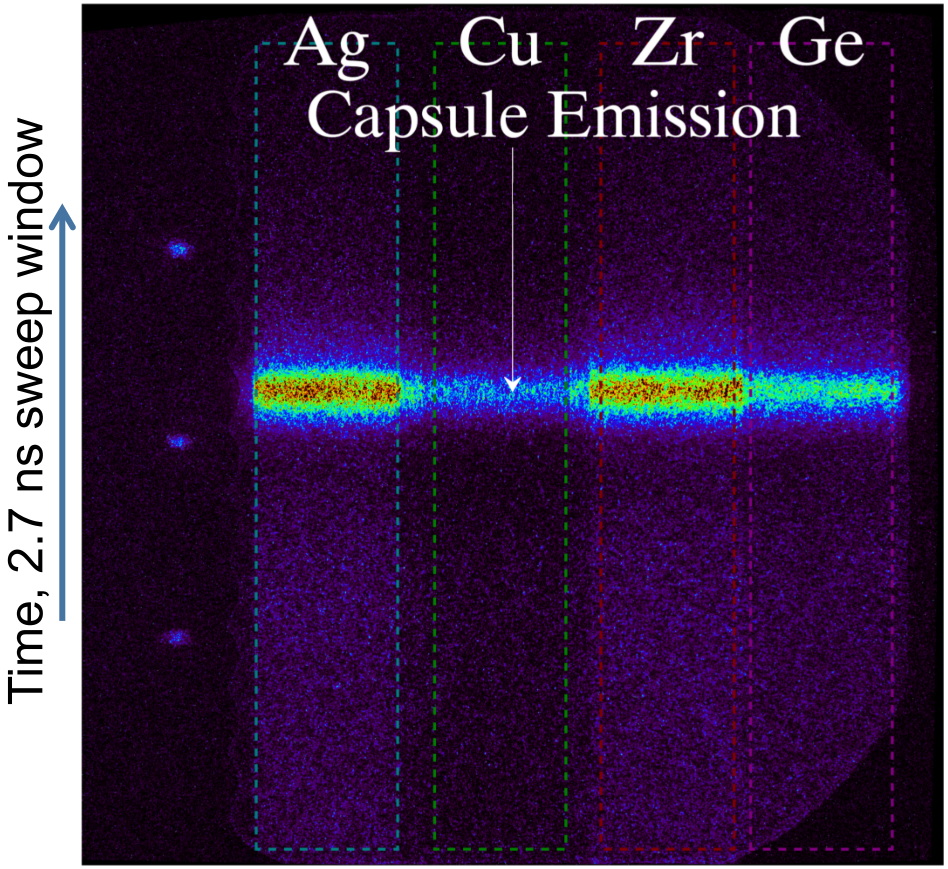


Tilted foil

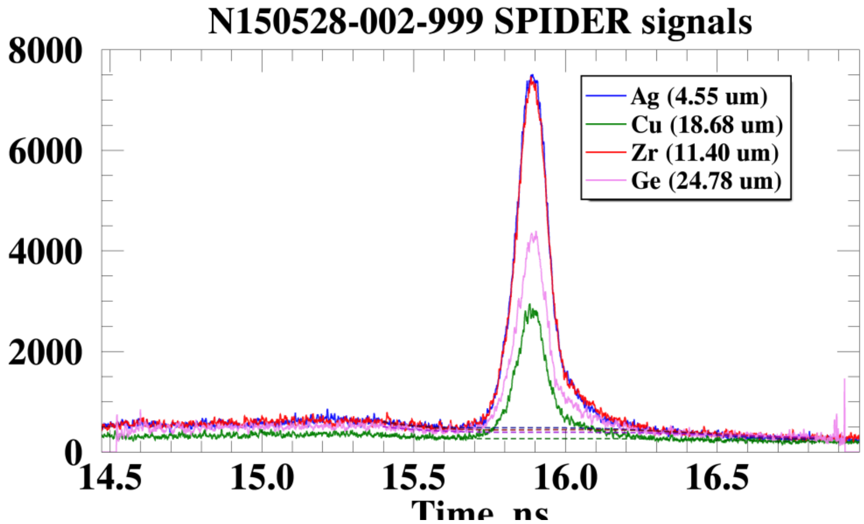
*S. Regan

Analyzed data on another DT symcap shot

DT shot using a 3-shock high foot pulse

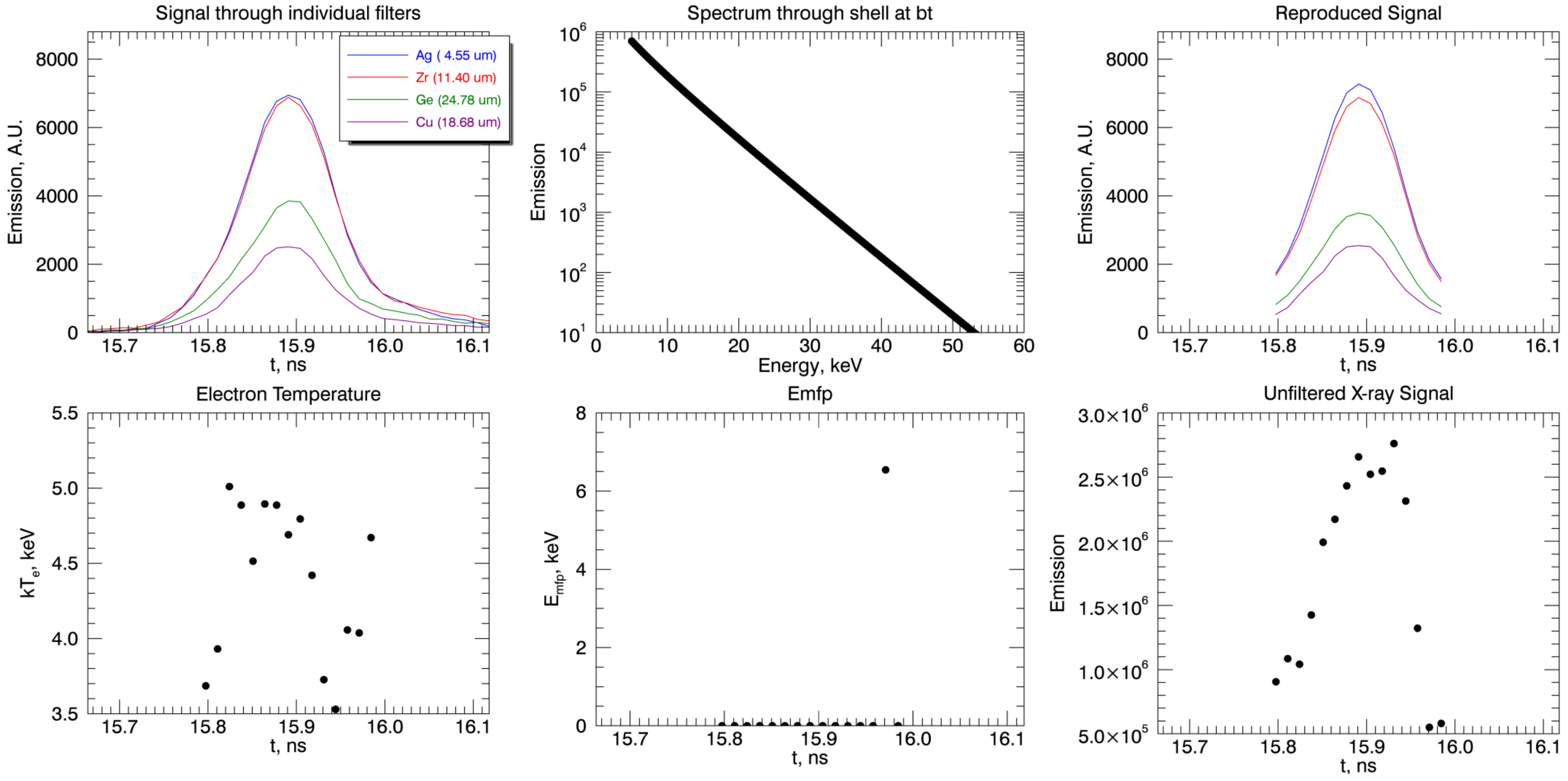


Performance:
DT T_{ion} ≈ 5.1 keV
DT Yield ≈ 6.2e15



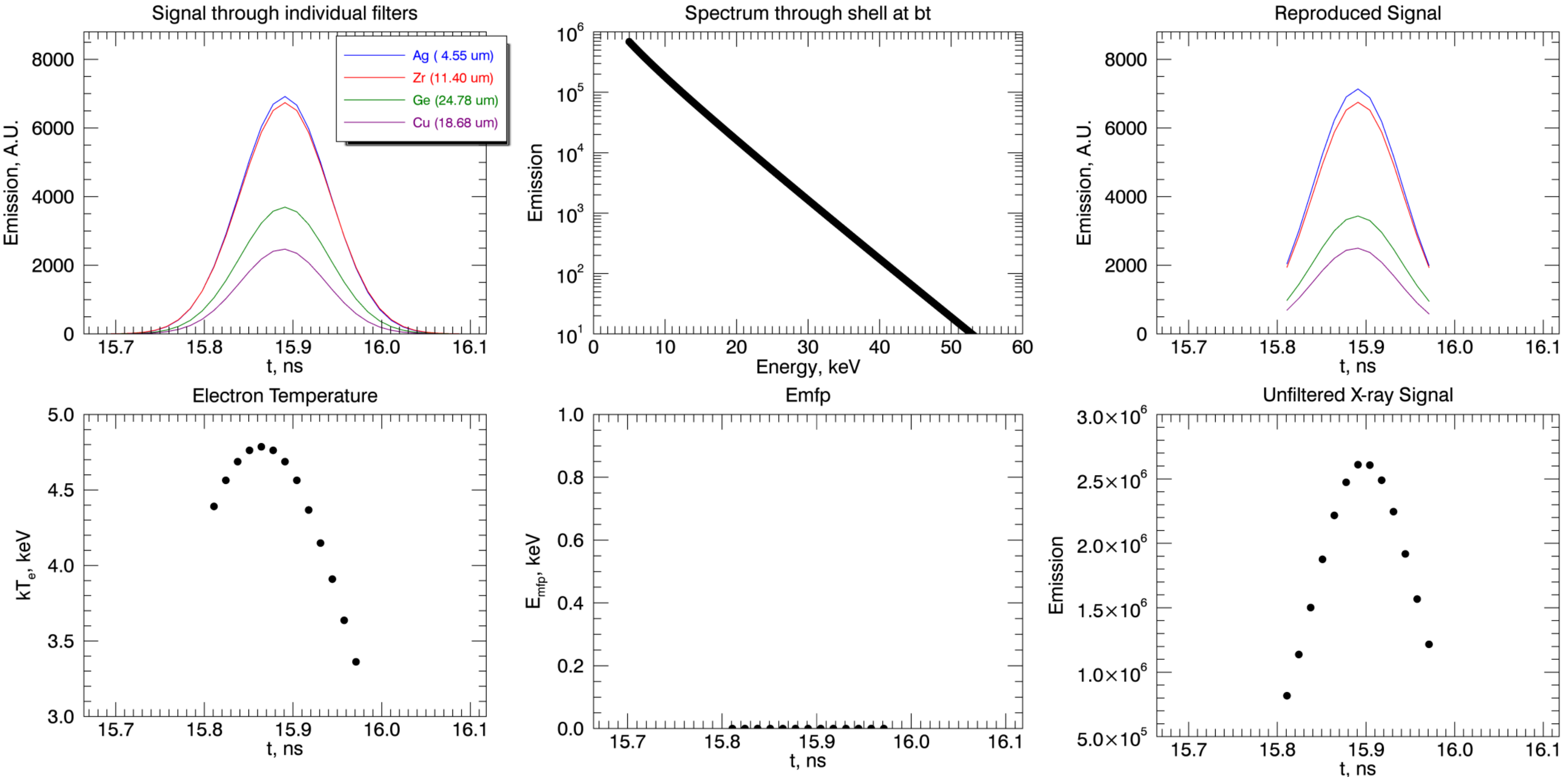
N150528:
High Foot DT, 1.78MJ, 390TW, DU nominal hohl, 1.6mg/cc He fill, 1xSi, T-1 shell, 0.8K quench, P1 asymmetry imposed ice layer

Calculated peak T_e is close to time-integrated T_{ion} measurement of 5.1 keV



T_e increases then decreases through x-ray emission

Calculated evolution of T_e is very smooth if using a Gaussian fit of the signal



T_e increases then decreases smoothly