3-D electron temperature and X-ray emission tomography of the ICF hotspot at the National Ignition Facility

APS DPP annual meeting 2020 poster session

November 13th, 2020

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Benjamin Bachmann

LLNL-PRES-816266, LLNL-VIDEO-816365

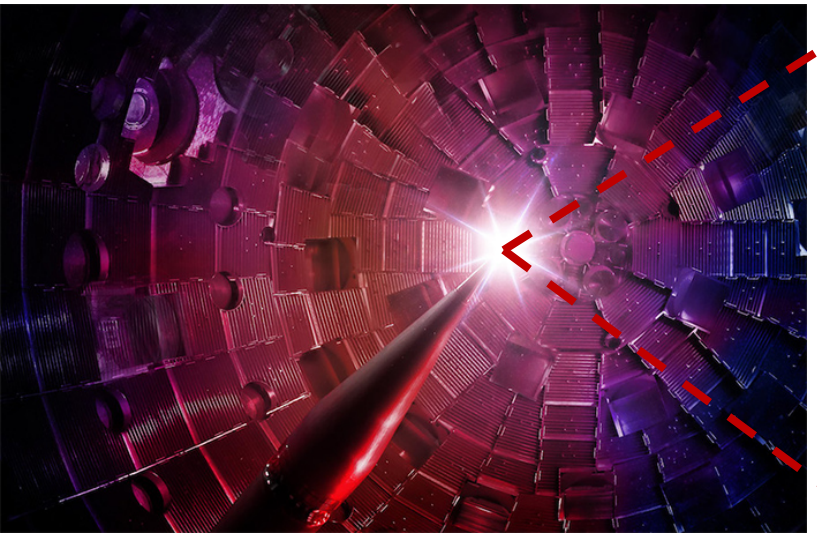
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

Measuring 3D electron temperature of the ICF hotspot is feasible

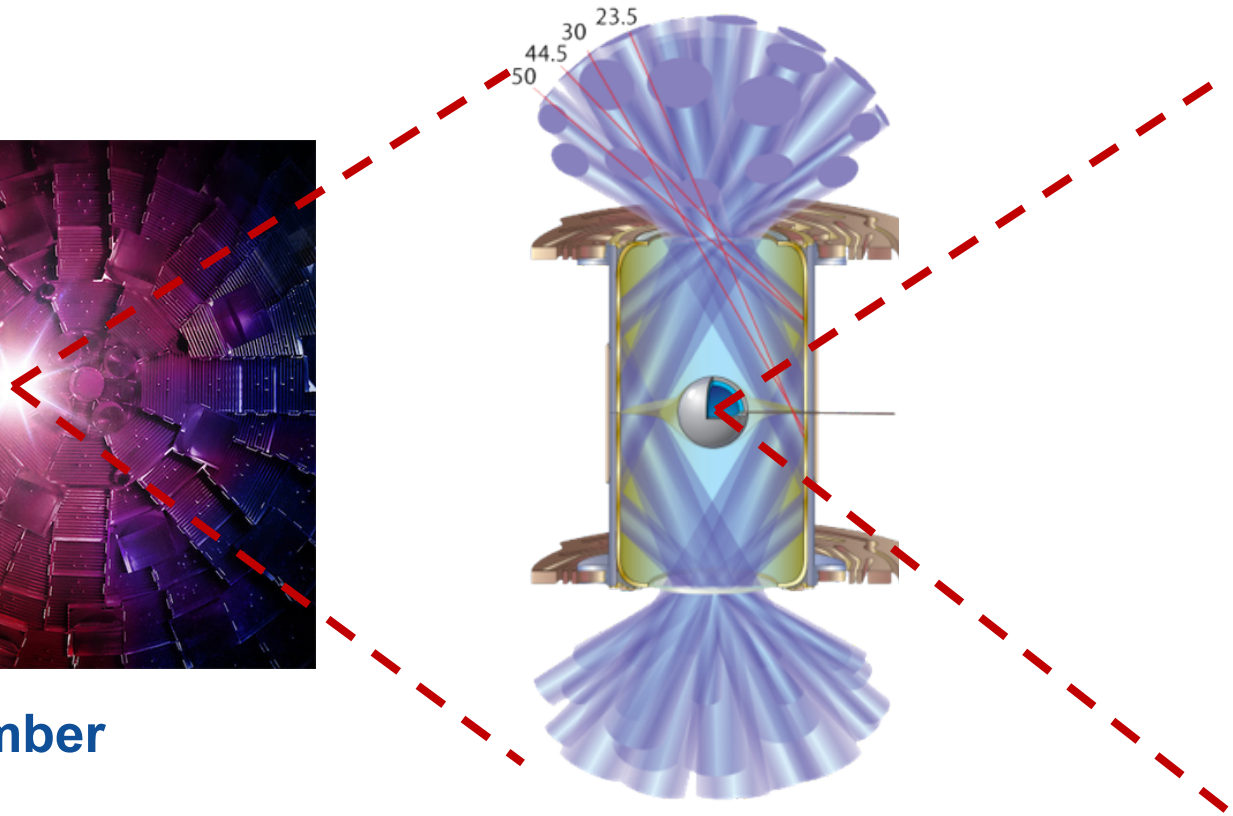
We have

- tested iterative algebraic method ART to reconstruct 3D X-ray emission distributions of the ICF hotspot.
- obtained 3D X-ray reconstructions with two or three LOS and made 3D electron temperature T_e measurement in the ICF hotspot using synthetic and experimental data
- laid out a future path on how to perform 3D T_e measurement on the NIF.

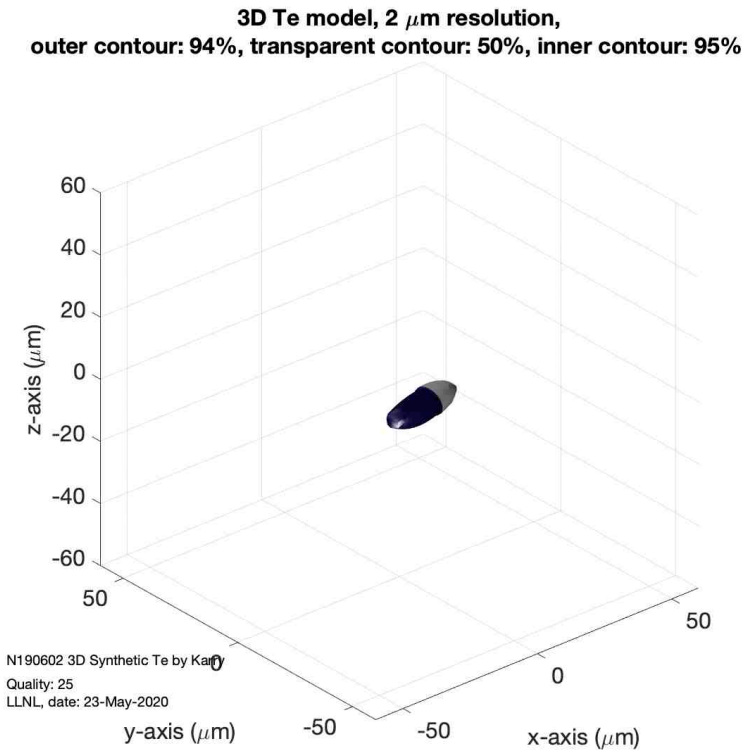
3D hotspot electron temperature T_e measurements can help to further our understanding of the ICF stagnation physics



NIF target chamber



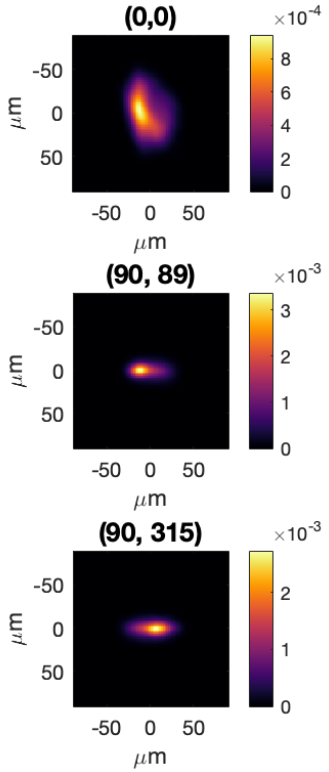
Hohlraum



Hotspot T_e distribution

We reconstruct 3D X-ray emission distributions from 2D projections and infer T_e using different X-ray energy channels

Input:
X-ray images



Our goal is to reconstruct a 3D T_e distribution of the hotspot plasma using very few 2D X-ray images from different directions.

Previous work done on 3-D reconstructions of neutron/x-ray source from 2-D projections. Ref:

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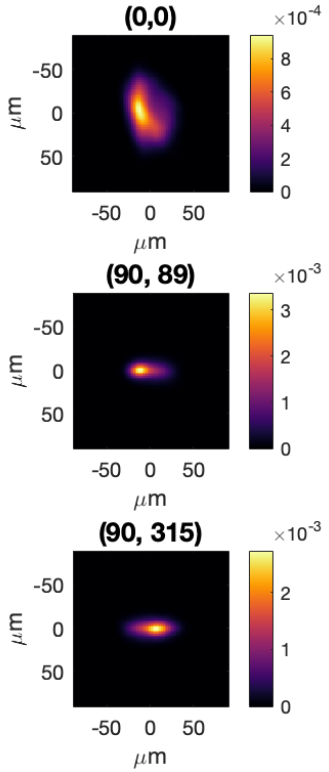
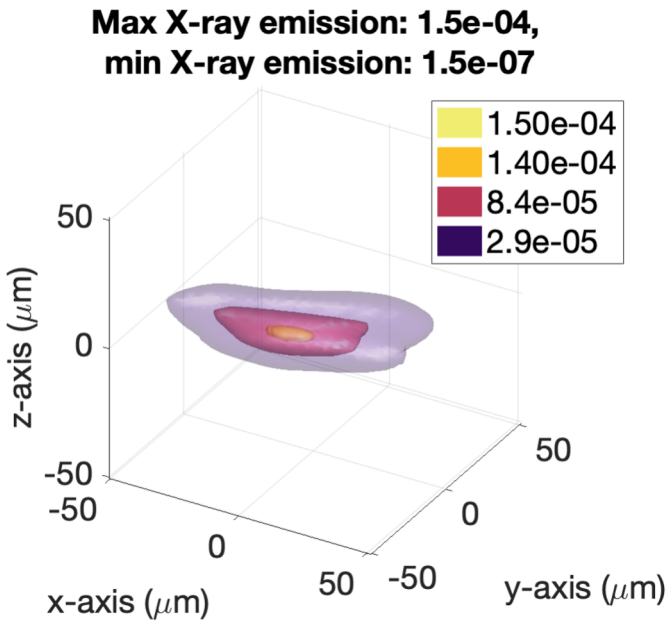


3D X-ray reconstruction



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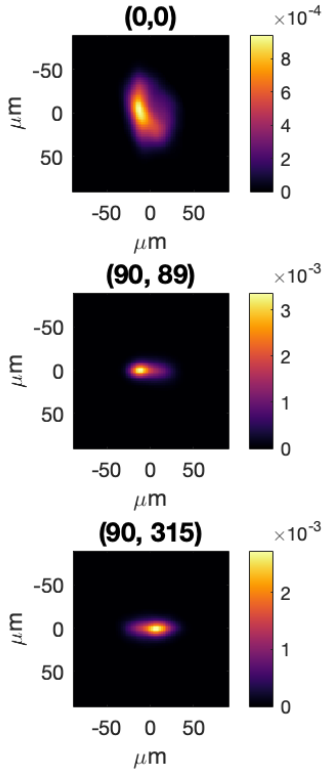
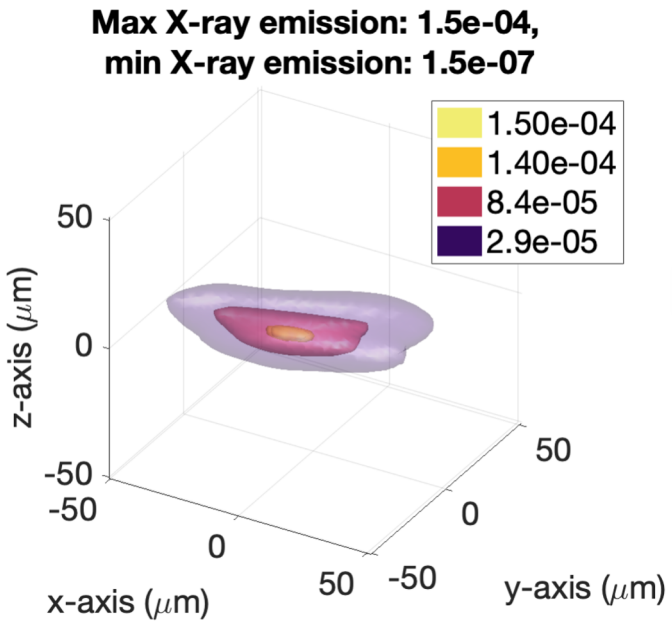
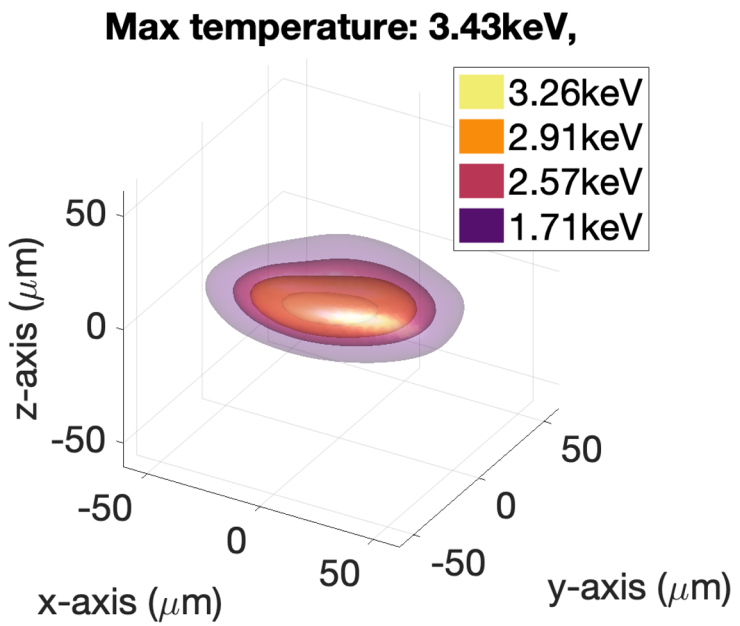


3D X-ray reconstruction



3D Te measurement



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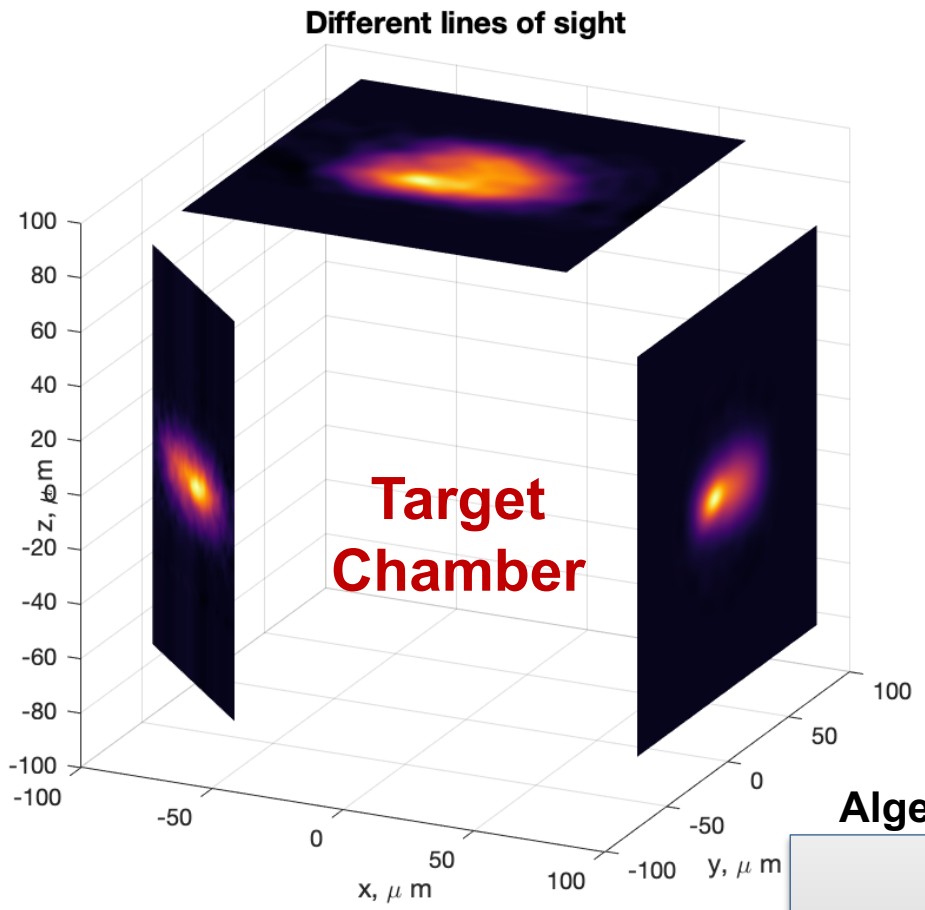
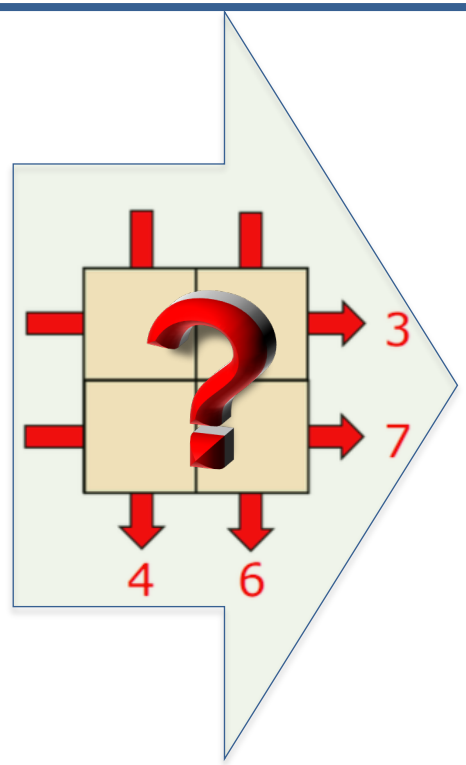
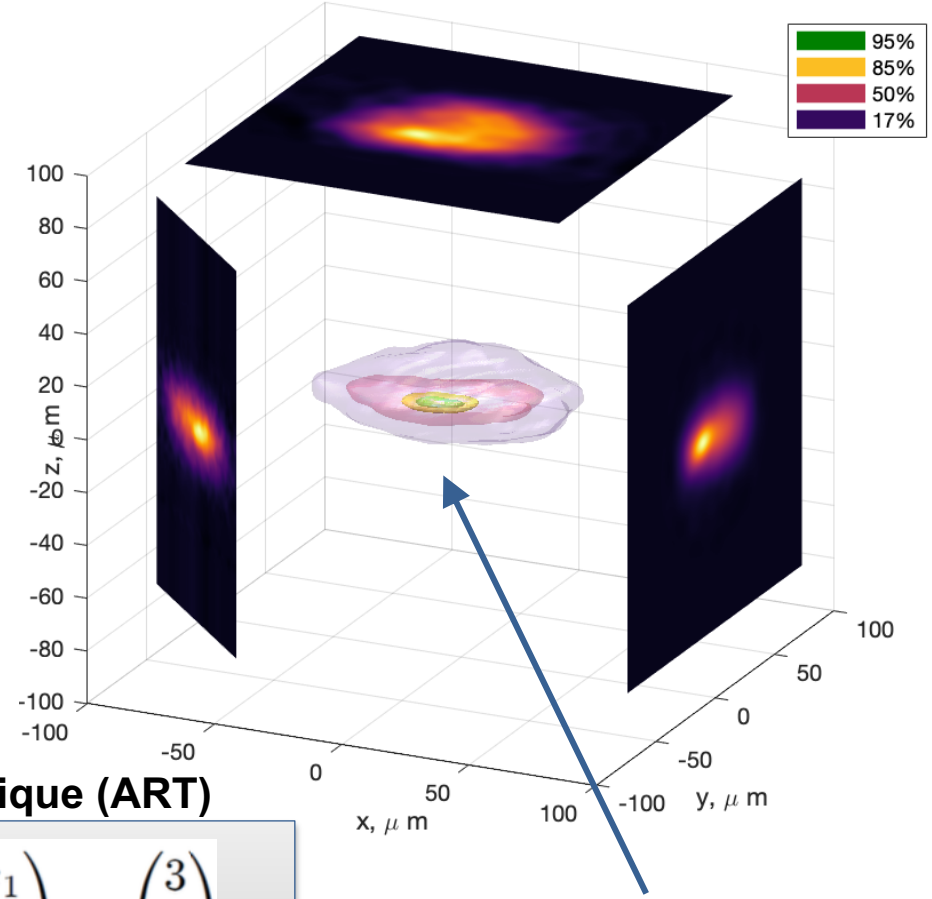
2. Volegov et al., On three-dimensional reconstruction of a neutron/x-ray source from very few two-dimensional projections. J. Appl. Phys. 2015

Step 1: We reconstruct 3D X-ray emission distribution using very few 2D X-ray projections via ART – like solving a "3D Sudoku" puzzle







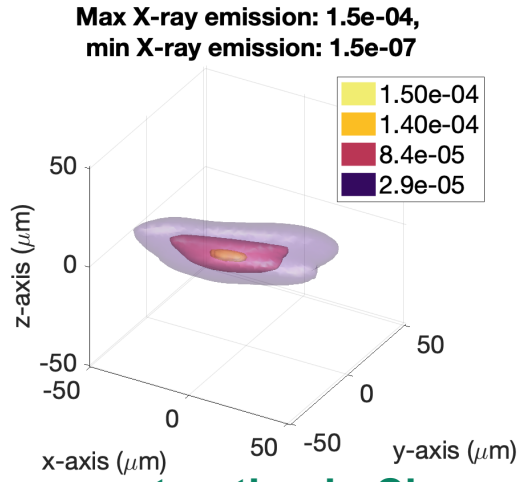
Reconstructed hotspot X-ray emission

Algebraic Reconstruction Technique (ART)

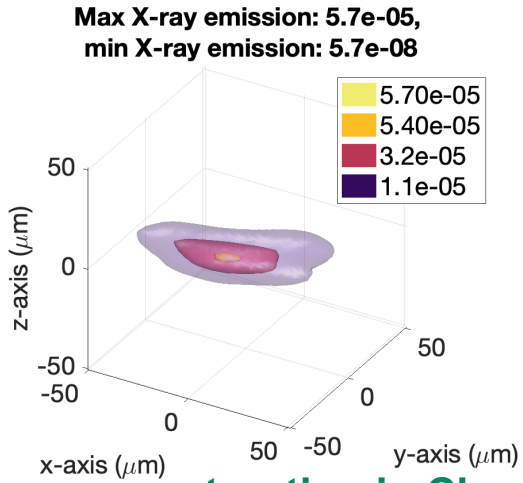
Solve $Ax = b$

$$\begin{pmatrix} 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \\ 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{pmatrix} = \begin{pmatrix} 3 \\ 7 \\ 4 \\ 6 \end{pmatrix}$$

Step 2: We compute T_e measurement from the ratio of detected X-ray emission values in channels 1 and 2



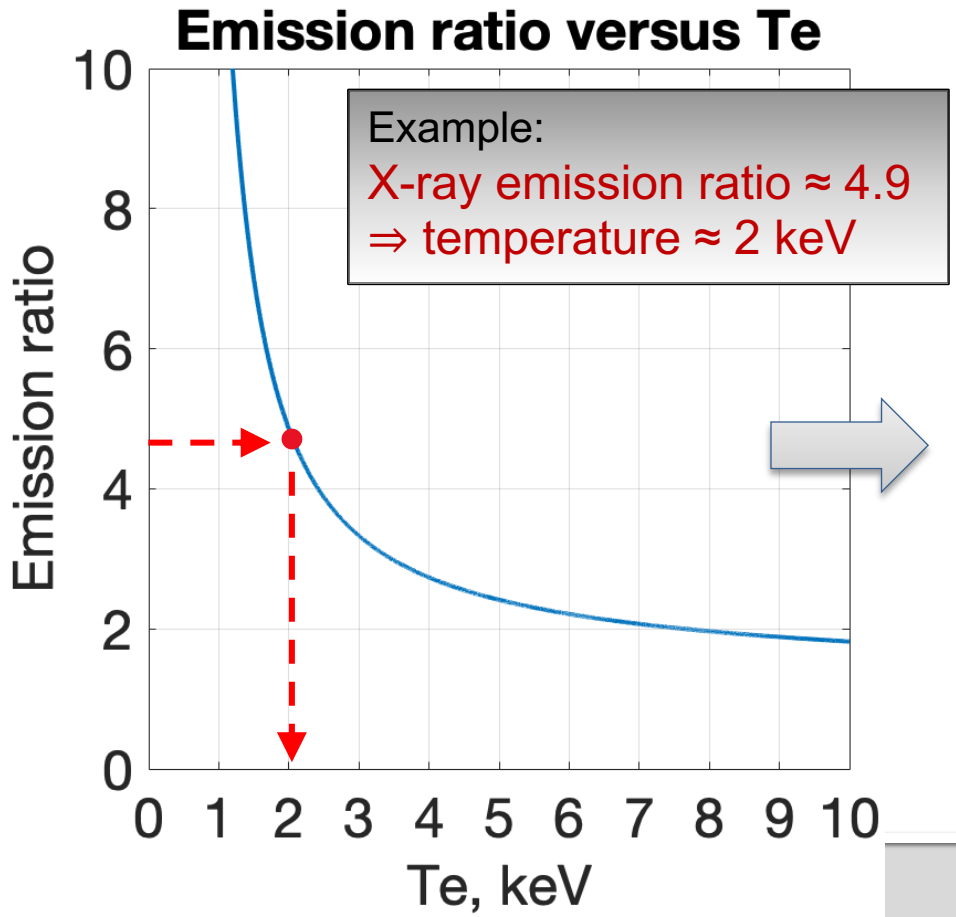
X-ray reconstruction in Channel 1

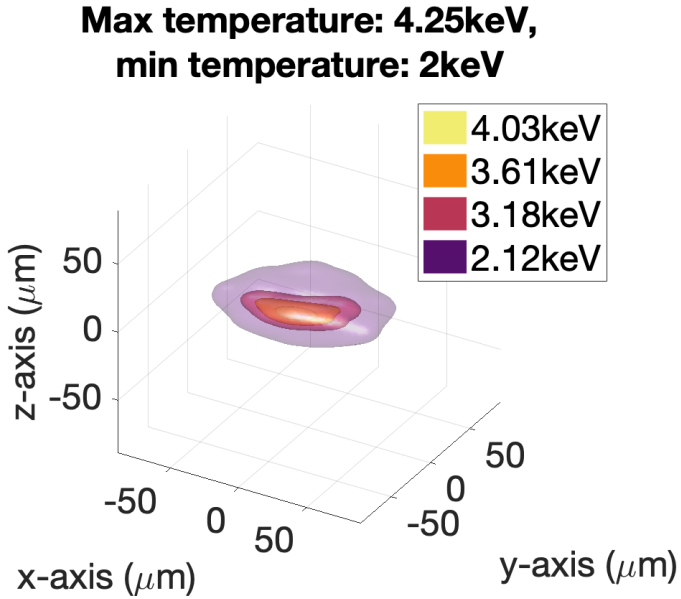


X-ray reconstruction in Channel 2

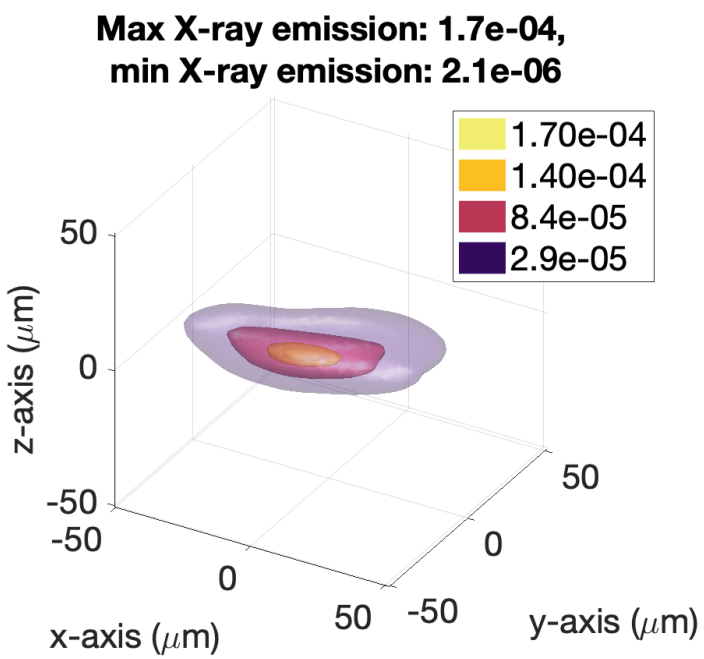
$$f(T_e) = \frac{\tilde{\varepsilon}_1(T_e)}{\tilde{\varepsilon}_2(T_e)} = \frac{\int \varepsilon(h\nu, T_e) \cdot s_1(h\nu)\, d(h\nu)}{\int \varepsilon(h\nu, T_e) \cdot s_2(h\nu)\, d(h\nu)},$$

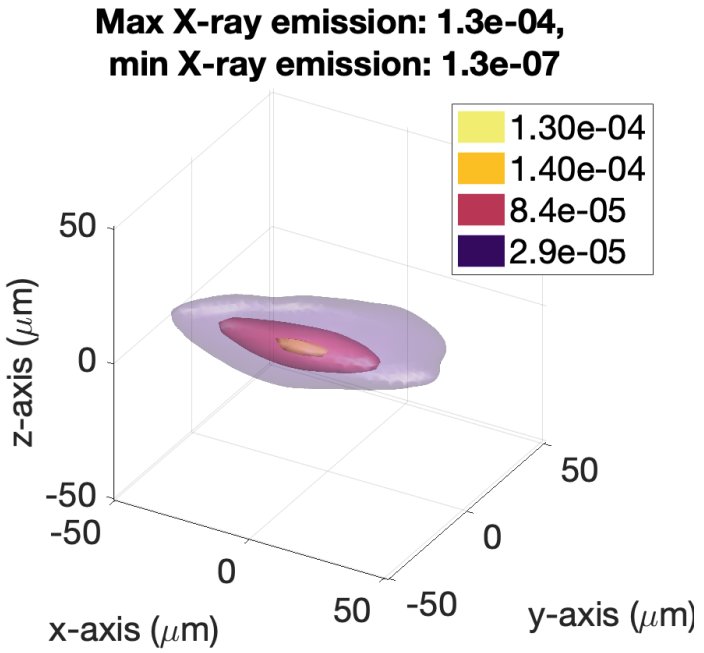
$\tilde{\varepsilon}$ detected x-ray emission
ε x-ray emission
s_i system response

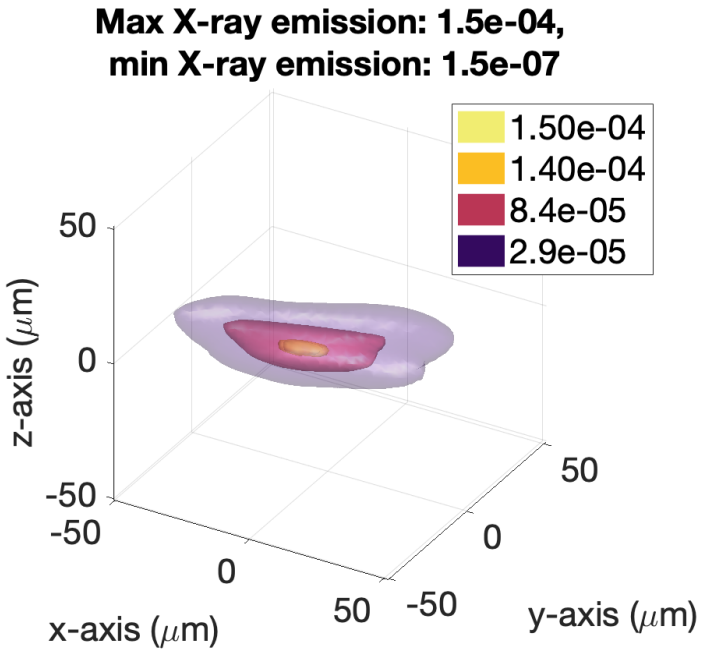




Synthetic data study: 3D X-ray reconstructions with two versus three LOS





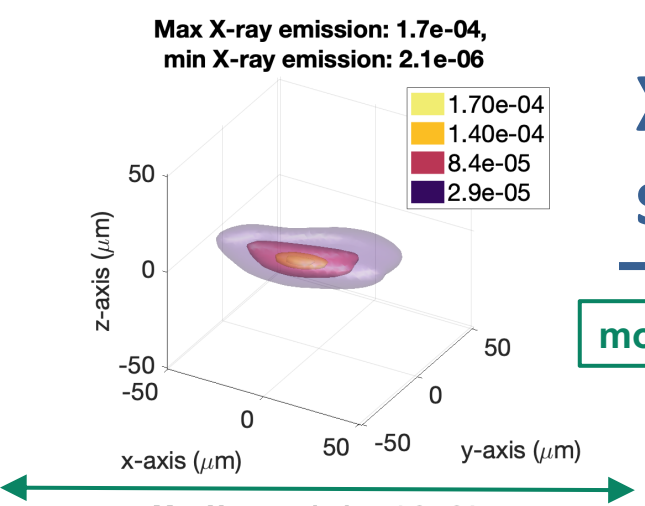


Synthetic data | **Reconstruction using 2 LOS** | **Reconstruction using 3 LOS**

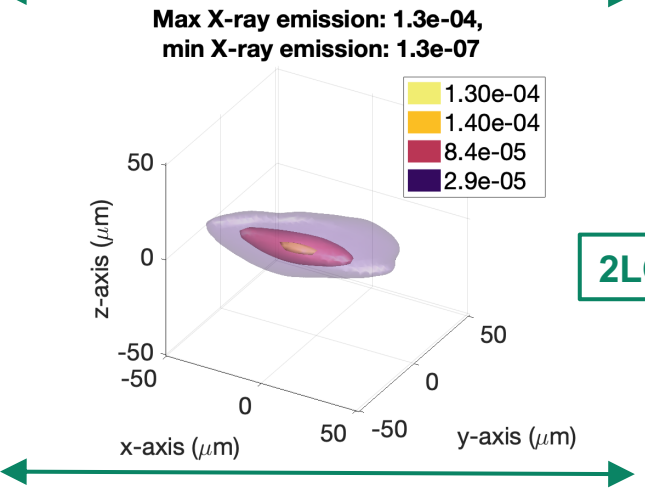
Contour percentages from innermost to outermost: **95%, 85%, 50%, 17%**

Reconstruction using three LOS has a more similar shape to the original model

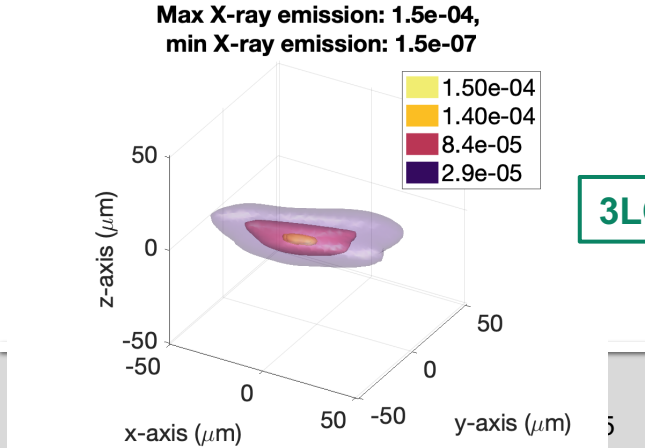
X-ray reconstructions using 3 LOS agree better with synthetic models than using 2 LOS



model



2LOS



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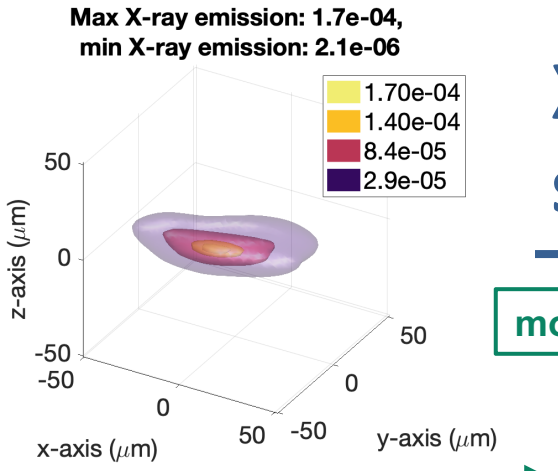

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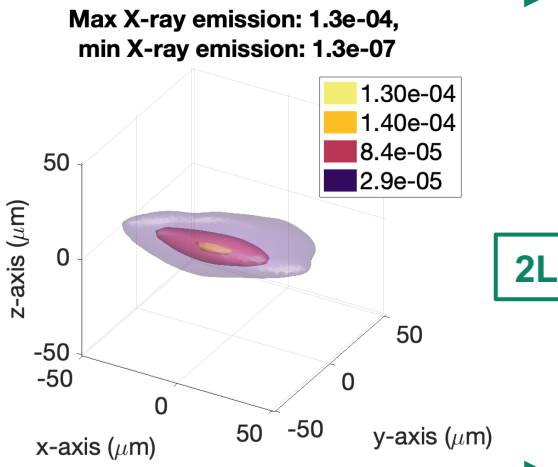

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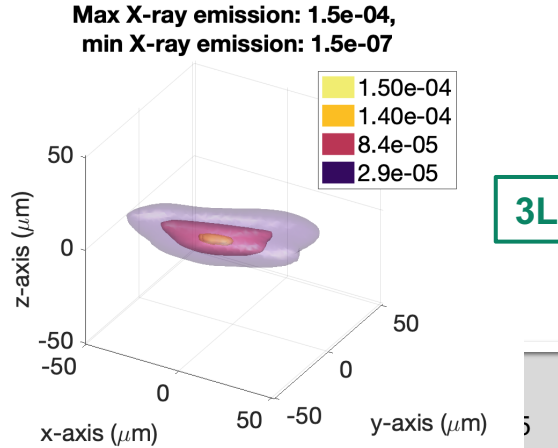

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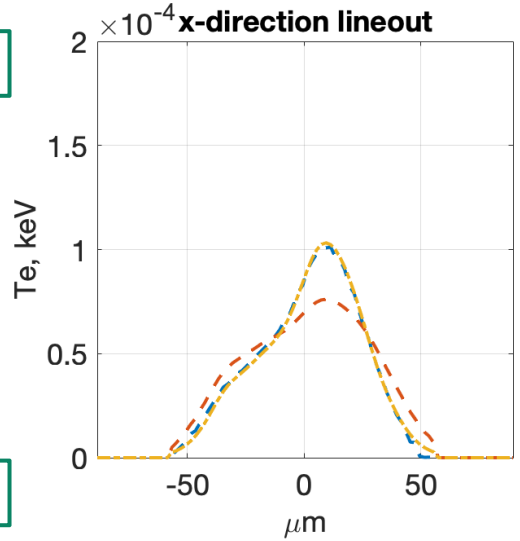

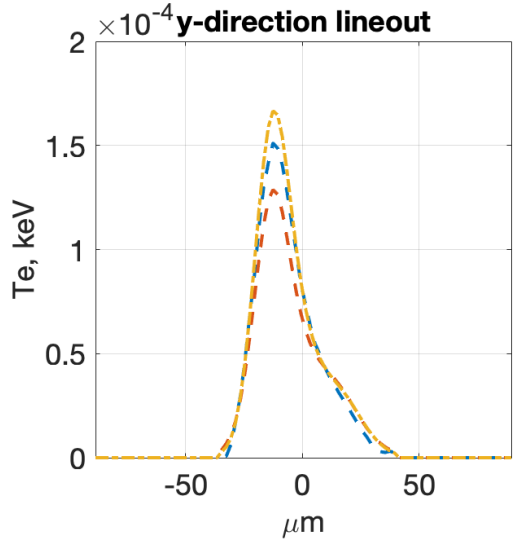

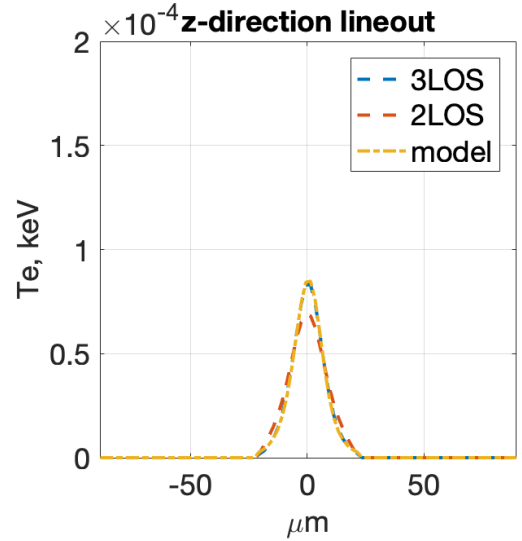

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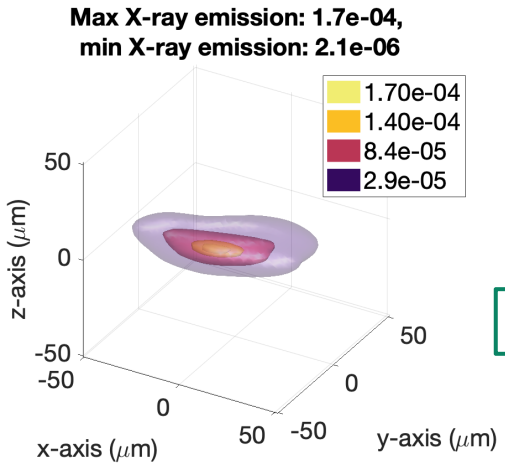

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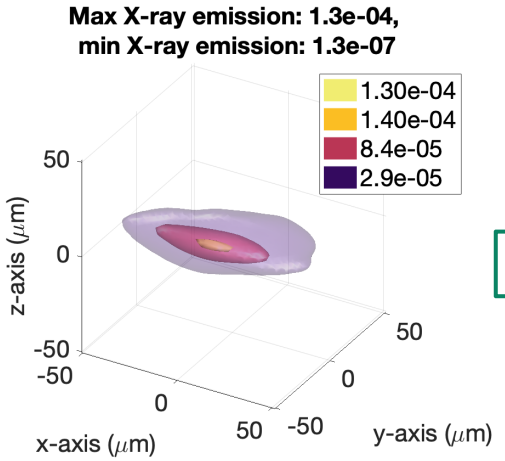

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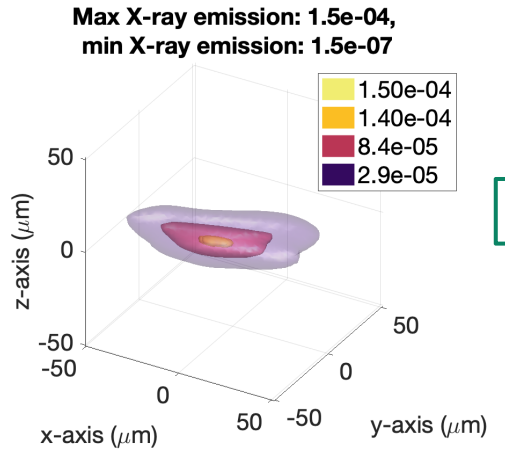

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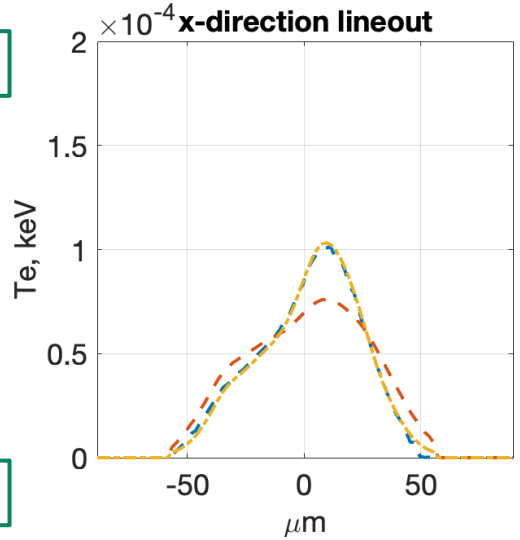
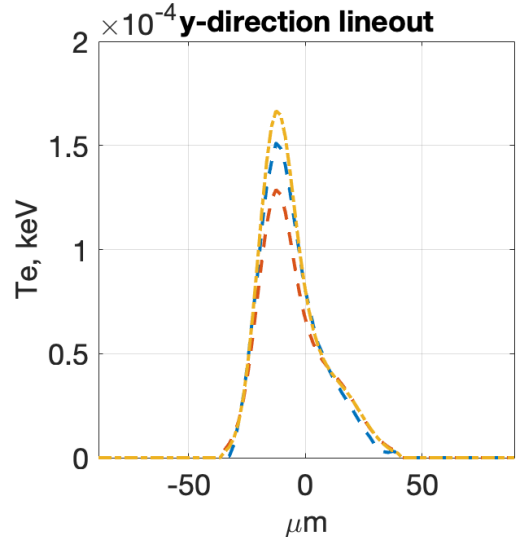
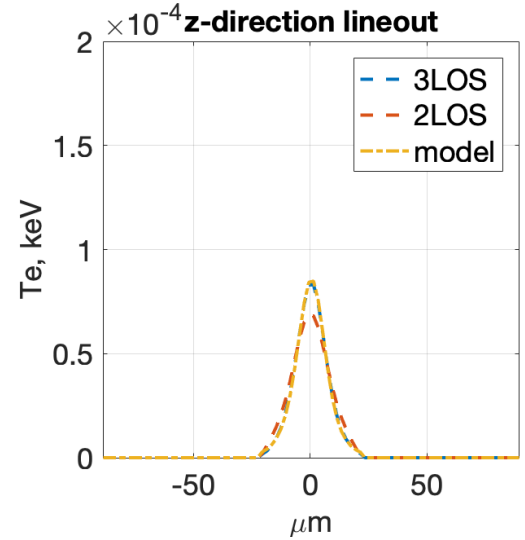
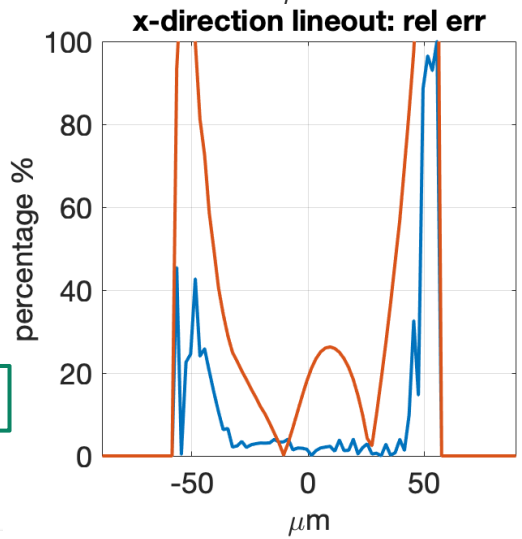
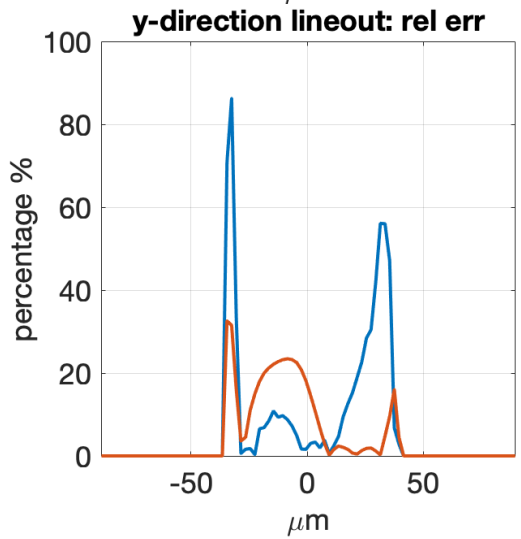
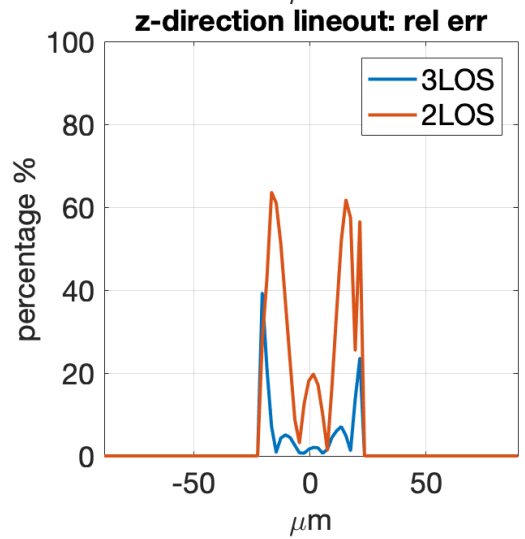




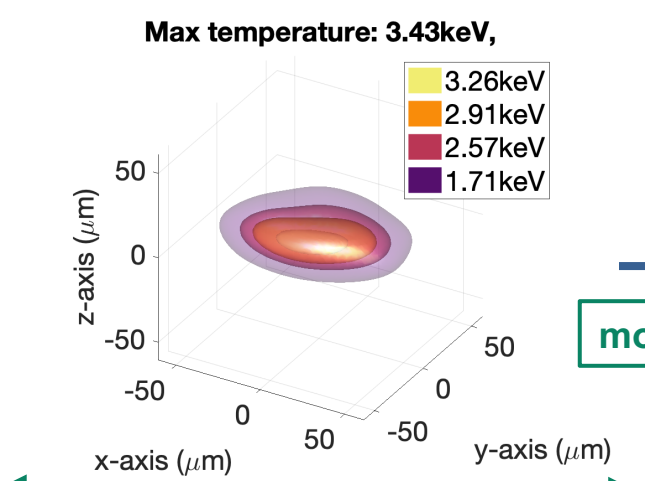








Relative T_e errors improve to below ~10% by fielding a third LOS



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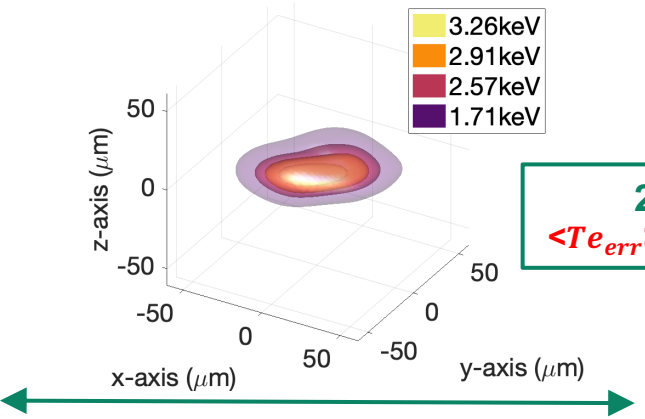
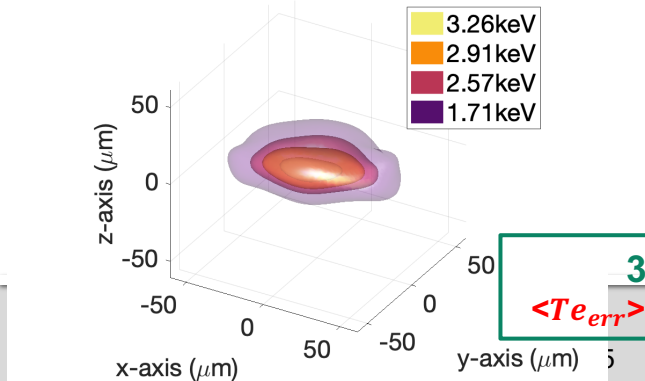


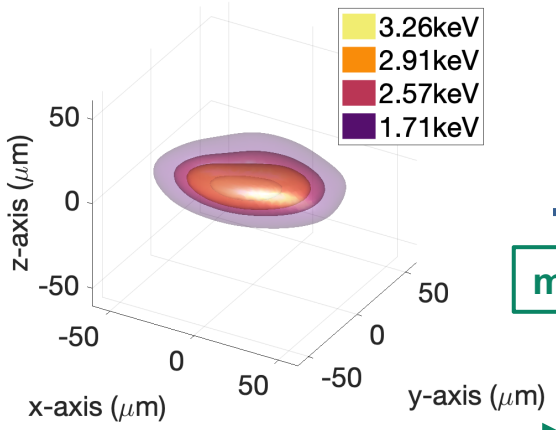
2LOS
<Te_{err}> = 0.26keV



3LOS
<Te_{err}> = 0.094keV

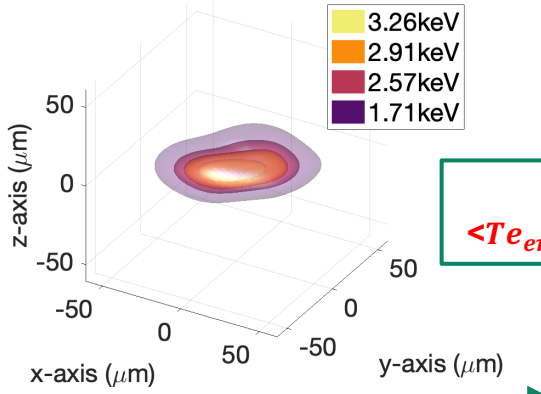
Relative T_e errors improve to below ~10% by fielding a third LOS

Max temperature: 3.43keV,



model

Reconstructed model - <Te error> = 0.26keV,
max temperature: 3.52keV



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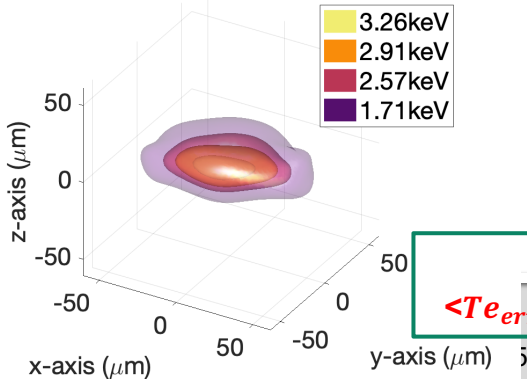
Reconstructed model - <Te error> = 0.094keV,
max temperature: 3.46keV



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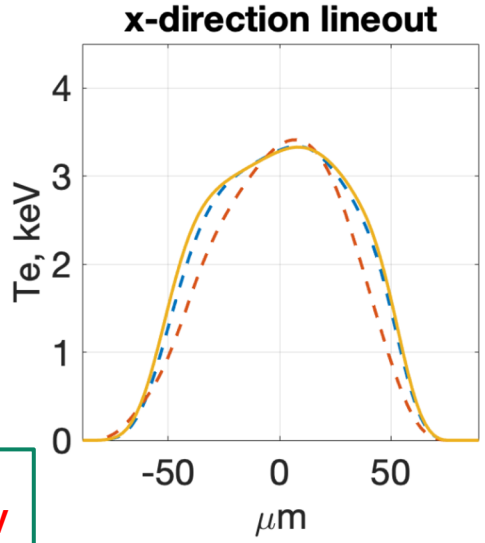

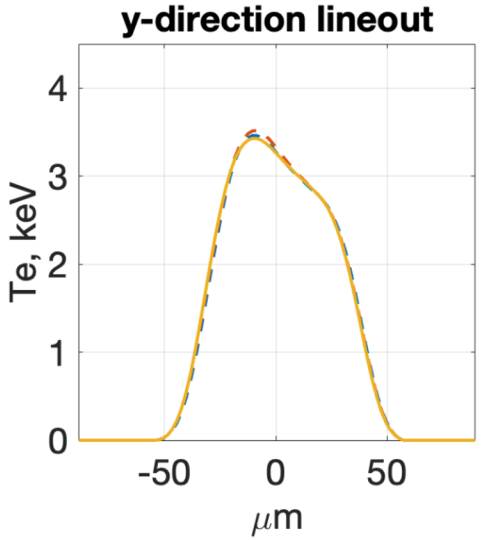

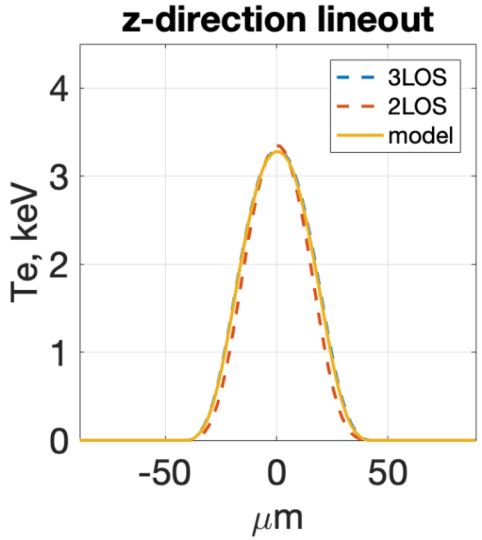

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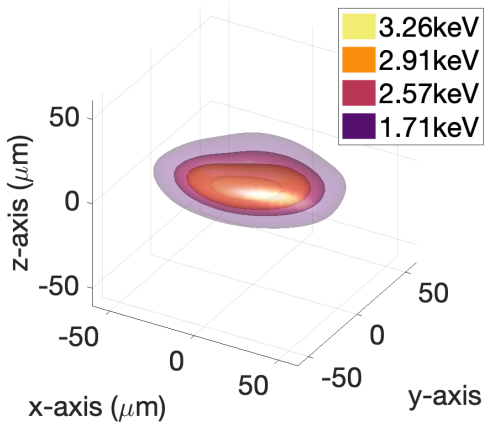

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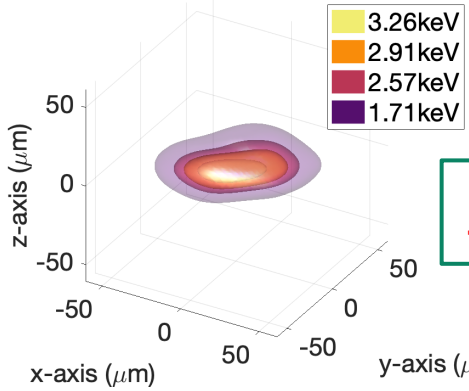

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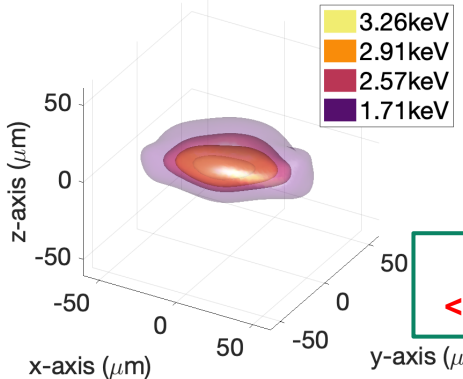

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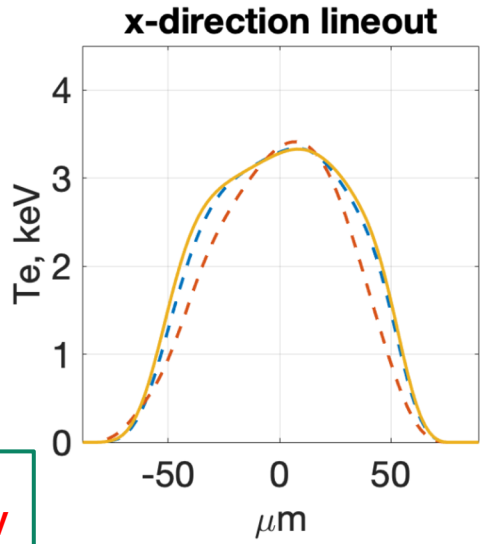
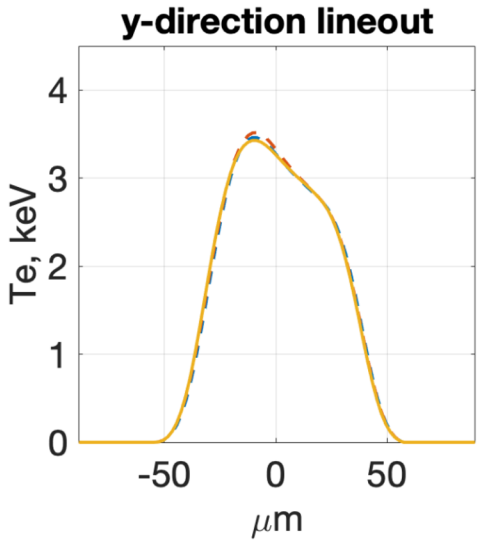
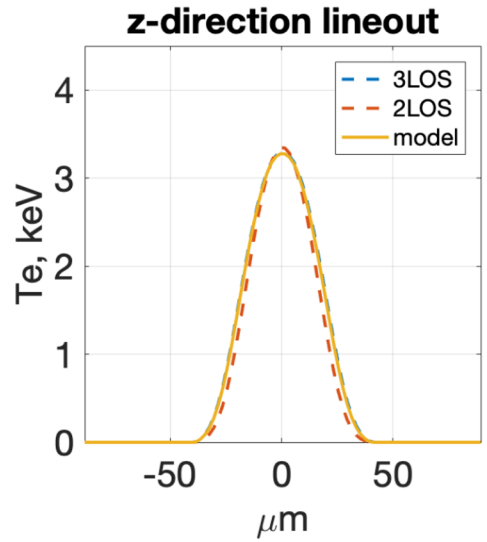
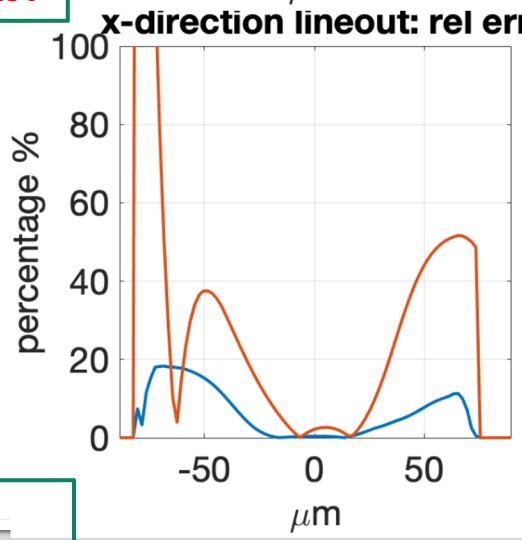
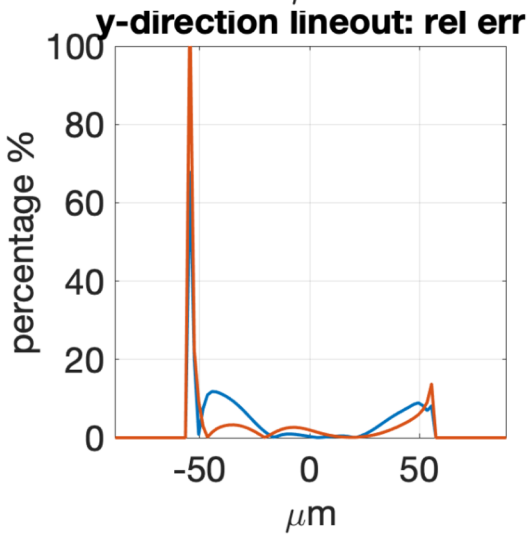
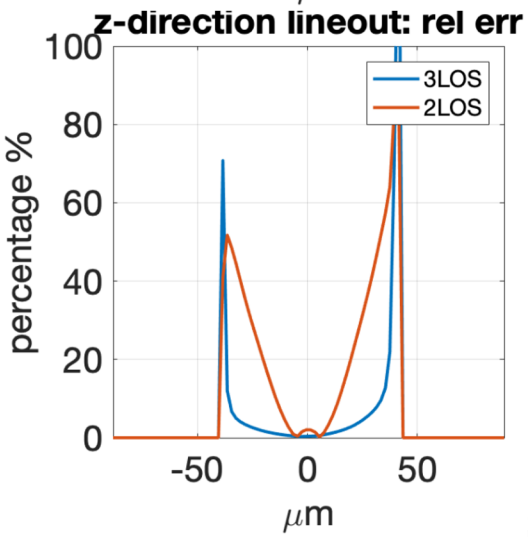






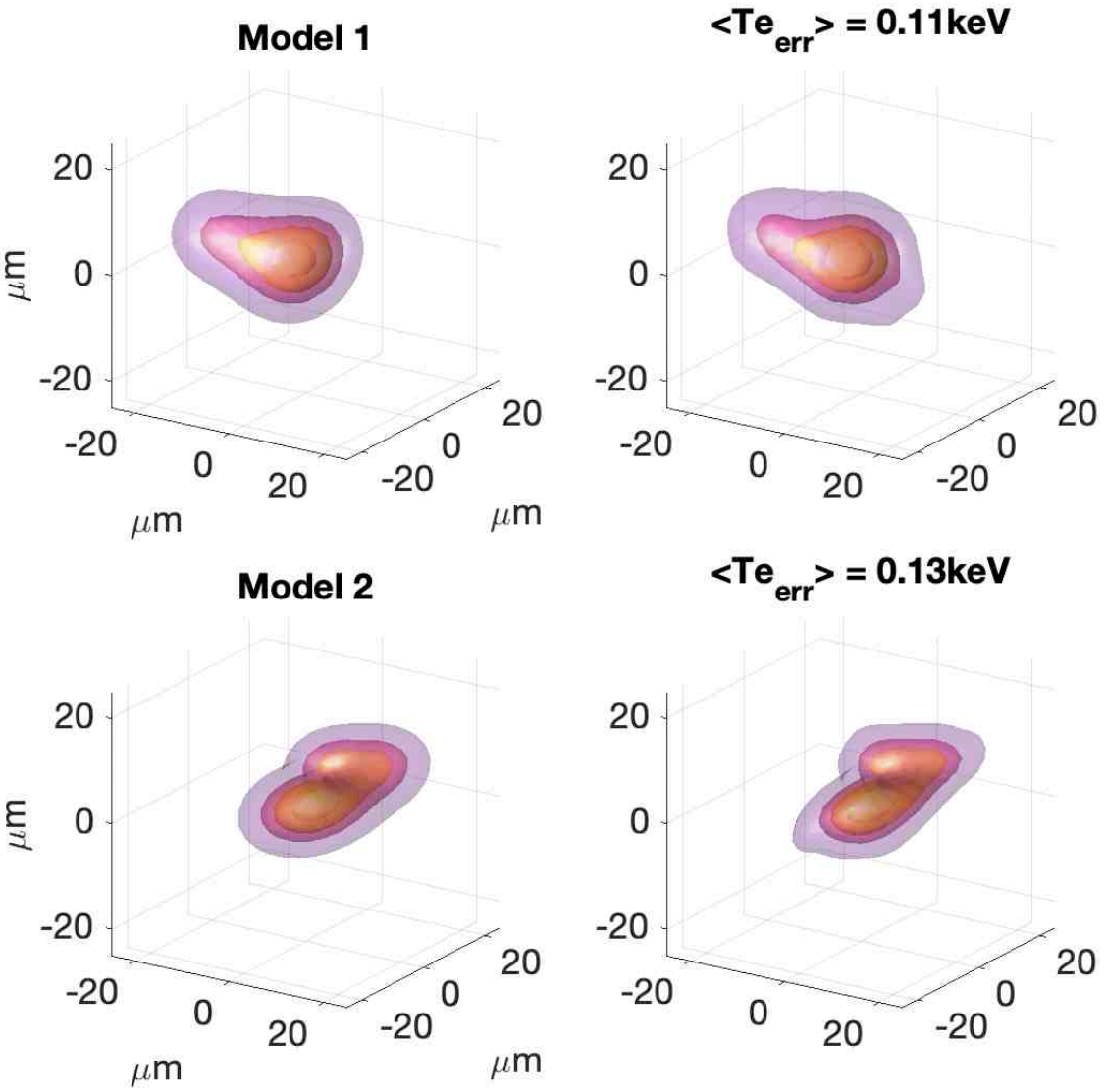






We tested a collection of synthetic T_e models with various shapes

Synthetic model



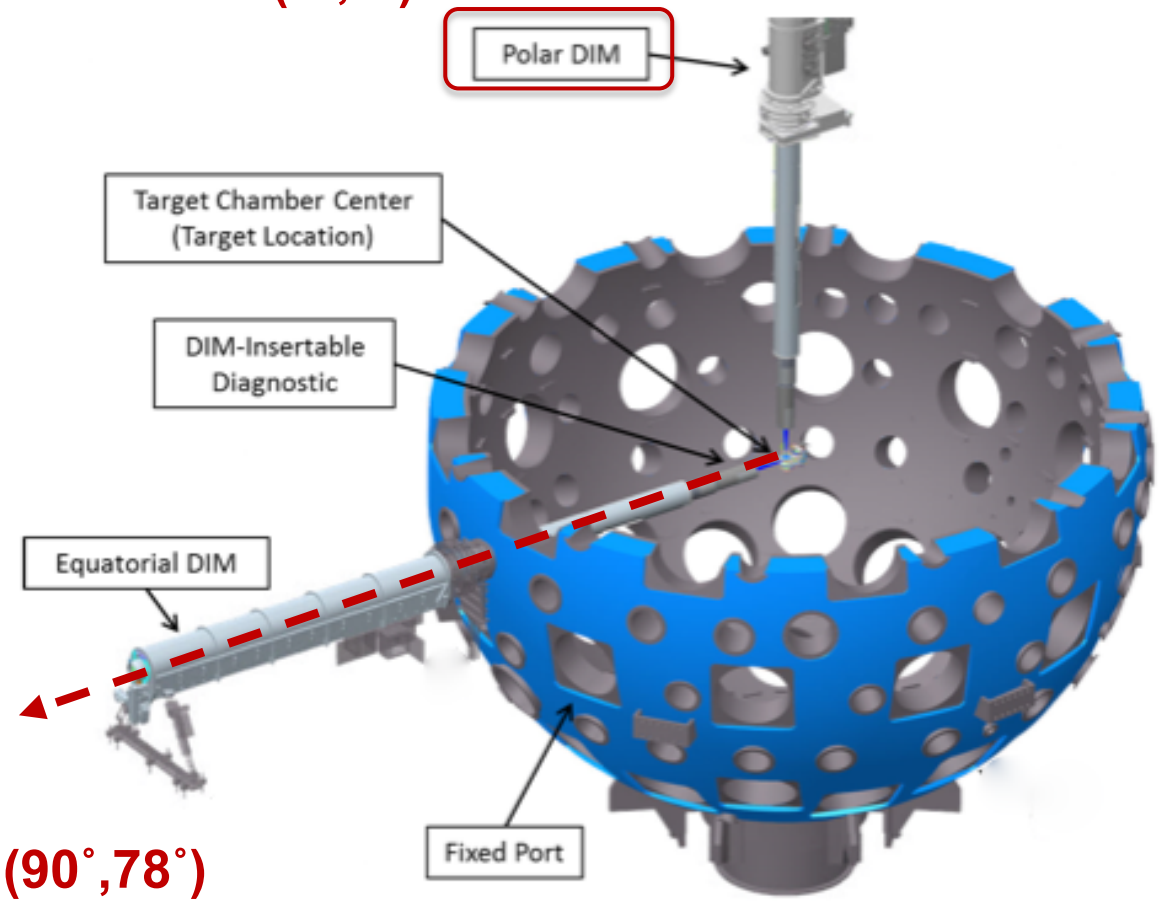
T_e measurements

Contour percentages from innermost to outermost:
95%, 85%, 75%, 50%

T_e measurements using 3 LOS have high accuracy despite complex geometries

Experimental data study: experimentally fielded diagnostic at two LOS PDIM (0˚, 0˚) and (90˚, 78˚)

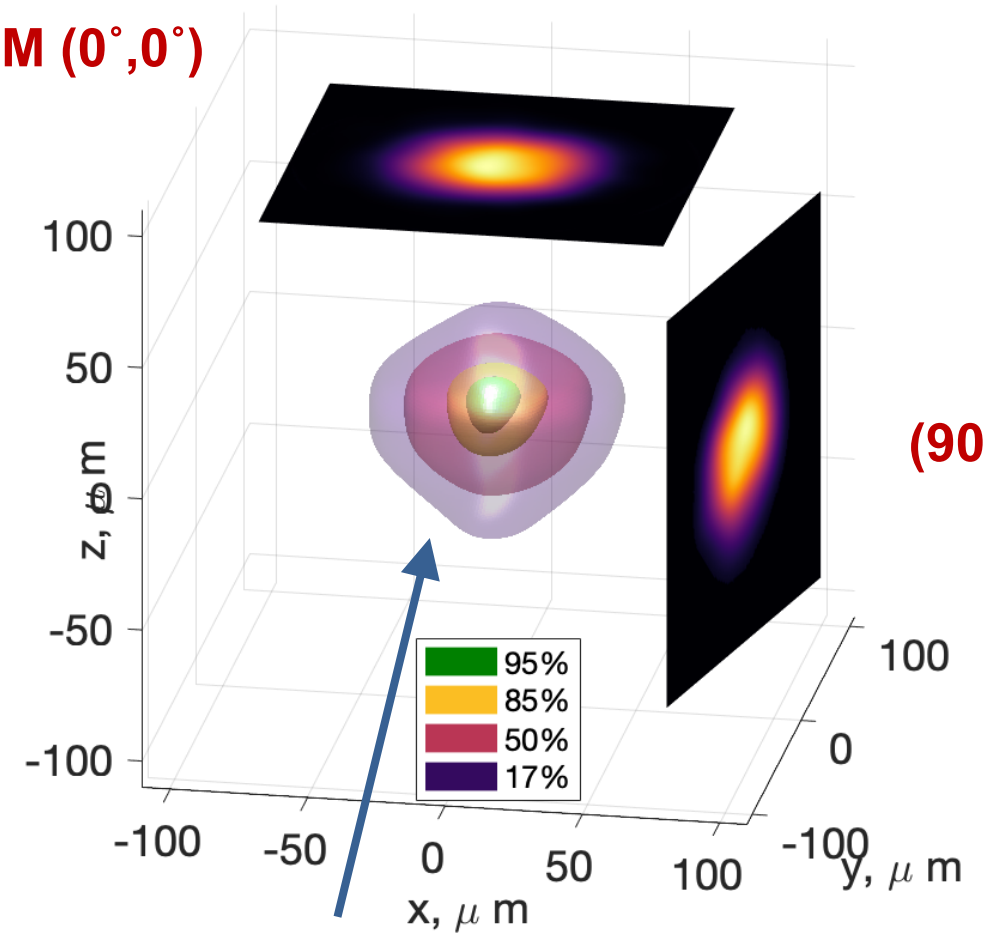
PDIM (0˚,0˚)



(90˚,78˚)

Two LOS

PDIM (0˚,0˚)



(90˚,78˚)

Reconstructed Hotspot X-ray emission

N181007: Noise causes discrepancy in the common integrated profile (CIP) between PDIM and (90˚, 78˚)

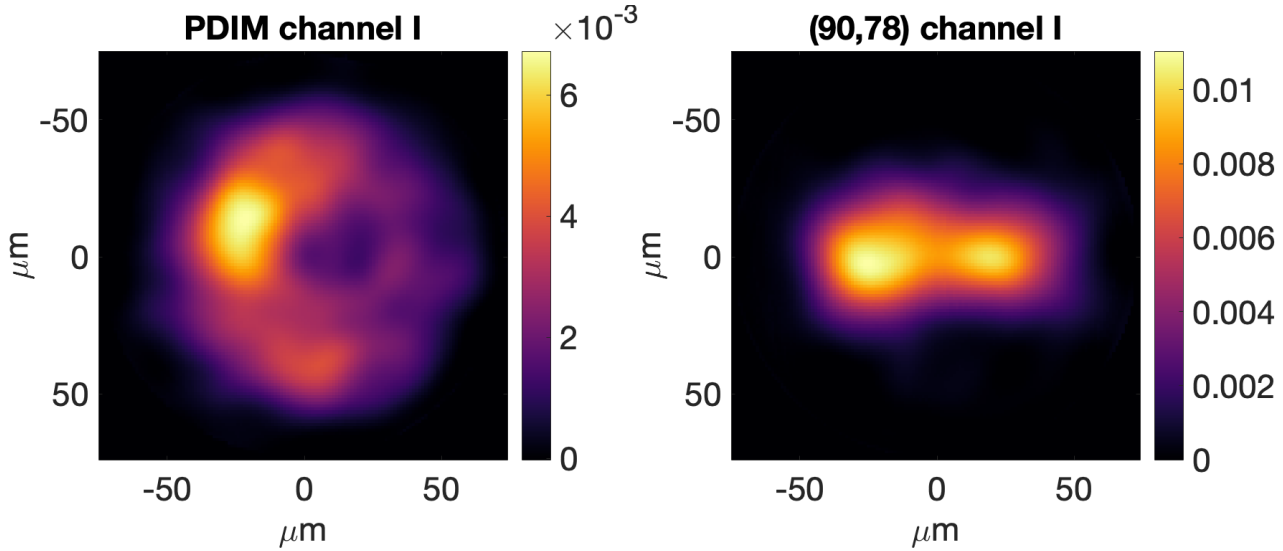
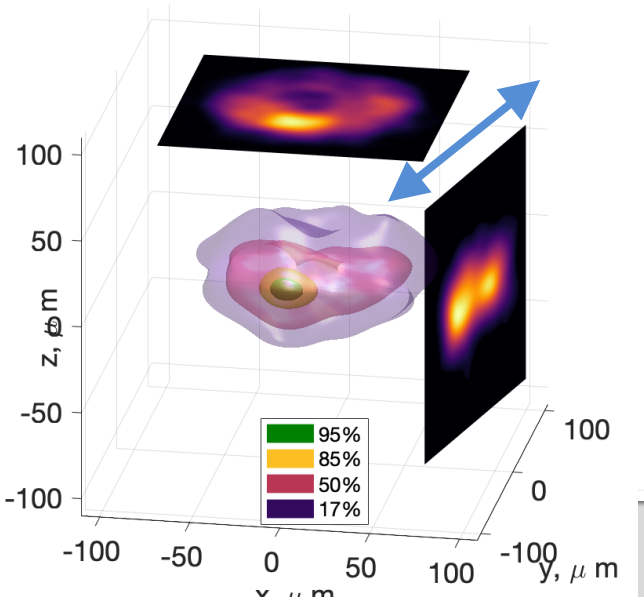
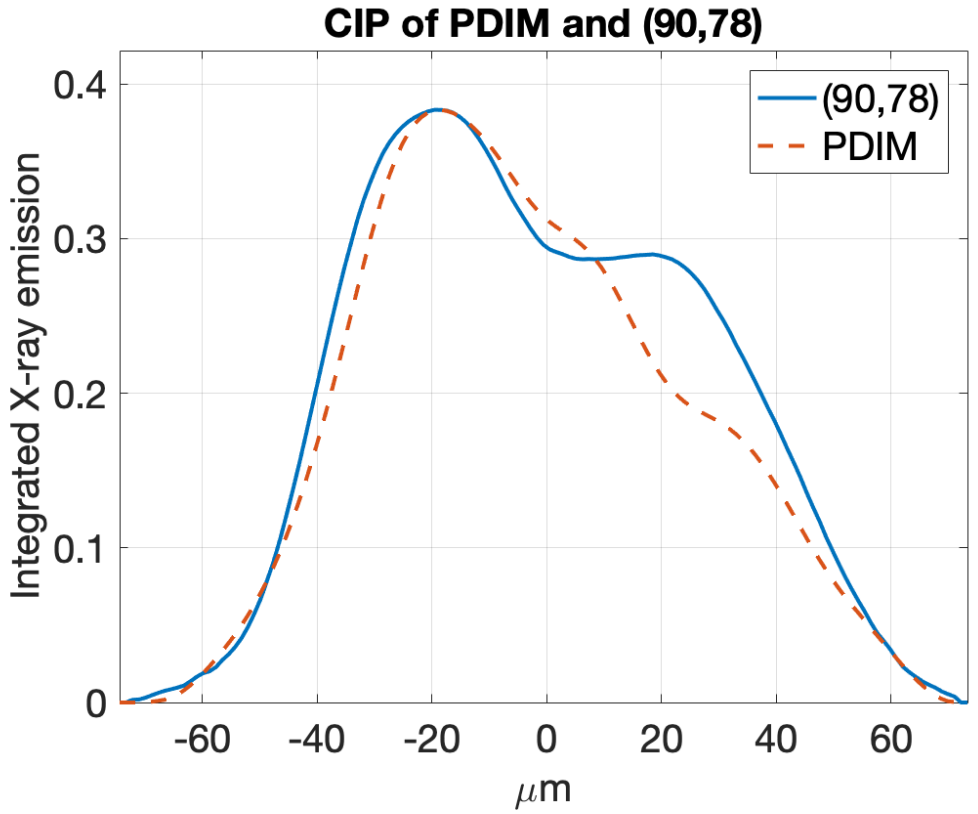


Image Resolution 14μm

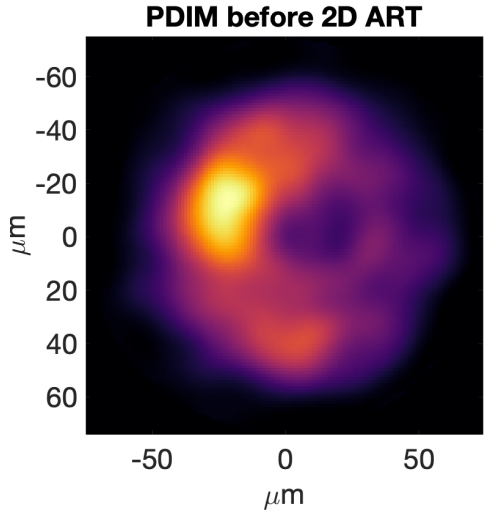
3D position



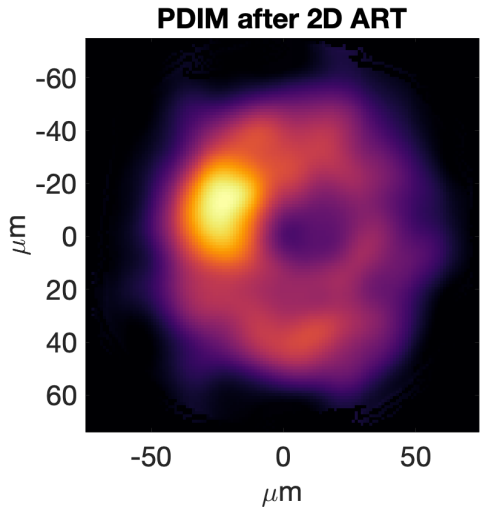


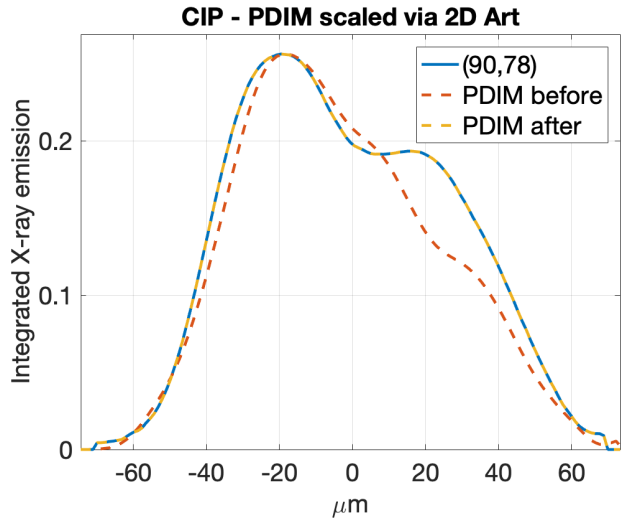
How to match PDIM and (90˚,78˚) CIP without compromising the hotspot structure in input images?

We apply 2D ART to modify PDIM image such that it matches with the CIP of the equatorial image (top row - N181007, bottom row - N190730)

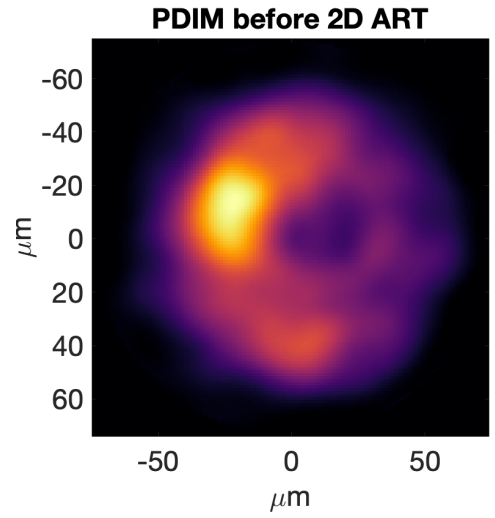


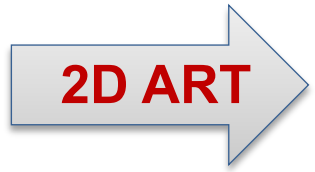
Integrated line profile at $(90°, 78°)$

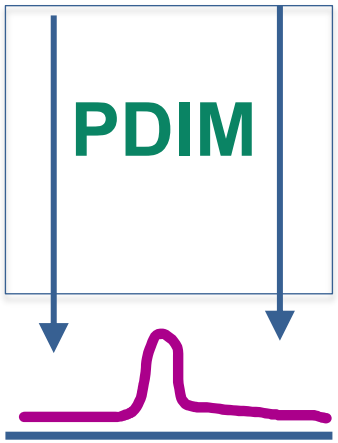


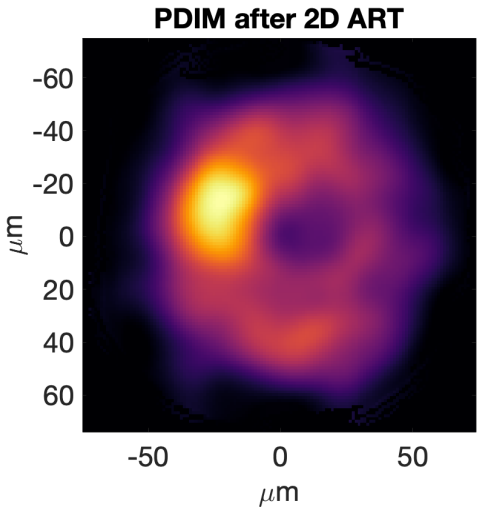


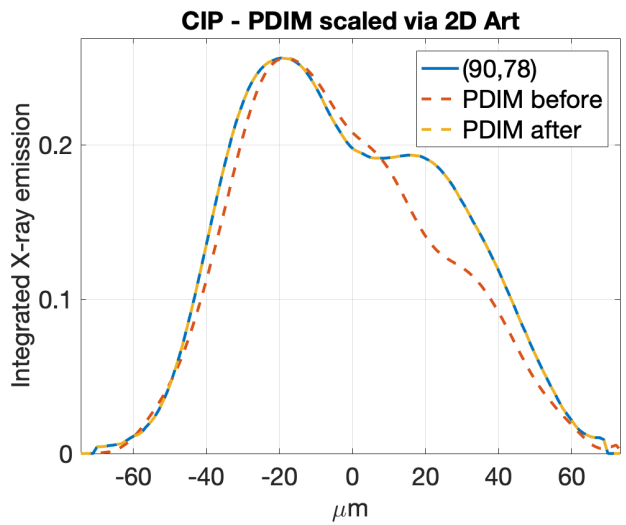
We apply 2D ART to modify PDIM image such that it matches with the CIP of the equatorial image (top row - N181007, bottom row - N190730)

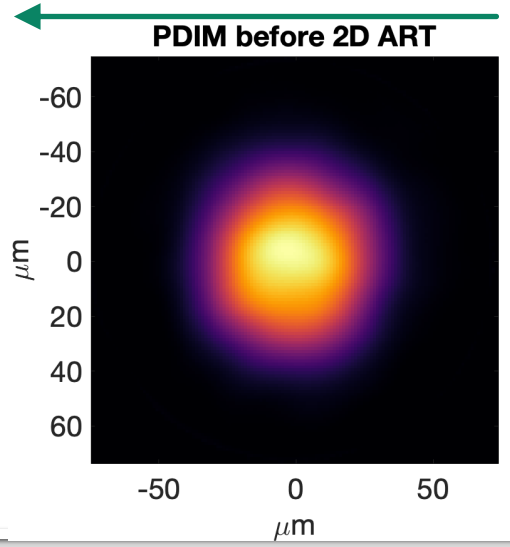




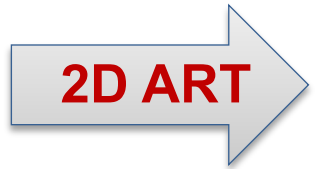


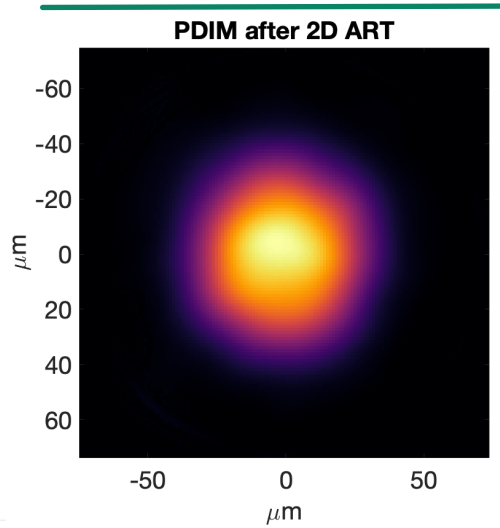


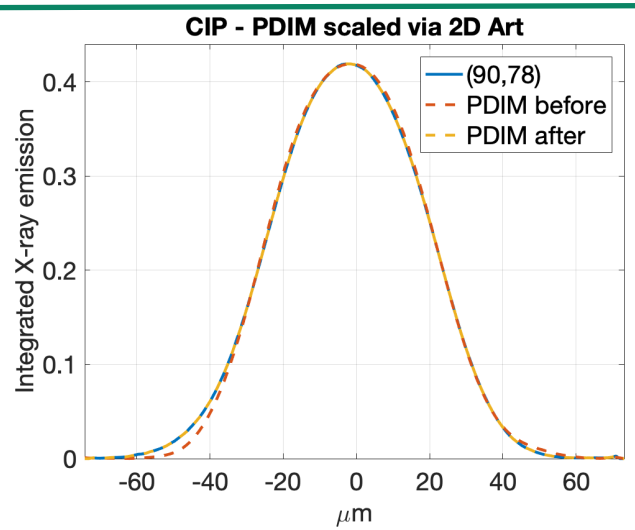




Integrated line profile at $(90°, 78°)$

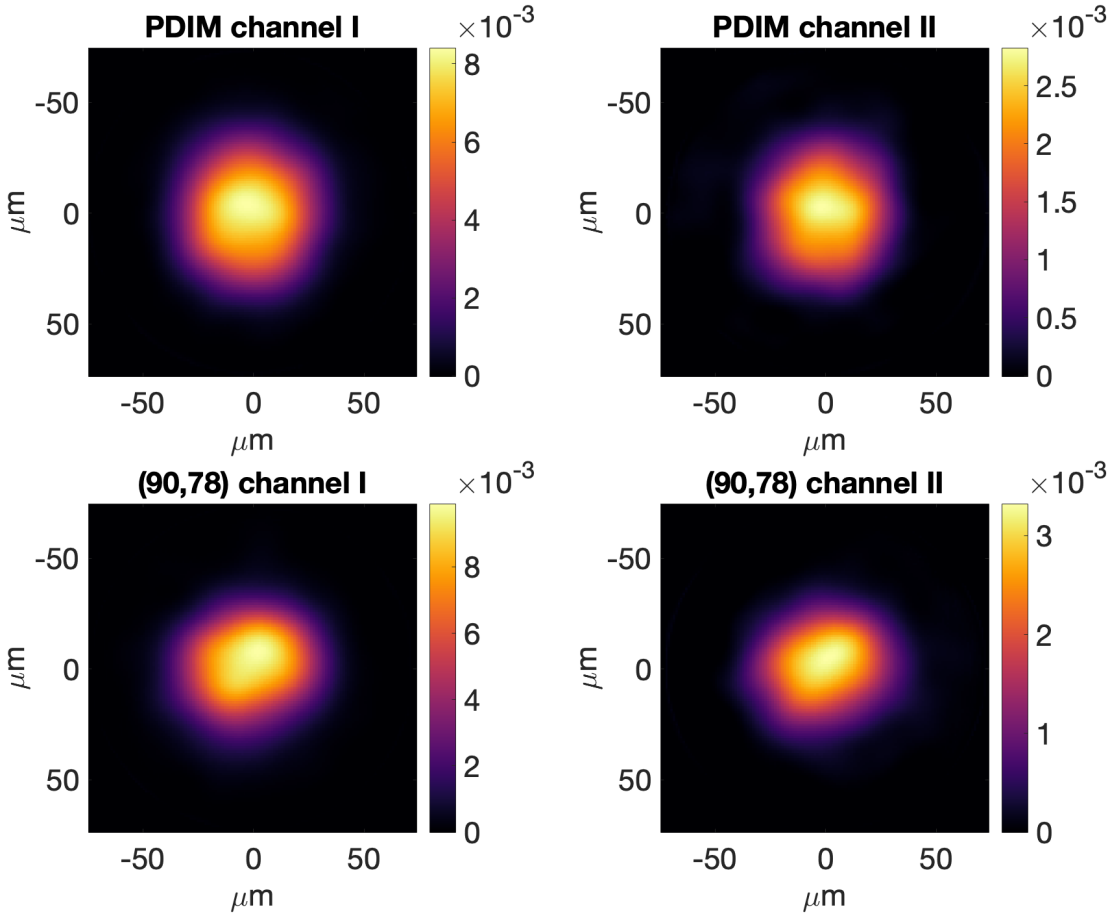






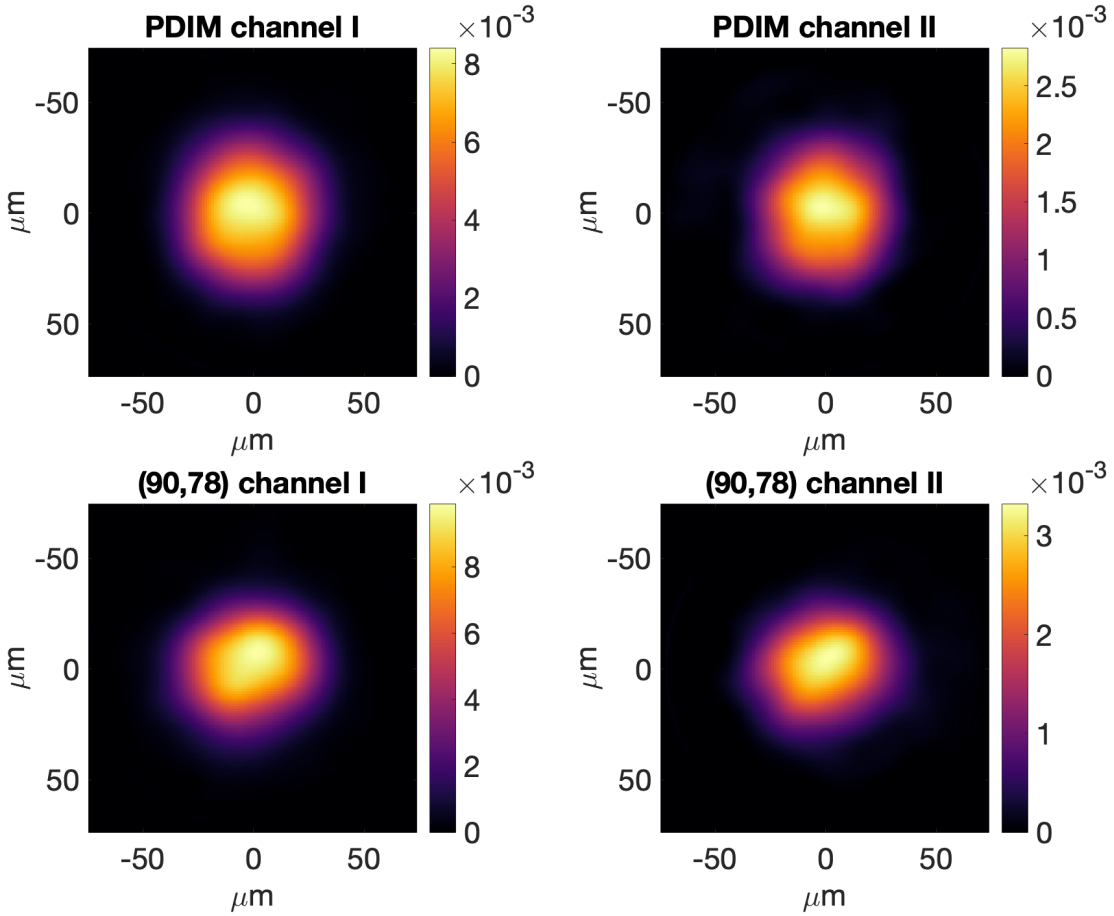
N190730: X-ray images and 3D X-ray reconstructions show a round hotspot

Experimental X-ray images

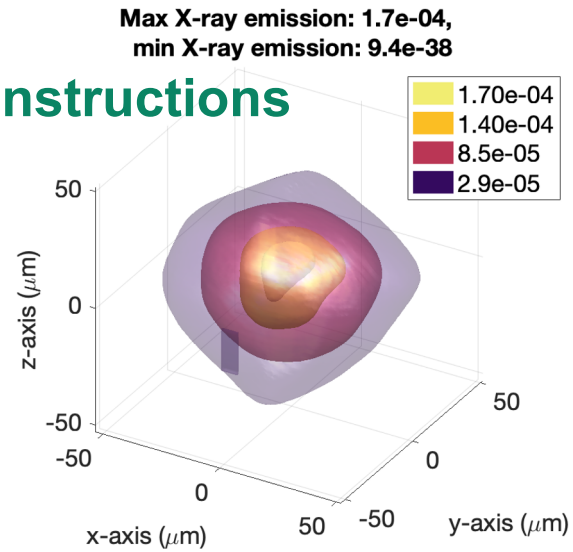


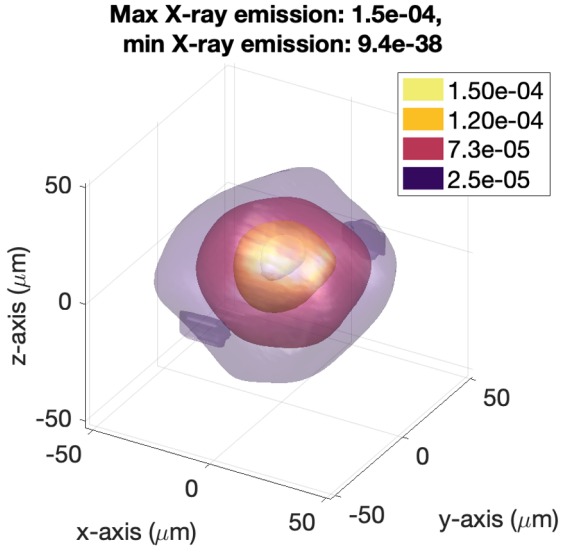
N190730: X-ray images and 3D X-ray reconstructions show a round hotspot

Experimental X-ray images



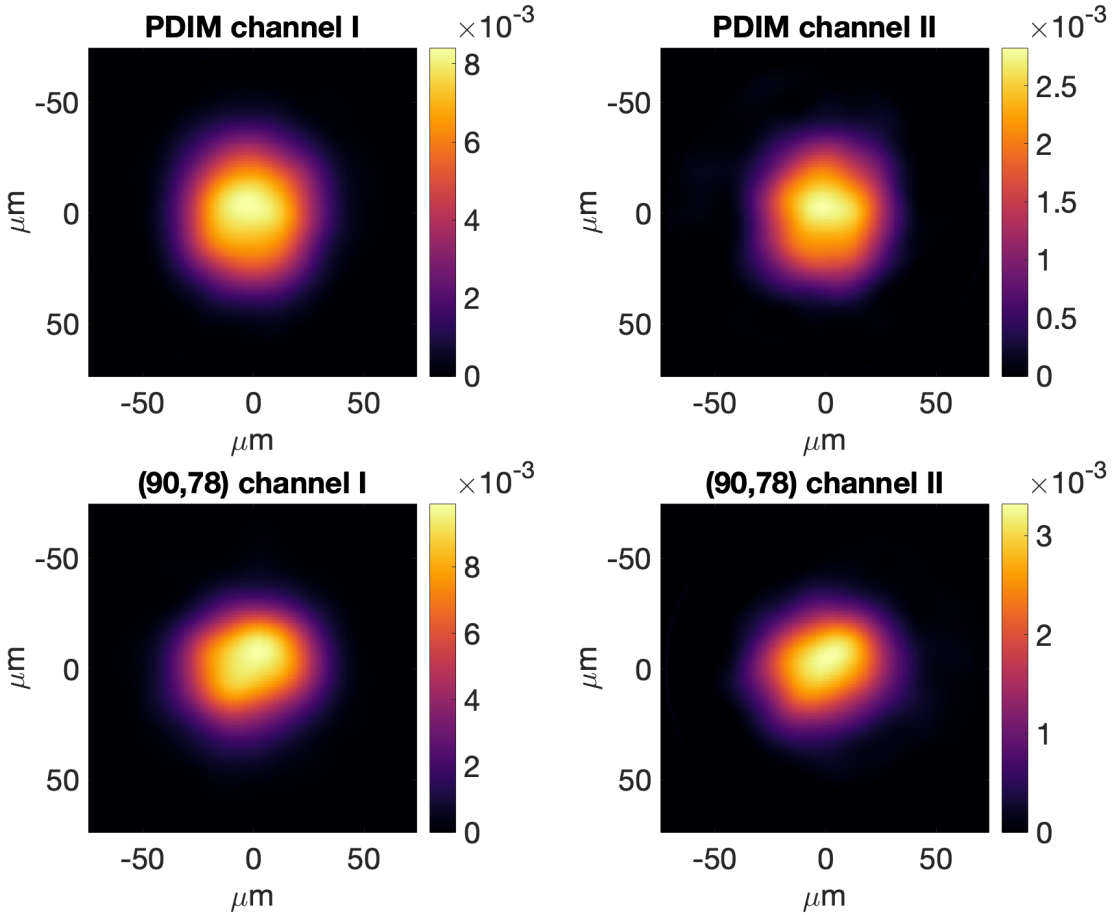
Reconstructions



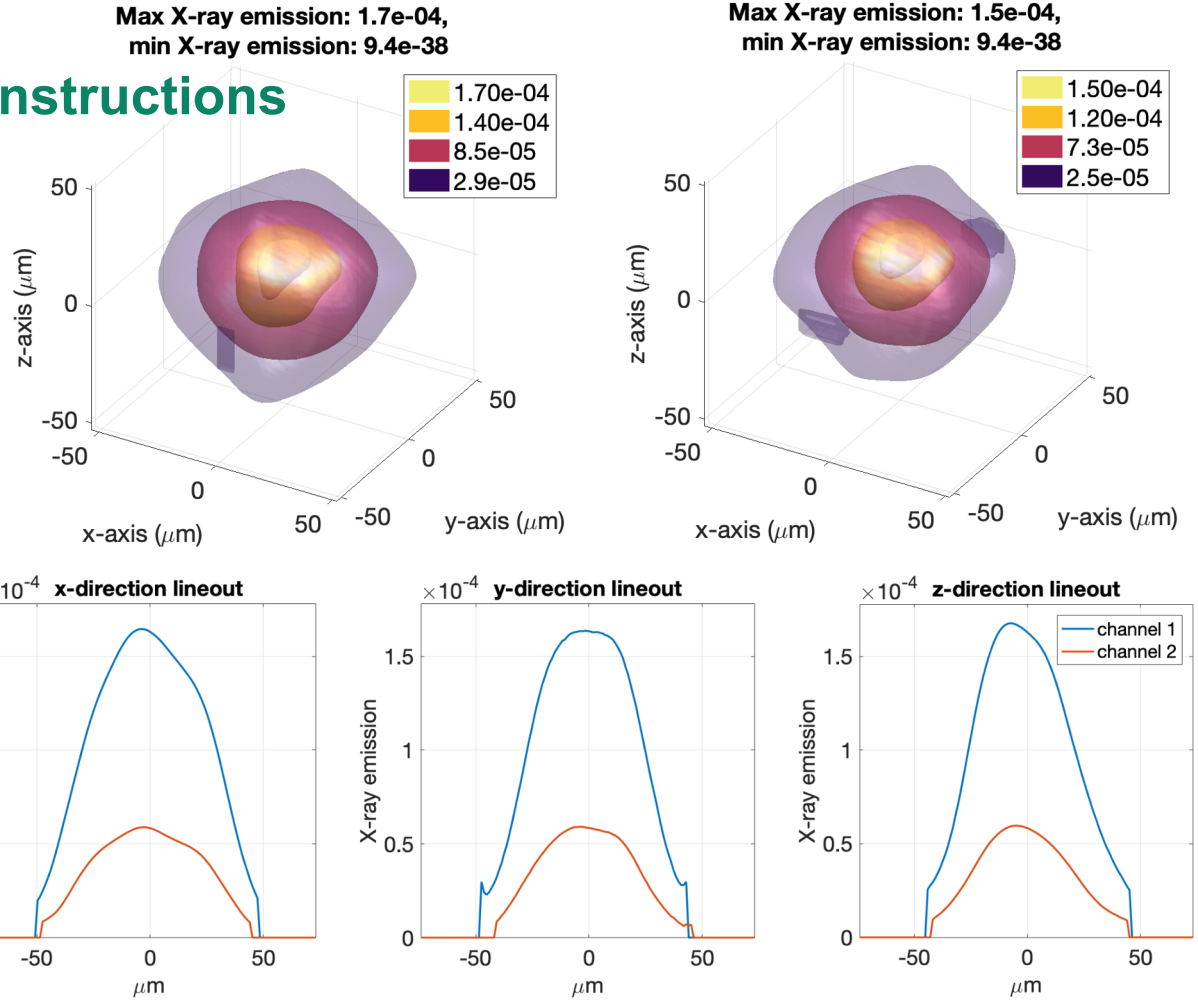


N190730: X-ray images and 3D X-ray reconstructions show a round hotspot

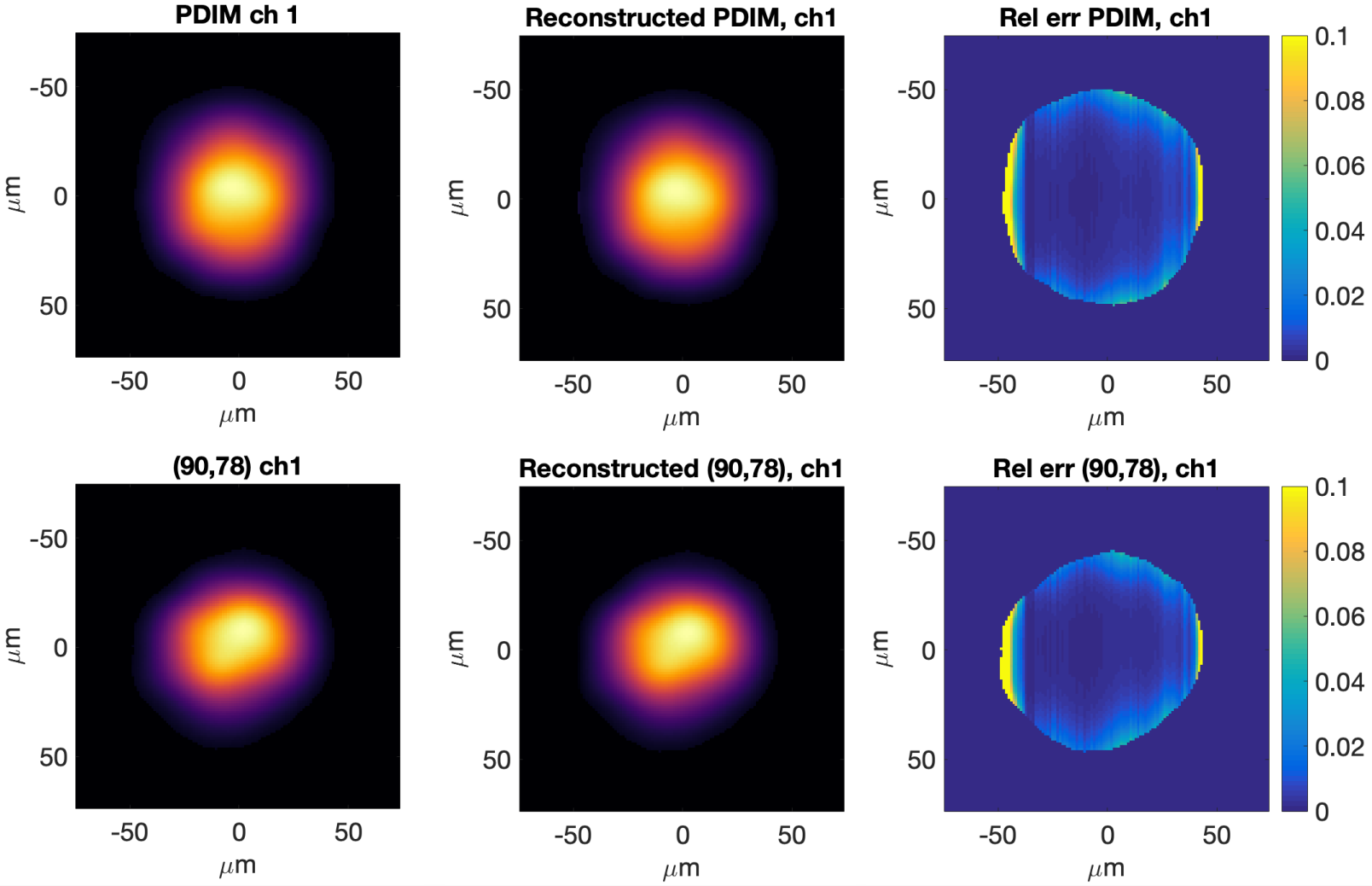
Experimental X-ray images



Reconstructions



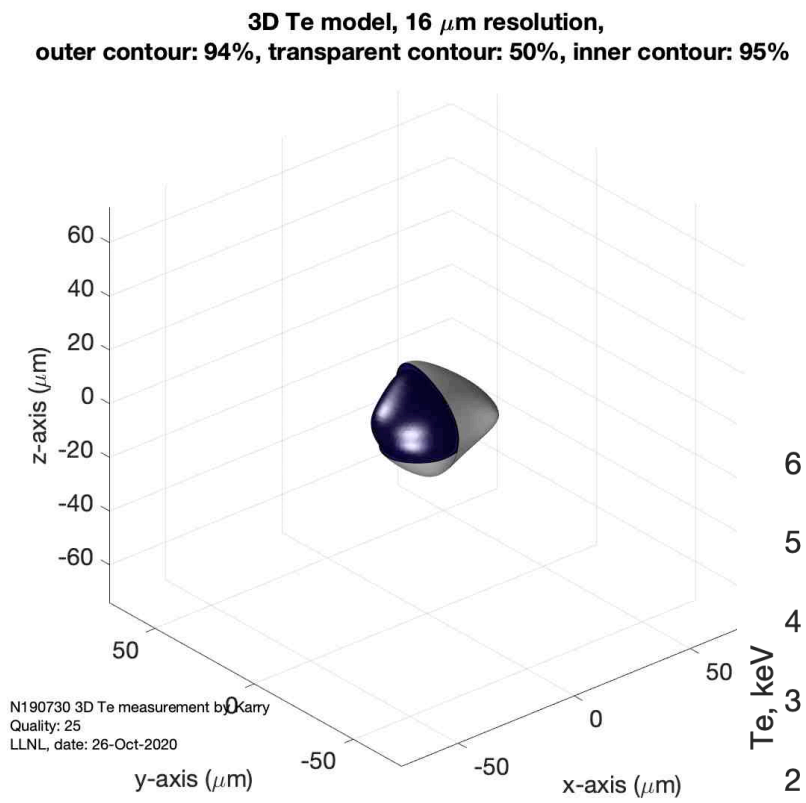
Our 3D X-ray reconstruction is consistent to input images



The reconstructed projections agree well with the input experimental images.

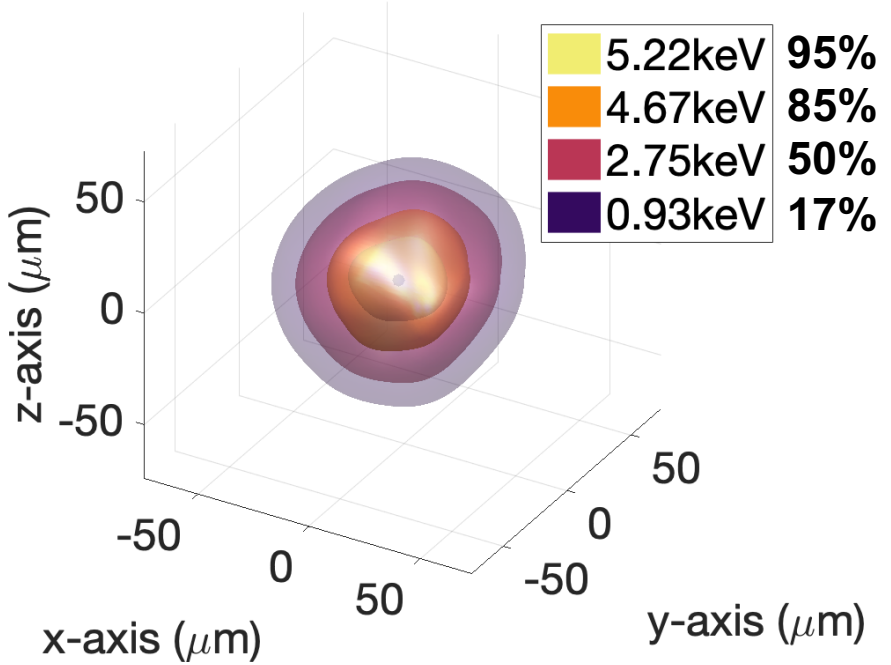
The relative errors in the hotspot are largely zero.

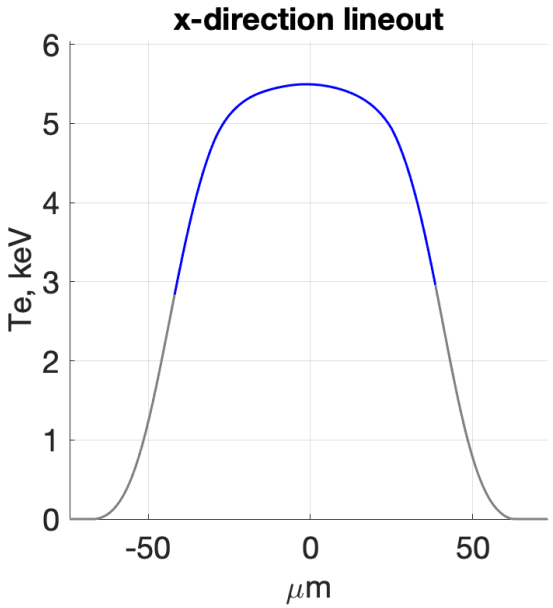
3D T_e measurement of N190730

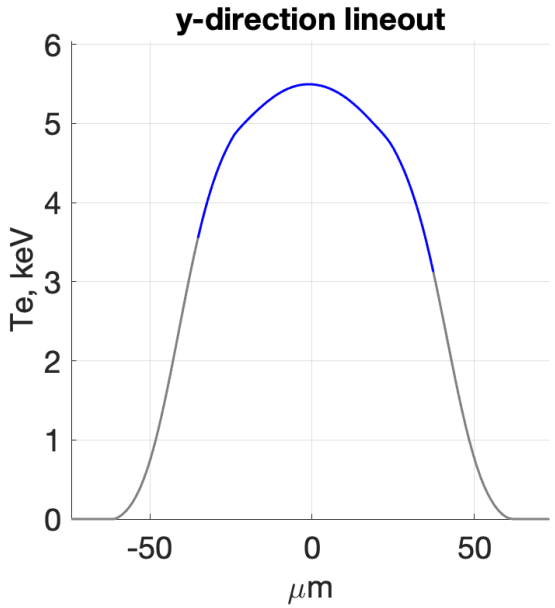


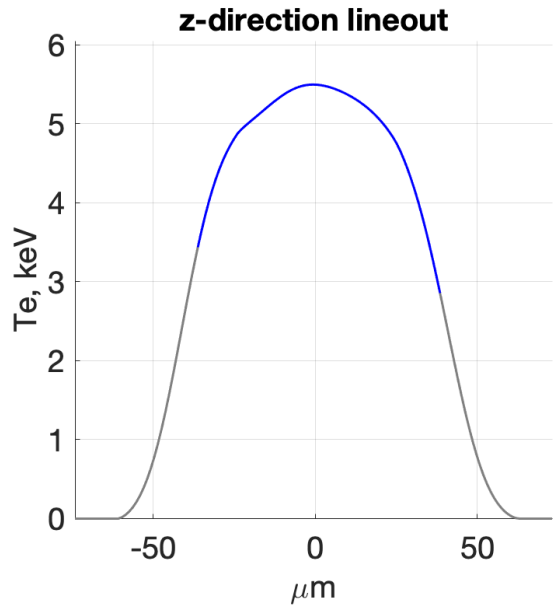
$$\langle Te \rangle_{(90^\circ,78^\circ)} \approx 4.5 \text{ keV}$$
$$\langle Te \rangle_{PDIM} \approx 4.2 \text{ keV}$$

Ref. *Jarrott et al., PRL 2018.*









Measuring 3D electron temperature of the ICF hotspot is feasible

We have

- tested iterative algebraic method ART to reconstruct 3D X-ray emission distributions of the ICF hotspot.
- obtained 3D X-ray reconstructions with two or three LOS and made 3D electron temperature T_e measurement in the ICF hotspot using synthetic and experimental data
- laid out a future path on how to perform 3D T_e measurement on the NIF.