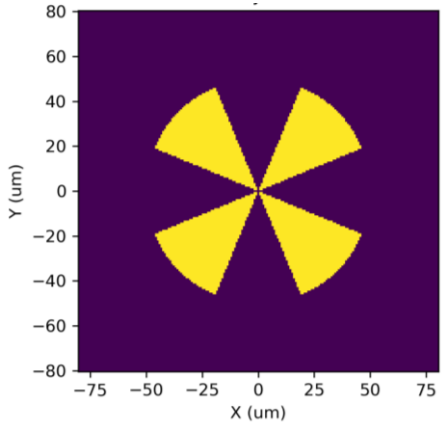
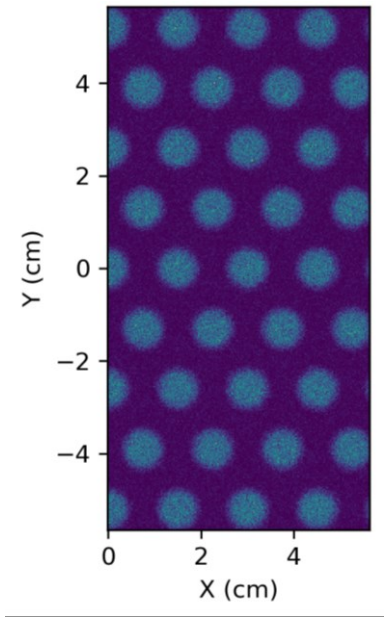
A Synthetic Diagnostic for the Knock-on Deuteron Imager

Test object



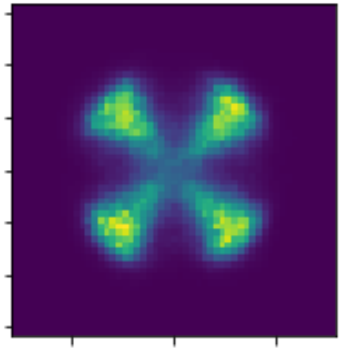
Synthetic Diagnostic

Synthetic Data



Reconstruction algorithm

Reconstruction



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Summary

A synthetic diagnostic has been developed for the Knock-on Deuteron Imager

- The Knock-on Deuteron Imager (KoDI) is a penumbral imaging diagnostic that aims to reconstruct the hotspot and cold fuel morphology in inertial confinement fusion (ICF) implosions from measurements of knock-on deuterons and tritons
- The resolution of any reconstructed penumbral image depends strongly on when the iterative reconstruction algorithm is terminated
- Therefore, the choice of the reconstruction termination condition is crucial
- A synthetic diagnostic has been developed to evaluate termination criteria using data with experimentally relevant statistics

Collaborators

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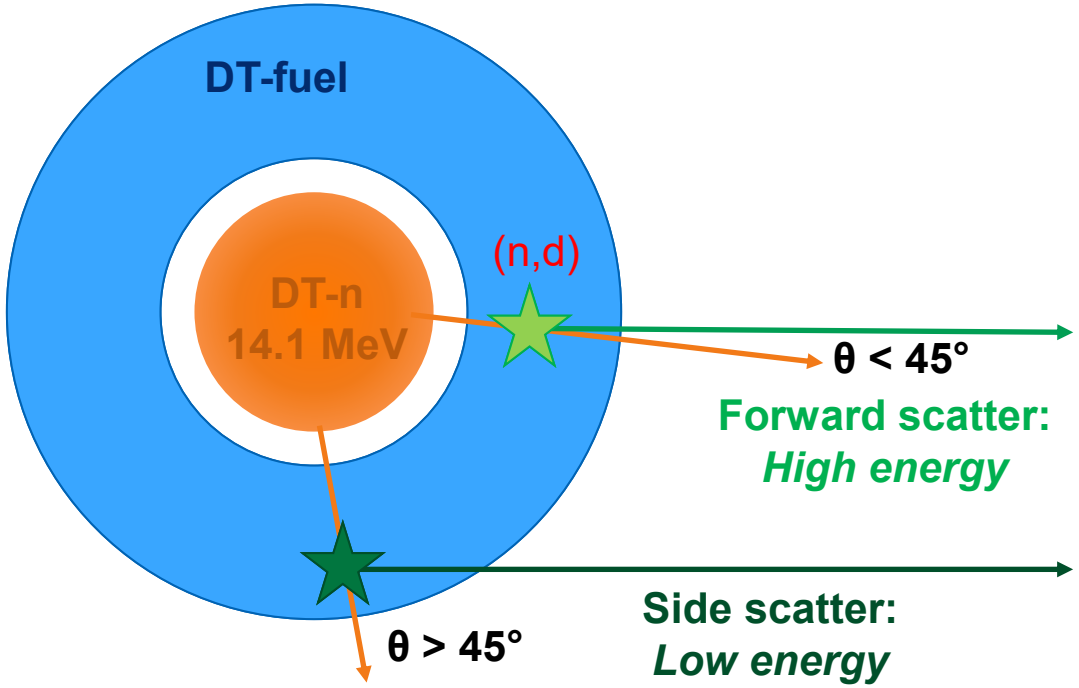
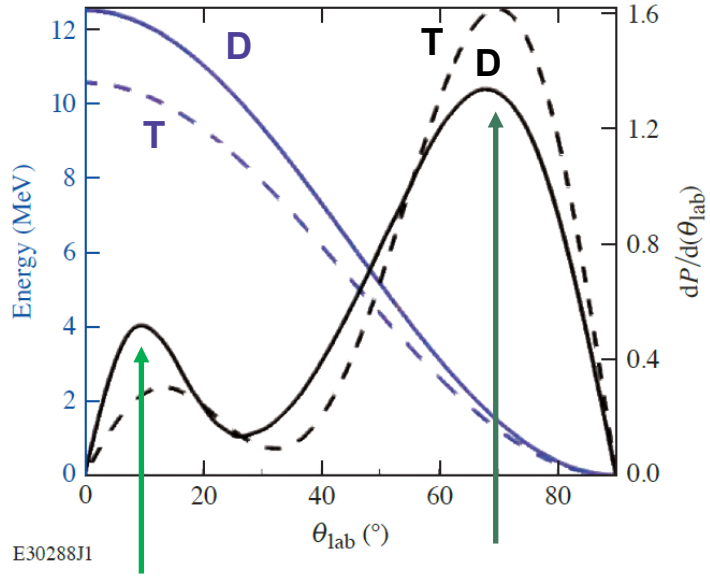
KoDI is a penumbral imager for knock-on deuterons



Detector

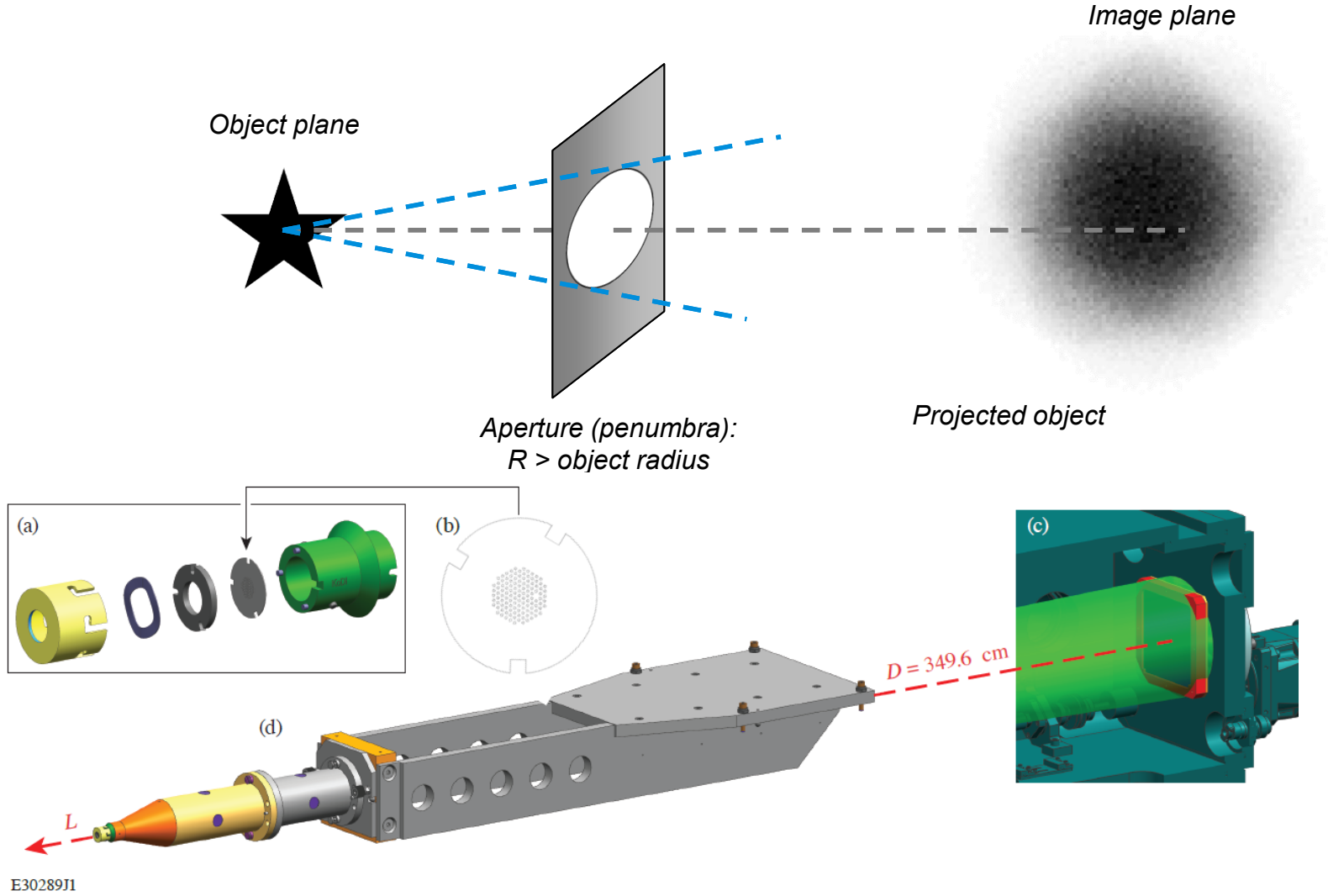


Scattering Probability

The spatial distribution of knock-on deuterons encodes information about the morphology of both the hot spot and the cold fuel

Image Credit: H. G. Rinderknecht

Penumbral imaging encodes spatial information in the penumbra of pinholes



Detector pack

CR39 with different filtration for high and low energy deuterons

Image Credit: H. G. Rinderknecht

An iterative maximum likelihood method is used to reconstruct the emitted deuteron signal from the penumbral images

$$g_k^0 = Uniform$$

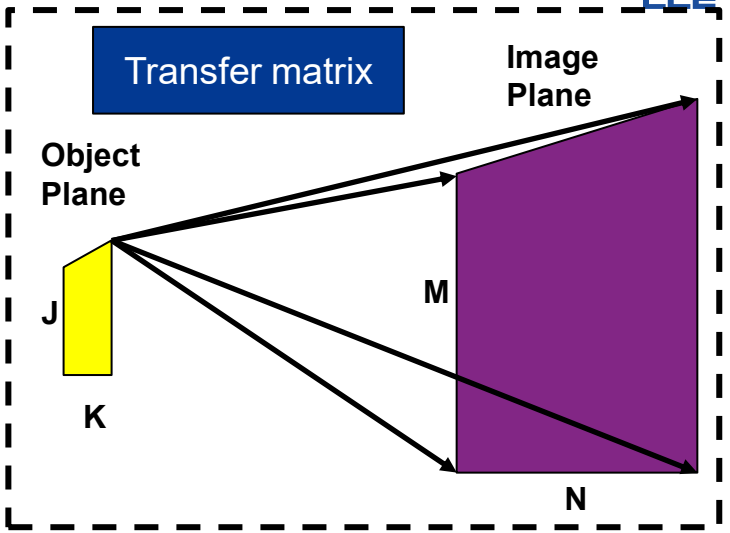
Calculate next change in guess based on current guess

$$\delta g_k^{(t)} = g_k^{(t)} \left[\sum_i p_{ik} \left(\frac{n_i/N}{\sum_j p_{ij} g_j^{(t)}} - 1 \right) \right]$$

Modify the guess accordingly

$$g_k^{(t+1)} = g_k^{(t)} + h \delta g_k^{(t)}$$

Choosing when to terminate this iterative process has a significant impact on the solution



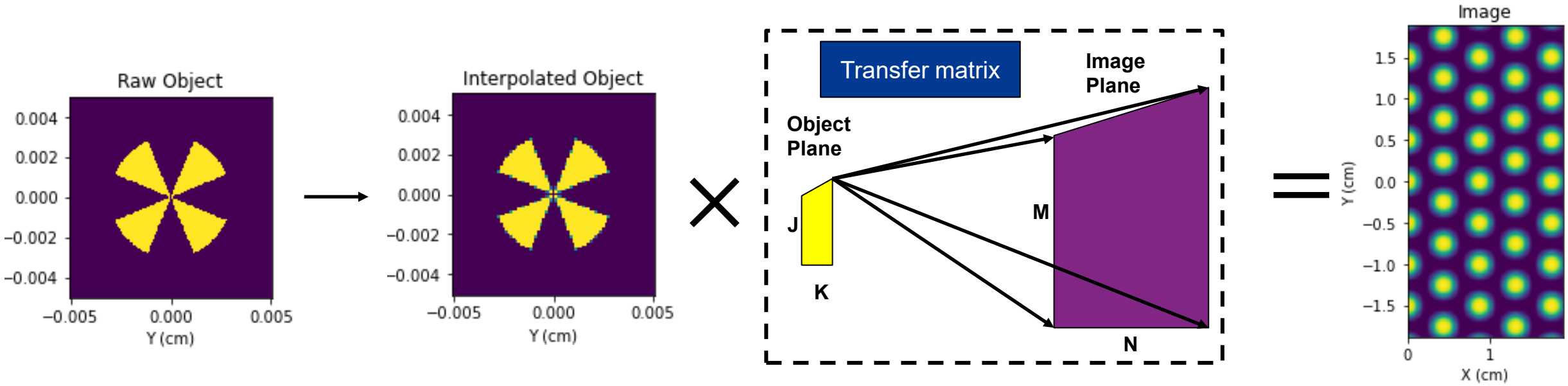
Variables	
n_i	Data
p_{ik}	Transfer matrix
g_k	Guess at object
h	Step size*

$$N = \sum n_i$$

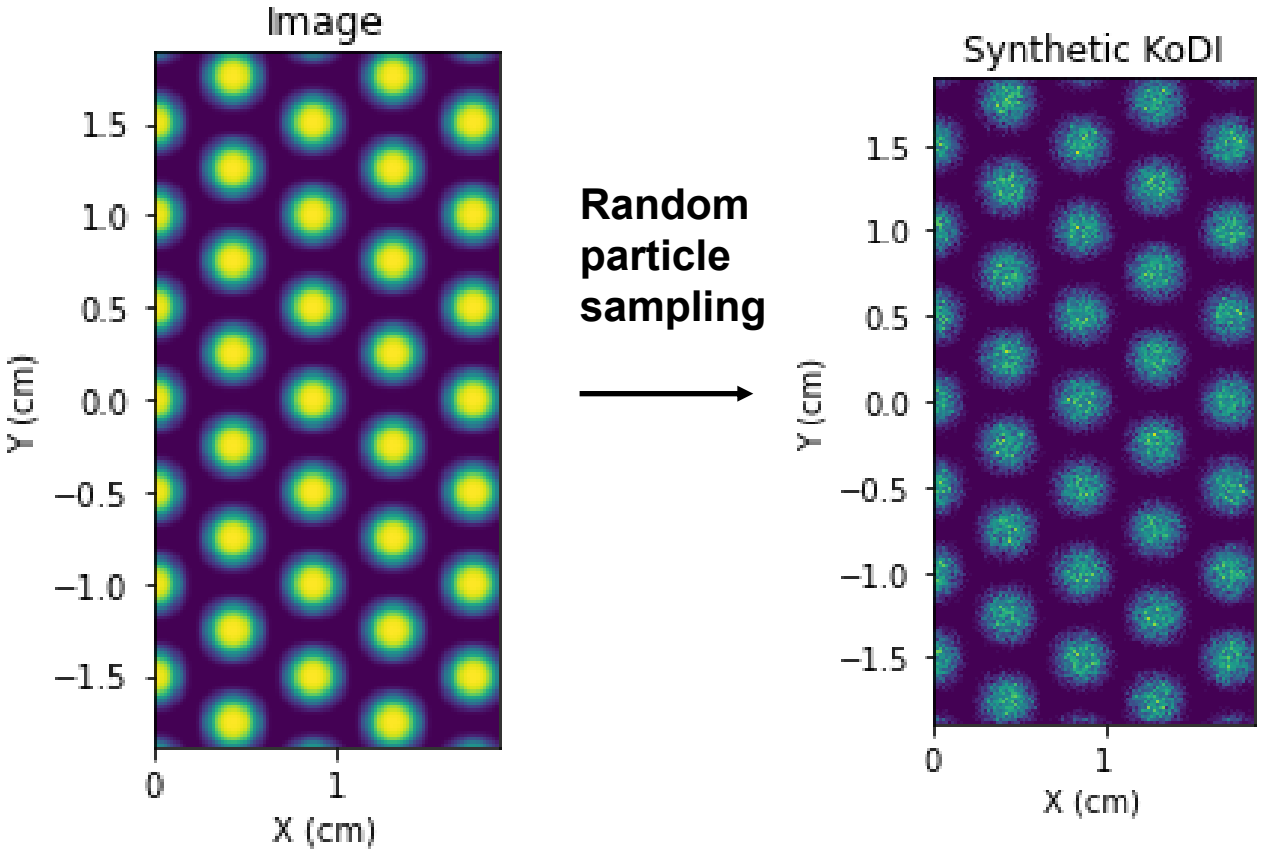
* V. I. Gelfgat 1993 Comp. Phys. Comm.
** H. G. Rinderknecht 2022 RSI

Synthetic images are created using a transfer matrix

- The “transfer matrix” is a point spread function for every point in the object plane to every point in the image plane
- Multiplying the transfer matrix by a synthetic object gives a synthetic image



Random particle sampling replicates experimental Poisson statistics



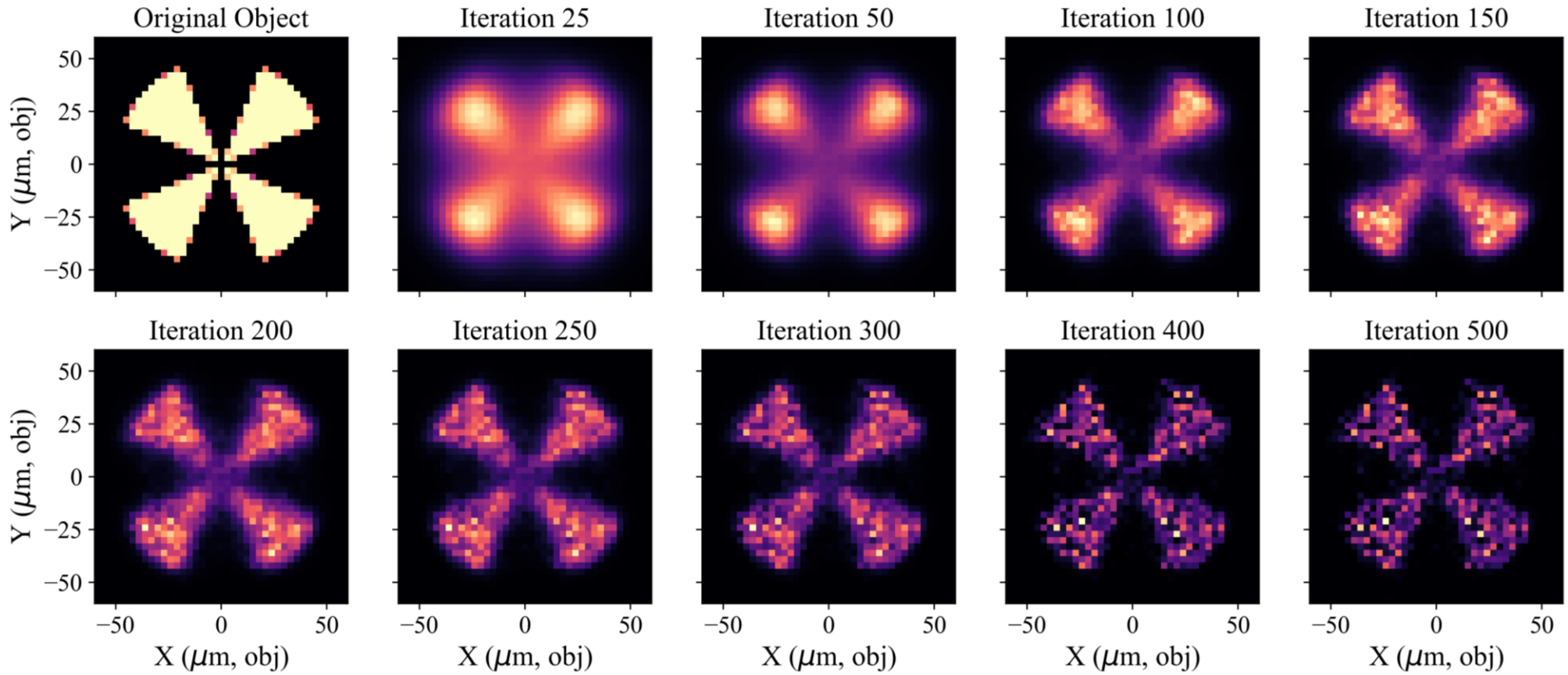
- **Poisson noise is then introduced by sampling the synthetic image with a realistic number of particles**
- **This is essential because the effective resolution of penumbral imaging is directly related to the sampling statistics**

$$\frac{\Delta x_{\mathrm{s}}}{R_{\mathrm{s}}} \approx \sqrt{\frac{D}{R_{\mathrm{s}}(M-1)}} \left(\frac{Y\#_{\mathrm{a}}}{4\pi}\right)^{-1/4}$$

Resolution **Yield**

* H. G. Rinderknecht 2022 RSI

Reconstructing synthetic data

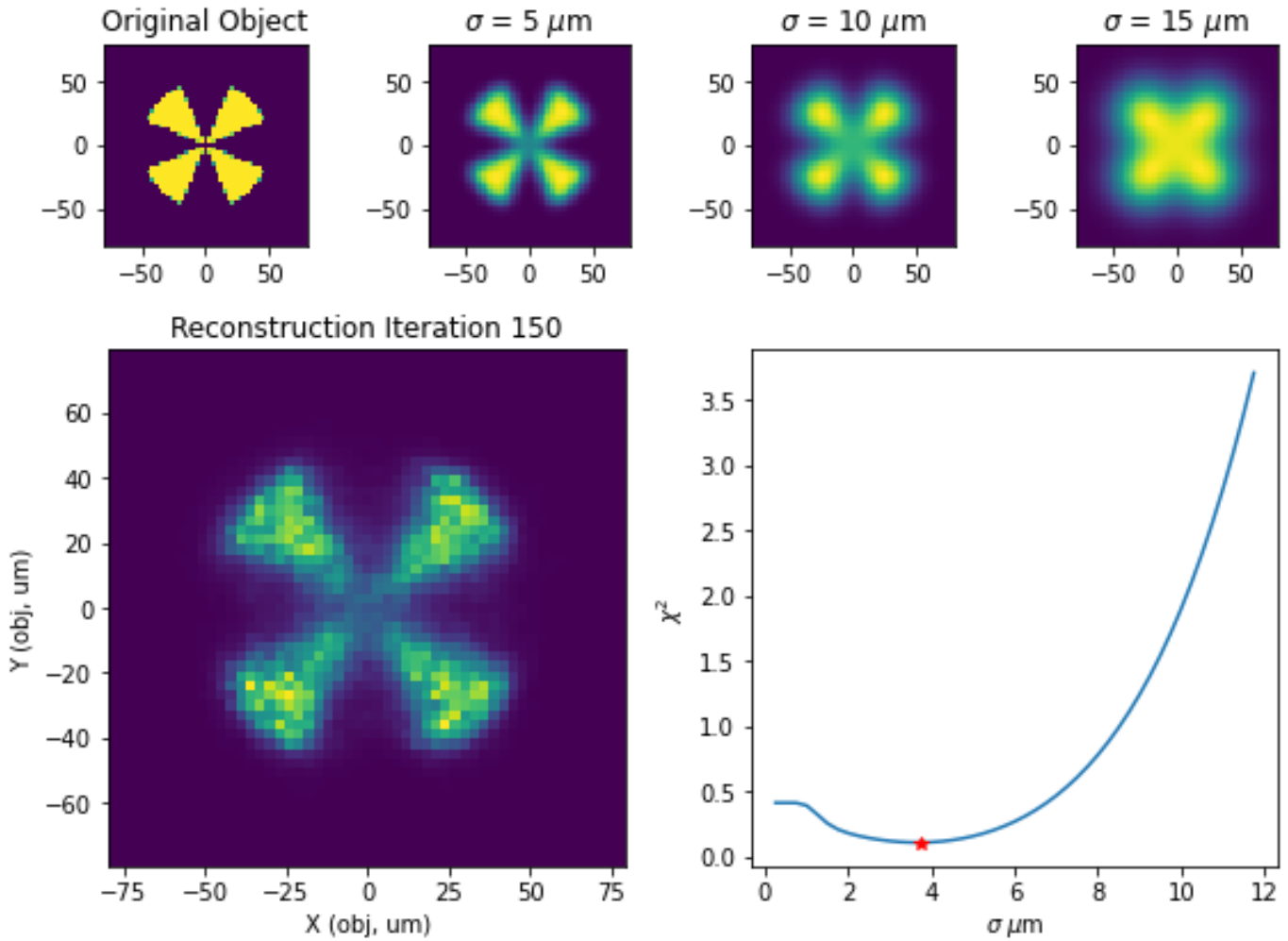


Terminating the algorithm is a tradeoff between resolution and noise from overfitting.

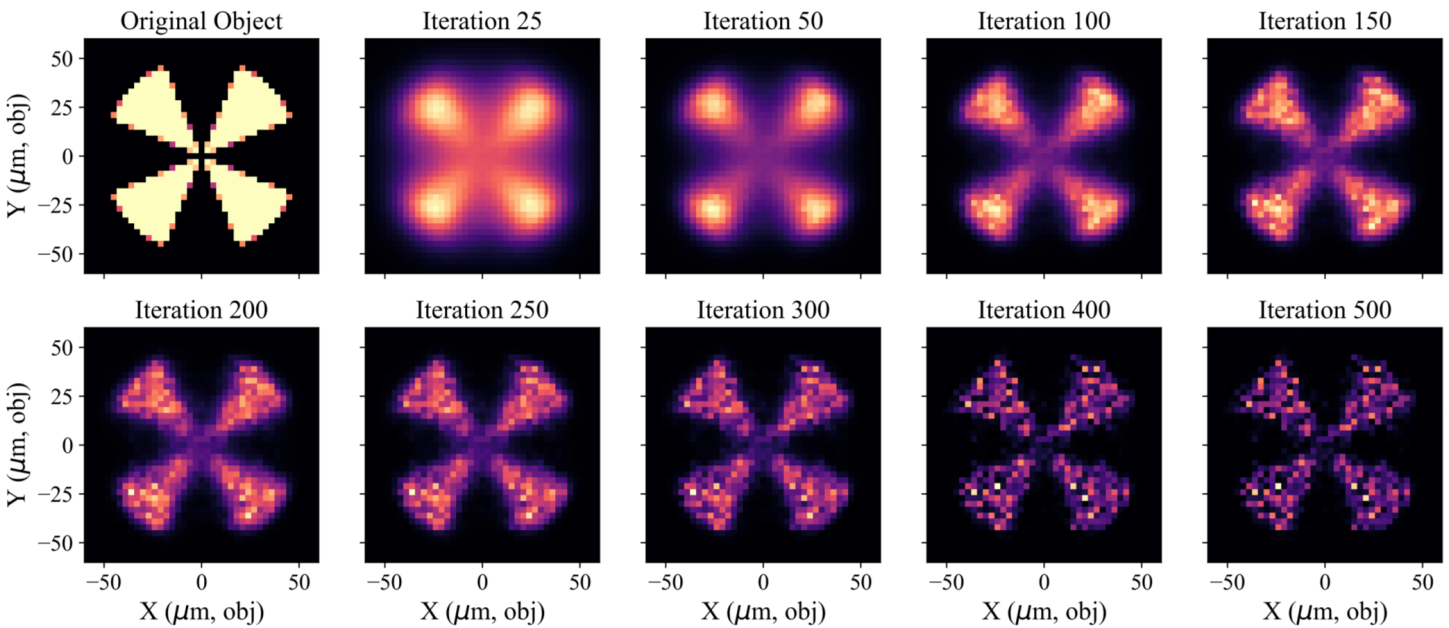
Estimating the spatial resolution of synthetic reconstructed images

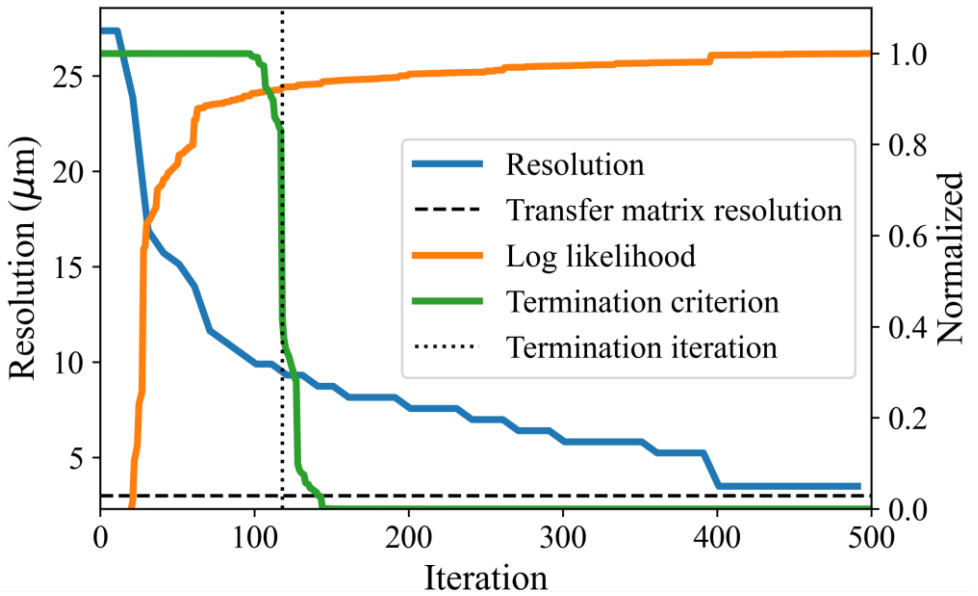
Estimate the resolution by convolving the known object with Gaussians of different width and comparing with the reconstruction

If we define the ‘resolution’ as the width of the Gaussian at 2σ, then the resolution is 4σ ~16 um



Investigating termination criteria with synthetic data





- **Log likelihood increases monotonically throughout the reconstruction**
- **Resolution asymptotes to the grid resolution of the transfer matrix**
- **A termination criterion is necessary to chose the solution!**

Our present work-in-progress termination criterion is based on Wilks theorem

$$C_i = 1 - \chi^2_{cdf}\left(\lambda_i, DOF_{\text{eff}}\right), \quad \text{where:}$$

$$\lambda_i = -2\left[\log \mathrm{L}_i - \log \mathrm{L}_{\text{max}}\right], \quad DOF_{\text{eff}} = \sum_j^J \frac{s_j}{s_j + J^{-1}}$$

* H. G. Rinderknecht et al. 2022

Summary/Conclusions

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