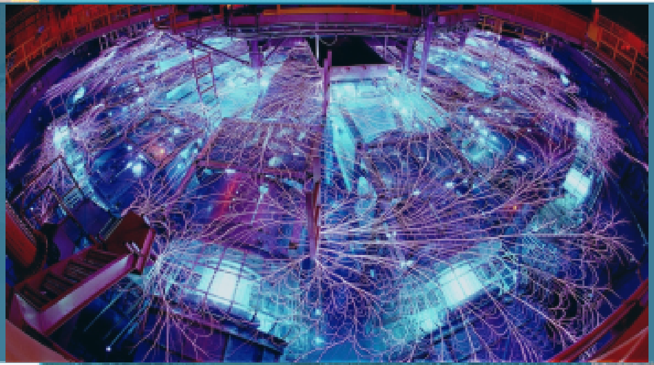
SAND2022-13977C

Sandia National Laboratories

Optimization of Diagnostic Configurations in the presence of Uncertainty using Bayesian Inference and Optimization



Patrick F. Knapp

American Physical Society, Division of Plasma Physics

October 18, 2022

LABORATORY DIRECTED RESEARCH & DEVELOPMENT
WHERE INNOVATION BEGINS

U.S. DEPARTMENT OF ENERGY
NNSA

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This work was done in collaboration with a large group

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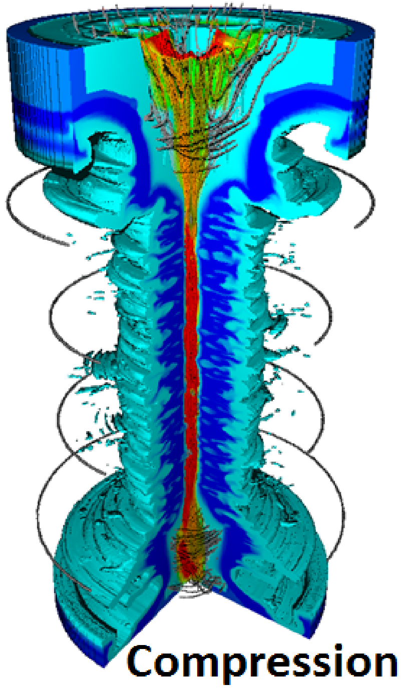
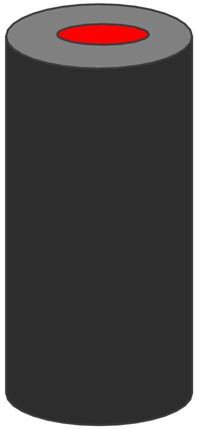
The models we use to analyze x-ray data in ICF experiments routinely make simplifying assumptions that can impact our interpretation

3D object, Evolving in time



Uniform, stationary plasma surrounded by homogeneous liner



- Temperature
- Pressure
- ρR
- …etc.

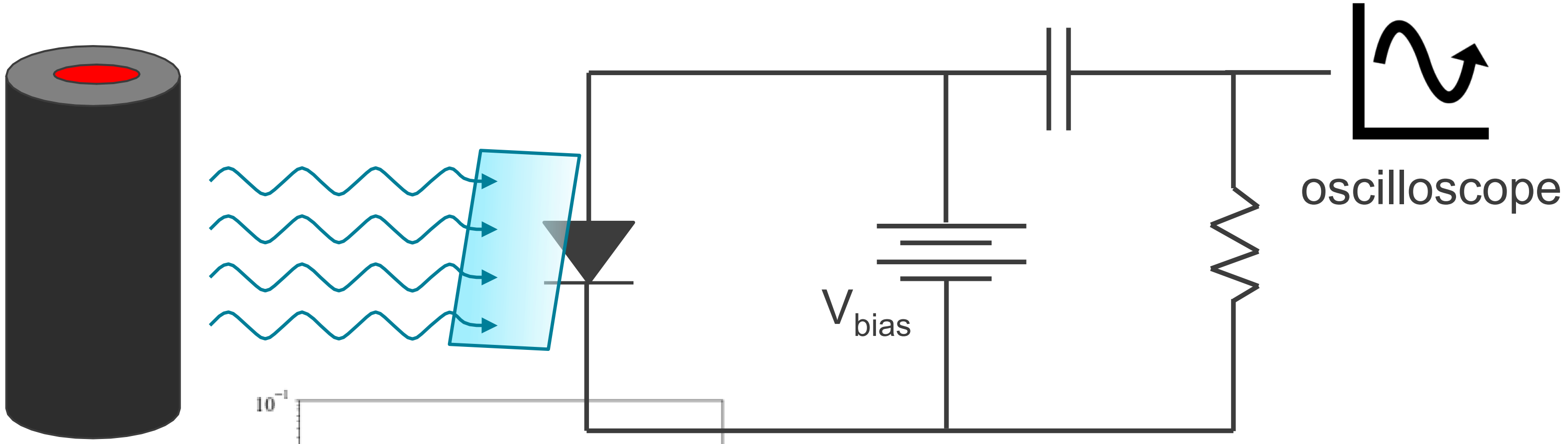
These simplifications can introduce bias into our analysis

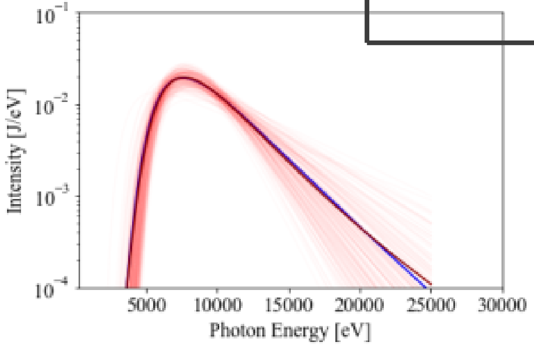
How do we configure an instrument to give us useful information in the face of this kind of bias?

We constructed a simplified problem to develop a method for optimizing filtered x-ray power detectors

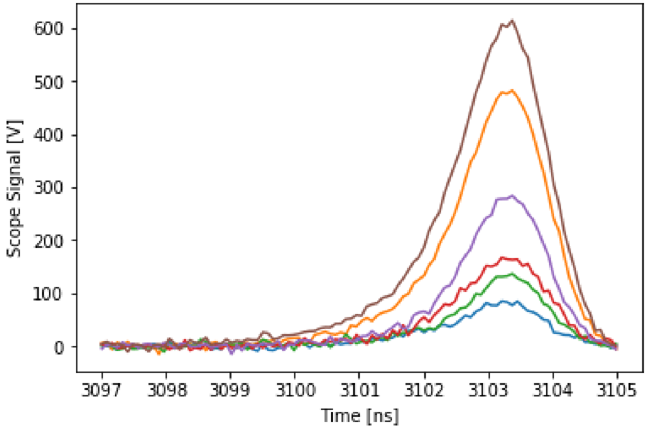
PCDs are a workhorse diagnostic on Z, but their highly integrating nature makes it difficult to extract source information

Using a database of 1D MagLIF simulations to optimize the detector and filter configurations to minimize uncertainty





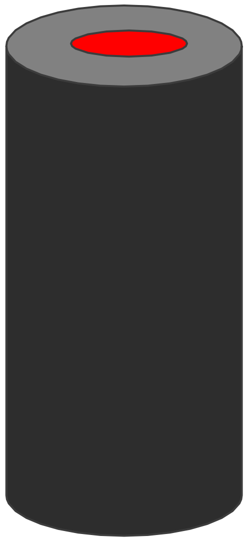
Filtered Power Signals



We use the fit to the reconstructed time-integrated spectrum as our optimization metric

There is no ambiguity in comparing a reconstructed spectrum to the simulation

Comparing physical quantities like temperature require a choice of mapping to the highly complex experiment

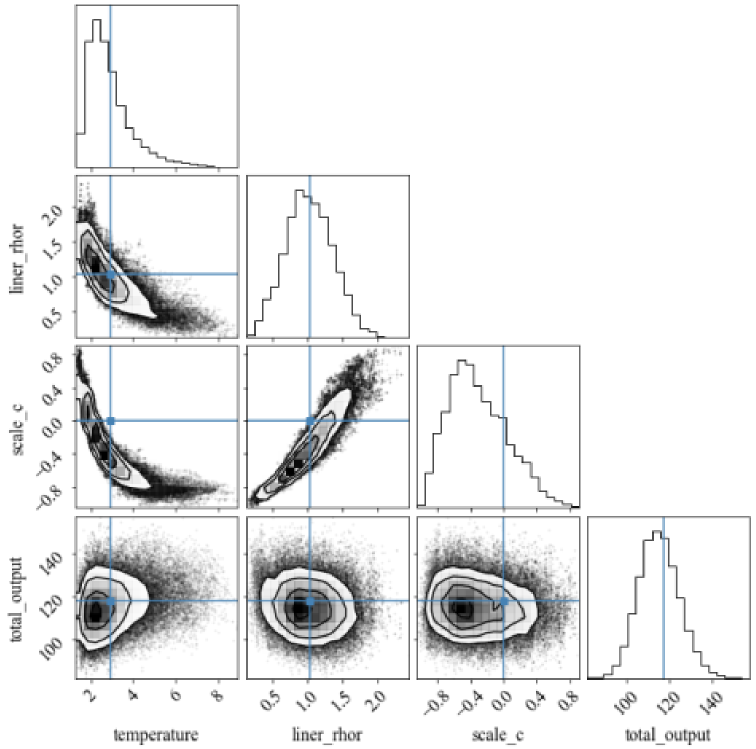


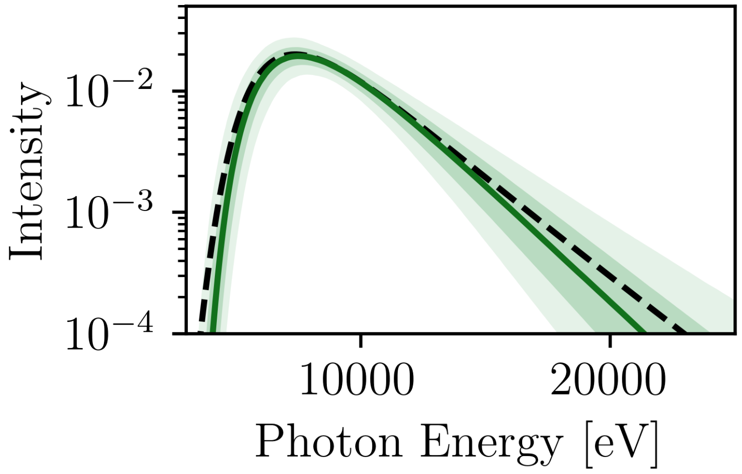
Parameters

T_e

ρR_ℓ

C



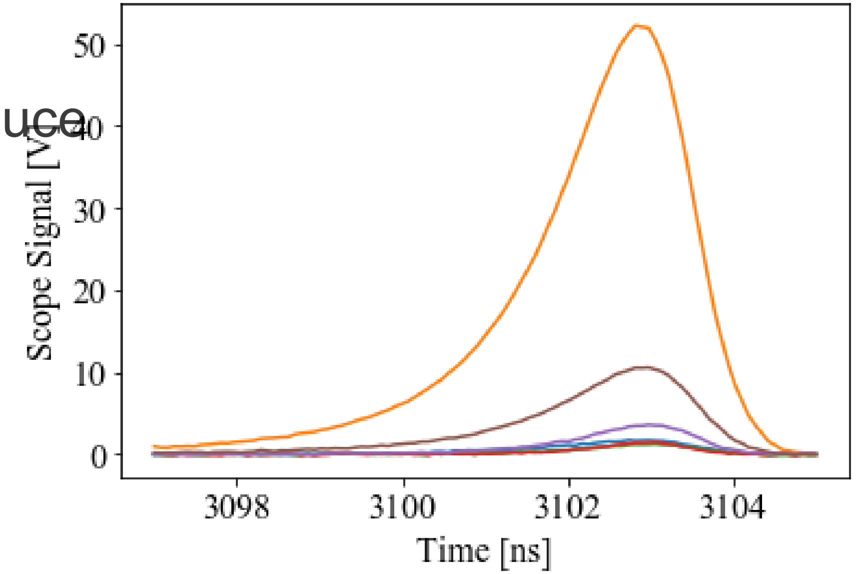


Quality of the inference is quantified by the MSE

$$\mathrm{MSE} = \frac{1}{N} \sum_{k}^{\#samples} \int d\nu (I_{\nu,k} - T_\nu)^2 = (\mathbb{E}(I_\nu) - T_\nu)^2 + \mathrm{var}(I_\nu)$$

PCD's will saturate as the peak voltage approaches the bias voltage

- The form of our model does not allow us to explicitly account for this during the inference
  - PCD's measure power, our model produces an energy
- Accounting for this would require more physics be added to our model
- We must include a penalty term for configurations that produce signals with large amplitude

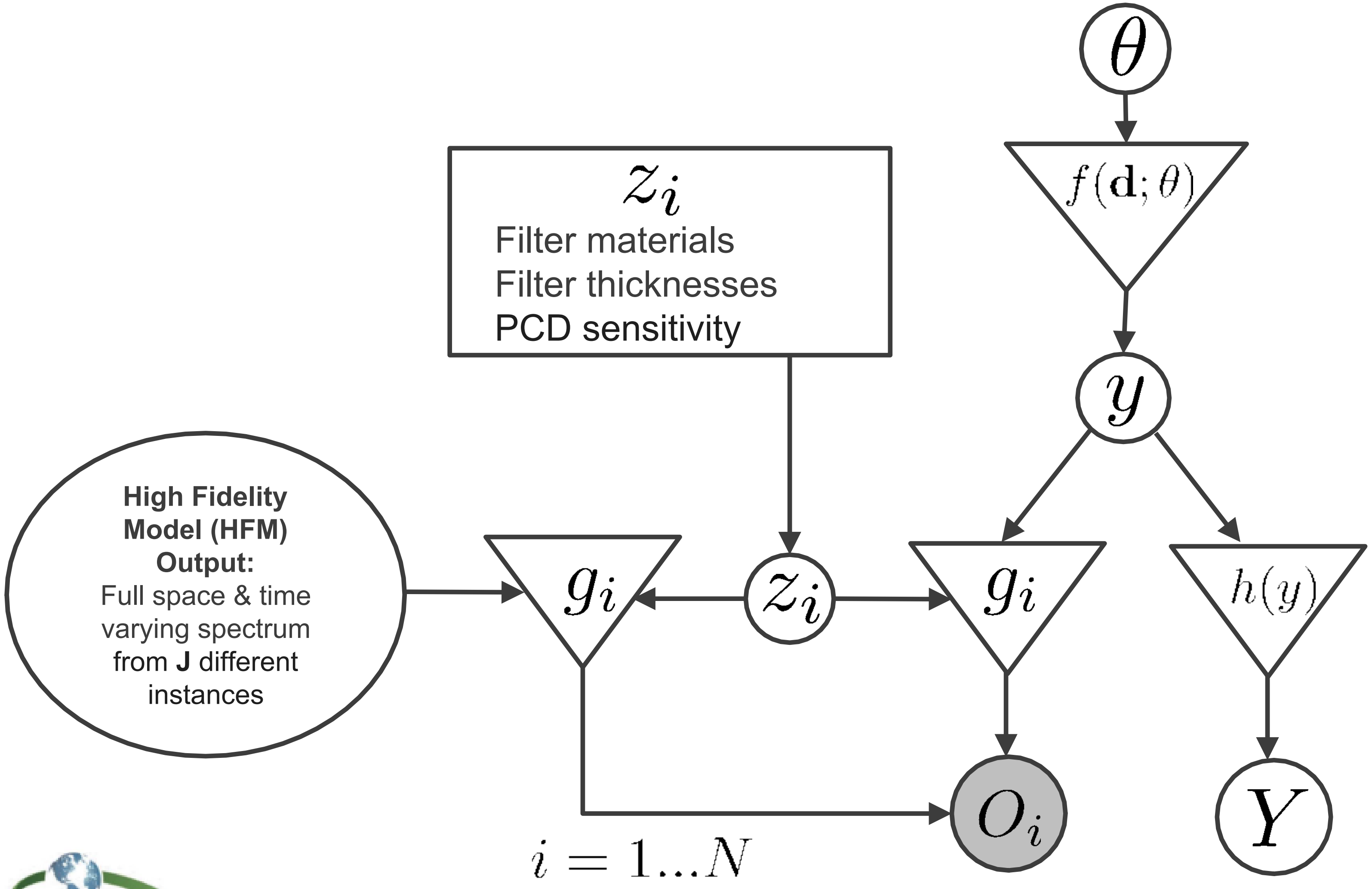


$$L = \exp\left(\frac{\max(V_{\text{peak},i})}{\alpha V_{\text{bias}}}\right) - 1$$

$$\mathcal{M} = \log(MSE + \lambda L)$$

Optimization metric

Our goal is to find the set of PCD filters and sensitivities that provide optimal reconstruction of the emitted spectrum



$$\mathcal{M} = \log(MSE + \lambda L) \qquad Z_{\text{opt}} = \underset{z_i}{\text{argmin}} \sum_{j=1}^{J} \mathcal{M}_j$$

Procedure

1. Choose z_i (filter material and thickness for each element)
2. Create O_i from HFM output for each element with chosen configuration
3. sample posterior with chosen configuration and new O_i
4. Compute MSE from posterior samples
5. Fit GP and compute EI to select new point
6. Go back to (1) with new choice, iterate until stopping criterion is reached

P.F. Knapp et al., under review, JPP

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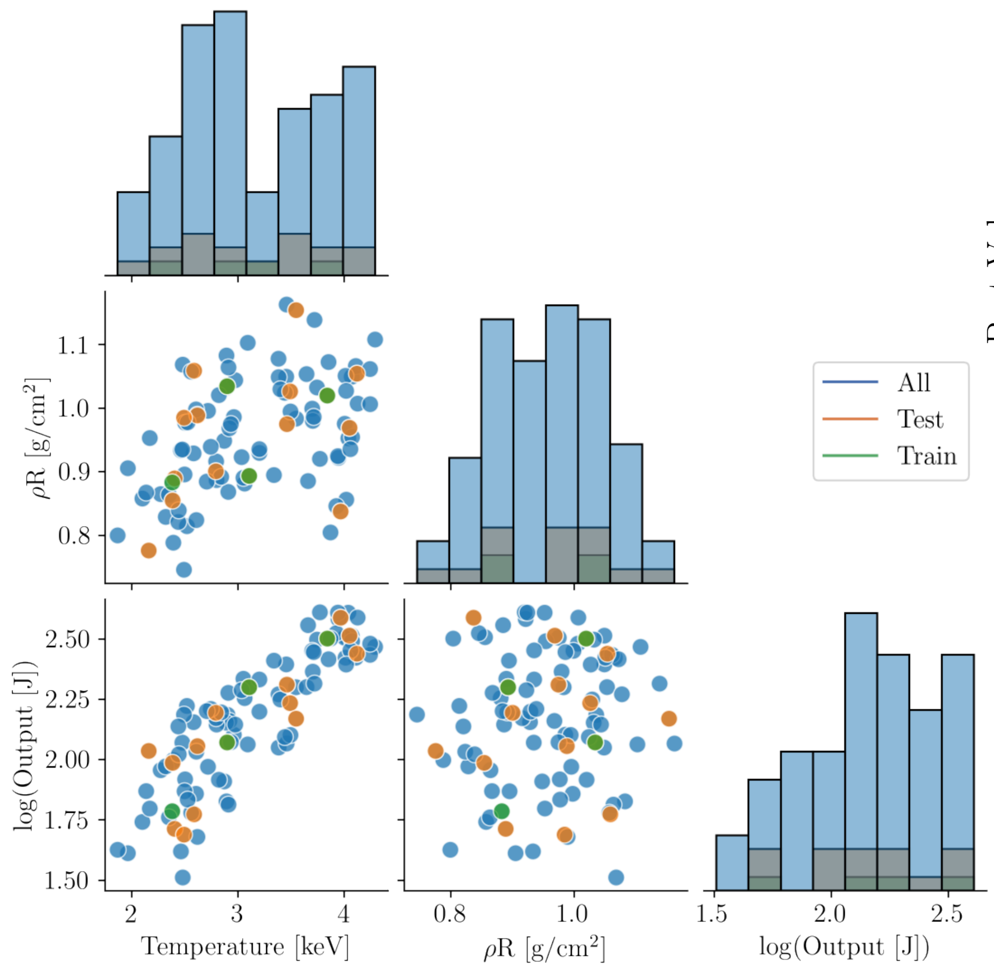
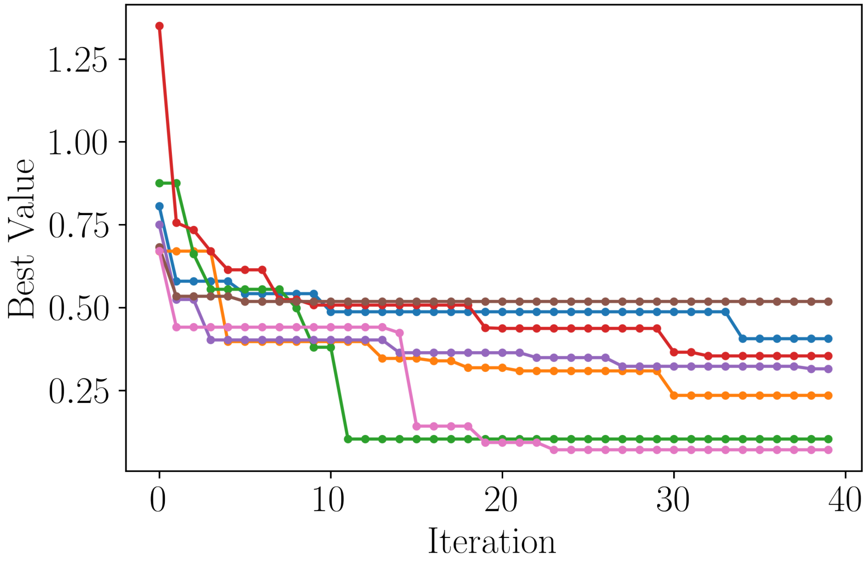
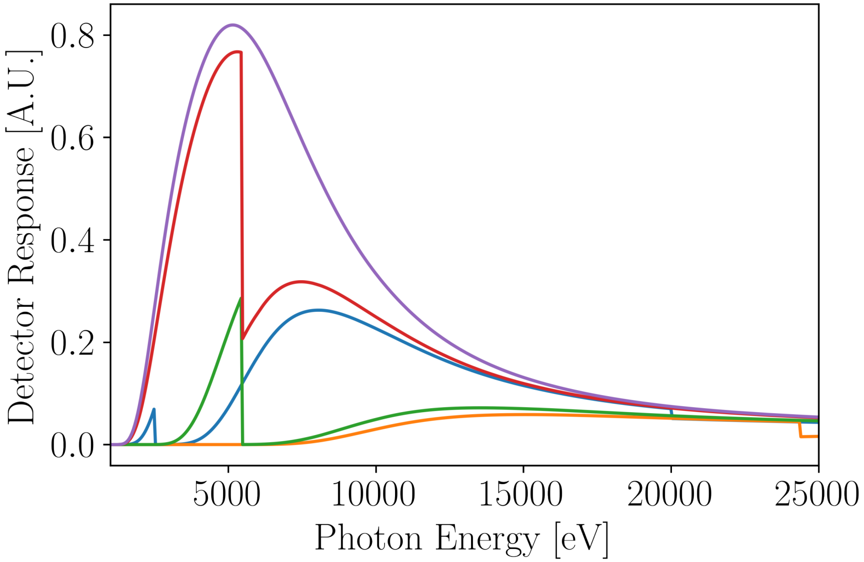
We leverage an ensemble of 1D Kraken-MagLIF calculations to train and validate our optimization procedure





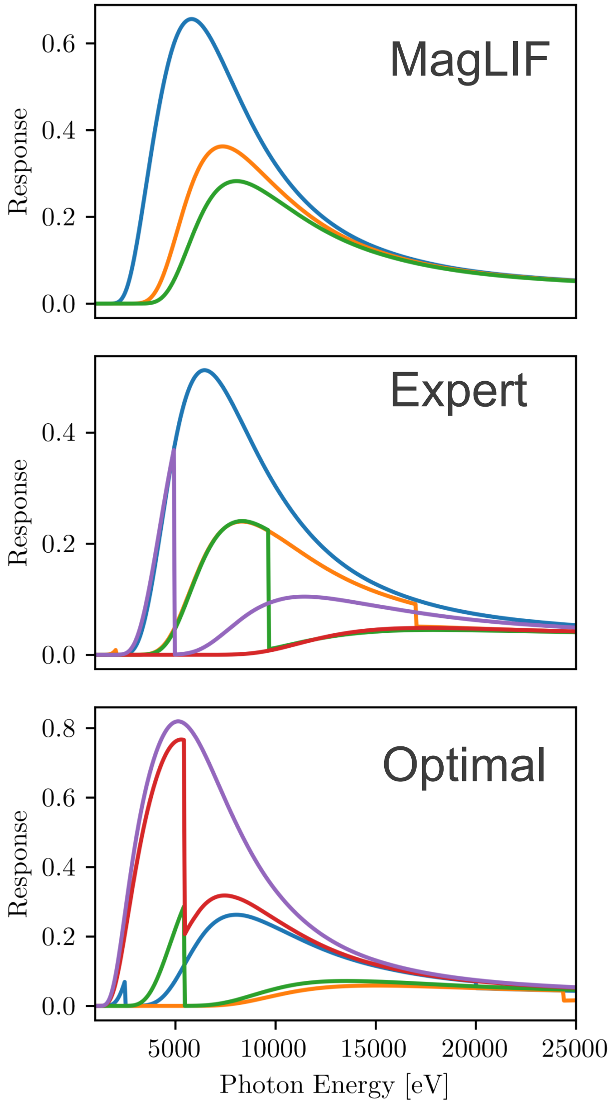


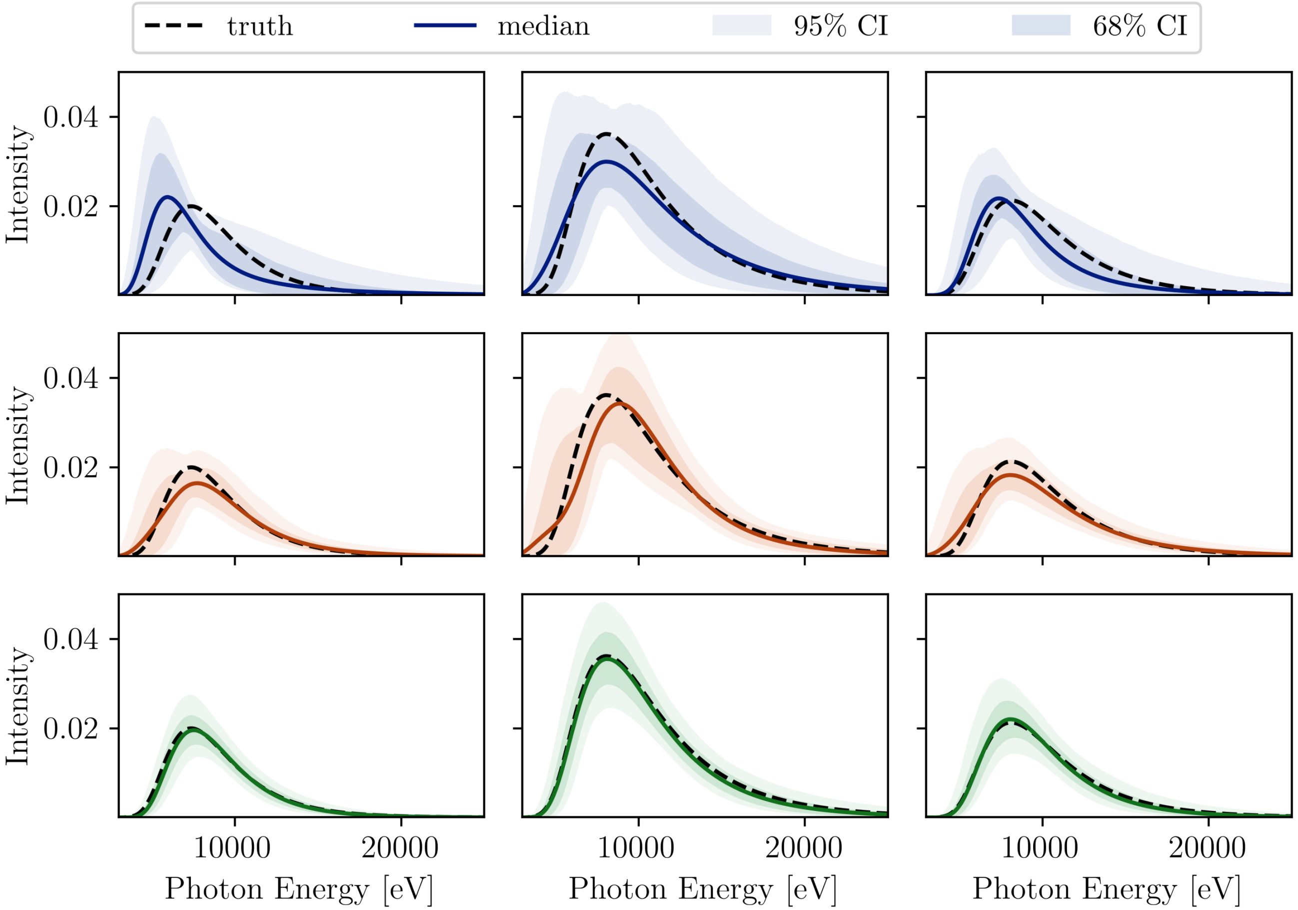
Due computational cost, only 4 training and 16 validation points were selected from the ensemble

Support points were used to ensure the samples represent the distribution

P.F. Knapp et al., under review

The performance of the optimum was compared against two reference cases





Total log(MSE)

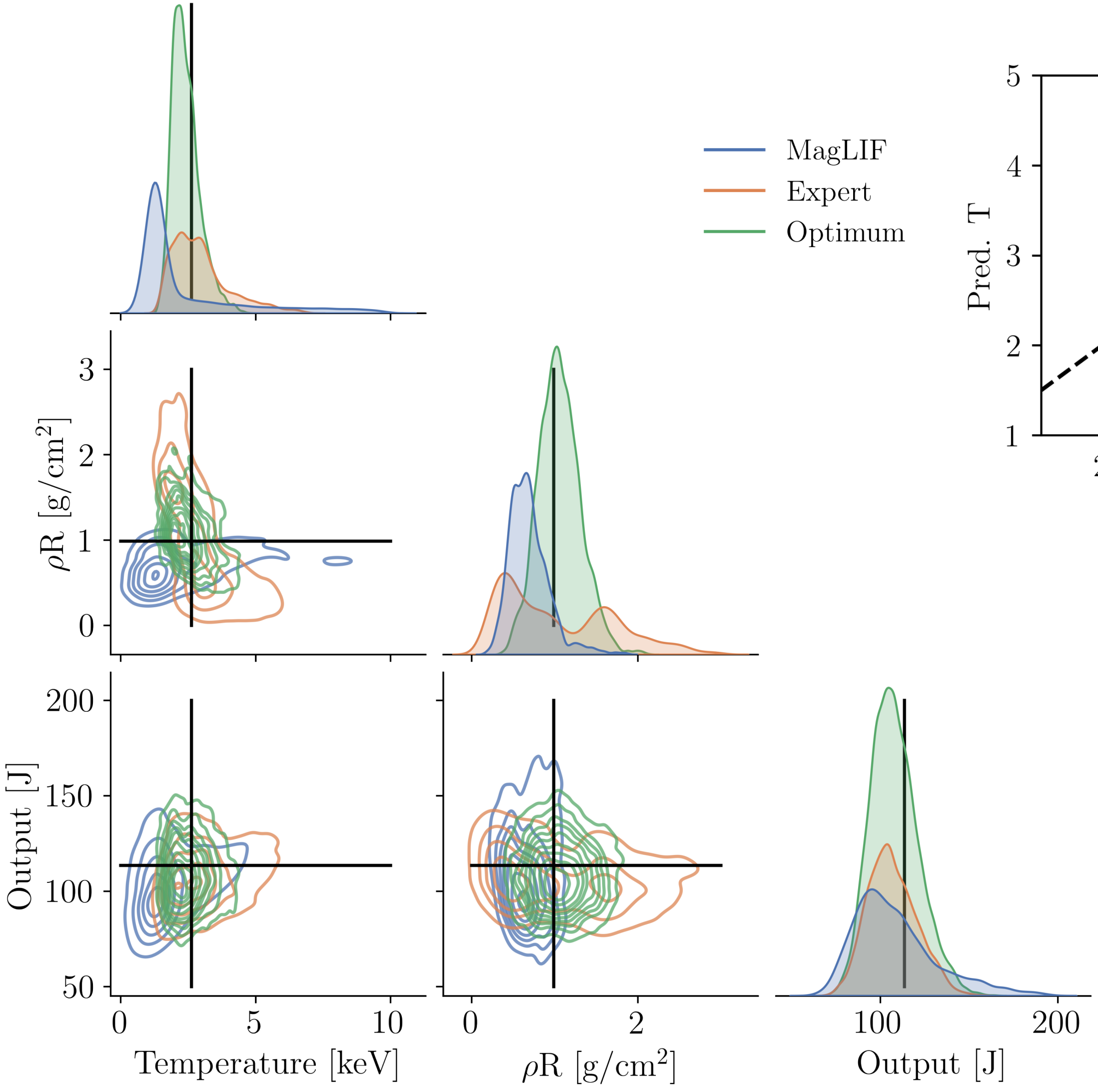
2.13

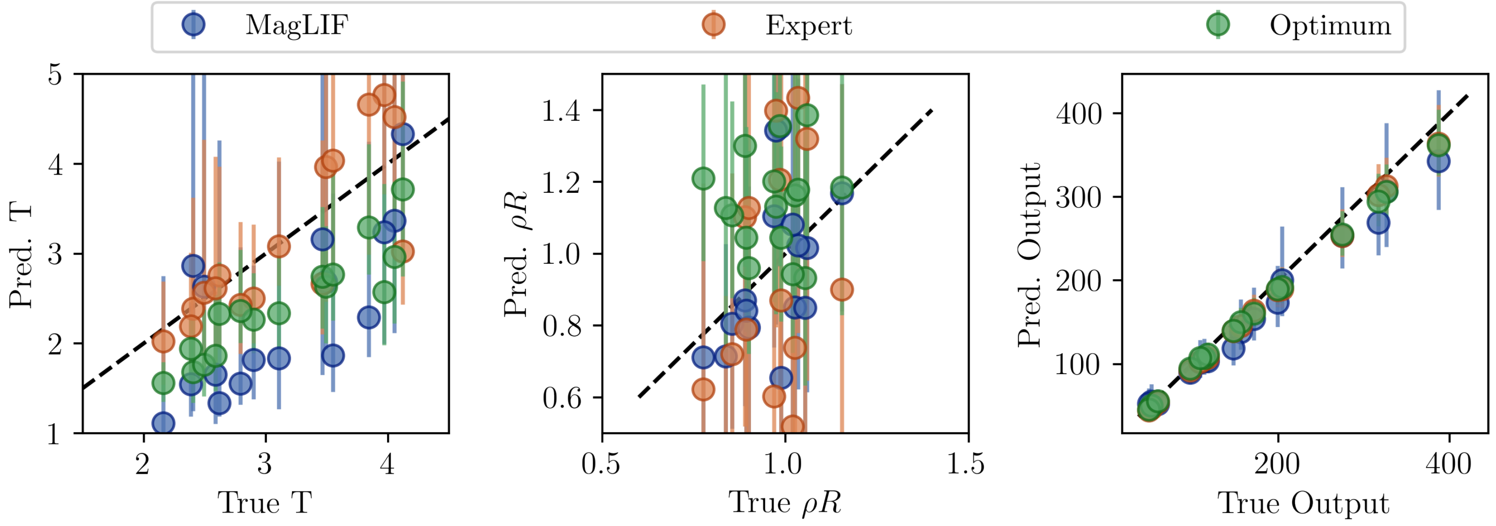
2.5

-0.22

Our optimal configuration performs markedly better on the validation set

Our optimized configuration also performs better on some of the physical parameters





The posterior is narrower with the optimal configuration

Liner ρR is poorly constrained in all cases

The temperature is biased somewhat low, but is inferred with better precision

The output is constrained more tightly and with less bias

P.F. Knapp et al., under review in Journal of Plasma Physics

Summary

- We have demonstrated a general method to optimize instrumental configurations to produce inferences with low combined variance and bias
- The metric utilizes the full posterior leveraging the uncertainty in the optimization
- The method explicitly acknowledges the impact of model assumptions in the interpretation of data
- Future work will look at:
  - Optimizing additional metrics
  - Pareto optimization to examine tradeoffs between e.g. bias and variance
  - Incorporation of more instruments
- Ultimately, this technique can be used to assess the value of new data and optimize proposed new instruments before they are built