Optimisation of high repetition rate diagnostic design using synthetic modelling

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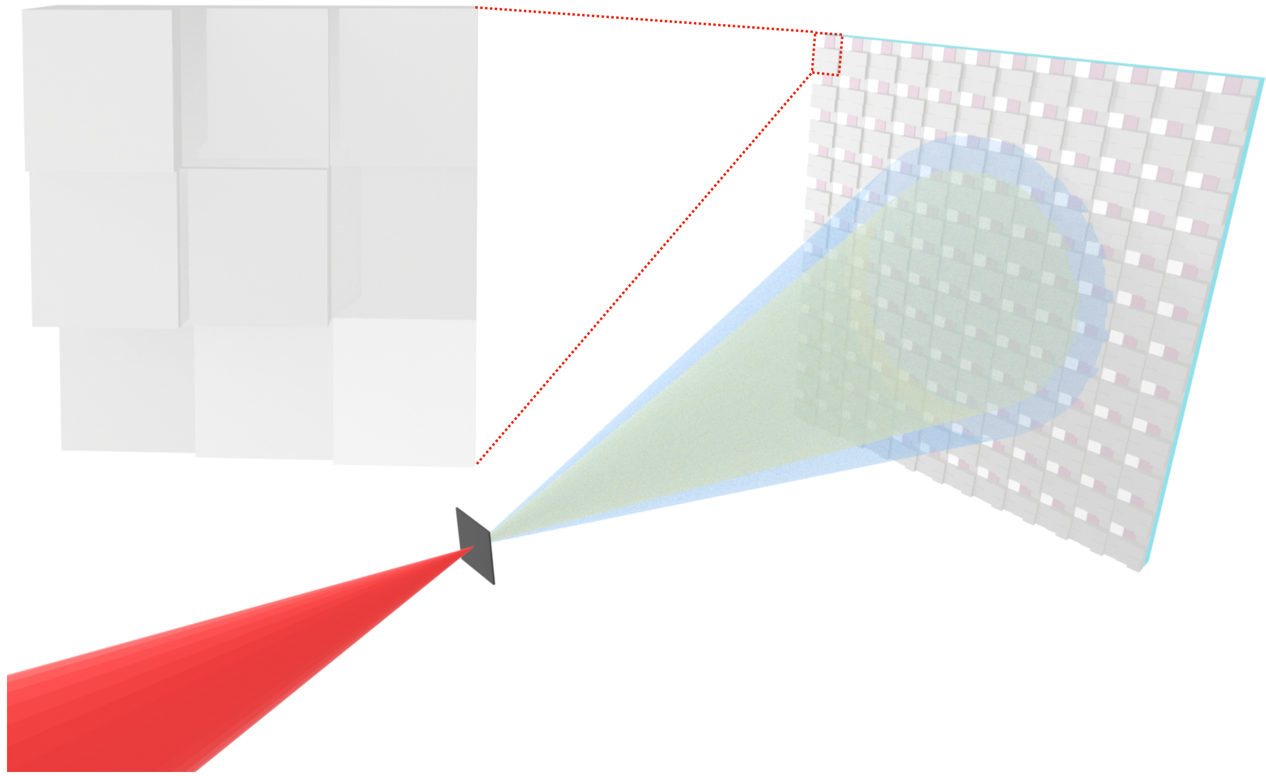
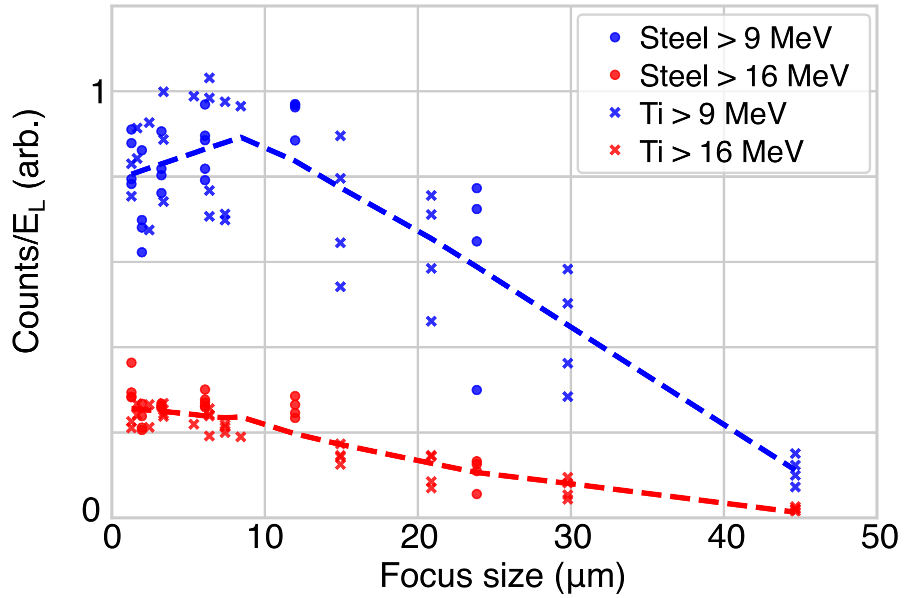
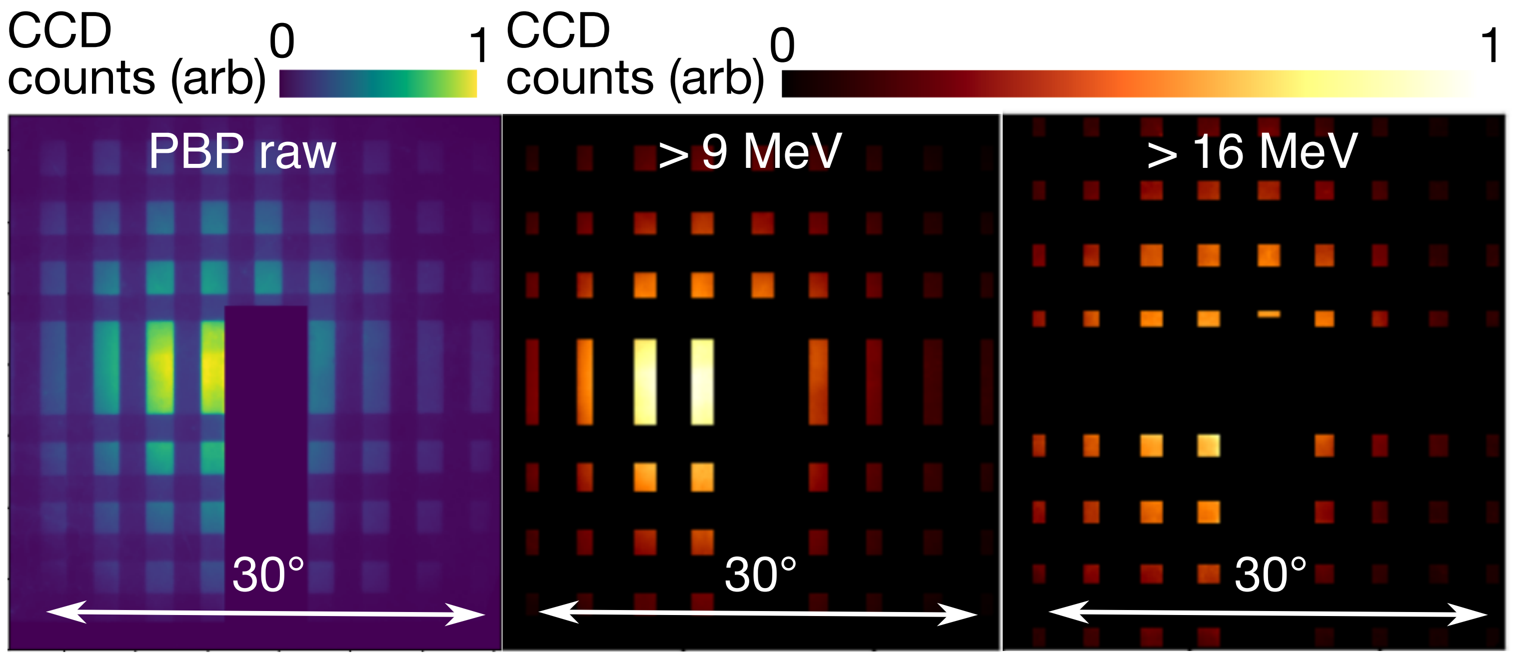
"PROBIES" diagnostic

- High repetition rate alternative to radiochromic film stack
- Differential filtering attenuates beam, visible on scintillator
- Source spectrum reconstruction solved as an inverse problem





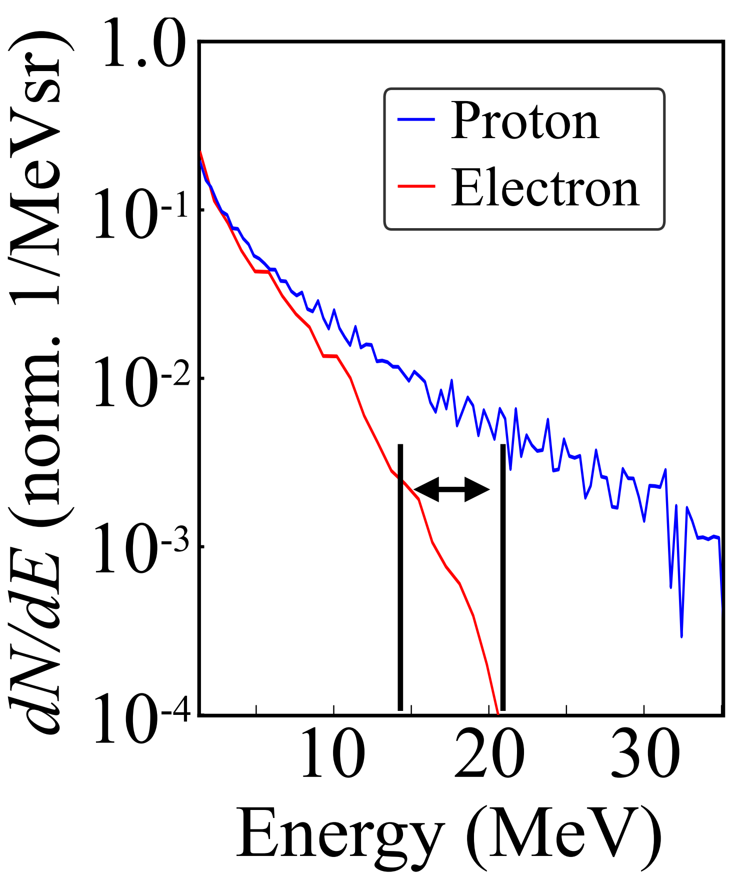


Dover+, High Energy Density Physics 37, 100847 (2020)

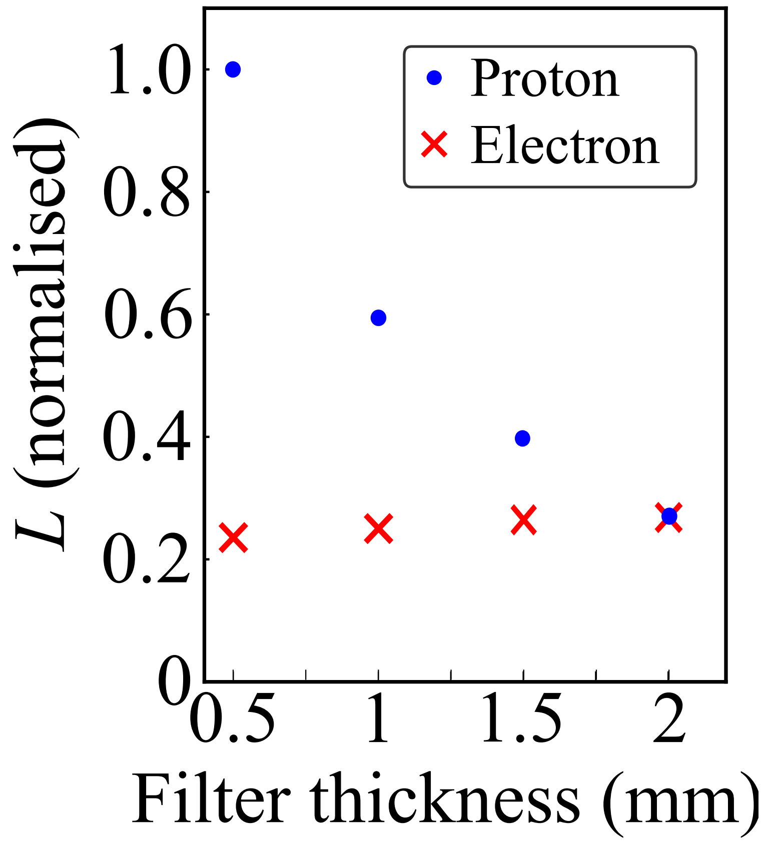
Problems with background

- Laser driven ion sources produce other radiation - relativistic electron beam is a major source of background
- Electrons penetrate through all filters - but most ions don't penetrate thickest filters

Example spectra (from simulation)



Dover+, Review of Scientific Instruments 88, 073304 (2017)



High energy ion spectrum is most susceptible to noise!

Synthetic data & CNN-guided analysis

IMPERIAL

LhARA Laser-hybrid Accelerator for Radiobiological Applications

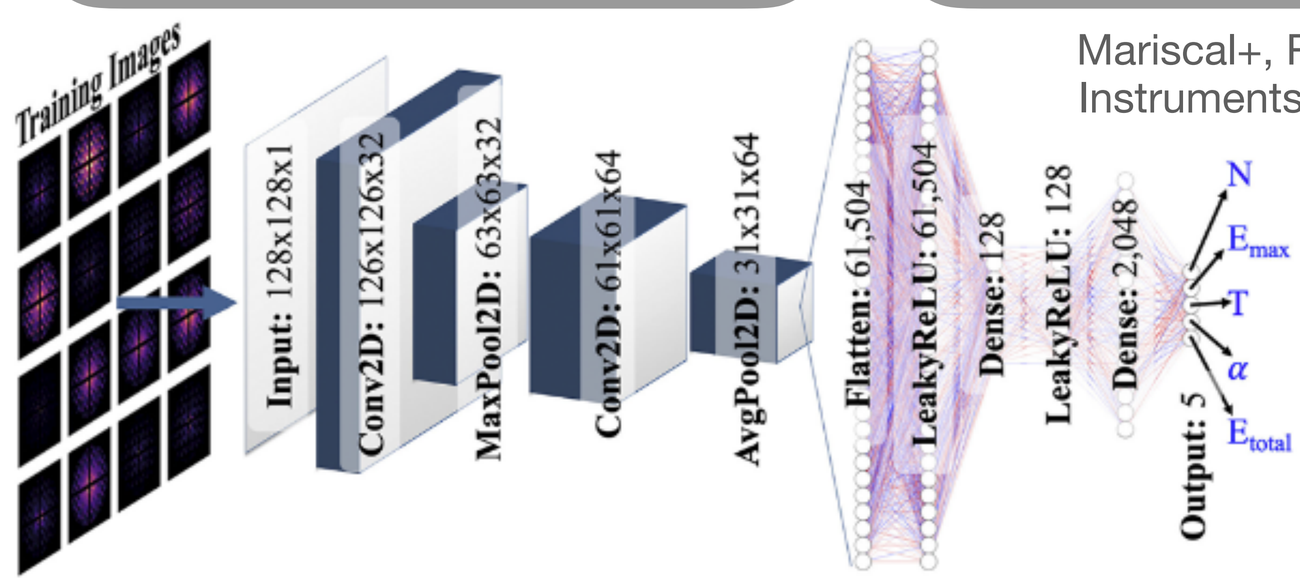
The challenge:

Solving for the source spectrum quickly	Making the best choice of filter array thicknesses	Dealing with electron background robustly

Synthetic data & CNN-guided analysis

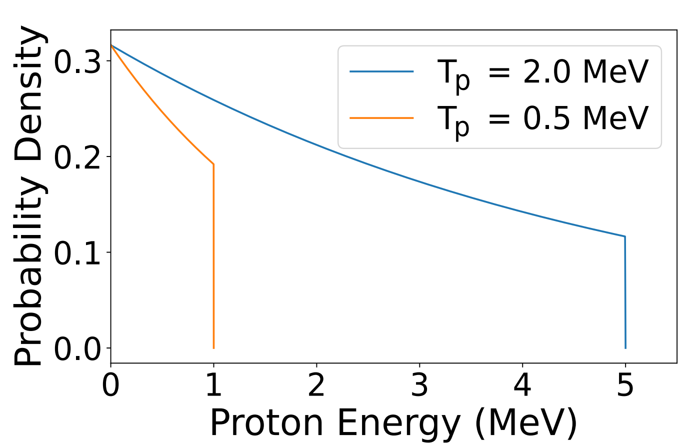
The challenge:

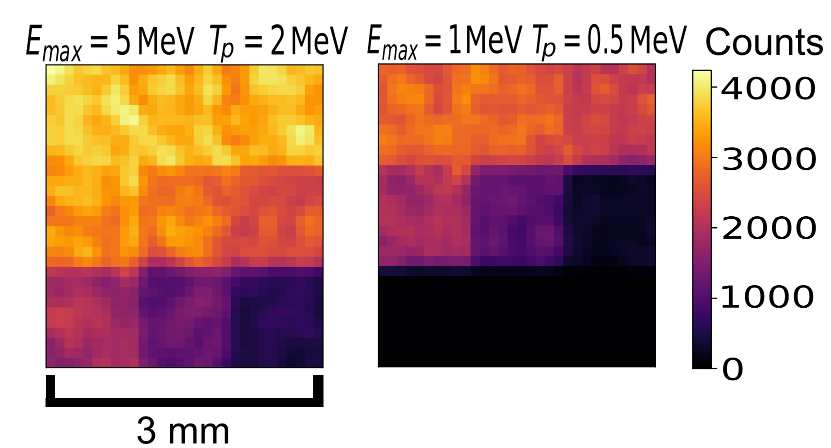
Solving for the source spectrum <u>quickly</u>



Mariscal+, Review of Scientific Instruments 94, 023507 (2023)

- Convolutional neural networks turn images into numbers
- Need training data - make a *synthetic diagnostic model*





Synthetic data & CNN-guided analysis

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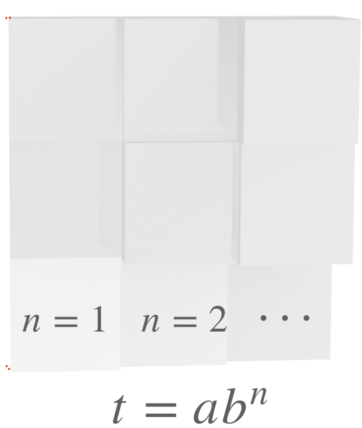
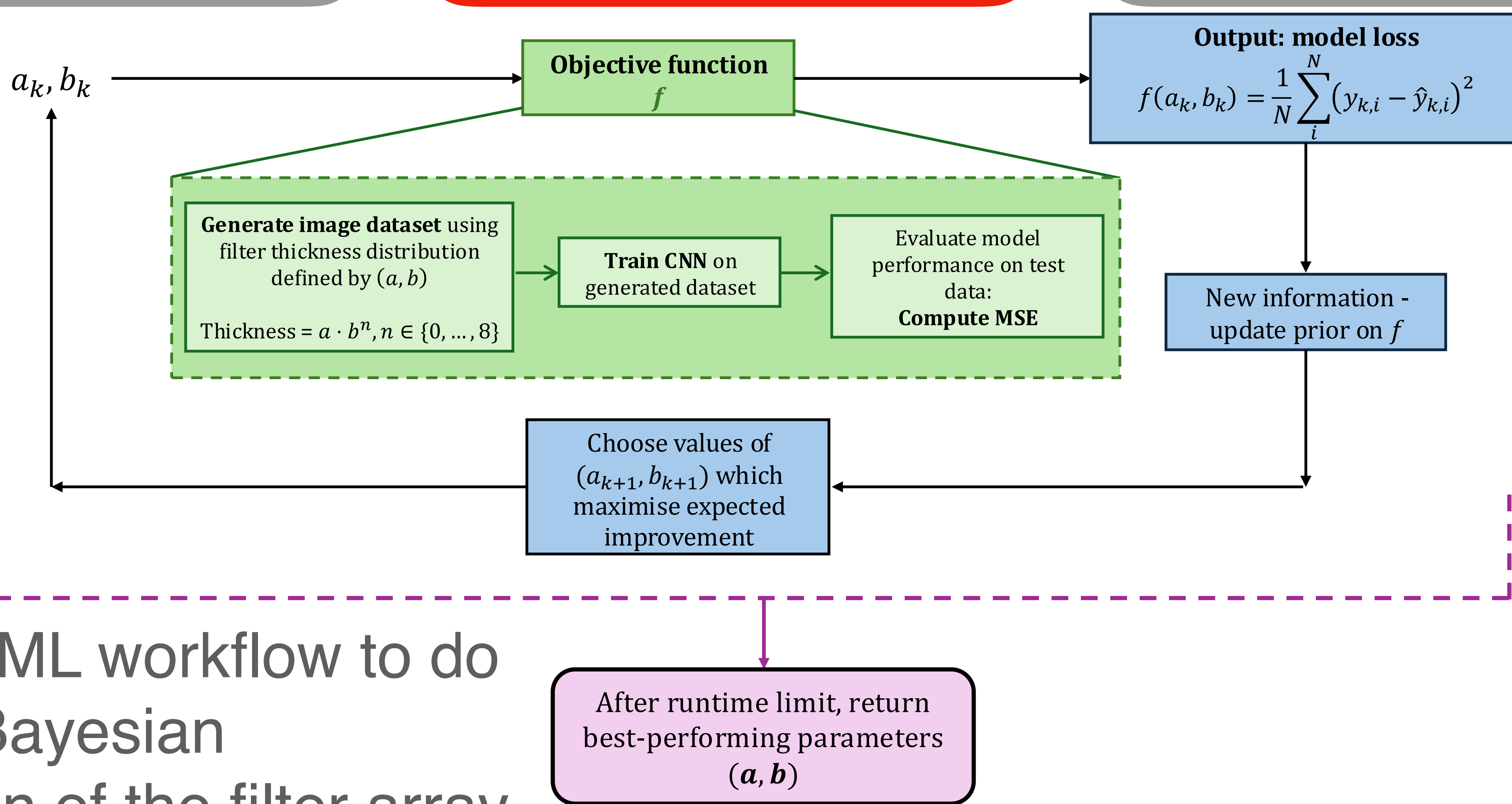
LhARA Laser-hybrid Accelerator for Radiobiological Applications

The challenge:

Making the best choice of filter array thicknesses





Utilise the ML workflow to do synthetic Bayesian optimisation of the filter array

Synthetic data & CNN-guided analysis

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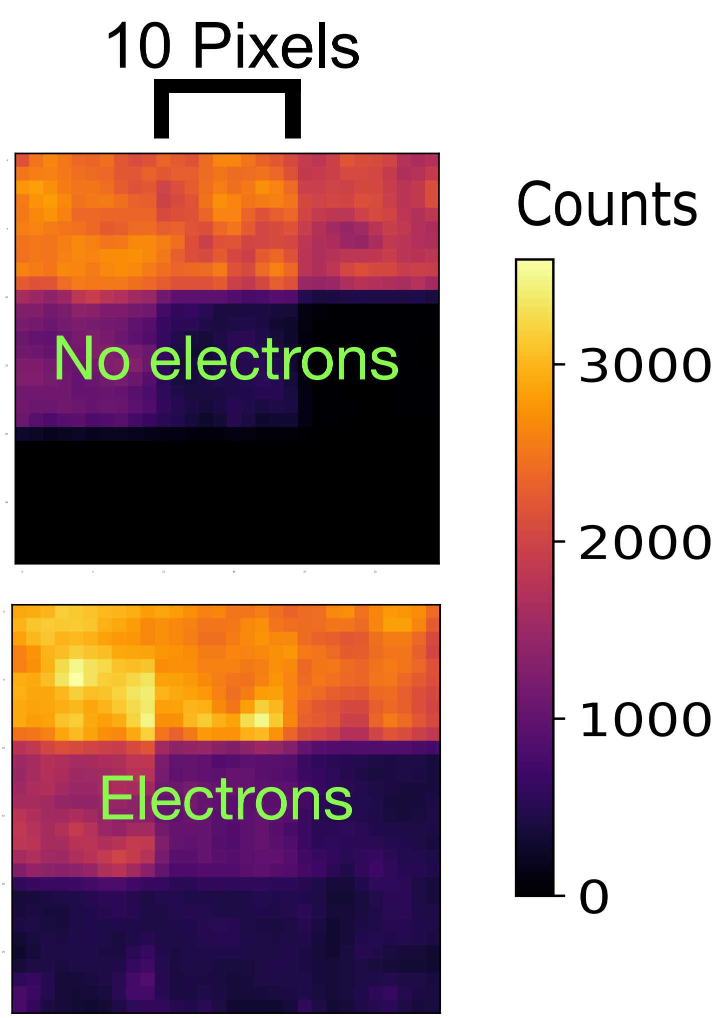
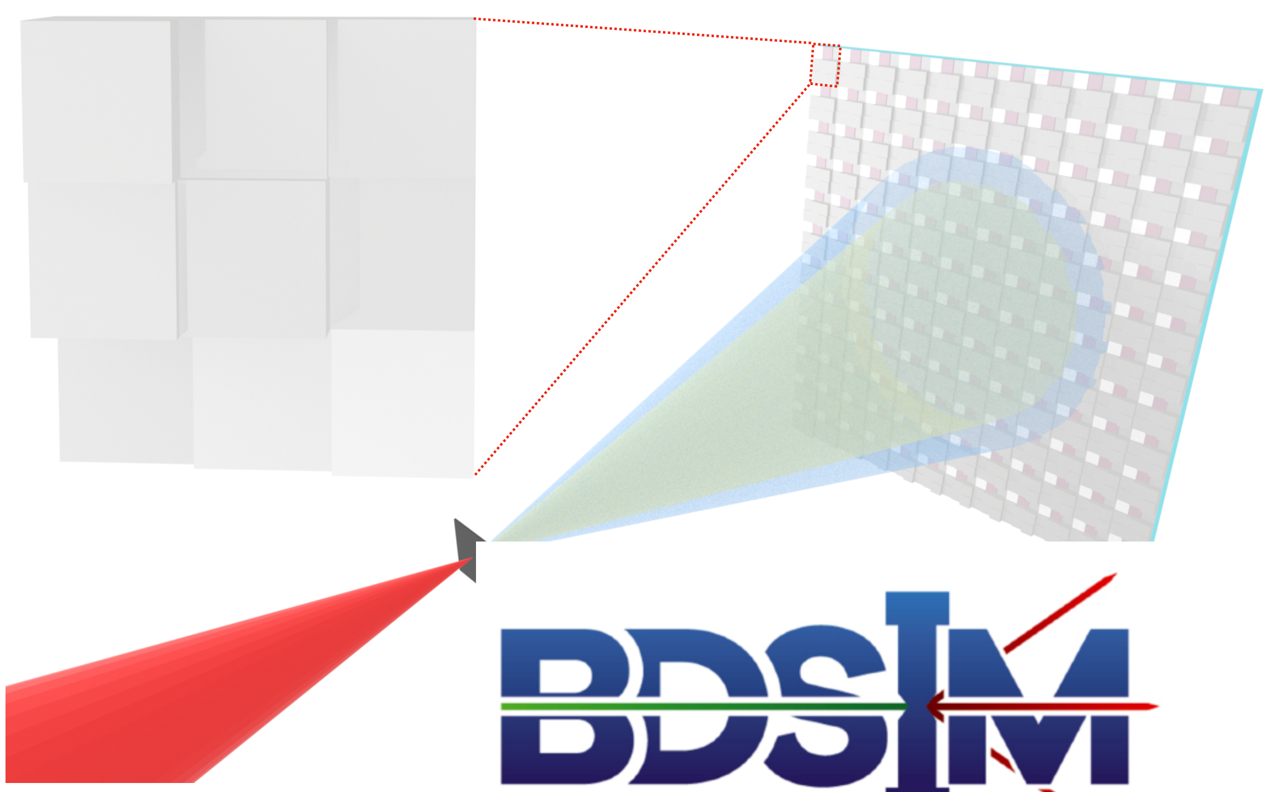
The challenge:

Dealing with electron background robustly



Include varying electron noise as part of the synthetic dataset



BDSIM

Optimised performance - protons only

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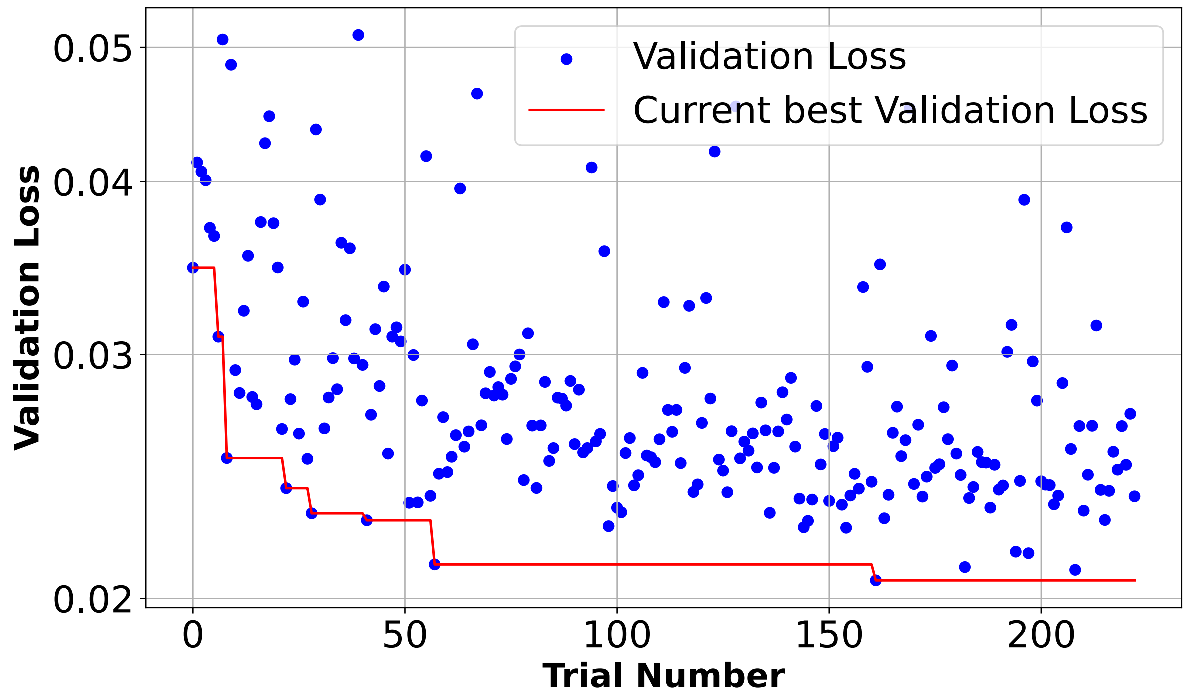
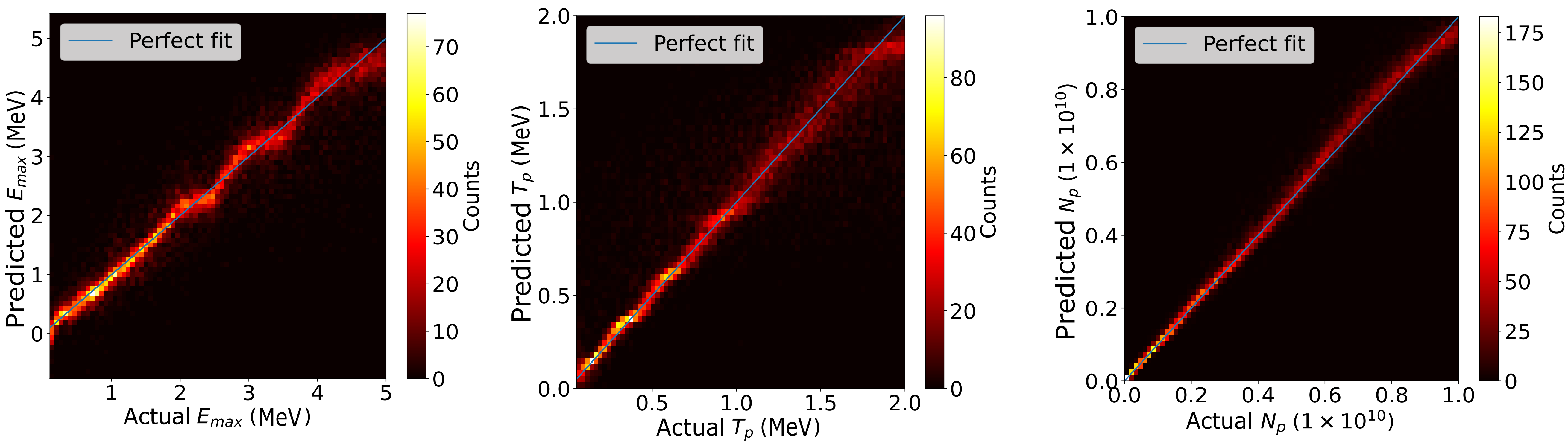
- The optimisation loop found a set of thicknesses that minimised the prediction error:

$$\frac{dN}{dE} = \begin{cases} N_p \exp(-E/T_p) & \text{for } E \le E_{max} \\ 0 & \text{for } E > E_{max} \end{cases}$$





Processing time ~ 5 ms per image on generic laptop

Impact of electron background

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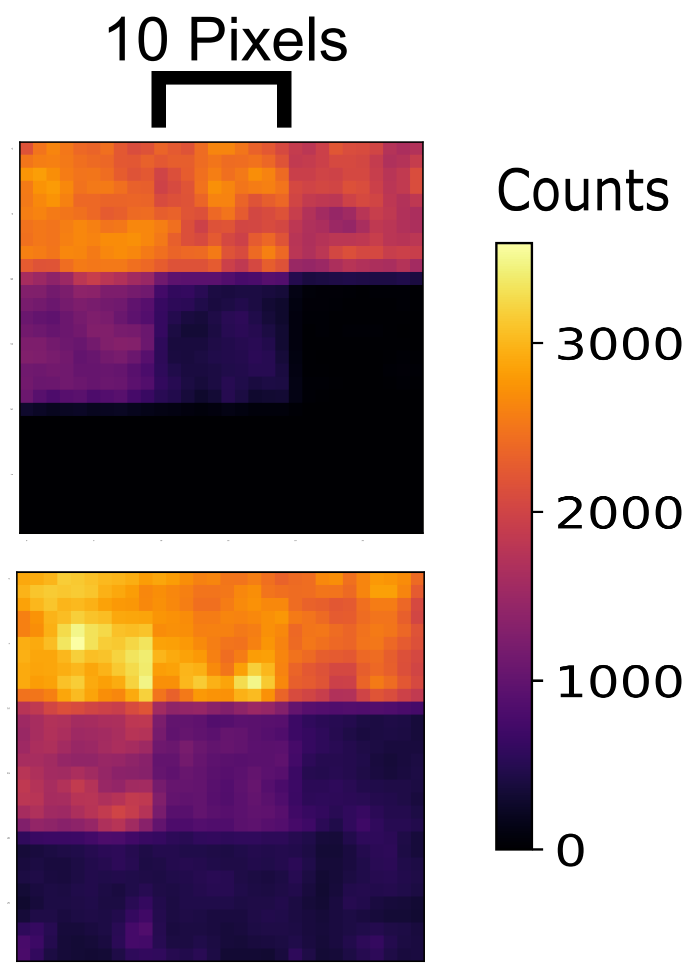
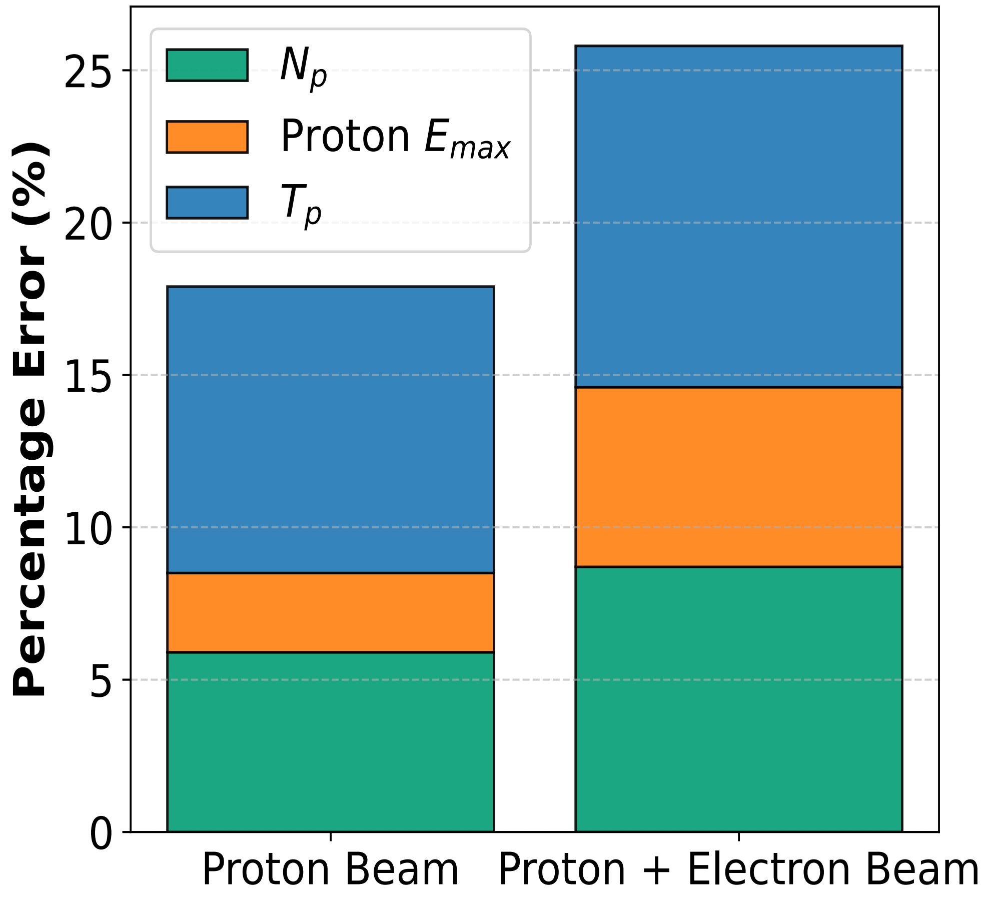
- Repeformed the optimisation loop including electrons
- Electron number & temperature varied randomly for each image
- Significant decrease in accuracy of prediction of maximum energy & temperature





Can we extract electron parameters from the diagnostic?

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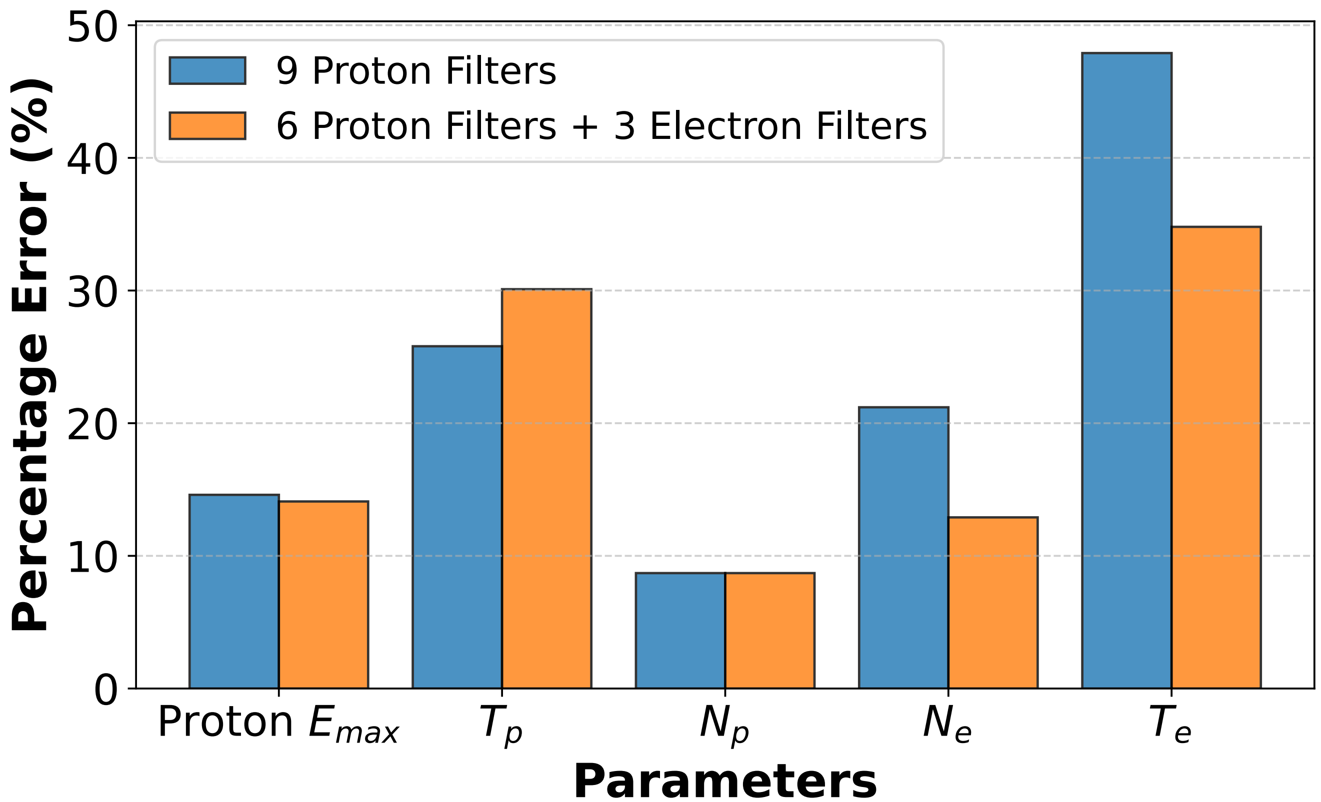
- Convolutional neural network asked to output electron parameters
- Re-ran filter optimisation including electrons in loss function

Protons

$$\frac{dN}{dE} = \begin{cases} N_p \exp(-E/T_p) & \text{for } E \leq E_{max} \\ 0 & \text{for } E > E_{max} \end{cases}$$

Electrons

$$\frac{dN}{dE} = N_e \exp(-E/T_e)$$



- New design includes *thicker* filters which only see electrons - allowing direct measurement of the ‘background’

Conclusion & next steps

- Built workflow for designing & analysing ‘PROBIES' diagnostic
  - Optimal filter configuration
  - Extremely quick analysis
  - Robustness to background
- Extended capability to provide electron measurement “for free” (which can be improved!)
- Of course, needs to be implemented experimentally!
- **Workflow transferrable to wide range of particle and radiation diagnostics**