Multi-channel, Multi-template Reconstruction for SuperCDMS SNOLAB Using Machine Learning

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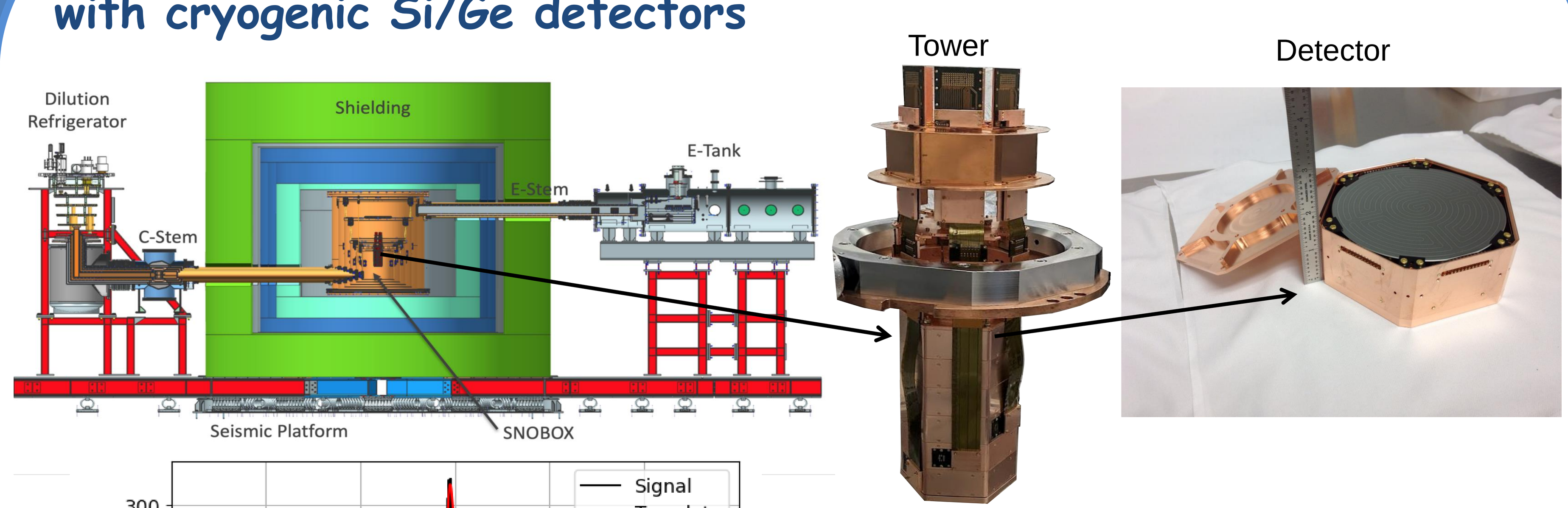
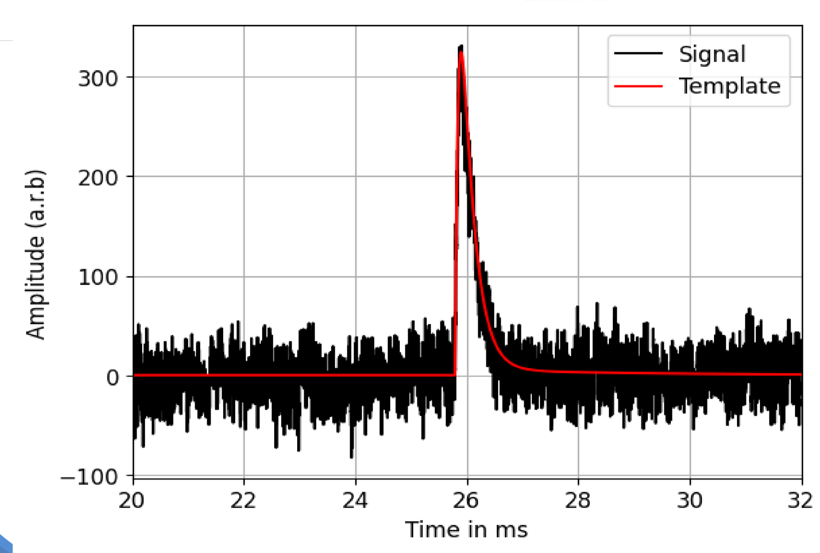
Correlated noise, position dependence & SuperCDMS detectors

SuperCDMS SNOLAB – a direct dark matter search experiment with cryogenic Si/Ge detectors





- Data acquired as **digitized waveforms** with time varying pulses
- Pulse amplitude (A) extracted with simple frequency domain χ^2 :

$$\chi^2 = \Sigma_i \frac{|s_i - Av_i|^2}{\sigma_i^2}$$

Factors not addressed by current techniques:

- Pulse shape variation
- Correlated noise sources (vibrational, electronic, etc.)

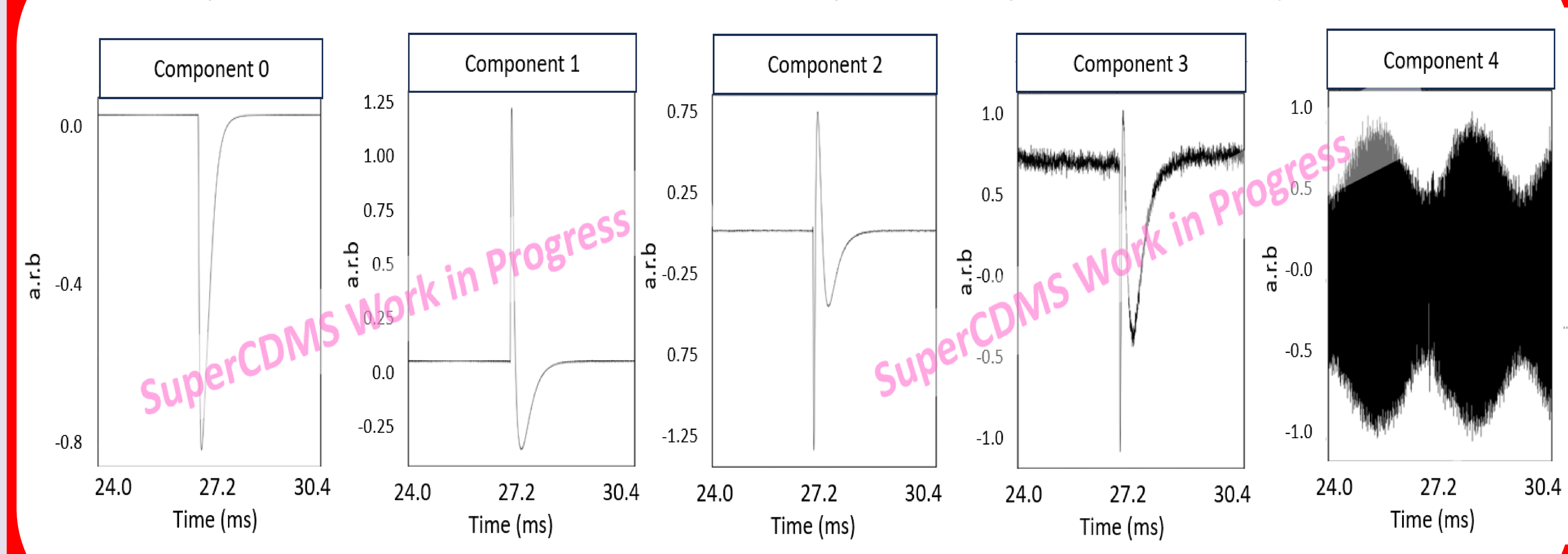
Solution: NxM filter that fits N channels with M templates simultaneously

$$\chi^2 = \Sigma_f (\vec{S}_f - T_f\vec{A})^T V_f^{-1} (\vec{S}_f - T f\vec{A})$$

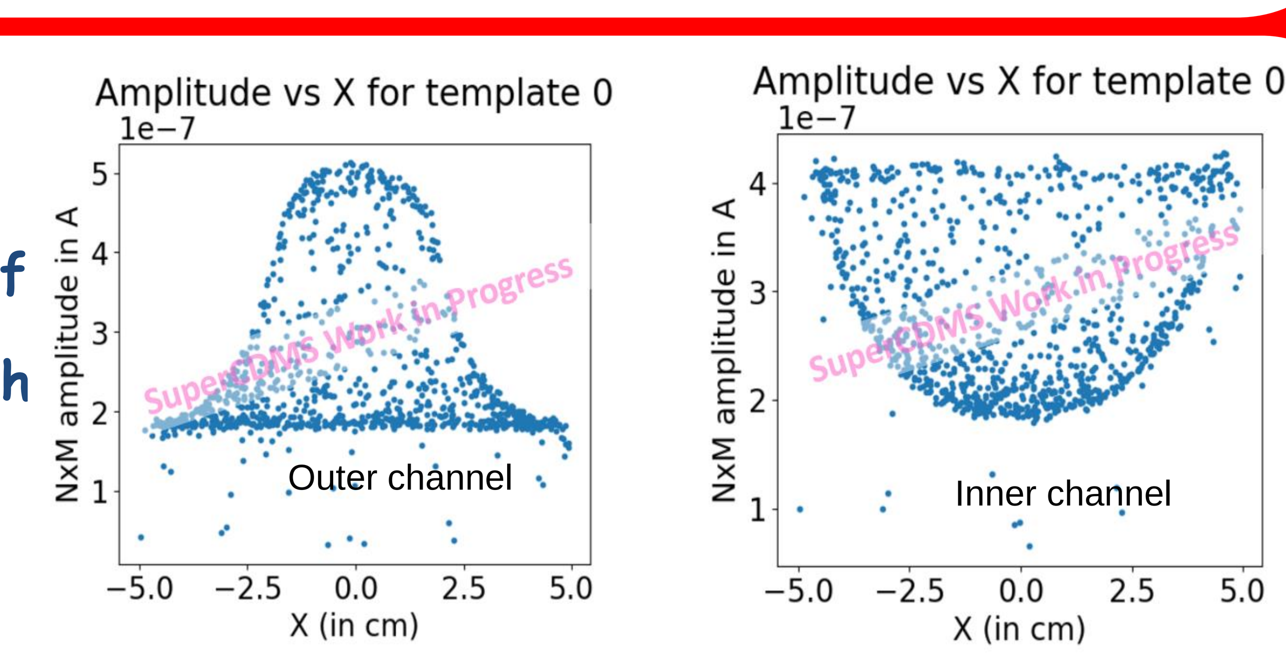
The machine learning angle

Use PCA to extract waveform components that capture pulse shape variation with position, then use linear estimator plus GBDT to map from amplitudes to energy & position.

Template generation with Principal Component Analysis (PCA)

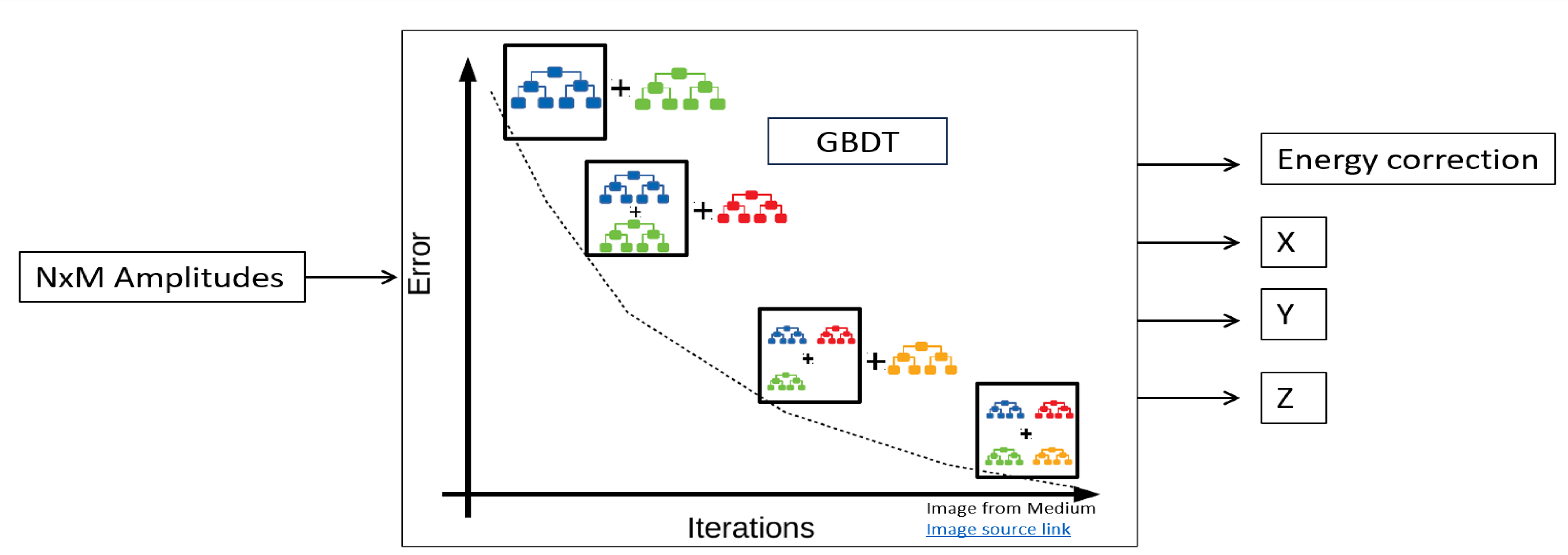


Amplitudes of components correlate with position



Gradient Boosted Decision Trees

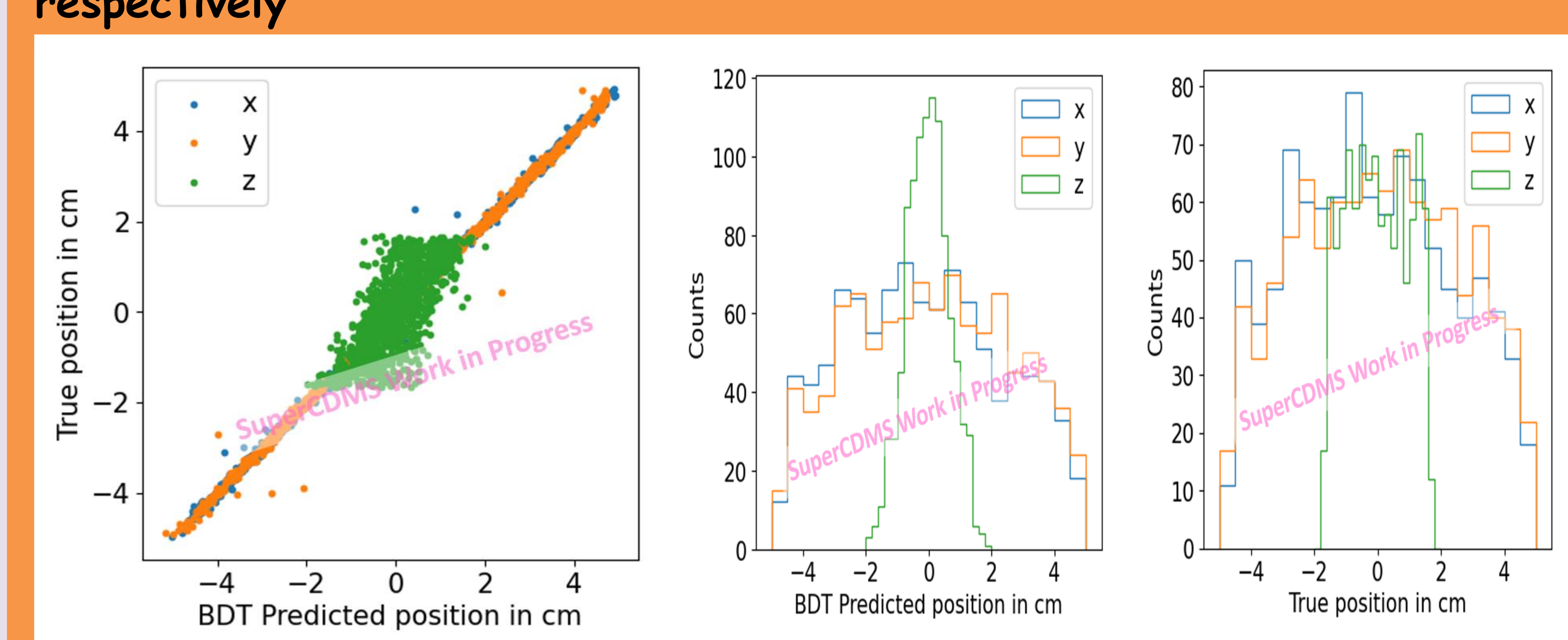
An ensemble of decision trees to empirically map inputs to outputs. Trees learn non-linear dependencies of output variables on the inputs.

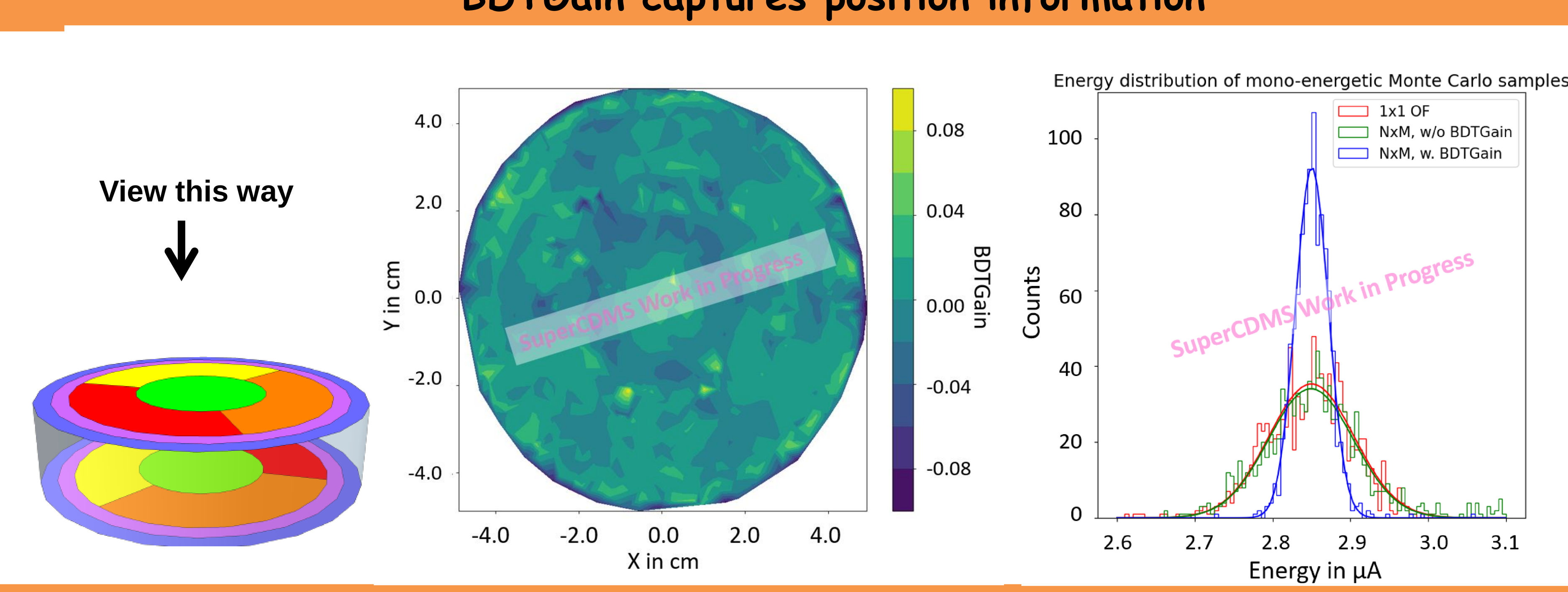


Results from 10,000 simulated events

X, Y and Z positions predicted within 0.52 mm, 0.55 mm and 5.49 mm, respectively

Nearly, threefold enhancement in energy resolution from NxM + GBDT; BDTGain captures position information



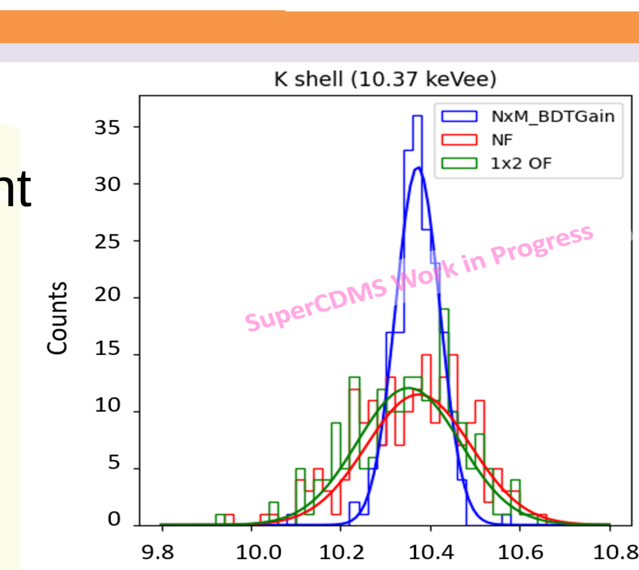


Conclusion and future directions

NxM filter combined with machine learning can produce significant enhancement in energy resolution

Future directions

- NxM applied to old SuperCDMS data: two-fold enhancement in energy resolution (see right figure →). **Apply to new real data**
- **Transfer learning to address limited training data size**



Acknowledgements

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