Data Reduction for the ECHo Experiment

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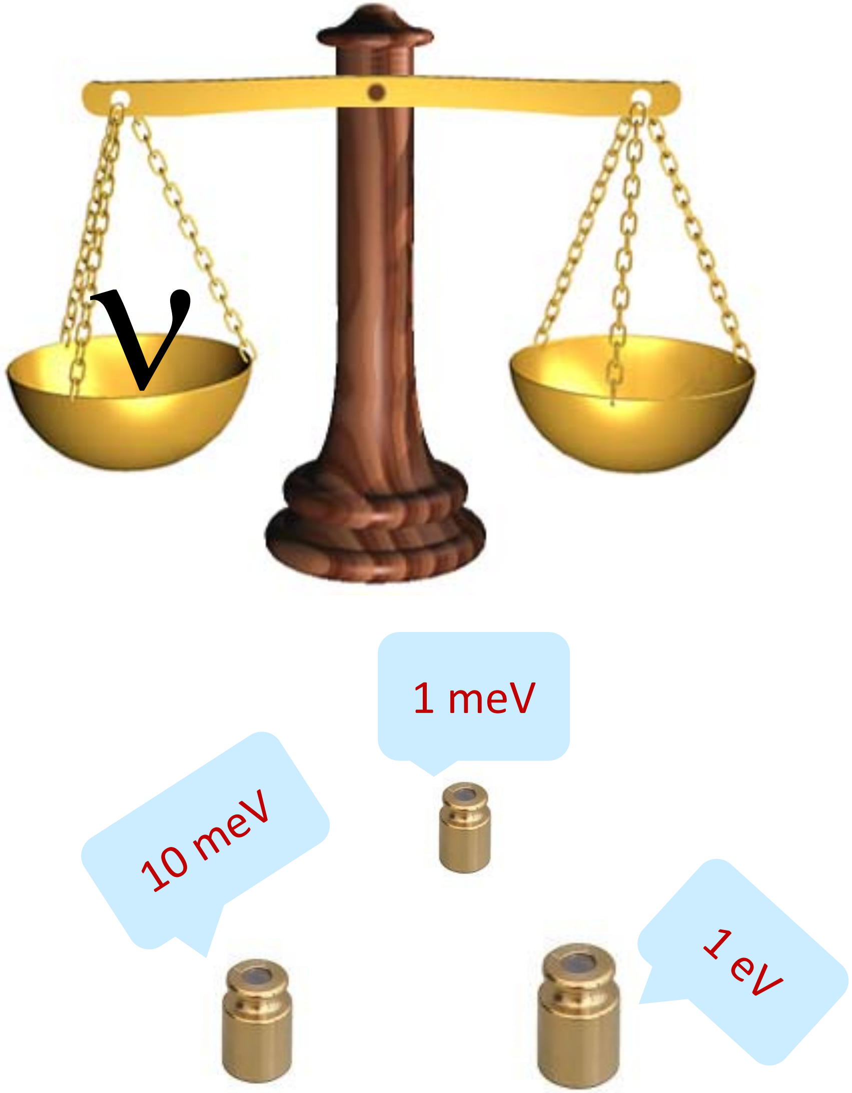
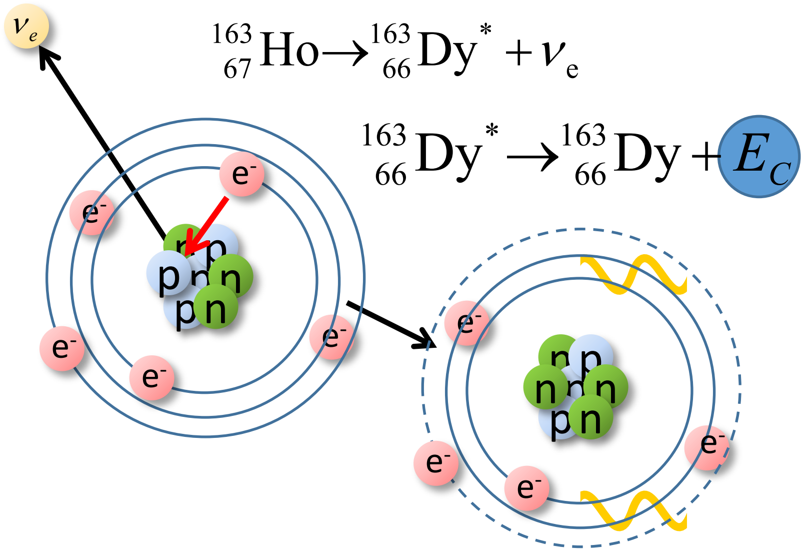
Heidelberg University

Outline

- Introduction
- Metallic Magnetic Calorimeters
- Data Analysis & Automization
- Conclusions and Outlook



Electron Capture in ^{163}Ho

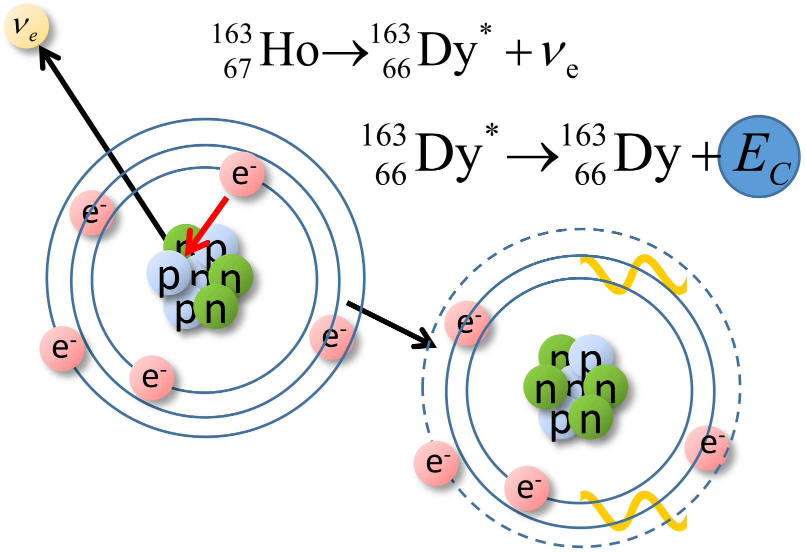


$$^{163}_{67}\mathrm{Ho} \rightarrow ^{163}_{66}\mathrm{Dy}^{*} + \nu_{\mathrm{e}}$$

$$^{163}_{66}\mathrm{Dy}^{*} \rightarrow ^{163}_{66}\mathrm{Dy} + E_C$$

- $\tau_{1/2} \simeq 4570$ years
- $Q_{\mathrm{EC}} = (2.833 \pm 0.030_{stat} \pm 0.015_{syst})$ keV S. Eliseev et al., *Phys. Rev. Lett.*, 115, 062501 (2015)
- $Q_{\mathrm{EC}} = (2.838 \pm 0.014)$ keV C. Velte et al., *Eur. Phys. J. C*, 79, 1026 (2019)

Electron Capture in ^{163}Ho



$$^{163}_{67}\text{Ho} \rightarrow {}^{163}_{66}\text{Dy}^* + \nu_e$$

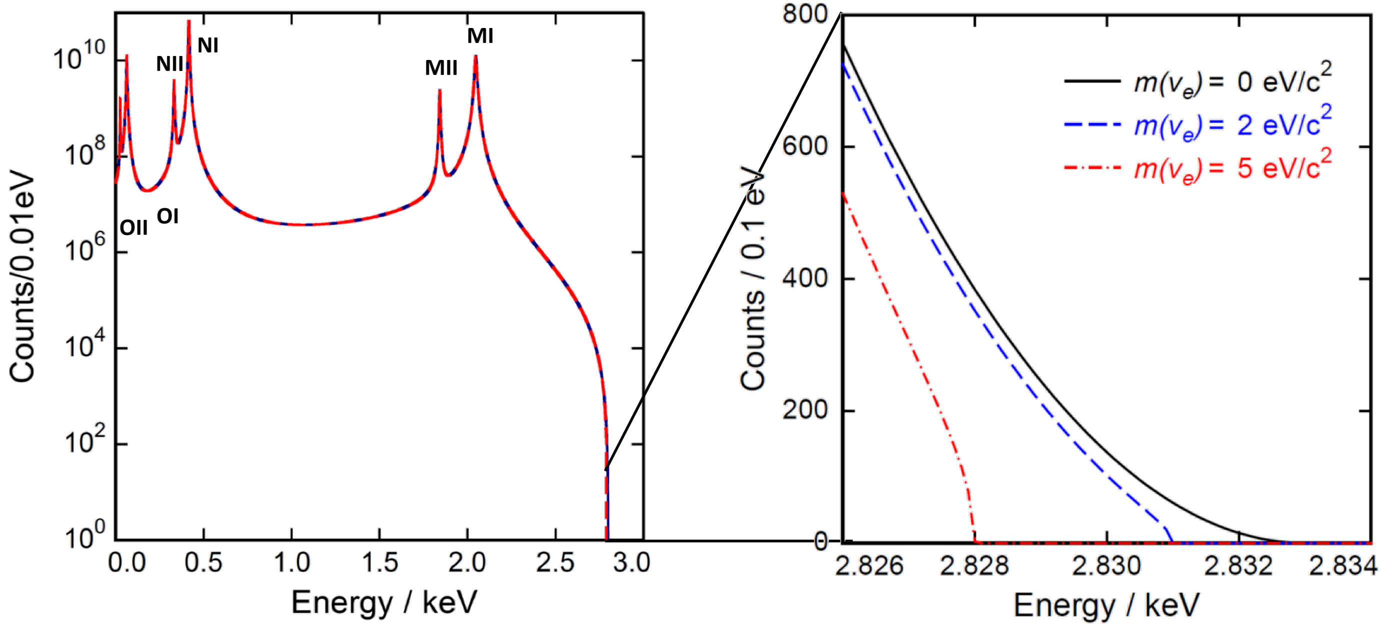
$$^{163}_{66}\text{Dy}^* \rightarrow {}^{163}_{66}\text{Dy} + E_C$$

Atomic de-excitation:

- **Auger electrons**
- **Coster-Kronig transitions**
- **X-ray emission**

Calorimetric measurement

A. De Rujula and M. Lusignoli
Phys. Lett. 118 B (1982) 118



Calorimetric spectrum dominantly affected in the endpoint region

Experimental requirements for sub-eV neutrino mass sensitivity

- Required statistics for sub-eV mass sensitivity

  $N_{ev} > 10^{14}$ ⟶ A_{tot} ~ 1 MBq

- Limitations on activity per detector pixel

  $f_{pu} \leq 10^{-6}$ ⟶ A_{pixel} ~ 10 Bq

- Necessary number of detector pixels

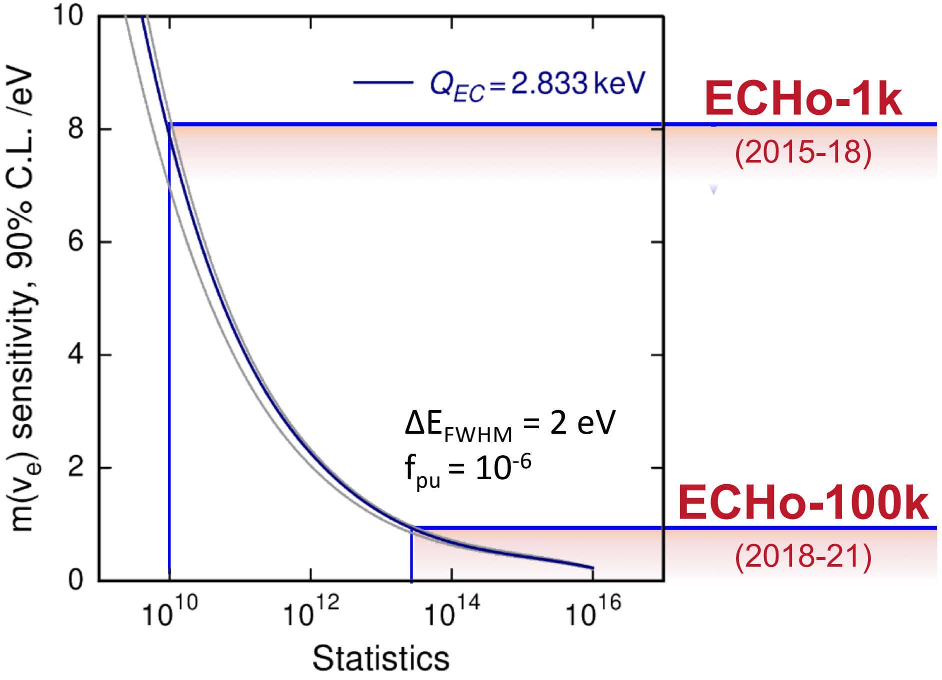
  N_{det} ~ 10^5 ⟶ multiplexing

- Precise characterization of endpoint region

  $\Delta E_{FWHM} < 3$ eV

- Very low background level

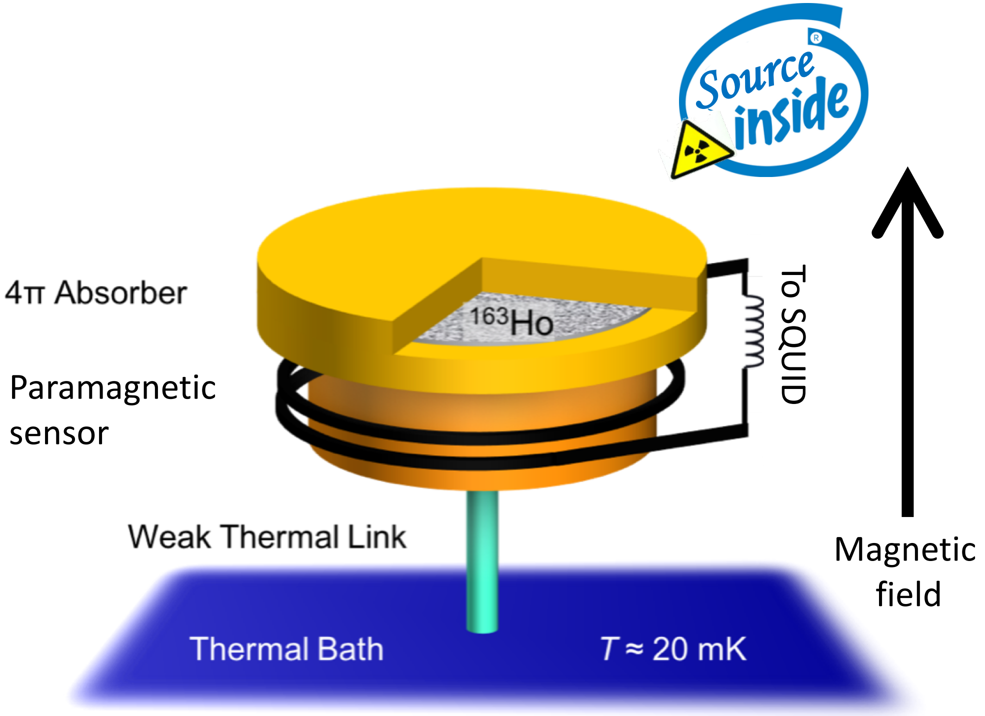
  BG < 10^{-6} events/eV/det/day

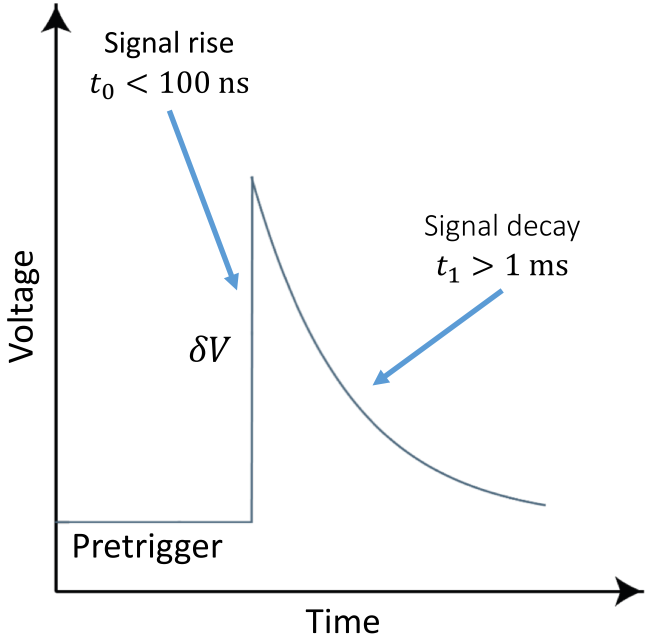


⟶ Metallic magnetic calorimeters

The ECHo Collaboration, *EPJ-ST* **226** 8 (2017) 1623

Metallic Magnetic Calorimeters





δE ⇨ $\delta V = \frac{\delta E}{C}$ ⇨ $\delta M = \frac{\partial M}{\partial T}\frac{\delta E}{C}$ ⇨ $\delta \Phi \sim \delta M \sim \delta T \sim \delta E$ $\sim$

Absorption of energy

Voltage output

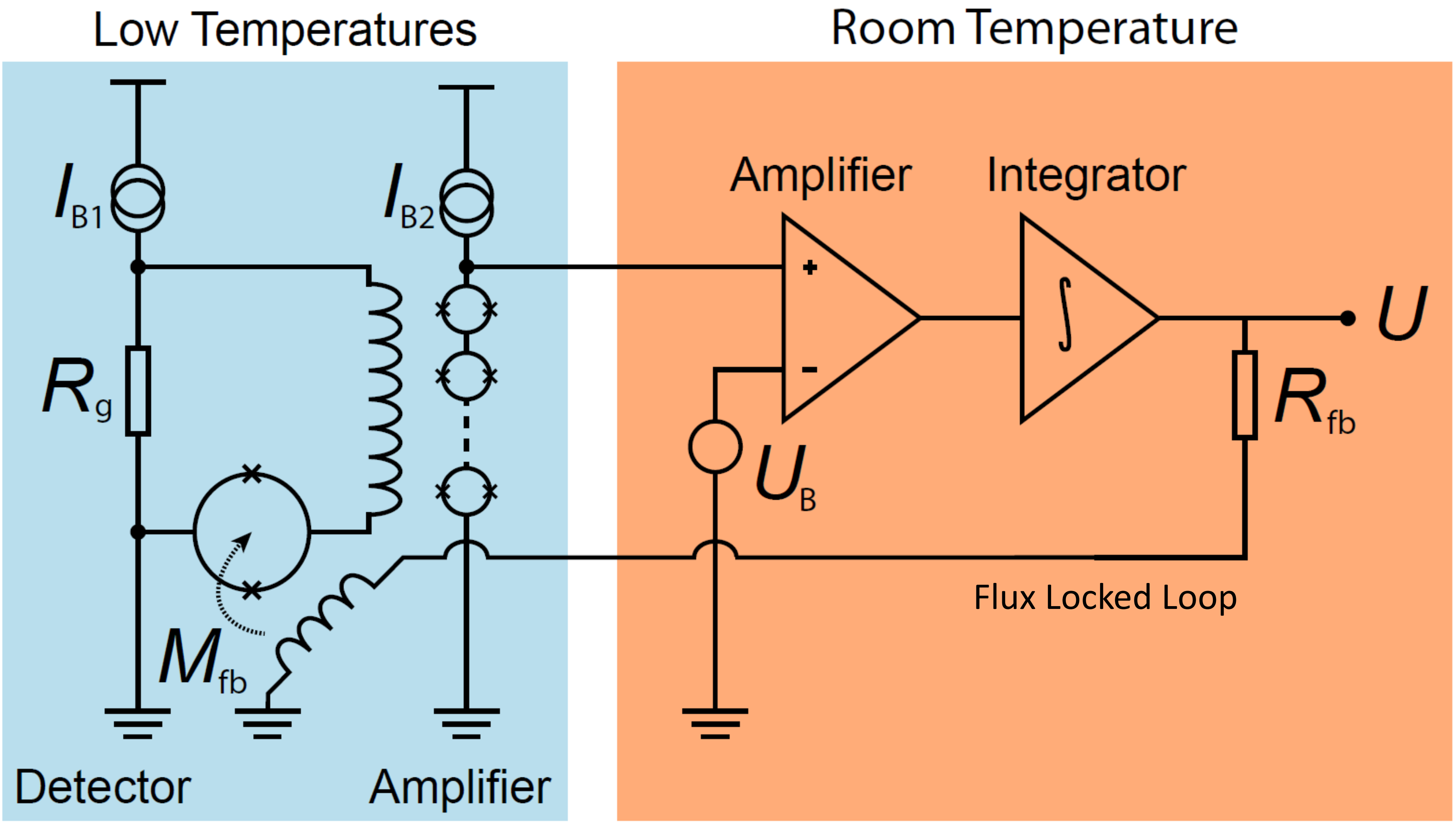
Increase of temperature

Change of magnetization

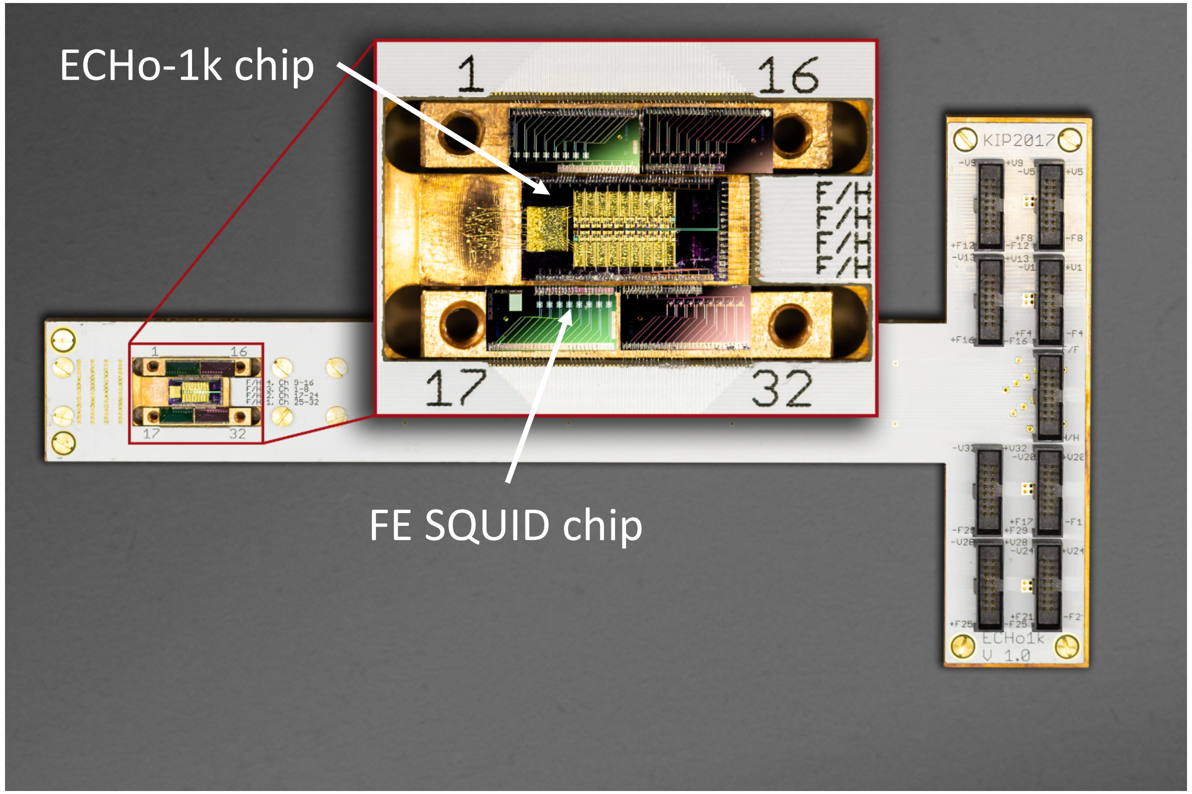
Change of magnetic flux

SQUID FLL voltage output

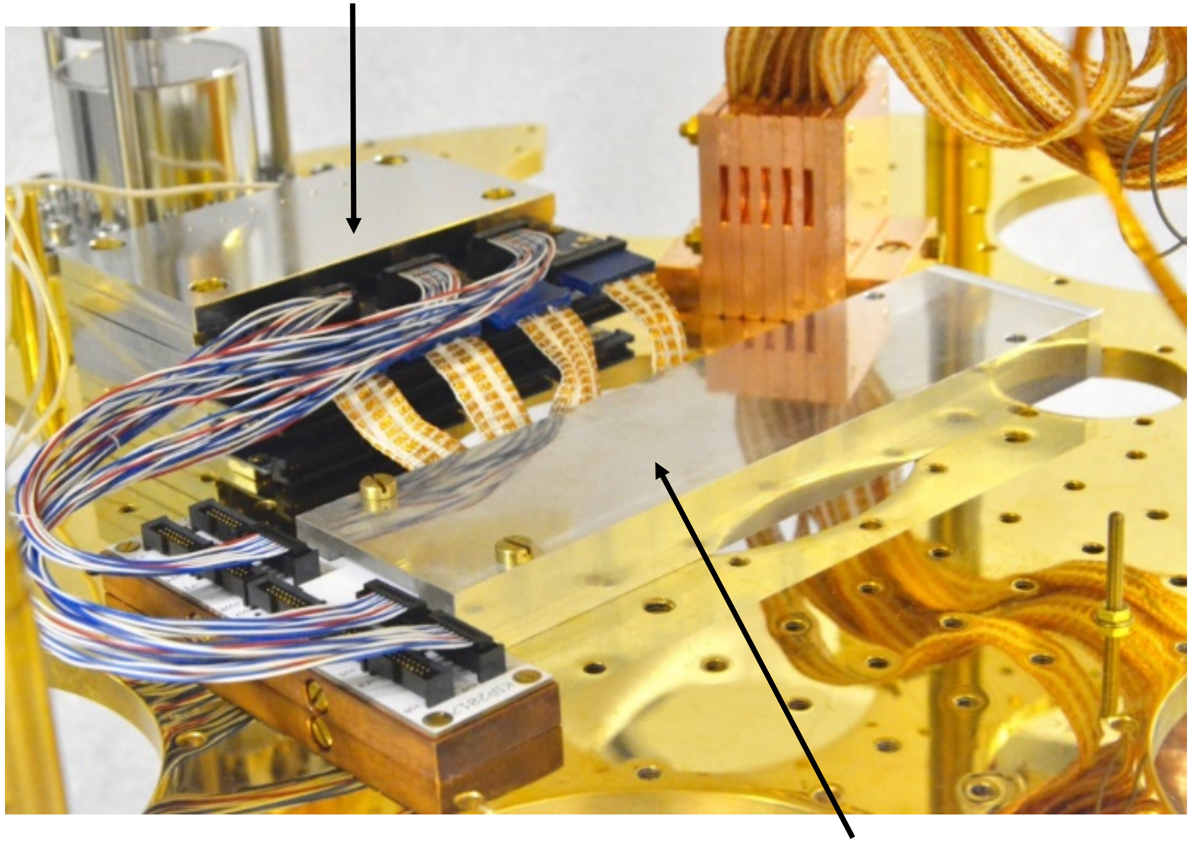
Two-stage SQUID Setup



ECHo-1k Detector Setup



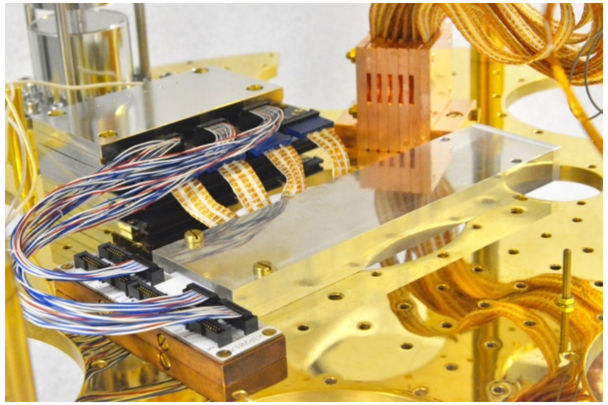
SQUID array module



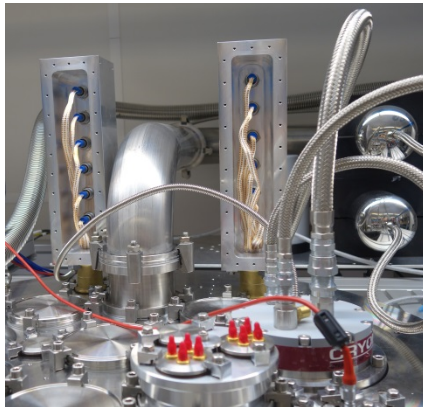
ECHo module

Readout

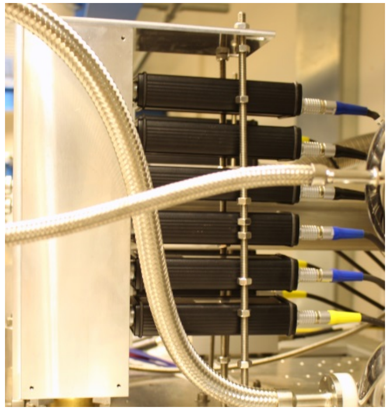
ECHo module with
Two-stage SQUID readout



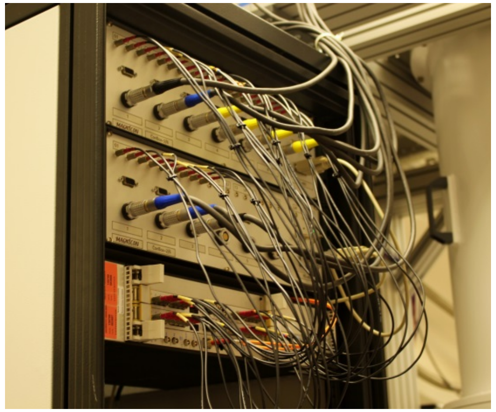
36 output channels
from the cryostat



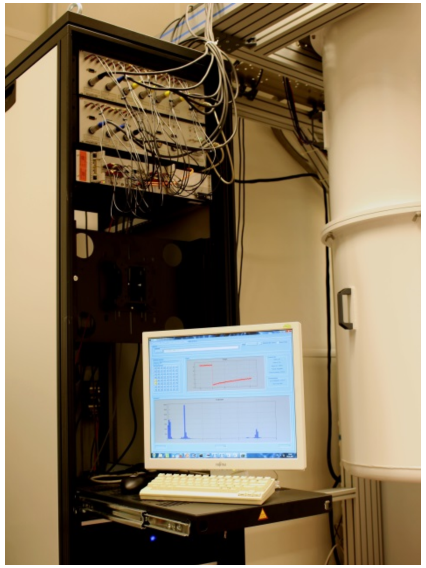
12 SQUID read-out
electronics



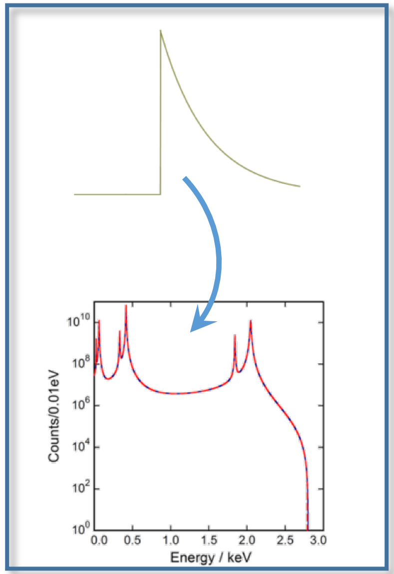
SQUID connector box &
ADC



DAQ



Data analysis

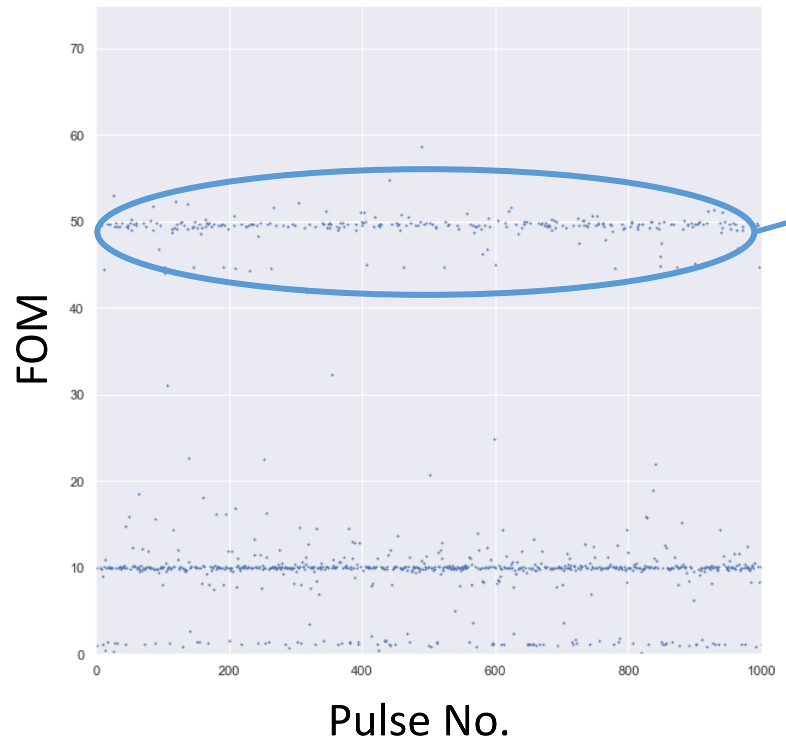


Fitting Method: Template Fit

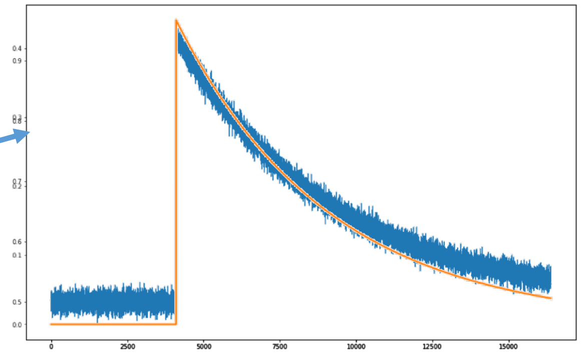
- Assumptions:
  - Signal shape independent of energy
  - Amplitude proportional to energy

MMCs

- Method:



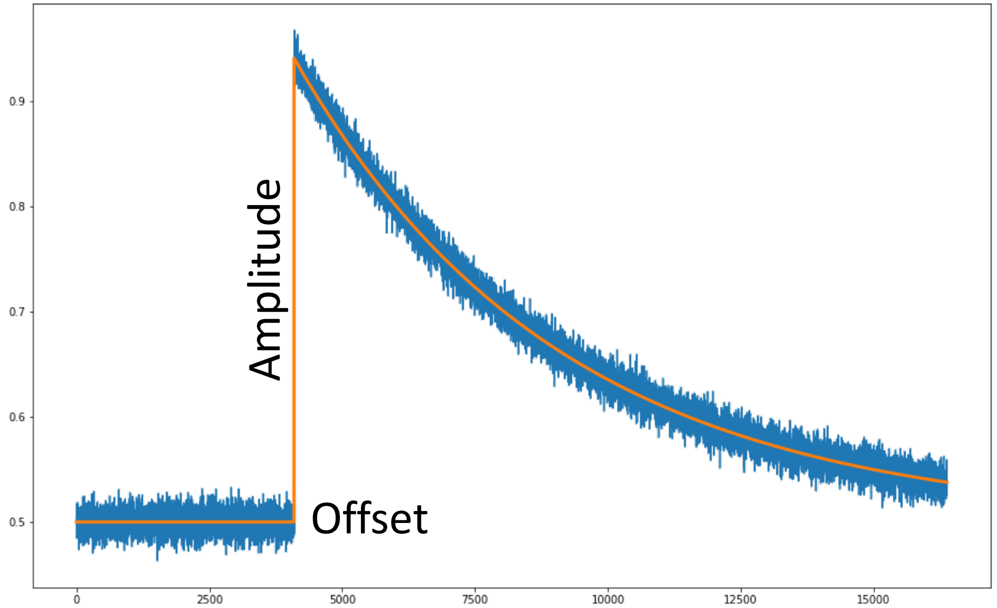
Template



$\times n$

FOM = 50 → **FOM = 10000**

Fitting Method: Template Fit



Linear fit of signal with template

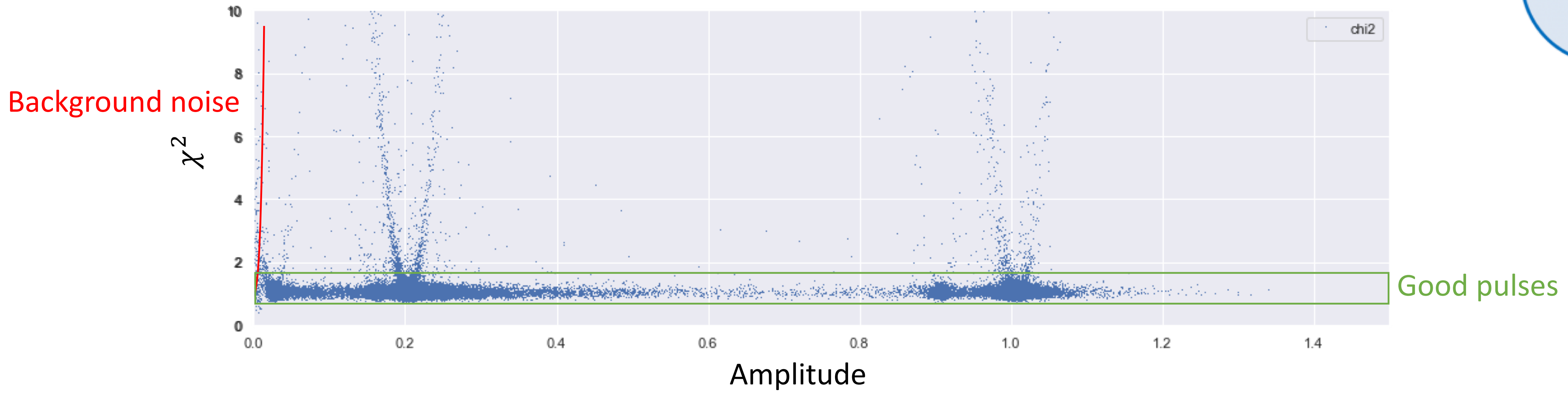
⇒ Amplitude	Offset	χ^2
Energy	Corrections*	Goodness

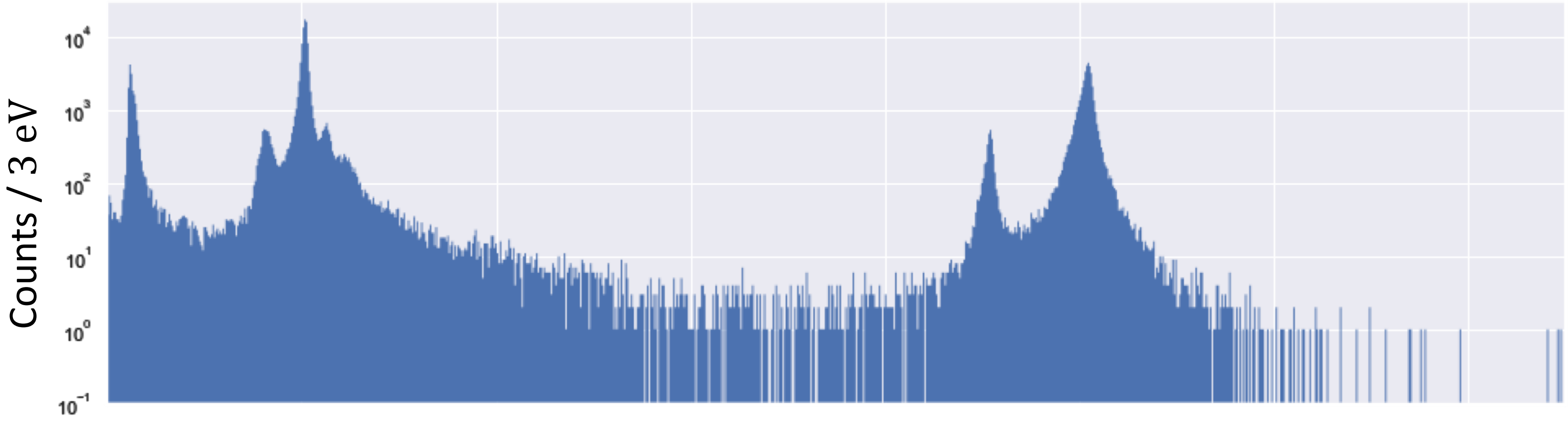
$$\underset{(normalized)}{\min \chi^2} = \frac{1}{N}\Sigma_{i=0}^{N}(\mathbf{s}_i - A * \mathbf{t}_i - \emptyset)^2$$

χ^2: Normal distribution → Cut data at e. g. 5σ

*Important for DC-coupled signal

Template Fit with χ^2 Cut

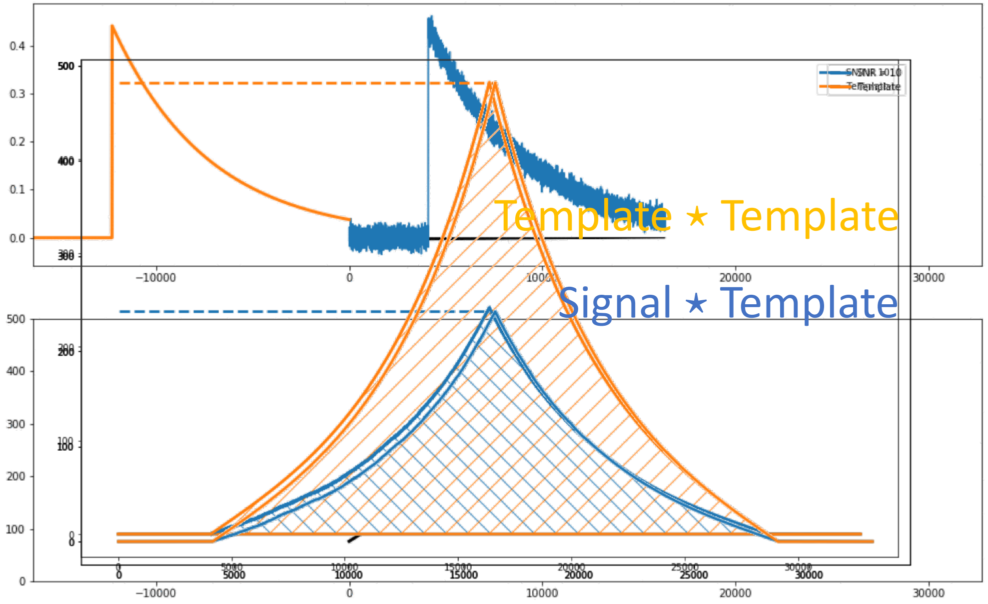




Fitting Method: Matched Filter

- Correlate signal with template

Ratio of maxima

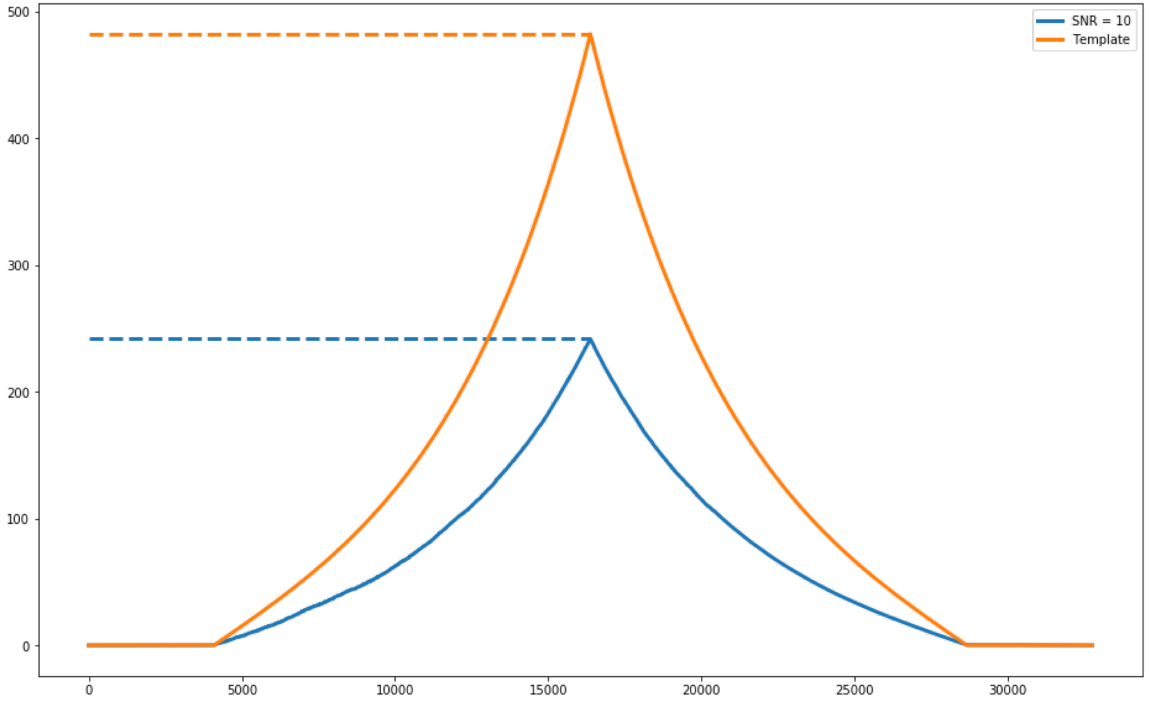


Ratio of areas

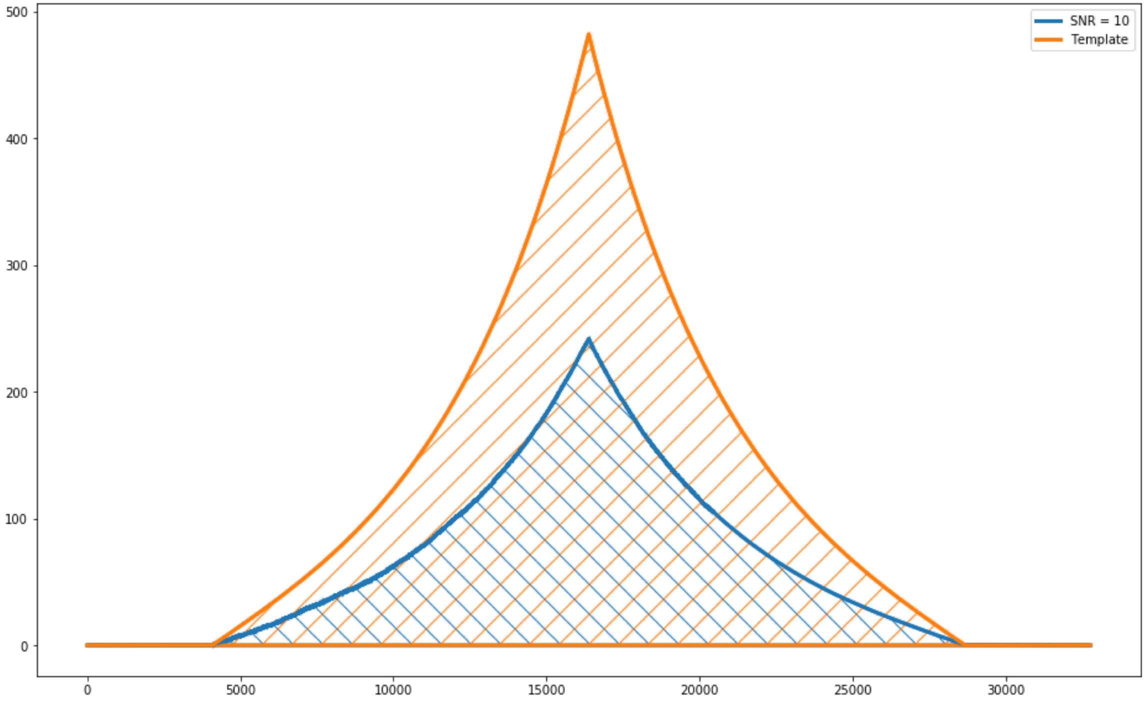
Extract amplitude

Fitting Method: Matched Filter

Ratio of maxima



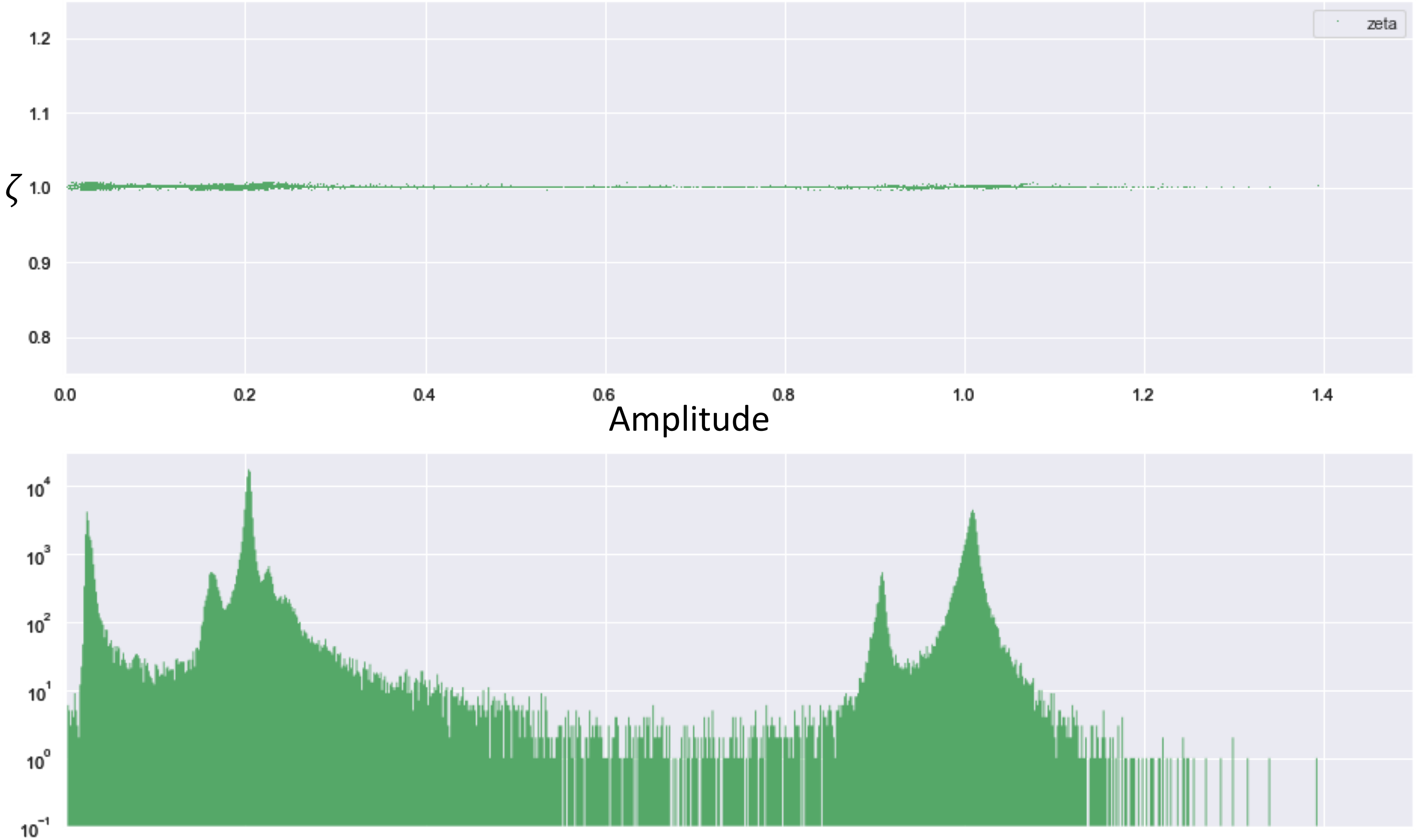
Ratio of areas



Goodness $\zeta = A_{\mathrm{max}} / A_{\mathrm{area}}$

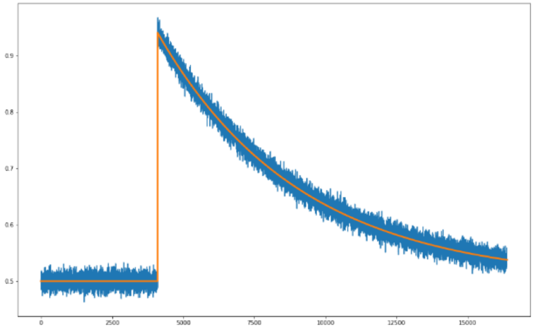
(normalized)

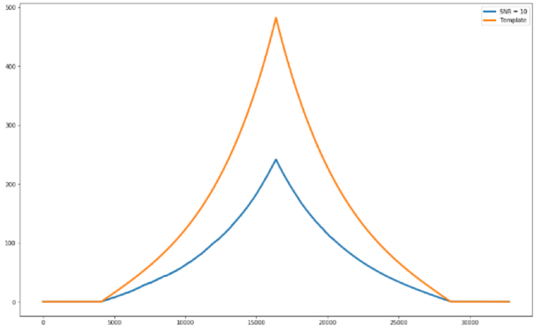
Template Fit with Zeta Cut



Good pulses

Comparison of Matched Filter with Template Fit

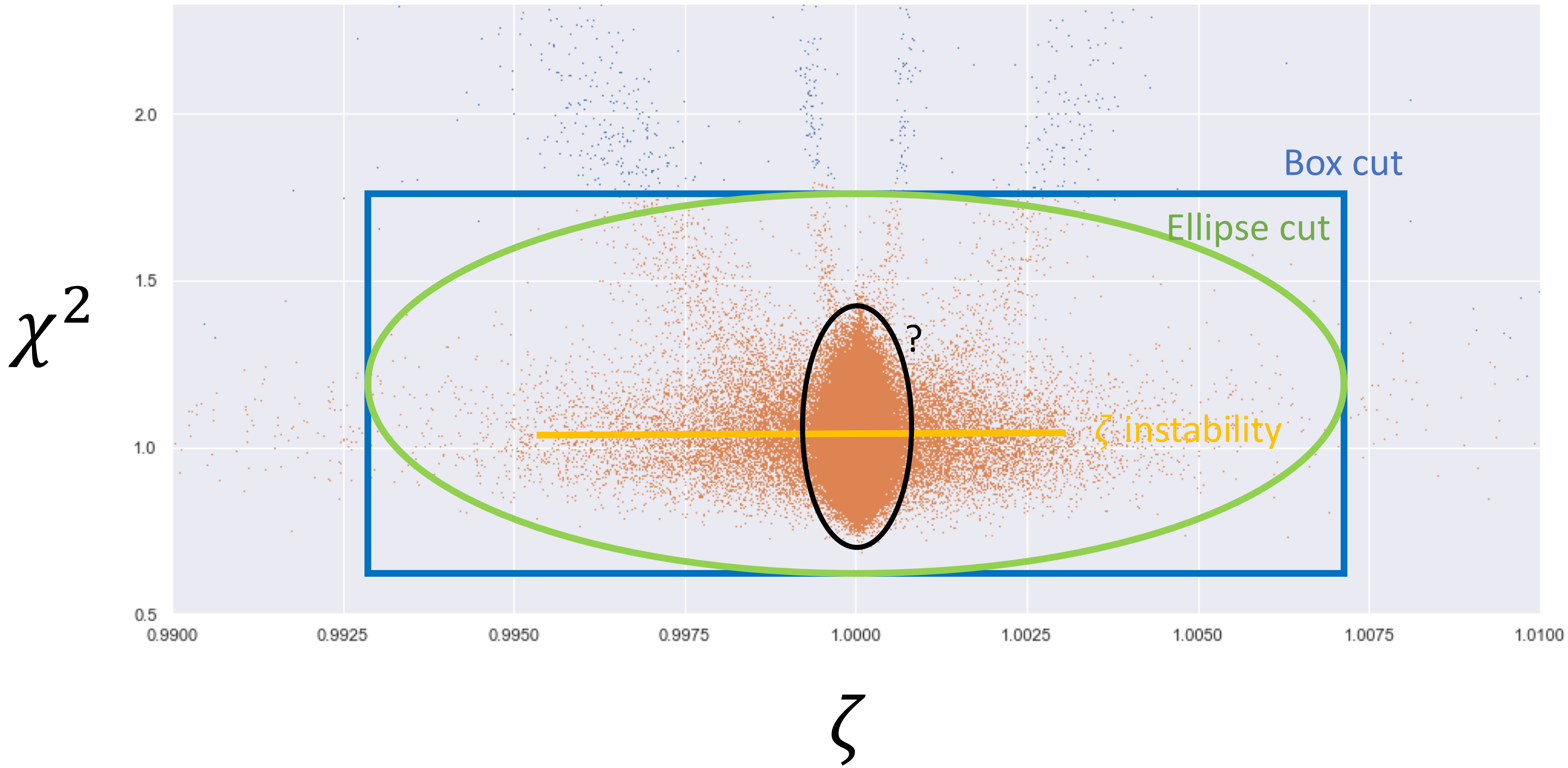




	Template Fit	**Matched Filter**
Computation Time/pulse	~ns	~µs*
Low energy stability	🟢	🟠
Low energy accuracy	🟠	🟡

*Reduce sampling rate, but lower accuracy

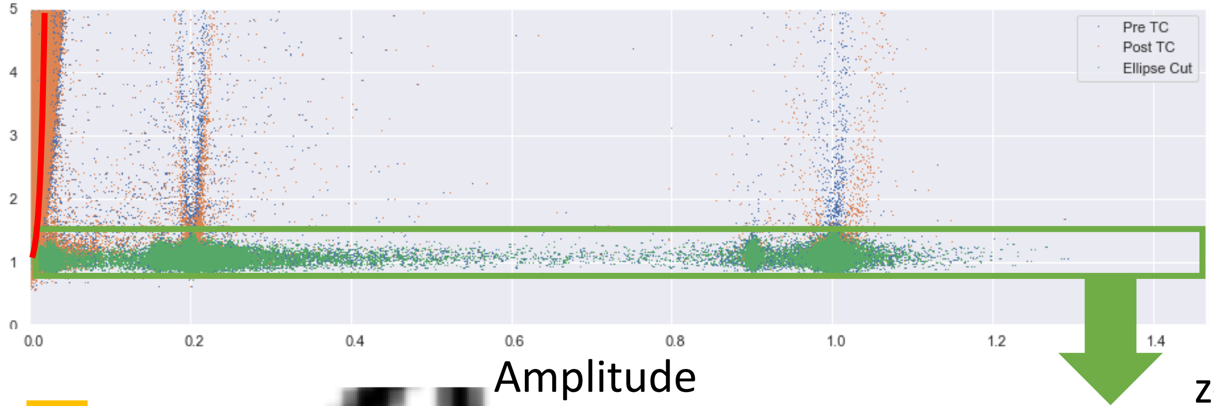
Solution: Combined Cuts



Proof of Concept for ζ (with a particularly bad data set)

Background noise

χ^2



Good pulses

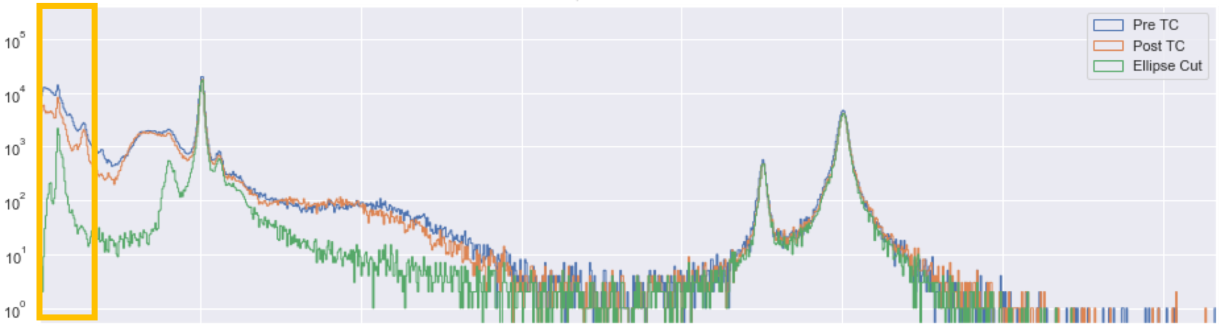
zoom

χ^2

OI and OII line!

χ^2 alone could not have resolved this

Counts / 3eV



Automatization

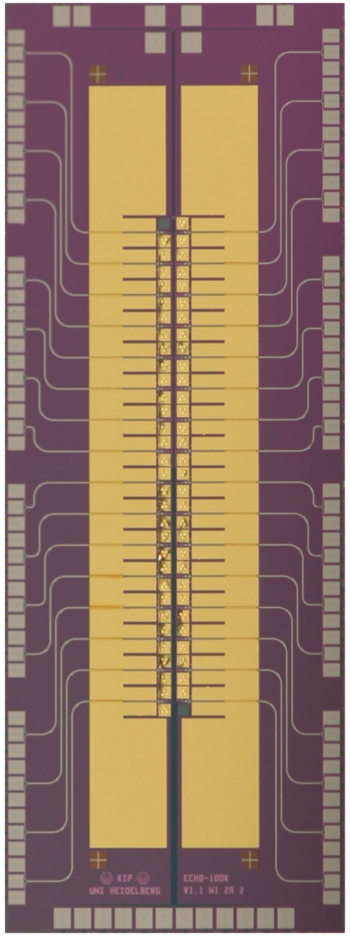
ECHo-1k

100 pixels -> 10000 pixels

Need for automatized algorithms:

- Template selection
- χ^2/ζ cuts
- Additional corrections

ECHo-100k



Automatization: Template Selection

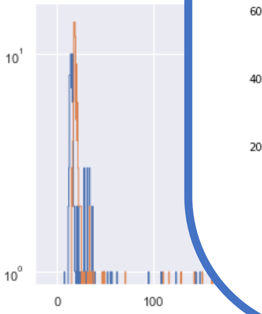
For each pixel

Preliminary S

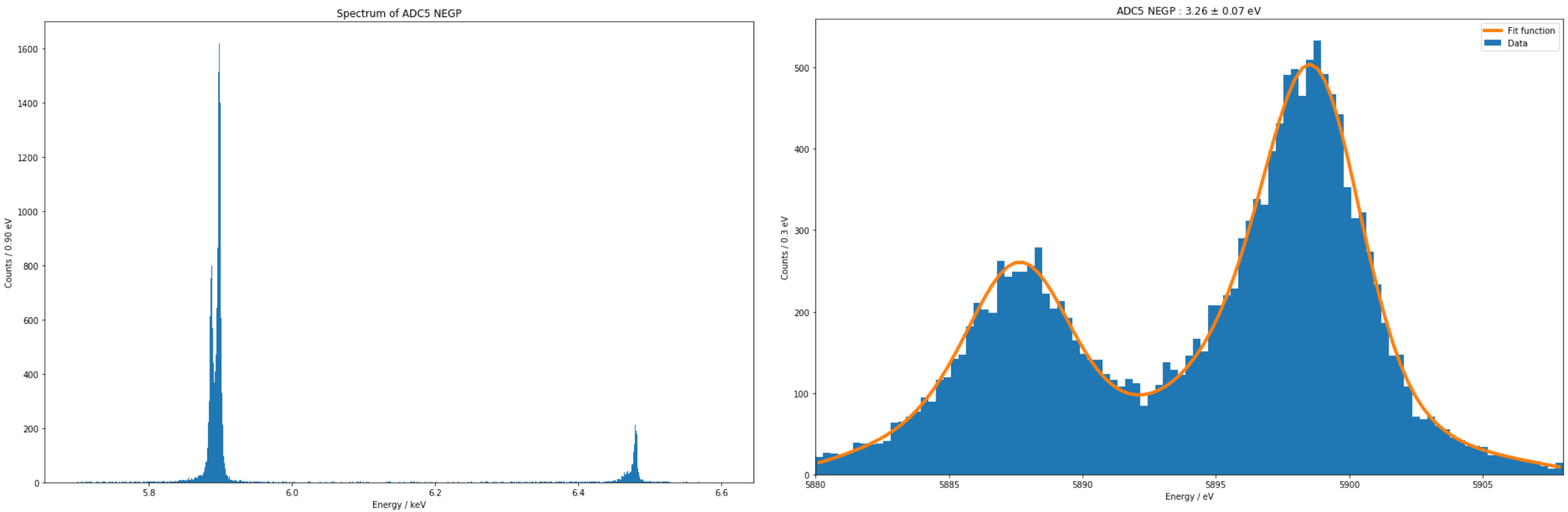
(FOM l

lidates

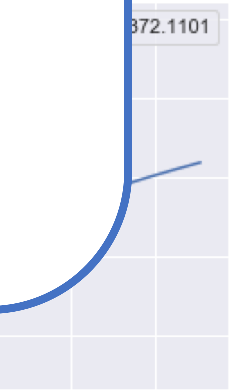
g

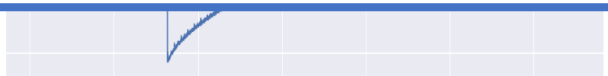


^{55}Fe Spectrum @3.3 eV Energy resolution



plate



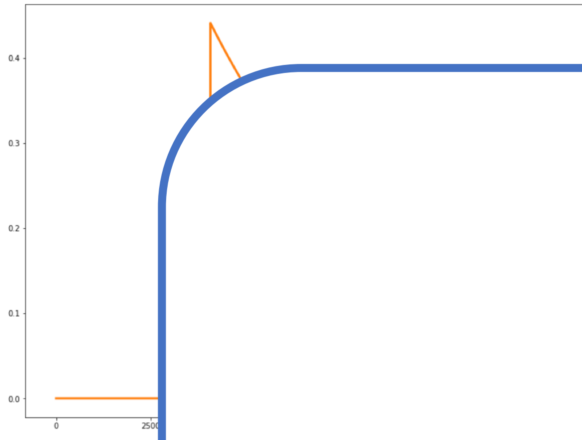


FOM: ~500

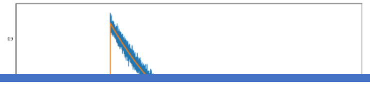
FOM: ~30000

Conclusion: From Single Traces to Spectrum

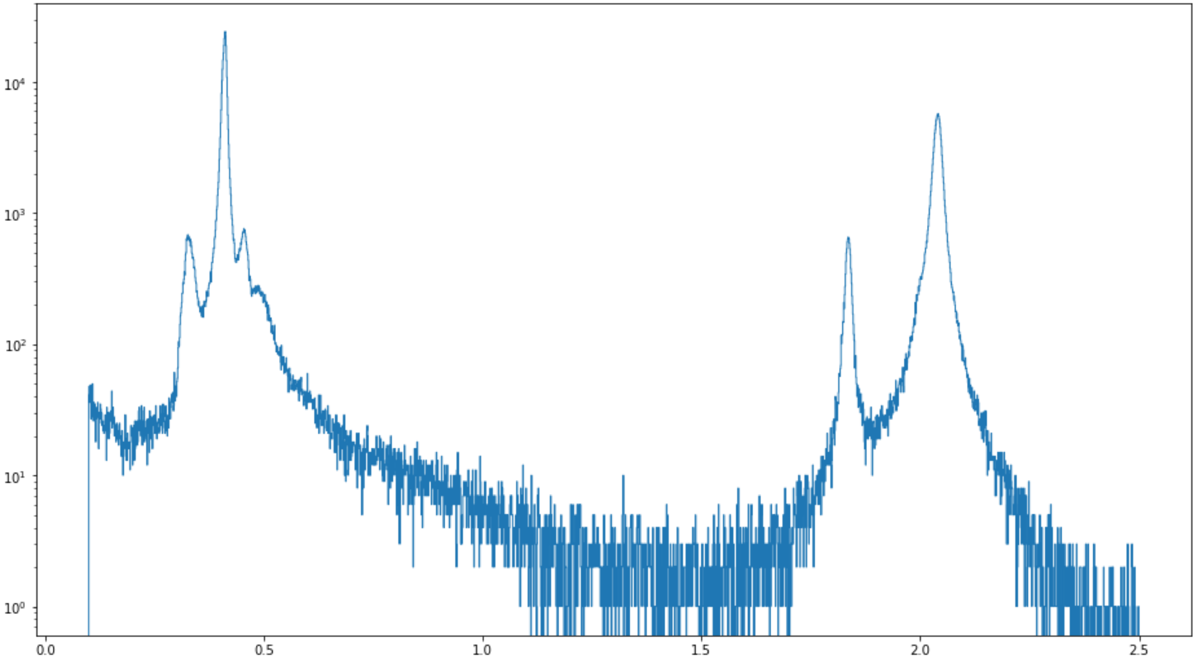
Template selection

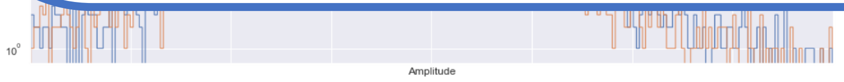


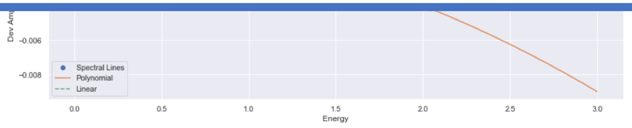
Fitting



^{163}Ho Spectrum, $5 * 10^5$ events

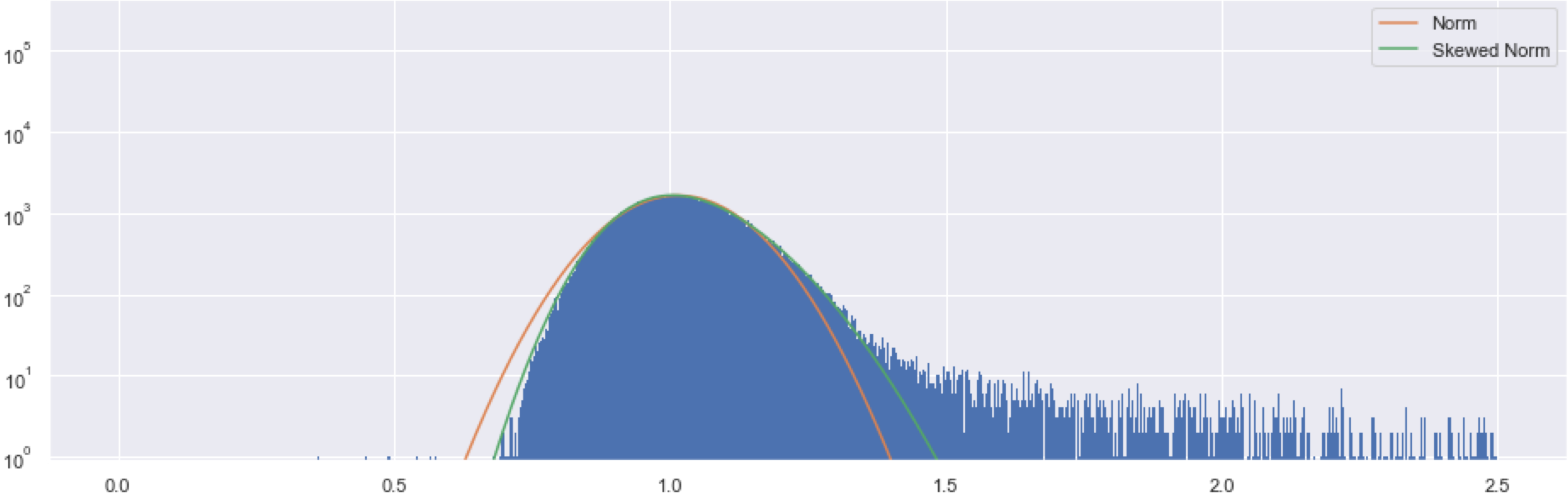




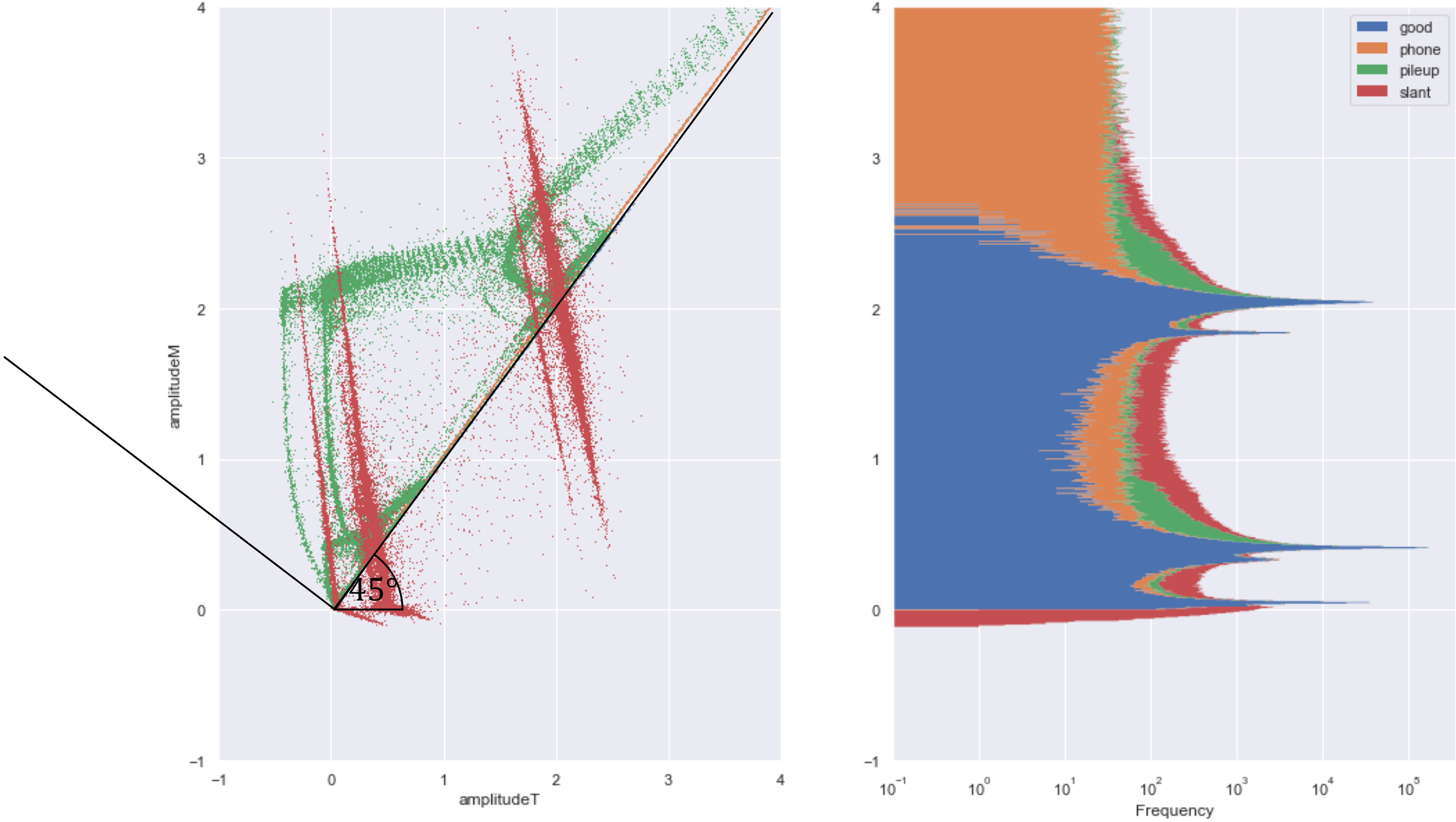


BACKUP

Gaussian vs. Skewed Gaussian Distribution



Decorrelation Cut (PCA)



Decorrelation Cut