AHEAD 2020

Integrated Activities for the
High Energy Astrophysics Domain

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Task 14.4: Machine Learning techniques for microcalorimeter data reduction

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Accepted
by PASP!

Event Detection and Reconstruction Using Neural Networks in TES Devices: a Case Study for Athena/X-IFU

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The context

IFU On board processing

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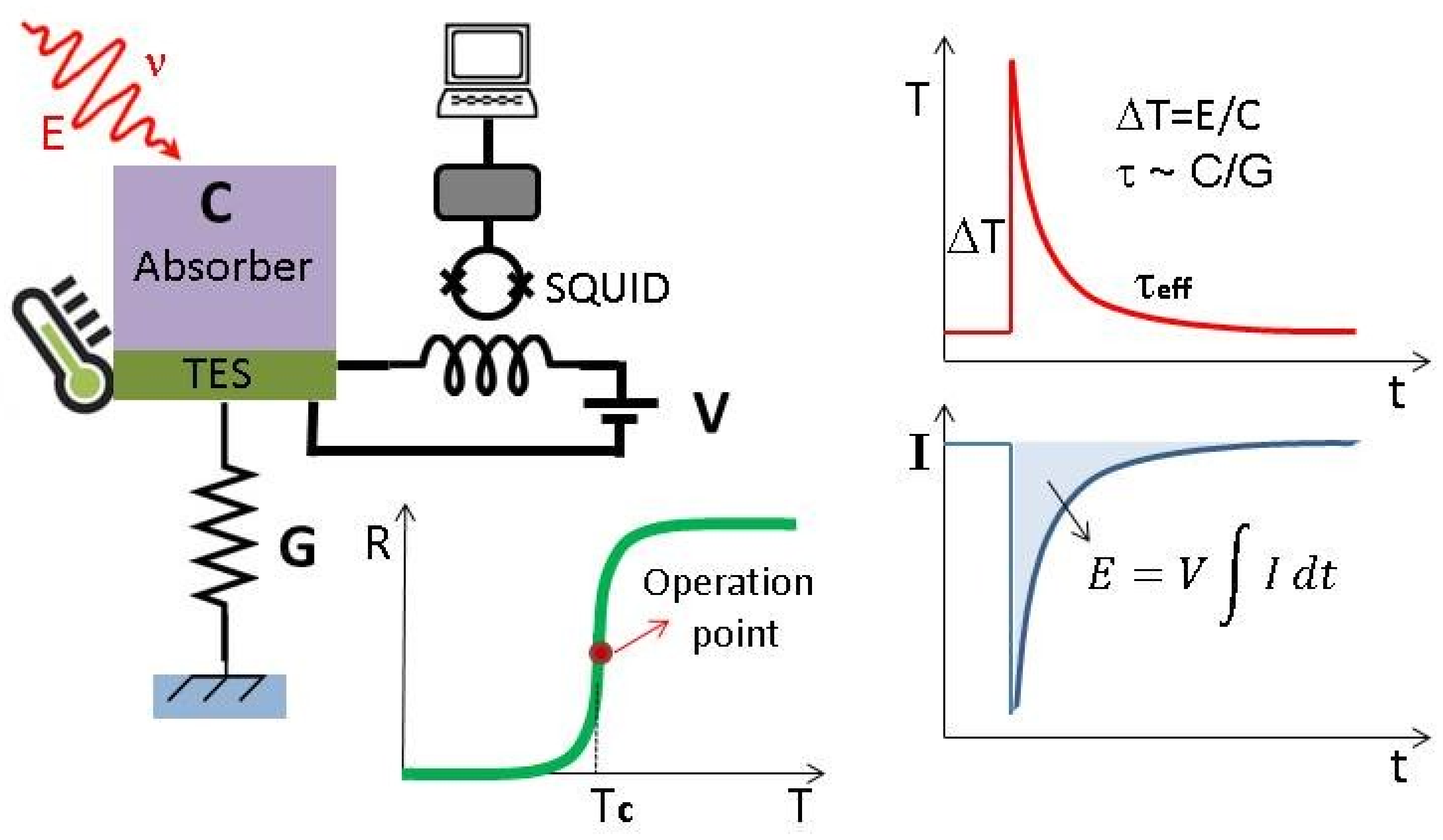

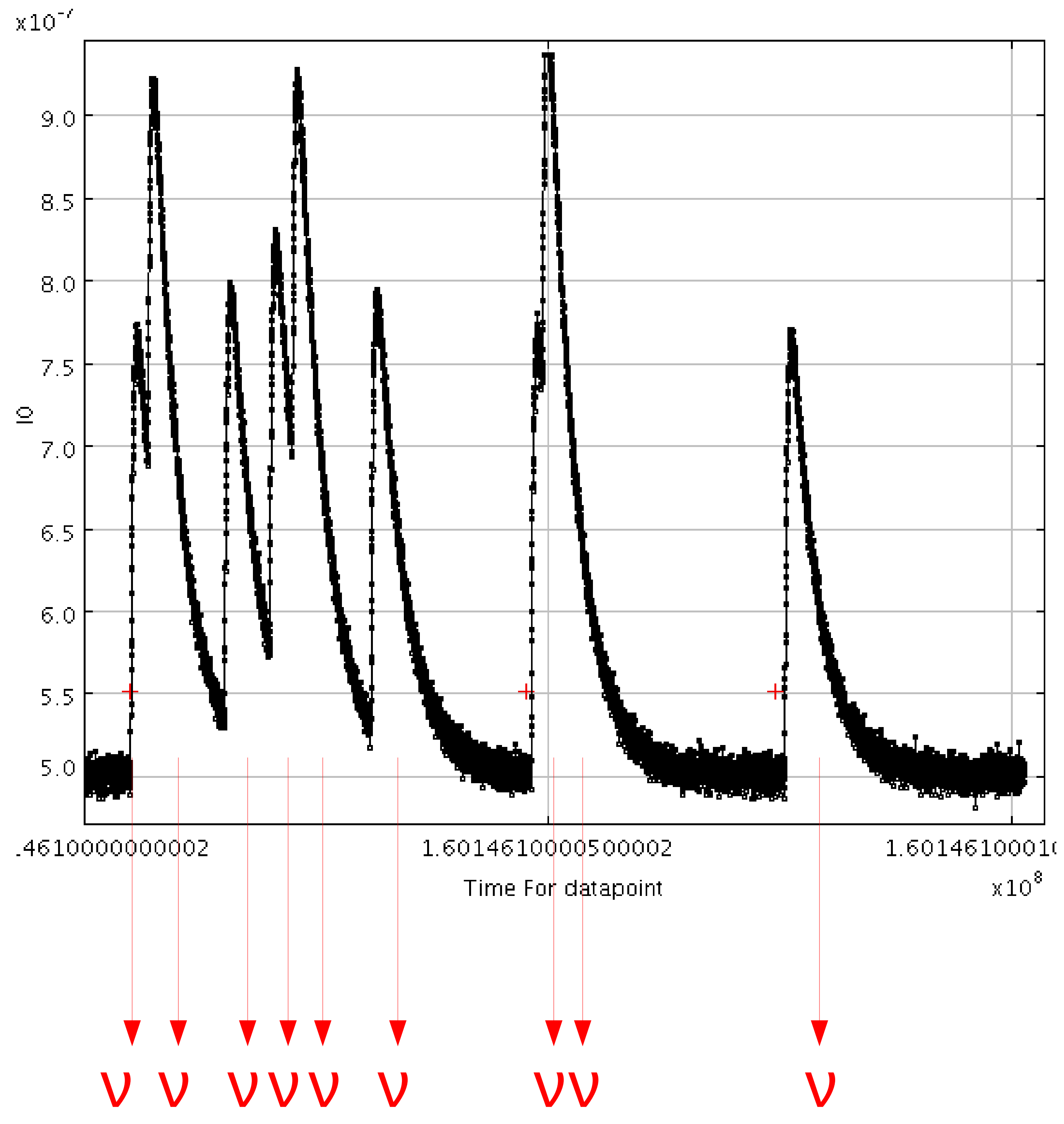

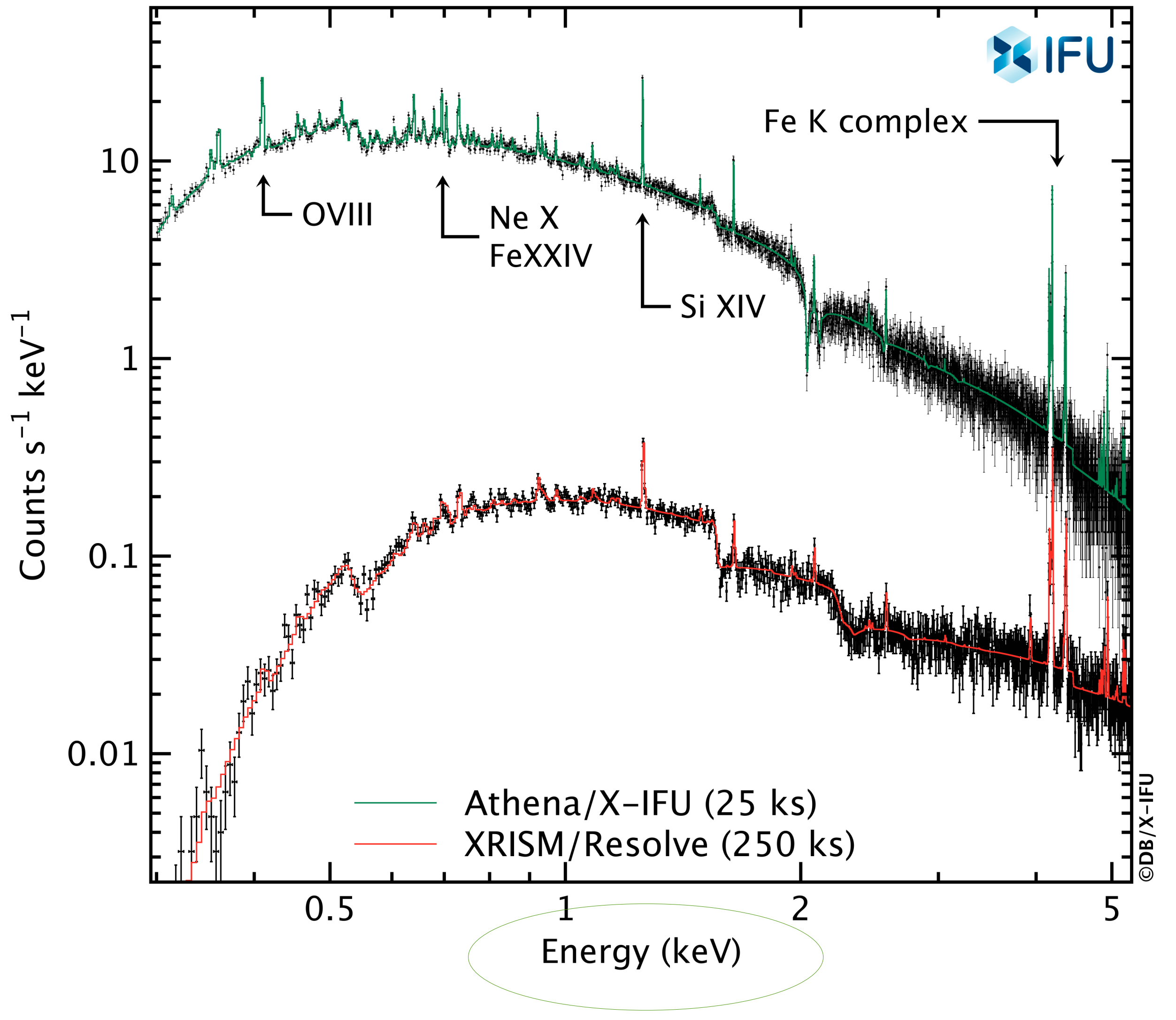

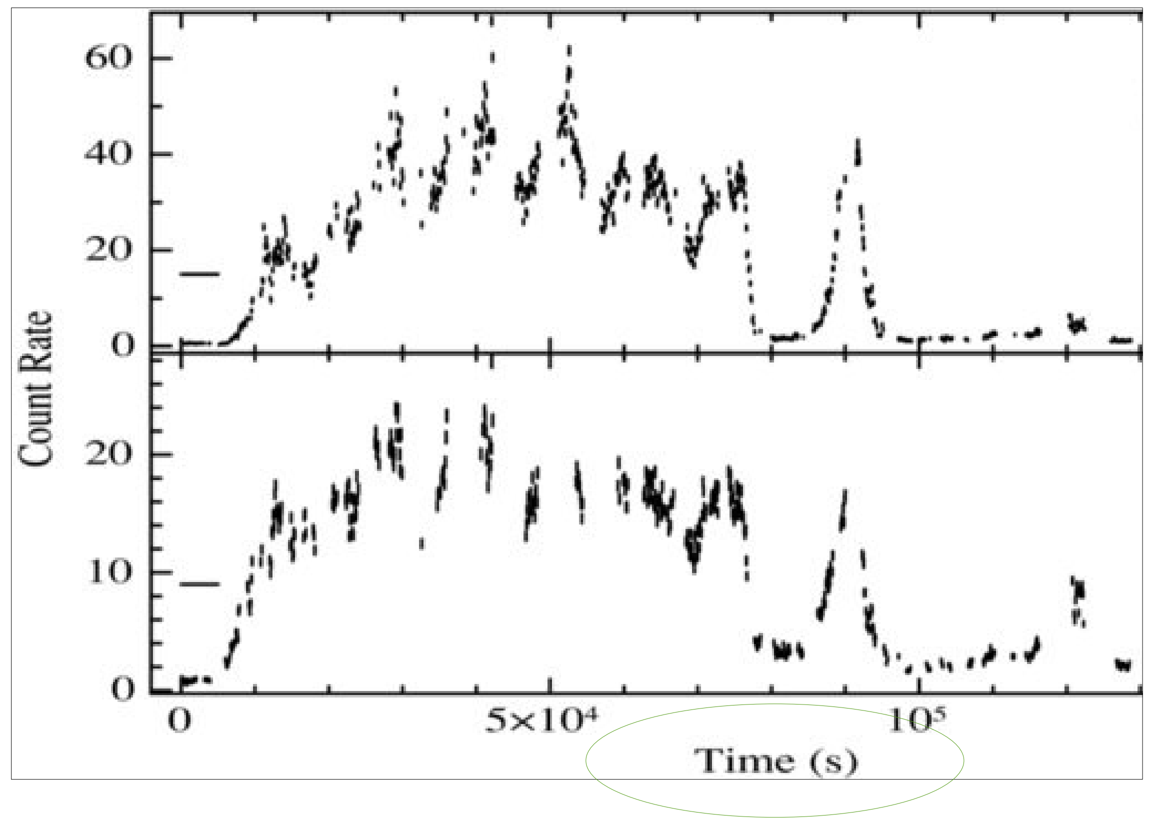

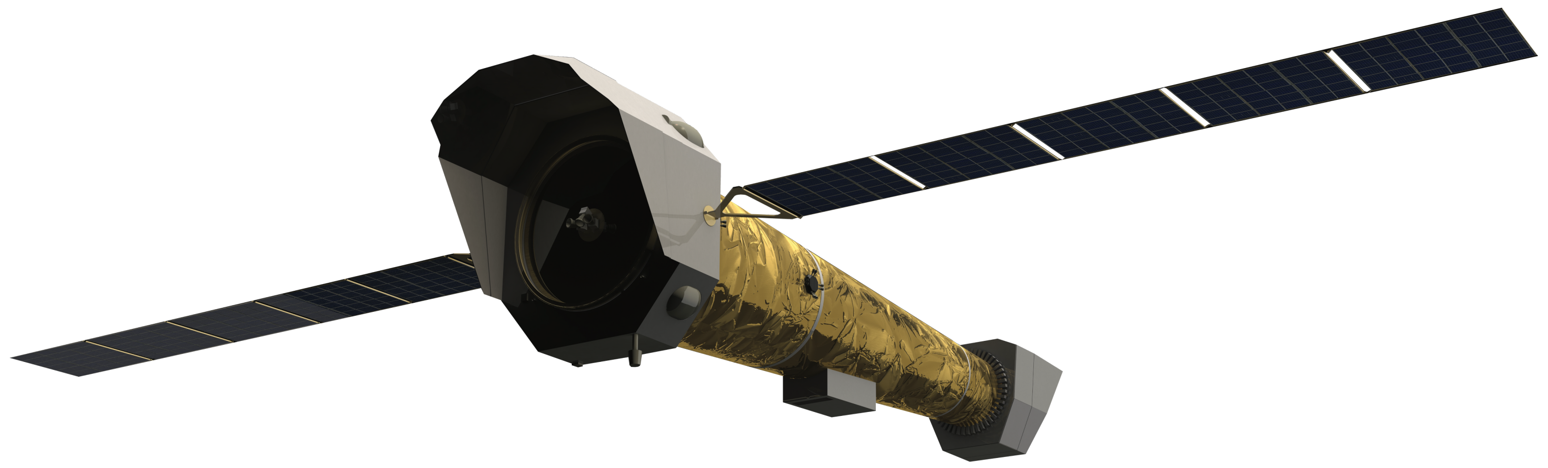

DETECTION +
RECONSTRUCION

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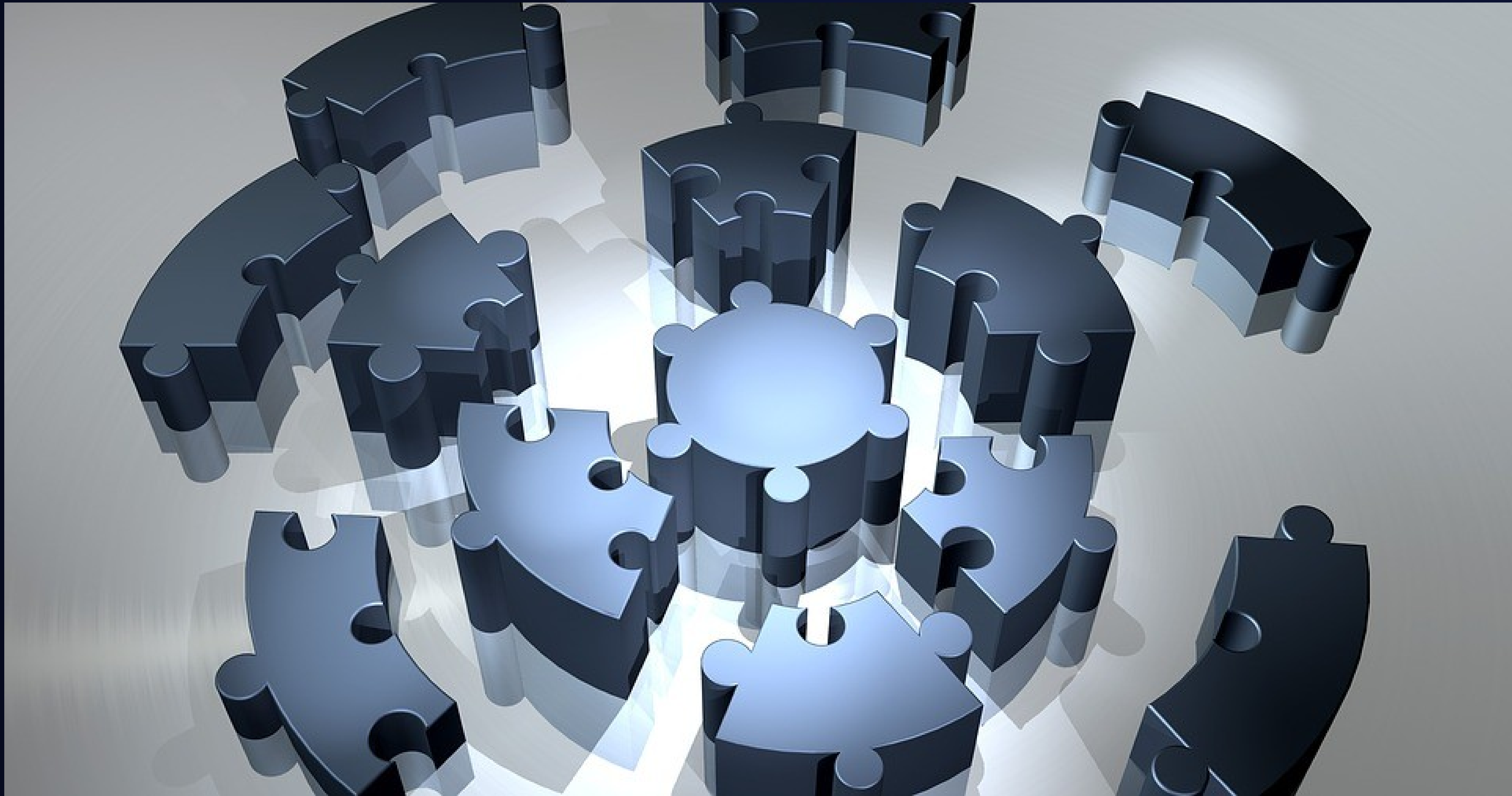
The problem



How to improve detection?

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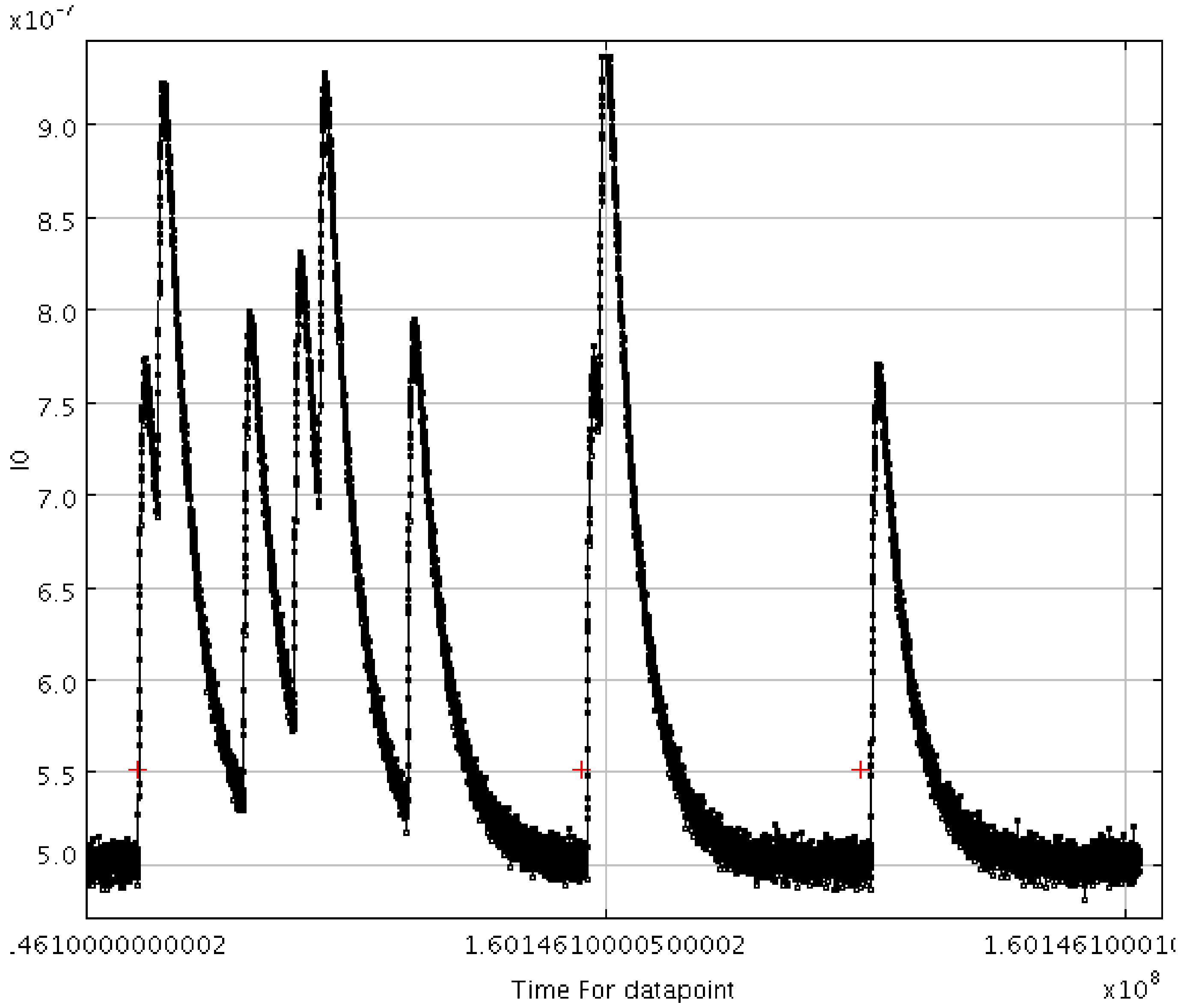
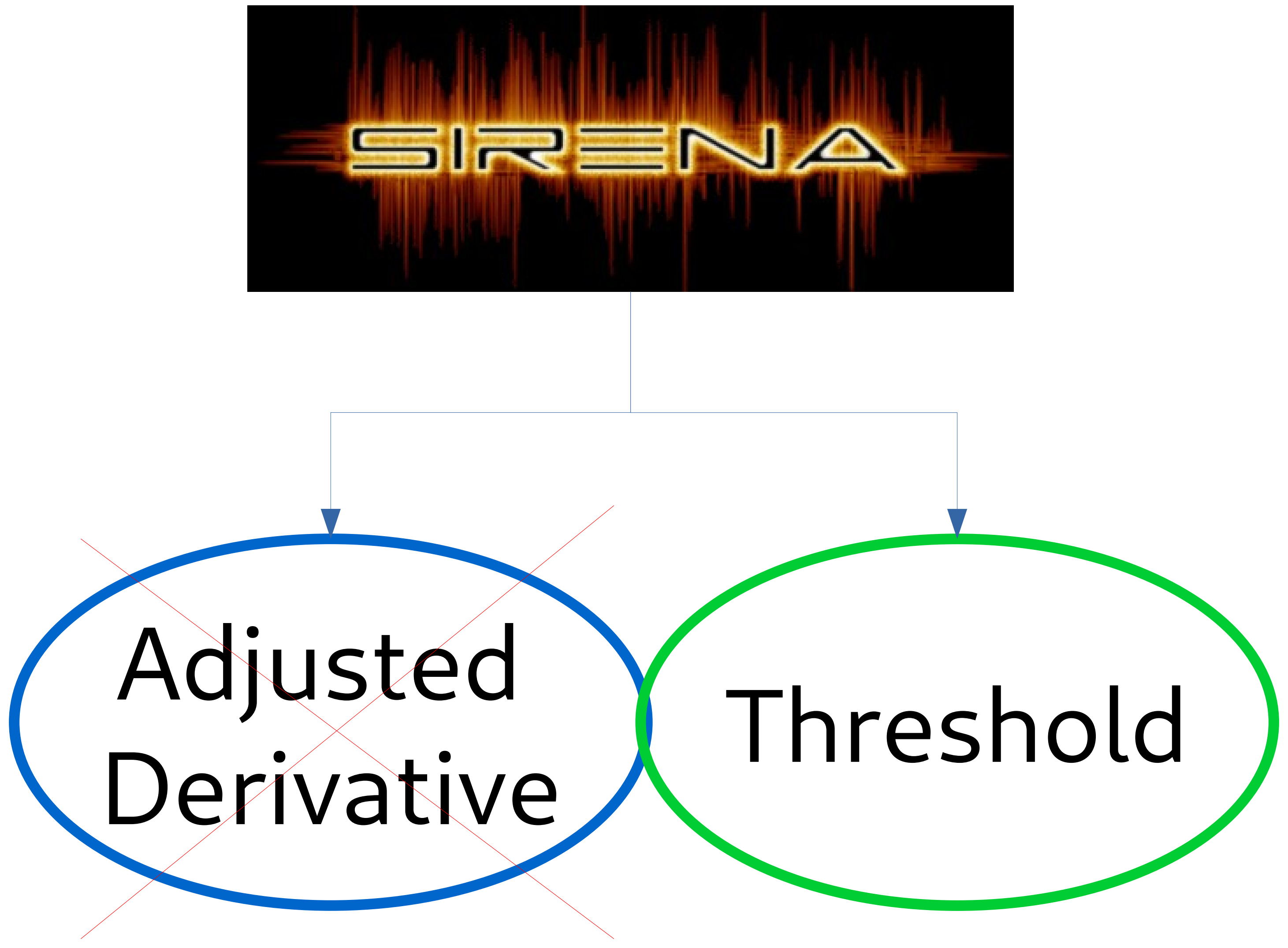
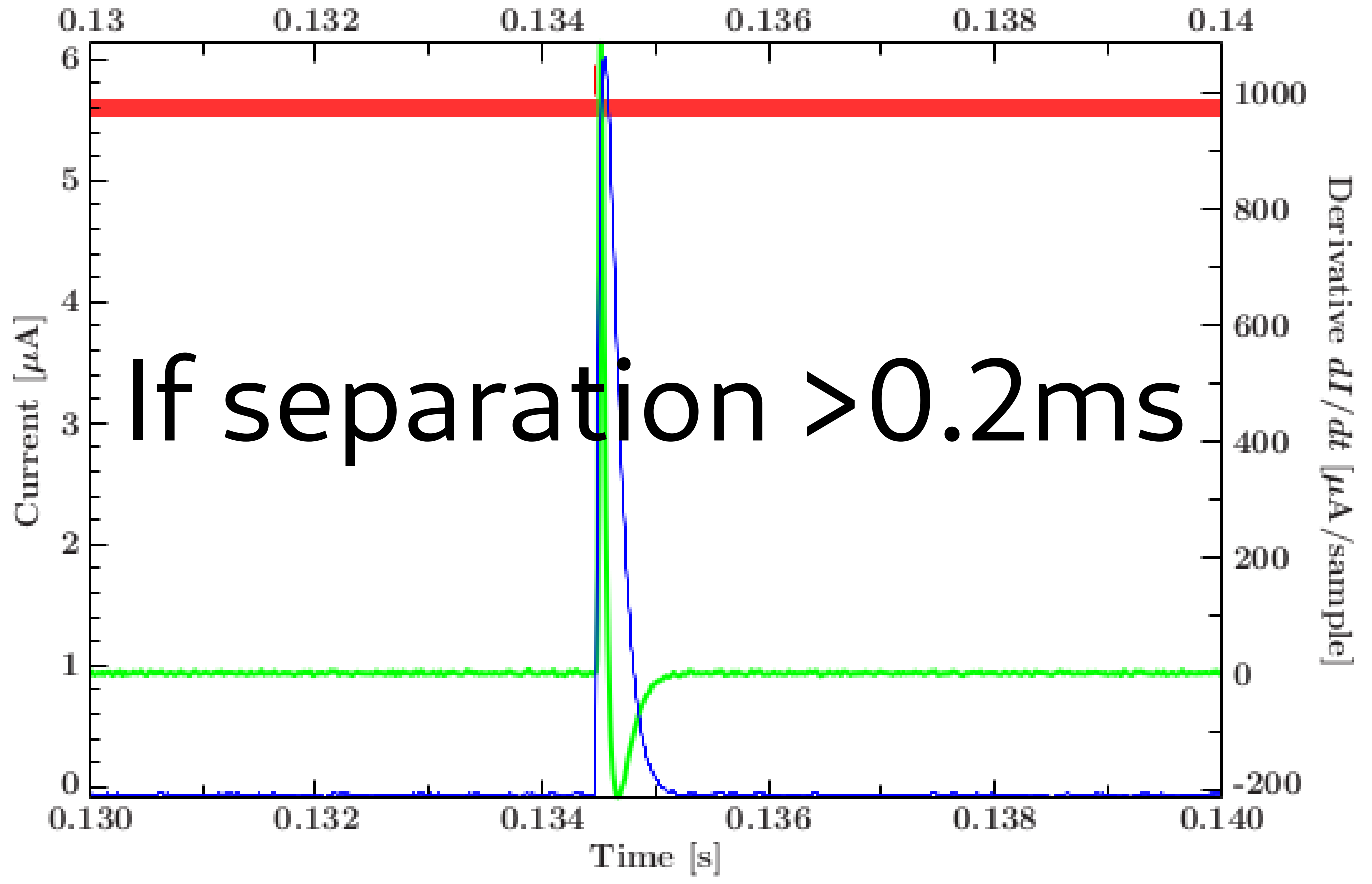


How many pulses?
Where are they?
Pulses energy?

SIXTE





- ? Can we use **ML techniques** to detect + reconstruct the pulses?
- ? Do they improve the detection limit?
- ? At which computational cost?

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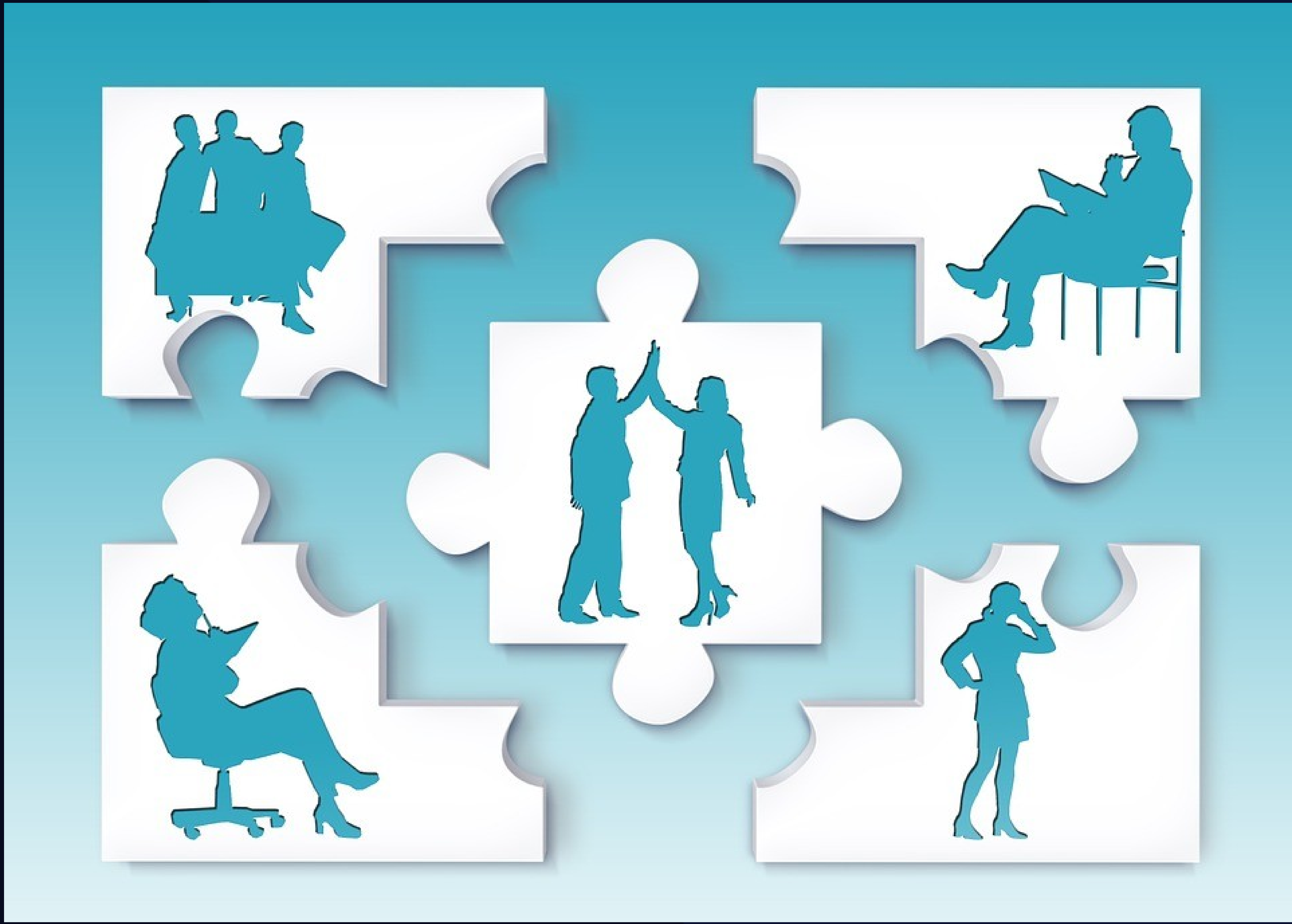
The analysis



XIFUSIM simulations of X-IFU events

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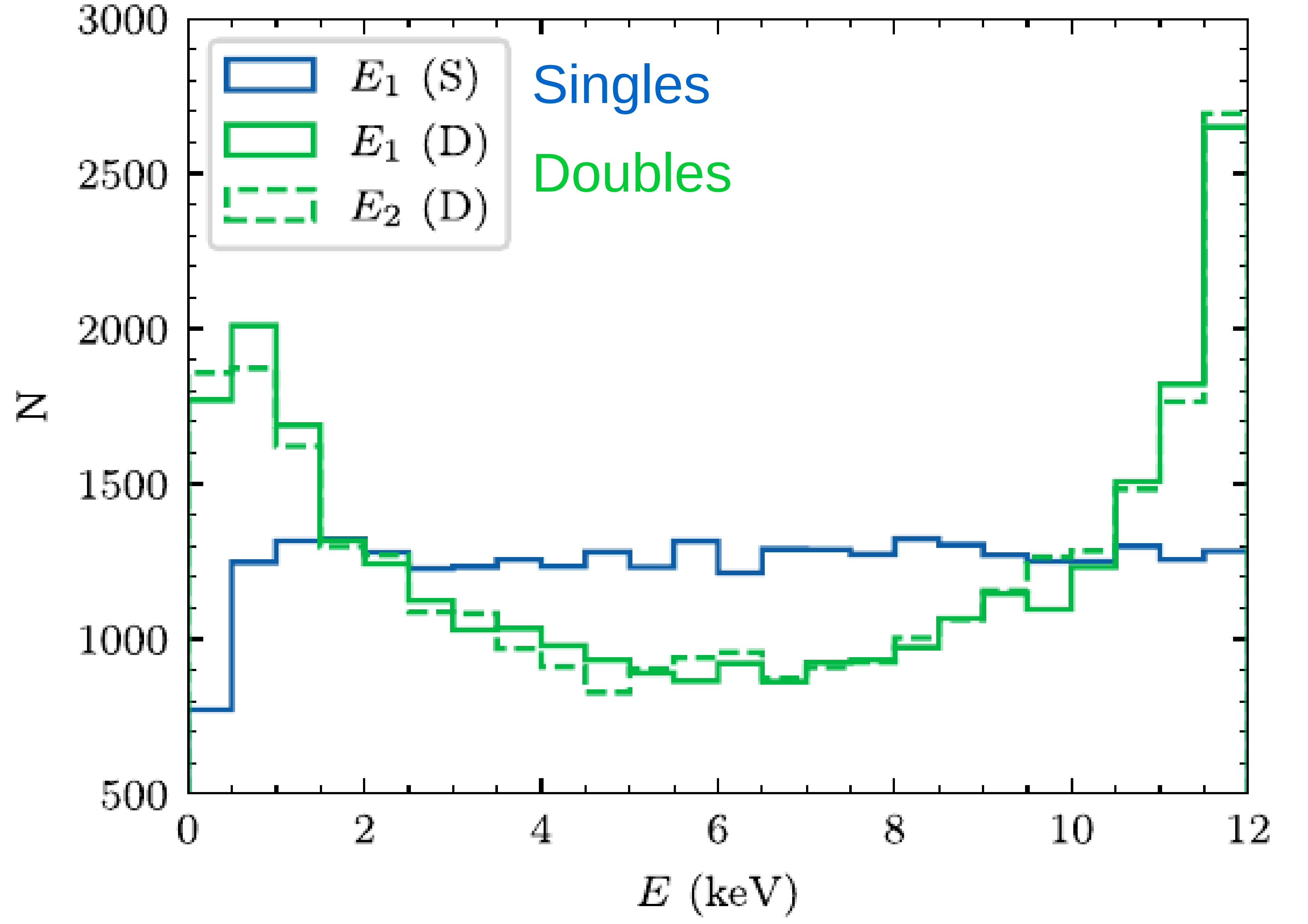
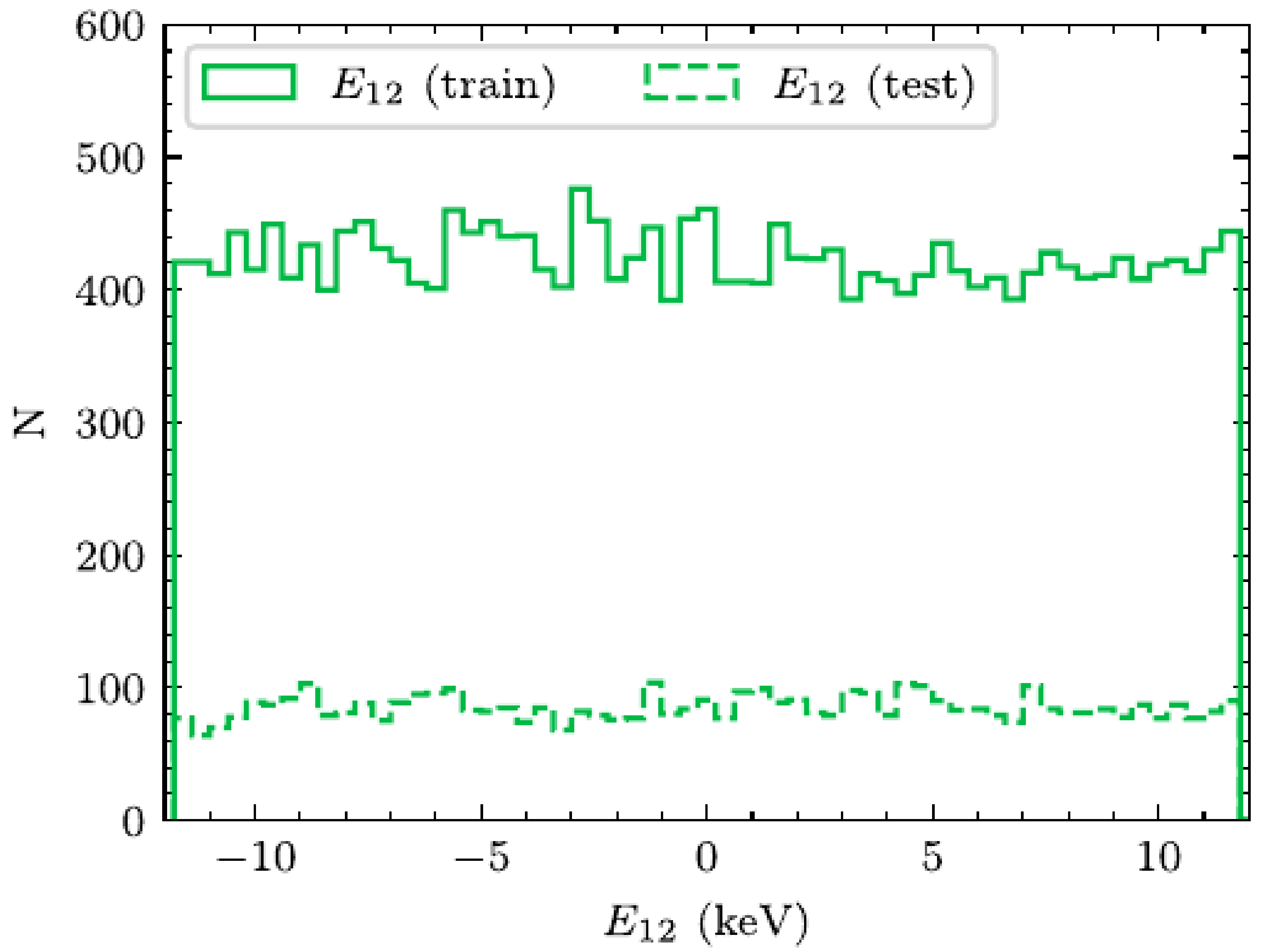


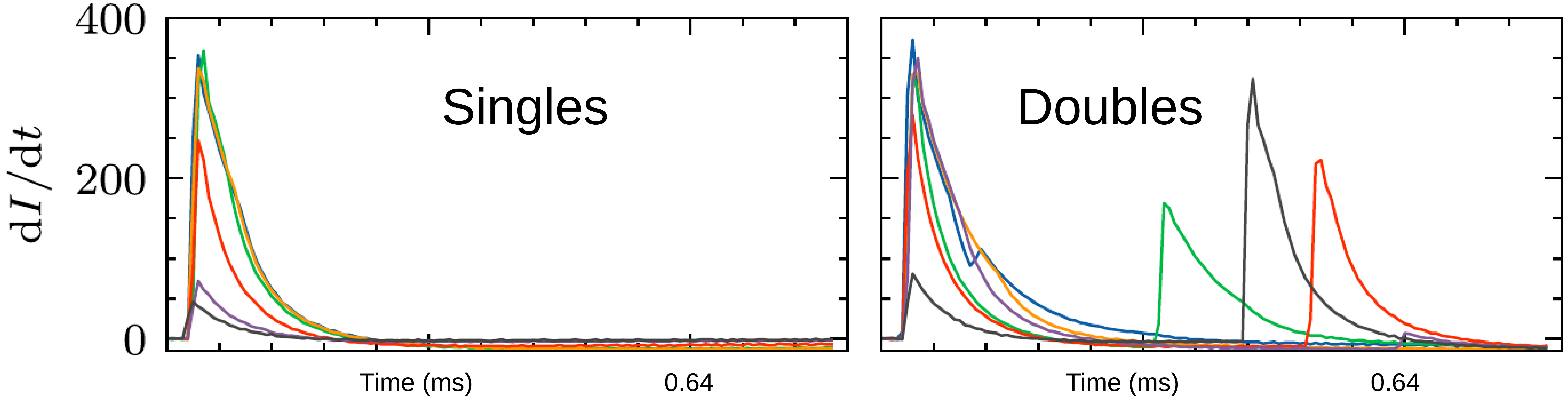


30000 **single** records

30000 **double** records

TRAINING 50000

TEST 10000



R range:
0.2 – 12.0 keV

Separation range:
0 - 0.80 ms

Neural Networks architectures

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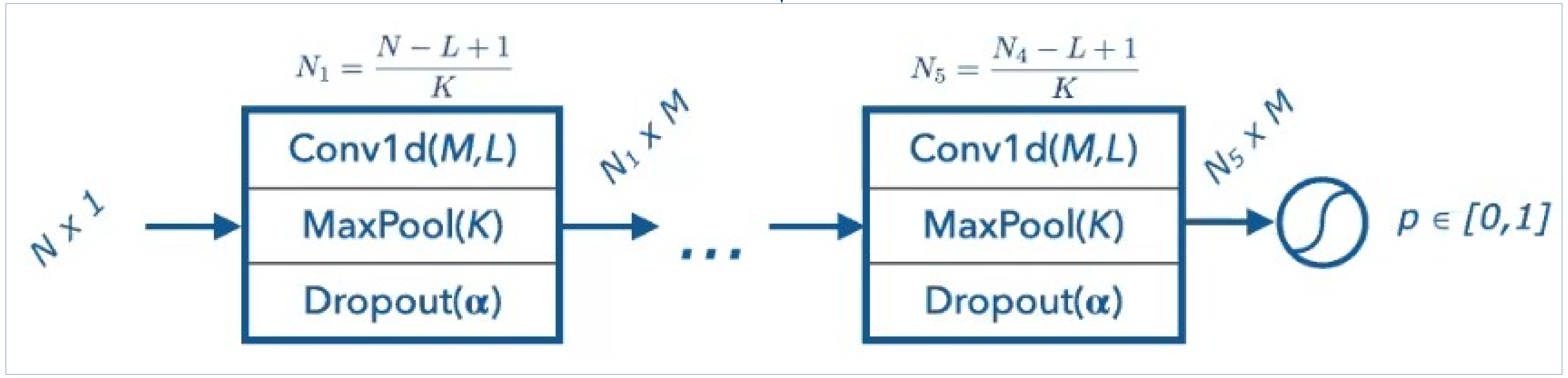
1D CNN

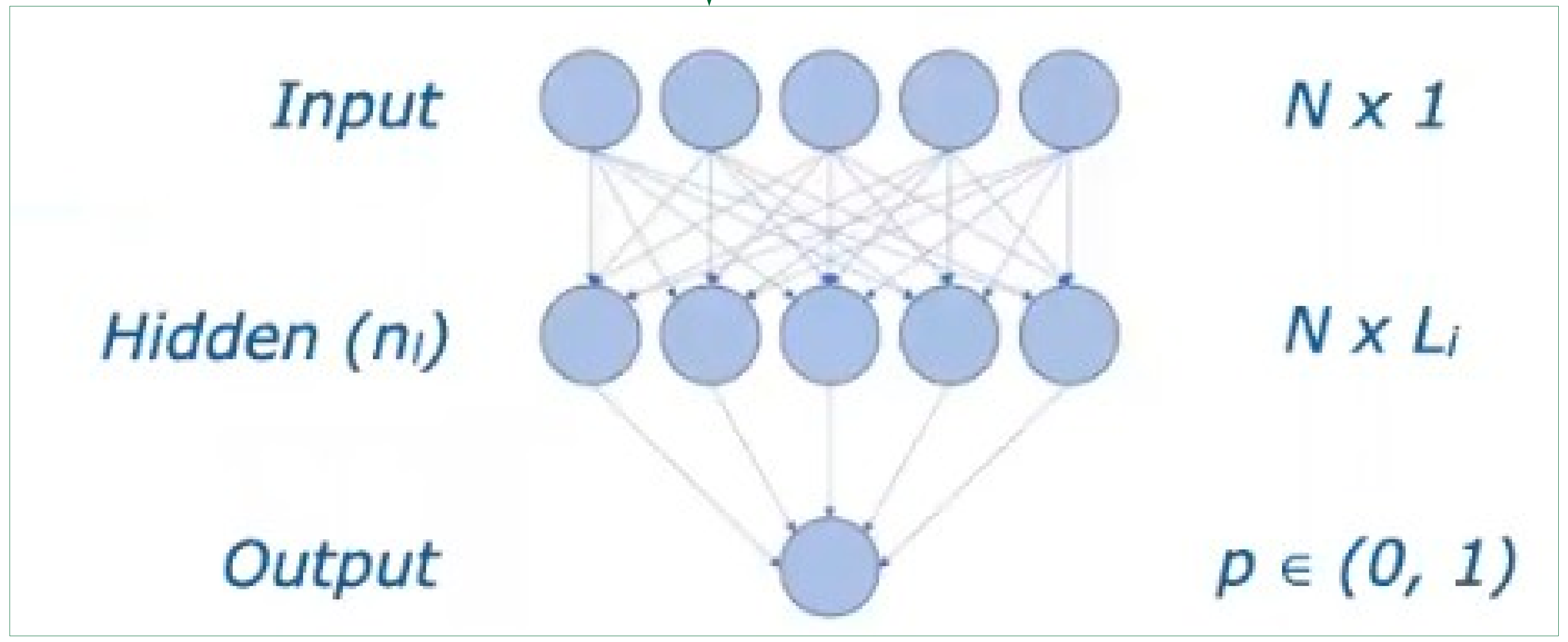
- 2,3,4 convolutional blocks (N_l : number of layers)
- Filters (M_i channels of length L_i) with *relu* activation
- Max pooling (K_i) + Dropout (d)

1D DNN

- 2,3,4 hidden layers (n_l : number of layers)
- Hidden layers of size L_i with *relu* activation
- Output layer: size 1 with *sigmoid* activation

- *adam* learning rate (l_r)
- **Binary class:** likelihood
  - p € (0,1) -> positive (Single)
  - (1-p) -> negative (Double)





PULSE CLASIFICATION

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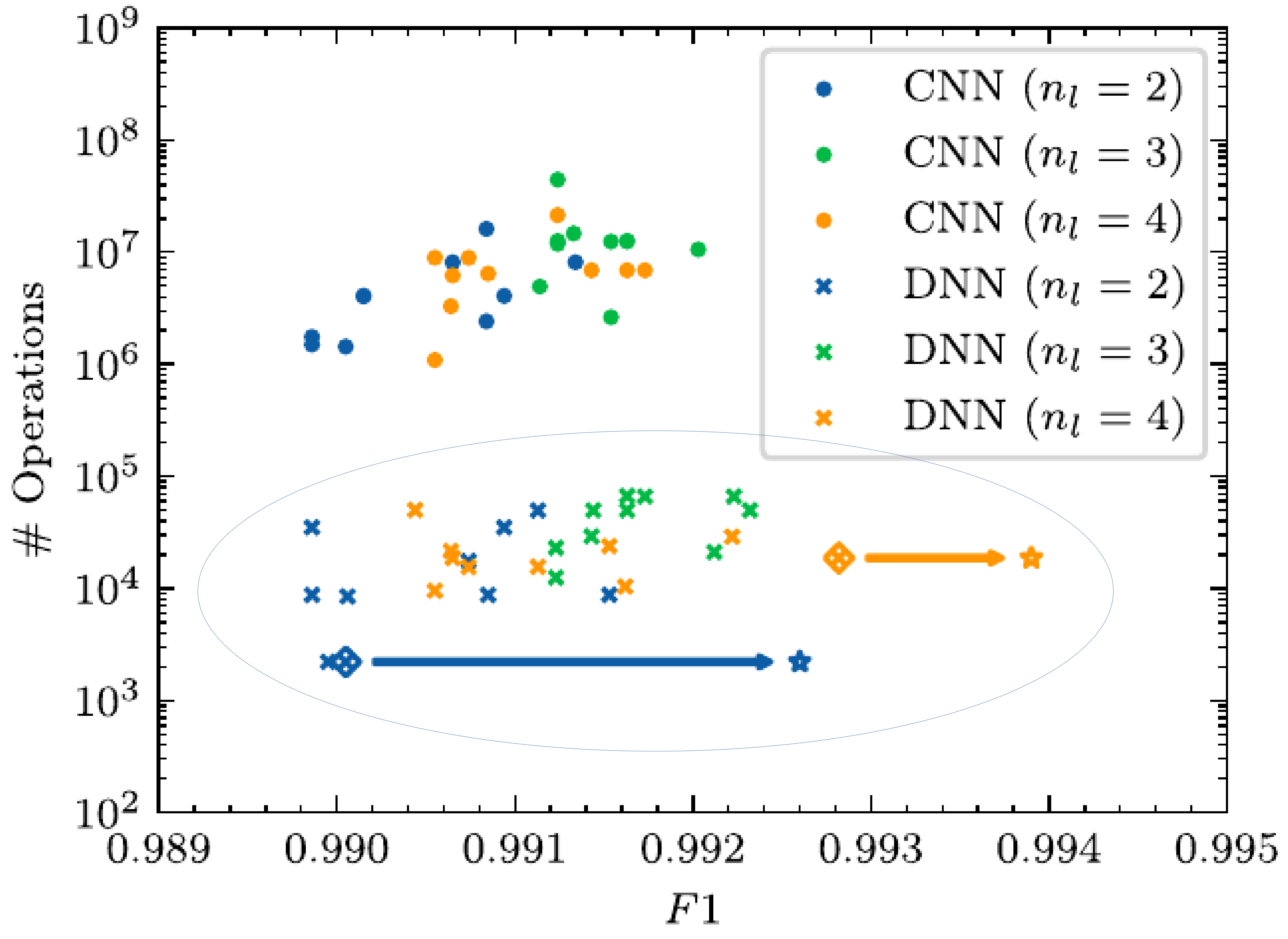
CNN (●) versus DNN (x)



(best 10trials/50 epochs shown)

$$Precision = \frac{TP}{TP + FP}$$

$$recall = \frac{TP}{TP + FN}$$

$$F1 = 2 \cdot \frac{precision \cdot recall}{precision + recall}$$

Contamination?

Completeness?

Weighted average of precision and recall

TP: True-positive: Single identified as Single
FP: False-positive: Double identified as Single
FN: False Negative: Single identified as Double

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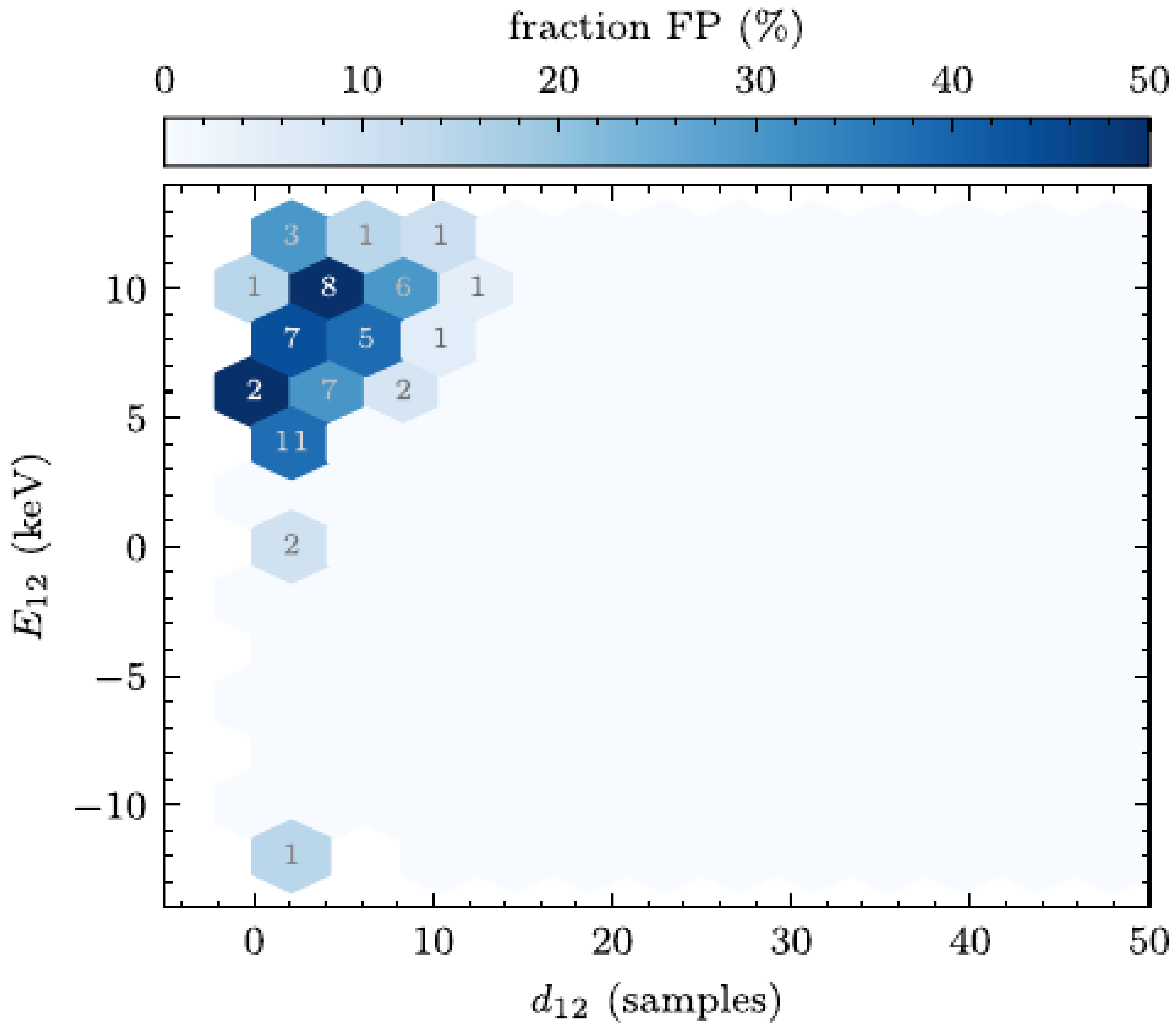
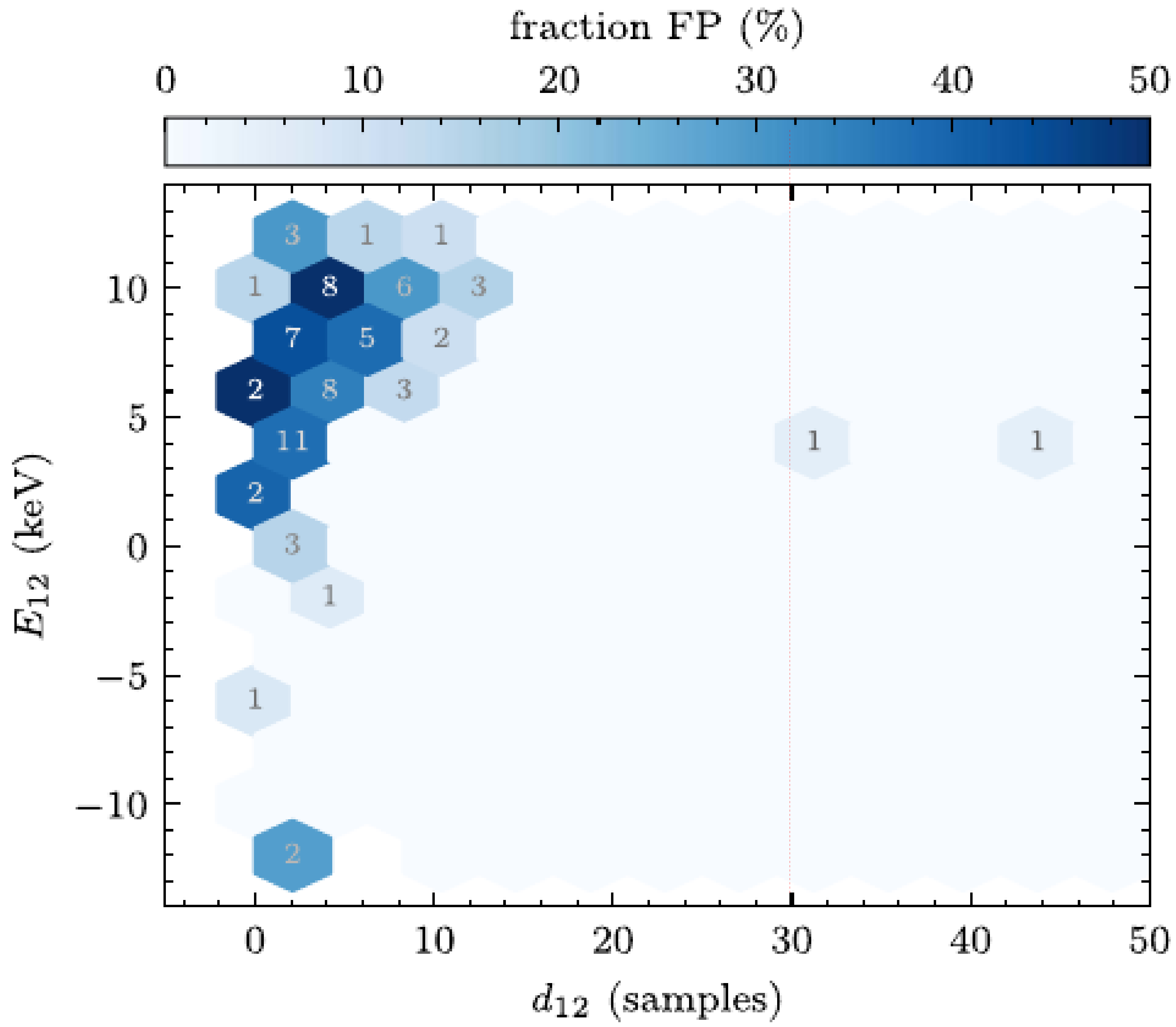


Best (F1) DNN



Best (operations) DNN

PULSE SEPARATION

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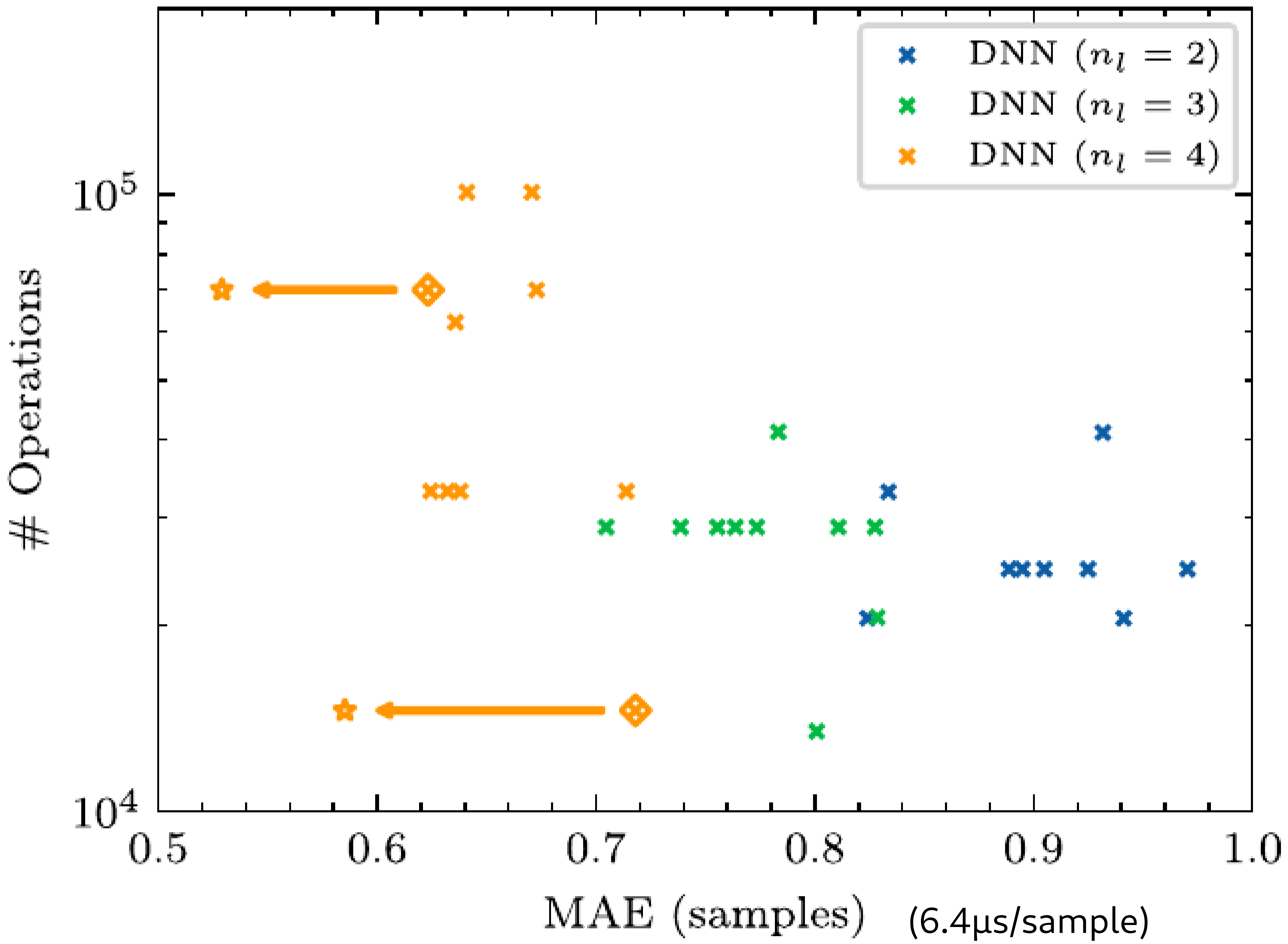

(6.4μs/sample)

(best MAE 10 trials after 100 epochs shown)

$$\mathrm{MAE} = \frac{1}{n}\sum_{i=1}^{n}|\tilde{y}_i - y_i|,$$

y_i : input separation

$\tilde{y}_i$: predicted separation

PULSE SEPARATION

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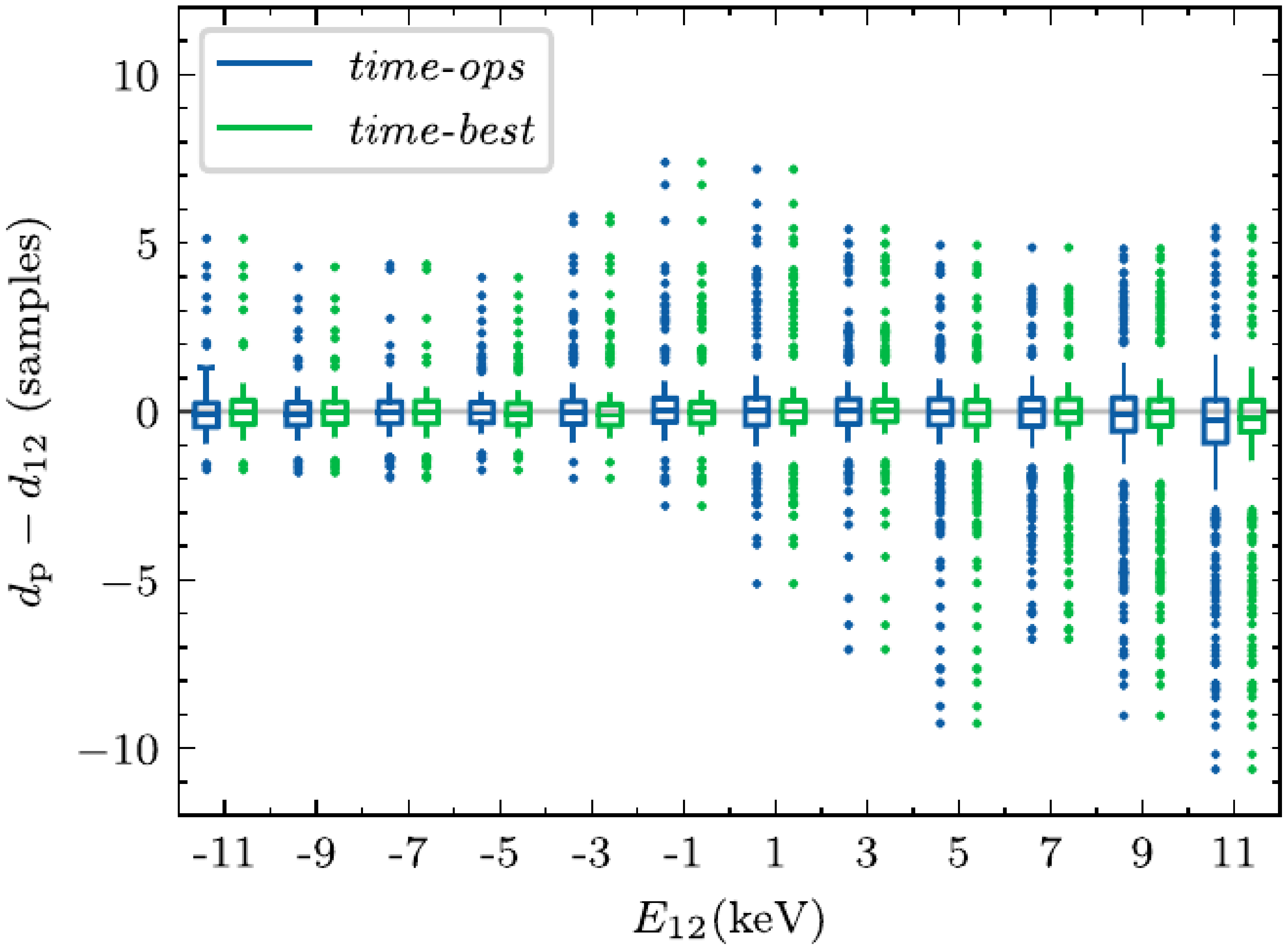

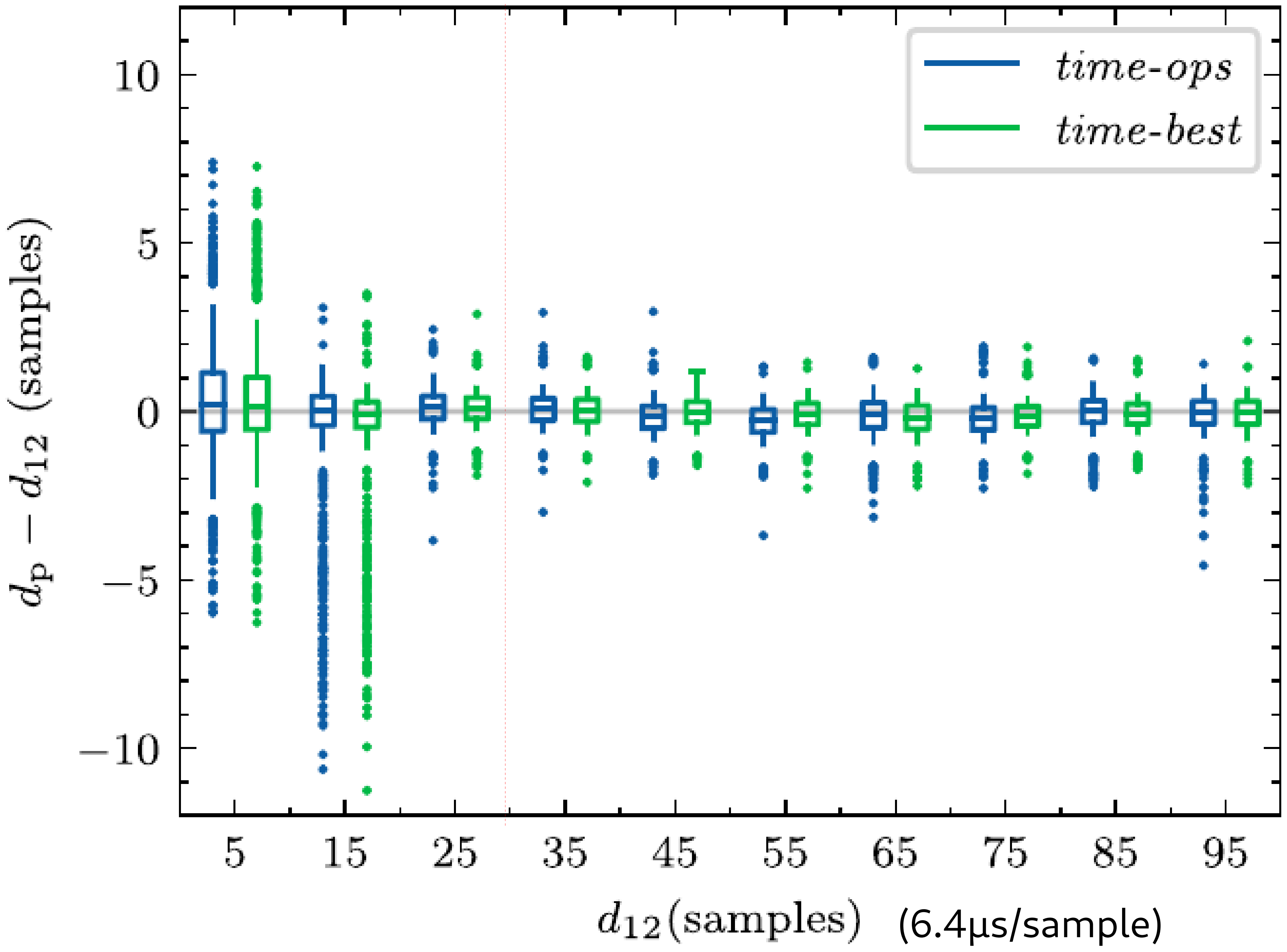

PULSE ENERGY

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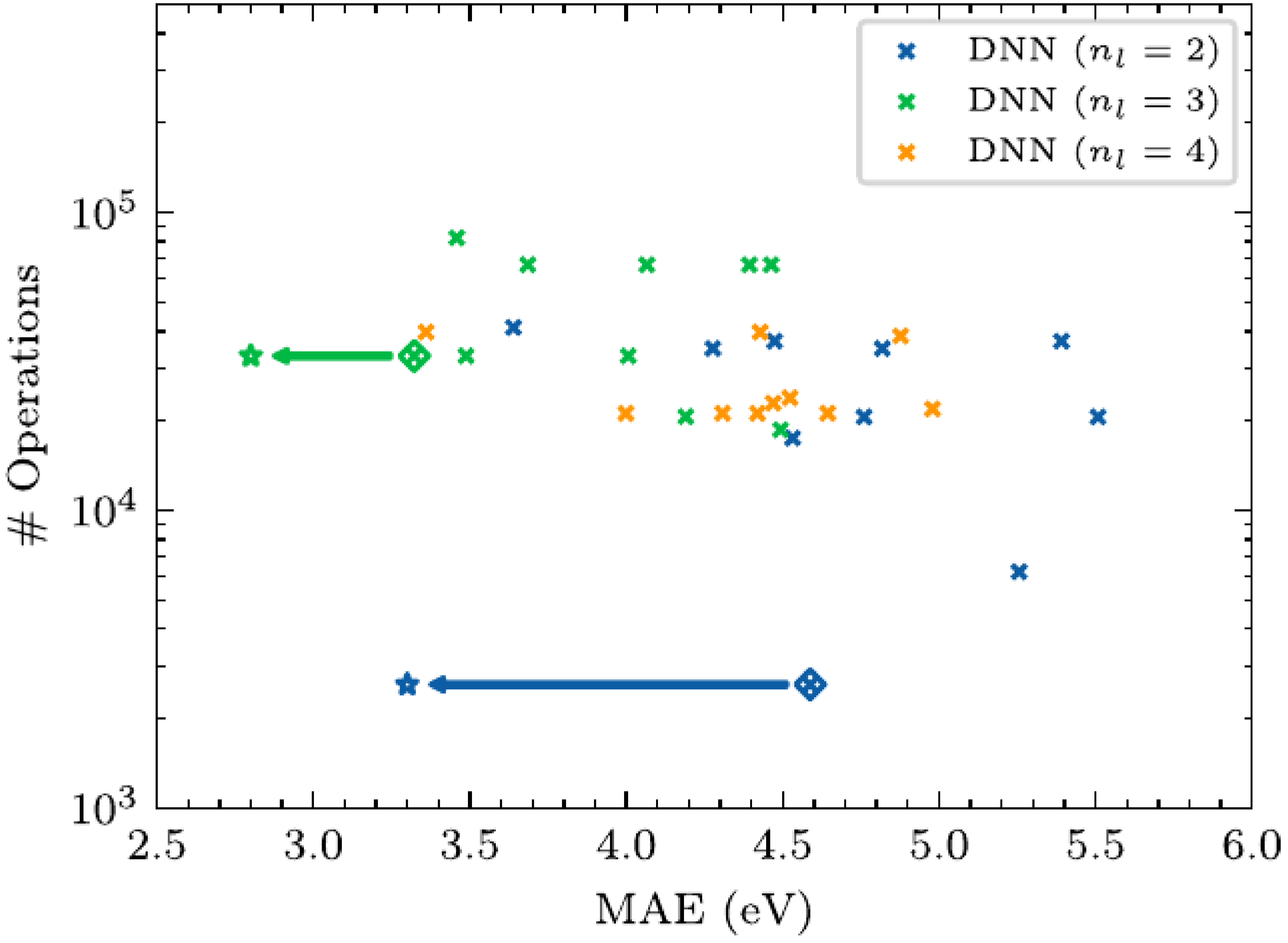

$$\mathrm{MAE} = \frac{1}{n}\sum_{i=1}^{n} |\tilde{y}_i - y_i|,$$

y_i : input single energy E_1

$\tilde{y}_i$: predicted energy E_p

SINGLE-pulse records

PULSE ENERGY

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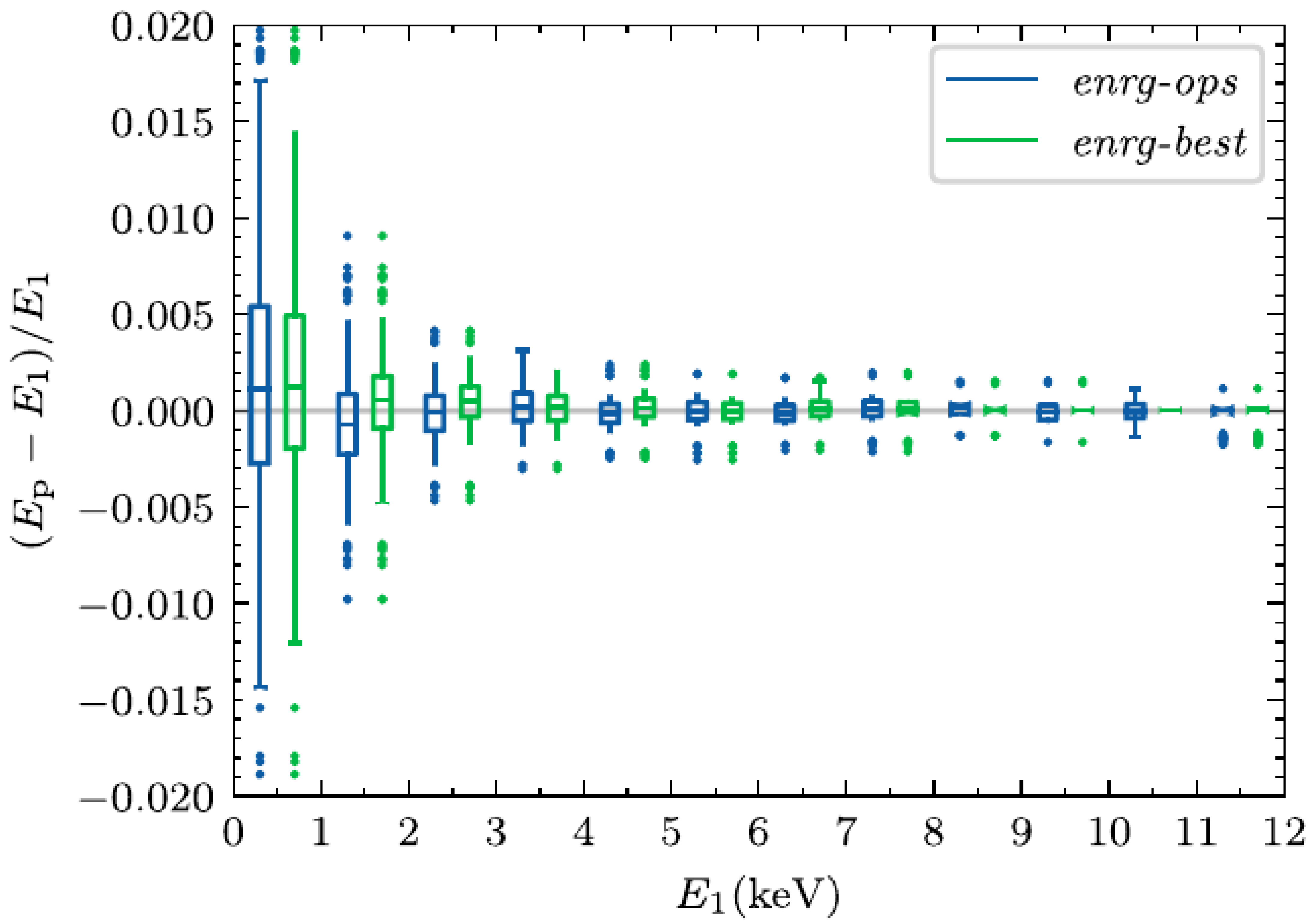

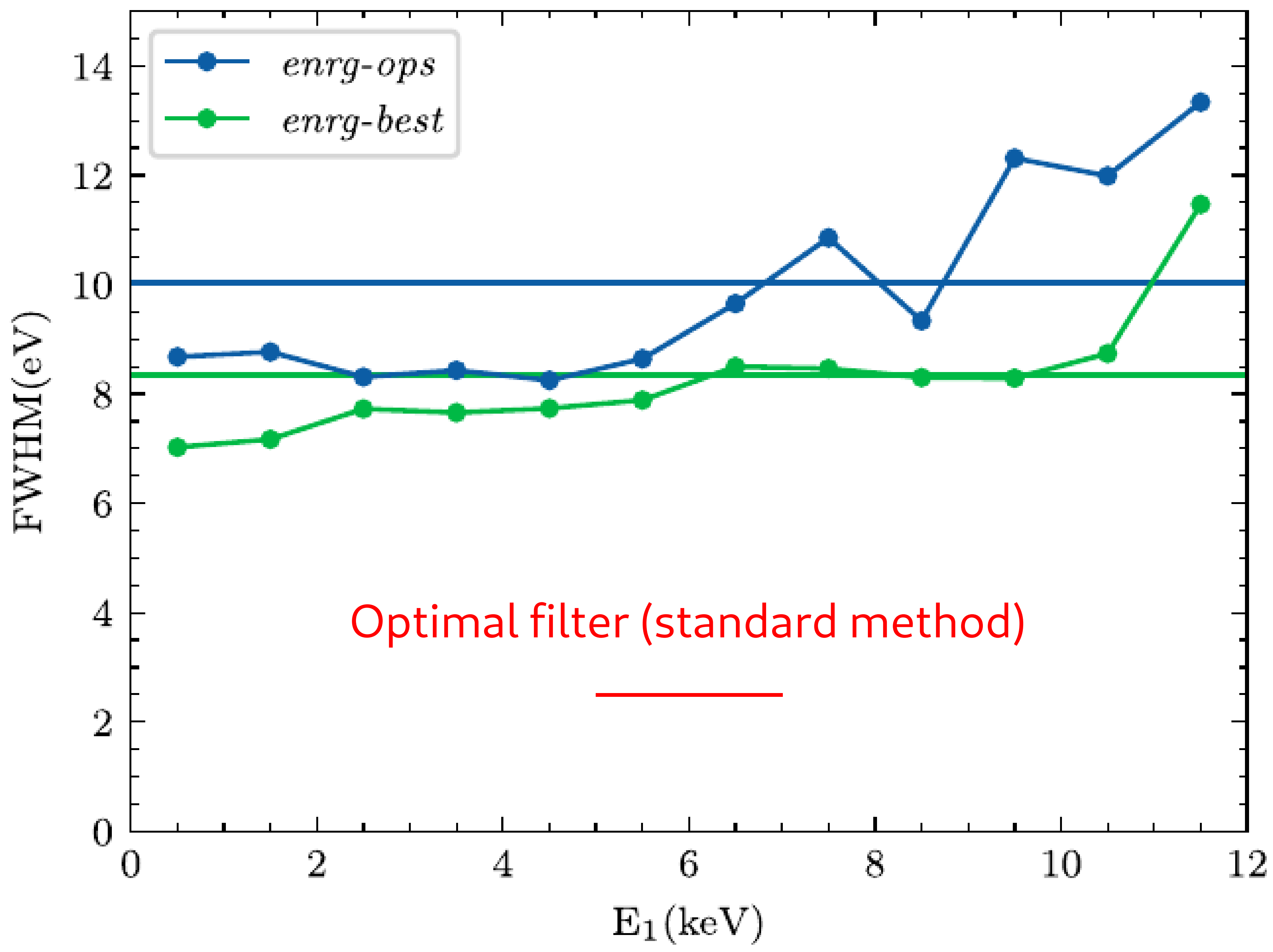

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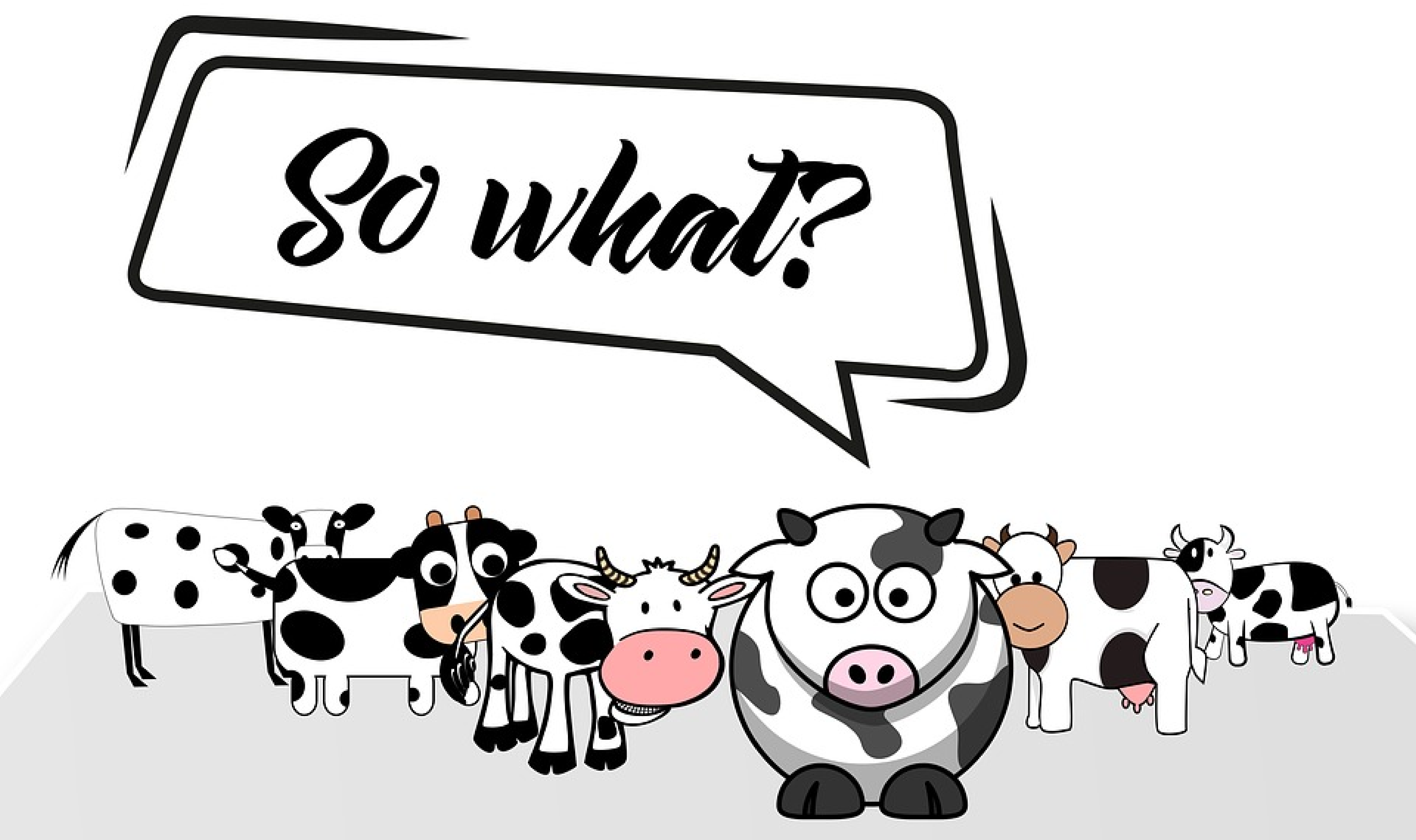
The conclusions



CONCLUSIONS

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DNN architecture

Model	Metric	# Ops.	n	l_r	b	L_i
bin-best	0.9928	1.9×10^4	4	0.001	250	(32, 32, 64, 32)
bin-ops	0.9901	2.2×10^3	2	0.001	150	(8, 8)
time-best	0.62	7.0×10^4	4	0.001	300	(64, 128, 128, 16)
time-ops	0.72	1.5×10^4	4	0.001	150	(32, 64, 16, 4)
enrg-best	3.3	3.3×10^4	3	0.0001	150	(32, 128, 64)
enrg-ops	4.6	2.6×10^3	2	0.001	200	(8, 32)

CLASSIFICATION

- Computational cost: +2200 ops/pulse
- **S** misclassified: 0.04%
- **D** missclassified: 1%
- Completeness of **S** ≈ 1.0
- Purity of **S** ≈ 0.99
- Fails for extreme cases of **D** records
- IMPROVES classical methods!

CONCLUSIONS

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SEPARATION

- Computational cost: +15000 ops/pulse
- Sub-sample estimation of separations
- IMPROVES classical methods!

CONCLUSIONS

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DNN architecture

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ENERGY

- Computational cost: +2600 ops/pulse
- OPT FILTERING ~ 50000 ops/pulse
- Sub-sample estimation of separations
- **Worse** FWHM ~ 9 eV @ 5-7 keV
- Increasing the pulse length (>0.82ms)?

DNN not viable alternative for energy determination BUT helpful for pulse classification (avoid contamination) **IF** computational cost affordable

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MORE INFO

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