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Reconfigurable in-pixel neural network for time-of-arrival (ToA) estimation in X-ray detectors

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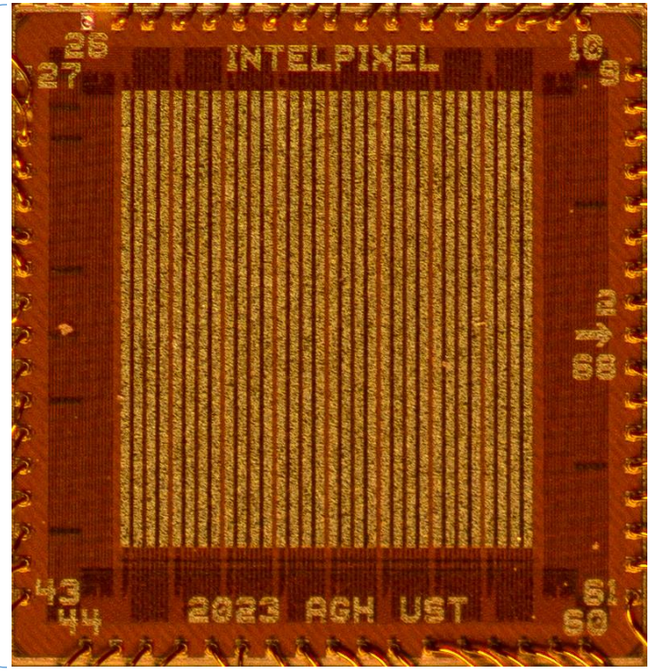
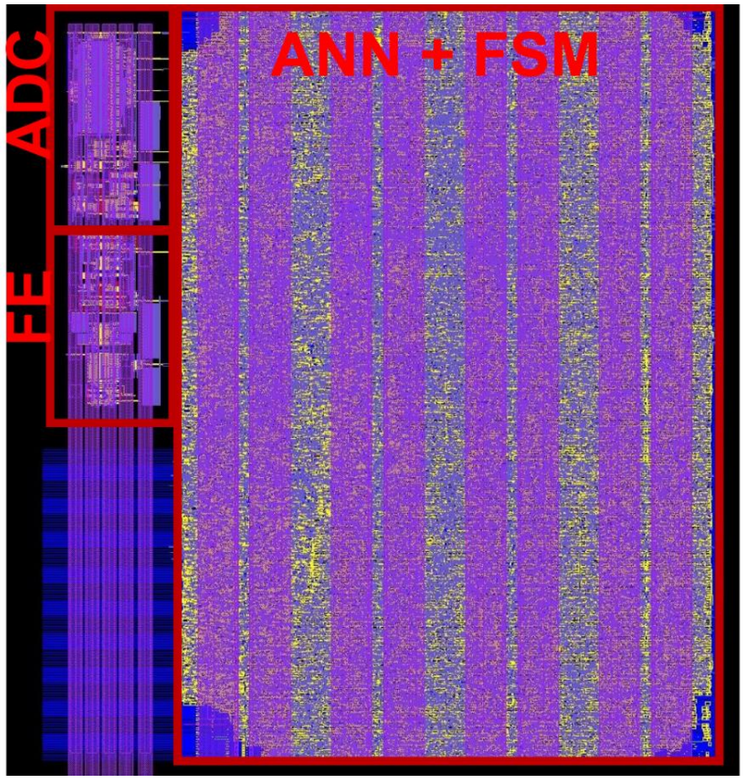
IntelPixel IC

2.48mm

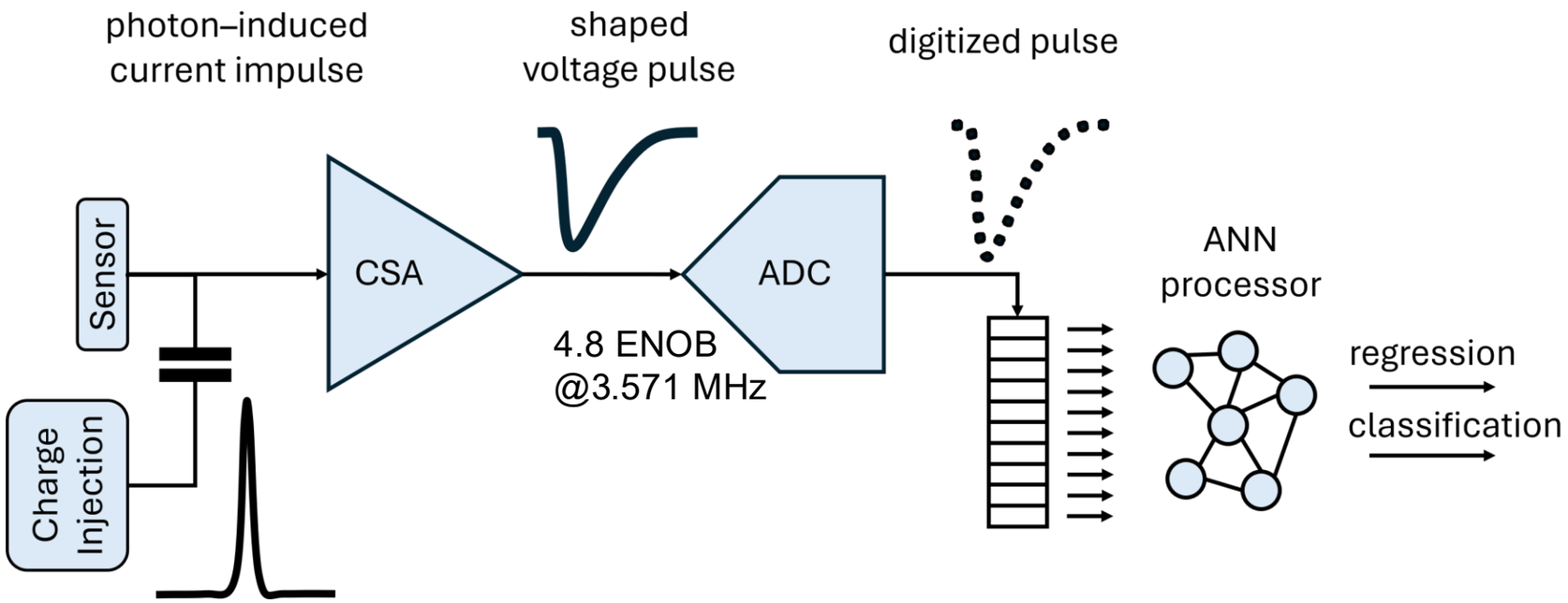


- HPAD readout ASIC
- 28 nm technology
- in-pixel ANN



- pixel pitch: 200µm
- fabrication: Dec 2023

In-pixel ANN principle of operation



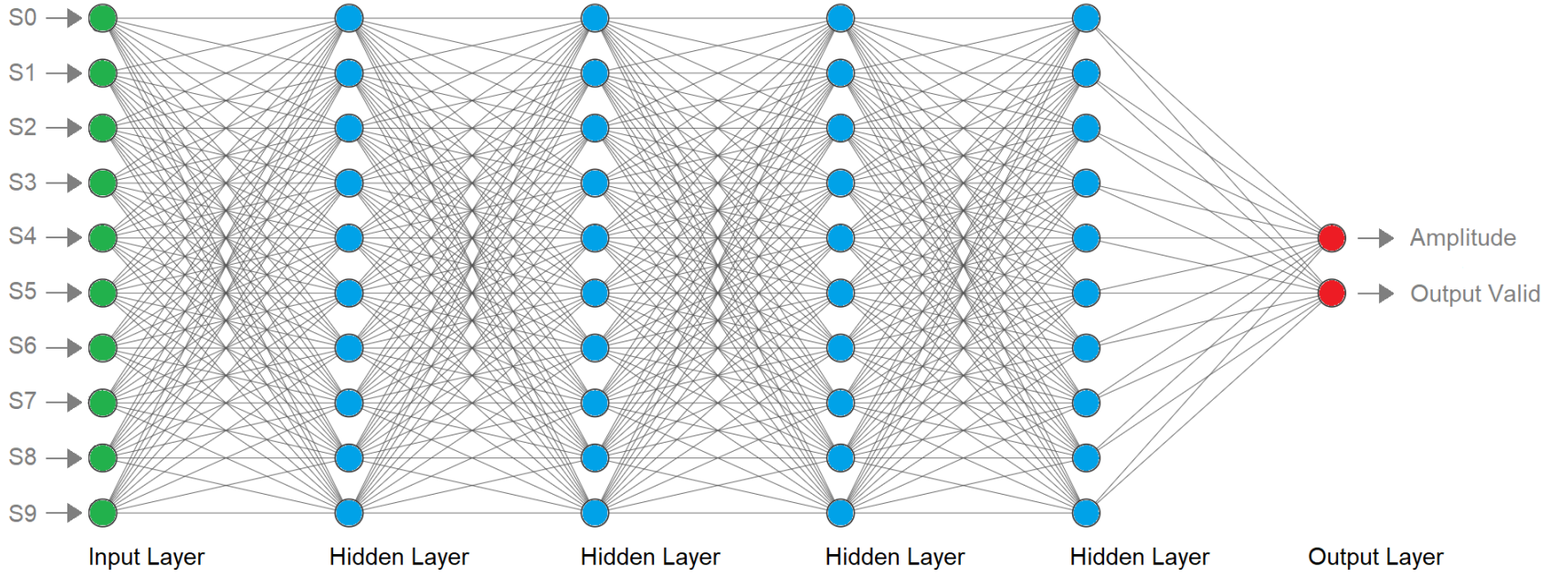
For every 10 ADC samples ANN returns:

- Regression
- classification

ANN operates continuously (Every ADC sample triggers recalculation).

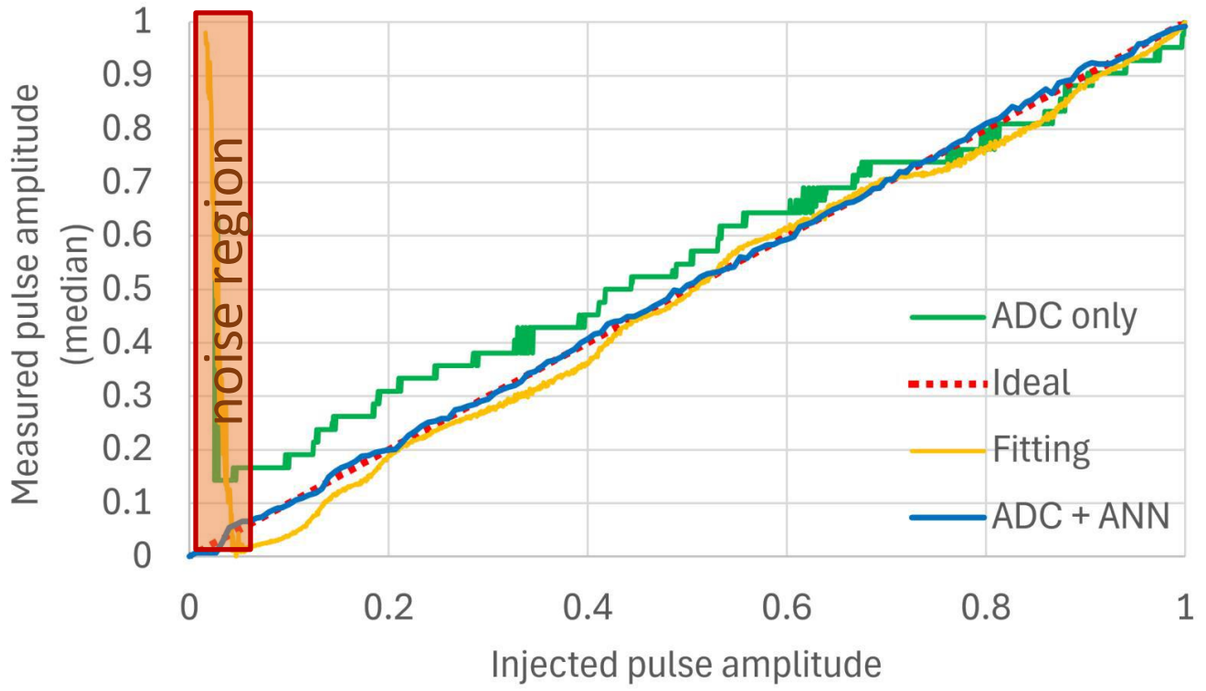
ANN architecture

- Architecture: Multi-Layer Perceptron (MLP)
- HDL reconfigurable processor (SPI memory)
  - weights representation -FXP 12 bits
  - accumulators datatype -FXP 24 bits
  - activation function – ReLU



"Design of artificial neural network hardware accelerator", JINST 2023, Damian Kuznar et al.

Pulse amplitude estimation



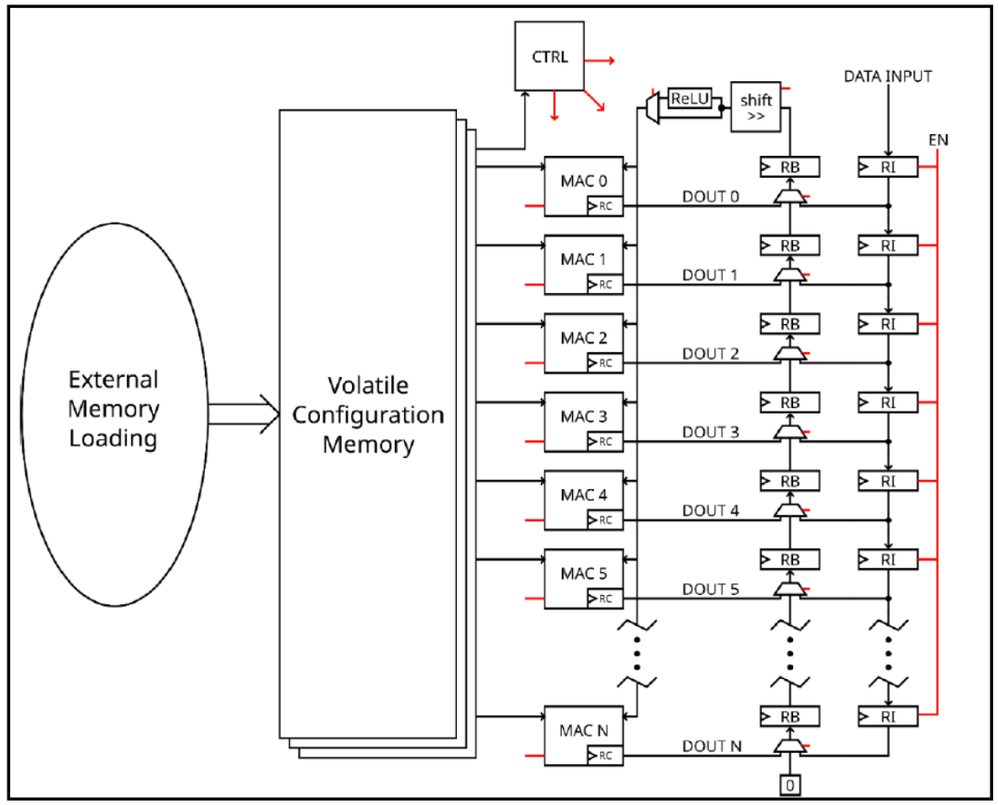
MAE – Mean Absolute Error

$$MAE = \sum_{i=0}^{n} \frac{|truth - meas|}{n}$$

Original use-case

	MAE
ADC + ANN	0.013
ADC	0.058

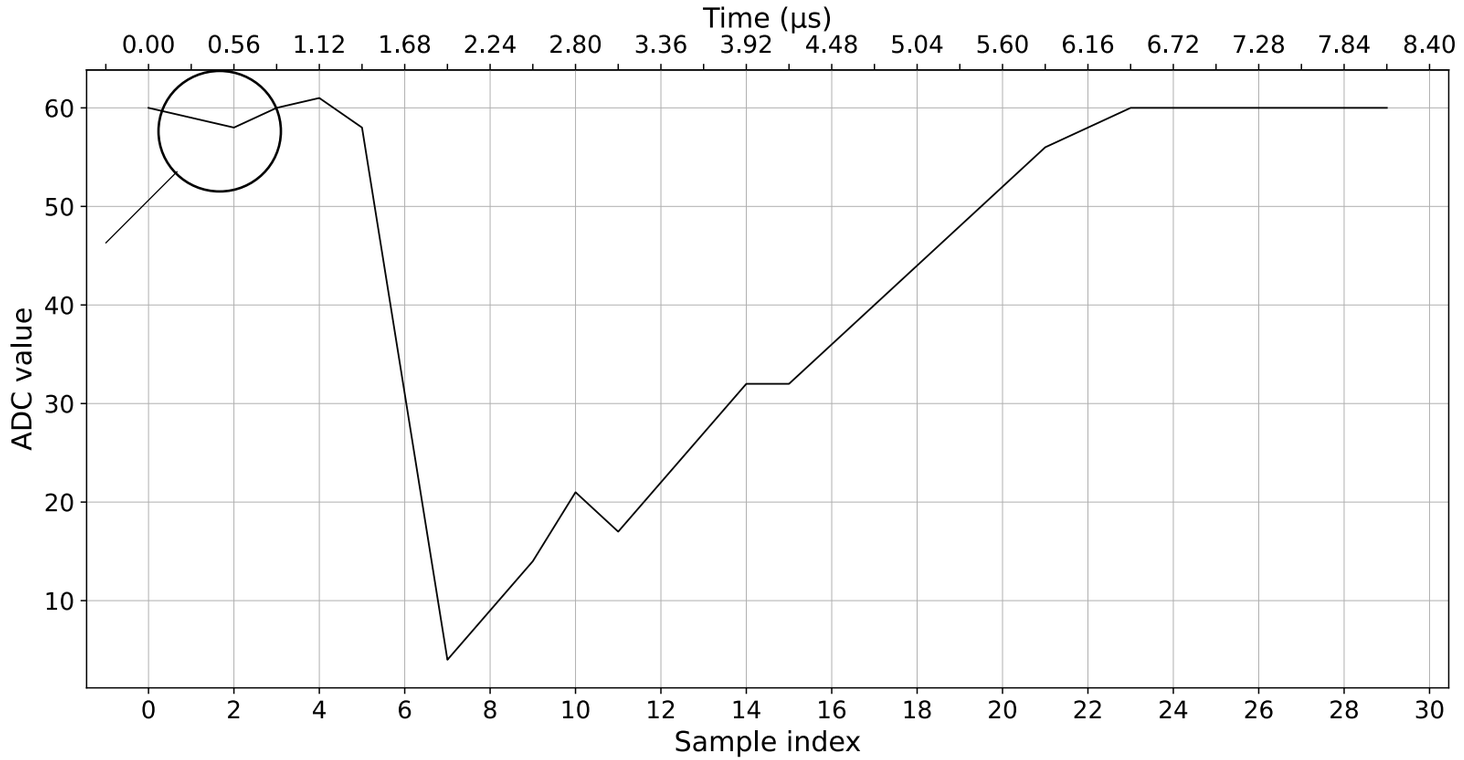
Reconfigurable ANN



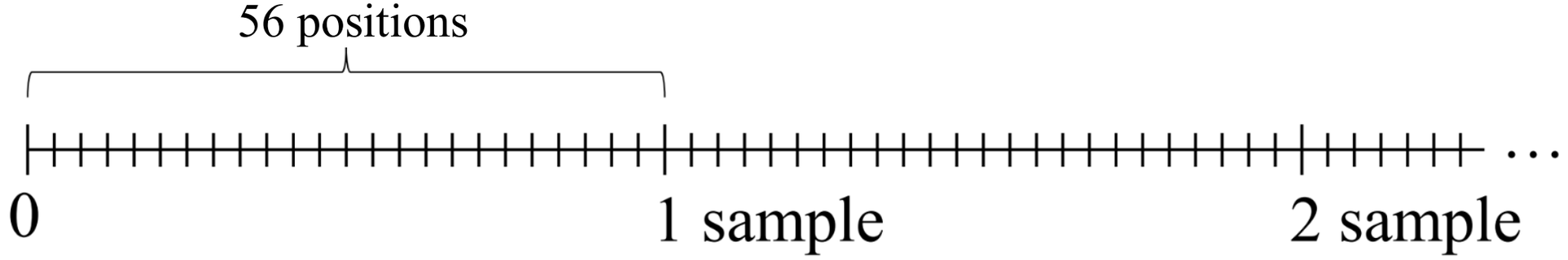
- Weights and biases are stored in volatile memory and are uploaded after IC reset
- ANN can be retrained for different purposes

Maybe pulse shape can be used to estimate ToA?

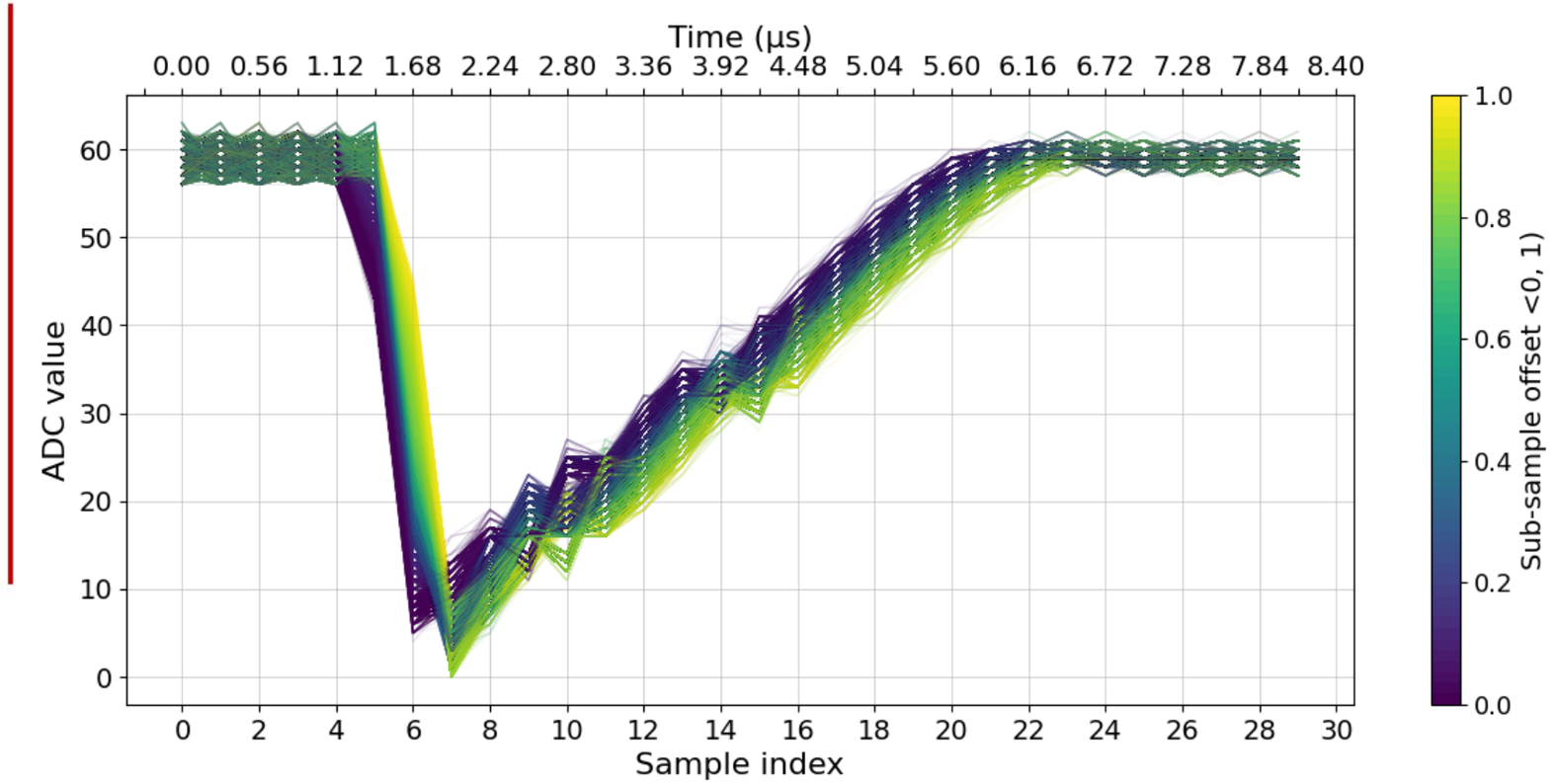
Time of arrival dataset preparation



- Limited by setup
- ANN can be retrained for ToA Measurement



Pulse shape - Feasibility

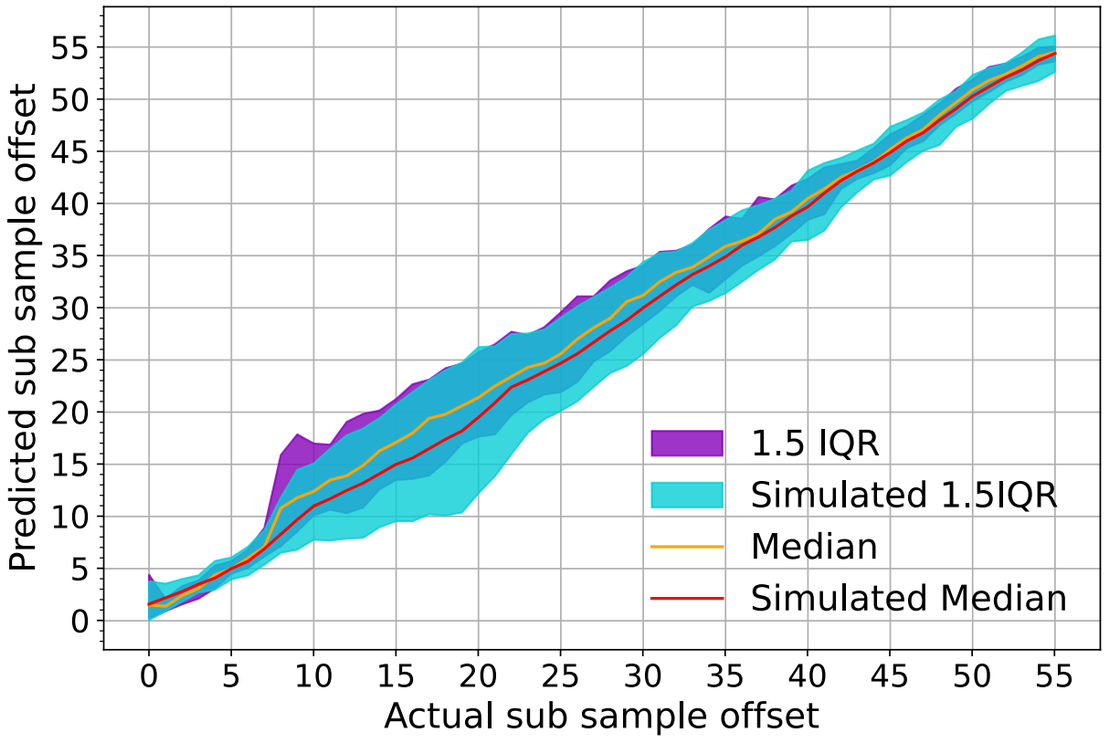


- A lot of noise
- ToA seems to be discernable

ANN is trained on 2 samples before event and 8 samples after

Measurements

Sample time = 280ns Sub sample determination LSB = 5ns (1/56 of ADC dt)



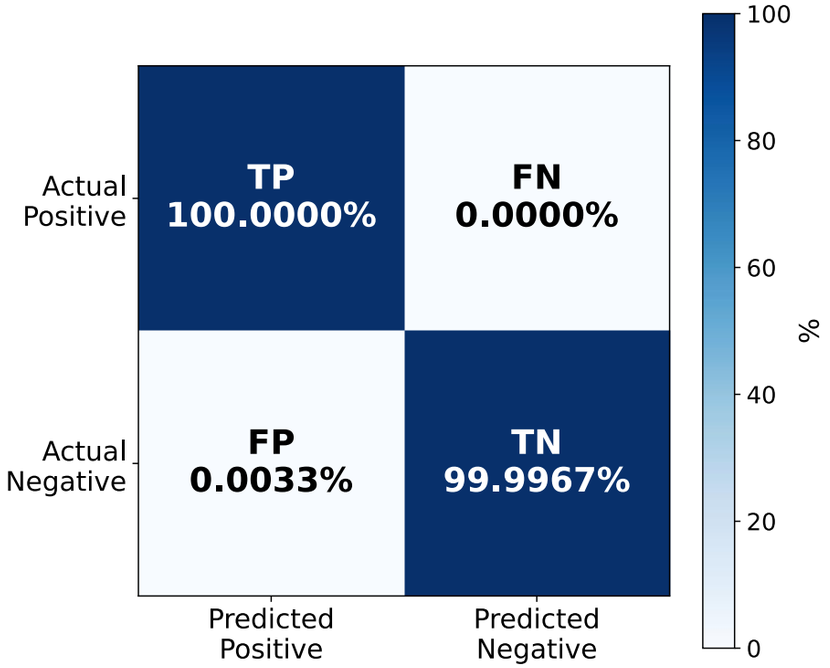
Parameters:

- Estimation is a fraction of sample timne
- Output valid is asserted 8 sample times after event

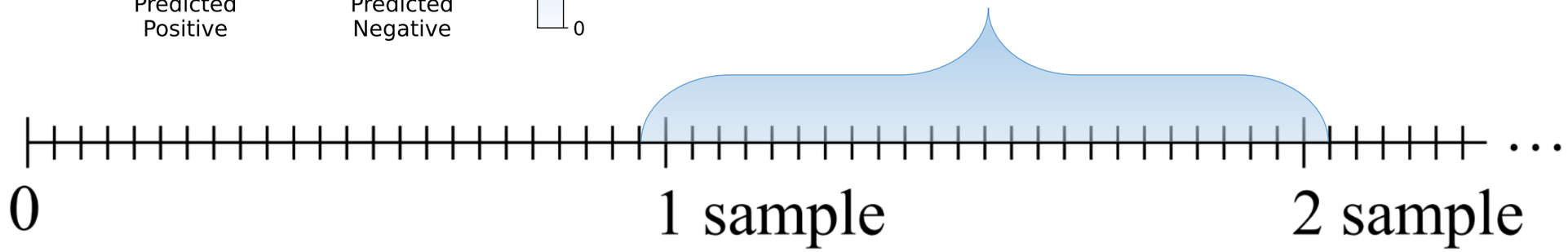
Estimation accuracy:

- Error < 15ns for 95% of pulses
- Error < 30ns for 1.5IQR
- 35ns maximum absolute error
- 6ns mean error
- 8.9ns RMS error

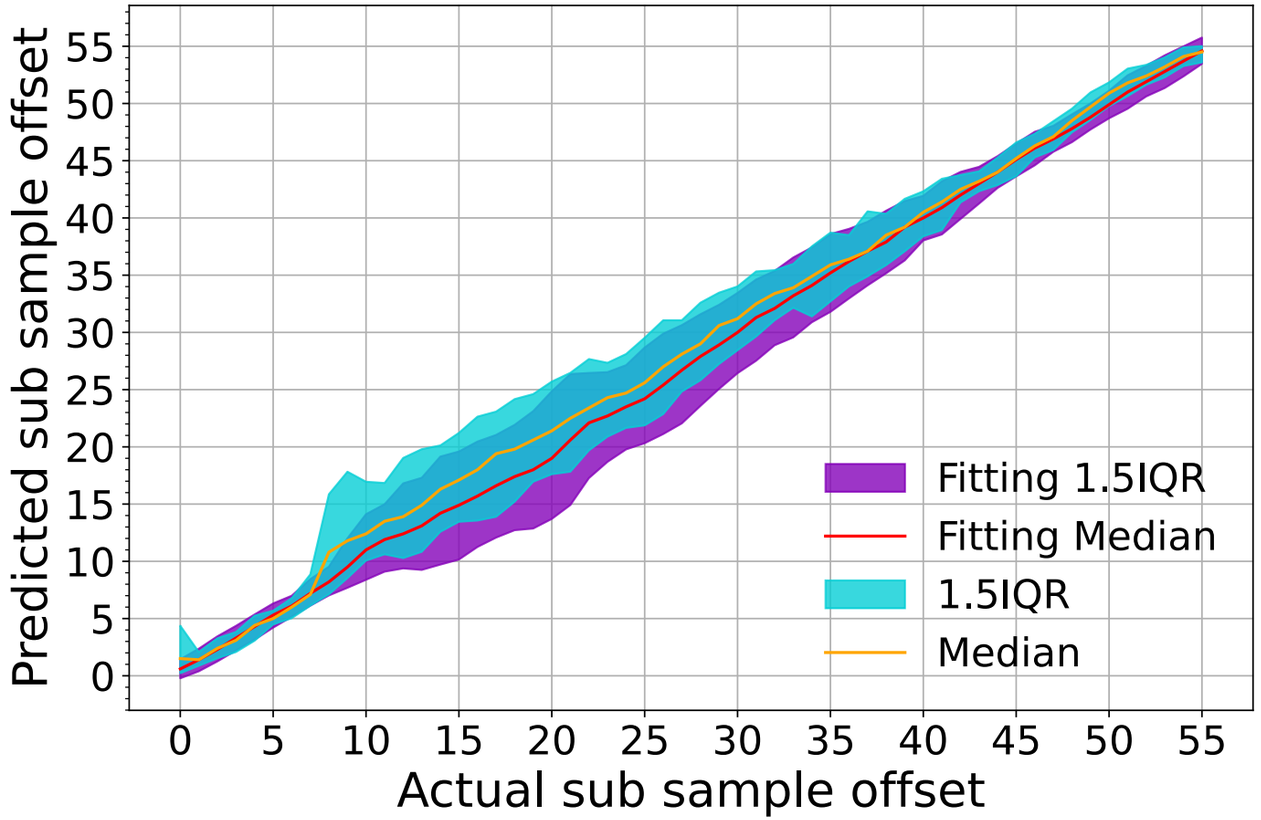
Measurements



- Best results are on the sample edges (Maximum error there is equal to 5ns)
- False positives are only generated within pulse window



Comaprison to offline fitting



Fit accuracy:

- Error < 15ns for 95% of pulses
- Error < 29.5ns for 1.5IQR
- 40ns maximum absolute error
- 4.5ns mean error
- 6.3ns RMS error

Summary

IntelPixel:

- HPAD IC with in-pixel ANN for X-ray signal processing
- Designed for amplitude measurements, retrained for time-of-arrival.

Time-of-arrival measurements:

- ANN was able to achieve sub-sample ToA estimation accuracy
- Achieved a 15ns accuracy with 35ns max error
- 100% of pulses were detected

Acknowledgement

- The research leading to these results has received funding from the Norway Grants 2014–2021 through the National Centre for Research and Development.