Can machine learning reduce the number of anode readouts for reconstruction coincident single photon in CDIR resistive sea photon detectors?

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INTRODUCTION

The Capacitive Division Image Readout (C-DIR) represents an efficient method for charge centroiding readout in single-photon imaging detectors like Microchannel Plate (MCP) detectors. Its reliance on purely capacitive components provides distinct advantages: a remarkably high signal bandwidth that allows for MCP-limited time resolution and measurement nodes with low capacitance. This setup enables improved precision in charge measurement and finer spatial resolution at high throughput.

CDIR's limitation is its inability to measure coincident photons. We're investigating increasing the number of anode readouts for coincident single photon reconstruction and comparing algorithmic and machine learning methods for spatial photon position reconstruction.

Resolving single photon spatial position using algorithmic vs machine learning techniques

To compare algorithmic methods to machine learning capabilities we instrumented a resistive sea imaging photon detector with multiple CDIR readout boards. A 650 nm laser was scanned across the $2x2mm^2$ active area at a pitch of 0.5 mm for a CDIR readout with/without a capacitive border. The capacitive border effectively stretches the localised charge reducing the pin cushion distortion typically observed with CDIR readout. Hence, the hypothesis that machine learning techniques could improve the resolution of photon position, and correct distortion especially in the readout with zero capacitance.

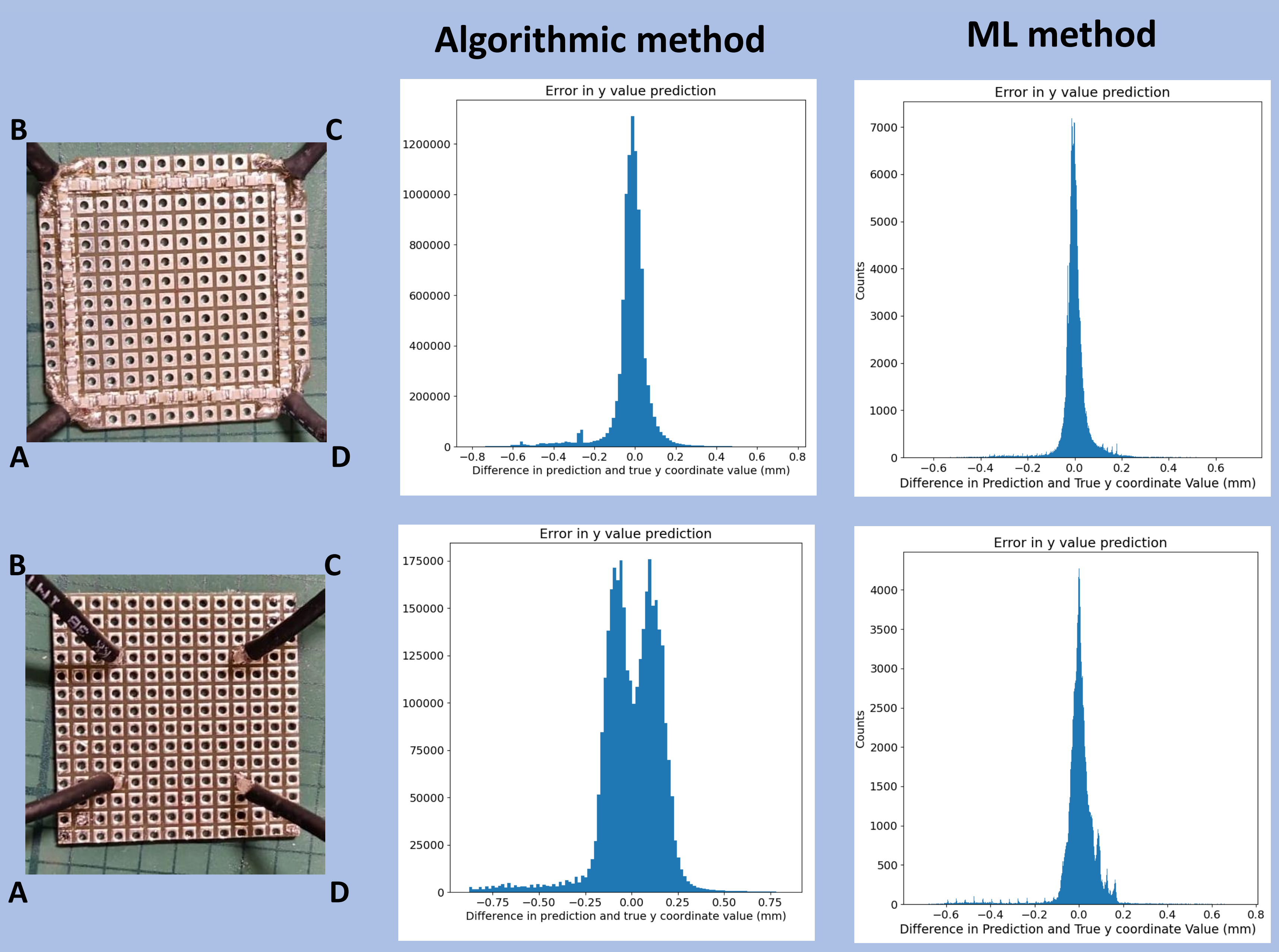


Figure 3: Comparison of photon reconstruction methods; algorithmic and machine learning for two CDIR readout boards.

FWHM and l-infinity norm values attained with algorithmic and ML:

	Algorithmic		ML method	
(Units in mm)	FWHM	L-infinity	FWHM	L-infinity
Capacitive border	0.23	1.51	0.16	0.80
Zero Capacitance	0.38	1.72	0.23	0.71

Proof in principle CDIR readout for coincident photons

The 4 corner CDIR readout is an efficient single photon readout, the limitation of this design is reading out coincident single photons. As a solution, we fashioned a 3 x 3 CDIR readout by soldering pogo pins to connect to the 8 x 8 anode. These 9 channels were instrumented using a Sampic waveform digitiser via preamps. A scan of pitch 0.5 mm was performed across the active area triggering off the active channels. As a preliminary result these waveforms have been captured with no pre-processing to assess the capabilities of the machine learning algorithm.

CDIR readout:

Charge signal localised on the resistive sea anode is capacitively coupled and divided to the four corners of the CDIR readout.

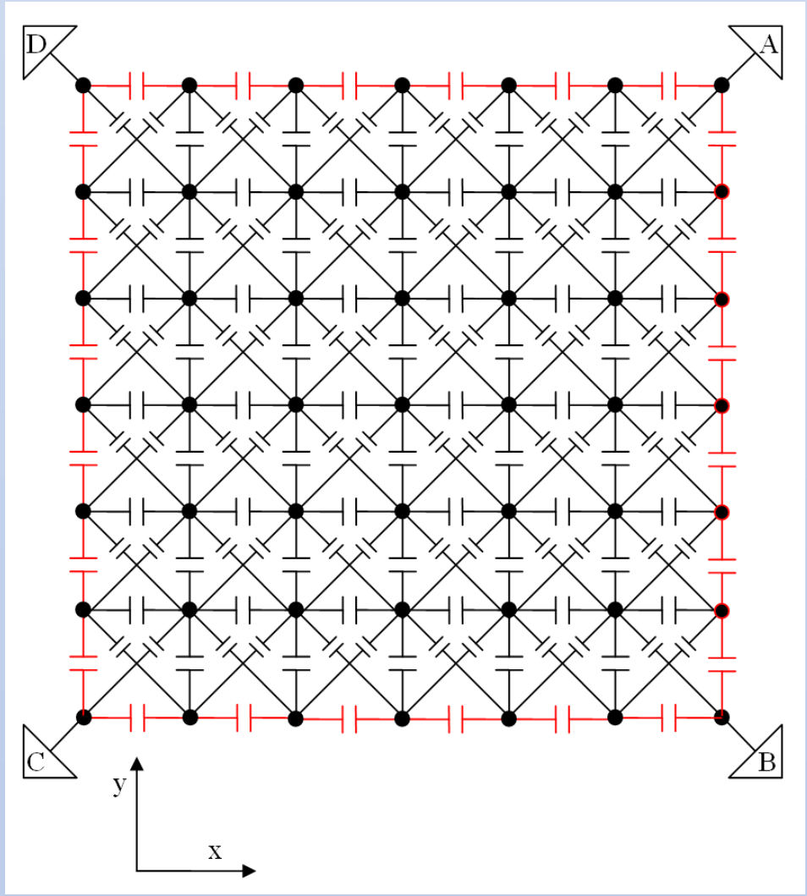


Figure 1: Capacitor schematic of C-DIR readout

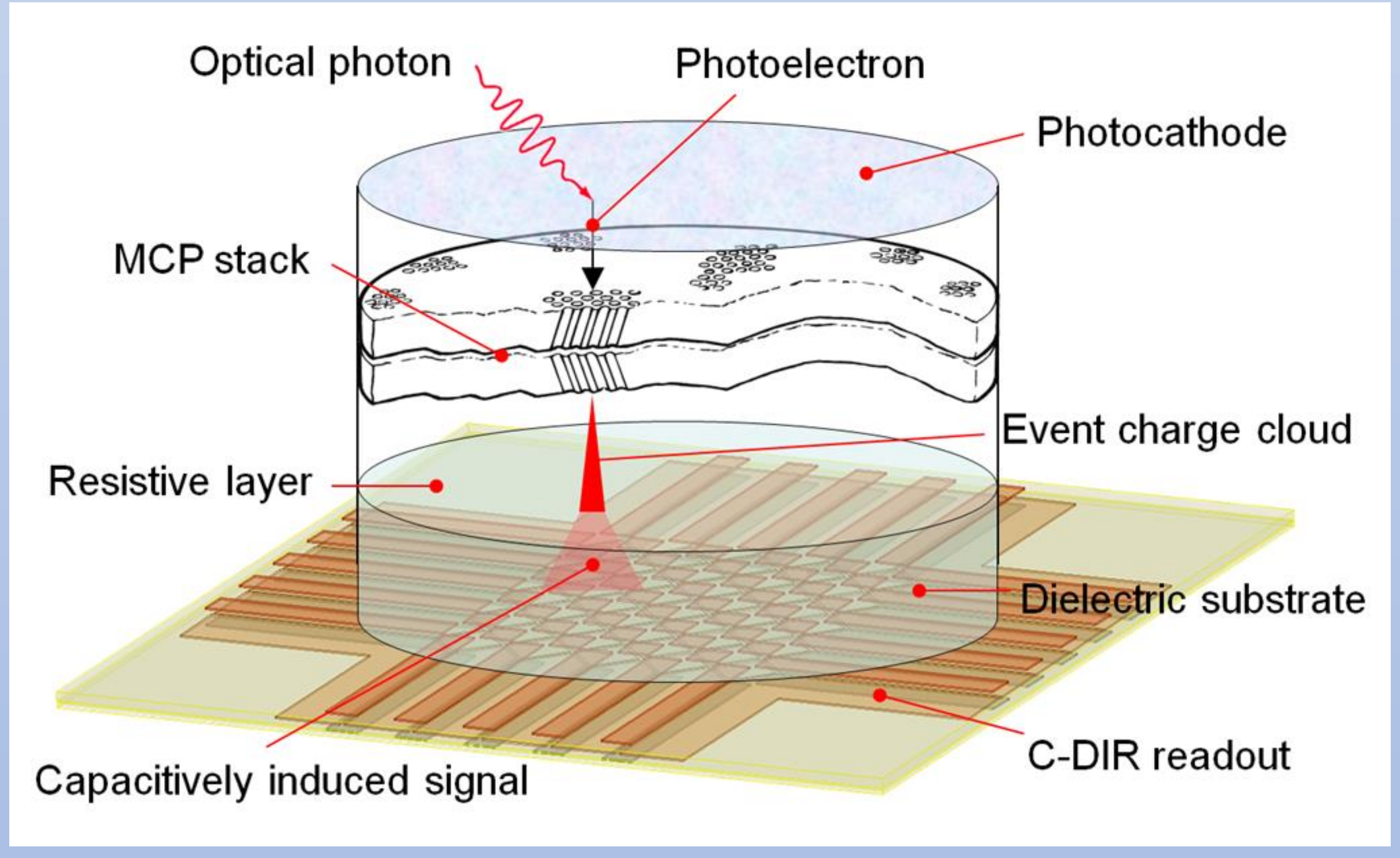


Figure 2: Schematic of MCP detector using C-DIR readout

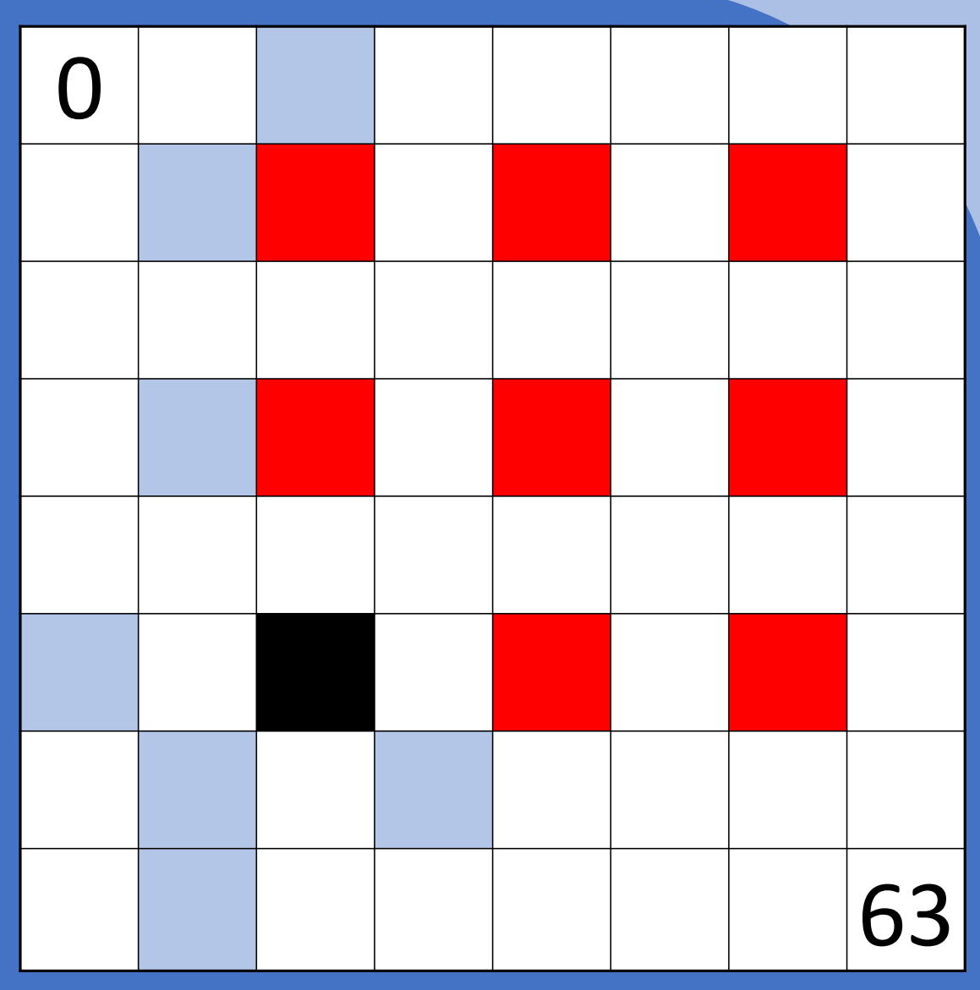
Algorithmic method for photon reconstruction:

$$X = \frac{C+D}{A+B+C+D}$$

$$Y = \frac{B+C}{A+B+C+D}$$

ML photon reconstruction of 9 node CDIR readout

Using the 8 active channels found using the Sampic digitiser, the waveforms for 10,000 triggered events at each scan position in multi-photon mode were recorded. The training data for the supervised NN included the channel number with the peak amplitude of the waveform with the expected output being the stage position of the laser. This preliminary results demonstrates the NN's capability to reconstruct with a FWHM = 0.27 mm and l-infinity norm = 0.82 mm, where l-infinity norm gives the largest magnitude prediction error. This was achieved with a simple NN which was given no prior information of the schematic of the anode.



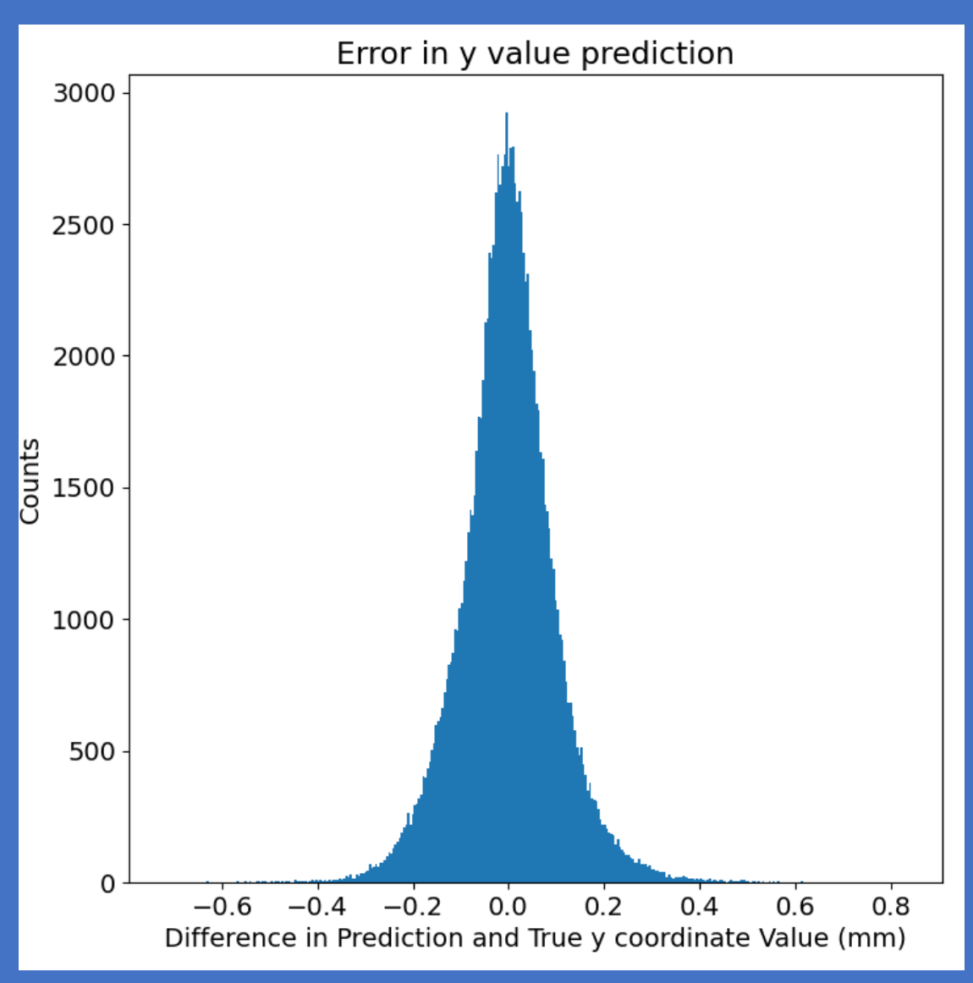


Figure 4: Red demonstrates expected trigger channels, while blue captures the observed active channels, **Figure 5:** Pictures the ML error in predicting the photon's spatial position.

Conclusion

This work has shown promising preliminary results, with a proof in principle of CDIR with zero capacitance can successfully read single photons, reducing the capacitance is advantageous in reducing the noise and allowing for faster throughput. Instrumentation of the 4 corner CDIR readout with and without capacitance demonstrates that utilising ML allows for improvement in the spatial reconstruction of single photons.

A proof in principle of a 3 x 3 CDIR readout has been demonstrated and further work will be done to investigate the possibilities to improve the accuracy of the spatial resolution, comparison of using the integration of the waveform rather than the peak. Further to this, other geometries will be assessed to optimise the readout electronics and bandwidth.

REFERENCES:

"High speed imaging using capacitive division", J.S.Lapington, Nuclear Instruments and Methods in Physics Research, Section A (2012); https://doi.org/10.1016/j.nima.2011.12.006

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