# High resolution imaging and timing using capacitive division

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## 1 Abstract

The capacitive division image readout (C-DIR) is a mechanically and electronically simple charge centroiding readout for single photon imaging detectors such as microchannel plate (MCP) detectors. Its purely capacitive nature endows it with a) very high signal bandwidth allowing MCP-limited time resolution, and b) low capacitance measurement nodes, allowing improved signal to noise charge measurement and correspondingly finer spatial resolution at high throughput. We describe an implementation of an MCP detector with C-DIR, optimised to provide combined high spatial and temporal resolution in single photon counting operation. The C-DIR is instrumented with high-speed front-end electronics utilising a fast waveform digitizer with a sample rate in excess of 1Gsample/s. We present results of the spatial and temporal resolution, and throughput of the detector, and discuss the possible design variations which trade off performance parameters against each other.

## 2 Technique

"**Image Charge**"

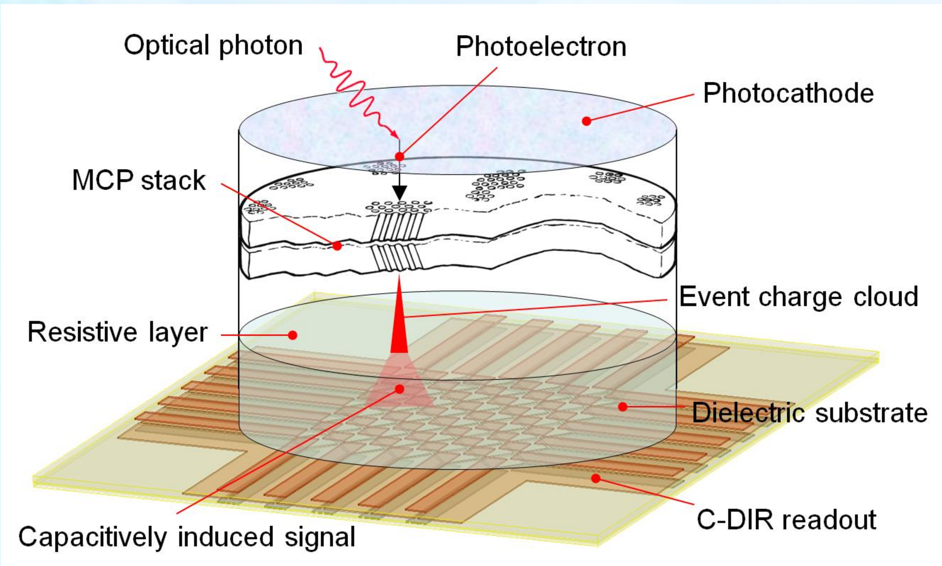
- Charge localised on a resistive layer
- Charge signal capacitively induced onto C-DIR readout
- Signal divided among corner nodes

**Advantages:**

- Simplicity – prototyping PCB
- Small capacitive load – low noise
- Capacitive – high speed
- Excellent spatial and temporal resolution – broad performance envelope

**Disadvantages**

- Non-linearity - correctable

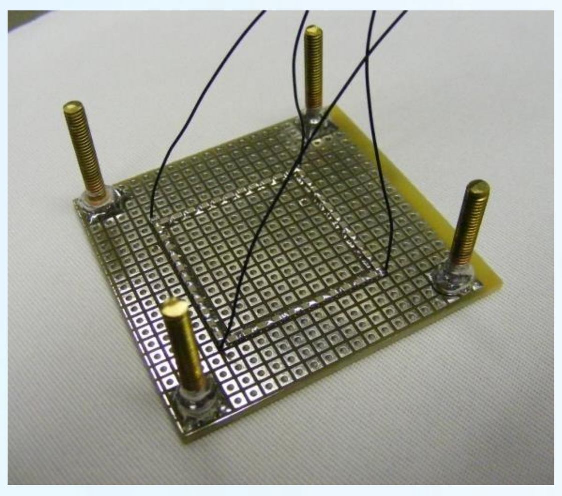



Schematic of MCP detector using C-DIR

## 3 Implementation

Prototype C-DIR

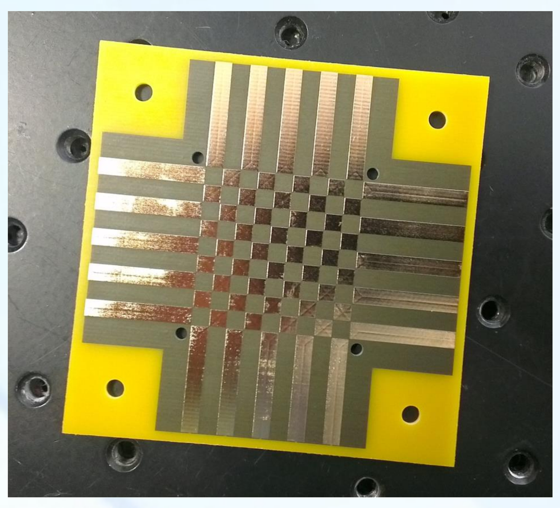
- C-DIR was prototyped using solderable prototyping breadboard
- 2.54 mm pitch double sided square pads linked with through-hole vias
- Active readout area of 25 x 25 mm$^2$
- Increased perimeter capacitance using surface mount capacitors
- The wires identify the readout nodes



C-DIR device using prototyping breadboard

Optimised C-DIR

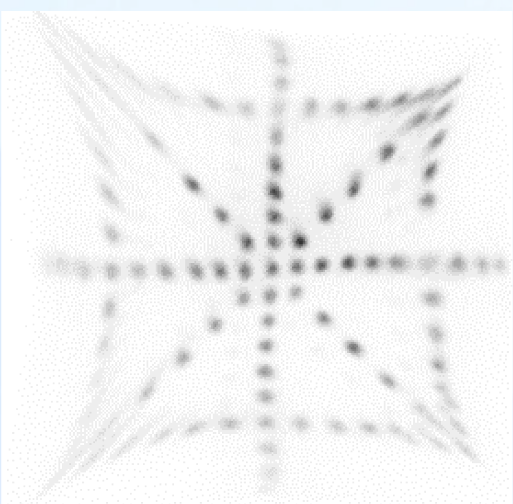
- 2-layer C-DIR with larger edge electrodes to produce larger perimeter capacitance
- Optimised for linearity
- 25 mm$^2$ active area visible as the checkerboard patterned area
- Three layers of isolated conductors separated by thin insulator



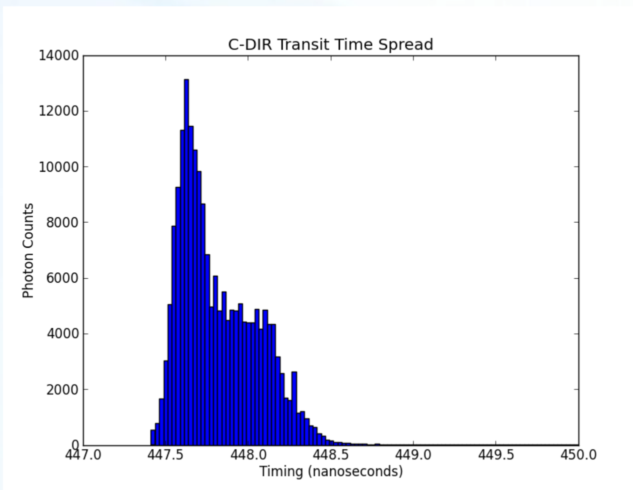
Optimised C-DIR with improved linearity

## 4 Temporal resolution

- C-DIR is a purely capacitive readout technique – it's very fast
- MCP-limited time resolution possible
- Simultaneous imaging and picosecond timing can be achieved
- So far demonstrated using NINO amplifier/discriminator + HPTDC
- Charge amplitude for centroiding obtained from time-over-threshold



A test mask image of 0.5 mm holes at 1mm pitch. Distortion is caused by the NINO input impedance

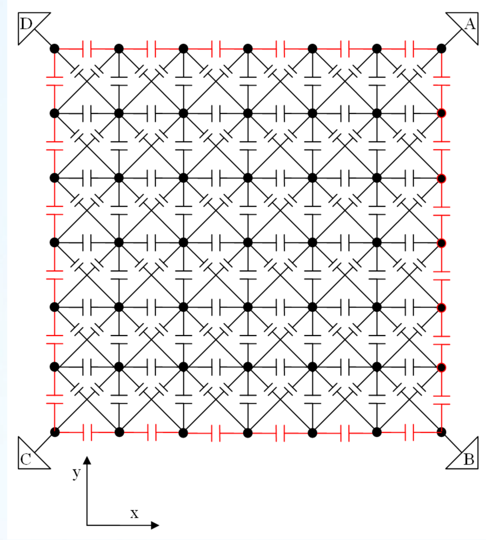



The event timing resolution from the C-DIR detector with a FWHM of ~200 ps with a broad, low amplitude shoulder

## 5 Spatial resolution

Major noise sources limiting resolution:

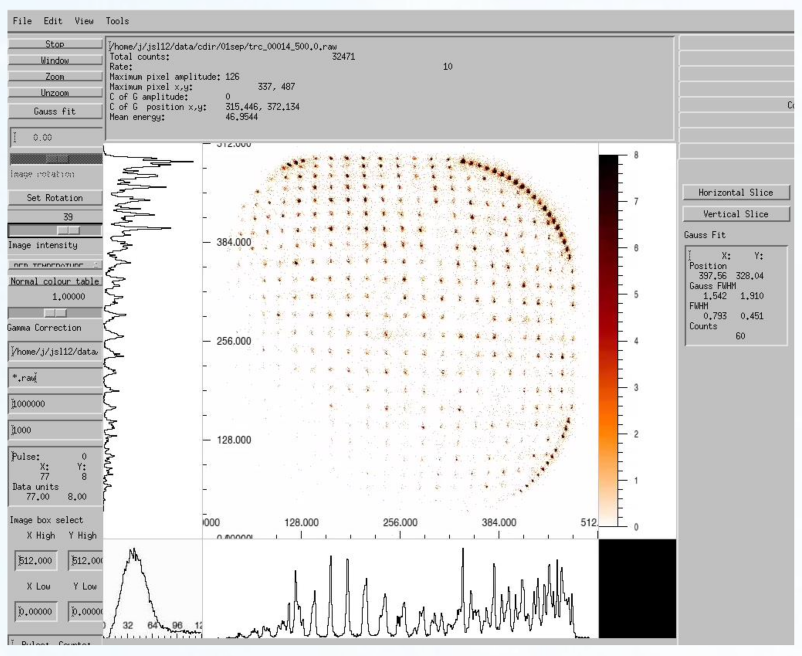
- Electronic noise – dominated by readout capacitance
  - C-DIR typically 10-20 pF
- Partition noise – Poisson statistics of quantised charge collection
  - Not present with induced charge technique used in C-DIR
- Charge centroid error – statistical uncertainty in charge centroid
  - Very small – scales as
  - footprint size and √Q
- Waveform capture + digital filtering → flexible analysis
- Spatial resolution/throughput performance envelope using the same raw data



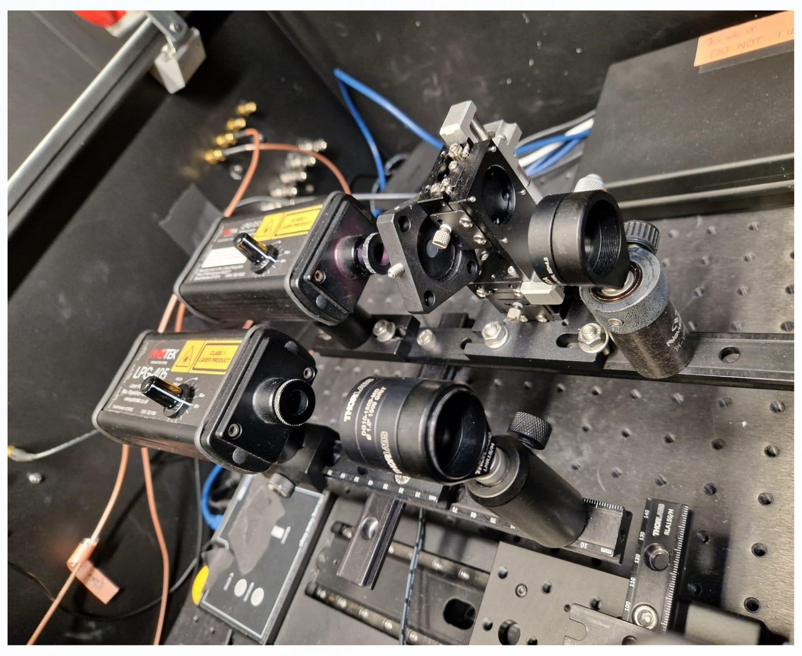
A schematic of the C-DIR capacitive network showing the readout nodes

## 6 Measurements

- C-DIR close coupled to Amptek A250 to minimize input capacitance
- A250s have very low noise ~500 electrons FWHM with C-DIR
- A pinhole mask was illuminated with a 405 nm pulsed laser via a diffuser
- The mask has 50 µm pinholes at 1 mm pitch in the centre, and 100 µm pinholes in arc
- The mask was held against the input window – no allowance for parallax or diffraction made

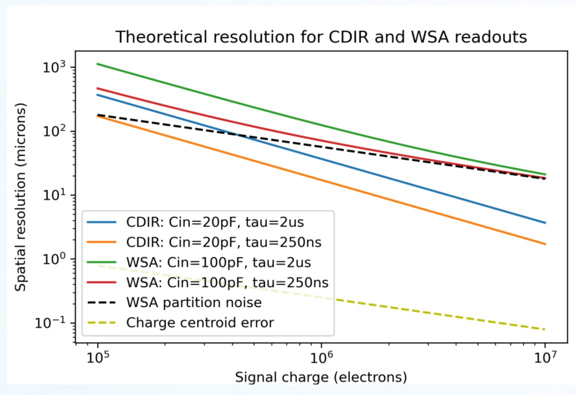


Sample of image data analysed. The missing area is due to a compromised photocathode

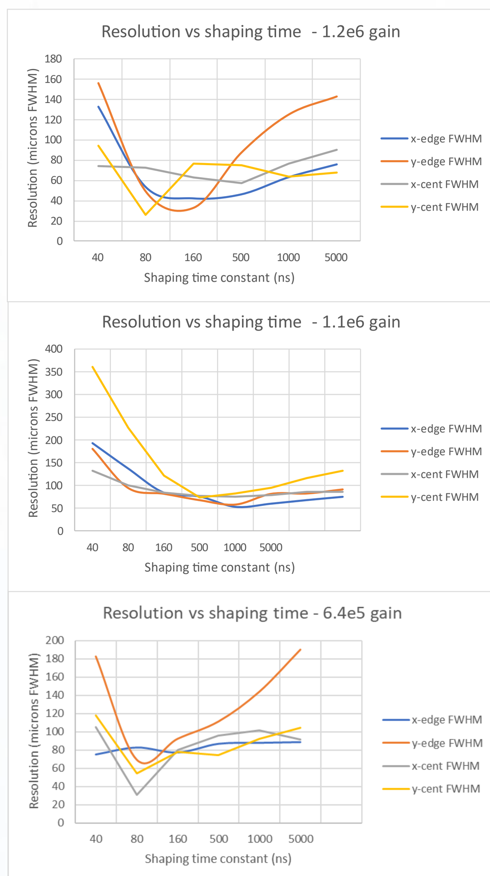


The illumination setup with 2 lasers: one with spatial filter for spot projection and one for mask illumination

- C-Dir waveforms captured on LeCroy 2GSa./s 12–bit 'scope
- Waveform sequenced saved to PC and digitally filtered with Semi-Gaussian filter using scipy in python
- Shaping times: 10, 20, 40 ,80, 160, 500, 1000, and 5000 ns
- Four peak heights were determined per event
- Pinhole FWHM data was analysed for pinholes at the centre and edge of the imaging area – see data right
- These are the first preliminary results optimised with a close-coupled low noise preamplifier but are a good match to theory

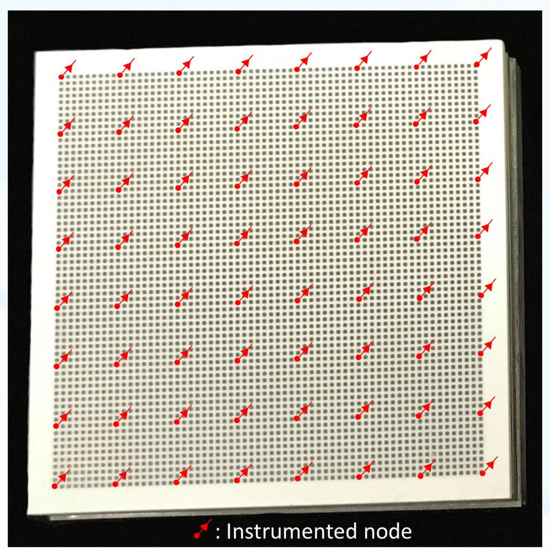



Theoretical comparison of resolution of C-DIR and WSA using Amptek 250 noise




Pinhole mask analysis

## 7 Further work




An existing 4096 pixel MCP detector readout developed by Photek Ltd.

- Optimise spatial resolution and timing in large readout arrays – SEE
- 4096 pixel array (right) instrumented every 9 pixels
  - passive pixels provide capacitive charge sharing network
- Instrument using multichannel ASICs:
  - SAMPIC waveform digitizer
  - TOFPET ASIC – using ToT
- See Amelia Markfort poster this session – "Can machine learning reduce the number of anode readouts .."

## 8 Acknowledgements

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