PImMS
a fast event-triggered pixel detector with storage of multiple timestamps

Mark Brouard, Ewen Campbell, Edward Halford, Alex Johnsen, Jason Lee, Craig Slater, Claire Vallance, Edward Wilman, Benjamin Winter, Weihao Yuen
Chemistry, University of Oxford

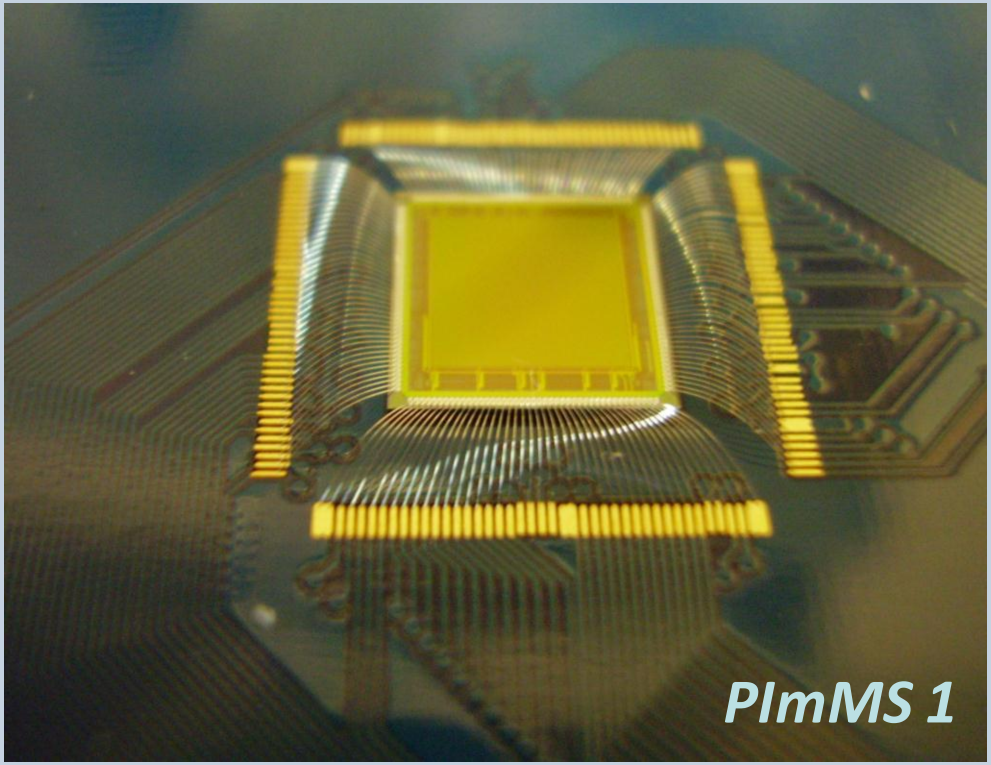
Iris Friedli, Laura Hill, Jaya John John, Andrei Nomerotski, Robert Pisarczyk
Physics, University of Oxford

Andy Clark, Jamie Crooks, Iain Sedgwick, Renato Turchetta
STFC Rutherford Appleton Laboratory

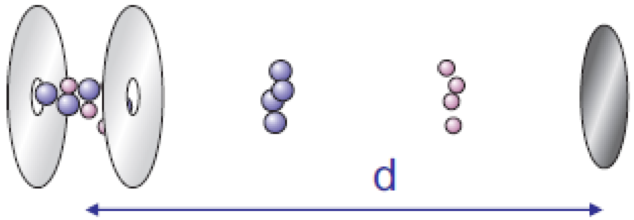
14 September 2011 - PSD9, Aberystwyth

Outline

- PImMS: Pixel Imaging Mass Spectrometry
- PImMS1 sensor
  - Context / requirements
  - Design
  - Initial results
- Future directions

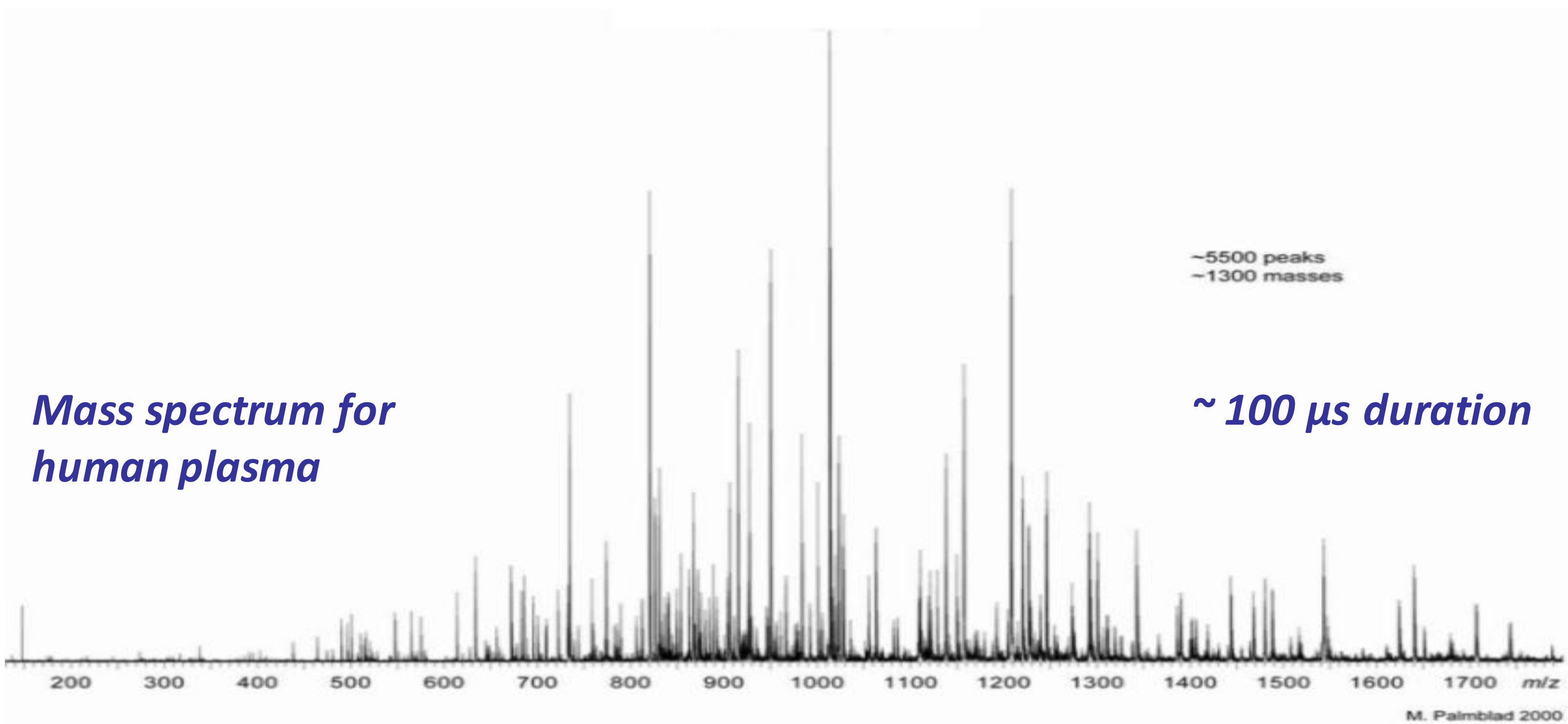


Context: time of flight mass spectrometry



$$E = zV = \frac{1}{2}mv^2$$

$$t = d / v \propto (m/z)^{1/2}$$

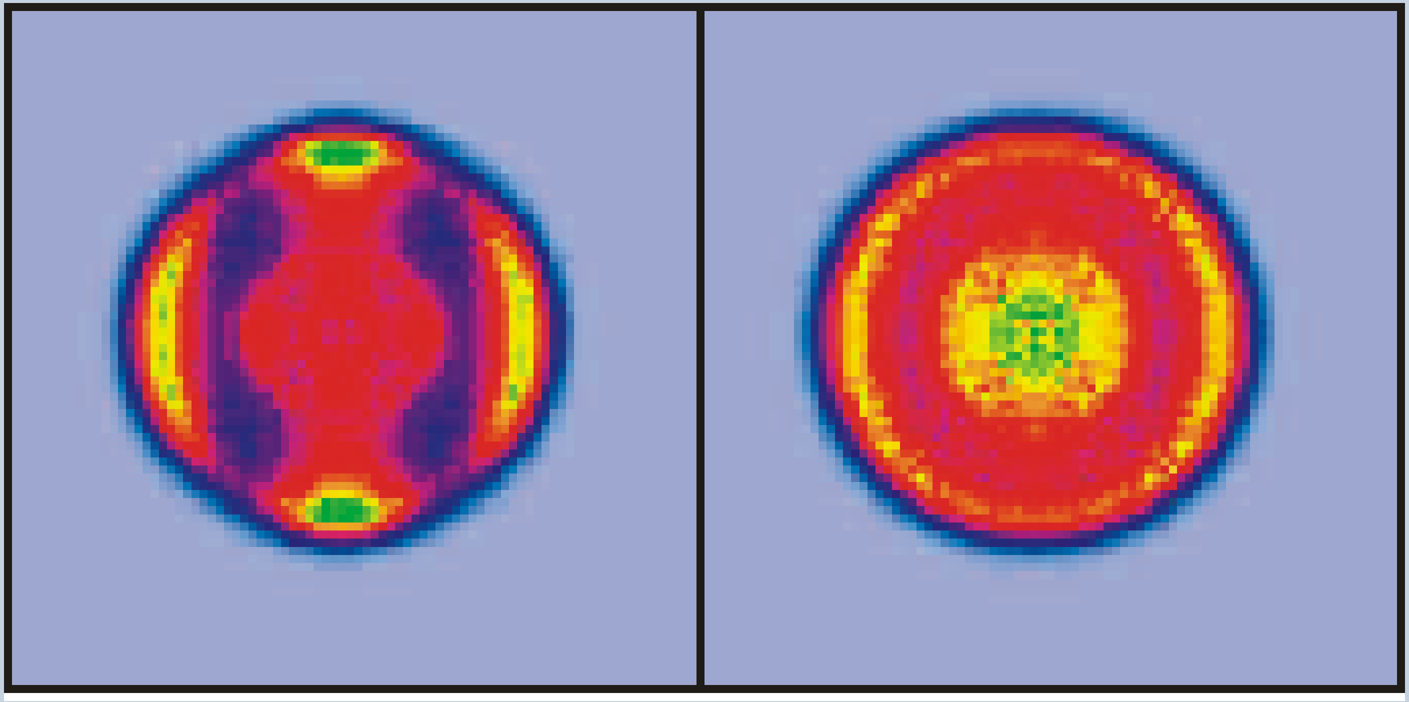


Mass spectrum for human plasma

~ 100 µs duration

Context: ion imaging

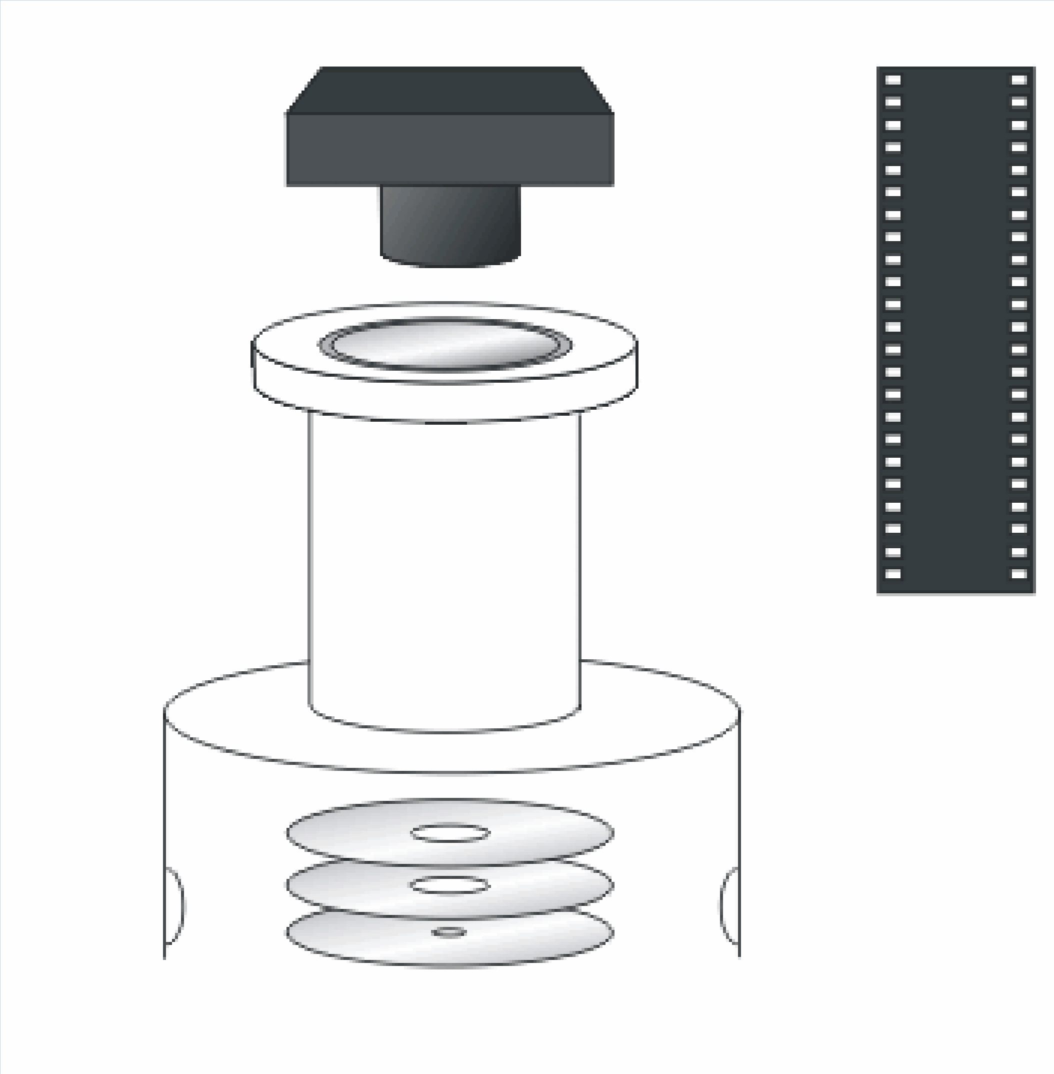
- Use a position sensitive detector to obtain x-y distributions – learn about reaction dynamics
- Need to tune the timing to select one ion



S atom ion images for OCS photodissociation at 248nm

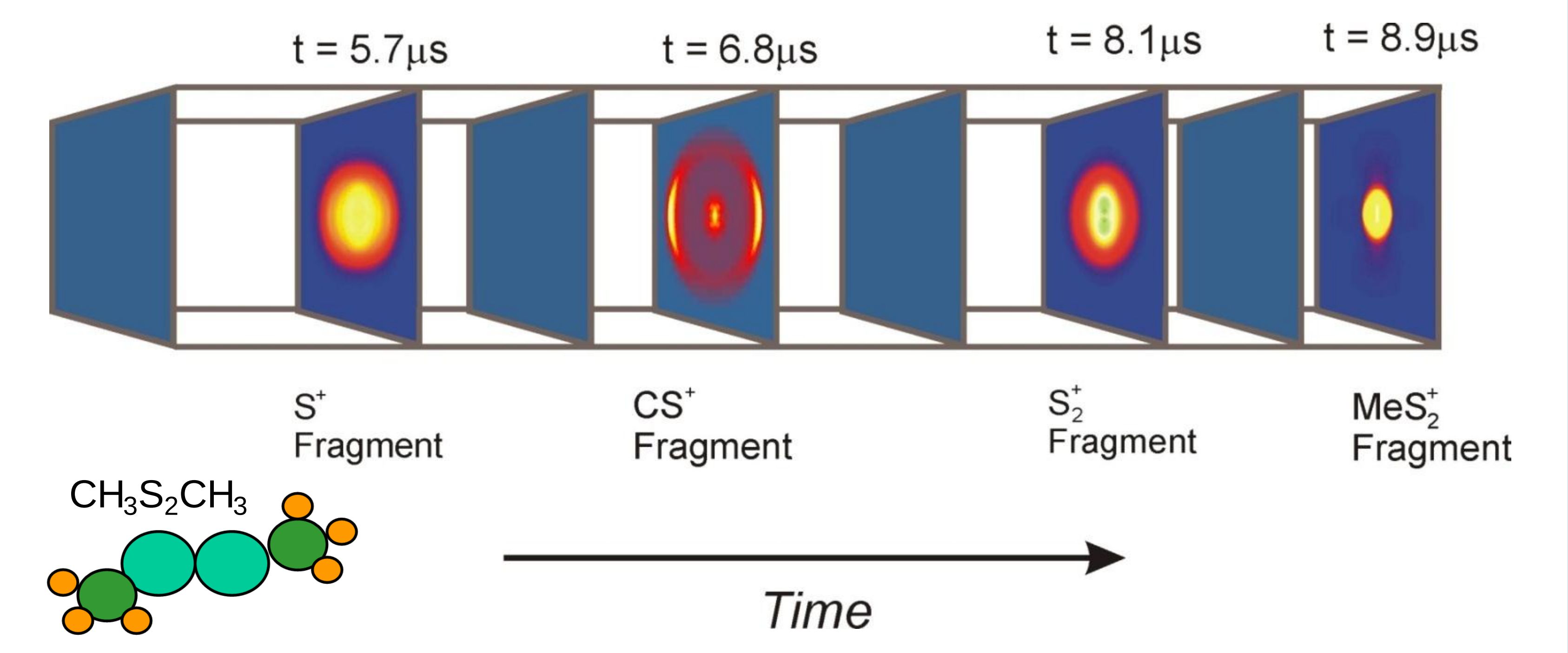
Pixel Imaging Mass Spectrometry

- Combines time of flight MS with 2D ion imaging
- Takes advantage of recent advances in silicon to image multiple ions in one cycle



Initial proof of concept

- Proof of concept experiments with a fast framing camera (Dalsa CCD) in 2007-8 for dimethyldisulfide

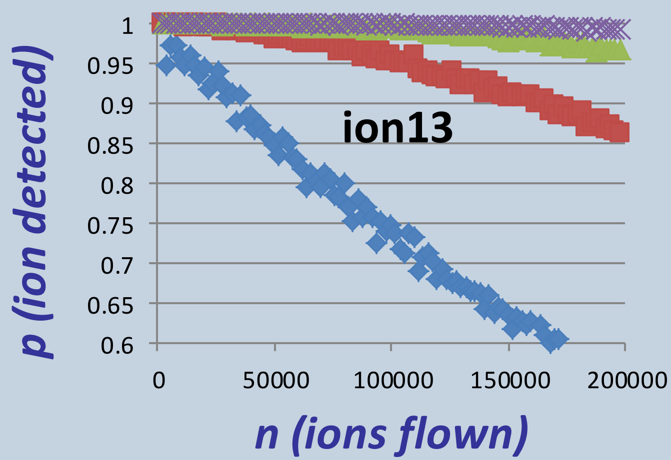


- Required prior knowledge of timing of mass peaks

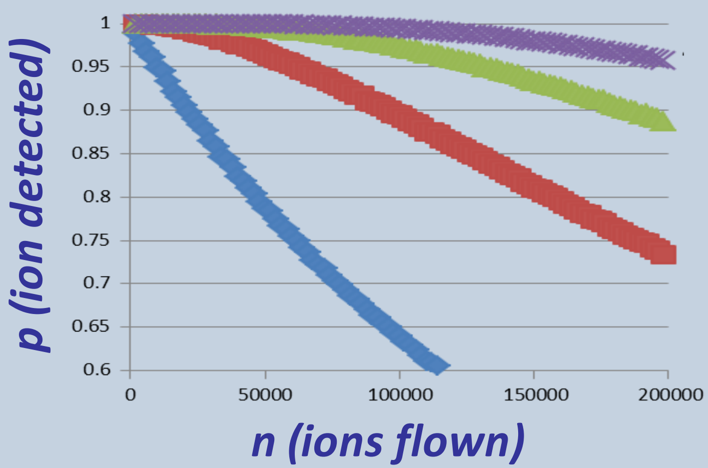
M. Brouard, E.K. Campbell, A.J. Johnsen, C. Vallance, W.H. Yuen, and A. Nomerotski, *Rev. Sci. Instrum.* 79, 123115, (2008)

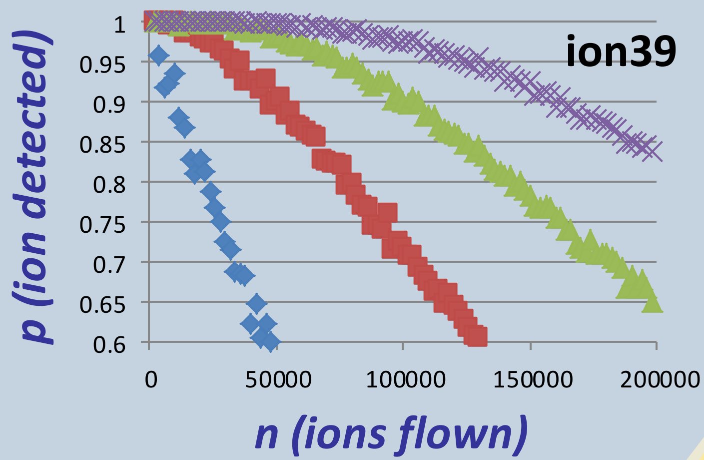
Towards sensor requirements

- Want a fast sensor, flexible to analyse any mass spectrum
- Sparse events → consider time-stamping approach
- To record both early and late ions, need multiple memories. How many? Simulate:



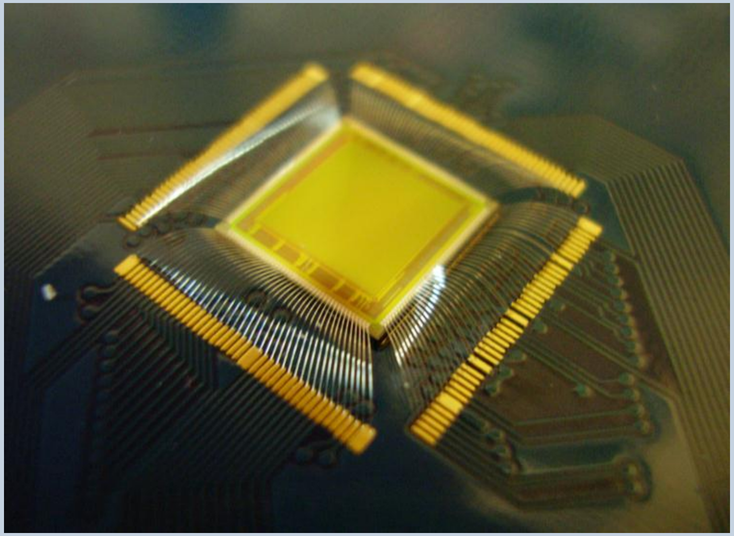
all 40 ions simulated





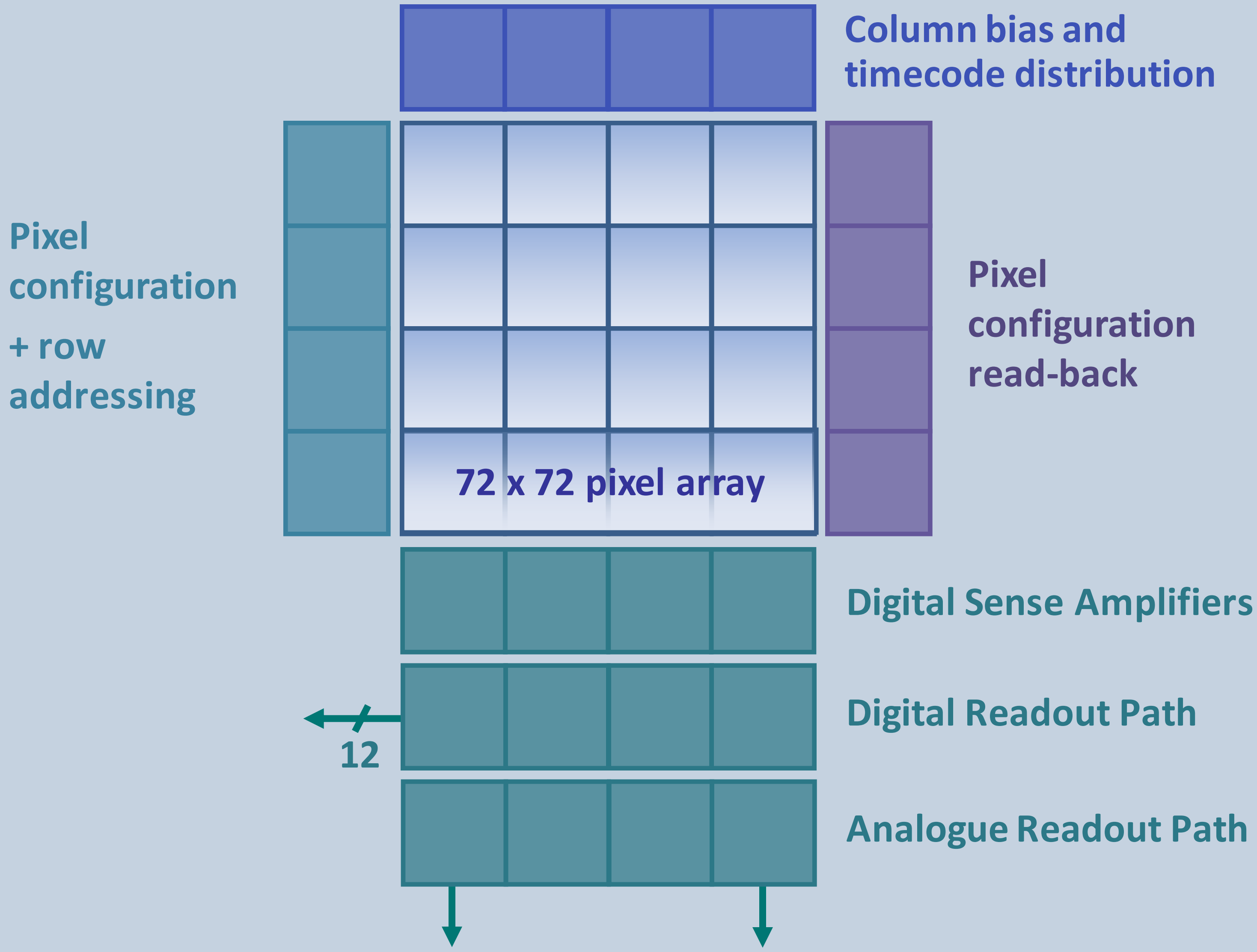
PImMS1 sensor: specifications

- 72 by 72 pixel array
- 70 µm by 70 µm pixel
- 5 mm x 5 mm active area
- < 50 ns timing resolution
- 12 bit time stamp storage
- 4 memories per pixel
- adjustable experimental period, up to ~1ms
- programmable threshold and trim – 4 bits per pixel
- one test pixel with access to intermediate analogue points



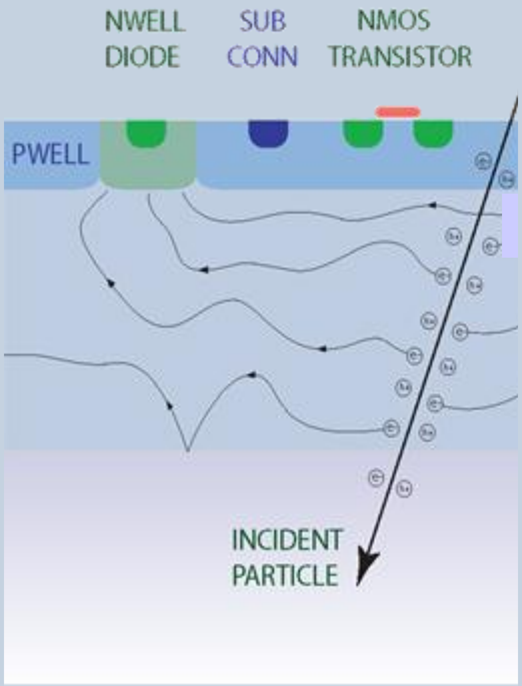
PImMS 1

Overview of the sensor



PImMS1 sensor: technology

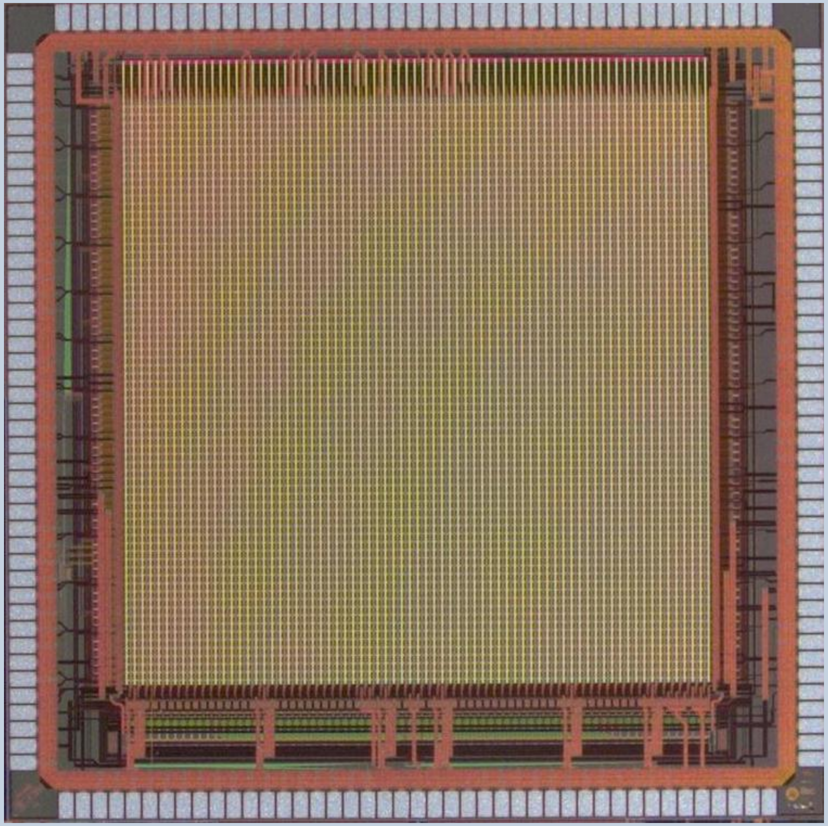
- Light is detected in the thin epitaxial layer, < 20µm
- With only NMOS transistors, obtain limited functionality
- PMOS transistors would compete for charge



- INMAPS process developed at RAL
  - Isolated N-well Monolithic Active Pixel Sensors – p+ shield
  - **Gain full CMOS capabilities**

PImMS1 sensor: technology

- 0.18µm CMOS fabrication
- INMAPS process
- 615 transistors per pixel
- over 3 million transistors in all

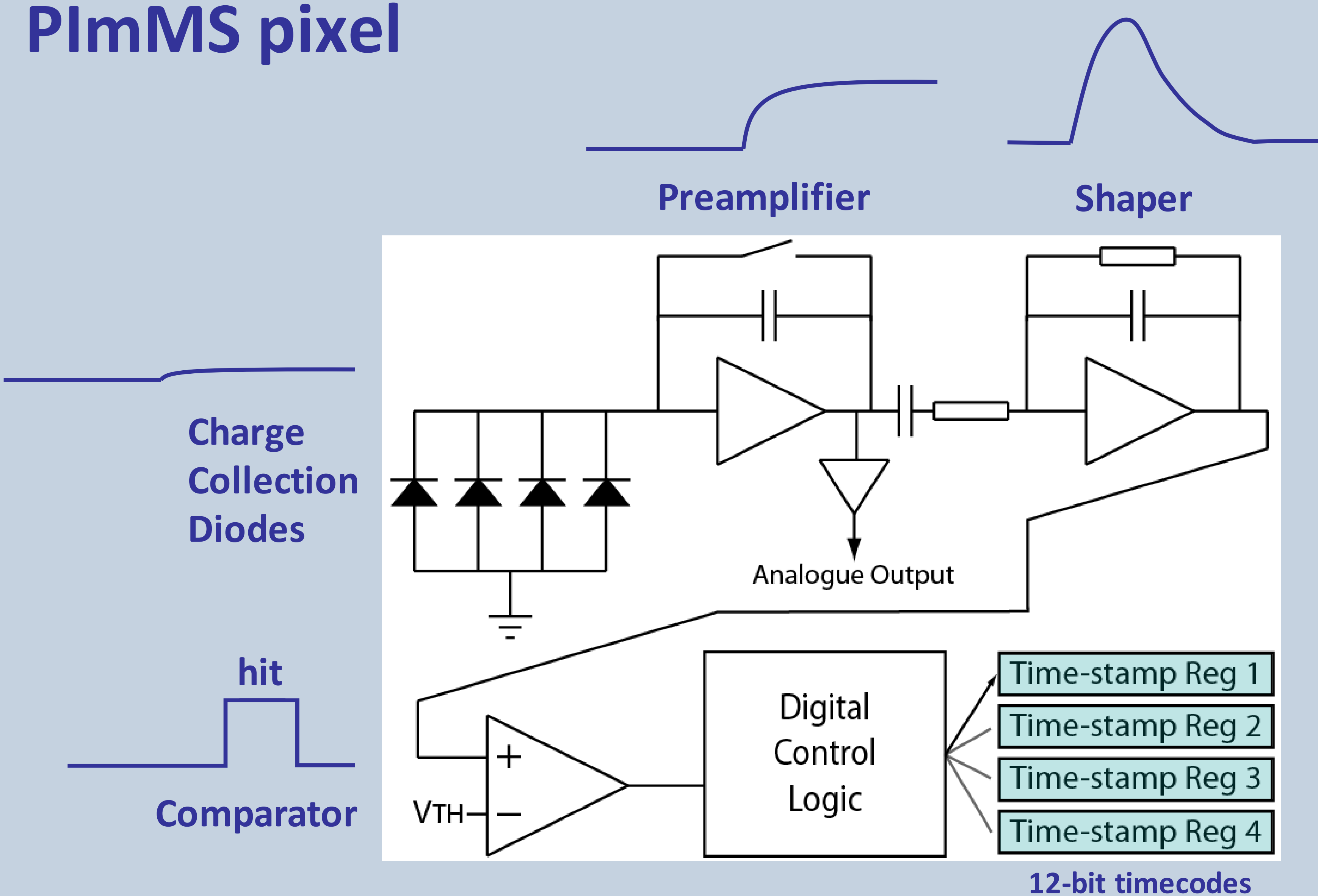


7.2 mm

Sensor design:

Andy Clark and Jamie Crooks,
STFC Rutherford Appleton Laboratory

PImMS pixel


Preamplifier
Shaper
Charge
Collection
Diodes
Analogue Output
hit
Comparator
VTH
+
−
Digital
Control
Logic
Time-stamp Reg 1
Time-stamp Reg 2
Time-stamp Reg 3
Time-stamp Reg 4
12-bit timecodes

Pixel operation

diode

preamplifier

shaper

comparator inputs

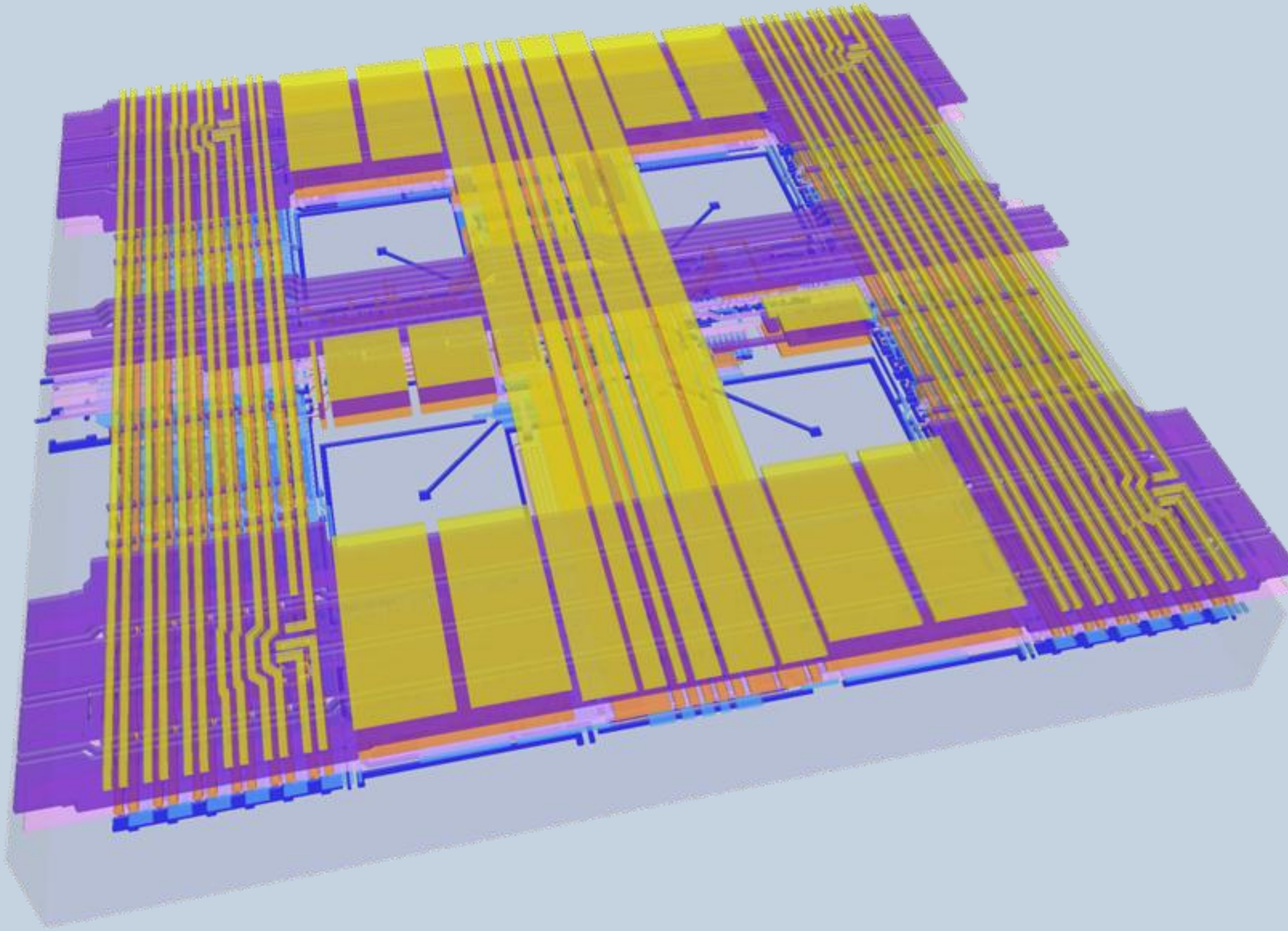
hit indicator

timecode

memory 1

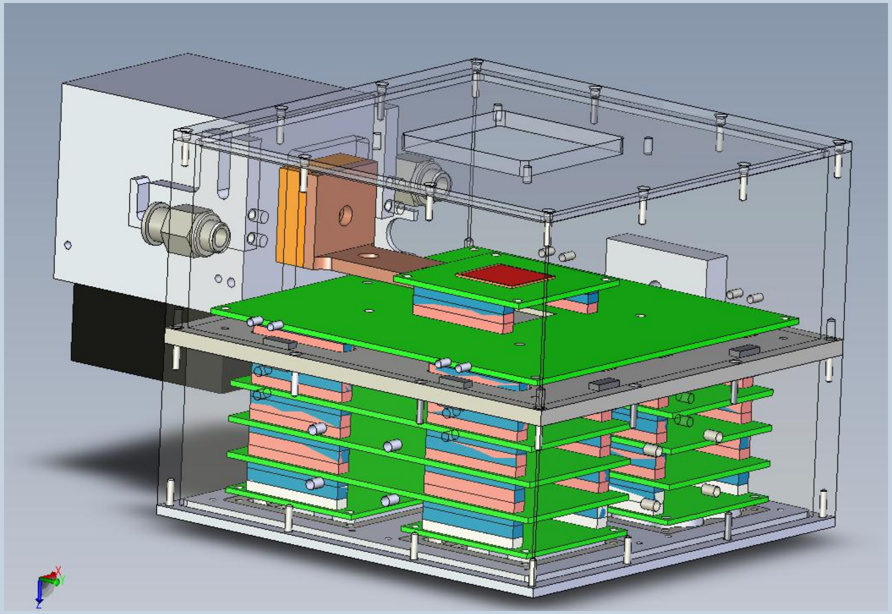
memory 2

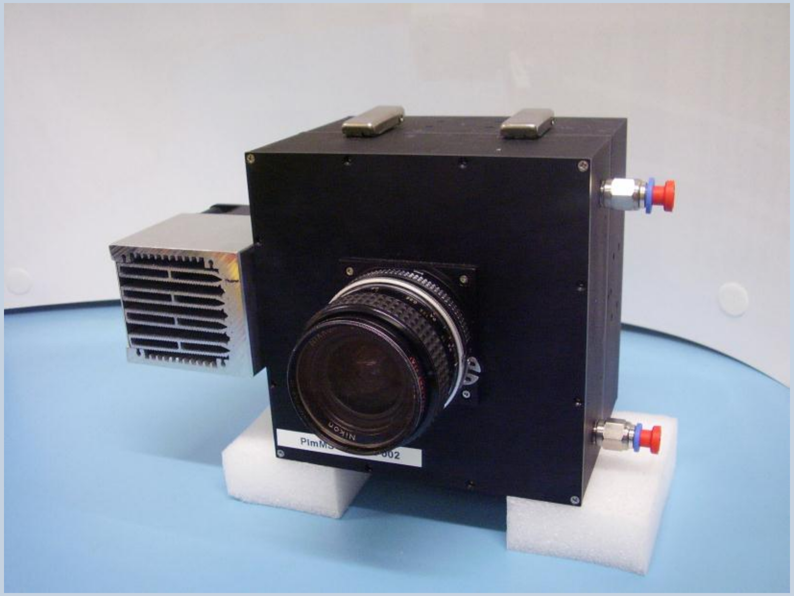
Pixel layout



Readout: camera

- USB control and readout
- F-mount SLR lens



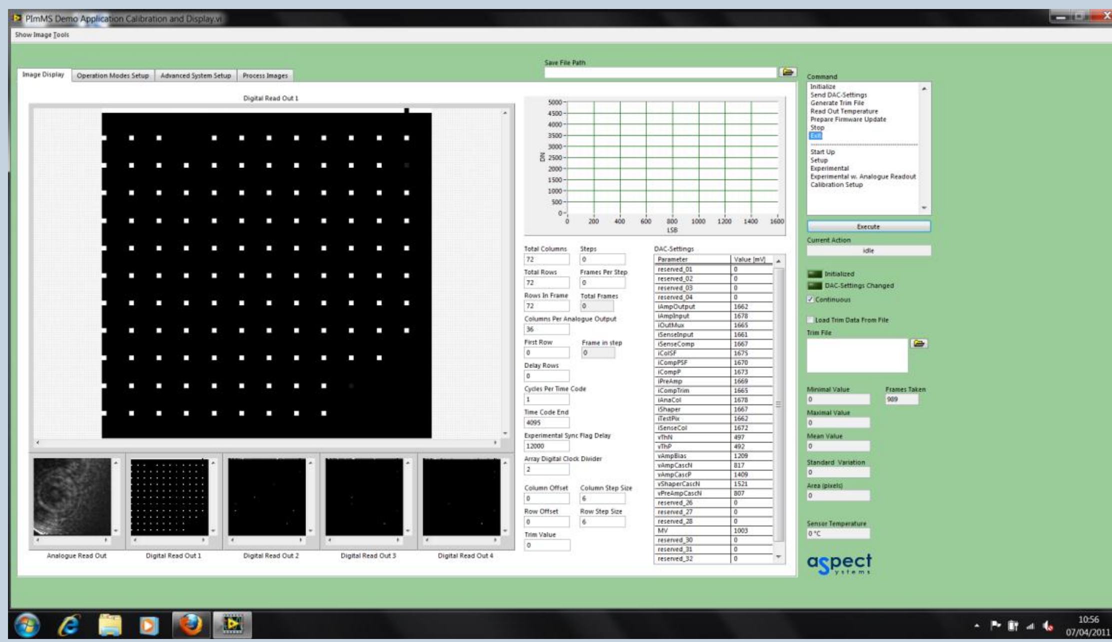


- Cooling system
- Option for nitrogen/dry air

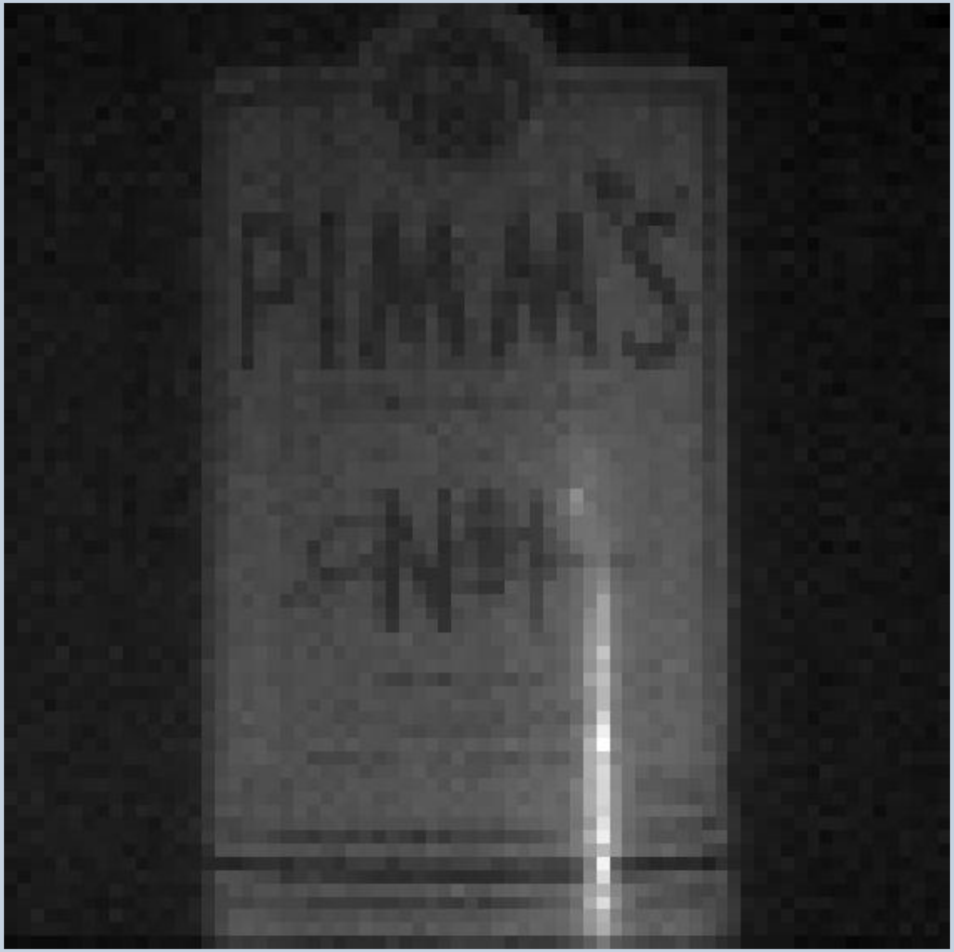
Readout: software

- The camera is controlled and read out by bespoke LabView software.
- Data can be saved to disk for offline analysis.
- A growing library of online and offline visualisation tools is available.

Software design:
Jason Lee,
Oxford Chemistry



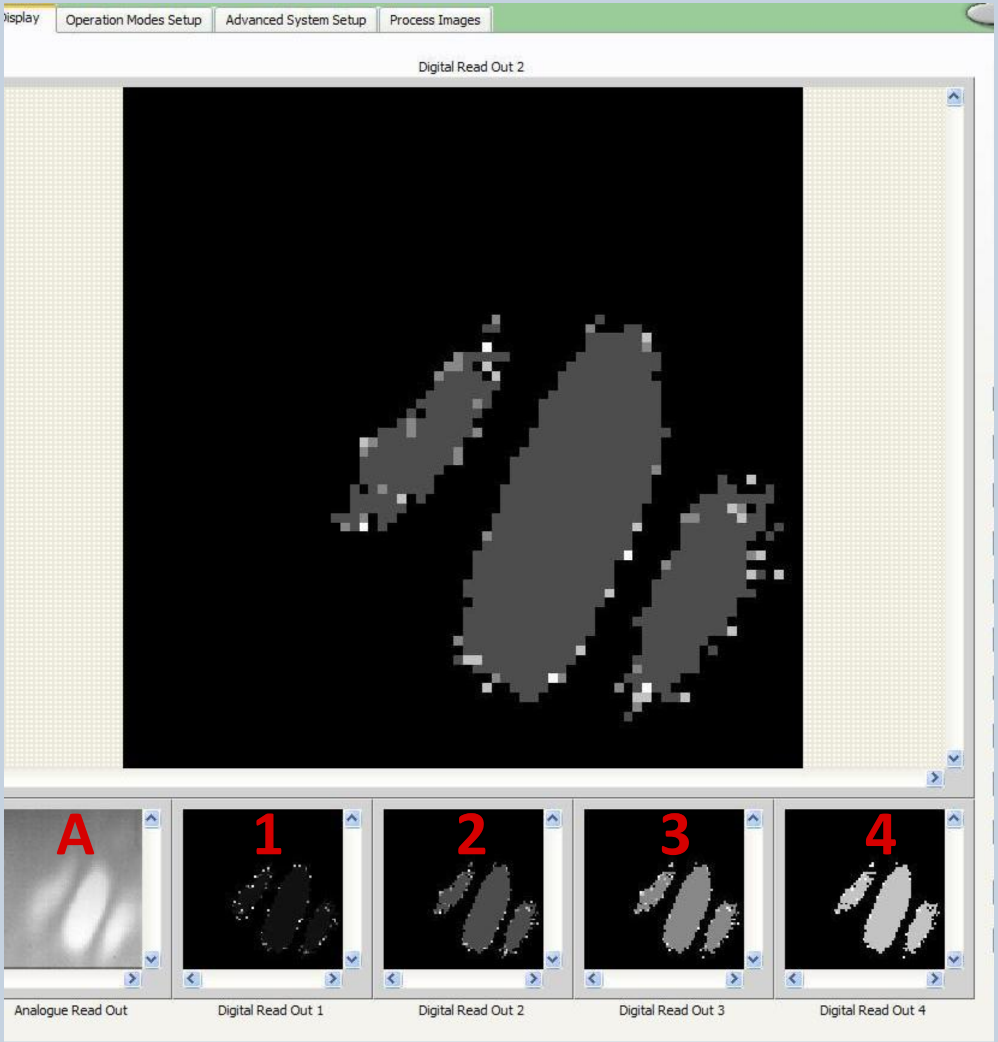
Analogue readout



- Corresponds to the output of the pre-amplifier
- Represents the total charge stored in each pixel, cumulative for all hits during a given experiment
- Mainly used for focusing an optical lens onto the phosphor screen

Digital readout – multiple hits

5 laser hits, 30μs apart



A = analogue image, integrated over all hits

1 = 1st memory

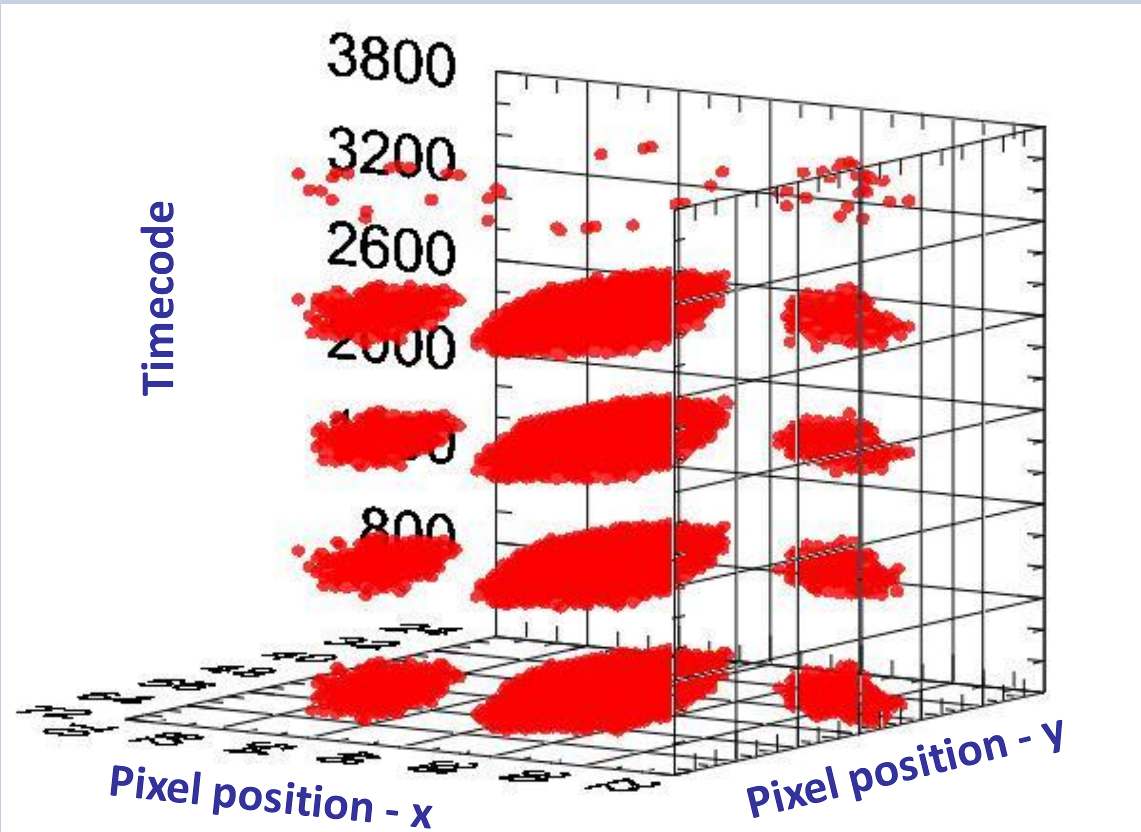
2 = 2nd memory

3 = 3rd memory

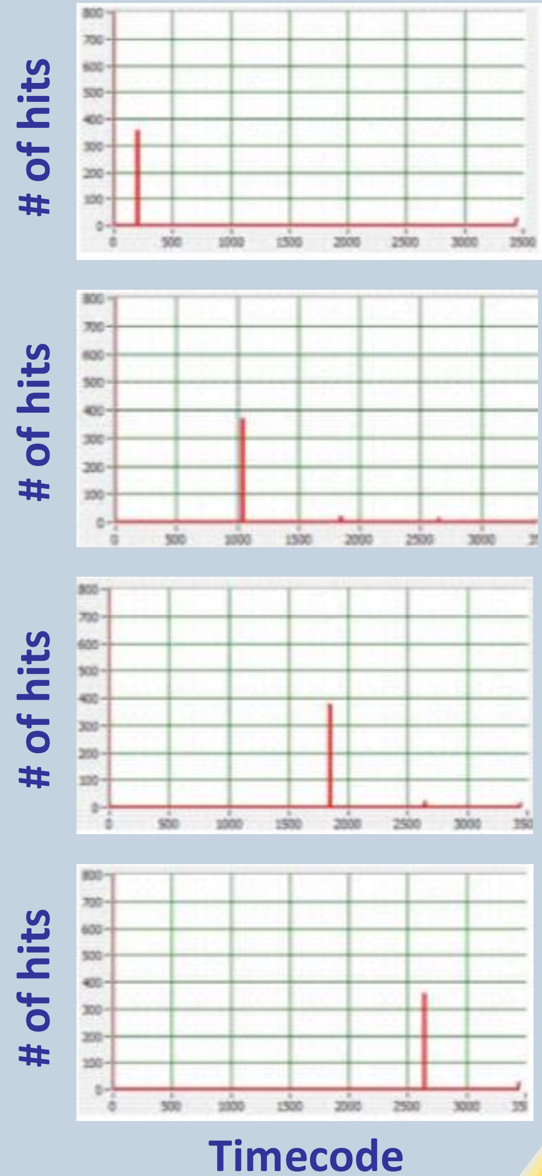
4 = 4th memory

Digital readout – 3D visualisation

- 5 laser pulses, 25ns long, at 405nm
- 40µs apart = 800 timecodes (50ns/timecode)



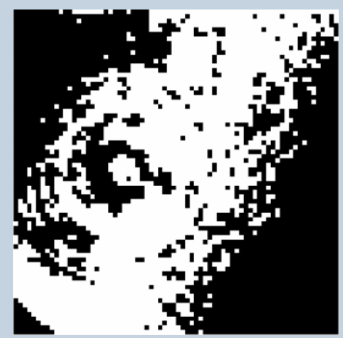
1st four pulses:



Threshold

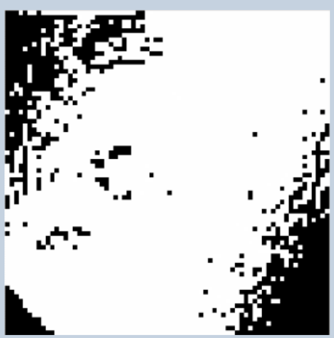
- The threshold for experiments is set by two adjustable analogue voltages (generated on the camera)
- This shows the spot produced by a defocused class 1 laser at increasing threshold levels.

400 mV

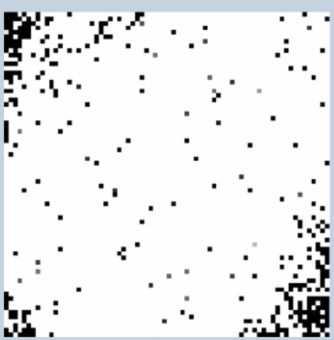


200 mV

100 mV



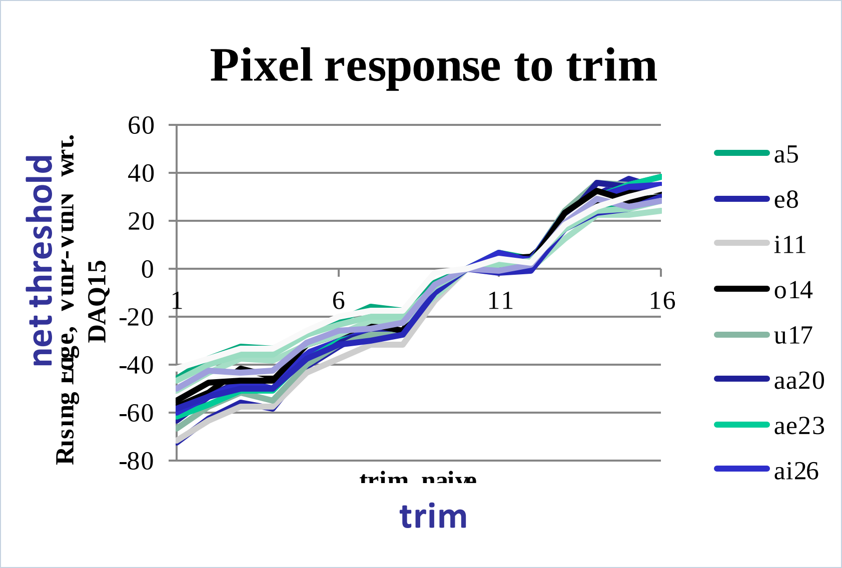
55 mV

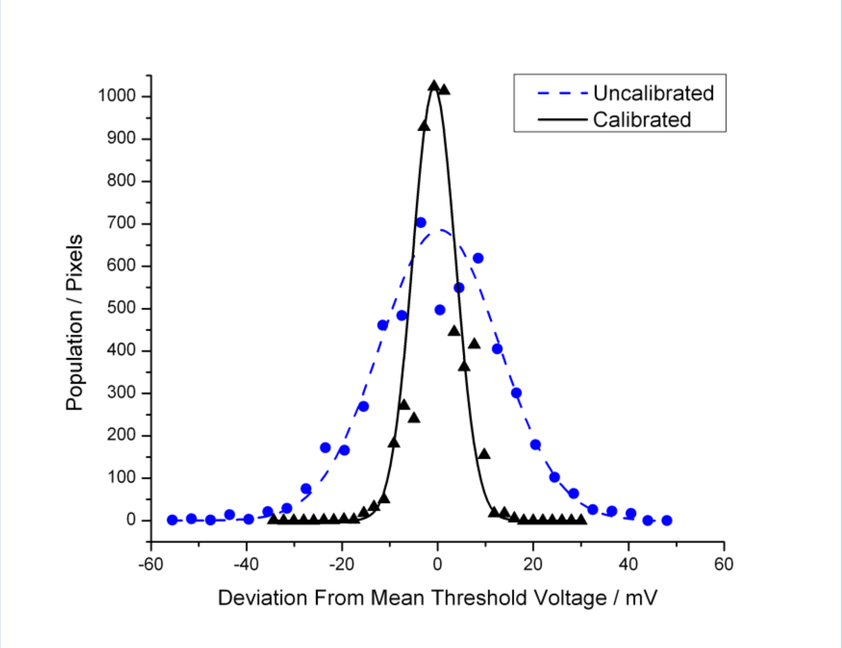


0.1 mV

Sensor calibration

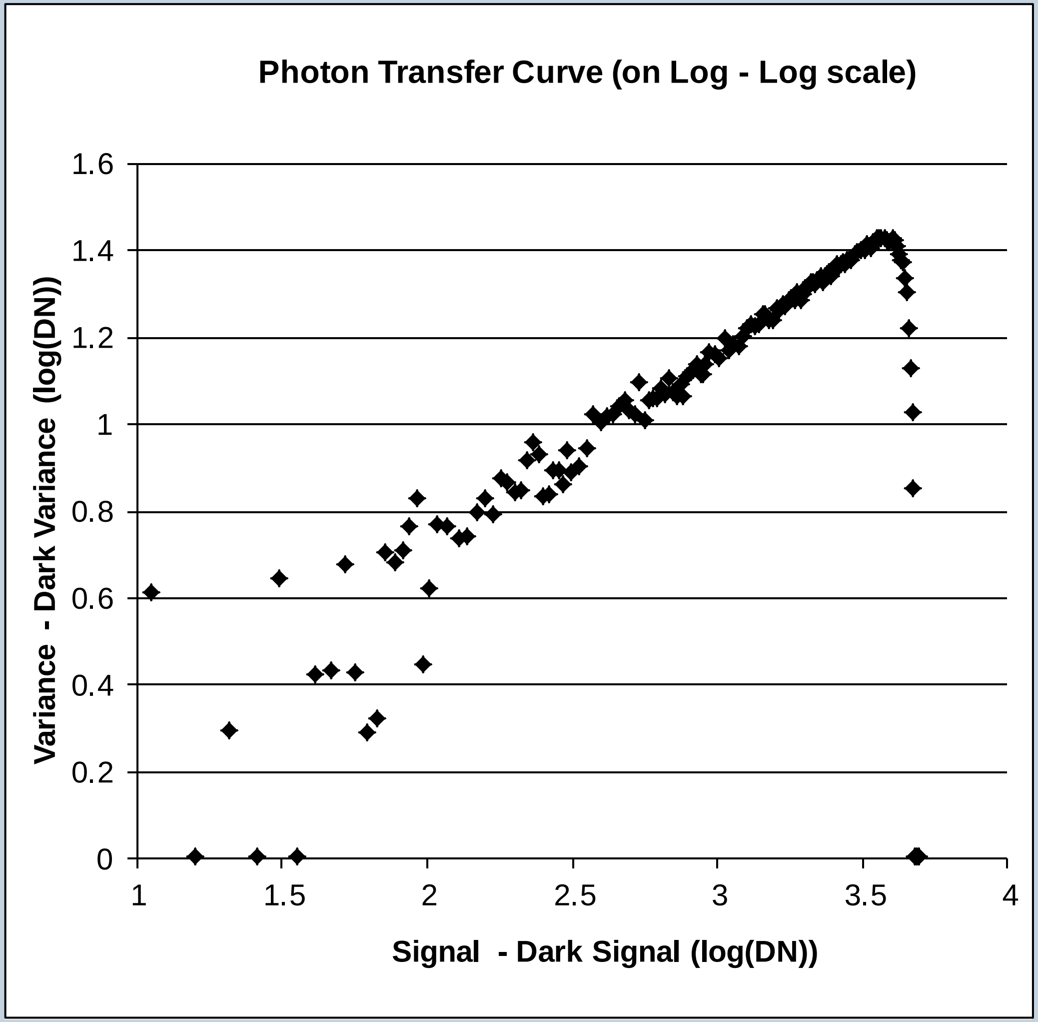
- Each pixel has 4 bits of trim and can be masked
- Maximum trim ~50mV
- Dispersion (sigma) before and after calibration: 12.5 -> 4.5 mV (this plot).
- With subsequent improvements to the software, the current dispersion is 2.3 mV.



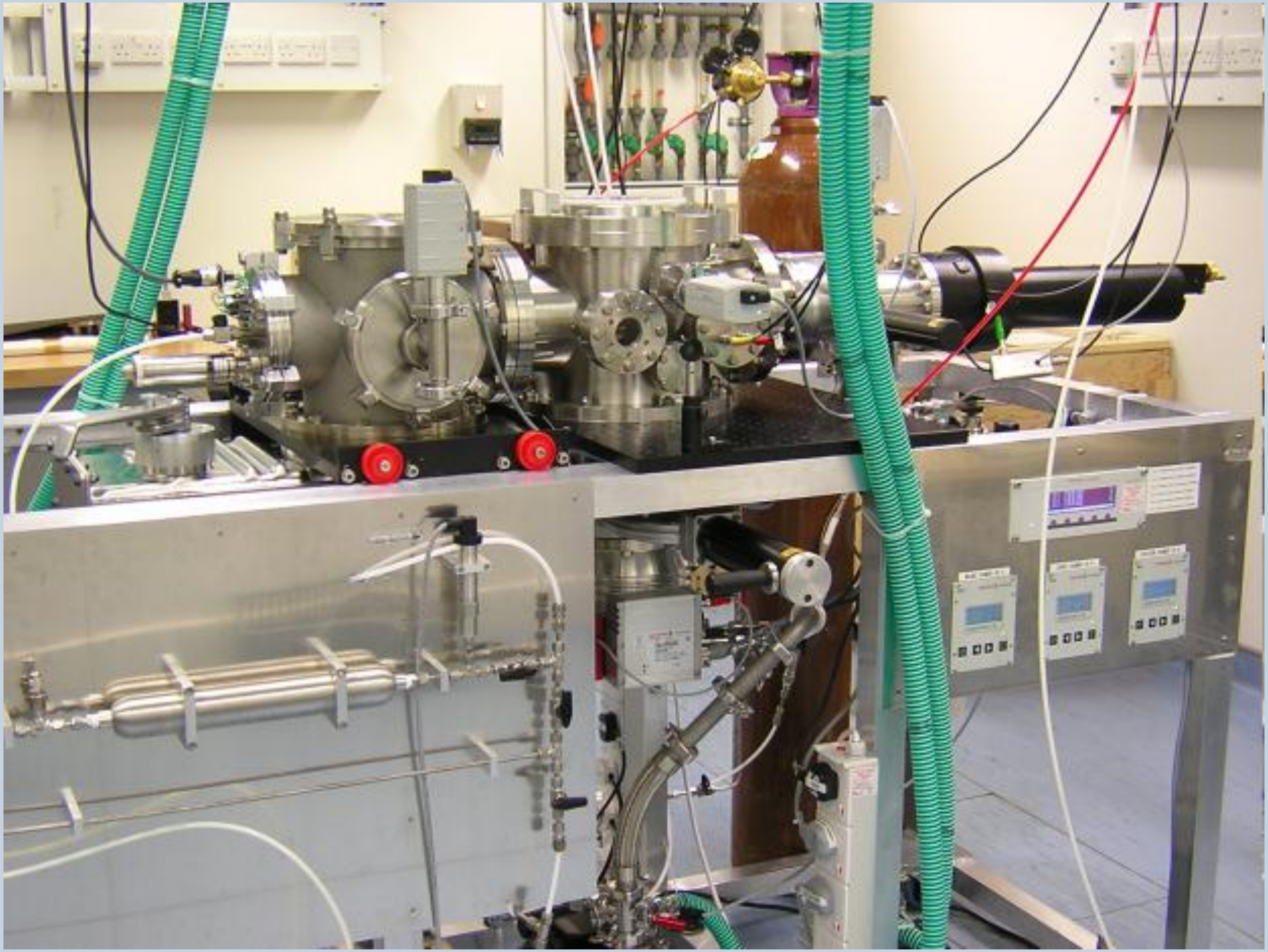


Optical testing

- Quantum efficiency 8-9% for visible light
- Max @ 470 nm
- Fill factor 20% for front illuminated
- Full well capacity 24,000 e-

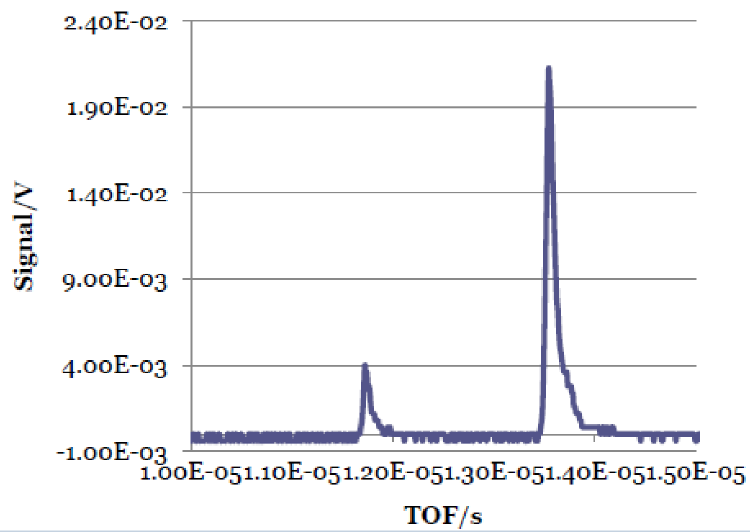


Mass spectrometry rig (Oxford Chemistry)

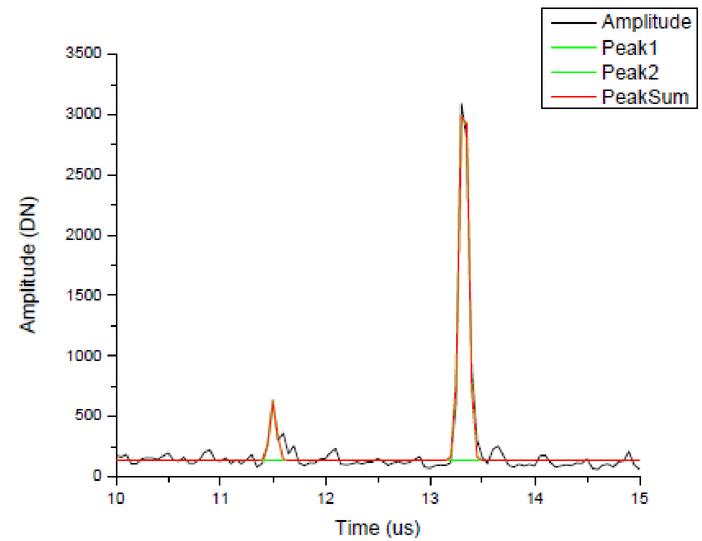


Comparison of PImMS and PMT

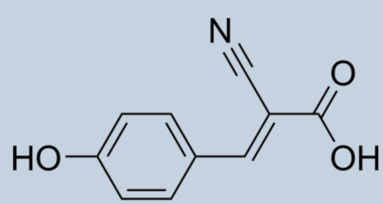
PMT signal



PImMS signal

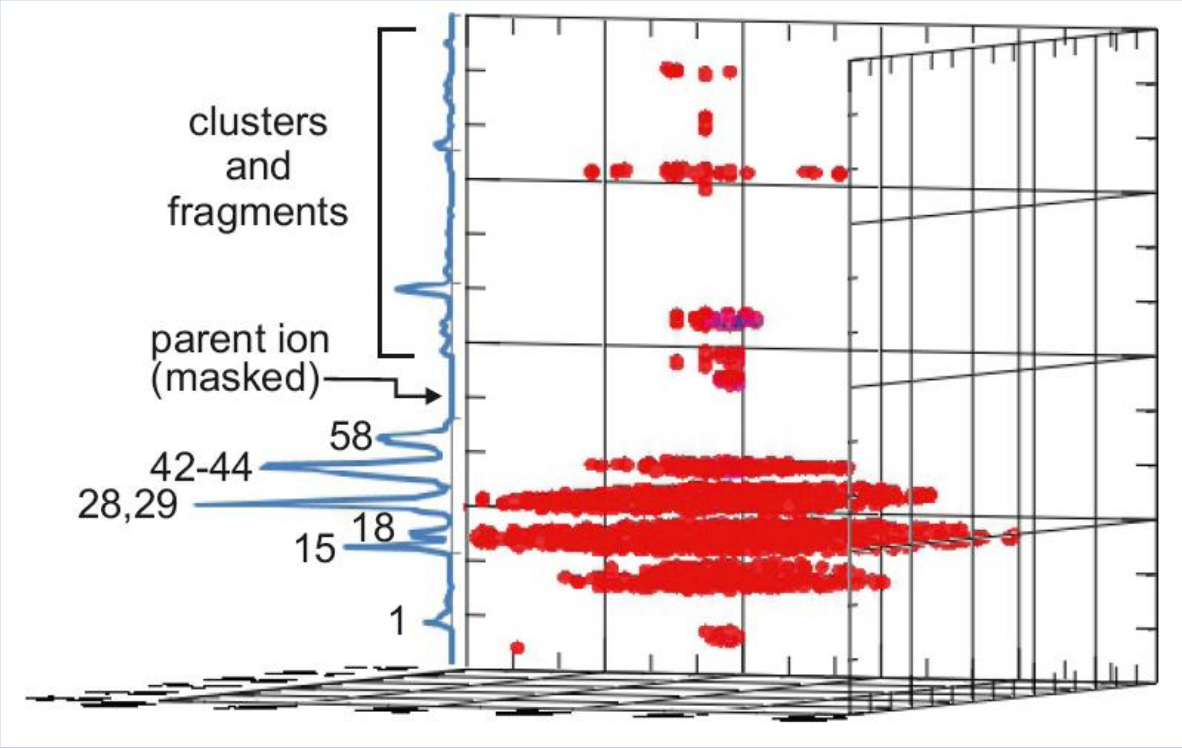


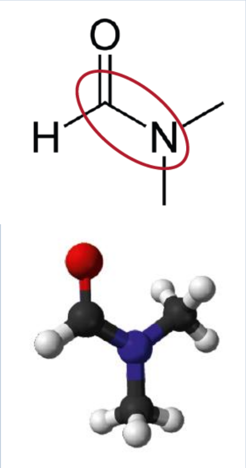
- Same mass peaks seen with PImMS as with a photomultiplier tube (PMT)
- 2 fragments of CHCA



Velocity map imaging

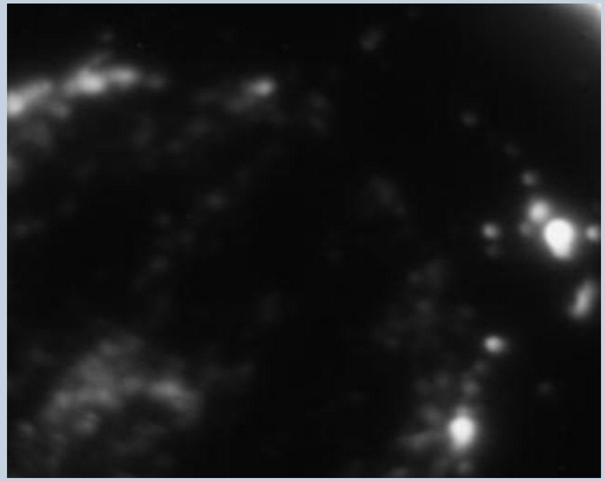
- N,N-dimethylformamide (DMF) is a prototype molecule for studying peptide bond cleavage.
- Early PImMS data on the 193 nm fragmentation of DMF is shown below.

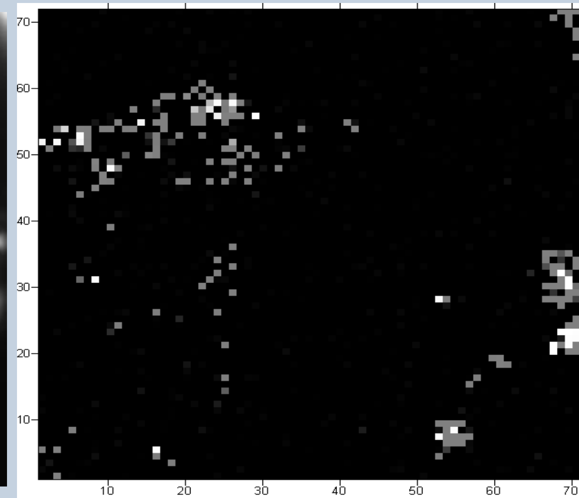


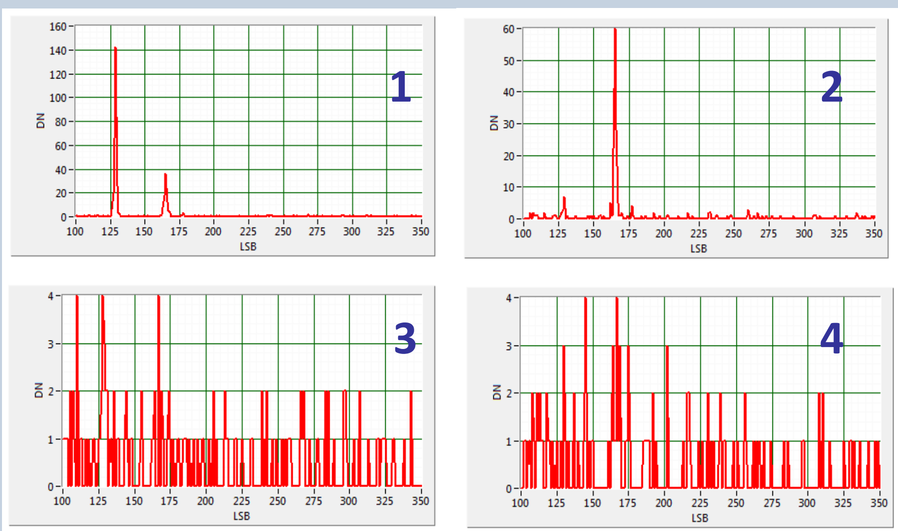


First PImMS spatial imaging results

- Comparison: conventional camera to PImMS





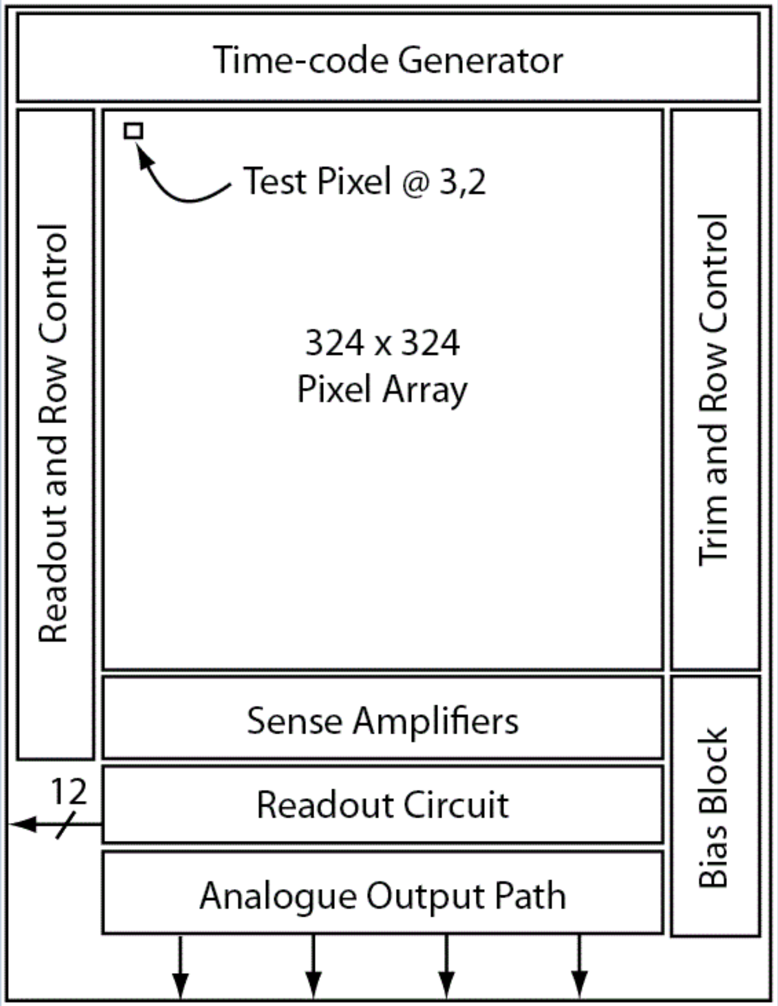


# of hits

timecode

PImMS2

- Larger array: 324 by 324 pixels
- 23 mm by 23 mm active area
- 380 experiments/sec
- Potential 400,000 measurements per experimental cycle
- Designed to also work directly after MCP – reduced pin count for vacuum applications
- Improved power supply, routing and trim
- Submission this autumn, ready by early 2012



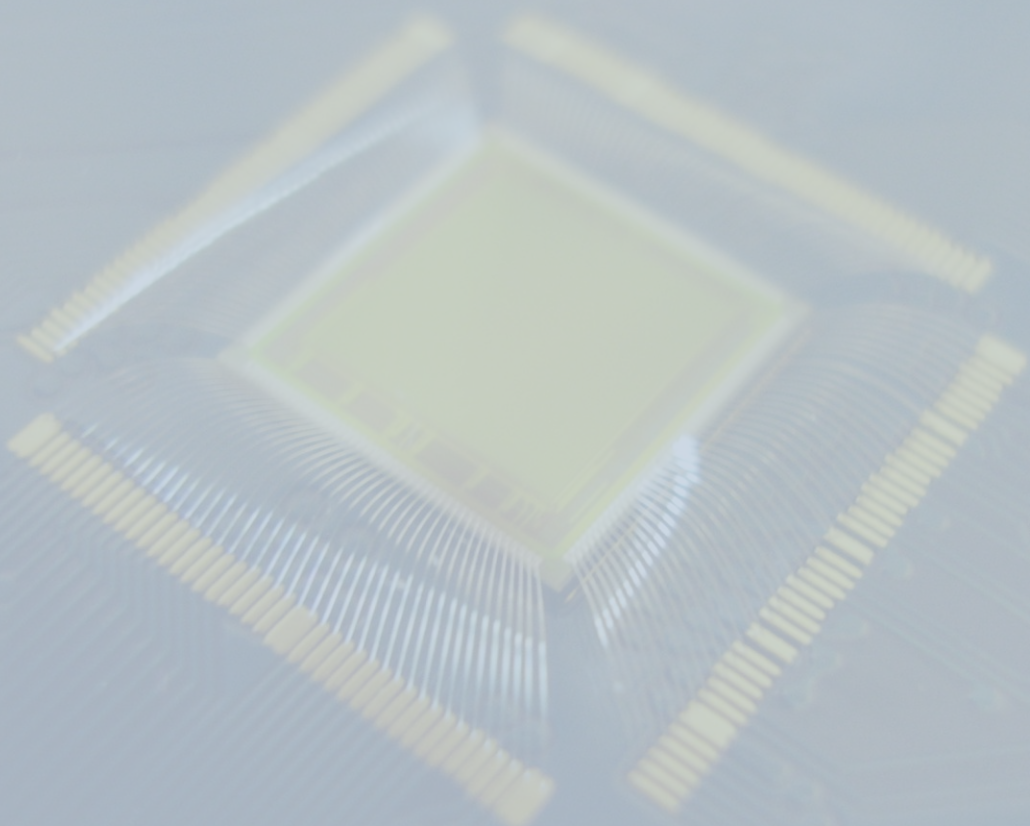
Future work and directions

- Sensor characterisation:
  - Currently working on: noise, time resolution
  - Next: spatial resolution, time walk versus light power
- In Chemistry, further spatial and velocity map imaging
- Possible new applications:
  - Atomic probe tomography (alloy analysis)
  - Fluorescence imaging
- Larger, improved sensor PImMS2
  - Submission this autumn; testing in early 2012

Summary

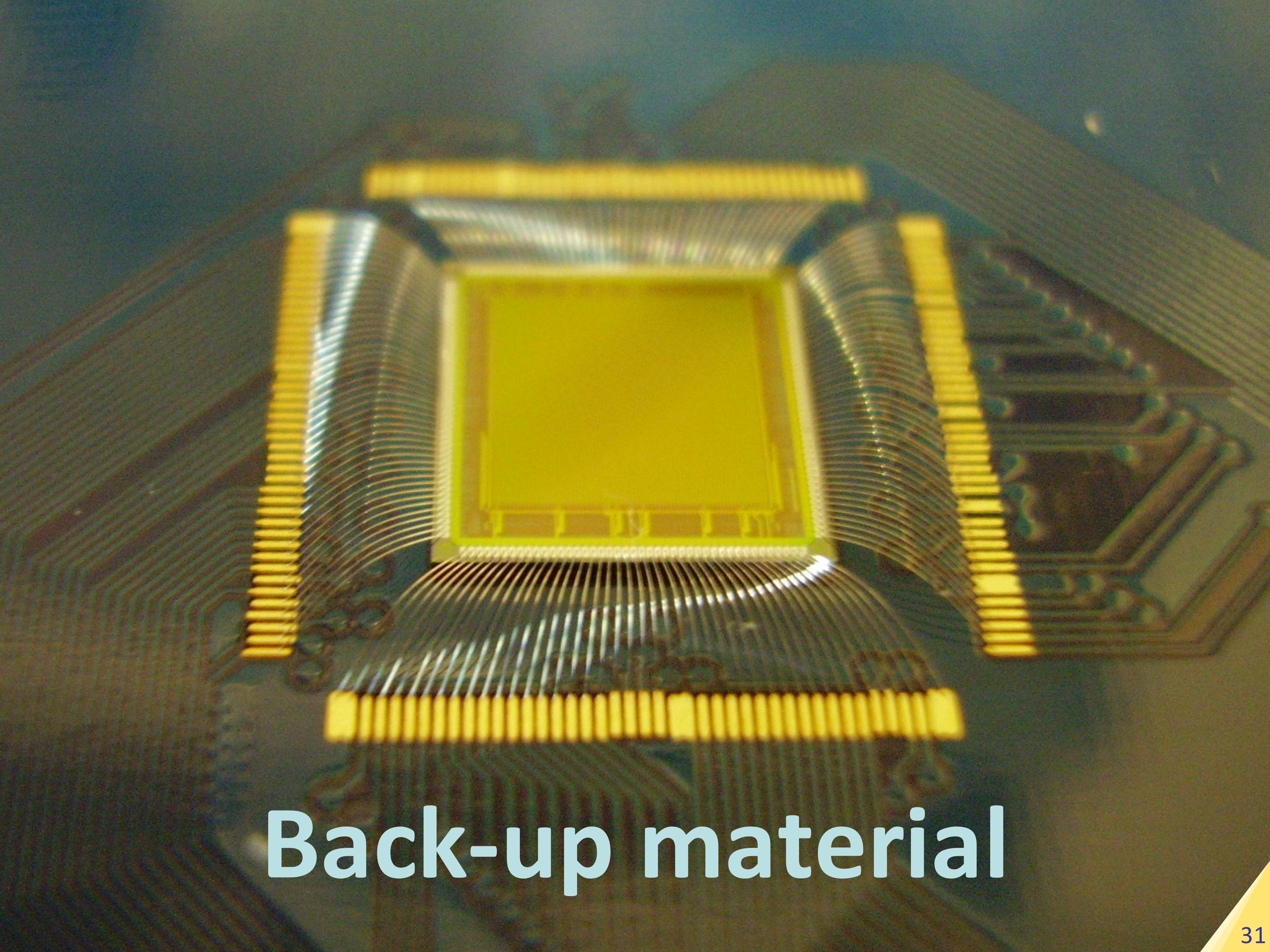
- PImMS is both a new technique in mass spectrometry and a specialised sensor for MS
- The first sensor has been proven for mass spectrometry
- Adding 2D sensing to a time-of-flight mass spectrum adds structural information and can increase throughput
- Multiple memories capture different mass peaks within one experimental cycle
- The second generation sensor will be ready in early 2012

Acknowledgements

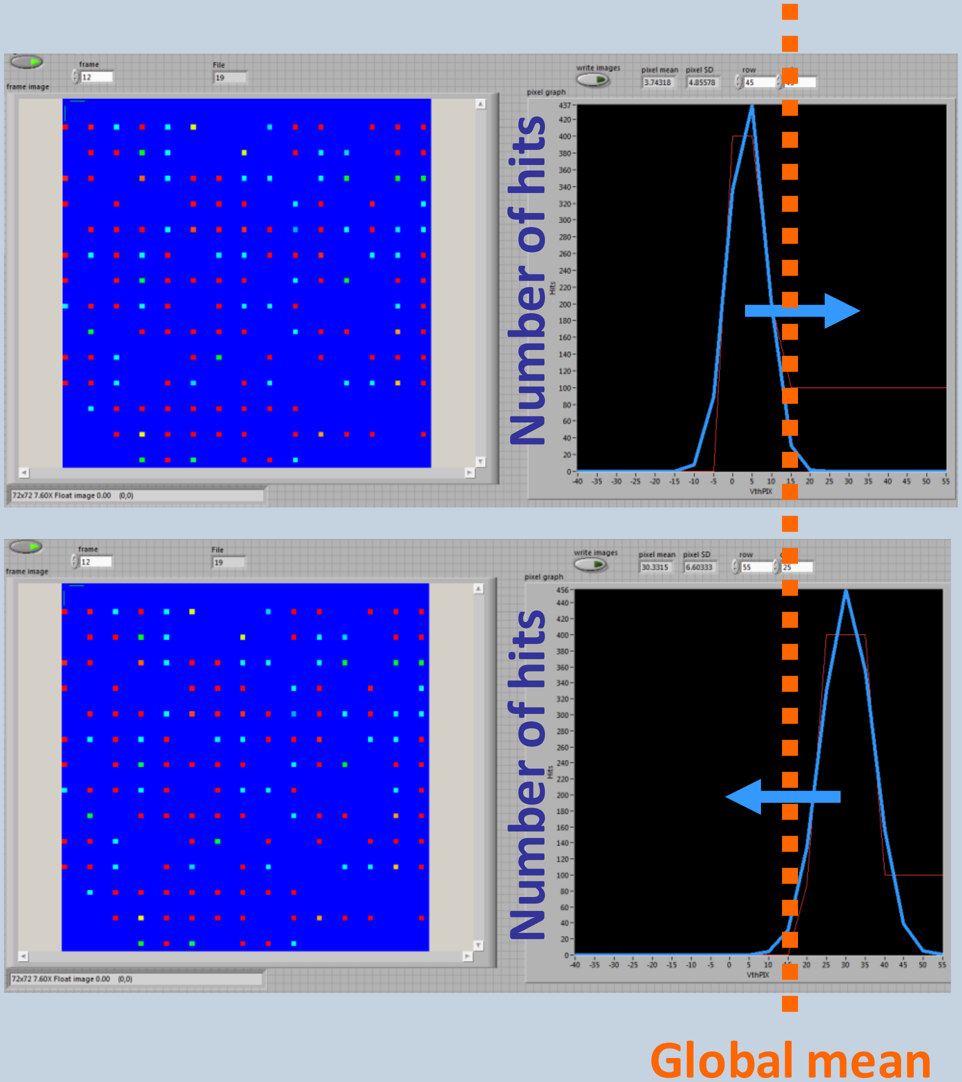


The support of the EPSRC through Grant EP/G00224X/1, of the STFC through PNPAS award, of the RC-UK through MI-3 programme (GR/S85733/01) and a `proof of concept' grant from ISIS Innovation Ltd. are gratefully acknowledged.

Thank you


Back-up material

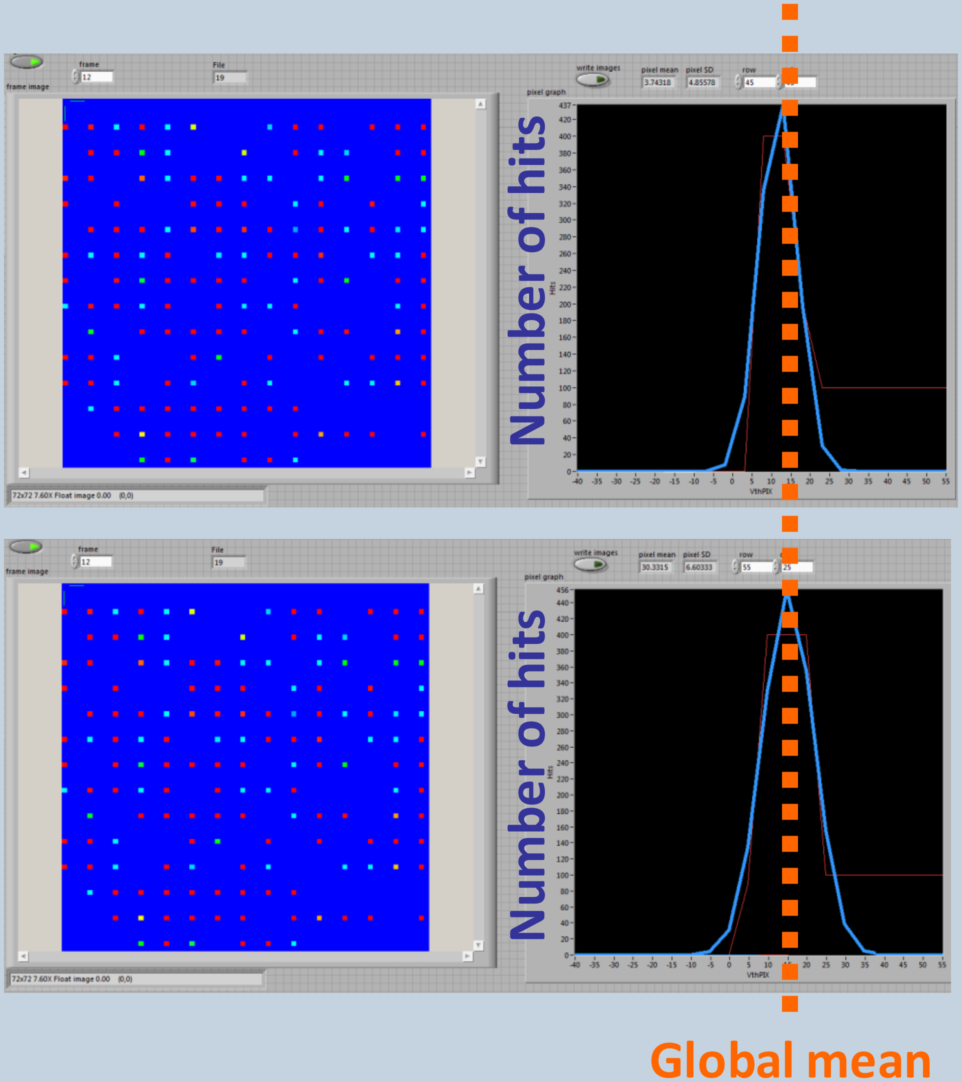
Sensor calibration



Pixels are characterised by plotting threshold voltage versus number of noise hits.

Limited floor space and manufacturing tolerances mean that pixel responses vary.

Sensor calibration



After trimming of pixels