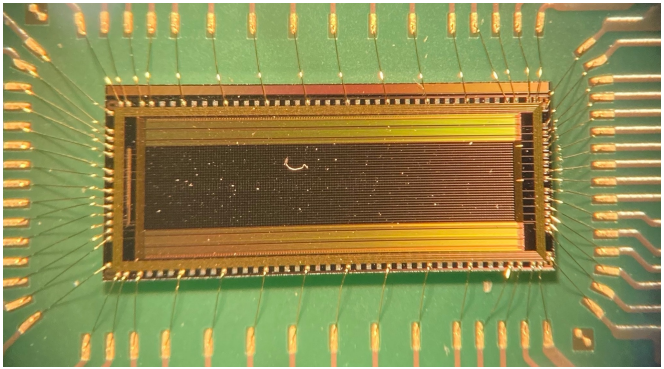
Fully Integrated CMOS SPAD Array Sensor for Optical Fibre Readout



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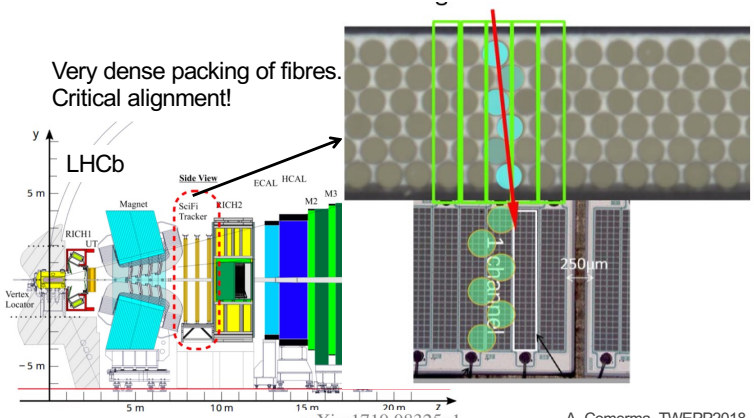
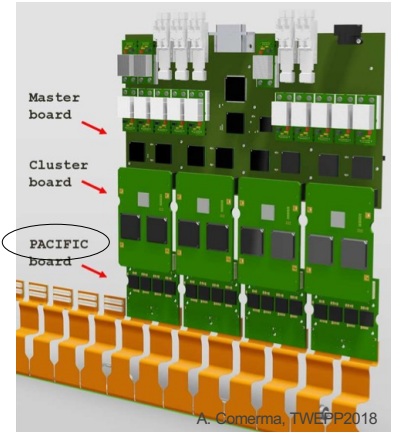
Motivation

- Some detectors place scintillating fibres in the acceptance and detect light ‘outside’
- Example: ‘Scintillating Fibre Tracker’ of LHCb
- Light is detected with SiPM Arrays + Boards + Cables + dedicated ASICs



arXiv:1710.08325v1

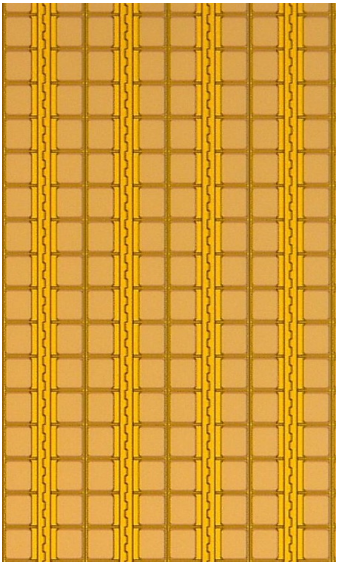
A. Comerma, TWEPP2018



A. Comerma, TWEPP2018

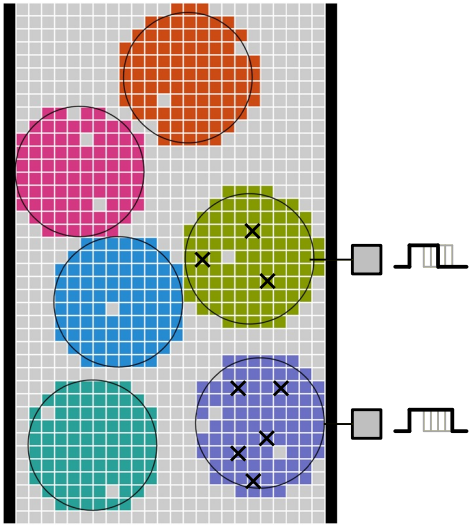
CMOS SPADs (‚Digital SiPMs')

- Combine SPADs *and* CMOS circuitry on *one* chip
- Advantages (compared to 'SiPM + ASIC')
  - Large ('digital') signal per SPAD
  - → Low power
  - Can disable noisy SPADs ($\lesssim$ 5%)
  - Integrated readout architectures ! (TDC, …)
  - Fine granular 2-D position information
  - Simple mechanics (only one component)
  - Low cost (?)
- Drawbacks
  - SPAD quality often not as good as SiPMs:
    - Higher DCR (but: can switch off noisy SPADs)
    - Lower quantum efficiency
  - Often reduced fill factor (if circuitry in pixel)



Fully Integrated SPAD Readout for Fibres: The Idea

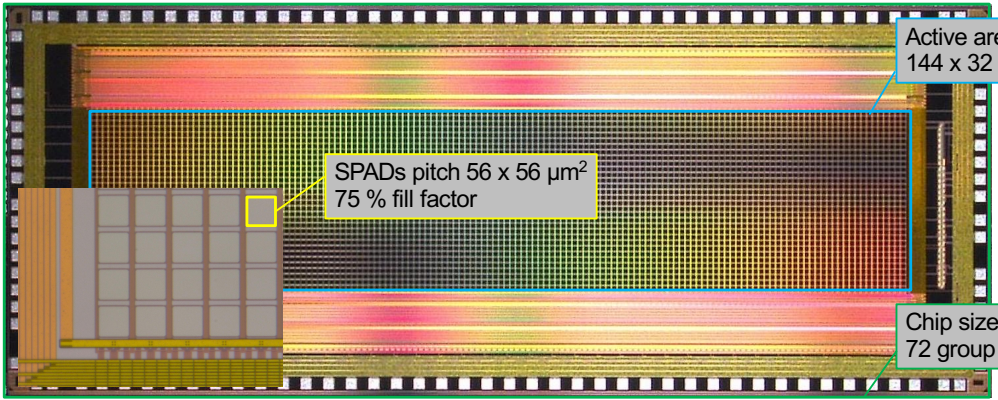
- Each SPAD can be assigned to a ‘group’ (= fibre)
  - Assignment is freely programmable (within limits)
- Each ‘group’ is routed to a *digital* output pin
- Number of hit SPADs is encoded in pulse width



- Advantages:
  - Alignment (of fibres) fully uncritical
  - No dark noise from ‘unused’ SPADs
  - ‘Noise-free’ (for small photon count)
  - Good timing (tbc)
  - Simple system with only *one* element: (sensor + readout)
  - Cheap

The Chips

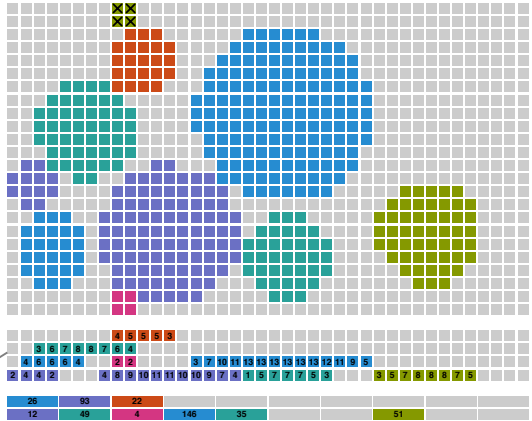
- 2 Chip versions with SPAD pitches 42/**56** µm have been designed
- Chips have been produced at IMS, Duisburg (350nm, 4 metals)



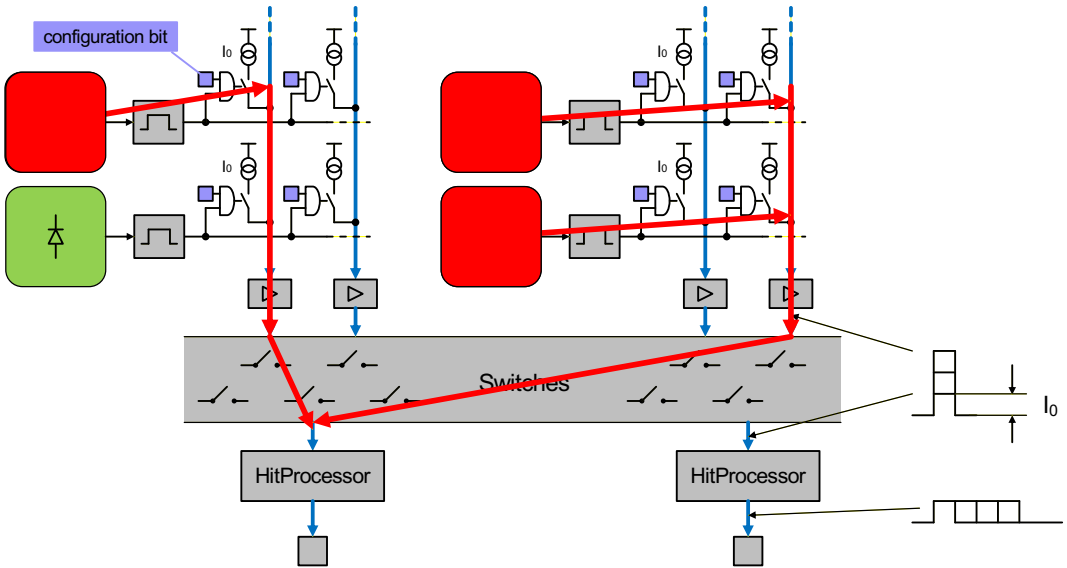
- (SCI42: 192 x 24 SPADs in 42 um pitch, ~8 x 1 mm² sensitive area, 67% fill factor)

Readout Architecture: Concept

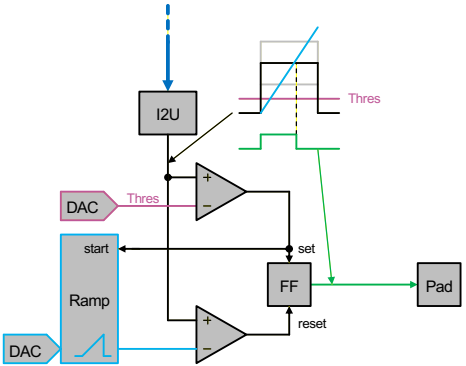
- A fully arbitrary assignment of *any* SPAD on the chip to *any* group is not required
  - This would need a large hardware effort and many storage bits
- We assume that the groups are ‘contiguous’
- Each SPAD in a column can be assigned to one of several (4) ‘column groups’
- The ‘column group’ signals are merged an assigned to output pads



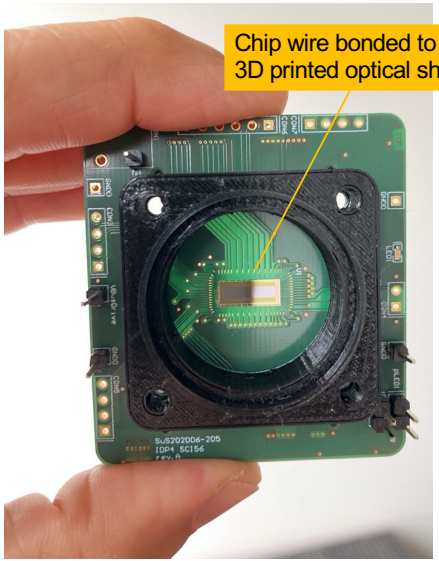
Readout Architecture: More Details

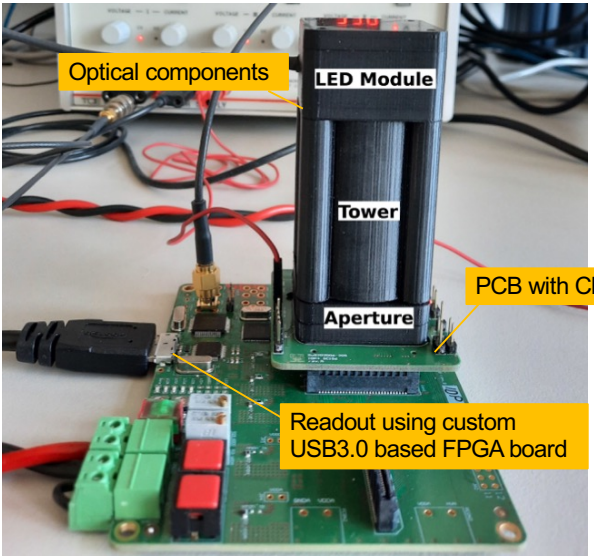


- Converts Multiplicity (current levels) to pulse width
- Threshold can be set to 1,2,… photons
- $-\Delta T$ per bin can be set in wide range by ramp current



Readout Hardware



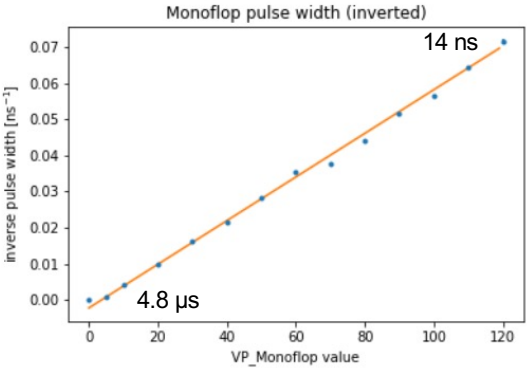


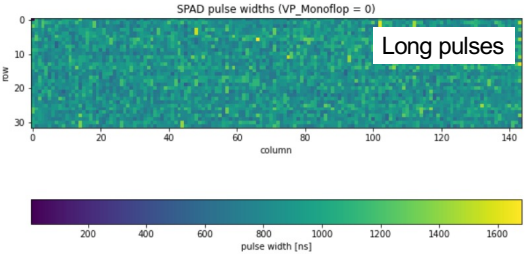
Preliminary Measurements

So far only in BSc thesis, 1 chip tested

Results: Monoflop Pulse Width

- Can be varied in wide range (14ns-4.8µs)
- Short times show some inhomogeneities in matrix (RC time)
  - Can be improved by higher bias in buffers

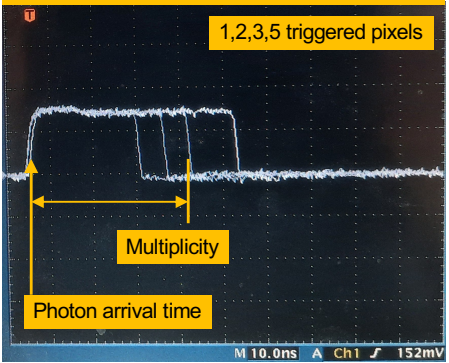




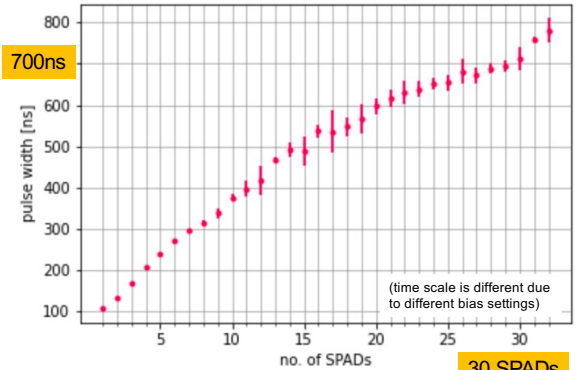
Results: Pulse Width Output

- Group Assignment and HitProcessor work! Wide range of settings.
- Multiplicities >20 can be measured. Single photon resolution for low multiplicities

Hitprocessor Output

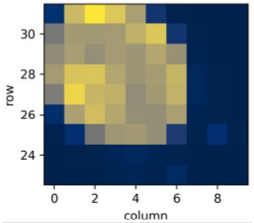


Pulse width vs. # triggered SPADs

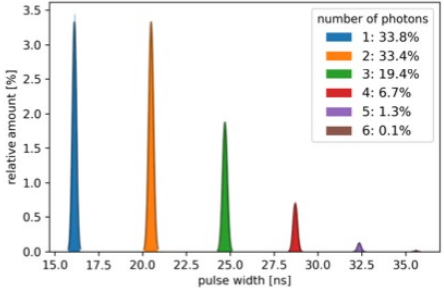


Results: Photon Multiplicities

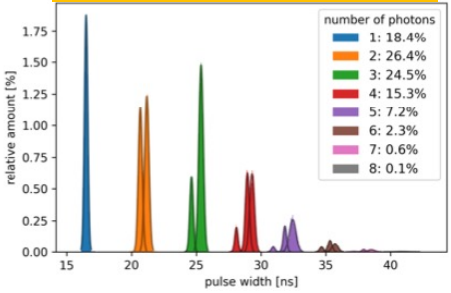
- Array is illuminated with de-focused laser spot:
- Multiplicities (from pulse width) in *one* column can be *very well* separated (left)
- When adding more columns, signals are (slightly) degraded by the switching network



Group includes only pixels in column 1:

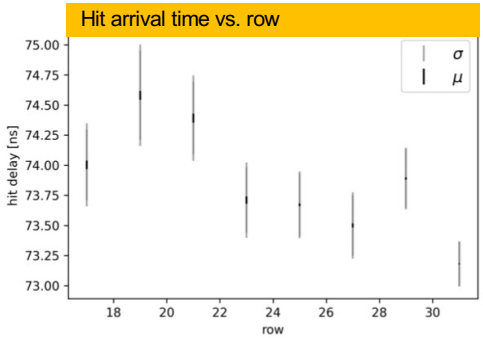


Group includes columns 0+1:



Results: Time Resolution (Preliminary)

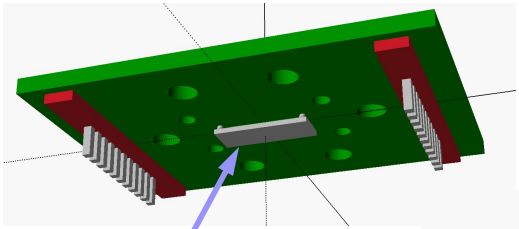
- By illuminating with a fast laser, single photon time resolution has been determined.
- For individual SPADs time resolution is <300ps (probably limited by setup)

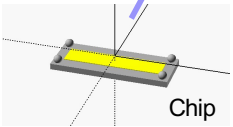


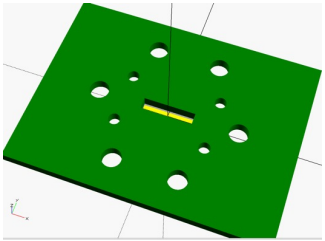
- However, systematic delays between pixels are of comparable size, and extra columns add further effects (see previous page)
  - This needs further investigation

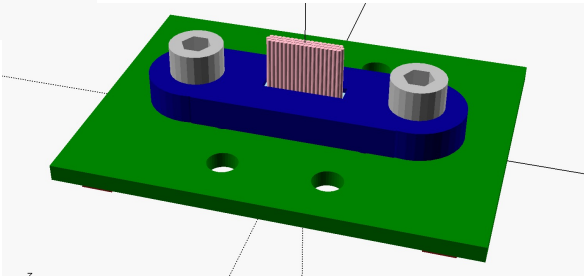
Plans: Connecting fibres

- In 2nd iteration, will use bump bonded chip
- Fibre ‘plugged’ and aligned in PCB hole









Summary

- A novel CMOS SPAD architecture with group readout is proposed
- It can offer a compact, performant readout of scintillating fibres

- Two chips have been designed and produced from scratch and are fully functional
- One chip has an array of 144 x 32 SPADs of 56µm pitch with 75% fill factor

- A hit threshold at 1 photon is straight forward
- Robust photon counting is possible for low multiplicities
- Photon multiplicities of up to 30 have been tested (more is probably possible)
- First measurements of time resolution show position effects, but ~1ns seams feasible

- (The technology has a typical DCR of 30 kHz/mm^2 @ RT, max QE of 45% at 500nm)

Thank you for your attention!