A Hybrid Photon Detector based on Timepix

DIRC2013

Castle Rauischholzhausen, 2013

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

Thilo Michel on behalf of the Medipix-HPD group

Friedrich-Alexander-Universität Erlangen-Nürnberg

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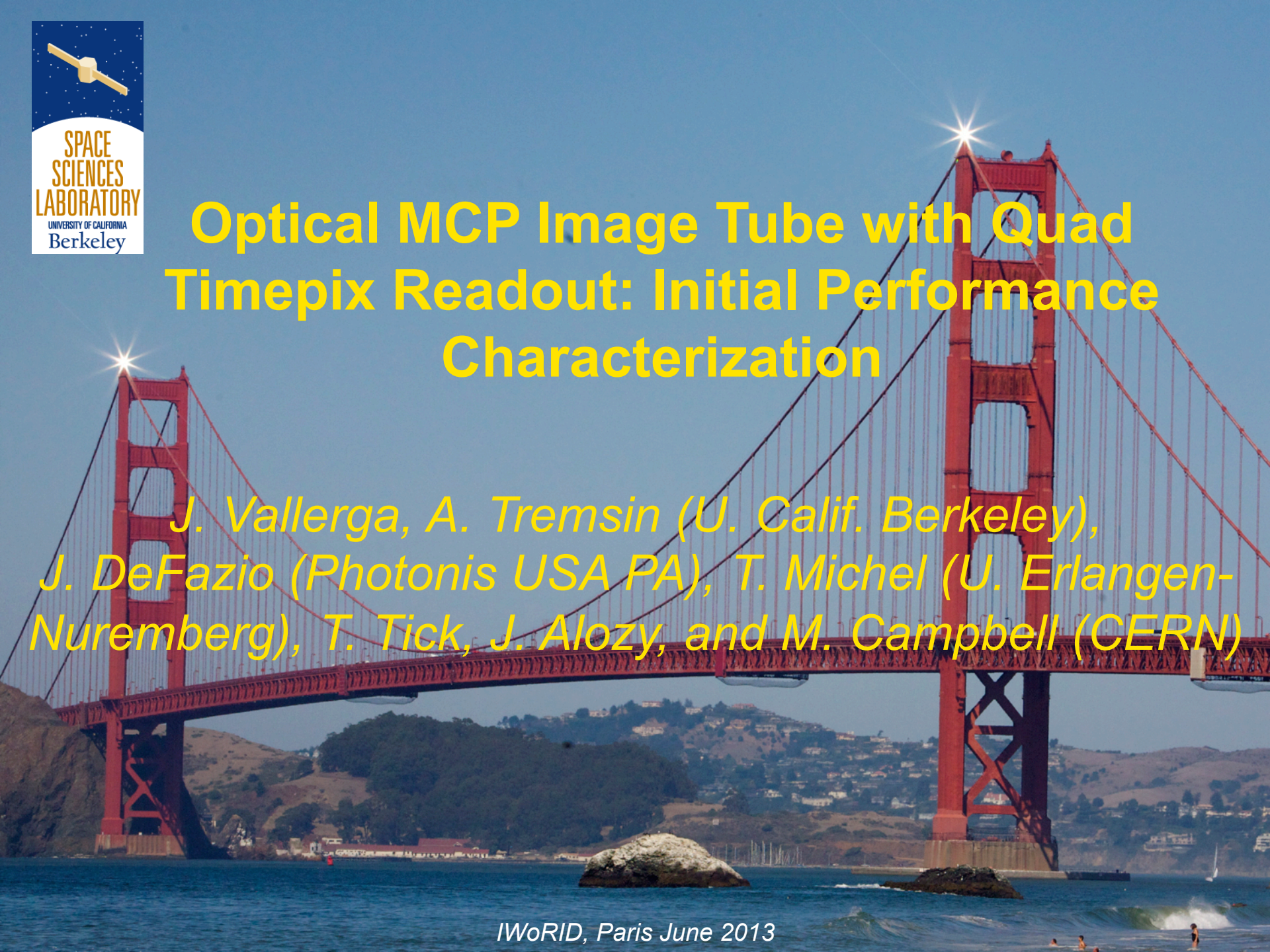

Optical MCP Image Tube with Quad Timepix Readout: Initial Performance Characterization

J. Vallerga, A. Tremsin (U. Calif. Berkeley), J. DeFazio (Photonis USA PA), T. Michel (U. Erlangen-Nuremberg), T. Tick, J. Alozy, and M. Campbell (CERN)

IWoRID, Paris June 2013

Agenda

- The anode: the Timepix
- HPD design
- Position resolution
- Time resolution

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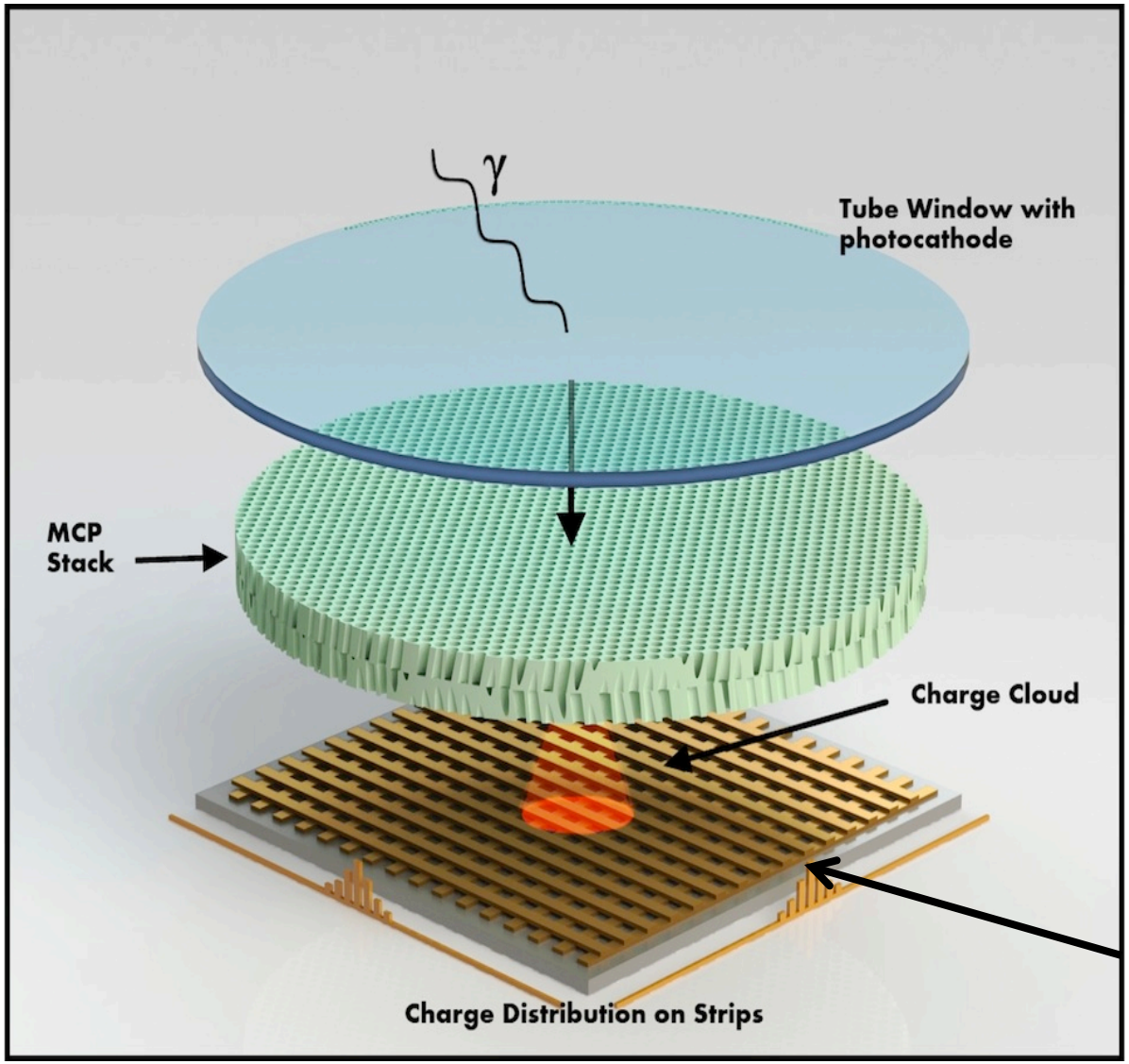
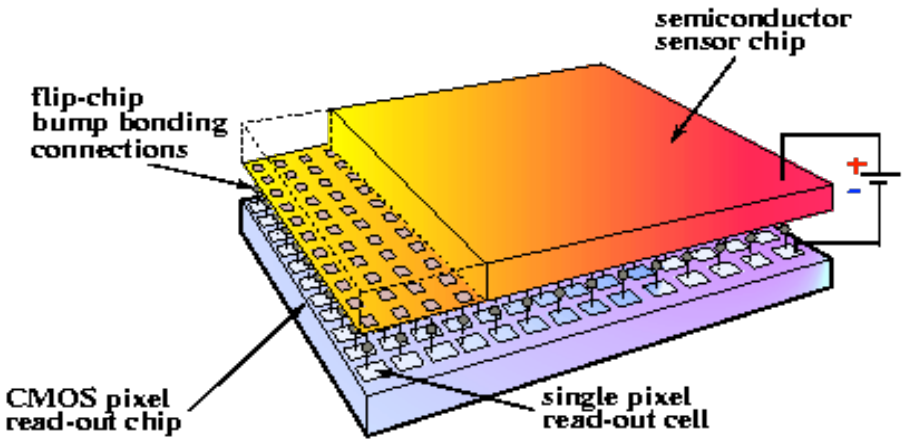
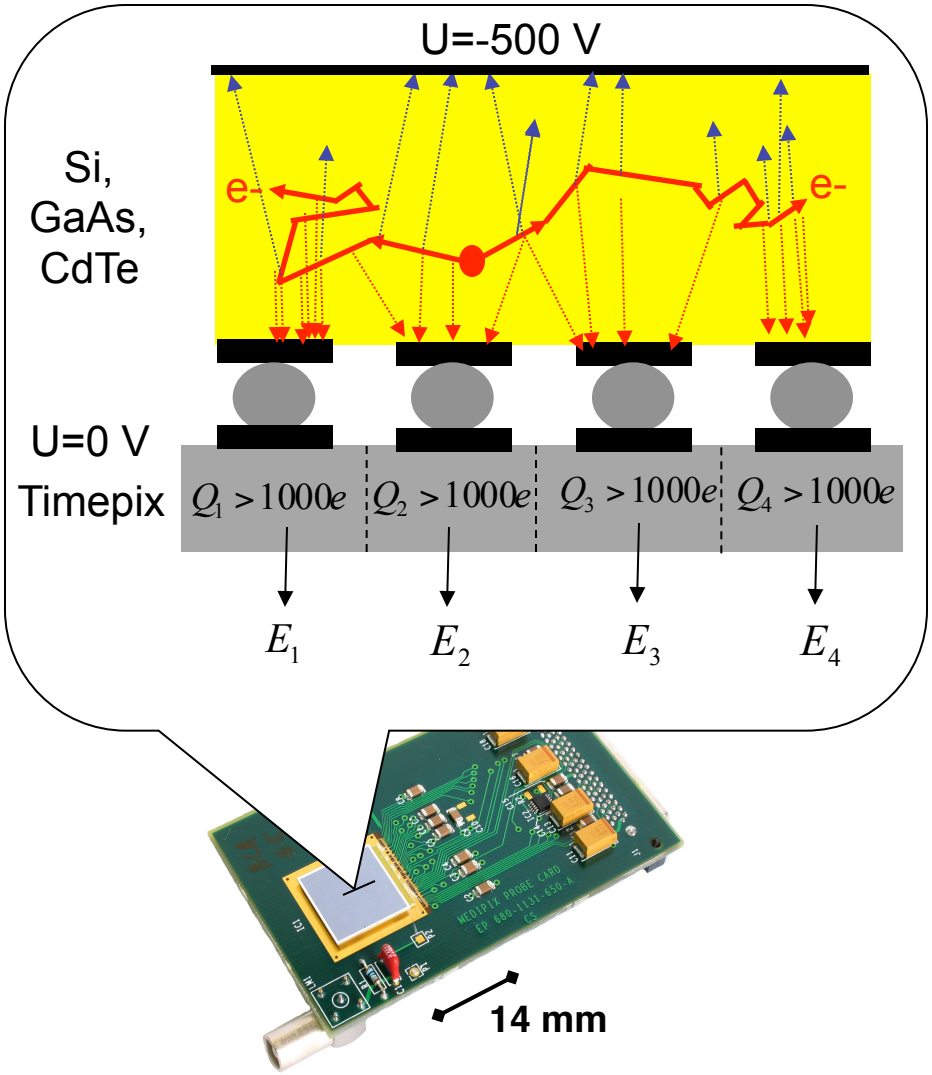
Microchannel Plate Detector



Use bare Timepix as *pixellated* anode

The active pixel detector Timepix

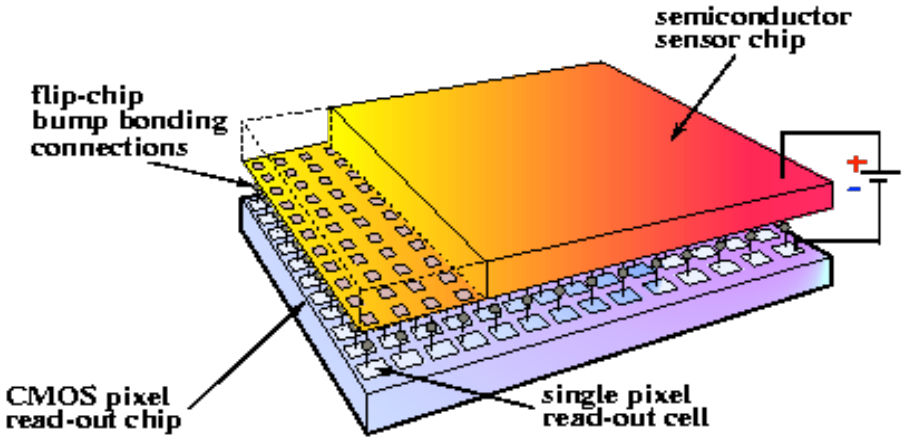


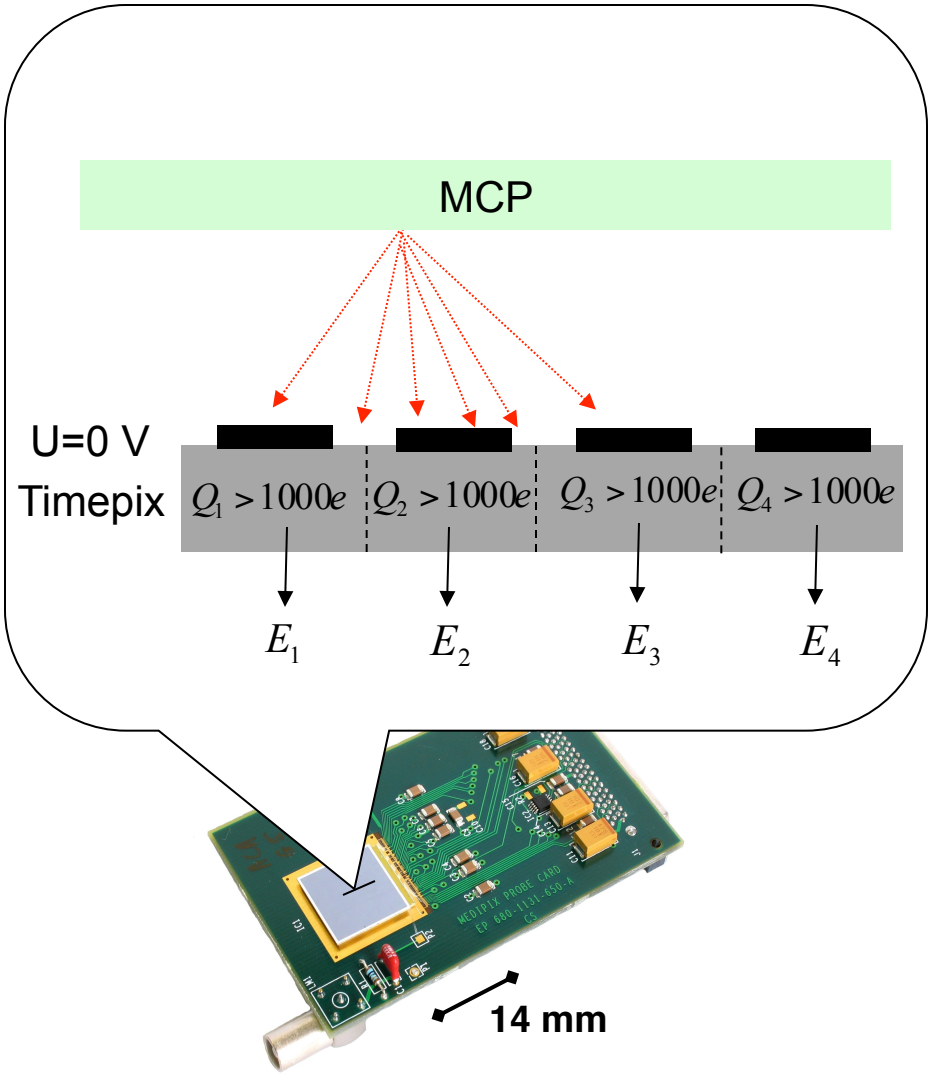


Properties

- Developed by Medipix-collaboration
- 65536 pixels
- Pixel pitch: 55 µm
- Size of pixel matrix: 14 x 14 mm^2
- Sensor layer: Si (300 µm), CdTe (1 mm)

The active pixel detector Timepix





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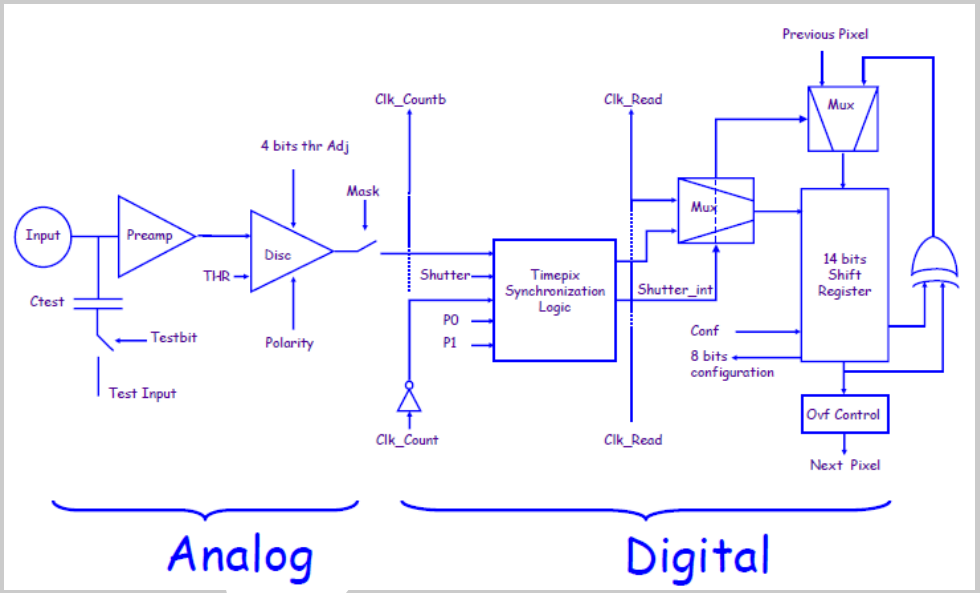
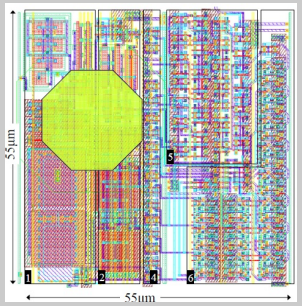
The Timepix-ASIC

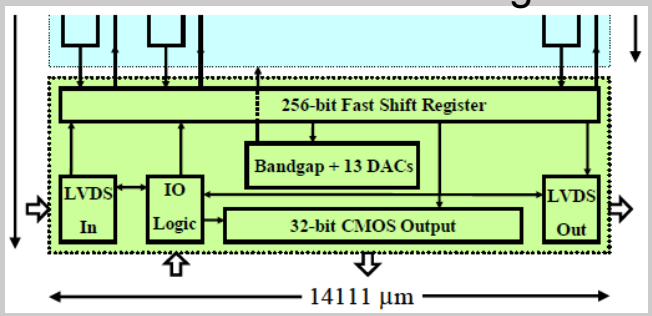
Pixel electronics



Pixel cell



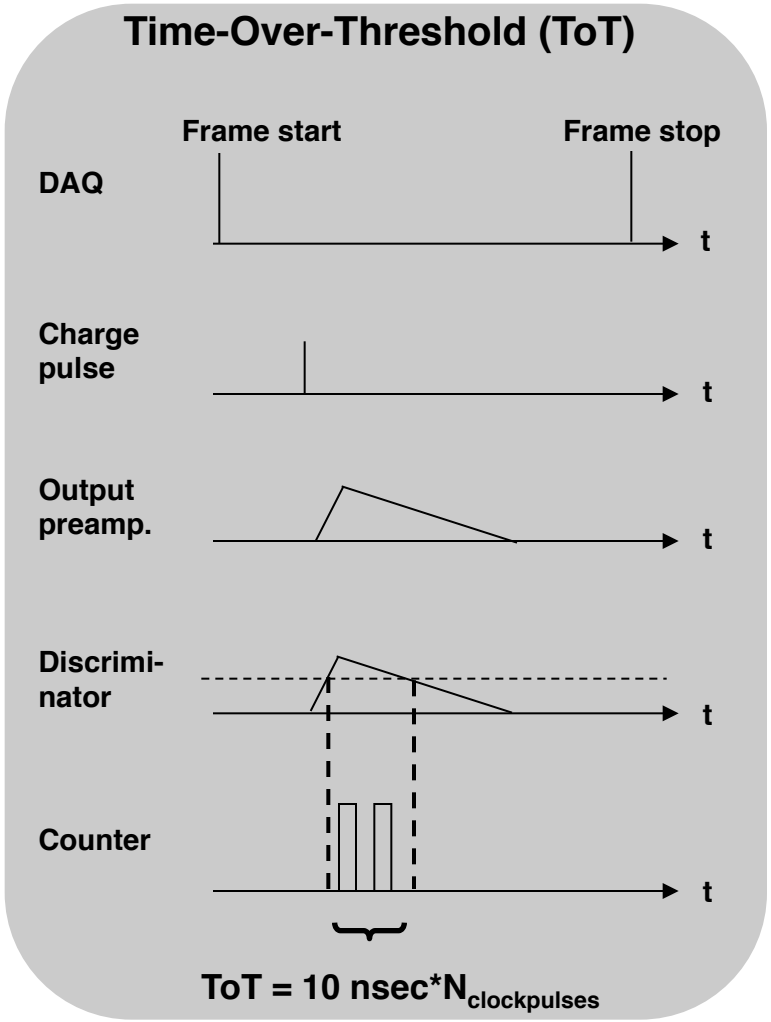
Readout zone block diagram

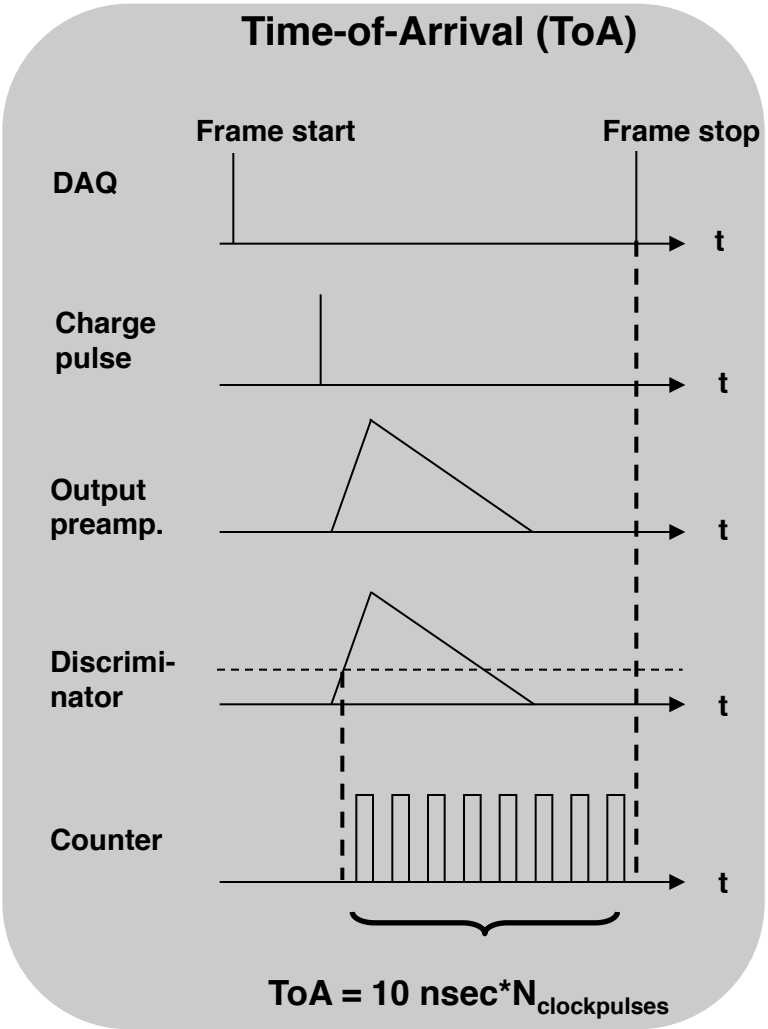


Principle

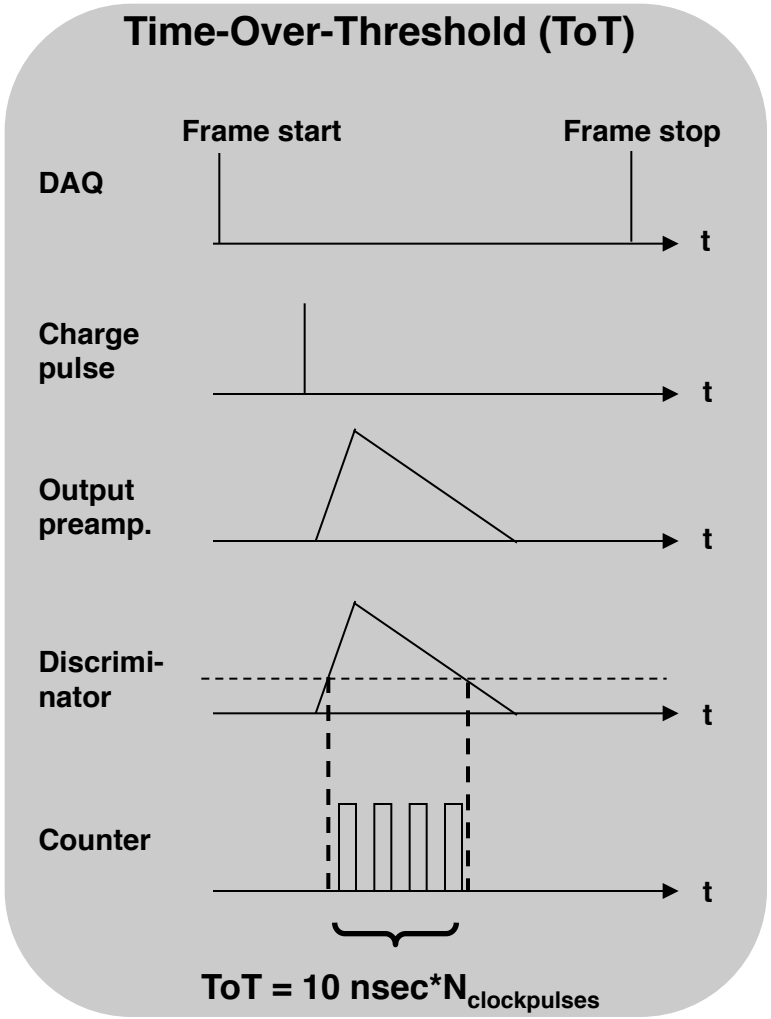
- **Pixel electronics**
  - Charge-Sensitive Preamp.
  - 1 discriminator (minimum threshold approx. 1000 e-)
  - 1 counter per pixel (depth of 11810)
  - Clock frequency variable up to 100 MHz (10 ns)
  - Readout time: 9 ms (serial), 265 µs (parallel)
- **Operation modes**
  - Counting
  - Time-Over-Threshold (charge measurement)
  - Time-Of-Arrival (time-stamps, min. TDC length about 120 µs)

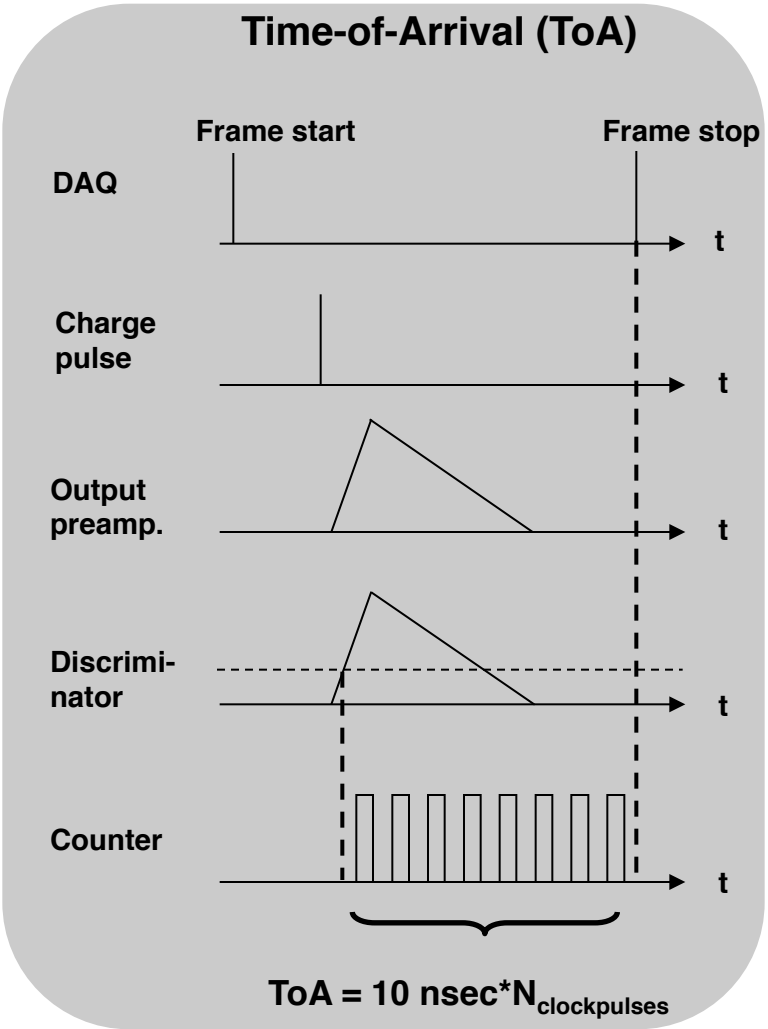
Timepix: counting or Time-Over-Threshold or Time-of-Arrival (exclusive ORs)





Timepix: counting or Time-Over-Threshold or Time-of-Arrival (exclusive ORs)



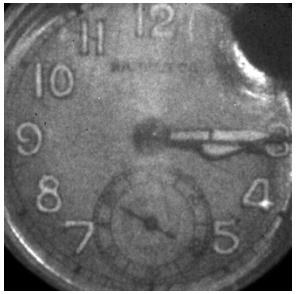


Agenda

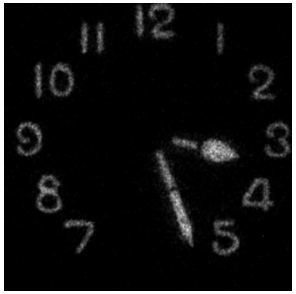
- The anode: the Timepix
- **HPD design**
- Position resolution
- Time resolution

Berkeley 18mm Image Tube (2008)

- Constructed "in-house"
- Proof of concept
- One Medipix2 chip
- Only photon counting
- Only low gain needed
- Huge dynamic range:
  - 66 MHz to a ~few Hz.



66 MHz



100 Hz

However:

- Low resolution (256x256)
- Low QE (4% max.)
- No timing information per event

Medipix2 Collaboration Optical HPD Effort

- Sept 2009, discussions started to fund optical HPD development.
- Sept 2010, Photonis-USA chosen as partner
  - CERN develops backside header + quad Timepix (Timo Tick)
  - Photonis-USA fabricates tube based on Planacon design with bi-alkali photocathode
- January 2013, first tube delivered to Berkeley for initial tests.

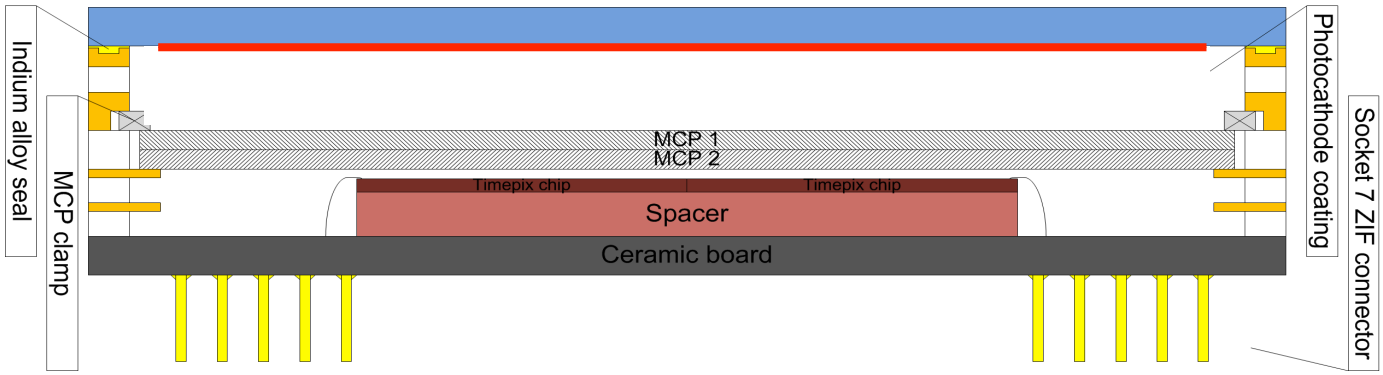
Tube set-up based on Planacon with 25 μm pore MCPs

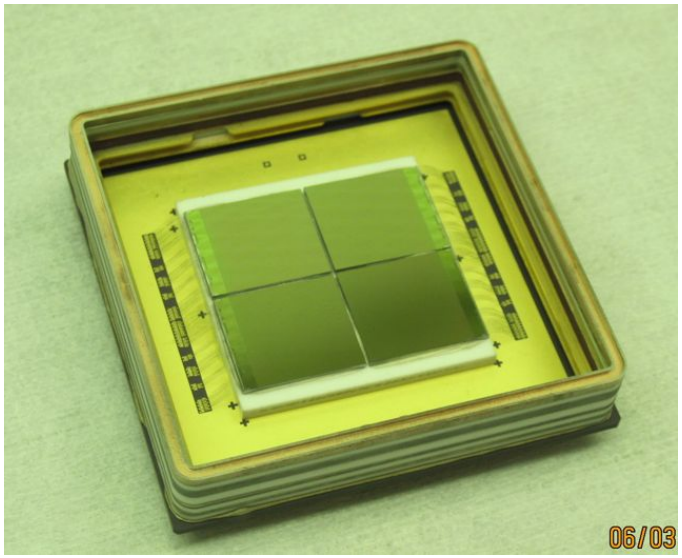
-2400 V

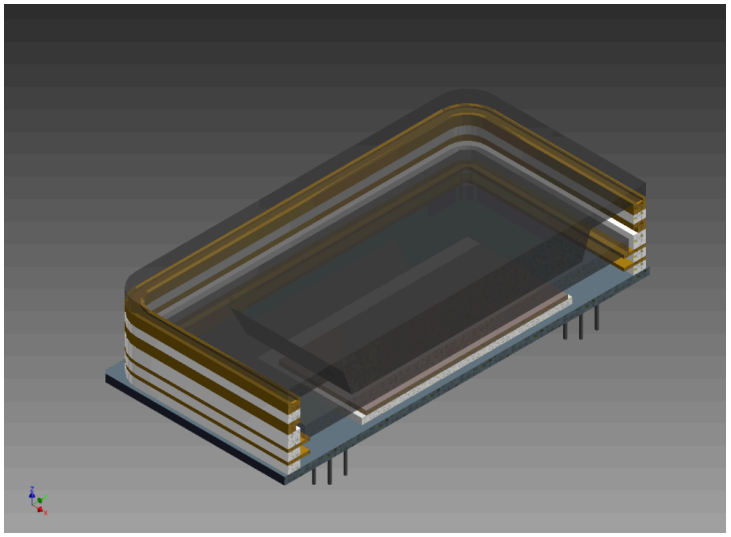
-1800 V

-600 V

0 V

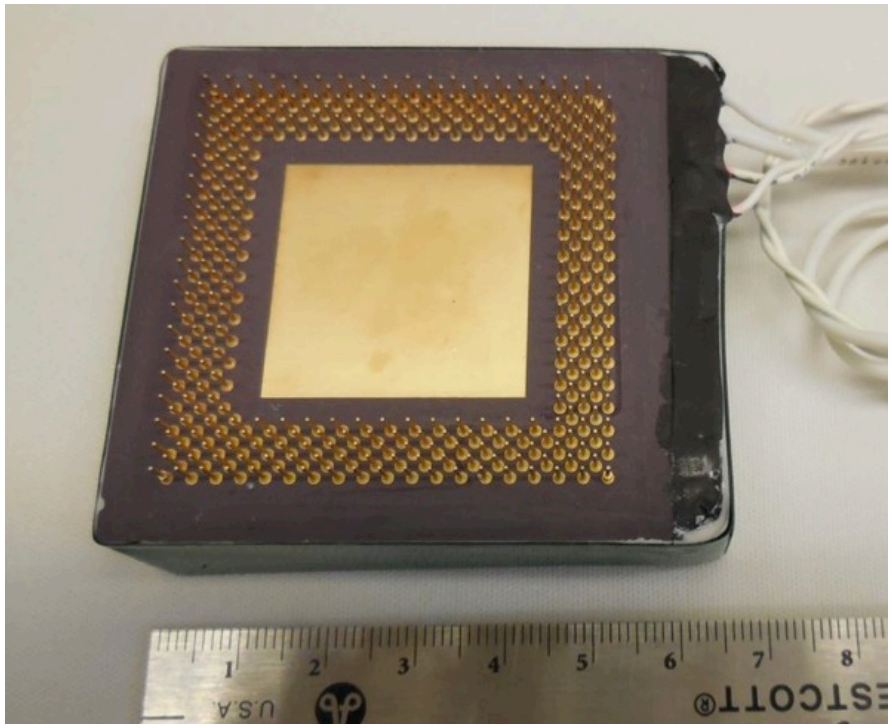




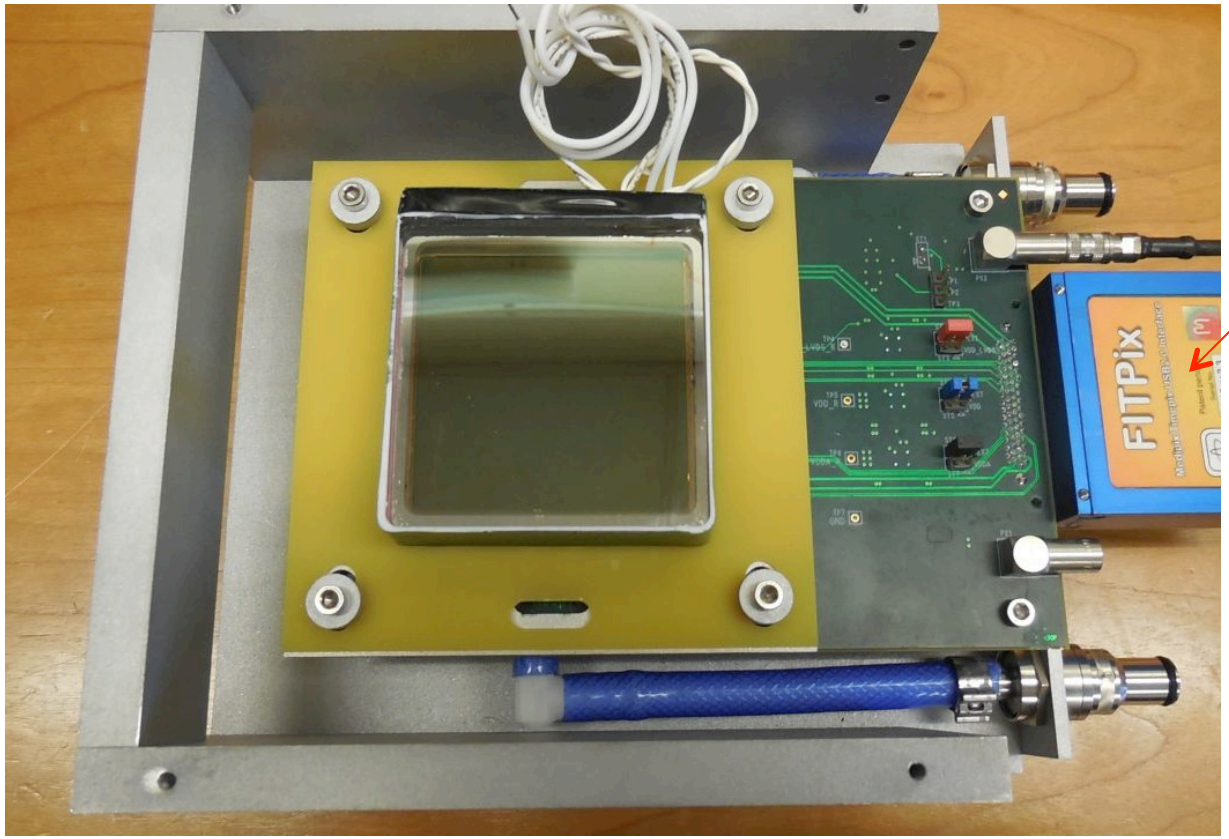


First tube delivered

- Bi-alkali photocathode
- Planar window
  - Photocathode-MCP gap ~4.5mm
- Rear field gap ~0.5mm

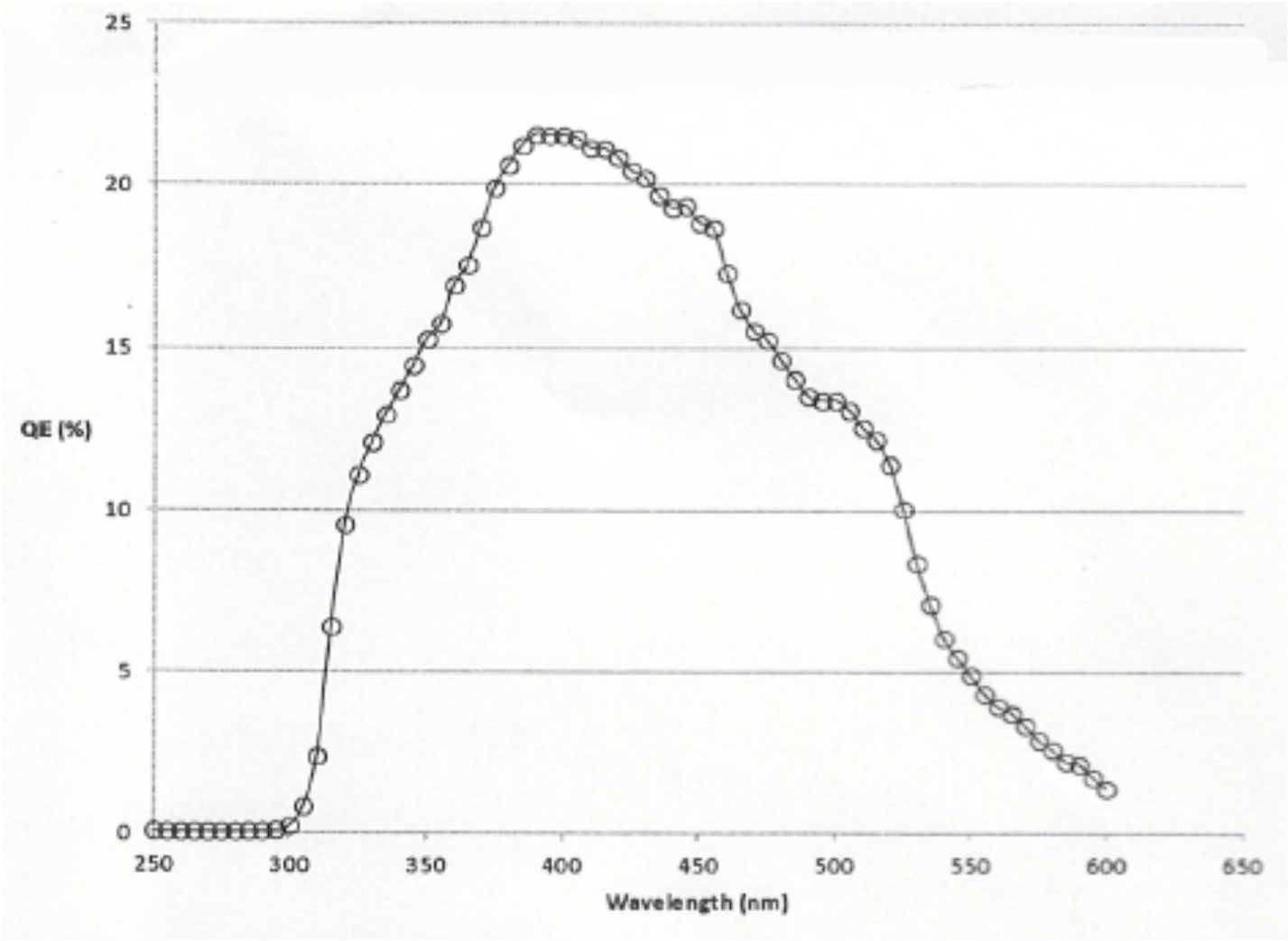


Tube Housing



Readout module from IEAP in Prague

Bi-alkali QE



Measured by Photonis-USA in January 2013 and *confirmed as stable* in June 2013 re-measurement

Agenda

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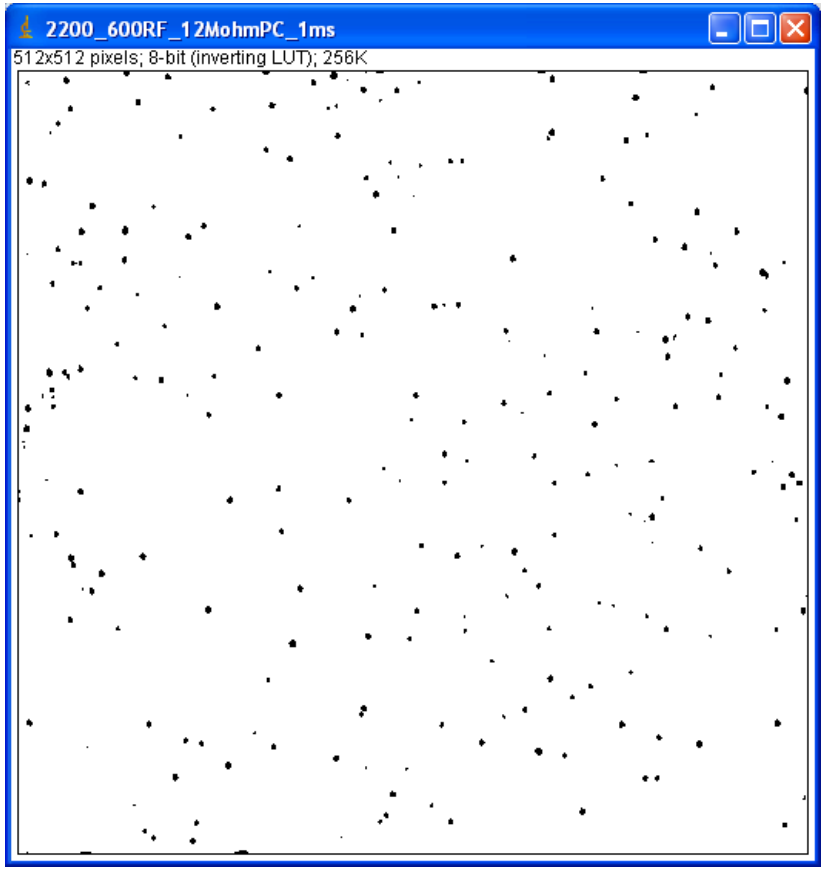
- **Position resolution**
- Time resolution

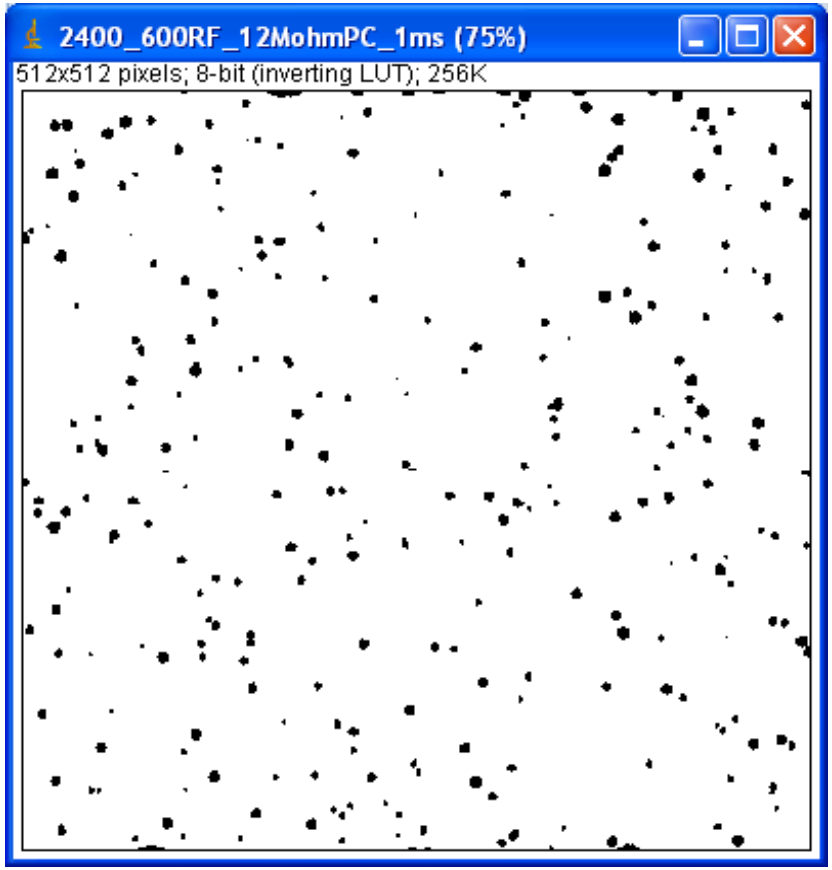
Event size *vs* MCP gain

Low gain



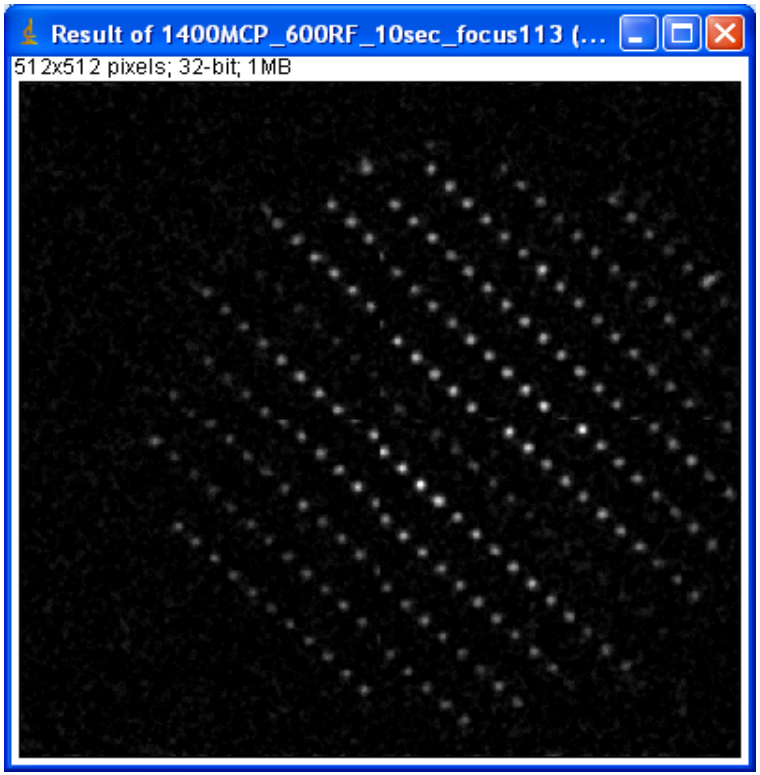
Events near charge threshold of pixel(s).

High gain

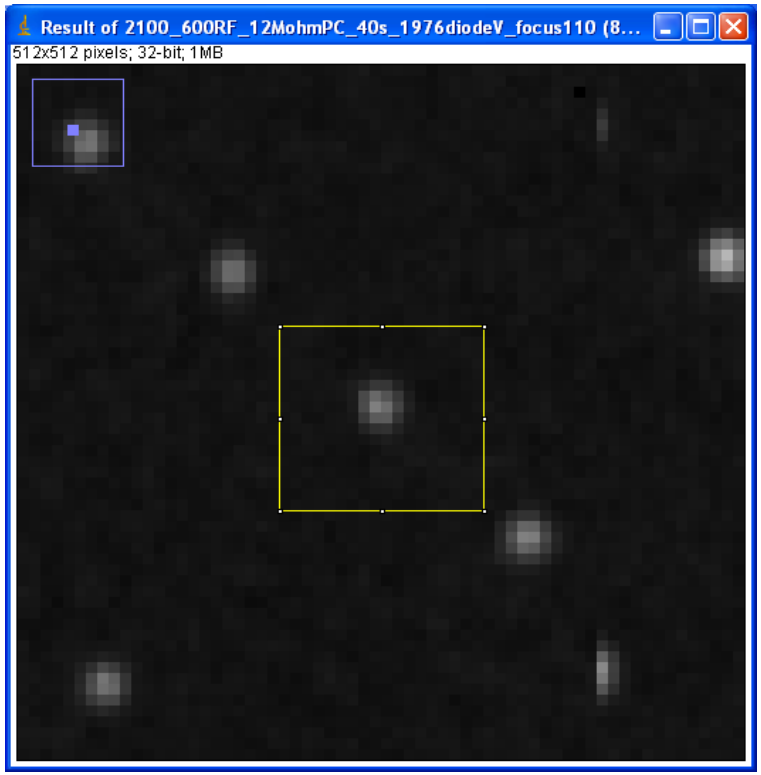


More pixels triggered in cluster per each photon event

Spatial Resolution: 165 μm

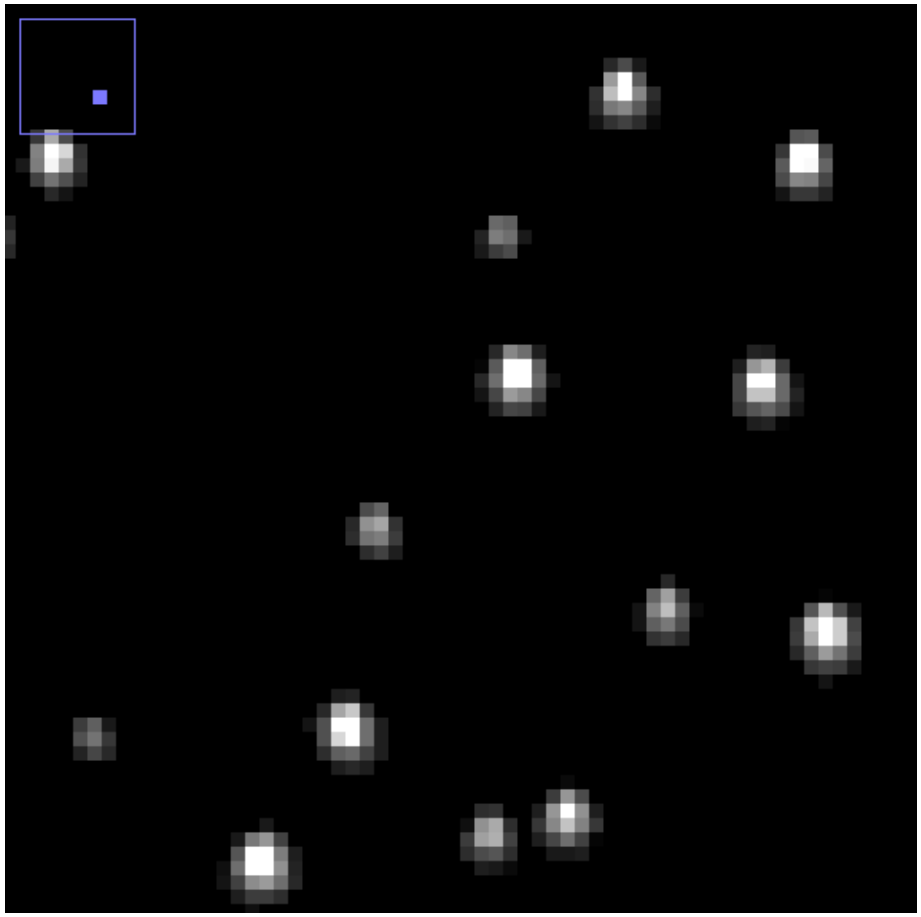


Optically project uniform pinhole pattern onto photocathode. Input psf < 20μm FWHM. Thousands of events per spot.



Best resolution achieved is 165μm FWHM with 600V across 4.5mm photocathode/ MCP gap. Charge cloud spread contributes a significant fraction.

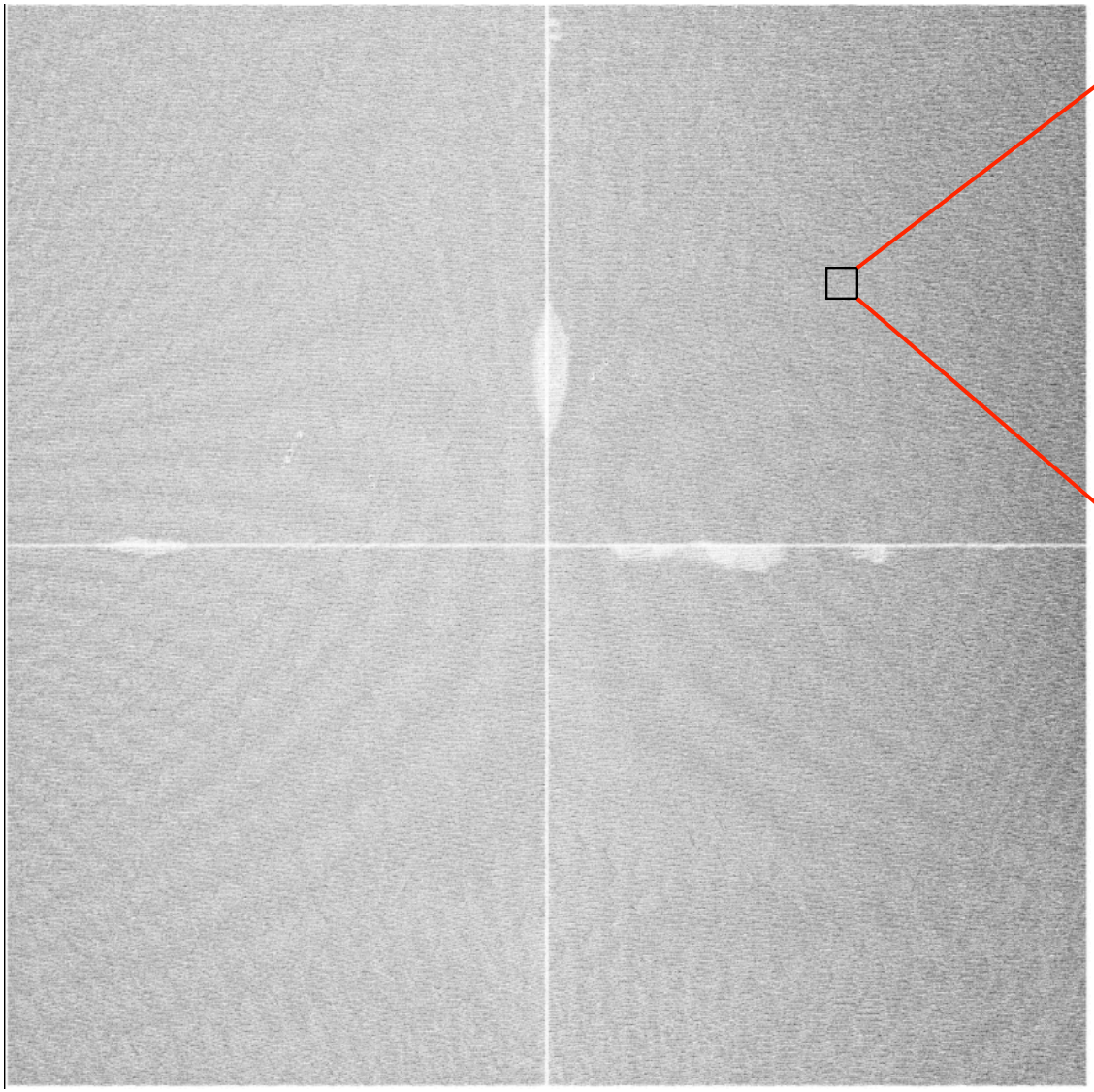
Timepix in TOT mode: subpixel centroiding

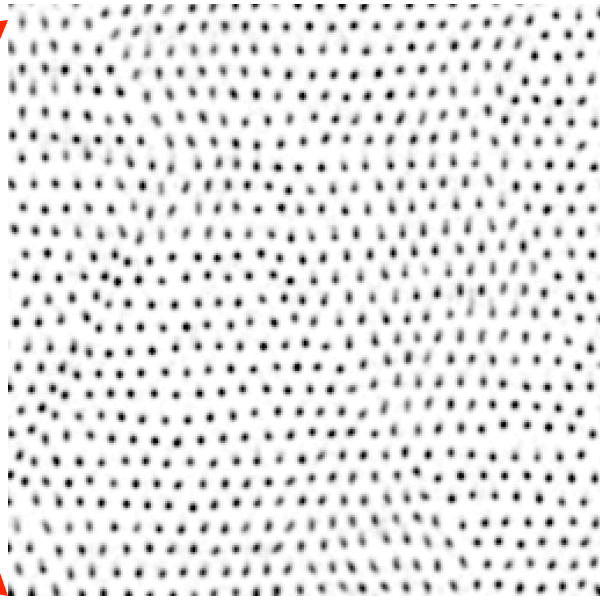


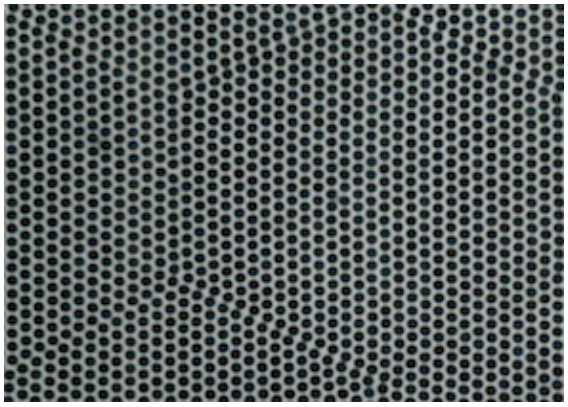
Single photon events with amplitude of charge per pixel in TOT mode

- Use charge cloud centroids as x,y positions of photon event and accumulate 2D histogram of centroids
- Removes charge cloud size as a blurring function, but must sacrifice count rate capability as events cannot overlap in a single frame.
- Rate limit in this mode is ~ 2500 counts per frame or 2.5 MHz at a kHz frame rate

6 hour dark image: 8k x 8k “image pixels”



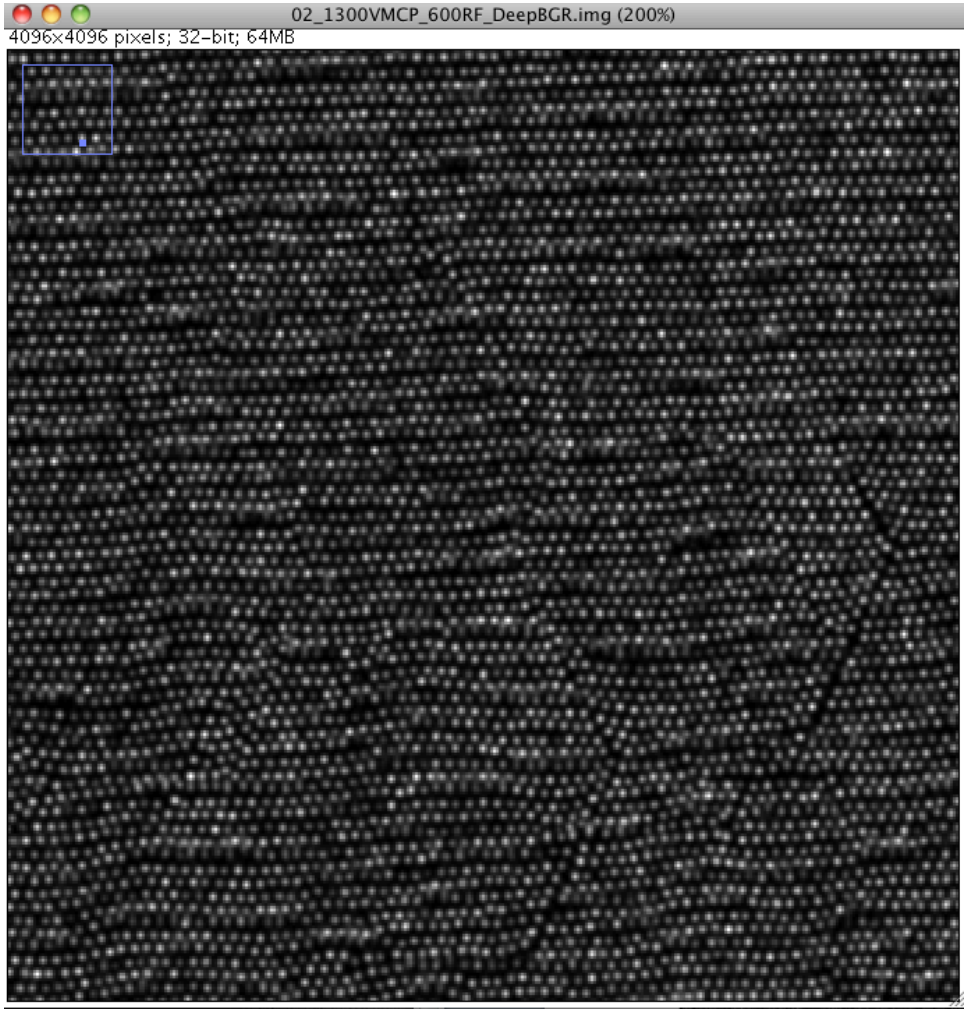




Actual microscope image of Photonis MCP input surface

Zoom (1.76mm)

- Resolving MCP pores on 32 µm centers hex.
- 6.9µm/pixel
- Mapping non-linearities due to coarse sampling and non-optimized charge cloud distribution
- Readout resolution greatly exceeds tube resolution (photocathode-MCP)



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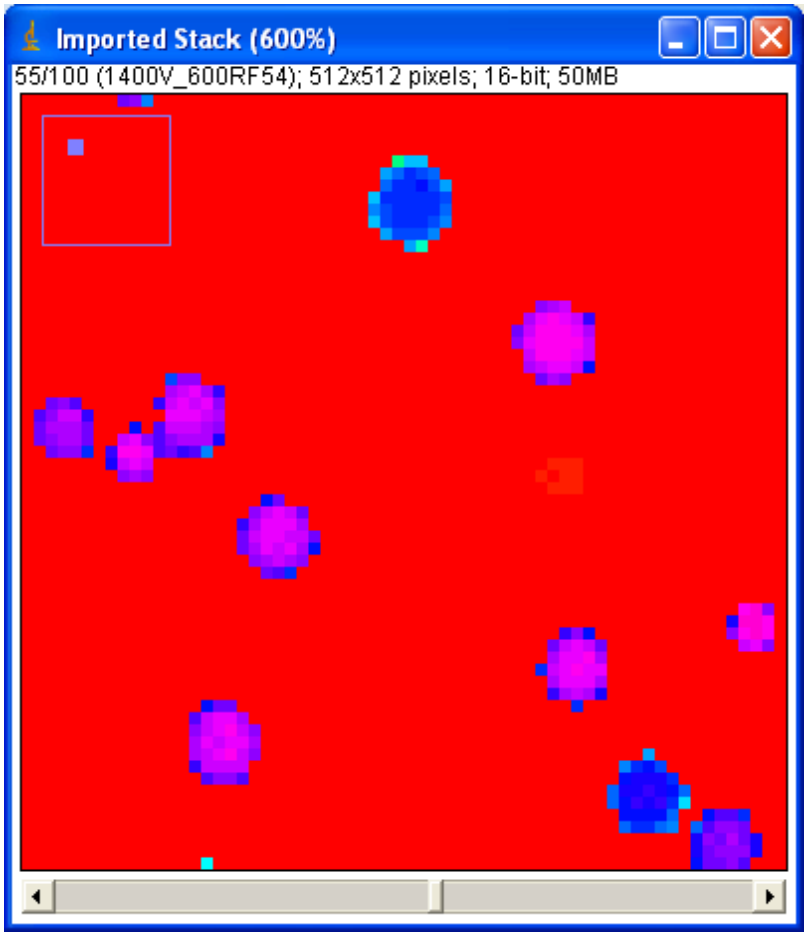
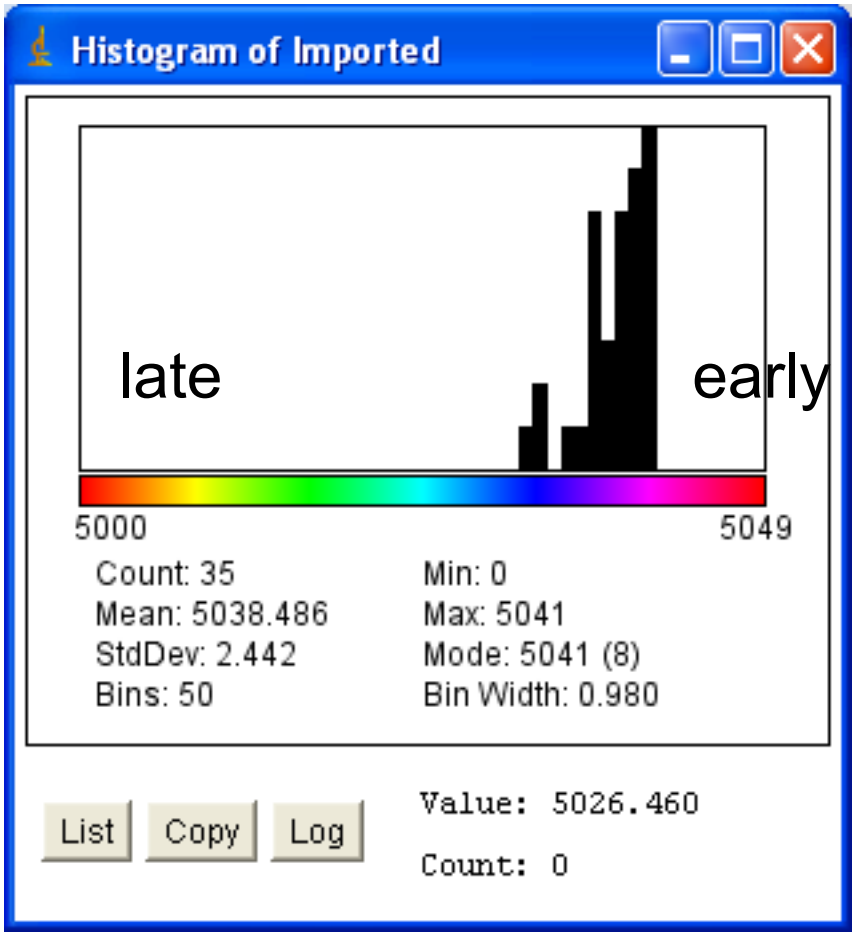
Temporal resolution

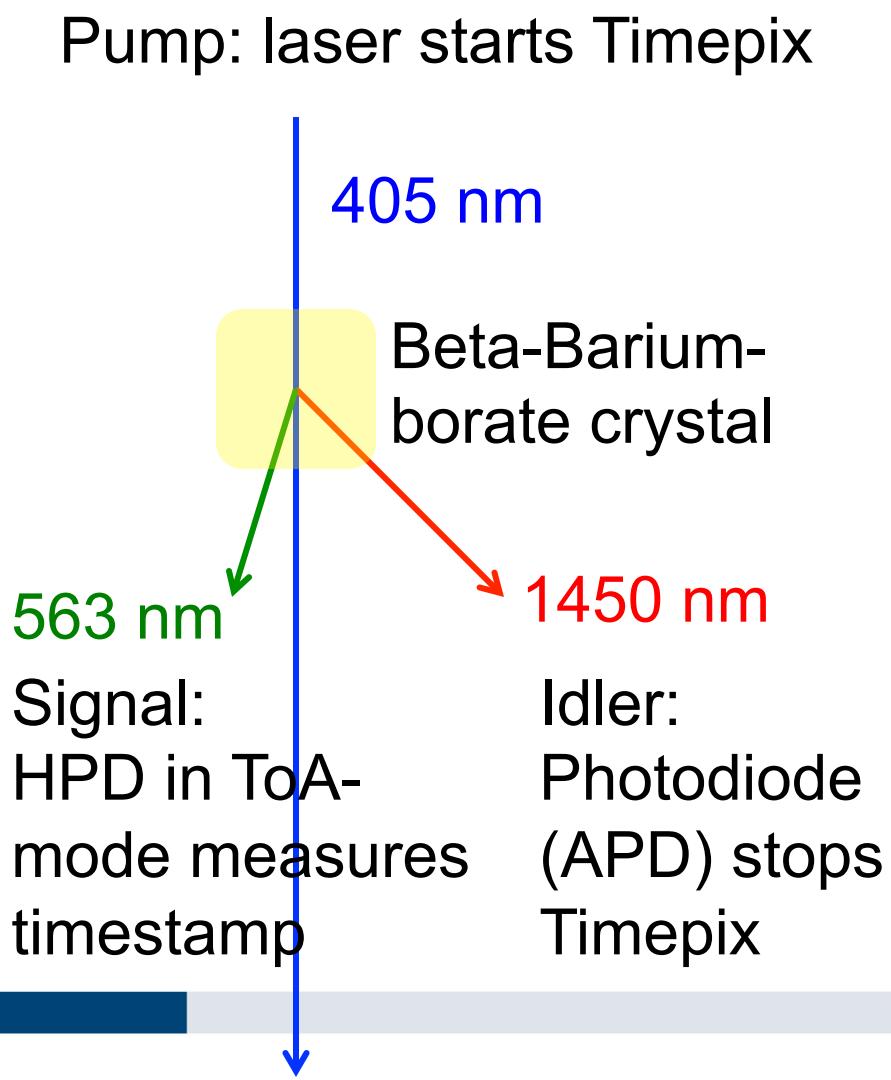


Multiple optical photons, time of arrival per pixel



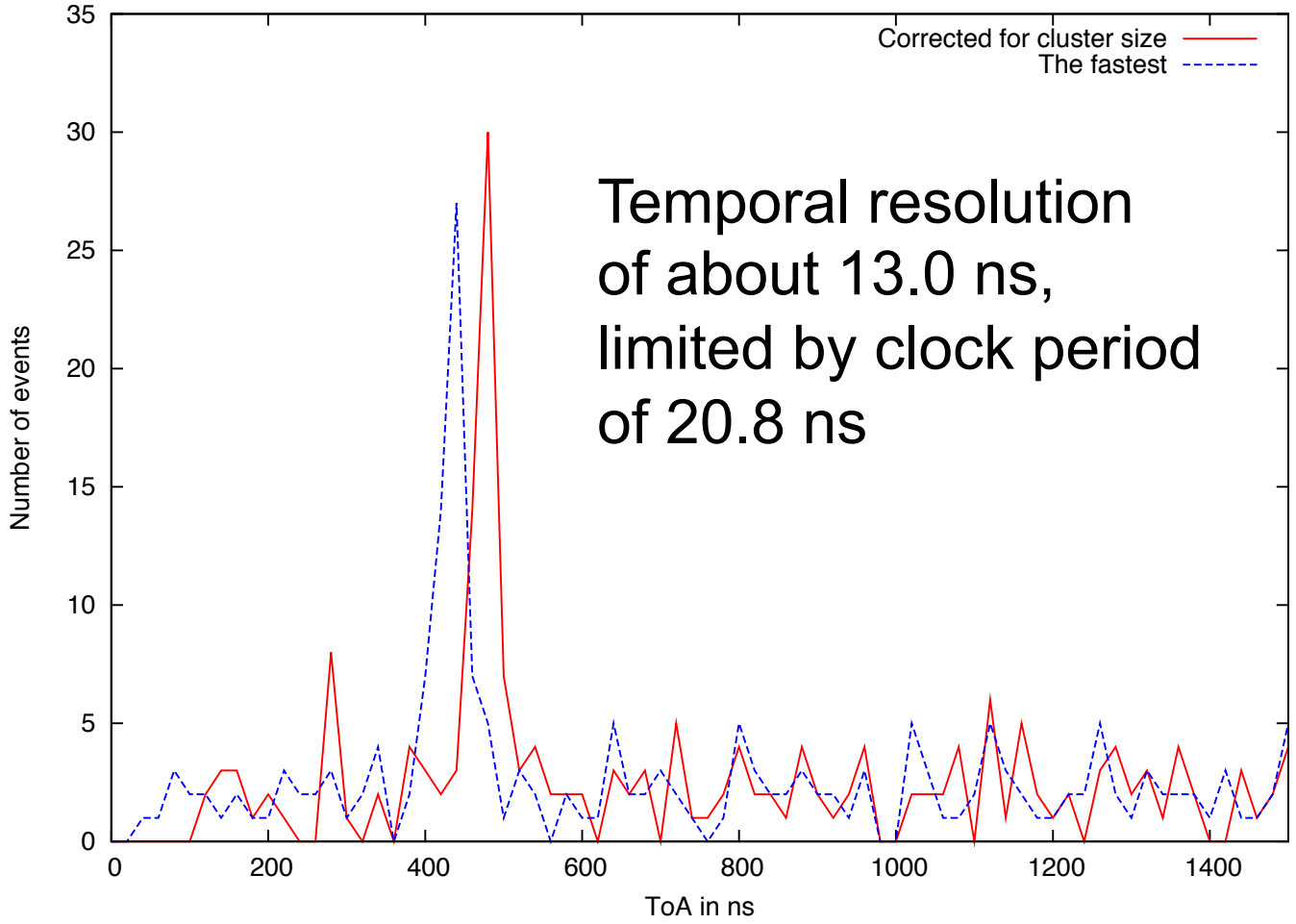
Distribution of time stamps from single optical photon

Experiment with single photons from spontaneous parametric down conversion



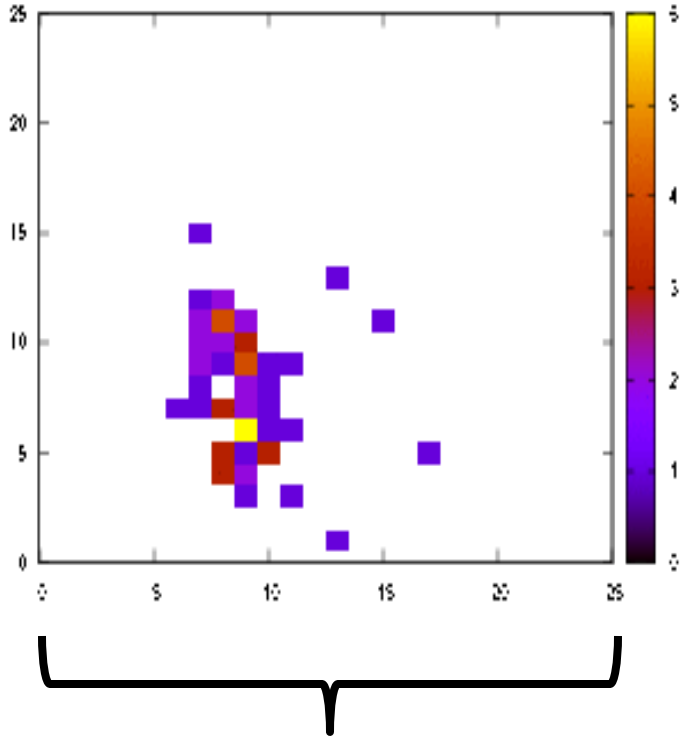
- Collaboration between ECAP and the Max-Planck-Institute for the Science of Light in Erlangen
- MPI: Maria Chekova, Felix Just, Andrea Cavanna
- ECAP: Mykhaylo Filipenko, Thilo Michel

Spectra of ToA in “earliest” pixel in cluster of single photons from spontaneous parametric down-conversion



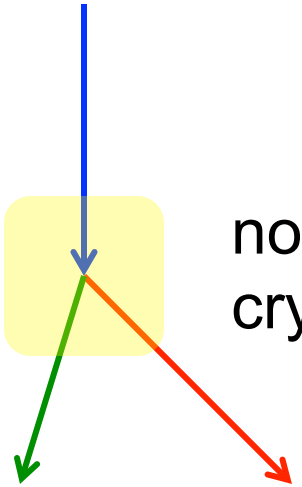
Images of a part of the rings from parametric down conversion

In coincidence with idler photon at APD



28 mm

Pump: laser starts HPD



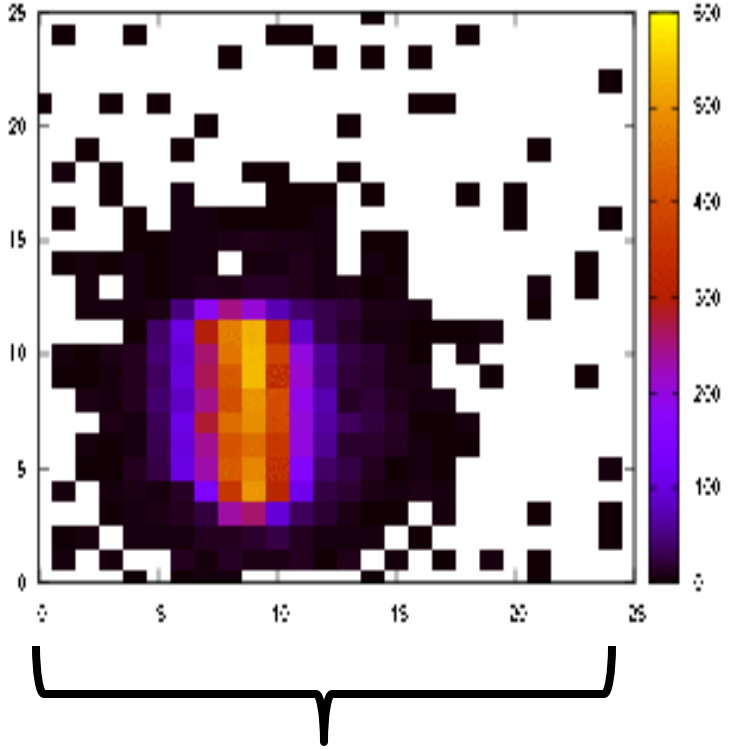
non-linear crystal

Signal: HPD in ToA-mode measures timestamp

Idler: Photodiode (APD) stops Timepix

Images of a part of the rings from parametric down conversion

No coincidence



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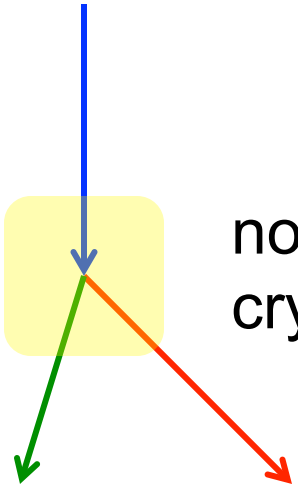
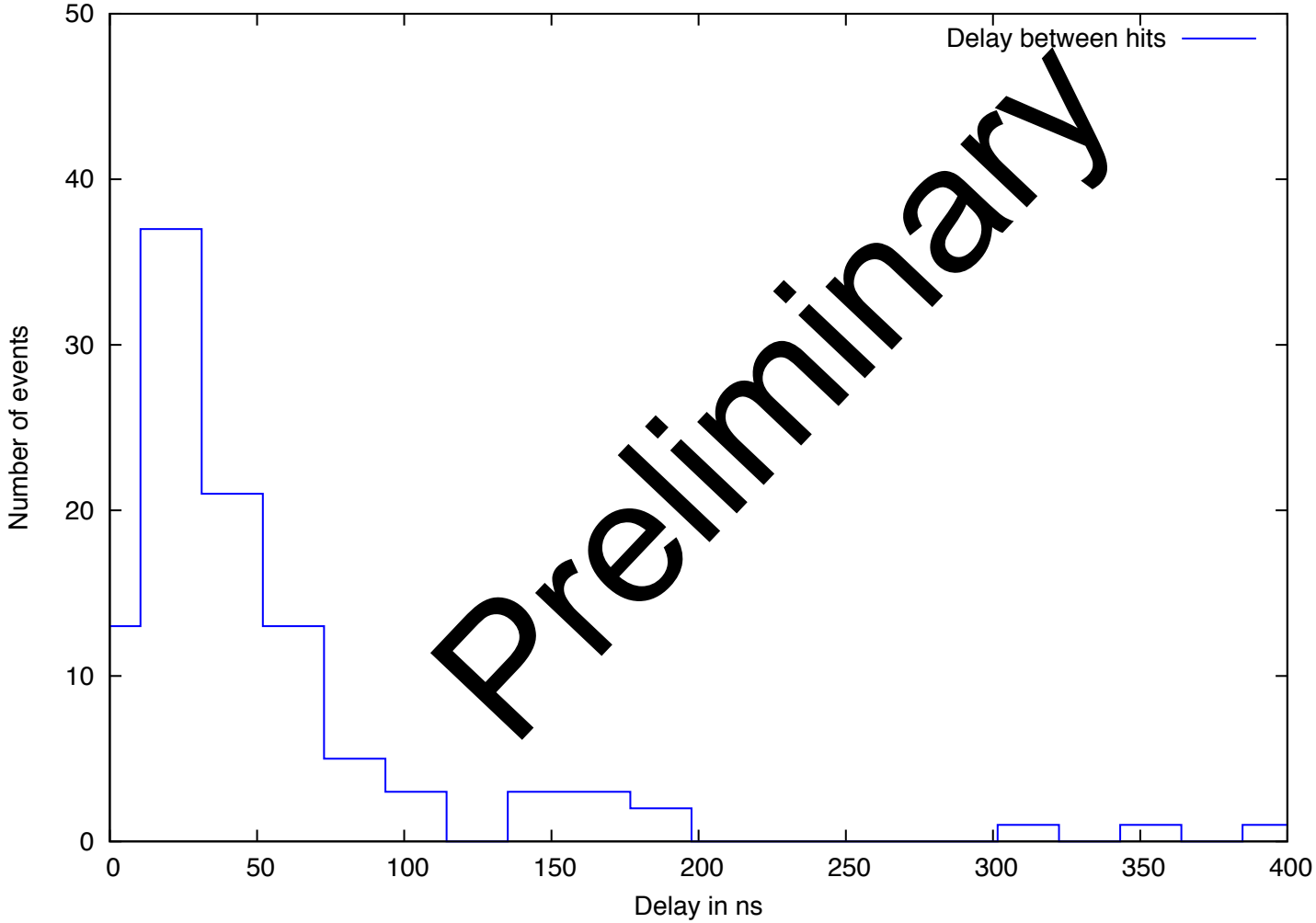


non-linear crystal

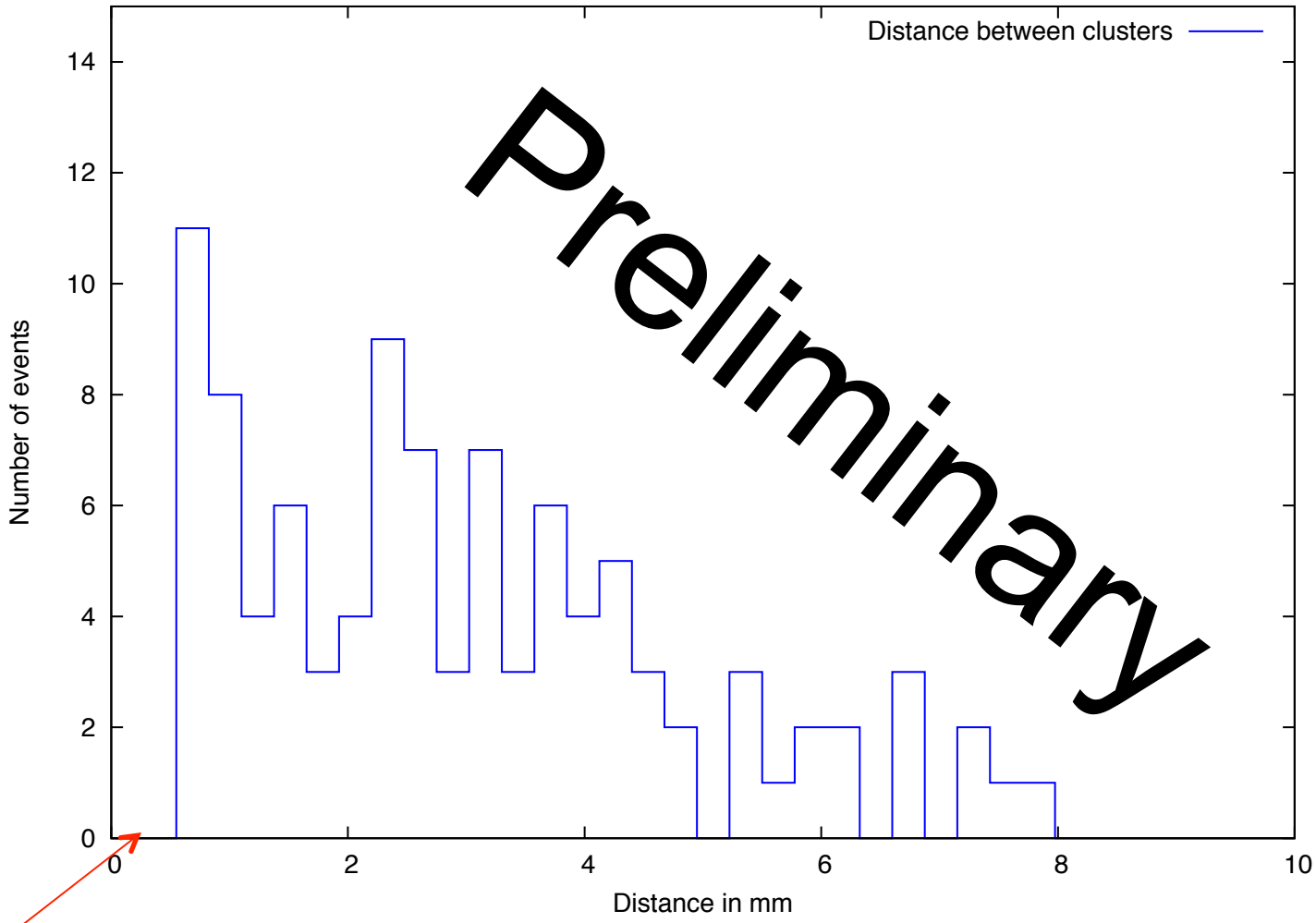
Signal: HPD in ToA-mode measures timestamp

Idler: Photodiode (APD) stops Timepix

Preliminary: About 5 % of the input rate is in “late coincidence” (probably linked to ion-feedback)

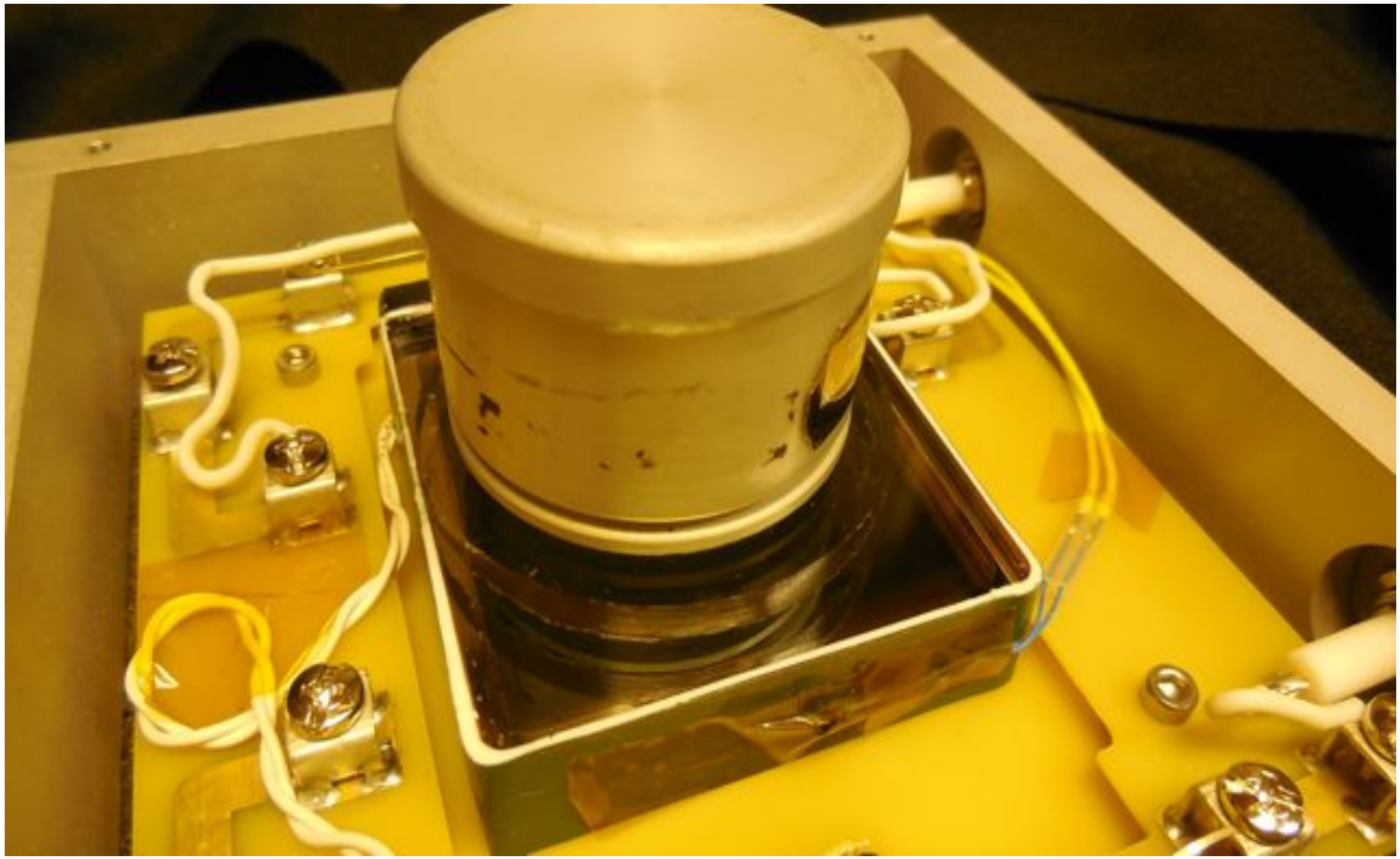


„Late coincidences“ are a long range effect



Gap is due to missing multi-hit capability of Timepix

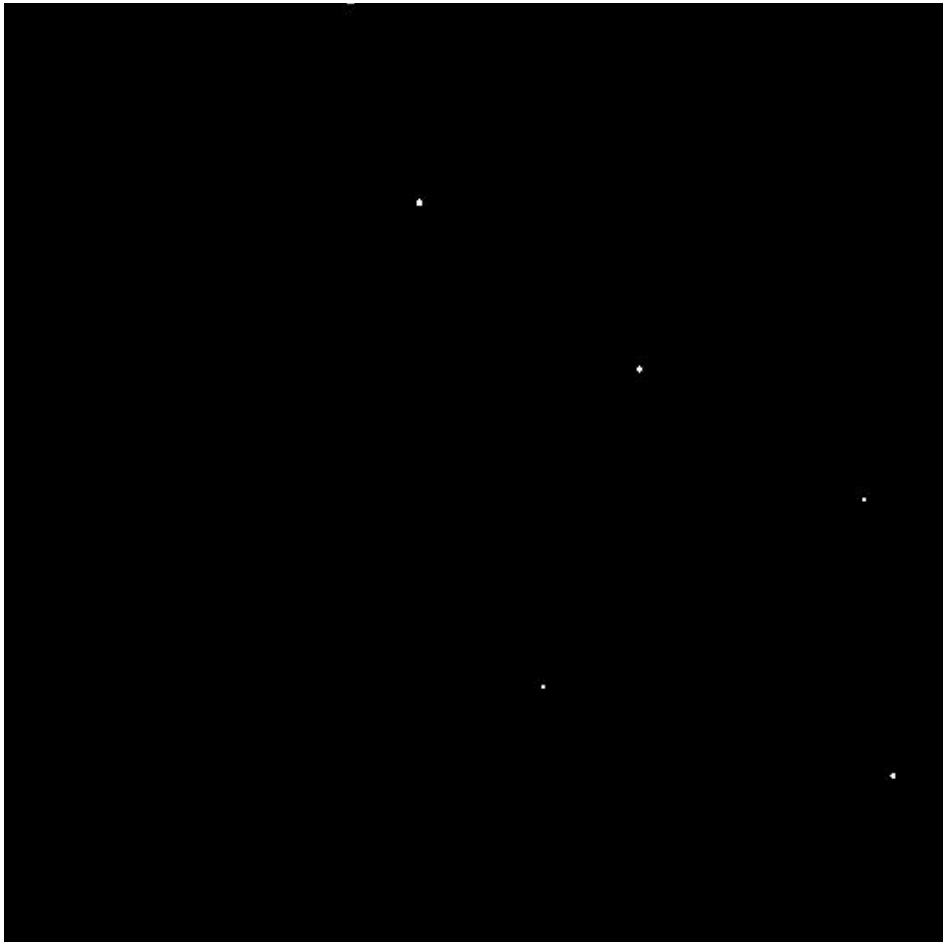
Scintillator Readout



40mm diam. BGO crystal, 5mm thick silicone coupler

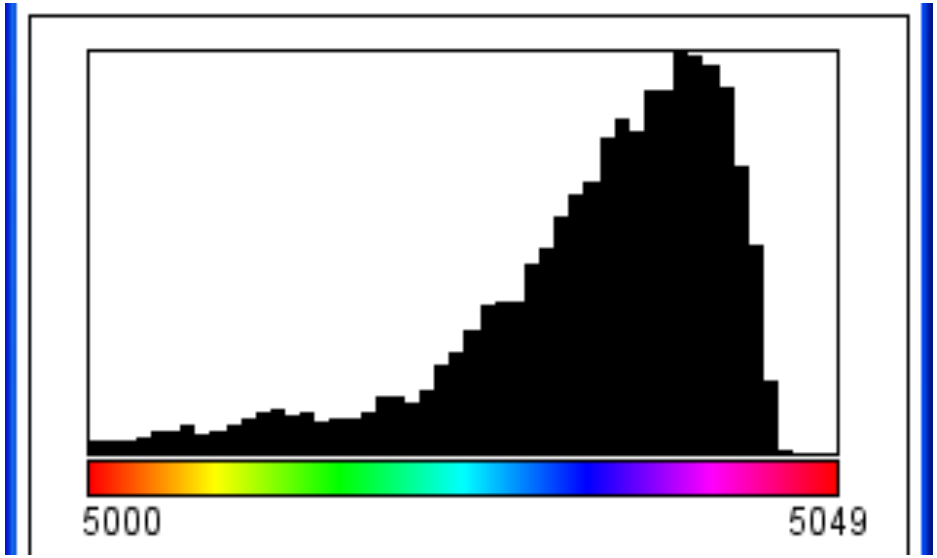
Gamma rays from Radium using BGO scintillator

100 frames at 100μs per frame

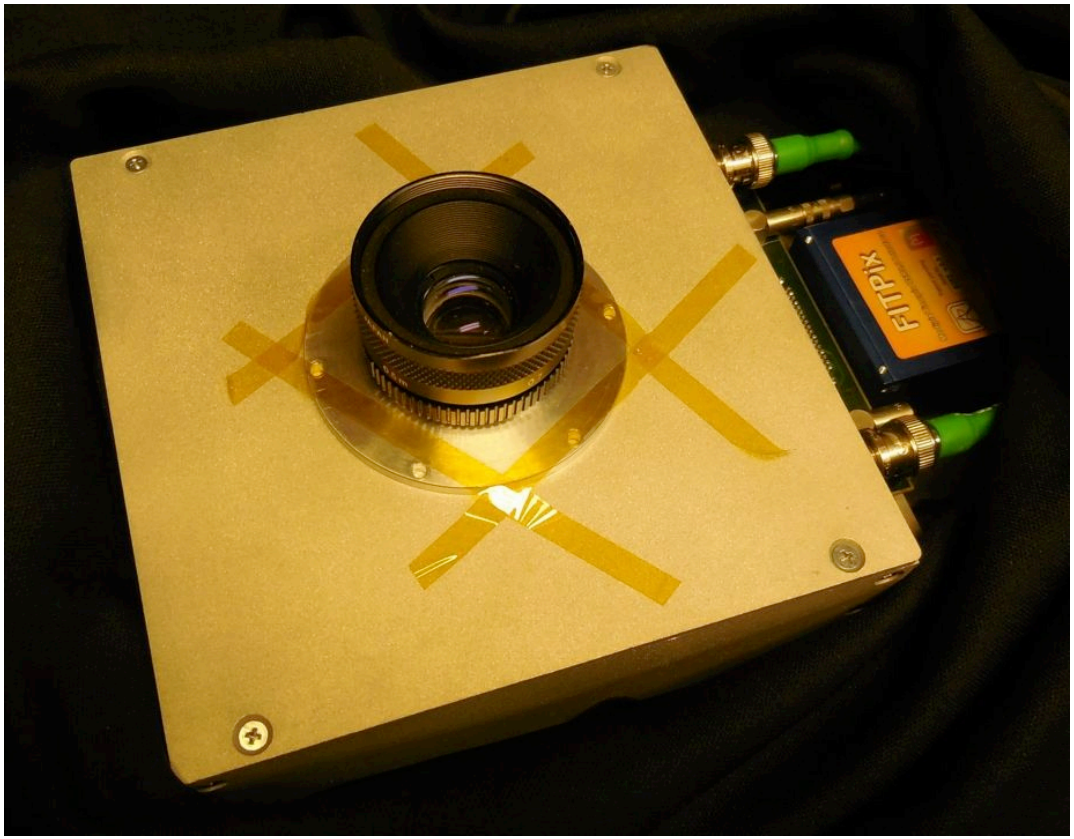


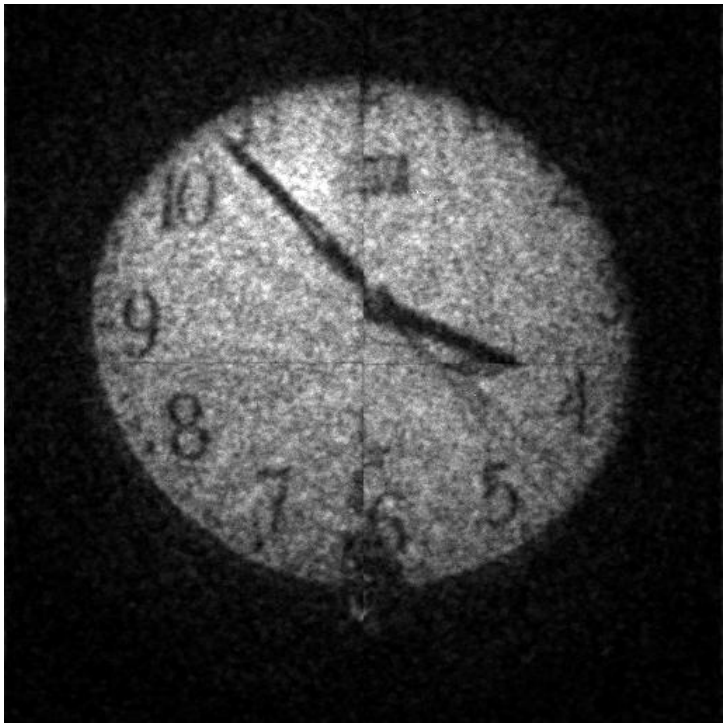
Temporal structure of photon pulse from one gamma ray in BGO crystal

- Histogram of Time stamps in single frame from one gamma ray
- Bin size is 20.8ns (48 MHz clock)
- 280ns FWHM with long tail (BGO decay time is ~300ns)



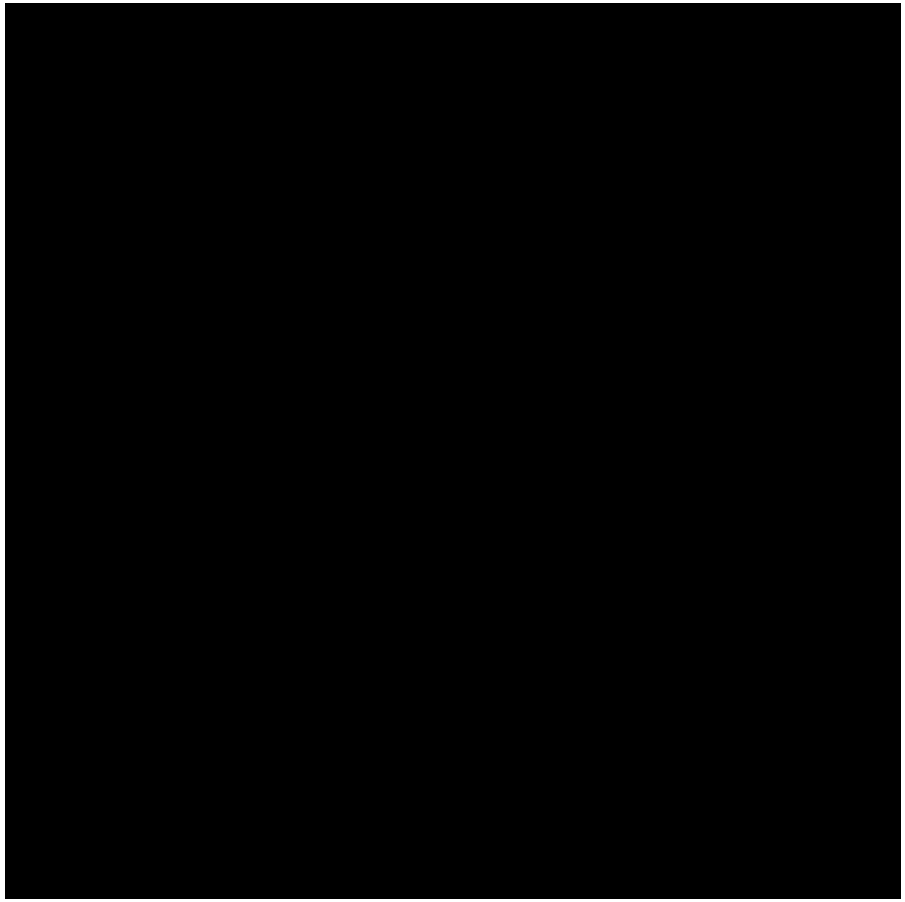
Optical Imaging



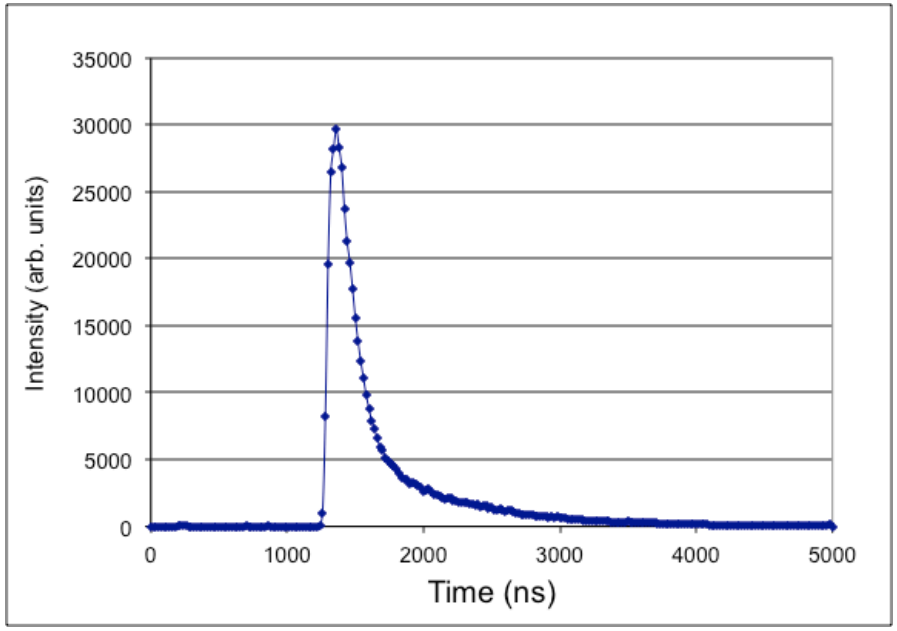


Short frames from ToA: Pulsed Diode (20ns/frame)

5 μs long movie, 20 ns per frame



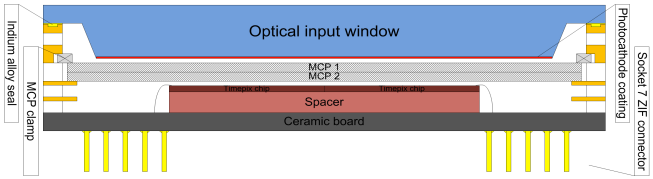
LED pulse is about 1.5 μs long



This is John Vallerga

What‘s next

- Test the second tube with drop-face-window (photocathode – MCP gap about 0.5 mm)



- New tubes with red-sensitive photocathodes would be better for quantum optics experiments (PDC, quantum dots) ???

- Increase pixel detector area to 3 x 3 $(\text{Timepix})^2$???

- Use Timepix3 with 1.6 ns time-resolution, data-push and TOT + TOA simultaneously ???

Thank you very much
for your attention!