Direct Measurement of Optical Cross-talk in Silicon Photomultipliers Using Light Emission Microscopy

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14th Pisa Meeting, La Biodola, Isola d'Elba, Italy
Photo Detectors and PID
May 28, 2018

Outline

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- Motivation for Silicon Photomultiplier (SiPM)
- Optical Cross-talk in SiPM
- Light Emission Microscopy and Experimental Setup
- Direct Measurement of Cross-talk in a sample SiPM
- Summary and Outlook

Silicon Photomultiplier (SiPM)

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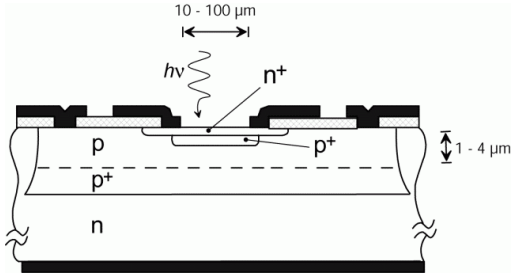
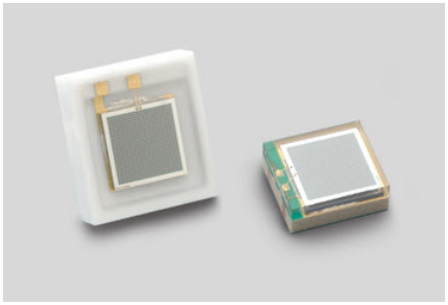
Solid-state single-photon-sensitive device
based on single-photon avalanche diode (SPAD)

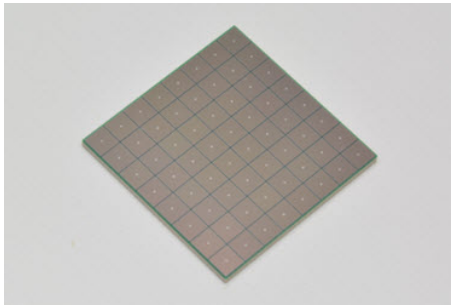
SPAD concept



Single element detector



Multi-element arrays



Advantages

Small cell sizes (10-100 um)
Nanosecond resolution
Low operating voltage
B-field insensitive
PDE greater than 40%
Large dynamic range

Disadvantages

High Dark Count Rates (wrt PMT)
Afterpulsing
Cross-talk

Optical Cross-talk in SiPMs

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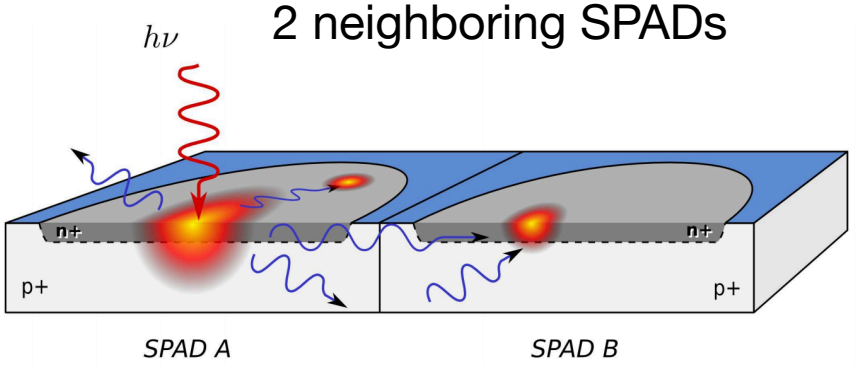
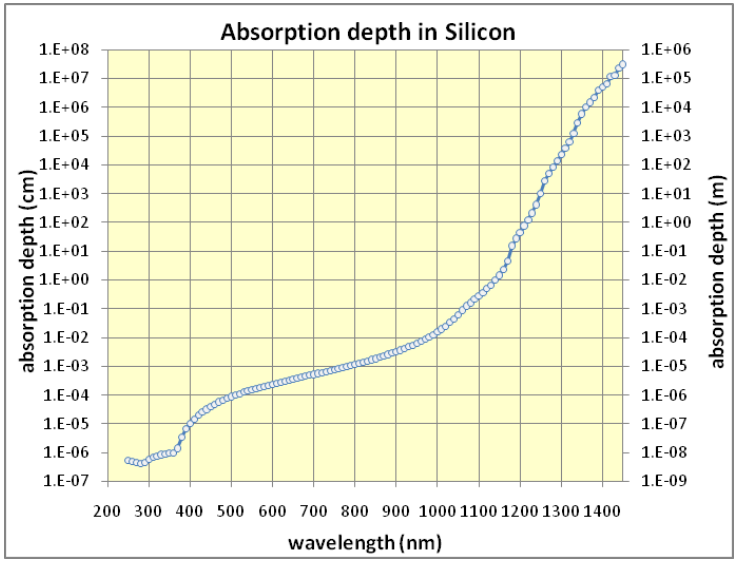


Strong energy dependence of photon absorption lengths in silicon



- Optical cross-talk
  - Probability for photons to trigger neighboring cells
  - Results in artificial increase in signal
  - Contributes to excess noise factor
  - Can be significant and problematic in applications

- Objective: to learn about cross-talk probability from light emission in SiPMs

Optical Cross-talk in SiPMs

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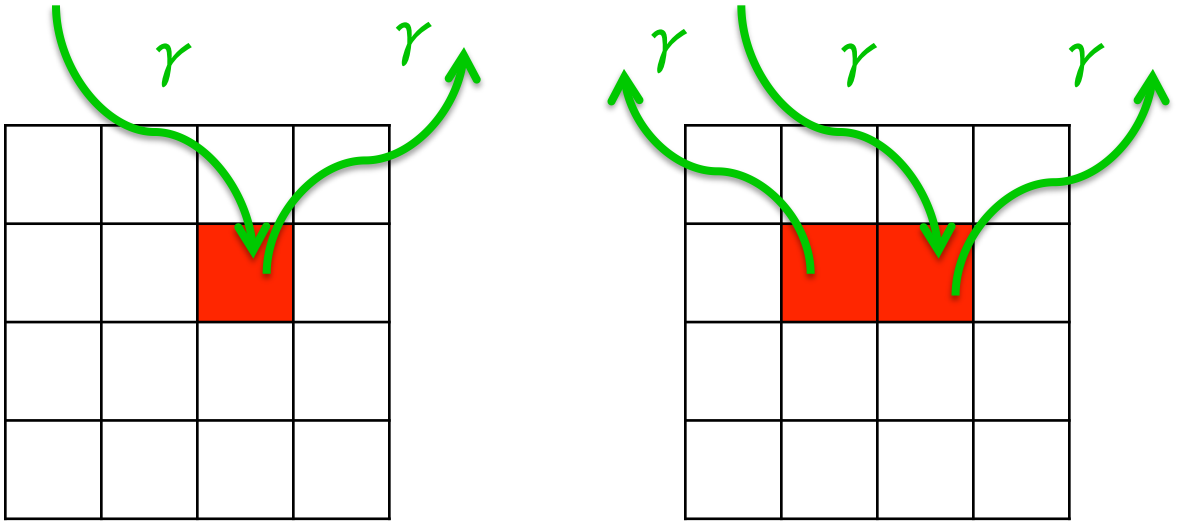
- How to measure cross-talk? By counting photons.

Avalanche

Avalanche & cross-talk

SiPM array



- Light emission microscopy (LEM) is a precise and powerful visual tool for directly measuring optical cross-talk.
- Useful to also observe defects in cells, morphology of the avalanche process, etc.

Light Emission Microscopy

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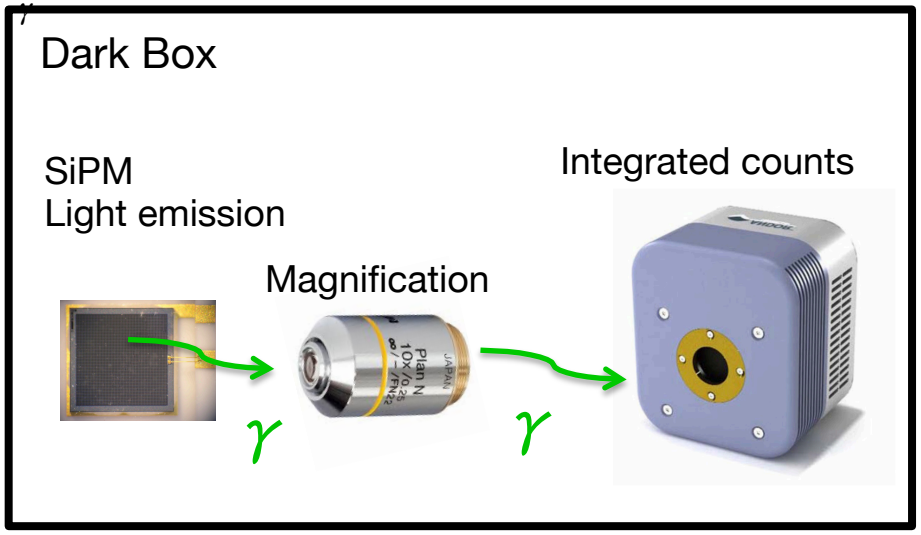
- LEM is a powerful root cause failure analysis technique for detecting low light levels otherwise not visible to an observer.
- Utilizes resolving power of an objective lens and a low-noise camera to detect weak light emission, e.g. from semiconductor devices such as SiPMs.



Direct Measurement of Cross-talk

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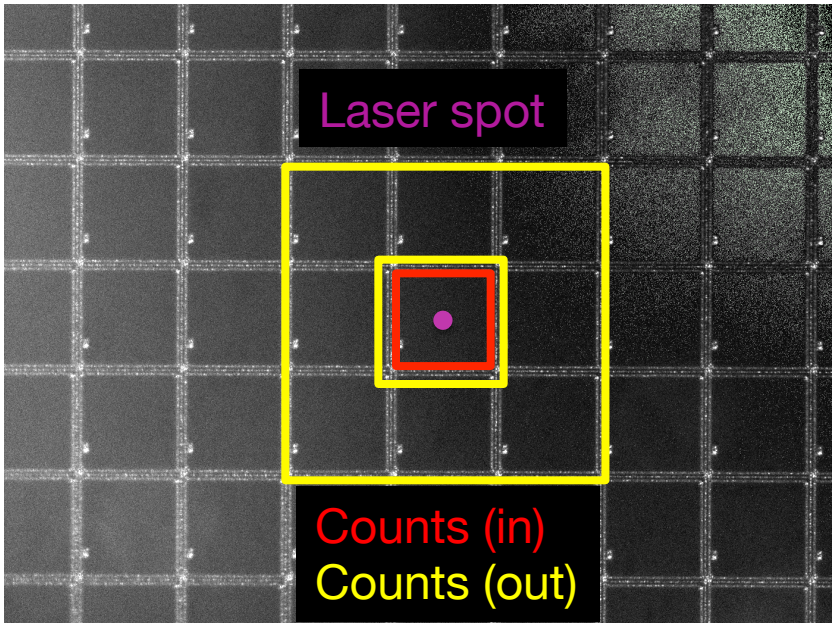
- Illuminate one SiPM cell with small laser spot (<< cell size).
- Observe emission of photons from primary and secondary avalanche processes using a microscope and record with a low-noise CCD.
- Count photons emitted from the central cell where laser is fired and from neighboring cells at distance 1 cell-unit away.
- Assume the counts outside central cell are all cross-talk counts since the laser is focused well within the central cell.

- Measure cross-talk

  Cross-talk = Counts (out) / Counts (in)

SiPM Array



Setup

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PC

CCD camera (Andor Clara)
1392 x 1040 sensor
2.5 e^- readout noise
1 e^-/hr thermal noise

Tube lens

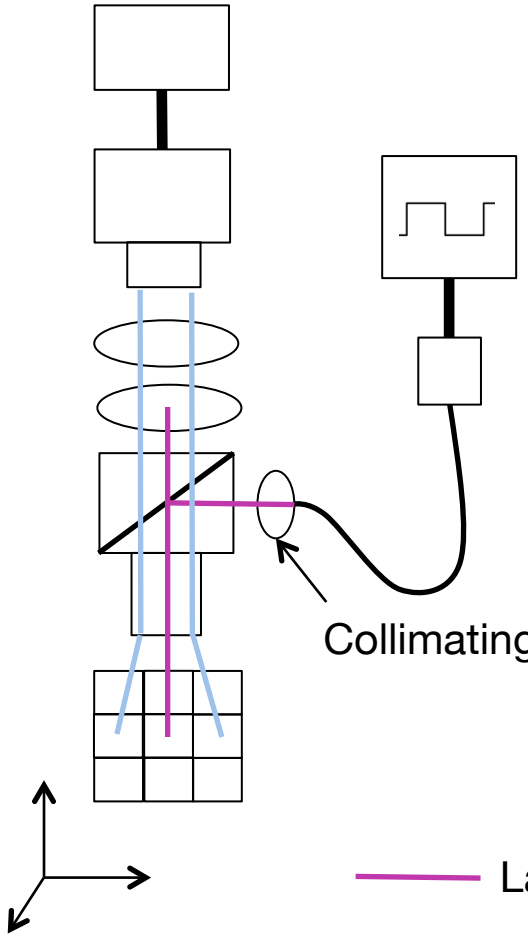
Long pass filter (495 nm)

Pellicle beam splitter

Objective Lens (Olympus 10X, 0.25 NA)

SiPM sample

X-Y-Z translation stage



Function generator

Laser (440 nm)
~10 ps pulse width

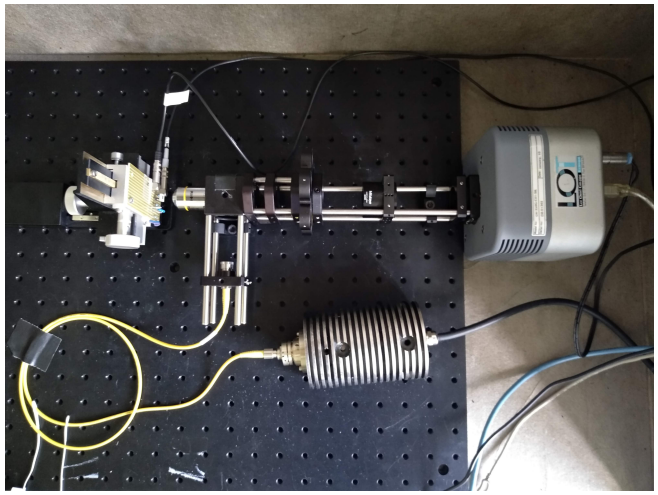
Single mode fiber

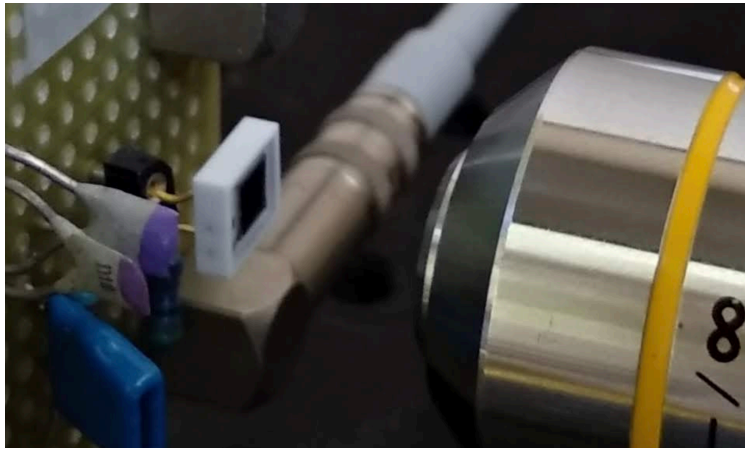
Collimating lens

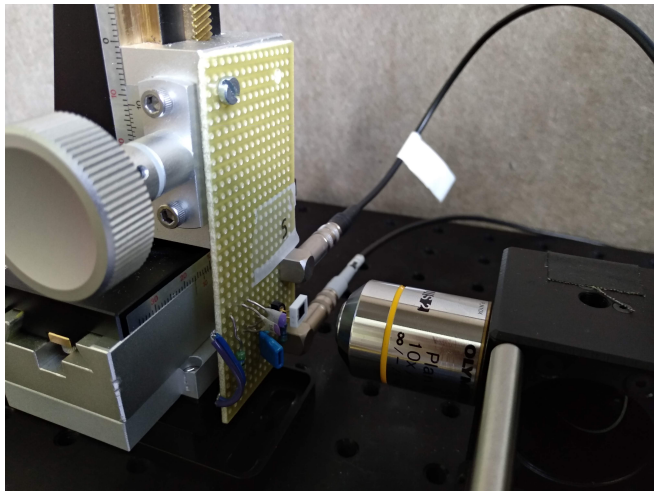
Laser

Light emission

Setup







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SiPM Sample

- Hamamatsu LCT4 single element
- Device size = 3 mm x 3 mm
- Cell size = 75 um x 75 um
- Breakdown voltage = 51.10V
- Cross-talk measured as function of overvoltage

SiPM under 10X Magnification

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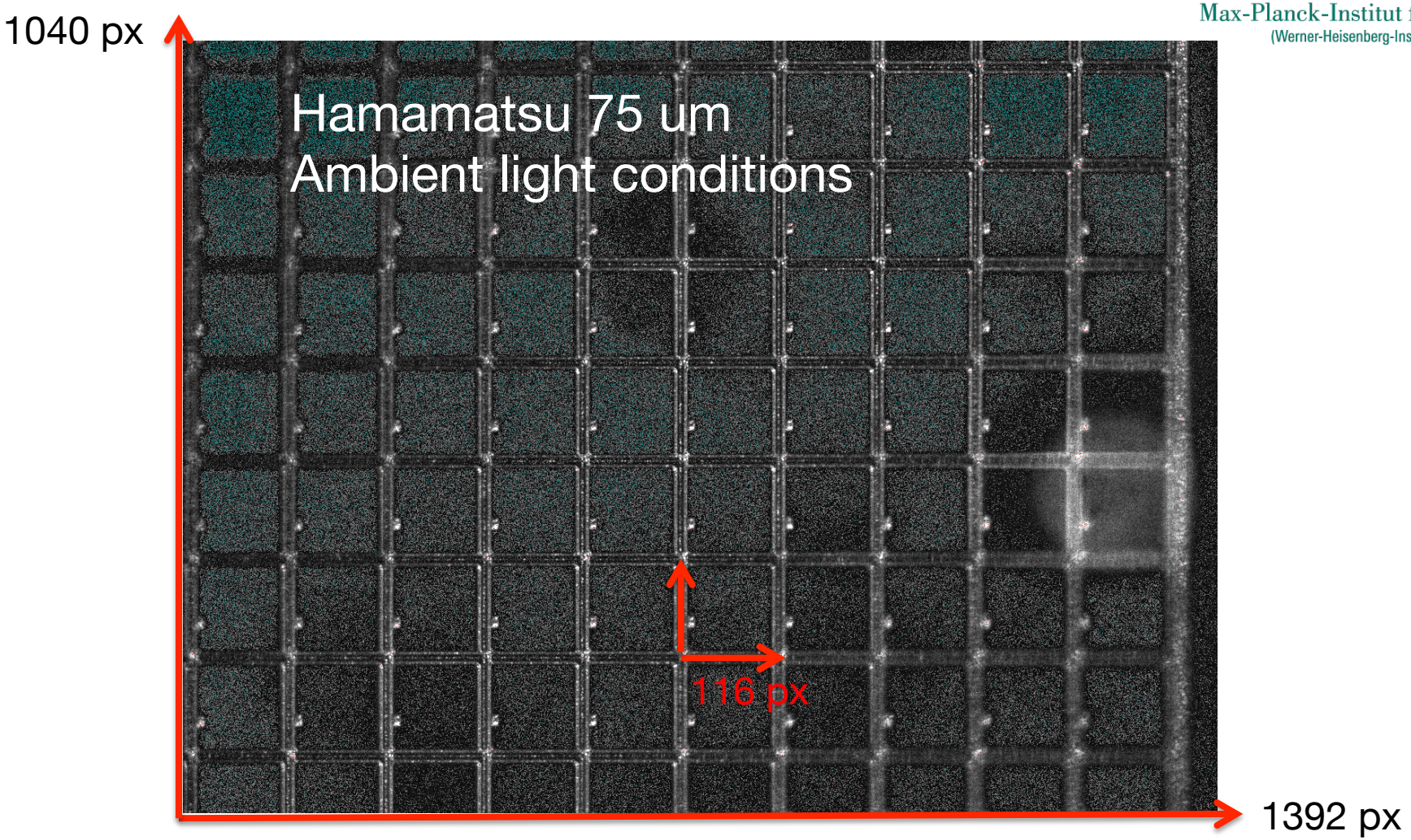

CCD Imaging Steps

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Step 1: Dark image

Step 2: Background image with laser light only

- To account for any reflections off surface of SiPM

Step 3: Background image with bias voltage only applied to SiPM

- To account for light emission from powered device

Step 4: Signal image with laser light and bias voltage applied to SiPM

Integration time for each step is 30 seconds

Beam Profile

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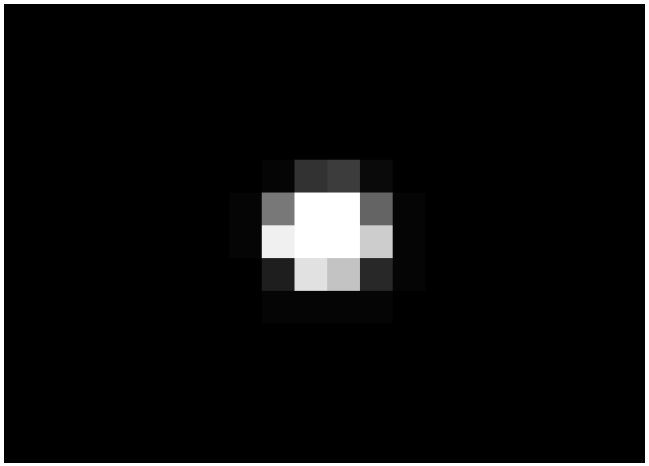
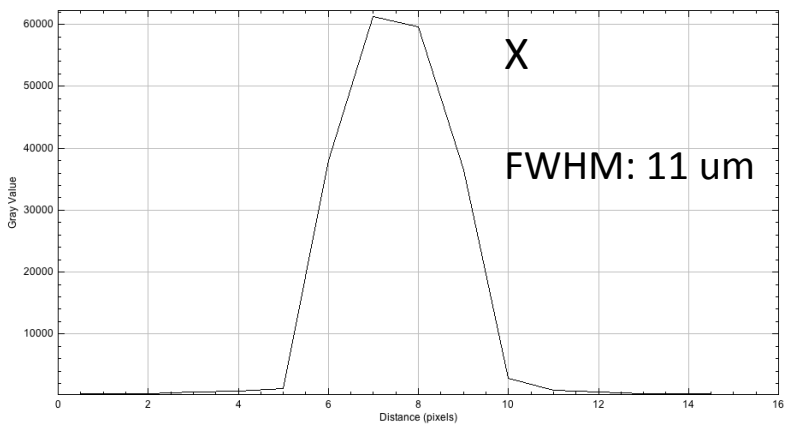
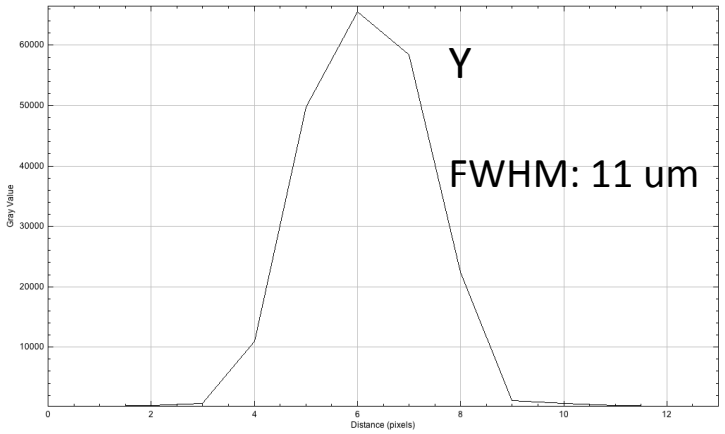


Measured with CMOS camera
1px = 3.8 um





Observed Light Emission

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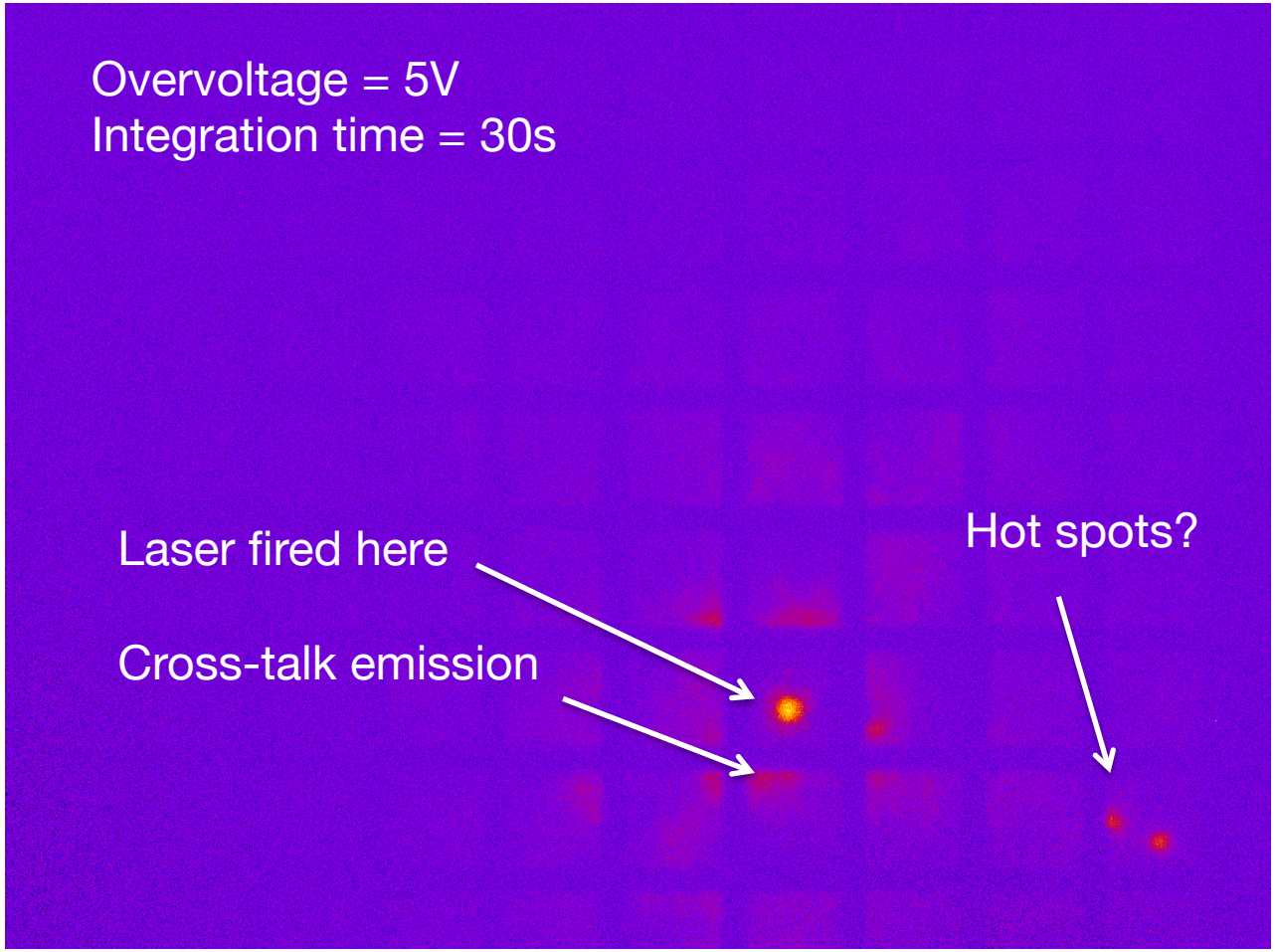

Observed Light Emission

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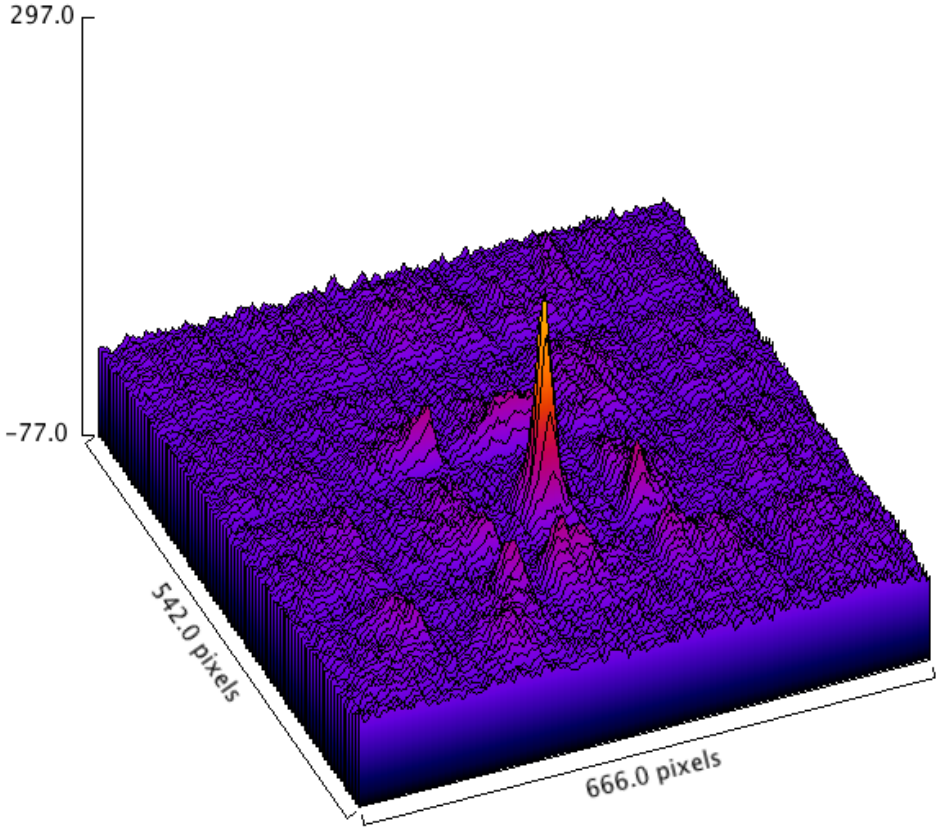
- The laser light is focused on a single cell.
- Light is observed from the fired cell and also neighboring cells.



Direct Measurement of Cross-talk

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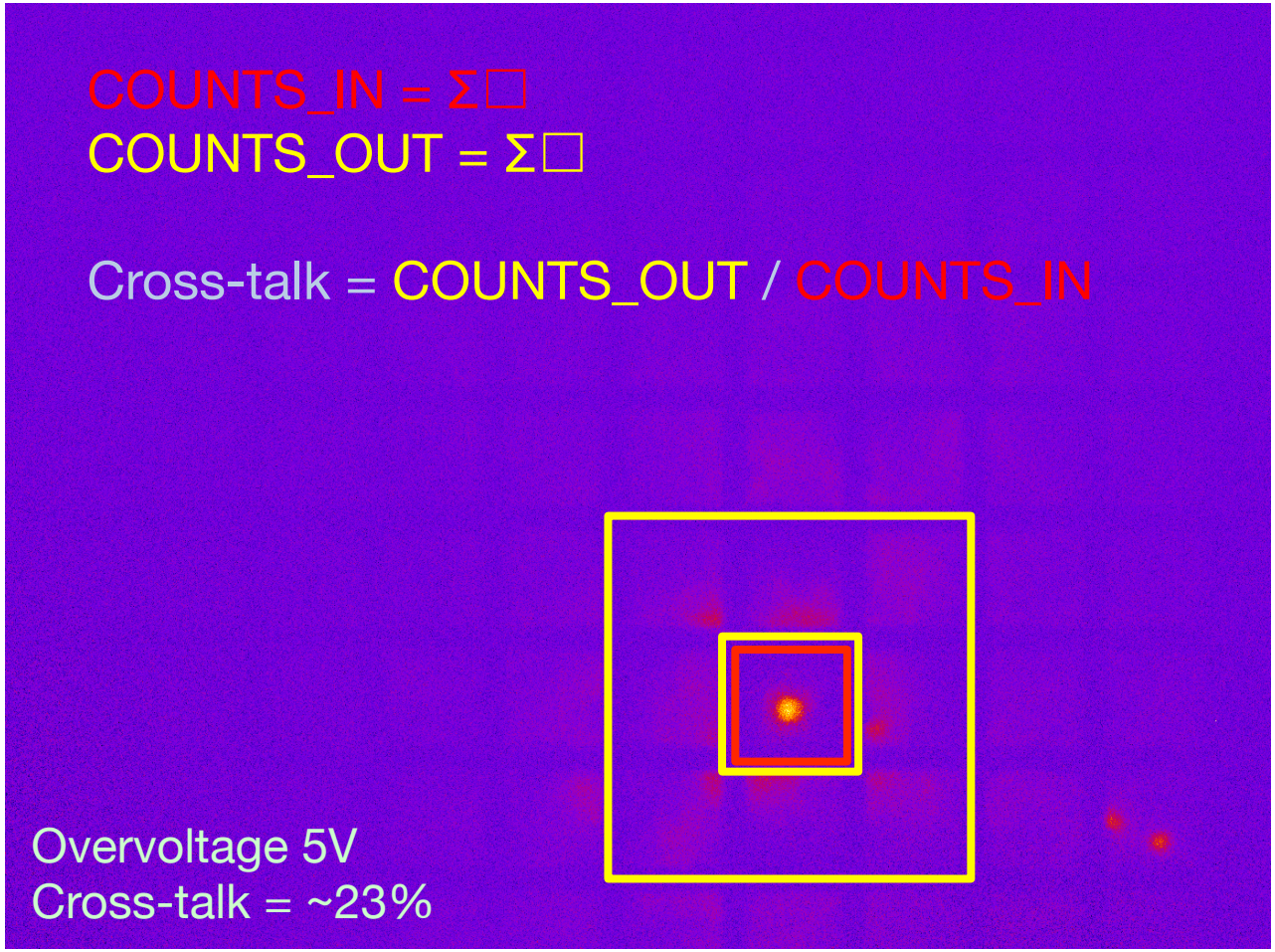

Optical Cross-talk vs. Overvoltage

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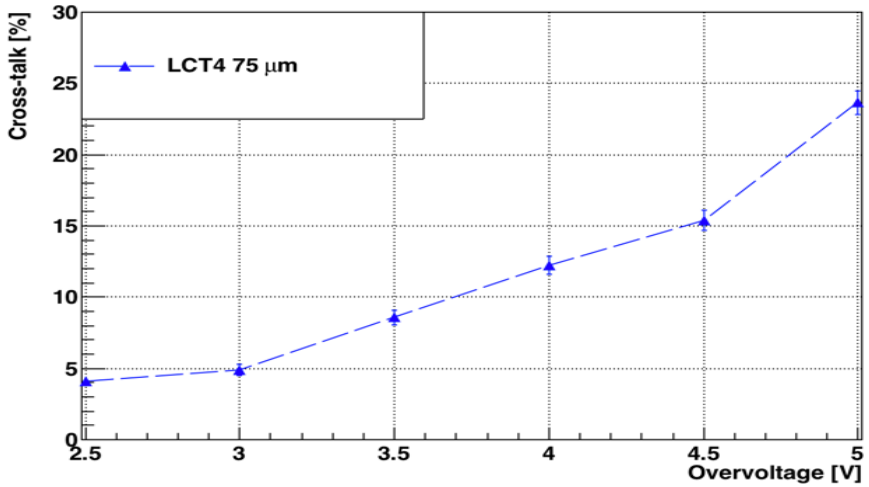
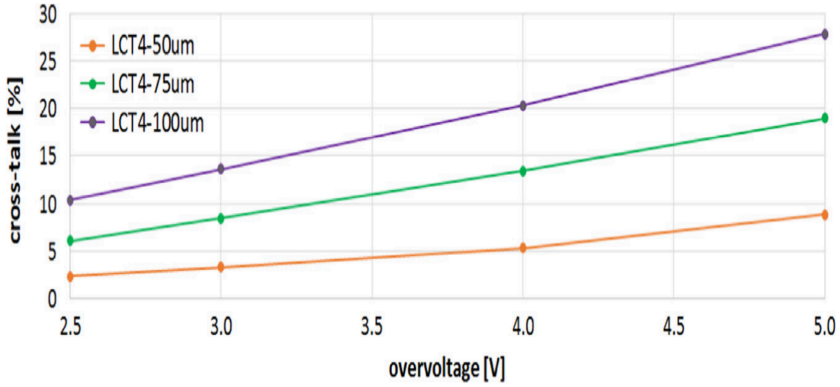
LEM Method - Preliminary



Standard Method (i.e. theshhold)



[NIM A 806 (2016), 383-394]

Summary and Outlook

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- SiPMs are attractive photo-detectors for high-energy and astroparticle physics experiments.
  - Compact in size
  - Fast (few ns) response time
  - Low operating voltages compared to classical PMTs
  - Insensitive to magnetic fields
  - Photon detection efficiencies greater than 40%.
- Crucial to reduce/eliminate cross-talk between neighboring cells.
- Light emission microscopy is a powerful visual tool for measuring and understanding the physics behind optical cross-talk, as well as for observing defects, avalanche morphology, etc.
- LEM method is the most precise measurement of cross-talk.
- Plans to measure cross-talk:
  - in new batches of SiPMs.
  - in cells > 1 unit distance away from center.
  - at different regions of the cell.
  - near the borders of the device.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no 713171

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Ultimate Low Light-Level Sensor Development

SENSE

sense-pro.org

See us at the poster session

Consortium Members

UNIGE: A. Nagai, D. della Volpe, T. Montaruli

KIT: A. Haungs, K. Link

DESY: K. Henjes-Kunst

MPI: R. Mirzoyan, D. Strom

Backup

Low Intensity Background Rejection

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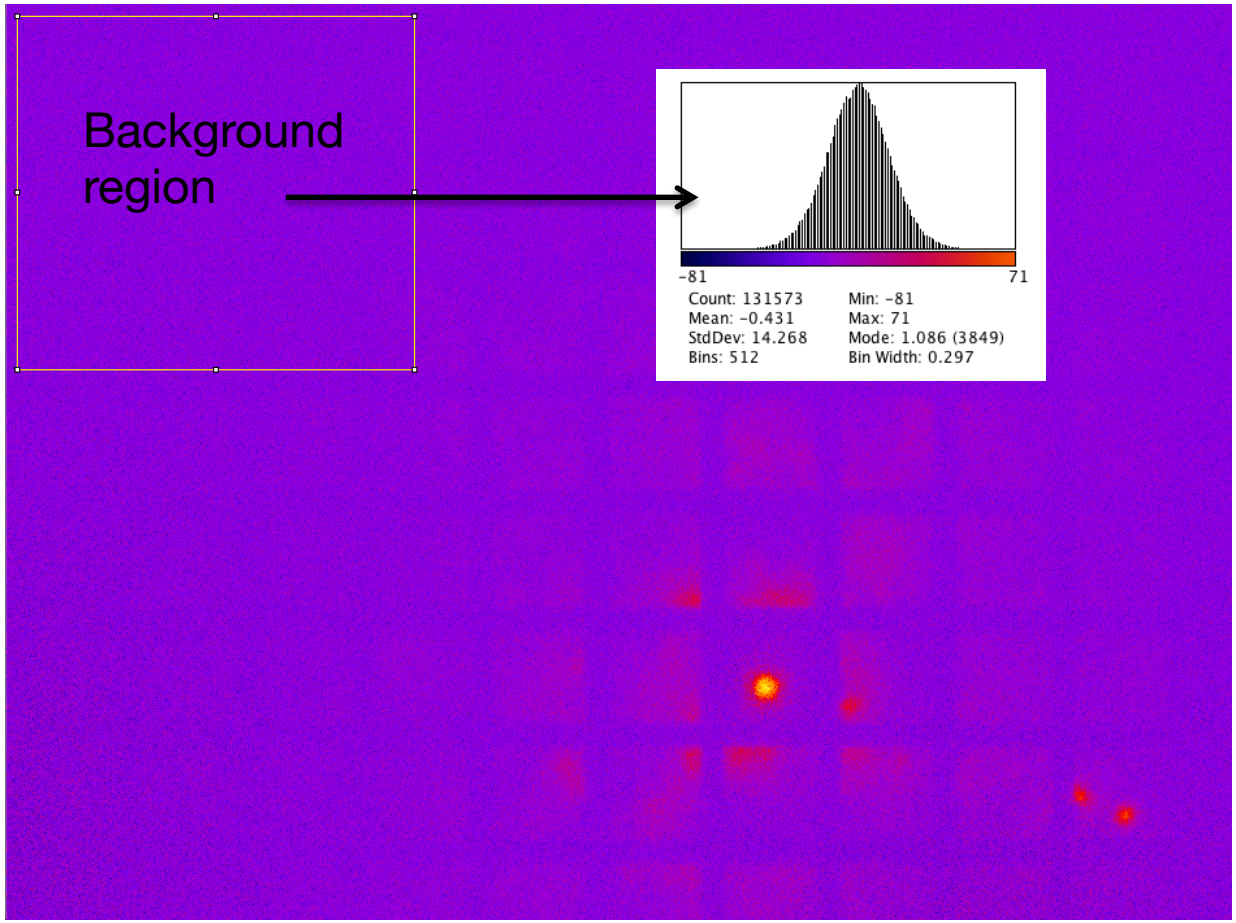

Low Intensity Background Rejection

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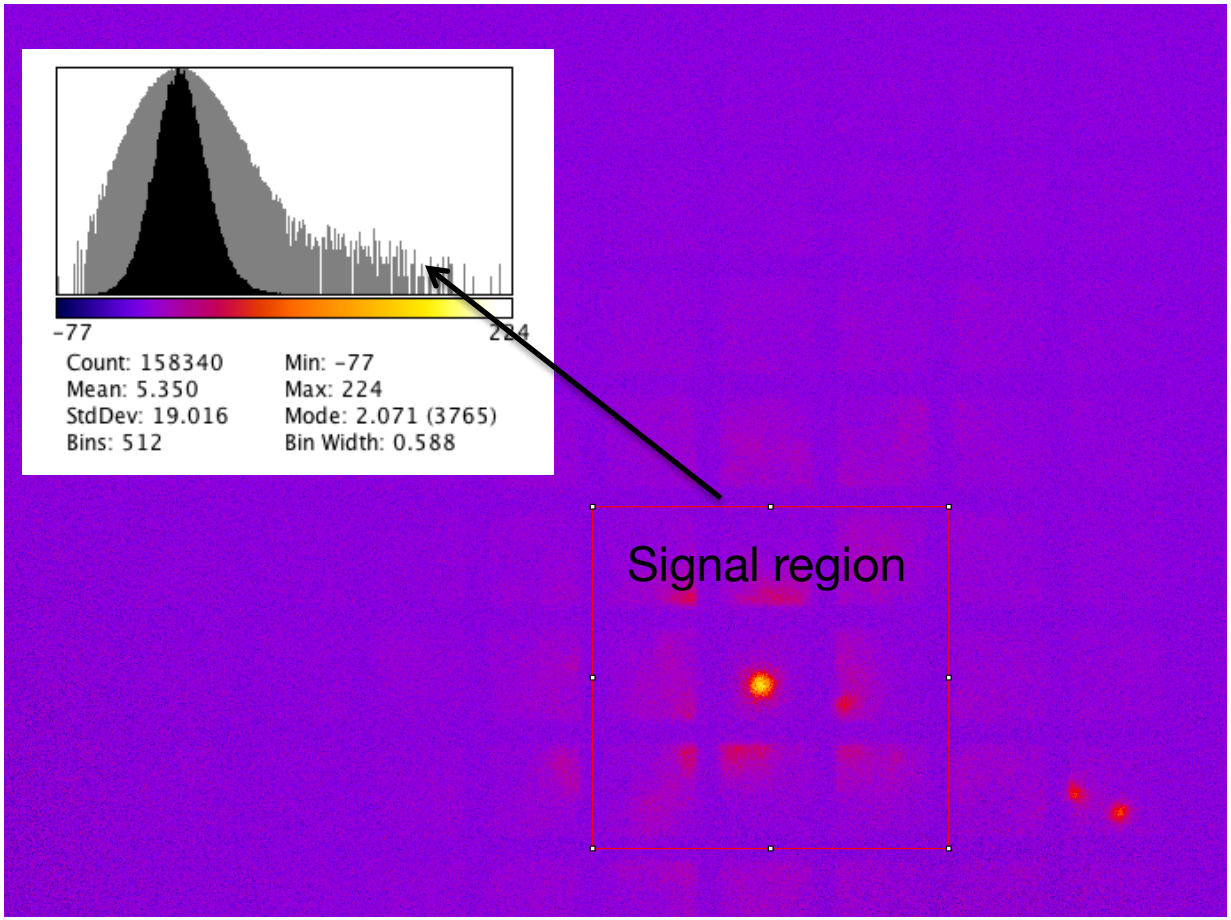

Hot Spot

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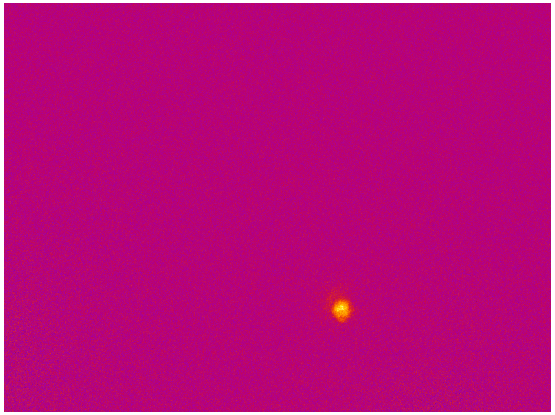
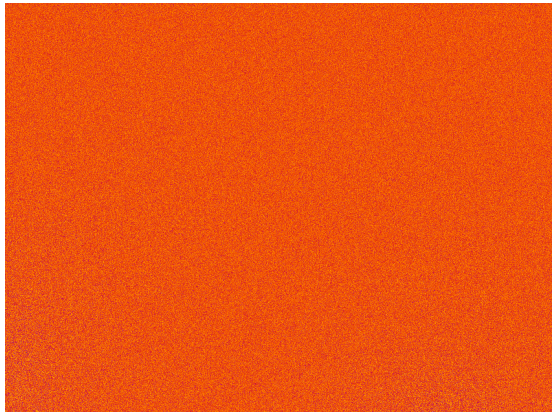
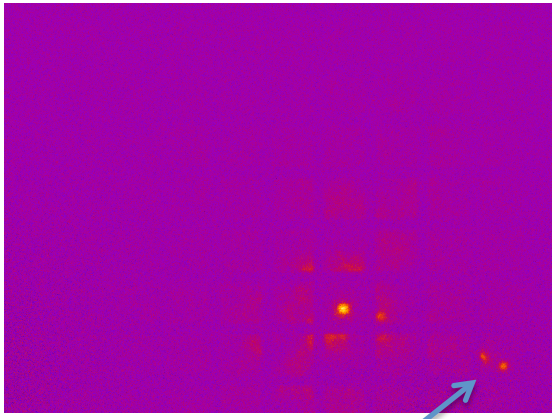
Bkg: Laser Only



Bkg: Bias Only



Signal



Emission observed in signal image only

SiPM under 10X Magnification

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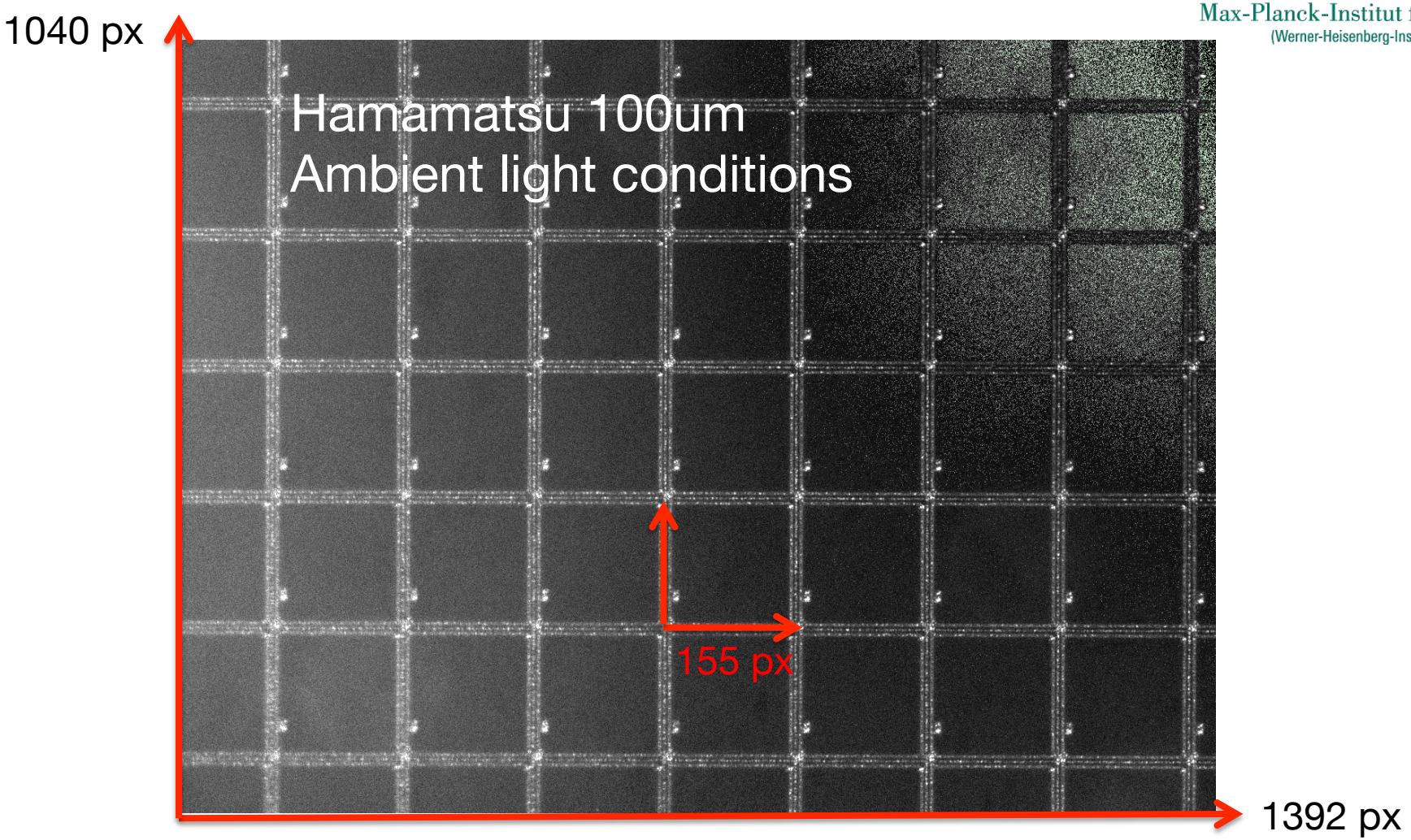

Scope Trace

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Laser pulse
500 kHz

SiPM output