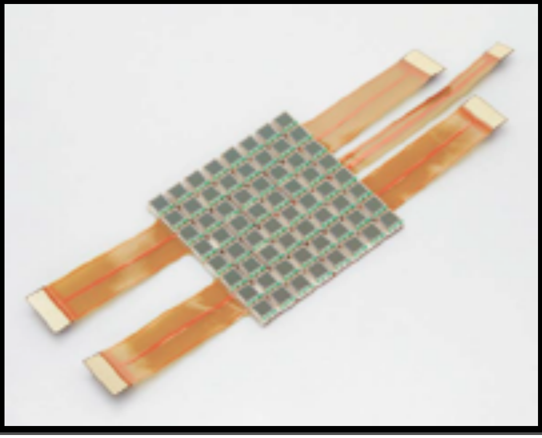
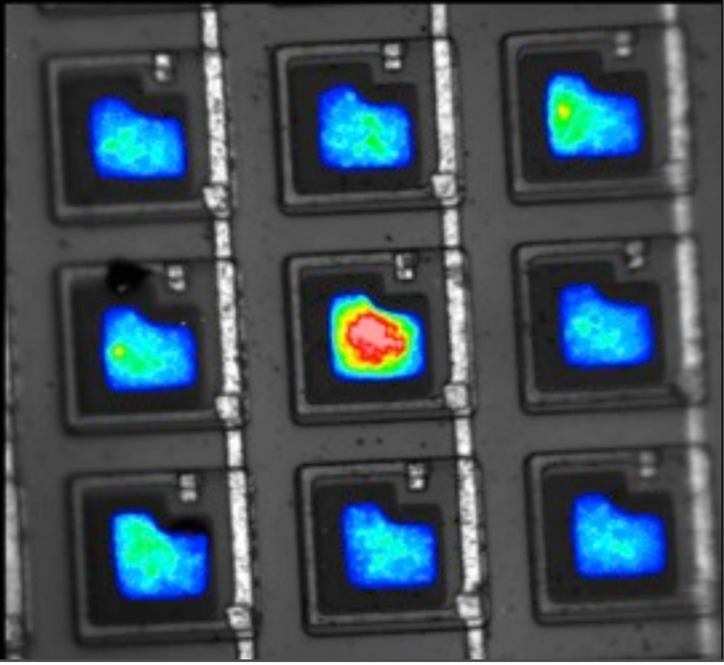
SiPM characterization, concept and measurements

SiPM workshop LIP, April 18, 2012

Thomas Schweizer





Principle of SiPM and some basic properties

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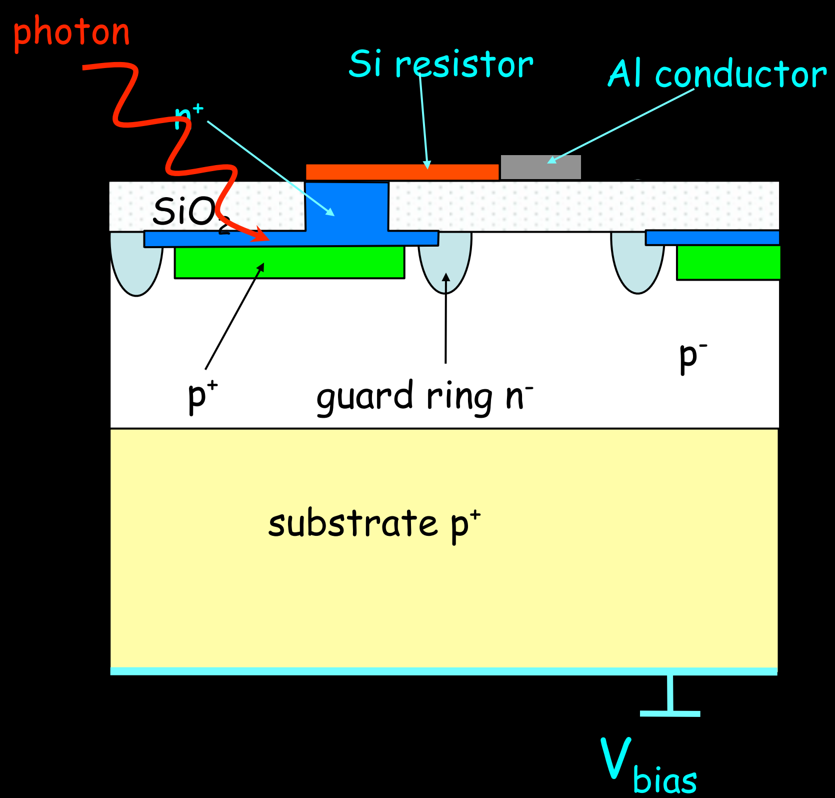
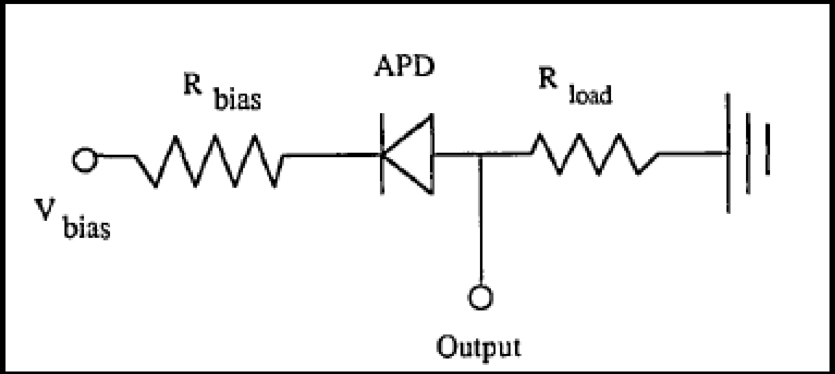
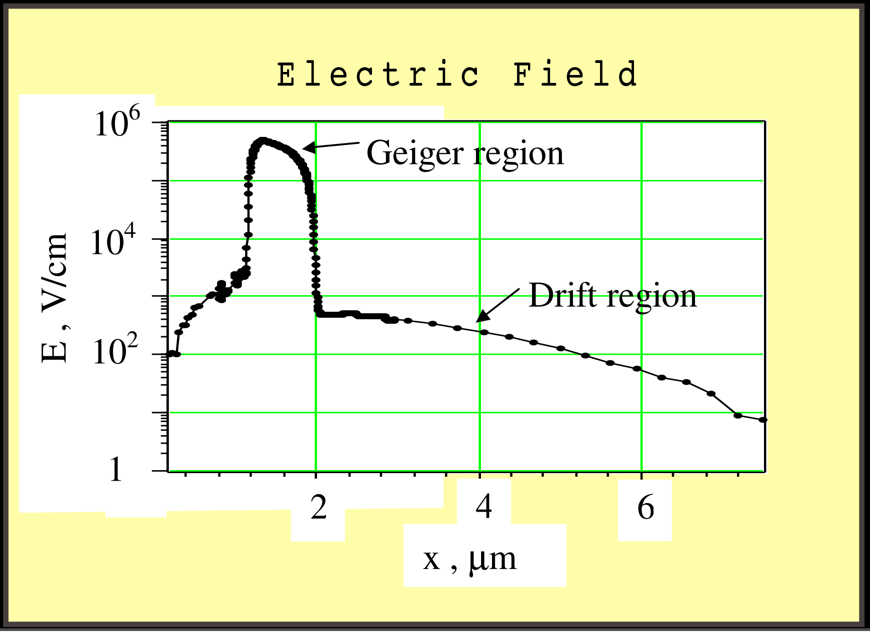
Concept of SiPM

- APD in Avalanche Geiger Mode
- Passive quenching resistor







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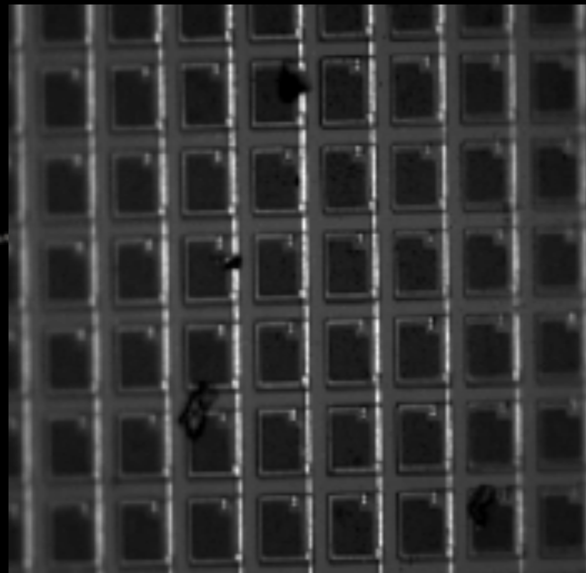
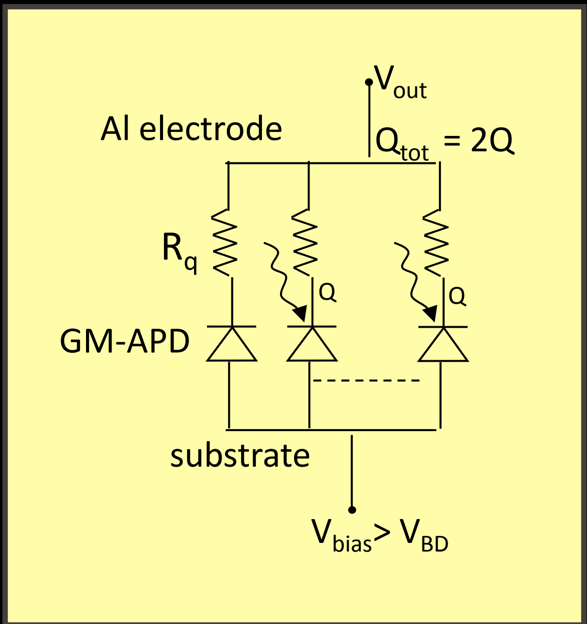
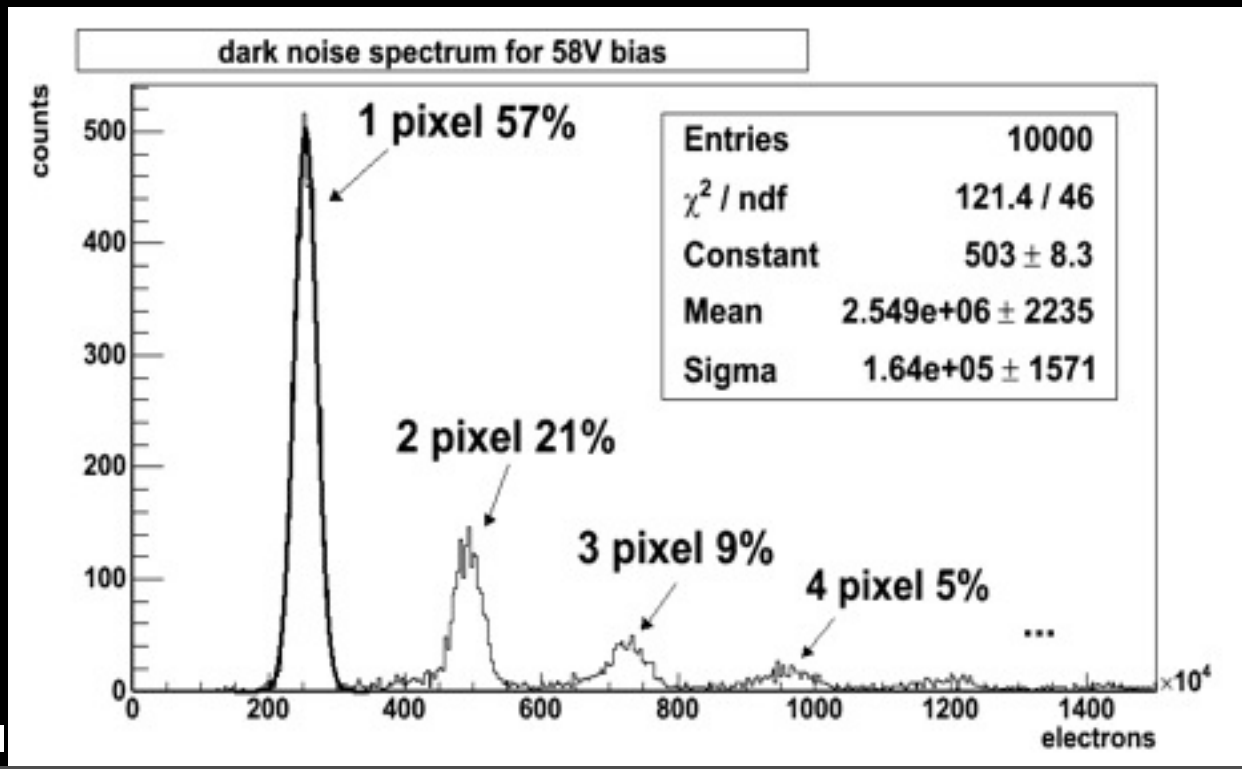
Summing many cells



Count number of cells fired





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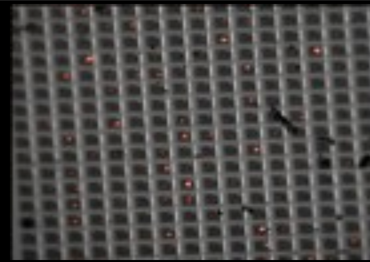
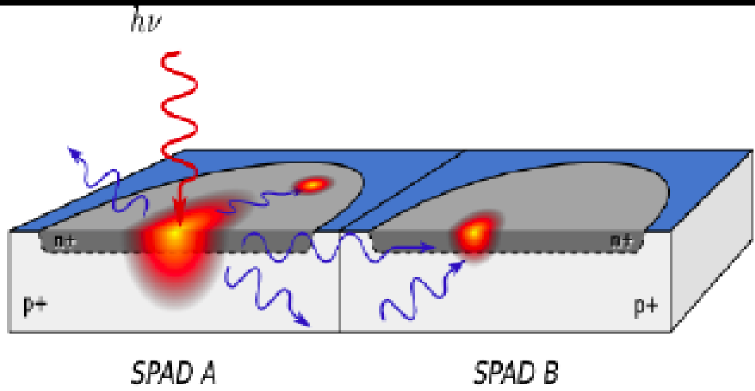
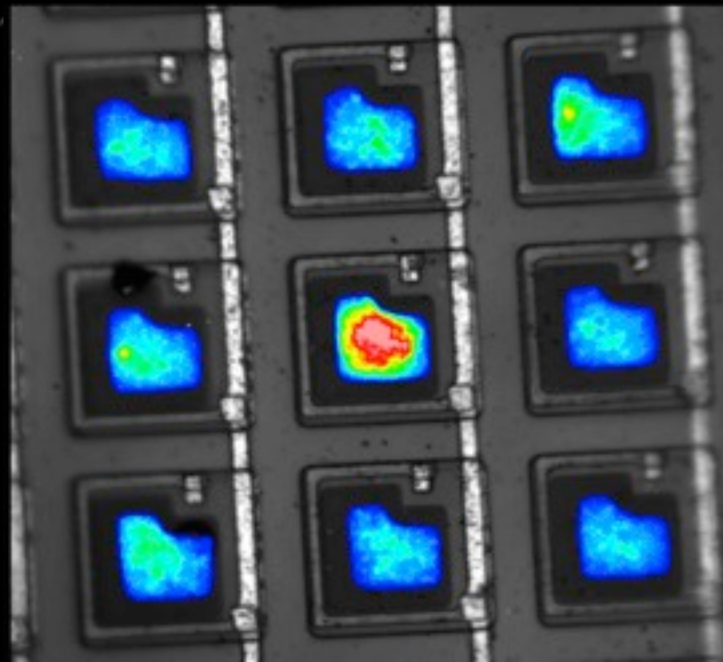
Problem: Optical crosstalk
Light produced in avalanche process

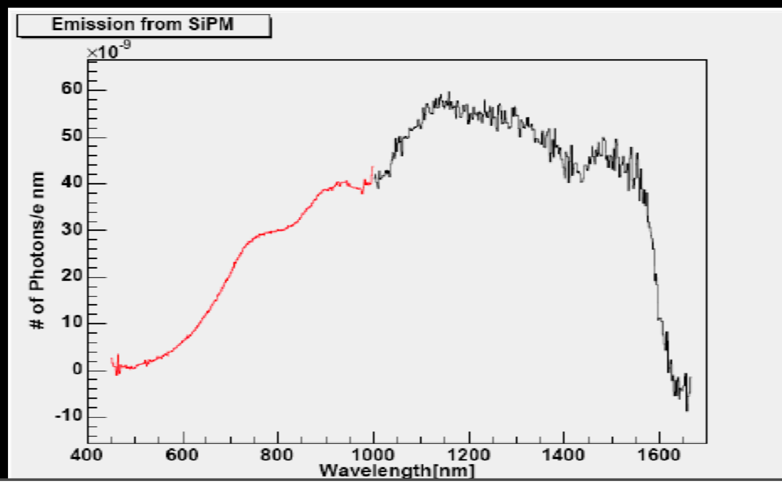






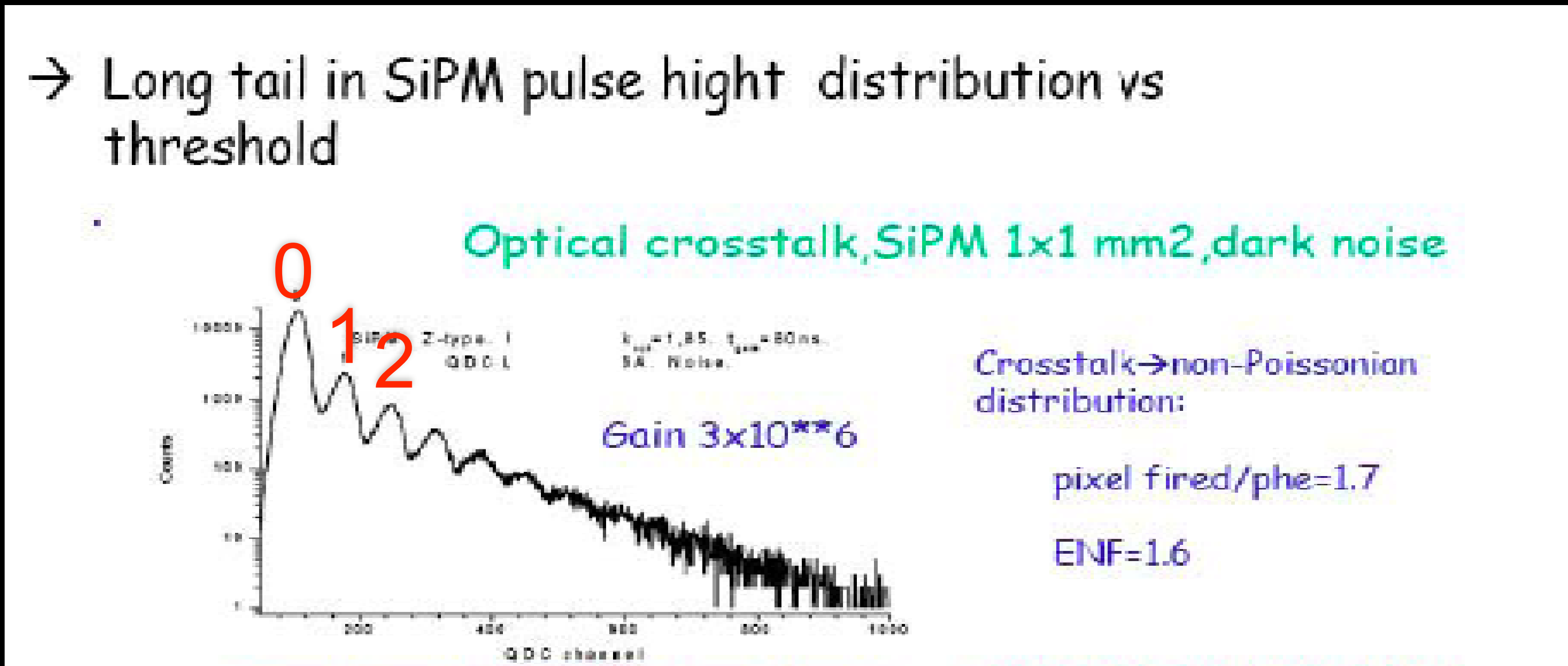
When an avalanche is triggered in one SPAD we have:

- Secondary photons emission due to the avalanche current
- Photons propagation throughout the chip
- Secondary photon detection by a nearby detector



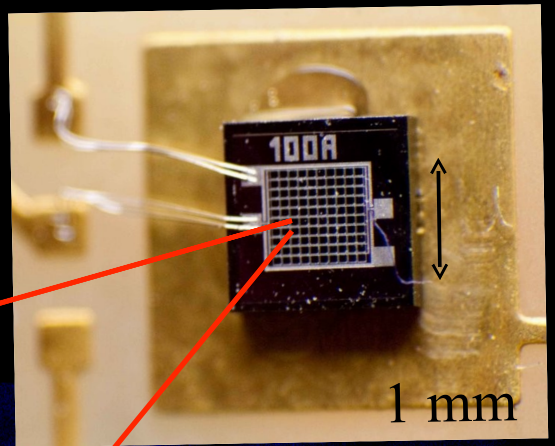
SiPM Spectrum with afterpulses

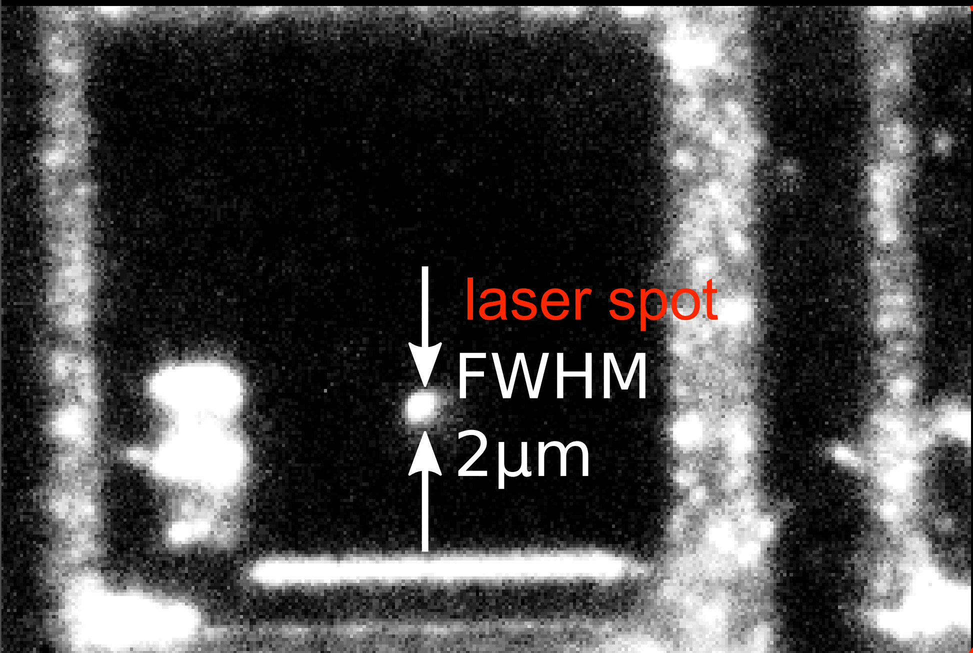
- Deviation from Poisson statistics
- Measurement of optical crosstalk probability:
  - Count Pedestal and 1. & 2. Photoelectron peak
  - Calculate deviation of 2. peak from Poisson

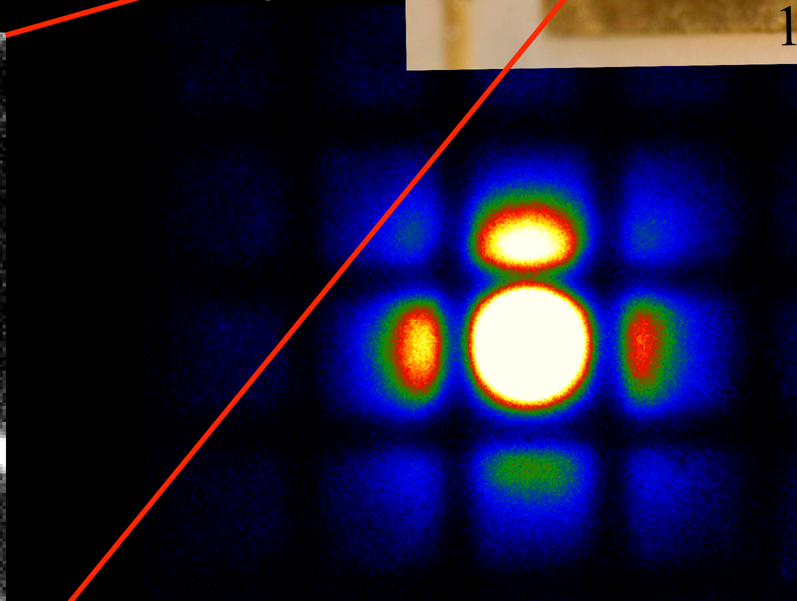


Measurement of photons from avalanche process (Max Knötig)

- Illuminate one SiPM cell with small laser spot
- Observe emission of photons from avalanche process (microscope)



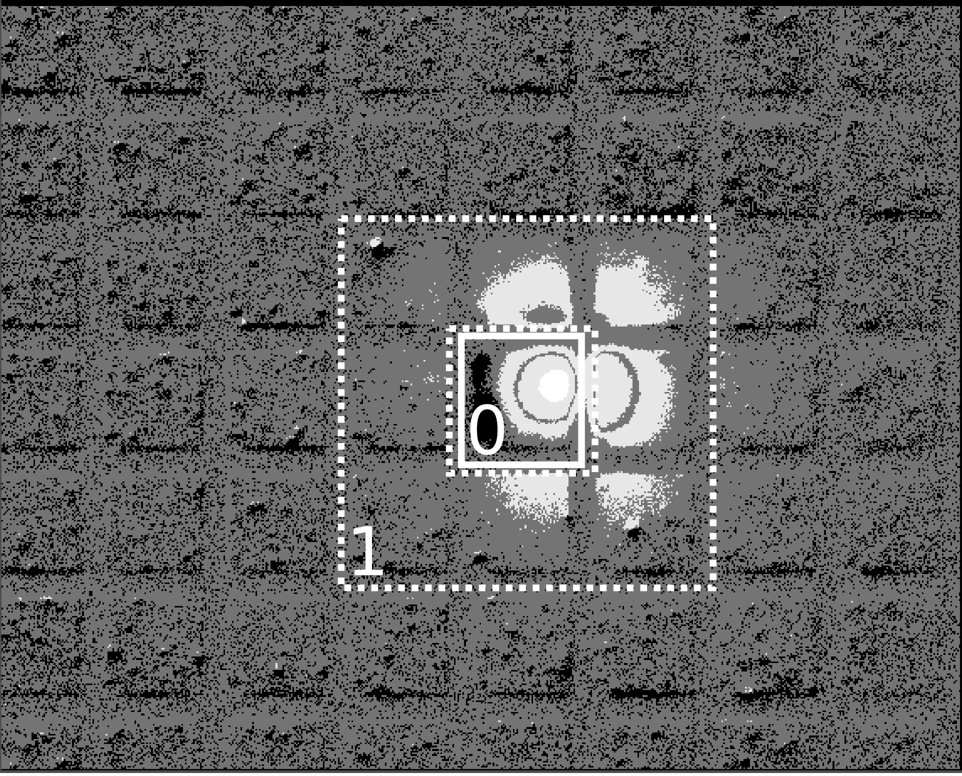


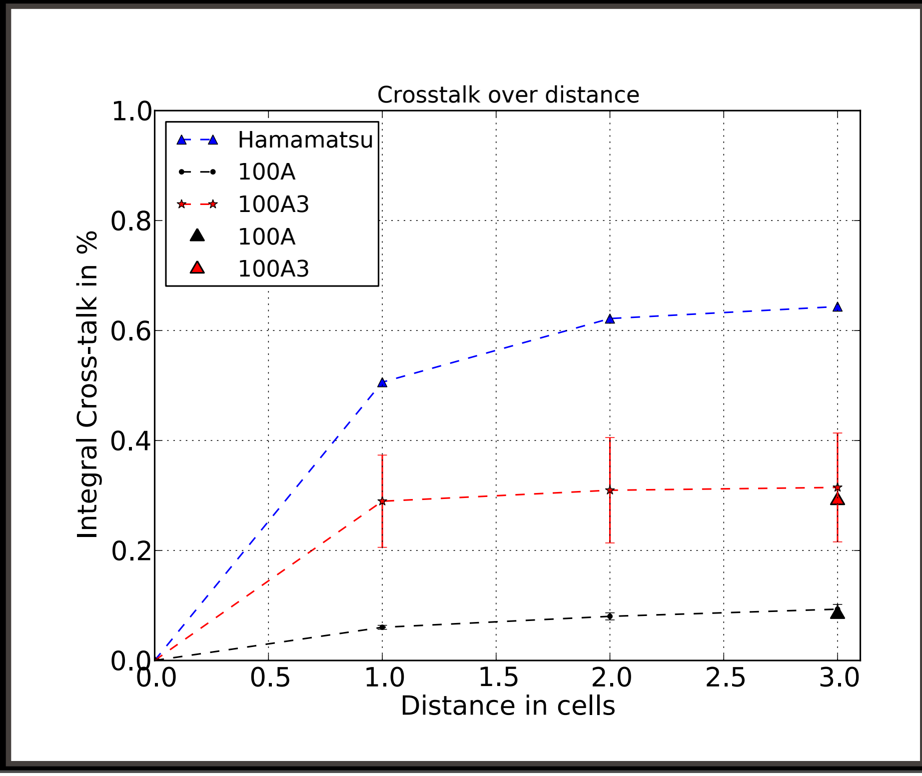


- Light emission from neighbouring cells

Alternative measurement of optical crosstalk (Max Knötig)

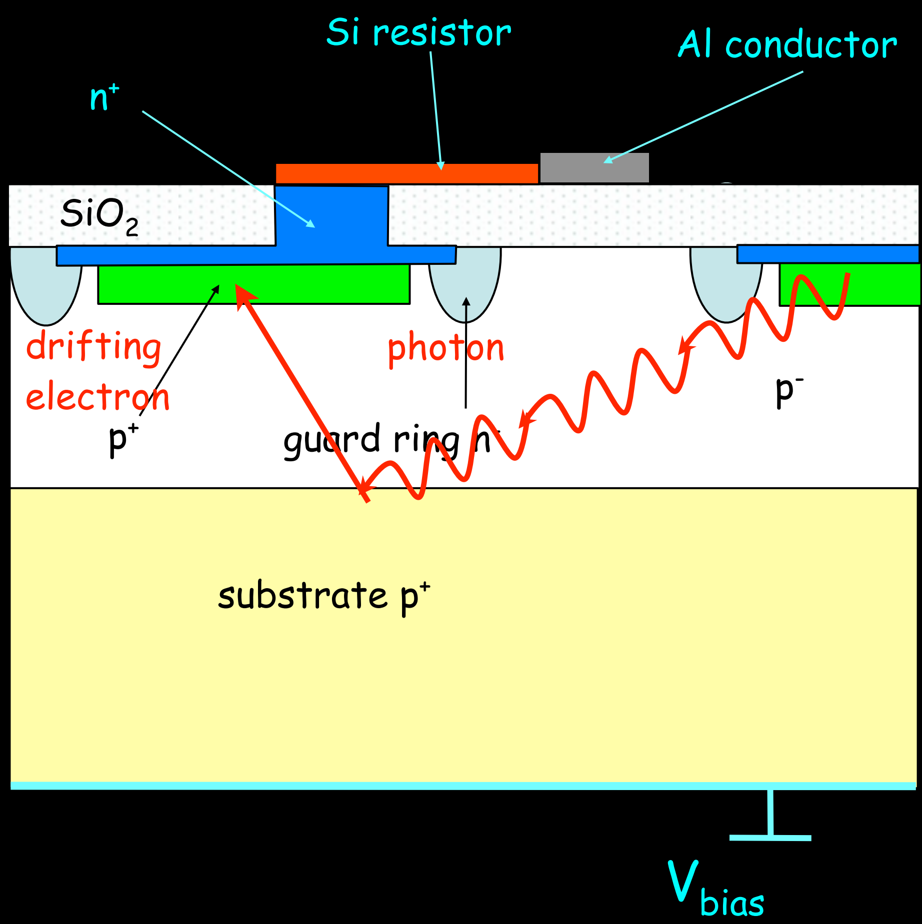
- Measure light in neighbouring cells with Microscope
- Good agreement with conventional method !





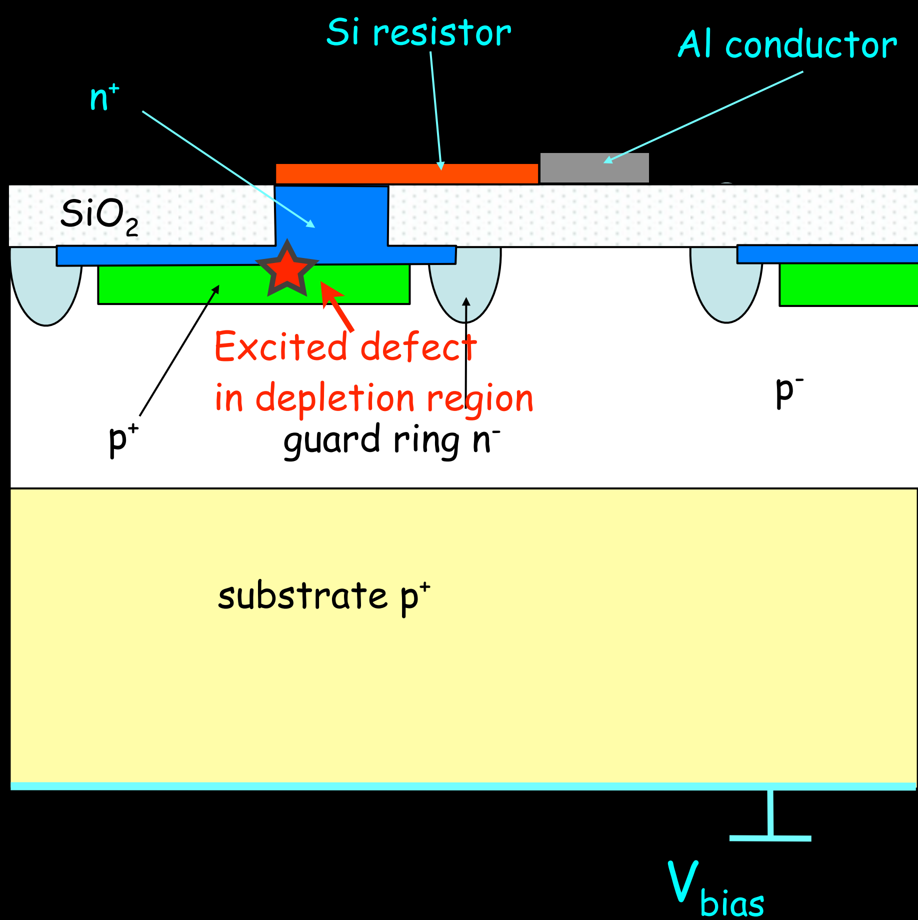
‘Delayed’ optical crosstalk in SiPM

- Photons are generated during avalanche process
- They create photoelectrons in bulk material
- Electrons drift back into the avalanche region and trigger cell
- Time characteristic: 1ns-20ns



Afterpulses in Silicon

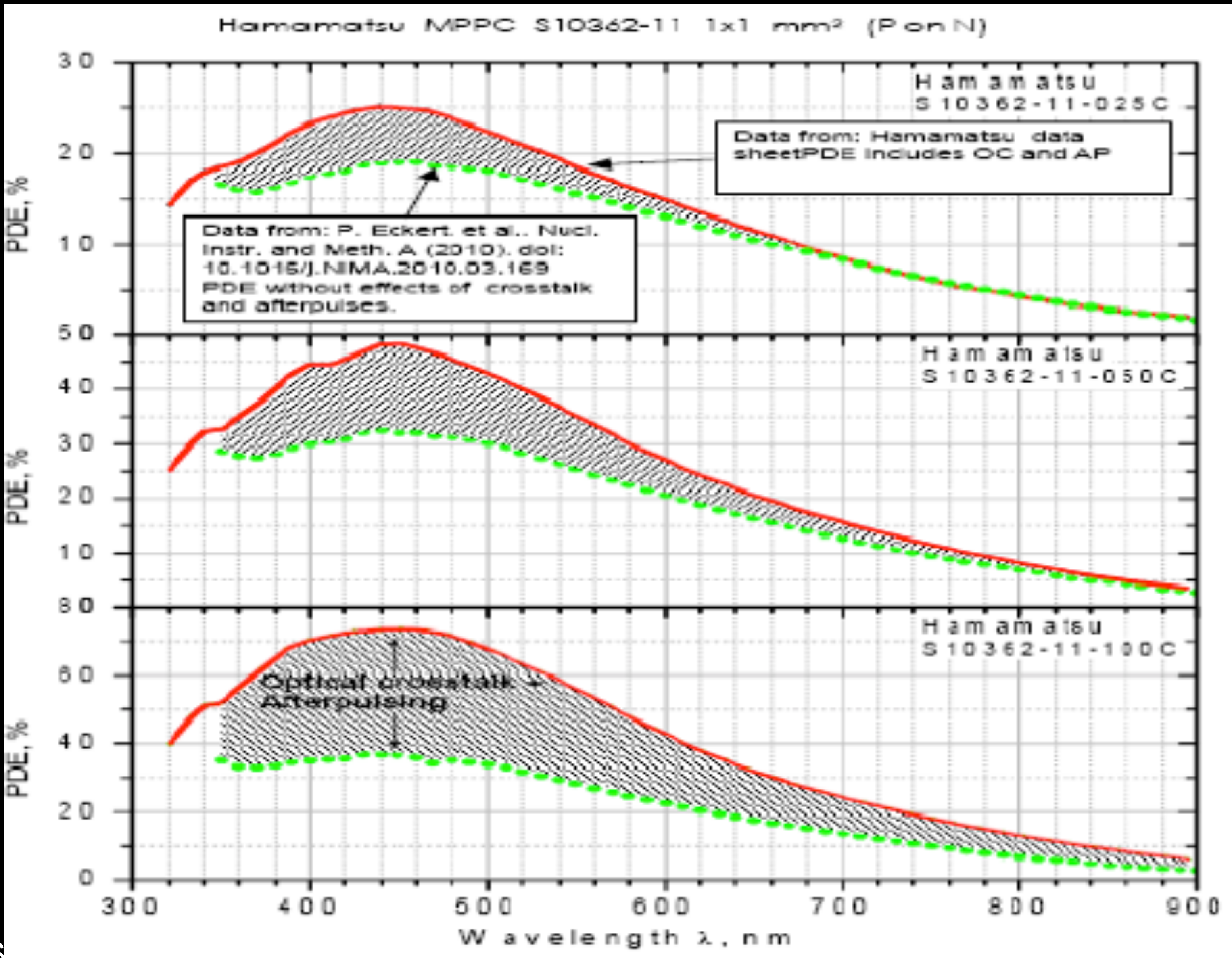
- Impurities and defects in the silicon lattice may have irregular behaviour
- Carriers during an avalanche discharge are trapped and released later in time
- Time characteristics: up to 100ns



Suppressing afterpulses

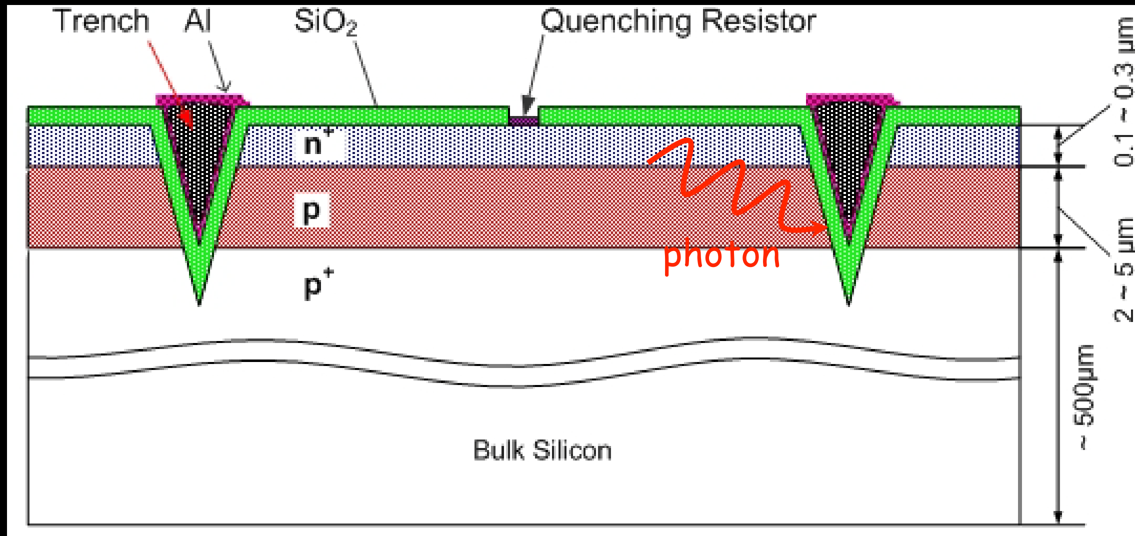
- Afterpulse-excitations have a lifetime of up to 100ns.
- By using quenching resistors of 1MOhm the recovery time of one cell that has fired increases to about 1usec (recharging time of capacitance)
- Afterpulses do not get a chance to trigger the same cell twice.
- Hamamatsu uses 100kOhm quenching resistor. The recharging time is faster and afterpulses appear.

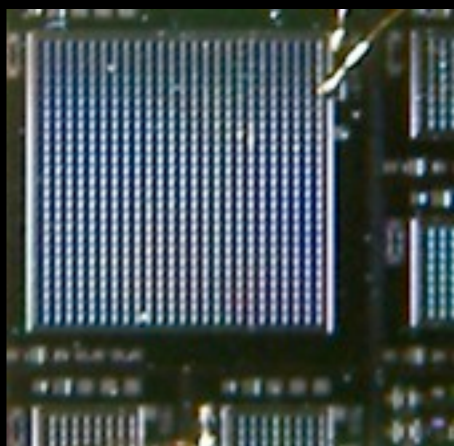
Counting crosstalk in QE measurement: Measured and real PDE: Hamamatsu MPPC

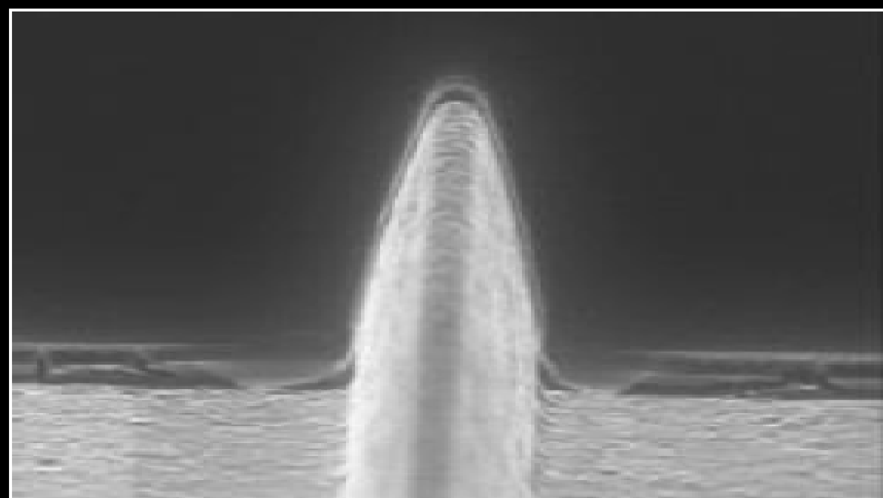


Solutions to reduce optical crosstalk: Introduce trenches

- Introduce optical barrier between cells
- block the instantanous photon crosstalk

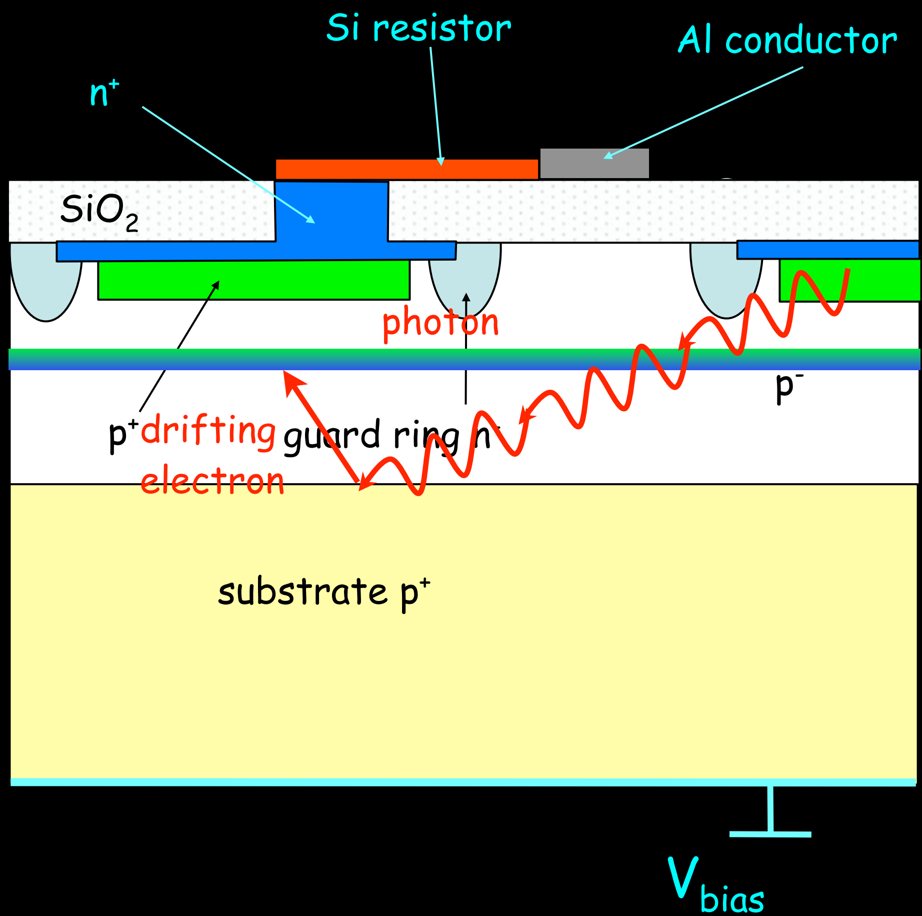




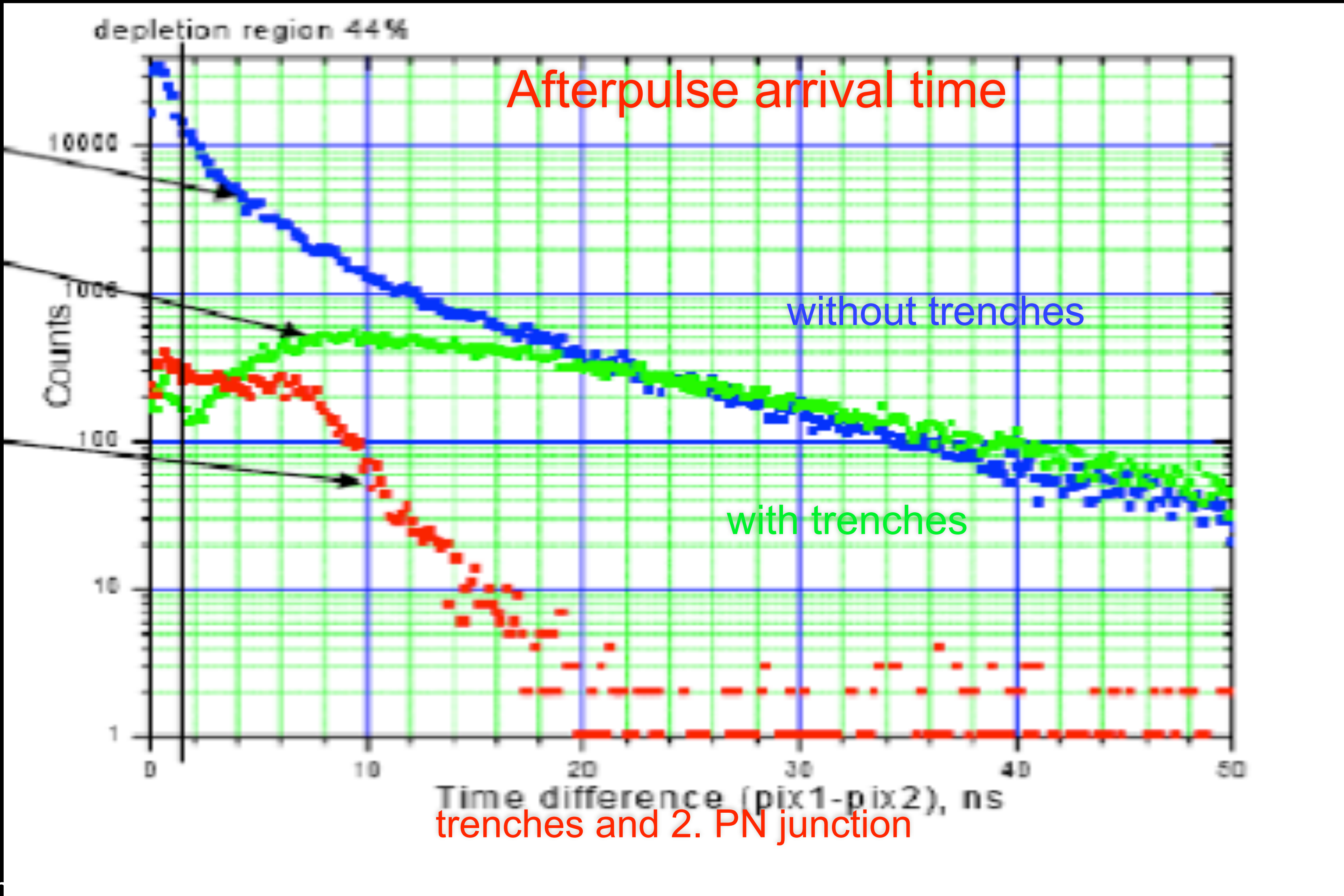


Solutions to reduce ‘delayed’ optical crosstalk: Block drifting electrons

- Introduce second p-n junction
- Potential barrier will block drifting electrons



Arrival time of ‘instantaneous’ and ‘delayed’ optical cross-talk



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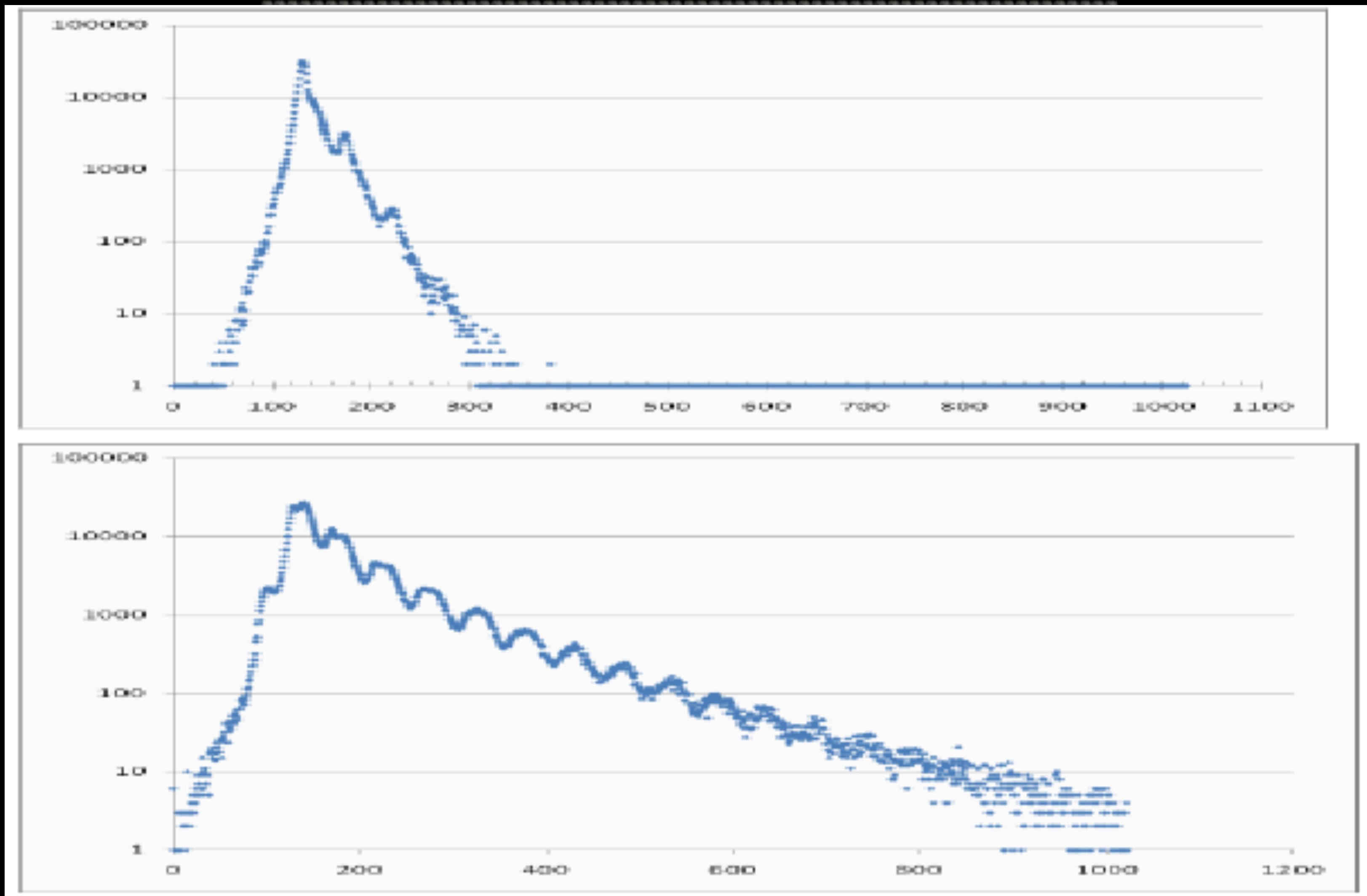
Interesting experiment: Mirror in front of Dolgoshein-SiPM

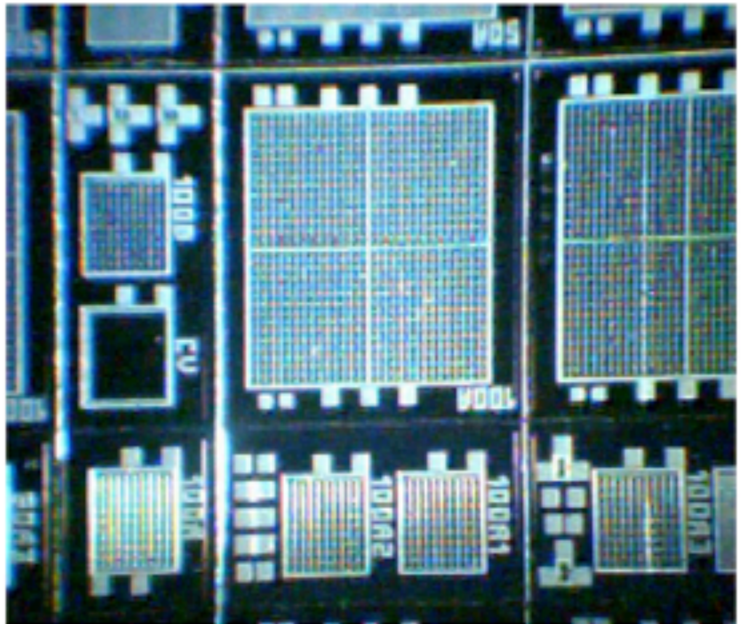


MEPhI - MPI for Physics R&D collaboration and cooperation with PerkinElmer Industries (now EXCELITAS)

Developing UV sensitive SiPMs with extremely high PDE,

Extremely low crosstalk and low dark rate

Pioneer and great Leader: Prof., member of Russian Academy of Sciences Boris Dolgoshein 1930-2010



SiPM Sizes	1x1 and 3x3 mm²
μ-cell pitch	50 and 100 μm
Geom. Eff.	40-80%

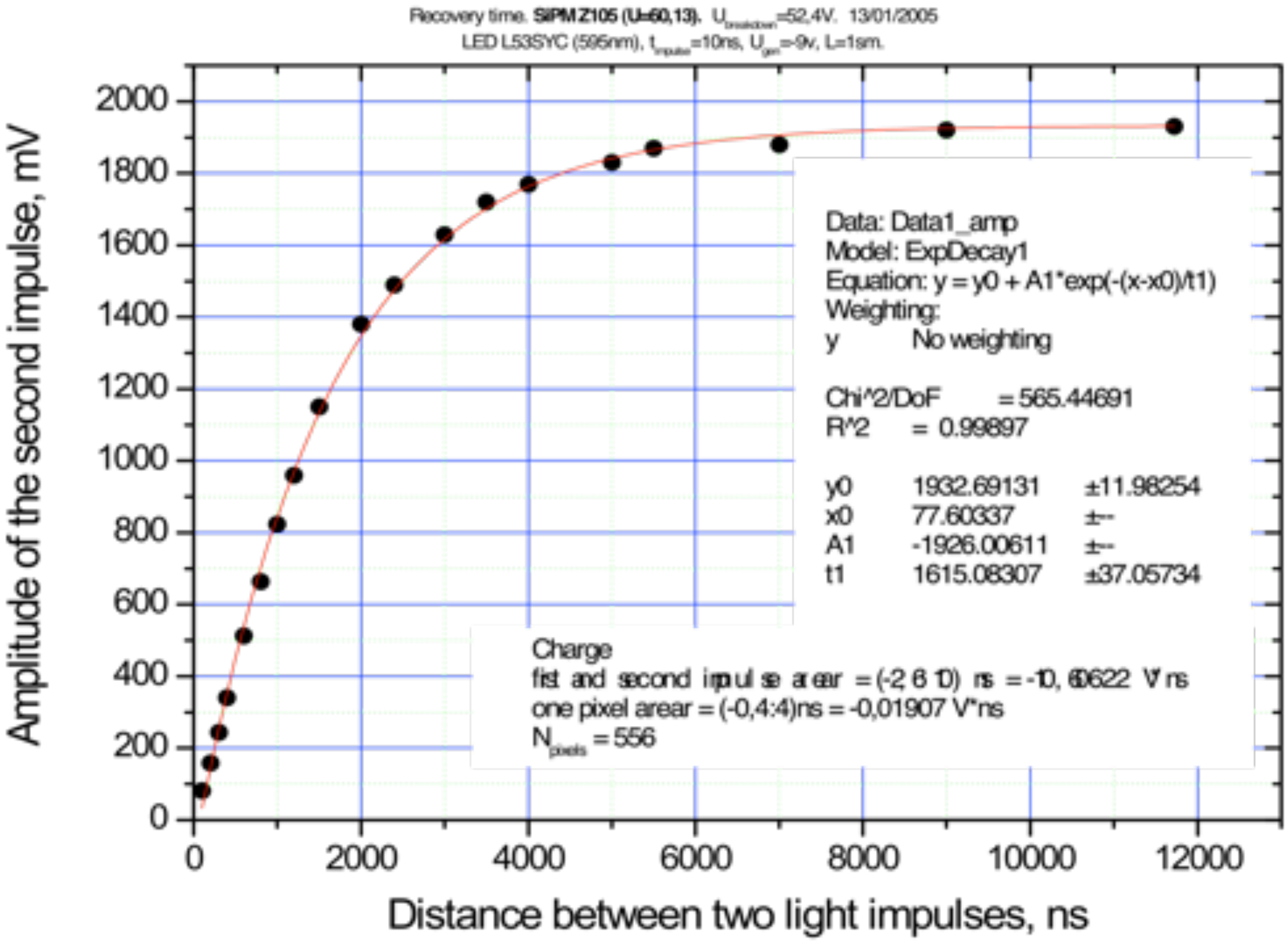
16-17 February 2011

B. Dolgoshein, R. Mirzoyan, E. Popova, P. Buzhan, PEI, et al.,

General specifications of SiPM

Recovery time of fired cell
(--> suppression of afterpulses)

Recovery time of SINGLE pixel: C(pix)xR(pix)-->20ns.....a few mks

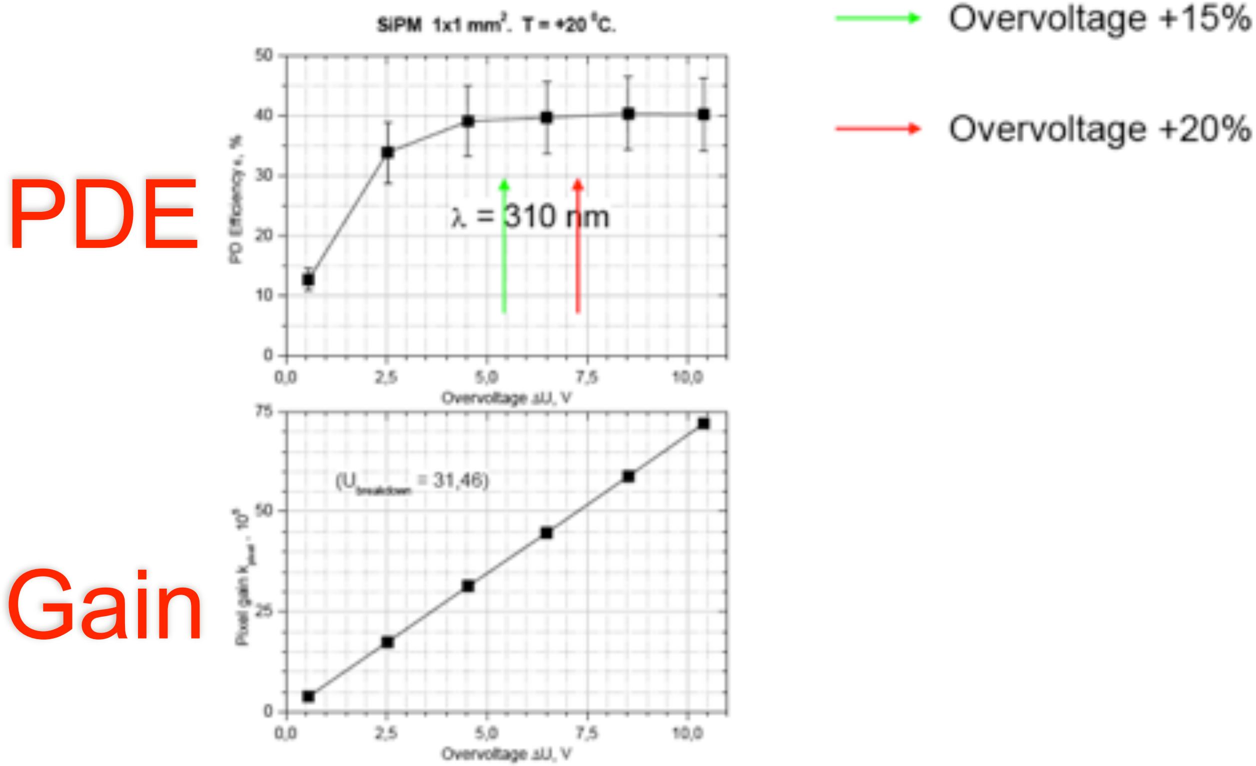


B.Dolgoshein,LIGHT06

Gain and PDE as function of overvoltage (Perkin-Ellmer-SiPM as example)

A PDE and gain of a 1x1 mm² SiPM produced by PEI measured at +20°C

Overvoltage = operational voltage – breakdown voltage



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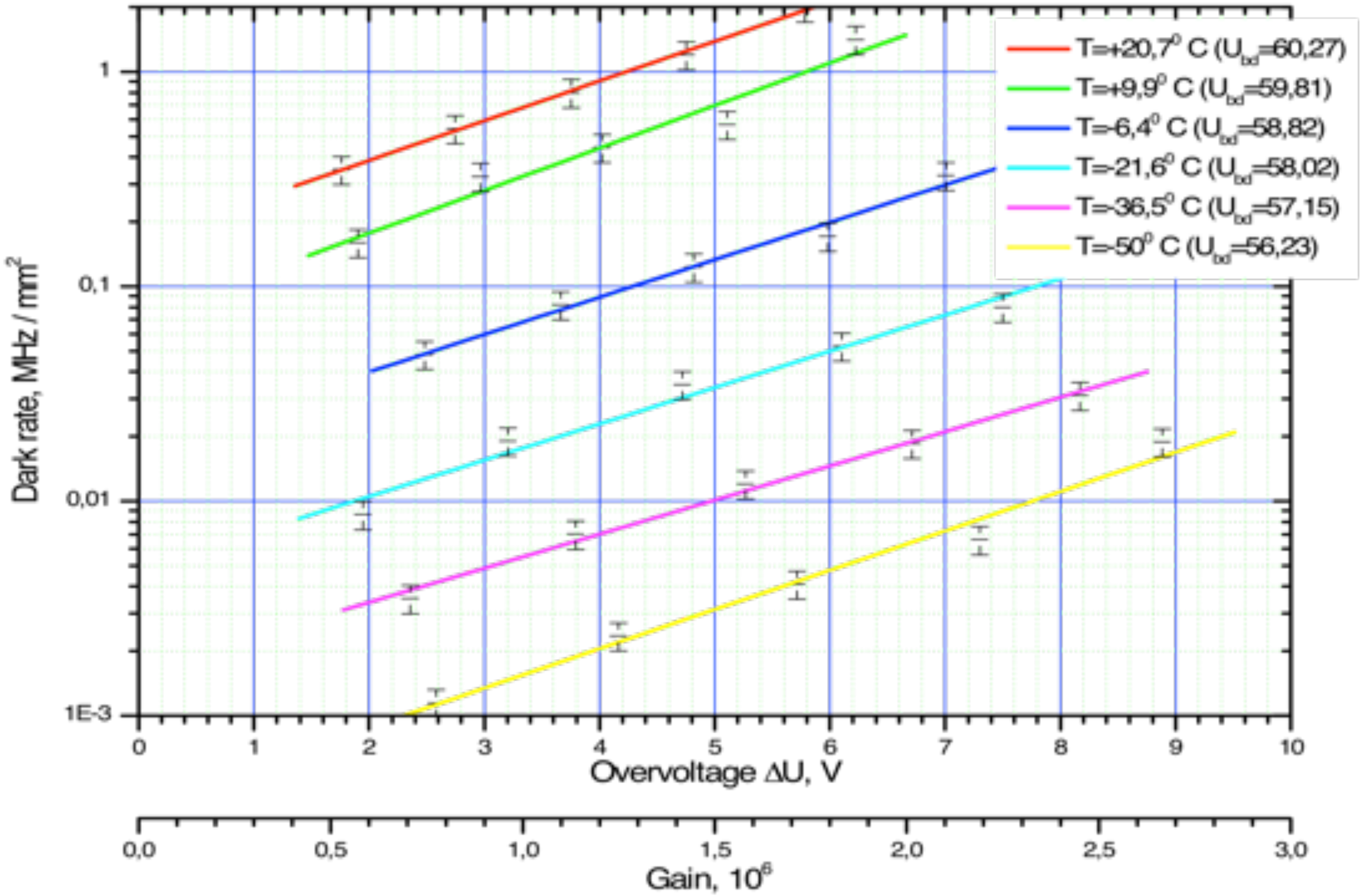
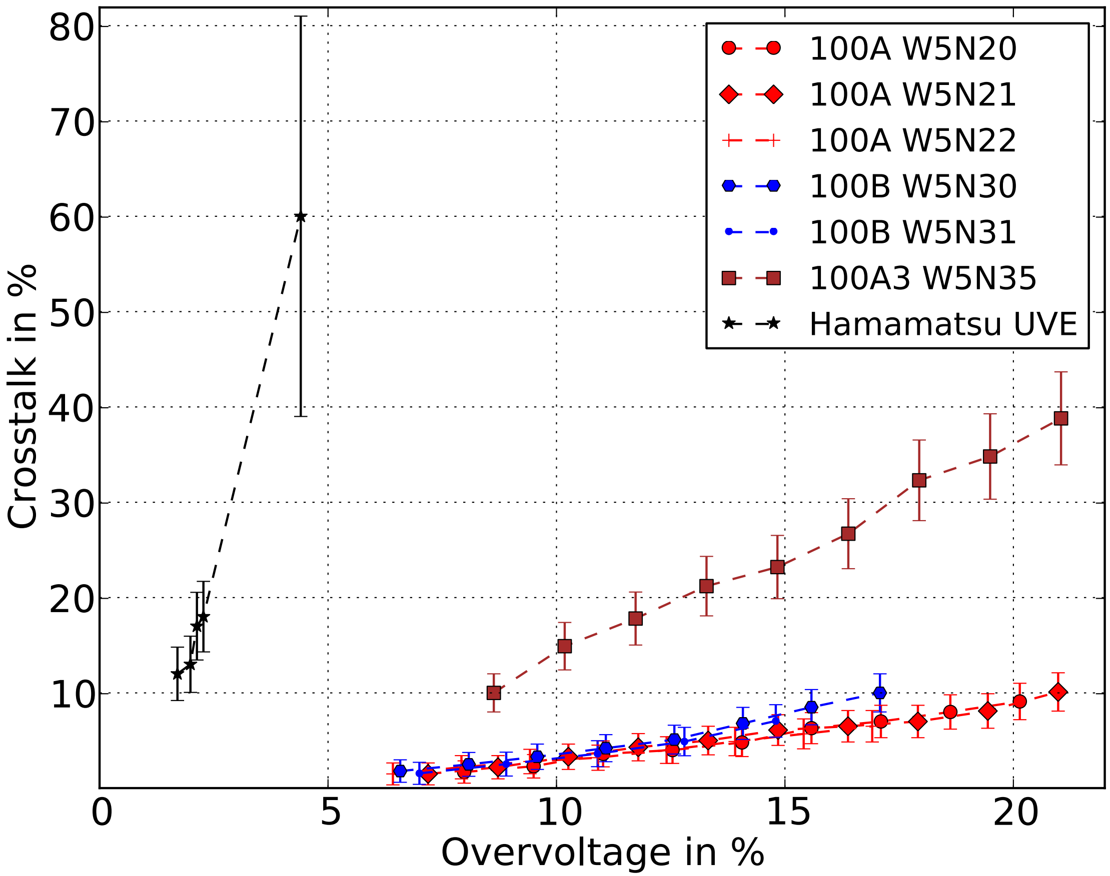
Temperature dependence of dark rate

Dark Rate(DR)



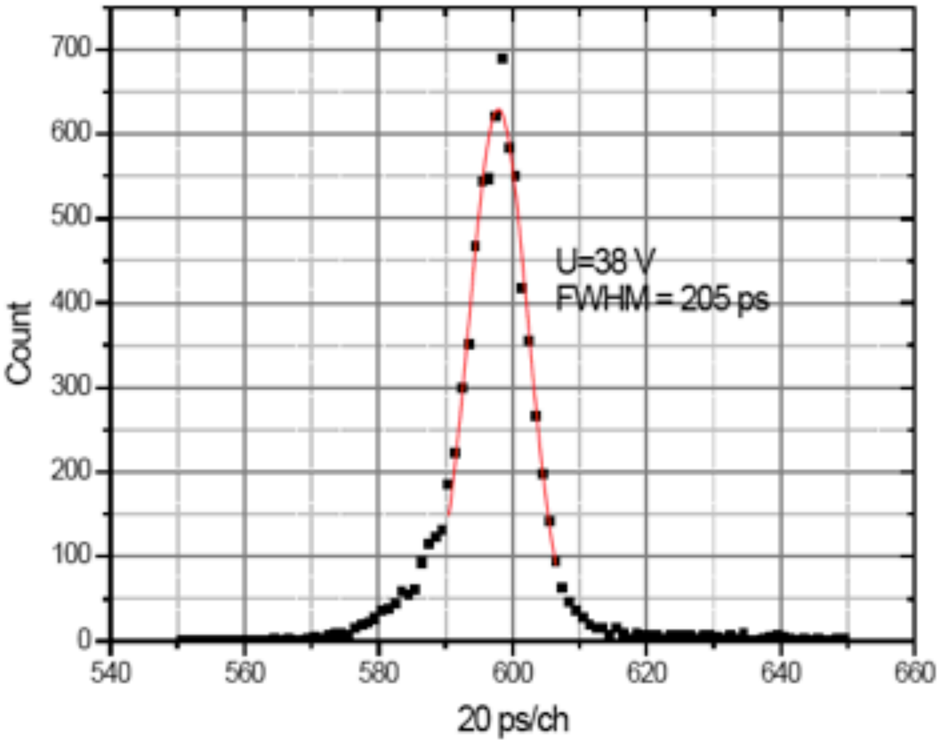
B.Dolgoshein,LIGHT06

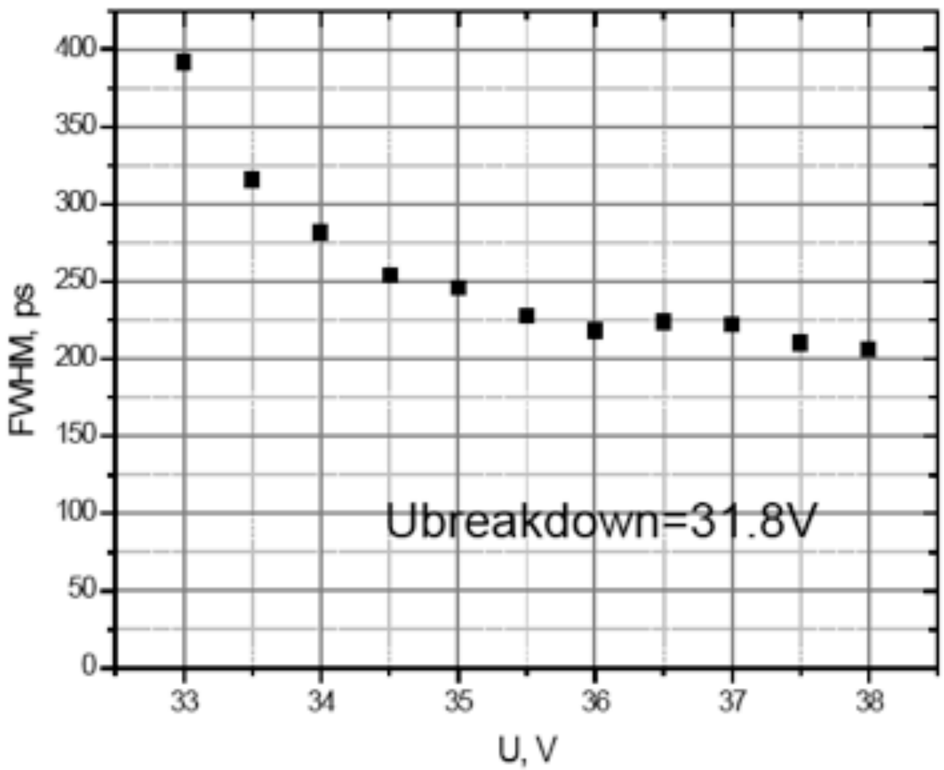
Cross talk comparison of different SiPM



Signal timing for 3x3mm² SiPM sample

40ps FWHM laser pulses, λ=405nm, single photon mode
T = -40° C



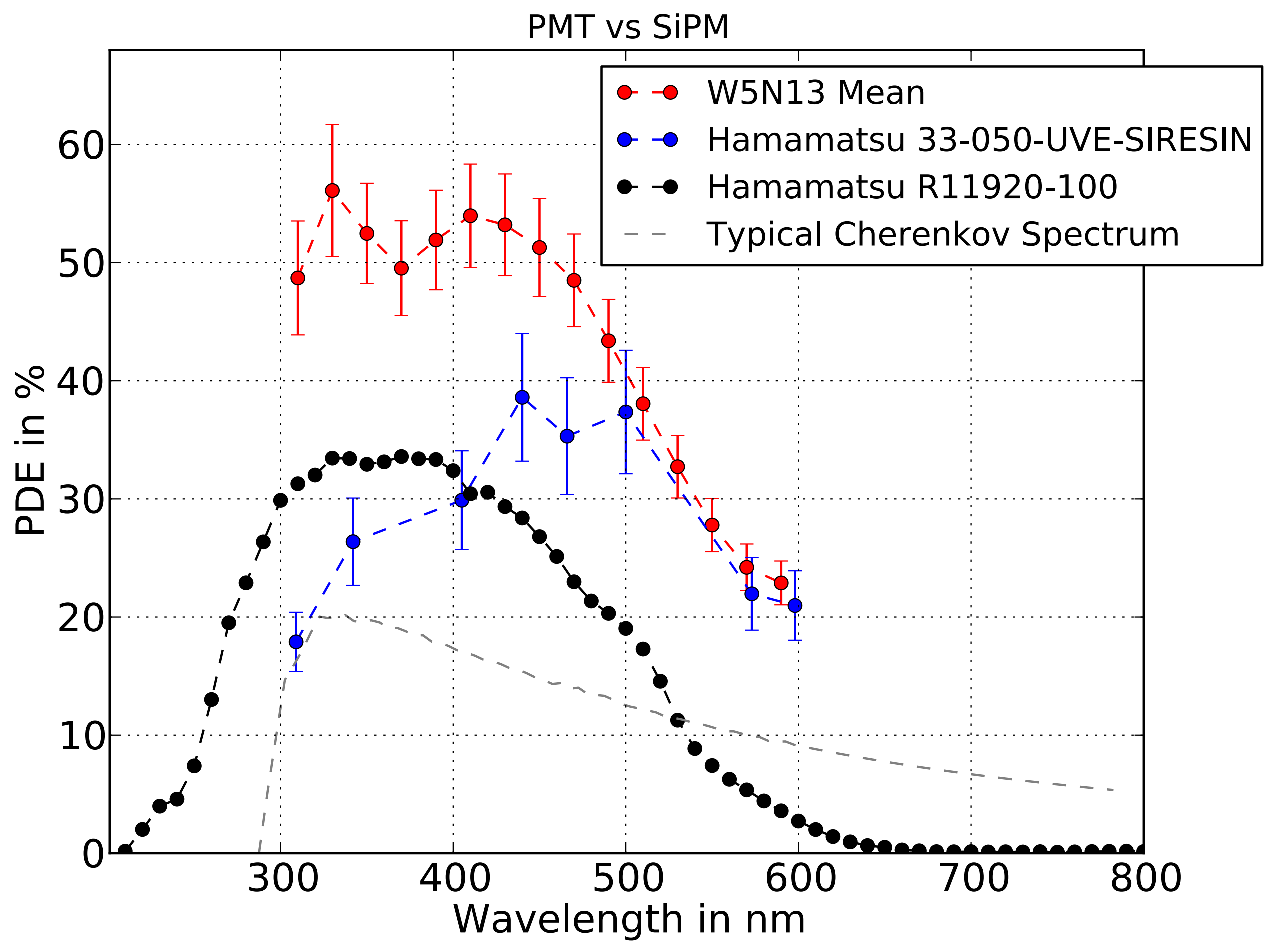


Samples for evaluation may become available very soon

16-17 February 2011

B. Dolgoshein, R. Mirzoyan, E. Popova, P. Buzhan, PEI, et al.,

General properties of SiPM



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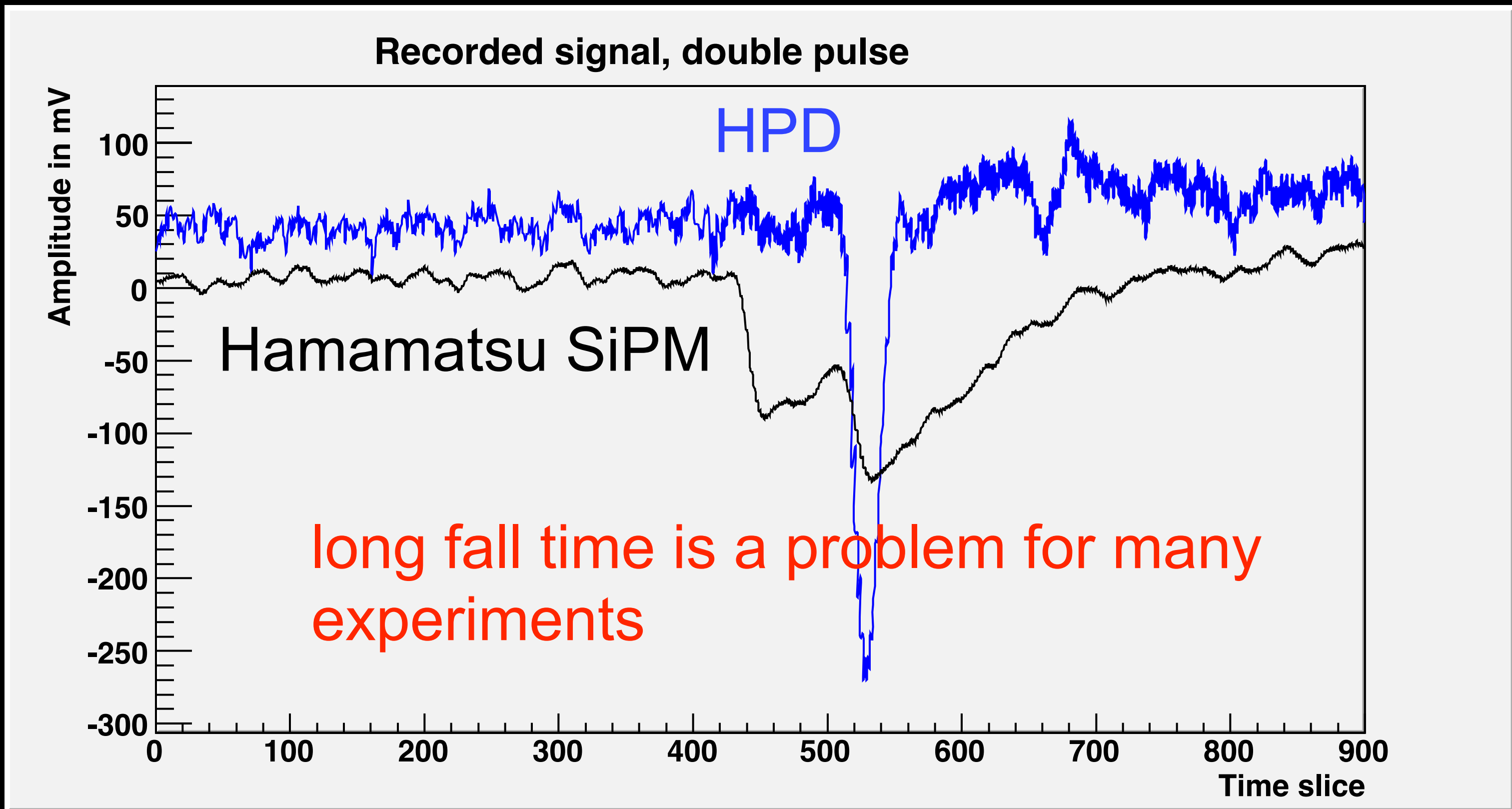
Measurement methods for characterization

Measurements of Hamamatsu SiPM: Pulse shape (HPD and SiPM)



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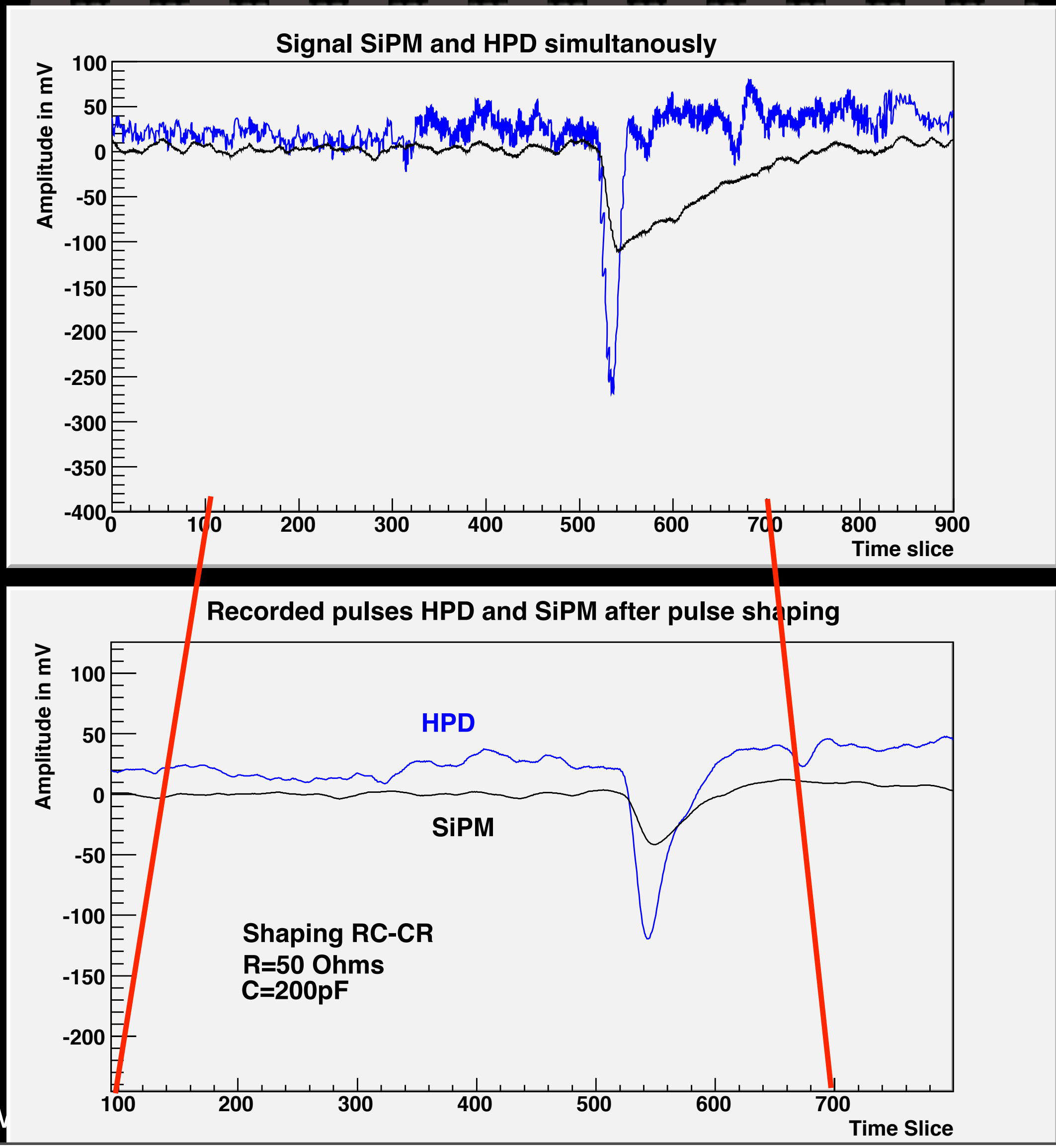
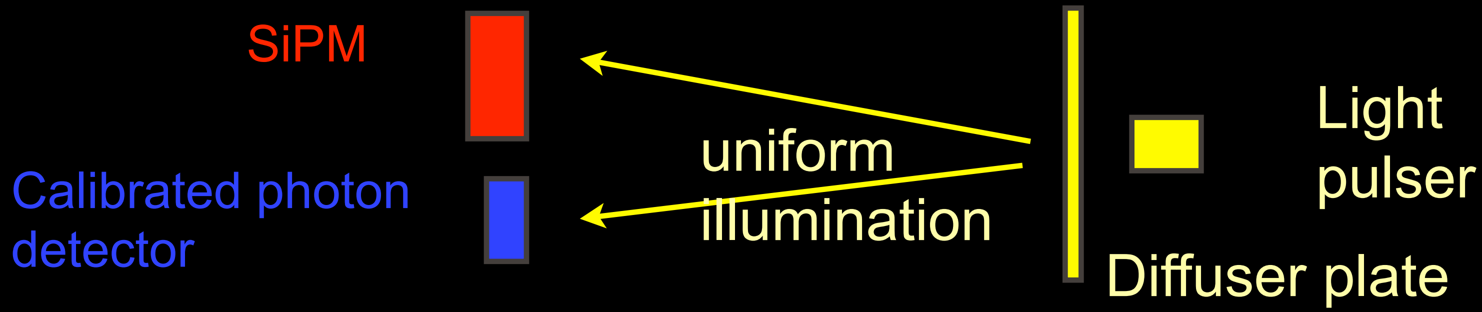
Passive shaping (simple capacitive coupling into 50 Ohms) reduces the fall time (needed for reduction of pile-up)



Thomas Schv

Measurement of QE

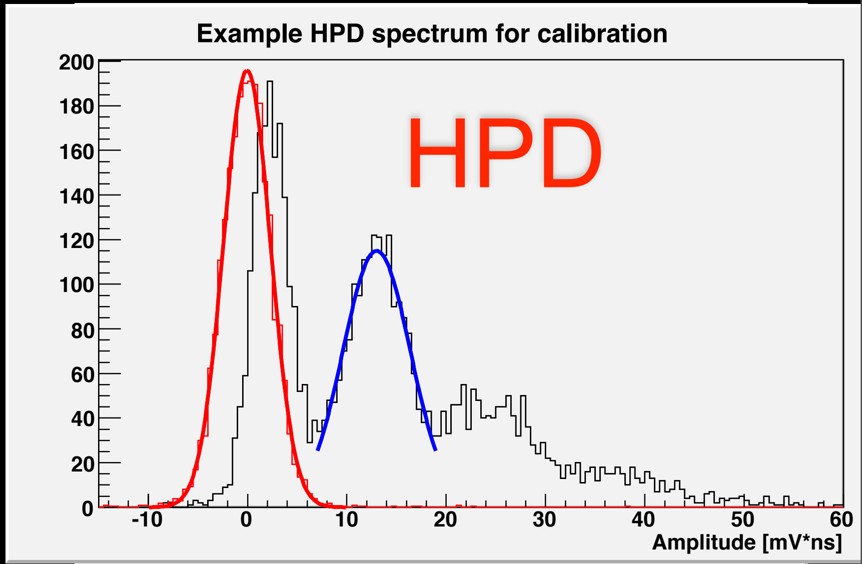
- Monitor the photon detection efficiency:

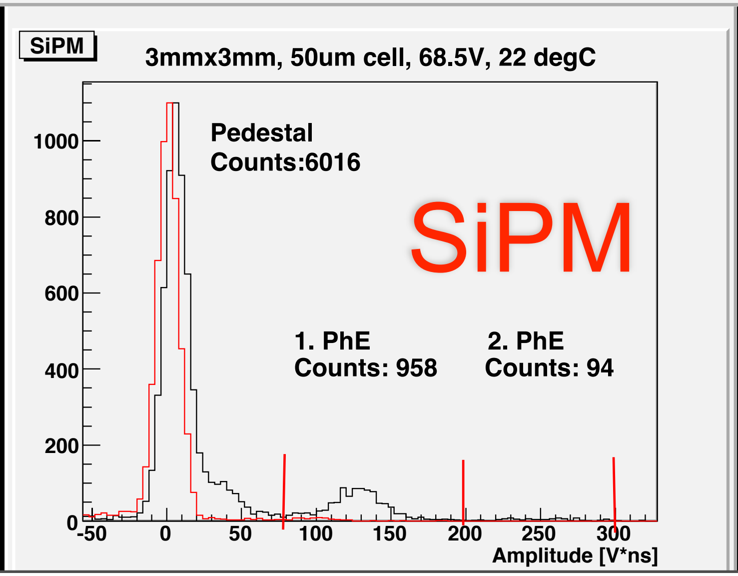


- Compare SiPM PDE with calibrated reference detector such as HPD

Measurements using pulses and FADC

- Illumination of SiPM and reference detector with same pulsed light flux
- Measurement of counts in pedestal and 1. PhE peak
- Calculation of Poisson mean
- Measurement of crosstalk of SiPM by 2. Peak
- Correction of mean counts of both detectors due to (detector dependent) losses
- Calculation of SiPM PDE by comparison of QE and mean counts





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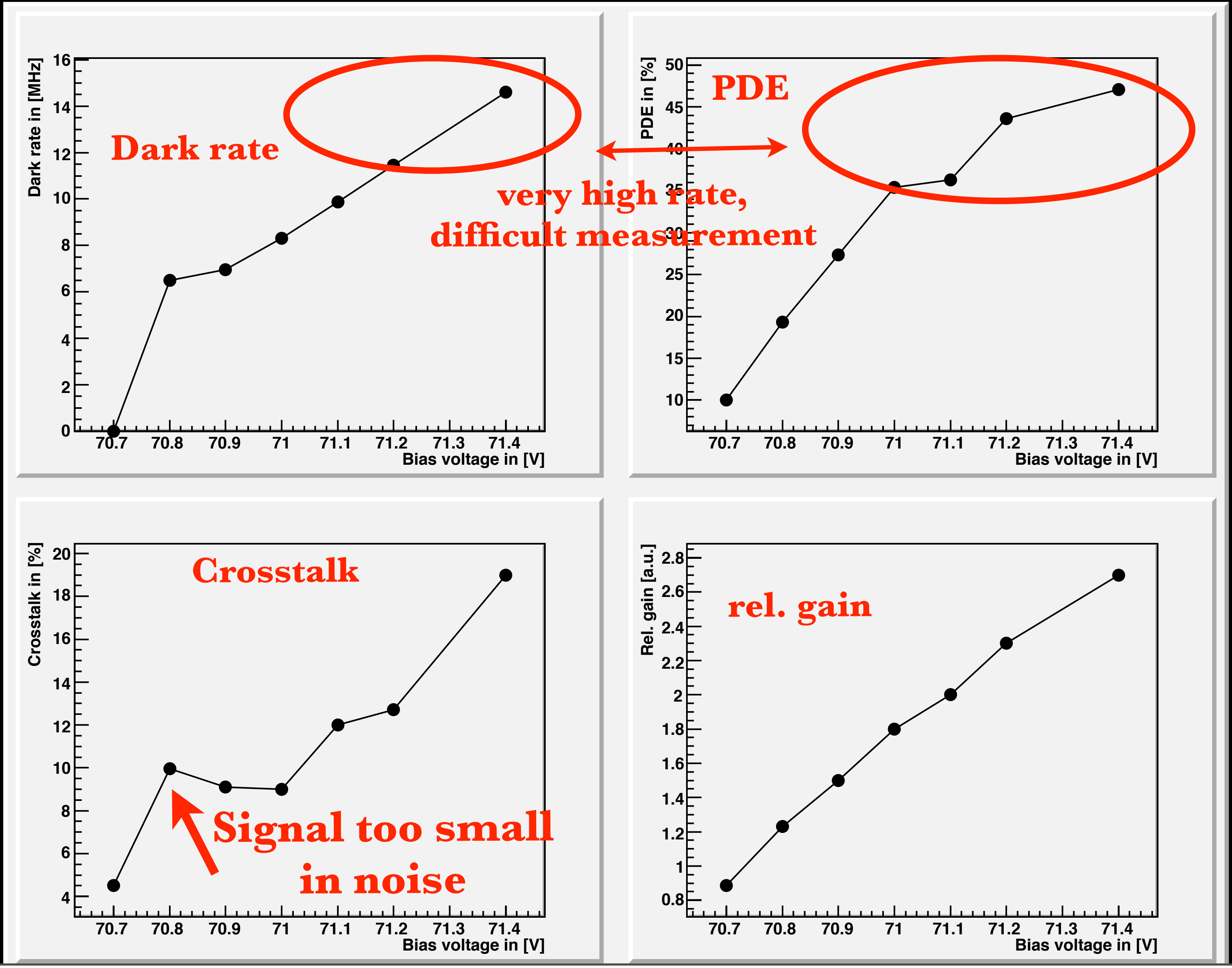
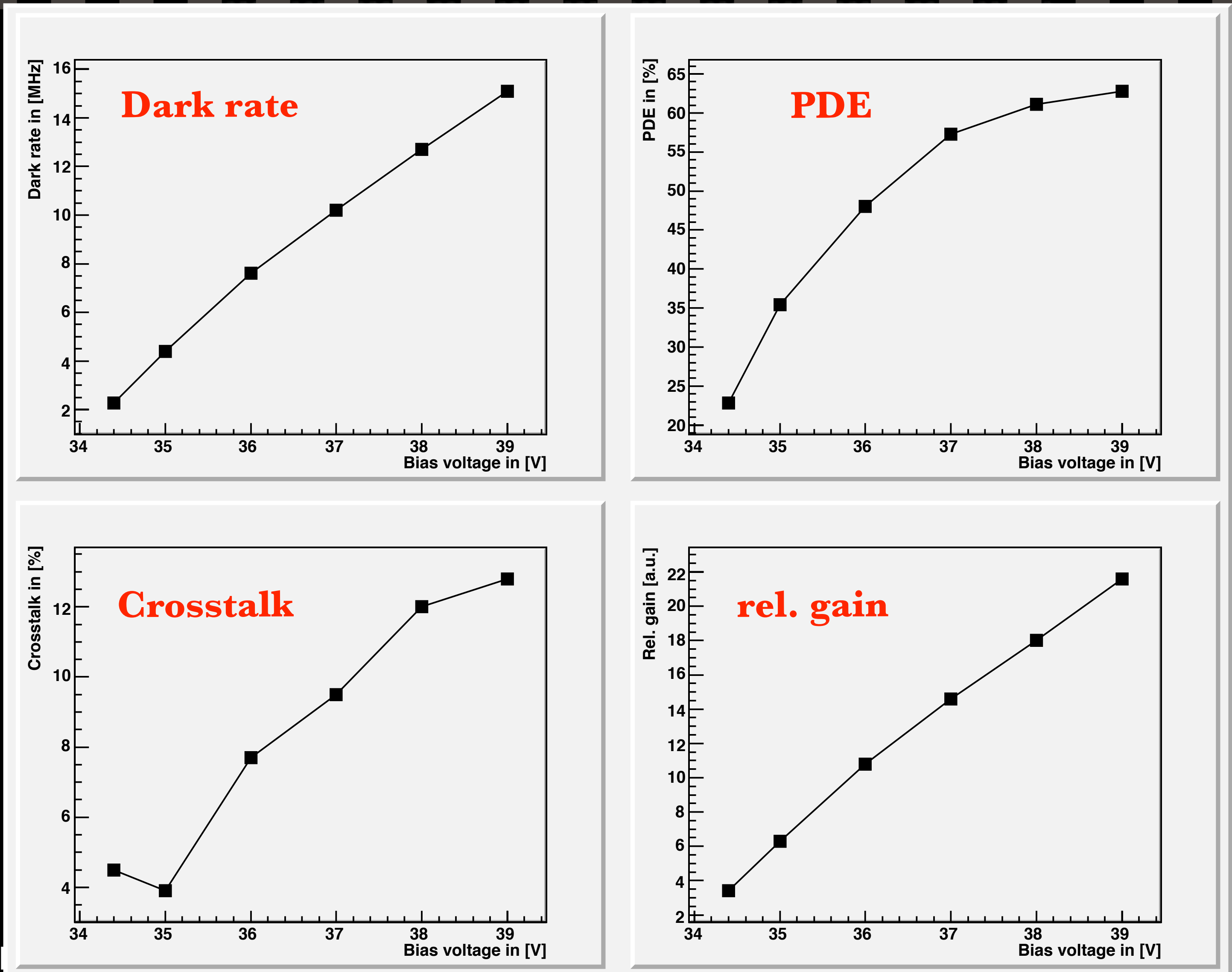
Voltage scan Hamamatsu



Voltage scan
Dolgoshein W5N42 3x3mm



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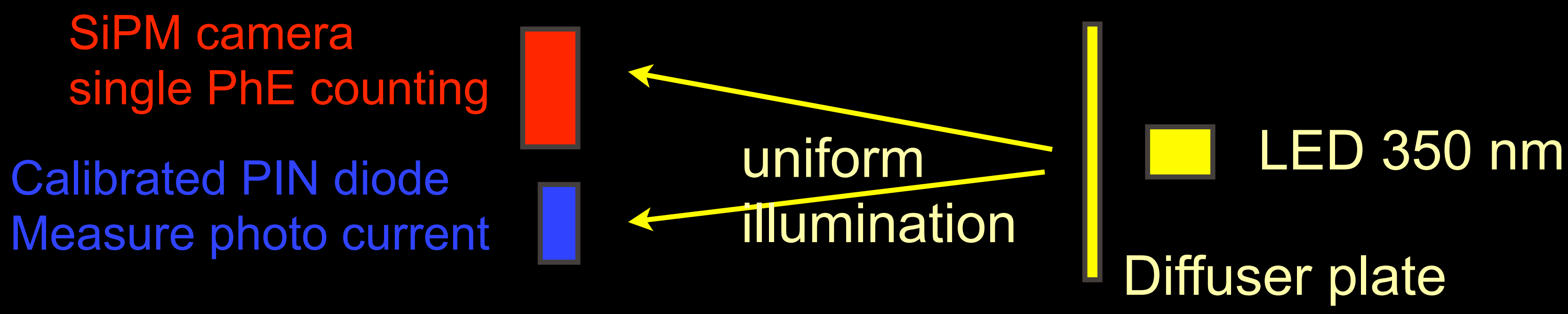
Wednesday, April 18, 2012

Measurements with discriminator

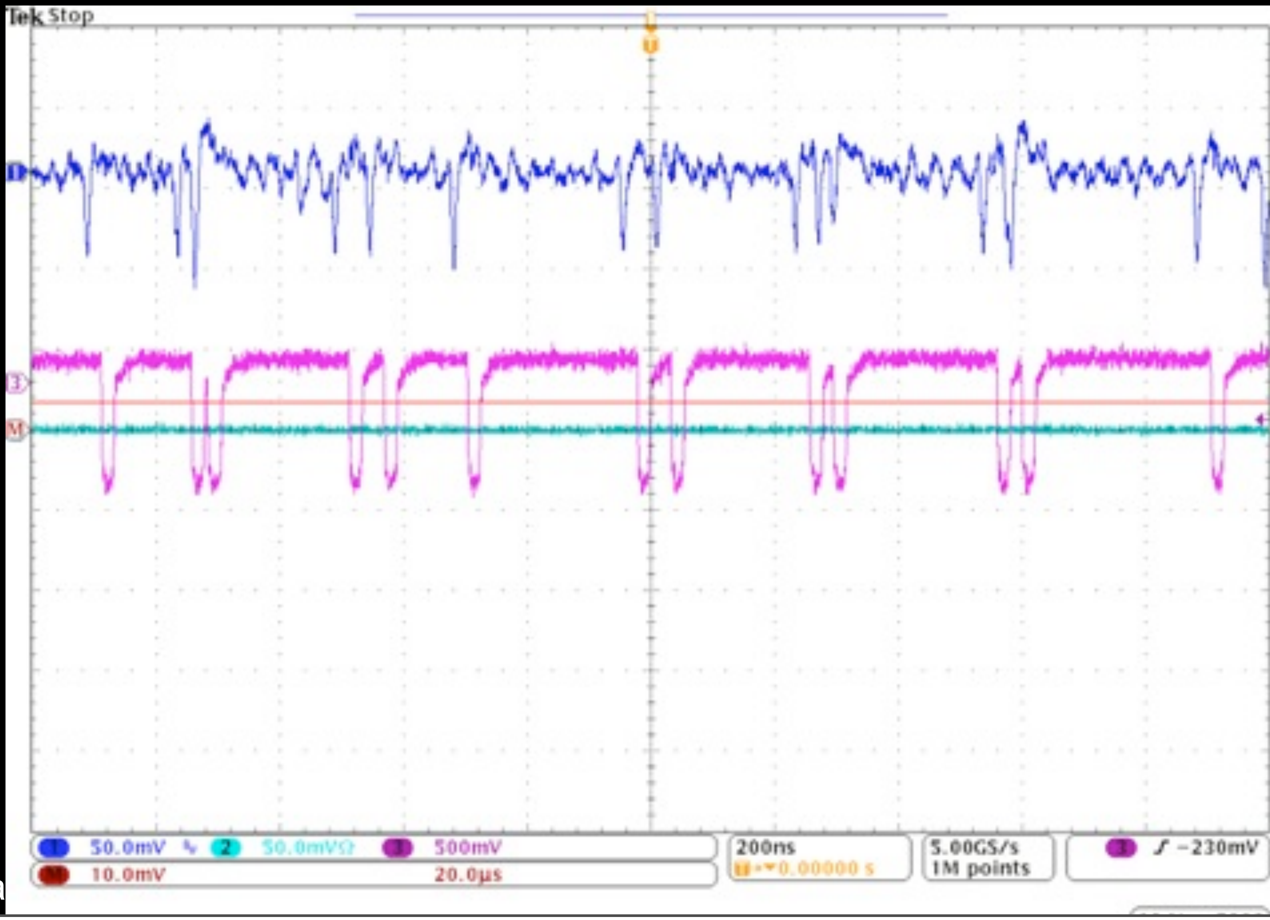
- Illuminate SiPM with continuous light flux



- Need a calibrated reference detector --> PIN diode

Measurements with Hamamatsu SiPM: Counting mode with signal shaping

- SiPM signal (with shaping) and discriminator (25ns pulse width)



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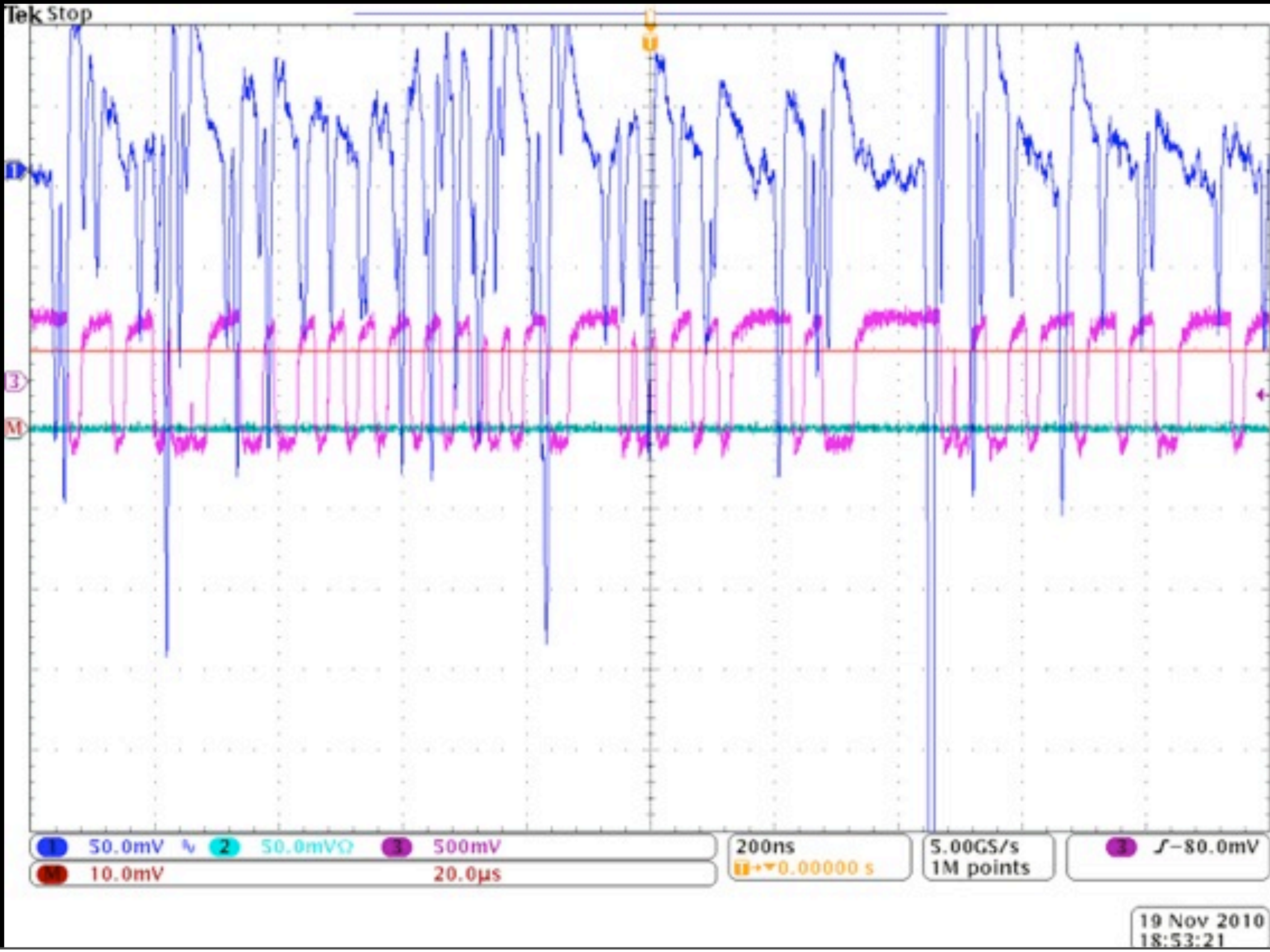
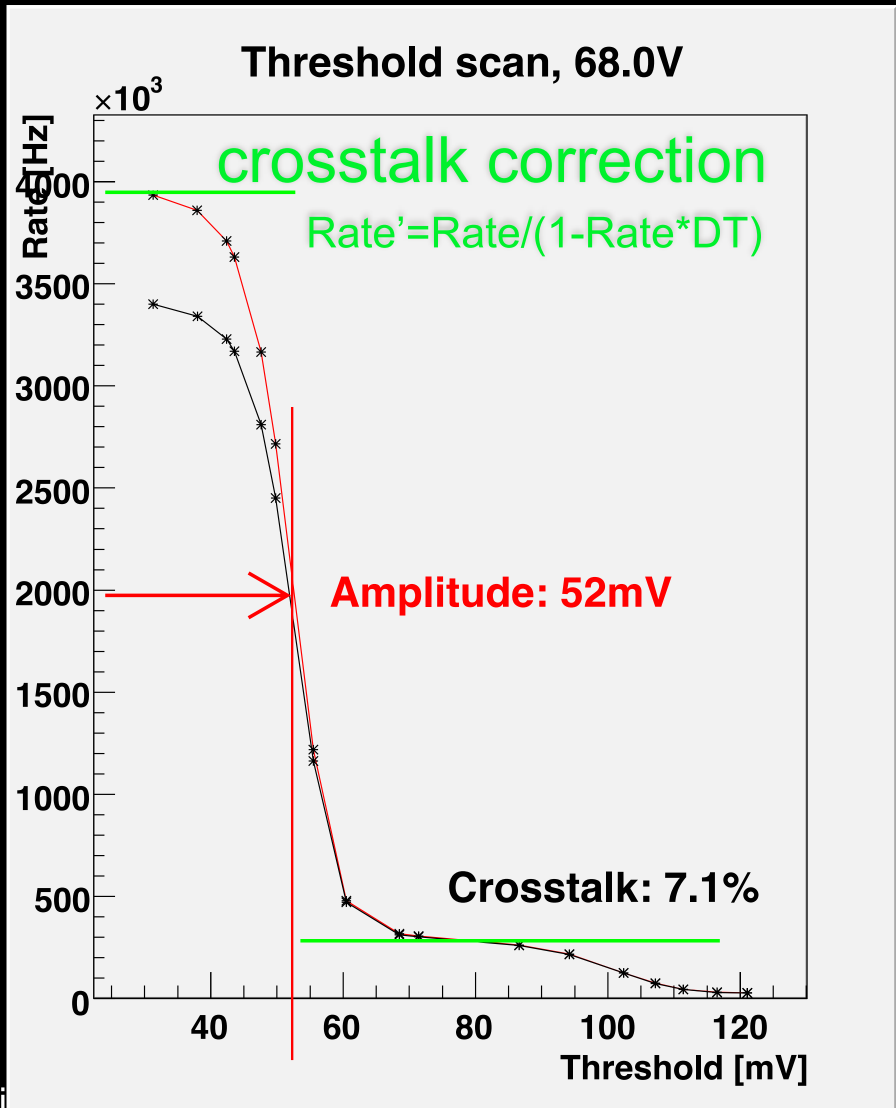
Pile-up and dead time at high rate:
--> cross talk correction



Measurement of gain and crosstalk by threshold scan



Cameras with SiPM

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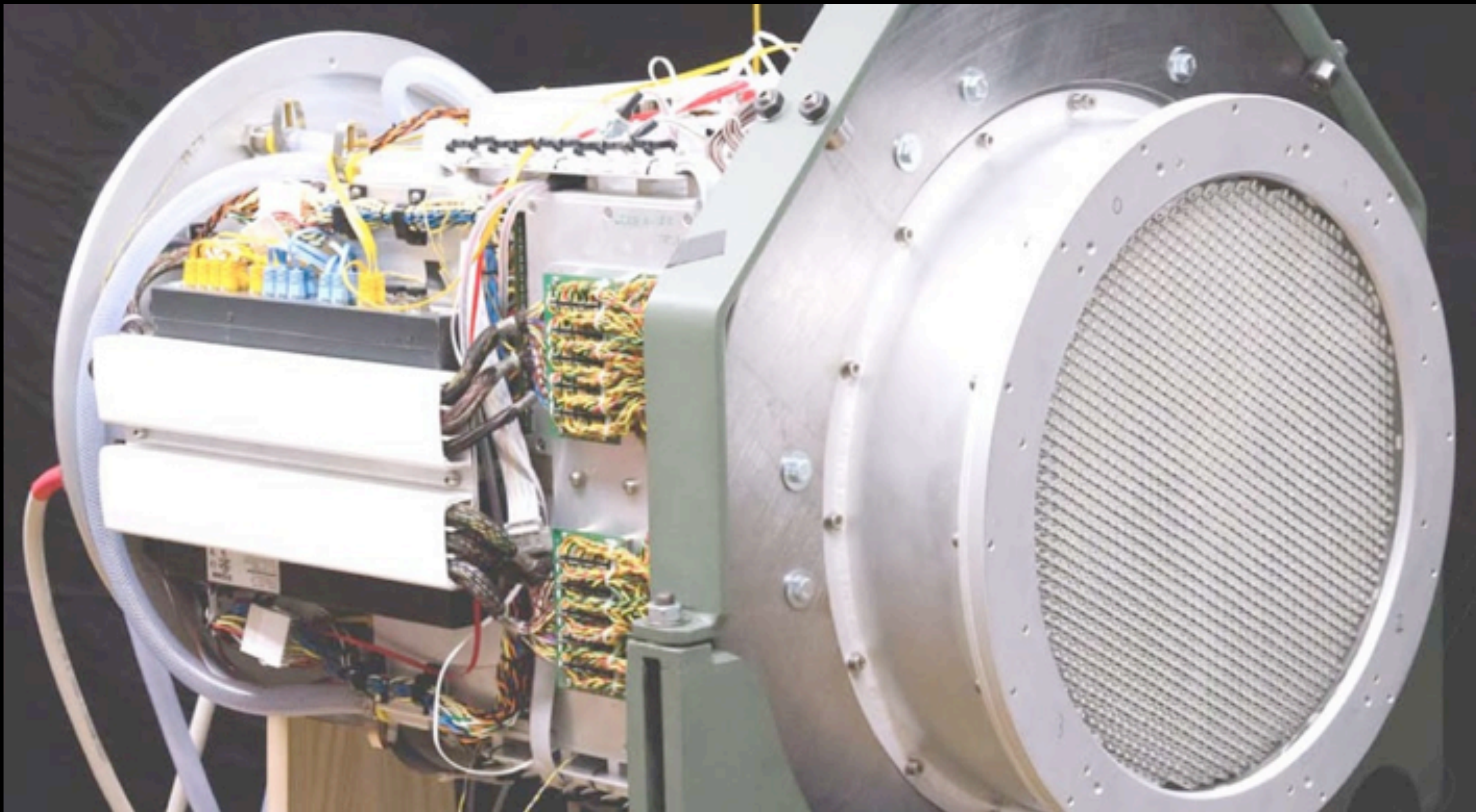
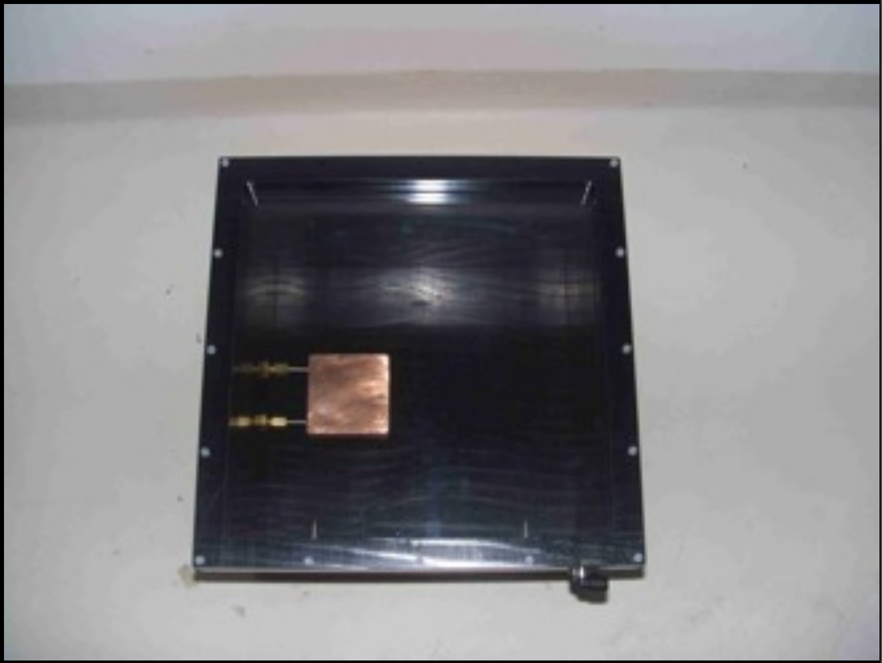
FACT camera with 1440 SiPM (First G-APD camera telescope)



Testcamera with cooling plate for possible future AUGER fluorescence detector



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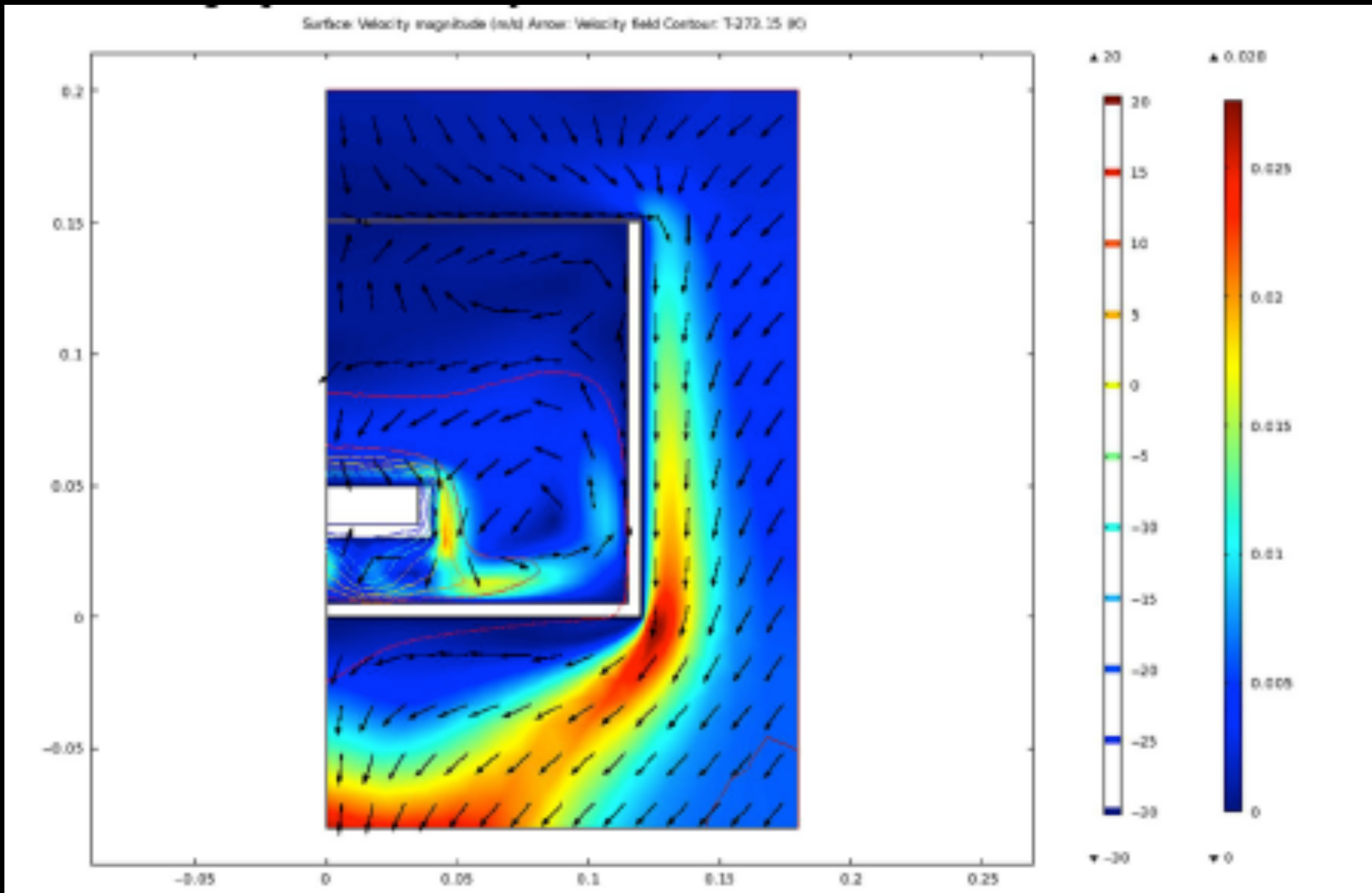
Thermal simulations: Condensation



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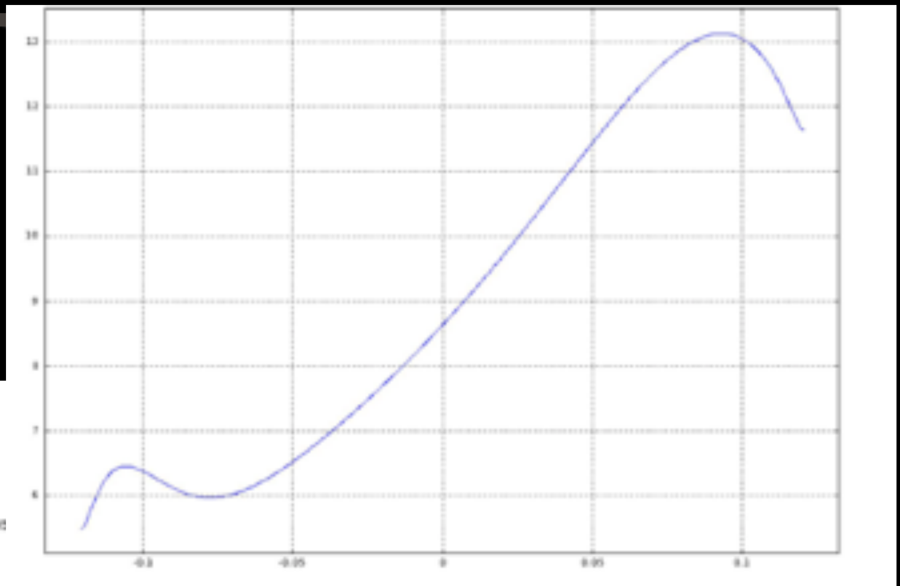
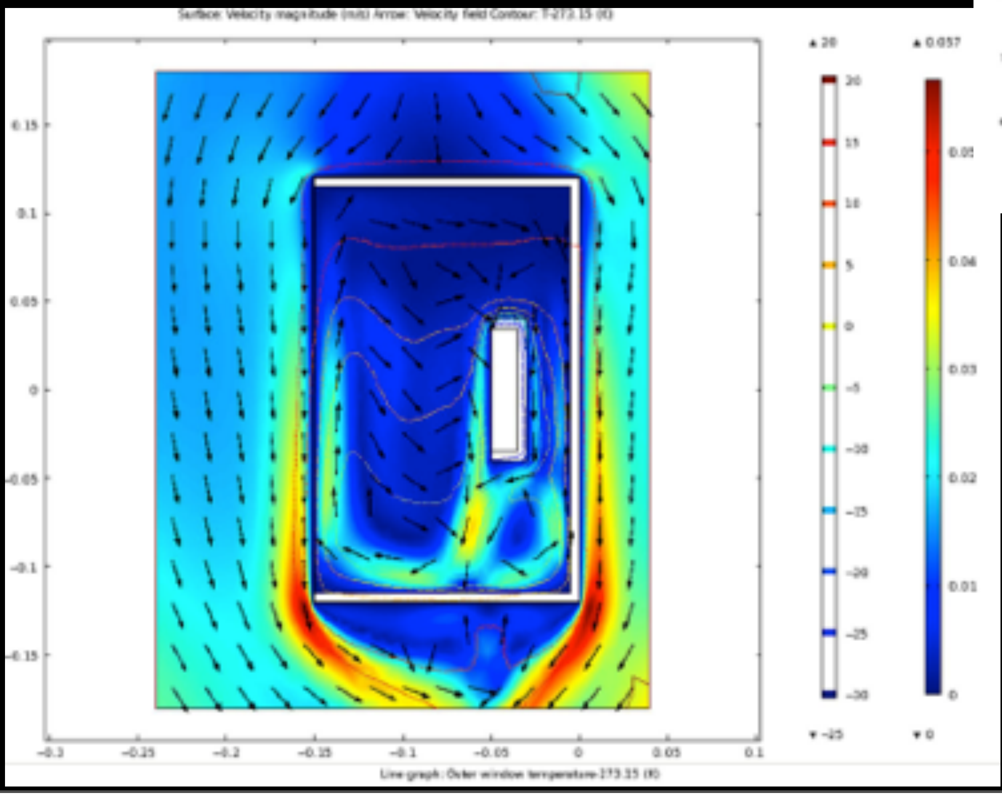
Temperature distribution at window
--> will get condensation

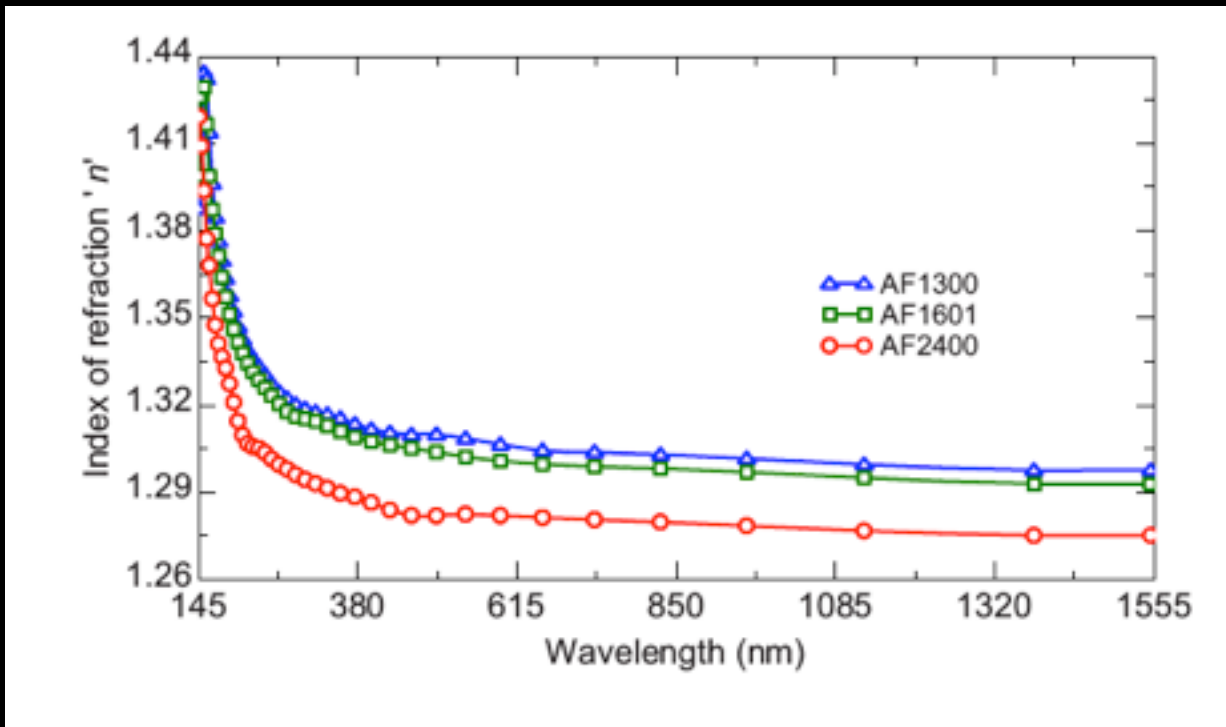
-> gravity !!
-> double glas window





Reduce reflectivity of entrance window

- Antireflective coatings with amorphous flouropolymer resin (Teflon) (companies: Cytop, DuPont)



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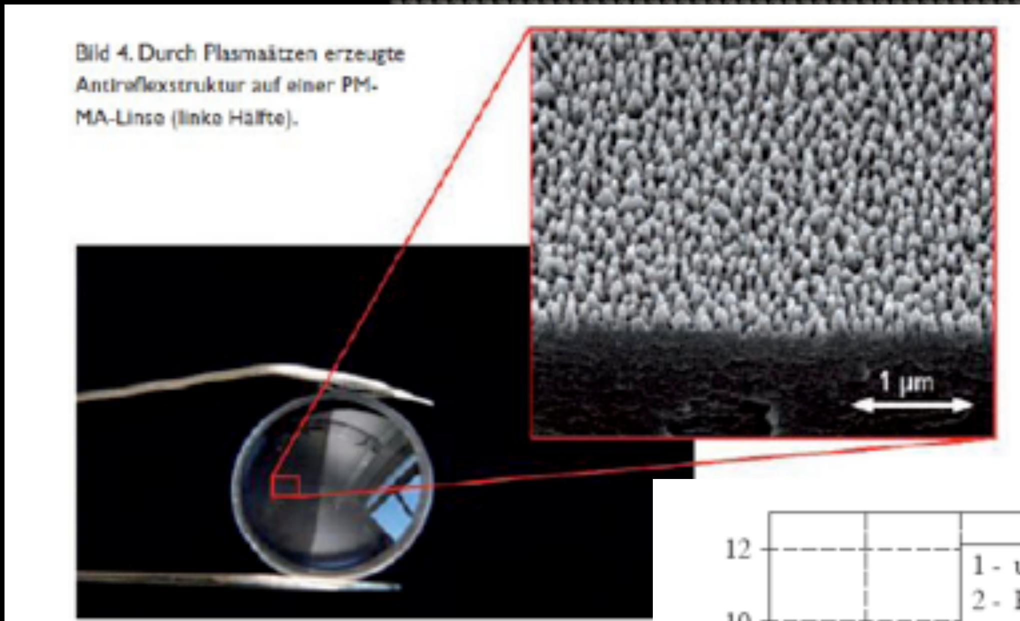
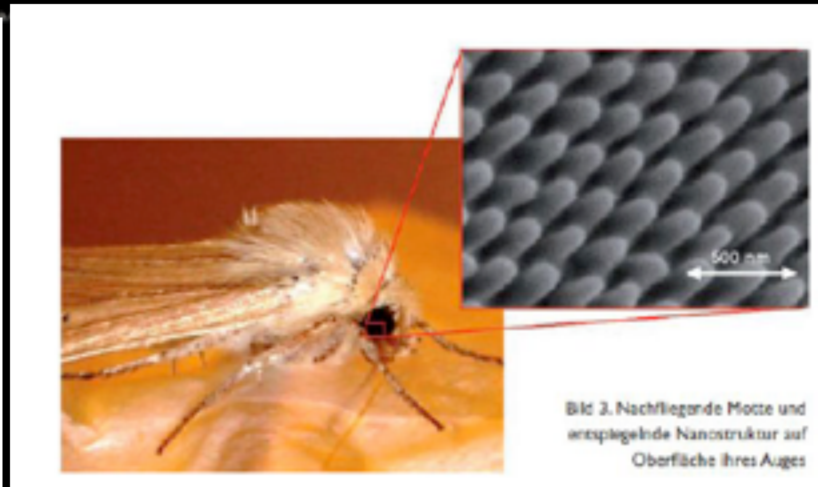
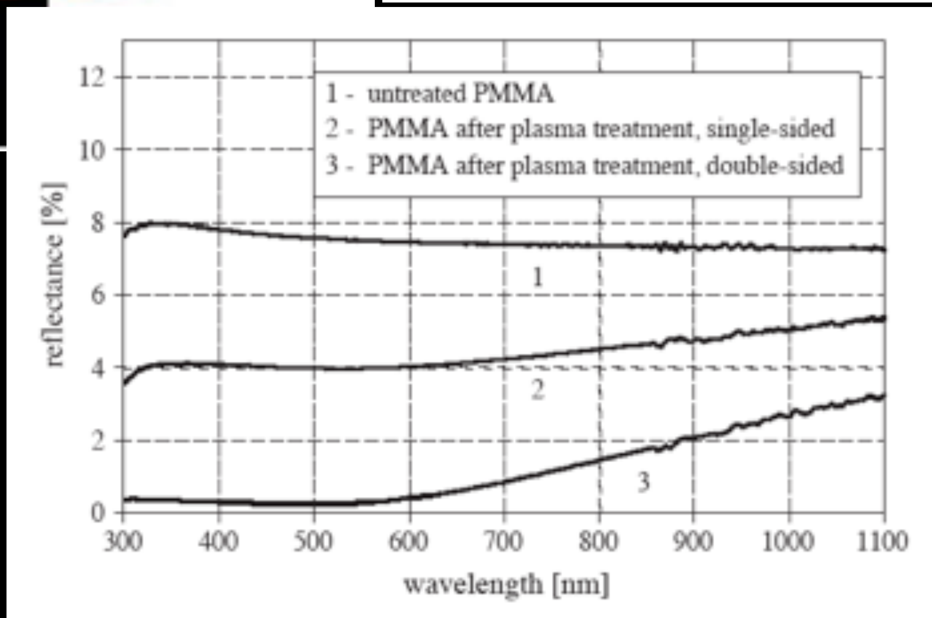
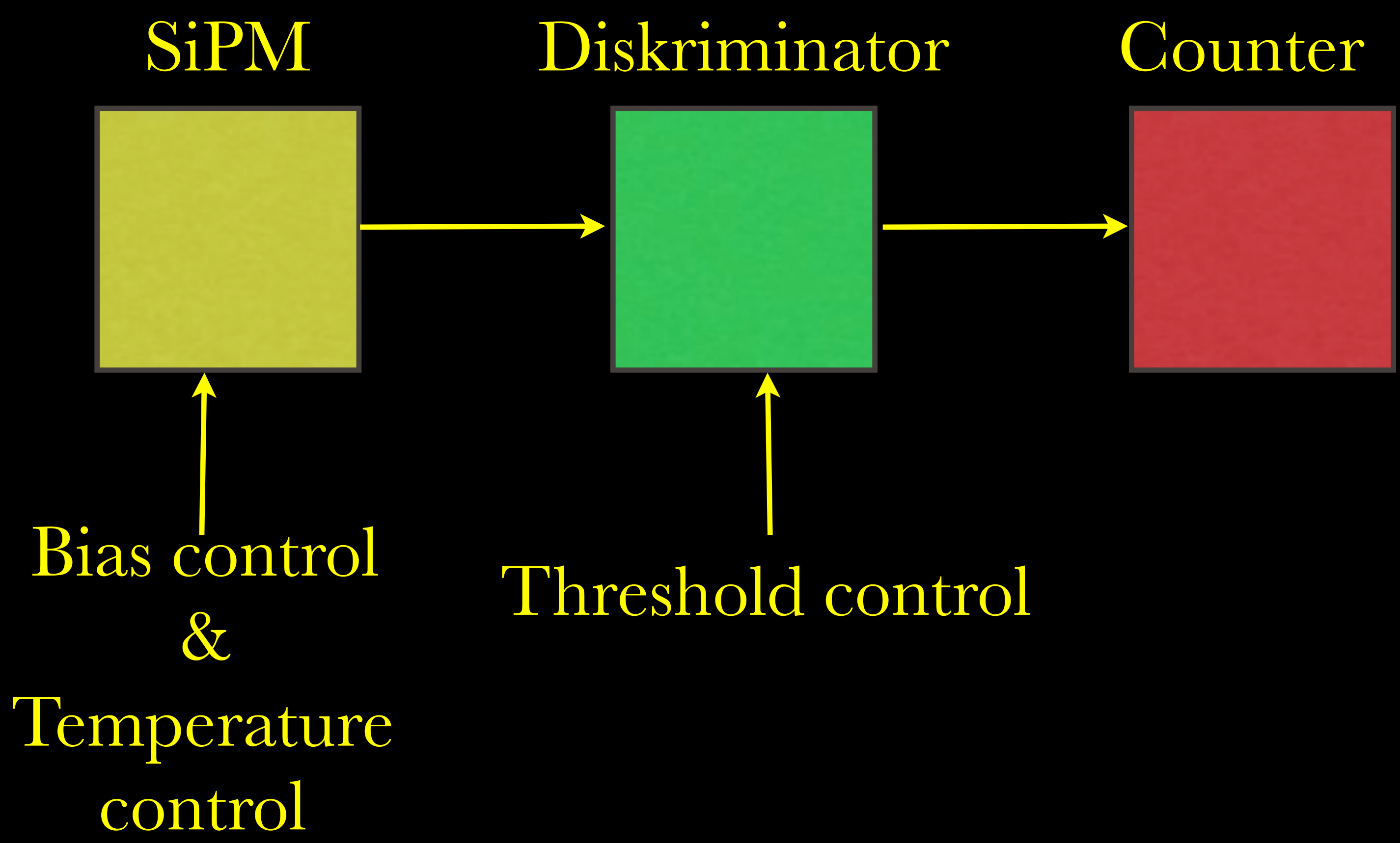
Significant reduction of reflection by moth eye structure





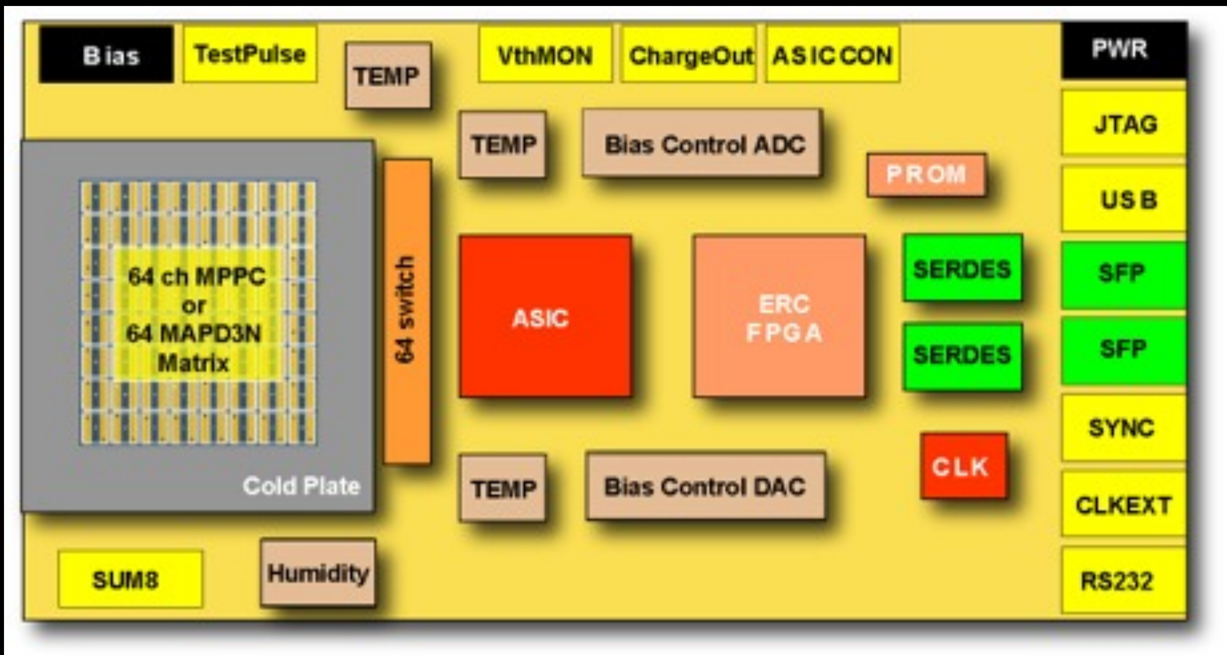


Sketch of readout and slow control for SiPM camera



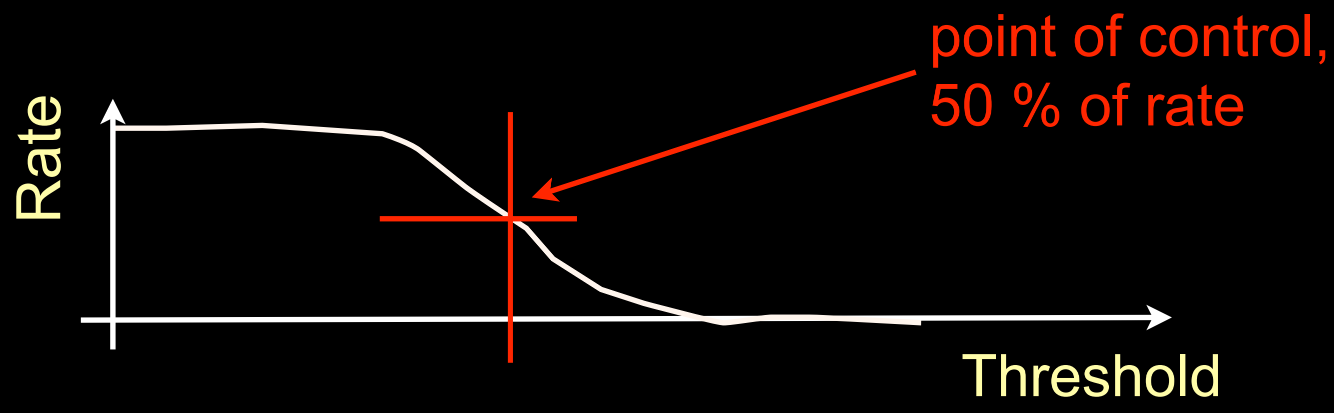
Development of a lowcost-lowpower readout with 64 programmable discriminators

- Front-end ASIC: MAROC III
- Programmable shaping time
- Programmable threshold
- Charge sensitive inputs, sensitivity 15 fC
- On-Board FPGA
- optical link transmission
- USB2 output



Online calibration (and adjustment) of both: Gain and PDE:

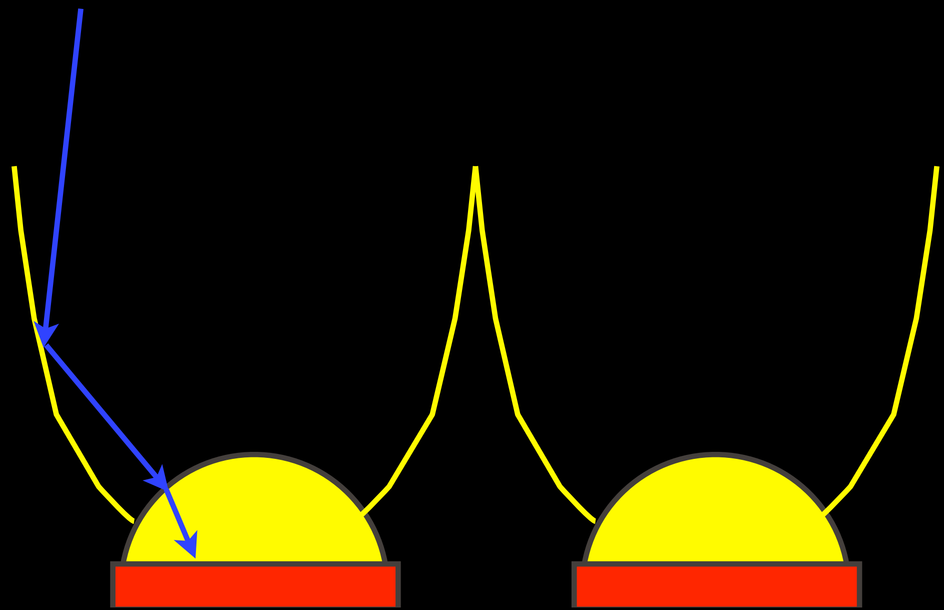
- Monitor gain and (relative) PDE with discriminator only



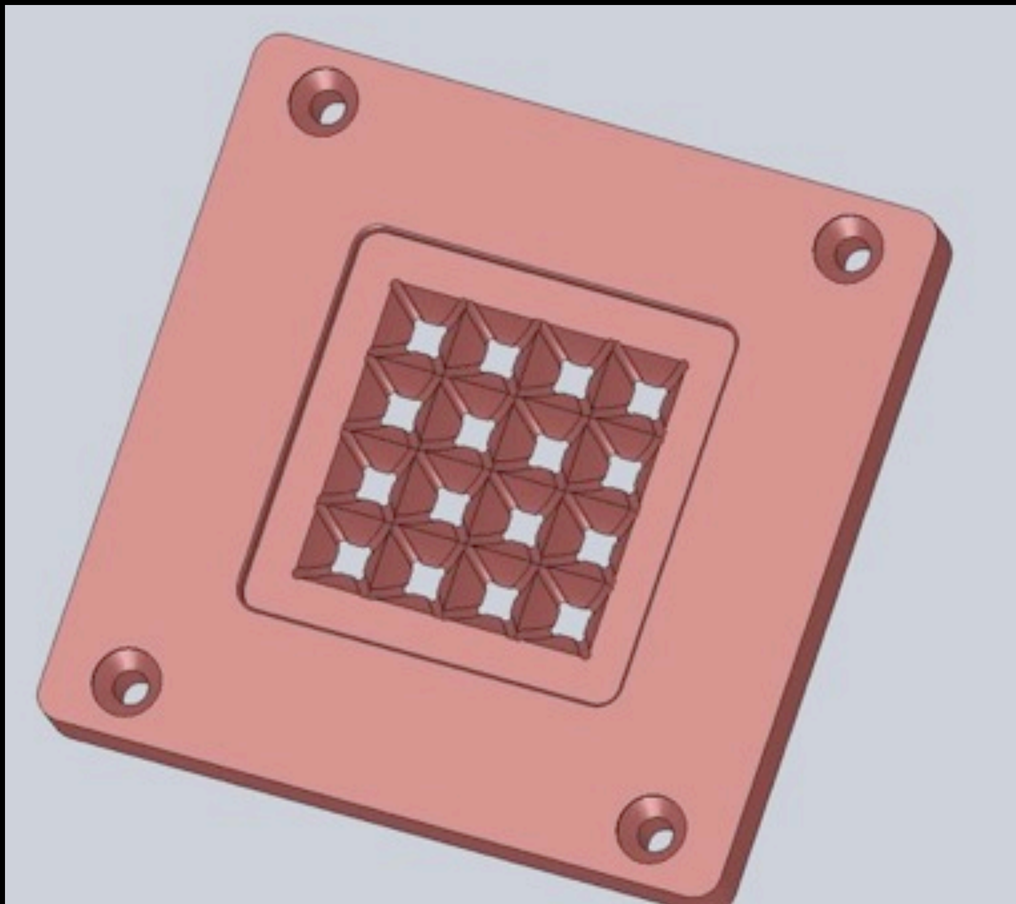
- In case of rate increase the point of 50% remains at the same threshold (--> gain or amplitude of pulses)

Optimize light collection on SiPM

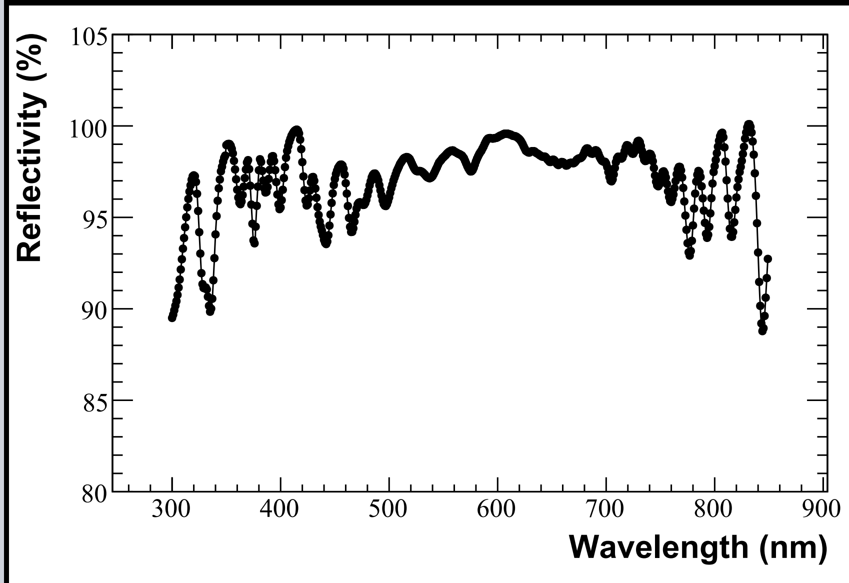
- ‘Perfect’ Winston cone
- Si has refractive index 3.6-3.8
  --> strong reflection
- Covered by SiO_2
- Additional protection layer with a resin
- Need an additional anti-reflective treatment
- PMMA layer with moth-eye plasma etching



SiPM light guides for test camera

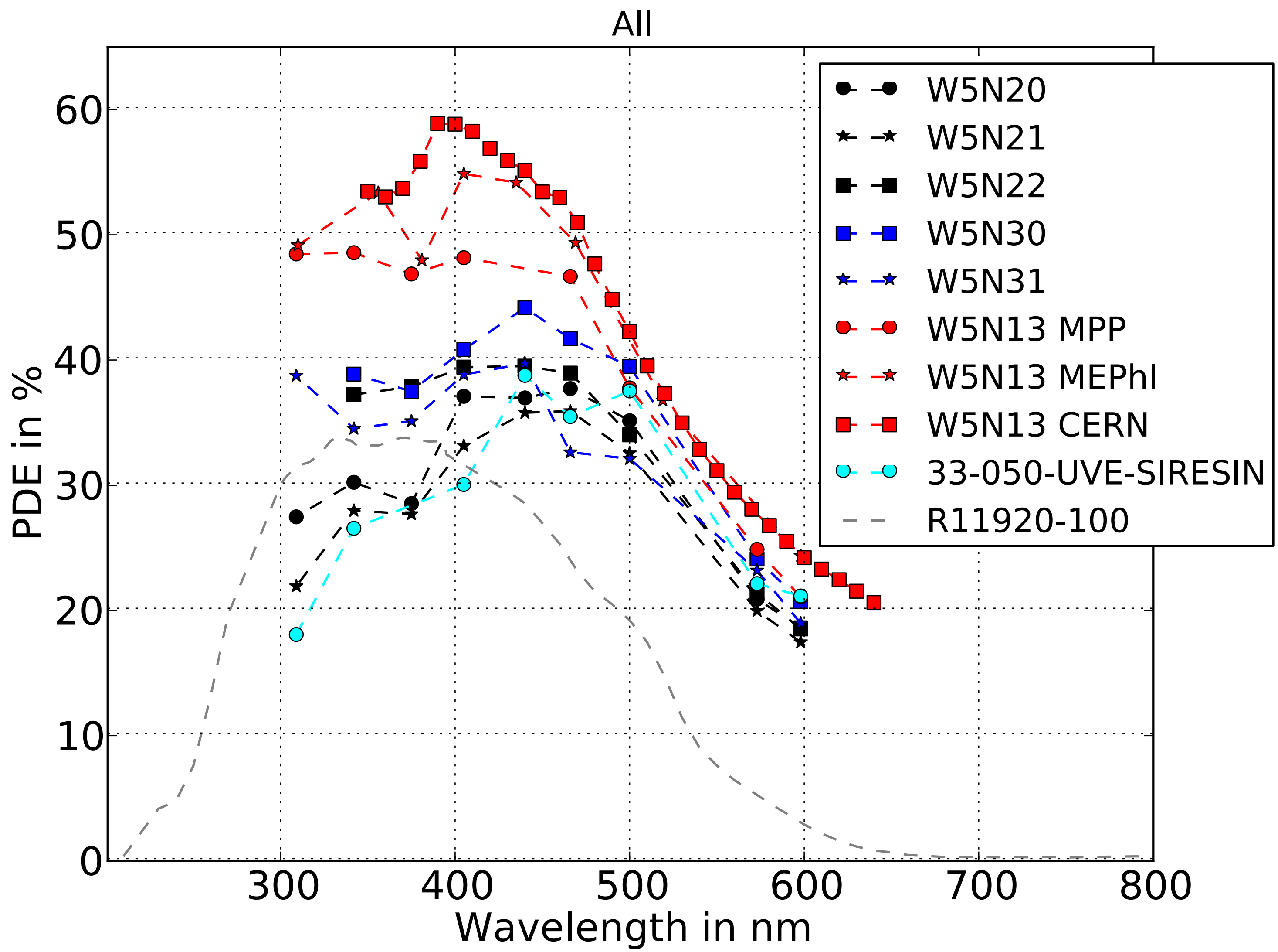


Reflectivity of coated 3M-Vikuity-foil




Thanks

Quantum efficiency of different SiPM



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