The SiPM Project at the MPI

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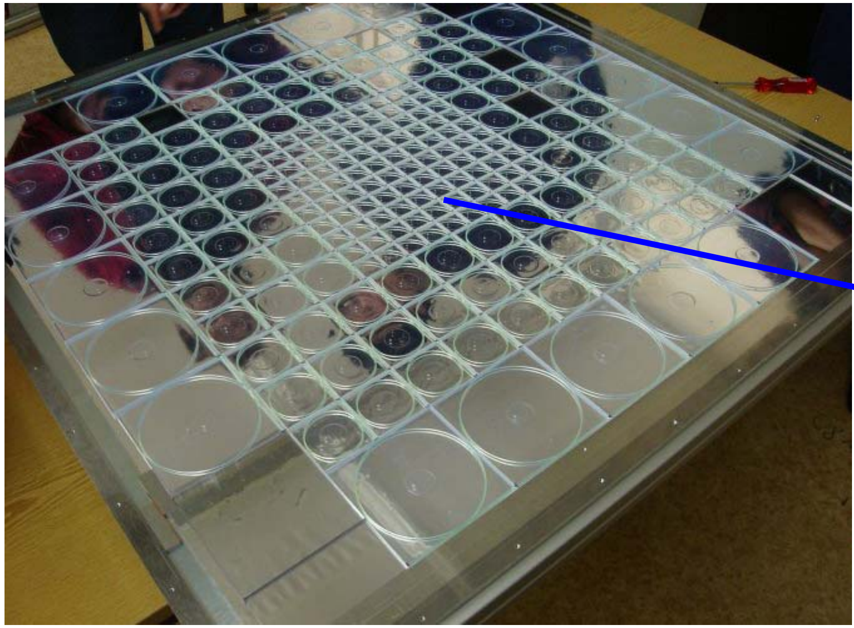
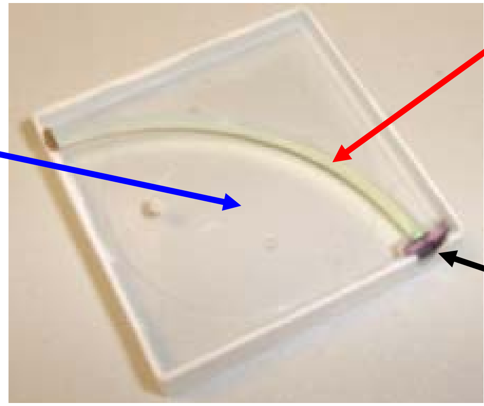
- **Introduction:** Why yet another SiPM development ?
- **Test setup at MPI:** First glance at known SiPMs
- **Planned measurements:** Optical coupling to HCAL tile
- **A new type of SiPM:** Why not ?
- **Conclusions**

1. Introduction





Single tile readout with WLS ...

… and
SiPM (Mephi)

R&D HCAL of the Calice Collaboration (MPI member since last fall)

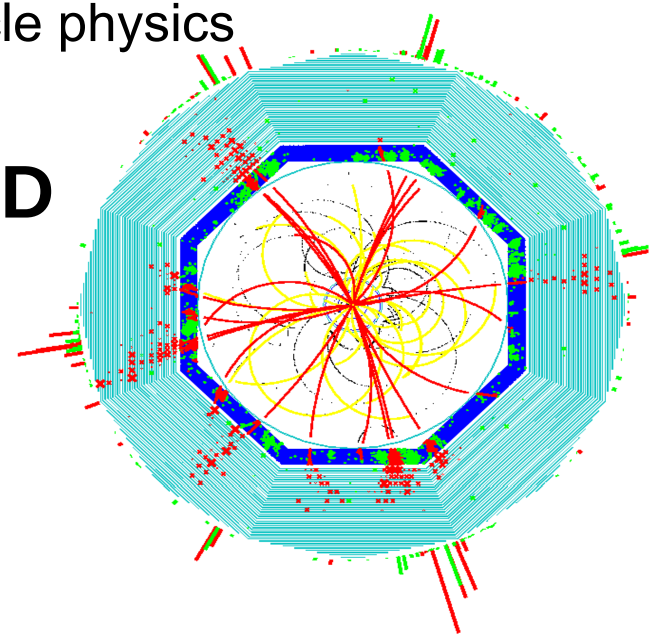
ILD

- need 5 x 10^6 cells for the ILD hadronic tile calorimeter
- difficult to produce (cutting, groove, WLS, mirror etc.)
- Look for simplification: no WLS, blue-sensitive SiPM

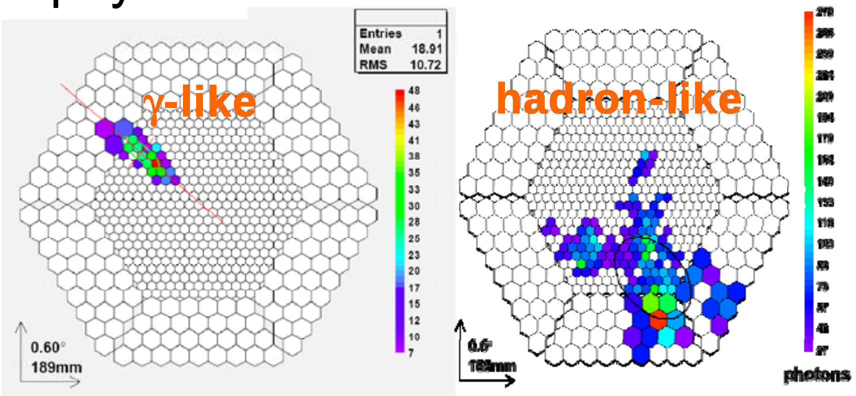
MPI's Interest in a SiPM Program

- Particle physics

ILD



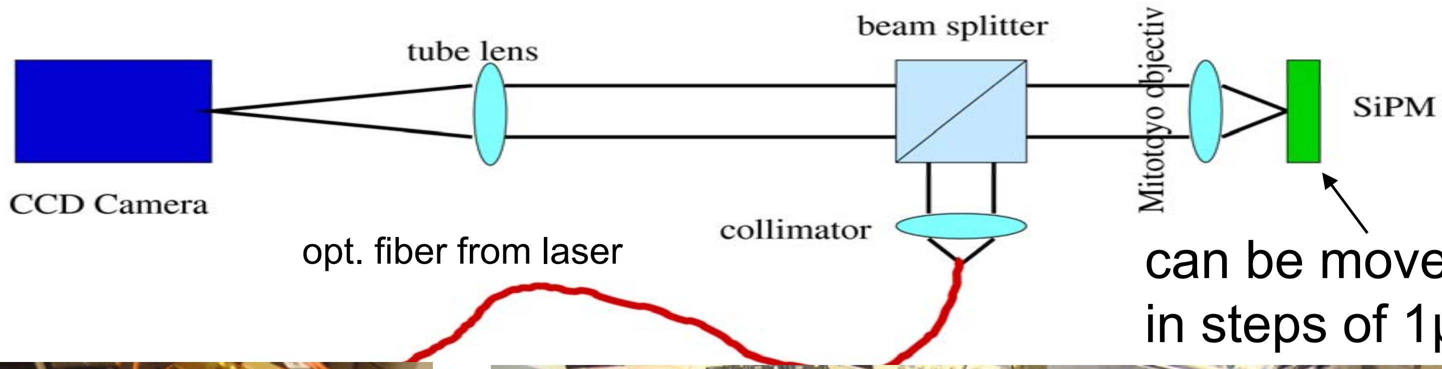
- Astrophysics



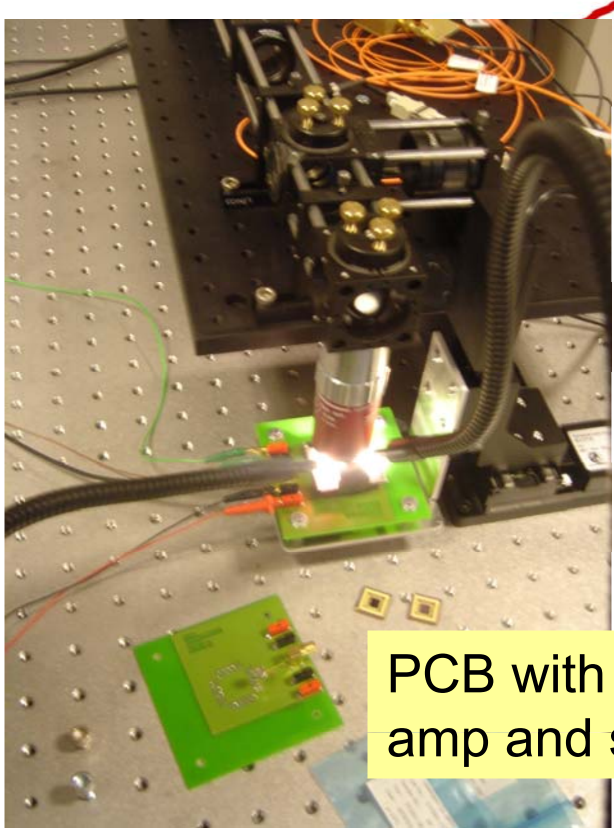
Who is involved within the ILC group?

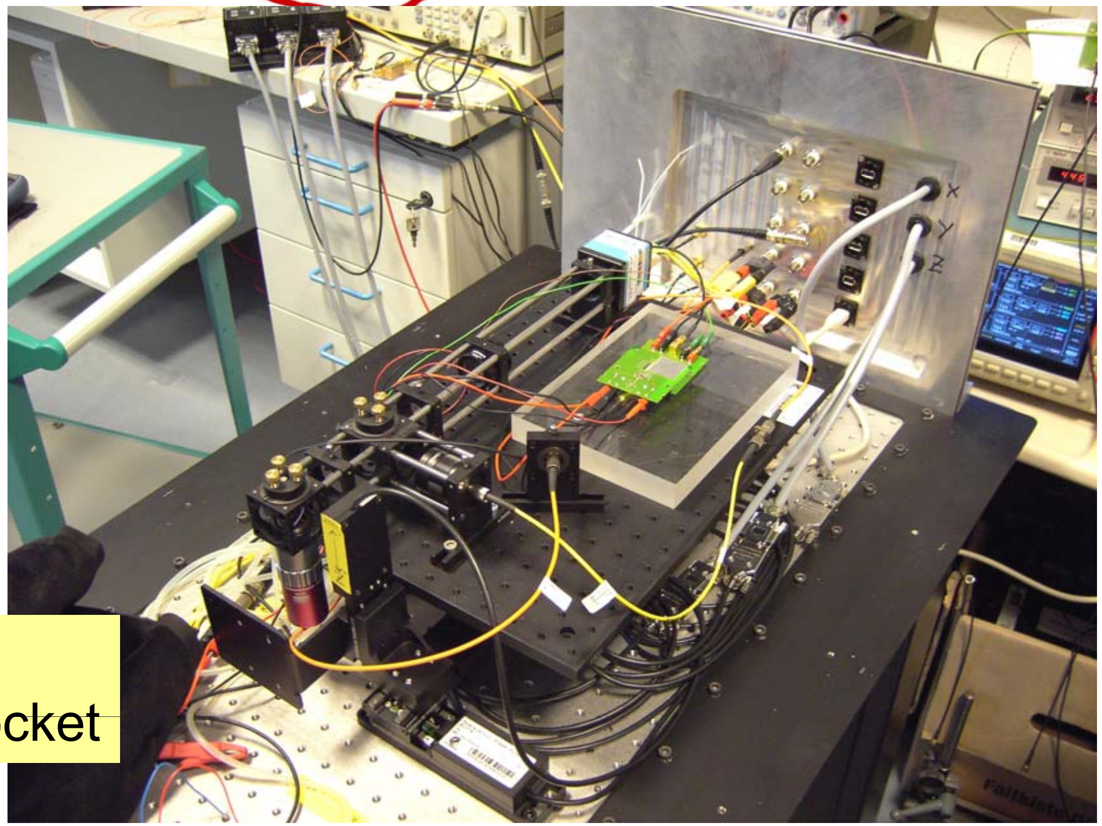
Kolja Prothmann Olaf Reimann Frank Simon C.K.	MPI for Physics, Munich
Laci Andricek Gerhard Liemann Hans-Günther Moser Jelena Ninkovic Rainer Richter	MPI & HLL „HLL“ = Semiconductor Laboratory of the Max-Planck-Society, shared by MPI for Physics and MPI for Extraterrestial Physics

2. Test Setup for SiPM Characterization



can be moved in xyz
in steps of 1µm





PCB with
amp and socket

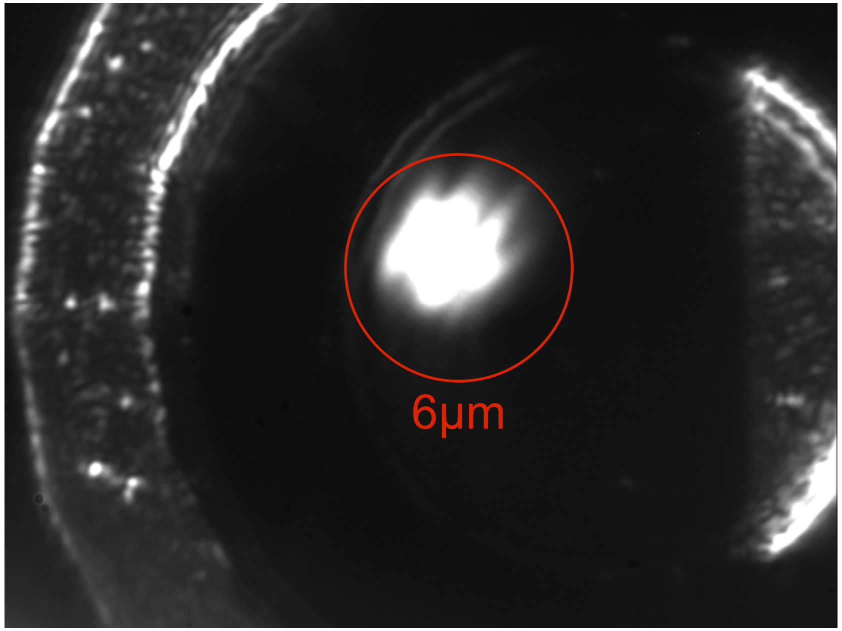
Laser and Optical System

Wavelength of laser: 850nm

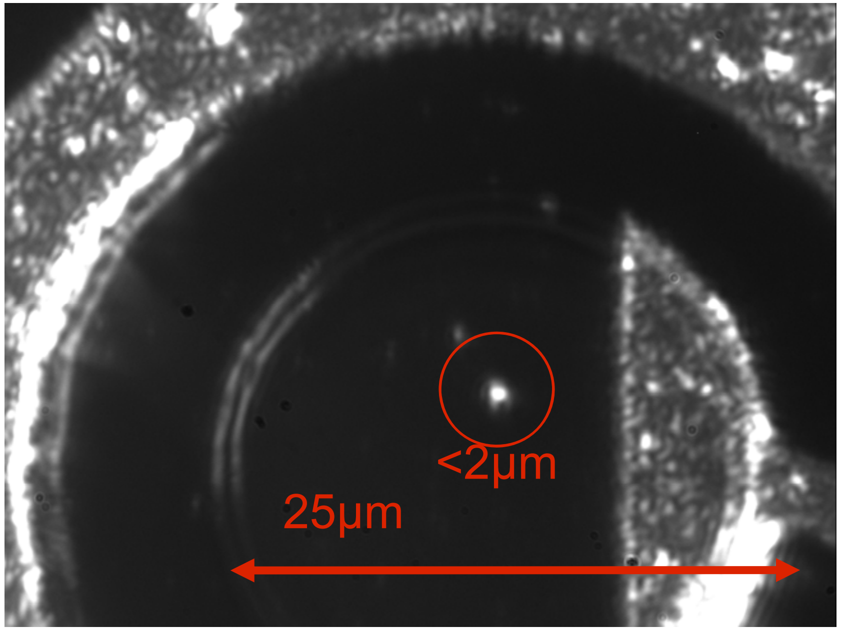
Goal: fine scan (order µm) to characterize the response of a single pixel

single „conventional“ pixel (HLL)

laser spot on SiPM pixel, sensitive area of pixel 25µm

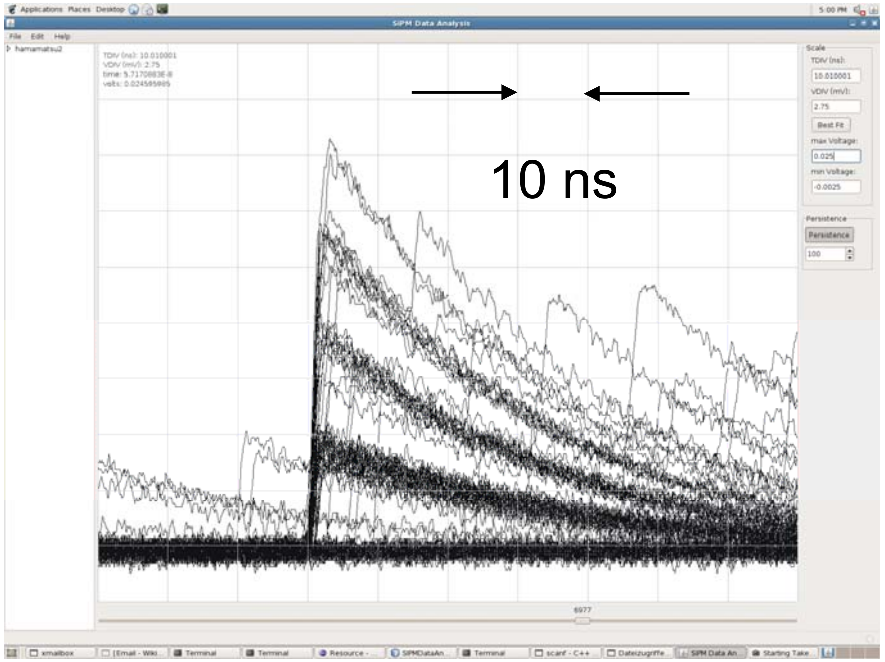


last December



now

Pulse Shape Analysis

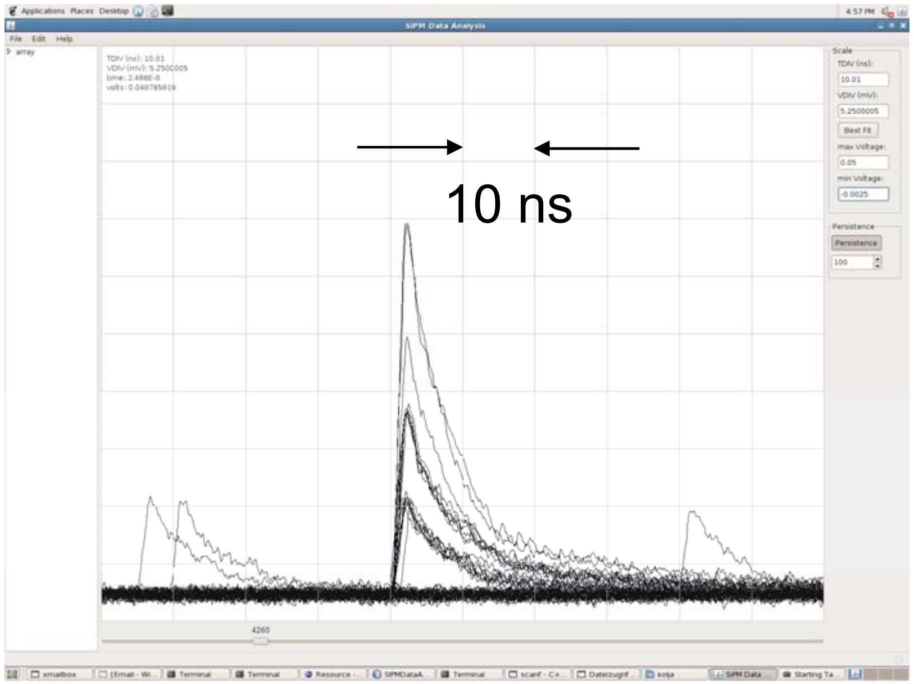


Hamamatsu
100UI

100µm pixel
100 pixels

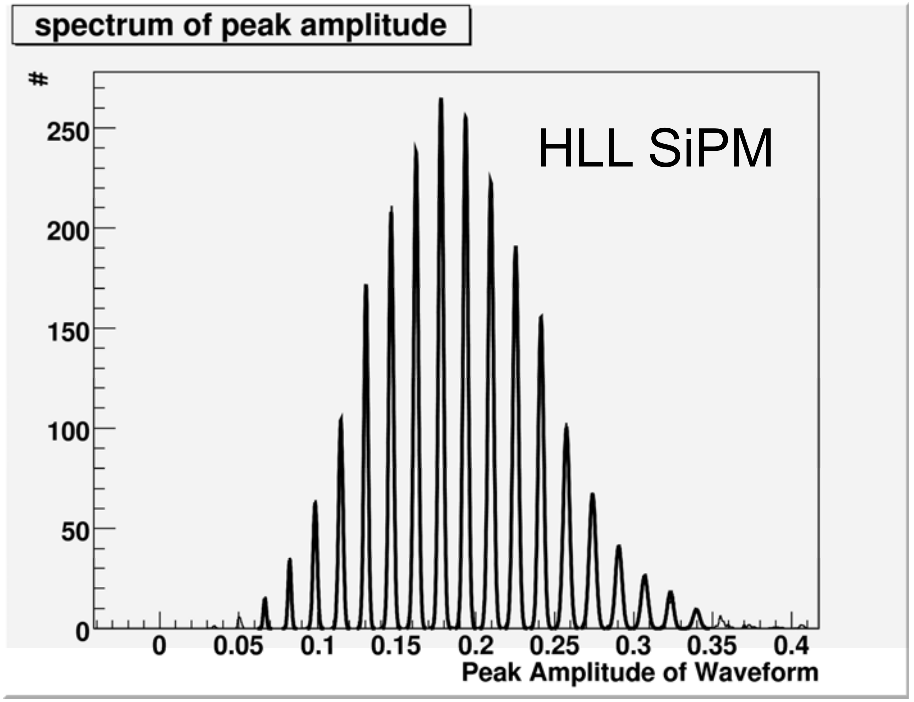
Wave forms from
oscilliscope

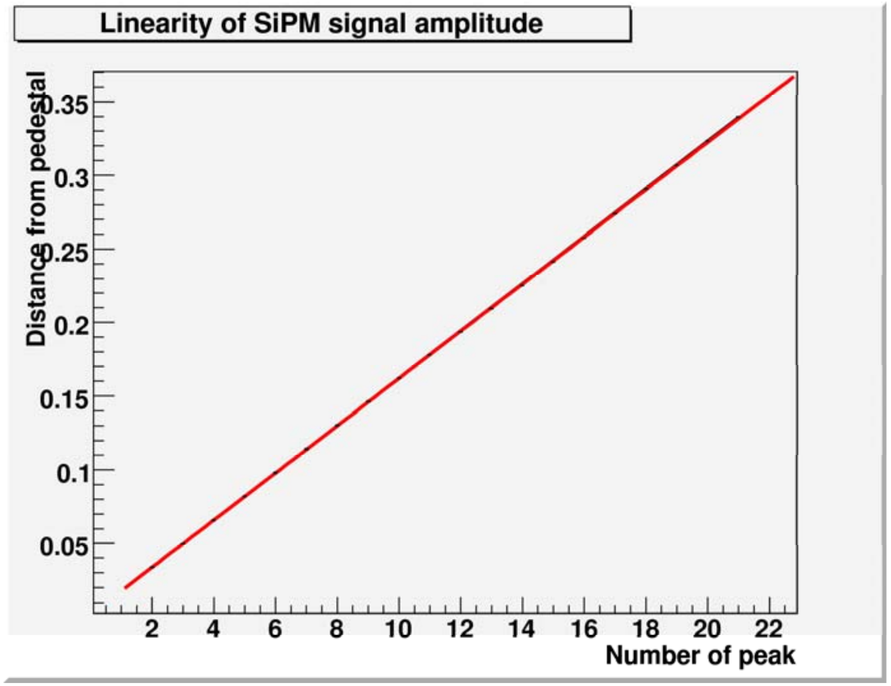
HLL Test array
25µm pixel
500 pixels



single waveform analysis:
- fourier analysis and lowpass filter
- offset correction
- darkpulse veto
- superimpose rising edges

„Energy“ Measurement





increase laser intensity:
nr of observed photons
obey ~ Poisson statistics

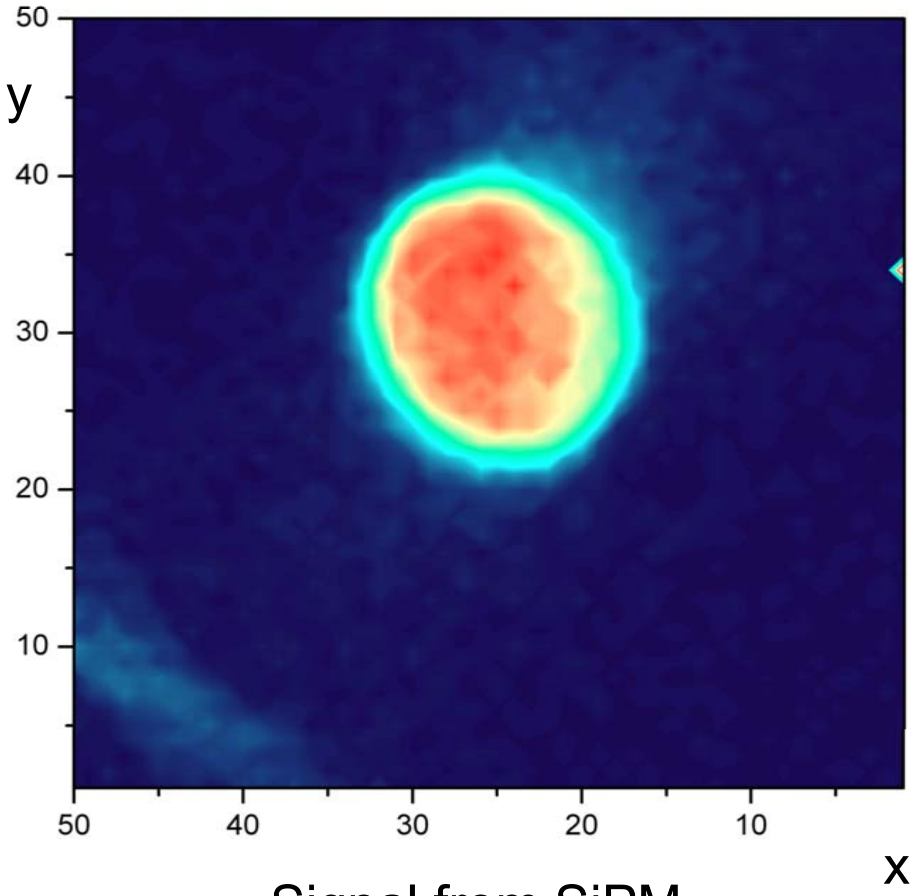
up to > 20 photons resolvable

linearity plot:

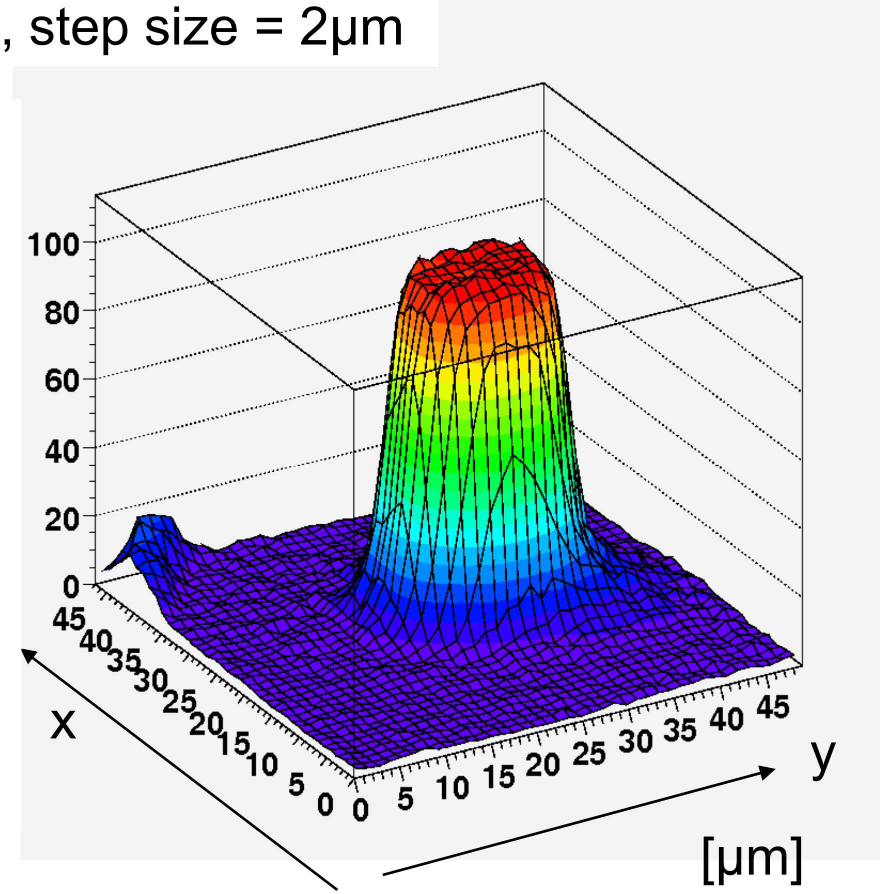
average photon yield vs
laser intensity
(still far away from saturation)

Uniformity over the pixel

Step with laser over the pixel (array), step size = 2μm

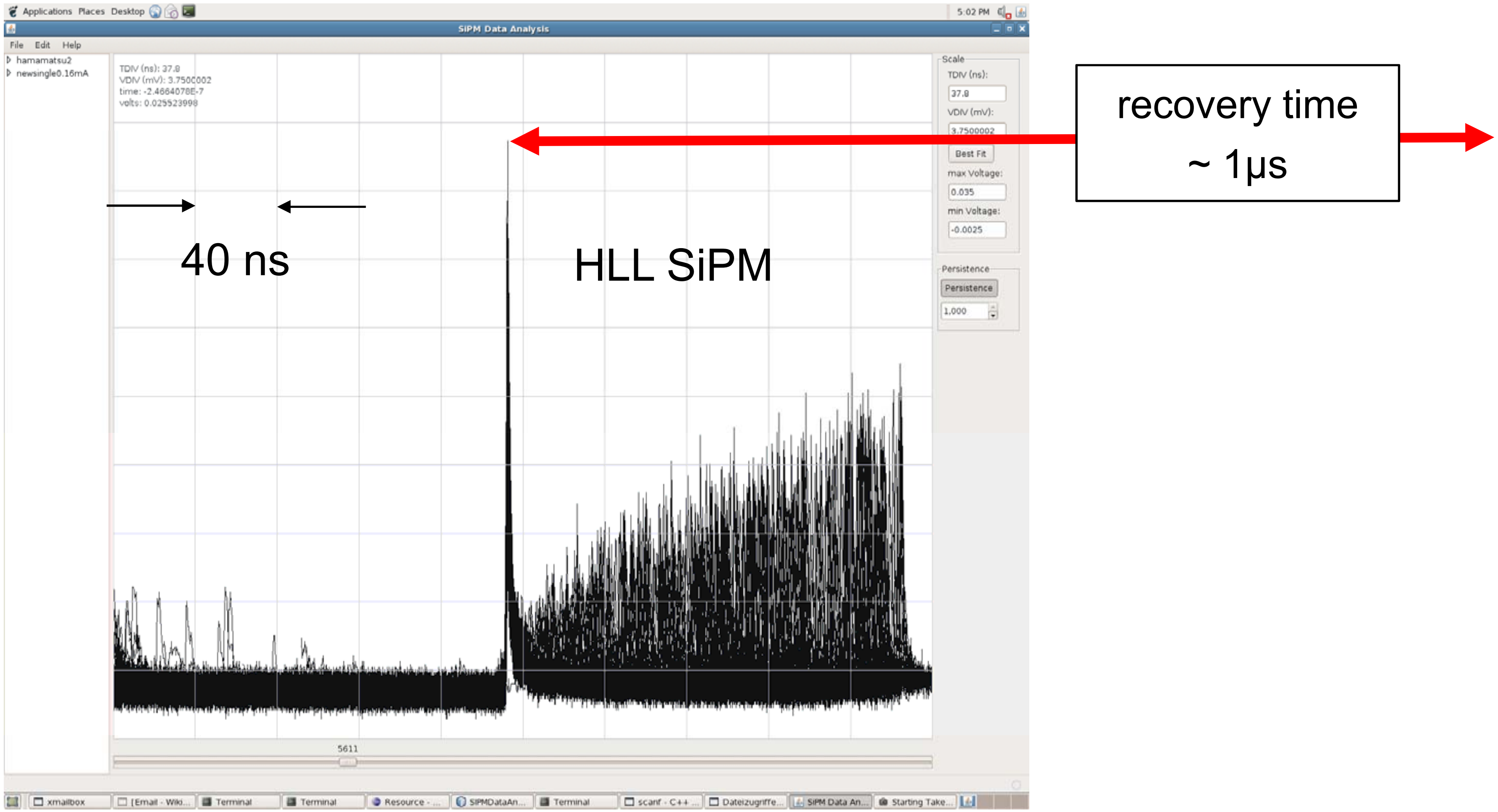


Signal from SiPM



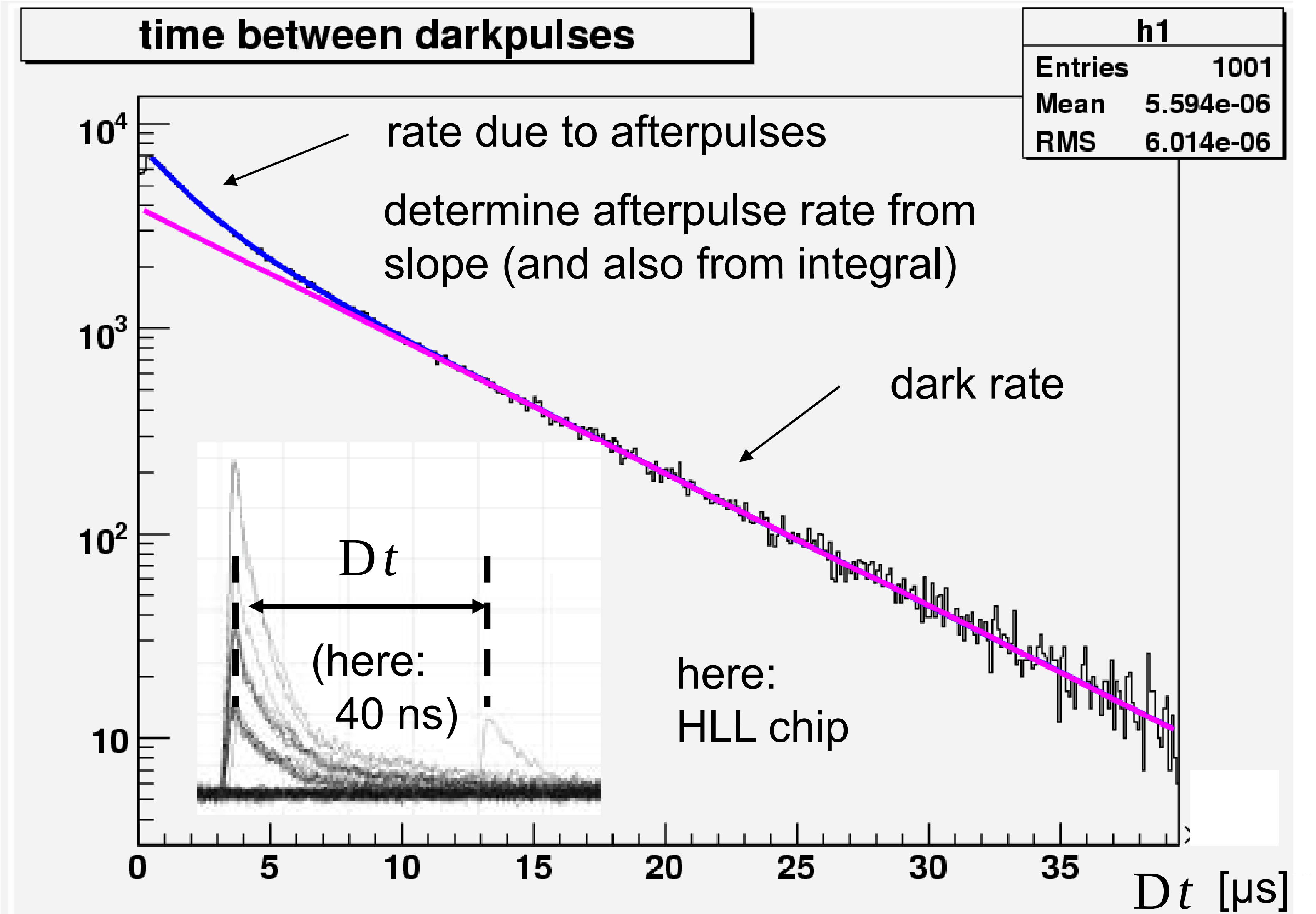
here: Single HLL pixel

Recovery Time



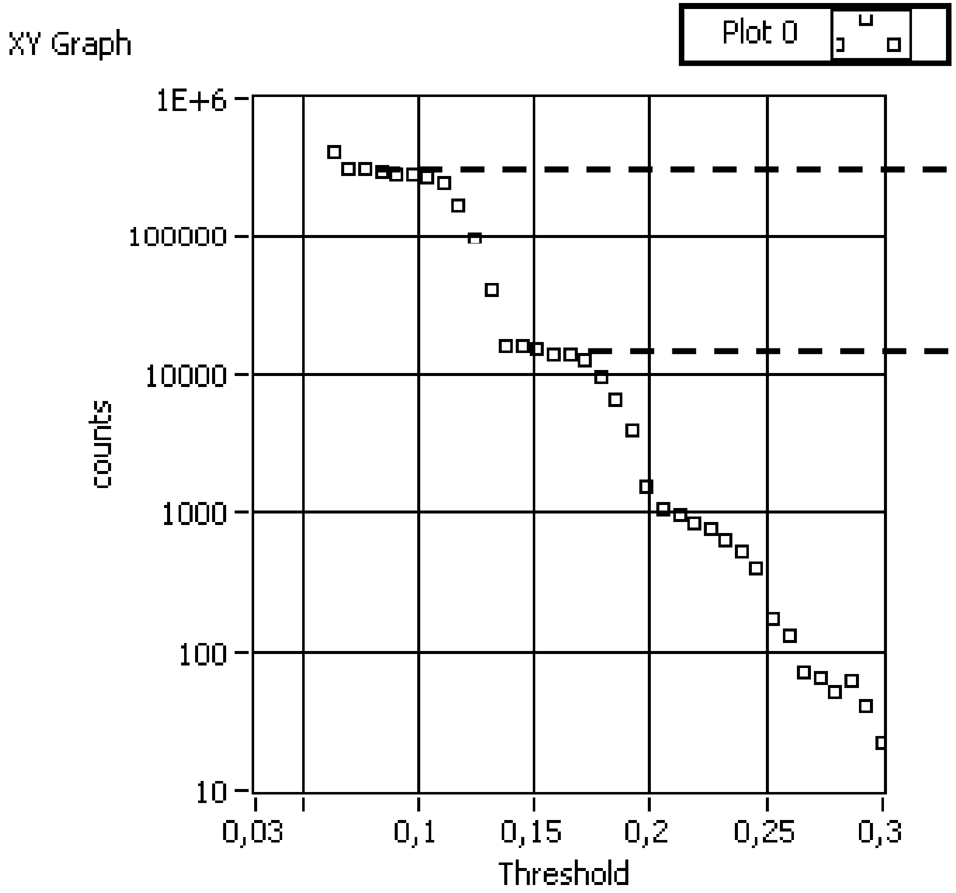
Recovery time calculated from single pixel data. Waveforms are sorted so that first peak (largest in scope time window) always at same position.

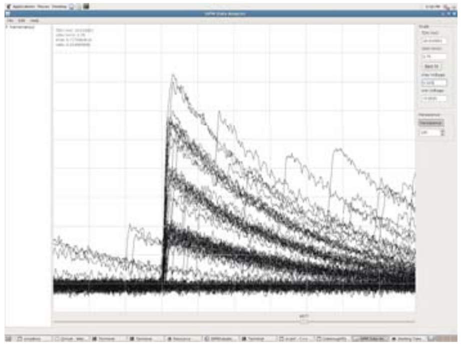
Afterpulse Rate



Cross Talk

- measure dark pulse height (laser is off)





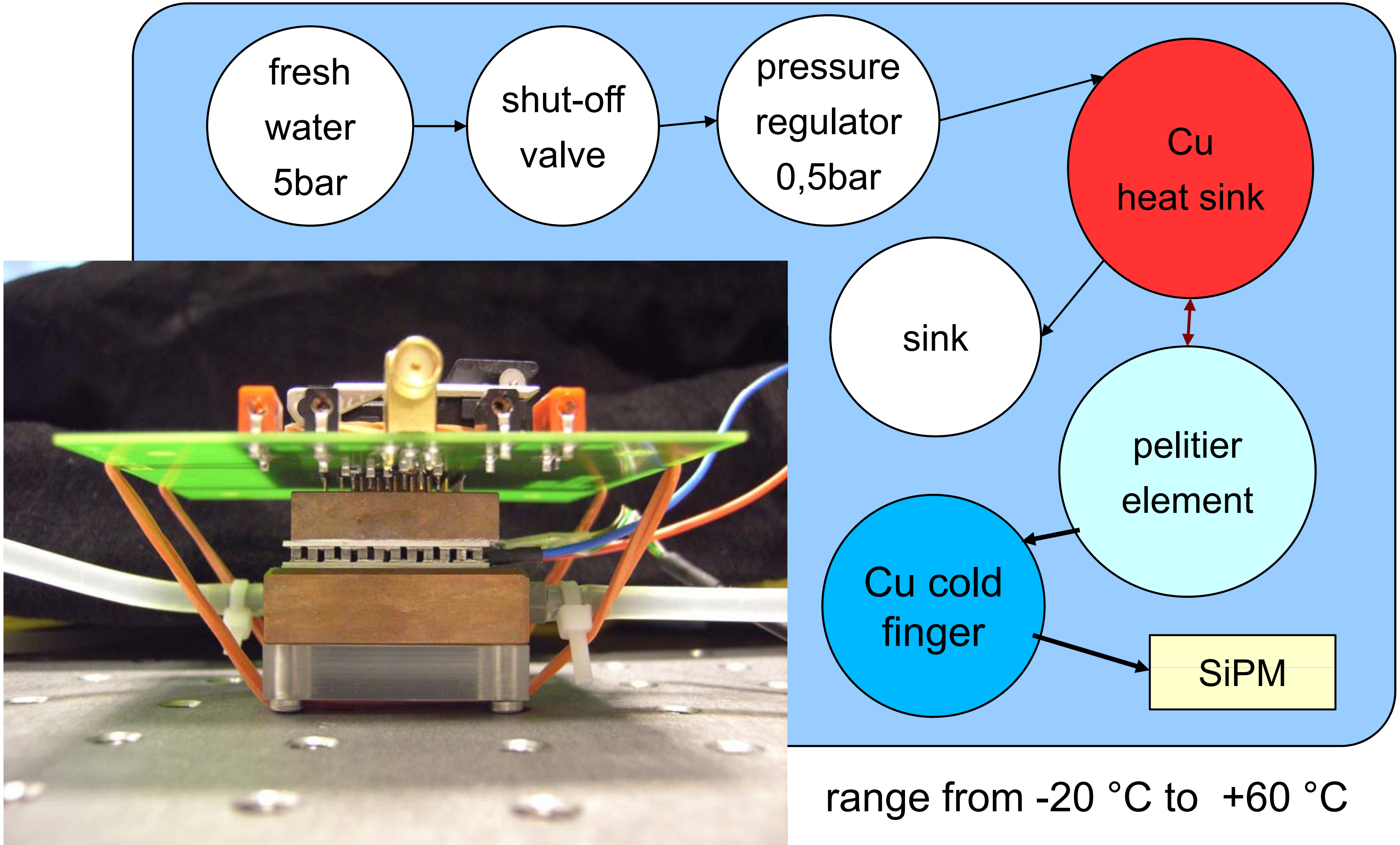
cross talk about 5 %

- Example: Hamamatsu MPPC (76V Bias)

- HLL “conventional” array (40V Bias)
  cross about 0.01 %
  (test chip, low fill factor)

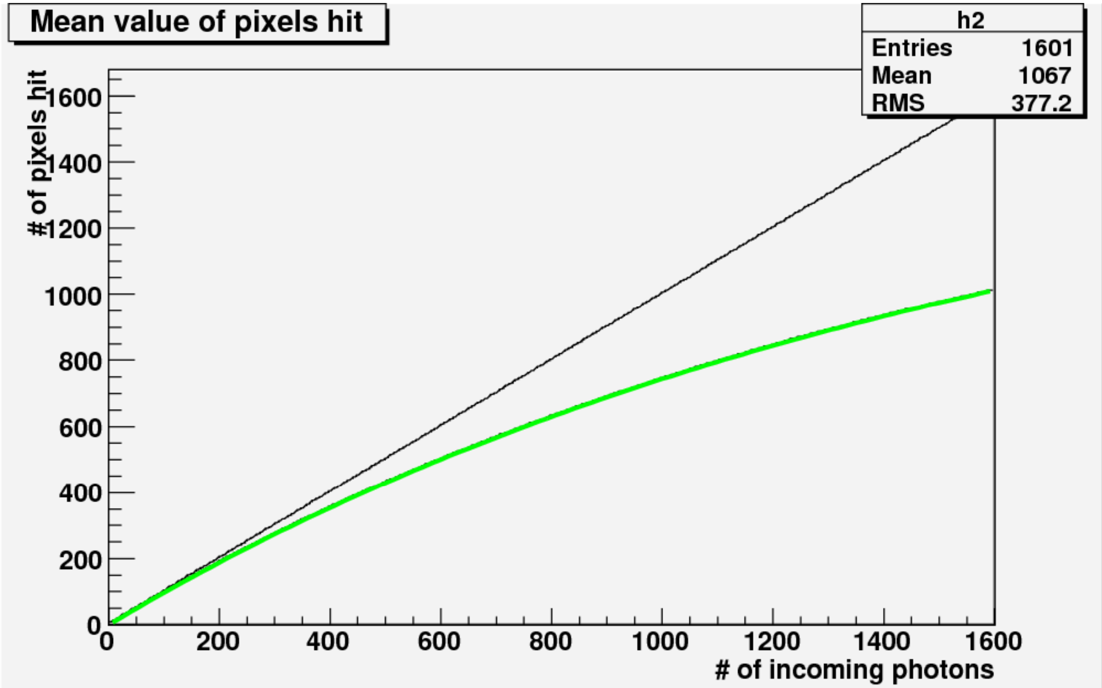
- Alternative method:
  focus on one pixel and count 2 pixel events

Temperature Dependence



range from -20 °C to +60 °C

Saturation

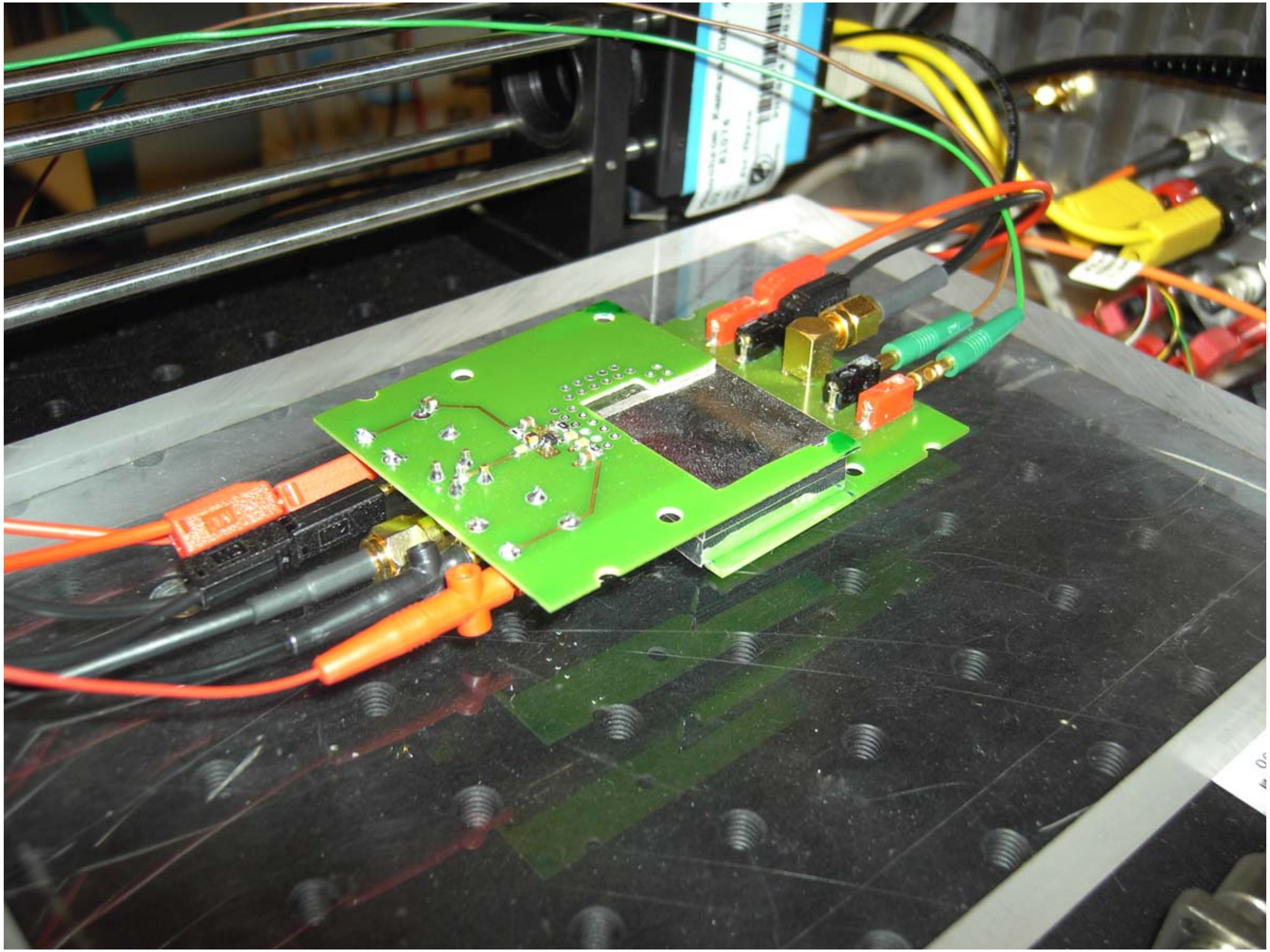


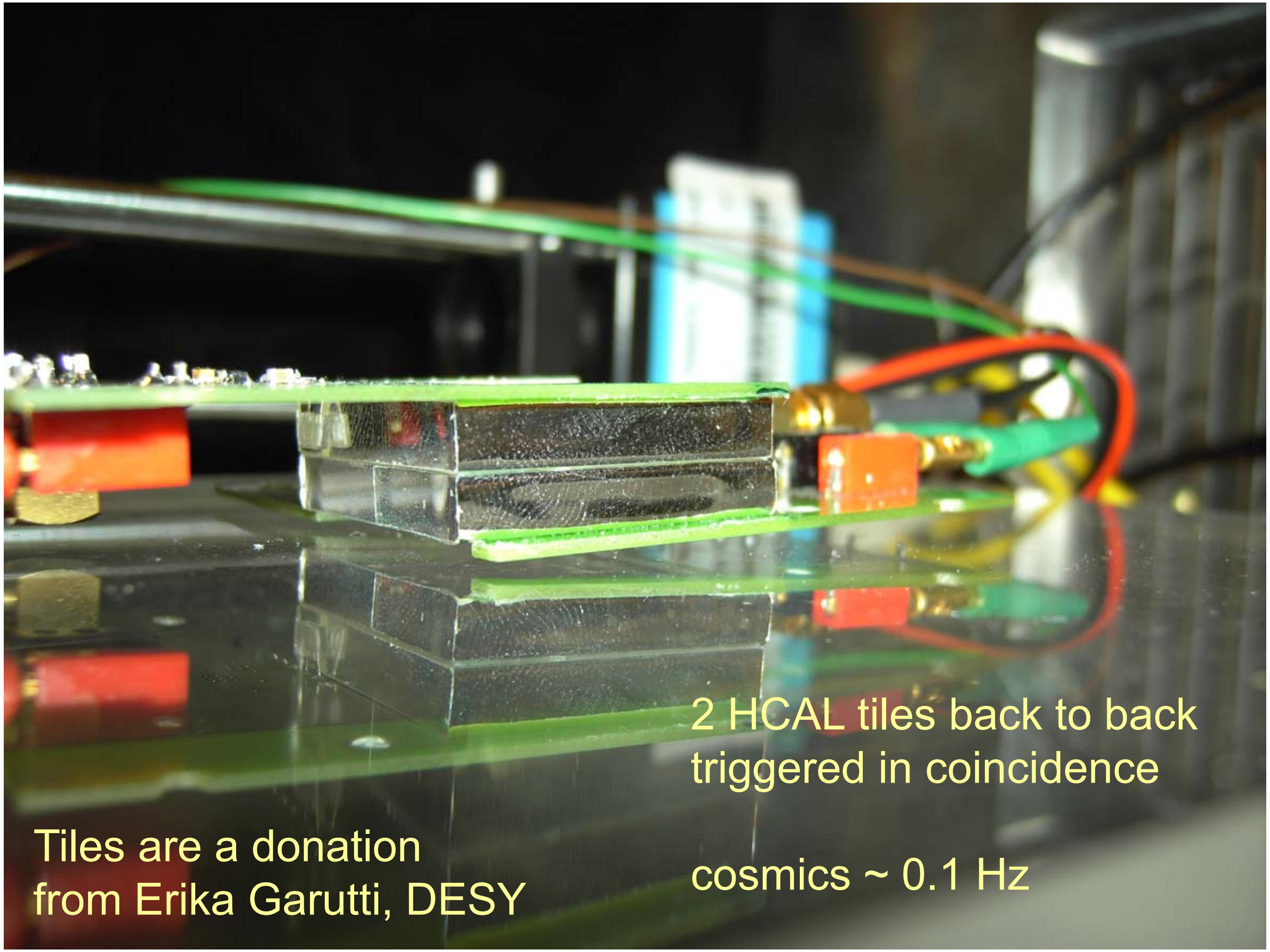
Saturation curve for perfect SiPM with no crosstalk or dark- and afterpulses (simulation)

…just a few of the many characteristics defining the SiPM performance:

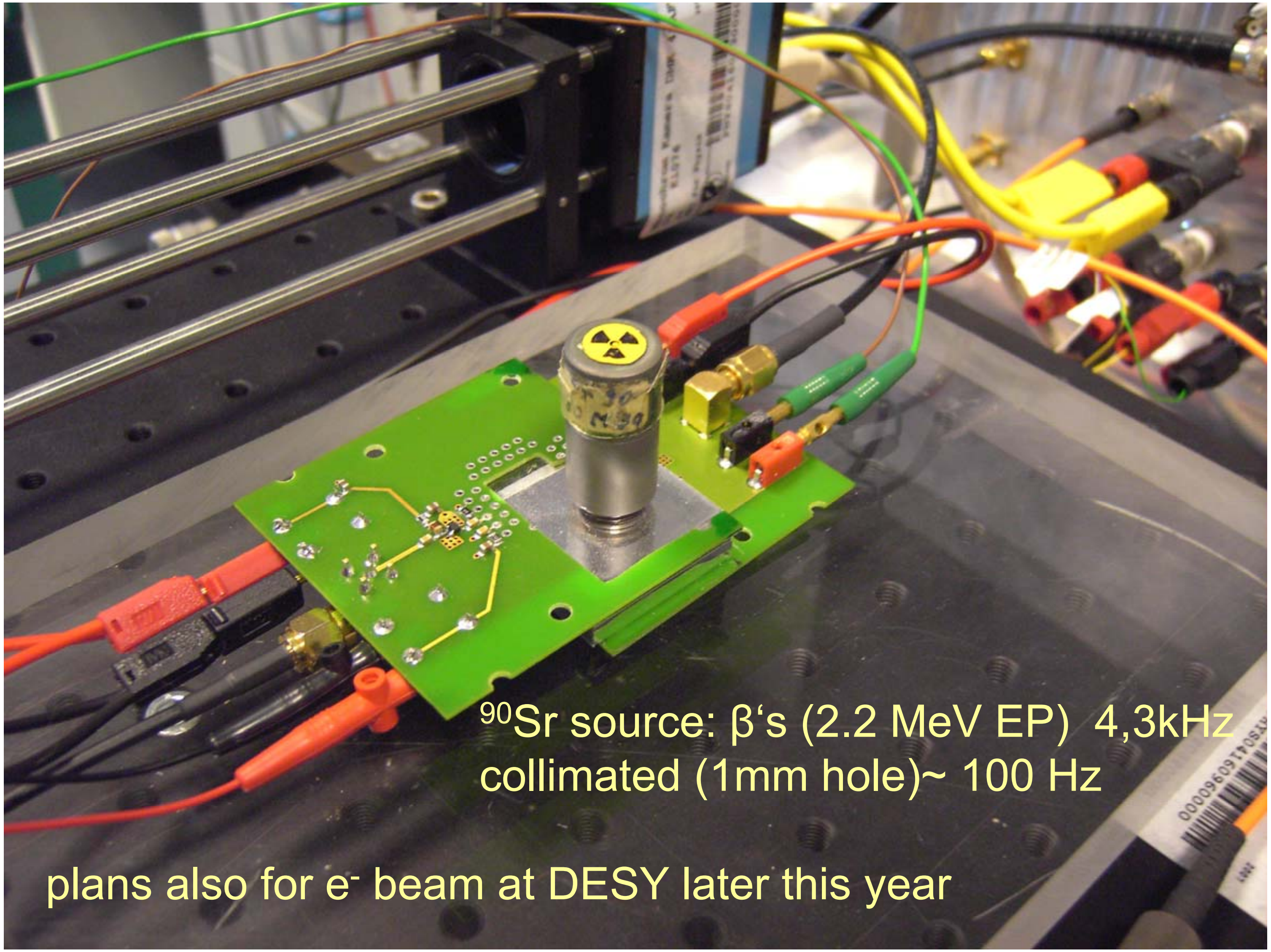
- gain
- uniformity
- cross talk
- afterpulse rate
- temperature dep.
  etc.

3. Coupling to HCAL Tile




2 HCAL tiles back to back
triggered in coincidence
cosmics ~ 0.1 Hz
Tiles are a donation
from Erika Garutti, DESY

Measure Uniformity of Response



Further Steps

- Systematically characterize existing SiPM‘s

  → compare to results in literature (establish method)

- Develop method for coupling of SiPM to tile

  → determine uniformity over tile as fct of position of SiPM on tile

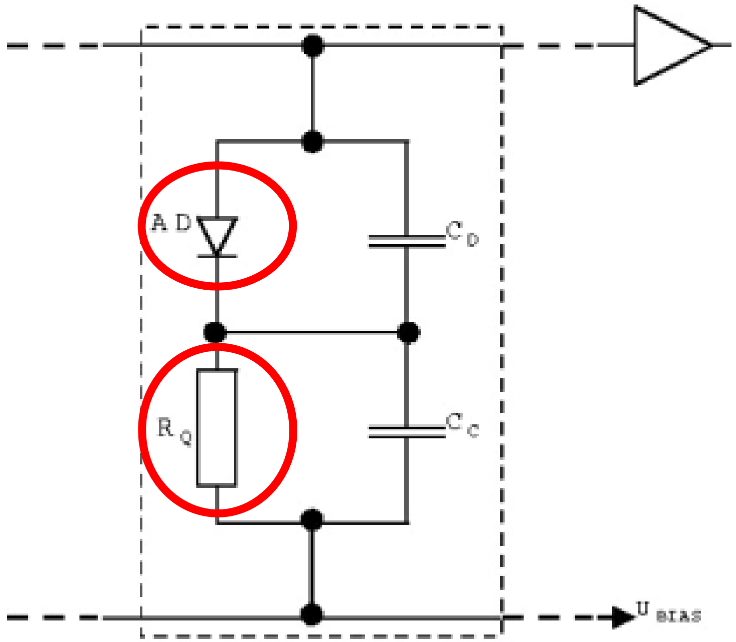
- Study custom-made SiPM, optimize performance (see next section)

  → find optimal SiPM for ILC HCAL

- Build setup (one, or more layers) for the Calice HCAL frame

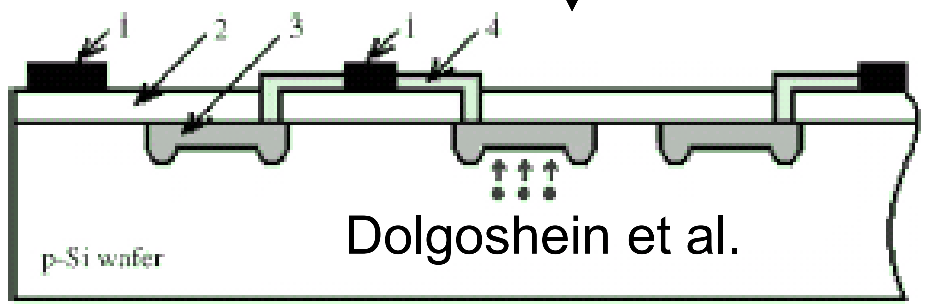
  → join the beam tests

4. New Type of SiPM

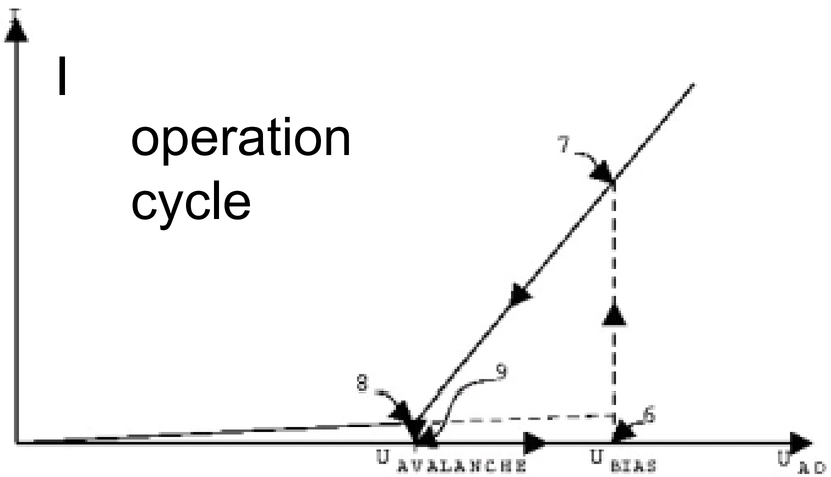


„conventional“
SiPM principle

photons

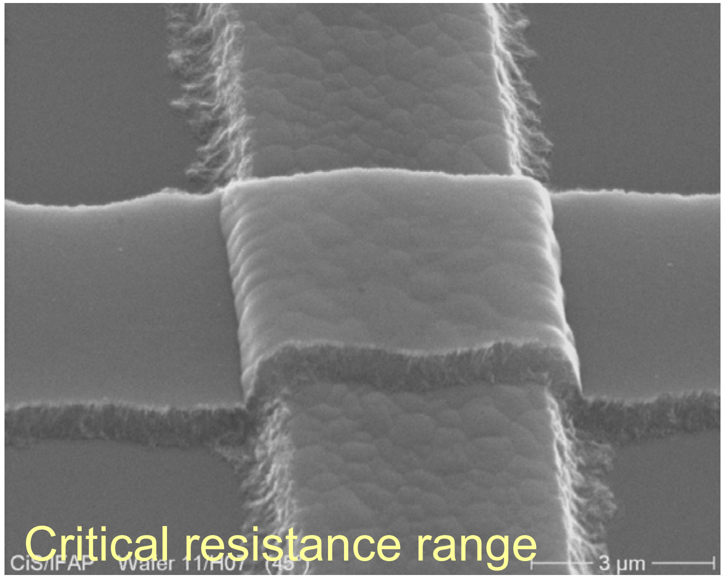


1 polysilicon quench resistor
2 insulating layer, highly doped
3 high field region
4 Al contacts



Surface structures represent
obstacle for light

Cost Driver: Polysilicon Resistor



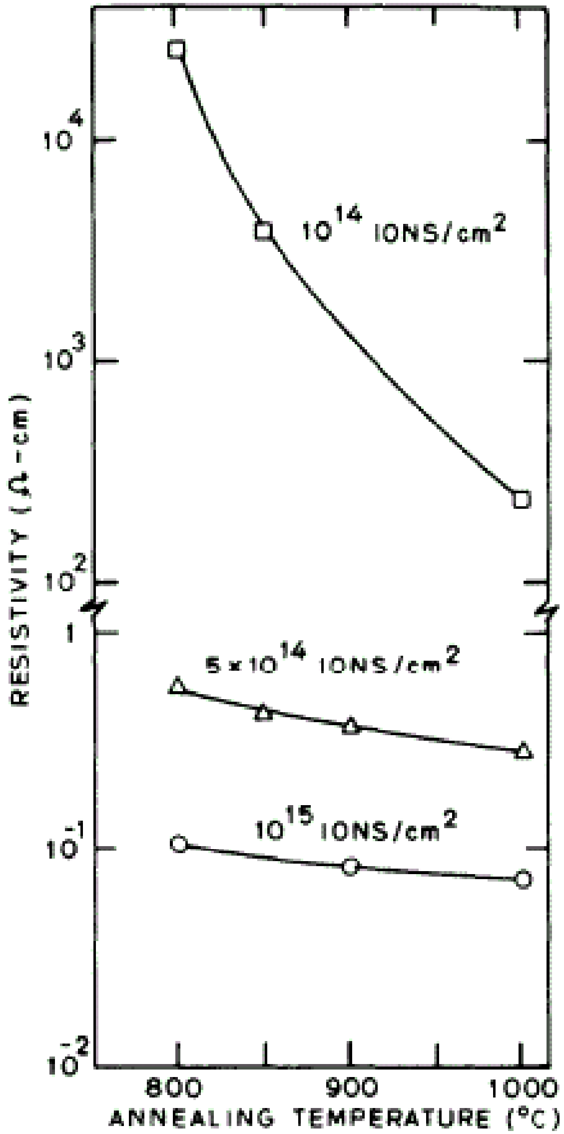
Polysilicon sheet resistor under the microscope

Critical resistance range influenced by many factors such as grain size, dopant segragation in grain boundaries, carrier trapping etc.

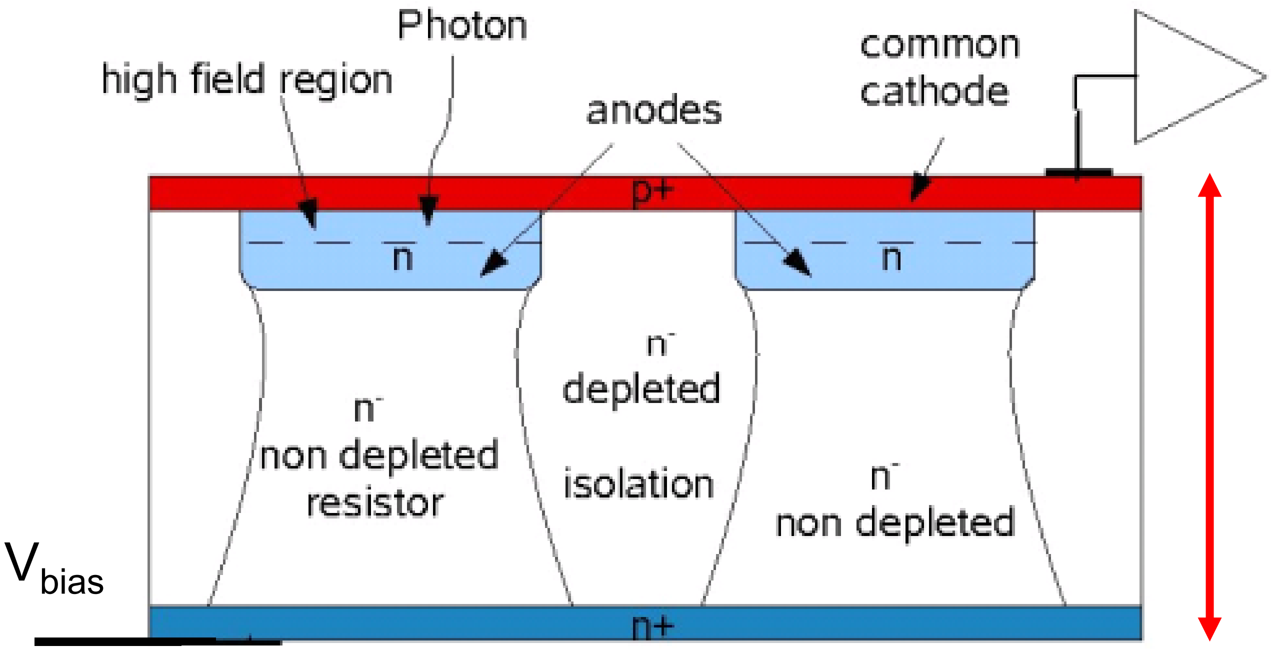
-> sheet resistance depends on deposition conditions, implantation dose, layer thickness, annealing temperature, preconditioning (cleaning steps before deposition) etc.

Rather unreliable (and costly) process step

Can one simplify the implementation ?



Why Not ?



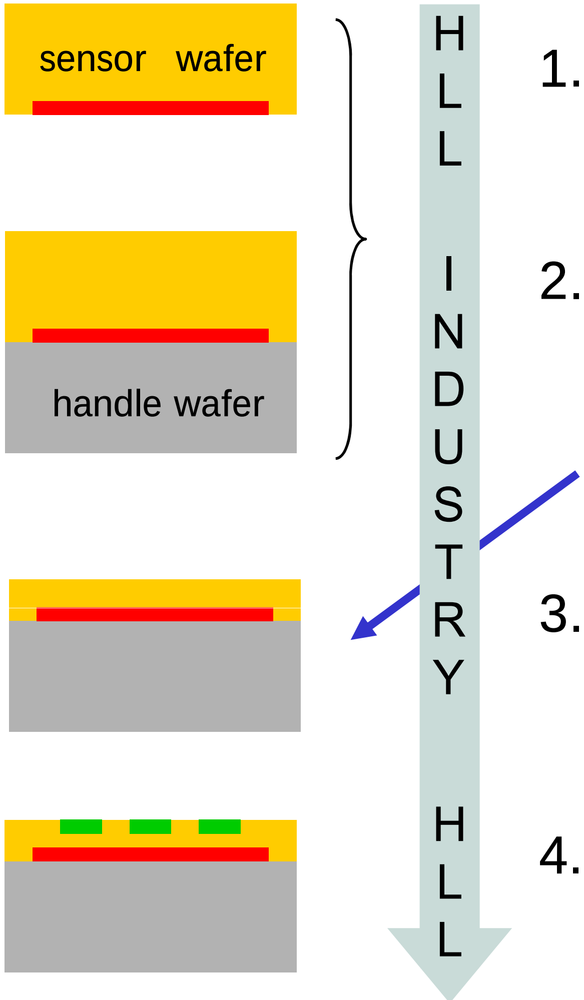
„SiMPL“

thin
silicon
needed
(or EPI material)

- Front side cathode and backside n+ region are common for the entire array
- Anode region becomes an internal node within silicon
- Bulk region beneath the anode acts as vertical resistor, shielded by the anode from depletion
- Gap regions are depleted and isolate the individual resistors

But resistor matching does not work with a wafer of usual thickness ! ☹

Steps in Production



1. implant backside on sensor wafer
2. bond sensor wafer to handle wafer

   (the whole SOI wafer can be ordered from industry)

3. thin sensor side to desired thickness (e.g. 50 µm)
4. Further processing on top side if needed (e.g. surface reflectivity etc.)

Matching of Resistor with Bulk

Actually a simple resistor problem (bulk resistivity and geometry)

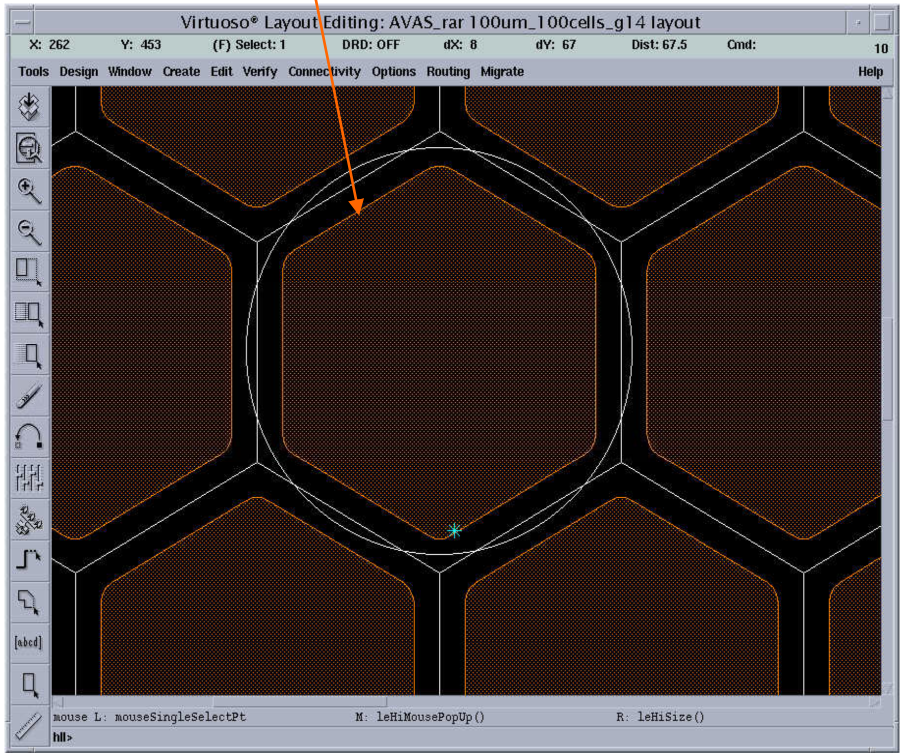
but ...

- carrier diffusion from top and bottom layer into the resistor bulk
- sideways depletion

and …

the lateral dimensions determine the required bulk resisitivity!

e.g.: cylindrical approximation of hexagons for quasi 3d simulation



➔ device simulations necessary

Pro‘s and Con‘s of „SiMPL“

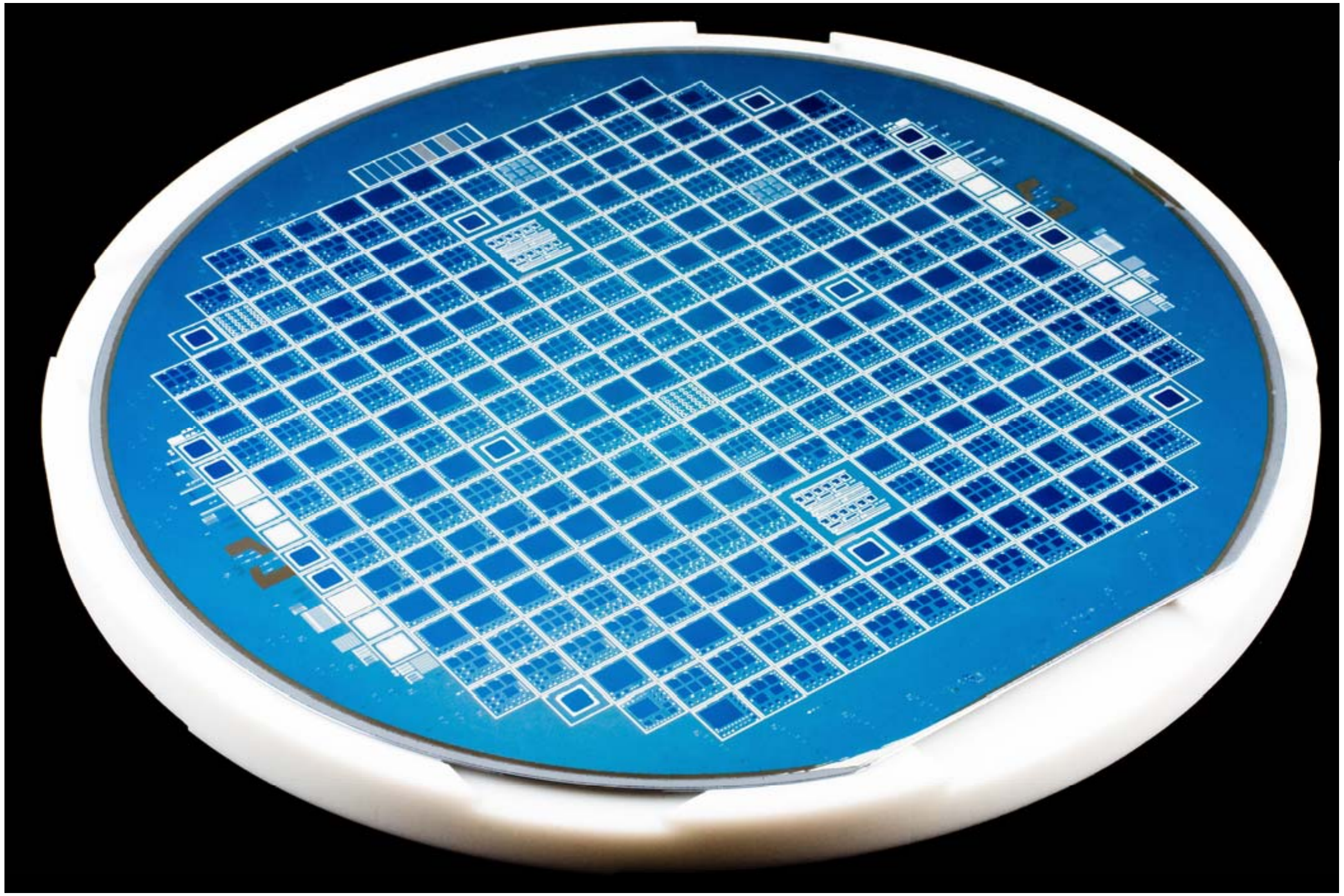
Advantages:

- no need of polysilicon
- free entrance window for light, no metal necessary within the array
- coarse lihographic level
- simple technology ➔ cheaper
- inherent diffusion barrier against minorities in the bulk -> less optical cross talk?
- hopefully better radiation hardness

Drawbacks:

- required depth for vertical resistors does not match wafer thickness
- wafer bonding is necessary
- changes of subpixel size requires other material (different resisitivity)
- vertical ‘resistor‘ is a JFET -> parabolic IV -> longer recovery times (factor 2-3)

First Test Production & Next Steps



150 mm wafer

- Tests at the wafer level in progress at the moment

Only 2.5 months production time

(HLL R&D Lab, parallel to main production line)

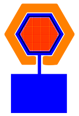
- Test at the chip level
- Optimize parameters for physics application, e.g. UV sensitivity

Conclusions

- MPI has a strong interest in SiPM sensor optimization, driven by astrophysics and particle physics (mainly cost/performance)
- Working test setup exists for characterization of SiPMs, all relevant parameters can be investigated
- MPI is interested in the large scale aspects of HCAL for ILD, strong wish to help working on a scalable solution (few million cells)
- Simplification of present Calice solution desirable (no WLS, blue-sensitive SiPMs, with all the „problems“ of coupling to tiles)
- Highly interesting development in MPI‘s HLL for low cost, blue-sensitive SiPMs, which can be optimized for HCAL
- Work will continue to provide SiPM/tile/layer(s) for future beam tests

Design Variants

- single cells



- Arrays:
  - 7 cells – flower formation
  - 19cells – double flower
  - 10x10
  - 30x30