Light Sensors for CTA
Light Emission Studies of PMT and SiPM

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CTA FPI WP

and

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LIGHT11, 11.1.11, Castle Ringberg

Light Sensor Candidates for CTA

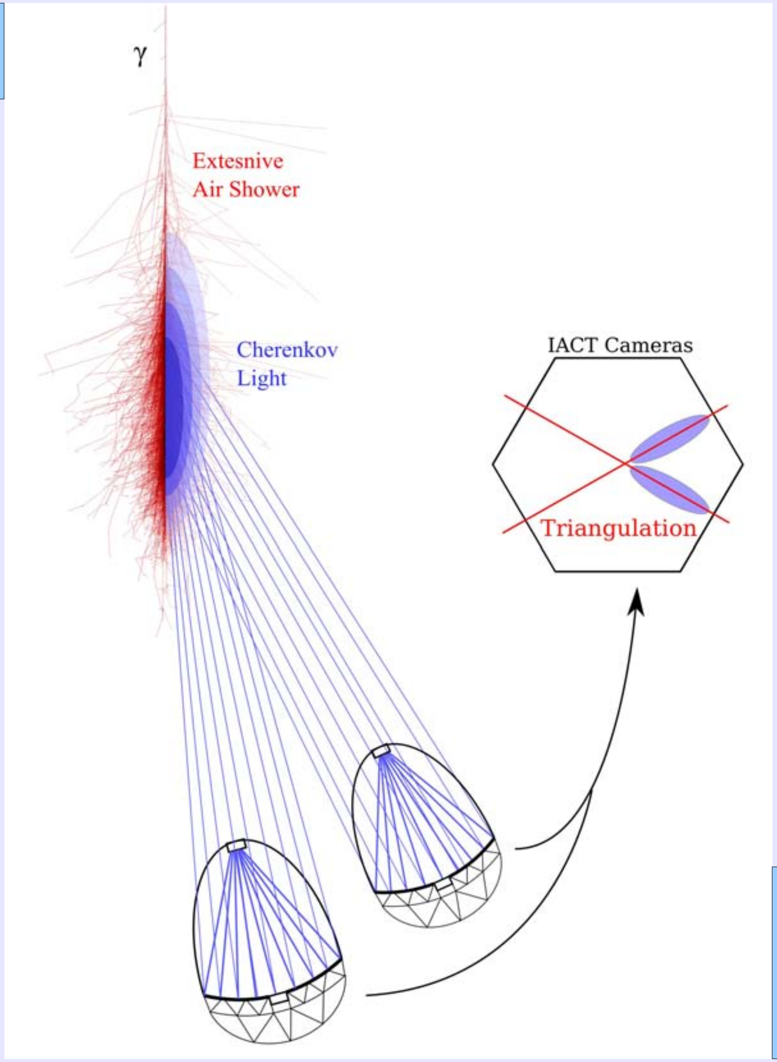
Outline

- The Cherenkov Telescope Array
- PMTs: as default sensor
- SiPMs: near future alternative
- Summary

The Cherenkov Telescope Array

Imaging Air-Shower Cherenkov Telescopes

- VHE cosmic particles ground based detection
- Imaging of the Cherenkov light from electromagnetic air shower with ultra-fast and low-light-level detectors



Working Principle, Illustration: C.Fruck MPI

The Cherenkov Telescope Array

Ground-Based VHE γ-ray Astronomy

Photosensor requirements:

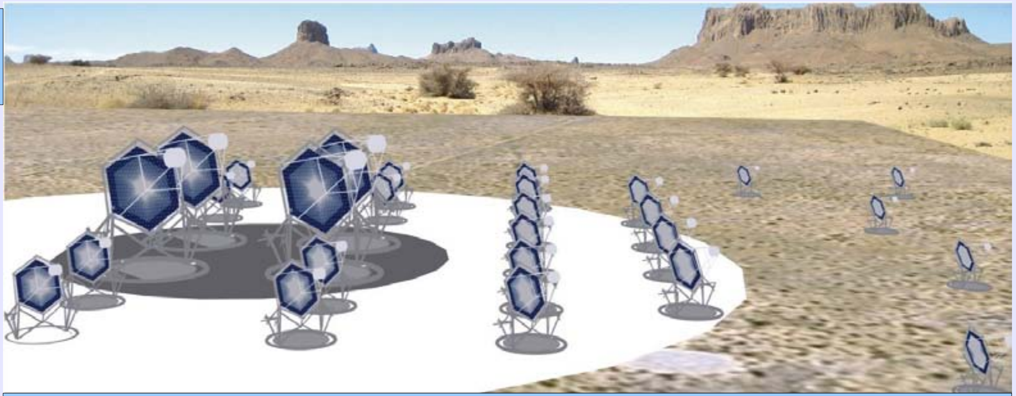
- MAGIC, H.E.S.S and Veritas collaborations and Japan groups

  → Collaboration for the next-generation instrument

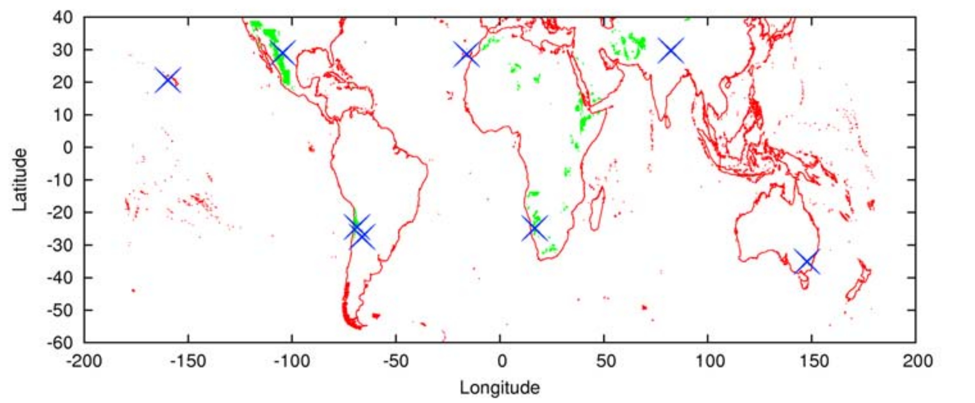
- Study distant AGNs, Black Holes, Gamma Ray Bursts and galactic sources (Pulsars, Supernovae, …)

  →The origin of the cosmic rays?

- ~100 telescopes, 3 telescope types, 2 arrays in N & S, Site search ongoing
- The project is in the road-map of the European Strategy Forum on Research Infrastructures **ESFRI**, the European Astroparticle Physics network **ASPERA** and the European Astrophysics network **Astronet**.



The different telescope types



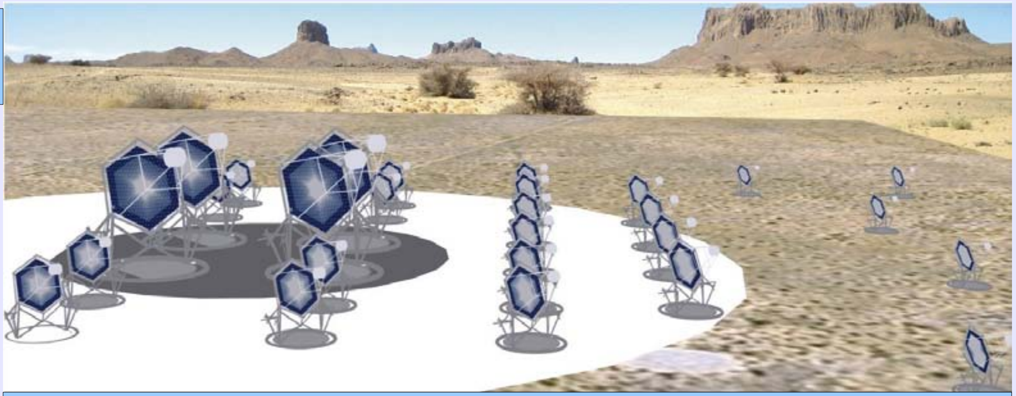
Candidate sites

The Cherenkov Telescope Array

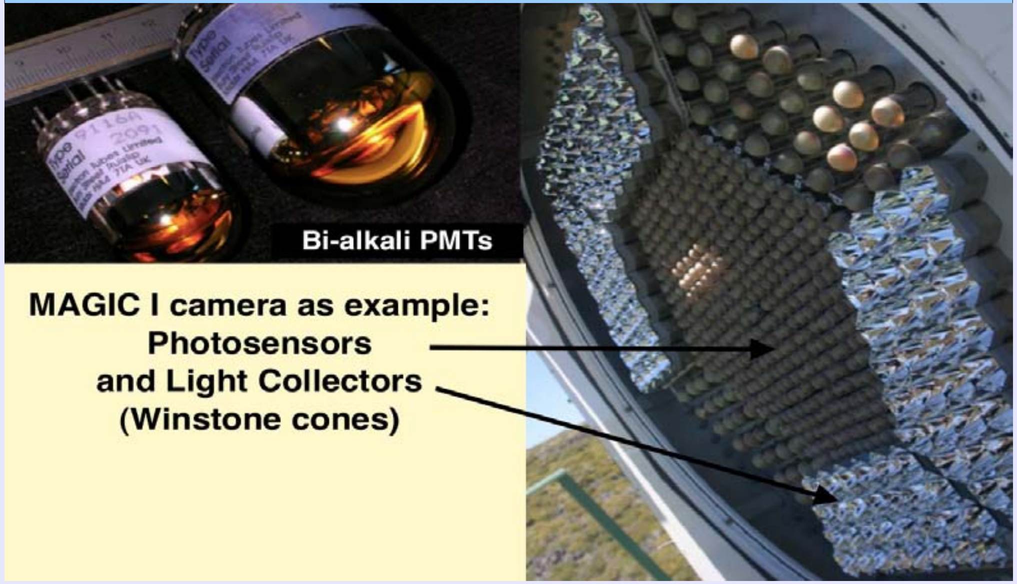
Low-Light-Level Detectors

Photosensor requirements:

- We need ~ 100k - 150k photosensors of PMT size
- High Photo Detection Efficiency (PDE)
- Low Afterpulsing in order to lower the energy threshold
- About 2 years ago we started a PMT development program with Hamamatsu and ET Enterprises
- New SiPM photodetectors have promising PDE. Along with commercial products we co-develop samples with MEPhI-Excelitas.



The different telescope sizes



FPI Parameter List

The whish list - main parameters	
Sensitivity range	290 – 600 nm
Peak QE	35%
Average QE over Cherenkov spectrum	> 21%
Operating gain	> 40000
Afterpulsing for threshold > 4 ph.e.	< 0.02%
Pulse width, FWHM (single ph.e.)	< 2.5 ns
Transit time spread, single ph.e., FWHM	< 1.3 ns
Protection from geomagnetic field	
Dynamic range	> 3000 ph.e.
Linear range	> 3000 ph.e.
Differential non-linearity	< 1%

PMT Candidates - Development

Hamamatsu
R9420 MOD F

Hamamatsu
R8619 MOD P

Hamamatsu
R11920-100

Combine the low AP Rate from the R8619 and the high QE from R9420!

Electron Tubes
9117B

Very good afterpulsing:
ET 9142B
QE needs to improve
(work in progress → Andy Cormack)

PMT Evaluation

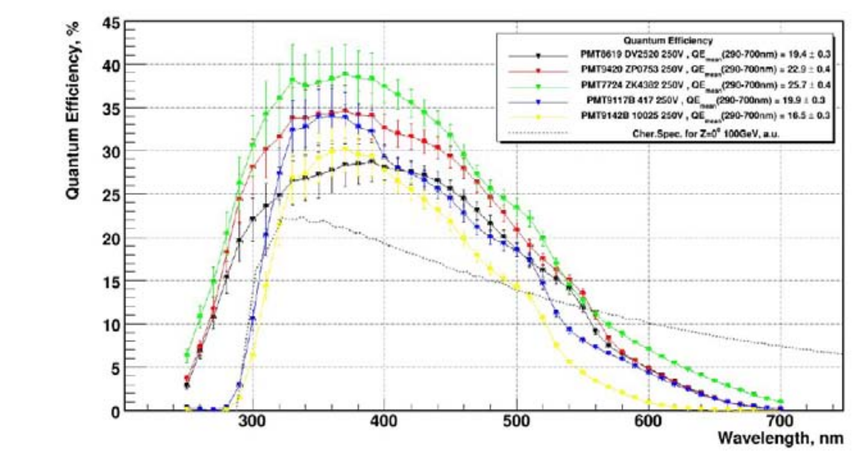
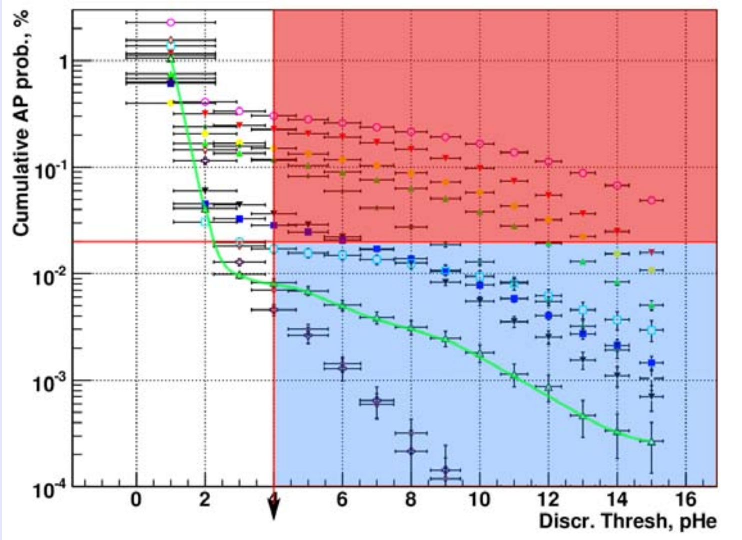
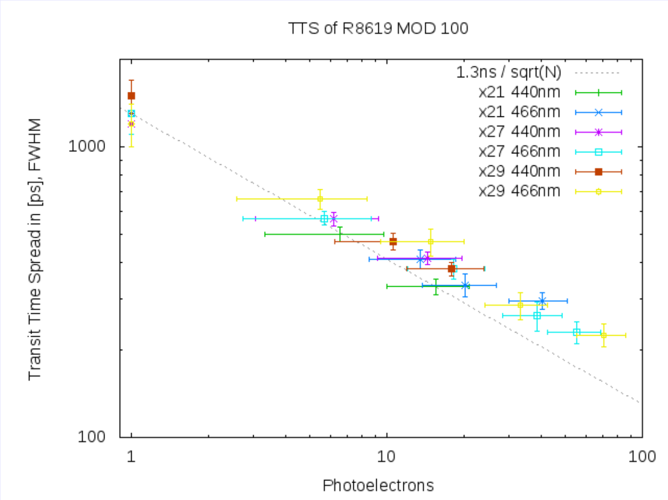
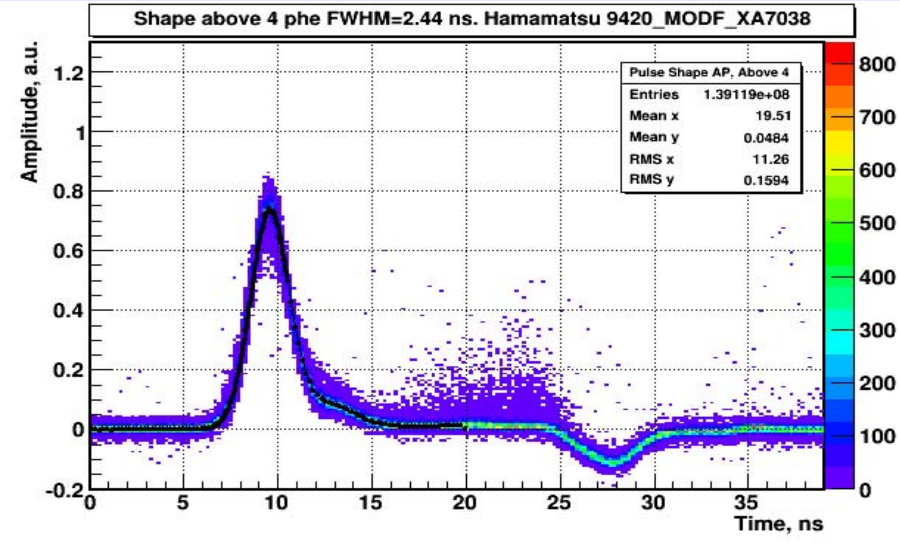


Figure 2.16: Quantum efficiency curves of tested PMTs. The dashed-line curve shows the Cherenkov spectrum from a 100 GeV gamma shower after propagation through the atmosphere.





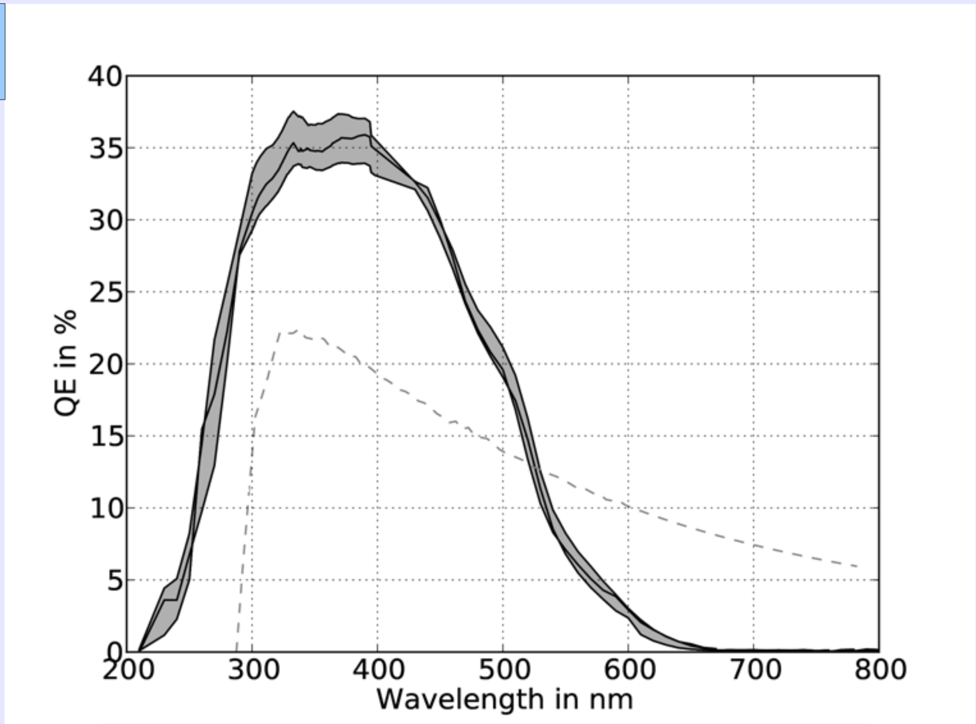


PMT Evaluation

PMT Candidate R11920-100

Table 1. The FPI sensor wish list — a selection of parameters in comparison with a target PMT

Parameter	Range Specification	Hamamatsu R11920-100
Spectral Sensitivity Range	290 - 600 nm	300 - 650 nm
Peak Quantum Efficiency	35%	(35.6±1.7)%
Average QE over Cherenkov Spectrum	> 21%	(22.8±1.0)%
Afterpulsing at 4 ph.e. Threshold	< 0.02%	≃0.03%
Transit Time Spread, single ph.e, FWHM	< 1.3 ns	(1.3±0.1) ns
Collection Efficiency 1.st Dynode	96%	≃93%



Quantum Efficiency
Dashed: Cherenkov spectrum after propagation

1.5 inch PMTs has been chosen as the target PMT for all 3 types of telescopes.

Ongoing investigations

- Curvature of the input window on R11920-100
  - Improves the collection efficiency at the expense of slight degradation of TTS

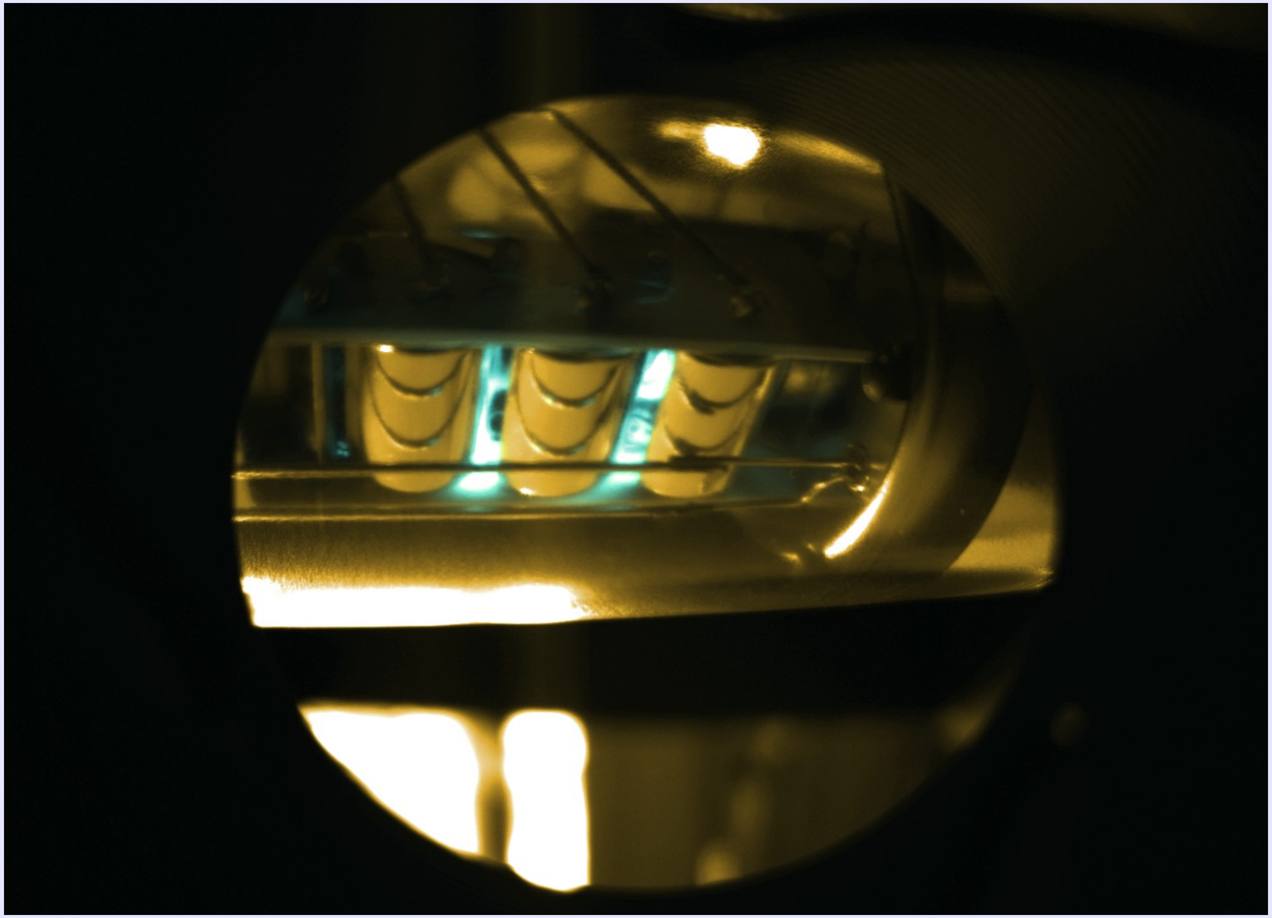
    CE. 92% → 96% , TTS 1.3ns → 1.5ns
- PMT Glowing
  - Investigate optical afterpulsing

PMT Glowing

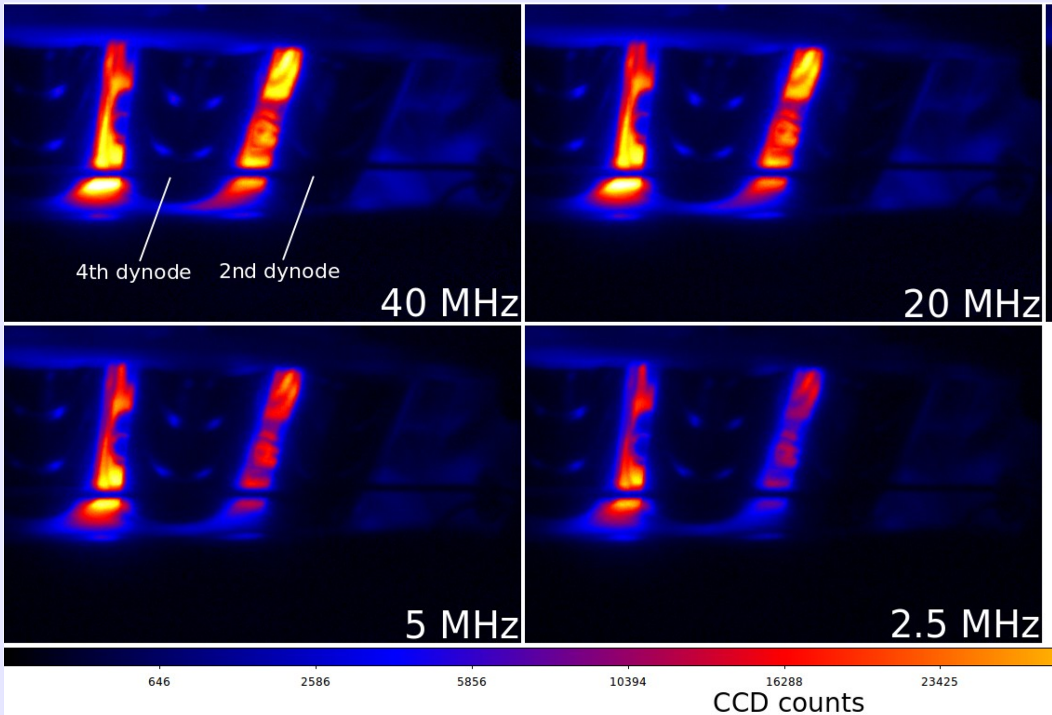
<u>The PMT emits light!</u>

→ known (see IEEE Transactions NS-14 1967, 455-459)

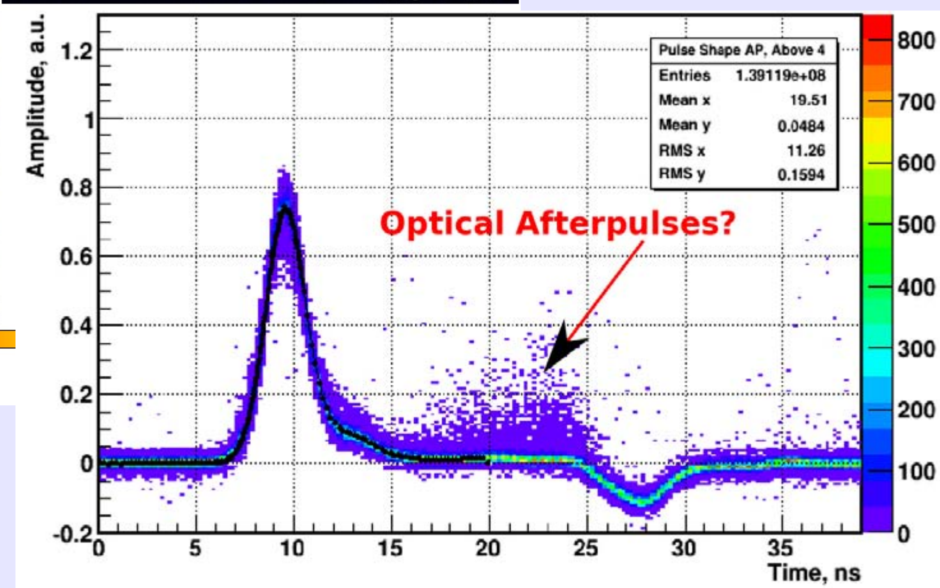
- We want to investigate it's role in afterpulses
- Give feedback to manufacturers and improve the product



PMT Glowing



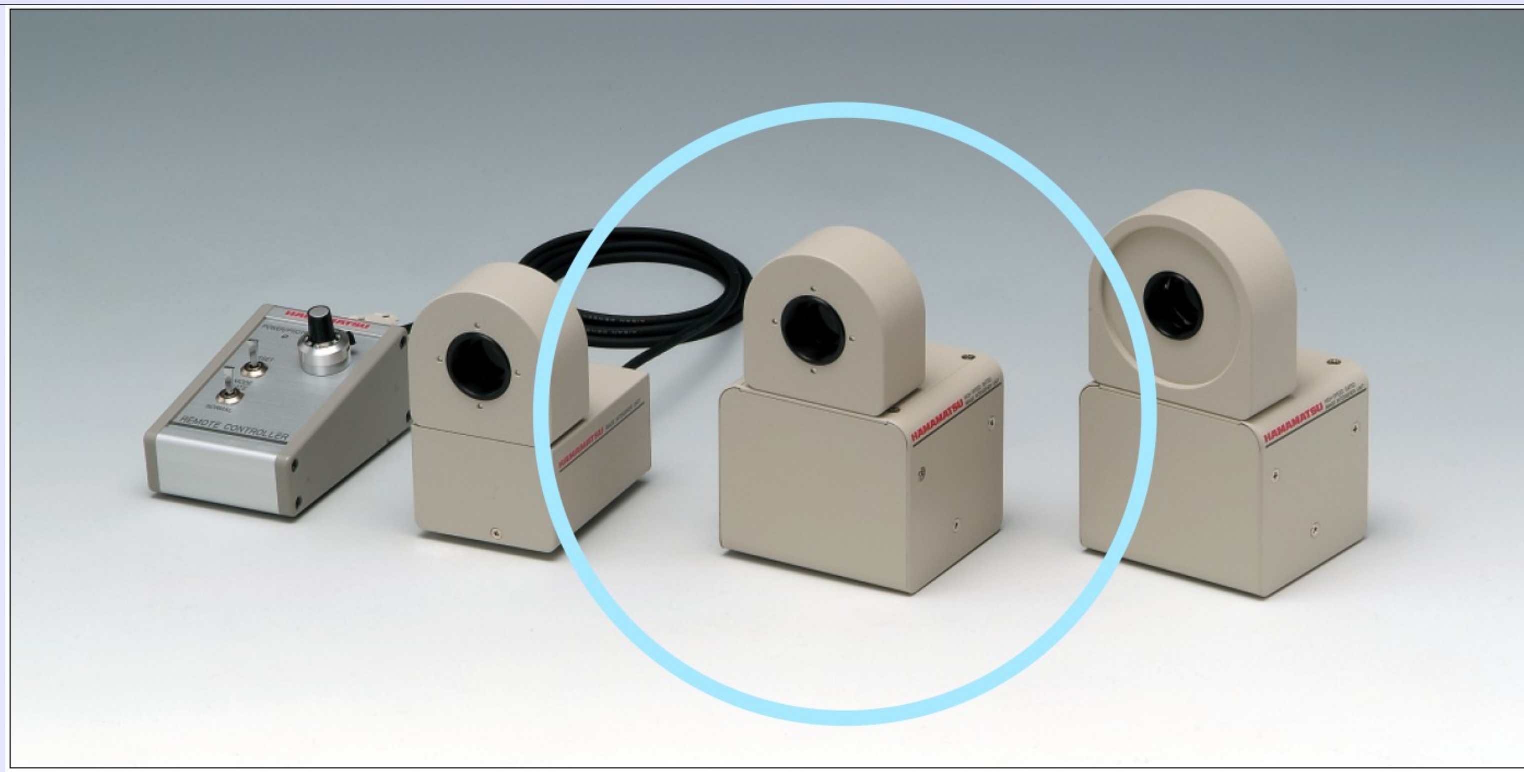
1s exposure time...



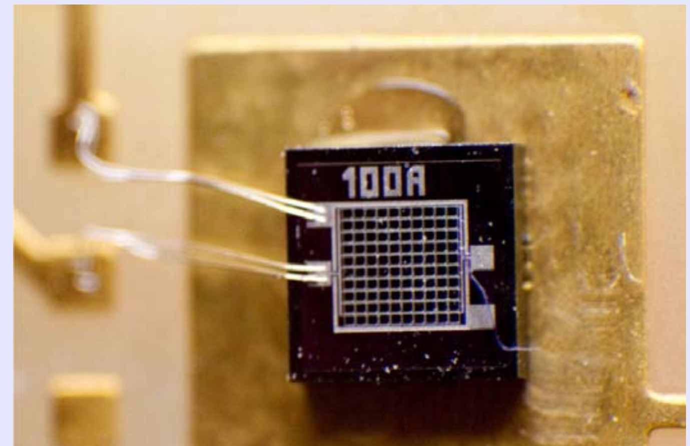
Plot by: M.Kurz, 2011 MPI

PMT Glowing

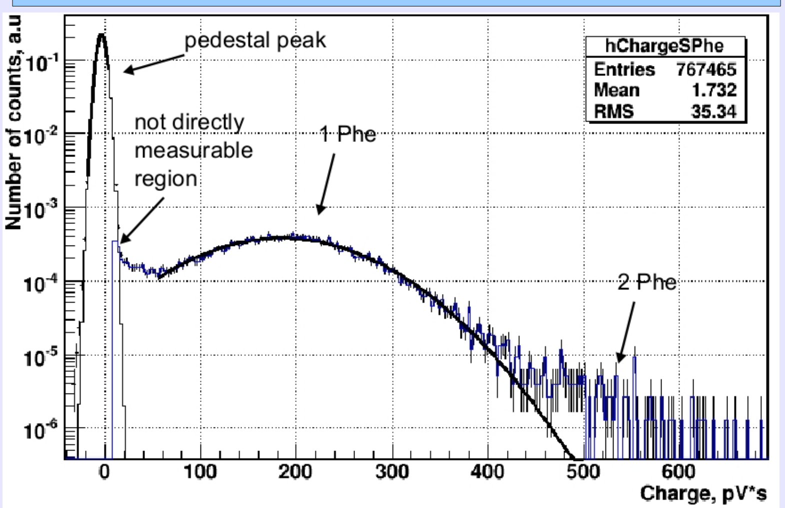
New measurements with high-speed gated image intensifier - 3ns gate
Hamamatsu C9546-05P47L



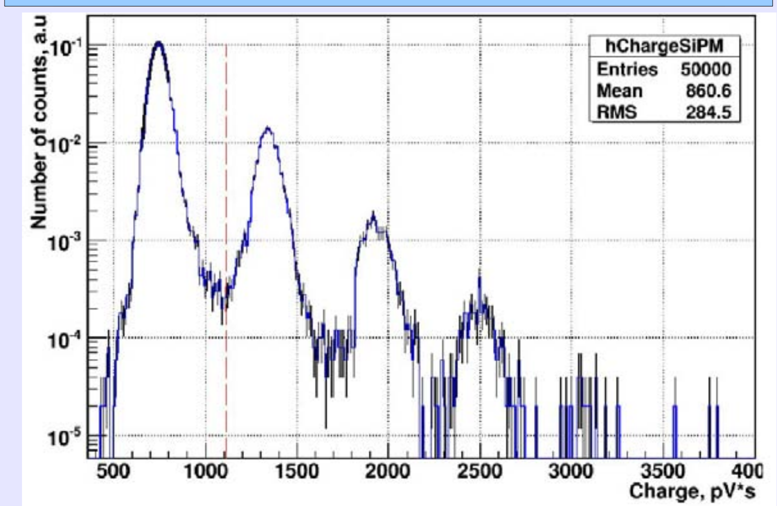
SiPM Introduction



PMT charge distribution



SiPM charge distribution



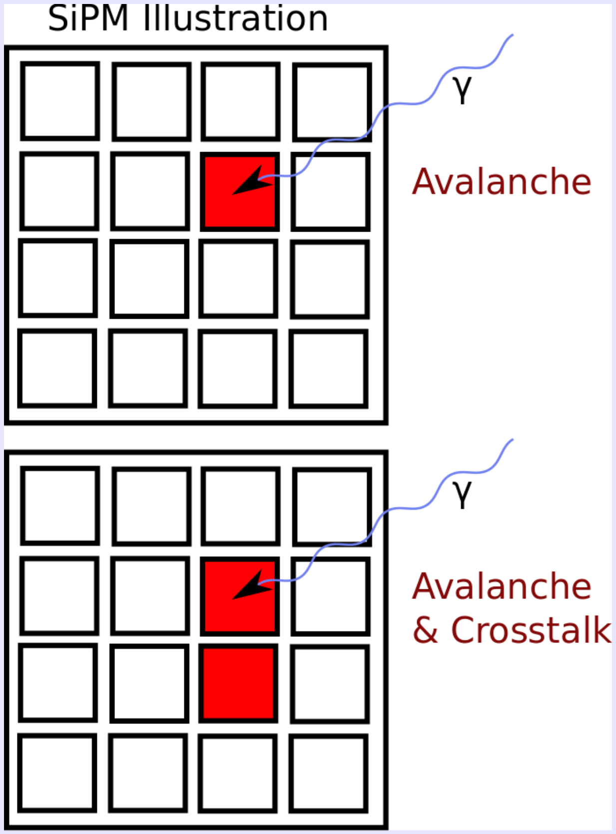
Plots by: M.Kurz, 2011 MPI

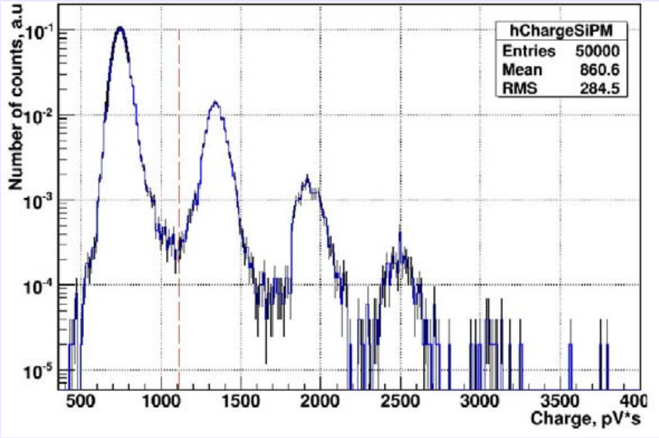
SiPM Evaluation

- SiPM have promising theoretical PDE
- But instead of the PMT-typical **afterpulsing** issue they have dominant **cross-talk**
- This cross-talk leads to a higher **excess noise factor** → Resolution of SiPM may be worse than PMT
- For Cherenkov telescopes: higher **trigger threshold**
- Meaning: Try to **reduce cross-talk**

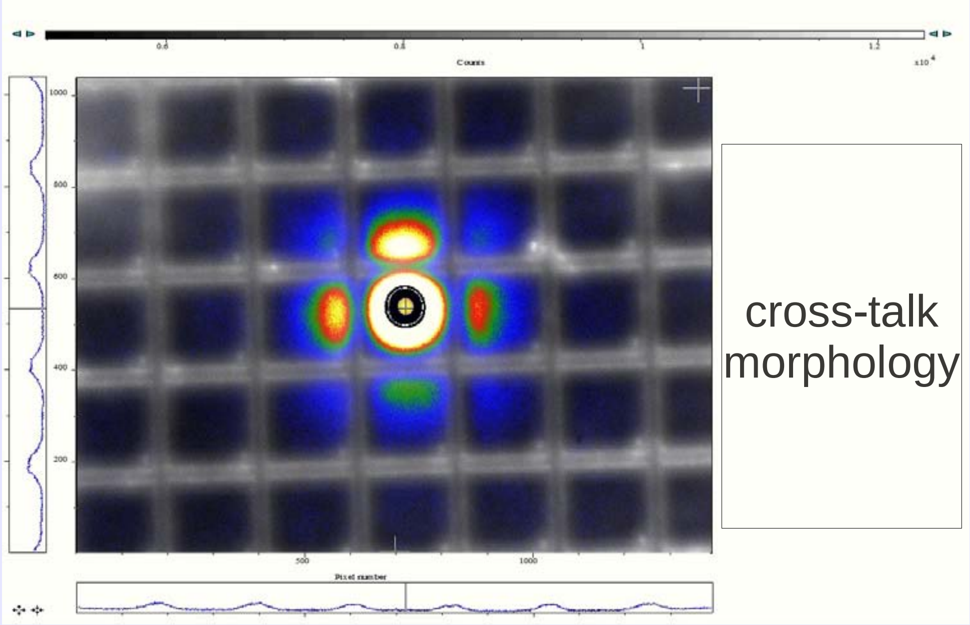
SiPM Introduction

SiPM cross-talk





Charge spectrum



cross-talk morphology

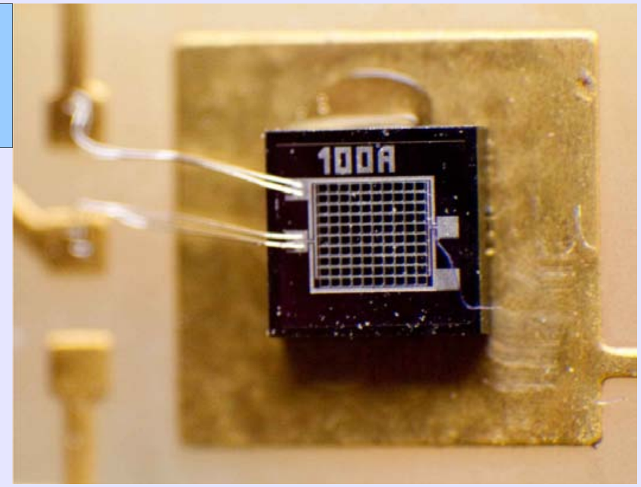
SiPM Evaluation

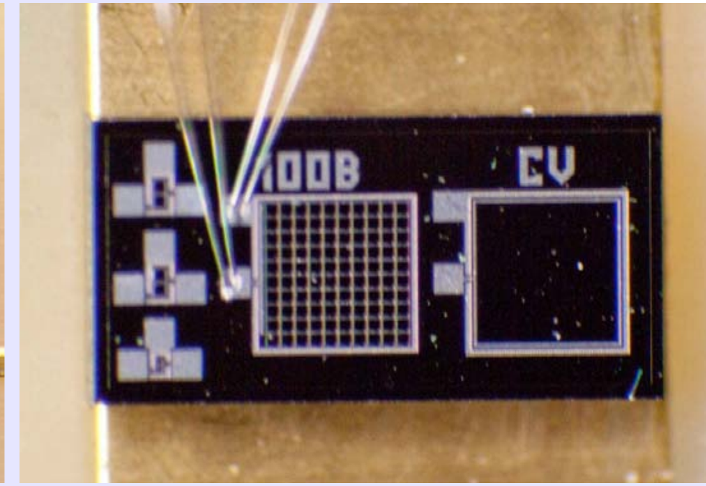
MEPhI - MPI samples (Excelitas support):

- p on n type
- Operation voltages ~ 26-39V

Also tested:

- Hamamatsu MPPCs
- Planning to test other available types

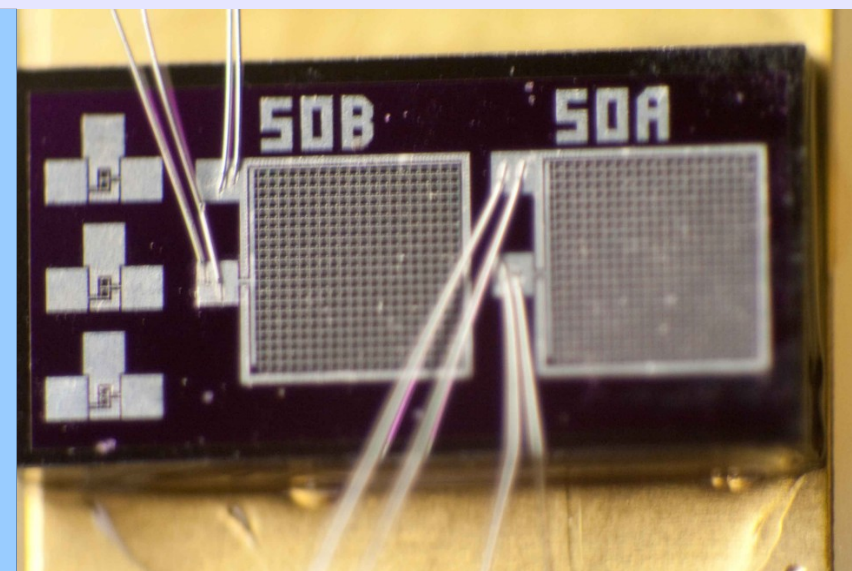




First Prototypes MEPhI:

1x1mm, U_{break} ~ 33V
100µm & 50µm cells

B,A: different geometries

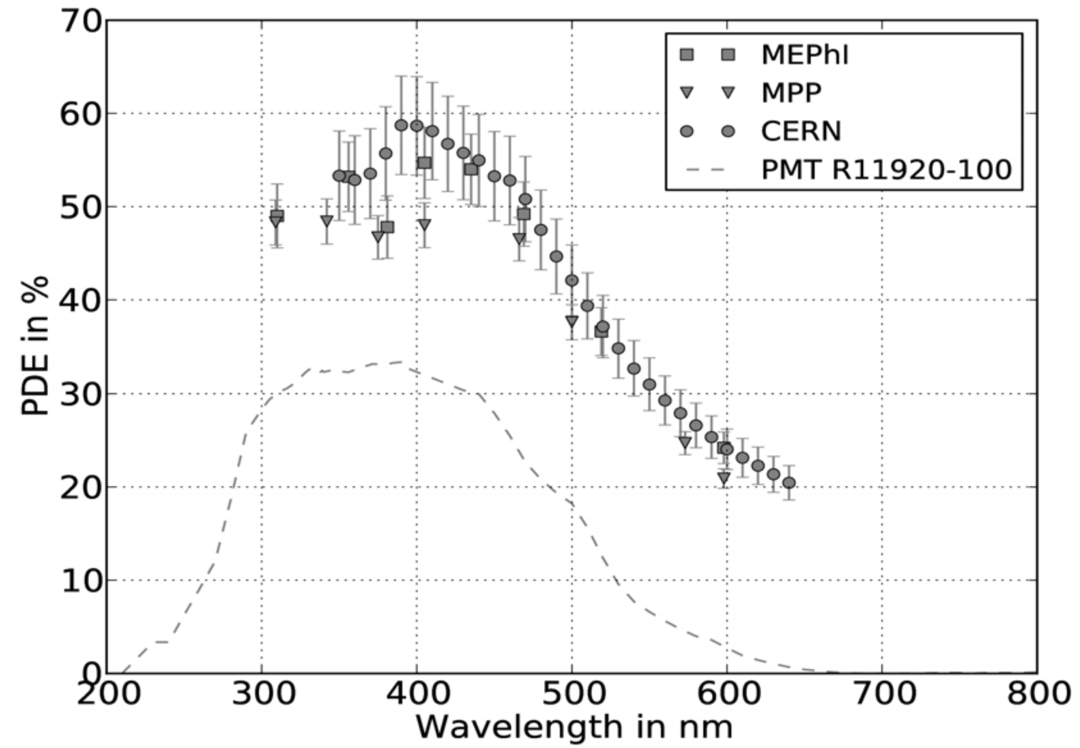


SiPM Evaluation

New SiPM samples - PDE

- Good PDE in UV region
- Measurements of type B reveal samples with high (and pretty “flat”) PDE:

PDE(400nm)~50% !



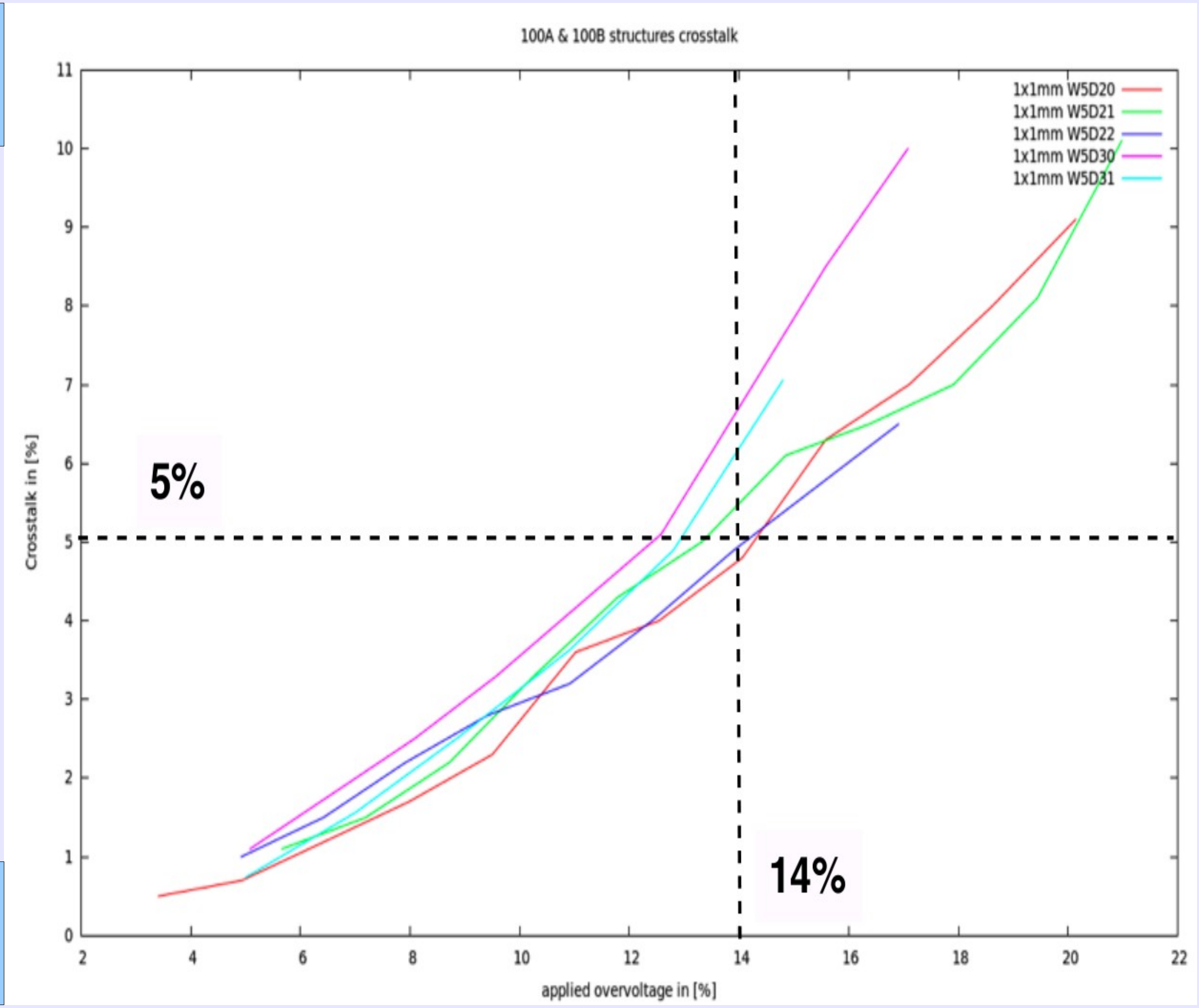
Independent measurements, Buzhan(MEPhI), Musienko (CERN), Knötig(MPP)
Dashed: Hamamatsu R11920-100 PMT

SiPM Evaluation

New SiPM samples - Cross-talk

- X-Talk suppression: Trenches, second p-n junction,
- Ion implantation...
- Cross-talk measurements: very low cross-talk of

$P_{xtalk}(\Delta U/U_b = 14\%) \sim 5\%$!



Optical cross-talk vs over voltage in %(Ubreak)

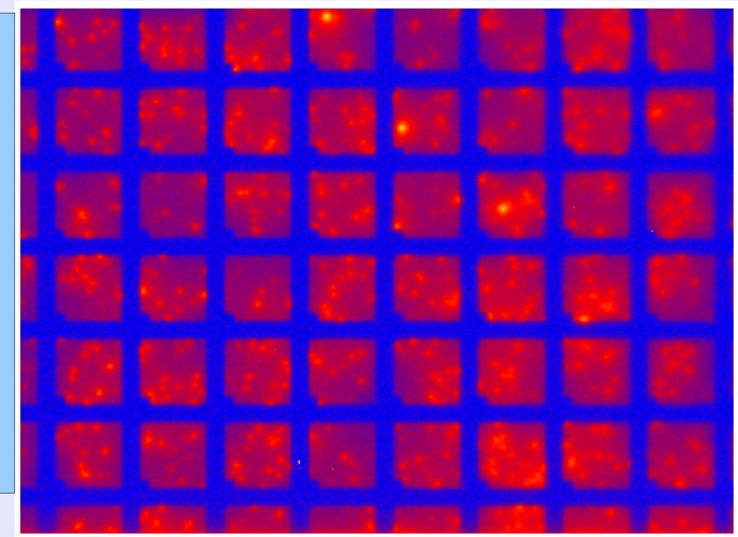
Ongoing investigations

<u>The SiPM also emits light!</u>

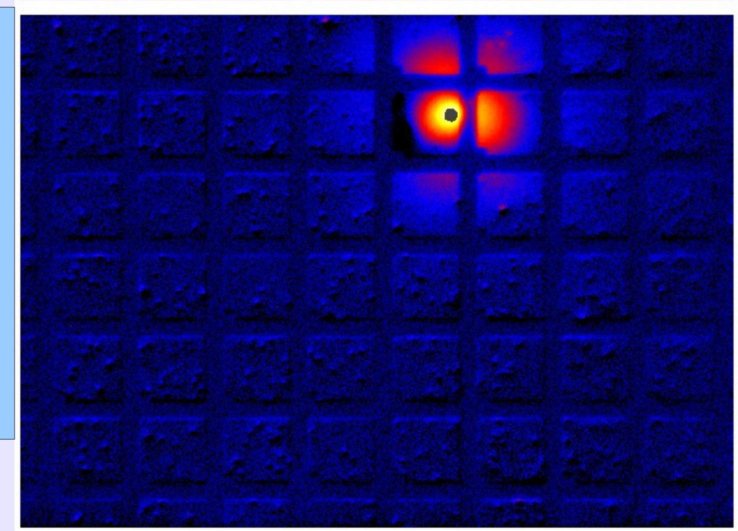
→ known: Avalanches in Si (for emission spectrum see: Mirzoyan et. al., NIM A 610 (2009) 98–100)

- We are investigating it's role in crosstalk
- Give feedback to manufacturers and improve the product

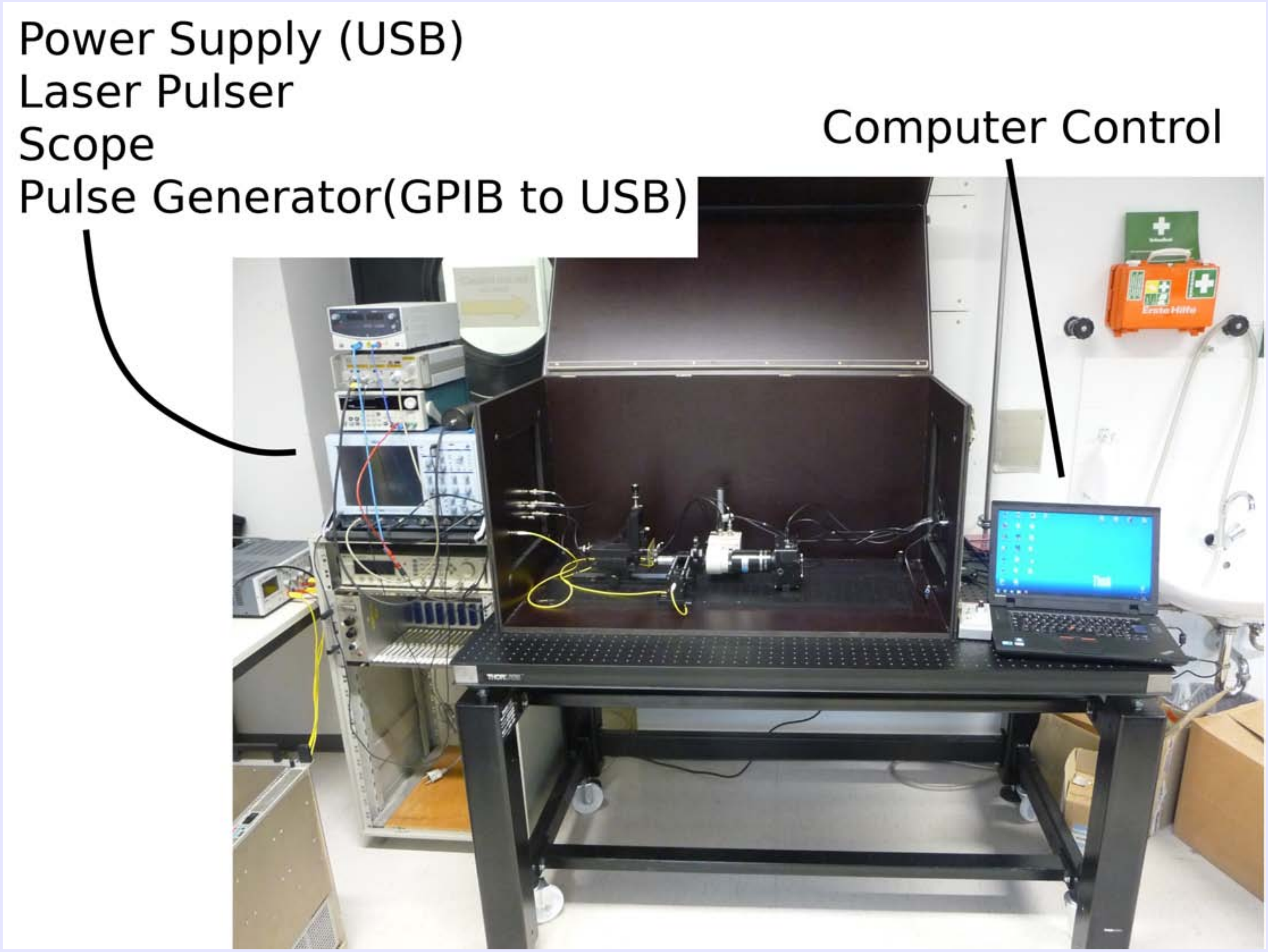
Darkrate emission



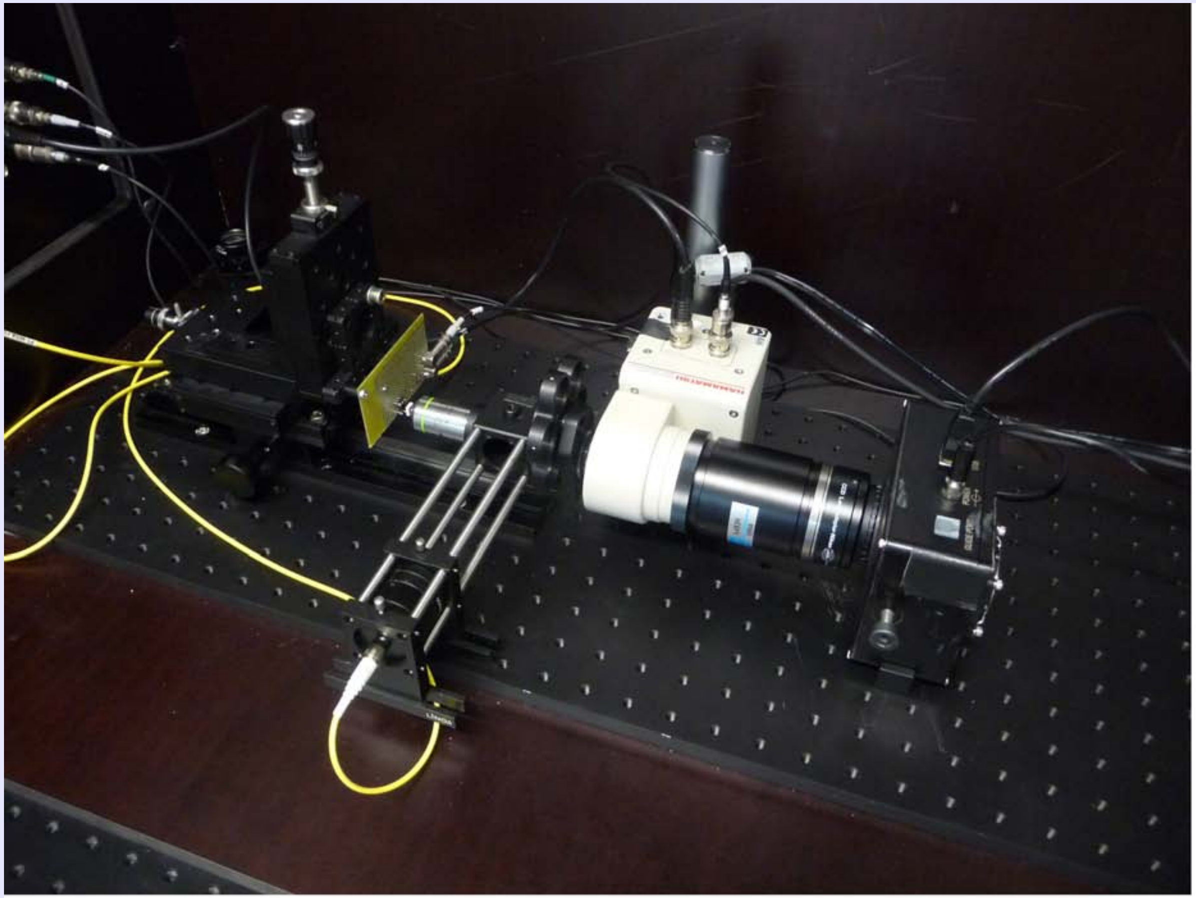
Focused Pulsed Laser Emission



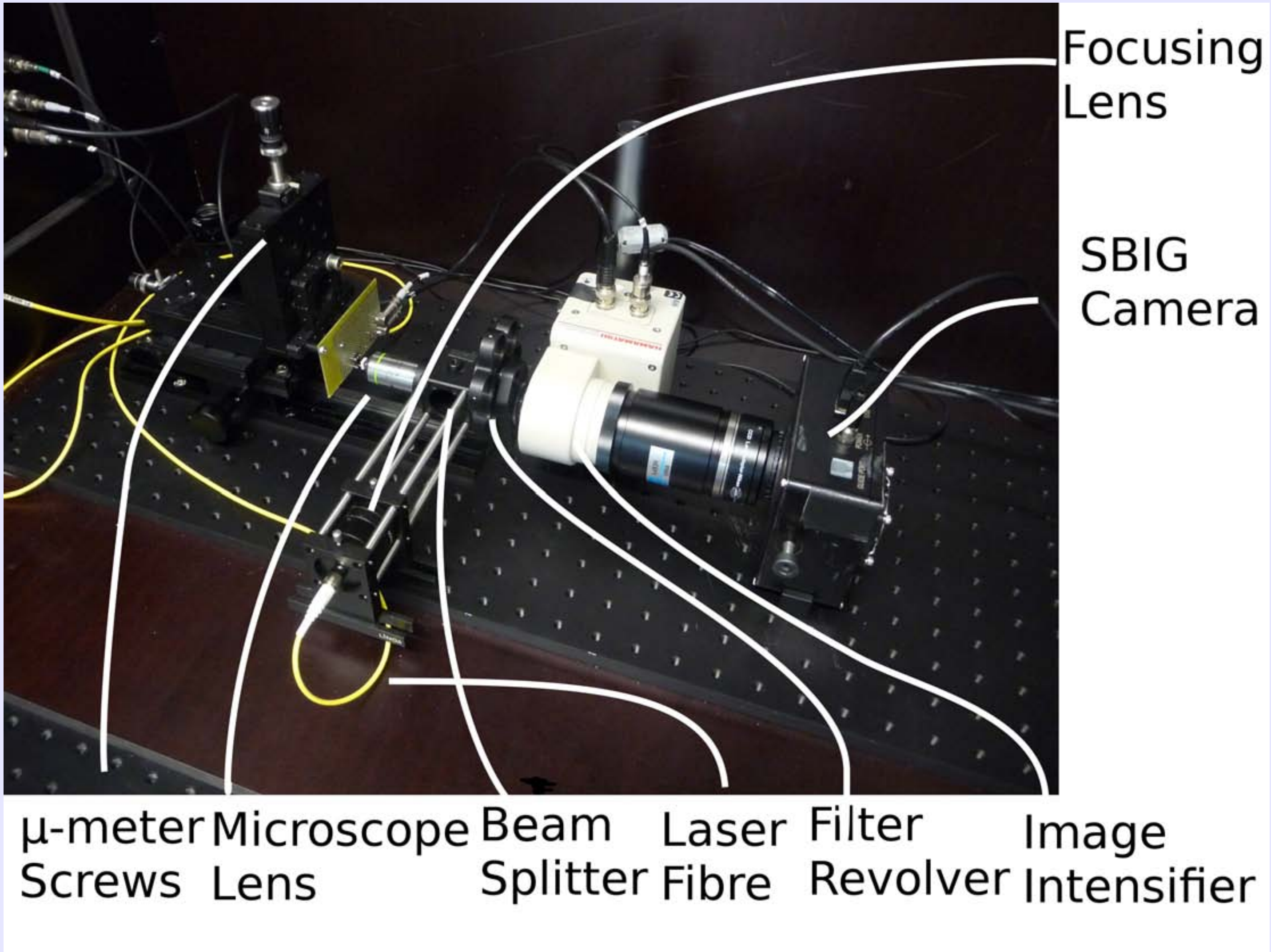
The Setup


Power Supply (USB)
Laser Pulser
Scope
Pulse Generator(GPIB to USB)
Computer Control

The Setup



The Setup


Focusing
Lens
SBIG
Camera
µ-meter
Screws
Microscope
Lens
Beam
Splitter
Laser
Fibre
Filter
Revolver
Image
Intensifier

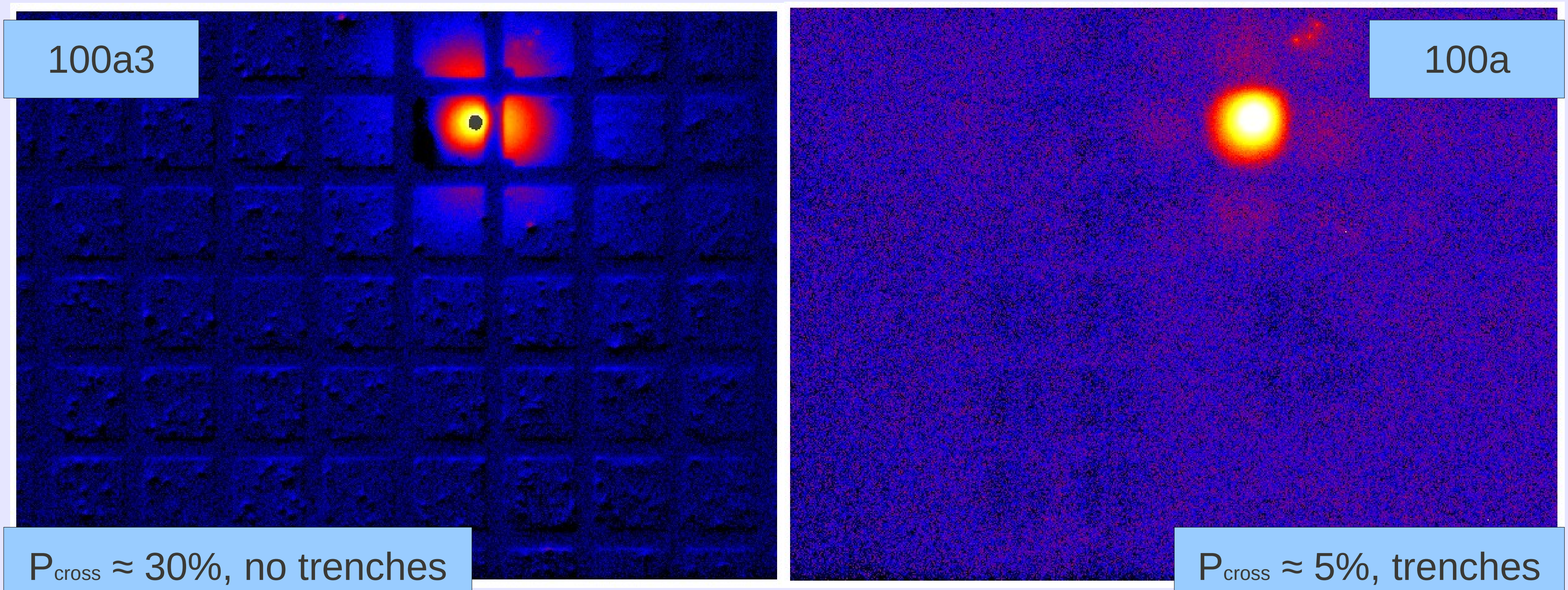
The Setup

The first measurements were done without Image Intensifier, but I did not take a picture of this setup.

- Imagine the image intensifier was a lens (for the moment)

Imaging of cross-talk

Study effects of trenches, second p-n junction, ion implantation,...
→ they can reduce the optical cross-talk



100a3

100a

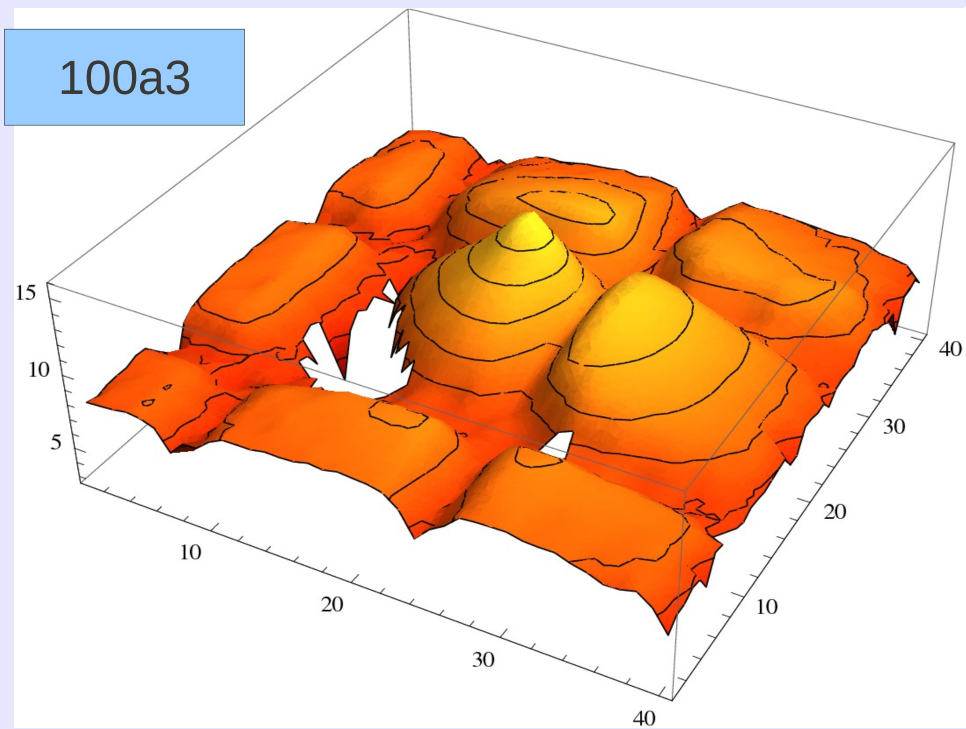
$P_{cross} \approx 30\%$, no trenches

$P_{cross} \approx 5\%$, trenches

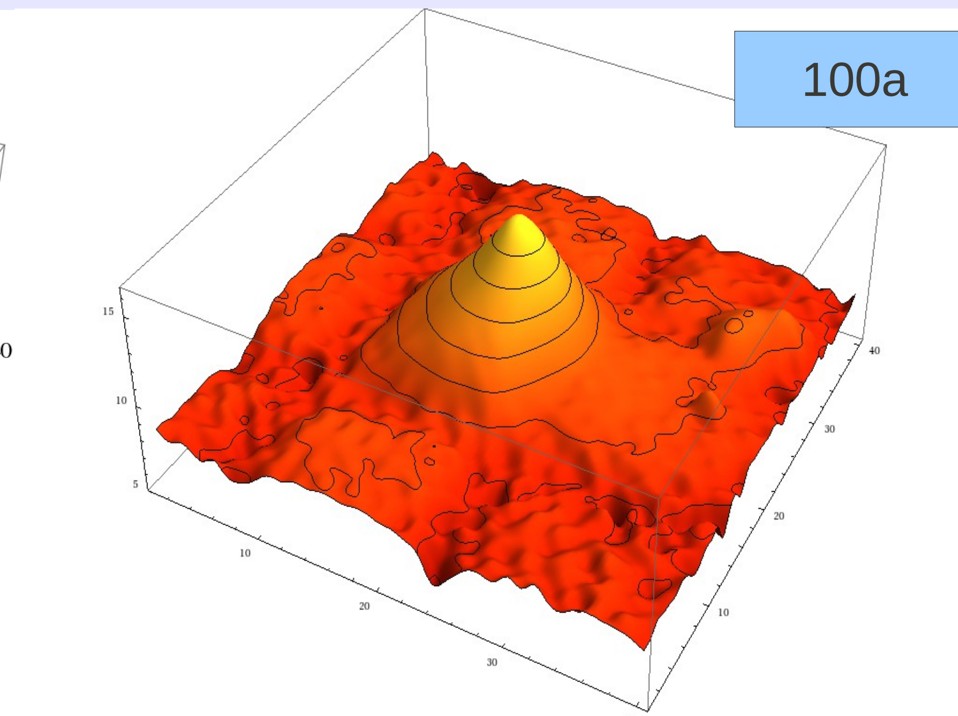
Imaging of cross-talk

We learn: Avalanches are local in the cells!
Determine → width of an avalanche → preferred size of a cell?

100a3



100a



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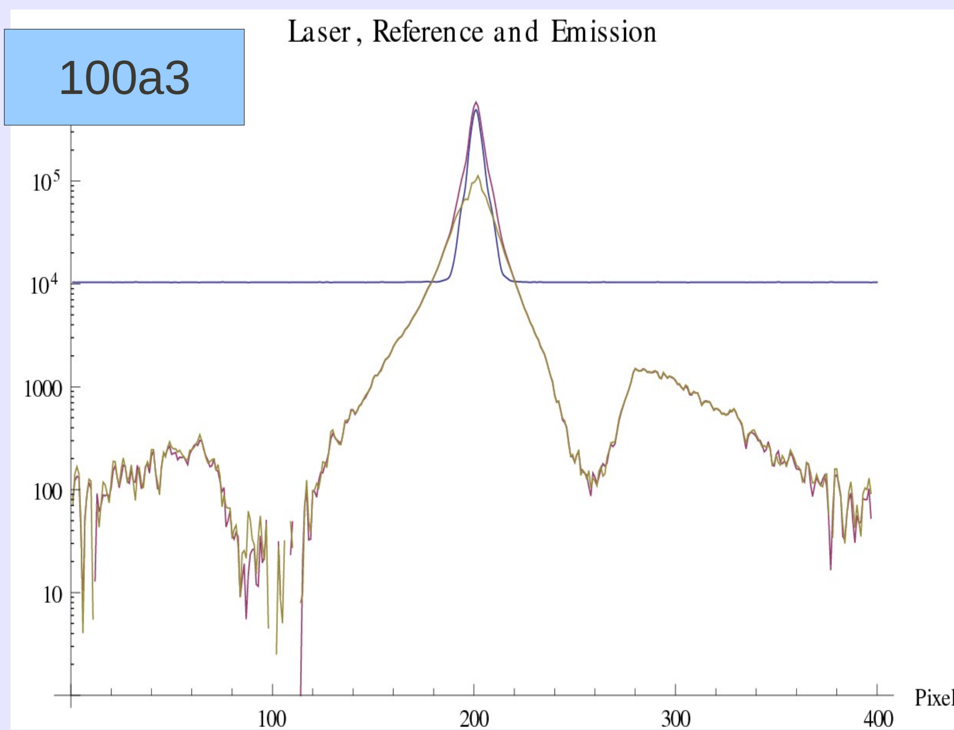
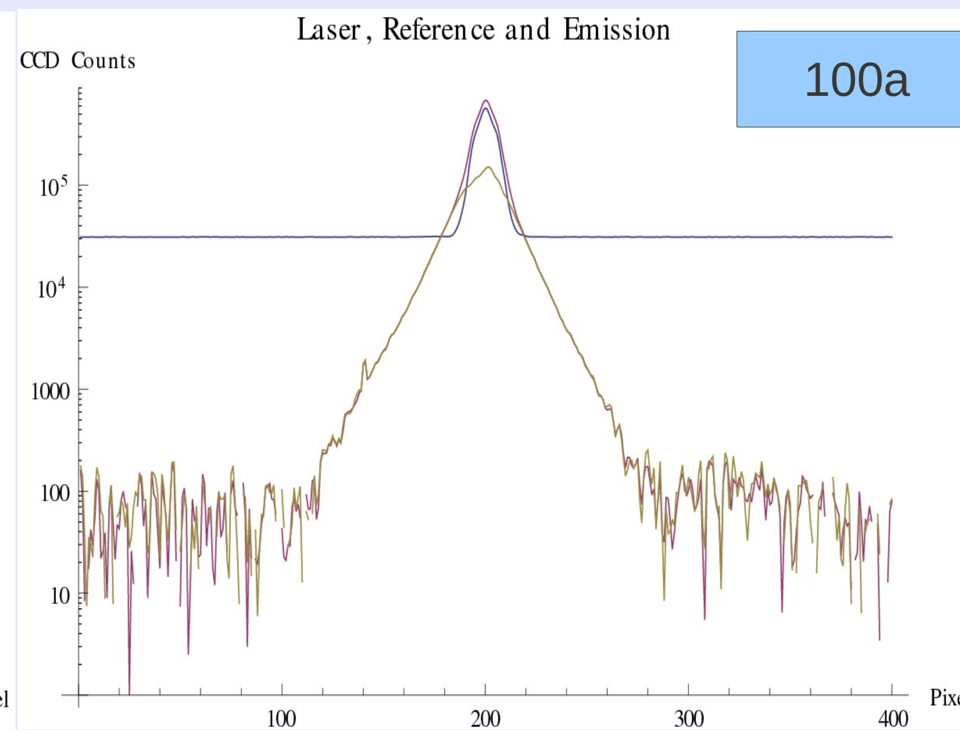




Imaging of cross-talk

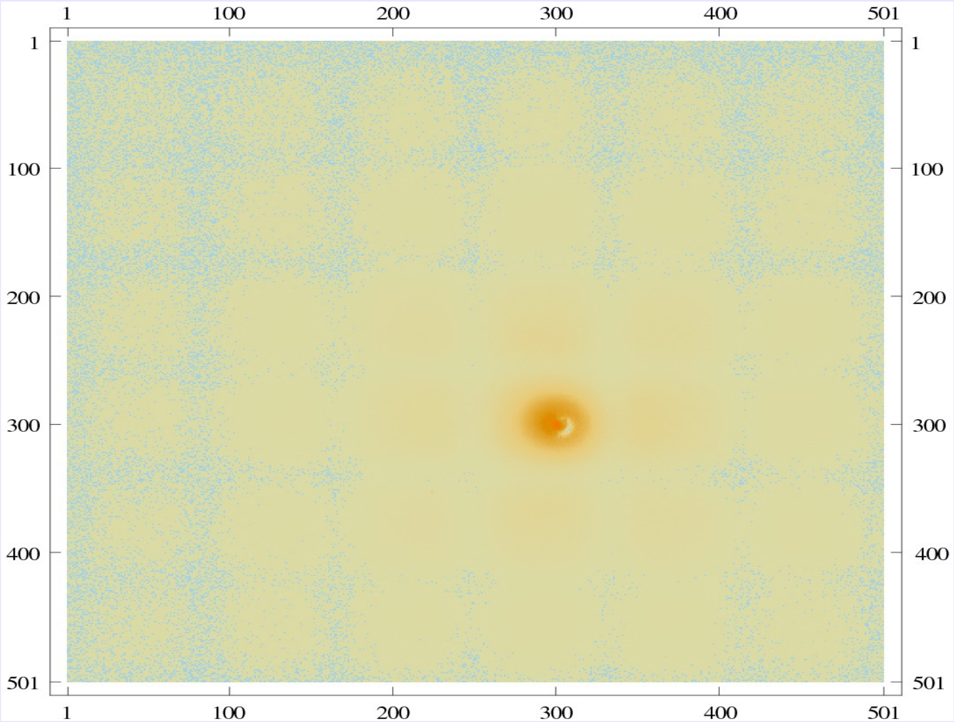
The following Hamamatsu MPPC are operated at 73.5 V (~ 5% U(overvoltage)/U(breakdown))

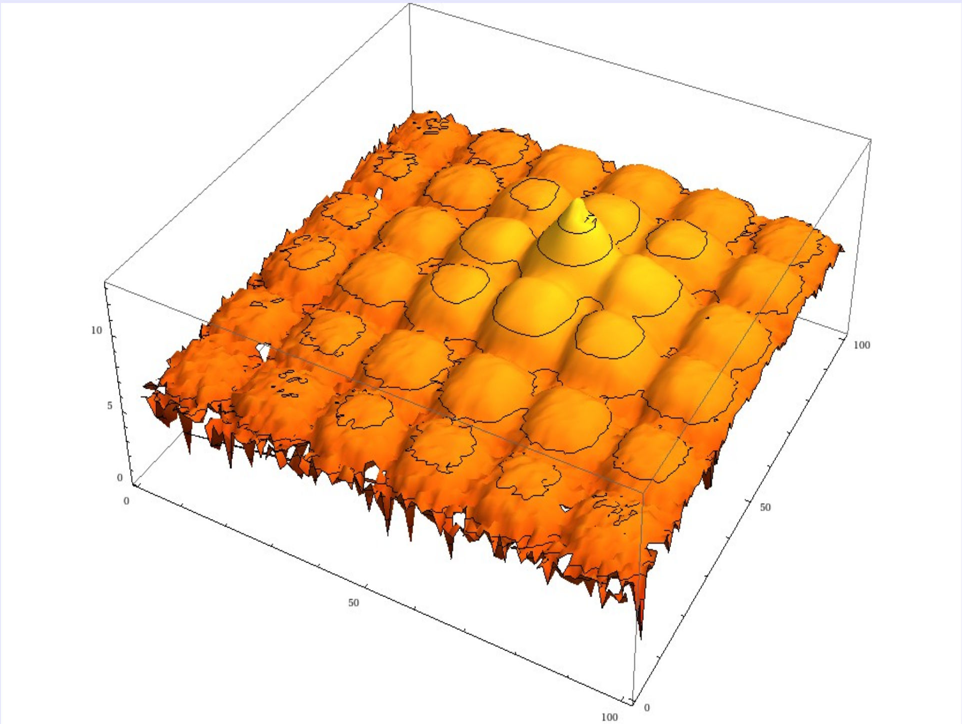
→ This is ~2V more than V_op

→ no more quenching, but more light emitted

Imaging of cross-talk

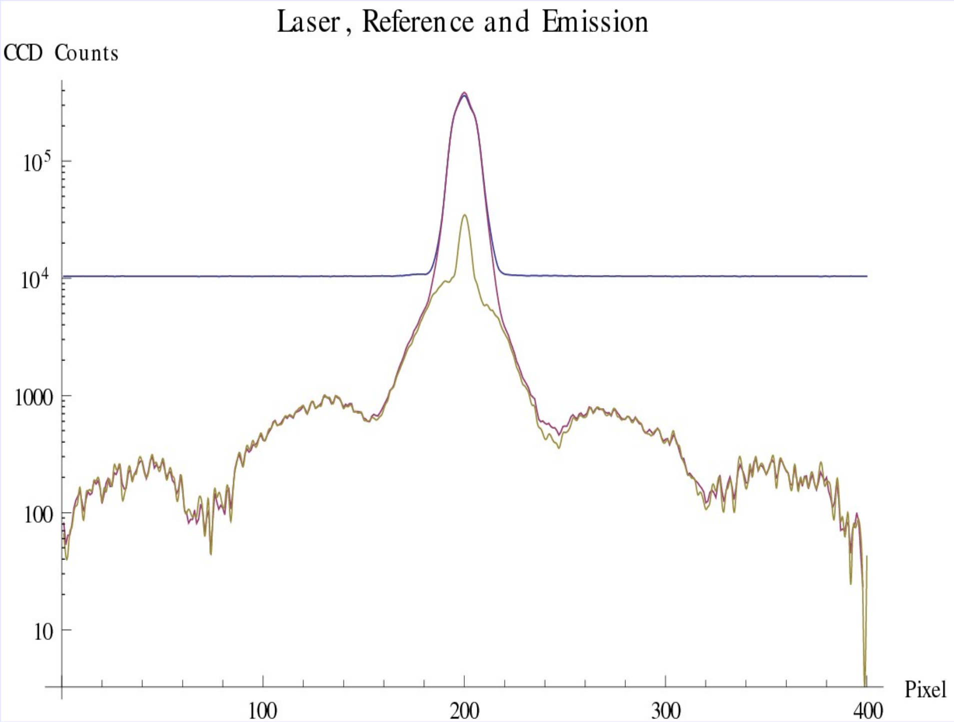
Hamamatsu MPPC
33-050-UVE-SIRESIN → 50 µm cell width
(Prototype with UV sensitive resin)

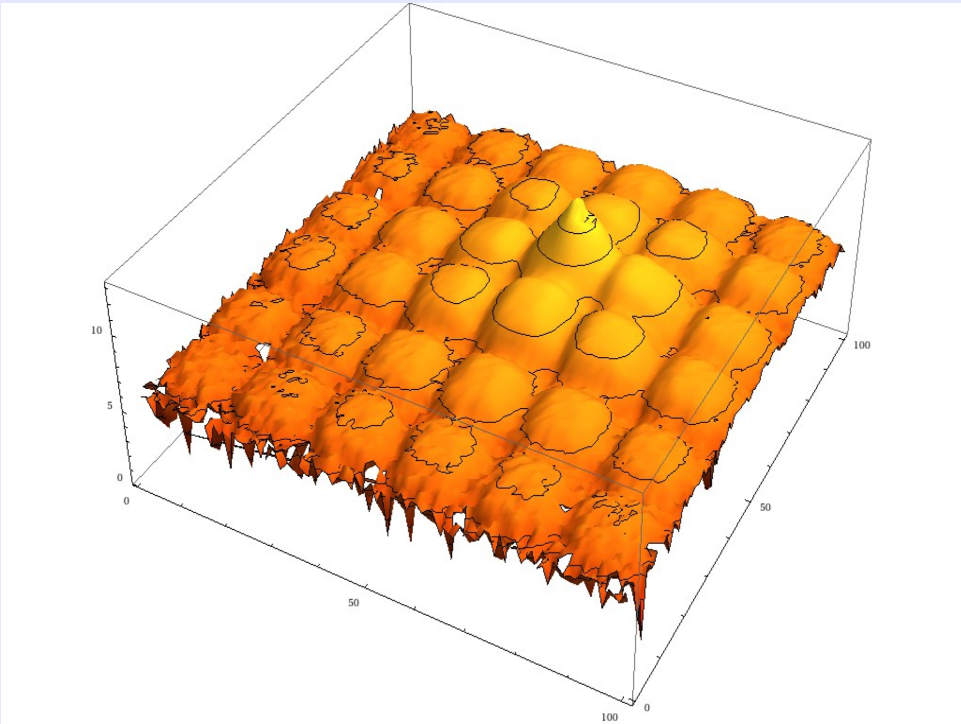




Imaging of cross-talk

Hamamatsu MPPC
33-050-UVE-SIRESIN → 50 µm cell width
(Prototype with UV sensitive resin)

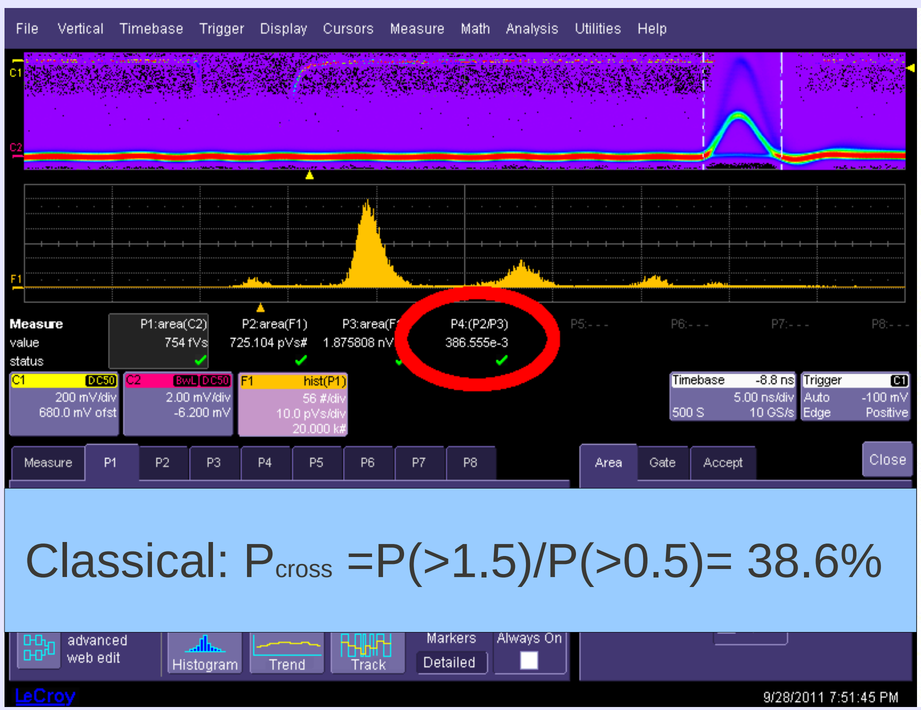




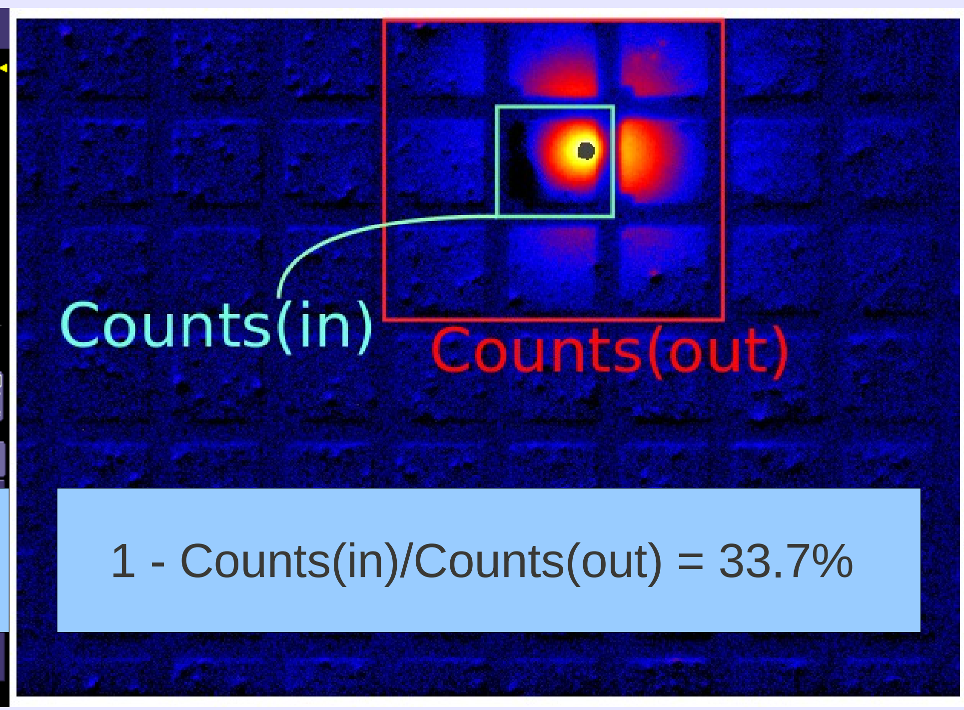
Imaging of cross-talk

Imaging of cross-talk

New imaging method for studying cross-talk morphology → Work in progress



Classical: P_{cross} =P(>1.5)/P(>0.5)= 38.6%

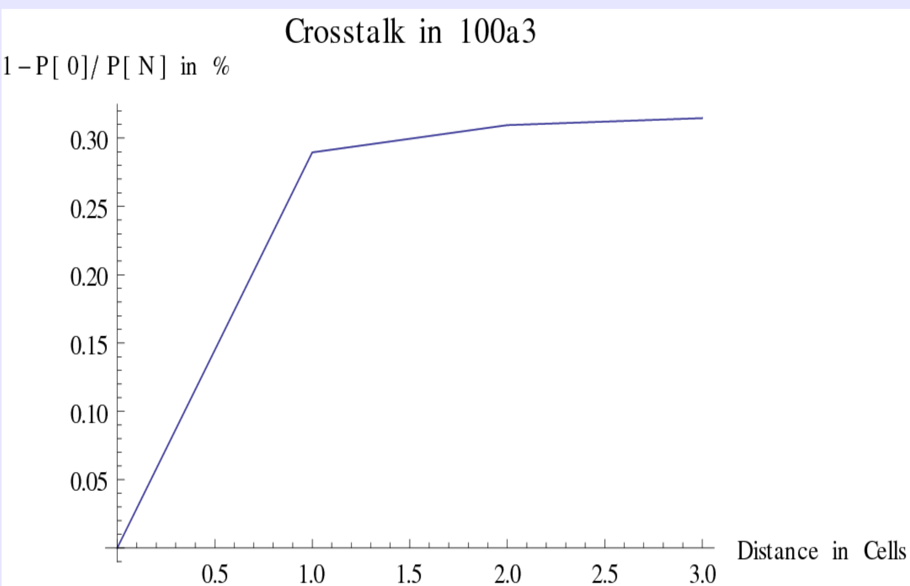


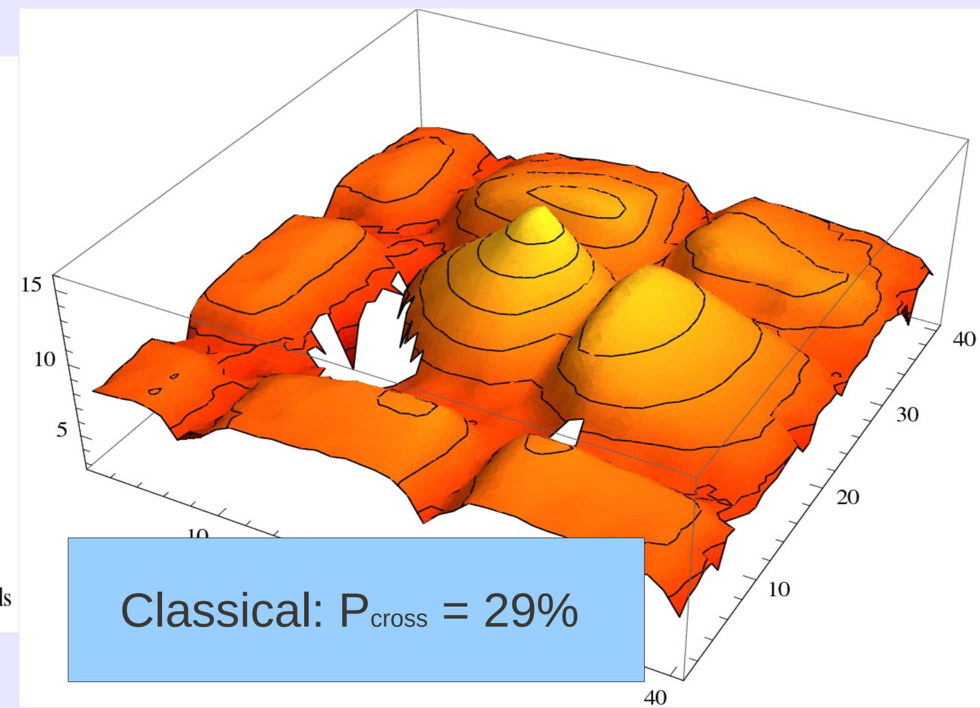
1 - Counts(in)/Counts(out) = 33.7%

Imaging of cross-talk

Imaging of cross-talk

New imaging method for studying cross-talk morphology → Work in progress





Classical: P_{cross} = 29%

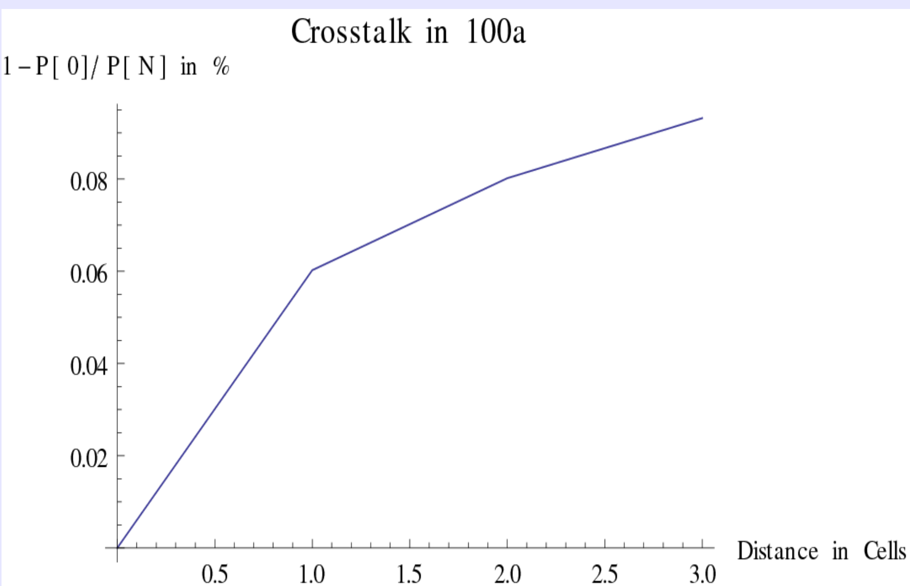
cta cherenkov telescope array

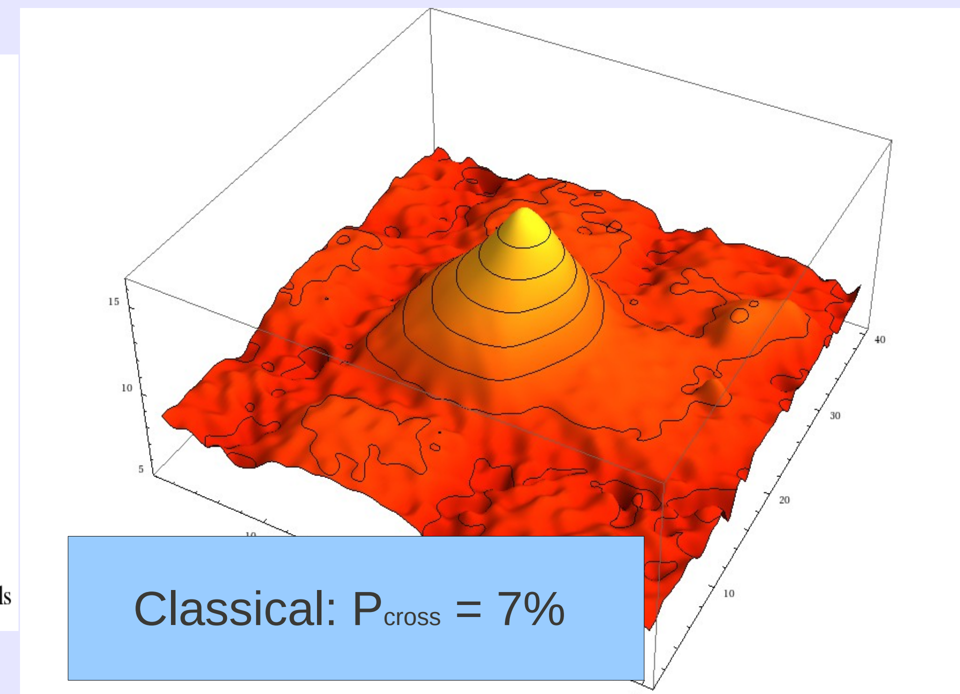
Imaging of cross-talk

Max-Planck-Institut für Physik (Werner-Heisenberg-Institut)

Imaging of cross-talk

New imaging method for studying cross-talk morphology → Work in progress



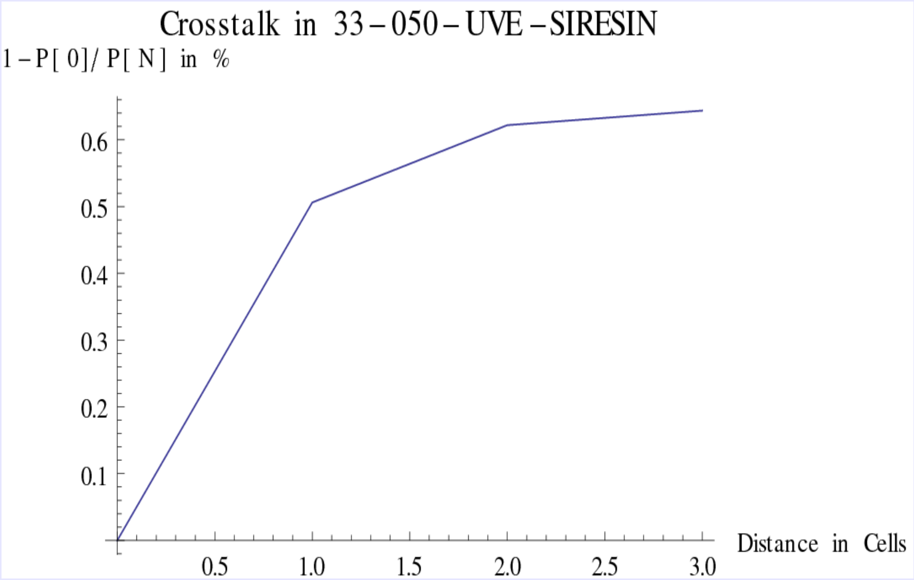


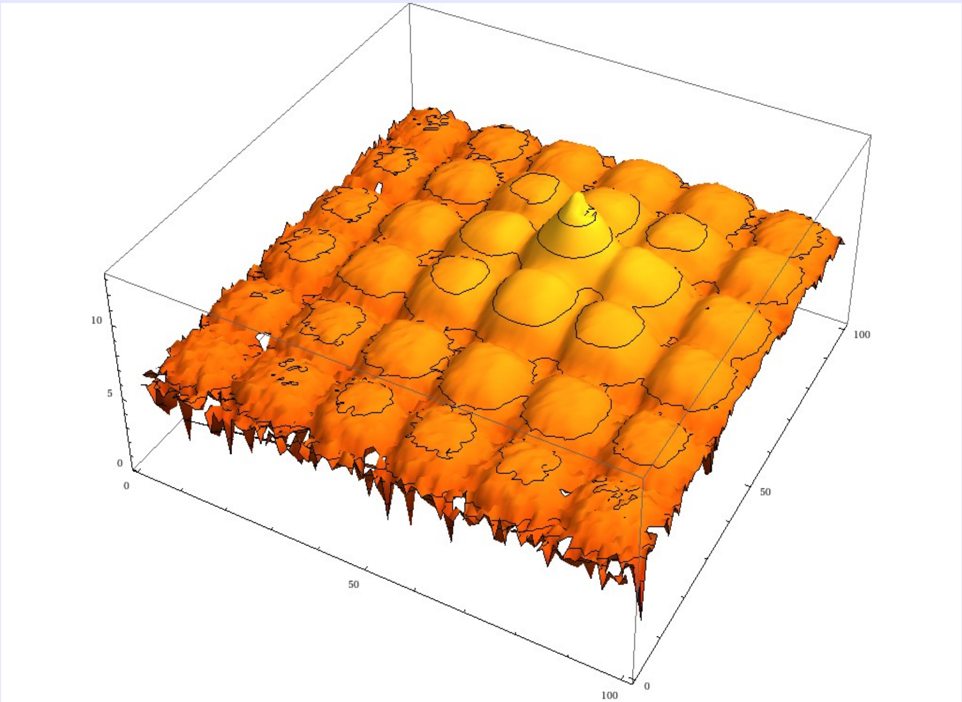
Classical: P_{cross} = 7%

Imaging of cross-talk

Imaging of cross-talk

New imaging method for studying cross-talk morphology → Work in progress





Time Resolved imaging of cross-talk

The first measurements were done without Image Intensifier, but I did not take a picture of this setup.

- The second measurements were done with the fast gated image intensifier → minimum gate ~ 3ns FWHM
- An externally controlled pulse generator allows us to scan the delay with 100 ps precision

→ Movie with 100 ps change from frame to frame

The following movies have 30 ns duration and 0.4 ns in between frames cta cherenkov telescope array

Time Resolved imaging of cross-talk

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

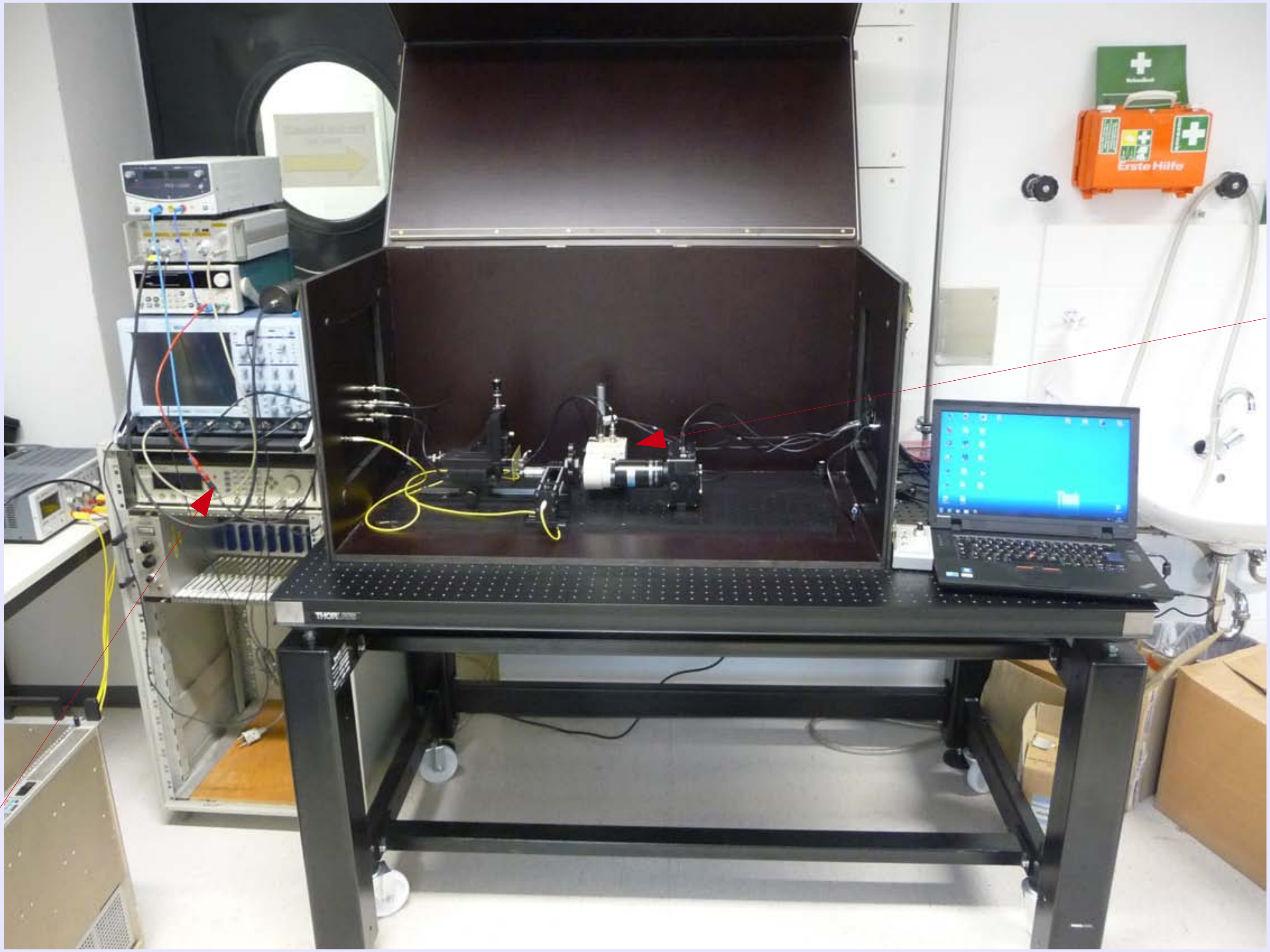


Image Intensifier

Pulse Generator

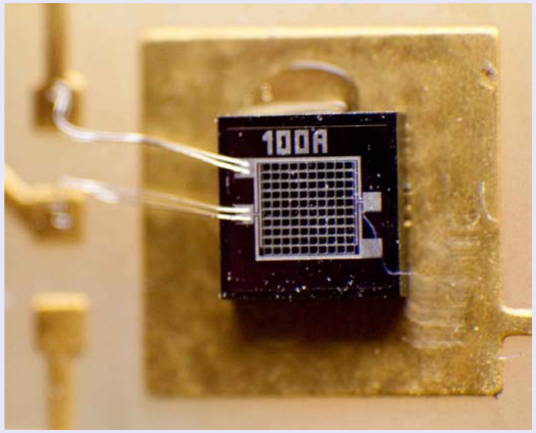
Summary:

PMT

- Already now the PMTs have almost achieved the specified target
- Hamamatsu R11920-100: Peak QE ~34%, After-pulsing ~ 0.03%.

  ET Enterprises 9142B: Peak QE ~30%, After-pulsing ~ 0.005%.
- We want use the image intensifier to study time dependent light emission
- Next two years further optimization of PMTs from both companies (some financial support is foreseen).

SiPM



- We think their use in CTA would be interesting when the peak PDE exceeds PMT by a factor of 1.5 - 2 at comparable costs
- MEPhI-Excelitas SiPMs are getting there with peak PDE = 50% @ $P_{cross\text{-}talk}$ 5%
- Imaging of the light emission from avalanches can be a powerful tool. Avalanches are local in cells and cross-talk reduction mechanisms show effect.
- Someday a serious alternative to the PMT?

Thanks.