On the emission of photons during avalanches

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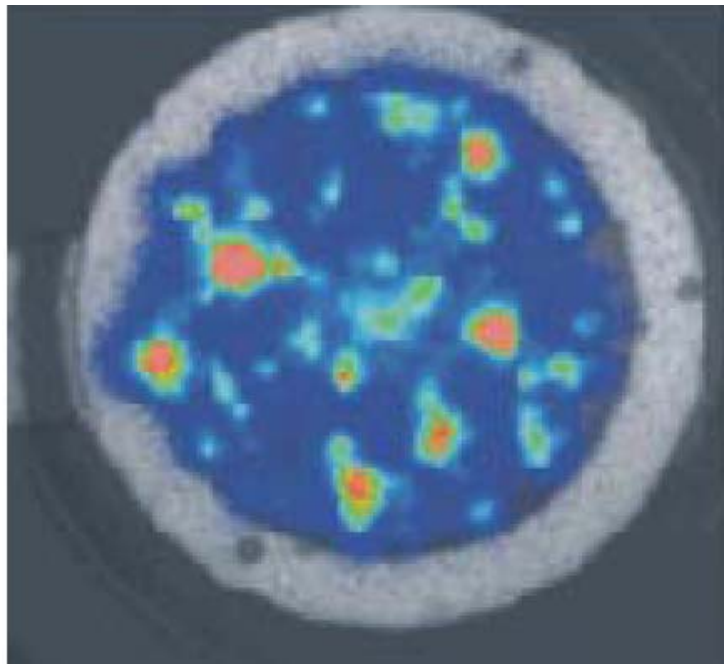
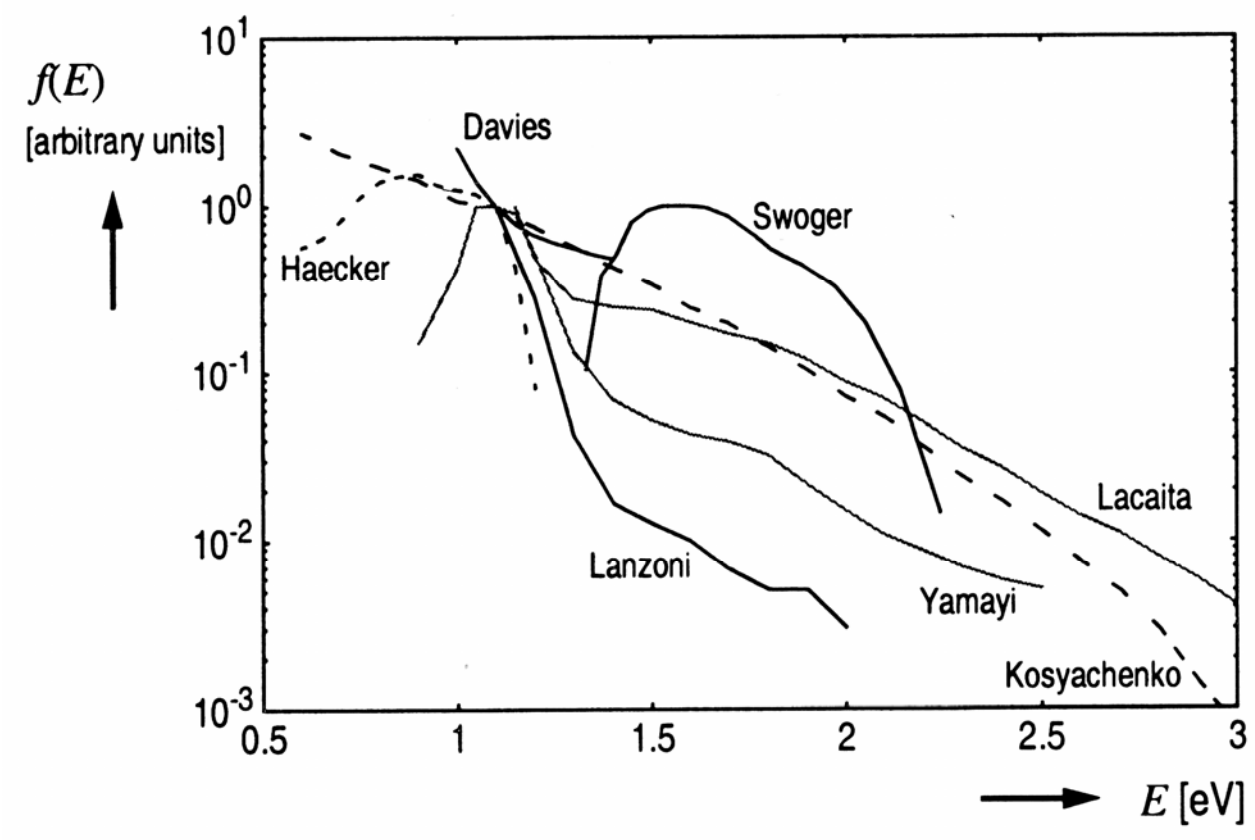


light emission during Geiger breakdown
(Sciacca, 2003)

Light Emission in Avalanches



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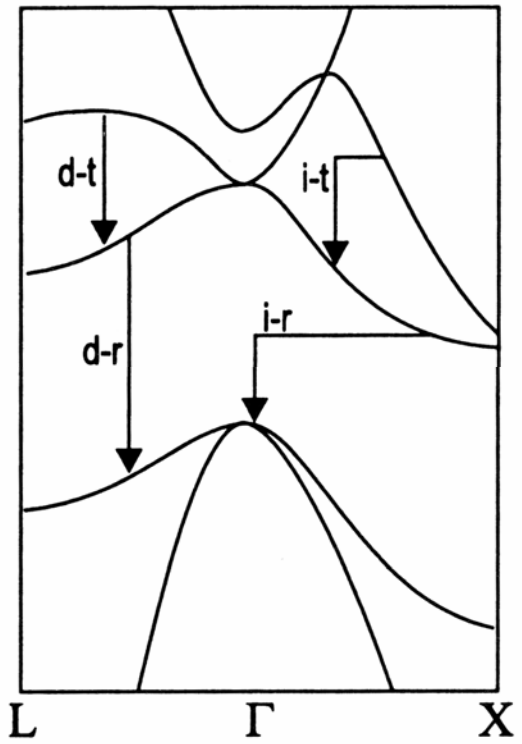
- measured spectra quite different

Proposed Light Emission Mechanisms

Discussed are:

- recombination (d-r, i-r)
- bremsstrahlung (i-t)
- intraband transitions (i-t, i-r)



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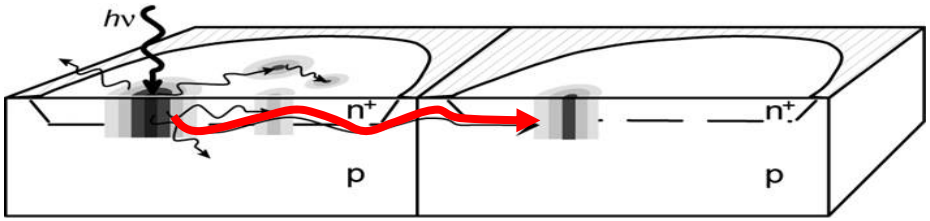
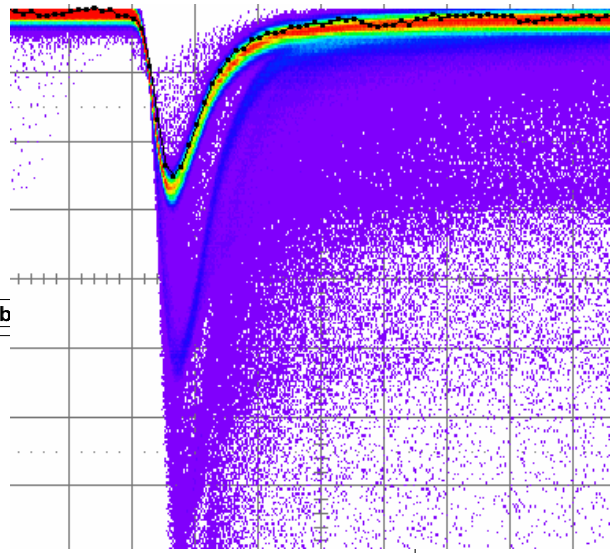
It is not clear, what the dominating process is!

Light Emission → Optical Crosstalk: an unwanted effect in G-APDs



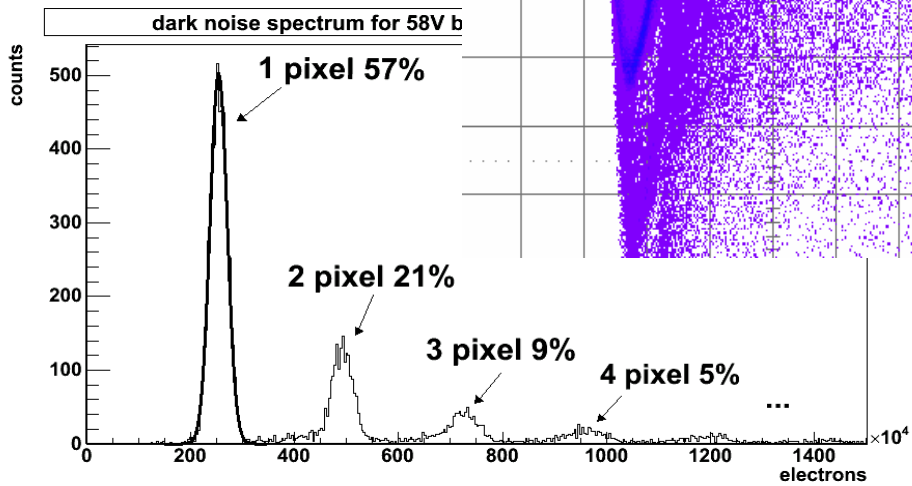
Sketch from Cova et al. NIST 2003
Workshop on single photon detectors

photons can trigger additional cells



→ artificial increase in signal

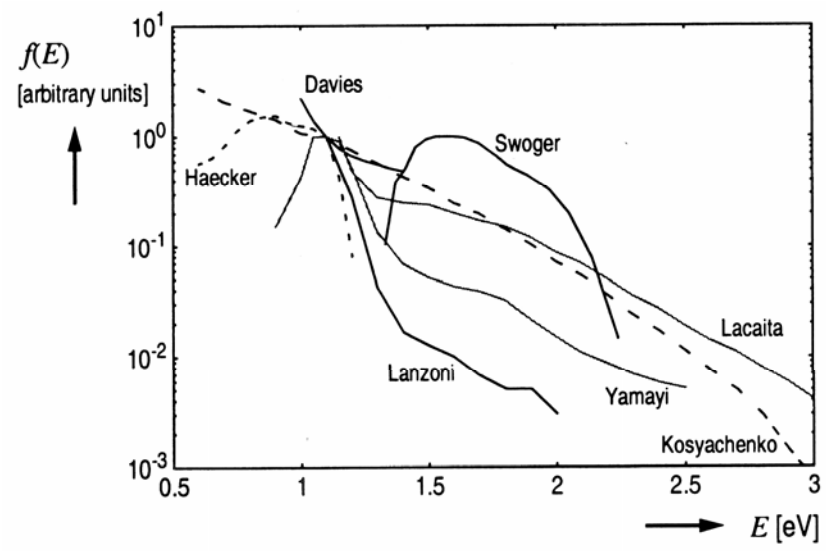
→ **E**xcess **N**oise **F**actor of SiPM



optical crosstalk probability distribution

can be quite significant
and
problem in applications

Objectives of this Study



- photons of what energy cause optical crosstalk?
- what is the intensity of photons ($N_{phot}/N_{e\text{-}h\ pair}$) emitted during an avalanche ?

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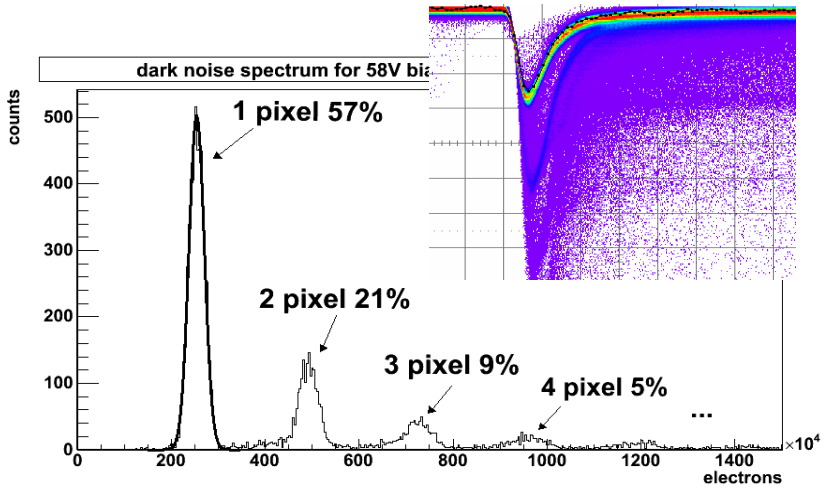
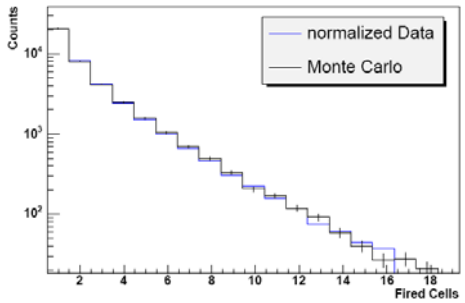
idea: use optical crosstalk to learn about the light emission in avalanches

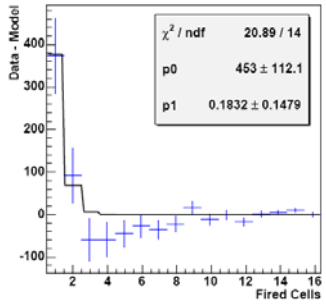
Procedure

1. Measure the probability distribution of optical crosstalk



2. Perform a MC-simulation of the SiPM





and try to reproduce the measured optical crosstalk distribution

SiSi: The **Si**PM **Si**mulator

*Elisabeth ”Sis(s)i” von Wittelsbach was the empress consort of Emperor Franz Joseph of Austria. She was born 1837 in Munich, Bavaria and murdered 1898 in Geneva, Switzerland

SiPM-Simulator

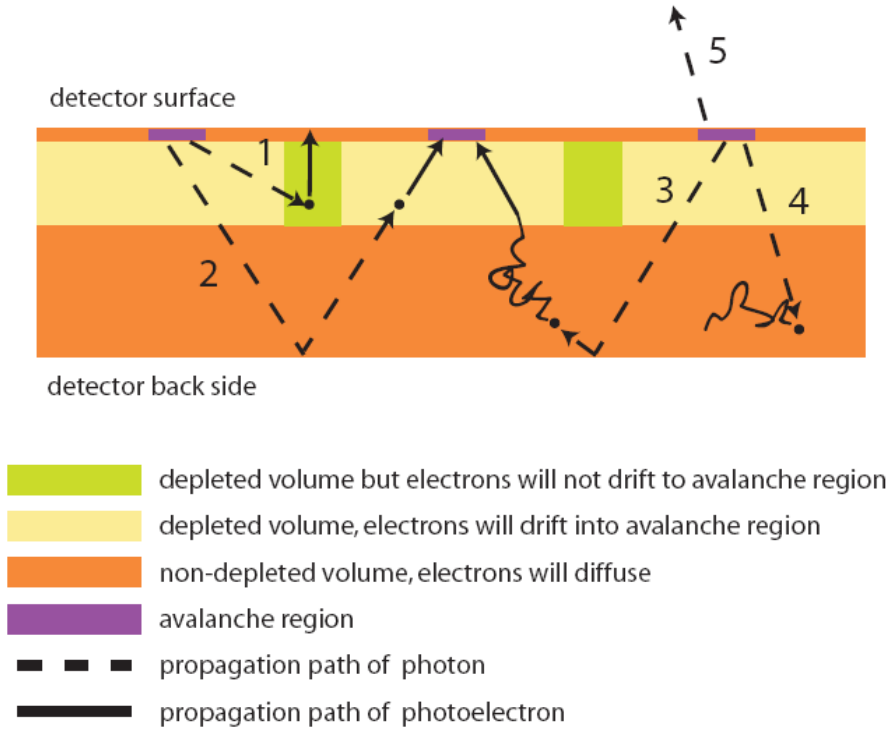
full geometrical description of a SiPM:

- number of cells
- active volume
- ...

simulation of avalanche photons:

- black body radiation with free parameters:
  - **temperature**
  - **intensity**
- isotropic emission

photoelectrons in non-depleted bulk are subject to simple diffusion model; lifetime of electrons is free parameter

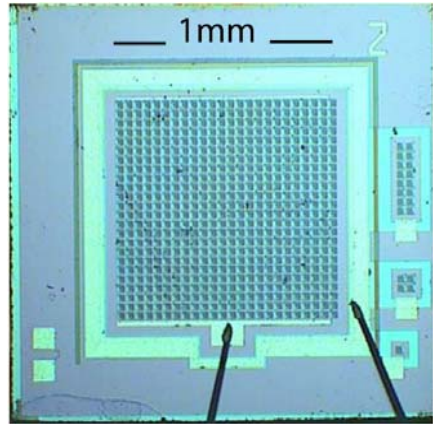


Tuning of Model Parameters

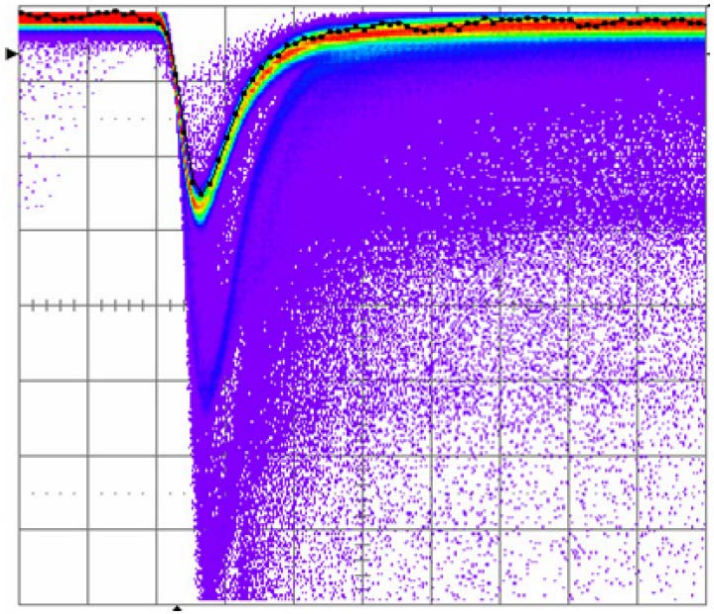
SiSi has three free parameters

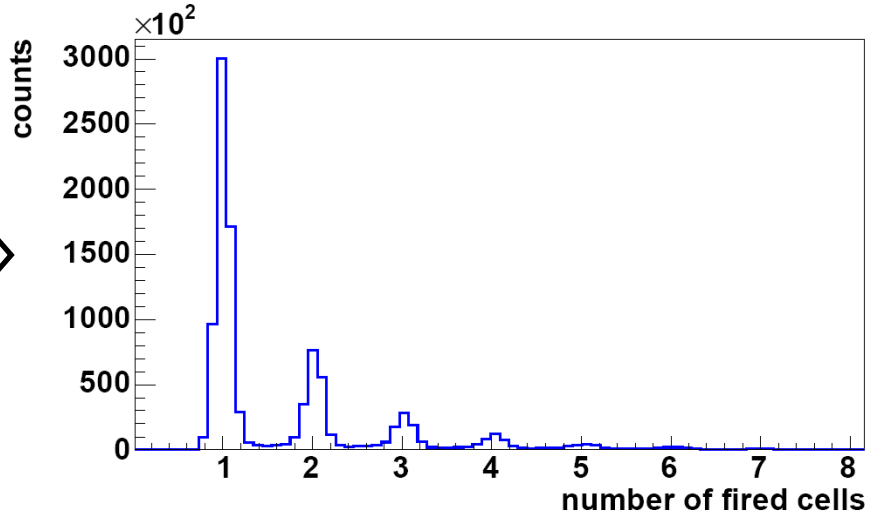
- temperature of photon spectrum
- intensity of photon spectrum /
  probability that avalanche carrier emits photon
- lifetime of electrons in non-depleted bulk

Model parameters tuned by reproducing measured optical-crosstalk behavior of a SiPM with SiSi.



SiPM by MEPhI/Pulsar

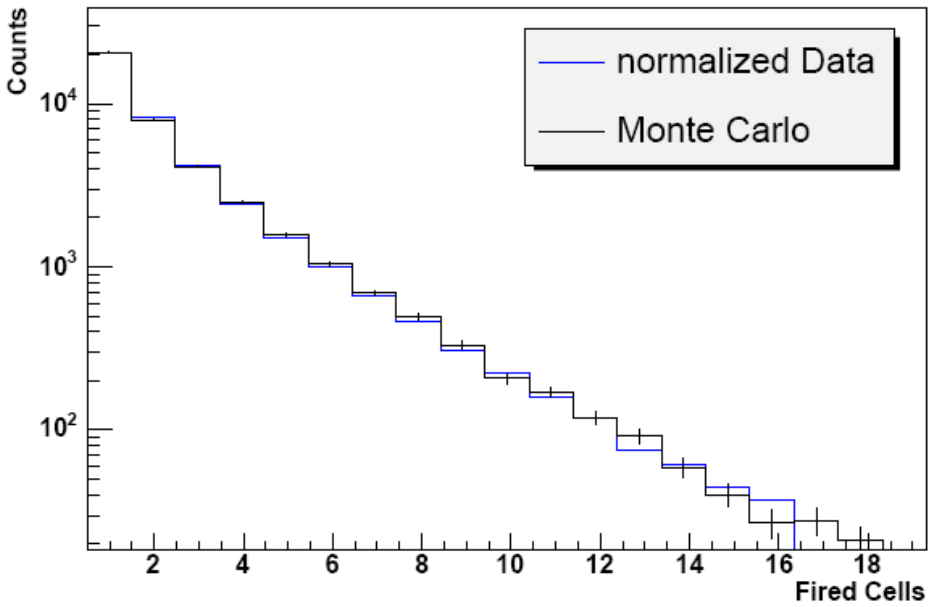




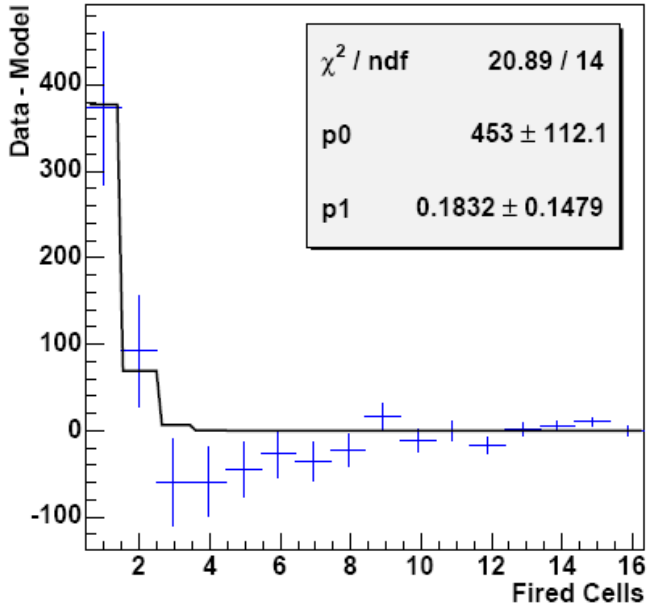
optical crosstalk (dark noise) spectrum (measured)

Simulation:

- Temperature 4500K
- Efficiency >1.015eV: 1.45×10^{-4} photons/electron
- electron lifetime 60 nsec



simulated and measured crosstalk distribution



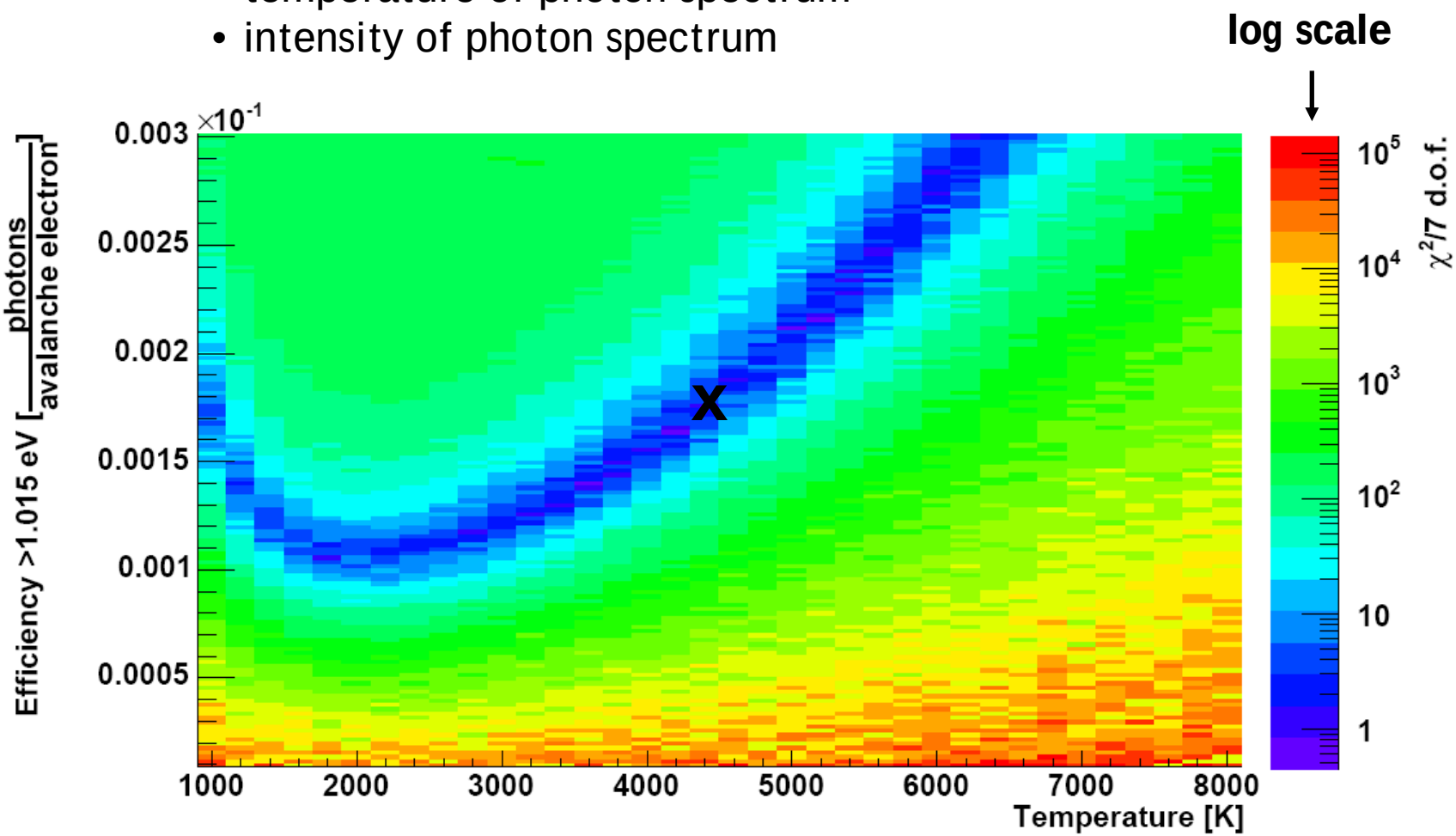
residuals

goodness of match quantified with a χ^2-test

Residuals can be explained by dark counts which are not simulated in SiSi

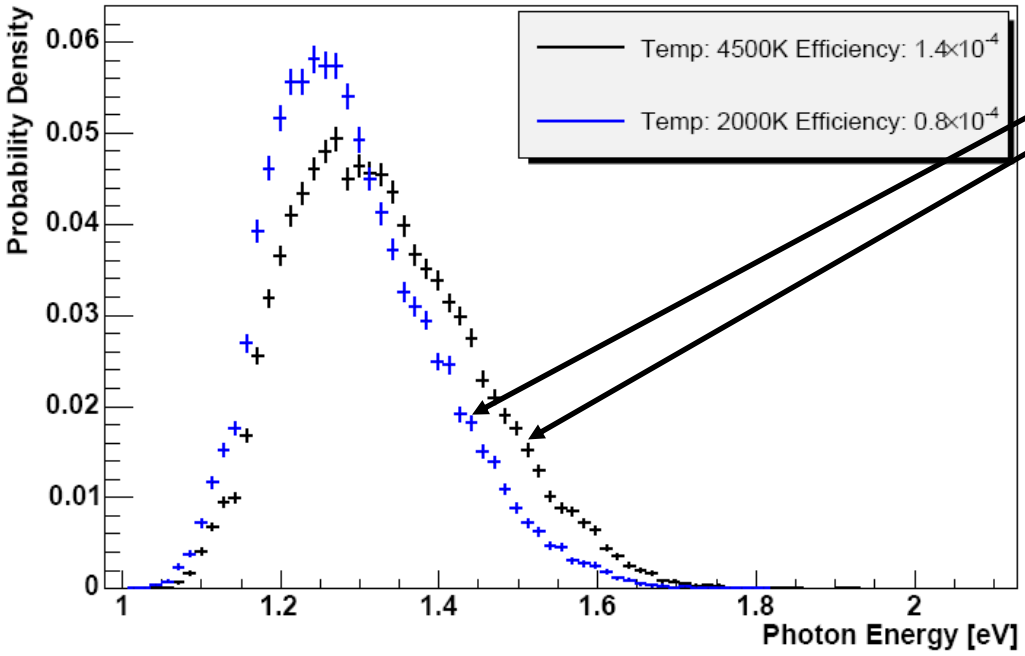
χ^2 -distribution of a scan in:

- temperature of photon spectrum
- intensity of photon spectrum

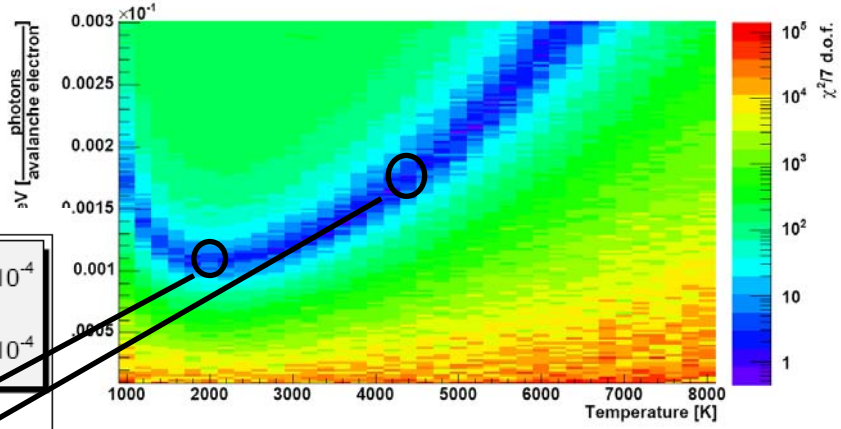


no unique solution of model parameters but

Characteristics of Photons responsible for Optical Crosstalk



simulated energy distribution of photons which caused optical crosstalk

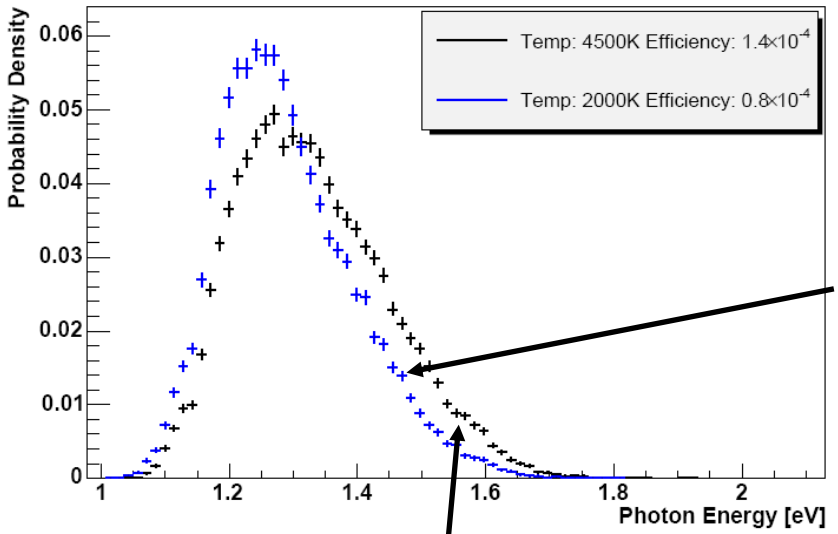


Peak: ~1.26eV

FWHM: ~0.21 eV

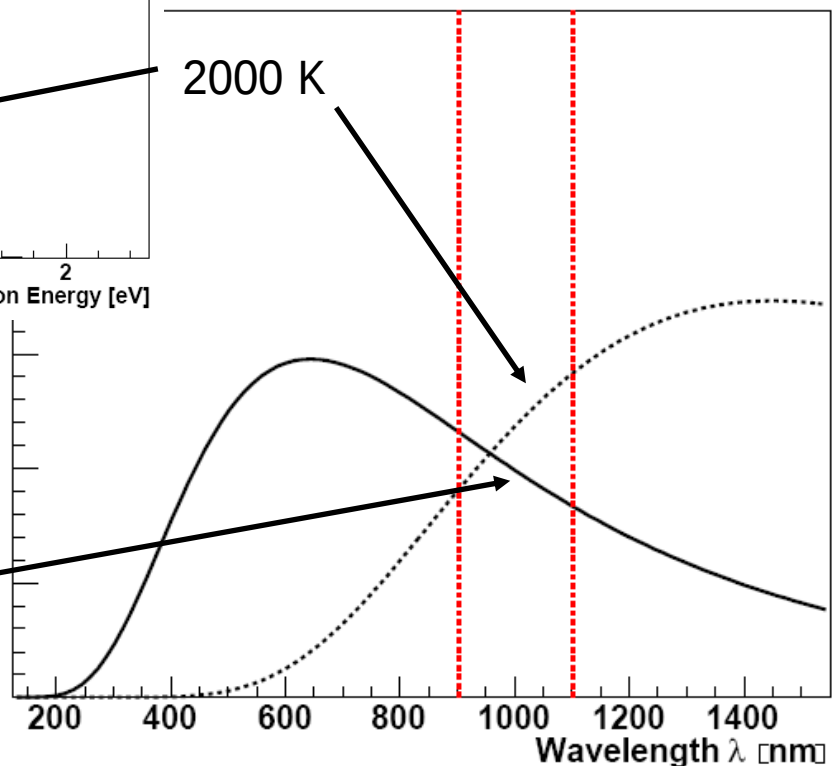
very narrow distribution

Intensity (1.15 … 1.40 eV):
~$3*10^{-5}$ photons / avalanche electron (uncertain by a factor of ~2)



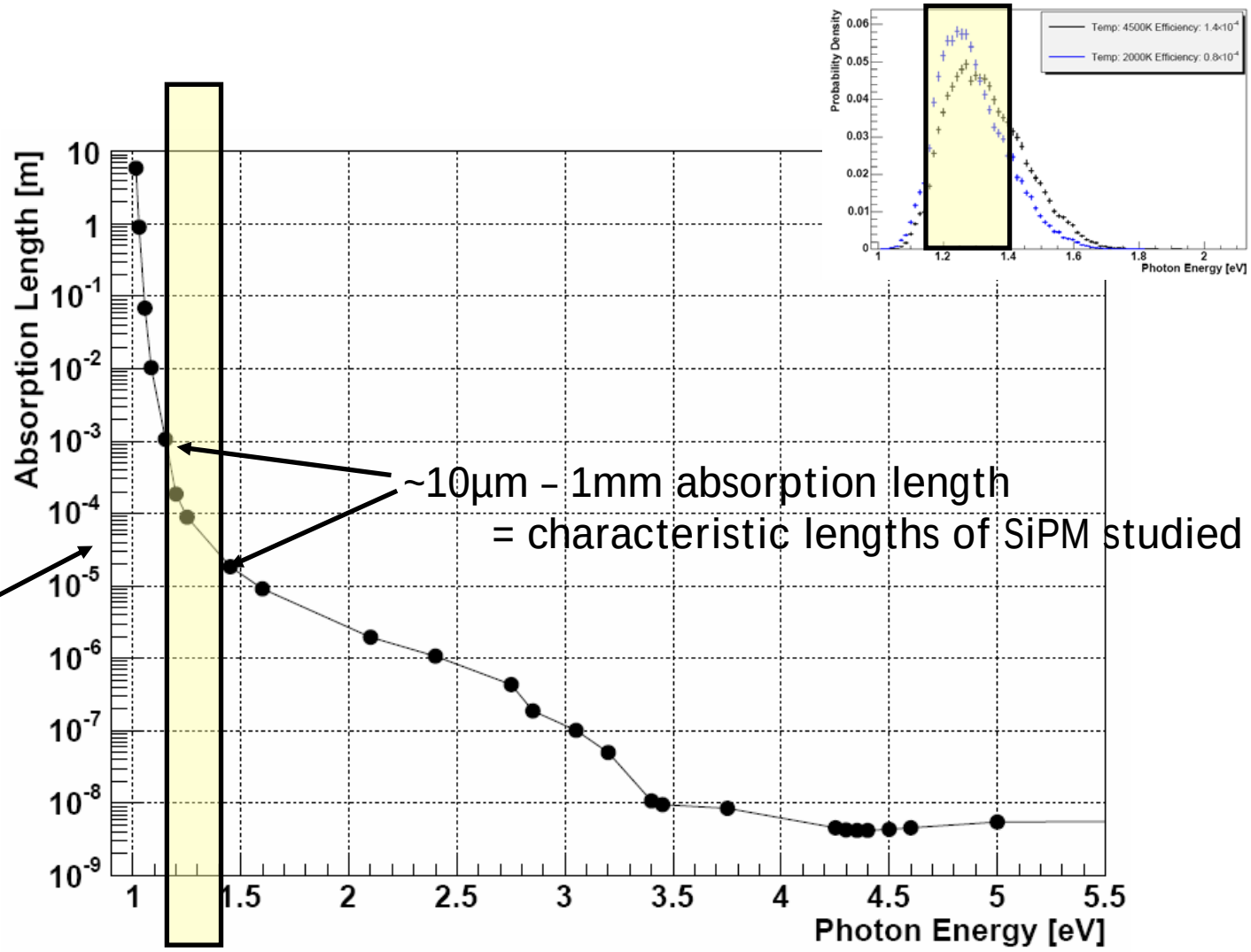
2000 K

4500 K



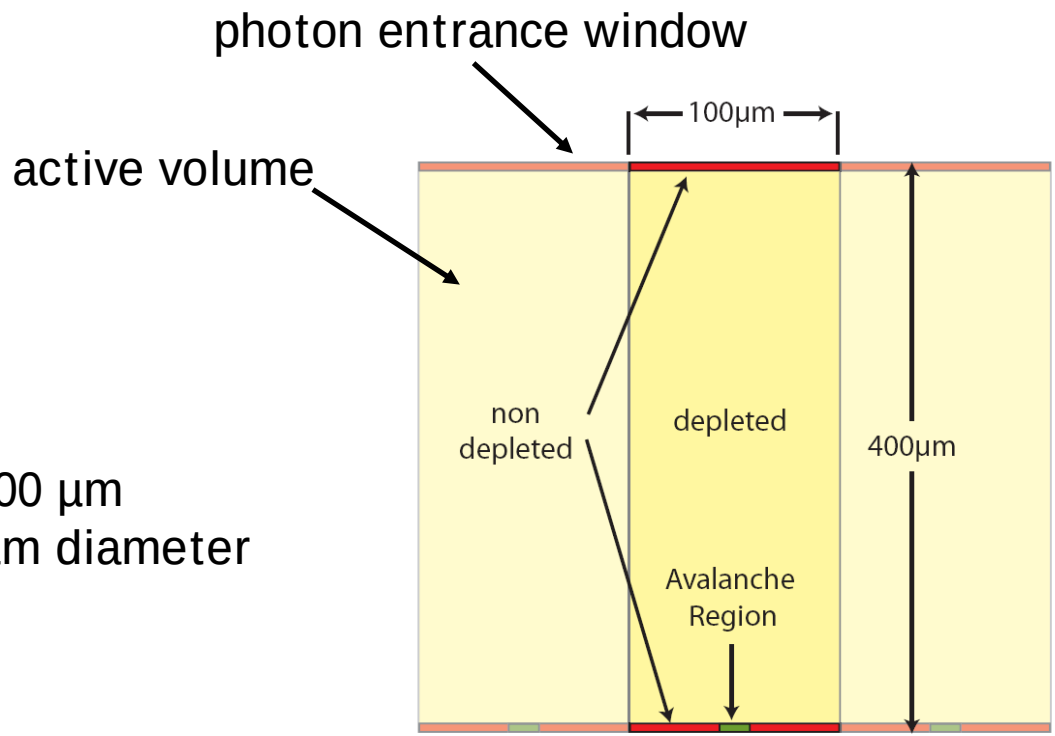
No need to precisely now spectral shape!

simulated photon spectrum



strong energy dependent absorption lengths
explains narrow photon energy distribution

Optical Crosstalk in Back Side illuminated SiPM



simulated structure:

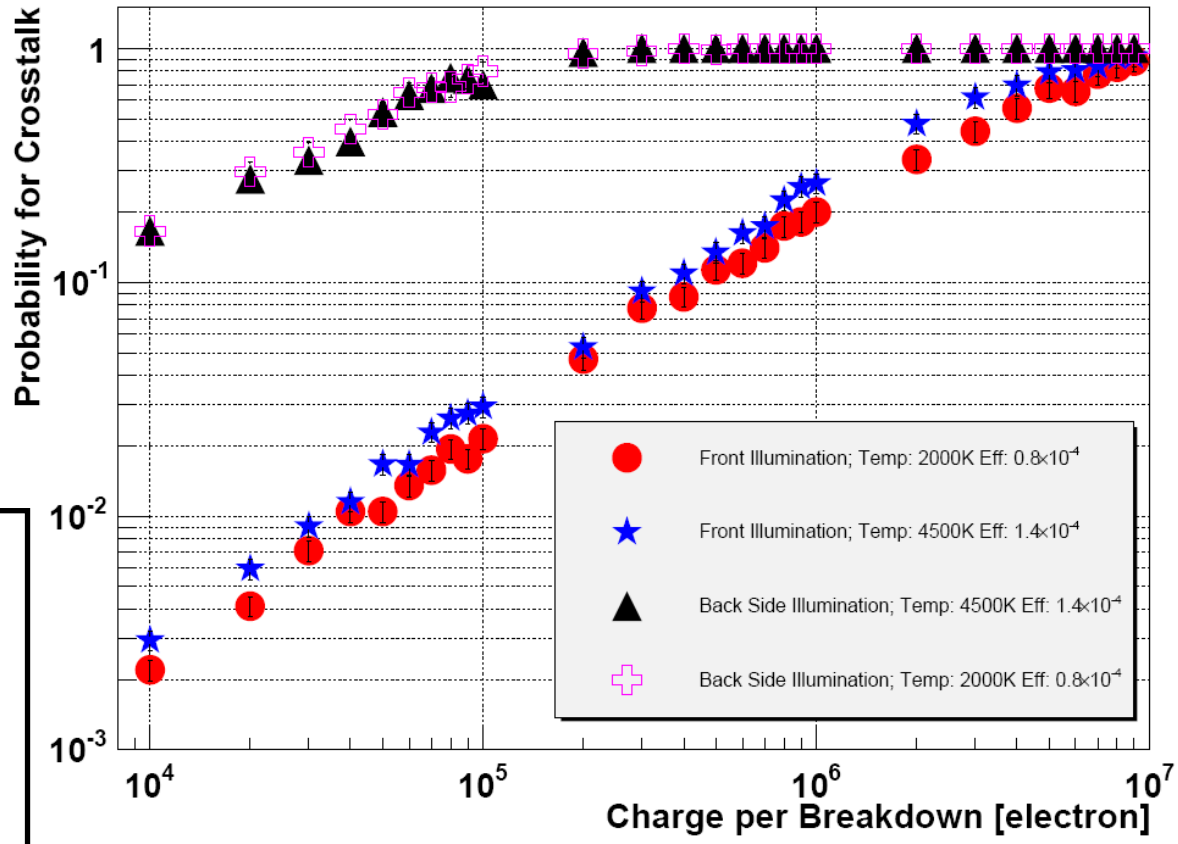
- pitch between cells 100 µm
- avalanche region 10 µm diameter
- 100% active volume

Crosstalk Probability in Back Side illuminated SiPM

assume breakdown probability = 0.9

For operation of back side illuminated SiPM need gain << 10^5

~20% crosstalk at gain 10^4



But:
absolute measurements always difficult!
e.g. Lacaita (1993) give five times lower intensity
→ ~4% crosstalk at gain 10^4

Repeated Study

done by Hans-Günther Moser

- SiPM produced by HLL: 170µm/200µm pitch and small active areas ~10µm
  → much lower Crosstalk probability
- Different MC code

→ Different systematics

<u>Extrapolation to back side illuminated SiPM</u>

Crosstalk probability: 20%-30% at gain of 10^5

i.e. 3-4 times lower

Extrapolation is difficult because photon spectrum becomes important

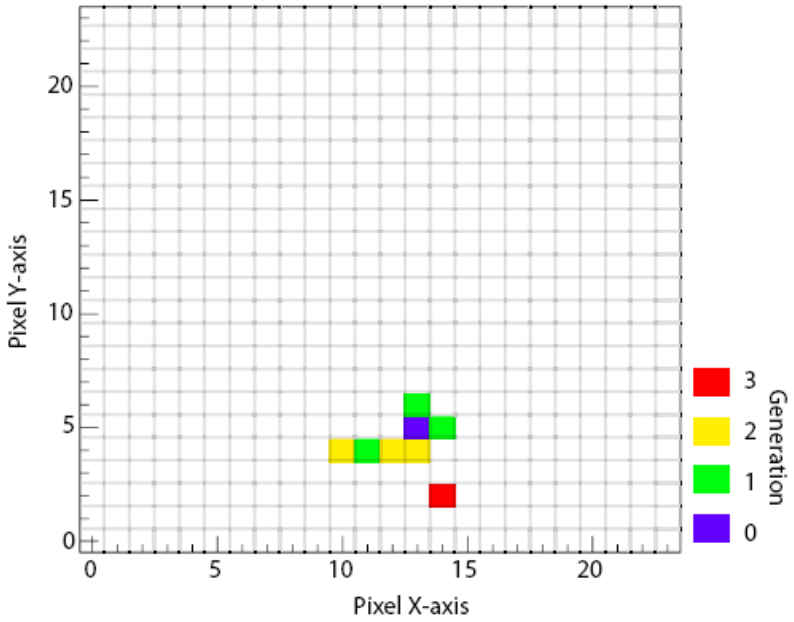
Needs clarification:

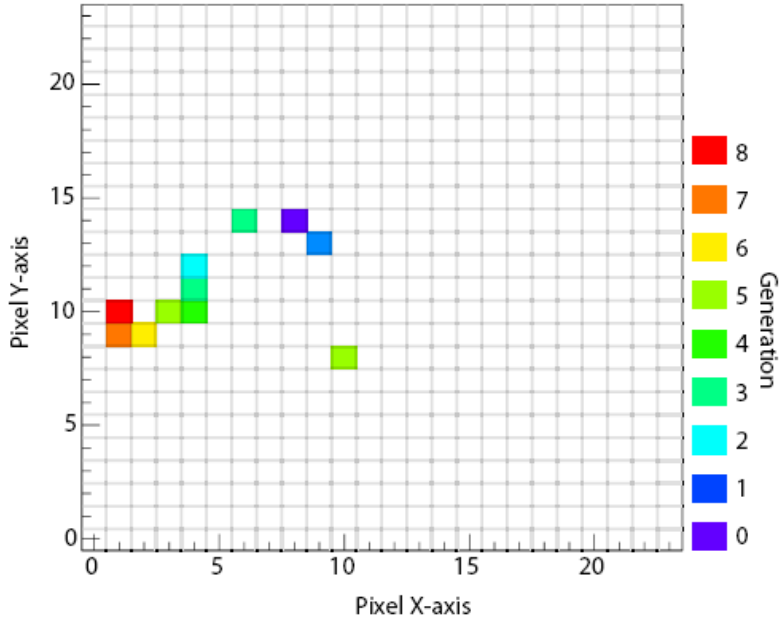
Have to wait for first prototypes of back side illuminated SiPMs

Conclusions

- SiSi is a nice tool to understand SiPM
- crosstalk behavior well described after tuning three free parameters in SiSi
- only photons within a narrow energy interval (1.15eV-1.40eV) give rise to optical crosstalk; reason: strong energy dependence of absorption lengths
- measured intensity of photons within 1.15eV-1.40eV : ~$3 \cdot 10^{-5}$ photons / avalanche electron-hole pair; estimated factor of uncertainty: 2
- optical crosstalk is a serious problem for back side illuminated SiPM, however two different studies come to different conclusions → have to wait for first prototypes

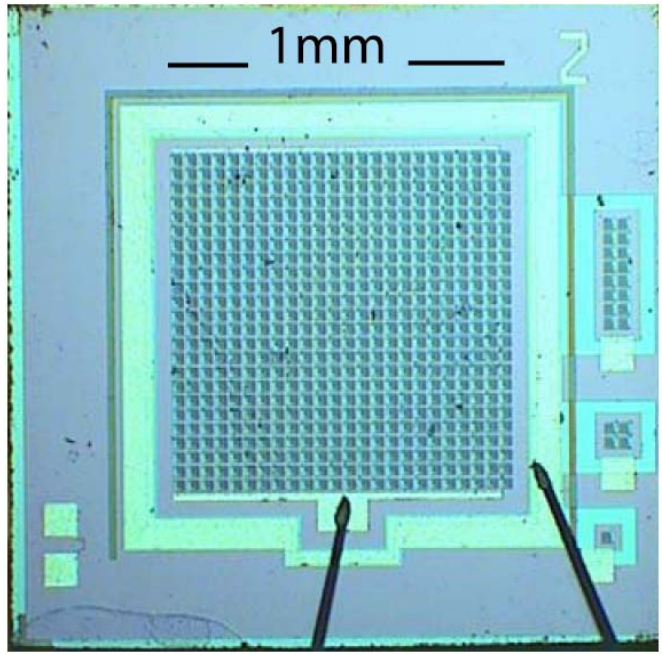
Two Examples of Crosstalk Events

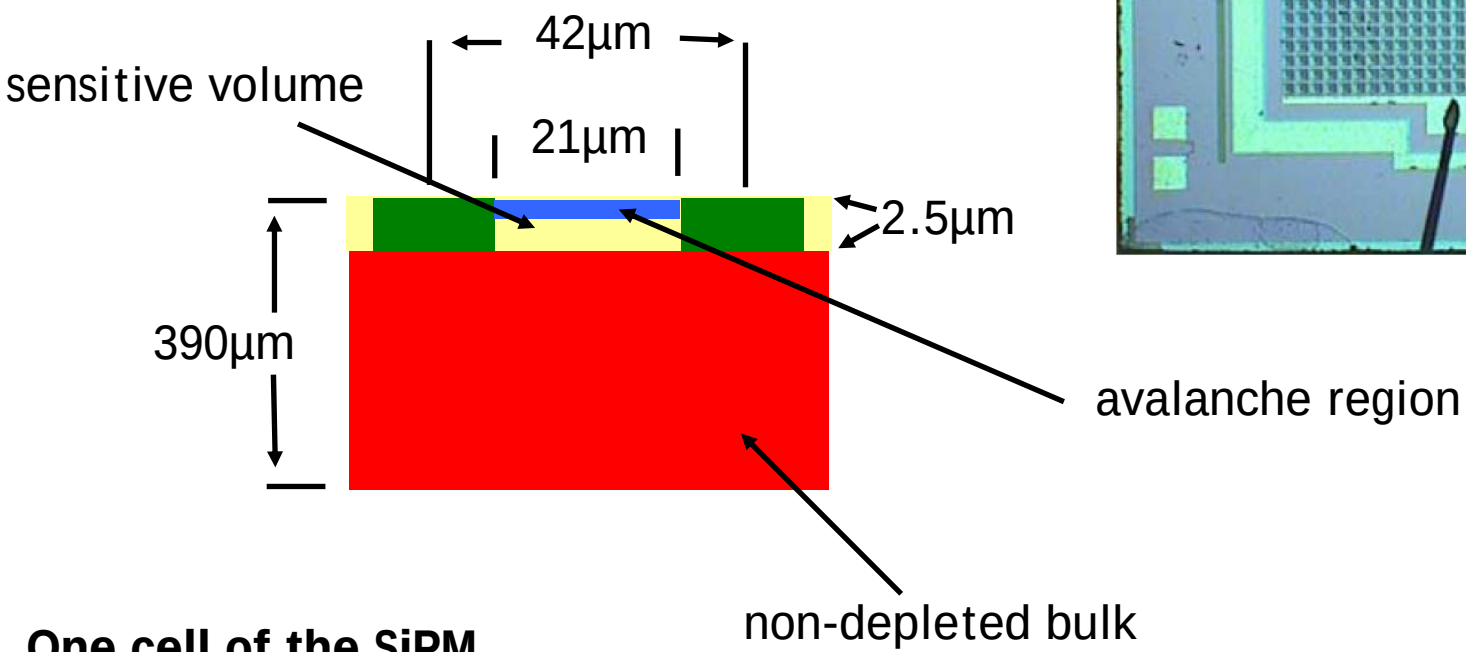




SiPM that was used to tune SiSi

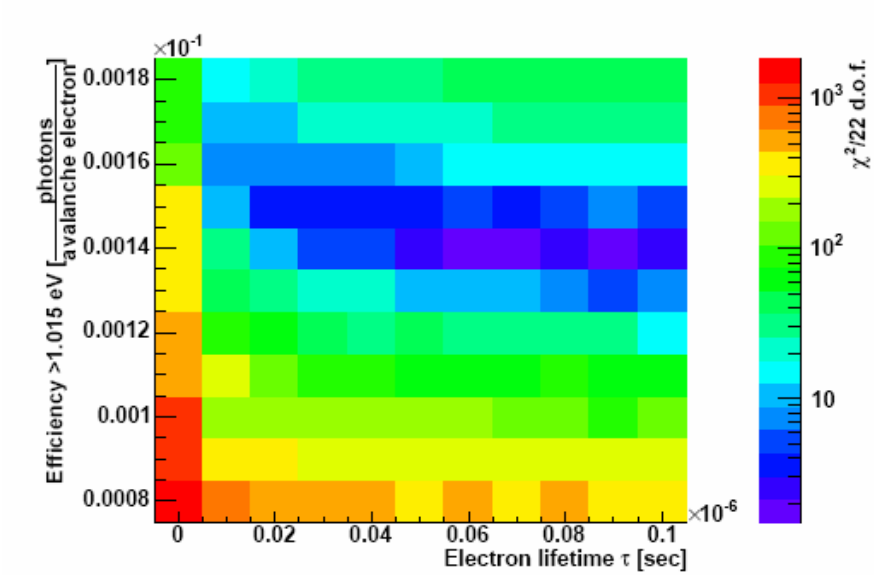
- produced by MEPhI/Pulsar
- 576 cells



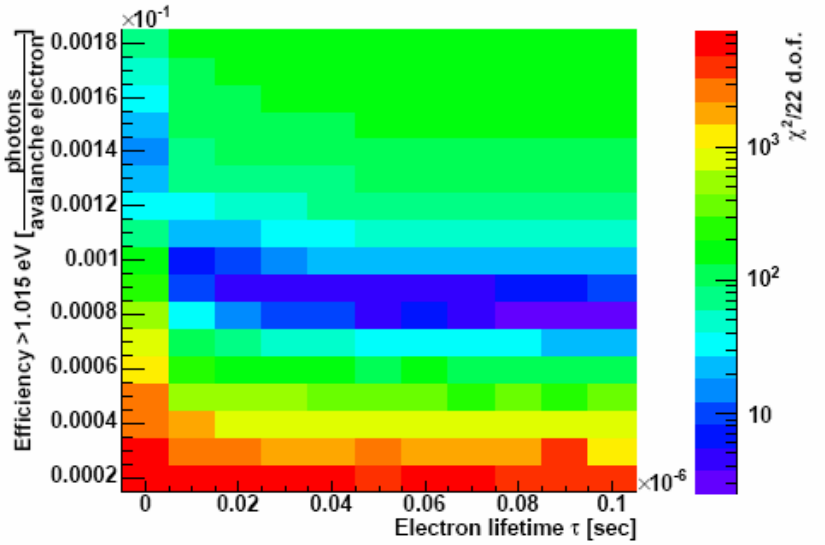


One cell of the SiPM

Electron Lifetimes



4500K



2000K

Intensity of the photons is reduced by ~30%
if lifetime of the electrons in the non-depleted volume is non zero