Light Emission from Avalanches in Si

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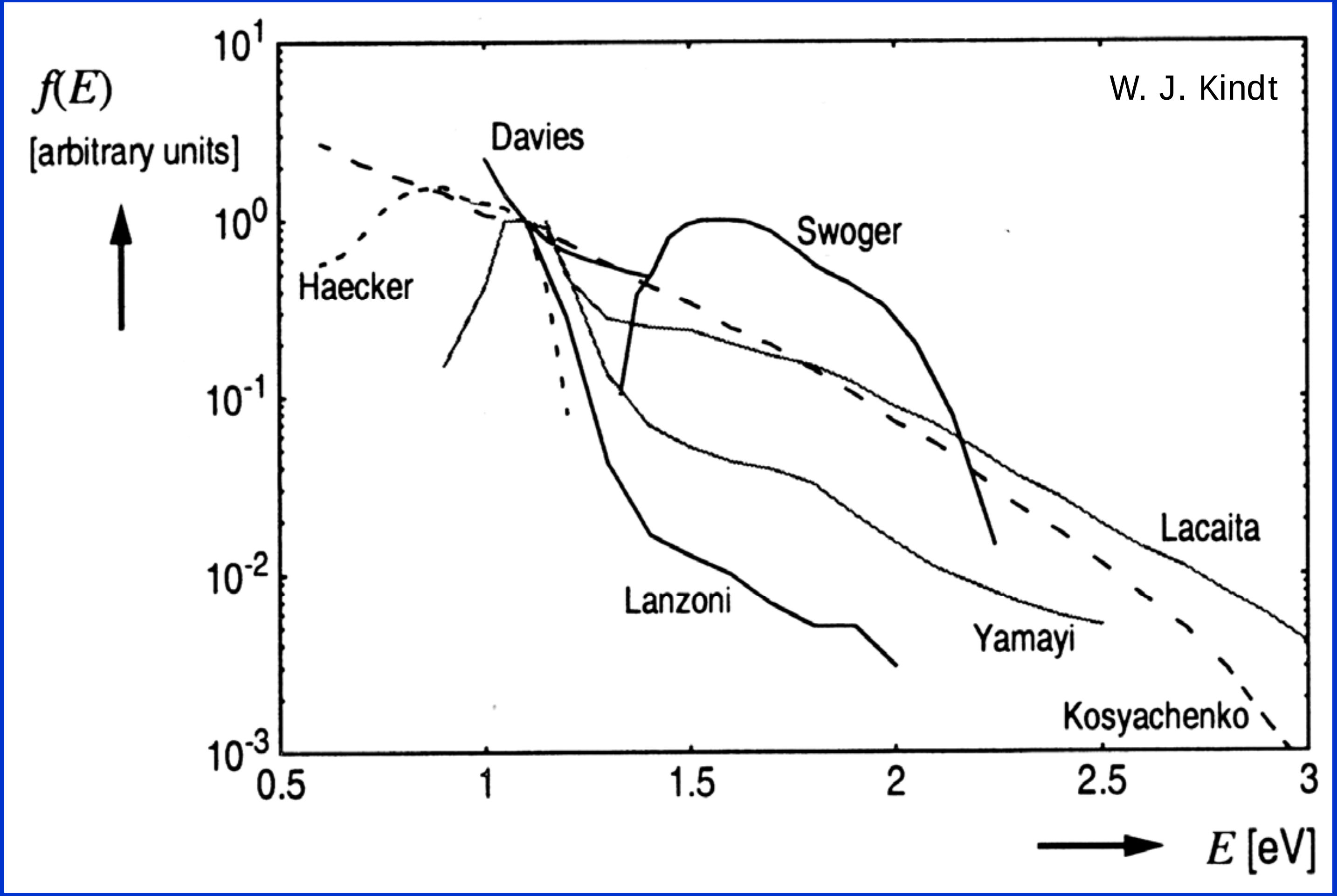
Light Emission in Avalanches: collection of different measurements



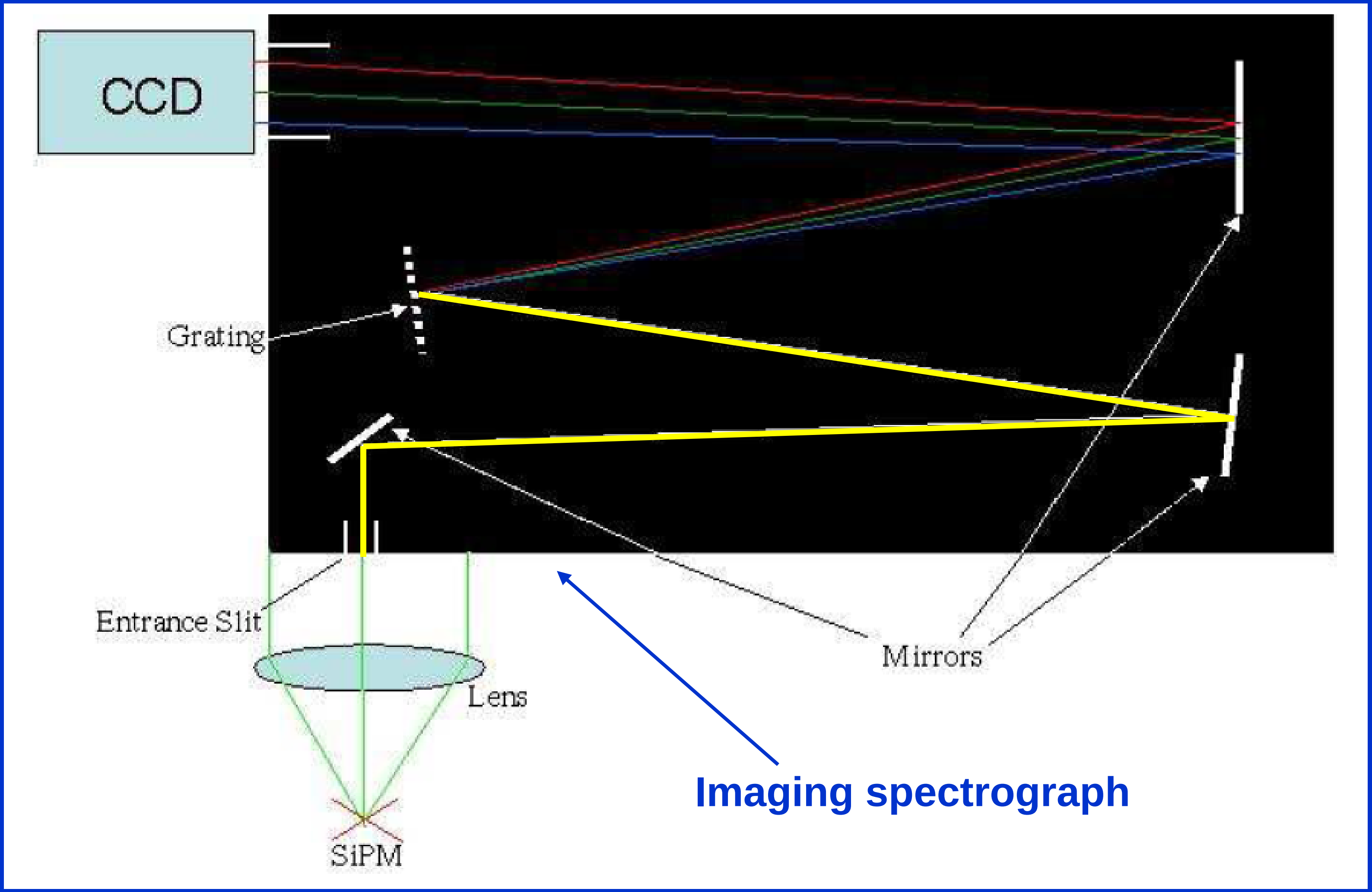
Why the light emission from Si avalanches is important

- First observation of the light emission from reversed-biased Si p-n junction in 1955 (Newman)
- Revived interest about the effect in recent years because of:
- Cross-talk in SiPMs (GAPD, MPPC, micro-channel APD,…) spoils the amplitude resolution
- The light emission is proportional to the number of e- in the avalanche. This puts a limit to the maximum gain under which one can operate the SiPMs
- If no measures are taken against the cross-talk, then the F-factor is worse than in classical PMTs
- As a consequence one encounters major problems in self-trigger schemes when measuring very low light level signals

The Setup

- List of the components used in our setup:
  - (SiPM) MPPC *S0362-11-100U* from Hamamatsu
  - Imaging Single ph.e. Sensitive Spectrograph *Shamrock 303i* from Andor
  - CCD-camera *Idus 420 OE* for optical spectrum 450-1000nm
  - InGaAs –camera *DU490 A-1.7* from Andor for NIR spectrum 900-1700nm

Sketch of the experimental setup



Parameters of the setup

CCD pixels (row x column)	1024 x 256 (VIS) 512 x 1 (NIR)
Preamplifier gain CCD	14 e/count (VIS) 300 e/count (NIR)
Grating, lines/mm	150
Blase wavelength of grating	800nm
Slit size	2.5mm
Focal lenth of lens	50mm
Used gain of MPPC	1.56×10^6
Calibrated diodes	Si PIN and GaAs diodes
Number of used calib. LEDs	14 (470 – 1700)nm

The Absolute Calibration

- 14 different LEDs were used for the absolute calibration. They were grinded flat, polished and installed in the same position as the SiPM, in the focus of the lens. The CCD had absolute calibration. Then 2 measurements were done:

1- the LED light was measured by the CCD

2- the same light was measured by a calibrated PIN diode just behind the slit

The amount of light emitted by the SiPM was measured from the known geometry. The tabulated values of the refraction index in Si and SiO_2 were used in order to calculate the emission solid angle.

The Absolute Calibration

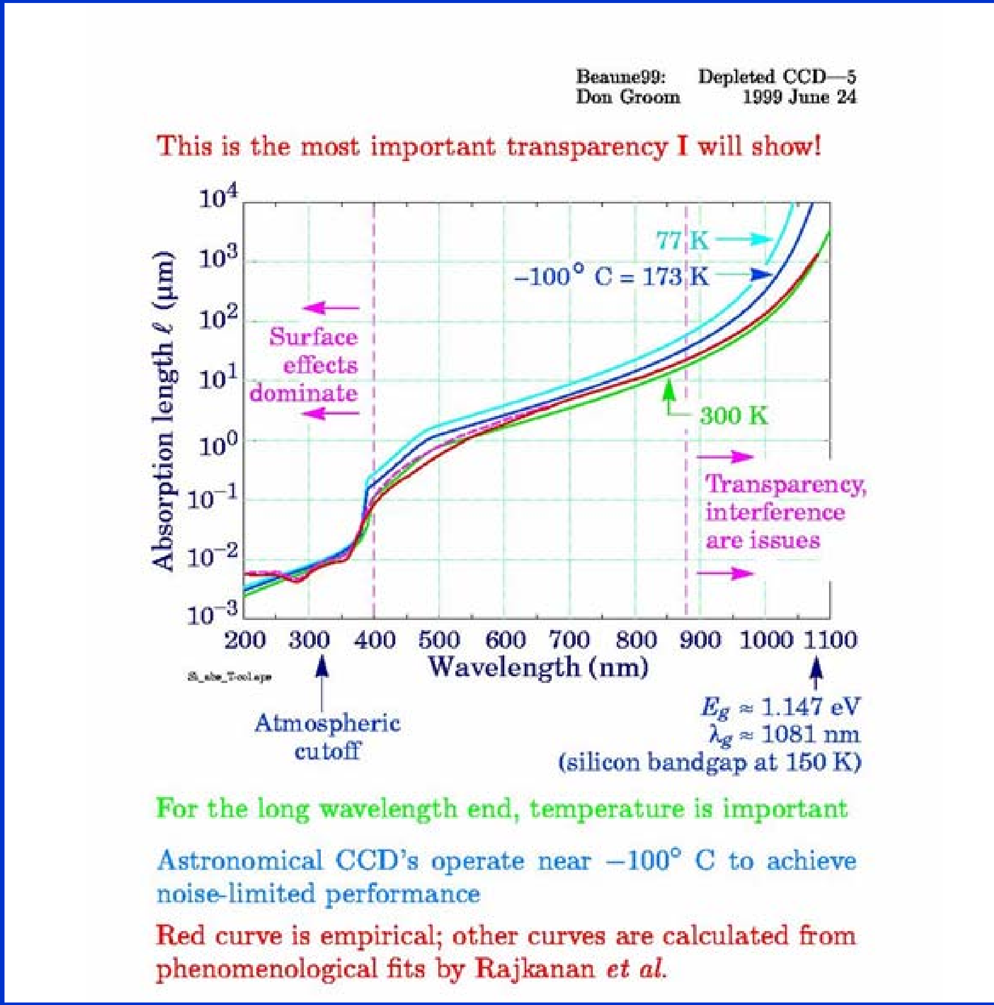
It was assumed that the used type of MPPC from Hamamatsu had an active zone of 1.8 μm in depth.

- The emitted light absorption in Si was simulated by using a simple Monte Carlo with a step size of 0.1 μm in depth. Tabulated values of the light absorption in Si were used for this calculation.
- Light reflection on the interface Si-SiO_2-air has been taken into account

The calibration LEDs

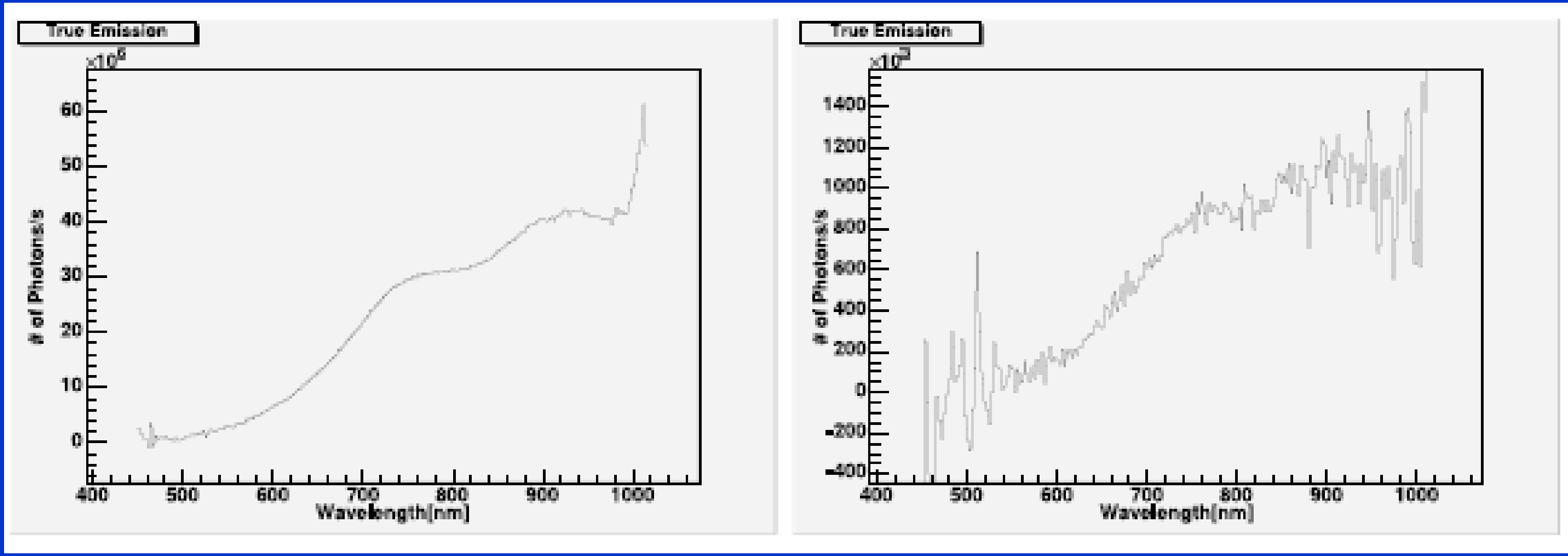
VIS LED, nm	470	520	621	700	750	810	910	1020
NIR LED, nm	910	1020	1200	1300	1450	1550	1600	1700

Reminder: light absorption in Si



- The related to absorption effects in Si were taken into account in our measurements
- Already from this graph one can get an impression about the relevant for the cross-talk effect wavelength range

Measured spectrum in visible

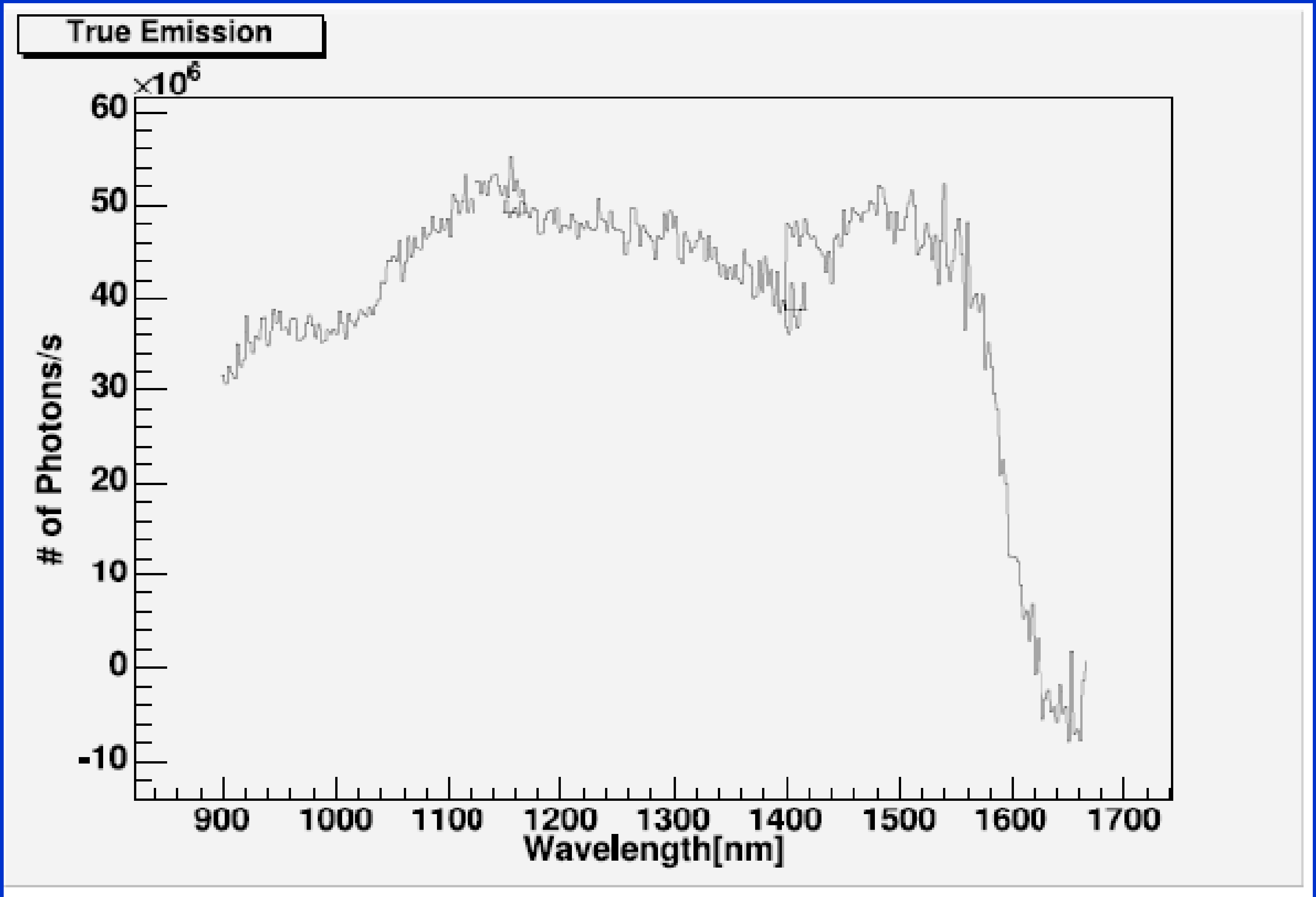


It was difficult to measure the light emission signal in the NIR because of a) high noise level, b) the InGaAs CCD had only 512x1 pixels. To overcome this at 1st the signal in the VIS was measured directly by integrating the signal from 256 rows operating the MPPC under the gain of 1.56x106.

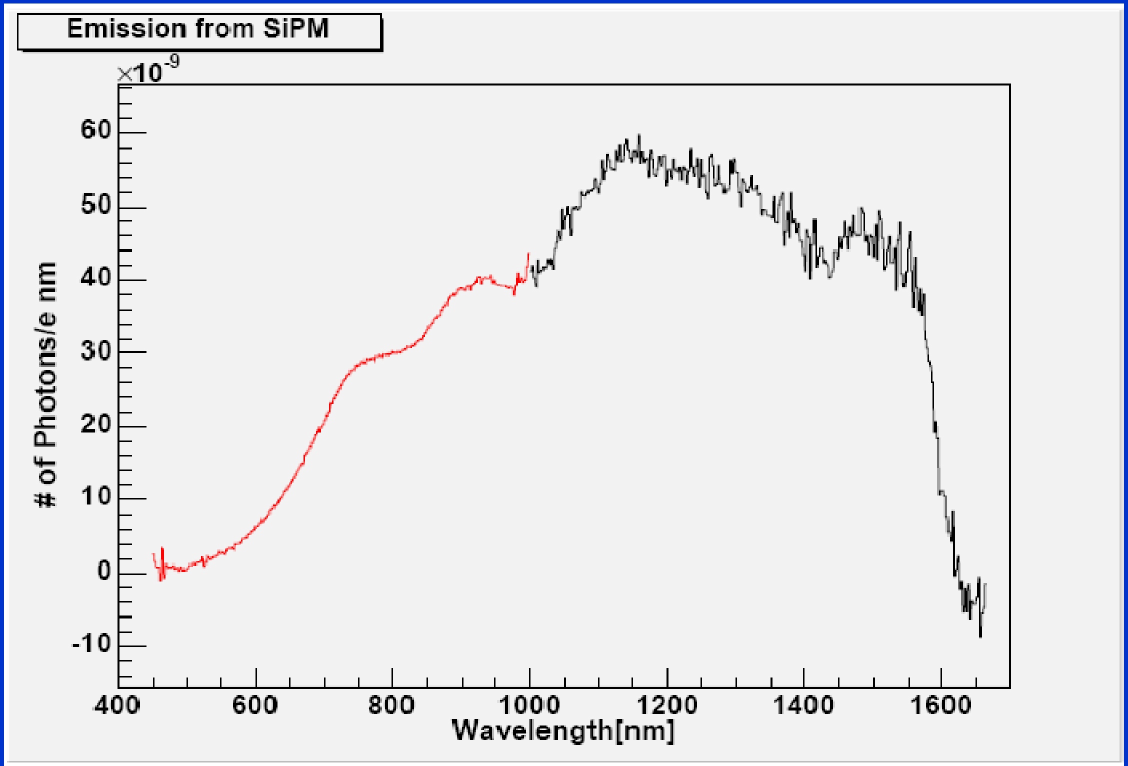
Controlled increase of the light emission in NIR

In order to amplify the light emission the MPPC was illuminated by an ultra-fast semiconductor laser (λ=440nm, τ=80 ps) at 2.5 MHz, producing an average amplitude of 13 ph.e. in the matrix of 100 pixels (the dark rate was about 0.6-0.7 MHz). In this way we achieved an emitted light amplification of ~50 times.
After that the applied voltage of the MPPC was increased putting it into a continuous trigger mode (no quenching) and the emitted light was again measured. By taking the ratio of the two measurements a scaling factor of 36.82 has been measured.
That factor was used to scale down the NIR emission to find out the emission rate at the used gain of 1.56×10^6.

Measured spectrum in infrared



Entire emission spectrum



The largest error is ≤ 19.7 % for the „worst" wavelength range < 600 nm

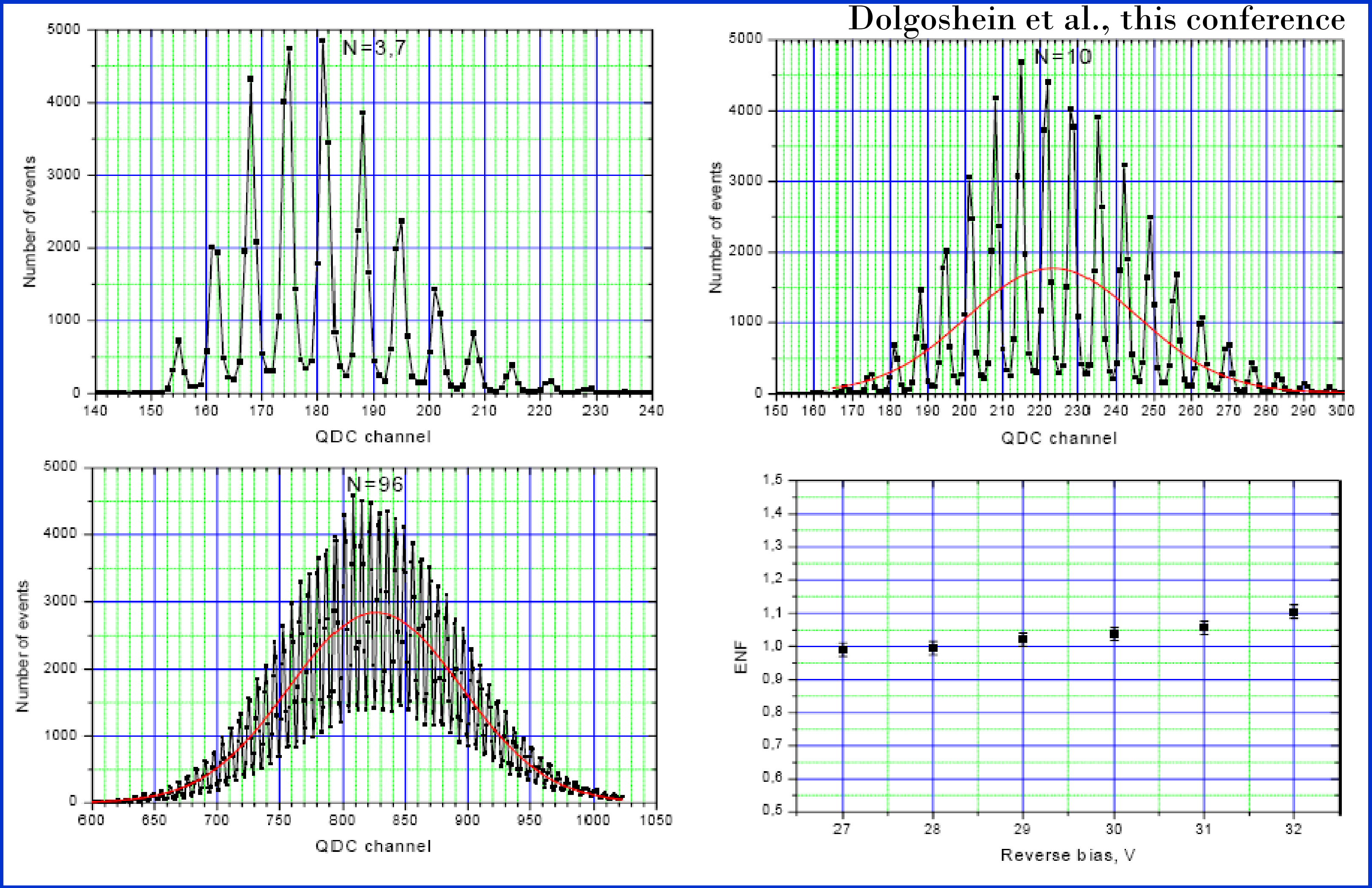
Wavelength range	450 – 1600 nm	< 1117 nm
This measurement	3.86×10^{-5} ph/e	1.69×10^{-5} ph/e
Lacaita, et al., 93		2.9×10^{-5} ph/e

Possible emission mechanisms

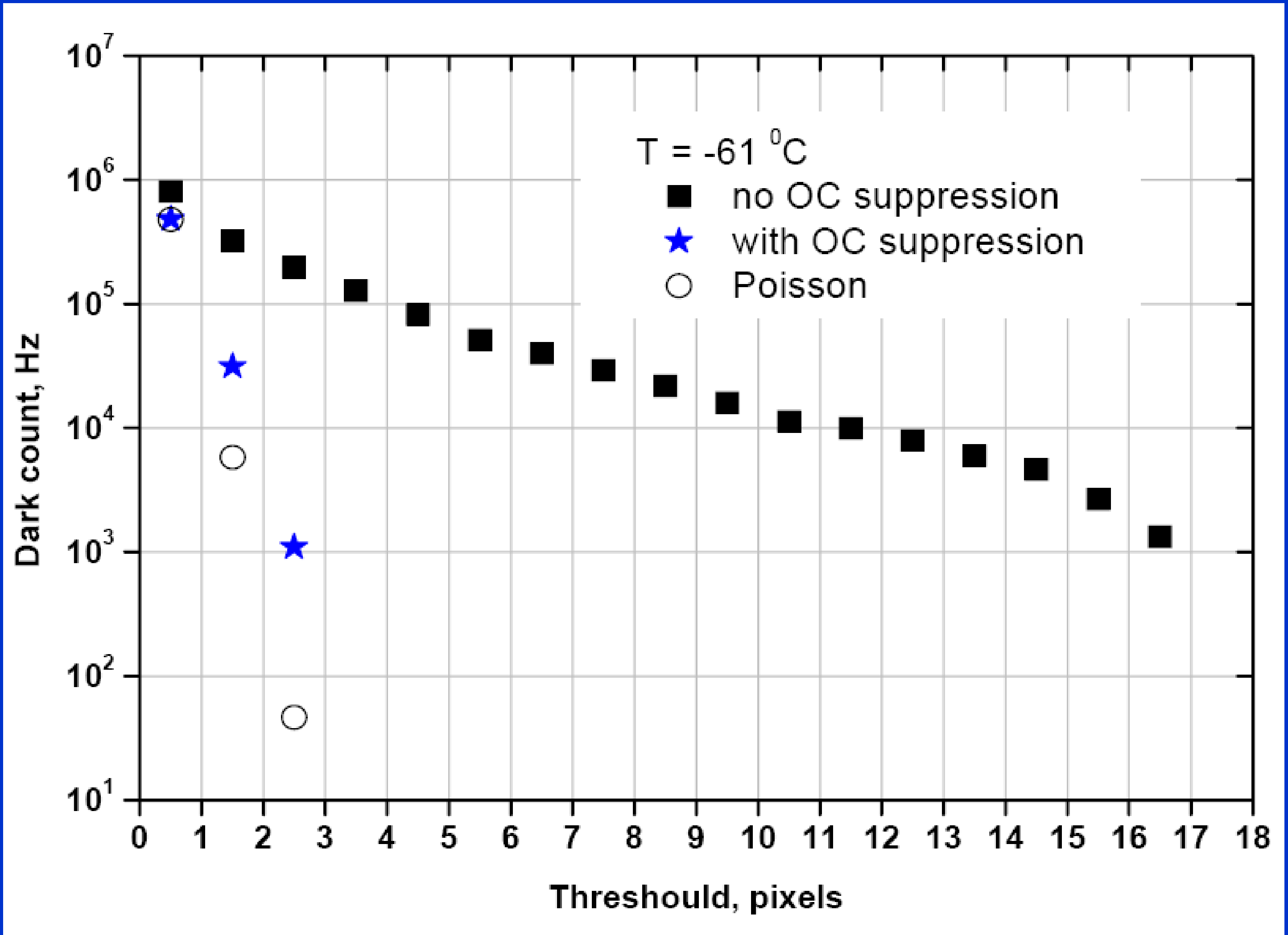
Akil et al., 1999, Villa et al., 1995, Bude et al., 1992, …

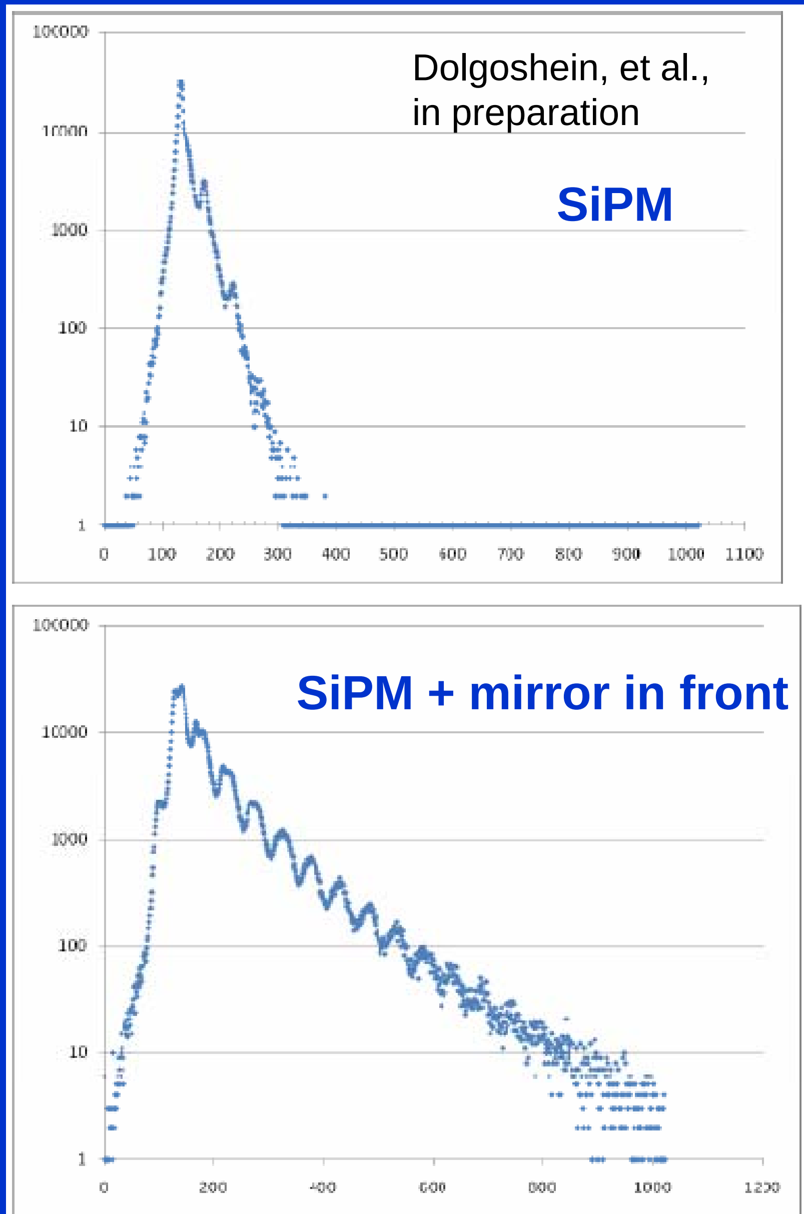
- Interband transitions between hot e- and holes
- Direct intraband e- transitions, Bremsstrahlung radiation from hot e- scattered by charged coulombic centers, and phonon-assisted e- transitions
- Ionization and indirect interband recombination of e- and holes under high-field conditions
- Intraband transitions of hot holes between the light and heavy-mass valence bands

What happens when the cross-talk is much suppressed



Low threshold setting that one can achieve depends on cross-talk level





- A curious experiment: what will happens if one will hold a mirror in front of a SiPM ?
- The emiited light bounces back strongly amplifying the cross-talk effect
- Similarly the amplitude resolution shall degrade when SiPMs are coupled to scintillators (Dolgoshein et al., under preparation)

Conclusions

- In the 1st time we have measured the absolute light emission from an avalanche process in Si in the entire wavelength range 450-1600 nm.
- The measured value in the optical is in agreement with some selected measurements within factor of 2
- This measurement may help researchers in modeling the theory aspects of the light emission in Si avalanches
- This measurement may help researchers to better the design of SiPM matrixes as well as of (SiPM + scintillator) detectors