## Dark Noise

Electron/hole pairs can be generated within the depletion region in a SiPM by thermal generation of carriers through Shockley-Read-Hall (SRH) recombination-generation centres or by bulk diffusion of minority carriers from quasi-neutral region.

The variance of the photocurrent in a bandwidth is:

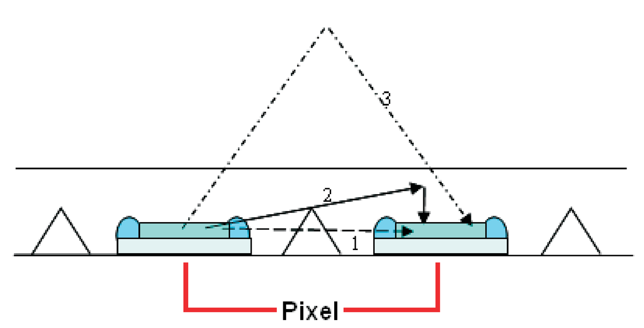
$$\overline{i_v^2} \quad \frac{q}{T} \quad {}^{2}_{N} \quad 2qi$$

where i is the number of carriers created for unit of time, q is the carrier and ${}^{2}_{N}$ is the variance of the Poissonian distribution.

**Other sources of noise**

- Gain noise is specific to avalanche detectors. All avalanche photodiode generate excess noise due to the statistical nature of the avalanche process. Gain noise is specific to avalanche detectors.

- Cross-talk due to the migration of photons towards neighbouring pixels. Hot carriers in avalanche p-n junction can emit photons even in the visible range, which hence fall in the detection range of other pixels.




**3 different ways of SiPM cross-talk:**

1 - Direct cross-talk
2 - Inside the depletion layer
3 - Through reflexion

- Afterpulsing caused by trapping centres in the depletion layer.

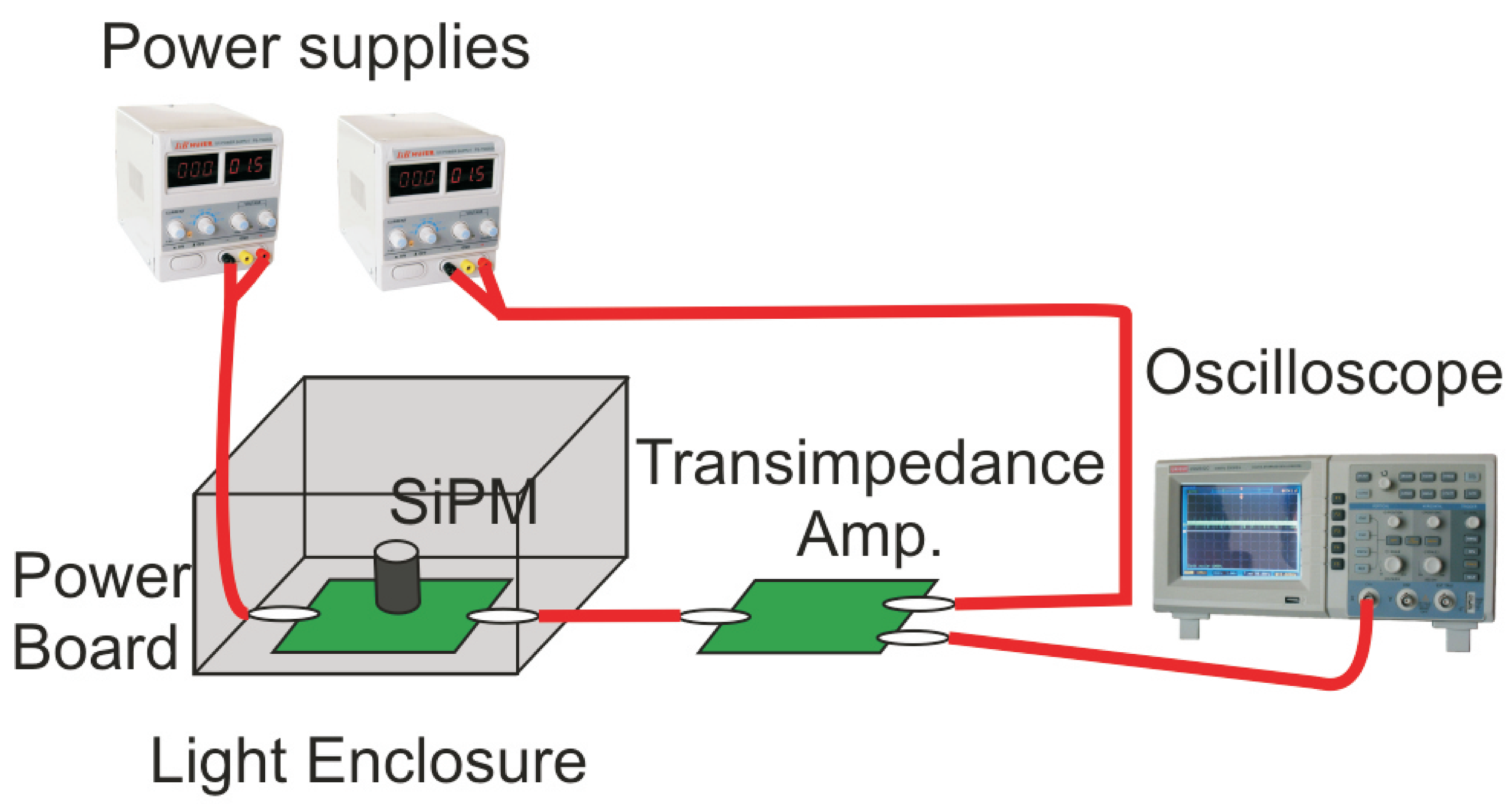
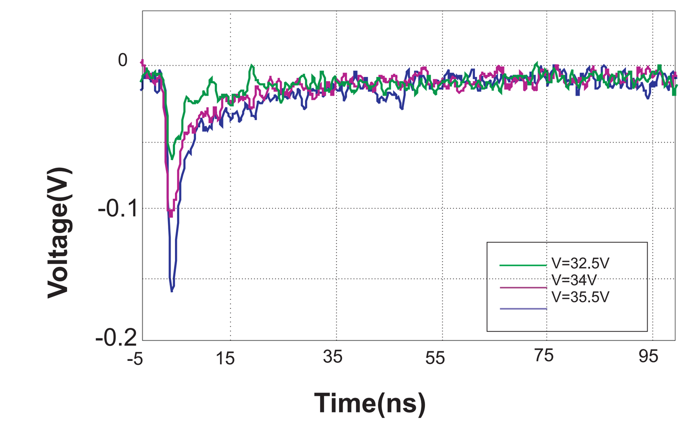


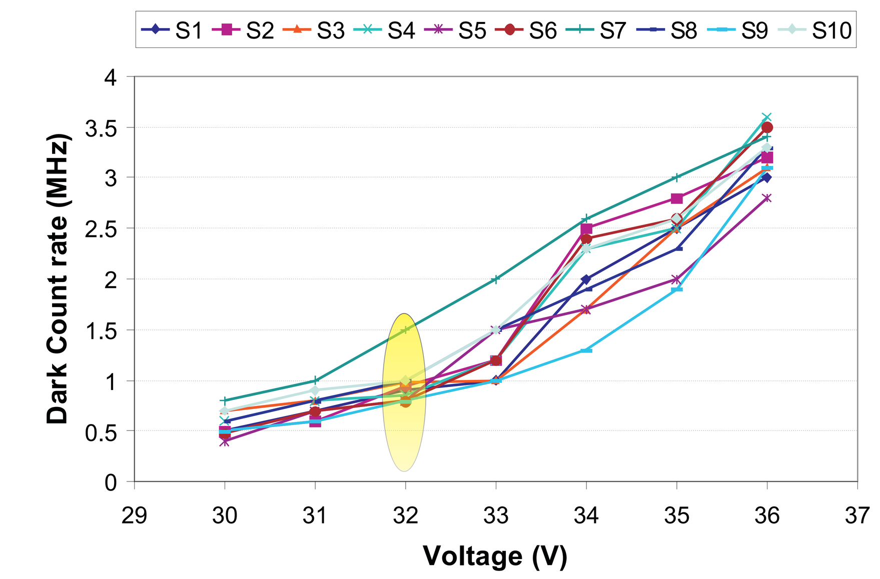

Illustration of the experimental setup used to characterize the SiPM dark noise.

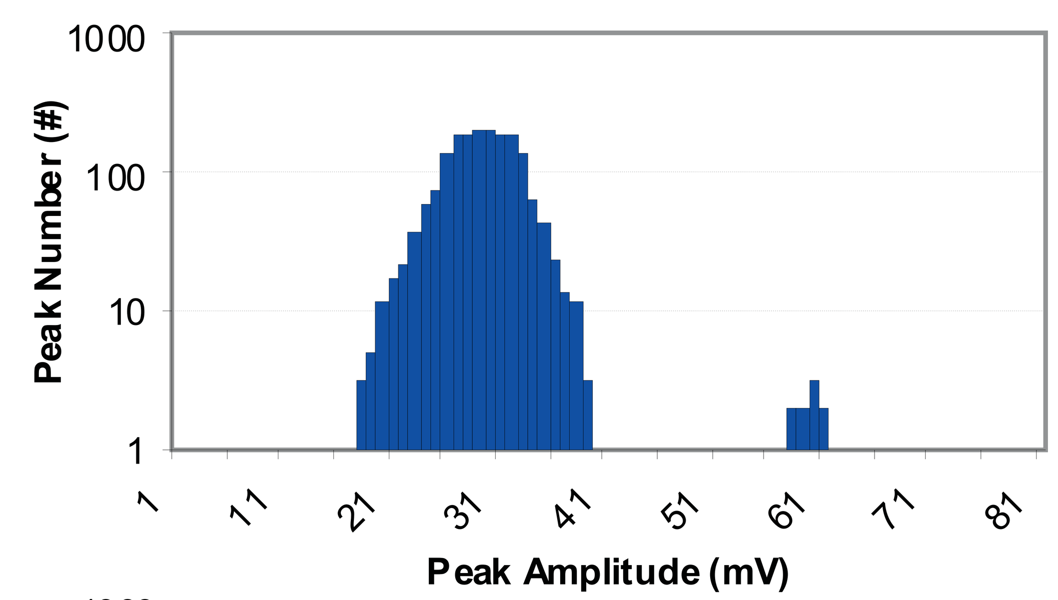
## Experimental results

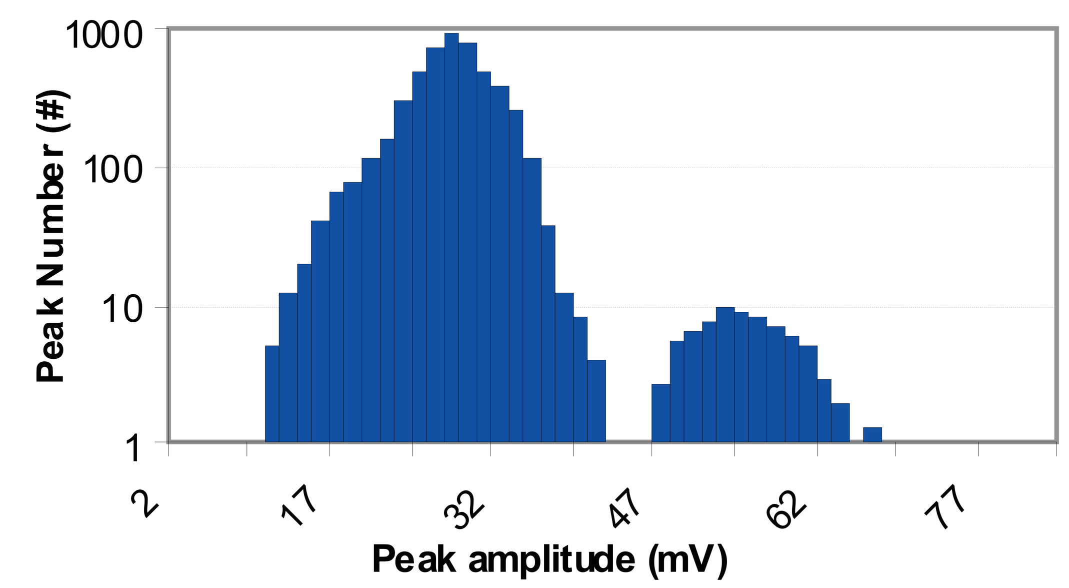
- Behaviour of the dark noise signal as a function of the bias voltage for a selection of our samples: increasing the bias voltage the peak height of the dark noise increases mainly because it is primarily due to thermal generation of electron/hole pairs in the depletion region and secondly to the thermal bulk diffusion of electrons in the depletion region.

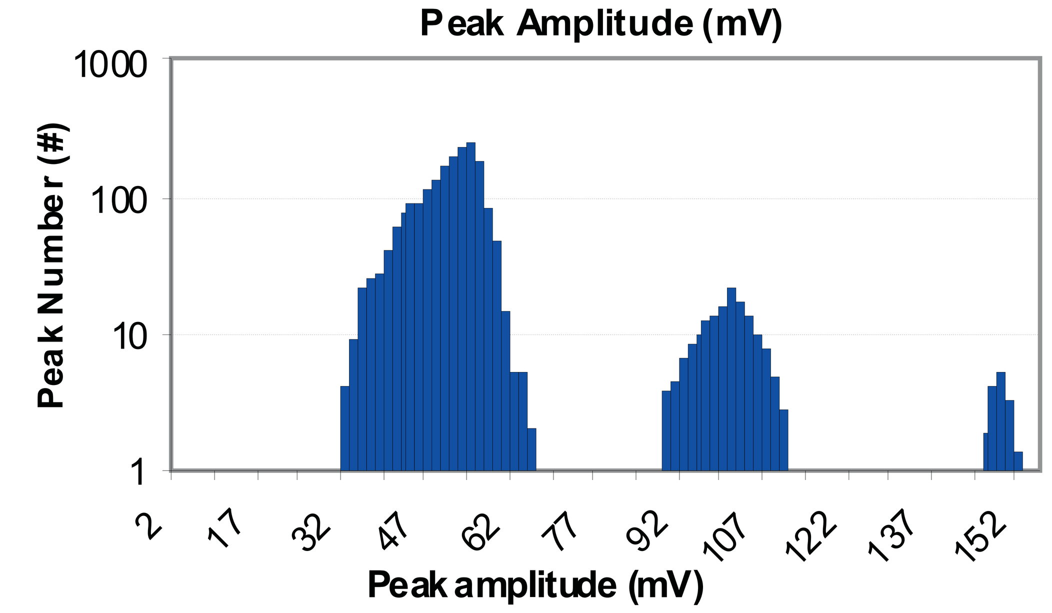



- Dark count rate for different samples of SiPMs with a breakdown voltage of about 29.5 V. A typical value of dark count rate for these devices is 1 MHz/mm$^2$ corresponding to the bias voltage of 32V.




- Three noise spectra of three different SiPMs. They correspond to the same overvoltage of about 3V.
  The analysis of the noise spectra give us information about the optical crosstalk.

## Conclusions and Outlook

Experimental tests on several commercial and pre-release samples yielded a typical dark count rate of about 1 MHz/mm$^2$ for a bias voltage of about 2V above the breakdown value for essentially all samples. Increasing the bias voltage was shown to proportionally increase the signal peak height and overall dark count rate by similar factors of about 3 for a 3V increase, while showing a slighter effect on increasing the cross-talk by a factor of 1.7 for the same voltage increase.
The influence of manufacturing techniques on the cross-talk was instead found to be severe, with spectra from different samples showing a difference in cross-talk occurrence by almost an order of magnitude.
Further tests and data acquisition are currently been carried out to improve the characterization of these devices and to select the best commercially available sample for a future beam loss monitor at CTF3/CLIC.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