Effect of SiPM correlated noise and Photo-Detection Efficiency into Imaging Atmospheric Cherenkov Telescope

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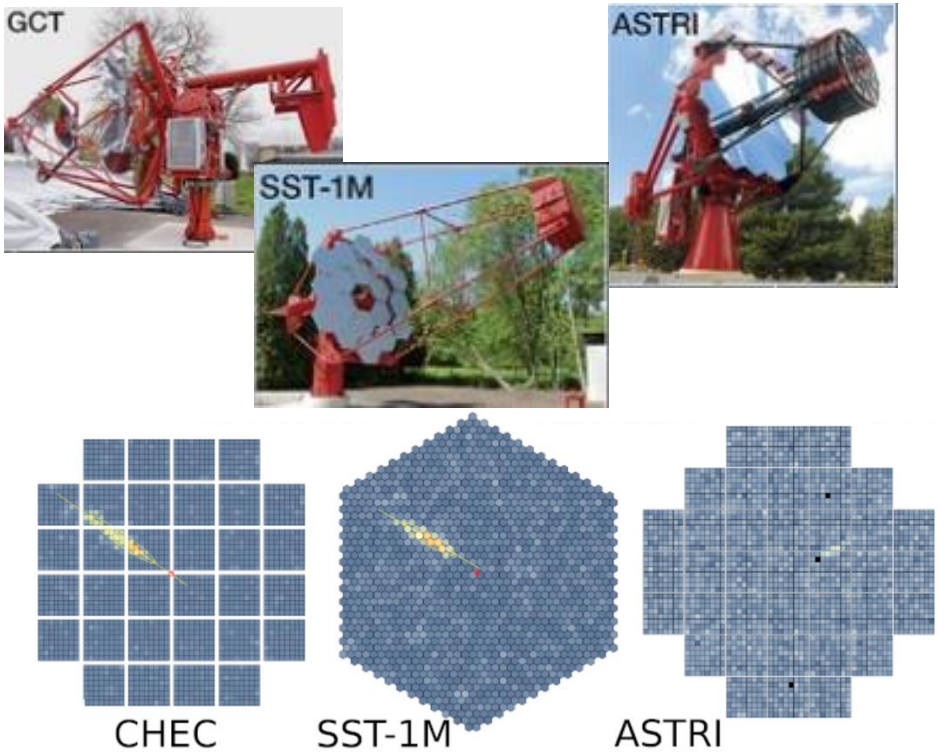
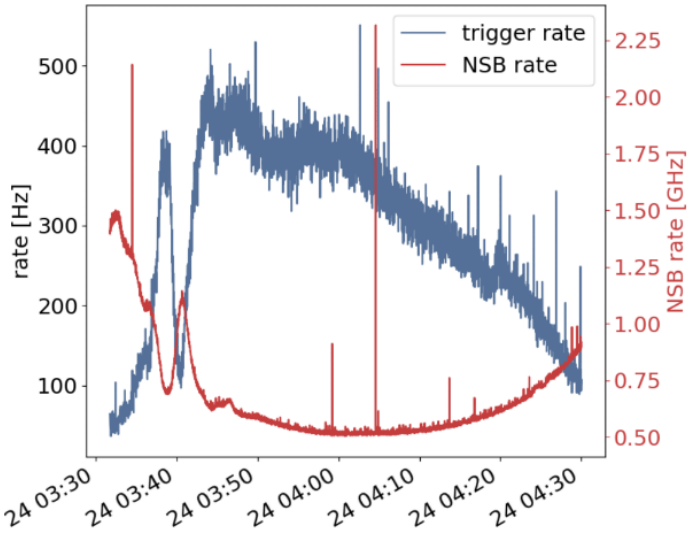
Introduction: SiPM devices for Imaging Atmospheric Cherenkov Telescope



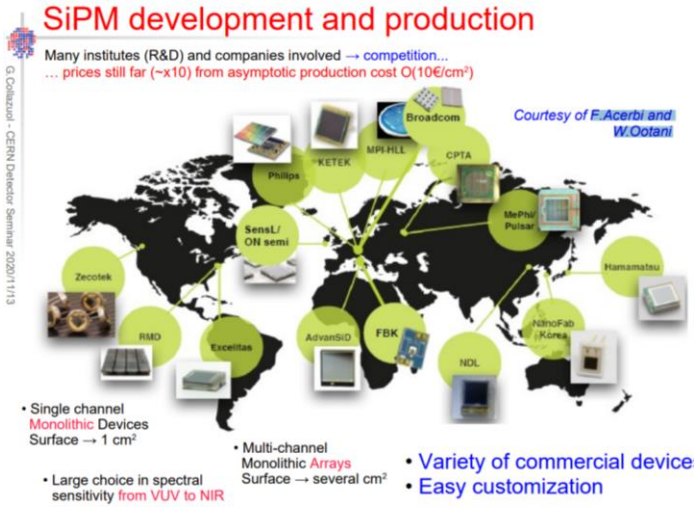
Rate of NSB in Krakow
(including clouds and airplanes...)



SiPM → robust against light →
→longer exposure to gamma-ray sources

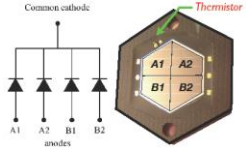
Introduction: SiPM Overvoltage and affects almost all relevant par

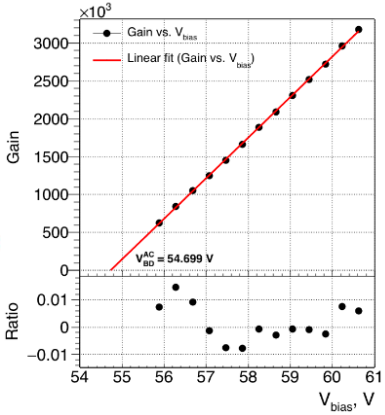
Zoo of SiPM devices:

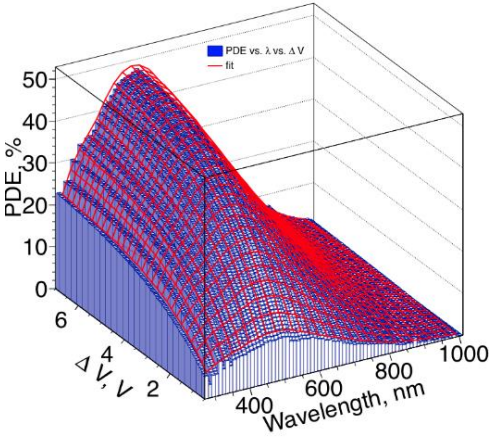


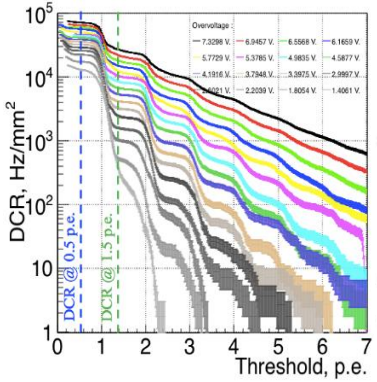
$\Delta V = V_{bais} - V_{BD}$ → drives the performance

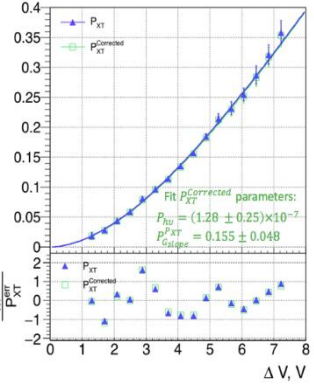
(& temperature)

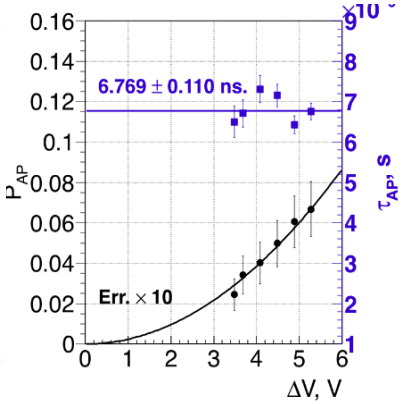




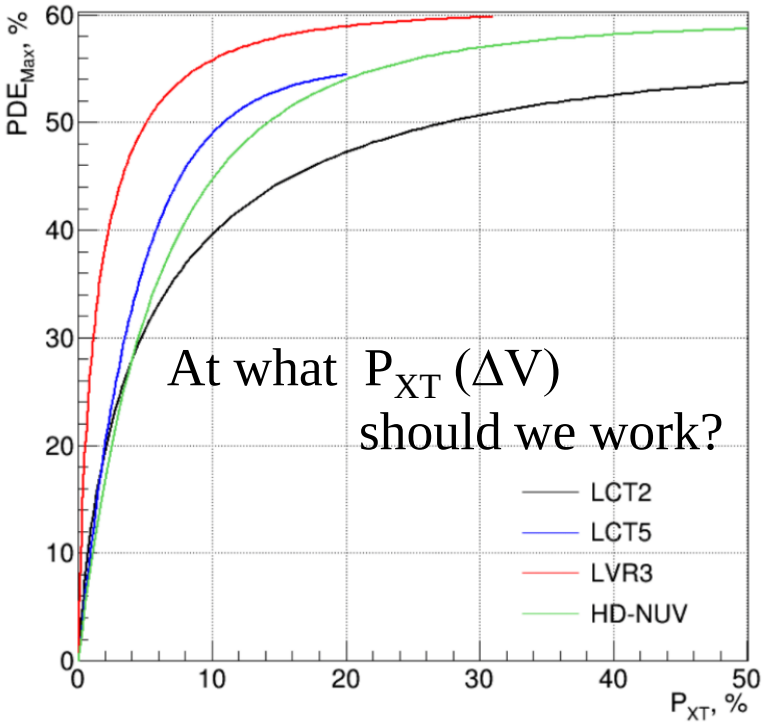




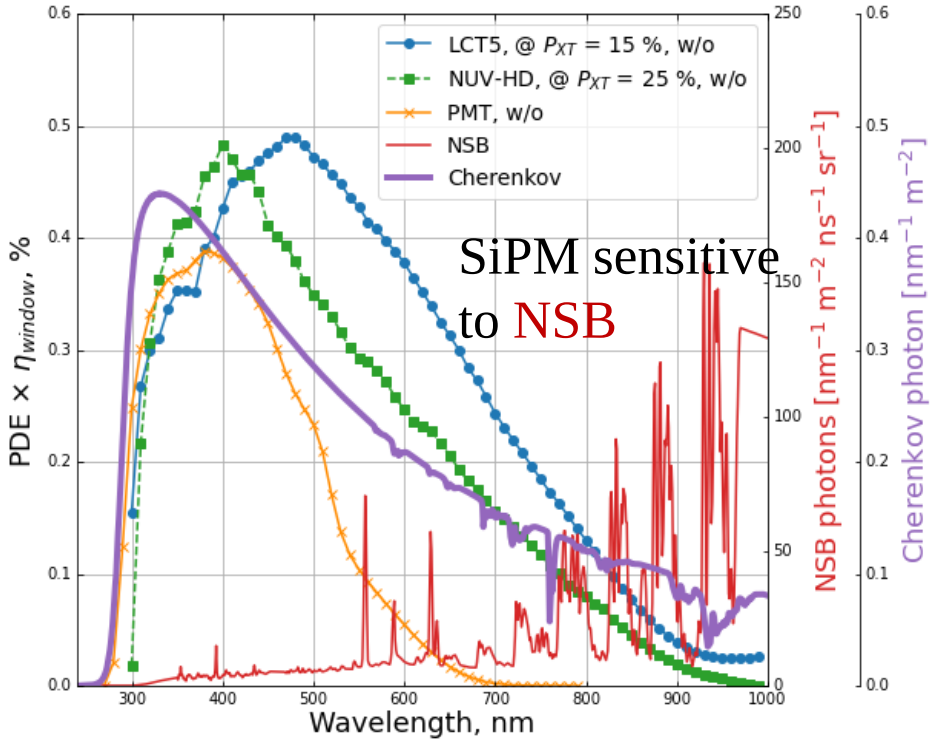




Introduction: Goal of this study



η_{window} – *camera entrance window transmissivity*



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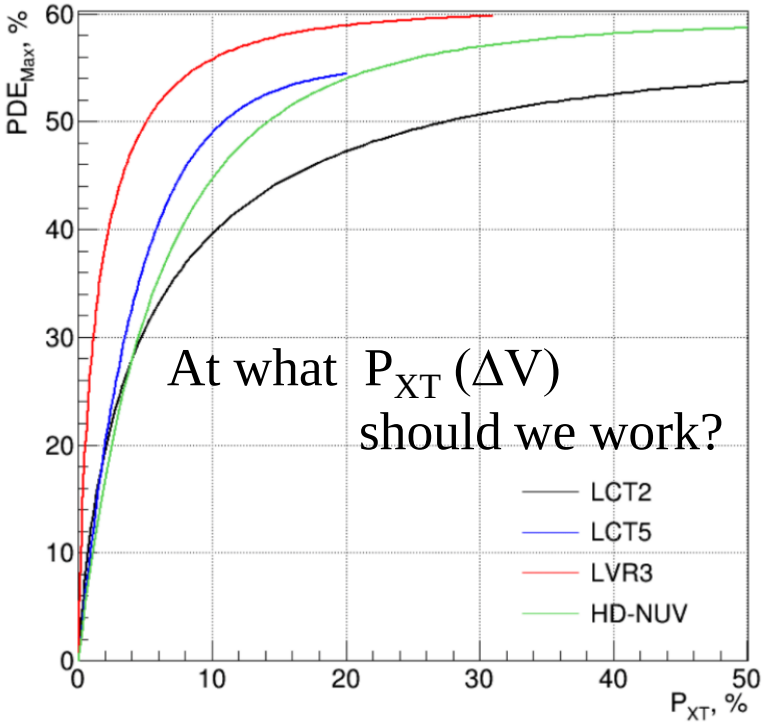

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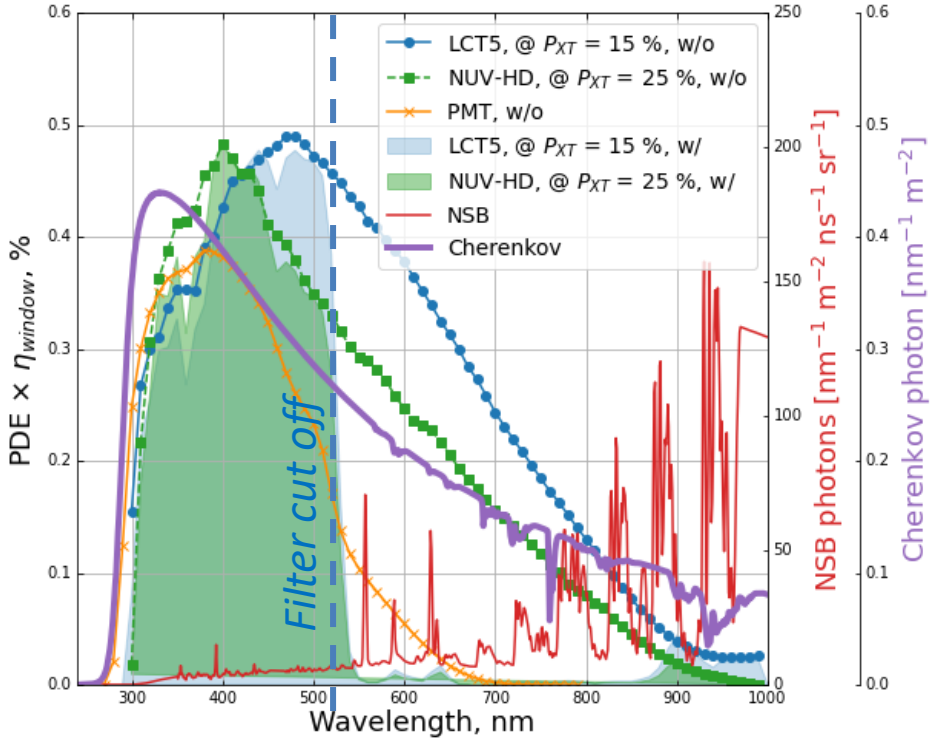
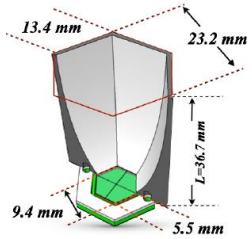
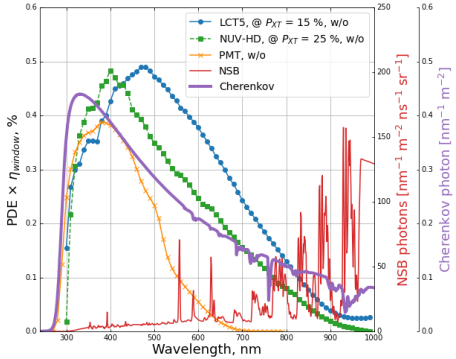


Is filter needed?

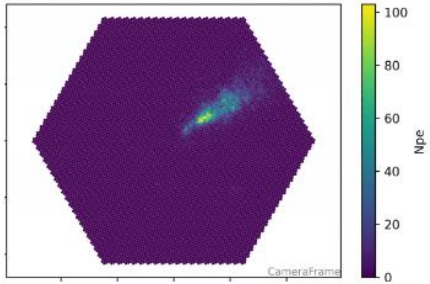
Sim_telarray simulation:

- SiPM based LST camera with 7987 pixels[1] :
  - based on SST-1M [2] hexagonal pixels with light cones;
  - Hamamatsu S13360 LCT5 device with 50 × 50 um^2
  - FBK NUV-HD with 40 × 40 um^2
- Pulse template from the nominal LST configuration;
- Entrance windows:
  - LST standard without filter (w/o)
  - SST-1M with (w/)
- Light Emission package (flasher) was used;
- Cherenkov spectrum → light wavelength
- 10k events per light intensity

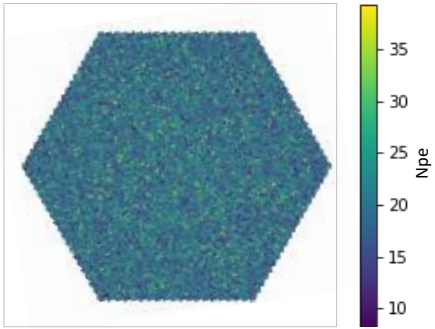




Gamma event



Flasher event



[1] see M. Heller "Development of an advanced SiPM camera for the Large Size Telescope of the Cherenkov Telescope Array Observatory"
[2] Heller M., et al., 2017, The European Physical Journal C, 77, 47

Sim_telarray simulation:

15 configurations were studied:

- 8 w/o filter:
  - 4 for LCT5 @ P_{XT} = 5, 8, 15, 25 %
  - 3 for NUV-HD @ P_{XT} = 8, 15, 25 %
  - 1 for PMT
- 7 w/ filter:
  - 4 for LCT5 @ P_{XT} = 5, 8, 15, 25 %
  - 3 for NUV-HD @ P_{XT} = 8, 15, 25 %
- NSB calculated for Dark Night

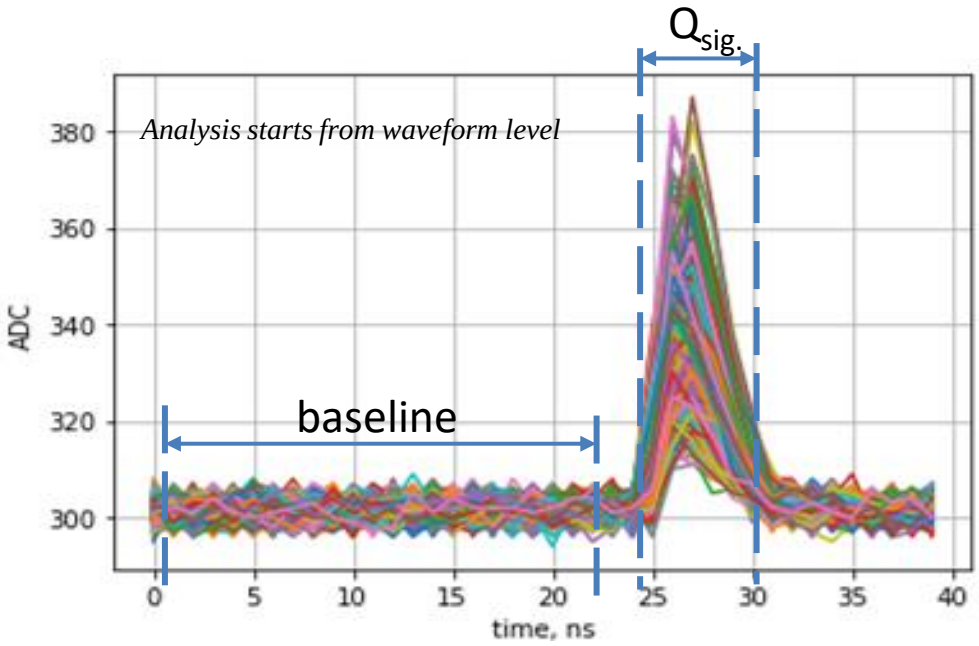
Cumulative efficiency: λ = 300 ÷ 1000 nm.

Includes:

- PDE vs. λ;
- Filter transmissivity vs. λ;
- Fill-factor of 91.94%;
- Funnel transmissivity of 88.55%;
- Spectrum weighted average reflectivity of 92.94%;

Photo detector	Window	Parameter		P_{XT} 5 [%]	8 [%]	15 [%]	25 [%]
LCT5		PDE_{Max} [%]		35	47	53	54
	without filter	NSB [MHz/pixel]		261.33	386	424	437.7
		cum. efficiency	NSB [%]	4.83	6.83	8.57	8.85
			Cherenkov [%]	16.87	21.61	24.98	25.76
	with filter	NSB [MHz/pixel]		73.4	107.6	109	110.3
		cum. efficiency	NSB [%]	1.35	2.1	2.69	2.76
			Cherenkov [%]	11.24	14.15	16.1	16.53
NUV – HD		PDE_{Max} [%]			40	49	52
	without filter	NSB [MHz/pixel]			160.4	224	271.4
		cum. efficiency	NSB [%]		3.2	4.55	5.53
			Cherenkov [%]		14.7	18.99	21.64
	with filter	NSB [MHz/pixel]			65.1	83.8	94.7
		cum. efficiency	NSB [%]		1.17	1.57	1.8
			Cherenkov [%]		11.03	13.9	15.46
PMT		PDE_{Max} [%]		43			
	without filter	NSB [MHz/pixel]		245.8			
		cum. efficiency	NSB [%]	1.61			
			Cherenkov [%]	14.67			

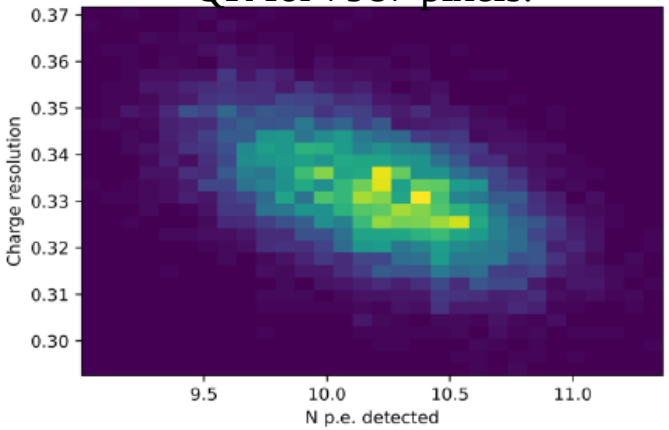
Charge resolution calculation:



$$N_{p.e.} = \frac{Q_{sig.}}{Q_{p.e.}} \times \left(1 - \frac{P_{XT}}{1 - P_{XT}}\right)$$

$$QR = \frac{\sigma_{p.e.}}{N_{p.e.}} = \frac{\sqrt{\frac{\sum_{n=0}^{N_{events}} \left(N_i - \langle N_{p.e.} \rangle\right)^2}{N_{events}}}}{N_{p.e.}}$$

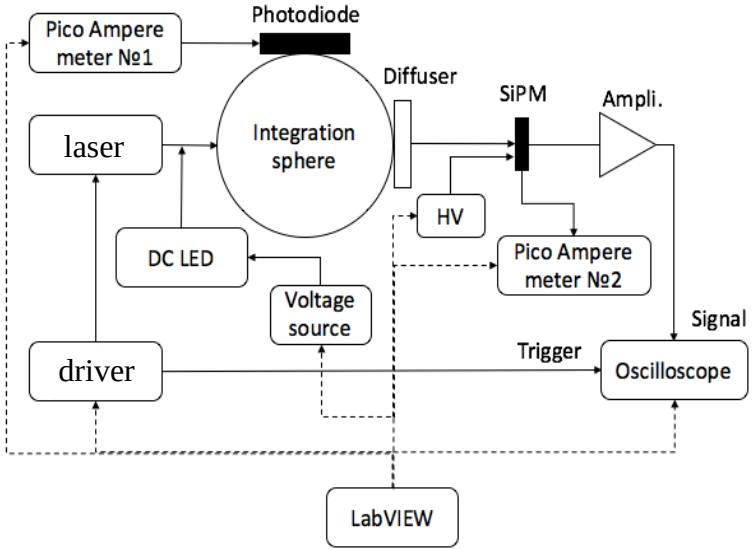
QR for 7987 pixels:

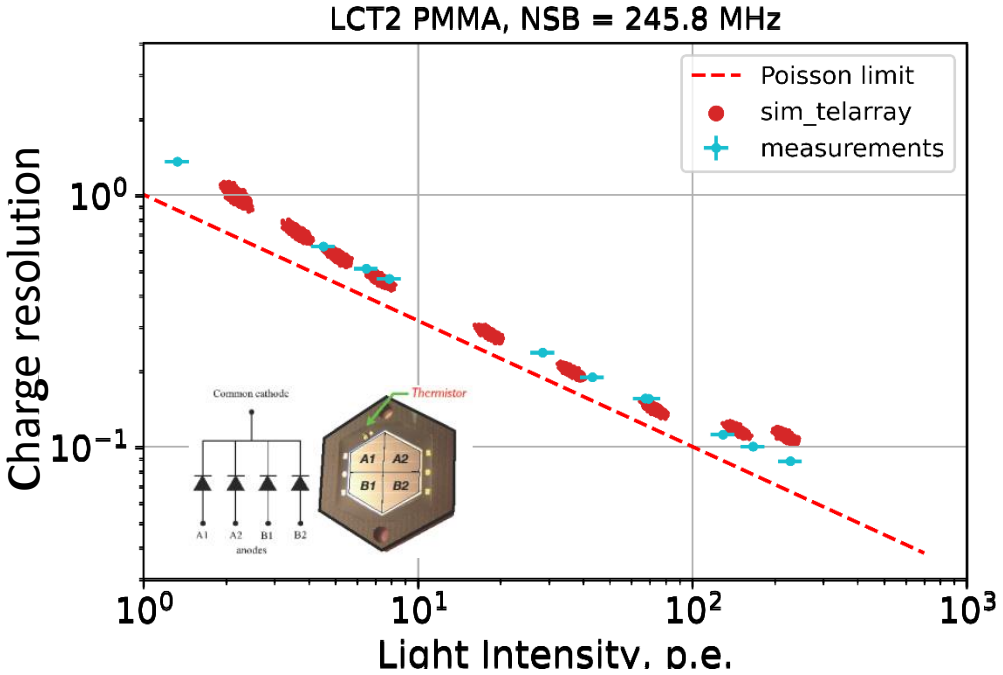


$$N_\gamma = \frac{N_{p.e.}}{\varepsilon_{eff}} \qquad \epsilon_{eff} = Cum.Cherenkov\ efficency$$

Sim_telarray simulation validation

Experimental set-up:



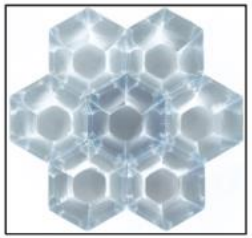


LCT2 device @ P_{XT} = 25% and NSB = 245.8 MHz

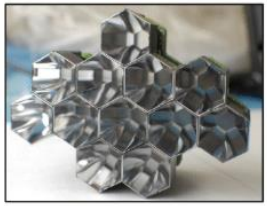
Good agreement between experimental results and simulation was found

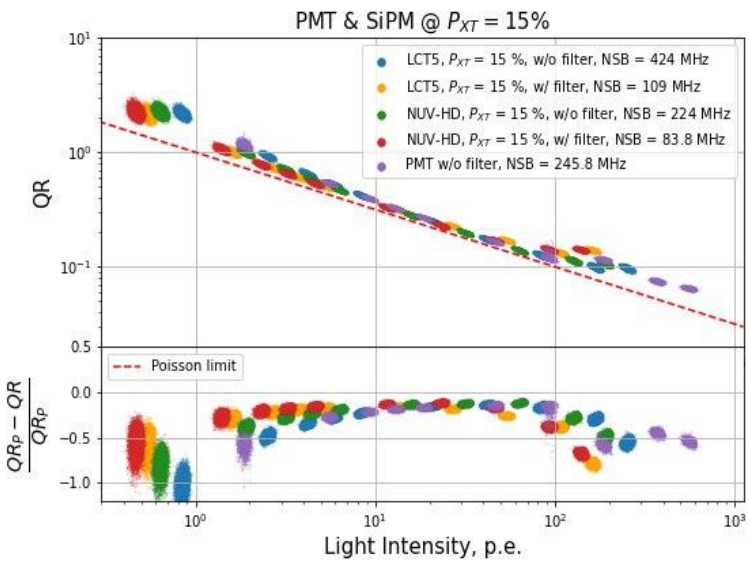
Results: light intensity/mm^2

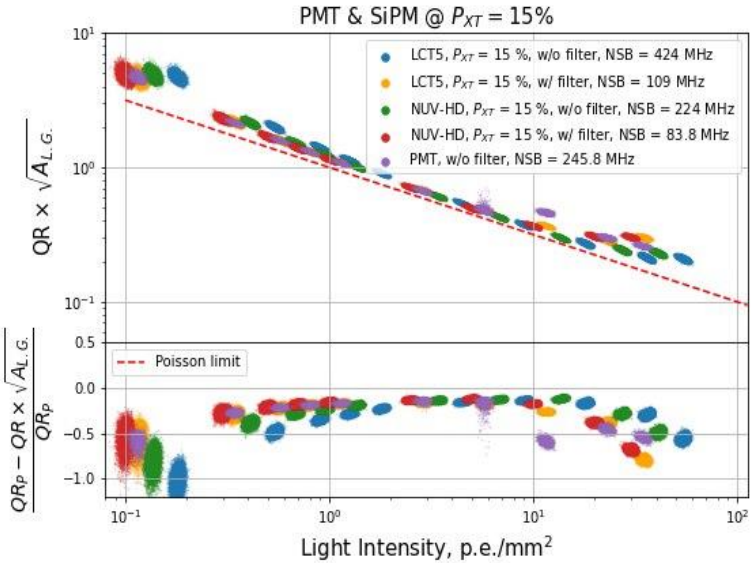
PMT:



SiPM:



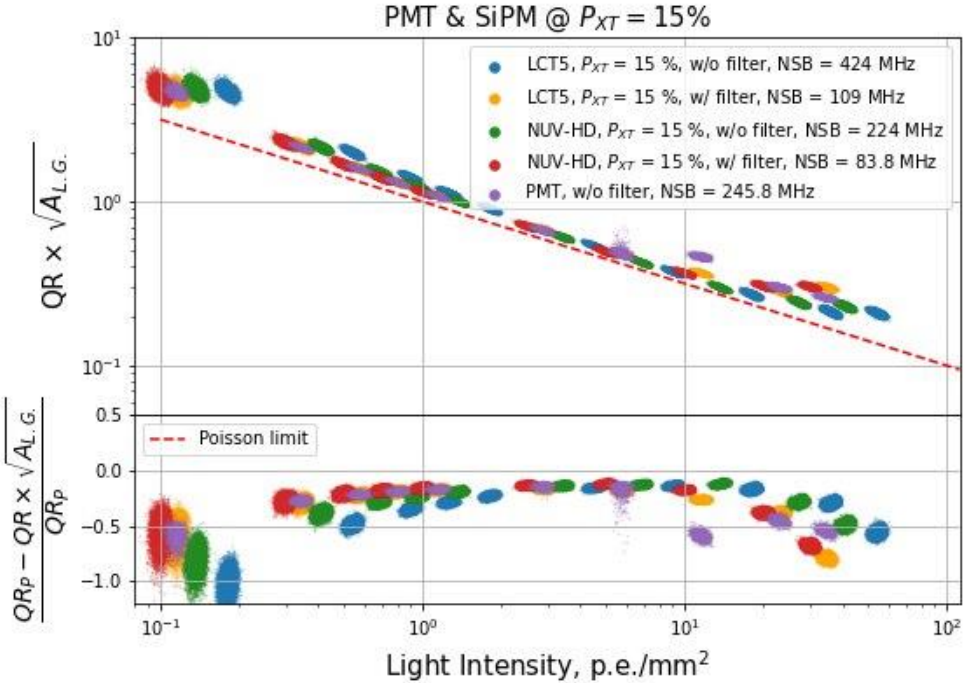




$A_{L.G.}$ – Light Guide active area:

- SiPM = 4.67 cm^2,
- PMT = 16.24 cm^2

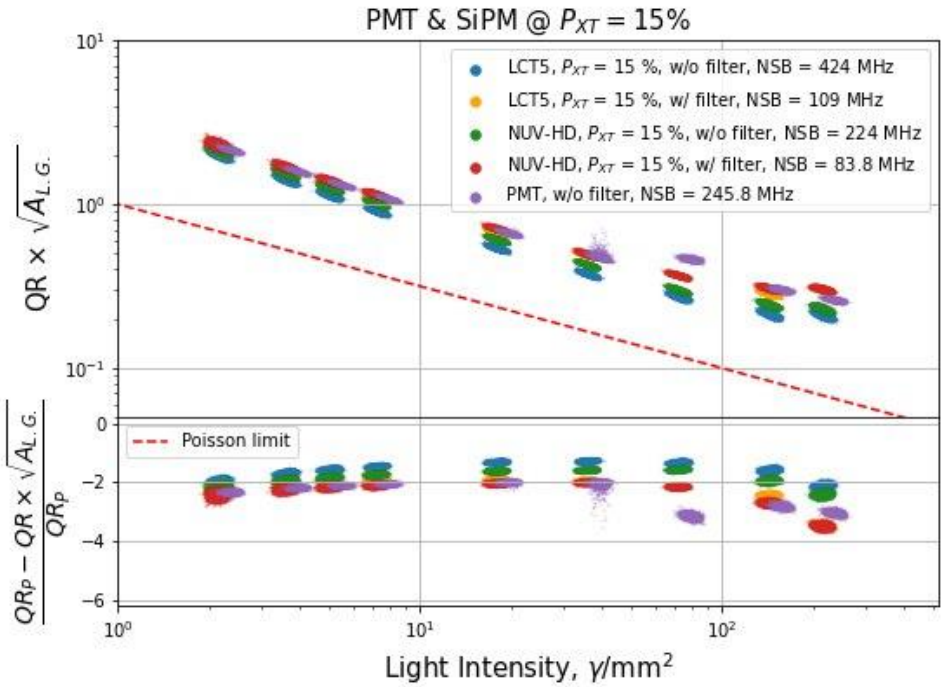
Results: QR vs. p.e./mm^2



Independent of SiPM device and P_{xt} filter:

- Improves QR p.e. < 10 (1p.e./mm^2), due to NSB reduction;
- Degrades the QR p.e. > 100 (10p.e./mm^2), due to decrease of Cherenkov efficiency
- PMT close to SiPM w/

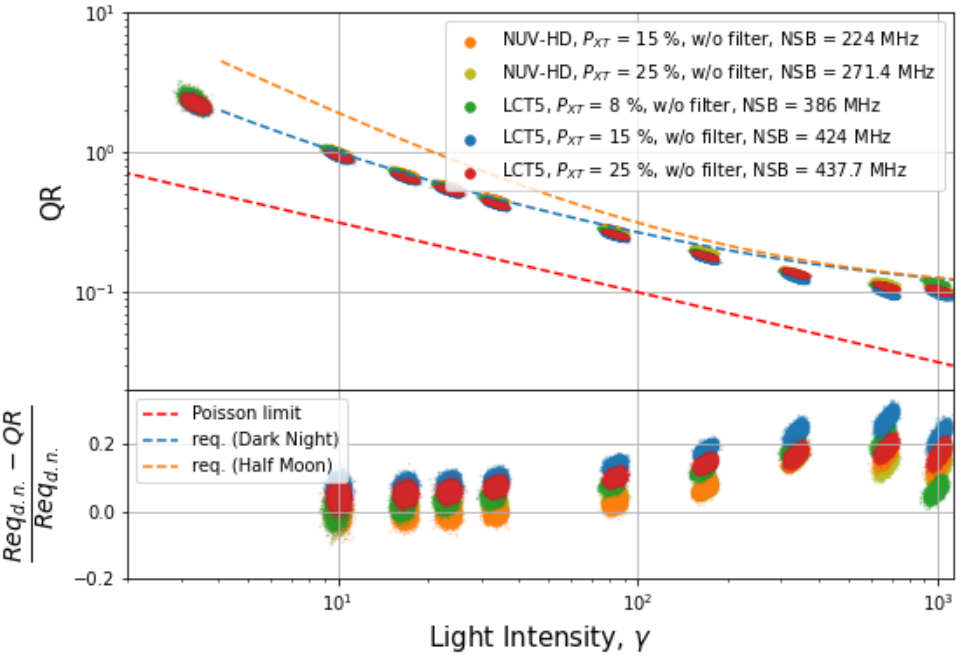
Results: QR vs. ɣ/mm^2



Independent of SiPM device and P_{xt}:

- PMTs are close to SiPM w/ filter due to similar Cum. Cherenkov Efficiency
- Filter is not important below 10 ɣ → electronics noise is dominated in this region;
- High Cherenkov Cum. Efficiency is preferable than Low NSB Cum. Efficiency

Conclusions:



- 5 configurations (over 15 tested) full-fill CTA requirements:
  - LCT5 @ $P_{XT} \geq 8\%$
  - NUV-HD @ $P_{XT} \geq 15\%$
- The best QR → LCT5 device @ P_{XT} =15%
- High Cherenkov Cum. Efficiency is preferable than Low NSB Cum. Efficiency
- Filter is not needed