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Measurement of the Response of Silicon Photomultipliers from Single Photon Detection to Saturation



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Results: SiPM Response Curves with Models Applied



General Considerations and Description of Models:

• Ideal function $N_{fired}(N_{seed})$: few parameters, coverage of full dynamic range, easy to apply in calibration (e.g. invertible)

- Dark counts (shift of QDC pedestal) and afterpulses (added to systematics) negligible
- Model 0 (no par., N_{total} fixed): $N_{fired}(N_{seed}) = N_{total} \cdot \left(1 exp\left(-\frac{N_{seed}}{N_{total}}\right)\right)$
- Model 1: same function as Model 0 with N_{total} as fit parameter
- Model 2 (two par., incl. crosstalk, [3]): $N_{fired}(N_{seed}) = N_{total} \cdot \frac{1-X}{1-\epsilon_c \cdot X}$ with $X = exp\left(-\frac{N_{seed}}{N_{total}}\right)$
- Model 3 (six par., α and β related to recovery time/pulse width, [4]): only $\alpha_{r} \beta_{r} \epsilon_{c}$ used in fits here

Comparison of Sensors:

- Combined data: curves **normalized** (to respective N_{total})
- 100/400-pixel SiPM with high crosstalk exhibit over-saturation
- Over-saturation difficult to explain (possible influence of pixel recovery time, "delayed crosstalk"?)
- Non-saturating SiPM with trenches easiest to model



Application in High-Granularity Calorimeters

Conclusions and References

Analog Hadronic Calorimeter of ILD@ILC by CALICE Coll. [5]: $(\rightarrow$ similar concept foreseen for CMS calorimeter upgrade, HGCAL)

- Operation in B-field, up to 8 million SiPM on integrated frontend boards (sandwich calorimeter structure with separation by steel or metal layers, 30 mm x 30 mm x 3 mm wrapped scintillator tiles)
- Dynamic range of 0.5 MIP to several hundred MIP (~15 p.e. per MIP if non-saturating)



• Improved jet energy resolution Reconstruct each particle and

PRISMA Detector Lab Contribution to Technological Prototype: (> 20k ch.)

- Automatic assembly of scintillator tiles for > 150 frontend boards
- Calibration with cosmic-ray muons



- Experimental setup covers full dynamic range of SiPM \rightarrow single p.e. to saturation
- SiPM with low crosstalk and many pixels best suitable for calorimeter applications → simple parametrization, large range
- If over-saturation occurs the simple models fail \rightarrow advanced model needed [4]

[1] L. Gruber, et al., Nucl. Instrum. Meth. A 737 (2014) 11-18 [2] E. J. Schioppa, arXiv:1710.11410v1 [physics.ins-det] (2017) [3] P. Eckart, et al., J. Instrum. 7 (2012) P08011 [4] K. Kotera, et al., arXiv:1510.01102v4 [physics.ins-det] (2016) [5] T. Behnke, et al., arXiv:1306.6329v1 [physics.ins-det] (2013)

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