Monte Carlo Analysis of Normally-Distributed Optical Crosstalk

J O D Williams, S R Rosen, J S Lapington

Department of Physics and Astronomy, University of Leicester, University Road, Leicester, UK

Introduction

- Silicon Photomultipliers (SiPMs) are compact, solid state, optical photon-counting photodetectors [1]
- SiPMs have a wide range of applications, including on the CHEC camera for the Cherenkov Telescope Array [2]
- Optical crosstalk (OCT), where photons emitted by triggered microcells can trigger others, is a crucial parameter that affects SiPMs
- OCT can be modelled analytically by Borel [3][4] and near-neighbour (Gallego) models [4]
- Normally-Distributed Crosstalk Model (NDCM) proposed, and simulated via Monte Carlo (MC) simulations

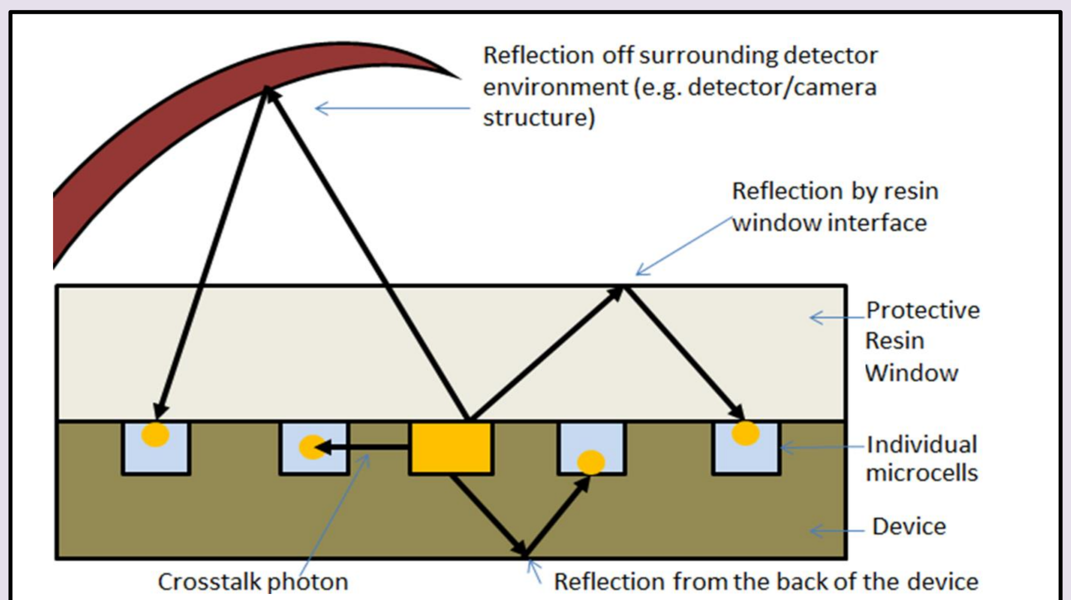
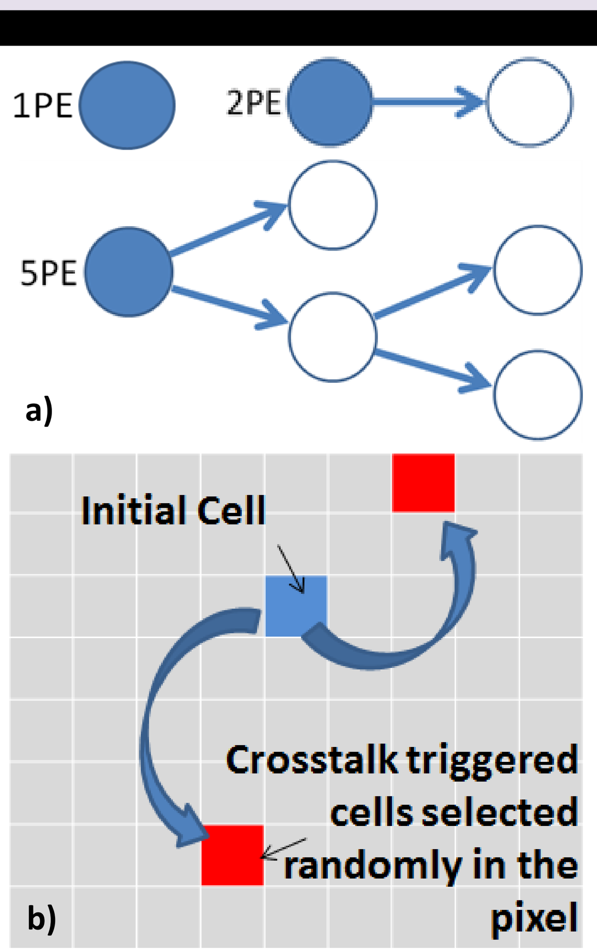


Fig. 1. Mechanisms for crosstalk in a SiPM such as reflection off surroundings and diffusion

Silicon Photomultipliers (SiPM) & Optical Crosstalk (OCT)

- SiPMs biased above breakdown produces a measurable photoresponse from a single photon striking a single microcell
- Photodetection generates Geiger breakdown via impact ionisation
  - 3 photons generated per 10^5 avalanche electrons
    - These photons can trigger other cells (fig.1) → crosstalk
    - OCT probability λ gives likelihood that more cells trigger
  - λ related to overvoltage, and architectural parameters e.g. microcell size, window thickness [6]
  - Number of triggered microcells characterised in terms of PE



Borel Model

- One event can trigger 1+ secondary events (fig. 2a), depending on λ [3]
- Equivalent to triggering 1+ microcells on a SiPM
- No spatial distribution → trigger anywhere on the pixel (fig. 2b)
- Can show good fit to experimental data [4]

Fig. 2. a) routes in which one triggered cell could lead to 1PE, 2PE + 5PE . b) Borel model, where secondary microcells trigger anywhere on the pixel.

Near Neighbour (Gallego) Model

- Near-neighbour (Gallego) models crosstalk by considering the triggering of the nearest microcells (fig. 3) [5]
- Spatially distributed, analytical model
- Constrains available microcells available to be triggered
- Has previously demonstrated better agreement with experimental c.f. the Borel model.

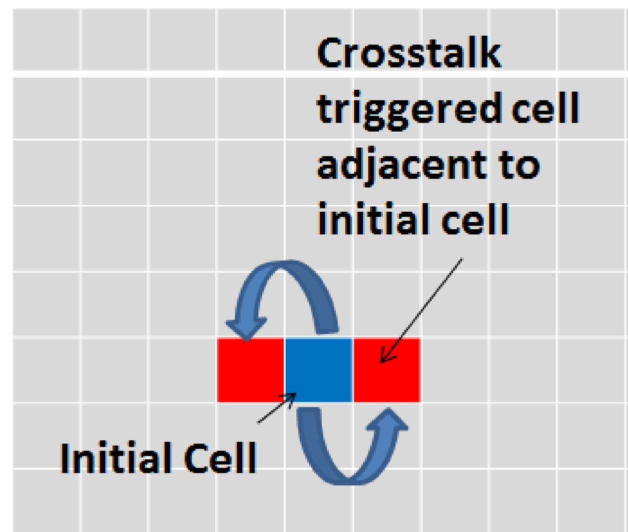


Fig. 3. Near-neighbour (Gallego) model, where microcells are triggered adjacent to the initial cell

Normally-Distributed Crosstalk Model (NDCM)

- Photon triggers a microcell
- Triggering of further microcells due to OCT weighted by 2-d normal distribution centred on triggered microcell, distribution width given by standard deviation σ (fig. 4)
- At small σ, NDCM predicts PE probability greater than Borel (for PE=1) and less than Borel (for PE>3) (fig. 5a)
- For $\sigma \approx 3$ microcells, distribution width means the PE probabilities approximately equal those from Borel
- For large σ, increasing probability that secondary microcells are triggered outside of the pixel
  - Lower probability of triggering a microcell within the pixel
  - PE=1 probability increases, PE>2 decreases

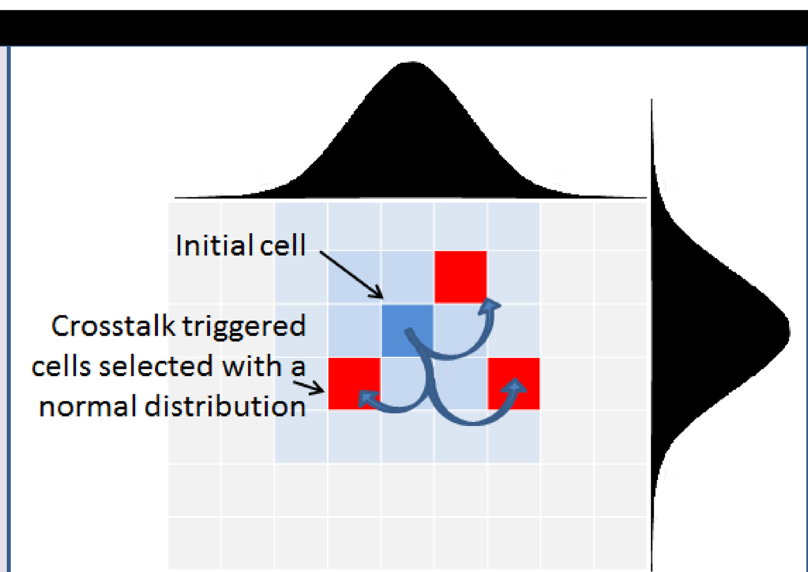


Fig. 4. NDCM on a SiPM pixel

- NDCM fitted against experimental data from CHEC-S camera [7]
  - CHEC-S silicon $\lambda \approx 0.5$
  - Data fit better by Borel model than Near Neighbour model (fig. 5b)
  - NDCM fits better for a wider normal distribution, σ≈5, over a large pixel size → consequence of high λ
- What is σ? Optical Path Length related to how far a crosstalk photon can propagate given architectural parameters
- Crosstalk related to the number of available microcells, operational and architectural parameters → therefore related to σ as well

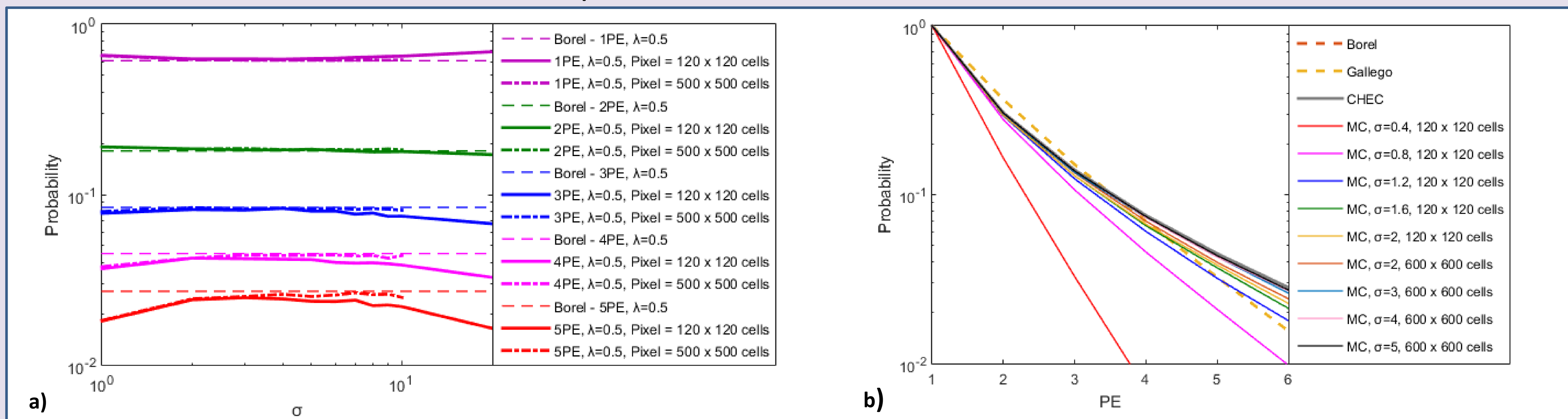


Fig. 5. a) PE probability as a function of σ, lower for higher PE as number of available cells is constrained. b) the CHEC-S data is approximated best for NDCM σ=5

Summary

- Normally-distributed crosstalk model (NDCM) with a standard deviation σ, can fit experimental data better than other models
- σ is a device-specific distance parameter, on the scale of the microcell size, akin to an optical path length quantifying how far an optical crosstalk photon could propagate from a triggered microcell.
- Crosstalk probability λ is related to device-specific σ

Acknowledgements Thanks to the GCT-CHEC consortium who obtained data from the CHEC-S camera. CTA-UK is funded by the UKRI-STFC.

References

[1] Buzhan et al, doi.org/10.1142/9789812776464_0101, 2002
[2] Hofmann, doi.org/10.1063/1.4968899, 2017
[3] Borel, "Sur l'emploi du theoreme de…", C. R. Acad. Sci., 214, 452-456, 1942
[4] Vinogradov, doi.org/10.1016/j.nima.2011.11.086, 2012
[5] Gallego et al, doi.org/10.1088/1748-0221/8/05/P05010, 2013
[6] Asano et al, https://doi.org/10.1016/j.nima.2017.11.017, 2017
[7] White, doi.org/10.1088/1748-0221/12/12/C12059, 2017