Improving CTA event reconstruction at the highest energies to benefit PeVatron searches

CTA-Oz Meeting #1

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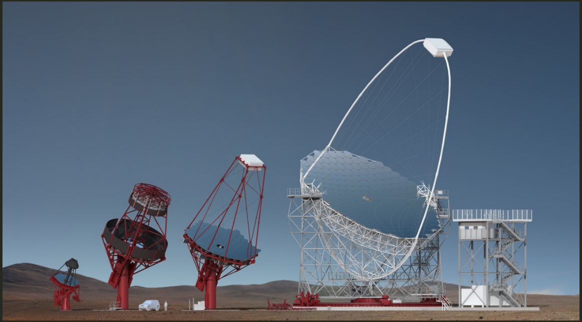
My project

- Optimise the reconstruction/identification of the highest energy γ-ray events.
- When within or near the array, existing stereoscopic techniques should handle well.
- Very rare but very bright, so *can* be seen from long distances...
- But might be seen by only one telescope ("mono"), or shower images may be "truncated" by edge of FOV of telescopes.
- The Small-Sized Telescopes (SSTs) are key to this work.



CTA telescope scales.
Credit: Gabriel Pérez Diaz (IAC).

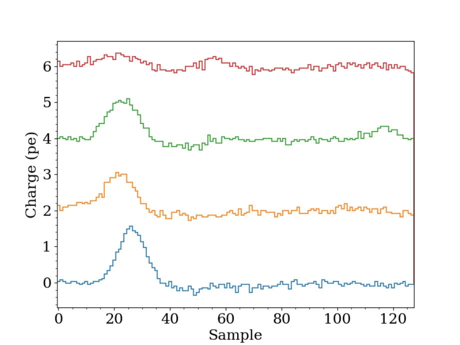
How can we recover these events?

I've been investigating ways to make better use of the per-pixel timing information. The CTA SSTs will have very good time resolution (see simulated pixel traces below) and we believe it is being underutilised.

We can use pixel trigger times in a number of ways:

- Time gradient – correlates with core distance.
- Time RMS – correlates with γ-score.
- "Out-of-time" pixels can be rejected during cleaning to improve results.
- Timing could improve determination of shower axis for truncated images.

This last point seemed promising, but unfortunately is strongly biased due to the camera geometry...

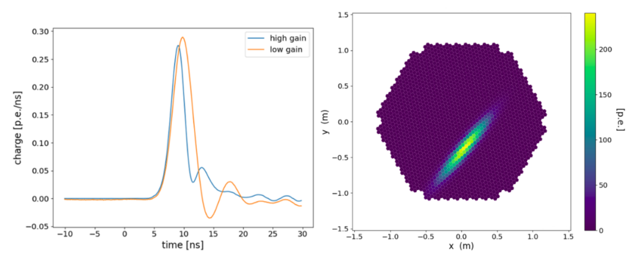


Charge–time traces of four pixels in an event (arb. vertical offset for each trace).

Likelihood analysis including time evolution

Now working with Sabrina Einecke on a likelihood analysis.

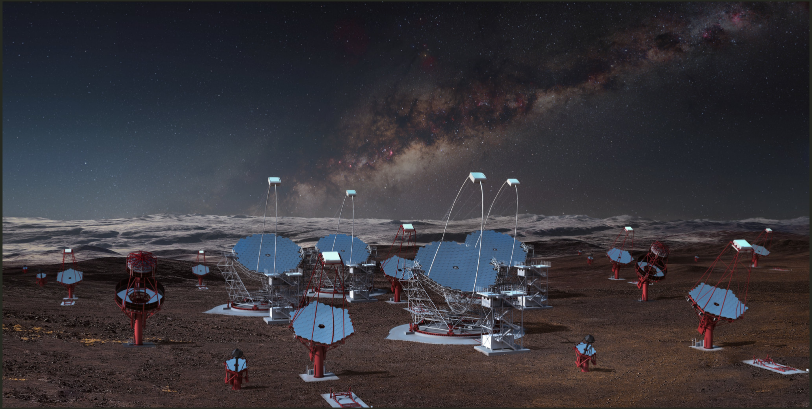
- Model shower image with 2D skewed normal distribution (other options exist).
- Model shower timing with linear time gradient (pixel trigger time vs position along axis).
- Parameters are fit by minimising the log-likelihood of a generalised Poisson distribution, which accounts for SiPM optical cross-talk (primary discharge triggers secondary discharges).
- Prior investigations (Alispach, 2020, Emery et al., 2021) use pulse templates, which we are experimenting with avoiding to work better with real data.



Figures from Emery et al., 2021.
Left: Pulse templates for LST-1.
Right: 2D skewed normal image model as fitted to an event in LST-1.

Conclusion

- Working on methods for using timing information to better reconstruct high energy events.
- A number of roadblocks so far (very many...), but learning a lot.
- Likelihood analysis is appealing for recovering truncated images and mono reconstruction.



Credit: Gabriel Pérez Diaz (IAC) / Marc-André Besel (CTAO) / ESO / N. Risinger (skysurvey.org)