Towards a Cherenkov Telescope Ring

Project Overview and Update

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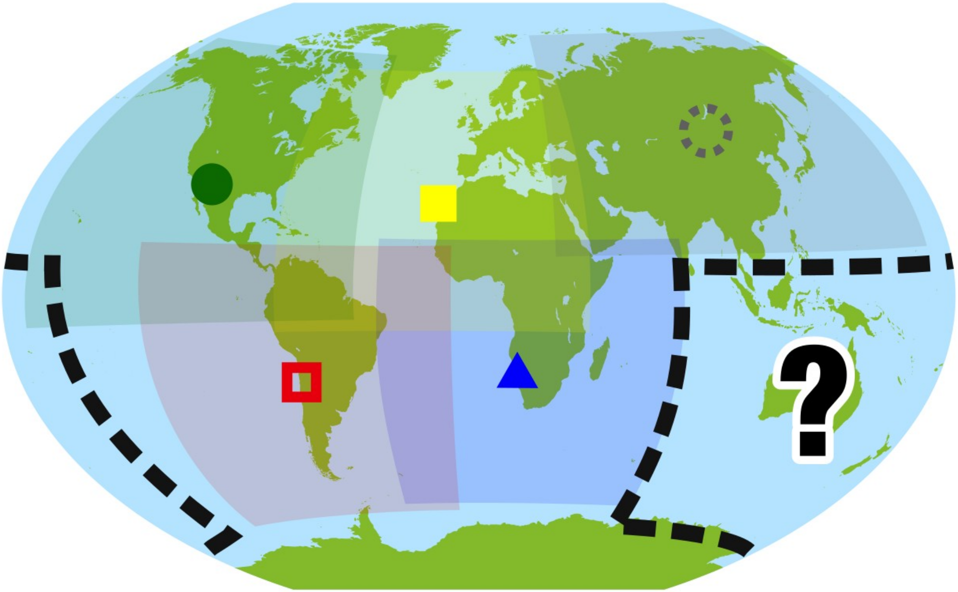
2020-11-03

Cherenkov Telescope Ring (CTR)

- An idea for a world-wide network of Imagin Air Cherenkov Telescopes
- Allows for instantaneous follow-up on transients
- Allows for continuous monitoring of sources over days
- Necessitates a telescope in Australia



VERITAS (●), MAGIC (■),
CTA-South (□), H.E.S.S. (▲)

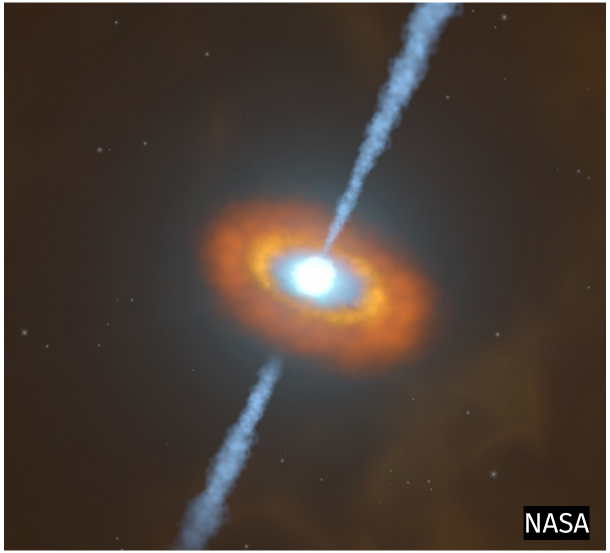
Motivation: AGNs

- Science drivers:
  - **Blazars**: Source type, jet dynamics, energy budget…
  - **Radio Galaxies**: Inner-jet behaviour, small-scale structure

- Day- & year-scale γ-ray flux variations

- Research requires:
  - Time-dependent spectral energy distributions
  - Multi-wavelength lightcurves

→ Requires continuous monitoring

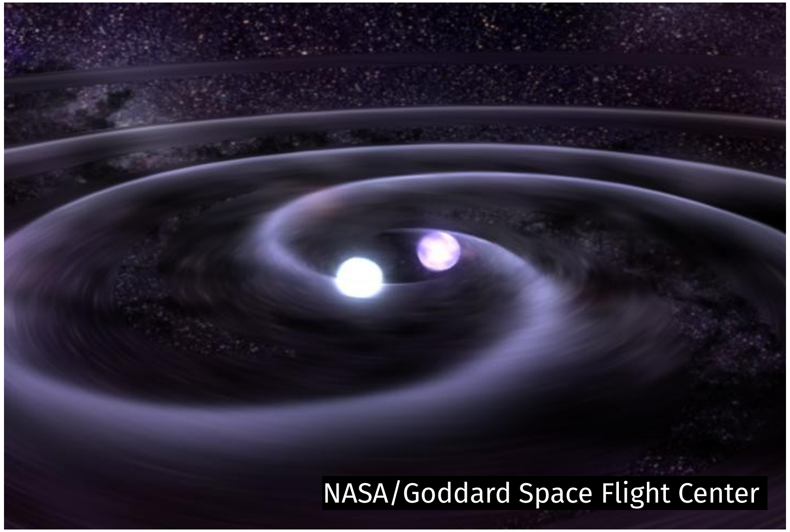


Motivation: Transients

- Science drivers:
  - **Neutrinos**: Probing particle acceleration processes
  - **Gravitational waves**: Neutron star merger contribution to very-high-energy γ-ray flux
  - **AGN flares**

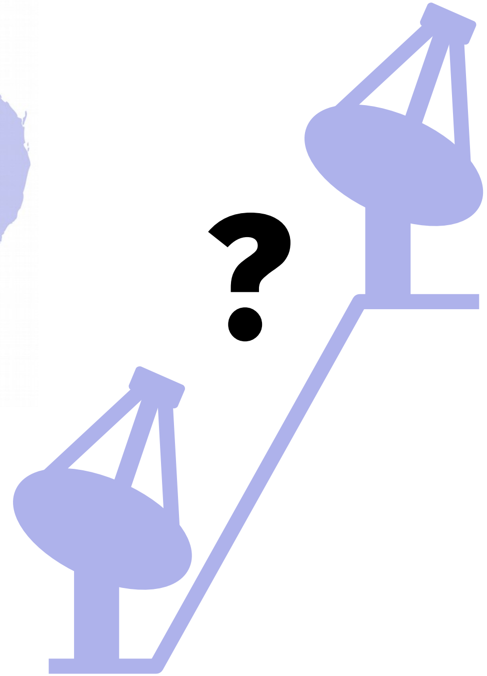
- Research requires:
  - Rapid & continuous followup

→ Requires 24-hour availability


NASA/Goddard Space Flight Center

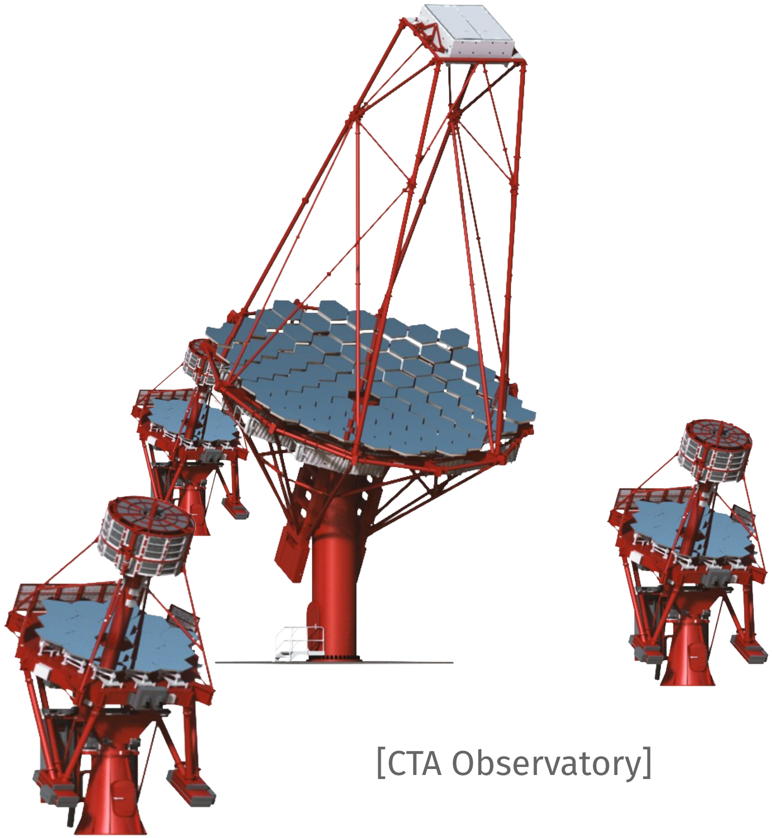
Australian site: Location

- An Australian site would be needed
- Which location?
- Weather conditions?
- Accessibility?
- Does altitude significantly affect performance ?



Australian site: Configuration

- How does the performance compare between:
  - A single MST
  - SSTs in an array of 2, 3, 4...
  - How widespread?
  - Multiple MSTs?

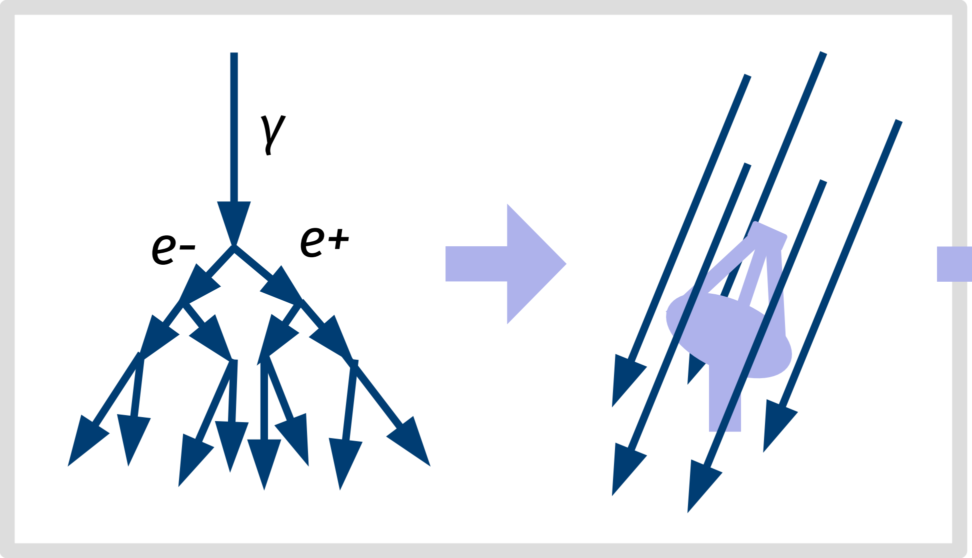


[CTA Observatory]

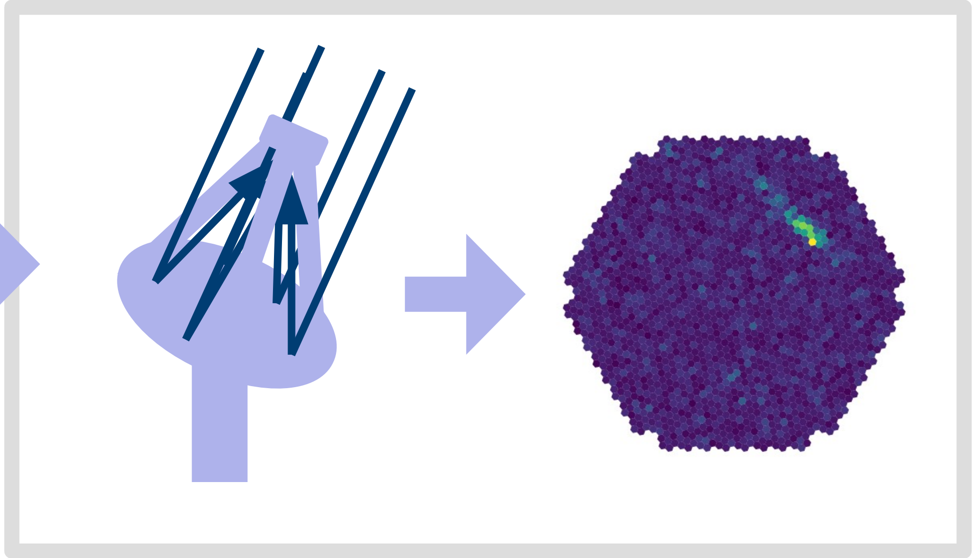
Project outline

- Investigate Australia telescope site possibilities with simulations
- Aiming to understand:
  - Significance of **altitude**
  - Performance difference between **telescope sizes**
  - Amount of improvement with **more telescopes**
  - Performance difference between **geometric configuration**

CORSIKA & sim-telarray



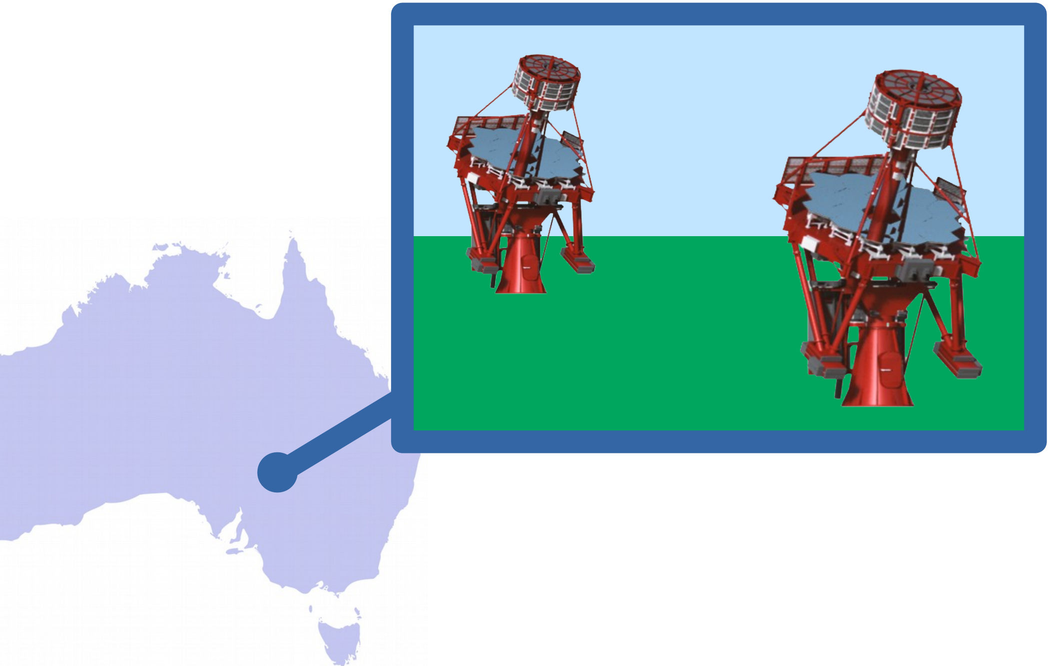
CORSIKA



sim-telarray

My current simulations

- Testing setups in Arkaroola at 1000m altitude

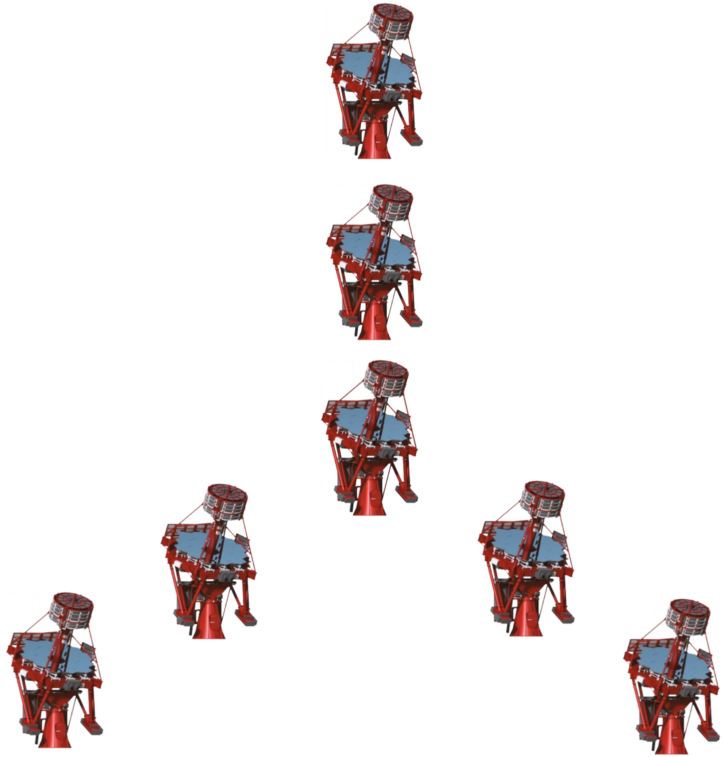


Simulation runs

- ***Source gammas***: gamma rays originating from a specific point-source
- ***Diffuse gammas:*** gamma rays coming from random places in the camera's FOV
- ***Diffuse protons***: proton coming from random places in the camera's FOV

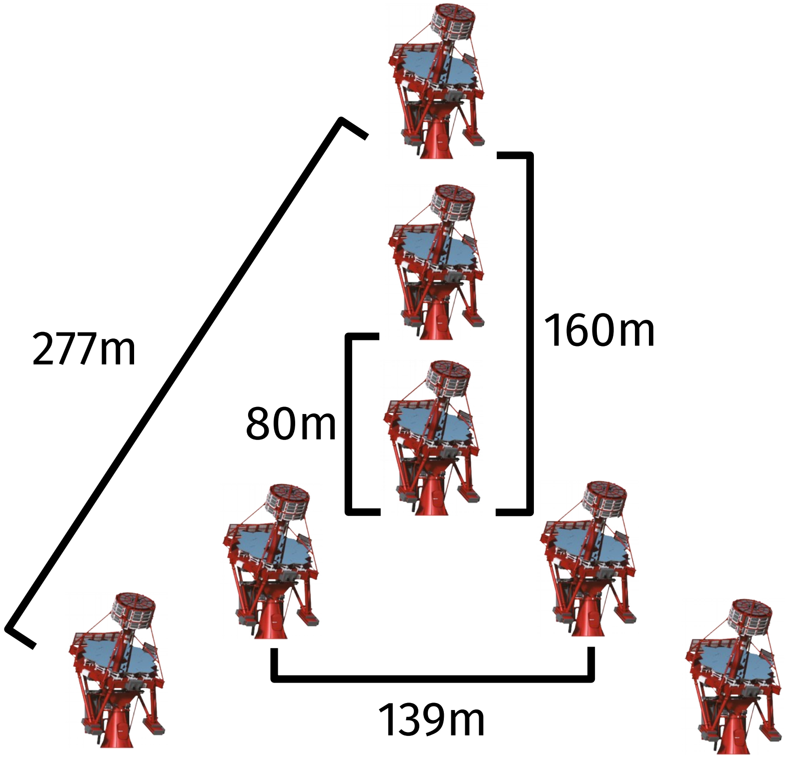
Simulation setup

- 7-telescope arrangement to investigate a variety of array setups
- Simulating both MST and SST arrays



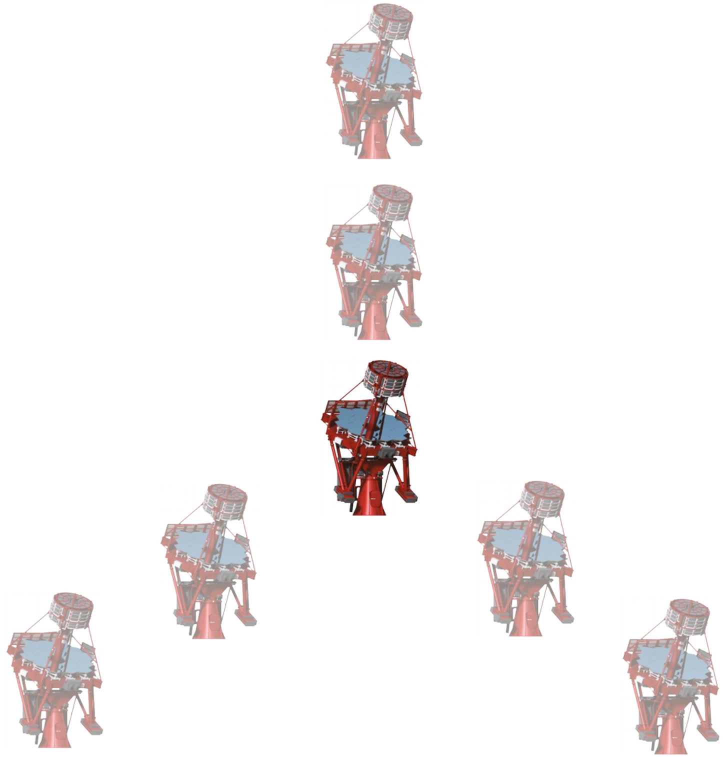
Simulation setup

- Single telescope centred in a smaller and a larger triangle



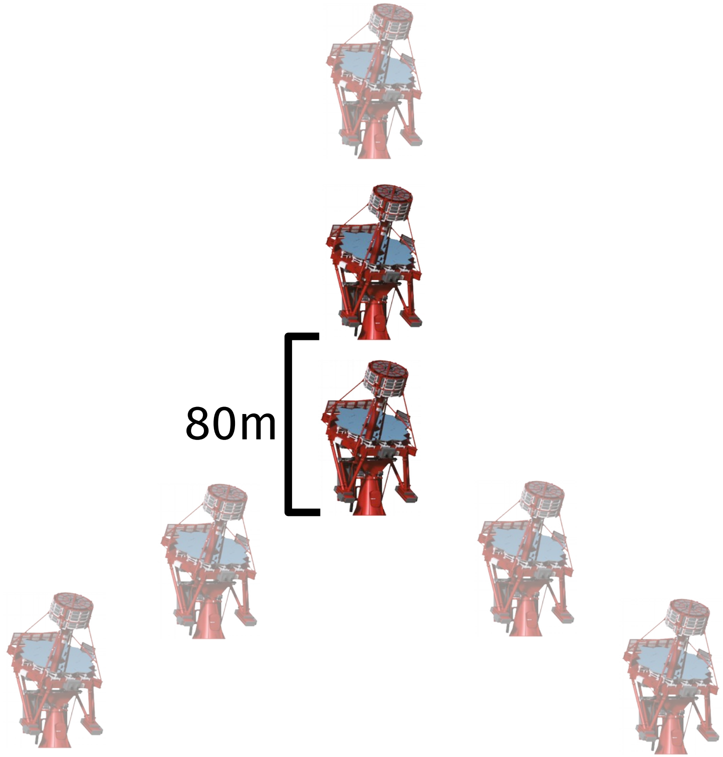
Simulation setup

- 1-telescope setup option to assess monoscopic performance



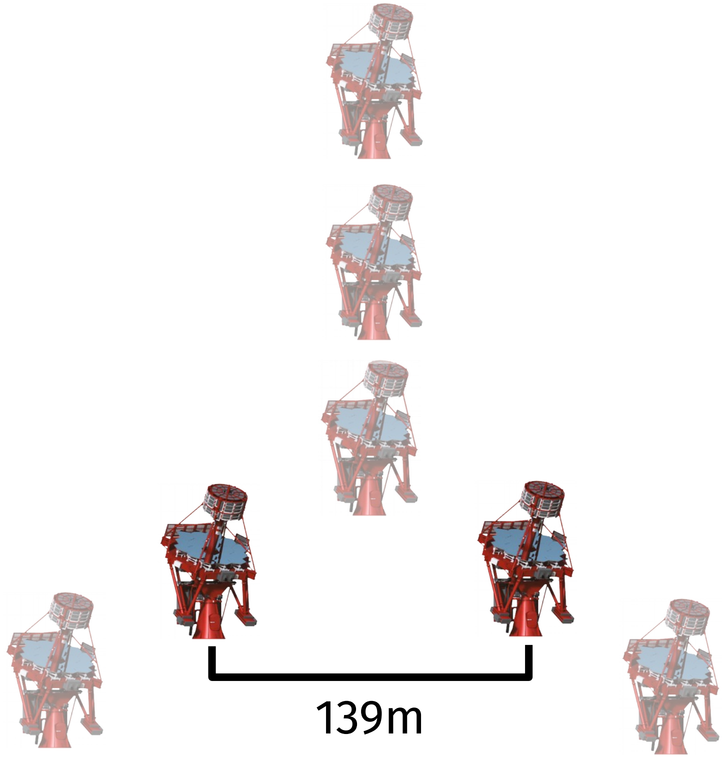
Simulation setup

- 2-telescope setup options with different baseline sizes



Simulation setup

- 2-telescope setup options with different baseline sizes



Simulation setup

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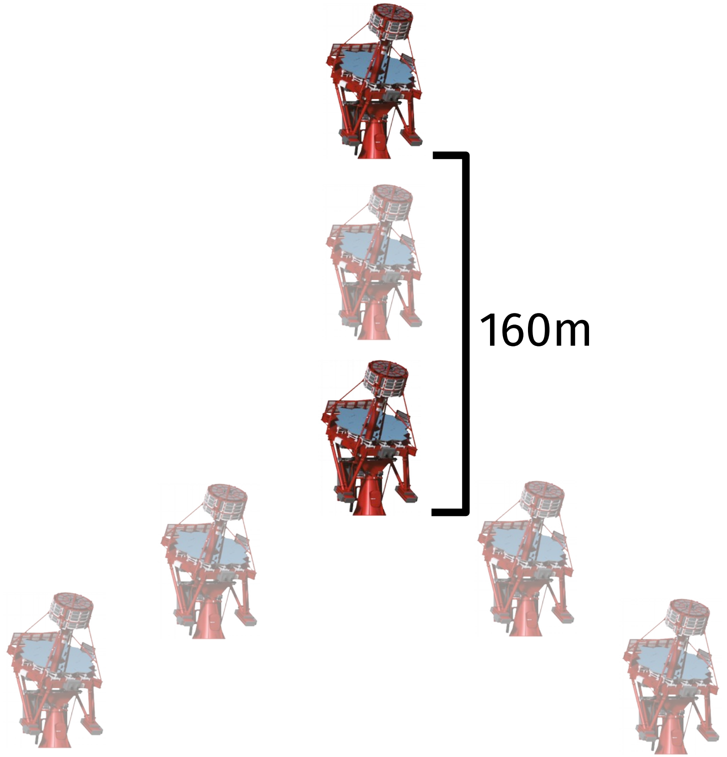
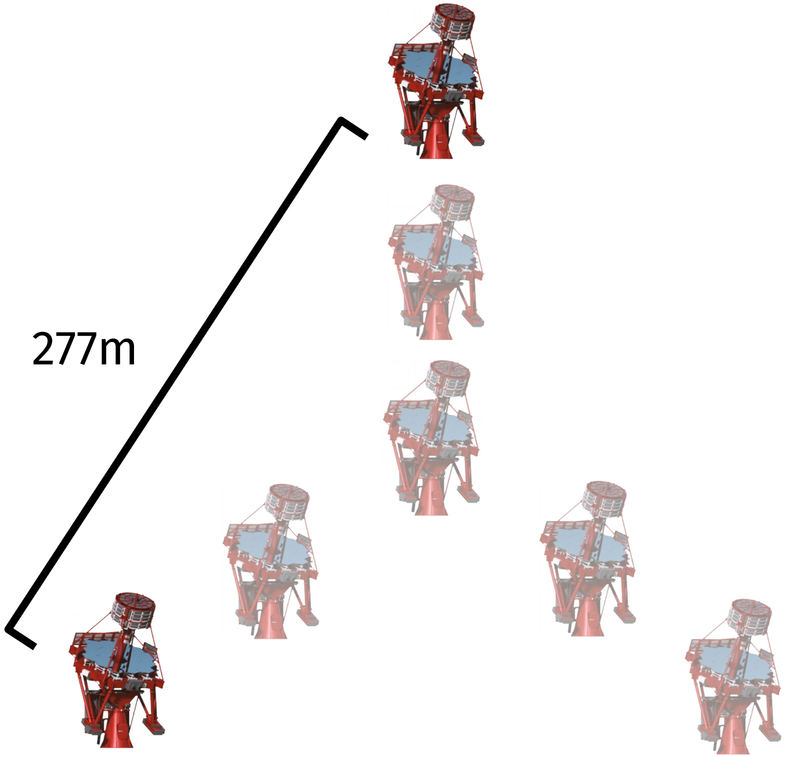


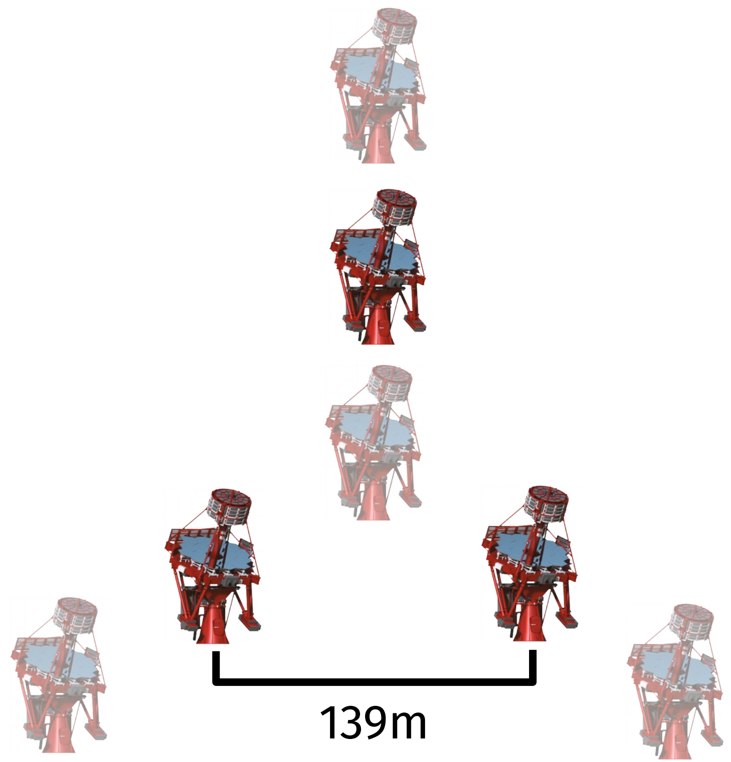
Simulation setup

- 2-telescope setup options with different baseline sizes



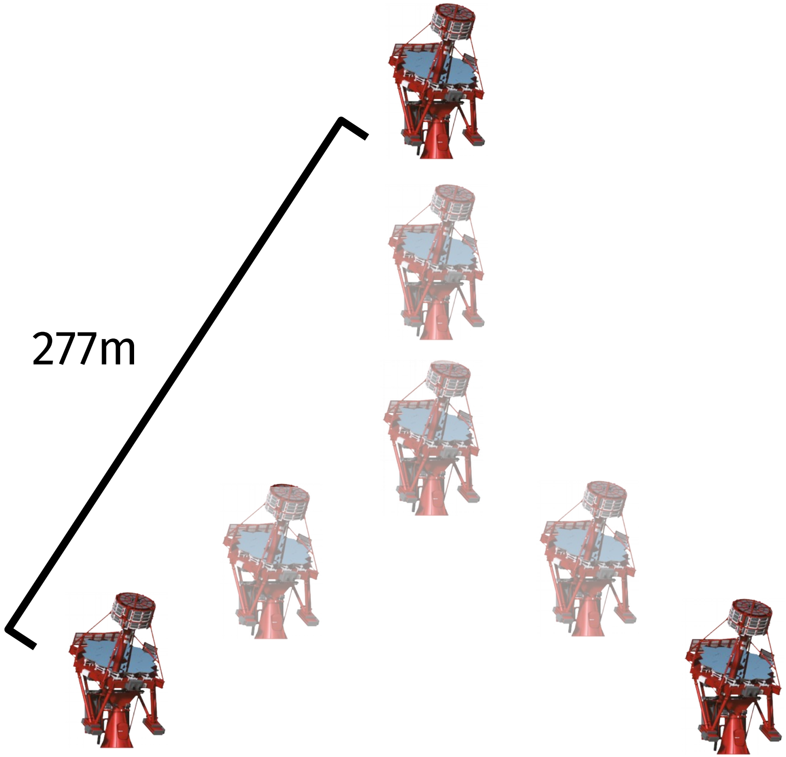
Simulation setup

- 3-telescope arrangements of different sizes



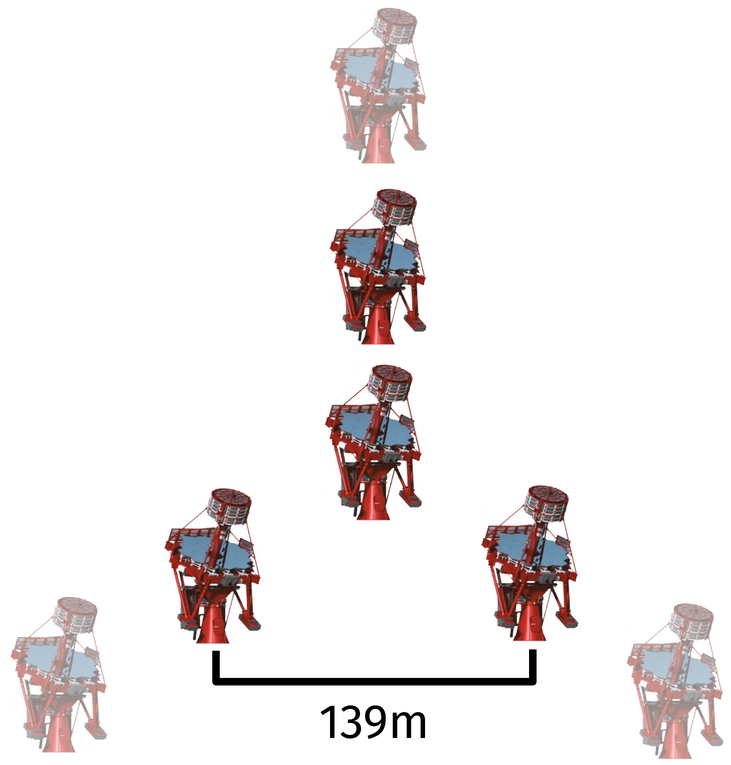
Simulation setup

- 3-telescope arrangements of different sizes



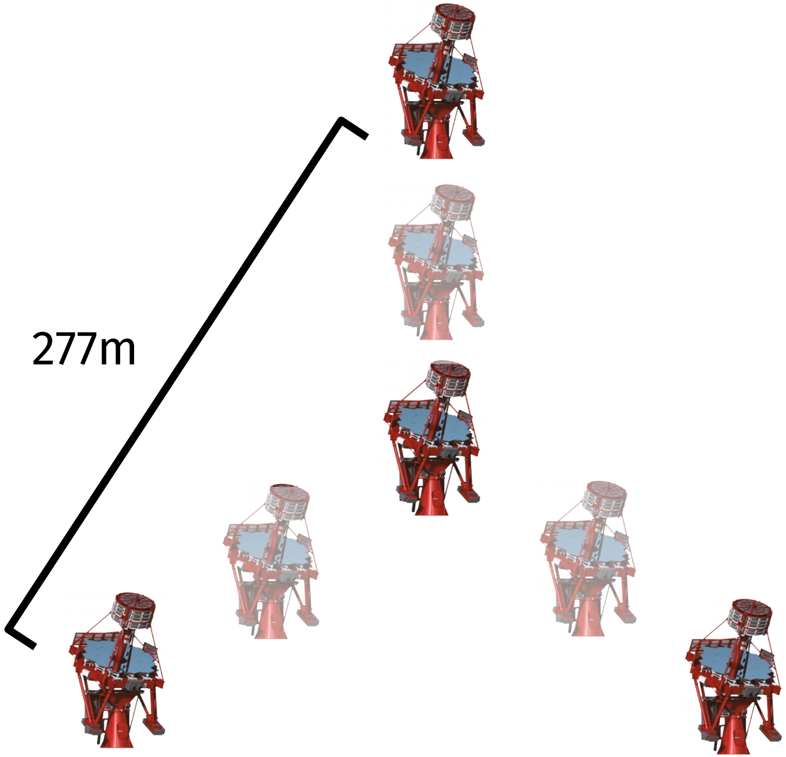
Simulation setup

- 4-telescope arrangements of different sizes



Simulation setup

- 4-telescope arrangements of different sizes



Simulation runs

Energy range	Particle type	Simulated particles
0.01-0.5 TeV	source gamma-rays	30,000,000
	diffuse protons	2,000,000,000
	diffuse gamma-rays	38,000,000
0.3-5 TeV	source gamma-rays	440,000
	diffuse protons	120,000,000
	diffuse gamma-rays	3,600,000
3-50 TeV	source gamma-rays	170,000
	diffuse protons	9,400,000
	diffuse gamma-rays	1,100,000
30-500 TeV	source gamma-rays	180,000
	diffuse protons	5,900,000
	diffuse gamma-rays.	500,000

Analysis pipeline

Low-level processing

Extraction
↓
Calibration
↓
Cleaning
↓
Parameterisation

→

High-level processing

Energy reconstruction
+
Direction reconstruction
+
Gamma/hadron separation

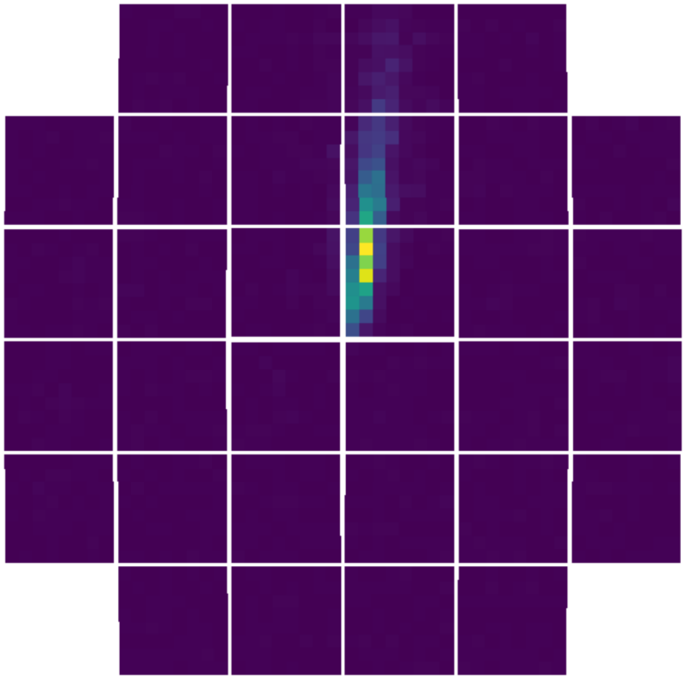
→

Performance

Angular resolution
+
Sensitivity
+
Energy resolution
+
Effective area
...

Low-level processing

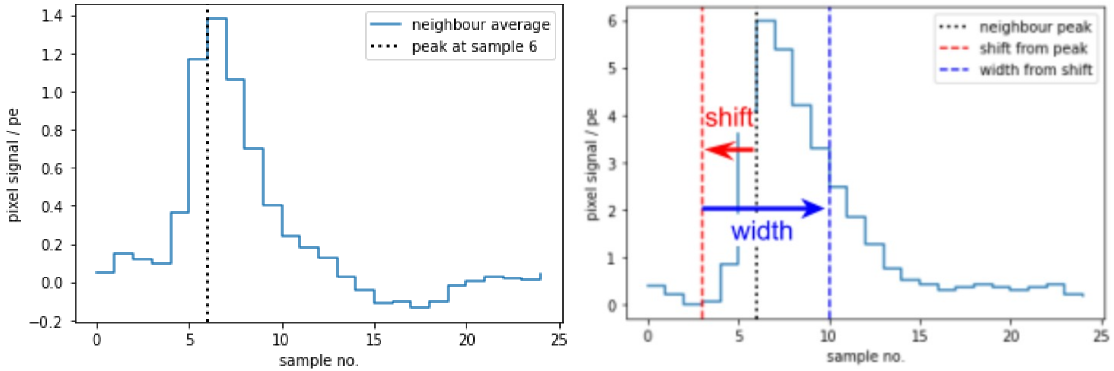
- Telescope simulations need to be calibrated and extracted
- Tools from ***ctapipe*** are used, the CTA low-level data processing pipeline framework prototype



An example gamma ray shower as seen by an SST

Extraction optimisation

- Extraction takes the waveform of a telescope camera pixels and outputs a charge value
- This charge estimates how many photon were incident on the pixel
- The extraction method used in ctapipe finds a peak and sums to the left and right of the peak

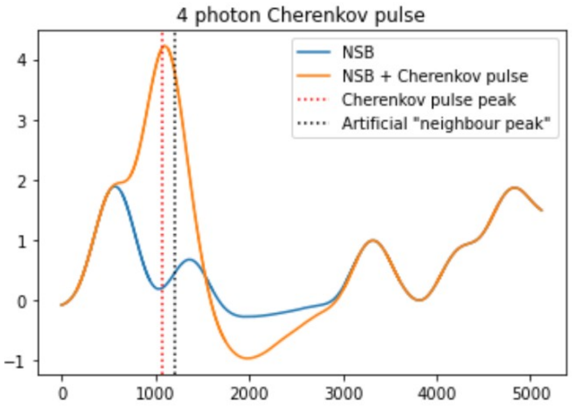


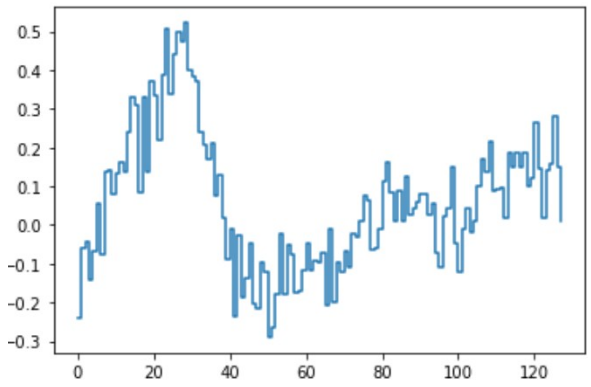
An example pixel signal with example shift and width parameters that are chosen for extraction

Extraction optimisation

- Optimising these parameters required simulating Cherenkov photon pulses with night sky background and electronic noise

- Extraction performance can be tested on many thousands of simulated pixel signals

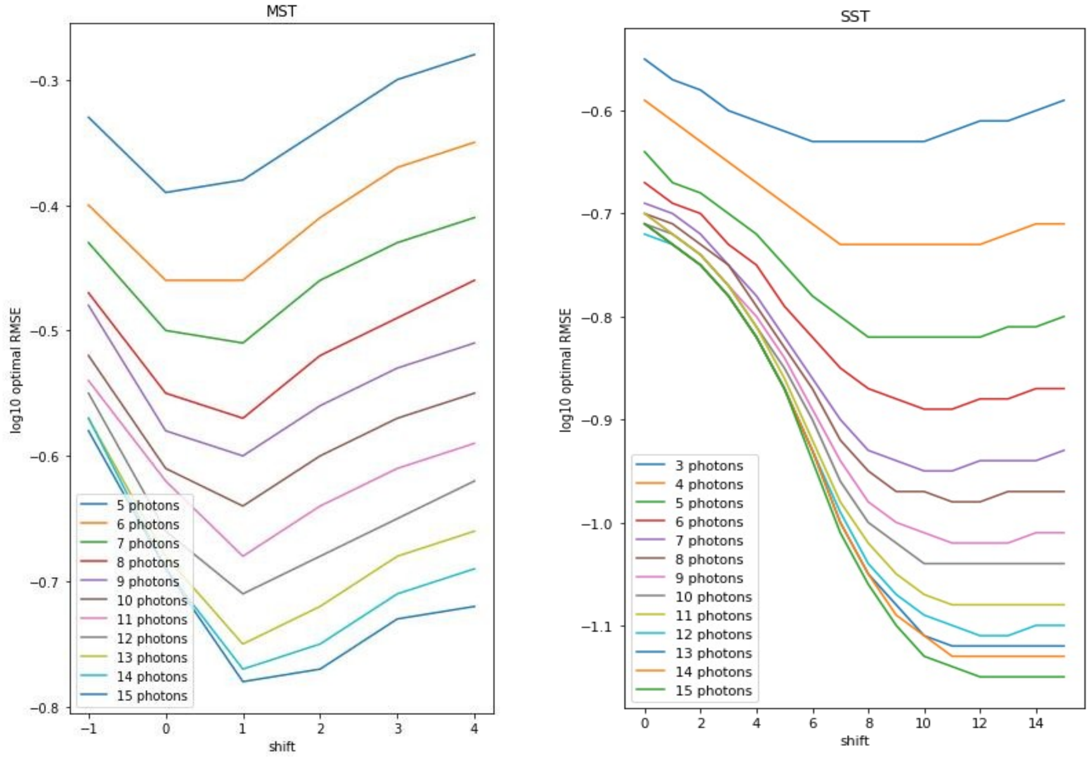




An example simulated pixel signal

Extraction optimisation

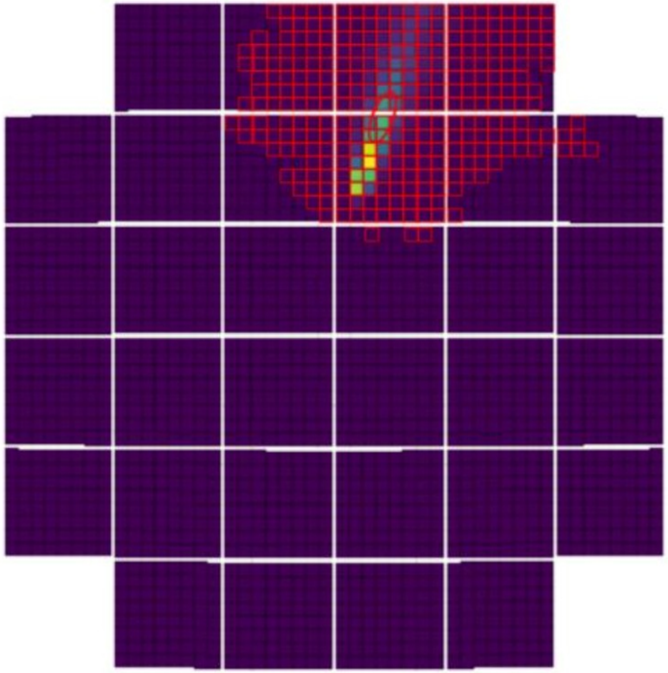
- These “shift” and “width” values were optimised for both MST and SST



Extraction performance for different shift values for different numbers of incident photons

Cleaning

- Removes background pixels so the remaining image can be parameterised
- Cleaning method:
  - Choose all pixels above a threshold A with at least 3 neighbours
  - Add all pixels above a lower threshold B that arrived within a given time frame
  - Remove pixels with no neighbors



An example shower with post-cleaning pixels highlighted

My script

- Uses tools from *ctapipe*
- Outputs to an .hdf5 files with tables for:
  - ‘runs’ - simulation settings
  - ‘array events’ - shower info (energy, direction, core position etc.)
  - ‘telescope events’ - Hillas parameters, telescope info etc.

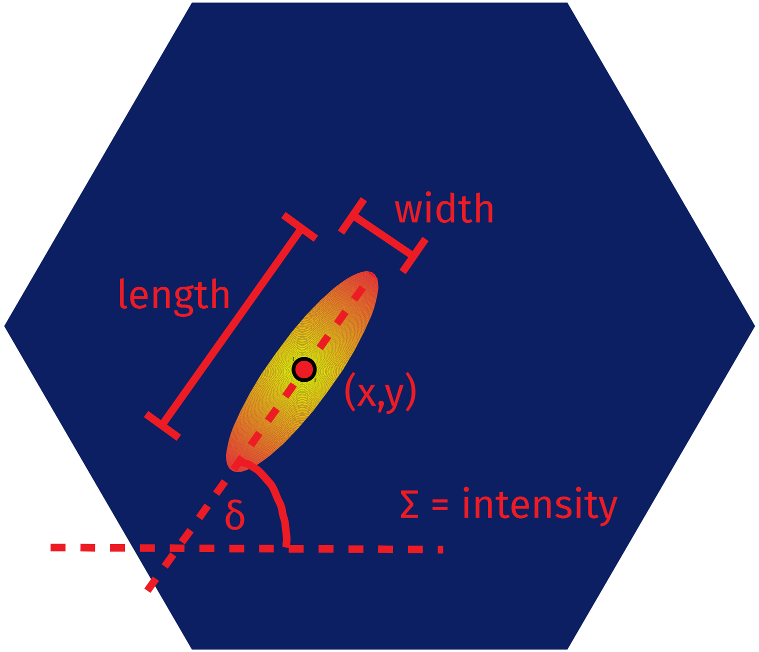
https://github.com/simonleeADL/simtel_processing

My script

- Useful for mono an stereo configurations

- Can process:
  - Arbitrary number of telescopes
  - Arbitrary telescope types

- Outputs:
  - Hillas parameters
  - Event time gradient
  - Geometric direction reconstruction
  - Per-telescope impact distance…



Some of the Hillas Parameters used for reconstruction

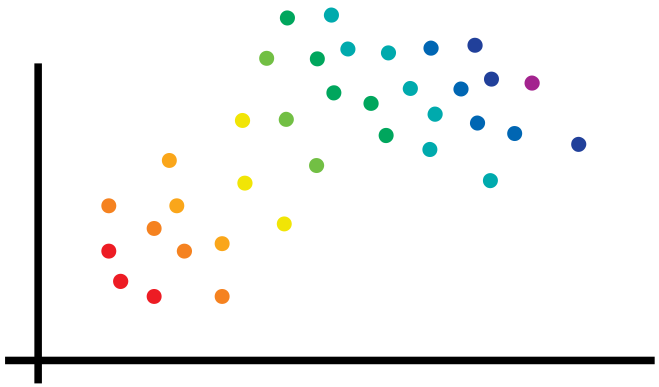
High-level processing

- ***aict-tools*** is a collection of AI tool for gamma-ray astrophysics
- For this project it is used to apply Random Forests on diffuse gamma-ray and diffuse proton simulations to create and implement models for:
    - Energy
    - Direction
    - Gamma / hadron separation

Regression & classification

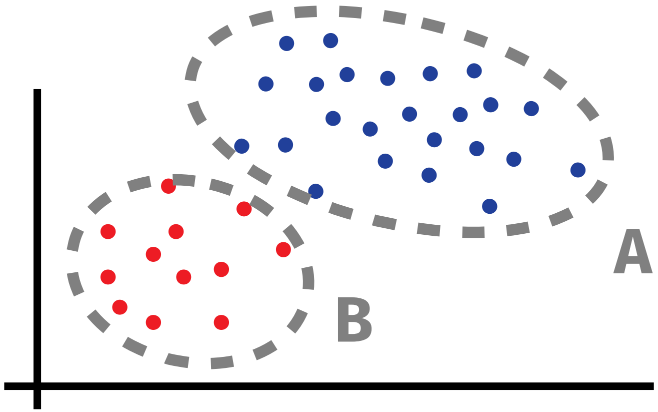
Regression

- Uses available parameters to estimate the value of a **continuous** variable for an input



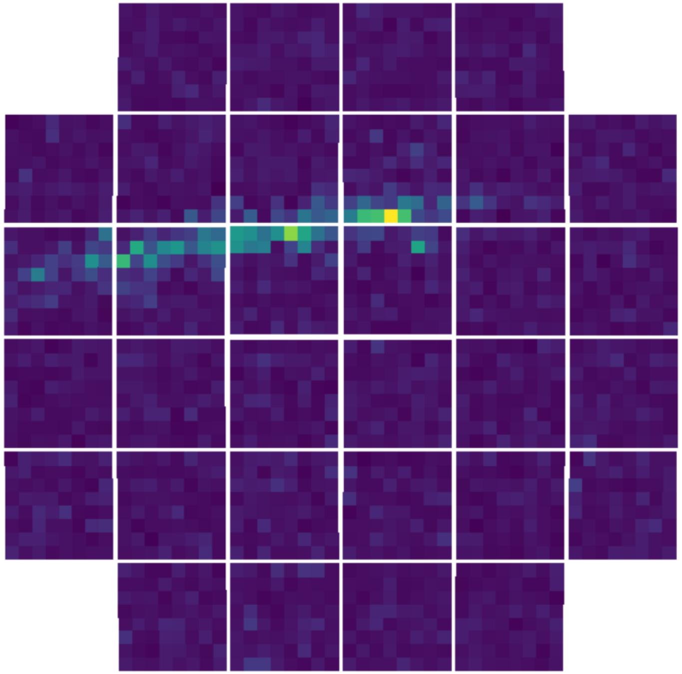
Classification

- Uses available parameters to predict the **discrete** category of an input



Gamma/hadron separation

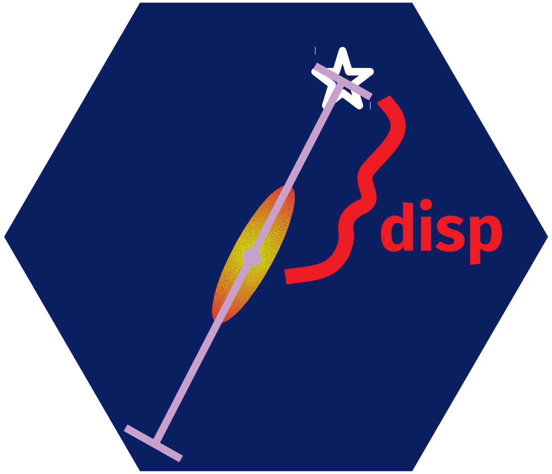
- A model is made to classify showers as being from gamma-rays or from hadrons
- The classifier is trained on diffuse gamma and diffuse proton data
- Assigns a score between 0 and 1 for relative “gamma-ness”

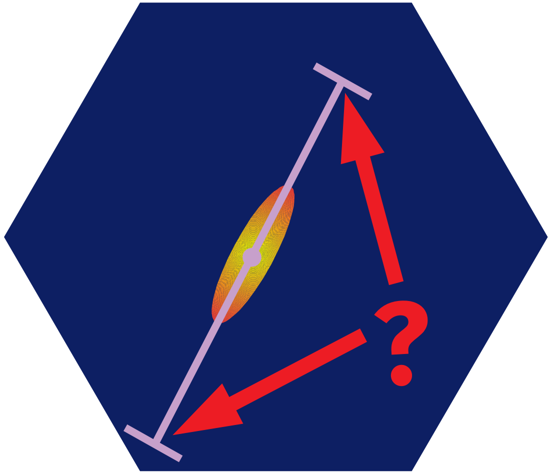


Example proton shower image

Direction reconstruction

- To reconstruct the direction of the source, the DISP analysis method is used
- The source is assumed to lie on the Hillas ellipse’s major axis
- disp is the distance along this axis from the centre-of-gravity to the source position
- Regression is used





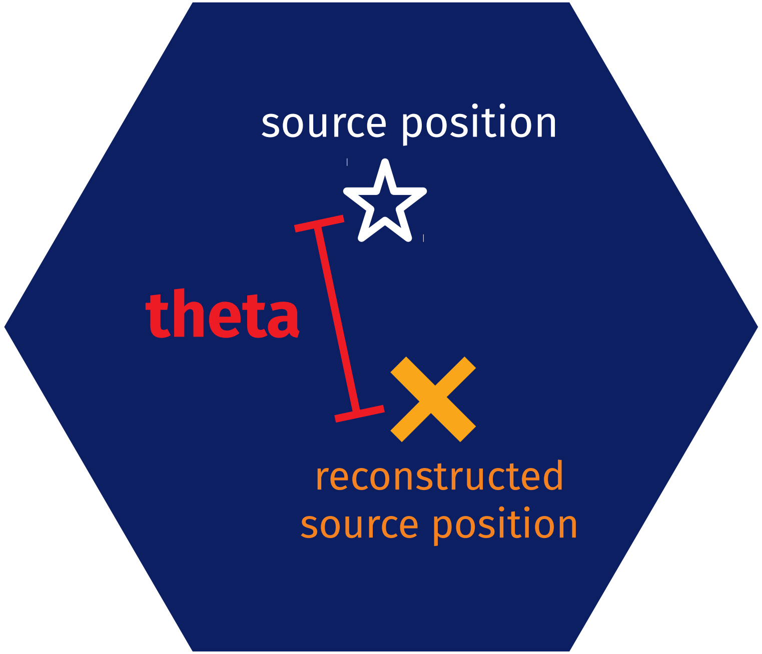
- The direction along the axis (the “sign”,) needs to be determined
- Classification is used

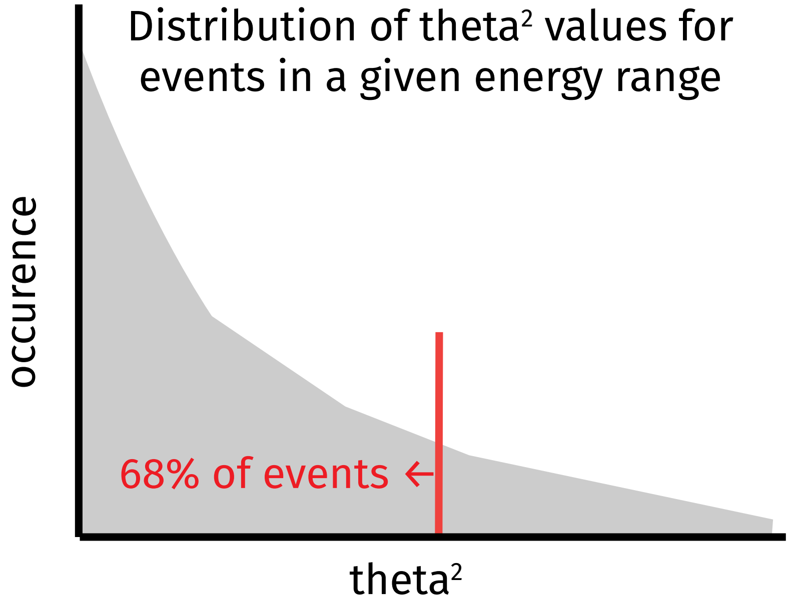
Performance

- Telescope performance can be estimated using the reconstructed source gamma and diffuse proton events

- ***pct-tools*** is a collection of scripts to calculate and plot
  - Sensitivity
  - Angular resolution
  - Energy resolution
  - etc.

Angular resolution



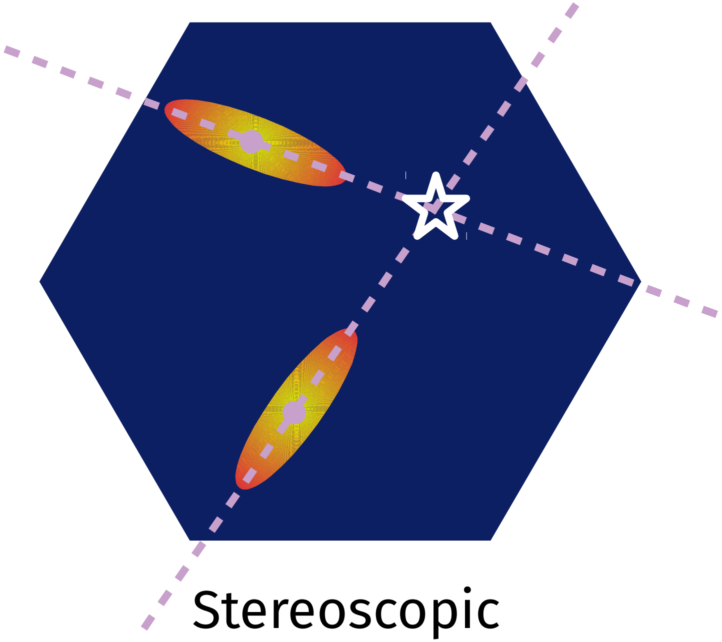


Tighter distribution of reconstructed directions around source position → better angular resultion

Stereo direction reconstruction

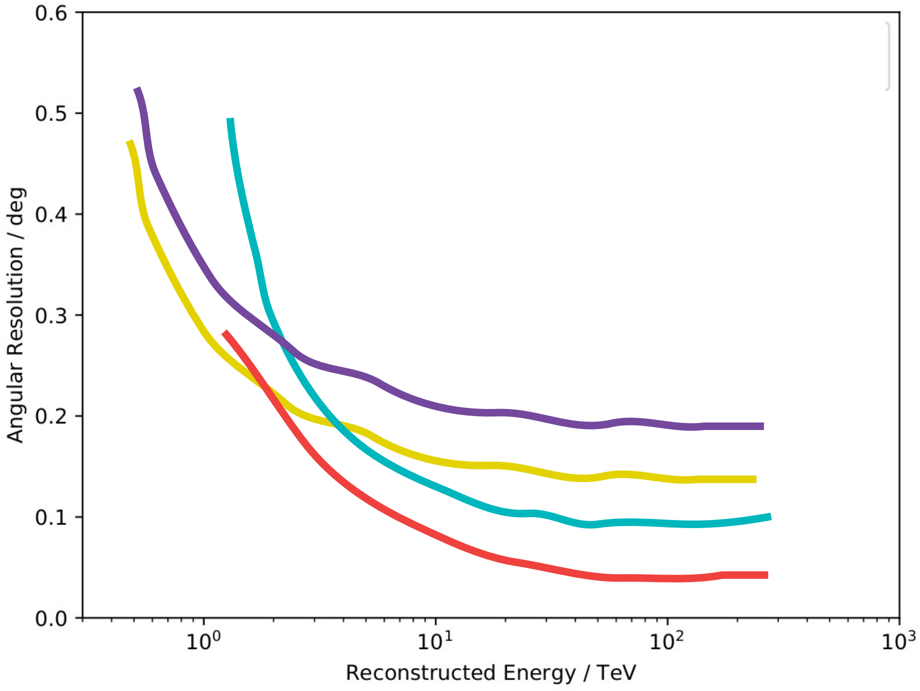
With more than one telescope, geometric direction reconstruction could be used

Monoscopic

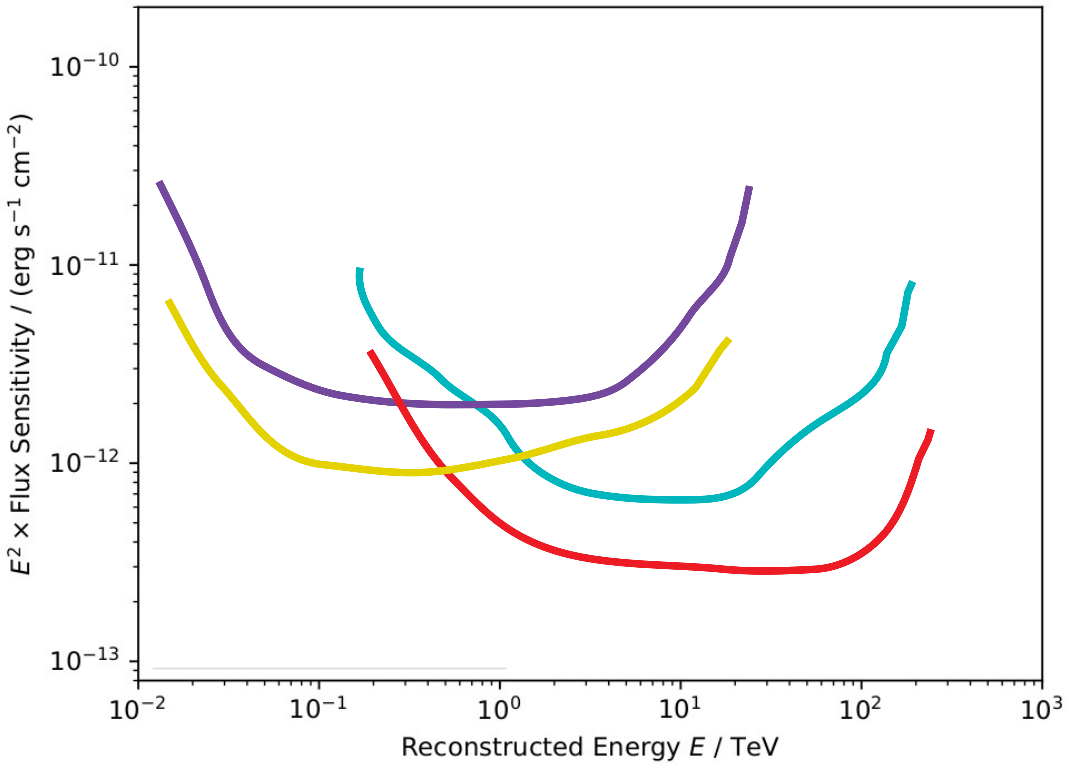


Stereoscopic

Angular resolution?



Sensitivity comparison?



Conclusion

- The **Cherenkov Telescope Ring** is an idea to have a worlwide network of IACTs
- Simulations have been made to compare performance of different array setups and telescope types for one altitude
- Performance calculations to be made soon
- Future simulations will compare with an altitude of 0m, compared to 1000m

Thankyou