Towards a Cherenkov Telescope Ring

Project Overview and Update

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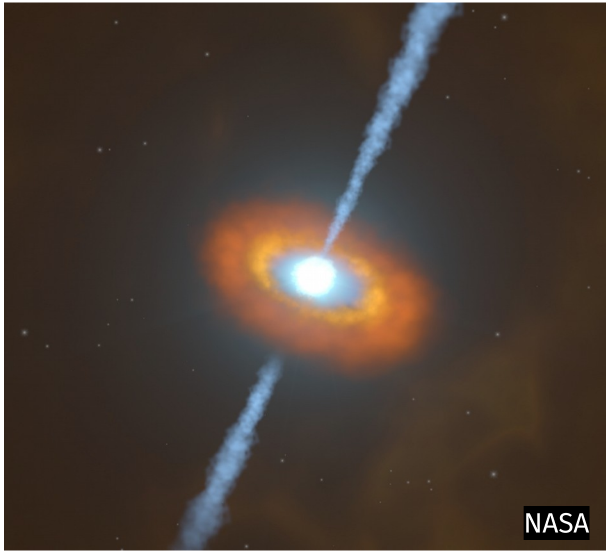
Motivation: AGNs

- 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

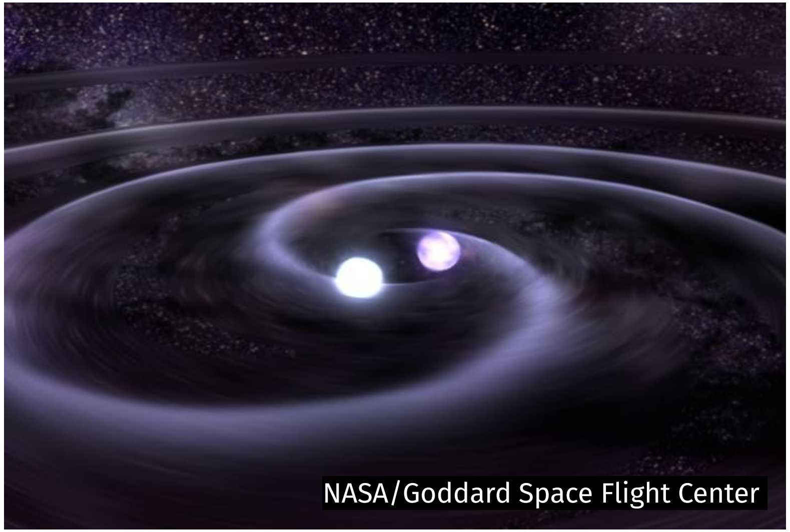

NASA

Motivation: Transients

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

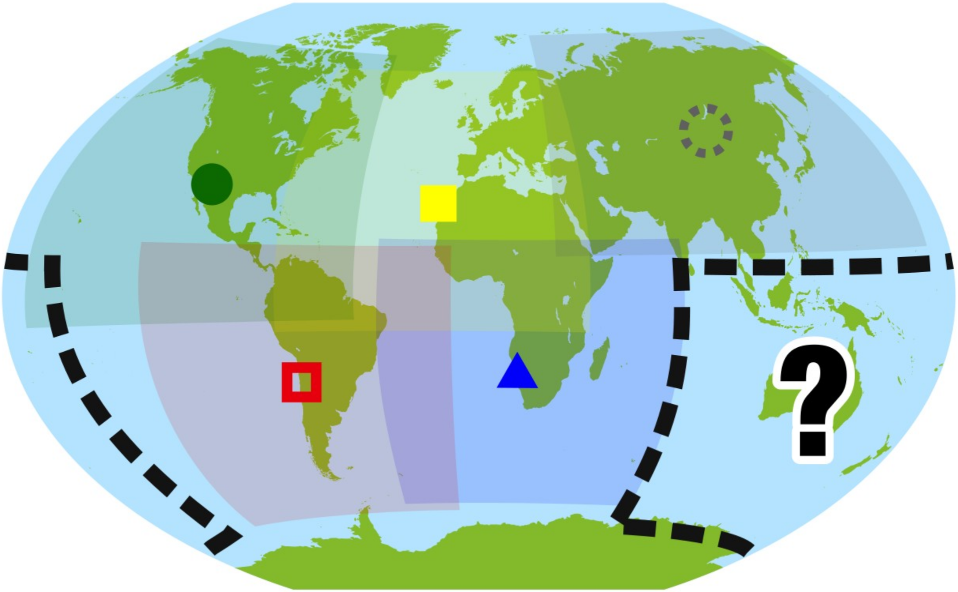
- Research requires:
  - Rapid & continuous followup

→ Requires 24-hour availability



Cherenkov Telescope Ring (CTR)

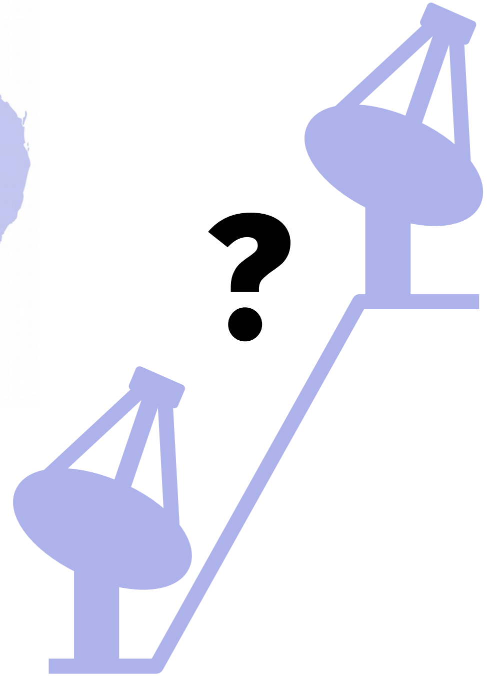
- An idea for a world-wide network of Imagin Air Cherenkov Telescopes
- Allows for instantaneous follow-up on transients
- Allows for continuous monitoring of sources over days
- Necessitates a telescope in Australia



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

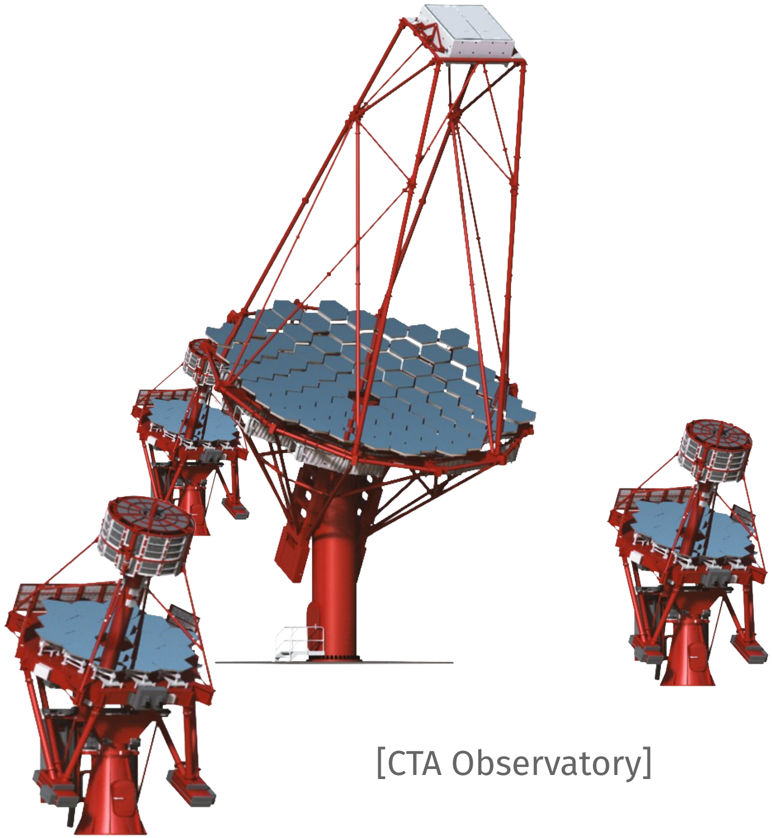
Australian site: Location

- 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?

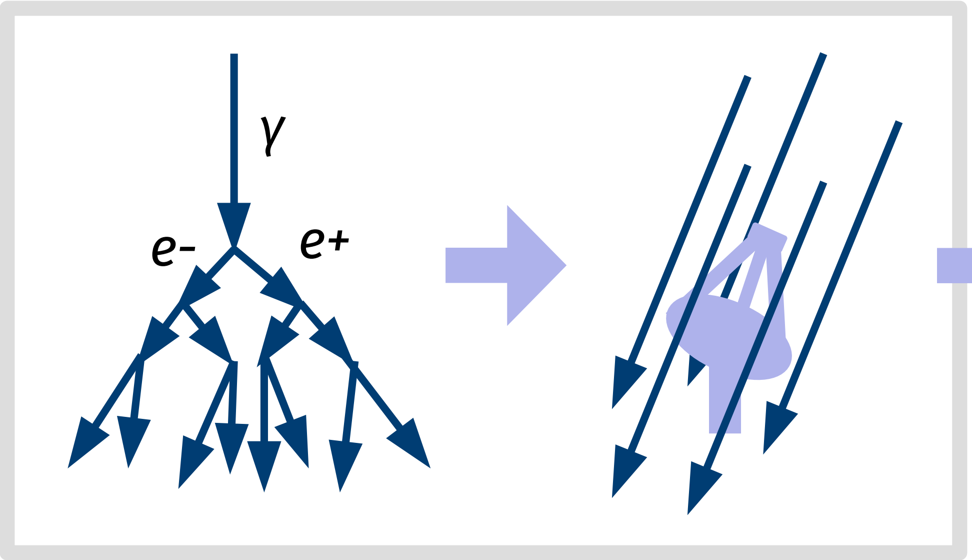


[CTA Observatory]

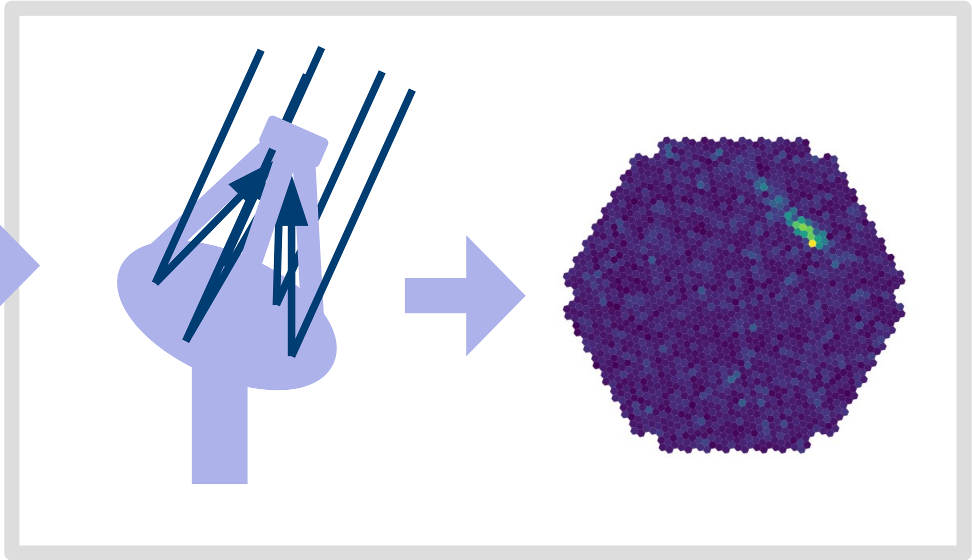
Project outline

- 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



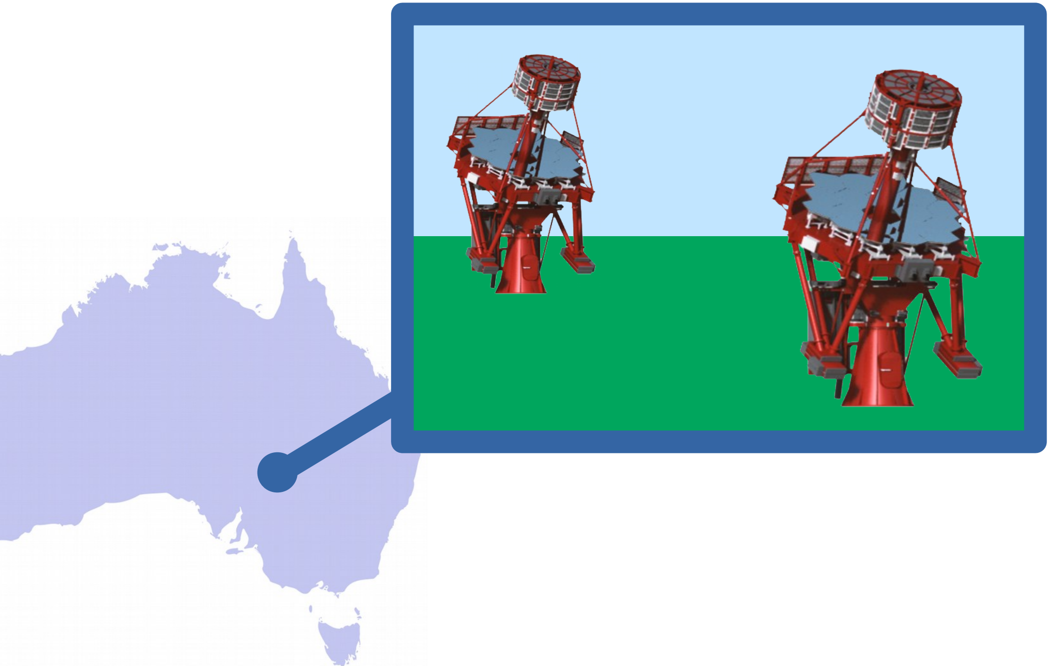
CORSIKA



sim-telarray

My current simulations

- Testing a stereo SST site in Arkaroola 100m apart 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

My current simulations

Main simulation runs

- Energy range: 0.5 – 400 TeV
- Spectral index: -2.0
- Scatter radius: 1000m

Low-energy supplementary runs

- Energy range: 0.05 – 1 TeV
- Spectral index: -2.0

High-energy supplementary run

- Proton only
- Energy range: 50-400 TeV
- Spectral index: -1.0

Analysis pipeline

Low-level processing

Extraction
↓
Calibration
↓
Cleaning
↓
Parameterisation

High-level processing

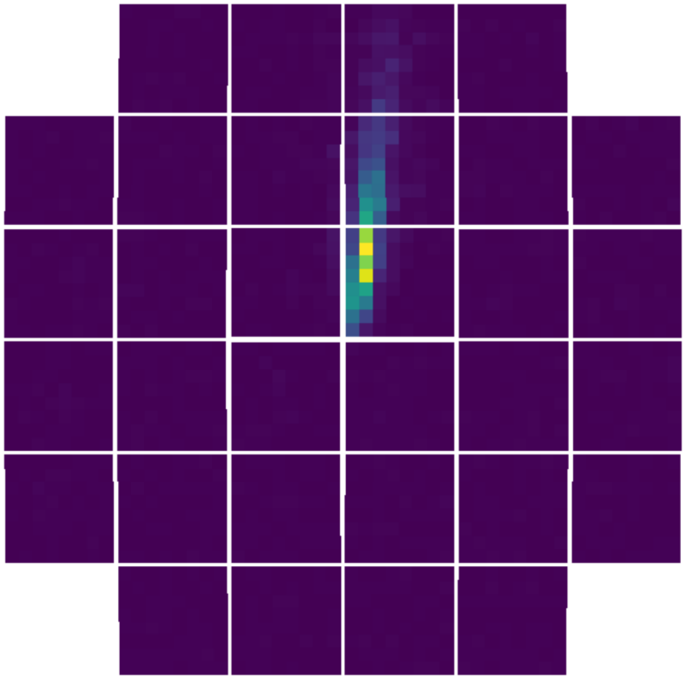
Energy reconstruction
+
Direction reconstruction
+
Gamma/hadron separation

Performance

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

Low-level processing

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

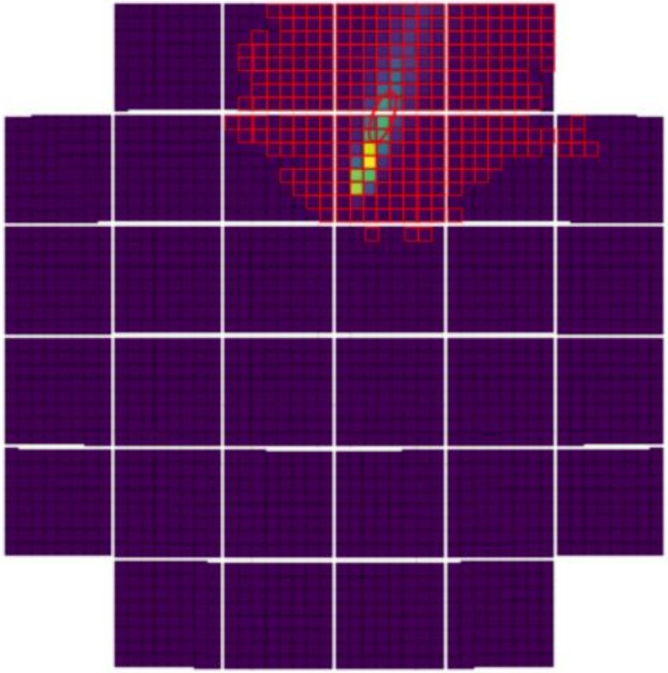


An example gamma ray shower as seen by an SST

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.

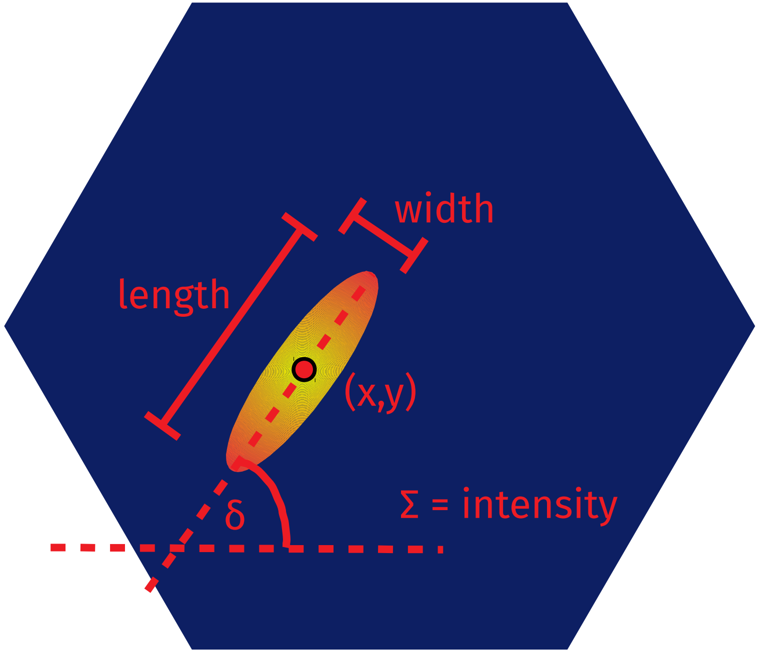
https://github.com/simonleeADL/simtel_processing

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

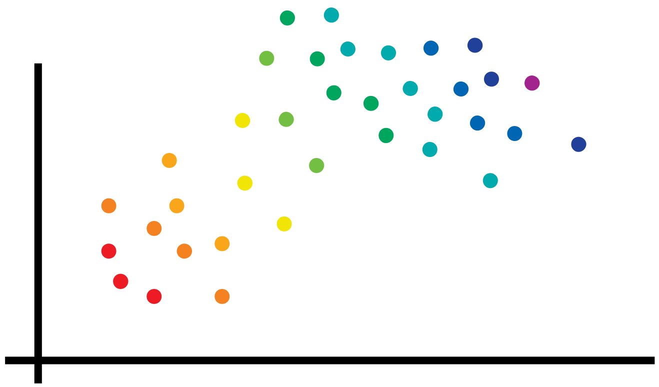
High-level processing

- ***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

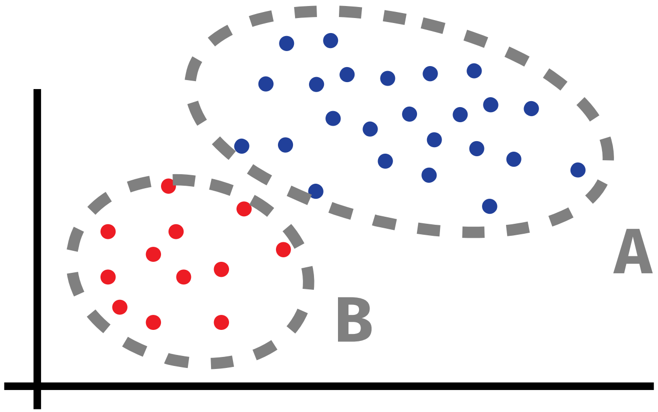
Regression

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



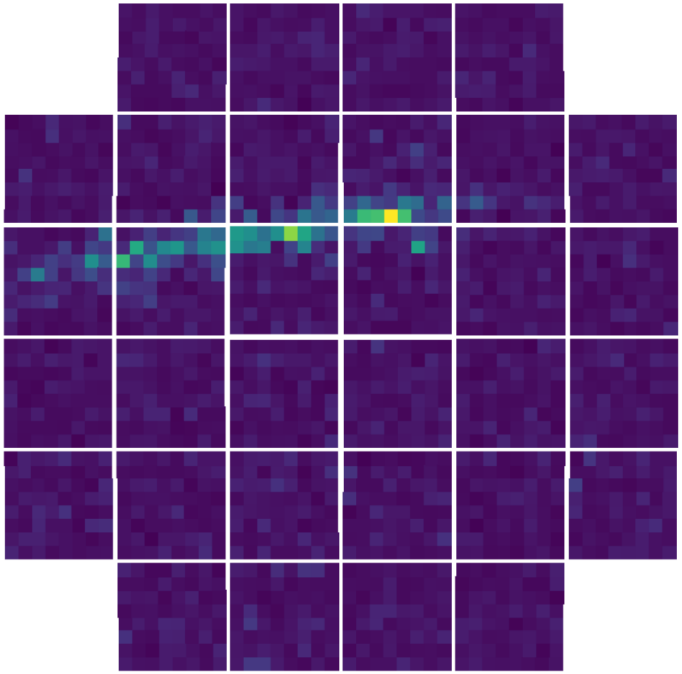
Classification

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



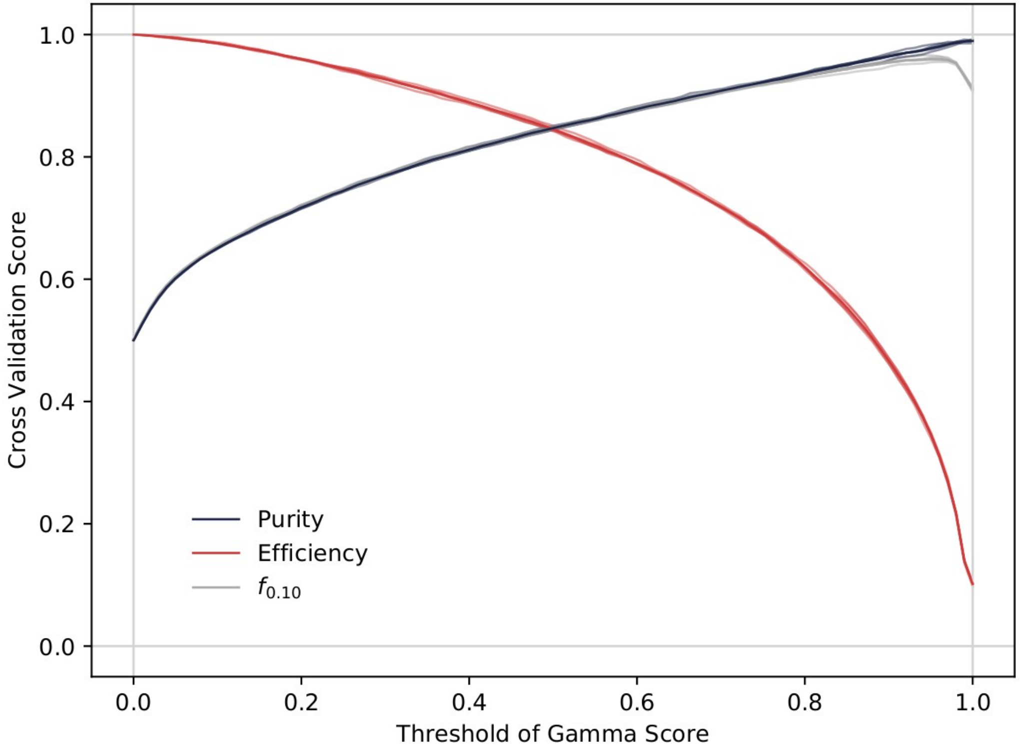
Gamma/hadron separation

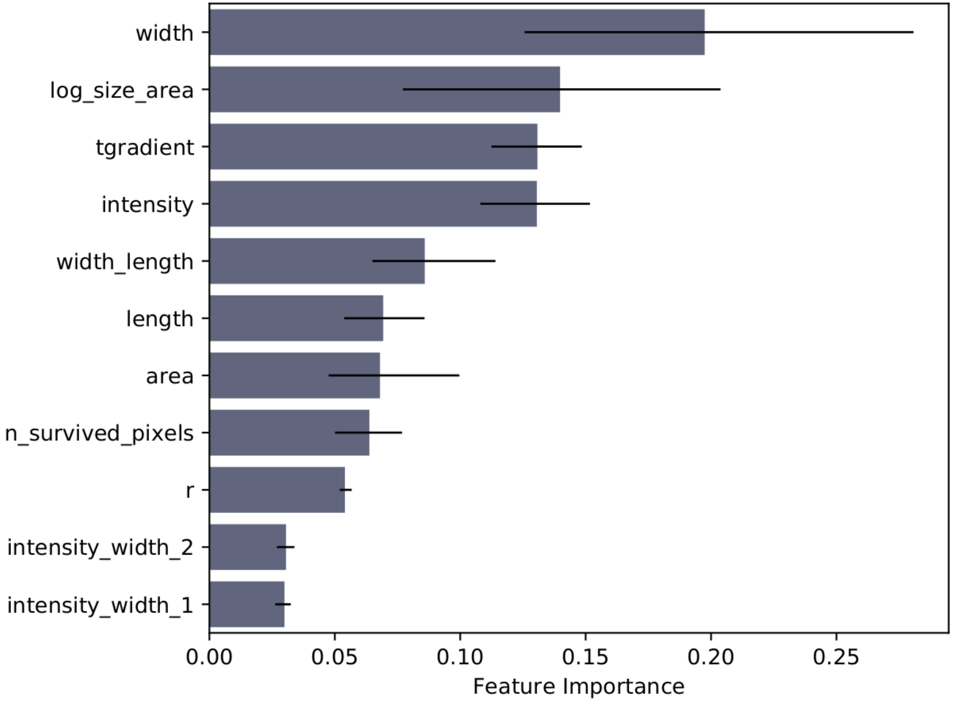
- A model is made to classify showers as being from gamma-rays or from hadrons
- The classifier is trained on diffuse gamma and diffuse proton data
- Assigns a score between 0 and 1 for relative "gamma-ness"



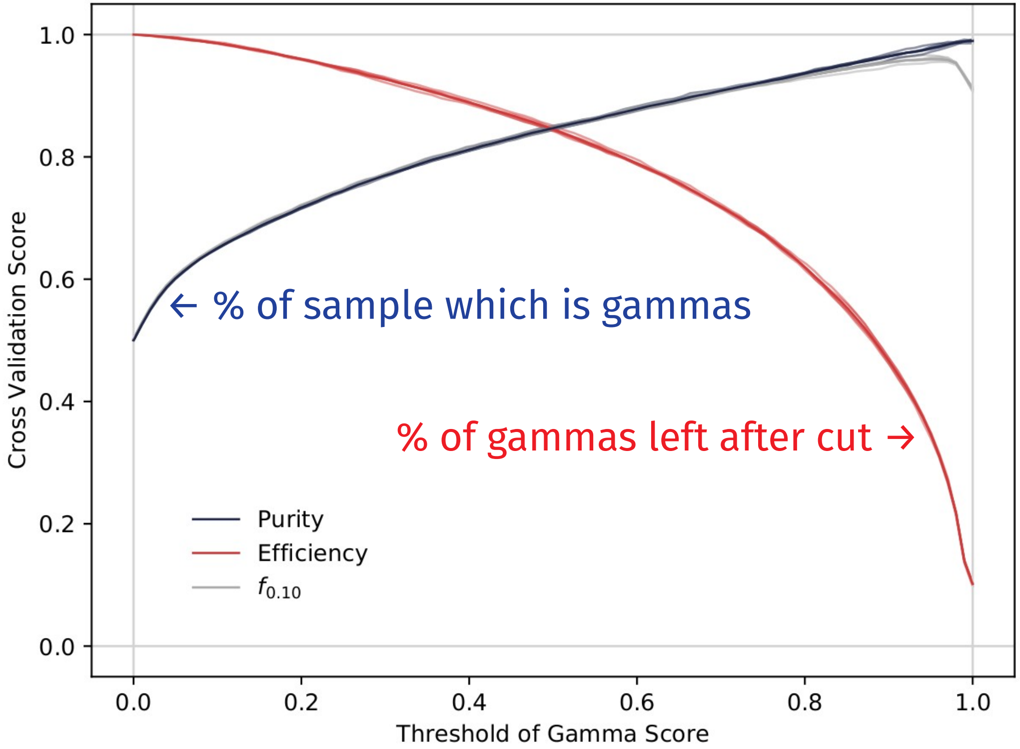
Example proton shower image

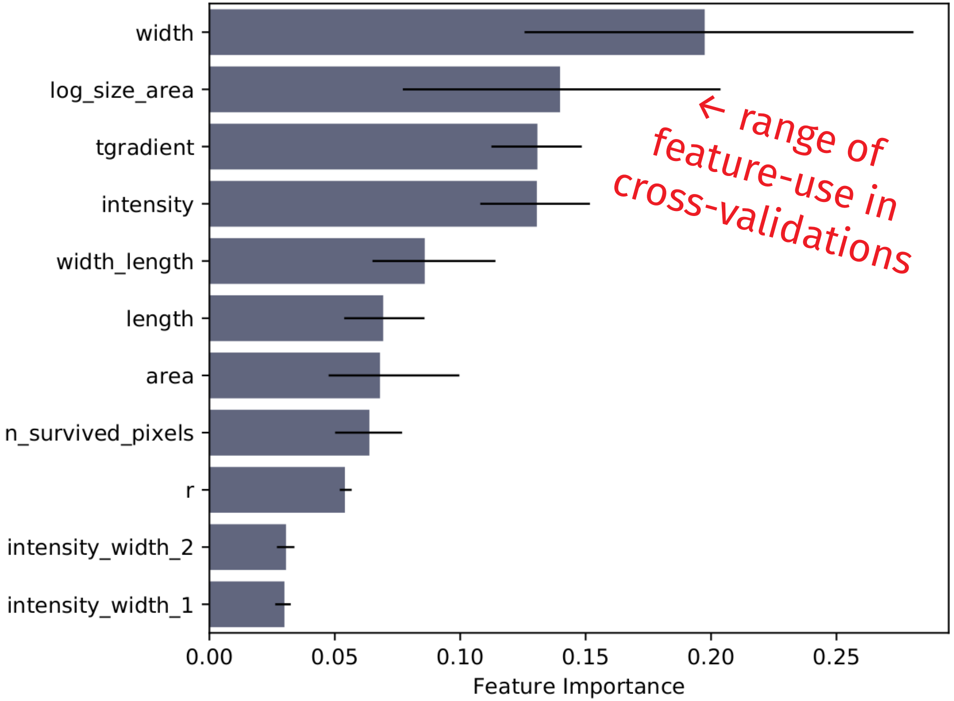
Gamma/hadron separation





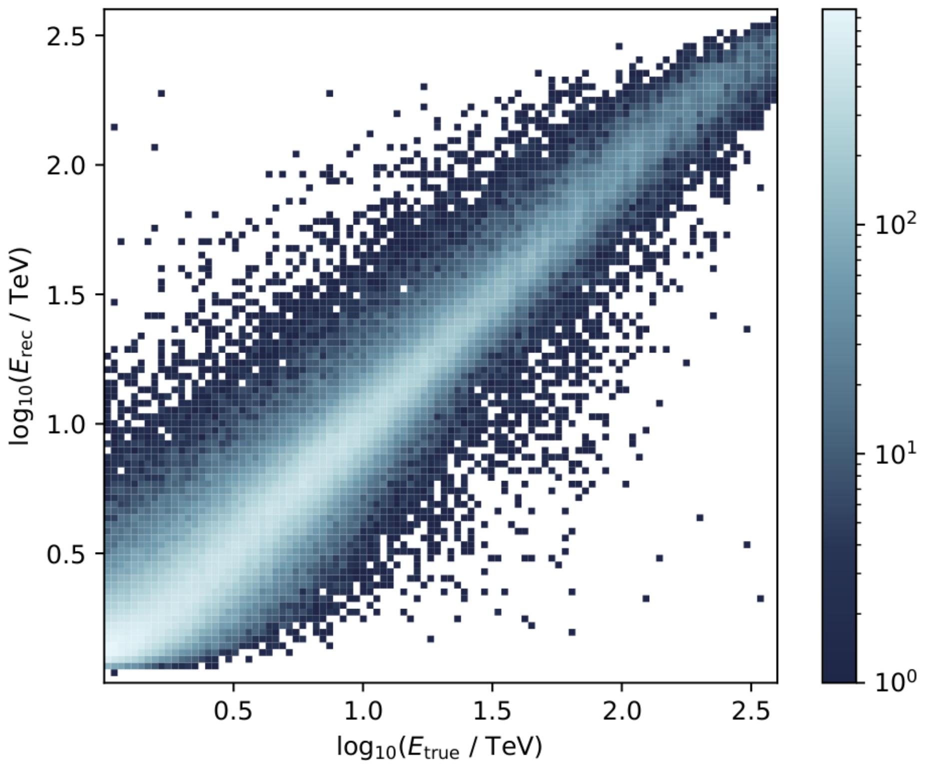
Gamma/hadron separation



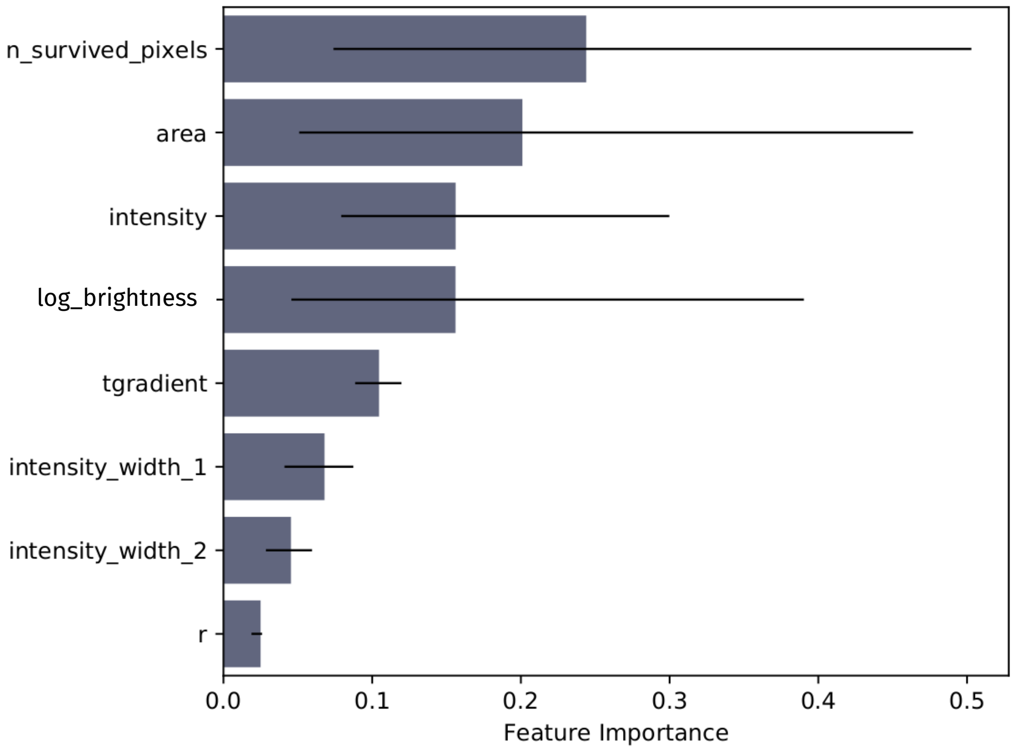


Energy regression

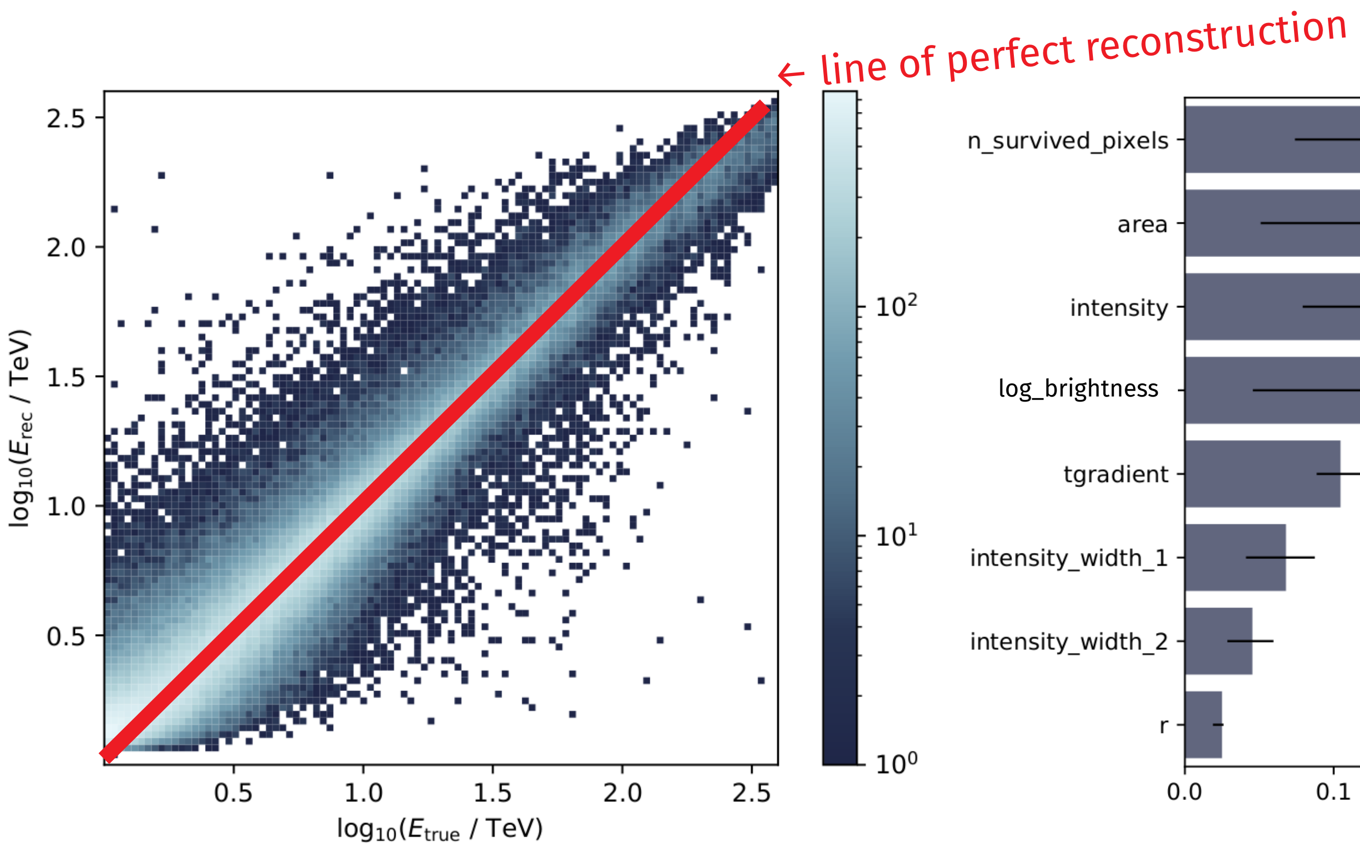
Model performance

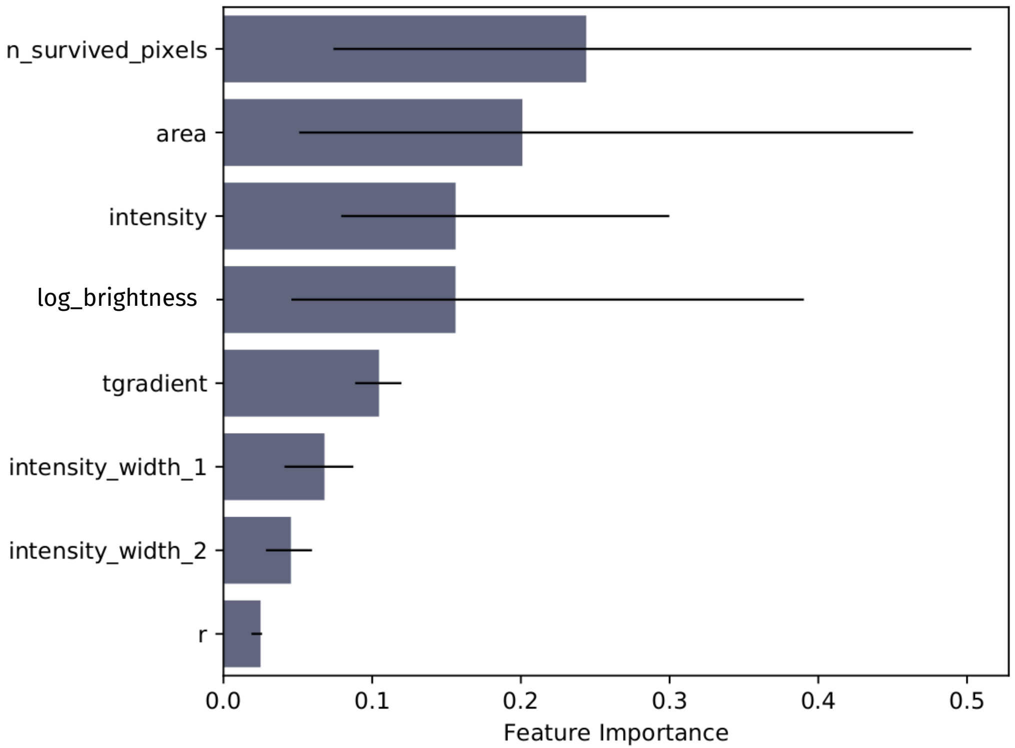


Important features



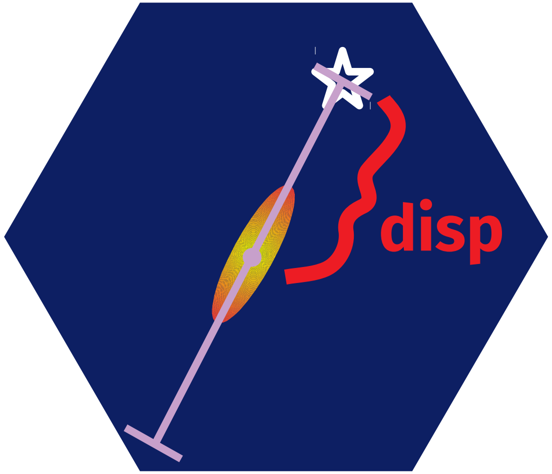
Energy regression

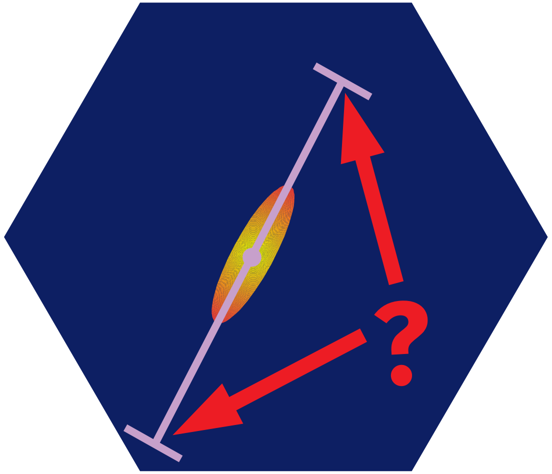




Direction reconstruction

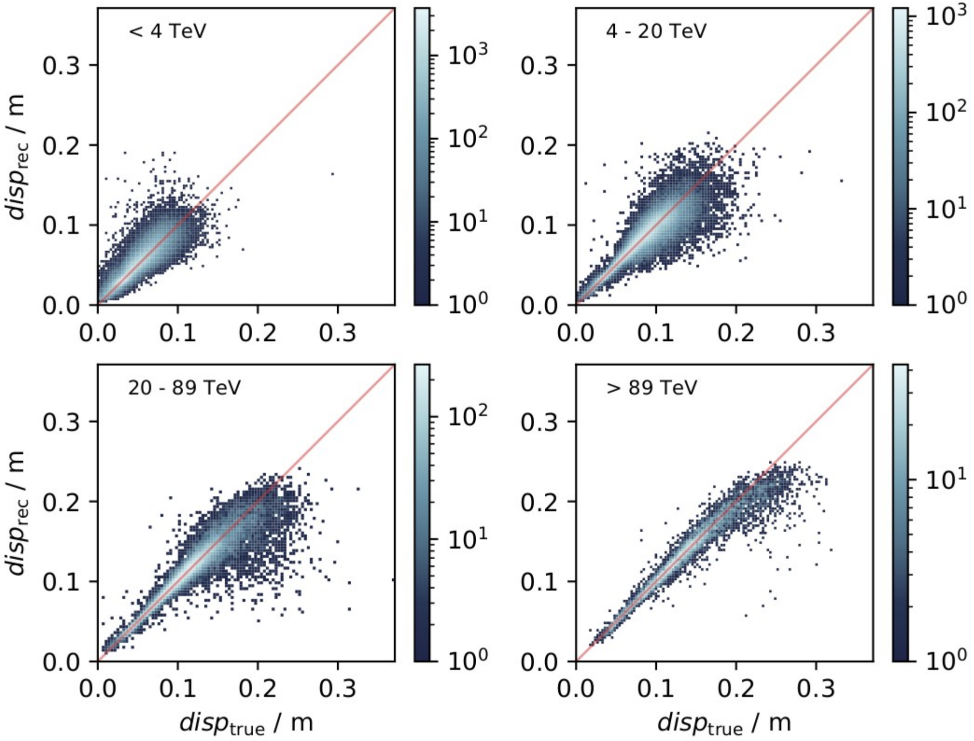
- To reconstruct the direction of the source, the DISP analysis method is used
- The source is assumed to lie on the Hillas ellipse's major axis
- disp is the distance along this axis from the centre-of-gravity to the source position
- Regression is used

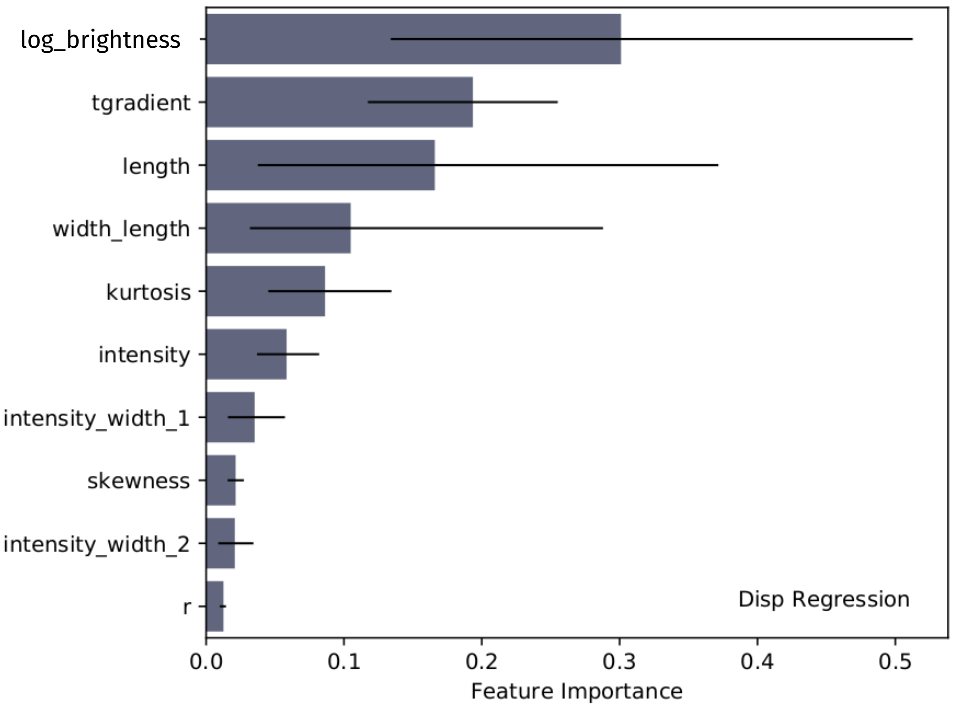




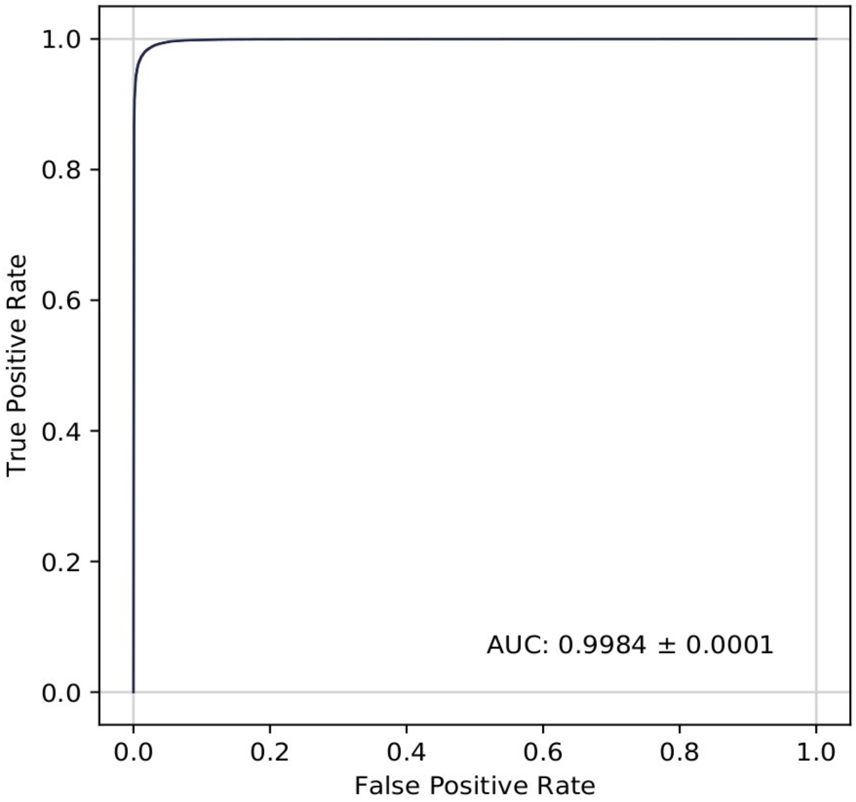
- The direction along the axis (the "sign",) needs to be determined
- Classification is used

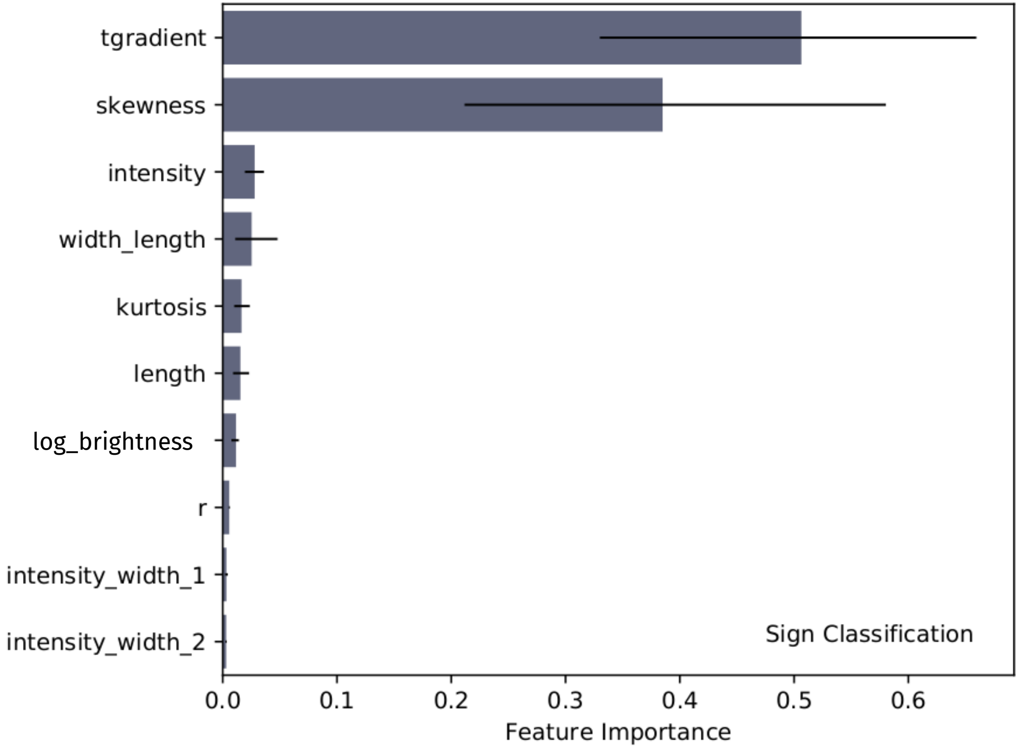
Disp regression



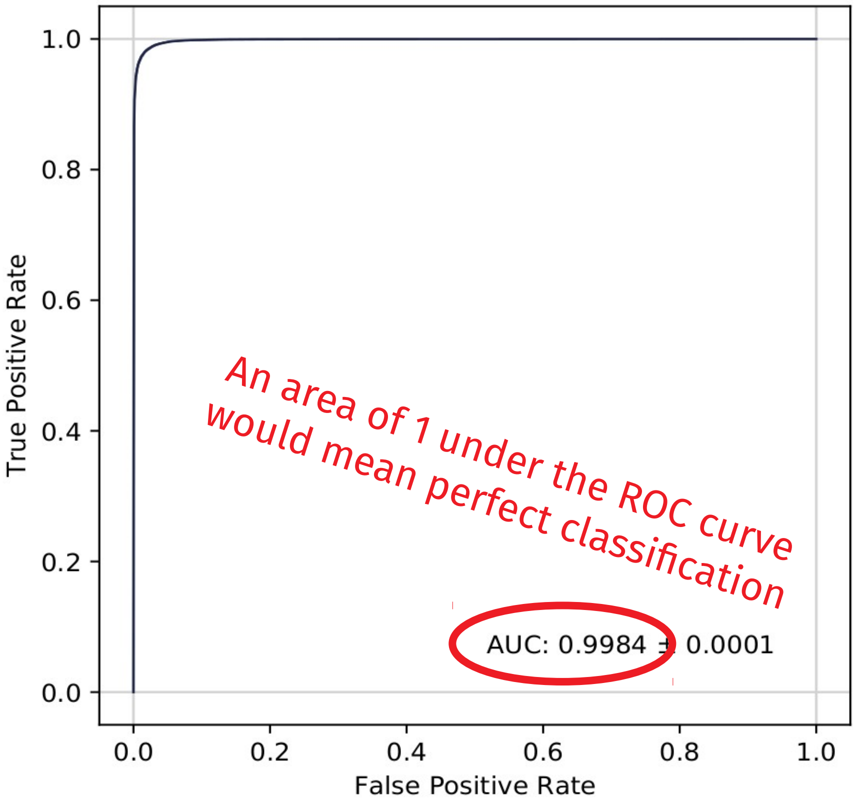


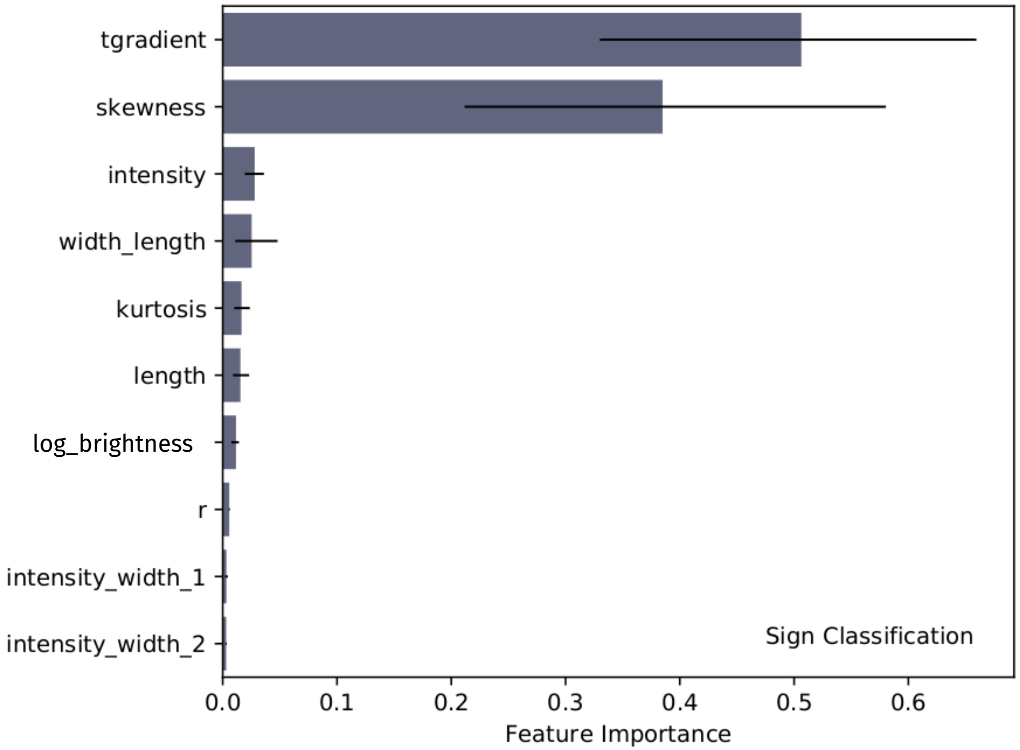
Sign classification





Sign classification





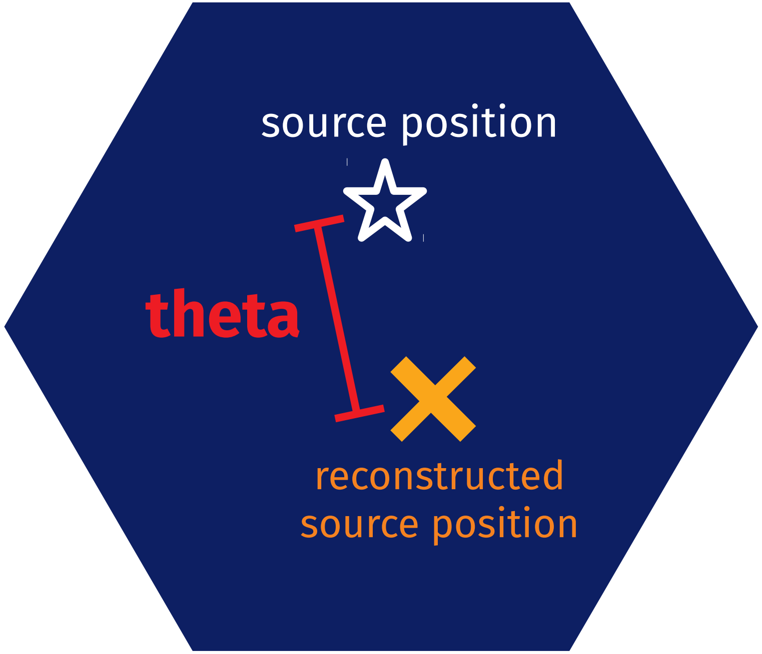
Performance

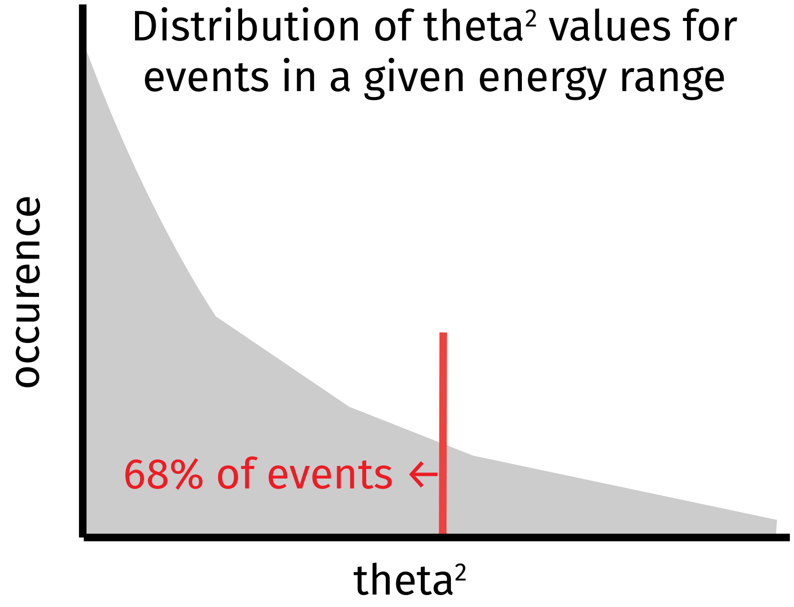
- Telescope performance can be estimated using the reconstructed source gamma and diffuse proton events

- I used simulation from the CHEC group to compare to my own simulations with similar settings (450m scatter radius)

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

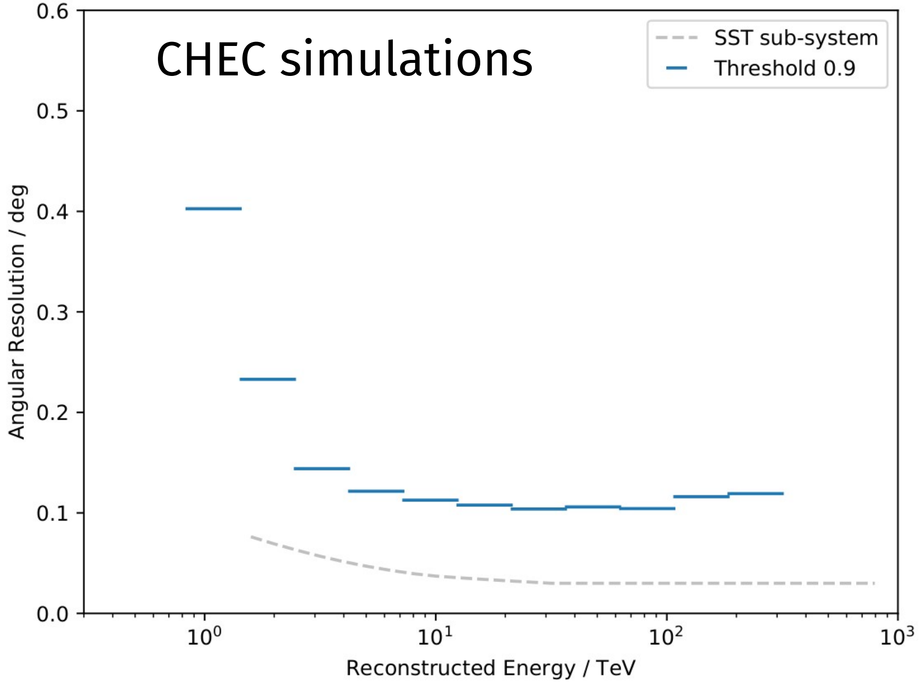
Angular resolution

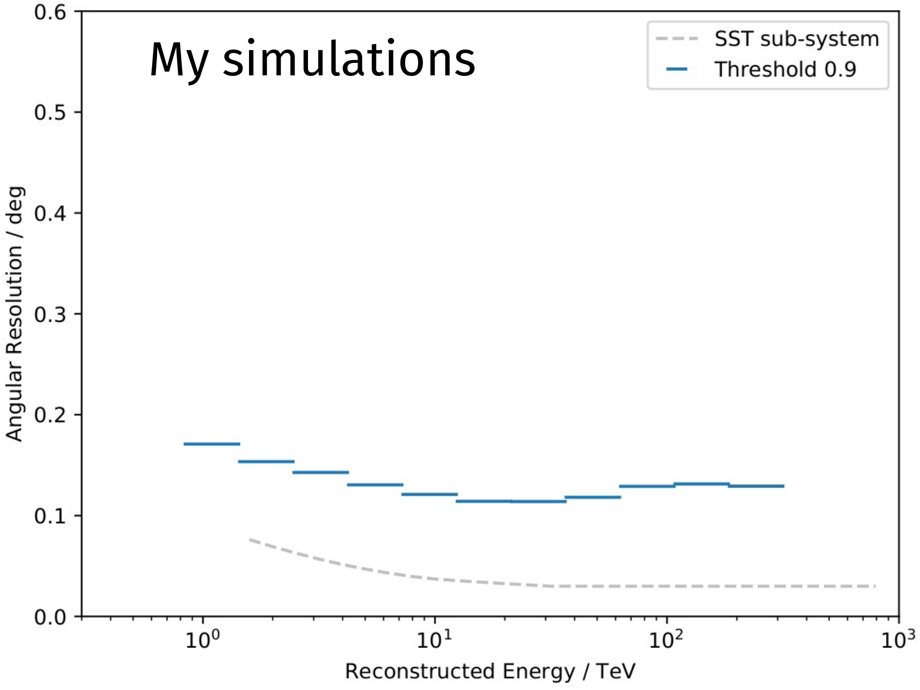




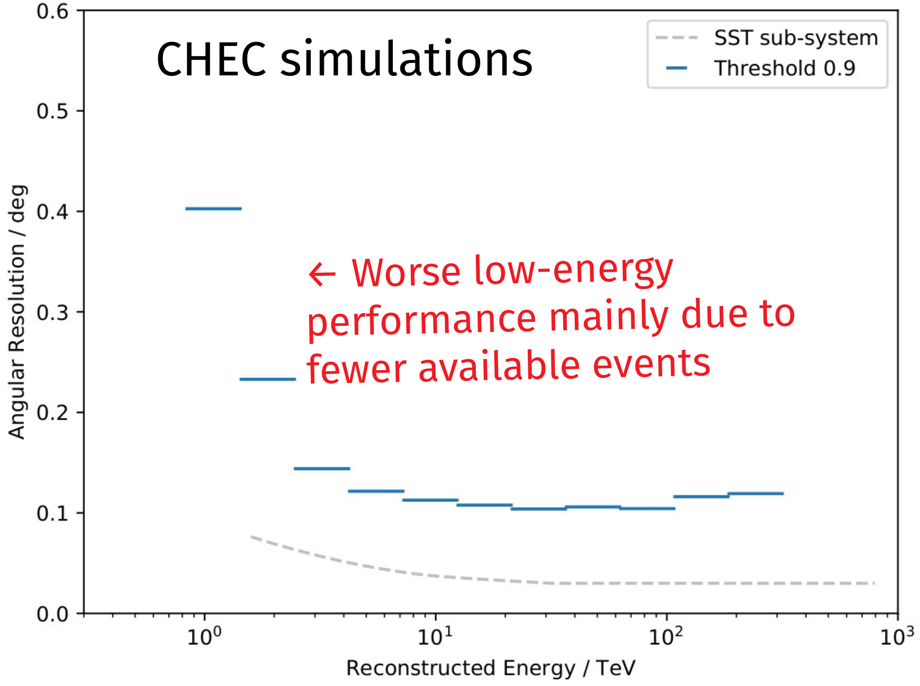
Tighter distribution of reconstructed directions around source position → better angular resultion

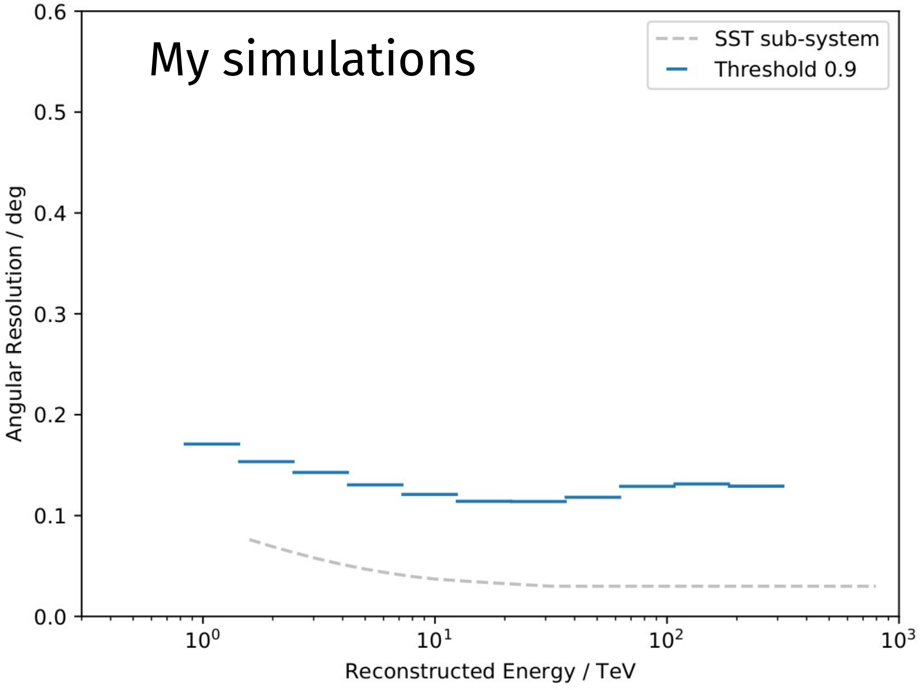
Angular resolution





Angular resolution

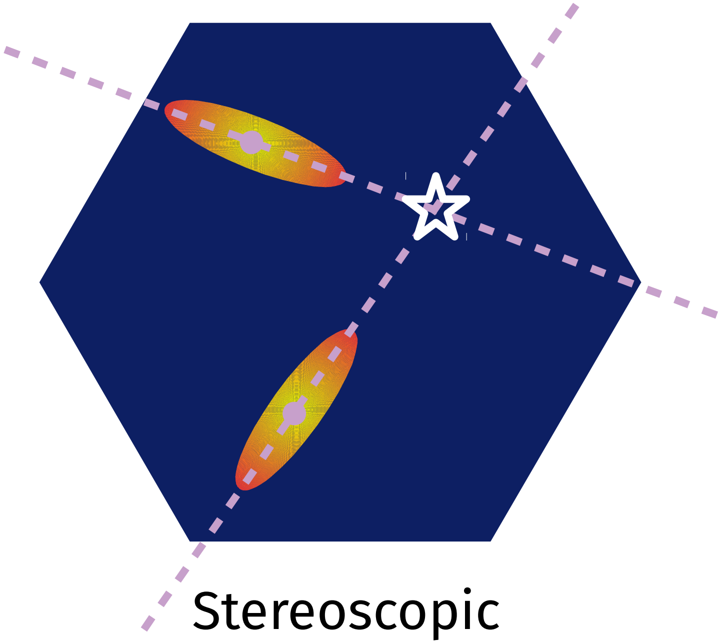




Stereo direction reconstruction

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

Monoscopic

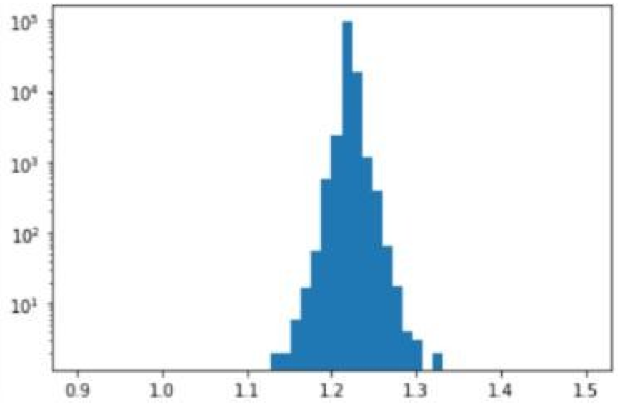


Stereoscopic

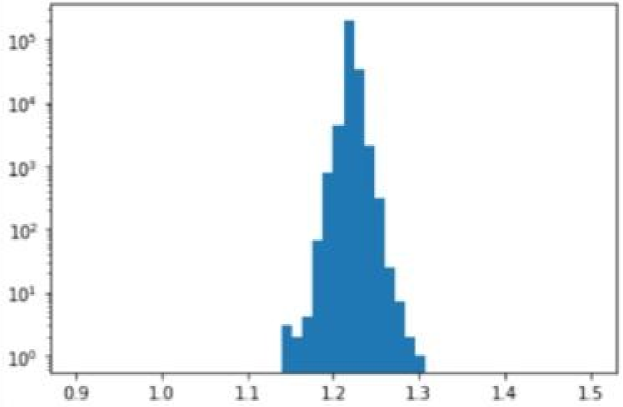
Stereo direction reconstruction

Initial tests showed that, with 2 SSTs, simple geometric reconstruction on its own provided worse results that monoscopic reconstruction

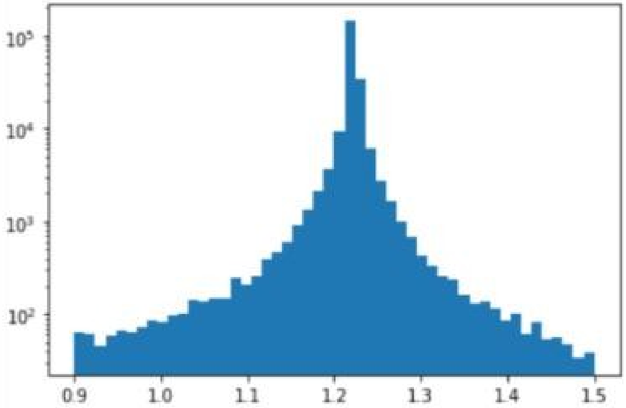
Mono



Mean of mono

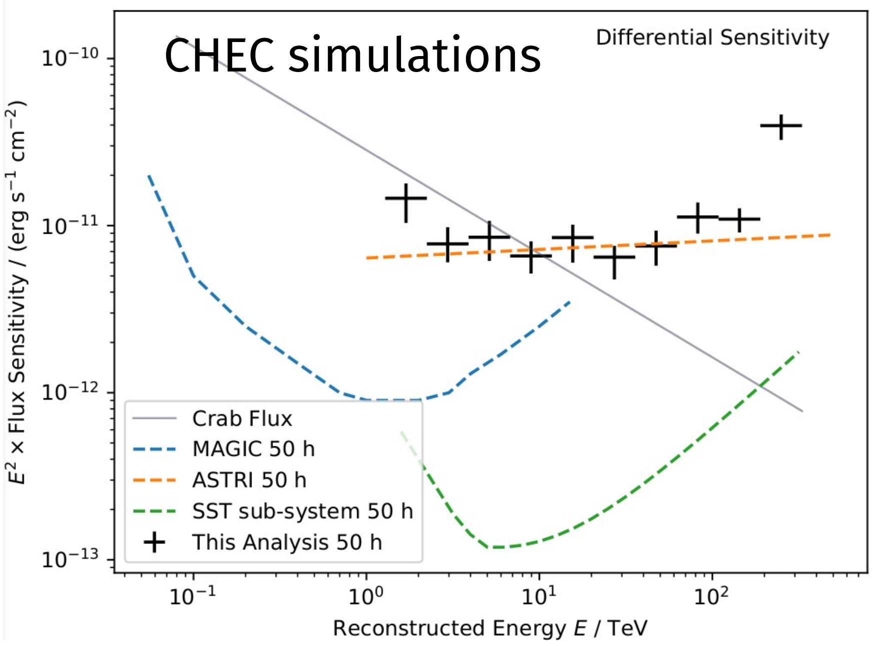


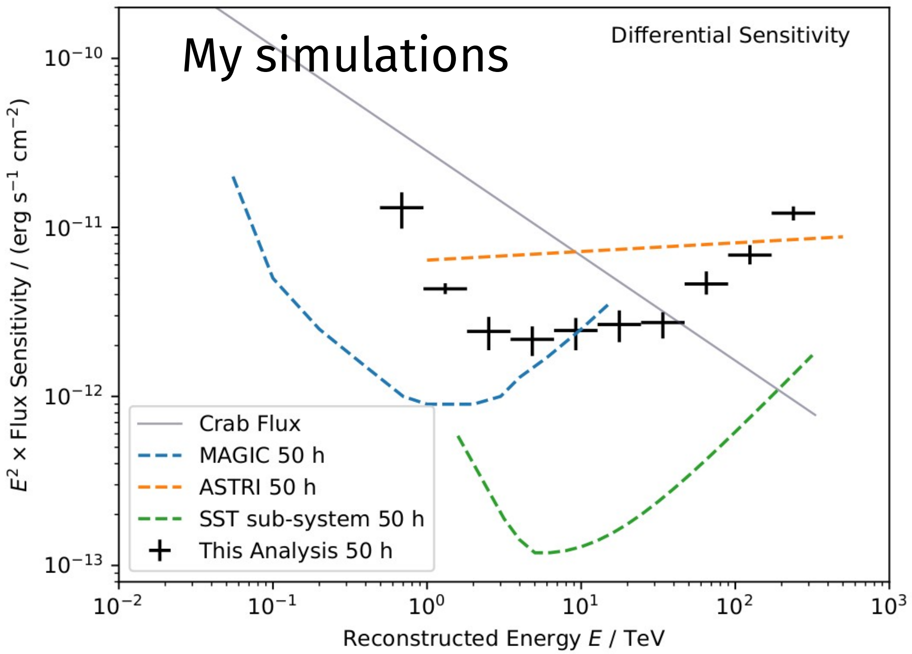
Geometric (ctapipe)



Reconstructed source altitude for point-source gamma-rays

Sensitivity



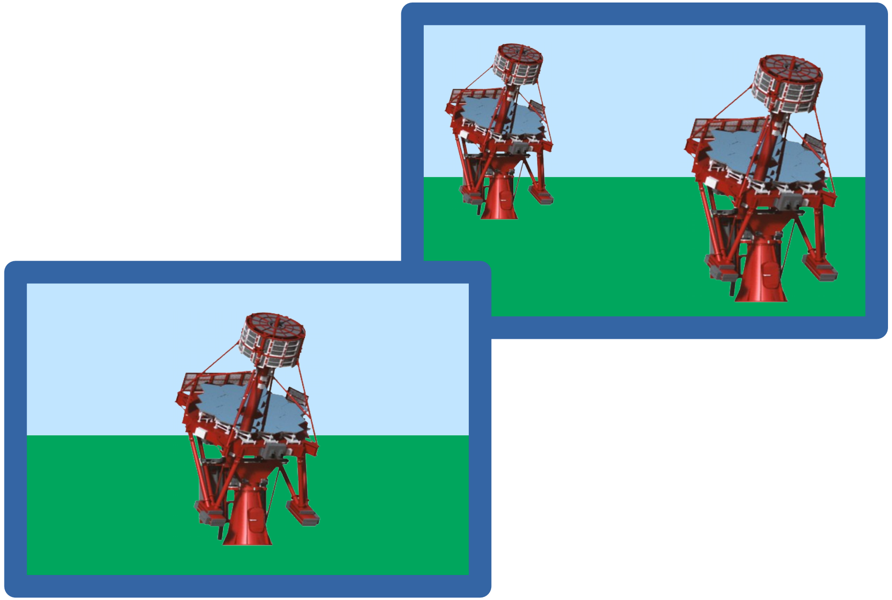


Preliminary simulation comparison

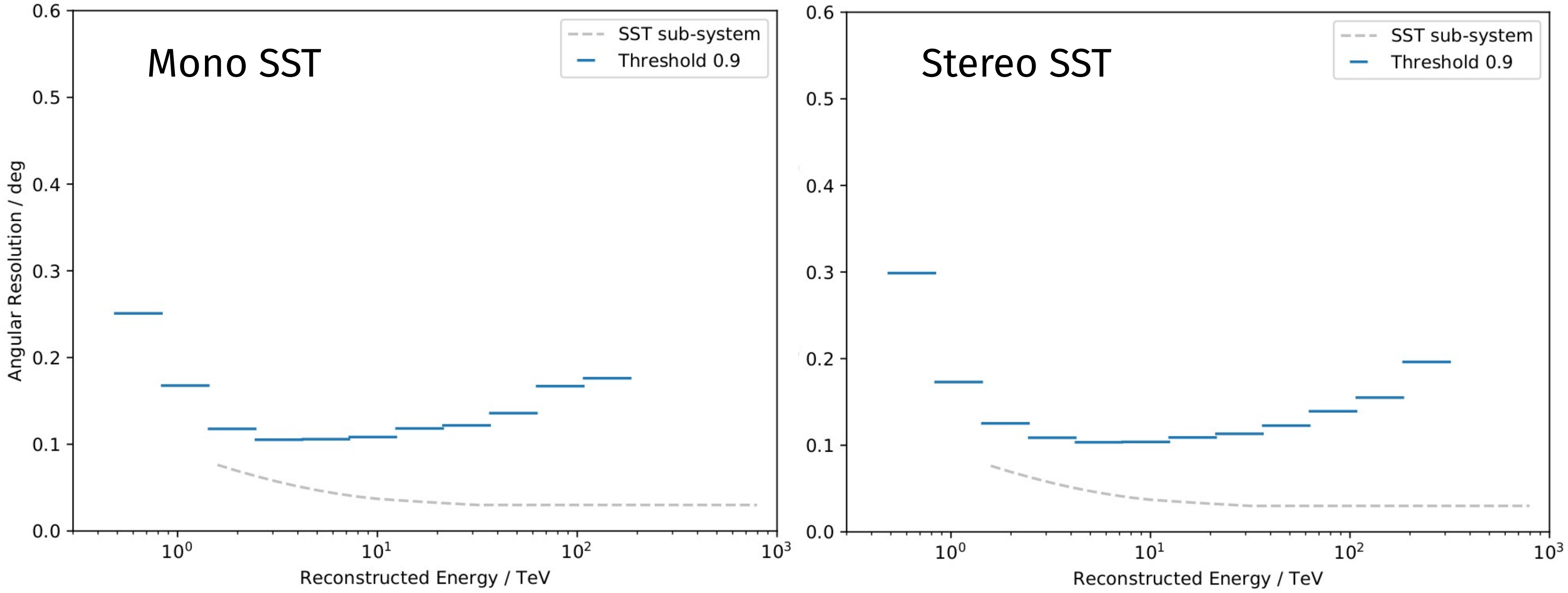
Main simulation runs

- Energy range: 0.5 – 400 TeV
- Spectral index: -2.0
- Scatter radius: 1000m
- ~670,000 surviving source gammas
- ~100,000 surviving diffuse gammas
- ~130,000 surviving diffuse protons

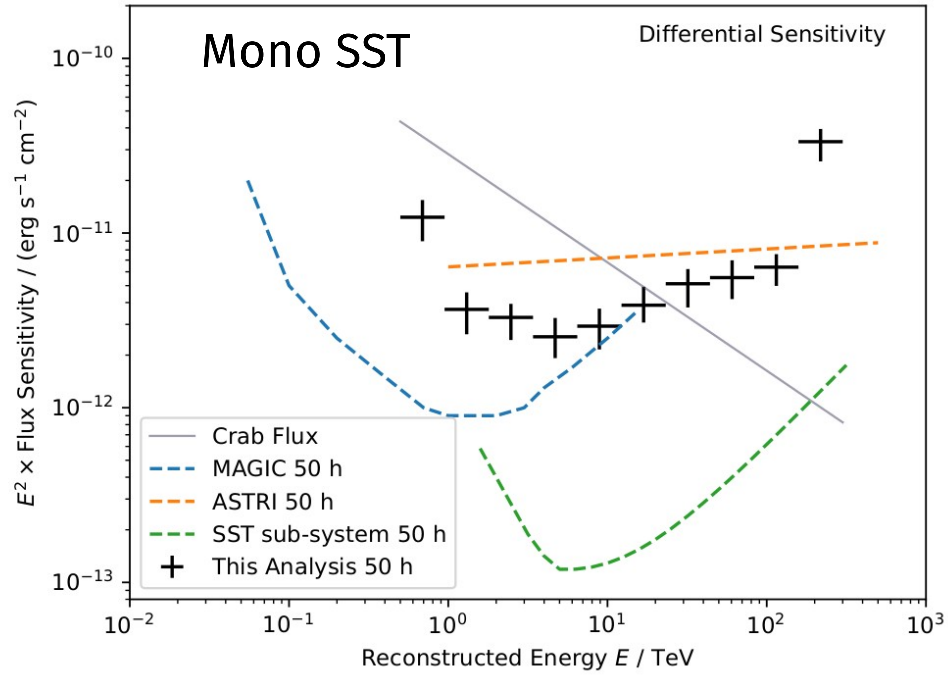
- No suplementary runs yet
- Comparing mono SST to stereo SST

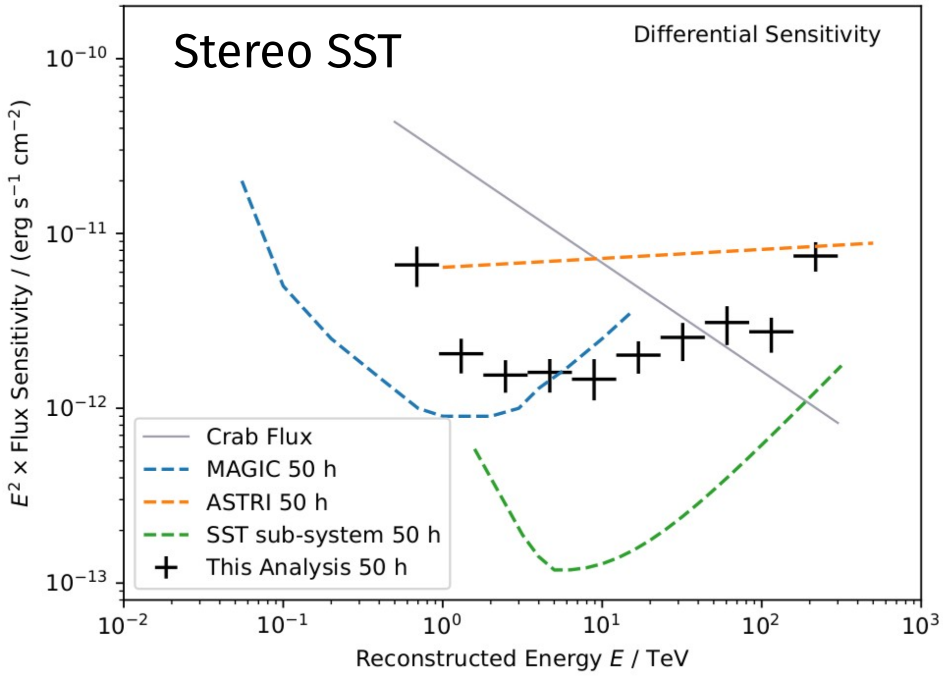


Angular resolution comparison



Sensitivity comparison





Conclusion

- The **Cherenkov Telescope Ring** is an idea to have a worlwide network of IACTs

- The simulational and analysis pipeline has been to be ready for use

- Preliminary simulations show encouraging results for performance

Thankyou