Data Analysis: Extracting science from MAGIC

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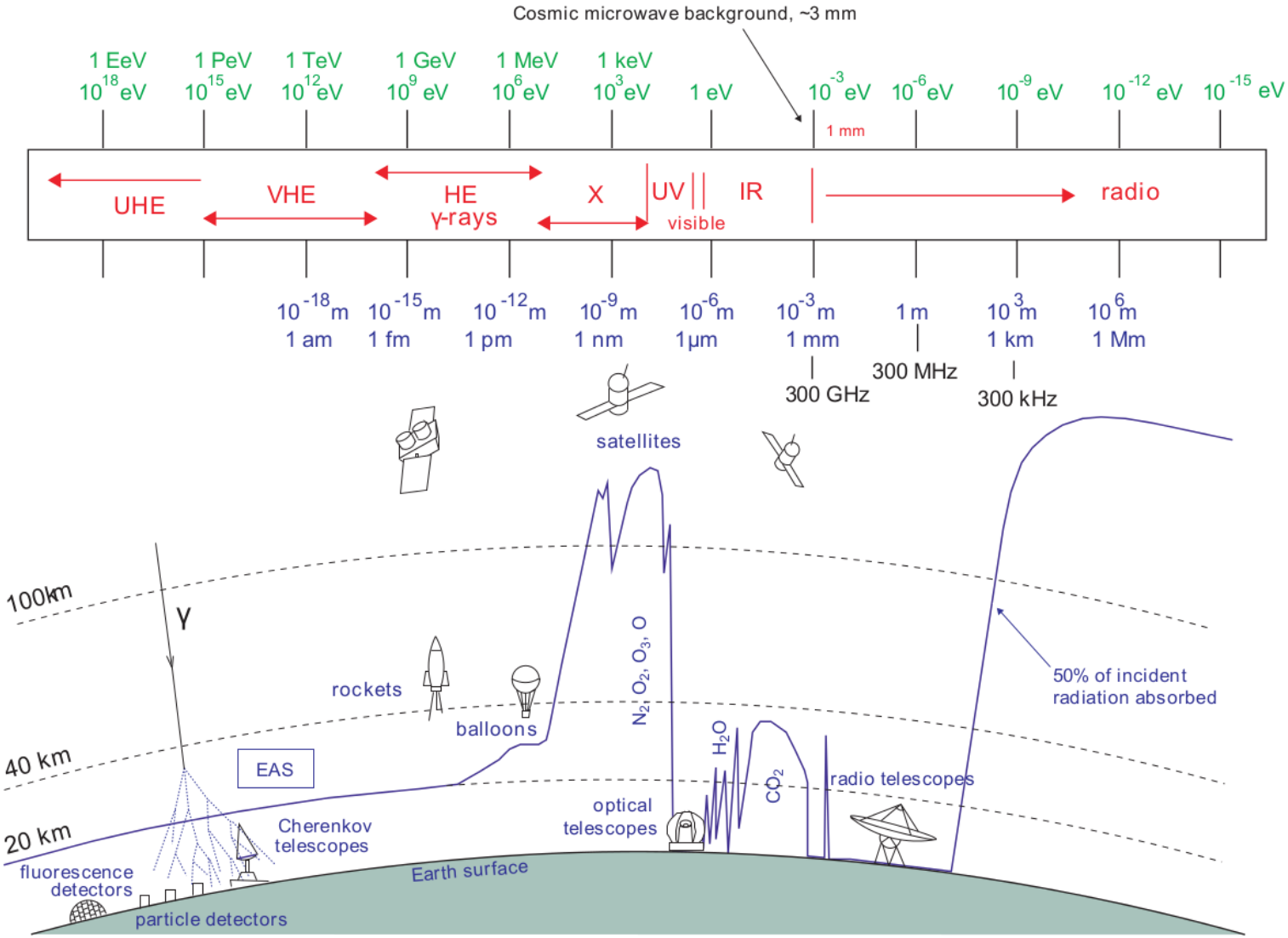
Outline

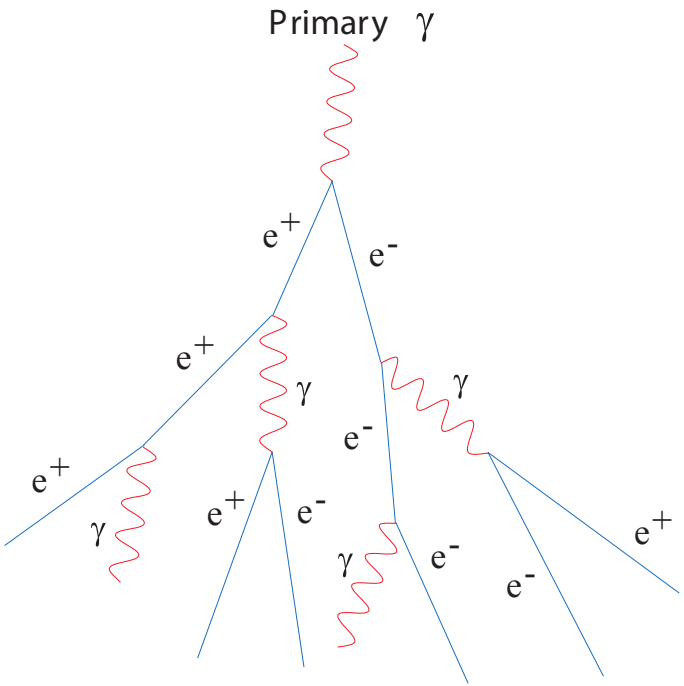
- MAGIC telescopes
  - Imaging Air Cherenkov Technique (IACT)
  - Telescope hardware
- Standard analysis
  - Signal extraction
  - Hillas parametrization
  - Determination of physical parameters
  - Final products
- My work - Template analysis

The Atmosphere



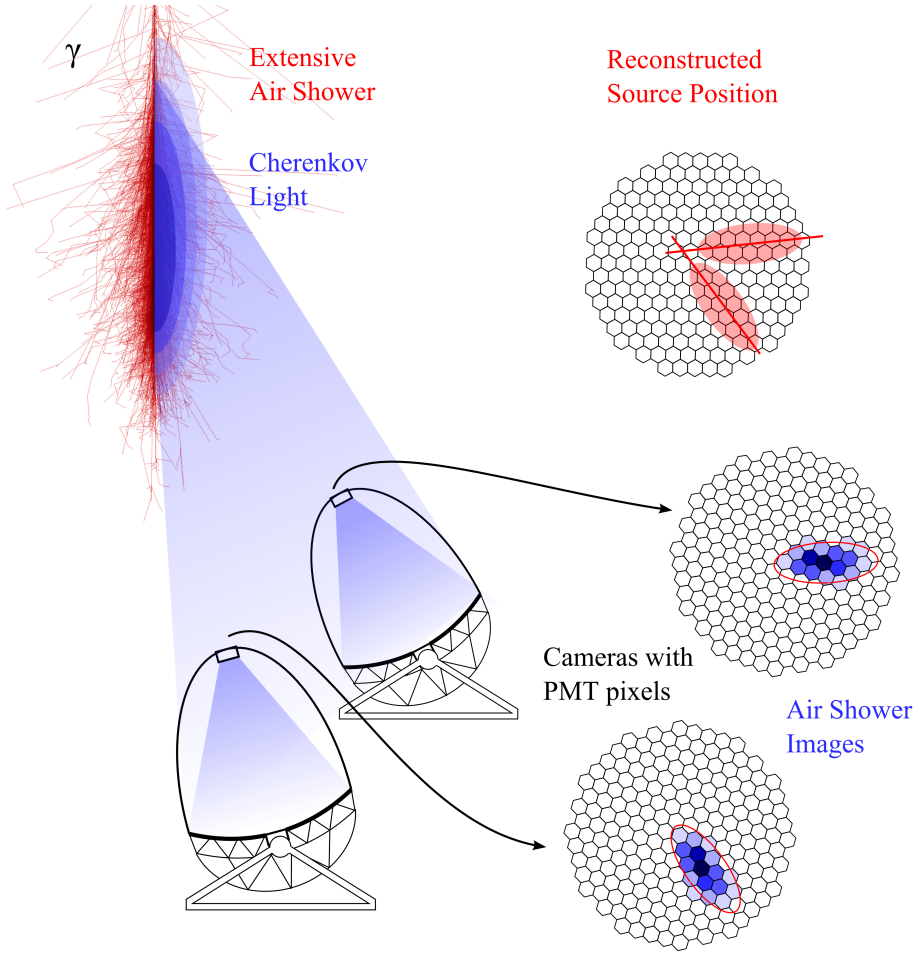
Extensive Air Showers

Electromagnetic shower



- particle cascade with
  - pair production
  - bremsstrahlung
- charged particles, faster than speed of light in air
  $\Rightarrow$ Cherenkov radiation

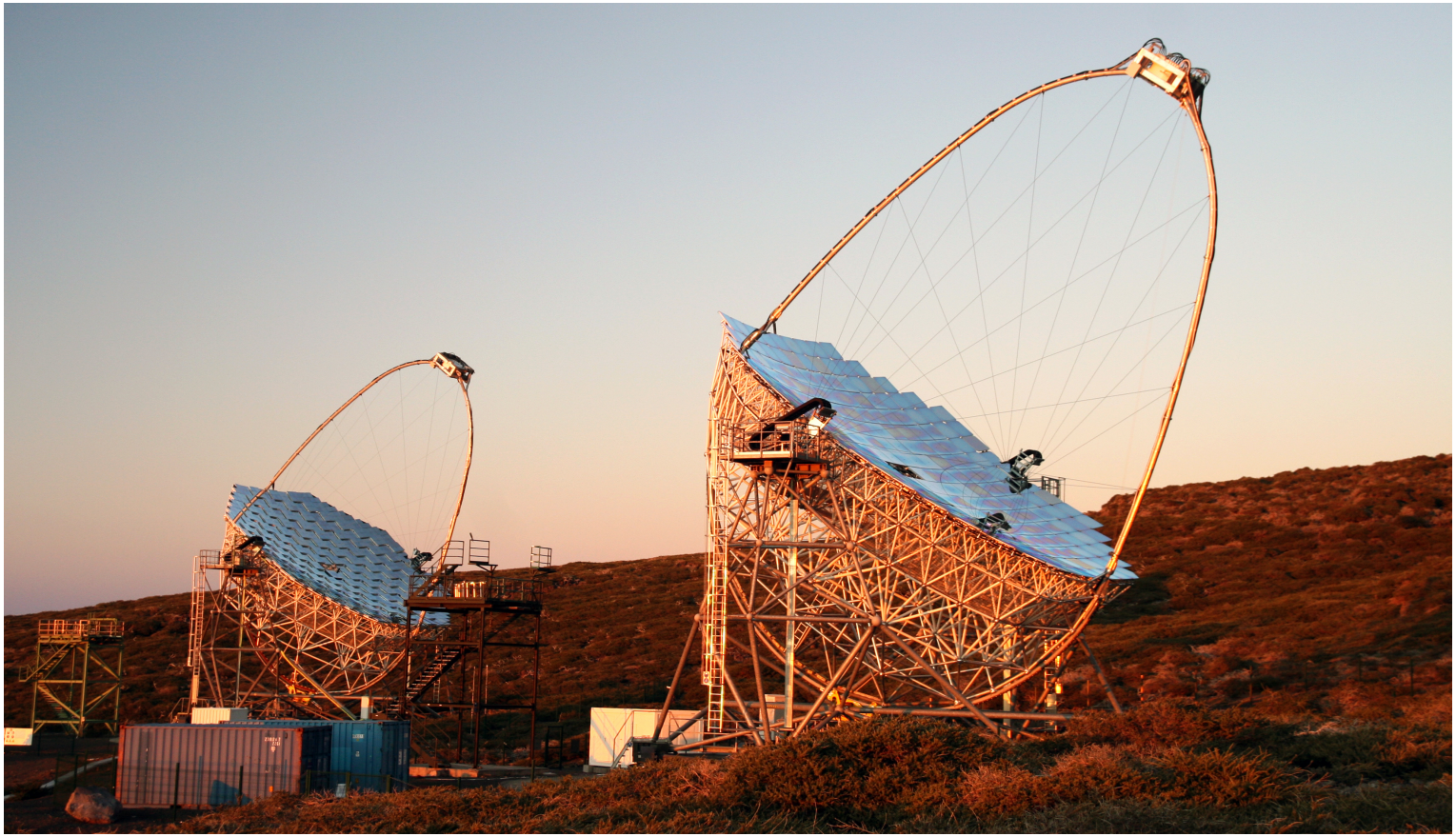
Imaging Air Cherenkov Technique



- image with elliptic shape
- stereo for better reconstruction
- background from cosmic rays, ~factor 1000

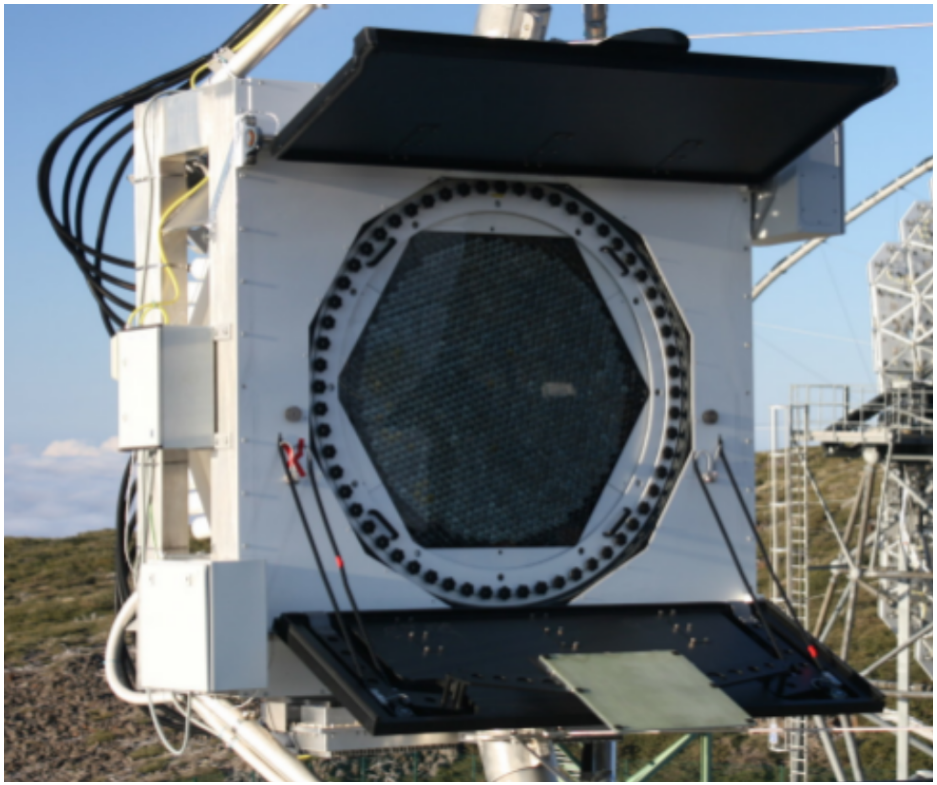
Main Imaging Air Cherenkov Telescopes

The MAGIC telescopes

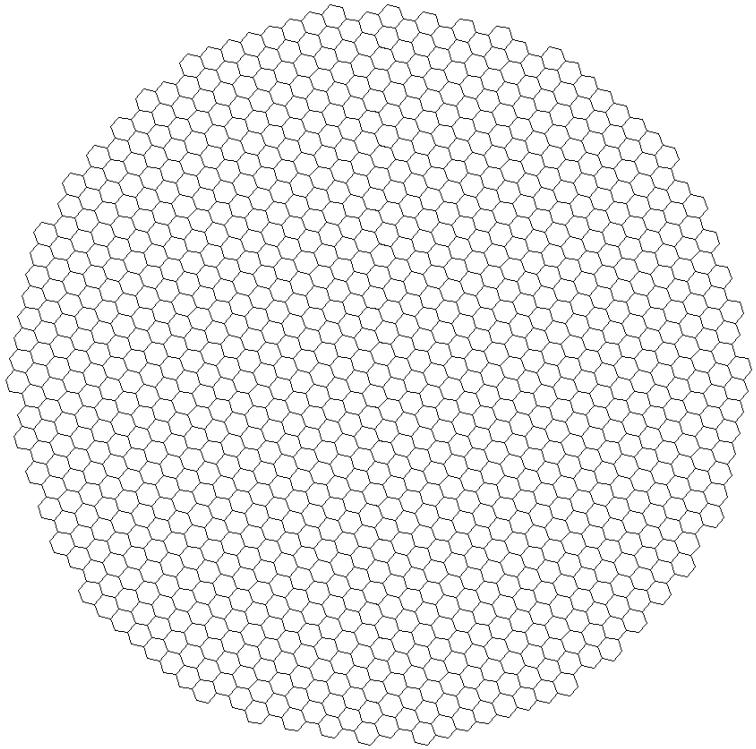


- 2200 m above sea level
- 2 telescopes, 85 m apart
- light structure $\rightarrow$ fast repositioning
- parabolic dish: 17 m diameter
- focal length: 17 m
- 1 m^2 and 0.25 m^2 mirrors

Camera

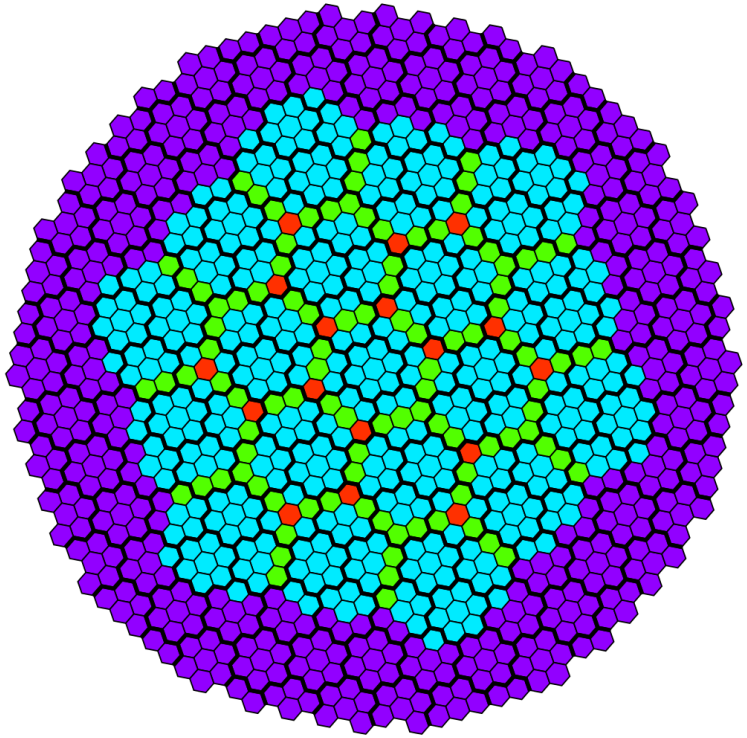


- PMTs (photo multiplier tubes) as photon detectors
- 1039 pixels per camera
- ~1 m diameter
- 3.5° field of view



Electronics

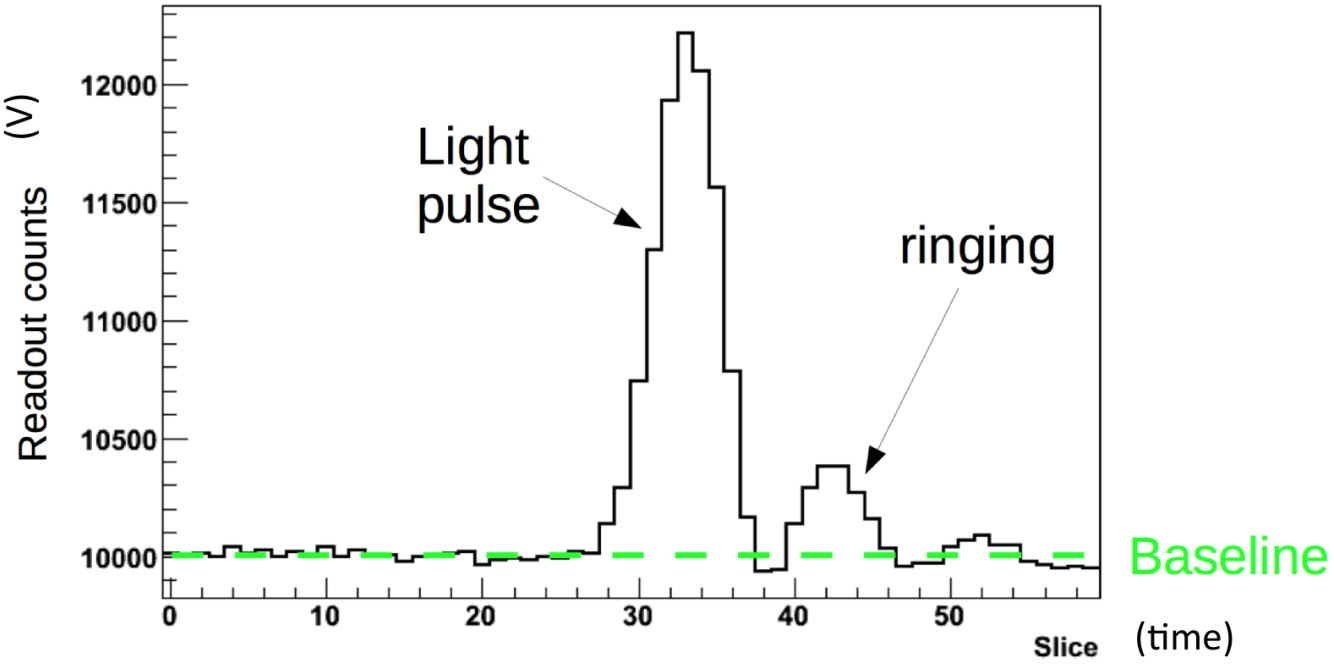
- trigger
  - L0: minimum signal in single pixel
  - L1: signal in neighbouring pixels
  - L3: trigger in both telescopes
- readout: DRS4 chip
  - up to 2 GSamples/s
  - 1024 capacitors



saved to disk: 60 time slices with charge (30 ns in total) for each pixel

Data Analysis

Signal extraction



- pedestal subtraction
- search for signal (sliding window)

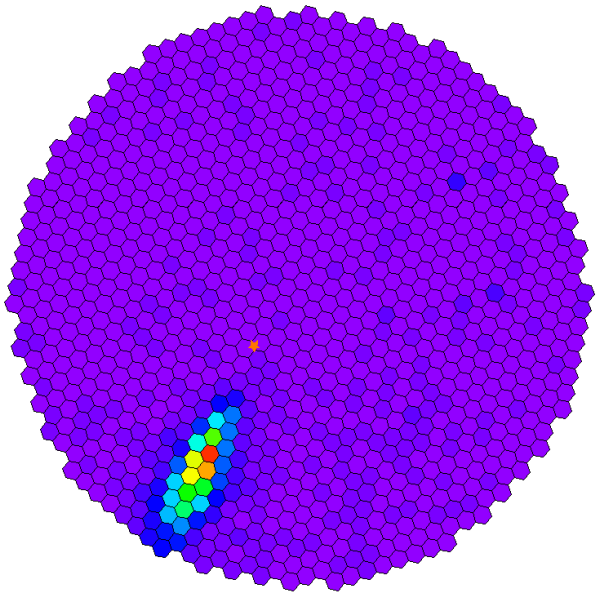
$\Rightarrow$ for each pixel:

- number of photo electrons
- arrival time

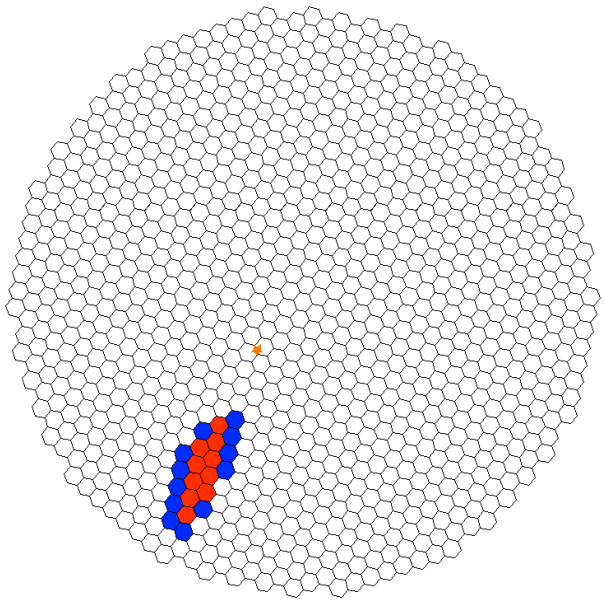
Image Cleaning

Two-level image cleaning

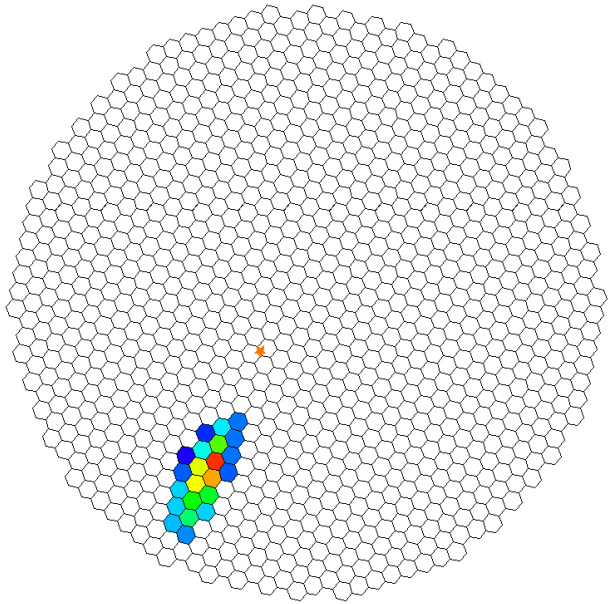
- core pixel: number of photons above threshold$_1$
- boundary pixel: neighbour of core pixel, number of photons above threshold$_2$<threshold$_1$
- include time contraints for core and boundary



calibrated image

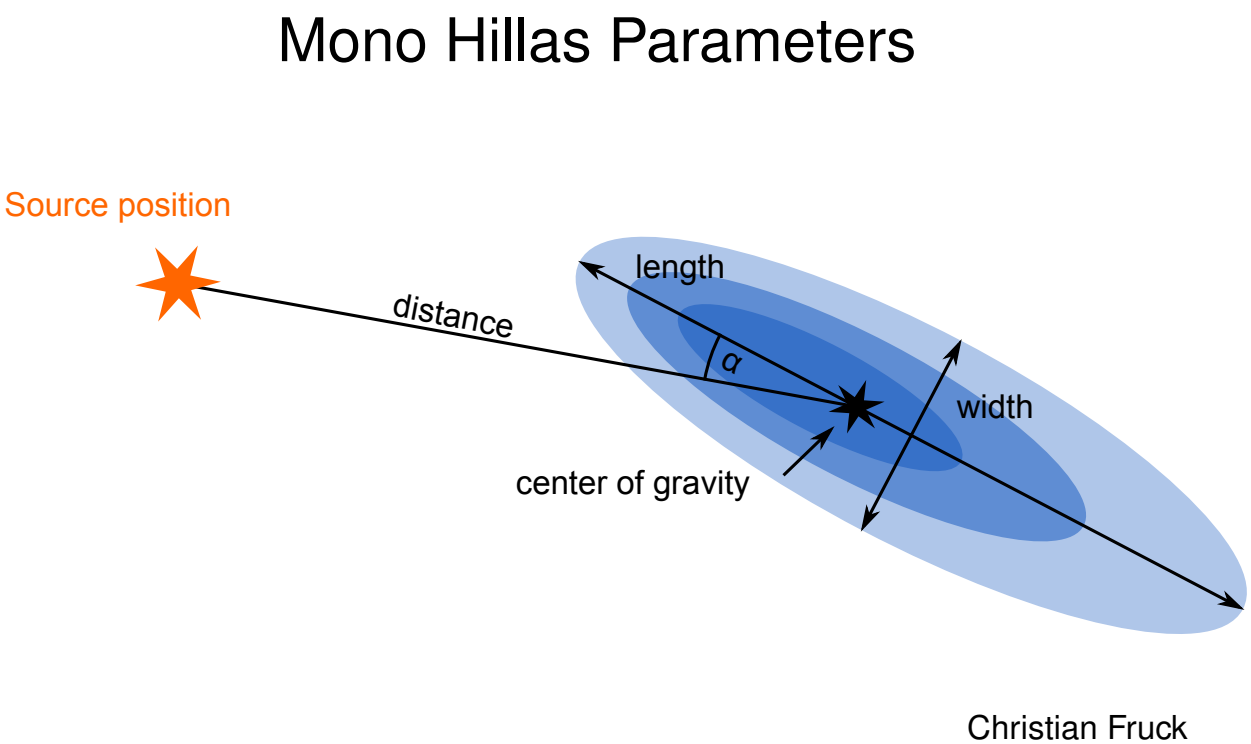


core and boundary



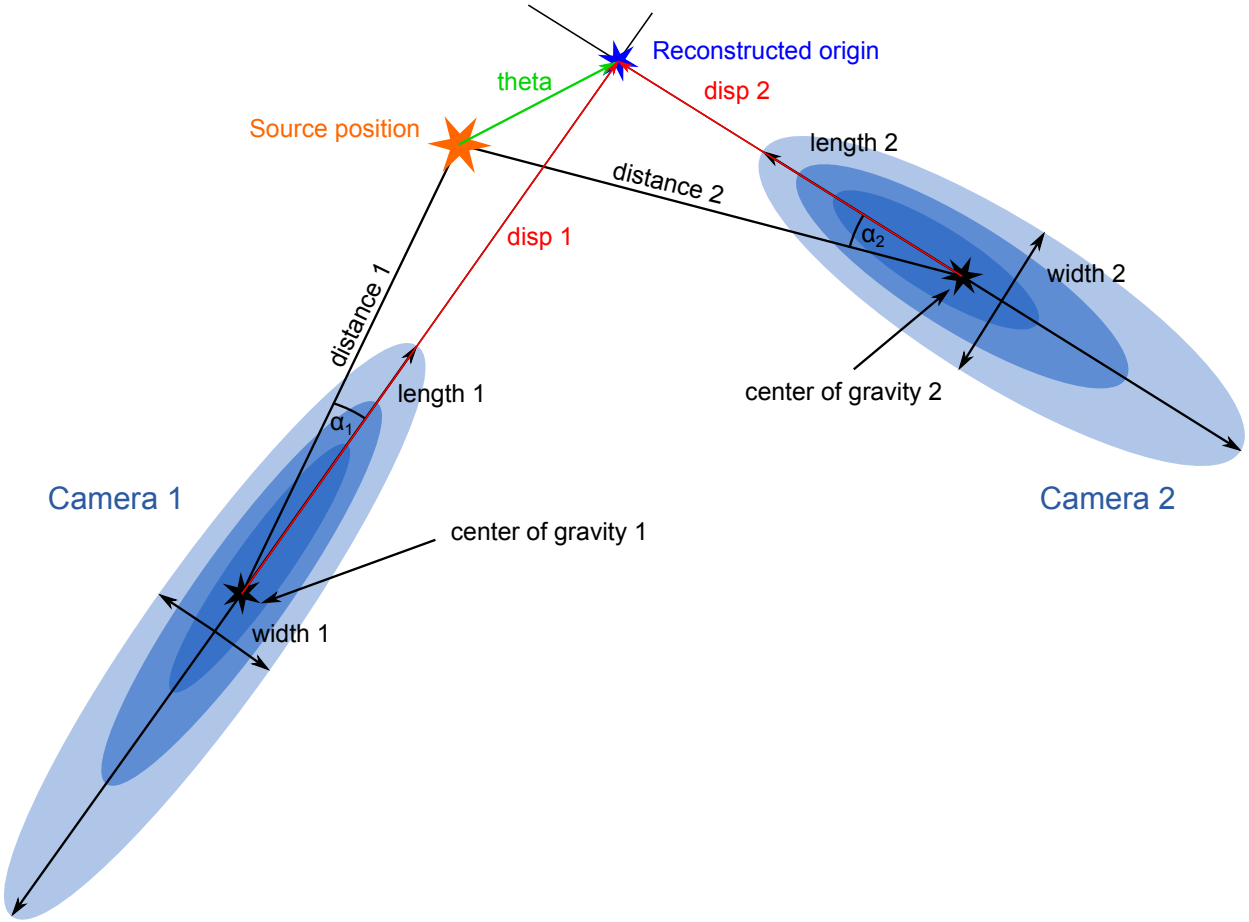
cleaned image

PARAMETRIZATION



- number of photons
- length
- width
- distance to source
- α
- time parameters
- ...

PARAMETRIZATION



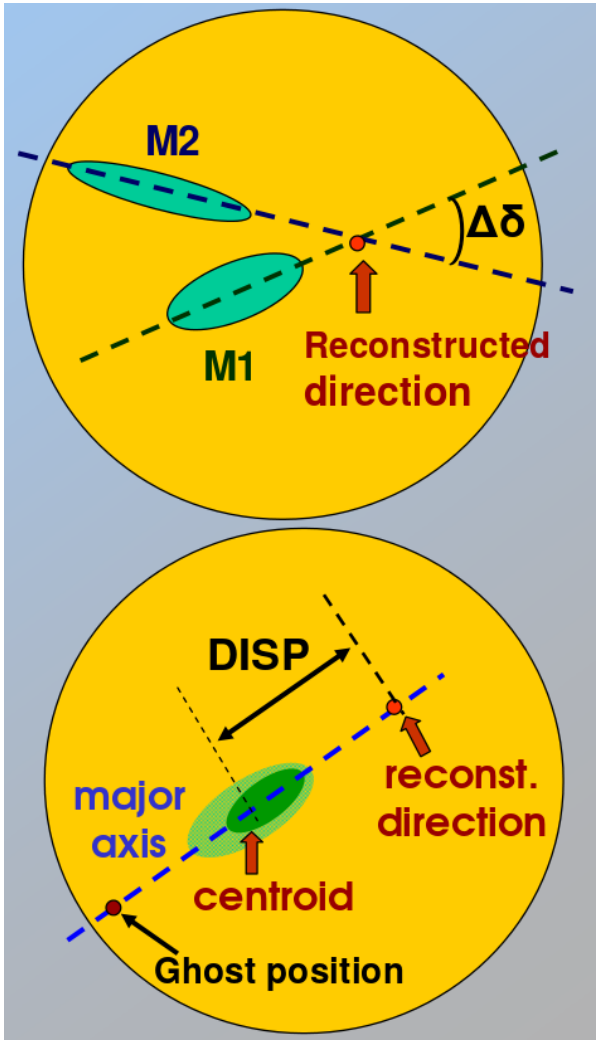
- number of photons
- length
- width
- distance to source
- α
- time parameters
- ...

Reconstruction

- based on Monte Carlo simulations
  - atmosphere as part of the detector
  - simulate the telescope response
  - analyze like data

- parameters to reconstruct:
  - energy of the primary particle: look-up table
  - direction the of primary particle: stereo disp method
  - hadronness: Random Forest

Direction reconstruction



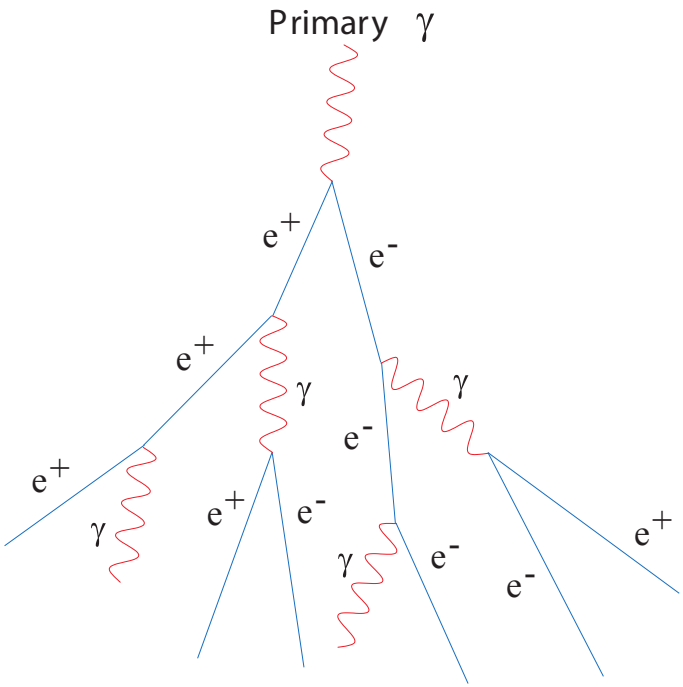
geometrical stereo reconstruction

mono DISP reconstruction with Random Forest

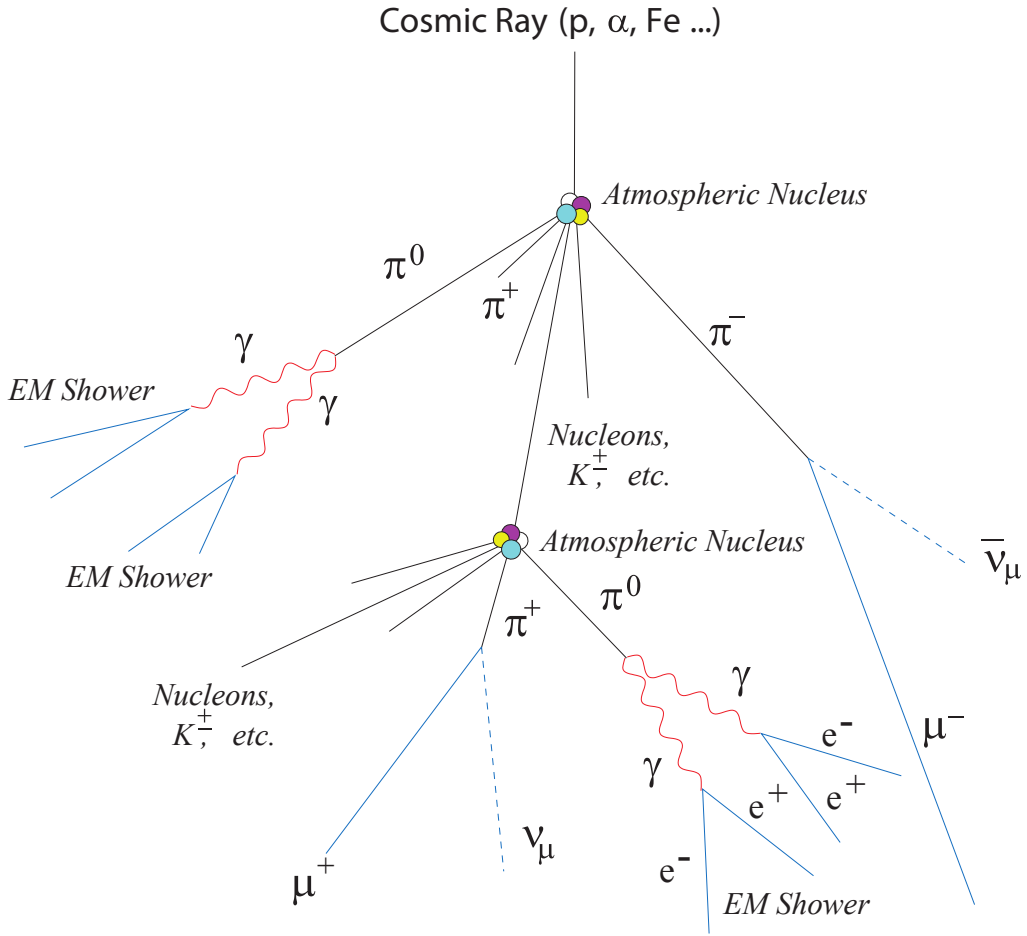
stereo DISP $\Rightarrow$ combine DISP of both telescopes to get direction

Gamma-Hadron separation

Electromagnetic shower

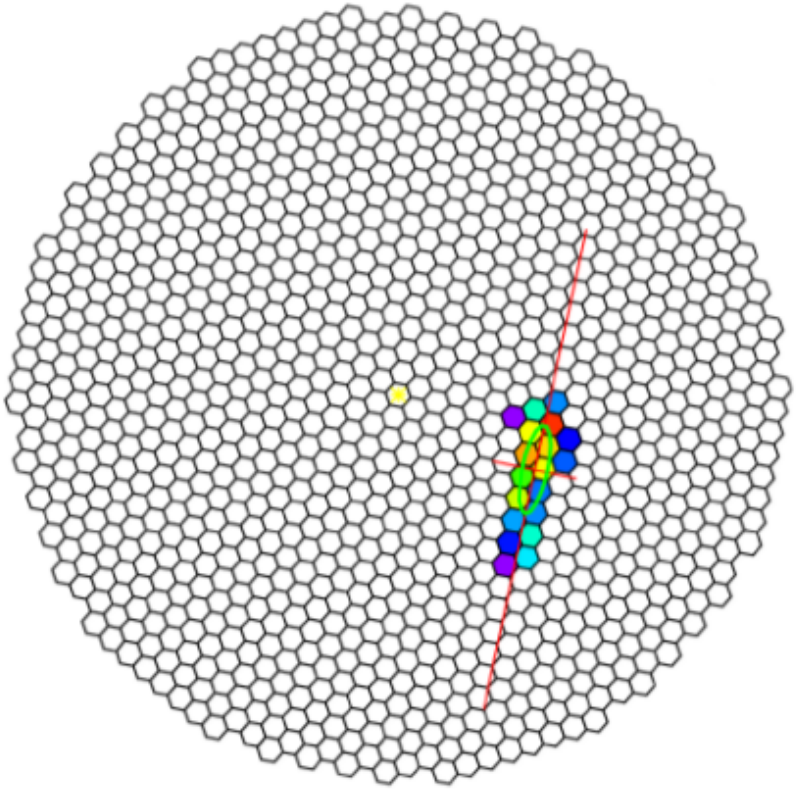


Hadron shower

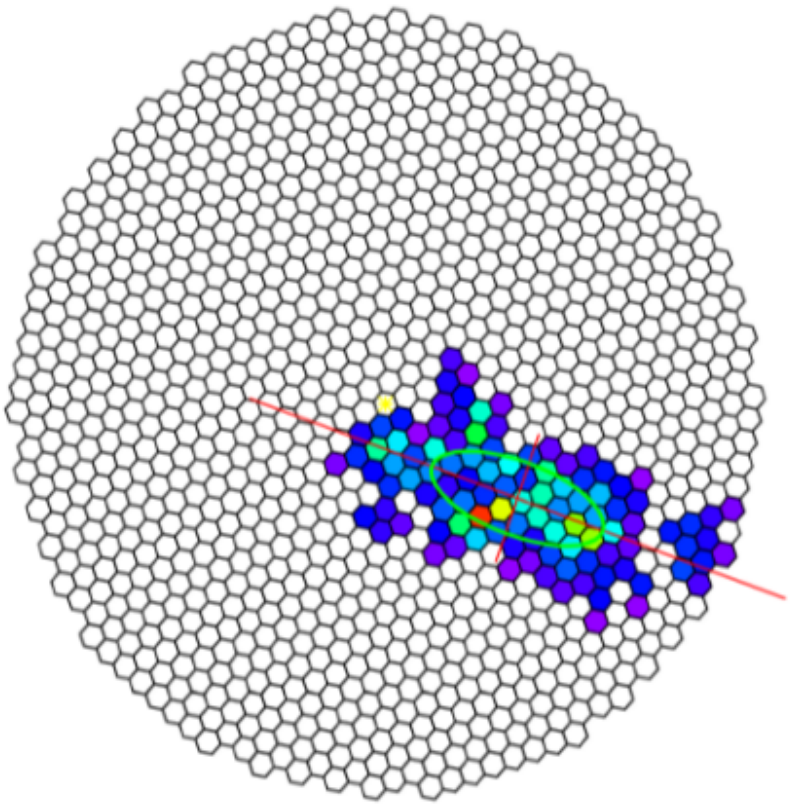


Gamma-Hadron separation

Gamma

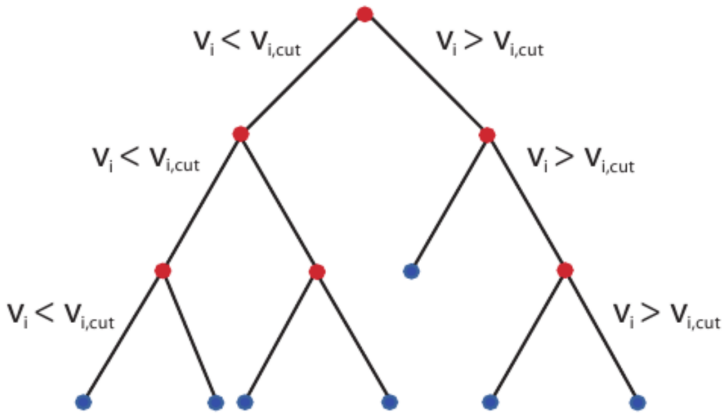


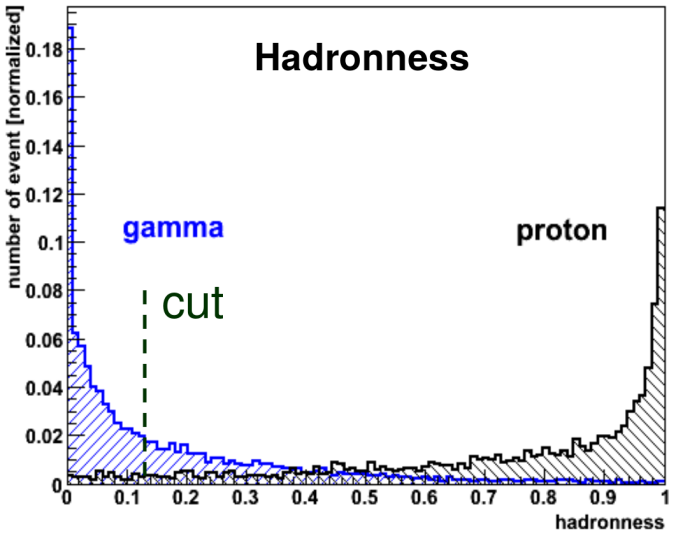
Hadron



Gamma-Hadron separation

Decision tree

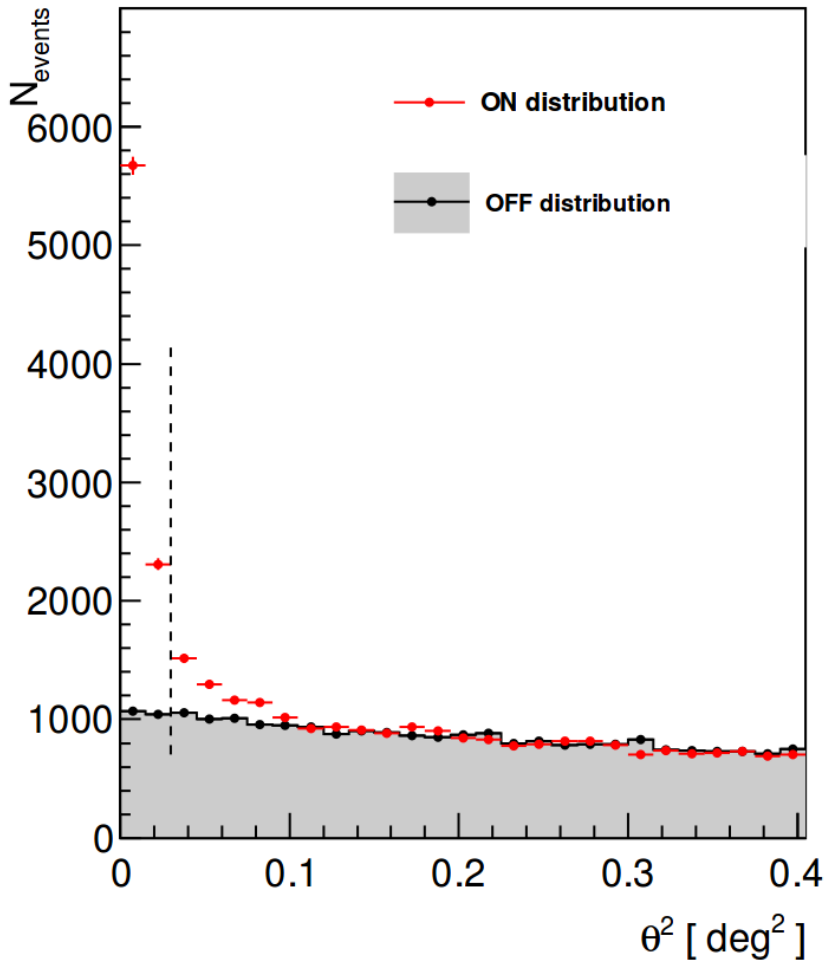




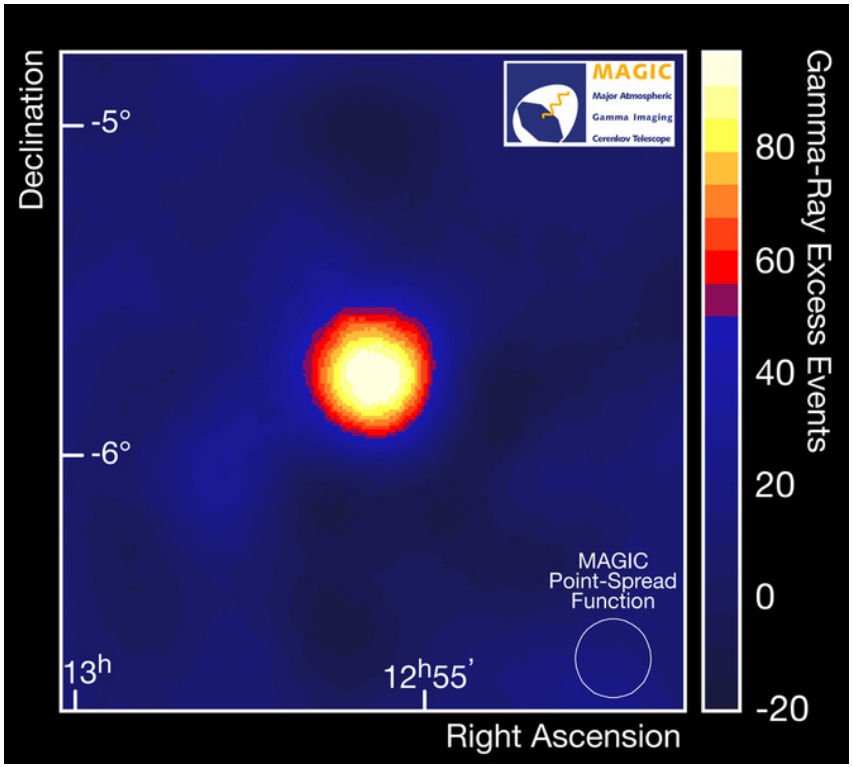
- Random Forest = many decision trees
- build with MC-gammas and real background
- determine hadronness of each event

Signal detection

θ^2-plot



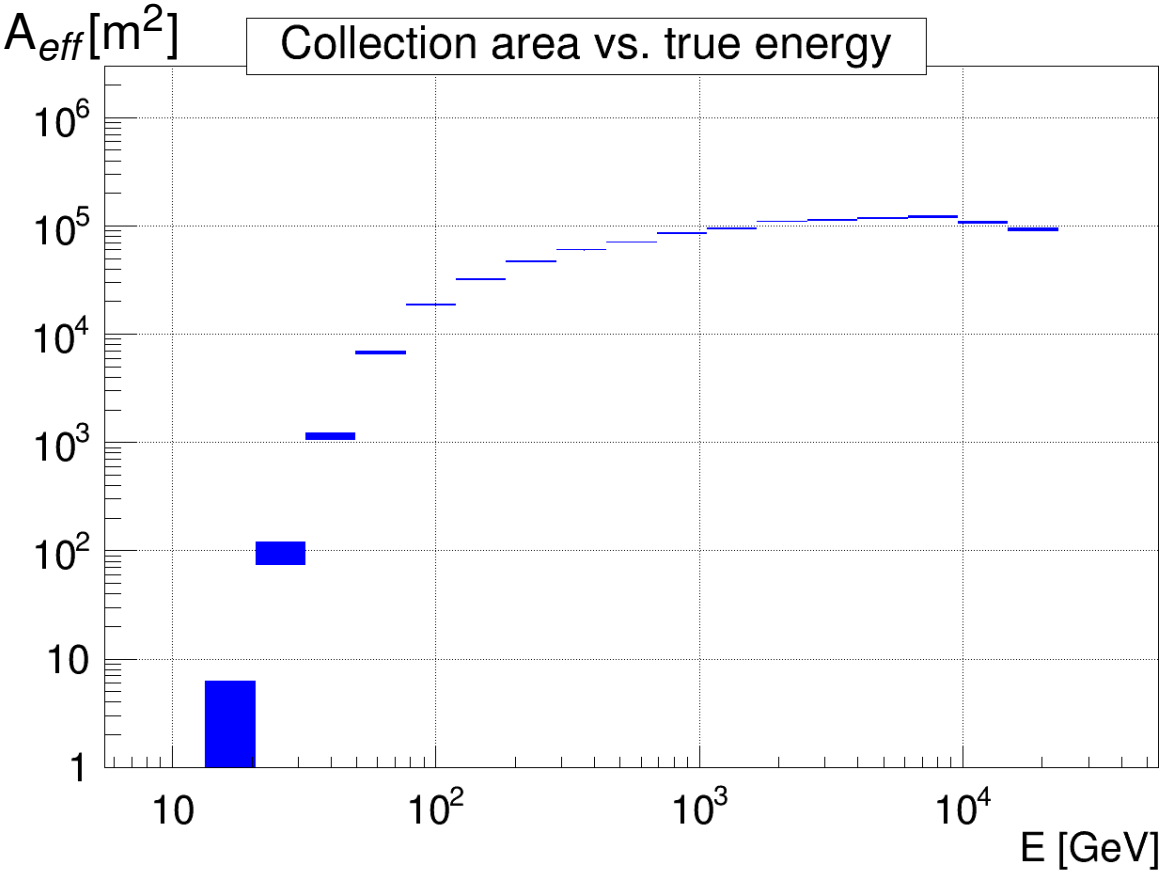
Skymap



angular resolution ~0.1°

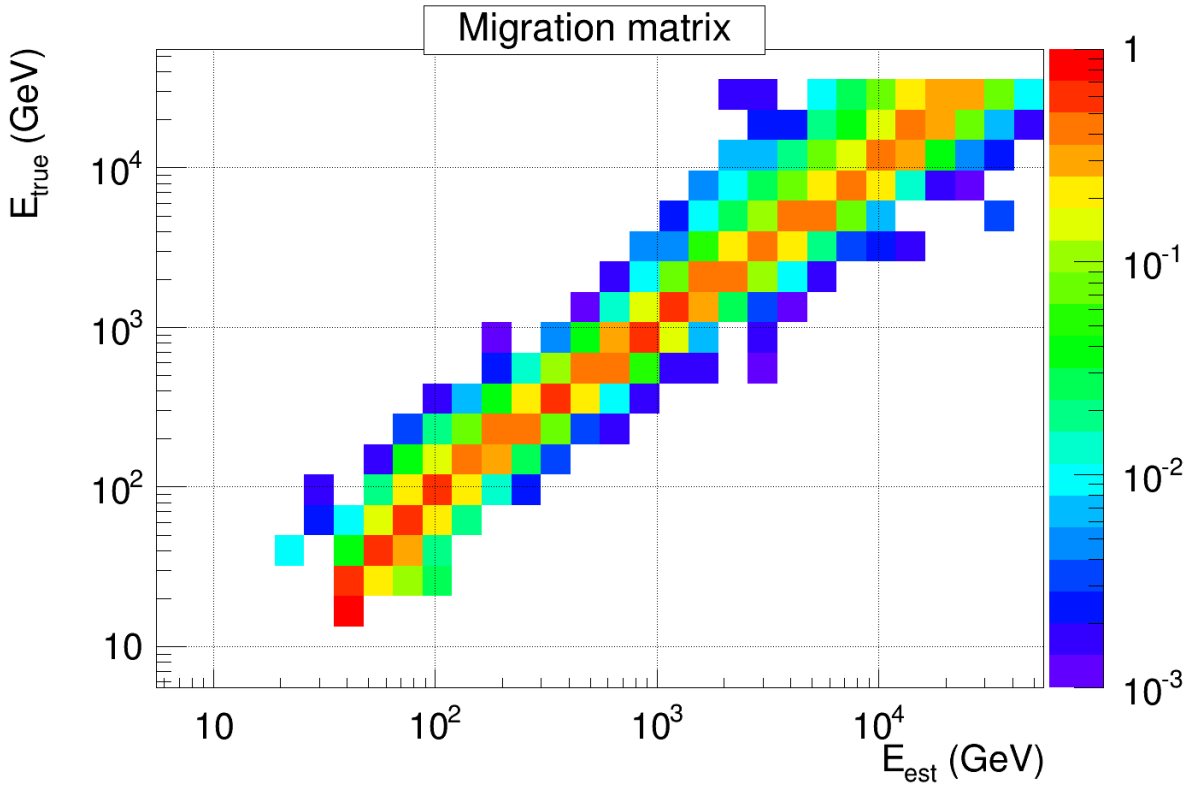
background estimated from camera region without source

EFFECTIVE COLLECTION AREA



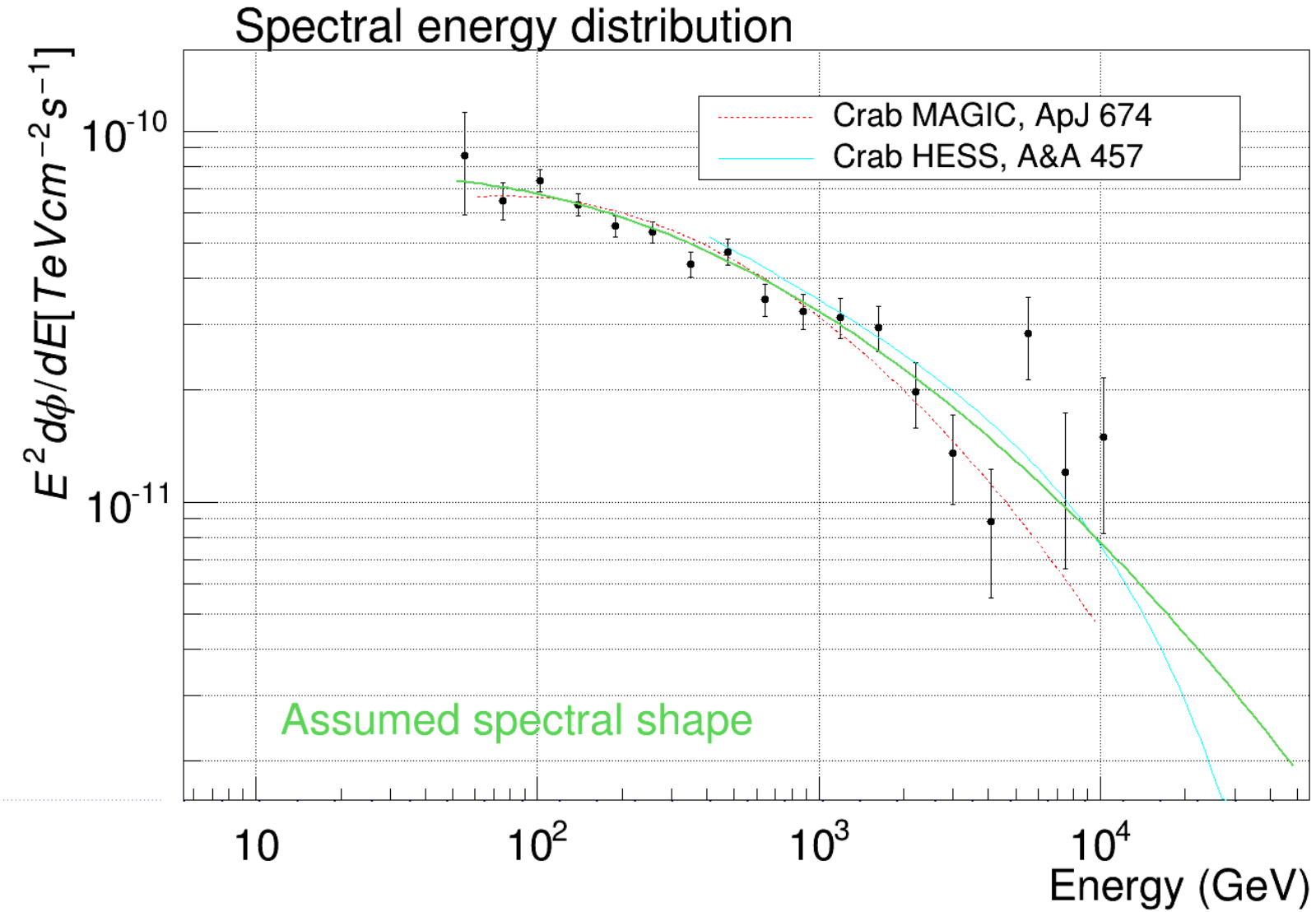
- determined from MCs (same analysis as data)
- $A_{eff} = \frac{N_{survived}}{N_{simulated}} * A_{simulated}$

Migration matrix



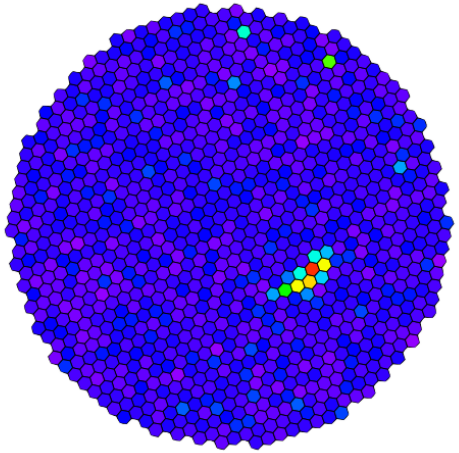
- relation between simulated and reconstructed energy
- energy spectrum needs unfolding
- energy resolution ~15%

SPECTRUM

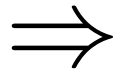

Spectral energy distribution
$E^2 d\phi/dE[TeVcm^{-2}s^{-1}]$
10^{-10}
10^{-11}
Crab MAGIC, ApJ 674
Crab HESS, A&A 457
Assumed spectral shape
10
10^2
10^3
10^4
Energy (GeV)

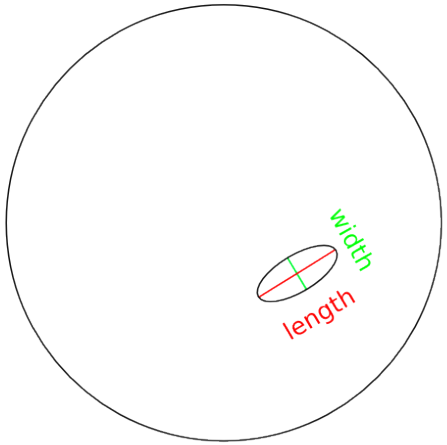
Alternative analysis method

Current analysis



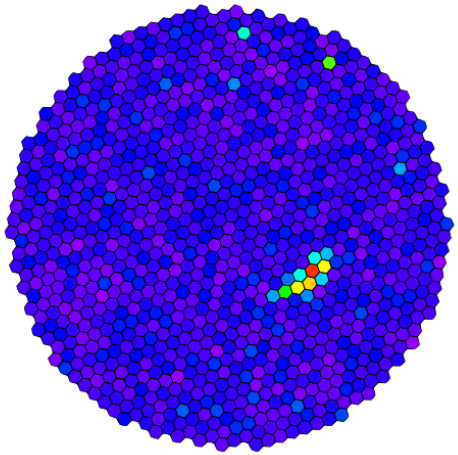
Calibrated data



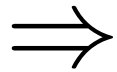


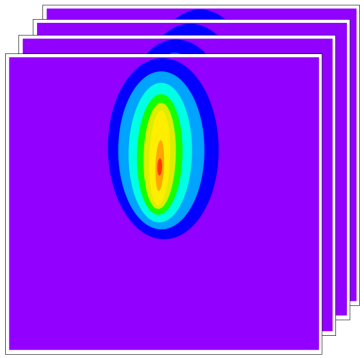
Hillas method

Template analysis



Calibrated data





compare to template images

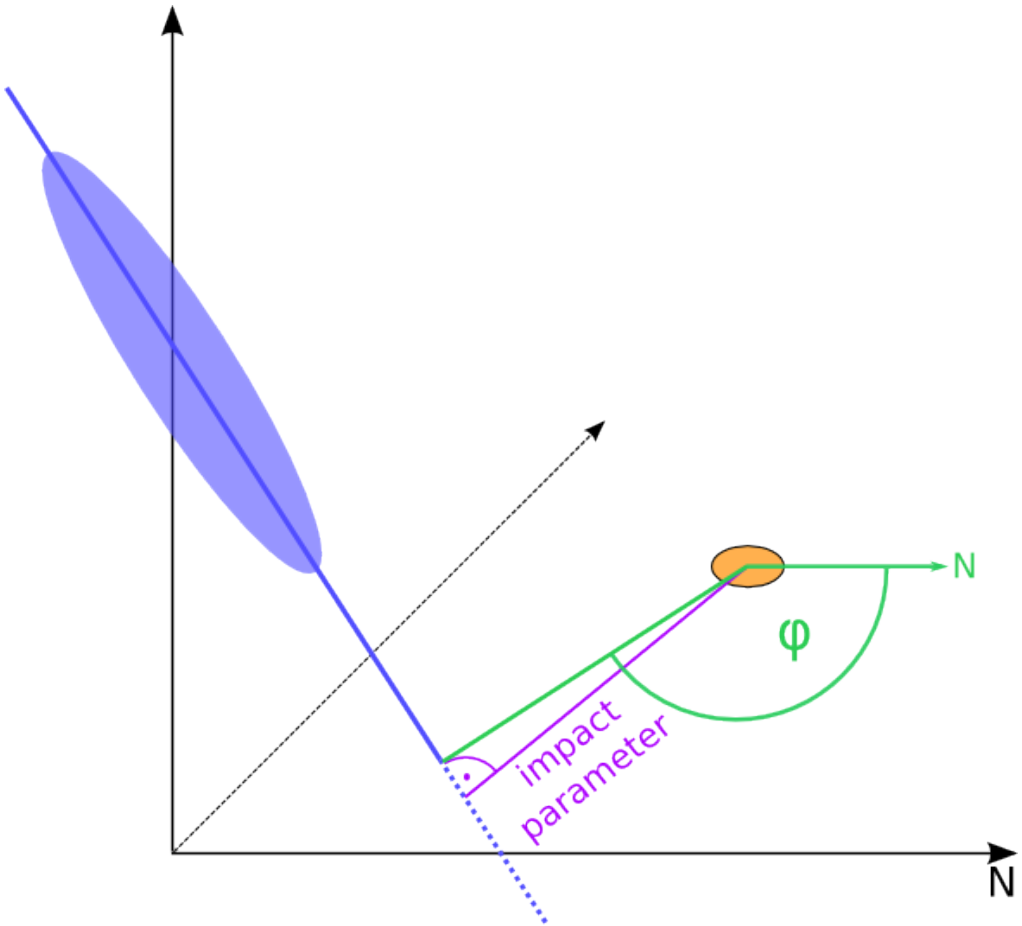
TEMPLATE DATABASE

parameters that change the image:

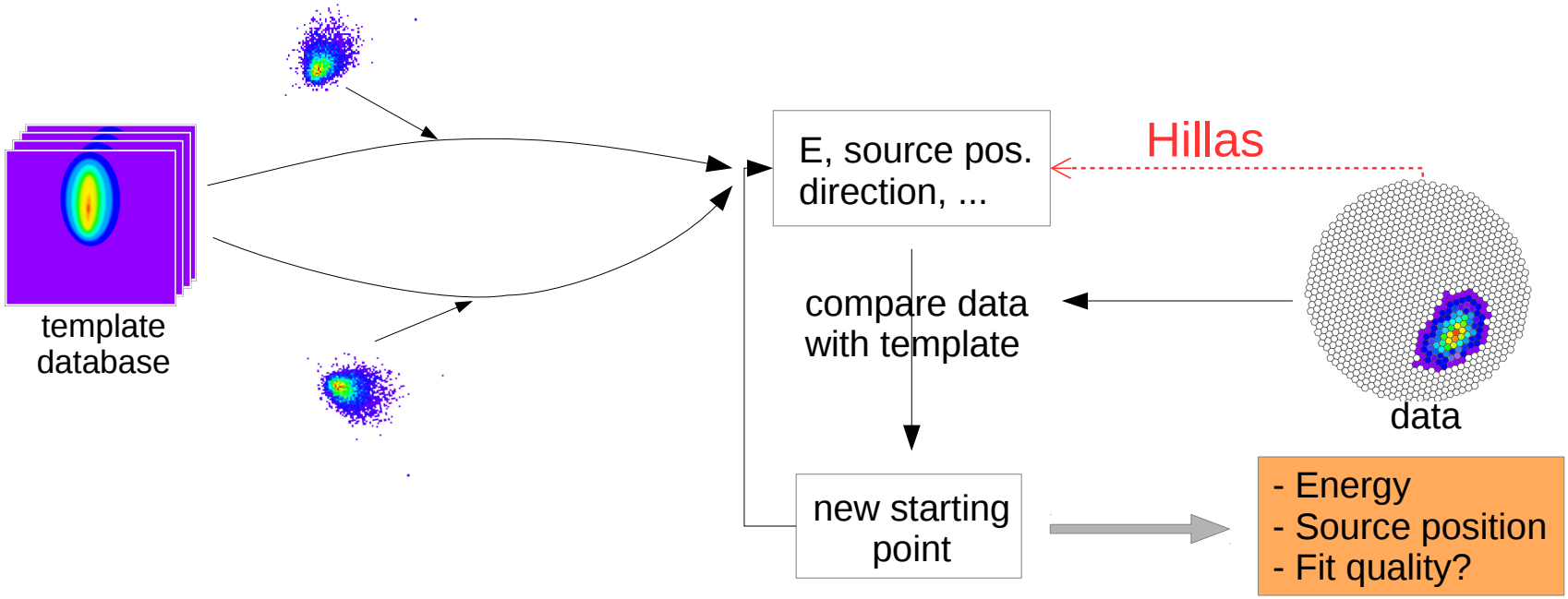
energy
azimuth
zenith angle
impact parameter
impact angle (φ)
first interaction height

$\Rightarrow$ 6D-database

+ pointing: $(x_{cam}, y_{cam})_{source}$



Template Analysis procedure



- comparison: likelihood function
- maximization of the likelihood

Conclusion

- IACT: new window to gamma-ray astronomy
- MAGIC: largest IACT stereo system
- standard analysis: based on image parameters
- possible improvement: template analysis
  - better angular resolution
  - better energy resolution
  - higher sensitivity