CORSIKA and IACTs

Cherenkov light simulations for Imaging Atmospheric Cherenkov Telescopes

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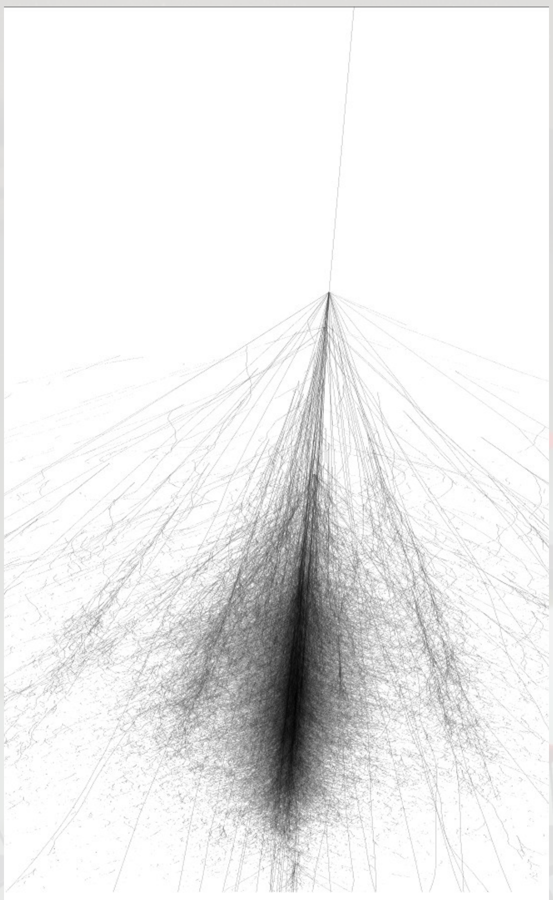
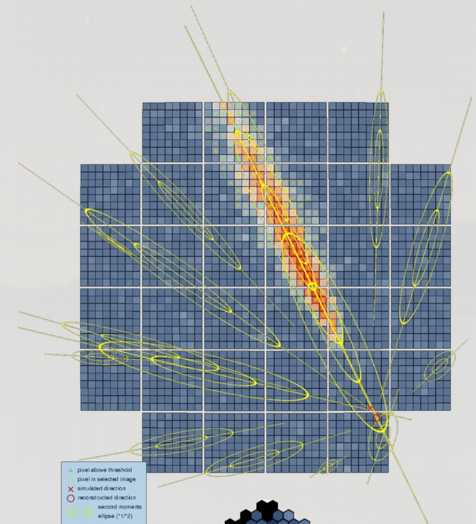
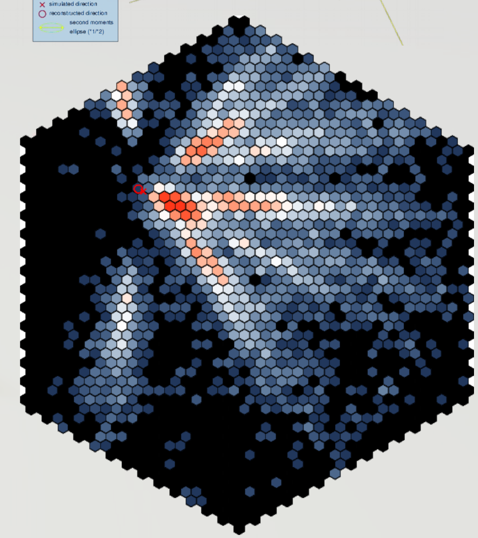
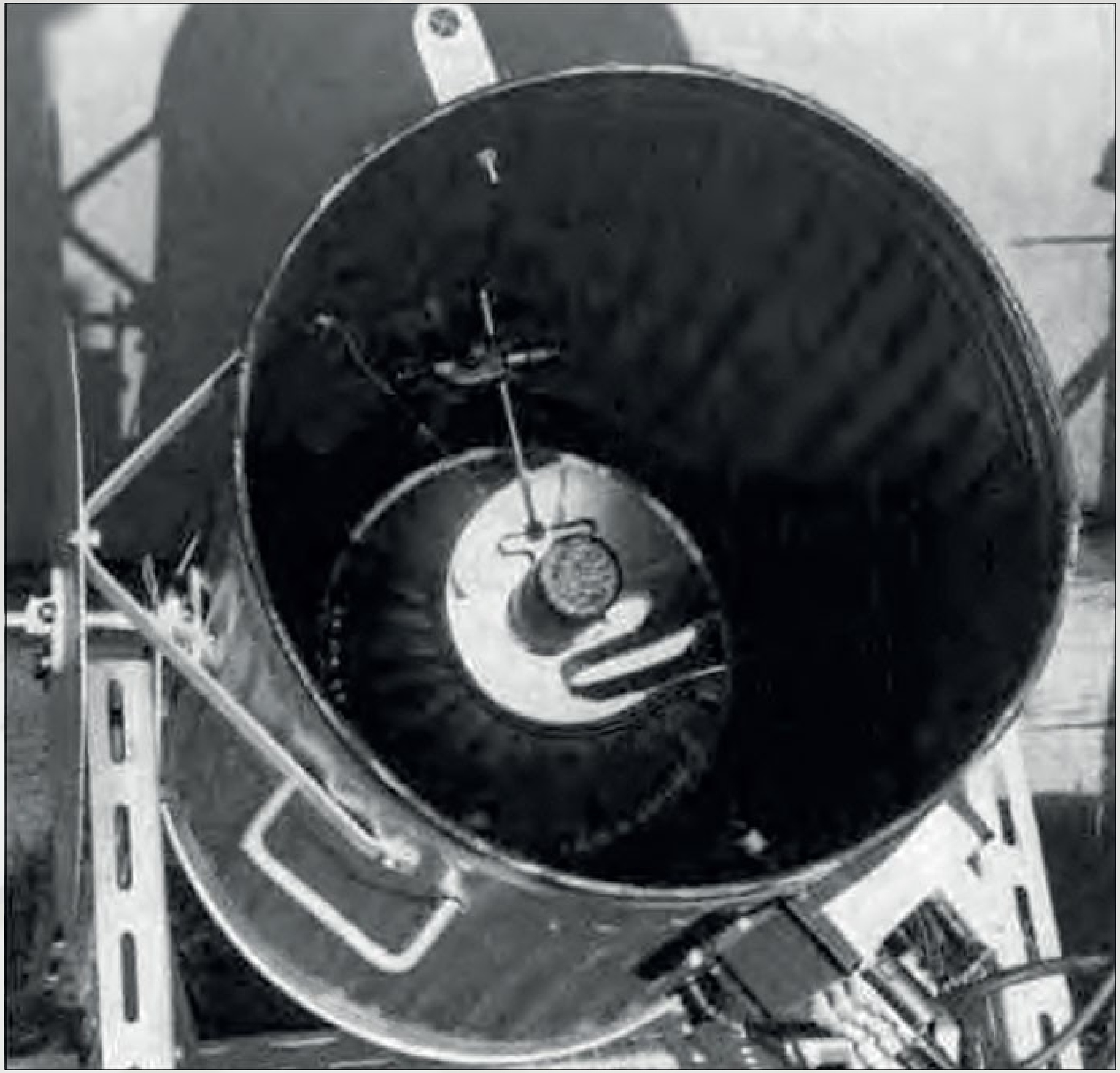






CORSIKA Cosmic Ray Simulation Workshop
Karlsruhe, 2019-06-18

Early Cherenkov instrumentation



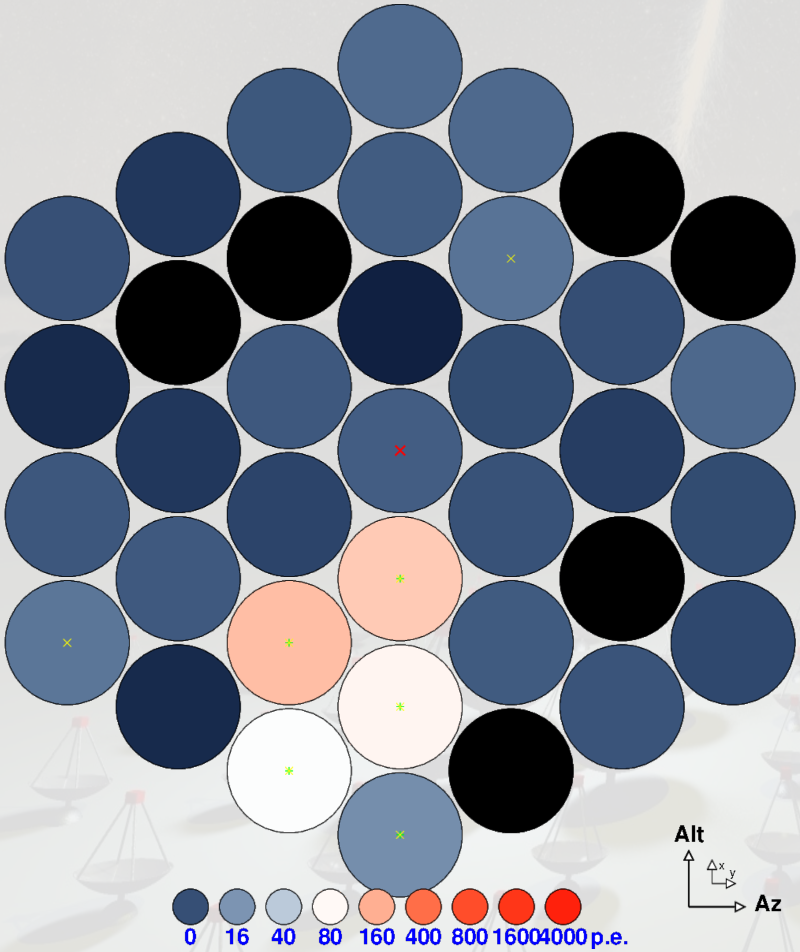
Galbraigh & Jelley, 1952

First IACTs with CORSIKA simulations applied

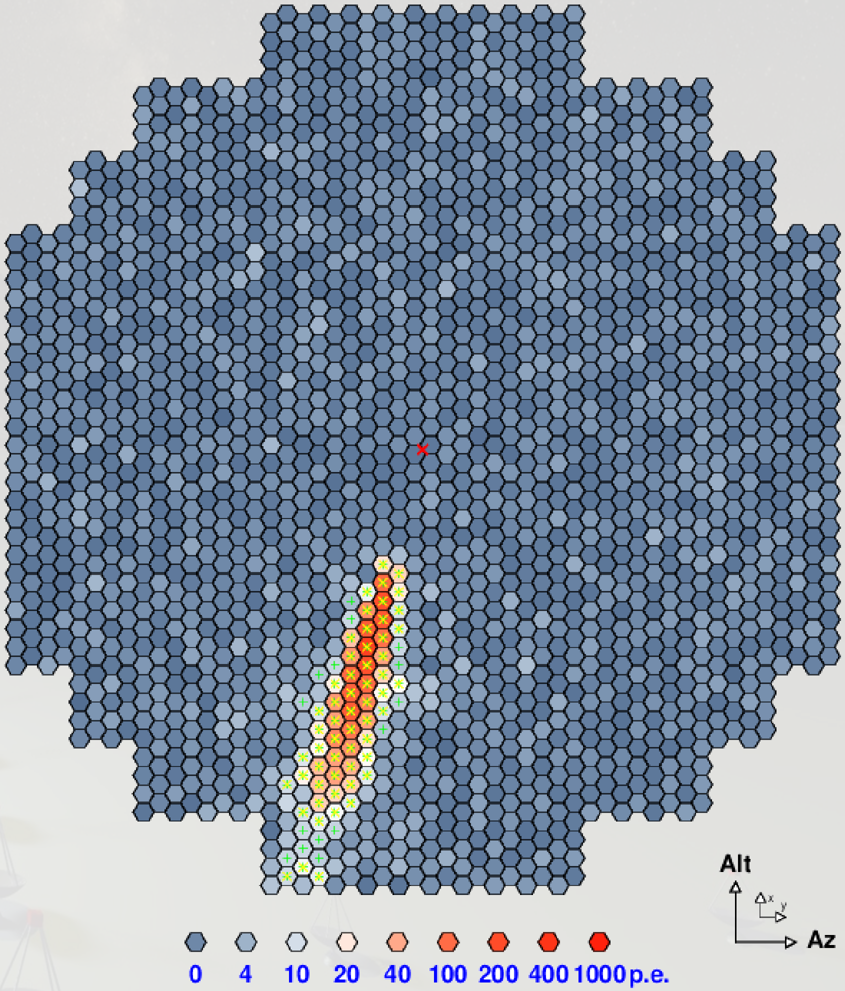
ca. 1997

Current generation IACT example: H.E.S.S.

IACT camera evolution

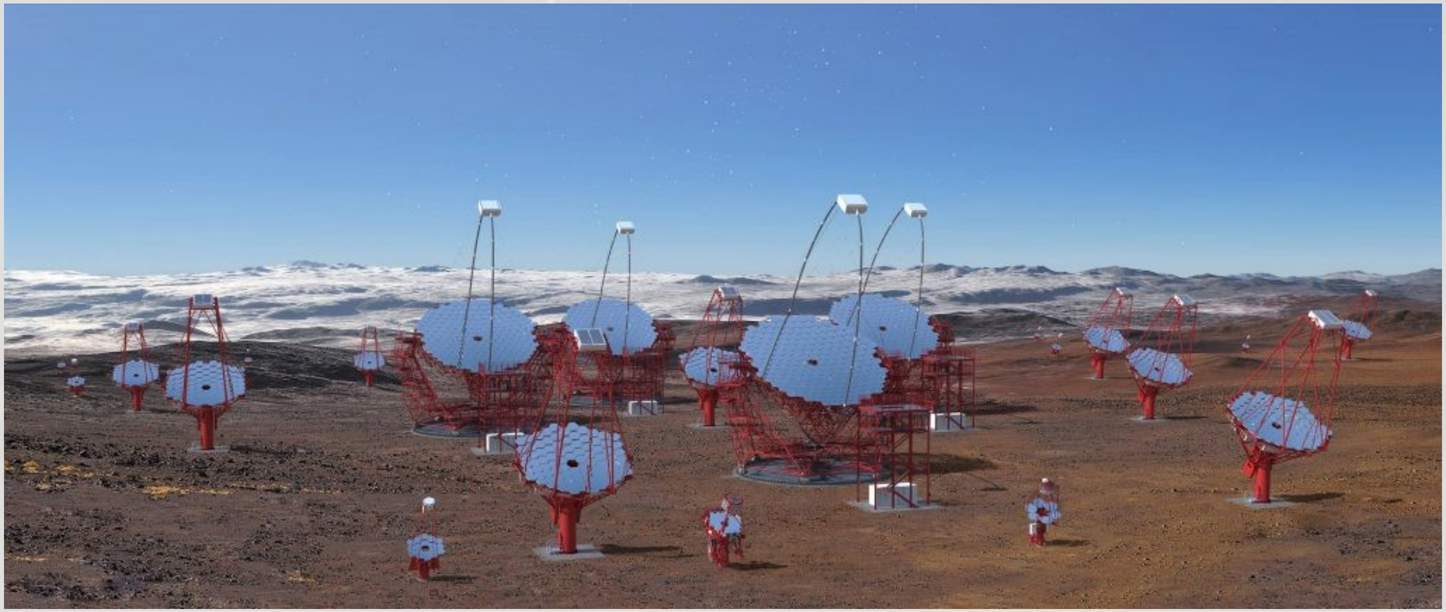


Whipple (1982/87): 37 pixels



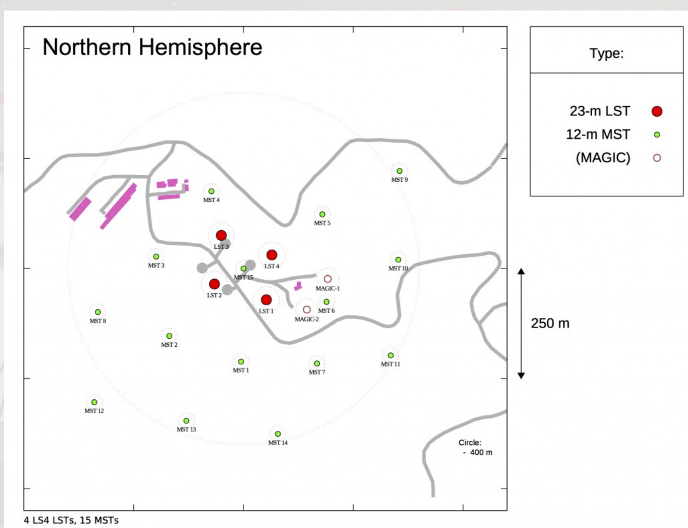
HESS CT5: 2048 pixels

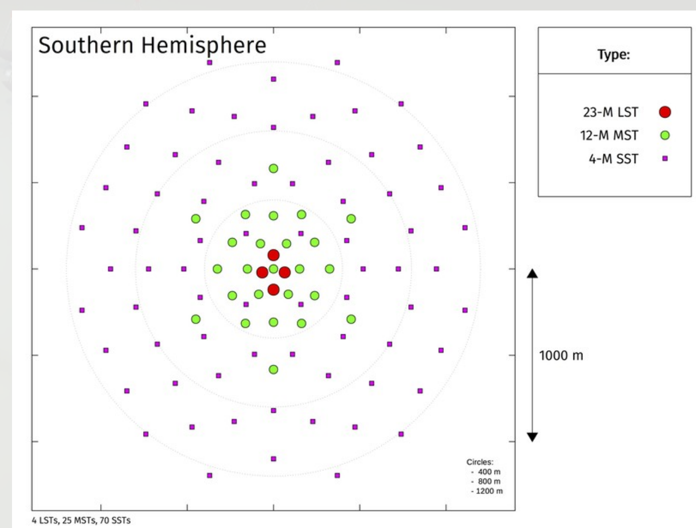
Future: Cherenkov Telescope Array



CTA North

4 LSTs
15 MSTs

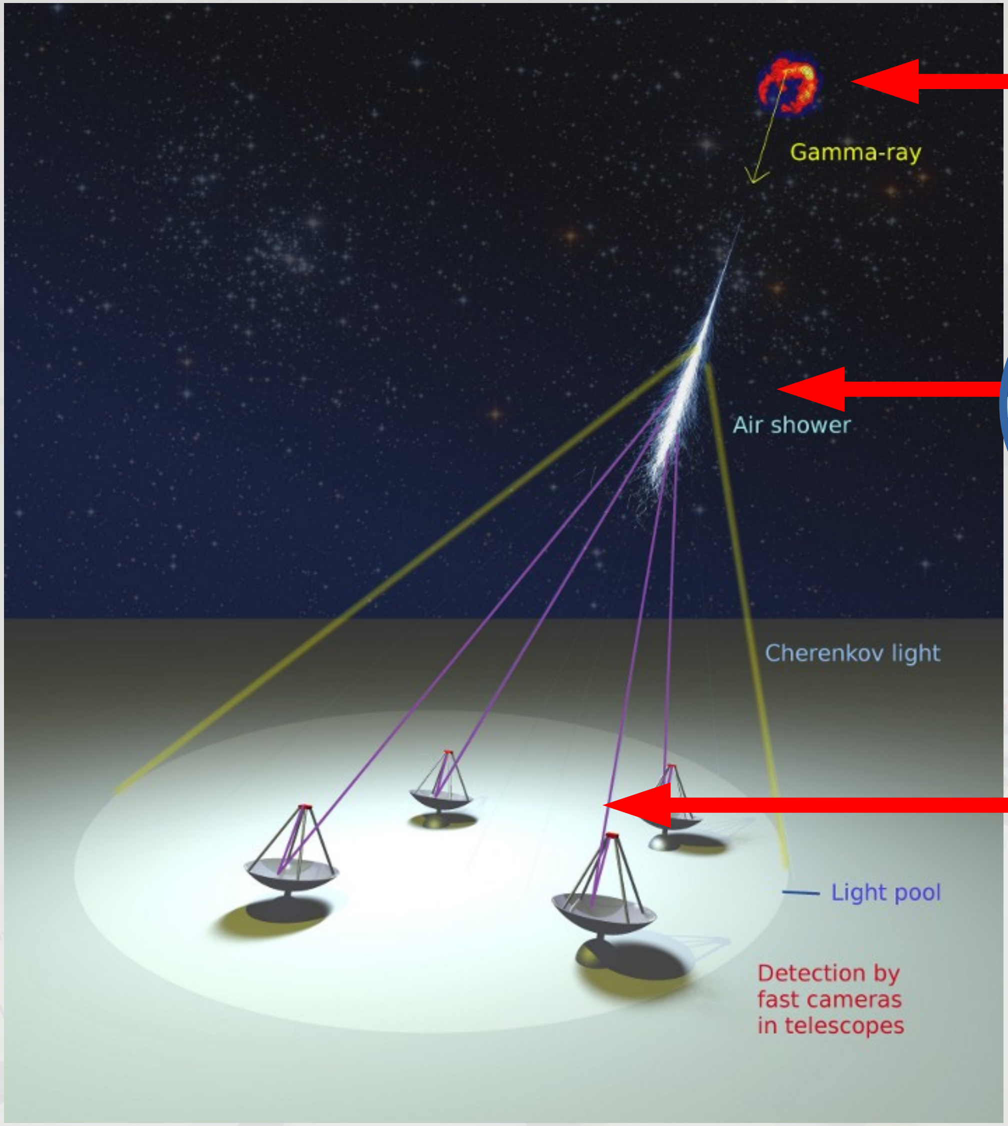




CTA South

4 LSTs
25 MSTs
70 SSTs

Simulation steps



Emission and propagation to Earth: Astrophysics (not dealt with here).

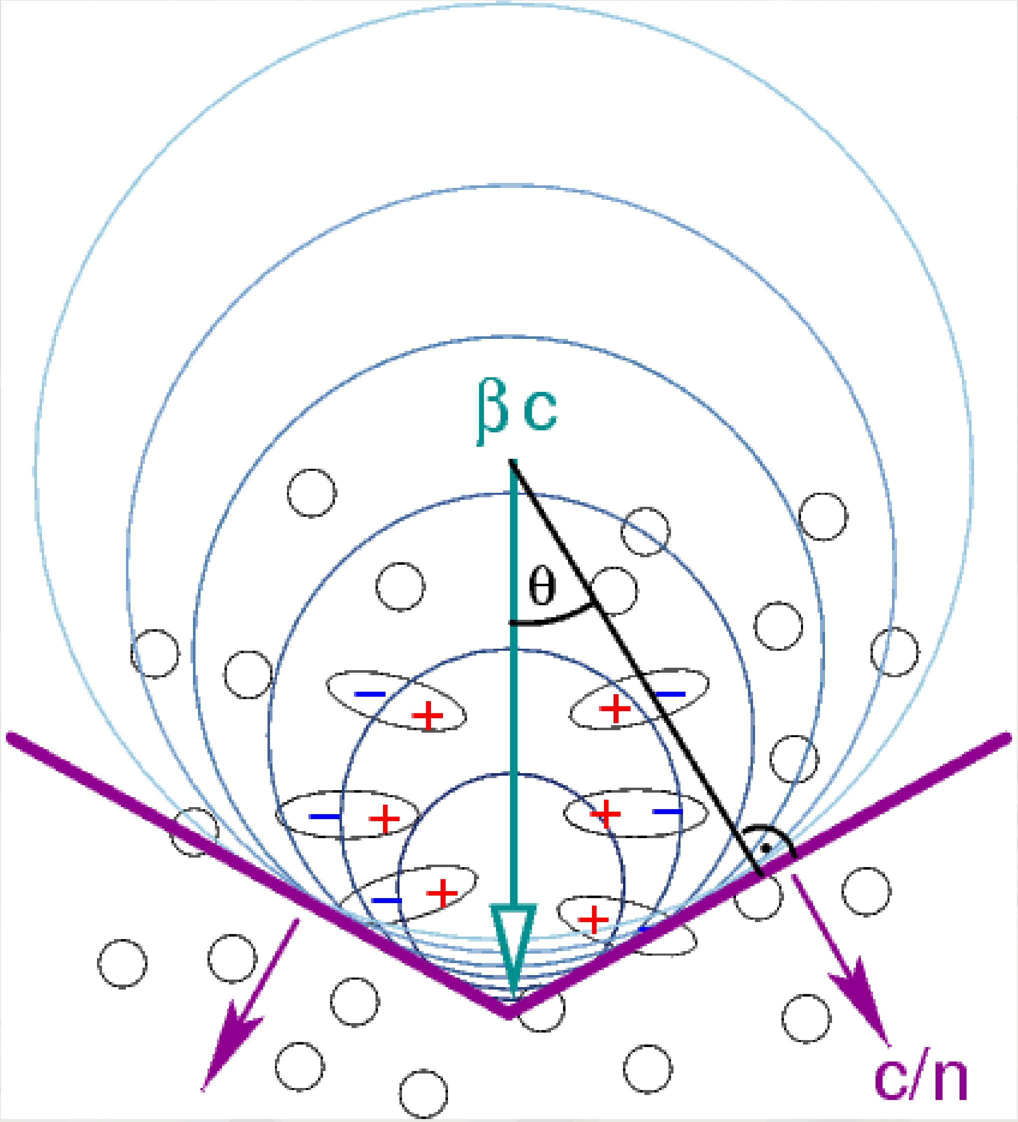
Particle cascade (“air shower”) is normally simulated with CORSIKA, up to light propagation to positions of individual telescopes.

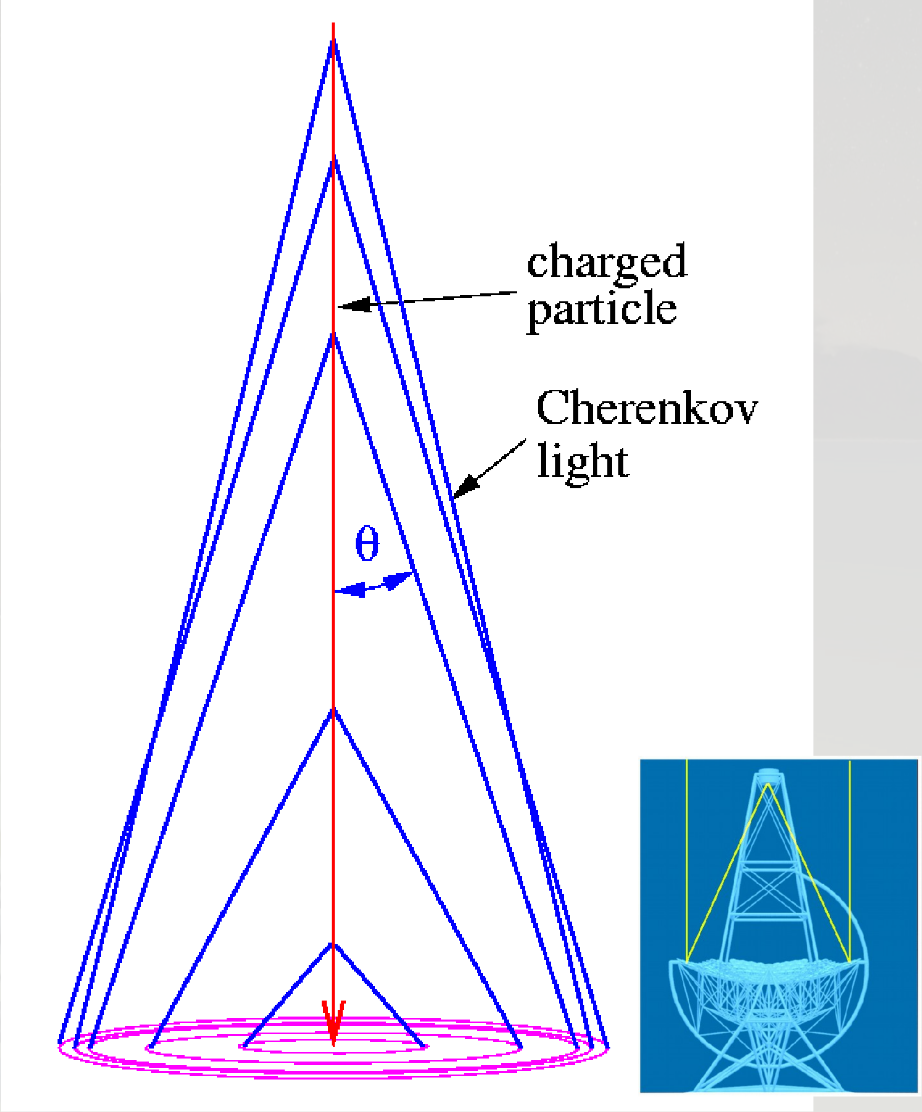
Shower simulation

Cherenkov light atm. transmission, optical properties of telescopes, photon detection, nightsky background, electronic signals, trigger decisions, digitization of signals, ...

Telescope simulation

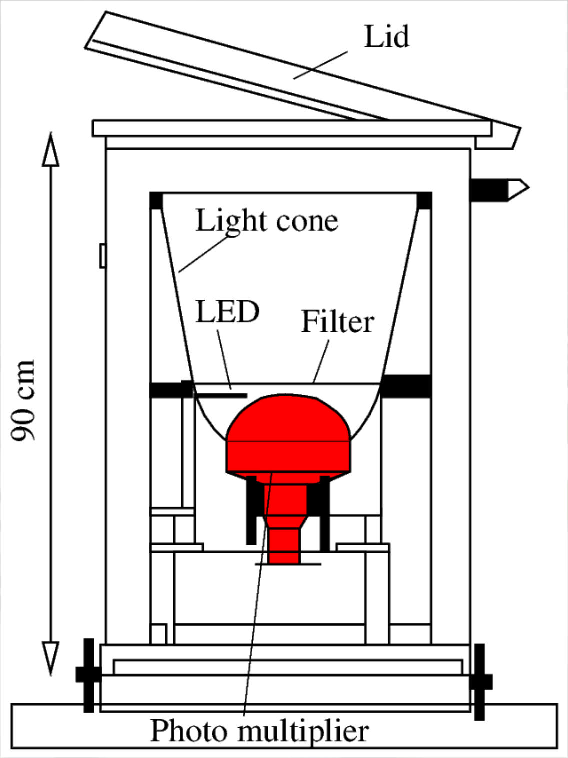
Cherenkov light



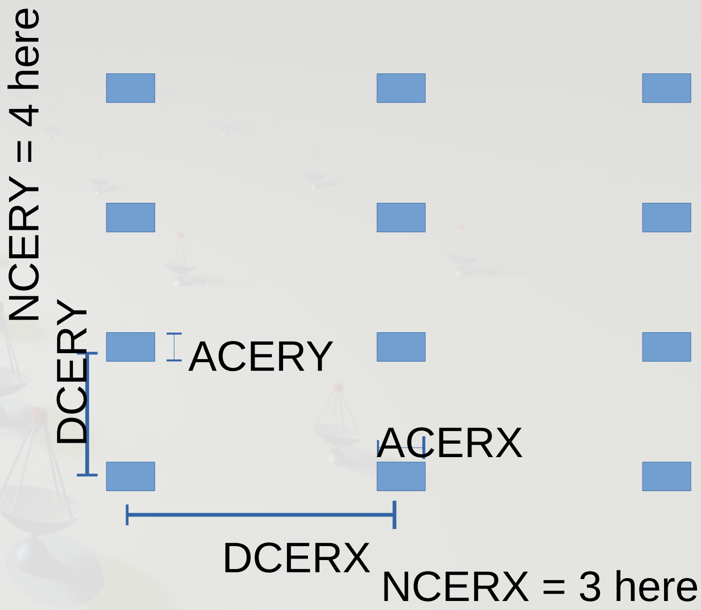


Cherenkov light in CORSIKA

- Initially introduced for non-imaging Cherenkov counters (AIROBICC / HEGRA)
  - by M. Rozanska, S. Martinez, F. Arqueros in 1992



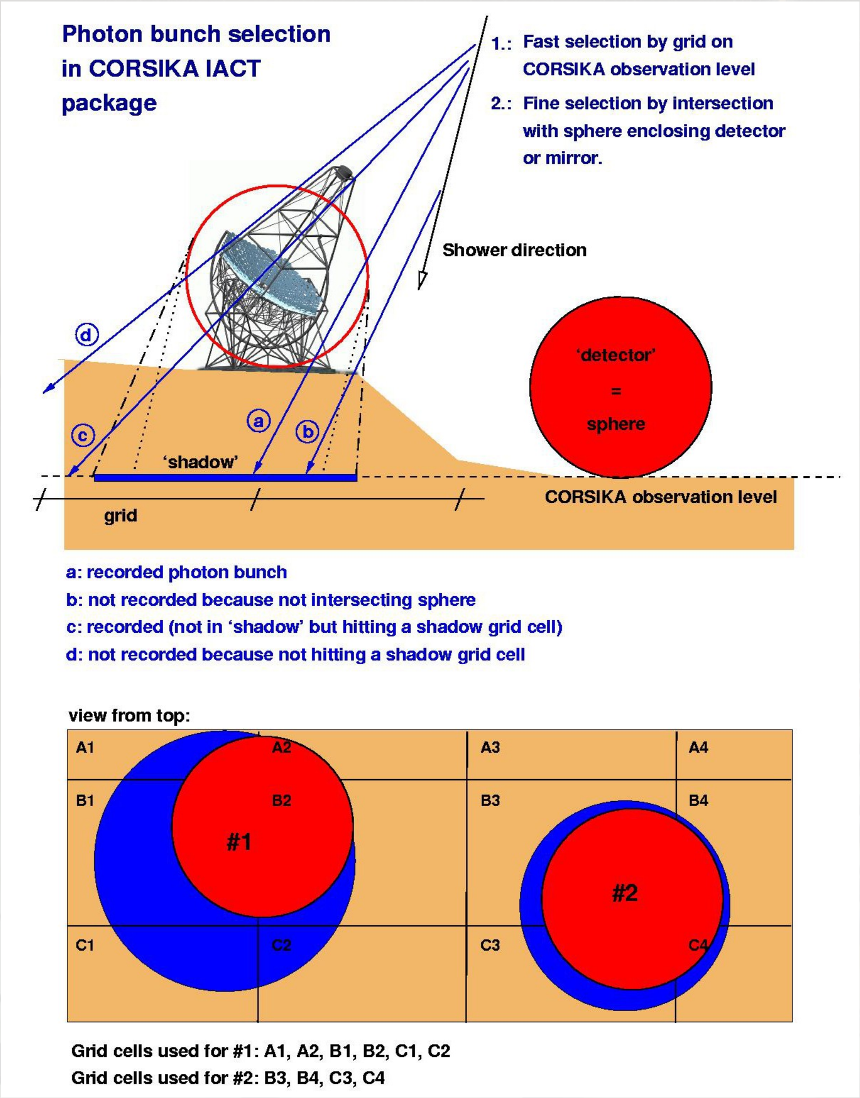
Array layout with CORSIKA CERENK option:



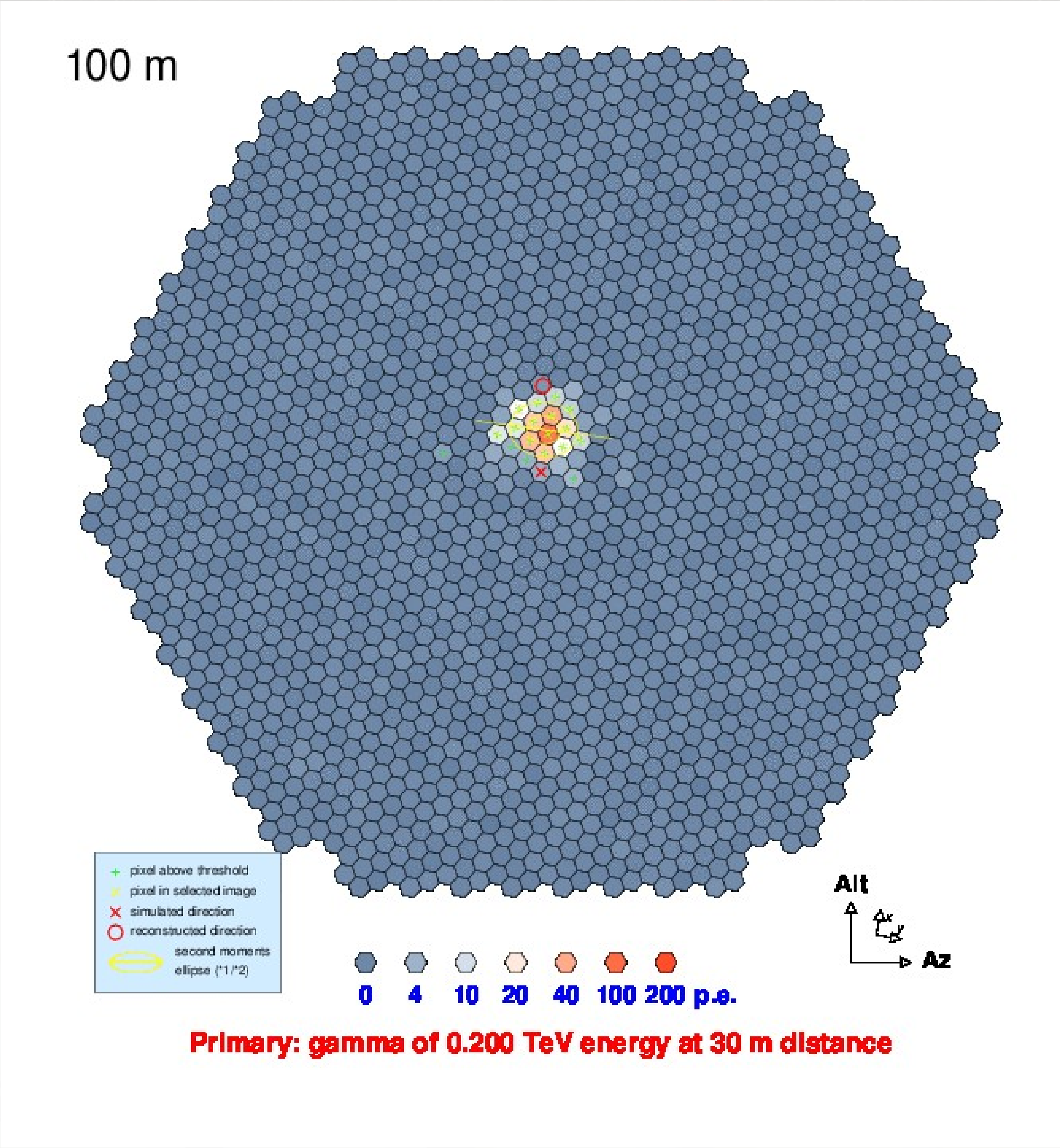
Cherenkov light in CORSIKA

- Later re-implementation with improvements in a number of details important with the angular resolution of Cherenkov telescopes:
  - Particle track steps should be short enough that neither the deflection in the geomagnetic field nor the expected multiple scattering exceeds the optical resolution / pixel size.
  - The Cherenkov emission angle along a track step may change due to energy loss and increasing density (and thus index of refraction).
  - Refractivity (*n*-1) not strictly proportional to density.
  - Refractivity may depend on wavelength.

Detector positions with IACT option



- A detector is defined by its fiducial sphere – e.g. for a telescope the reflector should fit into the sphere.
- Defined by x, y, z w.r.t. observation level and radius r.
- Up to 999 detectors. Showers used multiple times with random offsets.
- Observation level plane sub-divided into grid cells. Intersection with only those spheres registered for the grid cell hit by a photon bunch.
- Photon bunch can be used multiple times with overlapping spheres.
- Output format is machine- and compiler independent ('eventio').



Gamma-ray shower (vert.) of 200 GeV at core distance of 30 m, seen with an LST (no NSB) at different altitudes.

The atmosphere with the IACT/ATMO package

- Numerical tables of atmospheric profiles.
  - More fine-grained than 5-layer built-in profiles.
  - EGS part cannot use table directly but needs fit.
- Index of refraction (for λ = 400 nm or effective wavelength) as a separate column
  - Helps to take care of the impact of humidity etc.
- Atmospheric refraction can be accounted for in propagation of Cherenkov light to detector.
  - Important effect for γ-ray source localization.
- Transmission generally part of detector program.

Verification of simulations

- Few ways of verifying CORSIKA alone.
  - You need a detector simulation / telescope model in addition to CORSIKA and verify that as well.
- Basic tests with muon rings:
  - Intensity + ring width as function of ring radius.
- Complex tests with -rays (point source) and cosmic rays (off-source):
  - Image shapes, lateral distribution, shower maximum, image time gradients, trigger rates, ...
- Dependence of remaining cosmic-ray background on interaction model quite large.

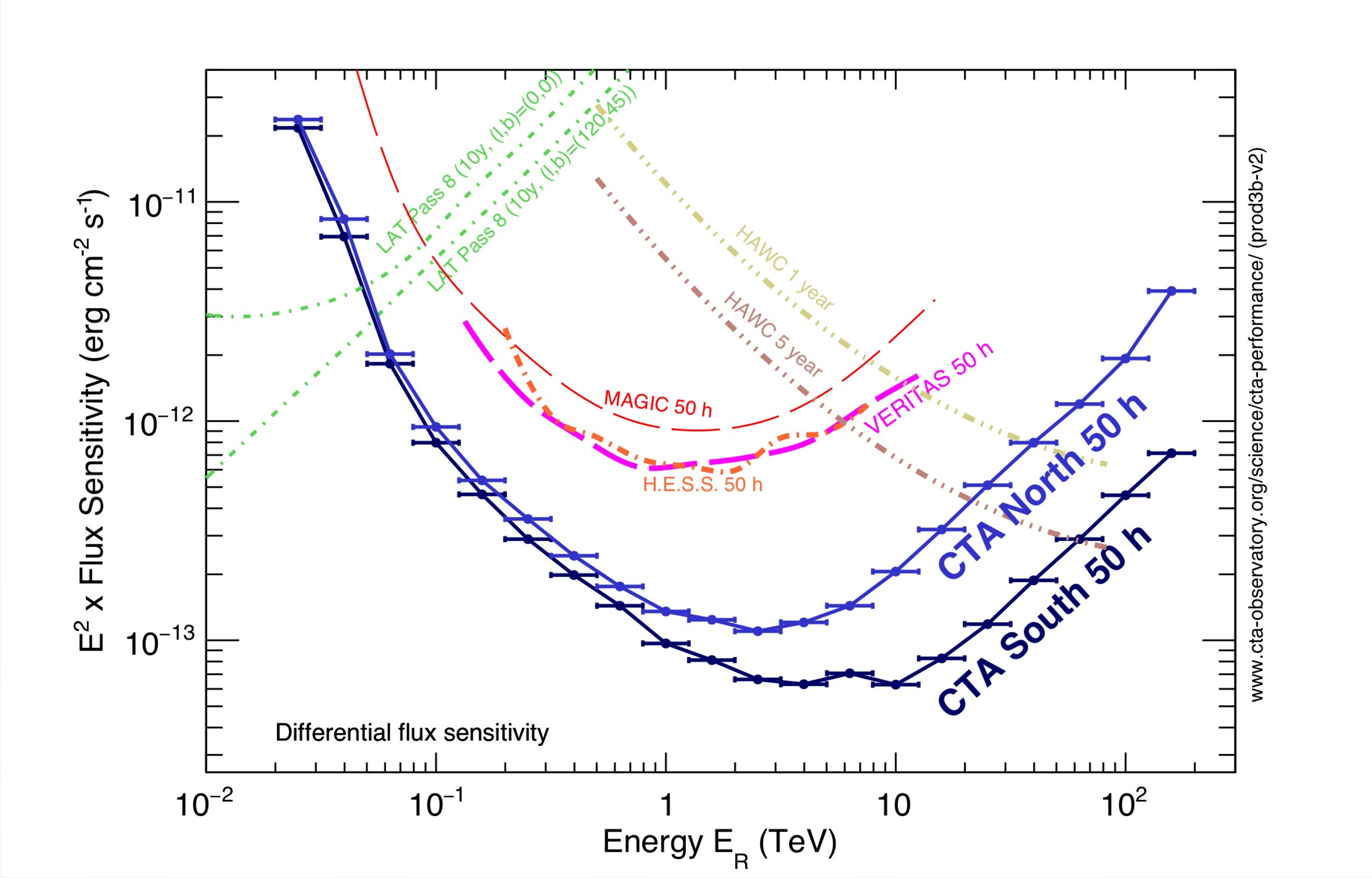
Big MC productions

- Monte-Carlo productions for CTA site and layout planning exceeding what used to be needed for simulations with current instruments, e.g. ‘prod3’:
  - Up to >600 telescope positions in CORSIKA input.
  - With telescope design variants >3000 telescopes simulated per event (shower used 10-20 times).
  - Due to excellent background rejection, need to simulate huge number of background events.
  - Millions of actual CPU hours.
  - Petabyte of data, even without keeping CORSIKA output.
  - Cost, shared by participating computing centers (GRID/non-GRID), probably order of 1 M€.

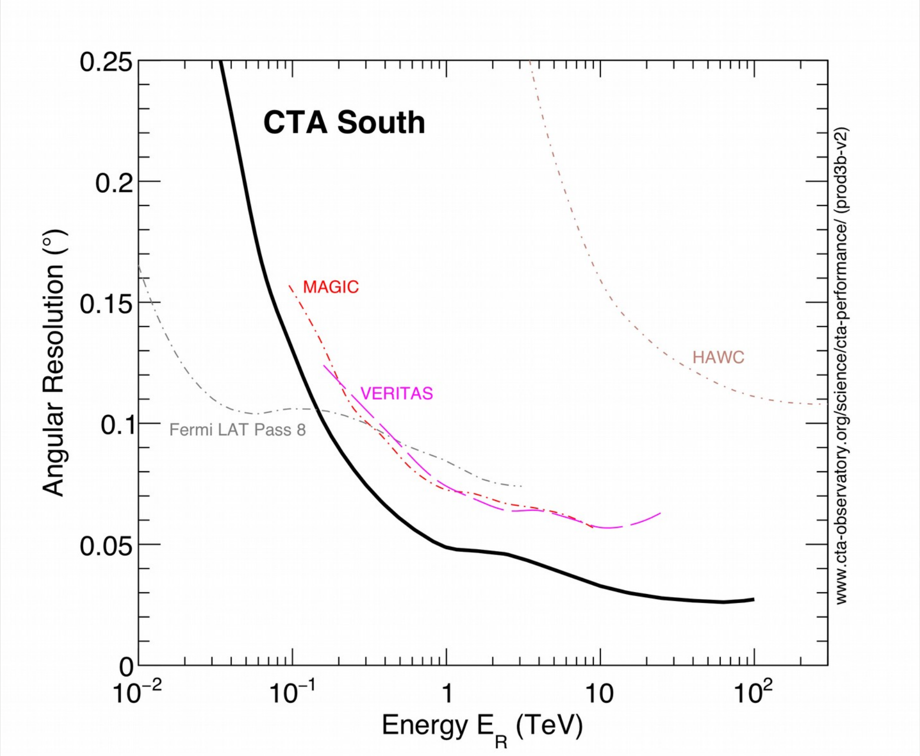
Performance of IACT arrays

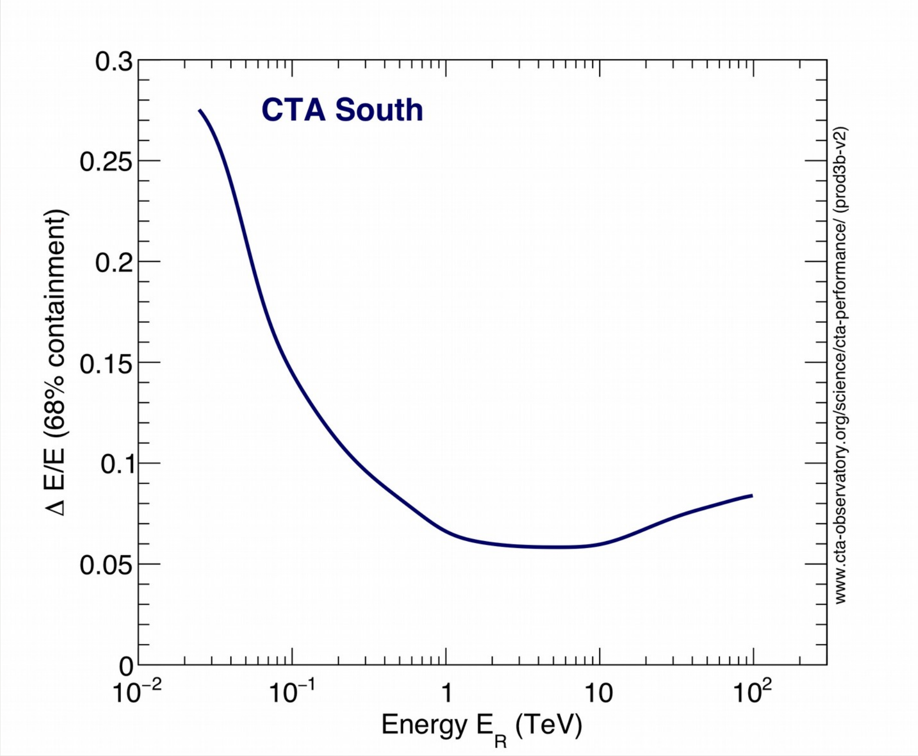
- Arrays of Imaging Atmospheric Cherenkov Telescopes, employing stereoscopic shower reconstruction outperform any other detection method in terms of
  - angular resolution (0.03° to 0.2°)
  - energy resolution (6% to 25%)
  - background rejection (except for Fermi)
- but suffer from small field-of-view and limitation to dark nights.

Point source sensitivity



CTA angular and energy resolutions





Better accuracy needed for CTA

- CTA will have unprecedented resolution and hadron rejection.
- High angular resolution, e.g. with dual-mirror MST-SC, should be met with shorter steps.
- To achieved desired energy scale accuracy, accurate atmospheric profiles have to be used.
- CTA (CTAO and CTAC member institutes) committed to contribute to CORSIKA development & maintenance – the Cherenkov emission part in any case.

Conclusions

- IACTs are high-precision, high-resolution instruments. In particular arrays of many IACTs.
- Accurate simulations are needed to make full use of the instruments.
- CORSIKA plus detailed instrument simulation can match measured data very well – if properly configured.
- Not everything is absolutely perfect yet – there is still room for improvements with CORSIKA 8.
- CTA (CTAO and CTAC member institutes committed to contribute to CORSIKA development & maintenance.