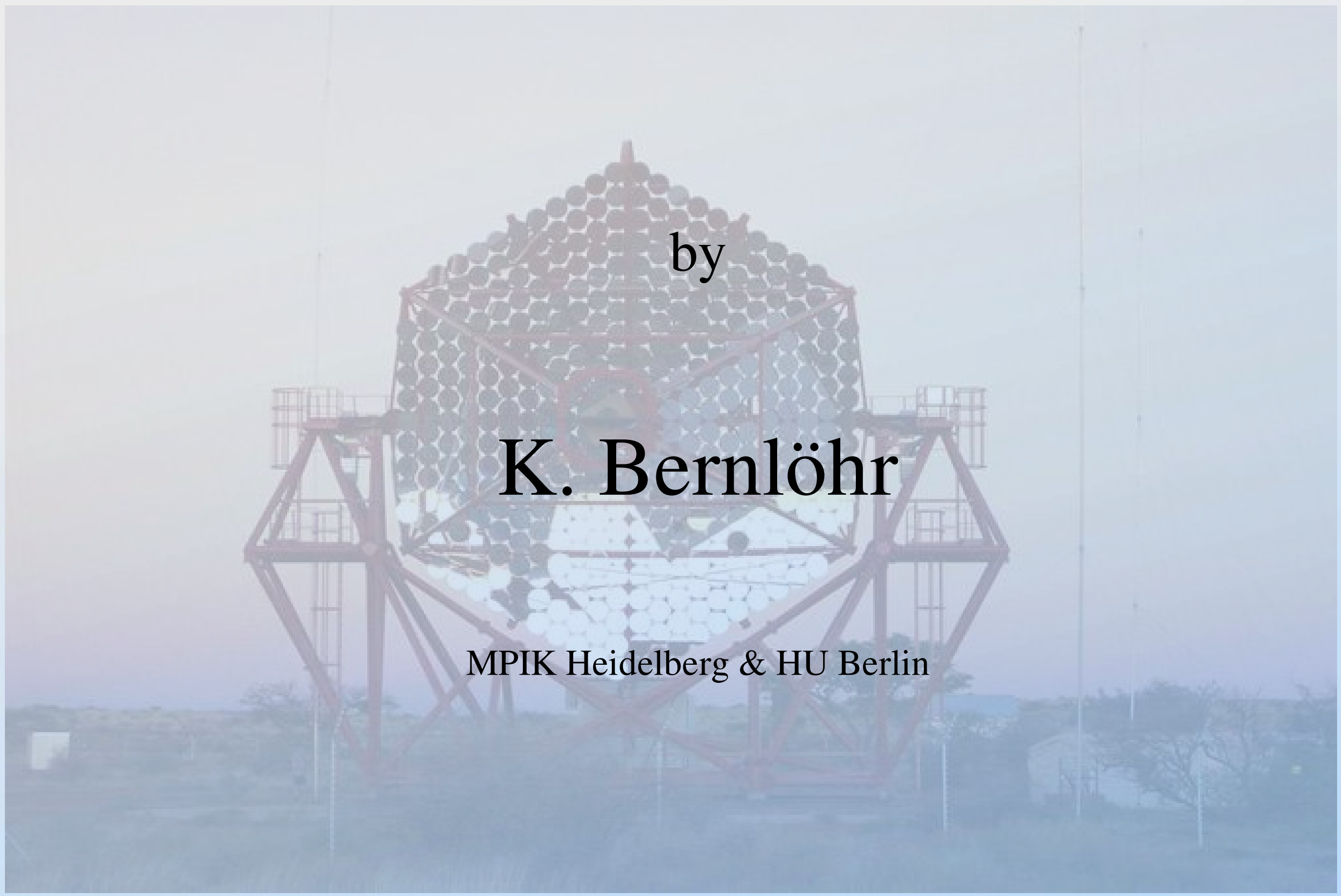
Simulations for H.E.S.S.

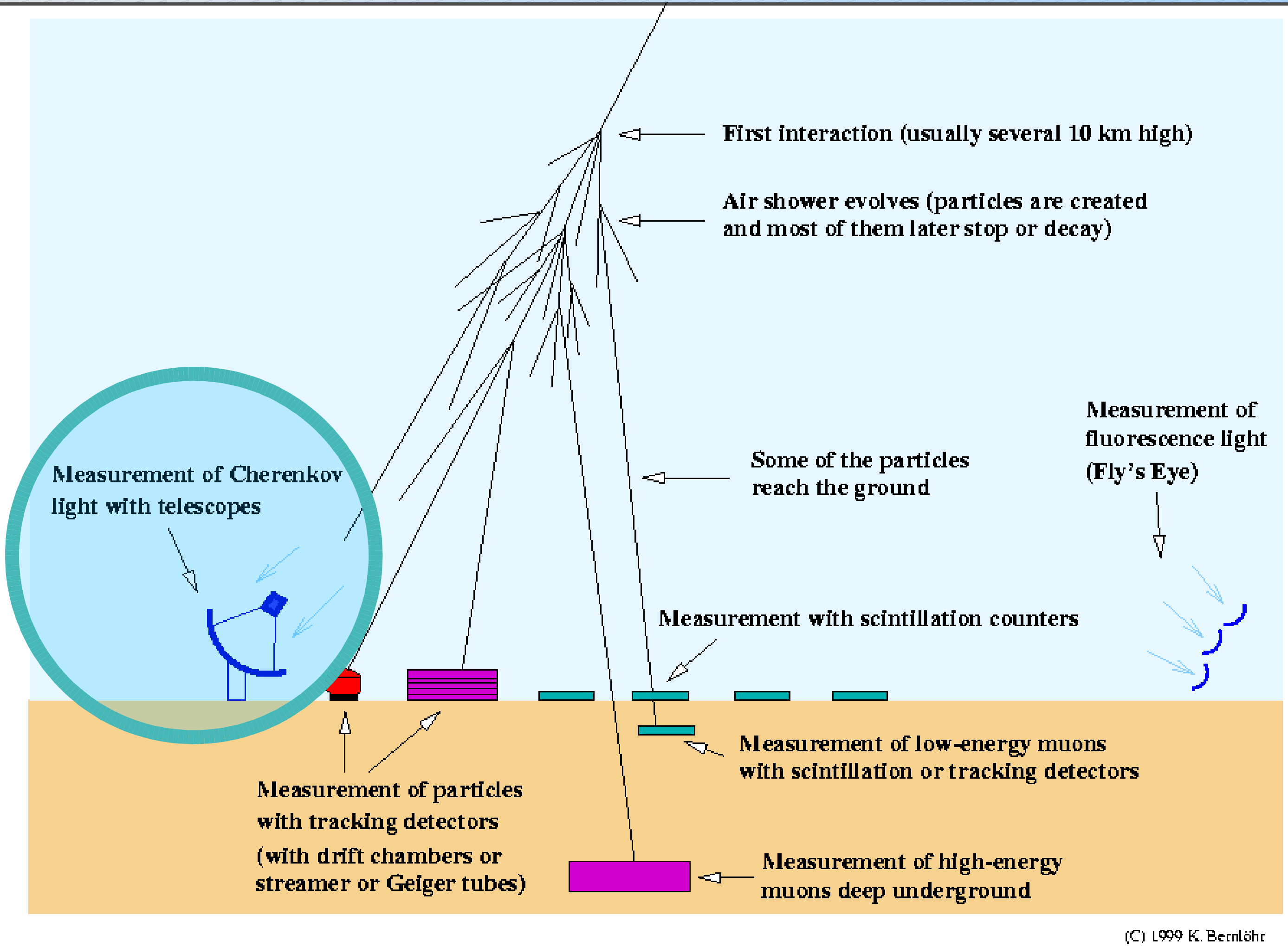


by

K. Bernlöhr

MPIK Heidelberg & HU Berlin

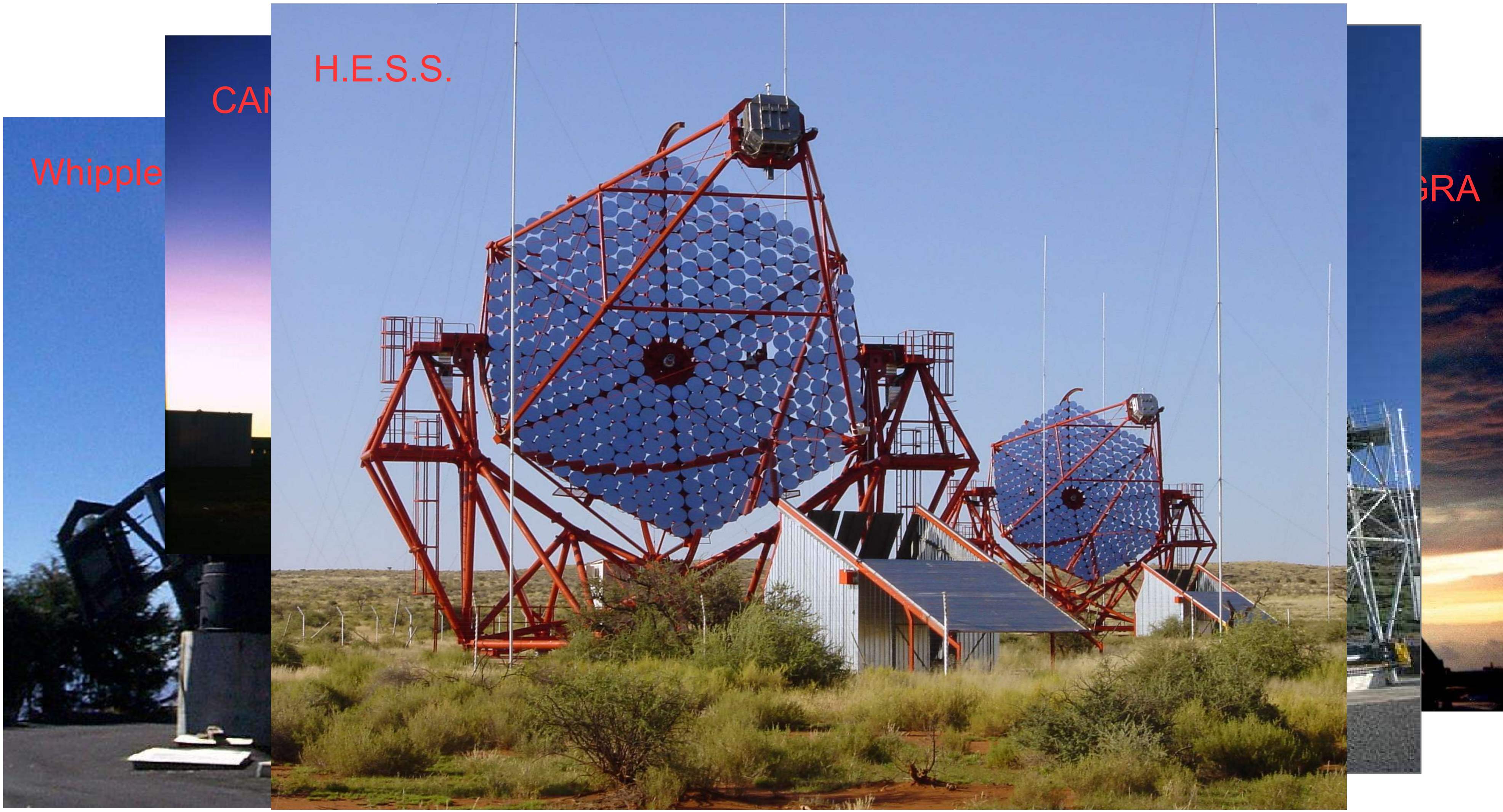
Air shower measurement methods



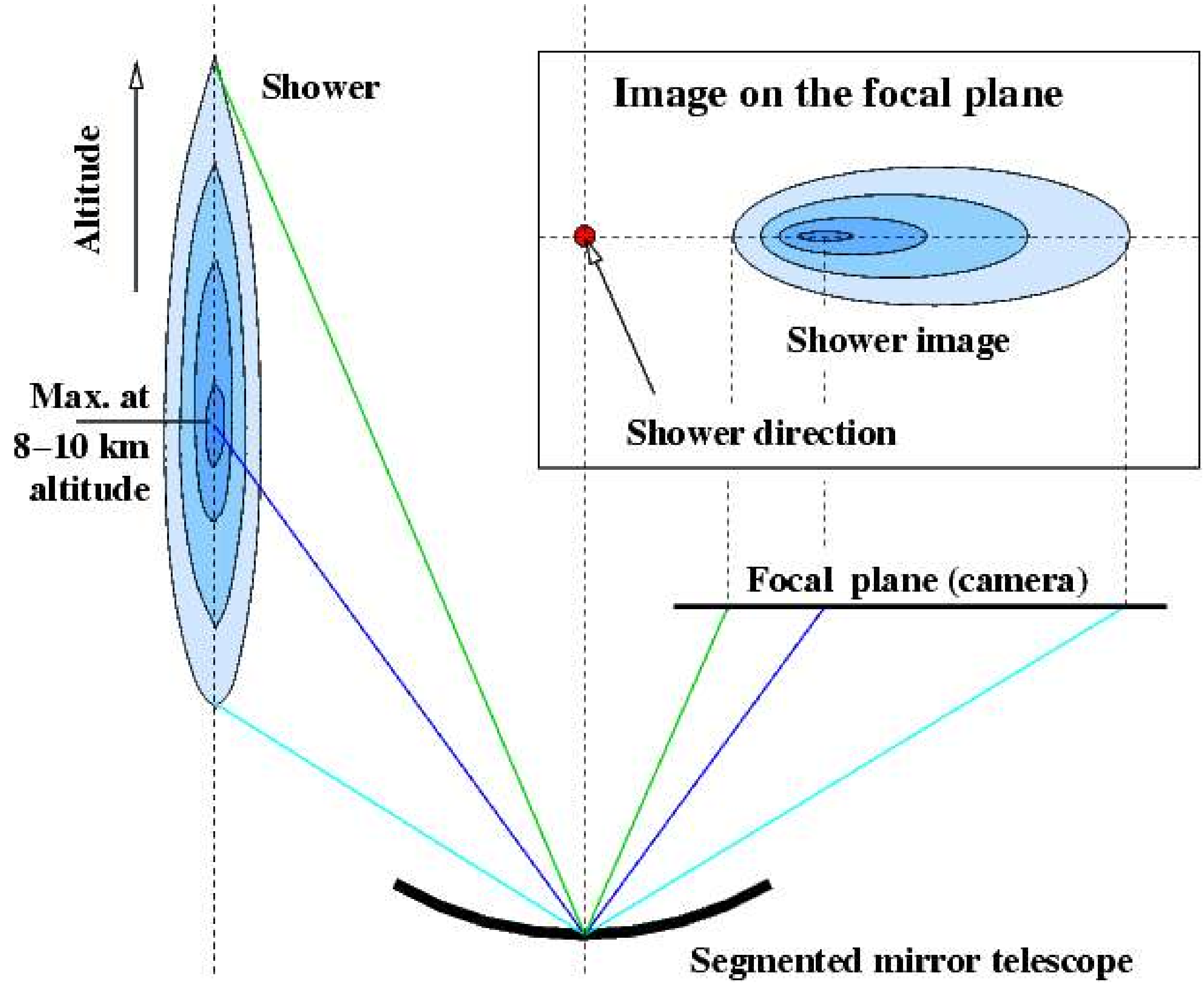
Imaging atmospheric Cherenkov telescopes

- In the imaging atmospheric Cherenkov telescope (IACT) technique, the showers are directly imaged onto very fast cameras.
- Imaging is achieved through segmented mirrors. This saves cost and allows for wider field of view at a reasonable resolution.
- Cameras are instrumented with photomultiplier tubes (PMTs). Integration time is < 20 ns.

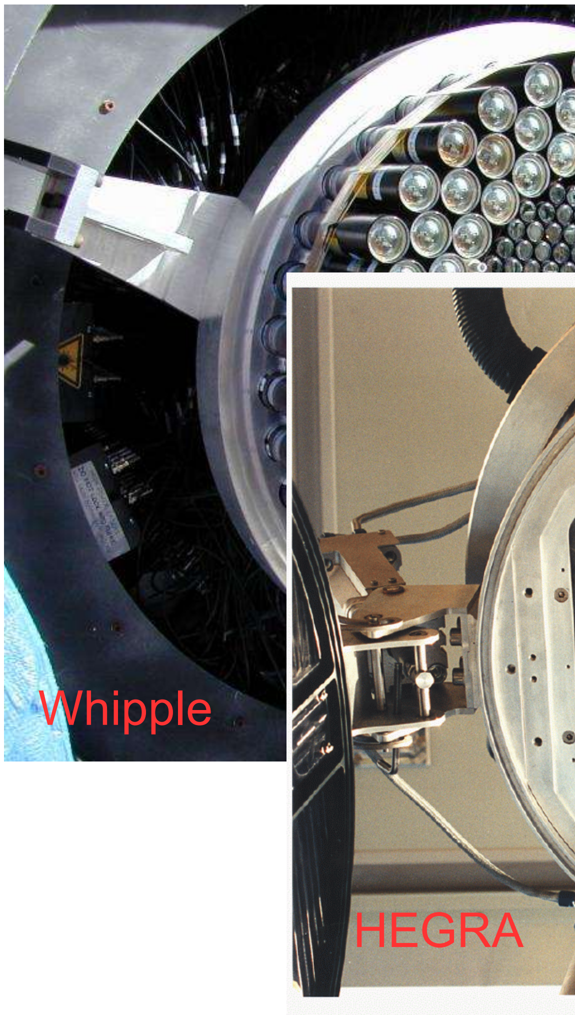
Imaging atmospheric Cherenkov telescopes



Shower imaging by telescopes



Cameras of Cherenkov telescopes



H.E.S.S. camera components

Camera organized with 60 drawers of 16 PMTs each:

H.E.S.S. cameras contain complete electronics and readout system. Connected to outside world by 4 optical fibres.

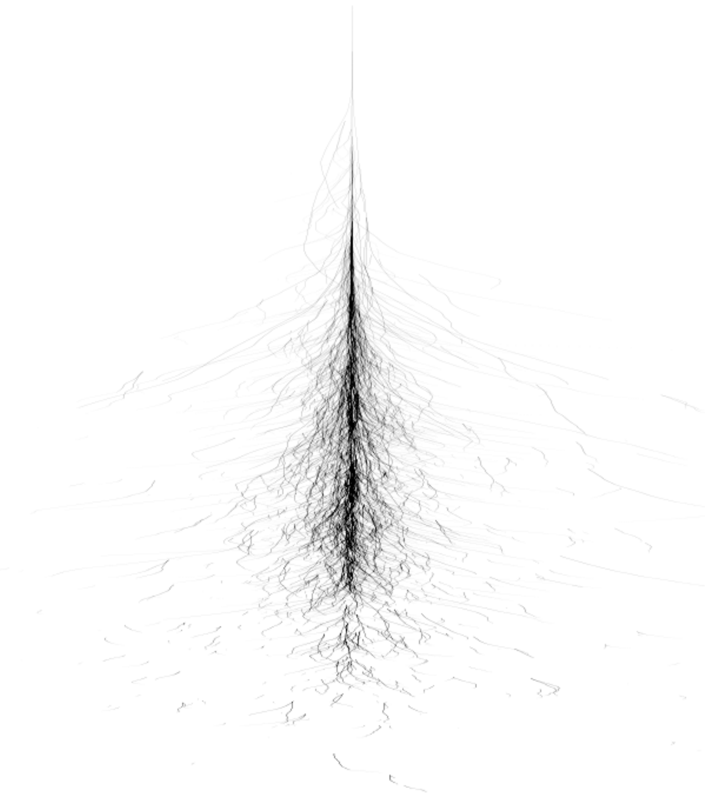
The H.E.S.S. telescope system

4 Telescopes in square configuration of 120 m * 120 m.

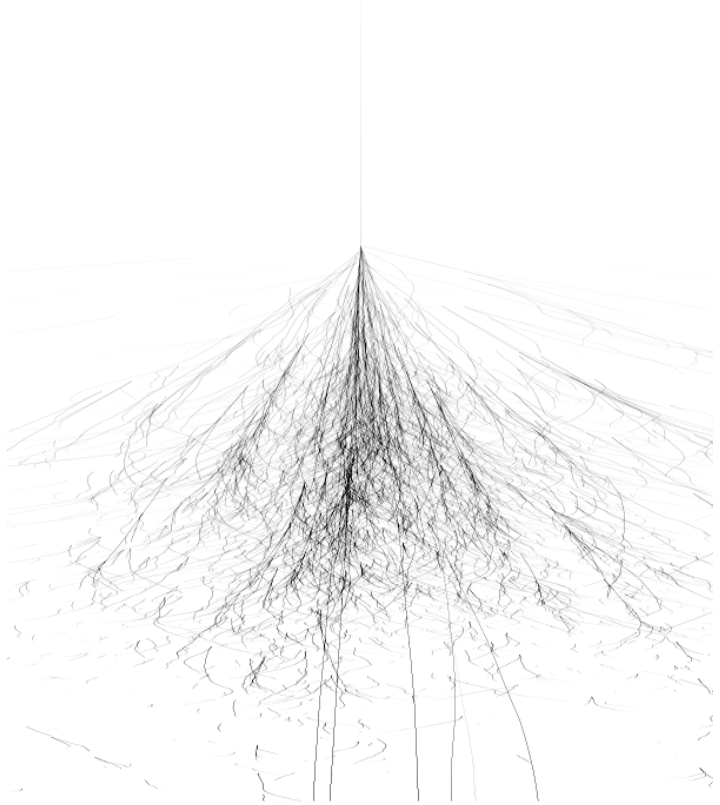
Trigger: at least two telescopes.

Gamma and hadron showers

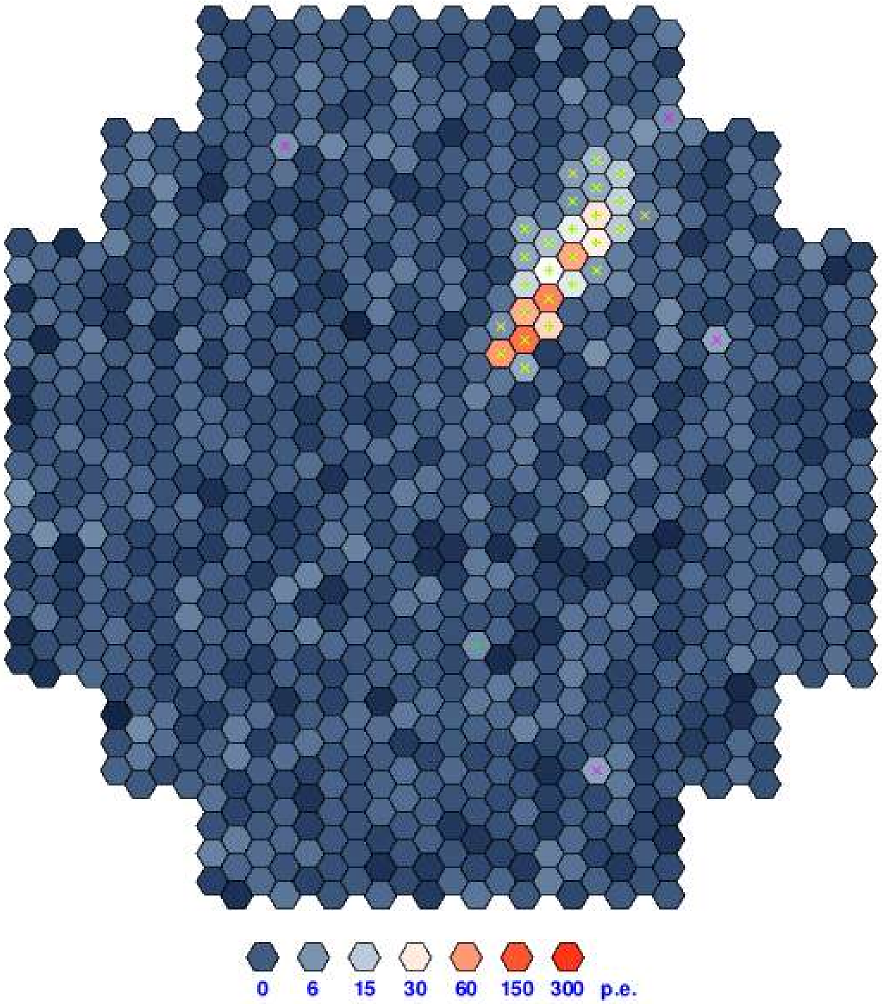
Gamma shower



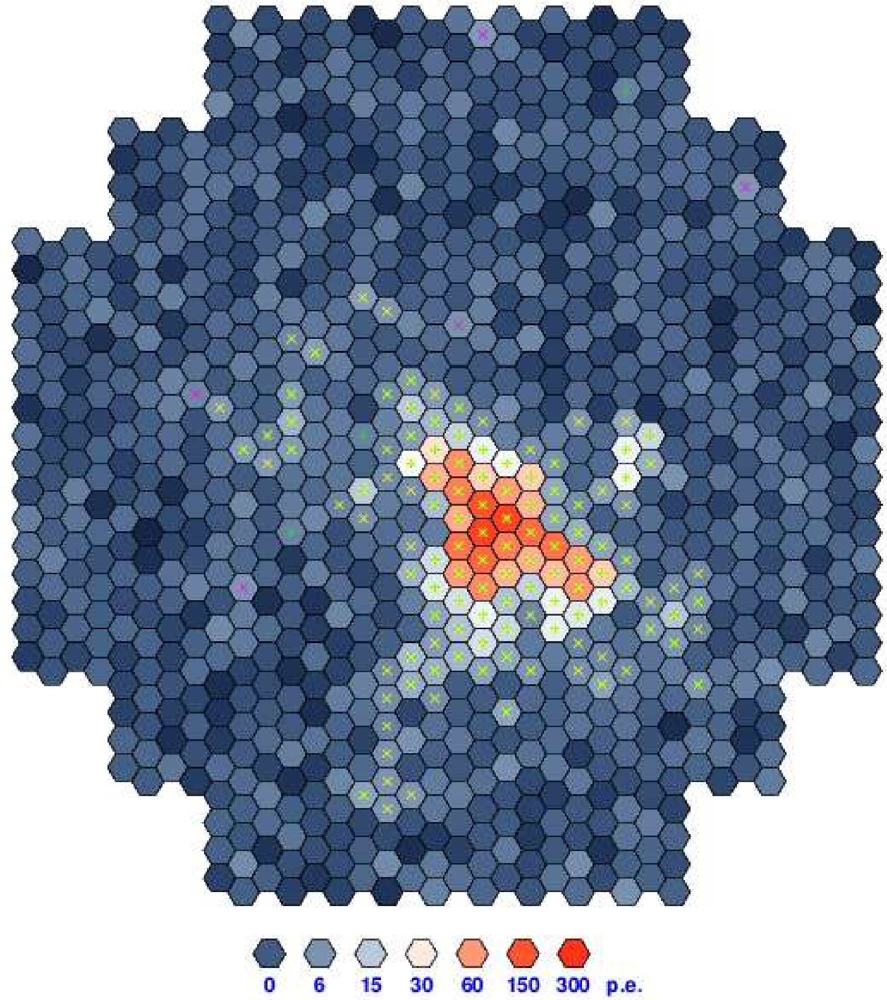
Hadron shower



Gamma and hadron showers

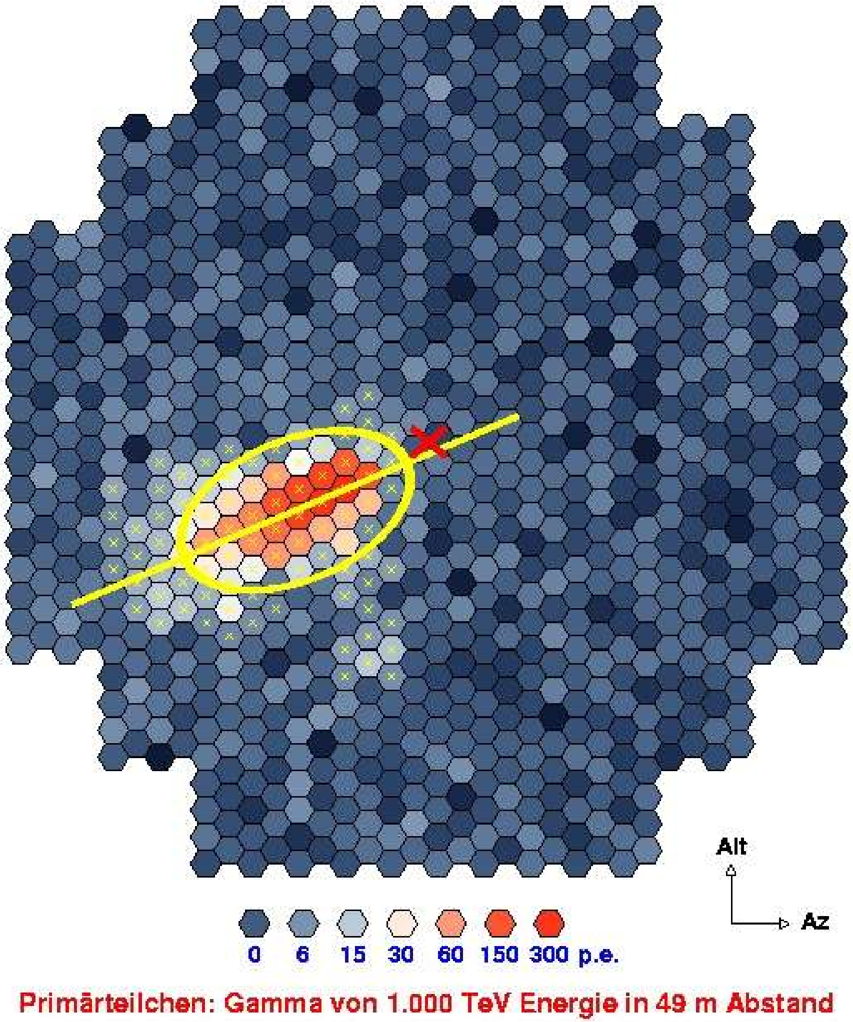


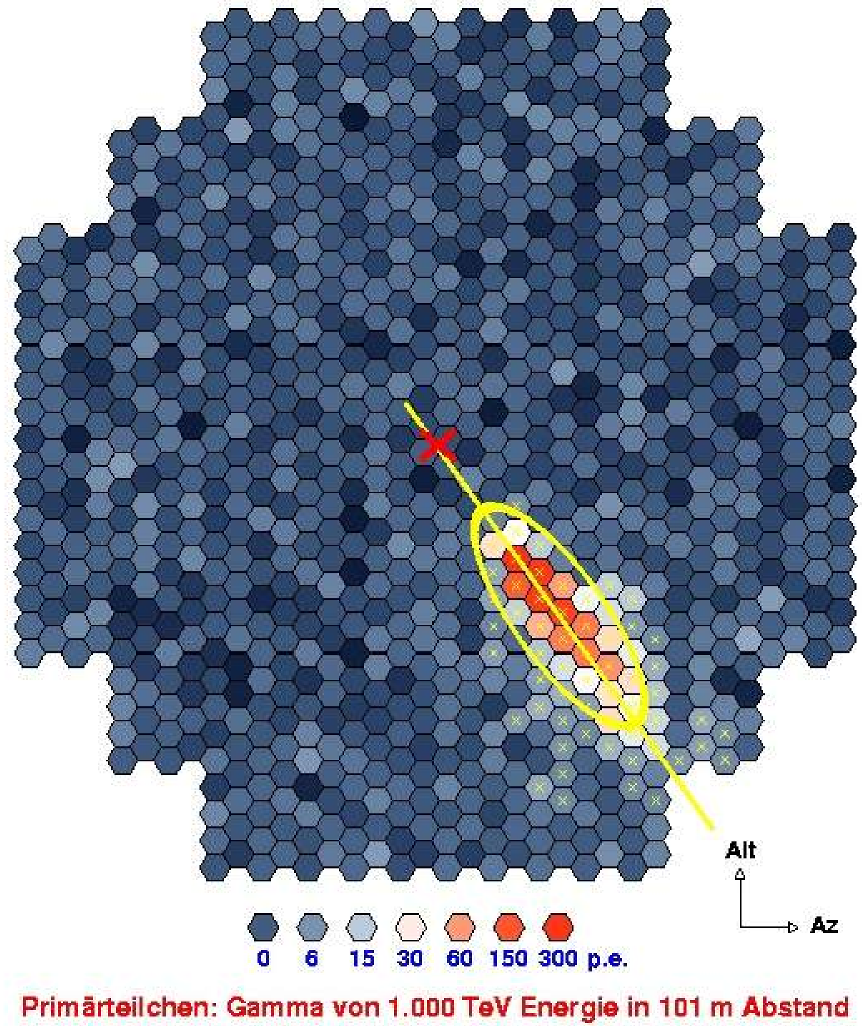
Gamma shower



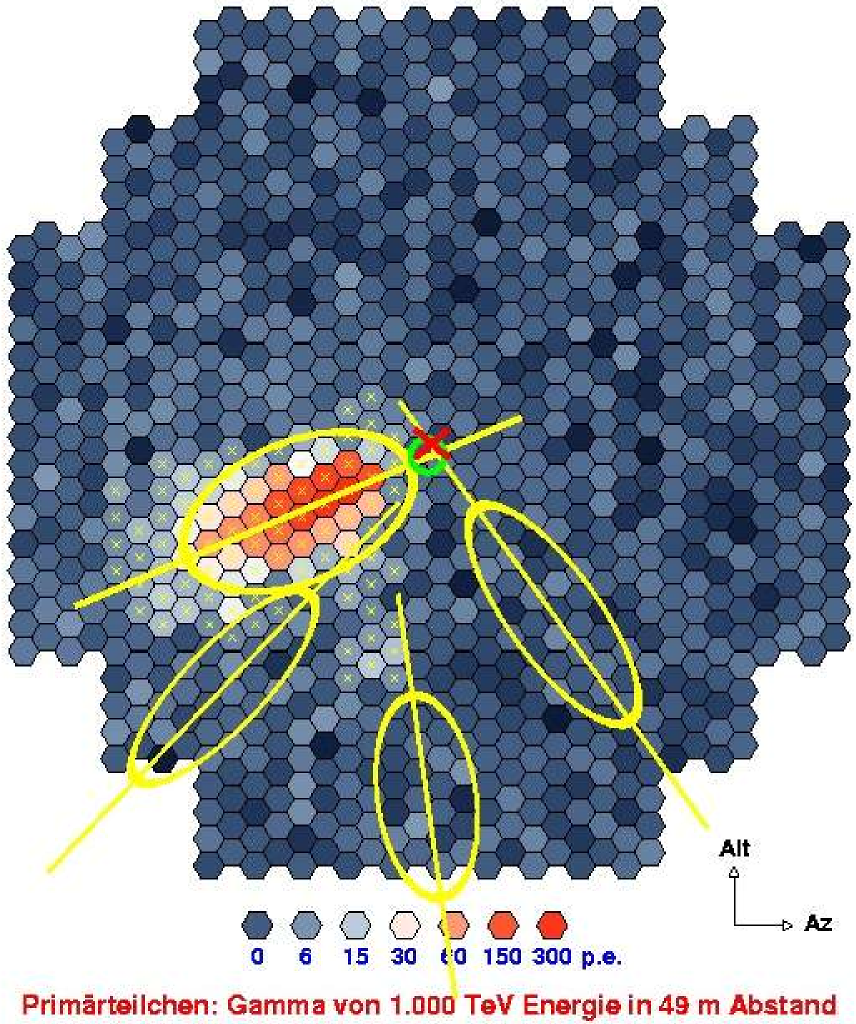
Hadron shower

Stereoscopic observations





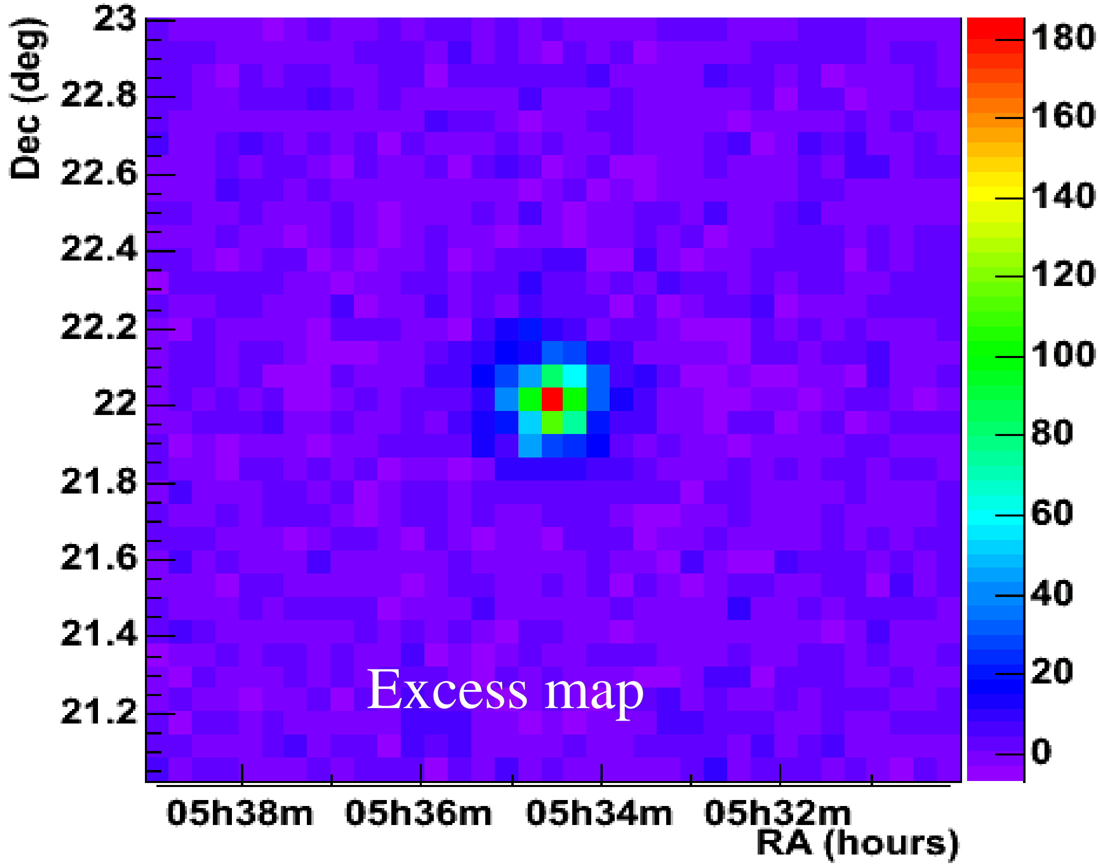
Stereoscopic observations



Advantages:

- No local muon triggers.
- Shower reconstruction in 3-D including height of shower maximum.
- Better gamma-hadron separation.

Example source: Crab Nebula

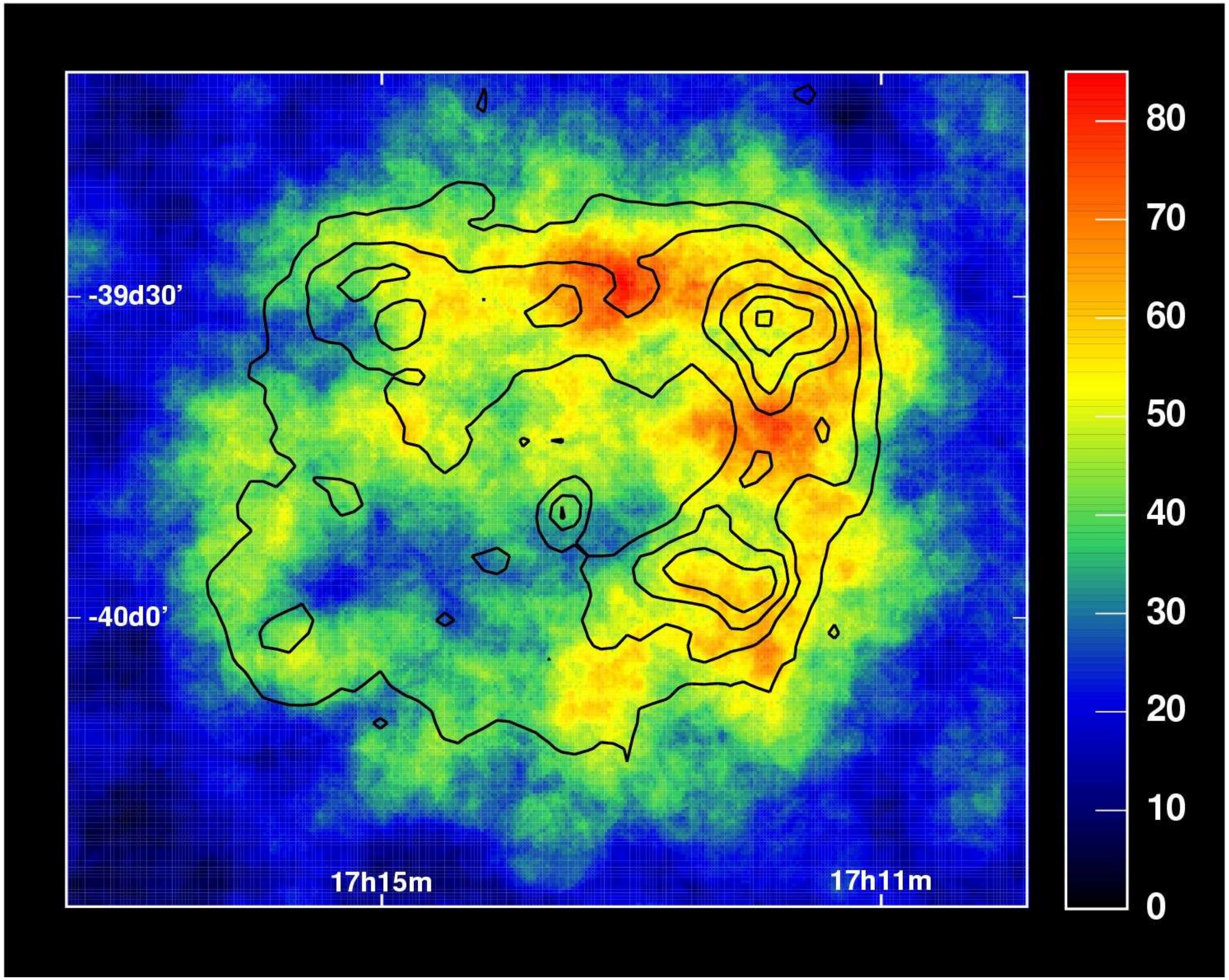


Crab Nebula is an unresolved source.

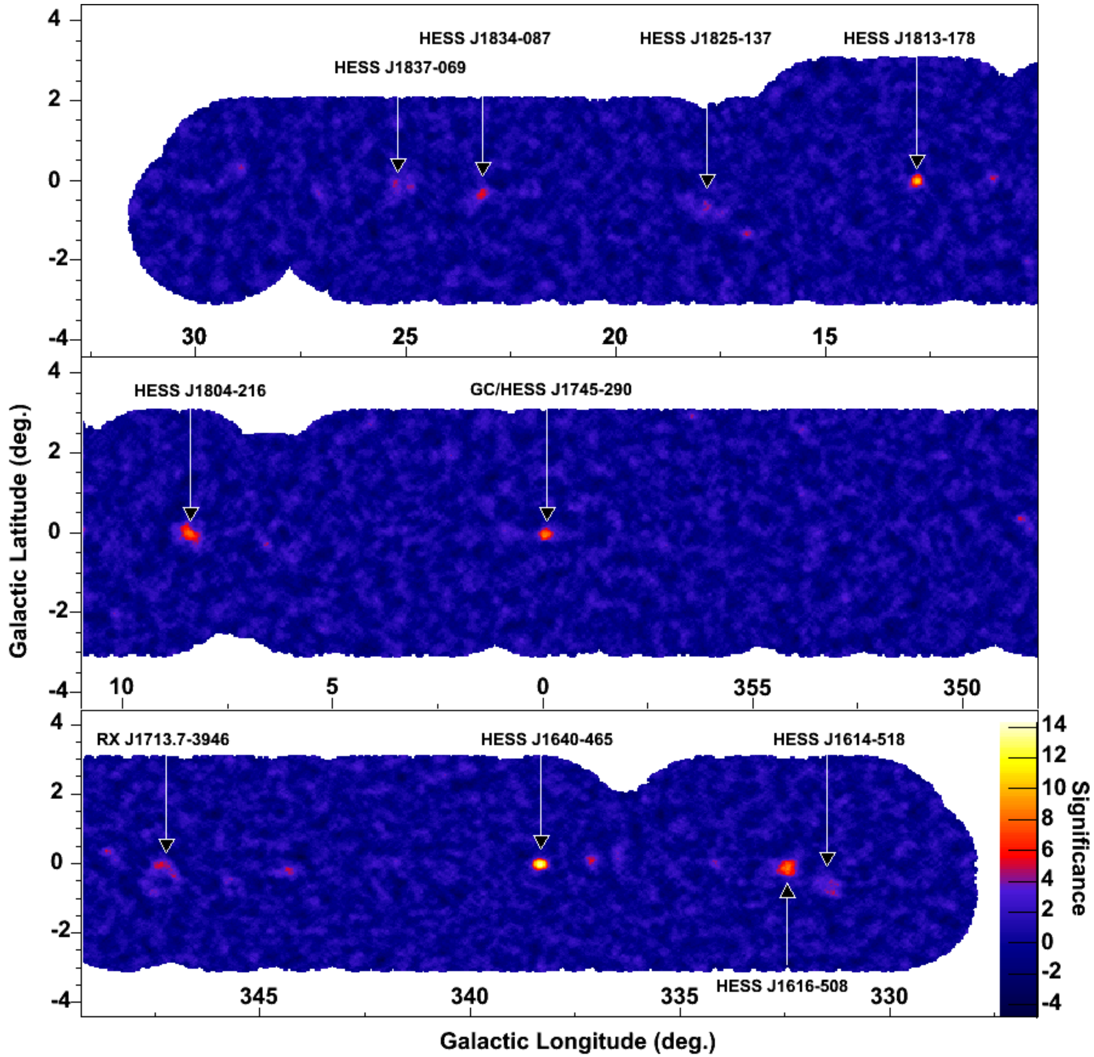
Distribution shows gamma-ray point-spread function (PSF).

Resolution: 0.1°.

Another one: RX J1713.7-3946



Many sources in the Galactic plane



Galactic plane survey revealed many more Galactic gamma-ray sources than we knew before.

Science 307, 1938 (2005)

Simulating H.E.S.S.

- All results are cross-checked by at least two independent processing schemes, with separate calibration and analysis schemes, with gamma-ray selection based on completely different Monte Carlo simulations.
- I will describe here only the CORSIKA / sim_hessarray line of simulations.

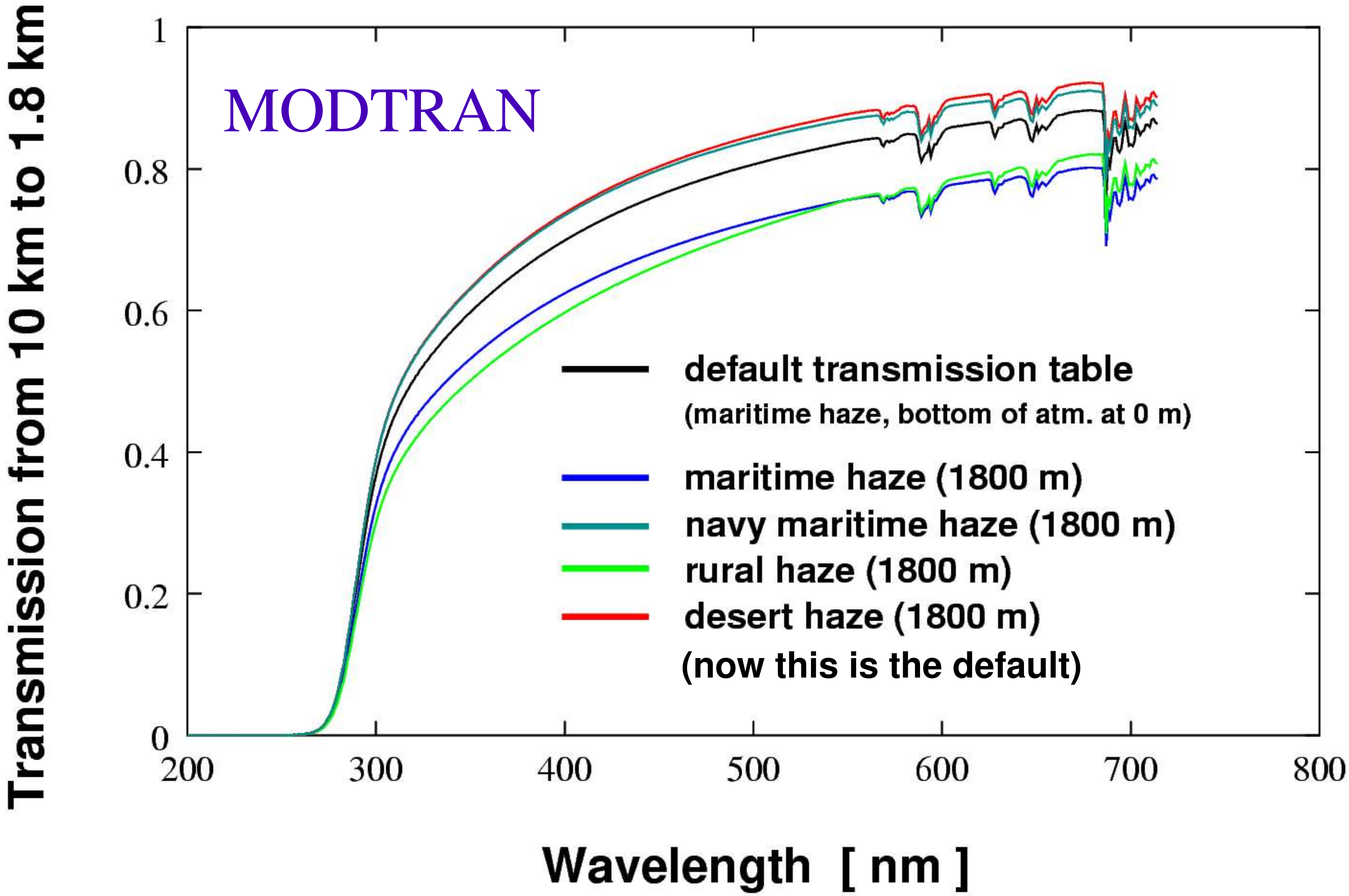
Simulation outline

- Shower simulation with CORSIKA with options CERENK, **IACT**, ATMEXT, VOLUMEDET.
- CORSIKA output is usually piped into the detector simulation with no intermediate storage on disk. Through utility multipipe_corsika the output is piped into different simulations at the same time (e.g. for gamma-ray point sources at different off-axis angles).

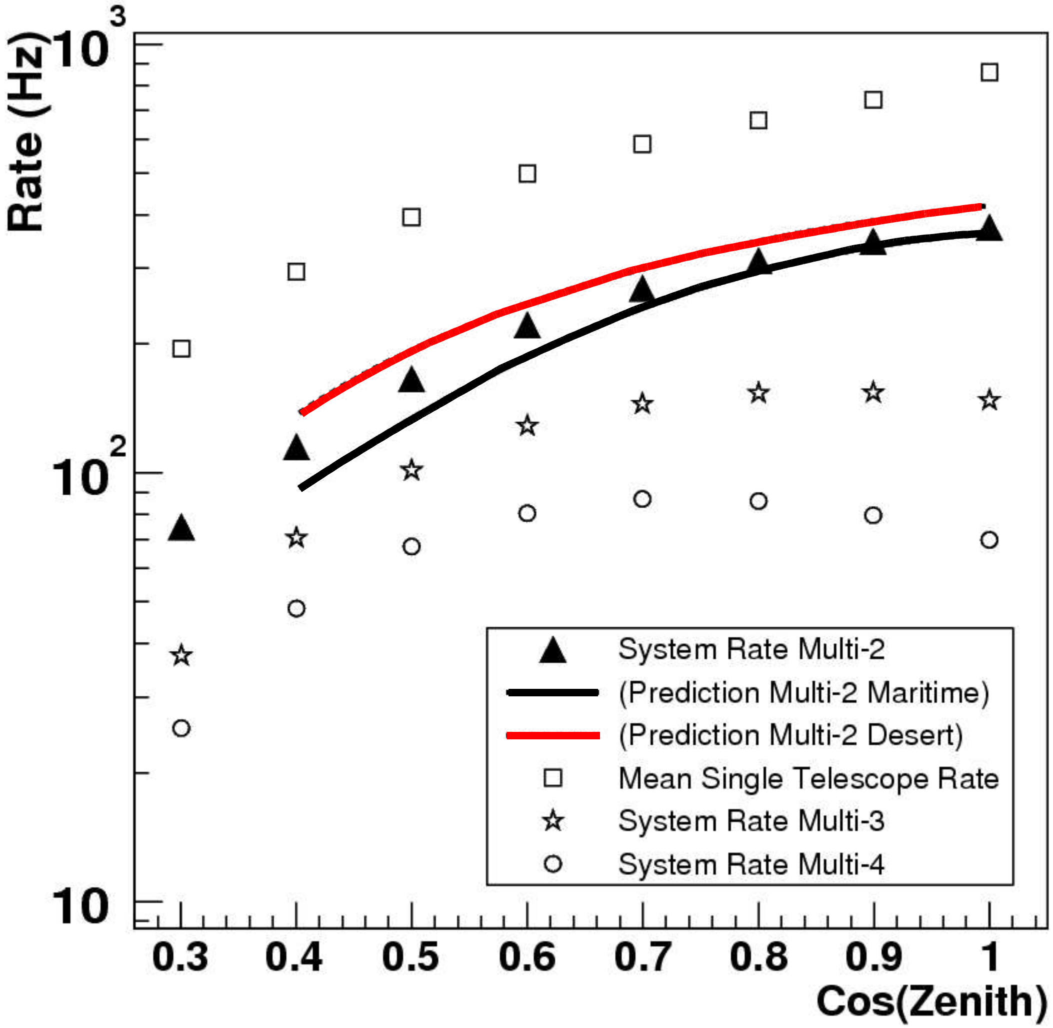
Optics simulation

- Optics simulation includes
  - Atmospheric transmission.
  - Ray-tracing and reflection on segmented mirrors.
  - Shadowing by camera support structure.
  - Angle-of-incidence dependent acceptence in pixels (PMTs with Winston-cone funnels).
  - Wavelength dependence of mirror reflectivity, funnel efficiency, PMT quantum+collection efficiency.

Atmospheric transmission



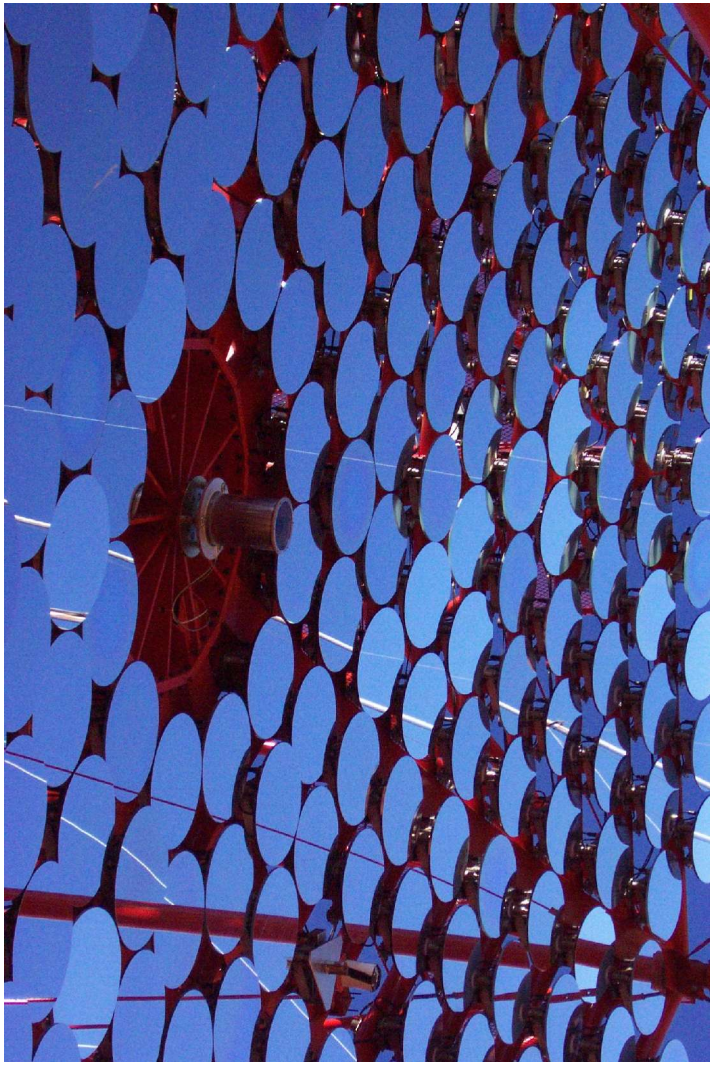
Atmosphere and trigger rate



The transmission model with less extinction (here desert) is in better agreement with measured zenith-angle dependence of the trigger rate.

The absolute rate is subject to CR flux uncertainty etc.

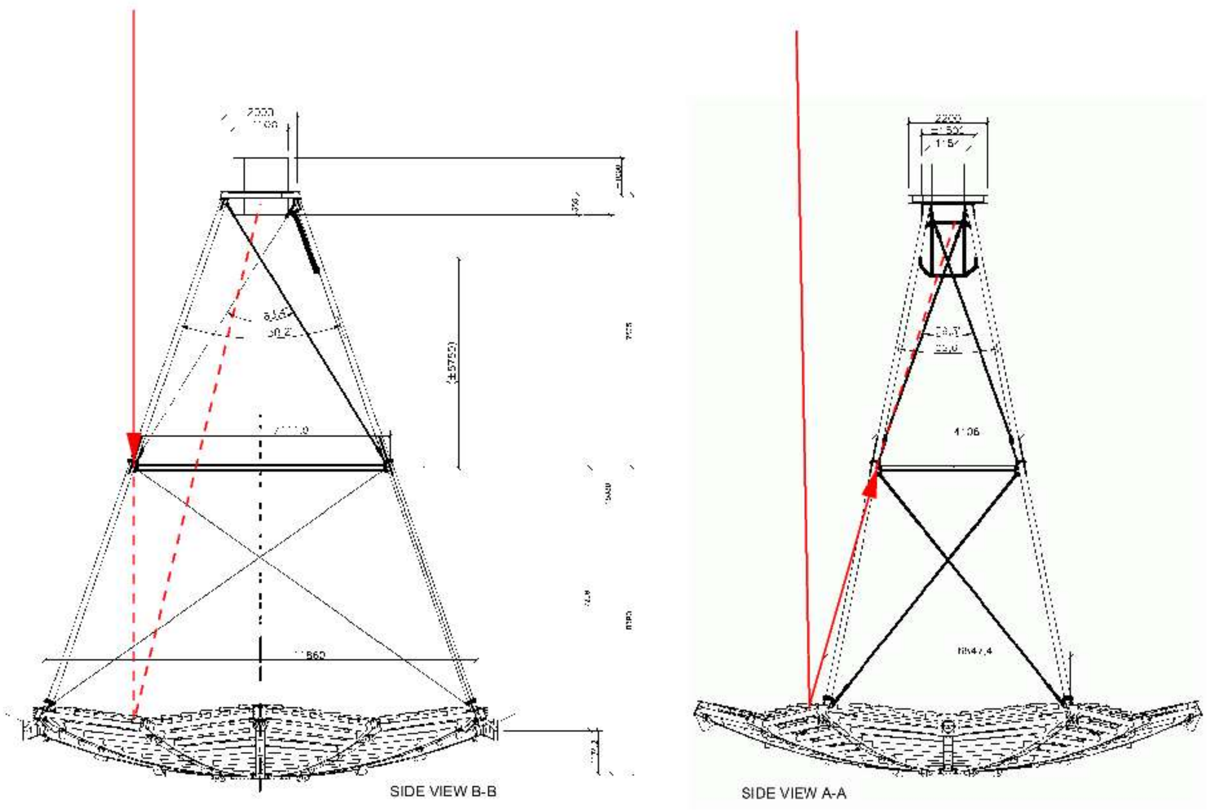
Optics simulation: ray-tracing



- Photons are fully ray-traced on non-perfect mirror facets with random misalignments.
- Acceptance in camera depending on angle of incidence.

Optional ray-tracing with shadowing

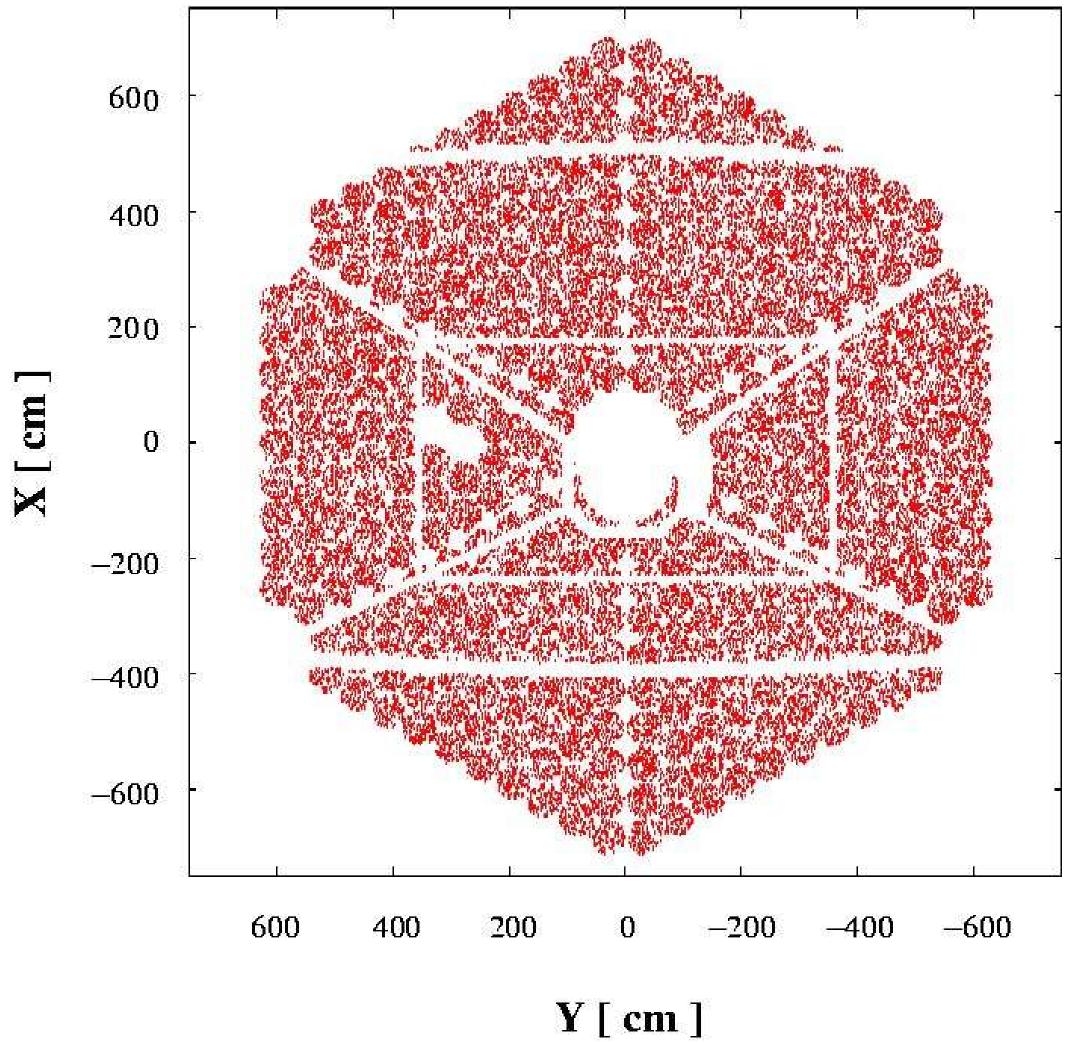
Shadowing by masts: two possibilities



Camera and its support structure can be fully included in the ray-tracing.

Normally just treated as a 'telescope transmission'.

Optional ray-tracing with shadowing



Shown here: photon impact positions on dish for photons reaching the camera.

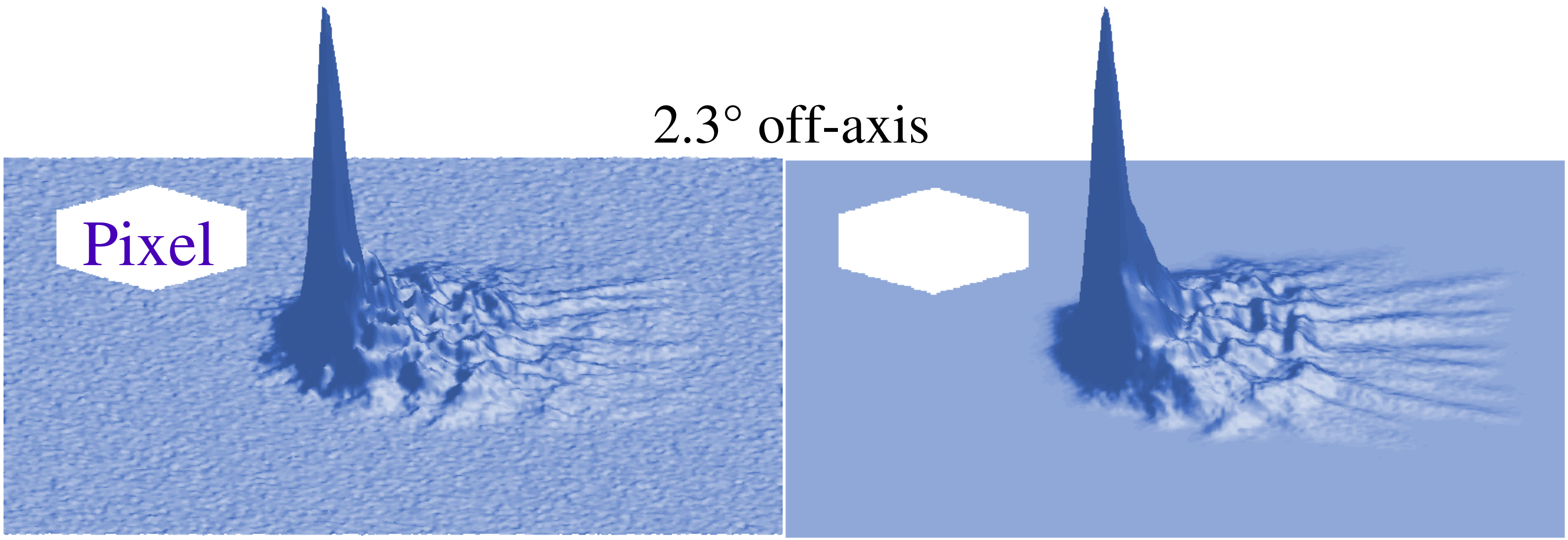
Light source is 2° off-axis.

Star light imaging

Measurement of star light imaged on the closed camera lid by a dedicated CCD camera mounted at the dish centre.

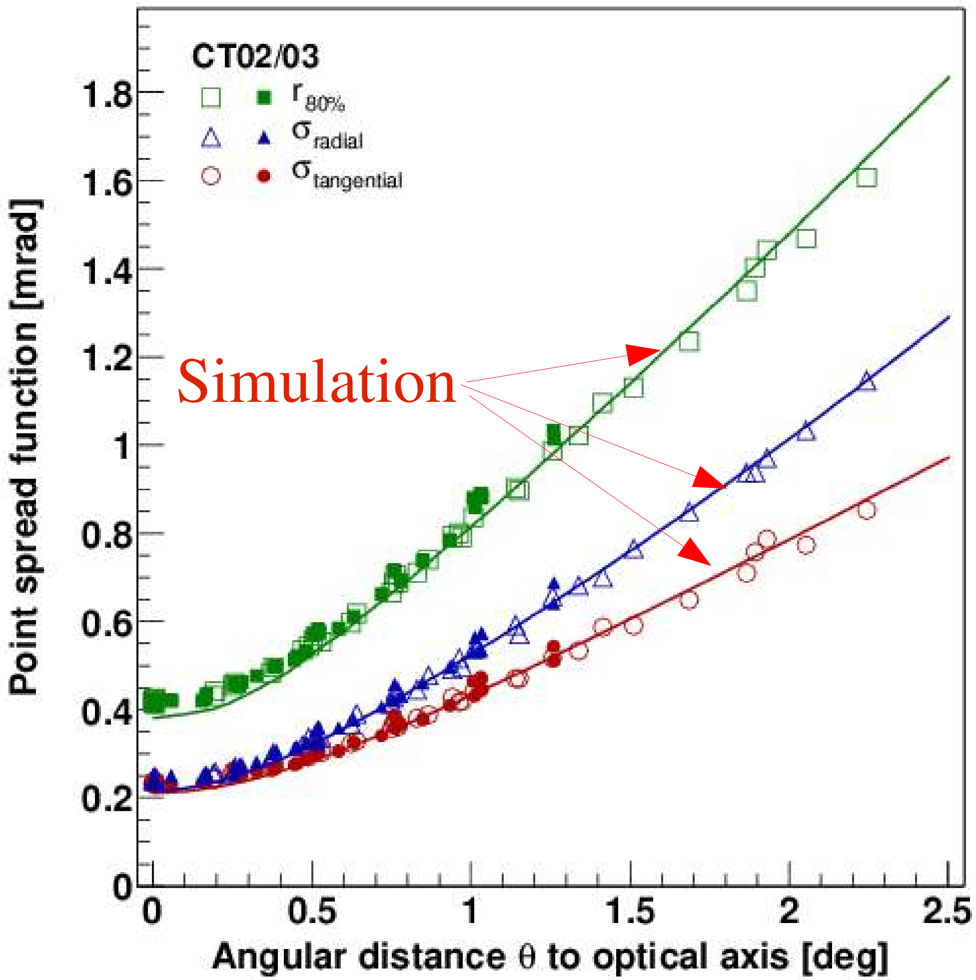
CT 4, measured

sim_hessarray ray-tracing



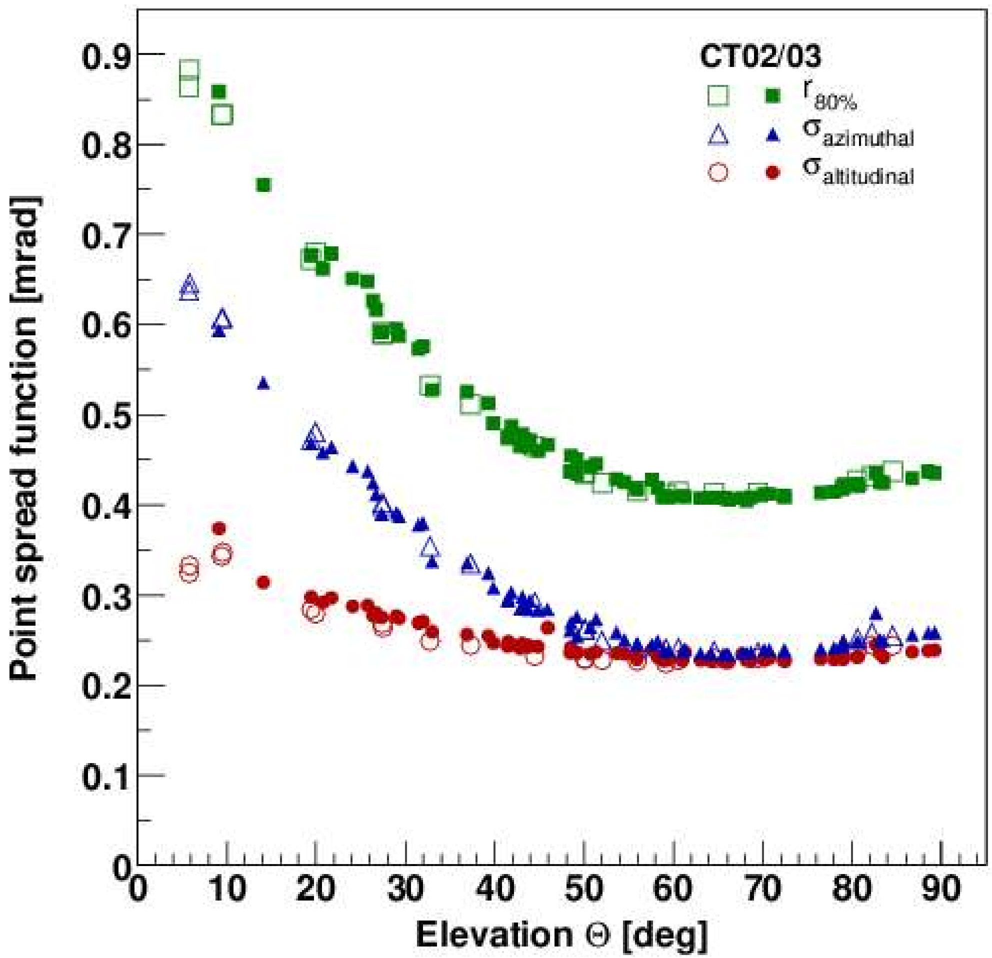
R. Cornils

Star light imaging



Star-light point spread function depending on off-axis angle is fully reproduced with just the measured mirror quality as well as the mounting and alignment accuracy as inputs.

Star light imaging



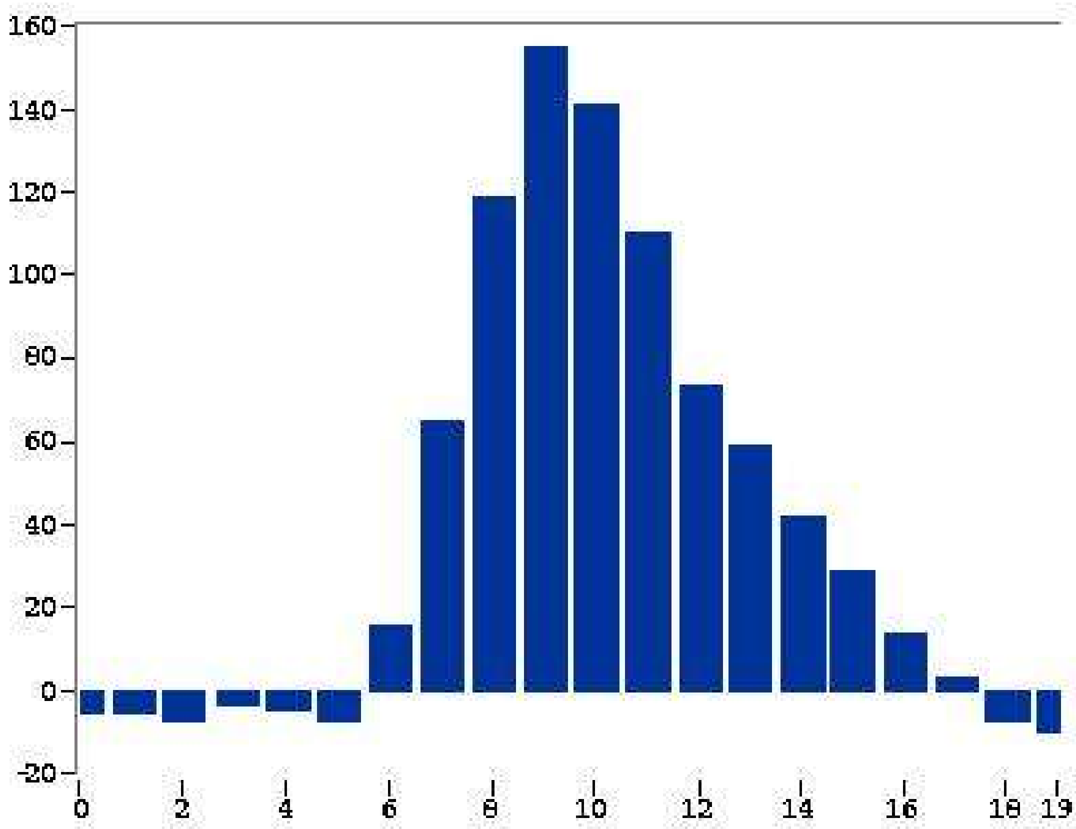
Zenith angle (or elevation angle) dependence is added to simulations as measured.

It depends on defor-mations of the dish and mirror supports.

Electronics simulated in detail

- Pixel trigger by fast comparator, then summing up comparator outputs and forming a sector trigger (=telescope trigger).
- System trigger by overlapping of at least two telescope triggers.
- Read-out with two different pre-amplifier gains, full simulation of raw data with night-sky background (may include stars).

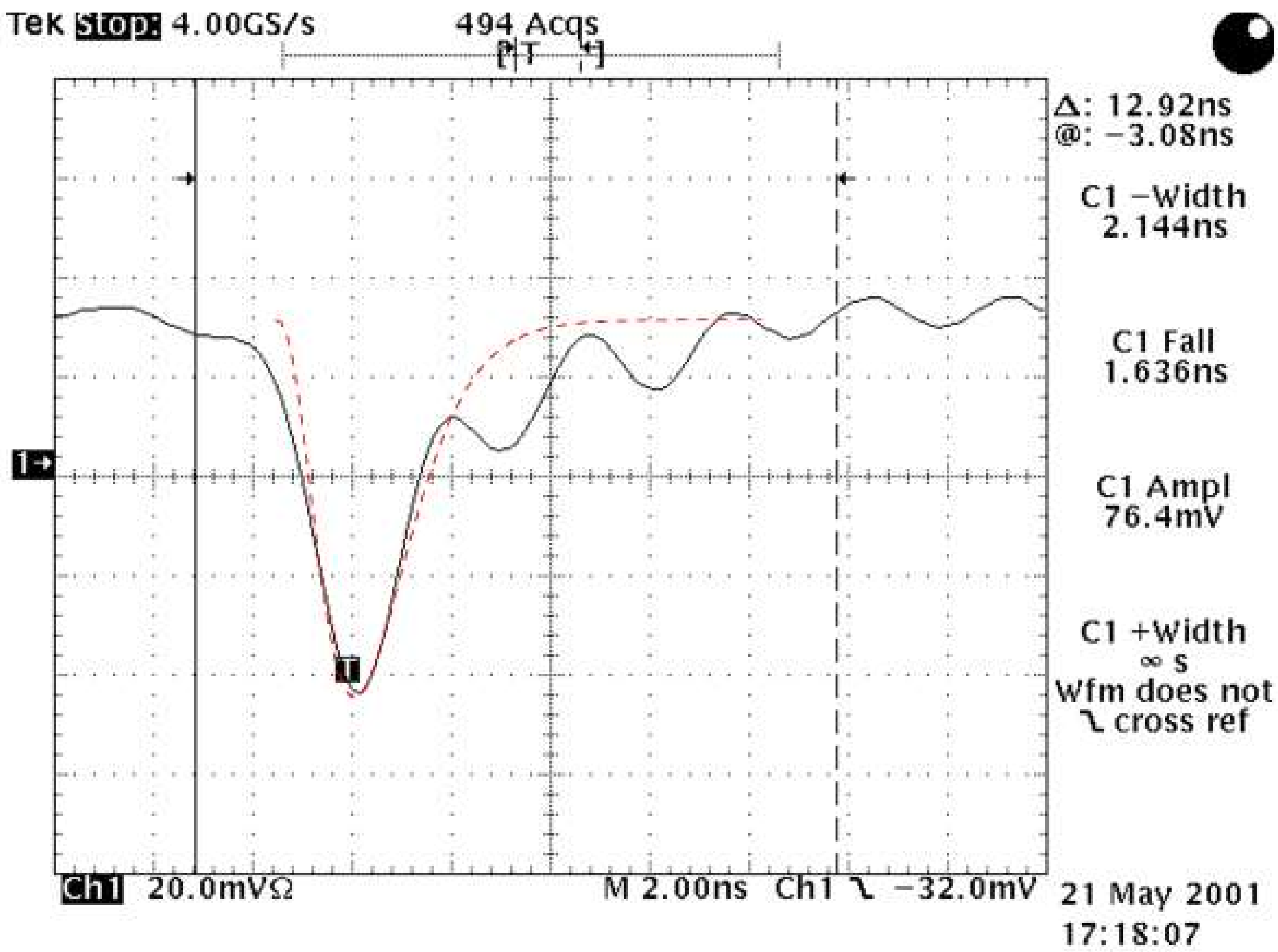
The recorded pulse shape



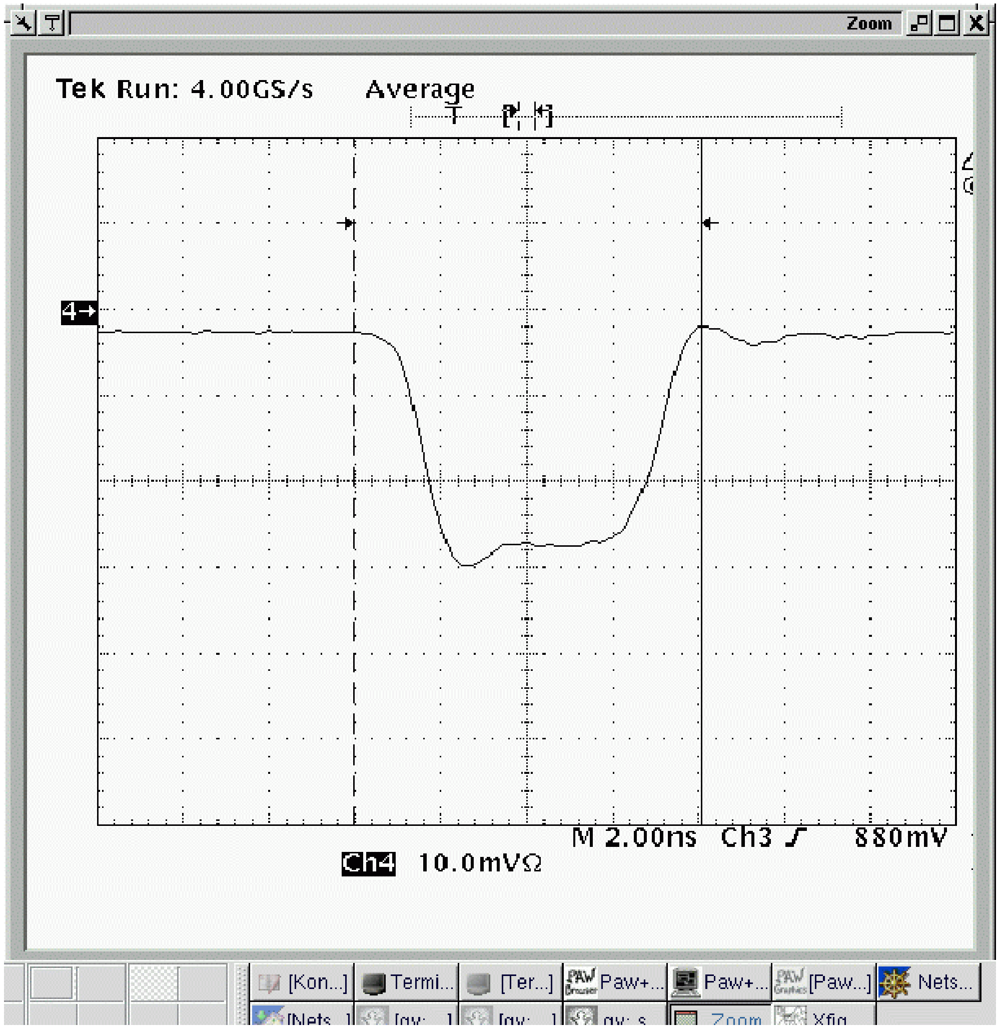
1 GHz analog memory digitized by 12-bit ADC after telescope trigger.

High gain + low gain.

Pulse shape at comparator input



Comparator output pulse

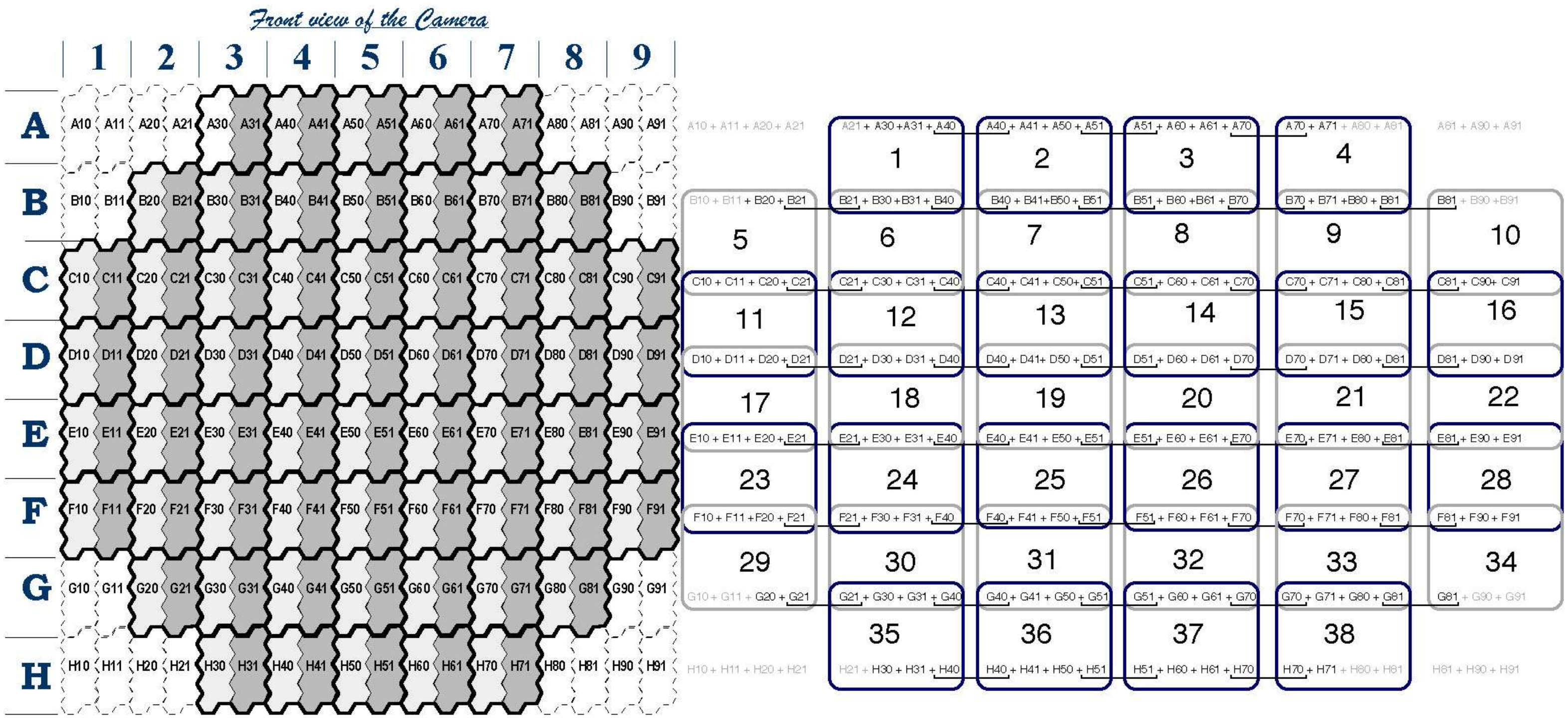


Comparator switching with minimum charge over threshold.

Rise and fall of the comparator output signal taken into account and summed up to form sector trigger input.

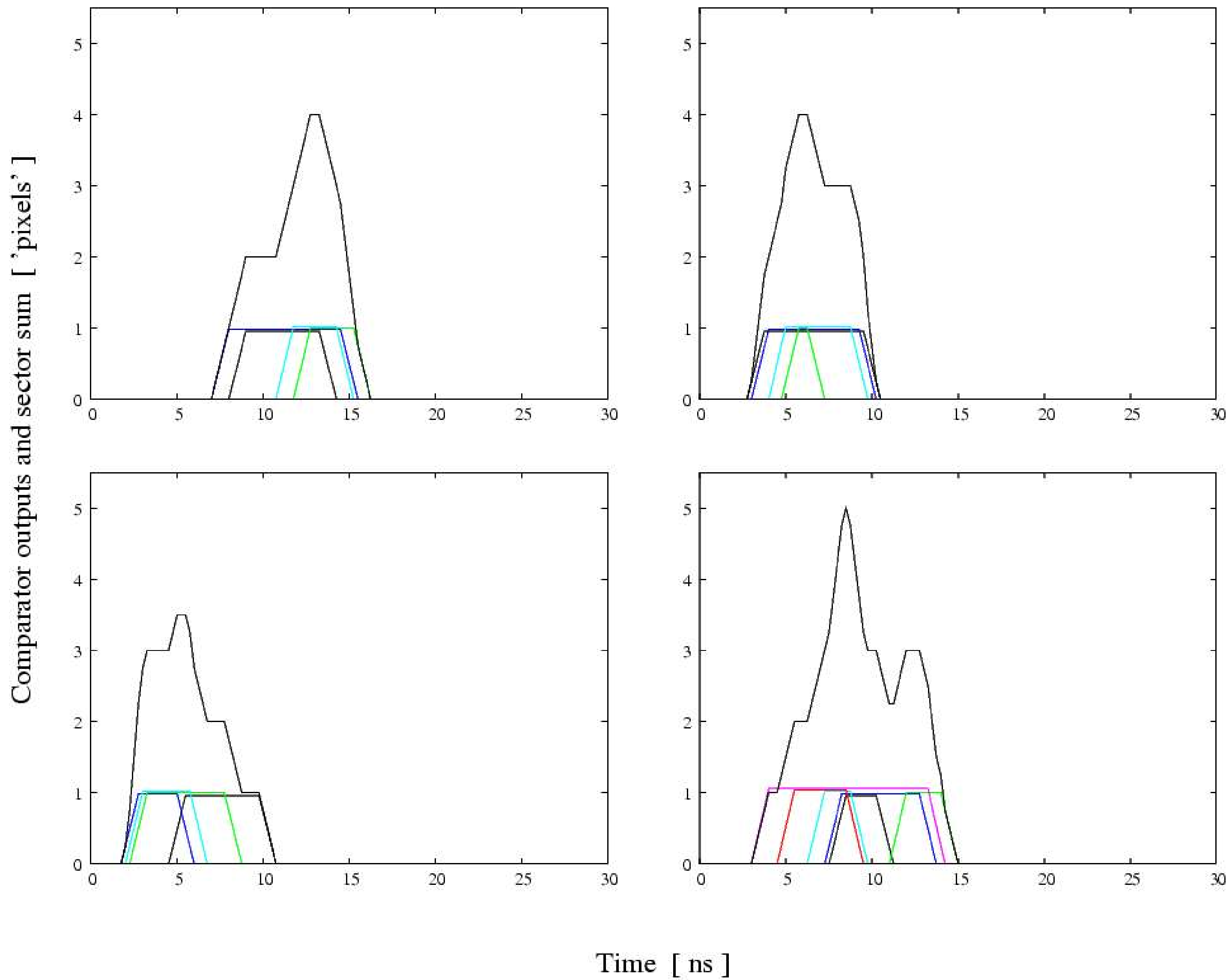
Trigger sector scheme

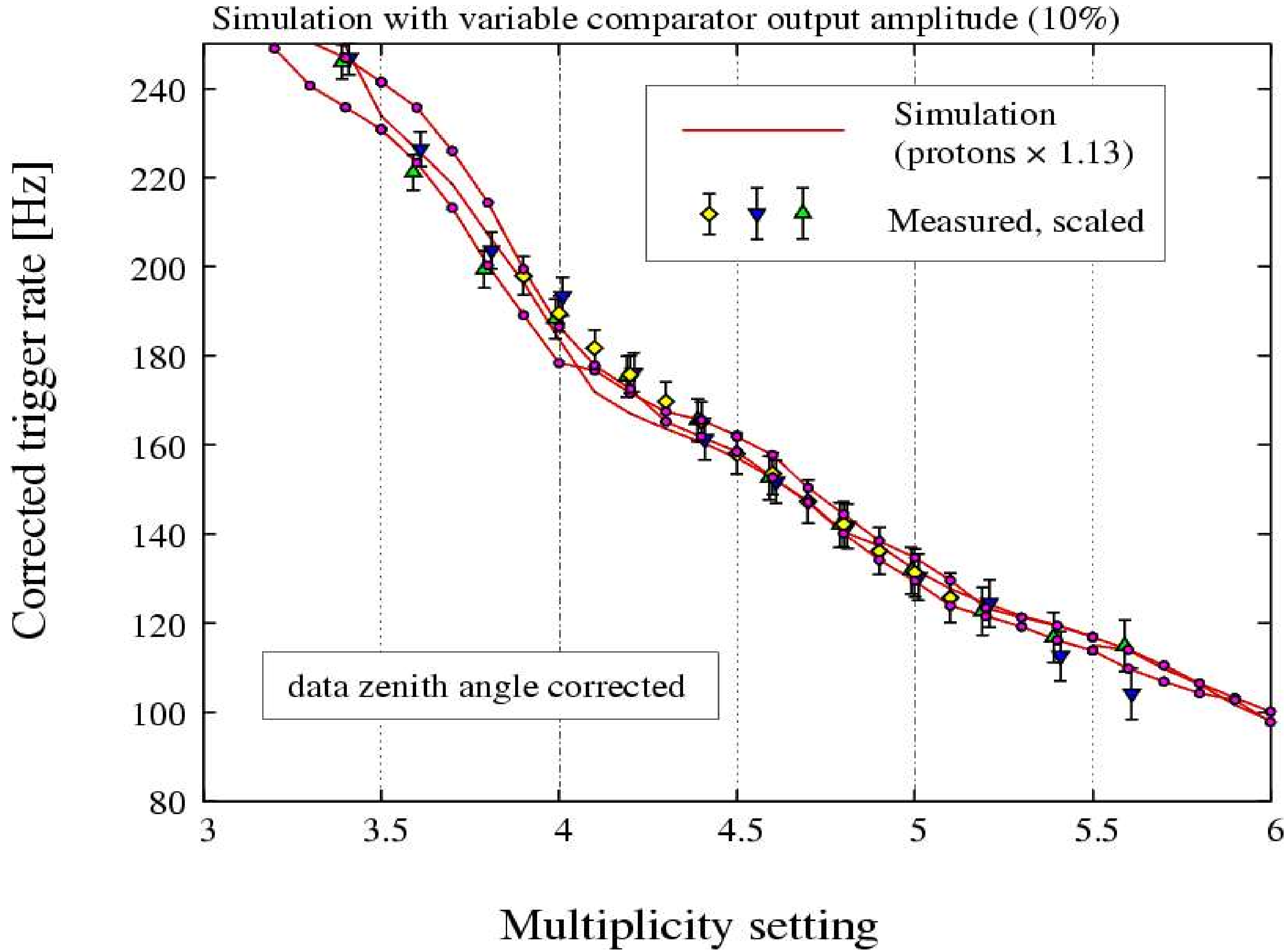
Caméra 5° (960 PMTs), Trigger



LPNHE-PARIS
MARCH 2001

Not all pixel comparators fire at the same time (4 showers):





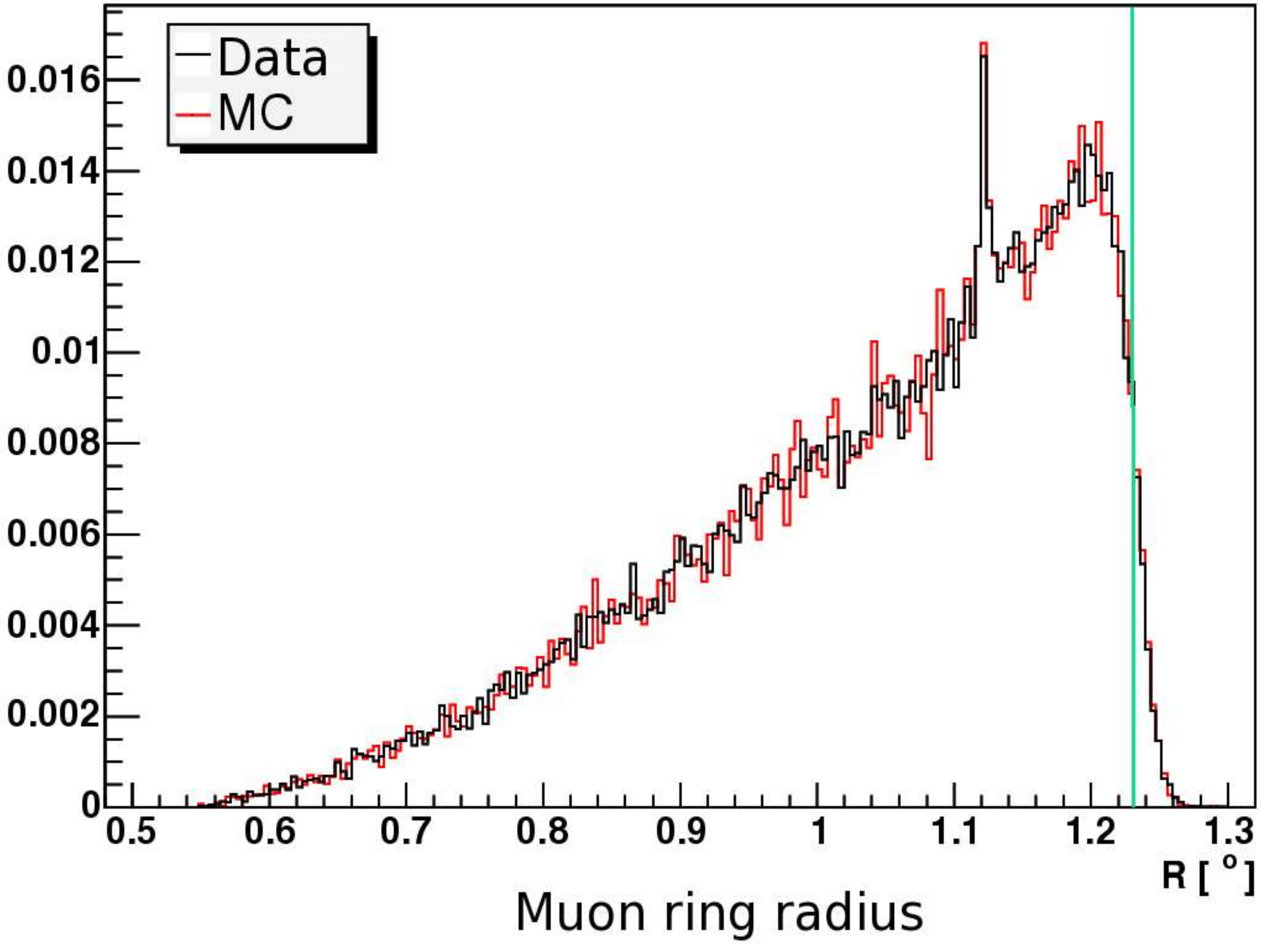
Simulation with variable comparator output amplitude (10%)
Simulation
(protons × 1.13)
Measured, scaled
data zenith angle corrected
Corrected trigger rate [Hz]
Multiplicity setting
240
220
200
180
160
140
120
100
80
3
3.5
4
4.5
5
5.5
6

Cross-checks with muons

- Muons directly hitting the telescope mirror are imaged onto complete rings. Light of such rings is emitted over the last 600 m.
- Slower muons result in rings of smaller opening angle (radius) and experience more multiple scattering (rings more diffuse).
- Maximum physical ring radius is 1.23°.

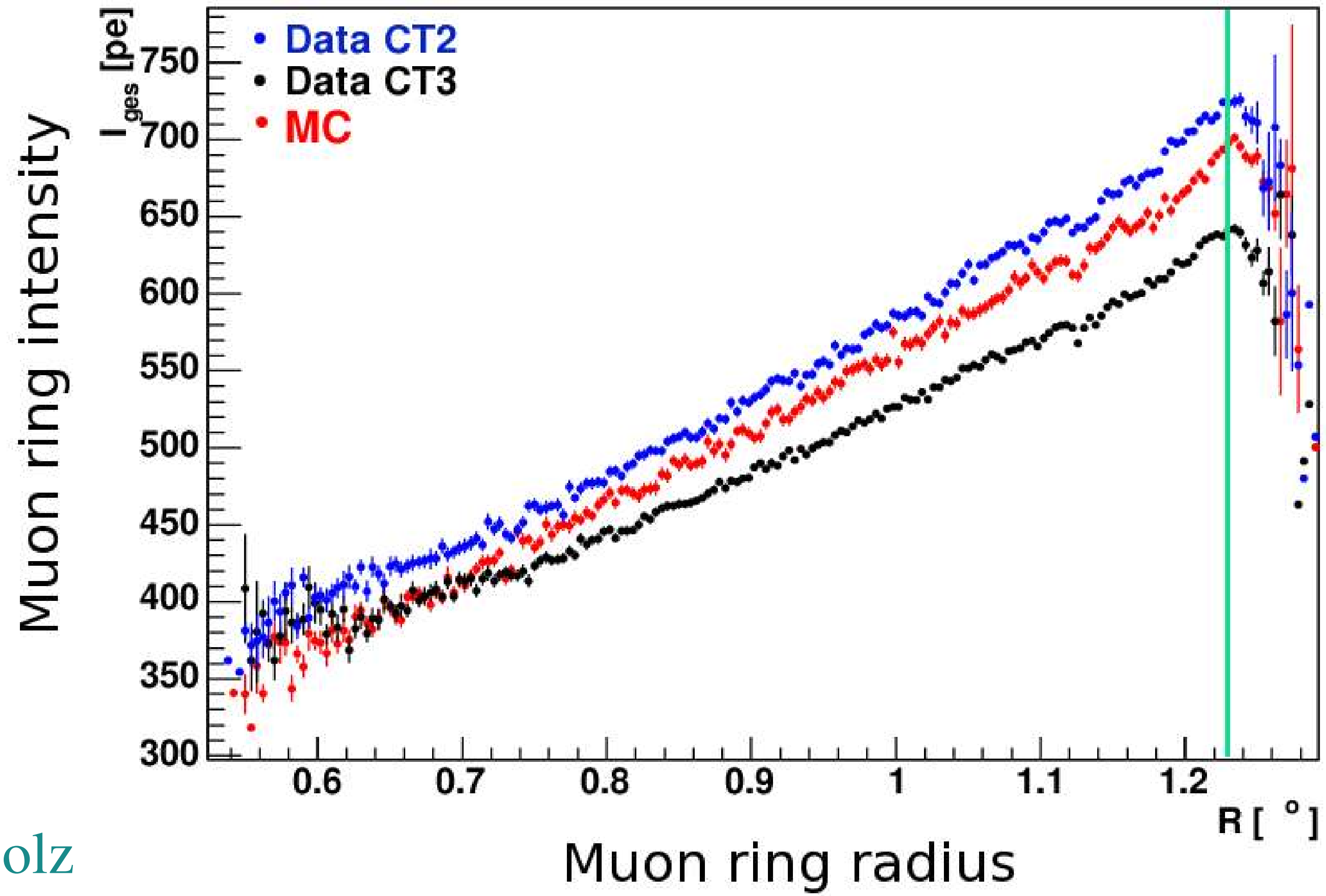
Muon ring radius

Note: requires use of proper muon energy spectrum



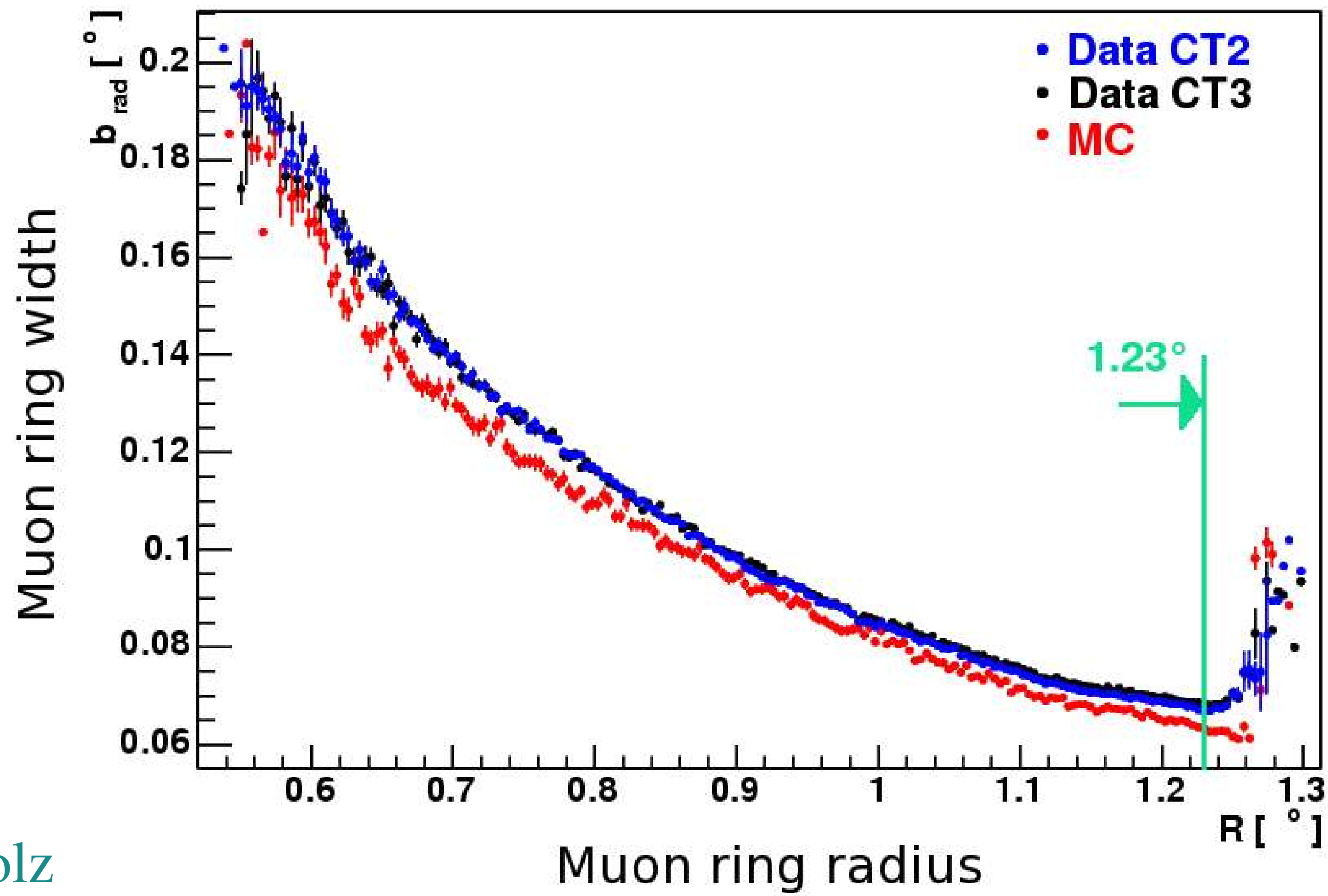
O. Bolz

Muon ring intensity



O. Bolz

Muon ring width

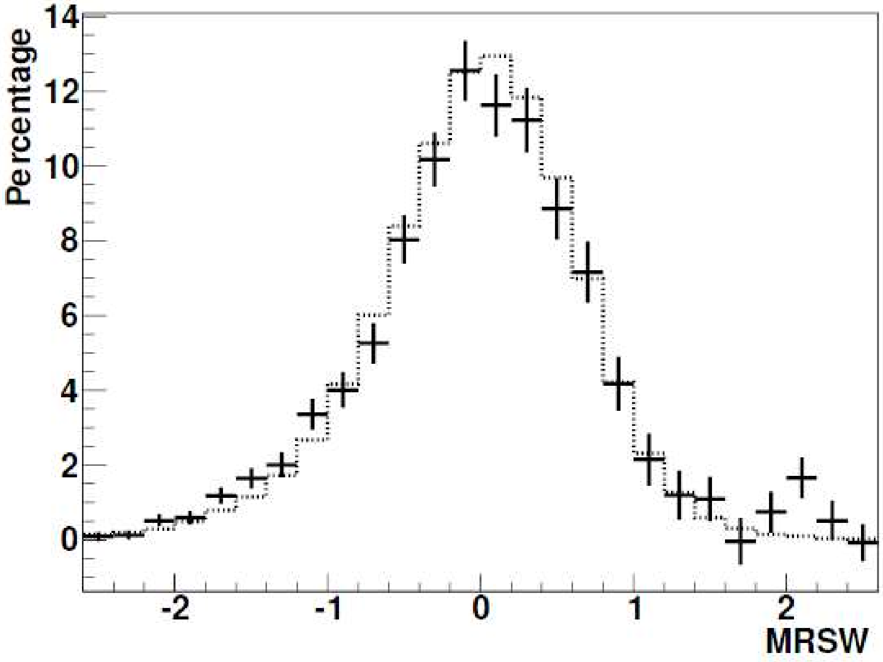


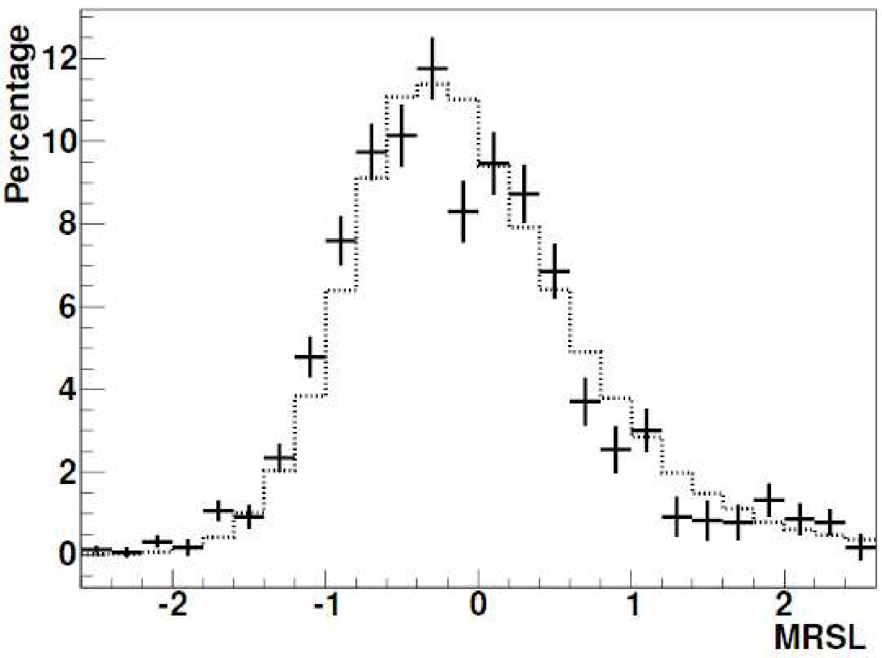
O. Bolz

Cross-checks with showers

- Shapes of air shower images can be compared to simulations.
- This can be done separately with gamma-ray showers from a source and with background (hadron) showers without a gamma-ray source.
- For gamma-ray showers, a correction for remaining background can be determined from an off-source region in the sky.

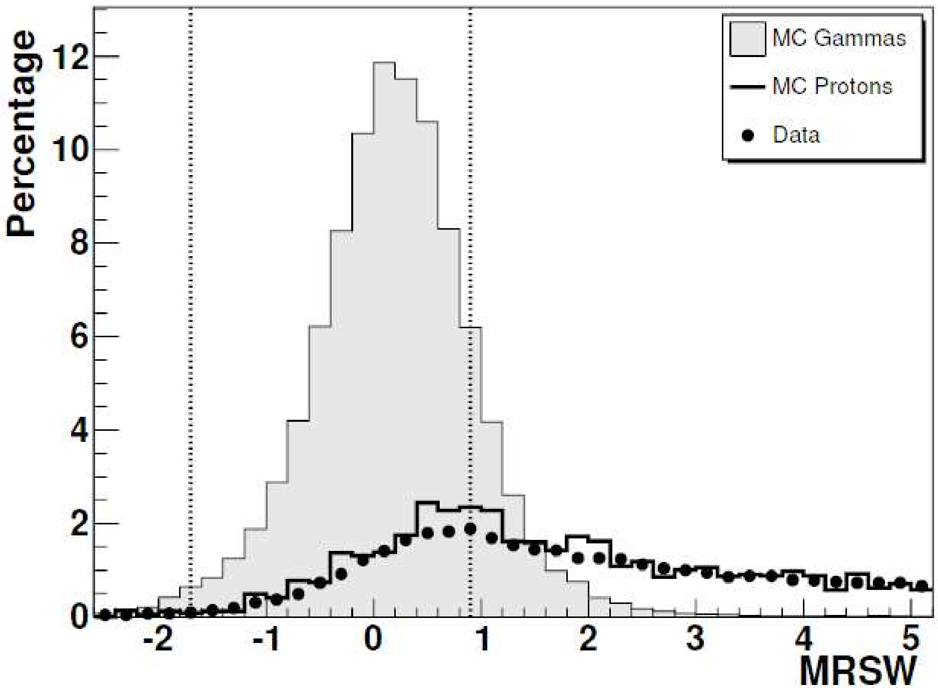
Scaled width and length

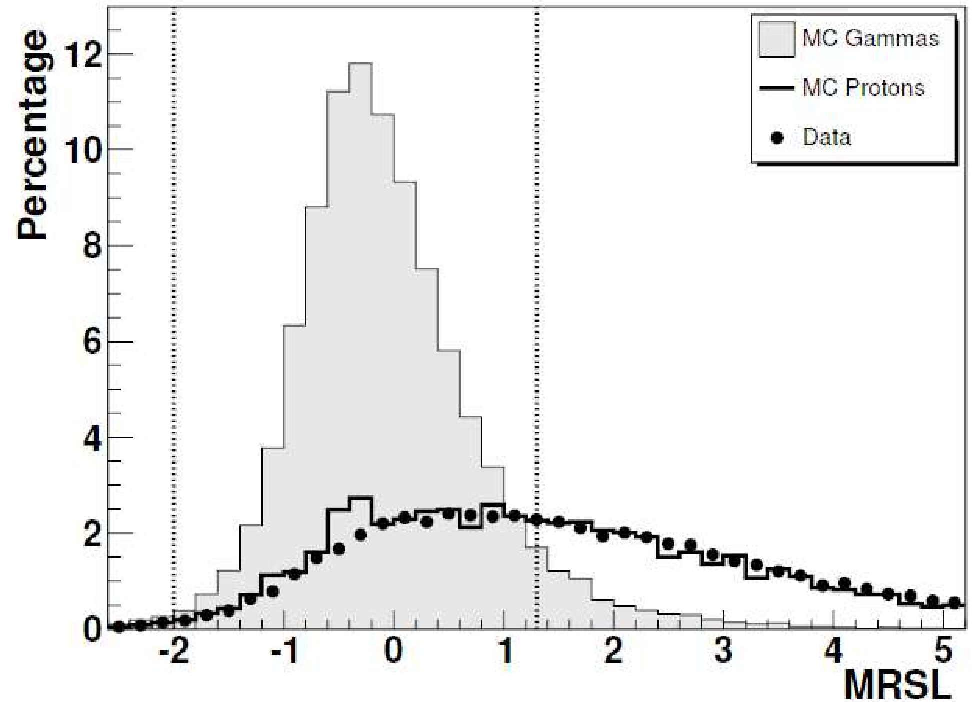




Mean reduced scaled width (MRSW) and length (MRSL) defined such that simulated gamma-rays have mean 0. and variance 1.
Here: comparing simulations and measured data from the Crab Nebula.

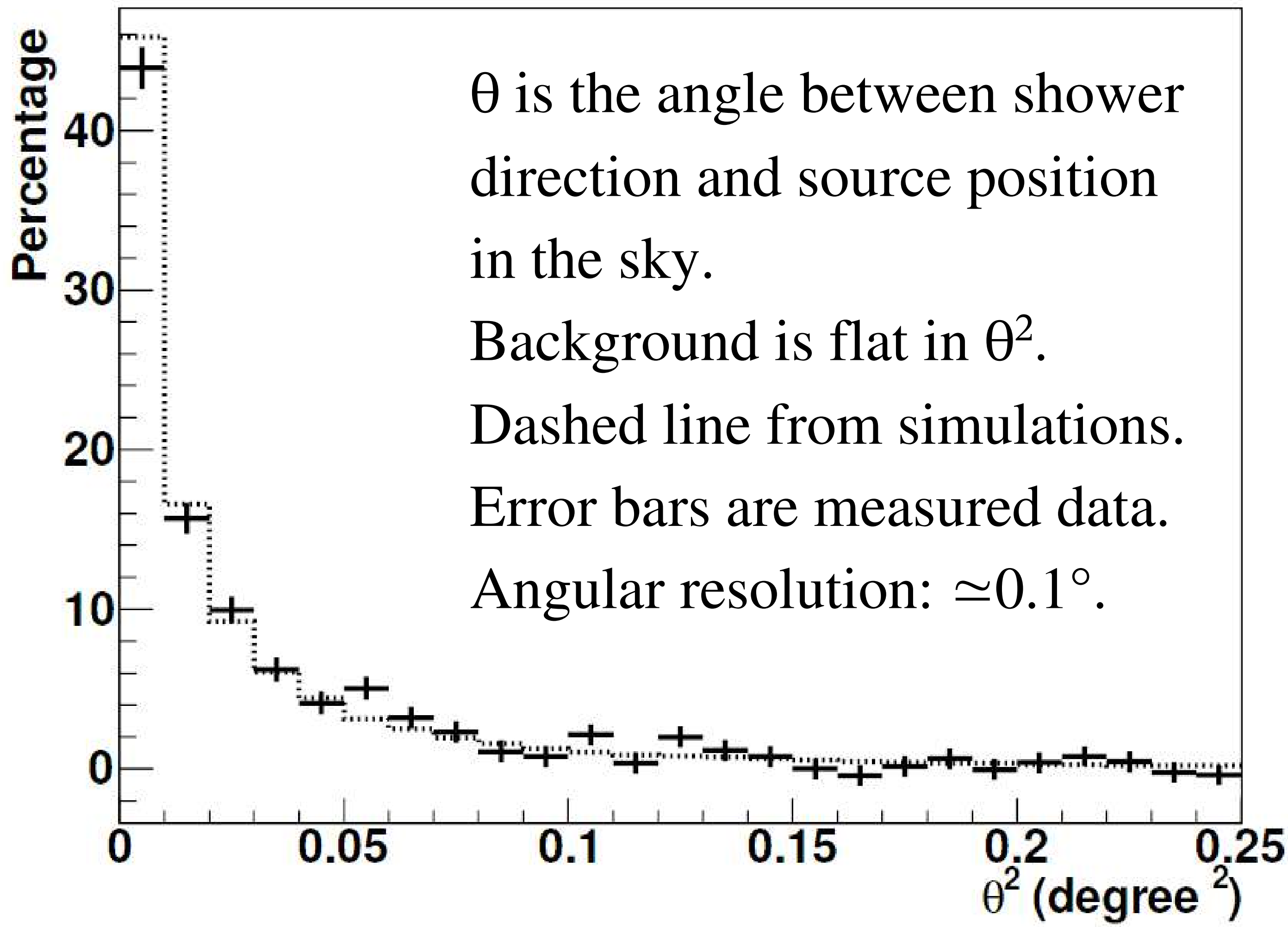
Scaled width and length





For hadrons both MRSW and MRSL are larger. Vertical bars indicate typical cut parameters for rejecting most hadrons and losing only few gamma rays.

The γ-ray point spread function



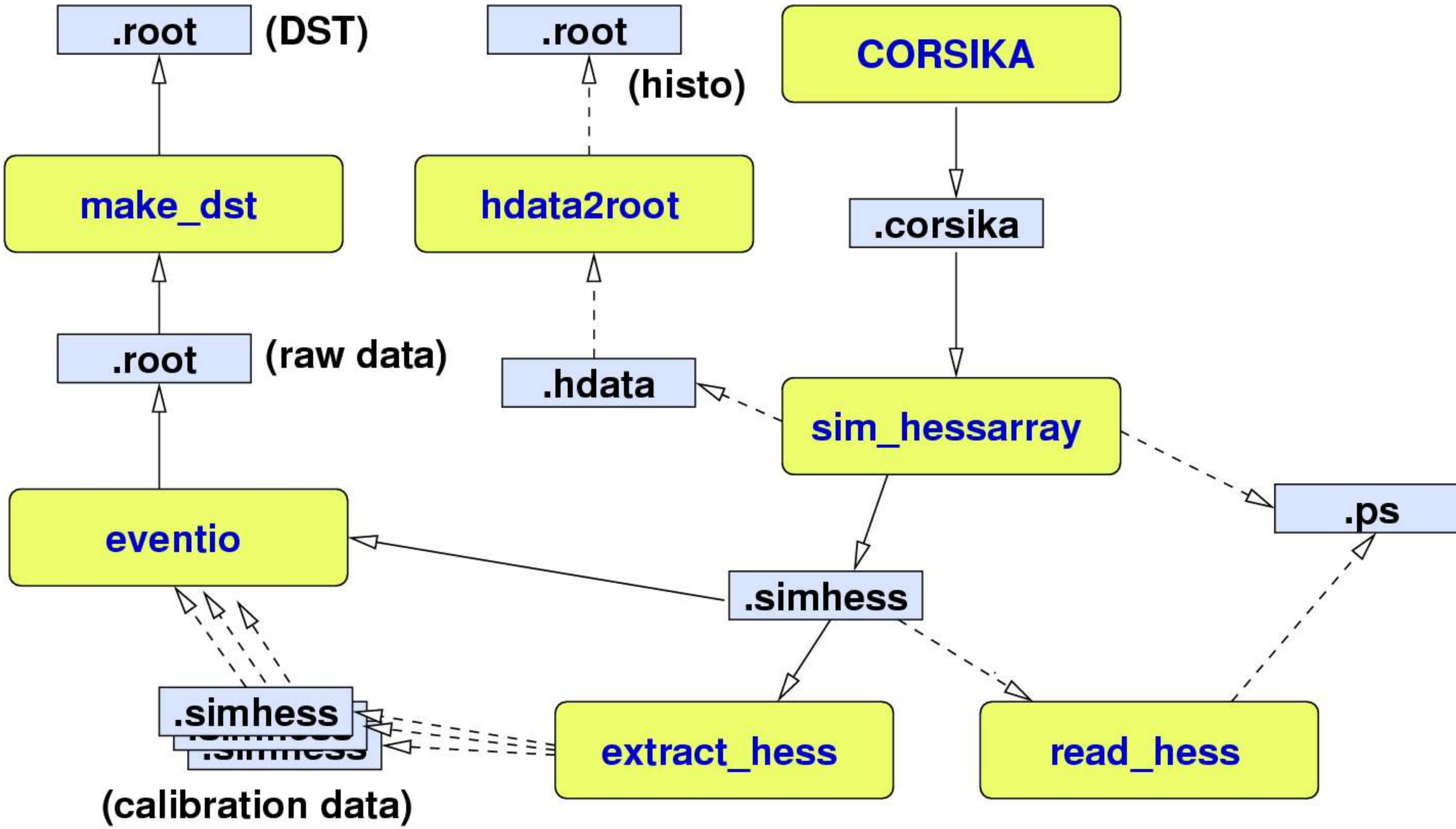
θ is the angle between shower direction and source position in the sky.
Background is flat in θ^2.
Dashed line from simulations.
Error bars are measured data.
Angular resolution: $\simeq 0.1°$.

Crab Nebula is consistent with a point source (actual size is much smaller than the PSF).

Processing pipeline

- CORSIKA simulations with IACT option piped into telescope simulation (sim_hessarray).
- Output file of sim_hessarray is converted into the same raw data format as measured data (but including calibration parameters).
- Same calibration and reconstruction software is applied as to measured data.

The processing pipeline



Summary

- H.E.S.S. works extremely well.
- Only one of two full simulation codes described here.
- Simulations can reproduce the experimental behaviour in great detail, without adapting any parameters. All parameters are determined from pre-installation test measurements.