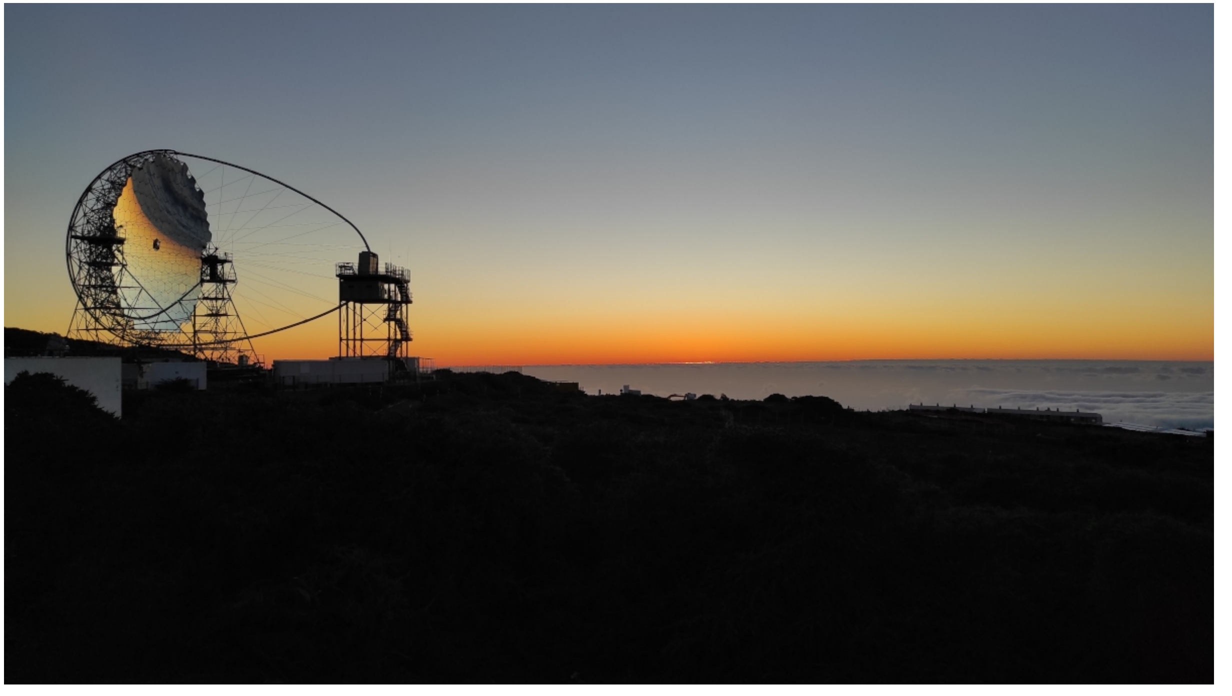
Cherenkov image correction method for cloud-affected observations

Natalia Żywucka[1], Julian Sitarek[1], Dorota Sobczyńska[1], Mario Pecimotika[2,3], Dario Hrupec[4], Dijana Dominis Prester[2], Lovro Pavletić[2], and Saša Mićanović[2] for the CTA LST Project



[1]Department of Astrophysics, University of Łódź, Poland; [2]Department of Physics, University of Rijeka, Croatia; [3]Ruder Boškovic Institute, Croatia; [4]Department of Physics, J. J. Strossmayer University of Osijek, Croatia

FACULTY OF PHYSICS AND APPLIED INFORMATICS University of Lodz

AtmoHEAD 2024, Ischia, 15. - 17.07.2024

CTAO

This work is supported by Narodowe Centrum Nauki grant number 2019/34/E/ST9/00224

Cherenkov Telescope Array (CTA)

→ Ground based very-high energy gamma-ray telescope array.

→ Three types of telescopes: large- (LST), medium- (MST), and small- (SST) sized telescopes.

→ Two sites of operation: northern site in La Palma and southern site in Chile.

→ Status: pre-production with a working LST, and MST and SST prototypes.

→ Explore on the CTA Observatory website and the Science with CTA

Rendering of the northern hemisphere CTA site; credit: Gabriel Pérez Diaz, IAC

Large-Sized Telescope (LST)

→ Located at the Roque de los Muchachos Observatory in La Palma, Spain.

→ Sub-array scheme: 4 LSTs at the centre of the northern array.

→ Sub-array provides full system sensitivity: **20-150 GeV**.

→ Mirror diameter: **23 m**.

→ Inaugurated in 2018.

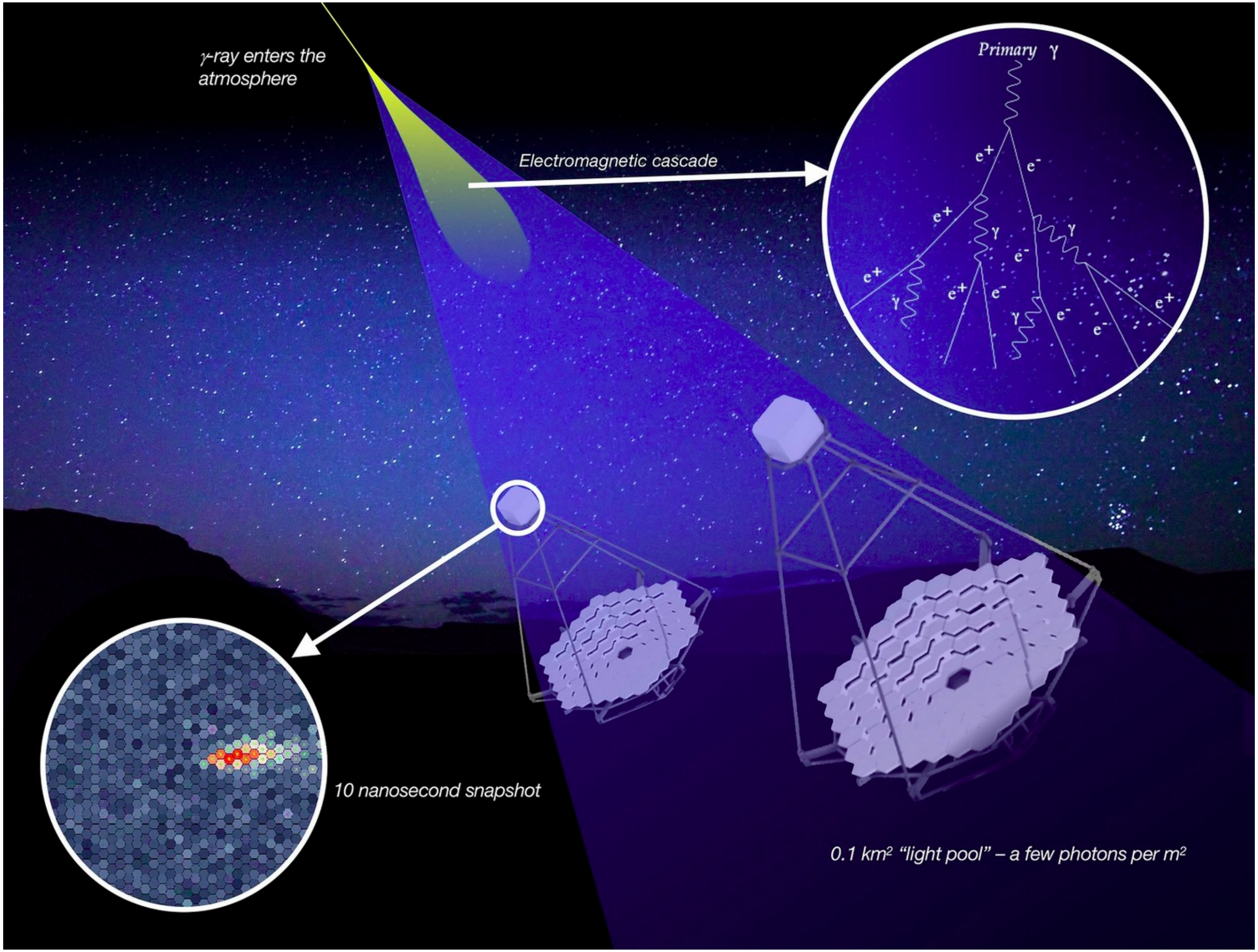
→ Status: commissioning test.

→ Scope of observations: galactic transients, active galactic nuclei, gamma-ray bursts, and other sources.

→ Observations: 1500 h per year, with a fraction affected by clouds.

LST-1 at the Roque de los Muchachos Observatory site

IACT technique



Credit: Ambrosi, G. & Vagelli, V. 2022, EPJP, 137, 170

Motivation

A variety of commonly used methods based on the fraction of light emitted above and below the cloud using average shower longitudinal distribution can only correct energy.

We propose an image correction method based on the geometrical model correcting the data itself for cloud effects. This aims to improve the gamma/hadron separation and shower direction reconstruction without the need for specialised Monte Carlo simulations.

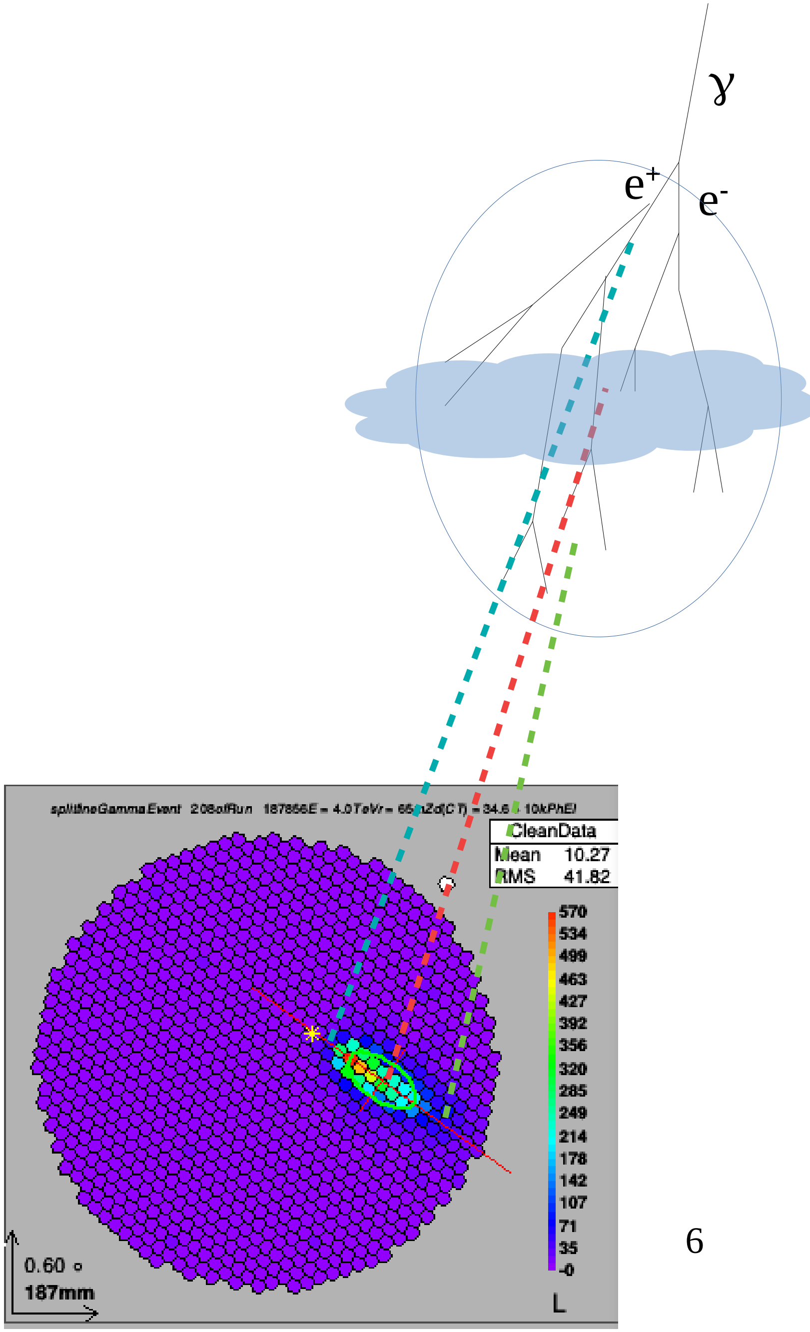
Image correction model

Assumption: light is emitted at the shower axis.

Idea: to use tentative reconstruction of the shower axis (with cloud affected image) to get the indicative direction of the image.

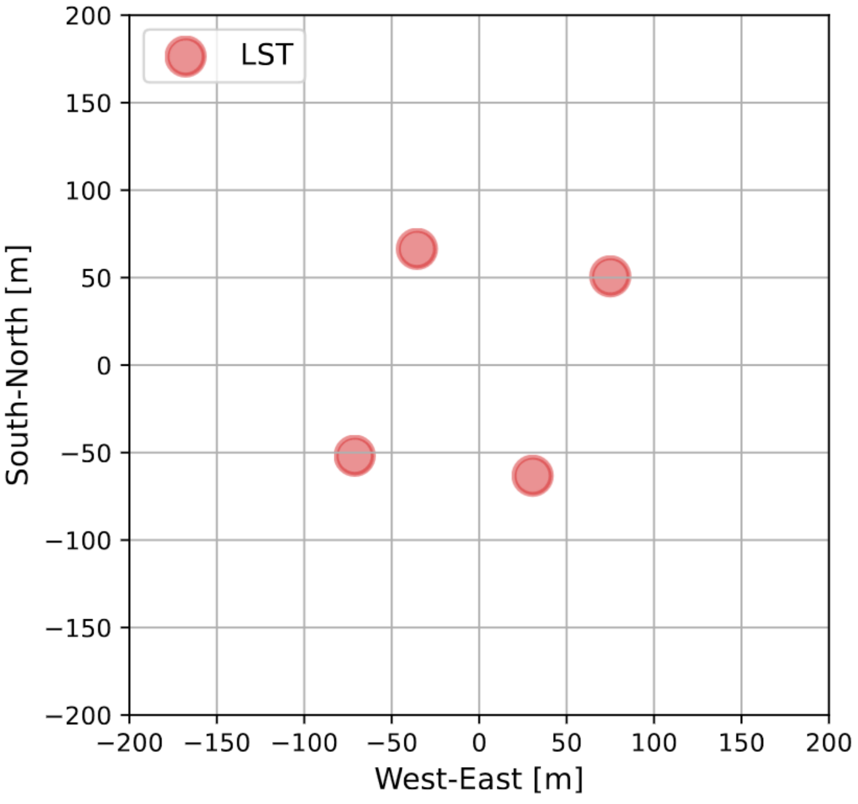
For each pixel, the height from which it gathers light is estimated and then it is corrected for h-dependent transmission.

Knowing a cloud profile from LIDAR we could correct the charge in each pixel and recompute the Hillas and stereo parameters.



Analyzed data

MC simulations were made in **CORSIKA** and **sim_telarray**:



	gamma rays	**protons**	**electrons**
ERANGE (TeV)	0.001 – 100	0.002 – 300	0.001 – 100
spectral index	-2	-2	-2
NSHOW	10^7	$2 \cdot 10^8$	$2 \cdot 10^7$
VIEWCONE (deg)	0.5	0 – 10	0 – 10
CSCAT	10	20	20
$Impact_{max}$ (m)	600	1400	900

Layout: 4 x LST-1

Analyzed data

The atmospheric profiles were simulated with **MODTRAN**.

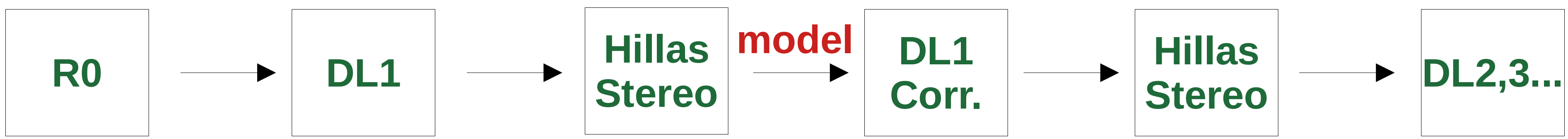
→ cloudless atmospheric profile: T = 1,
→ gray 1 km thick altostratus clouds:

T = 0.6, h = 5 km, 7 km, 9km,
T = 0.4, h = 7 km,
T = 0.8, h = 7 km,
double layer cloud.

Transmission	Base Height (km)	Thickness (km)
1	-	-
0.8	7	1
0.6	5	1
0.6	7	1
0.6	9	1
0.4	7	1
0.8×0.8	5 & 7	1 & 1

Data analysis chain

MC simulations were analyzed in the **ctapipe framework**:



1. data reduction and calculation of *Hillas parameters* from the image,
2. tentative stereo reconstruction,
3. correction of images with the cloud correction model,
4. recalculation of Hillas parameters,
5. gamma/hadron separation, direction reconstruction, and energy estimation with random forest models.

Image correction for attenuation of light in a cloud

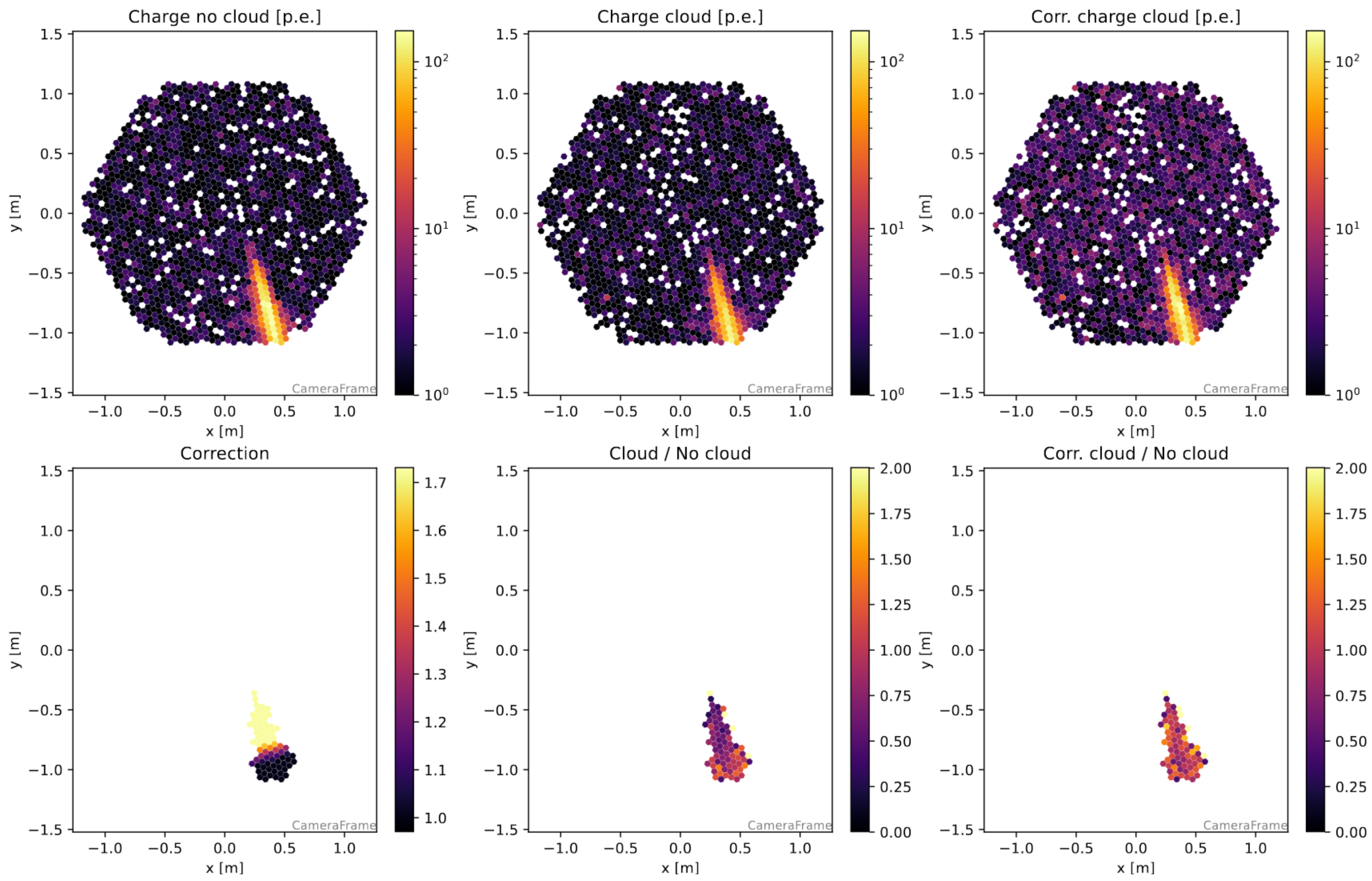
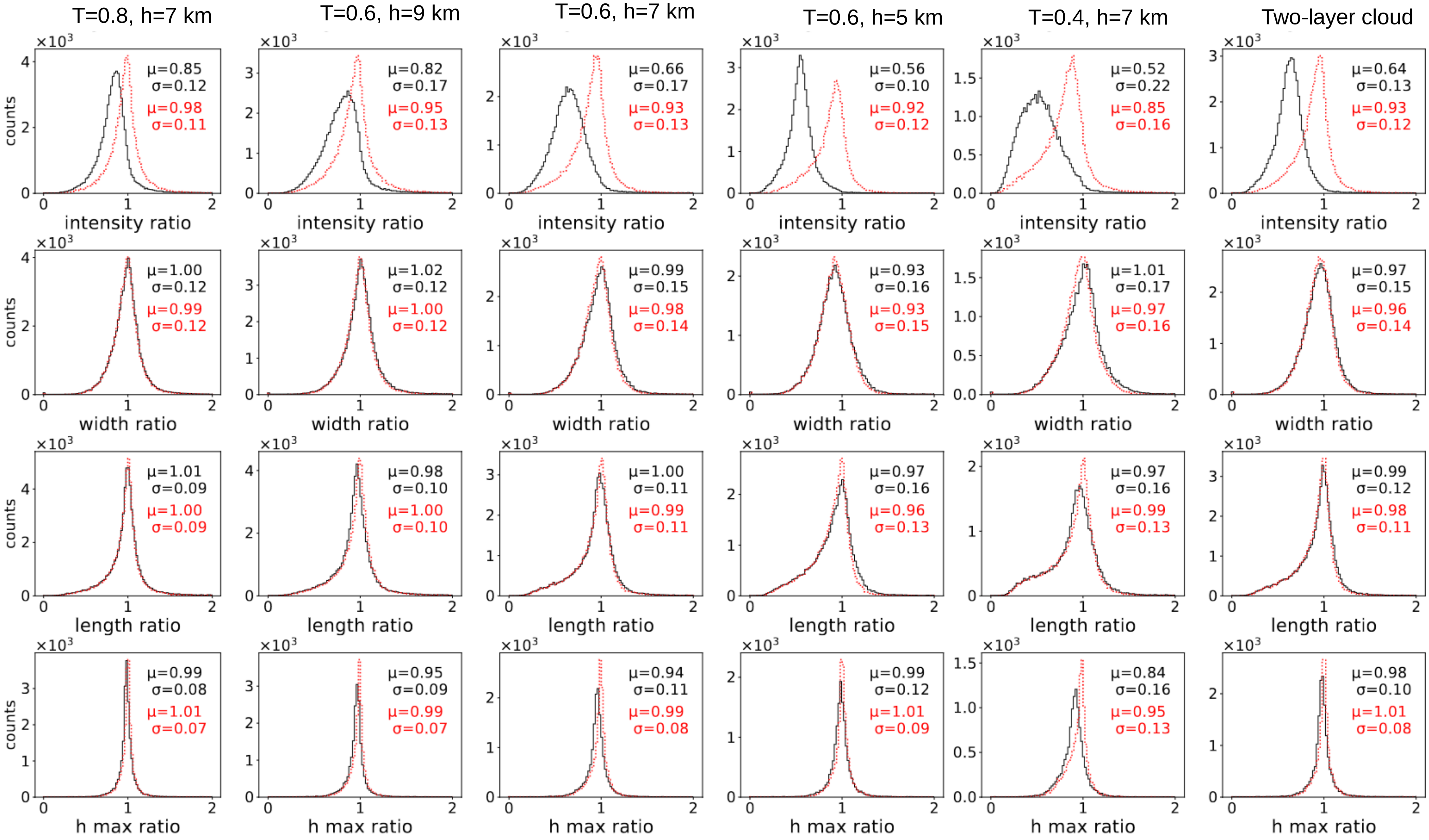


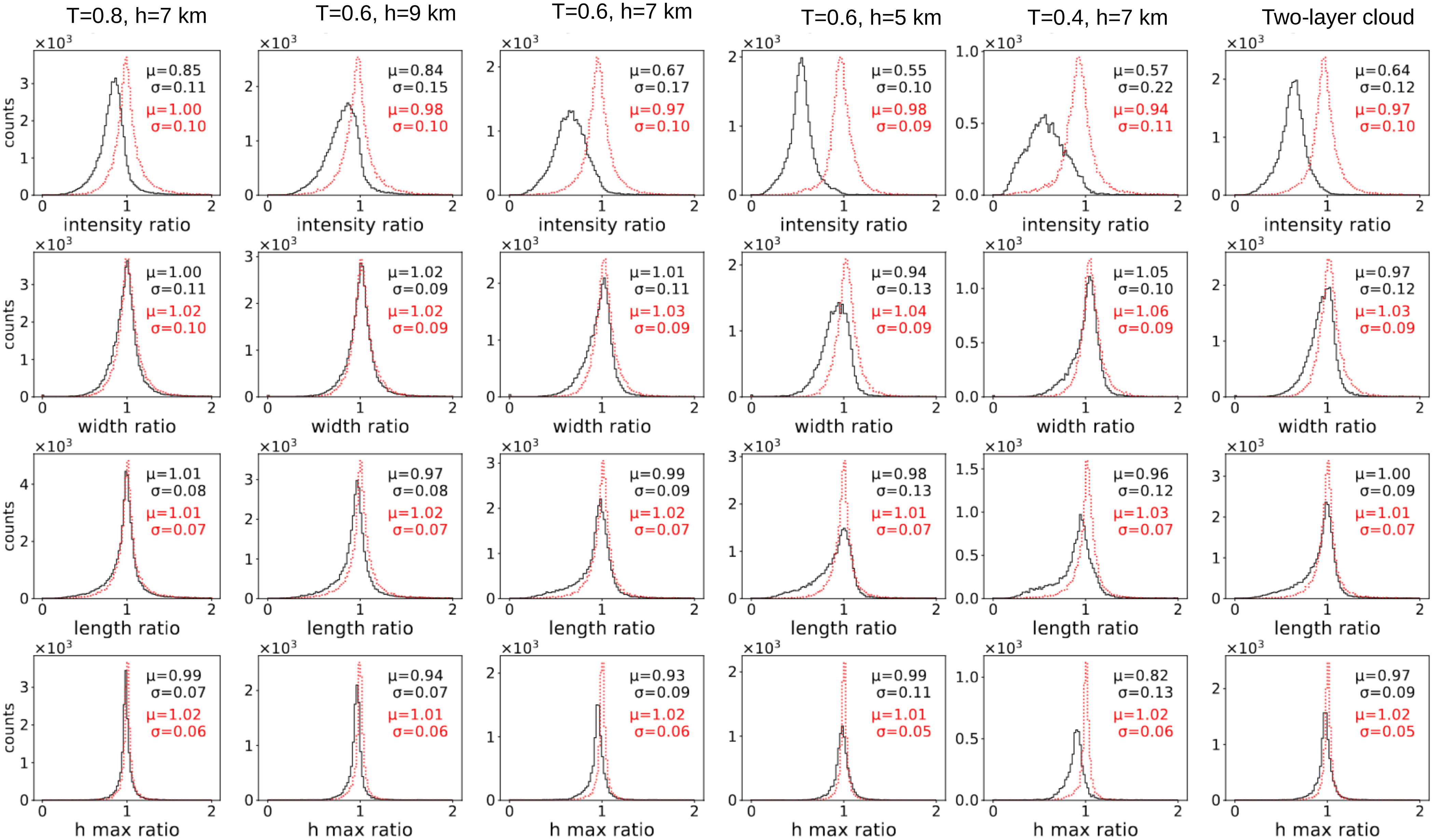
Image correction for light attenuation in h = 7km, T = 0.6 cloud. Simulations with the cloud result in reduced light yield in the “head” part of the shower. After the correction, the “head” part of the image recovers the light yield level of the no-cloud simulations.

The most affected Hillas parameters



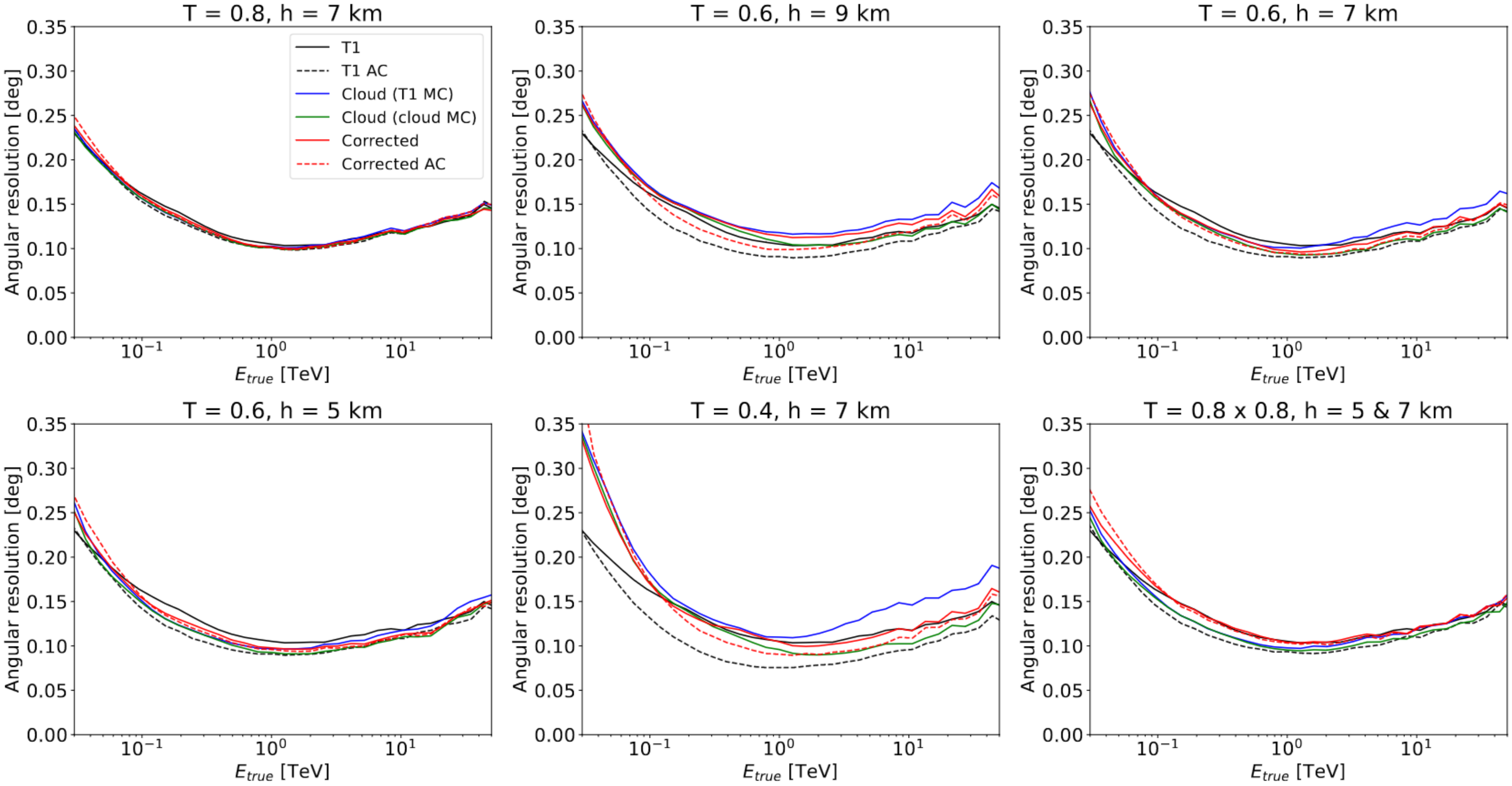
Original
Corrected

The most affected Hillas parameters AC



Original
Corrected

Angular resolution

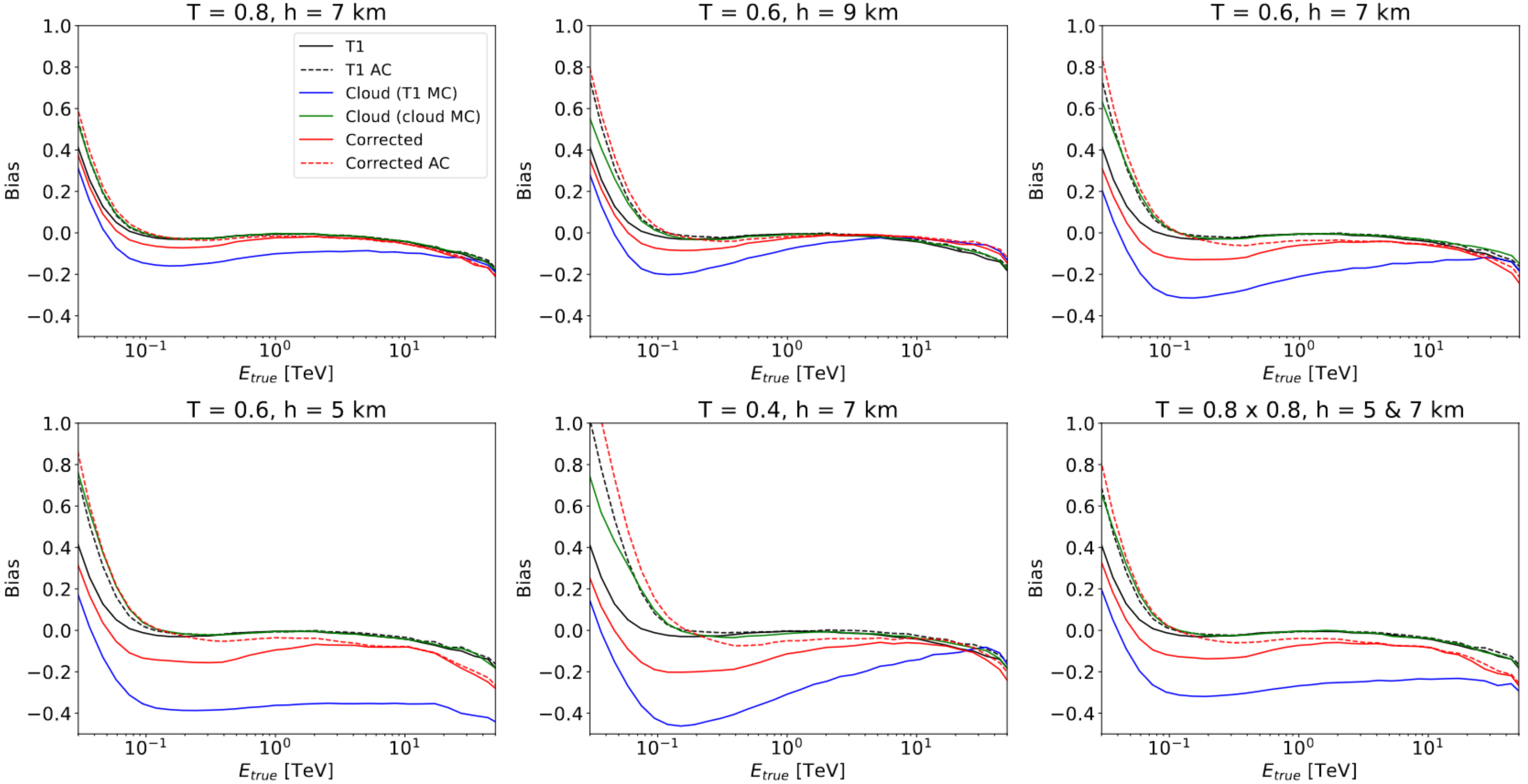


→ containment radius of 68% of gamma rays in a particular energy bin,

→ parameter least affected by the presence of clouds,

→ additional cleaning can slightly improve the angular resolution in the T1 case; it does not improve relative performance of the correction method.

Energy bias

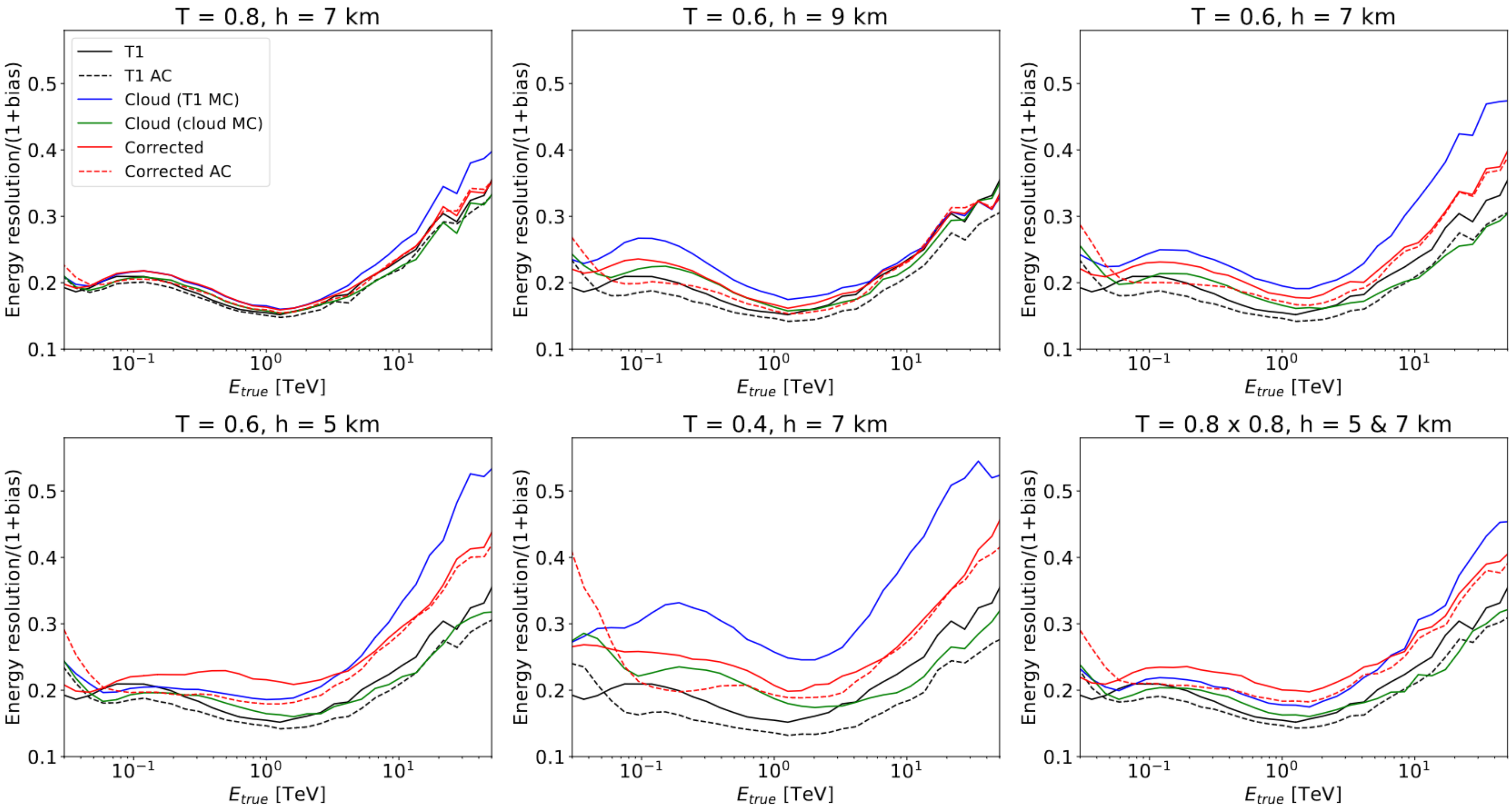


→ negative bias is the largest at ∼ 100 GeV and decreases at higher energies as a bigger fraction of the shower is developed below cloud,

→ additional image cleaning at medium and high energies - bias is nearly completely removed

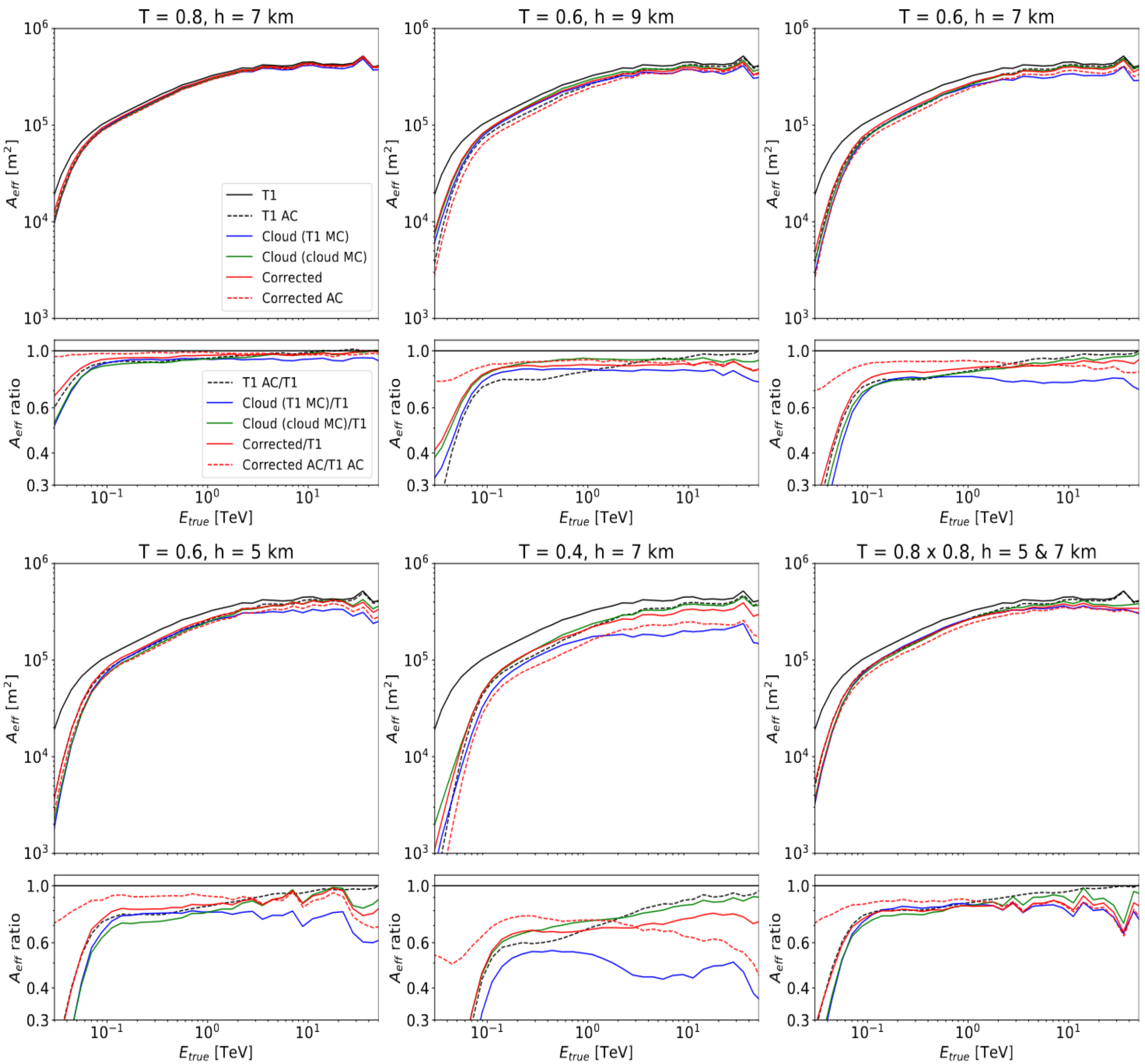
→ image correction method removes most of energy bias without need to generate special MCs.

Energy resolution corrected for bias



→ spread of the energy estimation at particular true energies,
→ energy resolution is degraded by presence of cloud (40 – 50% at ~10 TeV),
→ image correction method results in similar energy resolution as obtained with dedicated cloud MCs,
→ additional cleaning improves energy resolution also in case of T1.

Effective area



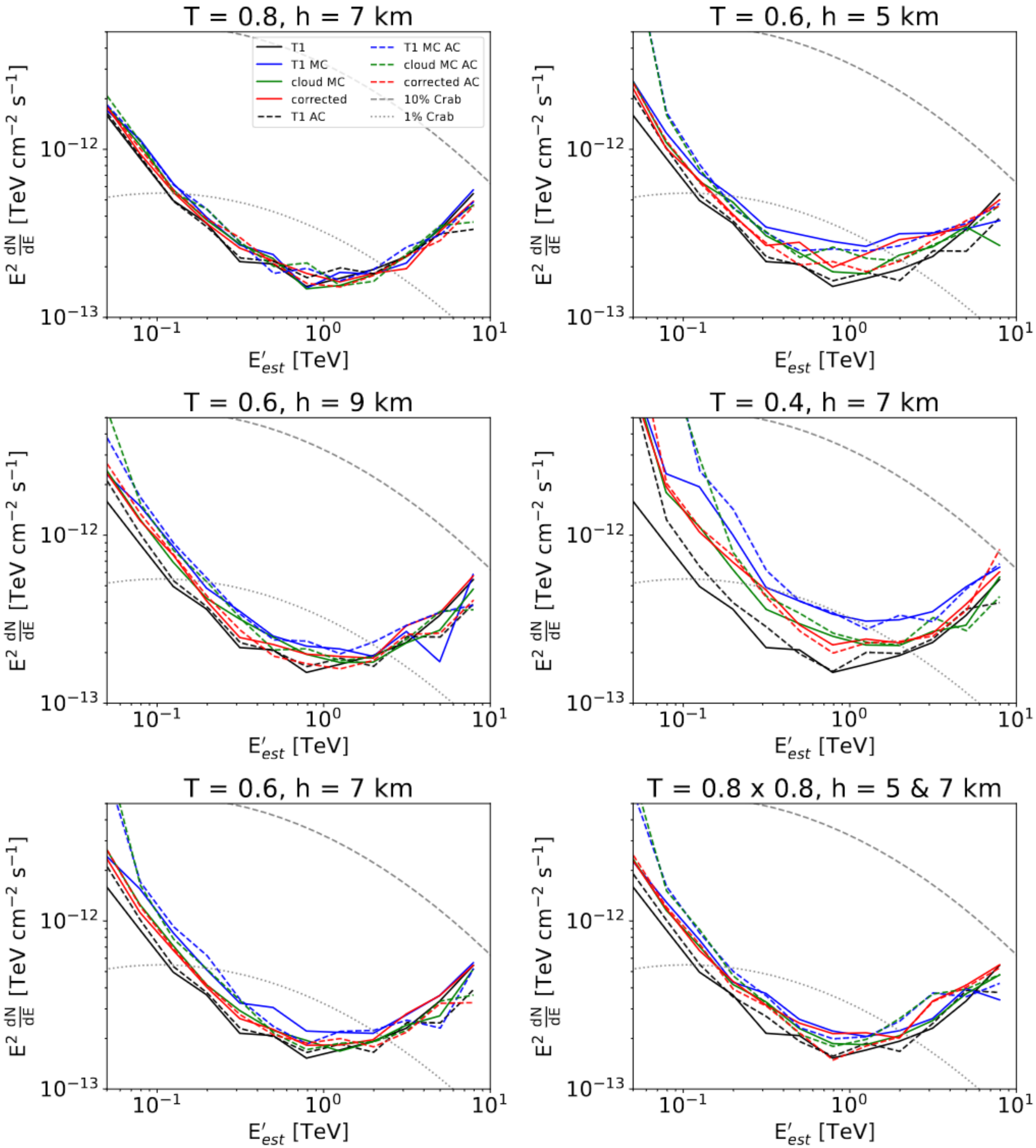
→ gammaness cut: 90% gamma-ray efficiency in each estimated energy bin; efficiency of the angular cut from the nominal source position is 70%,

→ the clearest effect is at the lowest energies, i.e. collection area drops due to increase of energy treshold,

→ drop at higher energies is related to worse gammaness evaluation and angular reconstruction,

→ similar correction as for MC is obtained with correction model at medium and high energies.

Sensitivity



→ sensitivity is derived in 5 bins/decade of energy for 50 h of observations and based on bias-corrected estimated energy,

→ the presence of a cloud worsens the obtained sensitivity,

→ additional image cleaning is degrading the performance at the lowest energies,

→ applying the correction model, we can reach similar sensitivity as with cloud MCs.

Summary & conclusions

1. The correction method is based on the atmospheric parameters provided by monitoring device, e.g. LIDAR.

2. The most affected parameters: intensity, height of the shower maximum, and length develop a bias towards lower values induced by the cloud. The bias is almost completely corrected with the proposed method.

3. Performance parameters are strongly affected by clouds. The proposed method provides similar improvements as using the dedicated MC simulations.

4. The method with additional cleaning is efficient in correcting most of the energy bias and provides comparable or slightly better sensitivity than dedicated MCs.

5. The method requires much less computational resources than producing the dedicated MCs.

Check Żywucka et al. 2024 for more details.