technische universität dortmund

Physik E5

MAGIC Major Atmospheric Gamma Imaging Cerenkov Telescope

Variable atmospheric transparency studies for the MAGIC telescopes

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Overview

- Atmosphere and clouds

- Bad weather as a problem for IACTs

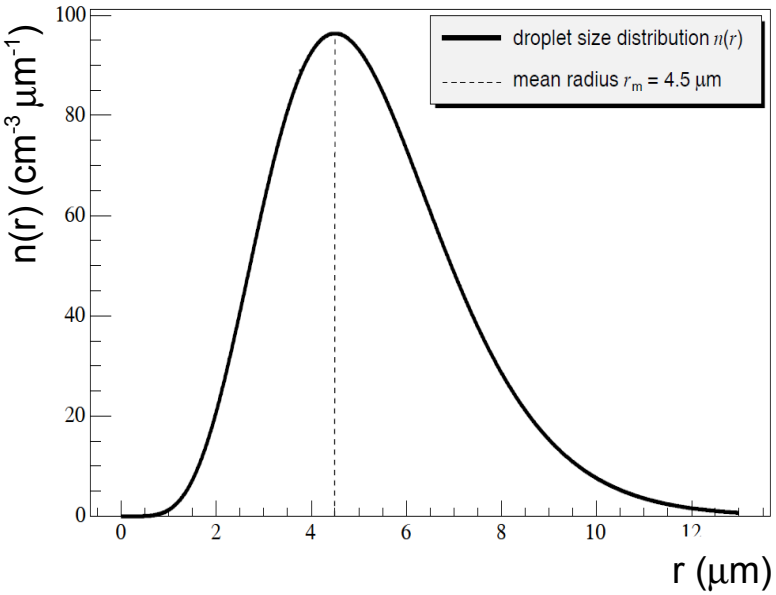
- Atmospheric properties, variable atmospheric transparency

- Variable atmospheric transparency (VAT) simulations

- Results

- Summary

Atmosphere and clouds

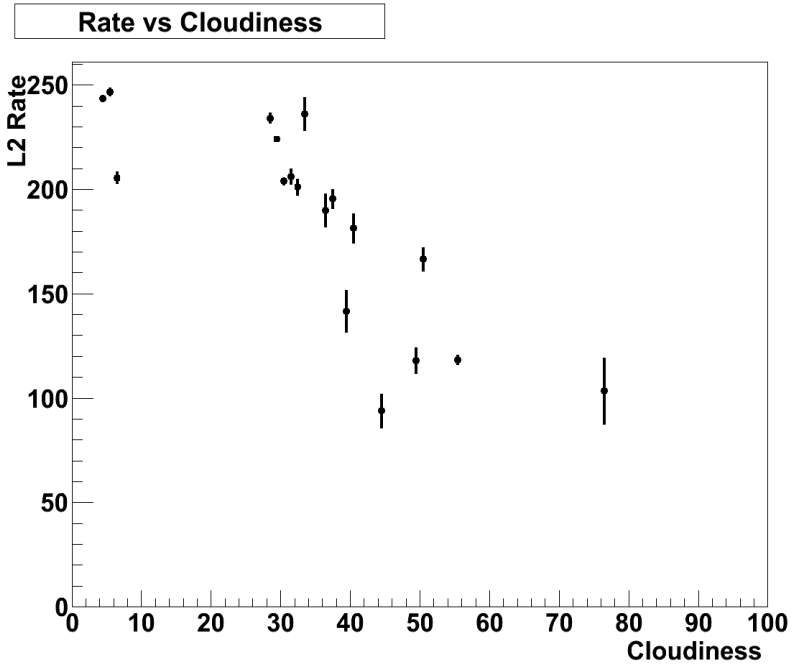


Altostratus water-droplet size-distribution for N=450 cm^{-3} (Hrupec, 2007)

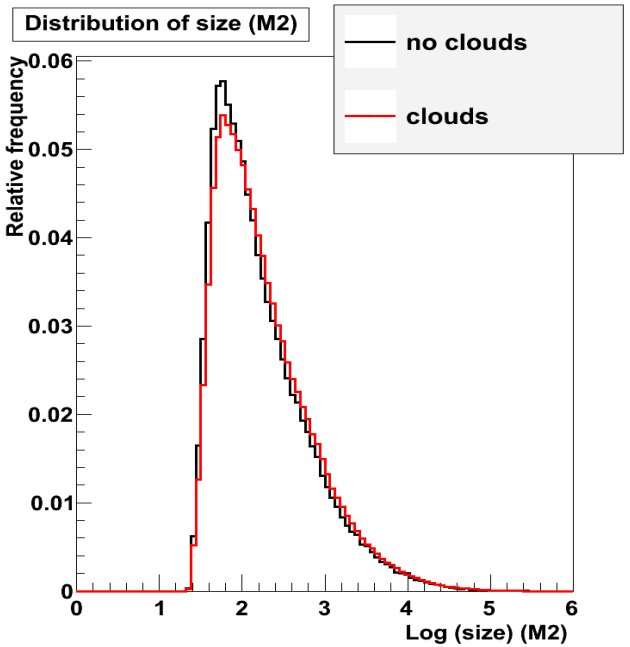
- atmosphere – natural calorimeter for high-energy cosmic ray particles, part of detector
- majority of air showers start in the troposphere, 10-15 km a.s.l.
- in MC simulations atmospheric models are used
- MAGIC uses parameterized atmospheric models „MagicWinter“ and „MagicSummer“ based on NASA empirical model NRLMSISE-00 and local data for La Palma

- clouds – visible clusters of liquid water droplets or ice crystals in the air
- droplets size 2 μm to 200 μm (average 5-20 μm) – modified gamma distribution
- cloud droplet density – 100 - >1000 cm^{-3}, typical 200 cm^{-3}
- Saharan Air Layer („calima“) – warm air with mineral dust, 1.5 – 5-5 km

Bad weather as a problem for IACTs



Dependence of MAGIC I trigger rate (L2 rate) on cloud cover parameter („cloudiness“)

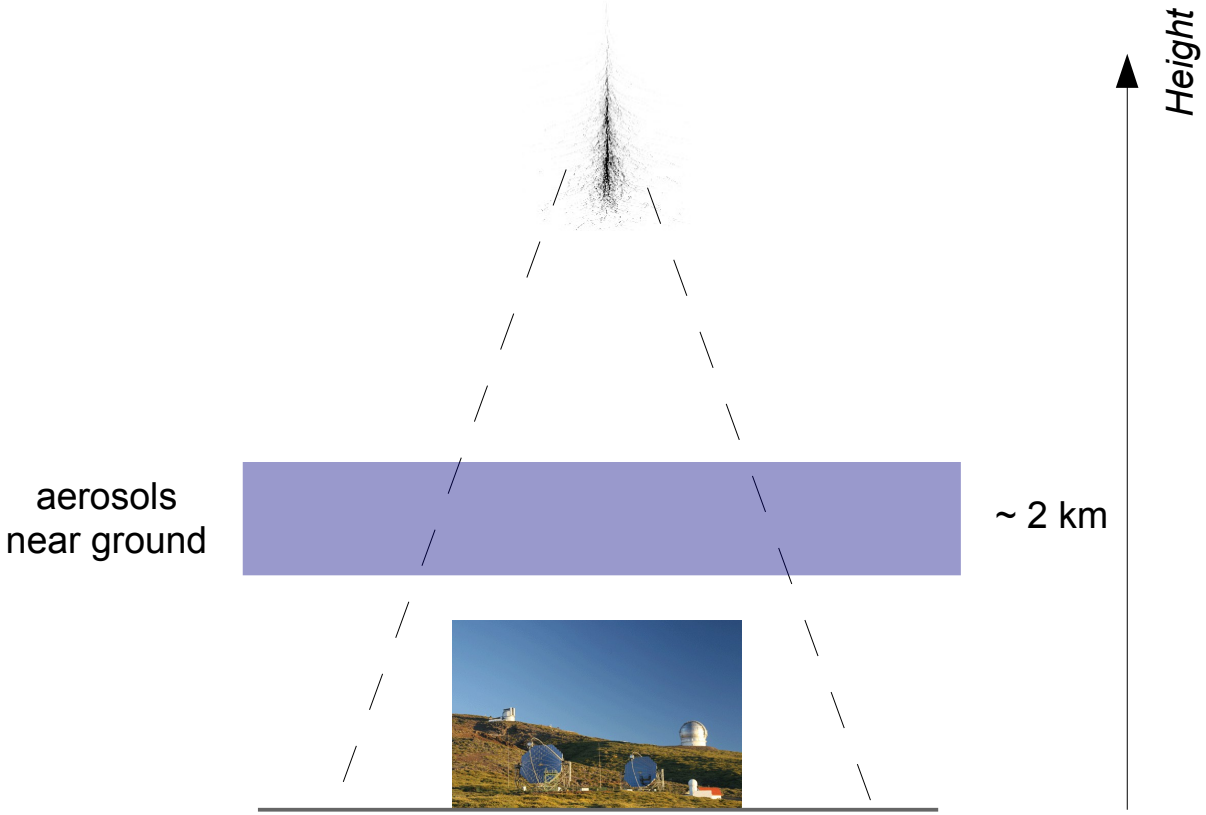


Example of effect of clouds on data – small shifting of distribution peak:
Size distribution (MAGIC-II) for dataset example (Crab Nebula, cloud cover distribution shown left)

- bad weather – presence of clouds or calima reduce data quality
- reduction of number of photons (Mie scattering)
- reduction of gamma rate and sensitivity in data taken under moderately high aerosol number density

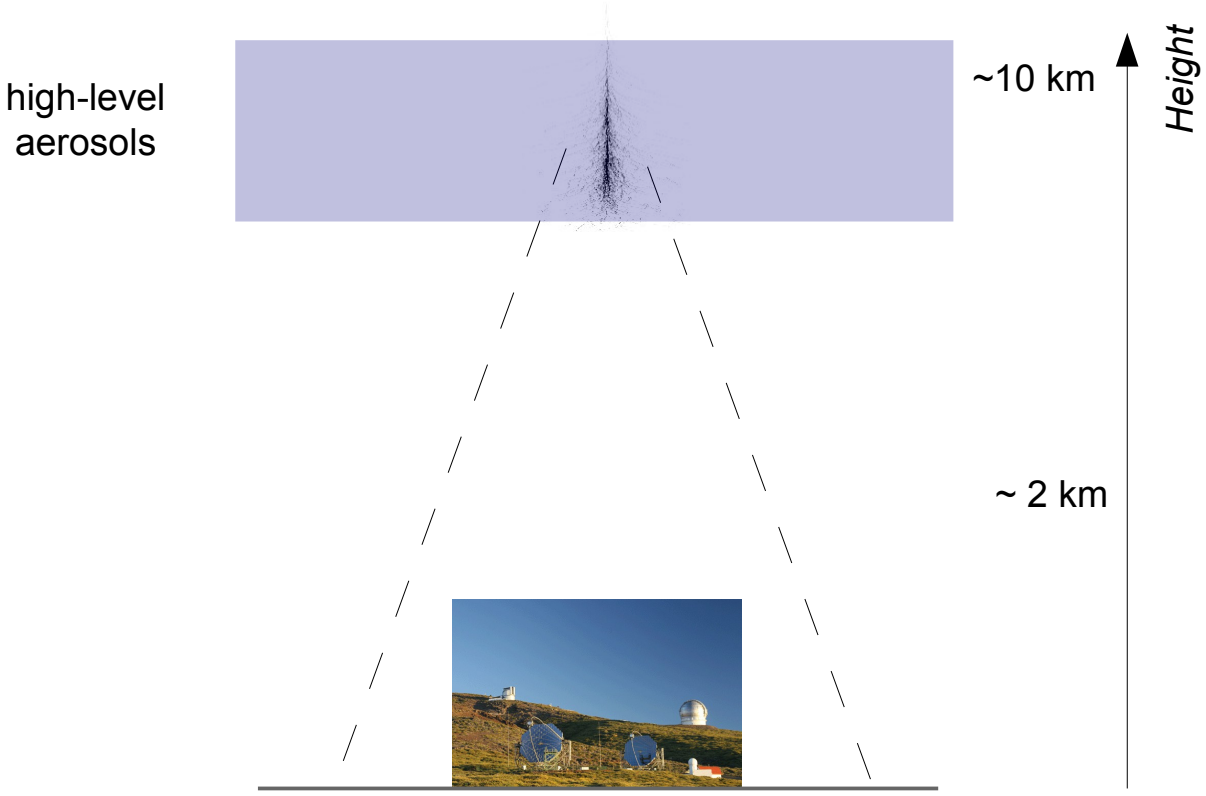
Bad weather as a problem for IACTs II

- density of molecules → height of shower development, refractive index of air
  → Cherenkov angle, number of emitted photons
- transmission of Cherenkov photons - Rayleigh and Mie scattering



- aerosols near ground – lower light yield, less triggered events, reduction of number of photons
- energy reconstruction affected

Bad weather as a problem for IACTs III



- high-level aerosols – image shape and shower height reconstruction affected

Measurement of atmospheric attenuation

- Atmospheric attenuation from measurements → signal correction, input for simulations

- Optical observations:

  - Carlsberg Meridian Telescope (CMT) observations

  - KVA telescope optical monitoring

- LIDAR measurements of atmospheric transmission

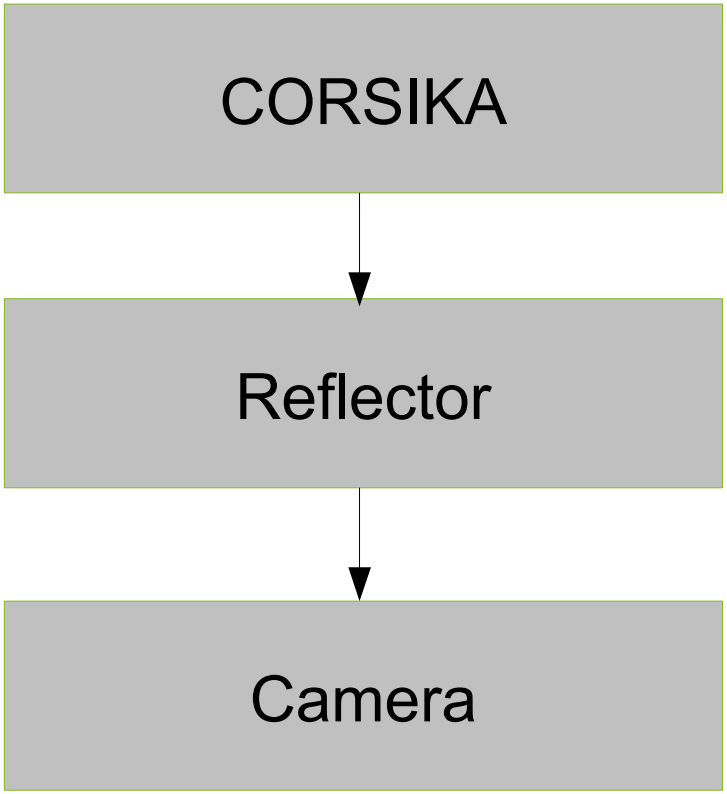
- From IACT data:

  - Distributions of image parameters (size) taken from data

  - Event rate (gamma-photons, hadrons)

  - Muons

MAGIC Monte Carlo chain

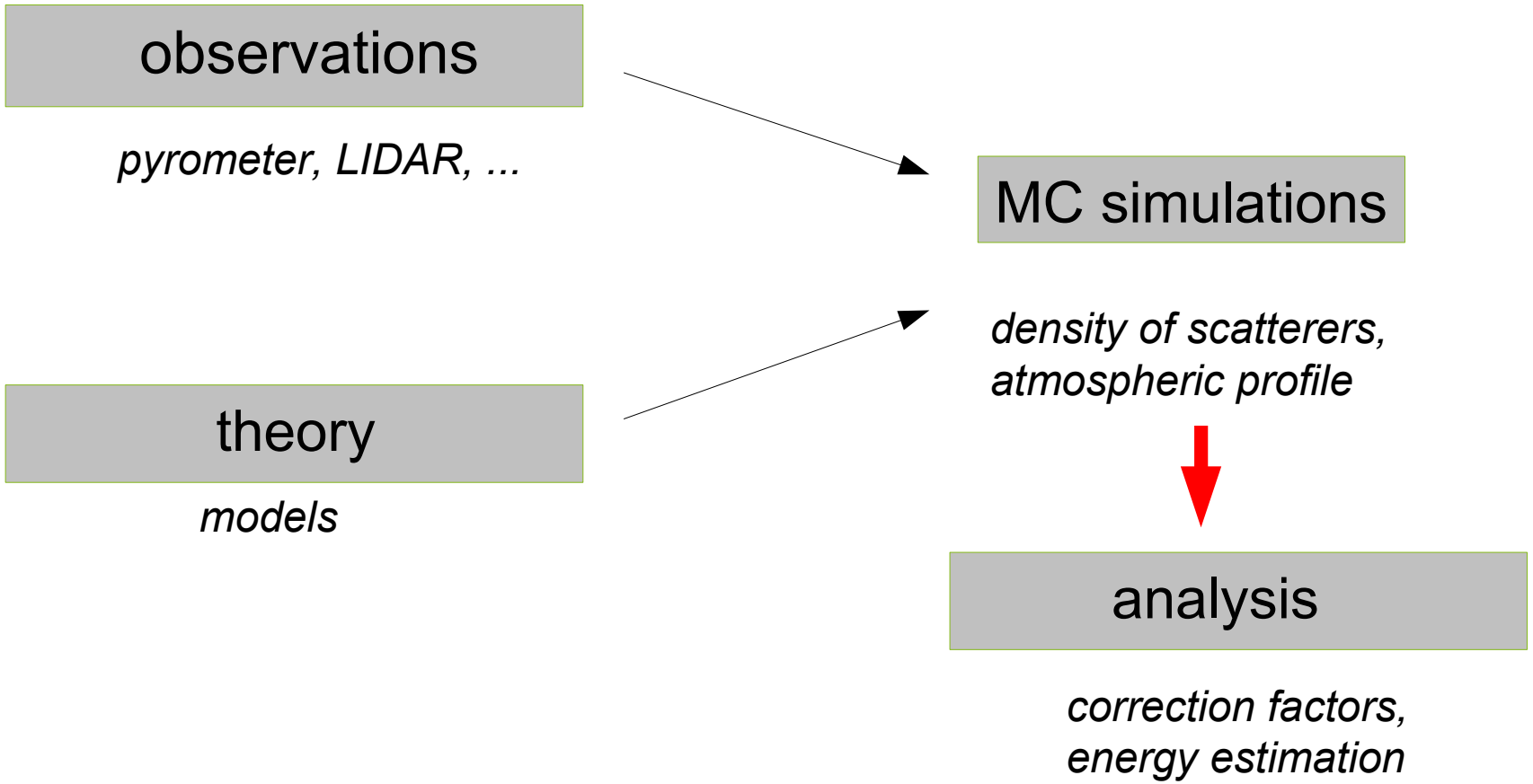


- generation of air showers and Cherenkov light emission
- light absorption and scattering in the atmosphere and reflection on the mirror
- PMT signal response, simulation of trigger and read-out chain

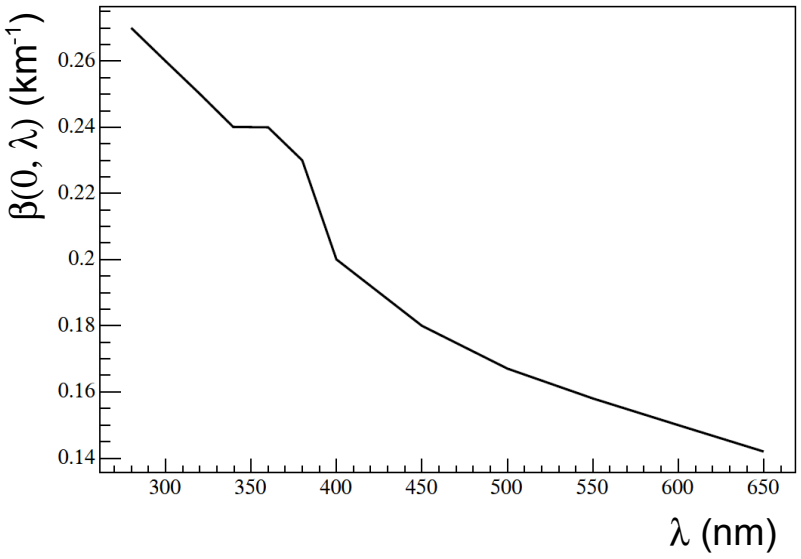
- MC raw data then processed (calibration, image cleaning) with MARS (MAGIC analysis and reconstruction software)

Variable atmospheric transparency

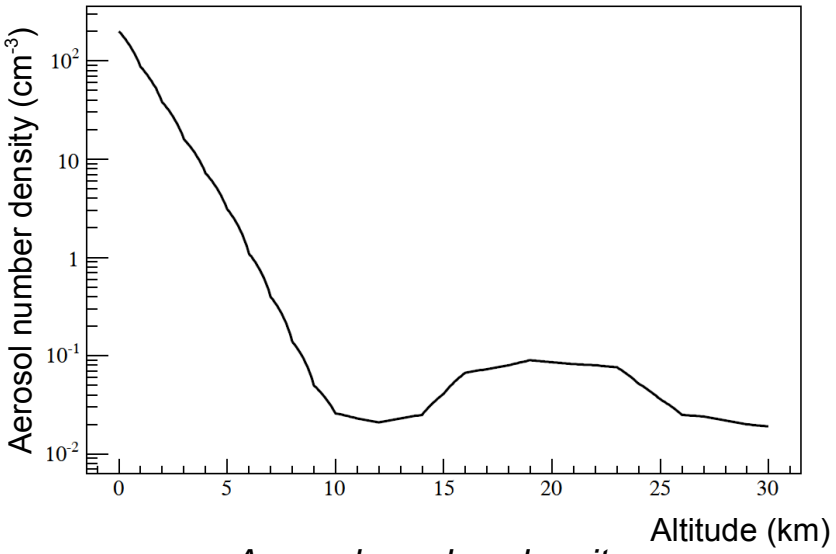
- principle: modification of atmospheric profiles in Monte Carlo simulations which characterize the atmospheric transparency for use in data analysis



VAT simulations



Spectral aerosol attenuation coefficients at sea level (Elterman, 1964; Hrupec, 2009)



Aerosol number density (Elterman, 1964; Hrupec, 2009)

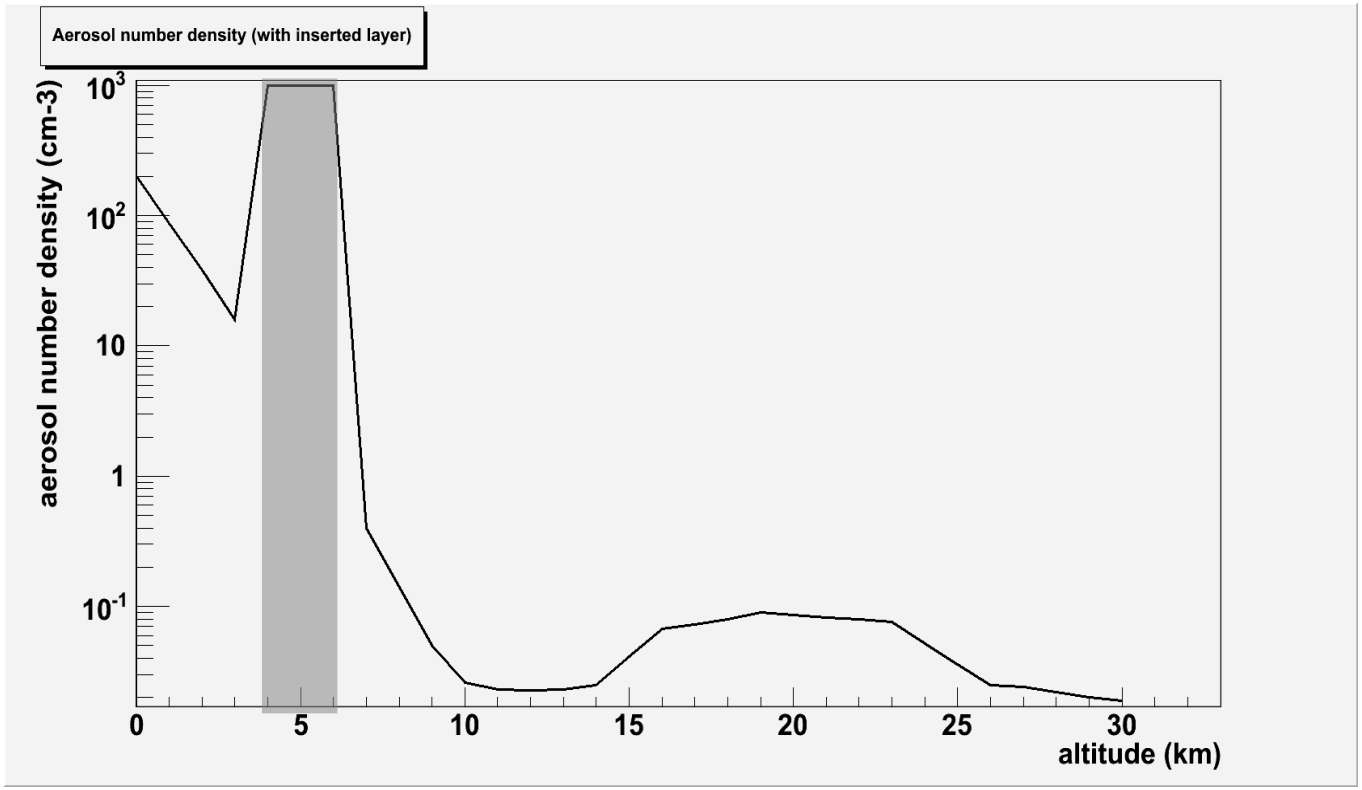
- simulation of atmospheric attenuation of Cherenkov light done in Reflector
- Rayleigh scattering on air molecules ($\beta_R \sim \lambda^{-4}$), simple exponential vertical density profile
- Mie scattering on aerosols
- exponential decrease of aerosol number density
- spectral attenuation coefficients measured
- ozone apsorption

$$\beta(h,\lambda) = \beta(0,\lambda)\frac{N(h)}{N(0)}$$

VAT simulations

- for MAGIC site, La Palma:
- cloud base 3000 – 8000 m, mean water droplet size 4.5 μm
- equal treatment of all aerosols, concentration – 400 cm^{-3} up to 1000 cm^{-3}

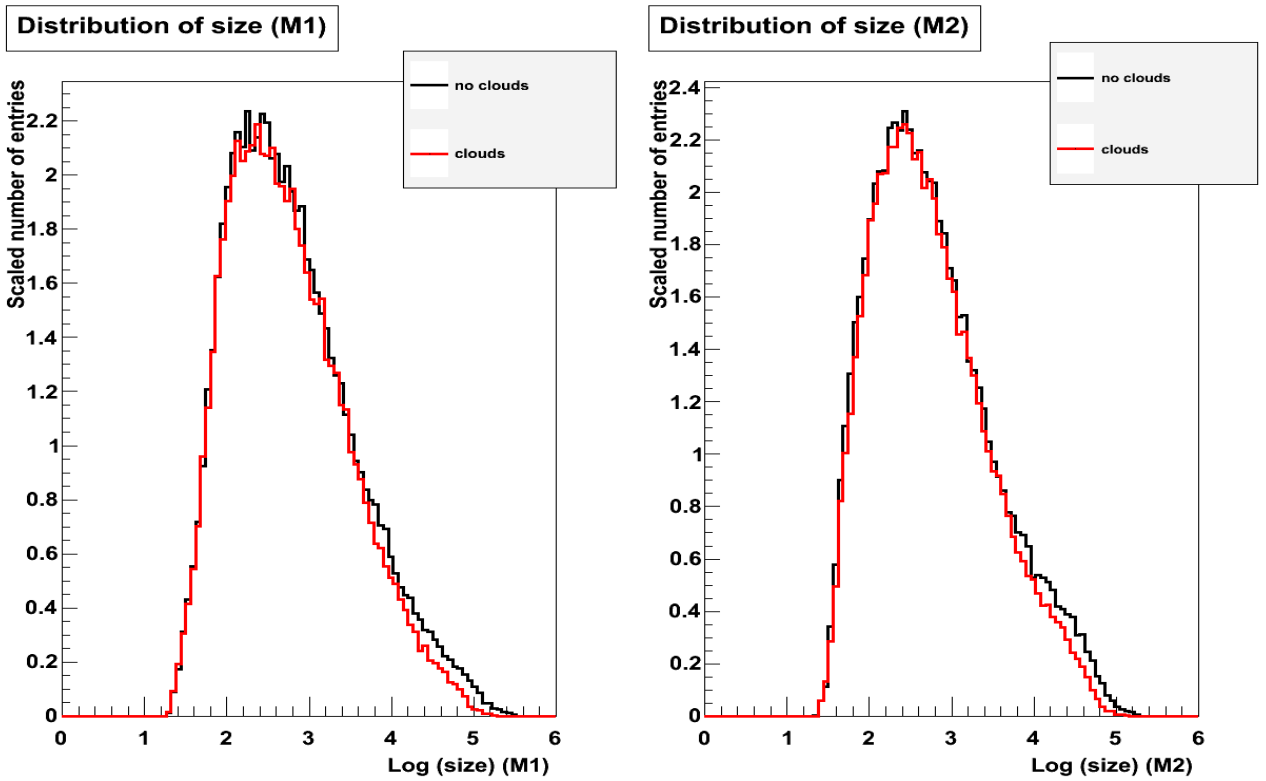
- here shown: inserted layer of aerosol number density 1000 cm^{-3} between 4-6 km



Results

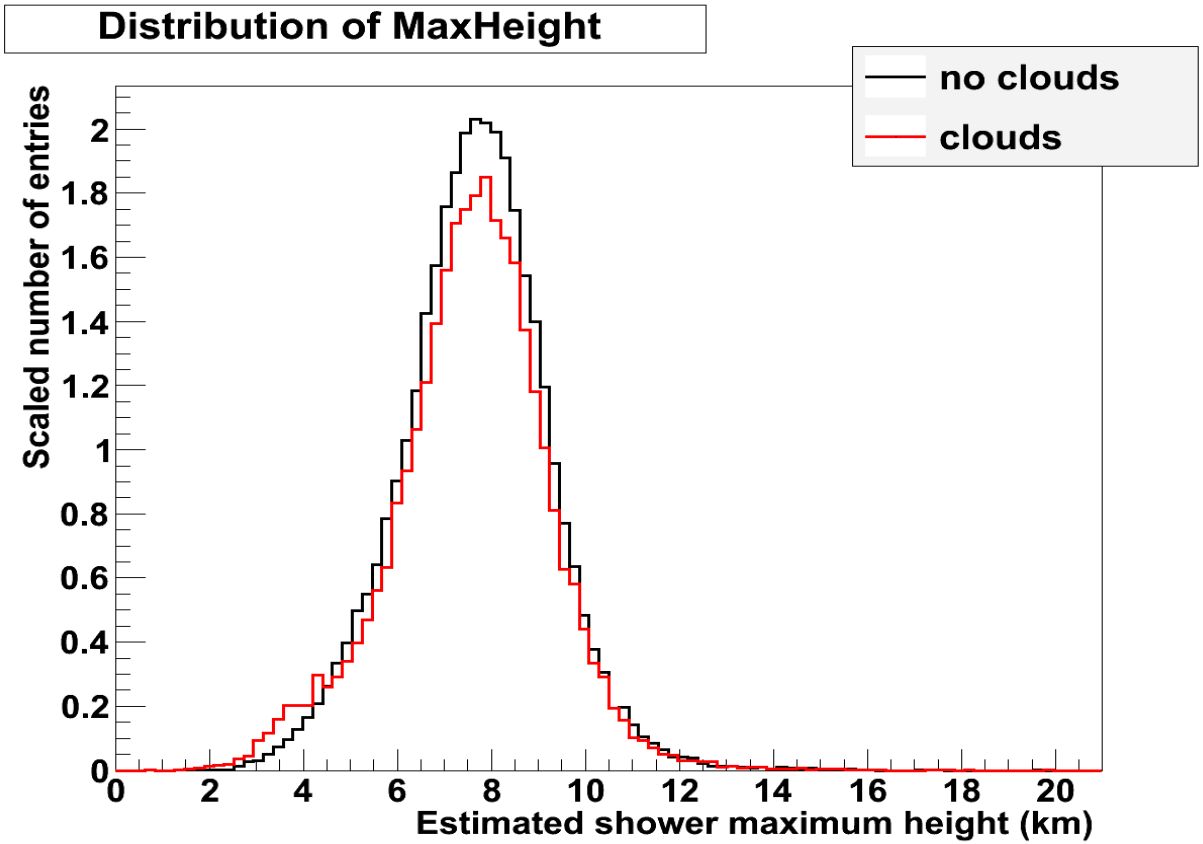
Comparison of parameter SIZE in Monte Carlo simulations

- two samples shown: standard MC, E = 10 GeV – 30 TeV, impact 350 m
- MC with a layer of increased aerosol number density,
  E = 10 GeV – 30 TeV, impact 350 m („cloud MCs“)



- difference visible for events with very large size

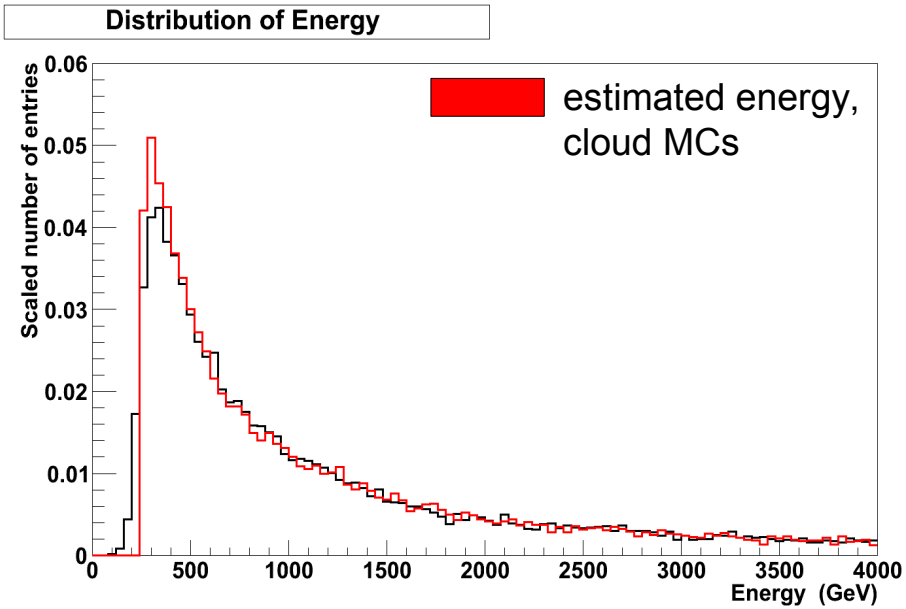
Results (cont'd)



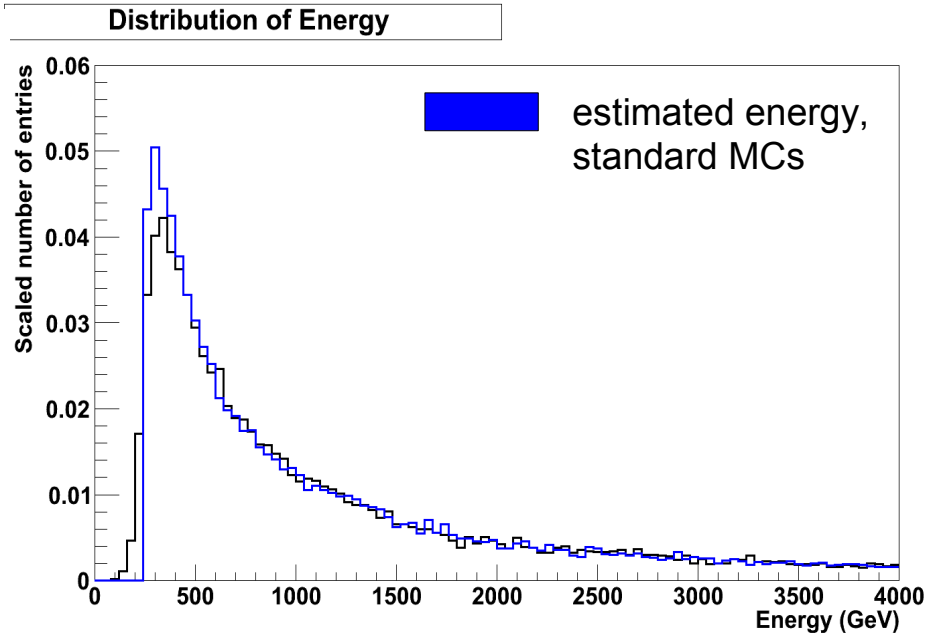
- stereoscopic reconstruction: estimated height of shower maximum for two MC samples (standard MCs and cloud MCs)
- differences small, reduction of photon number
- shower maximum height from cloud MCs matches the one from standard MCs

Results (cont'd)

Estimation of energy: original MC energy



Comparison of original MC energy and estimated energy with tables based on cloud Monte Carlo simulations



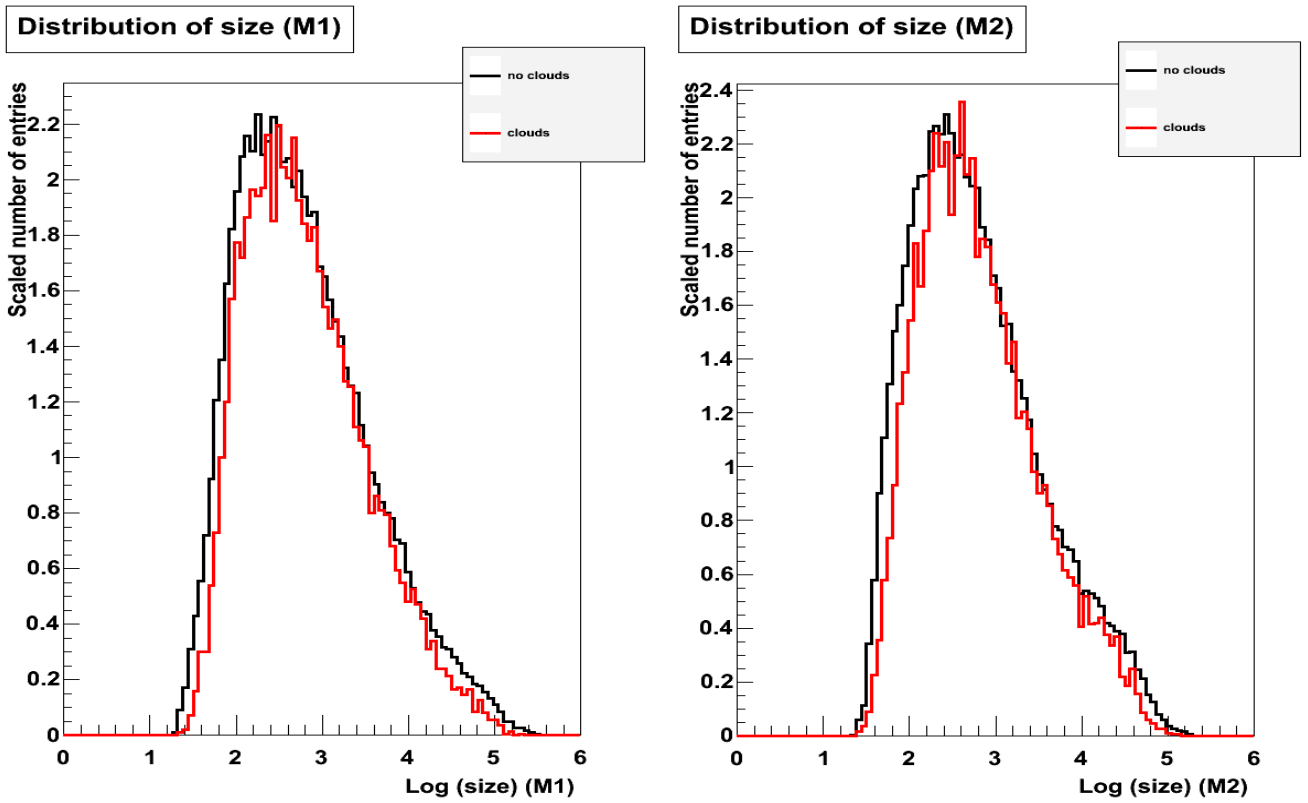
Comparison of original MC energy and estimated energy with tables based on standard Monte Carlo simulations

- Monte Carlo simulations used for energy estimation:
- comparison of original MC energy and energy estimated with look up tables (LUT) based on two MC samples
- energy estimation correct for cloud MCs

Results (cont'd)

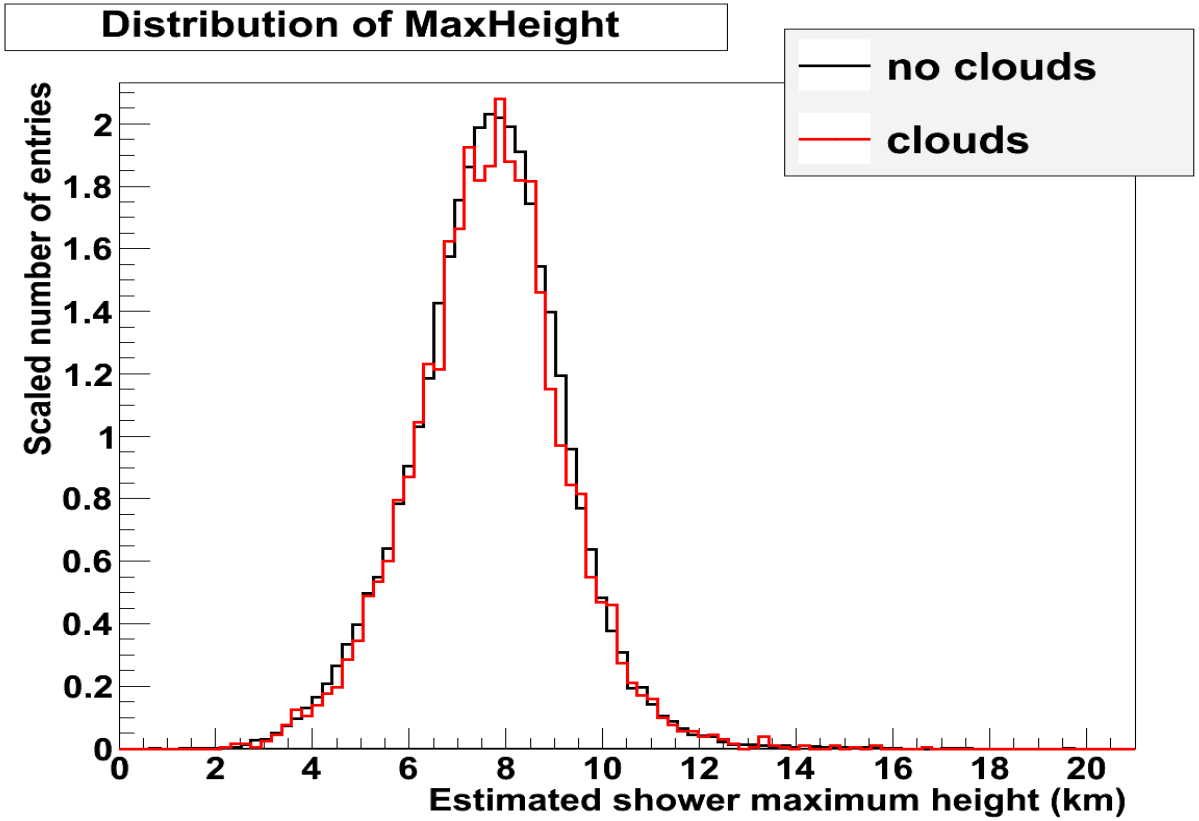
Comparison of parameter SIZE in Monte Carlo simulations

- standard MCs
- MCs with a layer of increased aerosol number density 2500 cm^{-3} between 6-8 km



- with cloud MCs less triggered events for small energies

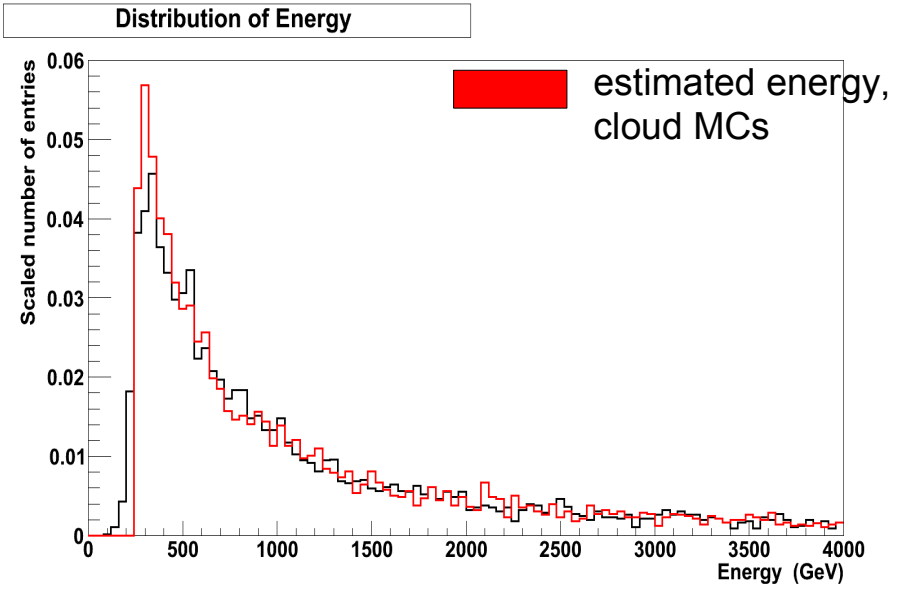
Results (cont'd)



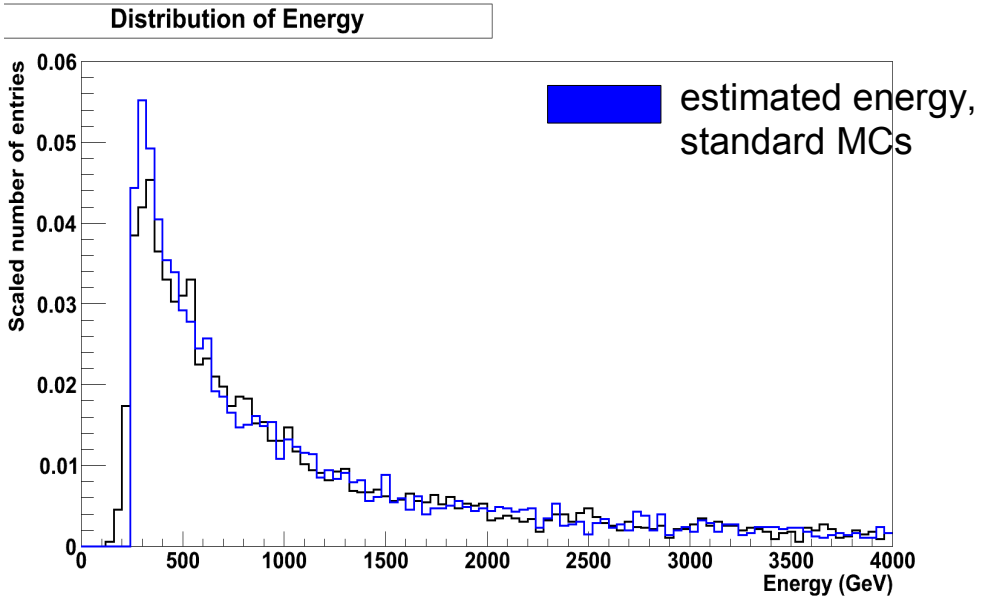
- estimated height of shower maximum for two MC samples (standard MCs and cloud MCs with higher aerosol density)
- very small differences – stereoscopic reconstruction fine

Results (cont'd)

Estimation of energy: original MC energy



Comparison of original MC energy and estimated energy with tables based on cloud Monte Carlo simulations



Comparison of original MC energy and estimated energy with tables based on standard Monte Carlo simulations

- comparison of original and estimated energy shows very little difference

Summary

- Bad weather (presence of clouds, calima) reduces gamma rate and data quality
  → impact on analysis results

- Monte Carlo simulations of variable atmospheric transparency can be used to:

    - to quantify the impact of clouds and calima on data

    - for the analysis of data affected with clouds or calima
      → leads to larger duty cycle

- Preliminary results – very small differences in parameters

- No significant effect visible for simulated MCs with layers of increased aerosol number density, but energy estimation correct

- Further systematic analysis necessary with Monte Carlo samples with higher aerosol number density

- Use of atmospheric attenuation measurements being implemented (atmospheric transmission → aerosol number density)