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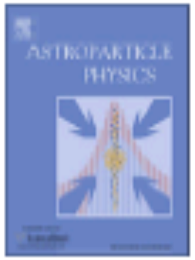
Contents lists available at ScienceDirect

Astroparticle Physics

journal homepage: www.elsevier.com/locate/astropart



Detailed studies of atmospheric calibration in imaging Cherenkov astronomy

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ARTICLE INFO

Article history:
Received 7 January 2010
Received in revised form 9 August 2010
Accepted 24 August 2010
Available online 31 August 2010

Keywords:
Gamma-ray
IACT

ABSTRACT

The current generation of imaging atmospheric Cherenkov telescopes are allowing the sky to be probed with greater sensitivity than ever before in the energy range around and above 100 GeV. To minimise the systematic errors on derived fluxes a full calibration of the atmospheric properties is important given the calorimetric nature of the technique. In this paper we discuss an approach to address this problem by using a ceilometer co-pointed with the H.E.S.S. telescopes and present the results of the application of this method to a set of observational data taken on the active galactic nucleus (AGN) PKS 2155-304 in 2004.

http://arxiv.org/abs/1009.0517

(Early Attempts at) Atmospheric Correction With H.E.S.S. (Phase 1)

Sam Nolan, Cameron Rulten

More Recent H.E.S.S. Related Work

- **Radiometers – See Michael Daniel's Talk**
- **Lidar – See George Vasileiadis Talk**
- **Aerosols at H.E.S.S. site – P Ristori**

- **and many others …**

- **The Problems**
- **Equipment in Namibia**
- **Relative Methods of Correction**
- **In Search of Absolute Correction**
    - Active Atmospheric Correction
    - Short Comings of This Method
- **Conclusions & Future Work**

Two Classes of Problem for IACT's

- **High Level Aerosols (e.g. clouds) which can occur around shower-max and so affect Cherenkov yield & image shape etc.**
- **Low Level Aerosols (near to ground level) which act as a filter, lowering the Cherenkov yield.**

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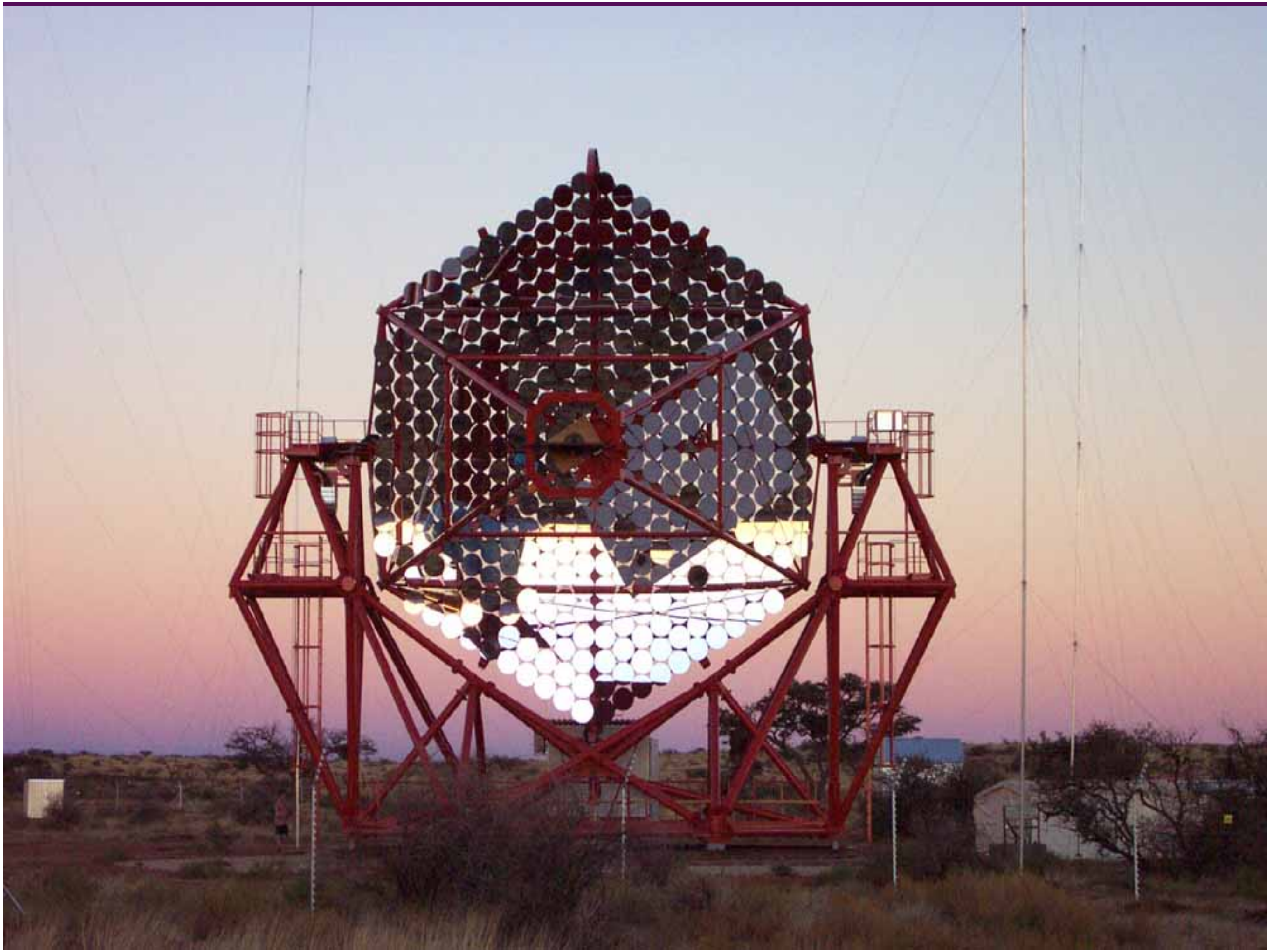

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- The H.E.S.S. telescope (background rates etc)

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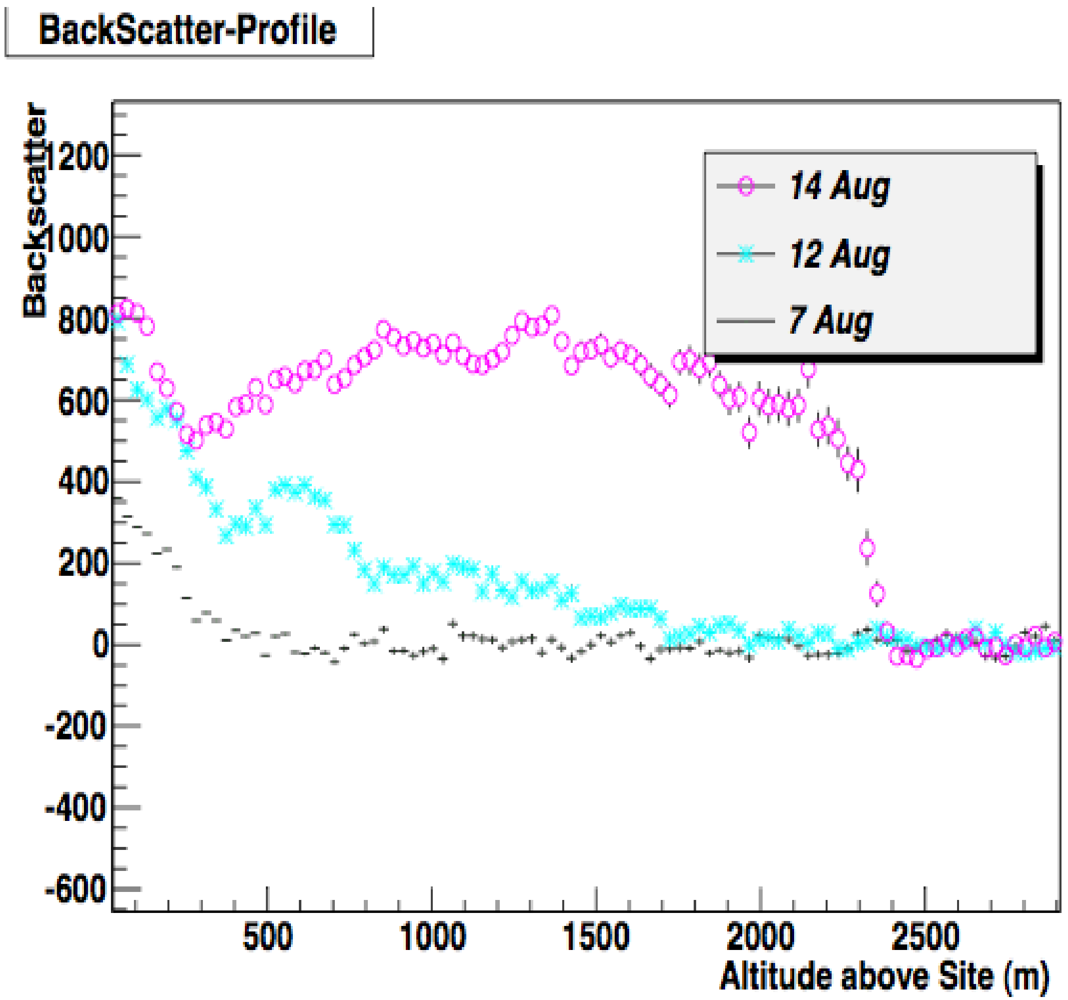
Ceilometer



- Commercial Ceilometer with 7km range operating at 905nm operated at H.E.S.S. site from 2002-2007.
- Co-pointed with telescopes
- Used routinely by shift crew to check atmospheric quality.
- Could be set to look at next observing position to check clarity elsewhere.

Methods of atmospheric correction (1)

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- Scale by differences in changing optical properties of starlight derived from optical telescopes relative to a “clear” night.

Methods of atmospheric correction (2)

- Utilise ceilometer to locate aerosol populations, model atmosphere, apply to cosmic-ray and gamma-ray simulation database, and compare telescope simulation to real data, varying atmospheric model (within limits) until simulations & real data agree.

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Method

Use Ceilometer to assess dust position

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Simulate atmospheres with dust of differing opacities

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Apply atmospheric model to gamma-ray simulations

Method

1. Use Ceilometer to assess dust position
2. Simulate atmospheres with dust of differing opacities
3. Apply different atmospheric models to cosmic-ray simulations
4. Compare simulations with real background cosmic-ray data until best match
5. Apply atmospheric model to gamma-ray simulations
6. Produce gamma-ray lookup tables

Method

Use Ceilometer to assess dust position

Simulate atmospheres with dust of differing opacities

Apply different atmospheric models to cosmic-ray simulations

Compare simulations with real background cosmic-ray data until best match

Apply atmospheric model to gamma-ray simulations

Produce gamma-ray lookup tables

Apply to the Data

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Apply atmospheric model to gamma-ray simulations

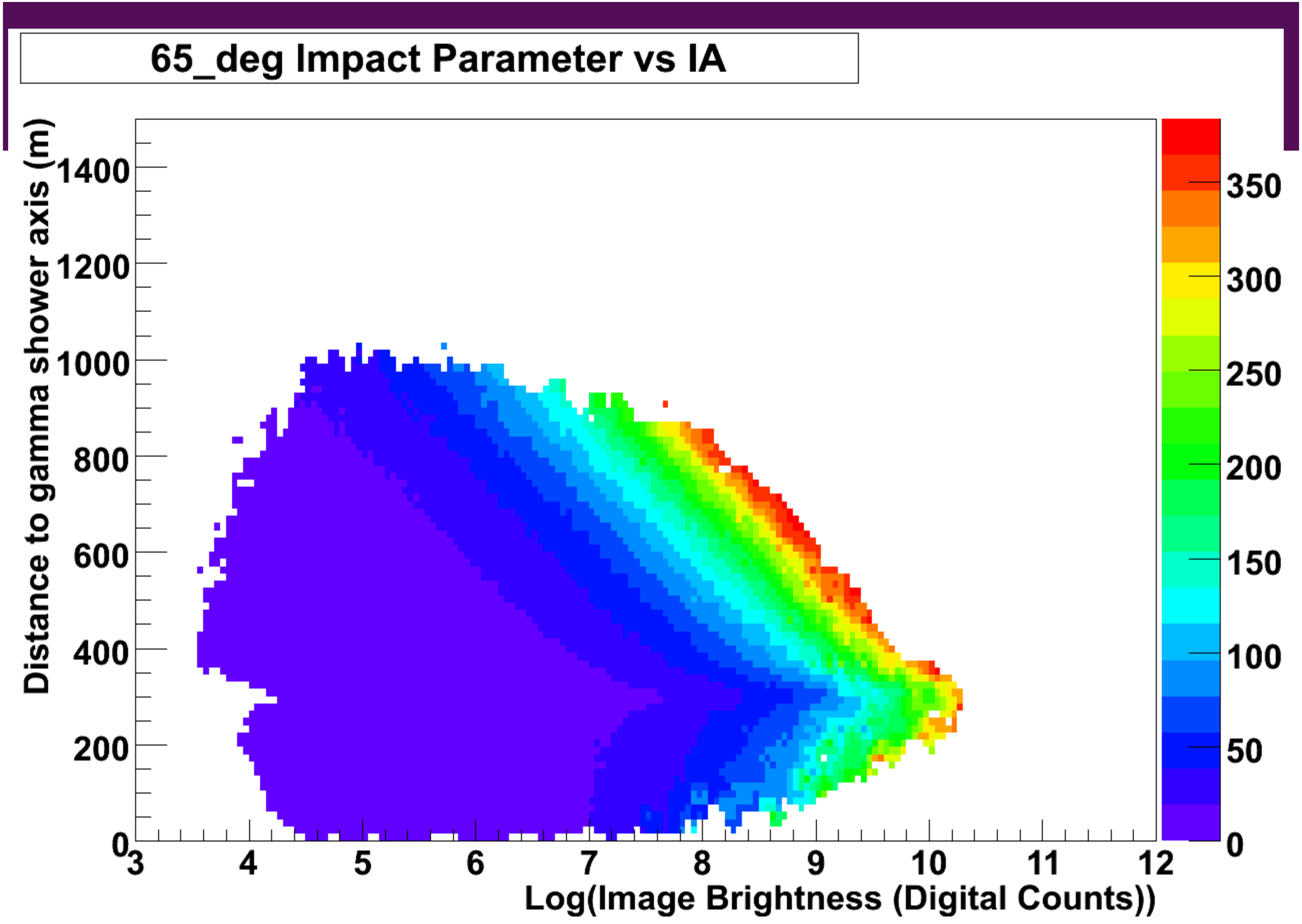
Produce gamma-ray lookup tables

Apply to the Data

Significant Computing Expense

Lookup Tables

- Energy (Core Position, Image Brightness, Zenith Angle)
- Effective Area(Reconstructed Energy, Zenith Angle, Offset)
- Mean Scaled Length (Core Position, Image Brightness, Zenith Angle)


65_deg Impact Parameter vs IA
Distance to gamma shower axis (m)
Log(Image Brightness (Digital Counts))
0
200
400
600
800
1000
1200
1400
3
4
5
6
7
8
9
10
11
12
0
50
100
150
200
250
300
350

Outcomes

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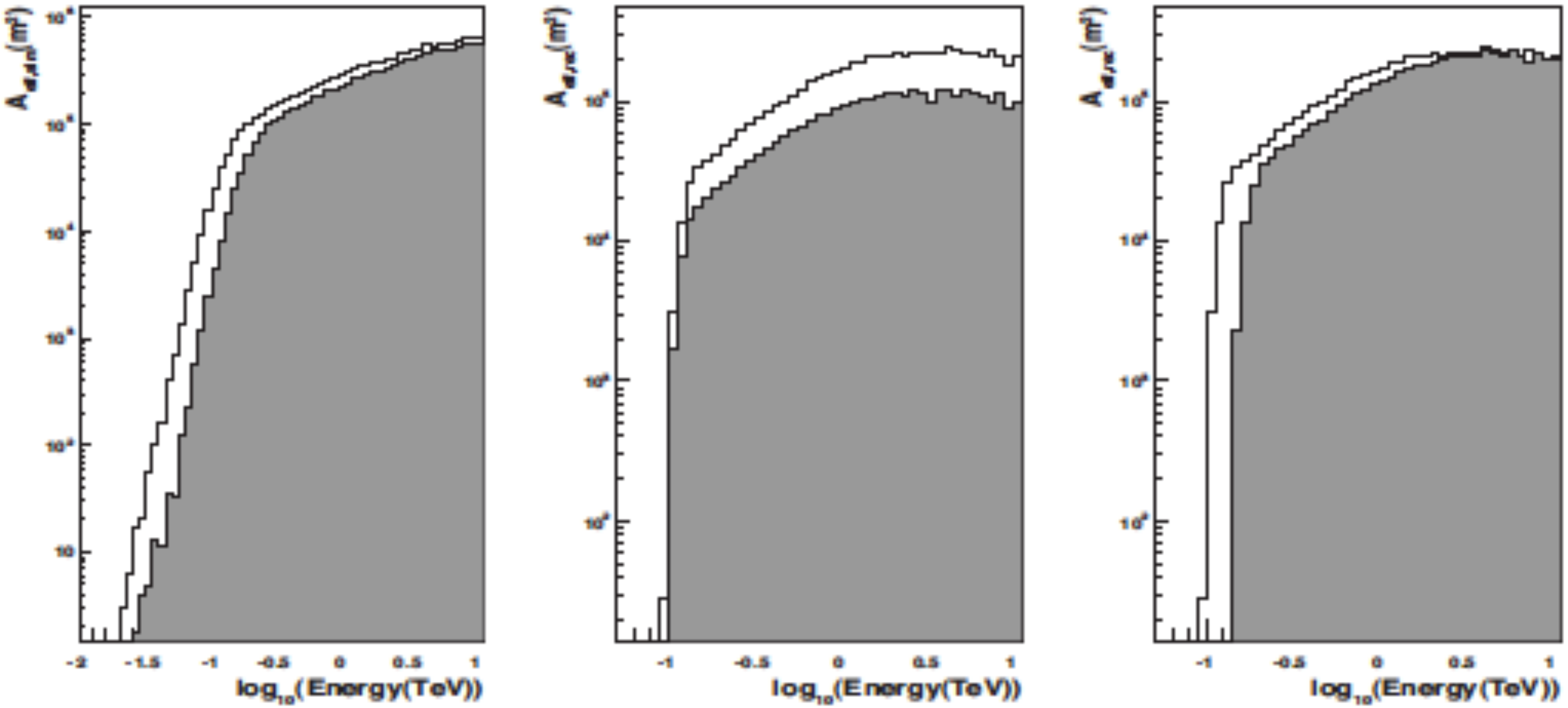
  - Decreasing the efficiency of the telescope for detecting gamma-rays, particularly those of lower energy.
  - Allow miscalculation of the energy of a given event. For the worst cases seen at the H.E.S.S. site can be out by almost 50%.

Changing Effective Area



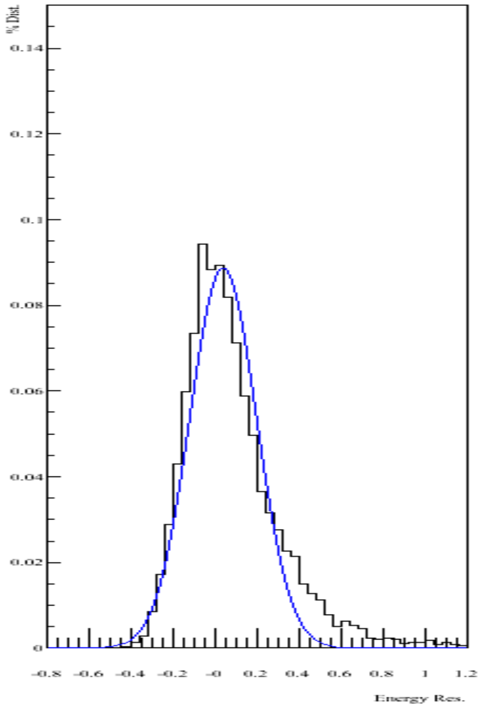
Low level aerosols effect both the triggering and the energy reconstruction, as shown here in terms of effective area - true energy (lhs) and reconstructed energy (centre and rhs)

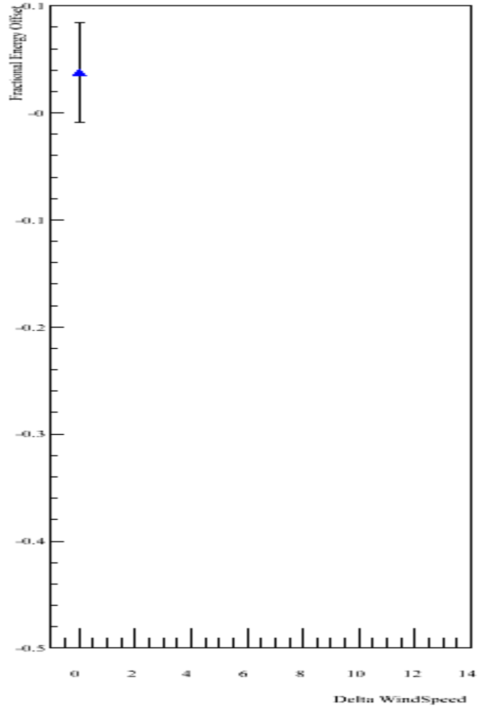
Changing Energy Resolution

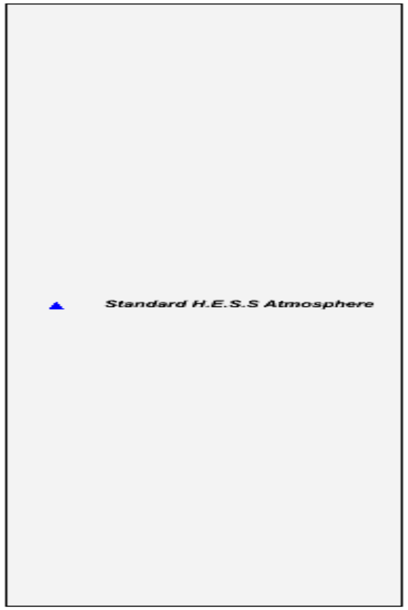
- **If no correction is attempted with increasing low level aerosols ("dust") the Cherenkov yield from an event of given energy and core location will be less.**
- **Without correction this will lead to a bias in the reconstructed energy**
- **This can be thought of as a systematic offset or bias in the energy resolution**

  $((E_{RECO}-E_{TRUE})/E_{TRUE})$.

Changing Energy Resolution

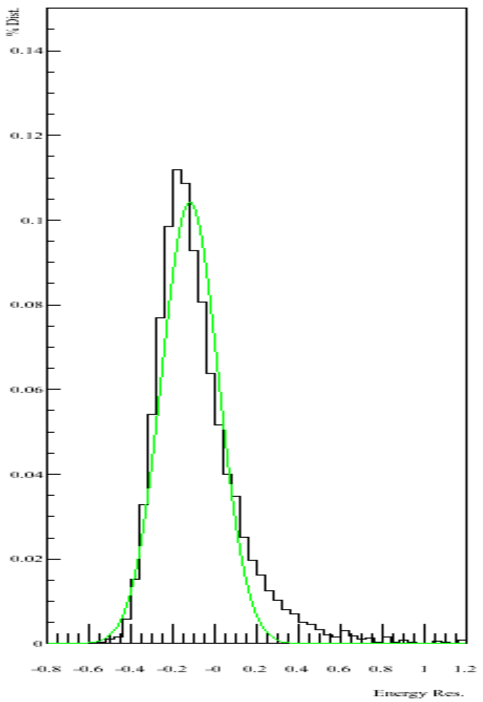


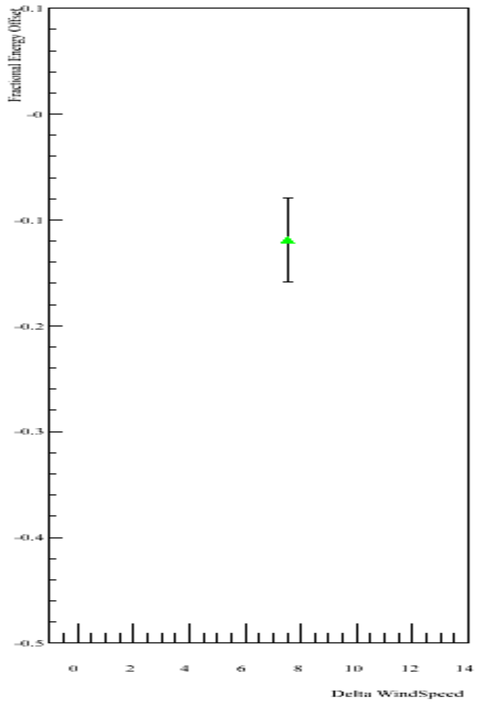


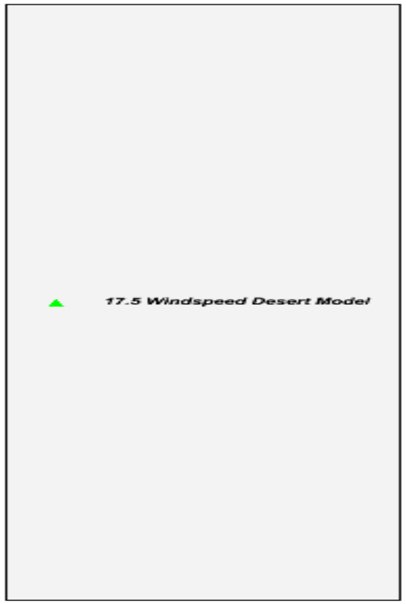


Energy resolution $((E_{RECO}-E_{TRUE})/E_{TRUE})$

Changing Energy Resolution







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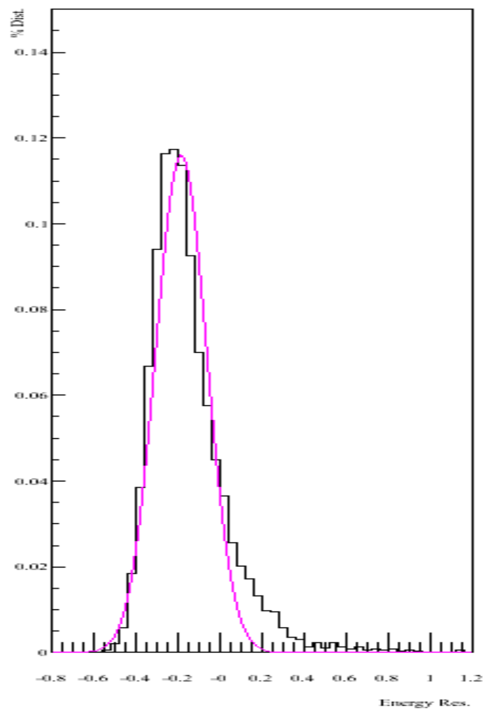

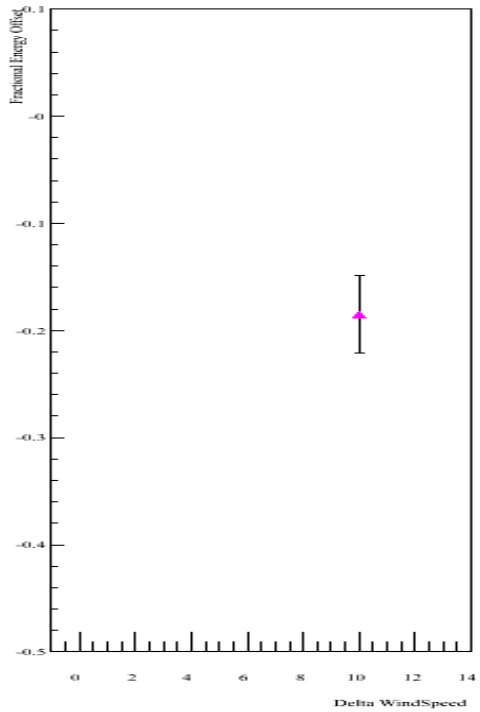

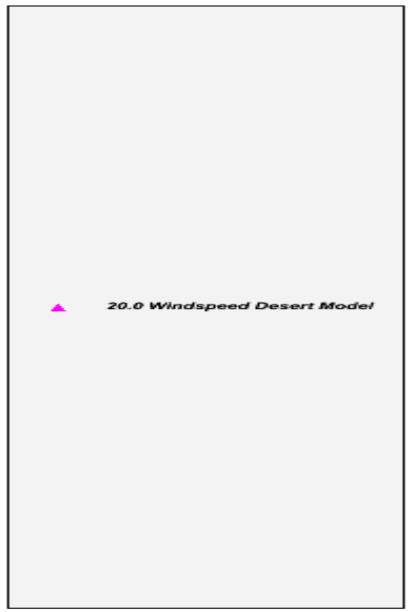

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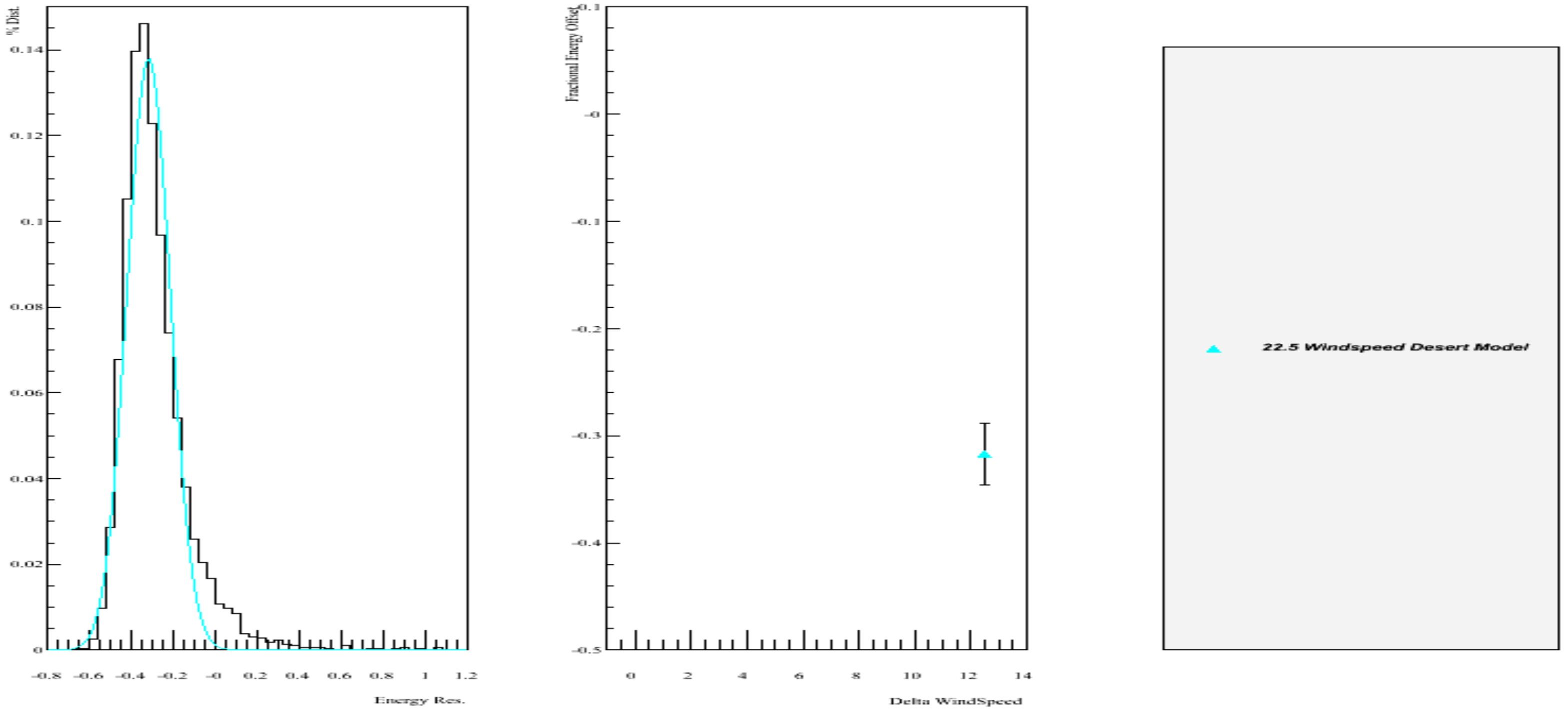

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Comparing With Real Data

- During August each year several nights of observations are lost due to low-level dust of the kind described.

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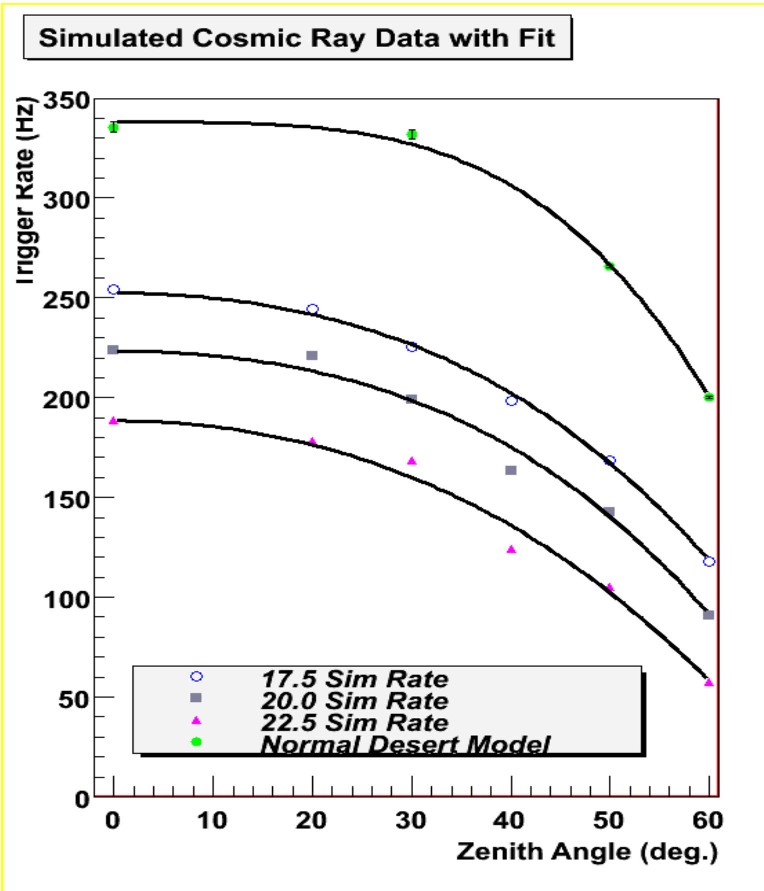
Comparing With Real Data

- **During August each year several nights of observations are lost due to low-level dust of the kind described.**
- **For example in 2004, a multi-wavelength campaign was running on PKS2155-304 and almost 70% (60 hrs) of the data was affected.**
- **Although the inter night variability in cosmic-ray trigger rate was high, the intra night variability was low.**

Modeling The Atmosphere: MODTRAN

- By increasing the wind speed parameter in the standard desert model of MODTRAN, dust (sand) in the region 0-3 km is increased.
- This parameter is tuned to the cosmic-ray trigger rate of the real data and simulations are compared with real data.
- 2006 so MODTRAN 4 was standard

Comparing With Real Data



The cosmic-ray trigger simulations therefore suggest 3 classes of low-level dust of increasing density. Image parameters in good agreement.

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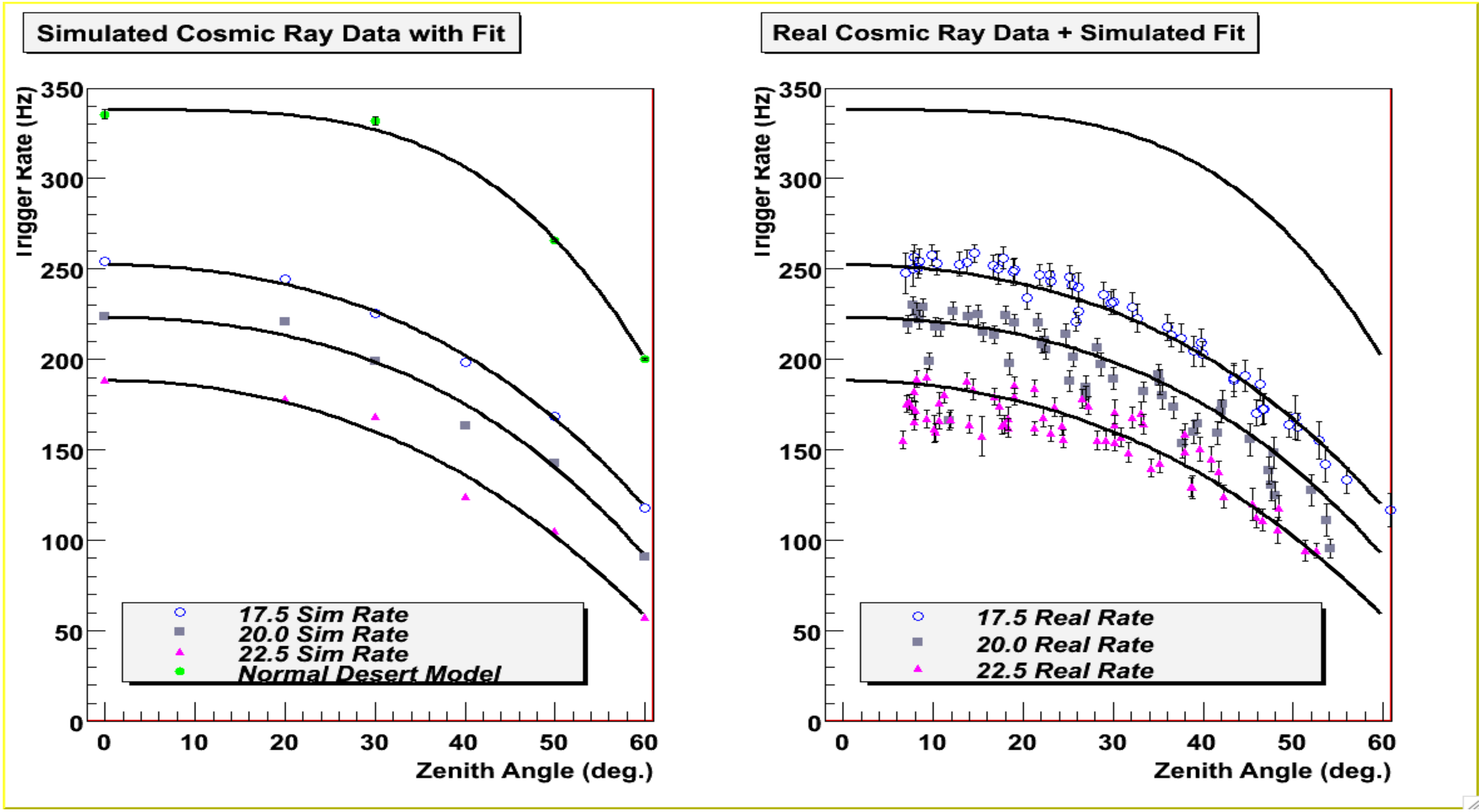

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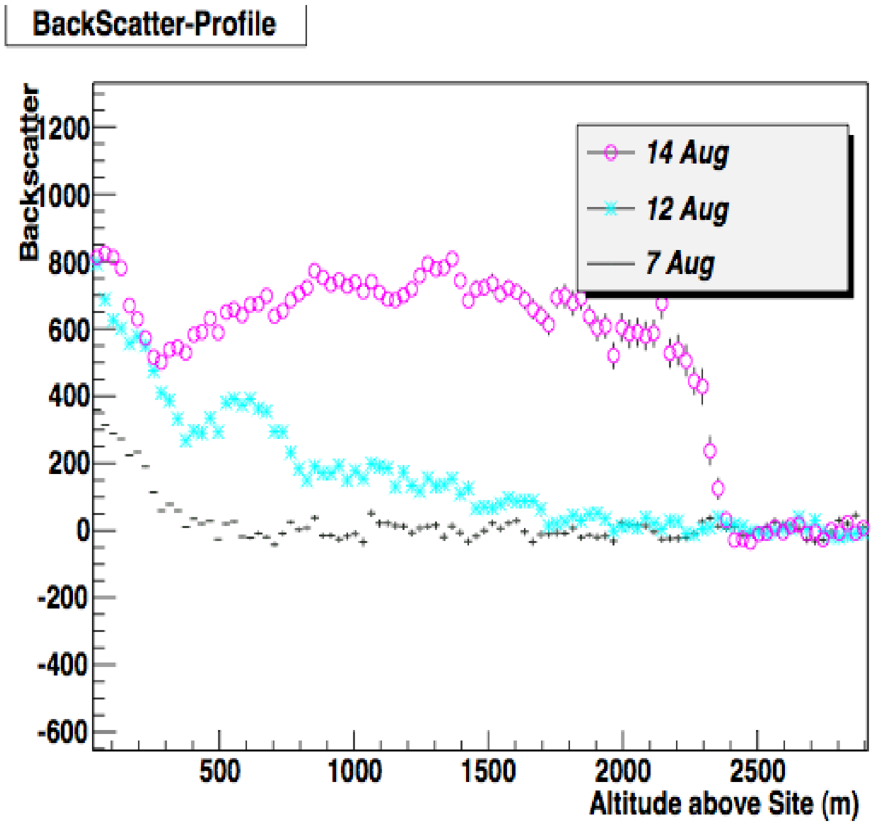
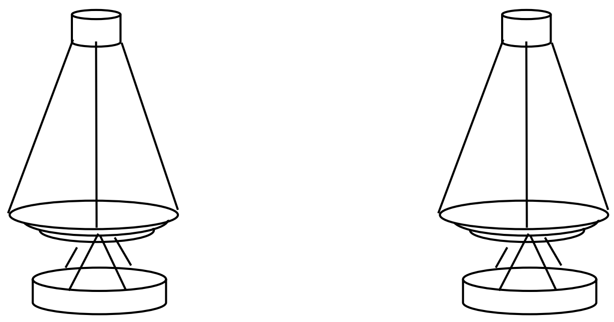
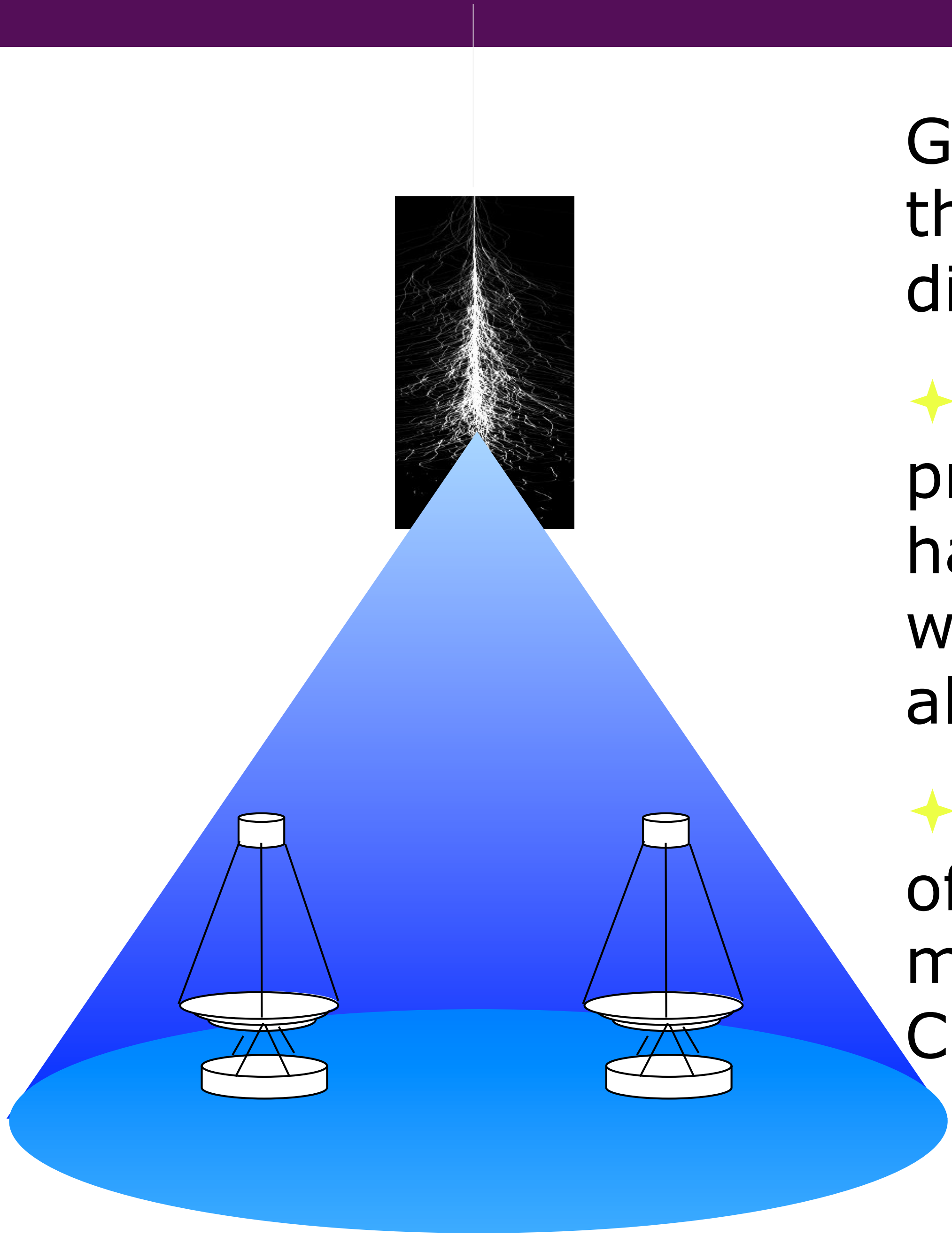


The Ceilometer and Transmissometer also supported three classes of atmospheric behavior. However this Ceilometer had a limited altitude range (7km), and so another method for deriving the prescience of aerosols was developed.



Geometric reconstruction of the shower allows you to distinguish:

- Place on ground where primary gamma-ray would have intersected, combined with image brightness this allows energy estimation
- The reconstructed depth of emission of the maximum number of Cherenkov photons D_{max}



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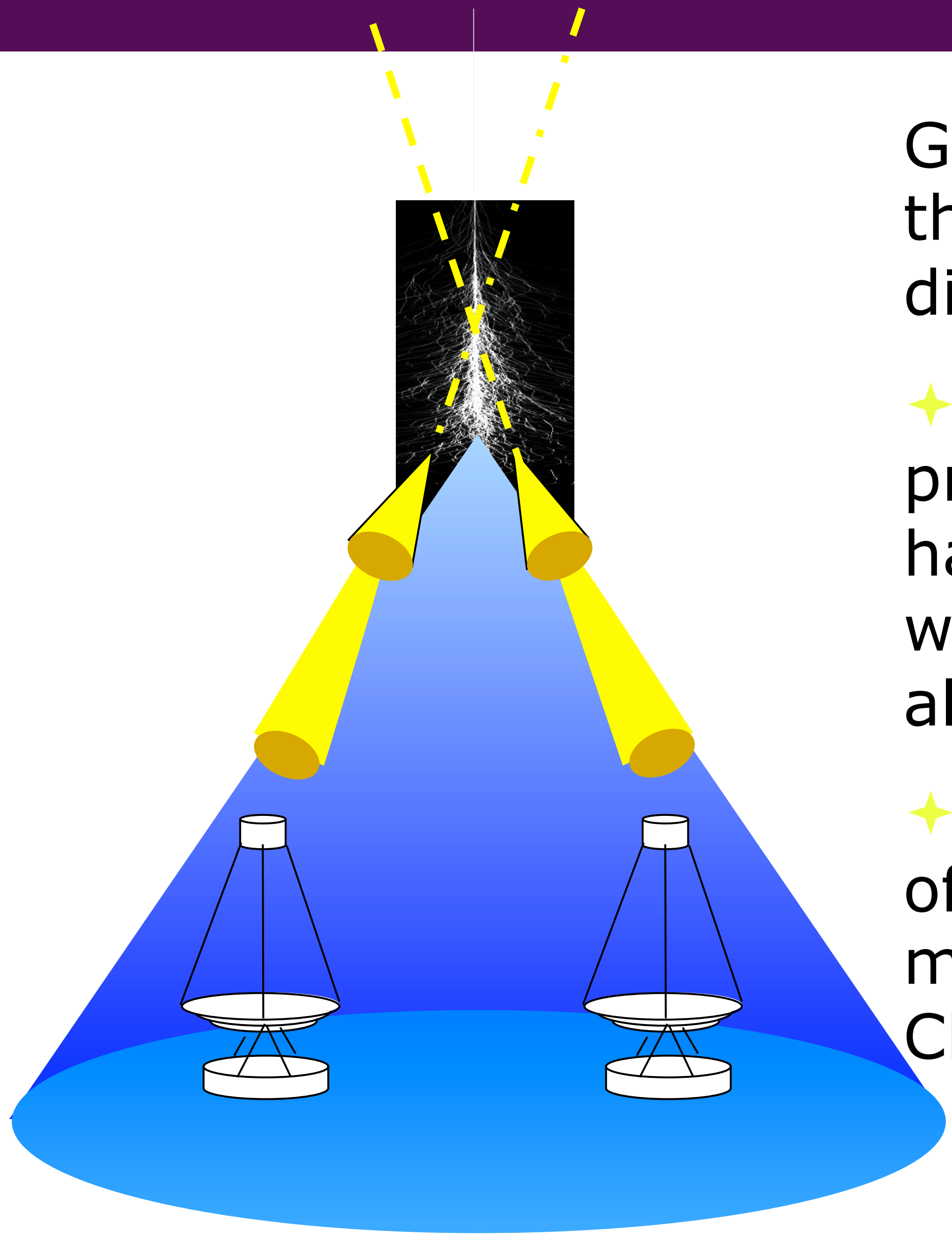

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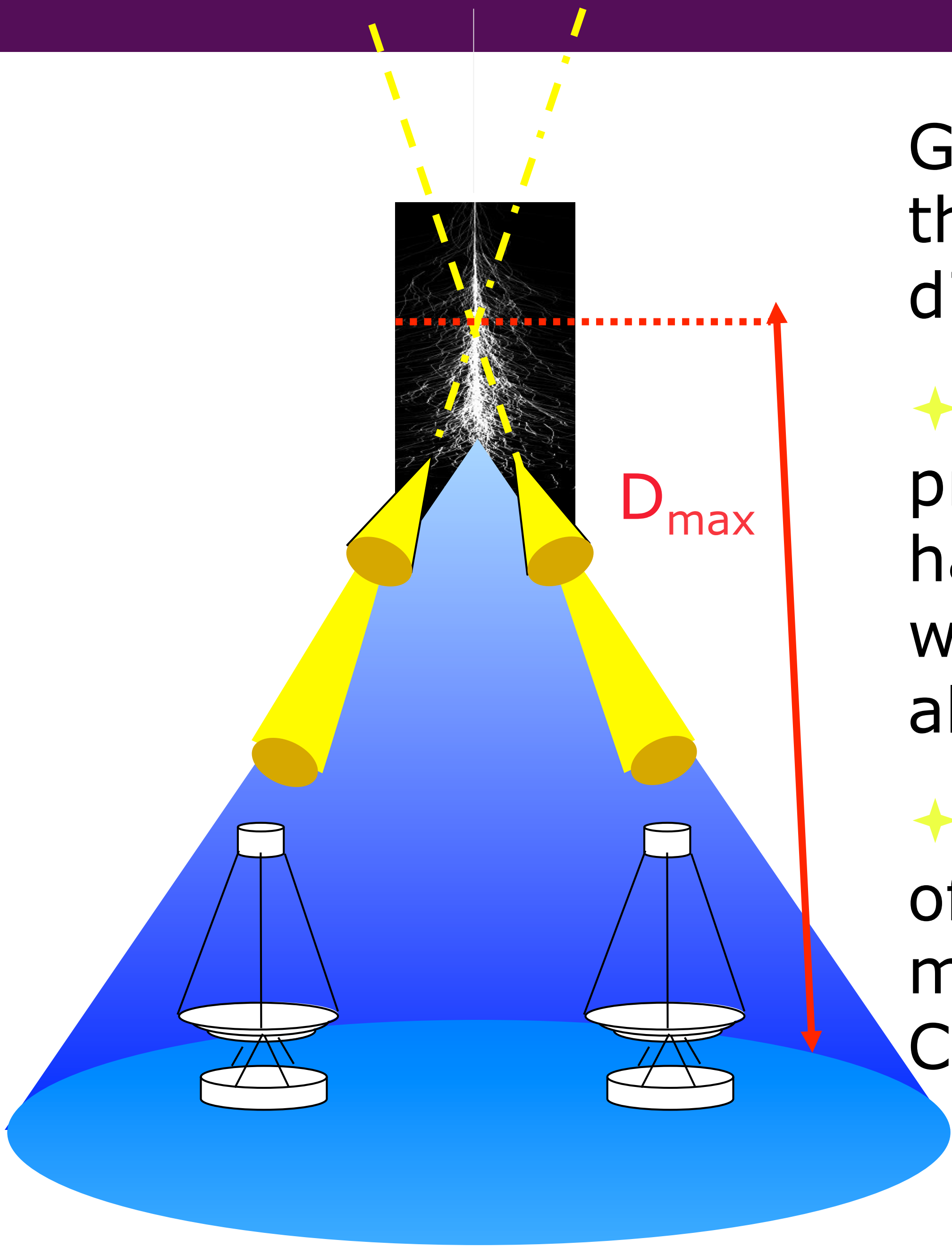

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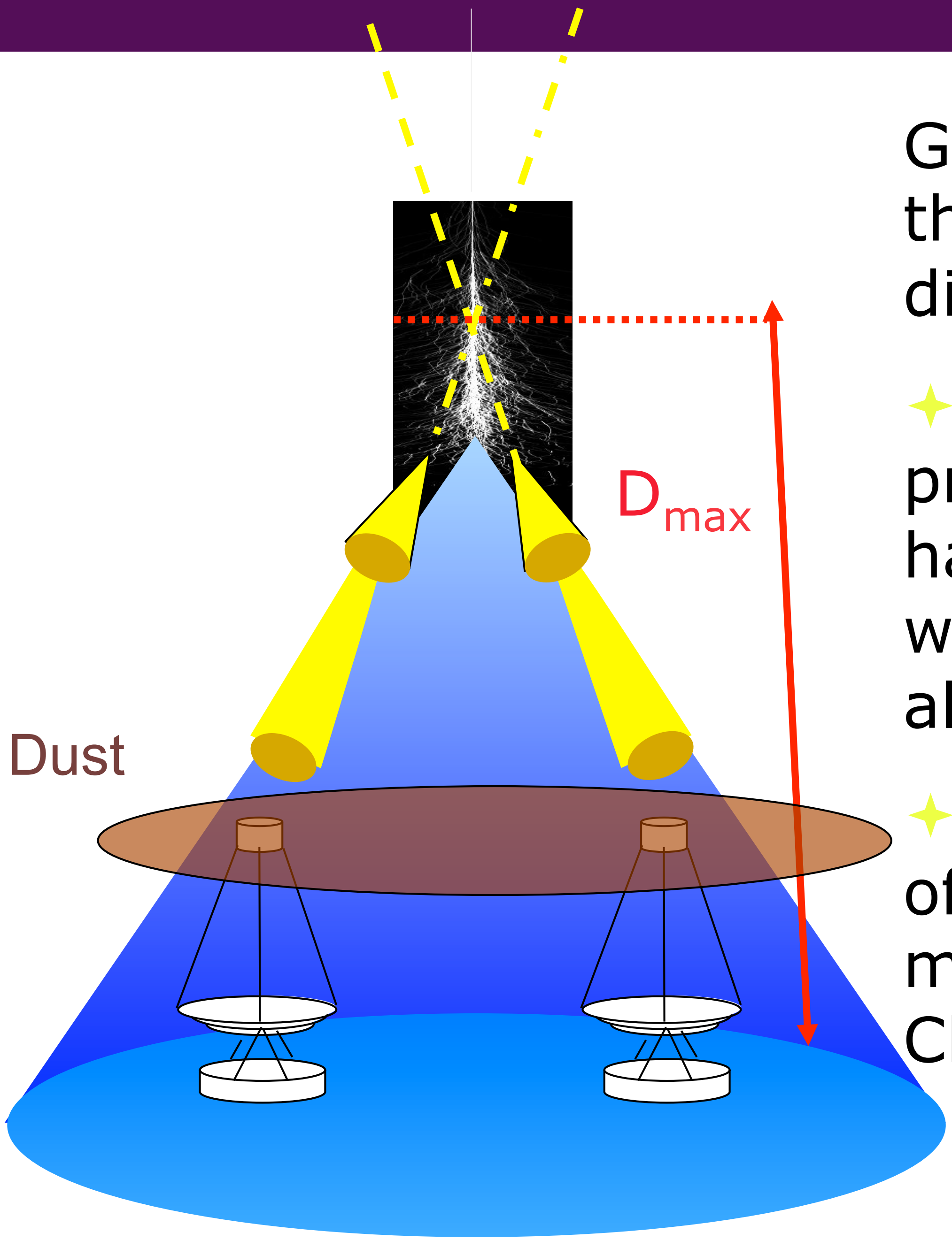

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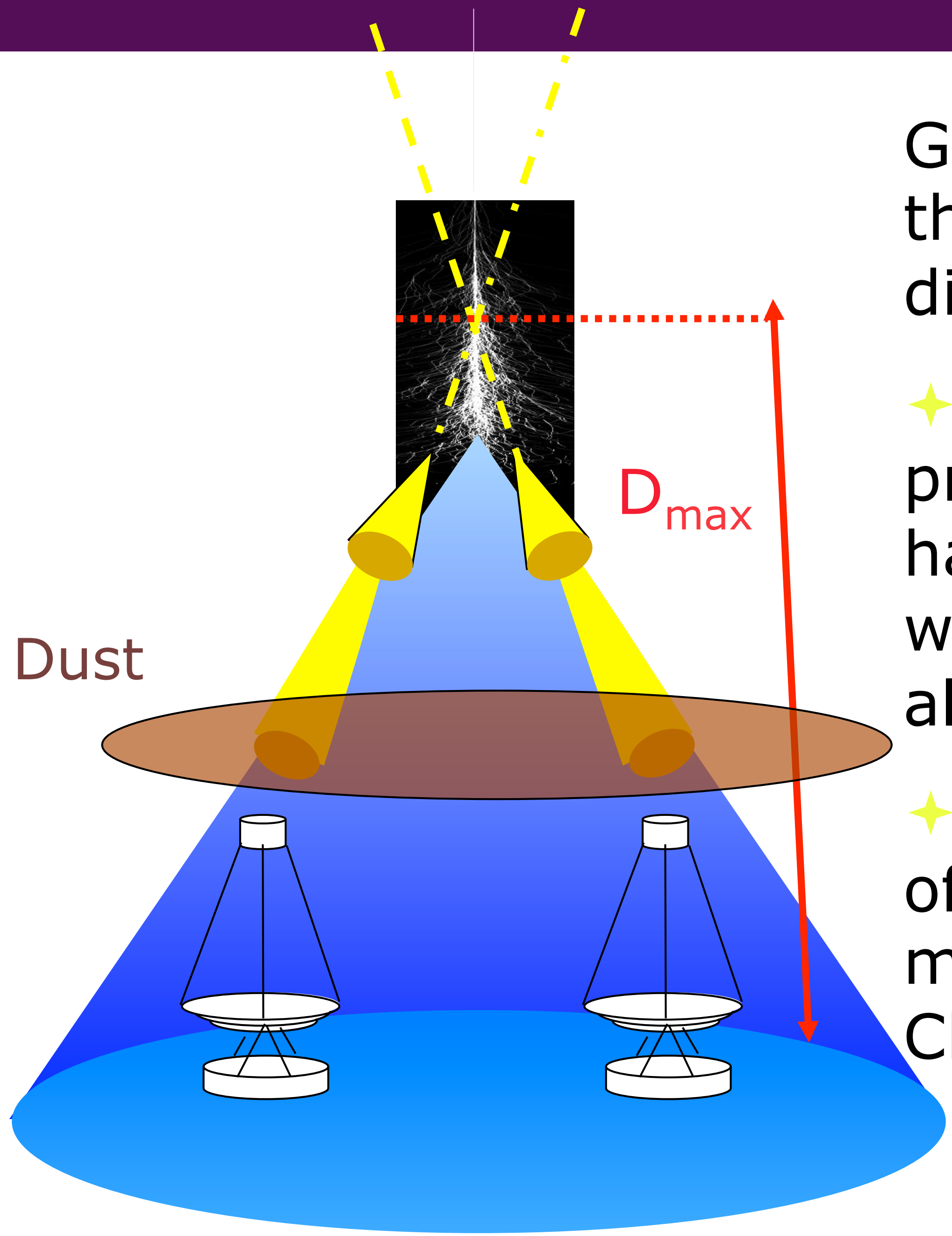

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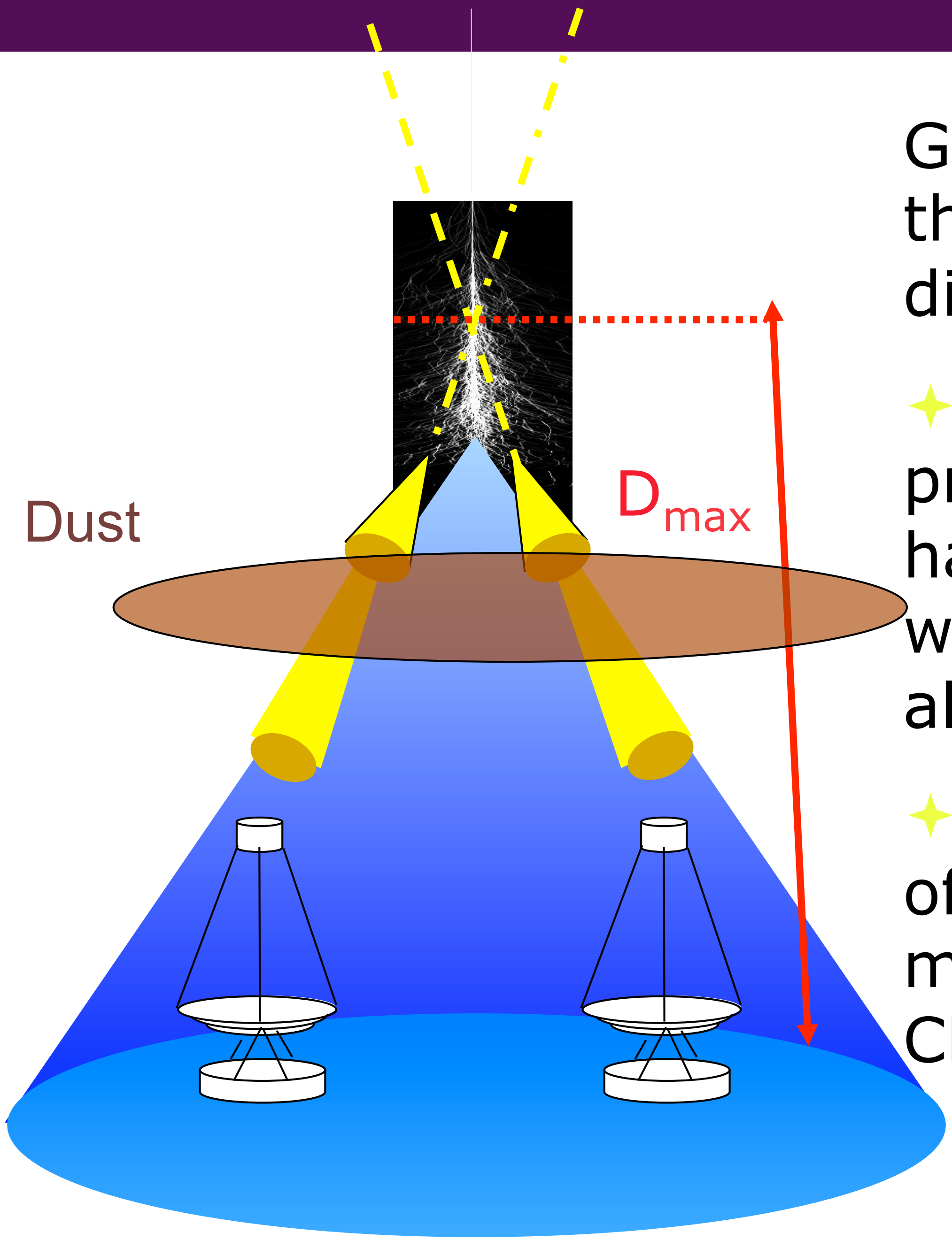

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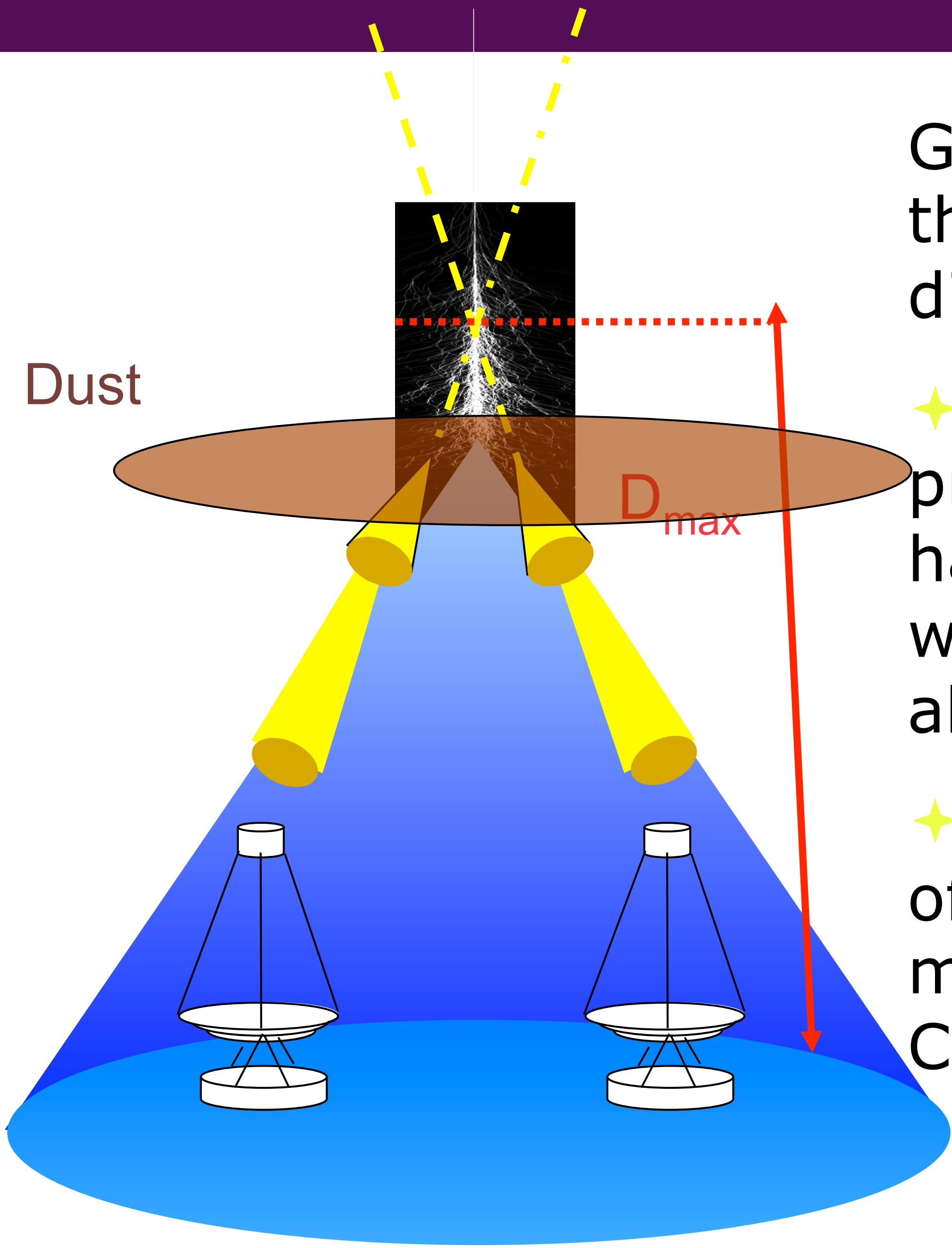

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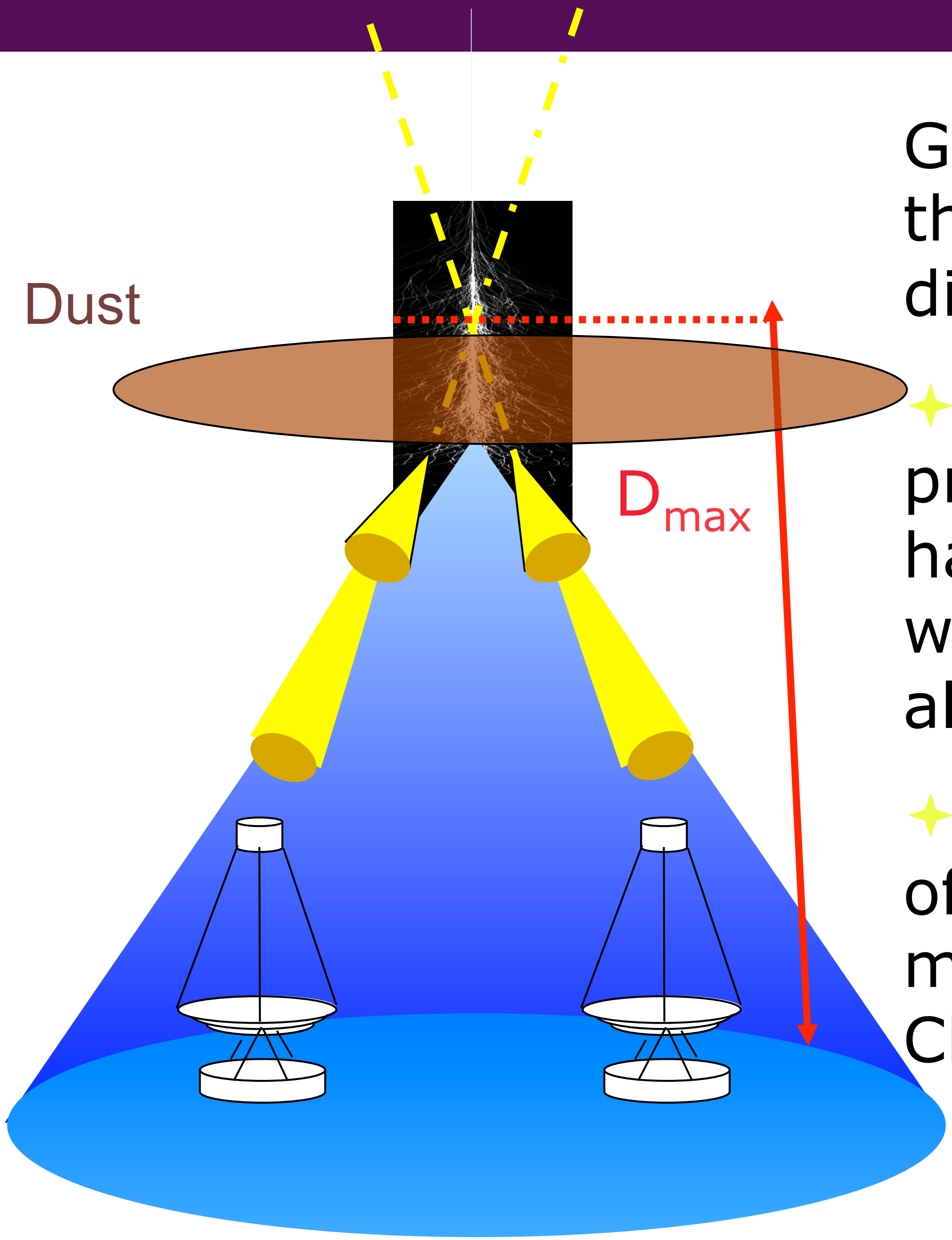

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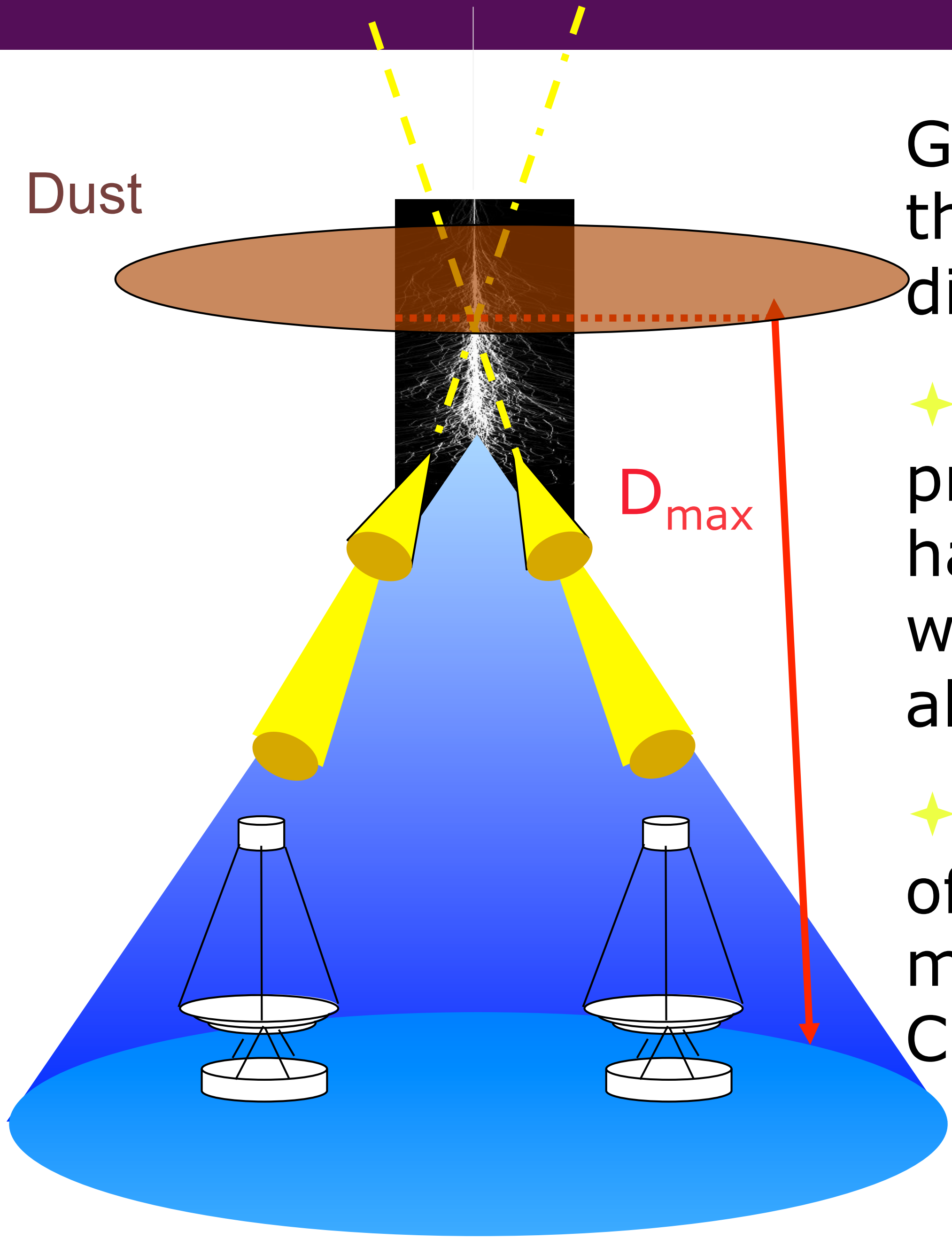

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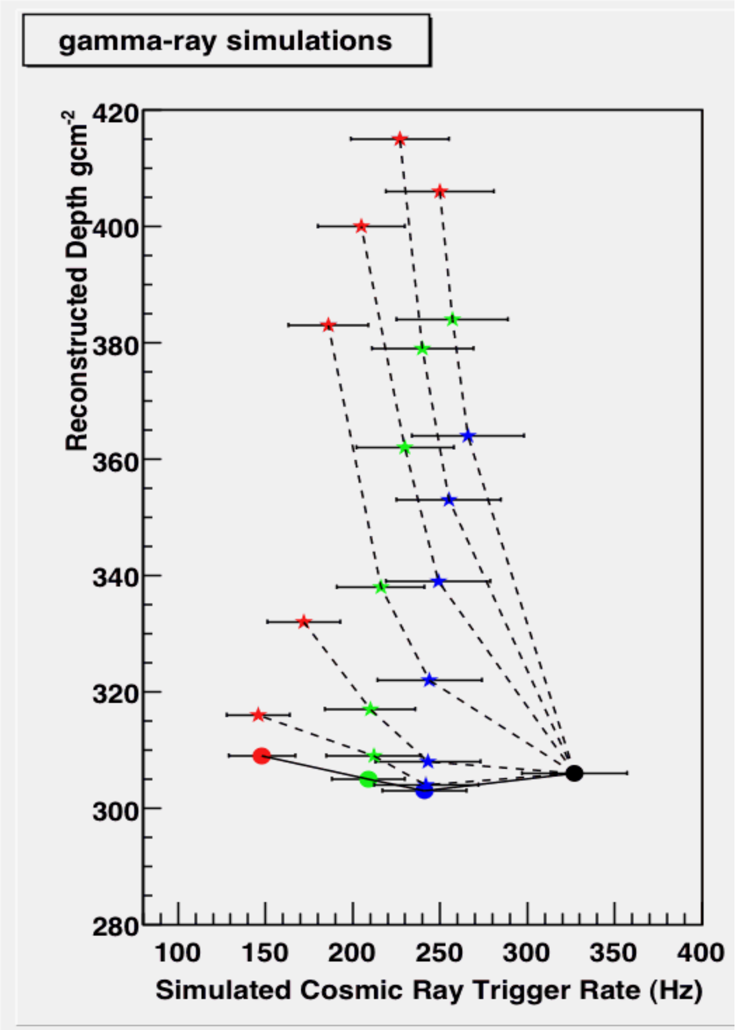
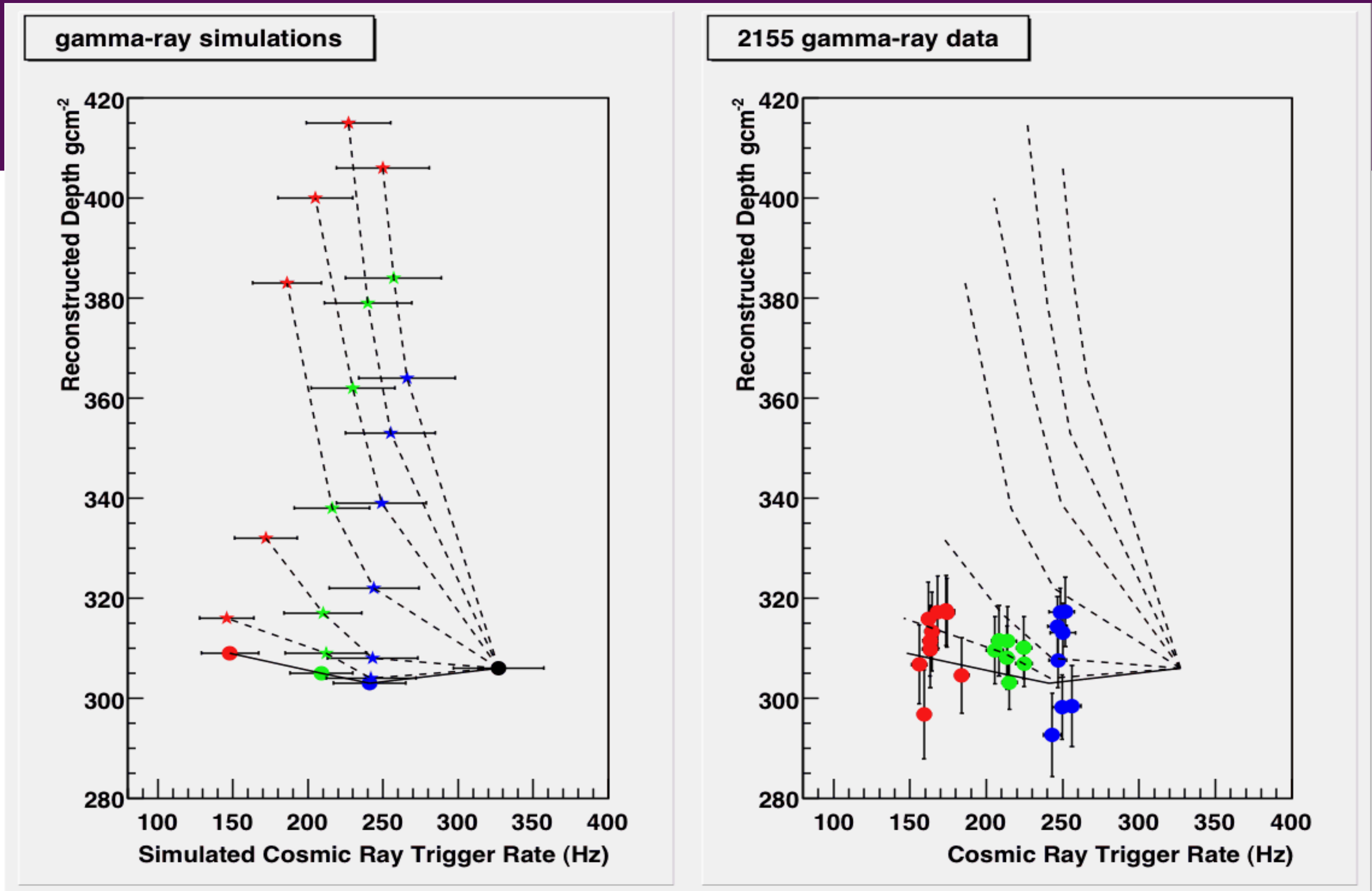
Using D_{max} to probe atmosphere

- Given the Ceilometer has a finite sensitivity and range its possible high-level aerosols may also be contributing to the reduced trigger rate. However these would affect the mean value of D_{max}

- By comparing D_{max} between simulation and real data, we can check for any signs of high-level aerosols in our data.



Here $<D_{max}>$ from simulation for various atmospheres (those selected by trigger rate (i.e. low-level aerosols only) are solid circles. Results agree well with our assumptions at 20 (shown) and 40 degrees from Zenith.



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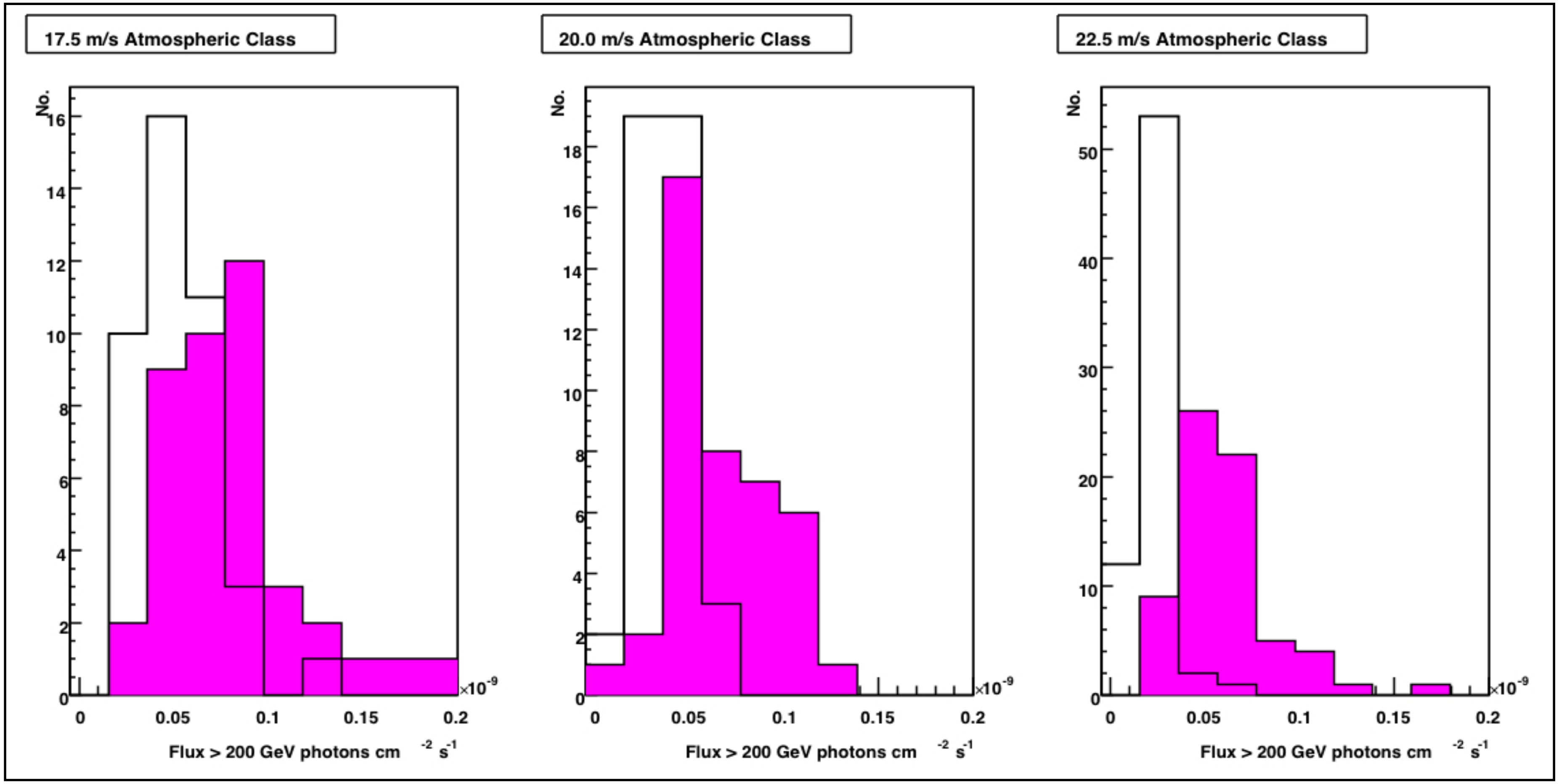
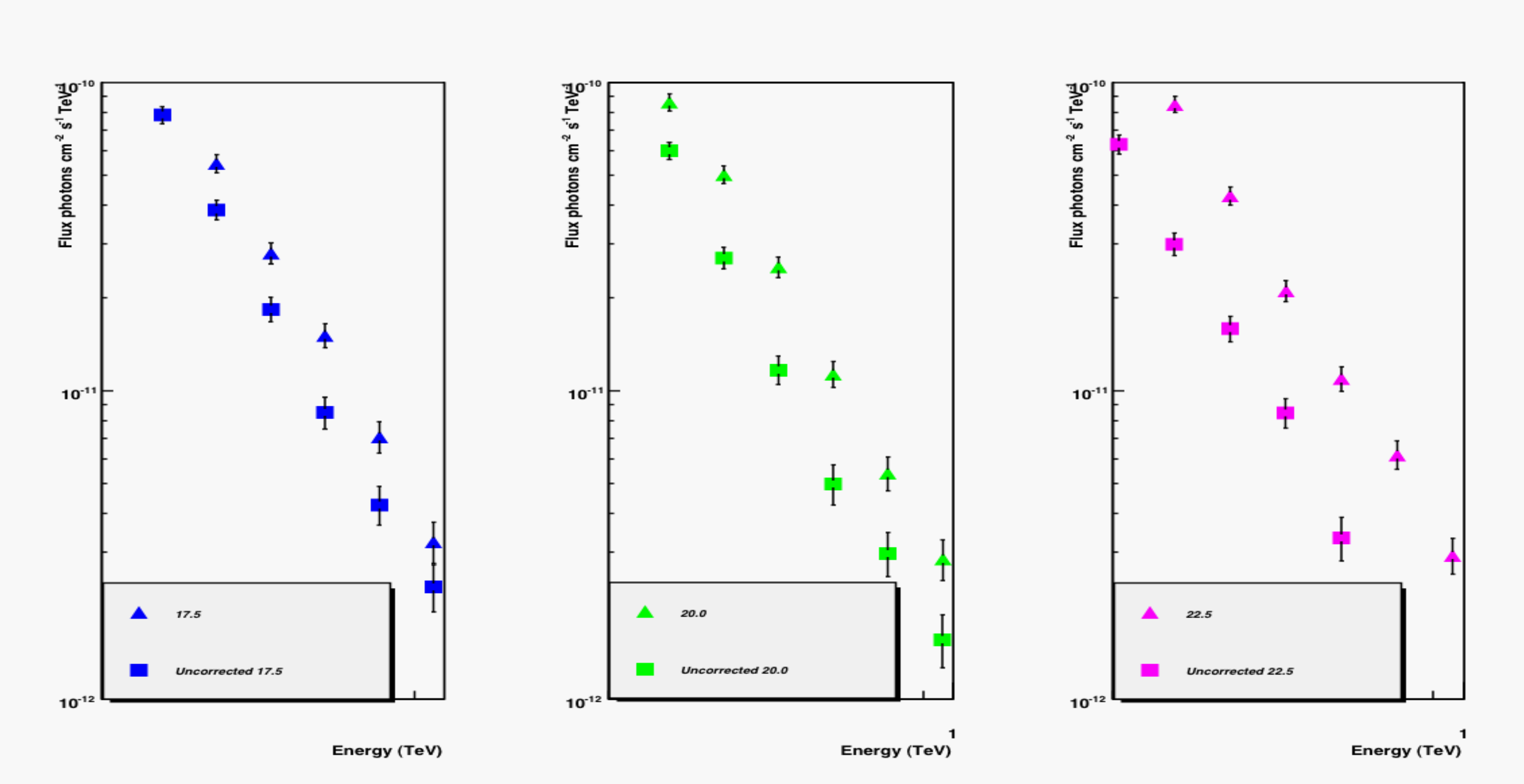
Corrected Flux Comparison



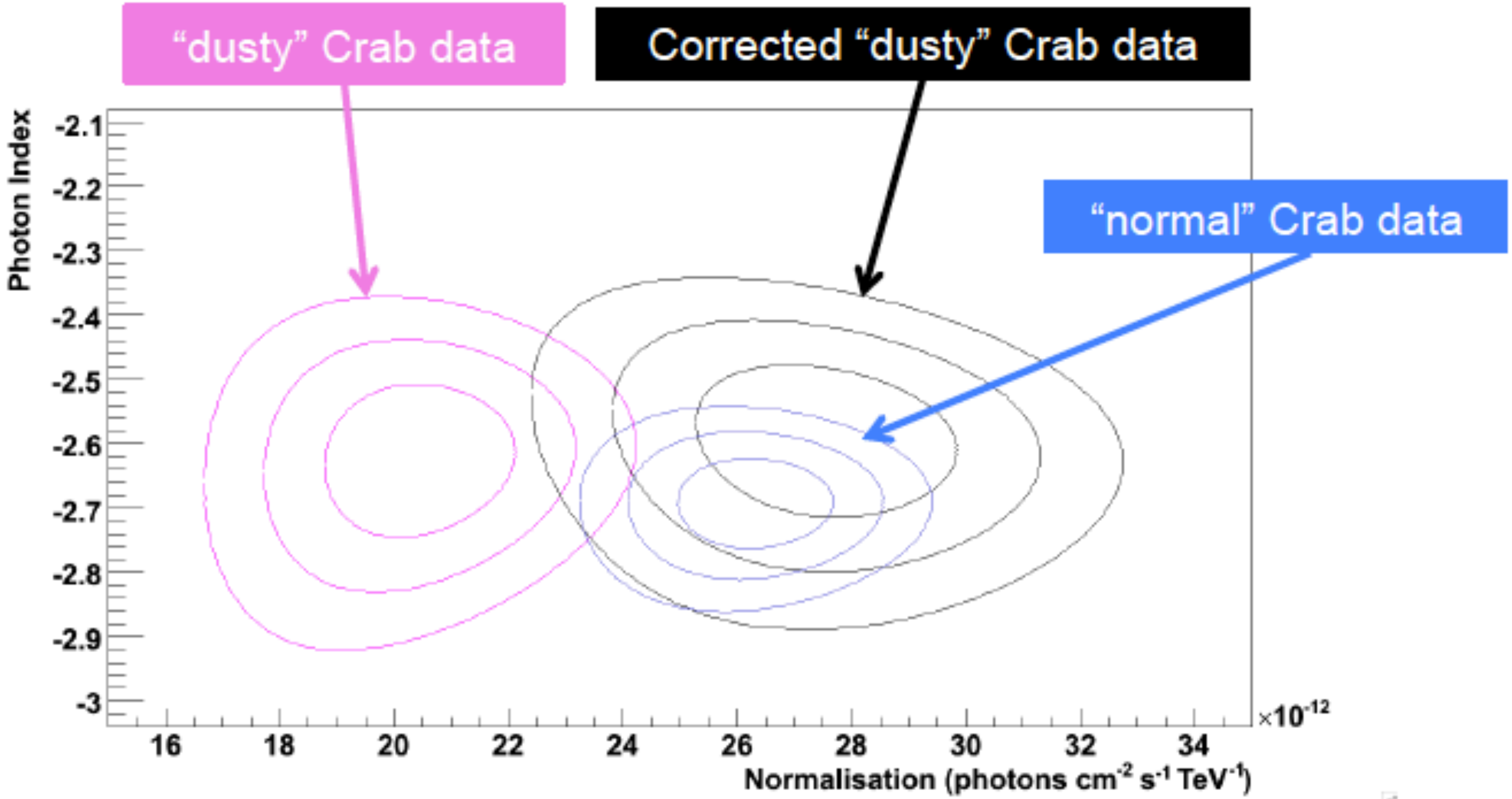
Here we see the uncorrected (white) and corrected (pink) integral flux (above 200 GeV) seen from a variable source (PKS 2155-304)

Spectrum Comparison



Without correction spectra of data subsets differ significantly in both normalization and slope, after correction they agree well. Corrected flux also correlated with measured X-ray flux.

Constant Flux Source Check



- technique results in a better fit
- proof of principle

Problems

- The old Ceilometer:
  - Range of 7km (doesn’t cover Dmax)
  - Wrong wavelength (905nm)
- Reliance on cosmic-ray simulations:
  - 15% systematic error in flux
  - Significant computing expense.
- Newer lidars:
  - Direct extraction of transmission at 355 nm.
- Dust isn’t dust
  - Biomass burning
- Old version of MODTRAN (4)

Conclusions

- H.E.S.S. operates (and has operated) many pieces of atmospheric monitoring equipment on site.
- These are routinely used in data quality checking.
- A method for correcting for the presence of low-level dust is presented, as is a novel method to use telescope data to isolate aerosol populations.