Atmospheric Simulation Outcomes of The CTA Design Study

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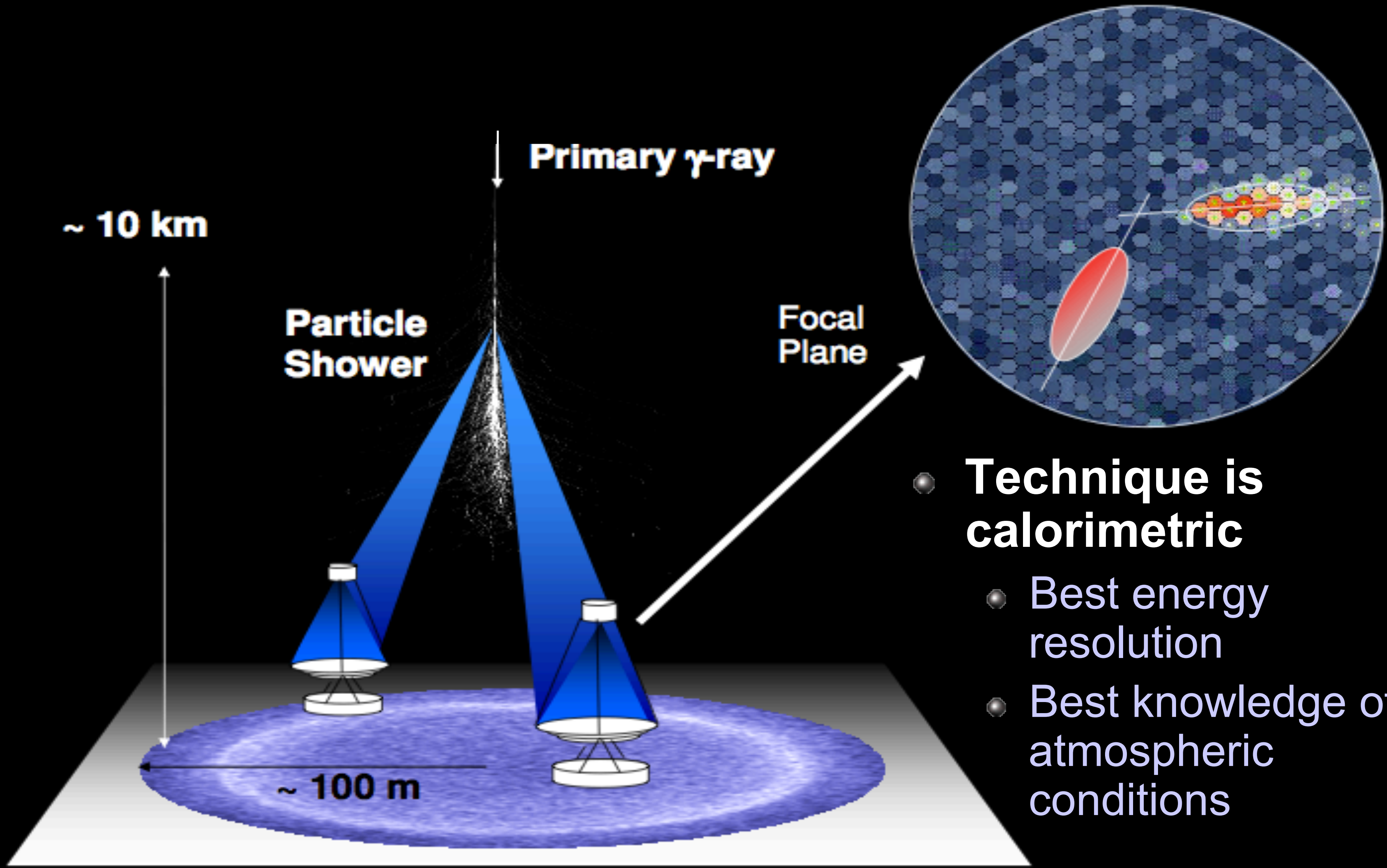
To Discuss

- **Introduction**
  - Imaging Atmospheric Cherenkov Astronomy
  - CTA & CTA Design Study
- **Atmosphere Simulation Studies**
  - Molecular Profile
    - Radiosonde Measurements
    - Shower & Telescope Simulations
  - Aerosol & Molecular Scattering
    - Lidar Measurements
    - Shower & Telescope Simulations
- **Conclusions & Future Work**

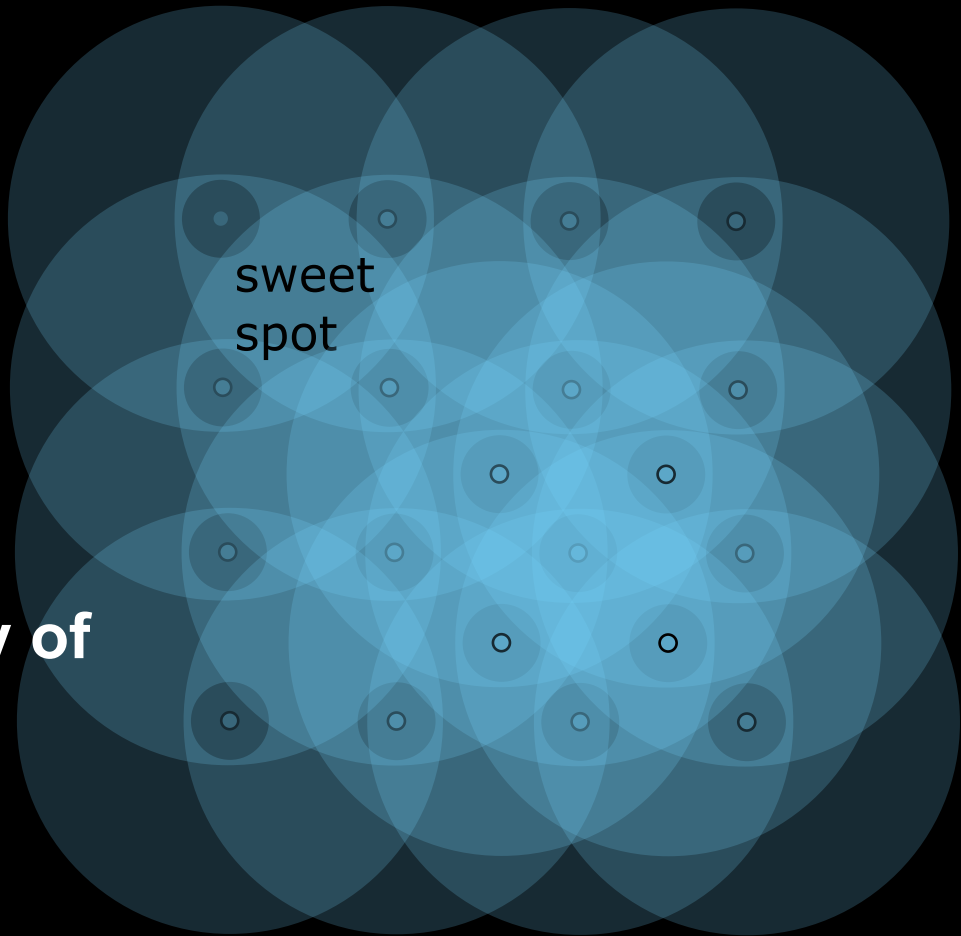
With Slides From: W. Hofmann, M. Martinez, J. Hinton, G. Hermann

Imaging Atmospheric Cherenkov Astronomy



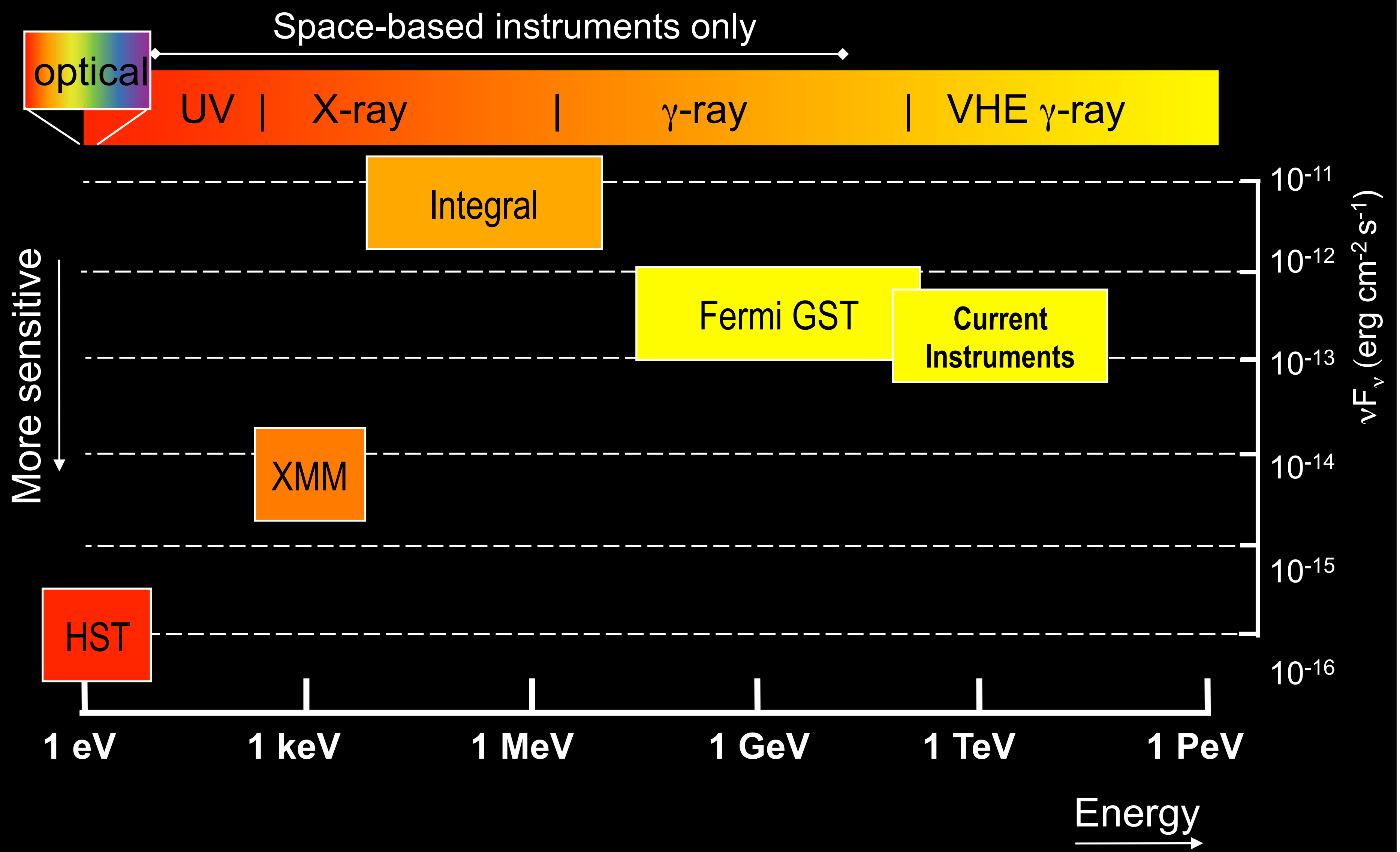
- **Technique is calorimetric**
  - Best energy resolution
  - Best knowledge of atmospheric conditions

Improving sensitivity & resolution



- **Increased Multiplicity of Events**
  - **Better Angular Resolution (0.08°)**
  - **Better Energy Resolution (10%)**

CTA: In Context



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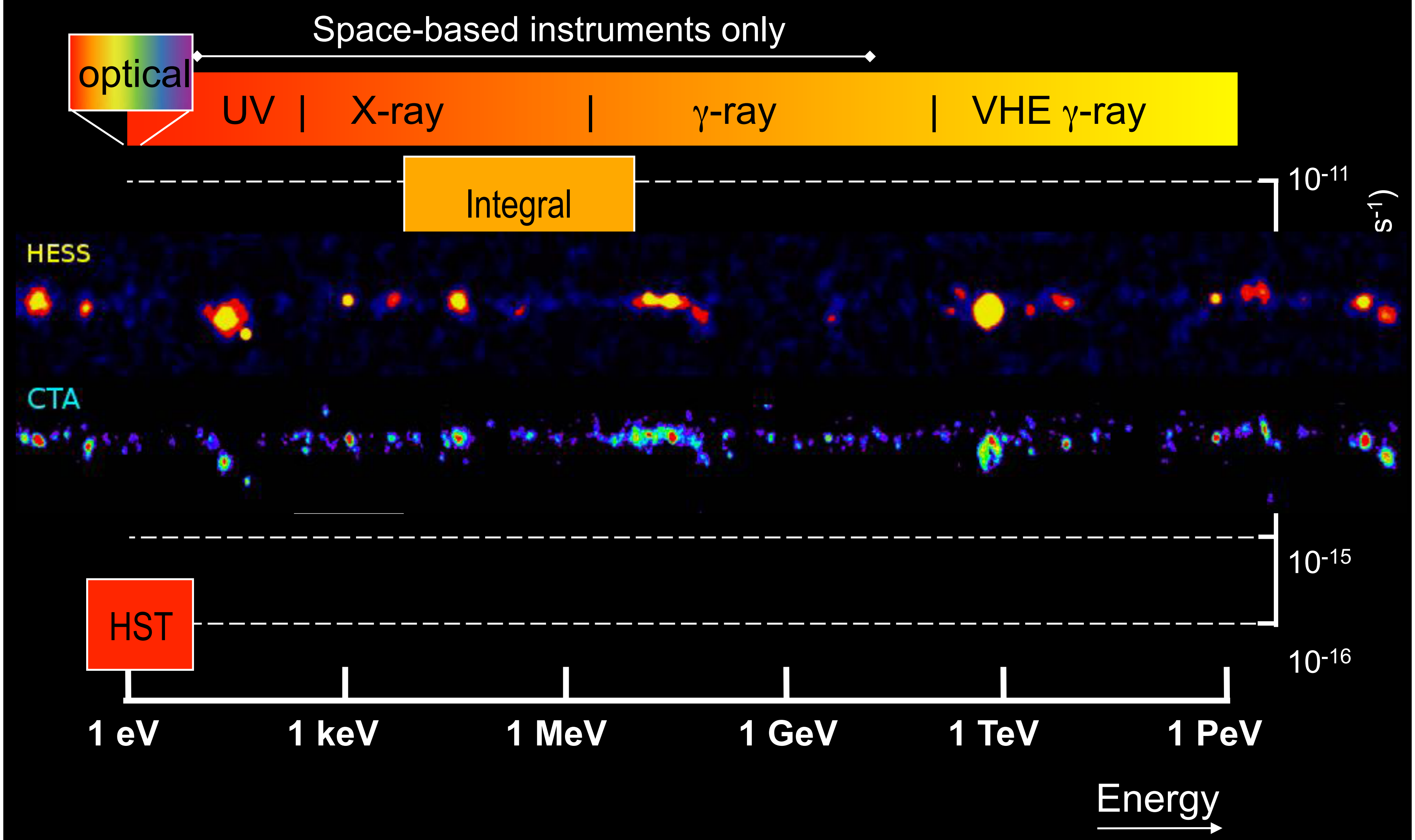
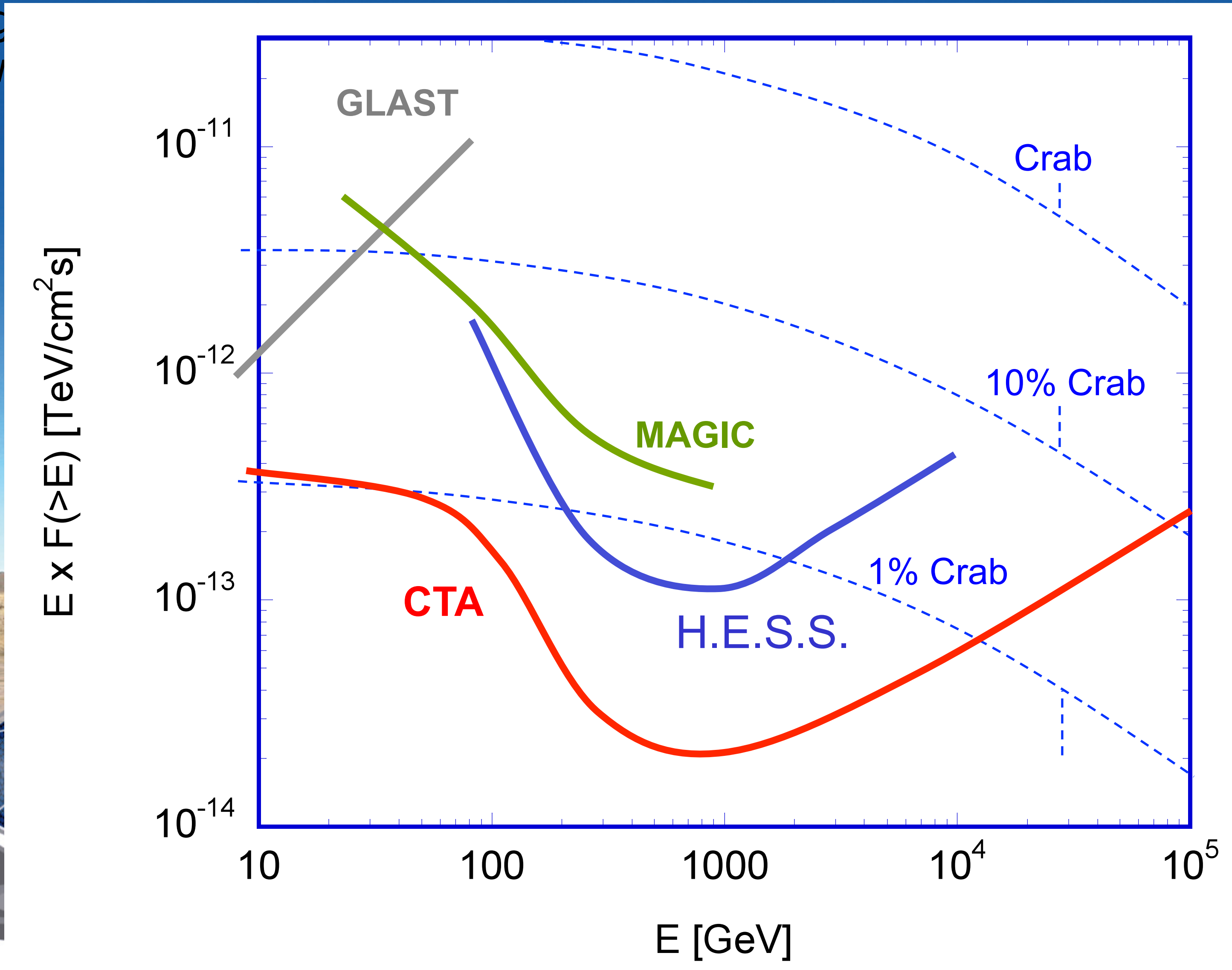


Low-energy section
energ
a few



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CTA Wish list

- **Higher Sensitivity at TeV energies (x10)**
  Deep Observations - > More Sources
- **Larger Detection Area**
  Greater Detection Rates - > Transient Phenomena
- **Better Angular Resolution (x2)**
  Improved morphology studies- > Structure of Extended Sources
- **Better Energy Resolution (x2)**
  - Studying AGN Spectral Hysteresis, Searching for Dark Matter
- **Lower Threshold (some 10 GeV)**
  Pulsars, distant AGN, source mechanisms
- **Higher Energy Reach (PeV and beyond)**
  Cutoff region of galactic accelerators
- **Wide Field of View**
  Extended Sources, Surveys

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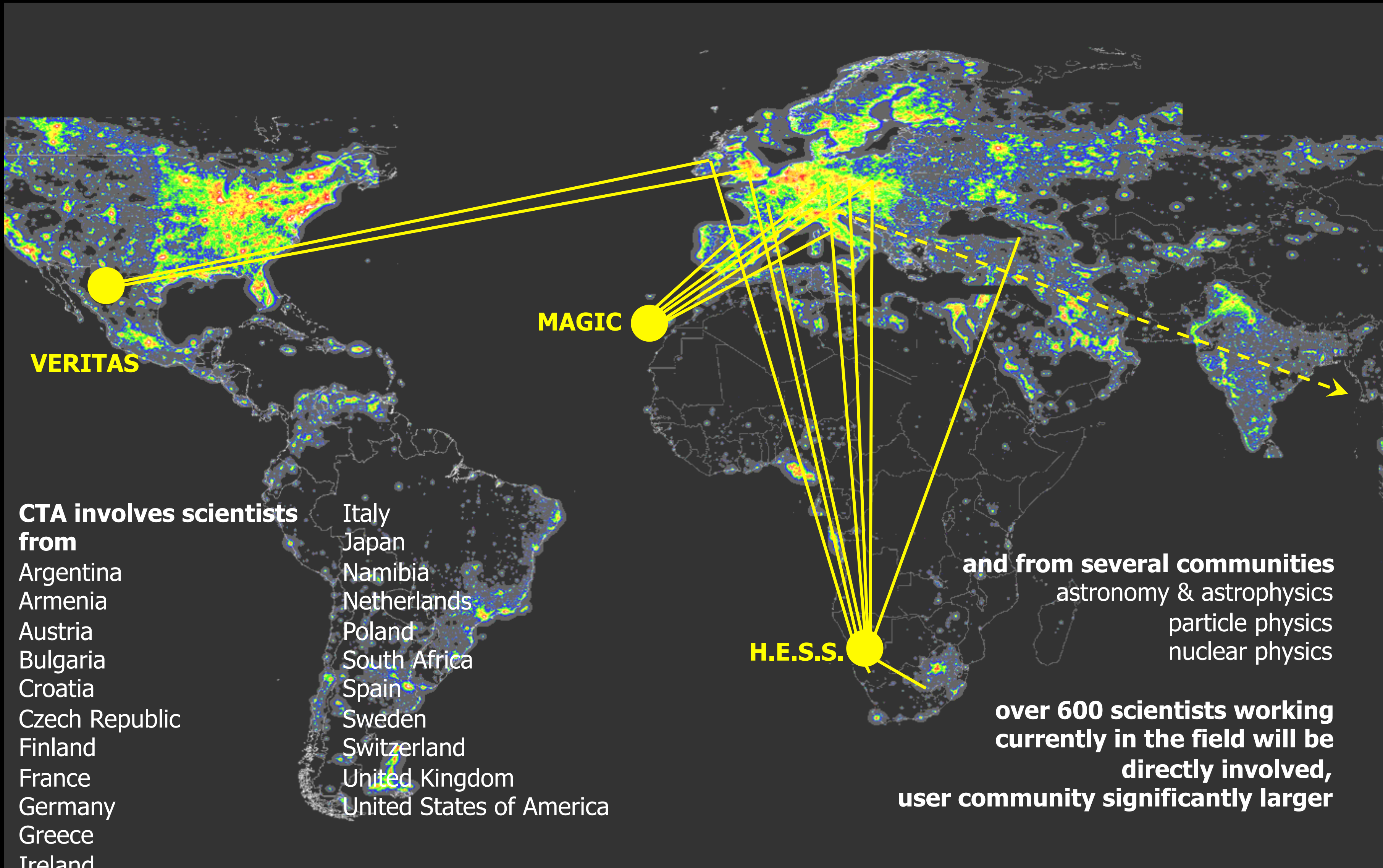
Worldwide Project



CTA involves scientists from

Argentina
Armenia
Austria
Bulgaria
Croatia
Czech Republic
Finland
France
Germany
Greece
Ireland
Italy
Japan
Namibia
Netherlands
Poland
South Africa
Spain
Sweden
Switzerland
United Kingdom
United States of America

and from several communities

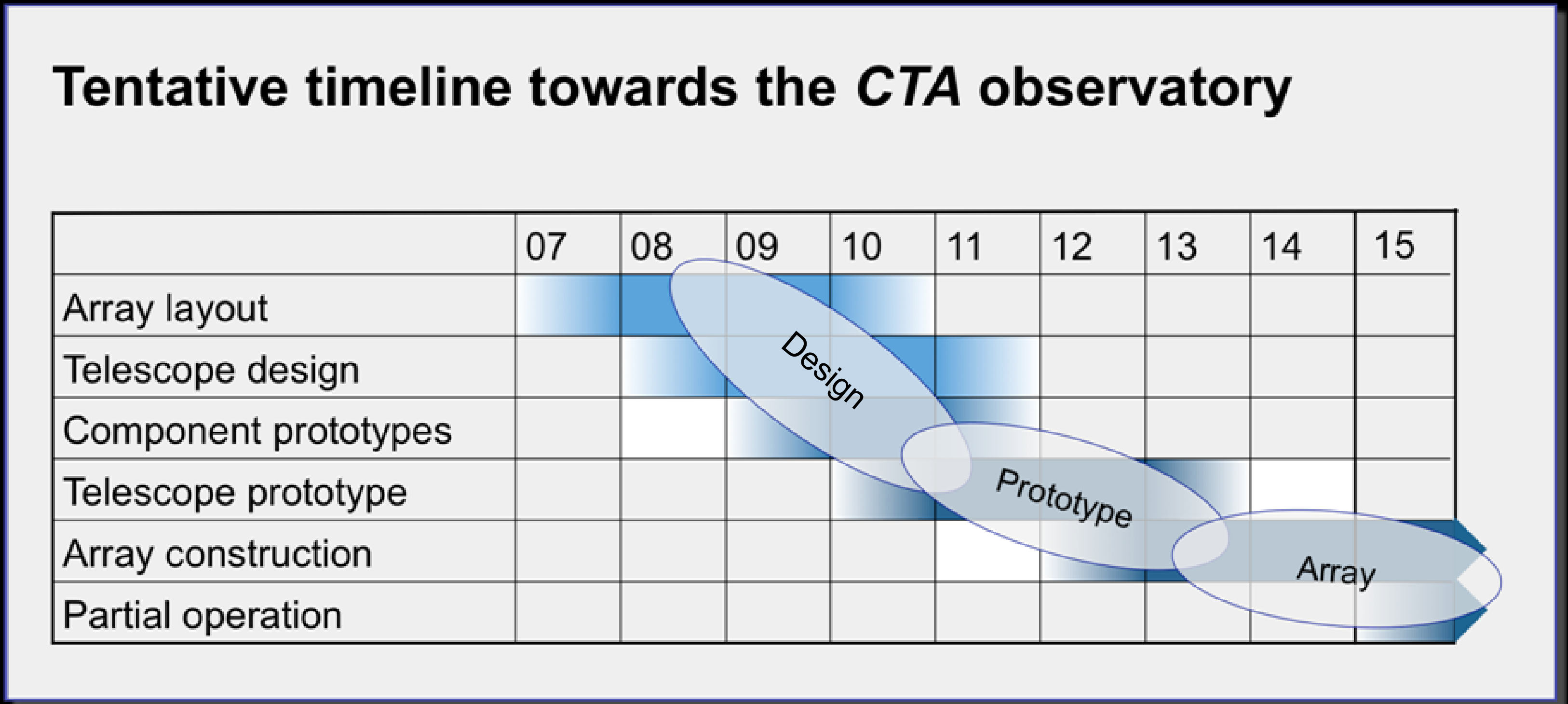
astronomy & astrophysics
particle physics
nuclear physics

over 600 scientists working currently in the field will be directly involved, user community significantly larger

Strong International Support

- **Project listed as priority in roadmaps in Europe**
  - ASTRONET (Astrophysics)
  - ASPERA (Astroparticles)
    - Targeted Design Study Common Call
    - €2.7M
  - ESFRI (European Strategic Forum for Research Infrastructures)
  - FP7 Preparatory Phase approved -> Up to €5.2M
- **And USA**
  - **"AGIS team should collaborate with European CTA team"** ***National Academic, Decadal Review, 2010***

Timeline



Tentative timeline towards the *CTA* observatory
07
08
09
10
11
12
13
14
15
Array layout
Telescope design
Component prototypes
Telescope prototype
Array construction
Partial operation
Design
Prototype
Array

Design Study
2007-2010
Preparatory Phase
2010-2013
Construction Phase
2013-2018
Now

Design Study Work Packages

WP1	Management of the design study
WP2	Astrophysics and astroparticle physics
WP3	Optimization of array layout, performance studies and analysis algorithms
WP4	Site selection and site infrastructure
WP5	Telescope optics and mirror
WP6	Telescope structure, drive, control
WP7	Photon detectors and focal plane
WP8	Readout electronics and trigger
WP9	Atmospheric monitoring and calibration
WP10	Observatory operation and access (TOC + SOC)
WP11	Data handling, data processing, data management and data access (SDC)
WP12	Risk assessment and quality assurance, production planning (?)

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Progress Since Prague

- **Previous Experience (HESS) has shown us that a good measurement of the atmospheric transmission profile allows**
  - Better Energy Resolution
  - Resurrection of otherwise unusable data
- **Detailed Simulation Studies of Atmospheric Effects on Imaging Cherenkov Telescope Arrays**
- **Design and Building of Several Raman Lidar Devices**
- **Study of HSRL as an alternative**

Talks of C Rulten & G Vasileiadis

Talks of A Lopez & G Vasileiadis

Talk of E Fokitis

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Simulation Studies

Two Classes of Problem for IACT's Addressed

- **Atmospheric Profile (density, thickness, refractive index) can change seasonally, so changing height of Cherenkov maximum and yield for a given shower. Derive quantities from (T,P,h) measured with Radiosondes.**
- **Aerosols**
  - High level (e.g. clouds) which can occur around shower-max and so affect Cherenkov yield & image shape etc.
  - Low Level (near to ground level) which lower the Cherenkov yield.
- **Aerosols measured with LIDARS**

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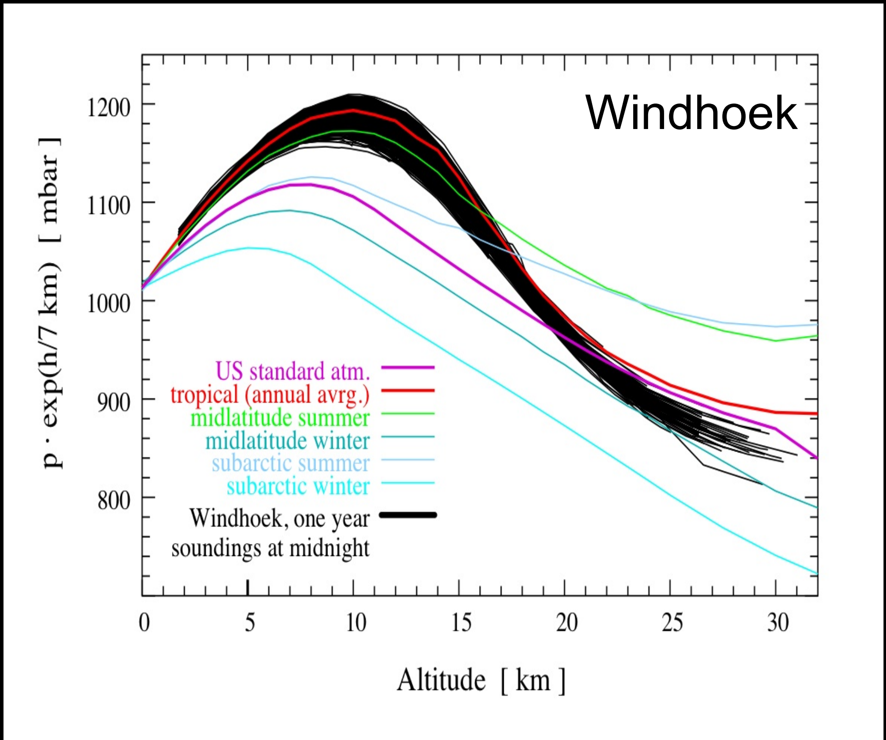
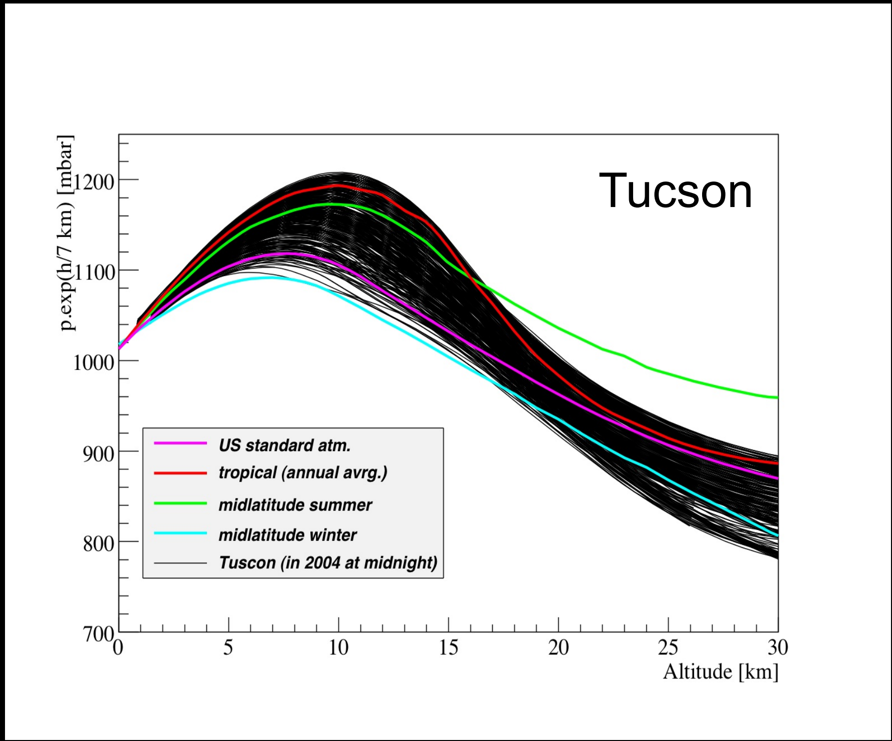
Should we fly Radiosondes ?

- Although every site suffers from aerosols scattering light, the seasonal stability of the atmospheric profile varies significantly from site to site.
- As a first order correction, we use database of radiosonde measurements available online.
- For Namibia, data taken at Windhoek (2007) and made available via BADC (British Atmospheric Data Centre)
- For Tucson, data taken at Tucson airport (2007) and made available via BADC
- The nearest base to La Palma is Tenerife

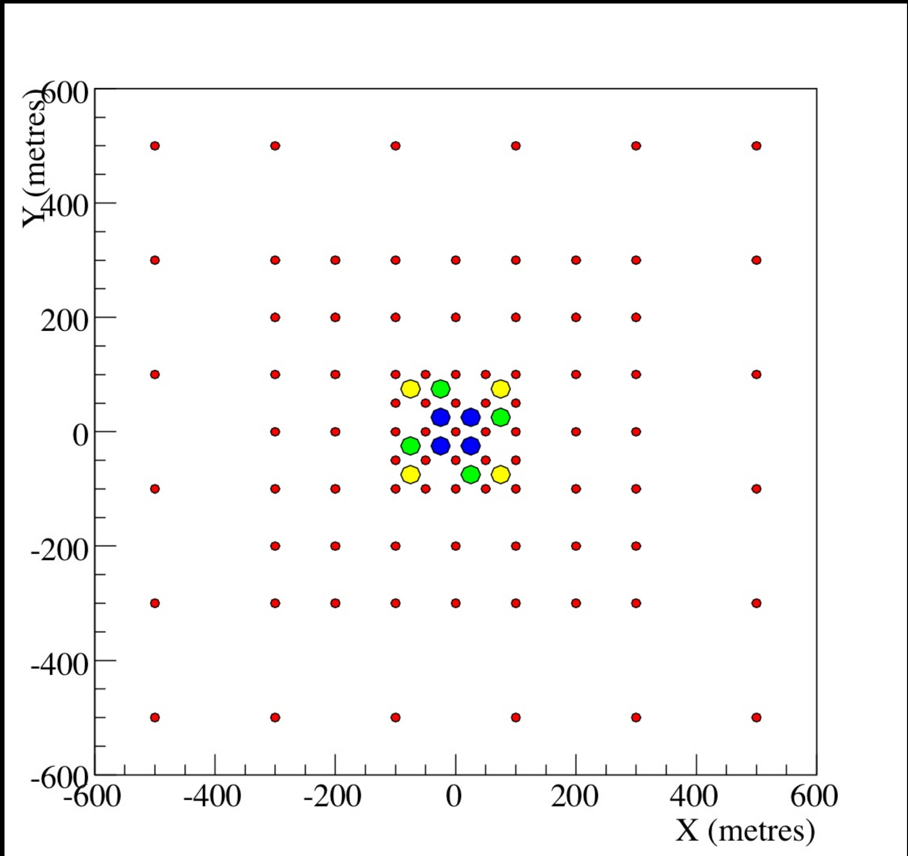
Comparing Sites of Current Experiments





- The seasonal variation in atmospheric profile at Windhoek is much smaller than that at Tucson (or Tenerife).
- The Windhoek atmosphere is quite close to the tropical model, whilst that in Tucson varies seasonally between the tropical and mid-latitude winter models.

Test Array



- 12 600m^2 telescopes
- 85 100m^2 telescopes
- 40% larger FOV & 50% Higher Q.E (than H.E.S.S.)

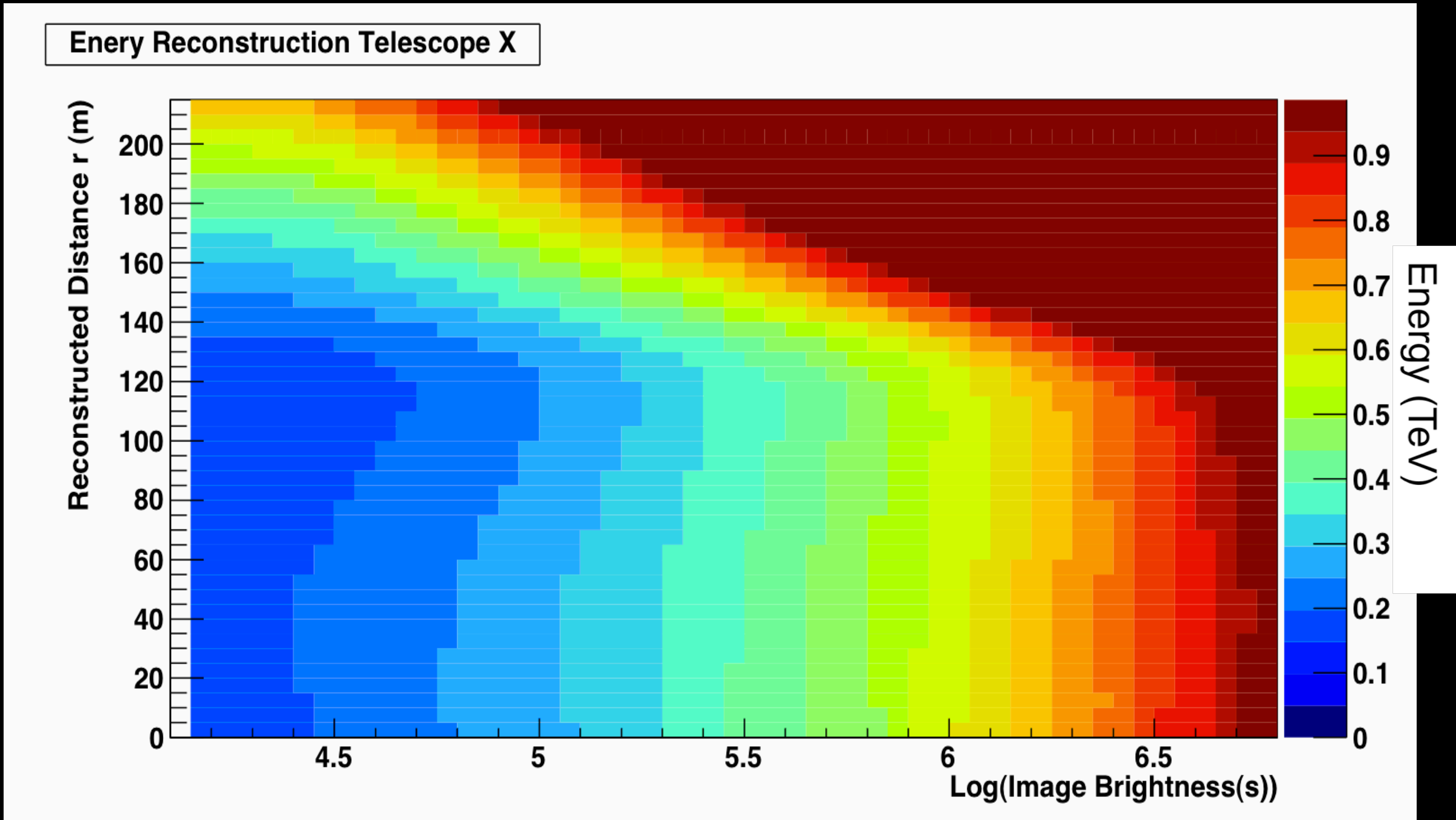
Test Array Analysis

- **Analysis followed current methods adopted by all existing telescopes**
- **To form an array trigger we require:**
  - >=5 Telescope Trigger
  - >= 10 Tubes in an Image Cut
  - Background removed by image shape cuts.
  - Form lookup table for energy and reconstructed effective area.
- **Definitely sub-optimal for lower energy events.**
- **For this study only comparison between response under different atmospheric conditions is important.**

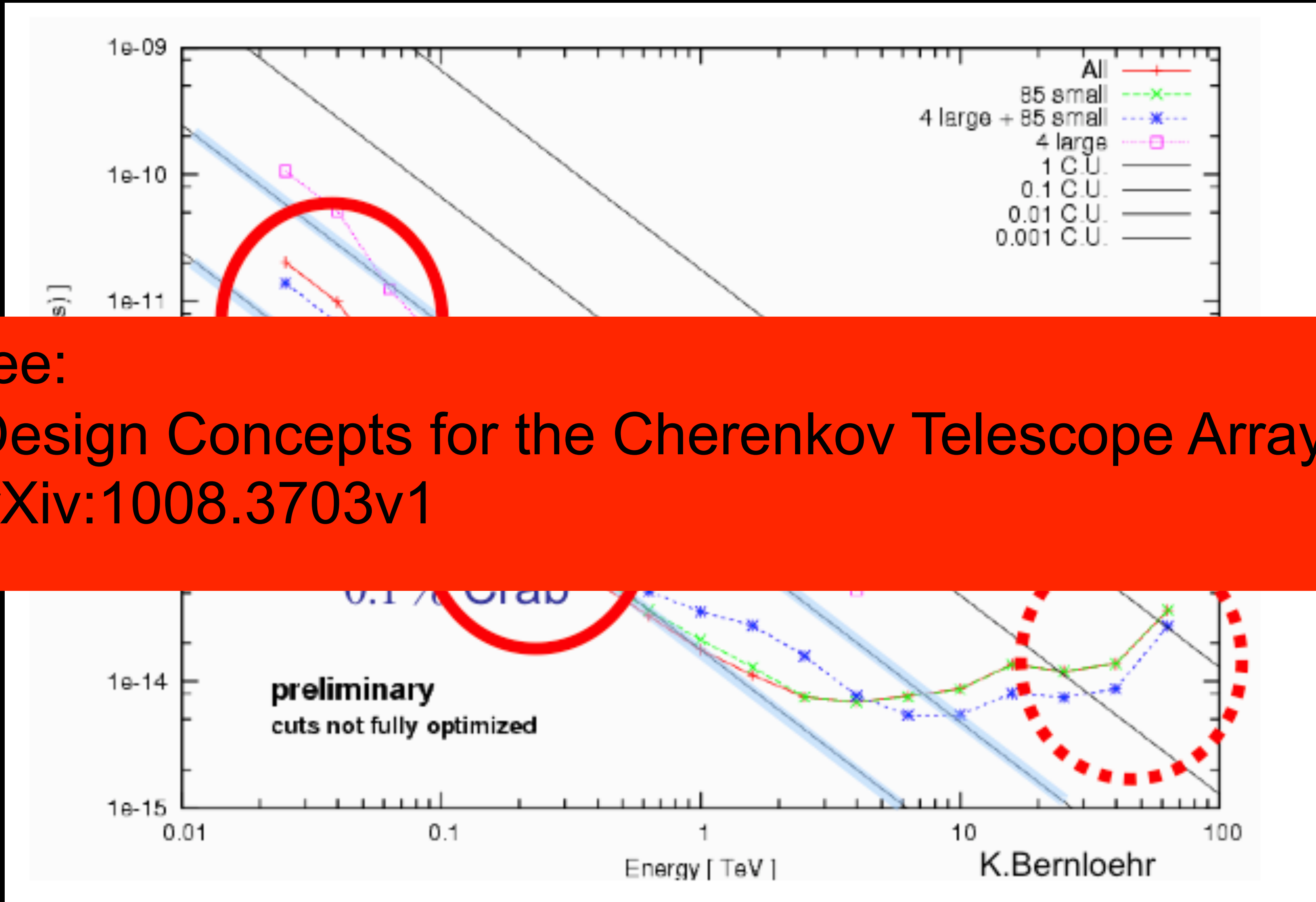
Simulations Database

- **Very limited so far (CORSIKA & SIM_TELARRAY)**
  - 20 deg ZA
  - From 5 GeV to 20 TeV with -2.0 differential slope.
  - 5 Million Gamma Showers (poor statistics at > 1 TeV).
- **Need to simulate:**
  - More showers
  - Different ZA
  - Background
  - North & South for Geomagnetic effects.
- **Fake Spectrum**
  - Sampling from an $E^{-2.3}$ spectrum of 100,000 simulated triggers
  - Using lookups derived from a tropical atmospheric profile.
  - Everything else is fixed.

Energy Calculation



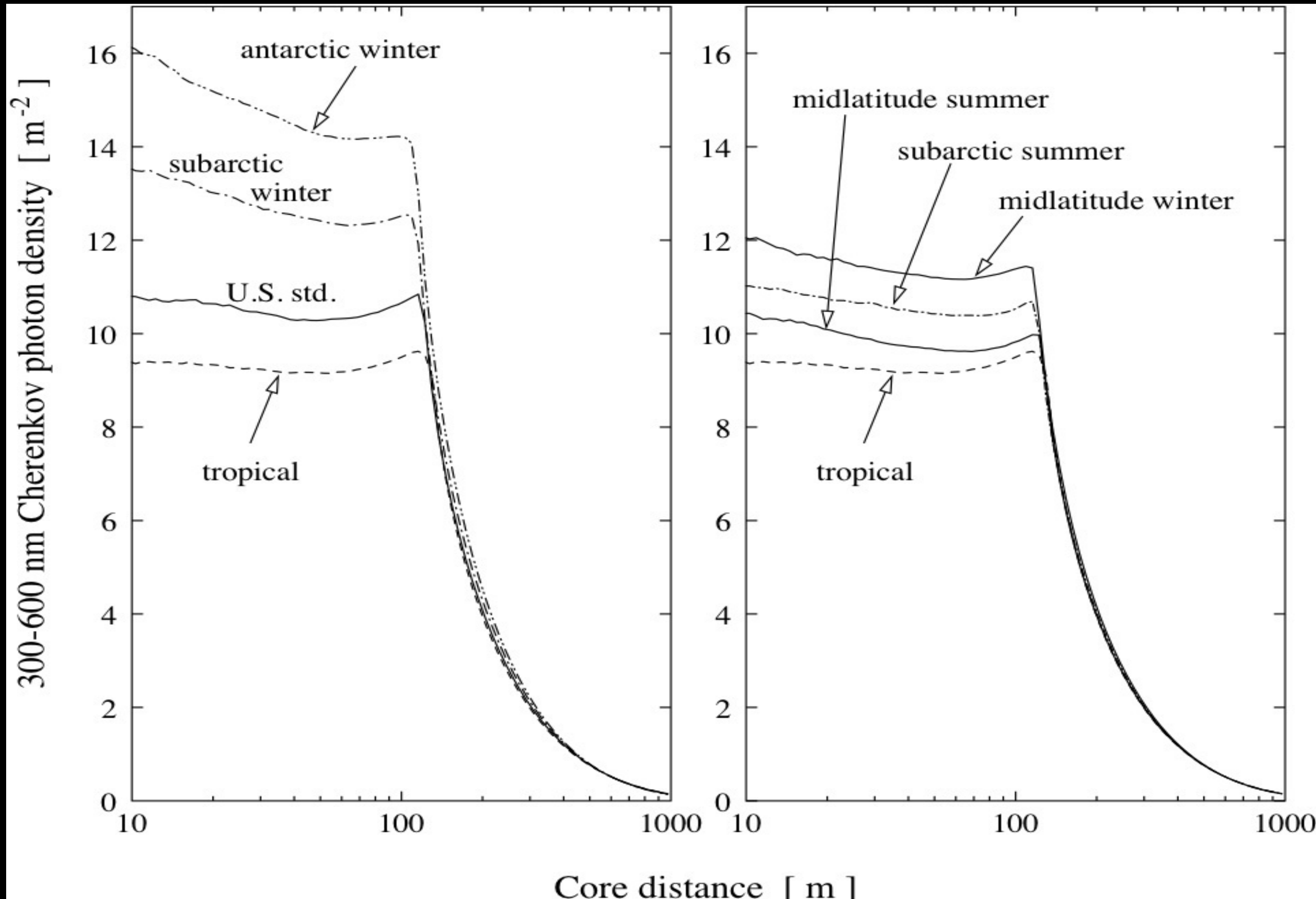
Sensitivity



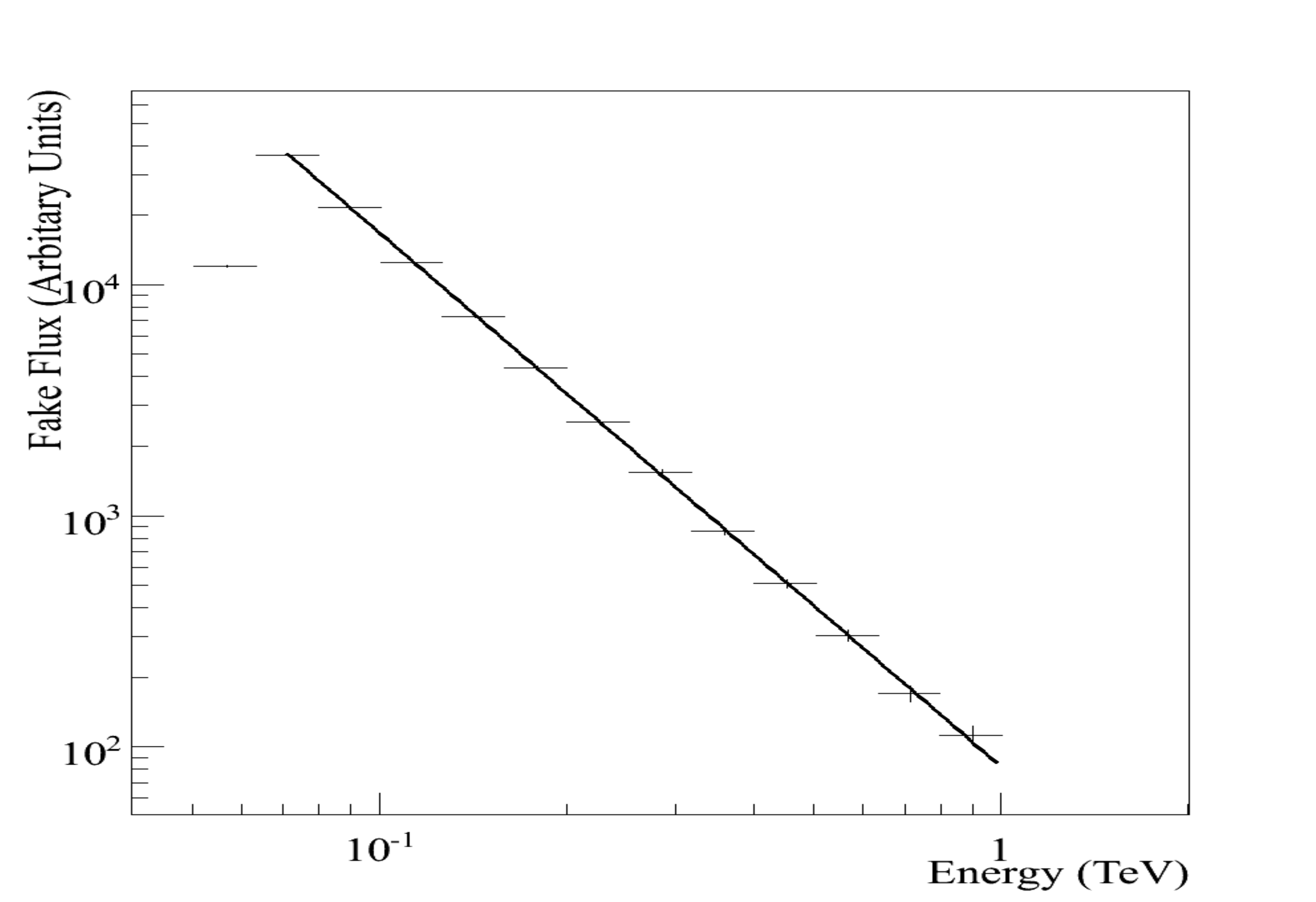
See:
“Design Concepts for the Cherenkov Telescope Array”
arXiv:1008.3703v1

What might we expect to happen ?

- For tropical atmospheric profile, the first interaction height and shower max are higher than for mid-latitude winter model.
- For a shower of a given energy and impact parameter, there is therefore a higher Cherenkov yield in the mid-latitude winter model.
- If at the site there is a seasonal dependence varying from mid-latitude winter to tropical, there will be a systematic shift in energy reconstruction if not accounted for.

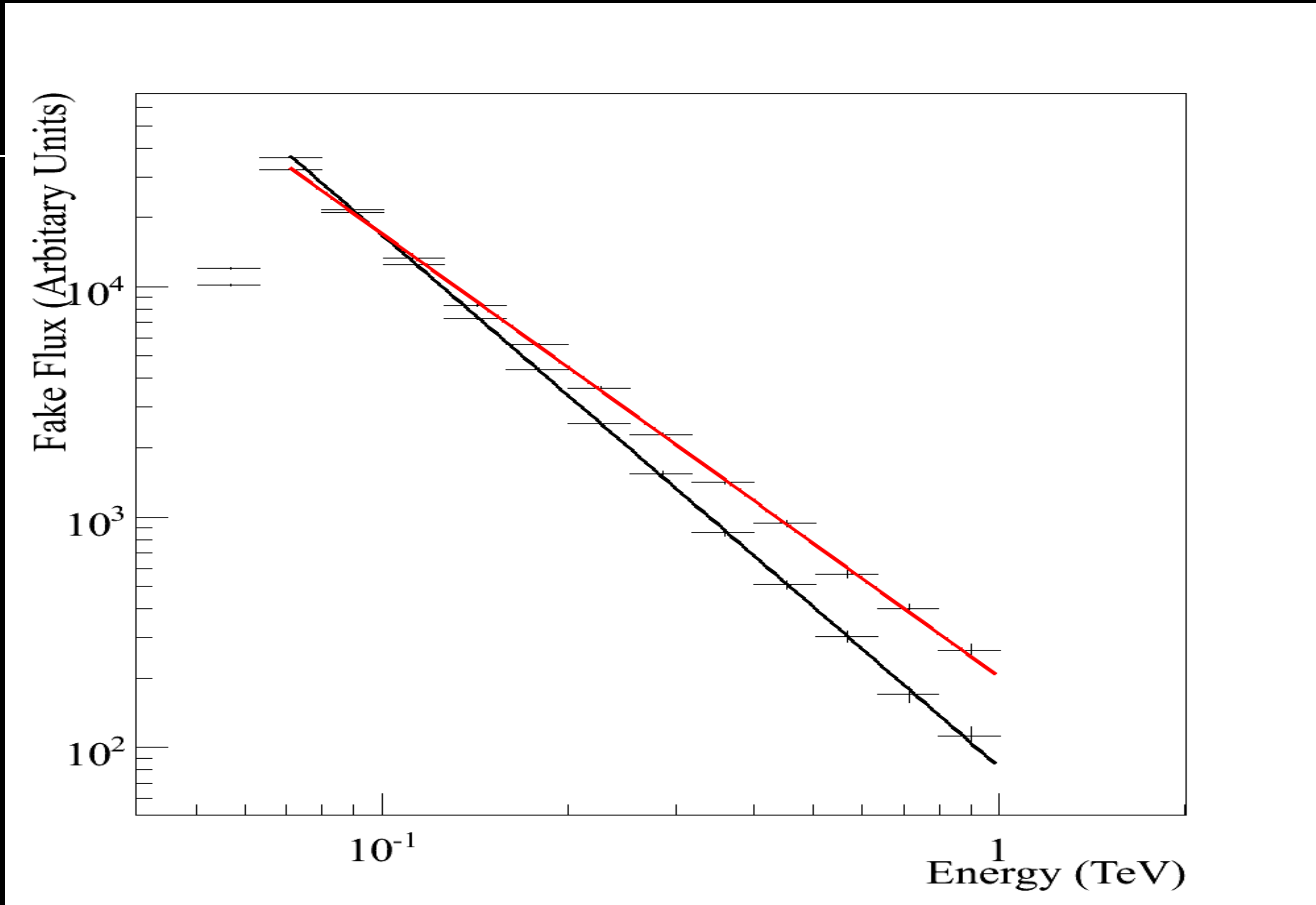


Taken from Bernlöhr K, *Astropart. Phys.*, **12**, 255, (2000)



Lookup Table : Tropical Simulations: Tropical

Normalization: 0.07 Slope: 2.31



Lookup Table : Tropical

Simulations: Mid Latitude Winter

Normalization: 0.2

Slope: 1.93

Result – Atmospheric Profile Studies

- **For mid-latitude site, without correction, get seasonal effect which moving from tropical to mid-latitude winter**
  - Increases the Cherenkov Photon Yield from a shower of a given energy
  - If uncorrected for this event looks brighter and is reconstructed as having a higher energy
  - Leads to an artificial hardening of spectrum
- **Under investigation by all current IACTs**
- **Microwave Radiometer ?**

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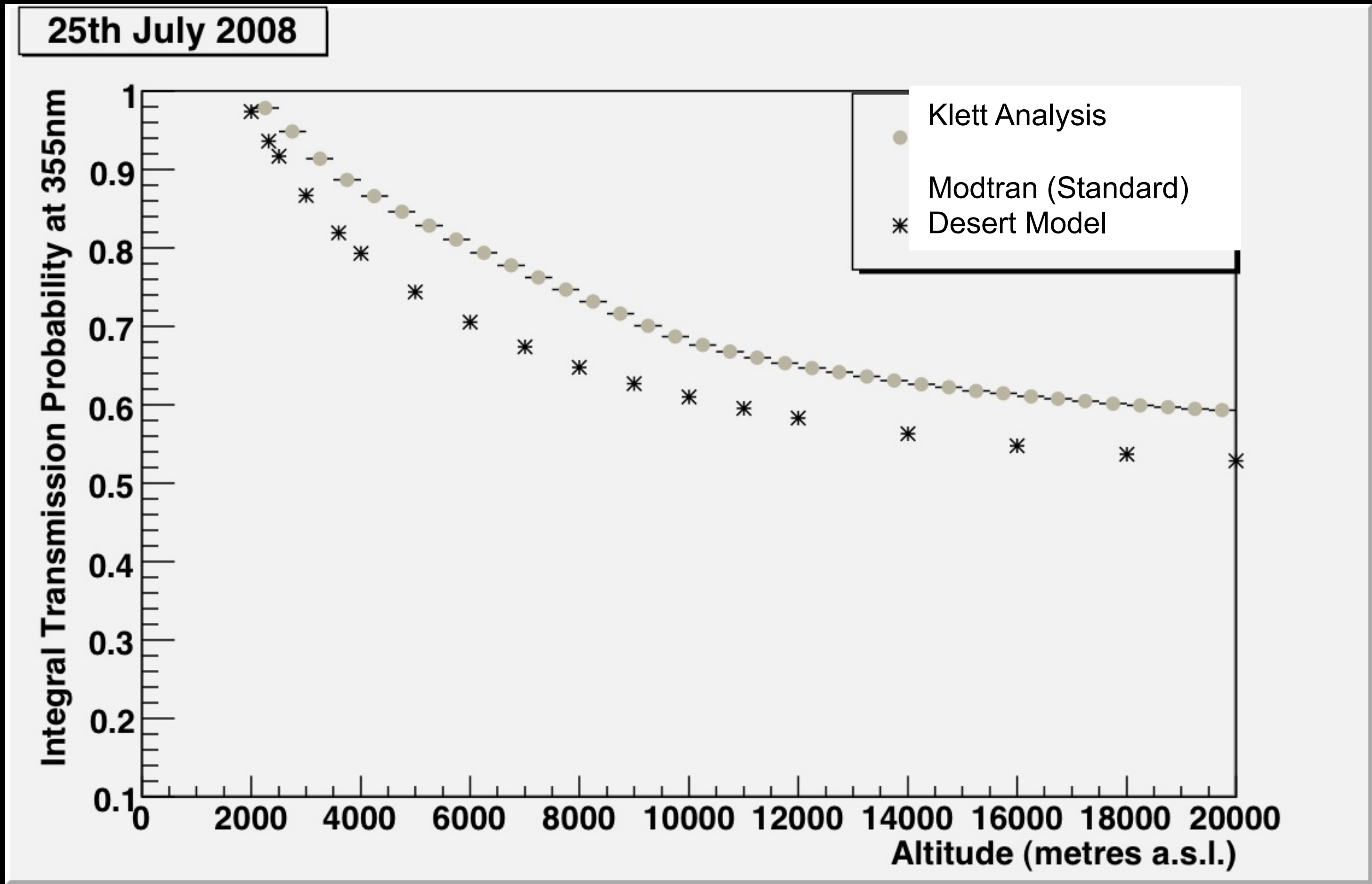
Tests Done on Namibian LIDAR

- **Wavelength:** 355nm
- **Frequency:** 10Hz
- **Pulse Width:** 5ns
- **Energy/Pulse** 20 mJ
- **Range:** 50m to 15km
- **Resolution:** 1.5m
- **Run By:** Durham

What might we expect to happen ?

- Low-level aerosols reduce the Cherenkov yield from a shower of a given energy and impact parameter.
- Thus without correction, they soften spectra, by moving reconstructed events artificially to lower energies.
- Measure aerosol properties using LIDAR

Namibian Lidar Results



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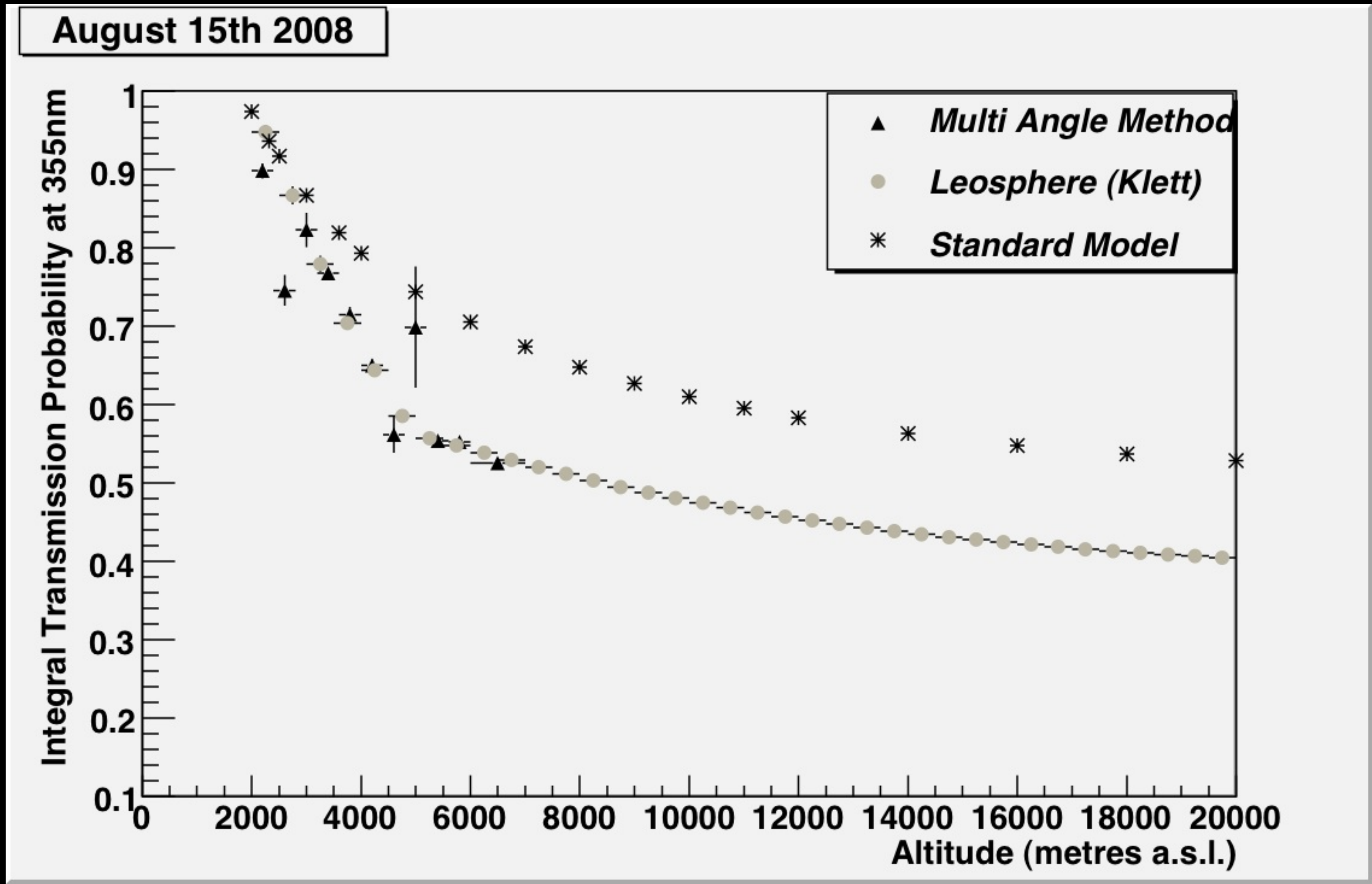
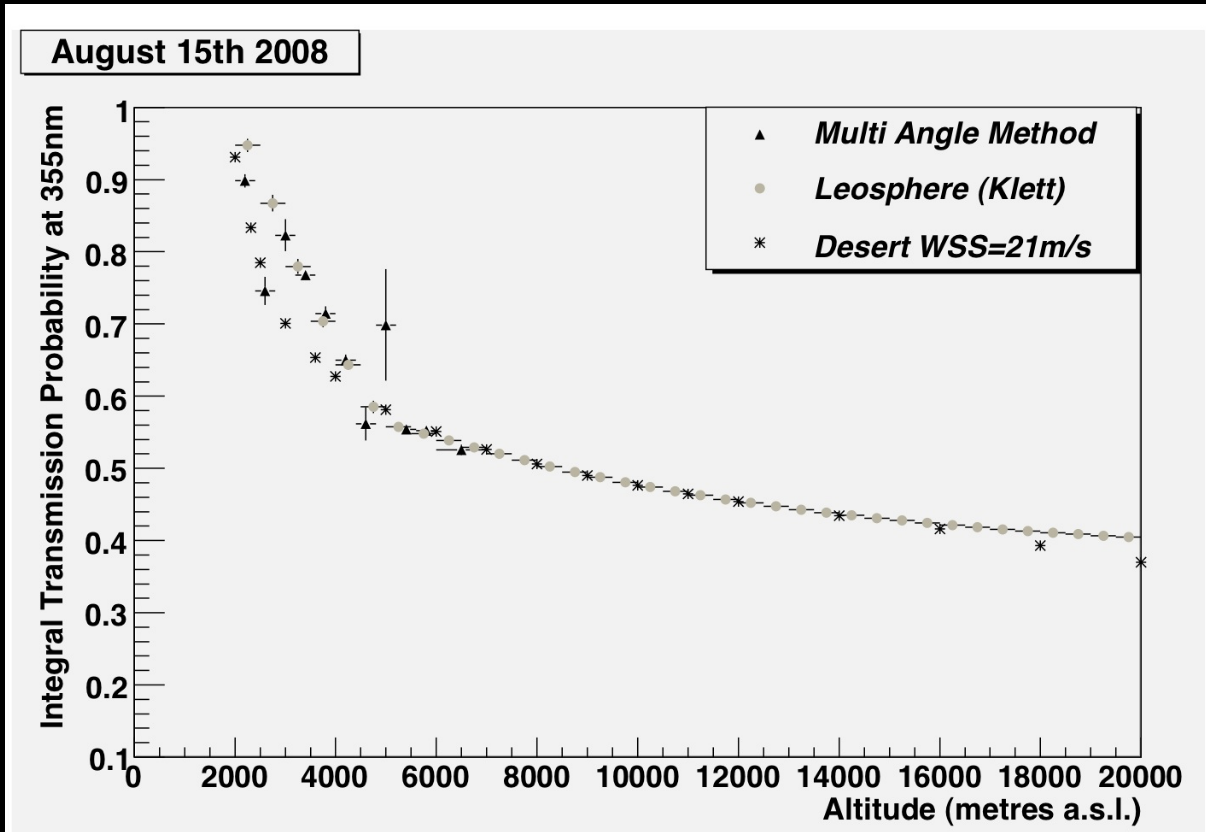


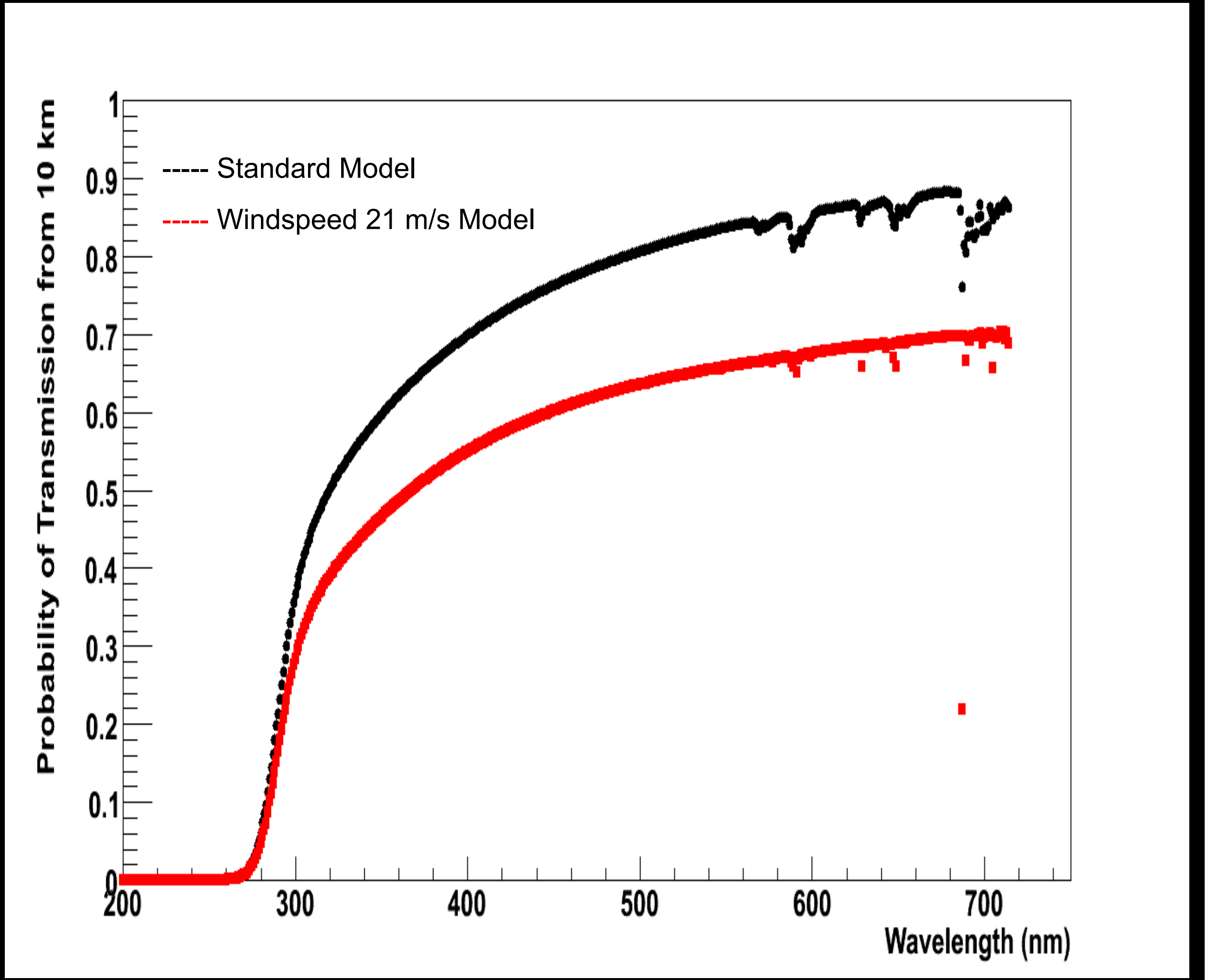
Using LIDAR data

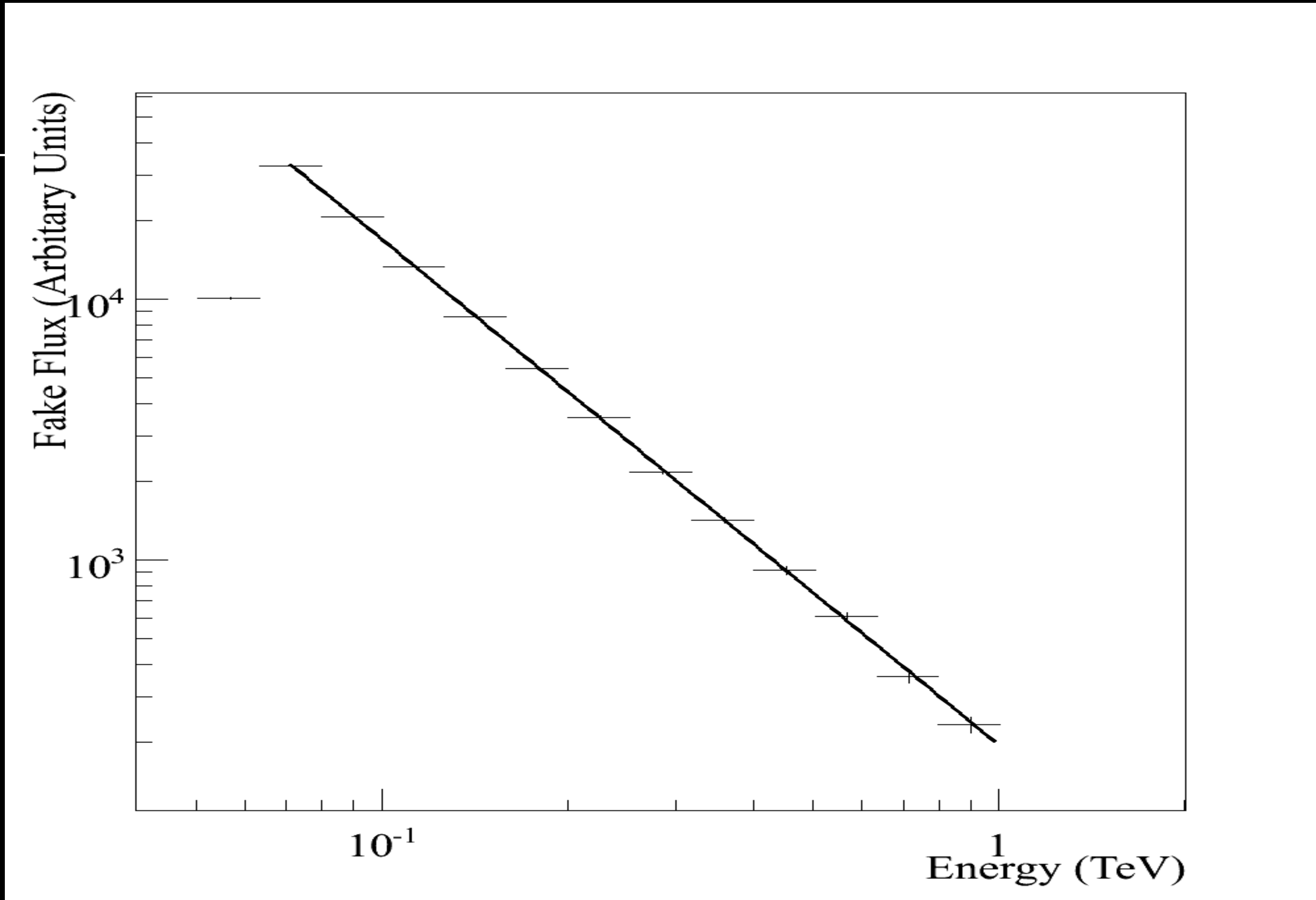
- **Single wavelength transmission versus altitude is fit with a MODTRAN model.**



Using LIDAR data

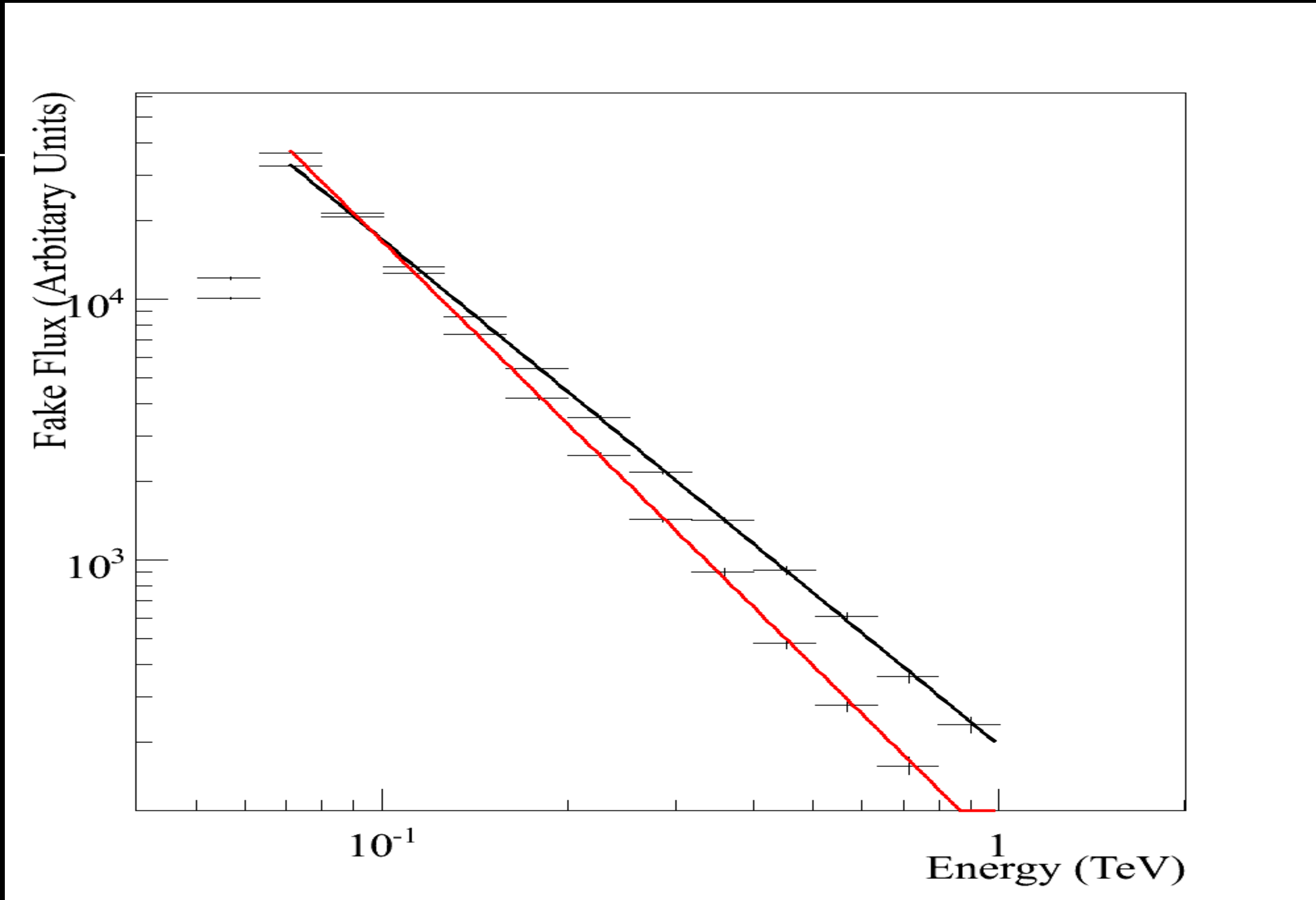
- **Here transmission from 10km versus wavelength shown for fit model and standard model.**





Lookup Table : Standard Simulations: Standard

Normalization: 0.2 Slope: 1.93

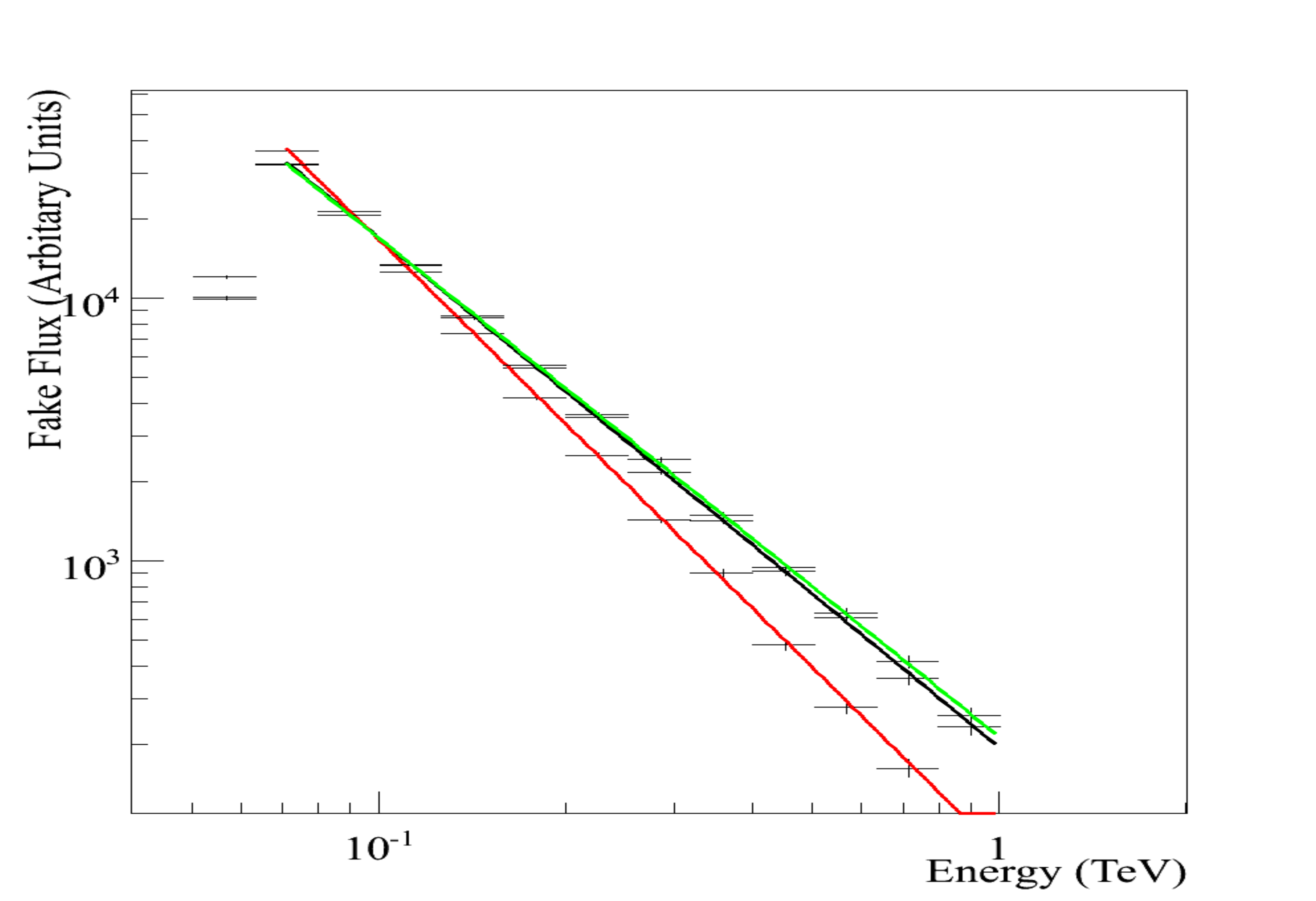


Lookup Table : Standard

Simulations: Lidar Dusty

Normalization: 0.1

Slope: 2.33



Lookup Table : Lidar Dusty Simulations: Lidar Dusty

Normalization: 0.18 Slope: 1.91

Result – Transmission Studies

- **For very dusty conditions, without data correction**
  - Images of a given energy have less light than under clear conditions
  - If this effect is ignored, events are reconstructed to have a much lower energy than their true energy
  - This leads to artificial softening of reconstructed spectra.
- **By a precise measurement of the transmission profile and through incorporation with simulation, otherwise unusable data may be resurrected.**
- **Under investigation by all current IACTs and CTA.**

Conclusions & Future Work

- **To further develop simulation studies using:**
  - More likely CTA designs
  - more realistic reconstruction algorithms, e.g.
    - Neural Nets for Background Supression
    - Minimisation Routines for Shower Reconstruction
- **To use data from soon to be deployed Raman Lidar to simulate real CTA response**
- **To use data from BADC then in field apparatus to study potential real site atmospheric variability effects**