Influence of atmospheric transmission on data taken by Cherenkov telescopes

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Belgrade, 2 Sept 2022

MAGIC
Major Atmospheric Gamma Imaging Cerenkov Telescope

cta
cherenkov telescope array

FACULTY OF PHYSICS
UNIVERSITY OF RIJEKA

Outline

- Motivation
- Imaging Atmospheric Cherenkov Telescopes (IACTs)
- Atmosphere and LIDAR
- Adaptive observation scheduling
- Recent results (MAGIC and CTA)
- Applications

Motivation

- For Lorentz Invariance Violation (LIV) studies, precise mesurements of photon energies are crucial, especially at Very High Energies (VHE)
- The atmosphere is not just an obstacle on the way, like for optical telescopes, but an active part of the detector generating Cherenkov light in case of IACTs
- Reduced atmospheric transmission by clouds, dust and aerosols accounts for up to 40% systematic uncertanities of IACTs
- Theorists, modelers and experimentalists should properly understand data and results from IACTs

See the talk by **Markus Gaug**
from our kick-off workshop (Barcelona 2019)
„Atmospheric Calibration of Cherenkov Telescopes“
(and their relationship with time-of-flight studies to constrain LIV)

Imaging Atmospheric Cherenkov Telescopes

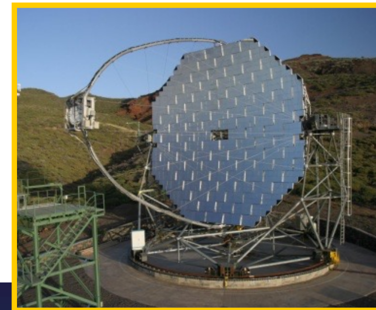
- MAGIC (Major Atmospheric Gamma Imaging Cherenkov telescopes)
- H.E.S.S. (High Energy Stereoscopic System)
- VERITAS (Very Energetic Radiation Imaging Telescope Array System)
- CTA (Cherenkov Telescope Array)

MAGIC I and II

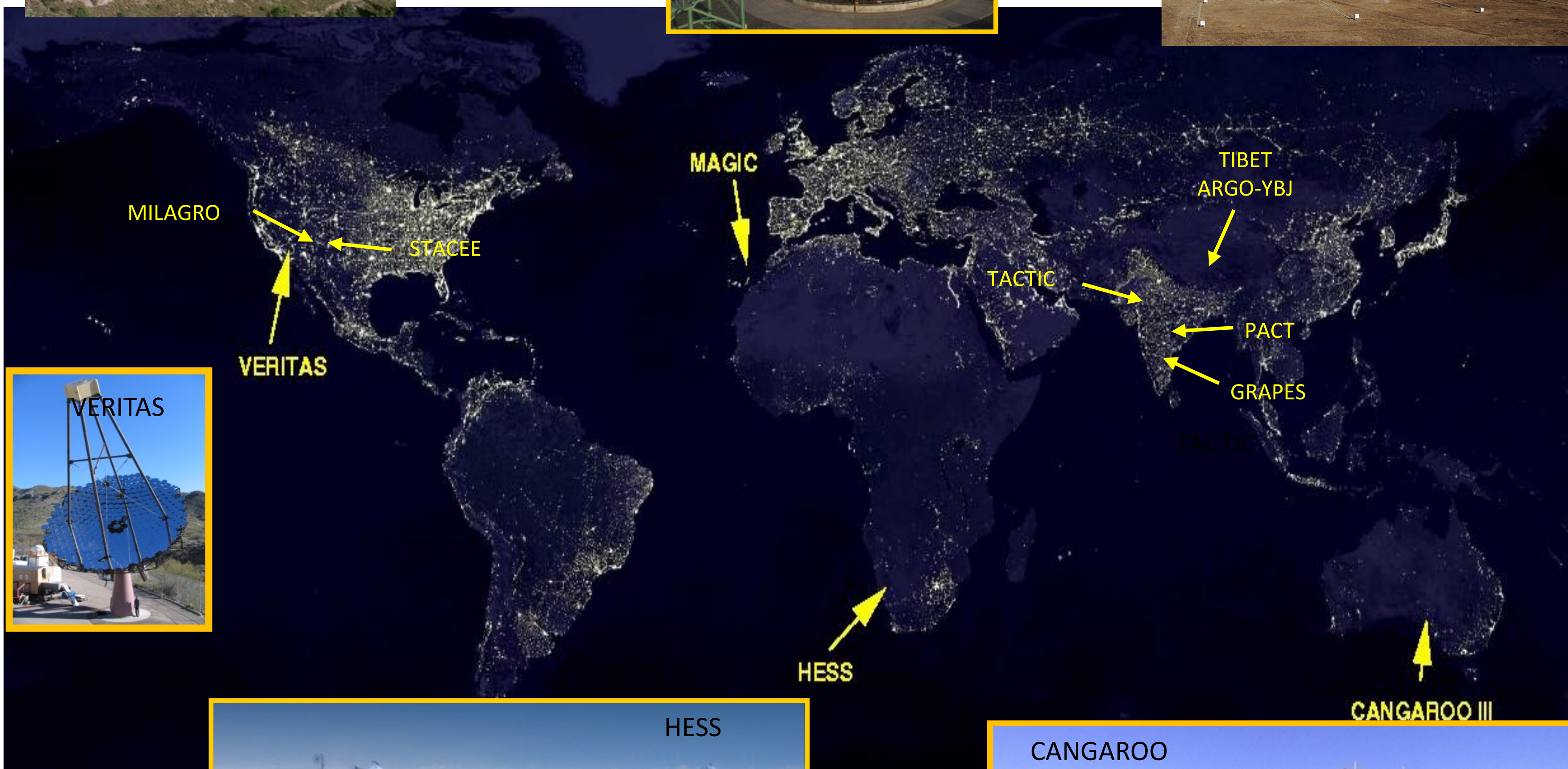
LST-1 (CTA)

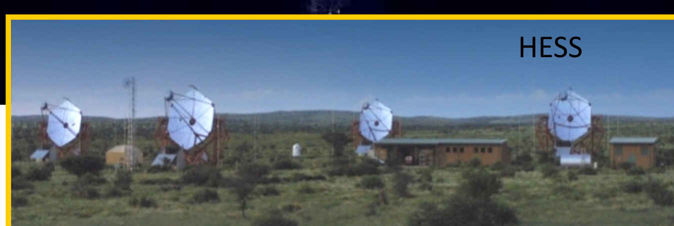
MILAGRO

MAGIC

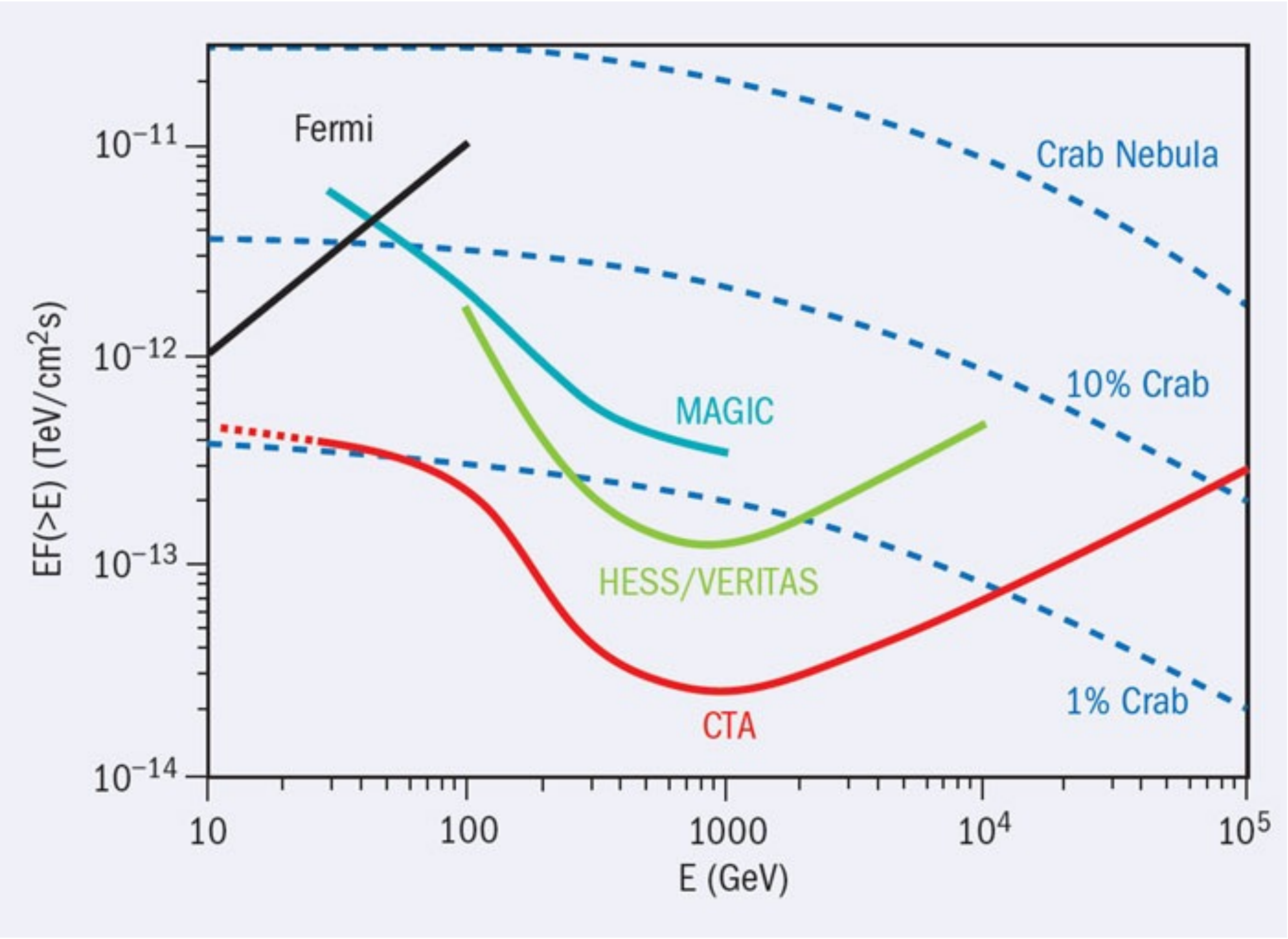


TIBET



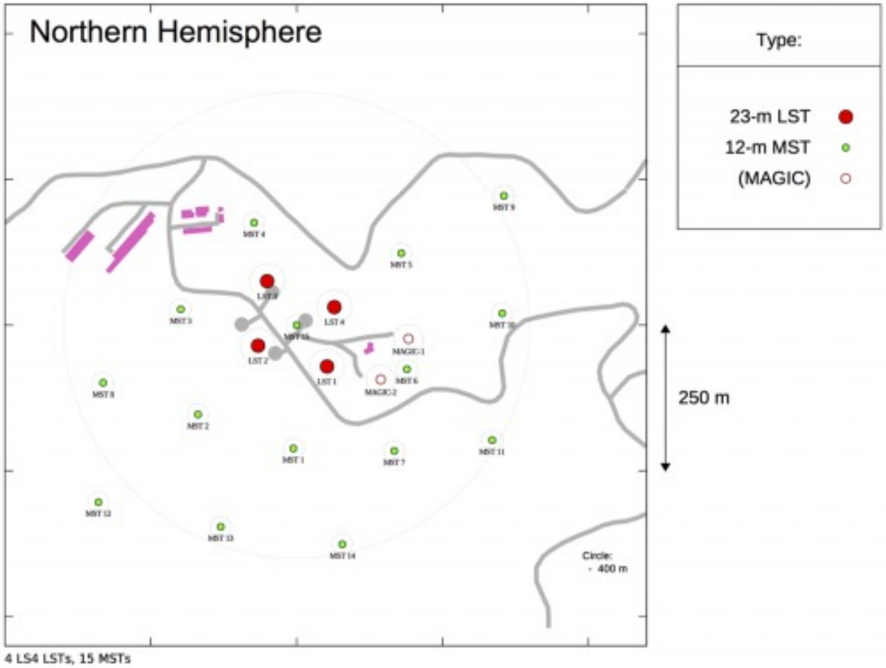


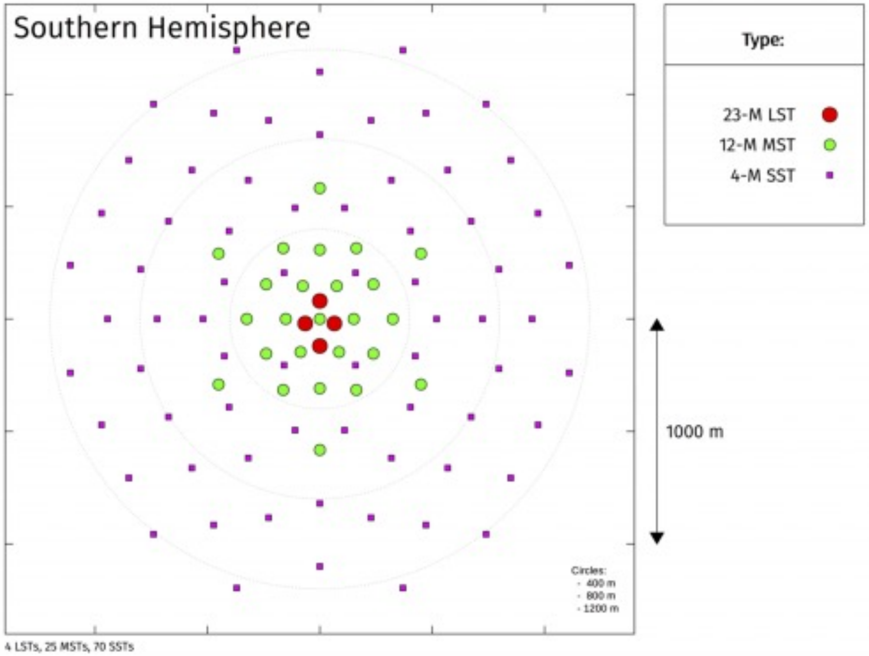
Sensitivity of current gamma-ray telescopes



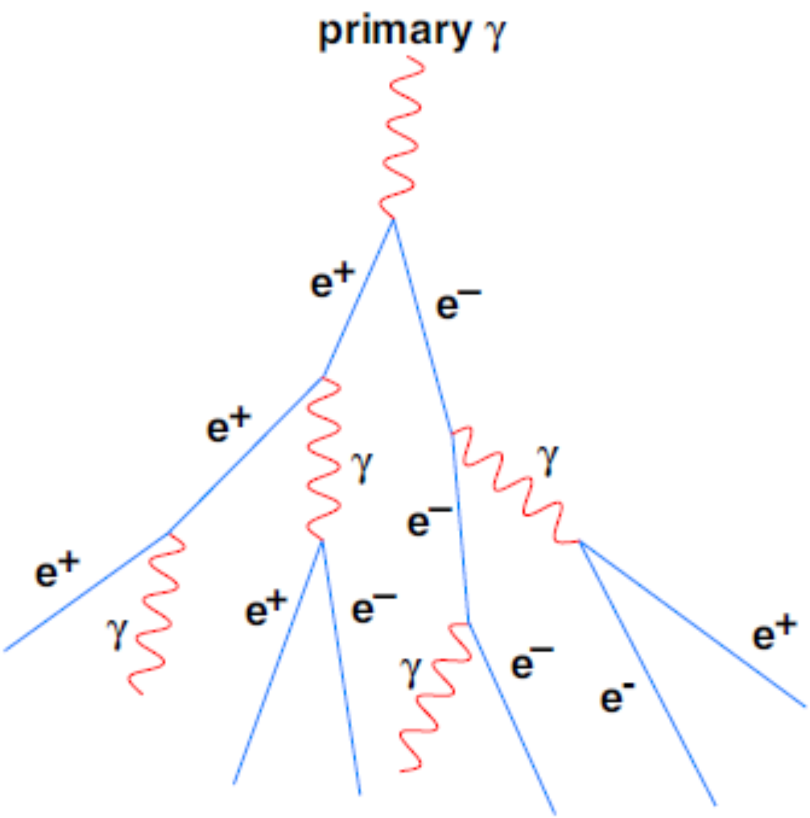
Observatorio del Roque de los Muchachos (European Northern Observatory)

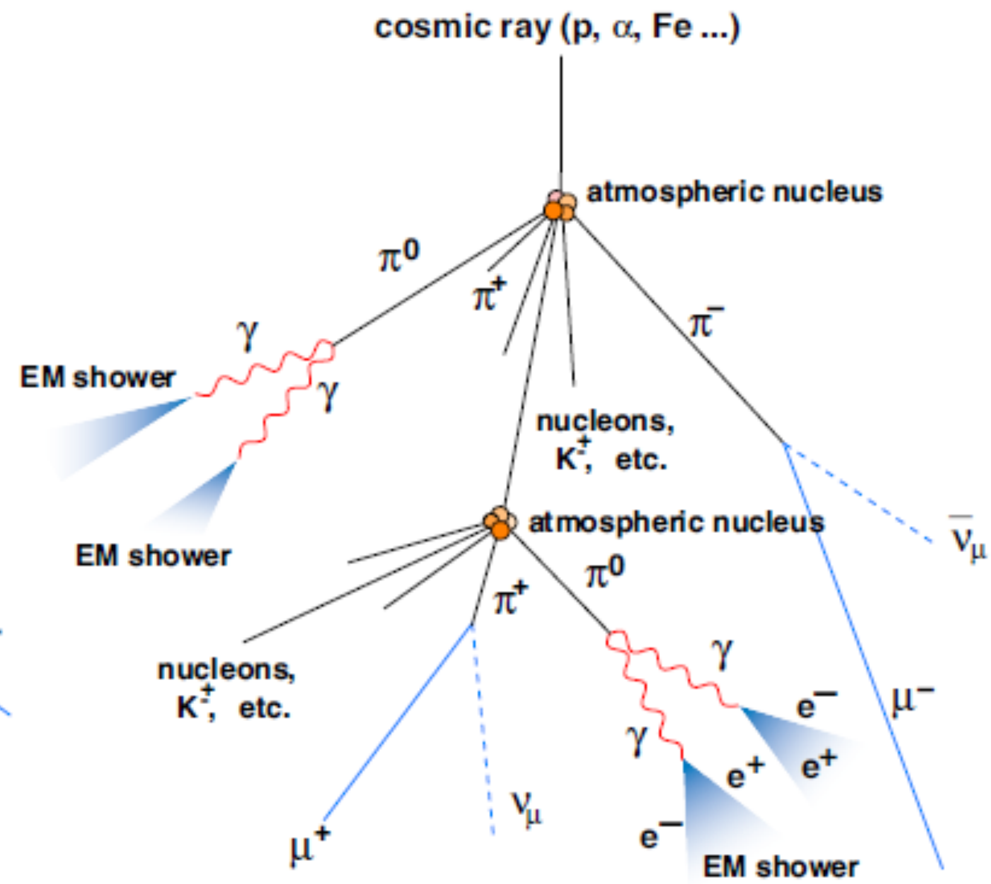
La Palma, Canary islands
2200 m a.s.l.


Northern Hemisphere
Type:
23-m LST
12-m MST
(MAGIC)
250 m
Circle:
400 m
4 LS4 LSTs, 15 MSTs


Southern Hemisphere
Type:
23-M LST
12-M MST
4-M SST
1000 m
Circles:
400 m
800 m
1200 m
4 LSTs, 25 MSTs, 70 SSTs

Electromagnetic shower vs. Hadron shower





Detection of atmospheric Cherenkov light

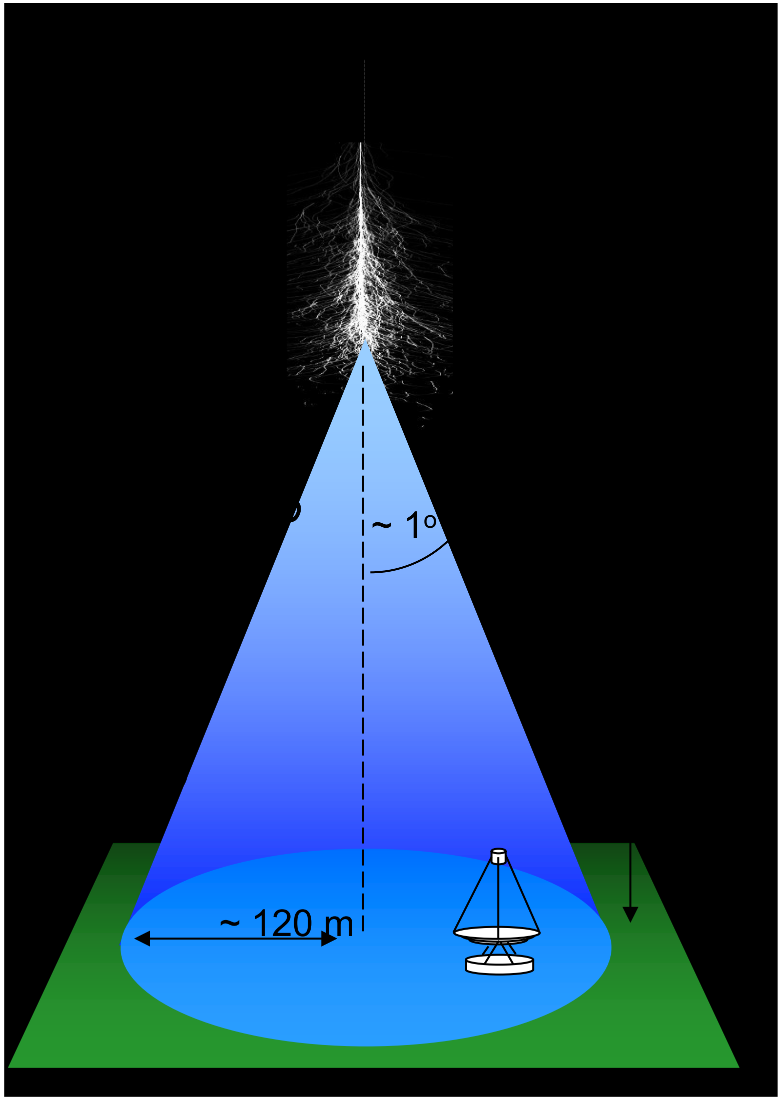
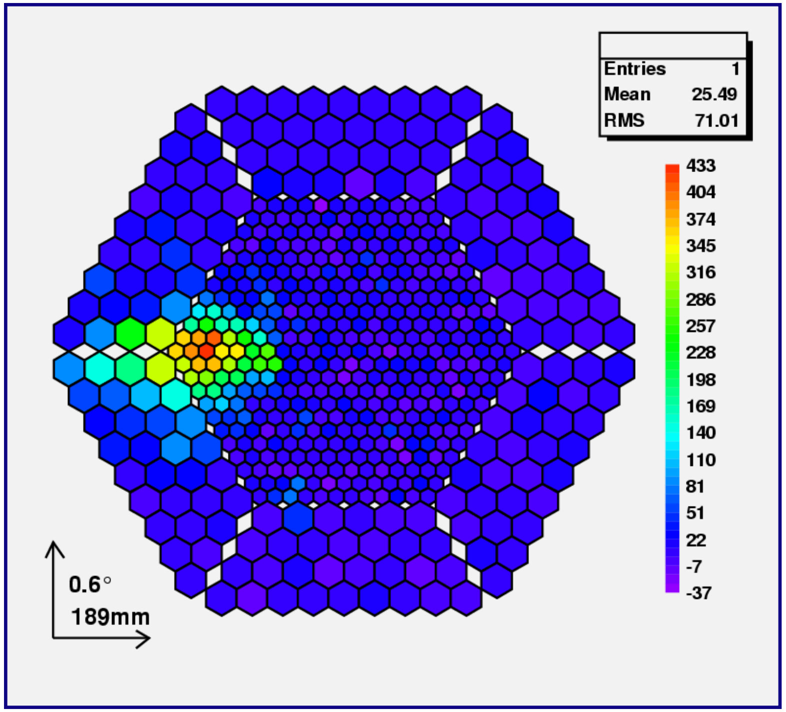
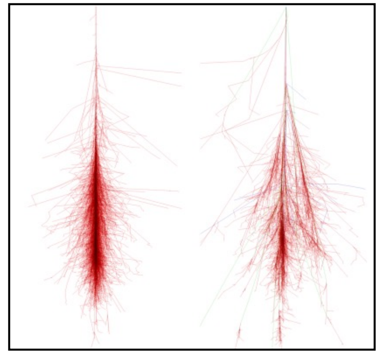
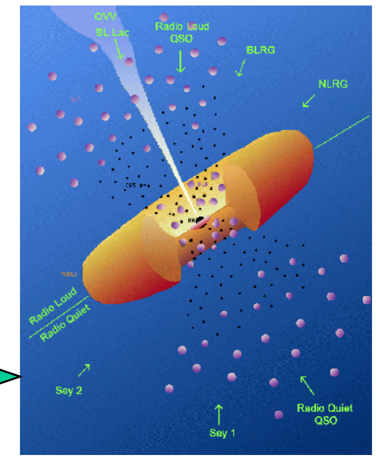


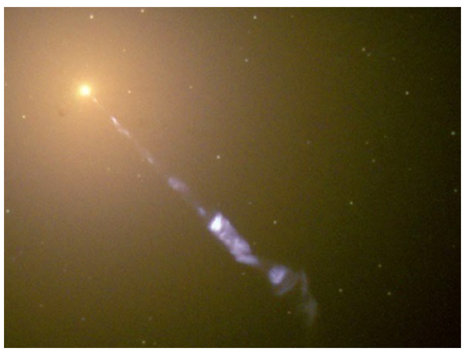
Image in the MAGIC I telescope camera:

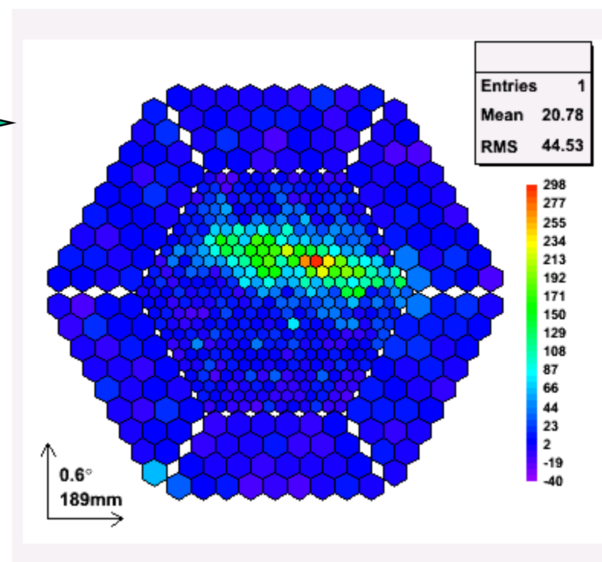


From observations to theory



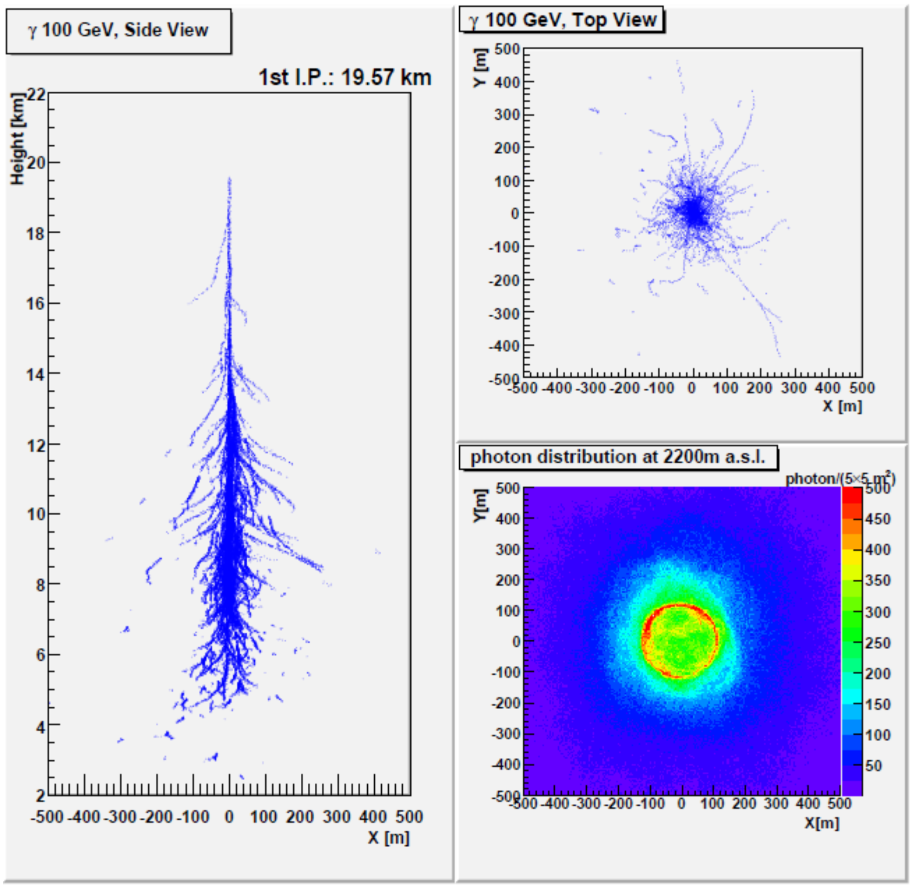




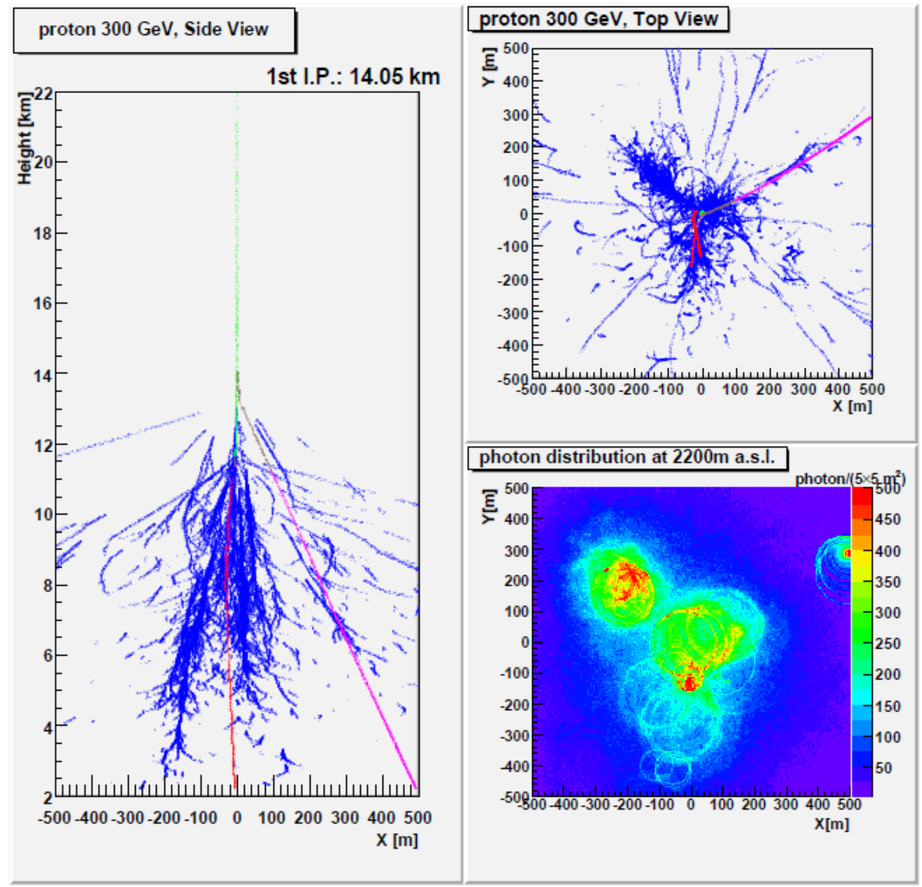


Gamma-ray vs. hadron

100GeV gamma-ray

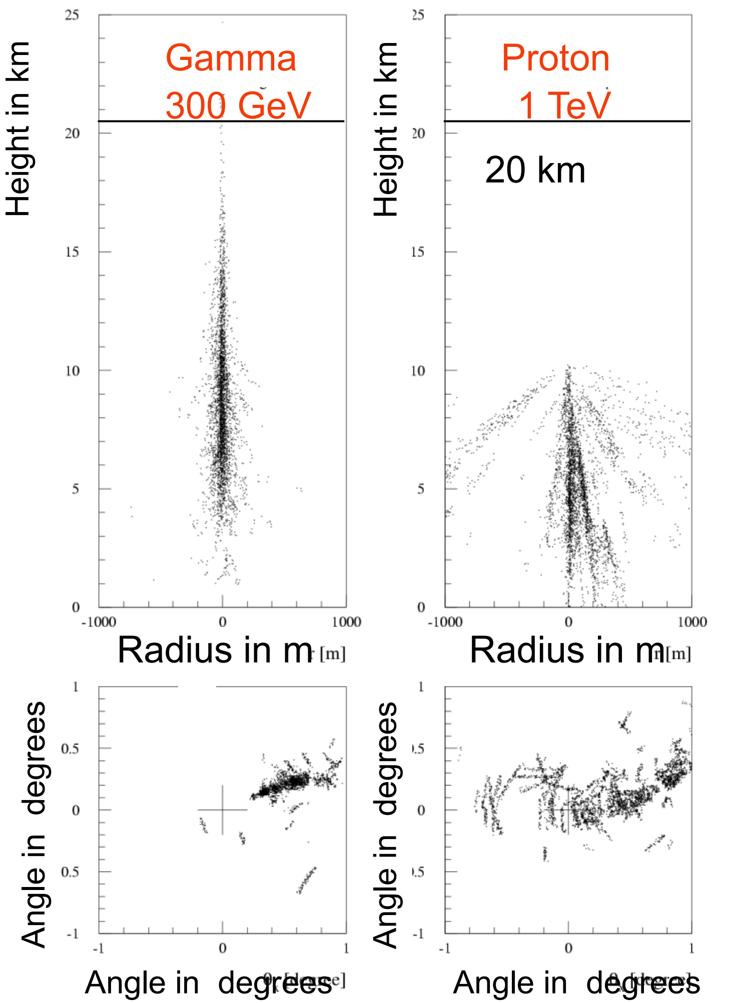


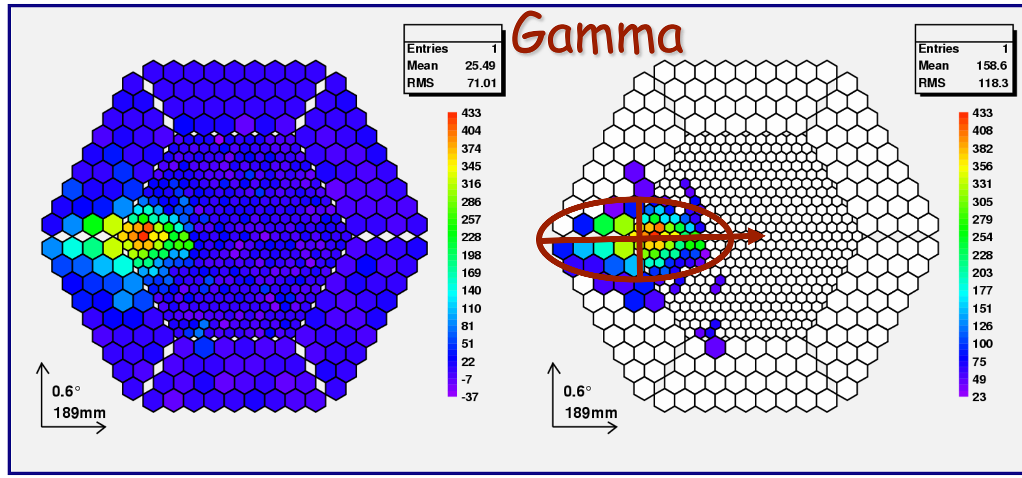
300GeV proton

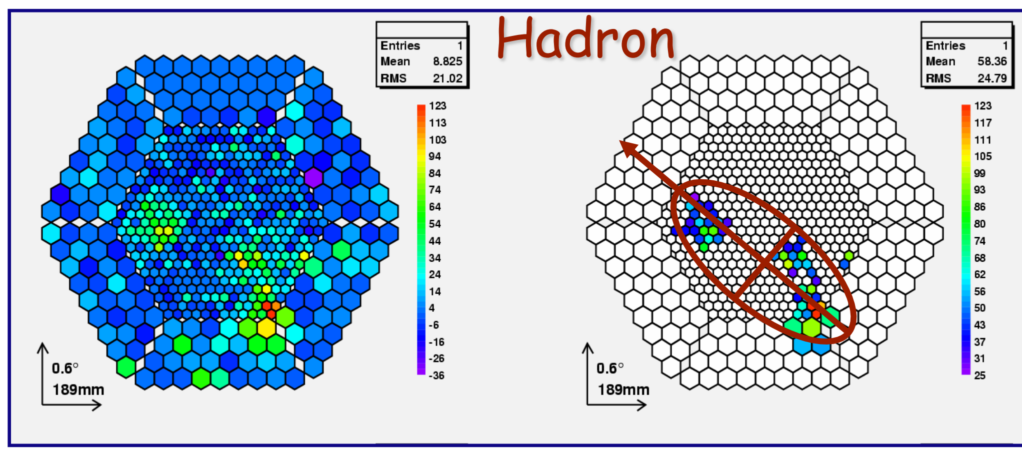


Gamma/Hadron separation

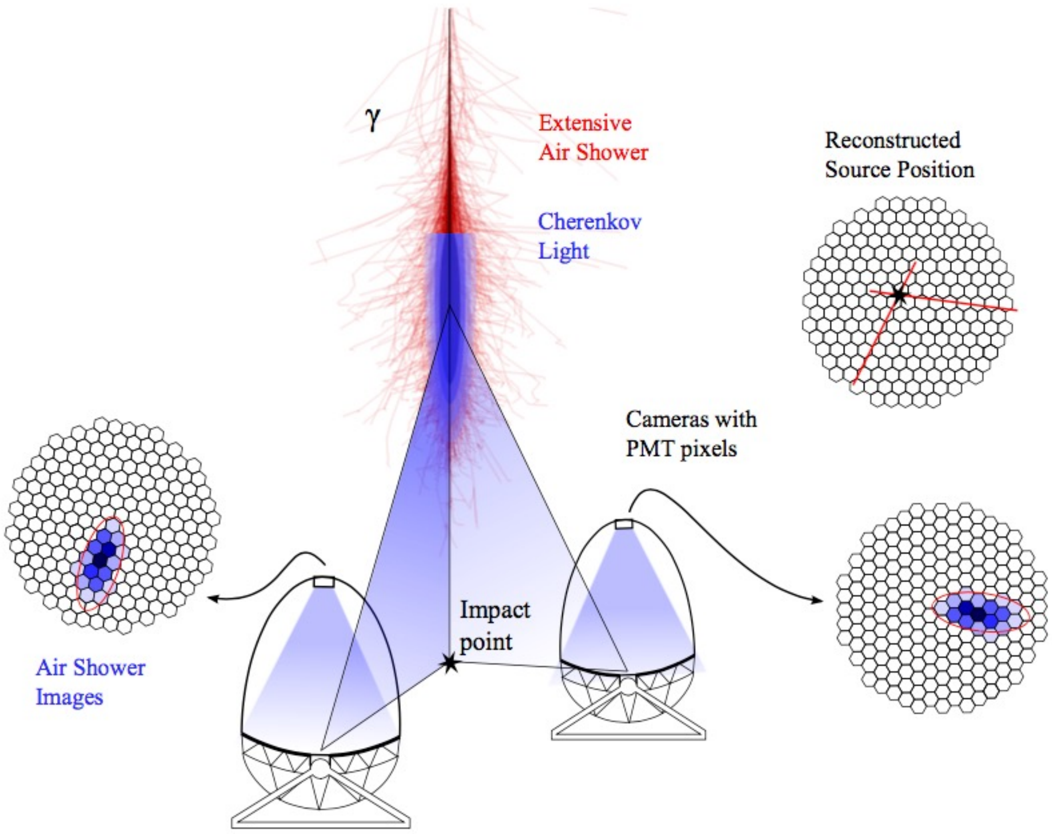
MC simulations





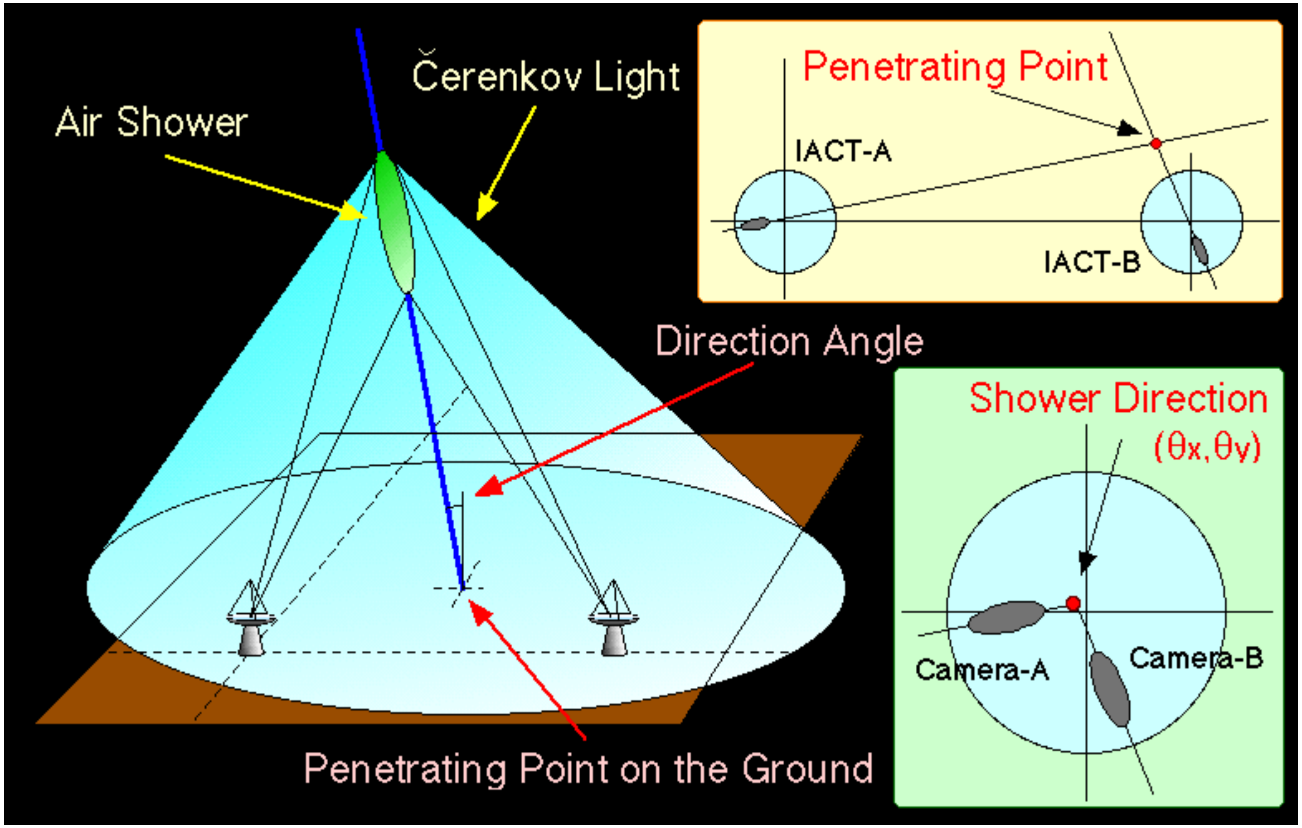


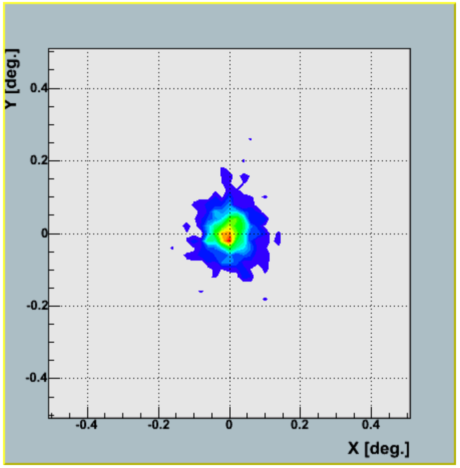
MAGIC stereoscopic system

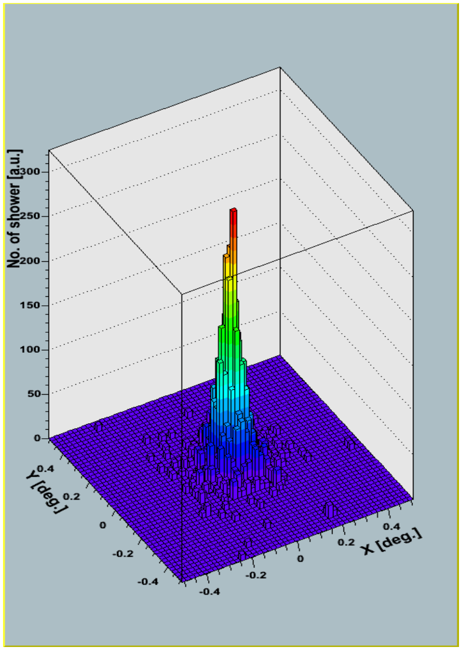


Angular resolution:

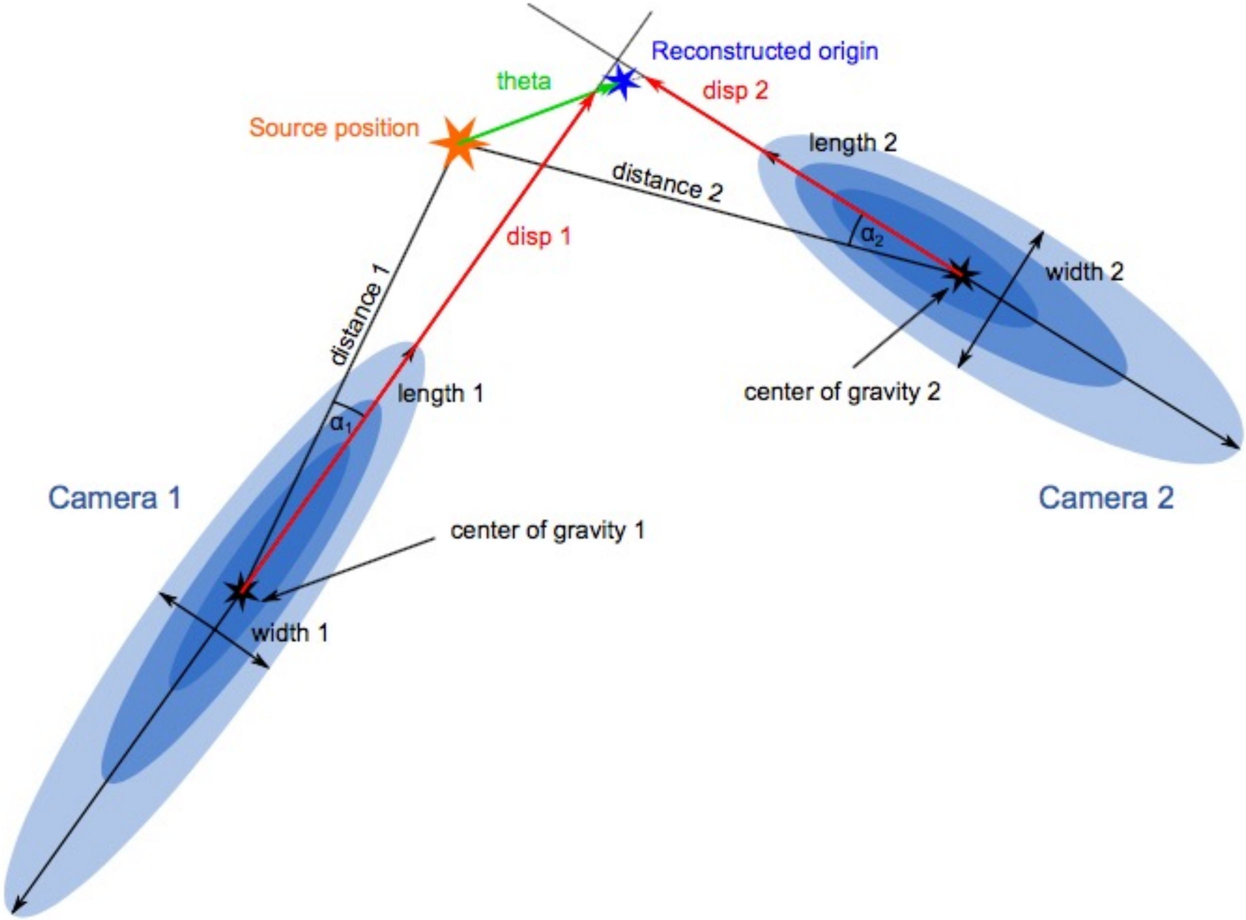
$\delta\theta$ ~ 3~4 arcmin at 1TeV



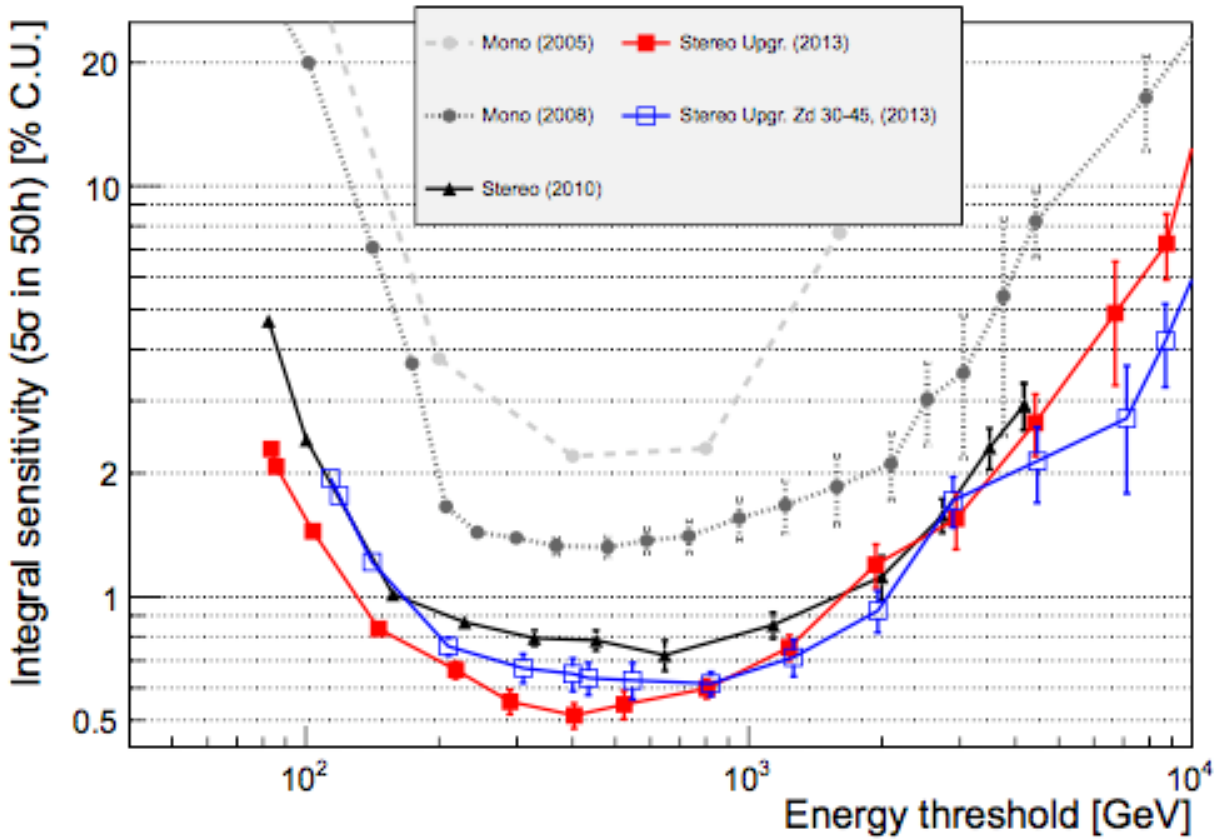




Stereo reconstruction



Differential sensitivity of the MAGIC stereoscopic system



Atmosphere above La Palma

Cirrus clouds

- Important for understanding the climate
- Around 9 km (5-20 km)

Calima

- Sahara dust
- Around 3 km

MAGIC Optical LIDAR


LIght Detection And Ranging

Pulsed optical laser at 532 nm

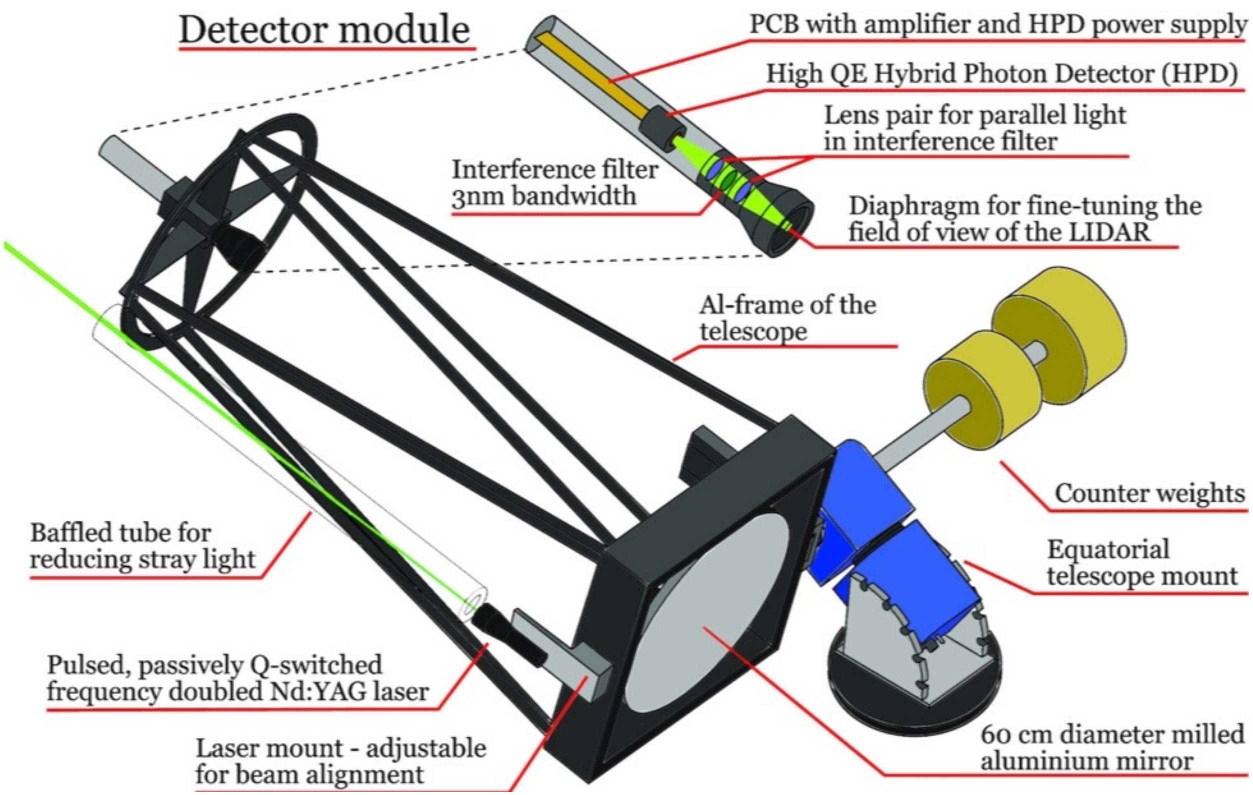
JOURNAL ARTICLE

Characterizing the aerosol atmosphere above the Observatorio del Roque de los Muchachos by analysing seven years of data taken with an GaAsP HPD-readout, absolutely calibrated elastic LIDAR

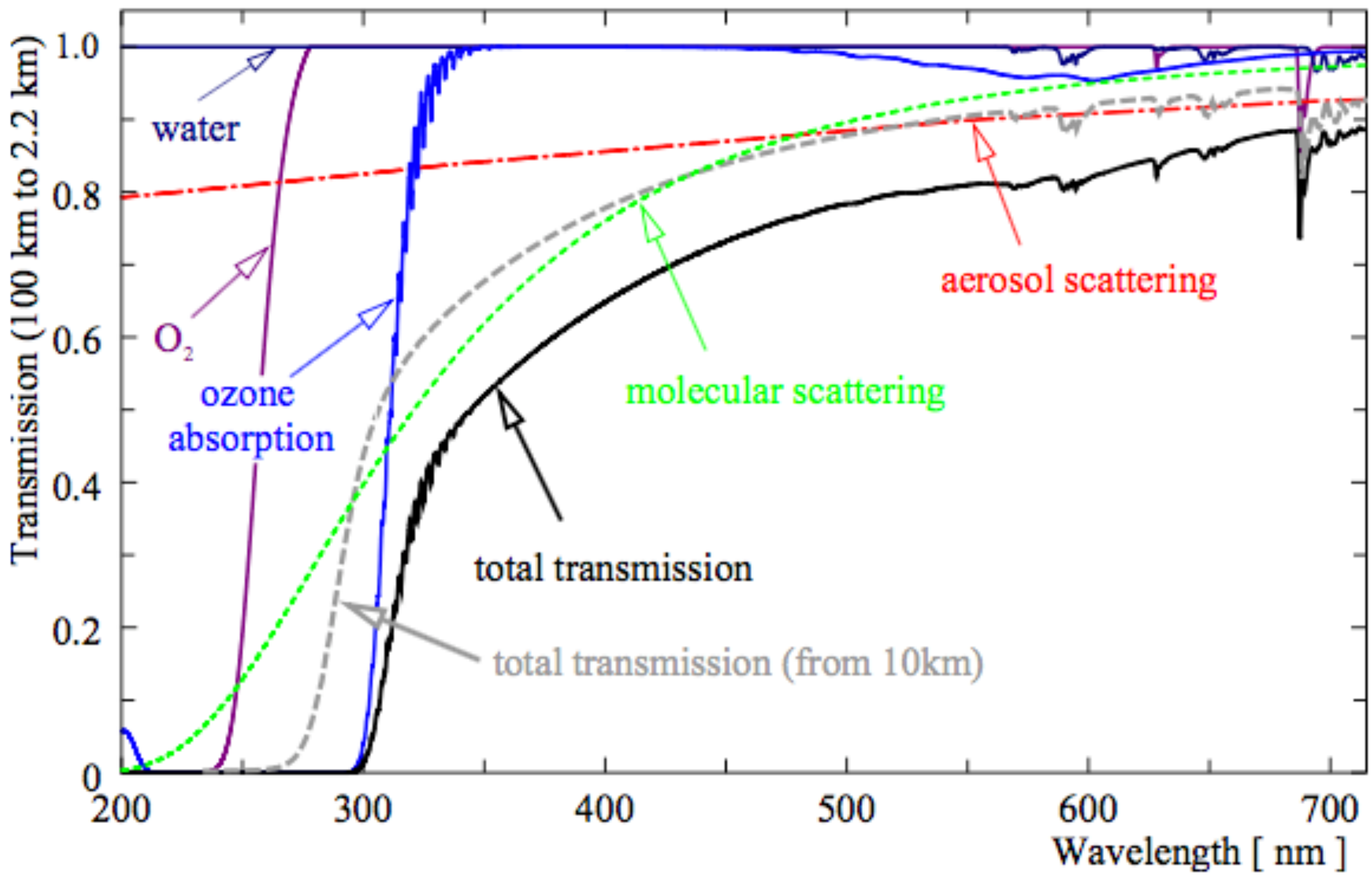
Christian Fruck, Markus Gaug ✉, Alexander Hahn, Victor Acciari, Jürgen Besenrieder, Dijana Dominis Prester, Daniela Dorner, David Fink, Lluís Font, Saša Mićanović, Razmik Mirzoyan, Dominik Müller, Lovro Pavletić, Felix Schmuckermaier, Martin Will

Monthly Notices of the Royal Astronomical Society, Volume 515, Issue 3, September 2022, Pages 4520–4550,
https://doi.org/10.1093/mnras/stac1563
Published: 15 June 2022 **Article history** ▾

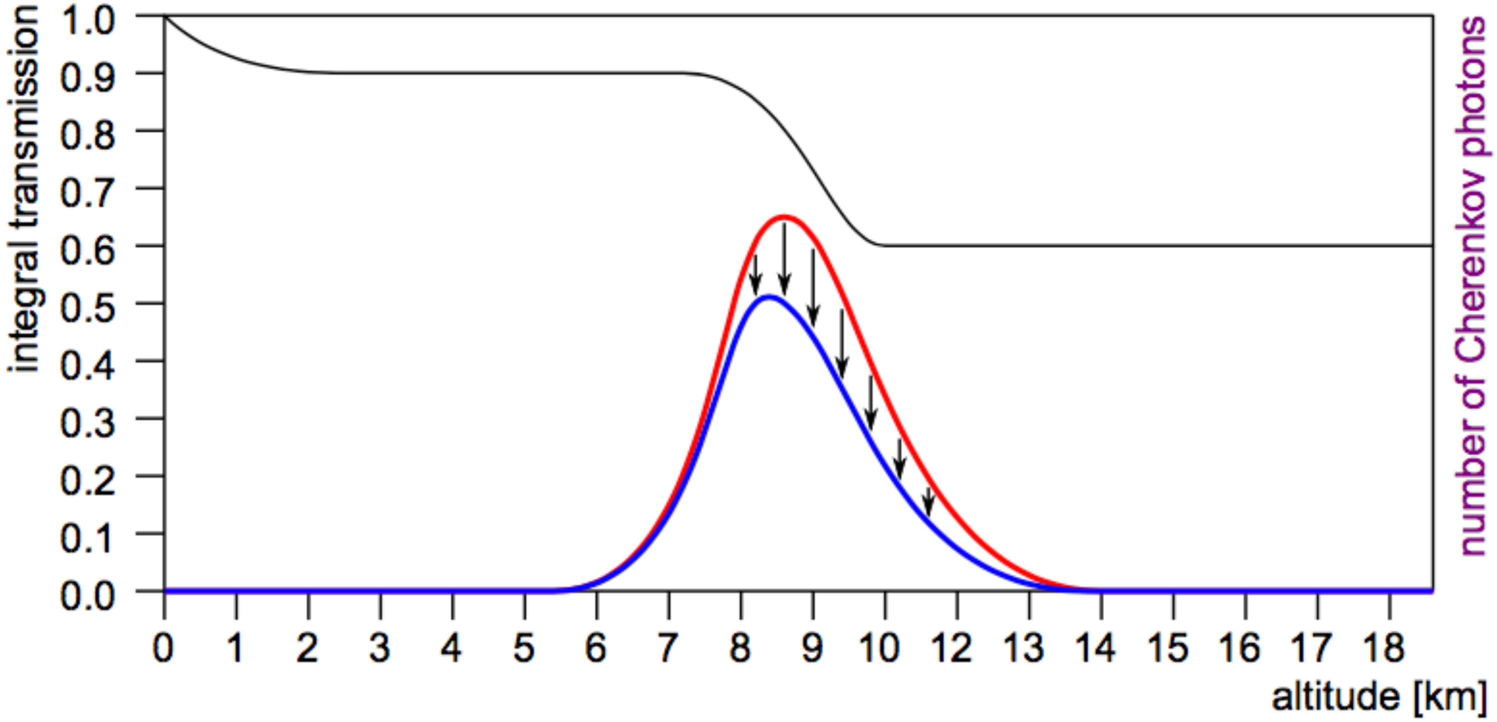
MAGIC Optical LIDAR



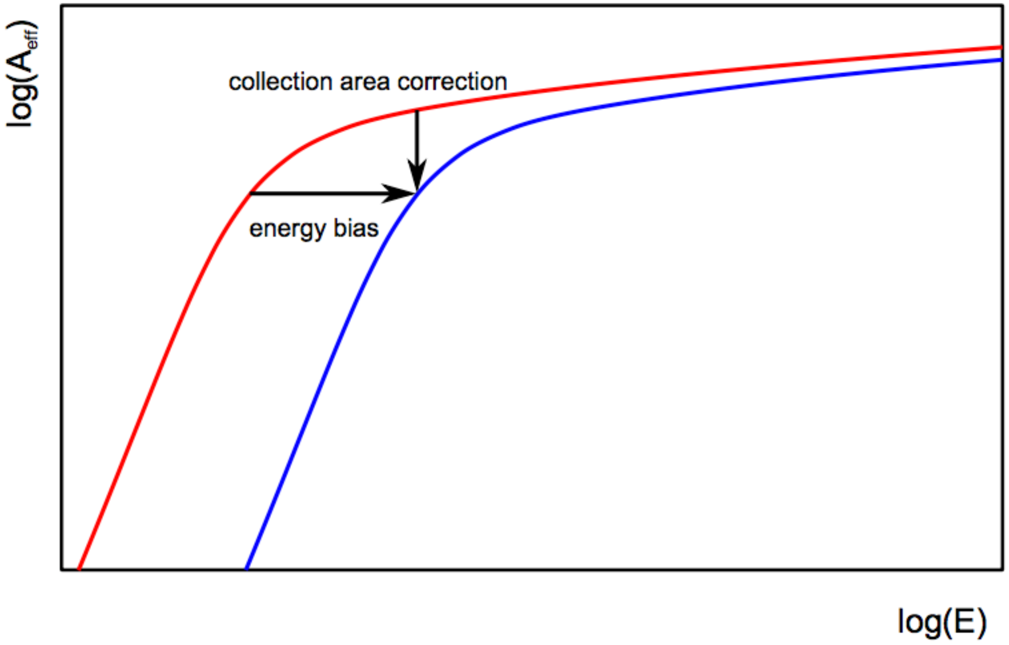
Atmospheric transmission



Effect of a cloud on atmospheric transmission

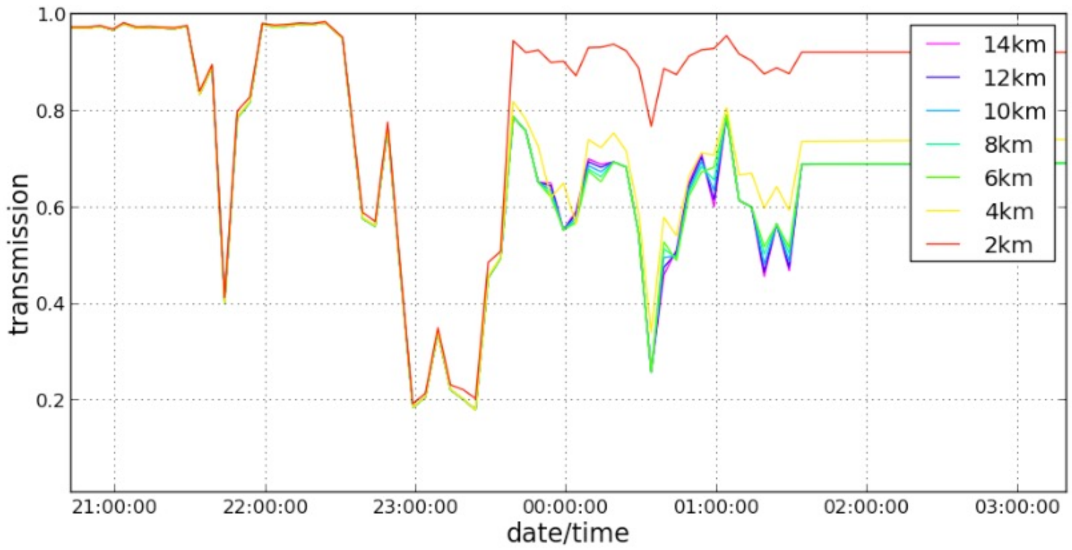


Energy threshold



Atmospheric transmission above La Palma

(example night for different cloud heights)



MAGIC - Atmospheric transmission

- atmospheric transmission measured at La Palma using LIDAR (532 nm)
- Testing of the effects: Crab Nebula
- Observations checked for different ranges of T at 9 km (cirrus clouds) and 3 km (calima):

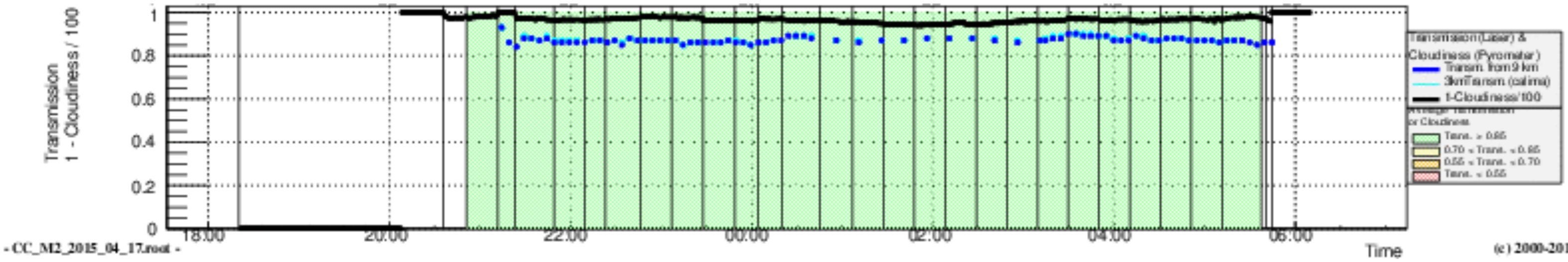
  T: 0-0.55 - reject data

  T: 0.55-0.7, 0.7-0.85 – corrections can be applied

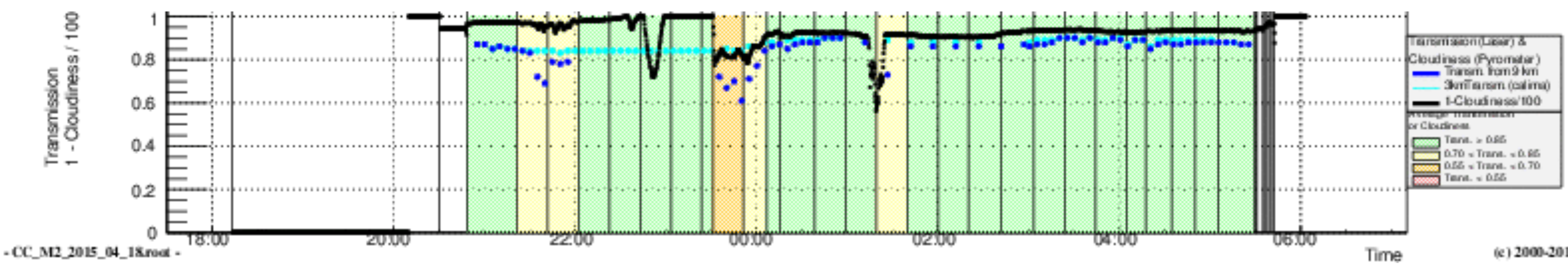
  T: 0.85-1.0 – no corrections
- Data quality check
- Calculation of proposal observing times
- Adaptive scheduling

MAGIC – Atmospheric transmission

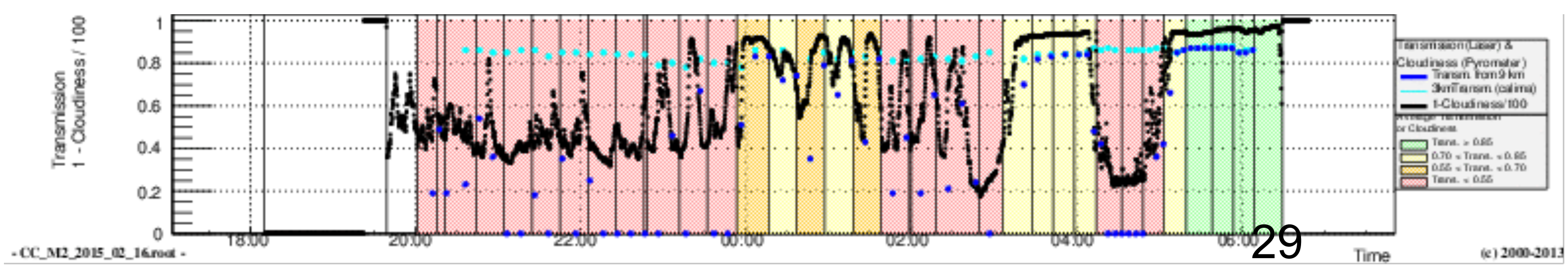
Perfect weather: no corrections



Easy corrections possible



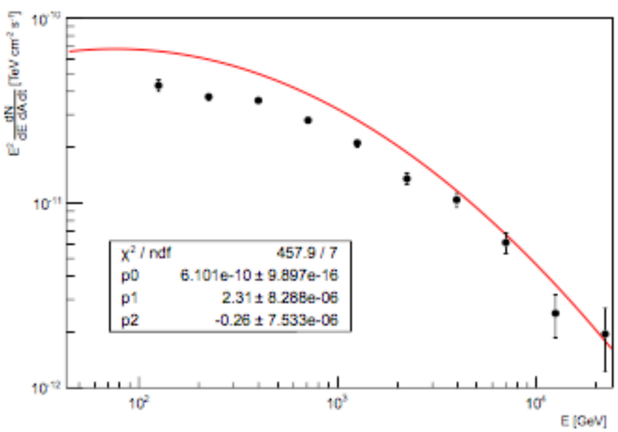
Very variable atmosphere



Data quality classes: MAGIC 2 year statistics

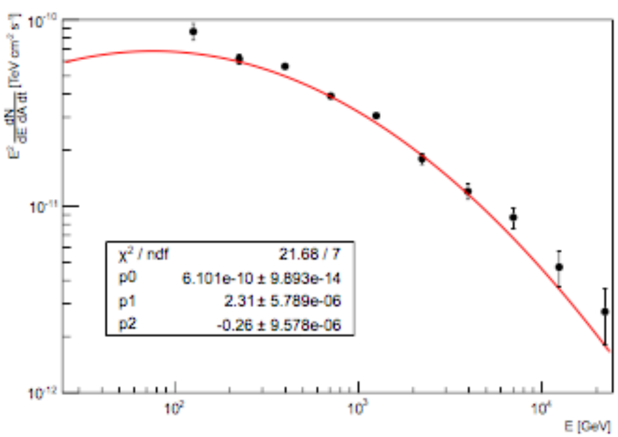
Data quality class	LIDAR T (9 km)	Without calima cut (% of time)	With calima cut
1. (no corrections)	1.00-0.85	69	85
2. (corrections)	0.85-0.70	17	9
3. (corrections)	0.70-0.55	6	2
4. (“garbage”)	0.55-0.00	8	4

Crab nebula spectrum
(with and without corrections for transmission)



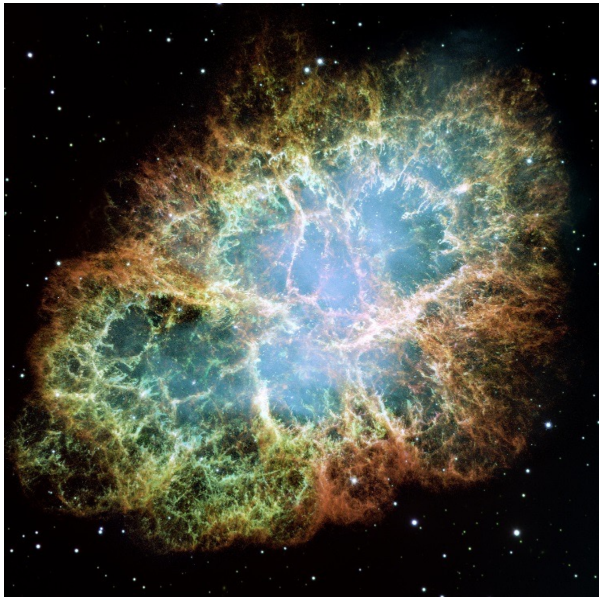
(a)

Without corrections



(b)

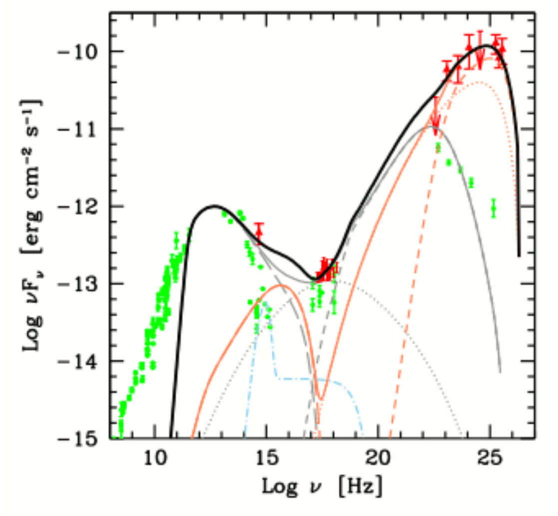
With corrections



C. Fruck (2015). New corrections are in preparations for a publication, including work within CA10108

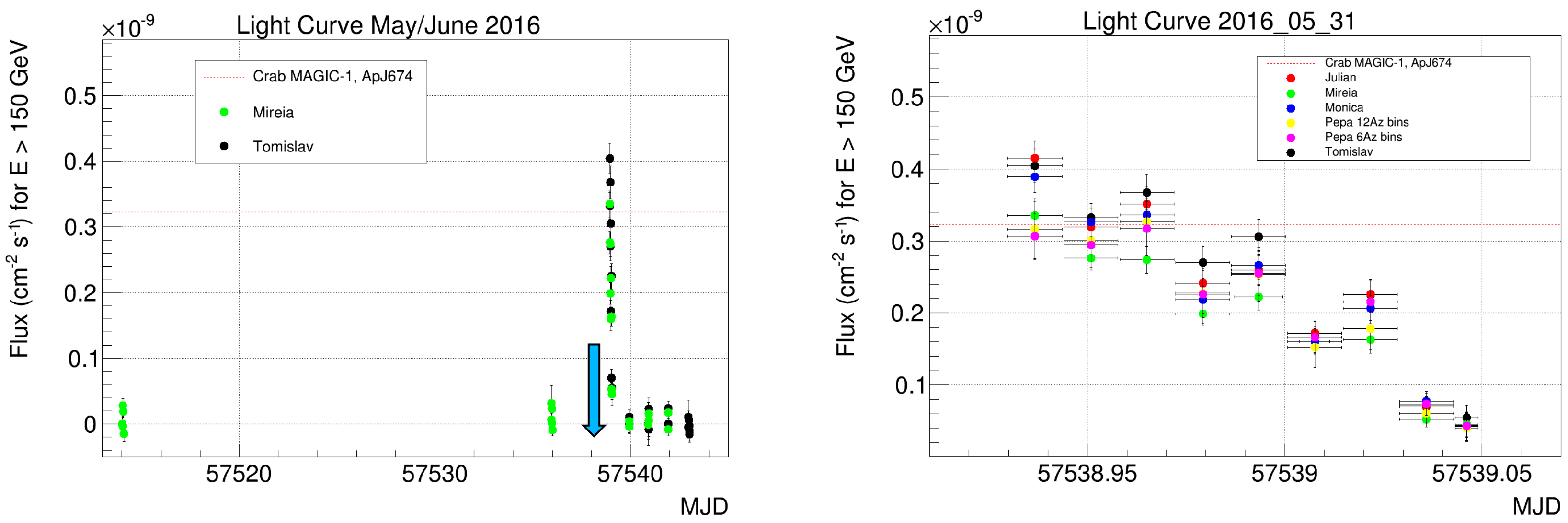
Observing flaring AGN with IACTs

- Fast variability of Active Galactic Nuclei (AGN)
- ToO (Target of Opportunity) observing strategy
- High-state (Flare) -> “harder” spectra
- EBL absorption increases with the redshift (z) -> spectral “softening”
- Different energy thresholds needed for observations of different source types, redshift and activity state
- Energy threshold increases with decreasing atmospheric transmission



Fast ToO-s

“Tonight is The Night – tomorrow may be ToO late!”



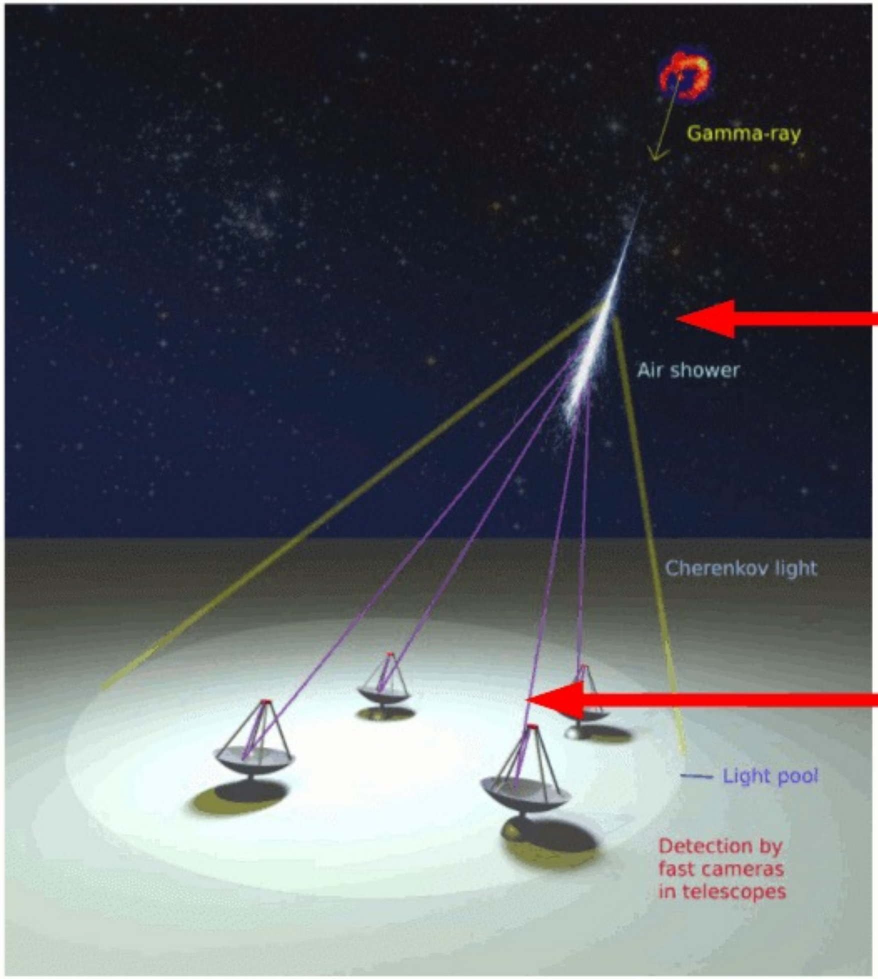
http://www.astronomerstelegram.org/?read=9105

MAGIC detects exceptionally high activity from PKS 1510-089 at very high energy gamma-rays (1 June 2016)

Adaptive observation scheduling

- 20-30% of the observing time at La Palma is affected by moderate atmospheric transmission levels that can be corrected using LIDAR data
- Estimated cost of 1 hour of MAGIC observations is around 20.000 EUR
- Sources with harder spectra are often observed also during moderate transmission (including flaring AGNs, and nearby AGNs) in order to allocate more observing time for sources that need lower energy thresholds
- It is highly probable that the data useful for Lorentz Invariance Violation (LIV) studies will be affected by transmissions that need corrections

Monte Carlo simulations for CTA

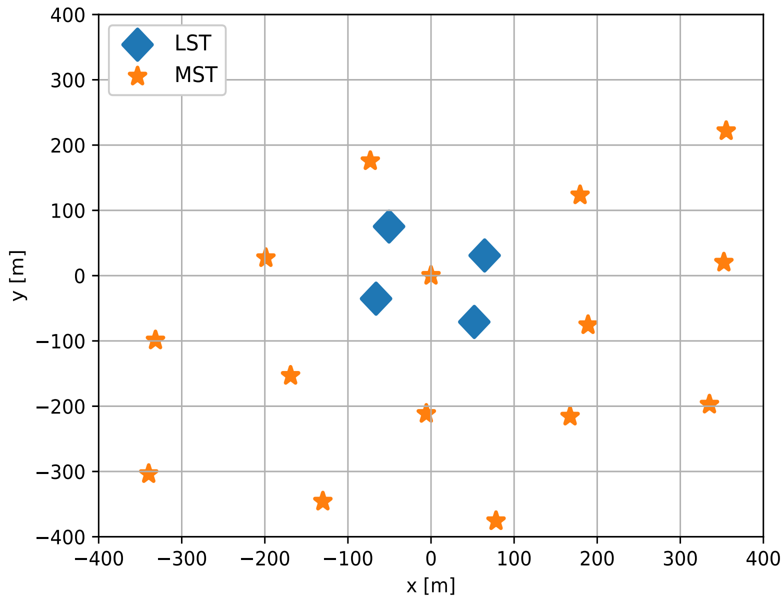


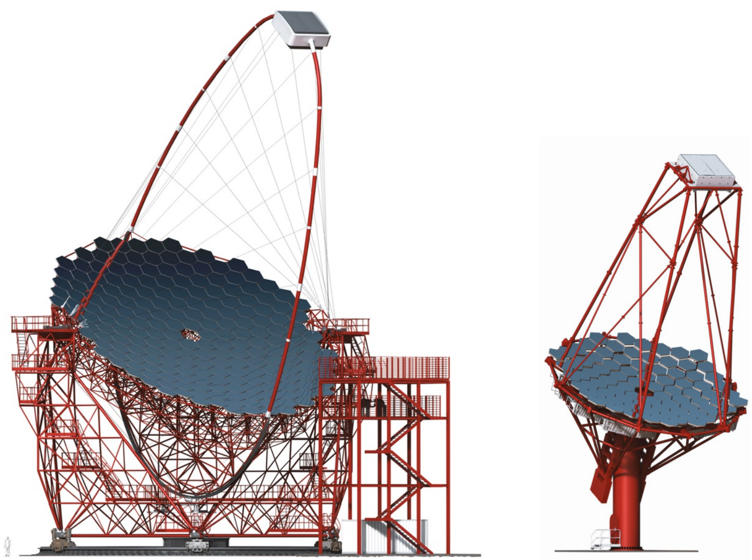
Shower simulation:
CORSIKA

Atmospheric transmission and telescope simulation:
sim_telarray

CTA simulations

- COsmic Ray SImulations for Kascade (CORSIKA) code version 7.6400
- study was performed for Northern CTA site (La Palma, Spain)

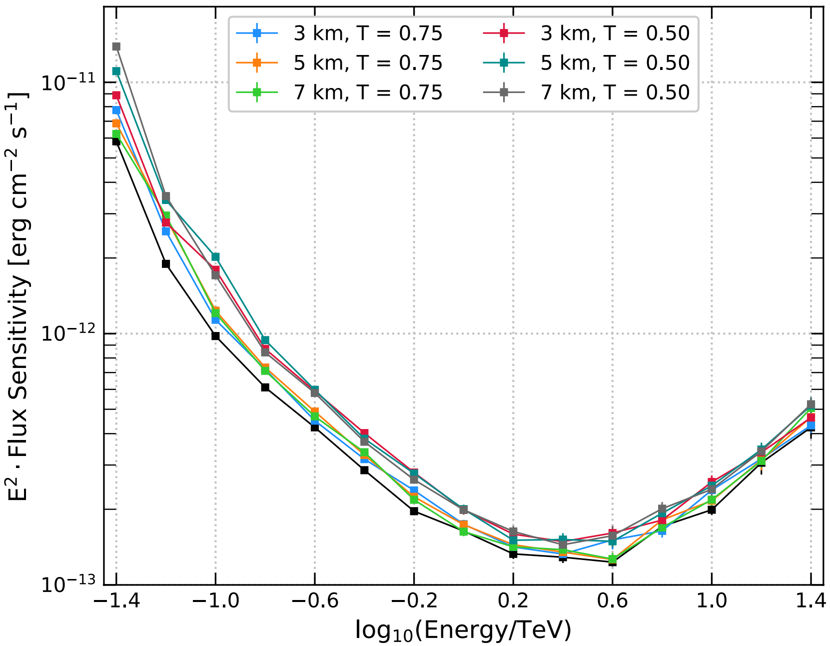


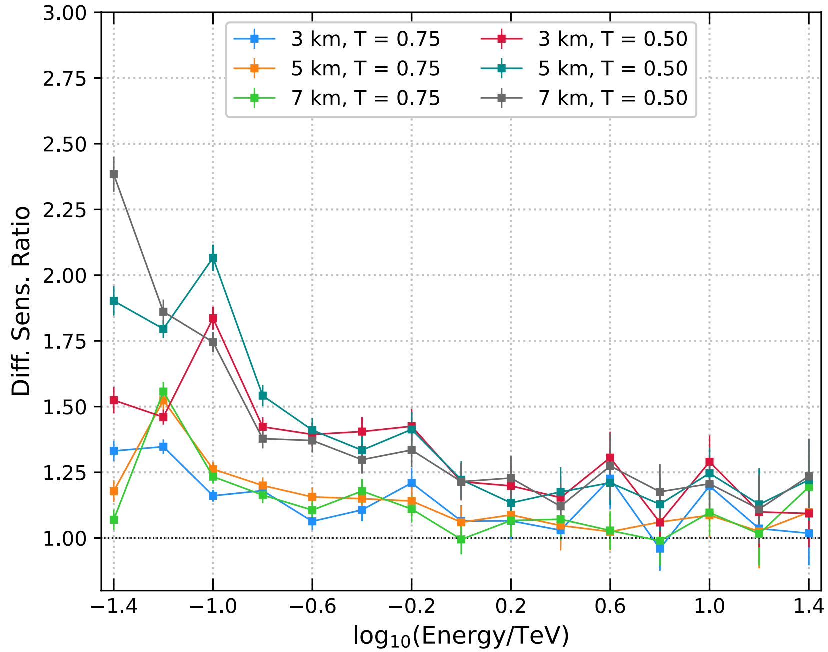


From: www.cta-observatory.org

- 20 degrees in Zenith, 180 degrees in Azimuth
- atmospheric transmission → within sim_telarray code

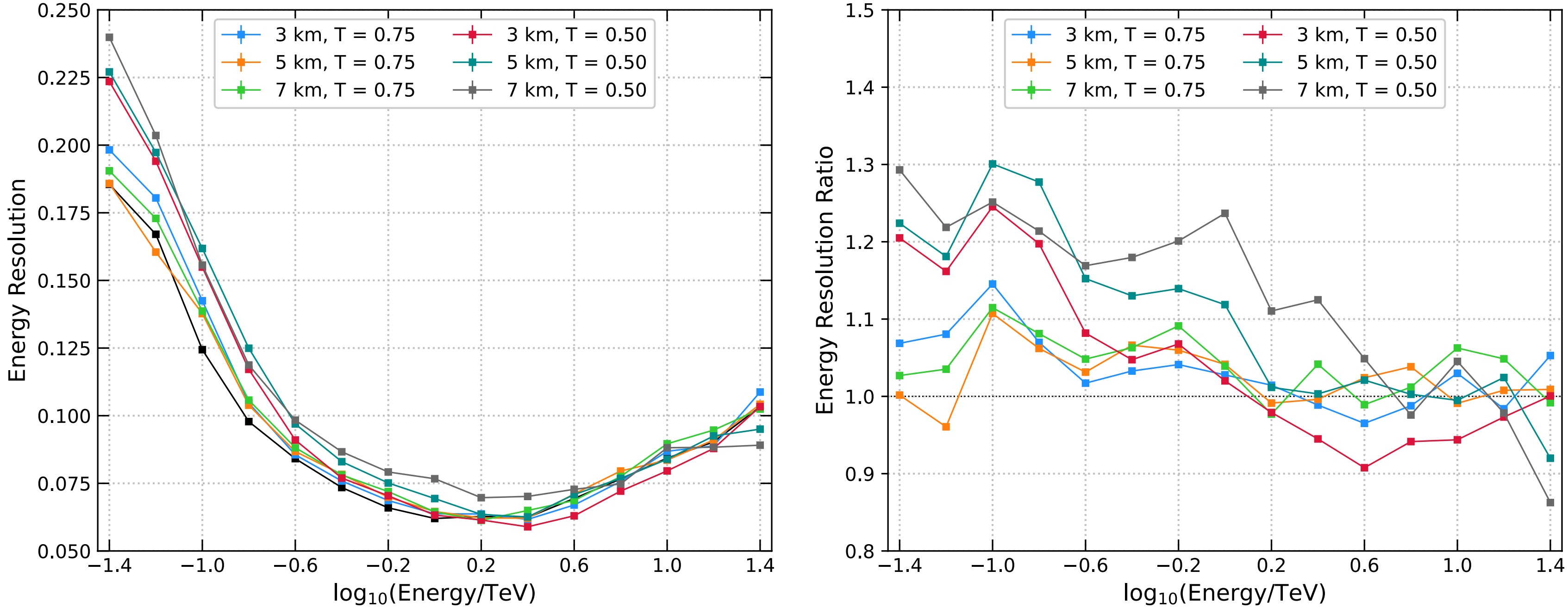
Differential Sensitivity – CTA North





- the most visible effect of clouds is at energies ≤ 150 GeV
- at energies ≥ 1 TeV the stability in reduction is achieved: ≈ 25% for $T = 0.50$, and ≈ 10% in the case of $T = 0.75$

Energy Resolution – CTA North



- varies between 0.18 and 0.24 in the lowest energy bin to ≈ 0.10 at the energy of 15; significantly degraded at energies below 250 GeV, by 30% for $T = 0.50$ and by less then 10% for $T = 0.75$

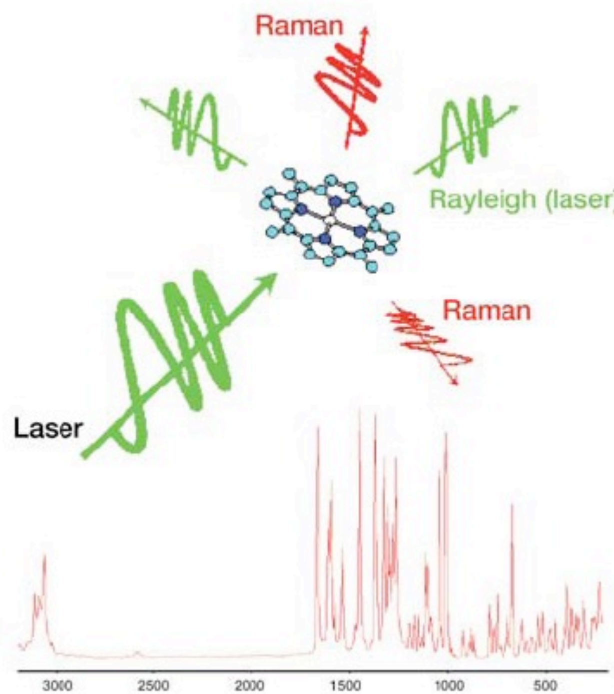
CTA Raman LIDAR

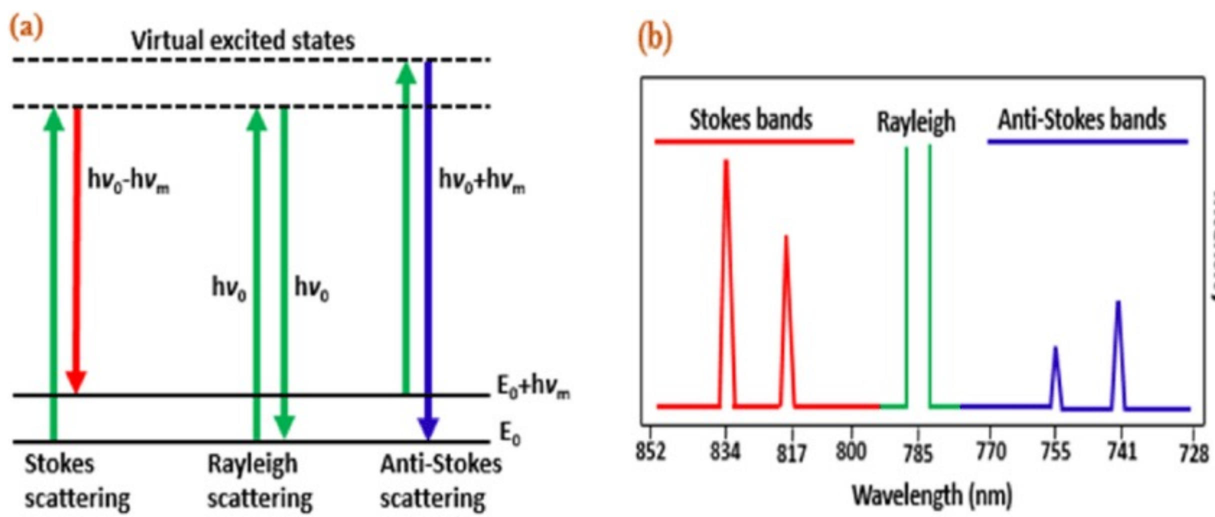
- Online atmospheric calibration of the CTA
- Characterize aerosol extinction to distances of more than 20 km with an accuracy better than 5%
- 1.8 m mirror and a powerful pulsed Nd-YAG laser
- 355 nm, 387 nm, 532 nm and 607 nm

CTA Raman LIDAR
(IFAE-BIST, U. Barcelona, 2019)

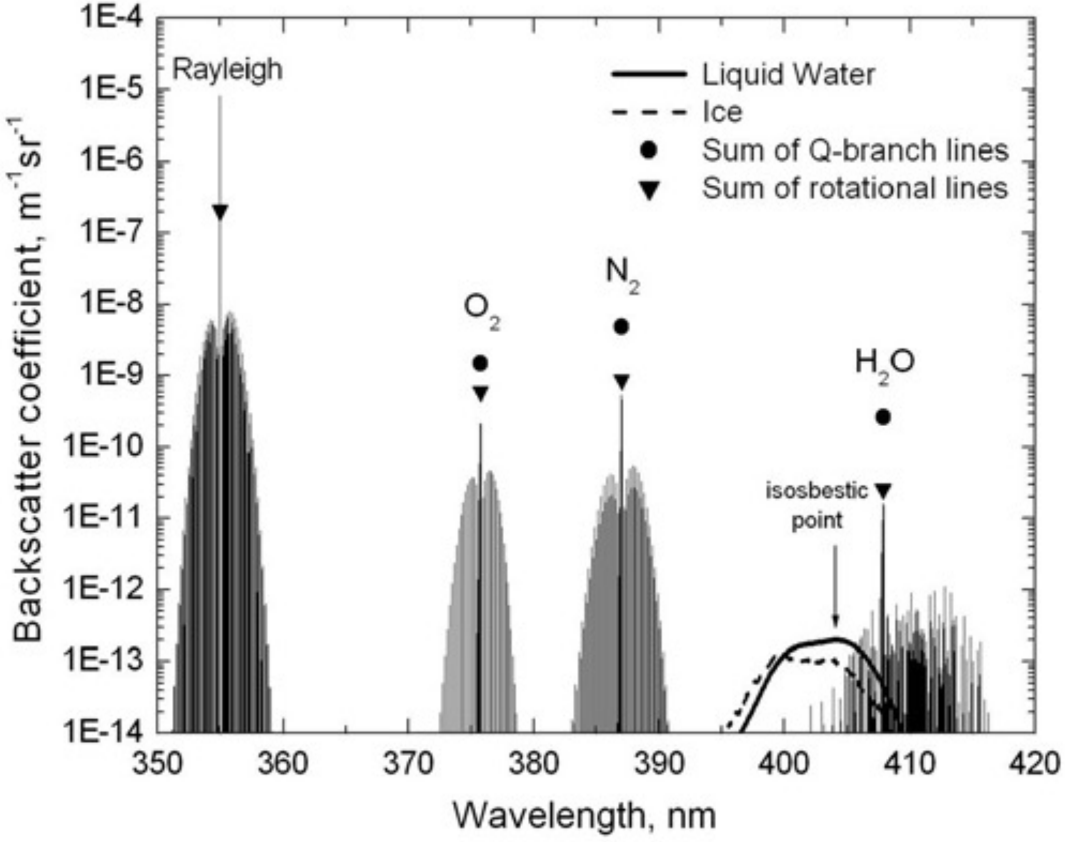
Gaug, M. et al., EPJ Conf. Proc. 197 (2019) 02005

Raman scattering





Atmospheric Raman spectrum



Applications of Raman LIDAR

- Mesurements of water vapor concentration
- Measurements of atmospheric temperature profiles
- Characterization and abundance of aerosols and molecules in the atmosphere (carbon dioxide, ozone, volcanic dust...)
- Climatology
- Environmental studies

Erruption of Cumbre Vieja
at La Palma (Sept-Dec 2021)

*“**Characterization of aerosols** in the atmosphere, important for precise calculations of data measured by Imaging Atmospheric Cherenkov Telescopes (IACTs), and needed for studies proposed in this project (Working Group 3), will **have a long-term impact on the development of environmental research and its application to climate research.** In particular, physical and chemical properties of aerosols will be assessed at the remote sites where IACTs are located”.*

(COST CA18108 funding proposal, 2017)

Summary and Conclusions

- Data taken by Cherenkov telescopes relevant for quantum gravity studies are likely to be affected by reduced atmospheric transmission
- Corrections of observations are calculated using LIDAR
- Proper understanding and characterization of the atmosphere is important for theoretical interpretations of data and multimessenger studies
- High potential for applications in environmental research


"I love the clouds
The clouds that pass up there
Up there the wonderful clouds!"
Charles Baudelaire: "The Stranger"

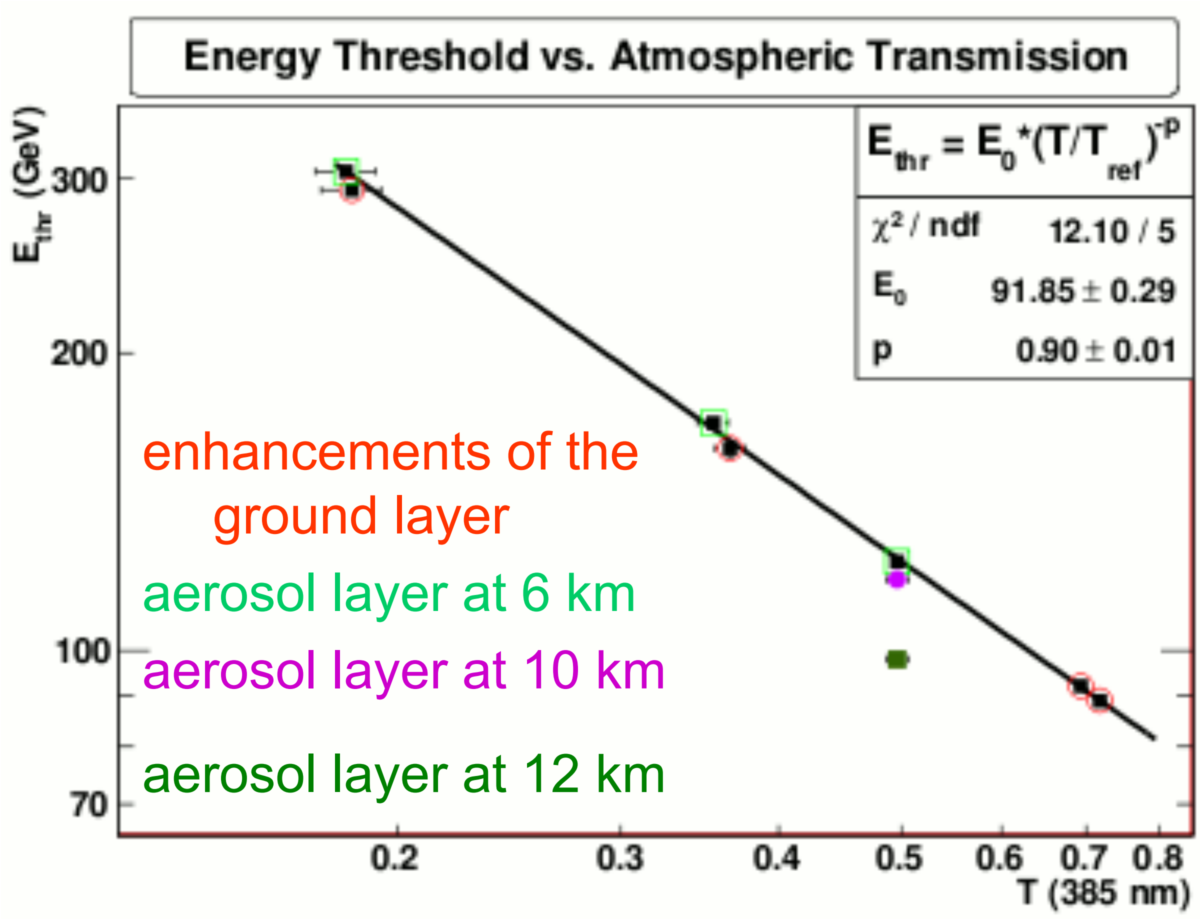
Backup slides

Supercomputer “Bura” – University of Rijeka, Croatia

- Operational since **2016**
- Multiprocessor: 2 nodes (256 processor cores and 6 TB of shared memory each)
- Cluster: 288 computing nodes with 6912 processor cores (each node has 24 cores and 64GB of RAM). In addition there are 4 nodes with graphical processing units (GPU) suitable for highly parallel applications

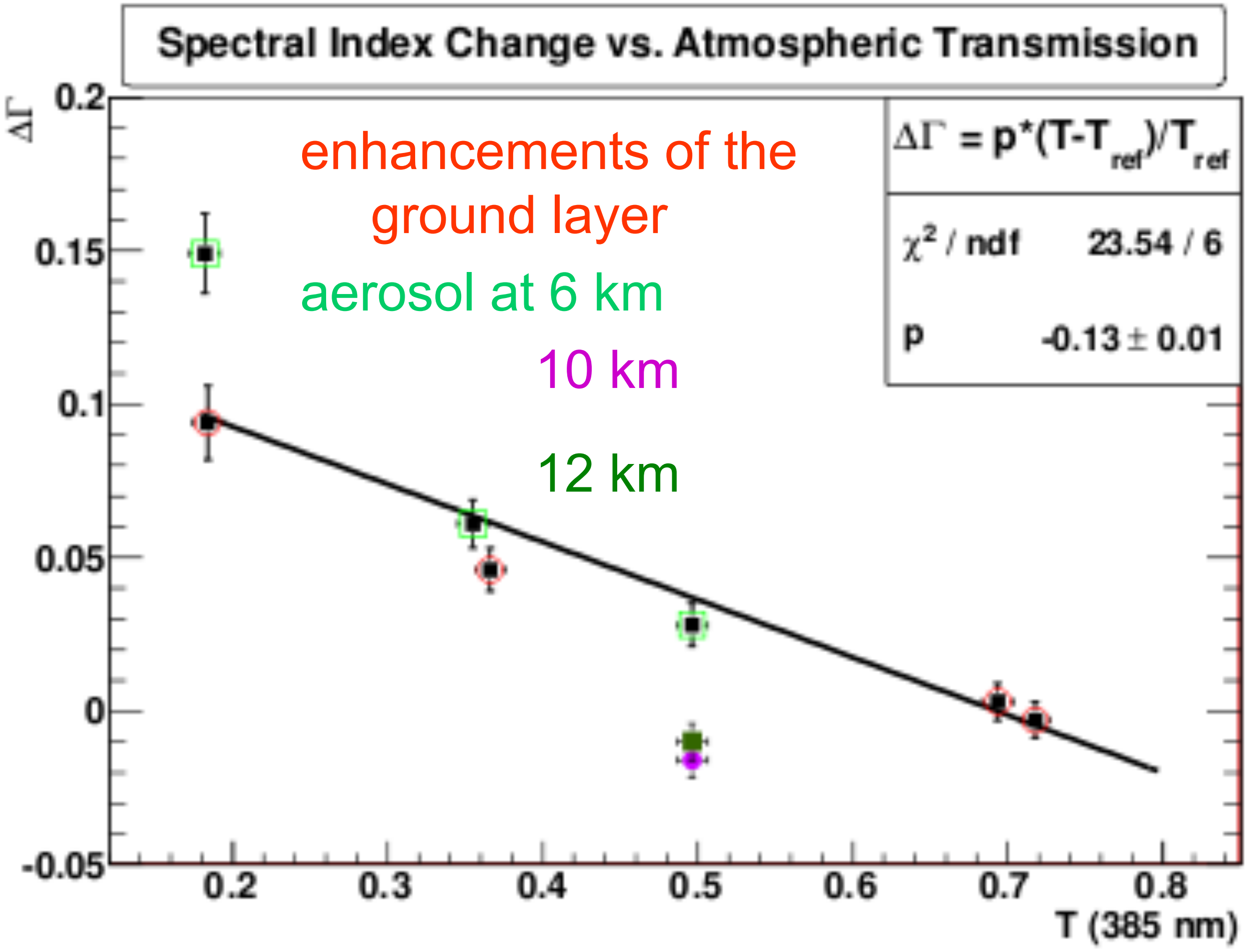
- 1 PB of data storage space (plus additional 2.5 PB for archiving on the tape drives)
- Achieved performance is 233.56 TFLOPS

Energy Threshold



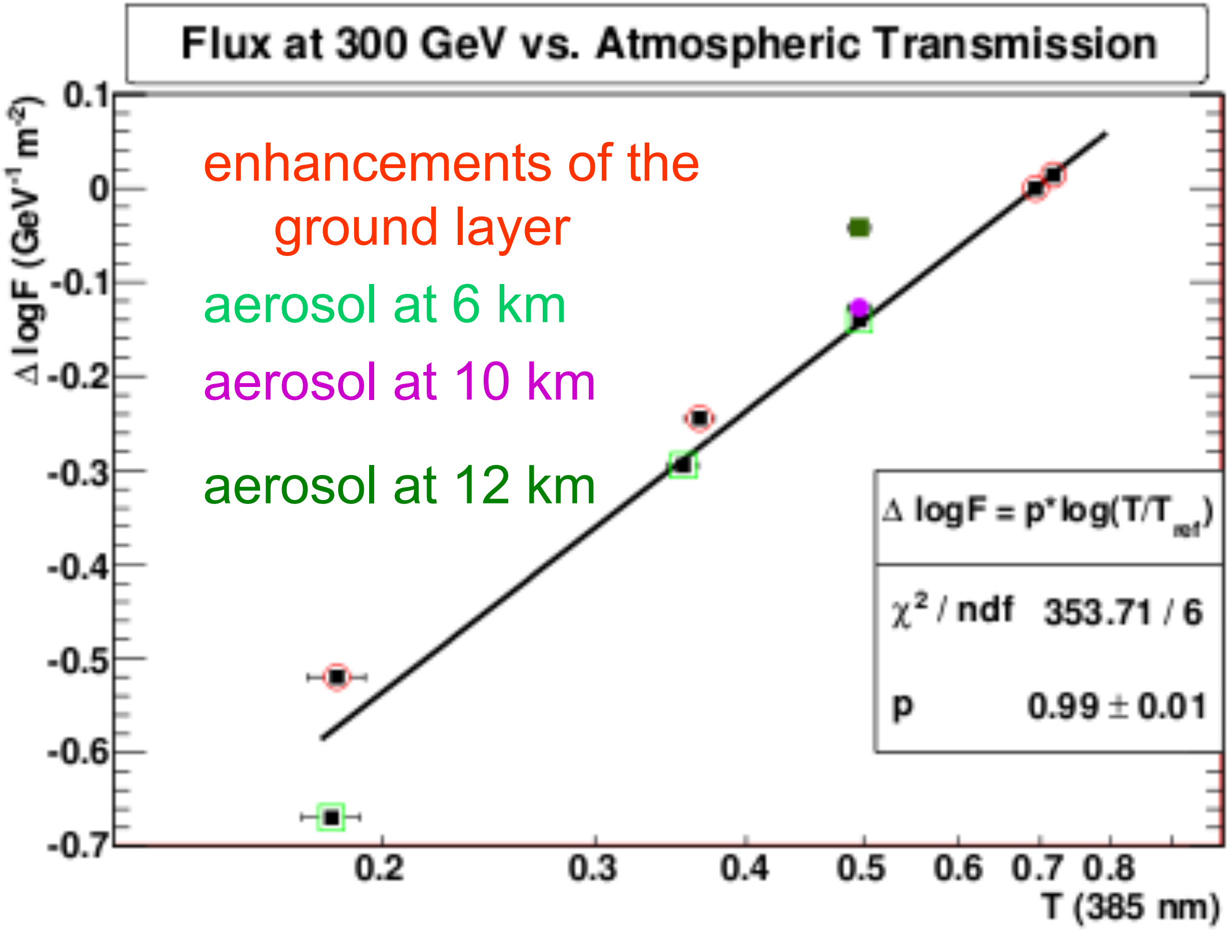
Garrido, Gaug, Font, Moralejo (MAGIC Coll.), 2014

Spectral index change



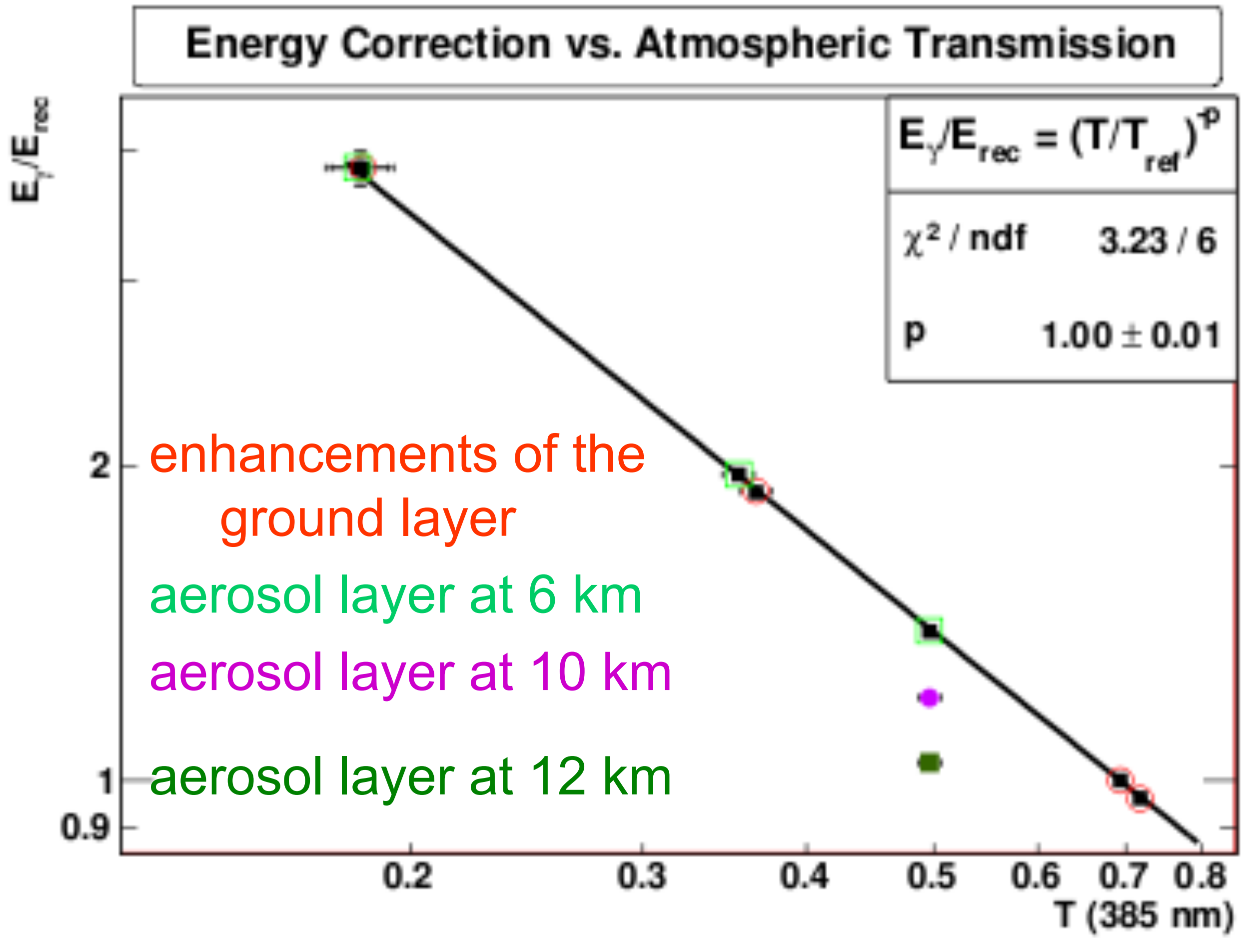
Garrido, Gaug, Font, Moralejo (MAGIC Coll.), 2014

Flux at 300 GeV

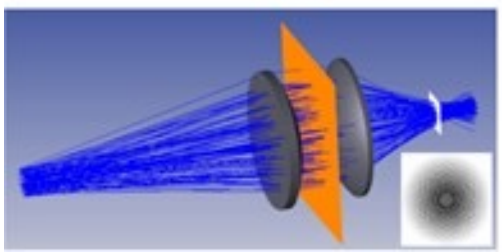


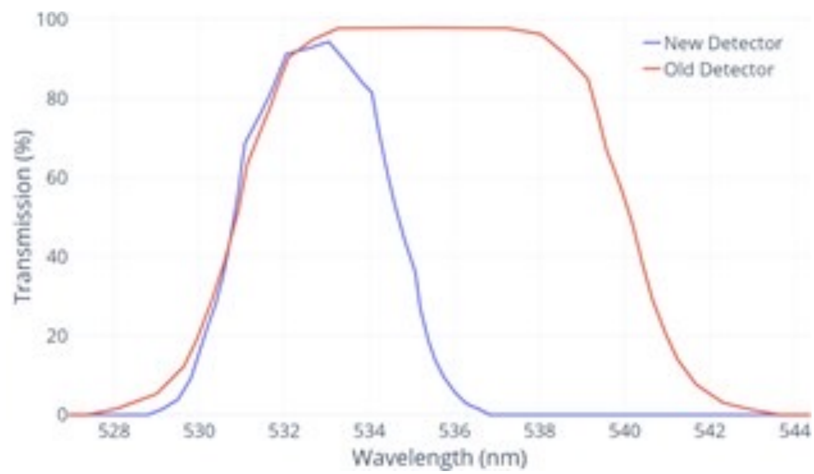
Garrido, Gaug, Font, Moralejo (MAGIC Coll.), 2014

Energy correction

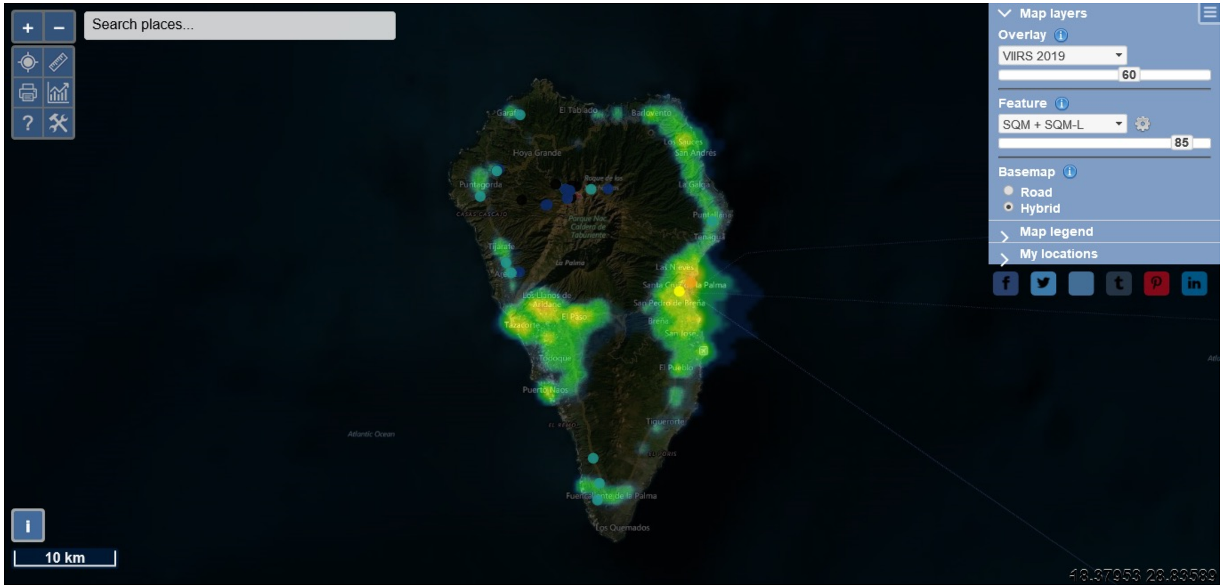


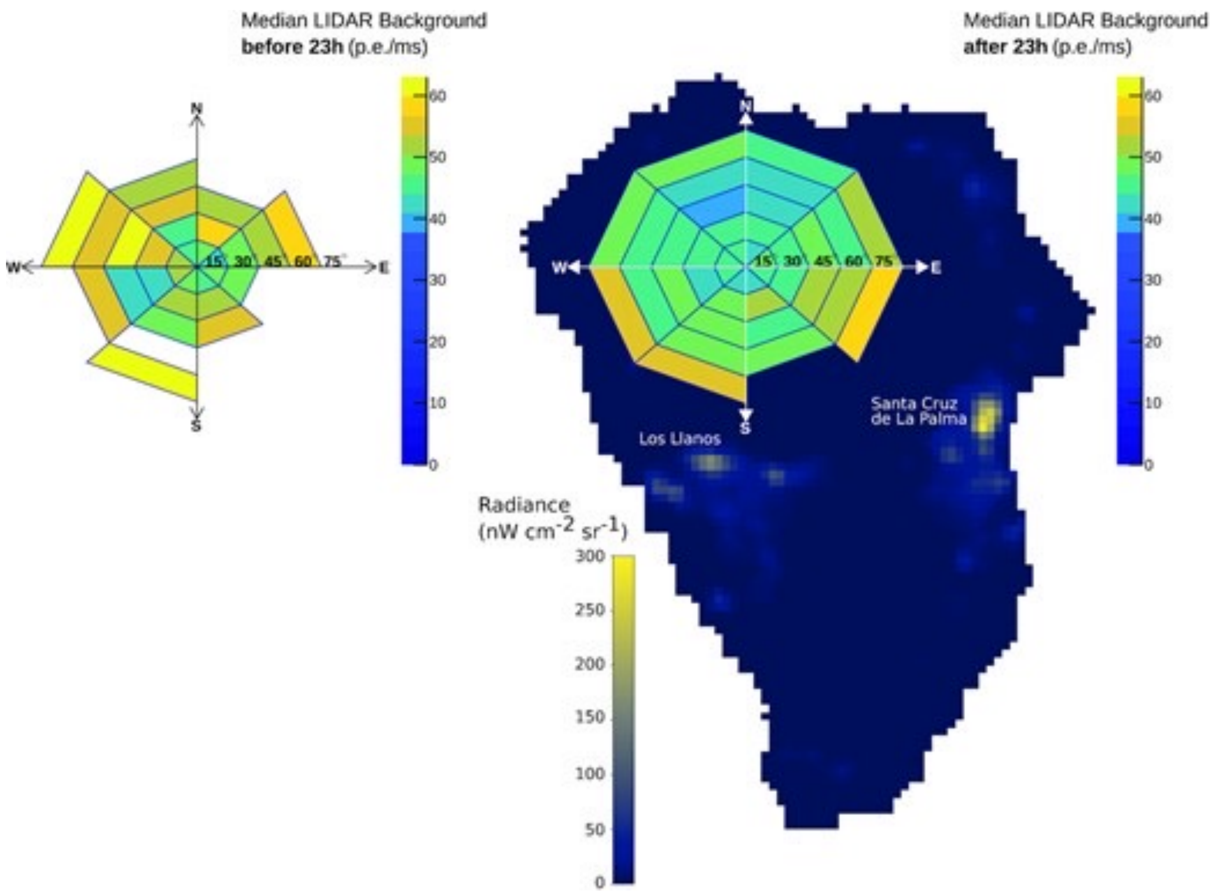
Garrido, Gaug, Font, Moralejo (MAGIC Coll.), 2014




New Detector
Old Detector
Transmission (%)
Wavelength (nm)
100
80
60
40
20
0
528
530
532
534
536
538
540
542
544

Light pollution at La Palma




Median LIDAR Background
before 23h (p.e./ms)
Median LIDAR Background
after 23h (p.e./ms)
Los Llanos
Santa Cruz
de La Palma
Radiance
(nW cm-2 sr-1)