Atmospheric Monitoring in MAGIC and Data Corrections

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MAGIC
Major Atmospheric Gamma Imaging Cerenkov Telescopes

Max-Planck-Institut für Physik

ATMOHEAD - Padova - May 2014

The importance of atmospheric monitoring in IACT

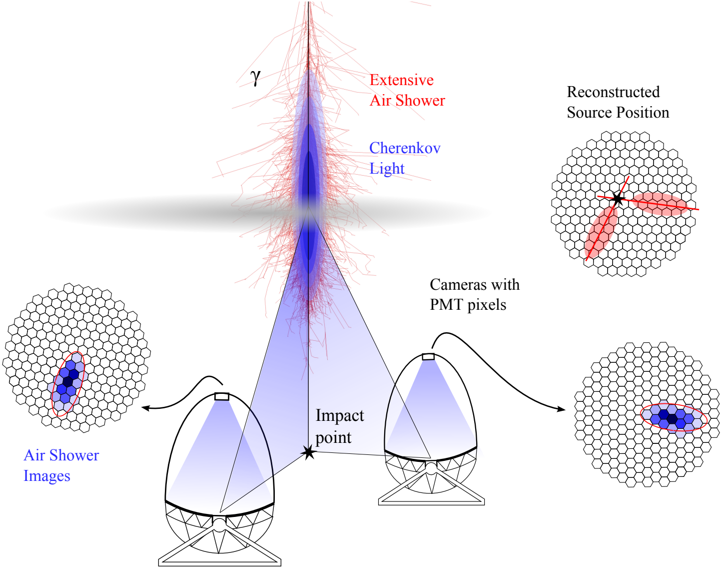
The MAGIC LIDAR system

A simple "signal inversion" algorithm for the MAGIC LIDAR

Event by event reconstruction of IACT data

Conclusions

IACT and clouds/aerosols



The MAGIC LIDAR system

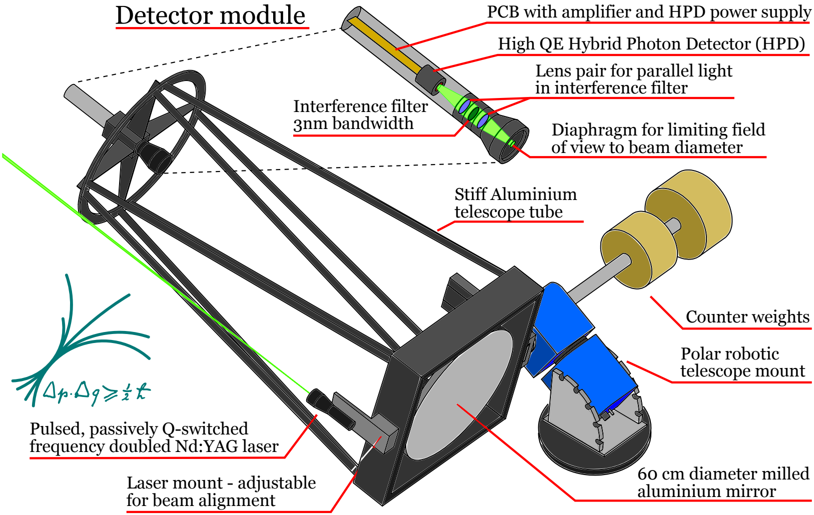
- Purpose: measuring the differential transmission of the atmosphere above MAGIC
- Characteristics: $5\,\mu\text{J}$ (pulse) / $5\,\text{mW}$ (cw) “micro LIDAR”, single and multi photon counting with very high QE detector
- Useful range: 15-20 km (at 50000 shots)
- Status: Automatic operation mode taking data all 5 Minutes during nightly observations, online data analysis available
- Final goal: improve source/data selection and finally apply individual corrections to the energy spectrum

The LIDAR system on the MAGIC site

- inside protective dome on top of LIDAR tower
- accessible from the counting house over the roof
- approx. 60m away from both telescopes

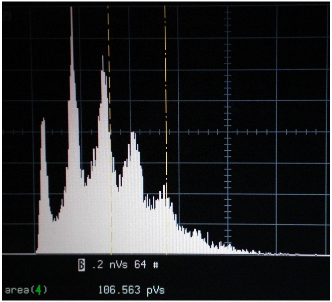
The LIDAR system on the MAGIC site

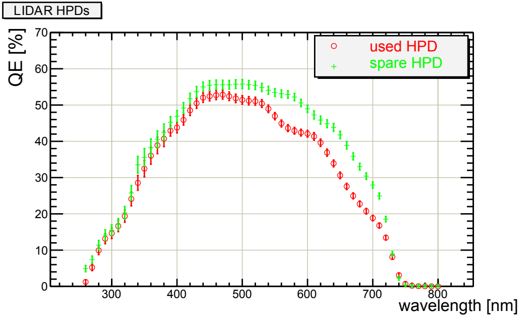
The LIDAR system on the MAGIC site

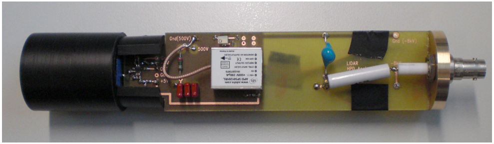

Detector module
PCB with amplifier and HPD power supply
High QE Hybrid Photon Detector (HPD)
Lens pair for parallel light
in interference filter
Interference filter
3nm bandwidth
Diaphragm for limiting field
of view to beam diameter
Stiff Aluminium
telescope tube
Counter weights
Polar robotic
telescope mount
Pulsed, passively Q-switched
frequency doubled Nd:YAG laser
Laser mount - adjustable
for beam alignment
60 cm diameter milled
aluminium mirror

Extremely sensitive photo detector: HPD

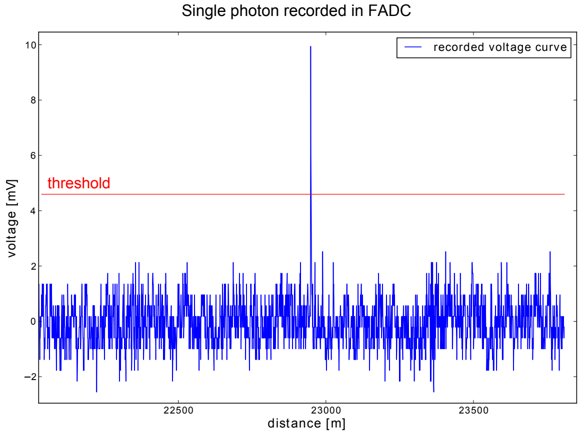
- very good single ph.e. resolution
- QE $\approx 50\,\%$ at 532nm





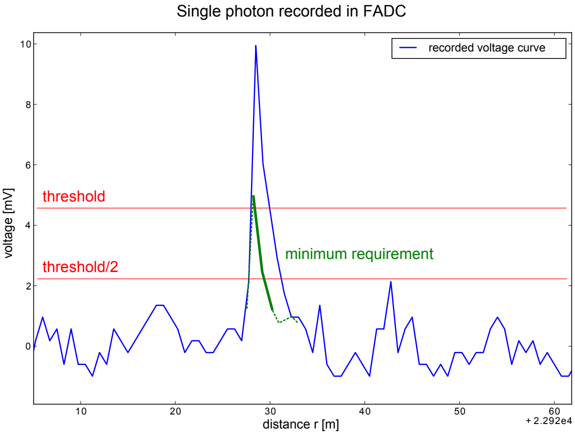


Photon counting using HPD



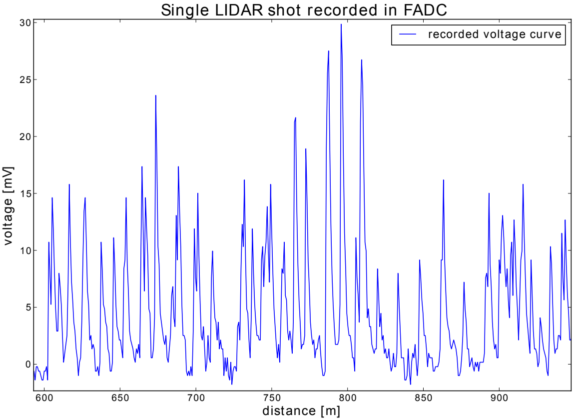
- can do real single photon counting with very low background/noise
- can reach ~15km in altitude with < 1mW

Photon counting using HPD



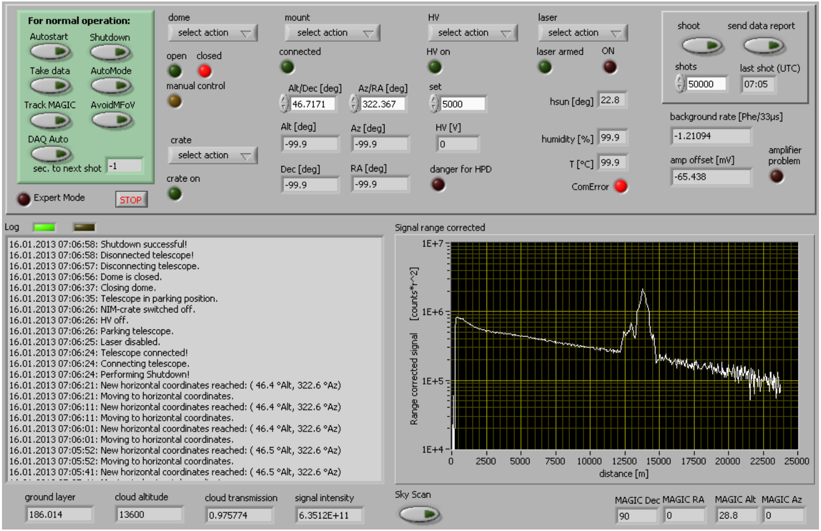
- adapted peak search to exclude occasional HF ringing noise
- requires peak (P) with $V[P] > V_{th}$, $V[P+1] > V_{th}/2$ and $V[P+2] > V_{th}/4$

Photon counting using HPD

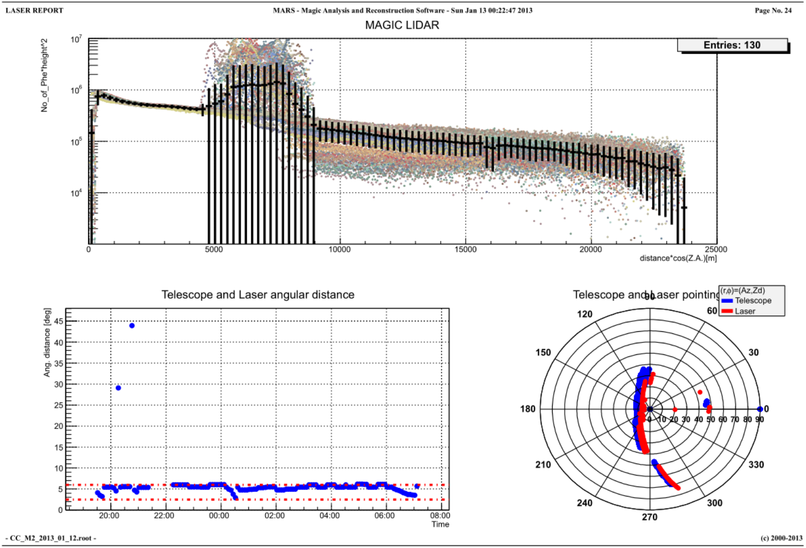


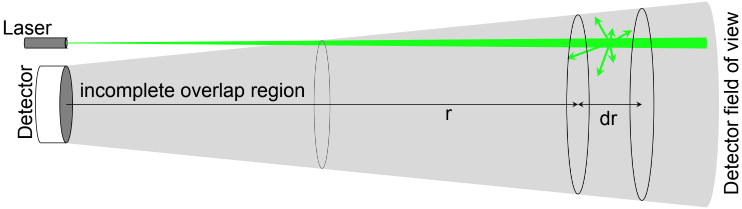
- signal integration needed in the high signal (pileup) region ($r <\sim 3km$).
- single photon "charge" measured in far range region (good matching of both methods)

The LabVIEW LIDAR control program



Datacheck


LASER REPORT
MARS - Magic Analysis and Reconstruction Software - Sun Jan 13 00:22:47 2013
Page No. 24
MAGIC LIDAR
Entries: 130
No_of_Phe*height^2
distance*cos(Z.A.)[m]
Telescope and Laser angular distance
Ang. distance [deg]
Time
Telescope and Laser pointing
(r,φ)=(Az,Zd)
Telescope
Laser
- CC_M2_2013_01_12.root -
(c) 2000-2013



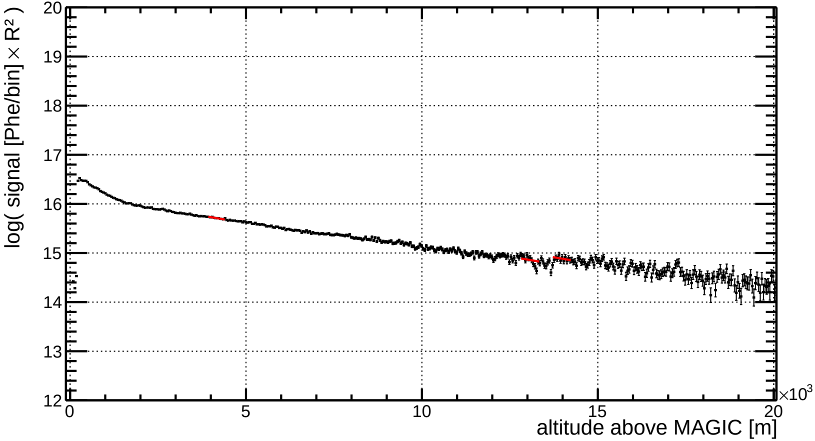
$$\mathrm{d}N(r) = N_0\ C\ G(r)\ \frac{A}{r^2}\ \beta(r)\mathrm{d}r\ \exp\left(-2\int_0^r \sigma(r')\mathrm{d}r'\right)$$

- N_0,$\mathrm{d}N(r)$: photons: in laser pulse, in range bin
- C,$G(r)$: overall efficiency, overlap (laser-FOV) and focus effects
- $\frac{A}{r^2}$: solid angle (detector seen from location of scattering)
- $\beta(r)\mathrm{d}r$: volume backscattering coefficient times range bin length
- $\exp\left(-2\int_0^r \sigma(r')\mathrm{d}r'\right)$ total attenuation on the way
- two unknown functions: $\beta(r)$ and $\sigma(r)$
- $\frac{1}{r^2}$ dependency demands for high dynamic range

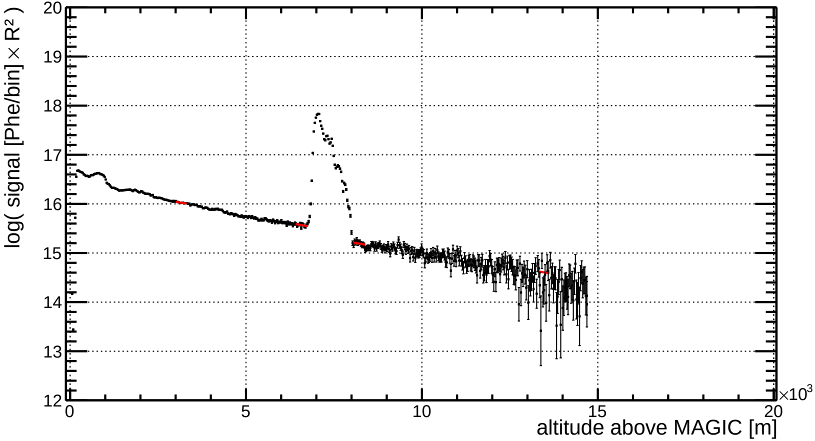
LIDAR “raw” data

- Photon counts from range $r = 0.5 \cdot c \cdot t$
- Have $1/r^2$ dependence due to collector solid angle effect
- Multiplication with r^2 gives “attenuated backscatter” signal
- Rayleigh scattering alone gives signal too
- Clouds/aerosols increase backscatter signal
- But also lead do increased extinction of what lies behind

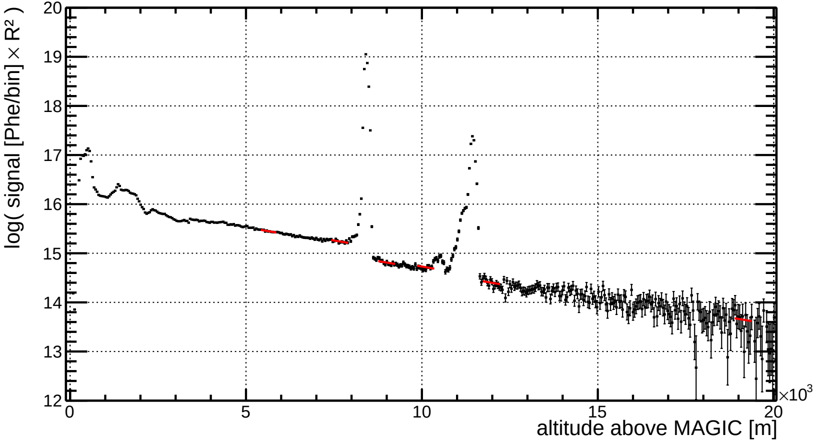
LIDAR "raw" data



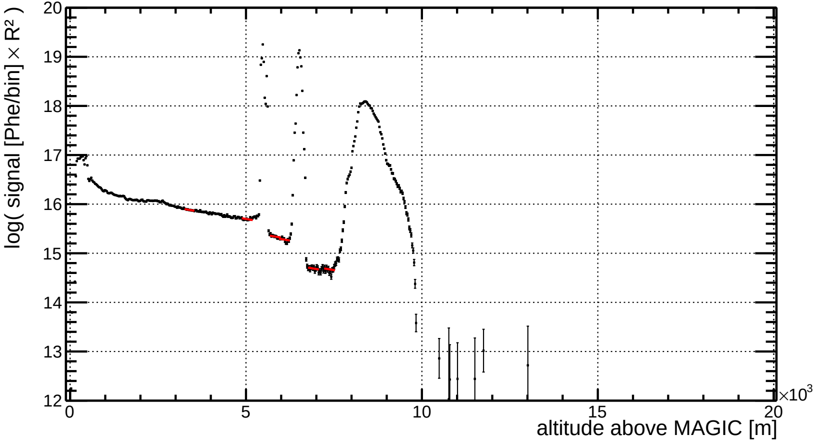
LIDAR "raw" data

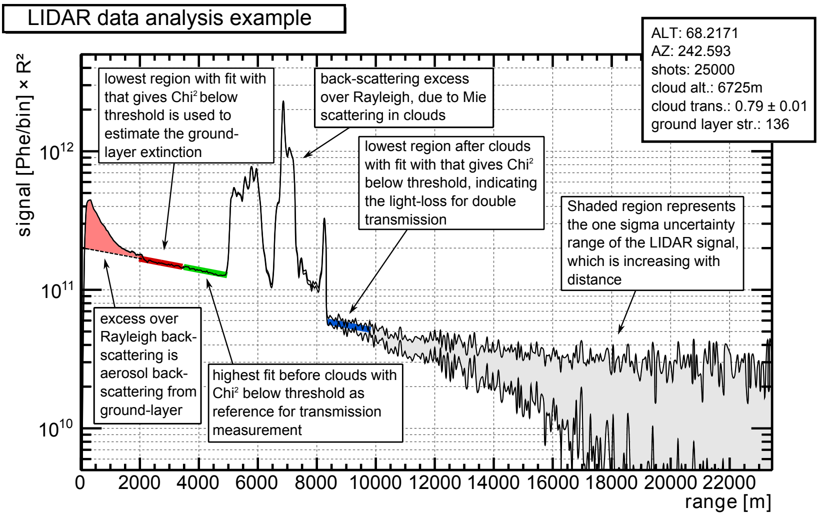


LIDAR "raw" data



LIDAR "raw" data

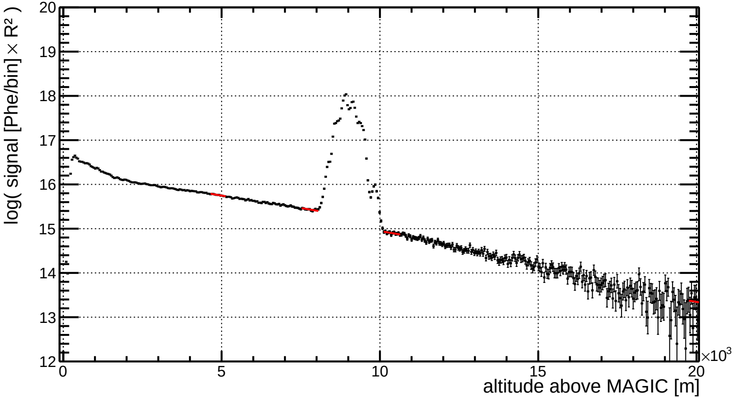



LIDAR data analysis example
ALT: 68.2171
AZ: 242.593
shots: 25000
cloud alt.: 6725m
cloud trans.: 0.79 ± 0.01
ground layer str.: 136
signal [Phe/bin] × R²
range [m]
lowest region with fit with that gives Chi² below threshold is used to estimate the ground-layer extinction
back-scattering excess over Rayleigh, due to Mie scattering in clouds
lowest region after clouds with fit with that gives Chi² below threshold, indicating the light-loss for double transmission
Shaded region represents the one sigma uncertainty range of the LIDAR signal, which is increasing with distance
excess over Rayleigh back-scattering is aerosol back-scattering from ground-layer
highest fit before clouds with Chi² below threshold as reference for transmission measurement

How to get extinction coefficient for single w.l. LIDAR

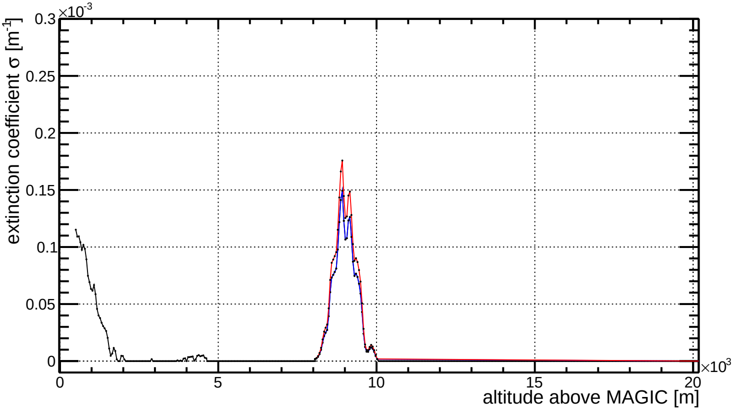
- Two independent methods:
- Extinction Method
  - Basic assumptions:
  - There is regions with highly dominant Rayleigh scattering
  - Atmospheric density profile is locally exponential
  - Extinction can be “measured” directly by comparing signals from Rayleigh scattering before and after the cloud
- LIDAR-ratio Method
  - Basic assumptions:
  - The LIDAR ratio (extinction to backscattering ratio) does not vary much for typical situations
  - This LIDAR ratio is known
  - Extinction can be calculated from aerosol scattering excess

Extinction Method



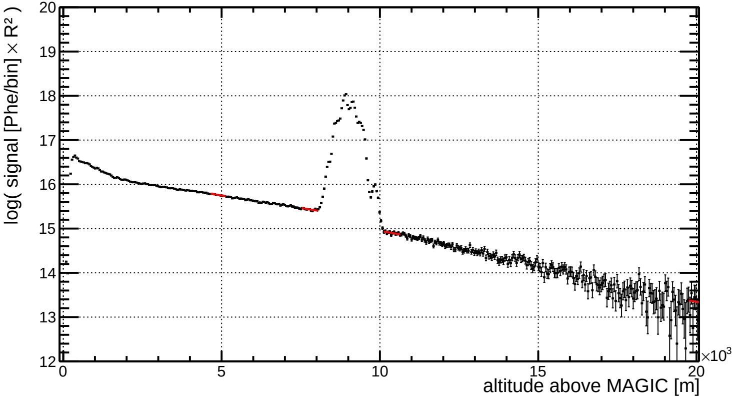
$$\alpha_{aer}(h) = \sqrt{\frac{C_2}{C_1}} \cdot \frac{S(h) - \overline{S}_{mol}(h)}{\int_{h_1}^{h_2} \left(S(h) - \overline{S}_{mol}(h)\right) \mathrm{d}h}$$

Extinction Method



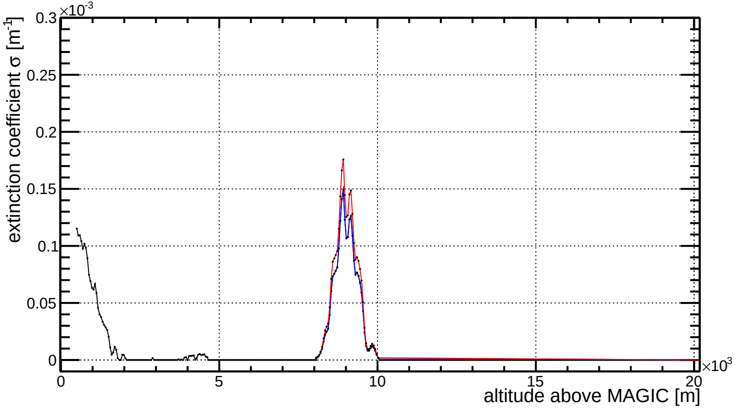
$$\alpha_{aer}(h) = \sqrt{\frac{C_2}{C_1}} \cdot \frac{S(h) - \overline{S}_{mol}(h)}{\int_{h_1}^{h_2} \left(S(h) - \overline{S}_{mol}(h)\right) \mathrm{d}h}$$

LIDAR-ratio Method



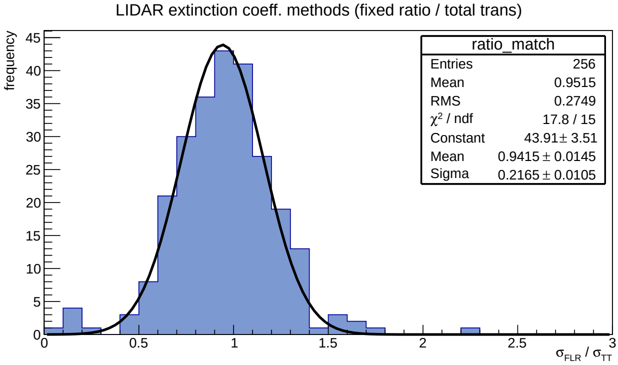
$$\alpha_{aer}(h) = K_{aer} \cdot \beta_{mol}(h) \cdot \frac{S(h) - \overline{S}_{mol}(h)}{\overline{S}_{mol}(h)}$$

LIDAR-ratio Method



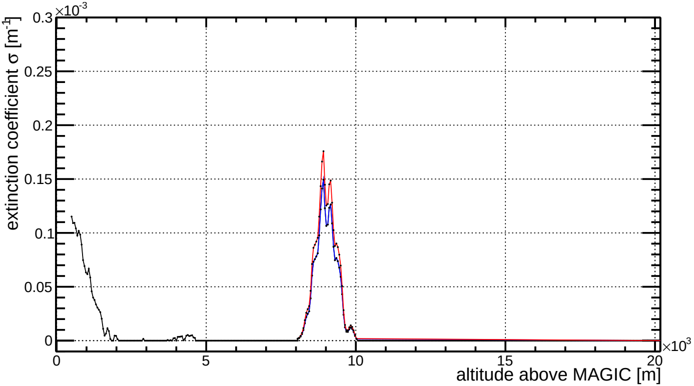
$$\alpha_{aer}(h) = K_{aer} \cdot \beta_{mol}(h) \cdot \frac{S(h) - \overline{S}_{mol}(h)}{\overline{S}_{mol}(h)}$$

Cross-checking both methods



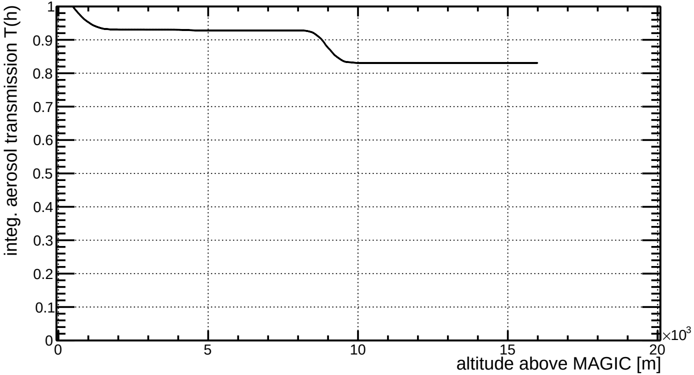
- Choose right method in right situation to minimize systematic errors
- Optically thin clouds ($T \lesssim 0.1$) $\Rightarrow$ LIDAR-ratio Method
- Optically thick clouds ($T \gtrsim 0.1$) $\Rightarrow$ Extinction Method

Total transmission



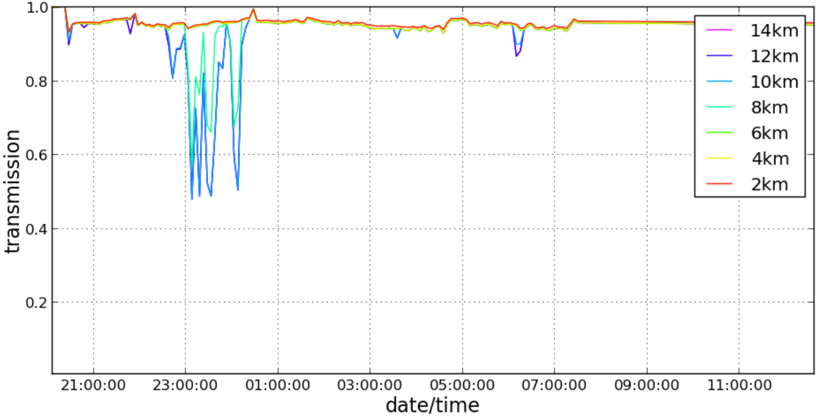
$$T_{aer}(h) = \int_{h_0}^{h} \alpha_{aer}(h)\mathrm{d}h \tag{1}$$

Total transmission

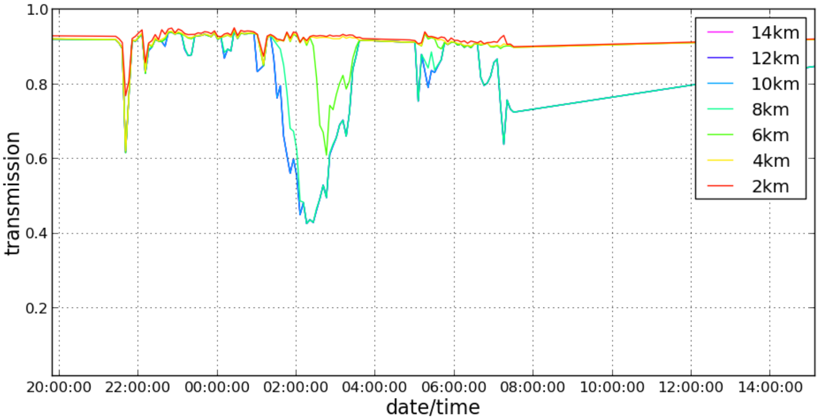


$$T_{aer}(h) = \int_{h_0}^{h} \alpha_{aer}(h) dh \qquad (1)$$

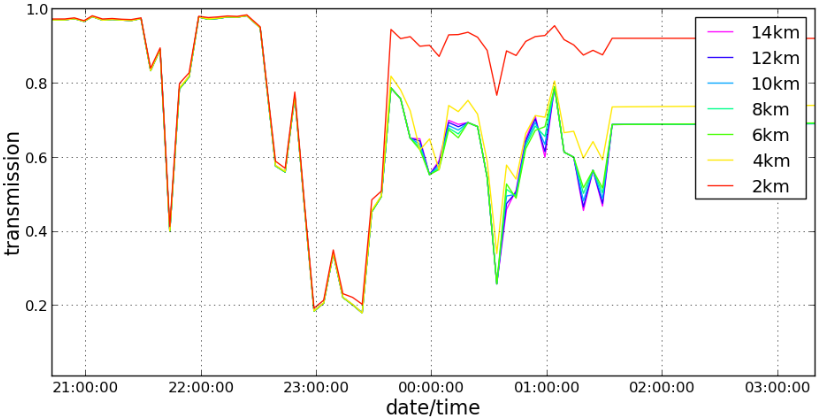
Examples


1.0
0.8
0.6
0.4
0.2
transmission
21:00:00
23:00:00
01:00:00
03:00:00
05:00:00
07:00:00
09:00:00
11:00:00
date/time
14km
12km
10km
8km
6km
4km
2km

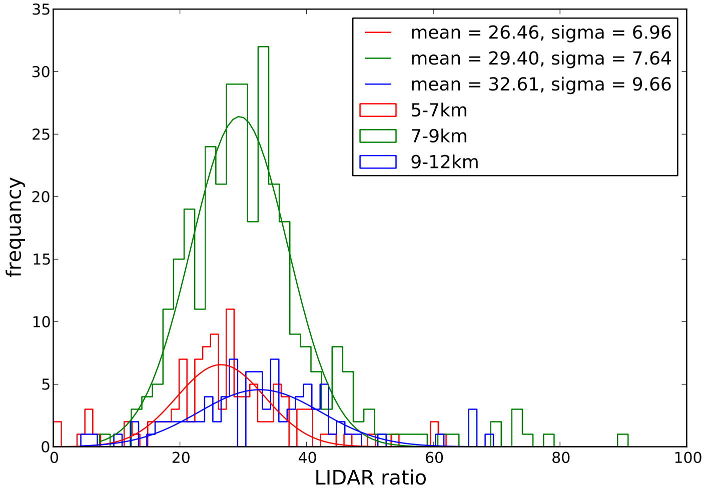
Examples


1.0
0.8
0.6
0.4
0.2
transmission
20:00:00
22:00:00
00:00:00
02:00:00
04:00:00
06:00:00
08:00:00
10:00:00
12:00:00
14:00:00
date/time
14km
12km
10km
8km
6km
4km
2km

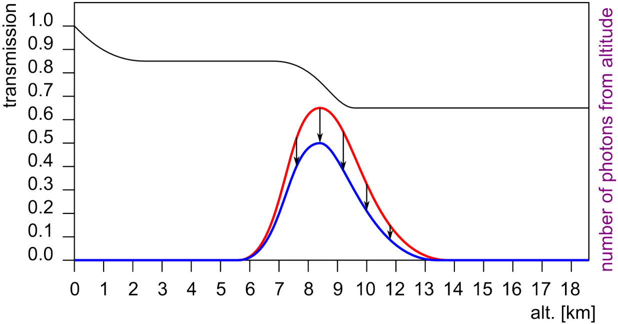
Examples


1.0
0.8
0.6
0.4
0.2
transmission
21:00:00
22:00:00
23:00:00
00:00:00
01:00:00
02:00:00
03:00:00
date/time
14km
12km
10km
8km
6km
4km
2km

Examples


mean = 26.46, sigma = 6.96
mean = 29.40, sigma = 7.64
mean = 32.61, sigma = 9.66
5-7km
7-9km
9-12km
frequancy
LIDAR ratio
0
5
10
15
20
25
30
35
0
20
40
60
80
100

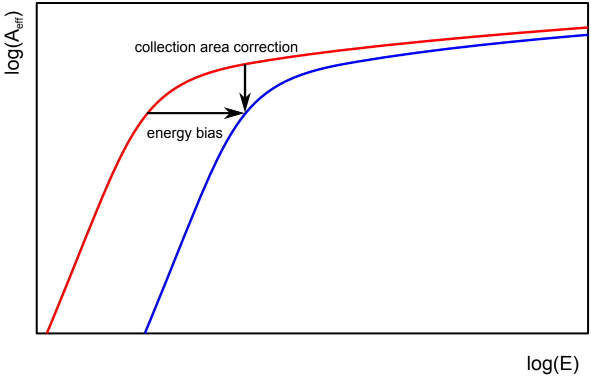
Energy correction



$$\overline{\tau} = \int_0^{h_{max}} \epsilon(h) \cdot T_{aer}(h)\, \mathrm{d}h \tag{2}$$

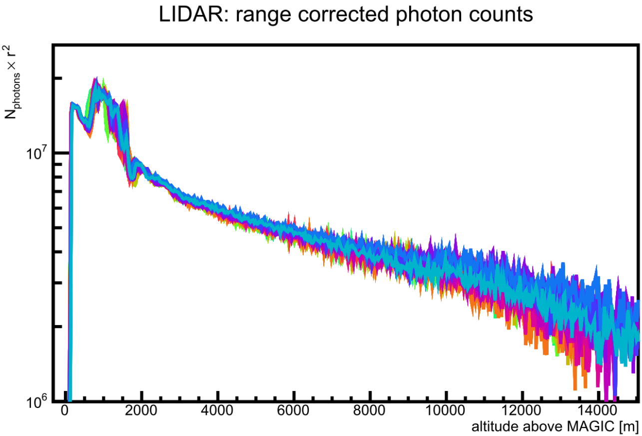
$$E_{true} = \frac{E_{est}}{\overline{\tau}} \tag{3}$$

Collection area correction



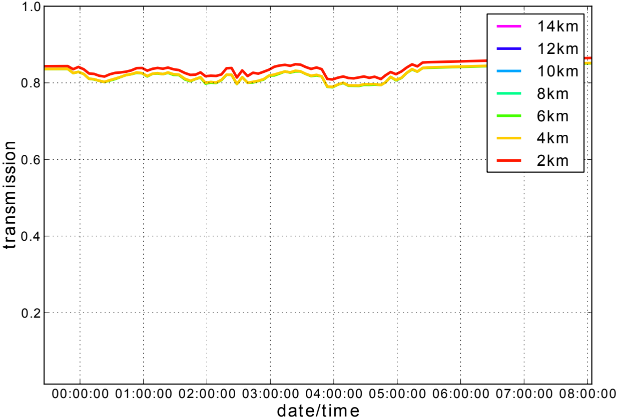
- Wrongly reconstructed energy also leads to error in A_{eff}
- Event migrates to higher energy bin (Energy correction)
- A_{eff} for this bin is higher but real trigger efficiency is decreased
- Can assume that “An event that is affected by atmospheric extinction looks like an event of lower energy to the telescopes”

First tests with the Crab Nebula



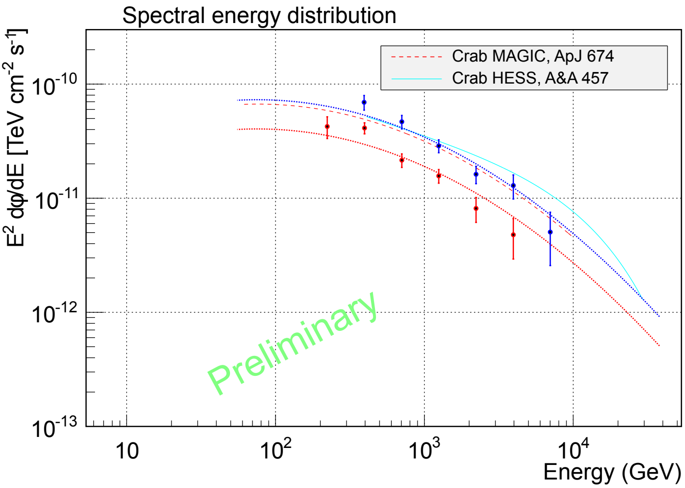
- last days with "Calima" (Sahara dust intrusion) in beginning of September 2013
- should be easy to correct since shower is not "deformed" by aerosol layer

First tests with the Crab Nebula

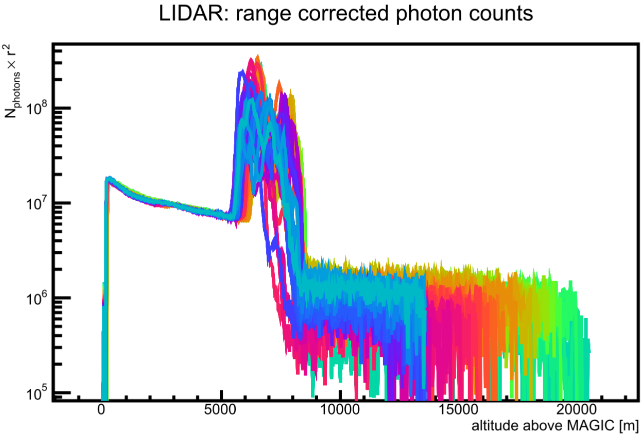


- transmission is at constantly $\sim 80\%$
- about 20% upscaling of the energy will be needed ...

First tests with the Crab Nebula

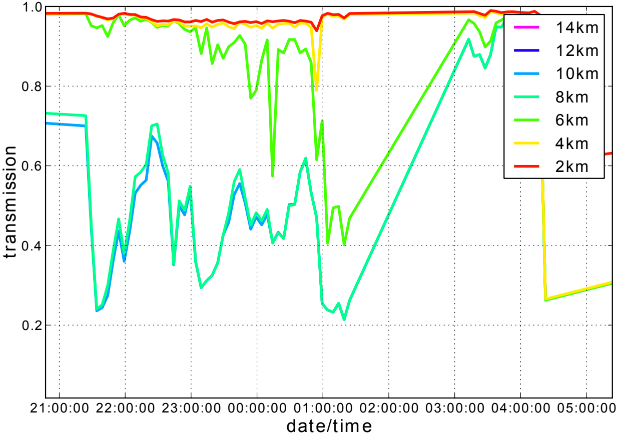


First tests with the Crab Nebula



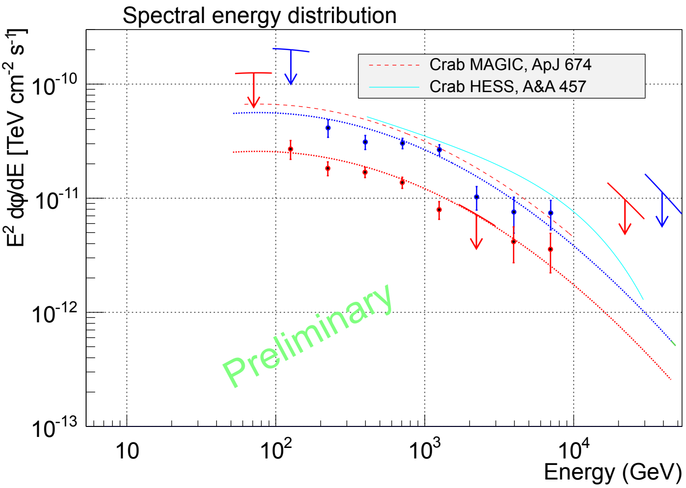
- this is a “horrible” example of cloudy sky conditions that can occur on La Palma from time to time
- it is hard to believe that IACTs can work properly under such conditions

First tests with the Crab Nebula

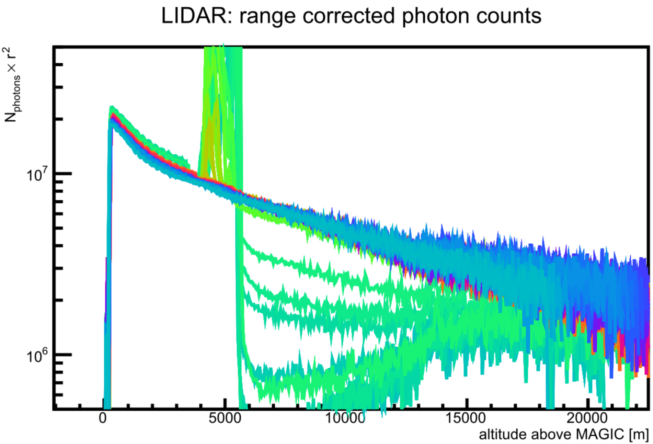


- actually part of the data (>50%) had to be removed because the transmission was below 40% for the given sample
- here air-showers get “truncated” and therefore the “hadronnes” cuts have to be relaxed to the maximum in order to not exclude such events

First tests with the Crab Nebula

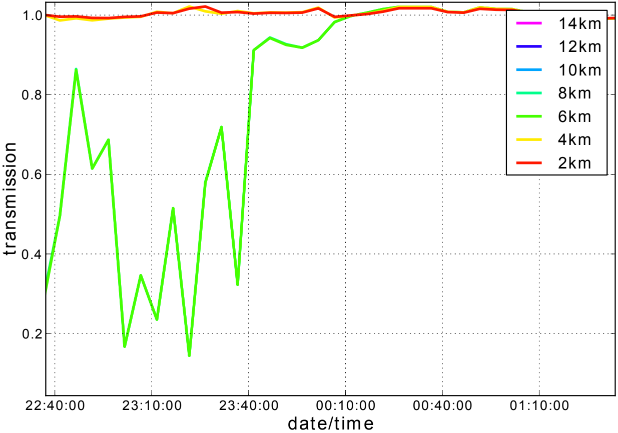


First tests with the Crab Nebula



- another quite cloudy example from Dec 24th 2013
- this time medium level clouds of quite high opacity

First tests with the Crab Nebula



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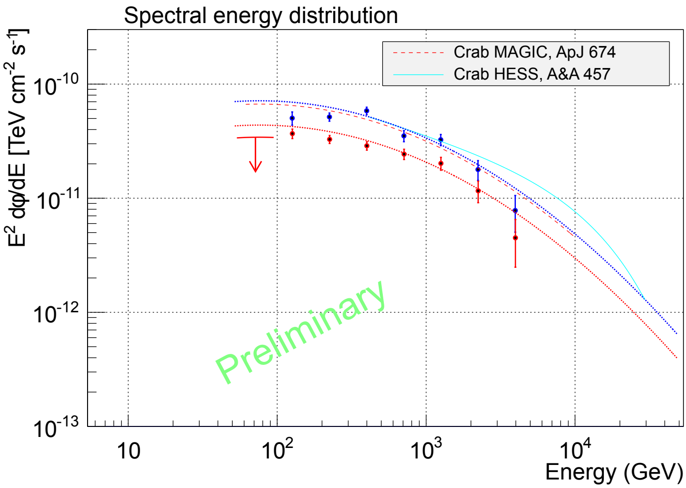
First tests with the Crab Nebula



- MAGIC LIDAR system running and providing useful data on a nightly basis
- introduced pragmatic method for extracting of the aerosol transmission from the LIDAR returns
- developed a straight forward approach for data correction based on simplified shower model
- first tests with Crab Nebula data promising good performance
- method will be very useful for making light-curves and precision measurements of strong sources

Thanks for your attention!