A new LIDAR system for the MAGIC telescopes

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MAGIC
Major Atmospheric
Gamma Imaging
Cerenkov Telescopes

Max-Plank-Institut für Physik

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Imaging Airshower Cherenkov Telescope (IACT) Technique and LIDAR

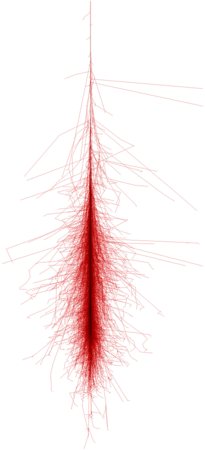
The MAGIC micro LIDAR system

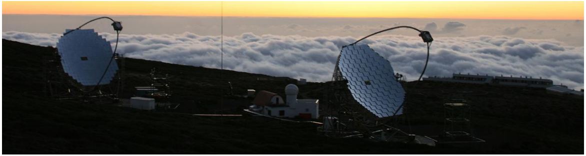
First measurements and their evaluation

Conclusion

The atmosphere as imaging calorimeter

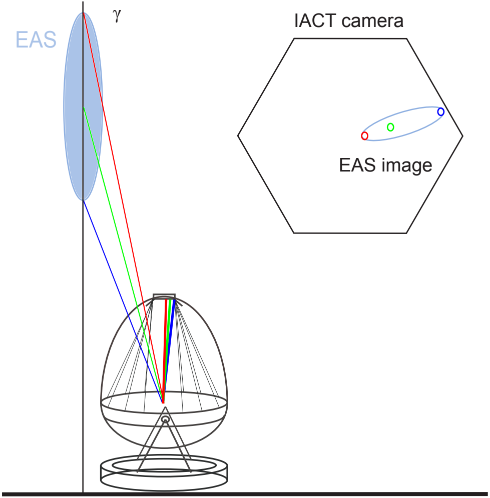
- indirect observation method in the VHE-γ regime
- light not from astronomical source but generated in the atmosphere
- precise knowledge of the optical conditions important to reconstruct primary energy





The IACT technique

- different altitudes are projected into different parts of the image
- airshower geometry can be reconstructed from image
- position in image can be related to altitude



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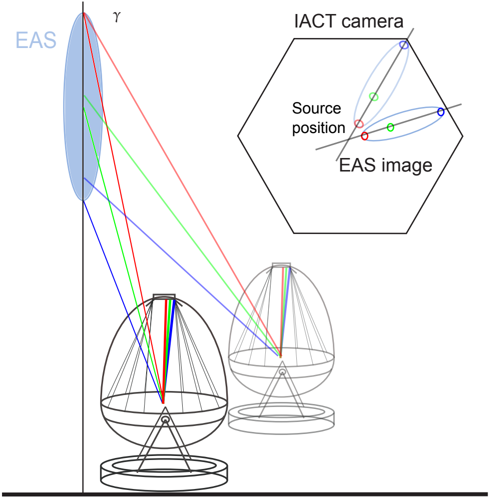
- position in image can be related to altitude
- stereo observations improve reconstruction accuracy



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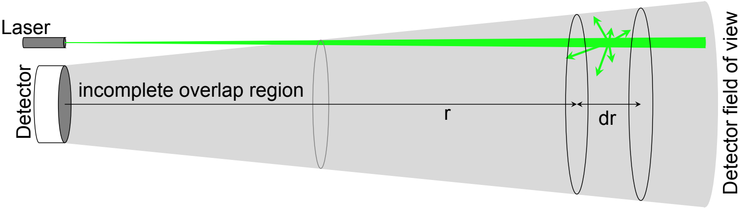
⇒ LIDAR: Light Detection And Ranging



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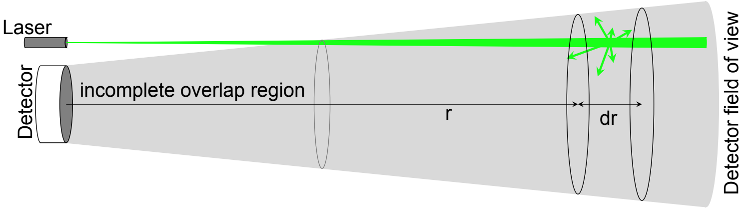

$$\mathrm{d}N(r) = N_0\ C\ G(r)\ \frac{A}{r^2}\ \beta(r)\mathrm{d}r\ \exp\left(-2\int_0^r \sigma(r')\mathrm{d}r'\right)$$

- 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 $\sigma(r)$

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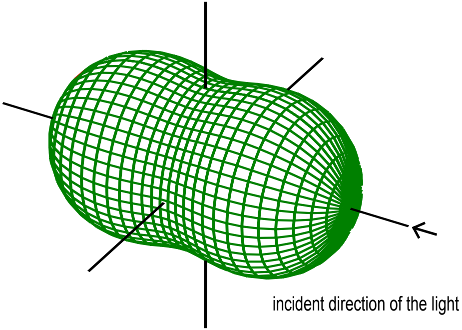

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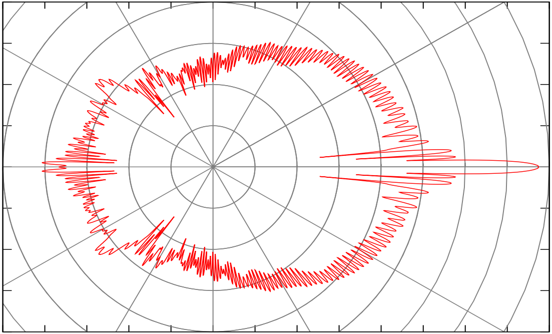
- otherwise solution of the LIDAR equation not possible (aerosols, example: Mie 10 $\mu\mathrm{m}$ water sphere, light from left)



Strategies about these difficulties

- multi wavelength, Raman or High Spectral Resolution LIDAR (HSRL)

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- Klett's backintegration method:
  need some relationship between backscattering β and total scattering σ (empirical) [J. D. Klett 1981]

$$\beta = const.\ \sigma^k, \quad k \approx 0.7\ ..\ 1.0$$

$$\sigma(r) = \frac{\exp\left(\frac{S(r)-S_m}{k}\right)}{\frac{1}{\sigma_m} - \frac{2}{k}\int_r^{r_m} \exp\left(\frac{S(r)-S_m}{k}\right) \mathrm{d}r'}$$

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- but: not really useful for our application

The LIDAR system at the MAGIC site

- recently installed inside the LIDAR tower in a weather proof dome
- on top of the counting house $\approx 50\,\mathrm{m}$ from both telescopes
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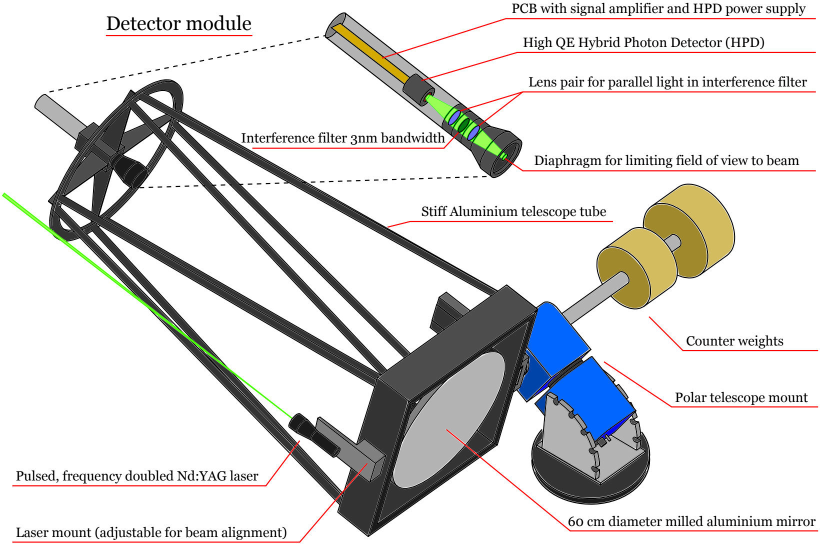
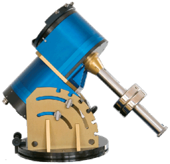

Detector module
PCB with signal amplifier and HPD power supply
High QE Hybrid Photon Detector (HPD)
Lens pair for parallel light in interference filter
Interference filter 3nm bandwidth
Diaphragm for limiting field of view to beam
Stiff Aluminium telescope tube
Counter weights
Polar telescope mount
Pulsed,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

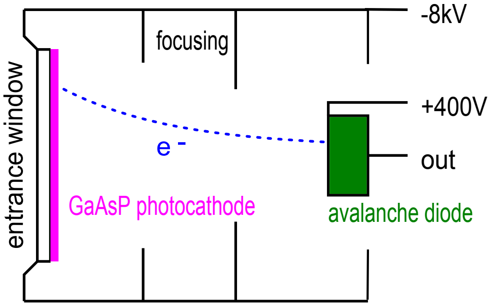
LASER, optics and mount

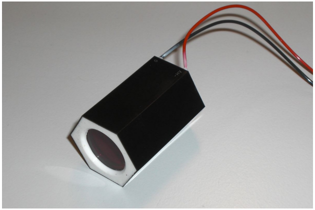
- frequency doubled, passively Q-swiched Nd:YAG 532 nm
- pulse energy and width: 5.1 μJ, 0.5 ns
- pulse frequency: with external trigger up to 2 kHz
- beam expander optics 10$\times$ to reduce the beam divergence
- telescope: mirror diameter 60 cm, focal length: 160 cm

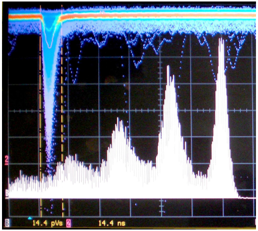


- equatorial robotic mount
- designed for EELT site-search
- 80kg load plus counterweights
- ASCOM interface support

- HAMAMATSU R9792U-40 operated at up to 8kV
- HPD gain ≈ 100000
- QE ≈ 50 % at 532nm







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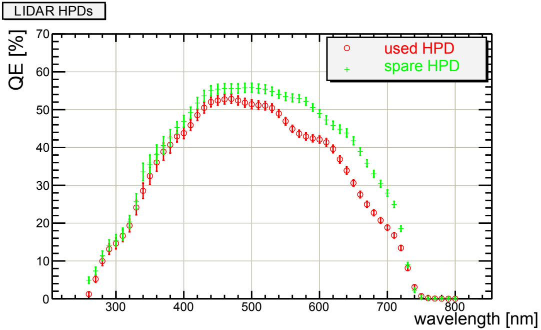
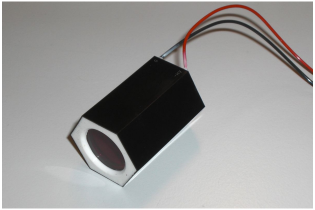
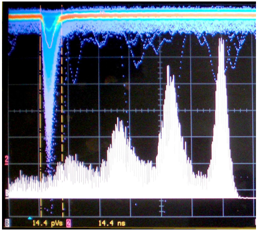
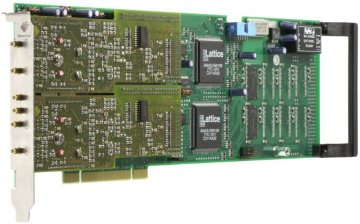




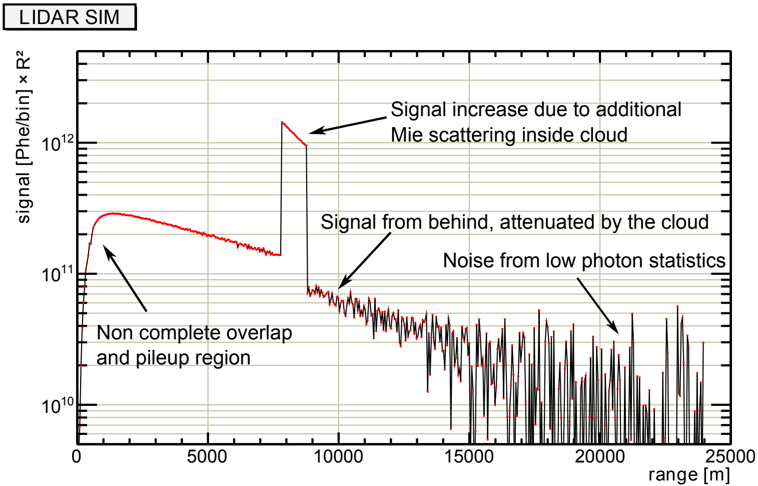


Readout and data analysis



- PCI FADC Spectrum MI.2030, 8bit, 200MSample/s in PC: Intel Q6600, 4GB
- recording triggered by internal laser PIN-diode
- for 50k shots, $\approx$ 2GB of memory are used for raw data
- single photon counting and background subtraction by software

Simulations and an introduction to LIDAR return signals



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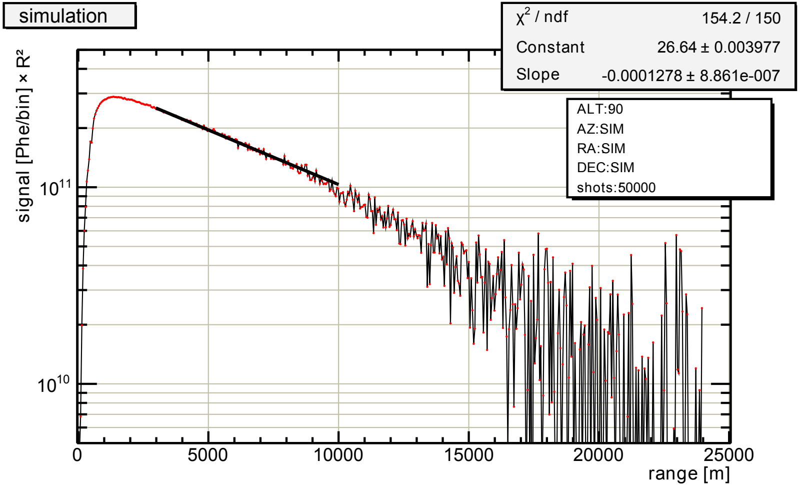

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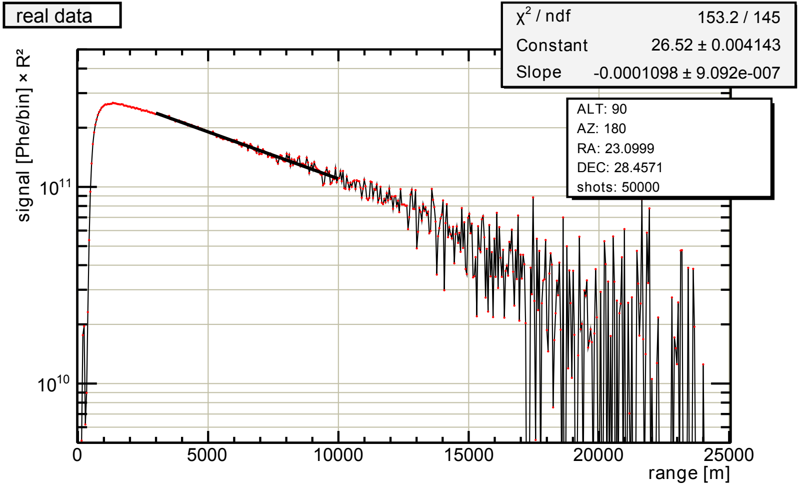
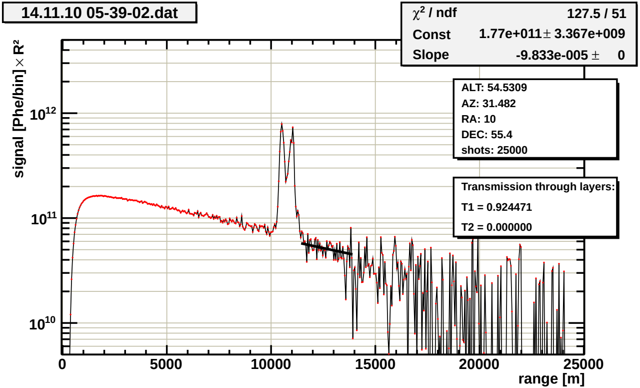


Determining the light extinction of a thin cloud layer



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$$N(r) \cdot r^2 = C \cdot \exp s \cdot r; \quad T = \sqrt{C_2/C_1}$$

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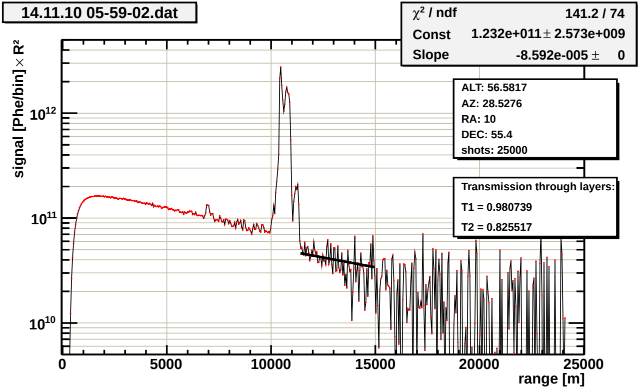

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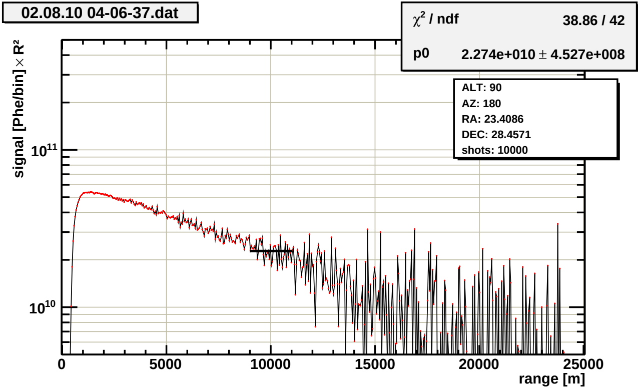

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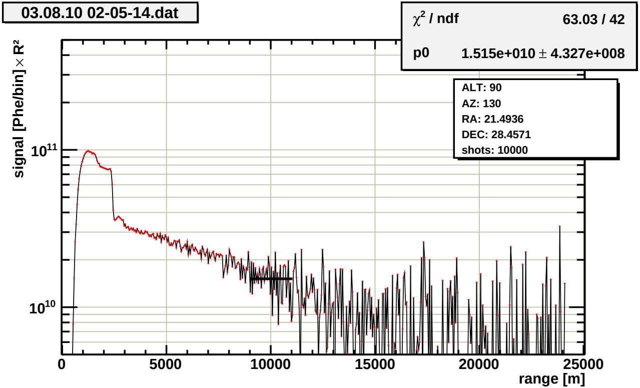

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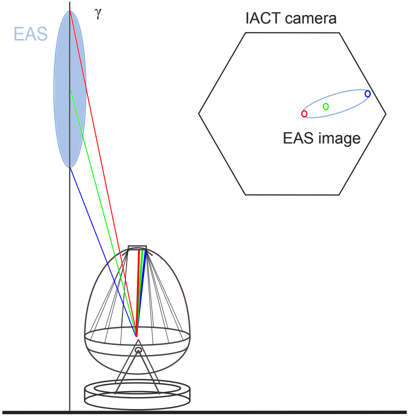
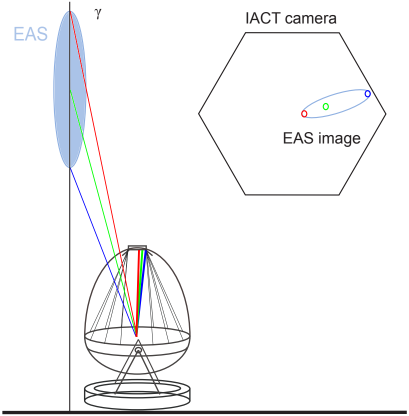


How to correct the energy spectra

- determine location and light extinction of a thin aerosol or cloud layer
- extrapolate extinction to Cherenkov spectrum (Mie scattering roughly wavelength independent)
- then either use large sets of Monte Carlo simulations
- or directly apply to data if possible



- still in testing phase
- need to avoid disturbing MAGIC measurements or the other telescopes on the Roque de los Muchachos
- parallel operation during MAGIC observations has already started

Thanks for your attention!