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A LIDAR for atmospheric studies for the 17 m diameter MAGIC telescope

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Abstract. A LIDAR, based on the detection of single backscattered photon, is under construction at the MPI for Physics in Munich. It is envisaged to be operated simultaneously with the 17 m diameter MAGIC air Cherenkov telescope. The LIDAR will allow one to measure the aerosol height distribution in the atmosphere. This information can be used to correct for light losses in air showers due to scattering on aerosols and thus to improve the energy estimate of the primary particles measured by MAGIC. A 50 cm diameter Al-mirror is used in the LIDAR together with a $2.5 \cdot 10^{-6}$ J per 0.6 ns pulsed Nd:YAG-laser at 532 nm. The status and the first measurements will be reported.

1 Introduction

The 17 m MAGIC telescope (Lorenz et al., 2001), (Barrio et al., 1998), presently under construction, is a new Imaging Air Cherenkov Telescopes (IACT) for gamma astronomy from 30 GeV (12 GeV in phase II) to 30 TeV. Since air showers develop in the atmosphere, changes of the atmospheric transmission due to dust, haze, water droplets etc. need to be monitored.

A promising solution might be provided by a low power LIDAR (LIght Detection And Ranging). It basically consists of a pulsed laser, a spherical mirror for collecting the backscattered photons and a photo detector sensitive to single photons. Measuring the arrival time and the intensity of the backscattered photons allows one to measure the transmittance of the atmosphere.

2 Motivation

The main development of air showers generated by cosmic rays respectively gamma rays takes place in the range of around 5 to 15 km above sea level. Cherenkov light emitted by relativistic charged particles still has to travel through a thick layer of atmosphere to reach the ground level. Different scattering and absorption processes affect the light on its way down. For the new generation of highly sensitive IACTs it is necessary to correct the data for these variable losses in order to make full use of the telescope's potential.

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The ozone layer which absorbs very effectively radiation in the UV from 280 nm to 340 nm is in the upper part of the atmosphere. This layer varies with time in height and concentration and makes it difficult to make predictions of losses.

Rayleigh scattering refers to the scattering of light off the air molecules and can be extended to scattering from particles up to about a tenth of the wavelength of the light.

$$\frac{dN_\gamma}{dl} = -\frac{\rho N_\gamma}{X_R}\left(\frac{\lambda_R}{\lambda}\right)^4$$

where ρ is the air density (can be approximated as $\rho(h) = \rho_0 exp\left(-\frac{h}{H}\right)$ where H is the atmospheric scale height, typically $H \sim 7$ km, h is the height above sea level and $\rho_0 = 0.00129$ g/cm^3 is the air density at 0^0C at sea level for an isothermal atmosphere), $X_R = 2970$ g/cm^2 is the mean free path for scattering at λ_R = 400 nm and N_γ is the number of photons in the light beam, and l the unit length. For the intensity of scattering around a specified direction, one can write (Sokolsky, 1989):

$$\frac{dN_\gamma}{d\Omega} = \frac{3}{16\pi}\left(\frac{dN_\gamma}{dl}\right)(1 + cos^2\theta)$$

The annual variation of the Rayleigh scattering is small since the density profile of the atmosphere changes by just $\sim$ 10 g/cm^2, while the whole atmosphere is 1037 g/cm^2. Rayleigh scattering is a molecular process and its effects are well predictable.

Aerosol, or Mie, scattering is quite complex. It has a strong dependence on scattering angle which varies with aerosol size, aerosol shape and dielectric constant. It is the scattering of an electromagnetic wave by particles or refractive index inhomogeneities of a size in the order of roughly the size of

the wavelength. This scattering produces a pattern like an antenna lobe, with a sharper and more intense forward lobe for lager particles. Mie scattering is not strongly wavelength dependent and produces for example the almost white glare around the sun when a lot of particulate material is present in the air or the white light from mist and fog.
Mie or aerosol scattering can change on a minute timescale. Therefore it is very important for the analysis of any IACT data to know the actual scattering parameters, i.e. the height, thickness and density of any aerosol layer overhead.

3 The prototype LIDAR

3.1 The operation principle

The LIDAR is pointing in the same observation direction as MAGIC. The pulsed laser produces a series of short light pulses. Along the path of the laser beam some photons are backscattered. Their intensity varying with the content of Mie scatterers. These backscattered photons are collected by a mirror and focused onto a Photo Multiplier Tube (PMT) which is able to detect single photons. The arrival time and the density of the backscattered photons provide information on the distance and the density of scatterers along the laser pulse path. This information is used to determine the coefficient for Mie scattering σ_M which can be used in Monte Carlo simulations for correction of the energy spectrum of γ ray sources. The following plot shows a simulated response of the LIDAR for the parameters of our setup.

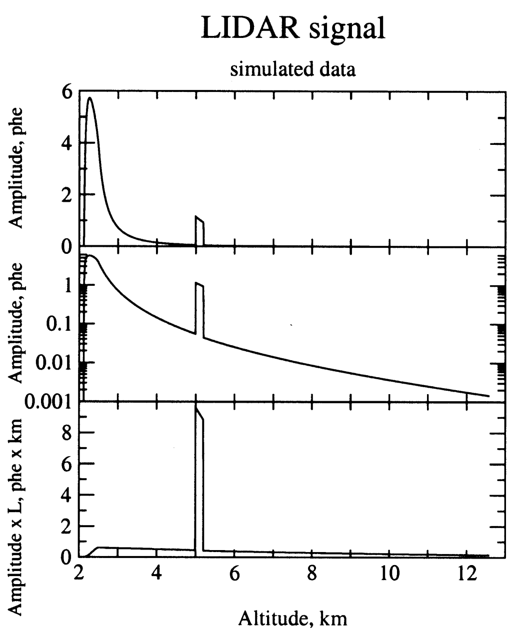

Fig. 1. Simulated LIDAR signals with 40 ns integration time (equivalent to 6 m bins) in different scales. The peak at 5 km altitude corresponds to Mie scattering layer with a scattering coefficient that is a factor 20 higher than the Rayleigh one

The actual drop in the signal after the peak at 5 km is barely visible on these plots. One can see, for example, if one wants to obtain a Rayleigh scattered signal of 20 photoelectrons (phe) from a layer at 10 km height, one needs 5000 laser shots, which means one has to shoot 50 s at a rate of 100 Hz (see middle plot in Fig. 1).

3.2 The technical realization

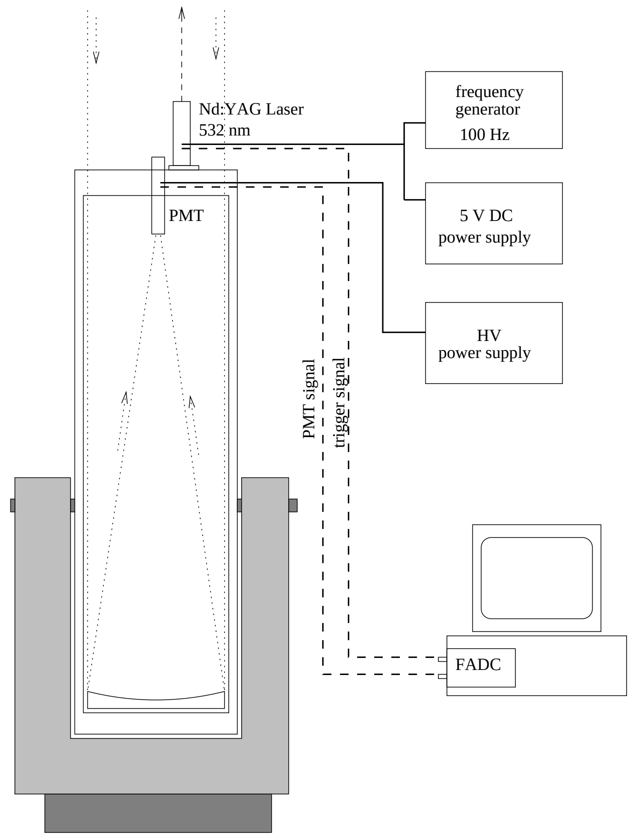

Fig. 2. Schematic diagram of the LIDAR

The laser is a pulsed Nd:YAG laser operating on the second harmonic, i.e. λ = 532 nm. The energy output per pulse is $2.5 \cdot 10^{-6}$ J with FWHM = 0.6 ns. The Pulse frequency is limited to 100 Hz, to allow operation as eye-save laser with less than 1 mW output. The laser beam is adjusted parallel to the optical axis of the telescope. The beam divergence is 1 mrad. A photo diode inside the laser provides a fast trigger signal for the data acquisition (DAQ) whenever a light pulse is generated.

The all aluminum 50 cm spherical mirror with a focal length of 145 cm and a reflectivity of 0.85 is diamond machined. The light detector consists of an adjustable diaphragm, two lenses, an interference filter with a transmission of 40 % at 532 nm and 10 nm bandwidth and a PMT with a quantum efficiency of 12 % at the observed wave length.

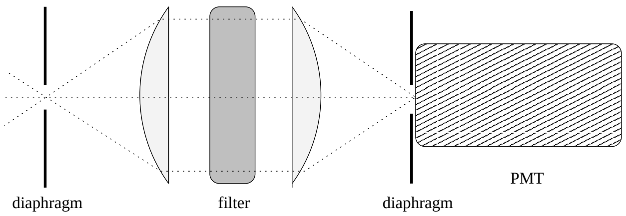

Fig. 3. Schematic diagram of the optical system

The custom made alt-azimuth mount is driven by two stepper motors with gear boxes. The motors are controlled by two CANopen motor controllers. The position of the telescope is indicated by two CANopen 14 bit shaft encoders. The main electronic components are the power supplies and frequency generator to operate the laser and a HV power supply for the PMT. The PMT is readout by a Flash Analog to Digital Converter (FADC) installed as an ISA card in a Linux PC. The bin size of the FADC determines the resolution along the light path. A custom driver has been written that allows to operate the card under Labview.

4 First results measuring distant thin clouds

The first measurements were obtained at the yard of MPI in Munich. Cloud layers are clearly seen in Fig. 4, which shows a typical time profile of a measurement (display copy of a storage scope). Channel 1 is the trigger signal from the photo diode (left lower corner) and channel 2 shows the PMT readout. The big peak is due to Rayleigh scattering in the first 200 to 300 m and the aerosol scattering in the ground layers of the atmosphere. The second peak is a cloud layer at 3.1 km distance while the third and fourth ones are layers 250 m and 350 m above the first cloud. Sampling time is 10 s.

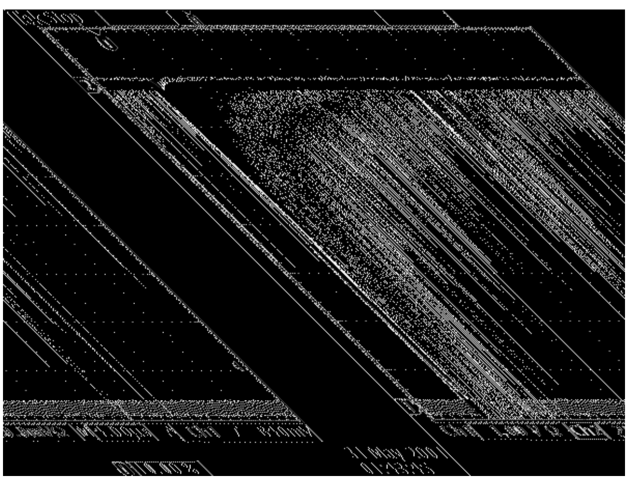

Fig. 4. The measurement of the Munich sky shows several cloud layers

4.1 Problems and Solutions

The first measurements show a high light background, which makes it difficult to measure small aerosol densities. Part of this problem is caused by strong light pollution of the Munich area. The next measurements will be carried out at darker sites. Also the use of a filter with narrower bandwidth should bring improvements. So far measurements are carried out only for a single fixed wavelength. The use of different wavelength would be useful and would make it possible to constrain the aerosol size.

5 Conclusion

The LIDAR will be a useful tool for the MAGIC telescope. There are still hardware and software improvements to be done. More thorough observation of the atmospheric conditions especially in La Palma at the site of the MAGIC telescope are needed.

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