The LIDAR System for Atmospheric Monitoring in Pierre Auger Observatory

S.Argiró, R.Cester, M.Chiosso, M.Mostafá, R.Mussa, G.Sequeiros
Università and INFN , Torino (ITALY)
J.Matthews, M.Roberts
University of New Mexico, Albuquerque, NM (USA)
A.Filipčič, D.Veberič, M.Horvat, D.Zavrtanik, M.Zavrtanik
Jožef Stefan Inst. , Ljubljana and Nova Gorica Polytechnic (SLOVENIA)

Atmospheric Monitoring in Auger Observatory

The Pierre Auger Observatory will study ultra high energy cosmic rays using two complementary techniques: muon detection at ground level , and atmospheric fluorescence. It is crucial to have a complete systematic understanding of energy measurements done by both detectors. The fluorescence detector (FD) substantially uses our atmosphere as a calorimeter, to detect the EM component of the cosmic air showers. Given the variability of its parameters, atmospheric monitoring plays a fundamental role [1] in our understanding of the energy corrections. A multi-fold plan of attack [2] is currently under preparation to get the most thorough understanding of the atmospheric conditions on site: balloon launches, IR camera imaging, LIDAR stations.
*In this paper we report about the LIDAR system, which is currently under construction on site, near Malargue, Mendoza (Argentina).*

Frames and Mirrors

The workhorse of such system will be four movable frames and twelve parabolical mirrors built in 1993 for the EAS-TOP [3] cosmic ray experiment, who took data at Campo Imperatore, Gran Sasso, Italy, and dismissed in 1999. Each mount is equipped with a UV laser source and three parabolical aluminum coated glass mirrors, to focus backscattered UV light on PMTs. Each mirror has an area~0.5m^2, a focal length = 402 mm, and has been aligned within 0.1 degrees to the UV laser source. Each mount is movable within an alt-altazimuthal reference frame.
The whole azimuthal orientation of each telescope is chosen to be pointing towards the axis of each FD building (namely at 30, 120, 210, 300 degrees with respect to North). The relative distance between Lidar station and FD site is ~150 meters. To minimize power consumption, a large counterweight allows to balance the frame within few kilograms. Two DC servomotors steer the frame axes to speeds up to 2 deg/s; active feedback is provided by relative encoders. The absolute pointing direction is known with 0.2 degree accuracy. The whole setup, mounted on a 20' container, is protected by a fully retractable motorized cover. Both frame steering and cover movements are controlled by the MC-204 motion controller, made by Control Techniques, which allows full remote operation of the system, via serial link to a Linux PC.
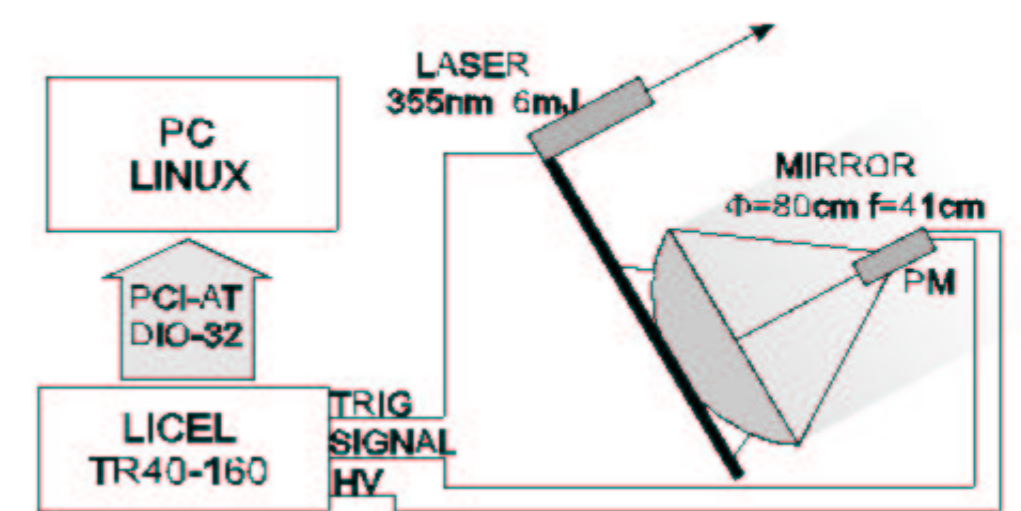
Laser source and trigger

The Lidar shooting activity will follow two schemes: (1) a continuous running on a discrete number of points, scanning the sky above each site on a ~50 degrees cone around the zenith direction; and (2) a shoot-the-shower fast sweep of the sky wherever an interesting event (labeled as T3) is been spotted by the FD. A server running on the Linux PC handles the trigger information from the FD . A GPSY module [4], connected via serial port to the Lidar PC, provides the trigger to the laser,with a fixed delay with respect to the GPS clock.
The currently operating Lidar system at Los Leones uses a 6 mJ flashlamp pumped YAG laser, frequency triplified, made by Brilliant. The laser source emits 5 ns pulses at λ=355 nm, at a repetition rate of 1-20 Hz. The beam divergence is <3 mrad, its stability is 4% at room temperature. In order to fit the dynamic range of the PMTs, though, it was necessary to operate the laser at energies about 0.1 mJ. We plan to replace the current laser with a diode pumped YAG laser , which can shoot 0.1 mJ pulses at >1 kHz repetition rates.

Signal Processing

The light reflected from each mirror is detected by Hamamatsu R7400 PMTs, operated at Voltages between 550 and 800 Volts. To suppress sky background, we use a UG-1 filter with 60% transmittace at 353 nm, FWHM=50 nm.
The PMT signals are digitized by a LICEL transient recorder TR40-160 with 12 bit resolution, 40 MHz sampling rate, 16k trace length.
The LICEL can be also operated in single photon counting mode at 250 Mhz.
Each raw Lidar event from 3 PMTs will be 300 kb wide. Averaging of the data is compulsory to reduce the data to a reasonable size. Preprocessing of the data sets will be performed in the Linux PC.
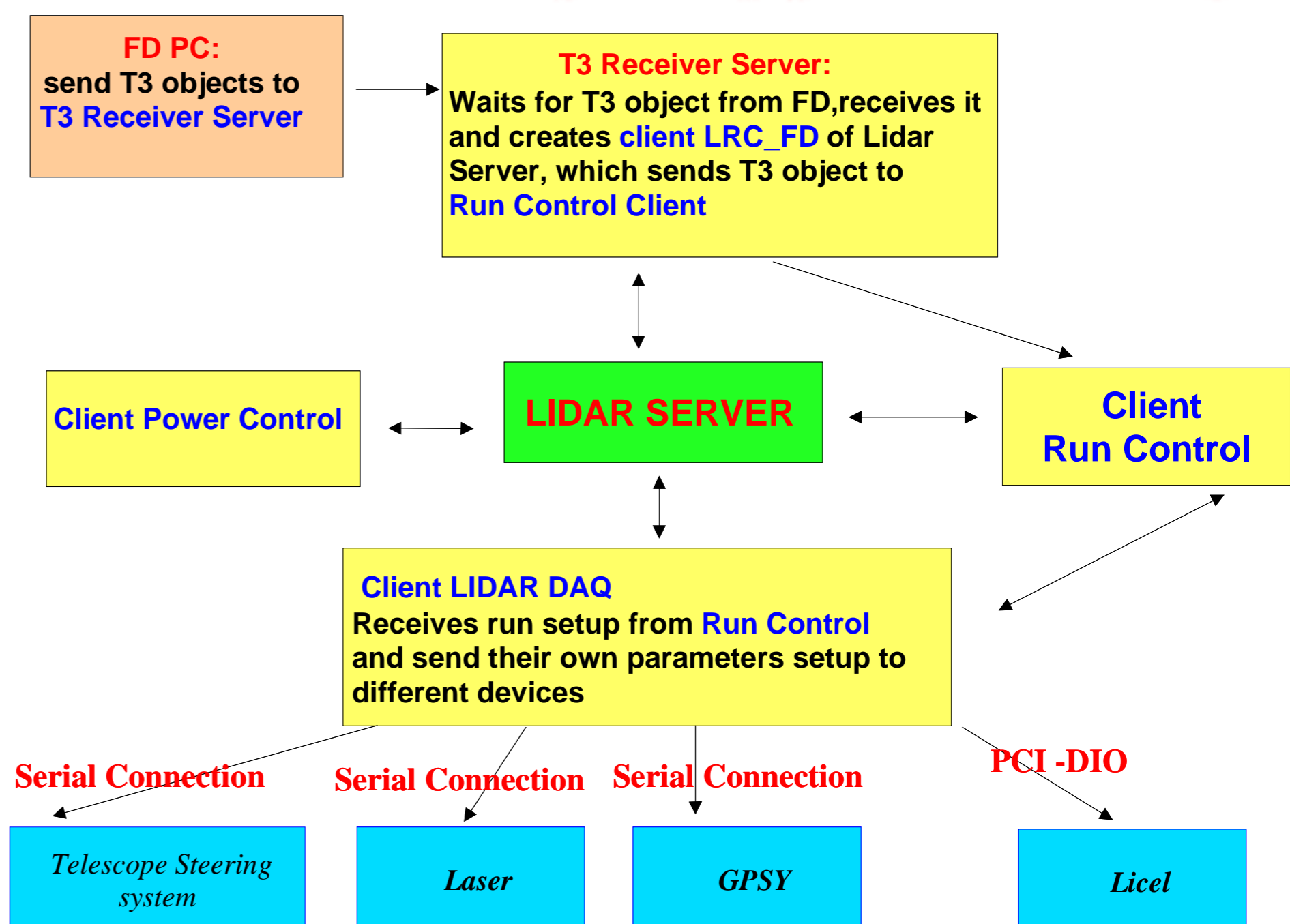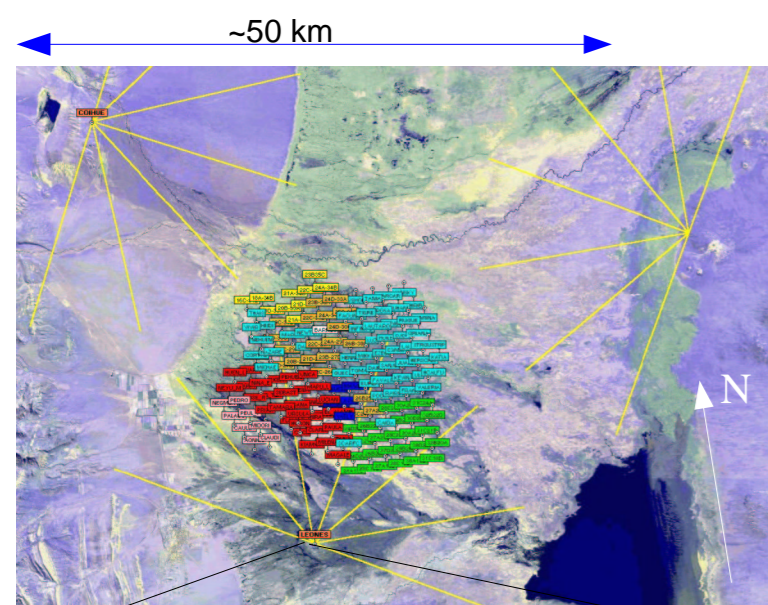
Data Analysis

The backscattered power observed at the PMT from distance R is given by the LIDAR equation:

$$P(R) = K* \beta(R) * R^{-2} * e^{-2\tau(R)}$$

where $\beta(R)$ is the backscattering coefficient and $\tau(R)$ is the optical depth:

$$\tau(R) = {}_0\int^R dr' \, \alpha(r')dr'$$

where $\alpha(r')$ is the extinction coefficient. The two quantities depend linearly on the density N(R) of scattering centers, and are sums of both aerosol and molecular contributions:

$$\alpha(R) = \alpha_{mol}(R) + \alpha_{aer}(R) \quad ; \quad \beta(R) = \beta_{mol}(R) + \beta_{aer}(R)$$

where all α_t's and β_t's are simply connected to total and differential cross sections at $\theta=\pi$:

$$\alpha_t(R) = N_t(R)* \sigma^t_{tot} \quad ; \quad \beta_t(R)= N_t(R)*d\sigma^t(\theta=\pi)/d\Omega$$

and both of them are linearly related to the density of scattering centers N(R).

The molecular (or Rayleigh) contribution can be evaluated within simple models, knowing pressure and temperature vs height from balloon measurements. The extraction of the aerosol coefficients from the Lidar equation uses either Klett's[5] or Fernald's[6] inversion algorithms to extract α and β from Lidar shots at a given polar angle θ. Both methods need *a priori* assumptions on the molecular vs. aerosol parameters functional relation. As an alternative, in case of smooth horizontal variation of atmospheric patterns, a multiangle inversion technique can be used [7], which fully exploits the steering capabilities of Auger Lidar systems. Fig.1 shows preliminary results from the analysis of March 2003 data. The optical depth $\tau(R)$ is then used to calculate the atmospheric light transmission coefficient T~ e$^{-\tau(R)}$, to correct the cosmic ray shower energy measurement.
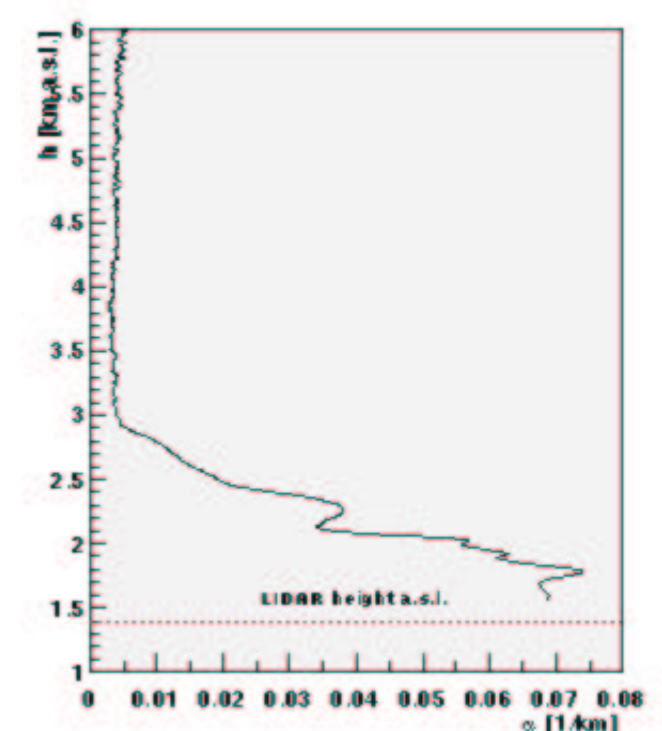
References

[1]D.J.Bird et al., Proc.24th ICRC, 560 (1995)
[2]M.Mostafa (for the Pierre Auger Collaboration), Proc.28th ICRC(2003)
[3]M.Aglietta et al., Nuovo Cimento 16, 813 (1993)
[4]J.D.Smith, S.B.Thomas, L.R.Wiencke, Proc.27th ICRC, 826 (2001)
[5]J.D.Klett, Appl.Optics 20, 211(1981); 24, 1638(1985)
[6]F.G.Fernald, Appl.Optics 23, 652(1984)
[7]A.Filipcic et al., Astropart.Phys.18,501 (2003)
[8]A.Filipcic et al., Proc.27th ICRC, 784 (2001)

```
Commissioning Summary
•April 2001: Preliminary tests on a Lidar prototype mount are done in Pino
Torinese[8].
•February 2002: The first Lidar setup is installed on the Los Leones FD site.
•April 2002: Start of Lidar data taking at Los Leones.
•February 2003: The temporary cover is substituted with a fully motorized one,
to allow remote operation.
•April 2003: The second telescope and cover are mounted at the Coihueco site;
•May 2003: Morados site survey, to spot optimal Lidar location;
•Mid 2003: installation of Laser, PMT's, and DAQ at Coihueco.
```