ARCADE
Atmospheric Research for Climate and Astroparticle Detection

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TARGET OF THE ARCADE PROJECT

Perform measurements of the aerosol attenuation of UV light in atmosphere simultaneously and on the same air mass using the typical techniques mainly used in the cosmic ray community:

LIDARs (elastic + Raman) and Distant Laser Facilities (CLF-like)

Multiangle analysis
Raman analysis
Data Normalized
Laser Simulation

Measurements will take place in Colorado (Lamar) in an arid environment with multiple instruments, without interference with other instruments for CR measurements.
WHAT WE ARE GOING TO DO IN DETAILS:

- Measure & compare aerosol attenuation profiles obtained with different instruments and techniques;
- Study the systematics related to these techniques & instruments aiming to a better understanding of the systematics and limits of applicability of each technique;
- Measure cloud layers altitude and cloud optical depth;
- Use WRF and WRF/Chem meteorology models to predict aerosol stratification and clouds distribution and compare predictions to direct measurements.
WHY AEROSOLS ARE SO IMPORTANT IN COSMIC RAYS PHYSICS?
The Pierre Auger Observatory experience

Surface Detector (SD)
(density of particles at ground)

Fluorescence Detector (FD)
(longitudinal development of showers)

A nearly calorimetric measurement of the energy is performed, since the flux of fluorescence photons produced during the development of the shower is proportional to $dE/dX$, the energy deposit per unit slant depth of the traversed atmosphere.

The calorimeter (the atmosphere) properties needs to be well known!
The calorimeter properties

*The atmosphere is responsible for production and attenuation of UV light.*

- **production**: the yields of light from Cerenkov and fluorescence emission processes depend on molecules in atmosphere.

- **attenuation**: the attenuation of light in the atmosphere depend mainly on molecules and aerosols. It can be factorized into separate molecular and aerosol components $T_{mol}$ and $T_{aer}$ ($+T_{abs}$):

  $$I^\lambda(s) = I_0^\lambda(s) \cdot T_{mol}^\lambda(s) \cdot T_{abs}^\lambda(s) \cdot T_{aer}^\lambda(s) \cdot (1+f)(d\Omega/4\pi)$$

- **$T_{mol}$**: can be analytically measured from balloons measurements or GDAS data (see M. Will talk).

- **$T_{abs}$**: $> 0.999$ for $\lambda > 340$ nm (Ozone) *below 15 km* (therefore neglected).

- **$T_{aer}$**: determination depends on frequent field measurement of the vertical aerosol optical depth $VAOD(h, \lambda)$, due to the rapidly changing conditions (*time scale of 1 hour or less*).

  $$T_{aer}^\lambda(s) = \exp (-VAOD(h, \lambda)/\sin \theta)$$
The effect of aerosol attenuation on air fluorescence measurements

Neglecting the presence of aerosols causes an underestimate in energy on average from 8% (at lower energies) to 25% (at higher energies)

- 20% of showers need a >20% energy correction
- 7% of showers need a >30% energy correction
- 3% of showers need a >40% energy correction

Neglecting the presence of aerosols causes a systematic shift in $X_{\text{max}}$ from $-1 \text{ g/cm}^2$ at lower energies to $10 \text{ g/cm}^2$ at higher energies

*from The Pierre Auger Collaboration, Astroparticle Physics 33 (2010) 108-129*
ARCADE: location and AMT/LIDAR system

COLORADO

LAMAR

$h_{\text{MAX}} \sim 10.8 \text{ km}$

$h_{\text{MIN}} \sim 1.5 \text{ km}$

$13^\circ$
LIDAR & AMT locations

\[ h_{\text{MAX}} \approx 10.8 \text{ km} \]

\[ h_{\text{MIN}} \approx 1.5 \text{ km} \]

AMT \hspace{1cm} 38.9 \text{ km} \hspace{1cm} \text{LIDAR}
The ARCADE LIDAR
fully designed and built within this project!

Construction at Torino INFN mechanical workshop – thanks to Vincenzo Rizi and Marco Iarlori for all the fruitful discussions and help!

- Steerable (0 to 90° in zenith)
- Laser: Quantel Centurion Nd:YAG, UV light at 355 nm energy \( \sim 6 \text{ mJ} \), variable frequency 1-100 Hz, beam divergence 0.3 mrad

RECEIVER:
- Primary mirror diameter 25 cm, f/3
- Elastic and \( \text{N}_2 \) Raman channels
- FOV = 3.3 mrad
- Overlap function = 1 @ 250 m

A very compact and portable device!

Remotely controlled
The ARCADE LIDAR - design

Primary mirror

Raman filters and PMTs

Light collection

Laser exit
The laser bench

Laser Bench

- A - Laser
- B, C - Dichroic mirrors
- D - Beam Splitter (95/5)
- E - Laser Probe
- F - 10X beam expander
- G - Depolarizer
- H - Motorized mirror mount

Zaber motorized mirror mount: computer-controlled fine alignment

Quantel Centurion Nd:YAG laser

Laser probe RjP-445

5 dichroic mirrors for ultra-pure 355nm laser line
Simulation of the optics

Overlap function

Zemax simulation of the receiver
Receiver
Signals are attenuated to avoid saturation, amplified 20X and then sampled with the CAEN digitizer DT5751 (1Vpp - 10bit - 1GS/s)

Software-based signal processing (charge integration, photon counting)

|   | Description                          | Manufacturer | Details                                               |
|---|--------------------------------------|--------------|-------------------------------------------------------|
| E | Beam Splitter                        | Materion     | Transmit avg > 90% 380-420 nm, Reflect > 90% at 354.7 nm, 25.4 x 36 mm, 45° incidence angle |
| F | Bandpass Filter                      | Materion     | notch @ 386.7±0.15 nm, OD 10 @ 354.7, 532, 1064 nm    |
| G | Bandpass Filter                      | Materion     | notch @ 354.7±0.15 nm                                  |
The housing
First tests at L'Aquila together with the EARLINET Lidar - February 4-13 2014

Many thanks to Dr. Rizi and Dr. Iarlori for their help!
The ARCADE LIDAR ARRIVED IN HOUSTON ON MAY 19TH

Next steps:
HOUSTON – DENVER BY TRAIN
DENVER – LAMAR BY TRACK
(ETA, 29th MAY)
Atmospheric Monitoring Telescope
Colorado School of Mines

CAMERA RECOVERED FROM HIRES, 3 COLUMNS OF 16 PMTS, UV BANDPASS FILTER

It was working well in 2010-2011 (Auger R&D) then -> back to Golden's lab
Golden, setting up the AMT camera
trip 28/4 – 11/5/2014

MAIN SBC → RUNDAQ

BOSS SBC

DAQ

SERVER

WEBCAM

INTERNET

ROUTER

HUB

OFFICE

AMT SBC

HUB

LED SBC

WS

DOOR, HV, WS DATA

AMT

WS

DOOR, HV, WS DATA
Golden lab, making the AMT camera to work again

FIRST DAYS IN GOLDEN LAB:
➢ Rebuild all connections and access to each SBC / DAQ / SERVER
➢ Turn on the camera
➢ Fire the LED
➢ Try to acquire signals with the camera
➢ Look at signals and identify bad pixels before going in the field
Moving the AMT system to Lamar

We unmounted the system, took a lot of pictures and make a diagram of all the connections;

We packed all the SBC, DAQ, server, cables and many other useful tools (not yet the camera);

Once in Lamar, we mounted and cabled the system again …

As always happens once in the field: cables no more working, problems with internet connection, webcam disappeared, RPC ports not working and a lot of things to solve …

Finally we had the system up and running and accessible from outside!
The AMT camera back to Lamar

L. Wiencke, M. Coco, J. Eser, M. Buscemi and L. Valore
The AMT camera installed and cabled
Once the camera was back in the container and fully cabled, we fired the LED and acquired some signals with the camera!
To do list (next trip in 2 weeks)

Flatfield the camera (if the LED light is uniform as expected and the electronics gain is set to the same value for each channel, we should just read the signal of each pmt)

Make the webcam and weather station working

See the LIDAR laser light with the AMT camera!
Simulation of AMT response to laser events: Geant4+AugerOffline

Simulation of the telescope via Geant4 + simulation of the laser track and transmission in atmosphere using the Auger software

2 different techniques will be applied on these data to measure aerosol profiles

By Mario Buscemi / Laura Valore
Conclusions

- The ARCADE project is currently in its 3rd and last year

- The newly built LIDAR has been tested in L’Aquila (Feb 2014) and has been shipped to the U.S. (ETA in Lamar, 28th May)

- The AMT camera is set up in Lamar and the calibration with LED source is working

- In June: installation of the Lidar in Lamar and tests for simultaneous acquisition with Lidar and AMT

- ~1 year of data acquisition!
laser-based methods for the determination of the atmospheric aerosol attenuation

Data Normalized Analysis
the aerosol attenuation is measured by comparing laser events with those of a reference purely molecular night in which the aerosol attenuation is negligible (Rayleigh Night)

Laser Simulation Analysis
the aerosol attenuation is measured by comparing measured and simulated laser events in different atmospheric conditions, described by a two parameters model.
The effect of aerosol profiles uncertainties on air fluorescence measurements

The uncertainty on aerosol profiles is large, due to many systematics related to the measurement techniques (laser calibration, detector calibration, reference clear night ...)

Propagating the uncertainty on aerosol profiles to air fluorescence measurements, leads to a 2.5% on energy.

from ICRC 2013 poster 920 – L. Valore for the Pierre Auger Collaboration
Data Normalized Analysis

Figure 3: Light profiles and vertical aerosol optical depth measured using the Data Normalized Analysis with the FD at Los Morados during an average night.

Laser Simulation Analysis

Figure 4: Left: four out of the 1540 simulated profiles of a monthly grid (red), superimposed on a measured profile (blue). Right: the four $\tau_{\text{aer}}^{LS}(h)$ profiles corresponding to the simulated CLF profiles.
Hazy atmo laser profiles

Average clean atmo laser profiles
Aerosol Attenuation Measurements

The analysis of the Lidar and AMT data will produce independent estimates of aerosol attenuation profiles of the UV light.

\[
I(\lambda, s) = I_0(\lambda, s) T_{mol}(\lambda, s) T_{aer}(\lambda, s)(1 + f) \frac{d\Omega}{4\pi}
\]

\[
T_{aer} = e^{-\int \alpha_{aer}(\lambda, s) ds} = e^{-\frac{-VAOD(h)}{\sin(\varphi)}}
\]

Aerosol extinction coefficient

\[
\alpha(\lambda, s) = \sum_i N_i(s) \cdot \sigma(\lambda)_i
\]

Lidar:

- multiangle analysis (elastic channel)
- Raman lidar analysis

AMT:

- laser simulation / data normalized analysis
Auger Lidars measure
clouds height and VAOD
only outside the FOV of FDs due to high interference with
data acquisition

Elastic Lidar

\[ P(\lambda, R) = \frac{K(\lambda)}{R^2} \cdot \beta(\lambda, R) \cdot e^{-\int \alpha(\lambda, R) dR} \]

Raman Lidar

\[ P(\lambda_{NR}, R) = \frac{K(\lambda_R)}{R^2} \cdot \beta(\lambda_R, R) \cdot e^{-\int \alpha(\lambda_0, R) + \alpha(\lambda_R, R) dR} \]

\[ \alpha_{aer}(R, \lambda_0) = \frac{d}{dR} \ln \left( \frac{N_R(R)}{S(R, \lambda_R)} \right) - \alpha_{mol}(R, \lambda_0) - \alpha_{mol}(R, \lambda_R) \]

\[ 1 + \left( \frac{\lambda_0}{\lambda_R} \right)^{a(R)} \]

Extinction coefficient

\[ \alpha(\lambda, s) = \alpha_{mol} + \alpha_{aer} \]

Back-scattering coefficient

\[ \beta(\lambda, s) = \beta_{mol}(\lambda, s) + \beta_{aer}(\lambda, s) \]