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AIRFLY: Measurement of the fluorescence yield in atmospheric gases

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The goal of the AIRFLY (AIR FLuorescence Yield) experiment is to measure the fluorescence yield (FLY) induced by electrons in air to better than 10% precision. A detailed knowledge of the fluorescence emission characteristics is crucial for UHECR (Ultra High Energy Cosmic Ray) air shower energy reconstruction using the fluorescence technique. AIRFLY has been taking data at the Beam Test Facility of the INFN Laboratori Nazionali di Frascati, Italy. The dependence of FLY on the atmospheric gas pressure and temperature has been studied. The dependence on electron energy has been measured in the range 50-420 MeV. A new method of absolute calibration by comparison with Cerenkov emission has been investigated. The status of the experiment and the results achieved so far are presented.

1. Introduction

The fluorescence technique has been used for detection of very high energy cosmic rays for more than twenty years. The interaction of the charged secondary particles of cosmic ray air showers, mostly electrons and positrons, with nitrogen molecules in the atmosphere is followed by the emission of photons in the near UV region (300-400 nm). The amount of light produced is proportional to the number of particles in the shower - one electron produces around 4 photons per a metre path in air. An insufficient knowledge of FLY and its dependence on atmospheric conditions at the point of the light production represents a major uncertainty in the absolute calibration of the ultra high energy ($>10^{18}$ eV) cosmic ray detectors based on the fluorescence technique. The AIRFLY experiment [1] has been taking data at the Beam Test Facility (BTF) of the Laboratori Nazionali di Frascati [2], delivering electron and positron beams in a wide energy range 50 - 600 MeV allowing the study of FLY in the region of the electron critical energy in air. Beams are available with intensities from a single particle up to 10^{10} particles per bunch. The AIRFLY scientific programme includes a measurement of

FLY dependence on pressure, temperature and gas composition corresponding to the atmospheric conditions at altitudes relevant for fluorescence detectors based on earth as well as in space.

2. Experimental setup

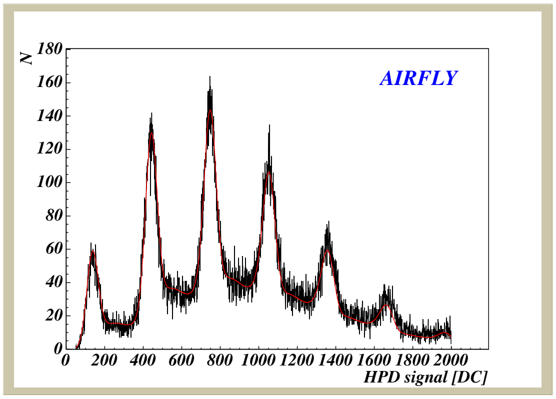

Figure 1. An example of HPD response to individual photoelectrons.

The AIRFLY apparatus consists of a cylindrical aluminium chamber, 200 mm in diametre and 400 mm along the beam with four positions for placing light detectors. To minimize the beam disturbance 0.5 mm beryllium windows are placed on the entrance and exit of the chamber. Two 50 mm diametre Hamamatsu H7195P PMTs were used together with a DEP Hybrid Photo Diode (HPD), allowing single photoelectron counting, see Fig. 1. Each detector was equipped with a 50 mm diametre narrow-band interference filters corresponding to the most prominent emission lines and with a remotely controlled iris shutter for background measurements. The detectors were surrounded by a lead shield in order to minimize the background. A fast scintillator 100 by 100 mm, 5 mm thick, was used to monitor the beam intensity. A remotely controlled gas system was used to fill the chamber to the desired pressure, from a few hPa up to atmospheric pressure. Measurements with dry air and pure nitrogen gas were performed. This chamber was used for the pressure and the energy dependence measurement.

A special aluminium chamber was designed for the temperature measurement. The chamber has a rectangular shape 360×280×210 mm, 30 mm wall thickness and 1mm thick beam entrance and exit windows. Cold nitrogen gas flowing into a copper exchanger placed inside the chamber allows cooling of the chamber down to 238 K. Several temperature sensors were used to monitor the temperature inside the chamber as well as on the HPD.

3. Pressure and temperature dependence

The pressure dependence was measured from 4 to 1000 hPa in dry air (78% nitrogen, 21% oxygen, 1% argon) with the electron beam set to 350 MeV. The intensity of the beam was about 2000 particles/bunch. The results obtained at 291.5 K are plotted in Fig.2. The fit of the data to the model

$$FLY = \frac{C}{\frac{1}{P} + \frac{1}{p'}} \tag{1}$$

yields the characteristic pressure $p' = 18.7 \pm 1.3hPa$. This value of p' is in good agreement with results published in [3].

The temperature dependence of the 337 nm line was measured from 238 to 291.5 K using a 173 MeV electron beam. This temperature interval corresponds to altitudes from ground level up to about 9 km. This measurement was also done with a broad band UG6 filter, commonly used by fluorescence detectors to limit

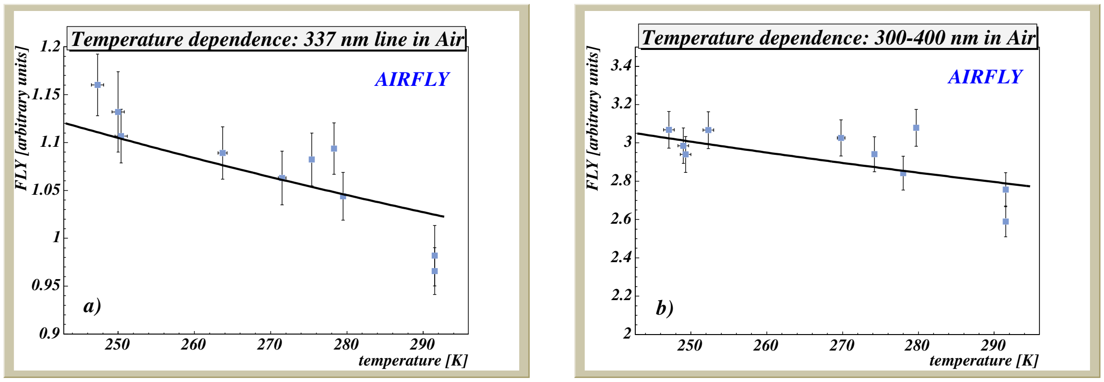

Figure 3. Temperature dependence: a) 337 nm line in Air, b) 300-400 nm (UG6 filter) in Air

the incoming light to 300-400 nm. The results are plotted in Fig.3. Superimposed is the model predicted by Nagano et al.[3]

4. Energy dependence

The energy dependence of FLY was measured in pure nitrogen in the range from 50 to 420 MeV. The beam multiplicity was kept approximately constant at the individual energy points. A UG6 filter was used to study the dependence over the whole fluorescence spectrum. The results are shown in Fig. 4. The superimposed curve shows the restricted dE/dx collisional loss for electrons in nitrogen corresponding to our field of view.

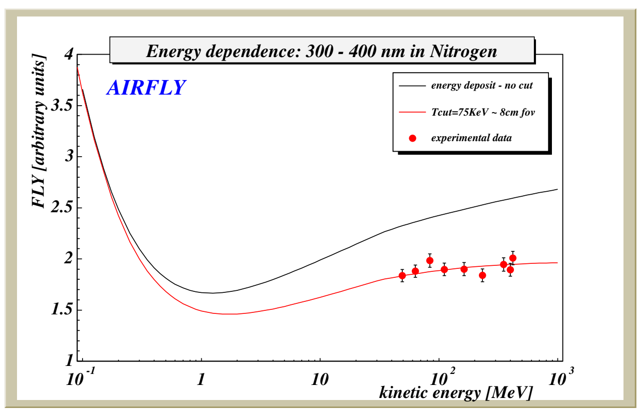

Figure 4. Energy dependence of FLY in Nitrogen

5. Absolute measurement

We have studied a new method to measure the absolute FLY of the 337 nm emission line, which has the advantage of reducing systematic uncertainties due to the photodetector calibration. The method is based on calibration of the measured FLY by a well known process – the Cerenkov emission. For this measurement a thin mylar mirror could be remotely inserted inside the chamber at an angle of 45° to the beam. The Cerenkov light cone is thus reflected towards the detector and fully dominates over the fluorescence contribution.

The absolute value of FLY is then determined as a ratio of the signal measured in fluorescence to Cerenkov configurations from equations

$$\underbrace{N_{337}(fluo)}_{measured} = \underline{FLY} \times \underbrace{Geom_{fluo}}_{MC} \times \underbrace{T_{filter} \times QE_{337}}_{\sim cancel} \times \underbrace{N_{e^-}}_{relative} \quad (2)$$

$$\overbrace{N_{337}(cere)}^{measured} = \overbrace{CERY}^{known} \times \overbrace{Geom_{cere}}^{MC} \times \overbrace{T_{filter} \times QE_{337}}^{\sim cancel} \times \overbrace{R_{mirror}}^{measured} \times \overbrace{N_{e^-}}^{relative} \quad (3)$$

where the Cerenkov yield is known from theory, apparatus geometrical factors are derived from Geant4 MC simulations and the relative number of incident electrons N_{e^-} is measured by a scintillator. The filter transmission T_{filter} and the detector quantum efficiency QE_{337} are the same in both configurations and therefore cancel. The reflectivity R_{mirror} of the 45° mirror is measured.

Monte Carlo simulations of the geometrical factors and the measured data are currently being evaluated.

6. Conclusions and future plans

We have measured the pressure dependence of FLY between 4 and 1000 hPa and the temperature dependence between 238 and 293 K. The energy dependence measured between 50 and 420 MeV is compatible with collisional losses.

In 2005 the AIRFLY is taking data at ANL Argonne, USA, where it will be possible to extend the energy measurement range to below 1 MeV. The high intensity and stability of the beam together with a low background will allow us to confirm our results and to measure the fluorescence spectrum in order to complete the AIRFLY programme. It is also envisaged to make measurements of the humidity dependence of FLY.

7. Acknowledgments

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