Available online at www.sciencedirect.com
SCIENCE DIRECT®
Nuclear Physics B (Proc. Suppl.) 150 (2006) 186–189
NUCLEAR PHYSICS B PROCEEDINGS SUPPLEMENTS
www.elsevierphysics.com

AIRFLY: Measurement of the Air Fluorescence Radiation Induced by Electrons

F. Arciprete[a], M. Bohacova[b], J. Bluemer[cd], E. Bollmann[d], R. Caruso[e], P. Di Carlo[e], M. Doubrava[f], A. Esposito[g], P. Facal[a], A.C. Fauth[h], C. Goletti[a], M. Hrabovsky[i], E. Kemp[h], H.O. Klages[d], M. Kleifges[d], S. Klepser[c], M. Iarlori[e], G. Matthiae[a], G. Mazzitelli[g], H. Nogima[h], L. Nozka[i], M. Palatka[i], S. Petrera[e], P. Privitera[a], P. Prosposito[a], J. Ridky[b], V. Rizi[e], G. Salina[a], P. Schovanek[i], A. Ulrich[j], V. Vacek[f], P. Valente[g], V. Verzi[a], T. Waldenmaier[d]

[a]University of Rome Tor Vergata and Sezione INFN di Roma II, Italy

[b]Inst. of Physics, Czech Academy of Science, Czech Republic

[c]University of Karlsruhe, Germany

[d]Forschungszentrum Karlsruhe, Germany

[e]INFN and Physics Department, L'Aquila University, Italy

[f]Czech Technical University, Czech Republic

[g]Laboratori Nazionali di Frascati dell'INFN, Italy

[h]Universidade Estadual de Campinas, Brasil

[i]Joint Laboratory of Optics of PU and Inst. of Physics AS CR, Czech Republic

[j]Munich Technical University, Germany

The AIRFLY (AIR FLuorescence Yield) experiment objective is the precise measurement of the fluorescence yield in atmospheric gases. AIRFLY takes data at the Beam Test Facility of the INFN Laboratori Nazionali di Frascati. A first test performed on the beam line has allowed to verify the feasibility of the physics program which includes an absolute measurement of the fluorescence yield with a precision better than 5%, the measurement of the spectrum and of the yield dependence on the electron energy, gas pressure, temperature and composition. Details of the experimental apparatus and preliminary results from the test are reported.

1. INTRODUCTION

Fluorescence detection of ultra high energy cosmic rays is a well established technique. It is based on atmospheric nitrogen excitation by the charged particles of the air shower, mainly electrons and positrons, followed by emission of photons mostly in the 300-400 nm range. One electron produces about 4 photons per m of air. A precise measurement of the fluorescence yield is essential for the absolute calibration of ultra high energy ($> 10^{18}$ eV) cosmic ray detectors based on the fluorescence technique. In fact, new generation experiments, like Hires [1] and Auger [2], have sensibly reduced the systematic uncertainties related to the measurement technique, and the knowledge of the fluorescence emission efficiency is currently one of the most relevant contribution to the absolute energy calibration.

The AIRFLY experimental programme is a detailed and precise measurement of the fluorescence yield: the emission spectrum and the dependence on the particle energy, on the gas pressure, temperature and composition will be mea-

0920-5632/$ – see front matter
doi:10.1016/j.nuclphysbps.2004.06.007

sured.

The AIRFLY experiment has been approved at the Beam Test Facility (BTF) [3] of the Laboratori Nazionali di Frascati. Electron and positron beams are available at the BTF, with intensities from single particle up to 10^{10} particles per bunch and with energies between 50 and 800 MeV. The measurement at the BTF represents the first measurement of the fluorescence yield in the range of the electron critical energy in air (80 MeV).

The most difficult part of the AIRFLY physics program is the absolute measurement of the fluorescence yield. The systematic error on this measurement is dominated by the uncertainty related to the absolute calibration of the photon detectors. An improvement of the recent results presented in [4] implies a measurement with a precision better than 10%. The AIRFLY collaboration has developed a new method for this task: the detector systematics will be cancelled normalizing the fluorescence yield to a well known process, the cherenkov radiation production [5]. The method is very promising and the accuracy is expected to be better than 5%.

Details of the experimental apparatus and preliminary results from the test performed on the beam line are reported in the following sections.

2. THE EXPERIMENTAL APPARATUS AND FIRST TEST BEAM RESULTS

2.1. The AIRFLY chamber prototype

A dedicated beam period for AIRFLY took place at the BTF in 2003 and 2004. The main objectives of this first test were the characterization of the beam and related background and the operation of the AIRFLY chamber, in preparation for the final design. The experimental apparatus consisted of a 6-way cross aluminum chamber, with 400 mm length along the beam. The beam entrance and exit aluminum flanges had a 1 mm thickness to minimize beam interactions. Three fused silica viewports are placed orthogonally to the beam direction, equipped with 2 inches diameter Photonis XP2262 photomultipliers, selected for low noise. A filter wheel was associated to each PMT. The filter wheels hosted interference filters of central wavelength corresponding to the main emission lines (315, 337, 360, 381, 391, and 401 nm), a M-UG6 band pass filter (300 to 400 nm) and a shutter used for background measurements. The effective aperture of the filters was 1 inch. In order to minimize the background, the PMTs are surrounded by a lead shield. A vacuum pump and a set of remotely controlled electromagnetic vacuum valves were used to allow the gas into the chamber at the desired pressure, from few mb to atmospheric pressure. Measurements with dry air and pure nitrogen gas were performed. The AIRFLY chamber installed in the BTF beam line is shown in figure 1.

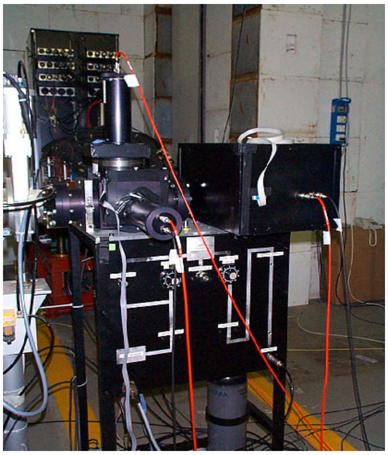

Figure 1. The AIRFLY chamber at the BTF beam line.

The data acquisition system, based on the VME standard, included scalers, charge integrating ADCs and TDCs. The trigger was provided by the accelerator timing signal. The beam intensity used in this first test was relatively low, ranging from a few to several hundreds of electrons per bunch at 24 Hz. It was monitored by a lead-scintillating fibers calorimeter placed at the end of the BTF line [3], having single electron resolution. A second beam monitor [3], based on cherenkov light production by beam particles in air, was also used, in particular for the highest intensities where the calorimeter saturated. Several checks of chamber operation were performed, including measurements with the filters and at different pressures. A first energy scan was performed in the range 100 to 650 MeV, with the main objective of understanding the characteristics of the beam at different energies. Preliminary results of the energy dependence of the fluorescence yield in pure nitrogen are shown in figure 2, together with the expected dE/dX.

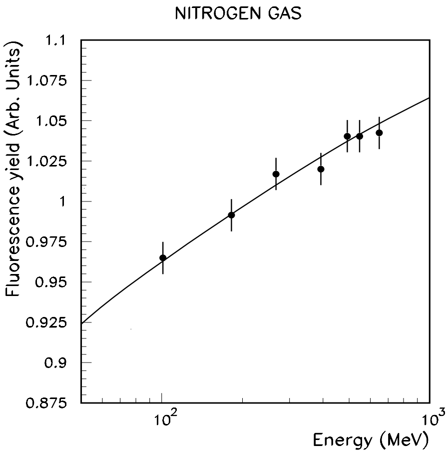

Figure 2. Preliminary measurement energy dependence of the fluorescence yield in nitrogen. The solid line is the theoretical dE/dX dependence.

2.2. The absolute measurement

The Airfly collaboration has developed a new method for the absolute fluorescence yield measurement. The normalization of the fluorescence yield to a well known process, the cherenkov emission, allows to cancel the systematics related to the absolute PMT calibration. The normalization is done at the main fluorescence line (i.e. 337 nm). While the fluorescence radiation is emitted isotropically in the space, the cherenkov radiation is produced along the particle direction and can be observed by placing, along the nominal beam line, a mirror inclined by 45° with respect to the particle direction. Using the same PMT during two different runs, the fluorescence and cherenkov signals in terms of number of detected photoelectrons (N_{pe}) will be given by:

$$N_{pe}^{flu.} = Y_\gamma^{flu.}\ g^{flu.}\ T_{filter}\ \epsilon_{pmt}\ N_e \quad (1)$$

$$N_{pe}^{che.} = Y_\gamma^{che.}\ g^{che.}\ R_{mirror}\ T_{filter}\ \epsilon_{pmt}\ N'_e \quad (2)$$

where Y_γ indicates the yield for the process, g is a geometrical factor, T_{filter} is the 337 filter transmission factor, R_{mirror} is the mirror reflectivity, ϵ_{pmt} is the PMT quantum efficiency and N_e is the number of electrons in the beam. All the quantities depending on the photon wavelength are calculated at $\lambda = 337$ nm. From the ratio of the two above expressions one has:

$$Y_\gamma^{flu.} = Y_\gamma^{che.}\ \frac{g^{che.}}{g^{flu.}}\ R_{mirror}\ \frac{N_{pe}^{flu.}}{N_{pe}^{che.}}\ \frac{N'_e}{N_e}\ . \quad (3)$$

Comparing equation (3) with (1) one can appreciate the power of the method. Essentially the PMT quantum efficiency, which is very difficult to measure, cancels out and the absolute normalization depends on the cherenkov yield which is known from the theory [5]. The geometrical factors can be evaluated using Monte Carlo simulations and the mirror reflectivity can be measured with high accuracy. The ratio of the number of electrons represents a relative measurement. Moreover, observing the fluorescence and cherenkov radiation at the same time with two different PMTs, and reapeting the measurement after having exchanged the two PMTs, the fluorescence yield measurement is even indipendent from the beam intensity.

The method has been tested on the beam line with the eperimental apparatus shown in figure 3. The shape of the box in front of the PMT was so that to fix to 5 cm the path along which the electrons produce the observed cherenkov photons. The beam intensity was tuned in order to have a fluorescence signal at most of 1 photoelectron. We didn't implement a gas system, so the gas was the BTF air. In this conditions the signal was around 1% of all triggers and the background was at the level of only few % of the signal. In order to have a cherenkov signal of similar intensity, a neutral density filter with trasmission factor of 10^{-2} was used to attenuate the cherenkov light.

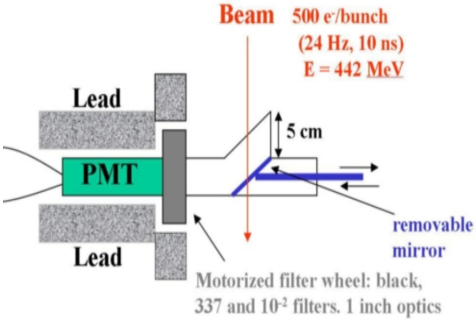

Figure 3. Sketch of the experimental apparatus used to test the new method for the absolute fluorescence yield measurement.

Using this simple experimental apparatus we have obtained a very preliminary measurement of the fluorescence yield in air: $Y_{\gamma}^{337nm} \approx 1.2\ \gamma/m$. This number is in agreement with the recent measurement presented in [4].

3. The final experimental setup

The test on the beam line has allowed to design the final experimental setup. The 6-way cross aluminum chamber will be 3 mm tick. The 4 entrances on the sides will hold the detectors, the one on the bottom will hold the gas system and in the one on the top a motorized mirror will be placed to detect the cherenkov radiation. The chamber will be placed at the end of the BTF beam pipe and it will be separated from the vacuum of the pipe by a 0.5 mm thick berillium window. This window has been choosen in order to minimize the multiple scattering of 50 MeV electrons. For the measurements of the yield dependence on the temperature, a special chamber is under development. The chamber surface will be crossed by pipes where liquid nitrogen flows.

Two different runs are foreseen: one with low intensity beam ($< 10^3\ e^-$/bunch) for the absolute yield measurement and for the energy scan, and one with high intensity beam ($10^8\ e^-$/bunch) for the study of the yield spectrum in different conditions of gas pressure, temperature and composition. Two Hamamatsu H7195PX photomultipliers absolutely calibrated and one DEP PP0475B HPD (Hybrid Photo Diode) will be used as photon detectors. The HPD has been choosen for its capability to distinguish the photoelectron peaks. Interference filter of 2 inches diameter will allow to increase the acceptance for the fluorescence radiation. The spectrum will be measured by a L.O.T. Oriel MS257 spectrograph with nominal photon wavelength resolution of 0.1 nm. At the end of the spectrograph the light will be detected by an Andor CCD DV 420 with 1024×256 active pixels which can work up to $-80°$ with a very low dark current. The acceptance for the fluorescence radiation will be increased putting a spherical mirror in front of the spectrograph. In few minutes of run we expect to reach a % statistical accuracy.

4. OUTLOOK

The preliminary measurements performed on the Beam Test Facility of the INFN Laboratori Nazionali di Frascati have shown the feasibility of the AIRFLY physics program. The fluorescence yield will be measured with a precision better than 5% and in a wide energy range around the critical energy of electrons in air. A detailed measurement of the fluorescence spectrum will be done in different conditions of gas pressure, temperature and composition. We expect to have preliminary results with the final experimental design by the end of 2004.

REFERENCES

1. J. N. Matthews for the HiRes Collaboration, Proceedings of the ICRC 2001, Hamburg, Germany, p. 350
2. H. Bluemer for the Auger Collaboration, Proceedings the ICRC 2003, Tsukuba, Japan
3. P. Valente for the BTF Collaboration, Proceedings of this conference
4. Nagano et al., astro-ph/0303193
5. Particle Data Group, Physical Review D Vol. 66 (2002) 2004.