

Study of the Performance of the ATLAS Monitored Drift Tube Chambers under the Influence of Heavily Ionizing α -Particles

D. Sampsonidis, M. Manolopoulou, Ch. Petridou, A. Liolios and C. Anastopoulos

Aristotle University of Thessaloniki, Greece

Abstract--The MDT chambers of the ATLAS Muon Spectrometer will operate in a heavy LHC background environment mainly from photons and neutrons. The ionization produced by neutron recoils is much higher than the one from photons or muons and can be simulated by the use of alpha particles. A systematic study of the behavior of the ATLAS Monitored Drift Tubes (MDTs) under controlled irradiation has been performed. The presence of alpha particles results in the reduction of the gas gain due to space charge effects. The gas gain reduction has been studied in a single tube set up using a well controlled radium (^{226}Ra) source in order to enrich the tube gas (Ar/CO_2) with the alpha emitter ^{220}Rn and irradiate the tubes internally.

The results are confronted with Garfield simulations.

I. INTRODUCTION

In the heavy background environment imposed by the LHC conditions [1],[2] the ATLAS muon spectrometer will operate and measure precisely the muon tracks. The physics demands a momentum resolution of 10% for muons with transverse momentum of $p_T=1$ TeV/c which translate into a single tube spatial resolution of better than 80 μm .

The radiation background consists mostly of neutrons and photons in the MeV range produced by the interactions of the primary hadrons with forward calorimeter, shielding, beam pipe and other materials. The influence of this background in the muon spectrometer are the rising of the occupancy of the muon detectors, space-charge effects, aging effects and high LVL1 fake muon trigger rate. The first three effects are determined mainly by the intensity of the neutron and photon flux resulting in degradation of the momentum resolution and the detection efficiency

The simulation of the background in the ATLAS hall indicates count rates up to 100 Hz/cm² for the MDTs which means that the count rates can reach hundreds of KHz/tube.

The alpha particles can imitate the neutron recoil atoms having equivalent ionization. Therefore the response of a

detector to neutrons can be studied by operating it under irradiation of alpha particles. A systematic study of the behavior of the ATLAS Monitored Drift Tubes (MDTs), under controlled irradiation with alpha particles is presented in this work.

The space charge effects has been studied theoretically [3]. The influence of space charge effects on the drift tube has been investigated by exposing detectors to high rates of muon beams or photons from sources [4],[5]. This work is focused on the study of the space charge effects due to heavily ionizing particles at various rates.

We report on the measurement of gas gain reduction of the monitored drift tubes operated with the nominal gas ArCO_2 (93:7) at 3 bars due to space charge effect from heavily ionizing particles. The experimental set-up and method is described in the next sections. The measurements of the pulse height analysis and the dependence on the alpha rate is presented. Finally the results are compared to simulation.

II. EXPERIMENTAL SET-UP

To study the influence of the heavily ionizing particles on the performance of the Monitored Drift Tubes a set-up of four tubes with a well controlled radium (^{226}Ra) source is used. The nominal ATLAS gas $\text{Ar}:\text{CO}_2$ (93:7) is distributed to the tubes using a parallel system for supplying gas to the four tubes simultaneously. The gas in the two of the tubes is enriched with the alpha emitter noble gas radon ^{222}Rn from the ^{226}Ra source and therefore irradiate the tubes internally. The other two tubes are used as reference tubes allowing monitoring the variation of operation conditions like temperature and gas pressure.

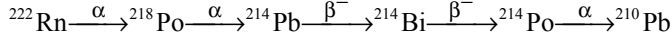
A calibration procedure is performed to all four tubes using soft gamma photons from an Am-Mo source with energy of 17.4 KeV. The tubes are operated at gas pressure of 3 bars and ADC spectra are taken at various high voltage values. The position of the peak of the gamma photons is a function of the gas gain. The test input of the preamplifiers is fed with pulses from a pulse generator and ADC spectra are taken with varying the height of the pulses. The gas gain is given by the formula

$$G = \frac{V_p C_{cal}}{E/w f e}$$

where V_p is the pulse height, C_{cal} is the capacitance of the test input of the preamplifiers, E/w is the number of ion pairs released in the gas from a photon conversion namely 670 for the 17.4 KeV, f is the fraction of total charge that the preamplifier sees and e is the electron charge.

A closed loop was setup with two of the tubes, a calibrated flow-through radium (^{226}Ra) source (20.6 kBq) which decays into radon (^{222}Rn), a flow-meter, a regulated pump and a Lucas Cell (α -scintillation detector). Initially the nominal gas mixture is circulated through the system, including the ^{226}Ra source. The radon concentration in the tubes is specified by the initial ^{222}Rn concentration in the source and the gas flow duration through the source. As a second step in the procedure the source is removed and the gas circulates 20 times the total volume of the system at atmospheric pressure for attaining homogeneity.

The radon concentration in the tubes is calculated from the initial radon concentration in the source and also measured using the Lucas Cell. The ^{222}Rn decay chain is:



The ^{222}Rn and its daughters emit in total three alphas and two betas. The lifetime of the decays are 3.8d, 3.05m, 26.8m, 29.7m and $16.37\mu\text{s}$ respectively. After about four hours from the radon insertion time radioactive equilibrium is established and we have at any time almost three alphas with energies 5.5, 6.0 and 7.7 MeV from the ^{222}Rn , ^{218}Po and ^{214}Po respectively and two electrons from the β^- decays.

III. RESULTS

The spectrum from a tube containing radon convolves from the signals from the alphas, the betas and the gammas from the decays of the nuclides. When the tubes are operated at the nominal gas gain value (2×10^4) the signal produced from a heavily ionizing particle is saturated. The same also happens for the electrons from the β^- decays with high energy. Lowering the gas gain by applying lower high voltage to the minimum possible in order to have signals, the spectrum from the alpha with mean energy of 6.4 MeV is seen as a Landau distribution. While the applied voltage is raised to higher values the peak due to alpha particles is moving towards higher channels. Figure 1 shows the spectra taken from a tube with radon at high voltages 2 kV, 2.3 kV and 2.7 kV. At higher gas gain values the spectrum becomes continuous with overflow events which correspond to the alpha particles.

Measurements are taken in a regular time interval at a range of gas gain. The integral of the peak is used in order to monitor the activity of the radon inside the tubes. Figure 2 shows the radon concentration inside the tubes calculated theoretically, measured by the Lucas Shell detector and the measured values from alpha peak integration at low radon concentration where there is no gas gain reduction. The different slope in the fitting is due to the leak of the detectors.

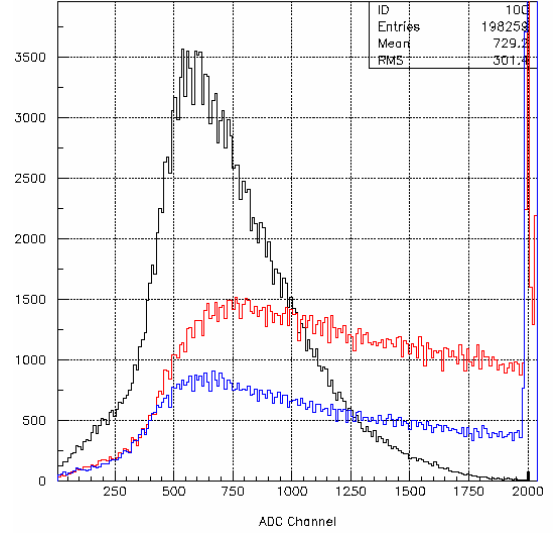


Fig. 1. ADC spectra taken at high voltage values of 2, 2.3 and 2.7 kV

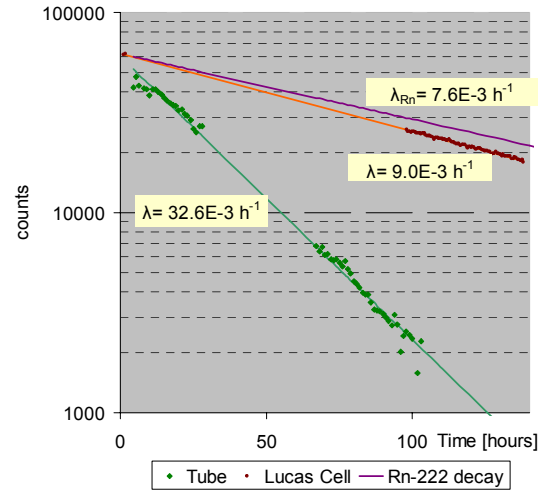


Fig. 2. The radon concentration inside the tubes theoretically, measured by the Lucas Cell detector and measured by the tube.

The ADC channel of the alpha particle distribution in the spectrum depends on the actual gas gain. The distribution is fitted with a Landau function and the most probable value of the distribution is determined. Taking data in a long period of days at the same high voltage while the radon decays and the activity is lowered the alpha distribution appears at higher

channels. This is a clear evidence of the space charge effect that reduces the gas gain of the tubes. Figure 3 shows the alpha distribution at the same applied high voltage with a time difference between the measurements of ten hours.

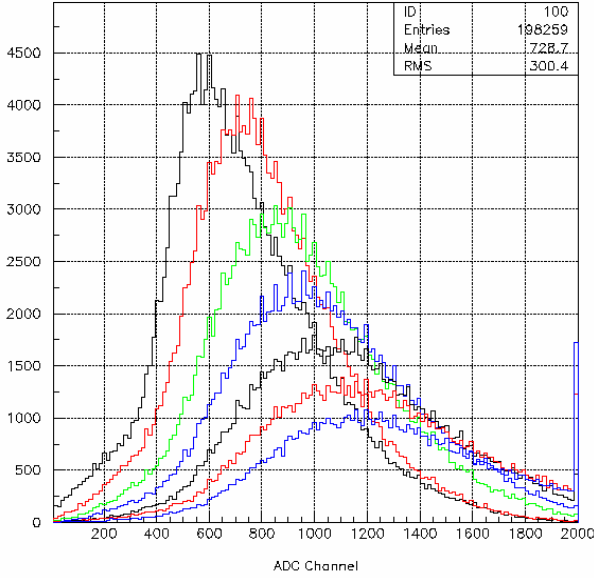


Fig. 3. Pulse height spectra taken at very low gain showing the peak due to alpha particles with mean energy of 6.4 MeV for a period of eight days.

The gas gain at a certain applied high voltage is determined by the position of the distribution of soft photons in the ADC spectrum using the absolute calibration as explained in section II. The presence of the radon reduces the gas gain and therefore the position of the peak depends not only to the applied high voltage but to the radon concentration too.

Figure 4 shows the gas gain as a function of rate of the alpha particles produced inside the tube. The measurements correspond to very low radon concentrations. At alpha rates less than hundred the space charge effects diminished.

The expected energy deposition from neutrons to the MDTs in the ATLAS experiments in the worst case was estimated to 2.46 MeV/cm²sec [6]. This corresponds to a rate of energy deposition of 1512 MeV/sec/tube for the BIS MDT chamber which has a tube length of 1.7 m. In the present experiment this energy deposition corresponds to an alpha particle rate of 250 Hz. As it is shown in figure 4 the gas gain reduction at about 200 Hz is of the order of 0.28.

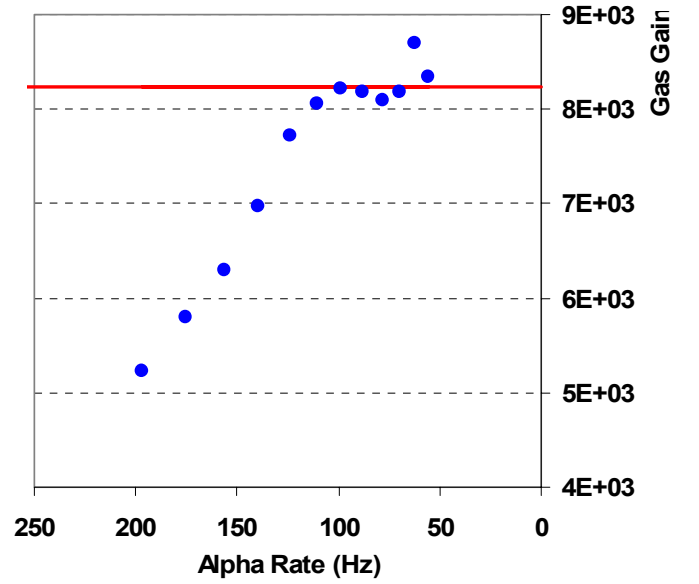


Fig. 4. Gas gain as a function of alpha particle rate production inside the tube. The straight line shows the gas gain at the same conditions without radon.

IV. GARFIELD SIMULATION

The response of the monitored drift tube to the alpha particles was studied with the GARFIELD simulation [7]. Since GARFIELD can simulate the ionization produced in drift detectors by particles with charge up to 1, new routines were implemented in order to describe the situation with alphas. The basic assumptions are the following:

The alpha particles are emitted from points which are uniformly distributed at random distances from the wire. The alpha trajectories are defined in the 3D space by two angles (phi and theta) uniformly distributed. The alphas lose their energy by ionizing the tube's gas and therefore producing the primary electrons. The position where each primary electron is produced are exponentially distributed with a mean value of $1/n_{\text{electrons_mm}}$, where $n_{\text{electrons_mm}}$ is the number of electrons produced per mm [8].

The number of electron produced per mm is calculated the following way. The mean ionization energy loss $\Delta E_{m,p}$ and the average energy loss ξ per mm are calculated using Bethe-Block formula. A random Landau number λ is produced and the actual energy loss ΔE is calculated using the following formula:

$$\lambda = \frac{\Delta E - \Delta E_{m,p}}{\xi}$$

The energy loss is divided by the average energy needed to produce one pair (W) and we get the number of electron produced per mm.

The arrival time of the electrons at the wire is calculated. The avalanche is considered to take place near the wire and the avalanche size follows a polya distribution with $\theta = 0.4$. The gas gain is user defined.

The ions that are created during the avalanche are tracked back to the tube wall and the induced current signal is calculated. The effect of the electronics is taken into account using an analytical transfer function. In order to calculate the charge the current pulses are integrated.

Figure 5 shows a pulse produced by an alpha with GARFIELD simulation at gas gain of about 50 and figure 6 a pulse from the tubes. The results from the simulation are in good agreement with the experimental data.

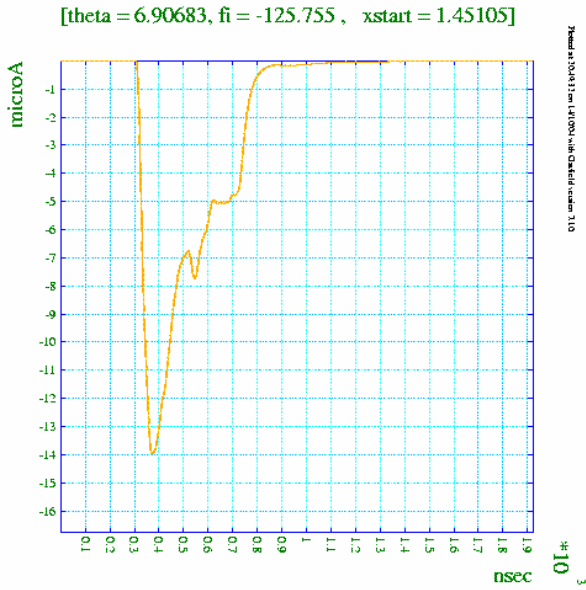


Fig. 5. Signal from an alpha produced by the GARFIELD simulation

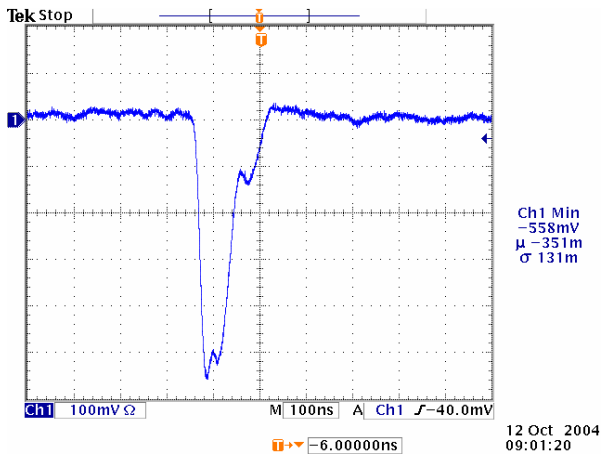


Fig. 6. Signal from an alpha particle produced in the tube.

V. CONCLUSIONS

A setup for alpha particles irradiation with a well controlled radium source was used. The influence of the presence of alpha particles in the response of the monitored drift tubes has been studied. The gas gain reduction due to space charge effects has been measured and found 28% at rates of alpha 250 Hz.

VI. REFERENCES

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