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Development of the ADAMO detector: test with cosmic rays at different zenith angles

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ADAMO is a magnetic spectrometer that has been developed to allow a precise measurement of the spectra of the main cosmic–ray charged components at ground level. The detector is composed of two main subsystems. The first is a permanent magnet with a cavity where the magnetic field is around 0.4 T. The second is a tracking system made of five double sided silicon micro-strip detecting units with spatial resolutions of $3\,\mu m$ and $11\,\mu m$ along two orthogonal directions (related to the two sides of the silicon sensors and conventionally referred to as "x" view and "y" view in this work). The whole spectrometer dimensions are $(25 \times 35 \times 25)\,\mathrm{cm}^3$; anyway it allows the measurement of charged particles in the wide range of momenta between about $100\,\mathrm{MeV}/c$ and $100\,\mathrm{GeV}/c$. During 2003 and 2004 the detector has been modified with respect to its original structure. The acceptance has been increased to allow the study of the rare components of cosmic rays at ground. At present, the magnetic cavity is $(60 \times 140 \times 210)\,\mathrm{mm}^3$. A new trigger system has been realized an it is under development to work as a TOF system, the first step to allow particle discrimination at low momentum. During 2004 a first set of data was taken at different zenith angles to test the functionality and the performances of the detector. In this work the apparatus and some analysis of these data are presented.

1. Introduction

ADAMO was presented for the first time at the 28^{th} ICRC [1], held in Tsukuba (Japan) in 2003. It is a small cosmic–ray detector that has been developed for the study at ground level of the main charged components of atmospheric showers (namely muons, protons and electrons) induced by the primary cosmic radiation entering the Earth atmosphere. This project is part of the cosmic–ray research activity of the Physics Department and INFN of Florence (Italy) and is managed by a group that is involved in the WiZard Collaboration. The activity of this group is mostly related to the PAMELA satellite experiment, whose launch is scheduled for the end of 2005 on board of the Resurs–DK1 Russian satellite. In particular the WiZard–Florence group has developed the tracking system of the PAMELA detector [2]. The aim of ADAMO is the measurement, for different incoming angles and at different altitudes and geographical locations, of cosmic–ray spectra in the wide momentum range between about 100 MeV/c and 100 GeV/c. Measurements in this momentum range are useful to improve the calibrations of the Montecarlo simulations which are used to simulate the atmospheric shower development, especially in relation to the study of the Atmospheric Neutrino Problem. Several muon data exist, which have been collected during the past century, but only in a limited number of cases measurements have been performed in non–vertical directions and no precise systematic studies exist of the dependencies of fluxes by the altitude and the longitude. Moreover only a few measurements exist for the proton component and all of them were done in vertical direction. For these reasons ADAMO could give a contribution to the understanding of the atmospheric shower development, allowing the study in a wide momentum range of the dependencies of cosmic–ray spectra at ground level by the latitude, the altitude and the incoming direction.

2. Description of the detector

The detector structure showed during the past ICRC [1] has been modified in such a way to get a bigger acceptance with respect to the original one. The geometric factor was increased from about 1 cm^{2}sr to 6.7 cm^{2}sr

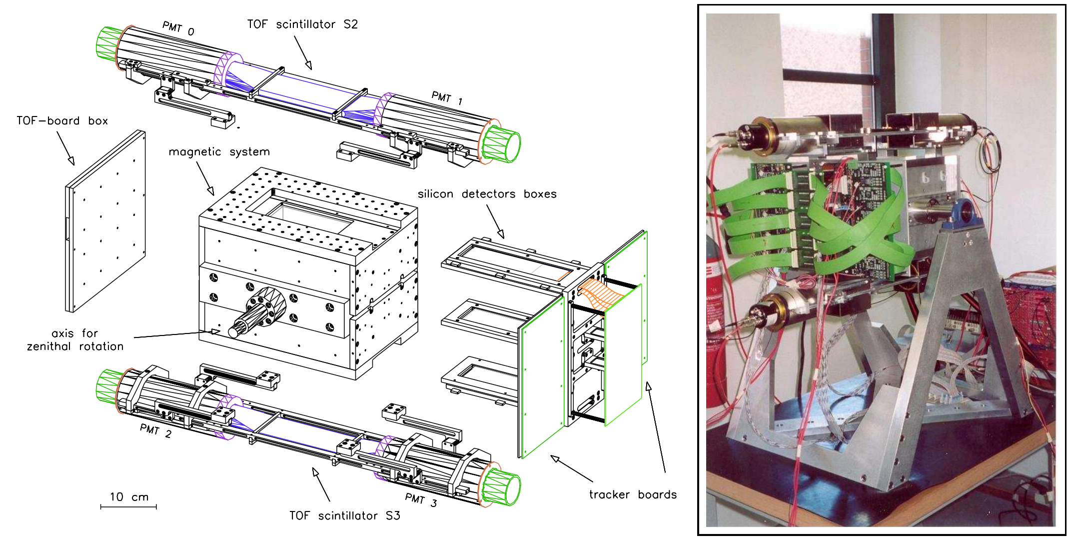

Figure 1. Left: schematic view of the parts that make up the detector. Right: a picture of ADAMO taken during a vertical direction data acquisition. Figures are taken from [3].

to allow the study of the rare component of cosmic rays at ground, protons and electrons, whose fluxes are about two orders of magnitude lower than the muons. The increase of the acceptance has been obtained by modifying the assembling of the magnetic system in such a way to enlarge the magnetic cavity. The cavity is now large enough that each complete silicon plane (5.33 cm $\times$ 14 cm) can be used for particle tracking, while only one half of each plane was used in the past. This modification caused a decrease of the magnetic field inside the cavity from about 0.6 T to less than 0.4 T in the center. The tracking detectors were not modified at all and also their placement was not changed. Of the five silicon planes, two are positioned just before the beginning of the magnetic cavity, two just after its end and one in the central region. The main drawback of the modification of the magnetic field is that the Maximum Detectable Rigidity decreased from 650 GV/c to 260 GV/c, but this value is still good for the aim of the detector.
Finally all the readout electronics was renewed to simplify the whole structure and a new trigger system has been developed to be used also as a Time Of Flight system [3]. The configuration of the detector as it appears at present is shown by the right picture of figure 1 and is clarified by the simple schematic description beside.

3. Test of ADAMO with cosmic rays

During a few months between 2003 and 2004, after the upgrade phase, a first set of data has been collected to study the functionality of the instrument [3]. Because the TOF system was not yet well screened from the magnetic field, it was not possible to use the information coming from this system to test the discriminating capability. In fact the performances of the PMT that has been used (Photonis XP–2020) are very sensitive to the magnetic field and the gain is halved for a field intensity of the order of 0.15 mT, while the field in the PMTs positions during the data taking was measured to be several mT. The gathered preliminary results, based on a total data taking lasted 13d 4h 30m, are thus relative to the “all particles” cosmic ray spectrum at ground. In the next paragraph the measurement of the detectors efficiencies is briefly discussed and in the following two paragraphs the results for cosmic–ray spectra are showed, both for the vertical direction measurement and for several measurements done at non–zero zenith angle direction.

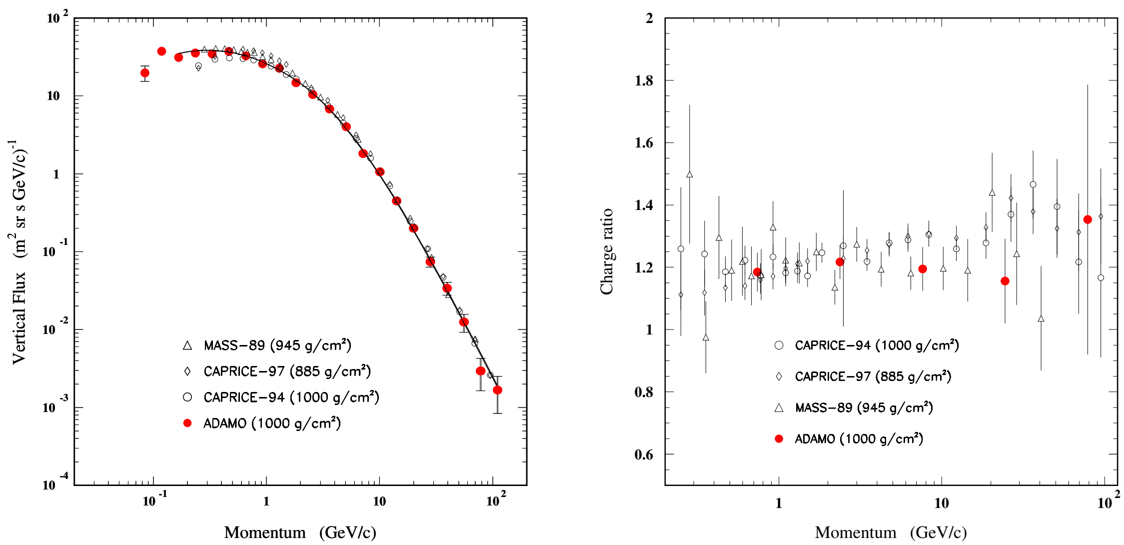

Figure 2. Comparison of the differential cosmic–ray flux (left) and charge ratio (right) measured in the vertical direction with the results of some previous experiments of the WiZard collaboration. Figures are taken from [3].

3.1 Sub-detectors efficiencies

The efficiencies of the tracker and the trigger system were both measured to allow the study of the absolute particle flux. A set of data taken in vertical direction was used. Particle tracking was performed for all events which produced signals on at least three "x" and three "y" views of the tracker, in such a way to understand if particles had crossed the not responding views, allowing the efficiency of each single side of the micro-strip silicon layers to be measured. For the trigger system the efficiency was determined similarly. Being this system composed of two layers only (S_2 and S_3), a certain number of events which produced a signal only in one layer were registered to determine the efficiency of the other layer. For the final data analysis events were accepted only if the trigger was produced by some PMTs from both the scintillators and only if signals were present on both sides of the central silicon plane and of at least two other planes, one at the beginning and one at the end of the magnetic cavity. As a result of this choice, the tracker and the trigger efficiencies resulted to be $\epsilon_{trk} = 0.811 \pm 0.003$ and $\epsilon_{trg} = 0.9534 \pm 0.0016$.

3.2 Measurements in the vertical direction

In the left graph of figure 2 the measured all–particles vertical differential flux is compared to the vertical muons fluxes measured at ground by some experiments of the WiZard collaboration. Above a few GeV/c, where the muon component represents more than 98% of the total flux, the ADAMO points are in agreement with the other points. At low momentum different effects can introduce sensible discrepancies. One is the electron contamination: at some hundred MeV/c the electron flux at ground is comparable with the muon one and is included in the ADAMO points while not in the other points. Moreover it should be considered the solar wind, which modulates the fluxes below a few GeV/c with a ciclic effect of 11 year period, and the different latitudes at which experiments are done. The right graph of figure 2 shows the measured charge ratio compared to the results of the same experiments considered before.

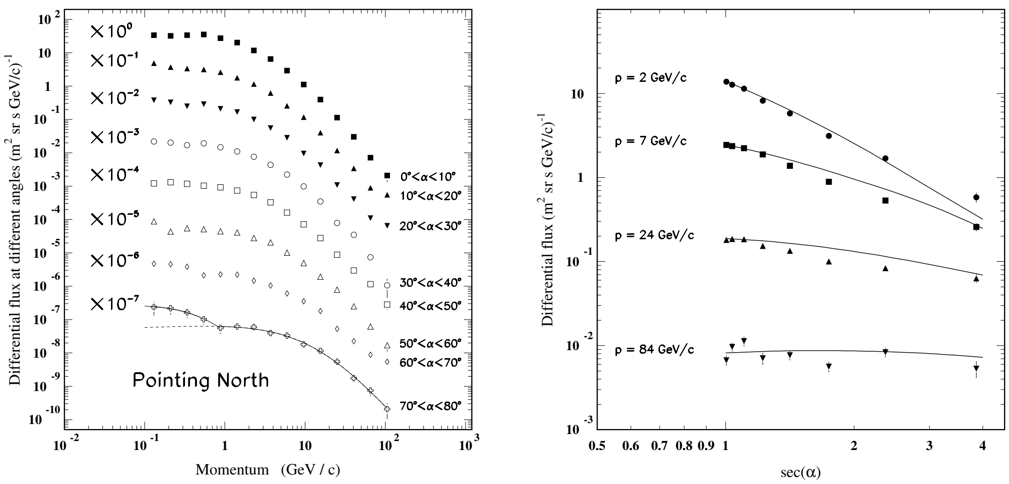

Figure 3. Left: differential flux measured in eight zenith angle intervals. Right: differential flux for fixed momentum values as a function of the zenith angle α. Figures are taken from [3].

3.3 Study of the zenith angle dependency of cosmic–ray flux

The left graph of figure 3 shows the all–particles differential fluxes measured in eight zenith–angle bins. The angular intervals are described on the right side of the points. Values of each bin are multiplied by a power of ten, like indicated on the left. At high zenith angle the low momentum electron contribution is more evident. The electron integral flux at 75° zenith angle, for momentum between 0.100 GeV/c and 1.091 GeV/c, was estimated by integrating the difference of the two fit functions used below and above 1.091 GeV/c. Neglecting the other rare components, in the first case the contribution of muons and electron is comparable, while in the latter the electron flux becomes negligible. The estimation obtained is $\phi_e \simeq 0.94\,\mathrm{m}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}$ and it is compatible with the old measurements found in [4]. The right graph of figure 3 shows the behavior of the differential flux for fixed values of the momentum, as a function of zenith angle. The superimposed lines are obtained by interpolating the calculations presented by S.A. Stephens in [5].

4. Conclusions

The ADAMO detector has been recently tested with cosmic–ray and some preliminary results has been obtained for the all–particles differential flux for zenith angles between 0° and 80°. In the next year the TOF system will be tested to allow the discrimination of the proton component up to 1 GeV/c.

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