Electron/proton separation and analysis techniques used in the AMS-02 ($e^+ + e^-$) flux measurement

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Abstract

AMS-02 is a large acceptance cosmic ray detector which has been installed on the International Space Station (ISS) in May 2011, where it is collecting cosmic rays up to TeV energies. The search for Dark Matter indirect signatures in the rare components of the cosmic ray fluxes is among the main objectives of the experiment. AMS-02 is providing cosmic electrons and positrons data with an unprecedented precision. This is achieved by means to the excellent hadron/electron separation power obtained combining the independent measurements from the Transition Radiation Detector, electromagnetic Calorimeter and Tracker detectors. In this contribution we will detail the analysis techniques used to distinguish electrons from the hadronic background and show the in-flight performances of these detectors relevant for the electron/positron measurements.

Keywords: AMS-02, cosmic ray, proton rejection, ep separation

1. The AMS-02 detector

AMS-02 is a magnetic spectrometer built for the detection of charged and neutral (photons) primary cosmic rays (CR). It has been launched with the space shuttle mission STS-134 (16th May 2011), and is taking data since its installation on the International Space Station (19th May 2011). AMS-02 has a volume of 5×4×3 m^3, weights 7.5 tons and was built to be operated in space for at least 20 years. This long exposure time combined with a large detector acceptance (0.5 m^{2}sr), give us the possibility to study the primary CR fluxes in the energy range 1 GeV - 1 TeV with high precision. The core of the instrument is a spectrometer, composed of a permanent magnet, which produces a magnetic field with an intensity of 0.14 T, and of 9 layers of double-sided micro-strip silicon sensors. The task of the spectrometer is the reconstruction of the trajectory and the measurement of the rigidity ($R = P/eZ$, momentum/charge ratio). From the curvature of the trajectory it is possible to know the charge sign. Above and below the spectrometer two planes of time of flight counters (ToF)

provide the main trigger of AMS-02 and distinguish between up-going and down-going particle. This information combined with the sign of the charge given by the spectrometer, is used in order to discriminate between matter and anti-matter. A Transition Radiation Detector (TRD) is located at the top of the instrument. The detector is completed with a Ring Imaging Cherenkov detector (RICH) and an electromagnetic calorimeter (ECAL). The central part of AMS-02 is surrounded by an anticoincidence system (ACC). The AMS-02 detector is described in details in [1]. The main goals of AMS-02 are the measurement of the composition and energy spectra of charged cosmic rays up to TeV energies, direct search of primordial antimatter (anti-nuclei), indirect search for dark matter (positron, anti-proton, anti-deuteron), gamma ray astrophysics, exotic physics (strangelets).

2. The importance of the electronic component in Cosmic Rays

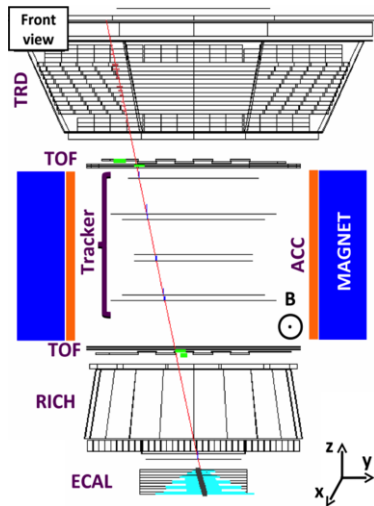The electronic component of CR carries important physics information. Due to their low mass, electrons

Figure 1: A 600 GeV electron event measured by the AMS-02 detector on the ISS in the bending (y-z) plane. The Tracker planes measure the particle charge and rigidity ($R = P/Ze$). The TRD identifies the particle as an electron. The TOF measures the charge and ensures that the particle is downward-going. The RICH independently measures the charge and the velocity. The ECAL measures the 3D shower profile, independently identifies the particle as an electron, and measures its energy.

and positrons are subject to important energy losses due to interaction with the Inter Stellar Medium, in their trajectory between the sources and Earth. For this reason they carry information about the origin and the propagation of CR complementary to the hadronic component. Due to their strong energy losses, electrons and positrons at high energies are unique probes to study the CR source property in the galactic neighborhood. The recent measurements of the positron fraction and positron flux performed by AMS-02 [1, 2] show an excess of positrons at high energies, that is not compatible with a secondary production predicted by the standard model of cosmic ray propagation [3]. Different models can explain this unexpected excess: it may constitute indirect evidence of dark matter particle annihilations, or it can point to positron production from nearby pulsars[4],[5].

3. The e/p separation

Charged cosmic rays between 1 GeV - 1 TeV observed at Earth, are made substantially of protons ($\sim$ 90%), Helium ($\sim$ 8%) and heavy nuclei ($\sim$ 1%). Electrons (e^-) and positrons (e^+) constitute respectively $\sim$ 1% and $\sim$ 0.1% of the total CR flux. The main challenge in the measurement of the electronic component

is the natural high background/signal ratio. The ratio to the main CR component, i.e. protons (p), amounts to $e^-/p \sim 10^{-3} - 10^{-2}$ and $e^+/p \sim 10^{-4} - 10^{-3}$ depending on the energy. In order to obtained the needed high e/p rejection power, AMS-02 uses mainly three sub detectors: The Radiation Transition Detector (TRD), the electromagnetic calorimeter (ECAL) and the Tracker (TRK).

3.1. The Electromagnetic Calorimeter (ECAL)

The ECAL is a sampling electromagnetic calorimeter with an active area of 64.8×64.8 cm^2 and 17 radiation lengths thickness [6]. It is made by 9 superlayers, each layer is composed by lead interleaved with scintillating fibers that run in one direction only. The superimposition of superlayers with fibers running parallel to the X and Y axes (five and four superlayers, respectively) allows the ECAL to reconstruct the 3D development of the shower. The energy resolution of ECAL is obtained from beam tests of the complete AMS-02 detector and is parametrized as a function of energy $\sigma(E)/E = \sqrt{(0.104)^2/E(GeV) + (0.014)^2}$. In order to cleanly identify electrons and positrons, an ECAL classifier, based on a boosted decision tree algorithm [7], is constructed using the 3D shower shape development in the ECAL.

3.2. The Transition Radiation Detector (TRD)

The TRD is constituted by 328 modules arranged in 20 layers [8]. Each module contains 20 mm of radiator made of polypropylene/polyethylene fiber fleece and 16 tube straws filled with a 90:10 Xe:CO_2 mixture. In the radiator material the refraction index changes several times. This increases the probability for the crossing particle to emit transition radiation X-rays. The emission probability is proportional to the Lorentz boost factor γ, therefore electrons produce more transition radiation than protons with the same energy. In order to differentiate between electrons and protons, the signals from the 20 layers are combined in a TRD classifier based on a likelihood method[9]. This allows the efficient discrimination of the proton background.

3.3. The Tracker (TRK)

The TRK is made of 2264 double-sided micro-strip silicon sensors distributed over 9 layers [10, 11] with an active area of $\sim$6.4 m^2. 3 of the 9 layers are located outside the magnetic field of the permanent magnet: one is located on top of the TRD, another one above the magnet, and the last one between the RICH and the ECAL. The others 6 layers constitute the inner Tracker

Figure 2: The different responses in case of an electron, positron or proton crossing AMS-02 in the main detectors used for e/p separation: TRD, TRK, ECAL.
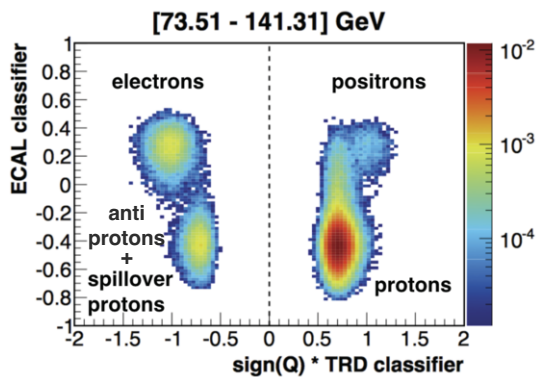

Figure 3: Distribution of the ECAL classifier and of the TRD classifier multiplied by the sign of the charge, obtained from the reconstructed rigidity, for a unitary charge sample, selected using the absolute charge measured by the TRK. The population of electrons, positrons, protons, anti-protons + spillover protons (i.e. protons with a wrong sign of reconstructed charge due the TRK finite resolution) are clearly separate.

which is contained in the permanent magnet field volume. The TRK is able to detect the crossing points of particles with high accuracy ($\sim 10\,\mu$m in the bending direction and $\sim 30\,\mu$m along the non-bending one). From the crossing points it is possible to reconstruct the trajectory of the particle and the curvature of the trajectory provides the measurement of the particle Rigidity. The ratio between the rigidity measured by the TRK and the energy measured by the ECAL (E) can be used to reject the proton background ($E/R \sim 1$ for electrons and positrons , $E/R \sim 0$ for protons). The TRK provides also a measurement of the absolute charge (Z) using the energy loss in each layer and can be used, in the electrons and positrons analysis, in order to select a unitary charge sample. Figure 2 shows the different responses of TRD, ECAL and TRK for an electron, positron or proton crossing AMS-02.

4. Conclusions

Figure 3 shows, in the energy range 73.51 - 141.31 GeV how AMS-02 can clearly separate electrons from protons, combining the information of TRD, ECAL and TRK. The plot shows the distribution of the ECAL classifier (on the Y-axis) and the distribution of TRD classifier (on the X-axis) multiplied by the sign of the charge, for a unitary charge sample. The population of electrons, positrons, protons, anti-protons + spillover protons (i.e. protons with a wrong sign of reconstructed charge due the TRK finite resolution) are clearly separate. ECAL and TRD allow to reach high protons rejection powers. The TRD rejection power measured using flight data amounts to $10^3 - 10^4$ at 90% signal efficiency[12]. The rejection power of ECAL combined with the energy-rigidity ratio reaches 10^4 at 90% signal efficiency[12]. Combining the signals from TRD, ECAL and TRK, is it possible to perform an high precision electrons and positrons measurement as described in detail in [13] and [9].

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