THE PERFORMANCE OF THE AMS-02 TRD

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The Alpha Magnetic Spectrometer (AMS-02) is an experiment which will be mounted on the International Space Station (ISS) in 2007 to measure primary cosmic ray spectra in space and to perrform an indirect search for dark matter in the universe. To this aim, AMS includes a Transition Radiation Detector (TRD) to be able to distinguish an e^+ or p^- signal, reducing the p^+/e^- background by a rejection factor $10^{-3} – 10^{-2}$ in the energy range 10-300 GeV. The TRD will be used in conjuction with an electromagnetic calorimeter to provide overall p^+ rejection of 10^{-6} at 90% e^+ efficiency. A TRD prototype has been calibrated and its performance measured in test beams with p^+, e^-, μ^-, π^- from 3 to 250 GeV/c and compared with MonteCarlo predictions. It achieved a rejection factor ranging from 2000 to 140 for protons with energy varying from 15 to 250 GeV. The TRD Modules and structures have undergone an extensive program of space qualification. Selected Modules have undergone a long term test in a vacuum chamber. TRD flight version is under construction, and so far within specifications and schedule.

1. Introduction

The Alpha Magnetic Spectrometer (AMS-02) [1-2] is an experiment which will be mounted on the International Space Station (ISS) to measure primary cosmic ray spectra in space. A main physics goal of AMS-02 is the search for dark matter.

One of the possible way to achieve this result is to search for an enhancement in the positron spectrum as a function of energy. Since the ratio of fluxes of p^- to e^+ in orbit is on the order of 10^4, AMS-02 must be able to distinguish between protons and positrons to a level better than 10^{-6}. To this aim, AMS includes as its uppermost element a Transition Radiation Detector (TRD). Transition radiation (TR) consists of soft X-rays which are emitted when charged particles traverse the boundary between two media with different dielectric constants. In the momentum range of 10-300 GeV/c, light particles such as electrons and positrons have much higher probability of emitting TR photons than heavy particles such as protons and antiprotons. At a single boundary, the probability of emission is still very small, on the order of 10^{-2}, but this is enhanced by using a fleece as a radiator. The fleece radiator, in turn, is divided into twenty layers 20 mm thick, with in between layers of straw tubes 6 mm diameter to detect the photons. The straw tubes are filled with an 80%:20% Xe:CO_2 gas m a rejection factor of 10^{-3}-10^{-2} for p^+ and e^- can be achieved against e^+ and p^- in the aforementioned momentum range. Combining the TRD rejection power with that of an electromagnetic calorimeter located at the bottom of AMS-02 increases the p^+ rejection to the goal value of 10^6 at 90% e^+ efficiency.

2. Verification of TRD performance

The TRD is described in detail in [2] to [4]. To verify its performance, a 20 layer prototype was built with two 16 tube modules side by side in each layer and used for a beam test at CERN. Aside from length, the tubes and radiator were identical to those of the flight TRD. In 16 layers the tubes ran horizontally, and in 4 layers the tubes ran vertically. They were filled with an 80%:20% Xe:CO_2 gas mixture at 1 bar absolute pressure. Runs were taken at 15 different beam energies recording over 3 million events: p^+ at 15-250 GeV, e^-, μ^- and π^- at 20-100 GeV. Particles were identified by Cerenkov counters and by penetration of an iron beam dump at the end of the beam line.

3. Calibration

To correct for differences in the electronics and mechanical construction of the different tubes, a tube by tube intercalibration with protons and muons was done to equalize the signals from each tube to a standard value. For each run, a Landau fit was done to each tube's energy deposit spectrum to determine its most probable value. These fits were used to prepare intercalibration tables of the tubes, run by run. They were then summed for all runs, using overlapping tubes. The intercalibrations were found to be accurate to the 1% level.

Pressure and temperature were monitored for gas density corrections between runs. At the standard density of 4.46 10^{-3}g/cm^3 with bias voltage at 1470 V for a gas gain of 5000, an increase of density of 1% leads to a decrease of gas amplification of 5.5%. The correction is accurate to 1.5%.

Fe^{55} spectra were taken between runs on the first and last layers to calibrate the energy deposition by photons to the ADC scale. 9.09 ± 0.05 eV of photon energy corresponded to one 12 bit ADC bin. The calibrations were done both for protons and for muons, with good agreement.

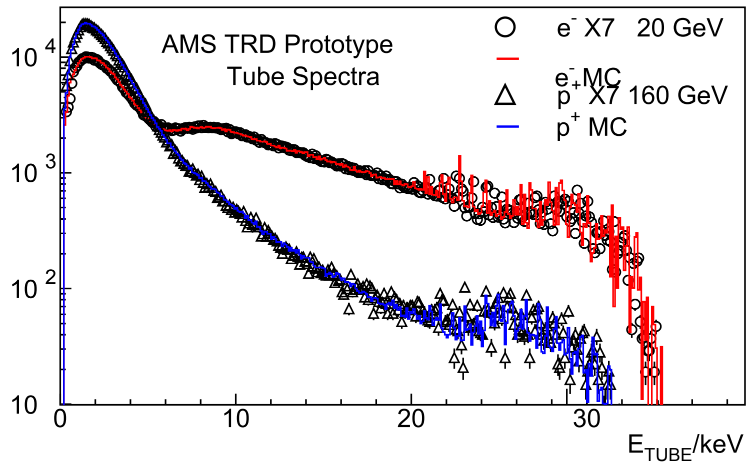

Figure 1. Energy Deposit Distributions for p^+ and e^-.

4. Radiator Test

The polyethylene/polypropylene fleece material LRP 375BK from Freudenberg Vliesstoffe KG to be used as radiator on the TRD has to be washed with CH_2Cl_2 to satisfy NASA outgassing requirements. The energy deposition spectra from single track electron events were used to compare the performance before and after cleaning, and also to compare it with a polyacryl fleece (Separet 405/Freudenberg Vliesstoffe) with known outgassing properties, but whose behavior as radiator was unknown.

The AMS radiator was unaffected by cleaning and was slightly better than the Separet 405.

5. Event Selection

Secondary particles produced before or in the TRD are eliminated by requiring clean single track events, which made up 50% - 80% of the data, depending on the beam setup.

6. Proton Rejection vs. Beam Energy

The separation of the electron and proton signals is obtained by the Transition Radiation effect in each layer, for energies greater than 6 keV. It is enhanced summing the energy deposition in all of the 20 layers of the detector.
We define *proton rejection* as the ratio of the number of incident protons to those selected, when the total number of electron events are not reduced below typically 90%, by applying the same cuts.
To measure proton rejection, two methods were used: cluster counting and maximum likelihood. In *cluster counting*, a particle is identified as an electron if there is a minimum number of hits (typically 5 or 6) on the track, with an energy deposit greater than a given energy cut (5 to 10 keV).
In the *maximum likelihood* method, the energy deposit distributions for protons and electrons as shown in Fig. 1 are normalized and used as the probability distributions for each hit, $P^i_{e,p}(E_i)$. A combined probability, $W_{e,p}$, is calculated and used to determine the likelihood ratio L_e:

$$W_{e,p} = \prod_{i=1}^{N} P^i_{e,p}(E_i); L_e = \frac{W_e}{W_e + W_p}$$

Figure 2 shows the proton rejection as a function of beam energy. Even the cluster method gives better than a factor of 100 proton rejection up to 200 GeV, while the maximum likelihood method gives a rejection of about 140 at 250 GeV.

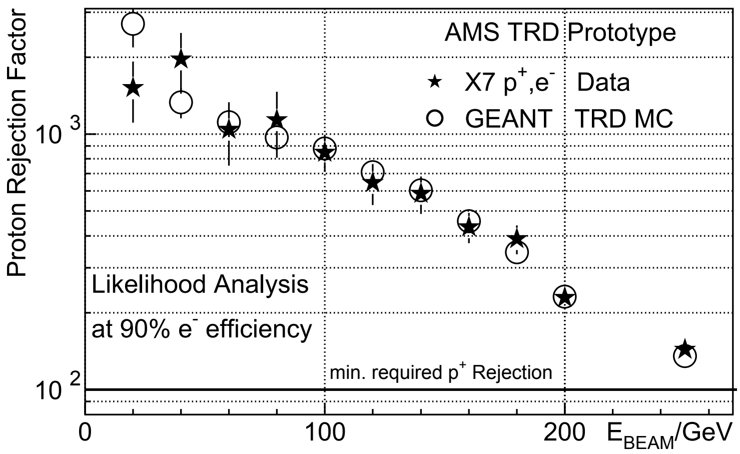

Figure 2. Proton Rejection vs. Energy.

7. Comparison Monte Carlo - Data

The beamtest results were compared with a GEANT 3.21 simulation with improvements in the dE/dx simulation for thin gas layers and inclusion of transition radiation as implemented by the HERA-B collaboration. After tuning the simulation to the AMS TRD fleece, the Monte-Carlo simulation reproduces the proton energy spectra over the full range of beam energies, and the proton rejection factors agree well with the values from the measured data (Fig. 2).

8. Space Qualification

There are stringent requirements on the TRD due to its operation on the ISS. TRD modules and structures are undergoing an extensive program of space qualification tests to verify, among other things, leak tightness and thermal performance in space, mechanical static and dynamic behaviour both on launch and on orbit, power consumption and electromagnetic interference.
The TRD flight version is under construction, and so far within specification and schedule.

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