The Performance of the AMS-02 TRD

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Abstract

The Alpha Magnetic Spectrometer (AMS-02) is an experiment which will be mounted on the International Space Station (ISS) to measure primary cosmic ray spectra in space. It includes a Transition Radiation Detector (TRD) to distinguish $p/\overline{p}$ from e^+/e^-. The TRD has been calibrated and its performance measured in test beams at CERN from 3 to 250 GeV/c and compared with Monte-Carlo predictions. It achieved a rejection factors from 2000-140 for protons in an energy range of 15-250 GeV/c. The TRD modules and structures have undergone an extensive program of space qualification. Selected modules are undergoing a long term test in a vacuum chamber.

1. Introduction

The Alpha Magnetic Spectrometer (AMS-02) [1] 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 way of doing this 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 avoid confusing protons with positrons to a level better than 10^{-6}. AMS includes a Transition Radiation Detector (TRD) as its uppermost element to distinguish e^+/p^- reducing the p^+/e^- background by a factor of more than 10^2 in the energy range 10-300 GeV. Combining the TRD rejection power with that of an electromagnetic calorimeter located at the bottom of AMS-02 increases the e^+/p rejection to the required level of 10^6 in this energy range.

2. Verification of TRD Performance

The TRD is described in [2] to [5]. To verify the performance, a 20 layer prototype was built with two 16 tube modules side by side in each layer. This

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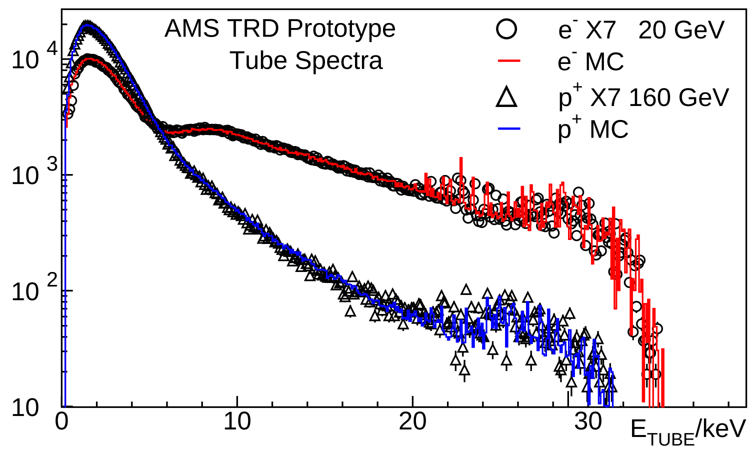

Fig. 1. Energy Deposit Distributions for p^+ and e^-

was used for a beam test at CERN. In 16 layers the tubes ran horizontally, and in 4 layers the tubes ran vertically. Aside from length, the tubes and radiator were identical to those of the flight TRD. 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 at test beams at CERN. Over 3 million events were recorded: 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

A tube by tube intercalibration with protons and muons was done to equalize the signals from each tube to a standard value. This was done to correct for differences in the electronics and mechanical construction of the different tubes. For each run, a Landau fit was done to each tube's energy deposit spectrum to determine its most probable value, and these were used to prepare intercalibration tables of the tubes, run by run, and then summed for all runs, using overlapping tubes. The intercalibrations are 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 HV 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.

4. Radiator Test

The polyethylene/polypropylene fleece material LRP 375BK from Freudenberg Vliesstoffe KG to be used as radiator 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. Rejection vs. Beam Energy

Proton rejection is defined 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, there must be at least a minimum number of hits (typically 5 or 6) on the track with an energy deposit greater than an energy cut (5 to 10 keV) for a particle to be classed as an electron. In the maximum likelihood method, the energy deposit distributions for protons and electrons are 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. In the cluster method, at least 6 hits with an energy deposit of at least 6.5 keV are required. Even the cluster method gives better than a factor of 100 proton rejection up to 200 GeV, and the maximum likelihood method gives a rejection of about 140 at 250 GeV.

7. Comparison Monte Carlo - Data

The beamtest results were compared with a GEANT 3.21 simulation with improvements in the $\frac{dE}{dx}$ simulation for thin gas layers and inclusion of transition

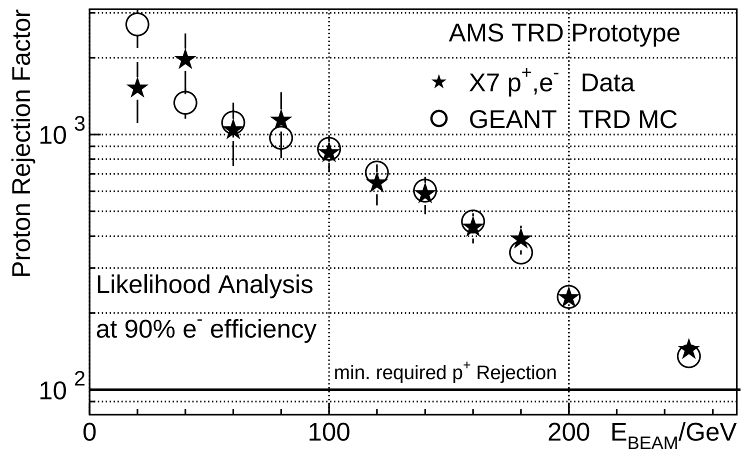

Fig. 2. Proton Rejection vs. Energy

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 have undergone an extensive program of space qualification tests to verify, among other things, leak tightness and thermal performance in space, mechanical stability both on launch and on orbit, power consumption and electromagnetic interference.

We want to thank the many organizations and individuals listed in the acknowledgements of ref. [1].

9. References

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