Positron/Proton Separation using the AMS-02 TRD

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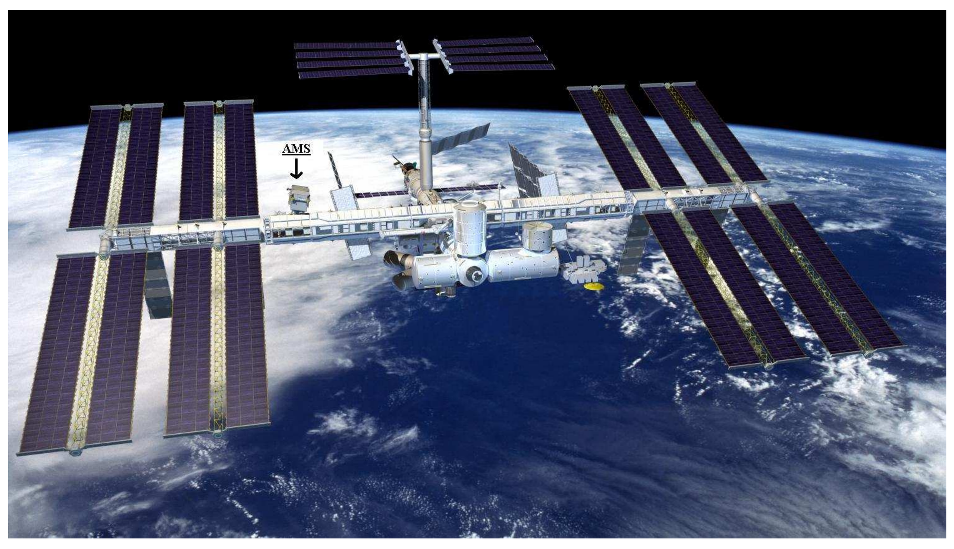
Abstract

AMS-02 is a cosmic ray experiment that will be placed on the International Space Station. One of the goals of this experiment is to search for WIMP Dark Matter, specifically from anomalous features in the positron spectrum. In order to identify positrons at high energy from the large background of protons a Transition Radiation Detector (TRD) will be used. This poster will discuss the prinicples of transition radiation, detail the TRD that will sit on AMS-02, and present progress on studies of positron/proton separation using the AMS-02 Monte Carlo.



AMS-02 on the ISS

Dark Matter Search

One of the current mysteries in science is the presence of Dark Matter which has been inferred to exist through various indirect signatures such as the rotation curves of galaxies.

One of the leading candidates for Dark Matter are WIMPs (Weakly Interacting Massive Particles) of which the most favored type is the supersymmetric (SUSY) neutralino; a linear superposition of the SUSY partners to the photon, Z^0, and Higgs bosons. It has an extremely low cross-section for interaction with normal matter (less then 10^{-5} picobarns)(ref 1) which is why we have not detected it yet, though there are direct detection searches currently running.(ref 1)

There is also a finite cross-section for the neutralino's to annhilate with eachother and thus produce normal particles such as positrons, electrons, anti-protons, or protons. The output of such annhilations in the Milky Way halo may be detectable as a bump in the power-law spectra of positrons or anti-protons (which would yield the most promising signal due to their inherently low background compared to electrons or protons) (ref 1).

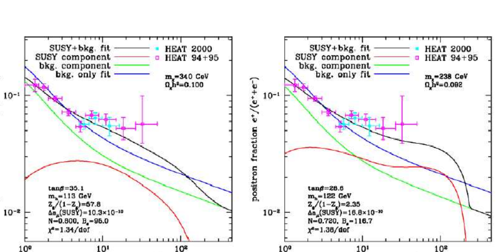
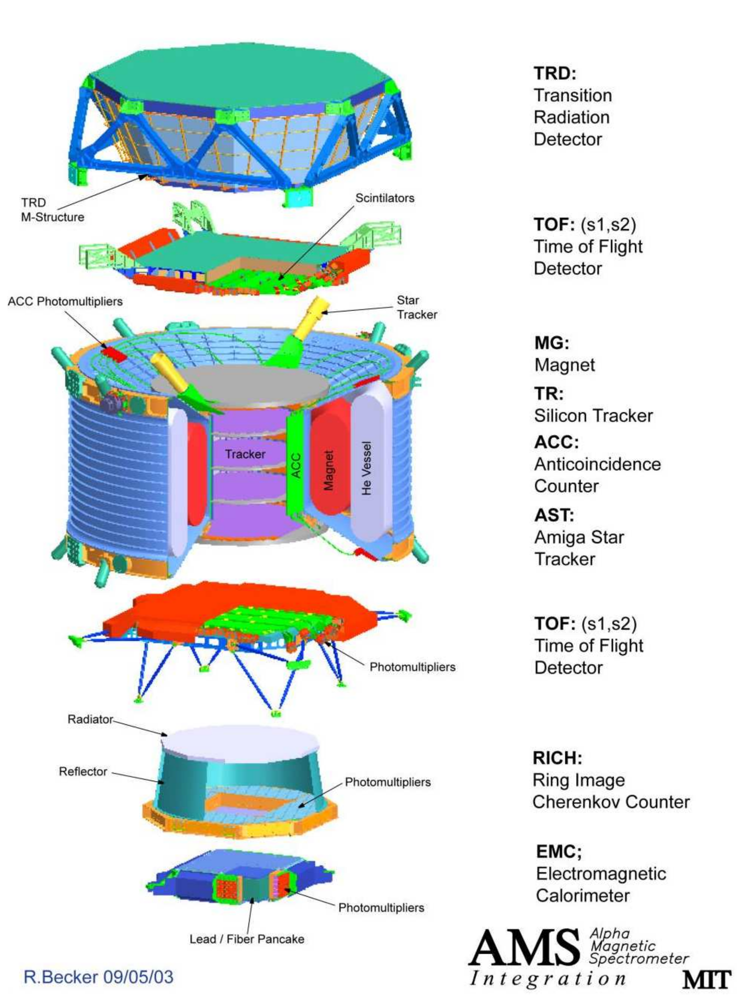


Figure 1. Hubble Telescope. Co. NASA/The Hubble Heritage Team. Figure 2. Baltz et al astro-ph 0109318

AMS-02 Experiment

The AMS-02 experiment is a magnetic spectrometer that is slated to sit on the International Space Station for 3 years of continuous operation. The experiment consists of the following subdetectors.



Exploded view of the AMS-02 experiment.

Acknowledgements

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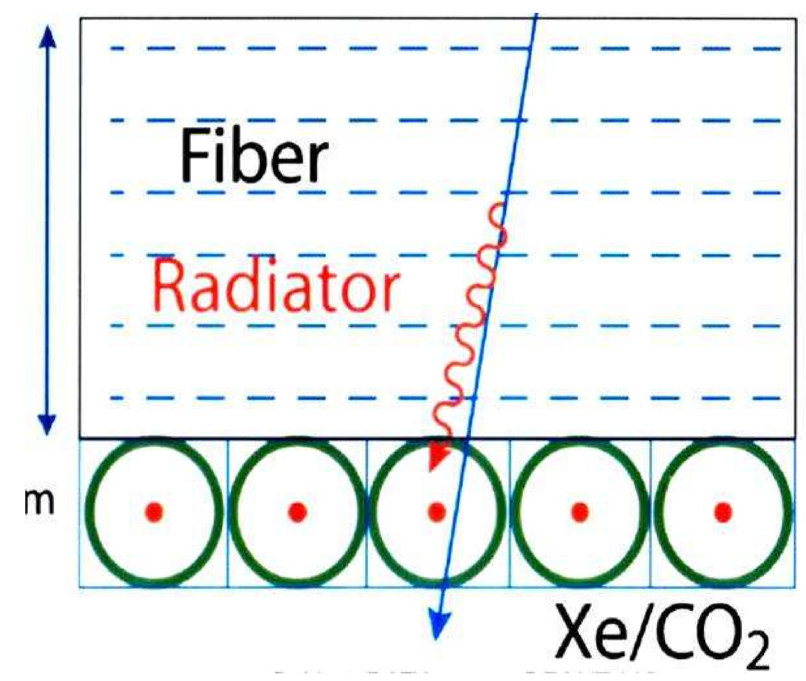
Transition Radiation Detector

Transition radiation (TR) occurs when ultrarelativistic charged particles pass into a medium with different dielectric properties. Crossing such boundaries is analogous to particle accelerating/decelerating. As a result TR photons may be shaken off, usually in the form of X-rays. The probability that a TR photon is emitted when a particle traverses a boundry is given by the fine structure constant $\alpha = 1/137$. As a result good radiators usually consist of many small interfaces to increase the probability of a photon being radiated, examples of which include polypropylene fibers and foil stacks (ref 2).

The flux of transition radiation goes as the relativistic γ and begins to turn on at $\gamma > 300$ for a typical radiator material. This photon flux tends to saturate at $\gamma > 1000$. As a result positrons will be giving off a maximum amount of transition radiation at momentum $> .5$ GeV while protons will not start emitting TR photons till 300 GeV.

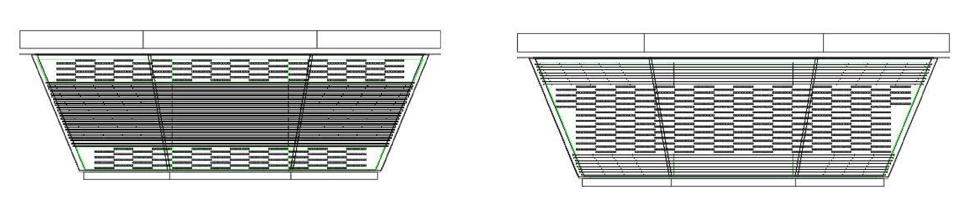
Once a TR X-ray is emitted it needs to be detected in order for the TRD to operate. This can be accomplished with proportional tubes which not only detect the standard dE/dX from the ionizing radiation, but are optimized to detect the X-ray photons as well. These X-rays have typical energies of a few keV and common gases used in these proportional tubes mixtures of Xe:CO_2 or Xe:CF_4.



Transition radiation is emitted in the radiator and is subsequently absorbed in the proportional tubes, along with standard dE/dX radiation from the primary particle.

Layout and Geometry of AMS TRD

The AMS TRD consists of 20 layers of 6 mm straw tubes sandwiched between radiator material which consists of polypropylene fibers. The geometry is such that the top/bottom 4 layers of straw tubes are parallel with the TRD x-axis and the middle 12 layers are parallel with the y-axis. This allows for tracking in the TRD.



Side view schematic of the TRD.

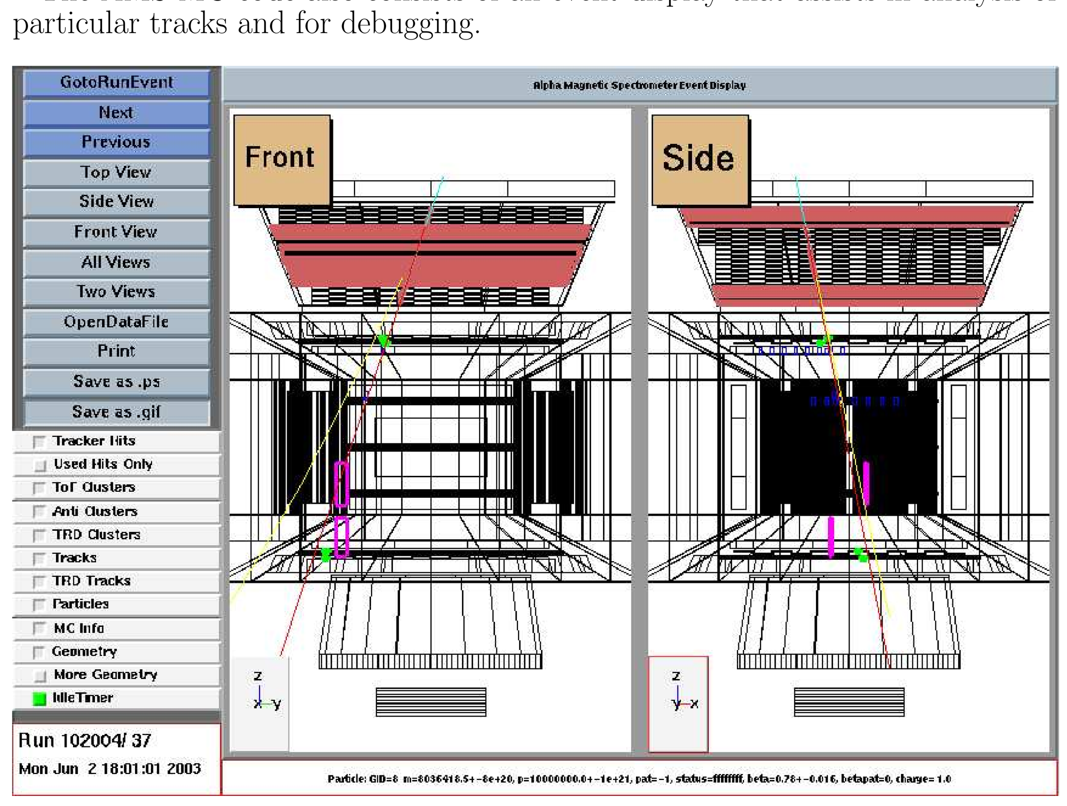
The proportional tubes are made primarily out of kapton and are filled with a mixture of Xe:CO_2 in a ratio of 80:20 by volume. A gas supply and mixing system will supply the TRD with fresh gas for the duration of the mission.

AMS TRD Simulation

The AMS MC simulation code is primarily based on Geant 3.21. The TRD geometry includes 20 layers of radiator and straw tubes arranged according to the latest design, carbon fiber bulkheads, and top and bottom honeycomb plates. (ref 3)

The transition radiation (TR) simulation used for these studies is based on code by Valeri Saveliev that has been integrated into the AMS MC. The Saveliev code also deals with dE/dx loss in the thin Xe gas layers of the straw tubes. It has been shown to reproduce reasonably beam test results (ref 4).

The AMS MC code also consists of an event display that assists in analysis of particular tracks and for debugging.



AMS-02 Event Display

References

1. "Supersymmetric Dark Matter", G. Jungman, M. Kamionkowski, K. Griest, June 1995
2. "Transition Radiation Detectors", B. Dolgoshein, NIM, A326 (1993) 434-469
3. Vitaly Choutko, http://ams.cern.ch/AMS/Analysis/hpl3itp1/ams02.html
4. "Study of Positron-Proton Separtion with AMS TRD MC", G. Carosi, K. Scholberg, AMS internal note, July 2002

Positron/Proton Separation Algorithm

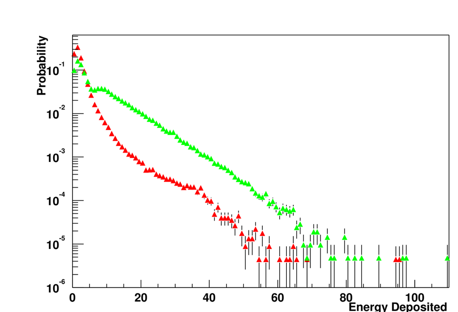
In these preliminary studies we used monoenergetic (50 GeV) protons and positrons. We implemented a log likelihood method:

$$\mathcal{L} = \sum_{i=1}^{N} log \frac{P\,(dE_i|e)}{P\,(dE_i|p) + P\,(dE_i|e)} \tag{1}$$

where N is the number of straw tube hits in a particular event. $P\,(dE_i|e)$ and $P\,(dE_i|p)$ are probability density functions for an positron (e) and proton (p) to deposit energy dE_i in the ith straw tube.

The current method of evaluating e/p separation consists of 4 steps:

1. Create histograms of the number of hits vs energy deposited in each straw tube for protons and positrons using the AMS MC simulation. (One hit refers to the total energy deposited in a particular straw tube for an event, and may include contributions from both $\frac{dE}{dX}$ and TR X-rays.) We normalize these histograms by the total number of proton or positron events. This gives us the probabilities that an positron or a proton will deposit a specific amount of energy in a certain straw tube. See Figure 1a.
2. Use the log likelihood ratio estimator in Equation 1 to create distributions of $\mathcal{L}$, for both positrons and protons. See Figure 2a.
3. The fraction of positrons (protons) above a threshold likelihood $\mathcal{L}_{th}$ defines the positron efficiency (proton contamination). We then integrate to the right of $\mathcal{L}_{th}$ in order to determine efficiency vs $\mathcal{L}_{th}$. Our goal is to minimize the proton contamination while maintaining a reasonable positron efficiency. See Figure 3a.
4. Finally we plot proton contamination vs positron efficiency, where each point of the plot corresponds to a different $\mathcal{L}_{th}$. See Figure 4. To compare particle separation qualities for different configurations, we choose a threshold likelihood for which 90% of the positrons satisfy the likelihood cut. (ref 4a)



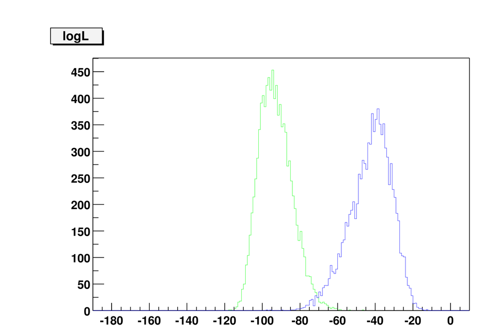
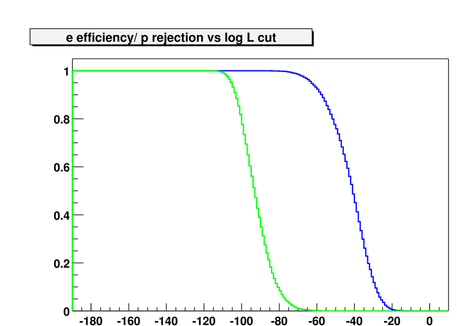


Figure 1a: Proton(red)/Positron(green) spectra Figure 2a: Likelihood distributions.



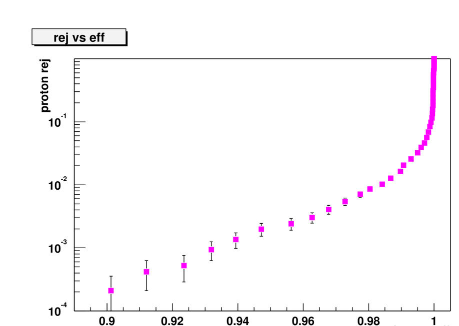


Figure 3a: Integrated Likelihood distributions. Figure 4a: Proton rejection vs Positron Efficiency.

Studies and Results

Initial results showed that proton rejections of approximately $10^{-}3$ could be achieved while only throwing away 10% of the positron signal. This was obtained by using all the hits in each event. A number of different studies have been run using the AMS Monte Carlo to look at various effects and explored possiblities to improve rejection by cutting off track hits which could be due to knock-off electrons.

1. Studies were conducted at different particle momentum. The results were in agreement with predictions with the separation becoming worse as the momentum rose and protons themselves began to emit transition radiation.
2. Studies were conducted that investigated the affects on rejection by cutting hits that were far from the tracks reconstructed from the tracker as well as the TRD. These investigations are ongoing as it was determined that off track hits seemed to help separation.
3. Studies were conducted to determine the effect that removing TRD layers might have on the rejection. As expected even the removal of 1 or 2 layers had a drasticly negative affect on the separation.
4. Studies were also conducted to determine how noise in the gas-gain would affect the positron/proton separation. It was determined that uncorrelated variations in the gas-gain did not really affect the separation until the variations reached 30% of the total gain. (ref 4)

Future Work

The Monte Carlo is continuely being updated with new geometry and structure and we will continue to check the separating power of the TRD as the code becomes more refined and approaches it's final state. We would also like to determine what the real physics reach of AMS is in terms of searches for Dark Matter.

Table 1:

Fig. 1.—

Fig. 2.—

Fig. 3.—

Fig. 4.—

Fig. 5.—

Fig. 6.—

Fig. 7.—

Fig. 8.—

Fig. 9.—

Fig. 10.—

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