Status of the Top and Bottom Counting Detectors for the ISS-CREAM Experiment

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Abstract. It is important to measure the cosmic ray spectra to study the origin, acceleration and propagation mechanisms of high-energy cosmic rays. A payload of the Cosmic Ray Energetics And Mass experiment is scheduled to be launched in 2017 to the International Space Station for measuring cosmic ray elemental spectra at energies beyond the reach of balloon instruments. Top Counting Detector and Bottom Counting Detector (T/BCD) as a two-dimensional detector are to separate electrons from protons for electron/gamma-ray physics. The T/BCD each consists of a plastic scintillator read out by 20 by 20 photodiodes and is placed before and after the Calorimeter, respectively. Energy and hit information of the T/BCD can distinguish shower profiles of electrons and protons, which show narrower and shorter showers from electrons at a given energy. The T/BCD performance has been studied with the Silicon Charge Detector and the calorimeter by using a GEANT3 + FLUKA 3.21 simulation package. By comparing the number of hits and shower width distributions between electrons and protons, we have studied optimal parameters for the e/p separation.

1. Introduction
Since cosmic rays were discovered in 1912 by Victor Hess [1], we have tried to understand the cosmic rays. But the origin, acceleration and propagation mechanisms of high-energy cosmic rays have remained unexplained. The flux of electrons plus positrons are measured by various experiments such as the ATIC (Advanced Thin Ionization Calorimeter) [2], Fermi-LAT (Fermi Large Area Telescope) [3], AMS (Alpha Magnetic Spectrometer) -02 [4], etc. The cosmic ray electron flux spectrum shows a significant excess above 20 GeV in results of the ATIC, Fermi-LAT and etc. However, the result of AMS-02 shows no significant structure at the same energy region [4]. In order to measure the cosmic ray electron spectrum clearly, it is important to separate electrons from protons.

The CREAM (Cosmic Ray Energetics And Mass) experiment was a balloon born experiment flown 6 times for which has been upgraded for the ISS (International Space Station) as ISS-CREAM. The ISS-CREAM experiment plans to measure the cosmic rays energy spectra from $10^{11}$ to $>10^{15}$ eV [5], and is scheduled to launch in 2017 to the ISS. The ISS-CREAM consists of the Silicon Charge Detector, a carbon target, the calorimeter (CAL), the T/BCD and a Boronated Scintillator Detector (BSD). A prototype BSD was test at CERN in 2012 and demonstrated e/p discrimination of 100 with 80% acceptance for 350 GeV pions/125 GeV electrons [6].

The T/BCD are designed for studying electron and $\gamma$-ray physics [7, 8]. The T/BCD also provide a redundant trigger to the high energy CAL trigger and a low energy electron trigger.
2. Top and Bottom Counting Detectors
The T/BCD consist of a plastic scintillator coupled with a PD array. Dimension of the plastic scintillator of the TCD is $500 \times 500 \times 5\ \text{mm}^3$, and that of the BCD is $600 \times 600 \times 10\ \text{mm}^3$. Dimension of the PD is $23\ \text{mm} \times 23\ \text{mm} \times 650\ \mu\text{m}$, and total 400 PDs are attached to the plastic scintillator of the TCD and BCD, respectively [7]. Figure 1 shows the assembled PD array and assembled plastic scintillator.

![Figure 1](image1.png)

Figure 1. (a) Photodiode array and VA/TA chips, and (b) plastic scintillator and photodiode array being assembled.

Figure 2 shows the photos of the TCD and BCD before assembling Al enclosure cover. The outer sides of the T/BCD are the electronics parts, and the center is the detector part. The electronics parts consist of 17 VA/TA chips, 4 high voltage circuits and 2 FPGA (Field-Programmable Gate Array) chips, respectively [7]. The TCD is located between the CAL and measures the transverse shower profile and back scattering particles. The BCD is located below the CAL and measures the transverse and longitudinal shower profiles. The electromagnetic shower is narrower and shorter than the hadronic shower. Thus the electrons are separated from protons by using these T/BCD information [7, 8].

![Figure 2](image2.png)

Figure 2. Photos of (a) TCD and (b) BCD before assembling Al enclosure cover.

3. Environmental Tests
Since the ISS-CREAM will be installed on the ISS, the T/BCD are constructed under critical requirements of mechanical structure [9].

The vibration test and the thermal vacuum test in the detector level are performed at the Keimyung University and the KARI (Korea Aerospace Research Institute) in Korea. The environmental tests in the payload level, such as EMI (Electro-Magnetic Interference) & EMC (Electro-Magnetic Compatibility) tests, vibration test and thermal vacuum test, are performed
4. A preliminary Study of e(γ)/p Separation by a Monte Carlo Simulation

Electron and proton events are generated by using a GEANT3 simulation package [10]. In order to study the proton rejection power, we simulate a $2.3 \times 10^7$ proton events with $150 \text{ GeV} \sim 15 \text{ TeV}$ and $5.7 \times 10^4$ electron events with $150 \text{ GeV} \sim 10 \text{ TeV}$ [11]. In this study, 300 GeV electron and protons which are expected to be simulated to the 300 GeV electron are used. The electronics noise level was smeared by using the previous CREAM experiment results assuming a similar performance to the CREAM [12]. The CAL trigger and TCD 2 MIP (Minimum Ionizing Particle) trigger were used for event selection. The e/p separation was studied by comparing the hits and RMS distribution of electrons and protons in the T/BCD [9]. Figure 3(a) shows the hit distributions in the T/BCD, and a two dimensional cut is applied for e/p separation. Figure 3(b) and (c) show the shower width distribution in the TCD and f-factor distribution in BCD, respectively. The RMS and f-factor are defined as

$$RMS^2 = E_{TCDi} \times \{(x_i - x_c)^2 + (y_i - y_c)^2\},$$

$$f - \text{factor} = RMS^2 \times \frac{E_{BCD}}{E_{CAL}},$$

where $x_i$, $y_i$ are the center coordinates of the sensor where energy $E_{TCD}$ deposited, $x_c$, $y_c$ are the coordinates of the energy center in the TCD, and $E_{TCDi}$ is the energy deposited in the $i$th sensor of the TCD. Also $E_{BCD}$ is the energy deposition in the BCD and $E_{CAL}$ is the total energy deposition in the CAL.

![Figure 3](image-url)

**Figure 3.** (a) TCD number of hits vs. BCD number of hits, (b) TCD shower width distribution, and (c) BCD f-factor distribution for electrons and protons.

The proton rejection power is defined as
In this study, the electron efficiency and proton rejection power are found to be approximately 60% and $4.7 \times 10^4$, respectively.

5. Conclusion

The T/BCD are one of the ISS-CREAM instruments, and the ISS-CREAM is being planned to be launched in 2017. The T/BCD are developed for $e/\gamma$ physics, providing a redundant trigger for CAL and providing a low energy electron trigger. Environment tests are performed at the NASA Goddard Space Flight center, and T/BCD behaved normally during these tests. The ISS-CREAM is currently being prepared for the launch at the NASA Kennedy Space Center. The capability of the T/BCD to separate electrons from protons has been studied preliminarily with a GEANT3 simulation. The proton rejection power is $\sim 4.7 \times 10^4$ and electron efficiency is $\sim 60\%$ at 300 GeV electrons.

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Acknowledgments

The authors thank the NASA GSFC WFF for project management and engineering support, and the NASA JSC ISS Program Office for the launch support and the ISS accommodation. This work was supported in the U.S. by NASA grants NNX11AC52G, NNX08AC15G, NNX08AC16G and their predecessor grants, as well as by directed RTOP funds to NASA GSFC WFF. It is supported in Korea by the Creative Research Initiatives of MEST/NRF and by National Research Foundation Grants NRF-2014R1A2A2A01002734, NRF-2014R1A1A2006456, NRF-2015R1A2A1A13001843. It is supported in France by IN2P3/CNRS and CNES and in Mexico by DGAPA-UNAM and CONACYT. The authors also thank H.S. Choi, Korea Institute of Industrial Technology, for contributions to the SCD thermal vacuum tests, M. Geske, Penn State, for contributions to the BSD, and M. A. Coplan, University of Maryland, contributions to CAL electronics vacuum tests.