The Time of Flight System for BESS-Polar II

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***Abstract*. This paper presents the design, fabrication, and performance of the outer Time of Flight system (Henceforth referred to as TOF) for BESS-Polar II. The TOF provides the trigger as well as the energy loss and velocity measurements for incident particles in the BESS-Polar II experiment. The TOF is comprised of upper and lower time of flight detectors formed into a cylindrical arrangement above and below the other detectors. It provides a geometrical acceptance of 0.3m^2 sr. Due to the absence of any outer pressure vessel, the TOF operated in the ambient environment and was designed to address the effects of exposure to stray sunlight, thermal expansion/contraction, and the low pressure environment. Modifications and improvements in performance from the BESS-Polar I TOF are reported.**

***Keywords*: scintillator, light guide, PMT, time-of-flight, BESS-Polar**

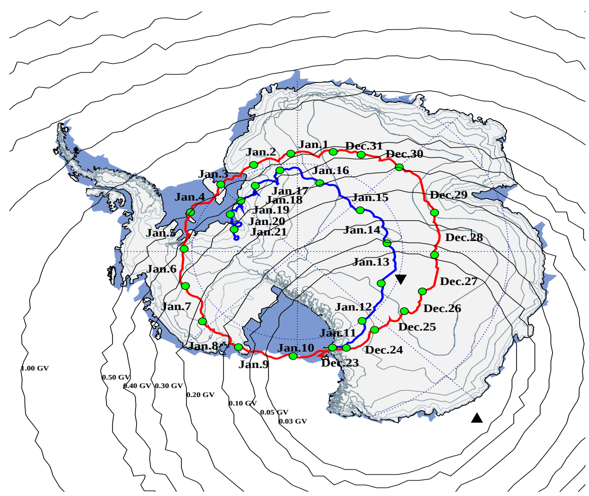

Fig. 1. BESS-Polar II flight trajectory, launched on Dec 23, 2007 and terminated on Jan 21, 2008 after 24.5 days of science observation.

I. Introduction

The BESS-Polar (Balloon-borne Experiment with a Superconducting Spectrometer) completed its second successful circumpolar flight from December 23, 2007 to January 21, 2008 from Williams Field near the McMurdo Station, Antarctica and acquired science data for 24.5 days [1]. The main scientific goals of the BESS program include search for cosmological antimatter, precise measurement of light elements in the cosmic radiation [2] [3] [4] [5], as well as study of the effects of any short term transients on the cosmic ray flux and are described in detail in these proceedings elsewhere [6] [7] [8] [9].

The cross section of the BESS-Polar II instrument is shown in Fig. 2. As a cosmic ray particle enters the instrument from the top and exits from the bottom, it traverses the upper TOF (UTOF), the superconducting solenoid magnet coil (MAG), the JET/IDC chambers, the middle TOF (MTOF), the silica aerogel Cherenkov counter (ACC), and the lower TOF (LTOF). The magnet operates at 0.8T. The JET/IDC is used to reconstruct the trajectory of the particle and the ACC is a threshold counter for rejection of lighter particles.

Particle identification is carried out by mass and charge. Mass is calculated from the rigidity of the particle which in turn is calculated from the curvature of the particle trajectory. The precision TOF measures the energy deposited in the detectors which leads to the calculation of charge of the particle.

This paper focuses on the outer Time of Flight detectors. The details of ACC and MTOF are discussed elsewhere in these proceedings. [10] [11]

The purpose of this outermost detector system is to provide the instrument trigger, measure the charge and velocity of the incident particles, and reject albedo. It consists of two arrays of scintillating paddles, one above and one below the other instrument elements. The TOF measures the amount of light deposited, and conse-

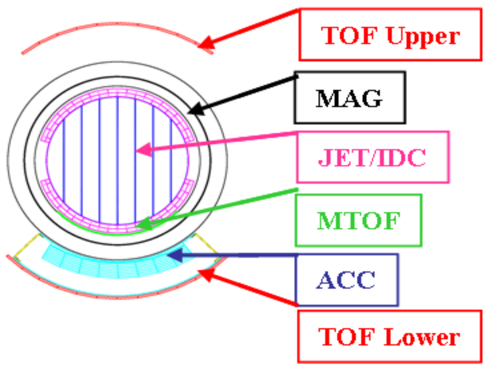

Fig. 2. Cross section diagram of the BESS-Polar II Instrument.

quently, the energy deposited, in the UTOF and LTOF. The charge of a particle is determined from the energy deposited in the UTOF and LTOF. The measurement of time of arrival of the particle by the TOF, in conjunction with the track reconstruction information from the JET chamber, provides the velocity of the particle.

For the lowest energies, where particles are stopped in the lower magnet wall, the MTOF has been installed between the lower wall of the magnet and the JET. The MTOF, in conjunction with the upper TOF, provides the charge and velocity measurements for the low energy particles.

II. Design

The outer Time-of-Flight system is comprised of an upper and a lower scintillator counter. These two TOF layers are cylindrical surfaces located approximately 0.75 meter from the center of the magnet. The upper and lower TOF layers are comprised of 10 and 12 closed-paced scintillator paddles, respectively.

Each TOF paddle contains a scintillator, two light guides, two adapter disks and two photomultiplier tubes (PMT). Since there have been significant changes from the TOF for BESS-Polar I (reference), we describe the detector here.

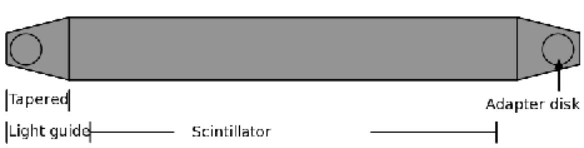

Fig. 3. The anatomy of a BESS-Polar II TOF paddle (PMTs not shown here)

A light guide is glued on each end of the scintillator. A circular ultraviolet transmitting (UVT) acrylic disk is glued on each light guide and is used as the adapter disk between the light guide and the PMT. This adapter disk fills the gap between the light guide and the PMT faceplate, which is slightly recessed due to its aluminum housing. Before gluing the PMTs to the light guides through the adapter disks, the paddle is wrapped in aluminized mylar followed by two layers of wrapping in tedlar. The purpose of the mylar is to achieve the reflection of any escaping light back in to the paddle in order to avoid any loss of photons generated in the scintillator due to the incident cosmic rays. The purpose of the tedlar is to disallow any ambient light from entering the paddle and being counted as the photons generated by the incident particle in the scintillator. The outcome is a paddle that has been optimized for maximum light collection by PMTs with no penetration by any outside light.

The scintillator material is Eljen Technologies' EJ-204 and has been cast to 1.2 cm thickness. Each paddle is diamond milled to an overall width of 10 cm and a length of 95 cm. The edges along each scintillator have been beveled to accommodate close packing on the cylindrical support frame and provide contiguous scintillator coverage of the respective TOF layers.

Fig. 4 describes how the beveled shape of the scintillators helps maintain contiguous coverage.

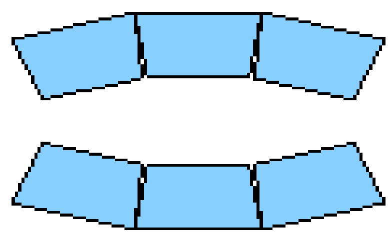

Fig. 4. Cross section view of paddle arrangement in UTOF(top) and LTOF (bottom)

Two UVT acrylic light guides are glued to scintillator with optical cement (EJ-500). The light guides are diamond milled from cast UVT acrylic stock with a nominal thickness of 1.2 cm and a length of 27 cm. The light guide positions the PMT such that the stray field of the magnet is axially aligned with the fine-mesh PMT. The width of the light guide is slightly smaller than that of the scintillator, to avoid potential interference of adjacent light guides and to allow the scintillators define the coverage area. In order to improve performance, the thickness of the scintillator has been increased to 1.2 cm from that of 1.0 cm in BESS-Polar I.

III. Factors that Influenced the Design of the TOF

The TOF PMTs are in a $\sim$0.150 Tesla magnetic field but any magnetic shielding is prohibitive due to the weight constraints on a balloon payload. Hence, the Hamamatsu R6504 2.5" fine mesh PMTs were selected. These PMTs can tolerate magnetic fields of such levels if the field lines are parallel to the axis of the PMT. In order to achieve this magnetic field alignment, the TOF PMTs are attached such that the faceplate of the PMT is glued to the surface of the light guide making the PMT normal to the surface of the light guide rather than head on. The light guide surface opposite to the PMT is tapered to improve the light collection. The shape of the light guide is optimized for light collection and time resolution using a Monte Carlo computer simulation.

In an effort to reach as low as possible in energy, the material in the path of the particle was significantly reduced for the BESS-Polar flights. The outer pressure vessel used in previous BESS experiments was eliminated and as a result, the outer most detector systems, including the TOF, operated in ambient flight conditions. Therefore, the outer detector design has to address the effects of exposure to the stray sun light, thermal expansion/contraction, and low pressure environment. The latter is particularly important with respect to coronal discharge on the high voltage (HV) components of the PMT.

In the BESS-Polar I experiment, the potted PMT assemblies for the TOF had a high failure rate when exposed simultaneously to low pressure and low temperature. Consequently, only 60% of the outer TOF PMTs were operational in BESS-Polar I (2004). To improve the reliability of the TOF PMTs for the BESS-Polar II flight, hermetic PMT housings were adopted. The hermetic housings had been successfully used in the BESS-Polar I ACC. In addition, a hermetic housing is $\sim$ 50g lighter than a potted one. Before its selection for the flight, each TOF PMT underwent a thermal vacuum environmental test.

To maintain atmospheric pressure inside each PMT housing, the PMT face plate is pressed against a gasket flange on the aluminum PMT shell. The optical coupling between the recessed PMT face plate and the light guide is provided by a UVT acrylic disk, which is glued with optical RTV on both sides. The PMT light guide holder has been designed to provide mechanical support of the PMT and act as the light barrier for ambient light. The light guide holder is shown below in Fig. 5 before the installation of the PMT and the Fig 6 shows the PMT after installation.

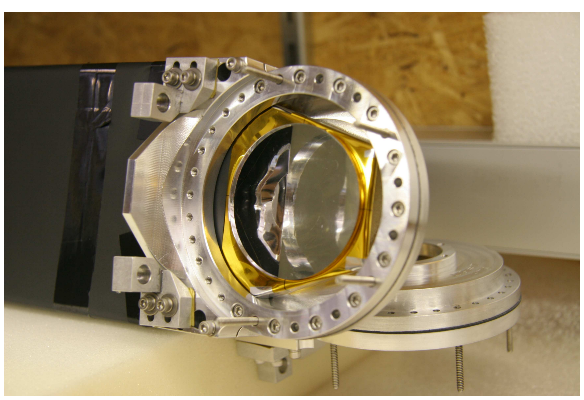

Fig. 5. a light guide holder, a PMT will be mounted here

The assembled TOF paddles are mounted on a thin carbon fiber support shell which is glued to a surrounding aluminum support frame minimizing the amount of material seen by the particle. To allow for differential thermal expansion, one end of each TOF paddle is fixed to the support frame while the opposite end only provides transverse support. The fixed ends alternate between the paddles, i.e., if one end of a paddle is fixed, its adjacent paddles will have their opposite ends fixed. The upper and lower TOF counters are shown in Figs. 7 and 8 respectively.

Fig. 6. a PMT has been glued to the light guide

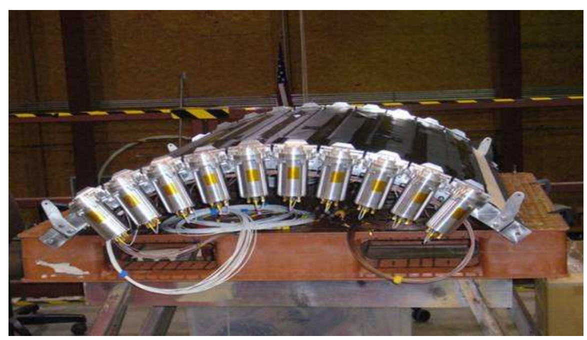

Fig. 7. UTOF with cables attached

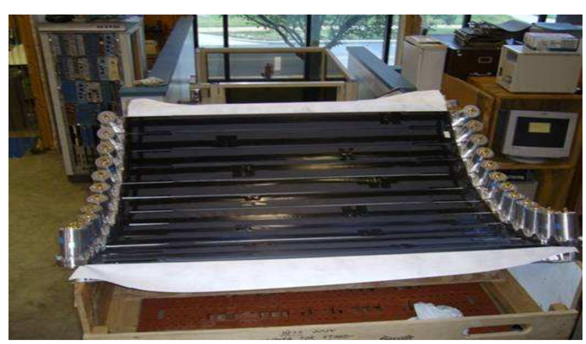

Fig. 8. LTOF before cables are attached

IV. Performance during flight

Fig 9 shows the particle identification plot for singly charged particles with positive rigidity. Fig. 10 shows the time resolution for a combination of upper and lower TOF detectors. For this combination we found a time resolution of better than 120 ps. Preliminary tests on the full data set show that the reported performance of the TOF and other systems is valid for the entire flight. During the flight only two PMTs were turned off because we could not control their target HV values.

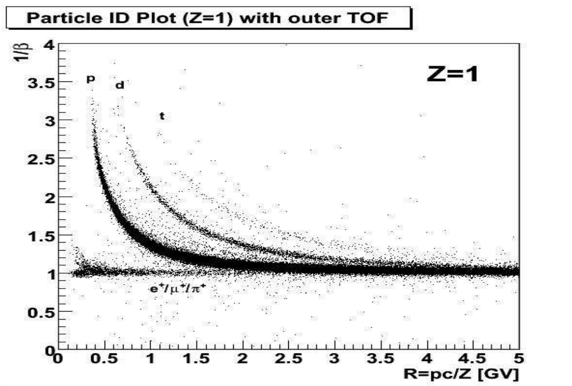

Fig. 9. particle identification: p, d, t are clearly separated

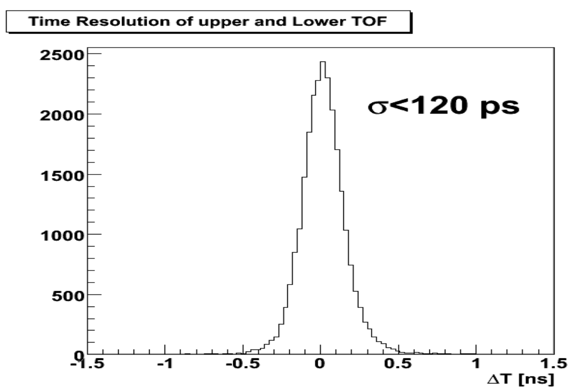

Fig. 10. timing resolution of UTOF and LTOF

V. Discussion and conclusion

A state of the art time-of-flight system was built and performed as designed. The use of aluminum hermetic housings for the PMTs was successful and resulted in stable HV and performance for all the PMTs. This was a marked improvement from the BESS-Polar I TOF PMTs, which used potted PMT assemblies from the manufacturer. Including the cable and support frame, the UTOF and LTOF weighed ∼53kg and ∼63kg respectively in comparison to ∼55kg and ∼65kg for those in the BESS-Polar I TOF. The other improvements from the BESS-Polar I TOF include the increase in the thickness of the scintillator by 20% and the use of adapter disk between the light guide and the PMT in order to maximize the collection of photons. These changes led to an improved timing resolution of 120 ps for the outer TOF as compared to 170 ps for BESS-Polar I TOF. The hermetic housings for the TOF PMTs performed very well without high voltage breakdown and ensured BESS' large aperture.

VI. Acknowledgment

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