In-flight Performance of the ISOMAX TOF

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Abstract

A state-of-the-art time-of-flight (TOF) system has been developed for the ISOMAX balloon-borne cosmic ray instrument. ISOMAX was built to measure the isotopic composition of the light elements in the cosmic rays, ($3 \leq Z \leq 8$), in particular beryllium. In-flight performance of the TOF, during the first flight in August of 1998, and some isotopic results are presented. The uncorrected timing resolution for a single paddle was determined to be ∼47 ps for helium and ∼23 ps for carbon.

1 Introduction:

The ISOMAX instrument (Streitmatter *et al.* 1993), a major evolutionary step up from its progenitor IMAX (Reimer *et al.* 1998), employs a system of drift chambers with a superconducting magnet to measure the magnetic rigidity, R, of cosmic ray particles (Hams *et al.* 1999), a three-level time-of-flight (TOF) system to measure the velocity, β, and the charge, $|Z|$, of the particles, and a set of aerogel Čerenkov counters, which are used to determine higher values of β (de Nolfo *et al.* 1999). ISOMAX can fully identify the incident particle, since its mass can be determined from R, β, and $|Z|$. The main focus of the ISOMAX program is the determination of the abundance ratio of radioactive ^{10}Be to stable ^{9}Be to energies where time dilation is significant.

The ISOMAX TOF system is made up of three layers of fast Bicron BC420 plastic scintillator with a fluorescence rise-time of 500 ps. The top and bottom layers consist of five paddles of 20 cm×100 cm; the intermediate layer is made from three paddles of 23 cm×69 cm. All scintillators are 1 cm thick. The spacing is 2 m between the top and middle layers and 2.6 m from top to bottom. The scintillator is wrapped in black.

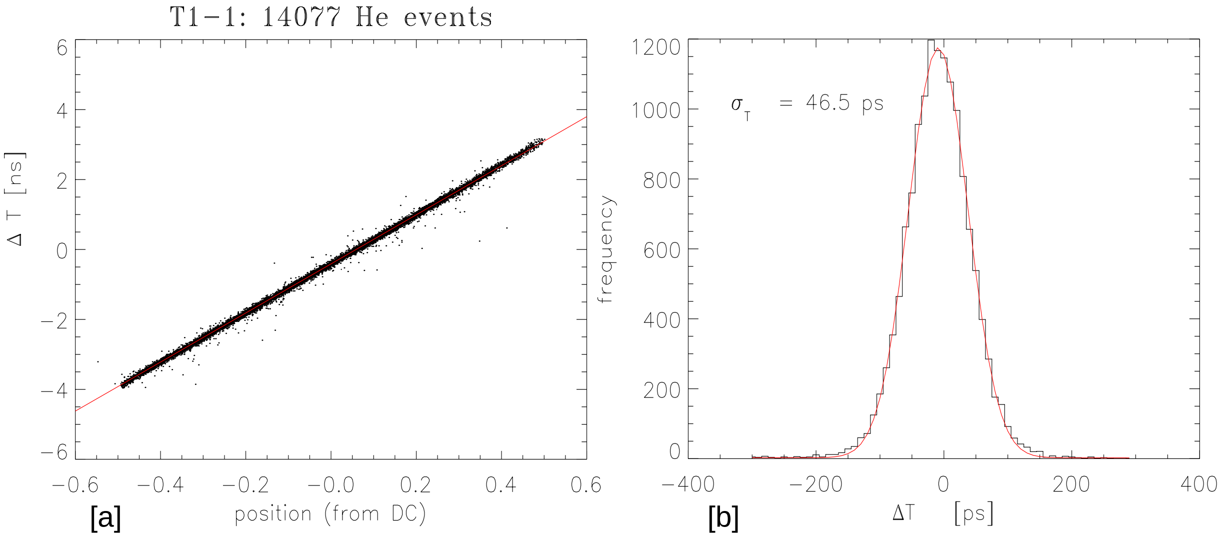

Figure 1: The single-paddle timing resolution for helium.

Both ends of each paddle are connected to adiabatic, UV-transmitting-acrylic light-pipes and attached through transition pieces to Hamamatsu R2083 photomultiplier tubes (PMT), which are 8-stage tubes with rise times of 700 ps that achieve an amplification of about 10^6 at 3 kV.

This system, which yields about 240 photoelectrons per PMT per minimum ionizing (Z=1) particle, measures flight times using leading-edge discrimination with dual thresholds and amplitude-correction in the analysis. It is also used to measure $|Z|$ and plays a cruical role in the trigger of the overall instrument.

The complete ISOMAX instrument and its first flight are described elsewhere (Mitchell *et al.* 1999).

2 Timing:

One of the ways to determine a representative figure for the timing resolution of the TOF system is shown for one of the paddles of the top layer in Figure 1a. For events that had been identified as helium (Z=2), the position of the incident particle along the paddle as determined from the timing of the pulses in the two PMTs (in units of nanoseconds) is shown plotted versus the position as determined by the tracker. Note, that this plot shows the raw timing measurements without any amplitude or position corrections.

A linear fit to the distribution is shown as well, and subtracting it yields the distribution of timing deviations from the tracker-position shown in Figure 1b. Assuming negligible uncertainty in the projected position, a Gaussian fitted to this distribution yields a single standard deviation of $\sigma \approx 47$ ps.

This is a preliminary result for the timing resolution, and the following additional factors have to be considered:

- The actual β for a particle will be derived from two paddles, which will degrade the resolution by a factor of $\approx \sqrt{2}$.
- The pulses are digitized at two different thresholds, which for all practical purposes constitutes an independent measurement of the same quantity and should improve resolution by a similar factor $\approx \sqrt{2}$ for pulse heights sufficiently above the upper threshold.
- Since the system has three layers, a second measurement of β for the same event is available, yielding an additional improvement of the timing resolution.
- Several additional corrections can still be applied to the measured values of β, notably corrections for systematic variations due to pulse-height (time-walk) and incident position of the particle.

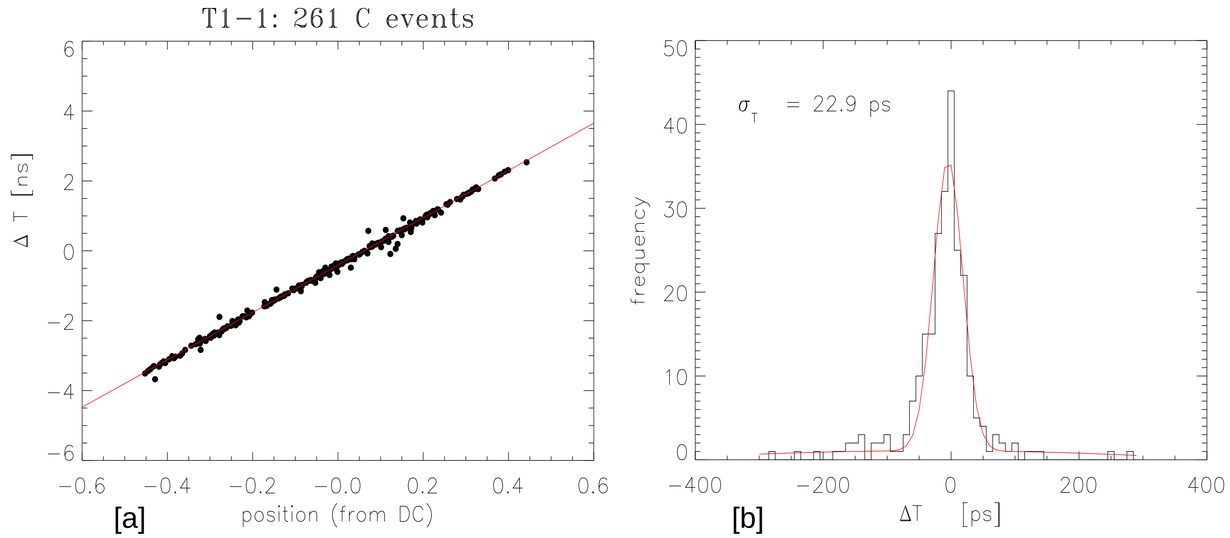

Figure 2: The single-paddle timing resolution for carbon.

Figure 2 shows the same plots for carbon. Since the number of events is considerably lower for carbon than for helium, the size of the dots has been increased in this plot for clarity. To account for the apparent low-level non-gaussian wings of the distribution, a baseline was added to the fitted gaussian as shown in the figure. The width of the gaussian fit to the uncorrected single-paddle timing distribution yields $\sigma \approx 23$ ps.

The contribution of the TOF to the mass resolution of the overall instrument can be expressed in terms of the variation in the determination of the mass, A, of the incoming particle due to variations in the determination of β alone. This contribution is $\sigma_A/A = (\sigma_t/d)\beta\gamma^2$ where d is the distance between the paddles under consideration and is replaced with an appropriately weighed mean for a three-layer system.

Taking ~50ps as a "typical" timing resolution yields a mass-resolution of $\sigma_A \leq 0.25$ amu for separation of beryllium isotopes up to relativistic time dilations of about $\gamma \approx 2.3$ or kinetic energies of about $E_{\rm kin} \approx 1.3$ GeV/nucleon, at which point velocity-measurement passes to the Čherenkov detector.

3 Elemental Separation:

Once the particle velocity, β, has been determined, the TOF system is used to identify the elemental species of an incoming cosmic ray. The energy deposit of the particle in any of the TOF layers will vary as a function of both β and the charge of the particle. Careful measurement of the charge-integral of the PMT-pulses, corrected for incident position, together with the determination of β will therefore yield a measure for $|Z|$.

As an example, Figure 3 shows a plot of the average pulse-integral in the middle TOF layer (in arbitrary units) versus β. The measured particles clearly fall into distinct, easily identified charge bands.

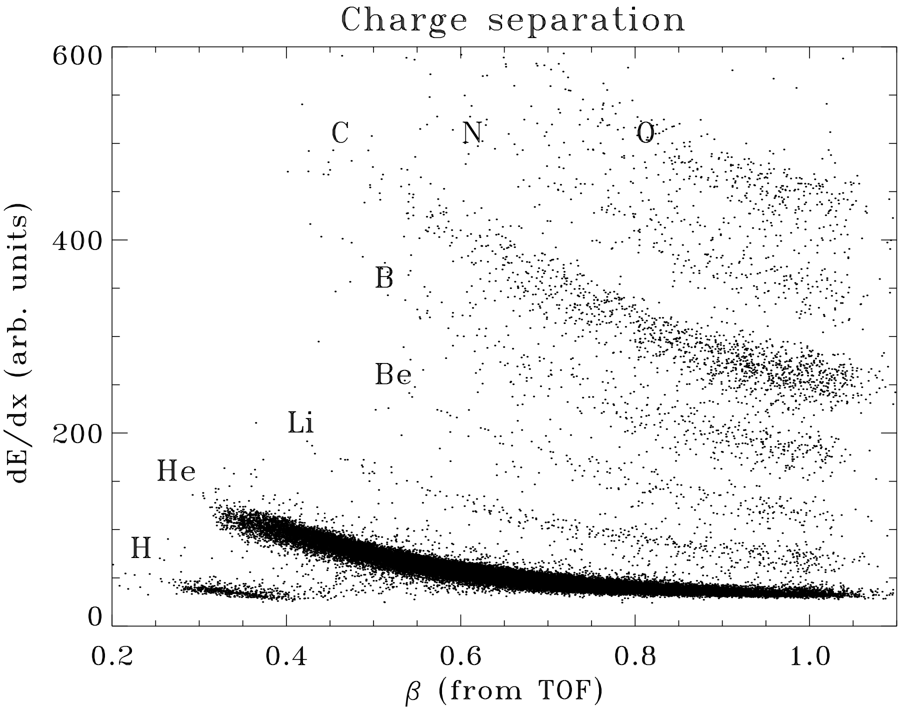

Figure 3: Identifications of elements.

4 Isotope Separation:

To illustrate the performance of the TOF in the context of the overall instrument, Figure 4a shows plots of the rigidity as measured by the spectrometer versus β as determined by the TOF for some 32,000 particles identified as helium. No amplitude or other corrections were applied to the data and no events were removed other than those with $Z \neq 2$.

Figure 4b shows the same events on an axis of kinetic energy per nucleon rather than β to show more clearly the capability of the instrument to separate isotopes in the interesting energy range around 1 GeV/nucleon.

The purpose of the ISOMAX instrument was the measurement of cosmic rays with $3 \leq Z \leq 8$ and we included helium in the data set mostly for calibration. Set to eliminate the majority of protons, the trigger therefore seriously cut into the acceptance of ^{3}He above ~900 MeV/nucleon.

As an example, Figure 5 shows the preliminary isotope separation for helium in two different energy ranges (0.2–0.4 GeV/nucleon and 0.8–1.0 GeV/nucleon).

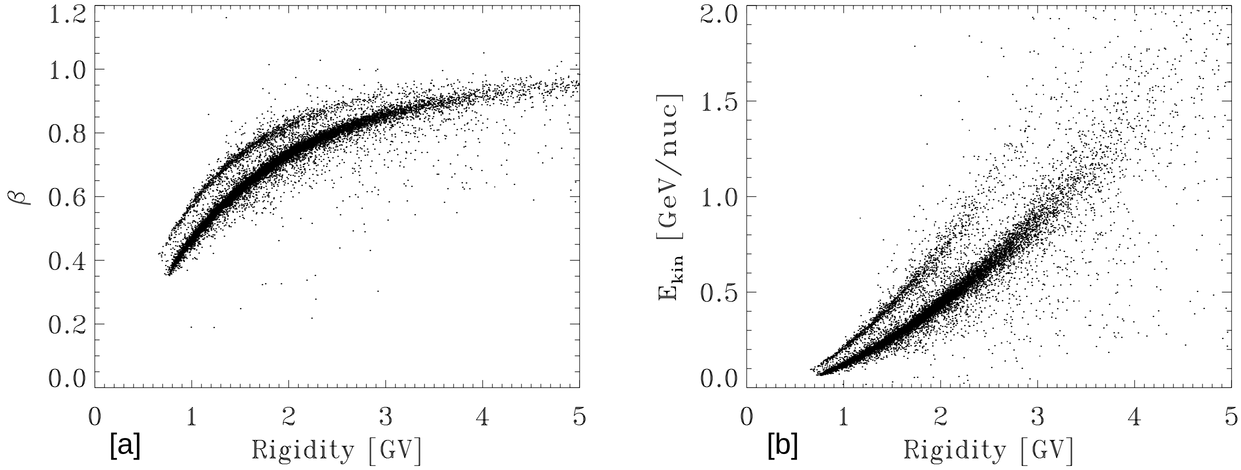

Figure 4: β and E_{kin} versus Rigidity. Helium nuclei; no corrections.

5 Conclusions

The three-layer time-of-flight system as realized in the ISOMAX instrument is capable of elemental and isotopic separation of light cosmic rays in the crucial energy-range around 1 GeV per nucleon. A longer ($>$ 3 days) flight, currently planned for the year 2000, will improve the statistics of the data and expand the energy range by using lower-index aerogel in the Čerenkov detector.

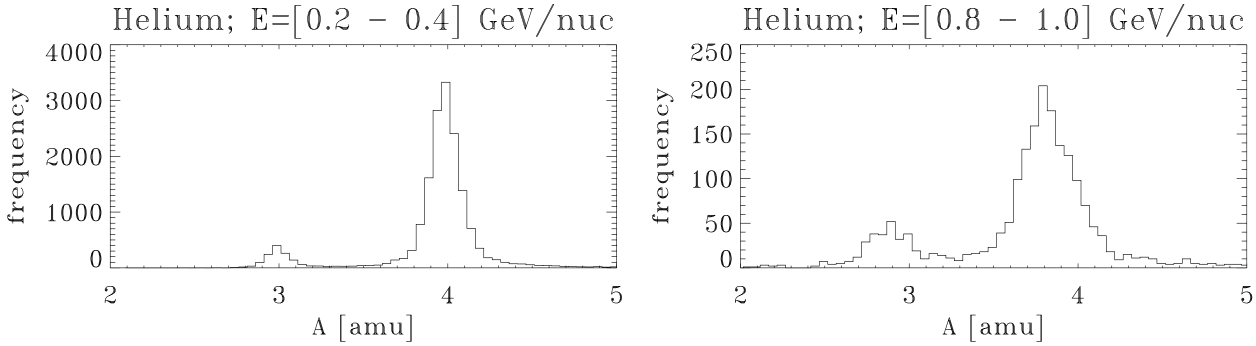

Figure 5: Sample isotope separation for helium.

References

de Nolfo, G. A., *et al.* 1999, Proc. 26th ICRC (Salt Lake City), OG 1.1
Hams, T., *et al.* 1999, Proc. 26th ICRC (Salt Lake City), OG 1.1
Mitchell, J. W., *et al.* 1999, Proc. 26th ICRC (Salt Lake City), OG 1.1
Reimer, O., *et al.* 1998, ApJ, 496, 490
Streitmatter, R. E., *et al.* 1993, Proc. 23rd ICRC (Calgary), 2, 623