Cosmic Ray Isotope Measurements using the Cherenkov-Rigidity Technique in ISOMAX

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Abstract

The Isotope Magnet Experiment, ISOMAX, which had its first flight in August 1998, is designed to measure the isotopic composition of the light elements ($3 \leq Z \leq 8$) using a complement of three major detector systems: a magnetic spectrometer, a time-of-flight (TOF) system, and two Cherenkov detectors. ISOMAX measures mass by combining the velocity measurement with charge and magnetic rigidity (momentum/charge) measurements. In the energy range from 1.1 to 1.7 GeV/nucleon, the velocity measurements are provided by two aerogel Cherenkov counters. The aerogel radiators have a nominal index-of-refraction $n = 1.14$ corresponding to an energy threshold of 1.08 GeV/nucleon, which complements and extends the energy range covered by the TOF. Combining the velocity measurement with a measurement of rigidity results in a determination of isotope mass with an expected resolution of $\leq$ 0.25 amu. We present preliminary isotope data.

1 Introduction:

The Isotope Magnet Experiment (ISOMAX) is designed to measure the isotopic composition and absolute fluxes of the light elements ($3 \leq Z \leq 8$), with particular emphasis on the measurement of the ratio of the radioactive isotope ^{10}Be to the stable isotope ^{9}Be over a wide range in energies (Mitchell *et al.* 1999; Streitmatter *et al.* 1993). ^{10}Be, with a half life of 1.6x10^{6} years, serves as a radioactive clock to investigate confinement times and density inhomogeneities within our Galaxy. At relativistic energies, time dilation extends the lifetime of ^{10}Be, making ^{10}Be measurements a useful probe of the age distribution of cosmic rays. Though the primary goal of ISOMAX is to measure the Be isotopes, observations of the isotopic composition of other light elements provide essential constraints on theories of the origin and propagation of galactic cosmic rays. For example, current models of cosmic ray origin are tested by measurements of the more abundant isotopes of carbon, nitrogen, and oxygen, all of which are important for stellar nucleosynthesis and galactic chemical evolution.

To measure the isotopic composition of the light elements with good mass resolution, ISOMAX was designed with three main detector subsystems: a time-of-flight (TOF) system (Geier *et al.* 1999), a superconducting magnetic spectrometer (Hams *et al.* 1999), and two Cherenkov counters (C1 and C2). ISOMAX incorporates detector subsystems improved from an earlier successful instrument, IMAX (Mitchell *et al.* 1996 and references therein). ISOMAX determines mass by combining measurements of the particle velocity and the particle rigidity (pc/Ze). The magnetic spectrometer provides particle tracking using drift chambers (DC), and thus yields the particle rigidity. The TOF system measures the particle velocity as well as the energy loss (dE/dx) in each of three layers of the TOF. Finally, the Cherenkov counters provide a measure of the velocity in the energy range 1.1-1.7 GeV/nucleon, which complements and extends the energy range covered by the TOF.

ISOMAX had its first flight August 4-5, 1998, from Lynn Lake, Manitoba, Canada. The flight lasted 29 hours with 16 hours of data at float altitudes ($>$ 36 km). Six hours of data were obtained at lower altitudes ($\sim$30-36 km), where one can better investigate the contribution from atmospheric secondaries. The payload was recovered in Peace River, Alberta, Canada. Isotopic composition measurements from the first flight of ISOMAX using the Cherenkov-rigidity technique are discussed below.

2 ISOMAX Cherenkov Counters:

2.1 Counter Design: The Cherenkov counters consist of two large-area diffusive-light-integration counters (88×88×14 cm^3). Each counter contains two layers of silica-aerogel radiator blocks with a nominal index-of-refraction $n = 1.14$ and thus an energy threshold ($\beta = 1/n$) of 1.08 GeV/nucleon. The blocks are ∼38×38×2 cm^3, arranged in a 2×2 matrix of aerogel blocks per radiator layer. The counters are lined with a highly reflective Tyvek coating. Light is collected with 16 Hamamatsu R1848 3-inch photomultiplier tubes (PMT) per counter, chosen for their single photoelectron resolution, high quantum efficiency, and magnetic field resistant dynode construction. Each PMT is surrounded by magnetic shielding using layers of steel tubing and high-μ material of varying thicknesses. The counters are designed to accomodate the short scattering and absorption lengths of aerogels (Labrador *et al.* 93), resulting in a total light yield for the two counters of ∼22 photoelectrons for relativistic, singly-charged particles. To achieve the large dynamic range required to measure the light isotopes, the PMT signals are read into Amptek-203 charge sensitive preamplifiers with both a low and high-gain output and subsequently digitized using LeCroy 2259 ADC modules.

2.2 Counter Performance: Cherenkov counters measure the light yield produced from a relativistic particle ($\beta > 1/n$) passing through a transparent radiator. The light yield is given by:

$$L = kZ^2(1 - 1/\beta^2 n^2) \qquad (1)$$

where Z is the particle charge, β is the particle velocity, n is the index-of-refraction, and k is a proportionality constant dependent on the counter geometry and light collection efficiency. Figure 1 shows the ADC distribution of a typical PMT high-gain signal for a sample of helium events. The zero, one, and two photoelectron (pe) peaks are clearly visible. Helium events are selected using the elemental charge separation obtained from the TOF (Geier *et al.* 1999). During the eight hours of float data thus far analyzed, the gondola temperature varied between 5-11°C, causing PMT gain variations of less than 4%.

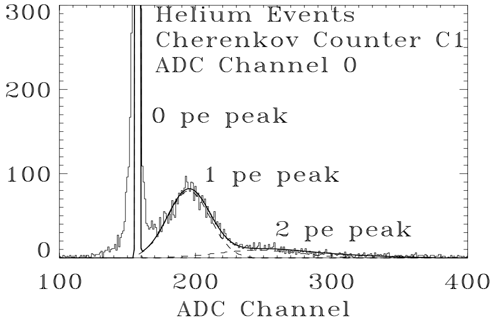

Figure 1: ADC distribution for a typical PMT.

The total light yield response of the Cherenkov counters is dependent on several factors, including position-dependent non-uniformities in the aerogel response and the counter geometry. Detailed response maps for both counters have been obtained from nearly 48 hours of pre-flight muon data. The counter is divided into 5×5

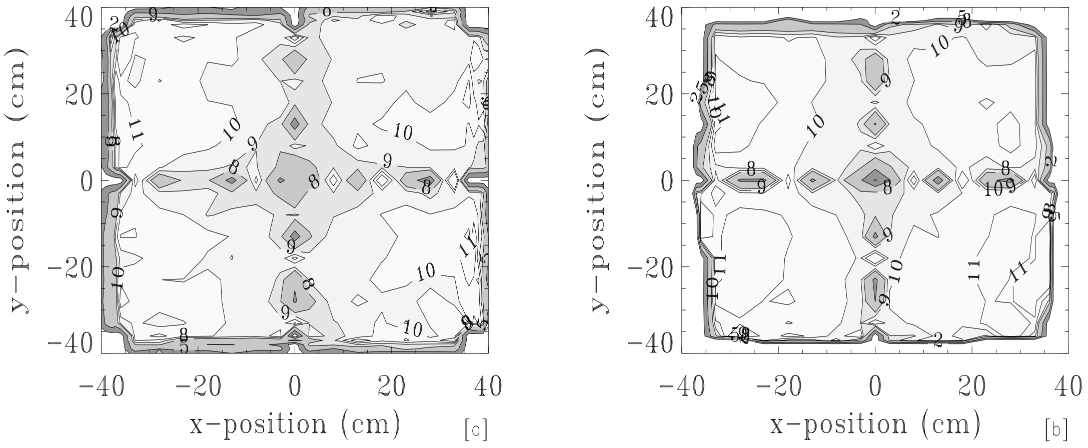

Figure 2: [a] Contour map of C1. [b] Contour map of C2. (Contour labels are in photoelectrons.)

cm^2 bins. The total response from all 16 PMTs is determined for each bin by fitting Poisson distributions to the light yield binned in ADC channel number. Figures 2[a] and 2[b] show contour maps of the aerogel response. While the counter frames that hold all four aerogel blocks in place are evident, the aerogel response variations within a given block are less than 20%. Helium events acquired during the flight, while having inadequate statistics to provide detailed response maps, nonetheless provide a valuable cross check to the response maps obtained from pre-flight muon data. The response maps are used to determine a normalized Cherenkov light yield, f, for each event given by:

$$f = L/L_{map}(x,y) = Z^2(1 - 1/\beta^2 n^2)/(1 - 1/n^2), \tag{2}$$

where the response map is defined as $L_{map}(x,y) = k(1 - 1/n^2)$ for a $\beta, Z = 1$ particle (Labrador 1996).

3 Isotope Measurements using the Cherenkov-Rigidity Technique:

In the energy range 1.1-1.7 GeV/nucleon, above the threshold for these aerogel radiators, the Cherenkov-rigidity technique is used to determine isotope mass (Reimer *et al.* 1998). The mass is given by:

$$m = \frac{ZeR}{c^2}\frac{\sqrt{1-\beta^2}}{\beta}, \tag{3}$$

where Z is the particle charge, R is the rigidity obtained from the spectrometer, and β is given by the map-normalized total Cherenkov response described in Equation 2.

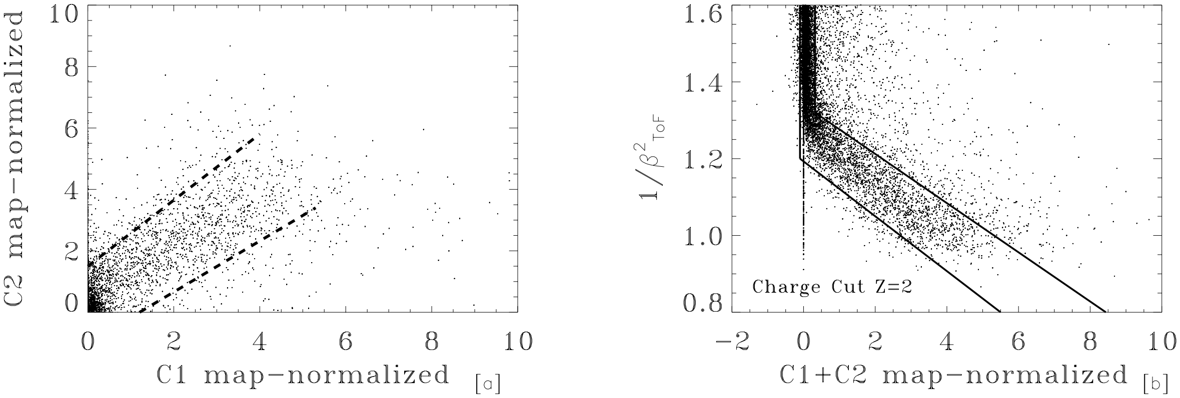

Figure 3: [a] Correlation between C1 and C2. For relativistic helium, the map-normalized signal is $Z^2 \propto 4$. [b] Correlation between C1+C2 and β_{TOF}.

Helium isotopes have been studied using the first eight hours of ISOMAX float data. Complementary measurements of particle velocities obtained from the two Cherenkov counters and the TOF furnish essential cross checks on the quality of the data. Figure 3[a] shows the correlation between the light-yield measurements obtained from both Cherenkov counters for a sample of helium events during the first half of the flight. The dashed lines delineate a minimum correlation cut between both counters. Similarly, Figure 3[b] shows a comparison between the velocity obtained from the TOF and the total light yield obtained from C1 and C2. The signal above Cherenkov threshold is clearly correlated with the velocity obtained from the TOF. Solid lines in Figure 3[b] indicate events accepted for this analysis. Table 1 lists the quality cuts applied to establish a clean sample of helium events.

3.1 Mass Resolution: Figure 4[a] demonstrates the mass separation obtained using the Cherenkov-rigidity technique for a clean sample of helium events at the current stage of this analysis. Helium measurements are not one of the primary goals of ISOMAX and the relatively low numbers of helium events reflect the trigger discriminator thresholds required to eliminate most of the hydrogen (Mitchell *et al.* 1999). Figure 4[b] shows the mass histograms for ^{3}He and ^{4}He in three separate energy ranges covered by the Cherenkov

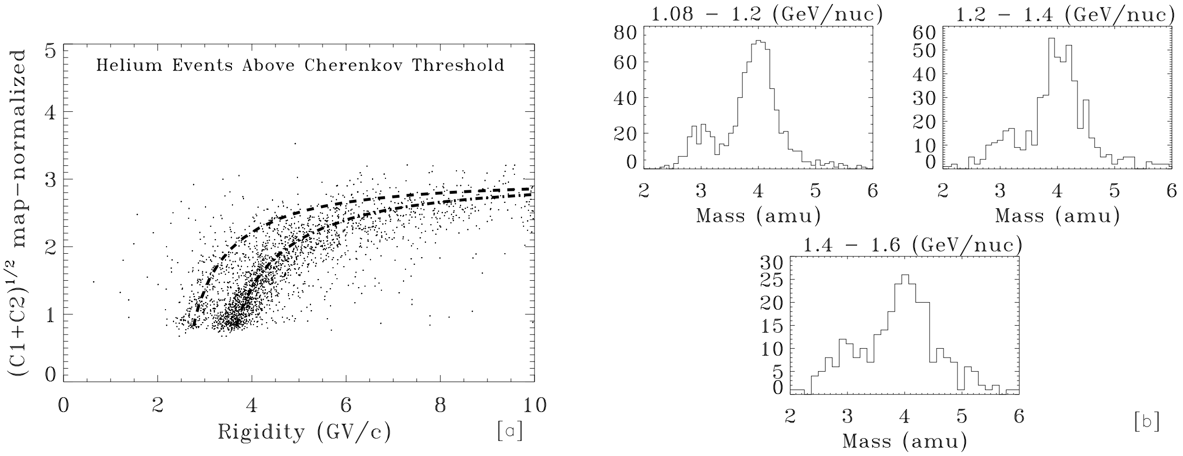

Figure 4: [a] Cherenkov signal versus rigidity. [b] Mass histograms for helium events.

1. Float Altitude$>$ 36 km	5. Correlation between C1 and C2 (Fig. 3[a])
2. Event Checksum = 0 (no digital errors)	6. Corr. between C1+C2 and β_{TOF} (Fig. 3[b])
3. $Z = 2$ (all three TOF layers)	7. Minimum DC tracking requirements:
4. Eliminate events passing through C1, C2 frames.	Track-fit: $\chi^2_x, \chi^2_y < 50$, N$_x > 8$

Table 1: Quality cuts required for clean sample of events. N$_x$ is the number of wires hit in x-direction.

counters. To properly estimate the ratio of isotopes, a correction must be applied to account for the contribution to the light yield from δ-rays or knock-on electrons produced during the passage of a particle through the overlying material above C1 and C2. This calculation is currently in progress.

4 Conclusions:

Using the Cherenkov-rigidity technique, ISOMAX is able to resolve the isotopes ^{3}He and ^{4}He above 1.08 GeV/nucleon. The mass resolution is expected to improve significantly with further refinements to the analysis, including more stringent requirements on quality cuts, cross-checks with flight data to improve aerogel response maps, a correction to the total Cherenkov light yield for δ-rays, and the addition of data covering the second half of the ISOMAX flight. Furthermore, results from the TOF can be combined with Cherenkov counter results to better resolve isotope masses above 1 GeV/nucleon. Based on the helium analysis to date, the Cherenkov-rigidity technique is expected to provide sufficient mass resolution for the identification of other light isotopes, including ^{10}Be. A second ($\geq$ 3 day) flight of ISOMAX is planned in the summer of 2000, both to improve the statistics and to extend the energy range through the use of low index-of-refraction aerogel radiators ($n = 1.04$).

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