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The ISOMAX Magnetic Rigidity Spectrometer

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Abstract

The Isotope Magnet Experiment, (ISOMAX), is a balloon-borne superconducting magnetic spectrometer with a time-of-flight system and aerogel Cherenkov counters. Its purpose is to measure the isotopic composition of the light elements ($3 \leq Z \leq 8$) in the cosmic radiation. Particle mass is derived from a velocity vs. magnetic rigidity (momentum/charge) technique. The experiment had its first flight in August 1998. The precision magnetic spectrometer uses advanced drift-chamber tracking and a large, high-field, superconducting magnet. The drift-chamber system consists of three chambers with 24 layers of hexagonal drift cells (16 bending, 8 non-bending) and a vertical extent of 1.4 m. Pure CO_2 gas is used. The magnet is a split-pair design with 79 cm diameter coils and a separation of 80 cm. During the 1998 flight, the central field was 0.8 T (60% of the full design field). Presented are results from flight data, for a range of incident particle Z, on the spatial resolution and efficiency of the tracking system, and on the maximum detectable rigidity (MDR) of the spectrometer. For in-flight data, spatial resolutions of 54 µm for Z=2 and 45 µm for Z=4 are obtained. An MDR of 970 GV/c is achieved for Z=2.

1 Introduction:

The goal of the ISOMAX program (Streitmatter *et al.* 1993; Mitchell *et al.* 1999) is to measure the isotopic composition of the cosmic radiation from lithium through oxygen to energies of several GeV/nucleon. In particular, ISOMAX was designed to accurately measure the ratio of radioactive ^{10}Be to stable ^{9}Be to energies where relativistic time-dilation becomes significant. Beryllium is produced by fragmentation of heavier cosmic rays and is entirely secondary. This measurement will probe the propagation conditions of the cosmic rays and will distinguish between the Leaky-Box Model and the Diffusion-Halo Model. For a review see Berezinskii *et al.* (1990). Measurements of other light isotopic and elemental spectra provide important tests of the origin and transport of the cosmic rays.

In order to derive the mass of an incident nucleus, ISOMAX measures its rigidity (momentum/charge), velocity, and charge. The rigidity is determined with the superconducting magnetic spectrometer, discussed in more detail in this paper. The velocity is obtained from two velocity measuring systems: a time-of-flight system (Geier *et al.* 1999), which also measures the charge, and silica-aerogel Cherenkov counters (de Nolfo *et al.* 1999).

ISOMAX was successfully flown on August 4-5, 1998, from Lynn Lake, Manitoba, Canada. The payload was recovered in Peace River, Alberta, Canada. The flight lasted 29 hours with 16 hours of data at float altitudes (> 36 km).

2 The Superconducting Magnet:

The ISOMAX superconducting magnet was constructed by the Special Projects Group of Oxford Instruments. It is a split-pair design with two 79 cm outer diameter filamentary NbTi (Cu matrix) coils separated by 80 cm face-to-face. The cryostat incorporates a vertical warm bore with a 61 x 66 cm² cross section. The two helium tanks have a combined reservoir volume of 390 liters and are interconnected, with magnet cryogenic services, charging, and venting handled through a single service turret. The magnet is charged through a single set of low-thermal-conductivity current leads. A helium-vapor-cooled radiation shield and 40 layers of superinsulation are employed within the cryostat vacuum jacket. Total empty weight of the magnet system is 477 kg.

The magnet was designed to operate at a maximum current of 200 A. At this current, the magnetic field at the center of the warm bore would be 1.3 T, giving an average magnetic field integral of 0.91 Tm. During acceptance testing, stable persistent-mode operation was demonstrated at a current of 160 A. Although there was no indication that higher currents would have quenched the magnet, testing was terminated at this point to begin system integration for the 1998 flight. For this first flight, the magnet was operated at a conservative 120 A, giving an average field integral of 0.54 Tm.

At present, the magnet has a cryogen hold time of 100 hours. All cryogenic and electrical services can be performed from outside the ISOMAX pressure vessel. Thus, the magnet can be filled shortly before flight, accommodating flight durations approaching 4 days.

3 The Tracking System:

The ISOMAX tracking system is based on a highly successful drift chamber design developed for the IMAX instrument (Hof *et al.* 1994). In their original form, these chambers have been flown five times as part of the magnetic spectrometers for IMAX and for the WiZard balloon program. The ISOMAX chambers use an array of 480 hexagonal close-packed drift cells, arranged in 24 layers, 16 in the bending view (X) and 8 in the non-bending view (Y), as indicated in Figure 1. The two outer drift chambers have volumes of 69 x 69 x 19 cm^3 and each incorporates 4 X and 2 Y layers. The outer tracking layers are separated by 1.4 m. The inner chamber, located within the magnet bore, has a volume of 47 x 47 x 58 cm^3 with 8 X and 4 Y layers. The chambers are filled with pure CO_2 drift-gas. In CO_2, the drift velocity is very slow and the drifting electrons experience relatively little Lorentz force. Hence, the drift-time to position relationship (DPR), which is used to determine positions from the measured drift times, requires little or no correction for magnetic field strength. Each chamber is a single gas volume with no interior divisions and gas is provided to the three chambers through a serial flow system. For more details on the wire structure and voltages, see Hof *et al.* (1994).

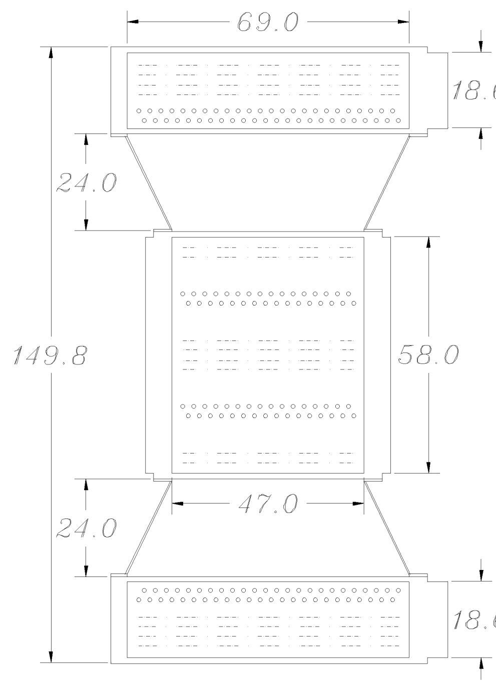

Figure 1: Schematic of drift-chamber system in the non-bending view.

For the 1998 ISOMAX flight, the drift chambers were read out using custom-designed low-power preamplifier/discriminator modules, located at the chambers. These fed LeCroy 4291B CAMAC time-to-digital converters modified for a least count of 3 ns and operating in common-stop mode.

4 Ground Test Results:

In a pre-flight phase the performance of the tracking system was tested with ground data runs. For Z=1 the operating anode voltage is +4.6 kV. The DPR is derived empirically by integrating the drift time distribution obtained for an ensemble of particle tracks distributed uniformly through the drift cell. In practice, the final DPR is obtained using an iterative procedure (Hof *et al.* 1994). For each drift chamber, a separate DPR is generated for different periods.

Using the derived DPR, particle trajectories can be found through the chambers. The spatial resolution of the tracking system can then be derived from the residual differences between the best-fit trajectories and the positions (radii) measured at the drift cells (residue), multiplied by a correction factor which takes a number of fitting factors into account. Figure 2 shows the spatial resolution obtained in this way for ground Z=1 data. Over most of the drift distances, the resolution is better than 65 μm, only increasing near the anode wire and near the cell boundary.

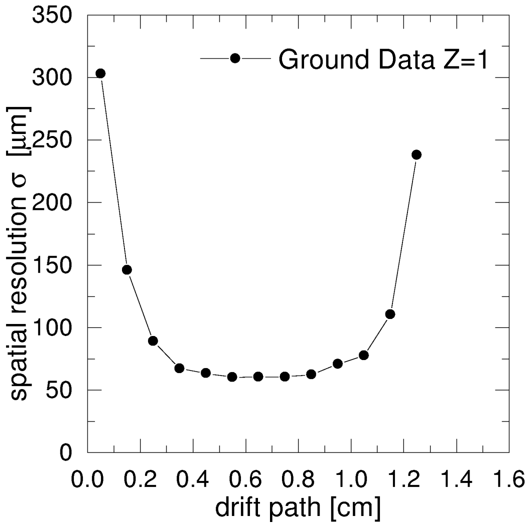

Figure 2: Spatial resolution for ground level data.

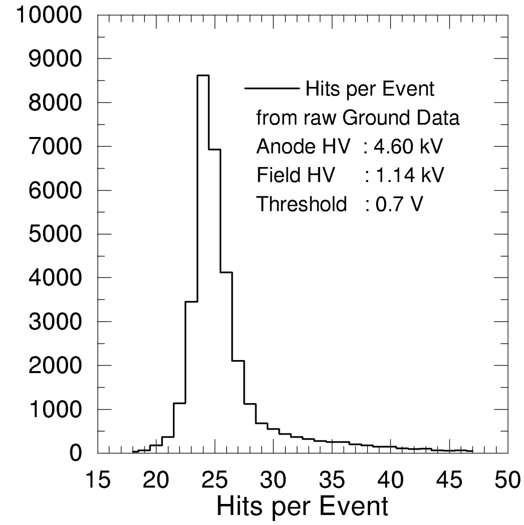

Figure 3: Wire hits per event for ground level data.

Figure 3 shows the wire hits per event for ground Z=1 data. Note that this distribution is strongly peaked at 24, the total number of ISOMAX drift planes, indicating that most events have a single hit in each layer. The tail with more hits is mostly due to particles penetrating a layer at an angle near a boundary between two cells and thus firing two adjacent wires.

5 Flight Performance:

To optimize drift chamber sensitivity for particles with Z=4, the anode voltage was reduced to +3.95 kV during flight. For this voltage, spatial resolutions of σ=54 μm for Z=2 and σ=45 μm for Z=4 are achieved for relativistic particles, as shown in Figure 4 for Z=2 and Figure 5 for Z=4, respectively. The DPR was iterated using relativistic in-flight helium and a charge correction was generated from the data.

Using the measured spatial resolution for a particular species, the magnetic field through which each particle trajectory passed, and the hit wires for each particle, an MDR distribution can be obtained for an ensemble of particles. The MDR distribution for ISOMAX in-flight helium (with the magnet at 120 A) is shown in Figure 6. The peak is at an MDR of 970 GV/c. A similar measurement for ground level Z=1 data yielded an MDR of 820 GV/c, compared with an MDR of 200 GV/c for Z=1 data in IMAX (Mitchell *et al.* 1996). For in-flight beryllium, the MDR, scaled using the measured resolution for beryllium, is 1.2 TV/c. This is far in excess of the minimum required for this flight, see Mitchell *et al.* (1999). As a result, rigidity resolution will not be a limiting factor in meeting any of the main ISOMAX science goals.

Since the MDR scales directly with applied magnetic field, at the highest current to which the ISOMAX magnet has been operated, 160 A (80% of full field), the MDR would increase to 1.1 TV/c for Z=1, 1.3 TV/c for Z=2, and 1.6 TV/c for Z=4. This performance (and possible further increases) would allow

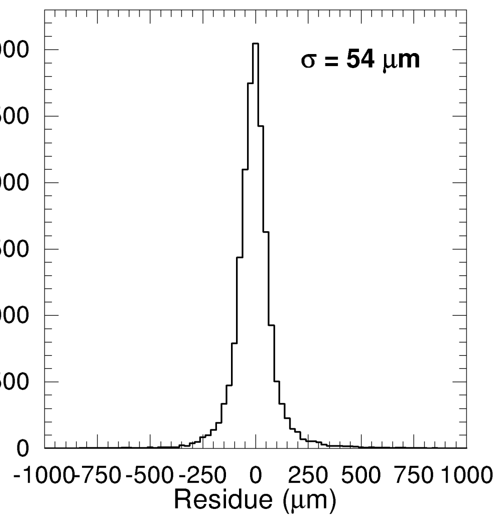

Figure 4: Resolution for helium.

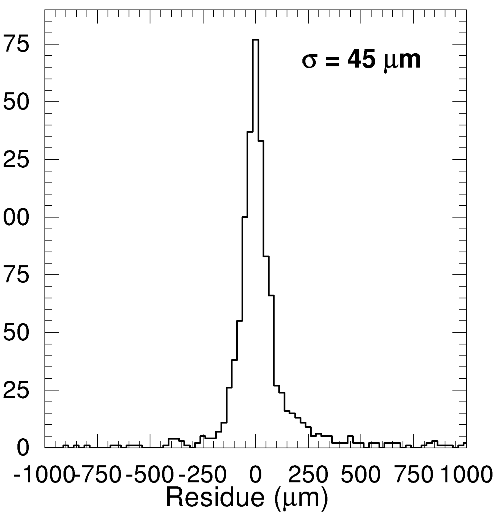

Figure 5: Resolution for beryllium.

ISOMAX to measure isotopes of higher-charge elements and would facilitate the measurement of elemental spectra to energies approaching 1 TeV/nucleon.

6 Conclusion:

The ISOMAX magnetic spectrometer, composed of a high-field superconducting magnet and a precision drift-chamber tracking system has demonstrated excellent performance in both ground and flight tests. The maximum detectable rigidity, for in-flight particles is 970 GV/c for helium and 1.2 TV/c for beryllium, well in excess of the MDR required to meet the ISOMAX goals. Operating the magnet at a higher field can increase the MDR further. This high-level performance provides ISOMAX with unprecedented flexibility in the range of cosmic ray species and energy that it can measure.

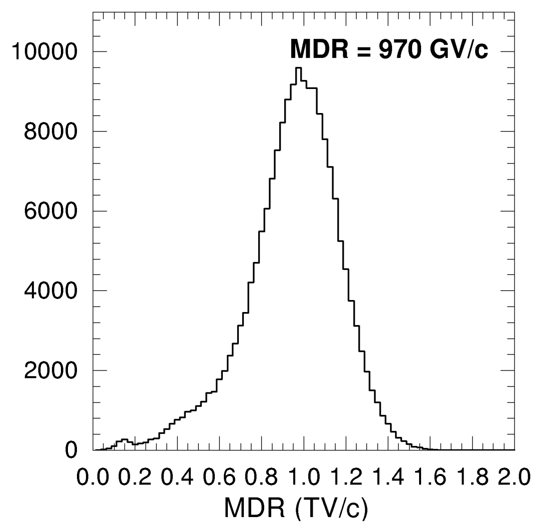

Figure 6: MDR for helium.

References

Berezinskii, V.S., *et al.* 1990, Astrophysics of Cosmic Rays (Amsterdam: North-Holland)

de Nolfo, G.A., *et al.* 1999, Proc. 26th ICRC (Salt Lake City), OG 1.1

Geier, S., *et al.* 1999, Proc. 26th ICRC (Salt Lake City), OG 1.1

Hof, M., *et al.* 1994, Nucl. Instr. Meth. A, 345, 561

Mitchell, J.W., *et al.* 1996, Phys. Rev. Lett., 76, 3057

Mitchell, J.W., *et al.* 1999, Proc. 26th ICRC (Salt Lake City), OG 1.1

Streitmatter, R.E., *et al.* 1993, Proc. 23rd ICRC (Calgary), 2, 623