Results of a Search for Deuterium at 25-50 GV/c Using a Magnetic Spectrometer

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Abstract

A method is presented for separately identifying isotopes using a Cherenkov detector and a magnet spectrometer. Simulations of the method are given for separating deuterium from protons. The simulations are compared with data gathered from the 1979 flight of the New Mexico State University balloon-borne magnet spectrometer. The simulation and the data show the same general characteristics lending credence to the technique. The data show an apparent deuteron signal which is (11± 3)% of the total sample in the rigidity region 38.5-50 GV/c. Until further background analysis and subtraction is performed this should be regarded as an upper limit to the deuteron/(deuteron+proton) ratio.

1. Introduction. Measurement of particle mass by combining information about a particle's velocity and its momentum is a concept usually introduced in lower division physics courses. We employ a variation on the technique wherein the quantities measured are the light level in a Cherenkov detector and the magnetic deflection (1/magnetic rigidity). Cosmic ray Cherenkov detectors and magnet spectrometers have limited capabilities at present. In this paper these limitations are explored using monte-carlo simulations based on the characteristics of the NMSU spectrometer. We then compare the expected performance with data gathered in the most recent flight of the spectrometer.

2. Simulations. The basic approach used here to separate isotopes is to plot the two measured quantities, light level (in the Cherenkov detector) vs magnetic deflection. For a given particle the light level should be consistent with zero at deflections larger than the Cherenkov threshold (ie at rigidities below the Cherenkov threshold). At deflections less than the Cherenkov threshold a small amount of light would be registered and at progressively smaller deflections, the light level should rise to a maximum which is determined by the characteristics of the particular detector (and the charge of the particle). The relationship between deflection and light level can be derived from the more classical representations (see eg (1)) by

defining d_T as the deflection threshold and Nmax as the light level for a $\beta=1$ (ie deflection = 0) particle. In this case we have:

$$\bar{N} = N_{max}(1 - (d_T/d)^2) \tag{1}$$

where $\bar{N}$ is the average number of photoelectrons and **d** is the magnetic deflection.

The deflection thresholds for particles of different masses are related by:

$$(d_T)_1 / (d_T)_2 = m_2/m_1 \tag{2}$$

For the flight in question, the Cherenkov detector had a proton Cherenkov threshold corresponding to a deflection of 0.43 c/GV (23 GV/c rigidity). Figure 1a shows light level vs deflection curves derived from equations 1 and 2 using a proton threshold of 0.23 GV. These curves neglect uncertainties in the light level and the deflection. Note that two types of particles (protons and deuterium) are shown. The two types have different Cherenkov rigidity thresholds and different light-level vs deflection curves owing to their different masses.

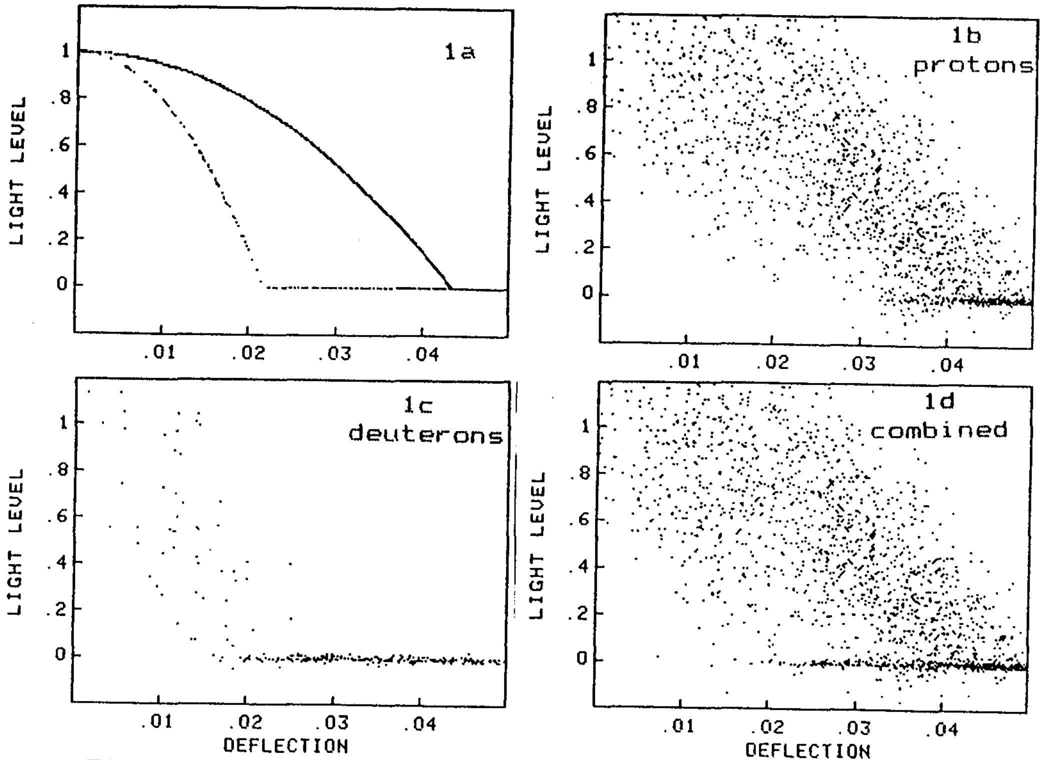

Figure 1. Simulation of Light Level vs Deflection

In order to assess the effects of finite deflection resolution and statistical fluctuations in the photoelectron count, we have repeated the calculation for Figure 1a with the addition of gaussian errors in the deflection and light level for each event. The deflection error distribution had a sigma of 0.029 c/GV (corresponding to an MDM of 350 GV/c), and the light level was varied by a gaussian whose sigma was sqrt(N). The maximum light level was taken to be 10 photoelectrons. A poisson distribution in light level would have been more correct but the difference is only noticeable at low light levels. Figure 1b shows the distribution for 3000 protons; Figure 1c shows the expected distribution for 300 deuterons, and Figure 1d shows the distribution for 3000 protons and 300 deuterons, combined. Note that the deuteron signal is still visible in Figure 1d. By comparing Figs. 1b, 1c and 1d we see that the best place to test for deuterons is at low light levels at deflections just to the right of the deuteron threshold. Note also that as one moves progressivly left of the deuteron threshold, the counts should diminish to zero.

3. Observations. Initial selection of events to be used in the deuterium hunt was similar to the selection of protons in the antiproton hunt reported elsewhere (2),(3). The quoted deflection resolution for this sample 0.08 c/GV corresponding to a maximum detectable rigidity of 125 GV/c. Studies of e- encountered during the flight showed that the maximum light level for the experiment (averaged over all trajectories) was about 7 photoelectrons. In order to obtain a data sample with a deflection resolution of 0.029 c/GV, only trajectories that traversed more than 5 KG-m of magnetic field were selected. Studies of the e- indicated that by eliminating trajectories that went near the mirror edges, and by using only events whose photons should have been centered within 14 cm of a phototube face, the average maximum light level could be raised to about 10 photoelectrons. About 15% of the protons reported in the antiproton papers (2),(3) survived these additional criteria. Figure 2 shows the light-level vs deflection points from the events selected. The similarity between Figure 2 and Figure 1d indicates that at least qualitatively the instrument response is as expected. The region where deuterons should be detectable does indeed have a few counts in it, and the region from zero deflection to the deuteron Cherenkov threshold appears to contain relatively few counts. The reader is cautioned however that a detailed background subtraction has not yet been performed. It is possible that the events at low light-level near the deuteron threshold are due to spillover from the protons near their Cherenkov threshold.

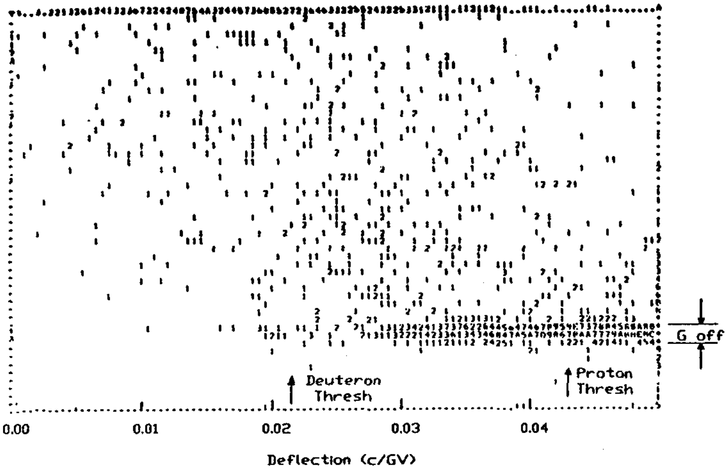

Figure 2.
Light Level vs
Deflection
(3115 events)

In order to estimate the deuteron content (upper limit for now) indicated by Figure 2, we have computed the ratio of G-off events to all events as a function of deflection. G-off events are defined as those whose light-level is within the limits shown on Figure 2. This ratio is shown in Figure 3. Note the apparent "shelf" in the deflection region 0.02-0.03 c/GV. The average value of the leftmost three intervals is (11± 3)%. This could be regarded as a measurement of the deuteron/(deuteron + proton) ratio except that a background subtraction has not been made. Thus the result must for now be regarded as an upper limit.

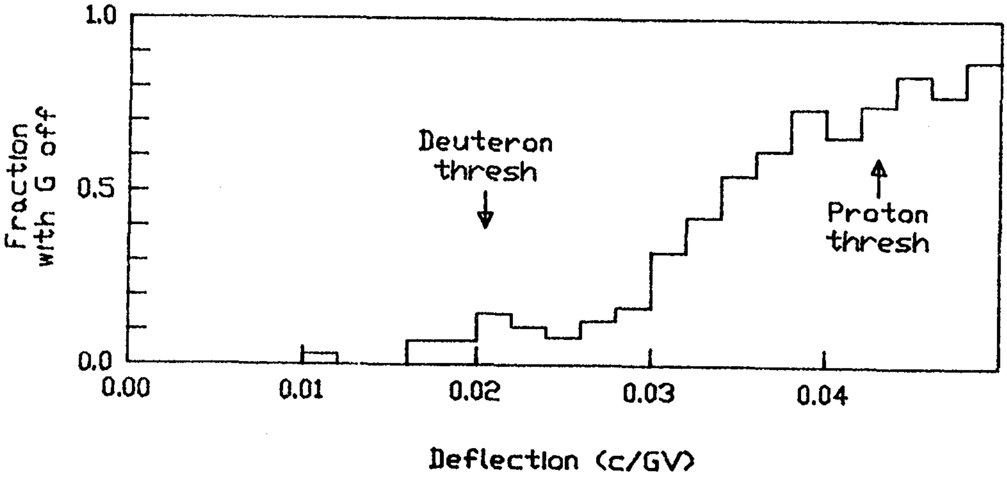

Figure 3. Fraction of G-off Events vs Deflection

References

(1) Jelly, J. V., (1958) Cerenkov Light and its Applications, Pergamon Press.
(2) Golden, R. L. et al. (1979), Phys. Rev. Let., 43, 1196.
(3) Golden, R. L. et al. (1984), Ap. J. Let., 24, 75.