Extraction of the Charged-Current Signal from the Angular Distribution

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Abstract

The magnitude of the charged-current signal can be determined from the angular distribution of the electrons from CC neutrino interactions relative to the Sun's position. This can be done even if a substantial instrumental, radioactivity, or neutral-current background exists underneath the CC spectrum, but the statistical precision is low. A year's worth of data would allow determination of the CC rate in this way to about 12%.

1 Introduction

The presence of an unsuspected or poorly determined background introduces a systematic error into the extraction of the charged-current interaction rate. Since instrumental and radioactivity backgrounds are not correlated with the Sun angle, however, it is in principle possible to extract Sun-correlated signals unambiguously, with only the statistical penalty of the added background. This is the technique used by Kamiokande and SuperKamiokande to extract the neutrino-electron elastic scattering signal in the presence of a much larger uniform background. It is successful mainly because of the strongly forward-peaked angular distribution of elastic scattering.

The charged-current interaction process,

$$\nu_e + d \rightarrow 2p + e^- \tag{1}$$

also has an angular distribution,

$$N(\cos\theta) = N_0[1 - \alpha\cos(\theta)] \tag{2}$$

in which the correlation coefficient α is 1/3 in the allowed approximation, appropriate to a pure Gamow-Teller transition with a spin change of 1. With the inclusion of weak magnetism, the correlation becomes slightly larger and weakly energy dependent; this is neglected in the following discussion.

2 Angular Distribution

In the presence of background and a contribution from elastic scattering $S(\cos\theta)$ the detected rate will have the following form:

$$N(\cos\theta) = N_0[1 - \alpha\cos(\theta)] + B + S(\cos\theta). \tag{3}$$

The elastic scattering contribution is small and makes a minor contribution to the statistics. To simplify the analysis, we neglect the elastic scattering for the moment, and will show later that this neglect is inconsequential. The data at an energy T then have the form of a constant term plus a term linear in $\cos\theta$:

$$N(\cos\theta, T) \quad = \quad N_0(T) + B(T) - N_0(T)\alpha\cos\theta \tag{4}$$

The constant term and the coefficient of $\cos\theta$ can be extracted by fitting the data to a function linear in $\cos\theta$ (at each energy T).

If the data are binned into n equal bins in $\cos\theta$ and each bin still has sufficient counts to justify the use of Gaussian statistics, it may readily be shown that the fractional uncertainty in $A \equiv N_0(T)\alpha$ is given by

$$\frac{\sigma(A)}{A} = \frac{1}{N_0\alpha}\sqrt{\frac{3n^2R}{(n+1)(n-1)}},$$

where n is the number of equal-width bins into which the $\cos\theta$ distribution has been divided and $R = N_0(T) + B(T)$. As n is made larger than 2, this expression quickly approaches $\frac{\sqrt{3R}}{N_0\alpha}$.

Therefore to achieve the same uncertainty in the solar CC rate N_0 from the angular distribution requires statistics in the total number of events $3/\alpha^2$ times larger (*i.e.* about 27 times larger) than would be needed with the direct counting of an ideal background-free statistical data set. Backgrounds large enough to contribute to the statistics increase this factor still further, in the ratio R/N_0.

This is a very steep statistical price to pay to eliminate the need to determine the instrumental backgrounds. Roughly speaking, one month of ideal data is equivalent to more than 2 years of angular-distribution measurement. Fig. 1 shows the kind of data one could expect after a year's data acquisition.

In Table 1, the results of some numerical fits are presented.

The factor of 5 worse precision in extracting the CC signal from the angular distribution (4th column) can be seen in comparison to the total counts (5th column), but when an 'unknown' background as large as the signal is introduced, the angular distribution still gives the CC rate correctly, while the total is, of course, a factor 2 higher. The elastic scattering component has here been modeled by a simple function, $S(\cos\theta)$ =ES $\exp[16(\cos\theta - 1)]$ that gives a reasonable approximation to the energy-averaged angular distribution.

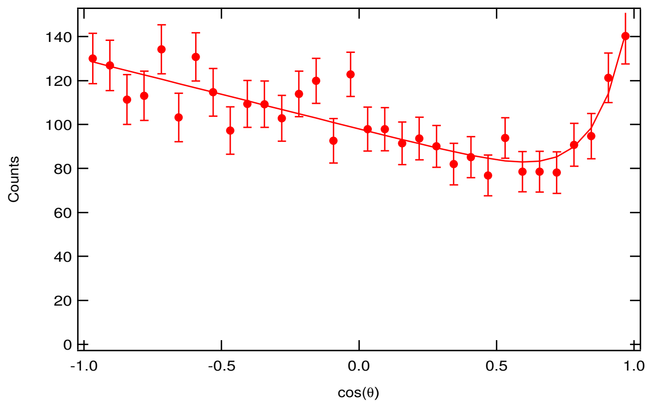

Figure 1: Angular distribution for 3200 CC events, 250 ES events, and no background.

Table 1: Results of fitting a year's solar-neutrino data in SNO to the angular dependence expected for charged-current and elastic-scattering interactions.

Input			Fit		
CC	Background	ES	CC	"CC" (+ Bkg)	ES
3200	0	-	3348(290)	3100(58)	-
3200	0	250	3023(375)	3136(64)	199(32)
3200	3200	250	3253(521)	6464(90)	220(43)
3200	3200	-	3012(415)	6400(80)	-

The neutral-current contribution (from capture of neutrons on deuterium) has not been explicitly put in, but would have the same effect at low energies as a background. In other words, the angular distribution can be used to extract the CC part without knowing anything about the NC part. It is also true that at the lowest energies the shape of the background wall underlying the CC spectrum is hard to determine experimentally, and the angular distribution may be the only available technique to get useful results for the CC spectrum in that region.

The 12% accuracy in the CC result (in this example, with no background) is larger than the 5% accuracy with which the CC cross section itself is known.

The accuracy of the CC result extracted in this way depends on the theoretical knowledge of α. No quantitative statement of the accuracy of α seems to exist, but it is likely to be better than the statistical uncertainties. At low energies (but with the electron still relativistic), α is exactly 1/3. At 40 MeV it has risen to about 0.43 due to weak magnetism [1]. Weak magnetism can be calculated *via* CVC to an accuracy that is probably of order 10% or better, which would make the precision in α better than 3%. Forbidden and other recoil-order terms would have to be examined.

3 Conclusion

The angular distribution can be used to determine the charged-current interaction rate as a function of energy, without systematic errors being introduced from unknown or poorly determined backgrounds, or neutral-current reactions. For a given running time and energy interval, the accuracy with which the CC rate is determined from the angular distribution is 5 times worse than from angle-integrated ideal CC data of the same statistics.

References

[1] "Neutrino Disintegration of the Deuteron at LAMPF Energies," J.S. O'Connell, unpublished (LASL Informal Report LA-5175-MS; UC 34, 1973).