Using the Acrylic Sphere to Define the Fiducial Region in the ES Analysis

Janet Conrad, April 11, 2005

The previous Elastic Scattering Analysis studies employed a fiducial volume cut that did not extend to the edge of the inner volume. This memo describes a technique for normalizing the ES to IBD events using the full fiducial region defined by the acrylic sphere. The "pros" of increasing the fiducial volume to the acrylic sphere are:

- The fiducial tonnage for the analysis goes from 51 tons to 70 tons.
- The error from the relative fiducial volume for ES vs. IBD events is negligible using the technique described below.

The "cons" are:

- An increase in the error from IBD events that are mis-identified because the neutron exit.
- Possible increased background from mis-identified background events coming from the surface of the detector.

Below, these "Cons" are shown to outweigh the "Pros." Nevertheless, the analysis method may be more robust since it removes an error that could not be verified in-situ. A possible approach would be to do the analysis in two ways: with and without a fiducial volume cut, and study the stability.

1 Pro: Increased Statistics

The increase in fiducial radius from 240 cm to 270 cm, using a 3.2 to 5 MeV cut (recommended in the memo "Target Contamination Levels for the

ES Analysis") increased fiducial volume changes the number of events from 24,000 to 34,000.

The statistical error goes from 0.6% to 0.5%.

2 Pro: Eliminating the Fiducial Volume Error

In the analysis technique used previously, the "Fiducial Volume Error" was the error in the relative fiducial volumes of ES and IBD events. This error could come about because the photons in the IBD events might lead to a pull in the vertex reconstruction. To attain an error of 0.3% in the relative fiducial volumes, the position reconstruction for IBD and ES events had to be the same to 3 mm. As was discussed in the memo "A First Study of IBD vs ES Fiducial Volume Reconstruction," this level of reconstruction appears to be possible based on Monte Carlo. However, it is unclear how to demonstrate this using events in the detector.

If we use the acrylic sphere to define the fiducial volume, then these concerns are eliminated. Here I discuss a 3 step analysis technique which removes the fiducial volume error from the ES cross section. Step 1: Get the shape of the IBD events using events in the interior. Step 2: Normalize that distribution to the total IBD events in the acrylic. Step 3: Divide by the IBD cross section to isolate $flux \times targets$, which is then used to extract the predicted ES cross section.

The first step is to obtain the energy dependence of the IBD events. A harsh fiducial volume cut of $<$ 200 cm is applied to identify IBD events in the center of the tank. For these events, the annihilation photons are well contained. Thus from these events, the energy dependence can be well measured.

The second step is to normalize the IBD spectrum. This is done by counting all identified IBD events in the fiducial volume defined by the acrylic sphere. One follows the same analysis technique as that proposed for the θ_{13} analysis. All IBD events, identified by the presence of a neutron, with visible energy above 0.5 MeV are simply counted. Since an IBD event must, at minimum, produce 1 MeV of energy in the form of annihilation photons, in principle, this counts 100% of the IBD events.

In practice, there will be an inefficiency from annihilation photons leaving the scintillator-doped region defined by the acrylic vessel. In this technique, the systematic error on the fiducial volume is the systematic error on the correction one must make for the IBD events which did not have > 0.5 MeV because of photon exits. Figure 1 (top left) shows the inefficiency (in percent) as a function of generated visible energy for a 270 cm sphere of scintillator. The inefficiency only occurs at low visible energy. The inefficiency averages to about 0.34% for neutrino energies below 2.2 MeV (top right).

The concern is that the acrylic vessel may have bumps and ridges that are poorly defined. In fact, the effect of bumps and ridges on the efficiency will be very small. To actually see a trend in the change in inefficiency with radius, one must study spheres which range between ± 5 cm in radius about the standard value of 270 cm. In Figure 1 (bottom right), the actual inefficiency for spheres in this range are plotted for neutrino visible energies of 1 MeV. The choice of a ± 5 cm error on the radius is a worst-case example assuming our only information on the sphere dimensions are from vertex reconstruction of IBD events, which may have an error of this size. However, it yields a 0.007% error for the analysis, which is negligible.

In fact, we should be able to have substantially better knowledge of the acrylic vessel through measurements and finite element analysis. As an example of what can be known, Peter Doe gave the following information on the SNO acrylic vessel: "for the SNO vessel we contracted a company to do detailed finite element studies of the acrylic vessel under many conditions...partially built, empty, full and including PMT implosions, which was why we went with 20cm tubes. The engineers quoted the deflections of the 12 meter vessel to 0.025 mm (!) but I could never get them to quote an uncertainty on their measurements. The maximum deflection that they calculated was 12 mm, which was a depression of the upper hemisphere of the vessel caused by the weight of the chimney. We have extensometers attached to the equator of the vessel and to the top of the neck so we can track differential movement between the two to a mm. We see no movement to the accuracy of our measurements so the original "sag" of the upper hemisphere is not changing." Thus the 5 cm range should be a gross overestimate.

In the third step, the resulting normalized IBD event distribution is divided by the IBD cross section to get $\phi = flux \times targets$. The number of ES events is then divided by ϕ to extract the ES cross section. In this technique, there is negligible fiducial volume error in the extracted ES cross section.

The Fiducial Volume Error goes from 0.3% to 0%.

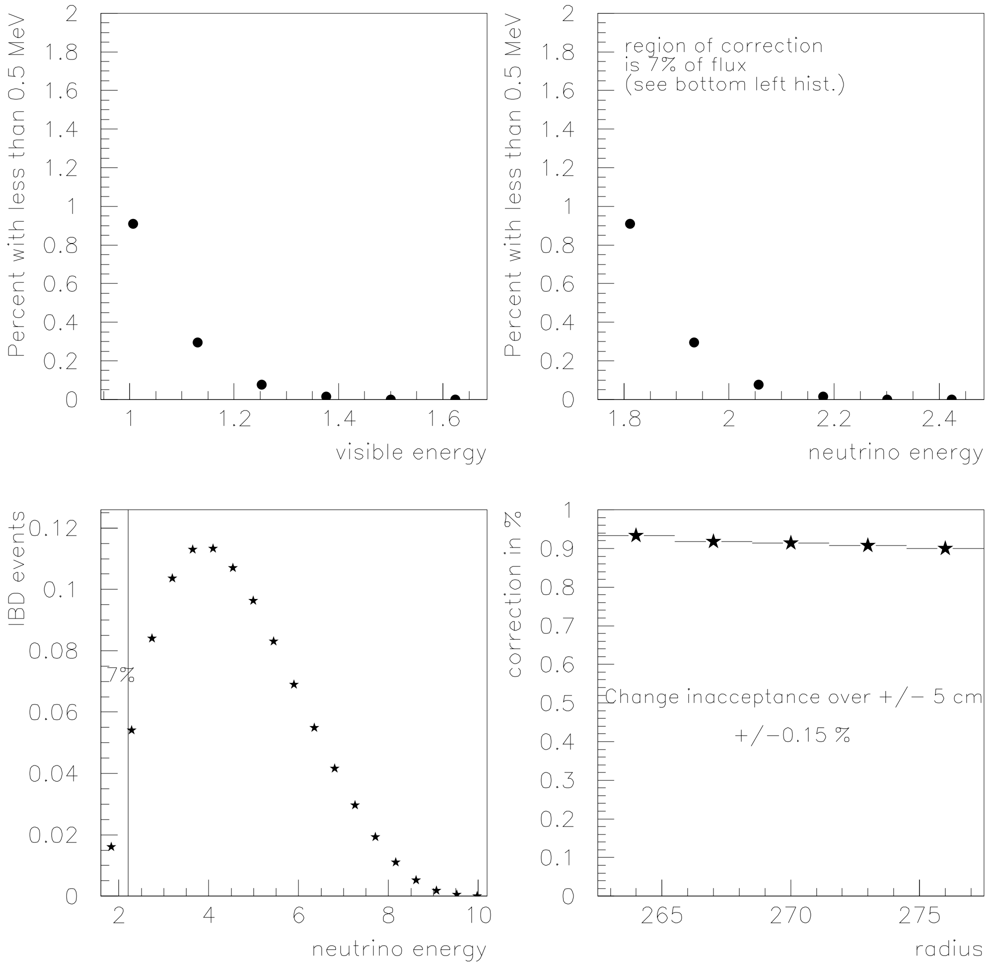

Figure 1: Top: Inefficiency (in percent) due to losing a photon, shown as a function of generate visible energy (left) and neutrino energy (right). Bottom left: the distribution of IBD events with energy. 7% are in the region of the inefficiency; Bottom right: The change in the inefficiency for spheres which are ± 5 cm from the proposed 270 cm.

3 Con: Increased IBD Mis-identification

The error from IBD Mis-identification comes from neutrons which exit the inner region and therefore do not produce light. Note that only IBD events with visible energy (without the neutron) in the 3 to 5 MeV energy window contribute (about 20% of the IBD total). The statistical error on these events goes from 0.18% to 0.36%. The systematic error is strictly a geometric issue that depends on how well we can understand the pathlength for neutrons and the edge of the acrylic vessel. A 1 cm mis-measurement of the edge of the vessel represents only a 1% change in the number of mis-identified events. So the systematic error on the mis-id due to inefficiency is negligible.

This calculation is simplistic in the assumption that if the neutron captures near the edge of the inner region that the photons produced by the Gd will be observed. The effect of this will be the subject of a further study using ReactorFSim. For now we will assume this is a negligible effect.

The IBD Misidentification Error goes from 0.3% to 0.7%.

4 Con: Tl Background events from the Acrylic

This background depends on the cleanliness of the acrylic, the thickness of the acrylic, and the fraction of ^{208}Tl within or on the acrylic which reconstruct in the energy window. The memo "Target Contamination Levels for the ES Analysis" describes the assumptions used here.

The error on contamination goes from 0.1% to 0.2%.

5 Summary

- The statistical error goes from 0.6% to 0.5%.
- The Fiducial Volume Error goes from 0.3% to 0%.
- The IBD Misidentification Error goes from 0.3% to 0.7%.
- The error on contamination goes from 0.1% to 0.2%.

Adding these in quadrature, the total goes from 0.7% to 0.8%.

The error goes up by a small amount if one eliminates the fiducial volume cut using the technique described here. On the other hand, an analysis with no fiducial volume cut may be more robust, justifying this choice. It is not necessary to make the decision on how to proceed until the contamination levels of the vessel are well understood. And the option is always open to pursue both methods and study stability. In conclusion, this method appears to be an attractive alternative to employing a fiducial volume cut.