Target Contamination Levels for the ES Analysis

Janet Conrad, April 11, 2005

This memo describes target levels for detector contamination in the Elastic Scattering analysis. The goal has been to define an acceptable level which is not overly costly to achieve. In order to reduce the contamination, this study recommends a 3.2 to 5 MeV window. In this case, the only contaminant that needs to be considered is ^{208}Tl which comes through the ^{232}Th decay chain and has a 20% branching ratio.

Three types of contamination are considered: 1) contamination in the scintillator oil (due mainly to the Gd doping), 2) on the surface of the acrylic sphere, and 3) within the acrylic sphere. The contamination within the acrylic sphere is the largest concern and is the main reason for the recommended 3.2 MeV lower energy cut.

% Decay	Mode	Type
49%	1.8 MeV β + 0.6 MeV γ + 2.6 MeV γ	1
22%	1.5 MeV β + 0.3 MeV γ + 0.6 MeV γ + 2.6 MeV γ	2
25%	1.2 MeV β + 0.3 MeV γ + 0.3 MeV γ + 0.6 MeV γ + 2.6 MeV γ	3
	1.2 MeV β + 0.3 MeV γ + 0.9 MeV γ + 2.6 MeV γ	4
	1.2 MeV β + 0.6 MeV γ + 0.6 MeV γ + 2.6 MeV γ	5
	1.2 MeV β + 1.2 MeV γ + 2.6 MeV γ	6
4%	1.0 MeV β + 0.2 MeV γ + 0.3 MeV γ + 0.3 MeV γ + 0.6 MeV γ + 2.6 MeV γ	7
	1.0 MeV β + 0.5 MeV γ + 0.3 MeV γ + 0.6 MeV γ + 2.6 MeV γ	8
	1.0 MeV β + 0.5 MeV γ + 0.9 MeV γ + 2.6 MeV γ	9
	1.0 MeV β + 0.3 MeV γ + 0.5 MeV γ + 0.6 MeV γ + 2.6 MeV γ	10
	1.0 MeV β + 0.8 MeV γ + 0.6 MeV γ + 2.6 MeV γ	11
	1.0 MeV β + 1.4 MeV γ + 2.6 MeV γ	12

Table 1: Major decay modes for Tl-208.

The techniques described in the memo “Cutting ^{208}Tl Background for the

$\sin^2\theta_W$ Analysis," were used to reduce background. This memo introduced a log-likelihood based on whether the vertex position, found using the charge in the phototubes, was consistent with the hit timing in the tubes. The scintillator timing was based on Butyl PBD, which was less optimal than PPO, and thus the conservative choice for this study. Table 1 lists the decay modes for ^{208}Tl. Type 1 was used in the analysis, and was shown in the previous memo to be representative of the other decay types.

The total error from contamination on the ES analysis given the target-levels below, is 0.2%. While we believe these target-levels are reasonable, even if they were incorrect by an order of magnitude, the analysis is still viable.

1 Contaminants within the Scintillator

This was discussed at length in the memo "Cutting ^{208}Tl Background for the $\sin^2\theta_W$ Analysis." The conclusion was that, through a combination of purification of the Gd and use of a log-likelihood cut, one can achieve an effective cleanliness of 10^{-15} g/g. This could be improved by an order of magnitude through an α-lookback which identified the parent of the ^{208}Tl decay. However, for this study we will not assume this extra factor, instead keeping it as "analysis contingency."

For 70 tons of Gd-doped scintillator, this corresponds to 1900$\pm$43 events in three years of running.

2 Contaminants on the Surface of the Acrylic

In this section, we consider surface cleanliness. We will assume that we can reasonably achieve levels which are at least within an order of magnitude of what was achieved at SNO. From http://neutrino.lbl.gov/~snoman/cont.htm, the level of cleanliness on the surface of the SNO acrylic vessel was better than 0.1 microgram/cm^2. Assuming Braidwood is an order of magnitude worse, or 1×10^{-6}g/cm^2, then there is 1 g of contaminant on the surface of the detector. Typically, ^{232}Th represents $\sim$ 1ppm of the contaminant. Thus, we consider 1×10^{-6} g distributed around the outer edge of the detector. Thus there are 6.9×10^{14} atoms of ^{232}Th on the surface. The result, folding in the 20% BR for ^{208}Tl is 29,000 total decays in three years.

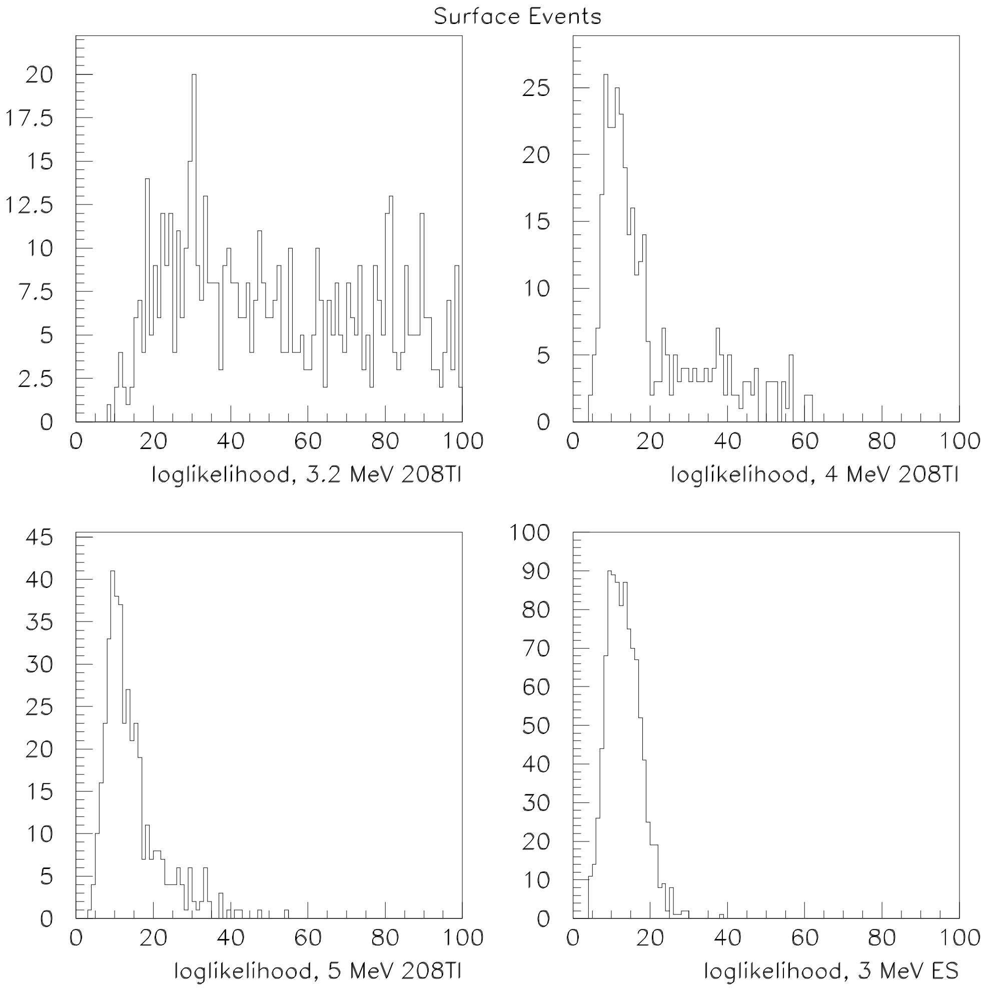

Figure 1: Applying the log-likelihood analysis described in "Cutting ^{208}Tl Background for the $\sin^2\theta_W$ Analysis." Top left: ^{208}Tl events with 0.0 MeV β; top, right: ^{208}Tl events with 0.8 MeV β; bottom, left: ^{208}Tl events with 1.8 MeV β; bottom, right: 3.2 MeV ES events.

Of these events, in 50% of the cases, the β will go into the inactive acrylic rather than the scintillator. These events are equivalent to having 0.0 MeV of β energy, with all visible energy coming from the photons.

For the surface events, β energies of 0.0 MeV (hence total visible energy of 3.2 MeV including all photons), 0.8 MeV (4.0 MeV visible energy) and 1.8 MeV (5.0 MeV visible energy) were studied in detail. If one or both γ's exit the active region, the event may fall below the 3.2 MeV threshold and be cut from the analysis. This occurred in 96% of the zero β energy surface events. This is because, for zero β energy, both photons must deposit all of their energy in the scintillator in order for the event to pass the threshold cut. If the β has 0.8 MeV then the fraction which fail the energy window cut is 62%. And for a β of 1.8 MeV, which is the endpoint, 58% of the events fail to reconstruct with more than 3.2 MeV of visible energy. This is simply a statement that it is easy for the γ's to scatter out of the detector.

One can then apply the likelihood method described above to identify surface events. The results are shown in Figure 1, for events in the energy window. Top, left is the case of zero β energy; top, right is for a 0.8 MeV β; and bottom, left is for a 1.8 MeV β. For comparison, the log-likelihood for a 3.2 MeV β on the detector surface is shown in bottom, right. One sees that the zero energy β events have a strikingly different distribution from the others because the visible energy is purely from scattered photons. On the other hand, the events where 4 and 5 MeV total visible energy were produced and at least 3.2 MeV observed, have a strong overlap in shape with the 3 MeV β. This is because, in most of these events, at least one photon scattered out of the scintillator region.

As a simple model, events were thrown with a triangular distribution representing the β energies, ranging from zero to 1.8 and peaking at 0.9. Only events within the 3 to 5 MeV reconstructed energy window were considered. Of these, 36% of events can be cut using the log-likelihood, while retaining 90% of the ES events.

Applying the energy window and log-likelihood, the result is 3600$\pm$60 events which enter the analysis.

3 Contaminants Within the Acrylic

For decays within the acrylic, we must estimate the contamination in the material. According to Peter Doe, for the SNO acrylic: "Regards radioactivity, the levels of U and Th are <1ppt. This is a limit which was obtained by neutron activating 1 kg block of acrylic. The faces were then machined off and the remaining acrylic was ashed in a Suprasil quartz tube. The remaining material was counted using 3 germanium crystals +Compton veto. Efficiency of extraction was checked by spiked samples. Your final radioactivity will probably be determined by how you handle/process the acrylic and will probably be a few ppt." Based on this, 1×10^{-9}g/g will be assumed.

This study assumes the Braidwood acrylic sphere is 0.5 cm thick. Therefore, there is 9.1×10^5 cm^3 of acrylic in the sphere. Assuming a density of 0.85 g/cm^3 and 1×10^{-9}g/g of Th, leads to 3.9×10^{-4} g of ^{232}Th. For 3 years of running, this yields 1.2×10^7 decays.

In these events, the β will not be observed. Thus they are like the events shown in Figure 1, top , left. These can be reduced by $\sim$ 100 through employing a log-likelihood cut. Folding in the fraction which appear in the 3.2 to 5 MeV window, which is 5%, there will be 5,100±72.

4 Error from Contaminants in ES Analysis

The errors from contamination of the scintillator, the surface and the acrylic are 43, 60 and 72 events, respectively. Adding these in quadrature yields 103 events. The result is a contribution of 0.23% to the total ES error. This is among the smaller errors – not negligible, but is still within reason.

If all three sources of background were an order of magnitude higher, the analysis would still be viable. The error to the ES rate would go up to 0.66%. However, the total background subtraction goes up to 100k in an analysis with only about 30k signal events. The analysis becomes less convincing with such a large background subtraction.

There are several methods for reducing the error from the "target level." The simplest solution to reducing background from these events is to reduce the thickness of the acrylic sphere. If a thin balloon, similar to that used by KamLAND or Borexino, is used, then this reduces the contribution from the within the vessel to a negligible level. The result is that the error drops to 0.16%. If a thicker sphere is required or there is concern from background in the analysis, then a less optimal solution is to increase the lower visible energy window to 3.5 MeV. This reduces the contribution from events within the acrylic, which have a true maximum visible energy in the detector of 3.2 MeV to a negligible level. For decays within the detector, if the parent of the ^{208}Tl decays can be tagged via the α, then the background events in the scintillator will be reduced by an order of magnitude. This, in combination with the thin balloon, would yield an error from this background of 0.13%.

The level of contamination background can be constrained by the data. In principle, there is a factor of 100 more ^{208}Tl events which were identified through the log-likelihood. These can be used to measure rate in-situ.

In summary, this memo has decsrined target-levels for contaminaton within the detector. The goal has been to achieve a reasonable level of background while not introducing high cost.