Summary of PCS Physics Motivations

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Abstract

This note outlines some of the advantages of the Proportional Counter Source (PCS), and summarizes the physics motivations for deploying the source to guide the discussion at the "PCS physics motivations conference call".

1 Scope

This report first discusses the running time with the two PCS sources necessary to attain a data set comparable to 1 live year of backgrounds in the SNO detector. Next the main advantages of the PCS are discussed. Finally the physics motivations for PCS deployment in the D_2O and H_2O are presented. This report is meant to facilitate the discussion regarding physics objectives on the "PCS physics motivations conference call".

2 ^{228}Th PCS Sources 'PCA' and 'PCD'

The reader is reminded that we currently have 2 working PCS calibration sources, both of which can be deployed as soon as the source has been reviewed. One of the sources labelled 'PCA' has 190 Bq ^{228}Th on the anode wire, and the other source labelled 'PCD' has 1000 Bq ^{228}Th on its anode wire. Documentation regarding the PCS can be found on the PCS website: http://www.physics.carleton.ca/∼snoman/

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> password: theneutrino
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In the table 1 below the running times are shown for the number of PCS source decays to produce 1 live year of data in the D_2O and H_2O. From the table it is clear that to obtain one year of ^{232}Th background data with source 'PCA' in the H_2O is prohibitive. However, deploying the PCS source 'PCD' for 1 hour will allow us to attain at least 1 live year of data in the H_2O. In the D_2O the background of ^{232}Th is much lower and PCS source PCA maybe used to attain a statistically significant data set.

3 Main Advantages of PCS

This section is taken almost verbatim from SNO-STR-2002-002 "Insertion of PCS in SNO". The document describes changes that have been made to

Source	Activity ^{228}Th	Time for 1 live year in D_2O	Time for 1 live year in H_2O	1 Million ^{208}Tl Decays
PCA	190 Bq	1/2 hour	19.8 hours	4 hours
PCD	1000 Bq	5.7 min	3.75 hours	3/4 hours
Conc. X10^{-15} g ^{232}Th /g	-	2.7	81	-

Table 1: PCS activity, running time for 1 live year of ^{208}Tl data, and to obtain 1 million ^{208}Tl decays for two sources PCA, and PCD. Also shown are the assumed concentration of ^{232}Th taken from the ex-situ measurements presented at the February'2002 collaboration SNO meeting. Note this is only the number of ^{208}Tl decays not the number of events observed in SNO.

the PCS over the past few months, and changes in procedure. For technical details related to the PCS please refer to this summary document.

[1] PCS closely approximates a ^{228}Th point source

The PCS has been designed to produce minimal distortion to the Cherenkov spectrum. This has been achieved by housing the ^{228}Th source in a cylinder with a 0.7 mm polycarbonate wall. Details on the design are described on the PCS website. The reader is reminded that hydrostatic tests have been done, where the polycarbonate cylinder was forced to collapse by 340 psia (A factor of 7 times greater than the pressure at the bottom of AV) of external pressure. The same cylinder was then pressurized internally to pressures exceeding 1000 psia (21 times the pressure at bottom of the AV) demonstrating that the seal has not been compromised.

The fact that the PCS approximates closely the free ^{228}Th source is evidenced by the NHIT spectrum obtained from the engineering run in Oct 2000 (see Figure 1 below). In this run NIM level logic was set-up so that whenever a beta or alpha was observed in the PCS, SNO was triggered (ext4 of the external trigger inputs). The shape of this shoulder must be measured with very high statistics so that SNO can determine the fraction of high NHIT Thorium events that leak into the neutrino dataset. Also shown in the figure is the scaled PCS SNOMAN calculation NHIT>17(dashed) that includes the full PCS geometry and the convolution of the $\beta - \gamma$ cascades

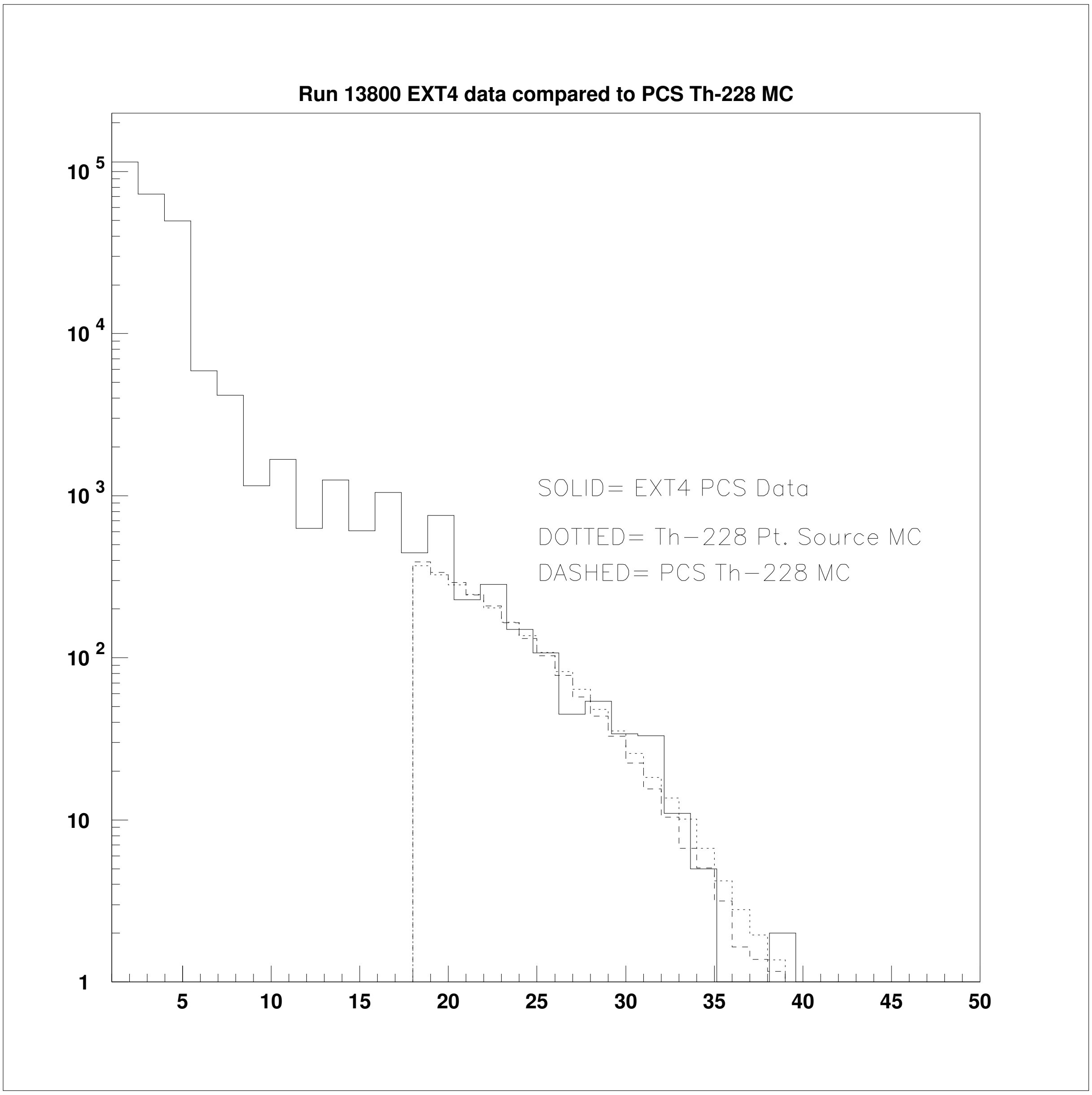

Figure 1: comparison of engineering run (run 13800 at center,solid) with PCS Monte Carlo (dashed)and a ^{208}Tl point source (dotted)

from ^{212}Bi and ^{208}Tl. The dotted line in the figure is for a ^{228}Th point source where the PCS geometry is turned off in SNOMAN. It is seen that the PCS SNOMAN simulation is in agreement with the ext4 triggered PCS data taken during the engineering run. We emphasize the data was taken with a <1 Bq source. Our current sources have 200 and 1000 Bq of ^{228}Th on them. One can suggest that if the SNO detector response of all the backgrounds, such as those from ^{232}Th chain are known, we may be able to push the analysis threshold down to lower energy.

[2] PCS can be triggered or tagged so that its contribution can be identified with respect to the rest of the triggers.

The PCS can be run in a tagged mode, such that when a beta or alpha exceeds the discriminator threshold of the PCS, a logic pulse is sent to one of the inputs of a FEC. If the decay observed in the PCS is due to a ^{212}Bi, or ^{208}Tl beta, the Cherenkov radiation may trigger the NHIT100 trigger, and the event is written out. This will allow us to determine the NHIT spectrum from the trigger threshold to high NHIT. The PCS can also be run in a mode where SNO is triggered whenever a pulse is seen in the proportional counter. This will alow us to determine the full NHIT spectrum. In both modes we determine the NHIT spectrum **independent of the photo-disintegration neutron that may follow** the initial $\beta - \gamma$ cascade.

[3] PCS ^{228}Th source activity is known and is constant

The PCS sources are essentially self calibrating, this is due to the self-consistency of many of the rate equations describing various event classifications. This is described in detail in the report SNO-STR-2001-017.

[4] PCS position is well determined in SNO

The PCS sources can be moved throughout the D_2O and H_2O, and (since the source is well defined) the position is assumed to be that reported by the manipulator computer. This is in contrast to other 'containerless sources' such as the proposed Radon spike and the ^{24}Na source.

4 Physics Motivations for PCS

4.1 Summary: List of PCS Physics Motivations

The main PCS physics motivations are summarized below. A more detailed description of each is presented in the next section. The motivations we consider to be the most important are italicized.

- *Calibrate the ^{208}Tl $\beta - \gamma$ events in the Cherenkov tail*(see Figure 2)
- *Calibration of the ratio of events in a background monitoring window to the number of ^{208}Tl decays*
- *Determination of the number of ^{208}Tl events reconstructing inside the D_2O*(see Figure 5)
- *Measurement of ^{208}Tl spectrum*(see Figure 4)
- Determination of shape of ^{208}Tl θ_{ij} distribution (See Figure 3)
- Determination of fitter Systematics
- Variations in the ^{208}Tl peak position throughout detector active volume
- Efficiency of low θ_{ij} cut to discriminate against H_2O ^{208}Tl events in the D_2O
- Systematics in Vertex Reconstruction (see Figure 6)
- Determination of low energy scale throughout active volume
- Assist in determination of AV PDF
- Determination of sacrifice

4.2 Deploying the PCS in D_2O in tagged mode

By running the PCS in tagged mode in the D_2O the ^{208}Tl NHIT spectrum can be measured with high precision from the NHIT trigger threshold to high NHIT independent of the photo-disintegration neutron and other backgrounds. Some important motivations for running in this mode are:

(1) Calibrate the ^{208}Tl $\beta - \gamma$ events in the Cherenkov tail

This will allow us to measure the number of beta-gamma events in Cherencov tails to quantify how many events due to a Thorium populate the neutrino data set. The advantage of using the PCS is that we will not have to depend on fitting the events to know which events are due to ^{228}Th decay, since we will be able to associate each individual event seen in the PCS with a response in SNO. The fact that the events need not to be fit will not only increase the efficiency of seeing the events in the tails of the NHIT distribution, but it will also allow us to determine the number of events under the neutron peak independent of other backgrounds, or systematics in the fitters. Rather than the systematics in the calculation of the number of events under the neutron peak to be due to the uncertainty in modelling the NHIT distribution of the encapsulated Thorium sources, the systematics will be in knowing the activity of the PCS ^{228}Th sources.

From Monte Carlo 1.3% of ^{208}Tl point source at the center of the D_2O events exceed NHIT=30 at the center of the D_2O. The PCS distorts the spectrum and produces 23% less events with NHIT>30. Thus we can fit a particular NHIT window of the measured low energy background wall with the spectrum observed from the PCS in the same NHIT window and calculate what activity the wall corresponds to if it were all due to contamination from Thorium. We can then calculate the number of tail events which we expect will have high enough energy to be under the neutron peak. For 3/4 hours running with source PCD we have $>10^4$ events exceeding NHIT=30. This is shown in Figure 2 for a ^{208}Tl point source and the PCS full geometry.

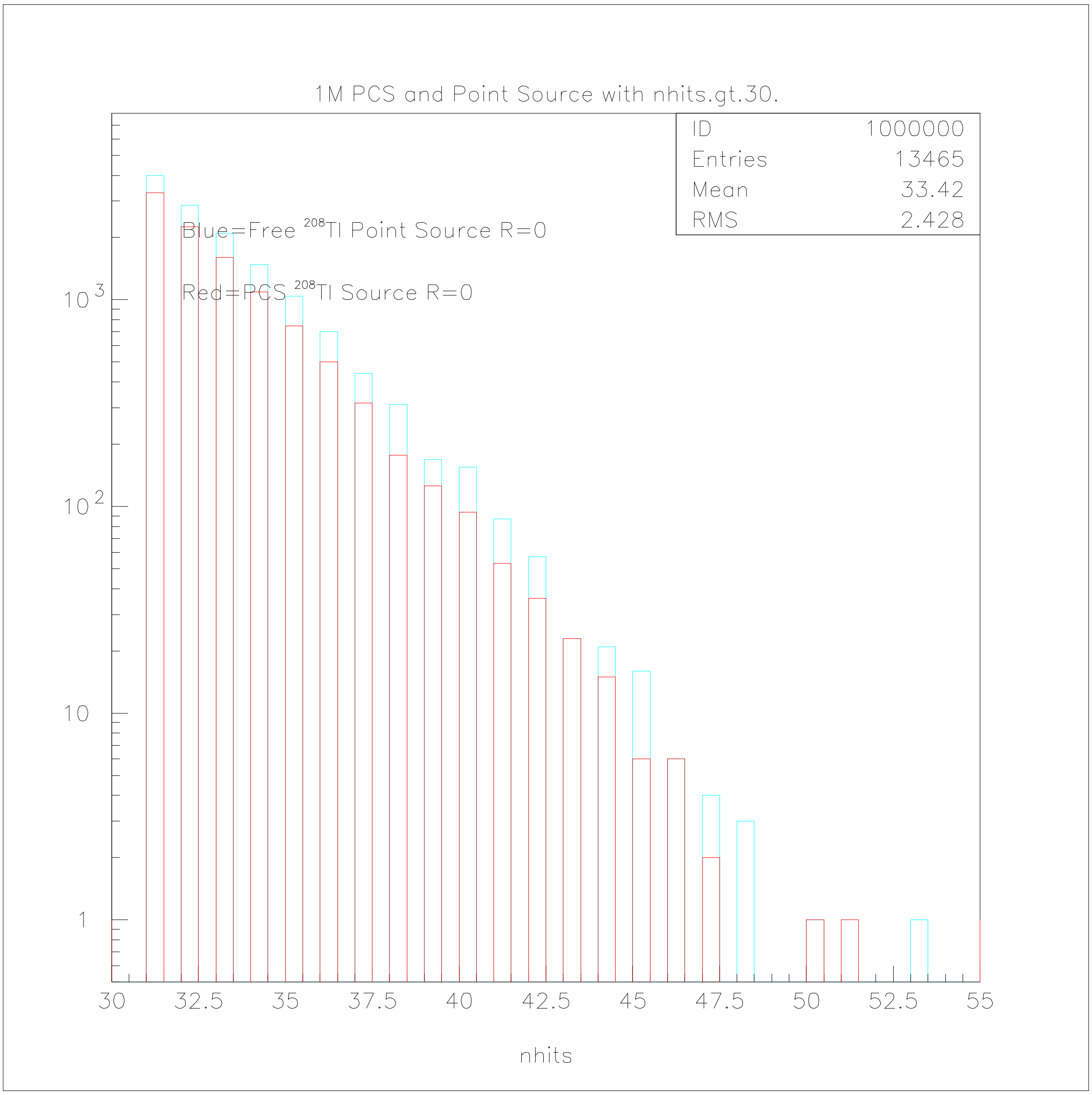

Figure 2: The unfitted NHIT spectrum for NHIT>30, PCS at center: $\sim$3/4 hours of PCS source 'PCD', and $\sim$4 hours 'PCA'. Also shown is the comparison to the ^{208}Tl point source

(2) Determination of shape of ^{208}Tl θ_{ij} distribution

Based on Monte Carlo it is expected that there will be little distortion to the PCS ^{208}Tl θ_{ij} distribution as compared to the ^{208}Tl point source (see Figure 3) Quantitatively based on Monte Carlo the difference between the 2 θ_{ij} distributions when the peaks are fitted to a Gaussian is that the PCS θ_{ij} distributions has a shift of approximately 1% towards lower θ_{ij} as compared to the ^{208}Tl point source. Most of the error in the extraction of the Thorium activity using X.Chen's "In-Situ" technique comes from uncertainty in modelling the acrylic sources[2]. Furthermore, even when the ^{24}Na source is deployed it has been determined that the extracted Th level using the "in-situ" technique has a strong dependence on the difference between the data and Monte Carlo θ_{ij} distributions (MC produces a θ_{ij} distribution with a mean that is 1% higher). Therefore another motivation for deploying the PCS is to measure quantitatively the ^{208}Tl θ_{ij} distribution.

(3) Calibration of the ratio of events in a background monitoring window to number of ^{208}Tl decays

The background region for the θ_{ij} analysis is performed in a particular NHIT window, with particular cuts applied, so it is necessary to be able to associate the number of events seen in the background window with the ^{228}Th activity. This is a major systematic to the "in-situ" technique because encapsulated acrylic sources have significant distortion to the ^{208}Tl as compared to the free source in the θ_{ij} NHIT window.

(4) Determination of sacrifice

The effect of the data cleaning on the neutrino data set using the standard suite of cuts need to be determined. This analysis needs to be performed with tagged/triggered sources as was done in Neil McCaulleys' thesis [1]. Doing this analysis with the PCS will be an important compliment to our knowledge, especially since the PCS is a low energy source.

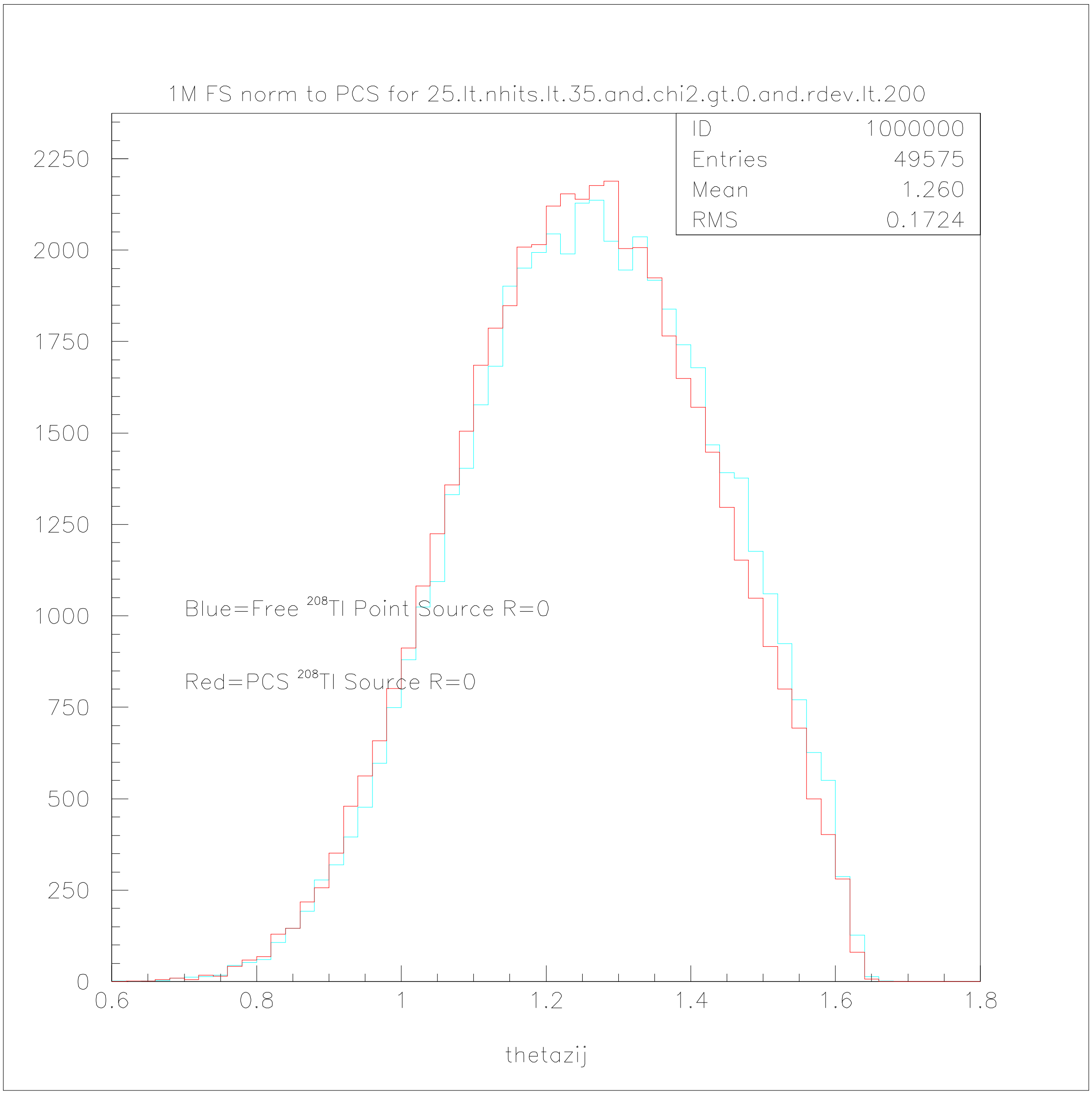

Figure 3: The θ_{ij} distribution for NHIT>30 and R$_{fit}$ <2m for ∼3/4 hours of PCS source 'PCD', and ∼ 4 hours 'PCA'.Also shown is the θ_{ij} distribution for a ^{208}Tl point source.

(5) Determination of fitter Systematics

Since the PCS will be a tagged/triggered source we will be able to associate every event seen in SNO with an event seen in the PCS. This will allow us to determine the performance of the fitter in vertex reconstruction by determining the mean and width of the fitted vertex distribution.

4.3 Deploying the PCS in D_2O in triggered mode

(6) Measurement of ^{208}Tl spectrum

As mentioned before the PCS tagged or triggered will allow us to measure the shape of the ^{208}Tl spectrum, independent of the photo-disintegration neutron that may follow. Measuring this shape will allow us to fit the background wall and extract the measured concentration (See W. Frati's paper [6]. It is suggested that if this shape of all the backgrounds [1] is known with high precision we may be able to lower the analysis threshold to lower energies. In Figure 4 the SNOMAN unfitted spectrum is shown for the PCS full geometry and a ^{208}Tl point source.

(7) Variations in the ^{208}Tl peak position

In triggered mode the Monte Carlo predicts that the ^{208}Tl spectrum has a peak at NHIT$\sim$16 and falls off with an exponential tail toward higher energies (see Figure 4). One can view the triggered PCS source as a single point low energy calibration source, with a known shape, but unknown energy at the peak. This means that even if we do not know the precise energy of the peak we will still be able to observe the variation in the mean and the exponential tail as the source is deployed throughout the D_2O. It is questionable whether we will actually be able to use the peak in the ^{208}Tl spectrum as a low energy calibration point, given the fact that the trigger efficiency shape is not well known. However, given that SNO currently does not have many low energy calibration sources, the PCS may be useful in this regard, especially in the H_2O where we do not have a ^{24}Na source.

[1] An electroplated ^{226}Ra PCS source will be constructed shortly. This source will allow us to measure the SNO detector response from the ^{214}Bi $\beta - \gamma$ cascade of the ^{238}U chain.

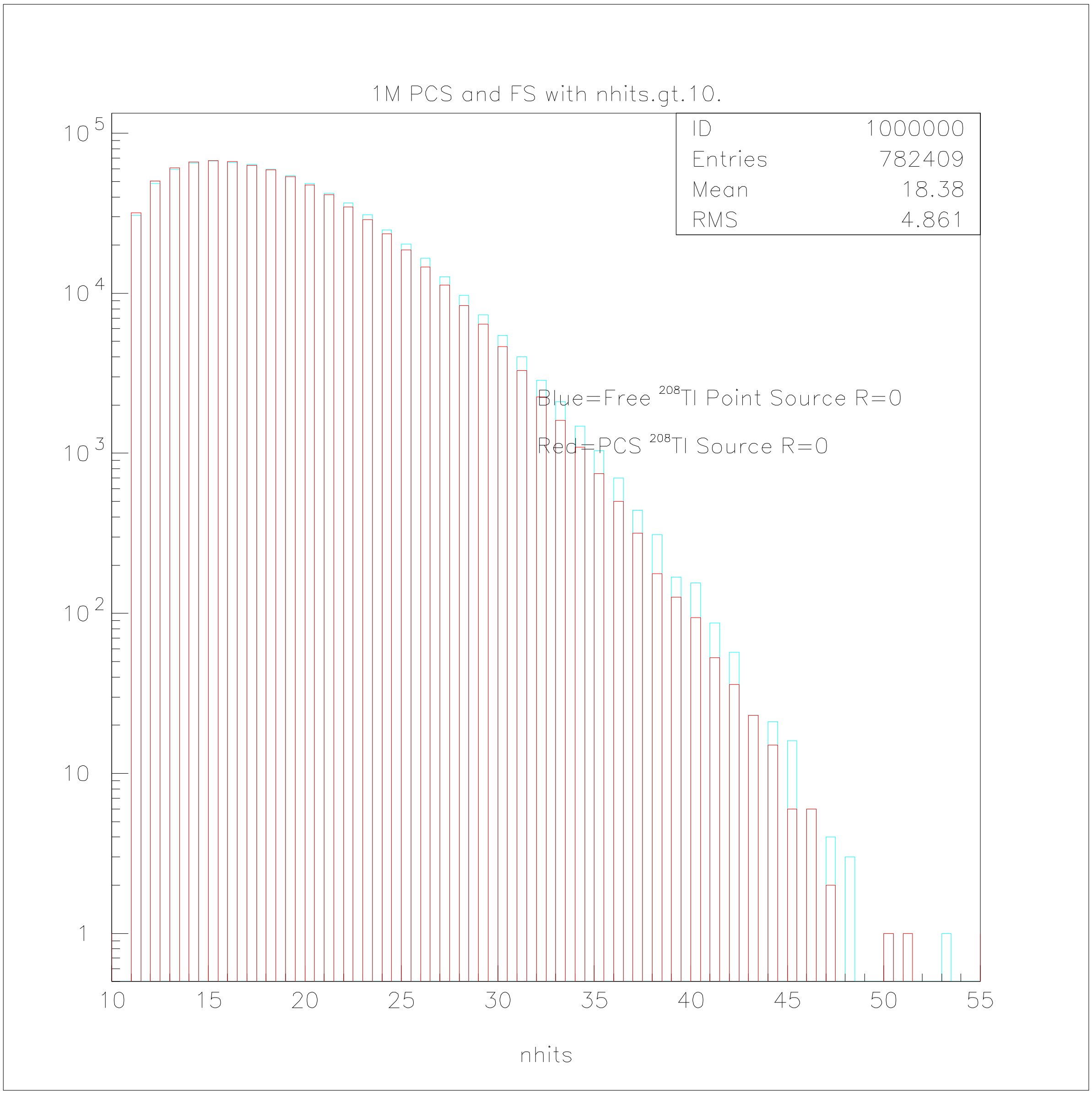

Figure 4: The unfitted NHIT spectrum for 1 million ^{208}Tl decays for NHIT>10: ∼3/4 hours of PCS source 'PCD', and ∼4 hours 'PCA'

4.4 Deploying the PCS in H_2O in tagged mode

Since we do not have a ^{24}Na source in the H_2O, our knowledge of the detector response and sacrifice is not as well understood as it is in the D_2O. Some of the physics motivations are the following:

(8) Number of ^{208}Tl events reconstructing inside the D_2O

By running the PCS in tagged mode in the H_2O in various positions radially throughout the H_2O the leakage of events reconstructing into the D_2O can be determined *independent of the photo-disintegration neutron* that follows. For example for 200k PCS ^{208}Tl events (10 min running with PCS source 'PCD') with the PCS deployed at R=653 cm we expect 200 events reconstructing inside the D_2O. Figure 5 illustrates this for the PCS and ^{208}Tl point source Monte carlo.

(9) Efficiency of low θ_{ij} cut to discriminate against H_2O ^{208}Tl events in the D_2O

It has been observed that the θ_{ij} distributions of neutrino data after low level cuts have been applied have 2 peaks. It is believed that the low θ_{ij} peak is due to AV/H_2O/PMT $\beta-\gamma$'s that contaminate the neutrino data set [2] [3]. Therefore a cut of $\theta_{ij} > 0.8$ (Note: G. McGregor employs a $\theta_{ij} > 1.0$ cut) has been applied to remove the external $\beta-\gamma$'s from the neutrino data set. If the PCS is deployed throughout the D_2O, AV, and near the PSUP, the effect of this high level cut can be determined.

(10) Systematics in Vertex Reconstruction

There is a systematic shift in vertex reconstruction of the shielded encapsulated acrylic sources as we move closer to the PSUP (see [4], Fig 13). Figure 6 shows a distribution for R_{dev} (Distance between fitted vertex and known PCS position) for the PCS source deployed at R=653 cm where the ^{208}Tl point source is normalized to the PCS source. Since there is little difference between the shape of the R_{dev} distributions in Figure 6, deploying

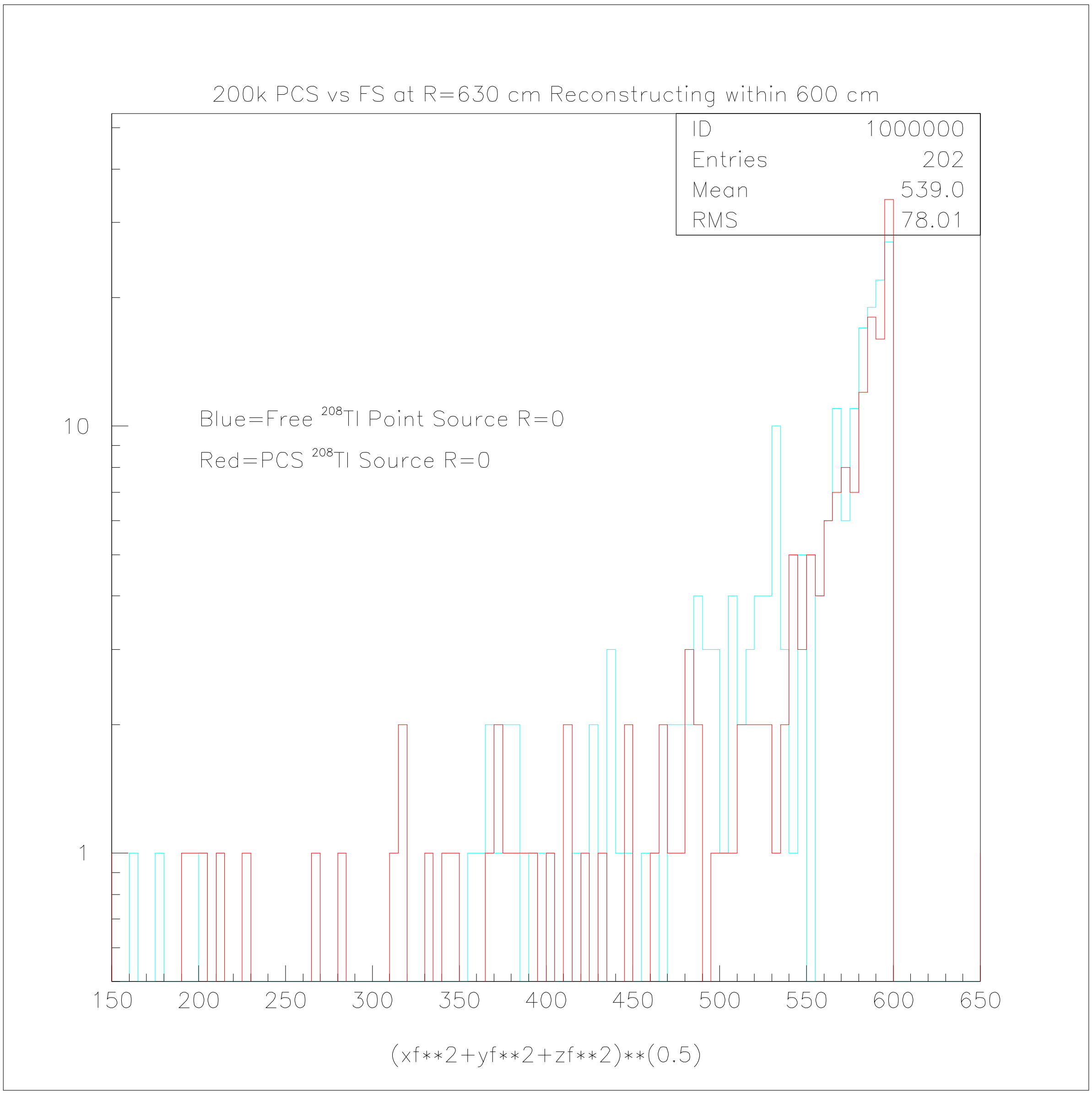

Figure 5: The distribution of distances from the fitted vertex to the center of the AV for PCS events deployed at R=653 cm with NHIT>30. Note this corresponds to ~10 minutes with PCS source 'PCD' and ~50 minutes with PCS source 'PCA'.

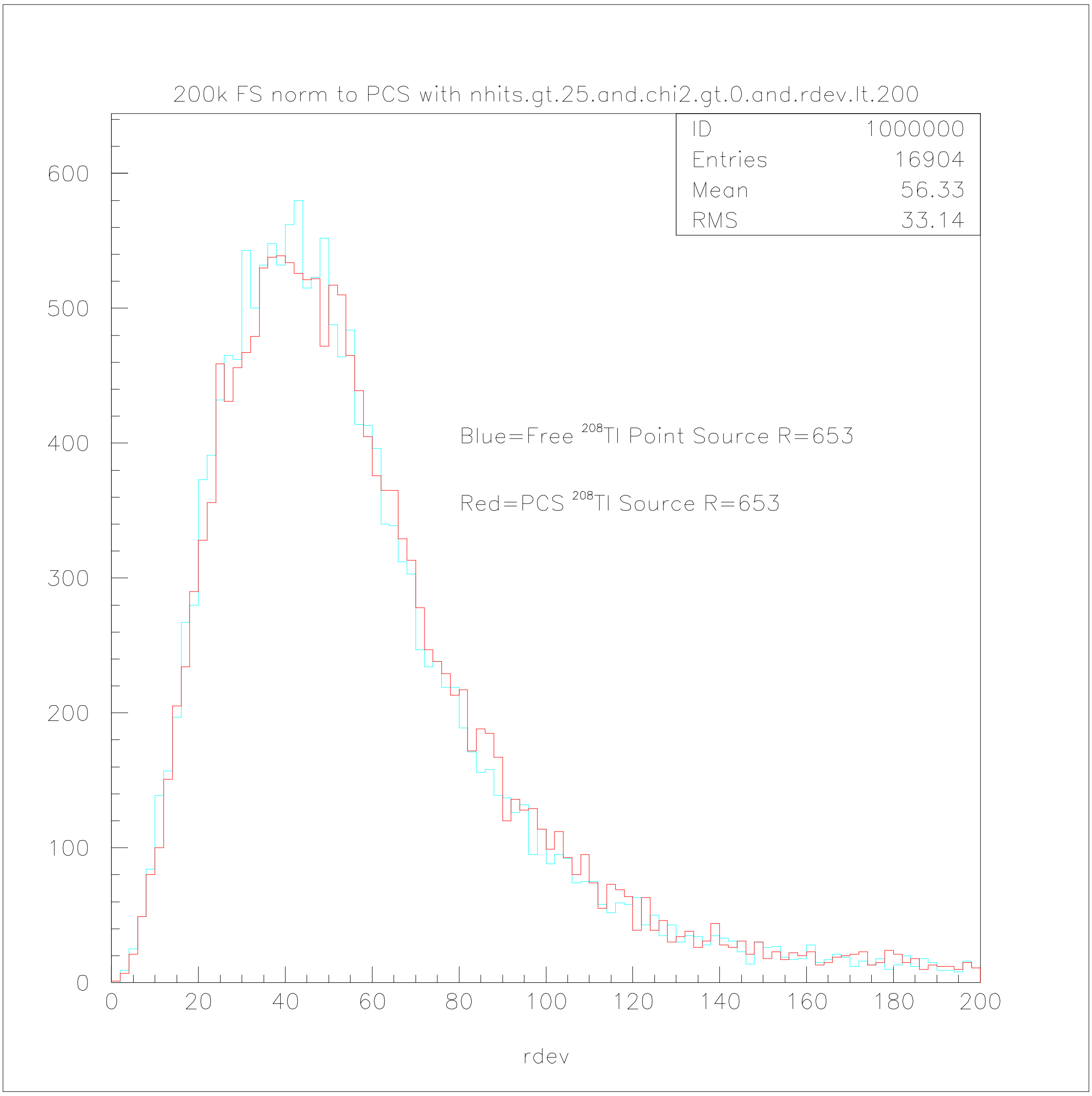

Figure 6: The R_{dev} distribution for NHIT>25 and R_{dev} <2m for the source at R=653 cm: ~10 minutes PCS source 'PCD' and ~50 min PCS source 'PCA'

the PCS throughout the H_2O will allow us to determine the systematics of fitter vertex reconstruction.

4.5 Deploying the PCS in H_2O in triggered mode

(11) Determination of energy scale throughout H_2O

V. Rusu recognized that the energy distributions of shielded encapsulated sources are not the same as neutrino data that reconstruct at the same radius as the source position in the H_2O. Consequently V. Rusu [4] compensates for this effect by applying an energy shift to the neutrino data. In triggered mode we should be able to see the peak in the ^{208}Tl spectrum, and use this as a single point calibration to estimate variation in energy scale as the PCS is deployed at various radii. As mentioned before the trigger efficiency may dominate the low energy SNO detector response so that we may not be able to use the peak as a single calibration point. However, in principle having this calibration point could be useful.

(12) Determination of AV PDF

The uncertainty due to AV $\beta-\gamma$'s is one of the largest uncertainty in V.Rusu's extended Maximum Likelihood R^3 analysis [5]. It will be useful to deploy PCS source 'PCD' near the AV both in the H_2O and in the D_2O to aid in determining the AV PDF.

5 Conclusions

The list above of physics motivations is far from exhaustive, but is only meant as a guide for the discussion at the "PCS physics motivations conference call". Given the schedule for the salt analysis, it may be most advantageous to deploy the PCS with source 'PCD' in the H_2O first, to determine quantitatively the leakage of Th events into the neutrino data set, and the efficiency of various high level cuts.

References

[1] N. K. McCauley, Producing a Background Free Data Set for Measurement of the Charged current Flux and Day-Night Asymmetry at the Sudbury Neutrino Observatory, University of Oxford, 2001,D.Phil.

[2] X. Chen and K. T. Lesko, In Situ Background Monitoring Technique for the SNO Experiment, Report on Manhattan under Analysis, August 6,2001.

[3] G. McGregor, D_2O In Situ Measurement of ^{208}Tl and ^{214}Bi (Part 1 and Part 2), Report on Manhattan under Analysis, October, 2001.

[4] V. Rusu, Low Energy Backgrounds with Acrylic Sources (I and II), Report on Manhattan under Analysis, October 2001, February 2002.

[5] A. Poon, SNO Low Energy Background Working Group Meeting Minutes (Jan 07, 2002), Note on Manhattan under Analysis.

[6] W. Frati Determination of uranium and thorium contamination in the D2O from the NPMT spectrum above 1.4 MeV SNO-STR-94-005 February 1994