Event reconstruction and background rejection in the SNO+ experiment

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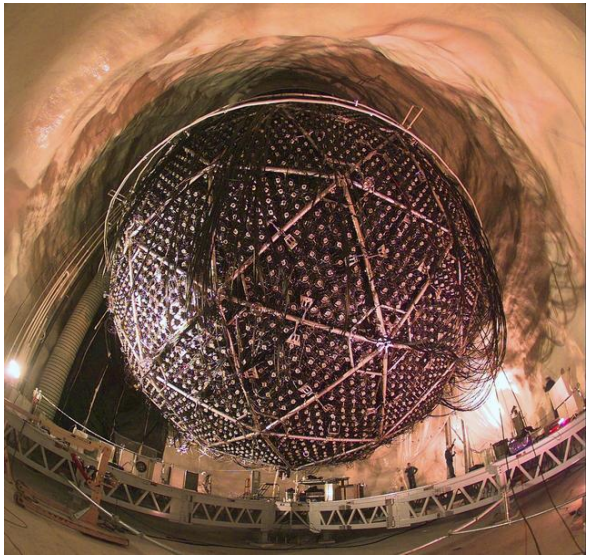
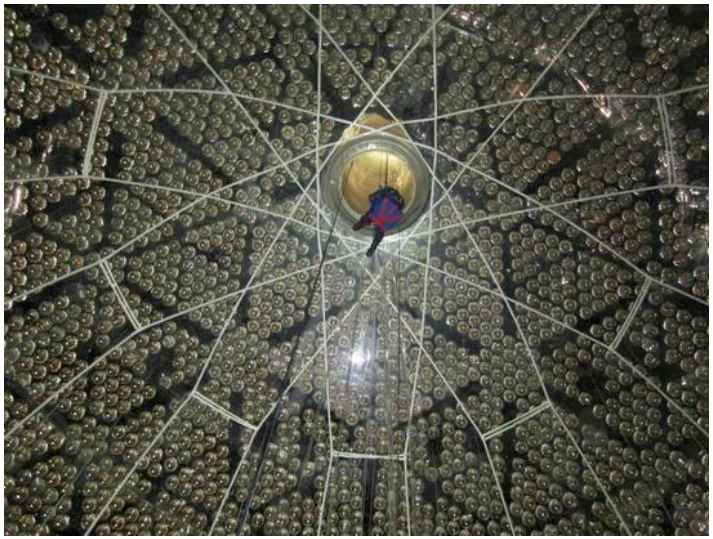
IOP Talk, Liverpool 2013

Overview

- Introduction to SNO+
- Reconstruction
  - In scintillator phase
- Background tagging
  - Tagging external ^{208}Tl backgrounds





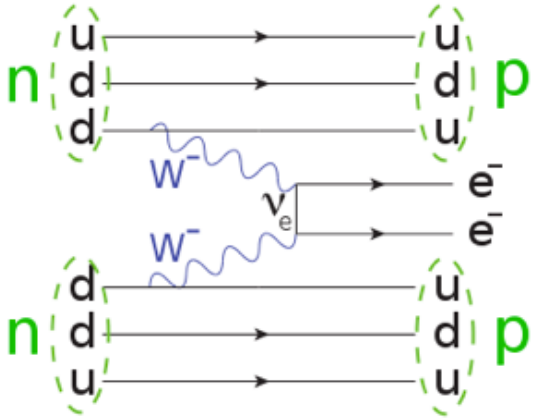
Introduction to SNO+

- SNO+ is a liquid scintillator experiment based in SNOLAB, Canada

- Several physics goals including:
  - Neutrinoless double beta decay
  - Low energy solar neutrinos
  - Reactor neutrinos
  - Geo neutrinos
  - Supernova
  - Nucleon decay (during initial water phase)

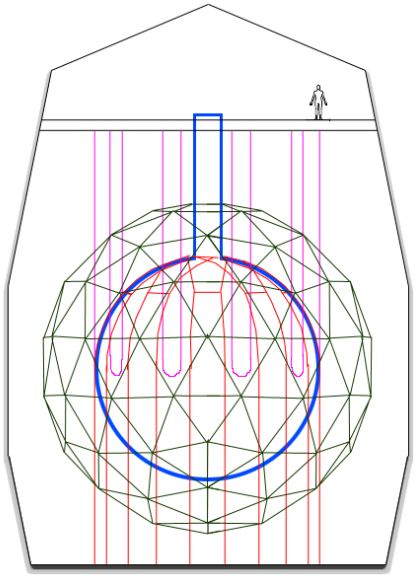
- Water fill in April

- Start scintillator fill towards the beginning of next year



Introduction to SNO+

- Makes use of the SNO detector:
  - 6 m radius acrylic vessel containing liquid scintillator
  - Surrounded by ultra pure water shielding and 9400 PMTs (54% coverage)



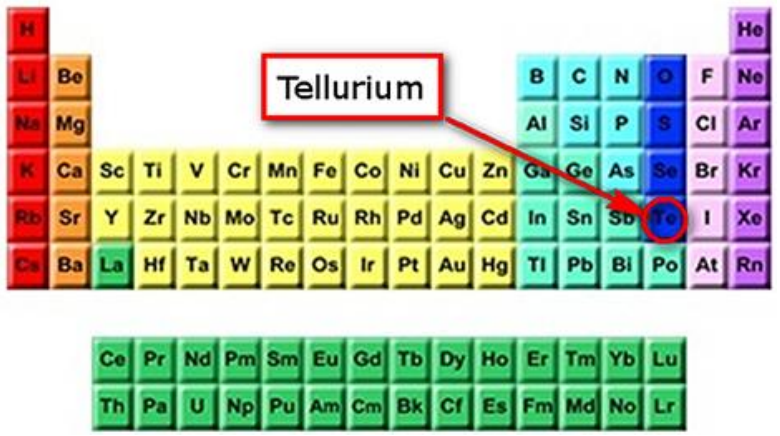
- Upgrades include:
  - New ropes to hold down the AV
  - Scintillator purification system
  - New calibration systems (discussed in parallel session talks by J.Sinclair and M.Mottram)
  - Upgrades made to some of the electronics
  - Of ~700 PMTs known to be faulty after SNO, ~200 have been repaired and reinstalled with more to happen this year during water fill

Introduction to SNO+

- Recently made decision to switch to Tellurium loaded scintillator for double beta decay phase of experiment

- More details given in plenary talks by J.Wilson & J.Evans

- Motivation:
  - Large natural abundance of isotope
  - Relatively low two neutrino double beta decay background
  - Should be able to tag or remove through purification a lot of the major backgrounds



At the energy of the Te signal, external gammas imposes a limit on the fiducial volume of the experiment.

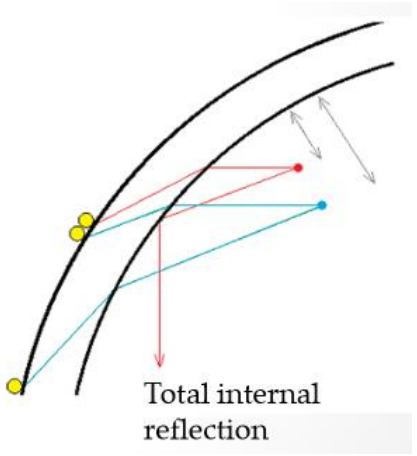
This talk discusses a method used to tag these events and so improve the fiducial volume.

Reconstruction in SNO+

- Fitters aim to use the time and charge of PMT hits to reconstruct the position, energy and particle type of events

- Water phase uses directional Cerenkov signal and so can use fitters based on SNO techniques to measure position, direction and energy.

- Scintillator phase events dominated by isotropic scintillation signal at much higher number of PMT hits than seen on SNO.
  - Cerenkov signal is hidden underneath scintillation light and so any measurement of directionality is lost
  - Additional challenges over reconstruction in water:
    - Much shorter absorption and scattering lengths
    - Re-emission can change photon wavelength and the speed of photon
    - Difference in refractive index between scintillator and water shielding cause significant optical effects near the edge of the vessel



Reconstruction in the Scintillator Phase

Several fitters and event classifiers have been developed for scintillator:

- Centroid – finds position using a charge-weighted sum of the hit PMTs
- Quadfitter – calculates an event vertex from position and times of four hit PMTs. Repeat for many random combinations until results converge
- Likelihood fitter – discussed in this talk
- Energy – uses a lookup table to convert number of hit PMTs and position in the detector into reconstructed energy
- Classifiers:
  - Near AV fitter – uses total internal reflection and refraction effects to tag events near the acrylic vessel (discussed in poster by A.Back & K.Majumdar)
  - Pile-up – uses changes to the characteristic timing shape and isotropic distribution of hits to distinguish pile up events
  - Alpha tagging – uses the difference in the scintillation time of photons to tag alpha events

Scintillator Phase – Likelihood fitter

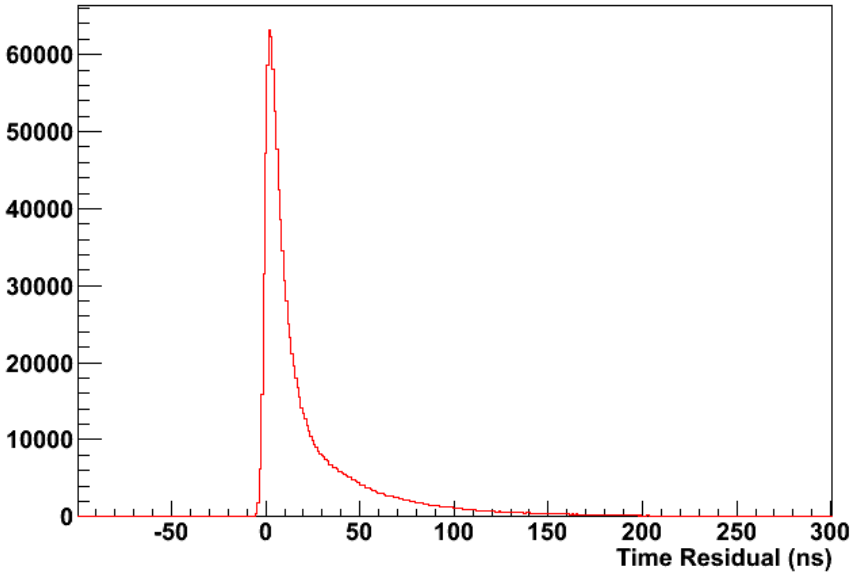
- Calculate the time residuals from PMT hits of an event

$$t_{res} = t_{pmt} - t_{time\ of\ flight}(\underline{pos}_{pmt}, \underline{pos}_{fit}) - t_{fit}$$

$$t_{time\ of\ flight} = d_{scint}/v_{scint} + d_{av}/v_{av} + d_{h2o}/v_{h2o}$$

- Compare to a time residual PDF based on Monte Carlo position and time and vary fitted position and time in order to maximise the log-likelihood

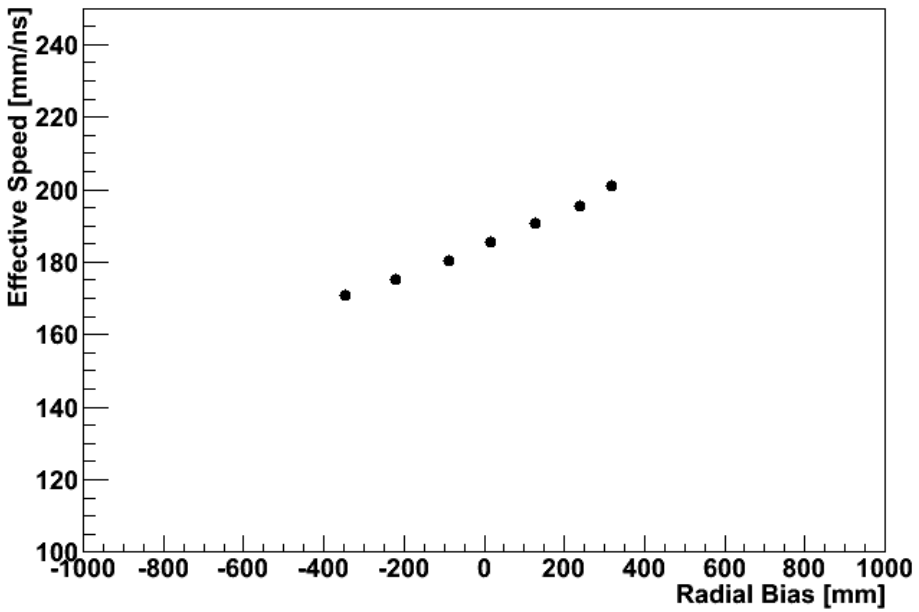
- Assumes:
  - Straight line path between event and PMT
  - Single PDF for whole volume
  - Use an “effective speed” within scintillator determined by minimising the radial bias of the fitter
  - Use group velocity within AV and water shielding since velocity won’t change in these media



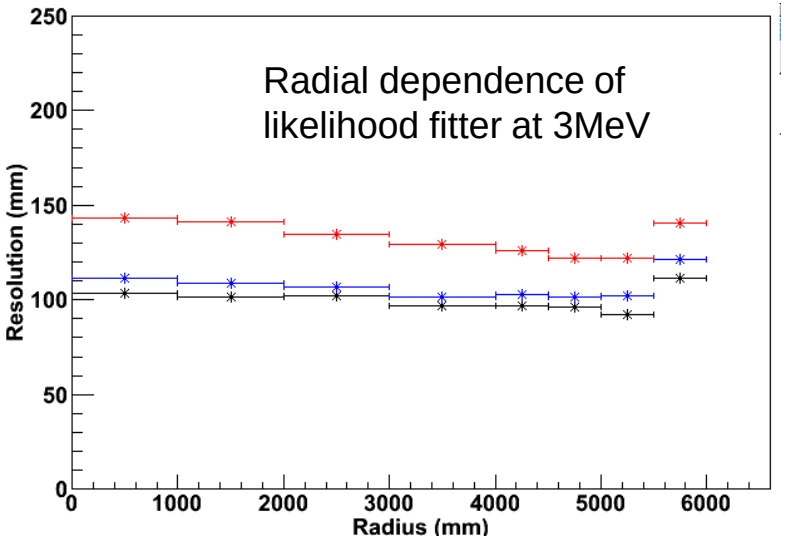
The plot shows measured time at PMT – time of flight (time residual) for events within a radius of 5.5 m.

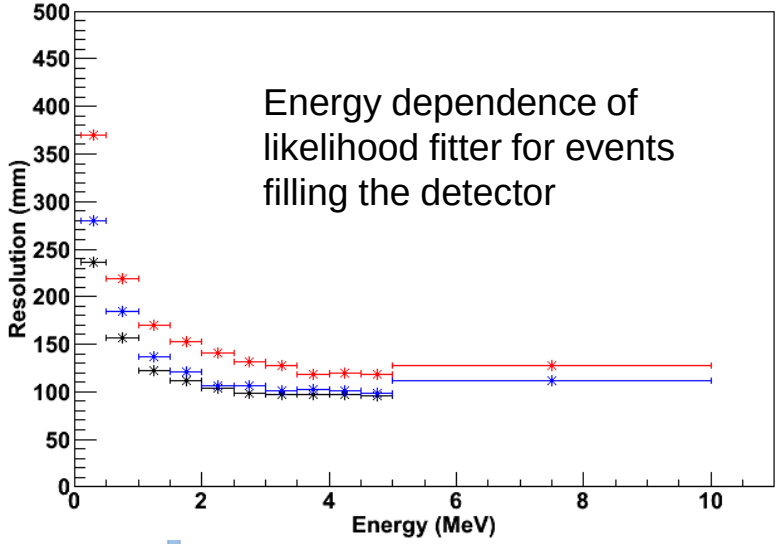
Scintillator Phase - Effective speed

- Find “effective speed” by minimising the radial bias of the fit
- Plot the effective speed against the radial bias of fit for MC events, fit linearly and take the y-intercept as the effective speed
- Will depend on the optics of the scintillator so will change with the amount of loading
- Can calibrate when detector is online by attempting to minimise the radial bias for events from actual sources



Scintillator Phase - Performance





10cm resolution for unloaded LS

13-14cm at close to optimal loading of Te (220 hits)

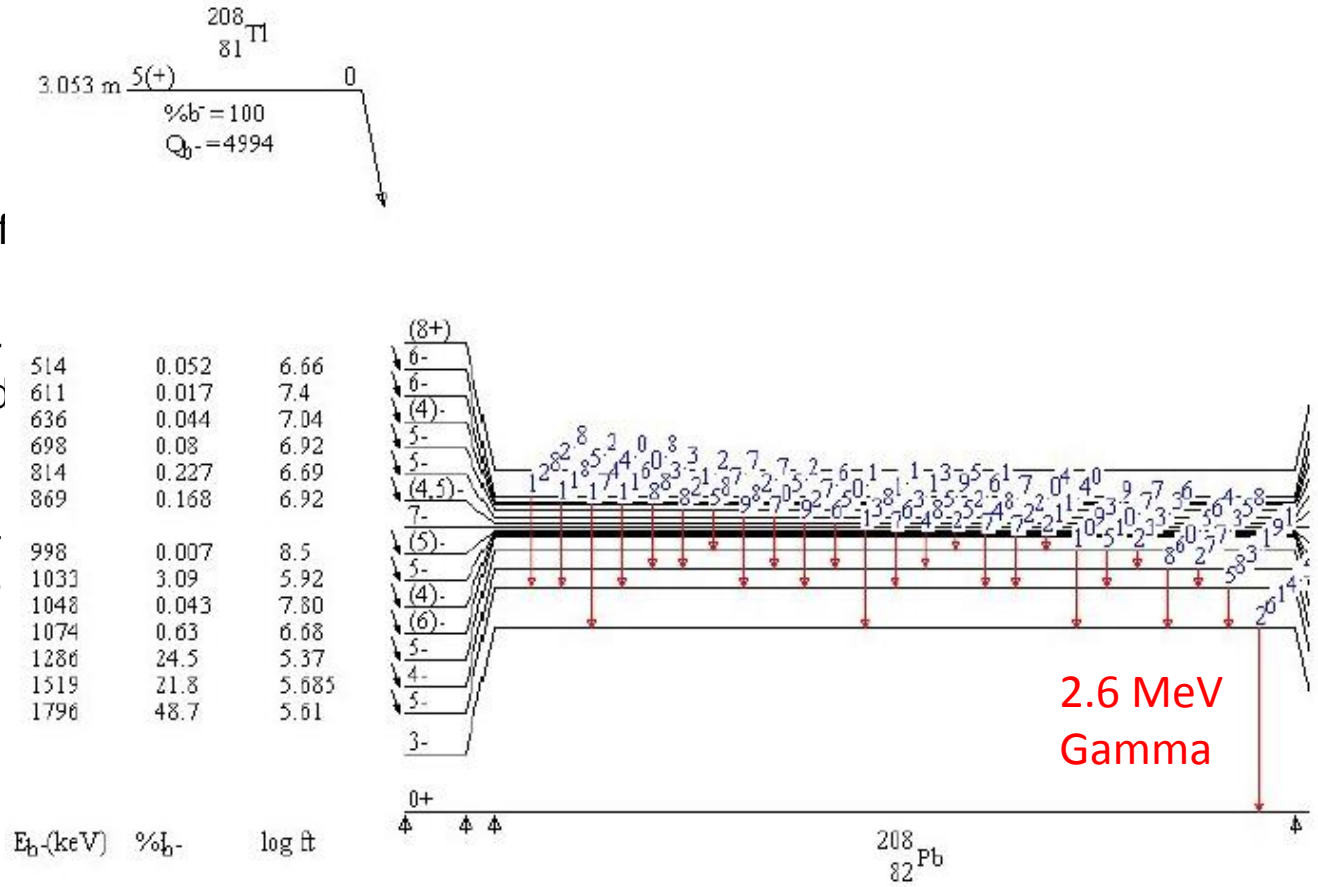
Background Identification

Work has been done on SNO+ to identify and tag some types of background events. These include:

- External ^{208}Tl decays in the AV & ropes (discussed in this talk)
- Alpha tagging of internal ^{208}Tl using ^{212}Bi alpha
  - (discussed in poster by A.Back & K.Majumdar)
- Alpha tagging of internal ^{214}Bi using ^{214}Po alpha

Tagging of external ^{208}Tl backgrounds

- ^{208}Tl occurs naturally in the Thorium chain
- Decays with a half-life of about 3 minutes to produce a 2.615 MeV gamma along with other low energy gammas and a beta
- Will be present in SNO+ acrylic vessel and ropes
- Can reconstruct in the scintillator within energy window of signal and be mistaken for physics events

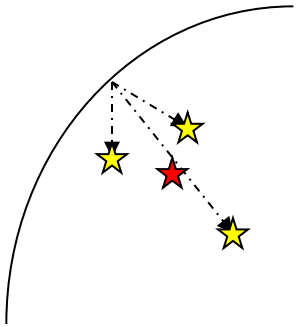


- These events fall off exponentially from the edge of the detector and so impose a limit on the fiducial volume of SNO+

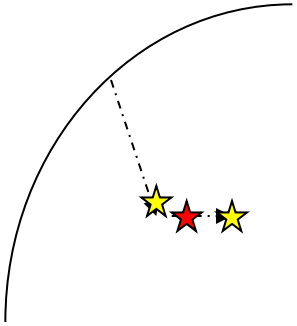
Tagging of external ^{208}Tl backgrounds

Work suggests that two mechanisms together may be responsible for an excess in early light and so allow identification of ^{208}Tl events from the AV

- Lower energy gammas can deposit energy in scintillator



- 2.6 MeV gamma deposits most of its energy in the first interaction
- Will deposit smaller amounts of energy further in



Tagging of external ^{208}Tl backgrounds

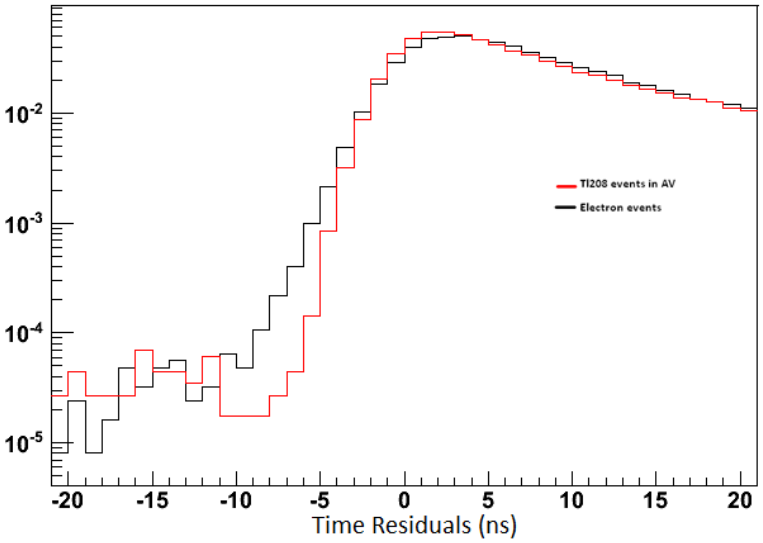
- Can distinguish these events based on difference in shape of distribution of early PMT time residual

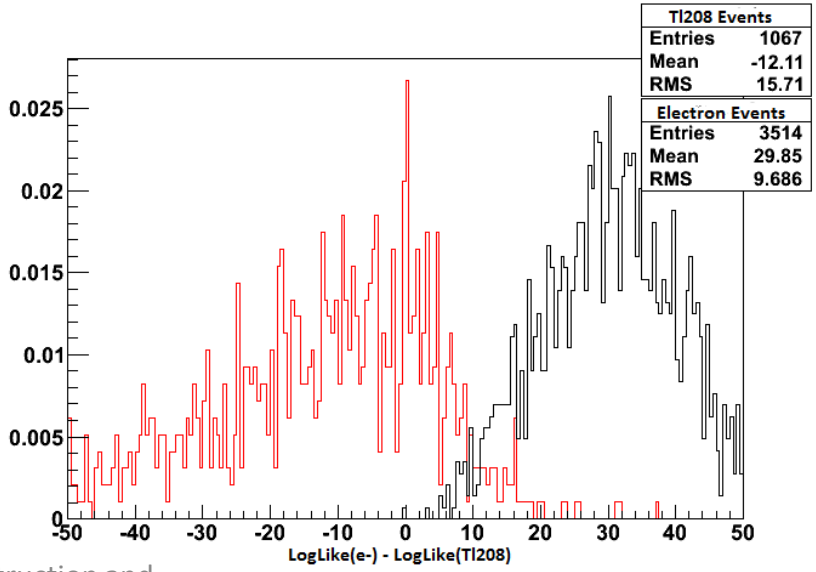
- Create PDFs based of MC distributions of electrons and ^{208}Tl events in the AV, reconstructing at the same energy and radius in the detector

- Compare an individual event to each PDF and get a log-likelihood value of each to get:

$$\Delta = \text{LogLike}(e^-) - \text{LogLike}(^{208}\text{Tl})$$

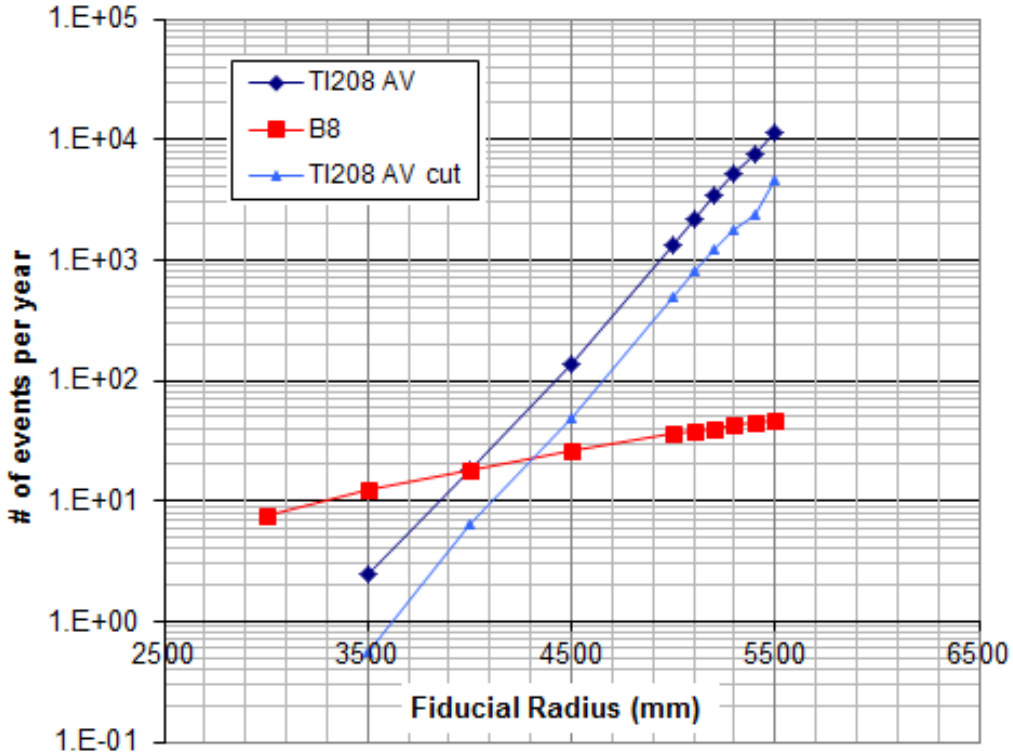
- Placing an appropriate cut on Δ, can tag a significant fraction of external background events while mis-tagging a minimal amount of signal (electron) events





Tagging of external ^{208}Tl backgrounds

- Plot shows number of events per year in signal window within a given fiducial radius
- Shows ^{208}Tl backgrounds from AV with and without cut applied compared with the expected event rate from solar ^{8}B neutrinos
- This technique has also been shown to work for external ^{208}Tl backgrounds from hold-down ropes
- Cut will reduce external backgrounds by over 50% (losing less than 5% signal).



Summary

- Talk describes only some of the work in progress on reconstruction and background identification on SNO+

- Reconstruction for position is based on a likelihood method and time residual PDF and has been found to produce good results and be adaptable to various phases of the experiment

- Method of background tagging of external backgrounds has been developed (and verified) based on the timing shape of early light. This will be important in improving the fiducial volume of SNO+.