# Supernova Energy Reconstruction Problems

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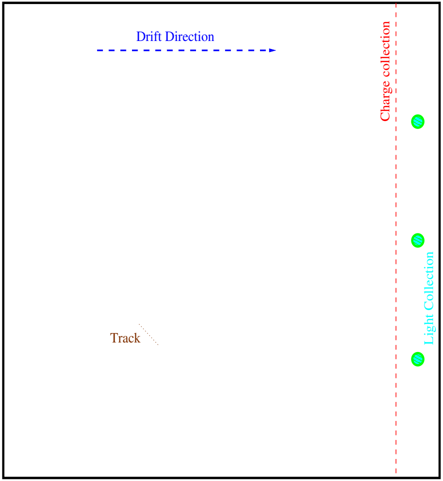
# Introduction

- Supernova neutrino physics measurables
  - time of the event
  - location of the interaction vertex – fiducial volume – target mass
  - neutrino energy
  - neutrino direction — but for most events not important
- Detection efficiency
- Reconstruction efficiency
- Resolution in time, space, energy and direction

# Outline

- TPC concept ... ionization cloud drifts to a collection plane
- Charge collection
- Electron lifetime correction
- Light flash for drift start time – for asynchronous (SN, proton decay, atmospheric neutrinos) events
- Pure signal – No backgrounds
- Flash from backgrounds
- Charge from backgrounds
- An important issue for “low” energy events

# TPC Fundamentals




The TPC observes the ion track left by ionizing radiation.

The energy is reconstructed from the integrated charge collected

There is an ambiguity between time and distance

Drift time is the time it takes the charge to reach the collection plane

The electronics can measure the arrival time but to get the drift time you need to know when the charge was created

For asynchronous events this "start time" is provided by scintillation light produced when the charge was created

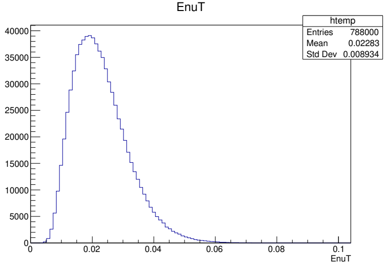
The light is registered with the light collection system

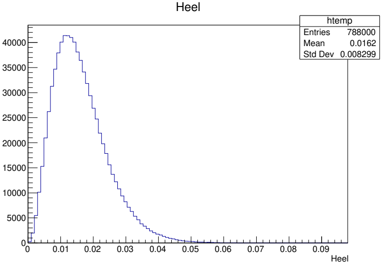
# Energy Reconstruction

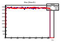
- Light flash observed
- Charge collected
- Flash time matched to charge collection
- Electron lifetime correction to charge
- Corrected charge converted into energy

Electrons have a finite lifetime before they are captured and no longer drift. The charge from energy deposited near the far wall is attenuated by about a factor of two while drifting to the collection plane.

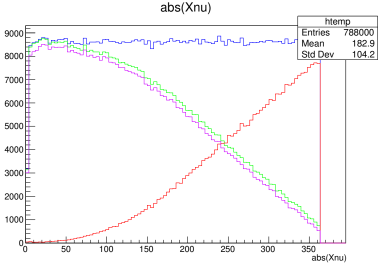
# Simulations

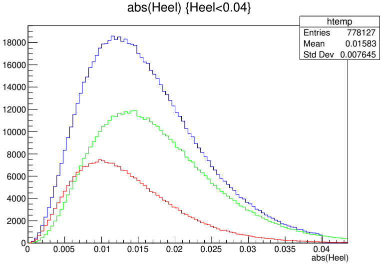



- Marley event generator
- Supernova $\nu_e$ spectrum; no oscillations – left figure
- Uniform in the detector *fiducial* volume 
- Compare with electron not neutrino energy – right figure
- Simulation “frame” is two full drift times
- Samples with and without radioactive backgrounds

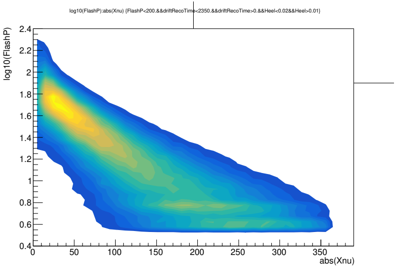
# Limitations – No Background Case

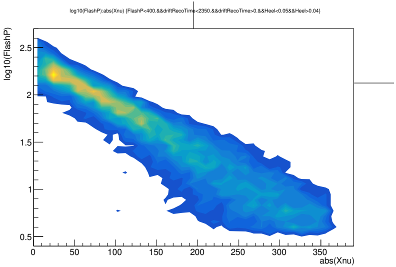



The figure on the left shows the true drift distance for events with a recovered light flash time, in green and those events with no recovered flash time in red. The generated distribution is flat in the drift distance Only 66% of these background free events are recovered. The figure on the right shows that the lost events tend to have a lower electron energy than those with a flash time.

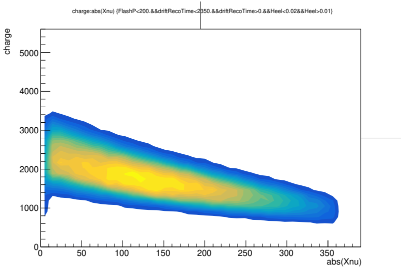
# Why is the Flash Lost – No Background Case

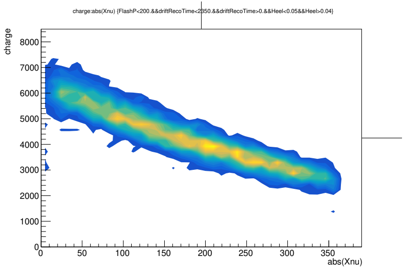



The left figure is the Log10 of the flash pulse height for electron energies from 10-20 MeV as a function of drift distance. The right figure is for 40-50 Mev. Note that the flash intensity drops by about a factor of 30 across the detector. This is best seen in the figure on the right which has enough light to be seen across the detector. At lower energies energy deposited on the far side does not make enough light to be recognized.

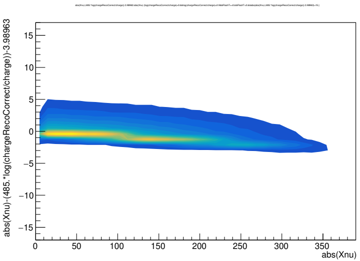
# Charge Attenuation – No Background Case

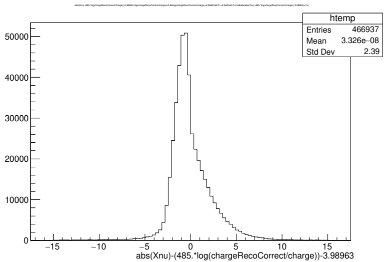



The left figure is the charge collected for energy deposition from 10-20 MeV as a function of drift distance. The right figure is for 40-50 Mev. As seen on the right the drift distance correction can be as big as a factor of two.

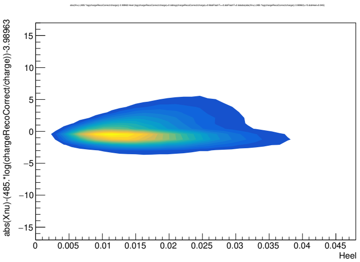
# X Resolution – No Background Case



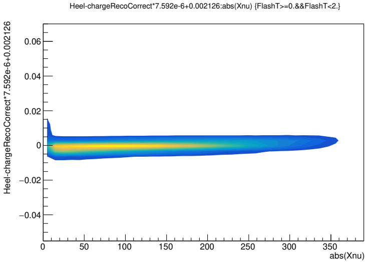

With quality cuts based on the known Monte Carlo Flash time the drift direction spatial resolution is about 2.4 cm. Comparable to the track length. The position is compared is the interaction vertex not the track centroid. The left figure is the position difference as a function of the position.

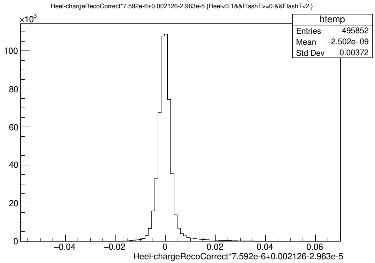
# X Resolution with Energy



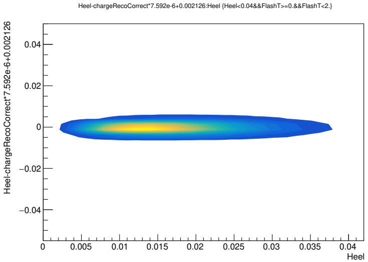

The X position difference as a function of the electron energy.

# Drift Corrected Energy – No Background Case




Drift corrected energy resolution (for the electron energy) of 3.7 MeV. Very little shift with drift distance, left plot.

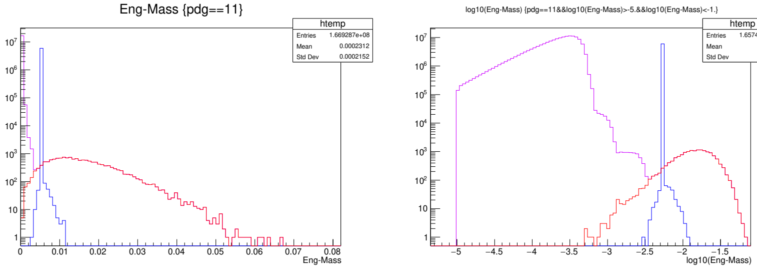



Left: True energy minus reconstructed energy as a function of true energy

# Open Problems – No Background Case

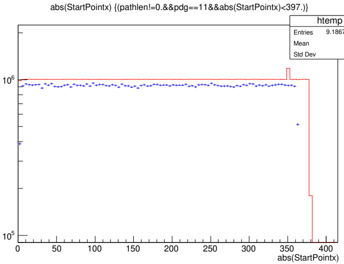
- Missing flash time (33%)– some reconstruction codes assign these events a flash time of zero. Zero is the right time for simulated events.
- 3% with the wrong flash time. Some outside the physical range ... before the interaction or after the charge is collected.
- Length correction – many tracks do not have an exact drift length. They extend in the drift direction.
- Nuclear effects – more than 4 low energy gammas per event not included in the reconstructed energy.
- Fluctuations in the collected charge.

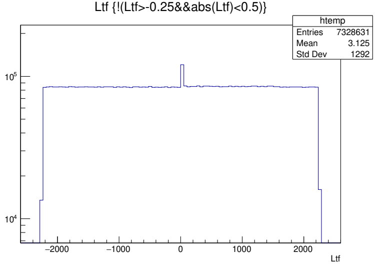
# Background Simulation – Radioactive Backgrounds




Above, left the kinetic energy spectrum of the signal (red) and the electron, beta decay, background (violet) and the alpha particle background (blue). The vertical scale is logarithmic.
The right figure is a log-log version of the signal and background kinetic energy as in the left figure. In the right plot -3 is 1 MeV and -2 is 10 MeV.

# Volume and Time




The left figure shows the simulated drift direction distribution of events for signal (blue) and for background (red). The vertical scale is arbitrary. Note that the background seems to be simulated in the full volume but the signal is only simulated in the fiducial volume. The figure on the right shows that the flash times are distributed between $\approx \pm 2245$ $\mu$s. This is twice the total drift time for any interaction. Twice as much background is created for the event. The relevant flash can occur no later than the time the charge is collected and no earlier than the drift time from the far side of the detector.

# Complications Due to Background

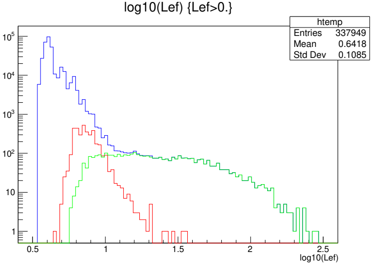
A serious complication due to background is the use of a background induced flash to replace the missing one in the clean sample. Also a background induced flash may be a better match to the collected charge than the correct one. For example a match made to the brightest flash in the "frame" can be misled by a background flash closer to the light collection system which has not been attenuated as much as the signal event flash. There is no independent drift distance measurement to remove this ambiguity. With no background there is no ambiguity, unless the signal rate were larger than the (drift time)$^{-1}$.

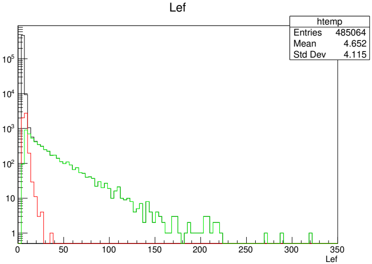
Flash mismatch gives an incorrect energy and the wrong interaction point for the event. The wrong interaction point means we do not know the fiducial volume of the events. Clean events which would have had a missing flash are moved closer to the collection plane.

# Complications II

Clean events with a good flash match may have the match replaced with a brighter incorrect flash. Making a broken event out of one that could have been correctly reconstructed in the absence of background. The current algorithm is to match to the brightest recorded flash since most signal events are higher in energy than the backgrounds. But the factor of 30 attenuation of light from the far side means that frequently a much more common background event closer to the light collectors will be measured as the brightest. This problem is made worse in the simulation where the background is doubled since it comes over two full drift times.

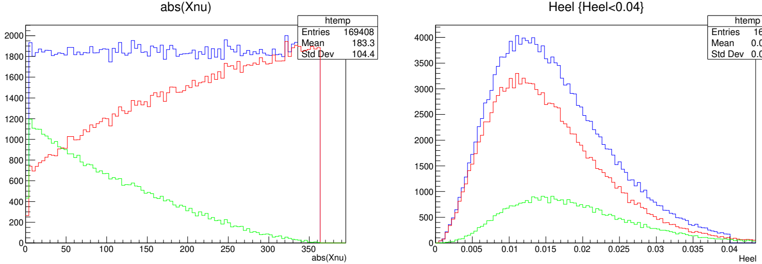
# Flash Integrated Pulse Height – Background



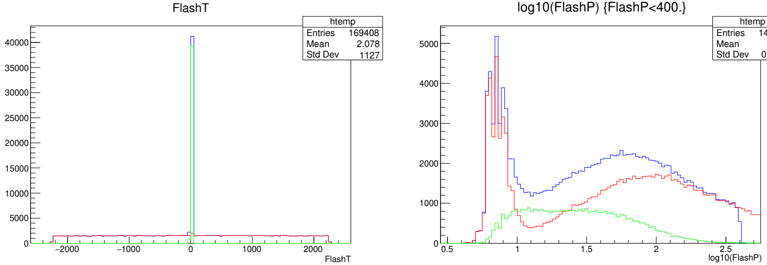

The reconstructed flash pulse height for all flashes. The red and green have been matched to a collected charge. The red are wrong time matches and the green are correct time matches.The vertical axis is logarithmic for both figures. The one on the left plots the log of the flash pulse height to clarify the low light region. Below 10 wrong matches dominate.

# Fiducial Volume and Energy Spectrum – Background



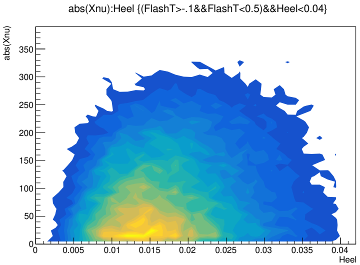

The true drift distance is on the left and the true electron energy is on the right. The red curve is for events with incorrect drift times. The green curve is for events with correct drift times. Less than 24% of the events have correct times (with this sim and reco).
A newer sim reco gives about 27%.

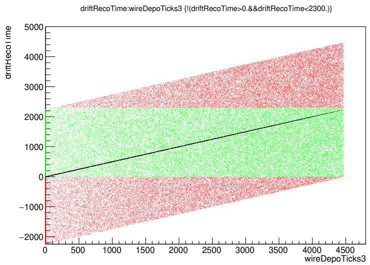
# Flash time and Flash pulse height – Background




Left is the reconstructed flash time. Right is the reconstructed flash pulse height matched to the flash. Green is for good matches. Red is for bad. In the simulation the correct flash time is close to zero. Note: the bad flash times run the $\pm$ the maximum drift time.

# Volume vs Energy and Drift Time – Background



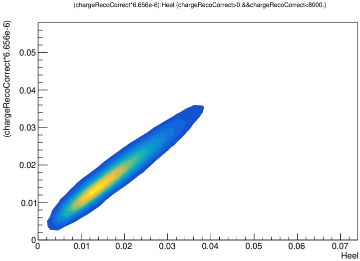



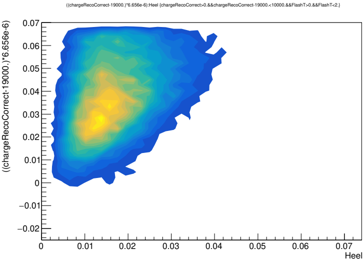

The figure on the left maps out the region of fiducial volume and electron energy correctly reconstructed. The figure on the right compares the reconstructed drift time to the correct drift time. Red points correspond to noncausal matches 37%. Green points correspond to points within the time interval between charge collection and drift time to the far wall. The black line are correctly reconstructed times. Excluding the 37% acausal region would not automatically give a good match.

# Summary – with Background

- Low energy background – primarily modeled as $\alpha$ and $\beta$
- Background produces about 44 flashes in a double frame
- No more missing flashes
- Now there can be a flash event charge mismatch
  - If a signal flash was missed a background flash is substituted
  - Due to light attenuation a background flash close to light collection can be brighter than the signal flash and used instead
- Wrong electron lifetime correction
- Wrong vertex location
- The integrated charge of the background is large compared to the signal charge. Reconstruction integrates all charge.
- Get very bad energy reconstruction for most events.
- Do not know the correct time match in the real world to know which subset of events has the correct energy.

# Results




Left, the reconstructed energy vs the true electron energy in a background free simulation for events with a correct flash match. Right, the reconstructed energy vs the true electron energy in a simulation with background. Only *correct flash matches* have been used. An average background charge has been subtracted.

# Fixes

- Improve light collection so that *all* events provide enough signal to reconstruct a flash
- Add light collection on the far wall to get an estimate of the event vertex location from the flash time and pulse height difference. –Redundant information.
- Improve flash and charge matching. Are the measured flash time and pulse height compatible with the observed charge collection? AI and neural net methods to consider all flash&charge pairs in the event to get the best one.
- Localized energy reconstruction. Only integrate charge from the spatial region of the particular event. For example use a narrow time slice not the two full drift time window. Cut in the transverse directions too.
- Without augmented light collection about 34% of the events for which the signal did not create a flash will be matched to a background flash. It is difficult to identify these mismatched events. Without perfect AI matching wrong matches will be higher.

# Backup Slides

- Monte Carlo Production
- Code Changes

# Monte Carlo Production

- Miscommunication with production team ... DAQ needs ... three events per frame.
- Production delays
- Alternative for small samples
- Larsoft releases can now be accessed from cvmfs
- Singularity containers for SL6 and SL7 can be found in cvmfs. No need to run SL6 or SL7 to run larsoft
- Can create local simulation samples up to disk and computing power limitations.

# Code Changes

- Add light collection
- Modify flash matching
- direction and length correction to charge collection
- Change detector geometry
- Localized charge collection for energy reconstruction