Reco / Sensitivity Update for DSNB Events

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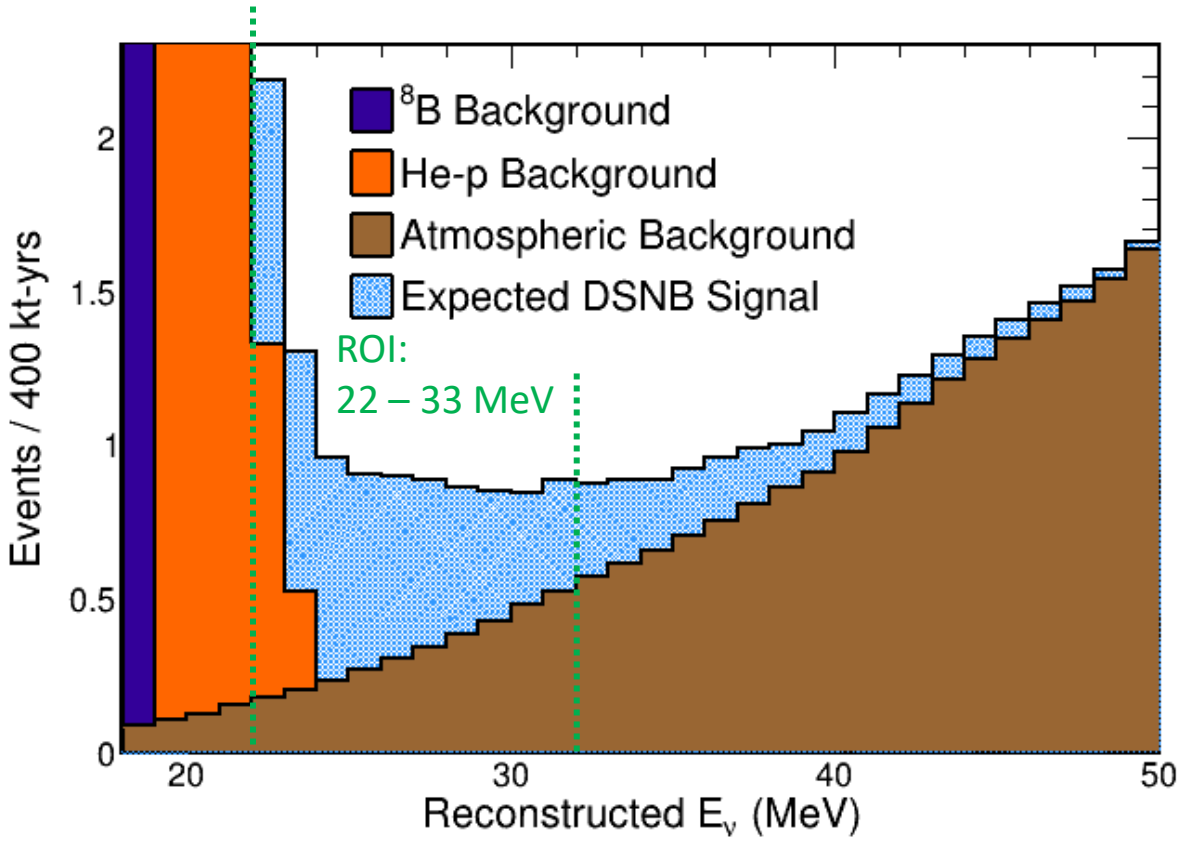
Last time: Expected DSNB spectra

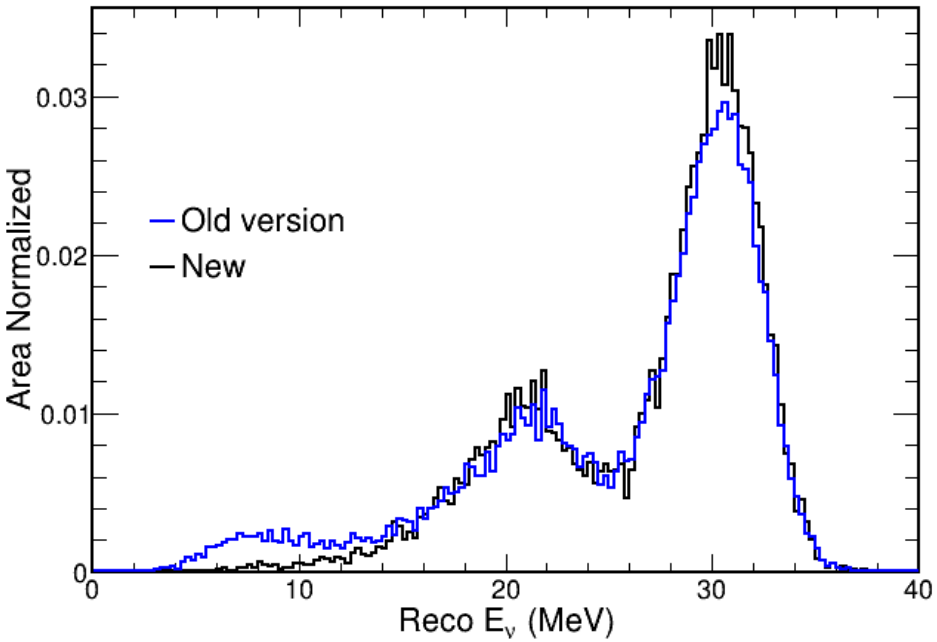
- With semi-realistic reconstruction, it looks like we have about 2.5σ sensitivity to DSNB after 10 years
- Event rate meager after 400 kt-yrs
- Quick-and-dirty analysis: single-bin fit with s/sqrt(b) optimization:
  - 22 < Enu < 33 MeV
  - 6.05 DSNB / 5.4 bkg
  - About 1 guaranteed SN event / 2 yrs



- For today, updated with full Marley/LArSoft simulation and reconstruction

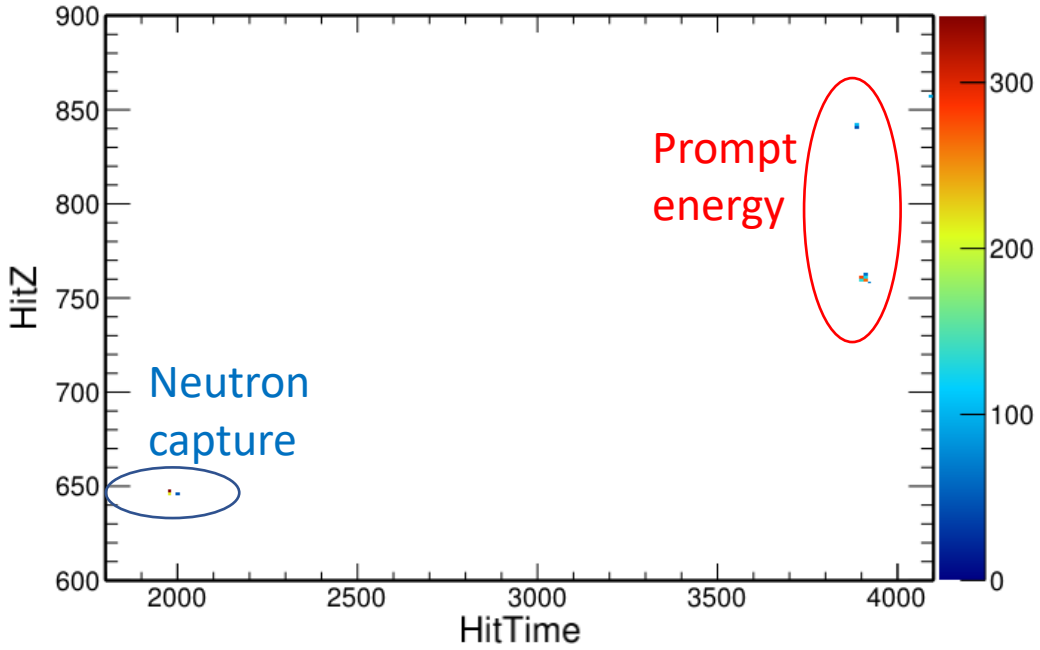
Updated reconstruction performance

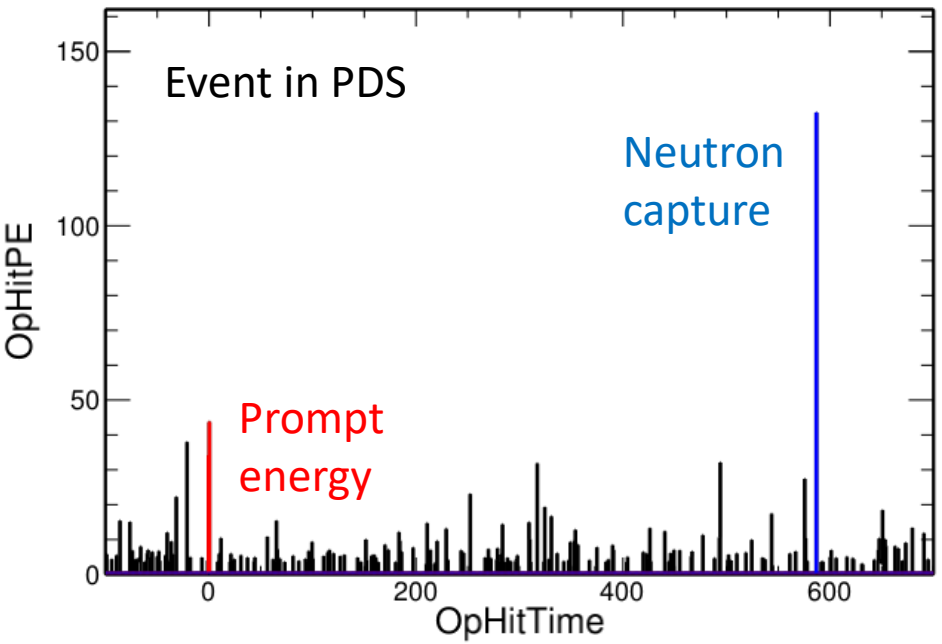
- Previously, when plotting the reconstructed energy distribution for a given true energy, there was a troubling bump at low energy
  - All come from events with more than one energy deposit that would trigger my selection
  - Turns out, these events are neutron captures
  - Neutron captures can travel far enough away from the prompt energy to not get grouped in
  - Can remove these by just taking the most energetic thing that is big enough to pass cuts



Catching neutrons in CC events

- DUNE can see neutron captures, so this is in principle a thing we could look for
- Would be very helpful in the event of a supernova – could alleviate the "physics resolution" from interaction model
- Example 25 MeV (17 MeV prompt) event with a neutron capture visible in TPC and PDS
- Would be interesting to look for these captures and figure out what efficiency we could expect
  - Mostly comes down to capture containment?
  - Pileup effects? Or are events spaced out enough?

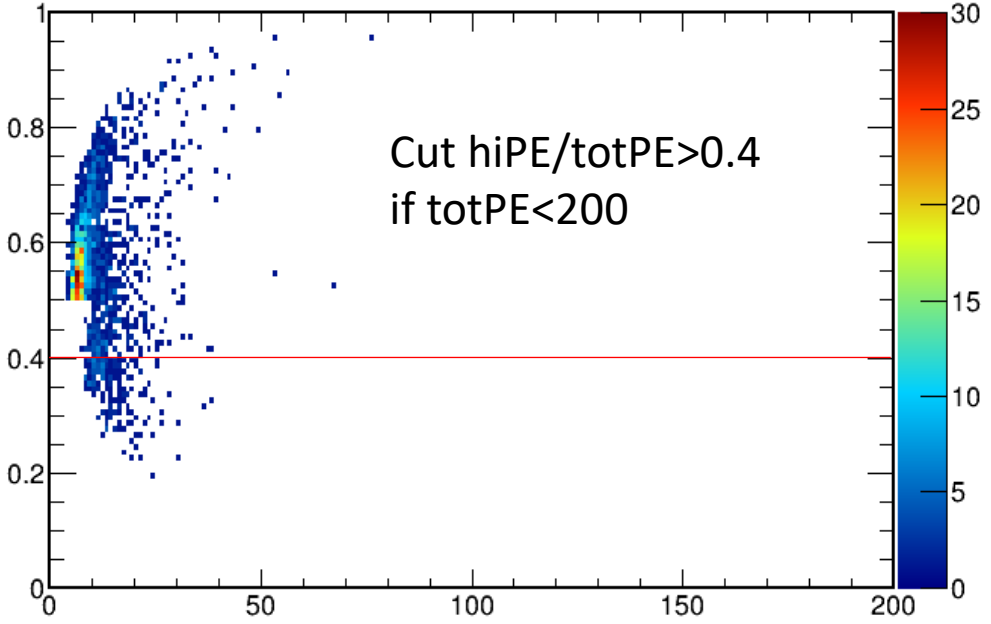




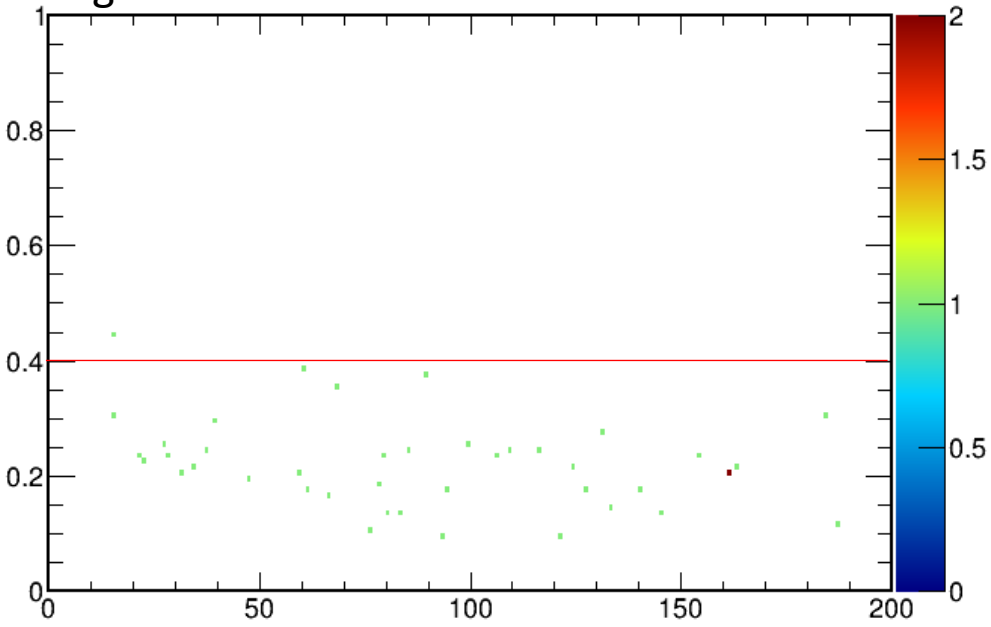
Updates to OpFlash matching: Simple topology info in the PDS

- When we see a low-PE flash from a neutrino, that implies that the neutrino scattered far away from the APA, and likely hit several photodetectors
- Background flashes are made by much lower energy physics activity, near APA's, and so most of the energy is deposited on a single PD
  - Look at the fraction of flash energy carried by the largest single hit as a selector
  - Reduces background flash rate by 27x while only removing about 1% of Marley flashes

Background flashes

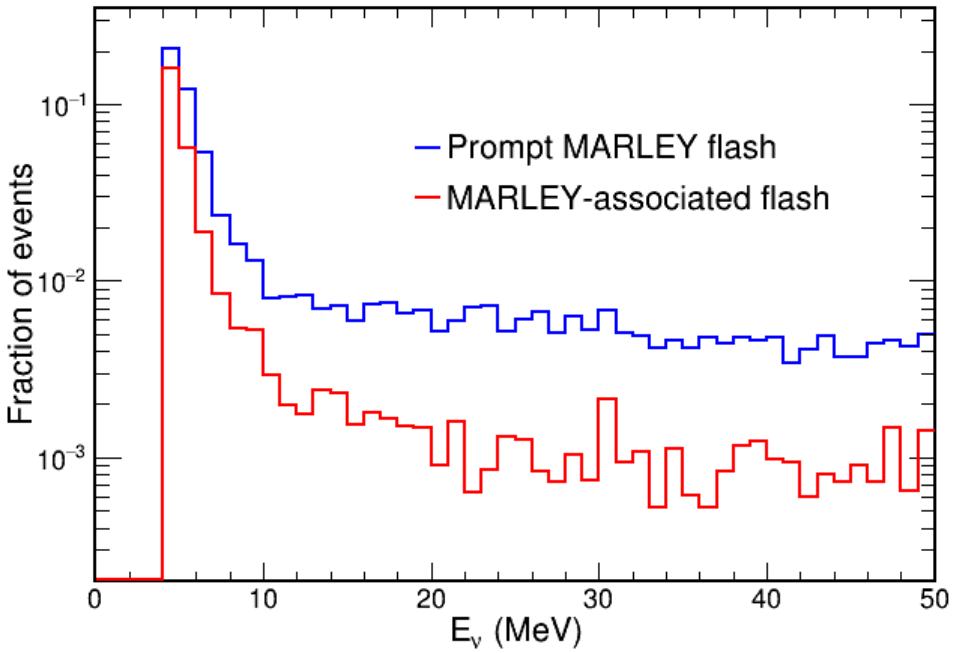


Signal flashes



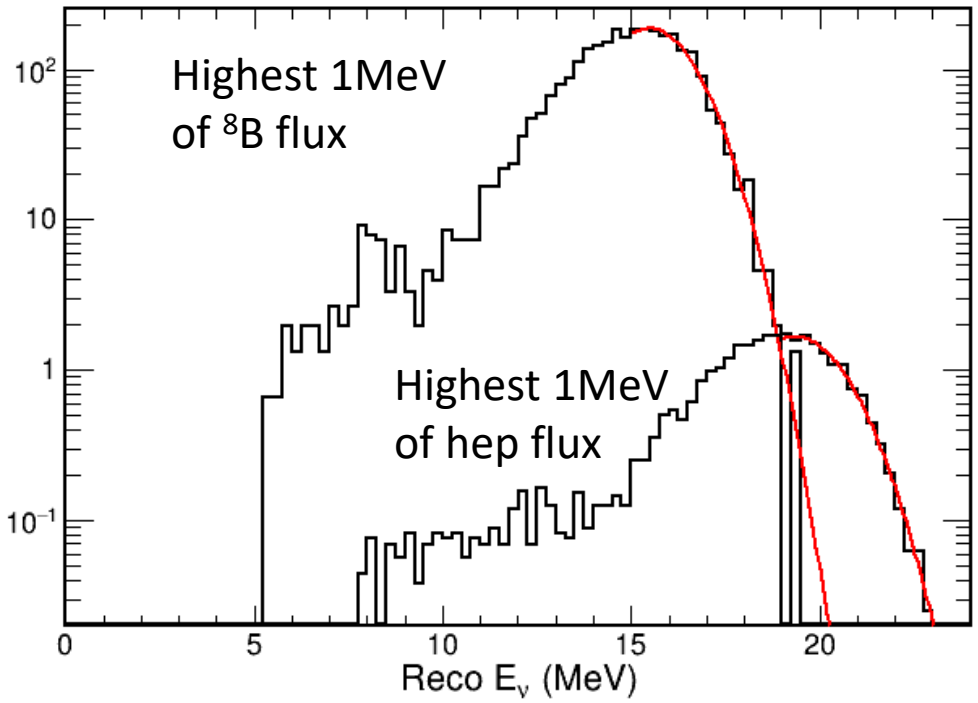
Improved flash matching

- The OpFlash selection criteria are much better at rejecting accidental radiologicals
  - Previously ≈3% of tagged solar events had an opflash not associated with MARLEY, now on the order of 0.1%
- Interestingly, about 0.6% of events have a flash associated with MARLEY, but not from the prompt neutrino energy
- Likely picking up neutron capture flashes



Event reconstruction for solar neutrinos

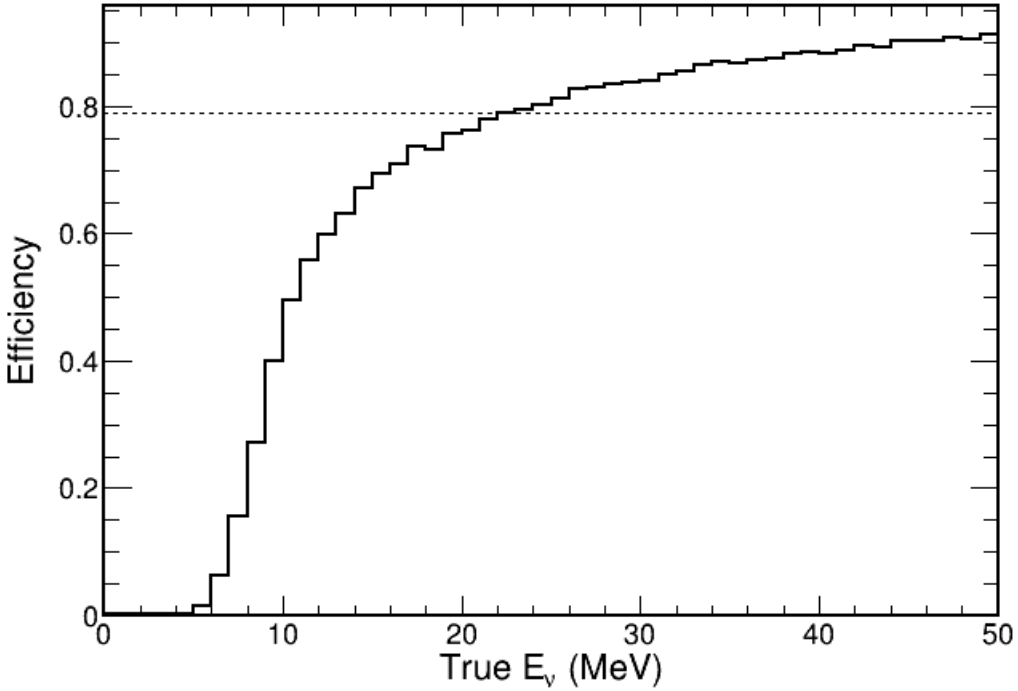
- There is some non-trivial non-Gaussian behavior below the mean, but above the mean, things distributions agree very well with a Gaussian
  - Great! DSNB wouldn't really work if there were spurious events that got reconstructed much higher than their true energy



Plotting efficiency

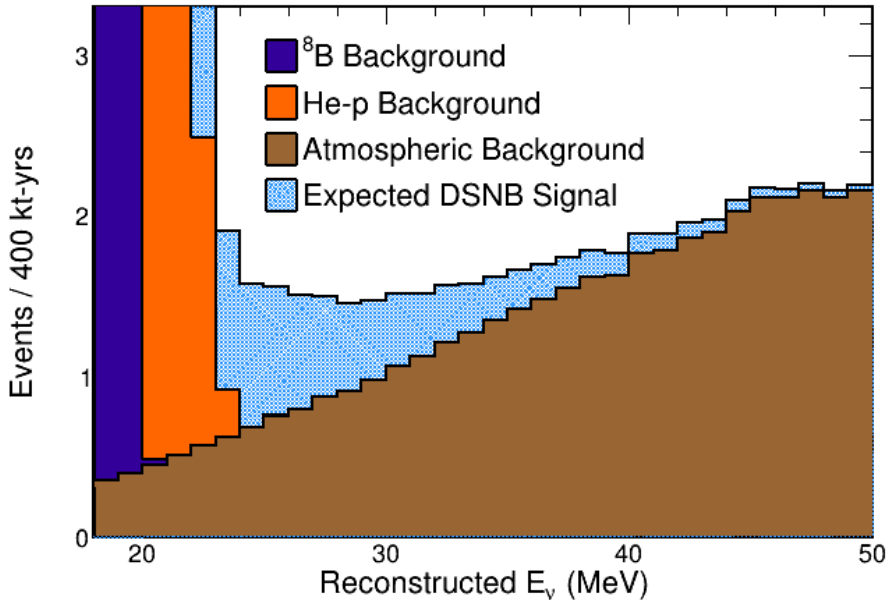
- Assuming a 20-cm veto region for fiducial cuts, I come up with a total active mass of 12.64 kt for a single SP module
  - Need 79.1% efficiency so efficiency-weighted fiducial mass is > 10 kt

- In last talk, assumed eff = 100% and fiducial volume is 10 kt
  - So, we're beating out event rate from last time if curve is over dashed line on this plot

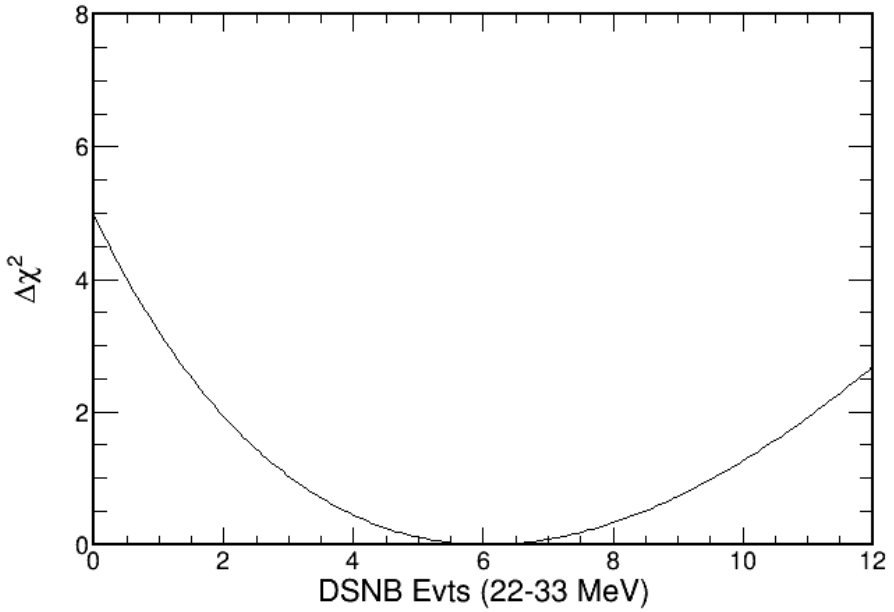


Pushing full reco to DSNB predictions

- Looks pretty similar to last plot except – the atmospheric background much more prominent

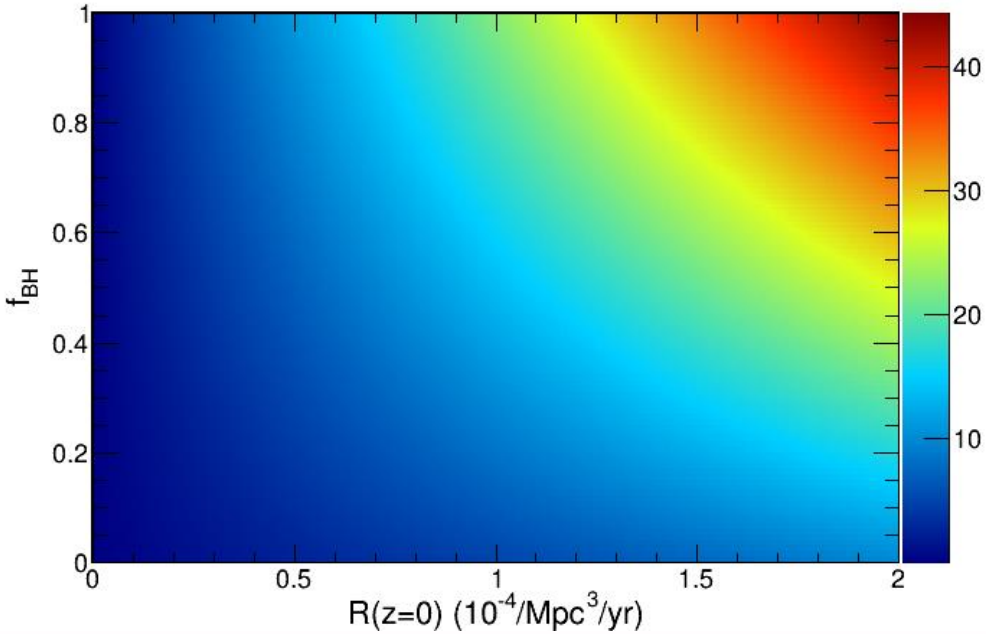


- Makes it harder for DUNE to see DSNB, but not a huge effect – still can see events, but only at a couple sigma
- dchisq 6.8 -> 4.9

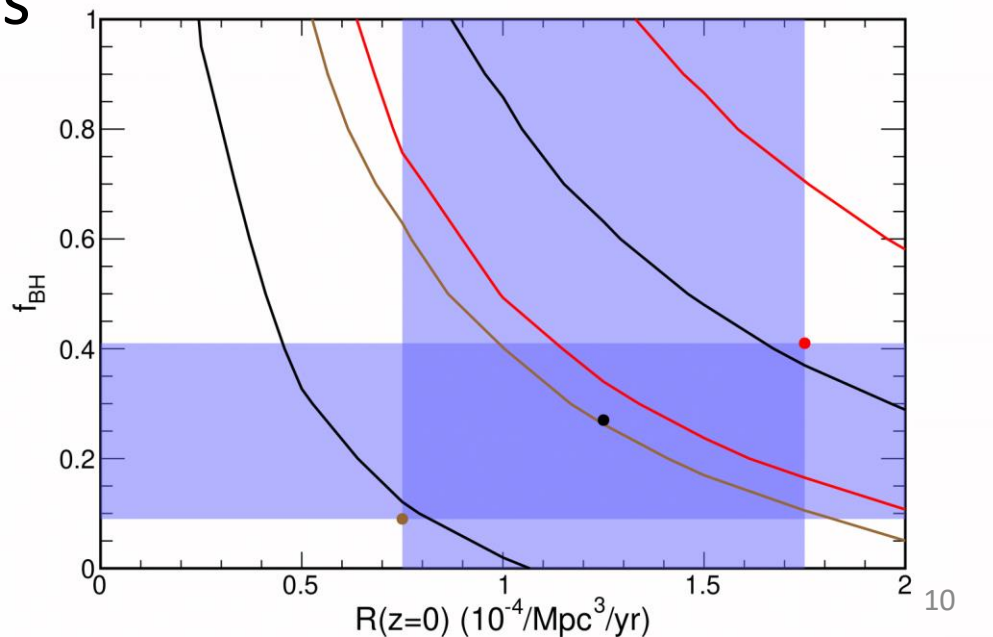


DSNB fitting

- DSNB flux comes down to two physics parameters: the supernova density at z = 0 and the fraction of supernovae that form black holes
- The DUNE region of interest is generally too high in energy to capture neutron star events, so event rate depends strongly on both



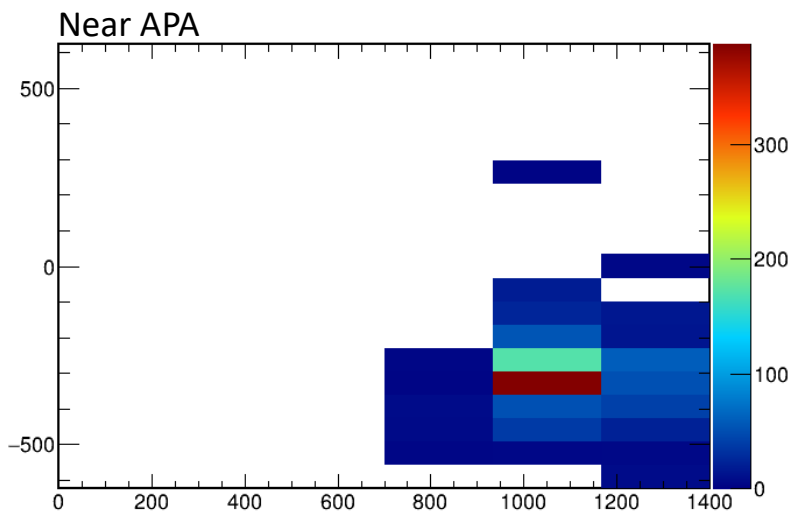
- Can do a likelihood fit to these model parameters given expected observed events (800 kt-yrs)
  - If true physical flux is in the middle of expectations, DUNE errors too big to really say anything
  - If flux is anomalously high or low, DUNE can limit some parameter space

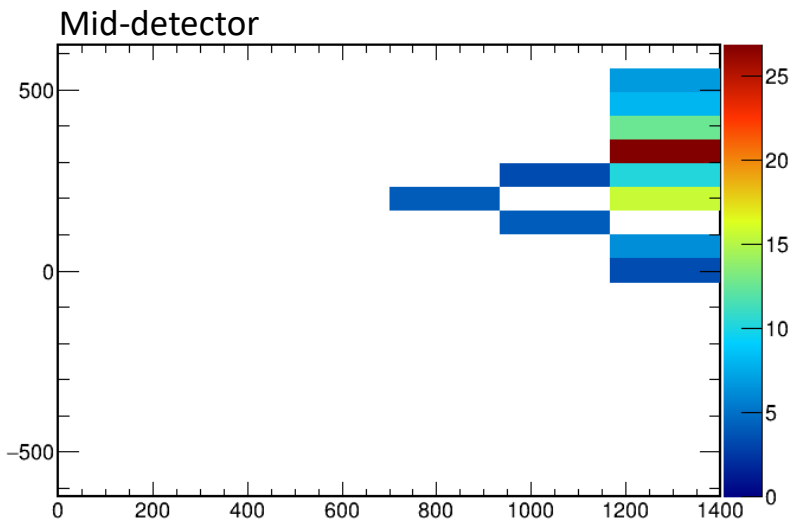


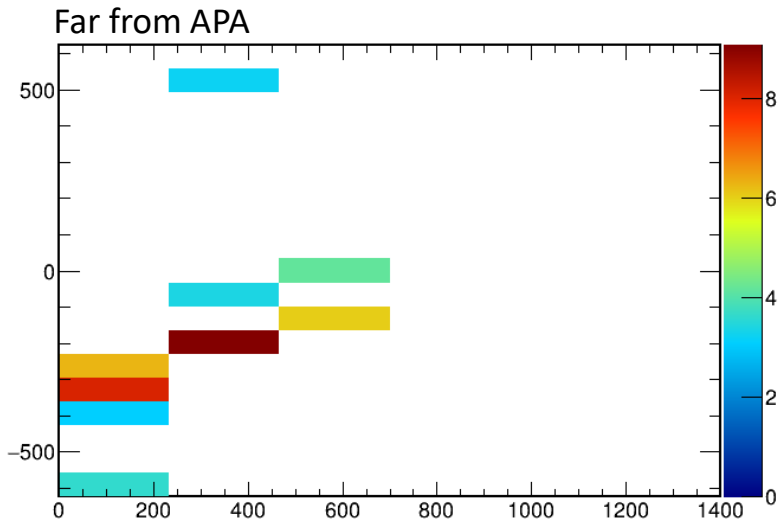
Aside: Fitting for 3D vertex with just PDS

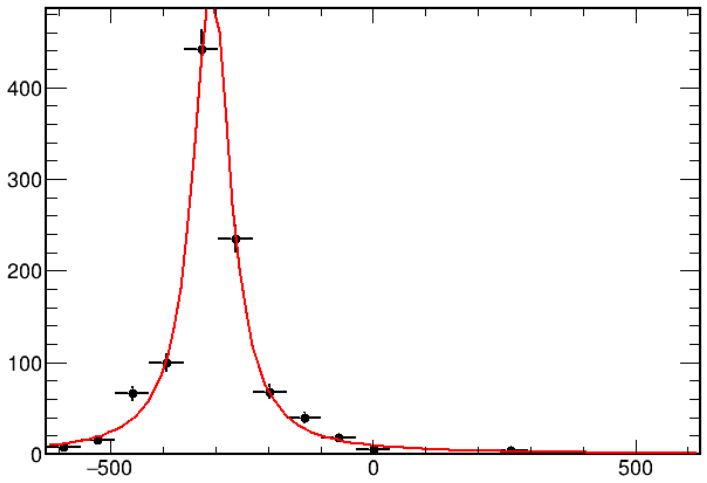
- Ignoring Rayleigh scattering, the observed number of PE on each photodetector should just scale like $1/r^2$
- If the true vertex is at (x0,y0,z0), then we get
  - $N_{PE} = A/[\ x0^2 + (y-y0)^2 + (z-z0)^2\ ]$
  - Depends on all three coordinates, in principle we can fit out full 3D vertex information with just the PDS
- Fitting observed PE in all photodetectors lets you
  - If x0 = 0, then $N_{PE} = A/[\ (y-y0)^2 + (z-z0)^2\ ]$ and the charge on each PD falls very quickly
    - Expect most charge to be collected in a single PD
  - If x0 >> spacing between PDs, $N_{PE} \approx A/x0^2$ and is independent of PD position
    - Expect several PD units to measure a small, roughly equal number of PE

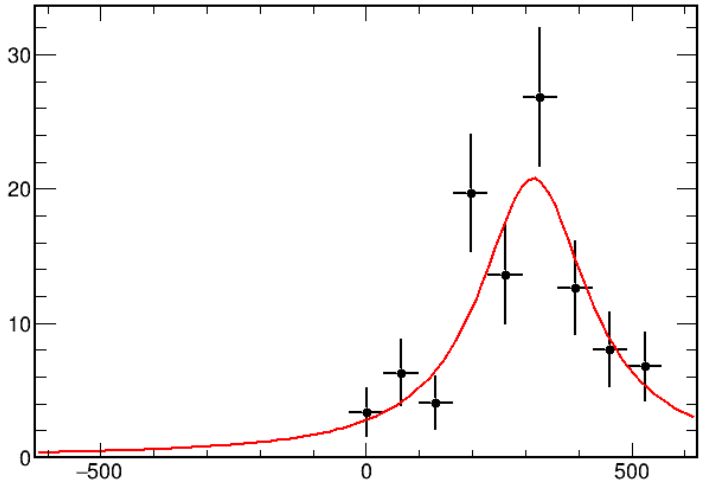
Example fits – 19.75 MeV neutrinos

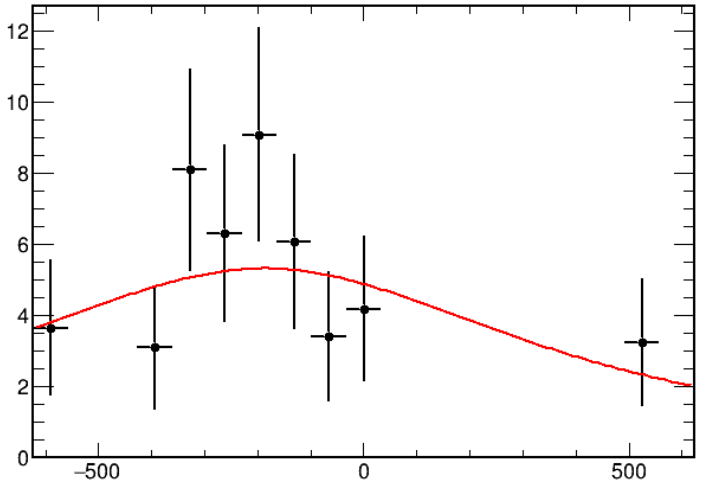












PE: 999.3
True: (28,-329,1130)
Reco: (42,-309,1131)

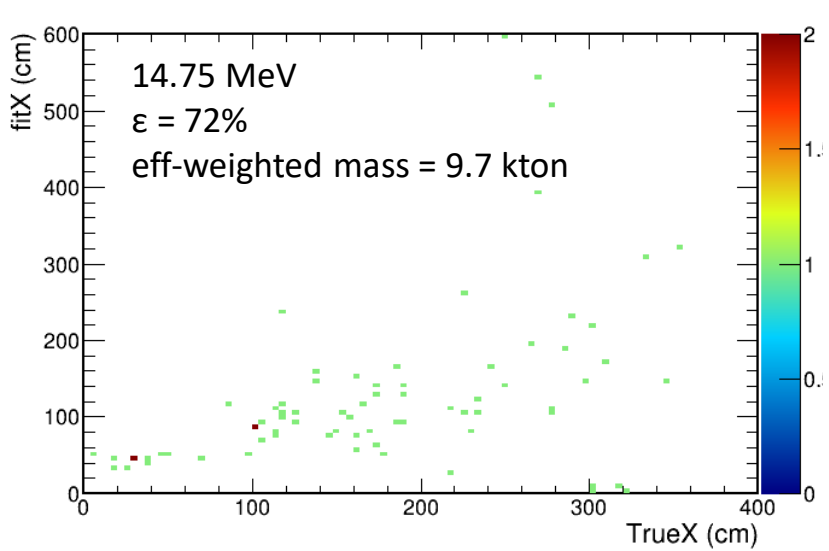
PE: 101.2
True: (167,323,1364)
Reco: (151,323,1443)

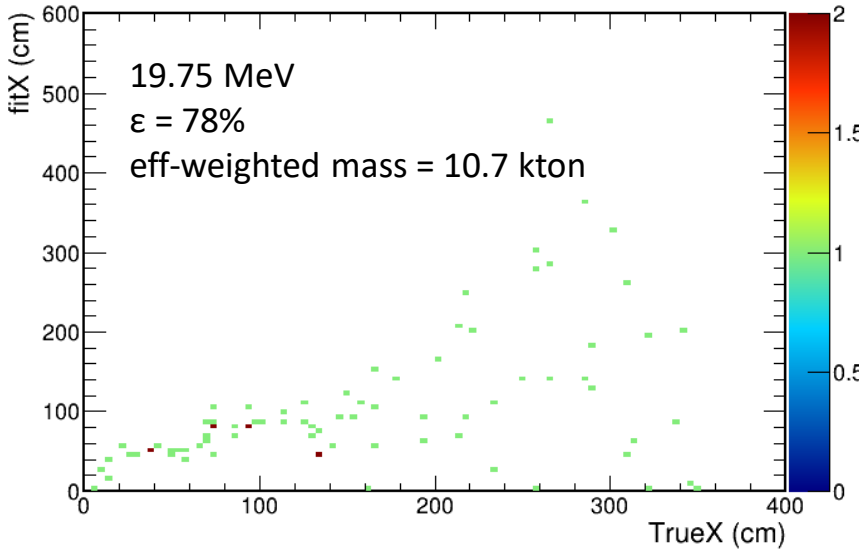
PE: 47.0
True: (324,-214,204)
Reco: (530,-189,164)

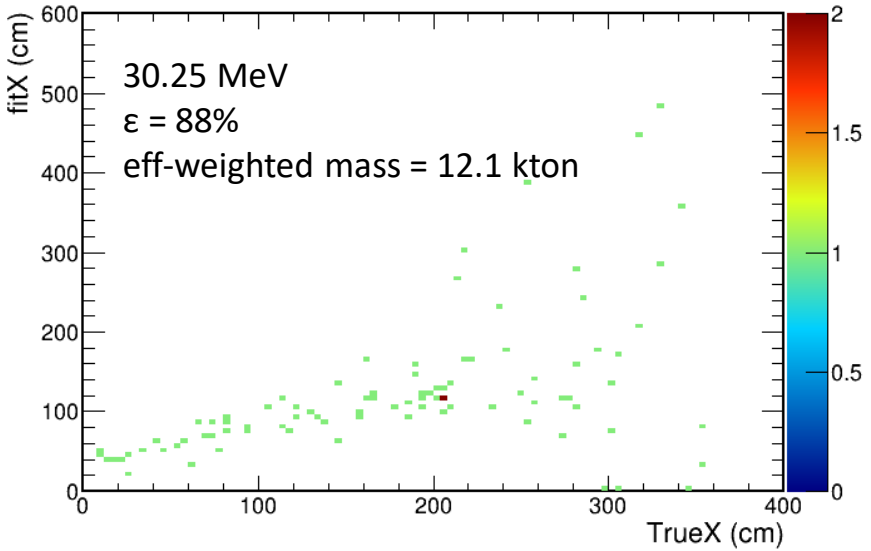
3D vertexing with PDS

- Run over small sample (100 events) at three different neutrino energies
- Look at the reconstructed vertices of every event, and look at how well we can reconstruct the x-component

- Scanned a few events with large true X, but low fit X, events are low PE, and concentrated in y-value, but fairly diffuse in z
  - 2D fit could improve reconstruction for these events







Summary

- Previously weary about applying solar reconstruction to DSNB-energy events
  - Weird behavior turned out to be a simple fix, just seeing neutron captures associated with MARLEY events
  - Also explains why we didn't see this problem at solar energies
- Some tweaks to the OpFlash matching which gets rate of associating TPC activity with non-MARLEY OpFlash to < 0.1%
- Full reconstruction shifts around predicted DSNB spectra and makes us slightly less competitive, but not enough that the measurement is not interesting