

Solar Neutrino Oscillation Fits

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From Last Time

□ We have a full-reconstruction sample of ν_e CC solar neutrinos with background estimates

- Background distributions smoothed by re-sim'ing different true interactions around the detector

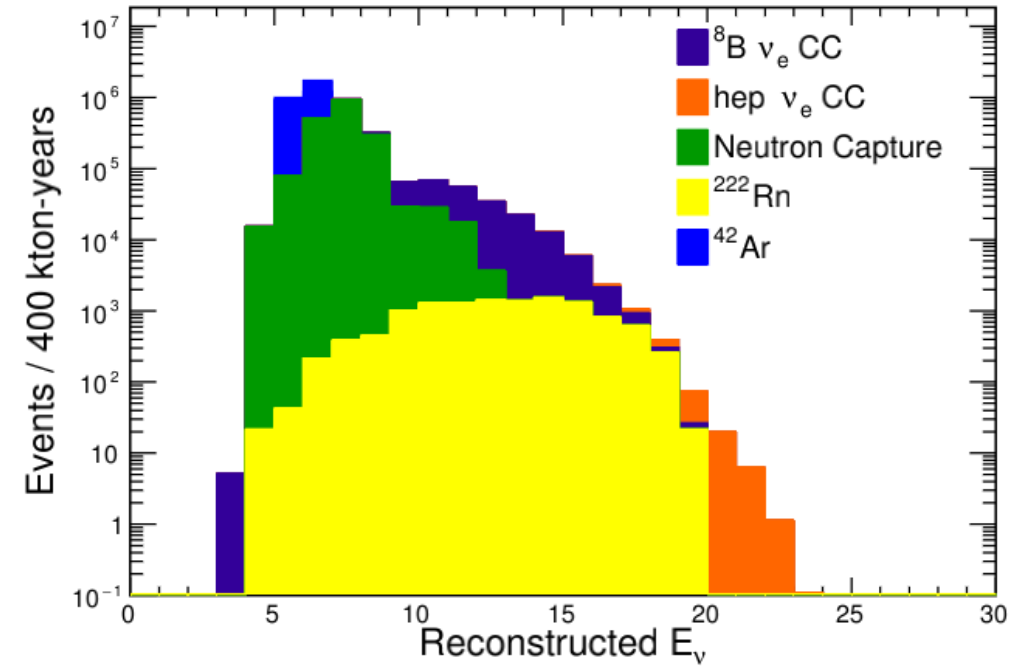
□ Have estimated very preliminary systematic uncertainties on backgrounds

- 1% on neutrons – chosen to be small due to in-situ constraints from our neutron calib
- 5% on $^{40}\text{Ar}(\alpha,\gamma)$ – chosen by possible stats available to an ancillary measurement

□ From here, it's relatively easy to modify the ν_e survival probability and draw some preliminary contours on oscillation parameters

- Today's topic

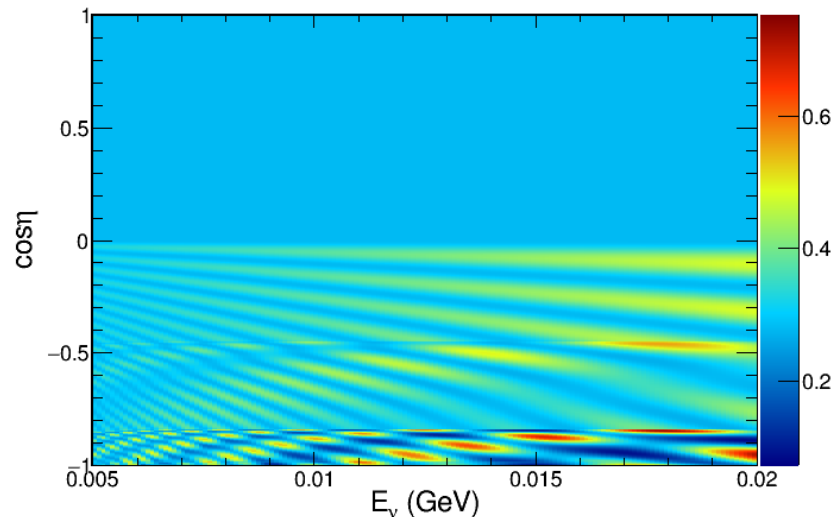
□ Next step would be to work on ν -e scattering sample and incorporate into fit



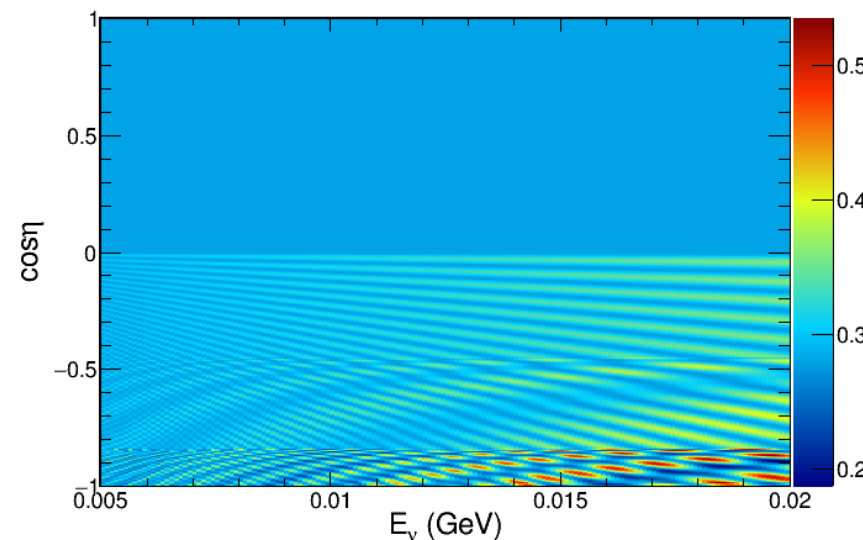
Incorporating Prob3++

- ❑ 3-flavor software Super-K uses to calculate atmospheric oscillation probabilities
 - Can also propagate neutrinos in a mass eigenstate \rightarrow for solar neutrinos
 - Depends on neutrino energy and nadir angle
- ❑ Need something more accurate at low energy to account for non-resonant MSW effects
 - But, slope in probability is not super visible in DUNE above a 9 MeV threshold, so initial sensitivity studies should be interesting with Prob3++
 - But, plan to move to better probability calculation in the future

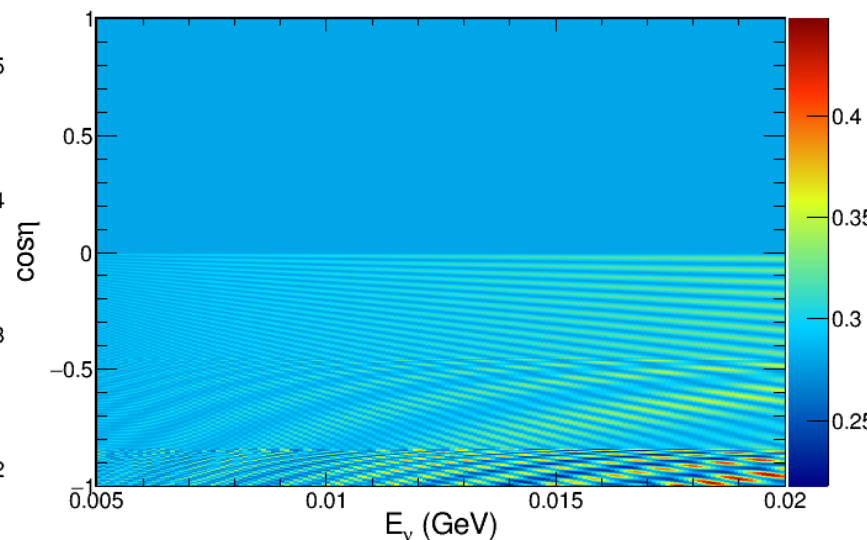
Low $\Delta m^2 = 2e-5 \text{ eV}^2$



Solar Best Fit



Reactor Best Fit



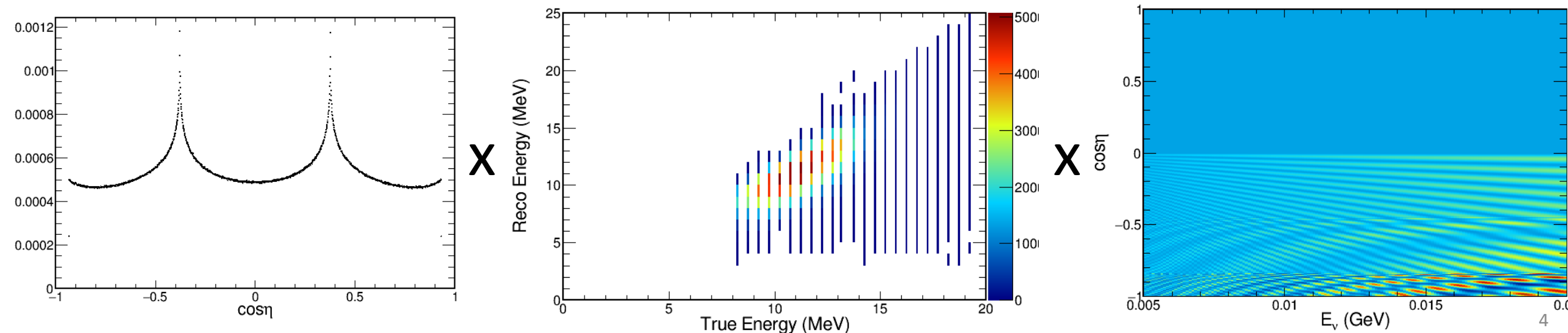
Convolving Osc Probability with Analysis Variables

❑ Survival probability depends on two variables – energy and nadir angle

- Also fit events in these two dimensions
- Plus, nadir angle is known with absolute precision from how planets move

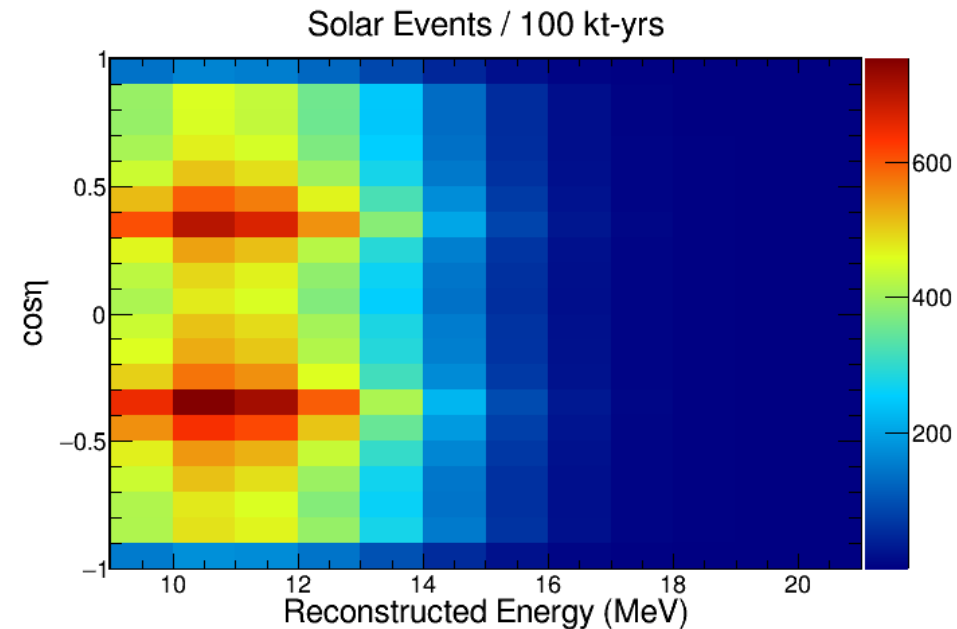
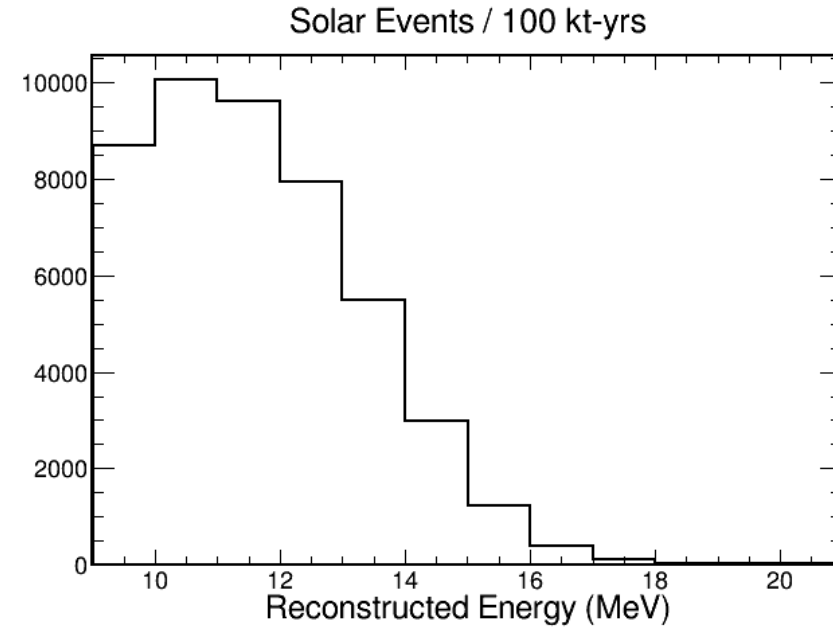
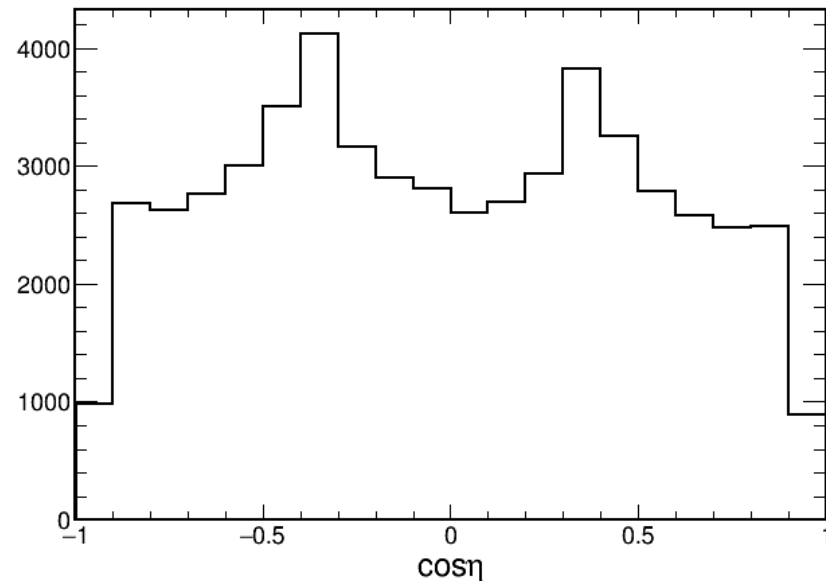
❑ Assume that efficiency and reconstruction independent of nadir angle, so we can convolve the migration matrix and nadir distribution

$$N(E_r, \eta) = \int_0^\infty dE_t \int_{\eta_0}^{\eta_1} d\hat{\eta} \times P(E_r | E_t) \times P(\hat{\eta}) \times p_s(E_t, \hat{\eta})$$

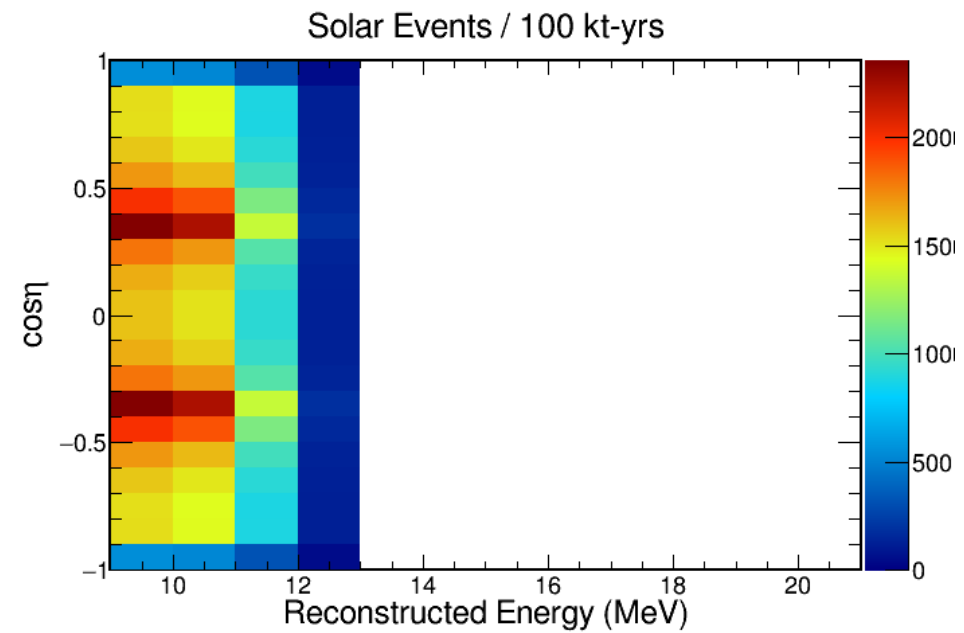
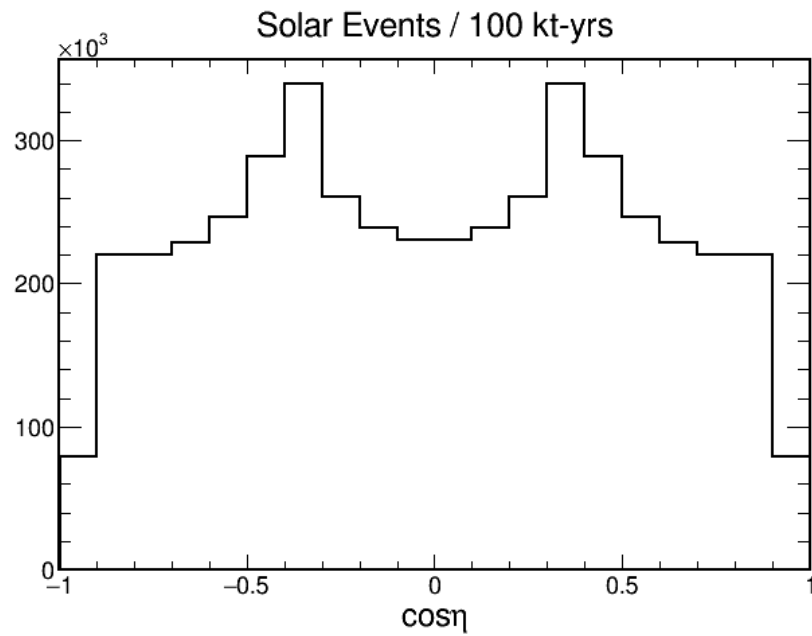
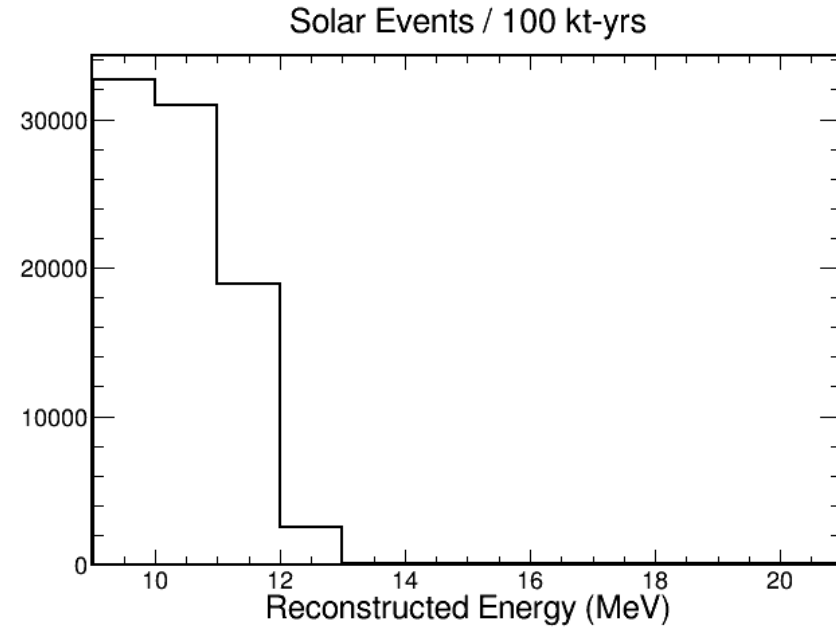


Signal Prediction

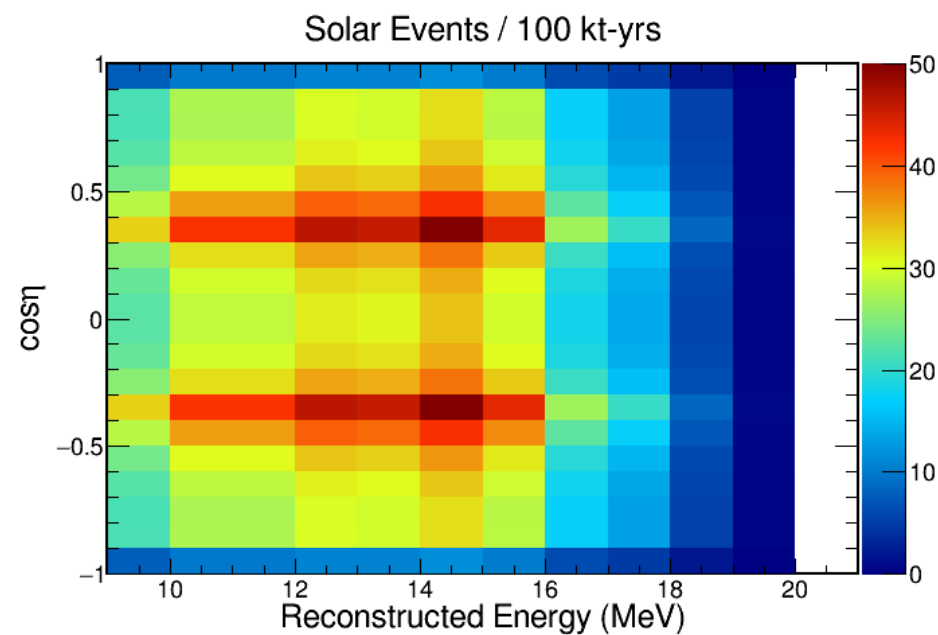
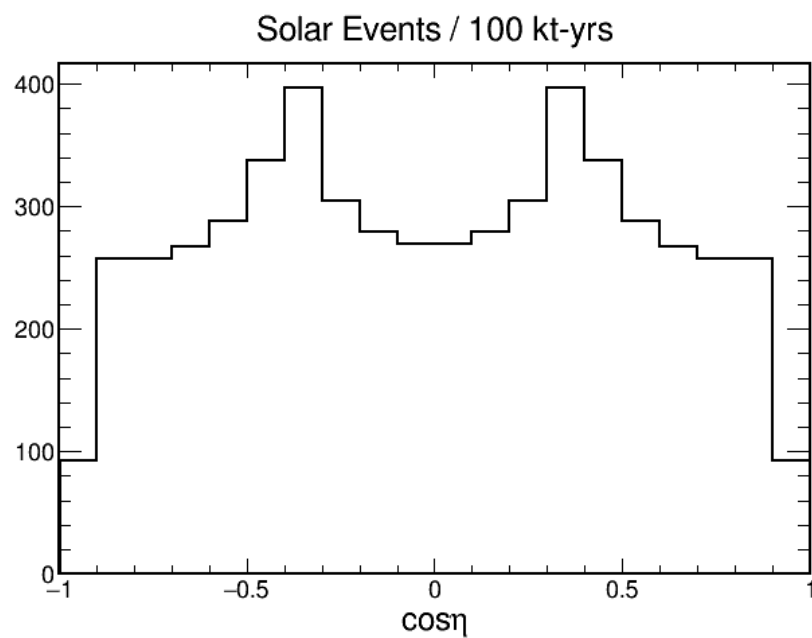
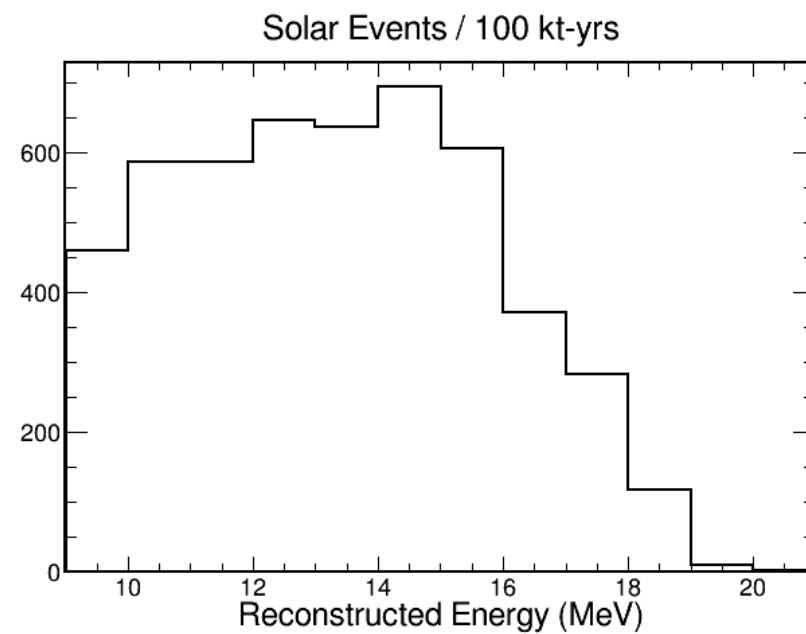
- Using the best fit to solar data
$$\Delta m_{21}^2 = 4.85 \times 10^{-5} \text{ eV}^2$$
$$\sin^2 \theta_{12} = 0.308$$
- 46655 evts / 100 kt-yrs
- 2032 event excess at night = 7.7%
 - 9.4σ (7.6σ with bkg)



Neutron Prediction



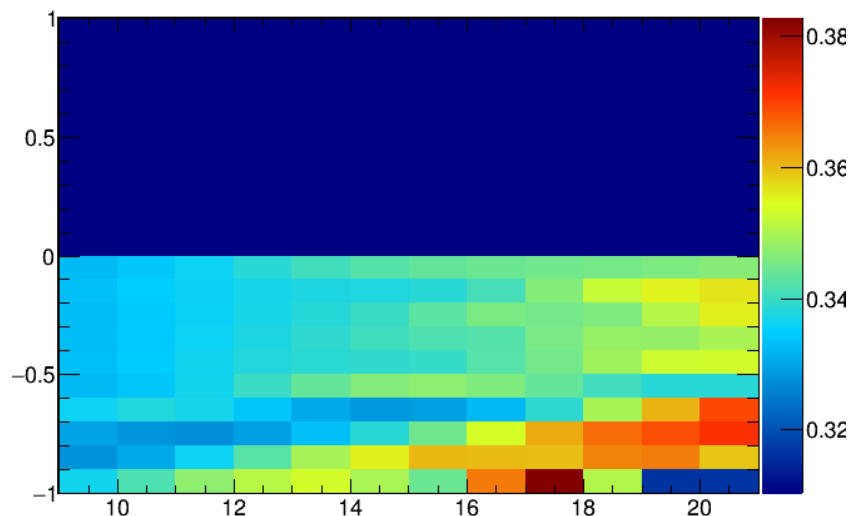
Radon Prediction



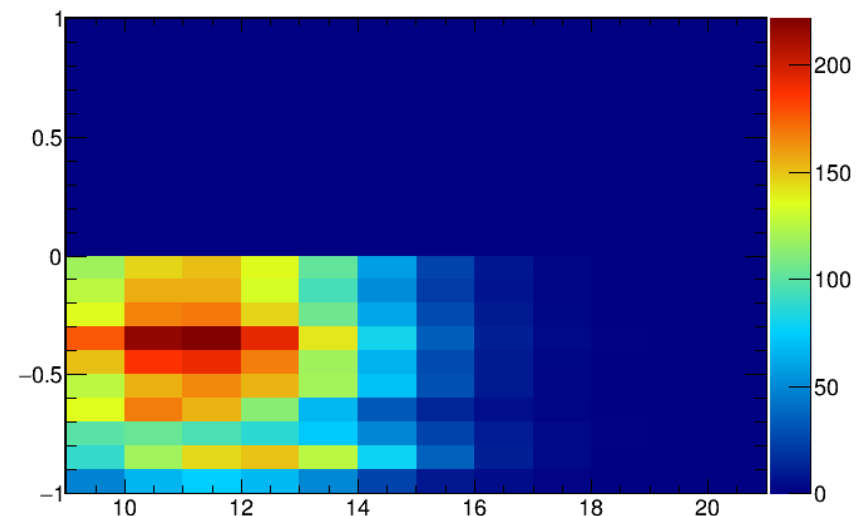
Can We See Wiggles?

- There are two main roadblocks – energy resolution and stat errors

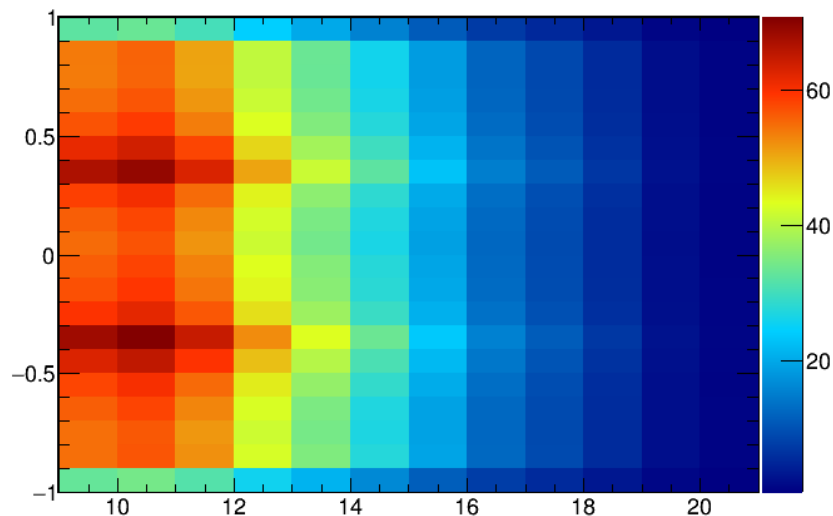
Calculate surv
probability
averaged over
each reco bin



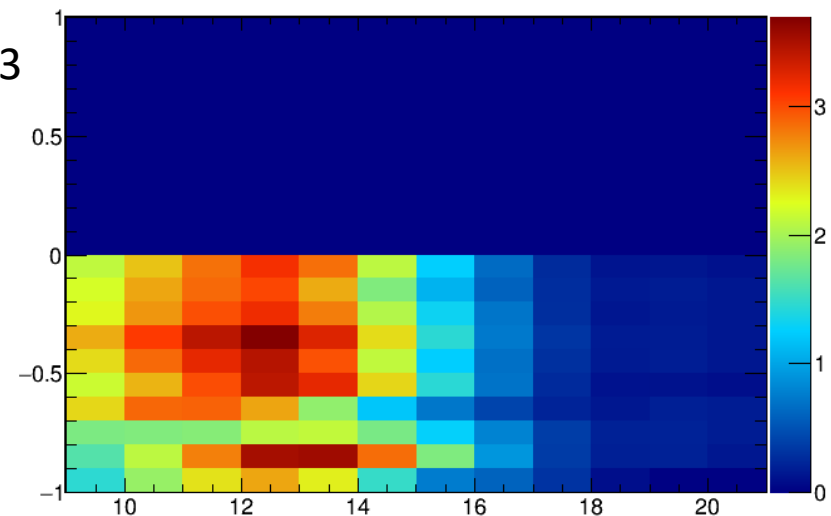
Multiply with
no-osc rates
and subtract
day prediction
to give night
excess in each
reco bin



Calculate the
stat error on
events in given
bin, including
error on
subtracting avg
day rate

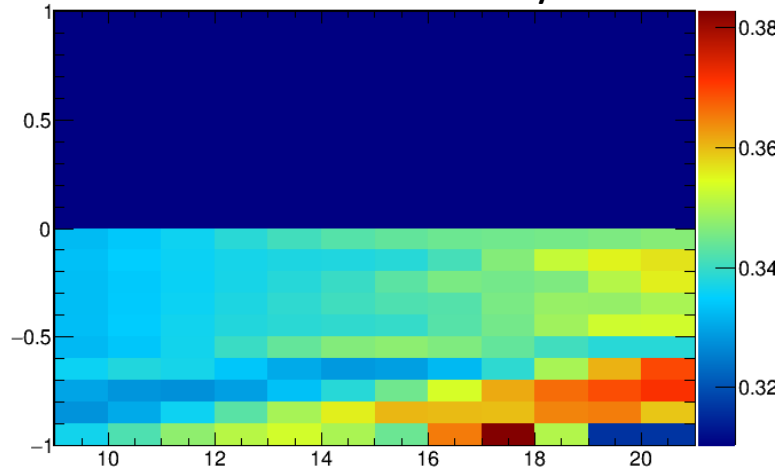


Divide hists 2+3
to get the bin-
by-bin stat
significance of
an excess over
the day
probability

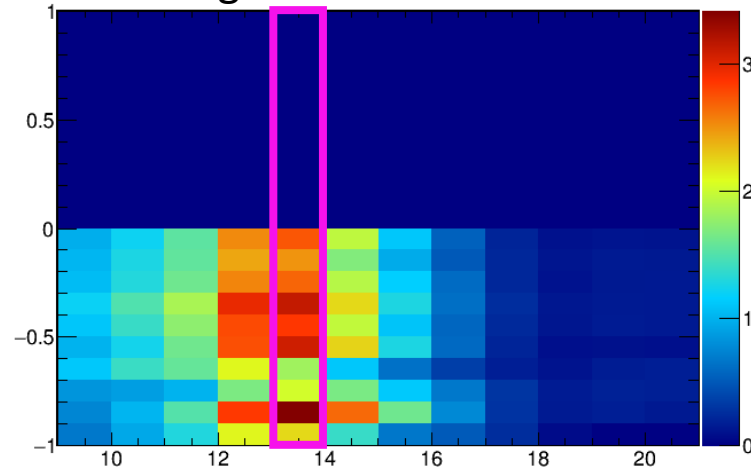


Outlook for Wiggles at Solar Best Fit

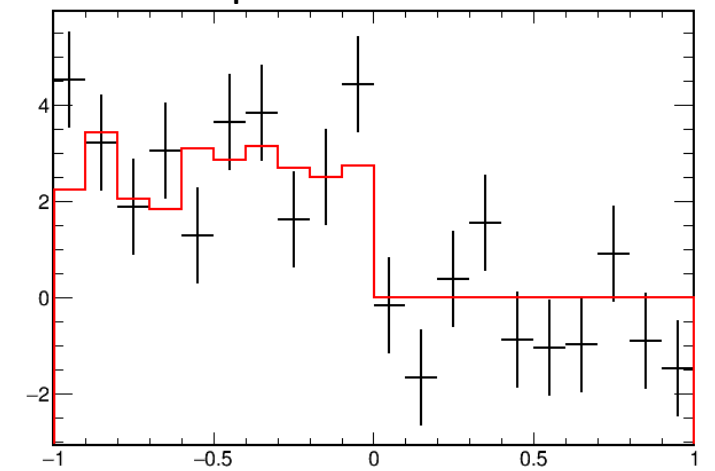
Survival Probability



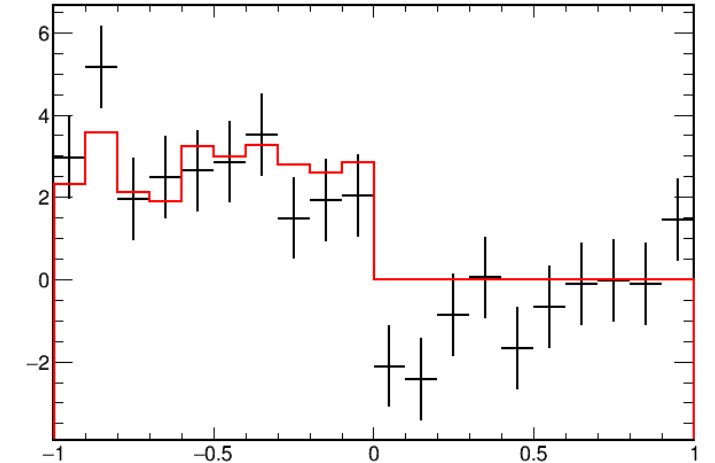
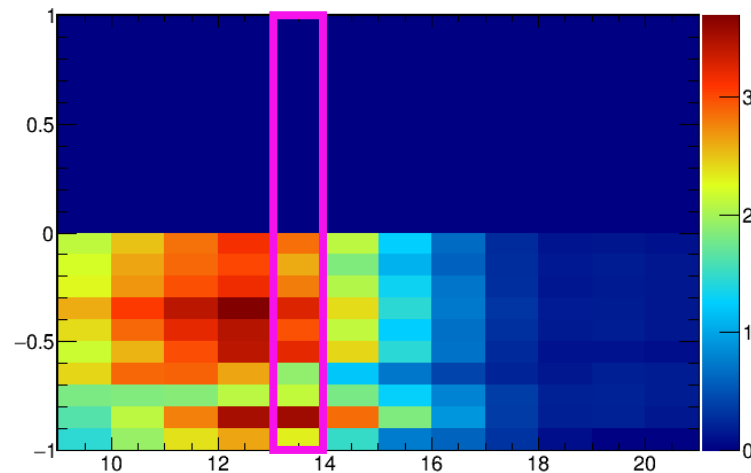
Significance of Excess



Example Data 13-14 MeV

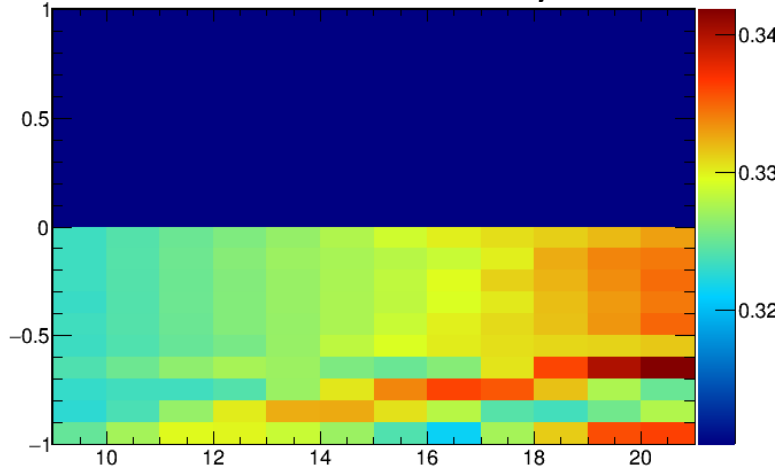


Or, if we can reduce backgrounds by 10x

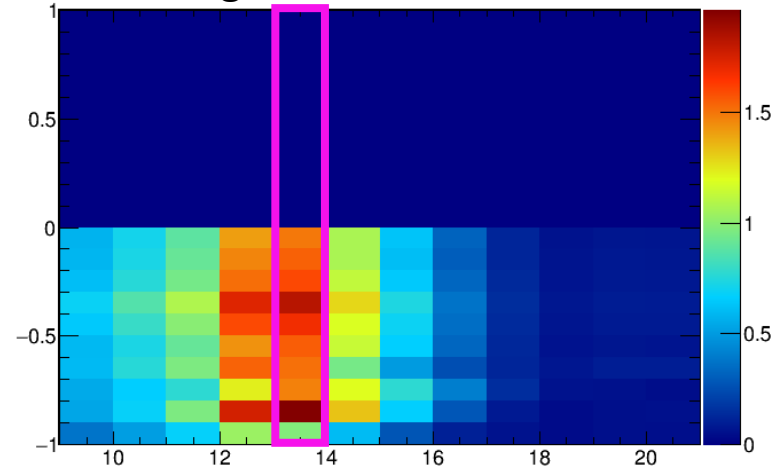


Outlook for Wiggles at Reactor Best Fit

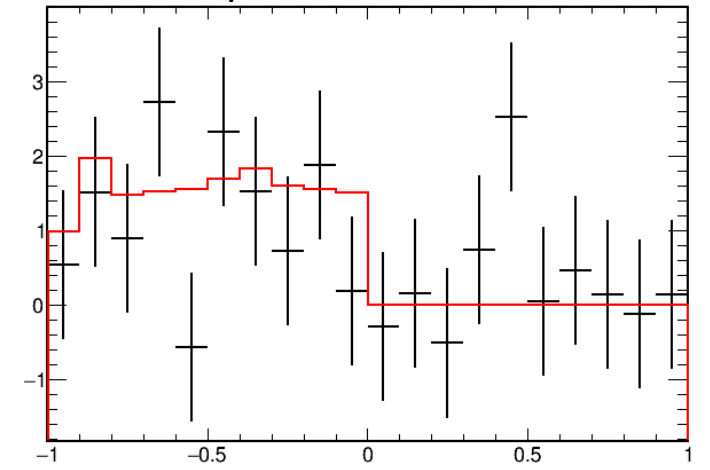
Survival Probability



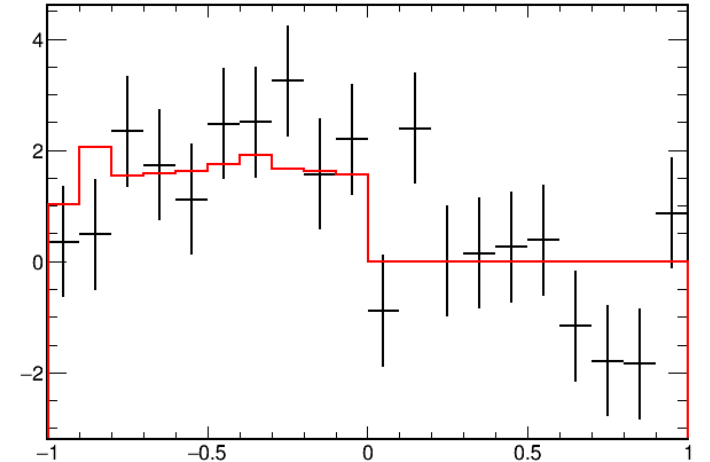
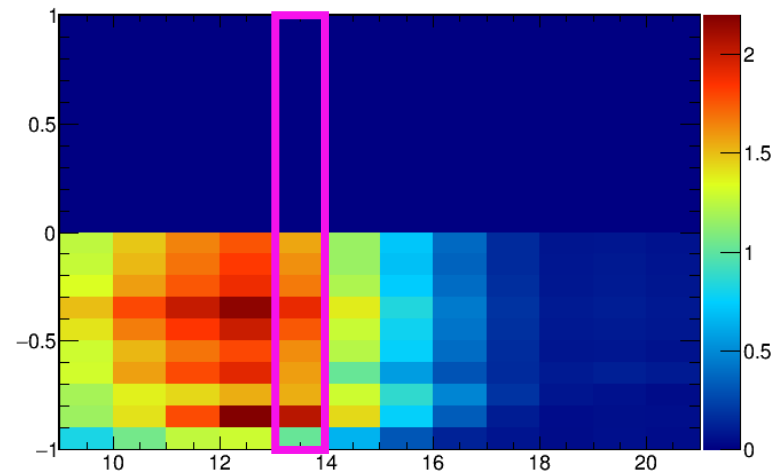
Significance of Excess



Example Data 13-14 MeV

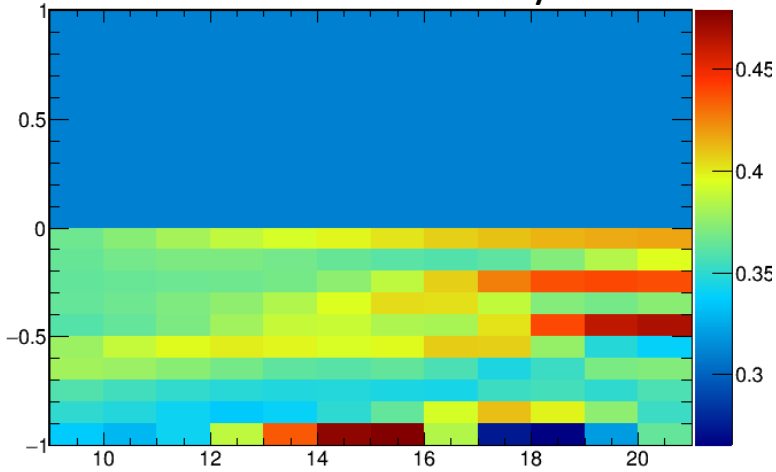


Or, if we can reduce backgrounds by 10x

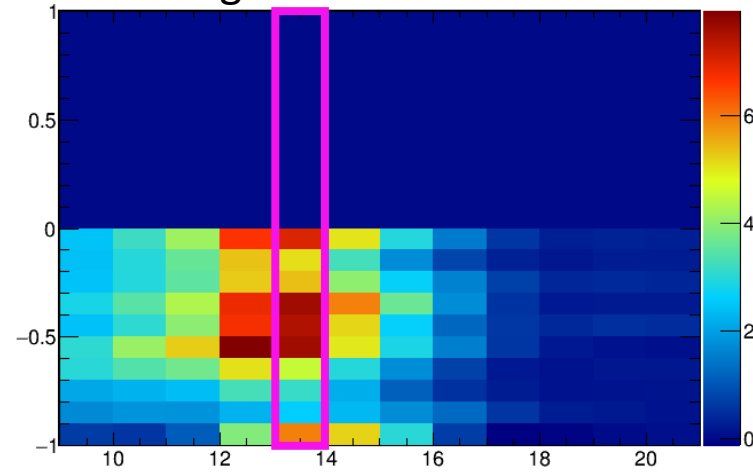


Outlook for Wiggles at $2e-5 \text{ eV}^2$

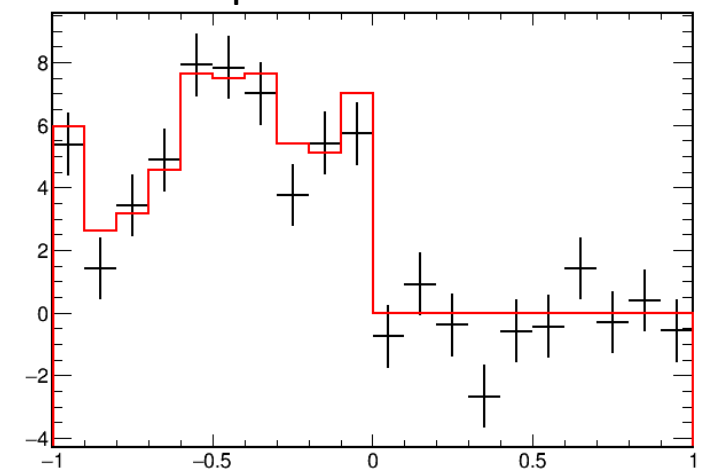
Survival Probability



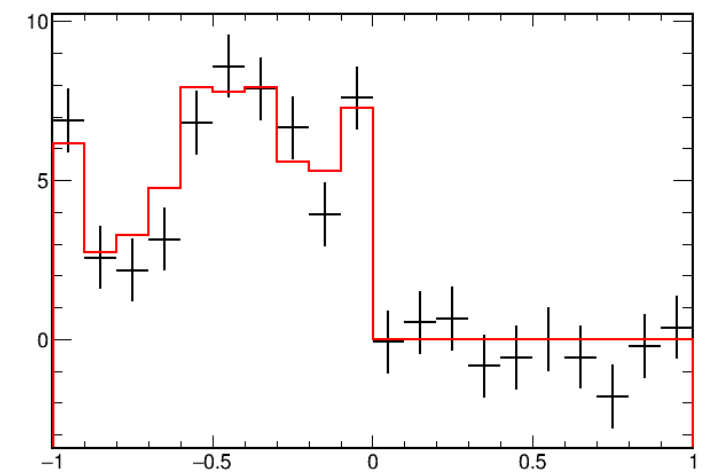
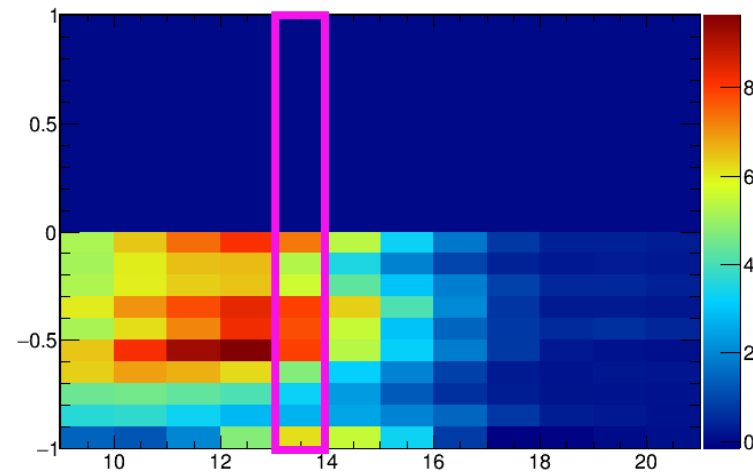
Significance of Excess



Example Data 13-14 MeV



Or, if we can reduce backgrounds by 10x



Fitting for Oscillation Parameters

□ All the pieces to draw contours are in play

- With what you've seen, is easy to calculate a $\Delta\chi^2$ map for these parameters
- Some bins have low event counts (down to 5), so fit uses Poisson logL formula
- Have done some fits for 400 kt-yr of exposure
- But it's slow... about 1 hour to make a single contour

□ Currently only using the ν_e CC sample

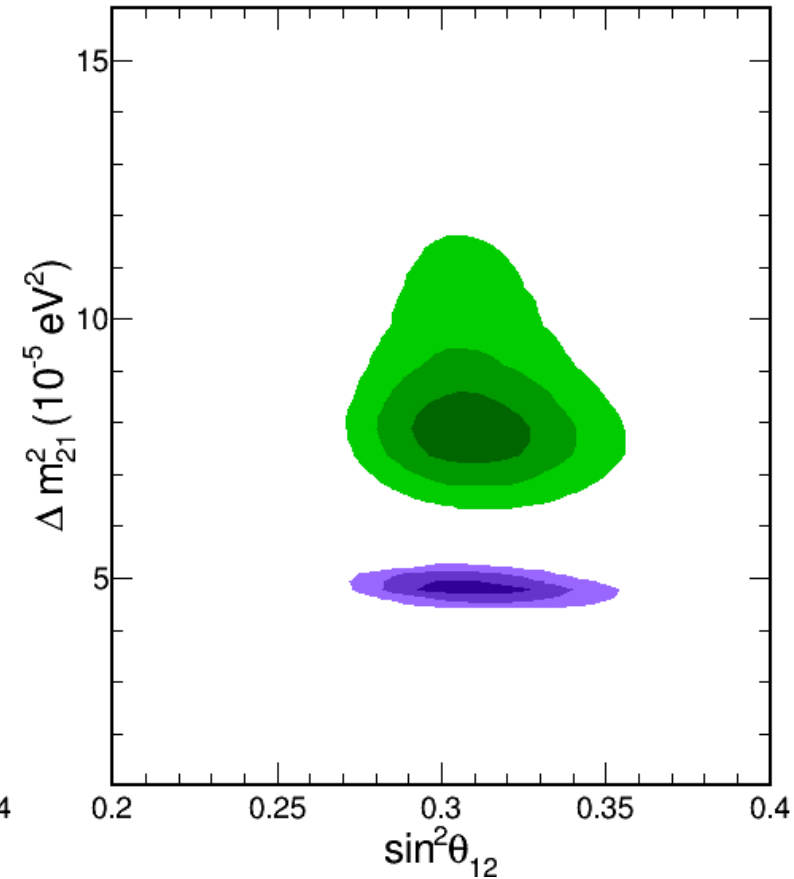
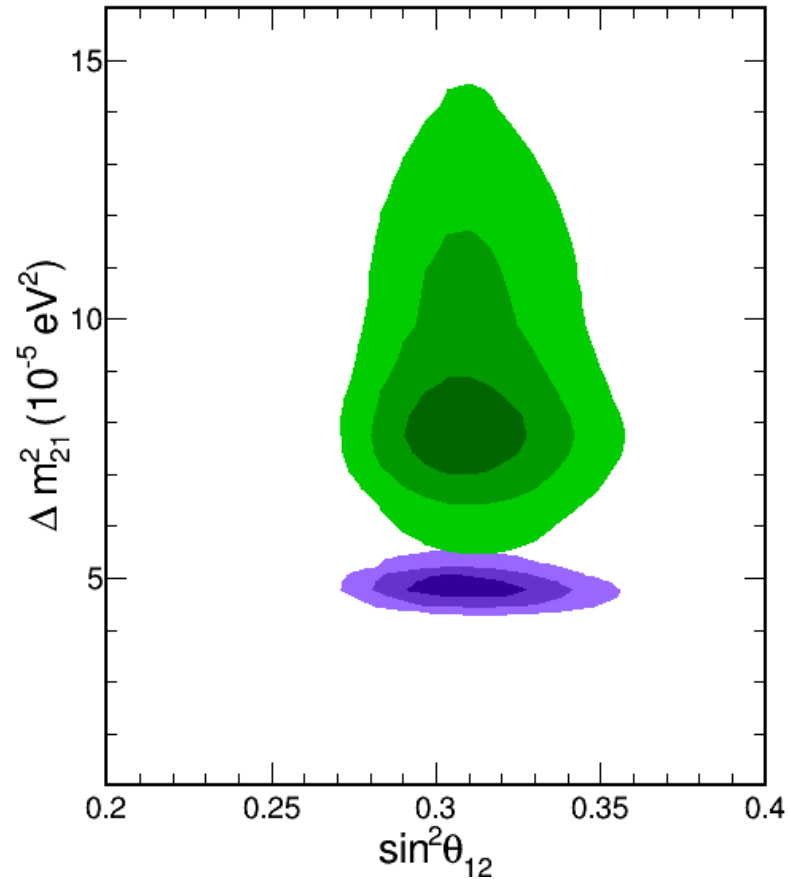
- Finding ν -e efficiency and backgrounds has notable priority
- Can't disambiguate $\sin^2\theta_{12}$ and $\varphi(^8\text{B})$ – instead bring in 4% prior uncertainty on solar flux and let the signal float within that pull
 - 4% from Beacom, reach of other solar experiments on determining that flux

□ Only account for two systematics – 5% uncertainty on $^{40}\text{Ar}(\alpha,\gamma)$ and 1% uncertainty on neutrons

- No shape uncertainties

Sensitivity to Parameter Space

- ❑ Solar analysis finally mature enough to make some sensitivity statements
- ❑ In both plots, green(purple) are the $1/2/3\sigma$ regions expected for true oscillation parameters at the reactor(solar) best fits
- ❑ Left / right plot shows expected sensitivity with nominal / 10% backgrounds
- ❑ Exposure = 400 kt-yrs

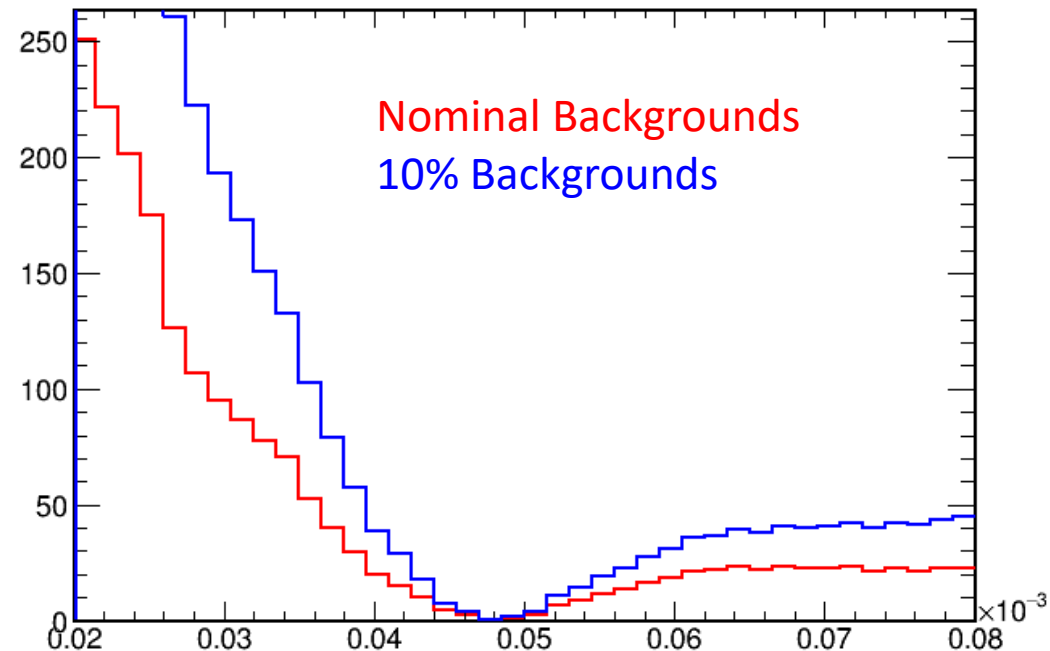


Solar / Reactor Best Fit Preference

- ❑ I feel like the most important number to stress is the significance that we would reject the solar(reactor) best fit points assuming true parameters at the reactor(solar) best fits
- ❑ Currently, there's a 2σ discrepancy in Δm^2 between solar/reactor experiments
- ❑ Pushing that up to $5+\sigma$ would present a genuine “problem”

Assuming solar best fit parameters, we reject the reactor best fit at $\Delta\chi^2 = 21.4 / 42.3$

Currently need some neutron reduction to Get 5σ



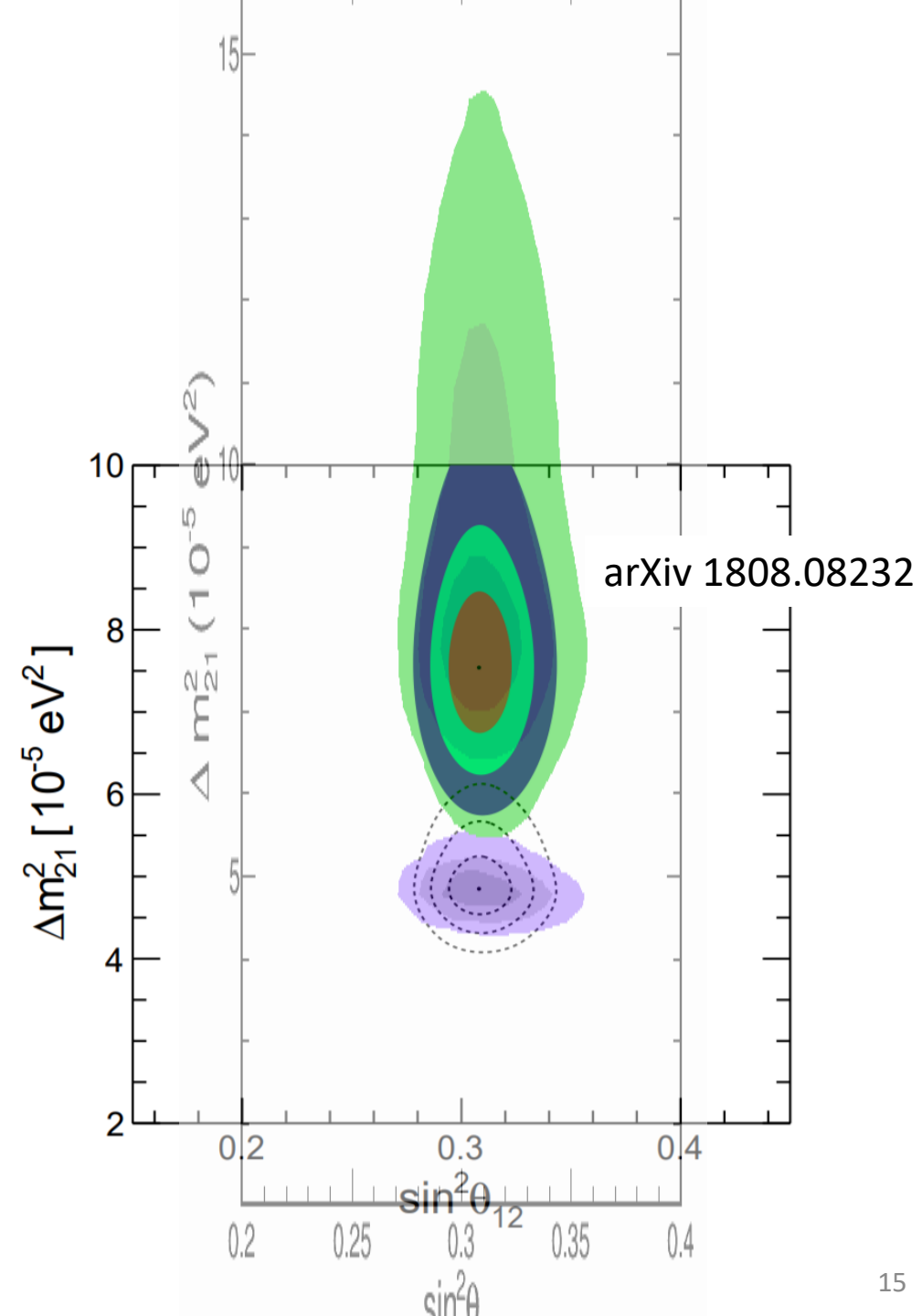
Sensitivity to Parameter Space

□ Our contours aren't better or worse, they're different

- Poorer determination of $\sin^2\theta_{12}$
- Notably more sensitive to Δm^2 than Beacom, but only at low values of Δm^2

□ My guess is wiggles are playing a role

- Wiggles aren't obvious outright, but still have non-trivial dips that pull on fit, isolating energy-nadir space where day-night asymmetry is highest
- Beacom fits Δm^2 using day/night asymmetry integrated over all nadir angles which washes the wiggle sensitivity out



Summary and Next Steps

- ❑ We have preliminary contours for solar oscillation parameters with full reco
 - With a prior constraint on $\sin^2\theta_{12}$
- ❑ Large backgrounds (primarily neutron capture on ^{36}Ar) significantly reduce our sensitivity
 - With(without) reducing backgrounds by 10x, we can rule out the reactor best fit at $\Delta\chi^2 = 42.3(21.4) \approx 6.51\sigma(4.62\sigma)$
 - Low-background sensitivity is almost exactly the sensitivity you'd have with 2x the data of full-background running
 - But this number depends on your systematic assumptions!
- ❑ Really want to build up a ν -e elastic scatters, and throw into fit the same way
 - Lifts degeneracy with flux, and would tie up DUNE's potential to fully determine PMNS
- ❑ What does a more realistic neutron systematic look like?
- ❑ How well do we need to know $\sigma(^{40}\text{Ar}(\alpha,\gamma))$ – study informs precision for ancillary measurement
- ❑ Cross section and det. response syts would affect $\sin^2\theta_{12}$ determination