Summary of Supernova T0 Studies

Erin Conley

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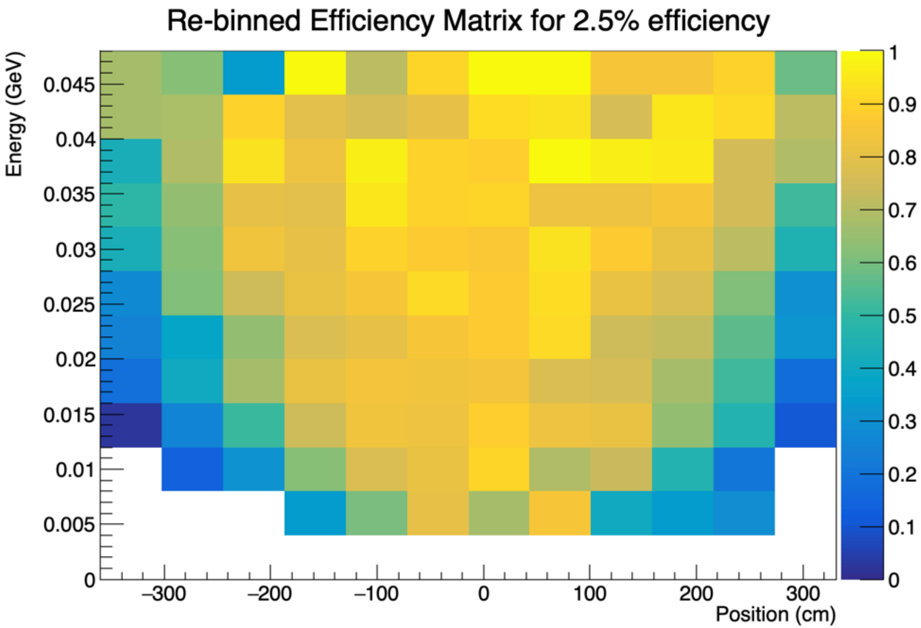
SNB/LE Working Group Meeting

Outline

- Introduction
  - Toy corrections
  - Factional difference from true neutrino energy
- T0 Studies:
  - Intrinsic resolution
  - Fraction of events in the largest peak
  - Studying the secondary peak (neutron emission)
- Summary

Introduction

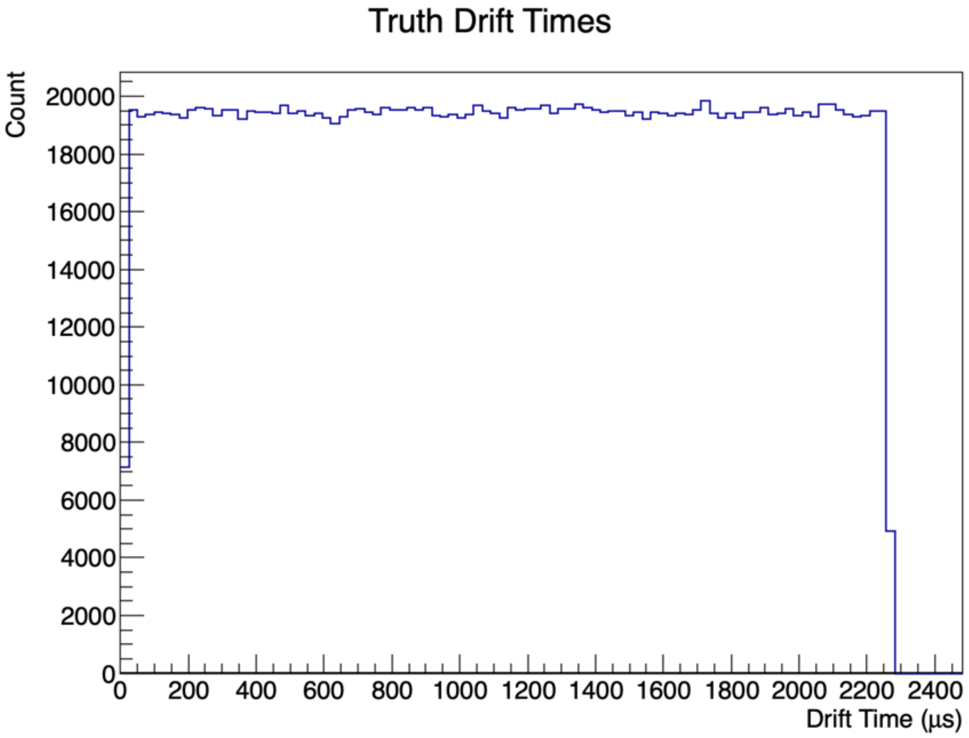
- Toy drift correction scheme to understand effects of PD system on supernova events
  - Use efficiency matrices corresponding to different PD performances
  - Studying energy resolution in MARLEY MCC11 clean events



Example efficiency matrix corresponding to 2.5% ARAPUCA; color scale represents probability of successful flash matching

Toy Drift Correction Scheme: “Random T0”

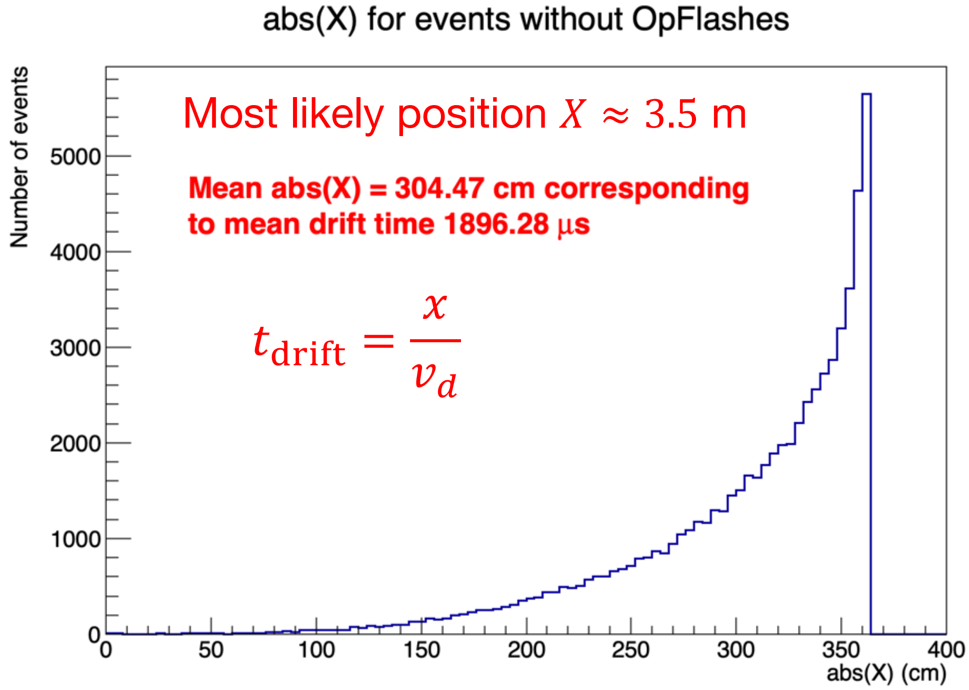
- Given MARLEY neutrino energy and distance from APA, find probability in efficiency matrix (different PD performances)
- Throw a random number [0.0, 1.0] to determine what correction will take place:
  - If less than efficiency, drift correct with MC truth T0
  - If greater than efficiency, correct with a random T0



Distribution used for random correction

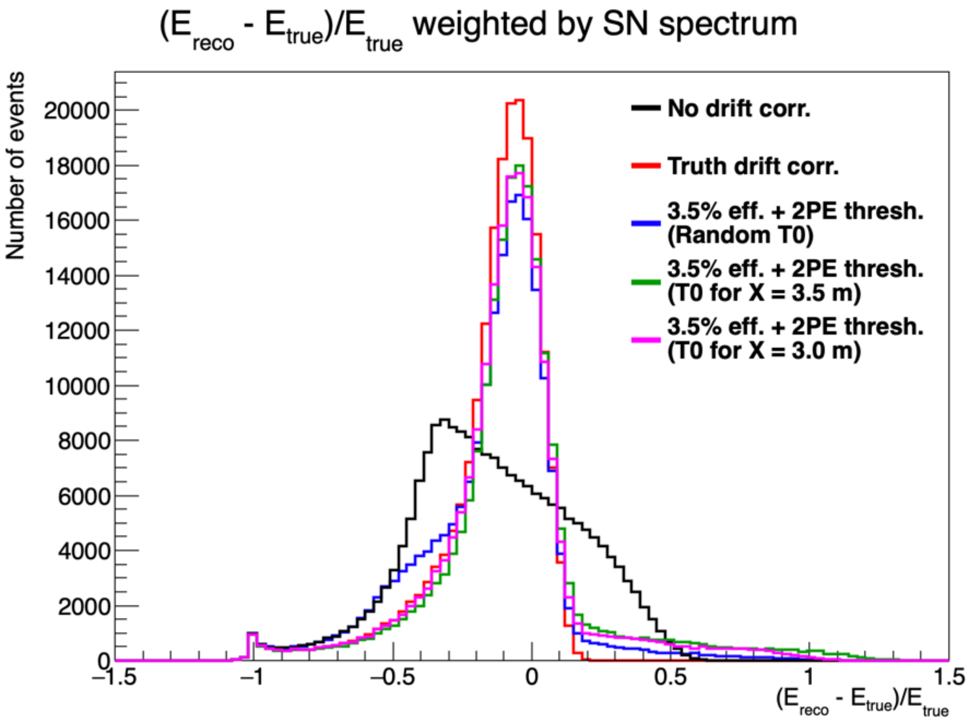
Other Toy Correction Schemes

- For events that don't find flash in toy method, drift correct with specific MC truth T0
  - Use mean, most likely position of events that don't have OpFlash's
  - Essentially making the assumption that we can identify bad flash matches



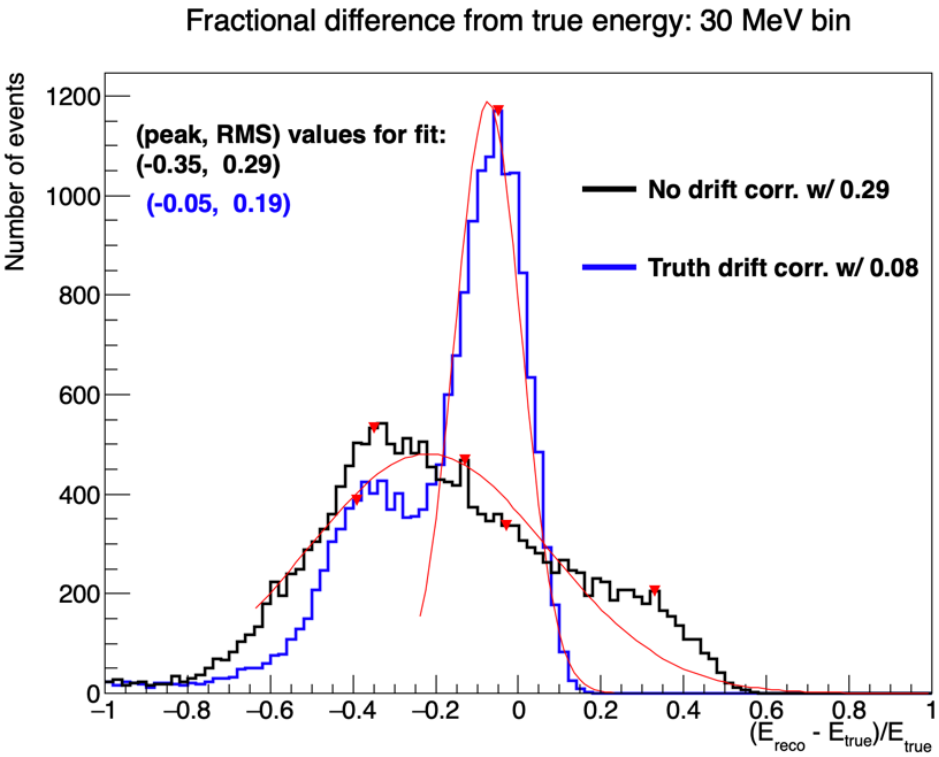
Comparing Toy Corrections

- Determine effect of different drift correction methods by comparing fractional difference distributions
- Right: $(E_{\text{reco}} - E_{\nu})/E_{\nu}$ distributions (weighted by SN energy spectrum)
  - "Random T0" less likely to over-correct and performs the worst among the three toy methods
  - All three toy methods introduce "positive tail" corresponding to over-correction
- Going forward, we focus on the method using T0 for $X = 3.5\text{m}$



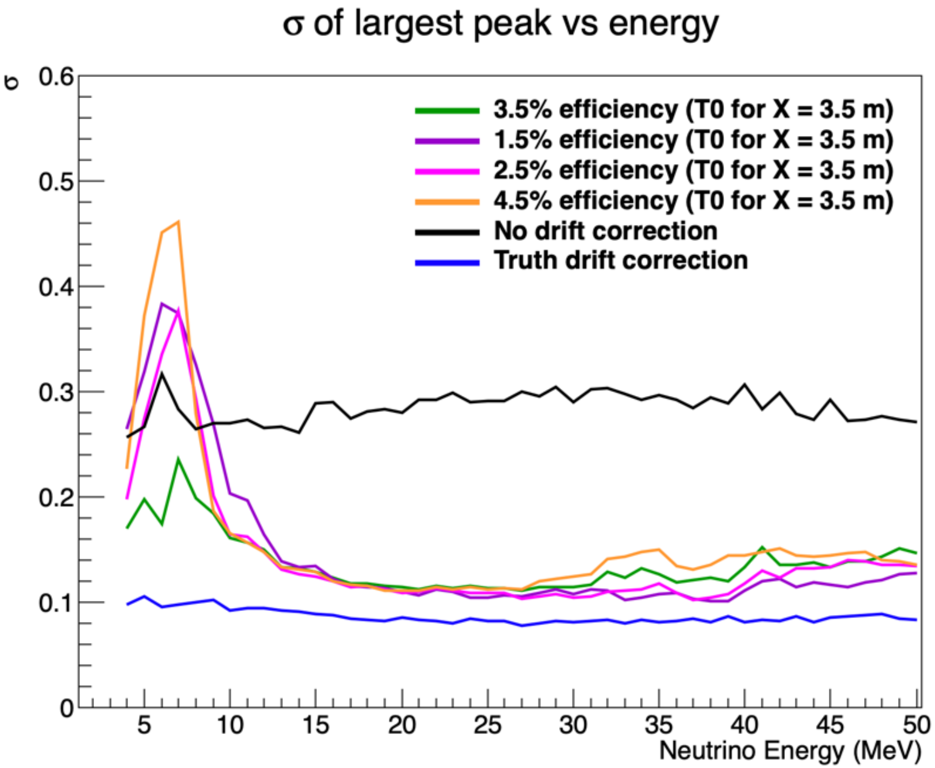
Studying "Intrinsic" Resolution

- Capture "true" resolution (i.e., resolution for events without nucleon emission)
- From histogram of $(E_{\mathrm{reco}} - E_{\nu})/E_{\nu}$, find largest peak and fit with gaussian
  - Fit window $(\mathrm{largestPeak} - \mathrm{RMS}, 1.0)$; σ is the parameter of interest
  - Window definition not constant, more motivated, includes positive tail introduced by toy methods
- This method doesn't work for "no drift corr." distribution due to different behavior



Intrinsic Resolution vs Energy

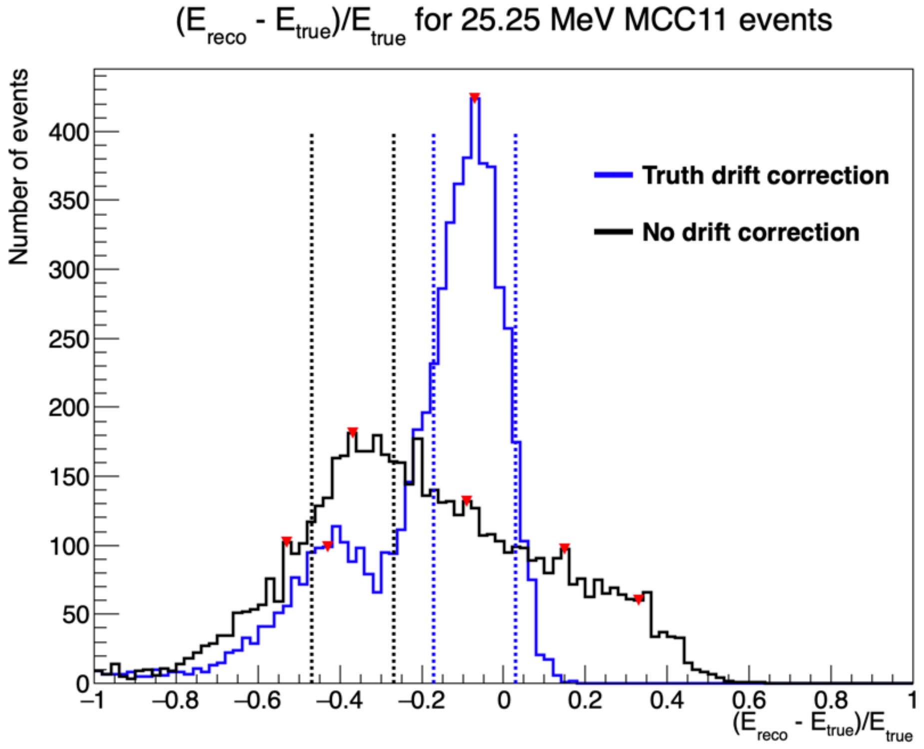
- "No drift corr." curve stable at ~30%; "truth drift corr." stable at ~12%
- Worse performance for PD systems at low energies
- Intrinsic resolution should be ~constant versus energy; doesn't capture over-correction effect



Studying Drift Correction Effects

- Fraction of events in largest peak; considered region $(\text{LargestPeak} - 0.12, \text{LargestPeak} + 0.12)$
  - 0.12 chosen as the intrinsic resolution of largest peak (from “truth drift corr.” distributions)
  - Metric:

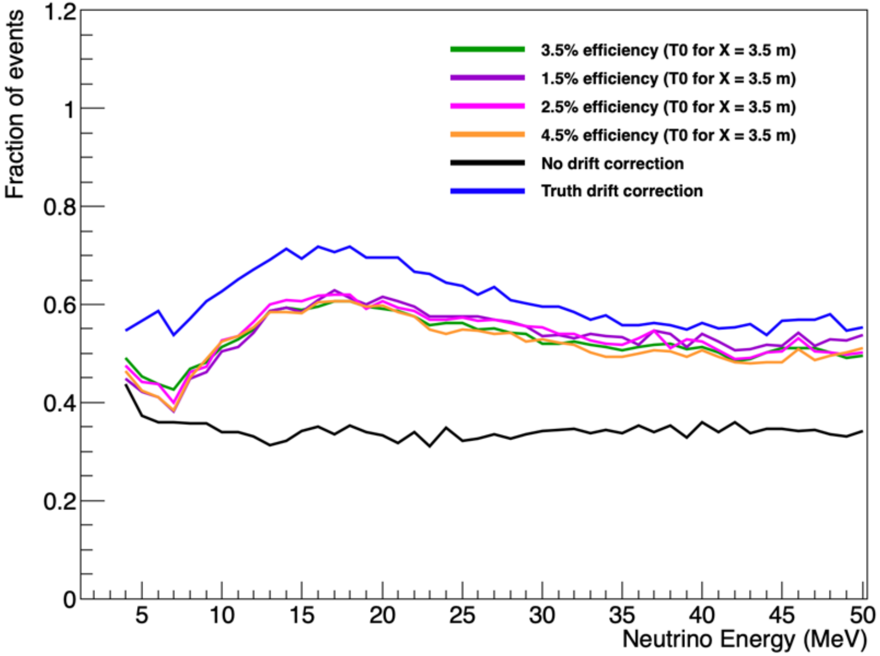
$$\frac{\#\text{ of events in region}}{\text{Total }\#\text{ events}}$$



Fraction of Events vs E_ν

- Similar performance among PD systems, same behavior as "truth drift corr."
- Improved performance up to 15 MeV: electrons have more energy to deposit; before neutron emission can occur
- Above 15 MeV, performance worsens and eventually stabilizes due to neutron emission carrying away some of the energy

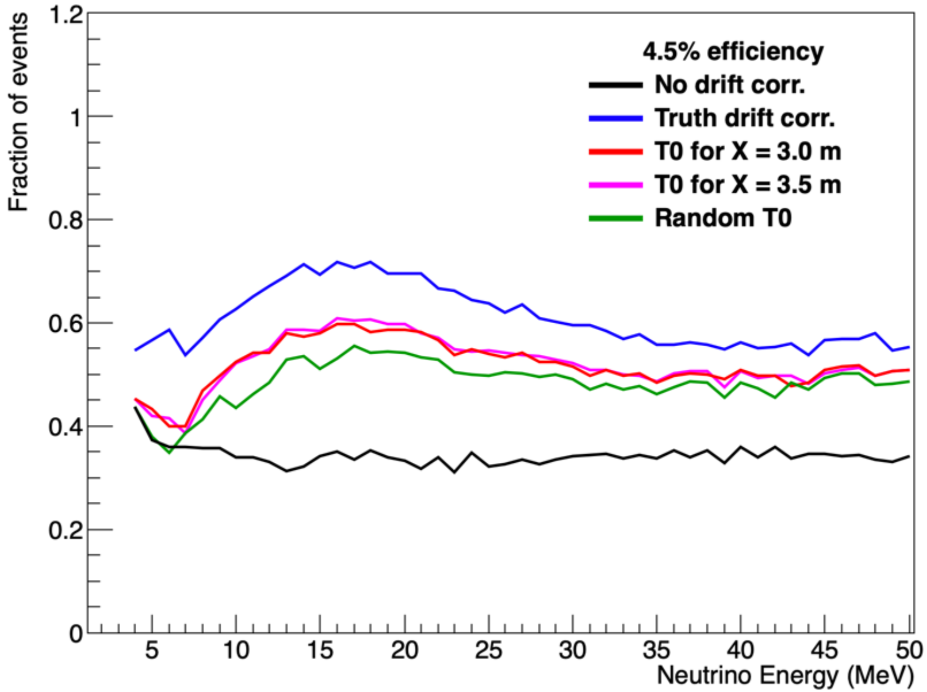
Fraction of events within ± 0.12 of largest $(E_{\text{reco}} - E_\nu)/E_\nu$ peak



Comparing Drift Correction Methods

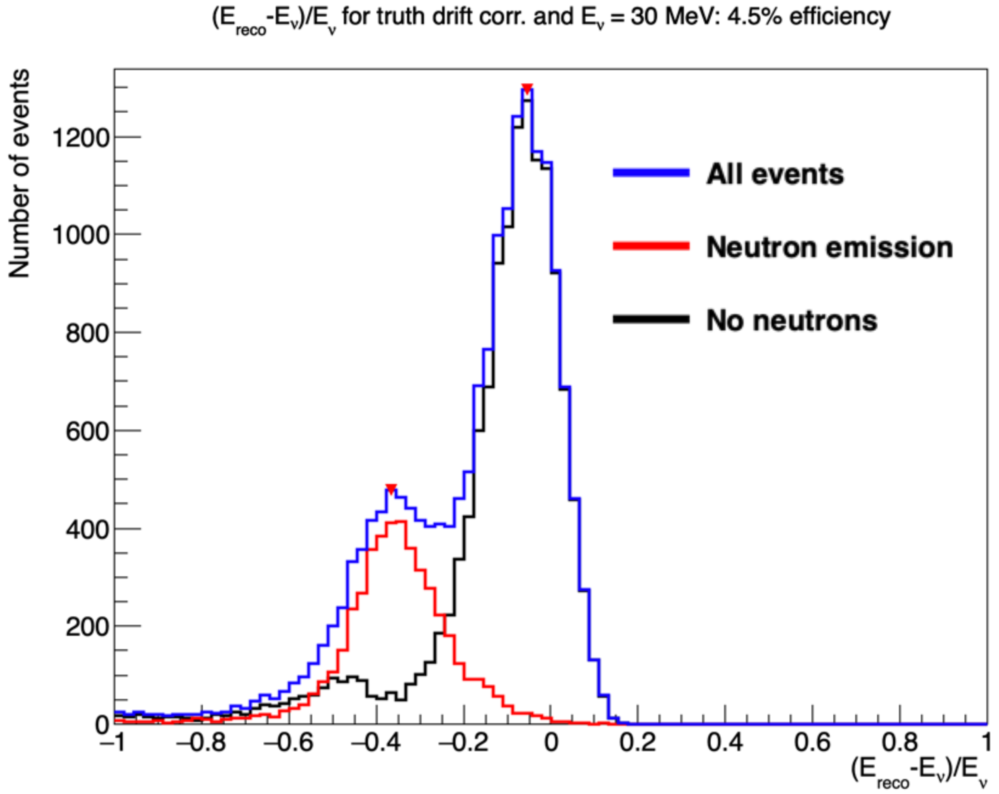
- Random T0 method performs the worst among the three toy methods
- Other two corrections tend to perform similarly – large, susceptible to overcorrection

Fraction of events within ± 0.12 of largest $(E_{\text{reco}} - E_\nu)/E_\nu$ peak: 4.5% ARAPUCA



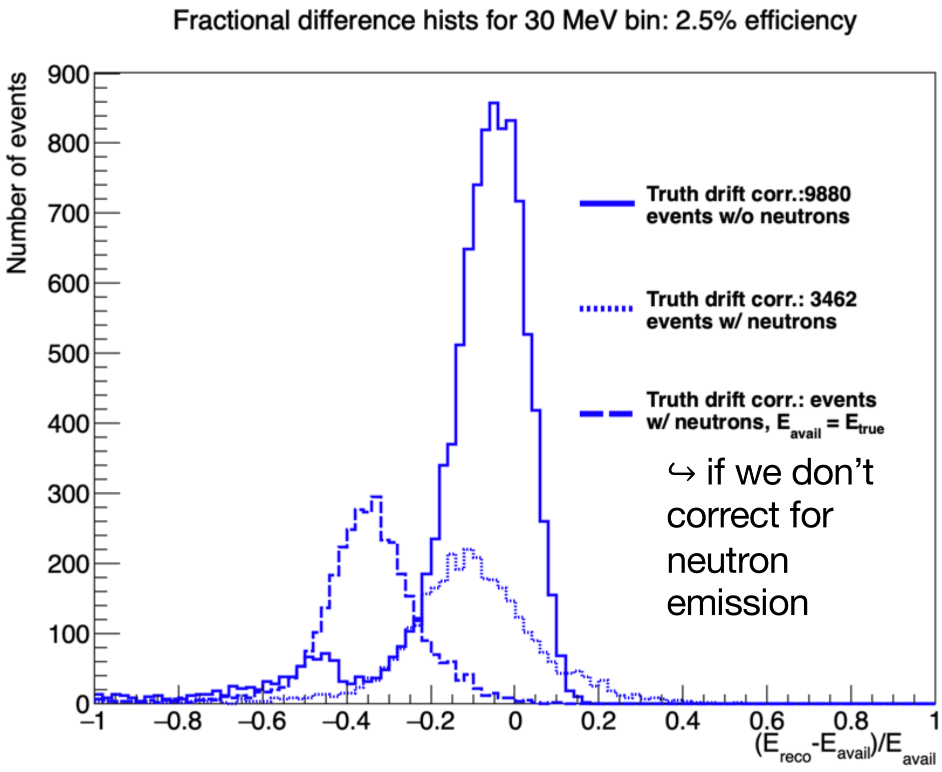
Studying the Double Peak

- For many E_ν values in the $(E_{\text{reco}} - E_\nu)/E_\nu$ distributions, double peak behavior appears
- Split events depending on whether neutron emission occurred; double peak predominantly contains events with neutron emission

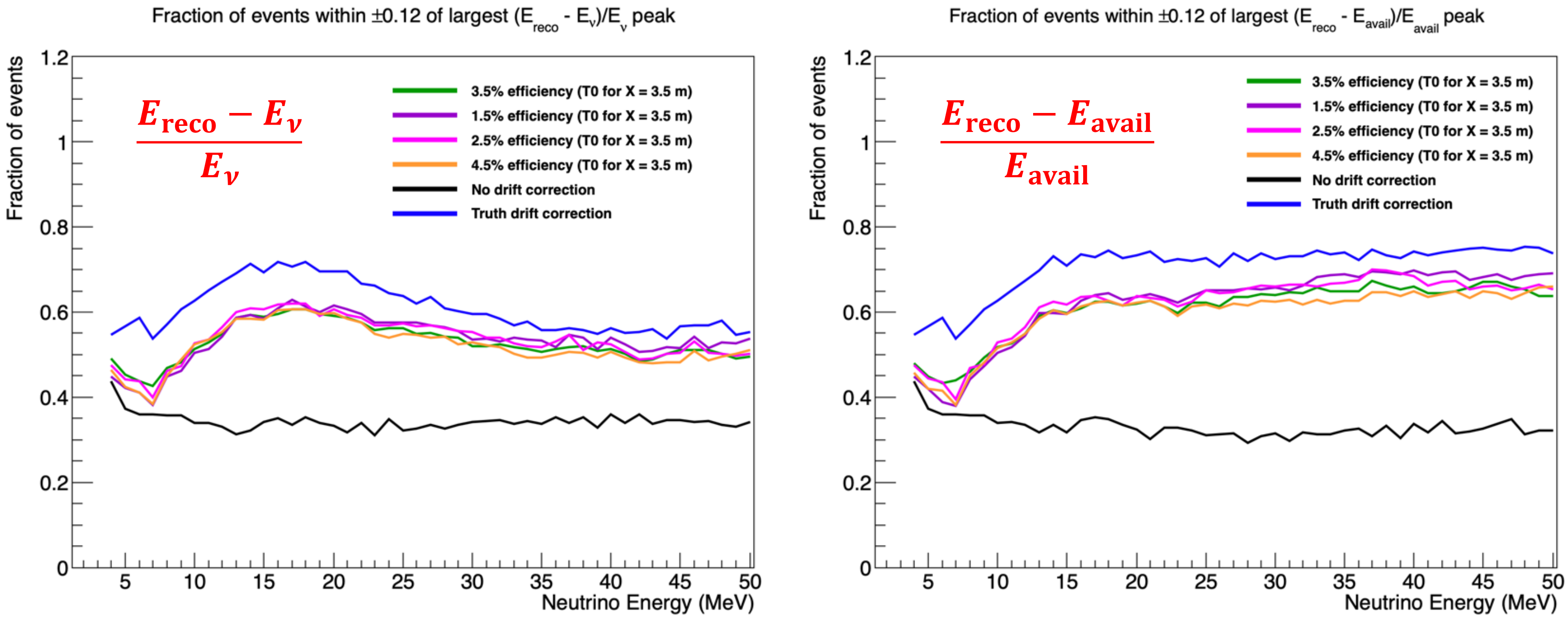


Available Energy

- Define "available energy": $E_{\text{avail}} = E_\nu - n \times 8\ \text{MeV}$
  - n: number of neutrons emitted
- Using E_{avail}, we can correct for the energy loss due to neutrons (if we can figure out which events have neutron emission!)



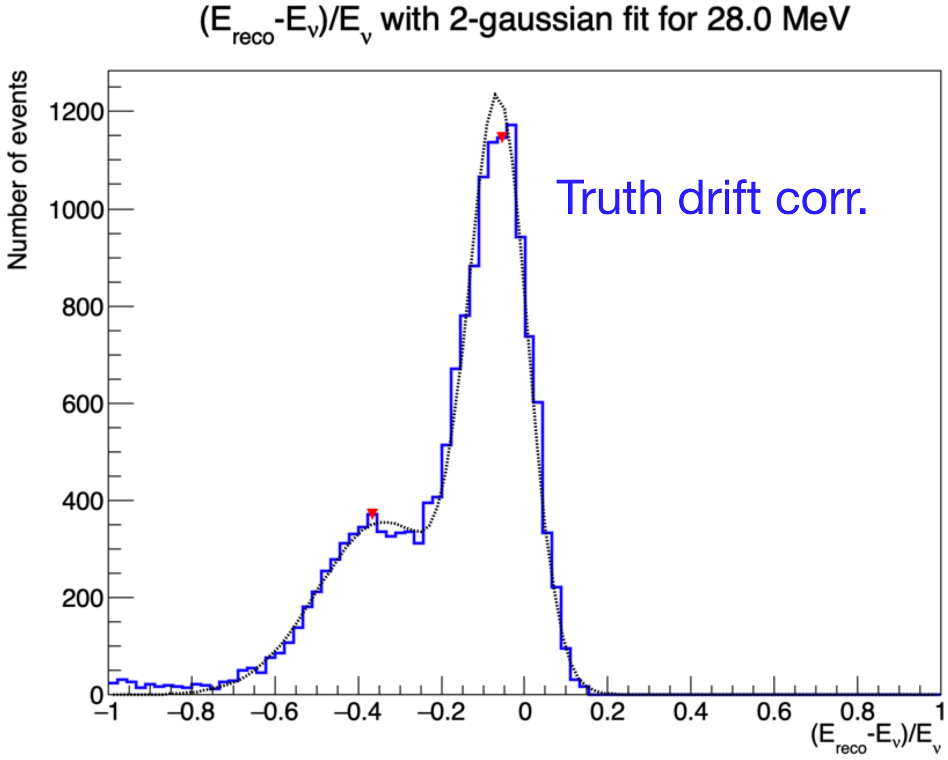
Impact of E_{avail} on metric plots



Same behavior at low energies; biggest improvements above 20 MeV

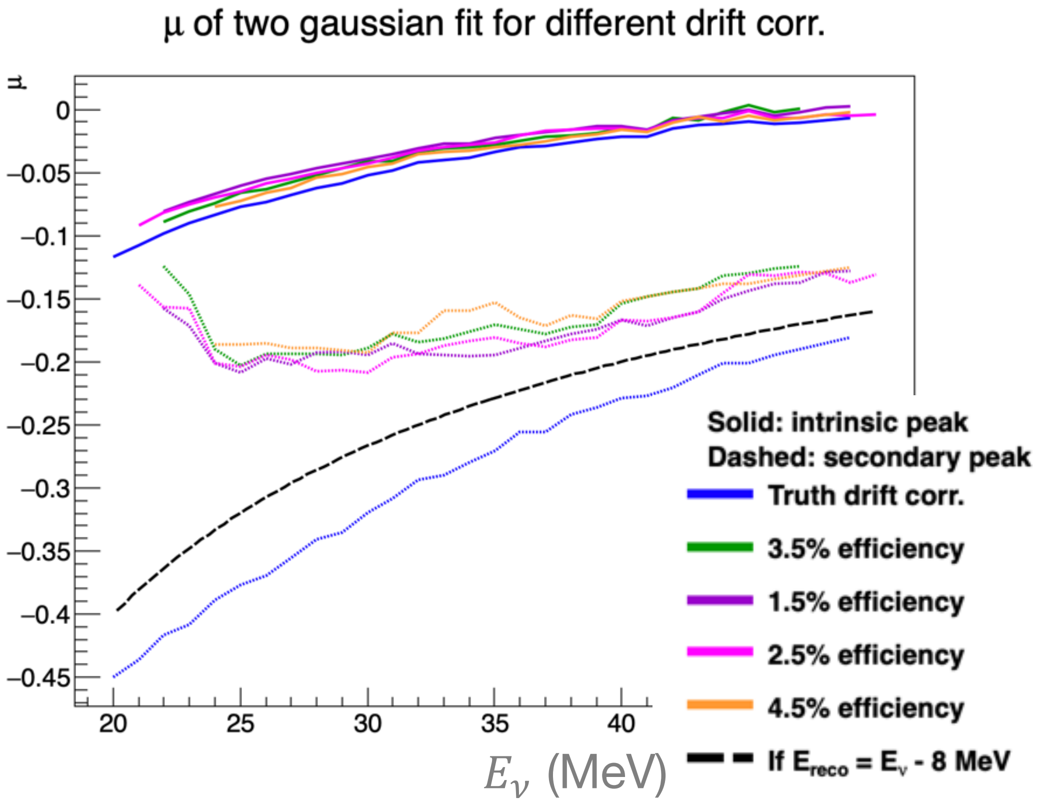
Two-Gaussian Fit

- Fit the two peaks using two-gaussian fit in order to study behavior versus E_{ν}
  - Find preliminary parameters using individual fits over range $[\text{peakLocation} - 0.18, \text{peakLocation} + 0.18]$ on the two peaks
  - Total fit over [-1, 1]



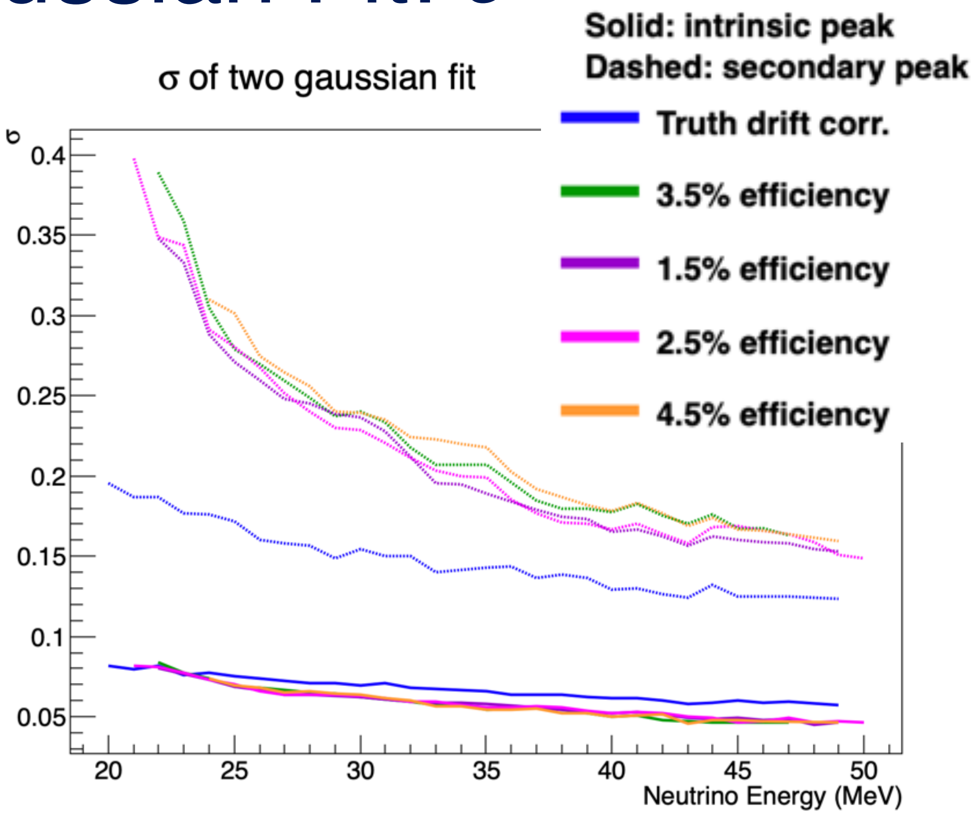
Two-Gaussian Fit: μ

- Intrinsic peak has less energy loss (smaller μ) compared to secondary peak
- Secondary peak for truth drift corr. has expected shape for ~constant energy loss over entire range
  - PD performance types do not exhibit this behavior; μ remains ~constant over energy range due to overcorrected events



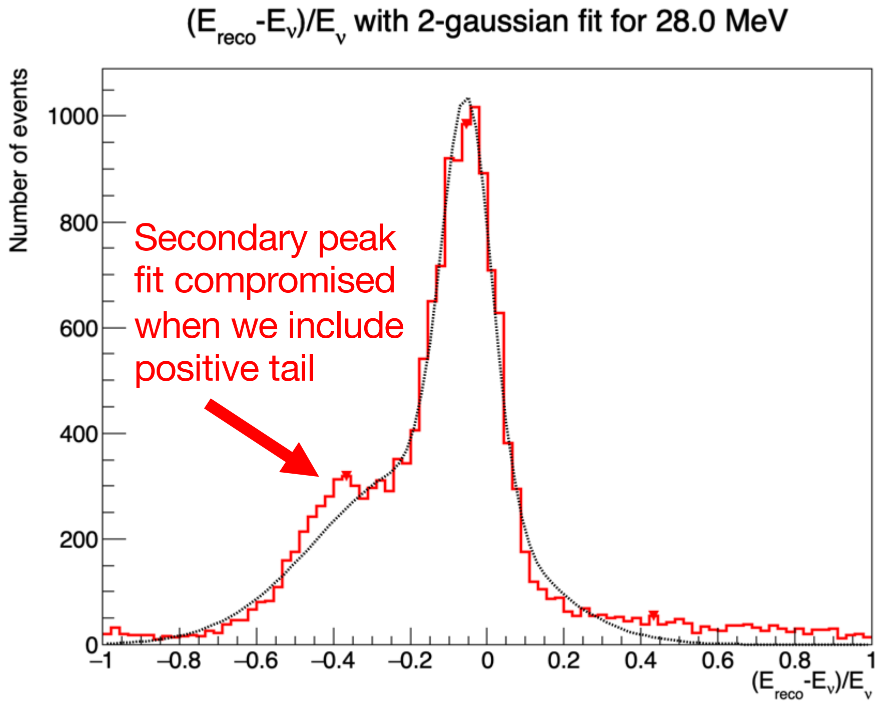
Two-Gaussian Fit: σ

- Intrinsic peak narrower (smaller σ) compared to secondary peak
  - PD systems have slightly smaller σ compared to truth drift corr.; effect due to overcorrected events
- Secondary peak becomes narrower as E_{ν} increases

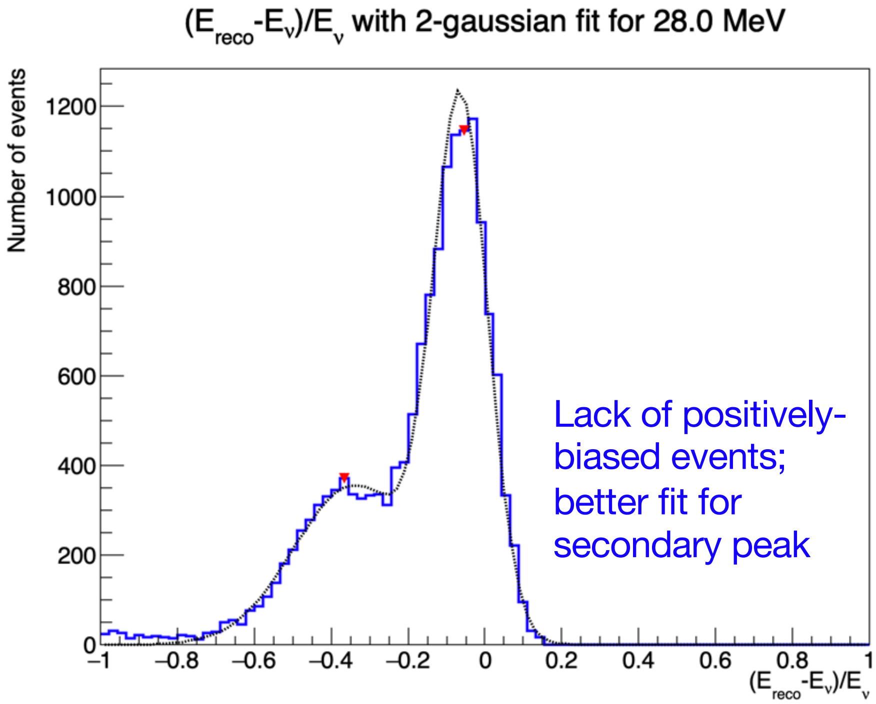


Why are the PD systems different?

3.5% ARAPUCA



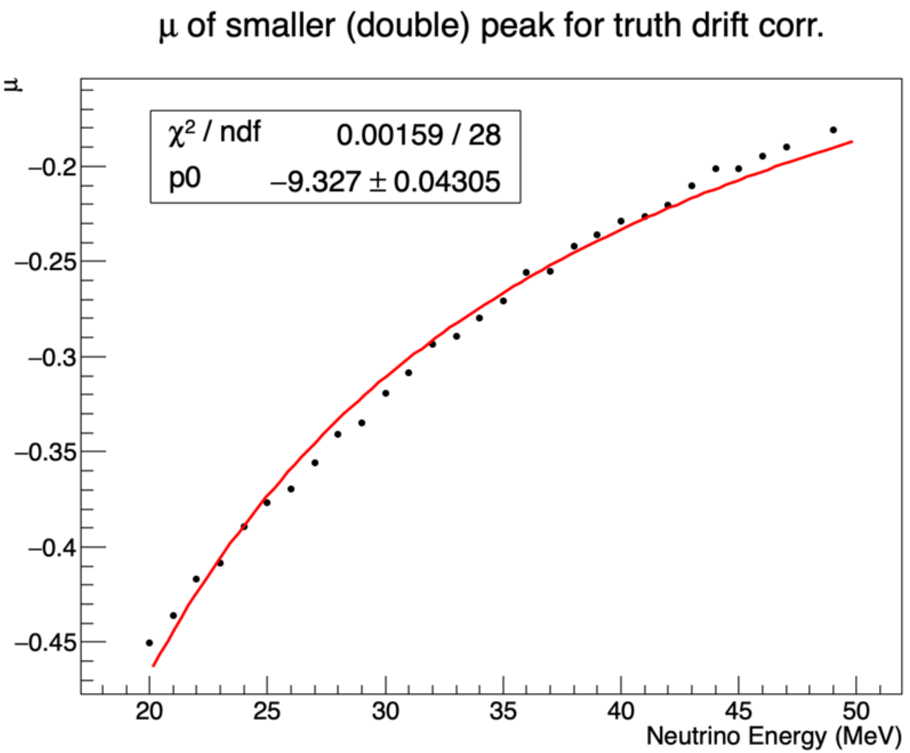
Truth drift corr.



Overcorrected events (i.e., events corrected with larger T0 than true T0) introduce positive tail in distributions for PD systems; produces behaviors seen in μ and σ plots

Measuring the Energy Loss

- Truth drift corr. had expected behavior of constant energy loss over entire E_ν range
- Fit $y = -\frac{p_0}{E_\nu}$ to measure energy loss
  - ~9.3 MeV over the entire range, consistent with neutron binding energy + a little extra lost!



Summary

- Various PD systems produce similar results in energy resolution performance for SNB neutrinos
- Nucleon emission plays role in the high-energy regime of SNB neutrinos
  - Two-gaussian fit enabled us to study how the two $(E_{\text{reco}} - E_\nu)/E_\nu$ peaks change versus neutrino energy
  - Also enabled preliminary fit of energy loss

Backup Slides

Drift Correction Reminder

True drift correction

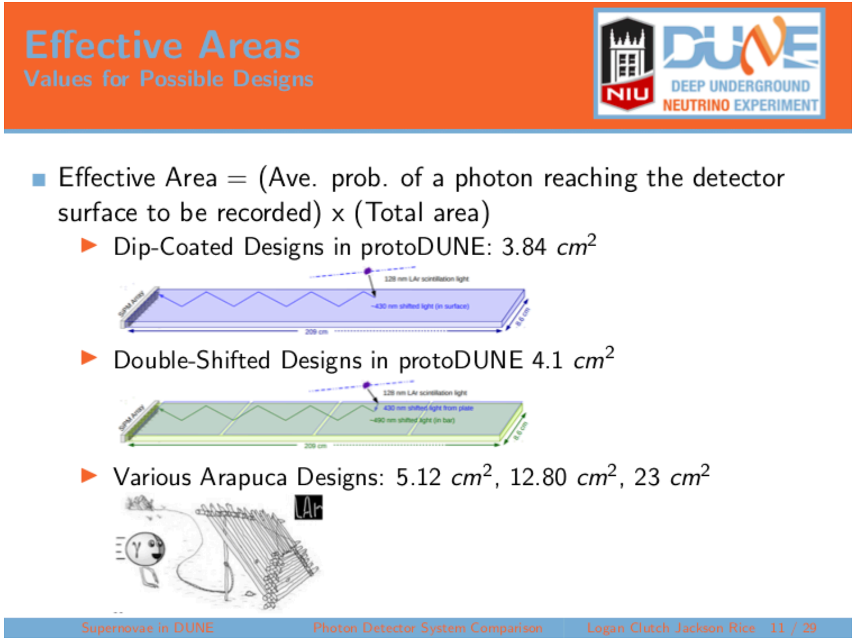
- $Q = Q_0 \exp\left(\frac{x}{v_d \tau_e}\right)$
  - Q: Truth charge
  - Q_0: Observed charge
  - x: Distance from electron vertex to APA (MC Truth)
  - v_d: Electron drift velocity
  - τ_e: Electron lifetime

Reco drift correction

- $Q = Q_0 \exp\left(\frac{t_0}{\tau_e}\right)$
  - Q: Truth charge
  - Q_0: Observed charge
  - τ_e: Electron lifetime
  - t_0: Reco interaction start time
- Find t_0 using photon flash, reco hit information (used longest track as reco electron track)

PD Performance Types: Reminder

- Motivation: evaluate photon detector requirements for SN physics; coupling physics to PD performance
- Distinguish photon detector performance variations based on “effective area”
  - Right: slide from a talk by Logan Rice

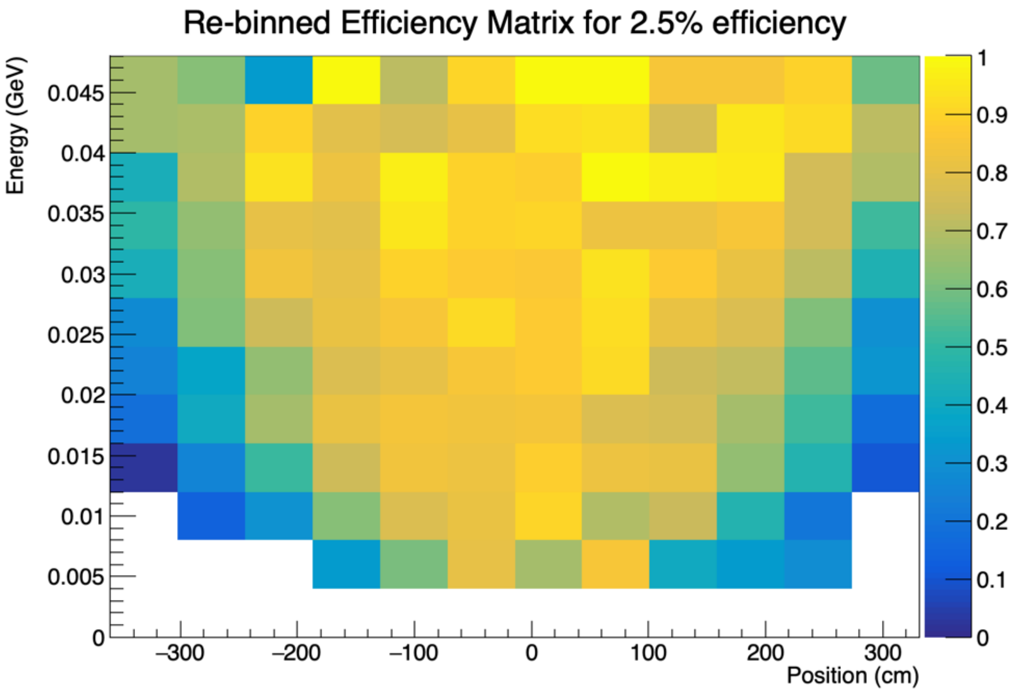


Bug found in March 2019

- Previously: code made the assumption that the events' interactions always began at $t = 0$
  - True for the MARLEY events but we can't make that assumption in real life…
  - This is probably why truth/reco drift corrections looked so similar
- Fixed by only drift correcting events with photon flash information
  - If the event does not have photon flash information, then we don't know when the interaction started, and thus we can't drift correct the event
  - Updated calibration constants

Efficiency Matrix

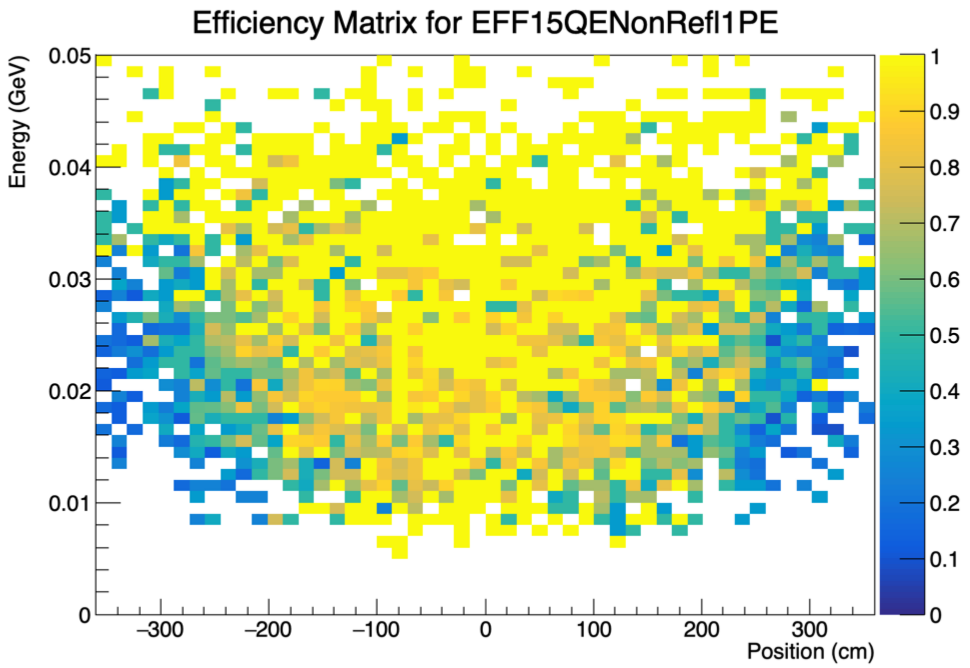
- Probability of successful flash matching as a function of energy and distance from APS
  - Re-binned; see backup
- Stringent efficiency definition (finding largest flash with distance cut associated with event)
  - Example matrix shown here; events farther from APA less likely to find photon flash



Example efficiency matrix

Un-binned Efficiency Matrices

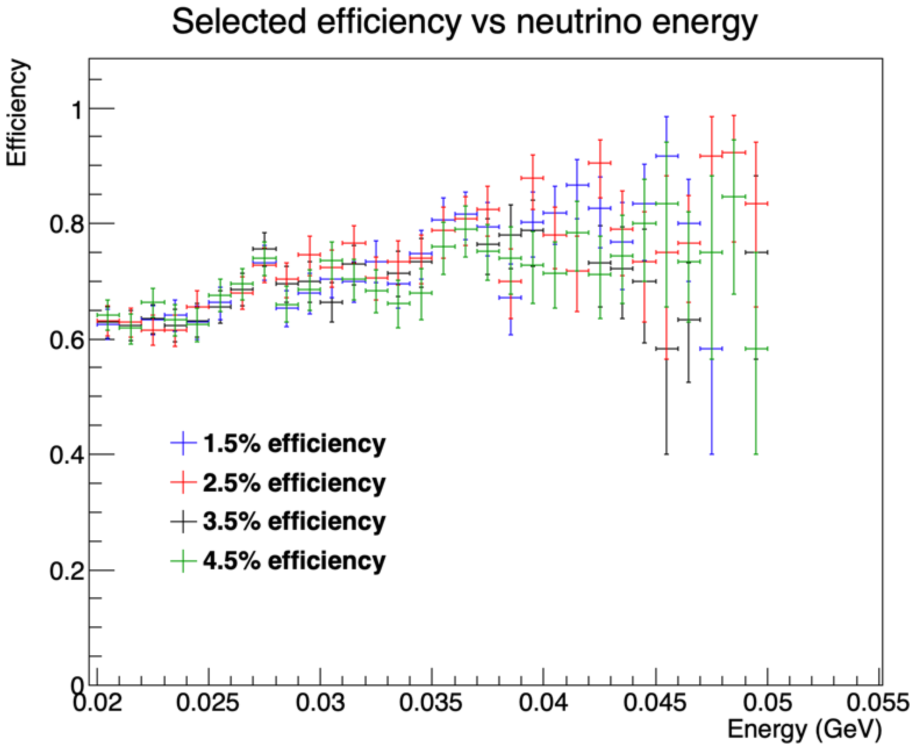
- Efficiency matrix: Probability of successful flash matching given true neutrino energy, distance from APA
- Less statistics compared to previous efficiency matrices; re-binned to reduce number of “holes”
  - Merged 4 bins into 1 for both axes



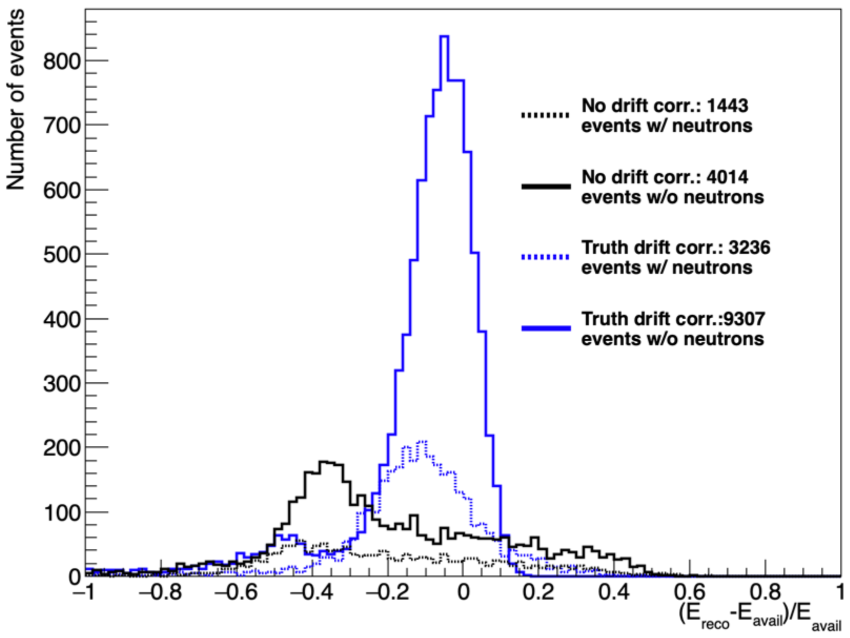
1.5% QE (before re-binning)

Understanding intrinsic resolution behavior

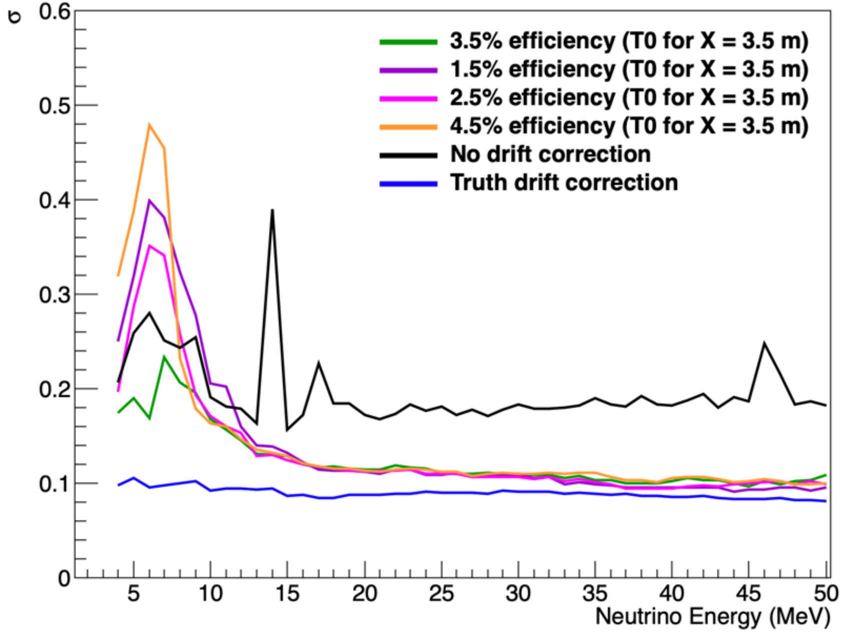
- 1.5% ARAPUCA actually has the best performance for mid to high energies, while 4.5% ARAPUCA has the worst
- Efficiency matrices contain the same behavior (see righthand plot); shows limitation in efficiency matrices



Using E_{avail} definition

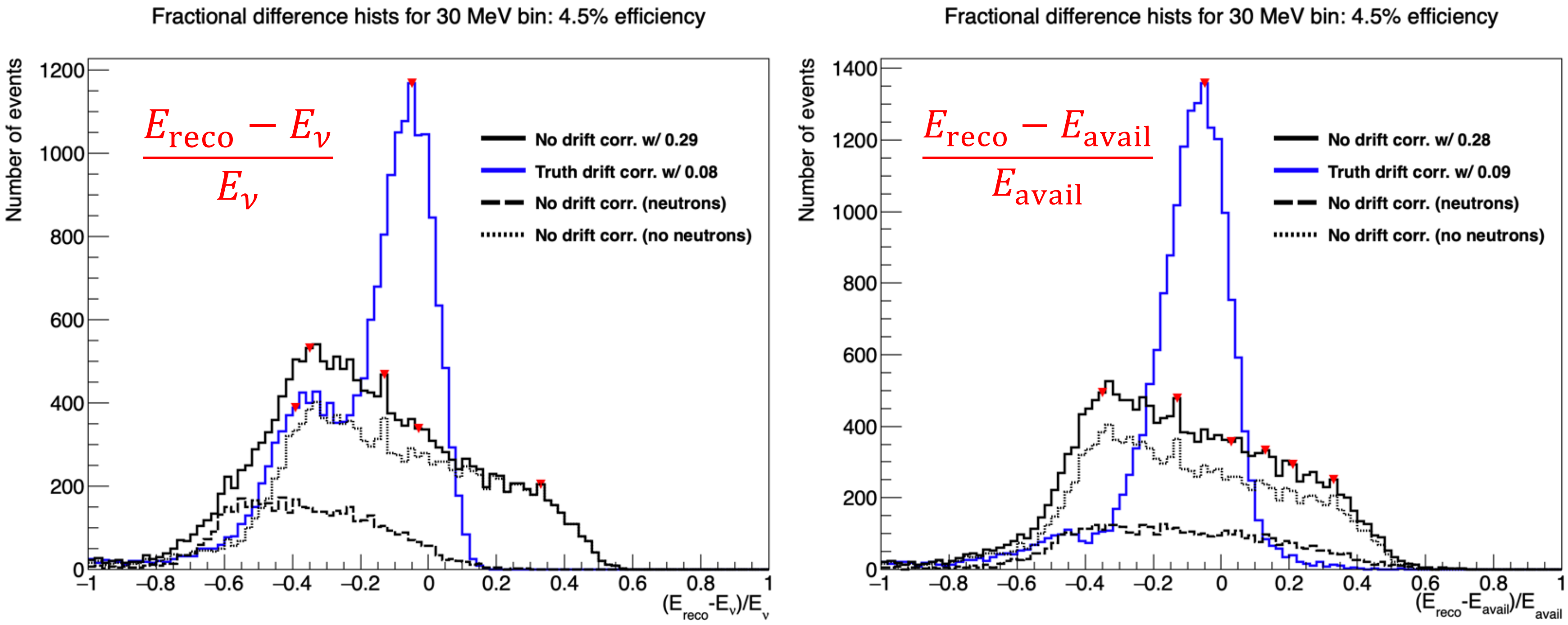


This plot implies that the “no drift corr.” events with neutrons don’t benefit from E_{avail} definition



Using extended Gaussian fits (except for no drift corr.); “no drift corr.” does improve, but overall same behavior

Sanity check the “no drift corr.” plots



The no drift corr. + neutron sample is corrected with the E_{avail} definition, but the distribution is so widespread that the correction is drowned out