Supernova Pointing Resolution of DUNE

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SNEWS 2.0 Workshop

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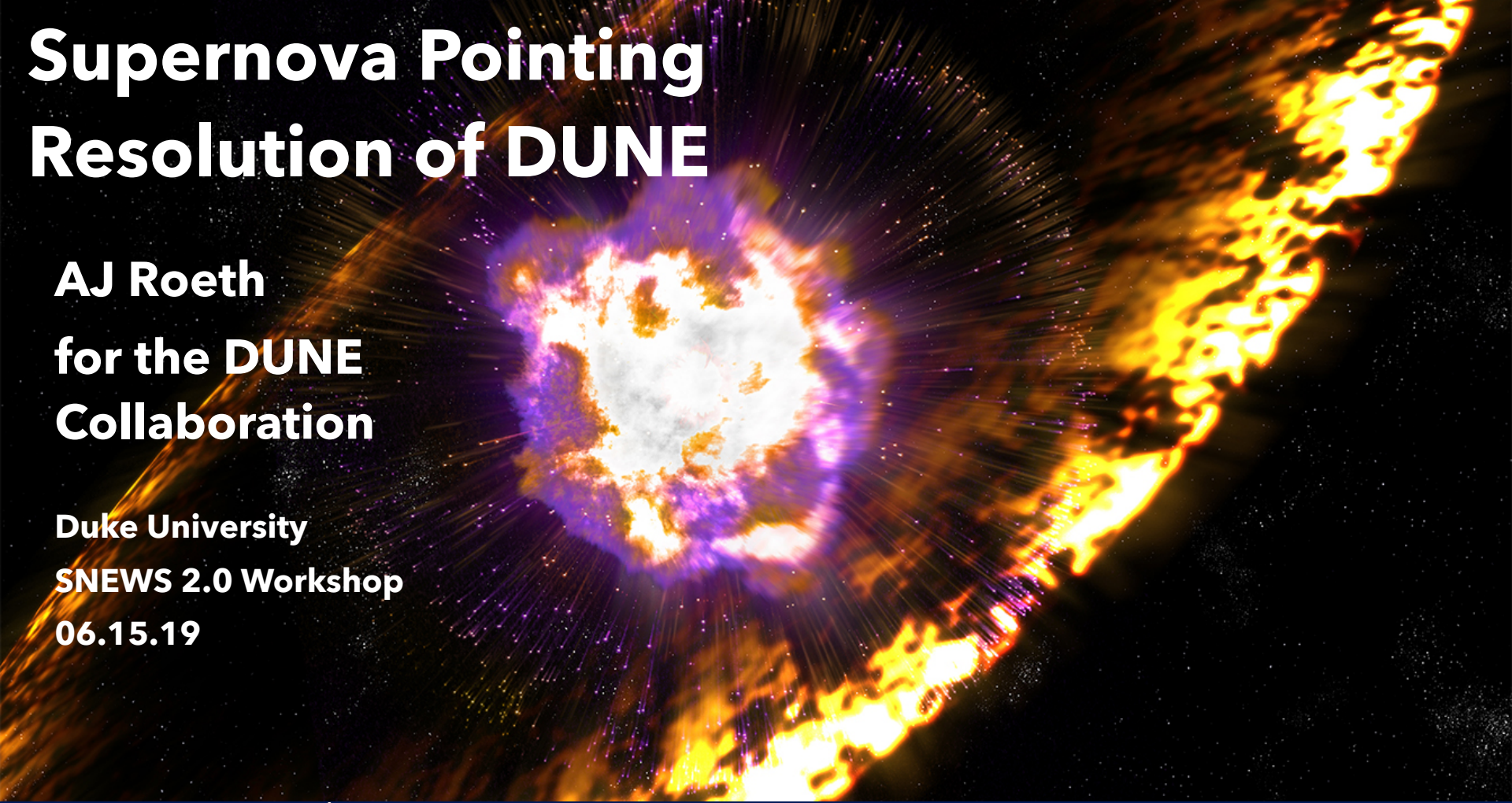


image: extremetech.com

Overview

- 40 kton fiducial volume liquid argon detector
- Capable of detecting supernova neutrinos
- Goal: Determine and improve detector's pointing resolution for supernovae
  - SNEWS, finding progenitor for no-supernova case
- Interactions
  - ν_e charged current - majority of events
  - elastic scattering of neutrinos on electrons - most anisotropic, correlated with supernova direction
- Steps: Use simulations to find pointing resolution for…
  - single electrons
  - neutrino-electron elastic scattering events
  - supernova samples of elastic scattering events
  - supernova samples of elastic scattering and charged current events

DEEP UNDERGROUND NEUTRINO EXPERIMENT

image: symmetrymagazine.org

Reconstruction of supernova direction

- Supernova neutrinos interact in liquid argon
- Detected by products of interactions - electrons, gammas
- Ionize liquid argon, ionized electrons are collected using electric field and wire planes
- Software used to reconstruct particle tracks
- Direction of particle tracks gives info about supernova direction

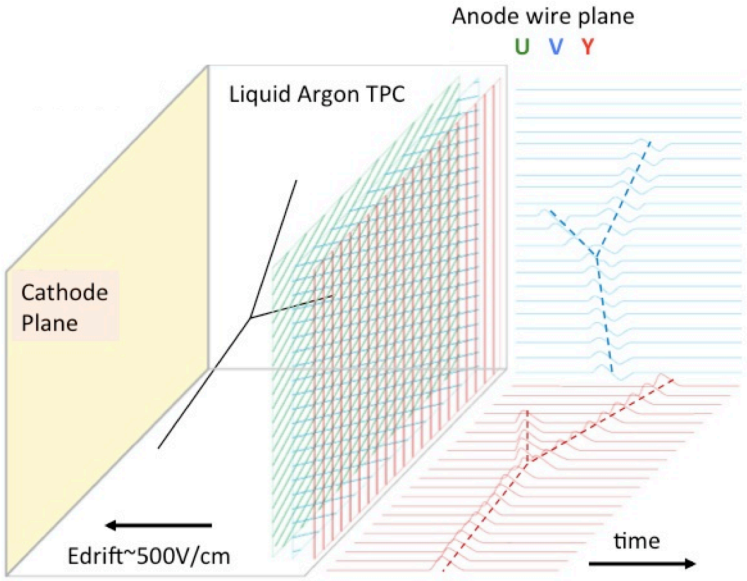
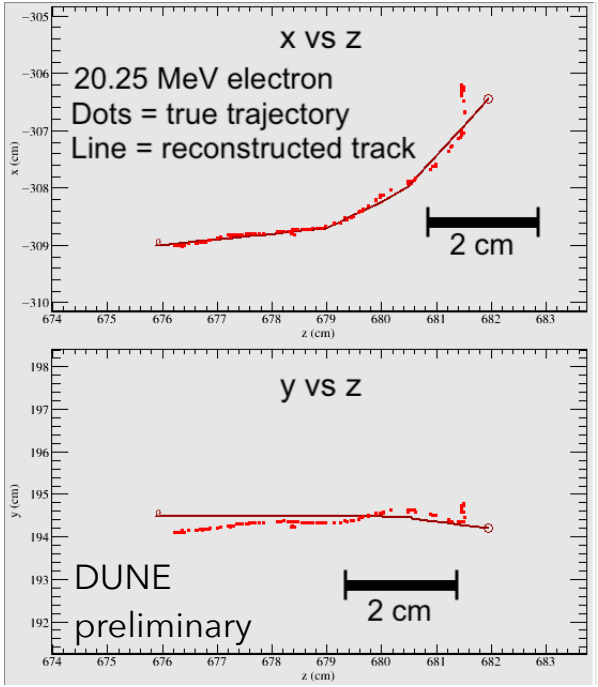
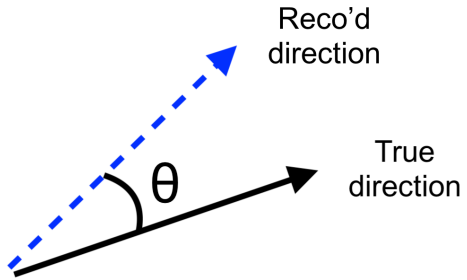


image: Bo Yu (BNL)

Single electrons

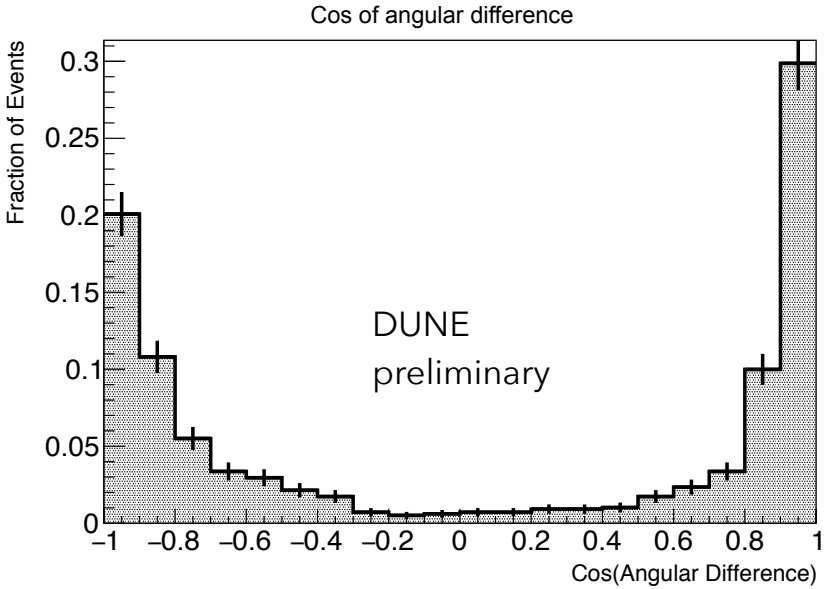
- Simulated and reconstructed isotropic single electrons
  - No noise or radiologicals (yet)
  - Several tracks, chose longest
    - Is primary electron ~90% of the time
- There is error between true and reconstructed directions
  - Reconstructed direction = direction vector of the first point of the track (as defined by track reconstruction software)
- Calculated angles between true start electron direction and reconstructed direction (θ)





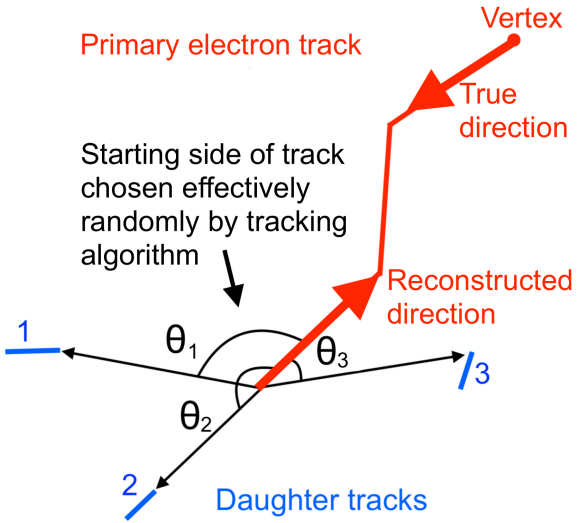
Directional ambiguity

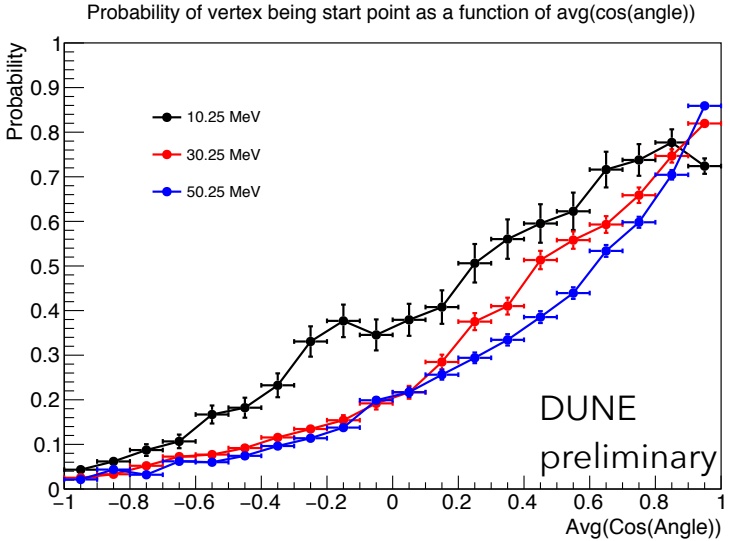
- Plotted cos of angles between true start electron direction and reconstructed direction (θ)
  - Can see directional ambiguity - two peaks
- Resolving this important for determining supernova direction
- One method: daughter tracks (from bremsstrahlung gammas compton scattering, ionized electrons, etc.) correlate with electron direction



20.25 MeV electrons

Daughter Flipping

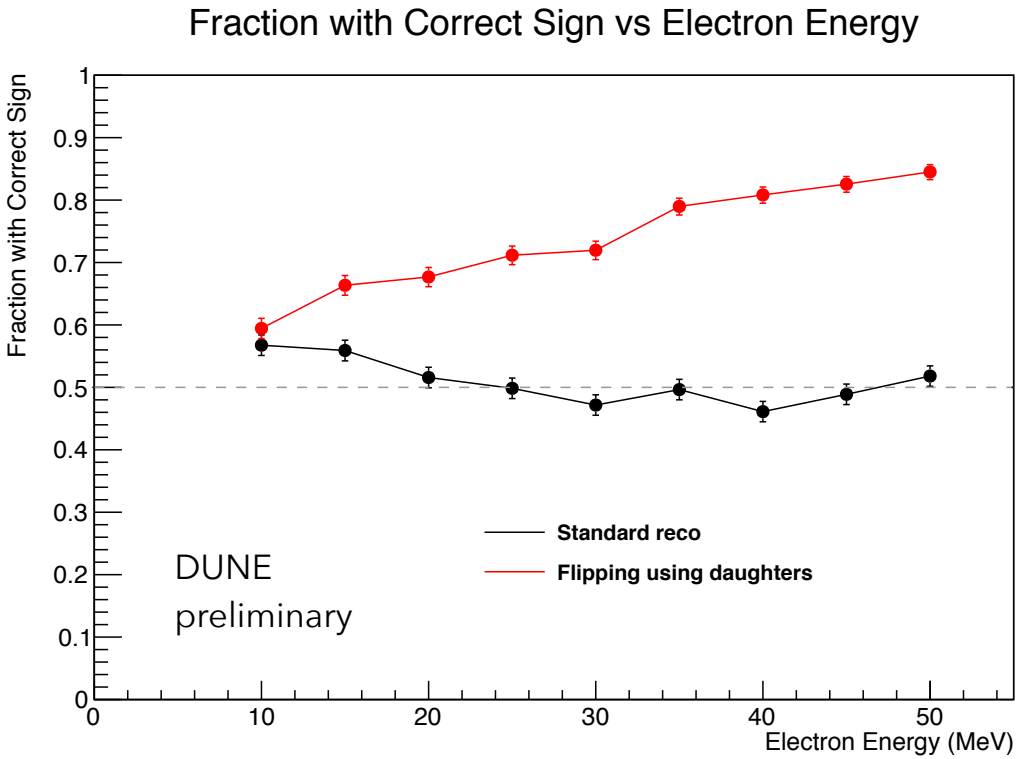




- Flipped tracks using reconstructed daughters
- Calculates average cos of angles between reconstructed track direction and location of daughter tracks, for each end of electron track
- Choose starting point of track to be the side for which avg(cos(θ)) is largest
- True starting vertex should have larger avg(cos(θ))

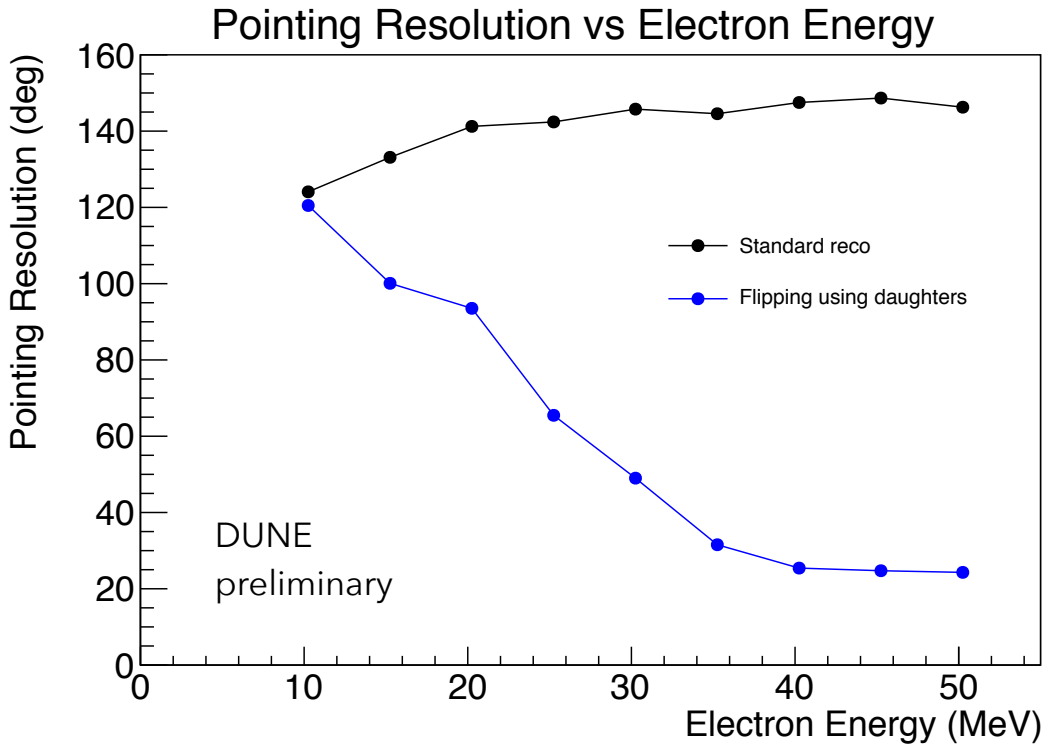
Directional ambiguity

- Fraction of tracks with correct sign ($\cos(\theta) > 0$) vs electron energy
- With daughter flipping, higher and above 50% correct



Single electron pointing resolution

- Pointing resolution = Angle at which 68% of events are closer to truth
- Daughter flipping helps more at higher energies - more daughter tracks with more energy



ν-e elastic scattering pointing resolution

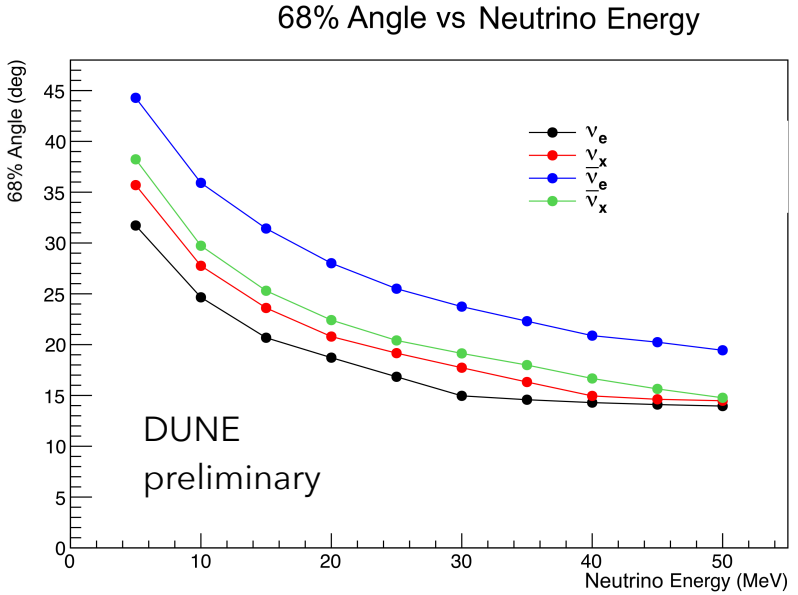
- Wrote event generator, simulated and reconstructed neutrino-electron elastic scattering events (500 per energy and per flavor, no noise or radiologicals)
- Total pointing resolution comes from combination of:
  - neutrino-electron angle spread
  - electron reconstruction error
- Computed angle at which 68% of true electron directions are closer to true neutrino direction

$$\frac{d\sigma}{dT} = \frac{G_F^2 m_e}{2\pi}[(g_A + g_V)^2 + (g_V - g_A)^2(1 - \frac{T}{E_\nu})^2 + (g_A^2 - g_V^2)\frac{m_e T}{(E_\nu)^2}]$$

species	g_A	g_V
ν_e	$\frac{1}{2}$	$2\sin^2\theta_W + \frac{1}{2}$
$\bar{\nu}_e$	$-\frac{1}{2}$	$2\sin^2\theta_W + \frac{1}{2}$
$\nu_{\mu,\tau}$	$-\frac{1}{2}$	$2\sin^2\theta_W - \frac{1}{2}$
$\bar{\nu}_{\mu,\tau}$	$\frac{1}{2}$	$2\sin^2\theta_W - \frac{1}{2}$

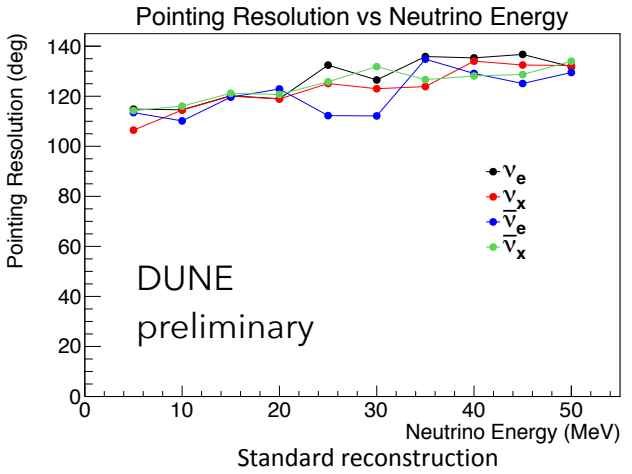
$$\cos\theta = \frac{E_\nu + m_e}{E_\nu}\sqrt{\frac{T}{T + 2m_e}}$$

Alex Nikrant, Ranjan Laha & Shunsaku Horiuchi, Phys. Rev. D **97**, 023019 (2018)

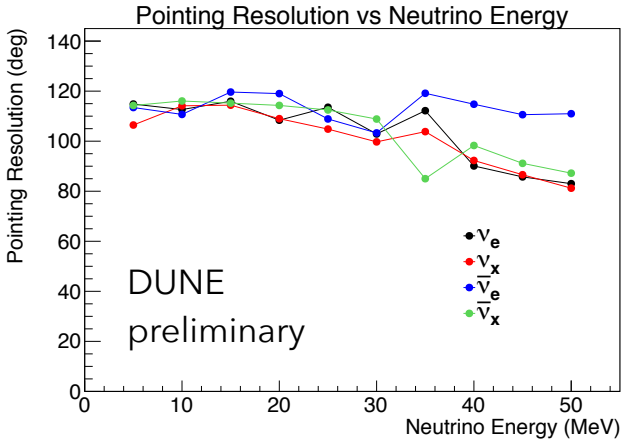


v-e elastic scattering pointing resolution

- Computed pointing resolution of reconstructed electron direction with respect to neutrino direction
  - Standard reconstruction vs daughter flipping
  - Daughter flipping helps resolve ambiguity



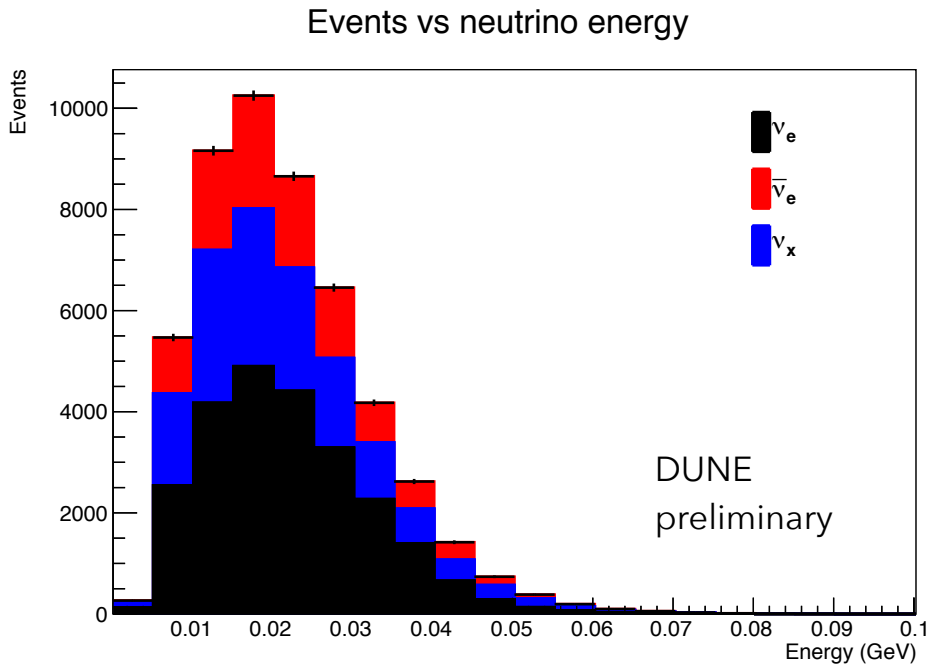
Standard reconstruction



After daughter flipping

Supernova samples of elastic scattering events

- Chooses neutrino interacted energy and flavor (GVKM model distribution from SNOwGLoBES)
- Simulated 500 isotropic supernovae
- 260 elastic scattering events each in same direction (GVKM model 10kpc SN)
- Elastic scattering events = ~7% of total, charged current ~93%
- No noise or radiologicals



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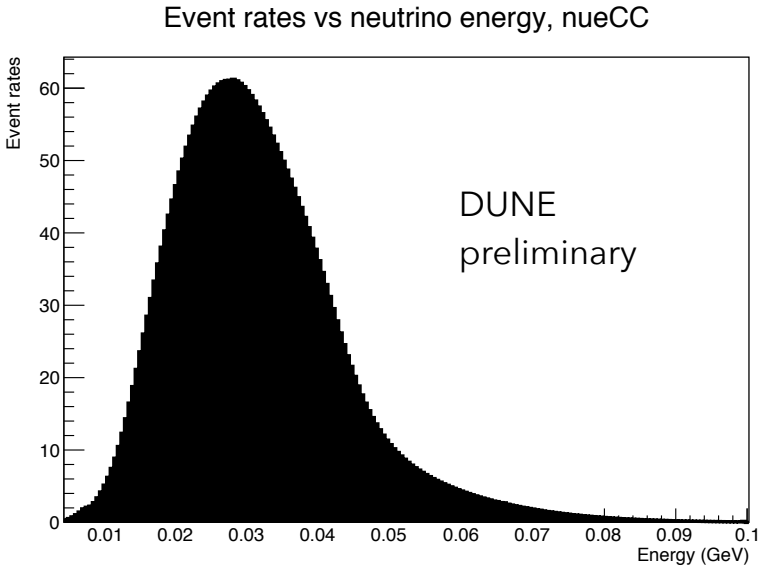
$\bar{\nu}_{\mu,\tau}$	$\frac{1}{2}$	$2\sin^2\theta_W - \frac{1}{2}$

$$\cos\theta = \frac{E_\nu + m_e}{E_\nu}\sqrt{\frac{T}{T + 2m_e}}$$

Supernova samples of ES + CC events

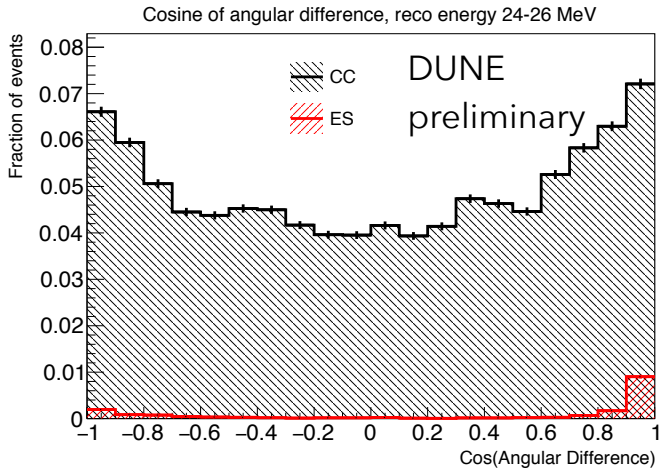
- Used a pre-existing CC sample (made using MARLEY generator)
- Sampled according to GVKM model SN energy distribution from SNOwGLoBES
- Rotated to match ES neutrino directions
  - Ignoring detector anisotropy for now
- Added to ES sample to get 500 ES+CC SN samples
  - Each SN has 260 ES and 3350 CC events (GVKM model 10 kpc SN)

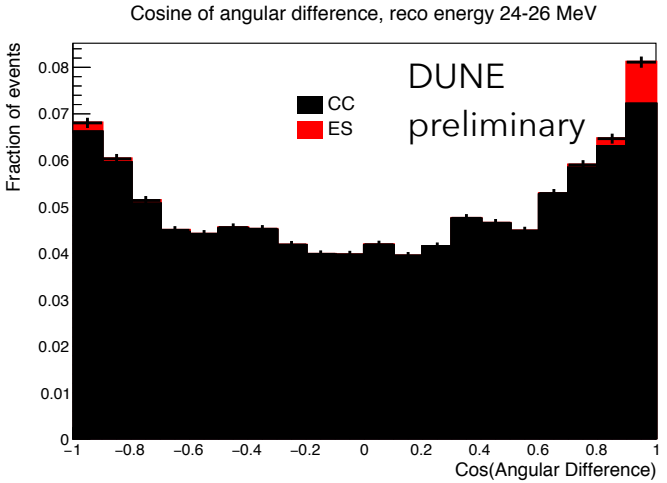


Charged current directionality

$$\text{Fermi: } 1 + \frac{v}{c}\cos\theta$$
$$\text{Gamow-Teller: } 1 - \frac{1}{3}\frac{v}{c}\cos\theta$$

- CC events less directional, but still have directional information
- We will include them in the fit





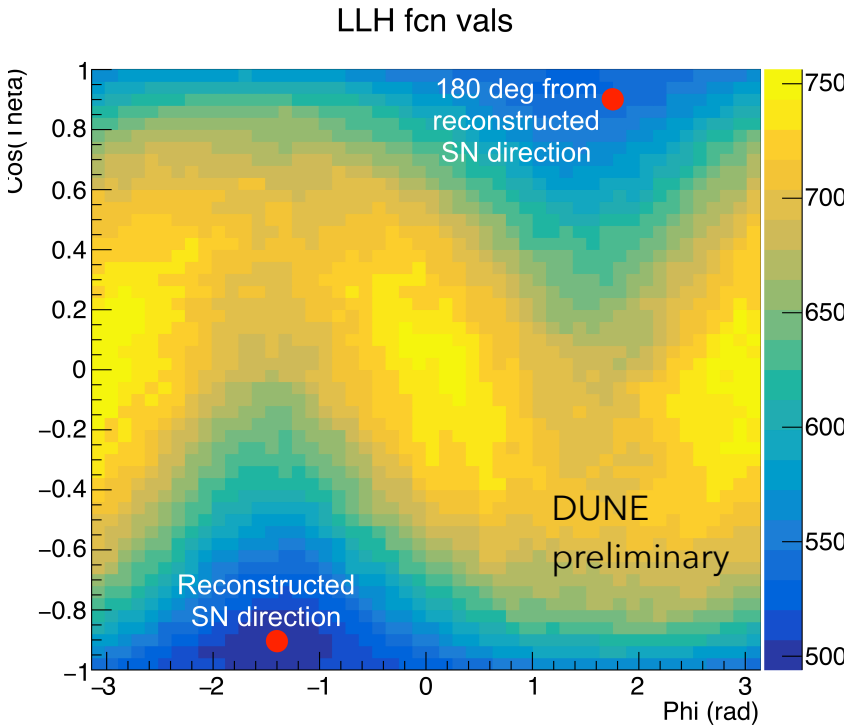
Reconstructed supernova direction

- Wrote likelihood function to find supernova direction from all electron directions and energies

$$L = \prod_i P(E_i, \hat{d}_i, \hat{d}_{SN})$$

E_i = reconstructed electron energy
$\hat{d}_i$ = reconstructed electron direction
$\hat{d}_{SN}$ = reconstructed SN direction

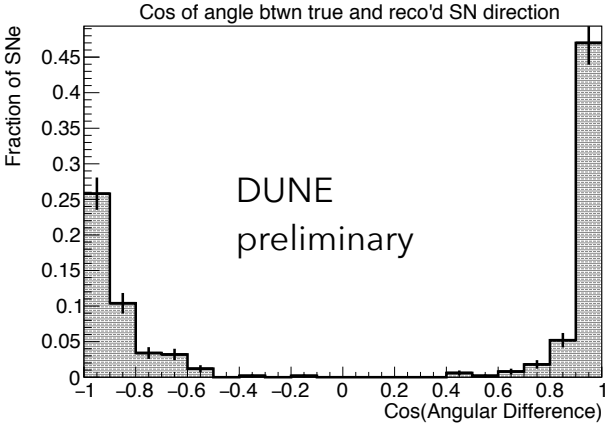
- Minimum of negative sum of log likelihood function is reconstructed supernova direction
- Used 250 supernovae to make probability distribution functions for likelihood function, then found pointing resolution of remaining 250
- PDFs only represent ES events for now
  - Adding CC events could make them more realistic



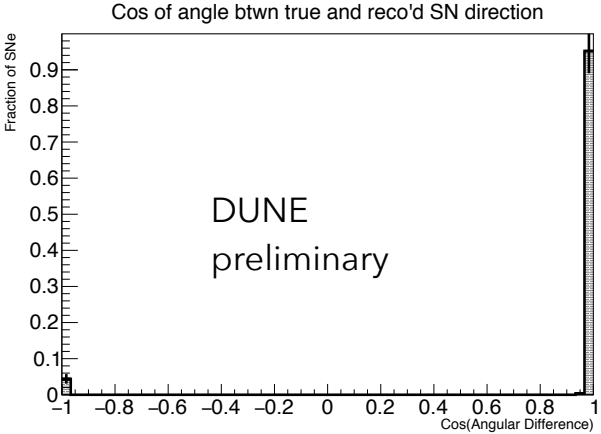
Supernova pointing resolution

- Daughter flipping & likelihood function help a lot
- Difference after adding CC events probably just small fluctuation (low statistics), but shows CC events don't drown out directionality of ES events

	ES only No extra flipping, maximum bin is SN direction	ES only Daughter flipping, maximum bin is SN direction	ES only Daughter flipping + likelihood function	ES + CC Daughter flipping + likelihood function
Pointing resolution	147.2°	30.6°	9.7°	7.5°



No extra flipping, no likelihood function



ES + CC, daughter flipping, using likelihood function

Future steps

- Add noise and radiological backgrounds
- Find pointing resolution assuming different ES/CC distinguishing capabilities
- Pointing resolution as function of SN distance
- Try to use multiple scattering to disambiguate direction and improve pointing resolution

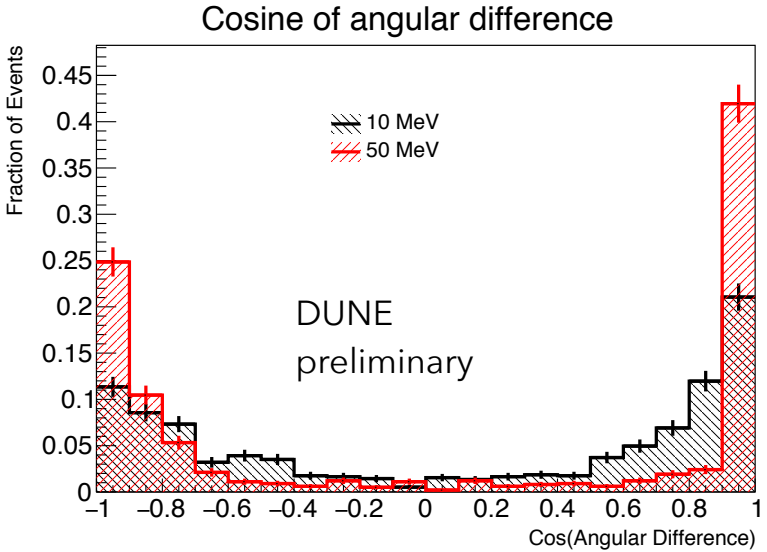
Summary

- Goal: Determine and improve DUNE's pointing resolution for supernovae
- Simulated and reconstructed
  - single electrons
  - neutrino-electron elastic scattering events
  - supernova samples of elastic scattering events
  - supernova samples of elastic scattering and charged current events
- Found current reconstruction has track direction ambiguity
  - Negatively affects pointing resolution
- Used daughter tracks to flip tracks
- Used a likelihood function
- Pointing resolution = 7.5 degrees (10kpc supernovae, elastic scattering + charged current events, no noise or radiologicals)
- Further work needed to get more realistic pointing resolution and study as function of supernova distance

Backups

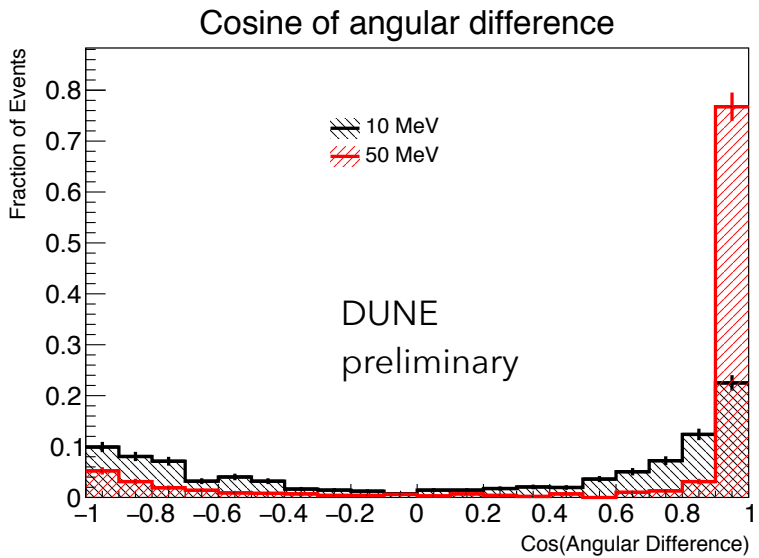
Single electron cos(θ) comparisons

Standard reconstruction



Pointing Resolution **gets worse** with energy because of directional ambiguity and inclusion of narrower peak at cos(θ) = -1

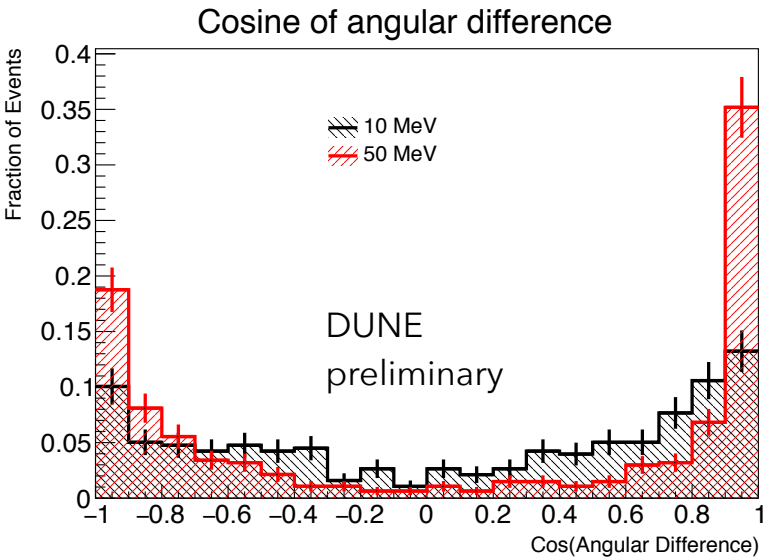
With daughter flipping



Pointing Resolution **improves** with energy because of better directional disambiguation

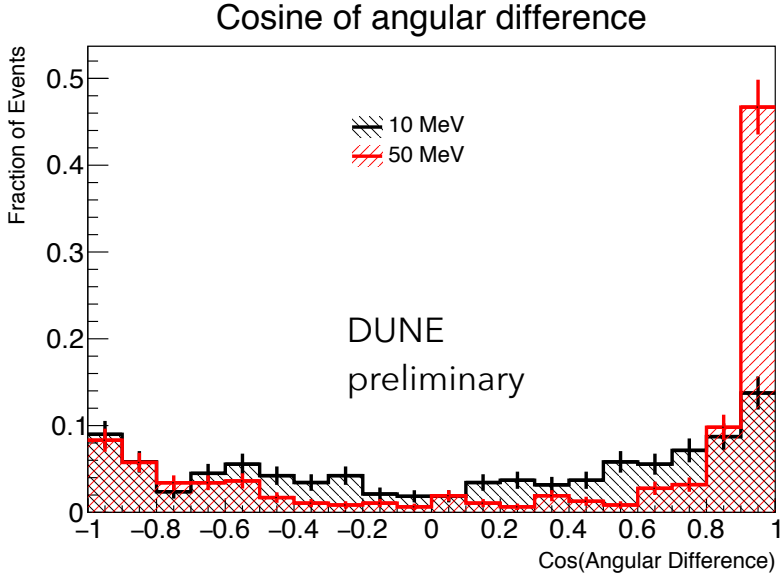
Elastic scattering cos(θ) comparisons (ν_e)

Standard reconstruction



Pointing Resolution **gets worse** with energy because of directional ambiguity and inclusion of narrower peak at cos(θ) = -1

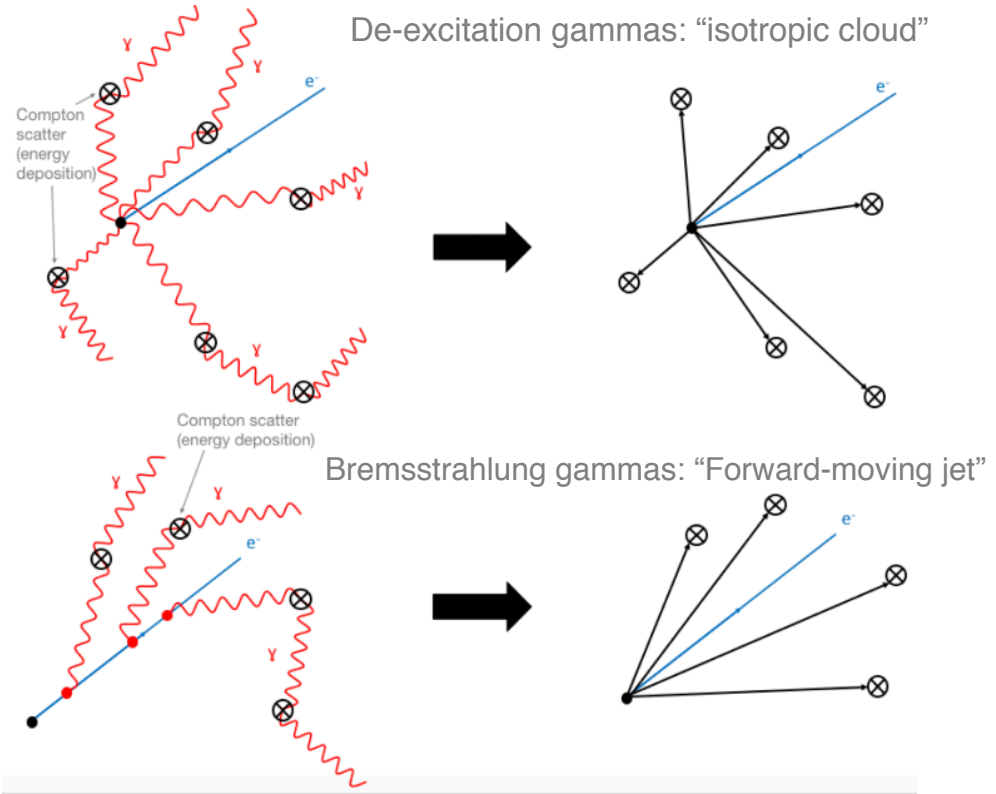
With daughter flipping



Pointing Resolution **improves** with energy because of better directional disambiguation

Channel tagging

- Work underway by Erin Conley
- Charged current and neutrino-electron elastic scattering produce different topologies
- Erin is attempting to use these to distinguish types of interactions in DUNE



Another view of the SN cosθ distribution (with daughter flipping and the likelihood function)