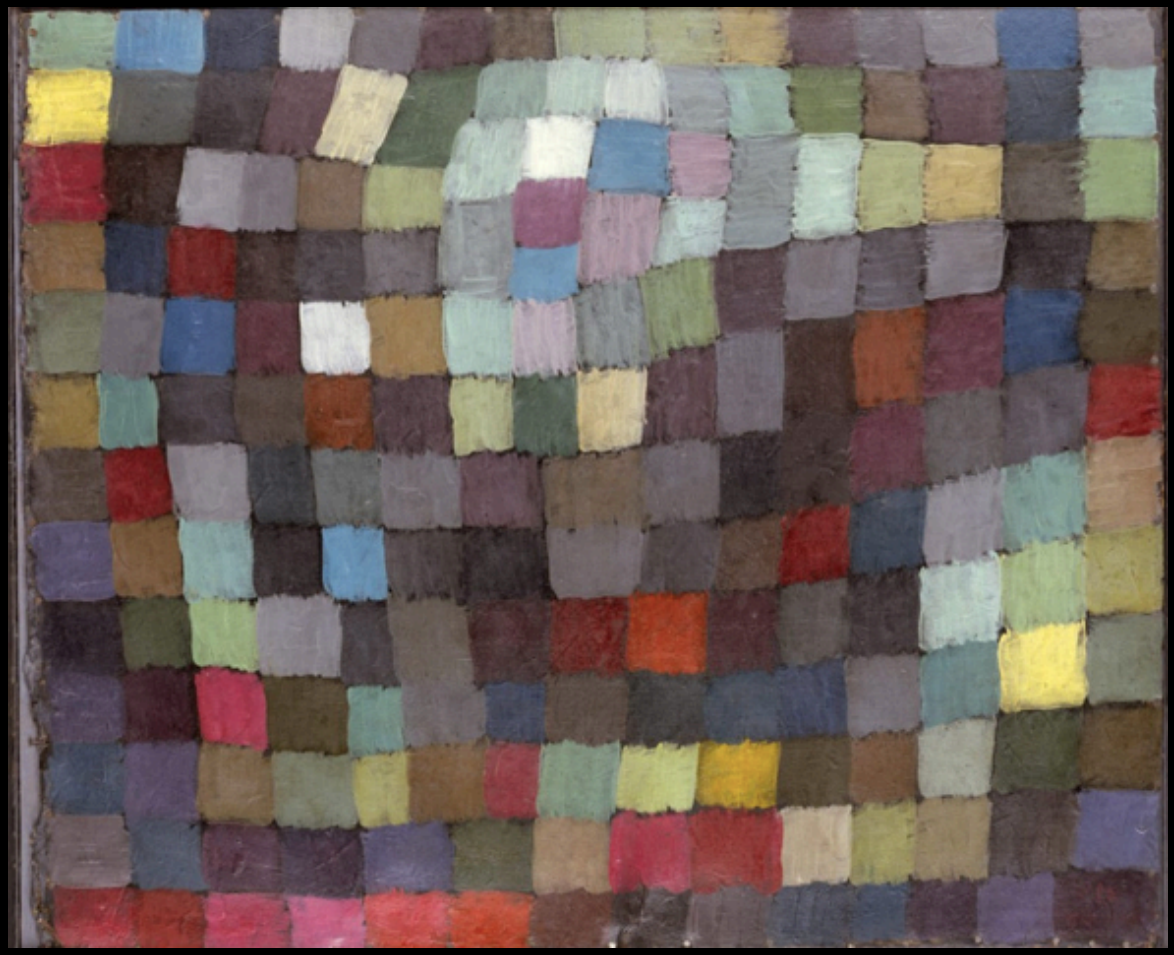
Pointing with Anisotropic Interactions



Kate Scholberg, Duke University
SNEWS 2.0 Workshop
June 2020

Neutrino Pointing Methods

- **Anisotropic neutrino interactions**
  combined with detector technology that can exploit it, using the burst neutrino signal
- **Triangulation**
  using inter-detector timing
- **Oscillation pattern pointing**
  in high-energy resolution detectors
- **High-energy (~GeV) neutrino follow-on pointing**
  in directional detectors, using later neutrinos
- **All of the above!**

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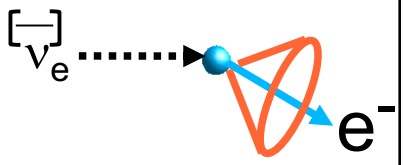
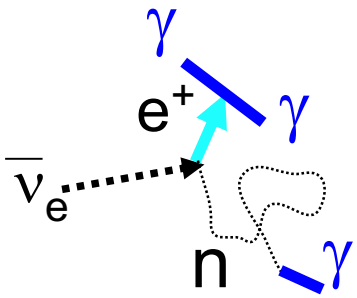
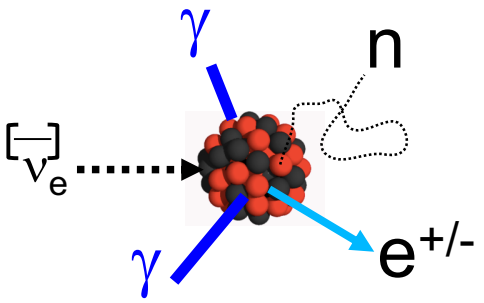
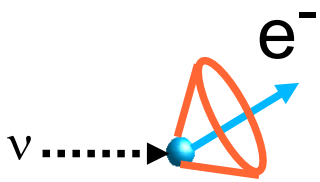
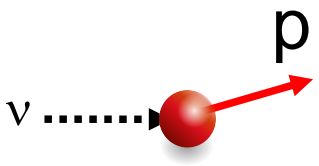
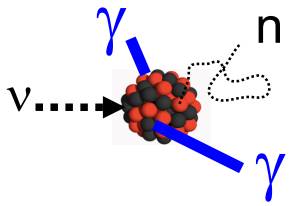
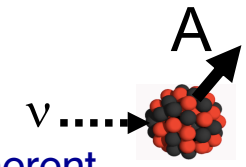
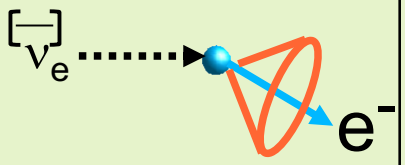
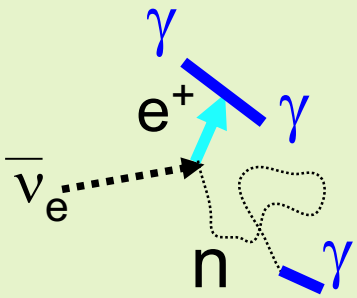
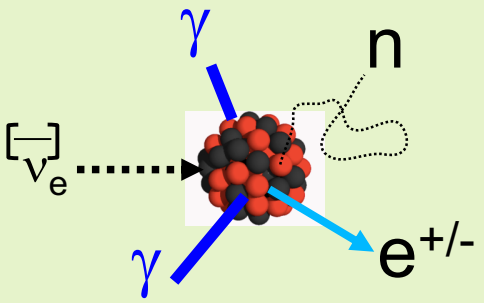
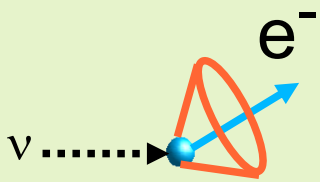
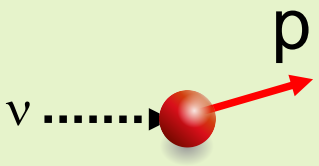
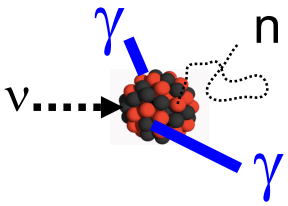
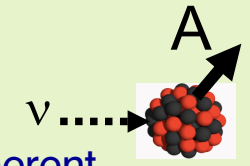
Supernova-relevant neutrino interactions

	Electrons	Protons	Nuclei
Charged current	Elastic scattering $\nu + e^- \rightarrow \nu + e^-$ 	Inverse beta decay $\bar{\nu}_e + p \rightarrow e^+ + n$ 	$\nu_e + (N, Z) \rightarrow e^- + (N-1, Z+1)$ $\bar{\nu}_e + (N, Z) \rightarrow e^+ + (N+1, Z-1)$ 
Neutral current	 Useful for pointing	Elastic scattering  very low energy recoils	$\nu + A \rightarrow \nu + A^*$  $\nu + A \rightarrow \nu + A$  Coherent elastic (CEvNS)

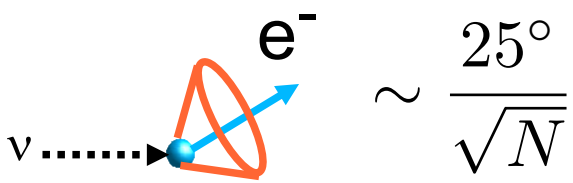
Various possible ejecta and deexcitation products

Most of these have at least *some* intrinsic anisotropy

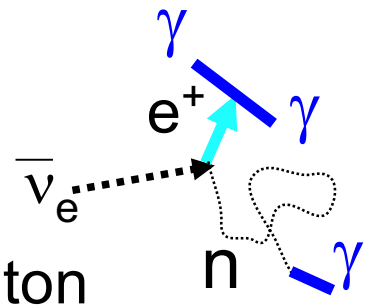
	Electrons	Protons	Nuclei
Charged current	Elastic scattering $\nu + e^- \rightarrow \nu + e^-$ 	Inverse beta decay $\bar{\nu}_e + p \rightarrow e^+ + n$ 	$\nu_e + (N,Z) \rightarrow e^- + (N-1, Z+1)$ $\bar{\nu}_e + (N,Z) \rightarrow e^+ + (N+1, Z-1)$  Various possible ejecta and deexcitation products
Neutral current	 Useful for pointing	Elastic scattering  very low energy recoils	$\nu + A \rightarrow \nu + A^*$  $\nu + A \rightarrow \nu + A$  Coherent elastic (CEvNS)

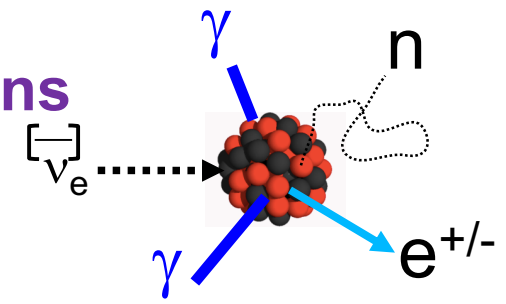
Anisotropic Neutrino Interactions

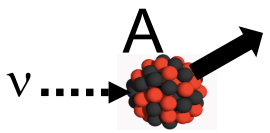
- **Neutrino-electron scattering (ES)**
  - Every detector has electrons
  - Good forward pointing
  - Low cross section, subdominant signal
- **Inverse beta decay (IBD)**
  - Dominant in water and scintillator
  - Weak energy-dependent anisotropy for lepton
  - Neutron capture position can help
- **Neutrino-nucleus charged-current interactions**
  - Some anisotropy of lepton wrt neutrino
  - Nuclear structure uncertainties $\sim 1 + a\cos\theta$
- **Elastic scattering on protons or nuclei**
  - Well-defined anisotropy [experimentally hard...]



$$\sim \frac{25^\circ}{\sqrt{N}}$$



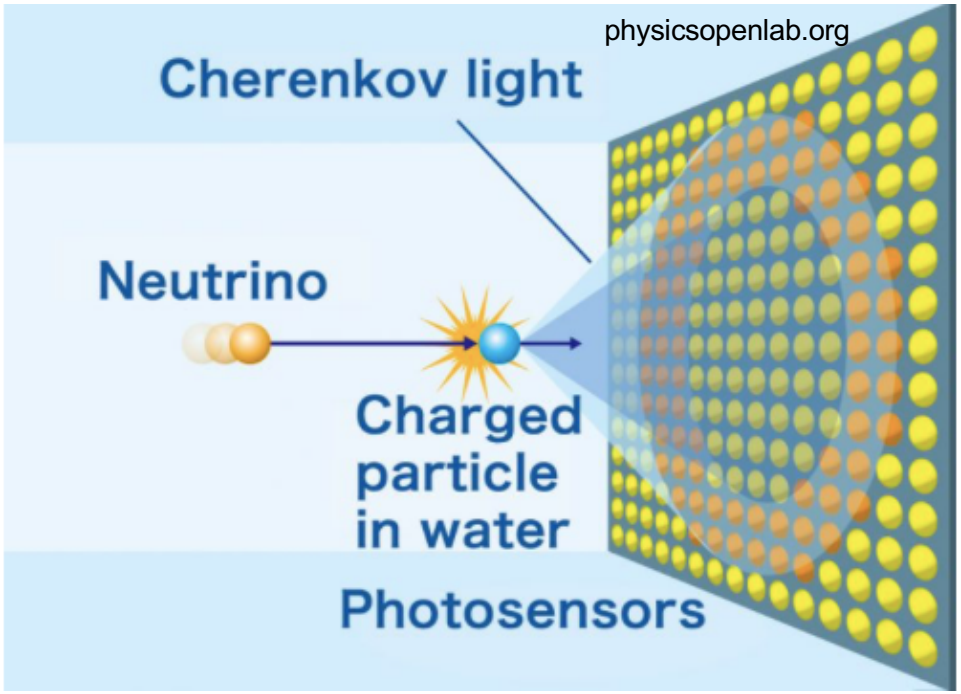


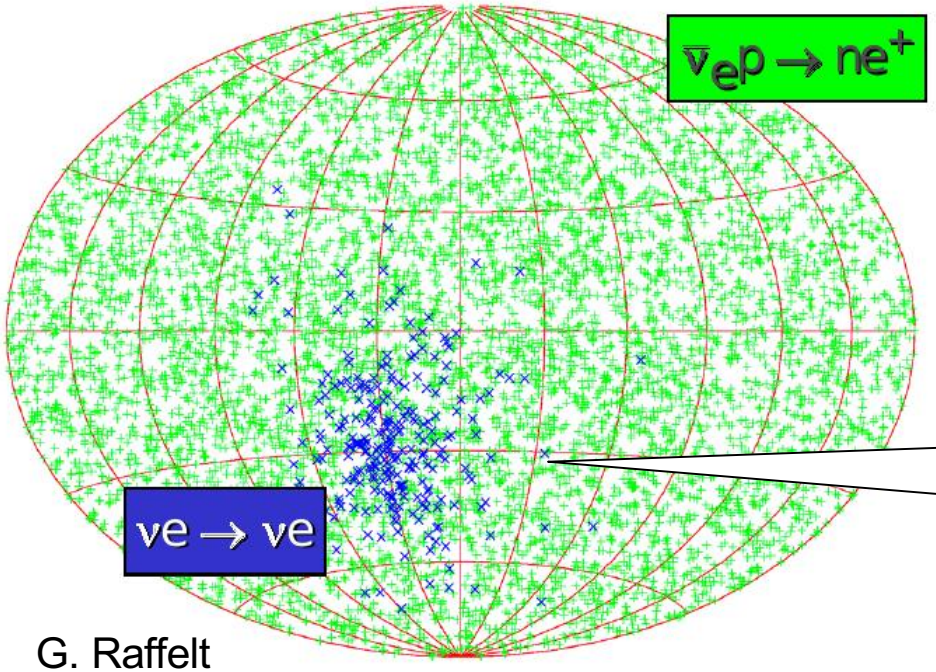


In all cases, the *detector* must be capable of exploiting directionality via tracking of some kind

Water Cherenkov Detectors

Excellent intrinsic directionality, including head-tail disambiguation

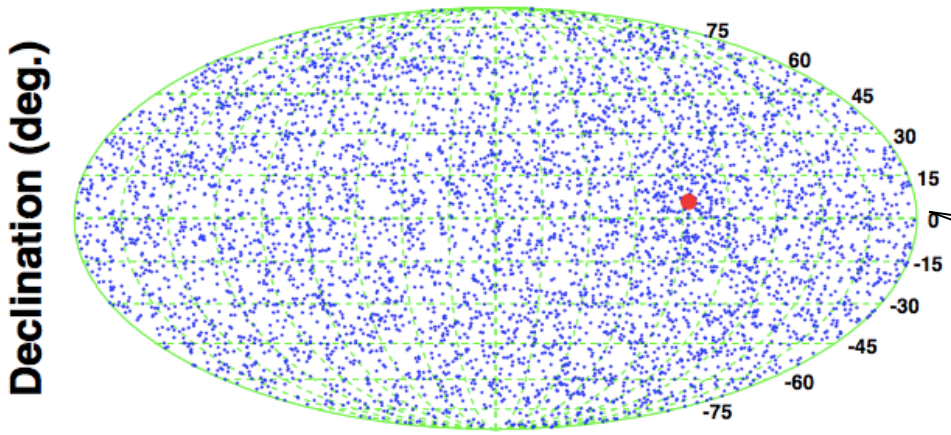




G. Raffelt

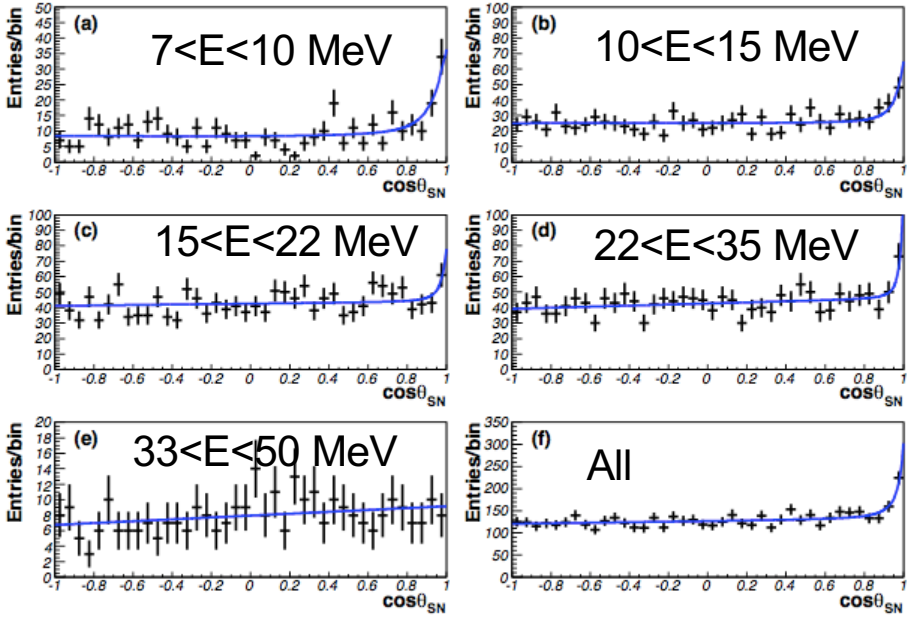
The go-to pointing method is ES in SK

Pointing in Water Cherenkov: Super-K

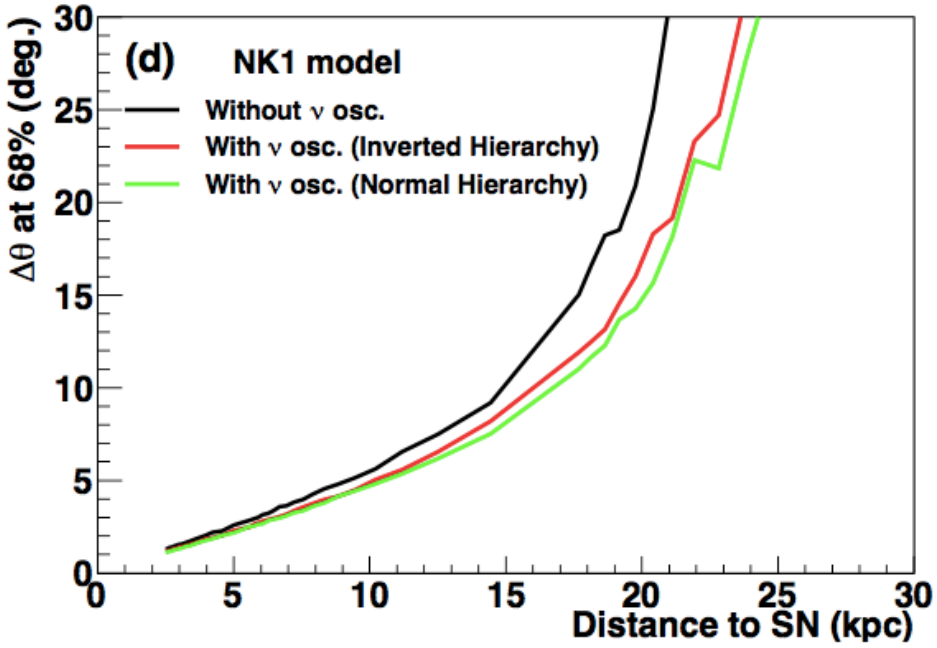


K. Abe et al., Astropart. Phys. 81 (2016) 39-48

Harder when you don't have the interaction truth!

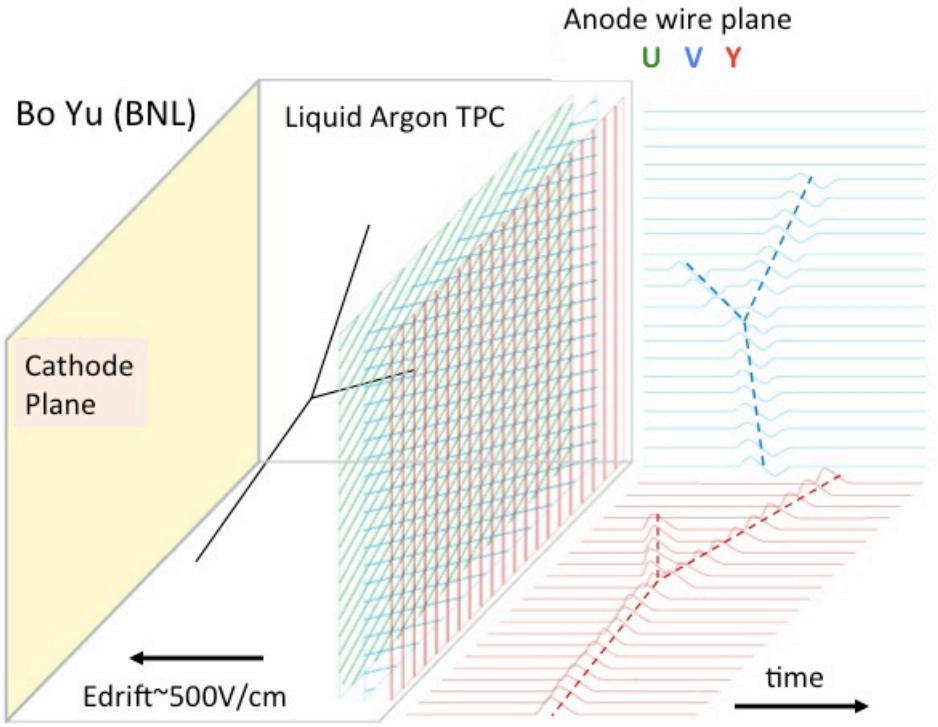


Fit to ES+ mildly anisotropic IBD (+^{16}O)

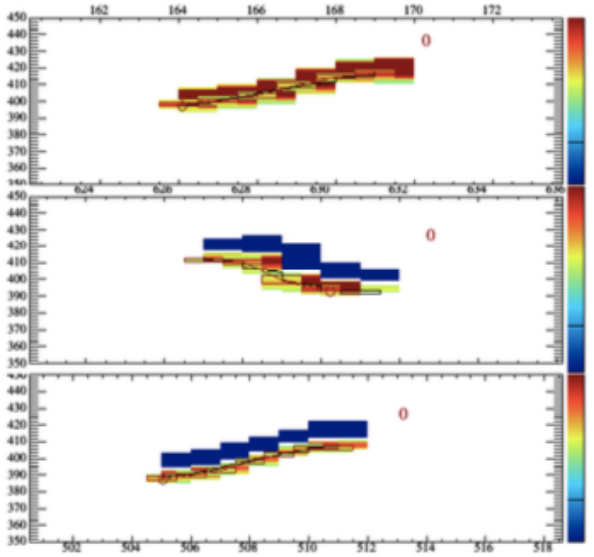


- Will improve w/SK-Gd
- HK will get to ~few deg

Pointing to the supernova with LArTPCs



10.25 MeV electron

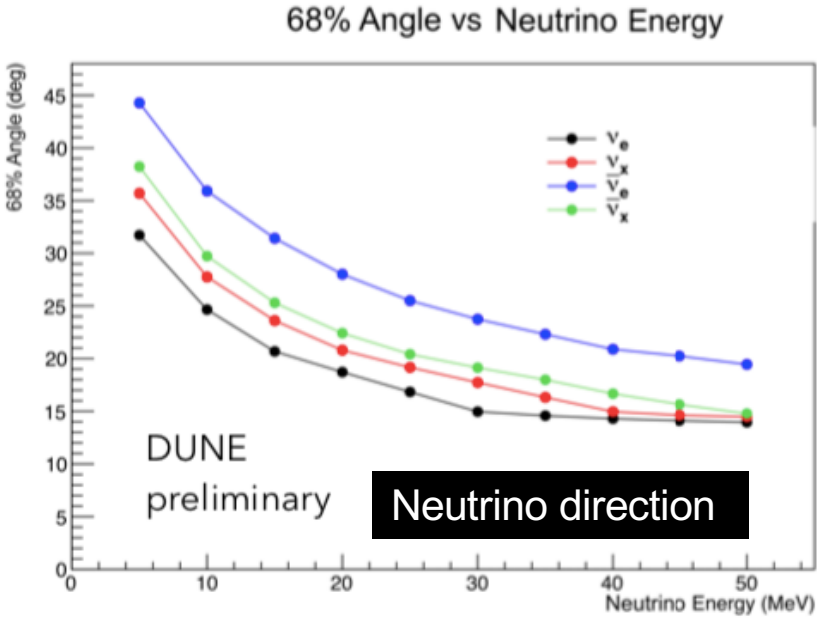


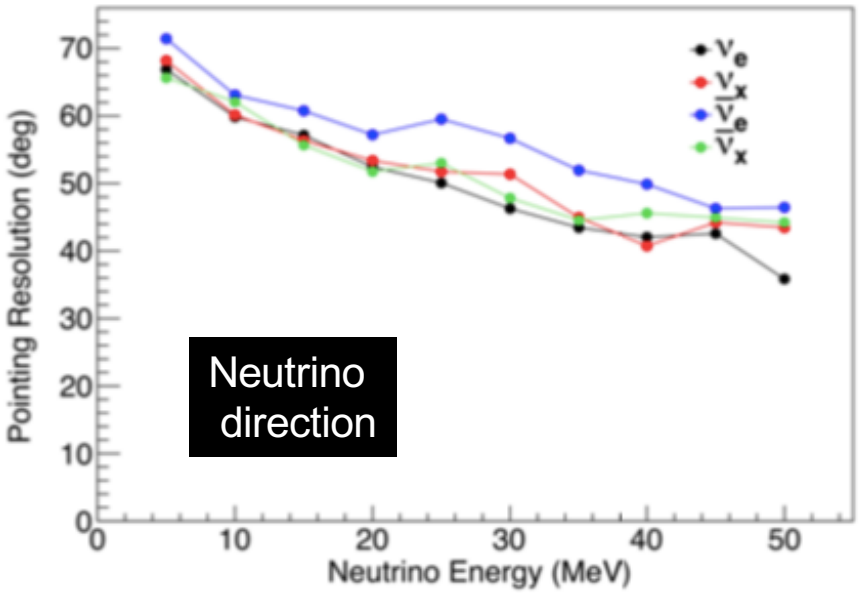
Fine-grained tracking...

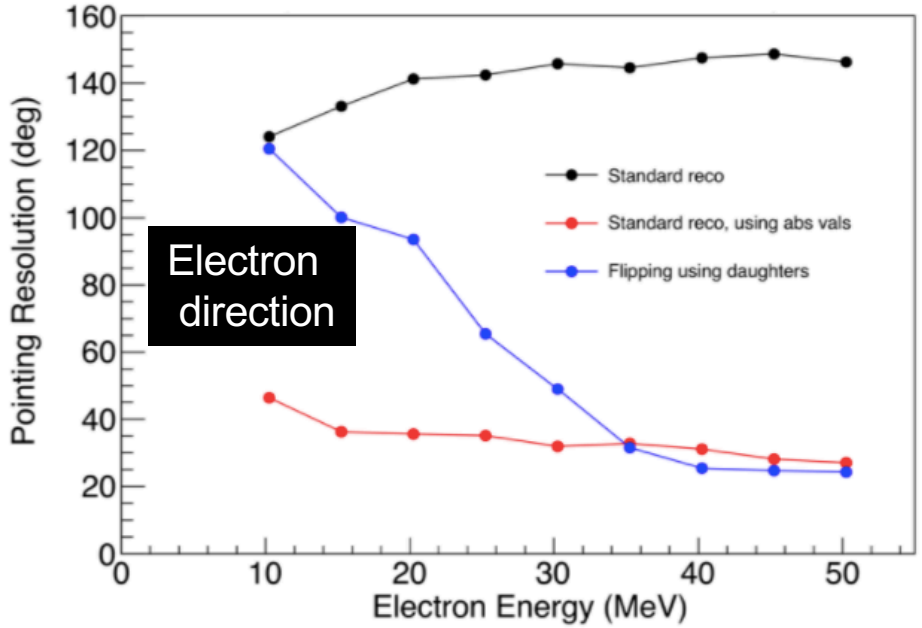
but note direction ambiguity, unlike Cherenkov!

... but can resolve statistically using bremsstrahlung directionality and multiple scattering

Pointing to the supernova with ES in DUNE

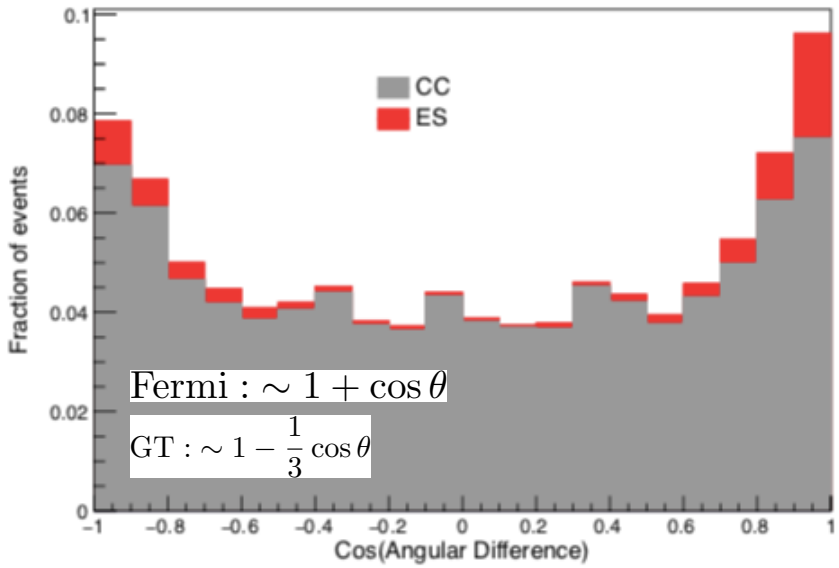




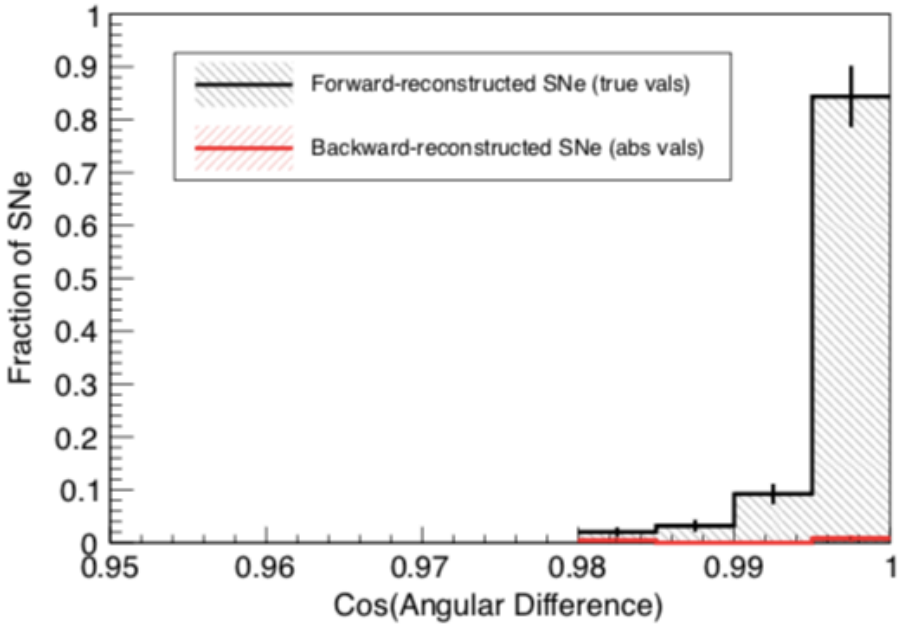


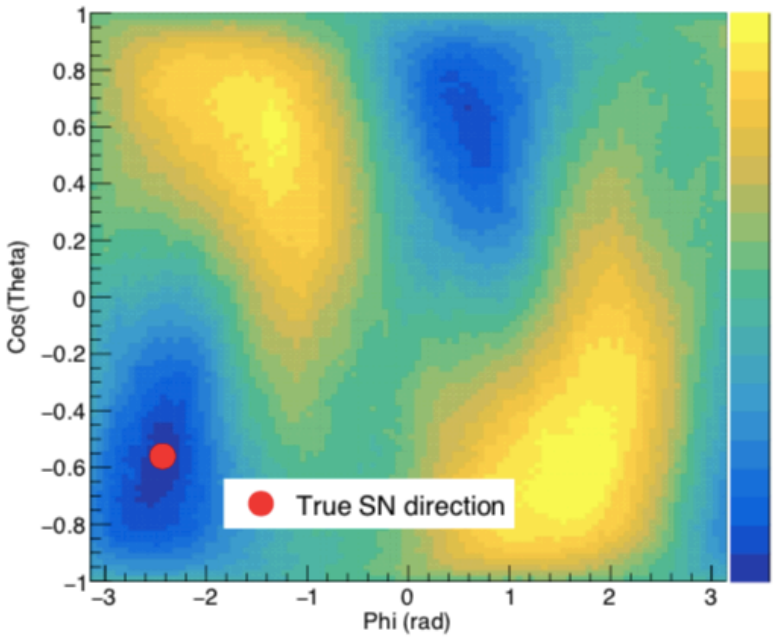
AJ Roeth, in DUNE TDR

Can make use of both ES and ν_eCC directionality



Maximum likelihood method





Overall pointing using an ensemble of events from a ~10 kpc supernova) → ~5°
...improvements still possible

AJ Roeth, DUNE TDR

Pointing with Liquid Scintillator

This is hard, as produced photons get quasi-isotropized...

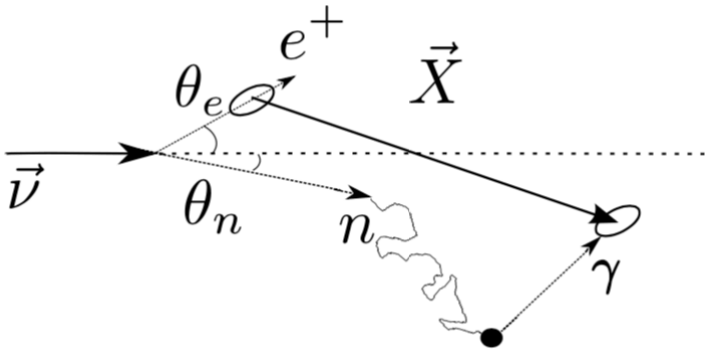
BUT, some statistical prospects using IBD kinematics

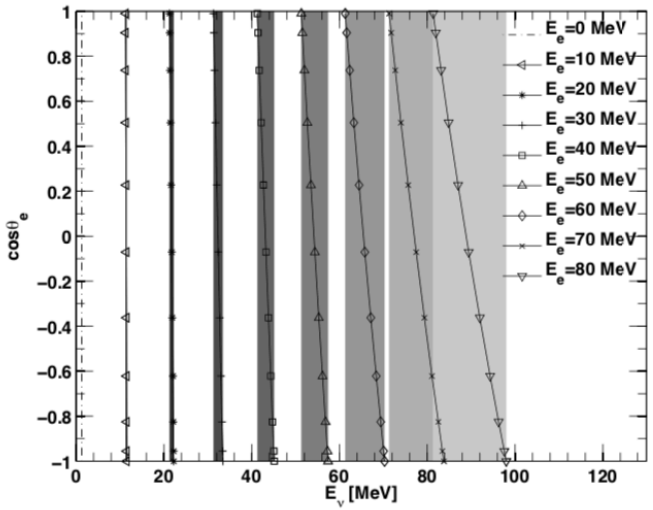
→ positron energy + reconstructed vertices of e^+ and n

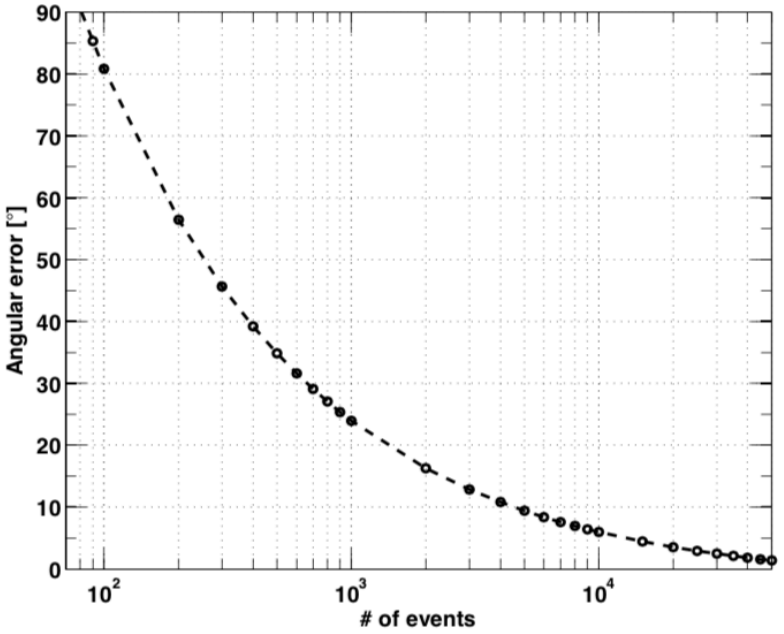
Prompt directional detection of galactic supernova by combining large liquid scintillator neutrino detectors

V. Fischer (IRFU, Saclay) *et al.*. Apr 21, 2015. 25 pp.

Published in **JCAP 1508 (2015) 032**







Needs good statistics!

Comments

- anisotropic interactions will likely be the best information from neutrinos
  - currently SK has best pointing
- unknown latency... may not be prompt
- we need to consider how to combine with (likely more prompt, but lower quality) triangulation information
  - need tiered strategy