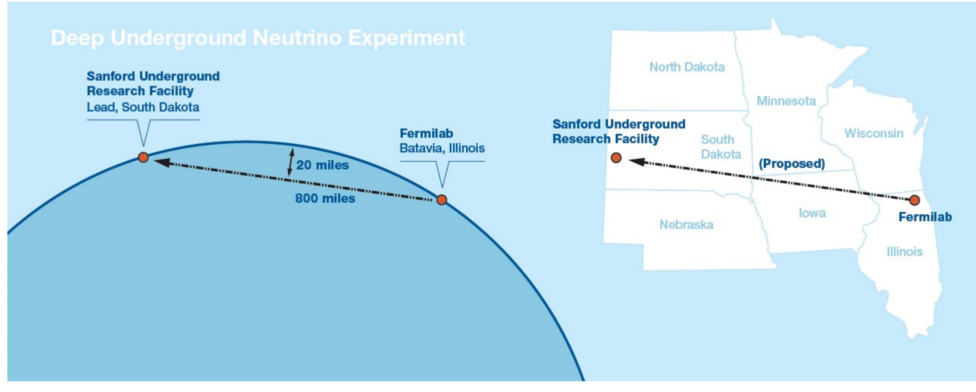
Supernova Neutrino Detection in DUNE

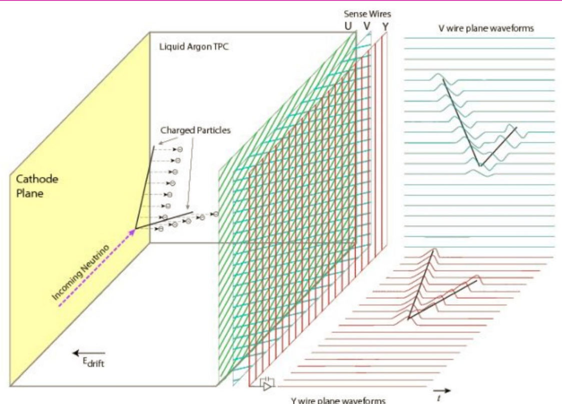
DEEP UNDERGROUND NEUTRINO EXPERIMENT

UMD
UNIVERSITY OF MINNESOTA DULUTH
Driven to Discover
Alec Habig
for the DUNE Collaboration

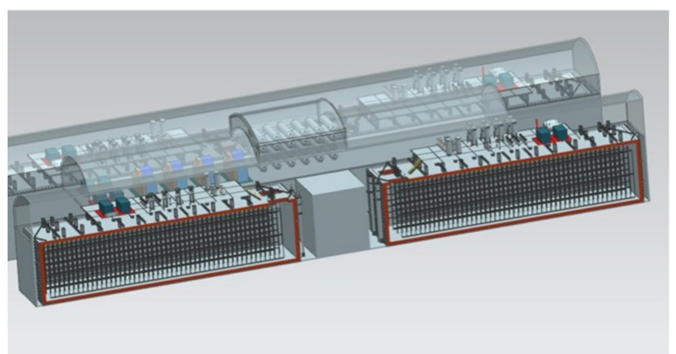


DUNE is a long-baseline (1300 km) neutrino experiment being built at Fermilab and the Sanford Underground Research Facility using a new ν_μ beam to study ν oscillations, mass ordering, and δ_{CP}.

Being large (40 kt) and deep (4300 mwe), it will also be sensitive to physics such as supernova ν and proton decay.

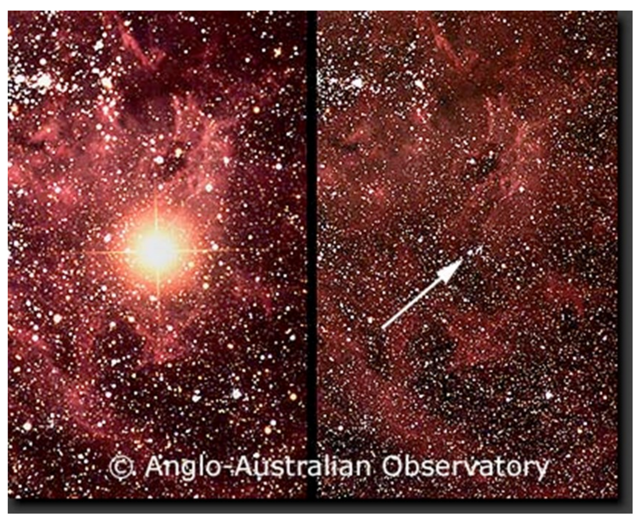


Particle detection via Single Phase (liquid argon) drift of ionization charge to readout wires.
Figure by Bo Yu, BNL



Two adjacent DUNE SP 10 kt LAr Time Projection Chamber (TPC) modules

DUNE will be composed of four 10 kt Liquid Argon TPCs. The first will be Single-Phase technology (*two "SP" modules shown above*); the second Dual Phase (*"DP", below*); the last two to be determined. The first 10 kt module will begin data taking in 2026.

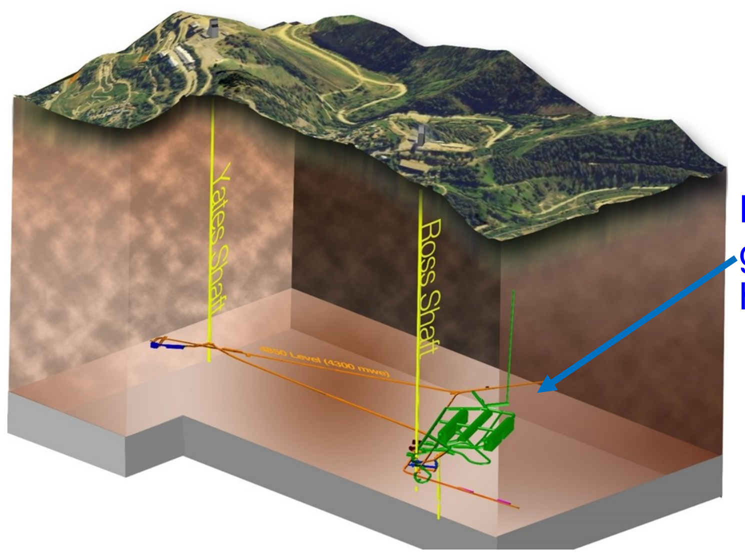


Only 0.1% of the gravitational binding energy released by the collapse of the core of a giant star into a neutron star is released as photons, yet it is still as bright as a whole galaxy for weeks. SN1987A showed that 99% is released in ν: the ~kt scale experiments of the day registered a couple dozen ν.

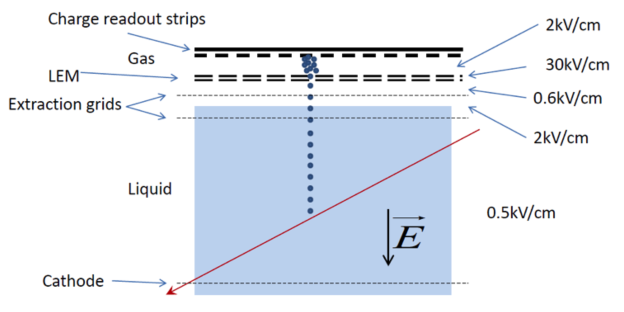
The infall phase ends at core bounce, the creation of the neutron star. This produces a short (~50 ms) burst of ν_e, but only about 1% of the total flux (Raffelt 1999).

In the next fraction of a second, neutrinos produced by accretion of matter on the new neutron star will carry information about the astrophysics of the explosion.

The bulk of the neutrinos are produced via pair production over tens of seconds as the neutron star cools.

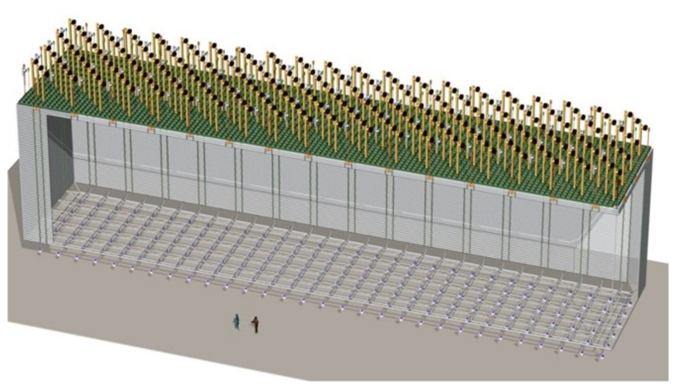


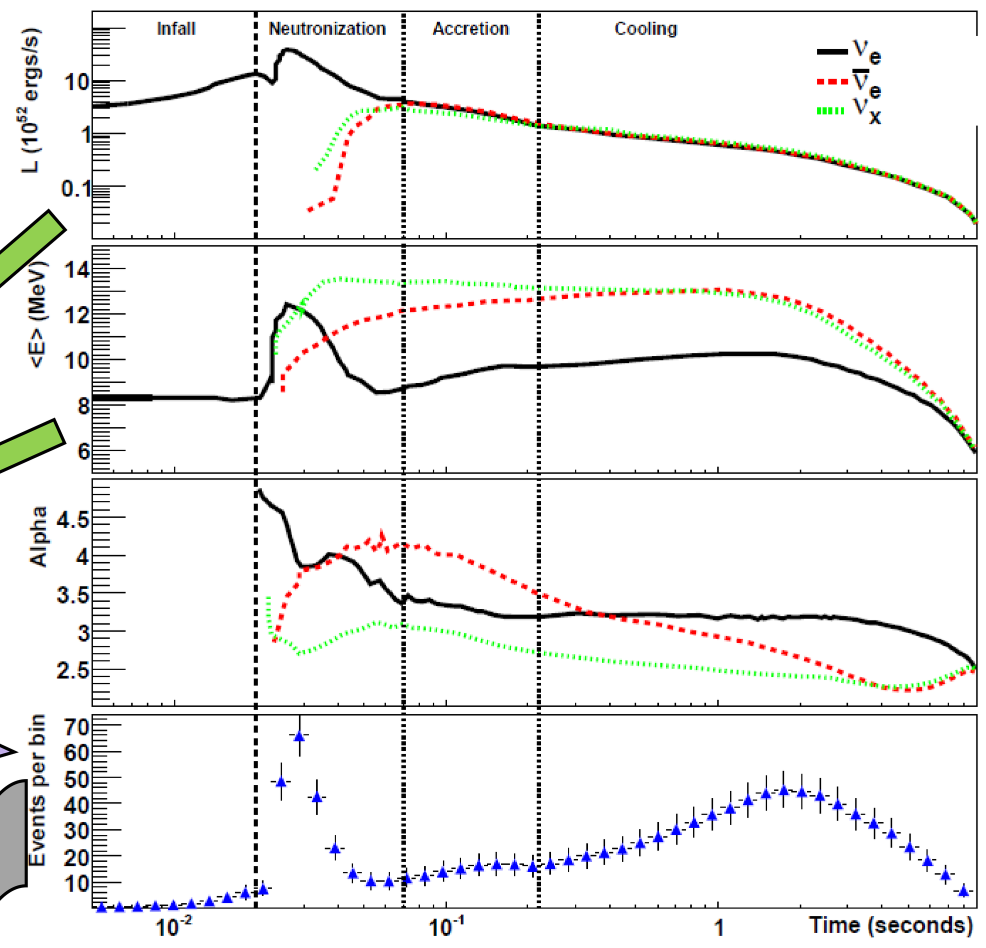
In a DP detector, ionization charge drifts upwards, producing light at the liquid/gas interface.



DP cartoon from Baller, B. *et al.* JINST 9 T05005 (2014)

One DUNE DP 10 kt LAr TPC module.

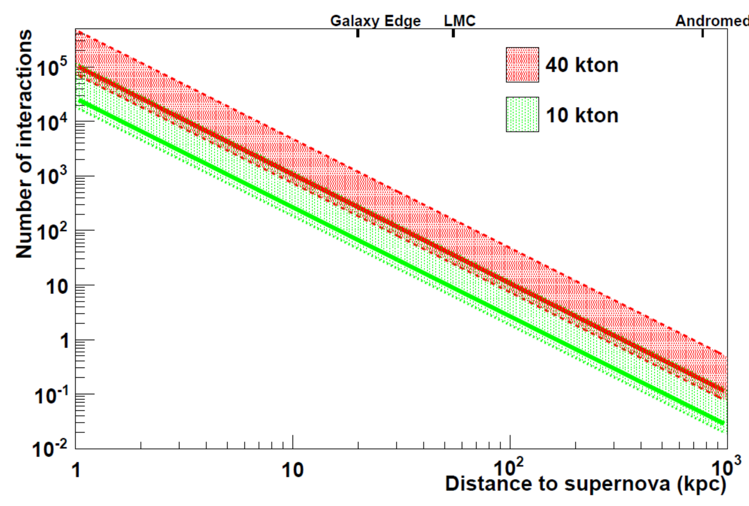




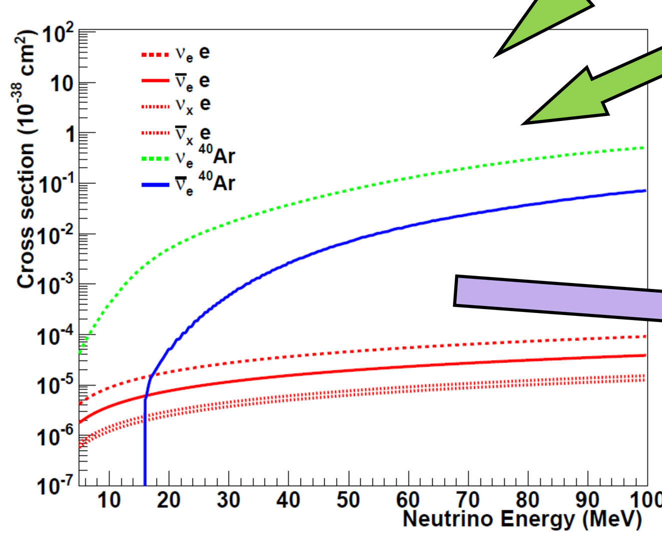
This model from Huedepohl (2010) is for a SN at 10 kpc. ν fluxes are presented pre-oscillation vs log time. The top graph is ν luminosity; the second the ν energy.

Pinching parameter α is third, and the resulting expected signal per time bin in 40 kt of LAr (from SNOwGLoBES, with statistical errors) are the blue points at the bottom.

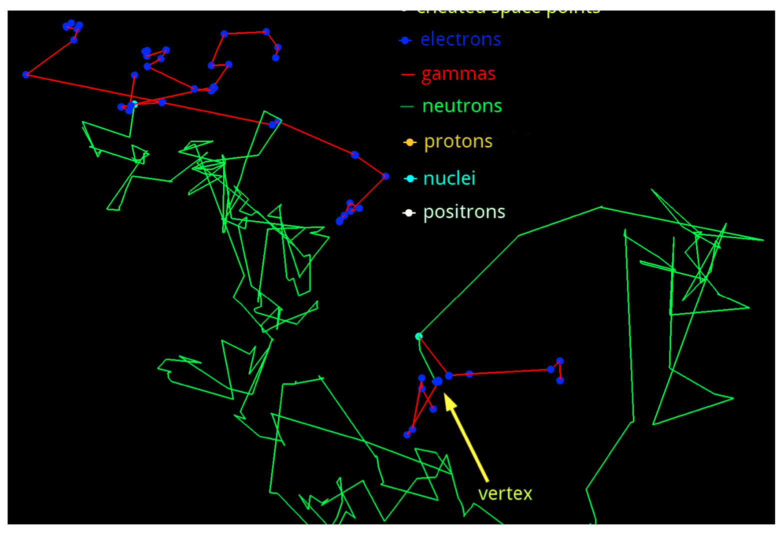
10's of MeV ν interactions often put energy into nuclear excitations and neutrons: modeled by MARLEY (*Model of Argon Reaction Low-Energy Yields*)
`http://www.marleygen.org/`
(*Steven Gardiner, UC Davis*)



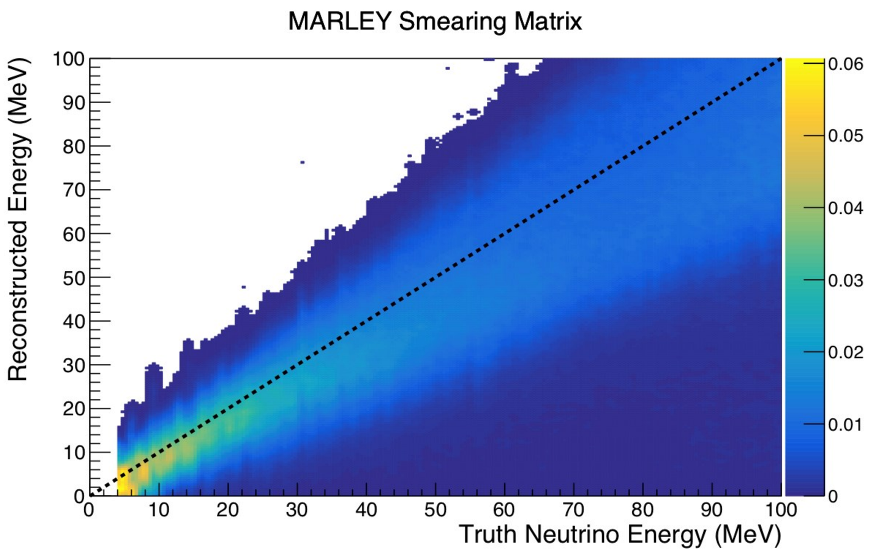
Expected total ν signal from *SNOwGLoBES*). Solid lines are from Huedepohl (2010), for both 10 kt and the full 40 kt DUNE: systematic bands are from the Garching parameterization (2014) of <E>=12 MeV and α=2 (top) and <E>=8 MeV and α=6 (bottom).

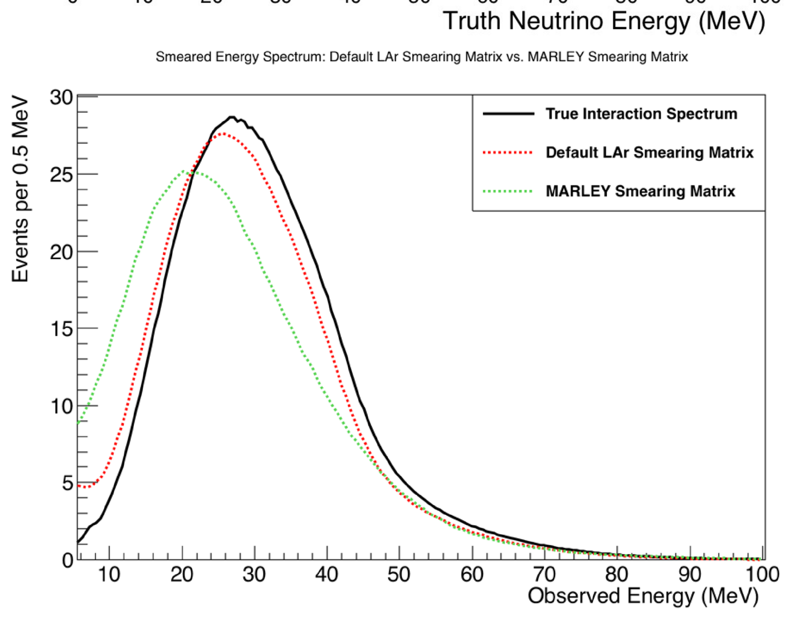


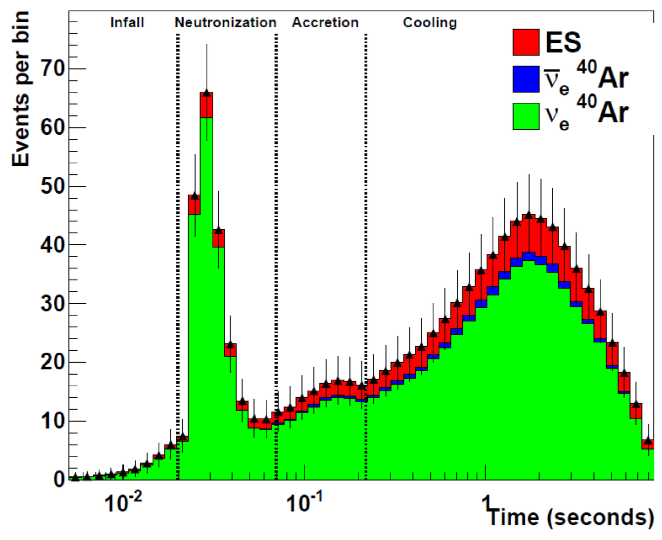
ν on Ar cross sections from Gil-Botella (2003) plotted using SNOwGLoBES. ν flux and energy are combined with these to find the signal in DUNE. DUNE is mostly sensitive to ν_e, while most other ν experiments see ν_e-bar.

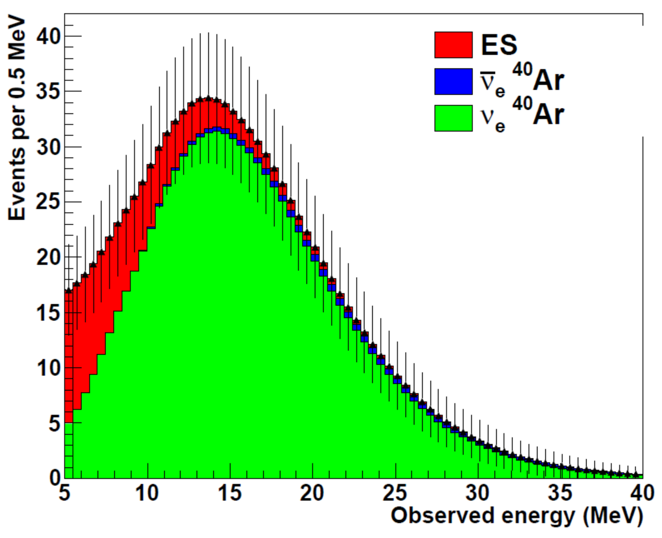


MARLEY is used to improve simulations and calculations of SN ν on LAr. Below, the resulting correlations between ν energy and reconstructed energy used to improve SNoWGLoBES SN ν response calculations (*top*) compared to pre-MARLEY version (*bottom*). (*Erin Conley, Duke*)

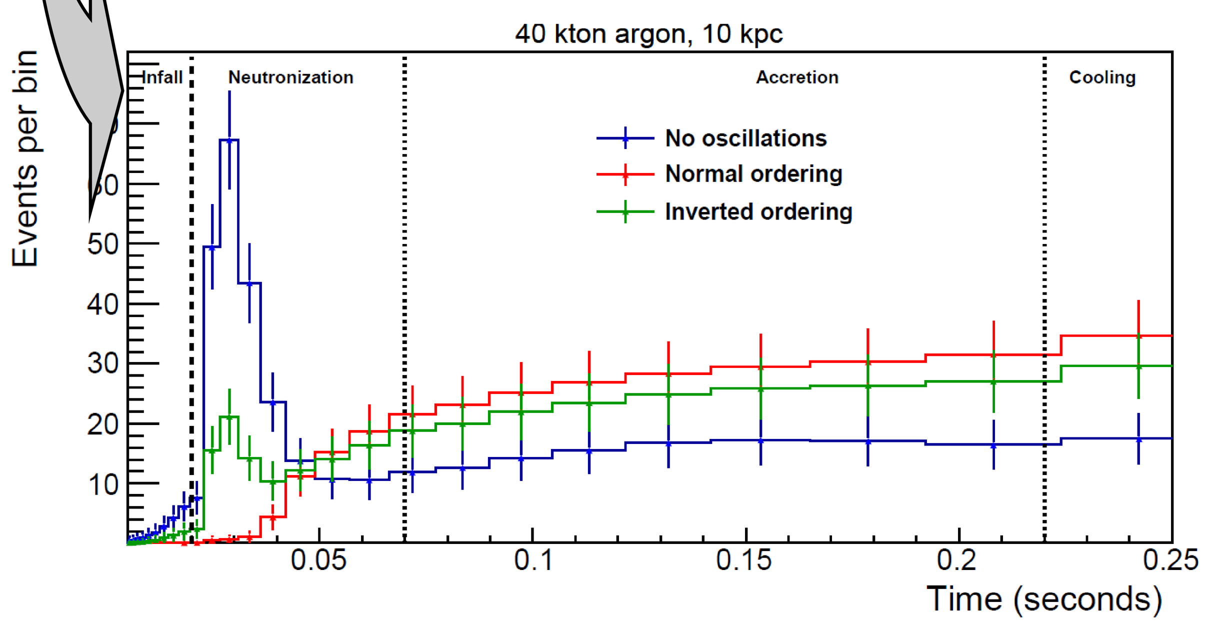








Time dependent signal (left) and spectra (right) for a SN at 10 kpc in 40 kt DUNE. (*flux from Huedepohl 2010*). Note all the ν_e (*in green*).



Of course, those ν do oscillate: experiencing strong matter effects in the dense neutron star. The ν_e in the neutronization peak behave very differently for Normal vs. Inverted ν mass ordering.

This figure is a close up in time of the bottom panel of the figure above, with oscillation scenarios applied.

DUNE's sensitivity to ν_e is needed to see this effect, which would unambiguously determine the ν mass ordering.

Based on observations of other, similar galaxies, we expect several core-collapse SNe per century in the Milky Way. A likely distance would be 10-15 kpc.

See Alex Booth's poster "Triggering on Supernova Burst Neutrinos at DUNE" (#3 in this session) for information on how DUNE can identify and save data from the next galactic Supernova.

Summary:

DUNE will see thousands of ν_e from the next galactic SNe. ν_e sensitivity is vital to sorting out ν mass ordering and could provide further clues to both the astrophysics and ν collective effects when compared to the rest of the world's sample of ν_e–bar.

"Collective Effects" on ν oscillations might also occur: the neutrinos themselves become an important part of the MSW potential given their huge numbers.

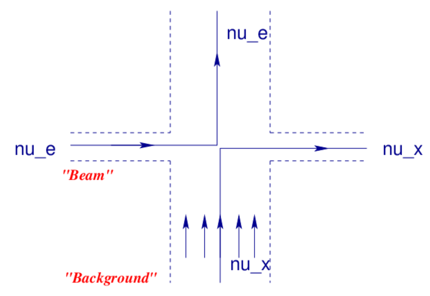


Figure from Friedland & Lunardini, Phys. Rev. D 68, 013007 (2003)

This could result in further spectral and time signatures in the different ν flavors. Work is in progress to define what DUNE could learn from this extreme environment.

References:
DUNE CDR, arXiv:1512.06148 [physics.ins-det] (2015)
Baller, B. *et al.* JINST 9 T05005 (2014)
Raffelt, G.G. Ann. Rev. Nucl. Part. Sci. 49, 163 (1999)
Hudepohl, L. *et al.* Phys..Rev..Lett. 104, 251101 (2010)
`http://www.phy.duke.edu/~schol/snowglobes`
Gil Botella, I. *et al.* JCAP 0310, 009 (2003)
Tamborra, I. *et al,* Phys. Rev. D 90, no. 4, 045032 (2014)
Friedland & Lunardini,Phys. Rev. D 68, 013007 (2003)

`http://www.dunescience.org`

NEUTRINO 2018
4-9 June
Heidelberg

The DUNE collaboration meeting
May 15, 2018, at Fermilab

The Deep Underground Neutrino Experiment collaboration is 1061 Scientists and Engineers from 175 Institutions in 31 countries.

This Poster supported by NSF RUI grant #1607381.
DUNE is funded in the U.S. by the U.S. Department of Energy Office of Science

U.S. DEPARTMENT OF ENERGY | Office of Science