Solar and Supernova Neutrino Detection for the Deep Underground Neutrino Experiment

Erin Conley
On behalf of the DUNE Collaboration
CIPANP 2018: May 29, 2018
Outline

• Solar and supernova neutrinos
  – Introduction
  – What and where to look?
  – Motivation for detection
• The Deep Underground Neutrino Experiment (DUNE)
  – Liquid argon time-projection chamber
  – Challenges DUNE faces in detecting these neutrinos
• Current Work
• Summary
Solar Neutrinos: Introduction

- Largest natural source of neutrinos
- Sun produces trillions of neutrinos via nuclear fusion
  - Various reactions produce solar neutrinos, e.g., proton-proton, \(^7\text{Be}\), \(^8\text{B}\), \(^{15}\text{O}\), etc.
- Low in energy (a few to tens of MeV)
  - For the purposes of this talk, we are interested in the \(^8\text{B}\) neutrinos (outlined in red)
- Solar neutrinos are useful:
  - Help test solar models
  - Determination of neutrino parameters
  - Matter effects/oscillations

Energy generation in the sun (Altmann et al.)
• Star at end of lifetime: core undergoes gravitational compression, collapses
• 99% of potential energy in the form of neutrinos is released (tens of MeV)
• Supernova core collapse physics is not well understood; neutrino burst contains valuable information about both the mechanism and phenomena associated with supernova bursts (K. Scholberg)
What to look for: Energy spectra

Supernova neutrino energy spectrum (K. Scholberg)  
Solar neutrino energy spectrum (Altmann et al.)

Both spectra have a similar energy range and similar reconstruction issues, although SN events come in ~tens of second burst. This talk will focus on supernova neutrinos.
Where can we look for supernova neutrinos?

• The closer the supernova is to Earth, the more neutrinos we can detect!
• Places of interest:
  – Milky Way
  – Large Magellanic Cloud
  – Andromeda Galaxy
    • Due to distance from Earth, not a lot of neutrinos could be detected…

Number of interactions expected to be seen in LAr detector
Detecting supernova/solar neutrinos

• Various properties of a detector that will help detect supernova/solar neutrinos:
  – Large detection medium
  – Low background
  – Good timing resolution
  – Adequate reconstruction abilities

Supernova 1987A
Relevant neutrino interactions

Charged Current (CC): $\nu_e + (N, Z) \rightarrow (N - 1, Z + 1) + e^-$

Neutral Current (NC): $\nu + A \rightarrow \nu + A^*$

$A^* \rightarrow \gamma + A$

Elastic scatter on electrons (ES): $\nu + e^- \rightarrow \nu + e^-$
Detecting electron neutrinos is useful

Example of robust mass ordering signature: the neutronization burst

An experiment sensitive to electron neutrinos is desirable and powerful!
• International experiment for neutrino science (1000+ collaborators!)
  – Origin of matter, **supernova physics**, nucleon decay

• Two detectors:
  – Near detector on-site at Fermi National Laboratory (near Chicago, IL)
  – Far detector at Sanford Underground Research Laboratory (SURF) in South Dakota
    • World’s largest liquid argon time-projection chamber

• Argon is sensitive to electron neutrinos, making DUNE unique with respect to other experiments (e.g., water and scintillator detectors are $\bar{\nu}_e$ sensitive)

---

http://www.dunescience.org/
Liquid Argon Time Projection Chamber (LArTPC): Introduction

- Neutrino-argon interaction: argon is ionized by charged secondary particles
  - Scintillation light detected by PMTs gives us timing information
- Charged particles drift toward induction planes, deposit charge on collection plane wires
- Charge deposited on collection wires
  - Reconstructed wire objects (signals for specific particles)
  - Reconstructed 2D hits (single ionized particles)
  - Reconstructed 2D clusters (ionization of multiple particles)
  - Reconstructed 3D objects like tracks, showers, space points

For more information
DUNE Event Displays

- Event display: charge depositions + reconstructed objects
  - Collection plane shown here
- Top: 30.25 MeV $\nu_e$CC event display
- Bottom: 9.8 MeV gamma NC event display
Challenges DUNE faces

• Understanding the SN model
  – Time profile studies depend heavily on the model
• Understanding the background
  – Radiological background, electronic noise
• Reconstruction algorithms
  – Low-energy interactions (small number of hits)
• Data acquisition (DAQ) challenges
  – Trigger rates
  – Data rates
• For the purposes of this talk:
  – What predictions can we make about the supernova signal in the DUNE detector?
  – How will we reconstruct the neutrino-argon events?
What kind of predictions can we make?
SNOwGLoBES: Introduction

- SNOwGLoBES: SuperNova Observatories with GLoBES
  - GLoBES: General Long Baseline Experiment Simulator
- Updated default LAr smearing matrix in SNOwGLoBES using MARLEY simulations

http://phy.duke.edu/~schol/snowglobes/
MARLEY: Model of Argon Reaction Low-Energy Yields

- MARLEY models low-energy $\nu_e$CC neutrino interactions
- More sophisticated modeling of final state particles
- http://www.marleygen.org/

Particle trajectories from a simulated SN event in DUNE

S. Gardiner
Improving the predictions made using SNOwGLoBES:

- Used GVKM flux model to make these spectra
- “True Interaction Spectrum”: interaction rates before smearing
- Energy loss between the default smearing matrix, MARLEY smearing matrix
- Shows that the default smearing matrix was unrealistic and more optimistic compared to more sophisticated MARLEY modeling
How will we reconstruct the neutrino-argon interactions?
Finding a Gamma-Tagging Algorithm

- Working on an algorithm to distinguish between bremsstrahlung, de-excitation gammas in CC, NC, ES events
  - Study differences between $\nu_e$CC events for the two types of gammas to learn how to tag them
- Performed studies on MC Truth information; distinct distributions in directionality, isotropy quantifications
- Currently studying reconstruction information

De-excitation gammas: “isotropic cloud”

Bremsstrahlung gammas: “Forward-moving jet”
MC Truth for trial gamma-tagging parameters

Truth Vector Lengths for Brems and De-excitation gammas

- Left: Summed MC truth vector lengths, normalized
- Right: Summed MC truth dot products between (normalized) electron, gamma vectors

Bremsstrahlung distribution shows positive, more “forward-moving” behavior
De-excitation distribution shows less positive, more isotropic behavior

10k 30.25 MeV $\nu_e$CC events
Summary

• Solar and supernova neutrinos have much lower energies (few to tens of MeV energy range) than those studied in the rest of DUNE's physics program
• The DUNE collaboration wants to be prepared for solar neutrinos and future supernovae (fingers crossed!)
• SNOwGLoBES gives insight into what kind of interaction rates long baseline experiments should expect to see
  – Efforts have been made to update smearing matrices so that our expectations are more reliable
• We are making progress on tagging interaction channels
• Supernova/solar neutrino studies improve expectations, advance the low-energy neutrino physics field, and prepare the DUNE detectors to detect these neutrinos under the most optimal circumstances!
Backup Slides
Solar neutrino rates for the DUNE detector

• Rate for 40kt LArTPC: 122 solar neutrinos per day
  – 4.5 MeV neutrino energy threshold, 31% $\nu_e$ survival
  – Signatures: ES, CC
• Observability will depend on backgrounds; under study
• For more information
Current default in SNOwGLoBES assumes all final-state energy recovered, which is likely much too optimistic
reco energy = true ν energy – 1.5 MeV, convolved with Icarus resolution