Supernova Observation via CEvNS Glow

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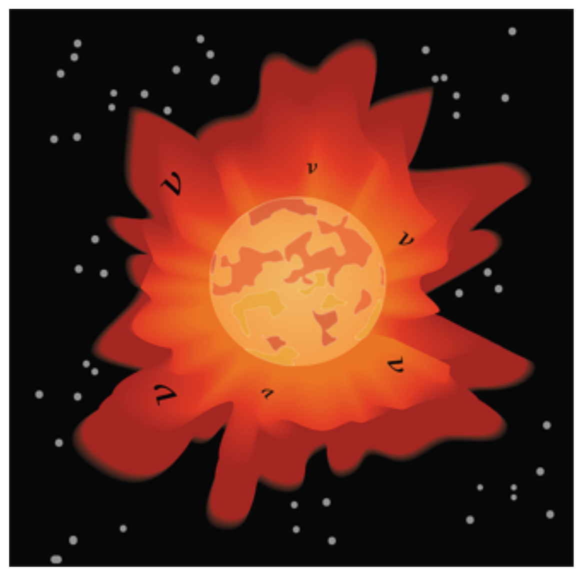
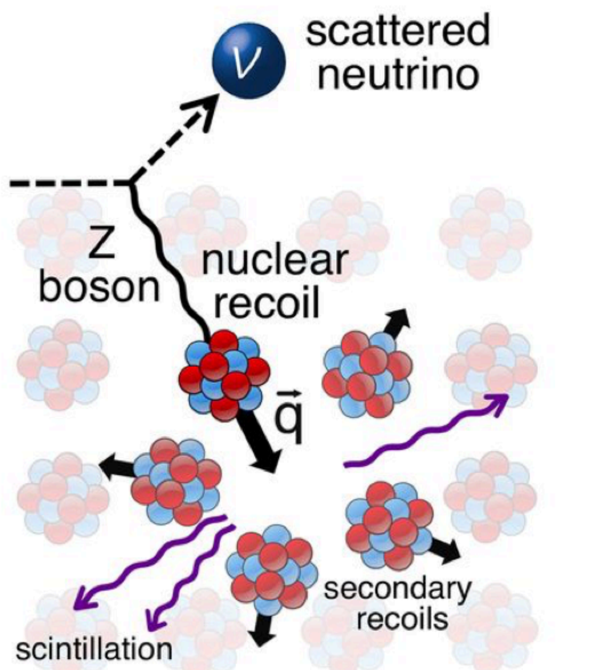
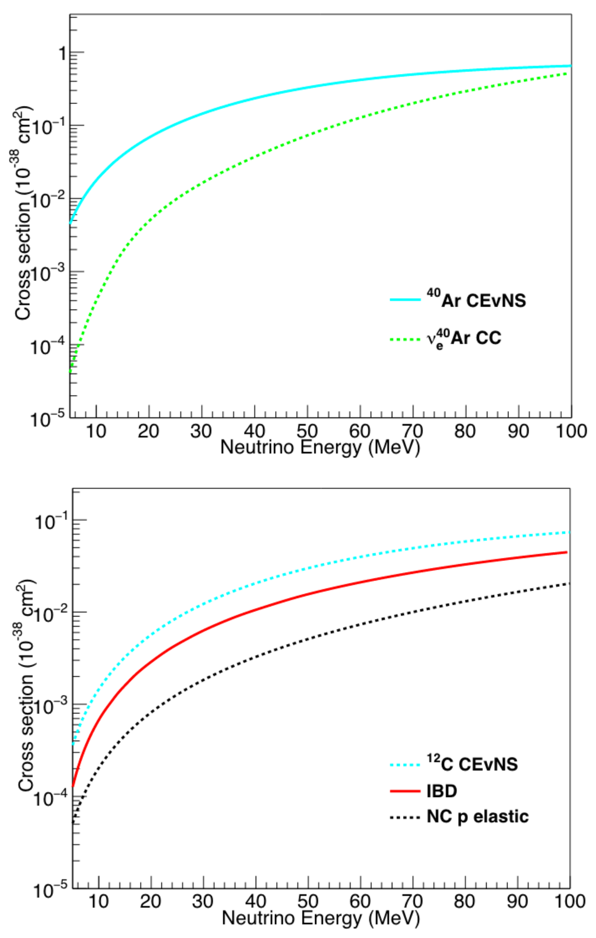
Coherent elastic neutrino-nucleus scattering (CEvNS) is a neutral-current process in which a neutrino scatters off an entire nucleus, depositing a tiny recoil energy. The process is important in core-collapse supernovae and also presents an opportunity for detection of the burst of neutrinos ejected in the collapse within low-threshold detectors designed for dark matter detection. Though the CEvNS process dominates low-energy interactions (tens of MeV), it produces very little energy deposition from the target nuclear recoil. The challenge of a CEvNS observation is reduced somewhat if a nearby core-collapse supernova acts as a high-flux source, producing thousands of CEvNS events in larger detector volumes over mere seconds. For detectors making use of scintillation to record particle energy loss, the effect would be a uniformly distributed, isotropic scintillation—a "CEvNS glow"—throughout the detector. Here we present an ongoing study of prospects for supernova burst detection via CEvNS in existing and future large-scale neutrino detectors.



Core-collapse releases an explosive wave of neutrinos in a characteristic burst



In the CEvNS process, a neutrino sees the entire nucleus as one unit, scattering coherently while the nucleus recoils slightly (ν A → ν A) [3]



CEvNS enjoys largest cross-section among low-energy neutrino couplings in LAr and organic liquid scintillator [3]

Supernova Neutrinos

During core-collapse supernovae, ~99% of the ***energy is carried away in neutrinos***. Insights into the neutrino mass ordering and oscillation parameters as well as the astrophysical supernova mechanism will be bundled within the ***tens-of-seconds burst***[1].

As these particles arrive to Earth, the flux spectra, time-sensitive flavor ratio, and rate will be ***key markers in tightening wide constraints made on supernova neutrinos*** from the most recent data in 1987[2].

CEvNS

Coherent elastic neutrino-nucleus scattering (CEvNS) is a neutral current interaction. Despite its high cross-section, CEvNS does not produce strong scintillation from the heavy nuclear recoils (< 50 keV), and backgrounds typically drown the signal.

However, measurements through this channel are flavor-blind and thus boosted by all six ν flavors, yielding ***critical information on the total flux*** of the supernova neutrinos. The sheer increase in neutrinos during the burst could make this low-light channel viable in even large-scale detectors.

Motivation

A lack of research exists for **CEvNS *detection within (kilo)ton-scale detectors***, which will have high statistics in other supernova neutrino channels. With several international neutrino detectors coming on the scene in the next decade and many currently in existence with different materials and sensitivities, a ***need exists for predicting the expected CEvNS signal*** during supernova core-collapse.

We seek to maximize the viability of on-line detectors and interaction channels monitoring supernova neutrinos. This present study will ***serve as a reference for expected light signatures in these large-scale experiments*** to better inform choices of bulk scintillator, photodetection, trigger functionality, and background reduction.

Method

During a supernova neutrino burst, CEvNS interactions will manifest as a ***diffuse isotropic "glow"*** throughout the liquid scintillator. A viable signal would appear as a slight, time-dependent signature encoding the features of the core-collapse.

We focus on this glow effect in two primary liquid scintillator materials: ***liquid argon (LAr) and organic liquid scintillator (LS)***, used in large-scale detectors DUNE and Borexino, respectively. Analysis is performed semi-analytically with no detector-specific software.

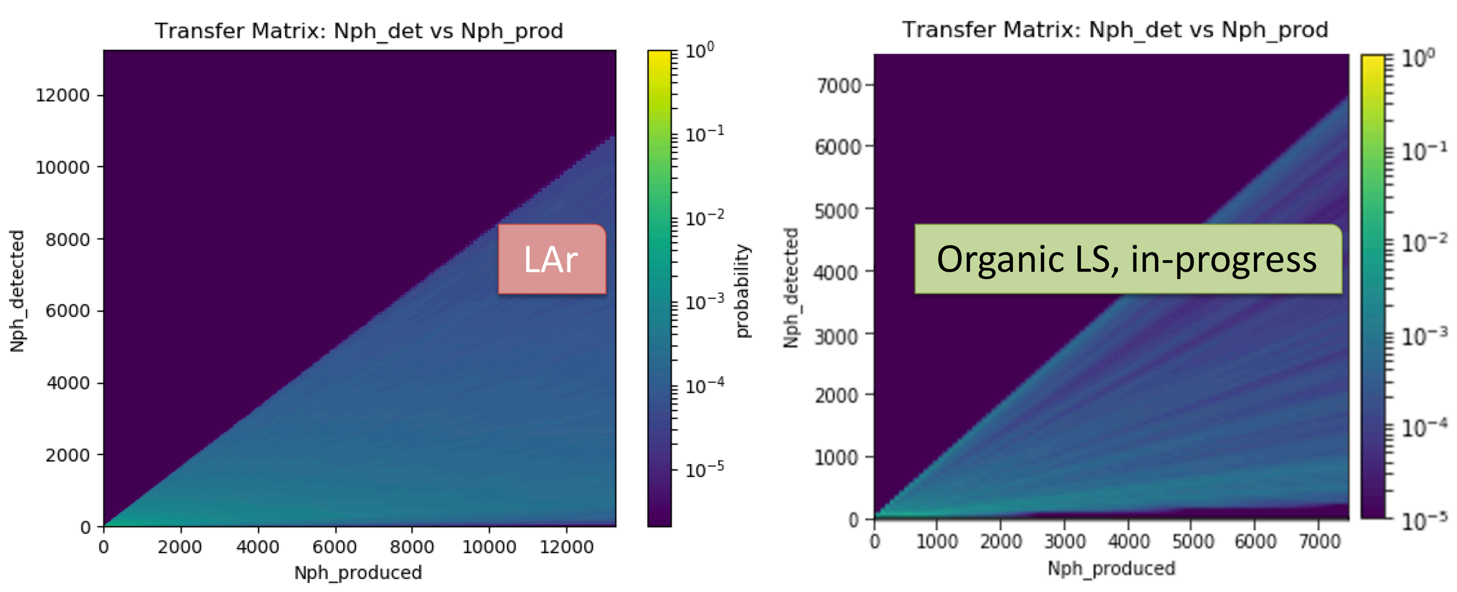
For given scintillator material:

- **Calculate CEvNS event rate** (with quenching [4] [5]) of a 10-kpc core-collapse [6]
- **Calculate quenched background event rates** [6] [7]
  - LAr: ν_e+^{40}Ar→e^-+^{40}K* (CC), constant ^{39}Ar beta decay [8]
  - Organic Scintillator: non-CEvNS interactions, radiologicals [5]
- **Create "produced" photon distributions** based on photon yield per MeV in material (e.g. see fig. at bottom of column)
- **Analytically simulate photon diffusion** (i) within detector volume to find probability of single-photon acceptance on photodetection plane (ii) [9]

(i) $$\frac{\partial}{\partial t}p(x,t) = D\frac{\partial^2}{\partial x^2}p(x,t)$$

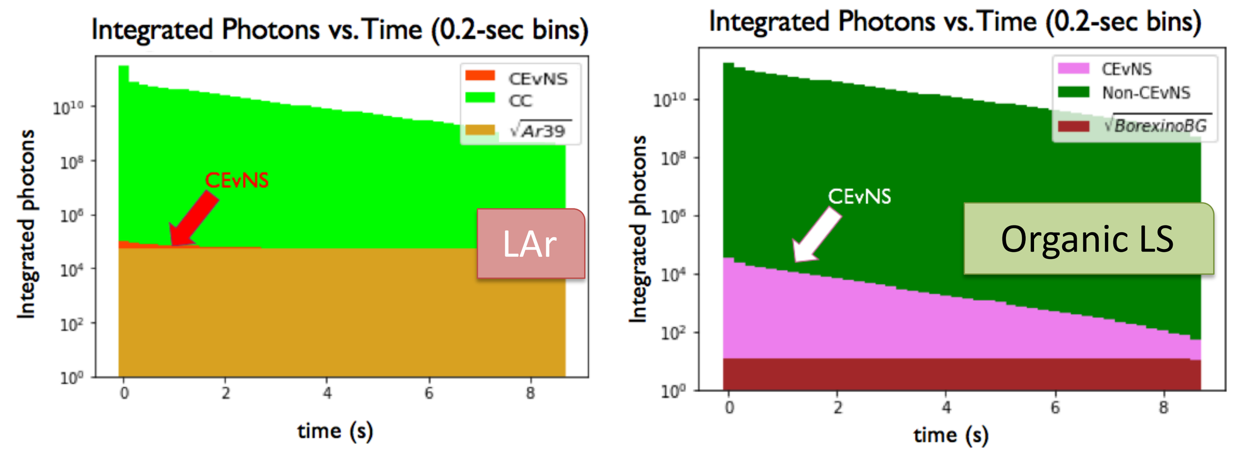
(ii) $$\int dt \int_{\Omega} \boldsymbol{dA} \cdot D\nabla p$$

- **Build transfer matrix** via binomial distribution using these probabilities (see figs. below)
- **Obtain "detected" photon distributions** by applying transfer matrix to "produced" photon distribution
- **Evaluate significance of signal** compared to background processes

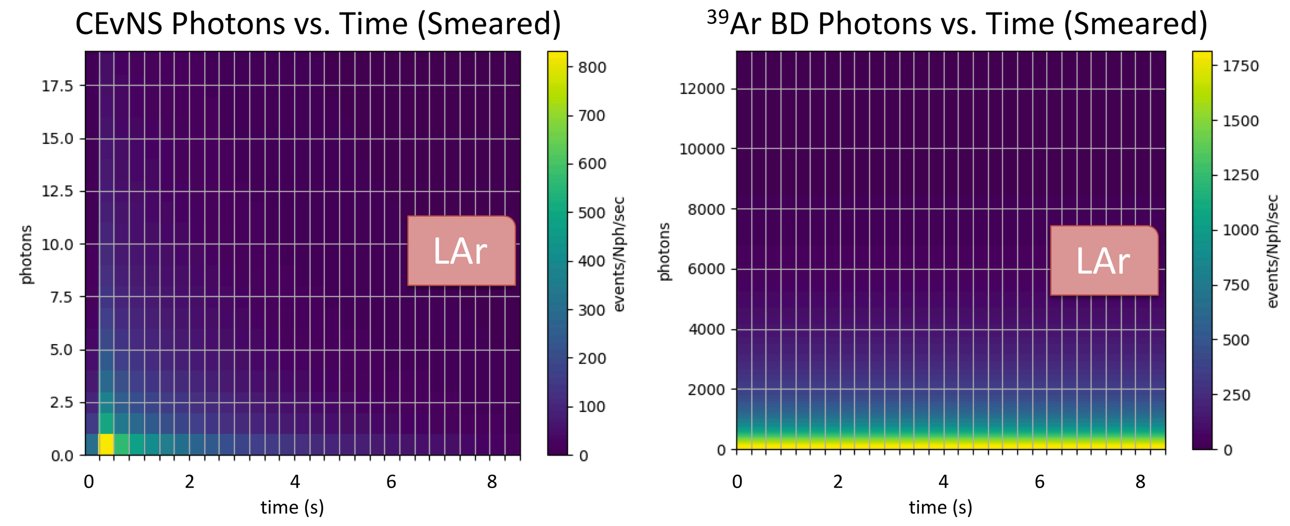


Transfer matrices within LAr / LS, used to transform "produced" photon distributions into "detected" distributions

Results

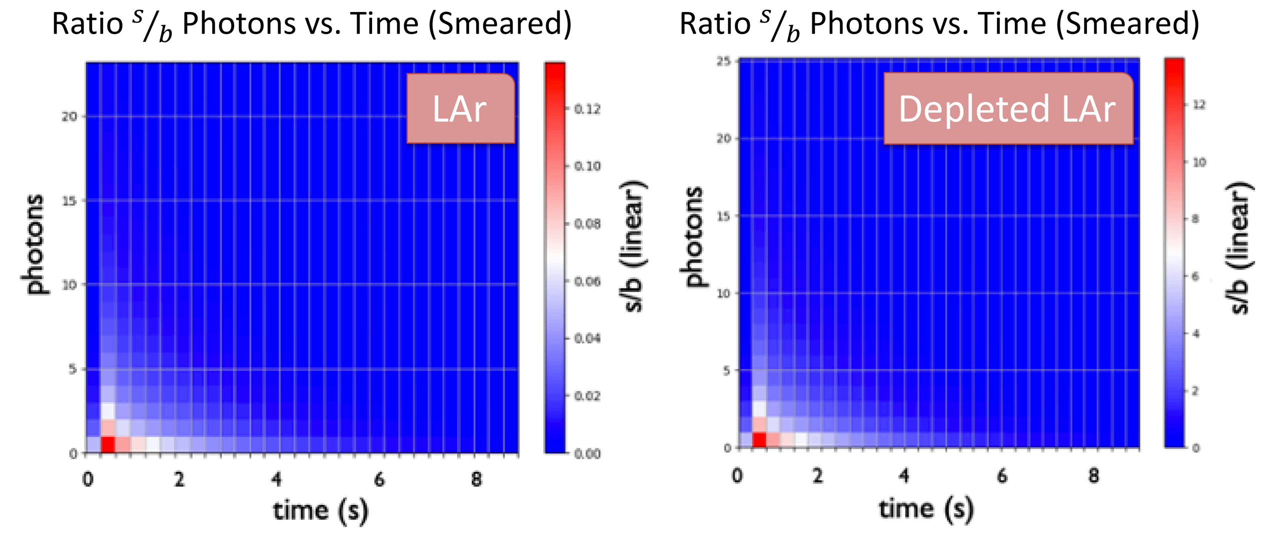


Integrated photons in 2.5 kT volume over ~10-sec burst (stacked and binned "produced" photon distribution)



"Detected" photon distributions for CEvNS (note the time-dependence influenced by physics of core-collapse) & ^{39}Ar BD (constant radiological)

*True bin size: 1 photon x 0.3 sec



Ratio of CEvNS signal to ^{39}Ar BD background for regular LAr (left) and conservative estimate of depleted LAr (right) (note: no CC interactions)

Outlook

- Analytic foundation for photon diffusion provides quick and flexible simulation; no need to rebuild transfer matrix if photon yield, quenching factors, or fluxes change
- Viability of CEvNS glow detection during supernova neutrino burst will depend on photodetection area, smart triggers, background reduction (depleted LAr), and longer buffer size
- The "glow" is only one avenue for detection – can also utilize wire data from TPCs, etc
- Need to consider photodetector dark rate, other backgrounds
- Flavor-blind supernova neutrino burst measurement would give us critical constraints on the total energy and flux of the explosion, and refined collaboration-specific studies of CEvNS glow remain essential
- Paper detailing present study and full results in LAr / LS coming soon

[1] K. Scholberg (2012), arXiv: 1205.6003
[2] L. Hirata et al (1987), DOI: 10.1103/PhysRevLett.58.1490
[3] D. Akimov, et al (2017), DOI: 10.1126/science.aao0990
[4] P. Agnes et al (2018), arXiv: 1801.06653v1
[5] M. Agostini et al (2017), arXiv:1707.09279v2
[6] https://github.com/schol/dukecevns
[7] http://webhome.phy.duke.edu/schol/snowglobes/
[8] J. Kostensalo et al (2017), arXiv:1705.05726v1
[9] V. Galymov (2017), https://indico.fnal.gov/event/15645/