Electron Neutrino Charged-Current Interactions on I-127 in the COHERENT NaIνE Detector

#420

Samuel Hedges, Duke University and TUNL
for the COHERENT Collaboration

Motivation

$$^{127}\text{I} + \nu_e \rightarrow {}^{127}\text{Xe}^{(*)} + e^-$$

- Few neutrino-nucleus interactions measured at $E_\nu < 300$ MeV (fig. 1), energies relevant for supernova ν
- ^{127}I charged-current interaction proposed for solar and supernova ν_e detection by Haxton[2], can study interaction with well understood neutrino source at SNS
- Measurement of cross section could provide insight for g_A quenching[3] at a momentum transfer of ~30 MeV, relevant for neutrinoless double beta decay

Isotope	Reaction Channel	Source	Experiment	Measurement (10^{-42} cm^2)	Theory (10^{-42} cm^2)
^{2}H	^{2}H(ν_e, e^-)pp	Stopped π/μ	LAMPF	52 ± 18(tot)	54 (IA) (Tatara *et al.*, 1990)
^{12}C	^{12}C$(\nu_e, e^-)^{12}$N$_{g.s.}$	Stopped π/μ	KARMEN	9.1 ± 0.5(stat) ± 0.8(sys)	9.4 [Multipole](Donnelly and Peccei, 1979)
		Stopped π/μ	E225	10.5 ± 1.0(stat) ± 1.0(sys)	9.2 [EPT] (Fukugita *et al.*, 1988).
		Stopped π/μ	LSND	8.9 ± 0.3(stat) ± 0.9(sys)	8.9 [CRPA] (Kolbe *et al.*, 1999b)
	^{12}C$(\nu_e, e^-)^{12}$N*	Stopped π/μ	KARMEN	5.1 ± 0.6(stat) ± 0.5(sys)	5.4-5.6 [CRPA] (Kolbe *et al.*, 1999b)
		Stopped π/μ	E225	3.6 ± 2.0(tot)	4.1 [Shell] (Hayes and S, 2000)
		Stopped π/μ	LSND	4.3 ± 0.4(stat) ± 0.6(sys)	
	^{12}C$(\nu_\mu, \nu_\mu)^{12}$C*	Stopped π/μ	KARMEN	3.2 ± 0.5(stat) ± 0.4(sys)	2.8 [CRPA] (Kolbe *et al.*, 1999b)
	^{12}C$(\nu, \nu)^{12}$C*	Stopped π/μ	KARMEN	10.5 ± 1.0(stat) ± 0.9(sys)	10.5 [CRPA] (Kolbe *et al.*, 1999b)
	^{12}C(ν_μ, μ^-)X	Decay in Flight	LSND	1060 ± 30(stat) ± 180(sys)	1750-1780 [CRPA] (Kolbe *et al.*, 1999b)
					1380 [Shell] (Hayes and S, 2000)
					1115 [Green's Function] (Meucci *et al.*, 2004)
	^{12}C$(\nu_\mu, \mu^-)^{12}$N$_{g.s.}$	Decay in Flight	LSND	56 ± 8(stat) ± 10(sys)	68-73 [CRPA] (Kolbe *et al.*, 1999b)
					56 [Shell] (Hayes and S, 2000)
^{56}Fe	^{56}Fe$(\nu_e, e^-)^{56}$Co	Stopped π/μ	KARMEN	256 ± 108(stat) ± 43(sys)	264 [Shell] (Kolbe *et al.*, 1999a)
^{71}Ga	^{71}Ga$(\nu_e, e^-)^{71}$Ge	^{51}Cr source	GALLEX, ave.	0.0054 ± 0.0009(tot)	0.0058 [Shell] (Haxton, 1998)
		^{51}Cr	SAGE	0.0055 ± 0.0007(tot)	
		^{37}Ar source	SAGE	0.0055 ± 0.0006(tot)	0.0070 [Shell] (Bahcall, 1997)
^{127}I	^{127}I$(\nu_e, e^-)^{127}$Xe	Stopped π/μ	LSND	284 ± 91(stat) ± 25(sys)	210-310 [Quasi-particle] (Engel *et al.*, 1994)

Fig. 1. Neutrino-nucleus cross section measurements for low energy terrestrial sources from [1].

Previous Measurement

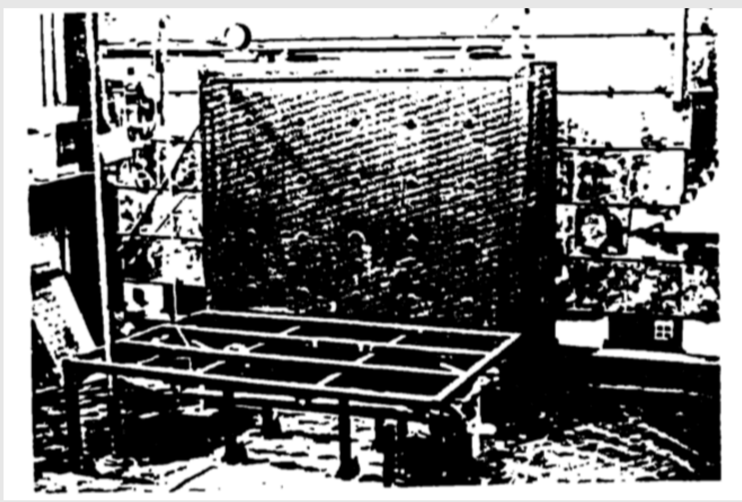


Fig. 2. Tank from E-1213 at LAMPF [4].

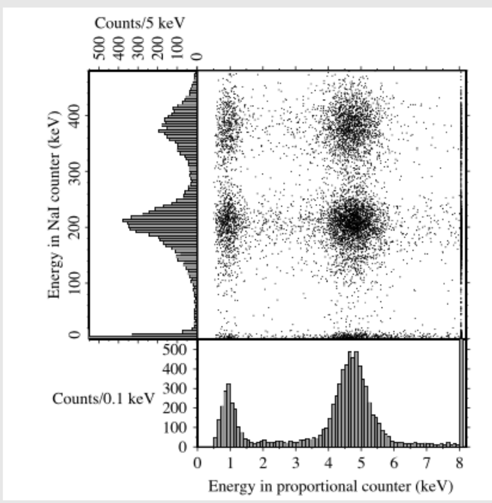


Fig. 3. Coincident ^{127}Xe decays and ^{127}I de-excitations from [4].

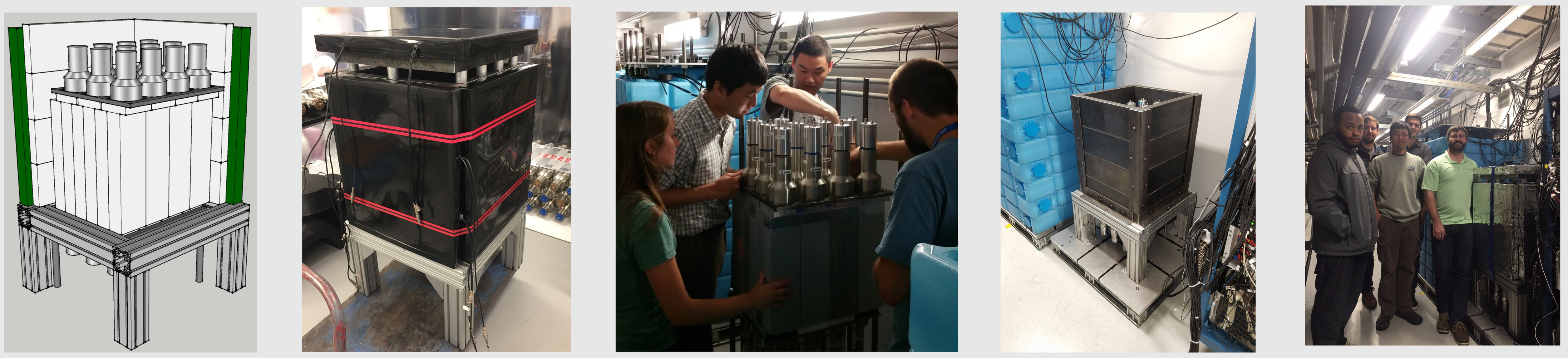
- Exclusive ^{127}I ν_e charged-current cross section measured at Los Alamos Meson Production Facility (LAMPF) in the 1990s, experiment E-1213[4]
- Required final state of reaction to be ^{127}Xe, **inclusive cross section never measured!**
- **No energy dependence measured** (flux-averaged only)
- Used coincidences from ^{127}Xe decays to calculate amount ^{127}Xe produced

$$^{127}\text{Xe} \rightarrow {}^{127}\text{I}^* + \gamma \text{ (203, 375 keV)}$$
$$^{127}\text{I}^* \rightarrow {}^{127}\text{I} + e^- \text{ (~0.9, 4.7 keV)}$$

- Reported flux-averaged cross section over stopped-pion source ν_e spectrum of

$$\sigma = 2.84 \pm 0.91 \text{ (stat)} \pm 0.25 \text{ (sys)} \times 10^{-40} \text{ cm}^2$$

The NaIνE Detector



- NaIνE (NaI ν-Experiment) designed to measure **inclusive** ^{127}I charged-current signals, **energy dependence**
- Consists of twenty-four 7.7-kg NaI[Tl] scintillators, ~20 m from SNS target, prototype for larger detector
- Triggers with internal logic, waveforms separated into eight 1250-ns windows, counts integrated in windows
- Calibrate and track gain changes over time using intrinsic ^{40}K and ^{208}Tl peaks
- Largest background for reaction from cosmic muons, veto panels and steel used to reduce backgrounds
- See poster #13 for a machine-learning approach to further reducing cosmic muon backgrounds

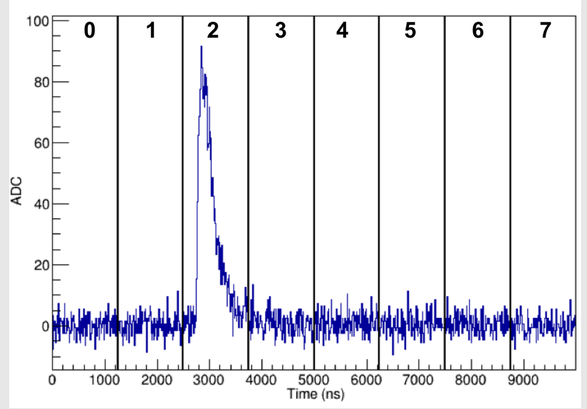


Fig. 4. Waveform showing accumulators configuration

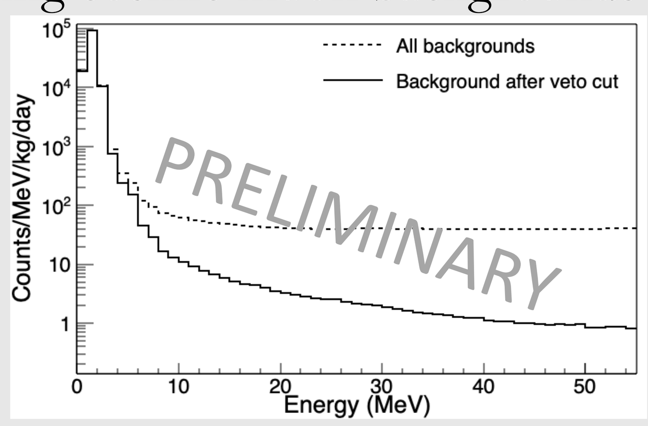


Fig. 5. Backgrounds with and without veto cut

Neutrinos at the SNS

- Spallation Neutron Source (SNS) creates neutrinos through stopped-pion decay

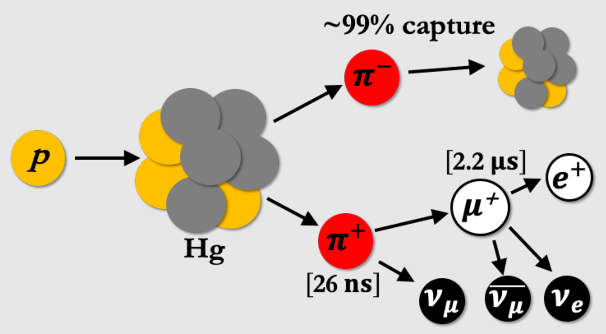


Fig. 6. Neutrino production at the SNS (simplified).

- 60-Hz pulsing, ~400-ns FWHM pulses, energy similar to supernova neutrinos
- ν_e delayed with respect to beam, reduces beam-related backgrounds for charged-current signals
- ν_e flux at 20m: $\Phi \approx 1.4 \times 10^7 \nu_e$ / cm^2 / sec

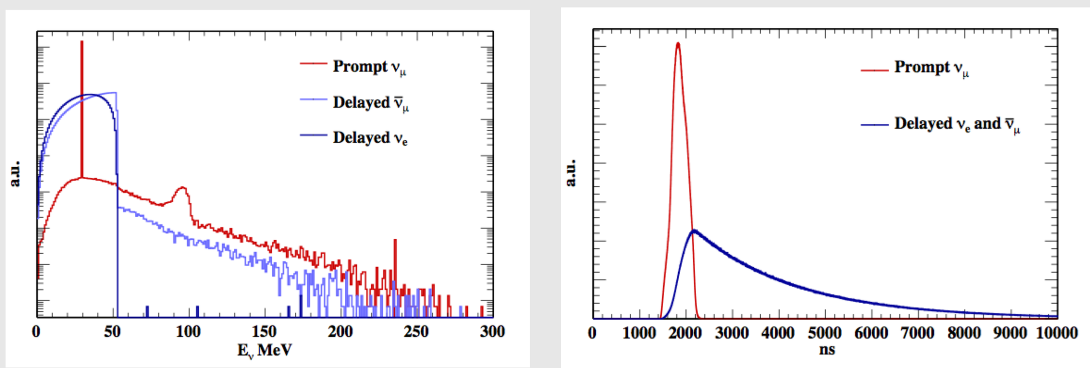


Fig. 7. Energy and timing distribution of neutrinos at the SNS

Signal Prediction & g_A

- Use MARLEY[5] to simulate allowed ν_e charged-current reactions on ^{127}I
- Total cross section, states excited depend on g_A[3]

J^π	$g_A = -1.0$	$g_A = -1.26$
0^+	0.096	0.096
0^-	0.00001	0.00002
1^+	1.017	1.528
1^-	0.006	0.008
2^+	0.155	0.213
2^-	0.693	1.055
3^+	0.149	0.171
3^-	0.017	0.025
total	2.098	3.096

Fig. 8. Effect of g_A quenching on calculated cross section, from [3]

- Forbidden transitions needed to understand g_A quenching's effect on energy spectrum, not yet included in MARLEY
- Simulations **do** predict a g_A quenching effect on total cross section

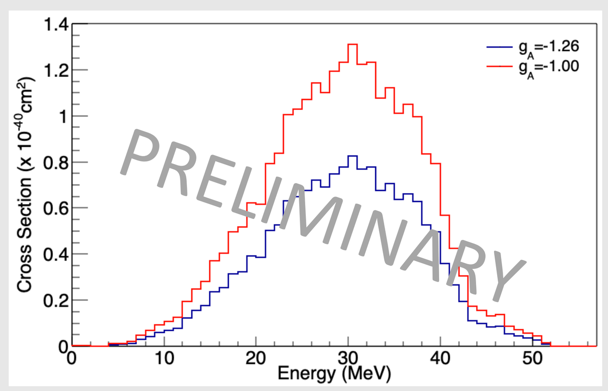


Fig. 9. MARLEY energy predictions showing effect of g_A quenching.

A Ton-Scale NaI Detector

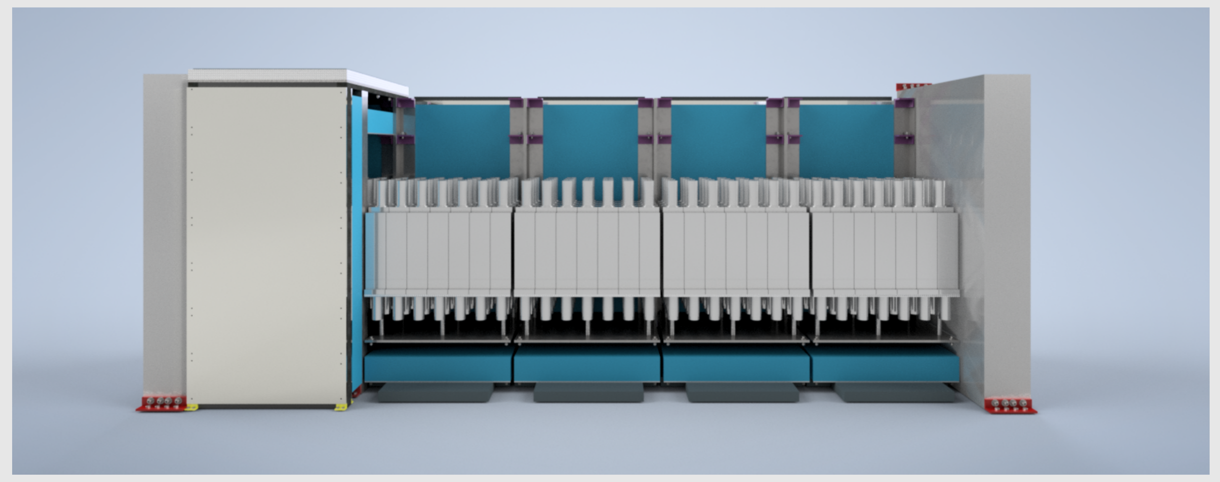


Fig. 10. Current design for ton-scale detector

- Larger detector (300+ crystals) would improve charged-current statistics, also measure coherent elastic neutrino-nucleus scattering (CEvNS) on ^{23}Na
- Dual gain base designed to achieve dynamic range for both CEvNS and charged-current signals (3 keV to 55 MeV)
- Each crystal deployed needs to be characterized first, completed for ~150 crystals so far!
- Construction will begin soon, deployment to start in 2020
- See poster #554 for more details on ton-scale detector

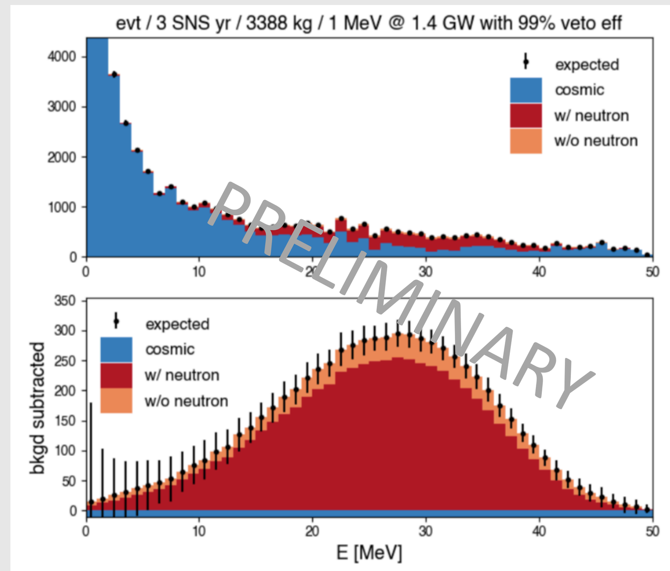


Fig. 11. Expected charged current signal for a 3388kg detector after 3 years of operation.

Conclusions

- NaIνE trying to measure unobserved inclusive ν_e charged-current cross section on ^{127}I
- Collecting data since 2016, analysis ongoing
- Investigating sensitivity to g_A quenching with MARLEY
- Larger detector deployment to start in 2020, design and crystal characterization underway

References

[1] J.A. Formaggio and G.P. Zeller, Rev. Mod. Phys. **84** (2012) 1307
[2] W.C. Haxton, Phys. Rev. Lett. **60** (1988) 768
[3] J. Engel, S. Pittel, and P. Vogel, Phys. Rev. C **50** (1994) 1702
[4] J.R. Distel, et. al, Phys. Rev. C **68** (2003) 054613
[5] https://marleygen.org