A 185 kg NaI[Tl] Detector for Observing the Charged-Current Neutrino Interaction on ^{127}I

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for the COHERENT Collaboration

Motivation

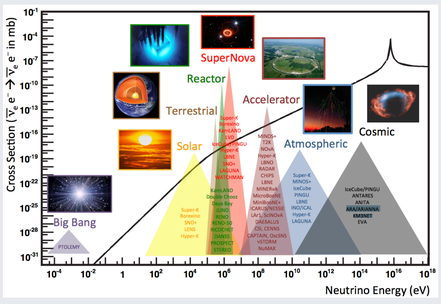


Fig. 1. Neutrino sources as a function of energy [1].

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(ν_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(ν_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(ν_μ, ν_μ)^{12}C*	Stopped π/μ	KARMEN	3.2 ± 0.5(stat) ± 0.4(sys)	2.8 [CRPA] (Kolbe *et al.*, 1999b)
	^{12}C(ν, ν')^{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(ν_μ, μ^-)^{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(ν_e, e^-)^{56}Co	Stopped π/μ	KARMEN	256 ± 108(stat) ± 43(sys)	264 [Shell] (Kolbe *et al.*, 1999a)
^{71}Ga	^{71}Ga(ν_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(ν_e, e^-)^{127}Xe	Stopped π/μ	LSND	284 ± 91(stat) ± 25(sys)	210-310 [Quasi-particle] (Engel *et al.*, 1994)

Fig. 2. Neutrino-nucleus cross sections for low energy terrestrial sources [2].

- Charged-current neutrino-nucleus measurements test nuclear models, g_A quenching measurement with neutrinos
- Necessary for proposed charged-current supernova and solar neutrino detectors
- Few measurements exist at these energies, large uncertainties

Charged-Current Interaction

$$^{127}\mathrm{I} + \nu_e \rightarrow {}^{127}\mathrm{Xe} + e^-$$

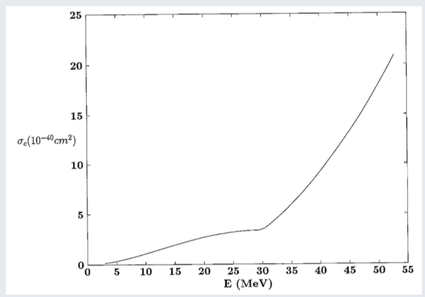


Fig. 3. Predicted ^{127}I charged-current cross section[3].

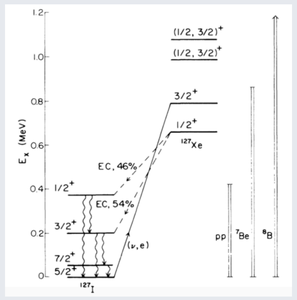


Fig. 4. Low energy transitions from ^{127}I to ^{127}Xe [4].

- ^{127}I charged-current proposed for solar, supernova neutrino detection by Haxton [4]
- Threshold $E_{\nu_e} \approx 789$ keV, particle emission threshold in ^{127}Xe ≈ 7.23 MeV
- Theoretical calculation by Mintz and Pourkaviani[3] for stopped-pion source ν_e

Previous Measurement

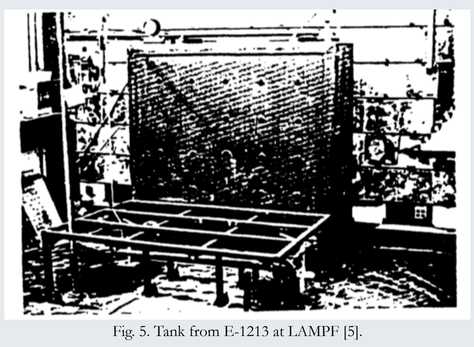


Fig. 5. Tank from E-1213 at LAMPF [5].

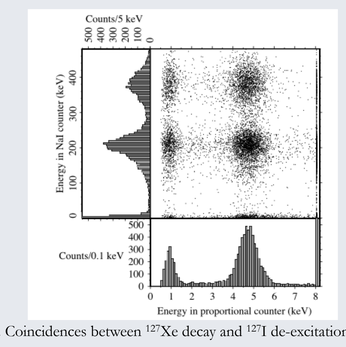


Fig. 6. Coincidences between ^{127}Xe decay and ^{127}I de-excitation signals [5].

- E-1213 at Los Alamos Meson Production Facility (LAMPF)[5]
- Radiochemical approach, required final state to be ^{127}Xe (no particle emission)
- Used coincidences from ^{127}Xe decays to calculate amount ^{127}Xe produced

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

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

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

Neutrino Production at the SNS

- Spallation Neutron Source (SNS) creates neutrons through stopped-pion decay
- 60 Hz pulsing, ~1 μs long pulses, energy similar to supernova neutrinos
- Electron neutrinos delayed with respect to beam, max energy of ~52 MeV
- Typical flux at 20m: $\Phi \approx 1.4 \times 10^7 \nu_e$ / cm^2 / sec

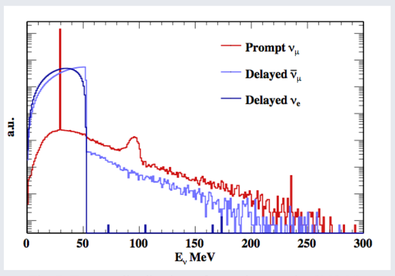


Fig. 7. Energy distribution of neutrinos at the SNS [6].

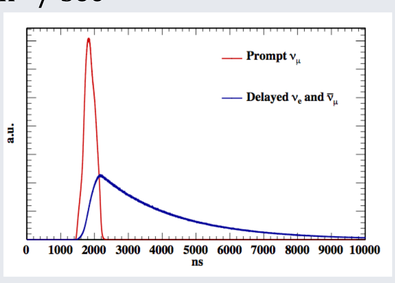
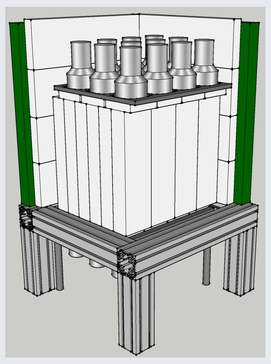
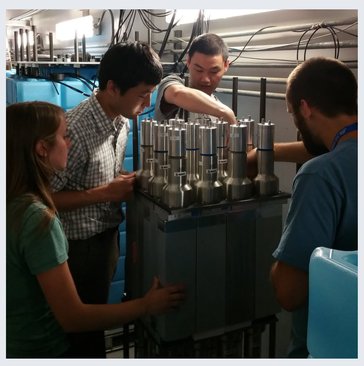


Fig. 8. Timing distribution of neutrinos at the SNS [6].

References:
[1] A. de Gouvea et. al, arXiv:1310.4340 (2013)
[2] J.A. Formaggio and G.P. Zeller, arXiv:1305.7513 (2013)
[3] S.L. Mintz and M. Pourkaviani, Nuc. Phys. A 584 (1995)
[4] W.C. Haxton, Phys. Rev. Lett. 60 (1988)
[5] J.R. Distel, et. al, Phys. Rev. C 68 (2003)
[6] D. Akimov, et. al, arXiv:1509.08702 (2015)
[7] R.O. Duda and P.E. Hart, Comm. of the ACM, 15 (1972)

The NaIνE Detector





- NaIνE (NaI ν-Experiment) consists of twenty-four 7.7 kg NaI[Tl] scintillators deployed ~20 m from the SNS target
- Detectors trigger based on digitizer logic, SNS timing signals digitized as well, timing correlations done in software analysis
- Waveforms separated into eight equally-spaced 1250 ns windows, counts integrated
- 100 ns window used to identify coincidences between detectors

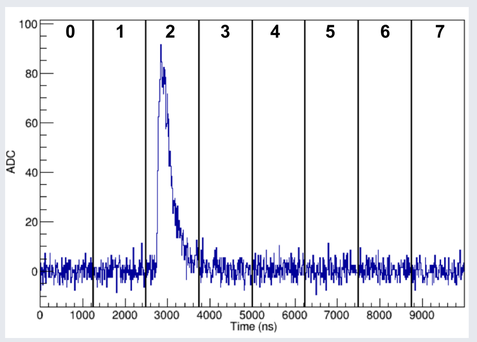


Fig. 9. Example waveform from NaI[Tl] detector showing accumulator windows

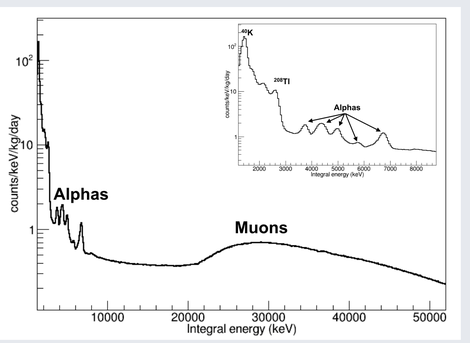


Fig. 10. Spectrum from a single NaI[Tl] crystal

Reducing Backgrounds

- Largest background for charged-current signal come from cosmic muons
- Vetos deployed in fall 2017, large improvement in S/B (signal acceptance still under investigation)
- Steel plates between vetos and NaI[Tl] to avoid vetoing charged-current signal
- Tracking algorithms also being investigated to identify muons [7]

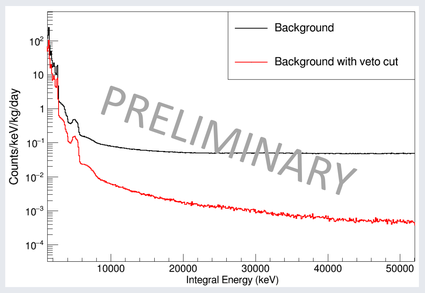


Fig. 11. Spectrum from NaIνE detector in delayed window with veto cut

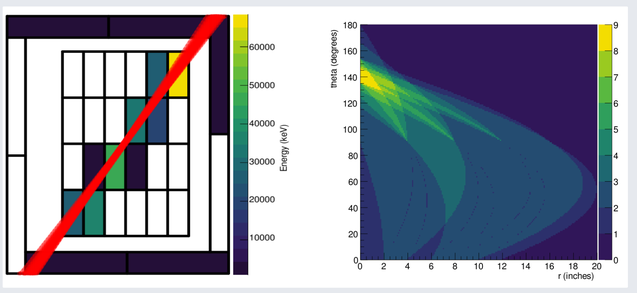
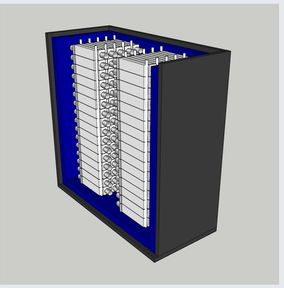


Fig. 12. Left: Energy deposited in NaI[Tl] detectors with reconstructed track. Right: Hough space for track

Future Plans



- Beam restarted in May 2018, operating at higher power
- Preliminary measurement with NaIνE, improve statistics with tonne-scale detector
- Plan to simultaneously measure charged-current interaction on ^{127}I and coherent elastic neutrino-nucleus scattering (CEνNS) on ^{23}Na using dual-output base
- Dual-output base will allow a ~3 keV threshold in low-energy channel, measure up to ~55 MeV in high-energy channel
- Shielding design and simulation underway

Acknowledgements

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