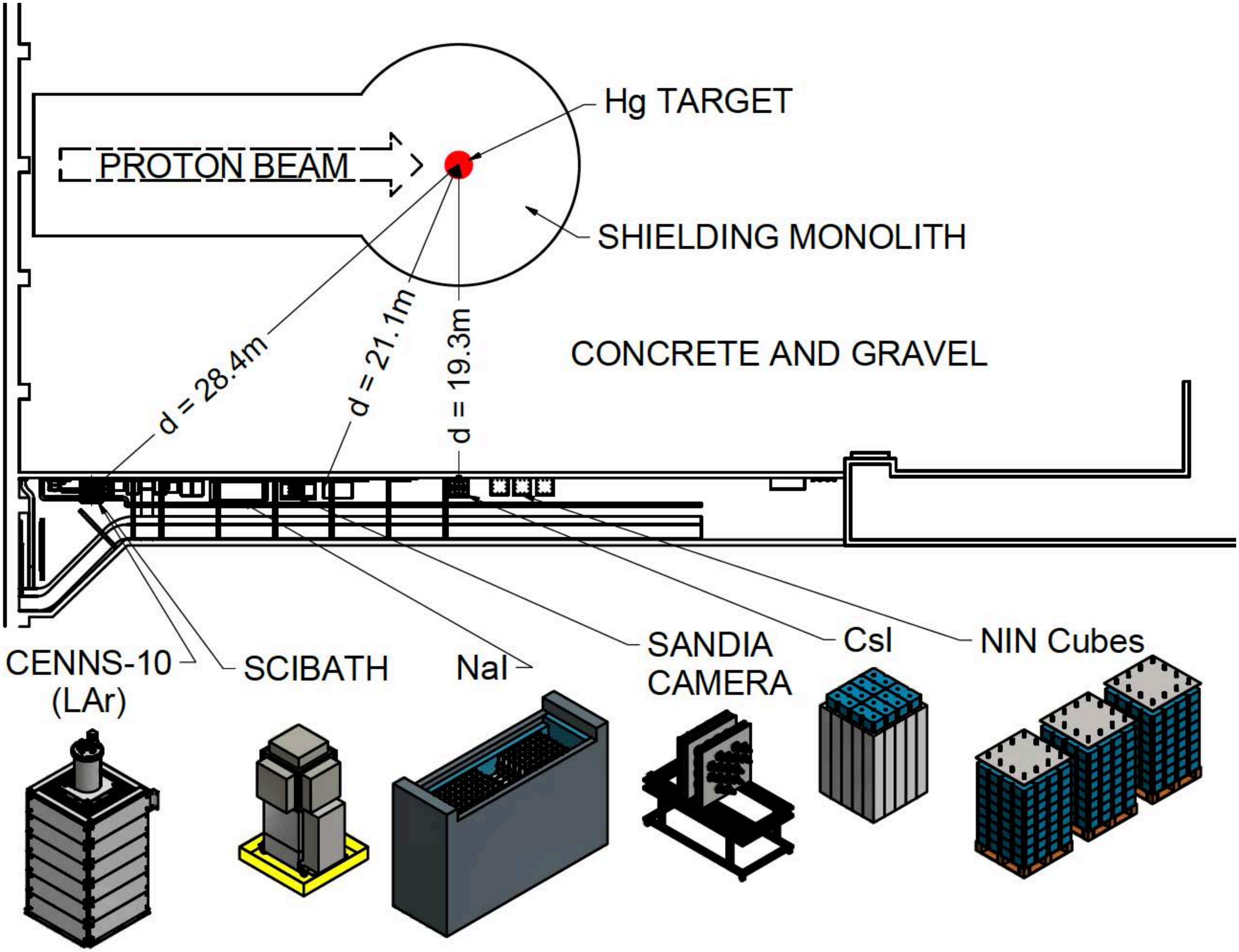
COHERENT @ ORNL



J.I. Collar

NuInt June 2017

A 10c introduction to coherent ν-N scattering (CEνNS)

- <u>Uncontroversial</u> Standard Model process
- Large enhancement in cross-section for E_ν < few tens of MeV ($\sigma \propto N^2$, possible only for neutral current)

D.Z. Freedman Phys. Rev. D 9 (1974) 1389

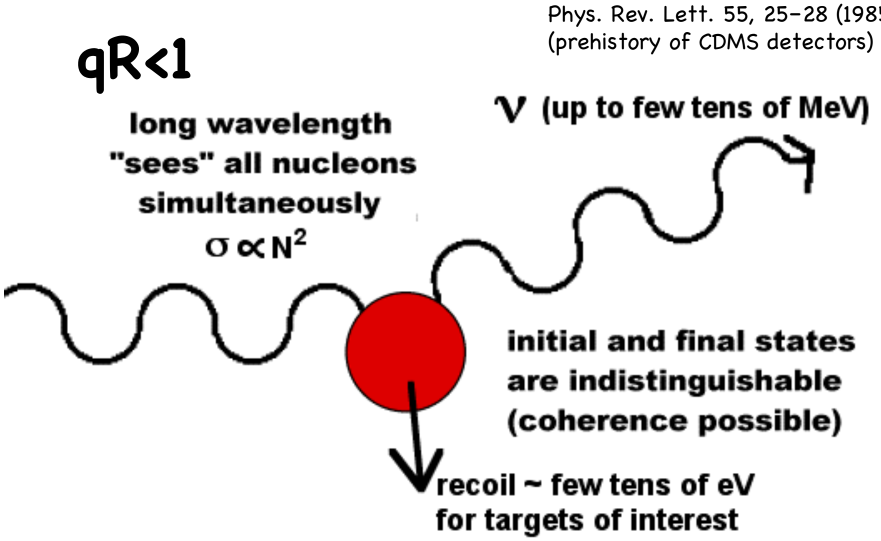
- However, not yet measured… combination of source & detector technology has been missing.

Detector mass must be at least ~1 kg (reactor experiment) + *<u>recoil</u>* energy threshold << 1keV

(low-E recoils lose only 10-20% to ionization or scintillation)

- Cryogenic bolometers and other methods proposed, no successful implementation yet

Cabrera, Krauss & Wilczek Phys. Rev. Lett. 55, 25-28 (1985) (prehistory of CDMS detectors)



Fundamental physics:

- Largest σ_ν in SN dynamics: should be measured to validate models (J.R. Wilson, PRL 32 (74) 849)
- A large detector can measure total E and T of SN ν_μ, ν_τ ⇒ determination of ν oscillation pattern and mass of ν star (J.F.Beacom, W.M.Far & P.Vogel, PRD 66(02)033011)
- Coherent σ same for all known ν… oscillations observed in a coherent detector ⇒ evidence for $\nu_{sterile}$ (A.Drukier & L.Stodolsky, PRD 30 (84) 2295)
- Sensitive probe of weak nuclear charge ⇒ test of radiative corrections due to new physics above weak scale (L.M.Krauss, PLB 269, 407)
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Smallish detectors… <u>"ν technology"?</u>

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- Geological prospection, planetary tomography… the list gets much wilder.

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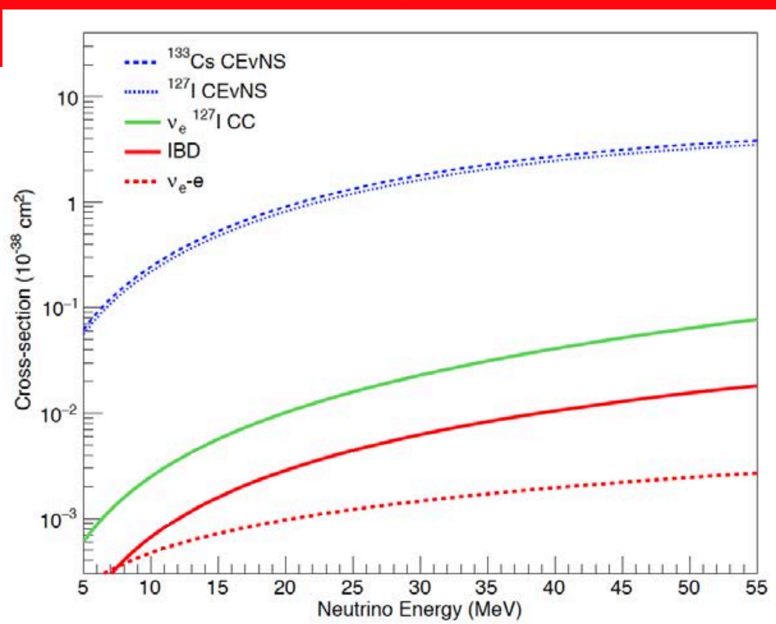

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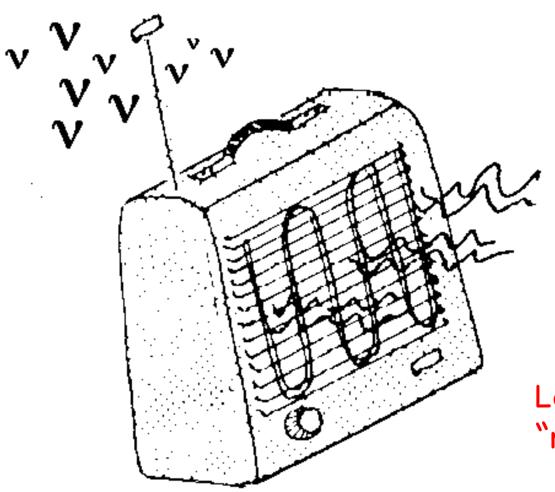

(my take on Leo Stodolsky's "neutrino radio")

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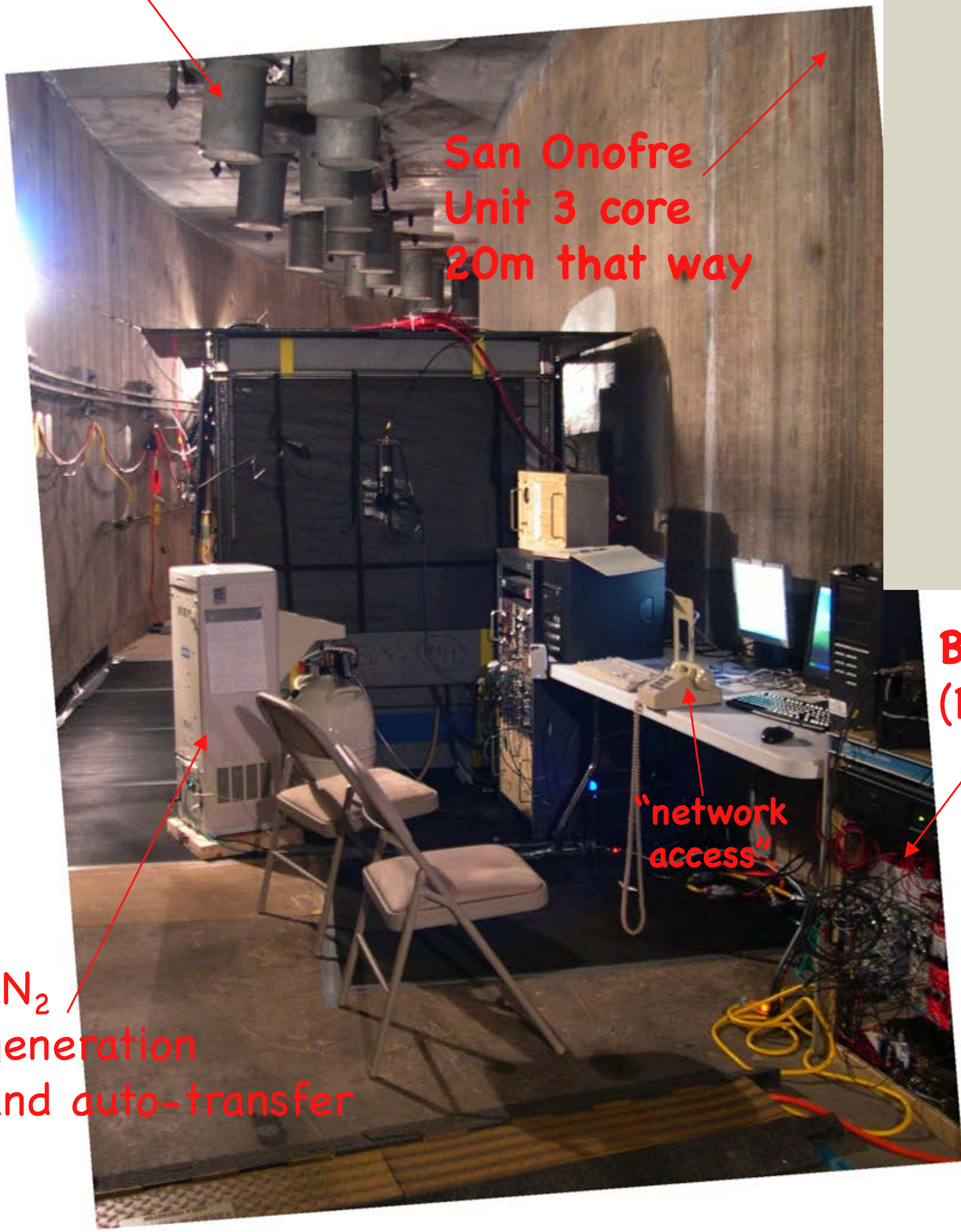
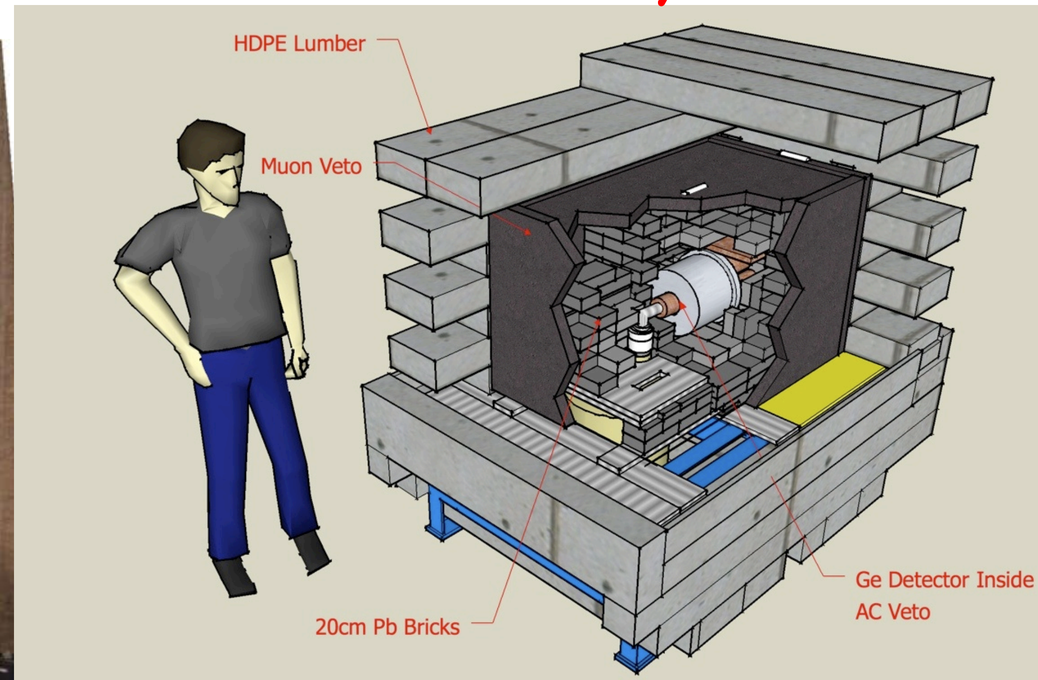
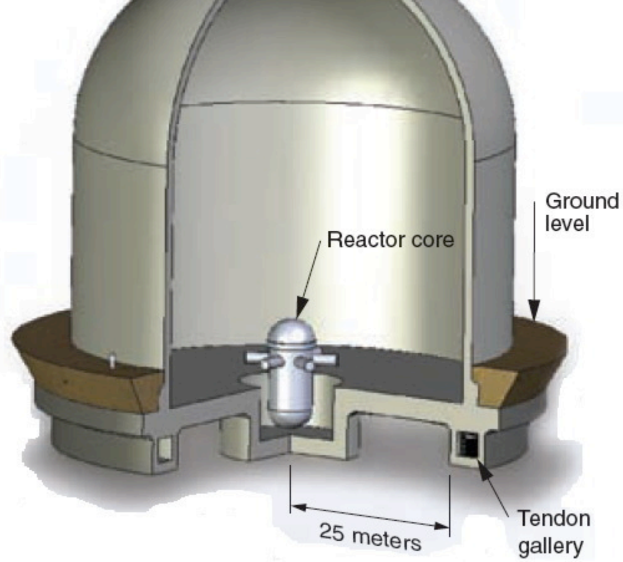
Everyone needs a hobby

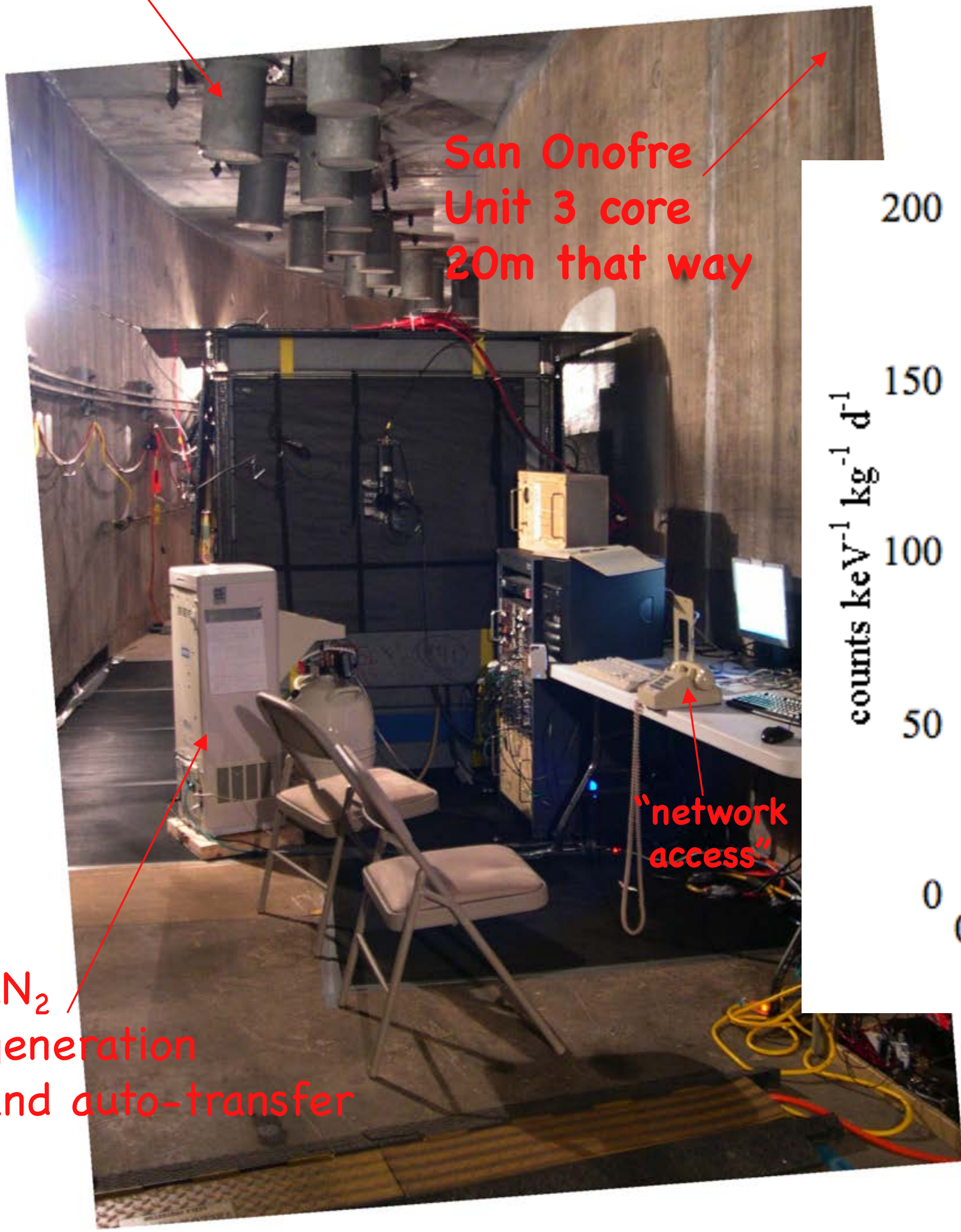


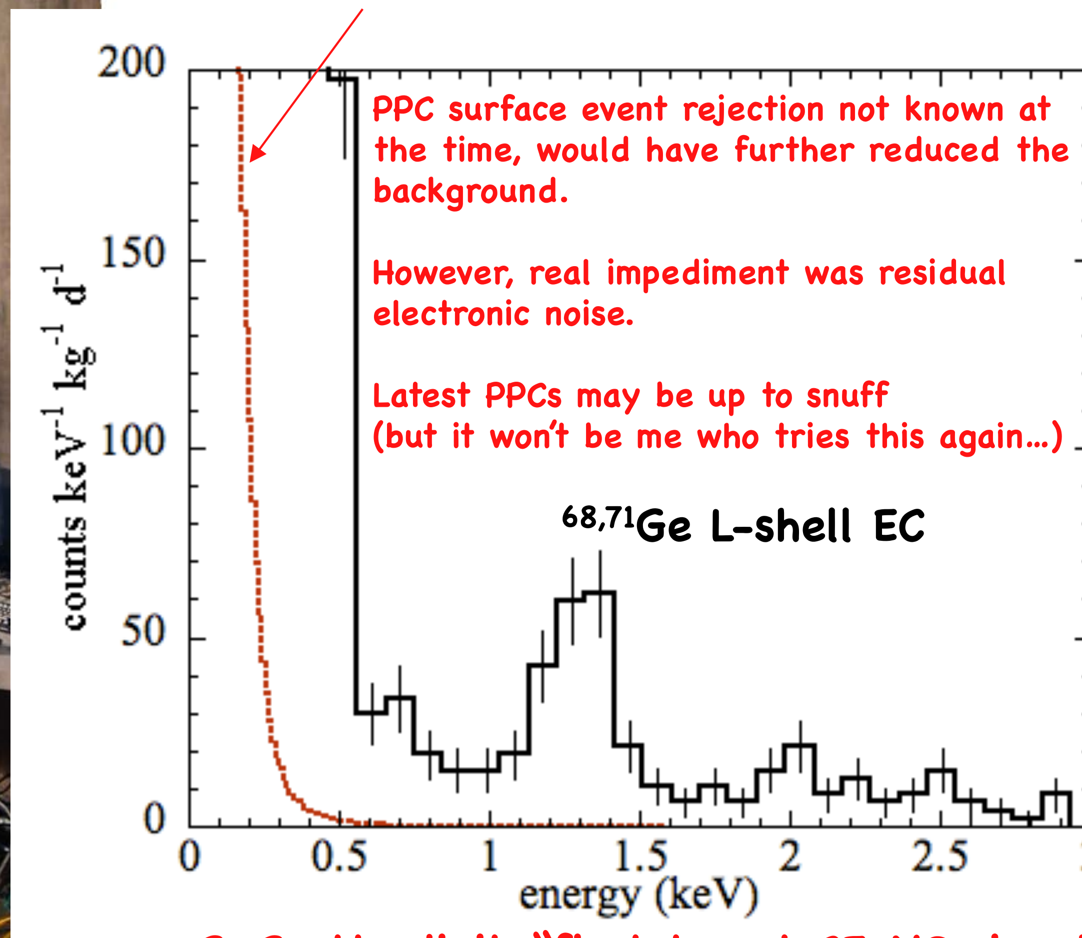


BaDAss
(Background Detector Assembly)



So close, and yet so far





G. Gratta dixit: “first to put CEνNS signal and backgrounds on a linear-linear plot…”

Other reactor enthusiasts:

RICOCHET

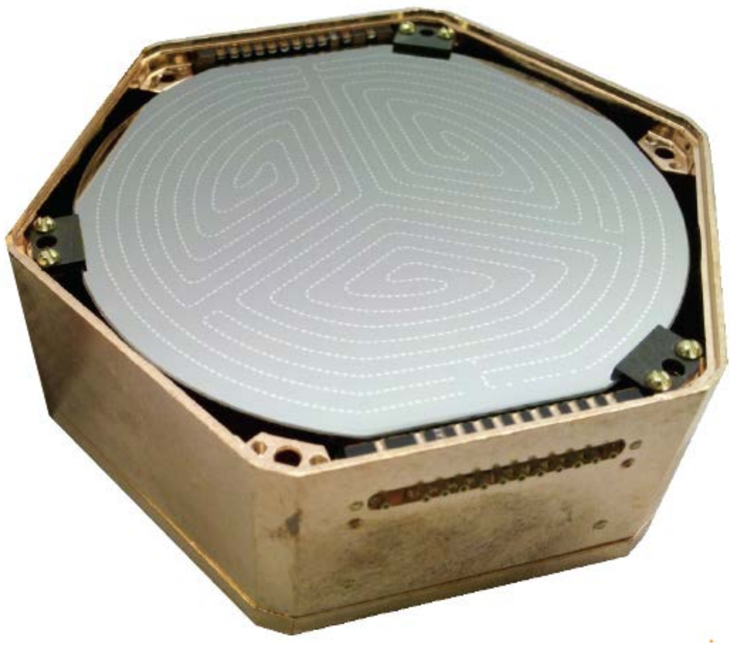
Coherent Neutrino Scattering with
Cryogenic Crystal Detectors

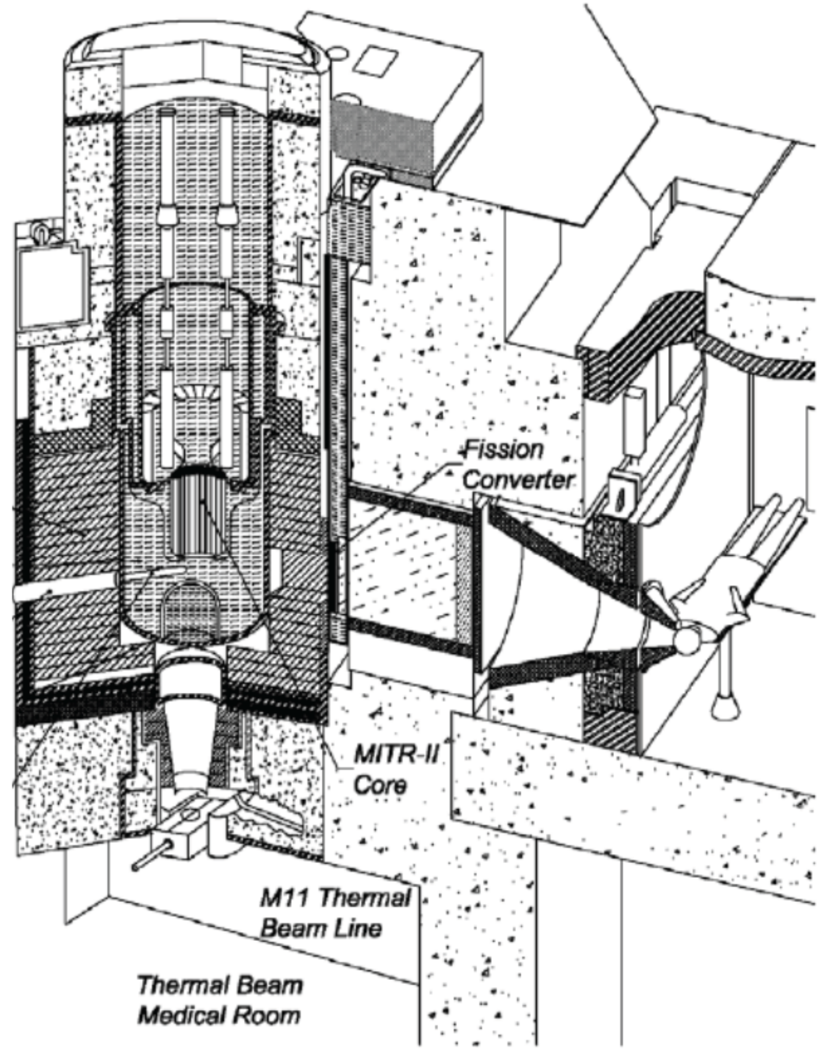
VOLUME 55, NUMBER 1 PHYSICAL REVIEW LETTERS 1 JULY 1985

Bolometric Detection of Neutrinos

Blas Cabrera, Lawrence M. Krauss, and Frank Wilczek
Department of Physics, Stanford University, Stanford, California 94305
Lyman Laboratory of Physics, Harvard University, Cambridge, Massachusetts 01238
Institute for Theoretical Physics, University of California, Santa Barbara, California 93106
(Received 14 December 1984)

Elastic neutrino scattering off electrons in crystalline silicon at 1–10 mK results in measurable temperature changes in macroscopic amounts of material, even for low-energy (< 0.41MeV) pp ν's from the sun. We propose new detectors for bolometric measurement of low-energy ν interactions, including coherent nuclear elastic scattering. A new and more sensitive search for oscillations of reactor antineutrinos is practical (~ 100 kg of Si), and would lay the groundwork for a more ambitious measurement of the spectrum of pp, ^{7}Be, and ^{8}B solar ν's, and supernovae anywhere in our galaxy (~ 10 tons of Si).

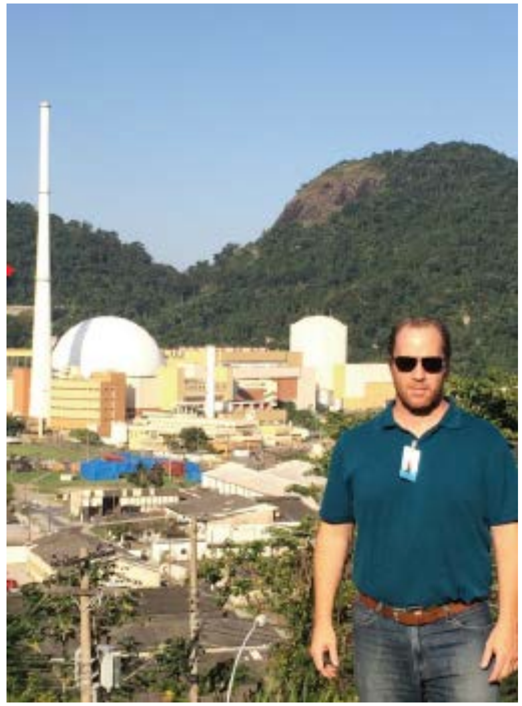


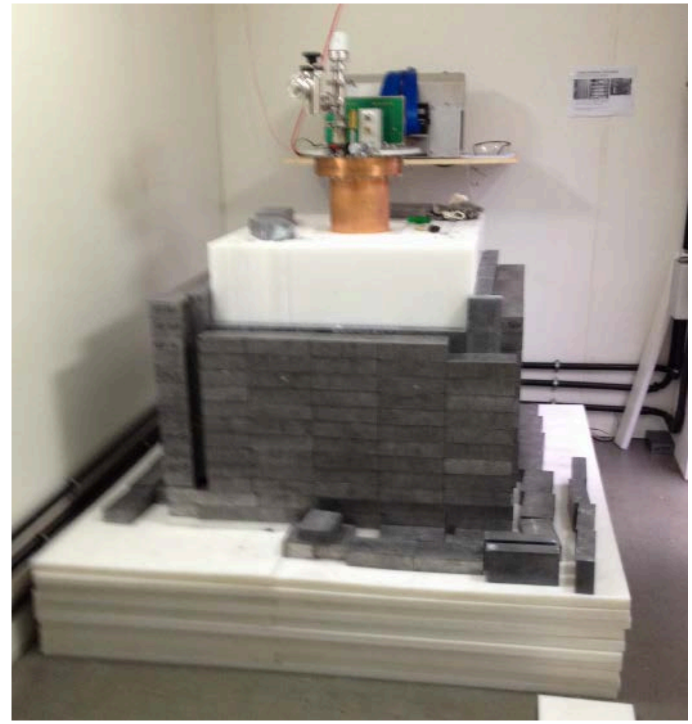


Other reactor enthusiasts:

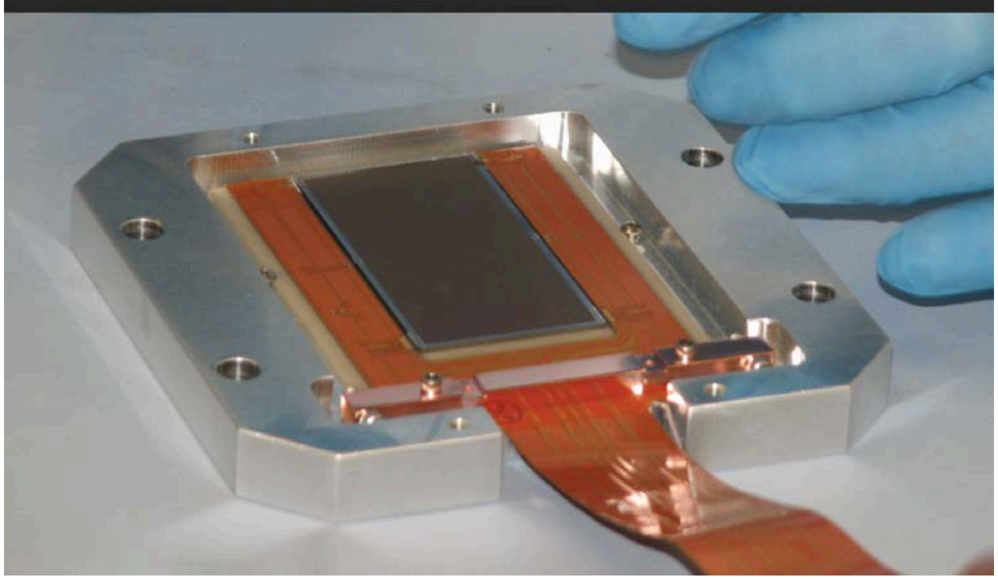
CO.νNIE

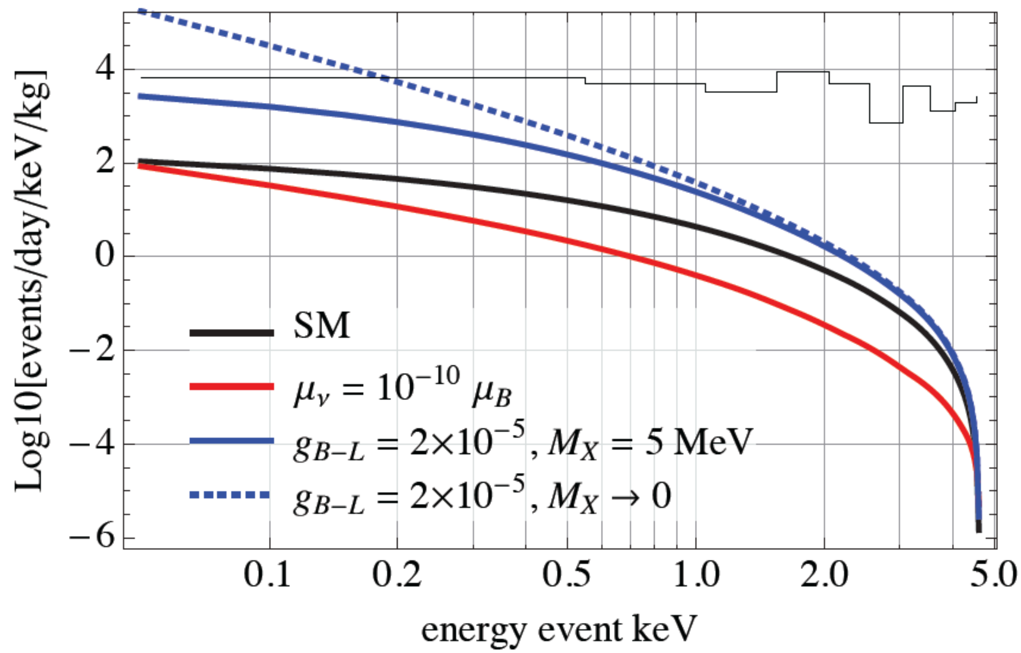
COHERENT NEUTRINO NUCLEUS INTERACTION EXPERIMENT



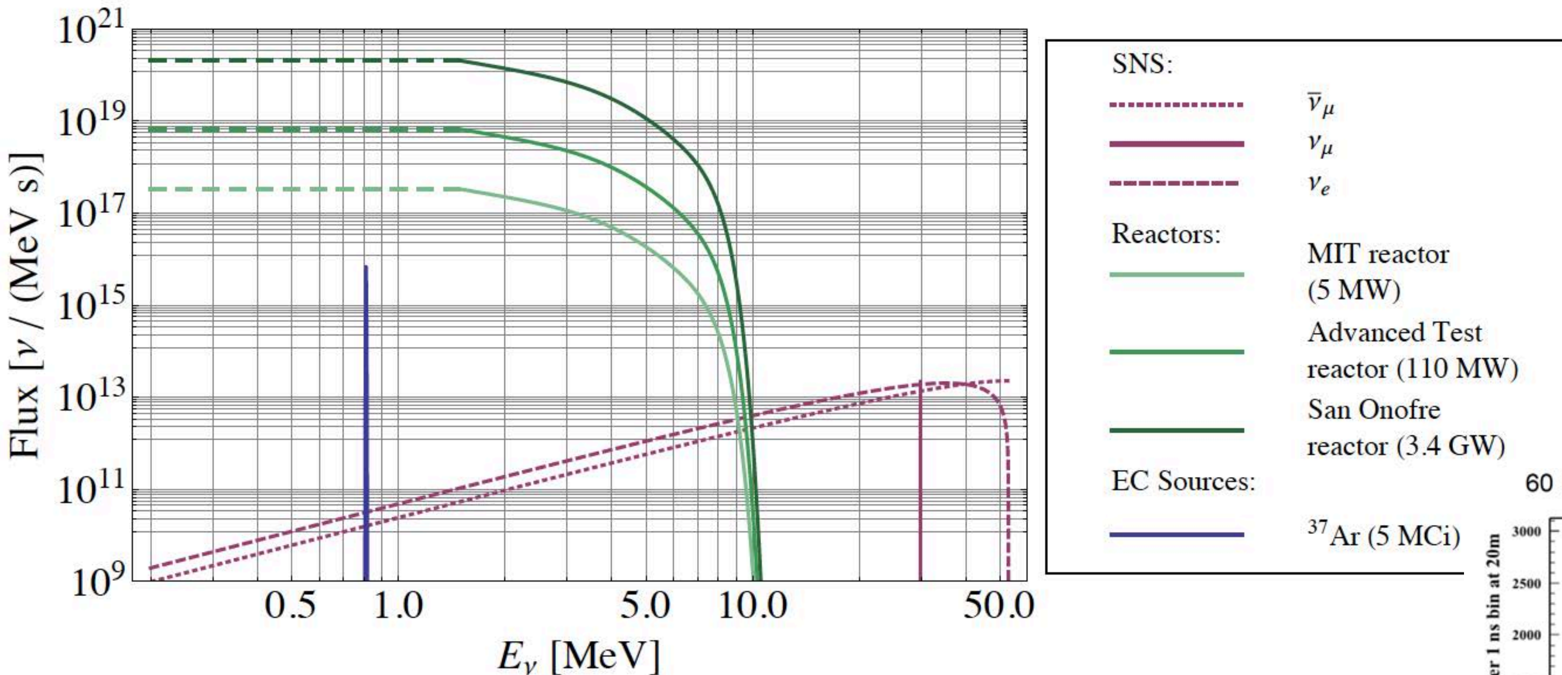


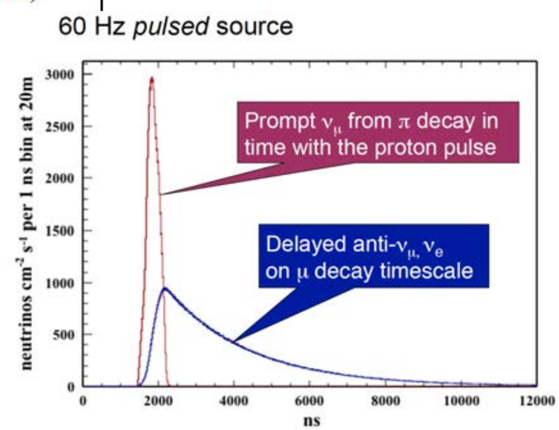
CONNIE 2014-2015 sensor:



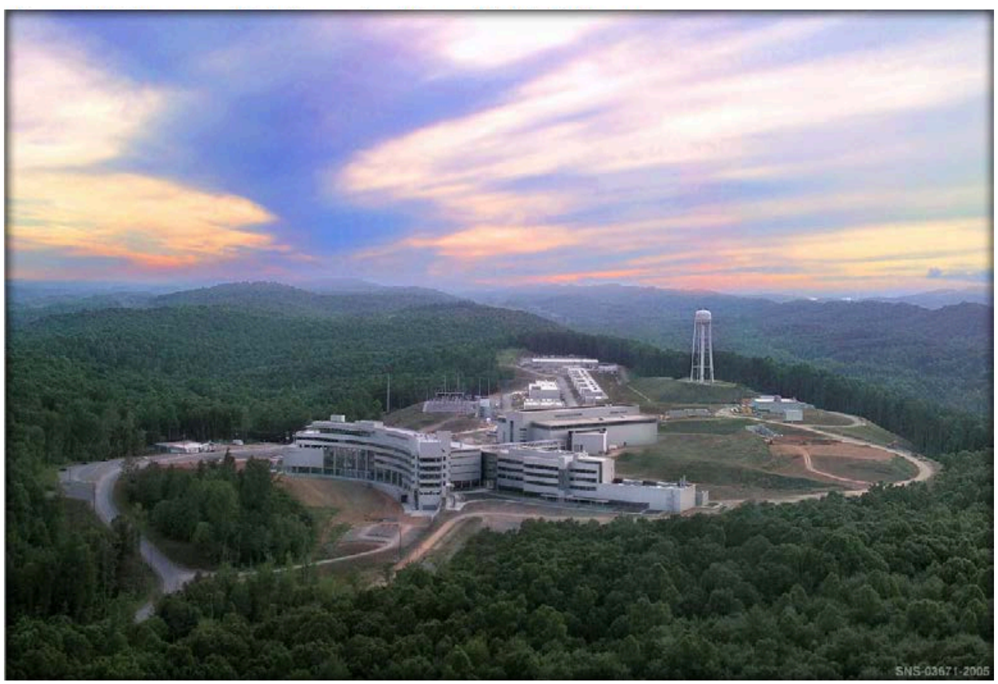


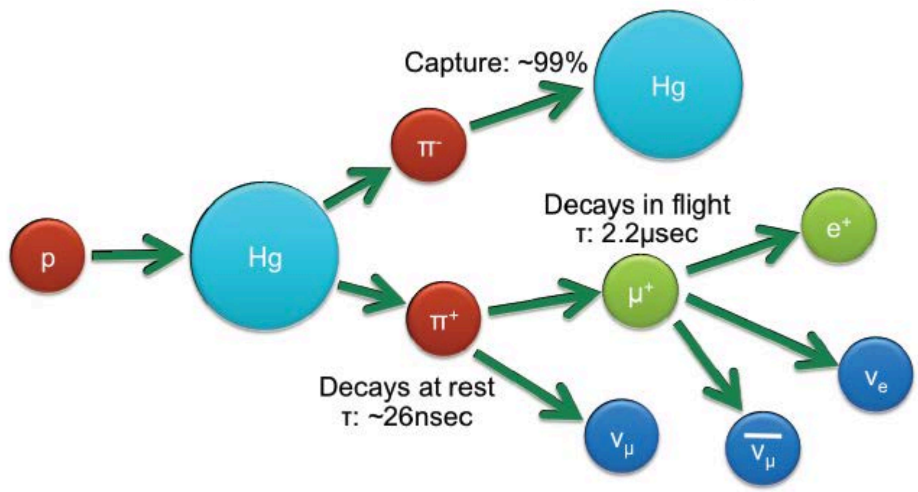
Fortunately, reactors are not the only game in town:





SNS @ ORNL: 200x more n's than ν's,
but we'll take it
(~10^{22} n/day...)





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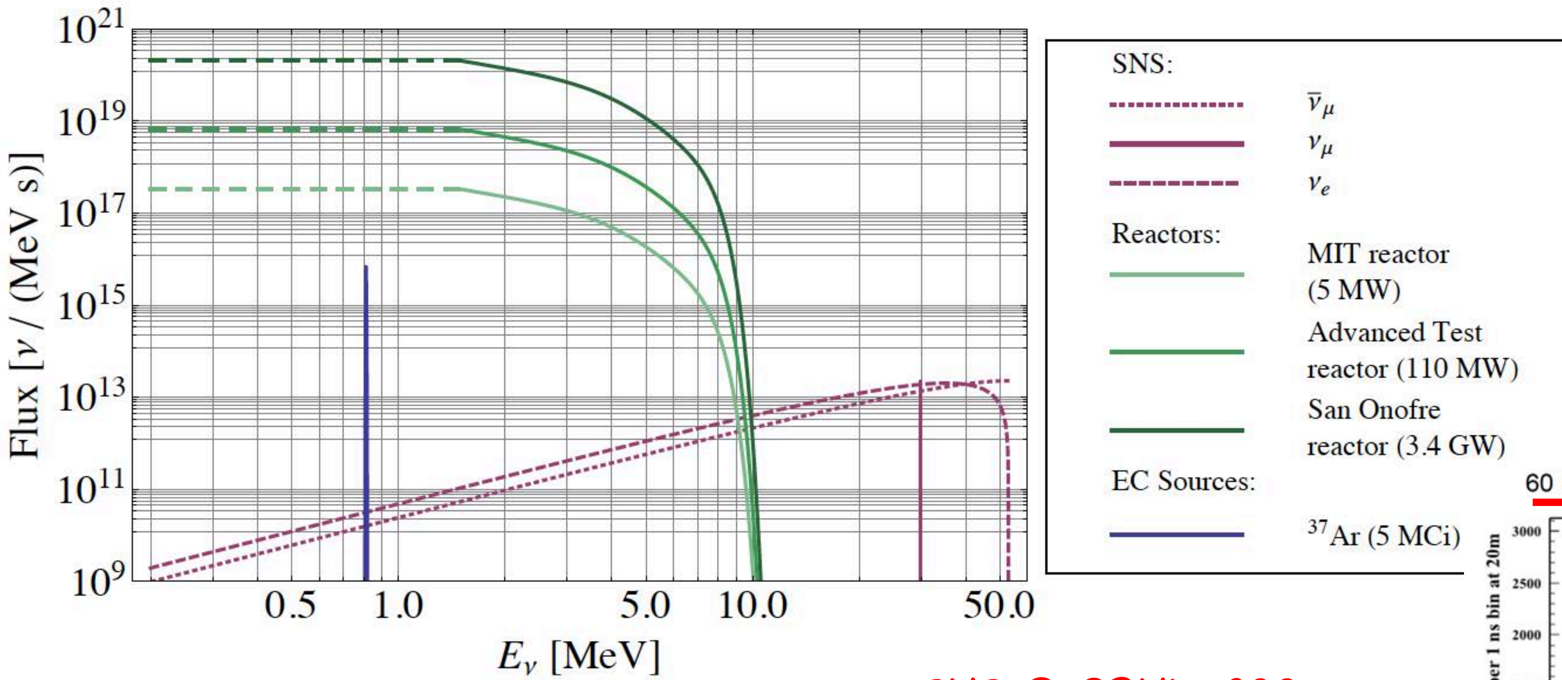
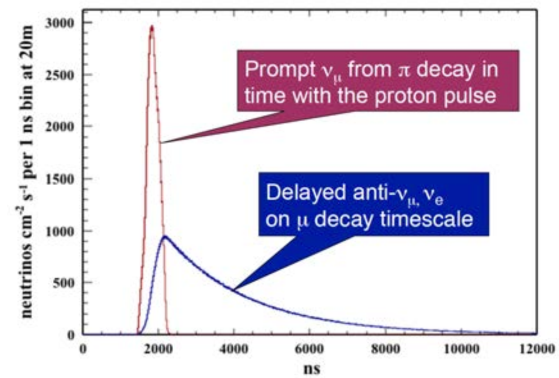


Means environmental background reduction by X 1,600

60 Hz *pulsed* source



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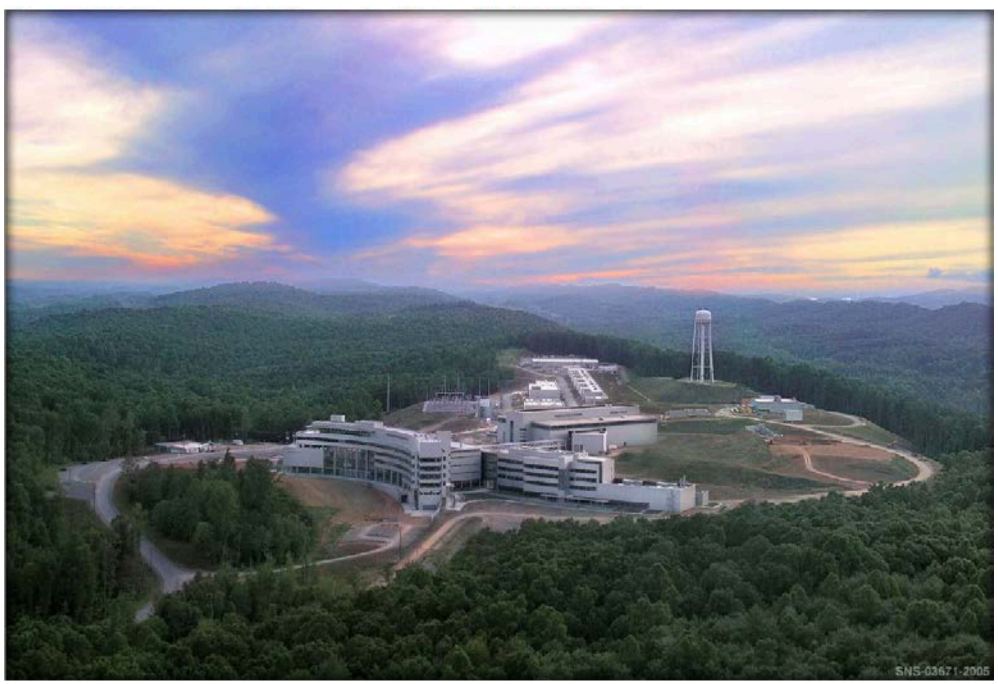
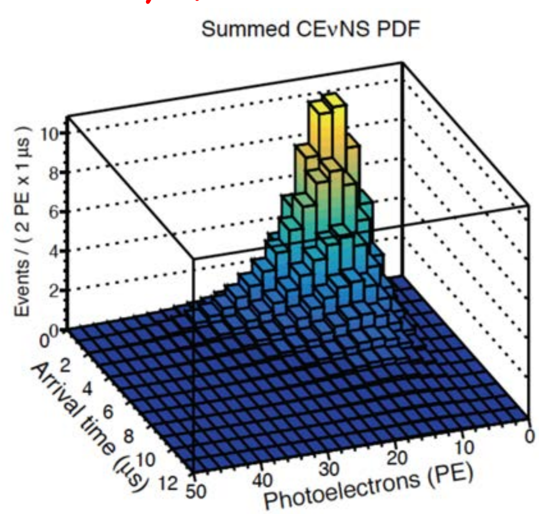


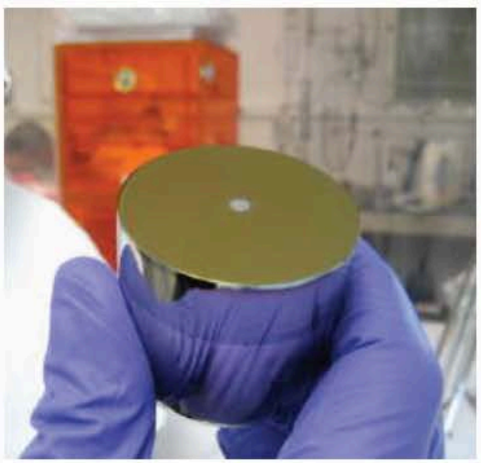


Expected CEvNS signal is characteristic in both energy and time

Enter COHERENT @ SNS:

How to Make an Unambiguous Measurement

- Observe the pulsed ν time-structure
- Observe the 2.2 μs characteristic decay of muon decay ν's
- Observe the N^2 cross section behavior between targets



P-Type Point Contact HPGe

Low-Background CsI[Na]

NaI[Tl]

Single Phase LAr

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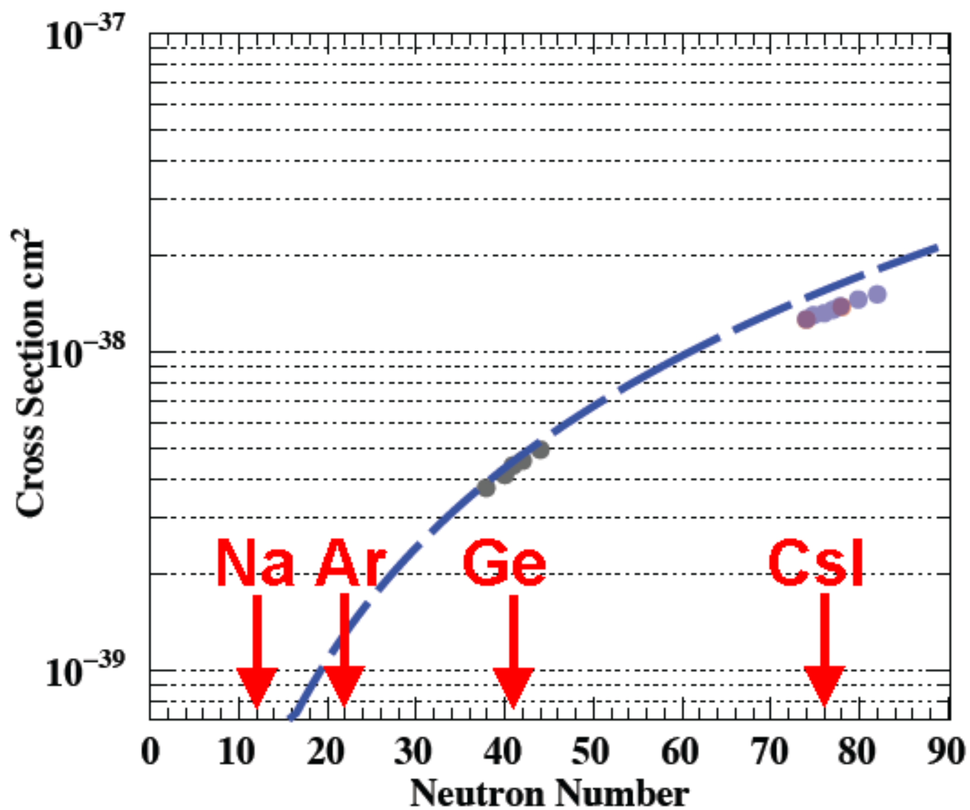
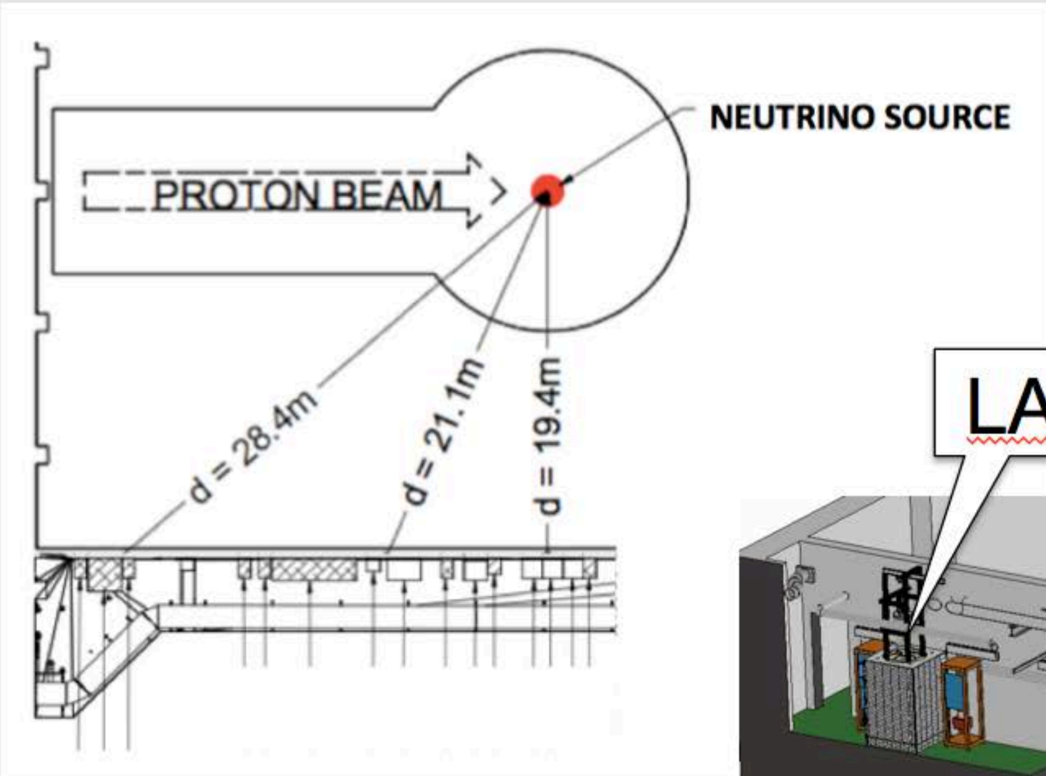
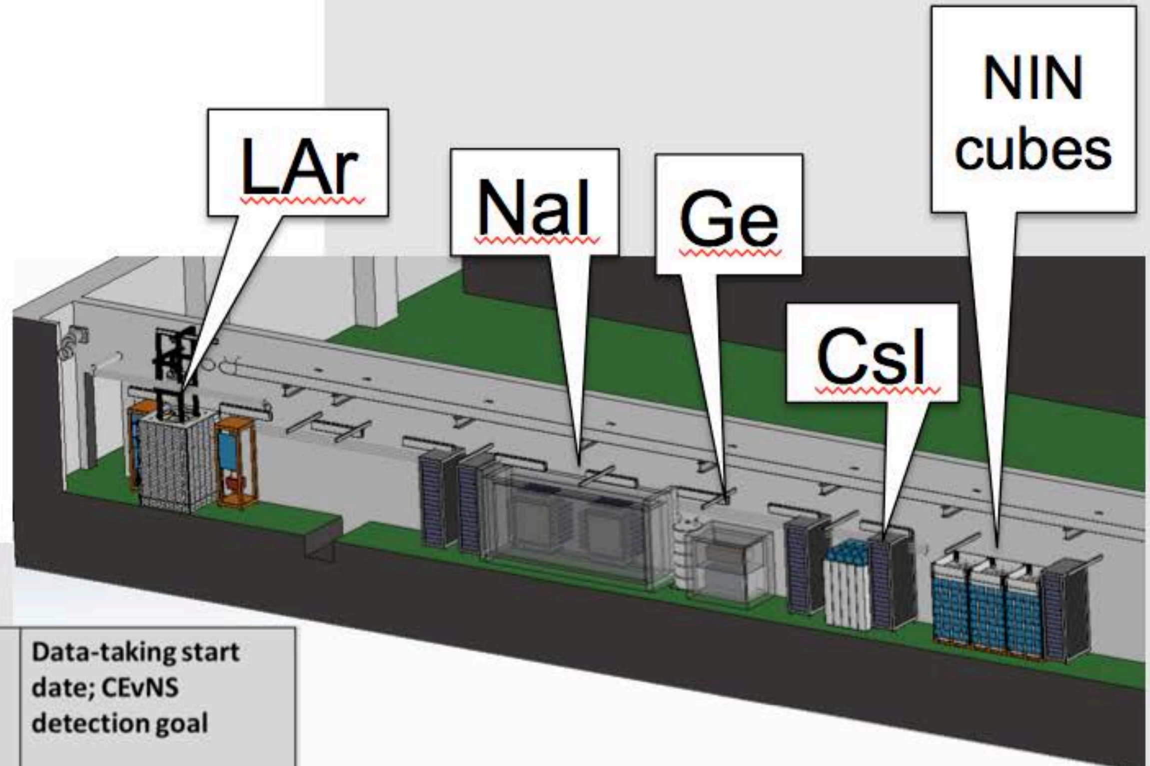


COHERENT DETECTORS AND STATUS



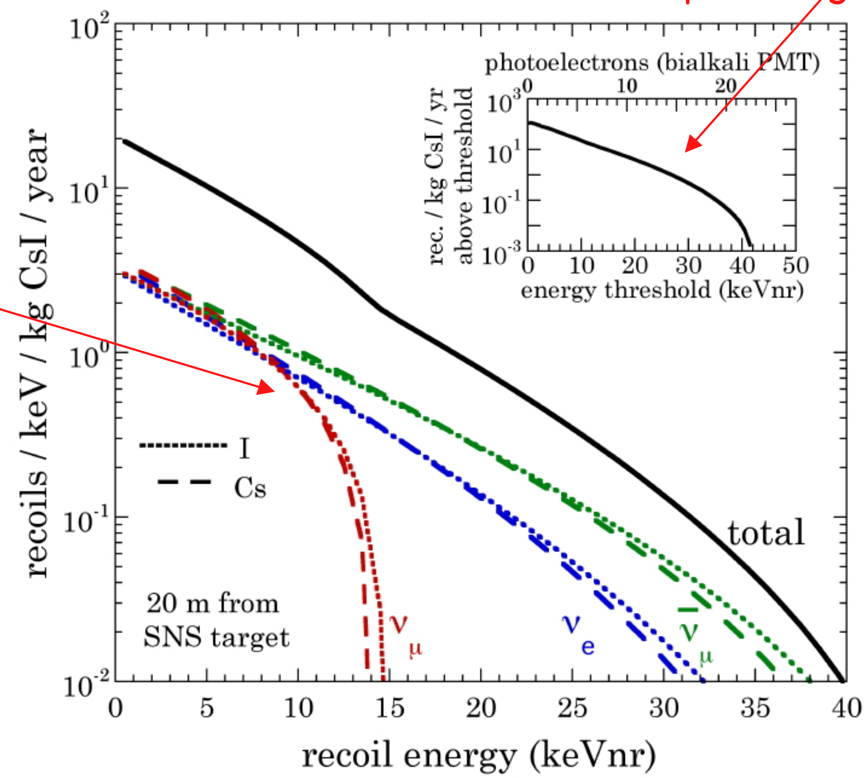


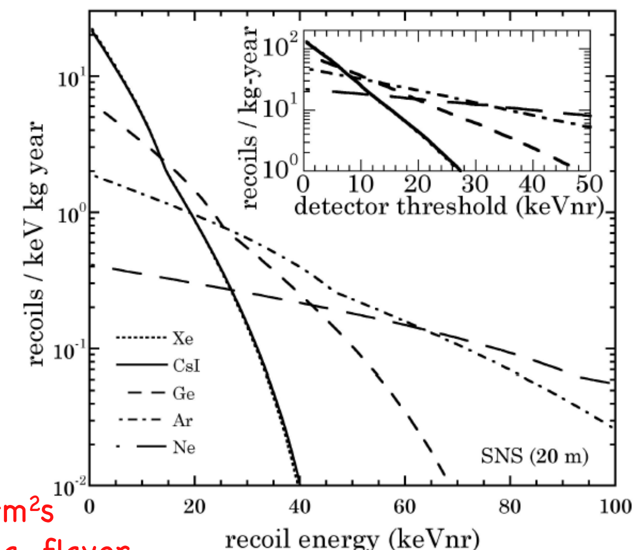
Nuclear Target	Technology	Mass (kg)	Distance from source (m)	Recoil threshold (keVr)	Data-taking start date; CEvNS detection goal
CsI[Na]	Scintillating crystal	14	20	4.5	9/2015; 5σ in 2 yr
Ge	HPGe PPC	10	22	5(2)	Fall 2016
LAr	Single-phase	35	29	20	Fall 2016
NaI	Scintillating crystal	185*/ 2000	22	13	*Summer 2016

Why CsI[Na]? (NIM A773 (2014) 56)

- Large N^2 => large x-section.
- Cs and I surround Xe in Periodic Table: they behave much like a single recoiling species, greatly simplifying understanding the NR response.
- Quenching factor in energy ROI sufficient for ~5 keVnr threshold (we have measured this).
- Statistical NR/ER discrimination is possible at low-E (but will need further improved signal-to-background).
- Sufficiently low in intrinsic backgrounds (U, Th ,K-40, Rb-87, Cs-134,137) Measurements in complete SNS shield and 6 m.w.e. indicate we are ready)
- Practical advantages: High light yield (64 ph/keVee), optimal match to bialkali PMTs, rugged, room temperature, inexpensive ($1/g), modest afterglow (CsI[Tl] not a viable option for surface experiment).
- Expect ~550 ν recoils/year in 14 kg detector.

Using **measured** quenching factor





1.7E7 ν/cm^{2}s @20m, e.a. flavor

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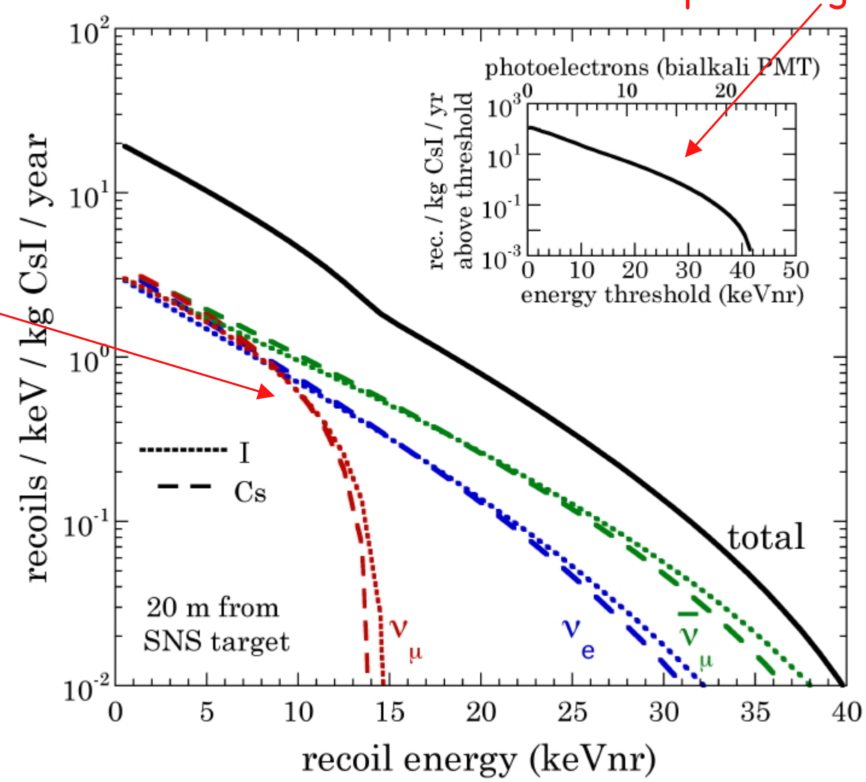
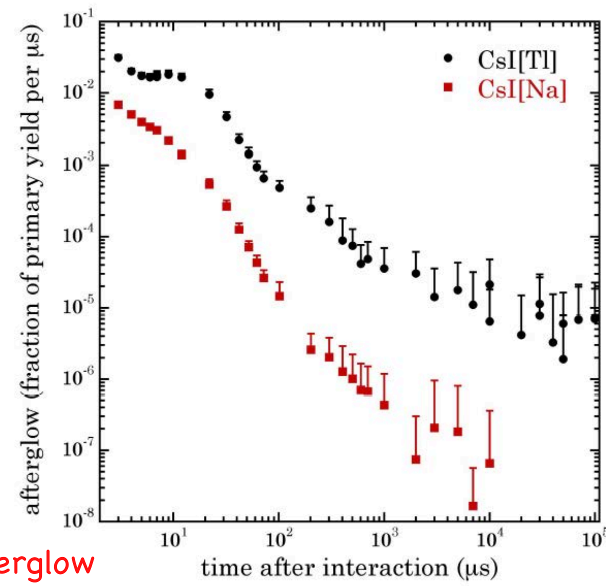
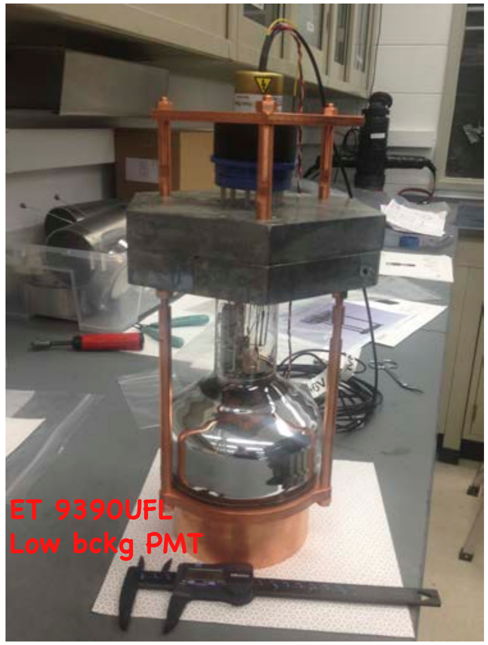
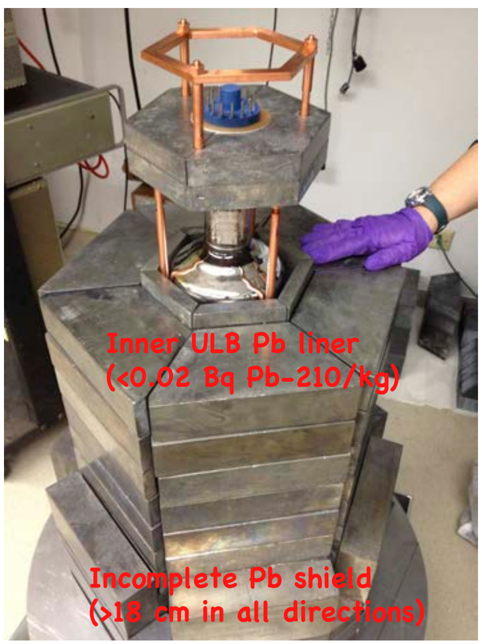


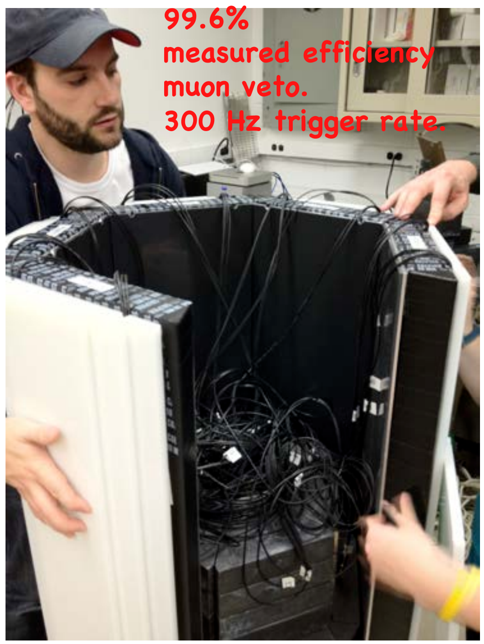


CsI[Tl] not an option due to excessive afterglow

Preliminaries: background studies w/ 2 kg prototype

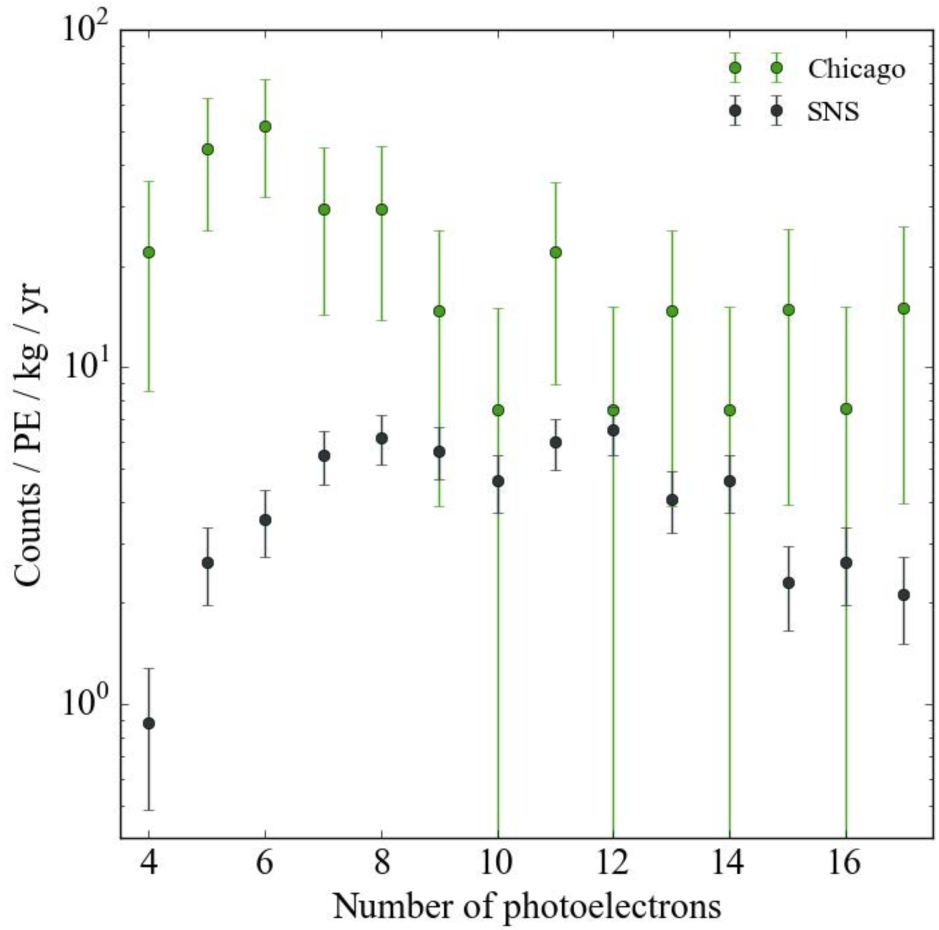






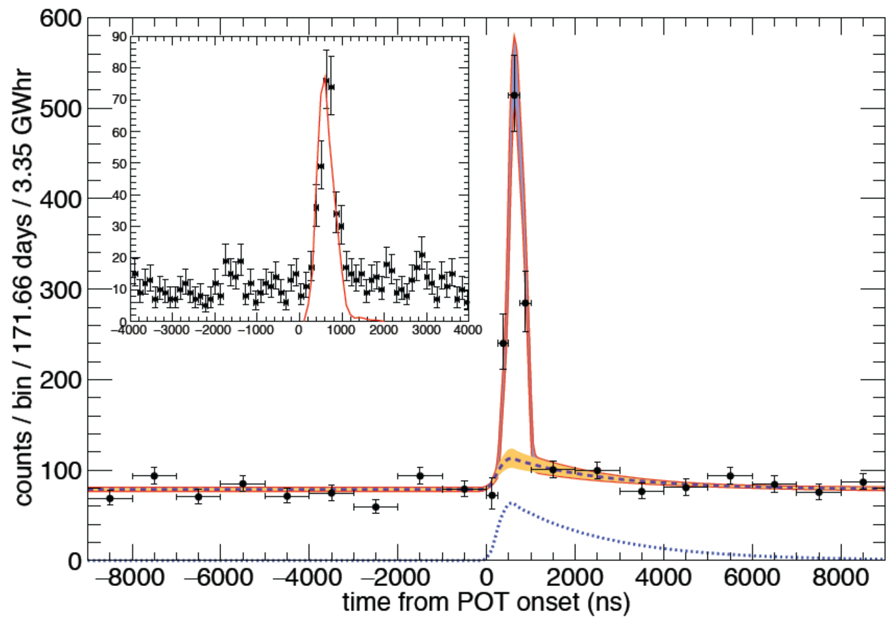
Pulsed SNS signal leads to very low bckg.

We improved on prototype background level!

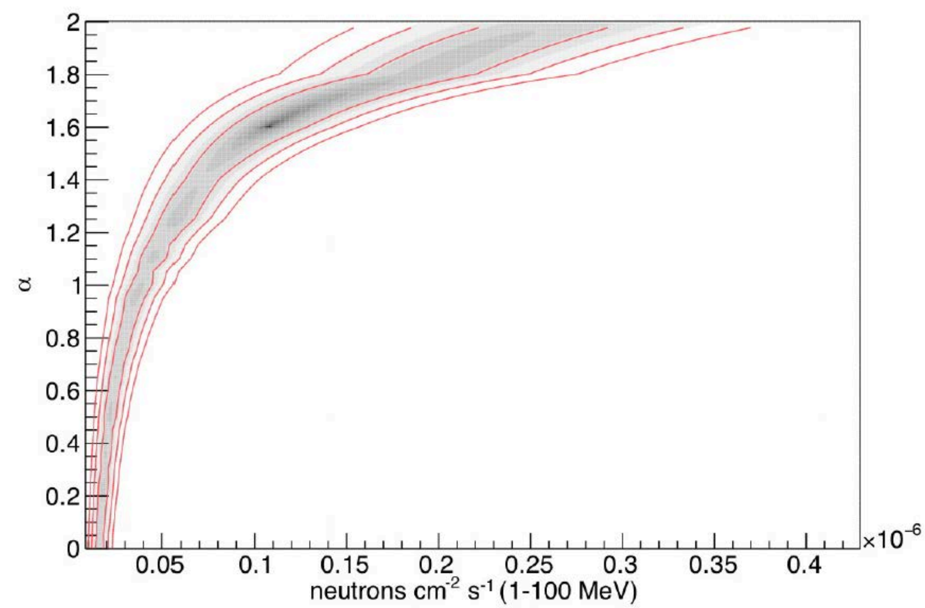


Preliminaries: *in situ* neutron bckg measurements

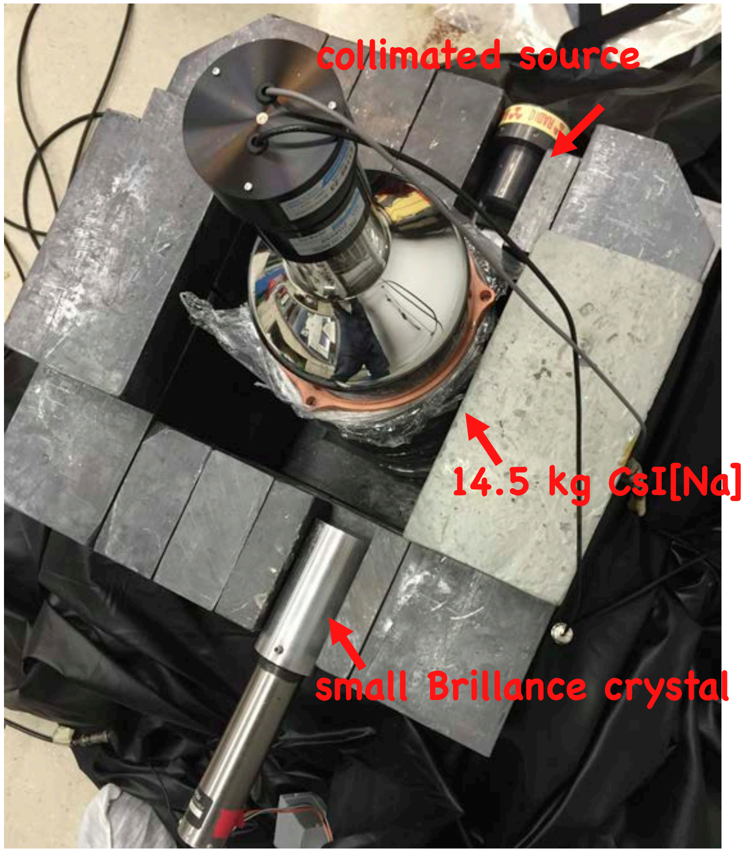
The “neutrino alley” @ SNS

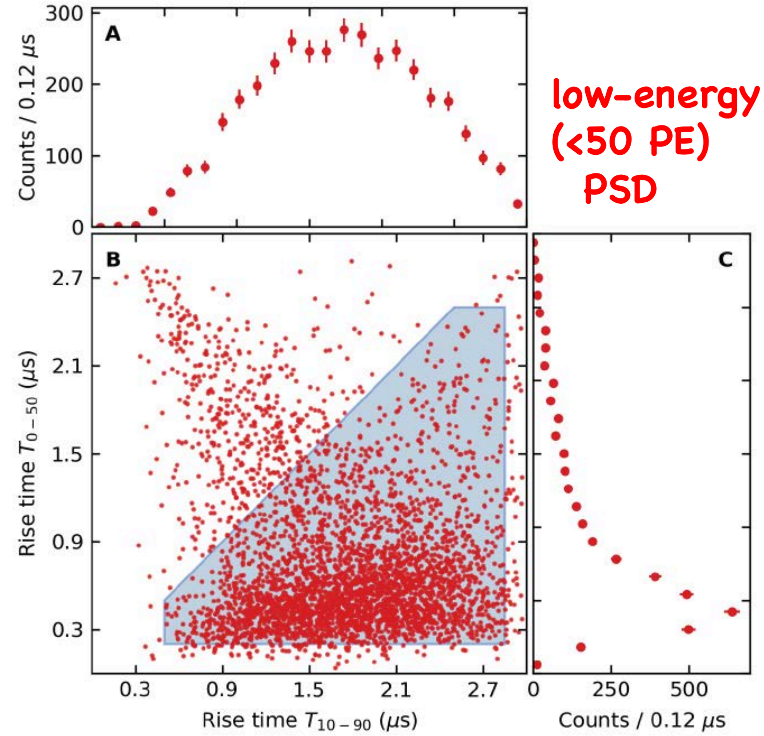


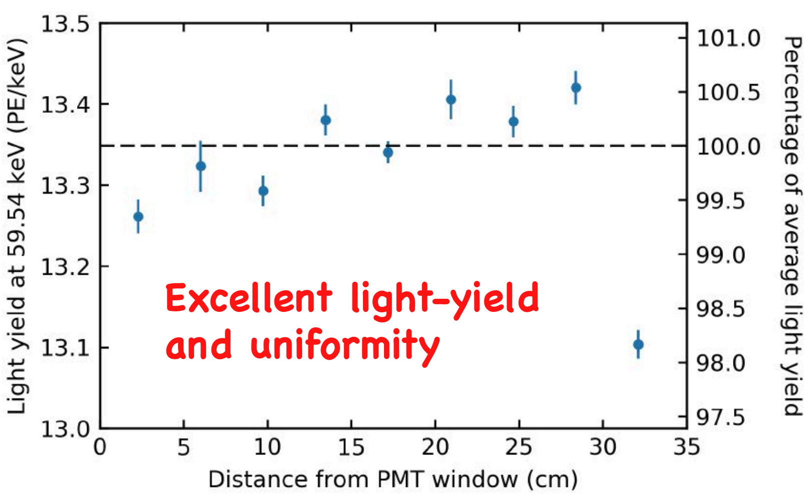
Measured NIN and prompt n bckg rates are x50 and x20 smaller than CEνNS signal rate.

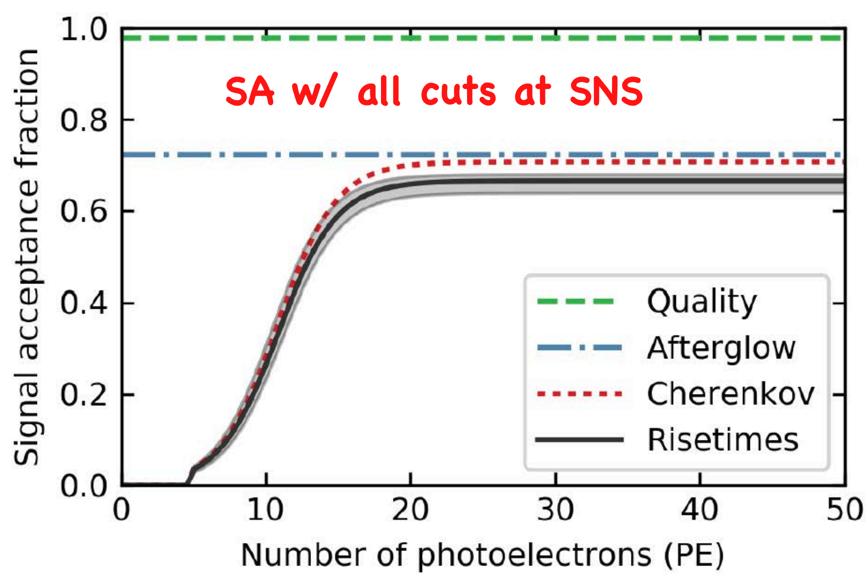


Preliminaries: 14.5 kg detector characterization

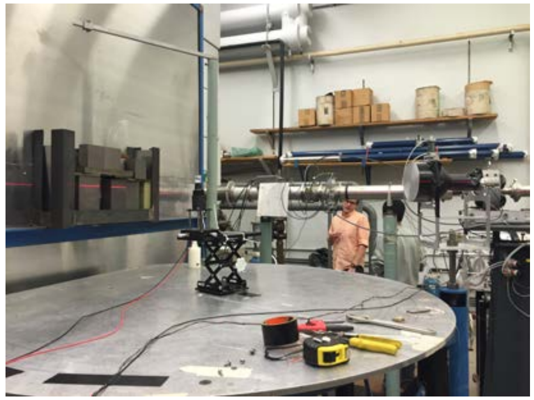


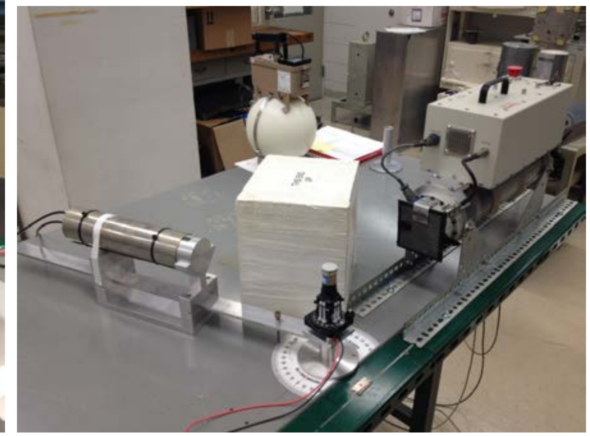


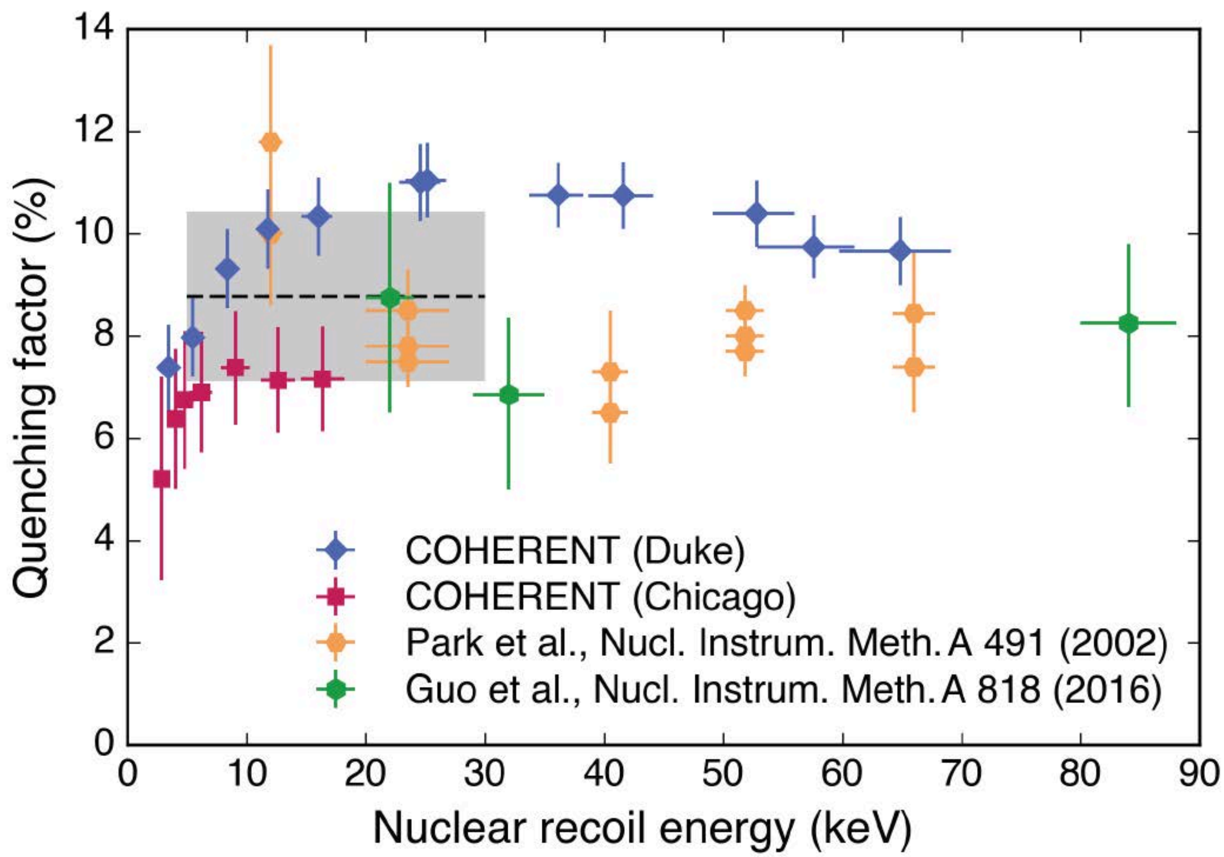




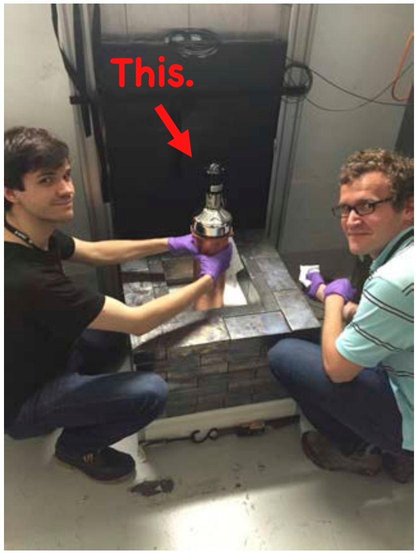
Preliminaries: Quenching factor measurements

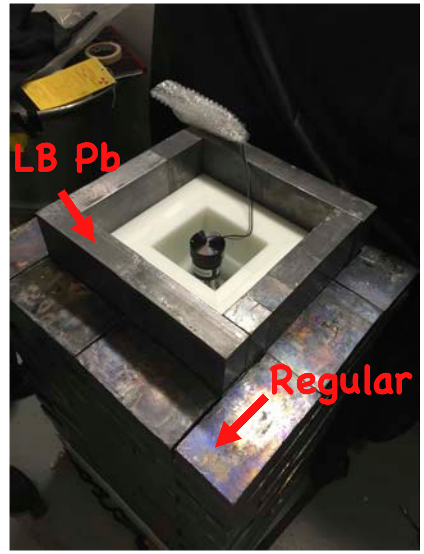


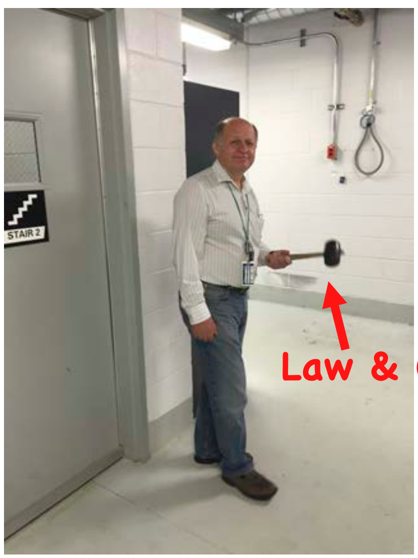




Installation of 14.5 kg CsI[Na] June 2015
(first "handheld" ν detector)

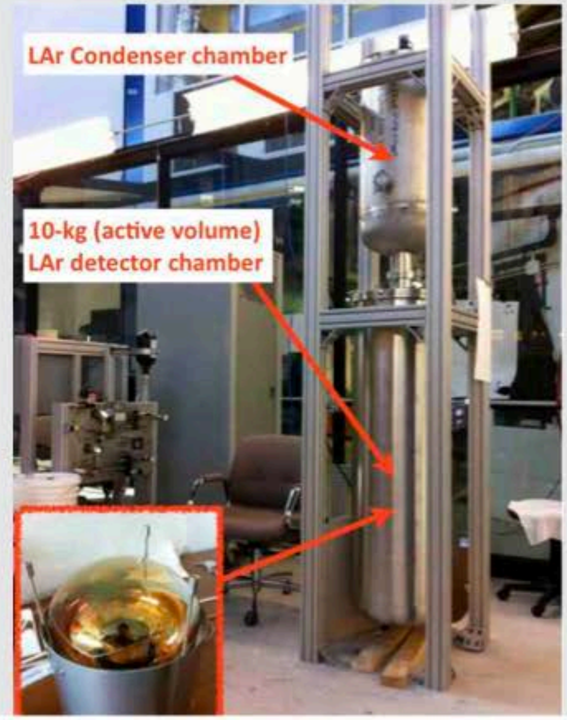


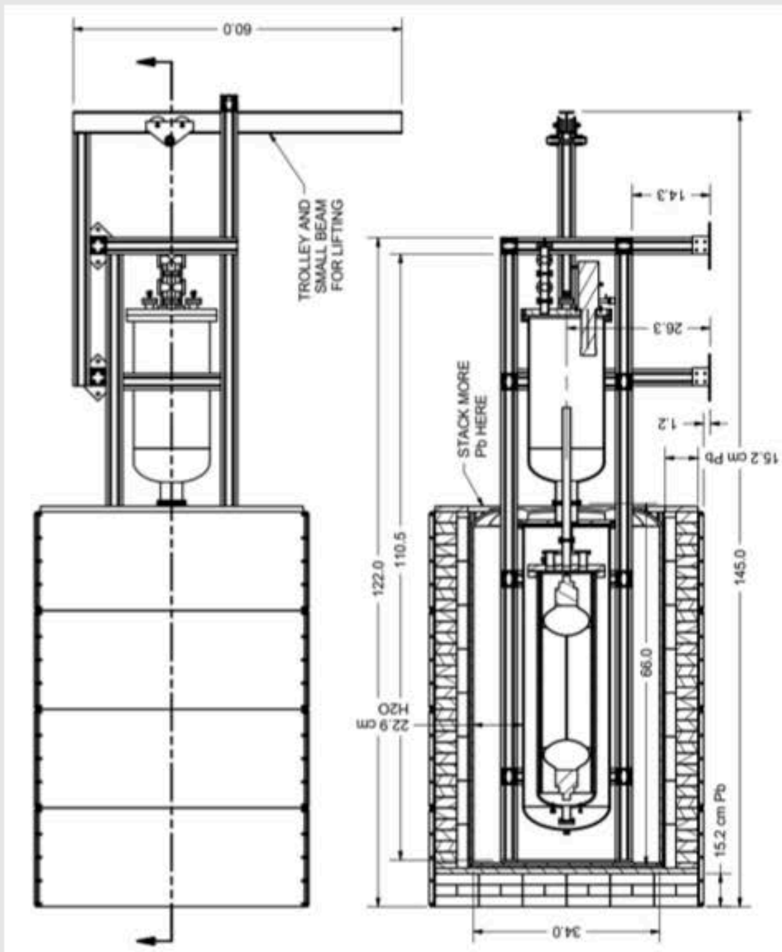


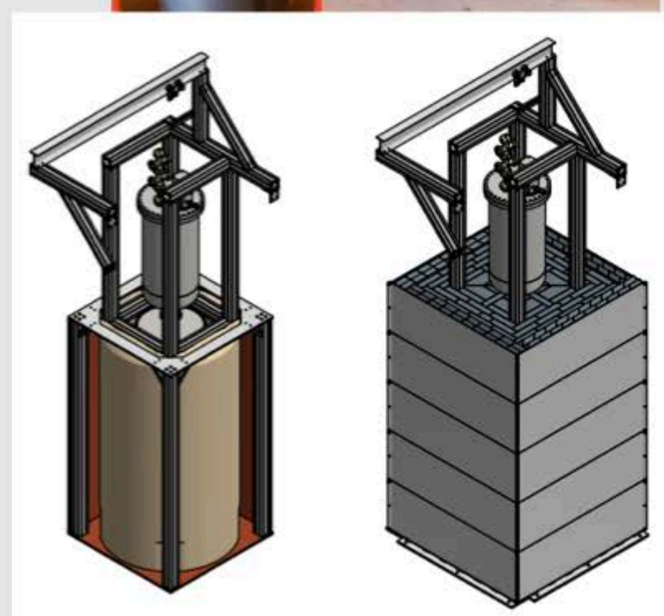


<u>CENNS-10 LAr detector for COHERENT</u>

- CENNS-10 detector built at Fermilab, modified by IU-group
- 35kg LAr fiducial mass. **NR/ER discrimination.**
- Pb, Cu, H2O shielding structure built for SNS neutrino corridor
- ~300/700 (prompt/delayed) CEvNS events/yr on 100/900 est. background evts
- QF measured







LAr QF measurements

Measurement of Scintillation and Ionization Yield and Scintillation Pulse Shape from Nuclear Recoils in Liquid Argon - SCENE Collaboration (Cao, H. *et al.*) Phys.Rev. D91 (2015) 092007 arXiv:1406.4825 [physics.ins-det] FERMILAB-PUB-14-204-AE-E

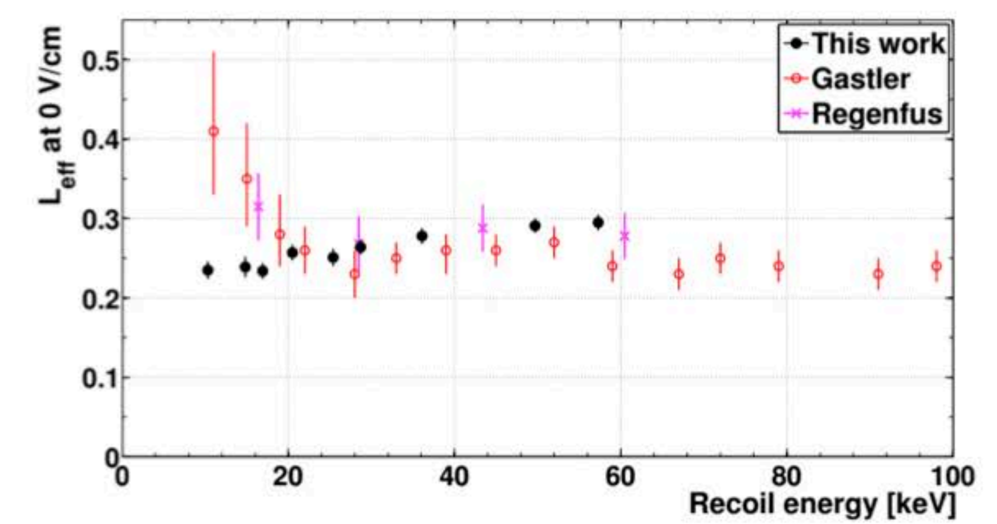
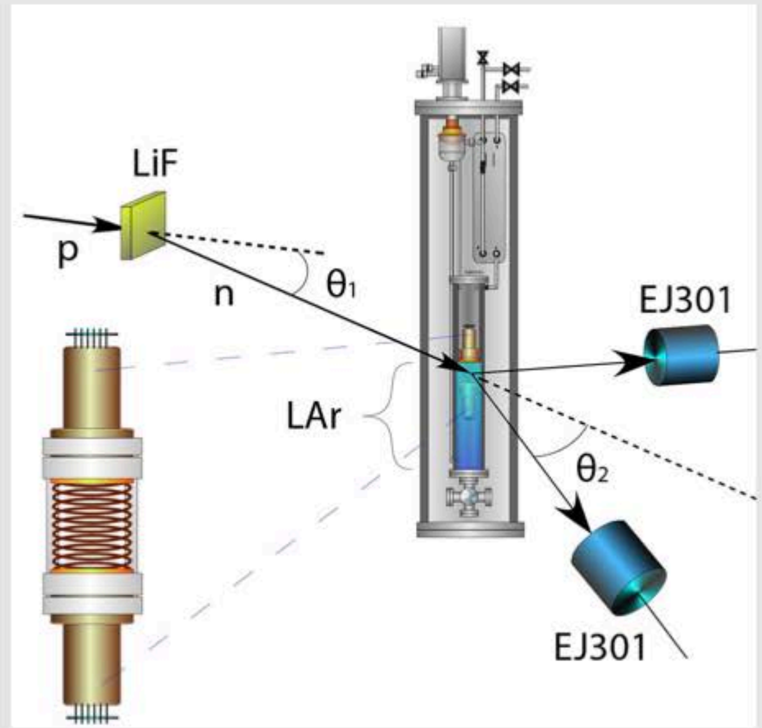


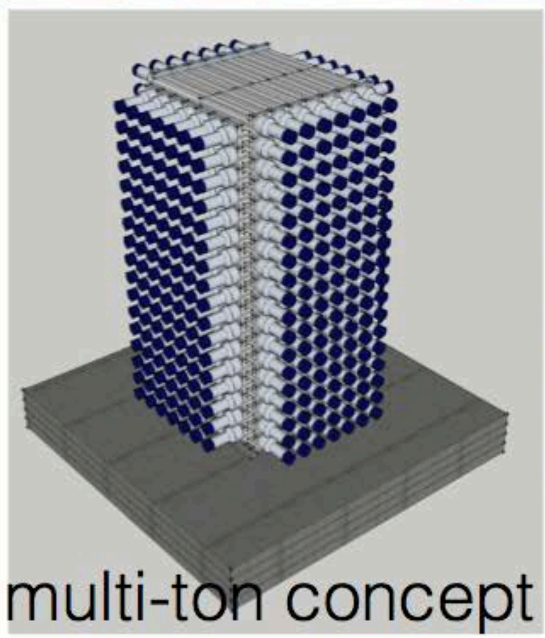
FIG. 10. S1 yield as a function of nuclear recoil energy measured at zero field relative to the light yield of ^{83m}Kr at zero field, compared to previous measurements[8, 9].



Detector Subsystems: NaI[Tl]

https://twitter.com/NaIvE_SNS

- Initial deployment 185 kgs
- Up to 9 T in hand
- N = 23 for Na
- Instrumentation tests underway at Duke and UW
- QF measured by collaboration



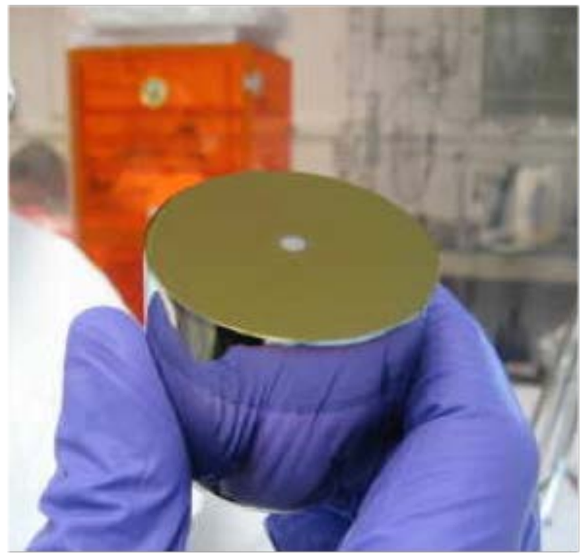
NaI[Tl]: Two primary measurement goals

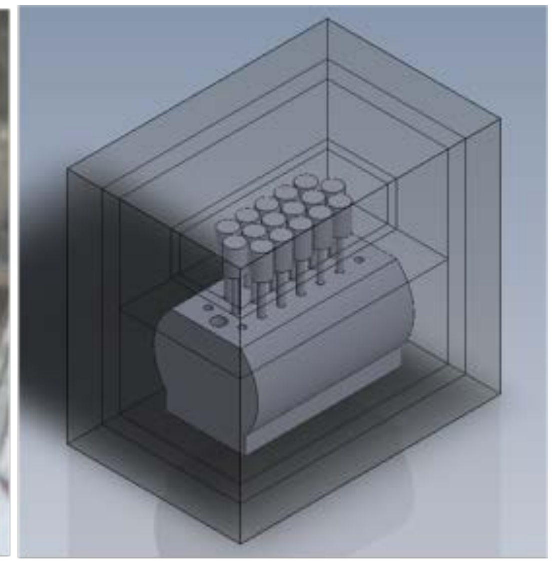
- CEvNS on Na
- The electron neutrino Charged & Neutral-Current interaction on ^{127}I

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$_{\text{g.s.}}$	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$_{\text{g.s.}}$	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)

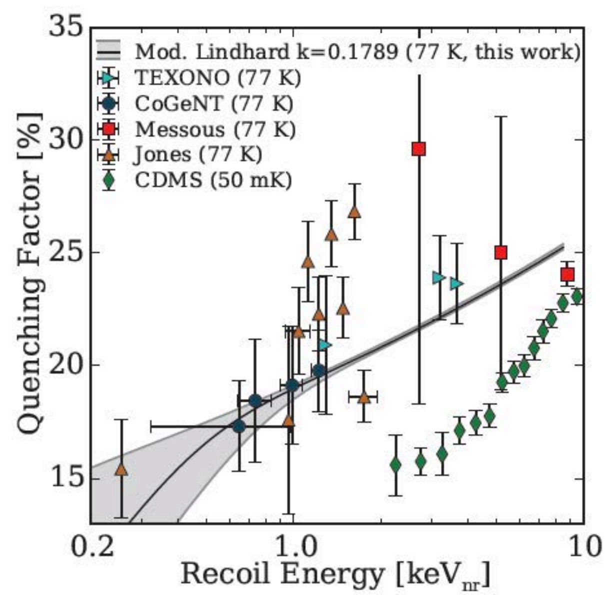
J. A. Formaggio and S. Zeller, Rev. Mod. Phys. 84, 1307 (2012)

Detector Subsystems: HPGe PPCs





- Smaller N: 38-44
- Excellent resolution at low energies
- Well-measured quenching factor
- Phase I: 5-10kg PPC Ge detector array:
  - **Repurposing on-hand Majorana Demonstrator/LANL ^{nat}Ge detectors.**
  - **Copper/Lead/Poly shield with Plastic scintillator μ-veto.**
  - **Installation in Fall 2016**
- **Potential Phase II: Expansion of target with larger-mass (C4-style) point contact detectors.**



COHERENT is marching along!