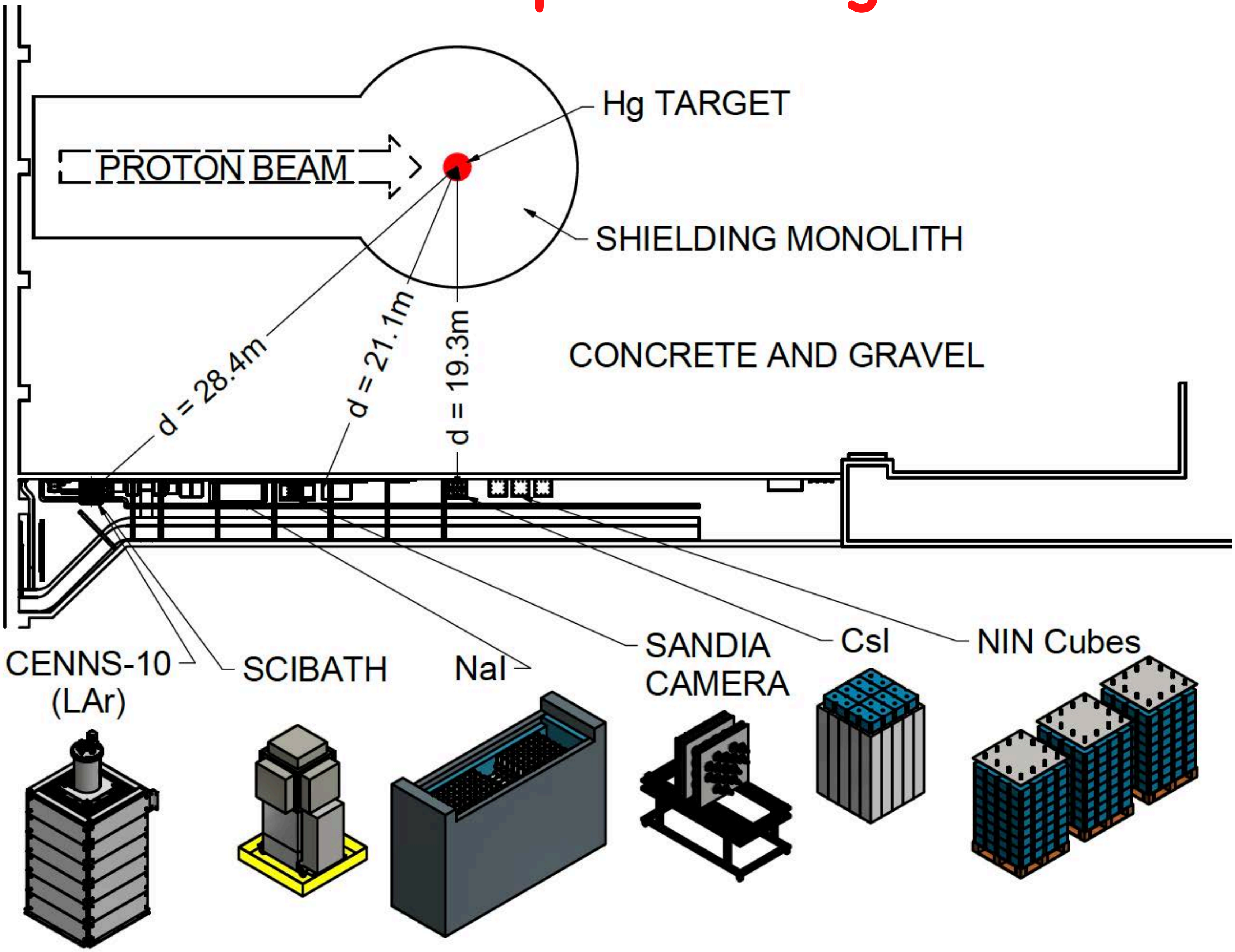
CEνNS: the shape of things to come



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

- Uncontroversial Standard Model process
- Large enhancement to 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

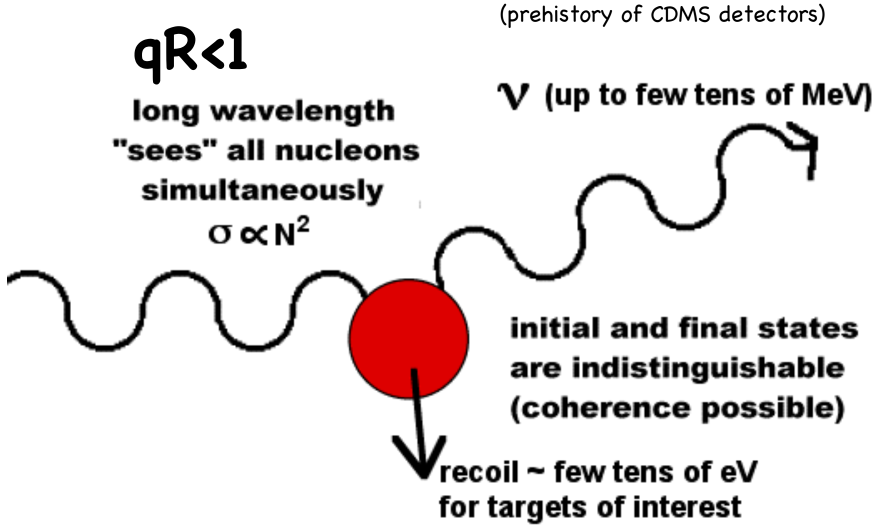
- 43 yrs until successful detection… combination of source & detector technology was missing:

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

(recoils lose just 10-20% of E to ionization or scintillation)

- Cryogenic bolometers and many other methods proposed over the last four decades.

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 $\Rightarrow$ 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 $\Rightarrow$ evidence for $\nu_{sterile}$ (A.Drukier & L.Stodolsky, PRD 30 (84) 2295)
- Sensitive probe of weak nuclear charge $\Rightarrow$ test of radiative corrections due to new physics above weak scale (L.M.Krauss, PLB 269, 407)
- More sensitive to NSI and new neutral bosons than ν factories. Also effective ν charge ratio
(J. Barranco et al., hep-ph/0508299, hep-ph-0512029)
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- Sensitive probe of neutron dens. distribution

Smallish detectors… "ν technology"?

- Monitoring of nuclear reactors against illicit operation or fuel diversion: present proposals using conventional 1-ton detectors reach only > ~3 GWt reactor power
- Geological prospection, planetary tomography… the list gets much wilder.

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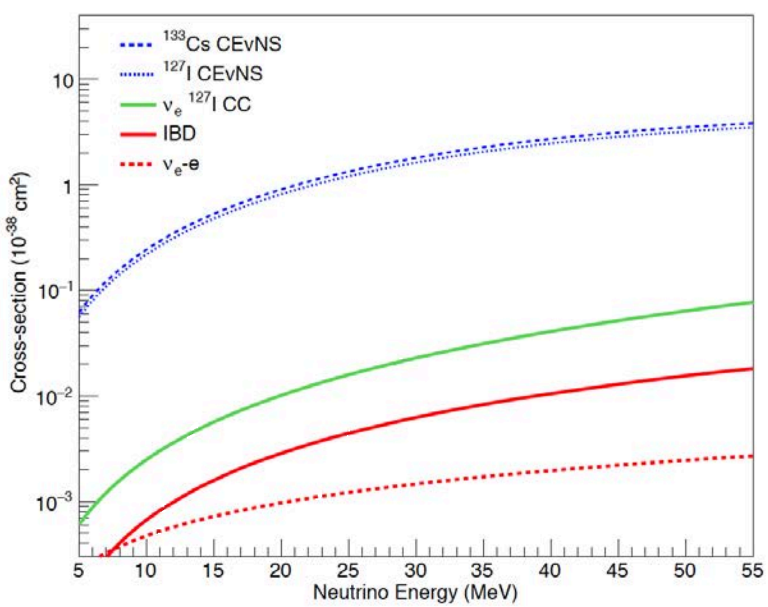

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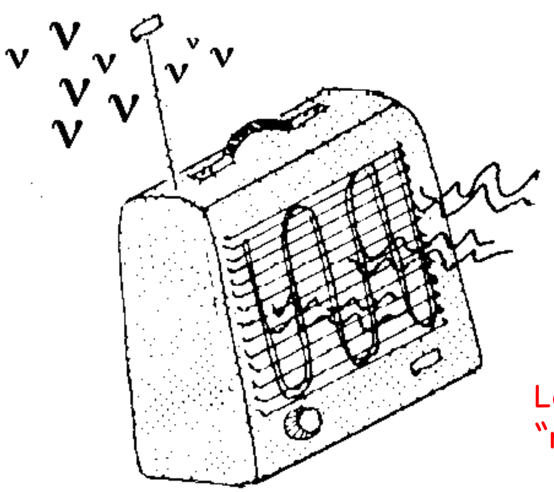

ONE IN EVERY HOME

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

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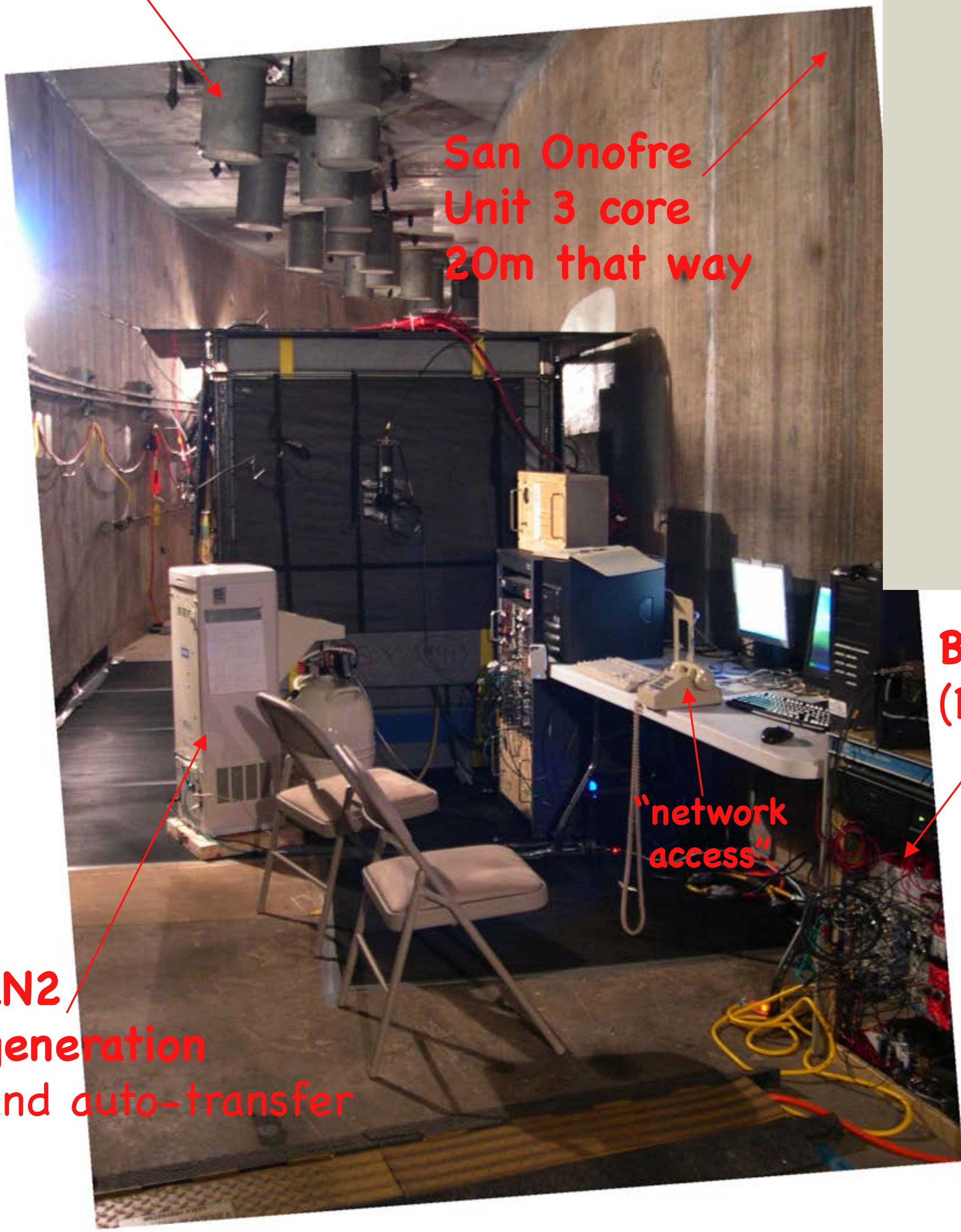
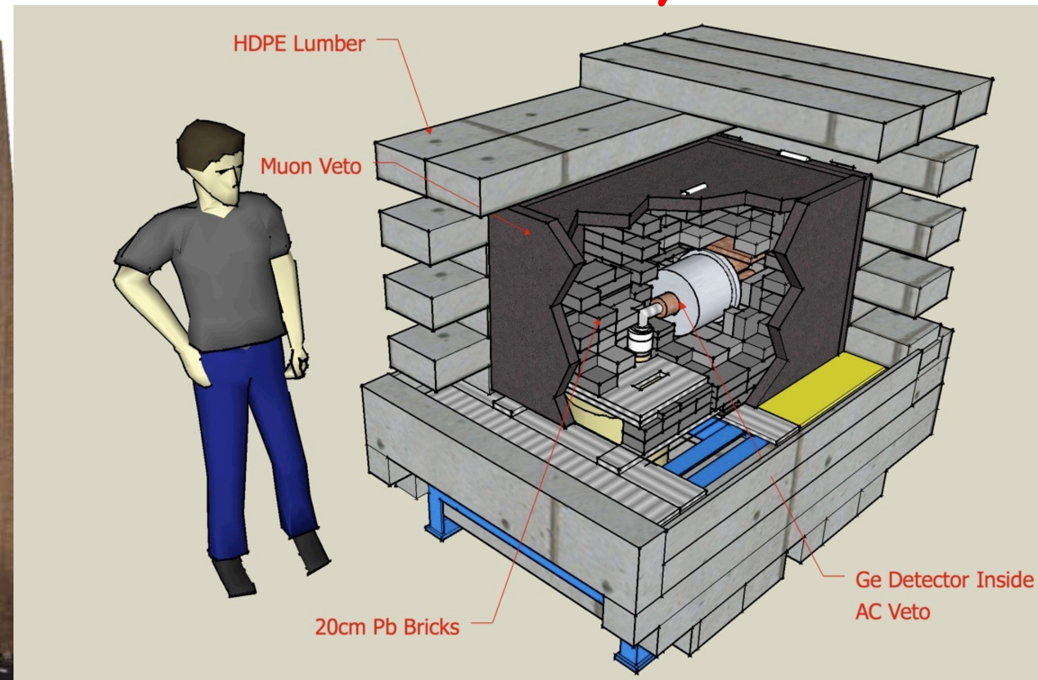
Everyone needs a hobby

"Tendons"

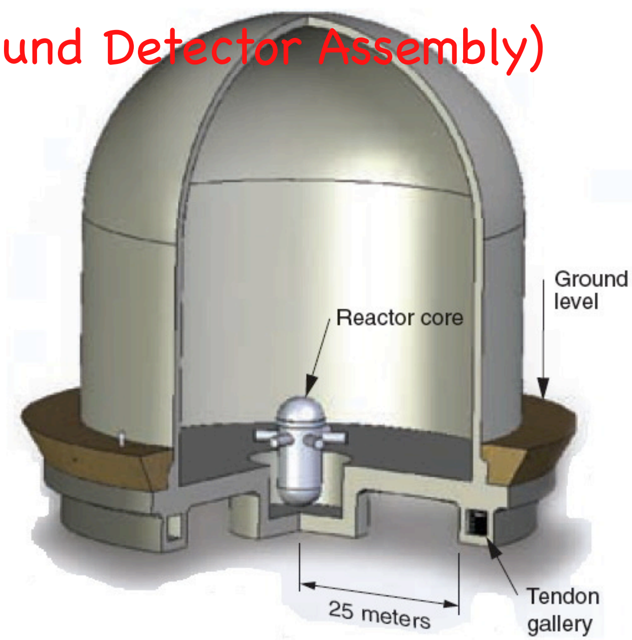
30 mwe



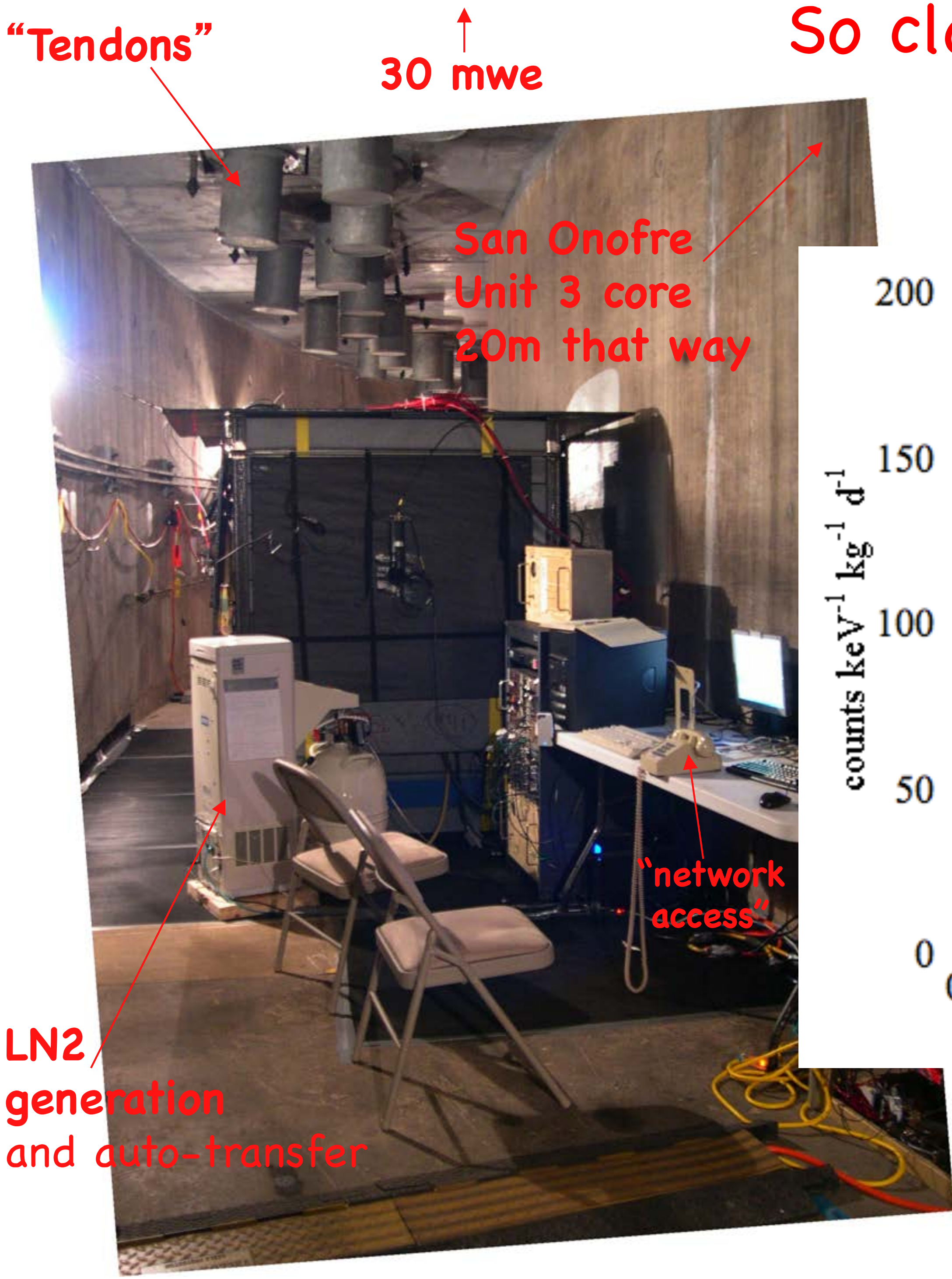
LN2
generation
and auto-transfer

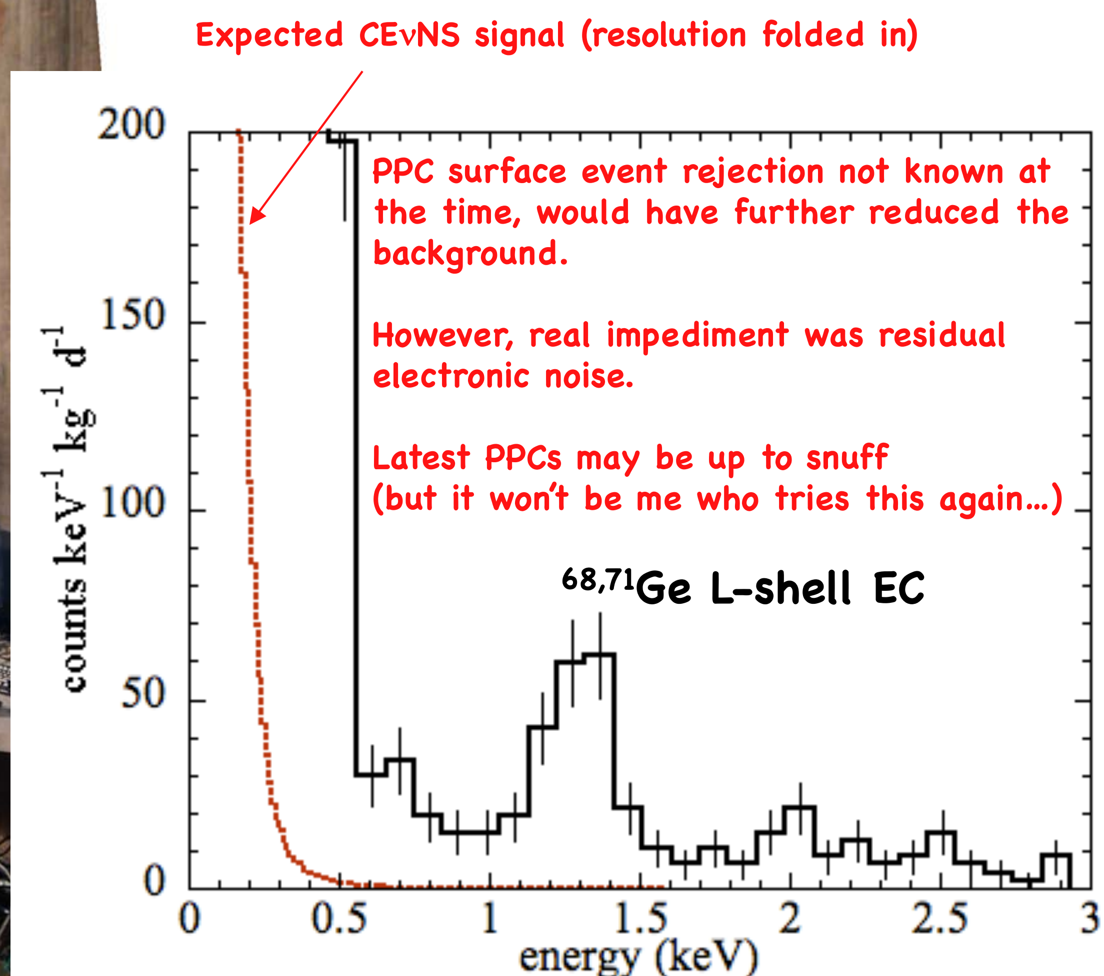


BaDAss
(Background Detector Assembly)



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 **(also MINER)**

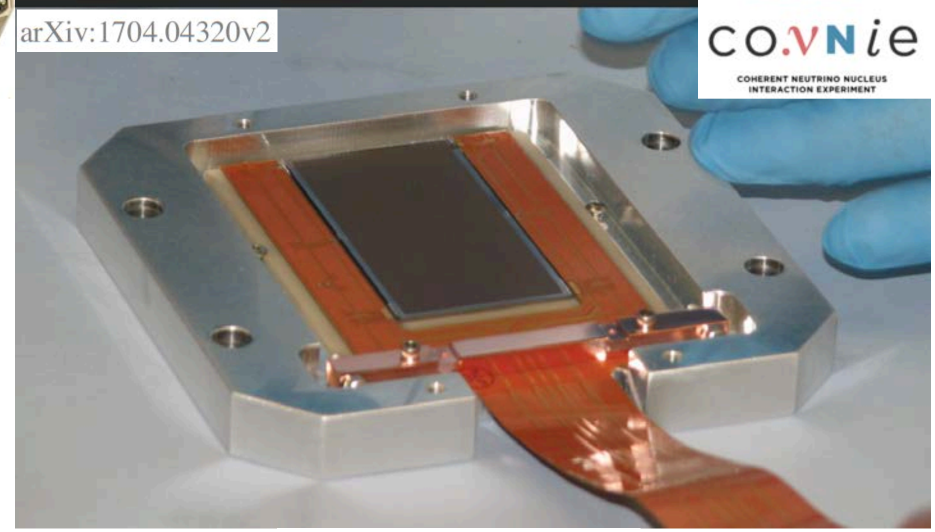
VOLUME 55, NUMBER 1 PHYSICAL REVIEW LETTERS 1 JULY 1985

Bolometric Detection of Neutrinos

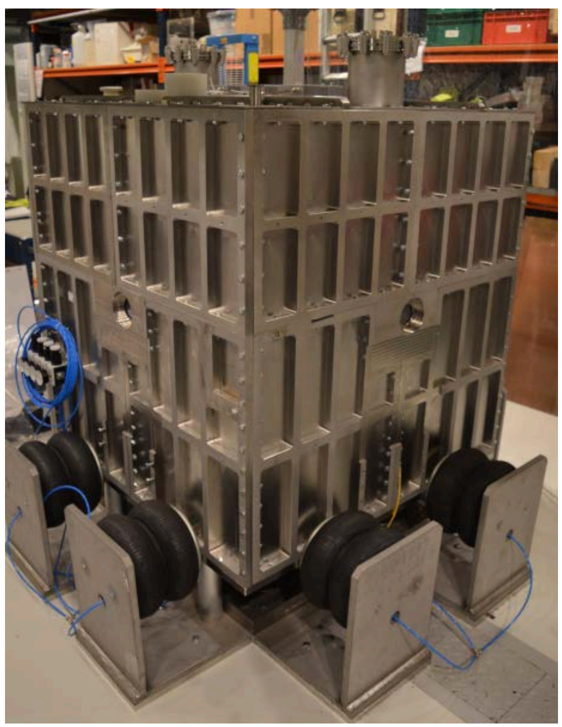
Blas Cabrera, Lawrence M. Krauss, and Frank Wilczek
Department of Physics, Stanford University, Stanford, California 94305
Lyman Laboratory of Physics, Harvard University, Cambridge, Massachusetts 01238
Institute for Theoretical Physics, University of California, Santa Barbara, California 93106
(Received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

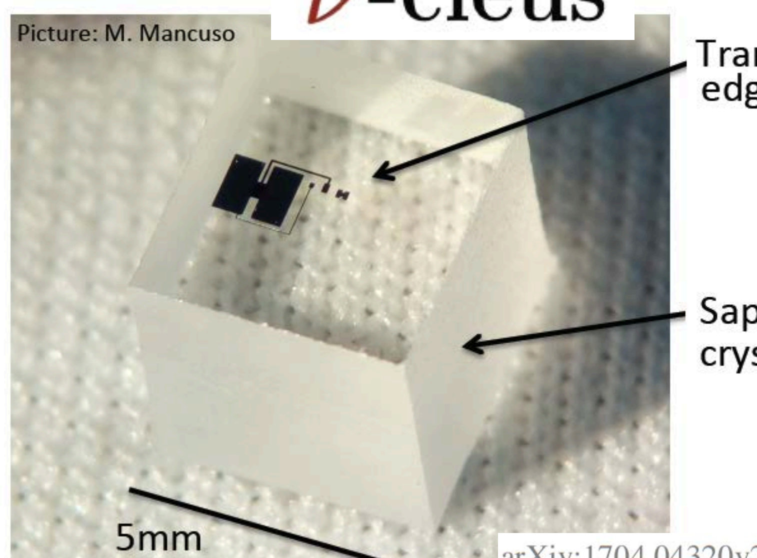
CONNIE 2014-2015 sensor:



CONνUS

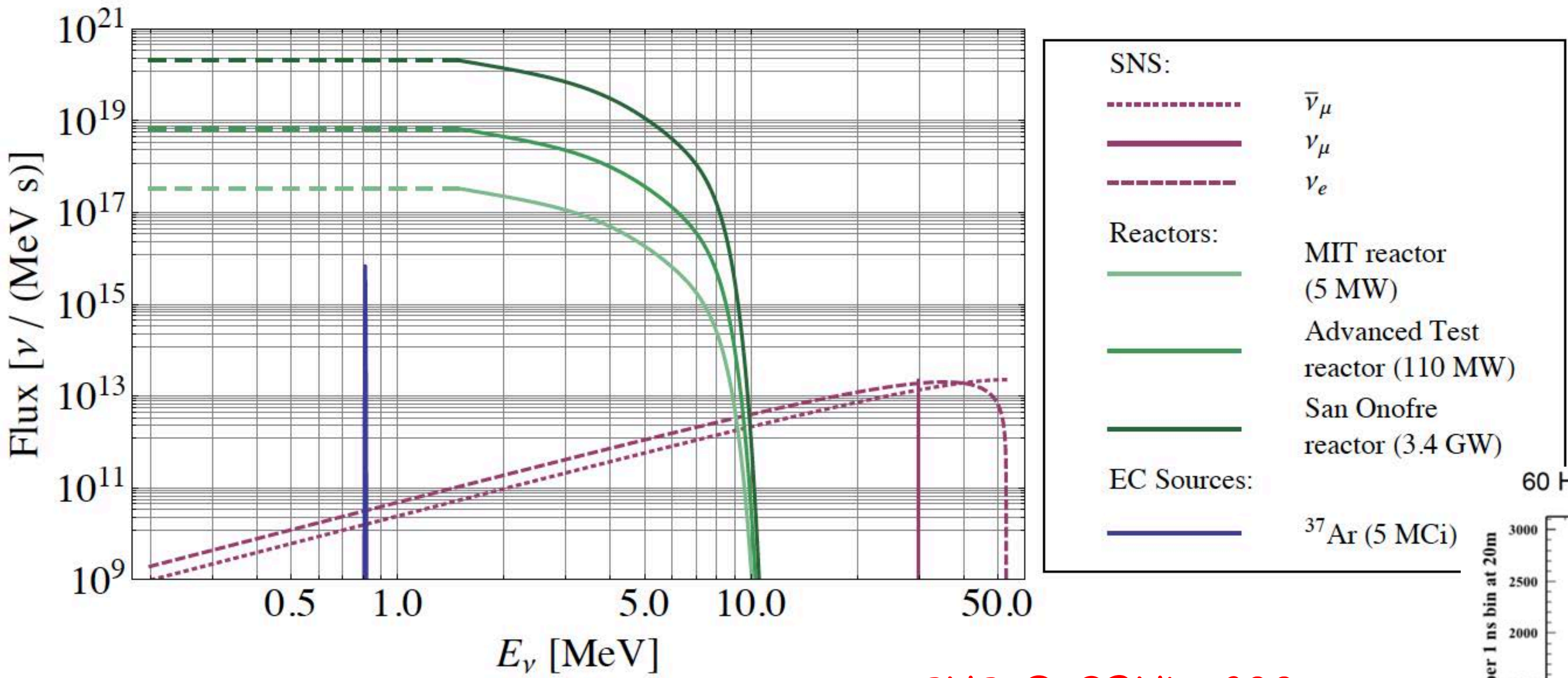


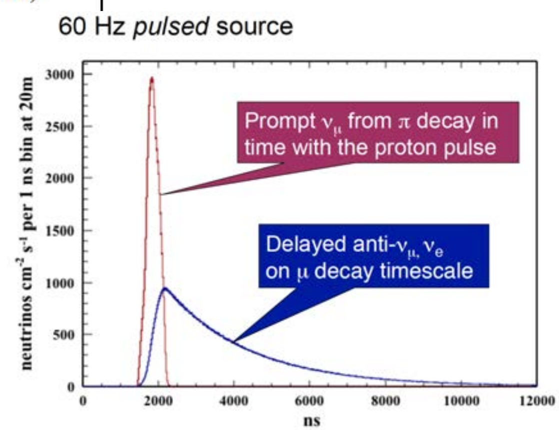
ν-cleus



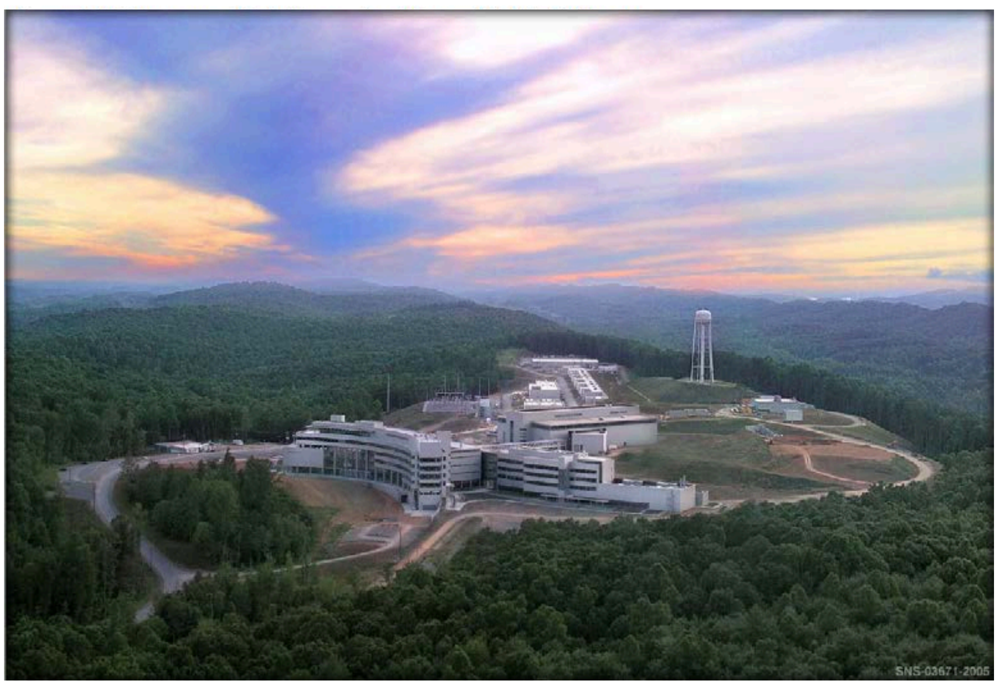
Technological applications: reactor monitoring is around the corner (compact microbolometer arrays and CCDs are almost there)

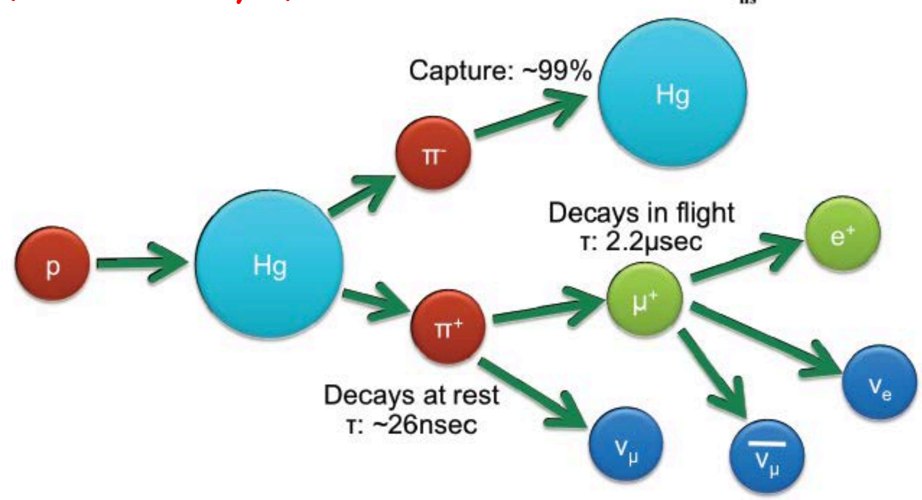
Fortunately, reactors are not the only game in town:





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





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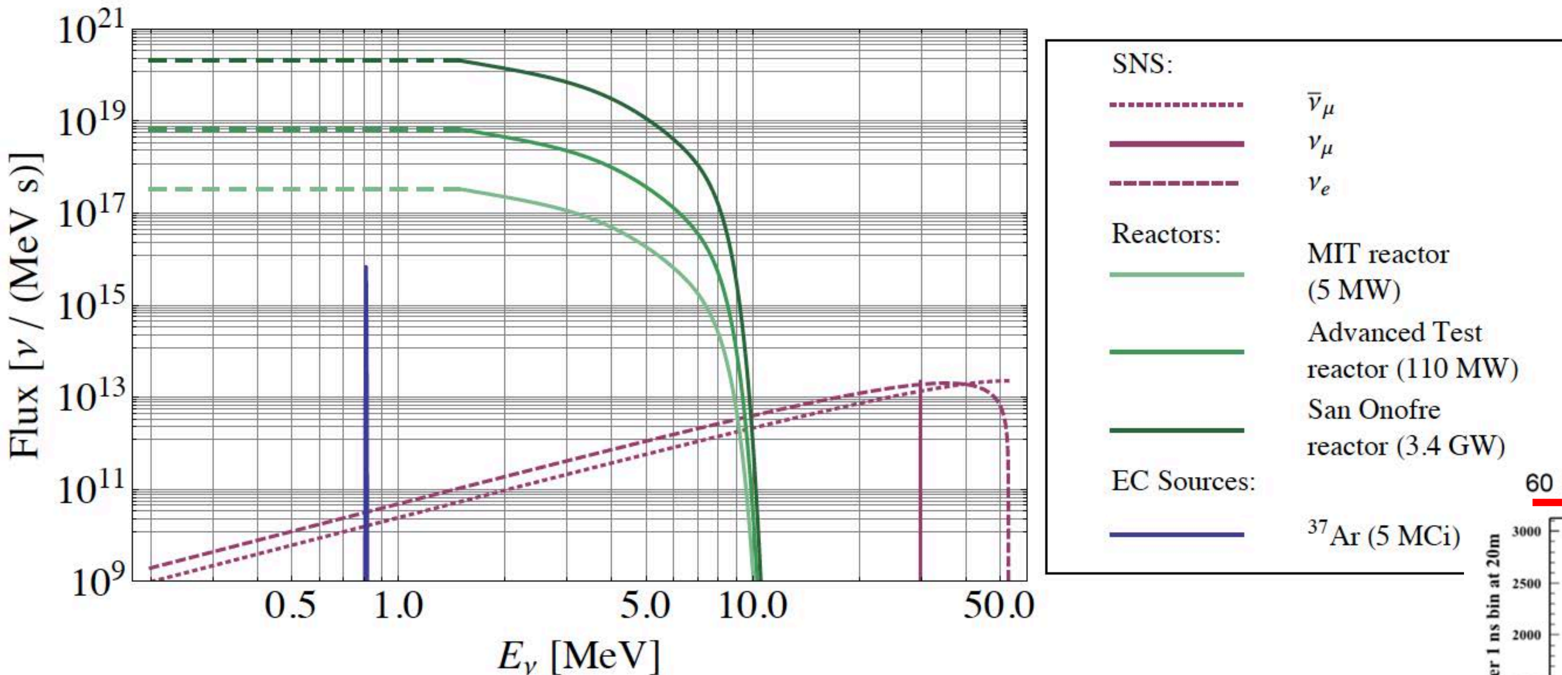
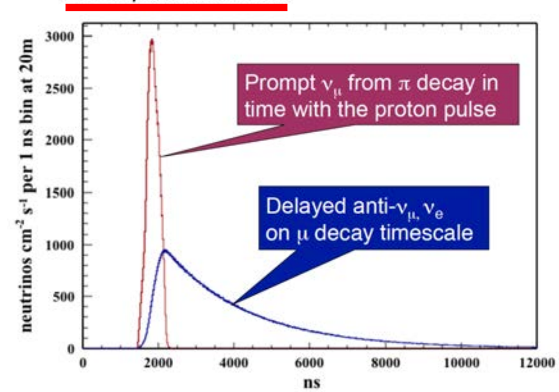
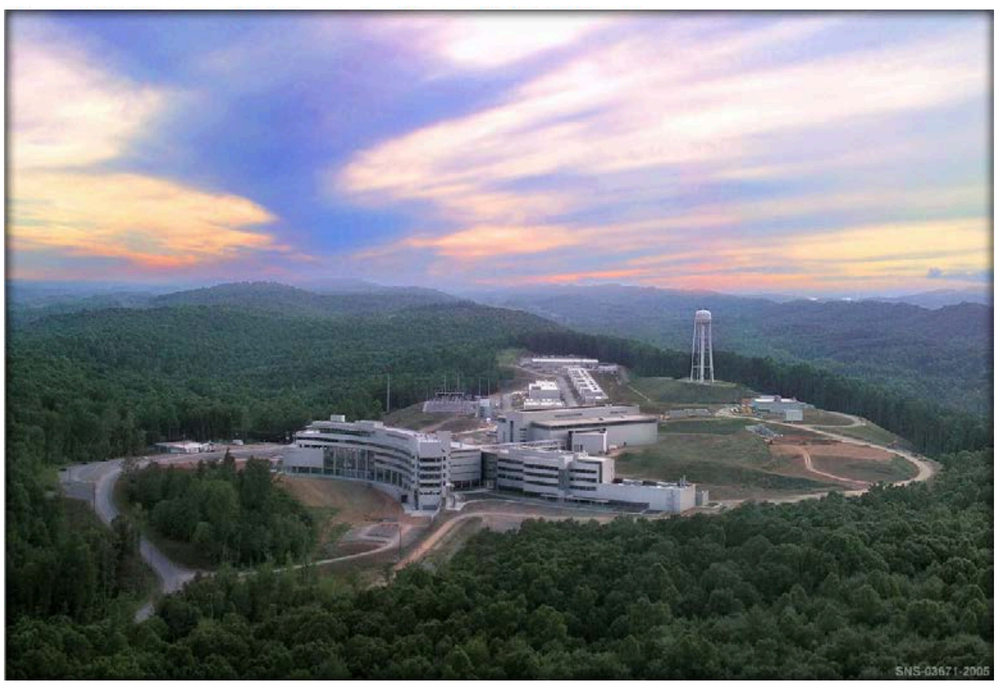


Means environmental background reduction by X 1,600

60 Hz *pulsed* source





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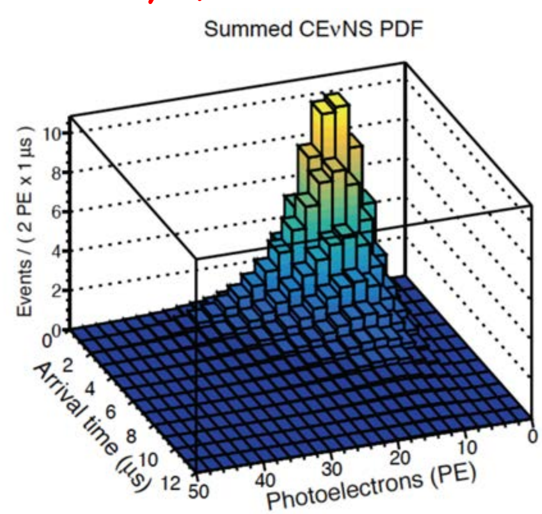
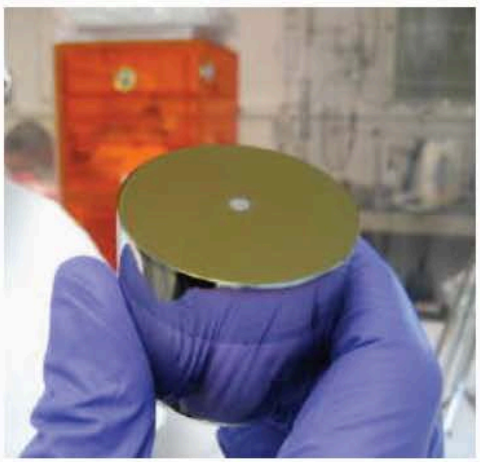


Expected CEvNS signal is characteristic in <u>both</u> energy and time

Enter COHERENT @ SNS:

How to Make an Unambiguous Measurement

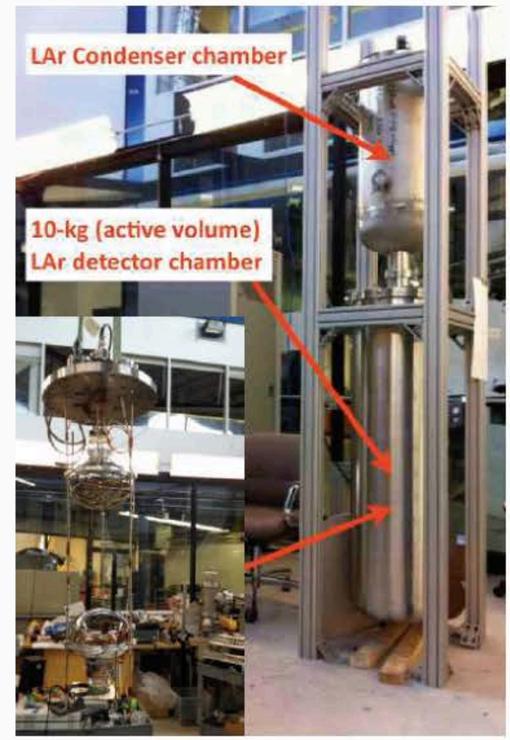
- Observe the pulsed ν time-structure
- Observe the 2.2 μs characteristic decay of muon decay ν's
- Observe the N^2 cross section behavior between targets



P-Type Point Contact HPGe

Low-Background CsI[Na]

NaI[Tl]



Single Phase LAr

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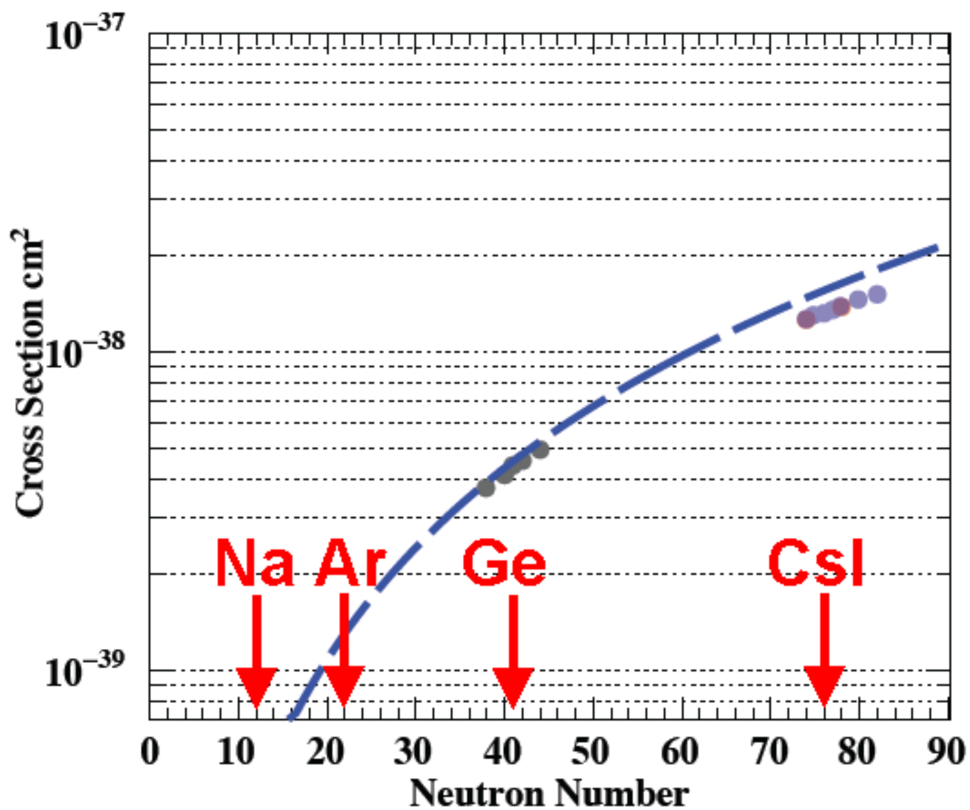
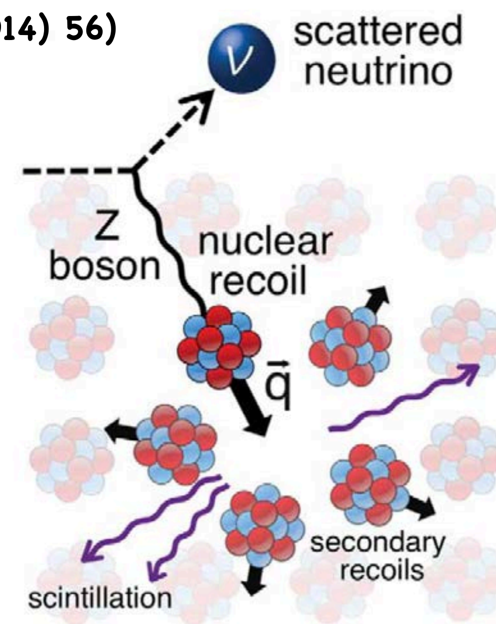
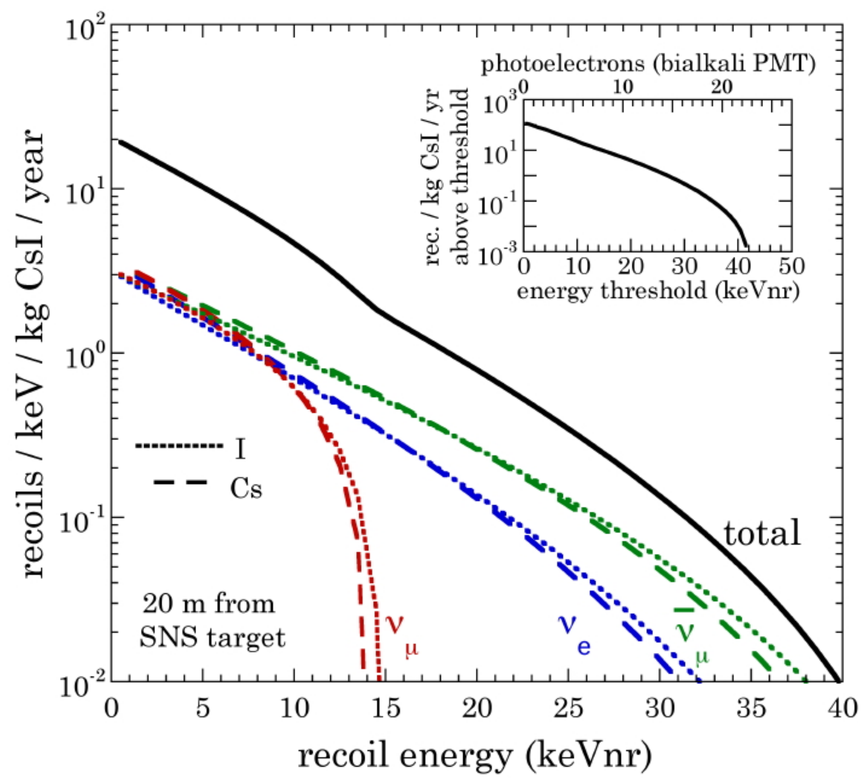


Why CsI[Na]? (NIM A773 (2014) 56)

- 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 with large statistics.
- Sufficiently low in intrinsic backgrounds (U, Th ,K-40, Rb-87, Cs-134,137) Measurements in complete SNS shield and 6 m.w.e. indicated we were 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.





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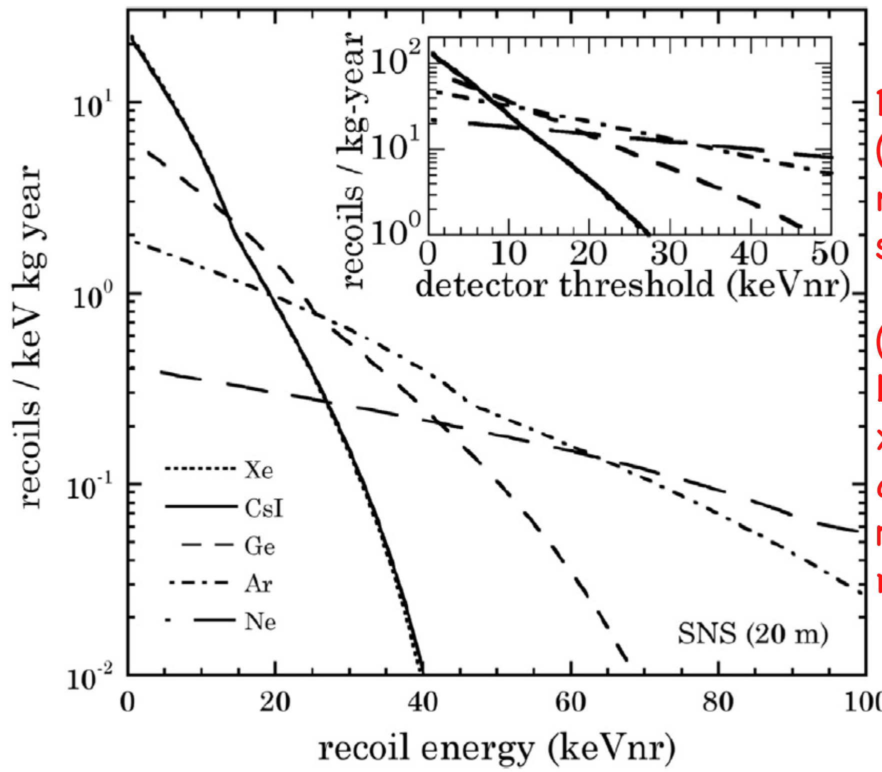
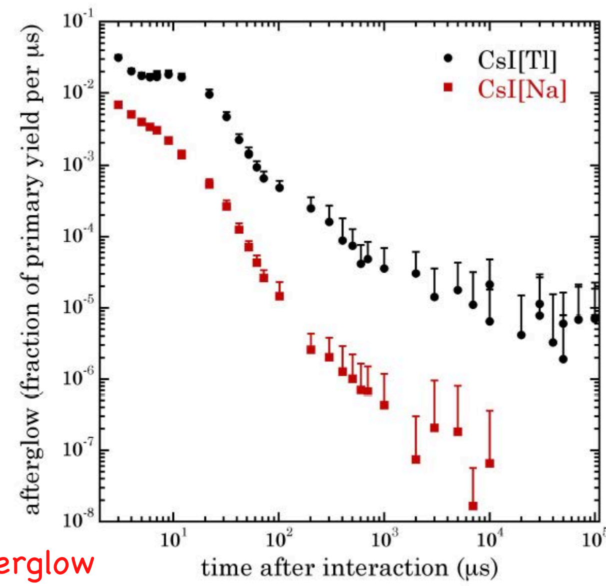


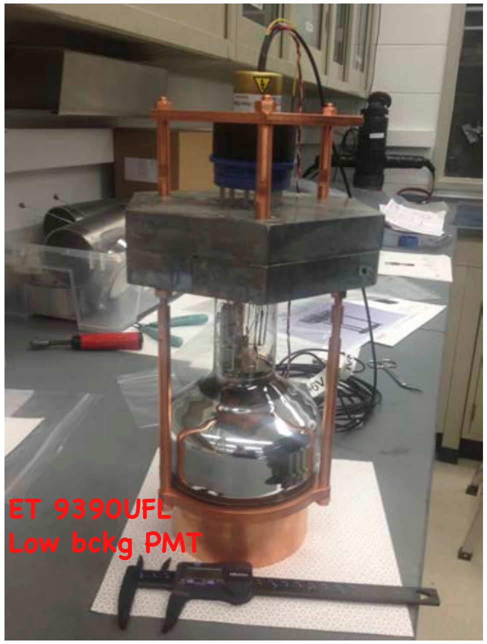
Brute force (large N^2) not sufficient!

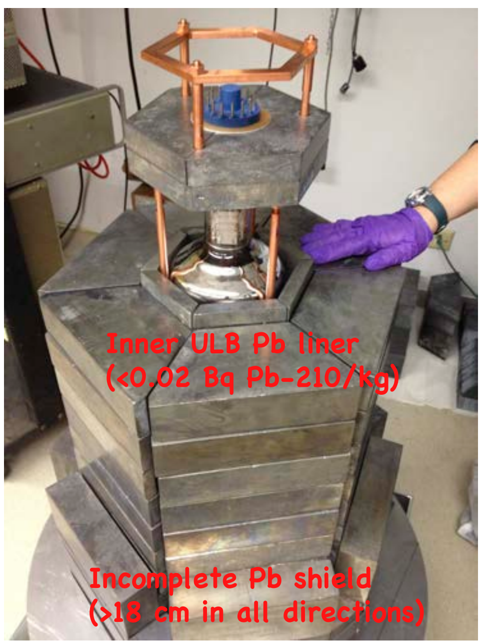
(tradeoff between x-section and maximum recoil E)

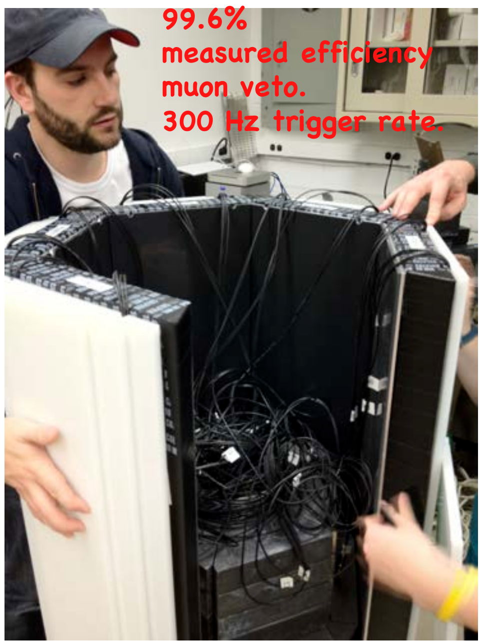


CsI[Tl] not an option due to excessive afterglow

Preliminaries: background studies w/ 2 kg prototype

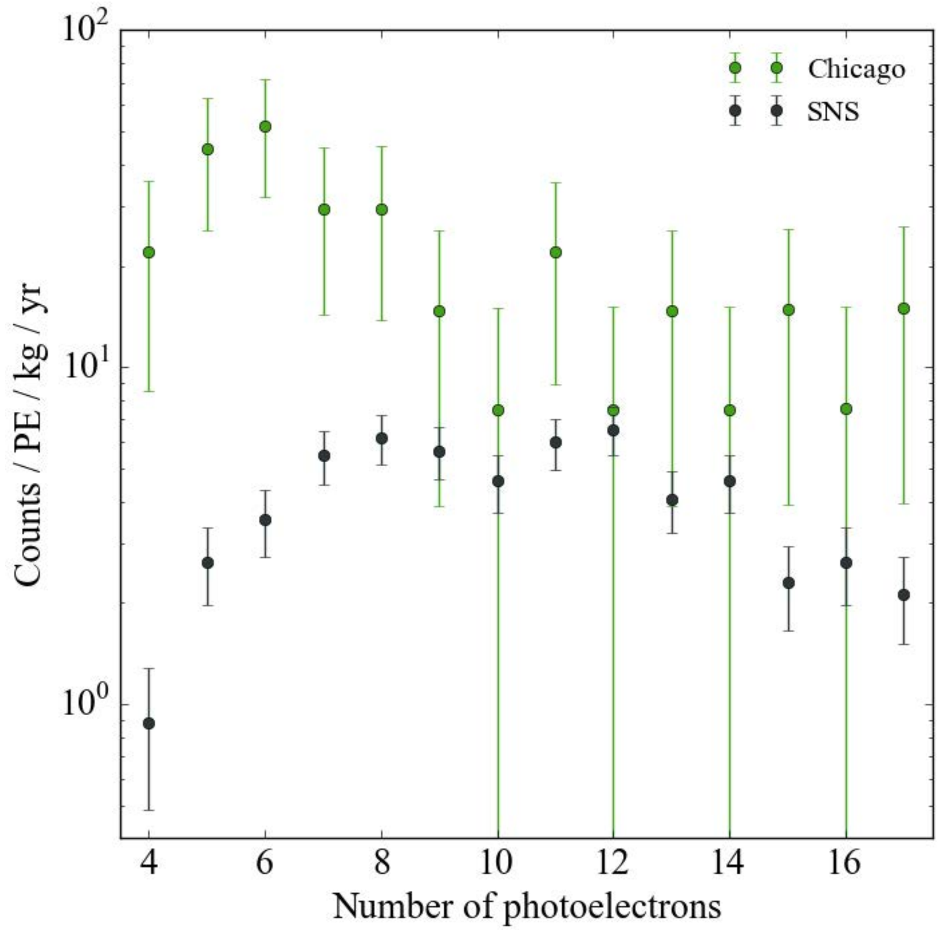






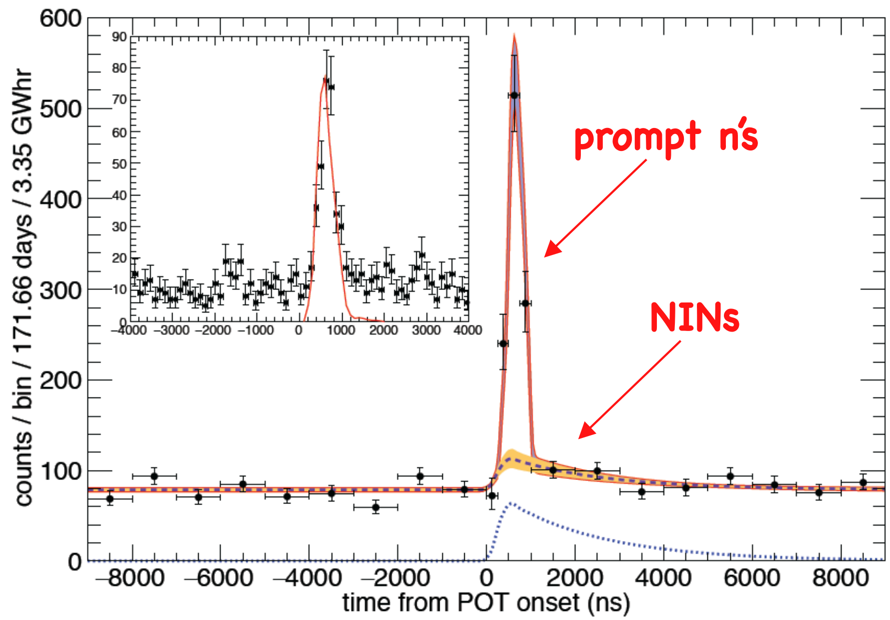
Pulsed SNS signal leads to very low bckg.

We improved on prototype background level!

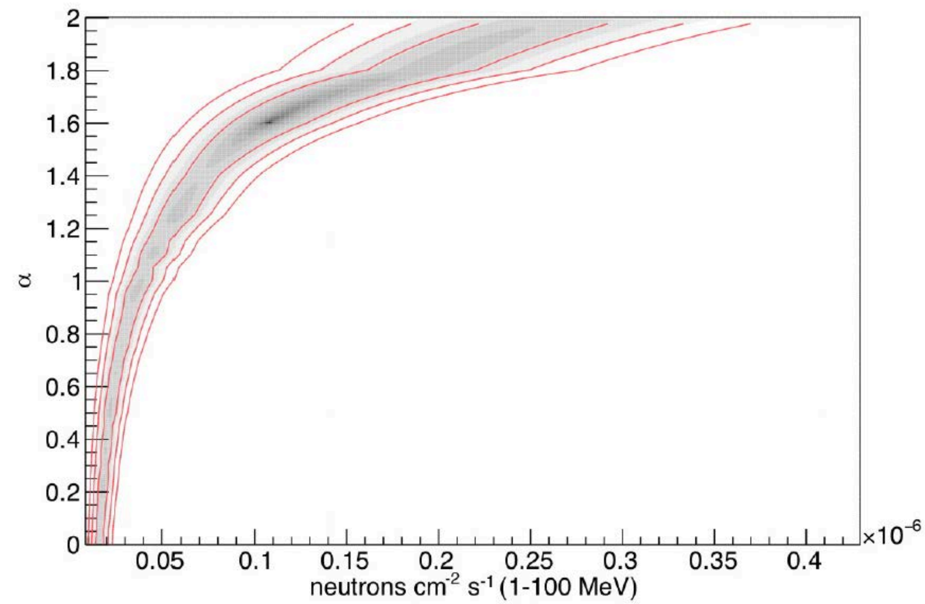


Preliminaries: *in situ* neutron bckg measurements

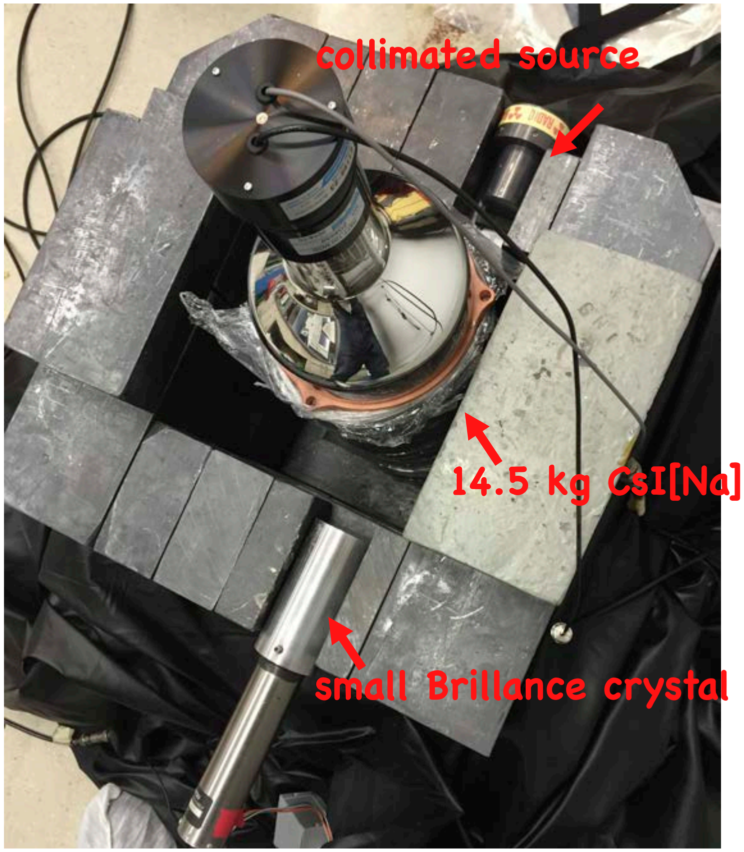
The “neutrino alley” @ SNS

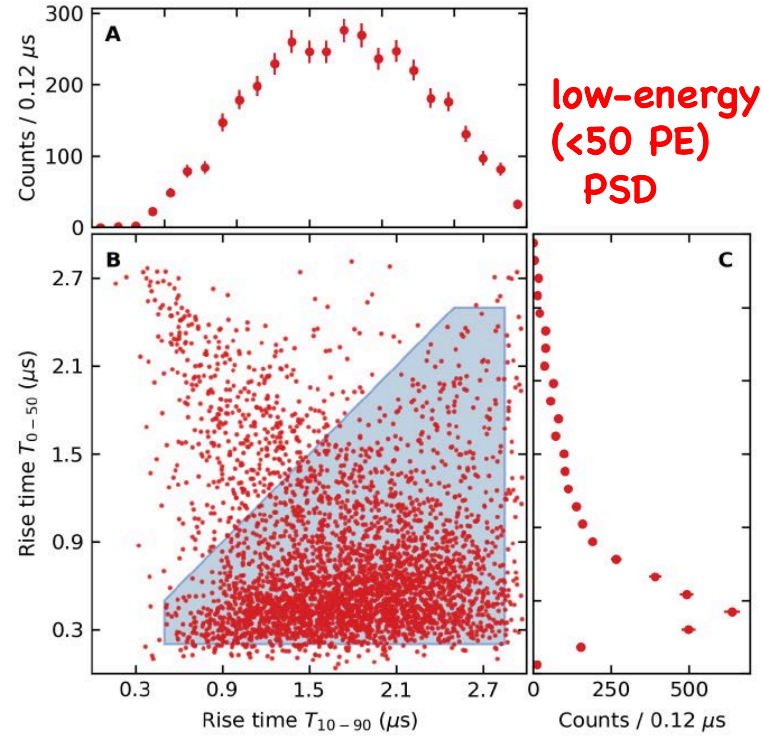


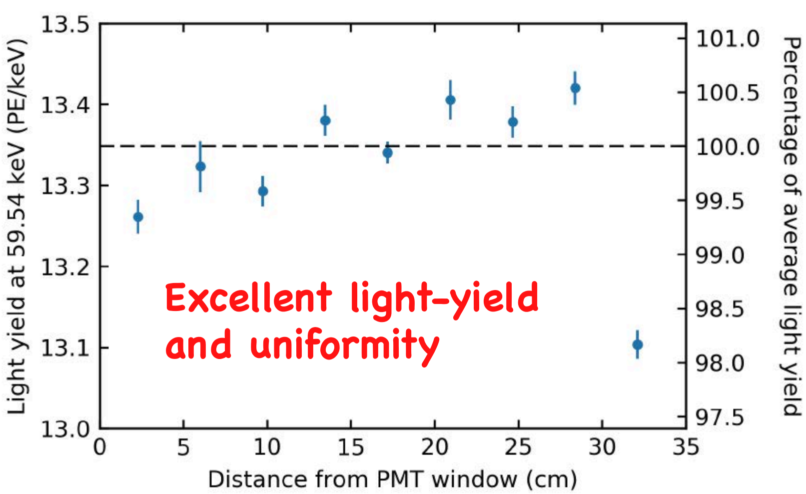
Measured NIN and prompt n bckg rates are x50 and x20 smaller than CEνNS signal rate.

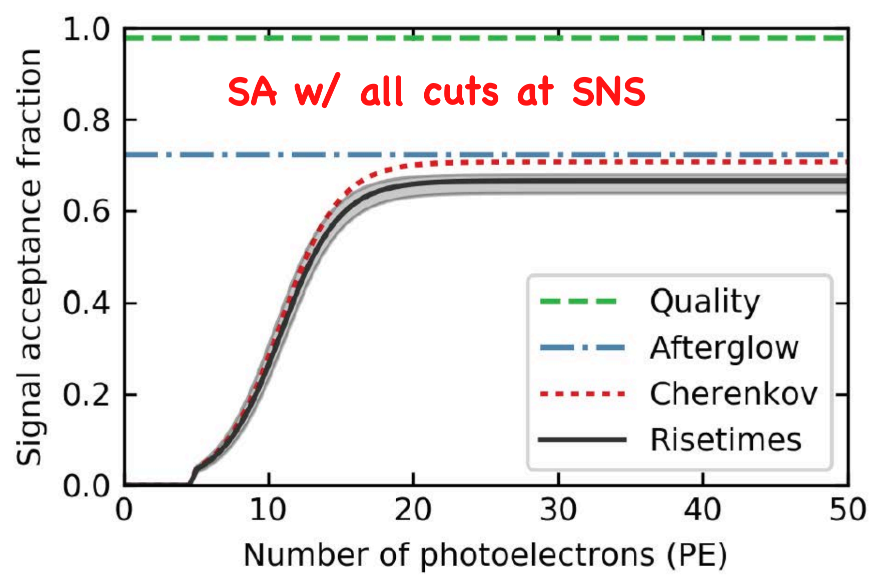


Preliminaries: 14.5 kg detector characterization

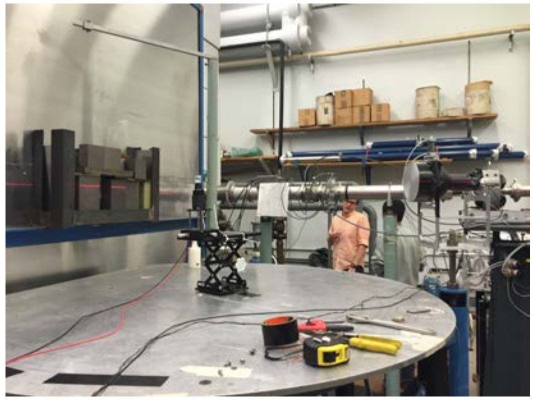


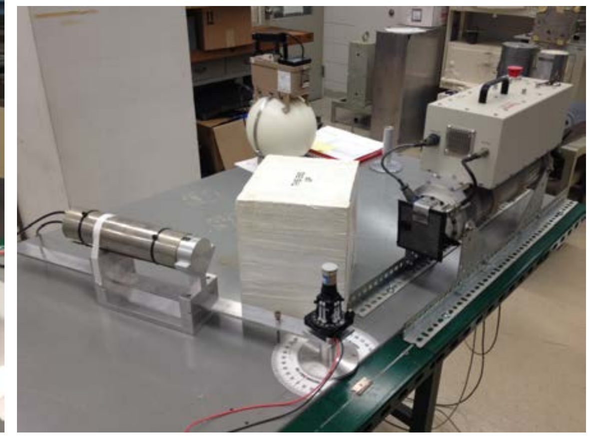


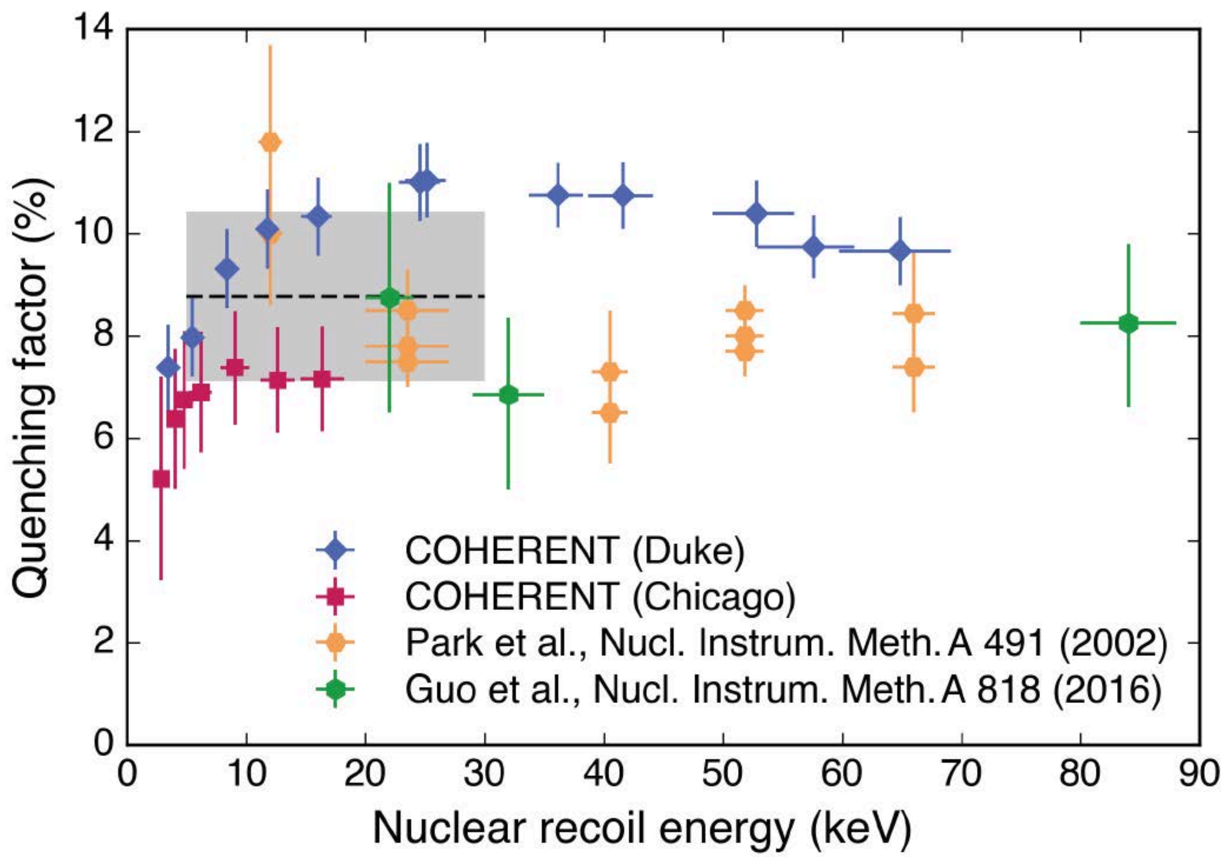




Preliminaries: Quenching factor measurements

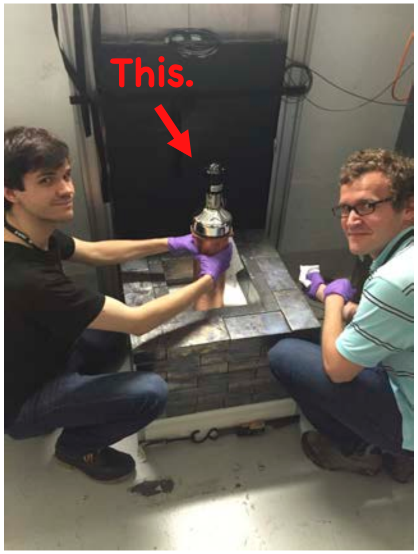


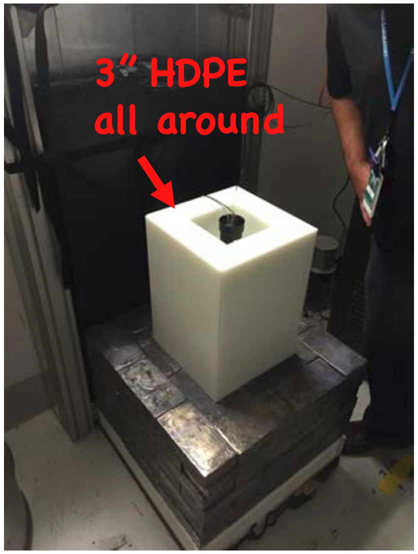


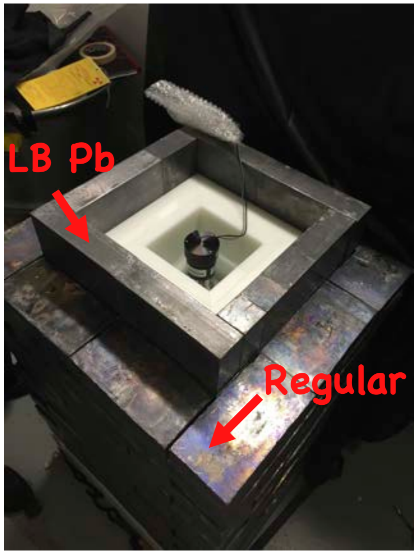


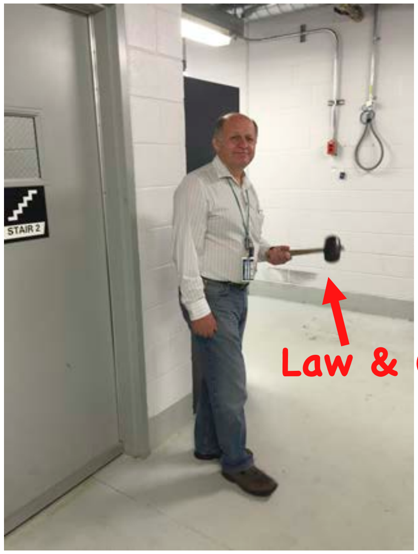
FOURTH measurement of CsI[Na] QF within COHERENT is in progress...

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



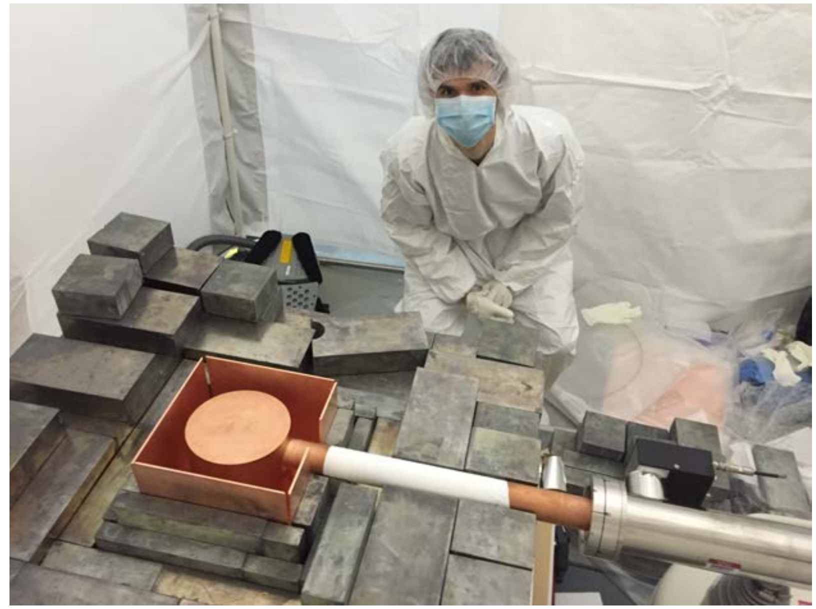




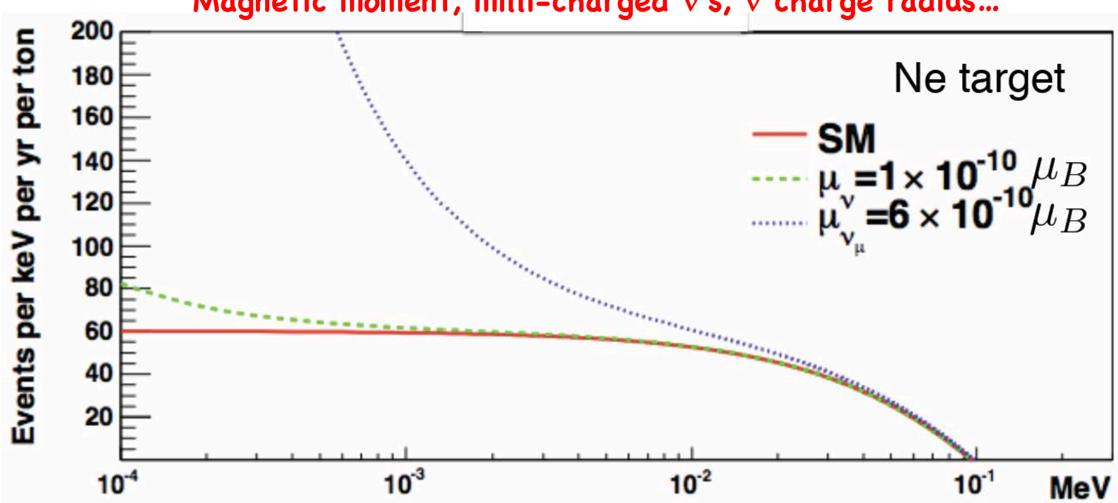


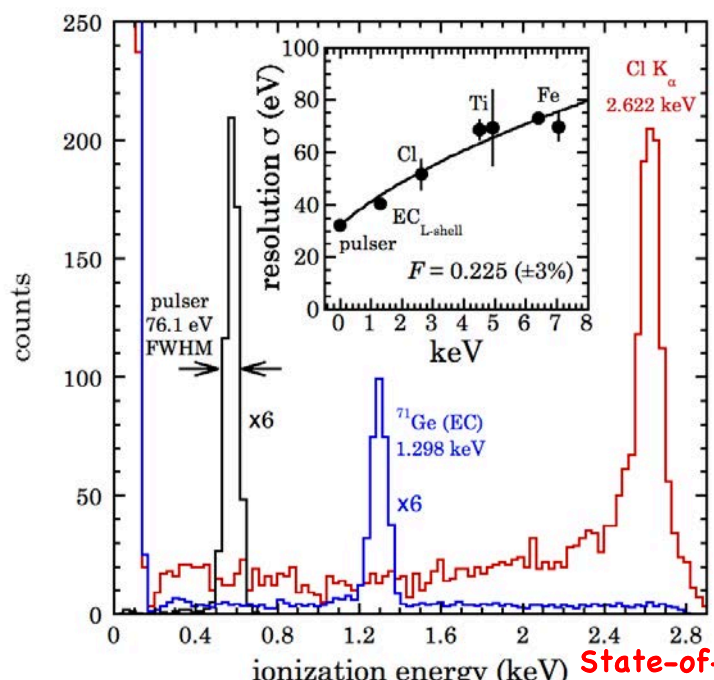
What next: precision CEνNS studies with PPCs

- Excellent energy resolution and low threshold (most SM deviations through new ν physics way down there).
- Best-measured quenching factor (and getting better).
- 10 kg of Ge in compact 4-crystal array (possible through CoGeNT/C-4 R&D).



Magnetic moment, milli-charged ν's, ν charge radius...





State-of-the-art in large PPCs

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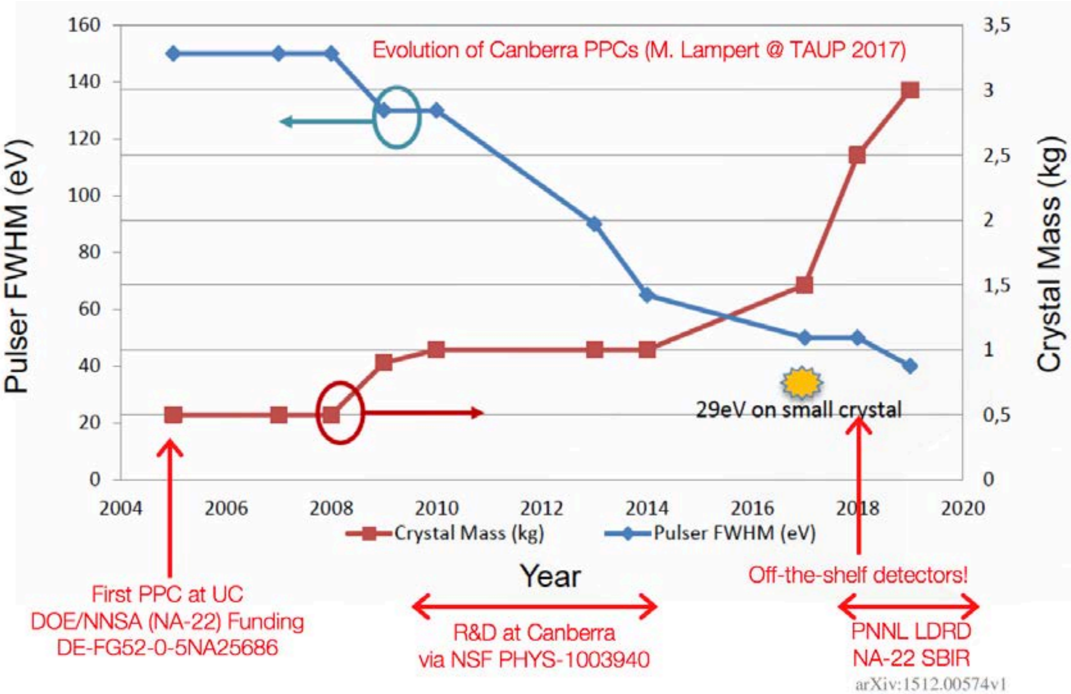
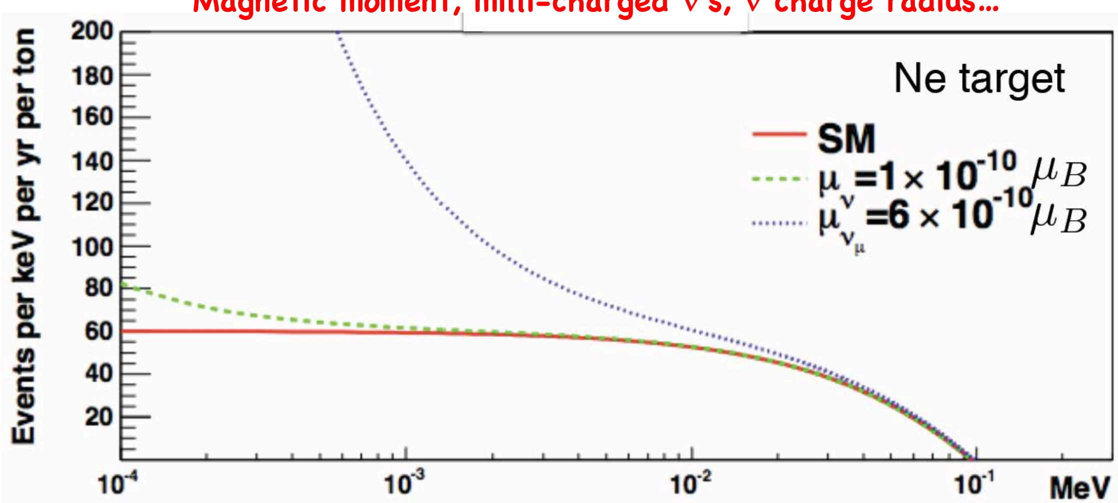
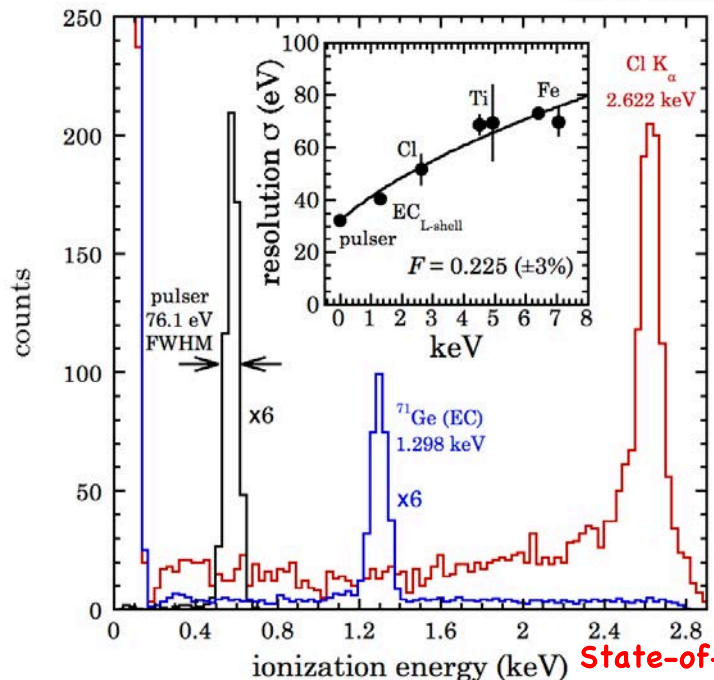


Magnetic moment, milli-charged ν's, ν charge radius...

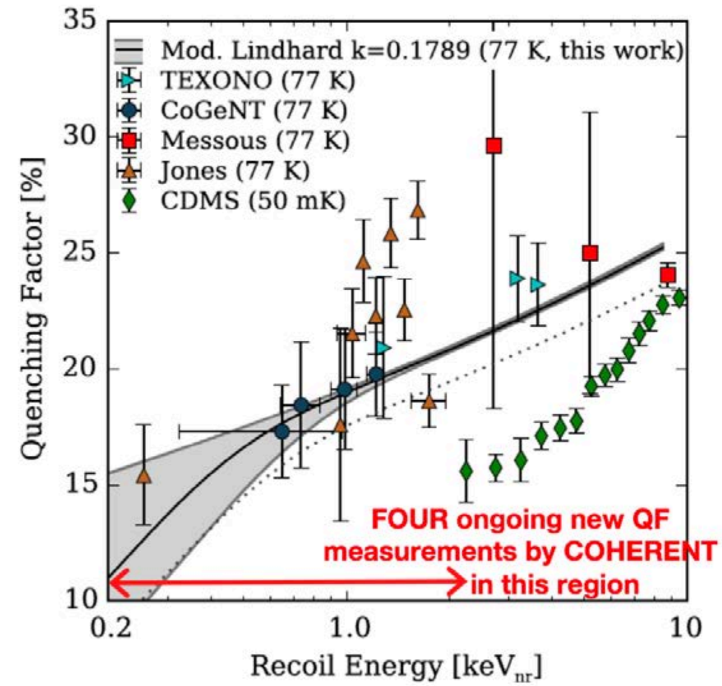




State-of-the-art in large PPCs

What next: precision CEνNS studies with PPCs

- Excellent energy resolution and low threshold (most SM deviations through new ν physics way down there).
- Best-measured quenching factor (and getting better).
- 10 kg of Ge in compact 4-crystal array (possible through CoGeNT/C-4 R&D).



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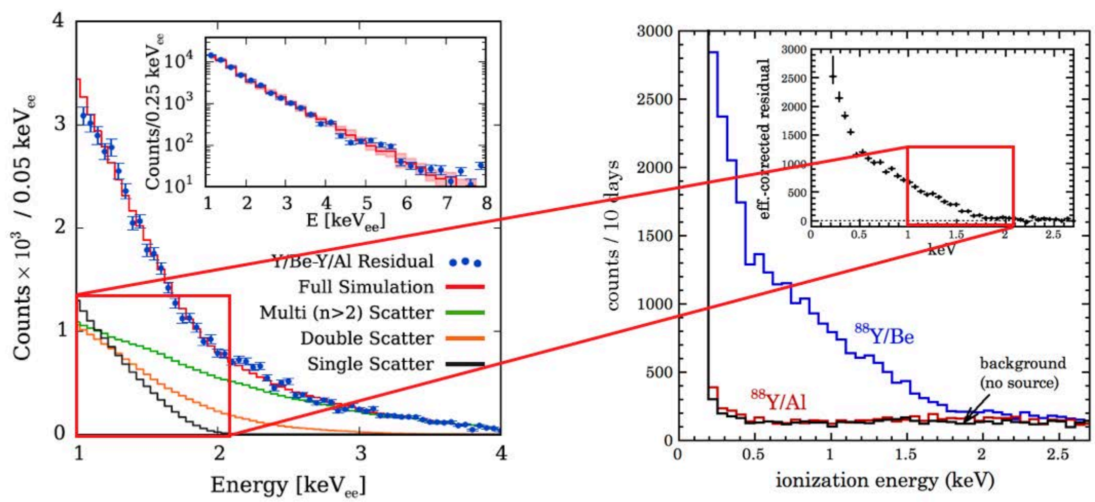

B.J. Scholz *et al.* Phys. Rev. D94 (2016) 122003

See also
J.I. Collar Phys. Rev. Lett. 110 (2013) 211101
A.E. Chavarria *et al.* Phys. Rev. D94 (2016) 082007

Ongoing new measurement isolating single scatters
Notice sub-keV energy reach

CEνNS holds great promise to expand our knowledge of neutrino properties.

However, we must expand our knowledge of detector response to low-E NRs first!