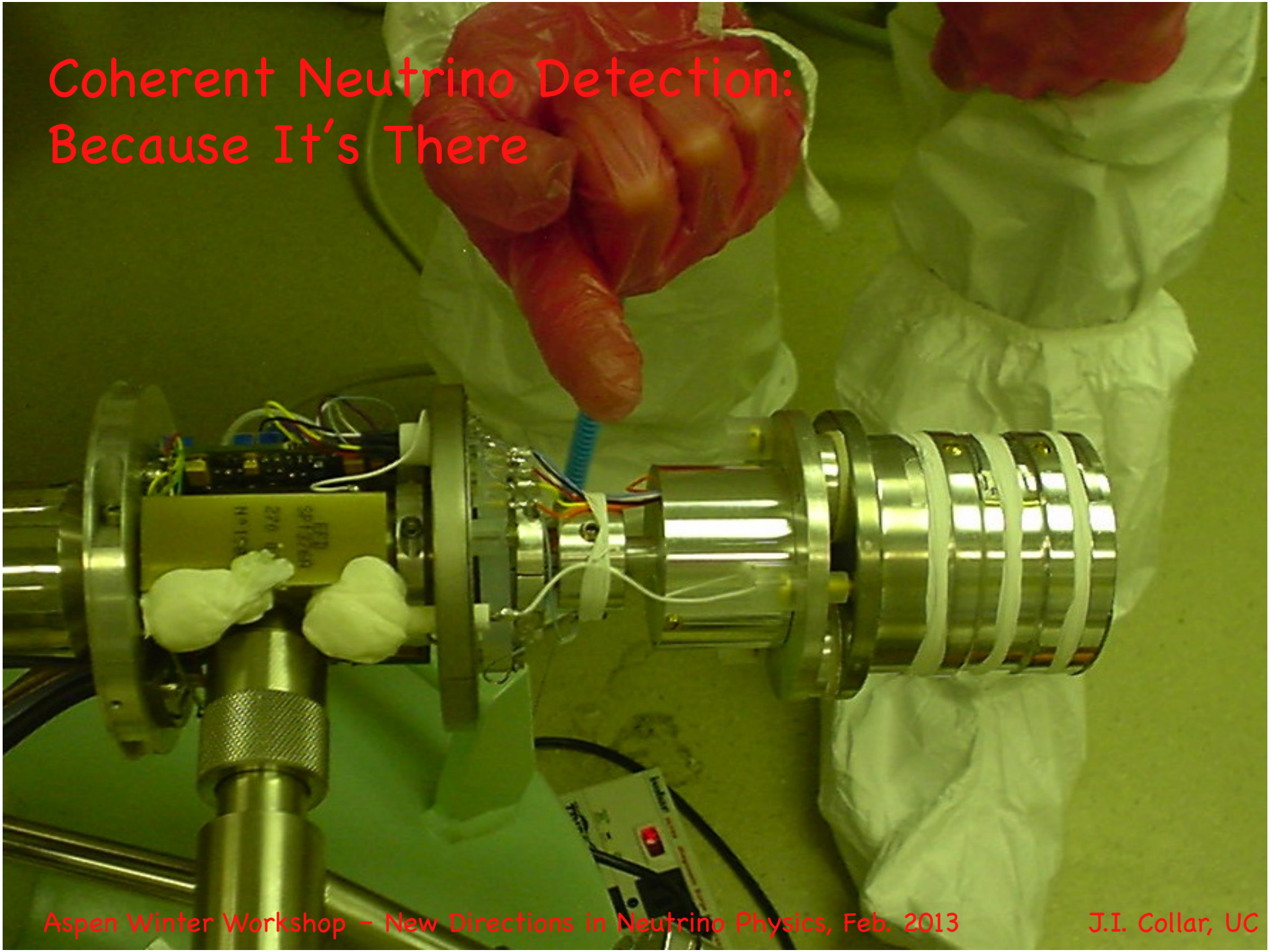
Coherent Neutrino Detection: Because It's There



A one-page tutorial on coherent ν-N scattering

- Uncontroversial Standard Model process
- Large enhancement in cross-section for E_ν < few tens of MeV ($\sigma \propto N^2$, possible only for neutral current)
- However, not yet measured... detector technology has been missing.

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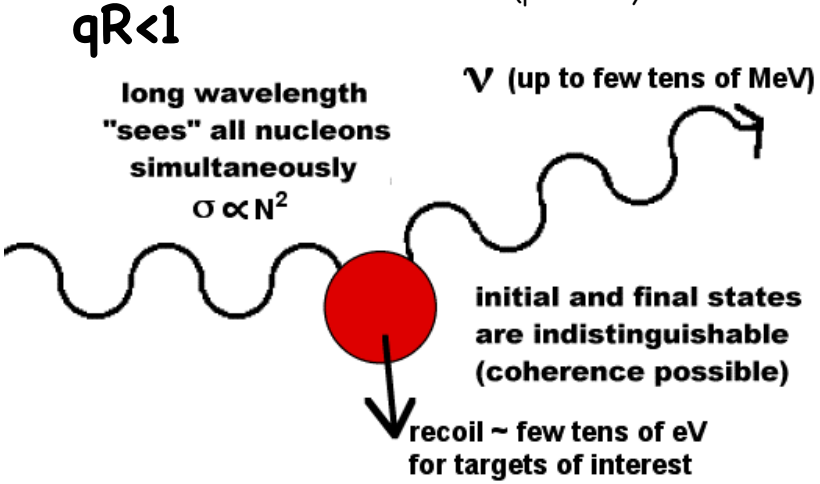
(low-E recoils lose only 10-20% to ionization or scintillation)

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

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



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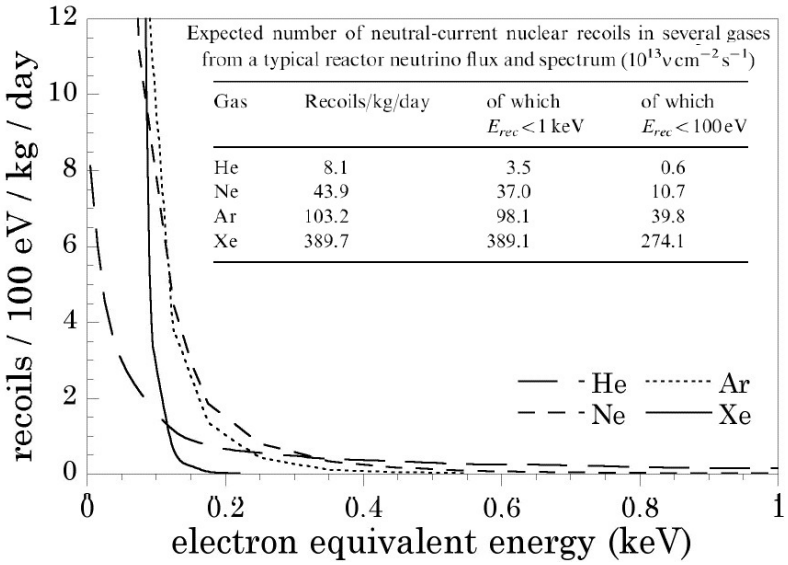

Expected number of neutral-current nuclear recoils in several gases from a typical reactor neutrino flux and spectrum ($10^{13}\nu\,cm^{-2}s^{-1}$)

Gas	Recoils/kg/day	of which $E_{rec}<1$ keV	of which $E_{rec}<100$ eV
He	8.1	3.5	0.6
Ne	43.9	37.0	10.7
Ar	103.2	98.1	39.8
Xe	389.7	389.1	274.1

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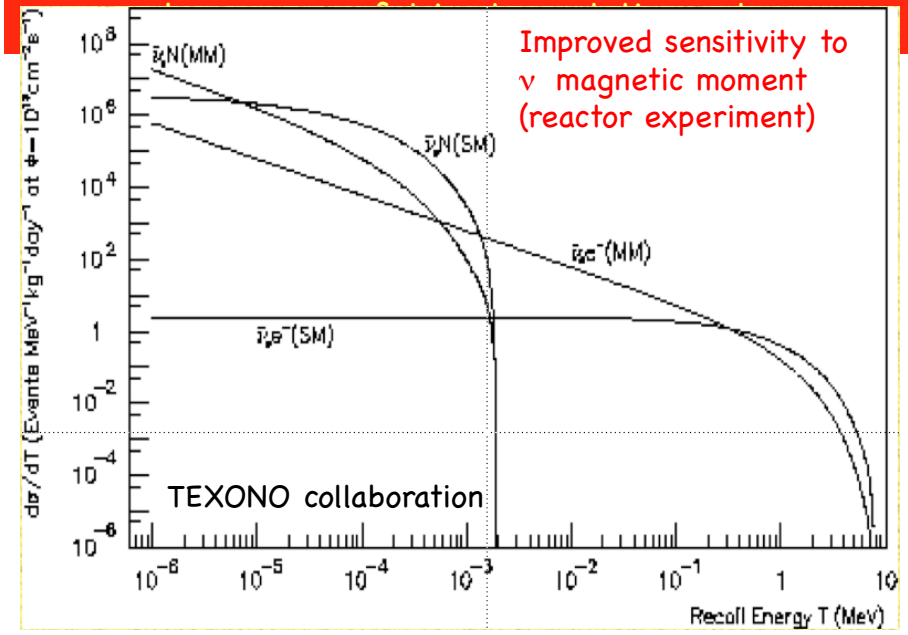

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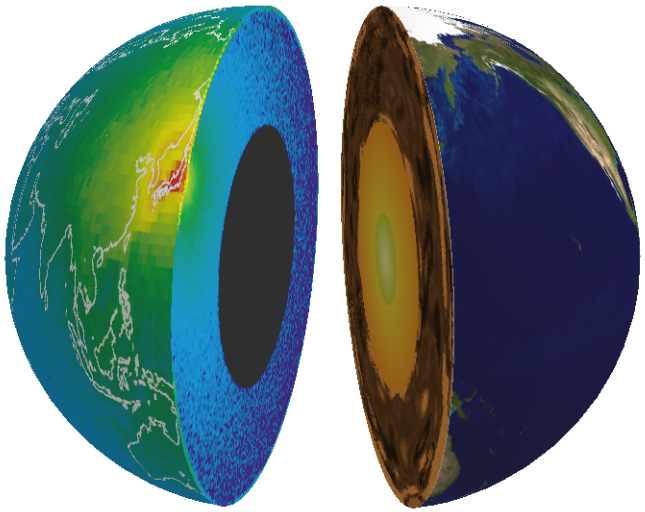

2005: Geoneutrinos detected.

Dawn of the applied neutrino physics era?

Applied Anti-Neutrino Physics Workshops

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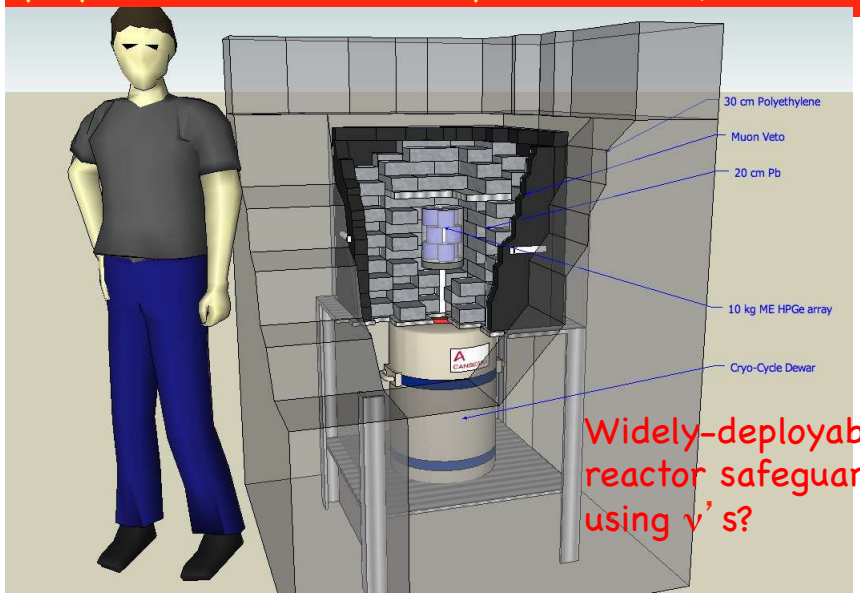

Widely-deployable reactor safeguards using ν's?

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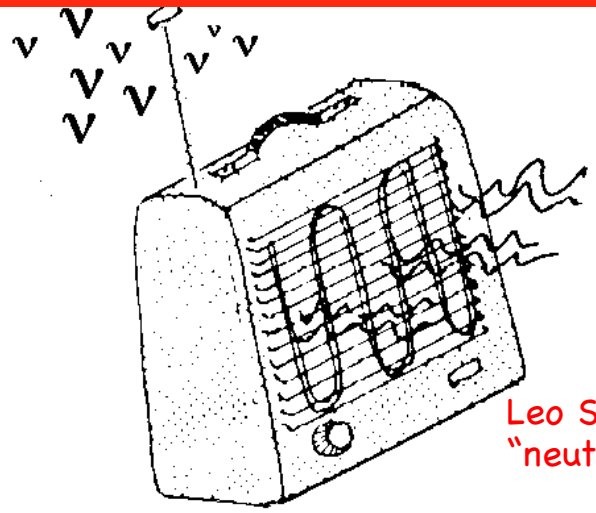

Leo Stodolsky's "neutrino radio"

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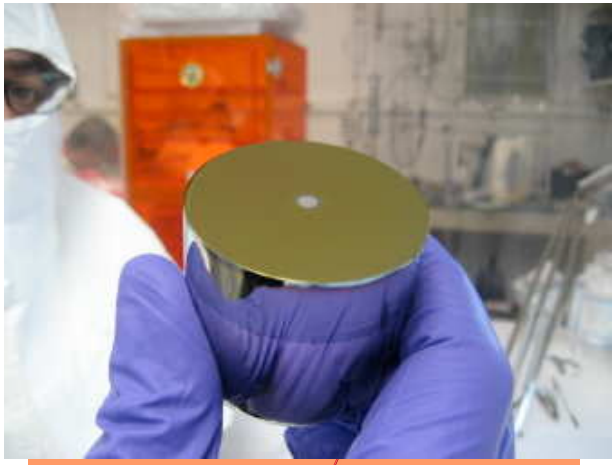
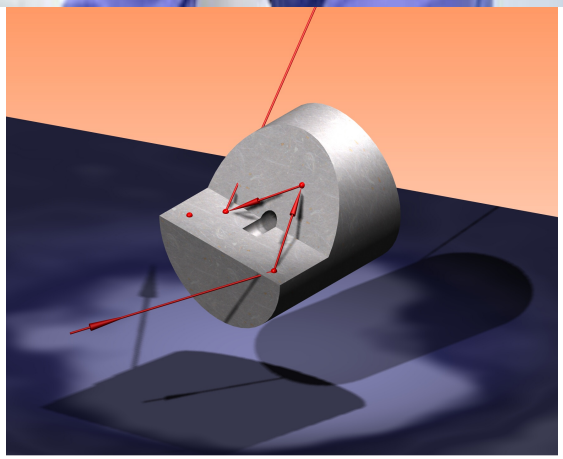
CoGeNT:
neutrino & astroparticle physics using large-mass, ultra-low noise germanium detectors

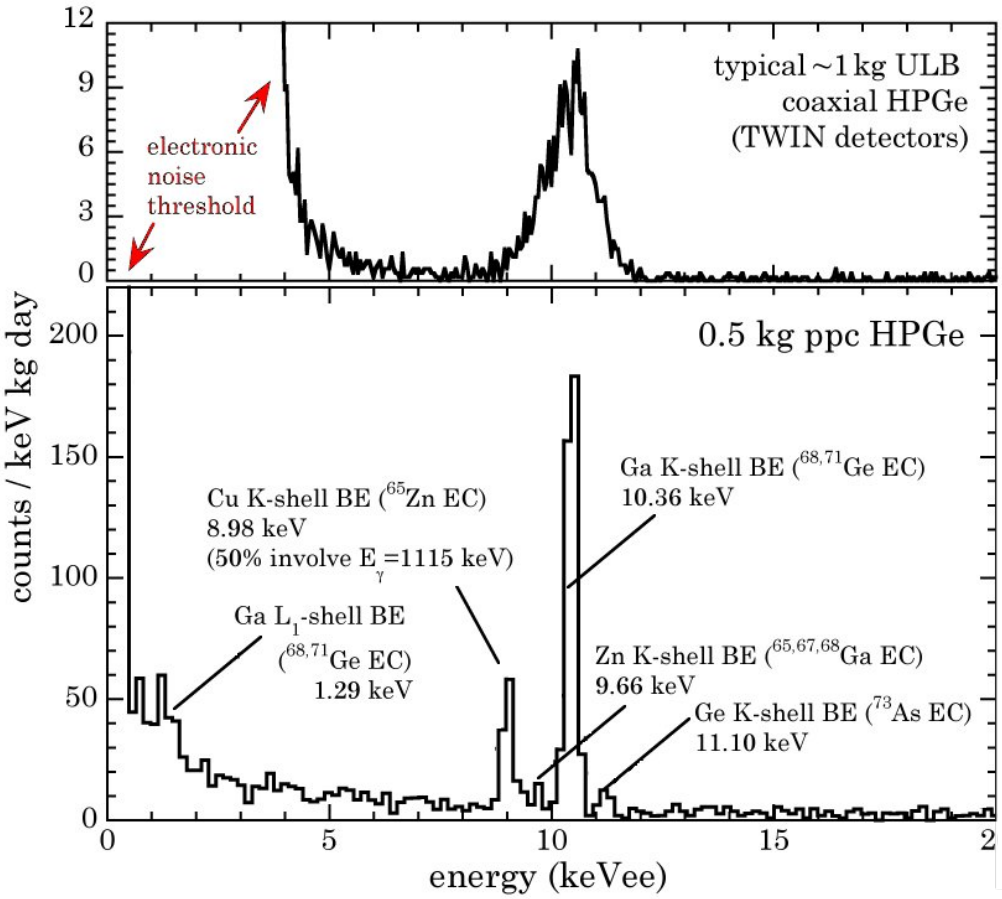
New PPC HPGe

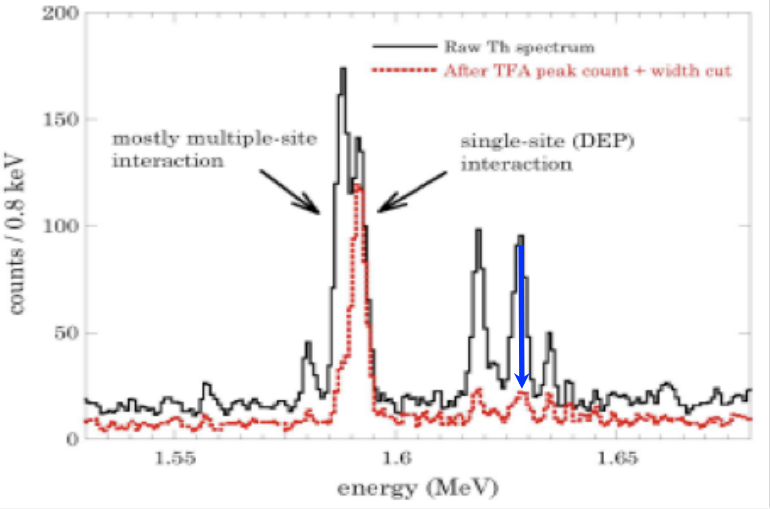
JCAP 09(2007)009

Applications:
- Light Dark Matter
- Coherent ν detection
- ββ decay (MAJORANA+GERDA)

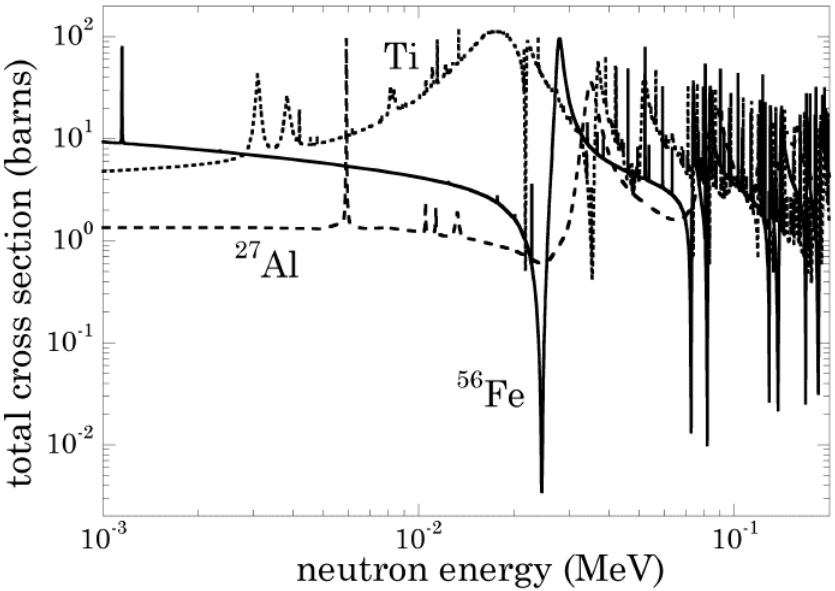






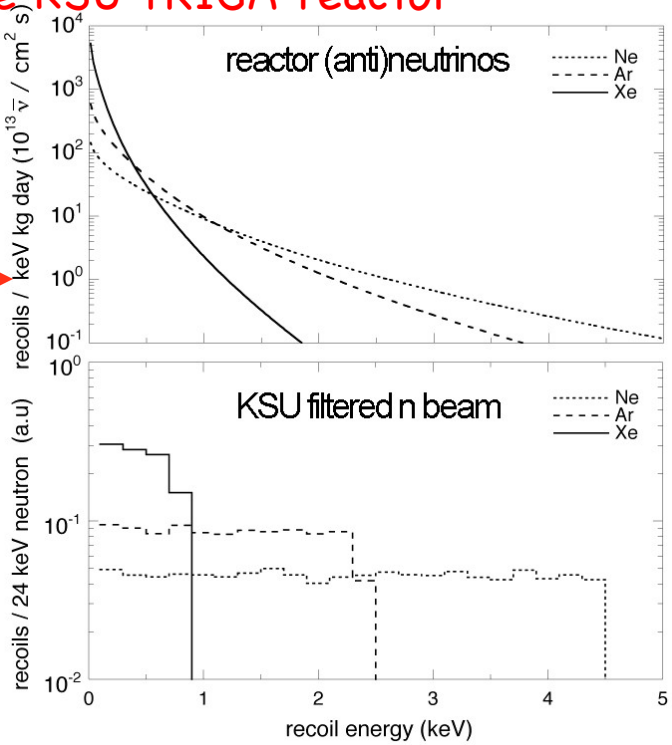


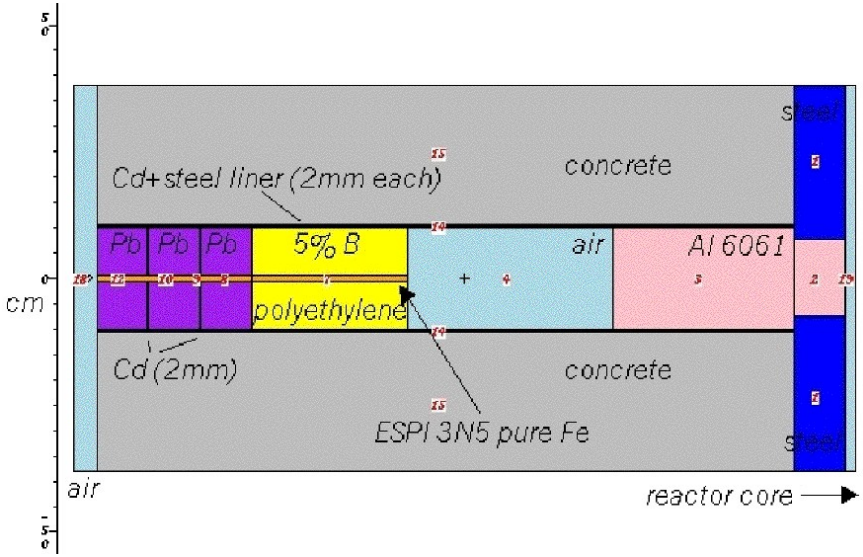
One should always start with the foundations: sub-keV recoil calibrations at the KSU TRIGA reactor



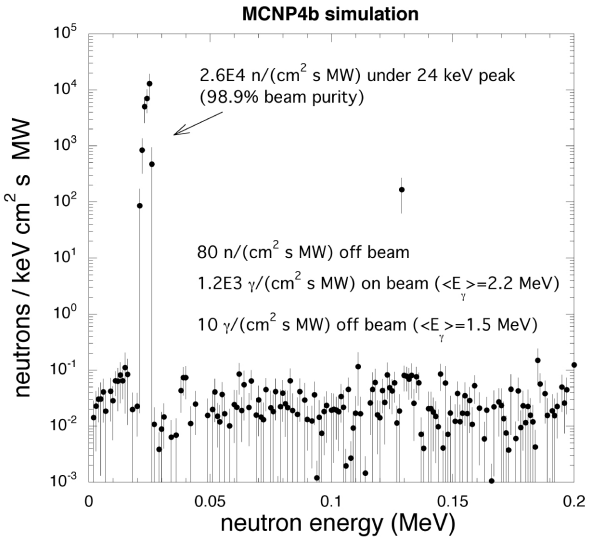
24 keV n's mimic reactor ν's

Fe-Al filter + Ti post-filter





MCNP filter design



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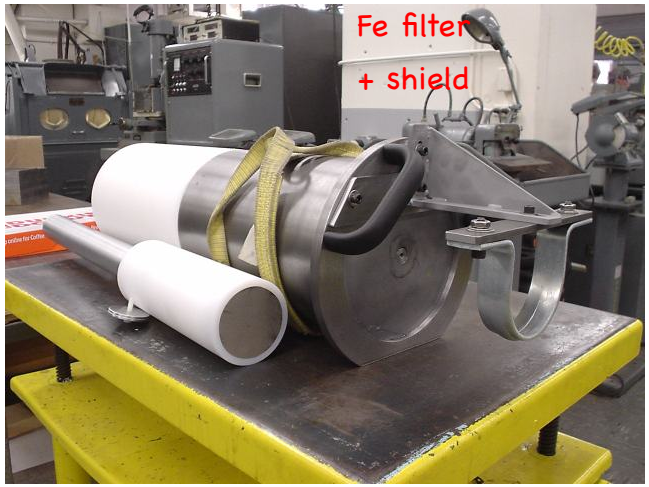
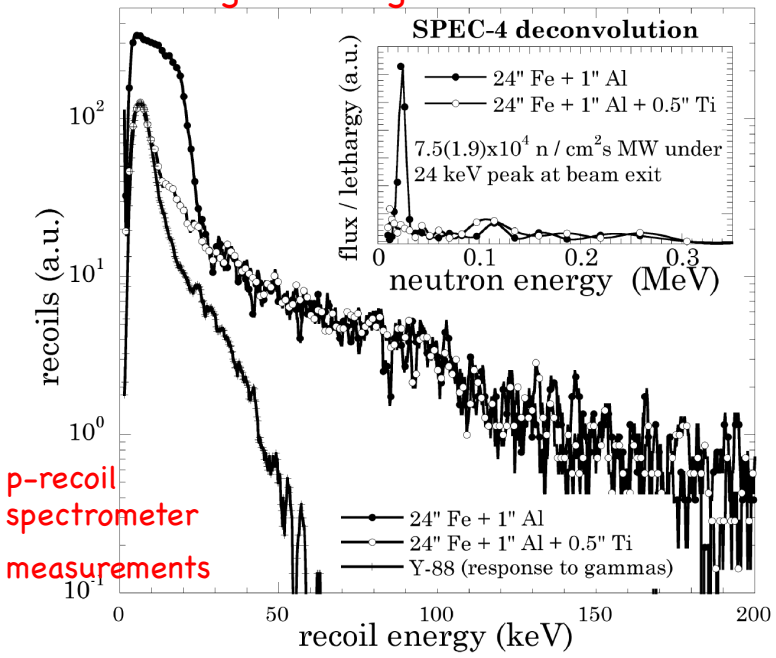
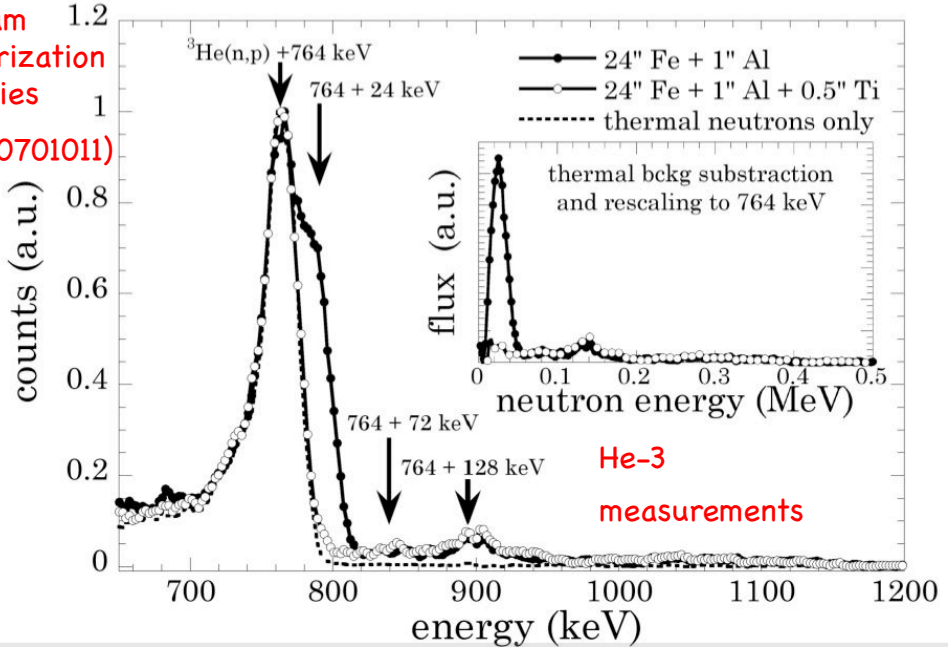


Ti post-filter "switches off" the recoils, leaving all backgrounds unaffected



p-recoil spectrometer measurements

Beam characterization studies (nucl-ex/0701011)

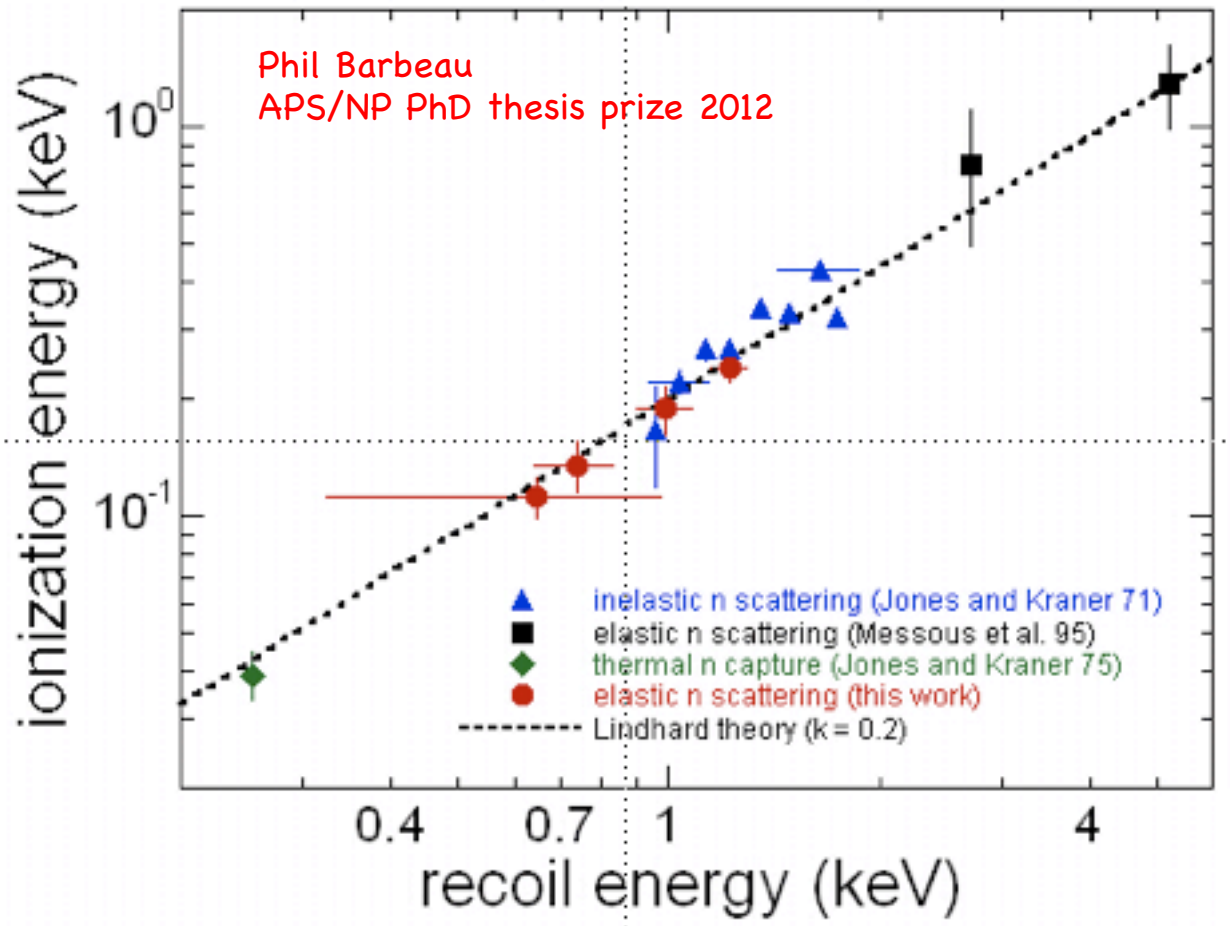


He-3 measurements

Kavli Institute
for Cosmological Physics
AT THE UNIVERSITY OF CHICAGO

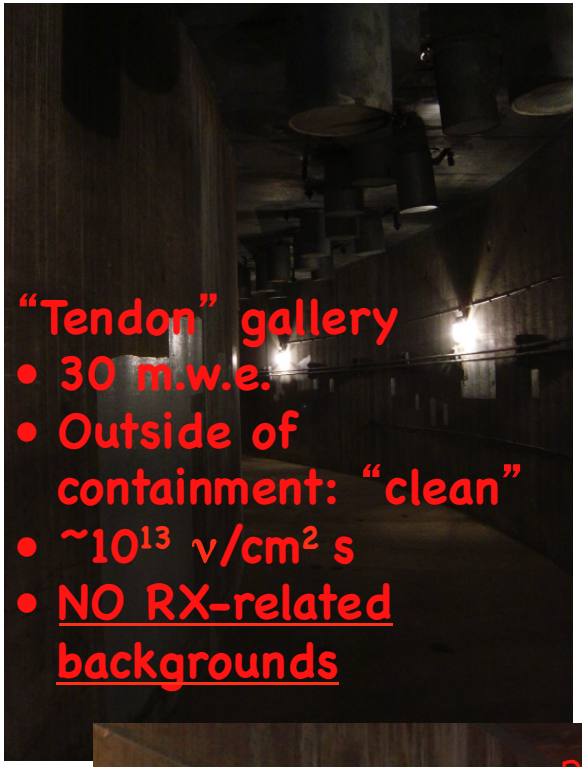
Quenching factor measurement for recoils at discrete angles

Phil Barbeau
APS/NP PhD thesis prize 2012

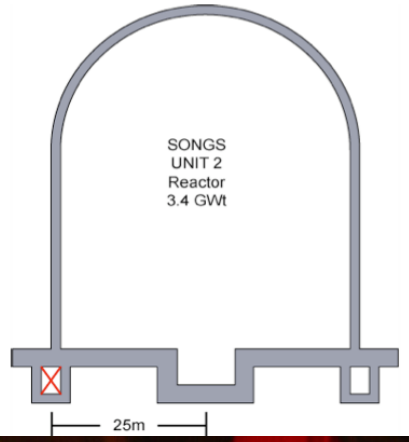


- Measurements of ionization from nuclear recoils in Ge is in excellent agreement with the Lindhard theory prediction.

SONGS-III deployment



"Tendon" gallery
- 30 m.w.e.
- Outside of containment: "clean"
- ~10^{13} ν/cm^2 s
- NO RX-related backgrounds



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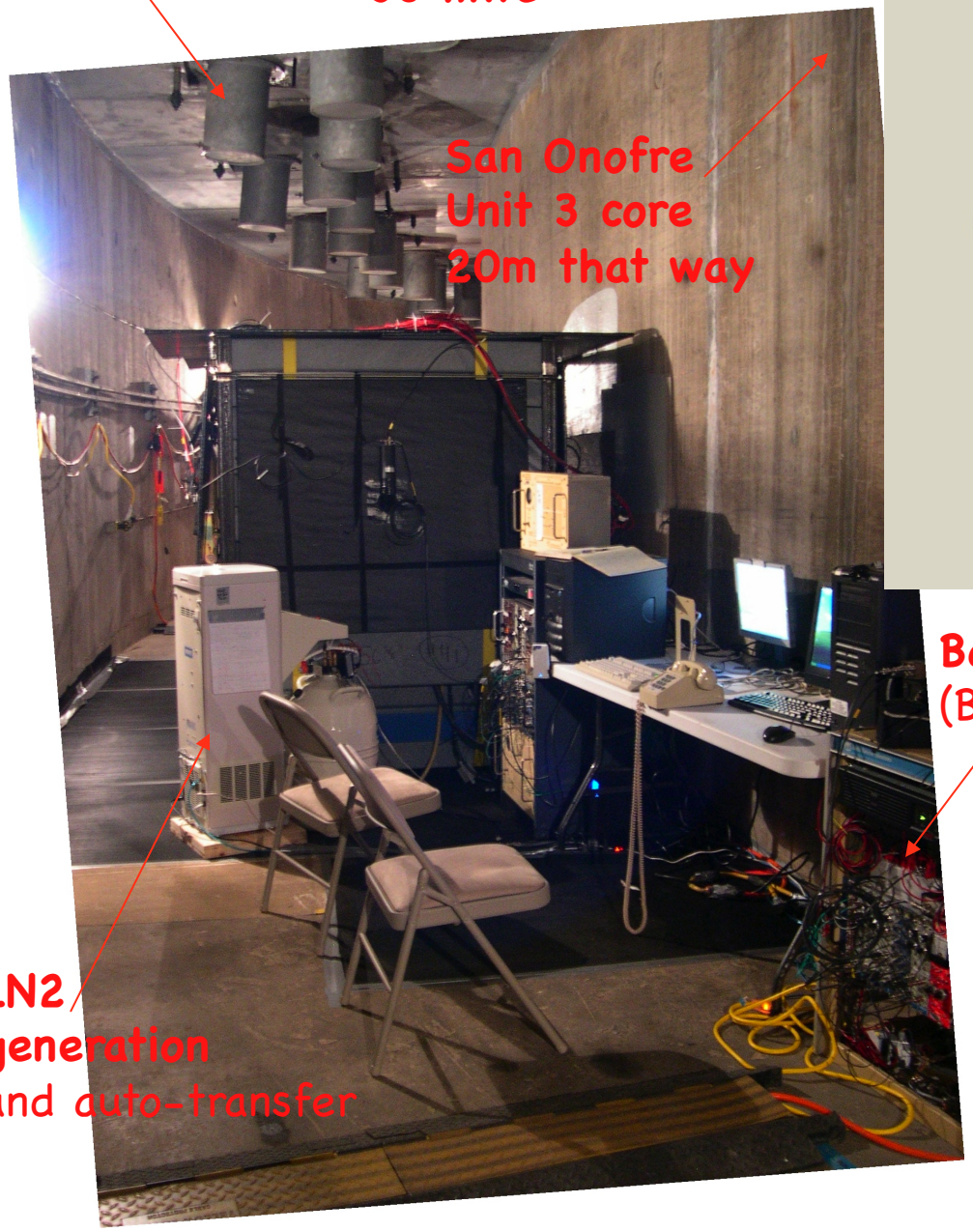
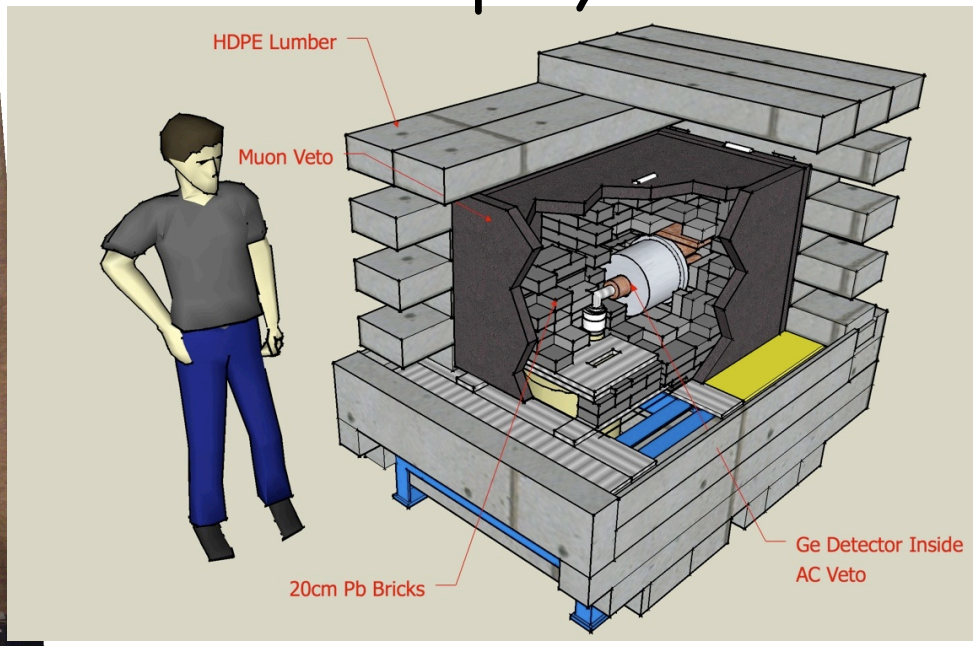
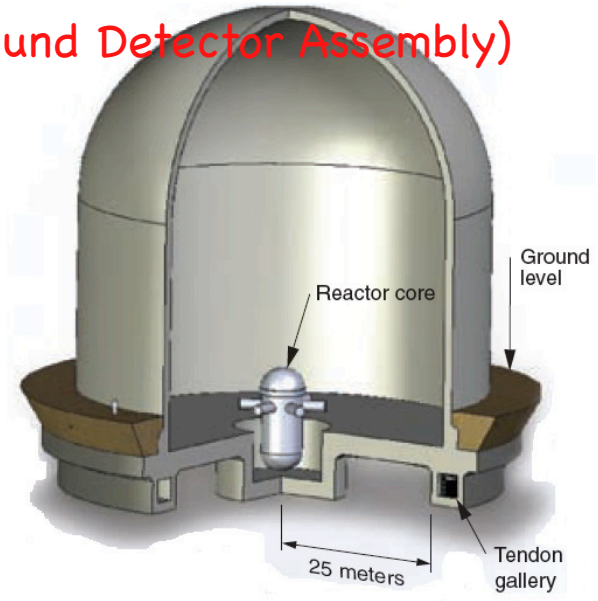
30 mwe





BaDAss
(Background Detector Assembly)

LN2
generation
and auto-transfer



SONGS-III deployment

Backgrounds well-understood
~30 m.w.e. equivalent
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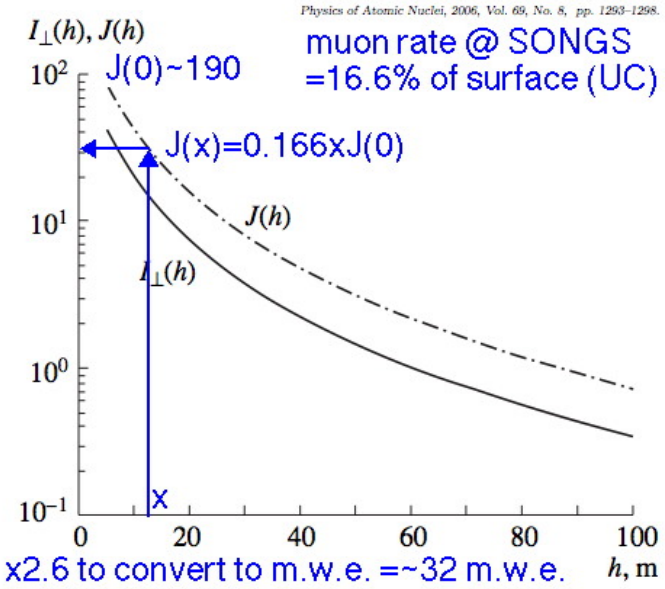
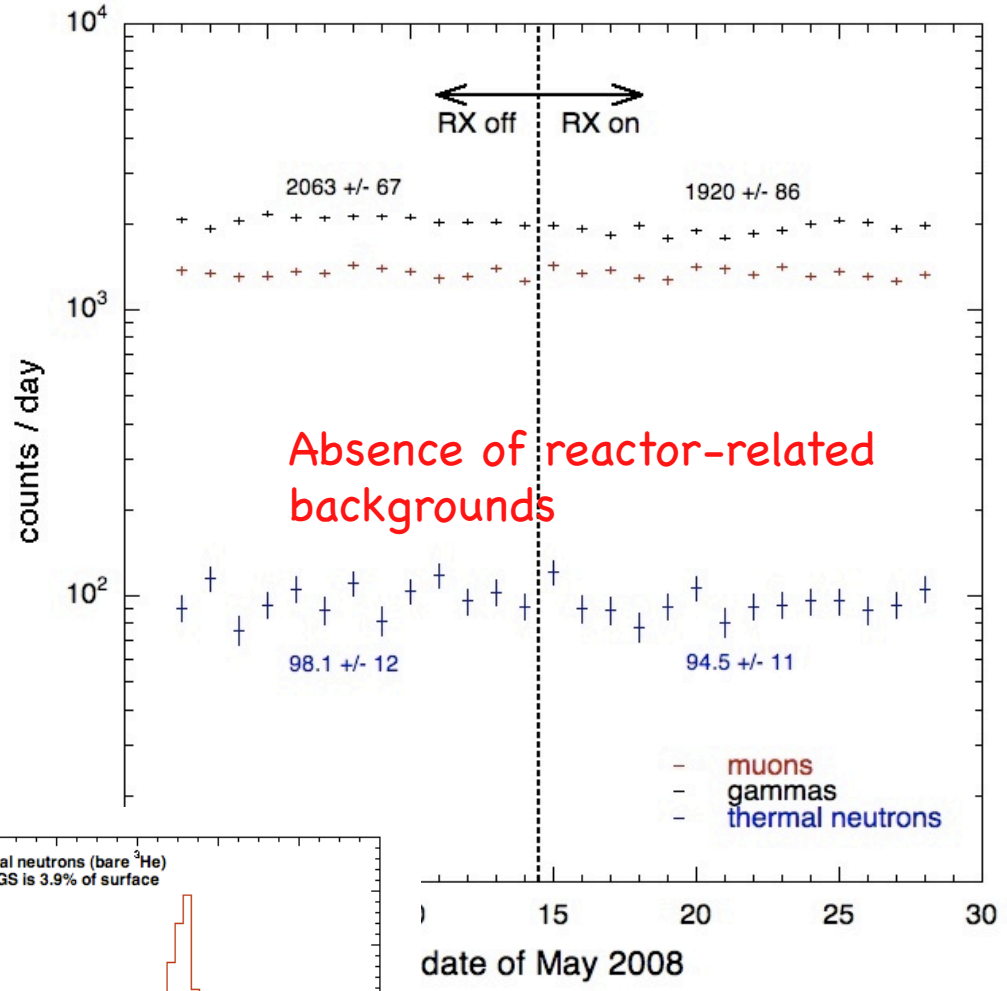
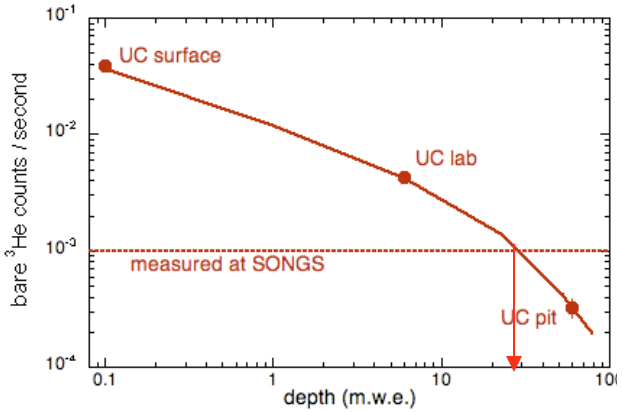
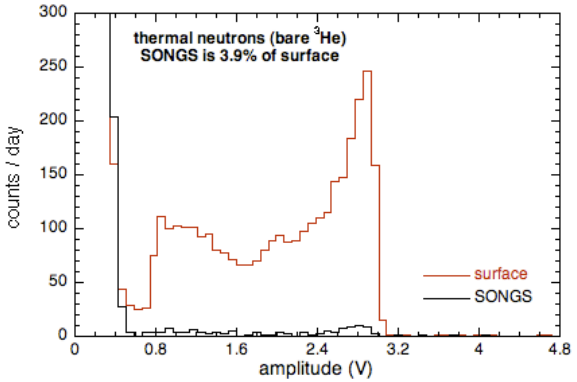


Fig. 2. Vertical muon intensity $I_\perp(h)$ [m^{-2} s^{-1} sr^{-1}] and the integral muon flux $J(h)$ [m^{-2} s^{-1}] vs. the standard rock overburden thickness h.



Absence of reactor-related backgrounds





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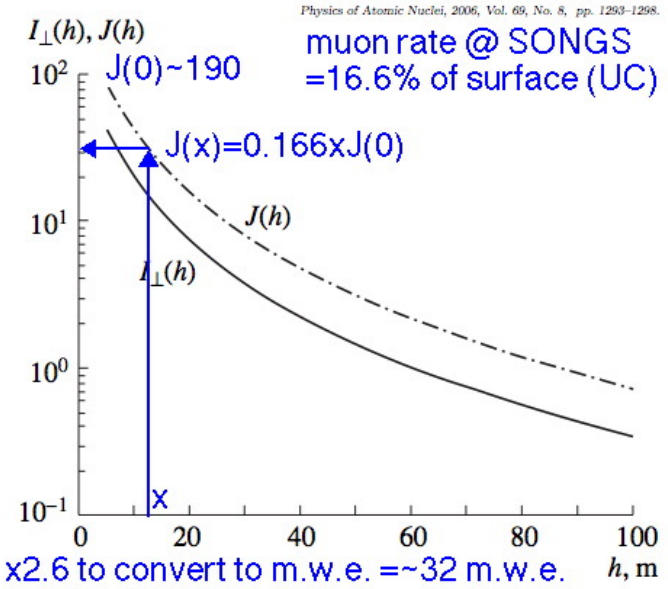

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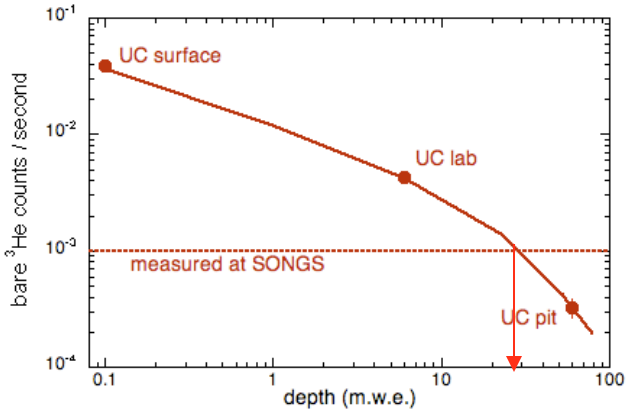

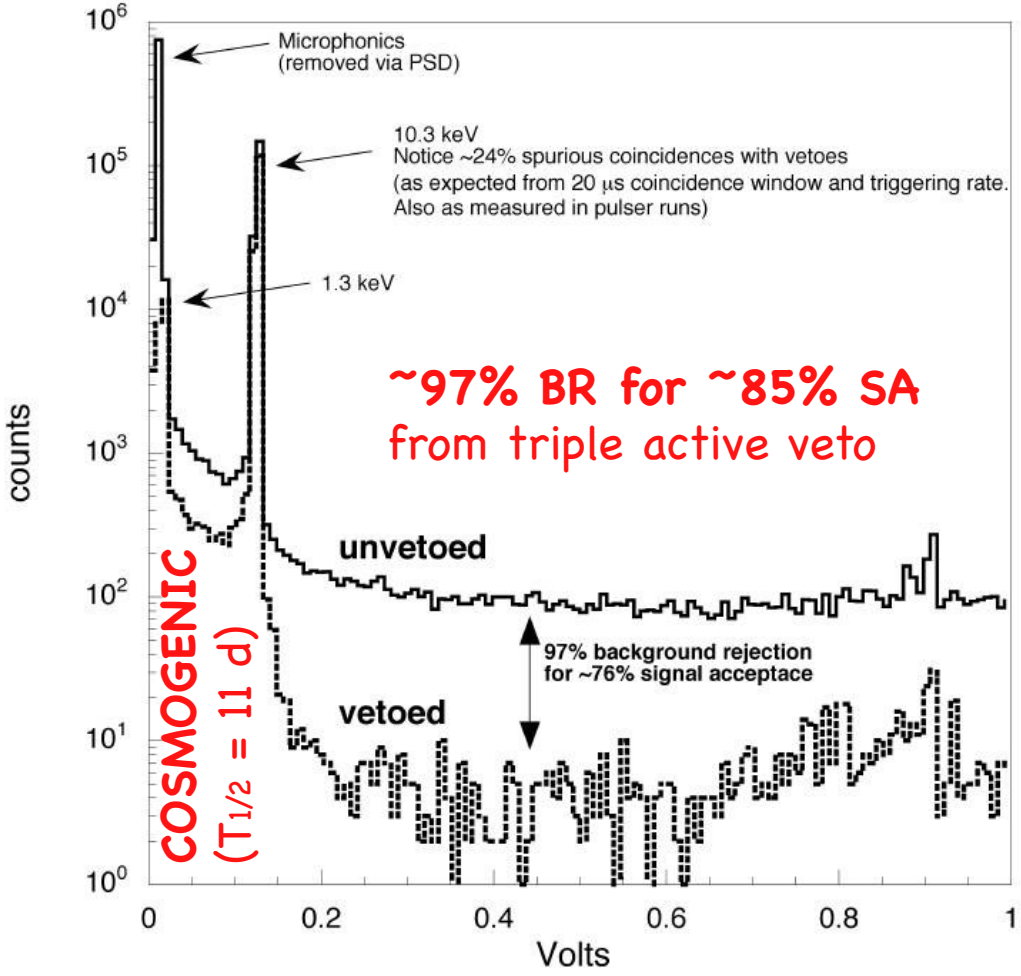

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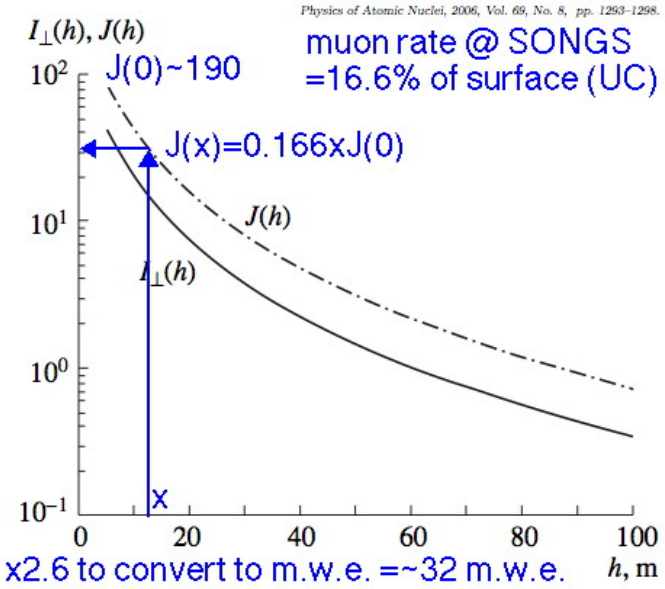

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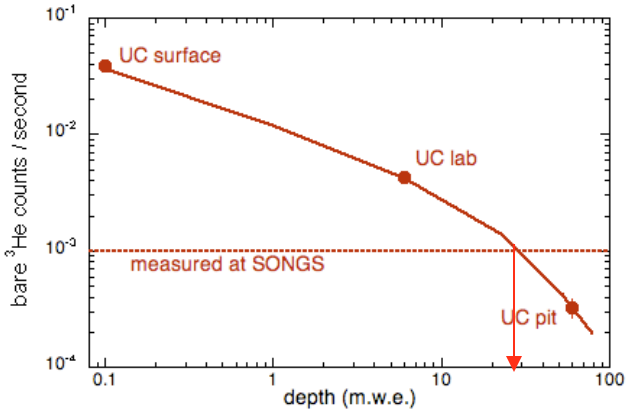
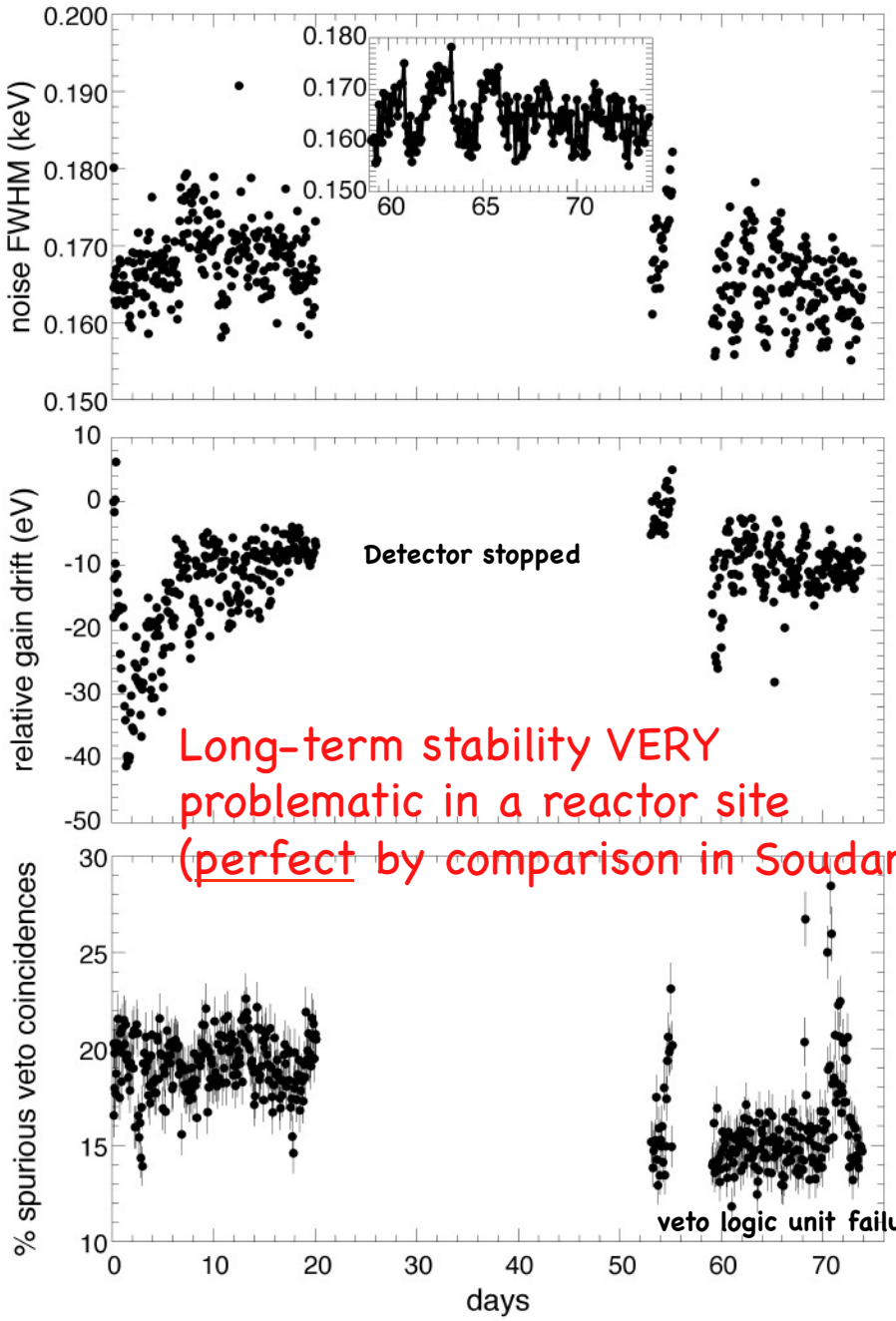
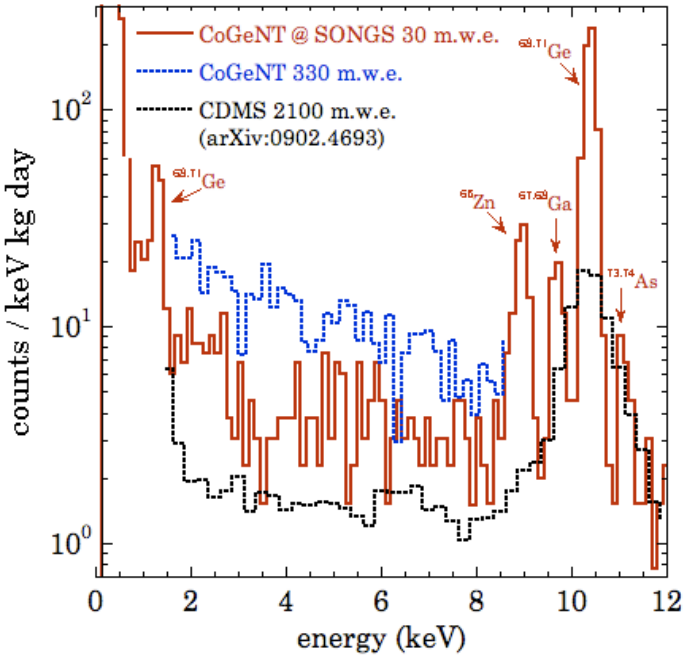


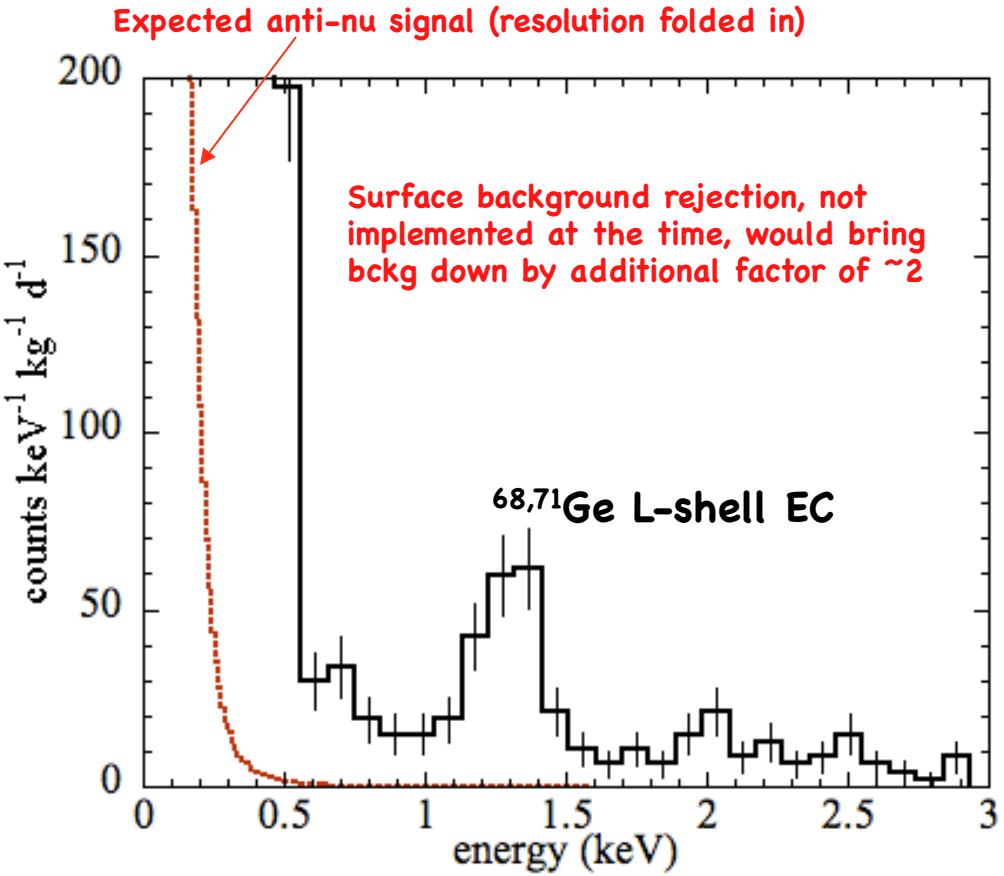


Long-term stability VERY problematic in a reactor site (perfect by comparison in Soudan)

The bottom line: so close, and yet so far

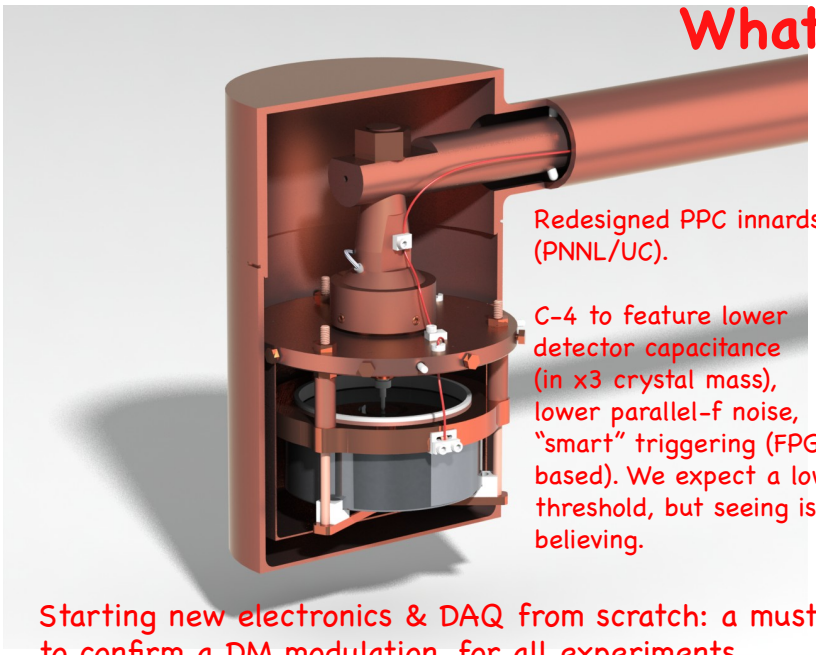
- We met our background goals. Factor ~2 larger background than CDMS in Soudan, at just 30 m.w.e. This takes a triple active veto. This before we learned about surface event rejection.
- Demonstrated long-term stability (under duress), absence of RX-associated backgrounds.
- Need ~2 improvement in noise to see neutrinos. C-4 detectors may fit the bill.





Giorgio dixit: "first to put signal and backgrounds on a lin-lin plot..."

What next? C-4



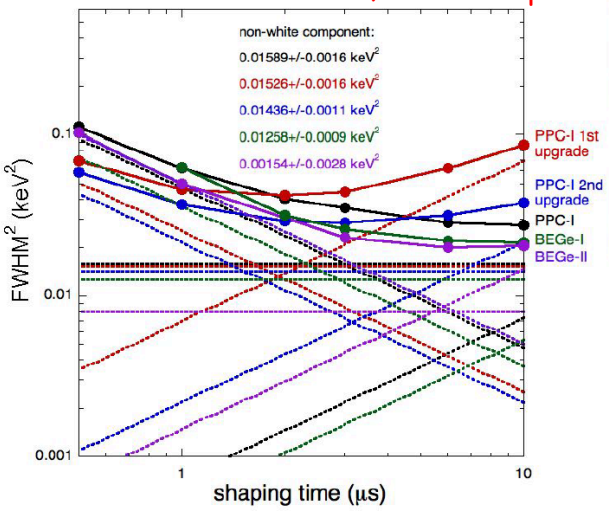
Redesigned PPC innards (PNNL/UC).

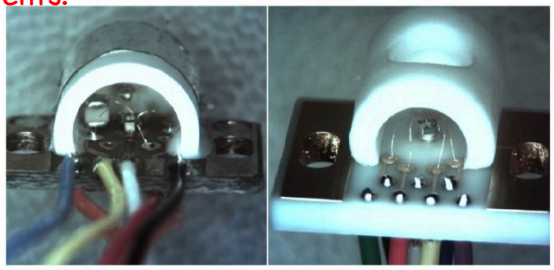
C-4 to feature lower detector capacitance (in x3 crystal mass), lower parallel-f noise, "smart" triggering (FPGA based). We expect a lower threshold, but seeing is believing.

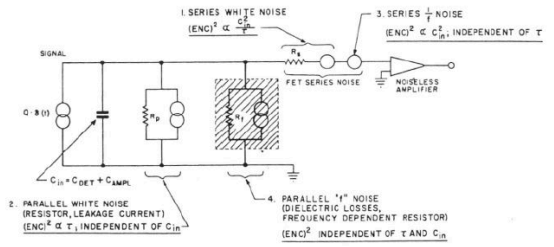
Taking shape:
First C-4 cryostat at PNNL

First detector arriving to UC Feb 2013

Starting new electronics & DAQ from scratch: a must to confirm a DM modulation, for all experiments.







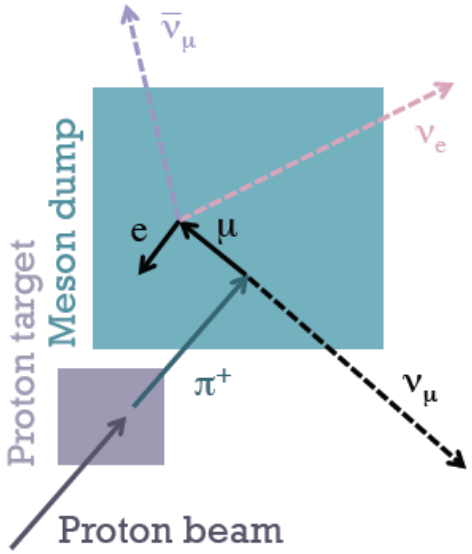
Crystal insertion full dress rehearsal:
T. Hossbach (PNNL),
M. Yocum & J. Colaresi (Canberra)

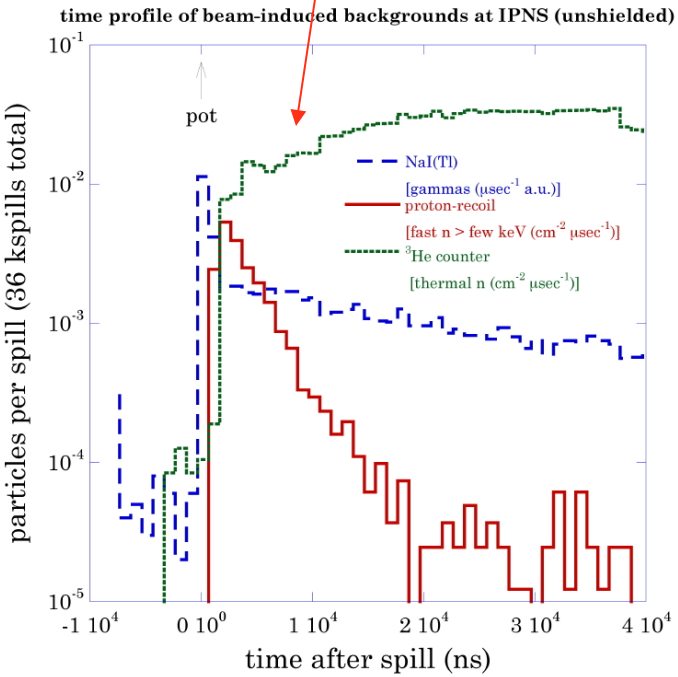
Noise abatement not dissimilar to background reduction:
one layer of crap hides the next one (but noise terms add in quadrature!!!).

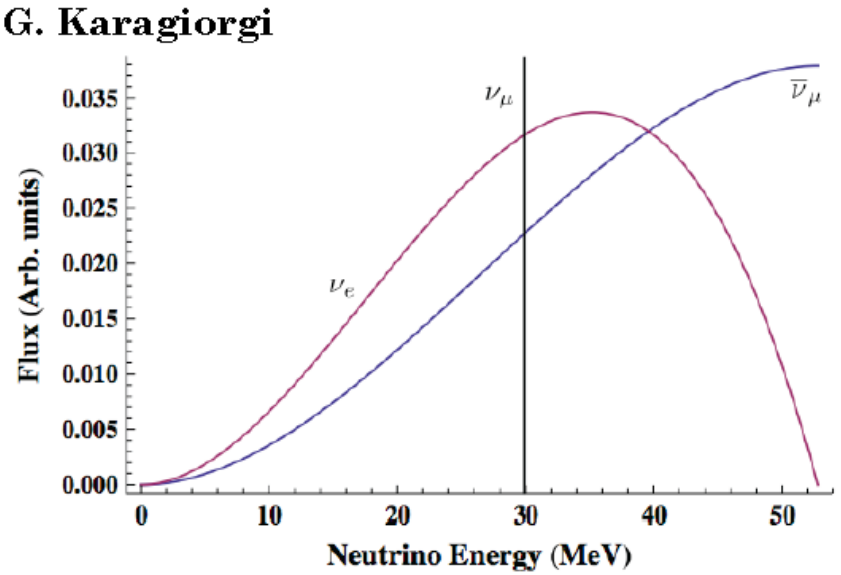
FIG. 2: *Left:* Electronic noise contributions measured with a pulser, for a number of PPC detectors and their upgrades. The (flat) non-white component remained invariable up to the last attempt (BEGE-II, see text). *Right:* Top left, commercial FET package employing a sub-optimal boron nitride and PCB package, and a surface-mount feedback capacitor. The improved package on the right uses a vacuum feedback capacitor, PTFE as the single dielectric, and improved mounting of the heating resistor. This package features not only the best available measures against non-white electronic noise, but is also constructed out of radioclean materials. Bottom: schematic illustrating the origin and characteristics of several sources of electronic noise in detector systems, with "parallel-f" highlighted [12].

Q: Is using an spallation source any easier? (A: not really)

- Recoil energies are larger, but neutrino flux is ~6 orders of magnitude lower.
- Pulsed signal allows to reduce background budget by ~4E-4. Background subtraction possible (anti-coincidence).
- Signal is pulsed, but so are the backgrounds (hard neutrons galore, ~1E-5/cm²s @20m). Time structure can be exploited to some extent to discriminate against neutron recoils. However, sufficient neutron shielding is the best solution.
- No significant overburden available. You get a lot of mileage out of those 30 m.w.e. in a reactor tendon gallery.







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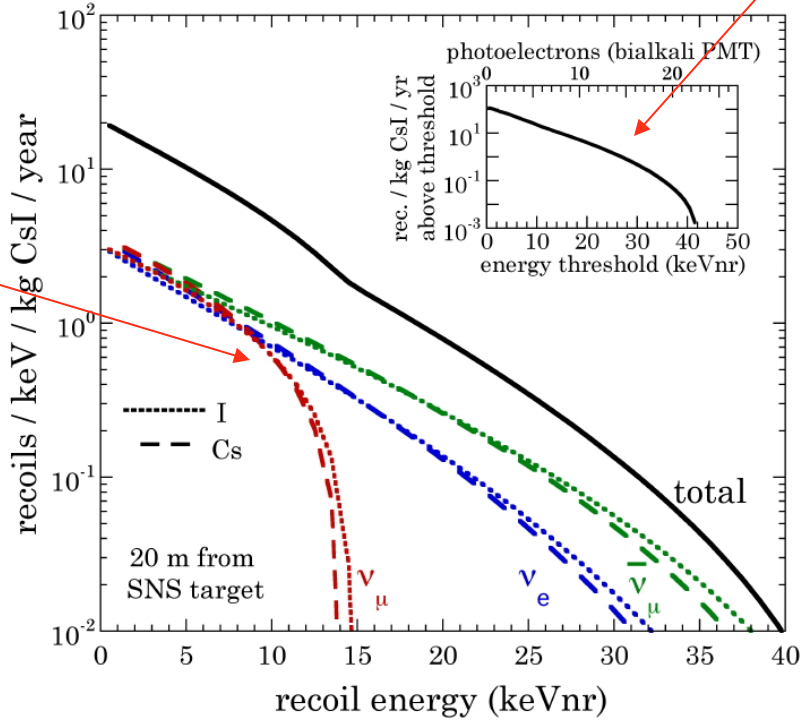
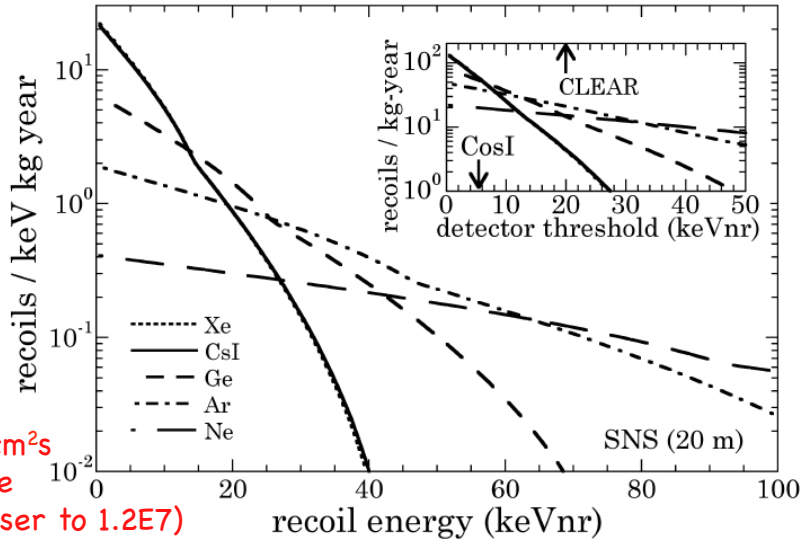
Using **measured** quenching factor





1.8E7 ν/cm²s used here (prob. closer to 1.2E7)

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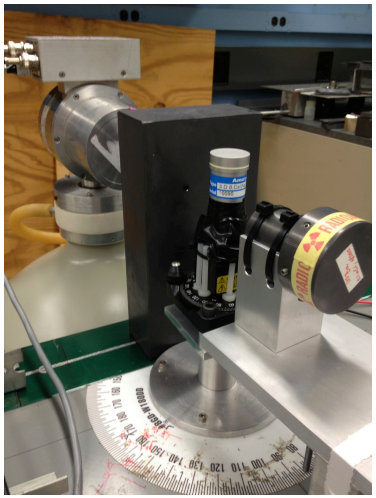
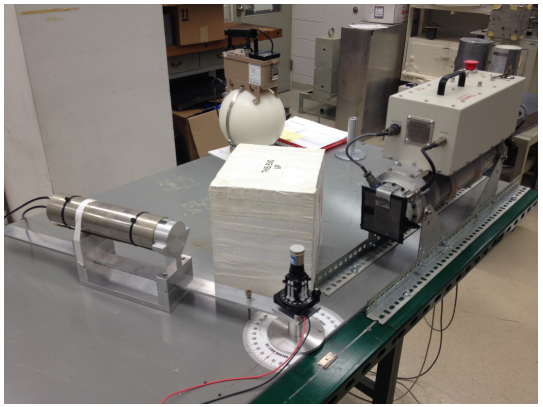
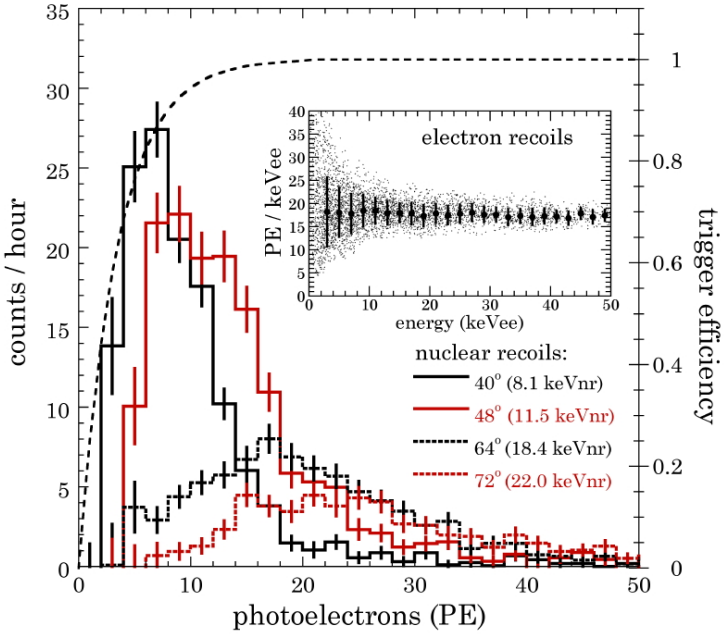
Simultaneous ER and NR low-E response measured via Compton scattering and D-D neutron gun (see arXiv:1302.0796)







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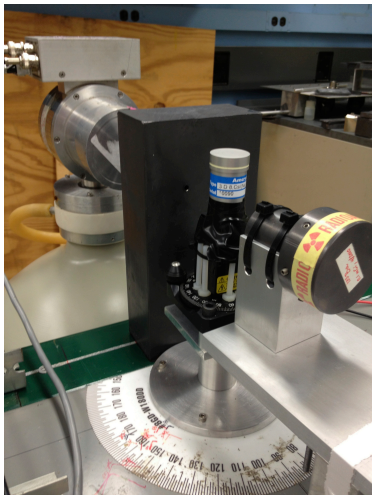

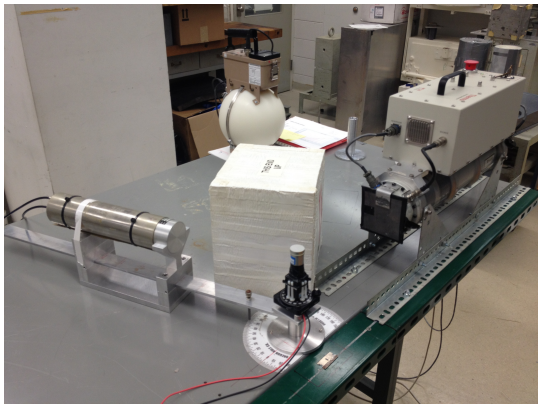

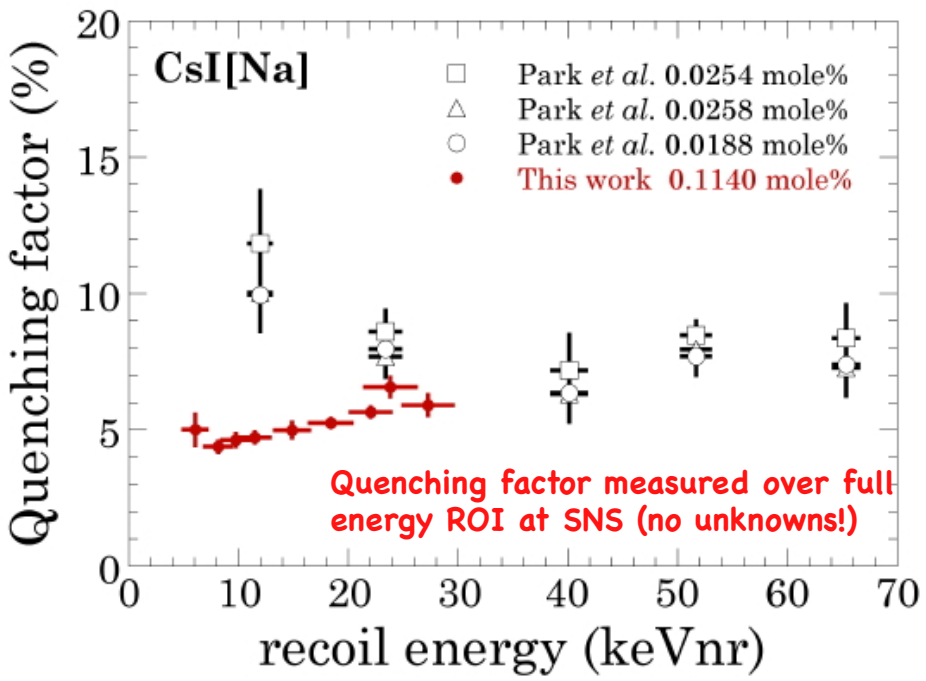

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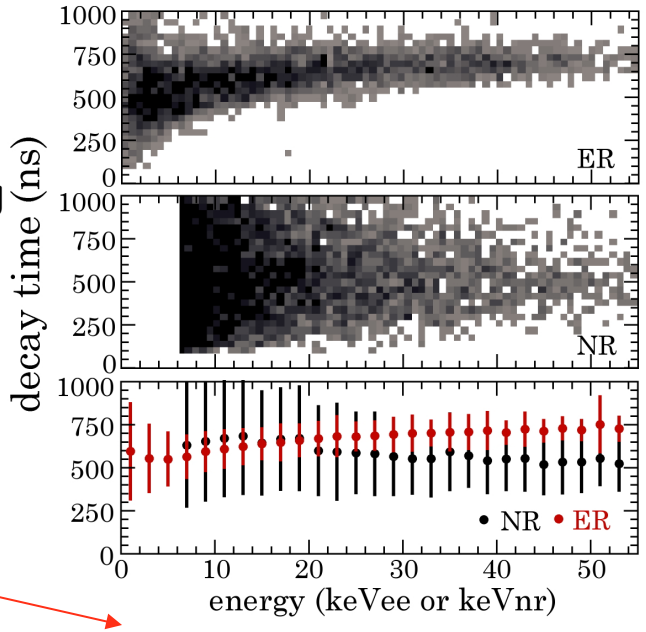


60 ns may not look like much, but has already been exploited in DM experiments (NaI[Tl])

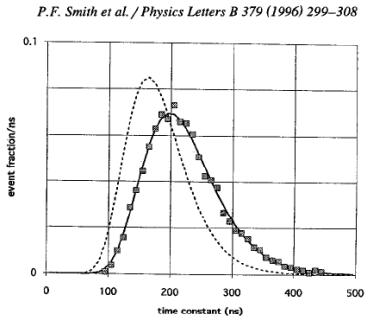
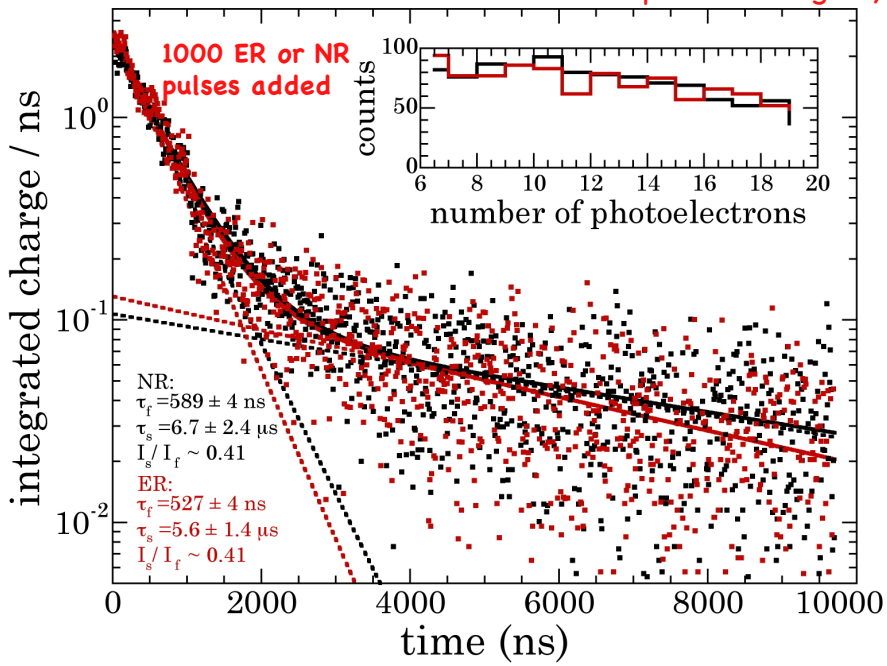


Fig. 4. Comparison of time constant data with γ and n calibrations: Full line: fitted γ calibration. Dashed line: fitted n calibration. Points: binned data for 13–16 keV energy span.

Statistical ER/NR discrimination possible already at the level of 1000 ev (~1 yr with planned 15kg crystal)



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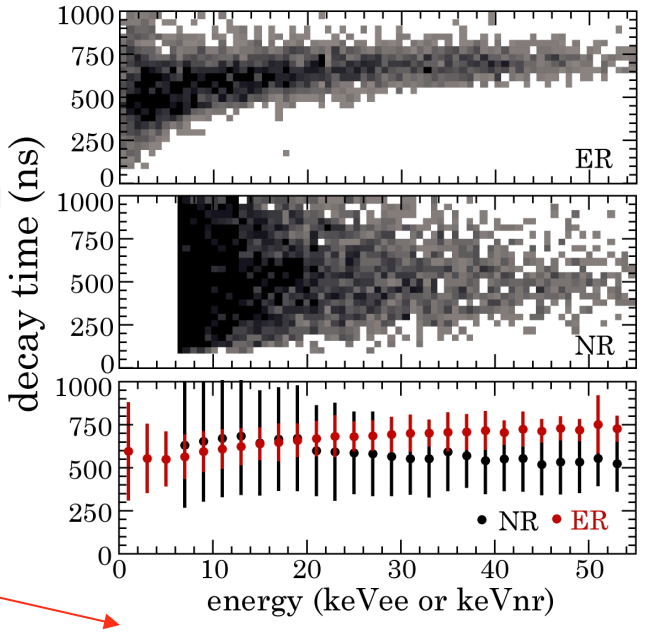
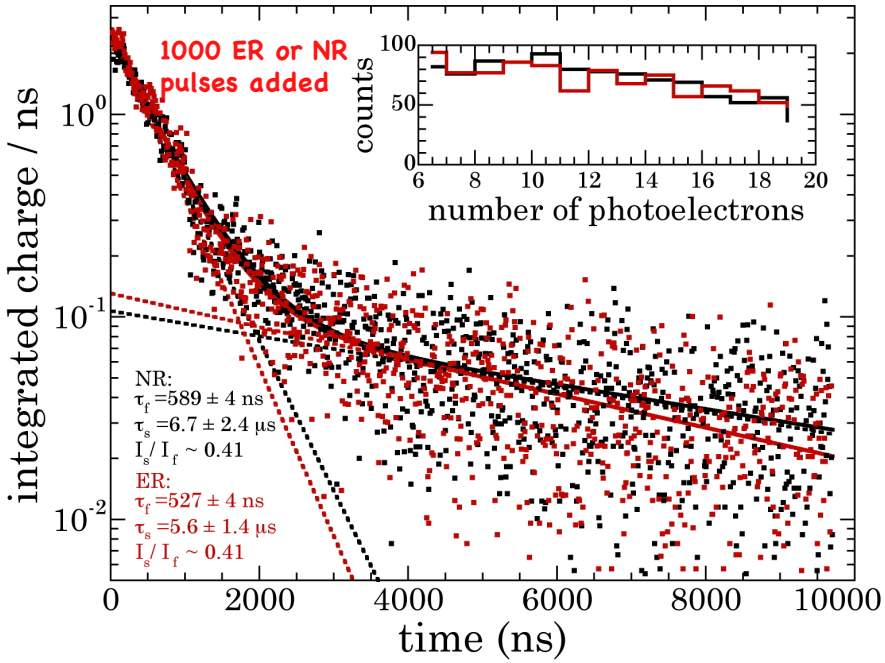


Additional measurements with new Y-88/Be technique in progress (preprint in preparation)



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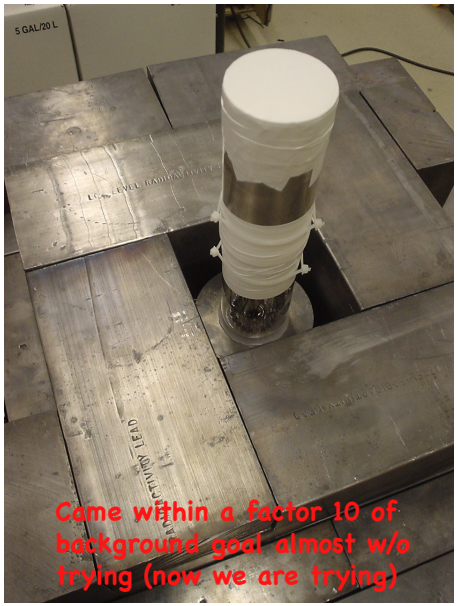

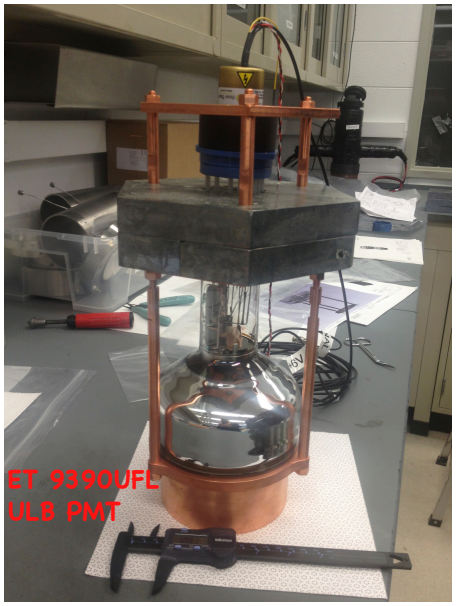

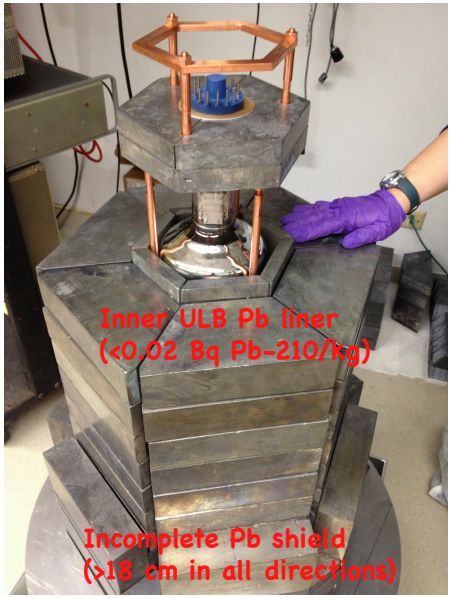

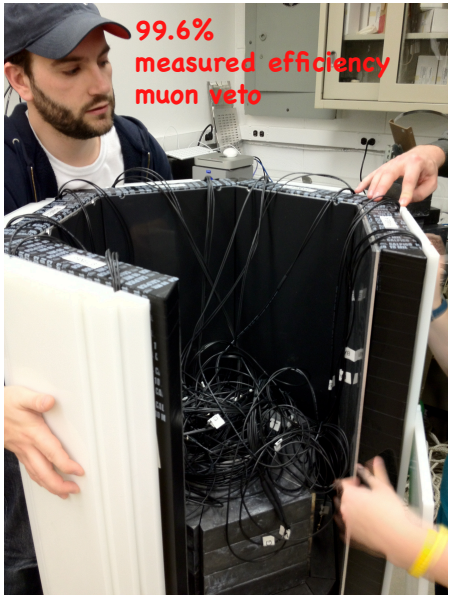

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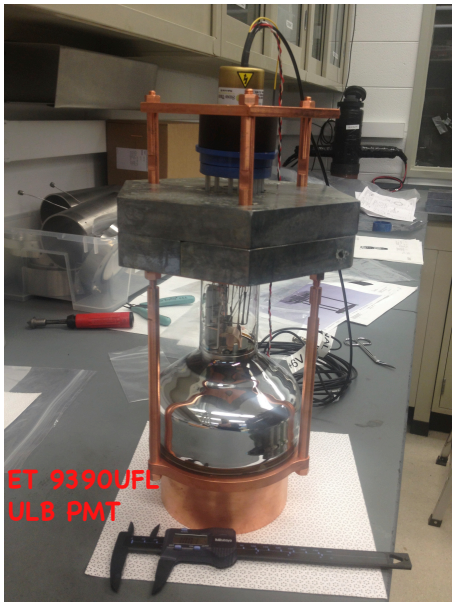

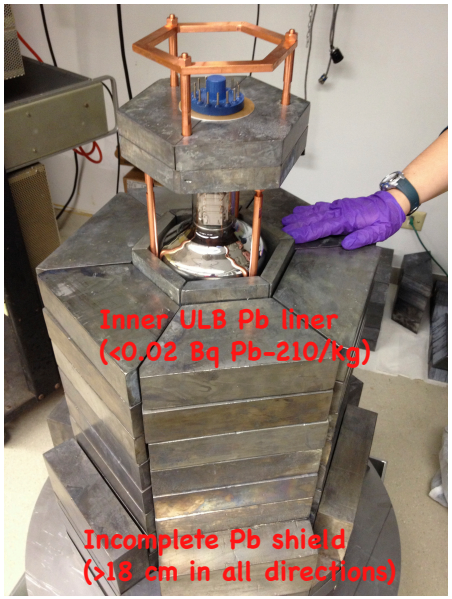

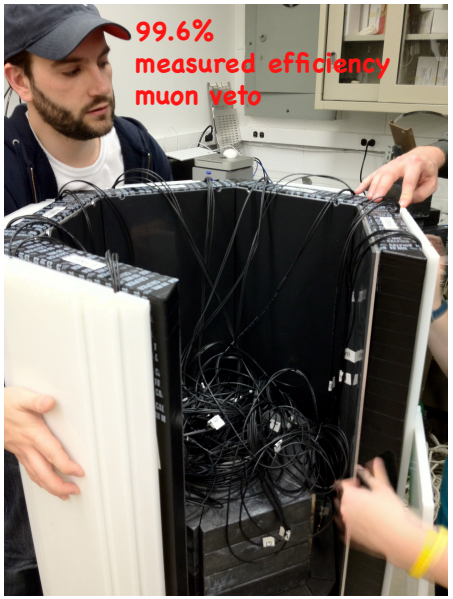

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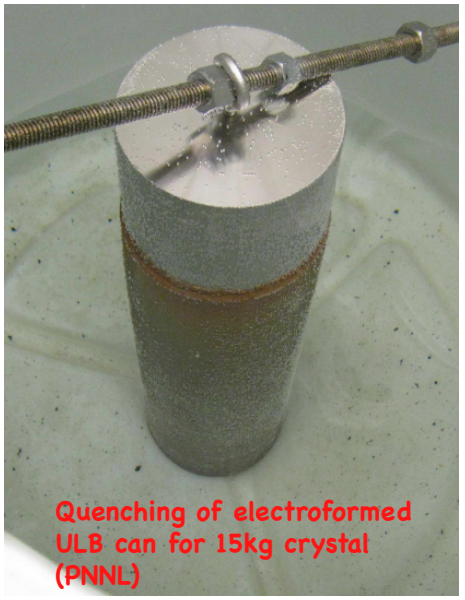

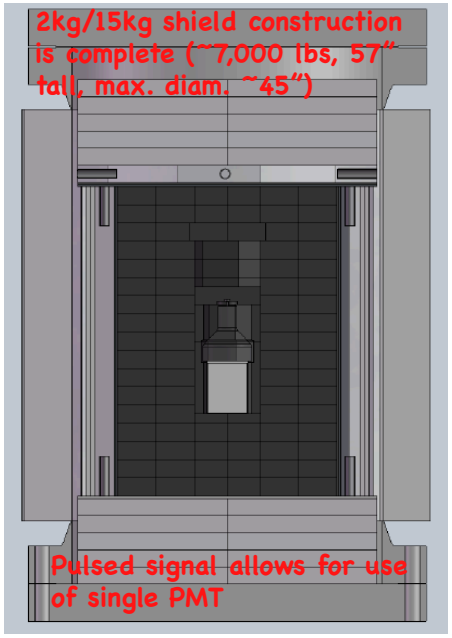

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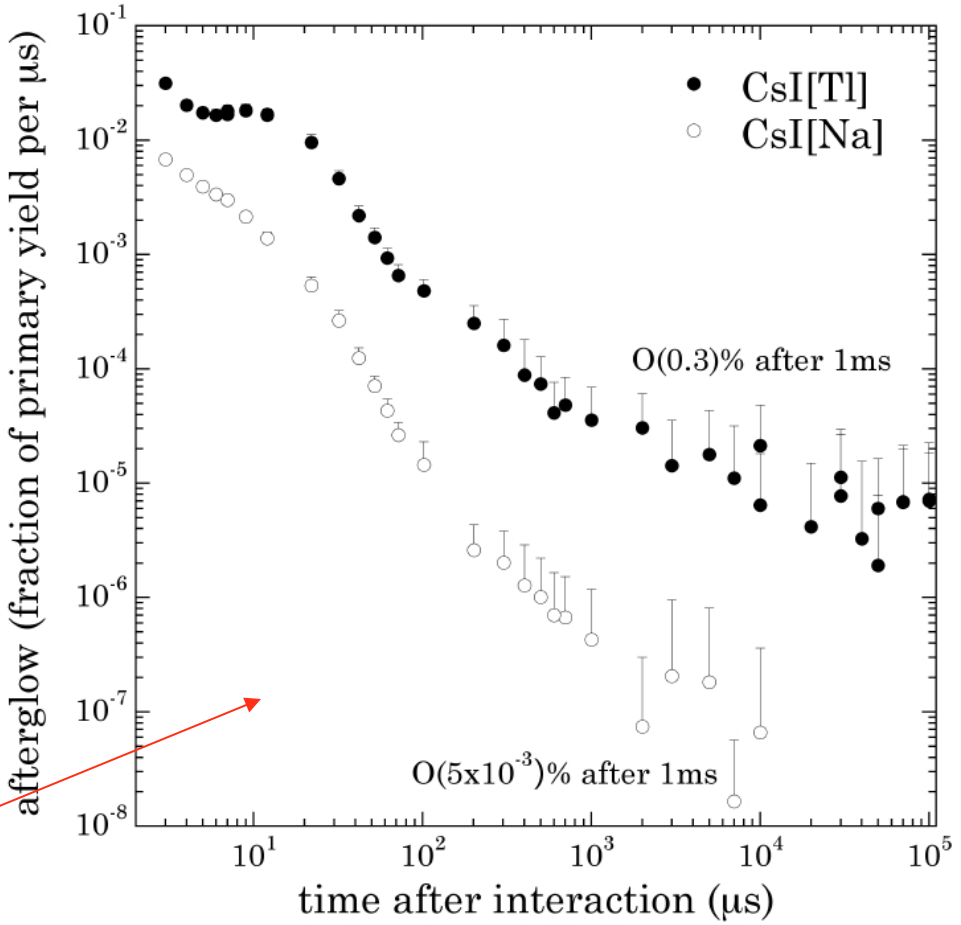
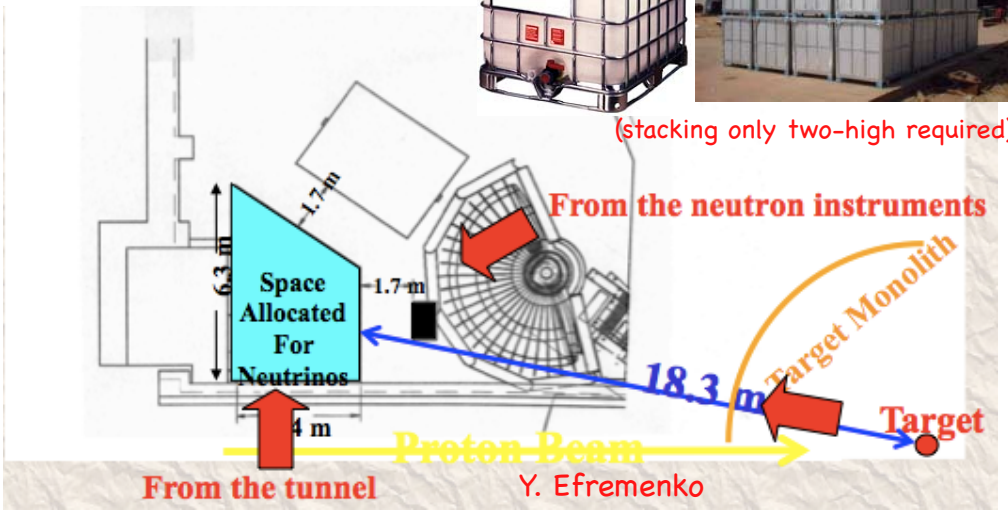


CsI : what's the plan?

- We want a solid proposal, one that <u>experimentally</u> demonstrates the three-legged stool (mass, threshold, background): if you build it, it will work. This is a must, given the present funding situation.
- After completion of bckg measurements at UC, move 2kg/15kg detector to SNS "neutrino room". Use of IBCs to provide inexpensive ~1m of moderator. Main purpose is to characterize neutron background and demonstrate readiness.
- Auger drilling (info from Y. Efremenko): contractor estimate $83k for 60" diameter, 42' deep lined pit (but ~1/3 the depth is plenty to block direct line-of-sight neutrons). <u>All other elements of detector/shield have been procured.</u> We are presently measuring bckgs at 6 m.w.e., i.e., similar conditions.
- 15kg detector in such a pit able to produce ~800 coh. ν scatters / year above <u>demonstrated</u> 5 keVnr threshold. Enough for measurement of x-section and proof-of-principle.
- Extrapolation to x10 the mass required to deliver most physics of interest. Only slightly larger pit needed.

(stacking only two-high required)



CsI : what's the plan?

- We want a solid proposal, one that experimentally demonstrates the three-legged stool (mass, threshold, background): if you build it, it will work. This is a must, given the present funding situation.
- After completion of bckg measurements at UC, move 2kg/15kg detector to SNS "neutrino room". Use of IBCs to provide inexpensive ~1m of moderator. Main purpose is to characterize neutron background and demonstrate readiness.
- Auger drilling (info from Y. Efremenko): contractor estimate $83k for 60" diameter, 42' deep lined pit (but ~1/3 the depth is plenty to block direct line-of-sight neutrons). All other elements of detector/shield have been procured. We are presently measuring bckgs at 6 m.w.e., i.e., similar conditions.
- 15kg detector in such a pit able to produce ~800 coh. ν scatters / year above demonstrated 5 keVnr threshold. Enough for measurement of x-section and proof-of-principle.
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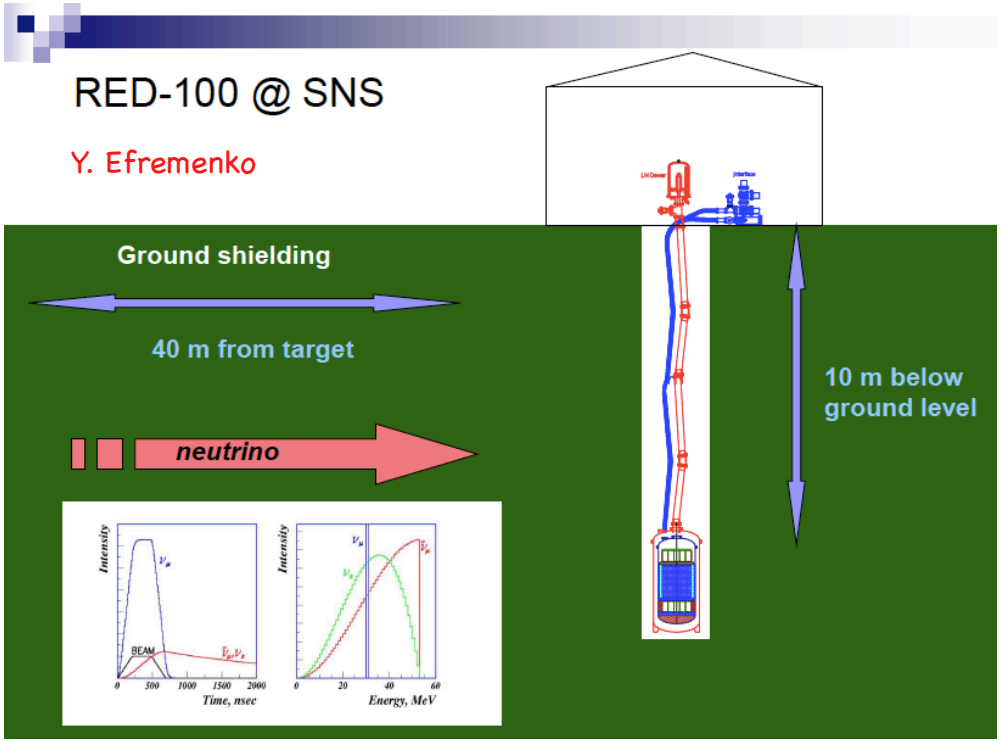

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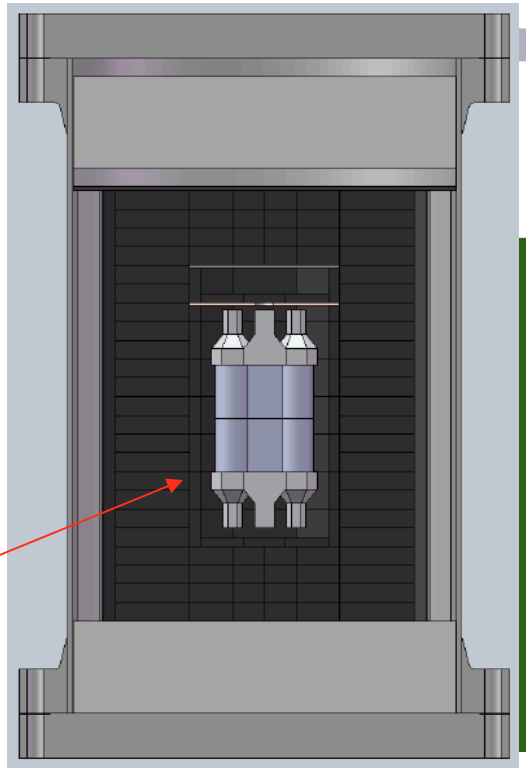

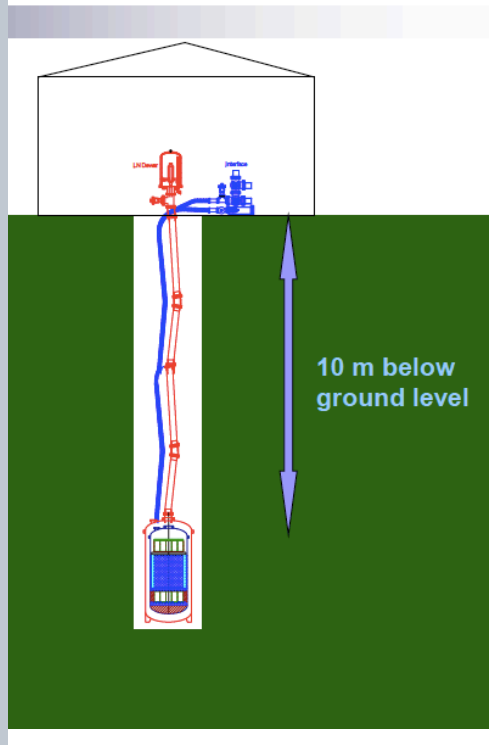

Coherent ν-nucleus scattering...

closer than you think!