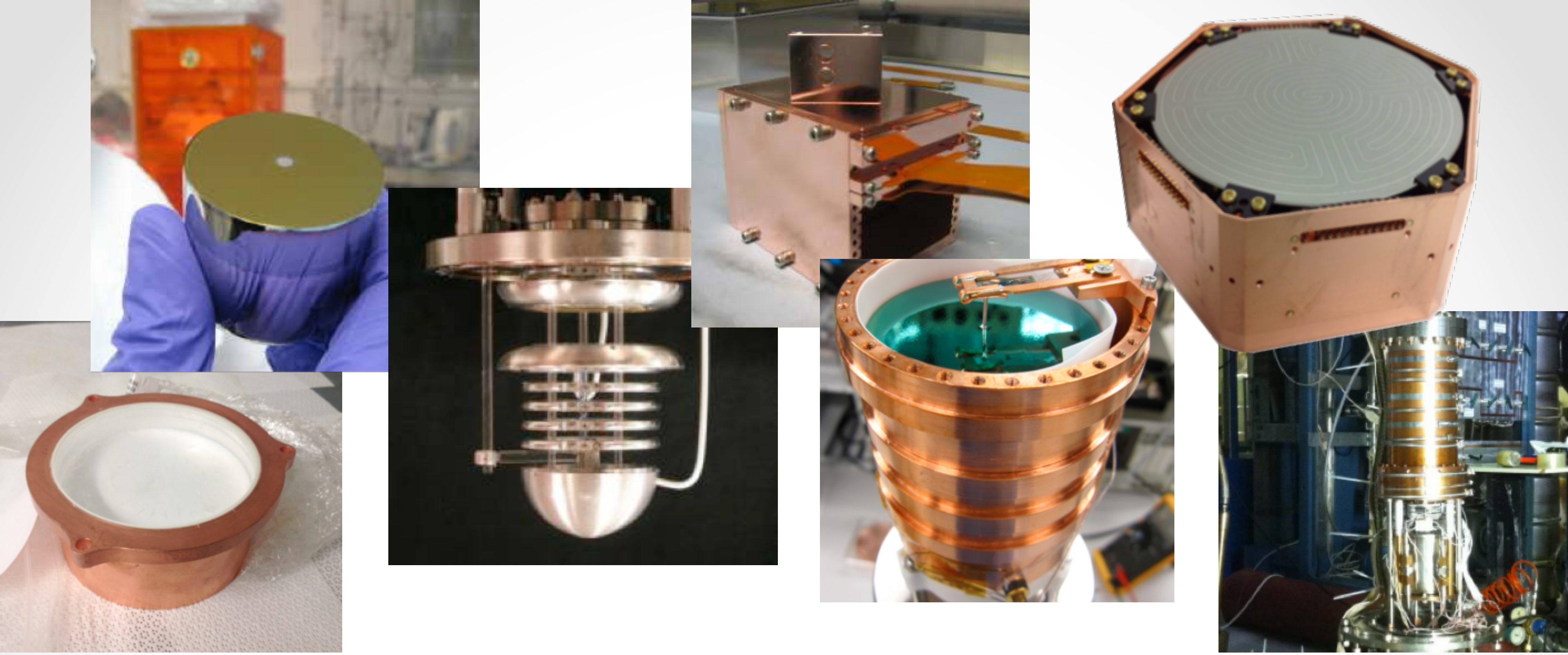

Detection of Coherent Neutrino Scattering

Phil Barbeau
Duke University

Observation Requires a Visit by all Three Marias

- The experimental signature is a difficult to detect low-energy nuclear recoil
  - sub-keV to keV
- Low backgrounds
  - 1-1000 counts $keV^{-1}\ kg^{-1}\ d^{-1}$
- Large masses
  - 1 kg – 1 ton

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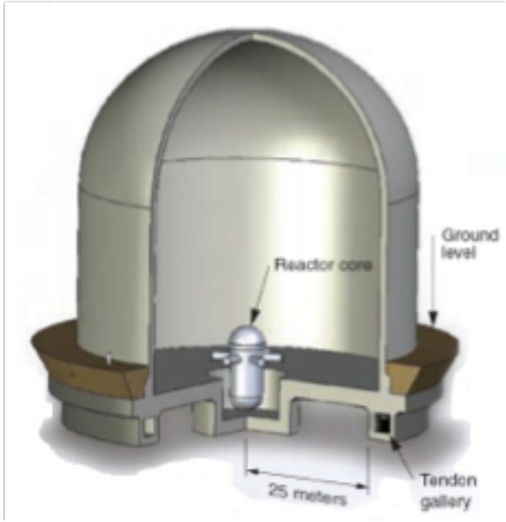
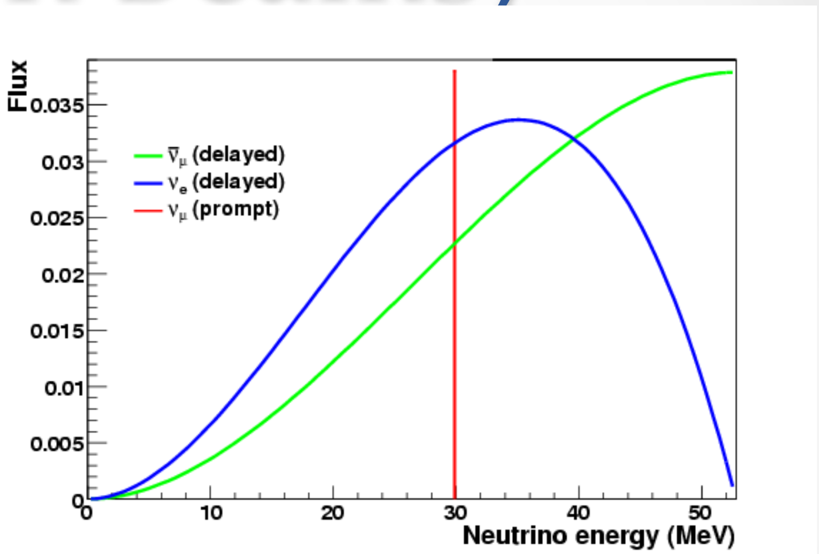
This is really a question of how far you can push the detector technology…

Relevant Neutrino Sources (reactors)



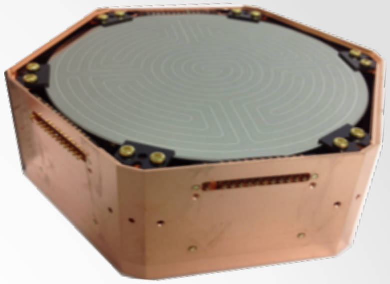
- High neutrino fluxes available 20 m from the core ~10^{13} cm^{-2} s^{-1}
- Modest overburden possible ~30 m.w.e.
- Low energy neutrinos -> scattering is point-like…
- … but produce nuclear recoil energies ~100’s eV

Relevant Neutrino Sources (Stopped Pion Beams)



- Lower total neutrino flux at 20 m ~10^7 cm^{-2} s^{-1}
- Pulsed beam for background reduction
- Better knowledge of neutrino spectrum
- Higher energy neutrinos -> keV nuclear recoils…
- …incomplete coherence for some energies/nuclei

In the beginning…



- In 1985 Blas Cabrera, Lawrence Krauss and Frank Wilczek proposed a new detector to observe Coherent Neutrino Scattering

- “Bolometric Detection of Neutrinos” **PRL 55, 25 (1985)**
- "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 pp, Be7 and B8 solar ν's, and supernovae anywhere in our galaxy (~10 tons of Si).”

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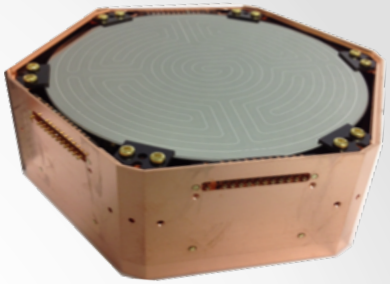

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- This was the precursor to the CDMS Dark Matter search

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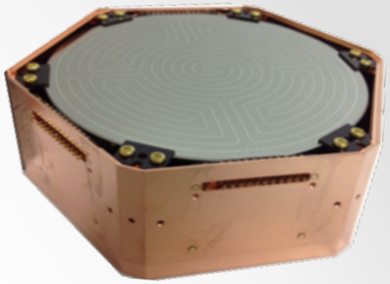

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- This was the precursor to the CDMS Dark Matter search
- *It turns out looking for dark matter was easier*

Fast Forward 20 years

- The Coherent Germanium Neutrino Technology collaboration (CoGeNT) resurrected an old detector concept for low-threshold detectors, and finally made it work

IEEE Transactions on Nuclear Science, Vol. 36, No. 1, February 1989
P. N. Luke, F. S. Goulding, N. W. Madden and R. H. Pehl
LOW CAPACITANCE LARGE VOLUME SHAPED-FIELD GERMANIUM DETECTOR

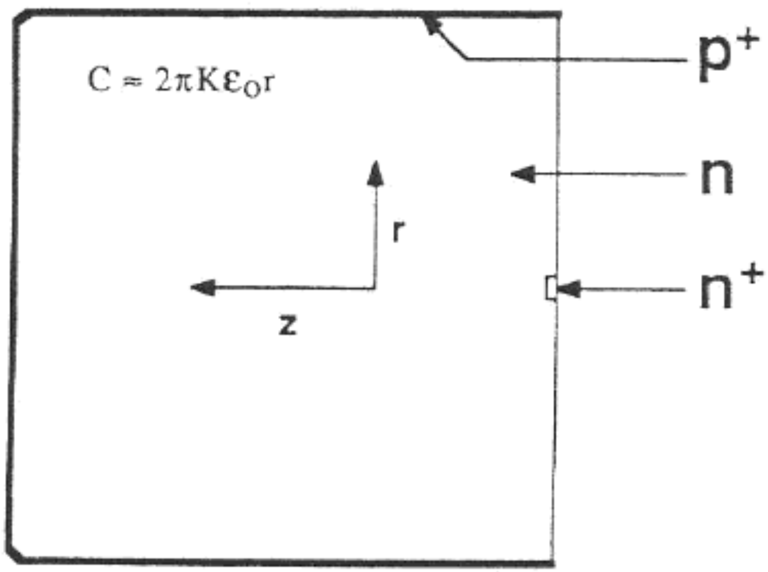

Fig. 3. Structure of the shaped-field detector.

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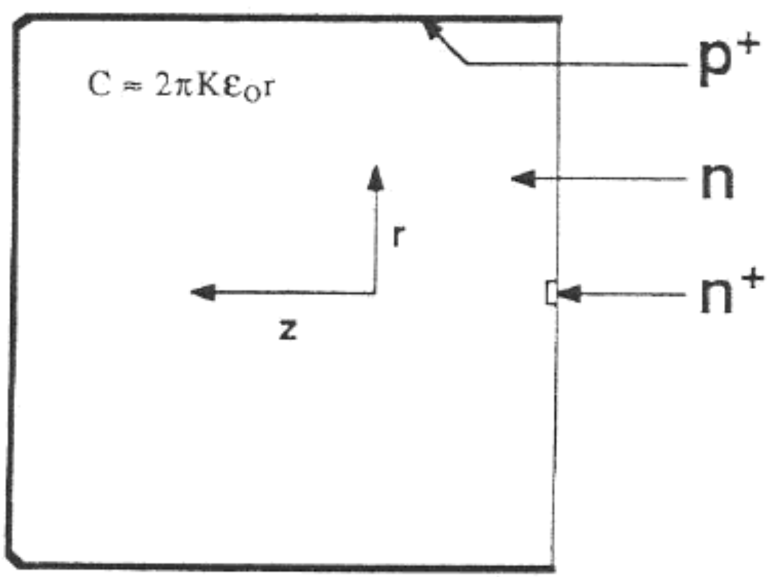

Fig. 3. Structure of the shaped-field detector.

Paul Luke's original intention was inspired by searches for the Cosmion, a hypothetical particle thought at the time to explain the solar neutrino problem

(G.B. Gelmini et al., Nucl. Phys. B281 (1987) 726.)

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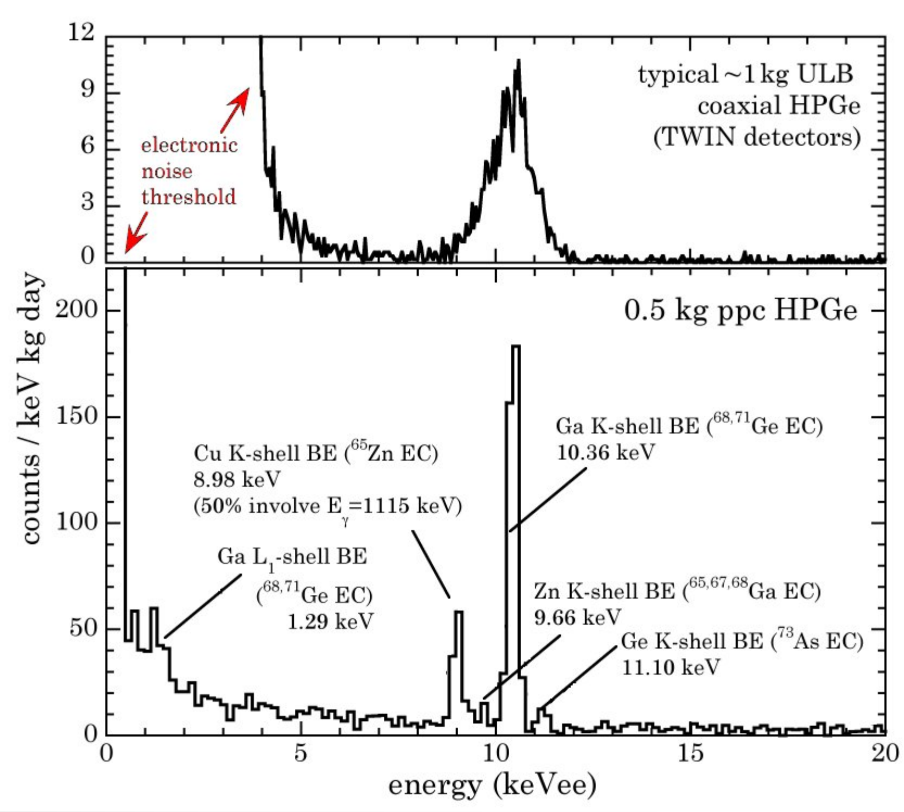


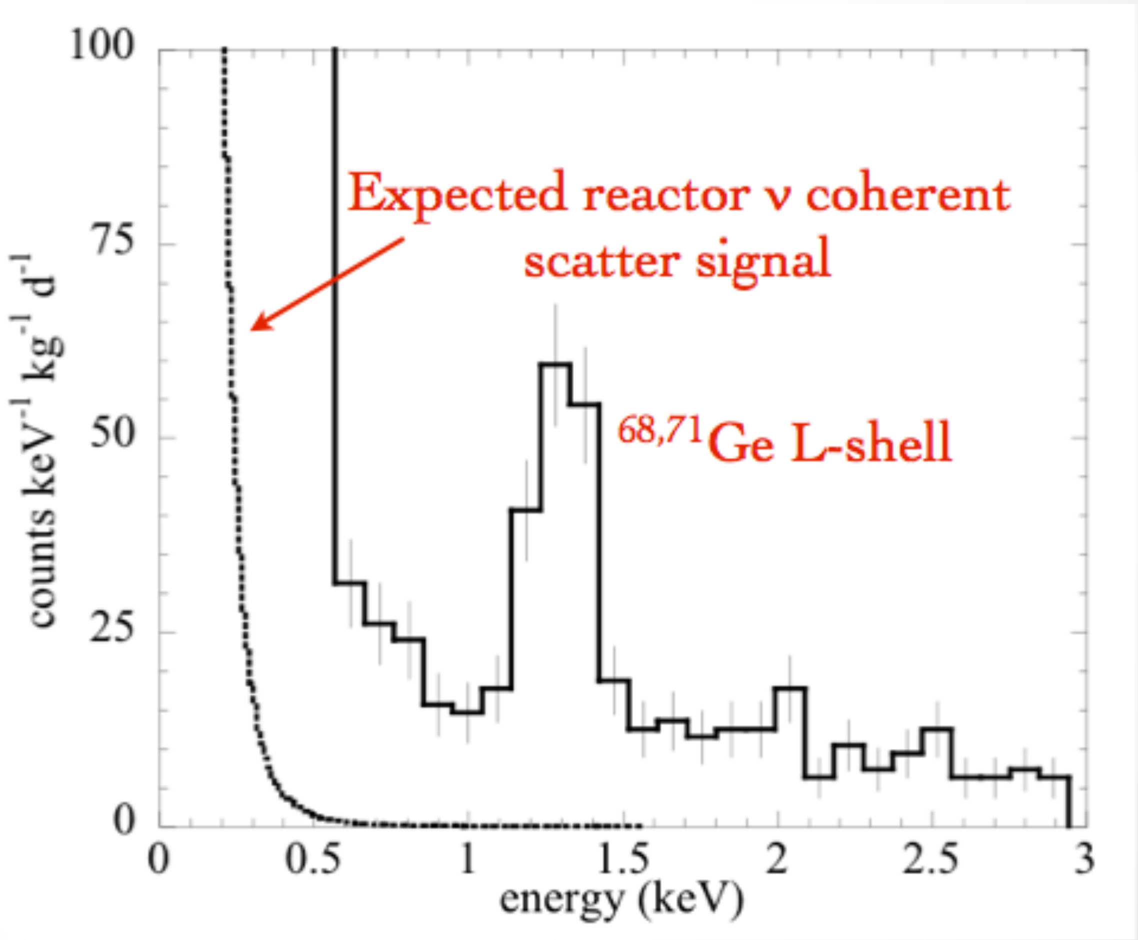
The resulting factor of 10 reduction in threshold made possible a search for coherent neutrino scattering

(P. S. Barbeau, J. I. Collar, and O. Tench., JCAP, 2007(09):009, 2007.)

CoGeNT @ SONGS

We deployed a detector to the SONGS power reactor

We didn't quite make it
500 eV threshold

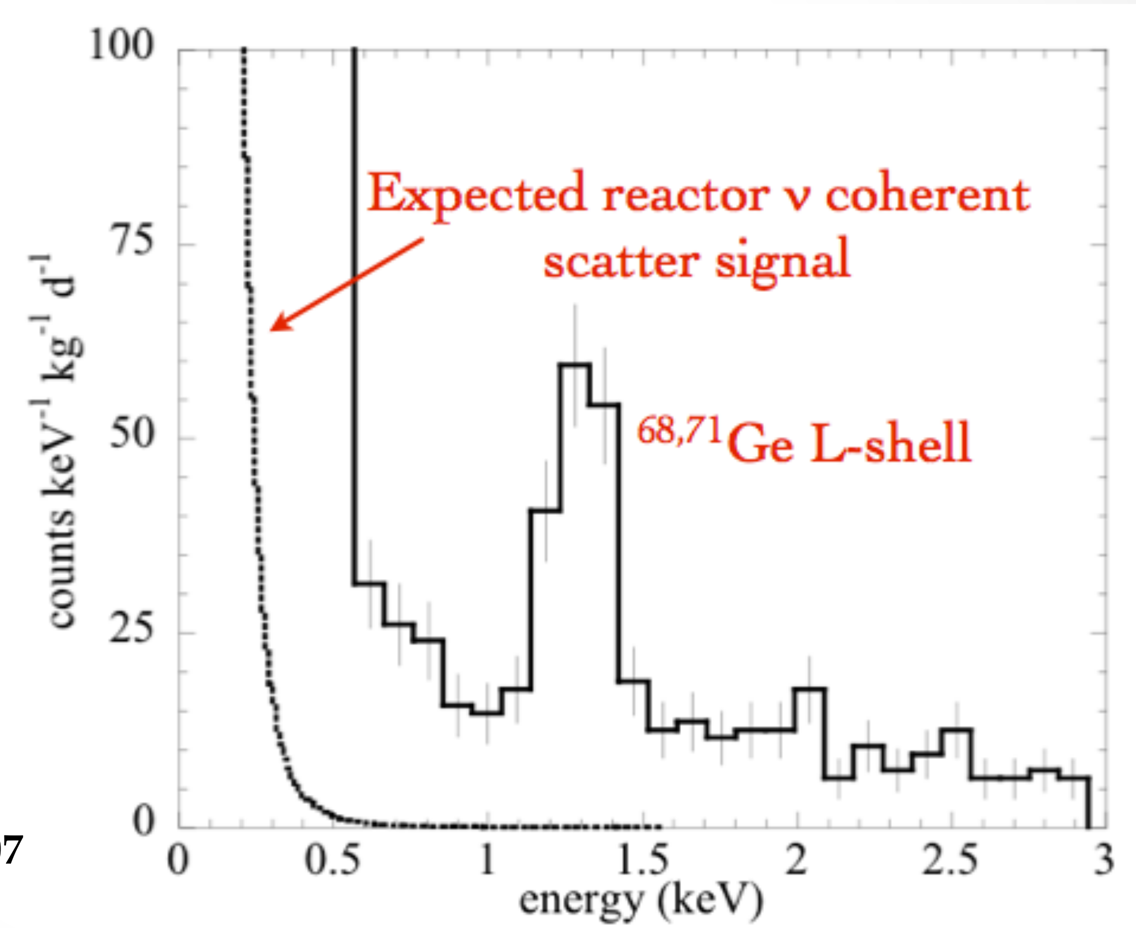


CoGeNT @ SONGS

We deployed a detector to the SONGS power reactor

We didn't quite make it
500 eV threshold

So we went to look for Dark Matter, because it was easier…

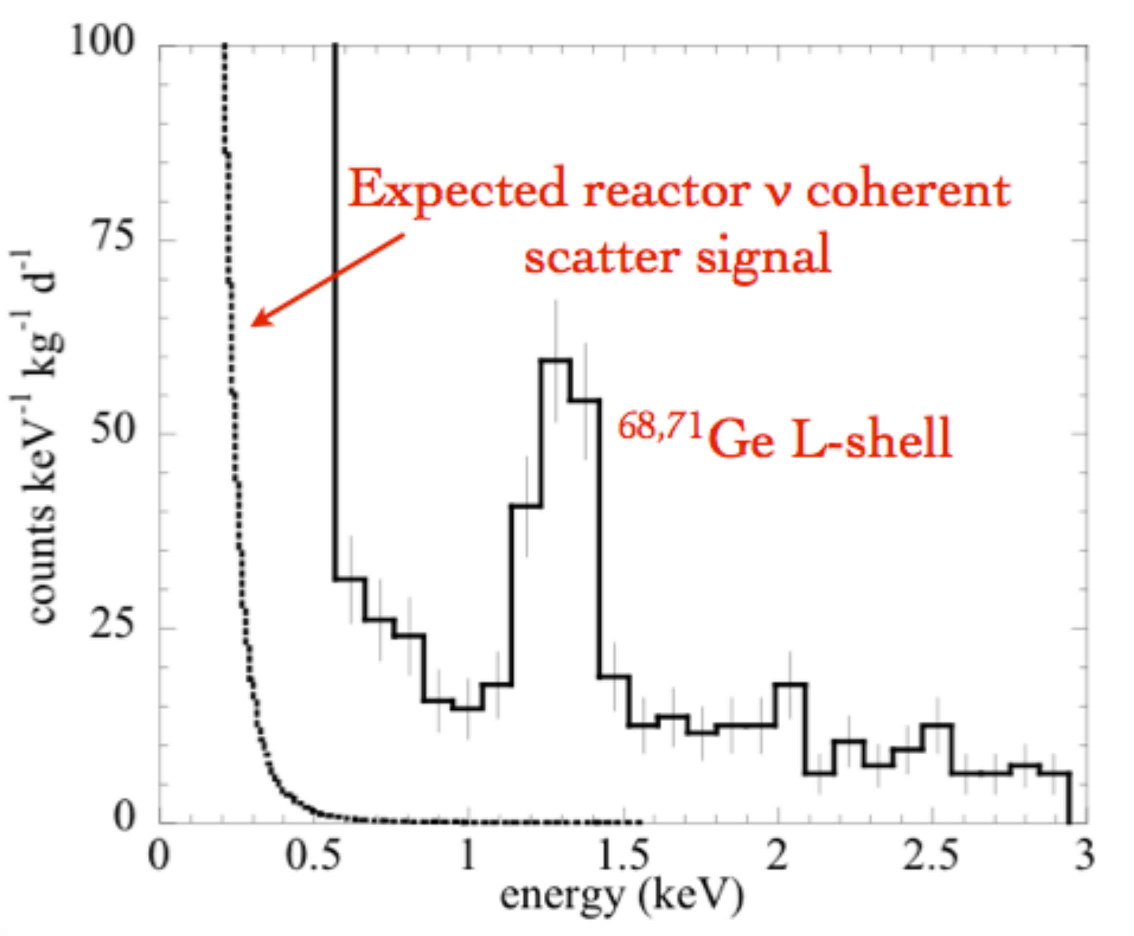


(C. Aalseth, P. S. Barbeau, J. Colarisi, et al., Phys. Rev. Lett. 107 (2011) 141301.)

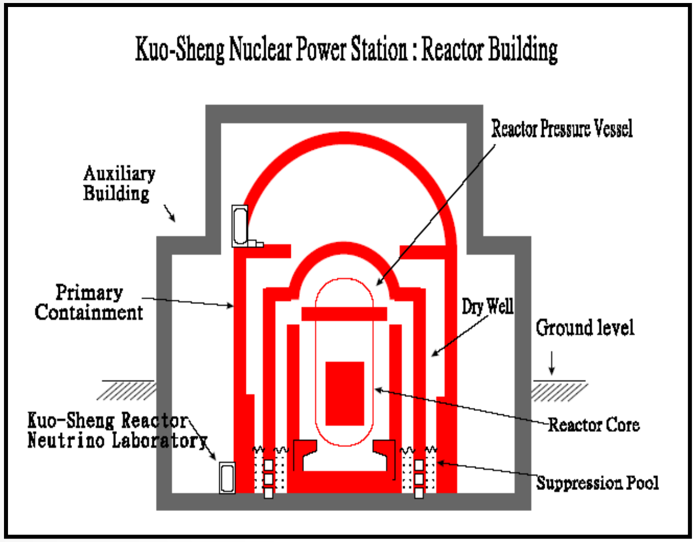
CoGeNT @ SONGS

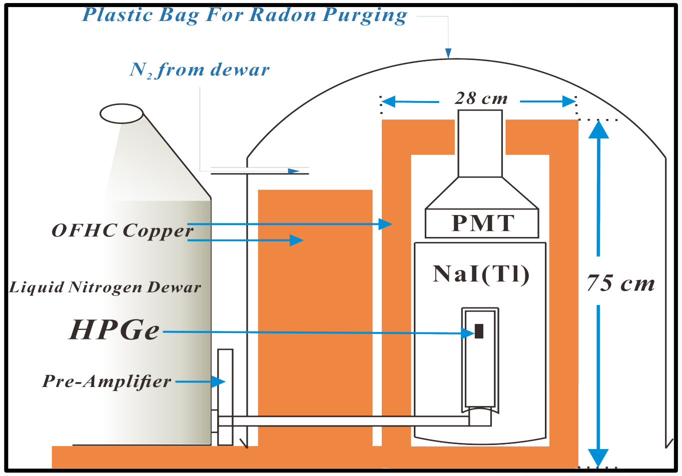
The CoGeNT detectors are now being used in many experiments, including the MAJORANA neutrinoless double beta decay experiment

And this has important implications for the recently formed COHERENT collaboration



TEXONO (Taiwan, China, India, Turkey)





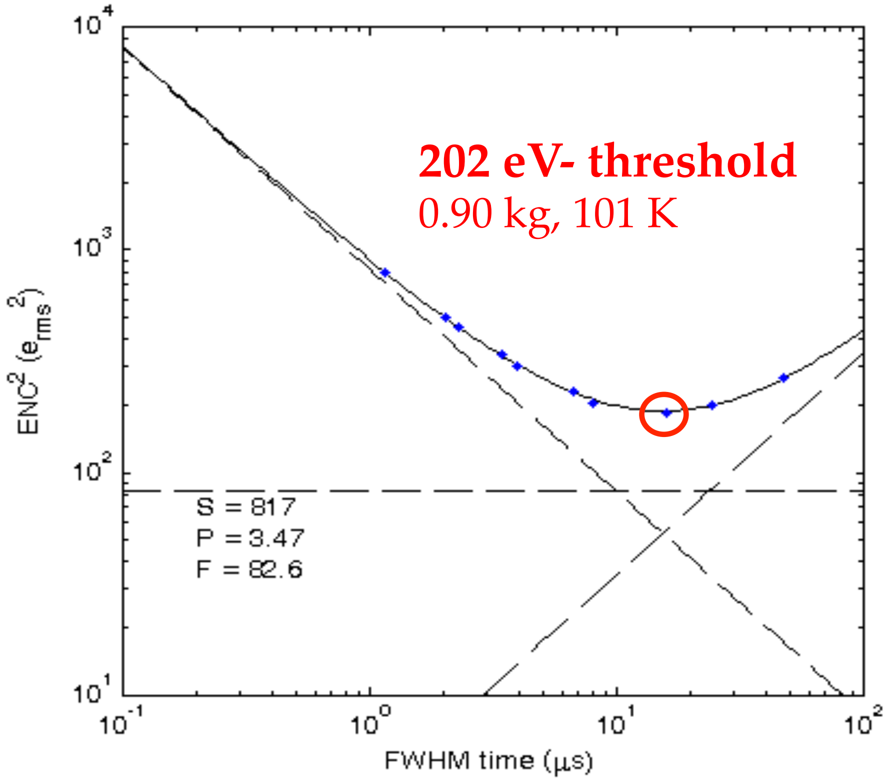
- Point contact Ge detectors part of broad program to search for new neutrino and dark matter physics

  Dark Matter @ KSNL: PRD09;PRL13,AP14
  Dark Matter @ CDEX @ CJPJ PRD13, arXiV: 1403.5241/1404.4946
  Magnetic Moments: PRL03,PRD05,PRD07

- Physics Goals: ~100 eV threshold - 1 kg mass - 1 $keV^{-1}\ kg^{-1}\ d^{-1}$

ULGeN (Ultra Low Noise Ge Neutrino)

- LBNL developed Low Mass Front End electronics for the MAJORANA collaboration



- Path to 100 eV: Exploration of 10-80 K operation of CMOS

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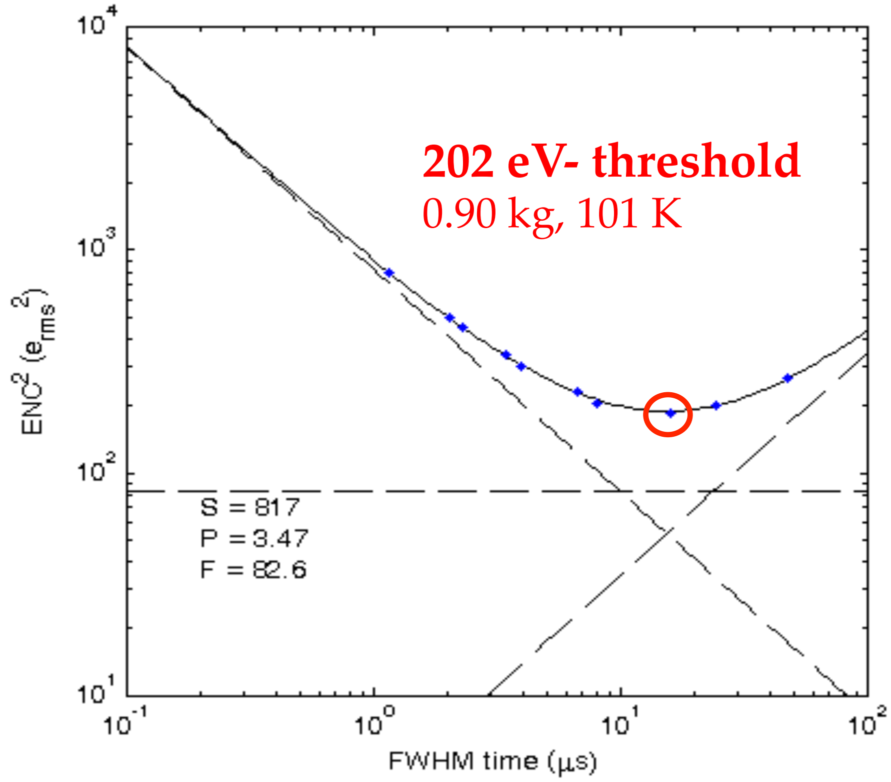
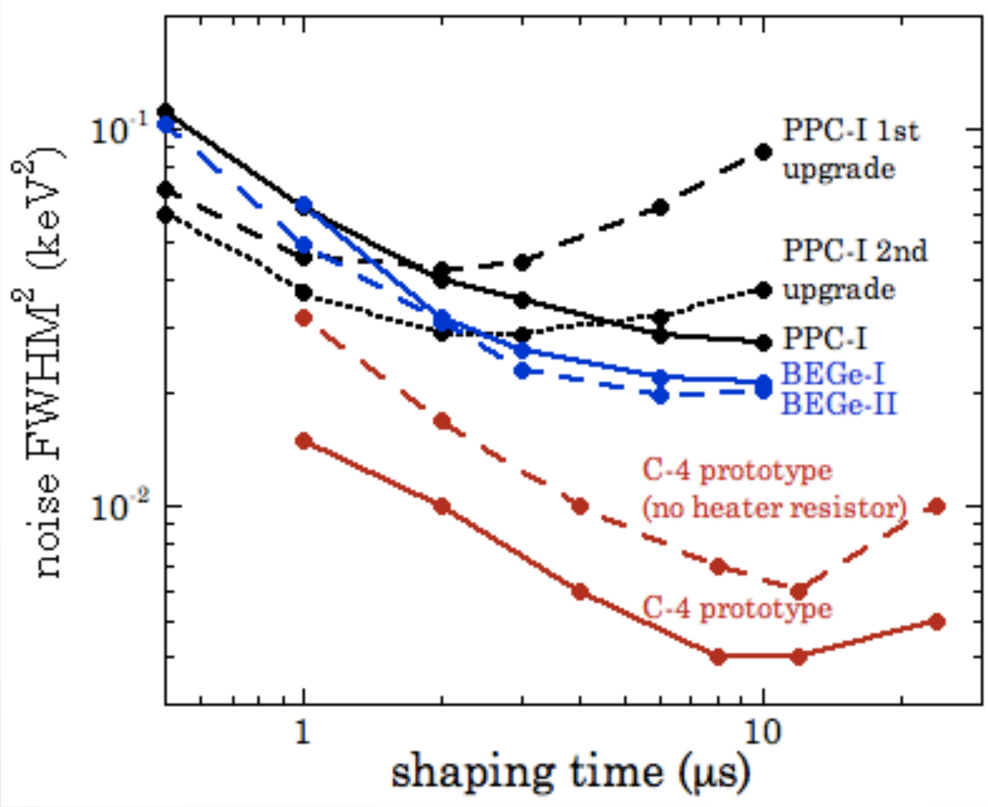


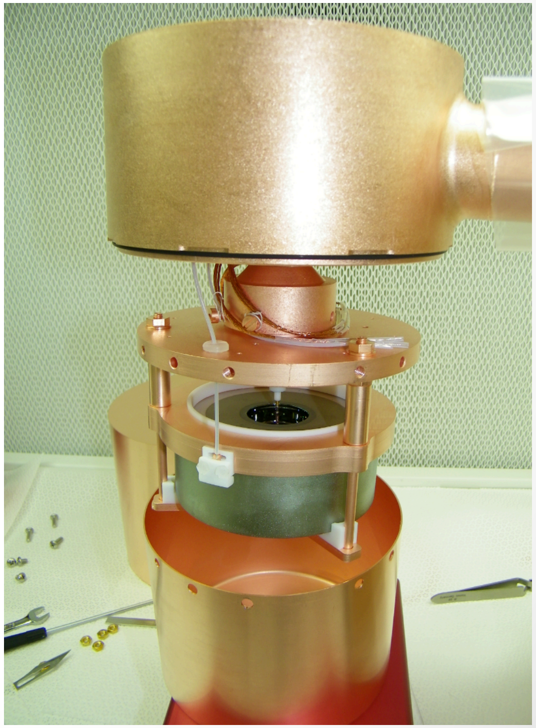
COHERENT

- Path to 100 eV: Exploration of 10-80 K operation of CMOS

C-4 (CoGeNT – 4)

- Recently demonstrated ~150 eV threshold
- 1.3 kg detector, expecting same noise for 2.7 kg crystals

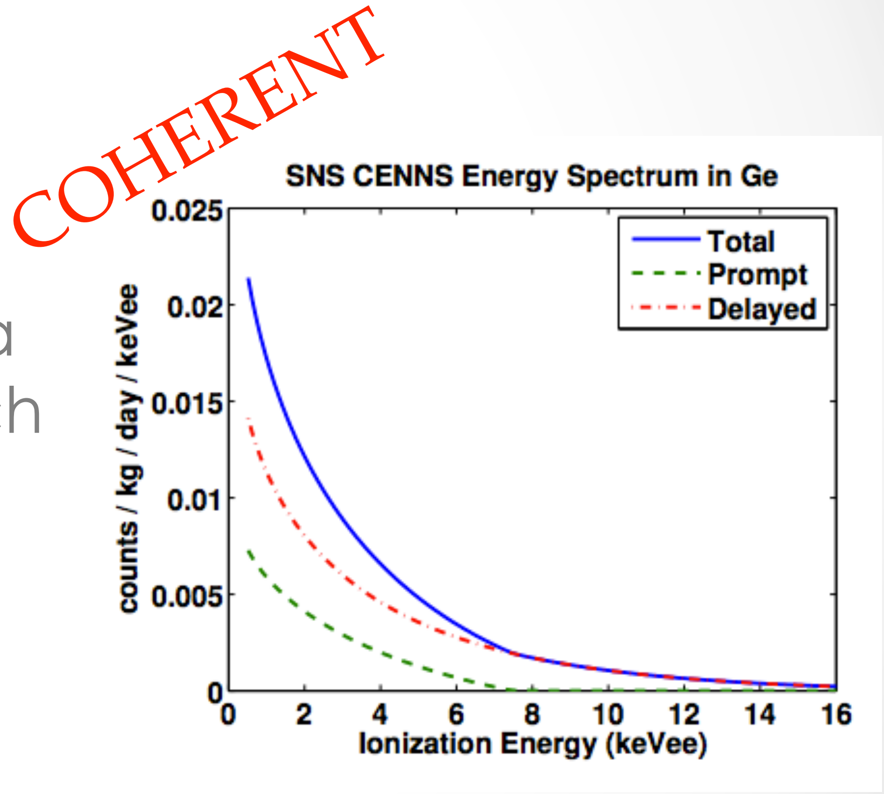




Point Contact Ge Detectors

- While coherent scattering from reactors may remain just out of reach, this is a very promising technological choice for a Coherent Scattering search at a stopped pion beam.

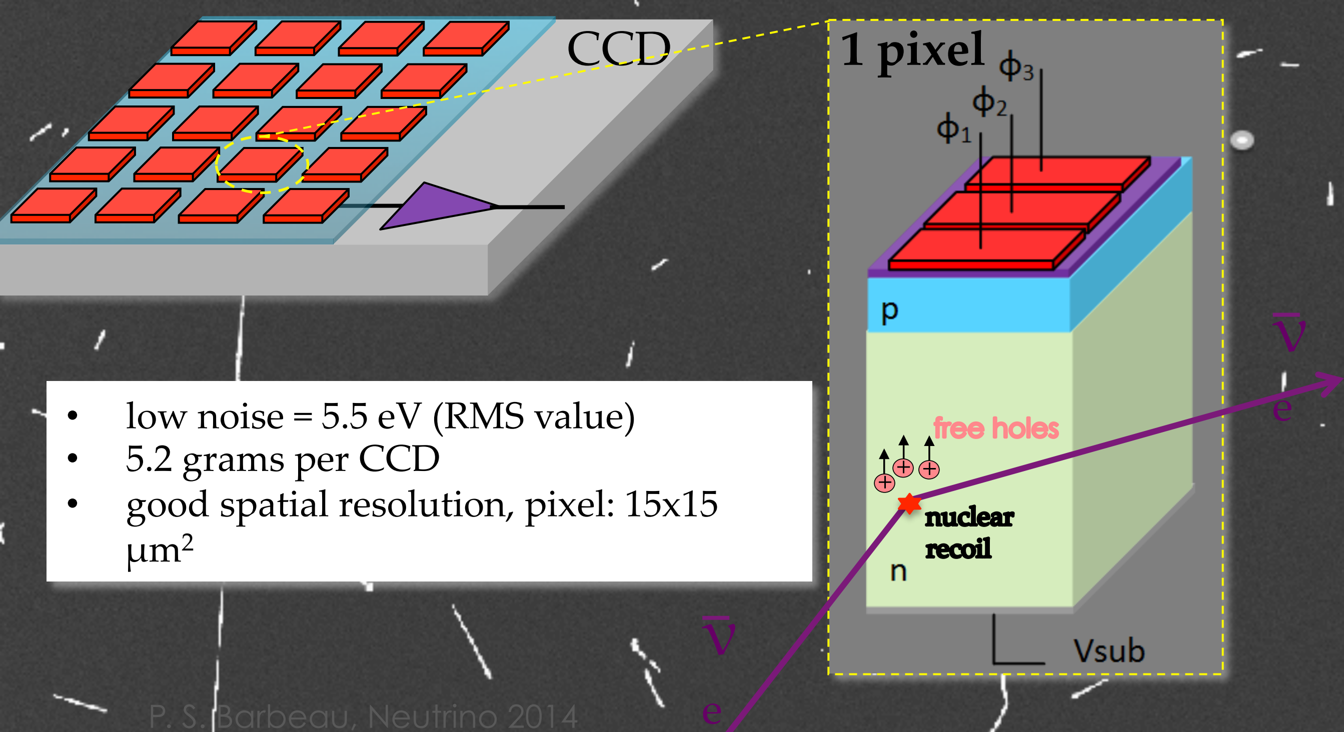
- Expect 4 events kg^{-1} $month^{-1}$ at a location 20m from the target of the SNS



CONNIE (Coherent Neutrino-Nucleus Interaction Experiment)

Fermilab · CONICET · CBPF Centro Brasileiro de Pesquisas Físicas · CIC · UFRJ

Detection of coherent neutrino-nucleus scattering interaction using CCD, at Angra nuclear reactor, Brazil.

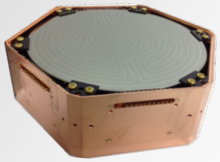


- low noise = 5.5 eV (RMS value)
- 5.2 grams per CCD
- good spatial resolution, pixel: 15x15 μm^2

P. S. Barbeau, Neutrino 2014

- Installation of 5.2 g CCD 30 m from 4 GW$_{th}$ Rx waiting until after the World Cup
- Energy interval for analysis: 28-300 eV
- Expected background: 600 keV^{-1} kg^{-1} d^{-1} (arXiv: 1405.5761)
- For 52 g of Si:

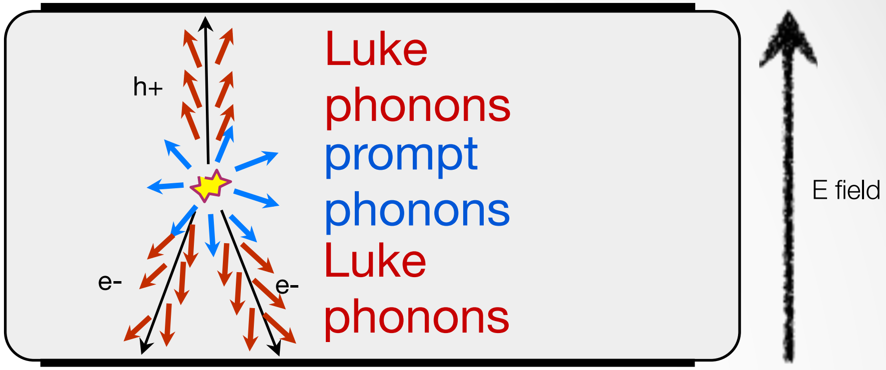
$E_{threshold}$	events/year
1σ (5.5eV)	532
5σ (28eV)	343



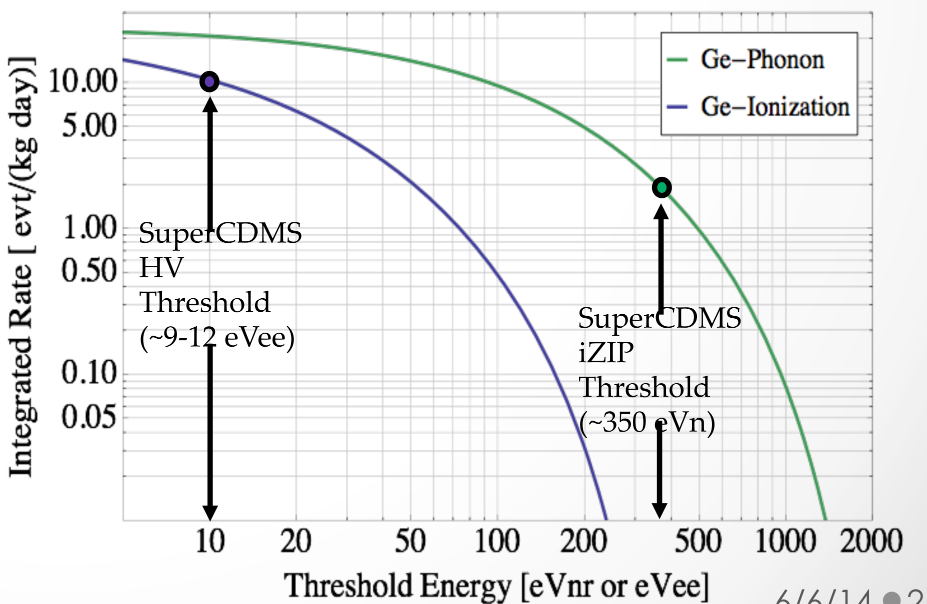
RICOCHET
A Coherent Neutrino Scattering Program

Leverage SuperCDMS R&D effort for neutrino physics

- iZIP detectors with two-sided phonon and charge readout will have excellent background rejection and a threshold ~350 eVnr
- High Voltage Operation: use the phonon signal to measure the charge
- Luke phonons come from the work done to move the charge through the crystal
- Recent lab devices showed stable operation with voltages of up to 400 V — single electron sensitivity may be possible!



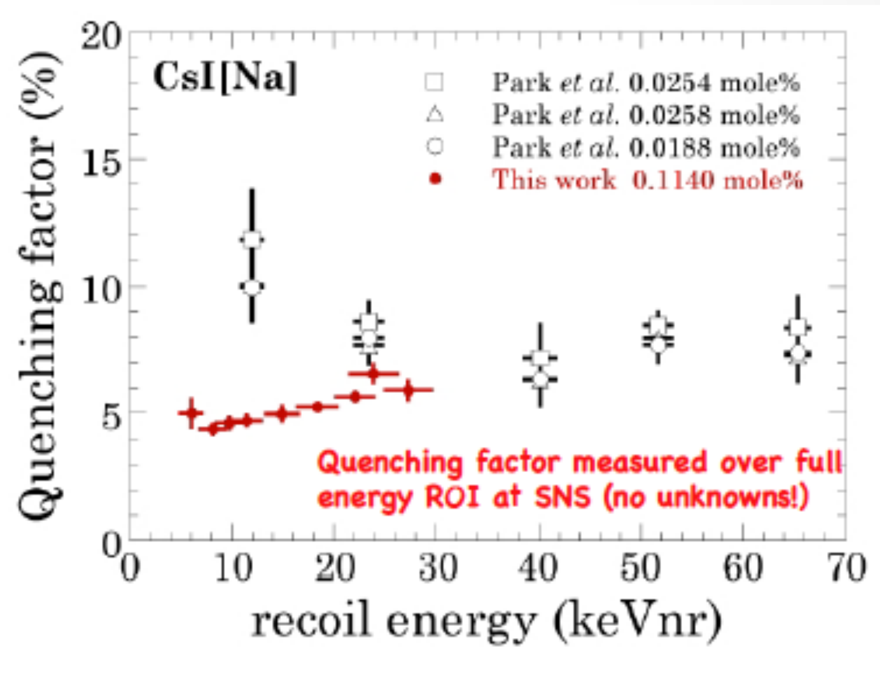
Rate at the Advanced Test Reactor
(110 MW reactor, 11 m from core)



CoSI

- Search for Coherent Scattering at a stopped pion beam with low-background CsI(Na) Scintillators

- ~800 recoils in 15 kg per year above threshold (5 keVnr) at the SNS (20 m)



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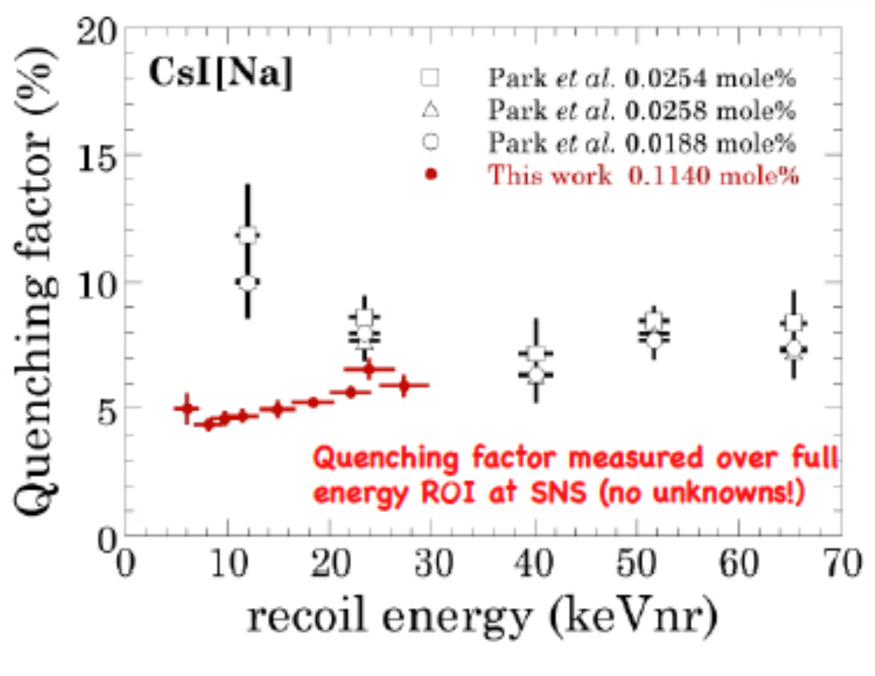
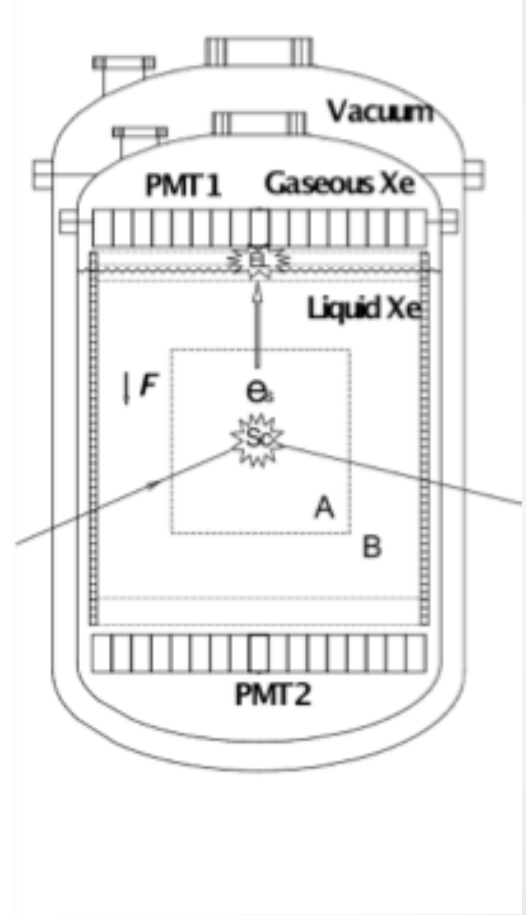


COHERENT

Two Phase Detectors

- The emission method of particle detection was invented at Moscow Engineering Physics Institute 40 years ago
- RED-100: Search for Coherent Scattering at a stopped pion beam (SNS) with a two-phase liquid xenon detector



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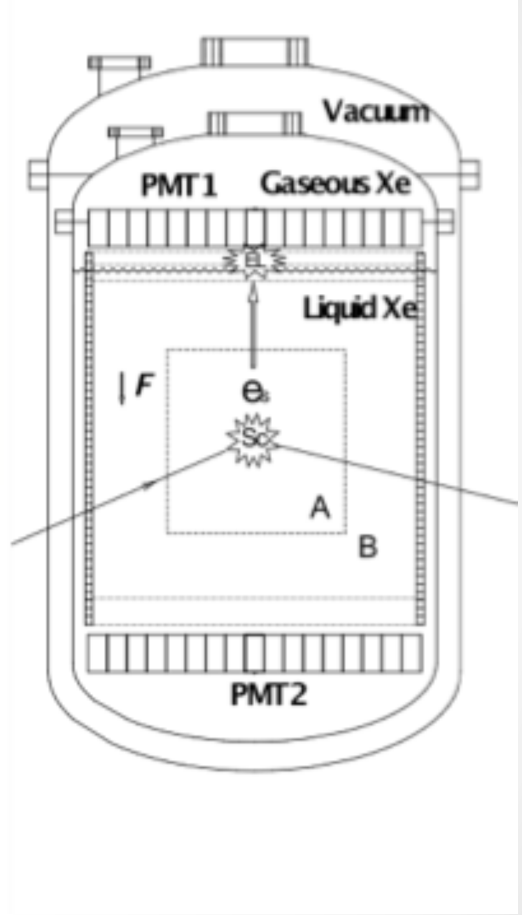
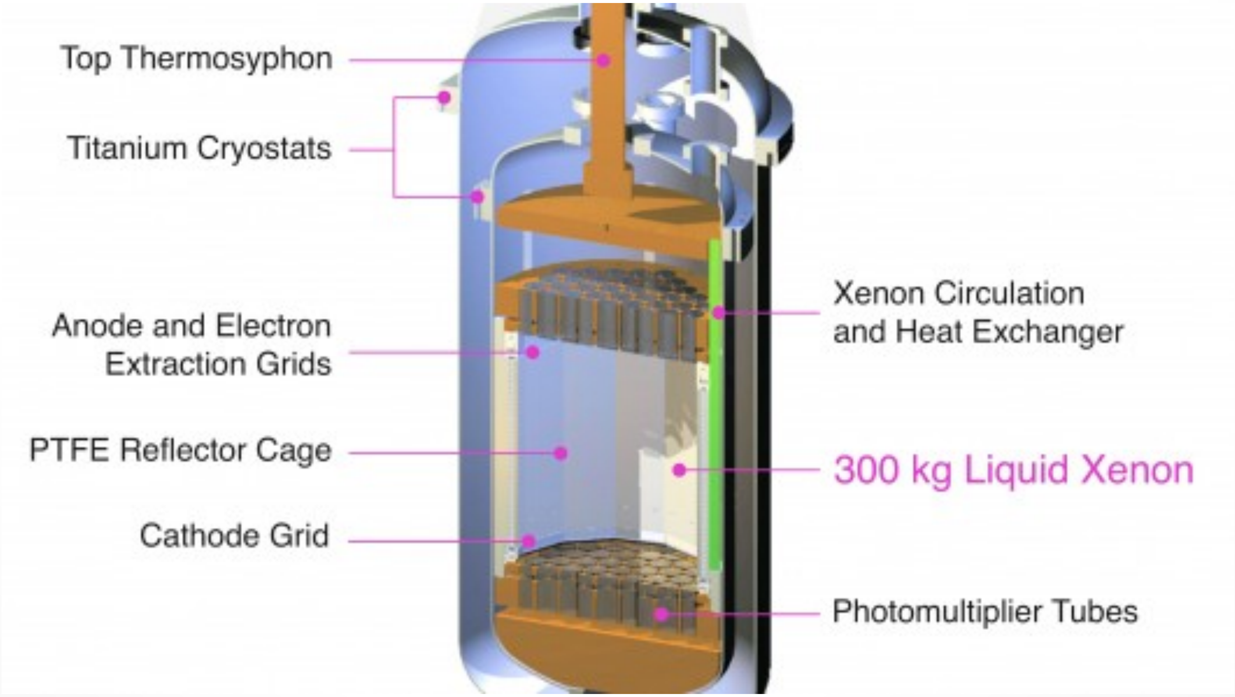


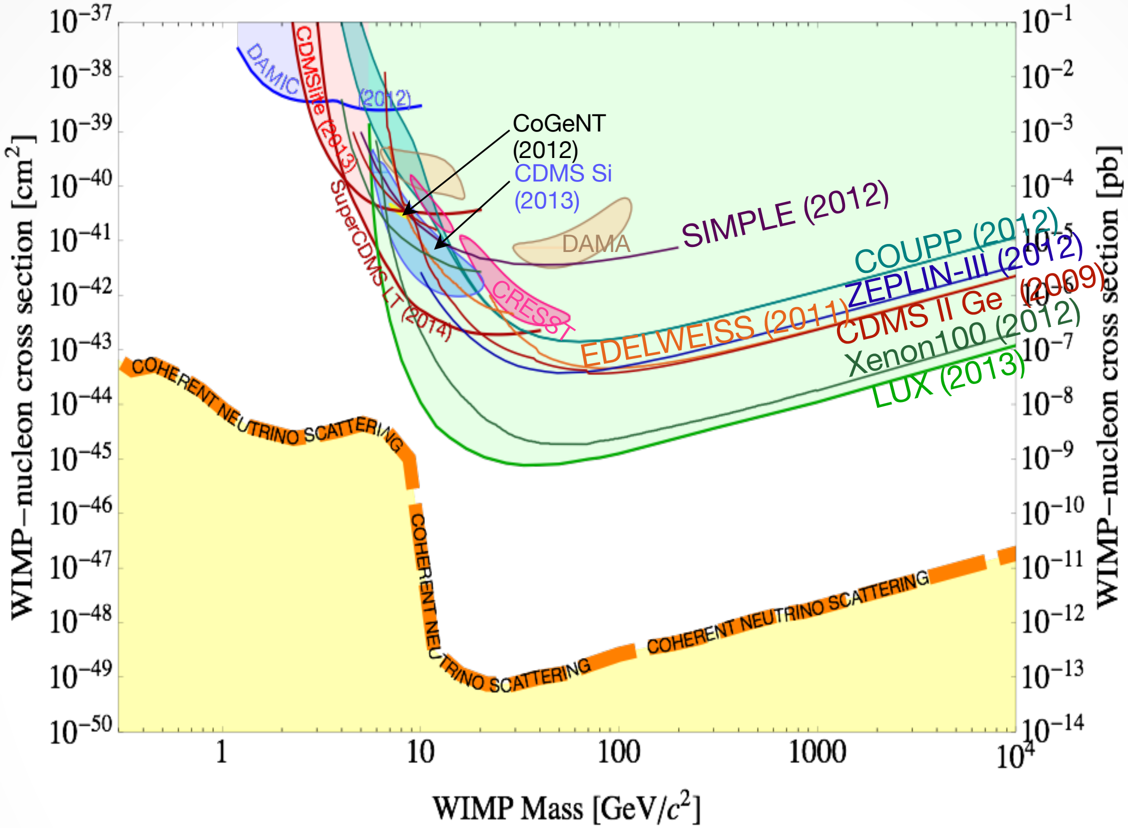
COHERENT

Two Phase Detectors

- Dark Matter experiments like the 2-phase liquid Xenon LUX experiment share the same technology as the RED detectors



Dark Matter Detectors



Direct detection Dark Matter experiments will eventually run into an irreducible background due to the coherent elastic scattering of solar, atmospheric and DSNB neutrinos.

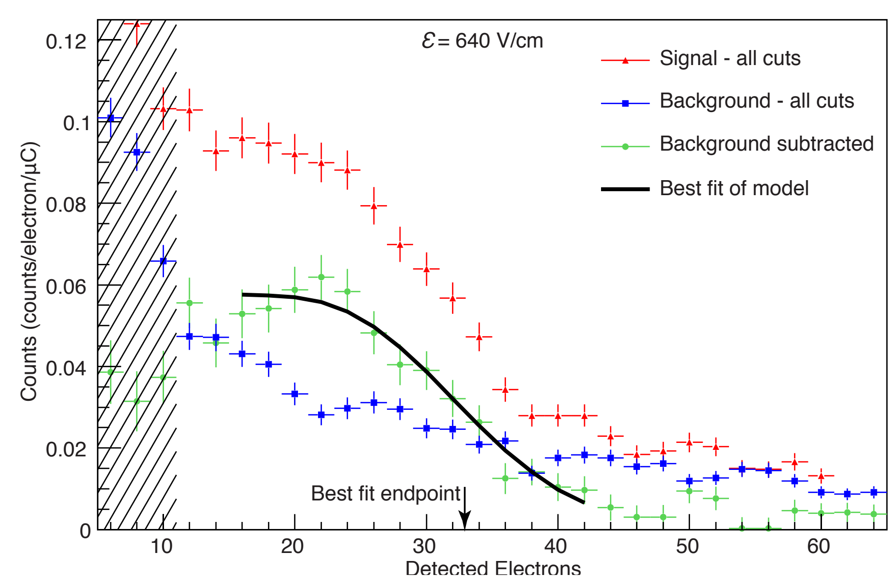
- LUX can expect to see anywhere from 0 to ~12 ^{8}B neutrinos in 300 days
- This has a fairly strong dependence on the actual nuclear recoil threshold

CEvNS in 2-phase LAr: efforts at LLNL

1. **Measure nuclear recoil quenching in LAr**
2. Demonstrate ultimate threshold of single ionization electron
3. Study backgrounds (radiation and detector-induced)

- Synergy with low-mass dark matter search in DarkSide

Measured 6.7 keV nuclear recoils at different E field. Upcoming: 2.4 keVr



T. Joshi, S. Sangiorgio, et al, PRL, 112 (2014)

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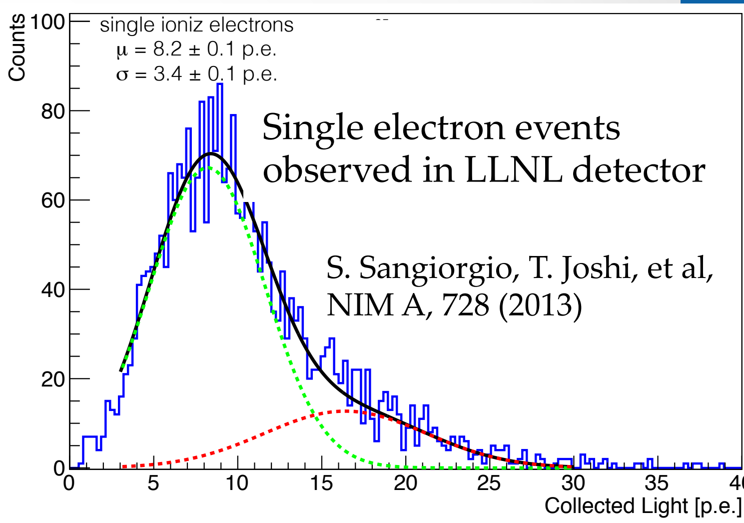

Single electron events observed in LLNL detector

S. Sangiorgio, T. Joshi, et al, NIM A, 728 (2013)

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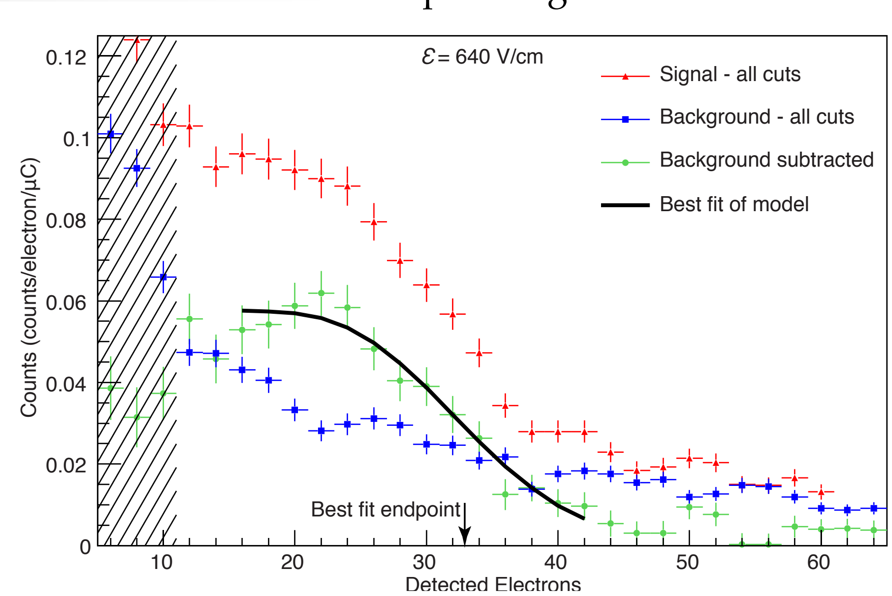

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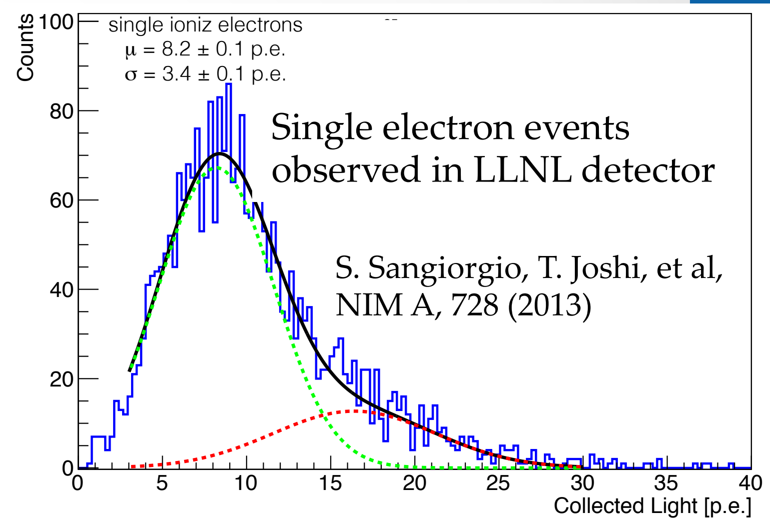

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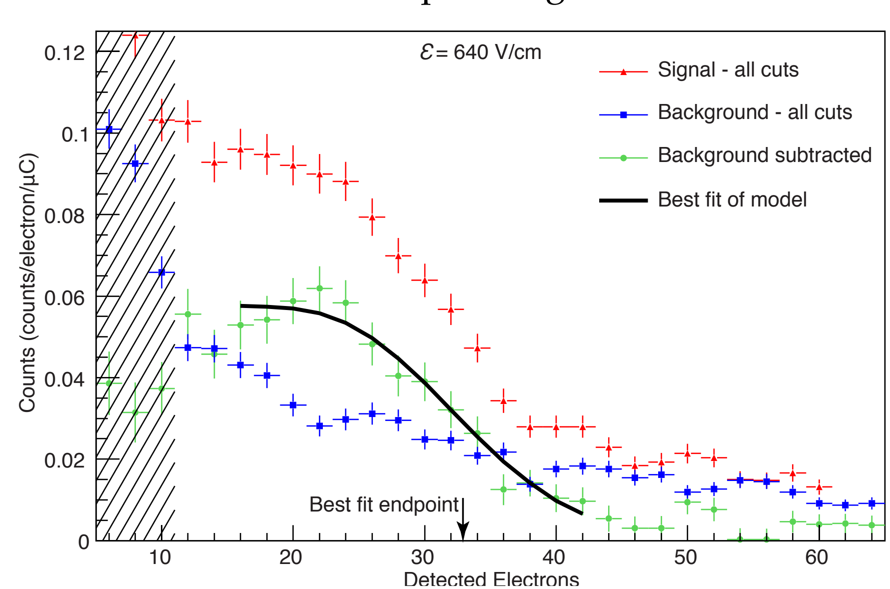
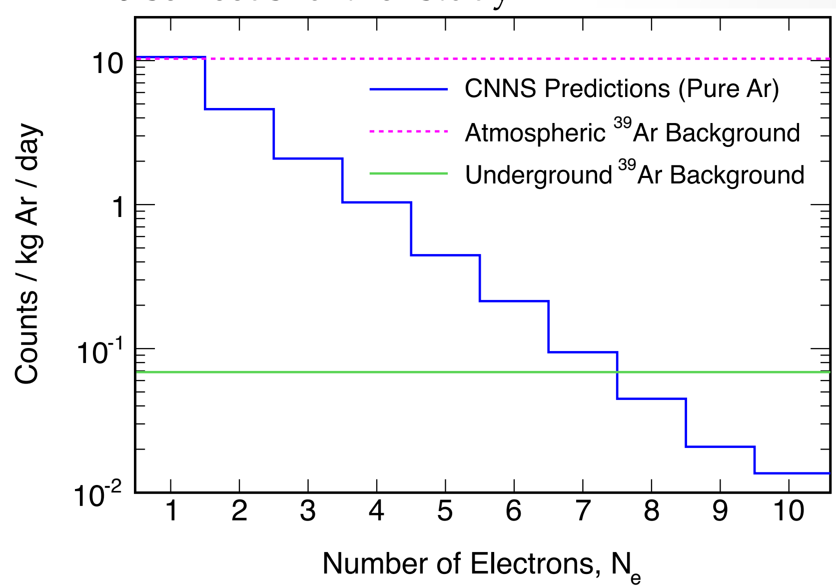


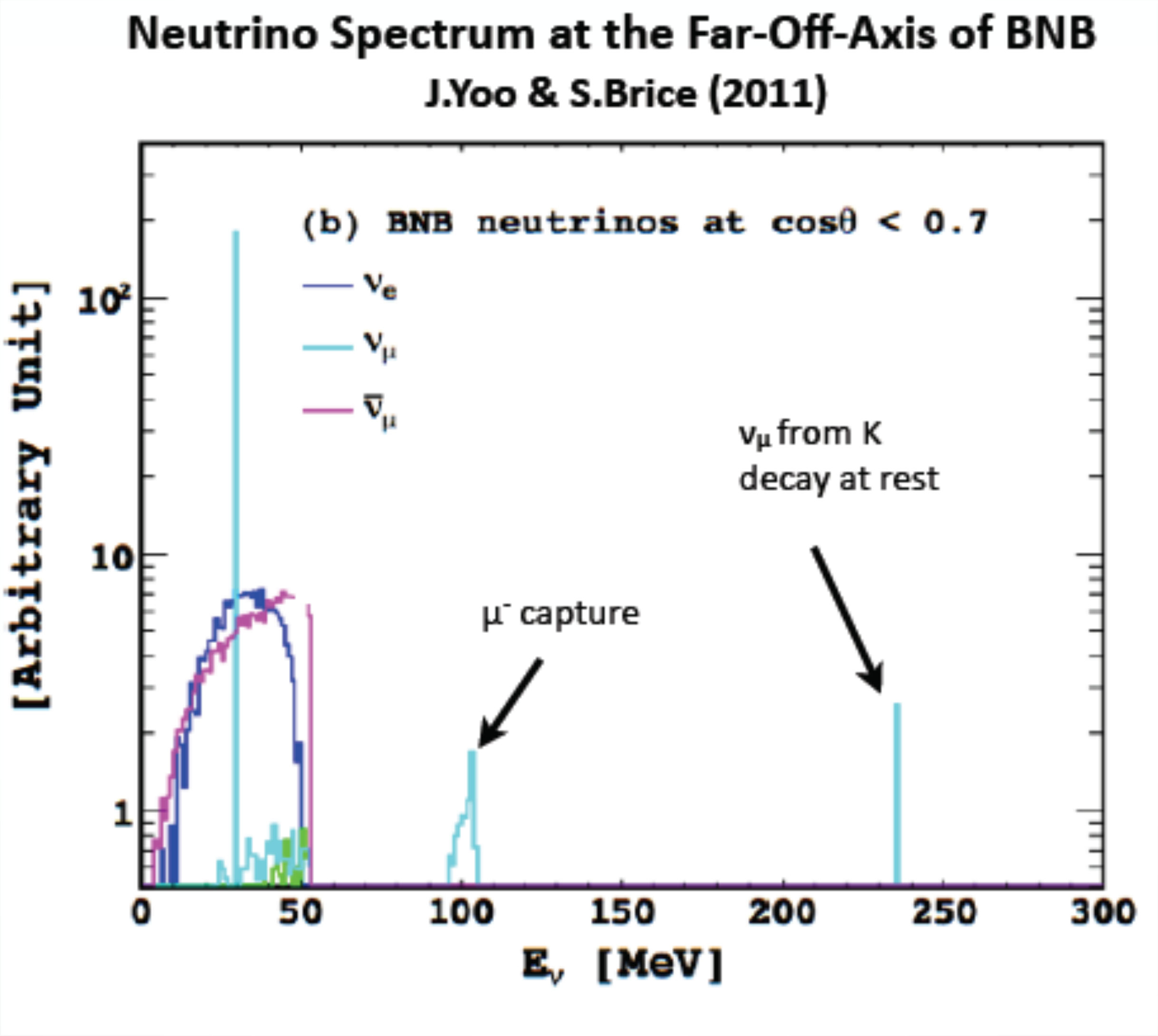
T. Joshi, S. Sangiorgio, et al, PRL, 112 (2014)

Underground Argon necessary. Few-electrons noise needs further study



Adapted from C. Hagmann, A. Bernstein, TNS, 51 (2004)

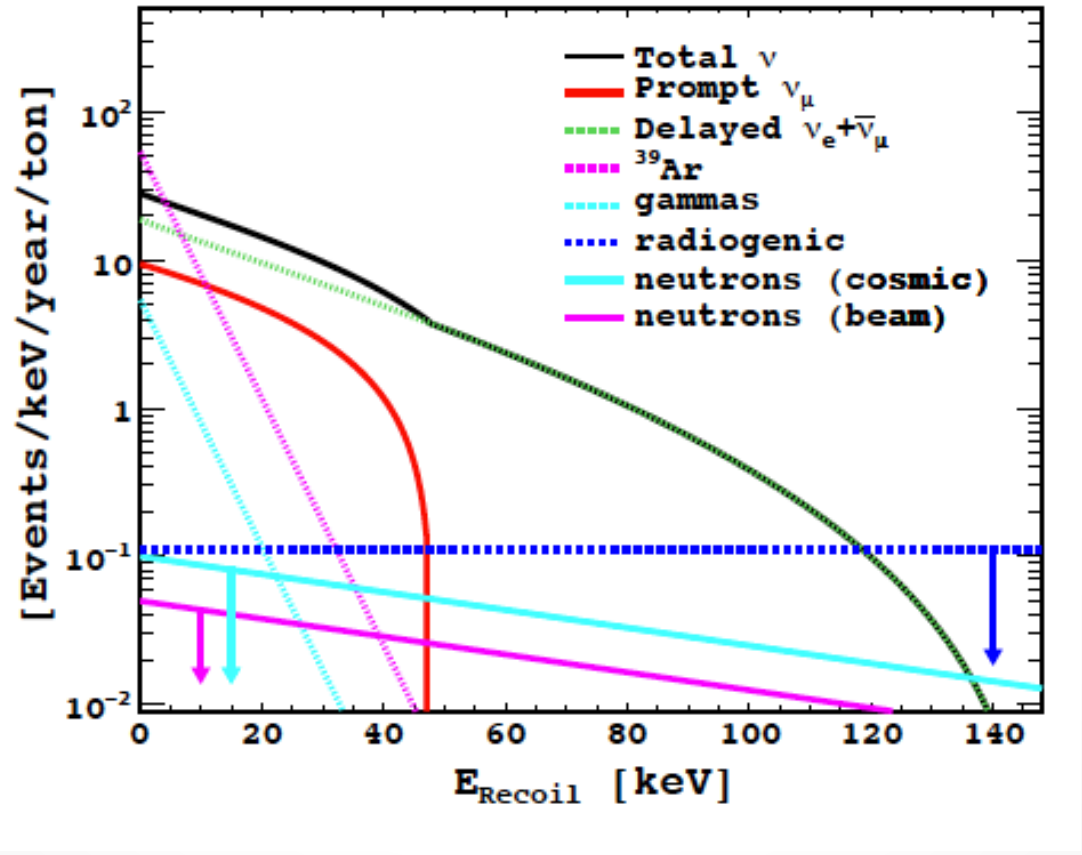
CEνNS@Fermilab



neutrino flux at 20 m ~ 10^6 cm^{-2} s^{-1}

CEνNS@Fermilab

- Plan to bring the MiniCLEAN detector to FNAL in 2017 after dark matter search mission is completed

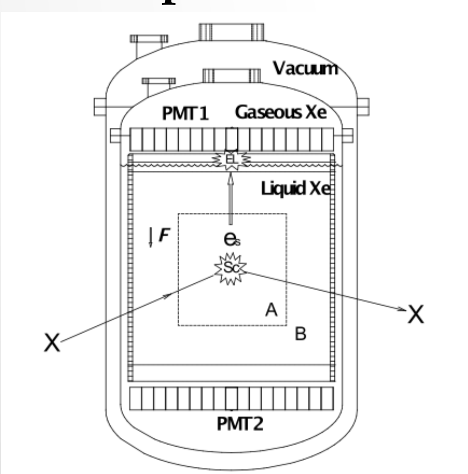


Prospects at the SNS: Free Neutrinos!

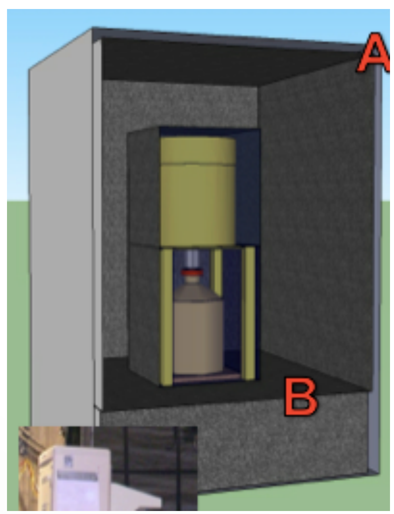
COHERENT

- A collaboration has recently formed (COHERENT) composed of a number of experts in nuclear & neutrino physics, as well as low-threshold detector development for a broad range of technologies.
- CosI, CoGeNT, RED, Majorana, ULGeN, among others
- LANL and LLNL exploring ways of contributing

Two-phase LXe



HPGe PPC



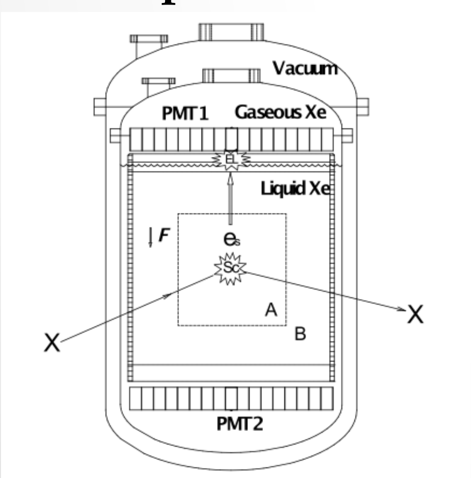
CsI

COHERENT

- The collaboration's goal is to measure Coherent Scattering with Multiple targets in order to address the interesting physics questions.

- Three technologies being planned for a first-phase deployment

Two-phase LXe



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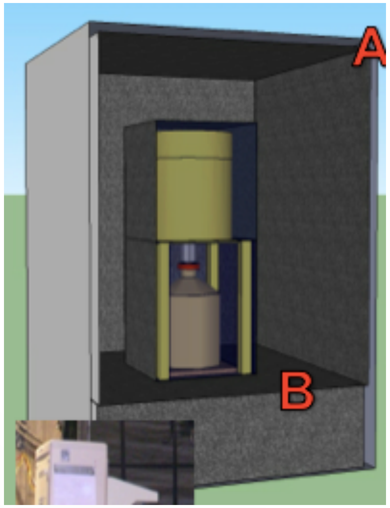


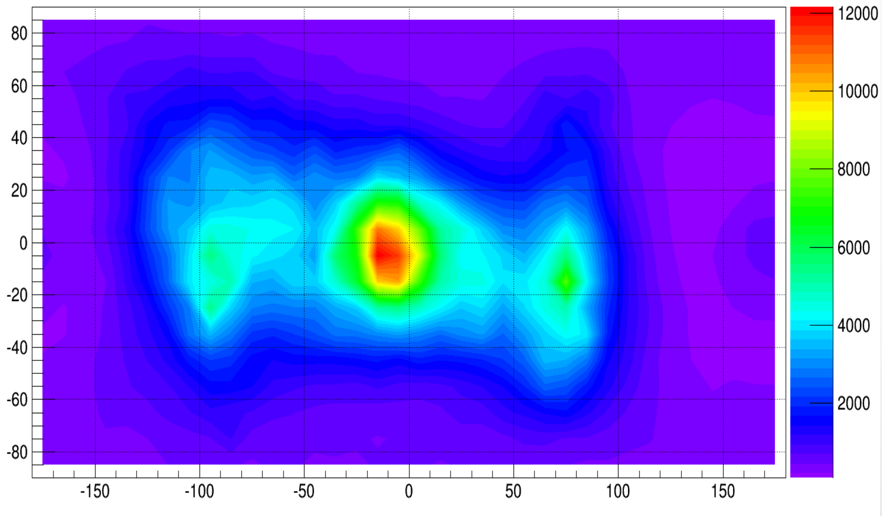
CsI

COHERENT

- Neutron backgrounds and overburden are being characterized at the SNS in order to determine optimal siting locations for experiment (with some promising recent results)

- Characterizations include a number of ORNL and Sandia detectors

Sandia Neutron Scatter Camera Image

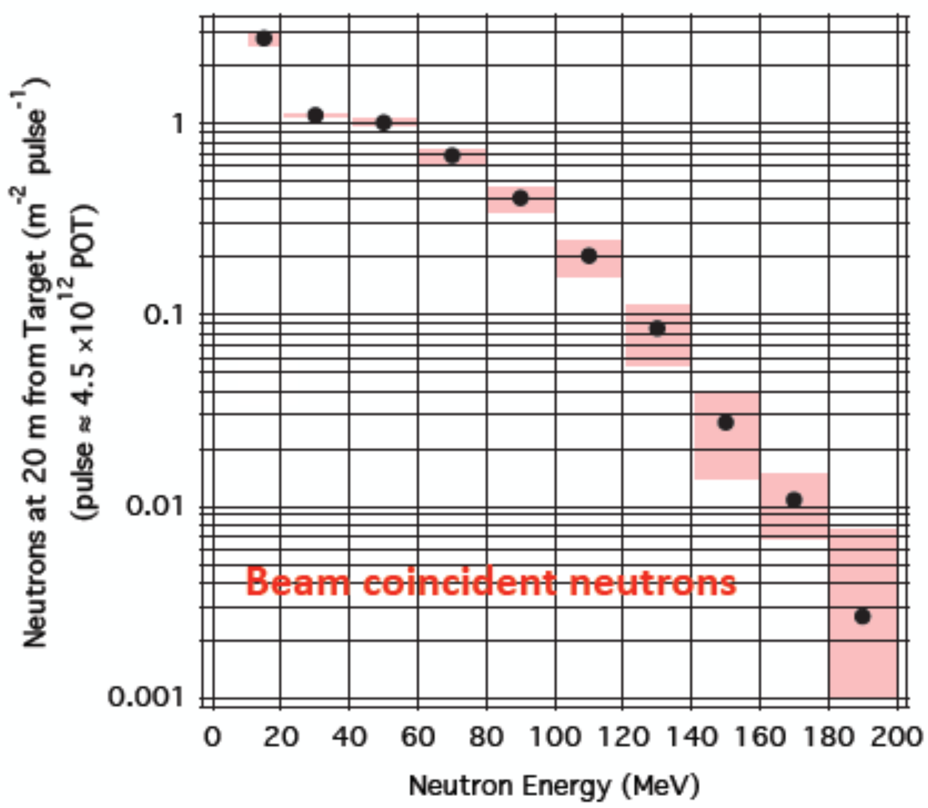


Coherent Neutrino Scattering

40 years in and closer than you might think

CEvNS@Fermilab

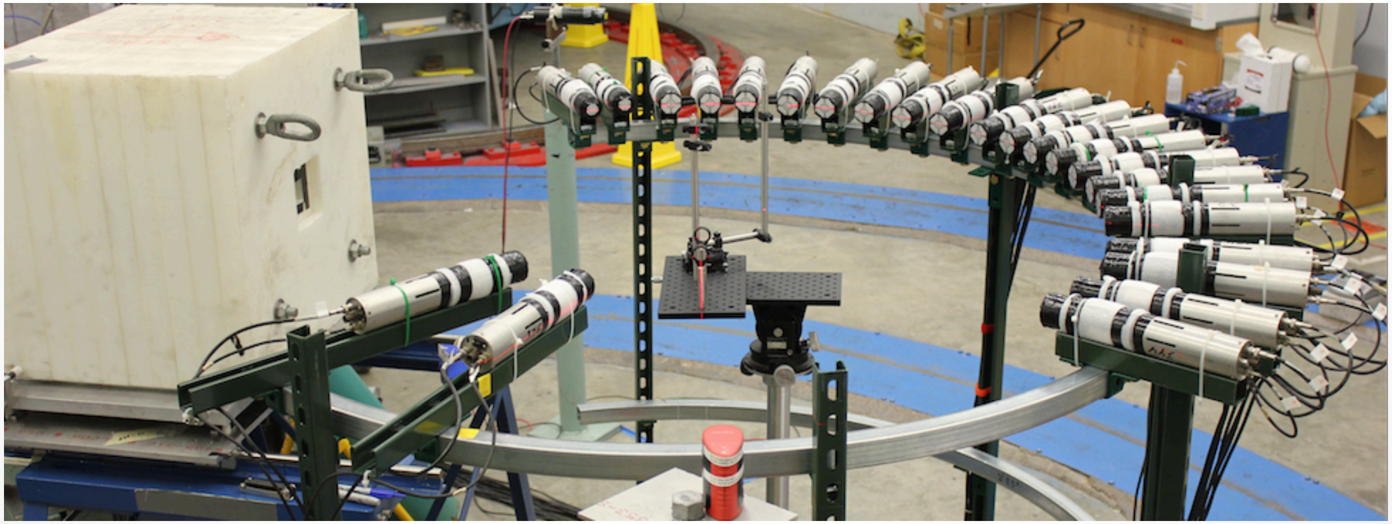
- The collaboration measured of the beam related neutron backgrounds using SciBath Detector (R. Tayloe & R. Cooper)



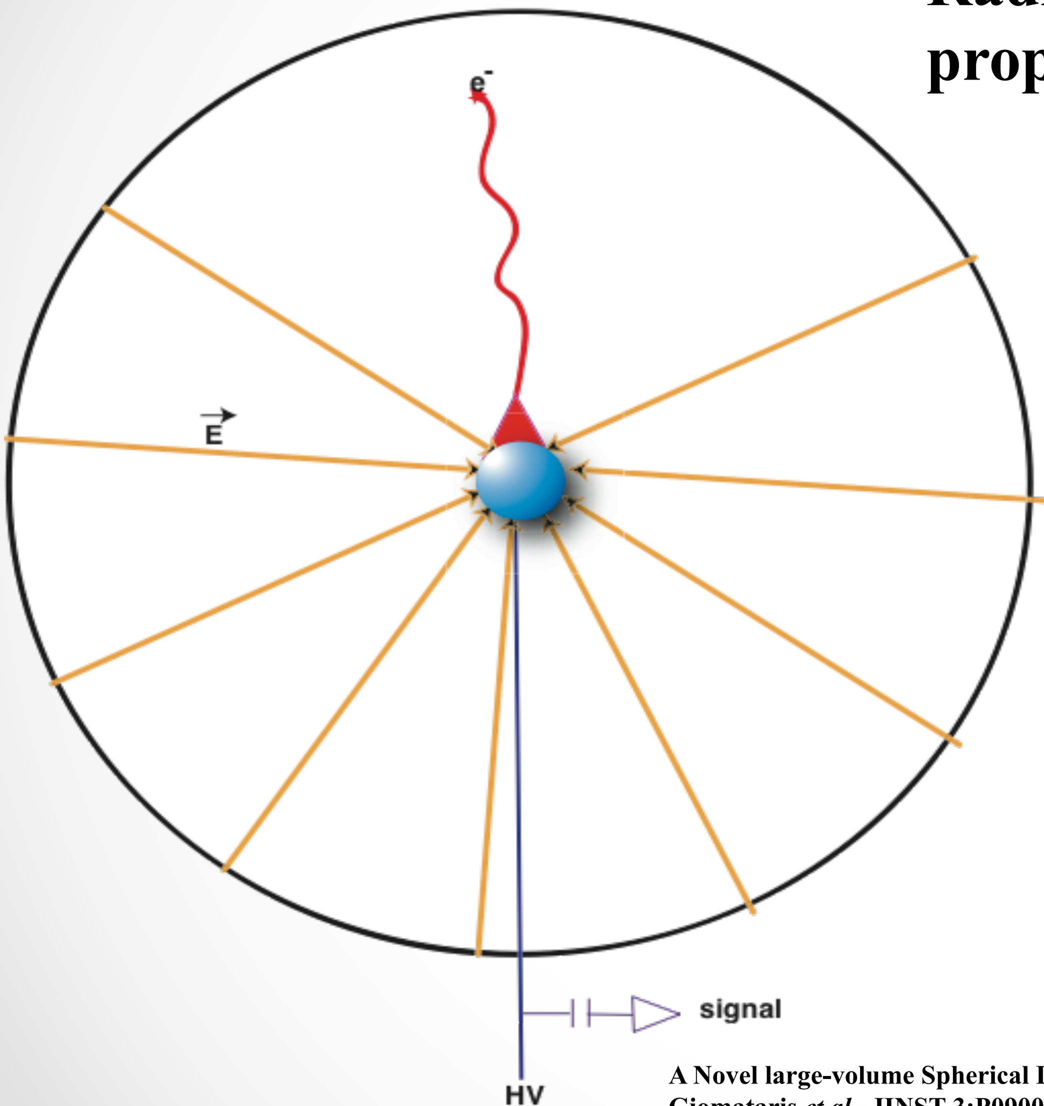
Phys.Rev.D89 072004 (2014);
arXiv:1311.5958

Low Energy Recoil Calibrations

- A Facility has been developed at Duke/TUNL to enable the precision calibration of all of these detectors at these previously unobserved *nuclear recoil* energies
- Neutron beam is Tunable (20 keV – 1 MeV), monochromatic (3 keV width), collimated (1.5 cm) and pulsed (2ns)



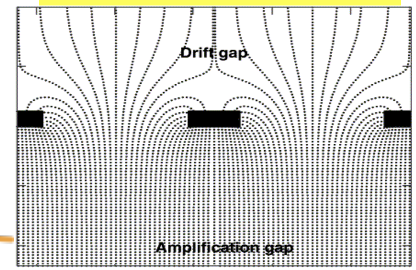
Spherical Gas Detector



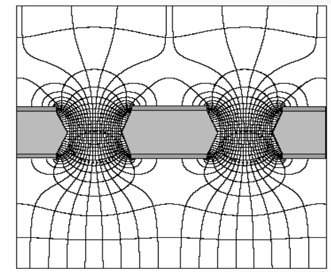
Radial TPC with spherical proportional counter read-out

Saclay-Thessaloniki-Saragoza

Micromegas



GEM



New detector made out of radiopure Cu vessel

- **Diameter = 60 cm**
- **Pressure = up to 10 bar**
- **Ar & Xe gas targets**

A Novel large-volume Spherical Detector with Proportional Amplification read-out, I. Giomataris *et al.*, JINST 3:P09007,2008

Spherical Gas Detector

Radial TPC with spherical proportional counter read-out

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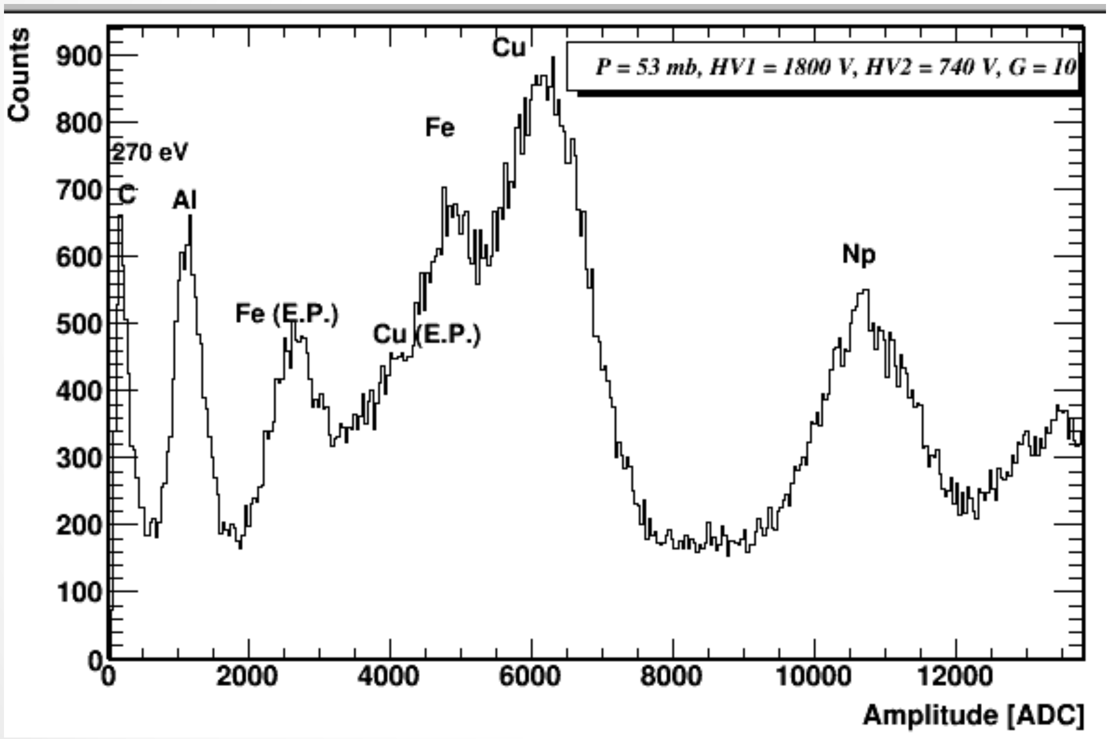

Ultra-Low energy calibration performed at 270 eV

Single electrons observed

A Novel large-volume Spherical Detector with Proportional Amplification read-out, I. Giomataris *et al.*, JINST 3:P09007,2008