Neutrino physics and dark matter searches at SNOLAB

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SNOLAB

23rd Rencontres de Blois
Blois, France
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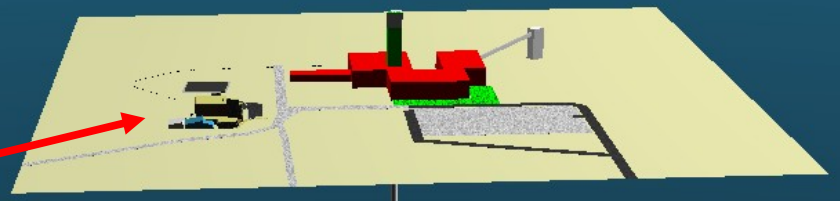
- The SNOLAB facility
- Neutrino programme:

  SNO+ and HALO
- Dark matter programme:

  COUPP, Picasso and DEAP/CLEAN



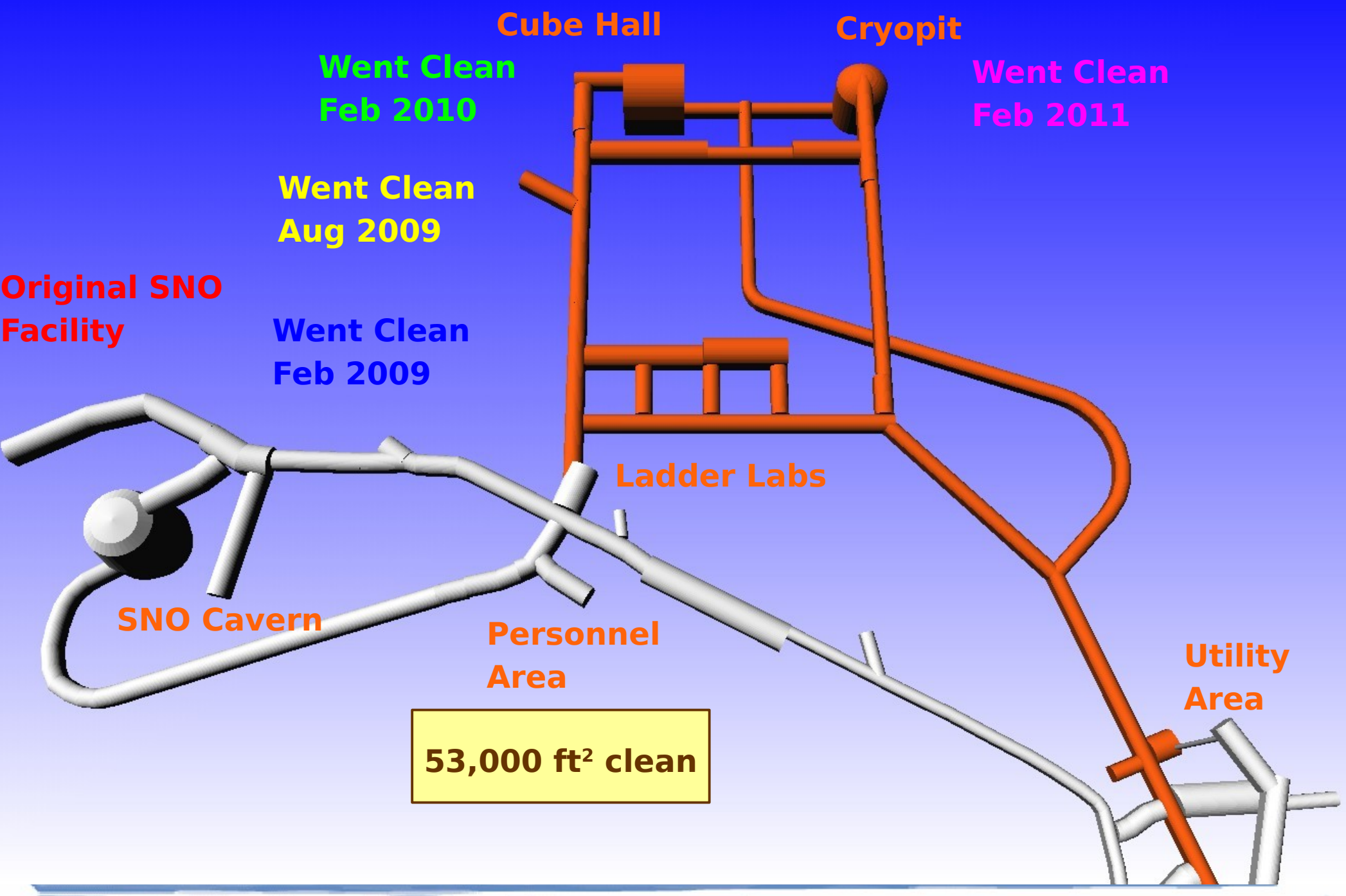
Surface
Facility

2km
overburden
(6000mwe)

Underground
Laboratory

Surface Facilities

SNOLAB facility



Facility Status

- **Experiment installation:**
  - **HALO**
  - **Picasso**
  - **COUPP**

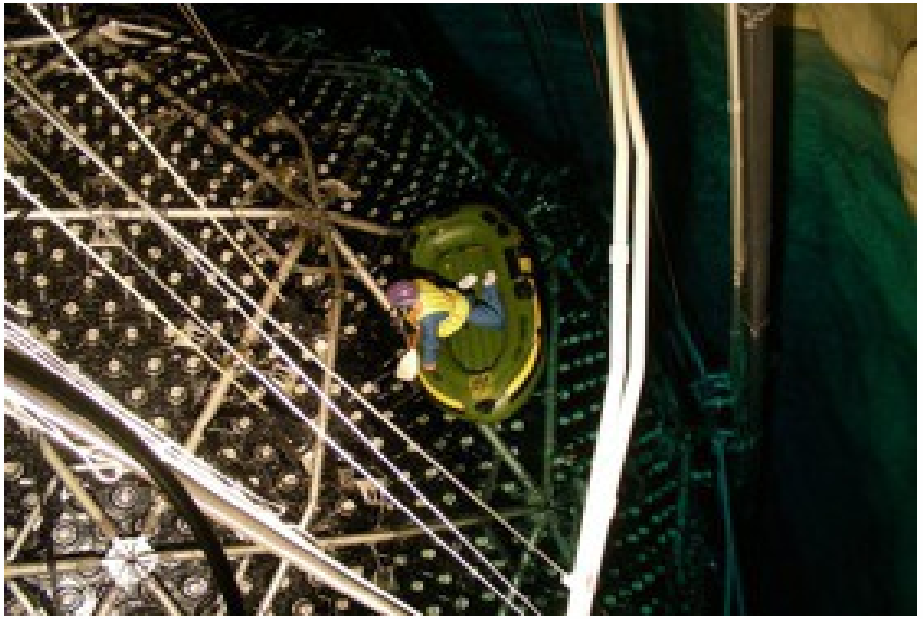

Running:
COUPP-4kg
Deploying:DEAP-3600
MiniCLEAN
Deploying:
HALO
Cryopit
Stub
Utility
Drift
Unallocated
Space
2012: COUPP
60kg
Running: DEAP-1
2012:
SuperCDMS
SNO
Cavern
South
Drift
Running:
PICASSO-III
Deploying: SNO+
Personnel
facilities
Utility
Area

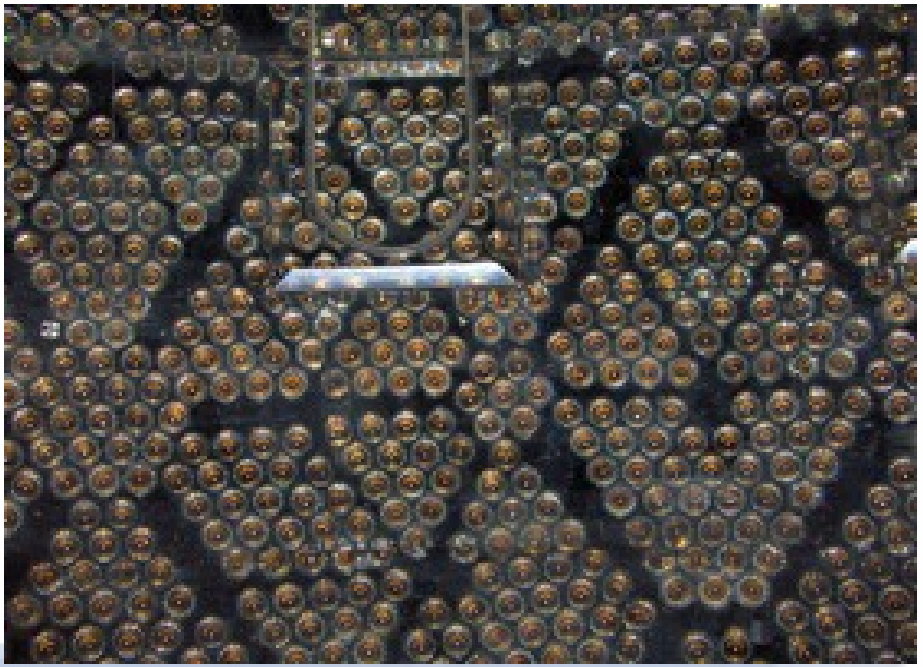
SNO+

Neutrino experiment with liquid scintillator:

-Solar neutrinos, reactor and geo neutrinos
- Supernova neutrinos

-Double beta decay by adding Neodymium





From SNO to SNO+

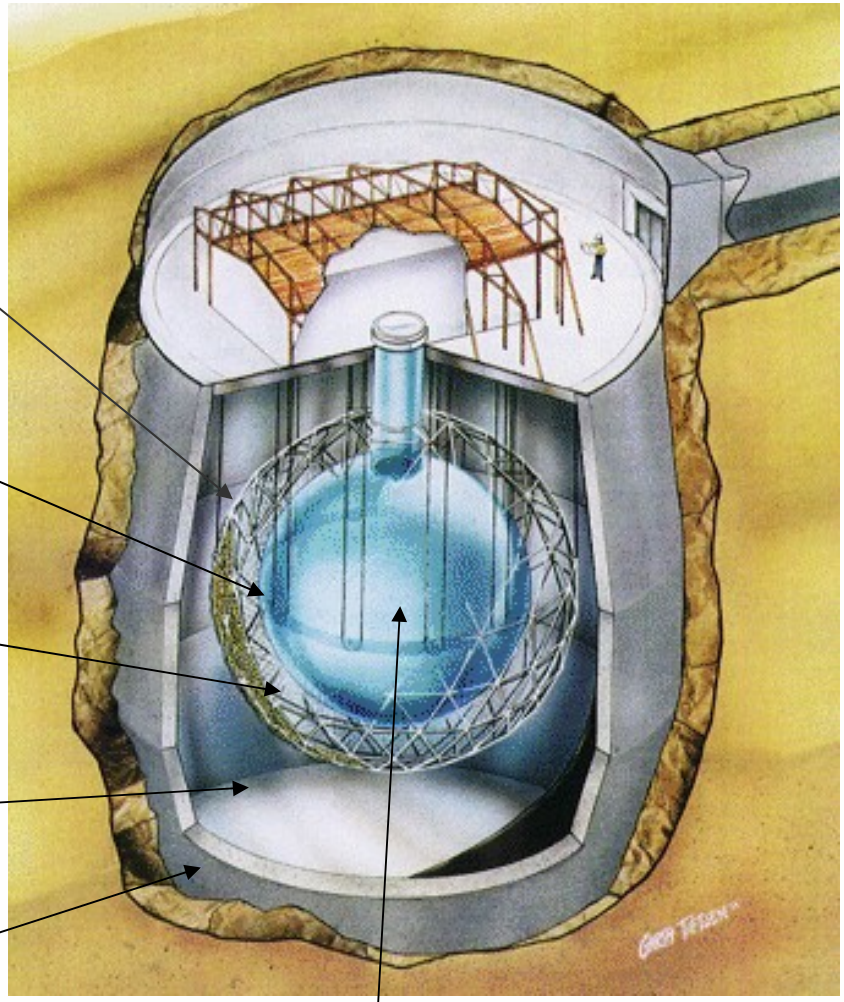
Support Structure for 9500 PMTs, 60% coverage

12 m Diameter Acrylic Vessel

1700 tonnes Inner Shielding H_2O

5300 tonnes Outer Shield H_2O

Urylon Liner and Radon Seal



Replace Heavy water with 1000 tonnes Liquid Scintillator

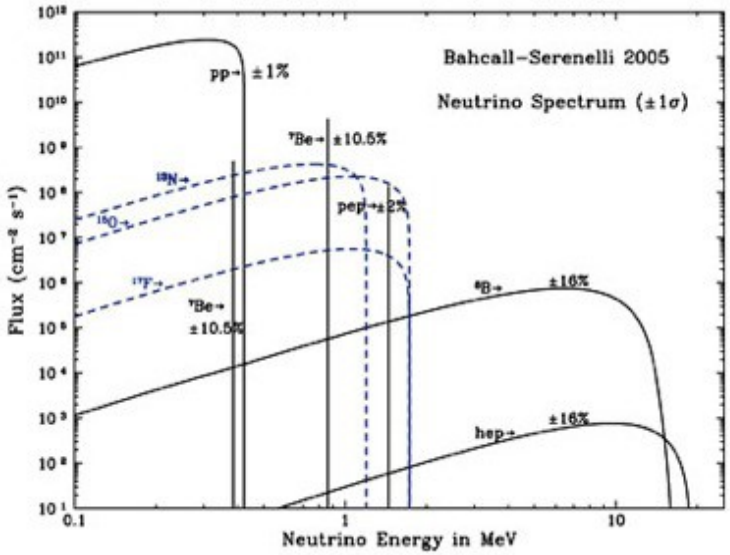
Solar neutrinos

^{8}B solar ν well studied by SNO and Super-K

there are good data for pp solar ν's from the Ga experiments

- must determine contribution of ^{8}B and ^{7}Be, subtract, and you get pp from the Ga experiments

Borexino has measured the ^{7}Be flux



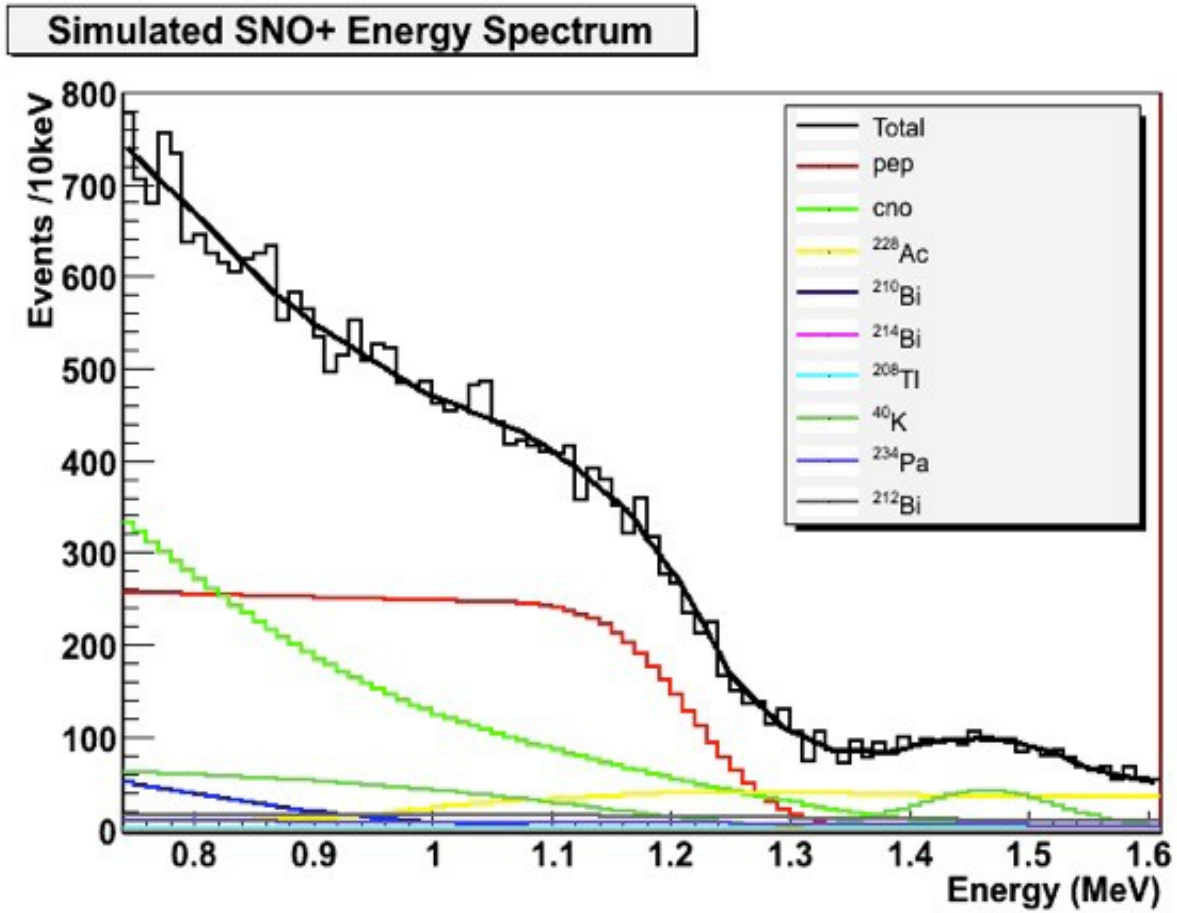
SNO+ aims to detect pep and CNO solar neutrinos

Neutrino matter interaction: exploring the vacuum-matter transition is sensitive to new physics

Solar neutrinos

an accurate measurement of the rate of pep solar neutrino interactions:
$R = \Phi\ Pee\ \sigma$
flux is calculated in SSM to ±1.5%; cross section is known (ν-e scattering)
➔ yields an accurate measure of the survival probability

CNO measurement uncertainty: ±7% statistical
after 3 years



3600 pep events/(kton·year), for electron recoils >0.8 MeV
±5% total uncertainty after 3 years (including systematic)

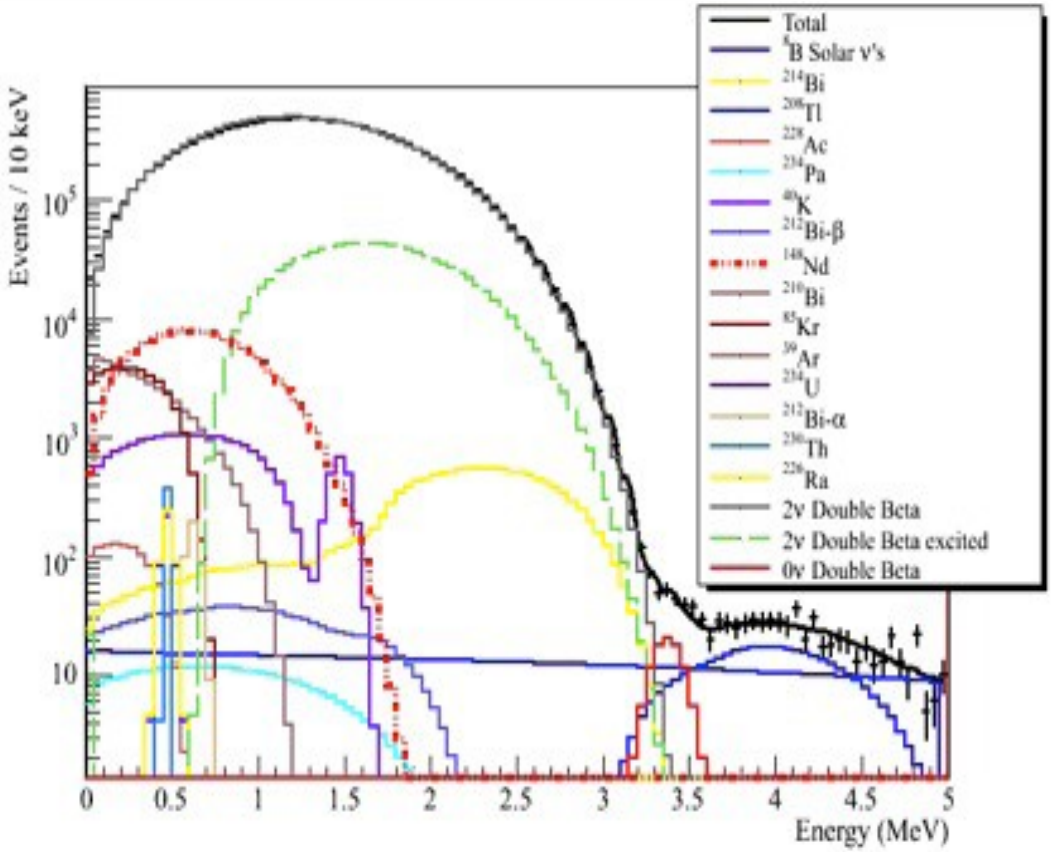
Double beta decay with Nd

SNO+ will have 0.1% (by weight) Nd-loaded liquid scintillator for a total deployed mass of 780 kg natural Nd

- 44 kg of 150Nd isotope
(150Nd has the second highest double beta endpoint at 3.37 MeV and the highest phase space factor)

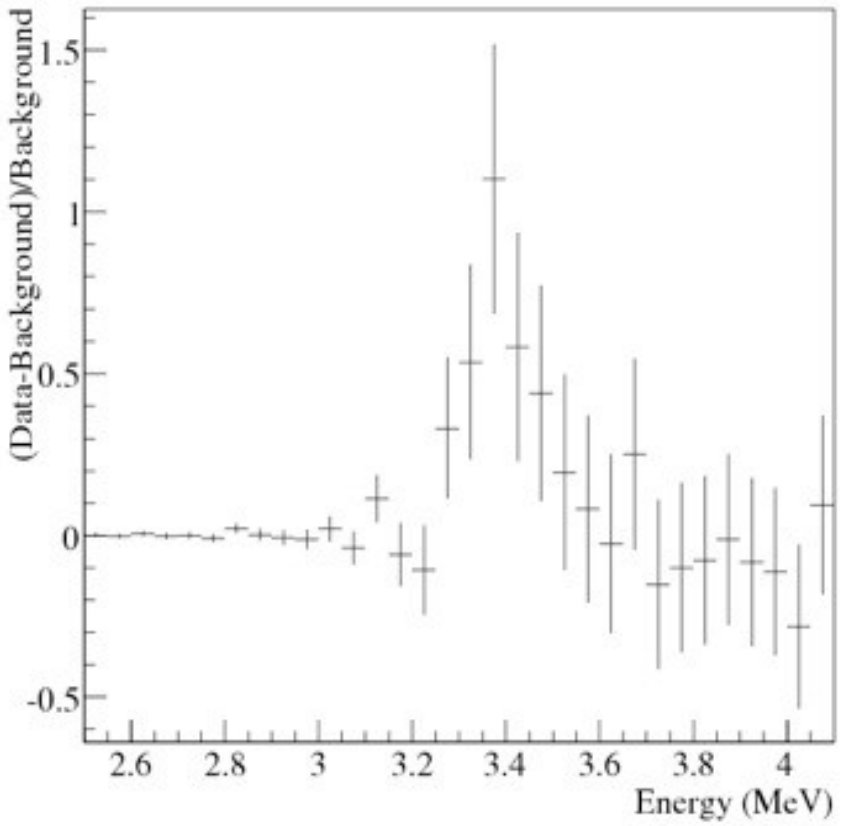
Recent NME calculations attempt to include the effect of deformation of 150Nd-150Sm nuclei
e.g. Interacting Boson Model (IBM-2) of Barea and Iachello naturally handles “the effects of deformation up to quadrupole deformation (d bosons)”

SNO+ 0νββ simulations



Simulation of signals and backgrounds for one year data

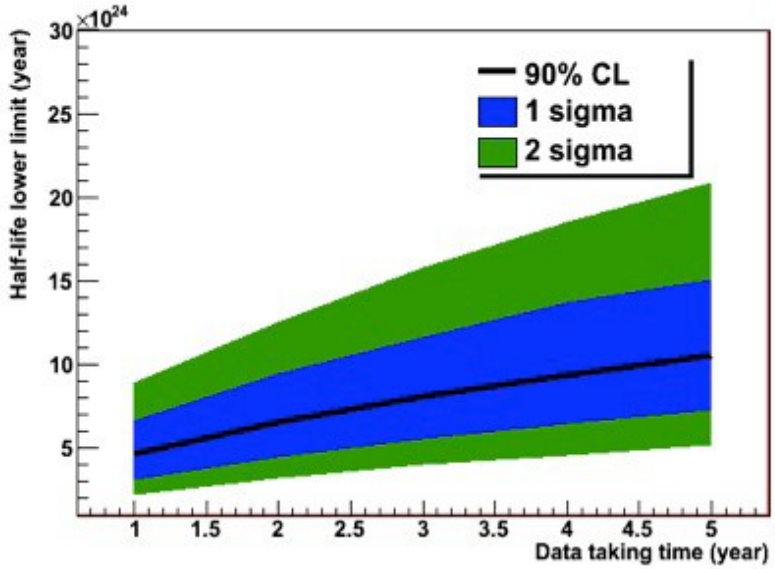
residual to fit with <mν>=0.27 eV

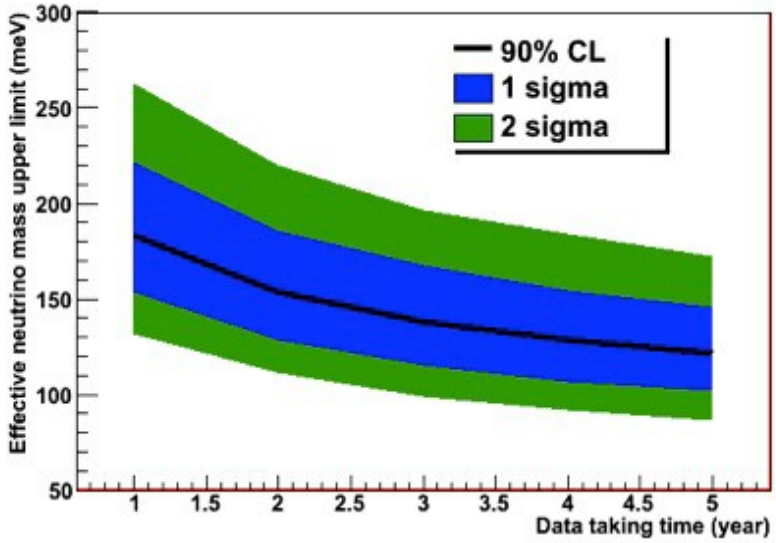


SNO+ 0νββ double beta sensitivity

shown (right) is the 90% CL lower limit on the half-life as expected sensitivity and the coloured bands show the "frequentist" interval in which the limit is expected to fall

- Modified Frequentist CLs method





and the corresponding Majorana effective neutrino mass upper limits expected sensitivity and frequentist interval utilizing IBM-2 NME

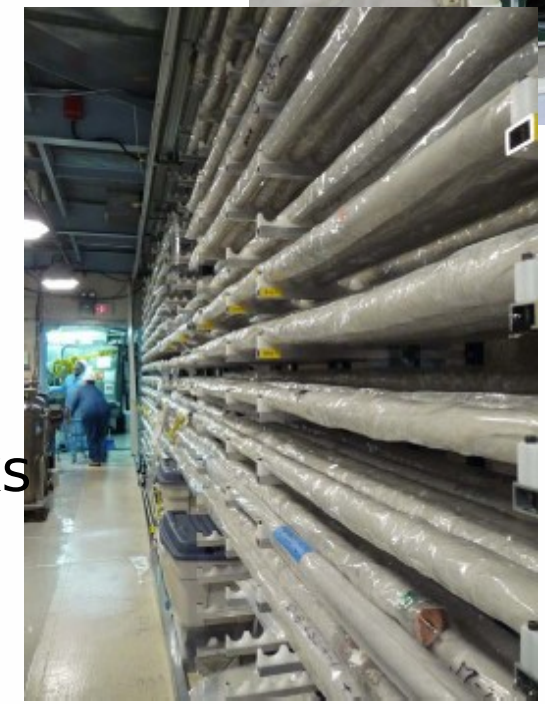
HALO

Lead Array:

-32 three meter long columns of annular Lead blocks
-76 tonnes total lead mass (864 blocks)

Neutron detectors:

-Four 3 meter 3He detectors per column
-384 meters total length



Moderator:

-HDPE tubing

Reflector:

-15 cm thick graphite blocks

Shielding:

-30 cm of water

Helium And Lead Observatory

SN neutrino signal in HALO

In 76 tonnes of lead for a SN @ 10kpc,

65 neutrons through ν_e charged current channels

-29 single neutrons

-18 double neutrons (36 total)

20 neutrons through ν_x neutral current channels

-8 single neutrons

-6 double neutrons (12 total)

~ 85 neutrons liberated;

i.e. ~1.1 n/tonne of Pb

CC:

$$\nu_e + {}^{208}\mathrm{Pb} \rightarrow {}^{207}\mathrm{Bi} + n + e^-$$

$$\nu_e + {}^{208}\mathrm{Pb} \rightarrow {}^{206}\mathrm{Bi} + 2n + e^-$$

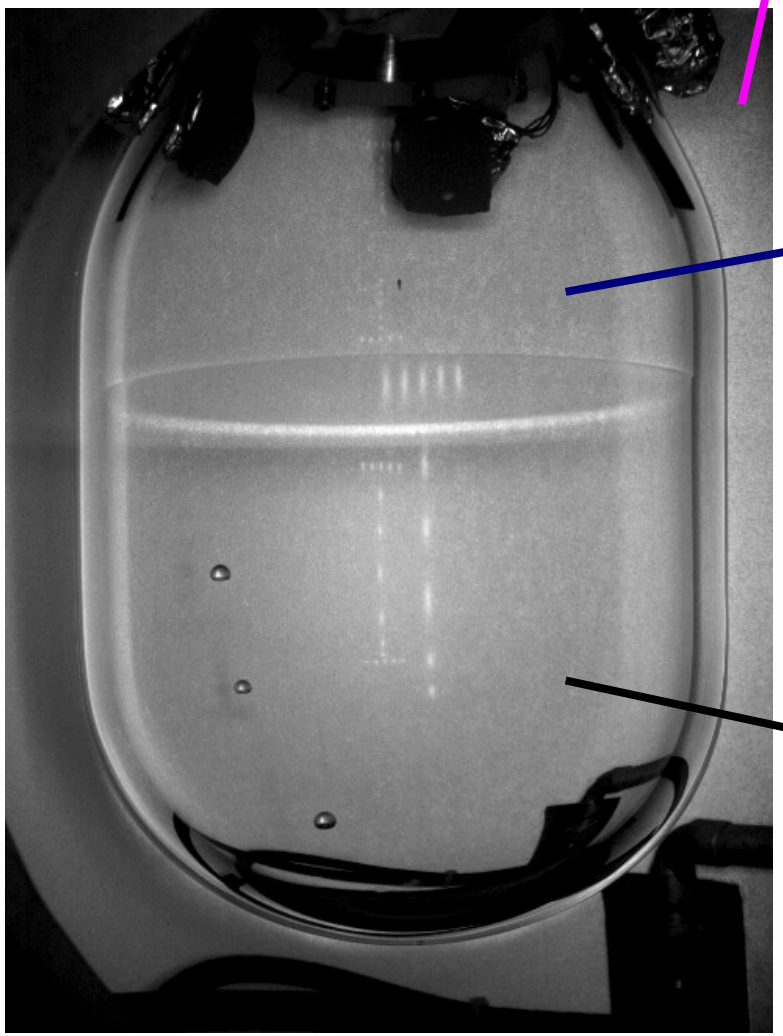
NC:

$$\nu_x + {}^{208}\mathrm{Pb} \rightarrow {}^{207}\mathrm{Pb} + n$$

$$\nu_x + {}^{208}\mathrm{Pb} \rightarrow {}^{206}\mathrm{Pb} + 2n$$

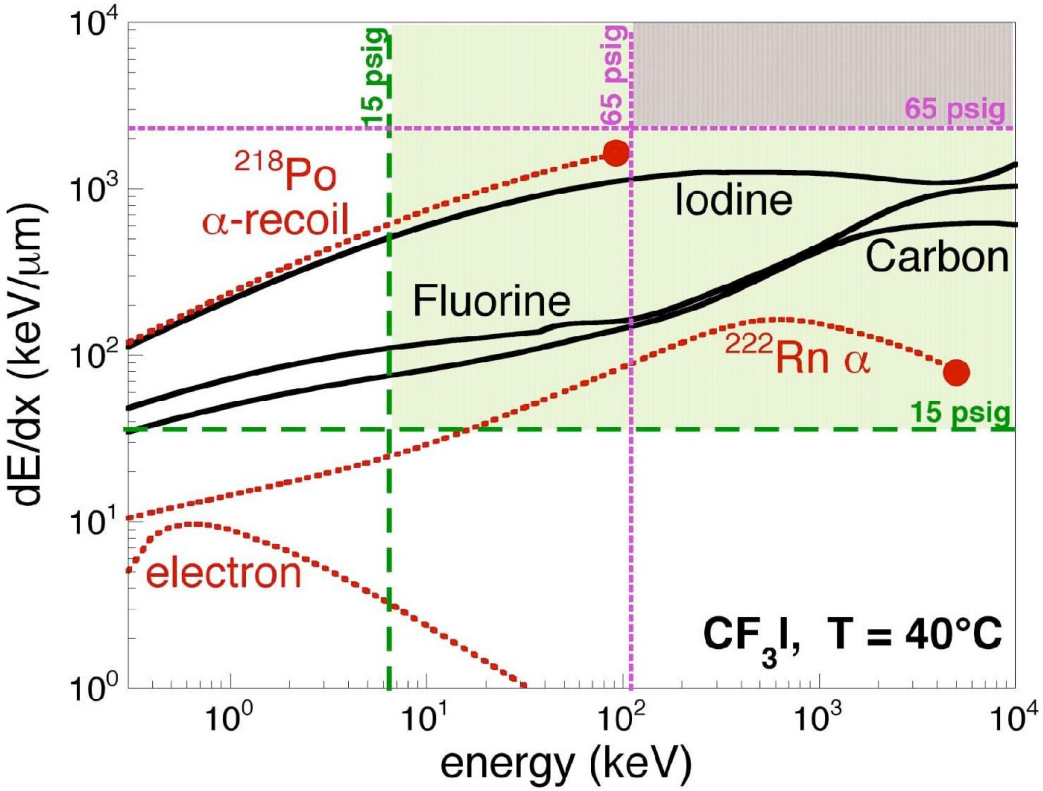
COUPP-4kg

- Superheated CF_3I target (Spin-dep: CF_3; Spin-indep: I)
- Particle interactions nucleate bubbles
- Cameras capture bubbles
- Chamber recompresses after each event



COUPP-4kg

- Only proto-bubbles with $r > r_{crit}$ grow to be macroscopic
- Critical proto-bubble requires minimum dE within minimum volume
- Recoil must be over thresholds in both E and dE/dx

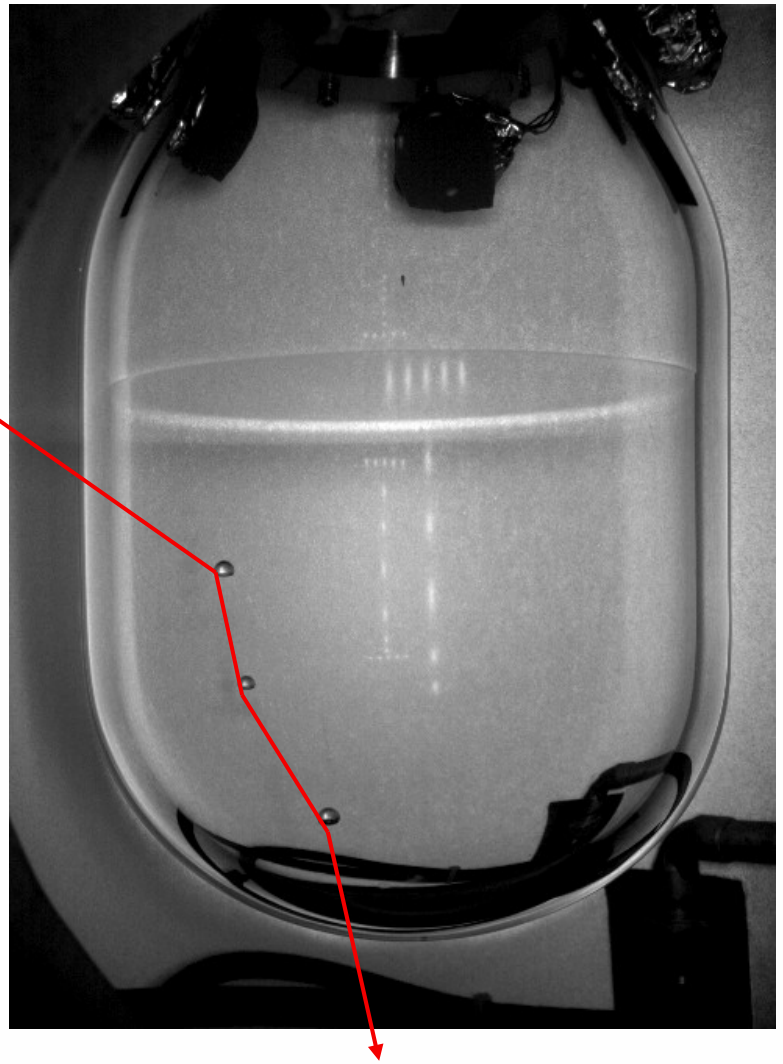


No sensitivity to γ's or β's,

but α's do make bubbles

COUPP-4kg

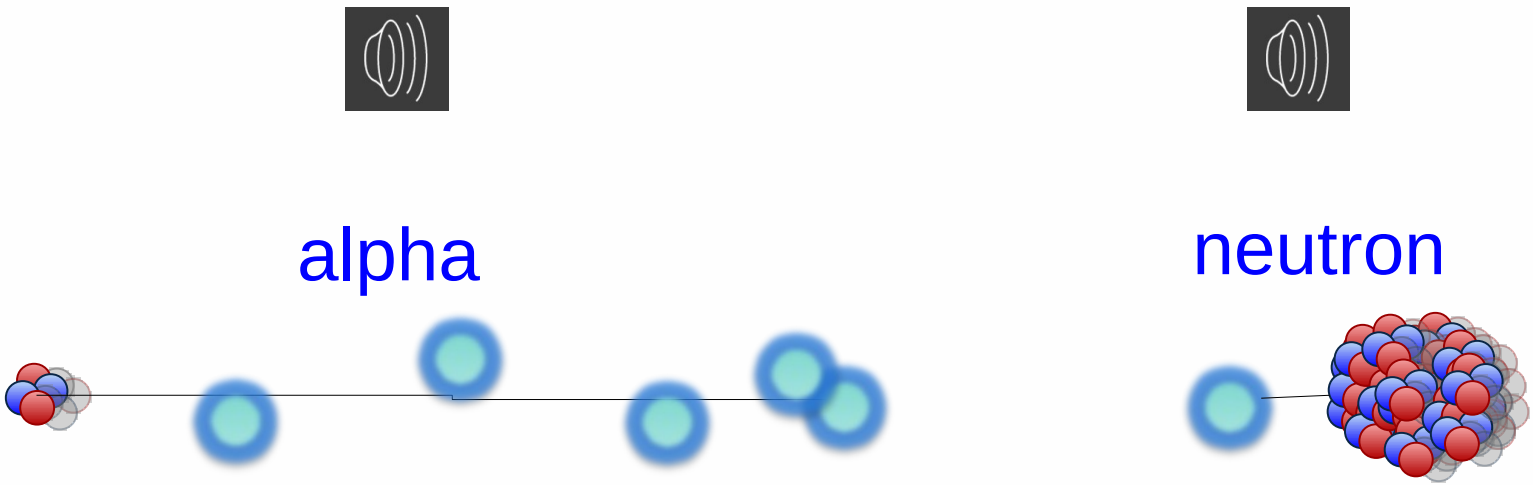
- alpha-decays
  - Nuclear recoil + 40 μm alpha track
  - U,Th chain impurities in fluid, especially radon and its daughters
- neutrons
  - Nuclear recoils, mean free path ~20 cm
  - Produced by cosmic muons, fission, and (α,n) reactions
- WIMPs
  - Single nuclear recoil (mean free path > 10^{12} cm)



COUPP-4kg

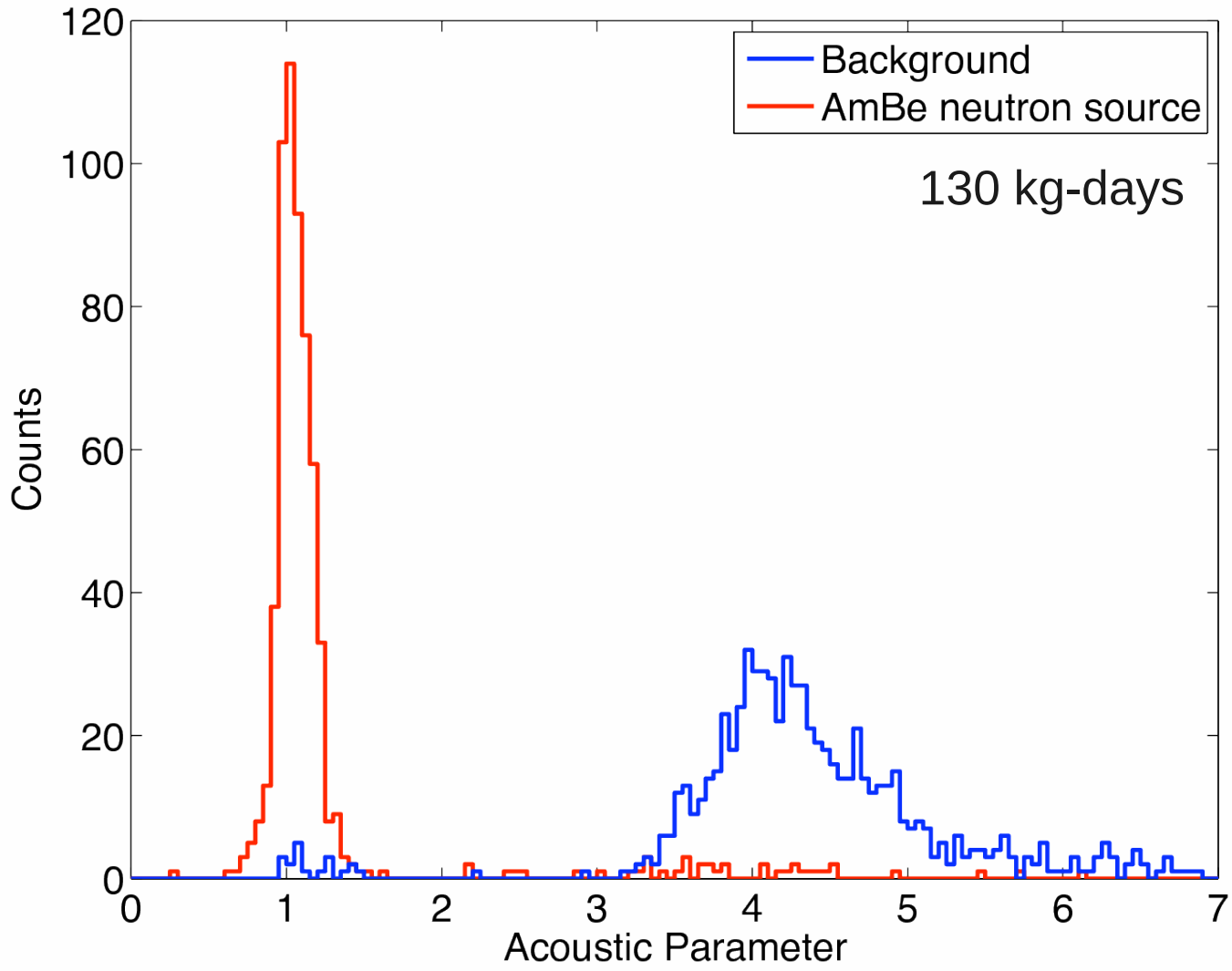
- Alpha louder when probing length scales <40 μm
- Acoustic emission peaks at ~10 μm

Acoustic discrimination >98%



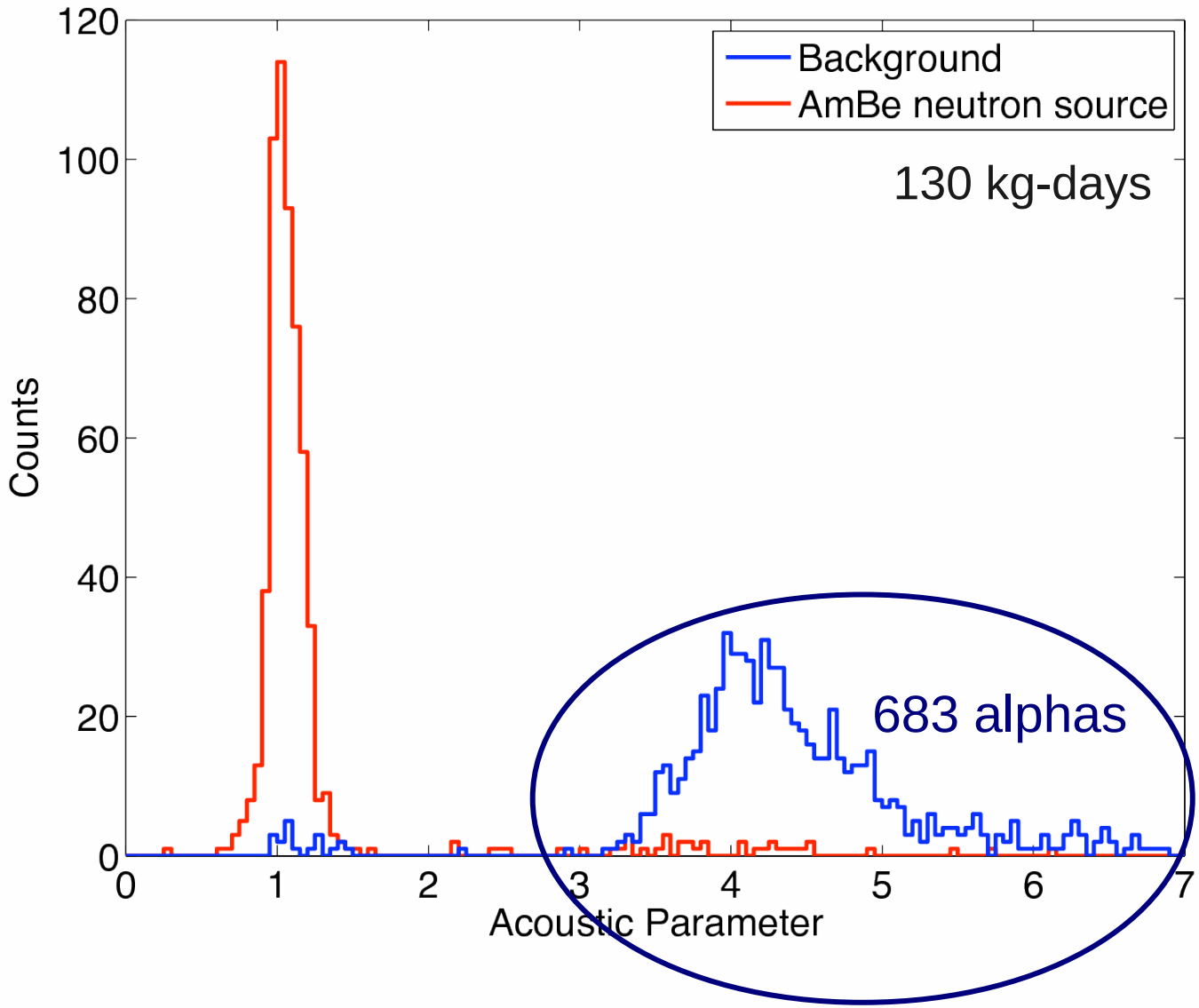
COUPP-4kg

- 18.1 live-days at 7 keV threshold
- 21.5 live-days at 10 keV threshold
- 3.3 kg fiducial cut (out of 4.0 kg)



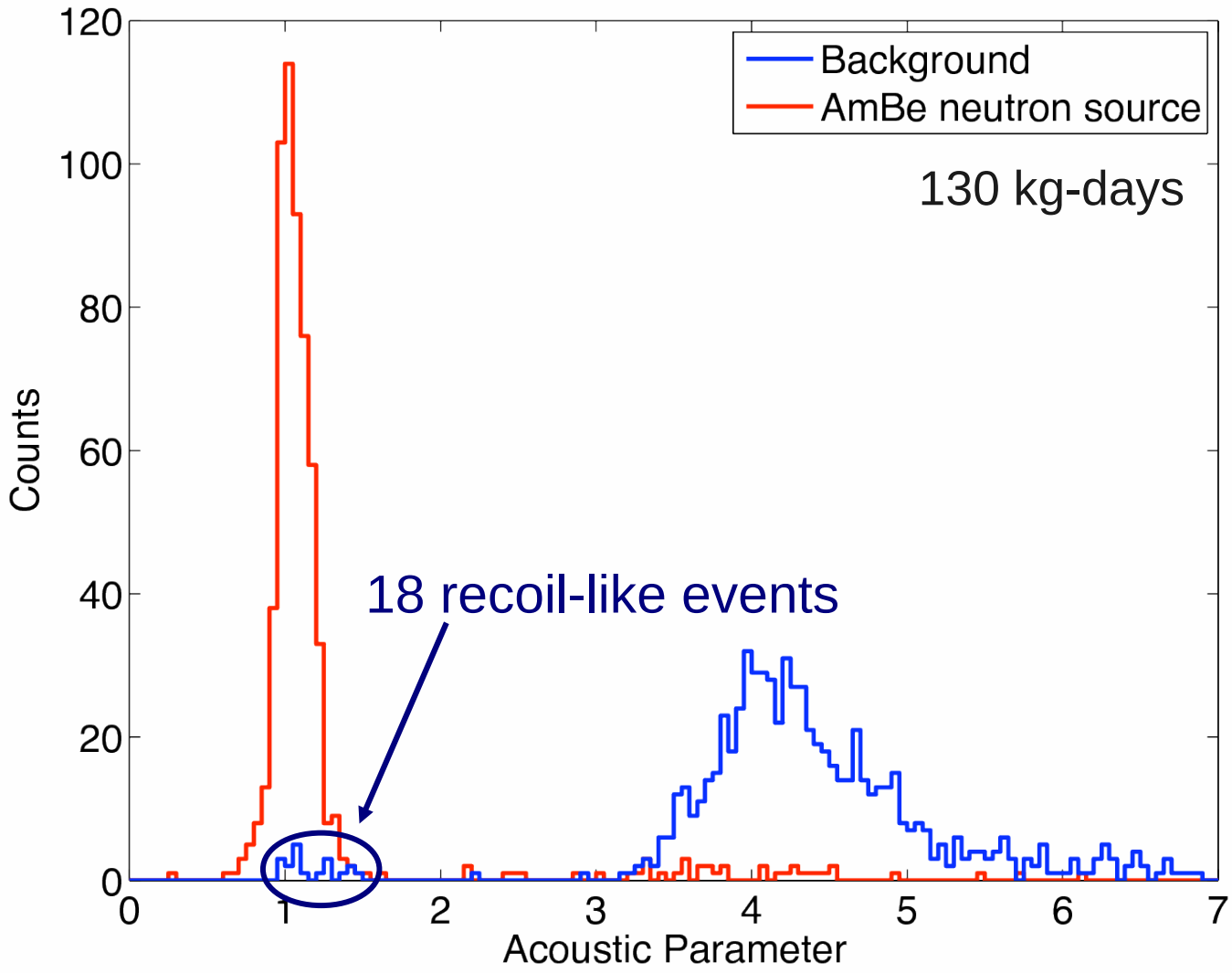
COUPP-4kg

- 5.3 alpha-decays / kg-day
  - 80% ^{222}Rn, ^{218}Po, ^{214}Po triplets
- >98% alpha rejection



COUPP-4kg

- 2 three-bubble events in this dataset!
- Single-bubble background of ~0.05 events/kg-day from neutrons (***big*** statistical error bar)
- *O*(1) event/year expected from cosmogenic and environmental neutrons

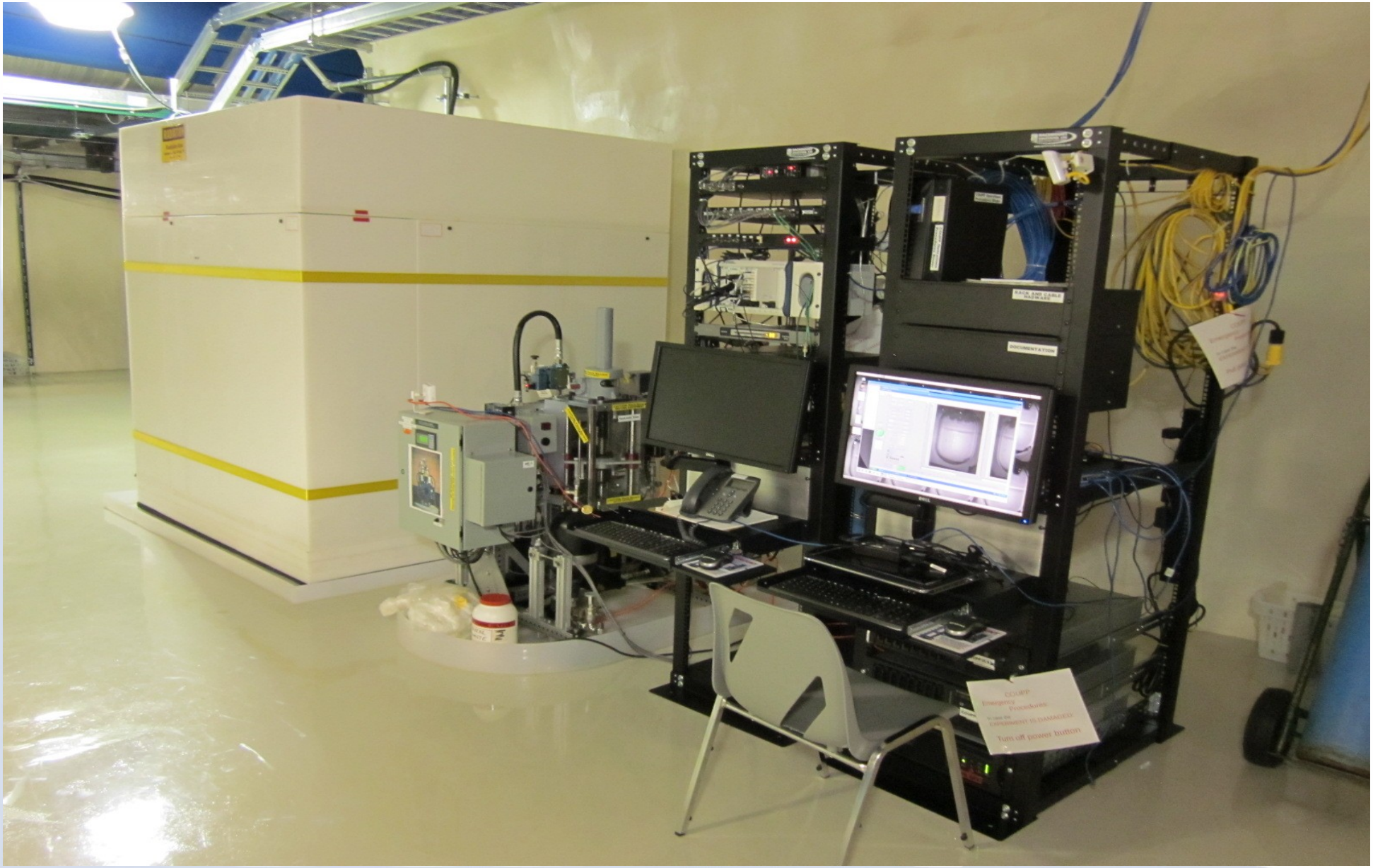


COUPP-4kg

- Piezoelectric is the ceramic PZT
  (Lead zirconate titanate)
- 4.2 ppm ^{238}U
  1.4 ppm ^{232}Th
  plus lots of modern lead with ^{210}Pb
- Both fission and (α,n) on light elements
- *Preliminary* calculation gives ~1 neutron/day from 8 acoustic sensors

- Evidence for 2nd, time-varying background
  - Clusters of 3 and 5 events in 3 and 9 hours, respectively at 7 keV threshold
  - Less clustering at 10 keV threshold, but several events are outliers at high AP
- Several plausible sources, still investigating…

COUPP-4kg @ SNOLAB

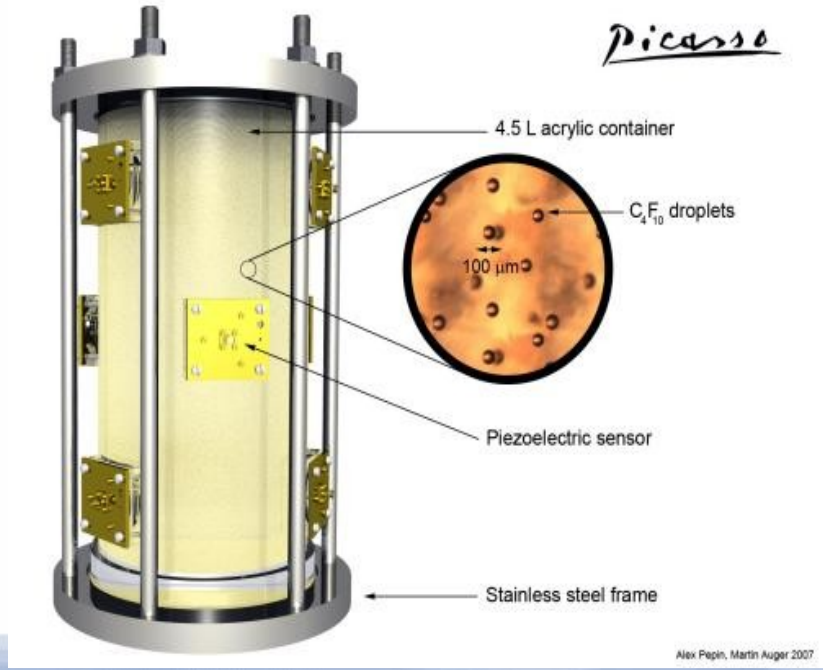


PICASSO

Suspended droplets of C_4F_{10} in an inactive polymerized gel matrix

The energy deposited by a nuclear recoil triggers a phase transition

The acoustic signal can be recorded by piezoelectric transducers.



PICASSO

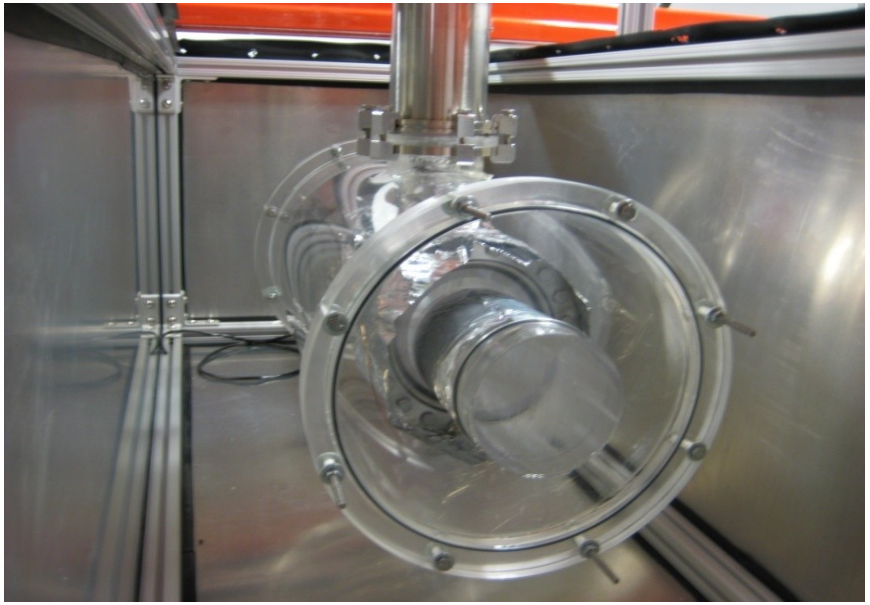
Low threshold of
2 keV for
nuclear recoil

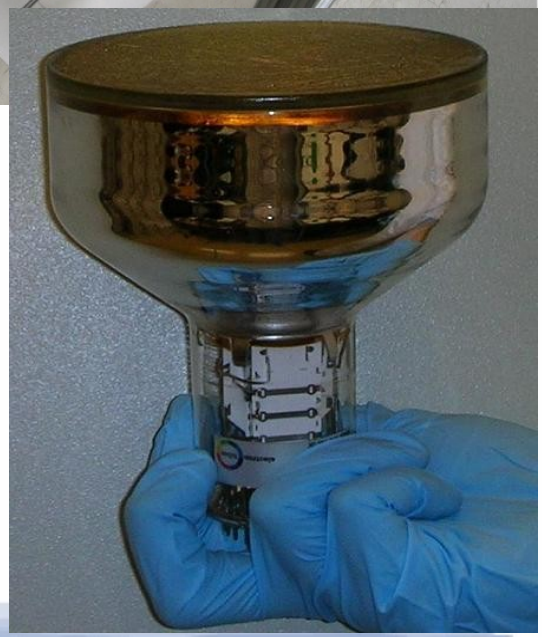
Limit of 13.9 pb
(90% C.L.) for masses
around 24 GeV
in 2009

Relocated recently and
back to operations

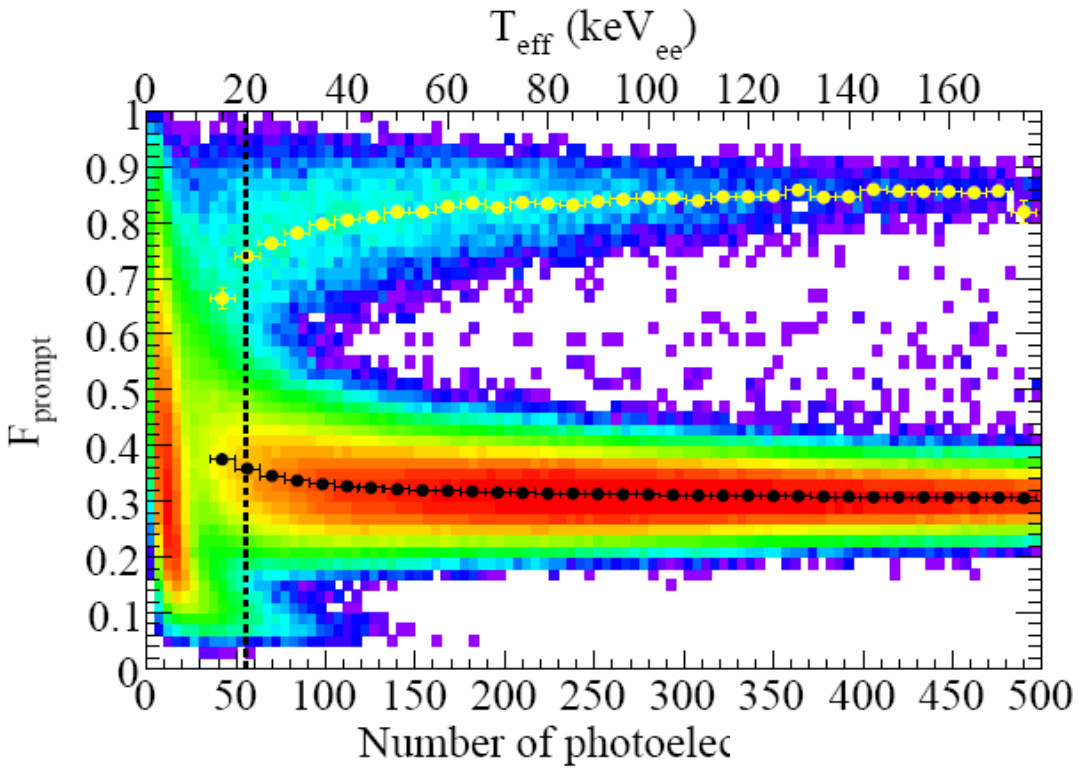
DEAP-1

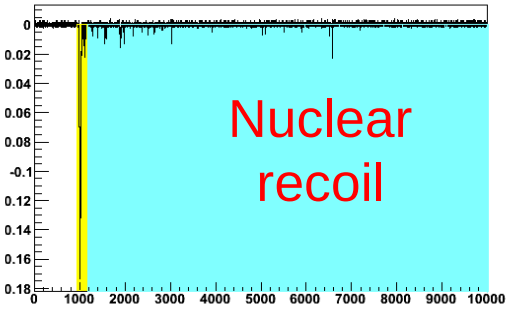
Dark matter Experiment with Argon and Pulse-shape-discrimination

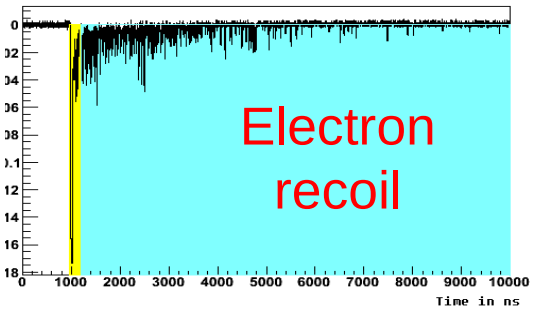




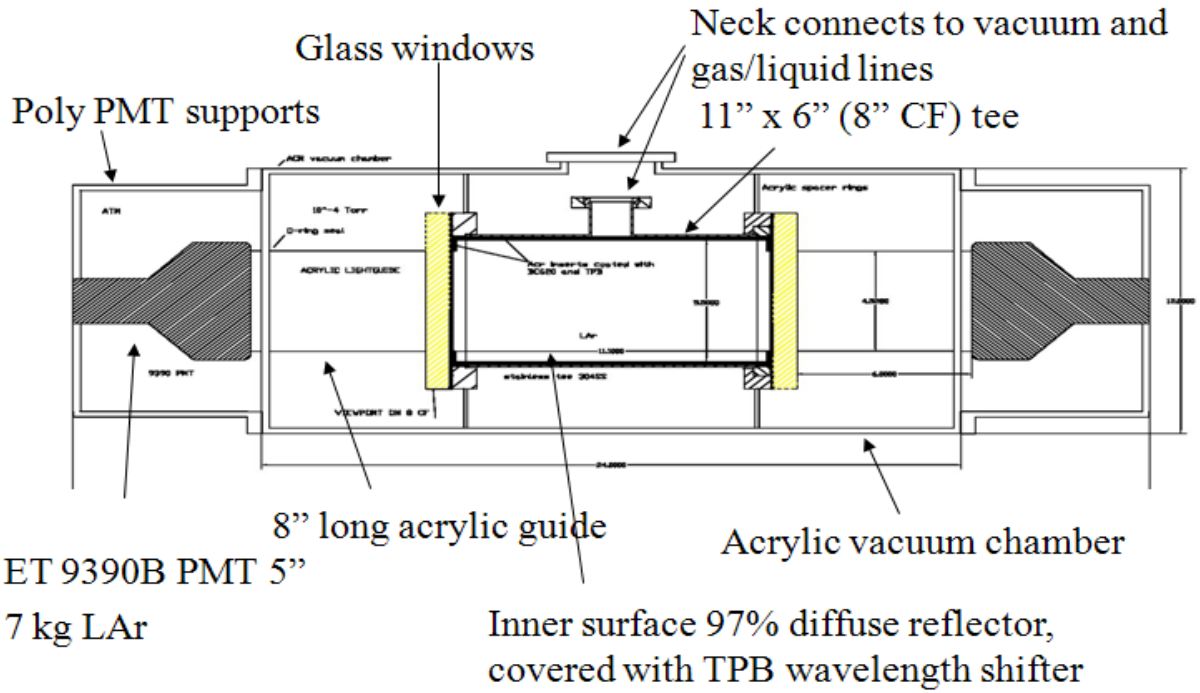
-7 kg LAr
-2 PMTs
-Demonstrate PSD (pulse-shape discrimination) between electromagnetic events and nuclear recoils



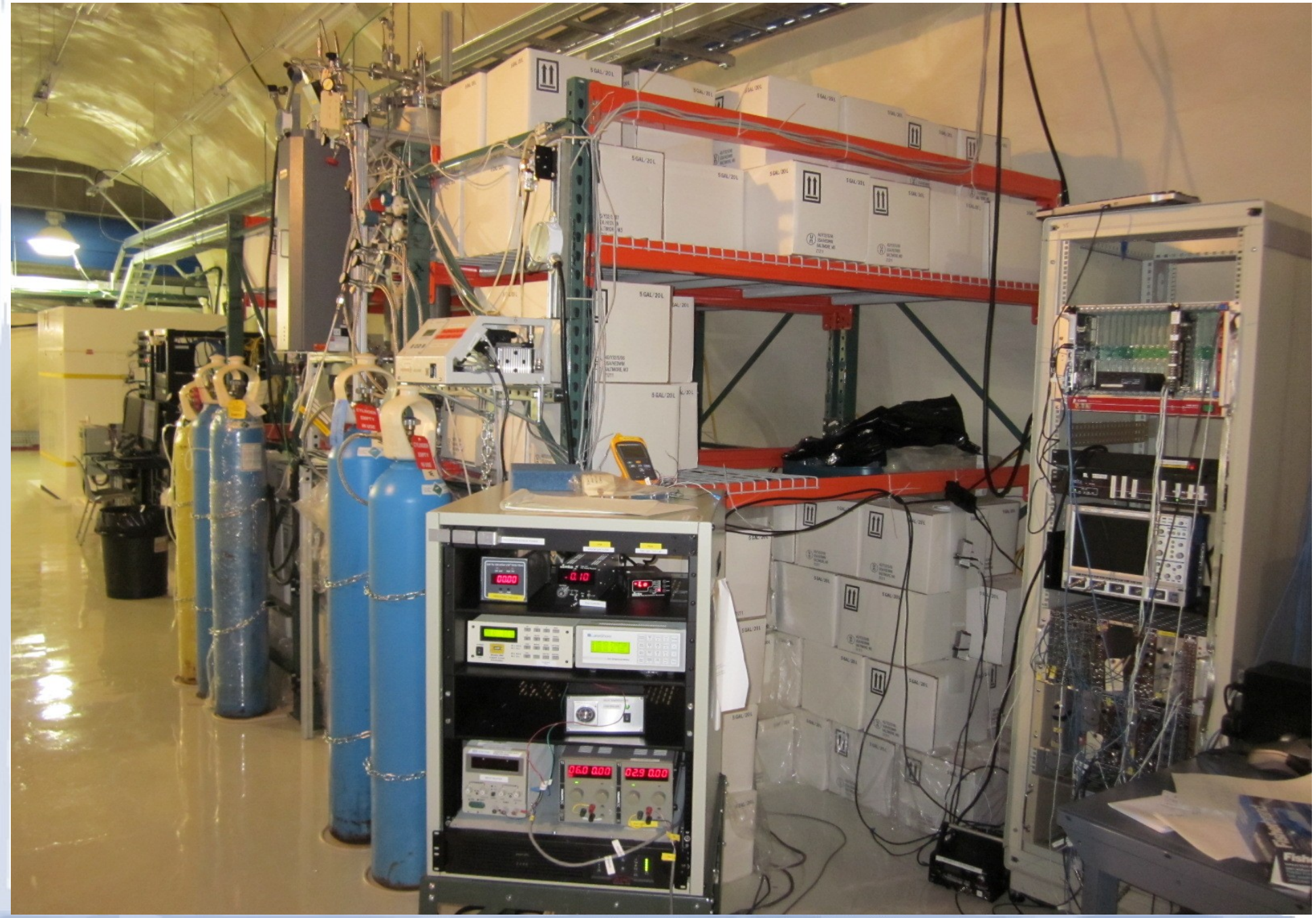




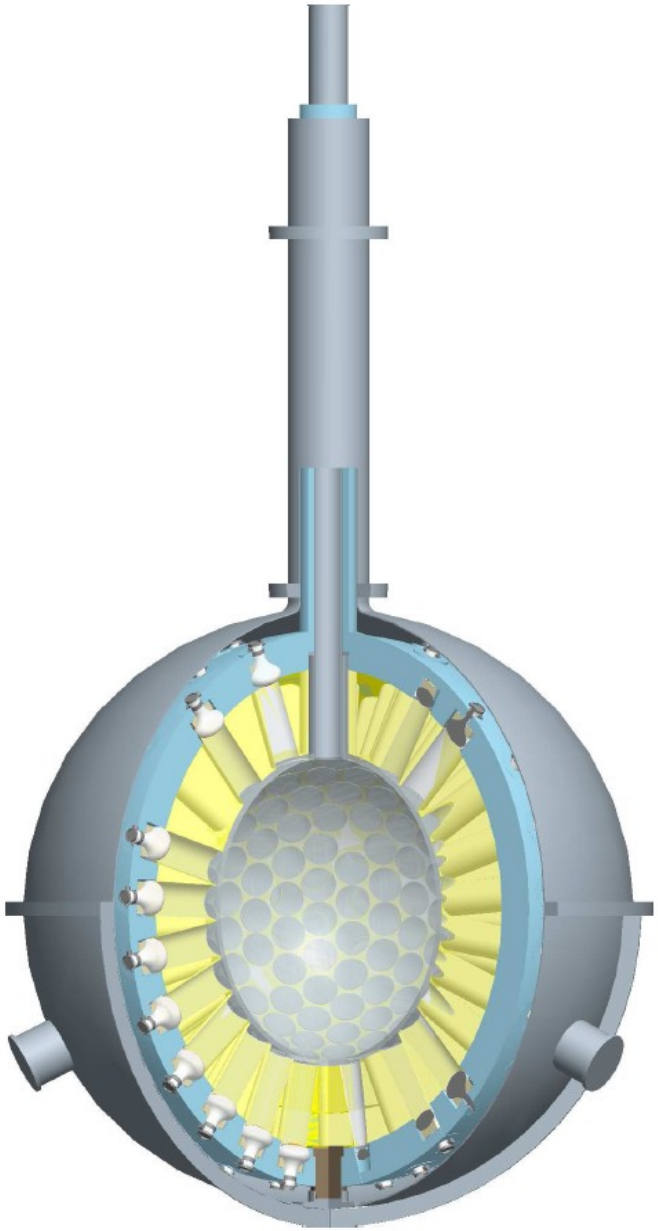
DEAP-1 prototype



DEAP-1 in J-drift



DEAP-3600



Acrylic vessel
85 cm radius
3600 kg LAr
(55 cm, 1000 kg fiducial)

255 8” PMTs

50 cm light guides

Water tank 8.5 m
diameter

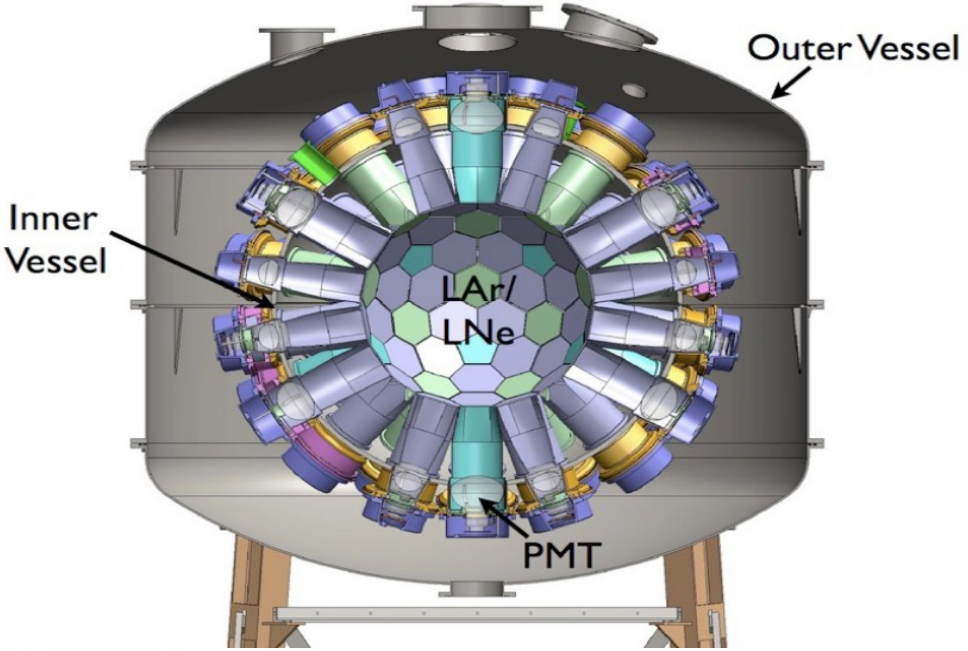
spin-independent WIMP-nucleon
cross section sensitivity
of 10^{-46} cm^2

MiniCLEAN

-500 kg cryogenic liquid (150 kg fiducial) with 92 PMTs

-Material interchangable between argon y neon

spin-independent WIMP-nucleon cross section sensitivity of 10^{-45} cm^2




SNOLAB

Conclusions

-The physics program at SNOLAB is making important contributions to experimental research in Astroparticle Physics

-Detectors for supernovae and double beta decay, for solar neutrinos, geo-neutrinos and reactor neutrino oscillations are being built

-Dark matter research experiments at SNOLAB are sensitive to spin dependent and/or independent interactions

-Searches are underway with noble gases and superheated liquids detectors; solid state detectors will be deployed soon

-SNOLAB is becoming one of the leading facilities in experimental research in Astroparticle Physics