SNO+

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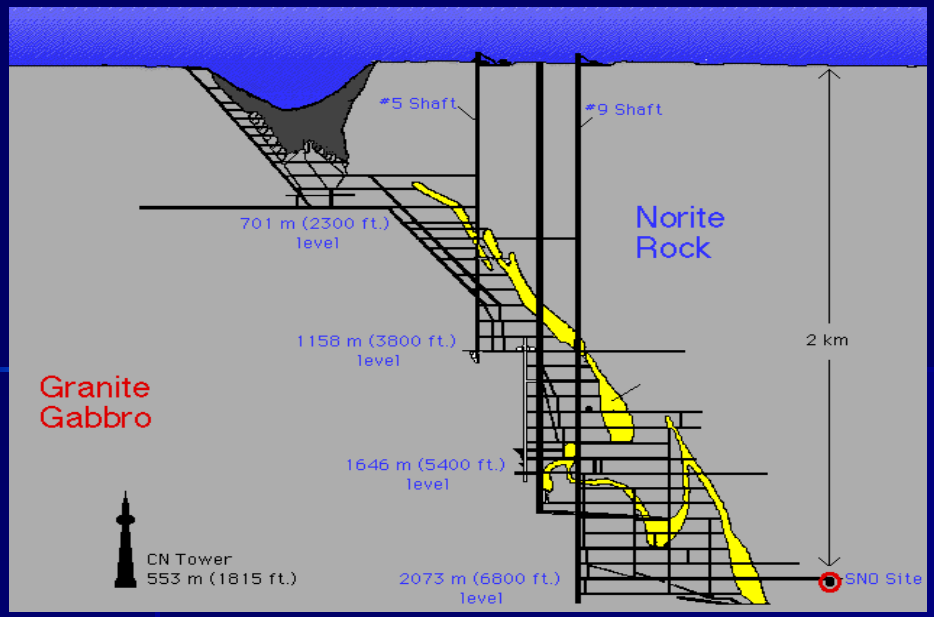
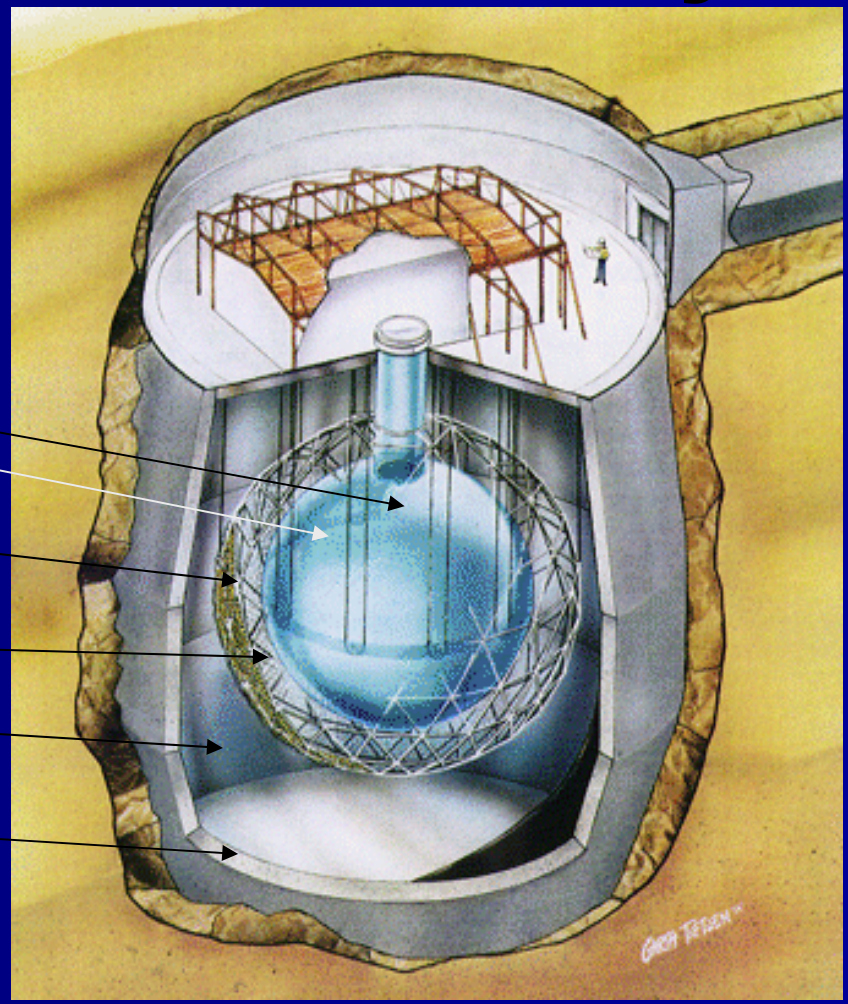
Sudbury Neutrino Observatory





1000 tonnes D_2O

12 m diameter Acrylic Vessel

18 m diameter support structure; 9500 PMTs (~60% photocathode coverage)

1700 tonnes inner shielding H_2O

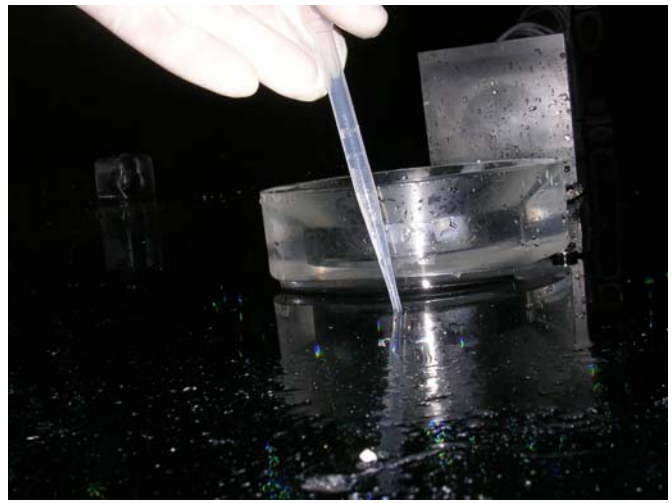
5300 tonnes outer shielding H_2O

Urylon liner radon seal

depth: 2092 m (~6010 m.w.e.) ~70 muons/day

The End of SNO Heavy Water

- the Sudbury Neutrino Observatory finished taking data with heavy water
- heavy water was drained and returned to Atomic Energy of Canada Limited
  - Nov 28, 2006
    - end of data taking and detector turned off
  - Jan 18, 2007
    - last NCD taken out
  - Jan 27, 2007
    - began removing D_2O from the neck
  - May 28, 2007
    - AV completely drained
      - using a submersible pump
      - plus entry into the AV using a bosun's chair
      - used pump hose to vacuum up the last D_2O
      - used pipette to get last ~200 mL

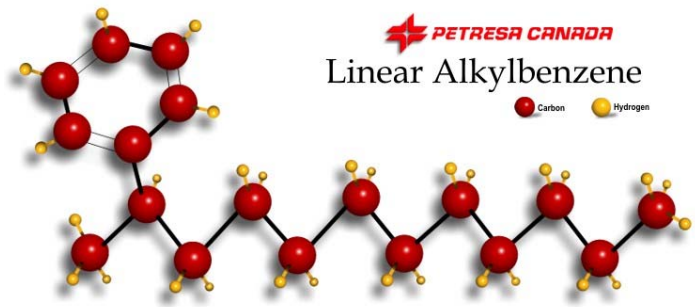


- what can we fill the detector with next?

SNO+

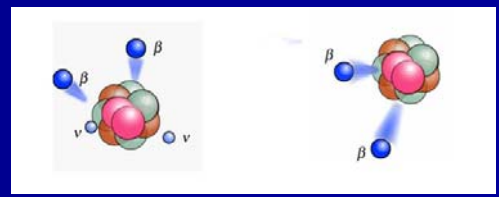
- we plan to fill the SNO detector with a liquid scintillator (50-100 times more light)
- linear alkylbenzene (LAB)
  - compatible with acrylic, undiluted
  - high light yield, long attenuation length
  - safe: high flash point, low toxicity
  - cheaper than other scintillators

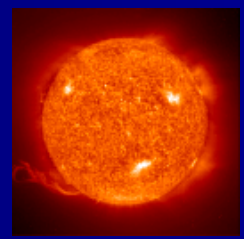
LAB is a commodity chemical used to make the surfactant in common, household detergents



SNO+ Physics Program

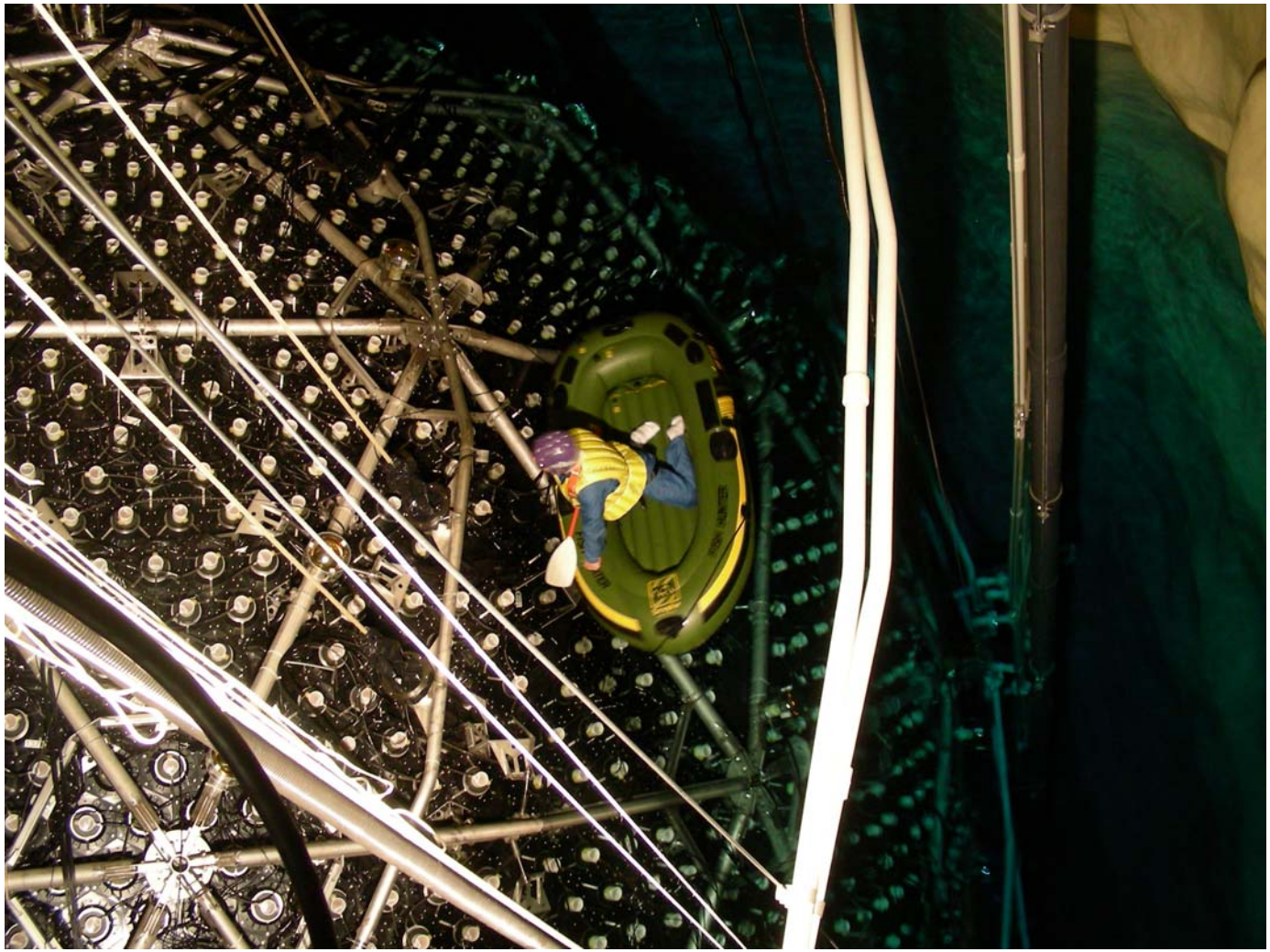
- search for neutrinoless double beta decay
- neutrino physics
  - solar neutrinos
  - geo antineutrinos
  - reactor antineutrinos
  - supernova neutrinos



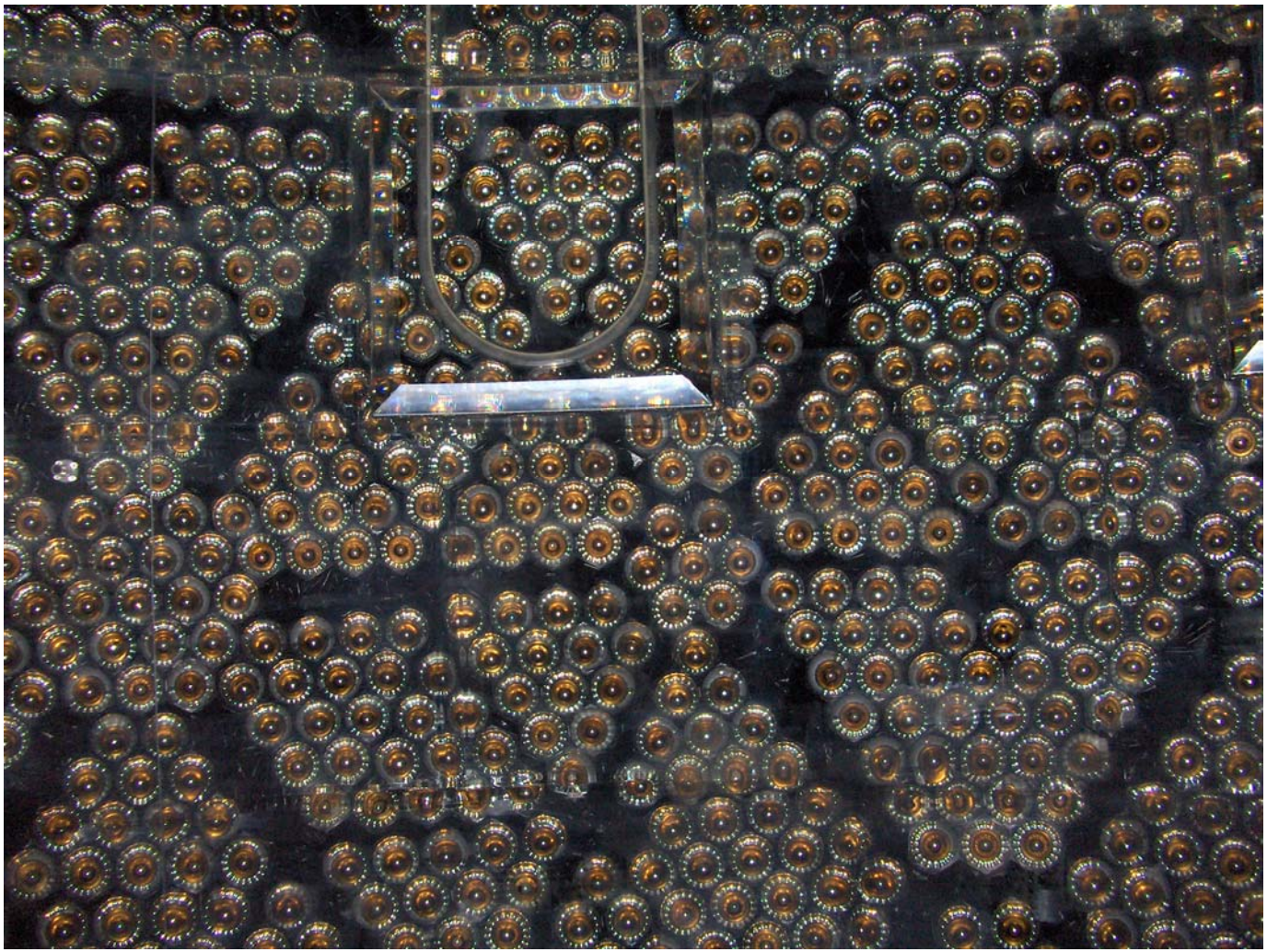


SNO+ Physics Goals

Draining SNO and Boating Inspections



Inside the SNO AV Looking Out



SNO Cavity Drained, Inspected

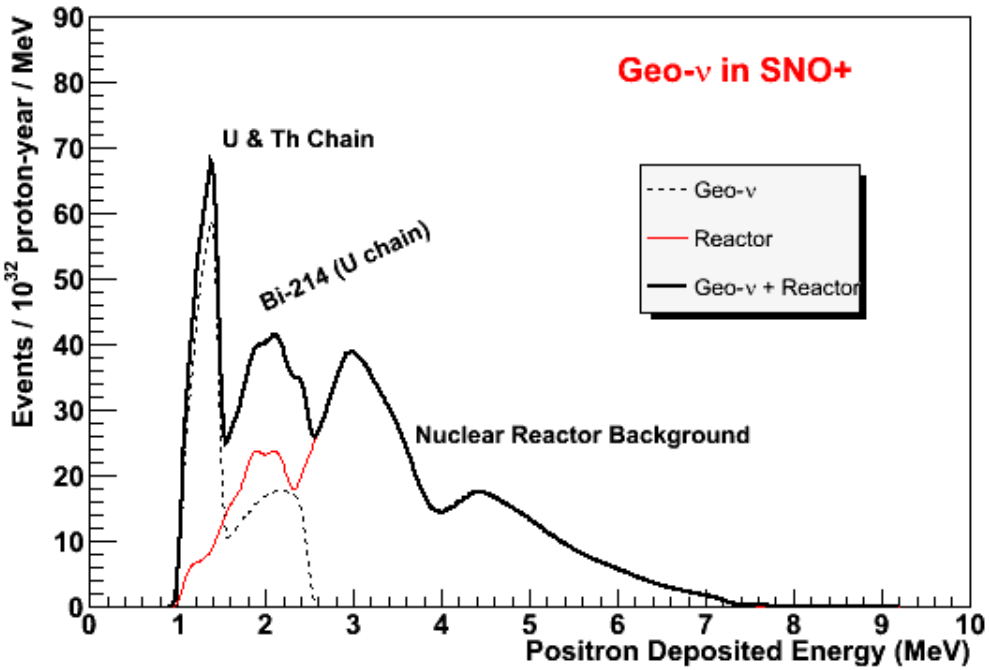
Geoneutrino Detection

$$\bar{\nu}_e + p \rightarrow e^+ + n$$

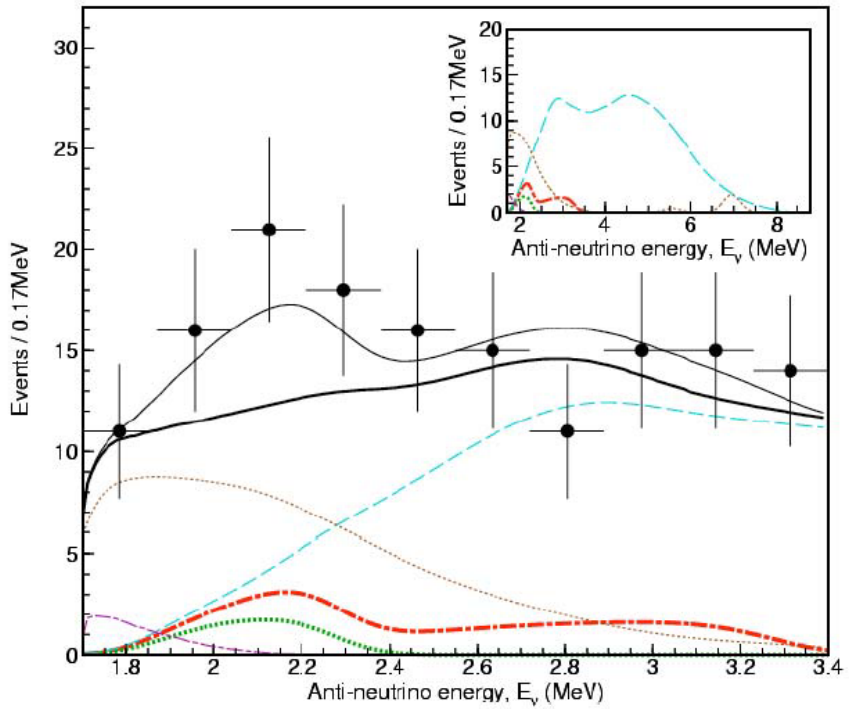
- a geoneutrino interacts with a proton in the detector
  - a few times per month
- the positron plus its annihilation gamma rays produce a flash of light (prompt signal)
- the neutron thermalizes and captures on another proton with mean lifetime 0.2 ms, producing a gamma ray of 2.2 MeV and a second flash of light (delayed signal)
- photomultiplier tubes measure the amount of light and time they were hit
  - allows reconstruction of the energy and position of the neutrino interaction
  - don't have information about the neutrino direction…the neutron is forward scattered, but wanders while thermalizing; plus 2.2 MeV gamma ray scintillation is displaced another few cm's

Geoneutrinos in SNO+

- KamLAND: 33 events per year (1000 tons CH_2) / 142 events reactor
- SNO+: 44 events per year (1000 tons CH_2) / 38 events reactor



SNO+ geo-neutrinos and reactor background

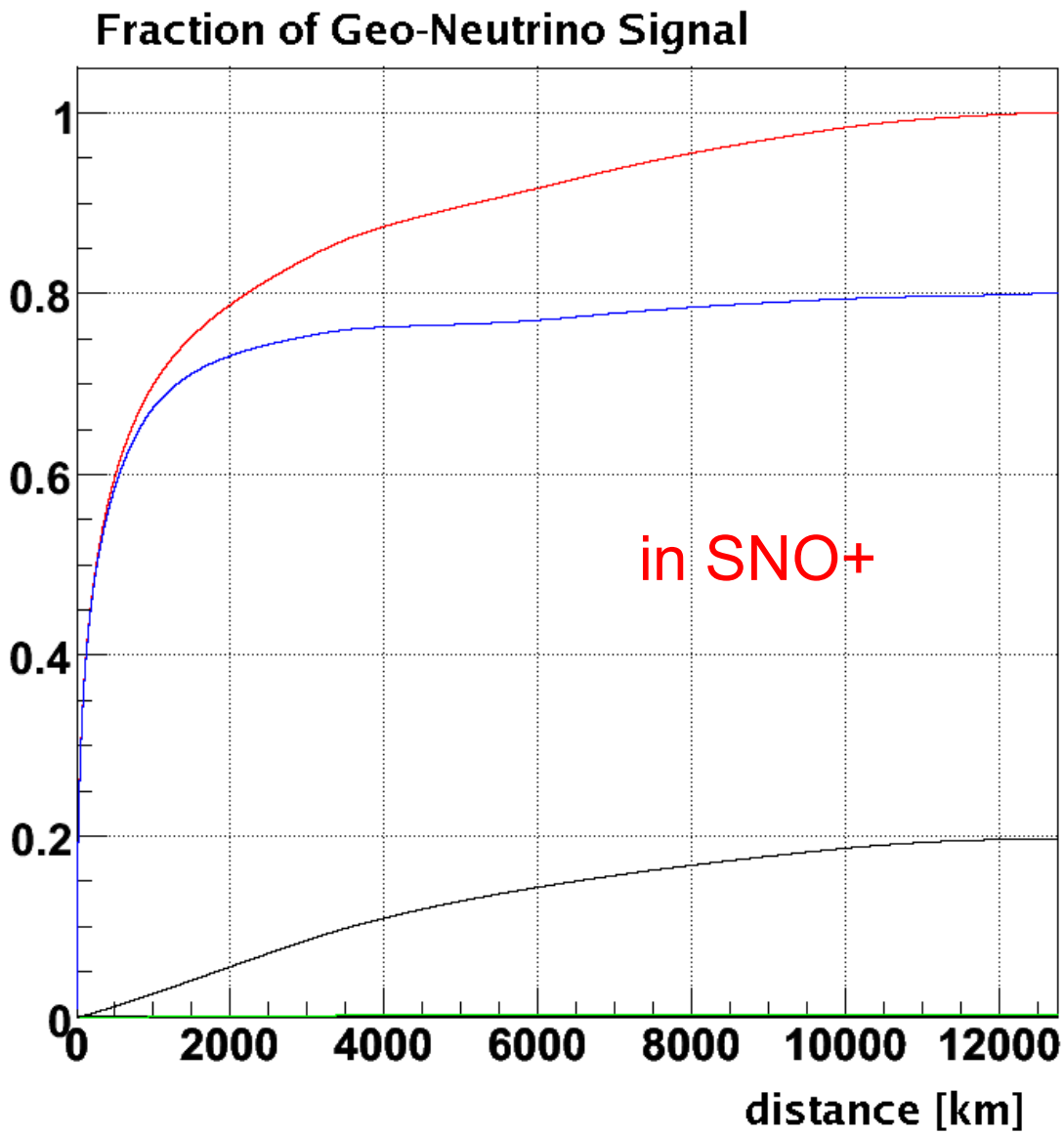


KamLAND geo-neutrino detection…July 28, 2005 in Nature

Count the Protons

- LAB is mostly approximately $C_{18}H_{30}$
  - more like 29 events per year
    - fiducial volume cut? 80%
    - livetime fraction? 75%
    - efficiency (high, depends on fiducial cut)
  - so it will be ~20 events per calendar year

Geo-ν from Continental Crust



crust: blue
mantle: black
total: red

SNO+ Geoscience Goals

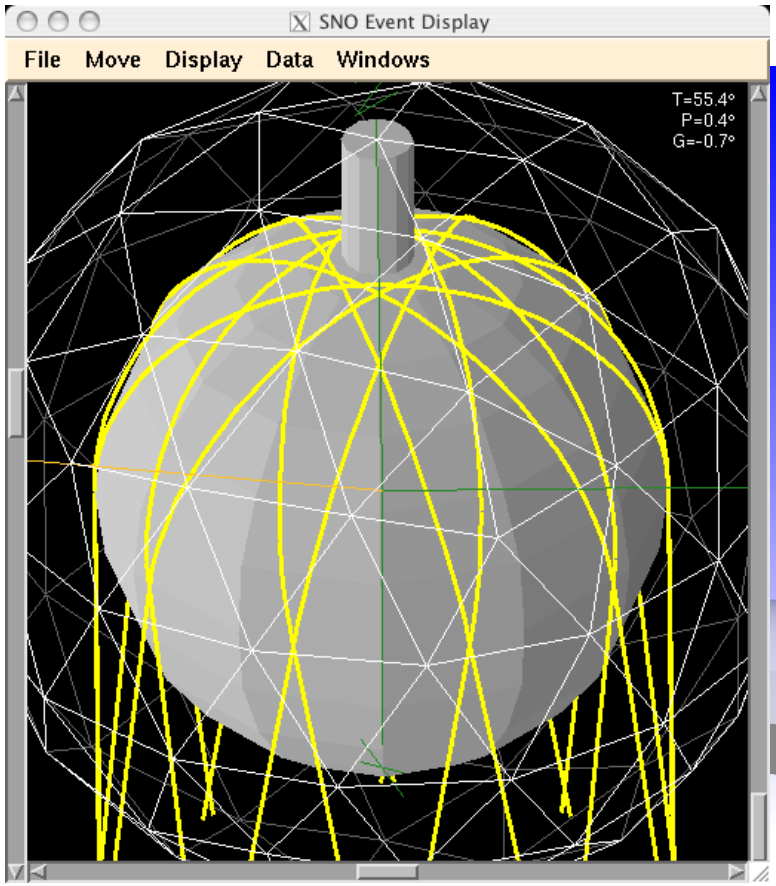
- test fundamental models of Earth's chemical origin
  - are measured fluxes consistent with predictions based upon the BSE?
  - so far yes, KamLAND 2008 measurement central value equals the BSE predicted flux
- test chemical composition of the crust
  - are the basic ideas about the makeup and distribution of elements in continental crust correct?
- with detailed local contribution study, can study the 20% deep Earth component
- global program: SNO+ and Hanohano would be a terrific combination

Steps Required

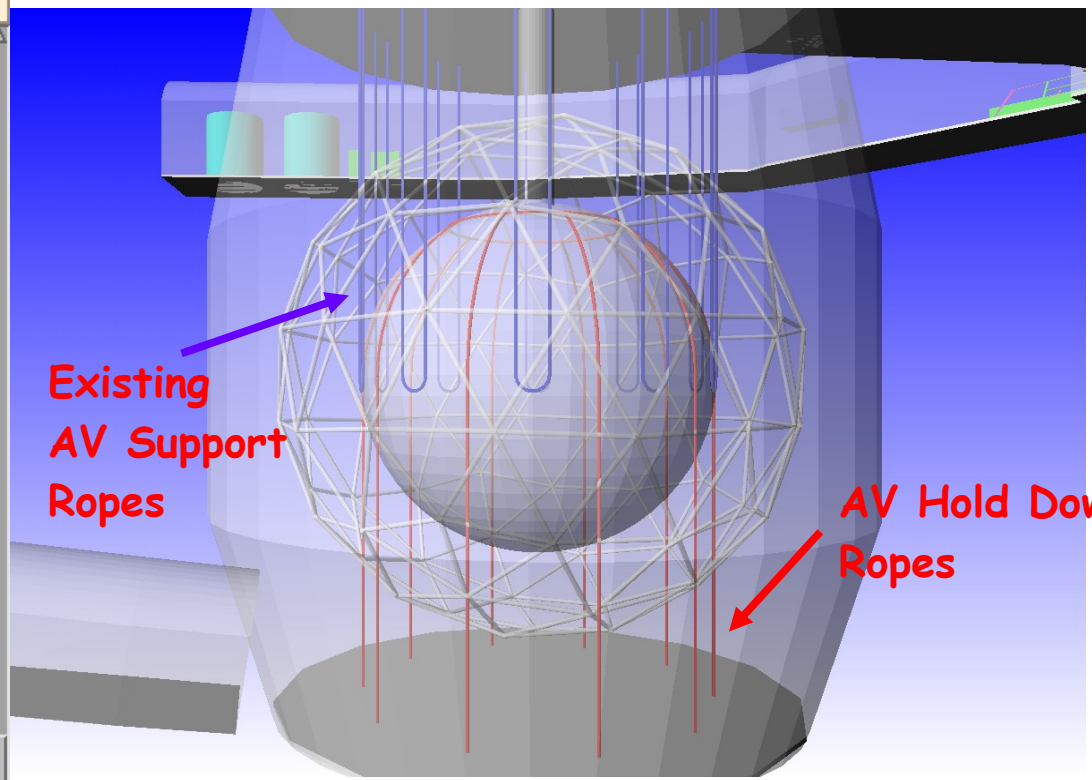
- build/install hold down for acrylic vessel [~$2M]
- procure liquid scintillator and components [~$2M]
- build/install scintillator purification [~$7M]

- upgrade cover gas and detector interface (glove box) [$0.35M]
- minor upgrades to electronics/DAQ [$0.2M]
- build calibration systems for [$0.3M]

SNO+ Hold Down Net



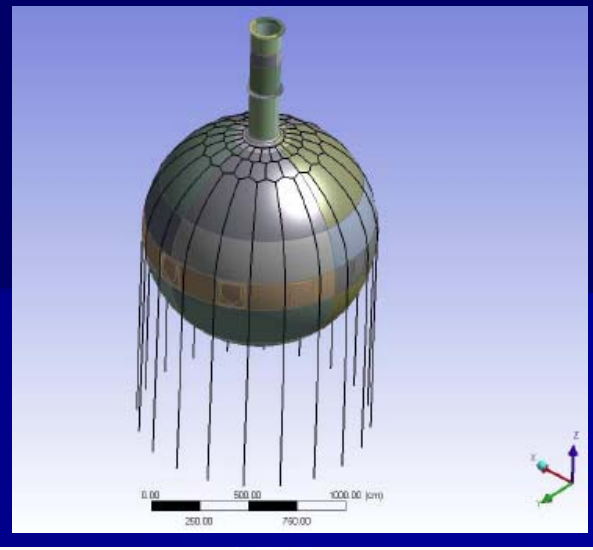
sketch of hold-down net concept



rope tension calculation as input for finite element analysis
and for PSUP penetration geometry

AV Hold Down

- FEA stress and buckling calculations completed



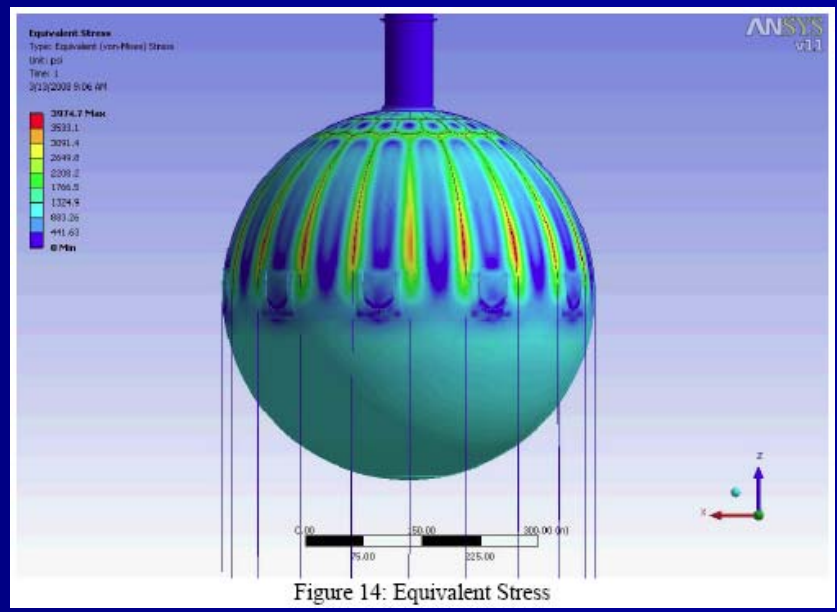
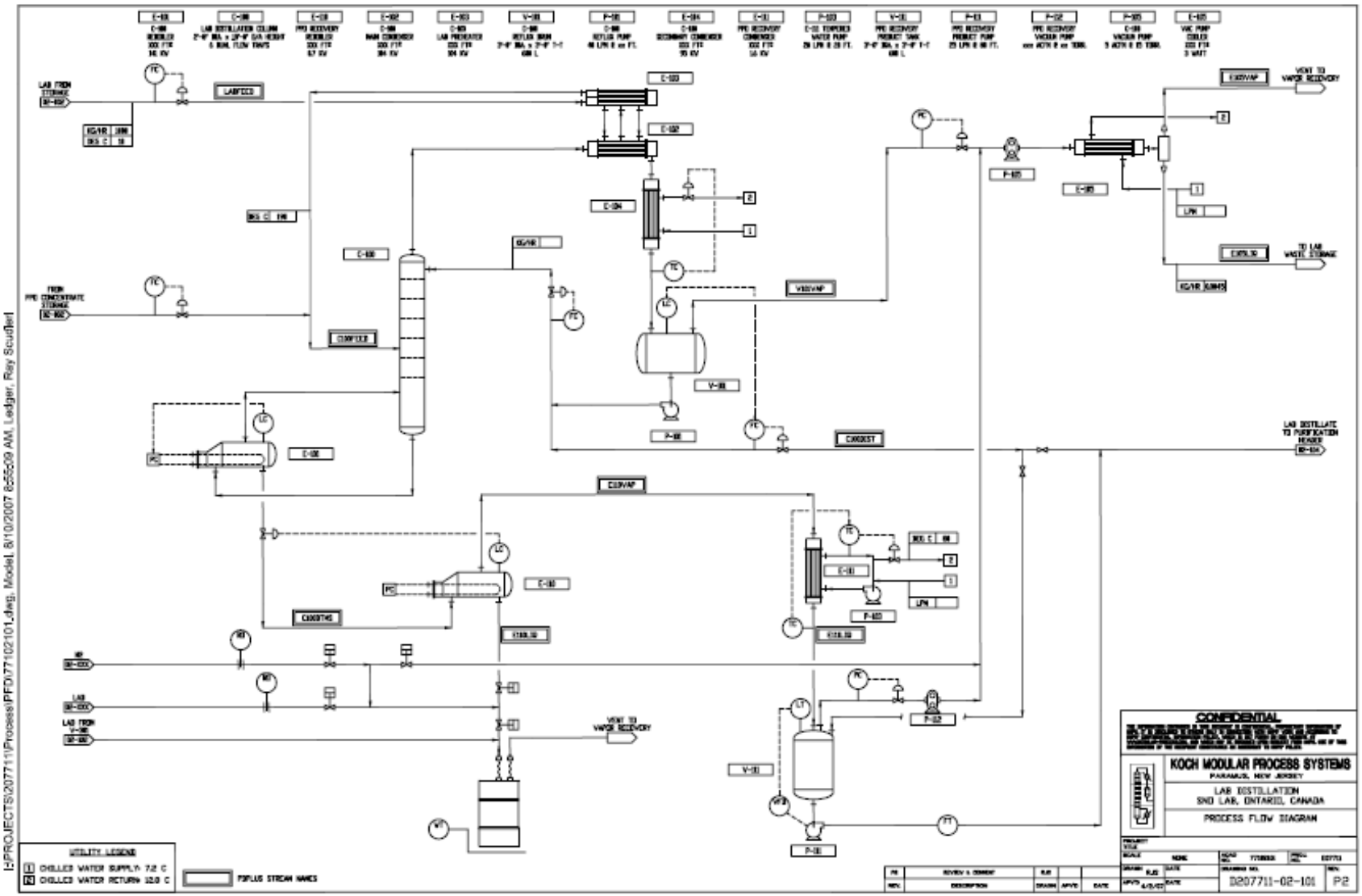


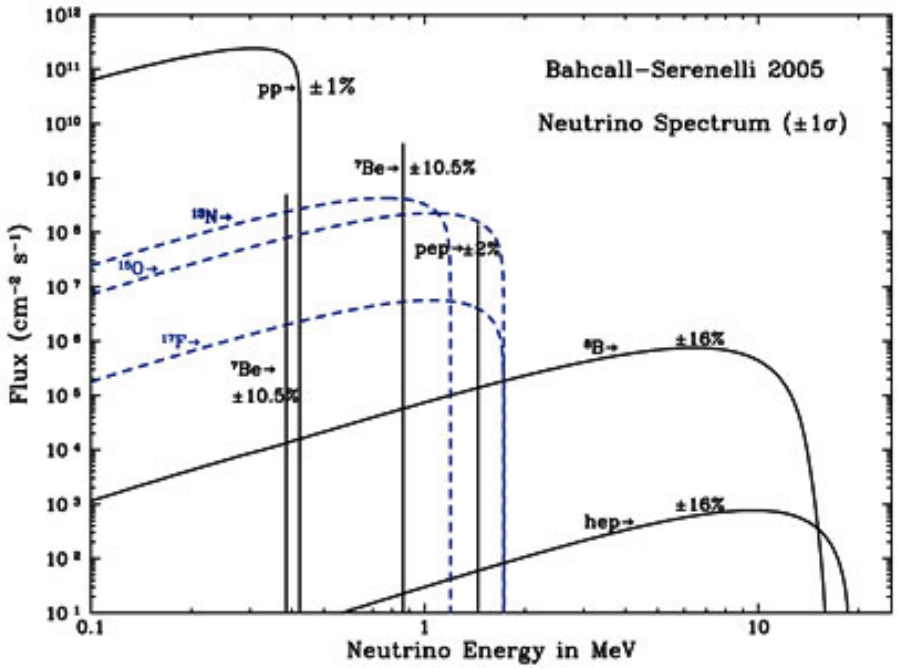
Figure 14: Equivalent Stress

Scintillator Purification



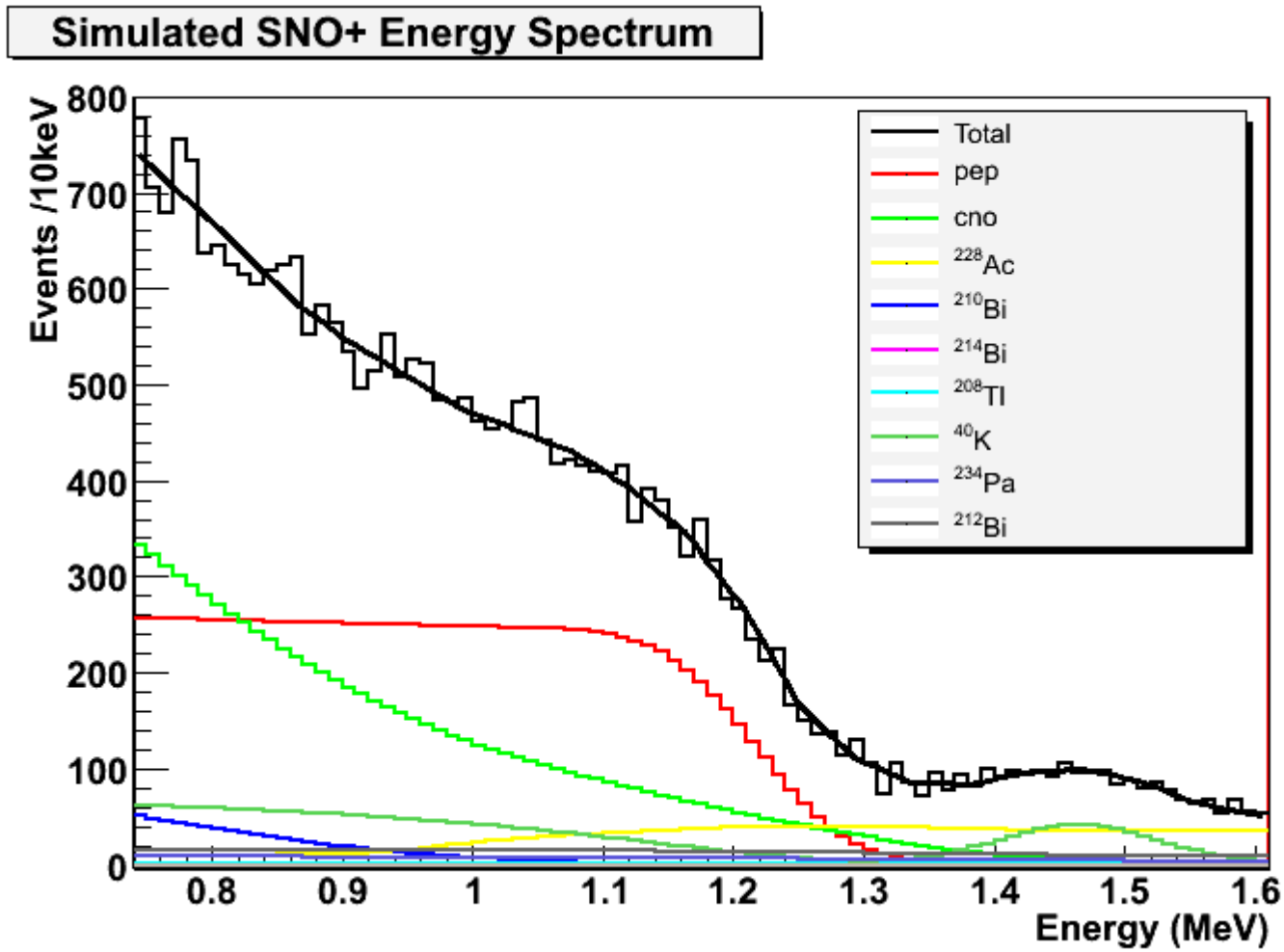
Solar Neutrinos at Low Energy

- ^{8}B solar ν well studied
  - Super-K and SNO
- there are good data on *pp* solar ν's from SAGE, Gallex and GNO
  - must determine contribution of ^{8}B and ^{7}Be, subtract, and you get *pp* from the Ga experiments
- Borexino and KamLAND will be studying ^{7}Be



…*pep* and *CNO* solar neutrinos are next

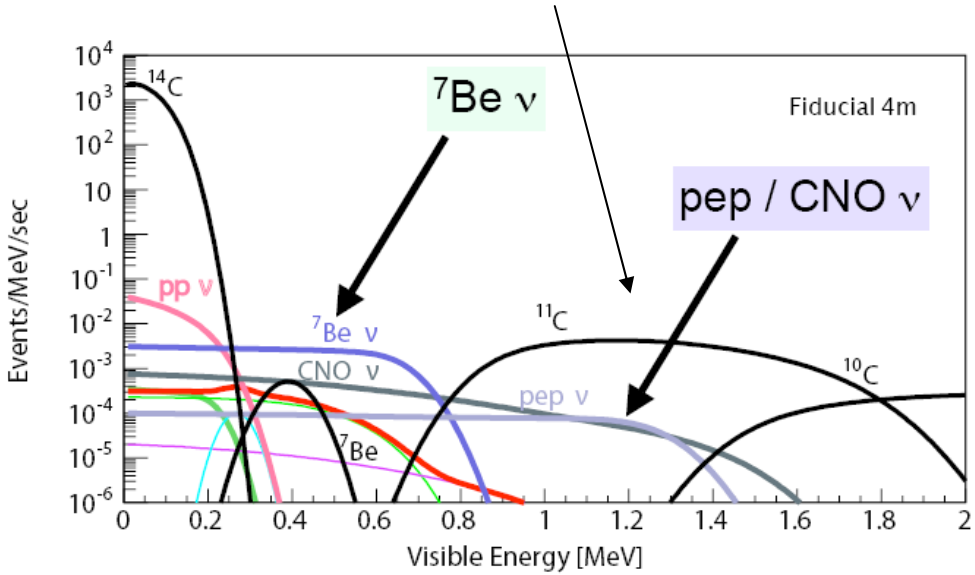
SNO+ *pep* Solar Neutrino Signal



3600 *pep* events/(kton·year), for electron recoils >0.8 MeV

Background from ^{11}C Eliminated

- SNO+ is at 6000 m.w.e. depth
  - muon flux reduced a factor 800 compared to Kamioka and a factor 100 compared to Gran Sasso
  - recall KamLAND's post-purification goal



KamLAND and Borexino will try to tag and veto the ^{11}C to suppress

at SNO+ depth this background is already smaller than the signal and one can still tag and veto

Survival Probability for Solar Neutrinos: All Experimental Data Distilled

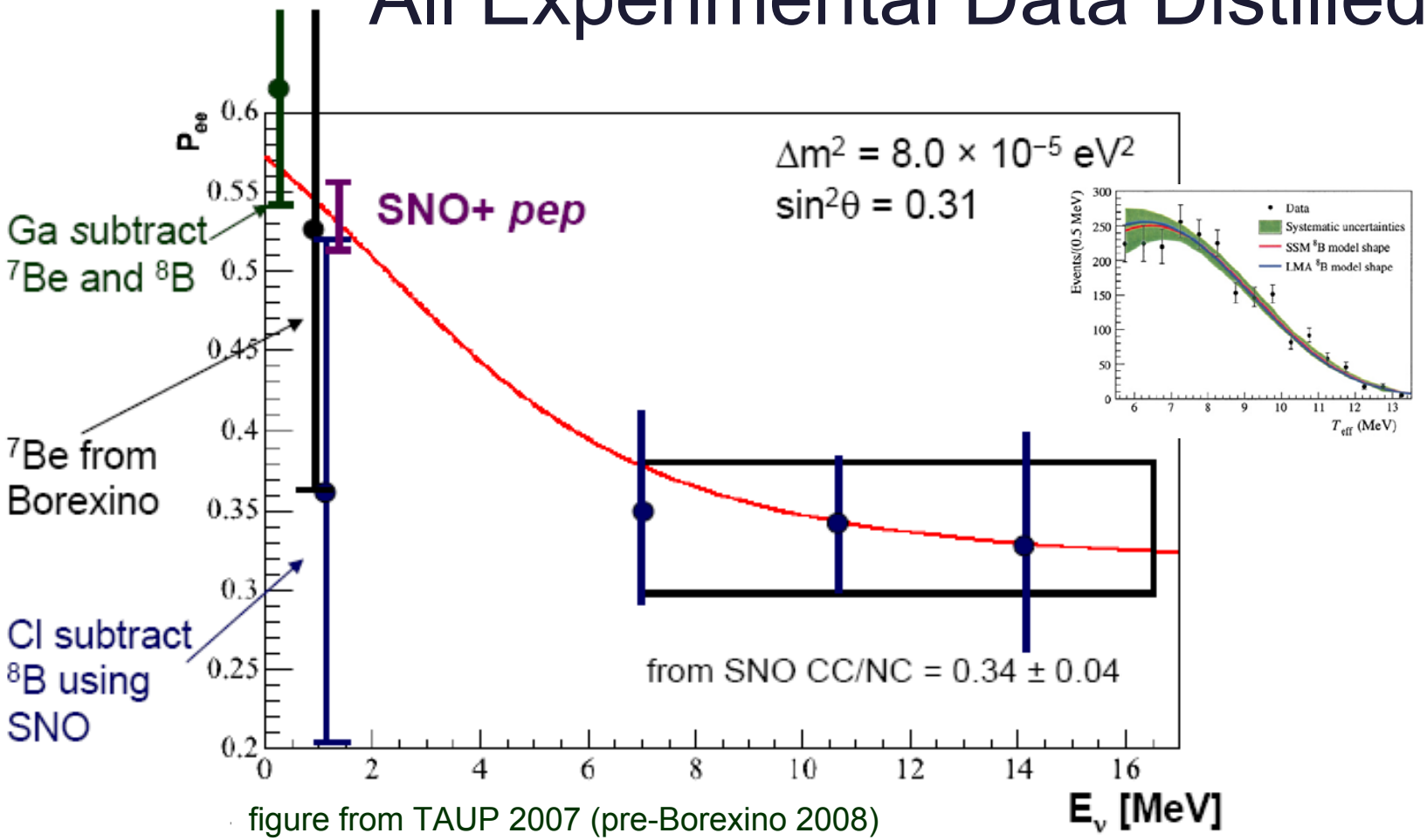
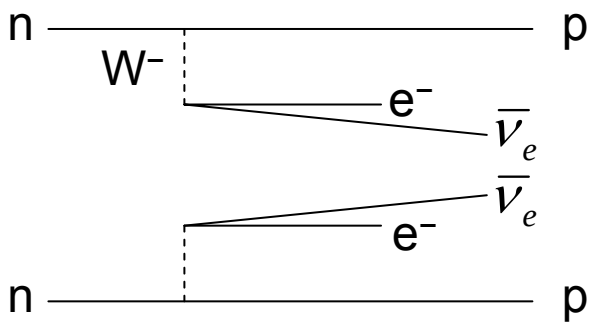


figure from TAUP 2007 (pre-Borexino 2008)

What is Double Beta Decay?

- some nuclei cannot β decay but can undergo double beta decay, a very rare process
  - e.g. ^{76}Ge has half-life 1.3×10^{21} years

- even rarer is neutrinoless double beta decay (has never been observed…well sort of never!)



$2\nu\beta\beta$

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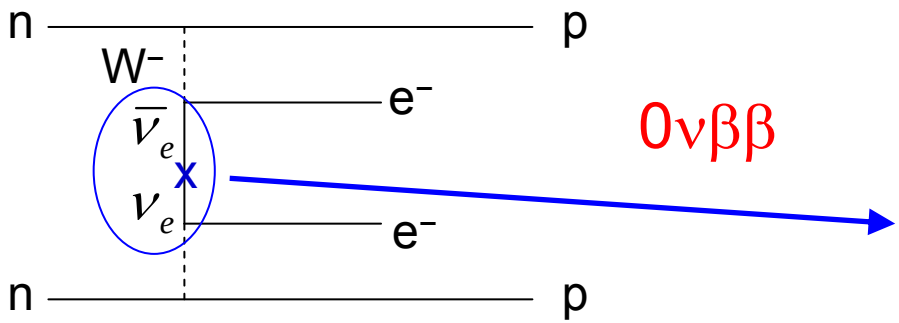


$0\nu\beta\beta$

requires neutrino to be it's own antiparticle − Majorana

SNO+ Double Beta Decay

- …sometimes referred to as SNO++
- it is possible to add $\beta\beta$ isotopes to liquid scintillator, for example
  - dissolve Xe gas
  - organometallic chemistry (Nd, Se, Te)
  - dispersion of nanoparticles (Nd_2O3, TeO_2)
- we researched these options and decided that the best isotope and technique is to make a Nd-loaded liquid scintillator

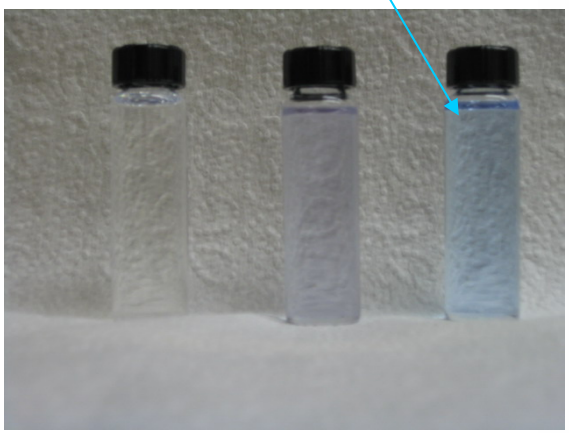
Why ^{150}Nd?

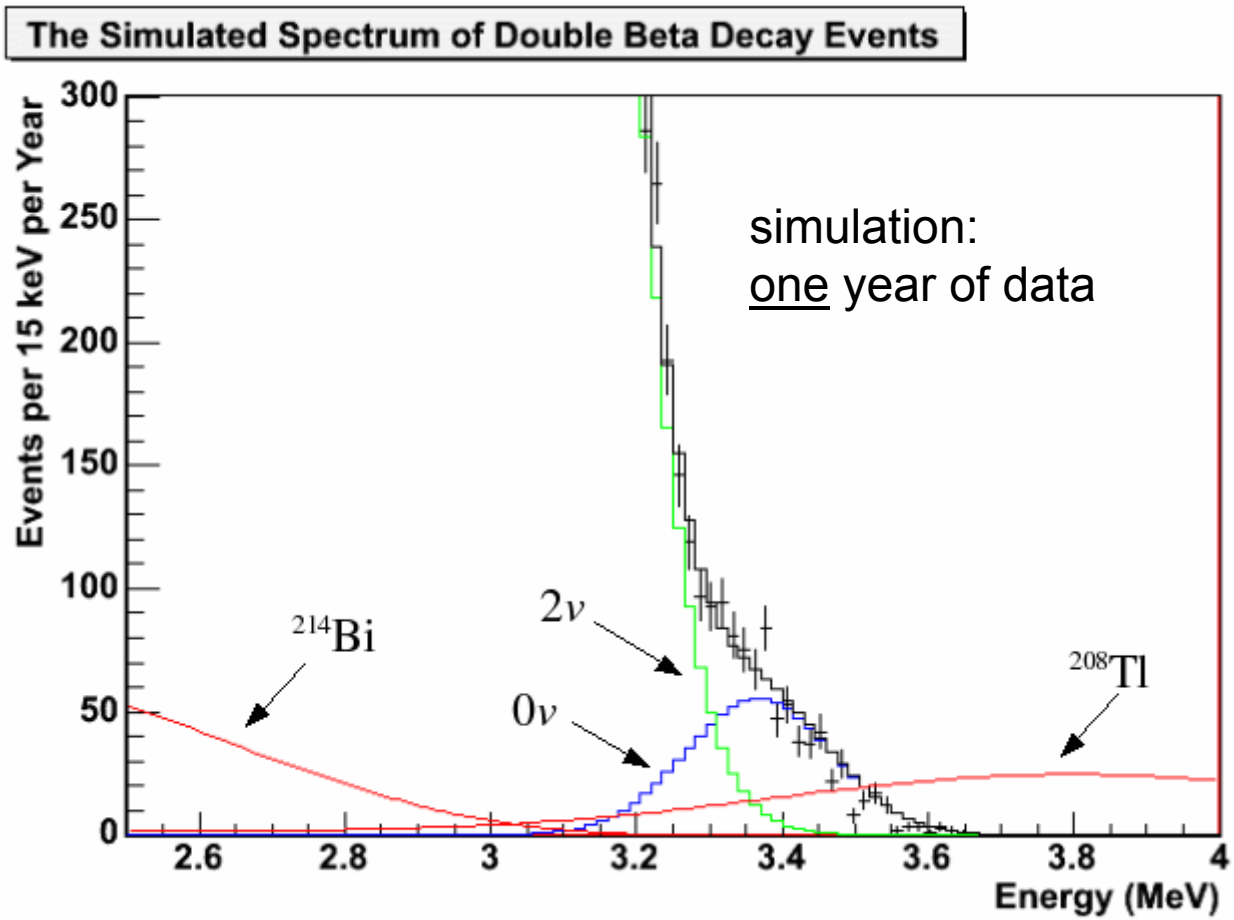
- 3.37 MeV endpoint (2nd highest of all $\beta\beta$ isotopes)
  - above most backgrounds from natural radioactivity
- largest phase space factor of all $\beta\beta$ isotopes
  - and favourable nuclear matrix element
  - for the same effective Majorana neutrino mass, the $0\nu\beta\beta$ rate in ^{150}Nd is fastest
- isotopic abundance 5.6%

  1% natural Nd-loaded liquid scintillator in SNO+ has 560 kg of ^{150}Nd compared to 37 g in NEMO-III
- cost $NdCl_3$ is $86,000 for 1 tonne
- upcoming experiments use Ge, Xe, Te; Cd and Se proposed…we can deploy a large amount of Nd

$0\nu\beta\beta$ Signal for $\langle m_\nu \rangle$ = 0.150 eV

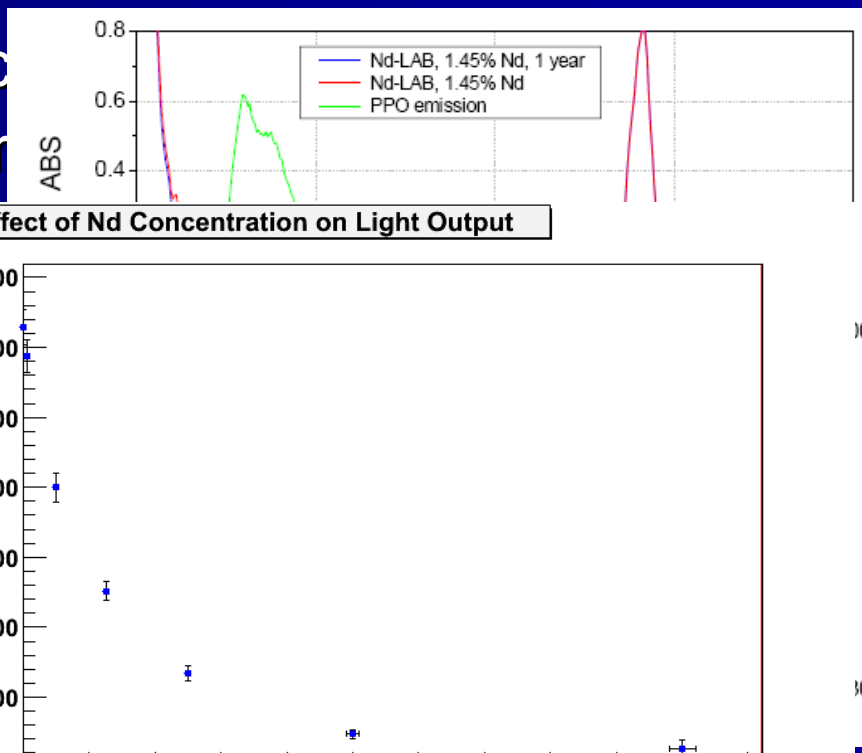
0ν: 1000 events per year with 1% natural Nd-loaded liquid scintillator in SNO++

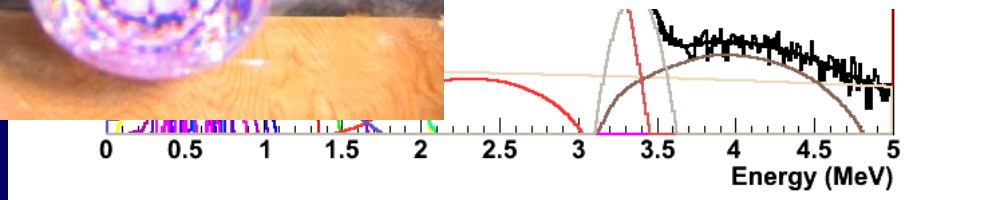




^{150}Nd SNO+ Summary

- stable Nd-loaded liquid sc
- scintillation optical proper
- tar
  pu
- ph
  –
  –
- thu
  loa





List of R&D Developments for SNO+

- developed the use of linear alkylbenzene as a solvent for large liquid scintillator detectors
  - high flash point, low toxicity, high light yield, long transmission length, inexpensive!
- developed Nd-loaded liquid scintillator (using same technique as for In, Gd loading)
- developed purification techniques to remove Ra, Th from Nd and Nd liquid scintillator
- physics potential: *pep* and *CNO* solar neutrinos, geoneutrino continental crust probe, double beta with Nd in liquid scintillator

SNO+ Project Status

- was funded by NSERC for R&D in 2005-2007; funded for continued development, engineering and transition activities in 2007-2008
- initial capital funding from NSERC for 2008-2010
- submission of full capital proposal to CFI in Q4 2008
- installation of hold-down net begins in Q2 2009
- installation of scintillator process and purification begins in Q2 2010
- end of 2010 → ready for scintillator filling

SNO+ Collaboration

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