The SNO+ Project

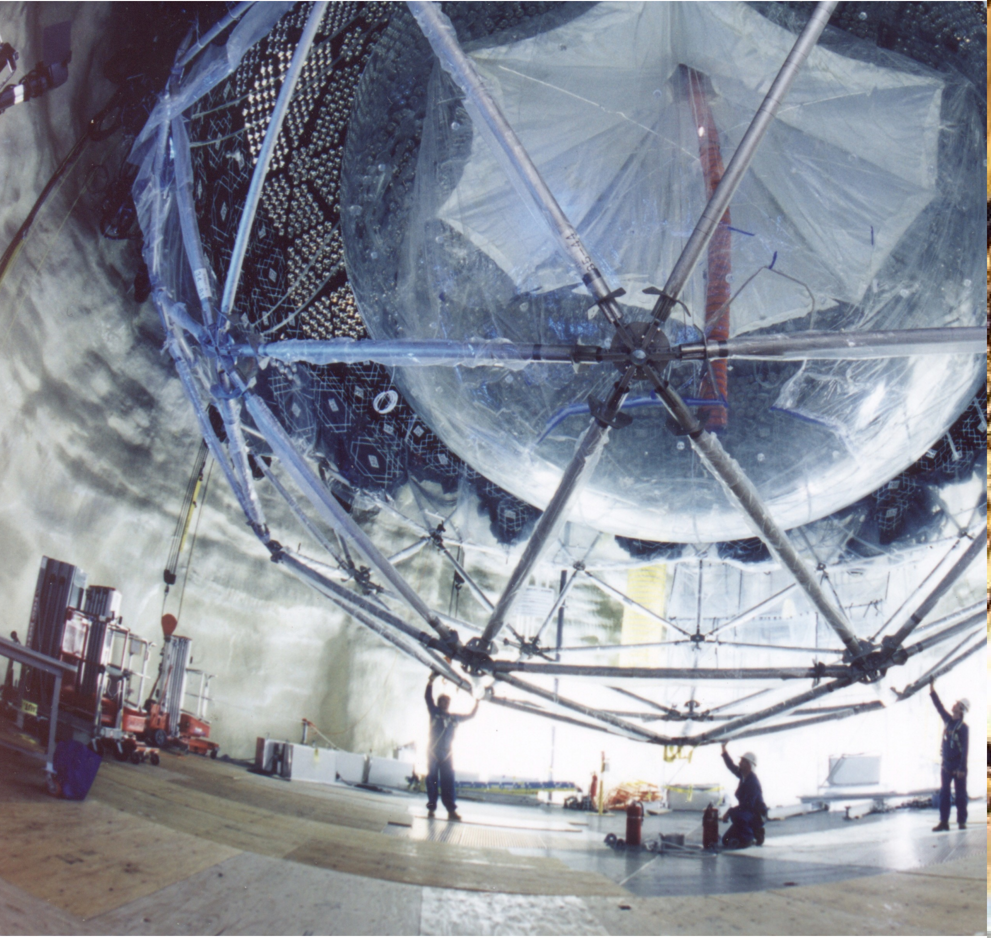
José Maneira, LIP-Lisboa
on behalf of the SNO+ collaboration
NWAP09, São Tomé
September 8, 2009

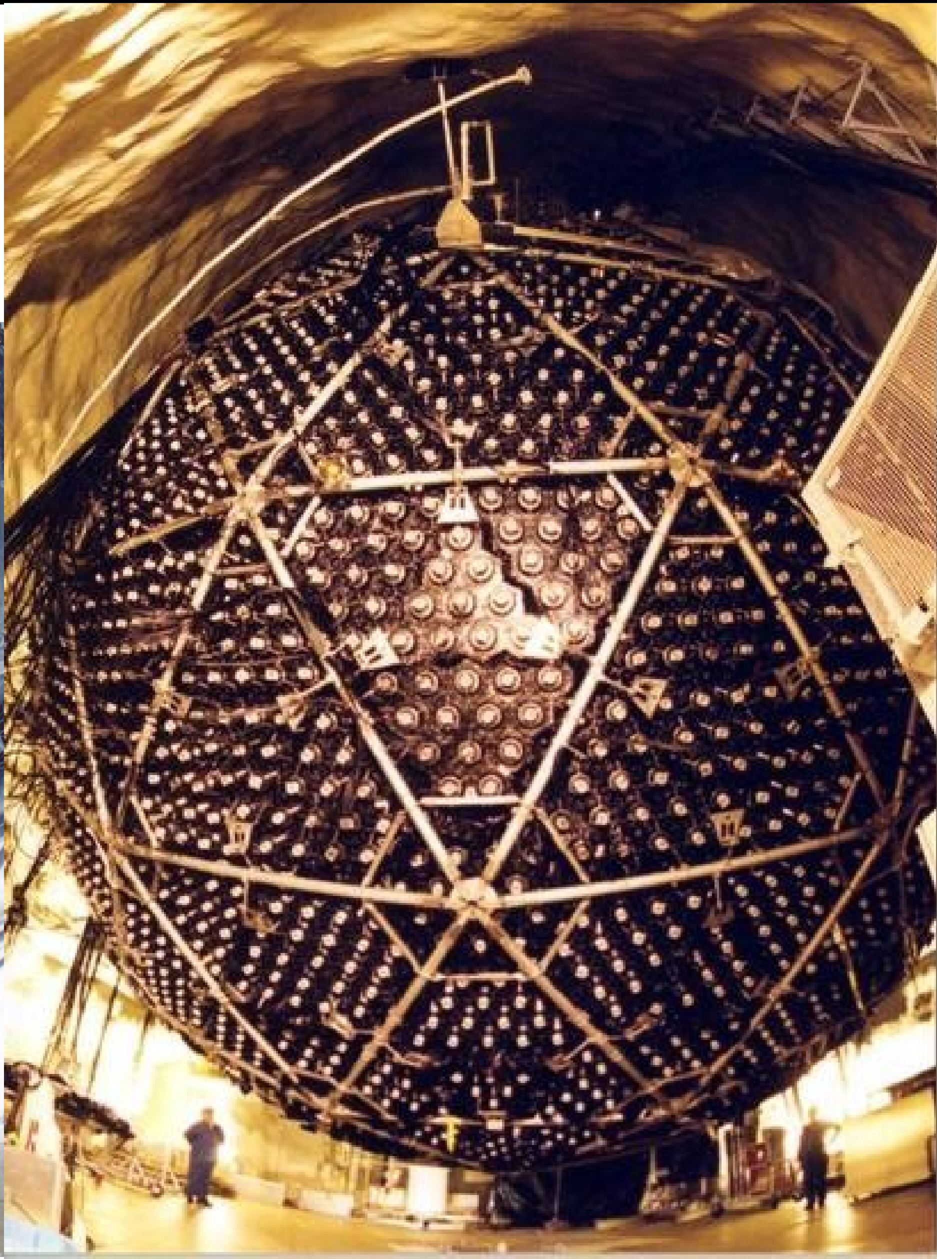
Outline

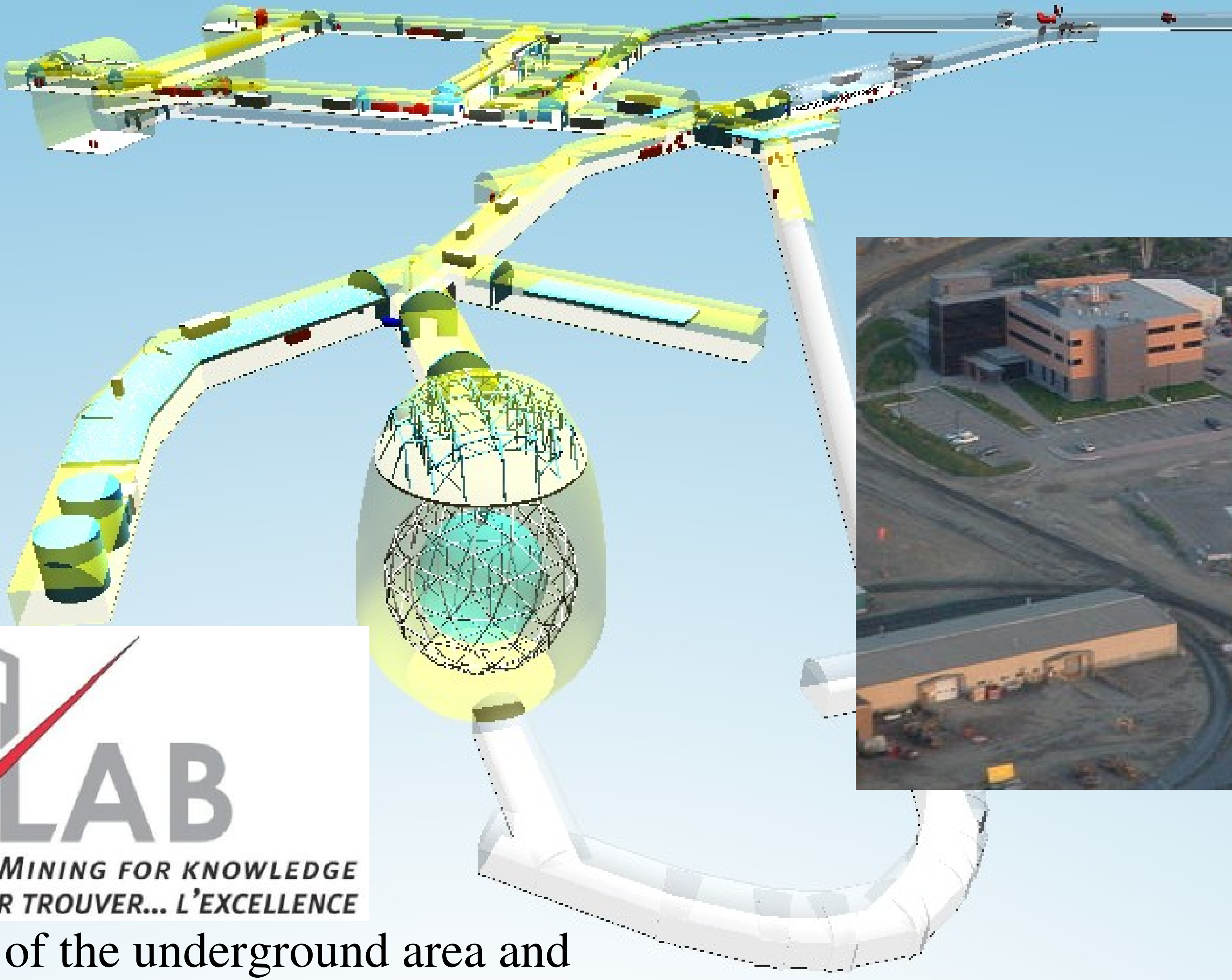
- Introduction
- Detector developments for SNO+
  - Scintillator
  - Acrylic Vessel
  - other
- Physics goals
  - Solar neutrinos
  - Geo-neutrinos
  - Reactor neutrinos
  - Supernova neutrinos
  - Double-beta decay

Sudbury Neutrino Observatory

- SNO
  - Deepest large underground detector
  - Can we re-use it after the heavy water phases?







SNOLAB

MINING FOR KNOWLEDGE

CREUSER POUR TROUVER... L'EXCELLENCE

Expansion of the underground area and
new surface facilities for SNO+ and several other
experiments in Dark Matter and Neutrino Physics


Cube Hall

Start of Clean conditions for the new SNOLAB: Feb. 2009

SNO+ Collaboration

University of Alberta
A. Bialek, P. Gorel, A. Hallin, M. Hedayatipoor, C. Krauss

Brookhaven National laboratory
R. Hahn, M. Yeh, Y. Williamson

Technical University of Dresden
K. Zuber

Idaho National Laboratory
J. Baker

Idaho State University
J. Heise, K. Keeter, E. Tatar, C. Taylor

Laurentian University
O. Chkvorets, E.D. Hallman, S. Korte, M. Schumaker, C. Virtue

University of Leeds
S. Bradbury, J. Rose

LIP Lisboa
S. Andringa, N. Barros, L. Gurriana, A. Maio, J. Maneira, L. Seabra

University of North Carolina at Chapel Hill
H. Howe, J. Wilkerson

Oxford University
S. Biller, P. Jones, N. Jelley, A. Reichold, J. Wilson-Hawke

University of Pennsylvania
E. Beier, R. Bonventre, W.J. Heintzelman, J. Klein, G. Orebi-Gann, J. Secrest, T. Sokhair

Queen's University
M. Boulay, M. Chen*, X. Dai, E. Guillian, P.J. Harvey, C. Kraus, X. Liu, A. McDonald,
H. O'Keefe, E. O'Sullivan, P. Skensved, A. Wright

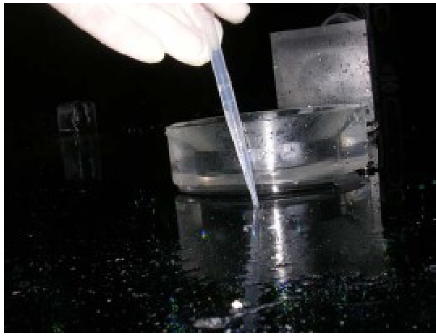
SNOLAB
B. Cleveland, F. Duncan, R. Ford, E.V. Jauregui, C.J. Jillings, I. Lawson

University of Sussex
E. Falk-Harris, S. Fernandes, J. Hartnell, S. Peeters

University of Washington
J. Kaspar, J. Nance, N. Tolich, H. Wan Chan Tseung

SNO+ plan

- End of SNO
  - Heavy water returned to AECL, to the last drop (really!)
  - Best analysis results still to come!
- SNO+
  - Replace D_2O by liquid scintillator
    - About the same mass as KAMland (800 t)
  - Very deep (6080 mwe) , good for pep and CNO solar neutrinos
    - KamLAND 1000 t at 2700 mwe
    - Borexino 300 t at 3500 mwe
  - Also geo-neutrinos, reactor and supernovae neutrinos
- SNO+ Nd phase
  - Neodymium-loaded liquid scintillator
  - Search for neutrinoless double-beta decay

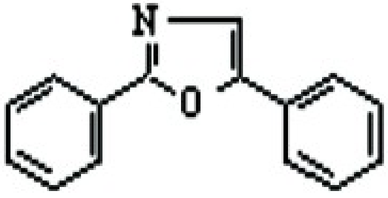


Ongoing developments for SNO+

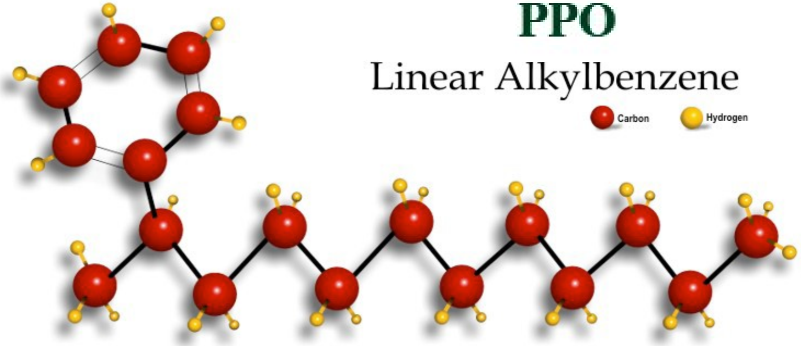
- Find a characterize a suitable scintillator
- Design and install purification plants
- Re-engineer Acrylic Vessel support for buoyancy force
- Maintenance of SNO cavity
- Re-design calibration systems
- Electronics maintenance and upgrades
- Software developments

Scintillator development

- “New” scintillator developed: LAB
  - Compatible with acrylic, undiluted
  - High light yield
  - Optical transparency
  - Low scattering
  - Fast decay, different for alpha/beta
  - High flash point, low toxicity

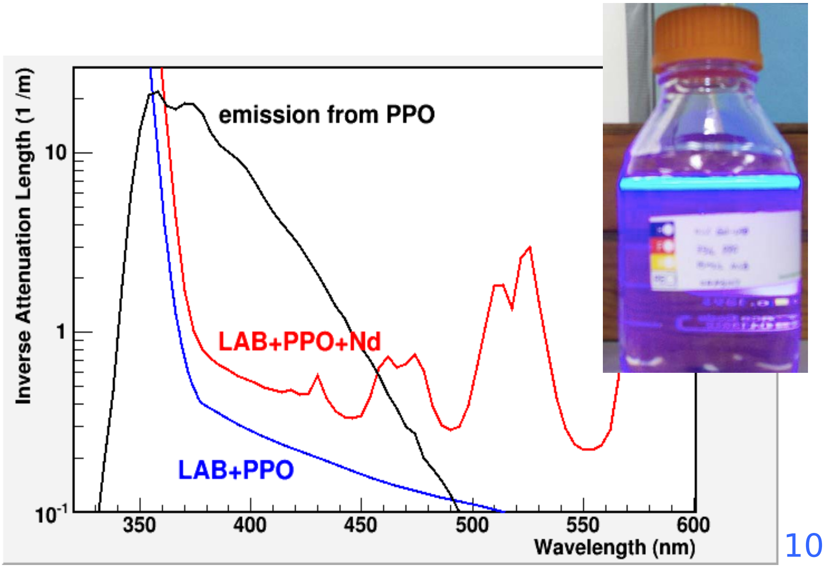


PPO



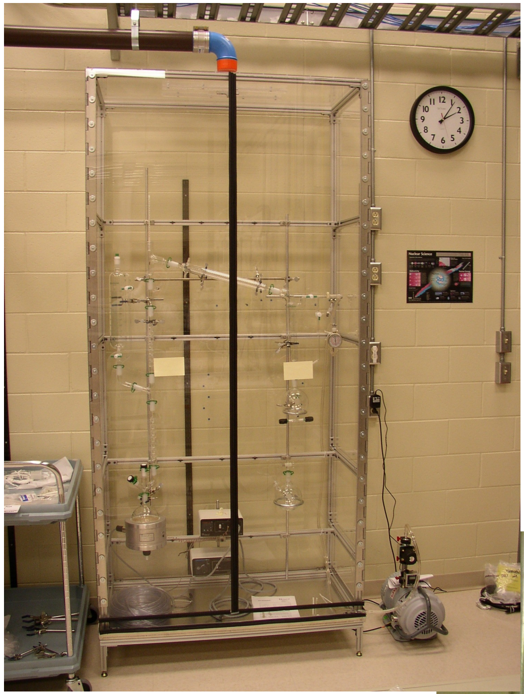
Linear Alkylbenzene

- Developing also metal-loading
  - Organometallic Nd compound
  - Nd has poor transparency
  - Considering a low loading of 0.1 %
  - That's ~50 kg of Nd-150 with natural Neodymium, not a small amount…



Purification systems

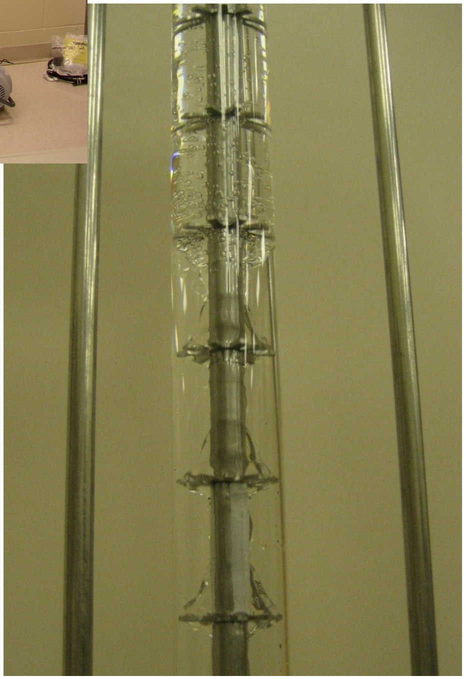
- Several fluids to handle
  - Light water
  - Bulk scintillator
  - Fluor (PPO) solution
  - Neodymium-loaded compound
- Scintillator plant
  - Distillation
  - Water extraction
  - Gas removal
  - Filtration and ultra-filtration
  - R&d on metal scavenger columns
- Goals
  - Scintillator purity of $1\text{x}10^{-17}$ g/g U/Th
    - Reached by Borexino
    - C-14,Kr-85 not a problem because of low energy, C-11 not a problem because of depth
  - Nd-compound purity of $< 1\text{x}10^{-14}$ g/g U/Th
    - Need factor of 10^{6} reduction



Distillation

Test plants
at SNOLAB

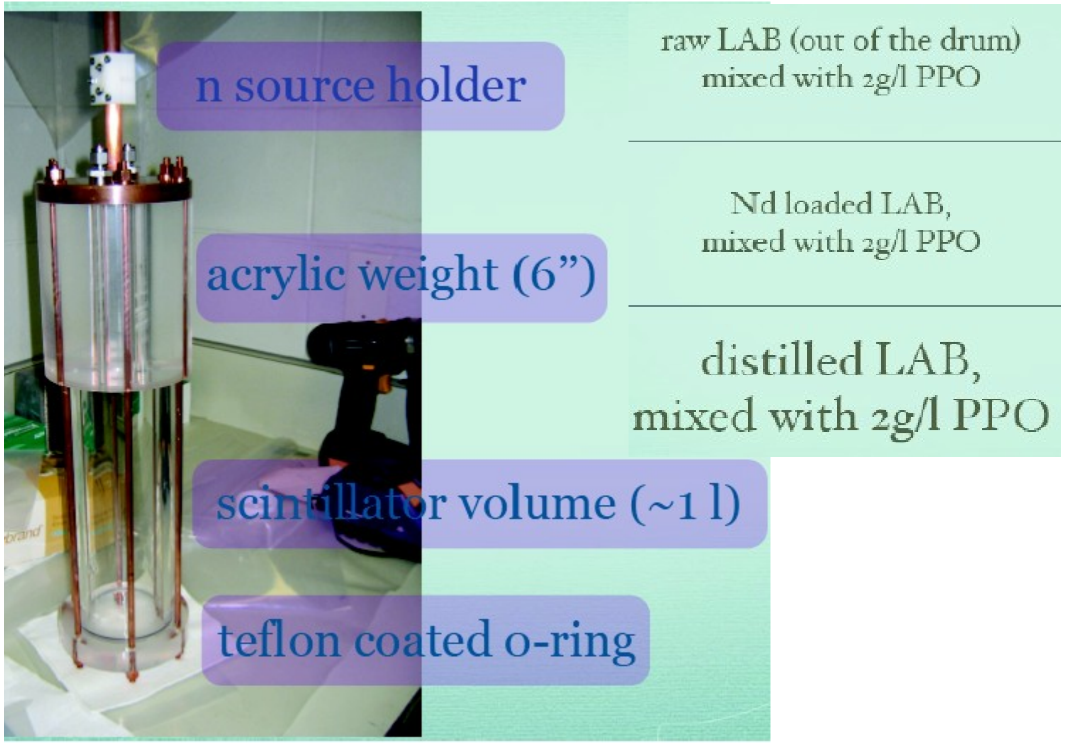
Water extraction



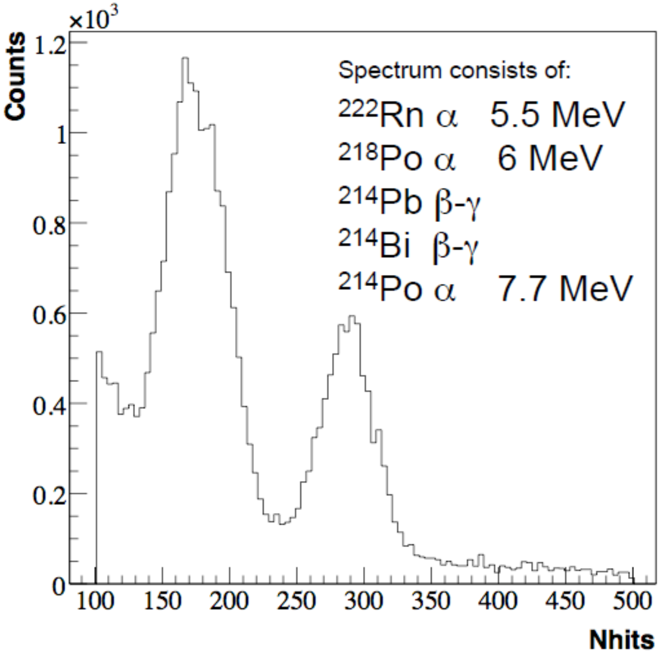
Scintillator tests in SNO

- “Bucket” source
  - 3 types of scintillator
  - with/without neutron source
  - Deployed Fall 2008, while AV was full with water

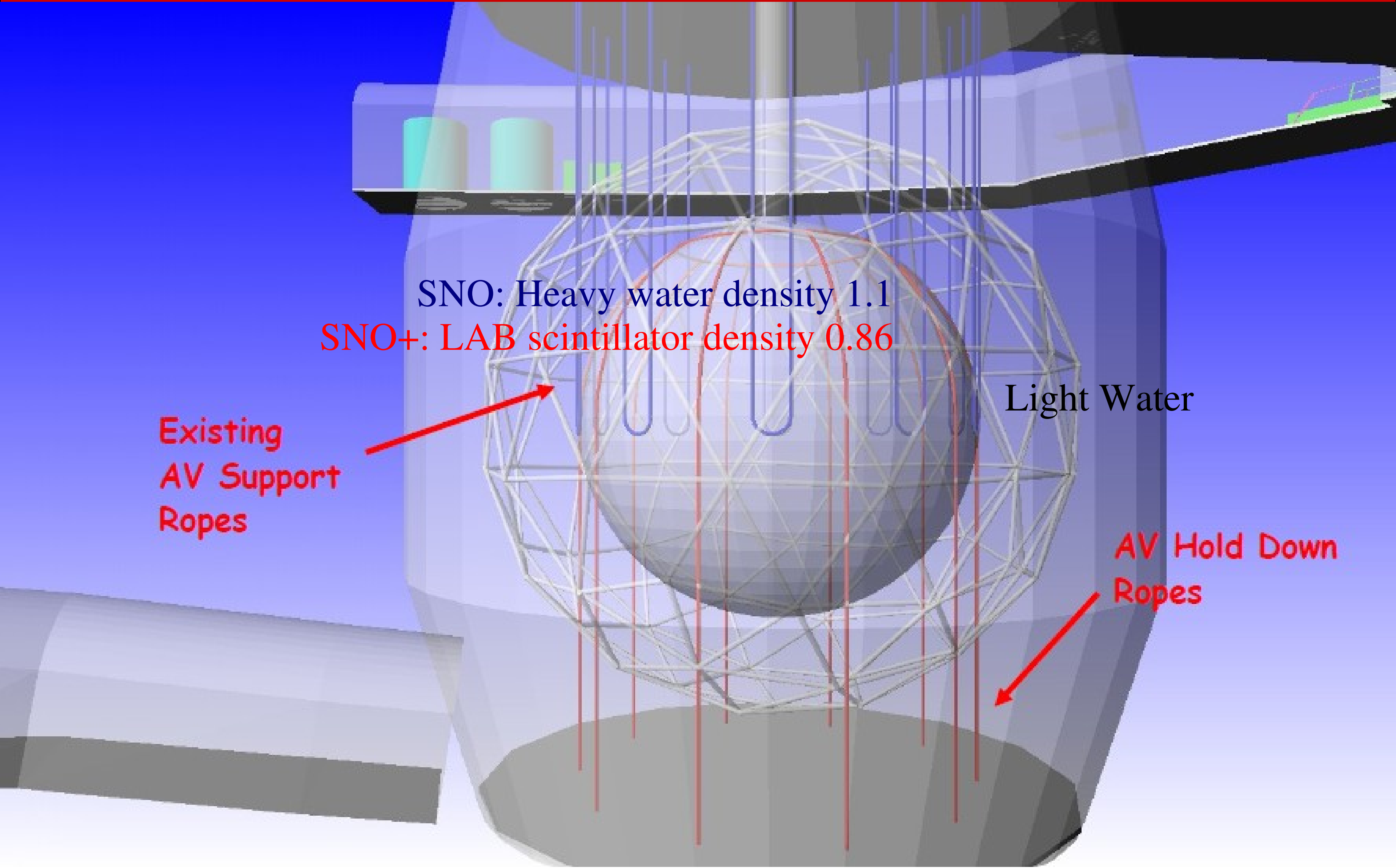
- Results
  - Light yields
  - Resolution 3.5% at 3.4 MeV
  - Alpha quenching factors
  - Birks parameters



Spectrum in raw Nhits



AV support

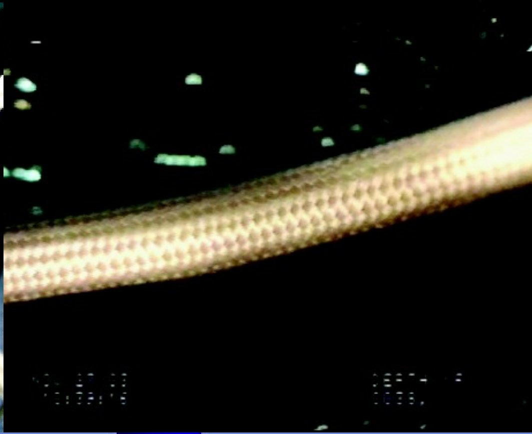


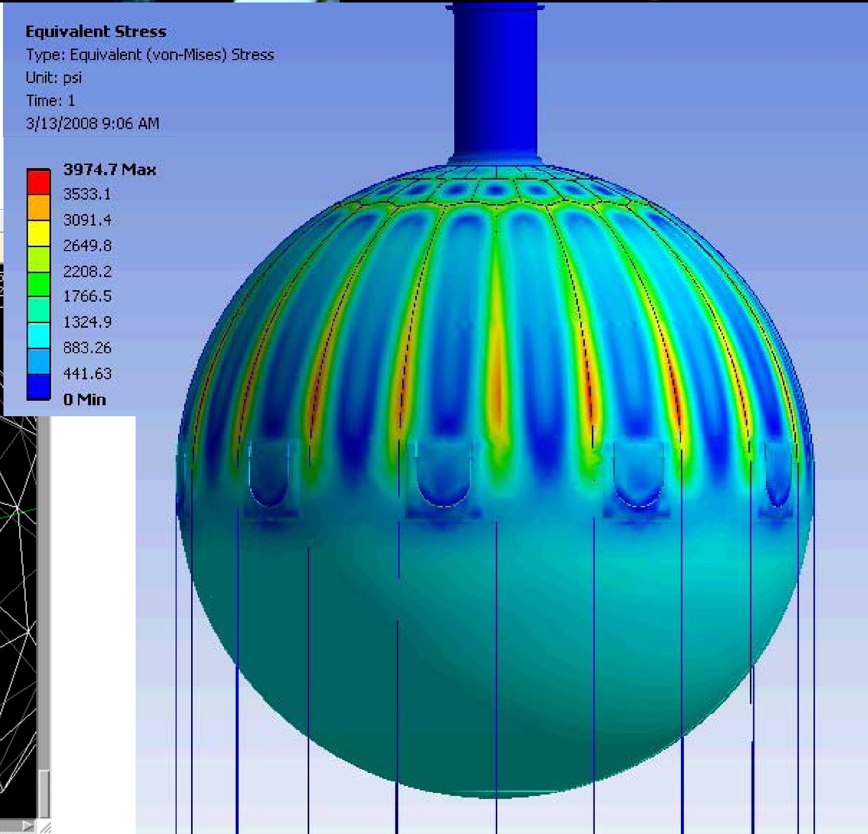
SNO: Heavy water density 1.1

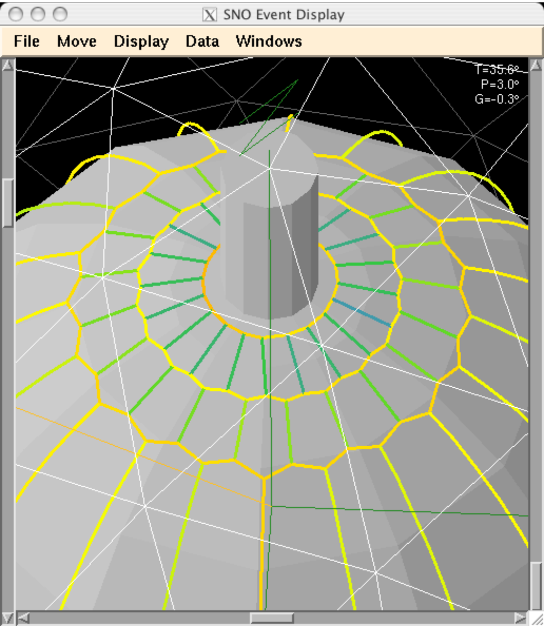
SNO+: LAB scintillator density 0.86

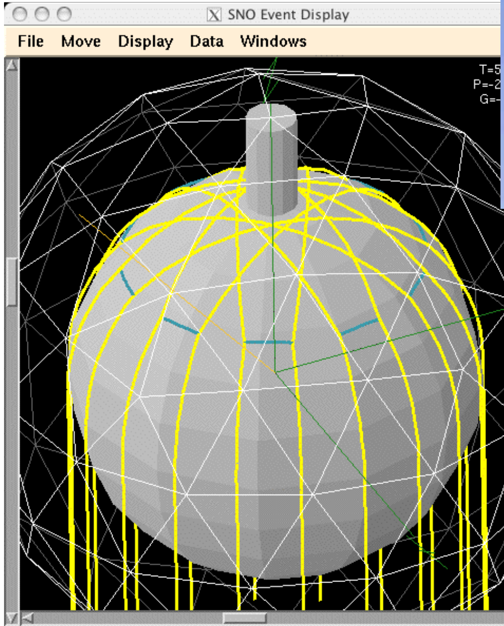
Acrylic vessel hold-down

- New rope system
  - Finite element analysis of AV stress and buckling done
  - Material constraints
    - Strength (reduced thickness)
    - Radiopurity (external background)
    - Tensylon chosen
  - Will replace also old support ropes



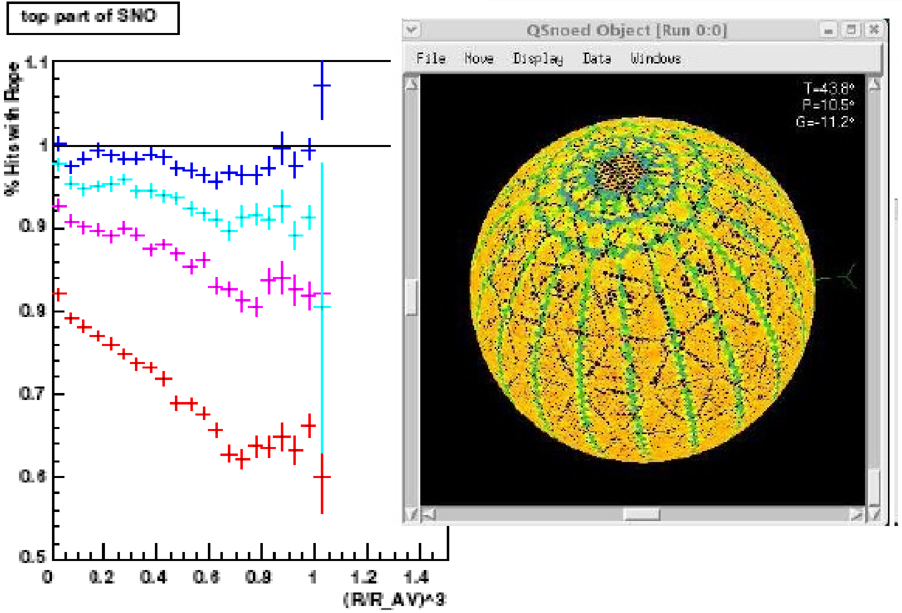


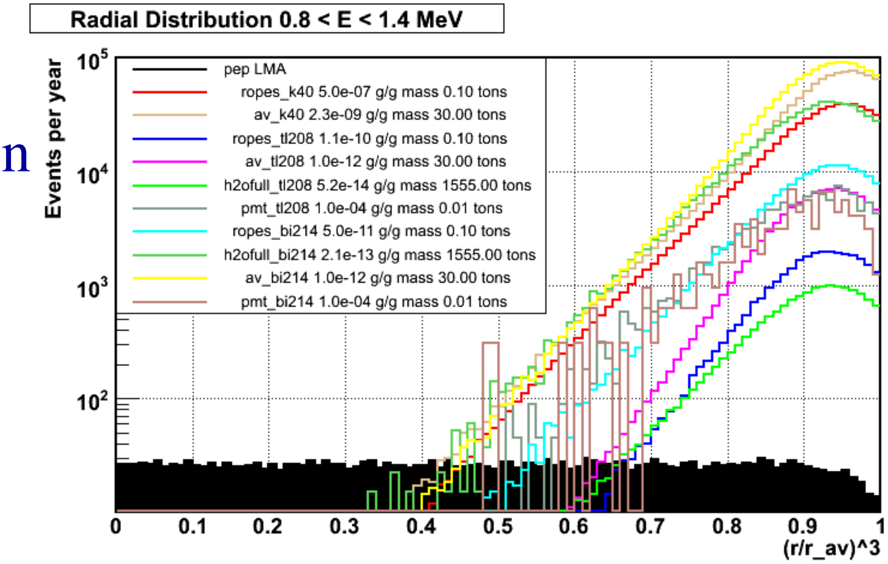




Detector simulation

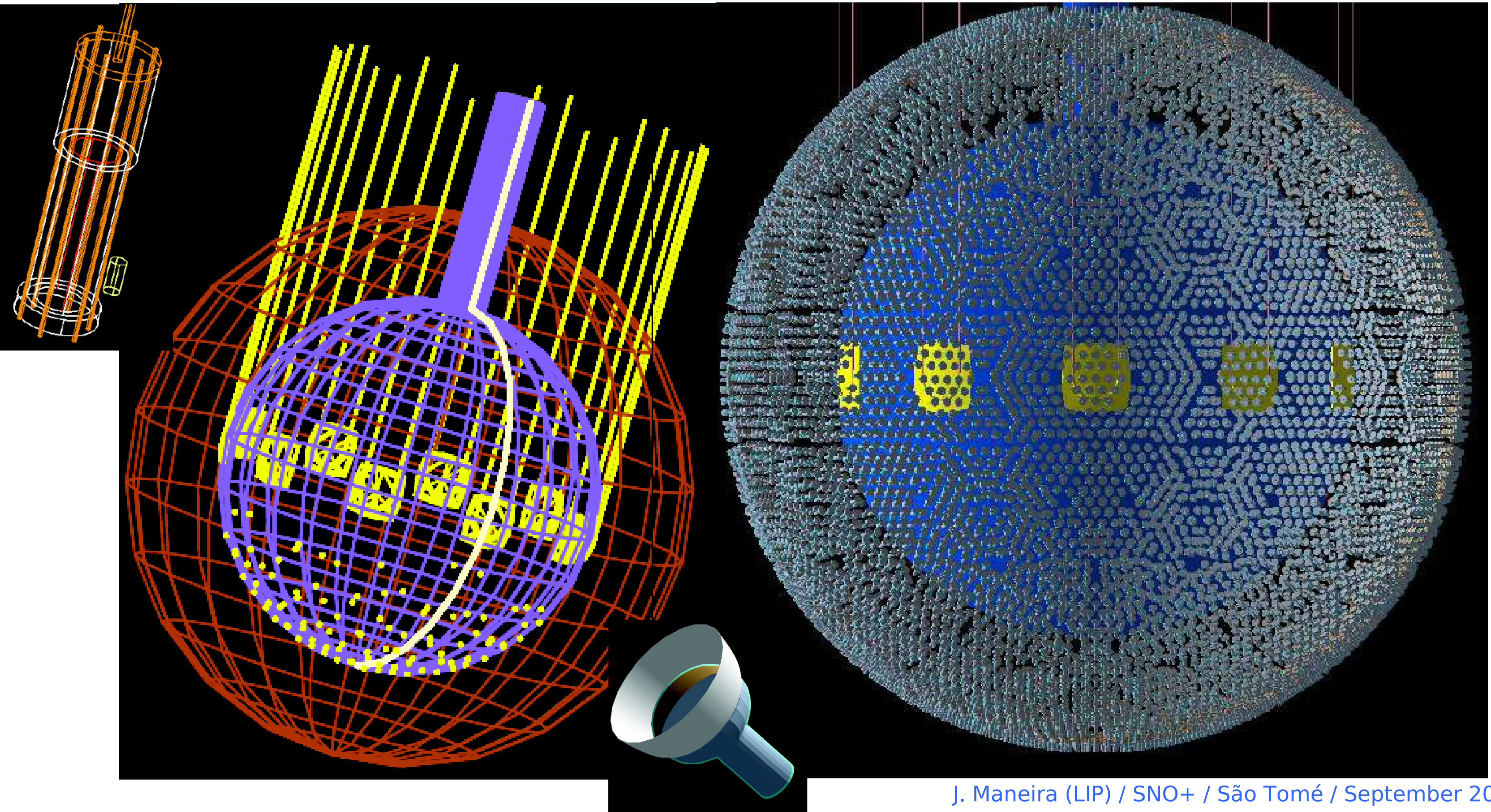
- Existing SNO simulation
  - SNOMAN: very detailed FORTRAN package
  - Adapted for liquid scintillator
  - Adapted with new rope geometry
- Used for rope design
  - Light loss in function of rope thickness
    - 5 cm acceptable
  - External background in function of material radiopurity
    - For solar neutrinos: 1 ppm of nat. potassium
    - For Nd DBD, 200 ppt of Th-232
    - Tensylon OK!





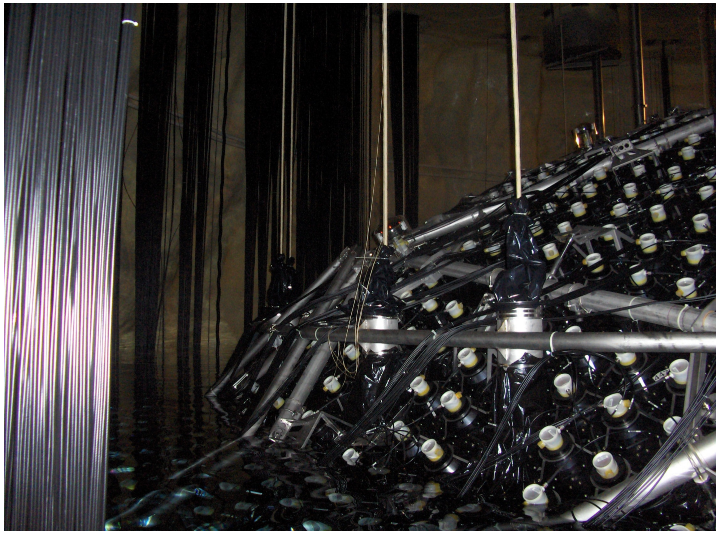
New SNO+ simulation

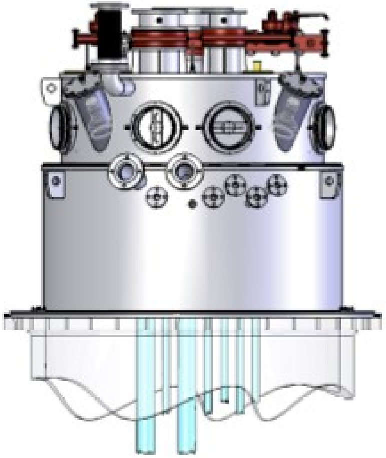
- Based on GEANT4
  - Adapted from GLG4sim and Braidwood package
  - In development now, being validated against SNOMAN and “bucket” source data

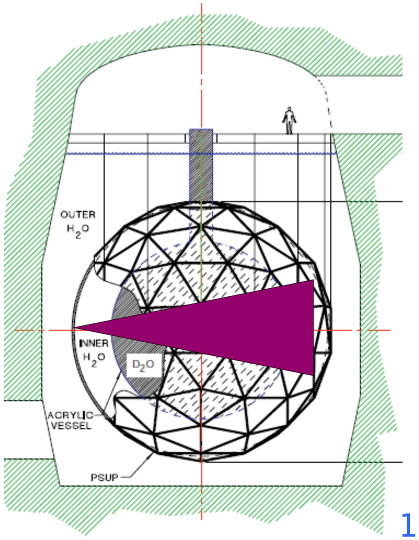


Other HW upgrades

- Electronics
  - Replace some boards
  - Improve data rate capacity
  - Re-map PMTs, matching dead ones with dead channels
  - Improve stock of spares
- Calibrations
  - Make existing HW scintillator compatible
    - New radon-sealed glove-box
    - Replace umbilicals
  - Make new, lower-energy, sources
  - Design new systems to calibrate from outside the AV
- Detector cavity
  - Re-seal floor lining



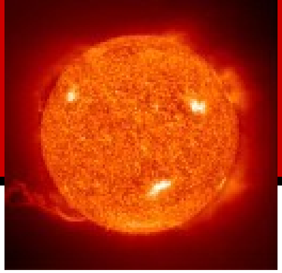




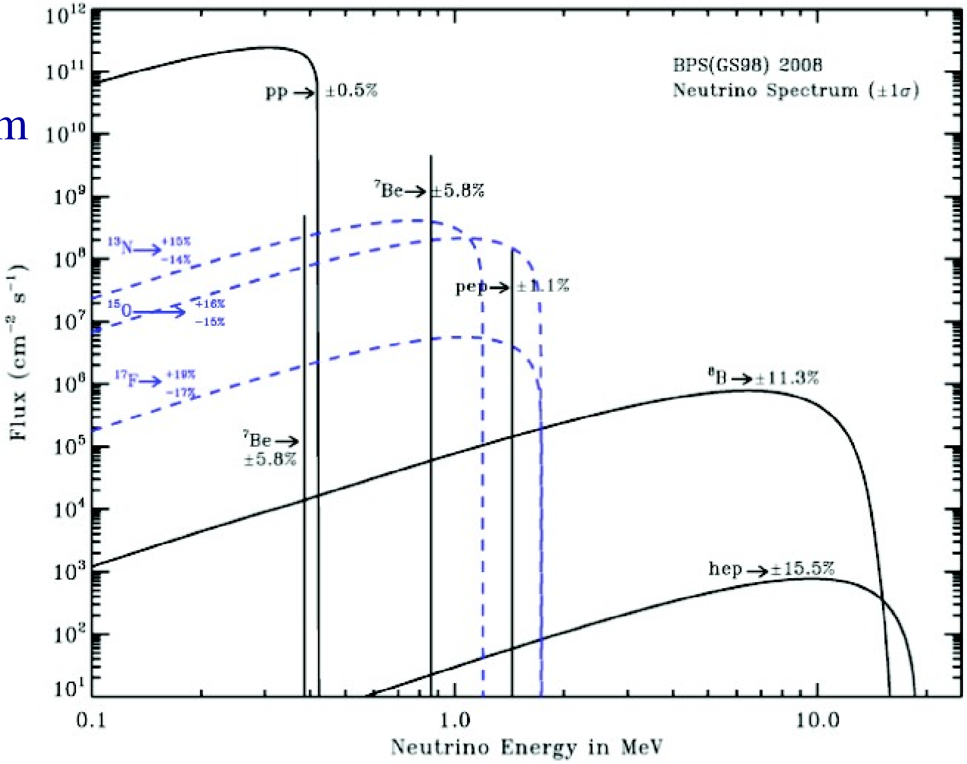
Physics program

- Solar neutrinos
- Reactor and Geo-neutrinos
- Neutrinos from Supernovae
- Neutrinoless Double-Beta Decay

Solar neutrinos



- Neutrino sources
  - Super-K and SNO measured ^{8}B
  - Borexino measured ^{7}Be
  - Subtracting ^{8}B and ^{7}Be, pp comes from Ga experiments
  - Still missing pep and CNO!
- Oscillations at low energy
  - New Physics models predict different survival probabilities in vacuum-matter transition region
  - Measurement reaction is ES
    - Need total flux from SSM
  - (after pp), pep is the best-known SSM flux
    - 1.1 % (2.8% from metallicity)
    - ^{7}Be: 5.8% (10% from metallicity)



New questions about the Sun

Metal abundances and helioseismology

- Improved 3-D models give a 30% lower metallicity (X)
- But then the sound speeds disagree with helioseismology!
- What if the Sun's metallicity is not homogenous?
  - According to Haxton and Serenelli, the core could have a higher X than the convective zone

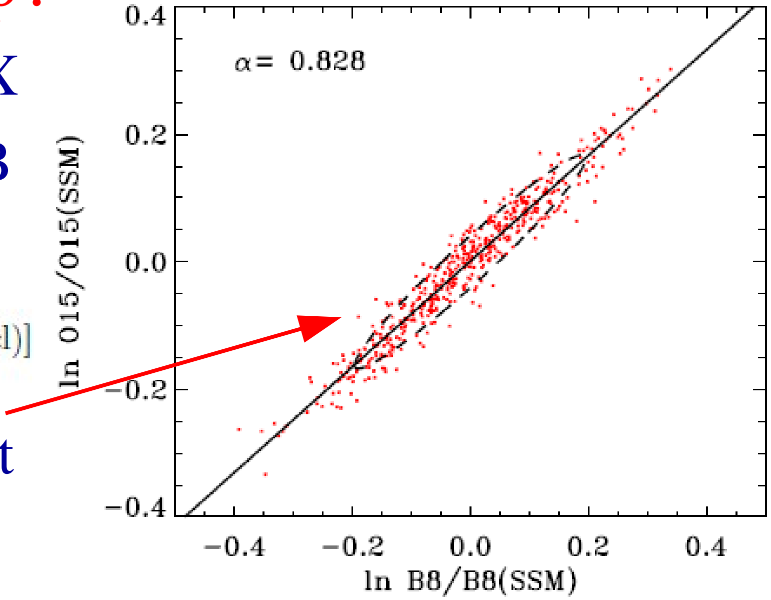
Can neutrinos (and SNO+) help?

- CNO neutrinos depend linearly on X
- Temperature dependence same as ^{8}B

$$\frac{R^{SNO+}(CN)}{R^{SSM}(CN)} = \frac{X(C+N)}{X^{SSM}(C+N)} \left(\frac{R^{SK}(^8B)}{R^{SSM}(^8B)}\right)^{0.828} \times [1 \pm 0.03(SK) \pm 0.026(\text{res env}) \pm 0.049(\text{LMA}) \pm 0.071(\text{nucl})]$$

- A measurement of CNO neutrinos at SNO+ can help pin down the Sun's metallicity

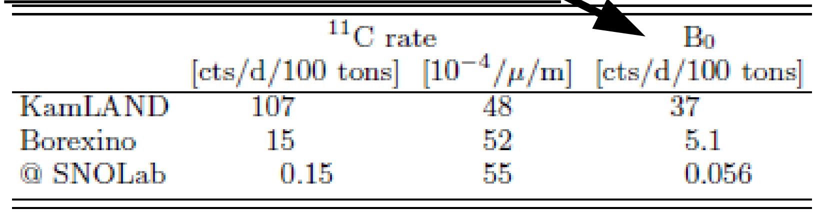
Haxton, Serenelli, astro-ph/0902.0036v1



Why SNO+ for pep?

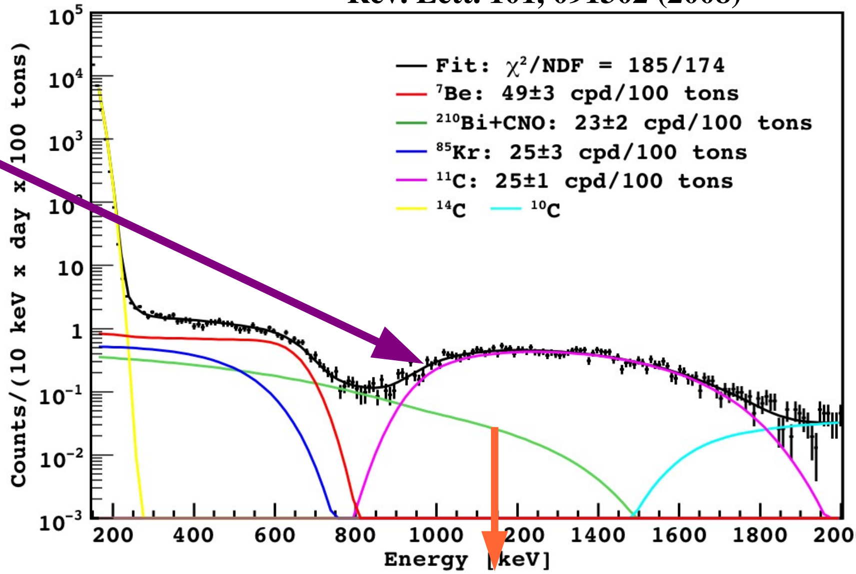
- Cosmogenic backgrounds
  - Carbon-11 decays cover pep and CNO energy window
    - Seen by Borexino and KamLAND

C-11 counts within 0.8-1.3 MeV



	^{11}C rate		B_0
	[cts/d/100 tons]	[$10^{-4}/\mu/m$]	[cts/d/100 tons]
KamLAND	107	48	37
Borexino	15	52	5.1
@ SNOLab	0.15	55	0.056

Franco, Galbiati et al., Phys.Rev.C71:055805,2005



Borexino Collaboration, Phys. Rev. Lett. 101, 091302 (2008)

pep edge

- Depth matters
  - Carbon-11produced by cosmic muons hitting organic molecules
  - SNO+ (6080 mwe) 100 times better than Borexino (3500 mwe), 600 times better than KamLAND (2700 mwe)
    - Borexino developing C-11 cut, SNO+ will not need it

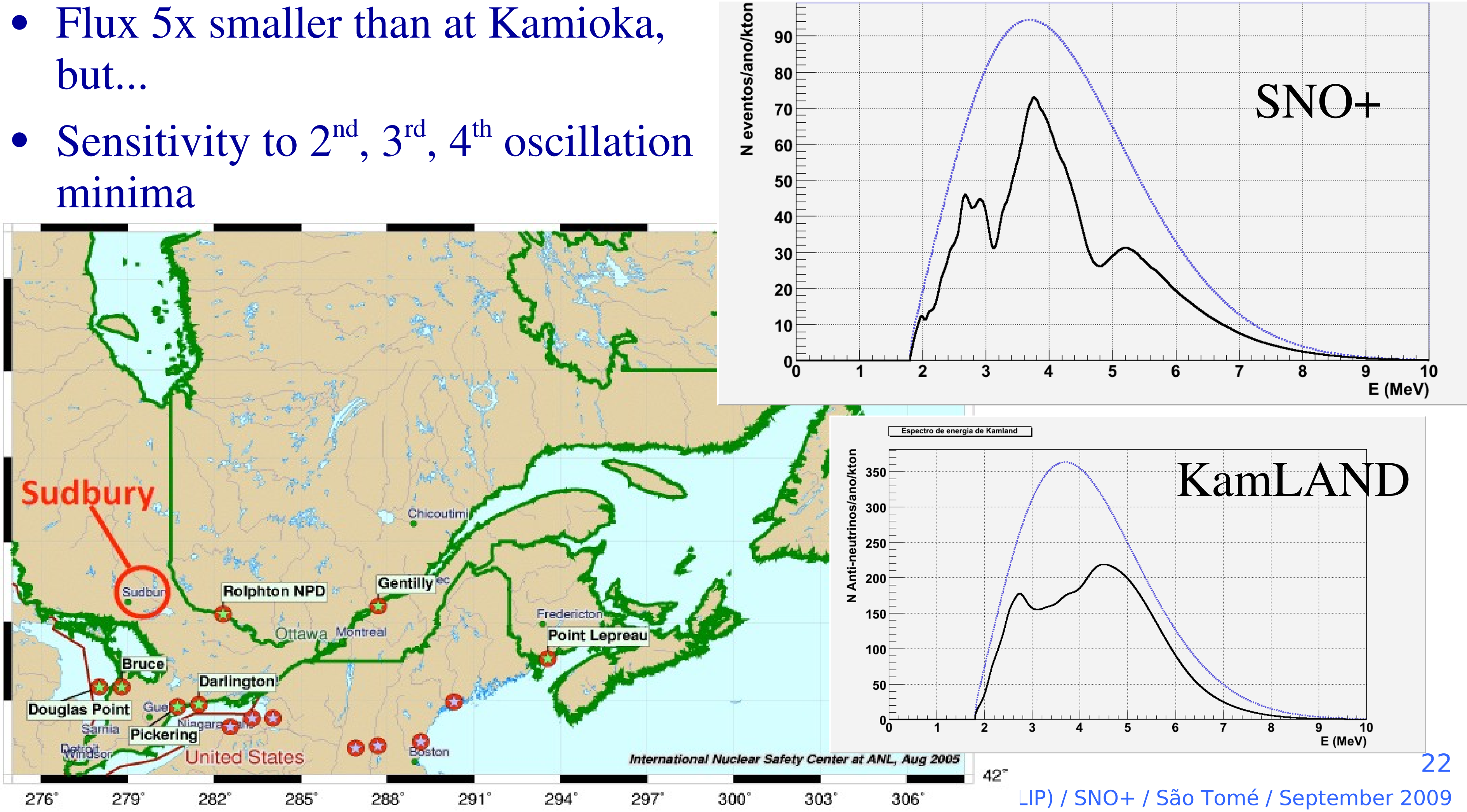
Reactor Neutrino Physics

Detection Rate

$$45.4\ \text{Events}\cdot\left(\frac{100\ \text{km}}{\text{Distance}}\right)^2\cdot\left(\frac{\text{Power}}{1\ \text{GW}_t}\right)\cdot\left(\frac{\#\ \text{protons}}{10^{32}\ \text{free protons}}\right)\cdot\left(\frac{\text{Live Time}}{1\ \text{year}}\right)$$

(Oscillation included)

- Flux 5x smaller than at Kamioka, but...
- Sensitivity to 2nd, 3rd, 4th oscillation minima

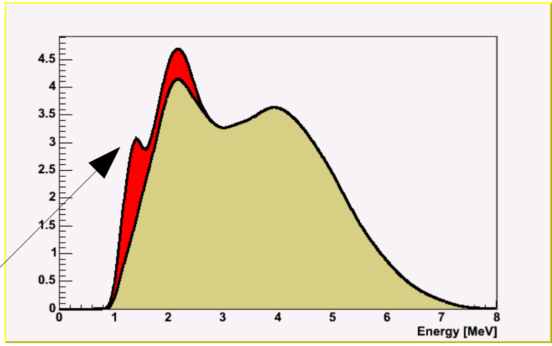


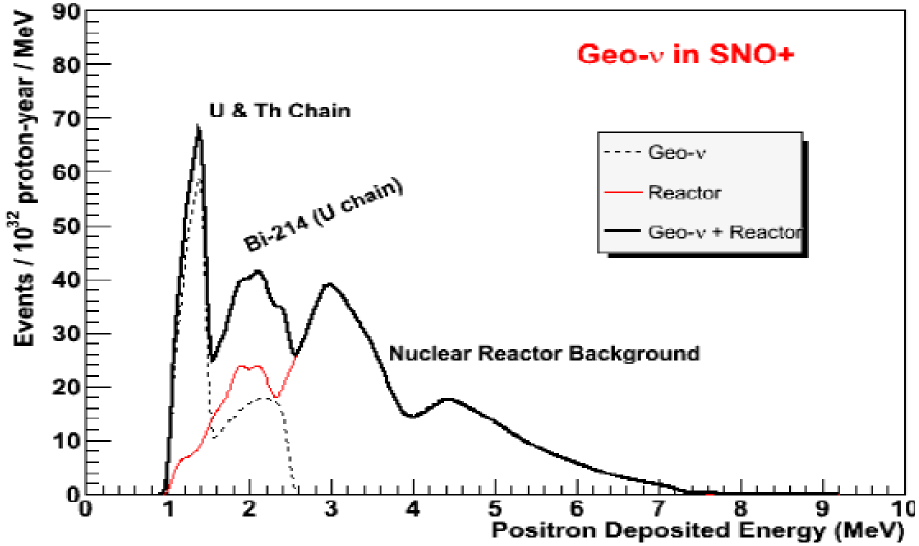
Geo-neutrinos

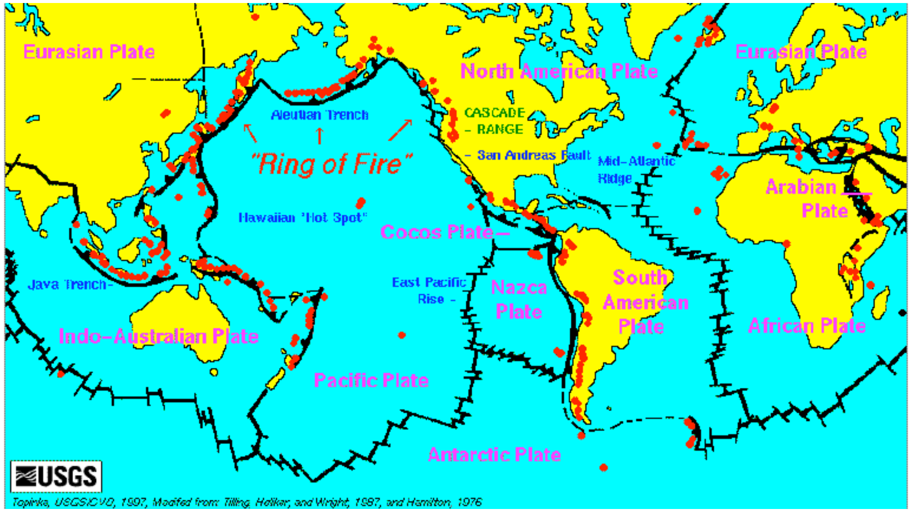
- Production
  - Anti-neutrinos from U-238, Th-232 and K-40 on Earth
  - Contributions from crust and mantle depend on location
    - 20% from mantle at SNO+
    - Check models of Earth heat production
- Detection

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

  - Around 20 events per year (efficiencies included)
  - Smaller background from reactors than KamLAND



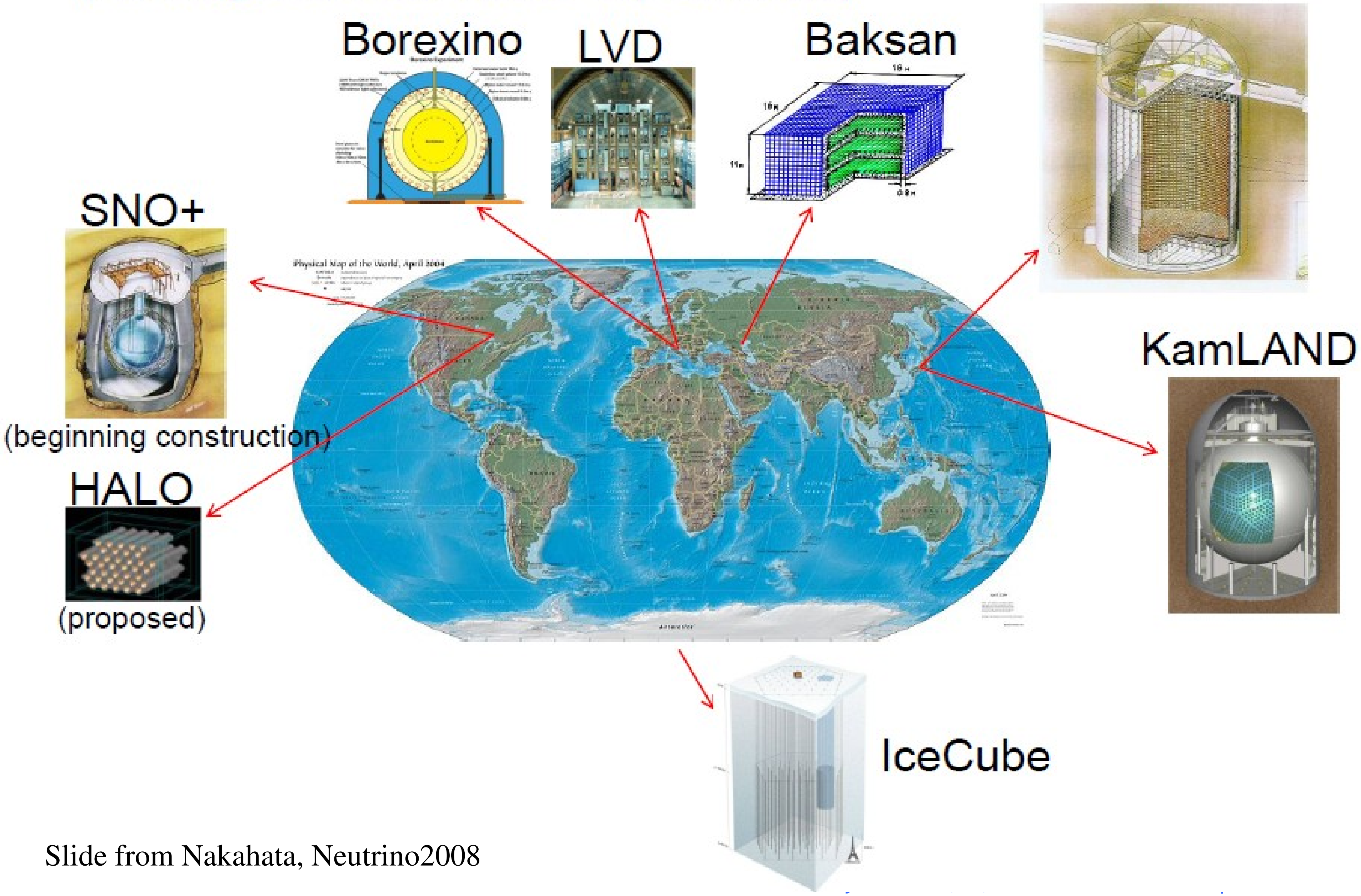




Topinka, USGS/CVO, 1997, Modifed from: Tilling, Heliker, and Wright, 1987, and Hamilton, 1976

Supernova detectors in the world

(running and near future experiments)



Borexino

LVD

Baksan

Super-K

SNO+

(beginning construction)

HALO

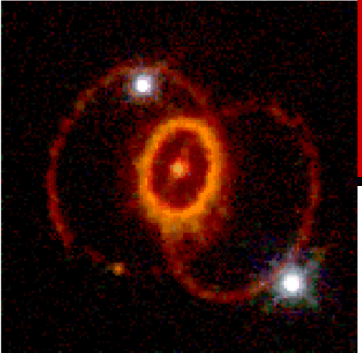
(proposed)

KamLAND

IceCube

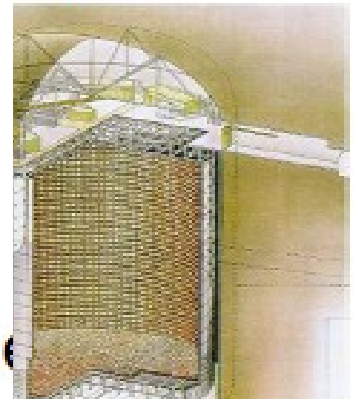
Slide from Nakahata, Neutrino2008

Supernovae



SNO
until 2006

uper-K

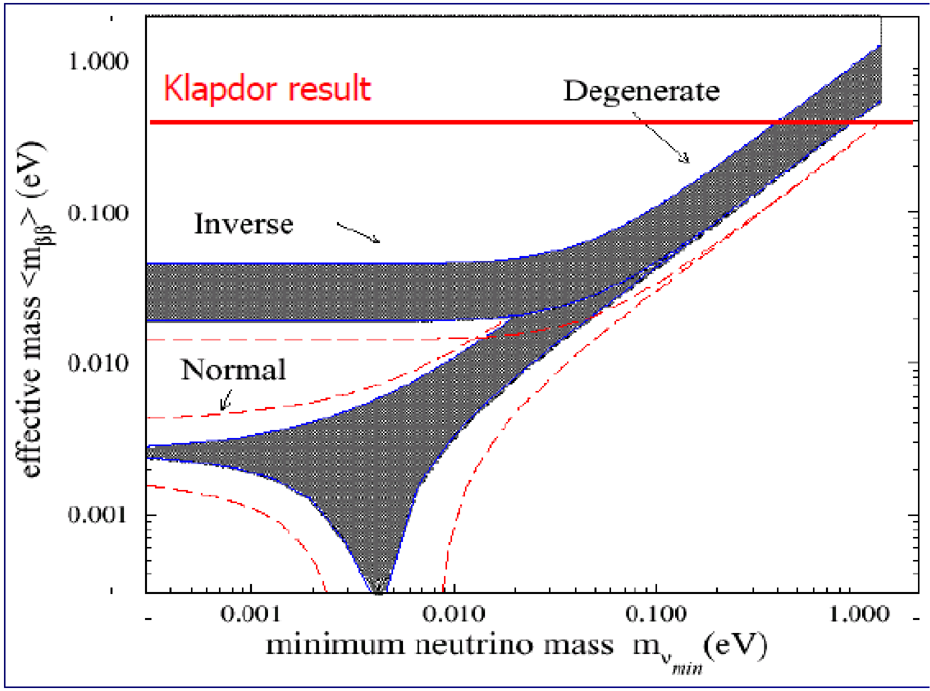


IceCub

- SNEWS
  - Supernova Early Warning System
  - Detection coincidence gives alert to astronomical community
  - SNO was in until Nov. 2006, SNO+ will join
- SNO+ SN signal from 10 kpc
  - About 600 events (1/10 of SuperK)
  - ½ Charged Current, ½ Neutral Current

Double-beta decay at SNO+

- Physics of neutrinoless double-beta decay
  - Already covered in Kai's talk
  - Very fundamental process: are neutrinos their own anti-particles?
  - Important to measure with different isotopes
    - Huge uncertainties in nuclear matrix elements
    - Must be careful in relating results to neutrino mass
- Experimental challenge
  - With respect to solid detectors:
  - Advantages of SNO+
    - Large mass
    - Low background
  - Disadvantages
    - Poor energy resolution



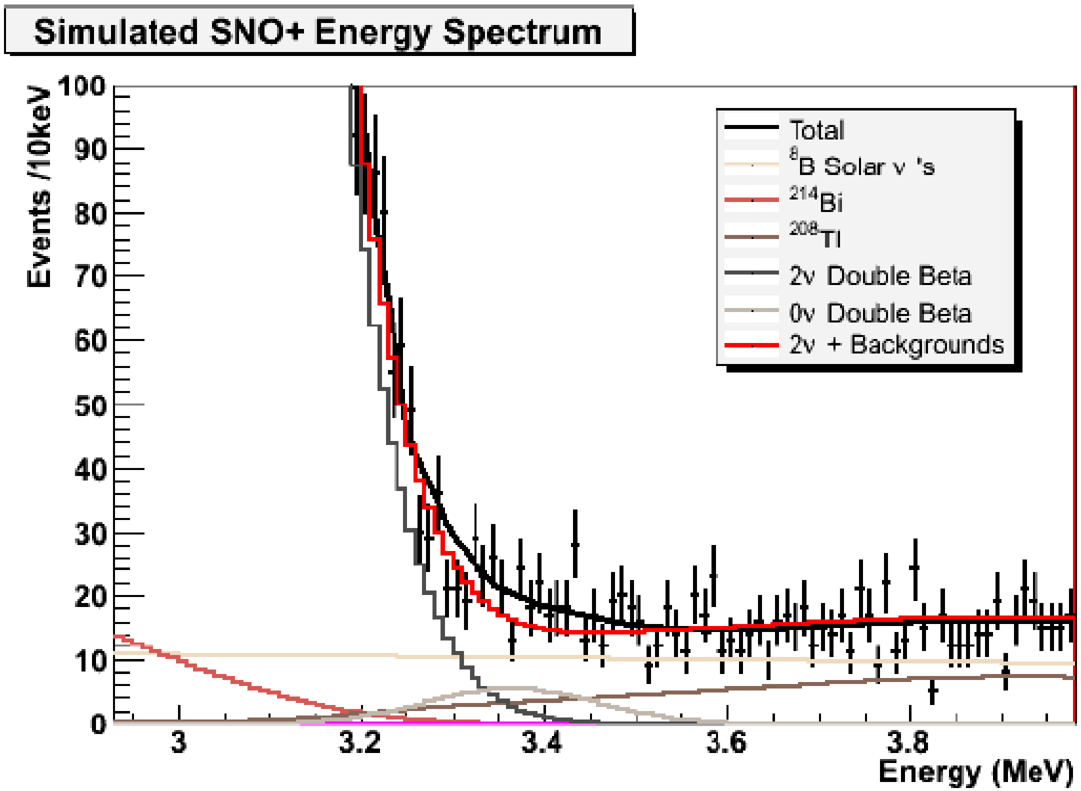
Double-beta decay at SNO+

- Neodymium loading in liquid scintillator
  - Successfully loaded large fractions of Neodymium in LAB
  - Optics properties suffer though, aiming for 0.1% loading
    - Attenuation measured, light yield expected at ~400 p.e./MeV
  - Natural Neodymium has 5.6% of Nd-150, that's about 56 kg
- Advantages of Neodymium
  - High endpoint of Nd-150: 3.37 MeV
    - Large decay phase-space, low backgrounds
  - Not expensive (86 kUS$/ton of $NdCl_3$)
  - 56 kg of Nd-150 compared to other isotopes:

	Phase-space only	QRPA matrix elements (large uncertainties!)
^{136}Xe	220 kg	1500 kg
^{130}Te	230 kg	400 kg
^{76}Ge	950 kg	570kg

Nd signal simulation

56 kg of ^{150}Nd and $\langle m_\nu \rangle = 100$ meV



- 6.4% FWHM at Q-value
- 3 years livetime
- U, Th at Borexino levels
- 5σ sensitivity
- note: the dominant background is ^{8}B solar neutrinos!
- ^{214}Bi (from radon) is almost negligible
- ^{212}Po-^{208}Tl tag (3 min) might be used to veto ^{208}Tl backgrounds; ^{212}Bi-^{212}Po (300 ns) events constrain the amount of ^{208}Tl

Expected timeline