Double Beta Decay Options and the Future of the SNO Detector

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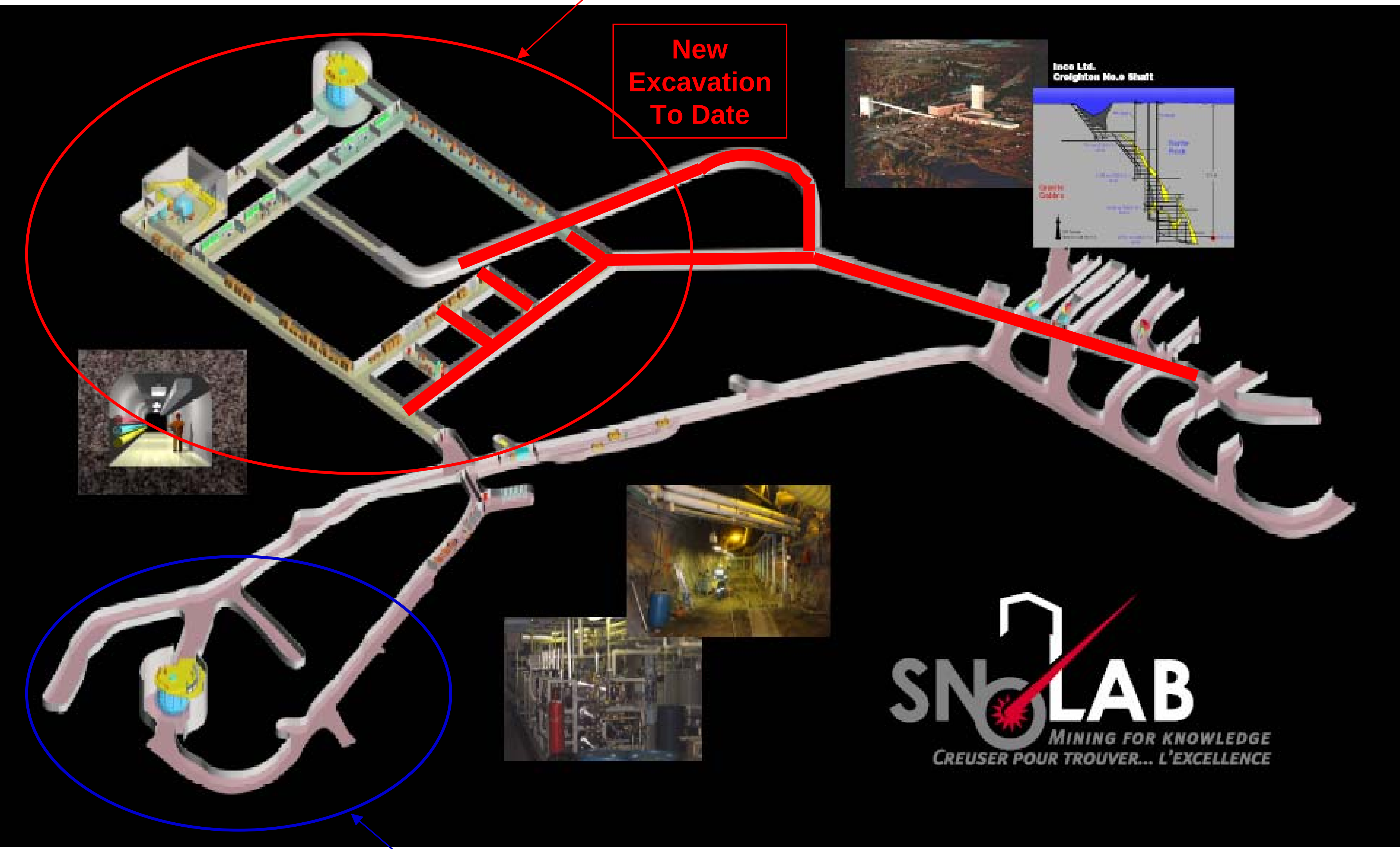
Queen’s University
JPS/DNP Hawaii, September 2005

The New SNOLAB



SNO

Plans for SNO

- SNO runs with D_2O and He-3 counters through December 2006
- 2007- return heavy water
- Add scintillator: **SNO+** (green light from SNOLab EAC, need to develop a full proposal)
  - liquid scintillator procurement
  - mechanics of new configuration, AV certification
  - fluid handling and safety systems
  - scintillator purification
  - spare parts for electronics?
- 2007- SNOLab experiments underway
- Add double beta decay candidates **SNO++**

SNO+: Low Energy Solar ν

WE RECOMMEND DEVELOPMENT OF AN EXPERIMENT TO MAKE PRECISE MEASUREMENTS OF THE LOW-ENERGY NEUTRINOS FROM THE SUN.

SSM pep flux:

uncertainty ±1.5%

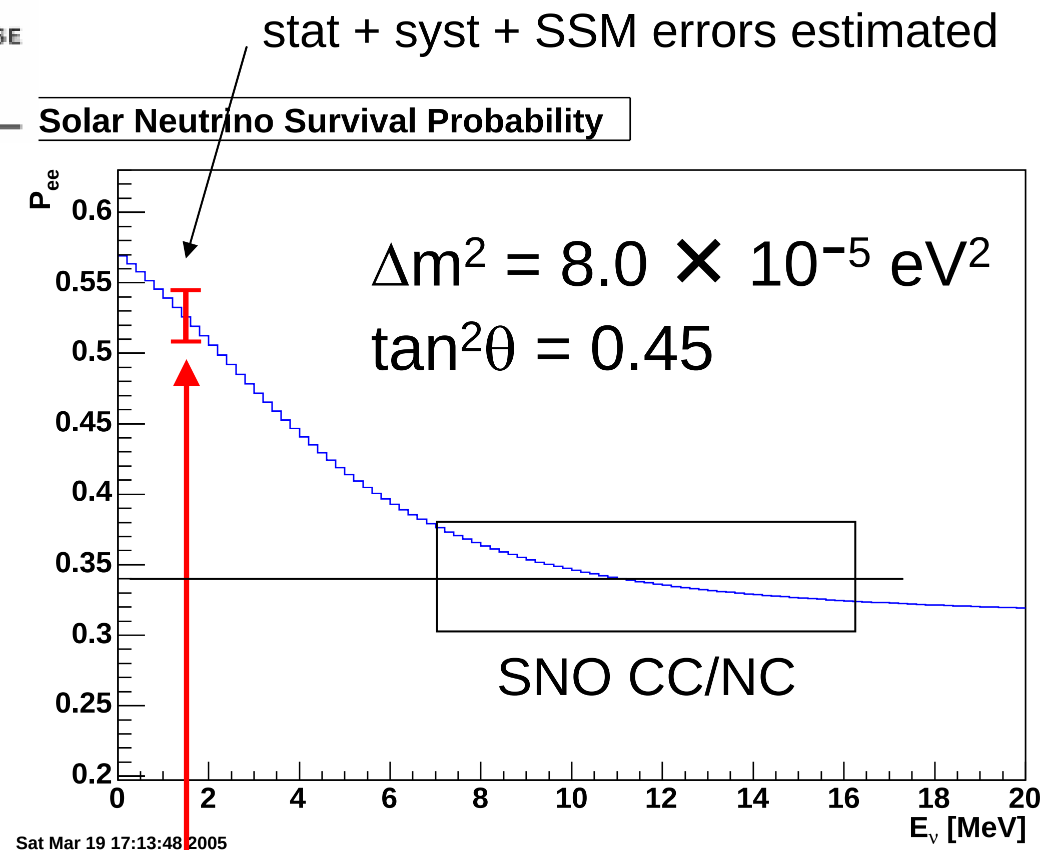
known source → precision test

improves precision on θ_{12}

transition from matter to vacuum dominance…tests the neutrino-matter interaction

sensitive to new physics:

- non-standard interactions
- solar density perturbations
- mass-varying neutrinos
- CPT violation
- large θ_{13}
- sterile neutrino admixture



observing the rise confirms MSW and that we know what's going on

New Physics

$$L^{NSI} = -2\sqrt{2}G_F(\bar{\nu}_\alpha\gamma_\rho\nu_\beta)(\epsilon_{\alpha\beta}^{f\tilde{f}L}\bar{f}_L\gamma^\rho\tilde{f}_L + \epsilon_{\alpha\beta}^{f\tilde{f}R}\bar{f}_R\gamma^\rho\tilde{f}_R) + h.c. \quad (1)$$

NC non-standard Lagrangian

$$\epsilon_{12} = -2\,\epsilon_{e\tau}\sin\theta_{23} = -0.25$$

$$|\varepsilon_{\tau e}^{dP}| < 0.5$$

CHARM limit

- non-standard interactions
- MSW is linear in G_F and

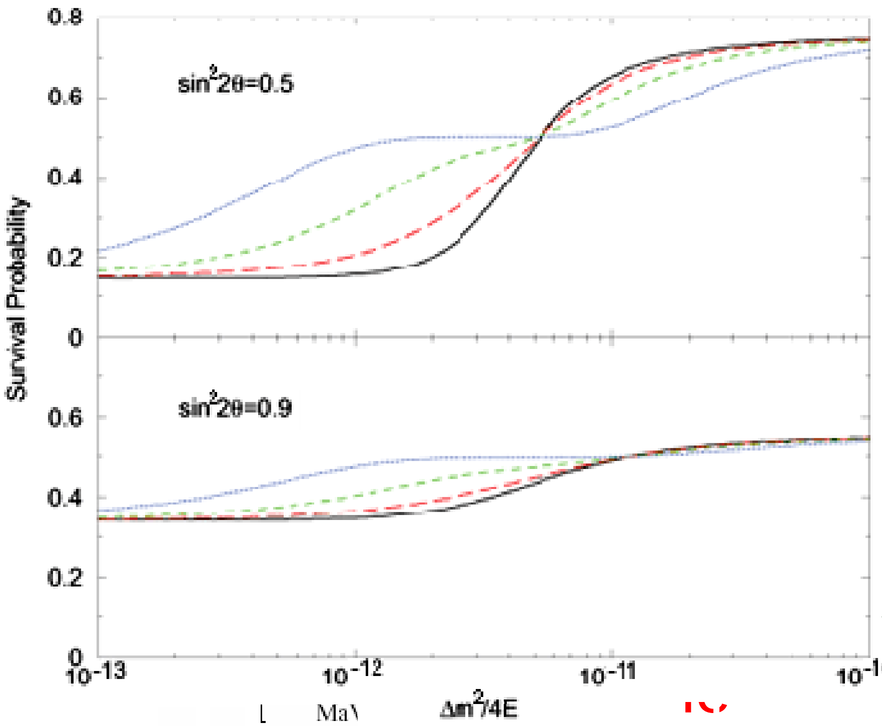
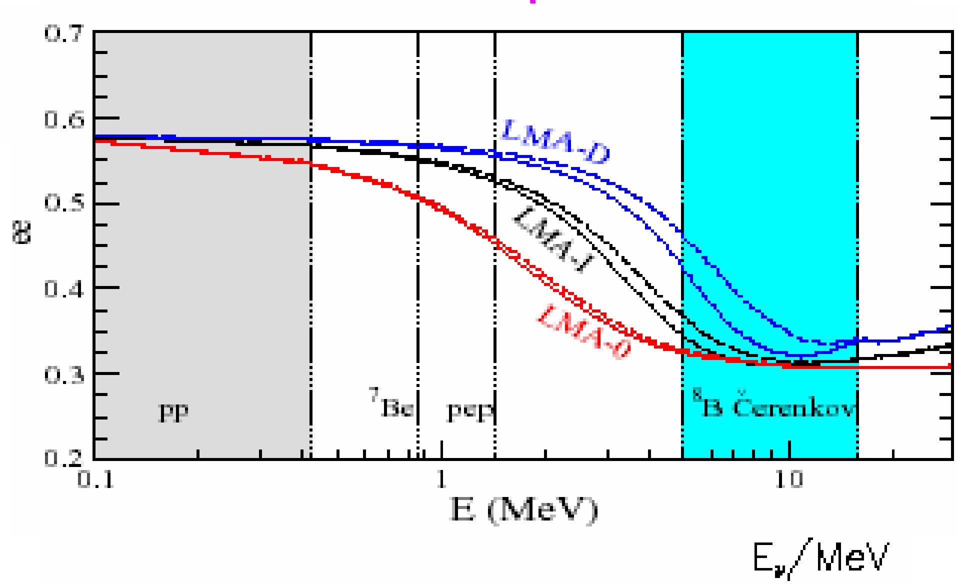


Figure 1. Neutrino survival probability for two values of the mixing angle, and several values of the perturbation amplitude, $\xi = 0\%$ (solid line), $\xi = 2\%$ (long dashed line), $\xi = 4\%$ (dashed line) and $\xi = 8\%$ (dotted line).



nd, Lunardini, Peña-Garay, hep-ph/0402266

Miranda, Tórtola, Valle, hep-ph/0406280

Guzzo, Reggiani, de Holanda, hep-ph/0302303

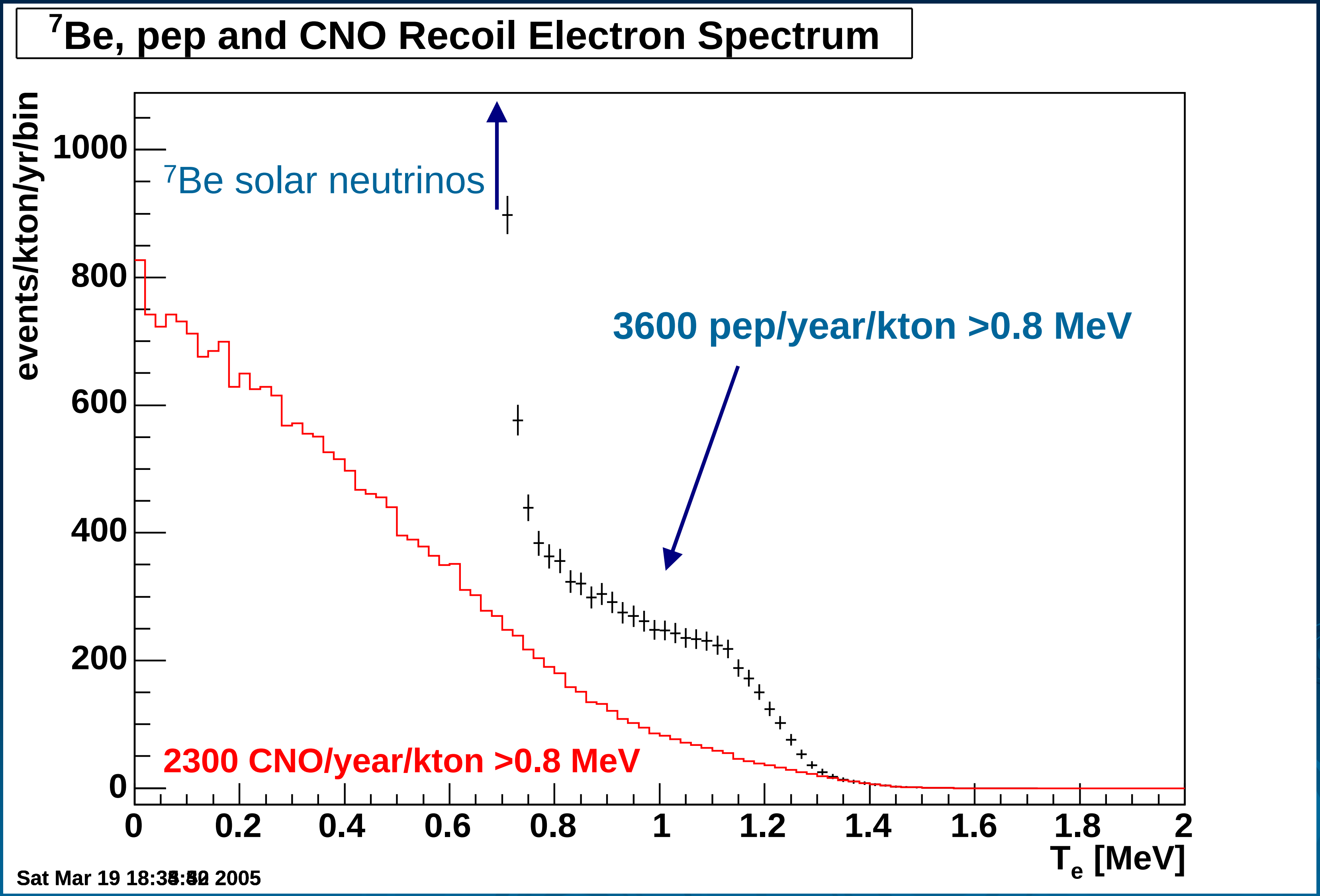
see also Burgess et al., hep-ph/0310366

neutrinos are at

…t spot” to test for new physics

…er, Marfatia, hep-ph/0502196

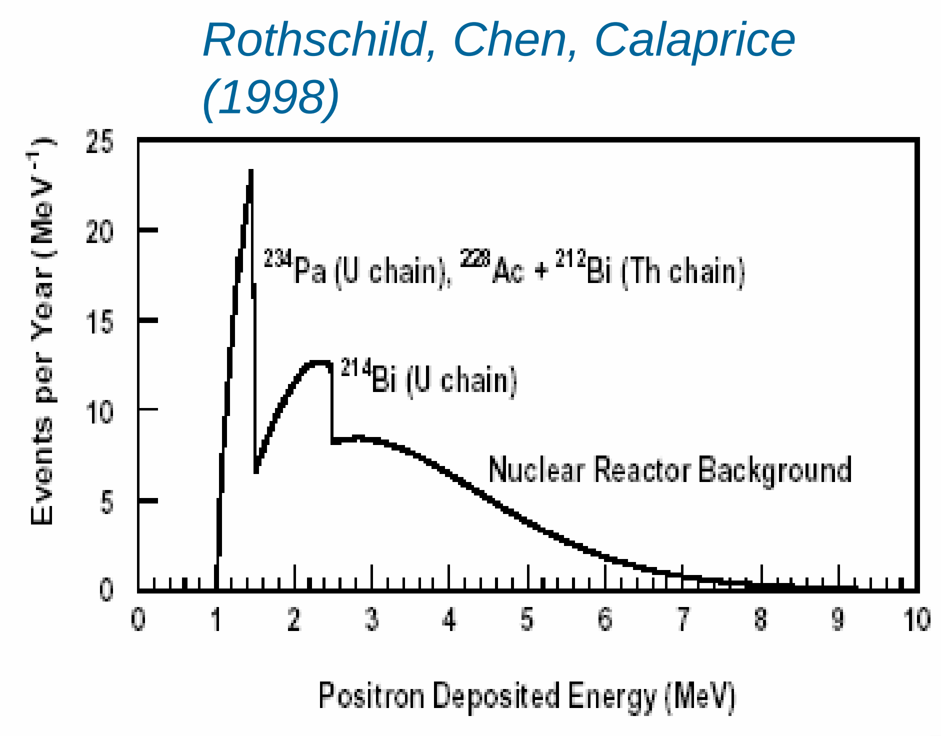
Event Rates (Oscillated)

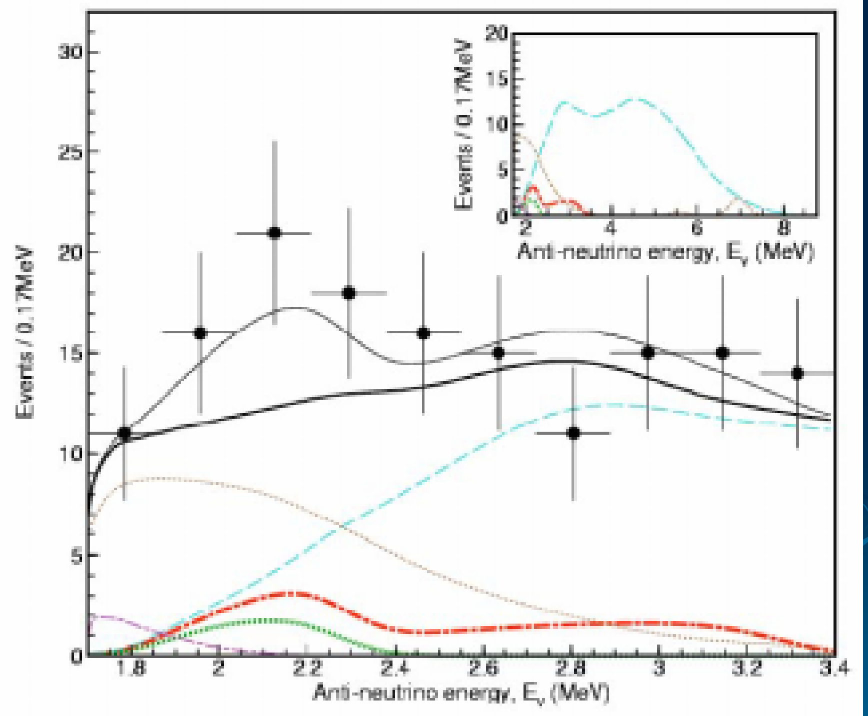


Geo-Neutrino Signal

terrestrial antineutrino event rates:

- Borexino: 10 events per year (280 tons of C_9H_{12}) / 29 events reactor
- KamLAND: 29 events per year (1000 tons CH_2) / 480 events reactor
- SNO+: 64 events per year (1000 tons CH_2) / 87 events reactor

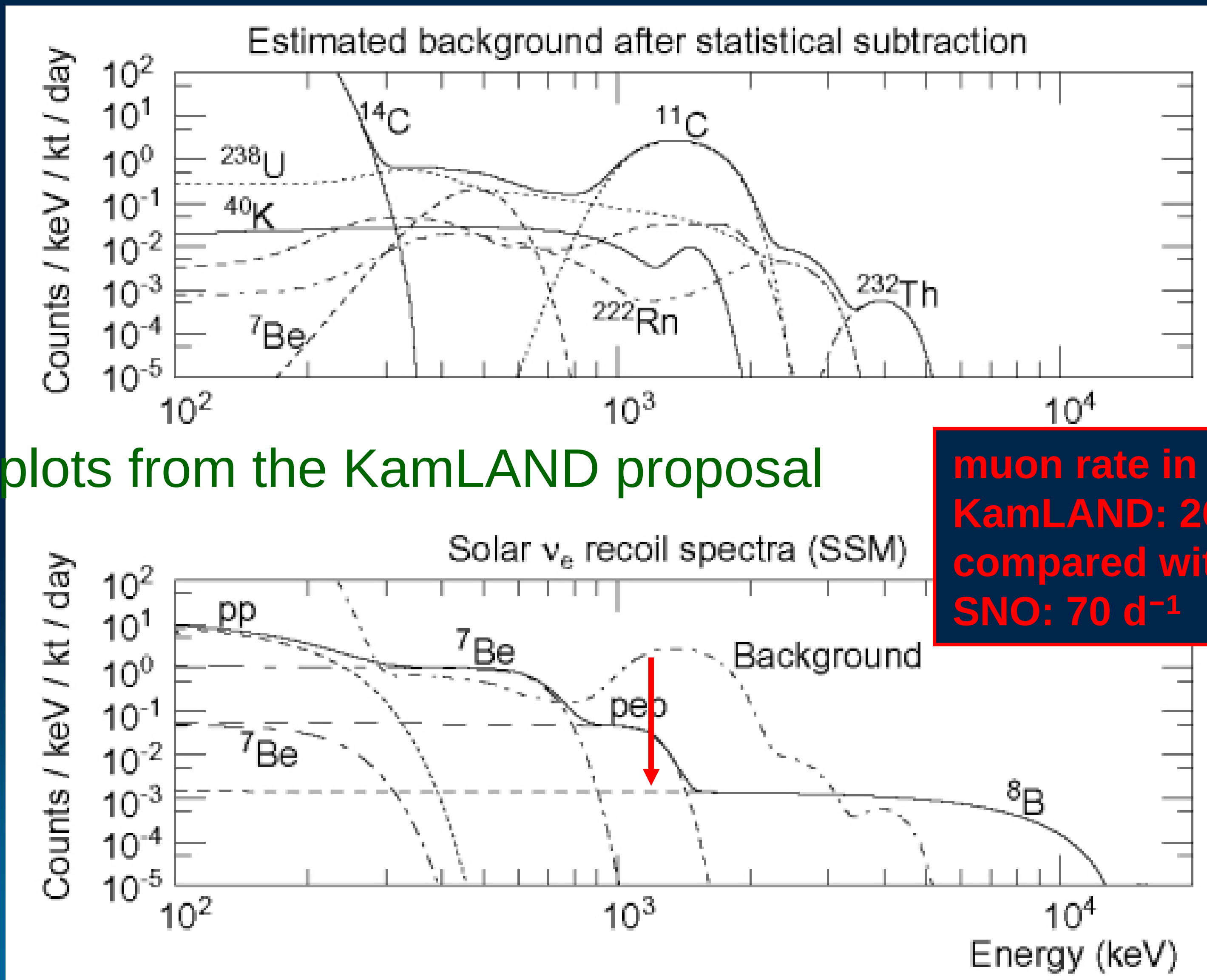




the above plot is for Borexino…geo/reactor ratio at Sudbury would be twice as high

KamLAND geo-neutrino detection…great start!

^{11}C Cosmogenic Background



these plots from the KamLAND proposal

muon rate in KamLAND: 26,000 d^{-1} compared with SNO: 70 d^{-1}

SNO+ *pep*

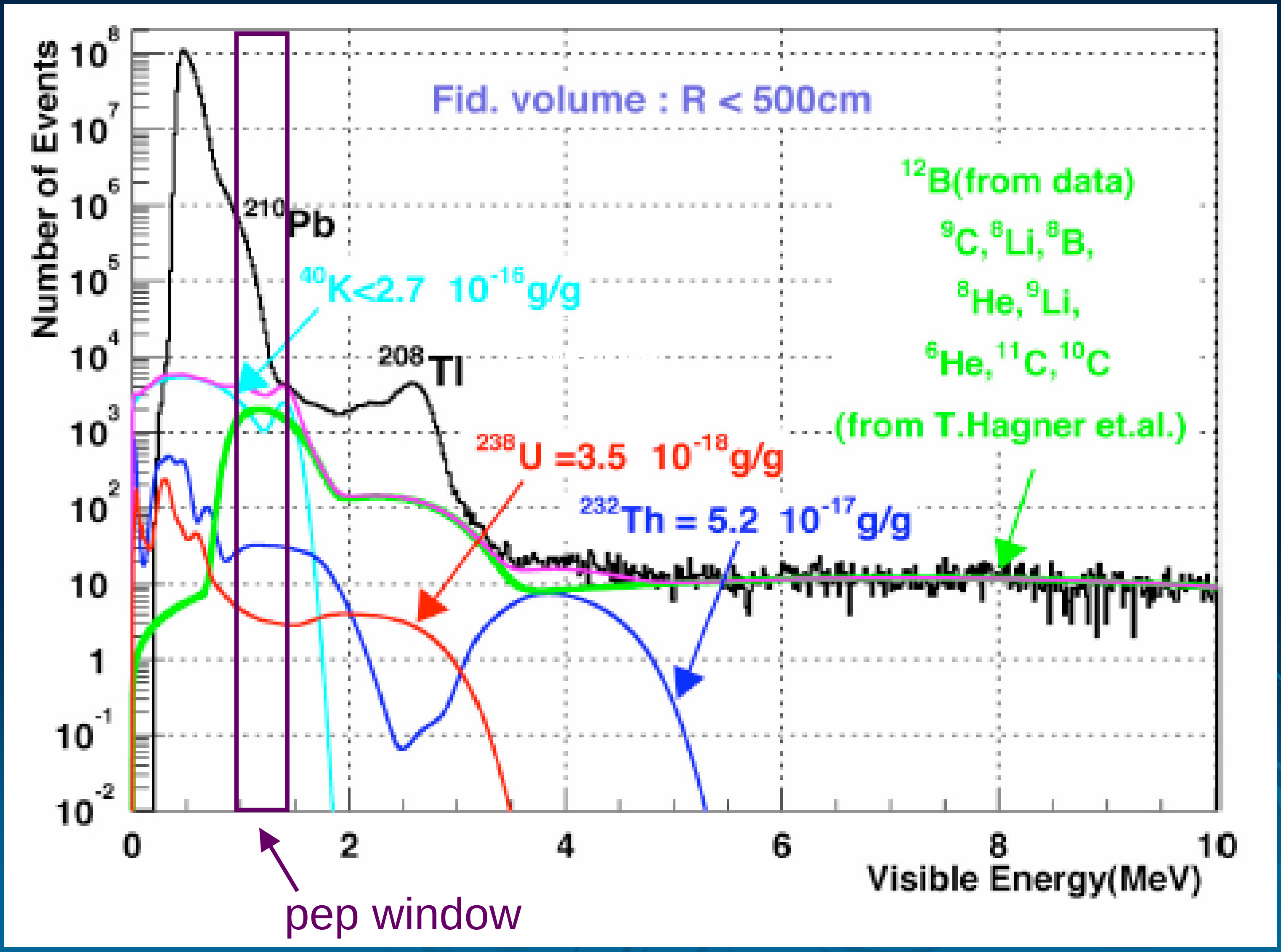
SNOLAB is the only deep site that exists where the *pep* solar neutrinos could be measured with precision.

pep solar neutrinos are a known source – enables a precision measurement.

pp solar neutrinos are more difficult and may not reveal as much as *pep* (*pp* survival probability set by the average vacuum P_{ee}).

First observation of the CNO solar neutrino would be important for astrophysics.

Real KamLAND Backgrounds



Backgrounds

- radiopurity requirements
  - ^{40}K, ^{210}Bi (Rn daughter)
  - ^{85}Kr, ^{210}Po (seen in KamLAND) not a problem since *pep* signal is at higher energy than ^{7}Be
  - U, Th not a problem **if** one can repeat KamLAND scintillator purity
  - ^{14}C not a problem since pep signal is at higher energy

Double Beta Decay: SNO++

- SNO plus liquid scintillator plus double beta isotopes: SNO++
- add ββ isotopes to liquid scintillator
  - dissolved Xe gas (2%)
  - organometallic chemical loading (Nd, Se, Te)
  - dispersion of nanoparticles (Nd_2O_3, TeO_2)
  - Large crystals
- enormous quantities (high statistics) and low backgrounds help compensate for the poor energy resolution of liquid scintillator
- Fiducial volume cuts, SNO calibration and knowledge of SNO optics, clean outer shield, great depth -> good understanding of backgrounds
- possibly source in–source out capability

SNO+ Technical

- liquid scintillator selection
- AV engineering

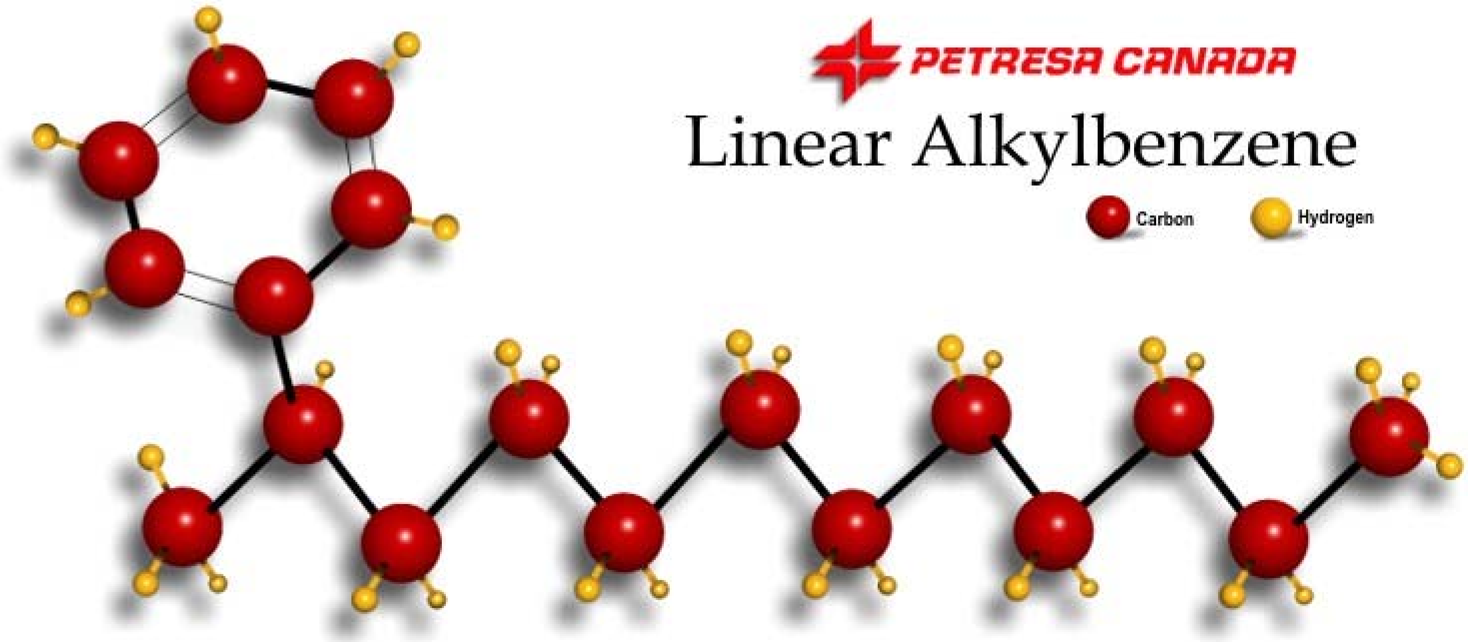
- cover gas, fluid handling, safety
- scintillator purification
- electronics/DAQ (spares, upgrade…)

Scintillator Design

- high density (>0.85 g/cm^3)
- chemical compatibility with acrylic
- high light yield, long attenuation and scattering lengths

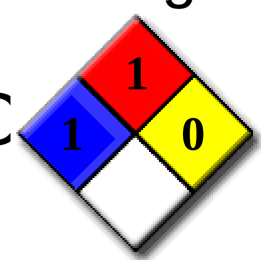
- high flash point
- low toxicity
- low cost

Linear Alkylbenzene



LAB Advantages

- compatible with acrylic (e.g. Bicron BC-531)
  - “BC-531 is particularly suited for intermediate sized detectors in which the containers are fabricated with common plastic materials such as PVC and acrylics. The scintillator provides over twice the light output of mineral oil based liquids having similar plastic compatibility.”
- high flash point 130 °C



- low toxicity (pseudocumene 2 4 0)
- cheap, (common feedstock for LAS detergent)
- plant in Quebec makes 120 kton/year, supplier has been very accommodating
- high purity

Scintillating SNOMAN

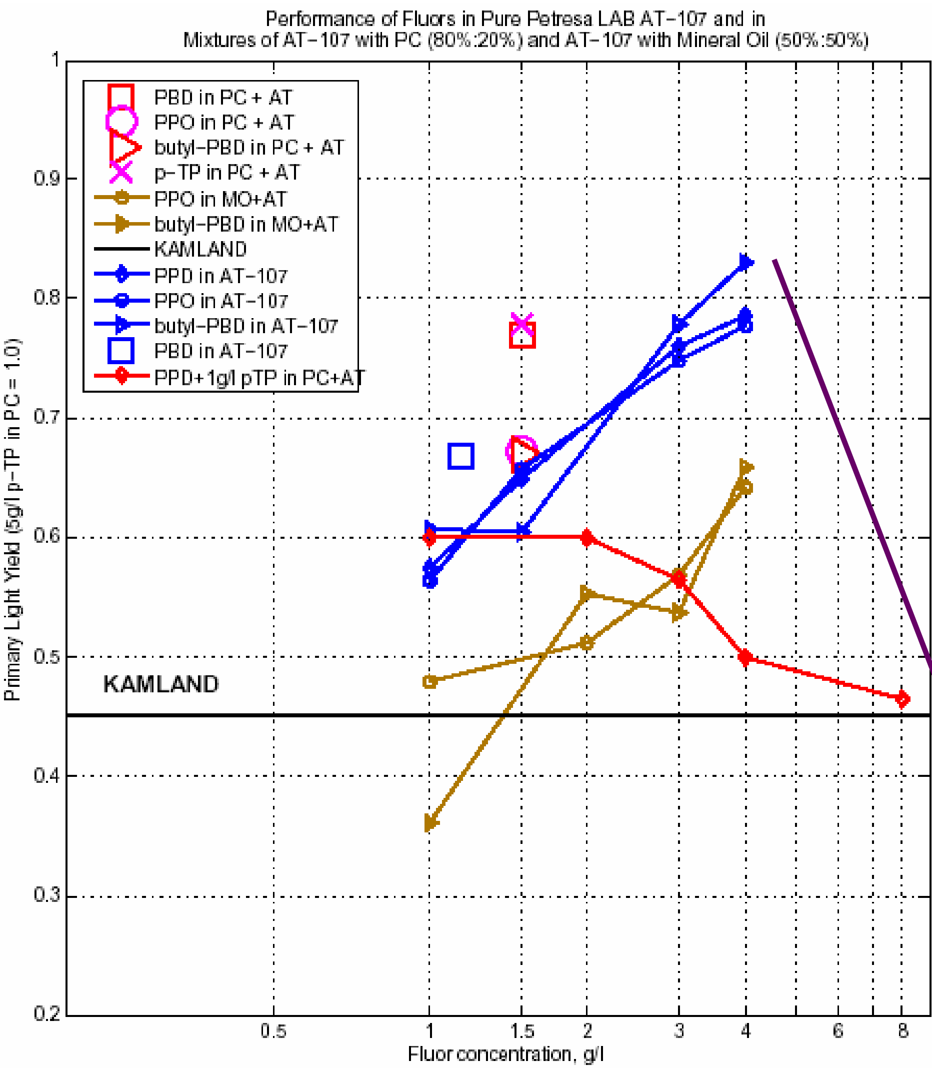
- Alex Wright's implementation and calculations

PC+1.5 g/L PPO with KamLAND yield	629 ± 25 pe/MeV
above no acrylic	711 ± 27 pe/MeV
PC+1.5 g/L PPO and 50 mg/L bisMSB	826 ± 24 pe/MeV
above no acrylic	878 ± 29 pe/MeV
KamLAND (20% PC in dodecane, 1.52 g/L PPO)	~300 pe/MeV for 22% photocathode coverage

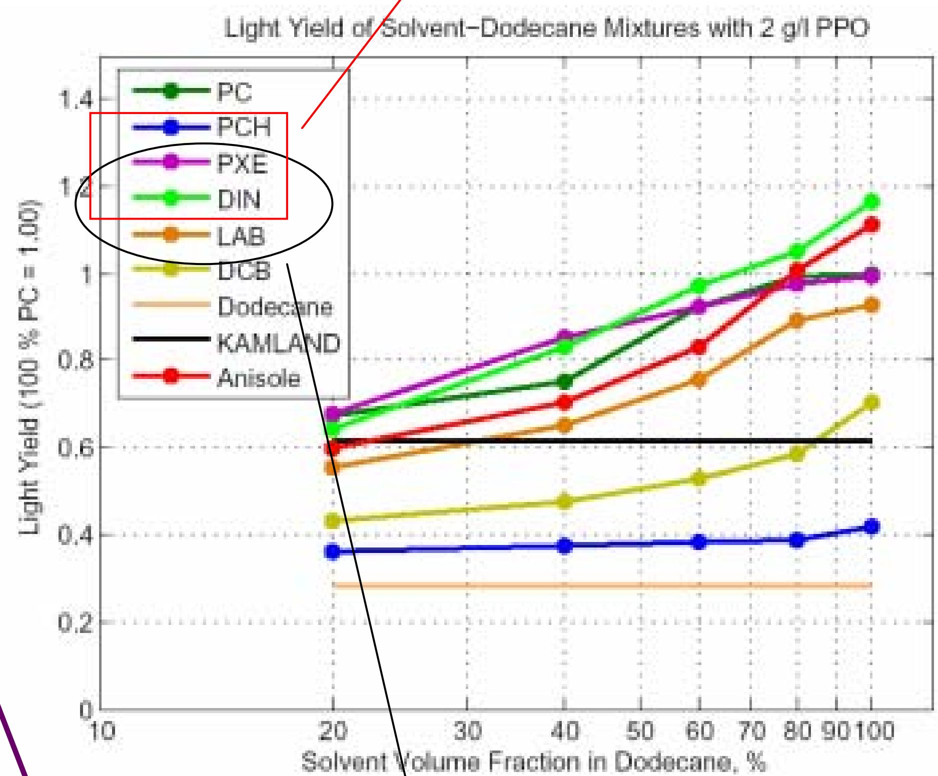
SNO+ has 54% PMT coverage; acrylic vessel only diminishes light ouput by ~10%

Light Yield

Vladimir Novikov's studies and results



high density

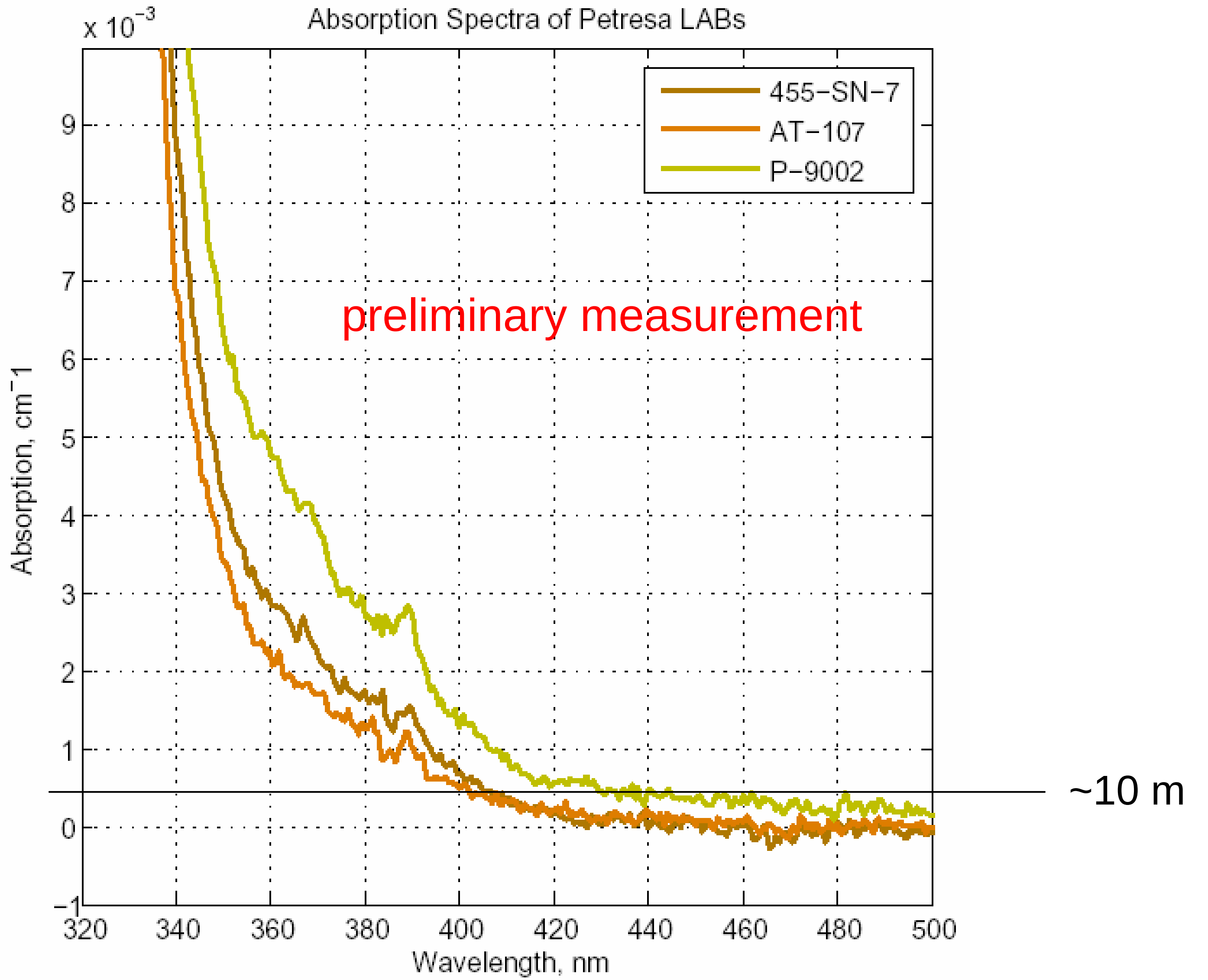


"safe" scintillators

LAB has 75% greater light yield than KamLAND scintillator

Light Attenuation Length

Petresa LAB as received



Default Scintillator Identified

- LAB has the smallest scattering of all scintillating solvents investigated
- LAB has the best acrylic compatibility of all solvents investigated
- density $\rho = 0.86$ acceptable
- …default is Petresa LAB with 4 g/L PPO, wavelength shifter 10-50 mg/L bisMSB
- for unloaded scintillator physics…light output (photoelectrons/MeV) around 3✕ KamLAND

Double Beta Decay: SNO++

- SNO plus liquid scintillator plus double beta isotopes: SNO++
- add $\beta\beta$ isotopes to liquid scintillator
  - dissolved Xe gas (2%)
  - organometallic chemical loading (Nd, Se, Te)
  - dispersion of nanoparticles (Nd_2O_3, TeO_2)
  - Large crystals
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table from F. Avignone Neutrino 2004

^{150}Nd

$$\overline{\eta} \equiv \langle G^{0\nu} |\mathcal{M}^{0\nu}|^2 \rangle \times 10^{13}$$

Isotope	$\overline{\eta}$
^{48}Ca	0.54
^{76}Ge	0.73
^{82}Se	1.70
^{100}Mo	10.0
^{116}Cd	1.30
^{130}Te	4.20
^{136}Xe	0.28
^{150}Nd	57.0

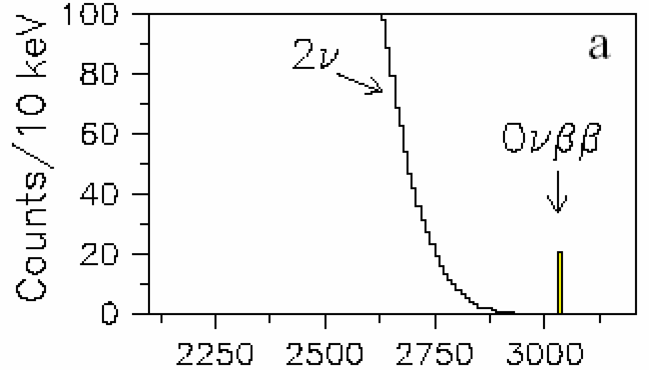
- 3.37 MeV endpoint
- $(9.7 \pm 0.7 \pm 1.0) \times 10^{18}$ yr $2\nu\beta\beta$ half-life measured by NEMO-III
- isotopic abundance 5.6%

  1% natural Nd-loaded liquid scintillator in SNO++ has 560 kg of ^{150}Nd compared to 37 g in NEMO-III

- cost: \$1/g for metallic Nd; cheaper as Nd salt…on the web $NdCl_3$ sold in lot sizes of 100 kg, 1 ton, 10 tons

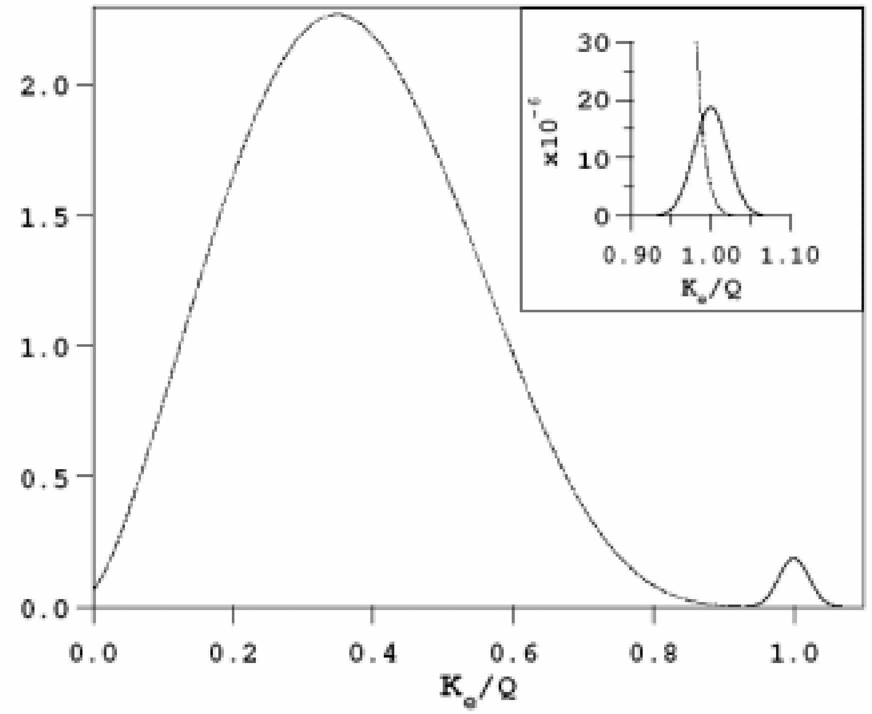
2ν ββ Background

- good energy resolution needed



- but whopping statistics helps compensate for poor resolution and…

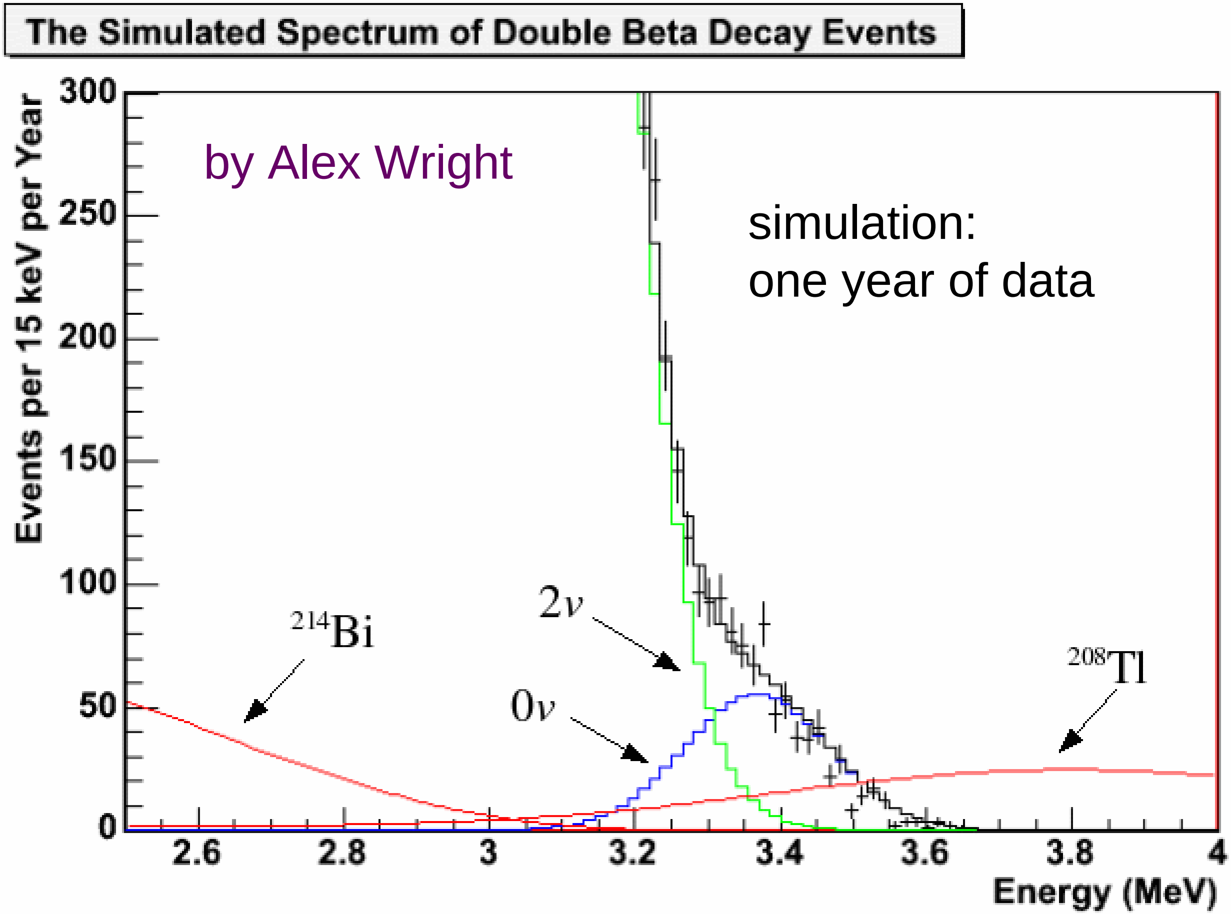
turns this into an endpoint shape distortion measure rather than a peak search



Test $<m_\nu> = 0.150$ eV

Klapdor-Kleingrothaus et al., Phys. Lett. B **586,** 198, (2004)

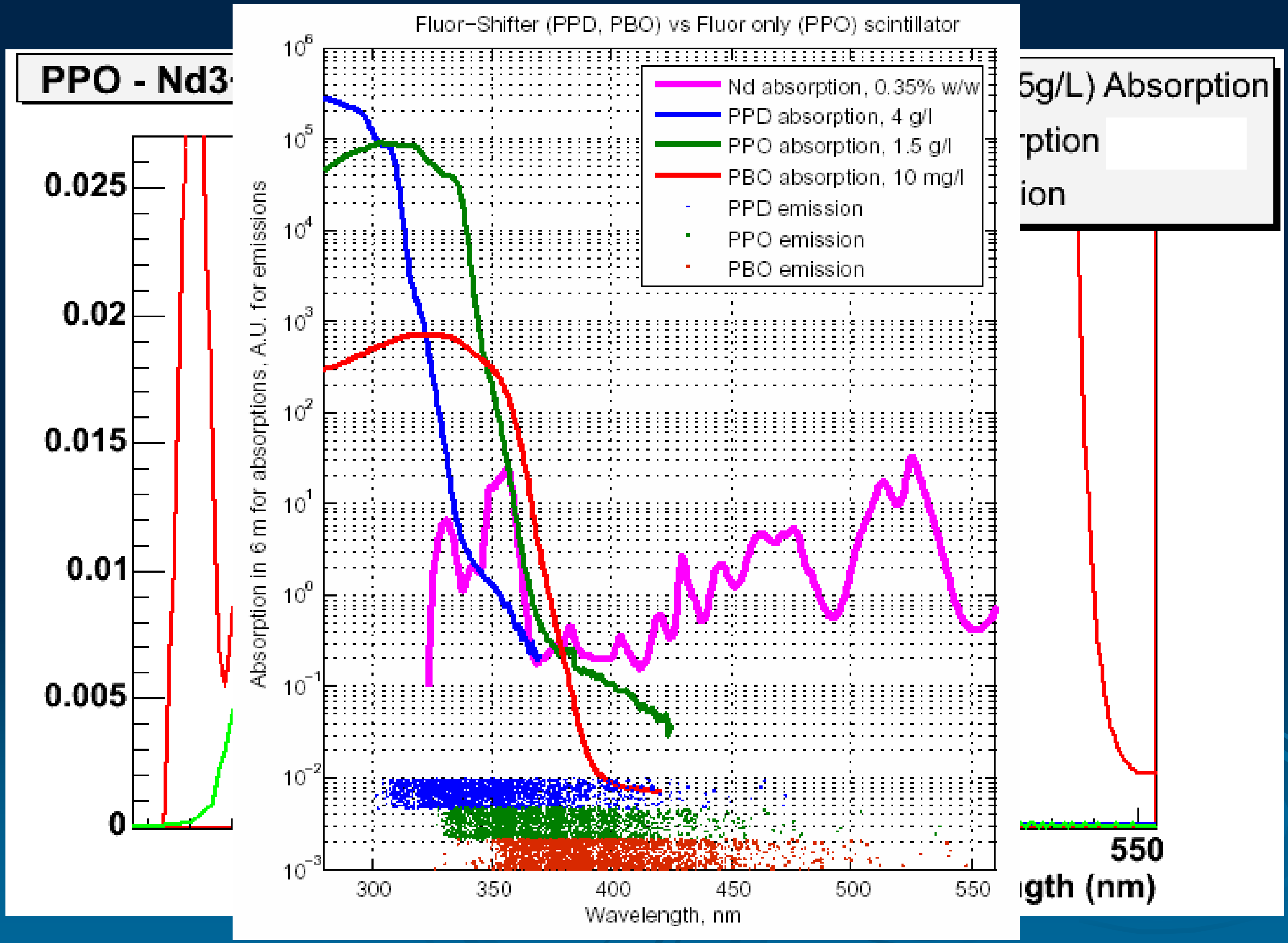
0ν: 1000 events per year with 1% natural Nd-loaded liquid scintillator in SNO++



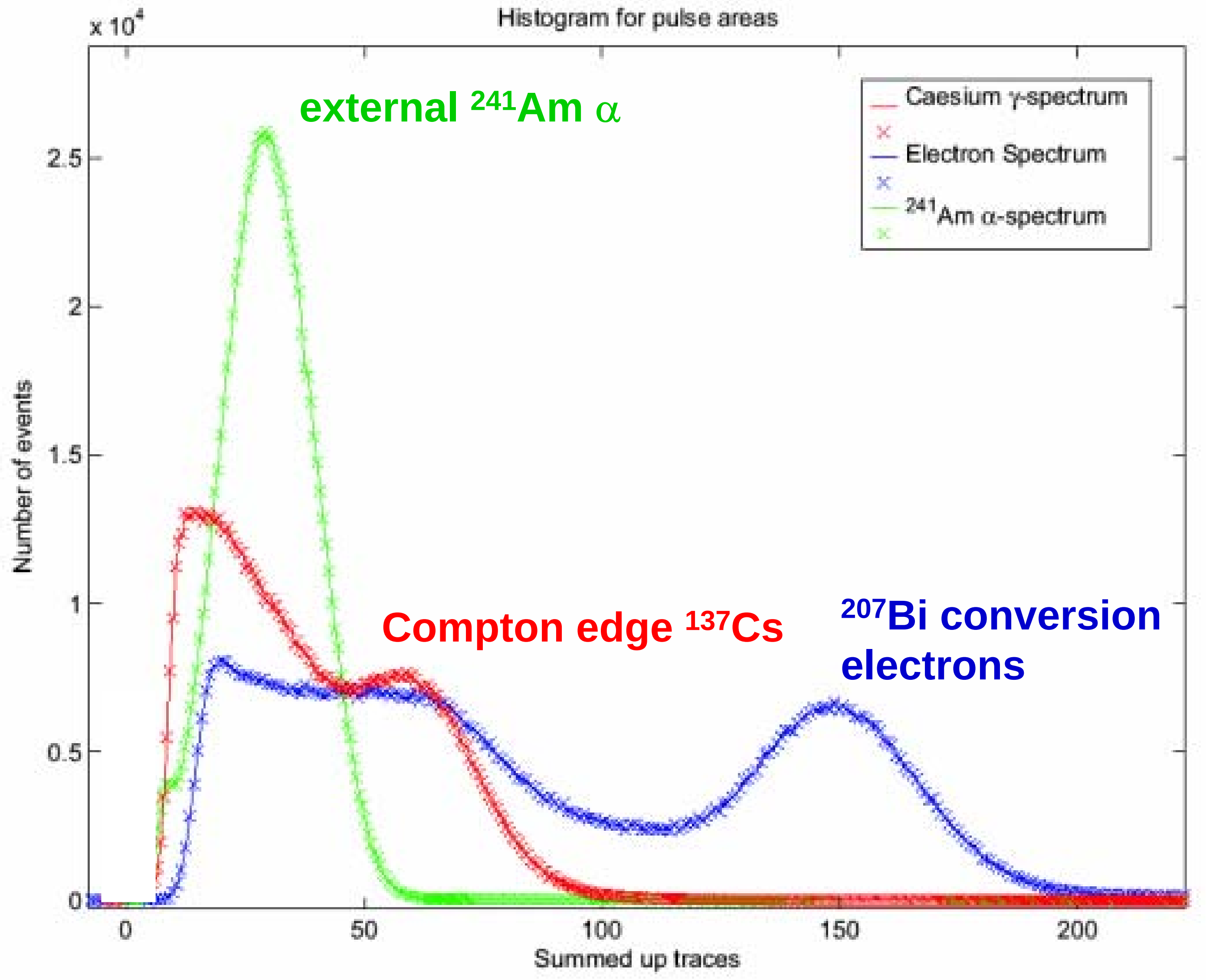
maximum likelihood statistical test of the shape to extract
0ν and 2ν components…~240 units of $\Delta\chi^2$ significance after only 1 year!

made by Yeh, Garnov, Hahn at BNL

Nd-carboxylate in Pseudocumene



Nd LS Works!



Histogram for pulse areas
x 10^4
Number of events
Summed up traces
Caesium γ-spectrum
Electron Spectrum
241Am α-spectrum
external 241Am α
Compton edge 137Cs
207Bi conversion electrons
0
0.5
1
1.5
2
2.5
0
50
100
150
200

Near Term Project Schedule

- SNO+ is an NSERC-funded R&D project
- goal is proof of principle by Fall 2005
  - AV hold-down engineering solution demonstrated
  - liquid scintillator mixture selected/designed with demonstrated compatibility with acrylic and suitable optical properties
  - fluid handling and safety underground discussed
  - scientific motivation fully developed for proposal
  - ballpark project cost estimates
- inclusion in Canada’s IPP-NSERC long range plan

SNO+ in 2006

- need more collaborators
- project management
- scintillator purification R&D
- electronics/DAQ plans…
- full TDR by Fall 2006
  - including process engineering and AV mechanics
- proposals to funding agencies by Fall 2006

SNO+ in 2007

- start of capital funding
- construction of hold-down net
- access detector after D_2O removed
- scintillator procurement contracts
- …and on to converting SNO into an operating, multi-purpose, liquid scintillator detector with interesting physics capabilities