SNO+

PANIC Neutrino Satellite Meeting

Santa Fe, NM
October 29, 2005

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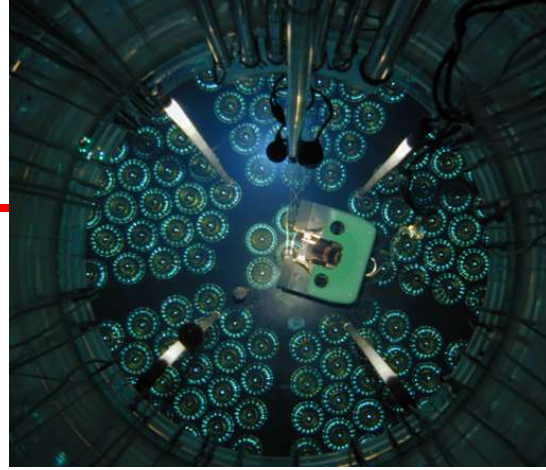
Queen's University

Beyond SNO

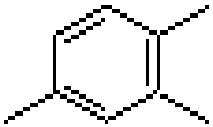


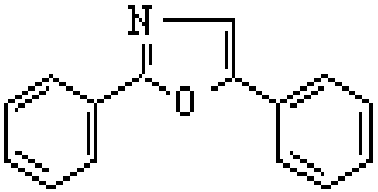
- Fall 04 to Dec 06: SNO Phase III
  - ^{3}He proportional counter array now in place
    - dedicated Neutral Current Detectors (NCDs)
    - taking production data
  - data taking end date: 31 Dec 2006
    - will bring total uncertainty on ^{8}B solar ν NC signal below 5%
  - physics with heavy water will be complete
  - in 2007, heavy water will be returned to Atomic Energy of Canada Limited

what should be done with the detector after?

Fill with Liquid Scintillator

- SNO plus liquid scintillator → physics program
  - *pep* and CNO low energy solar neutrinos
    - tests the neutrino-matter interaction, sensitive to new physics
  - geo-neutrinos
  - 240 km baseline reactor oscillation confirmation
  - supernova neutrinos
  - double beta decay?

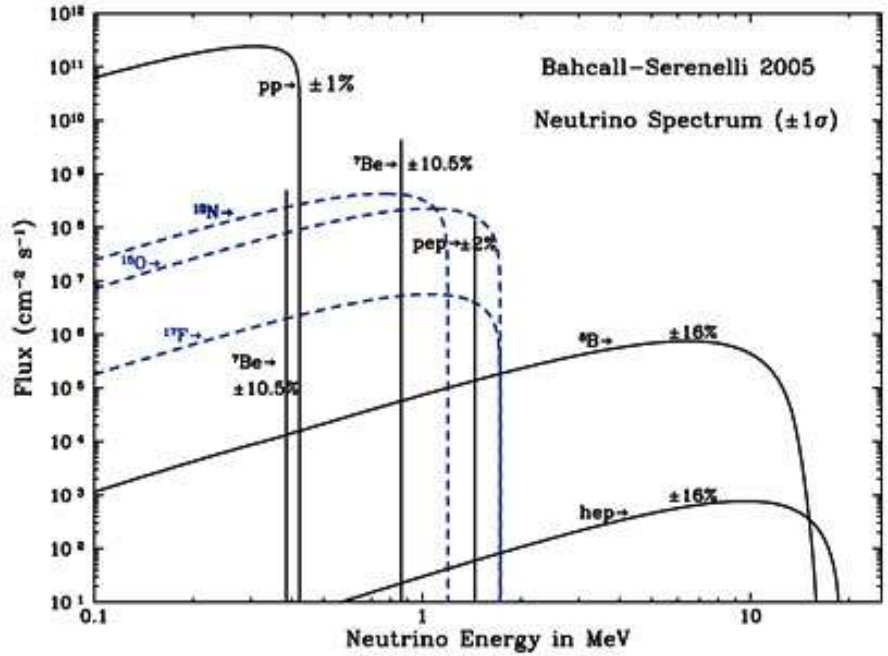


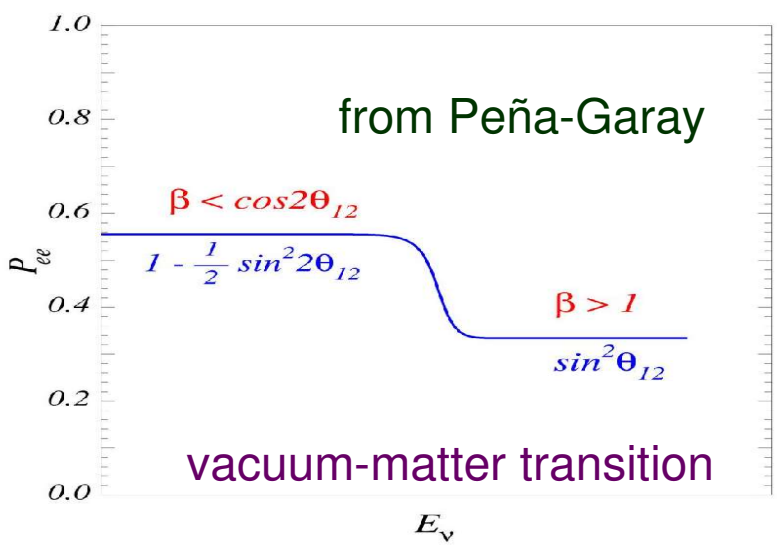


Low Energy Solar Neutrinos

- complete our understanding of neutrinos from the Sun

  pep, CNO, ^{7}Be
- probe the neutrino-matter interaction which is sensitive to new physics





$$\begin{pmatrix} -\frac{\Delta m^2}{4E}\cos 2\theta + \sqrt{2}\,G_F N_e & \frac{\Delta m^2}{4E}\sin 2\theta \\ \frac{\Delta m^2}{4E}\sin 2\theta & \frac{\Delta m^2}{4E}\cos 2\theta \end{pmatrix}$$

- day-night effect not observed
- no spectral distortion for ^{8}B ν's

Will SNO Phase III Show MSW?

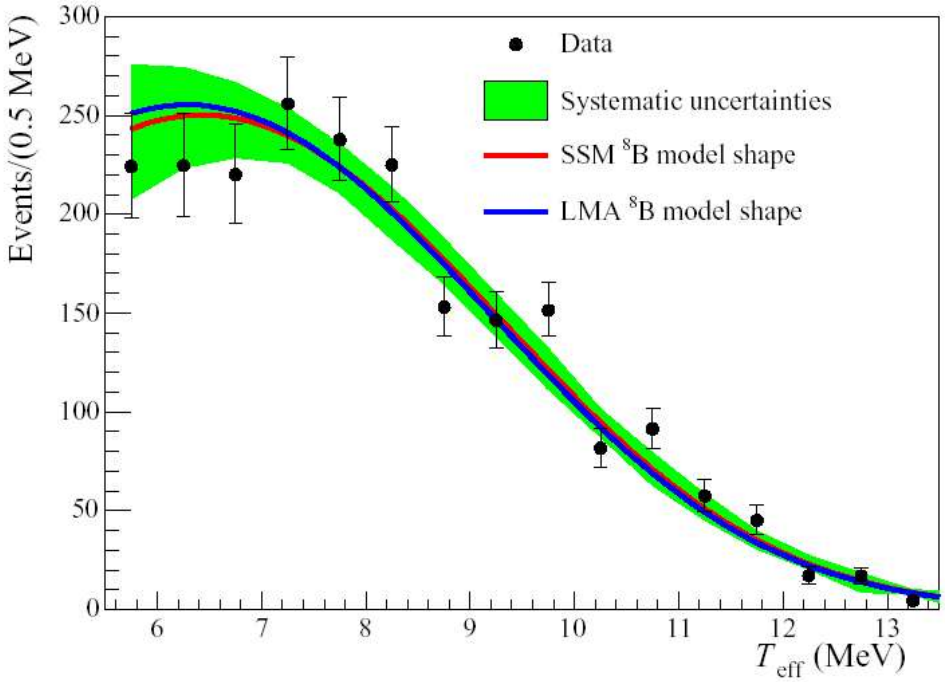
Day-Night Effect

- SNO I-II combined $A_e = (+3.7 \pm 4.0)\%$
- Super-K equivalent $A_e = (+3.3 \pm 3.7)\%$
- best-fit oscillation parameters predict: $A_e = +2.7\%$

  where $A_e = 2*(N–D)/(N+D)$ for the electron flavour

Spectral Distortion

- NCD phase breaks CC-NC correlations
- helps reduce systematics at low energies
- still, will be difficult to see spectral distortion

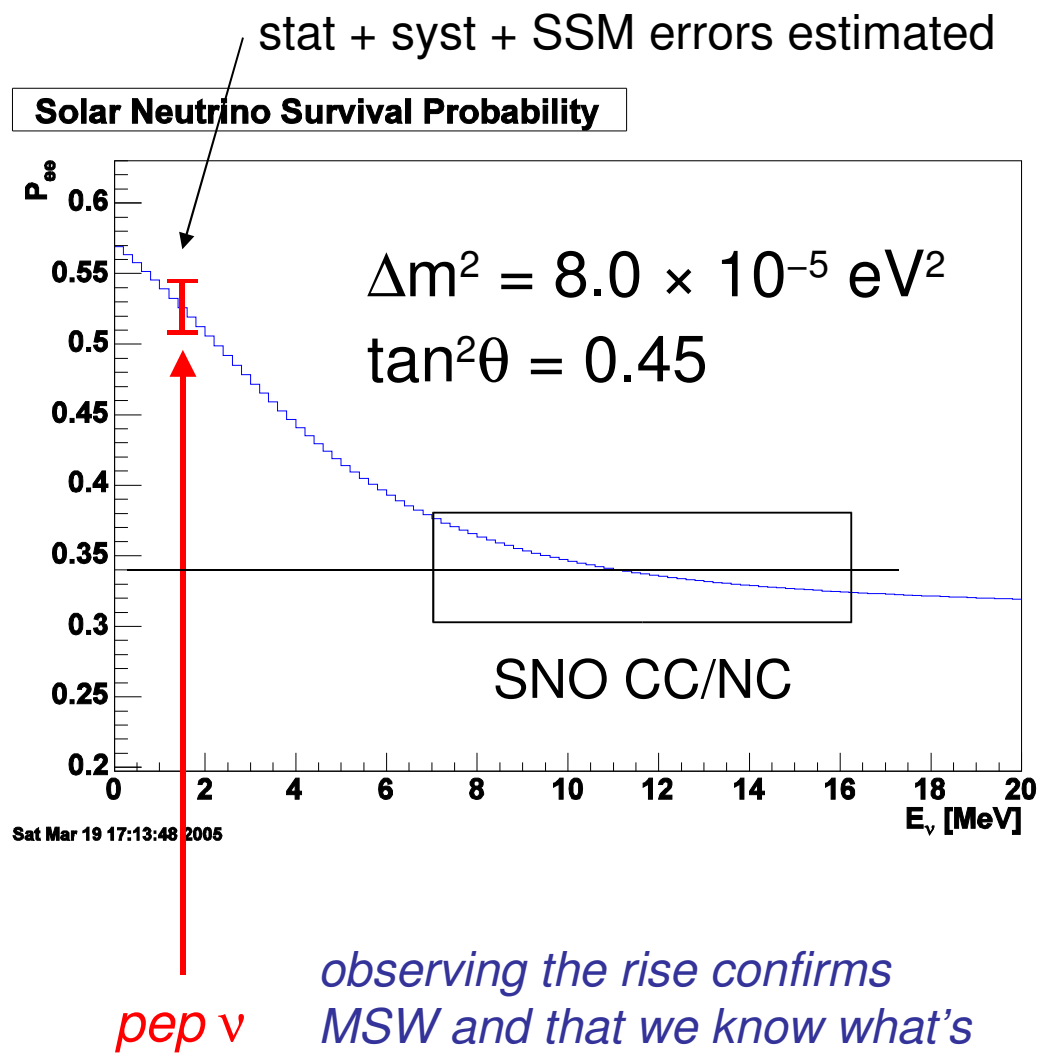


Survival Probability Rise

SSM pep flux:
uncertainty ±1.5%
known source → precision test

improves precision on θ_{12}

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

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

NC non-standard Lagrangian

$$\epsilon_{12} = -2\,\epsilon_{e\tau}\sin\theta_{23} = -0.15 \qquad |\varepsilon^{dP}_{\tau e}| < 0.5$$

CHARM limit

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

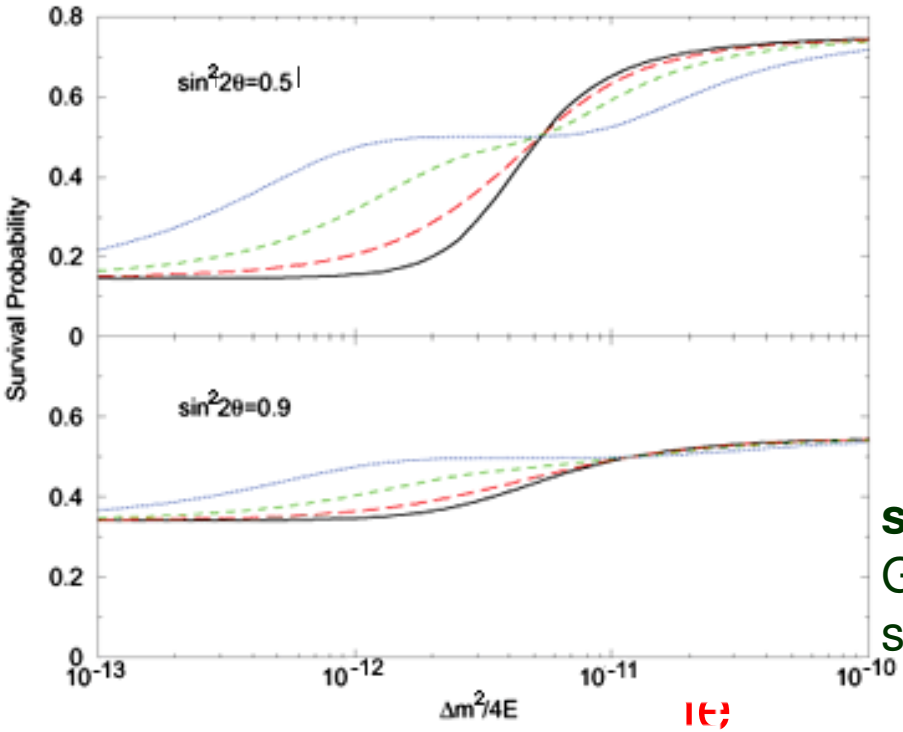
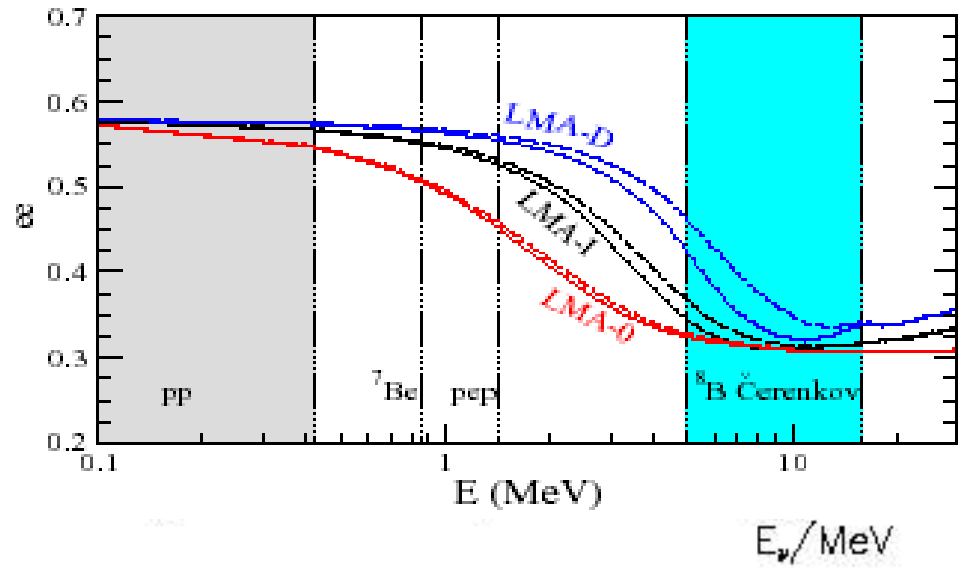


Figure 1. Neutrino survival probability for two values of the mixing angle, and several values of the perturbation amplitude, $\xi = 0\%$ (solid line), $\xi = 2\%$ (long dashed line), $\xi = 4\%$ (dashed line) and $\xi = 8\%$ (dotted line).



nd, Miranda, Toreña, Valle, hep-ph/0402266

solar density fluctuations:

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

see also Burgess et al, hep-ph/0310366

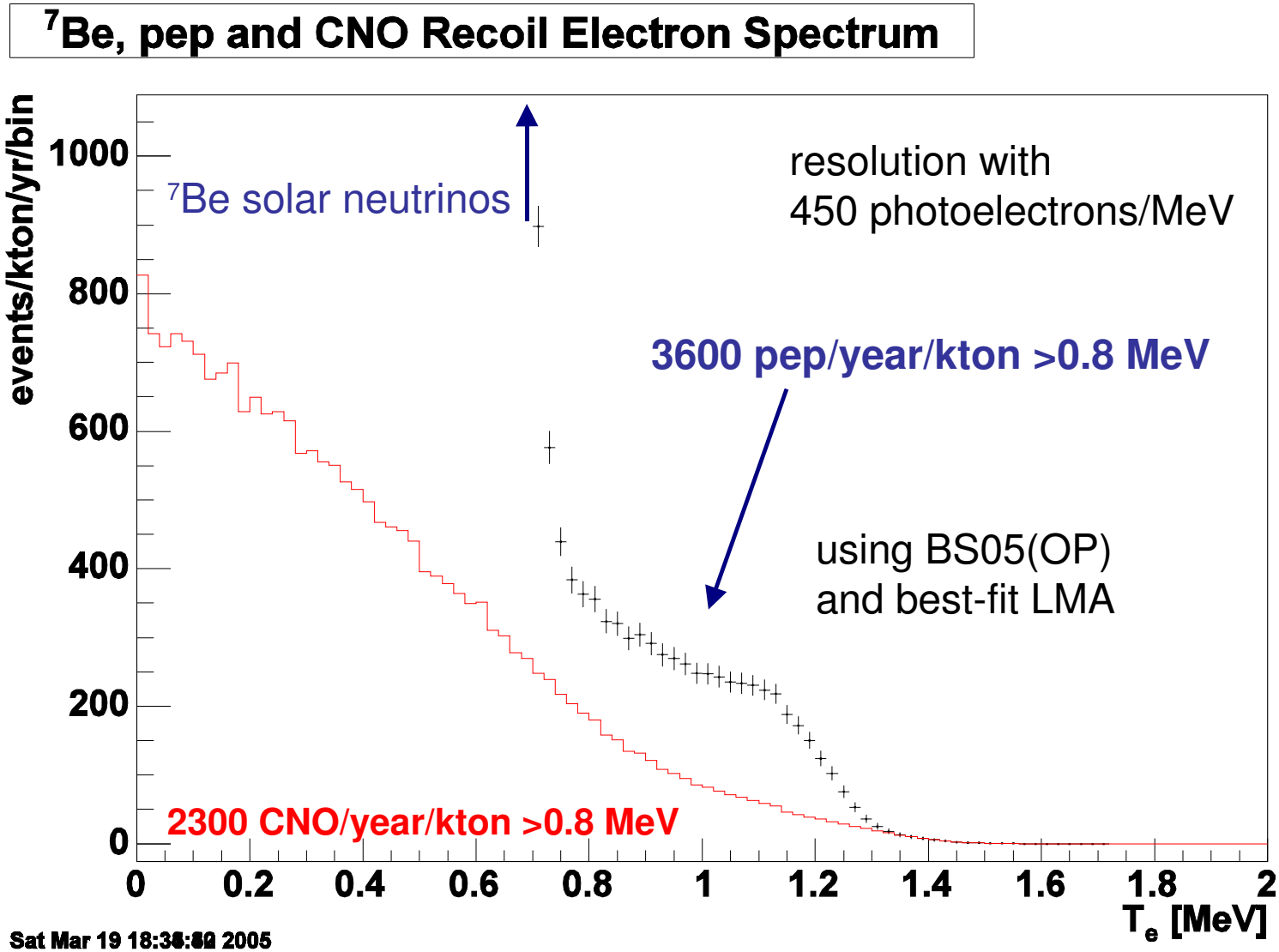
and also Balantekin et al.

neutrinos are at

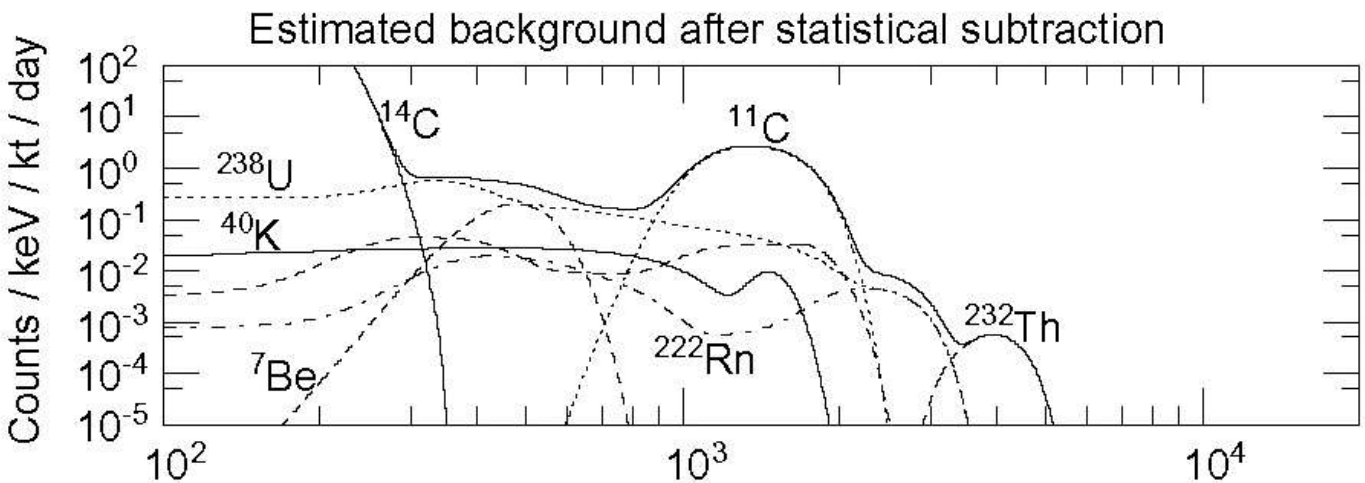
et spot" to test for new physics

er, Marfatia, hep-ph/0502196

Event Rates (Oscillated)

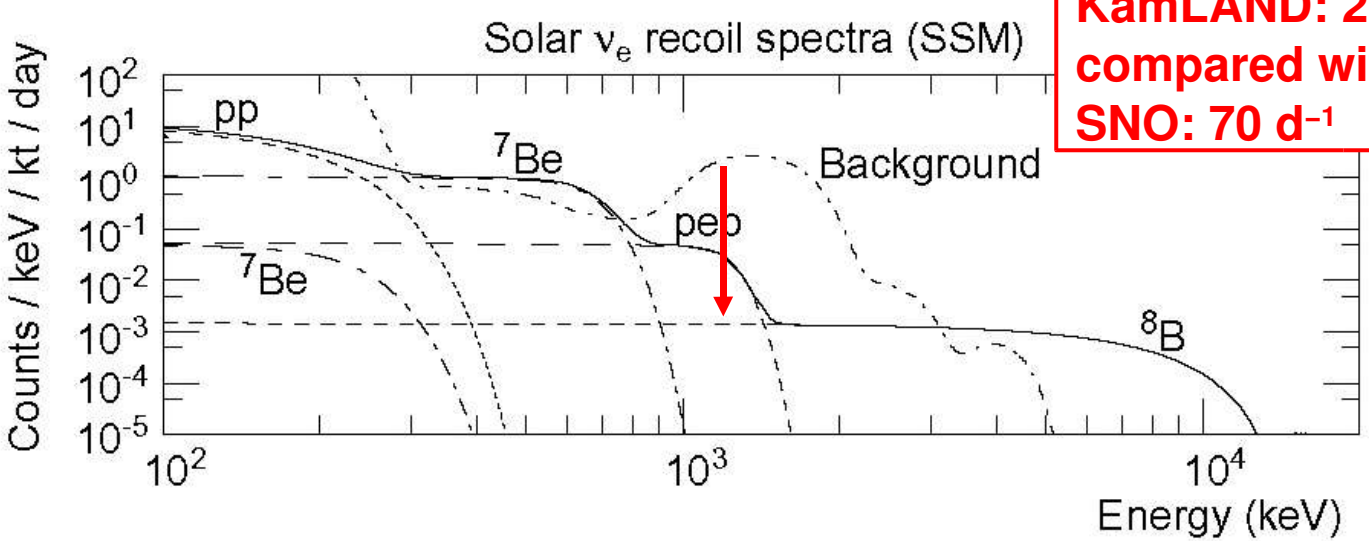


^{11}C Cosmogenic Background

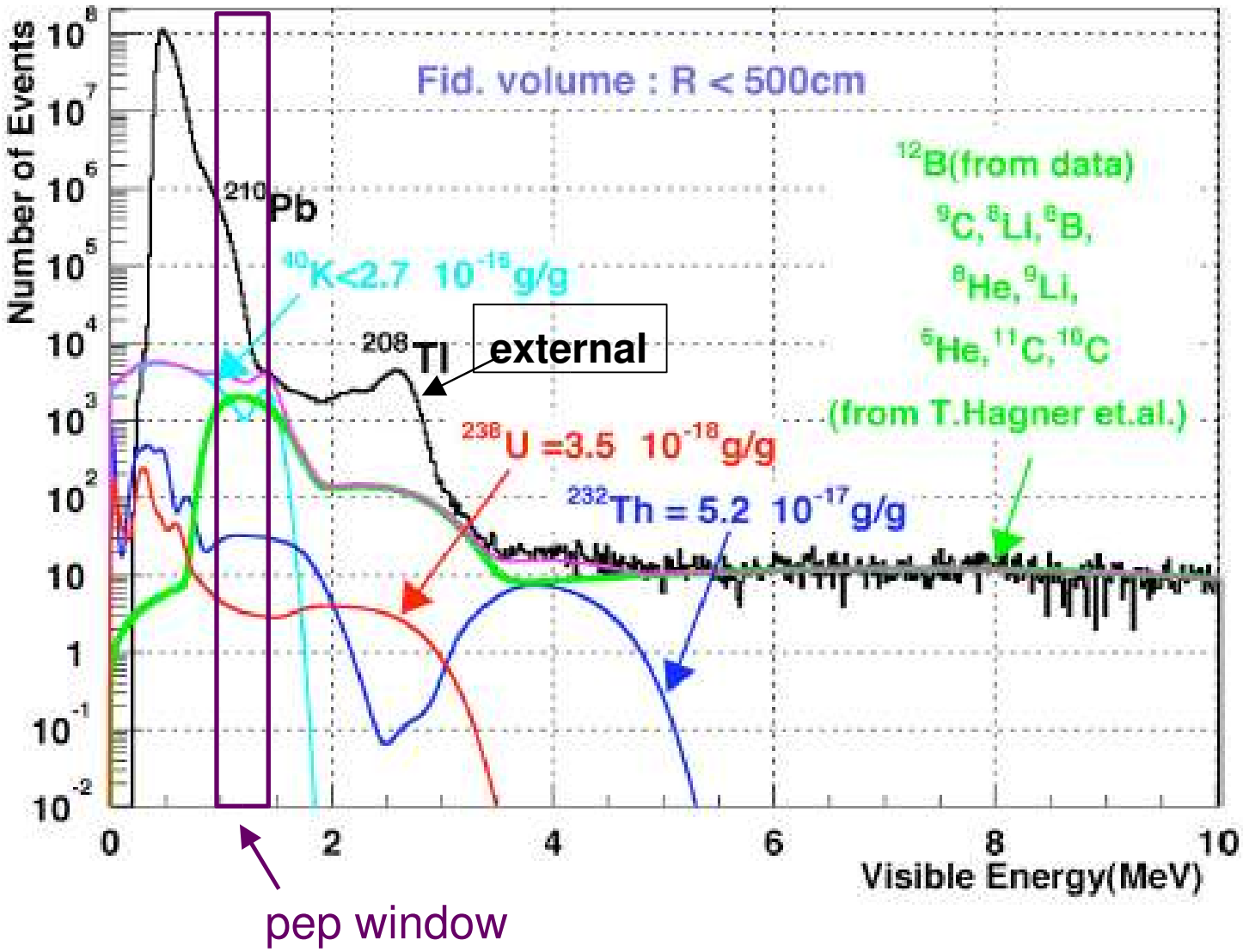


these plots from the KamLAND proposal

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



Real KamLAND Backgrounds



pep Solar ν 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

SNO+ *pep*

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

	sensitive probe neutrino-matter interaction?	precision measurement (SSM flux)?
pp	✗	✓
^{7}Be	✓	✗
pep	✓	✓

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

Geo-Neutrinos

- can we detect the antineutrinos produced by natural radioactivity in the Earth?

radioactive decay of heavy elements (uranium, thorium) produces antineutrinos

$$\bar{\nu}_e$$

assay the entire Earth by looking at its “neutrino glow”

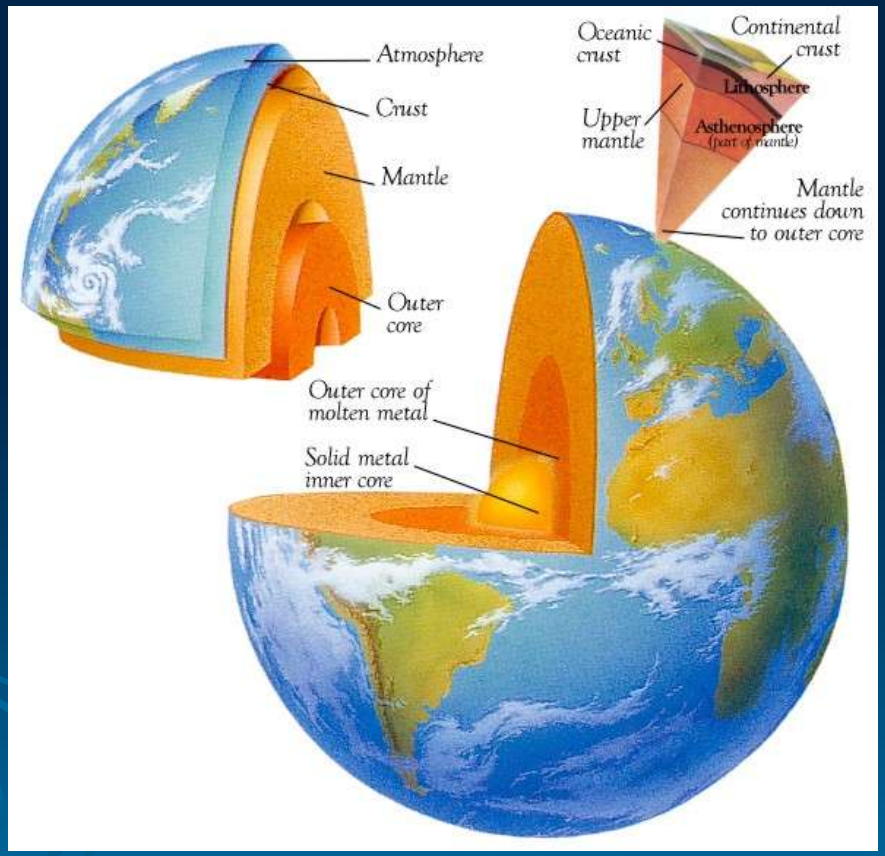
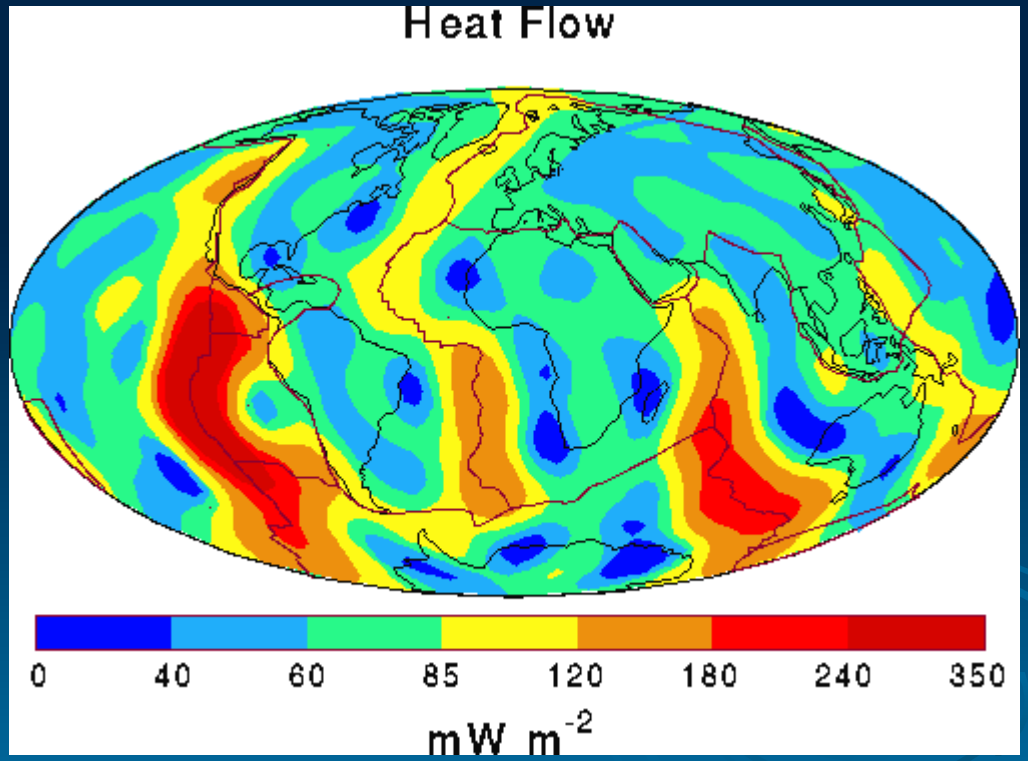


Image by: Colin Rose, Dorling Kindersley

Earth's Heat Flow

- models of Earth's heat sources suggest that radioactivity contributes 40-100% towards Earth's total heat flow



the radiogenic portion is not that well known!

geophysicists want to understand Earth's thermal history

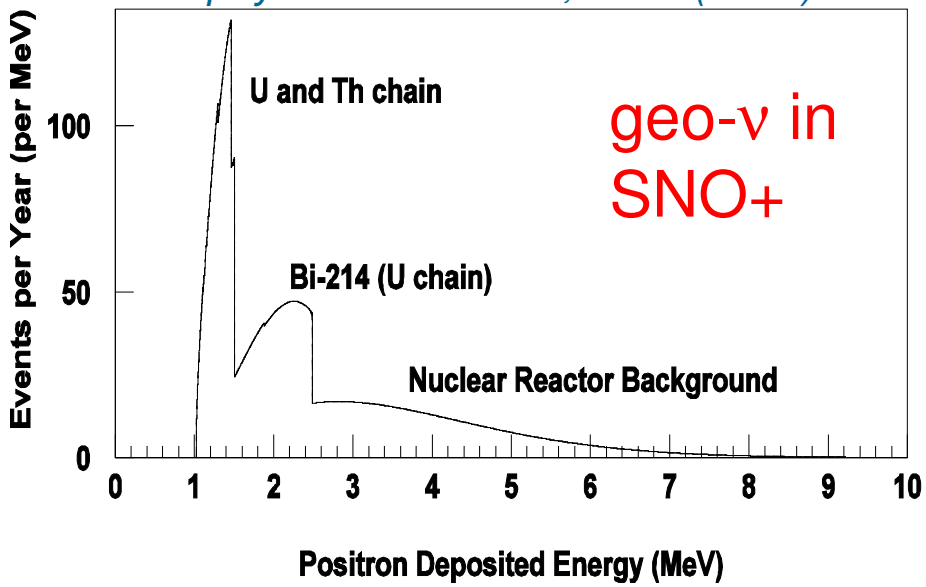
H.N. Pollack, S.J. Hurter and J.R. Johnson, *Reviews of Geophysics* **31**(3), 267-280, 1993

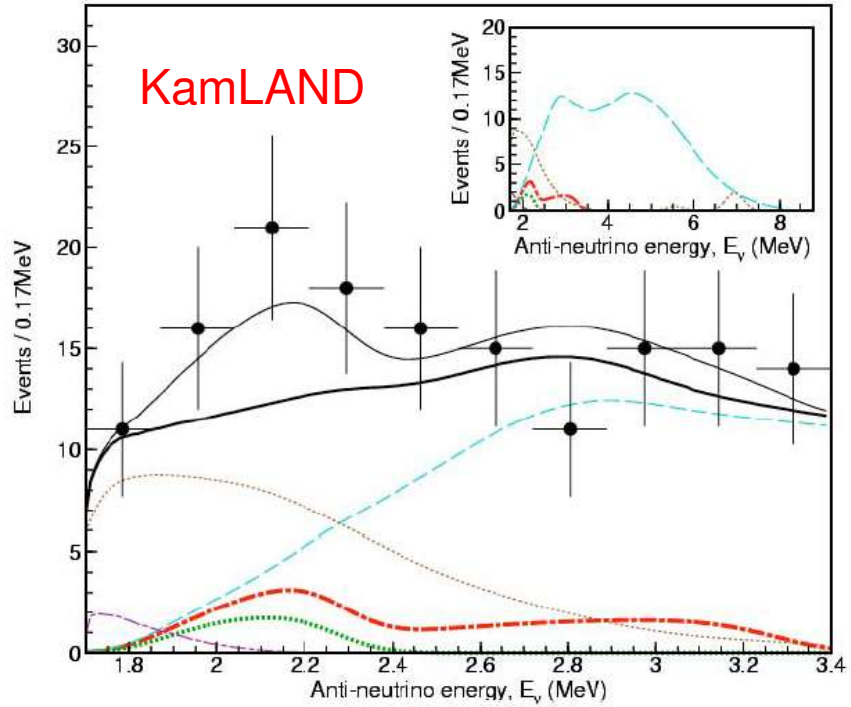
Geo-Neutrino Signal

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

*based on Rothschild, Chen, Calaprice Geophys. Res. Lett. **25**, 1083 (1998)*





SNO+ geo-neutrinos and reactor background

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

Fundamental Geophysics

- SNO+ geo-neutrinos: a good follow-up to KamLAND's first detection
  - potential to really constrain the radiogenic heat flow
  - potential for geochemistry (U and Th separation)
  - tests models of Earth's chemical origin
  - simple geological configuration (smaller uncertainties)

Supernova Neutrinos

- 1 kton organic liquid scintillator would maintain excellent supernova neutrino capability
  - $\bar{\nu}_e + p$ [large rate]
  - $\bar{\nu}_e + {}^{12}C$ (CC)
  - $\nu_e + {}^{12}C$ (CC)
  - ν_x NC excitation of ${}^{12}C$ (NC)
  - $\nu_x + p$ elastic scattering (NC) [large rate]

see Beacom *et al.*, PRD **66**, 033001(2002)

Extension of SNO Science

- leverage existing investment in SNO to get new physics for relatively low cost
- SNO+ is uniquely positioned to make several measurements (due to depth, geology, appropriate distance to reactors, low backgrounds)
- costs are:
  - liquid scintillator procurement
  - mechanics of new configuration, AV certification
  - fluid handling and safety systems
  - scintillator purification
  - electronics/DAQ spares or upgrades?

SNO+ Technical

- liquid scintillator selection and design
- AV engineering

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

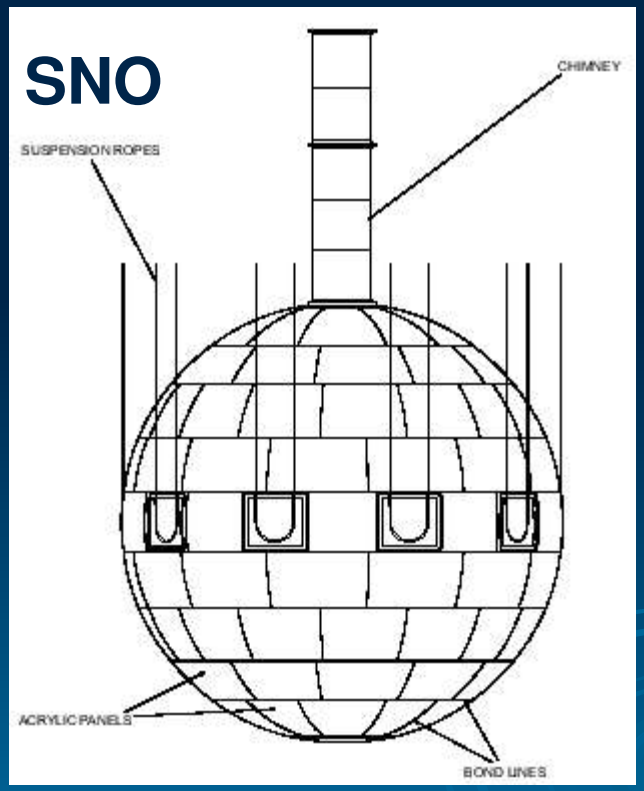
to be tackled next year

SNO+ Technical Issues

- liquid scintillator selection
  - compatibility with acrylic vessel
  - high light yield, long attenuation length
- reversing the acrylic vessel mechanics
  - SNO: AV contains heavy water, must hold up
  - SNO+: AV contains scintillator, $\rho < 1$ g/cm^3, must hold down

Acrylic Vessel Hold-down

- "rope net" being designed to hold down 15% density difference (buoyancy)

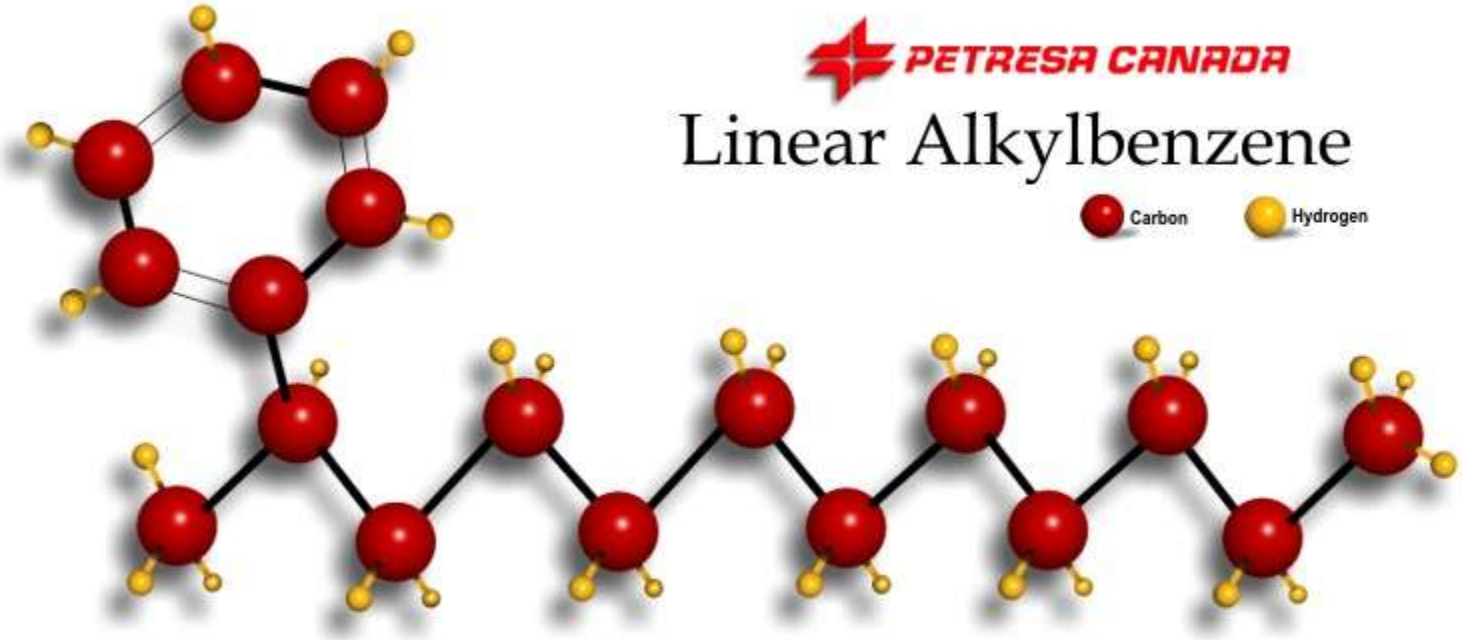


Scintillator Design

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

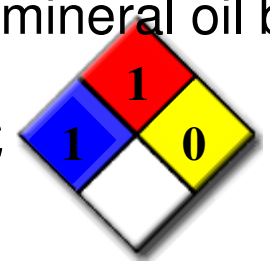
- high flash point
- low toxicity
- low cost

Linear Alkylbenzene



LAB Advantages

- compatible with acrylic (e.g. Bicron BC-531 is 95% LAB)
  - "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, producer has been very accommodating
- high purity

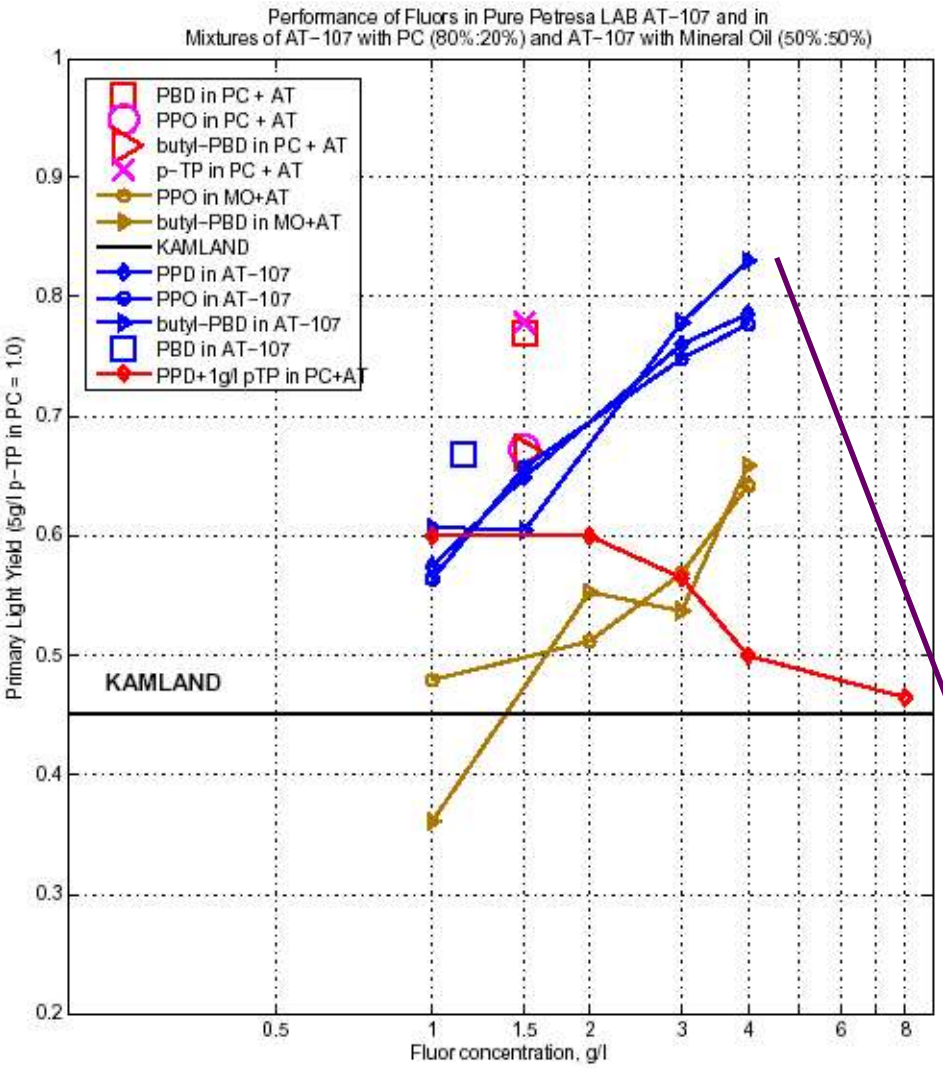
SNO+ Monte Carlo

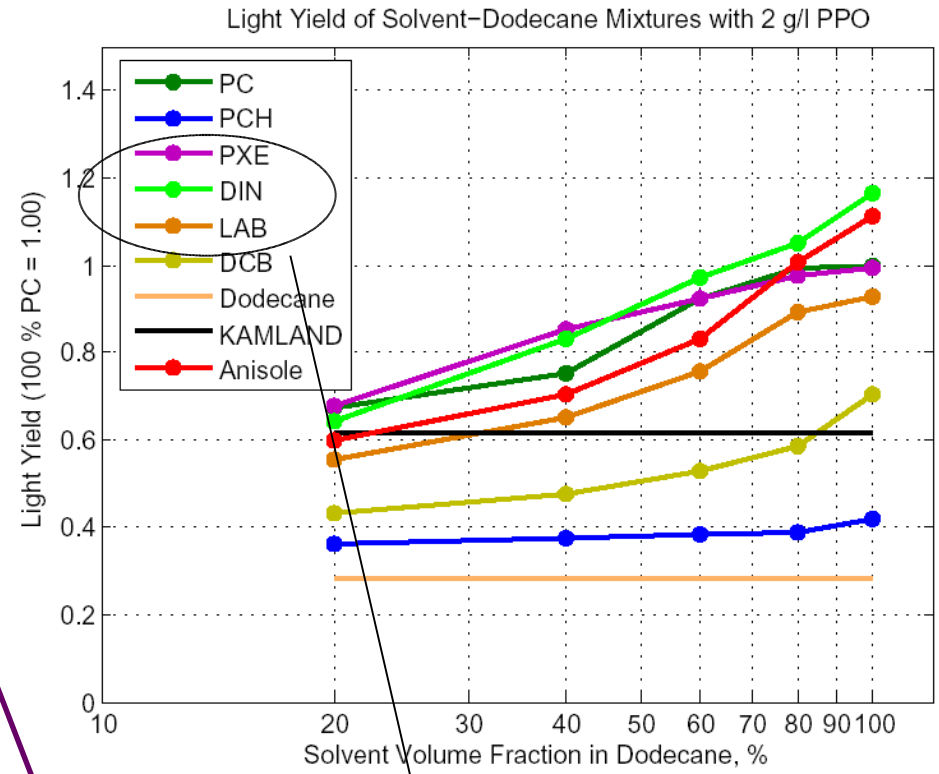
- light yield simulations

KamLAND scintillator in SNO+	629 ± 25 pe/MeV
above no acrylic	711 ± 27 pe/MeV
KamLAND scintillator 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%

LAB Scintillator Optimization





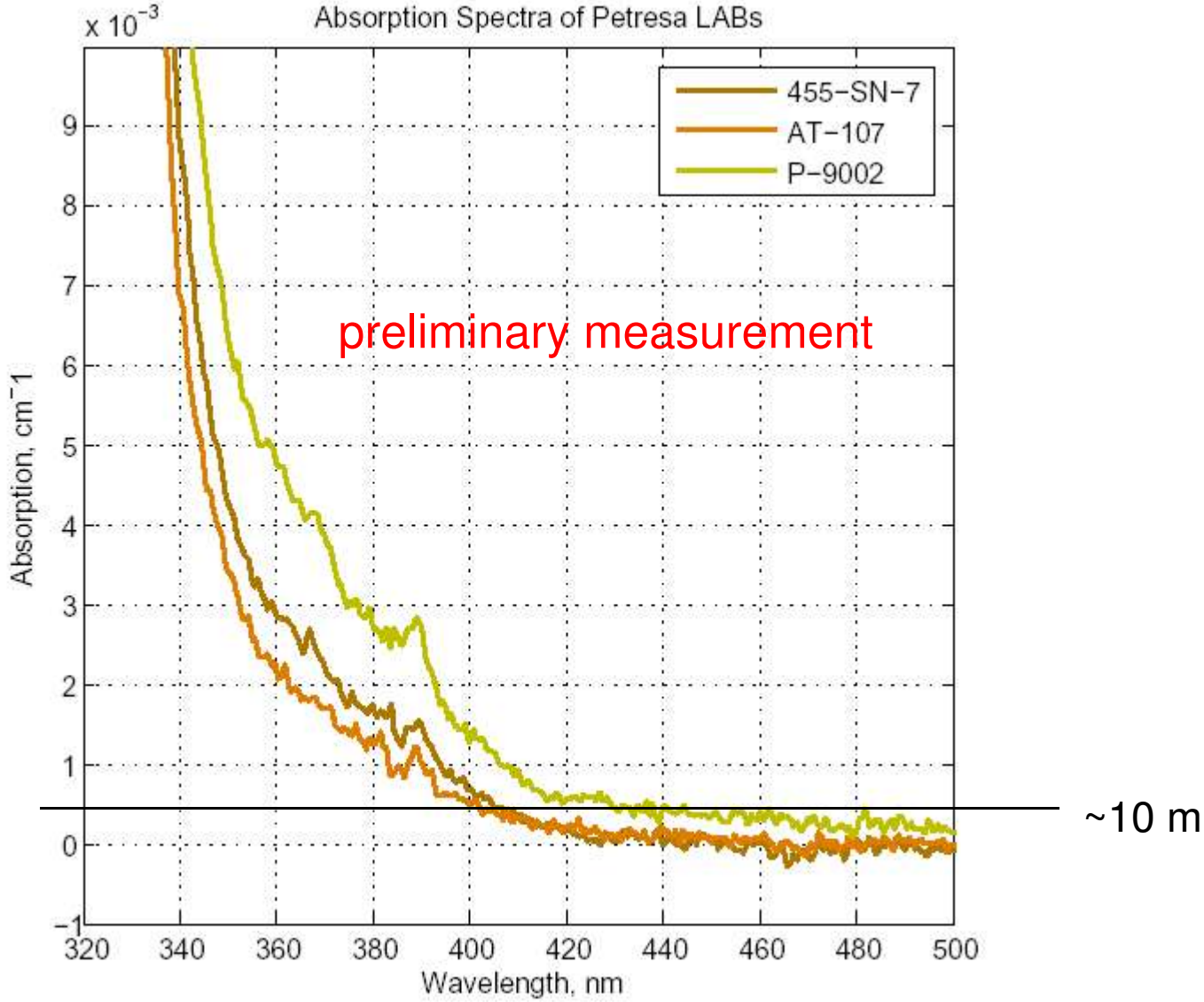
"safe" scintillators

LAB has 75% greater light yield than KamLAND scintillator

Light Attenuation Length

Petresa LAB as received

attenuation length exceeds 10 m



Default Scintillator Identified

- LAB has the smallest scattering of all scintillating solvents investigated
- LAB has the best acrylic compatibility of all solvents investigated
- density $\rho = 0.86$ g/cm^3 acceptable
- …default is Petresa LAB with 4 g/L PPO, wavelength shifter 10-50 mg/L bisMSB
- because solvent is undiluted and SNO photocathode coverage is high, expect light output (photoelectrons/MeV) ~3× KamLAND

SNO+ Status

- SNO+ is an NSERC-funded R&D project
- SNO+ endorsed by the SNOLAB Experiment Advisory Committee

"Exploit low-energy solar neutrinos for precision neutrino physics and stellar physics"

"We endorse development toward **SNO+** for pep solar neutrinos and geo-neutrinos. We applaud the technical progress in developing the liquid scintillator and encourage continued R&D, development of the necessary collaboration and proposal to secure funding. We look forward to a receiving a full technical proposal."

SNO+ in 2006

- SNO+ in Fall 2005 “proof of principle”
  - liquid scintillator identified
  - preliminary design to holddown the acrylic vessel
- 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 unique physics capabilities*

SNO+ Collaboration

Queen's

M. Chen*, M. Boulay, X. Dai, K. Graham, A. Hallin, C. Hearns, C. Kraus, C. Lan, J.R. Leslie, A. McDonald, V. Novikov, P. Skensved, A. Wright, U. Bissbort, S. Quirk

Laurentian

D. Hallman, C. Virtue

SNOLAB

B. Cleveland, R. Ford, I. Lawson

Brookhaven National Lab

A. Garnov, D. Hahn, M. Yeh

Los Alamos National Lab

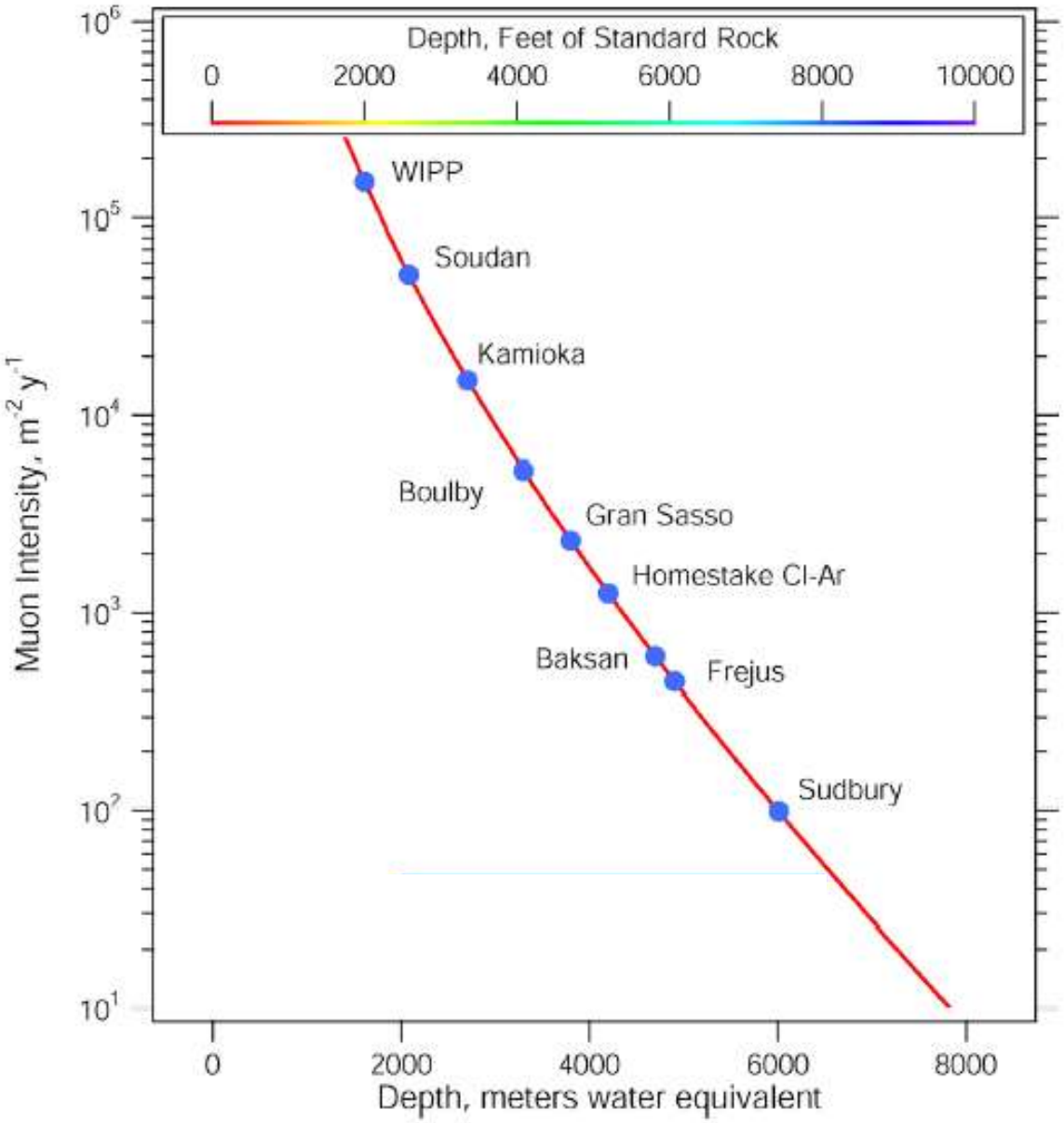
A. Hime

LIP Lisbon

J. Maneira

only a subset of the SNO collaboration will continue with SNO+

- potential collaborators from outside SNO (Italy, Germany, Russia) have indicated some interest

new collaborators welcome

Depth Matters!