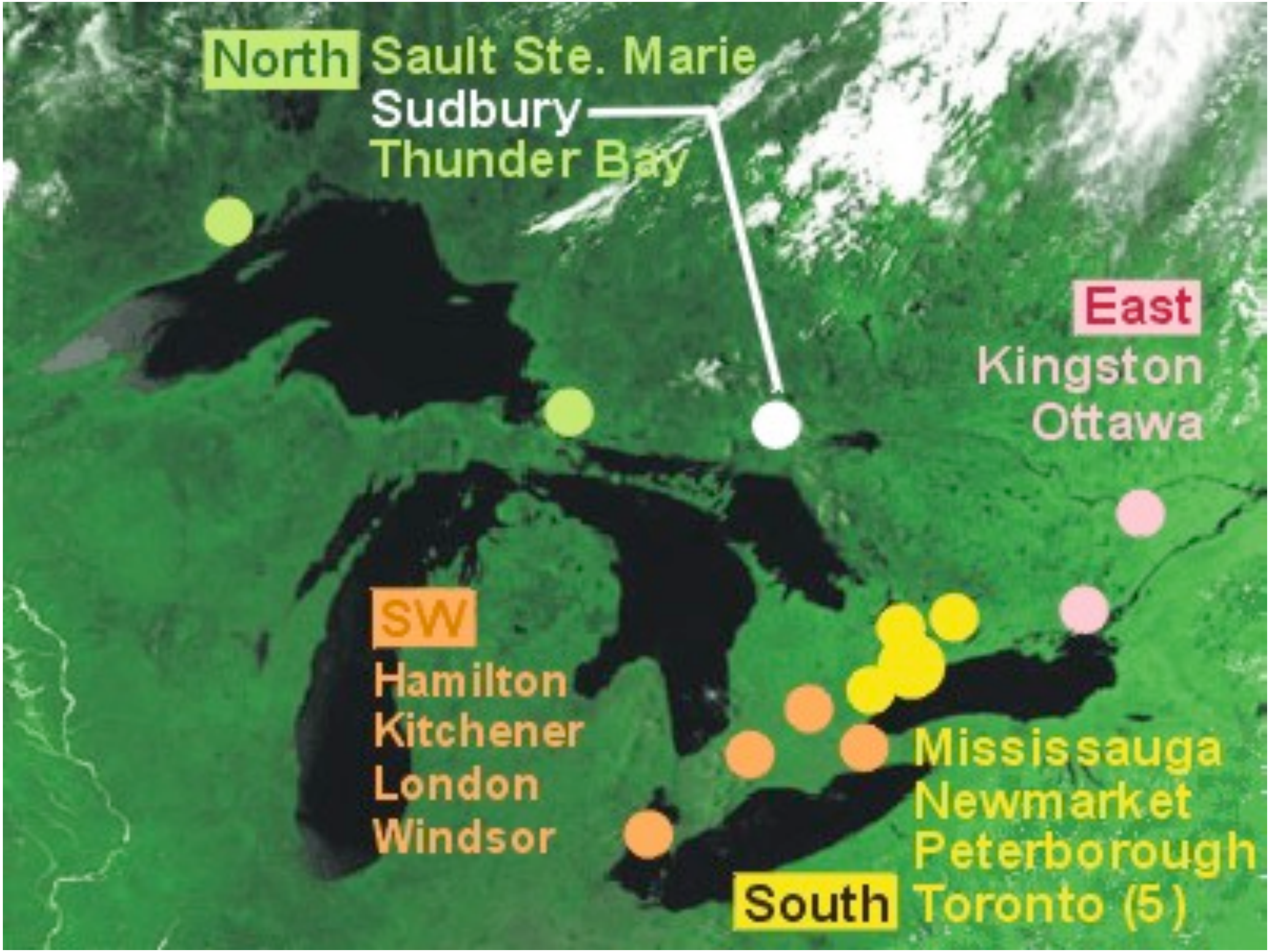
Current Activities:

From SNO to SNO+

Because there's SNO place like Home!

S. Biller, Oxford University

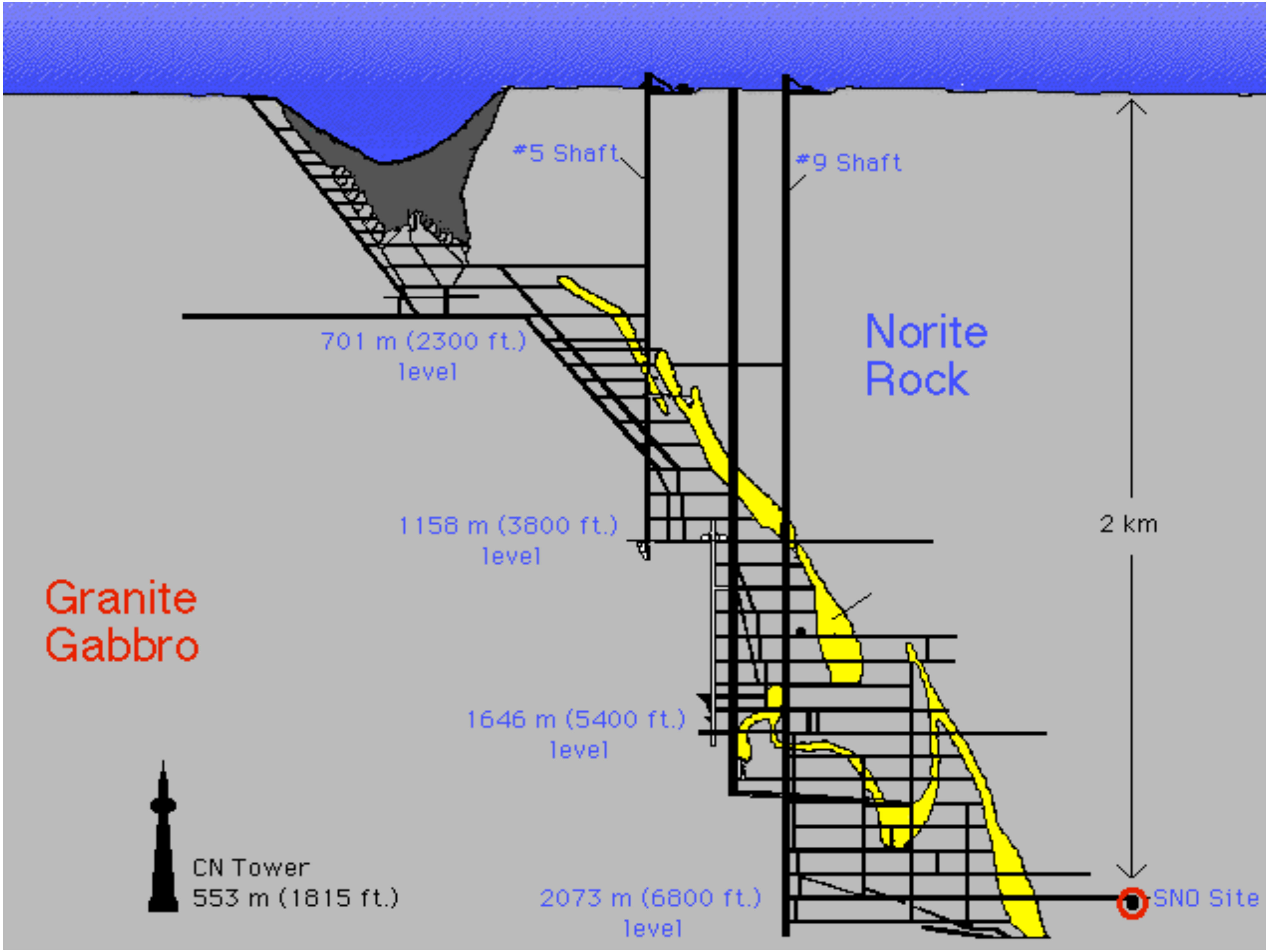

North
Sault Ste. Marie
Sudbury
Thunder Bay
East
Kingston
Ottawa
SW
Hamilton
Kitchener
London
Windsor
Mississauga
Newmarket
Peterborough
South
Toronto (5)


CANADA
NICKEL
5
1751-1951
CENTS


TIMBITS
20 Per Pack
Snack Pack
TIMBITS

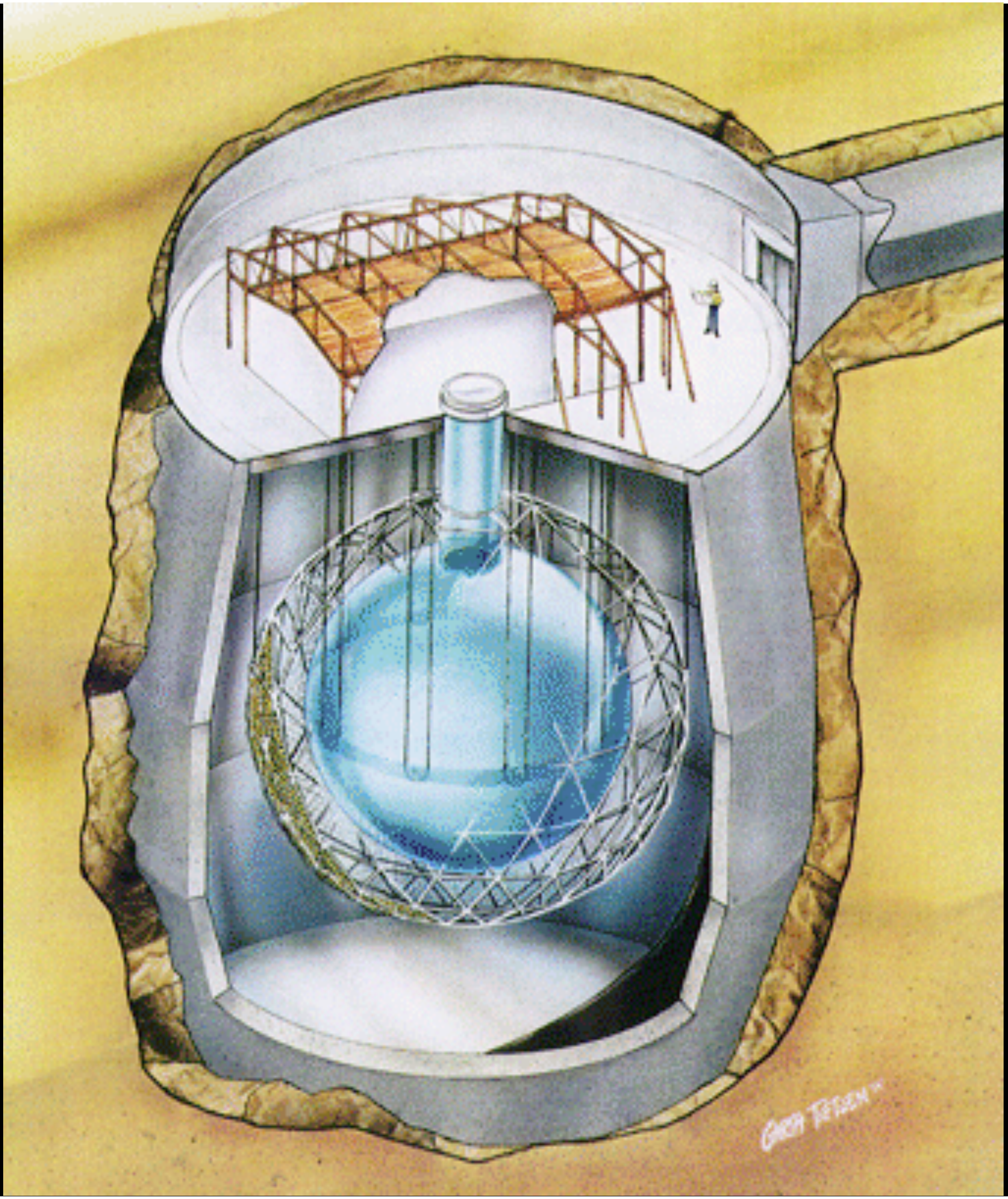

Tim Hortons
Tim Hortons
Coffee

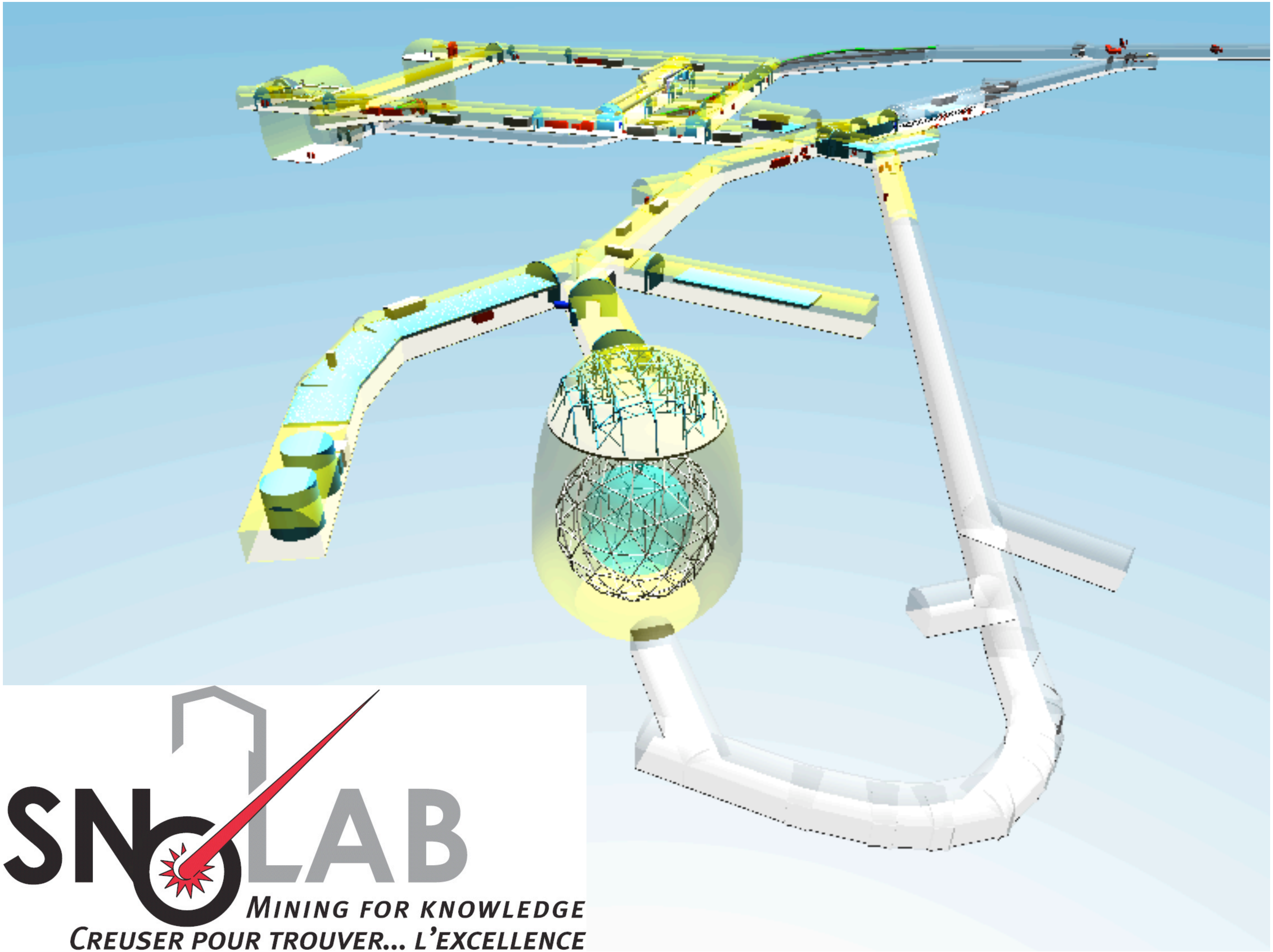

MEATBIRD
BEACH
TOWN OF WALDEN


#5 Shaft
#9 Shaft
Norite Rock
701 m (2300 ft.) level
1158 m (3800 ft.) level
2 km
Granite Gabbro
1646 m (5400 ft.) level
CN Tower
553 m (1815 ft.)
2073 m (6800 ft.) level
SNO Site


AG IN BOARD


Dr. SNO





SNOLAB

Mining for knowledge

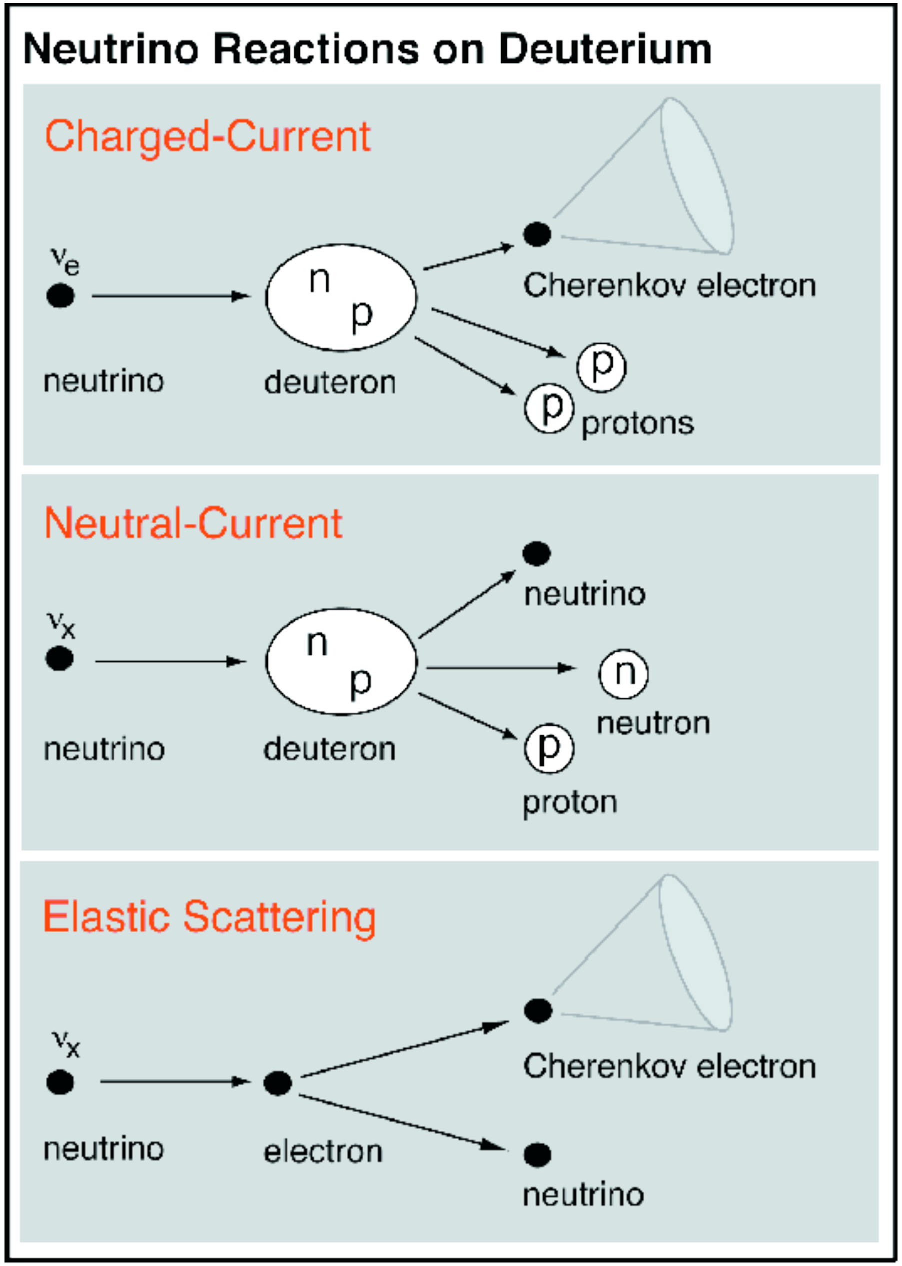
Creuser pour trouver… l'excellence

ν Reactions in SNO

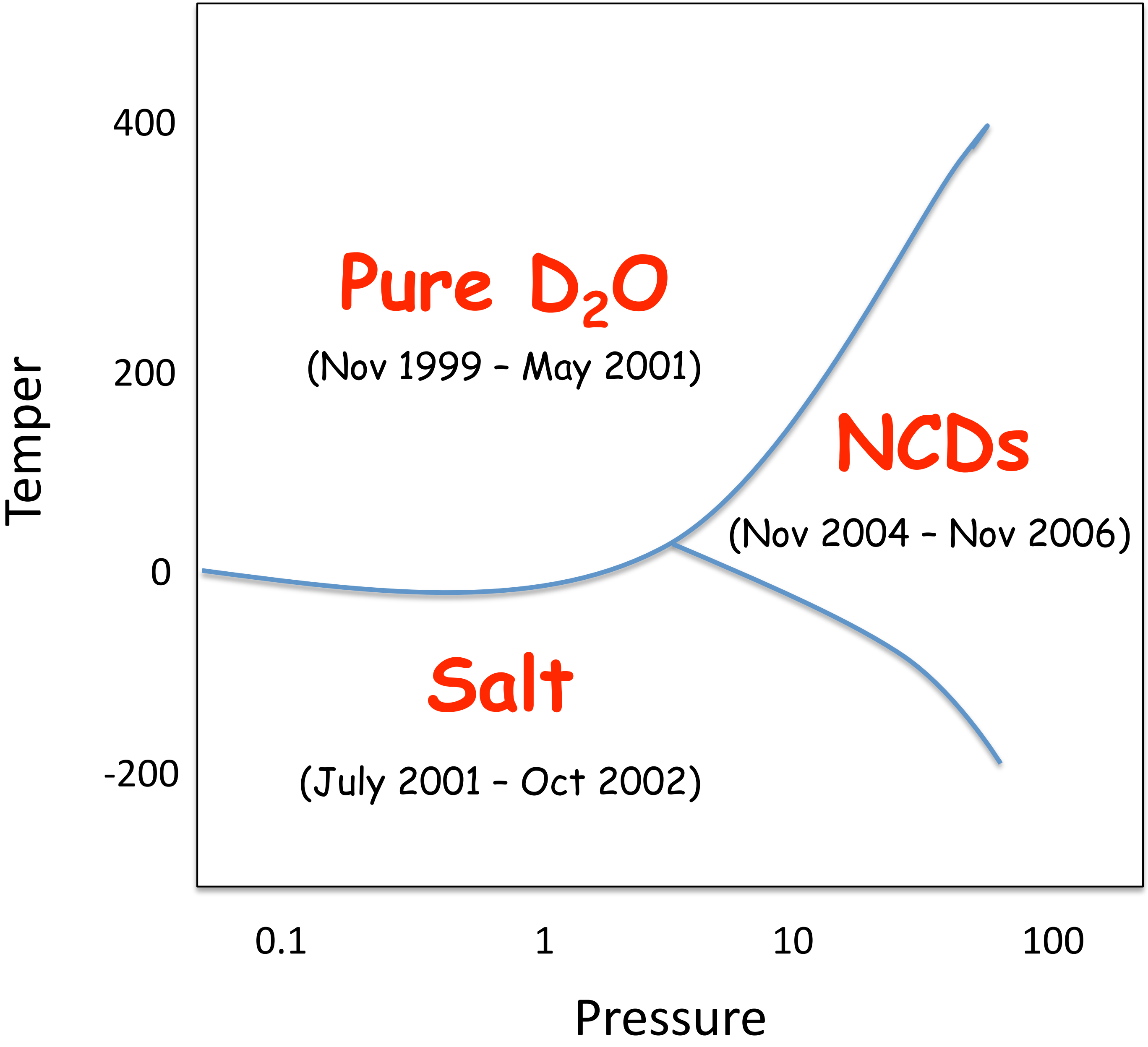
CC $\nu_e + \mathrm{d} \Rightarrow \mathrm{p} + \mathrm{p} + \mathrm{e}^-$

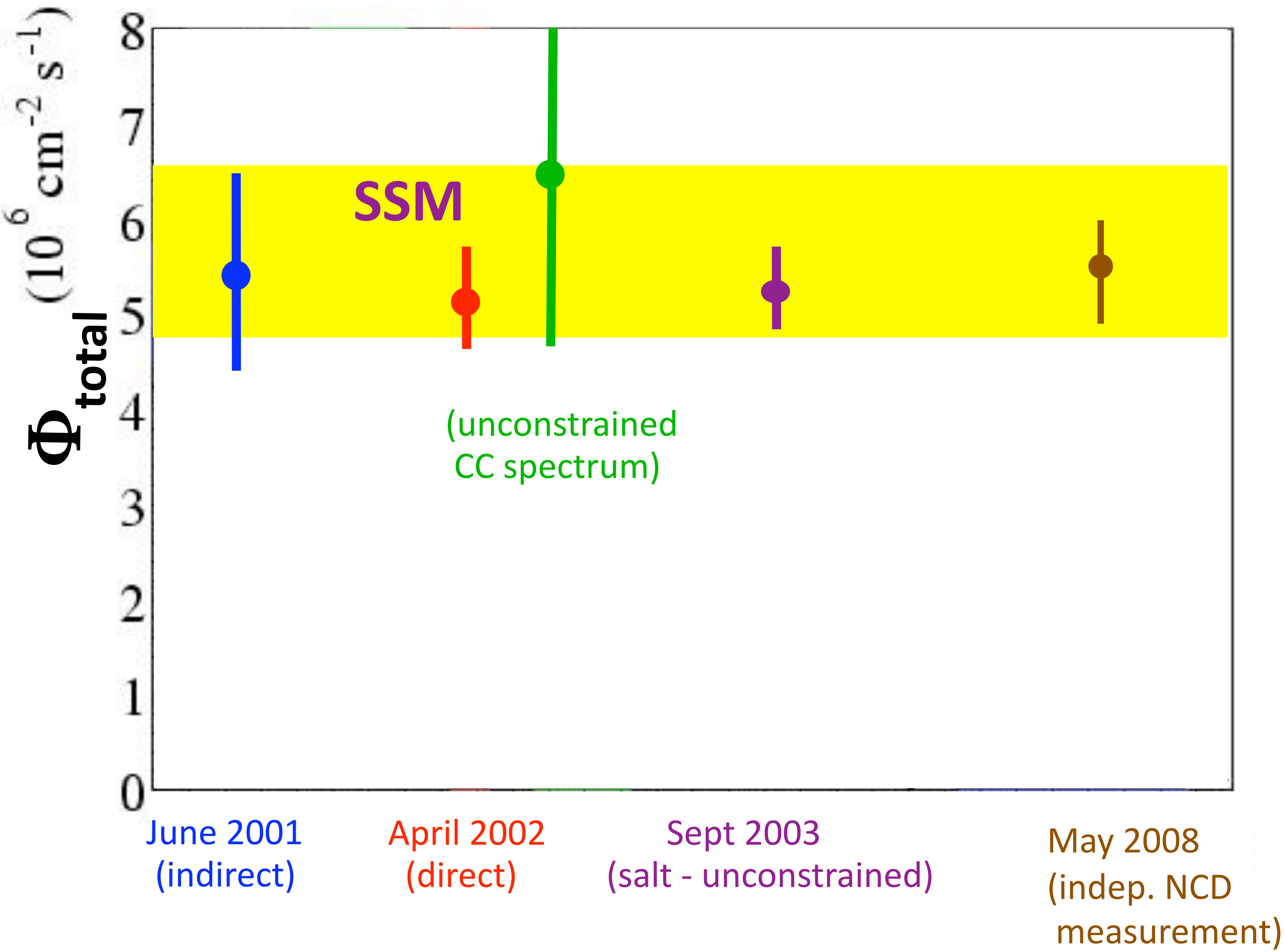
NC $\nu_x + \mathrm{d} \Rightarrow \mathrm{p} + \mathrm{n} + \nu_x$

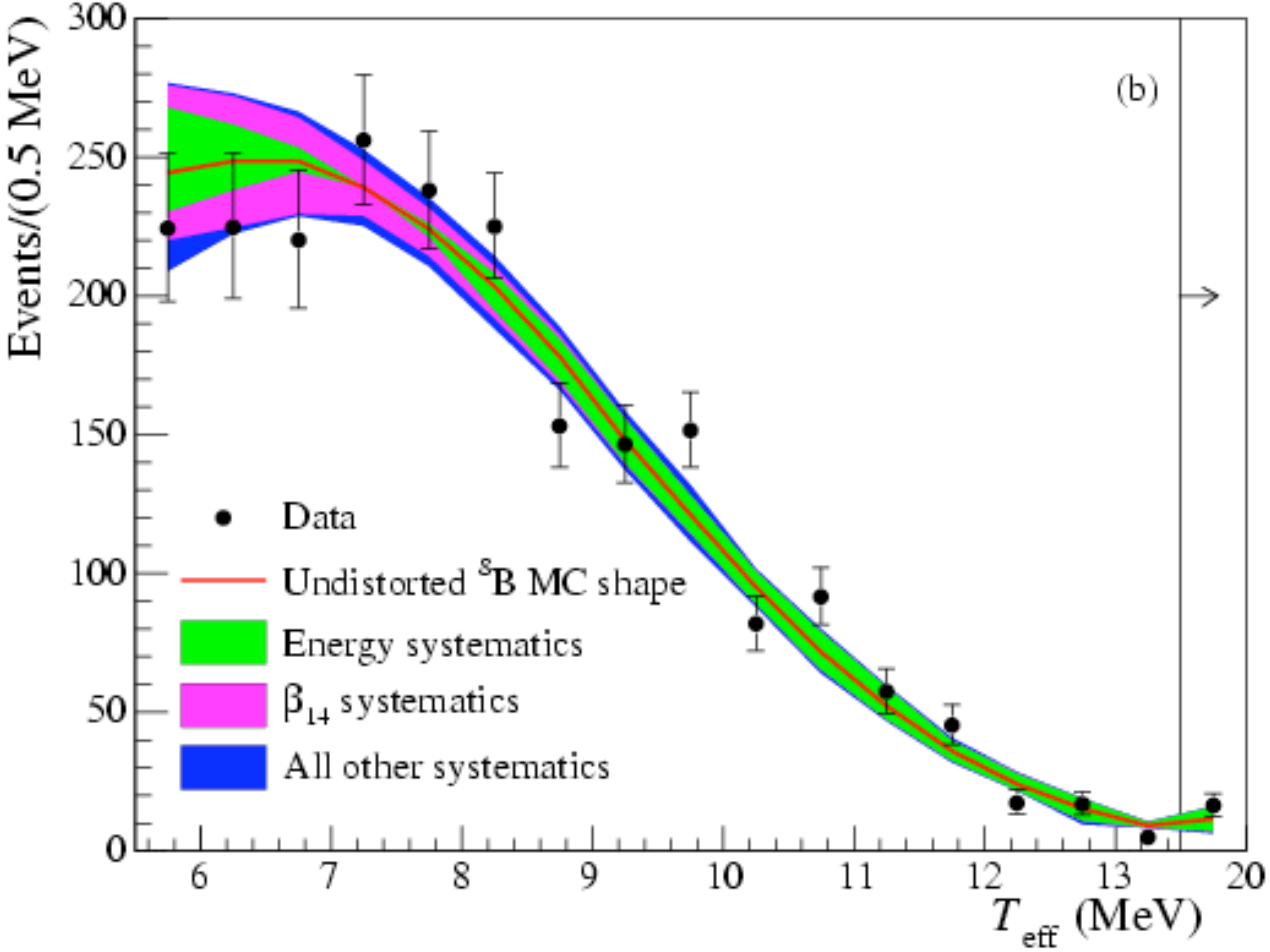
ES $\nu_x + \mathrm{e}^- \Rightarrow \nu_x + \mathrm{e}^-$

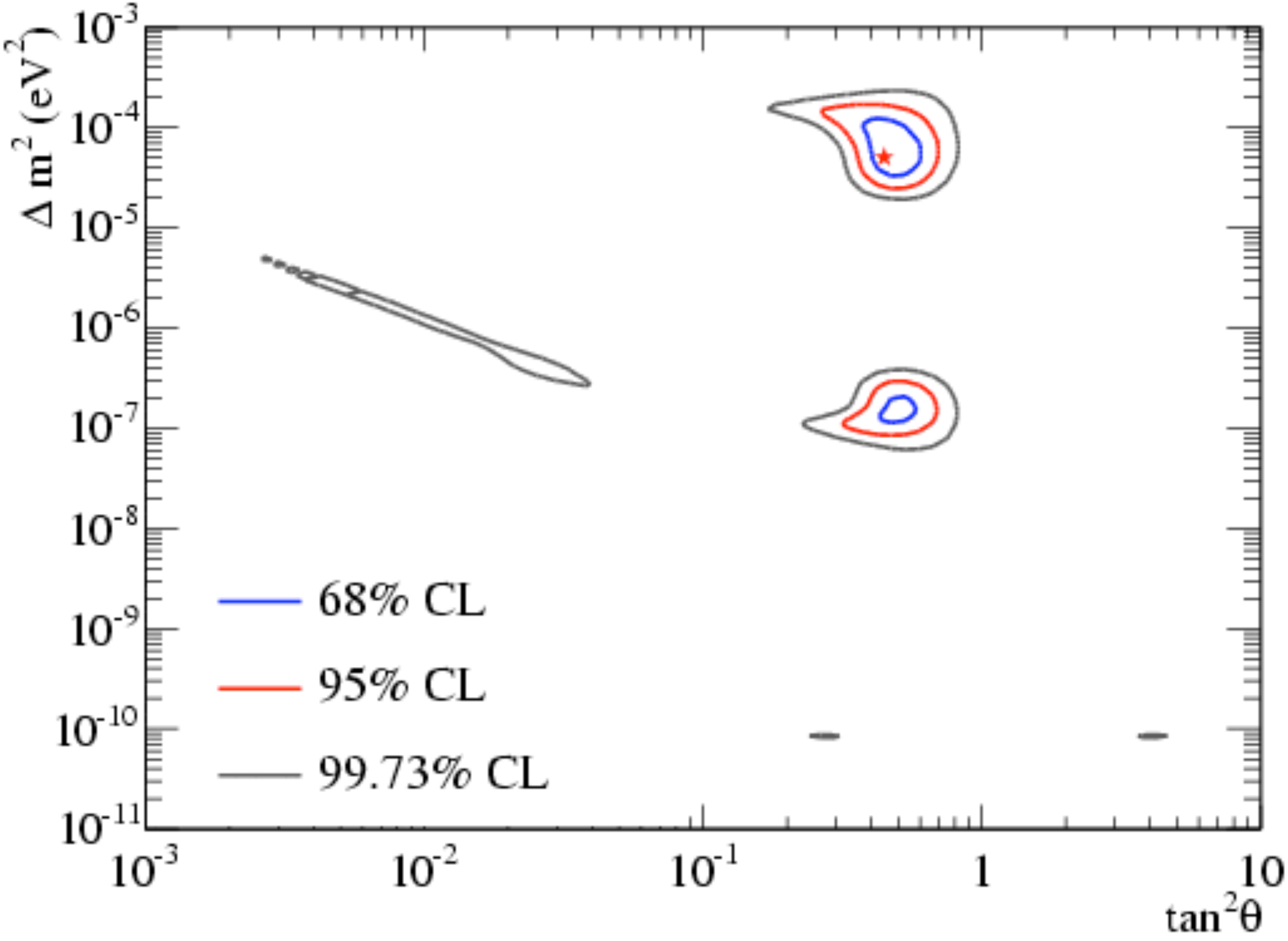


Phases of SNO:




Φ_{total} $(10^6 \text{ cm}^{-2} \text{ s}^{-1})$
8
7
6
5
4
3
2
1
0
SSM
(unconstrained
CC spectrum)
June 2001
(indirect)
April 2002
(direct)
Sept 2003
(salt - unconstrained)
May 2008
(indep. NCD
measurement)


(b)
Events/(0.5 MeV)
300
250
200
150
100
50
0
6
7
8
9
10
11
12
13
20
T_{eff} (MeV)
● Data
Undistorted ^{8}B MC shape
Energy systematics
β_{14} systematics
All other systematics


Δm^2 (eV^2)
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
68% CL
95% CL
99.73% CL
10^{-3}
10^{-2}
10^{-1}
1
10
$\tan^2\theta$

How Do You Do Better?

→ Do It Again!

D_2O and Salt phases had the lowest analysis energy thresholds, best spectral information and simplest detector configurations (good place to start):

- Do a more careful combined signal extraction from these phases
- Lower analysis energy threshold as much as possible
- Take more time to understand and reduce systematic uncertainties
- Put more effort into modeling low energy backgrounds
- Take advantage of recent improvements in algorithms and simulations
- Pay closer attention to propagation of correlated uncertainties

Current SNO Efforts

- High frequency periodicity studies
- Burst searches
- Exotics
- 3-Phase analysis
- Low Energy Threshold Analysis (LETA)

Joint Phase I+II down to $T_{eff}>3.5$ MeV

(Previous SNO analysis thresholds: T>5.0 MeV/5.5 MeV/6.0 MeV Phase I/II/III)

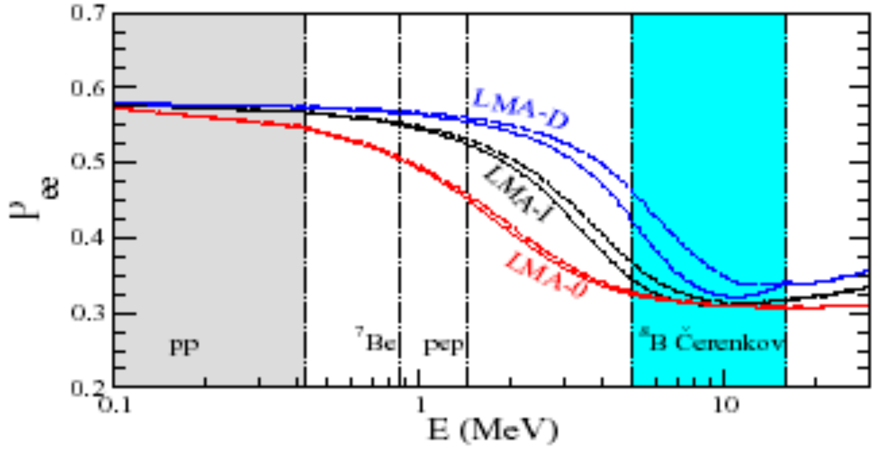
Significantly reduced systematics

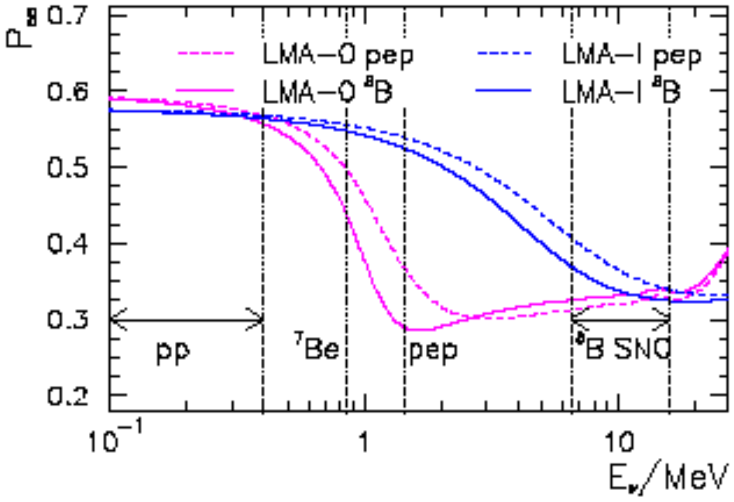
Direct ν_e survival probability fit

Physics Motivations for Low Threshold Analysis

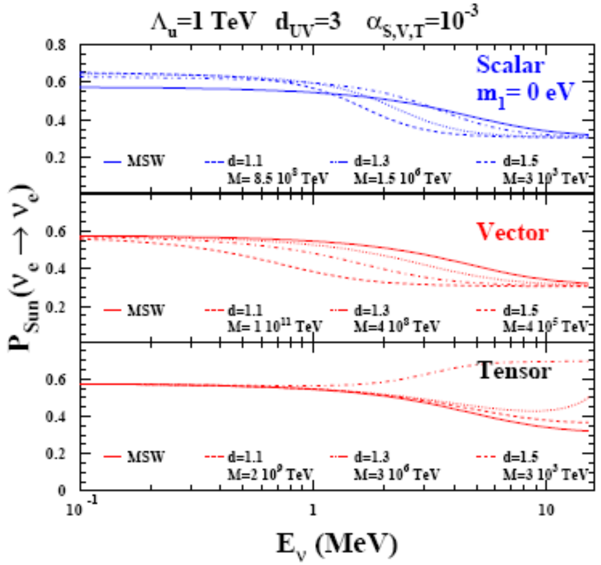
Nonstandard effects can be enhanced by MSW-like resonance

Miranda, Tortola, Valle, hep-ph/0406289 (2005)

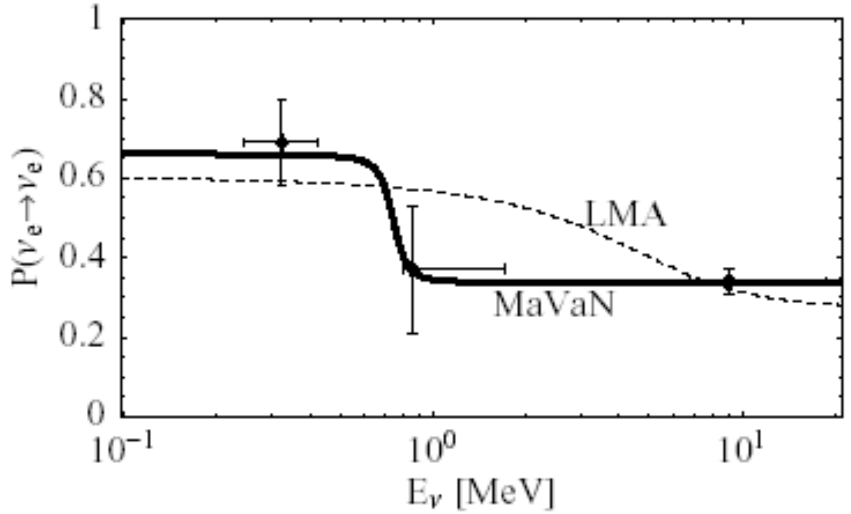




Friedland, Lunardini, Peña-Garay, PLB 594, (2004)



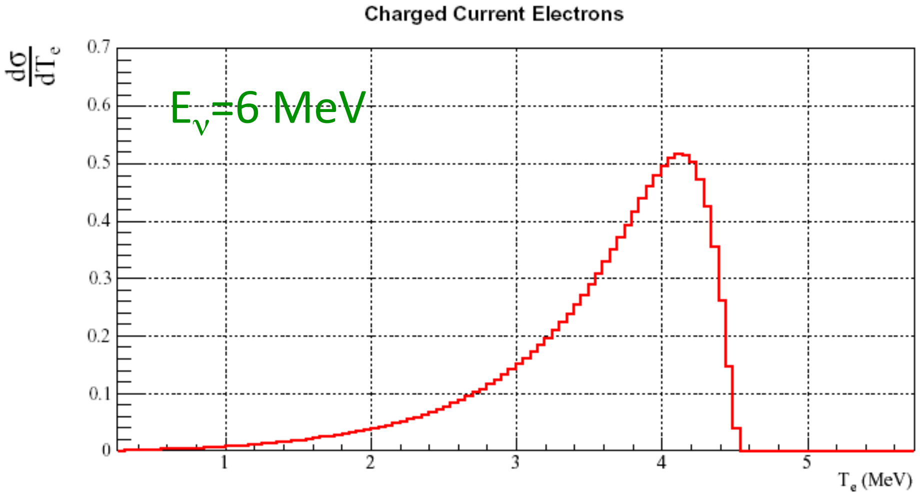
M. C. Gonzalez-Garcia, P. C. de Holanda, E. Masso and R. Zukanovich Funchalc, hep-ph/0803.1180



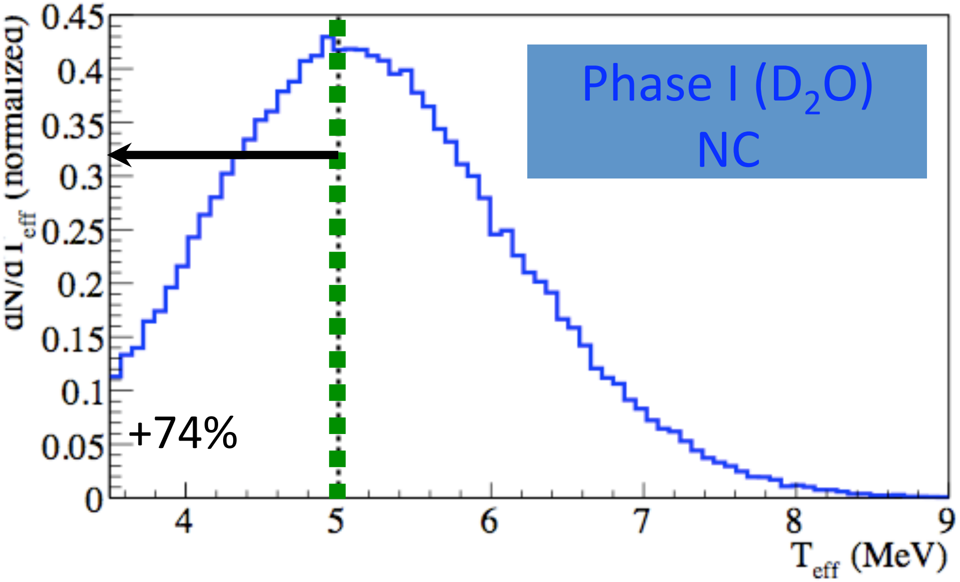
Barger, Huber, Marfatia, PRL95, (2005)

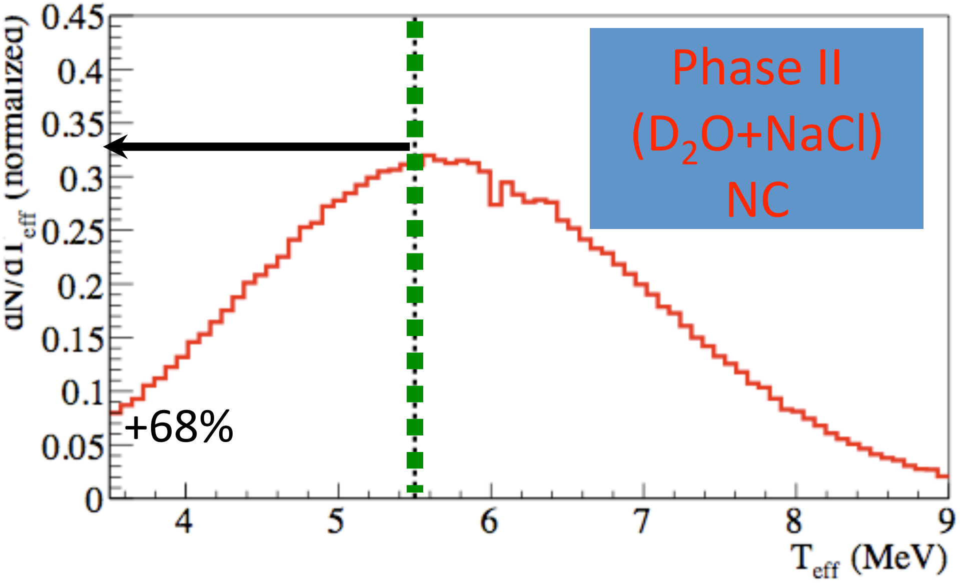
Advantages of Low Threshold Analysis

- ν_e Statistics



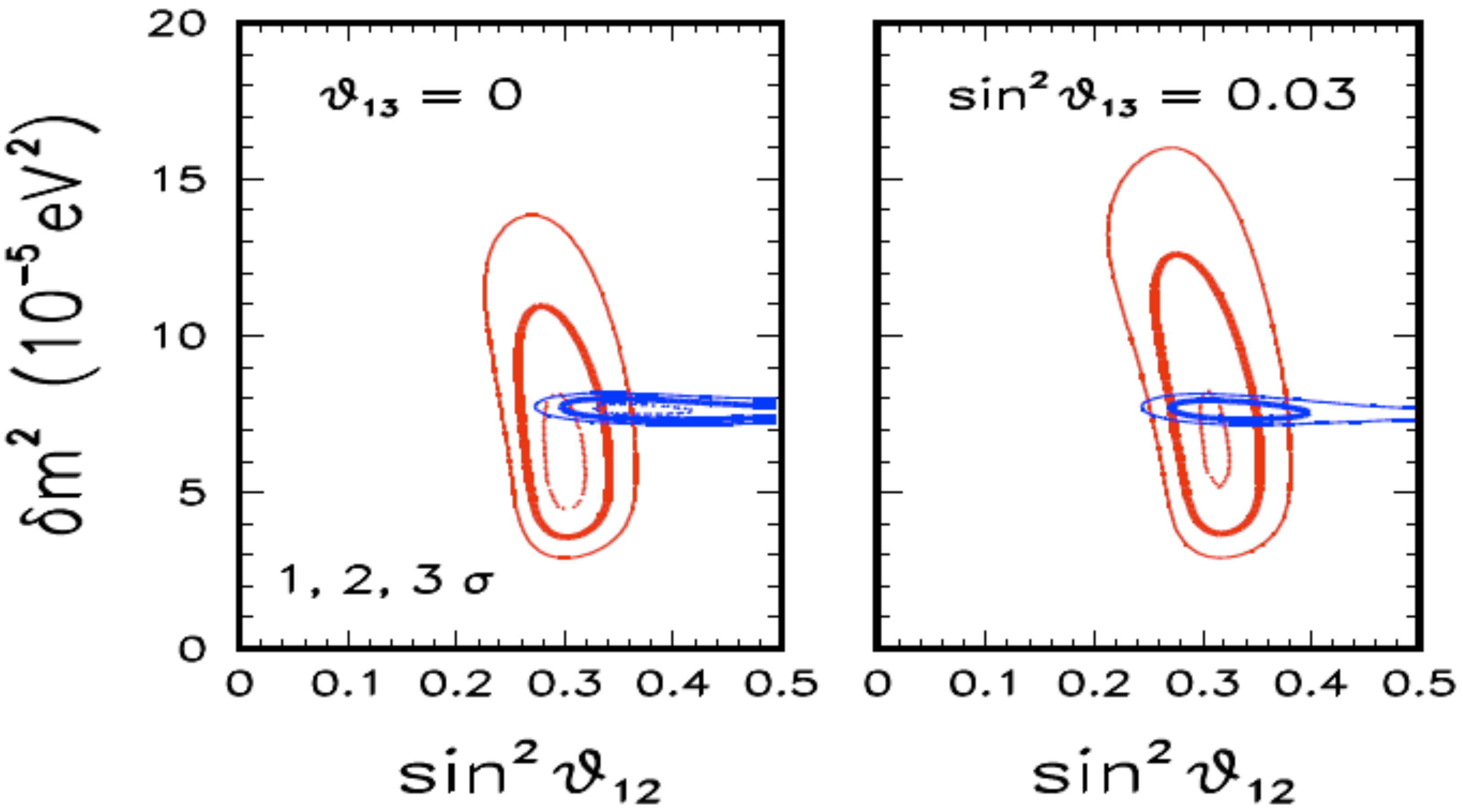
- ν_x (NC) Statistics





Physics Motivations for Low Threshold Analysis

- Test the model of massive neutrino mixing
- KamLAND+Solar provides possible handle on θ_{13}

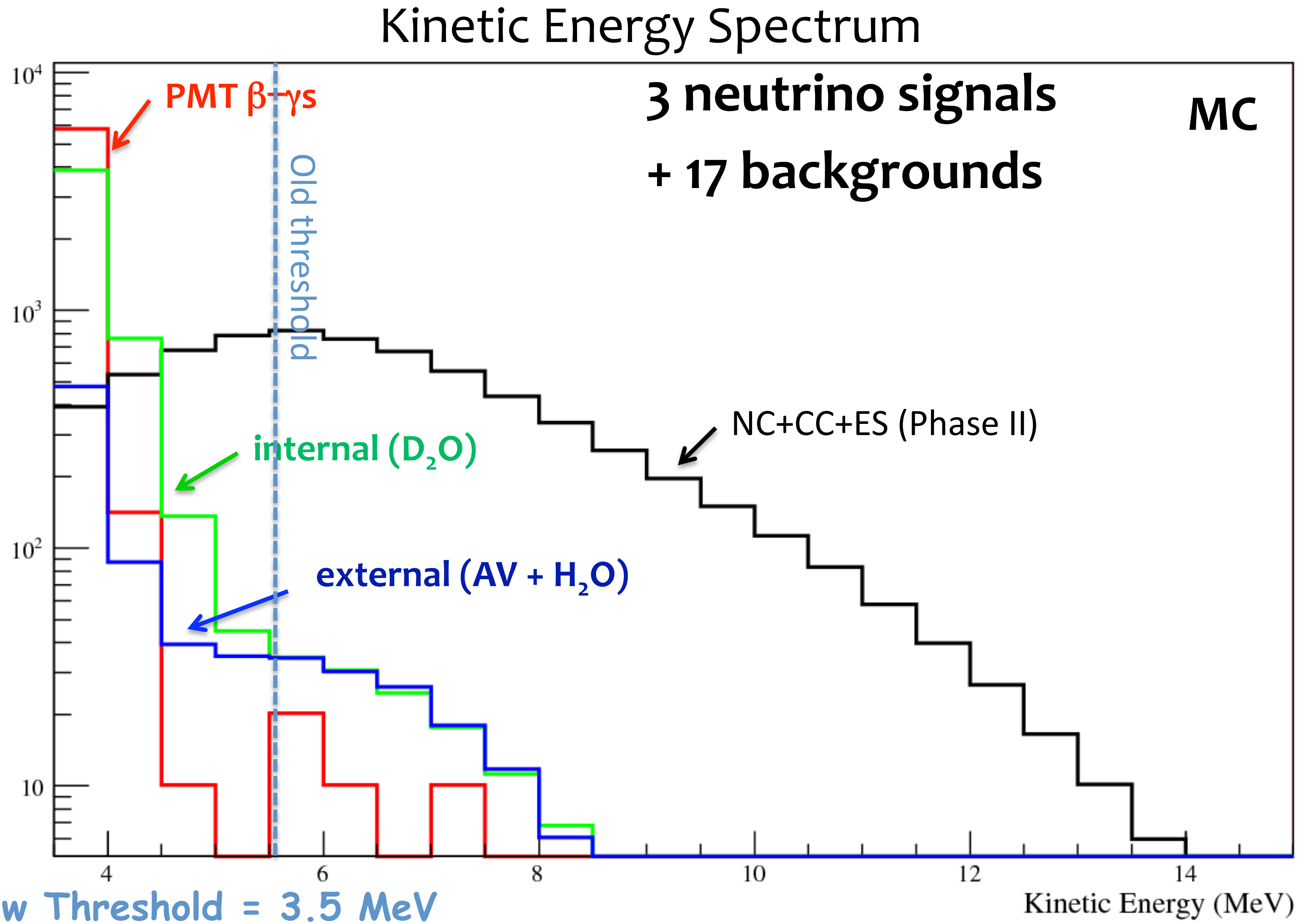


G.L. FOGLI [1,2*], E. LISI [2], A. MARRONE [1,2], A. PALAZZO [3], A.M. ROTUNNO [1,2]

arXiv:0905.3549v1

Challenges of a Low Threshold Measurement

- Low Energy Backgrounds



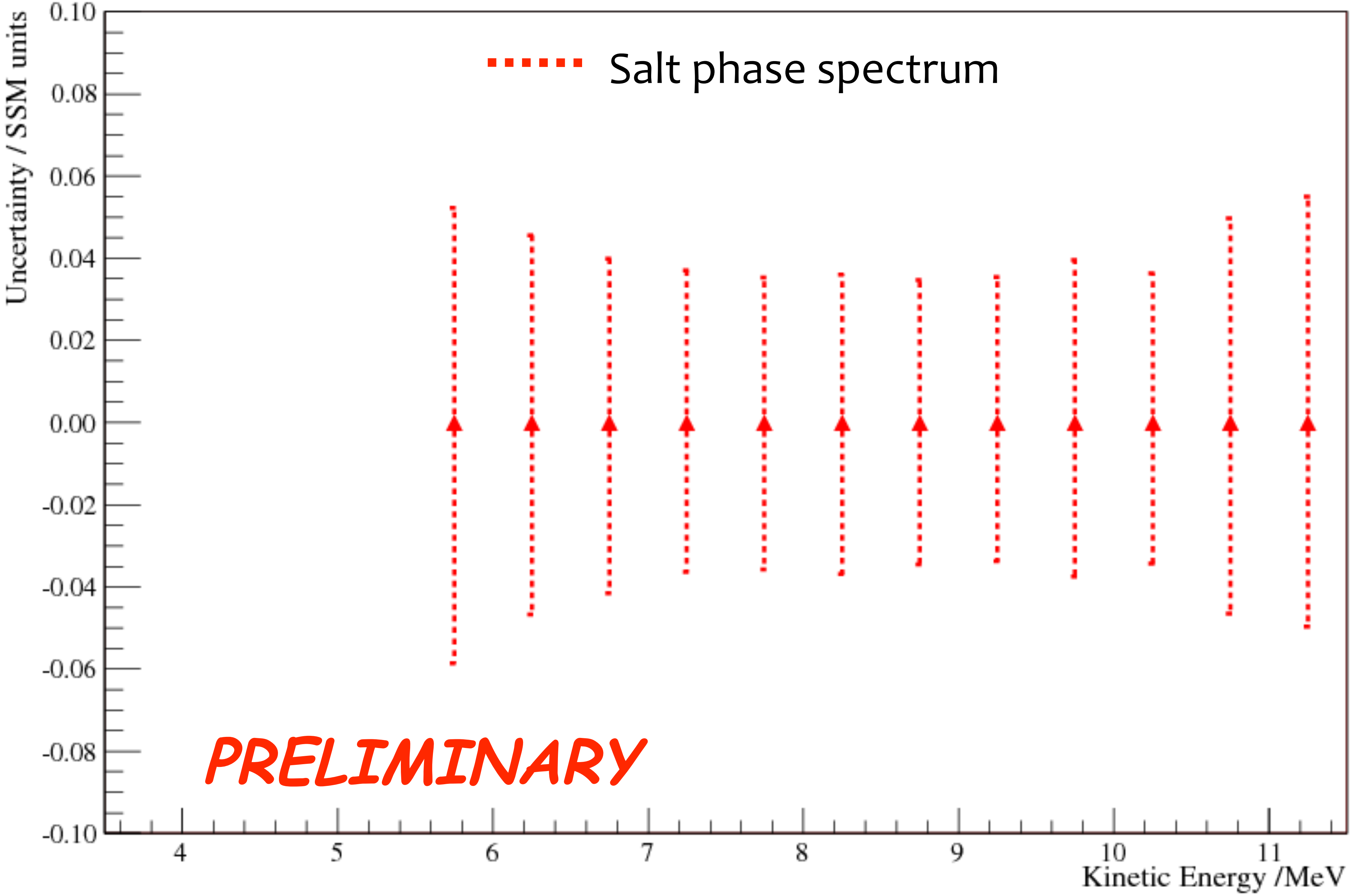
3 neutrino signals

+ 17 backgrounds

New Threshold = 3.5 MeV

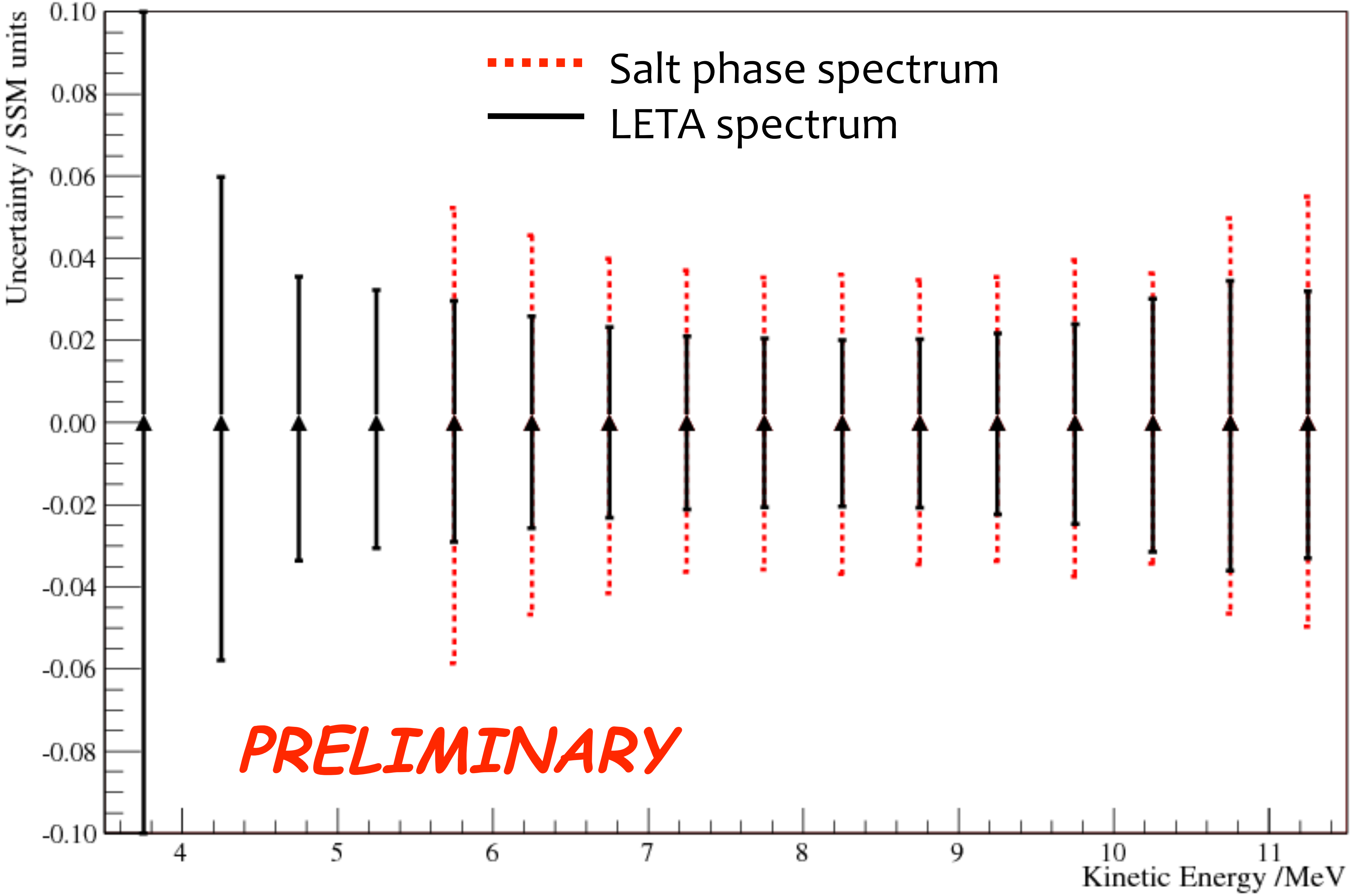
Low Energy Threshold Analysis

- ➢ Uncertainties on CC Electron Recoil Spectrum



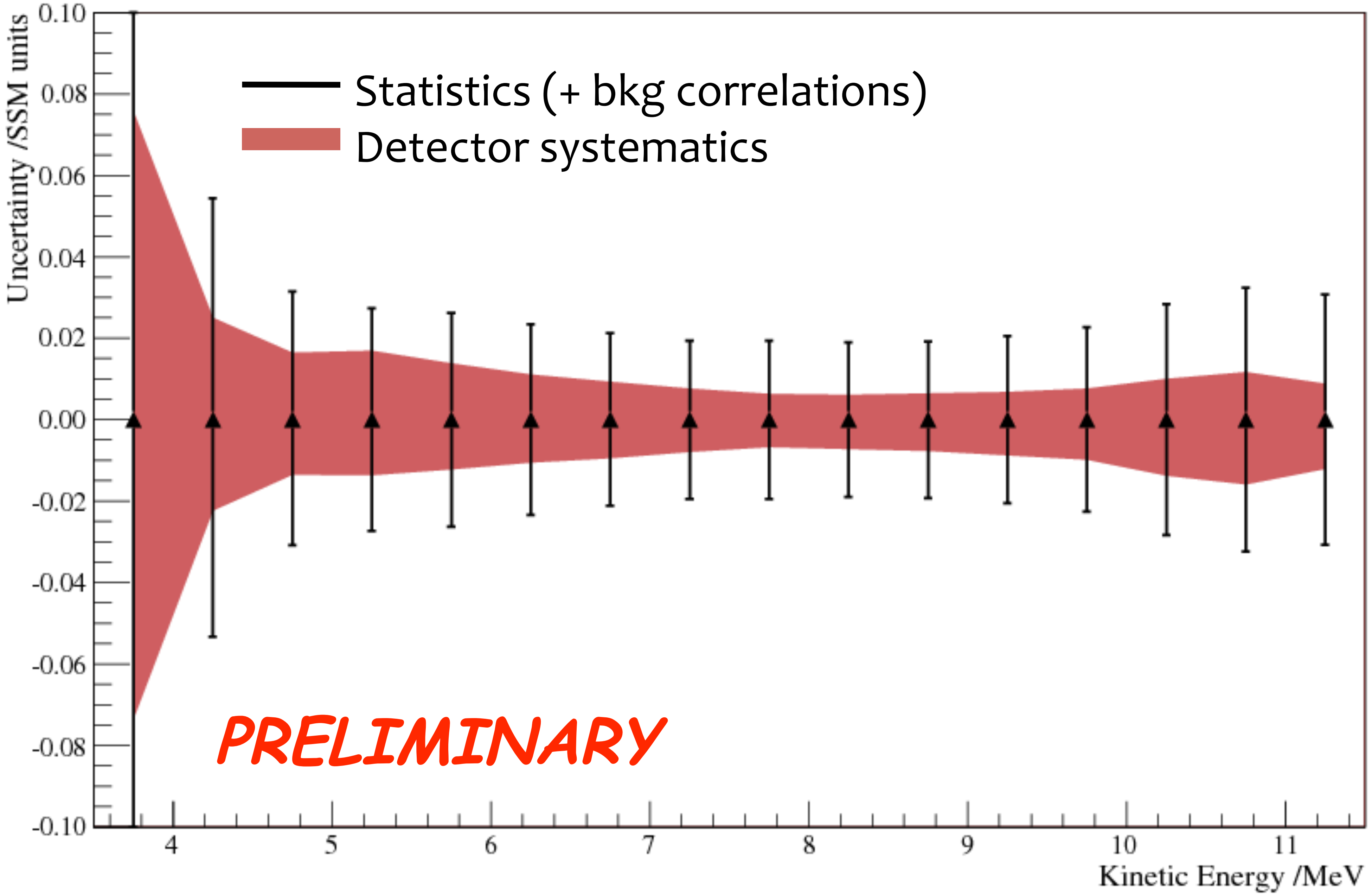
Low Energy Threshold Analysis

➢ Uncertainties on CC Electron Recoil Spectrum



Low Energy Threshold Analysis

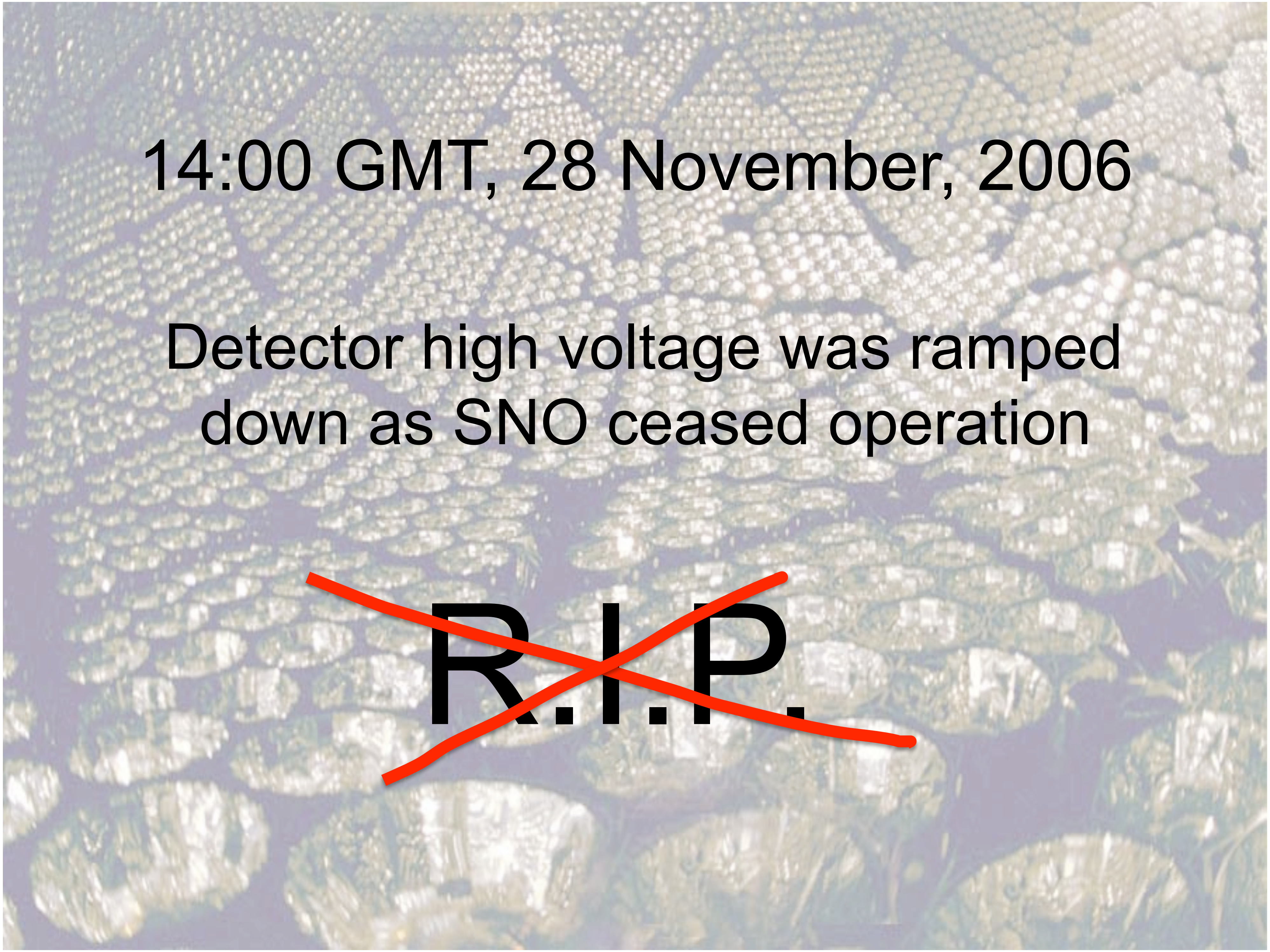
- Uncertainties on CC Electron Recoil Spectrum



Low Energy Threshold Analysis

Results to Look for in Upcoming Paper

- CC & ES binned recoil spectra at reduced threshold
- NC-measured total flux (~4%)
- Direct extraction of survival probability P_{ee}
- Solar+KamLAND two-flavor contours
- Solar+KamLAND three-flavor contours

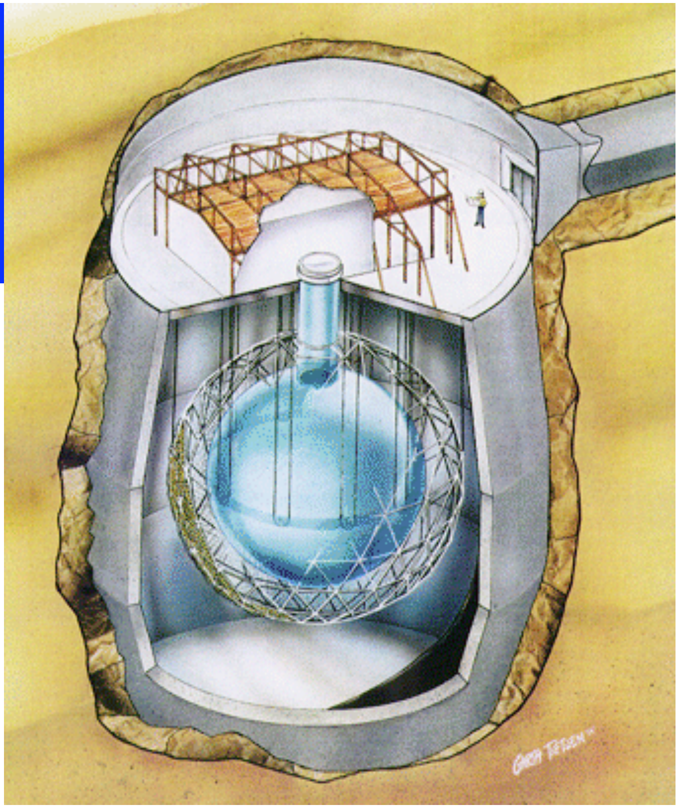


14:00 GMT, 28 November, 2006

Detector high voltage was ramped down as SNO ceased operation

~~R.I.P.~~

SNO+



Replace 1000 tonnes of ultrapure D_2O
with 800 tonnes of ultrapure scintillator

(so, technically, should be "SNO-")

Physics with Liquid Scintillator

- **Neutrinoless double beta decay**
- **pep and CNO low energy solar neutrinos**
  - tests details of neutrino-matter interaction
  - solve "Solar Composition Problem"
- Low energy ^{8}B solar neutrinos (& possibly ^{7}Be)
- Geo-neutrinos
- 240 km baseline reactor neutrino oscillations
- Supernova neutrinos

SNO+ Collaboration

Queen's University

M. Boulay, M. Chen*, X. Dai, E. Guillian, P. Harvey, C. Kraus, X. Liu, A. McDonald, V. Novikov, H. O'Keeffe, E. O'Sullivan, P. Skensved, A. Wright

University of Alberta

A. Bialek, P. Gorel, A. Hallin, M. Hedayatipoor, C. Krauss

Carleton University

K. Graham

Laurentian University

D. Hallman, S. Korte, C. Virtue

SNOLAB

B. Cleveland, F. Duncan, R. Ford, C. Jillings, I. Lawson

Brookhaven National Laboratory

R. Hahn, M. Yeh, Y. Williamson

Idaho National Laboratory

J. Baker

Idaho State University

J, Heise, K. Keeter, E. Tatar, C. Taylor

University of North Carolina at Chapel Hill

M. Howe, J. Wilkerson

University of Pennsylvania

G. Beier, R. Bonventre, B. Heintzelman, J. Klein, G. Orebi Gann, J. Secrest, T. Sokhair

University of Washington

[illegible]

Dresden University of Technology

K. Zuber

LIP Lisbon

S. Andringa, N. Barros, J. Maneira

University of Oxford

S. Biller, I. Coulter, N, Jelley, P. Jones, A. Reichold

University of Sussex

A. Baxter, E. Falk, S. Fernandez, J. Hartnell, S. Peeters

University of Leeds

S.M. Bradbury, H.J. Rose

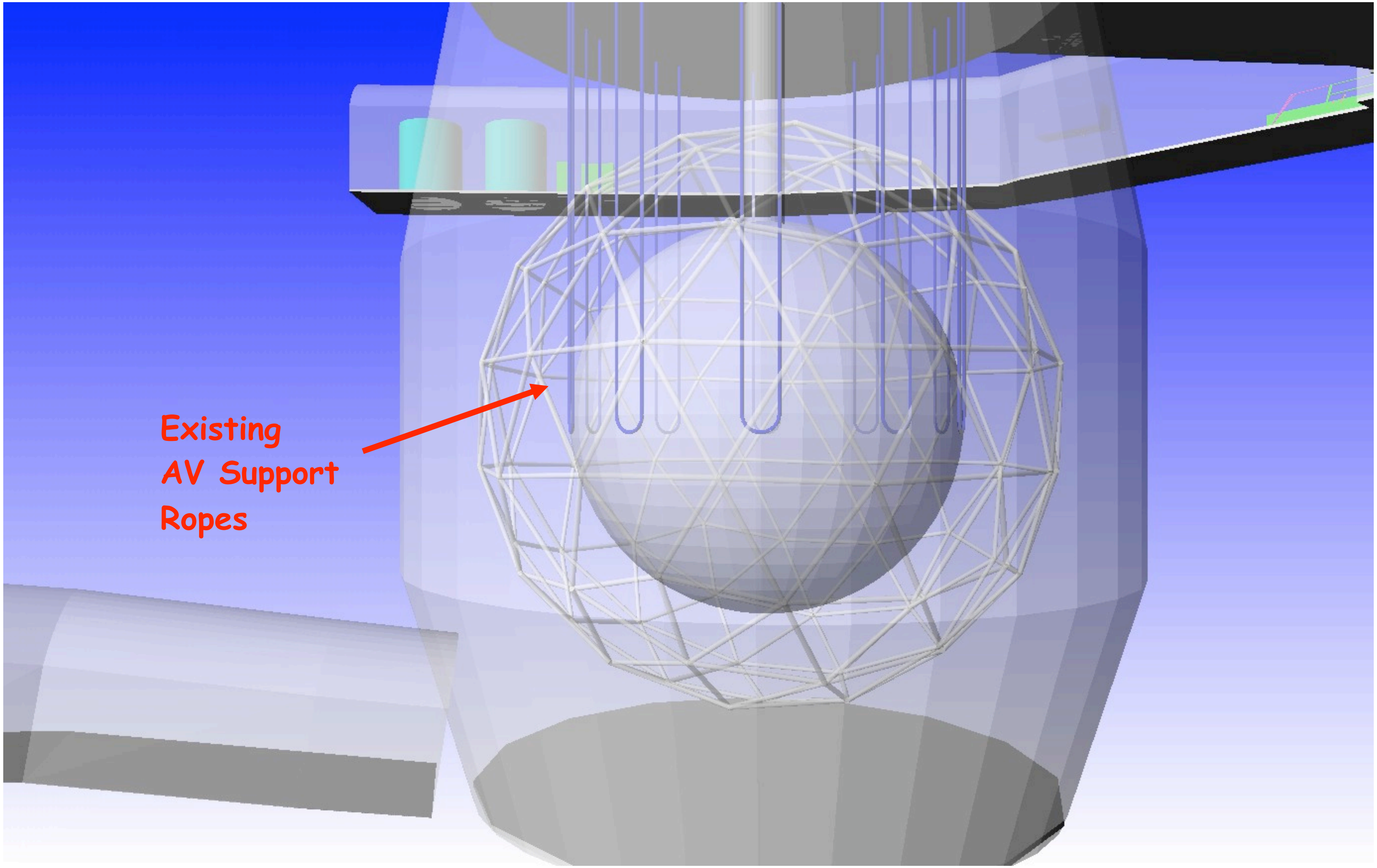
Queen Mary University of London

J. Wilson

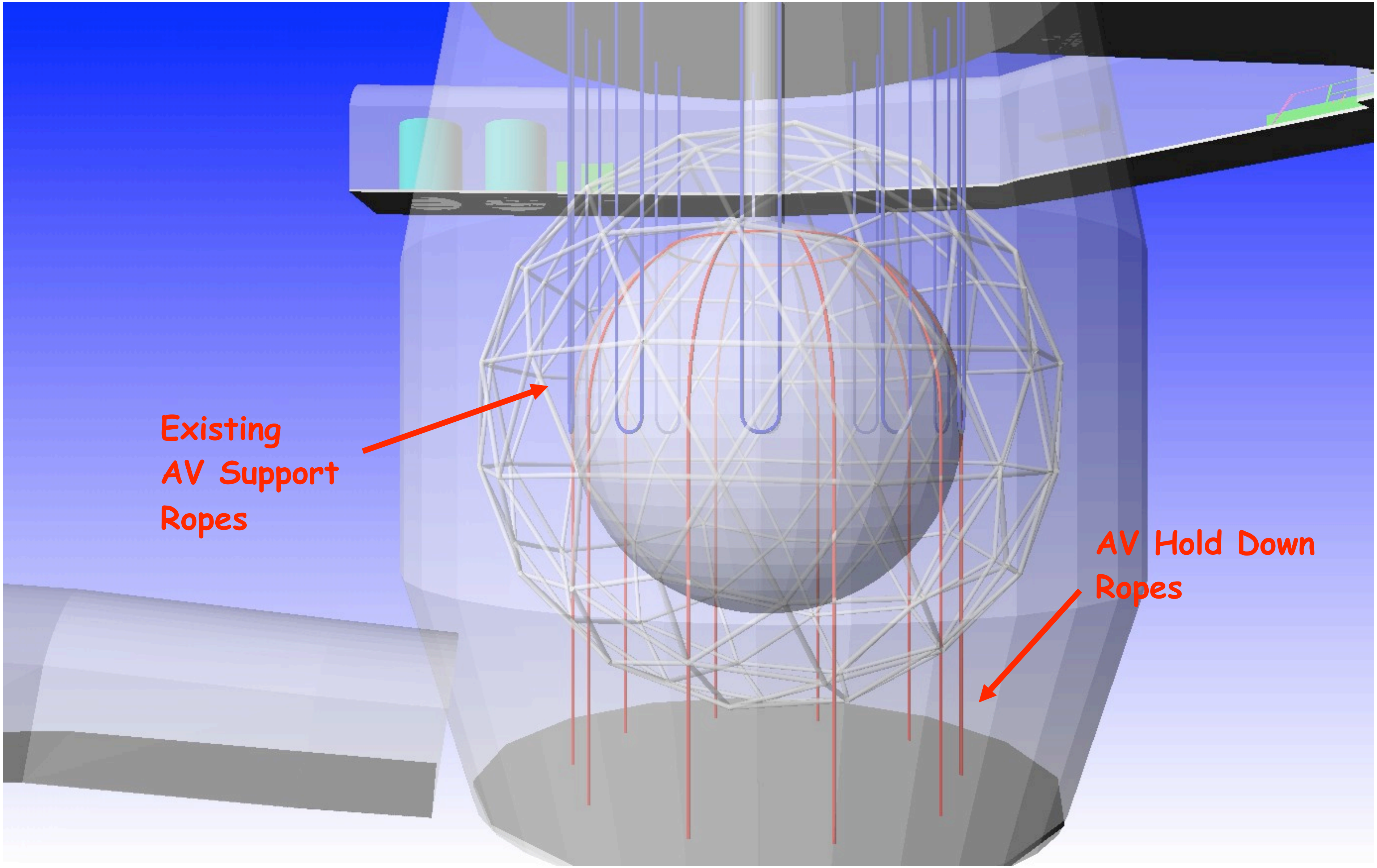
University of Liverpool

N. McCauley

SNO+ AV Hold Down

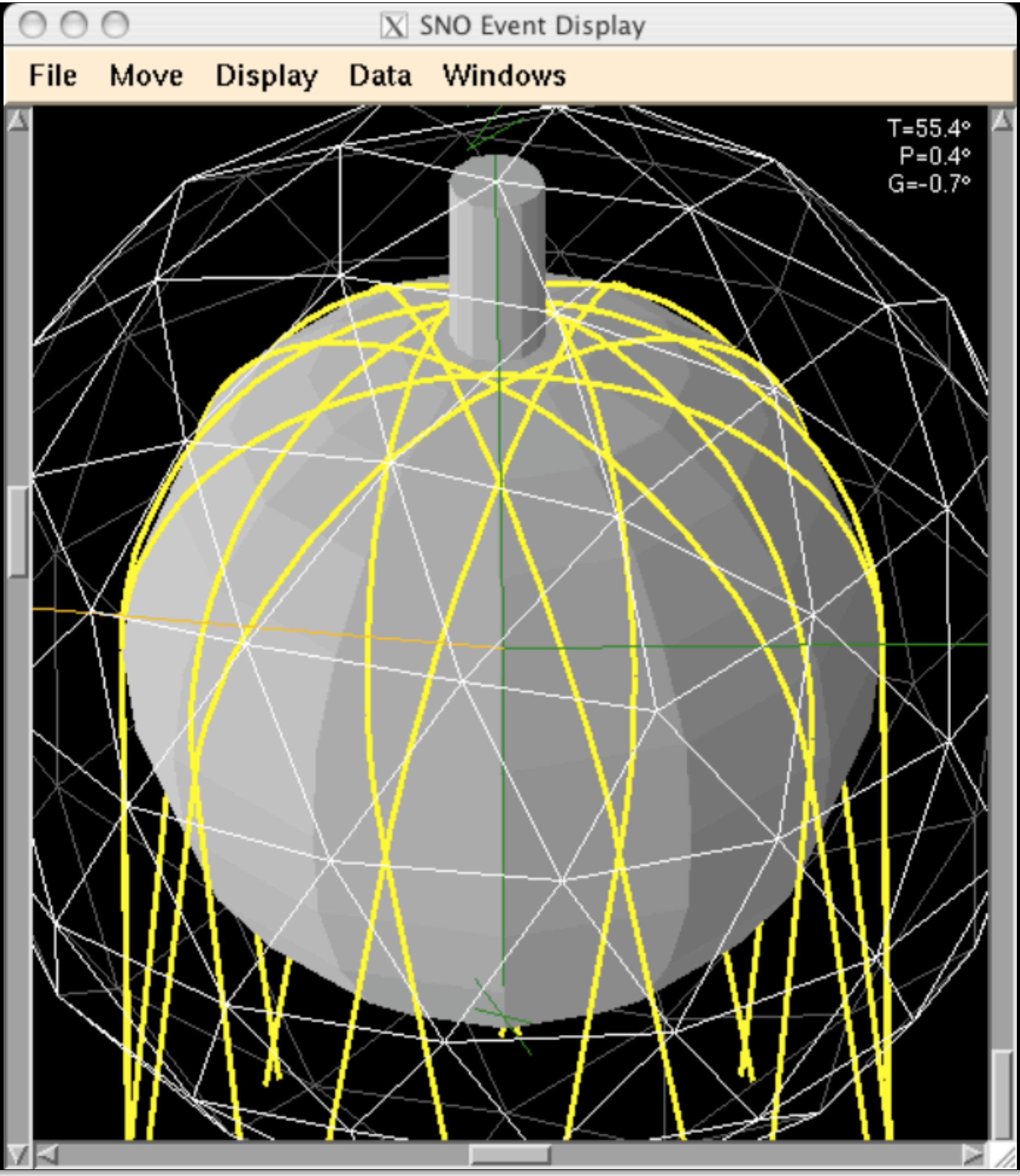


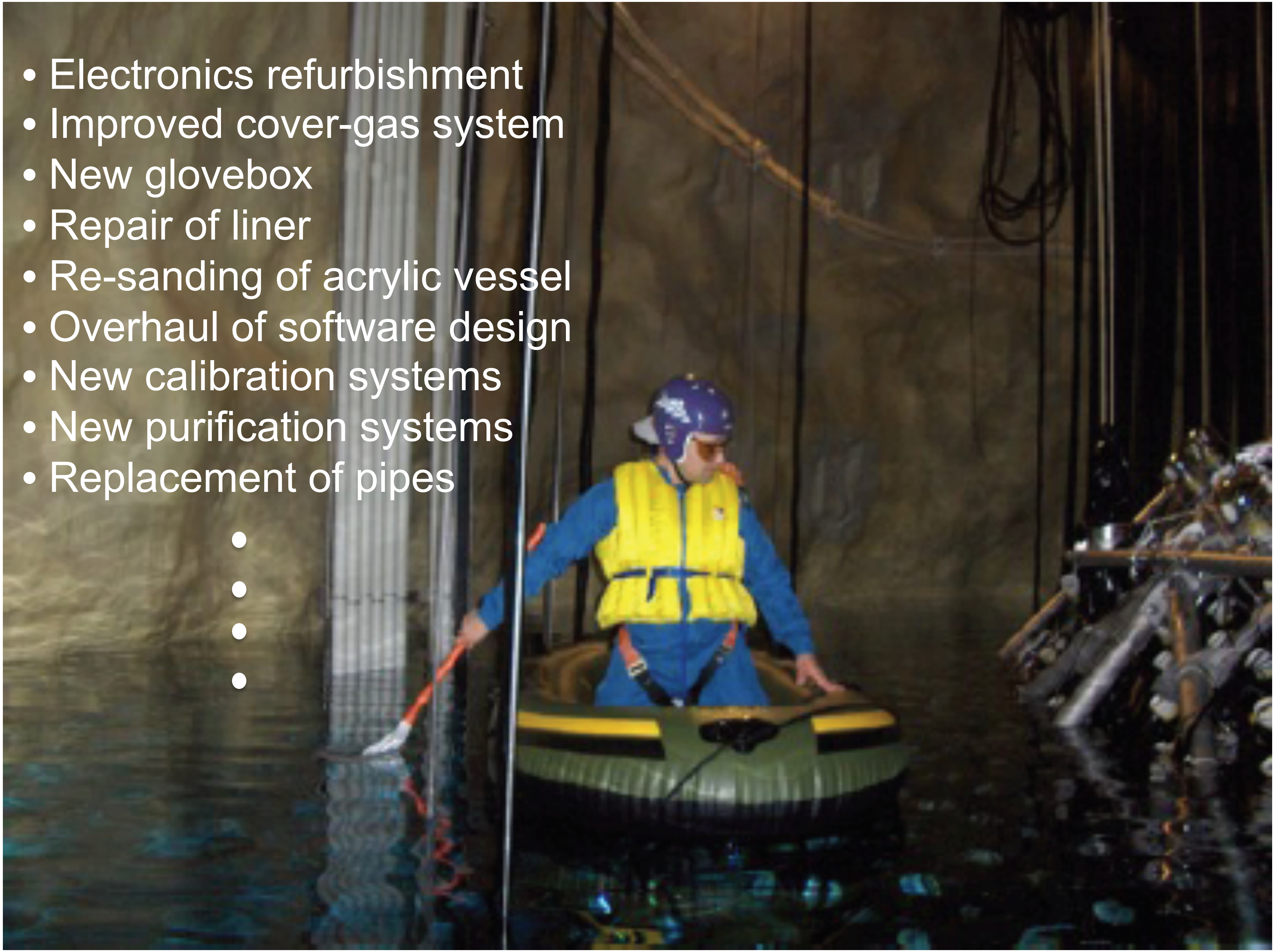
SNO+ AV Hold Down



Existing AV Support Ropes

AV Hold Down Ropes


SNO Event Display
File
Move
Display
Data
Windows
T=55.4°
P=0.4°
G=-0.7°



- Electronics refurbishment
- Improved cover-gas system
- New glovebox
- Repair of liner
- Re-sanding of acrylic vessel
- Overhaul of software design
- New calibration systems
- New purification systems
- Replacement of pipes

⋮

SNO+ Double Beta Decay

- A liquid scintillator detector has poor energy resolution... but HUGE quantities of isotope (high statistics) and low backgrounds help compensate

- Large, homogeneous liquid detector leads to well-defined background model
  - fewer types of material near fiducial volume
  - meters of self-shielding

- “Source in”/“Source out” capability to test backgrounds, improve purification, etc.

- Interesting new technique with a rapid timescale that could perhaps be pushed even further

^{150}Nd

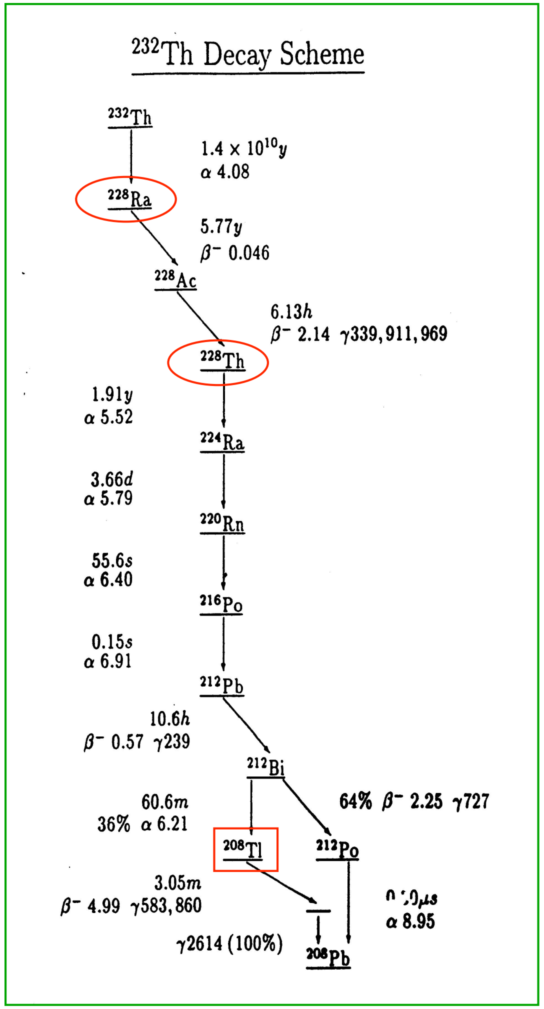
(5% natural abundance)

Radio-purification goals:

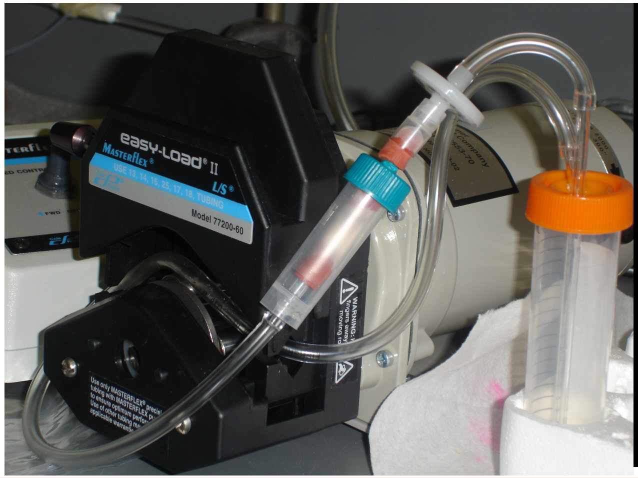
^{228}Th and ^{228}Ra in 10 tonnes of 10% Nd (in form of $NdCl_3$ salt) down to

$< 1\times10^{-14}$ g ^{232}Th/g Nd

A reduction of $>10^6$ relative to raw salt measurement!!!



Purification Spike Tests

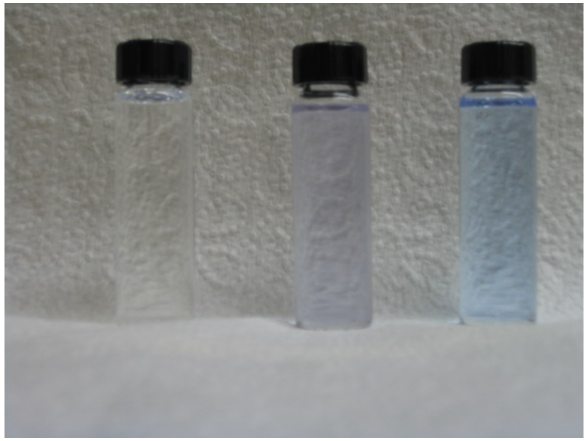


- **Spike scintillator with ^{228}Th (80 Bq) which decays to ^{212}Pb**
- **Counted by β-α coincidence liquid scintillation counting**

Factor of 1000 purification per pass achieved for both Th and Ra with 2 different techniques (HZrO and BaSO4): Use multi-pass system

Example: Test $\langle m_{\nu} \rangle = 0.150$ eV

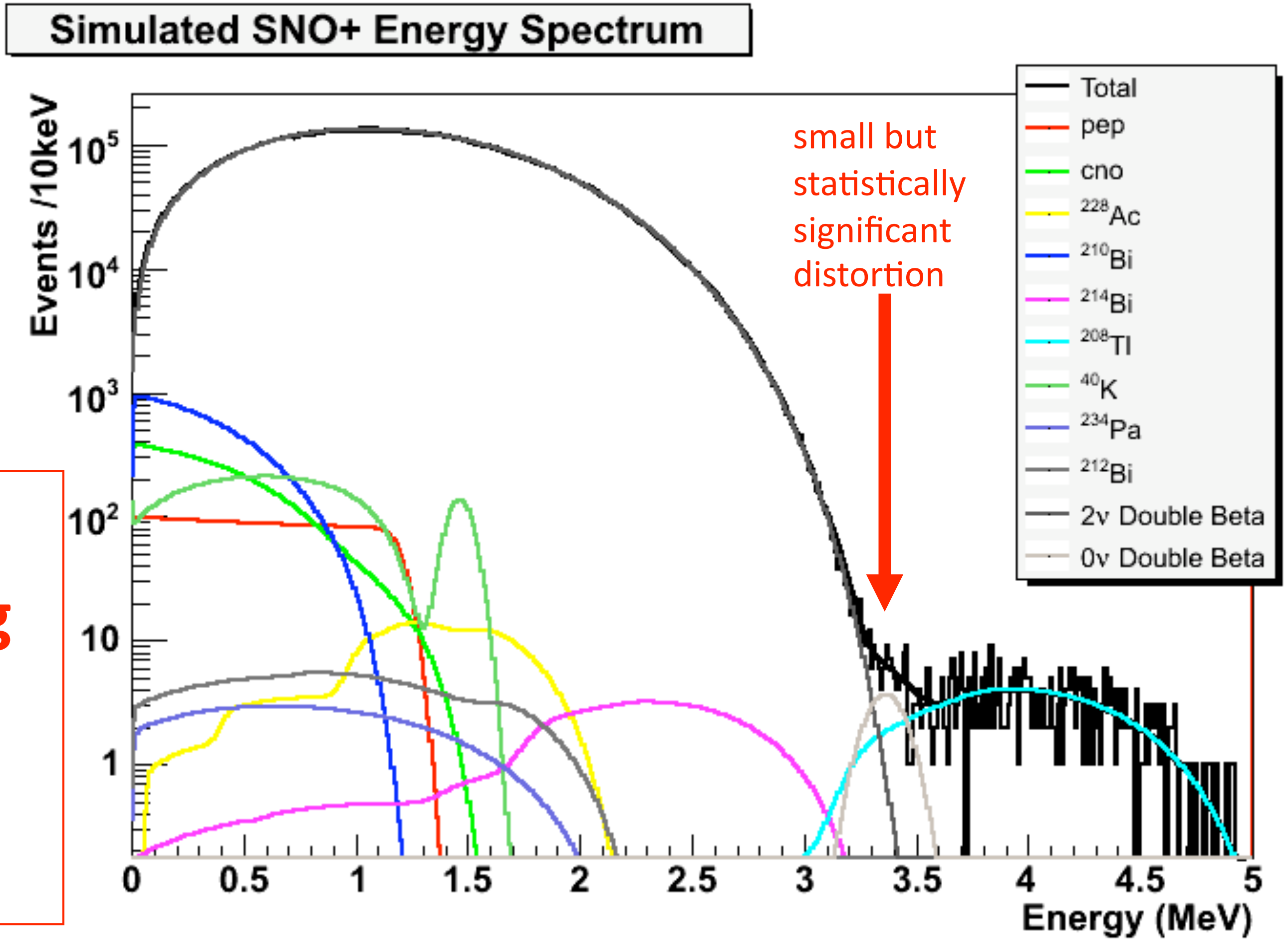
Klapdor-Kleingrothaus et al.,
Phys. Lett. B **586,** 198, (2004)



Initially may be limited to ~ 0.1%
owing to opacity of loaded scintillator

One year with 0.1% of natural Nd-loaded liquid scintillator in SNO+ :

Better suppress ^{208}Tl and enhance loading (or enrich) to increase the sensitivity further

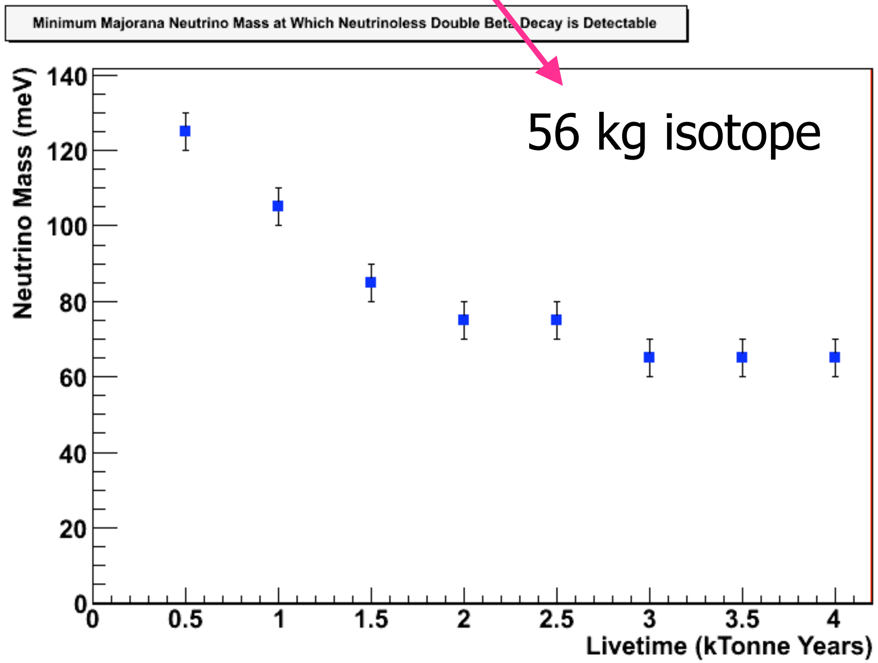


Simulated SNO+ Energy Spectrum

small but statistically significant distortion

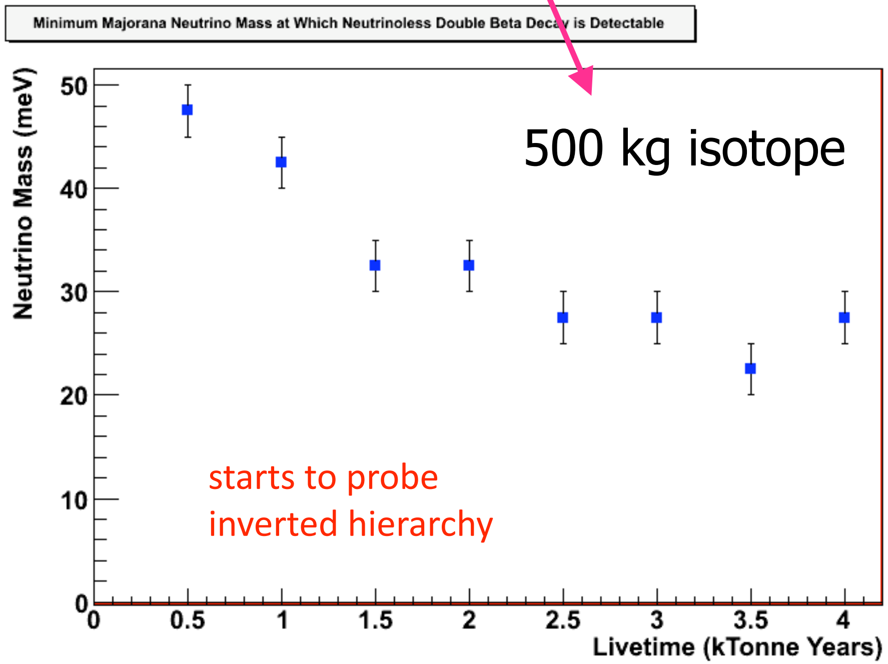
3 Sigma Statistical Sensitivity in SNO+

corresponds to 0.1%
natural Nd in SNO+



56 kg isotope

If Nd can be enriched or concentration
boosted by other means

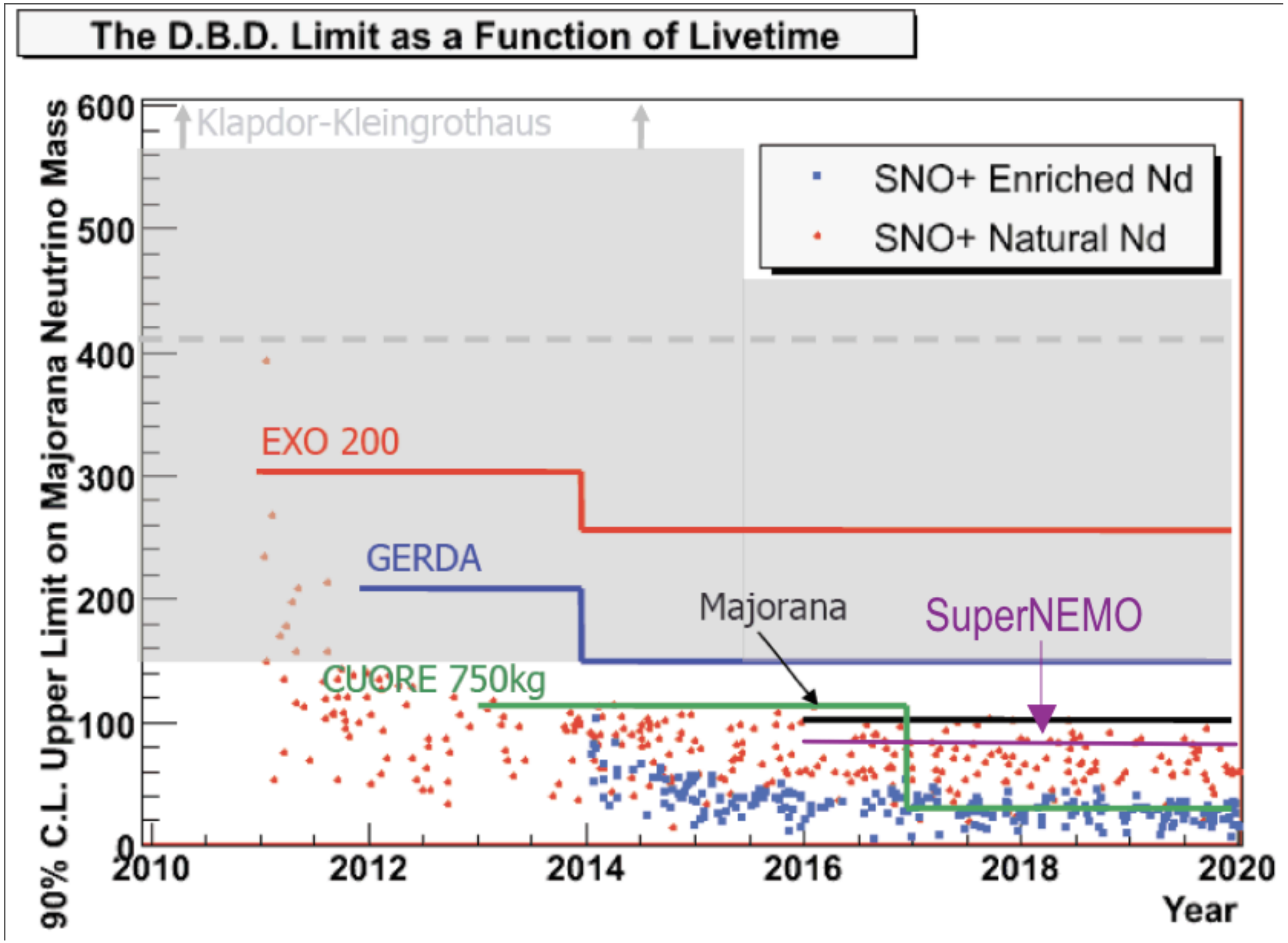


500 kg isotope

starts to probe
inverted hierarchy

- 3 sigma detection on at least 5 out of 10 fake data sets
- $2\nu/0\nu$ decay rates are from Elliott & Vogel, Ann. Rev. Nucl. Part. Sci. **52**, 115 (2002)

Note: These are statistical sensitivities only... systematics will degrade this to some extent. However, below 100meV & 50meV, respectively, are not unreasonable expectations if backgrounds are controlled.



Each SNO+ point represents a different MC "experiment" so as to reflect the statistical spread of derived limits.

Ultimately, the ability to achieve such sensitivities in practise may rest on securing sufficient control of backgrounds due to unwanted isotopes in the Nd itself through:

1) careful sourcing of the Nd metal; 2) chemical purification techniques;

3) possible use of additional physical barriers (such as a Borexino-style inner "bag"))

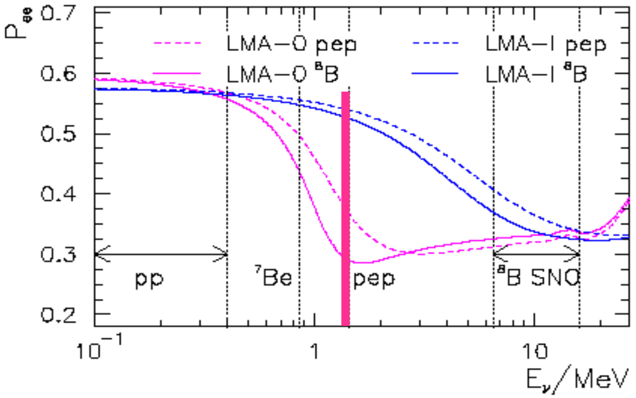
4) development of software techniques to discriminate against backgrounds;

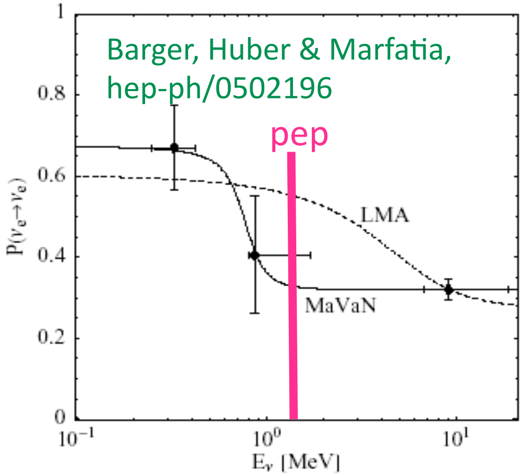
5) further efforts to secure enriched Nd.

pep & CNO Solar Neutrinos

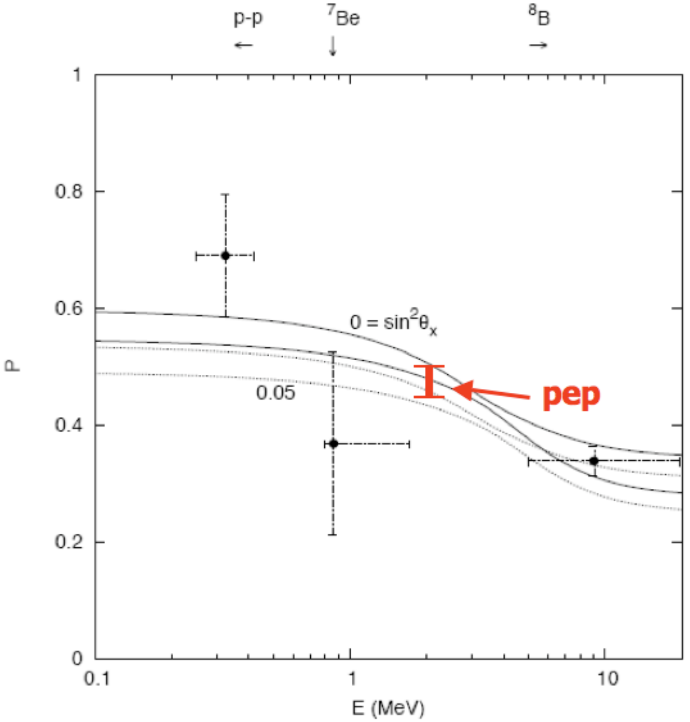
- pep ν directly tests solar luminosity constraint & probes MSW in sensitive 1.4 MeV regime to test for non-standard interactions:

Friedland et al., Phys. Lett. B, **594**, (2004)





Barger, Huber & Marfatia, hep-ph/0502196



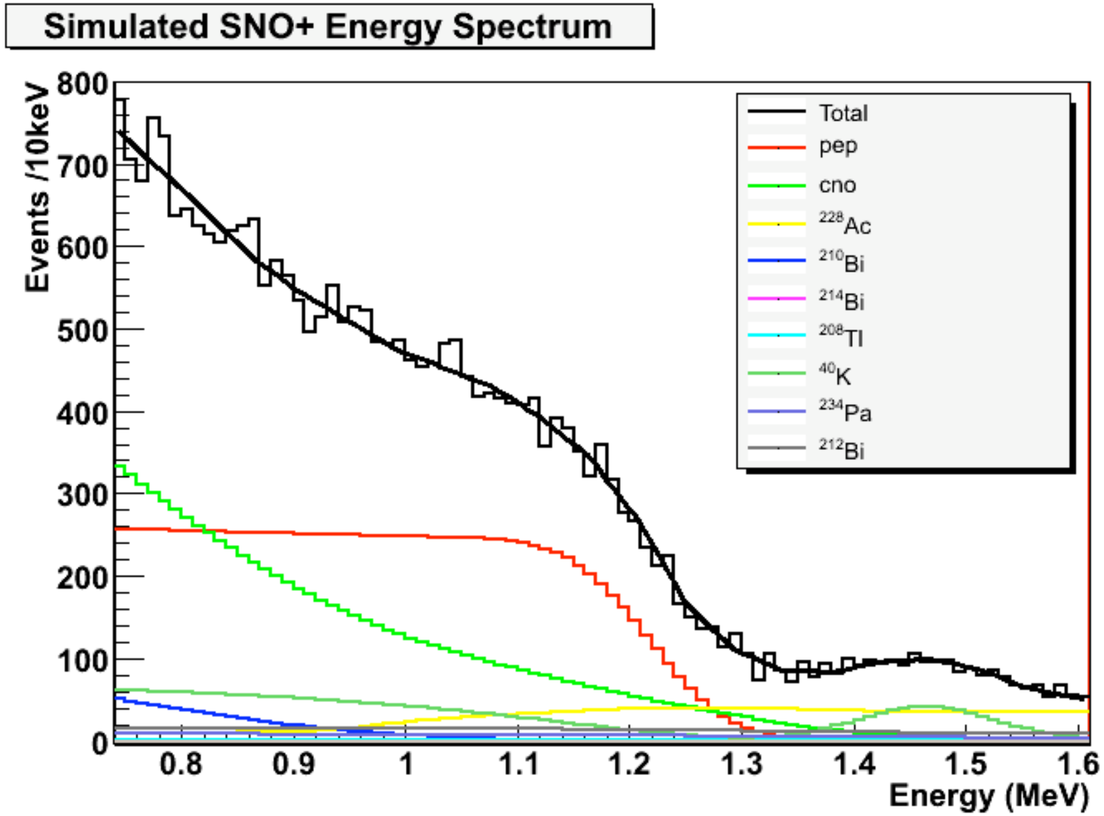
Also sensitive to θ_{13} - complementary to long baseline and reactor experiments:

(hypothetical 5% stat. 3% syst. 1.5% SSM measurement has discriminating power for θ_{13})

- CNO ν gives information on age of Globular Clusters and also aims to solve "Solar Composition Problem" (contradictions with helioseismology)

(Pena-Garay & Serenelli, arXiv:0811.2424)

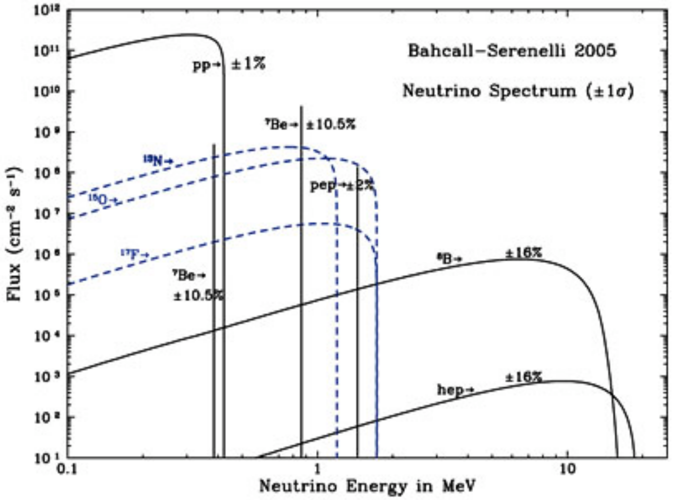
SNO+ pep & CNO Solar Neutrino Signal



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

SNOLAB depth of 6000 mwe gives a muon flux 800 times less than KamLAND and virtually eliminates background from ^{11}C, making SNO+ uniquely sensitive for a **precision** measurement.

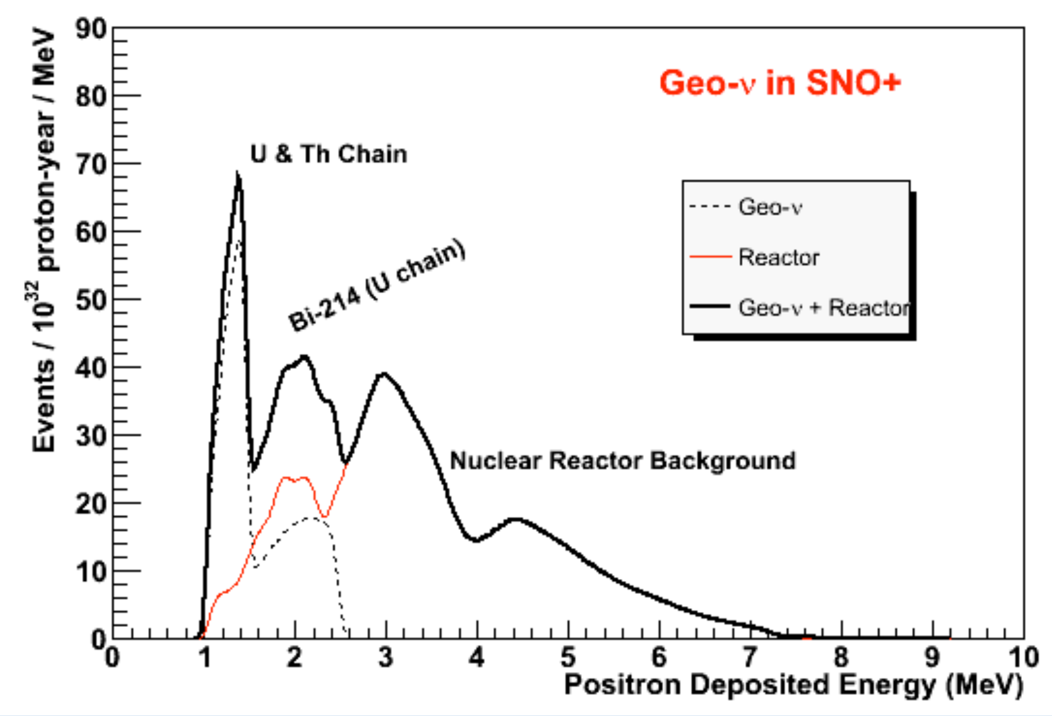
Plus, can also make ^{8}B measurement below SNO energy and likely measure ^{7}Be with more statistics than Borexino, providing a truly comprehensive and definitive solar neutrino study!



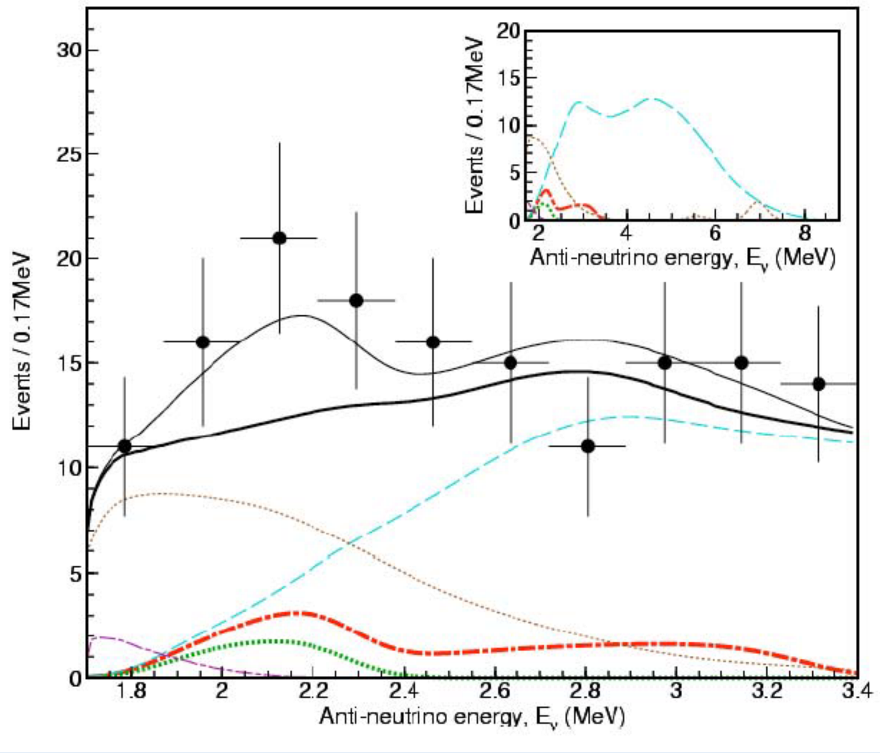
Geo-Neutrino Signal

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

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

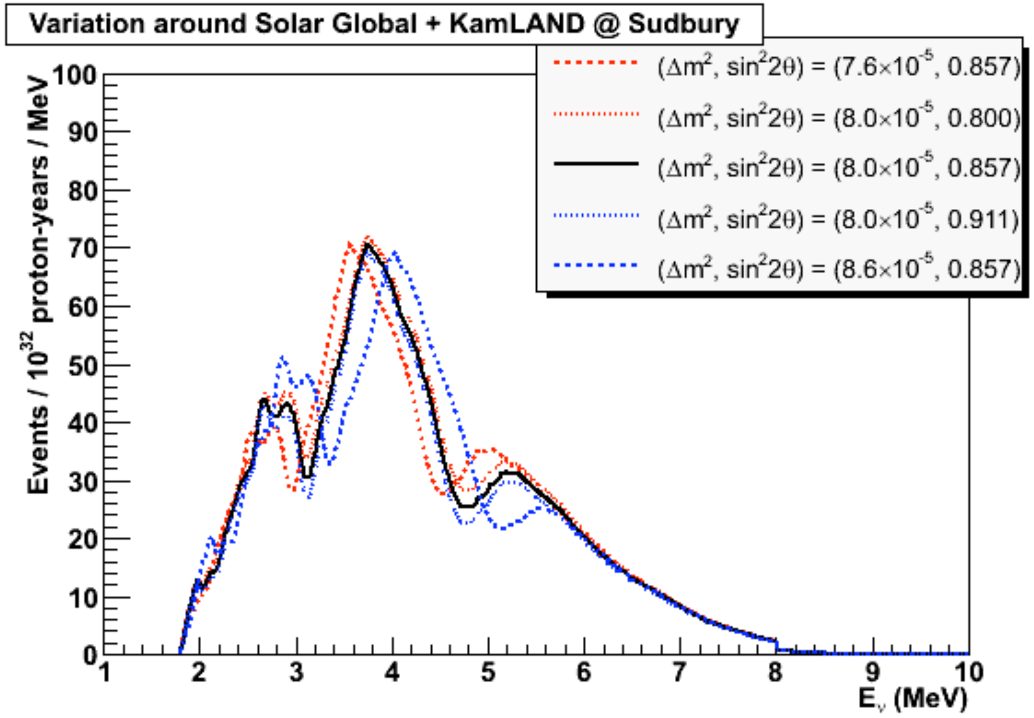


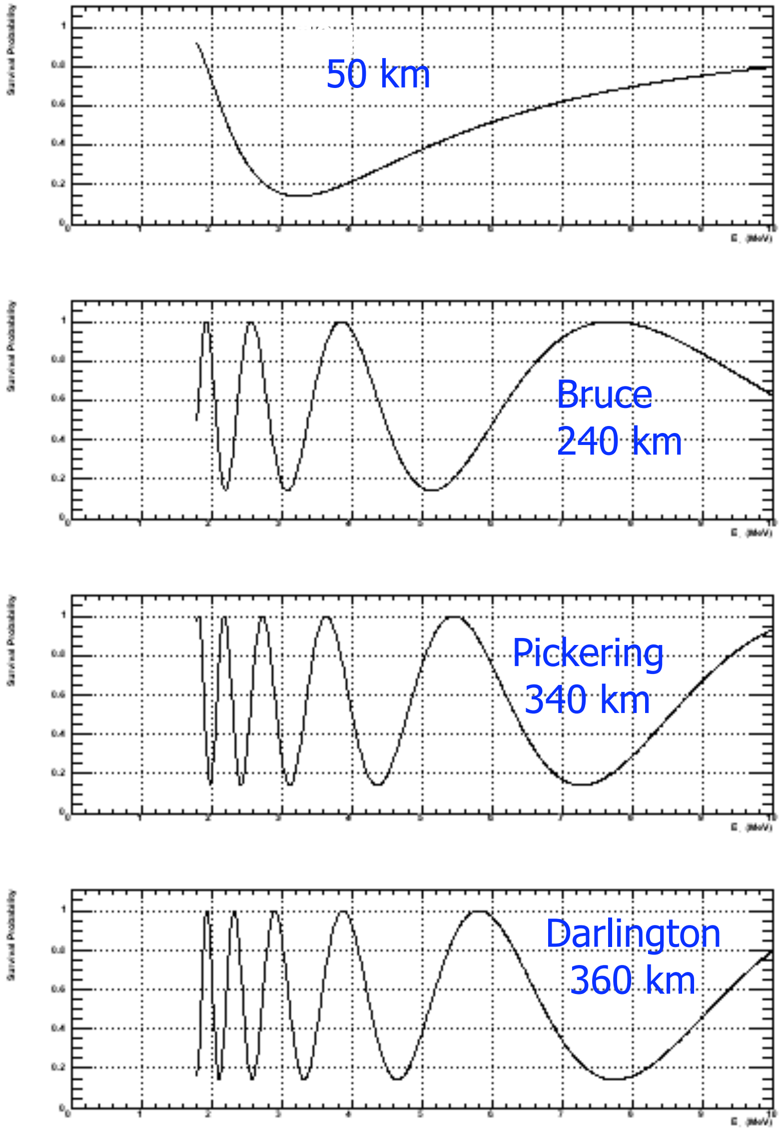
SNO+ geo-neutrinos and reactor background



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

Reactor Neutrino Oscillations





oscillation spectral features depend on Δm^2
and move as L/E

Status:

Canadian CFI grant approved to provide vast majority of funding for SNO+, strengthening the major investment in SNOLAB underground facility.

US DOE support is also in place.

UK and other European support expected soon.

Detector fill will take place end 2010/start 2011:

1) Light water
2) Scintillator substitution
3) Introduction of Nd

Current plan is to start Double β Decay phase by end 2011.