Solar Neutrinos at SNO+

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U. C. Berkeley / LBNL

PhySun '12 Conference

Overview

- The SNO+ Experiment
- SNO+ Physics goals
- Solar Neutrinos at SNO+
- SNO+ Status and Outlook

Overview

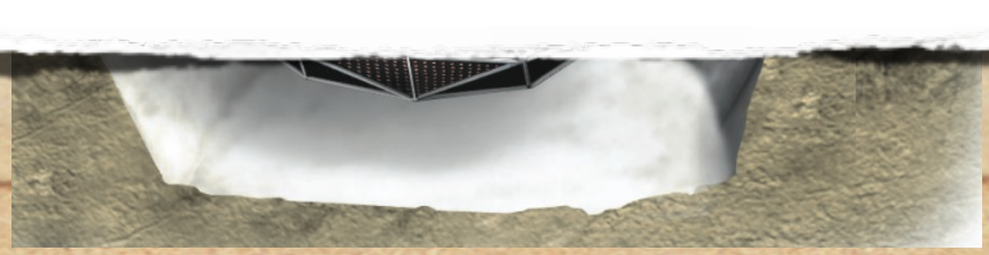
- The SNO+ Experiment

SNO ⇛ SNO+

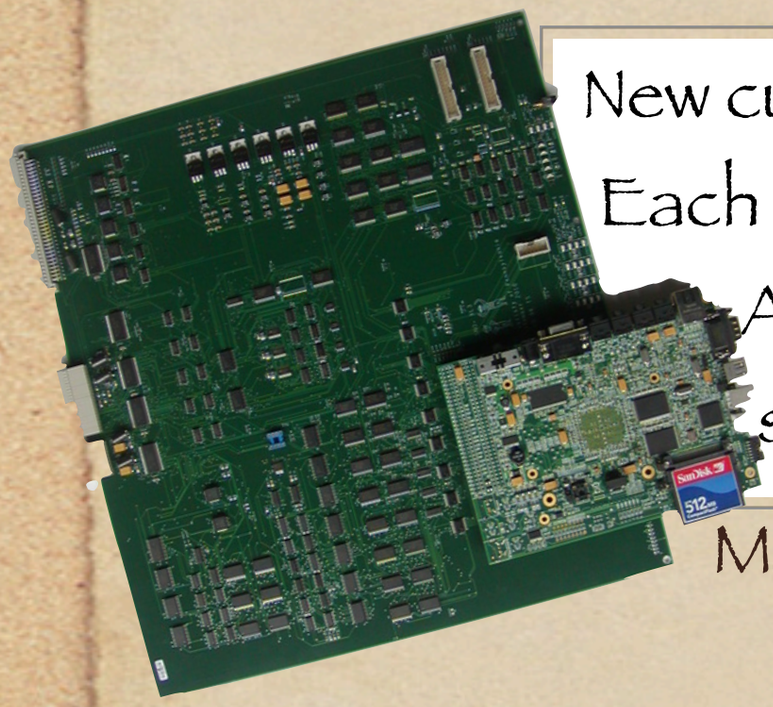
- 12
- 1k
- 6
- 5890 m.w.e.

Re-use SNO detector
Replace D_2O with liquid scintillator
+ minor upgrades

Basement space! Six million cubic ft., large deck, showers. Laundry facilities and a/c. Just 10 min. walk to elevator access. V. low radon, shielding from dangerous `cosmic' radiation.



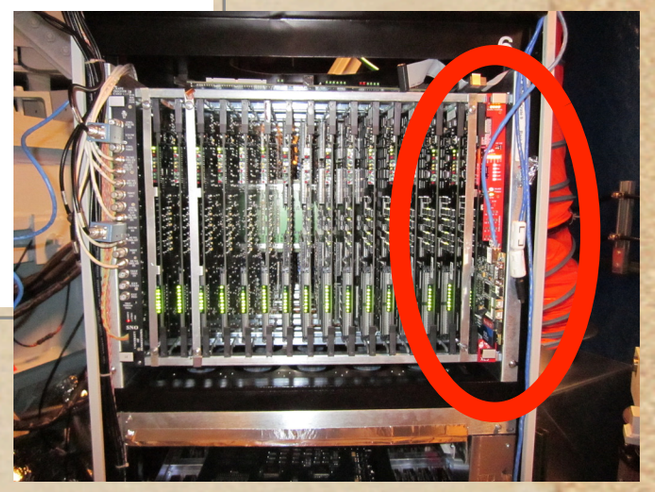
Electronics & DAQ



New custom crate-readout cards in each crate

Each crate now has local intelligence

Autonomously push data to central switch via TCP/IP



Max data rate for SNO: 2.4MBits/s

SNO+: 250 MBits/s

High rate/occupancy

=> need new trigger board

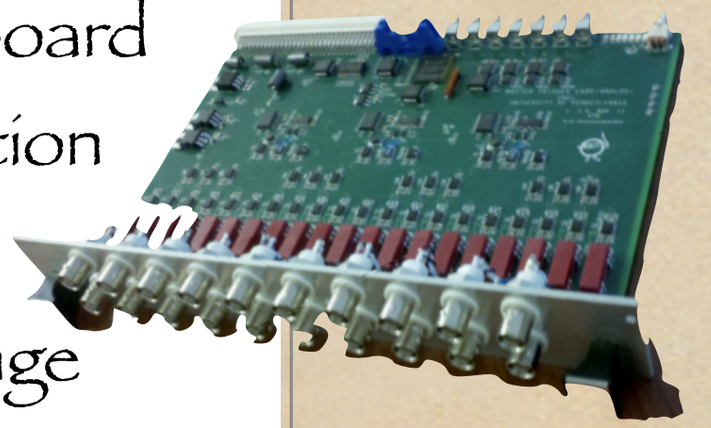
Low power dissipation

Reduce deadtime

Larger dynamic range

+ Auto retrigger

+ Remote crate disconnects



Plus:

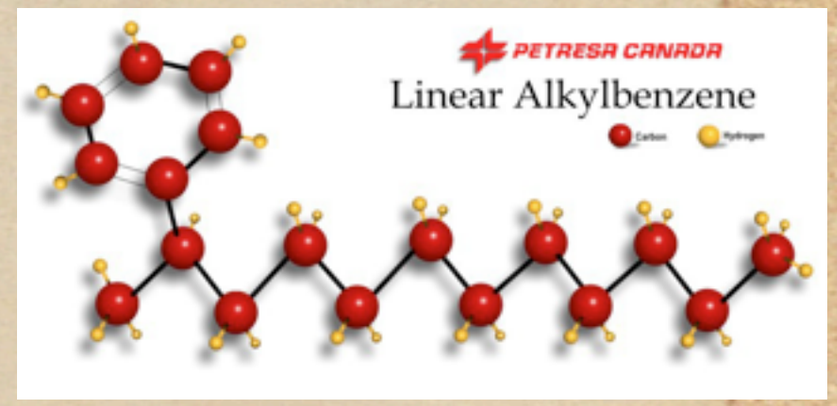
New interface board

CAEN digitizer board

New GPS receiver

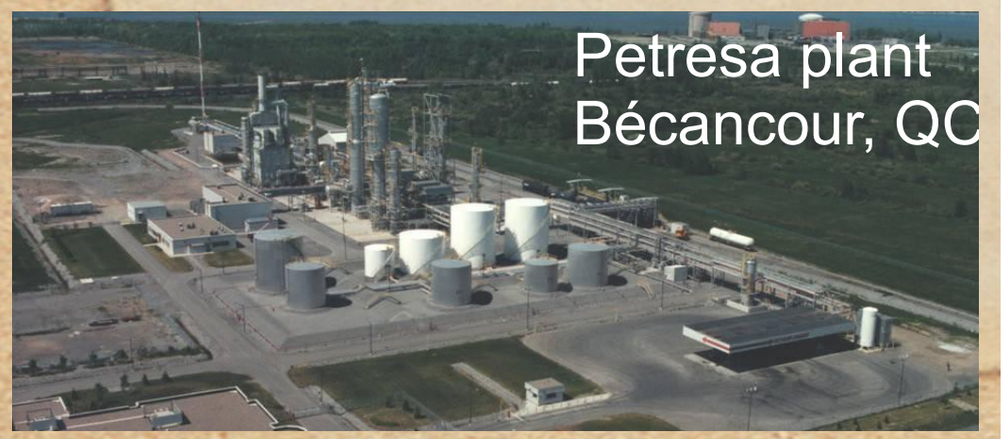
Scintillator Development

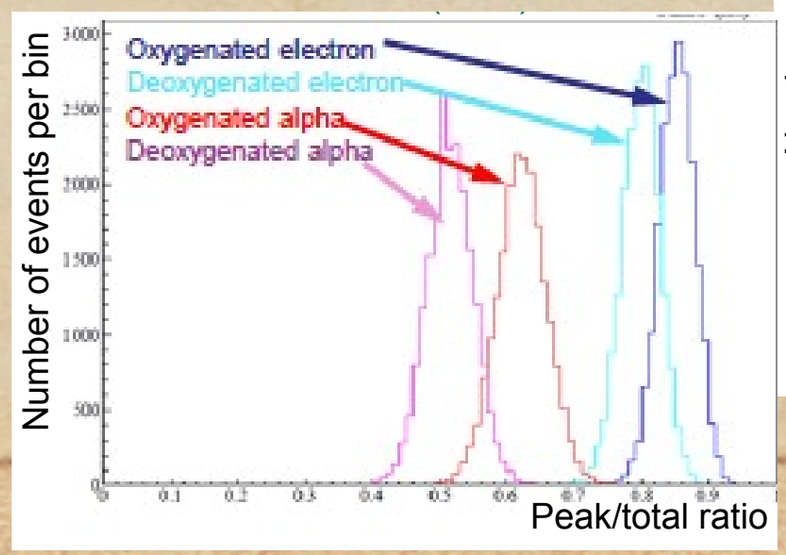
- Chemically compatible with acrylic
- High flash point, low toxicity
- Readily available (detergent production)
- Loading of metallic ions to few %, stable for 3+ yrs

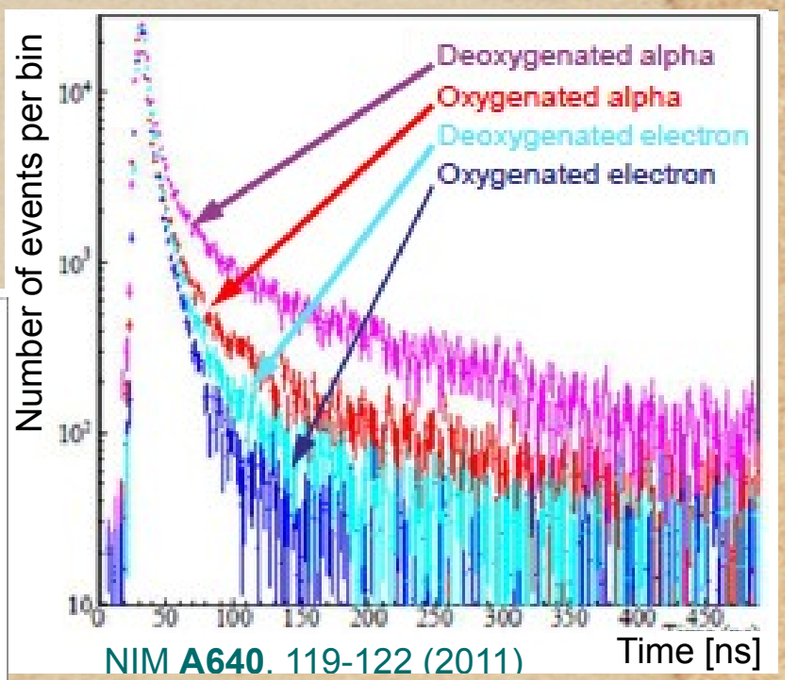


NIM A 578 (2007) 329-339

- High light yield (10,000 γ / MeV)
- Decay times: α-β separation
- Now in use by reactor & other experiments







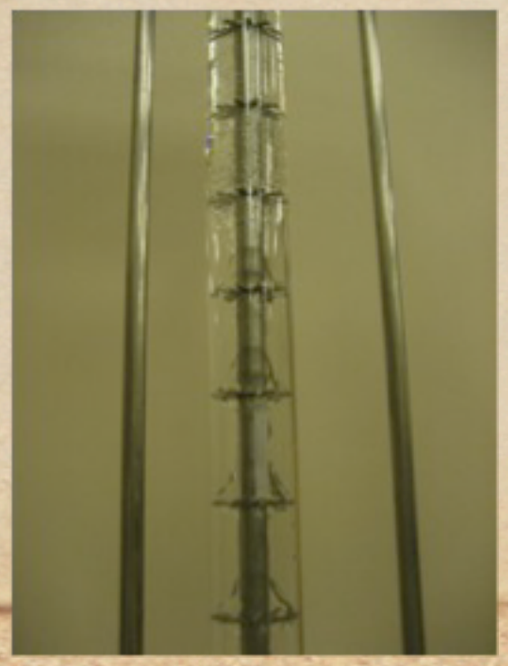
NIM **A640**, 119-122 (2011)

Purification Plan

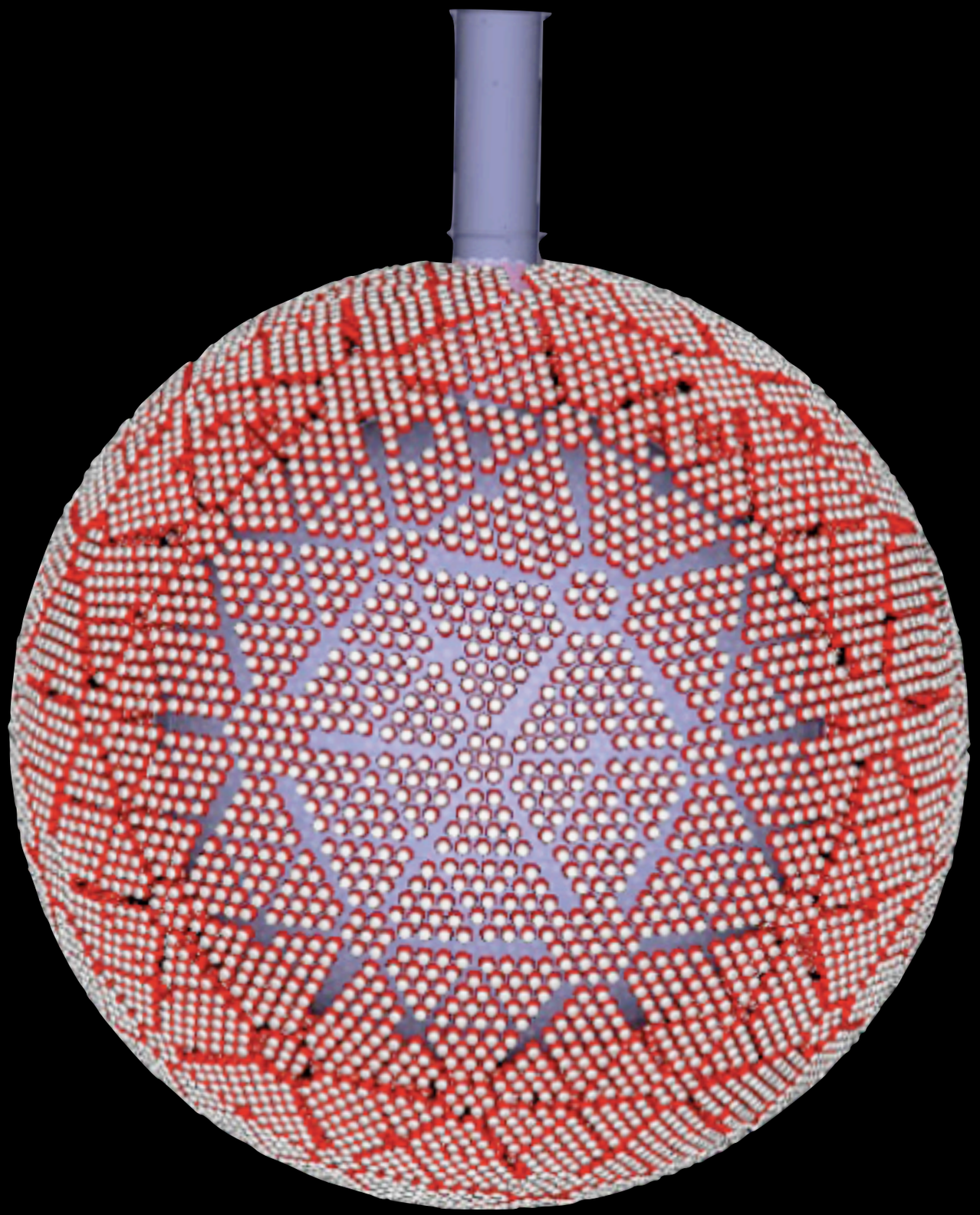
- Multi-stage distillation
  - Removes heavy metals
  - Improves UV transparency
  - Dual-stream PPO distillation
- N_2 / steam stripping
  - Removes Rn, Kr, Ar, O_2
- Water extraction
  - Removes Ra, K, Bi
- Metal scavenging
  - Removes Bi, Pb
- Microfiltration
  - Removes dust

Distillation

Water extraction



World's Largest Spherical Lens?



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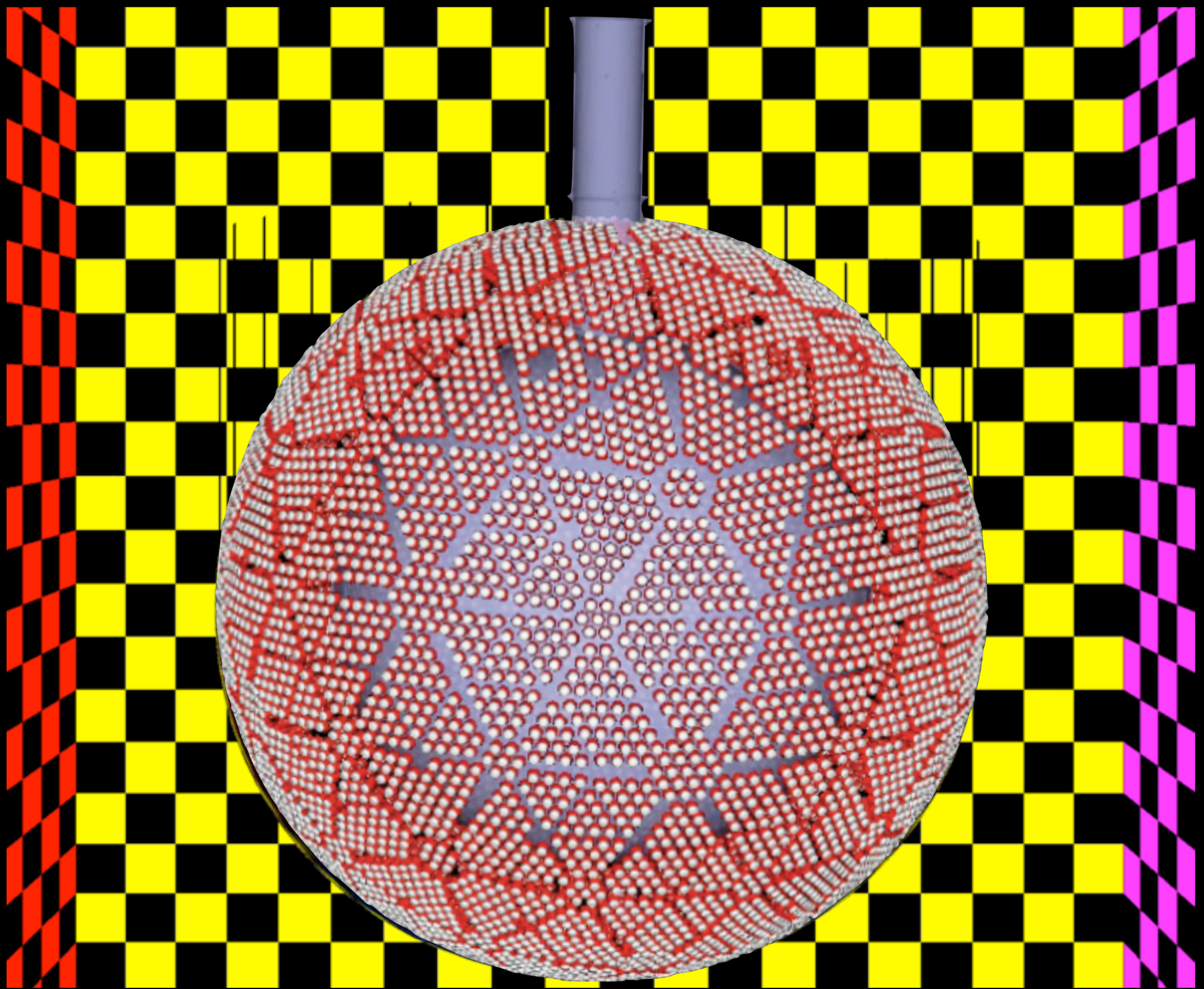


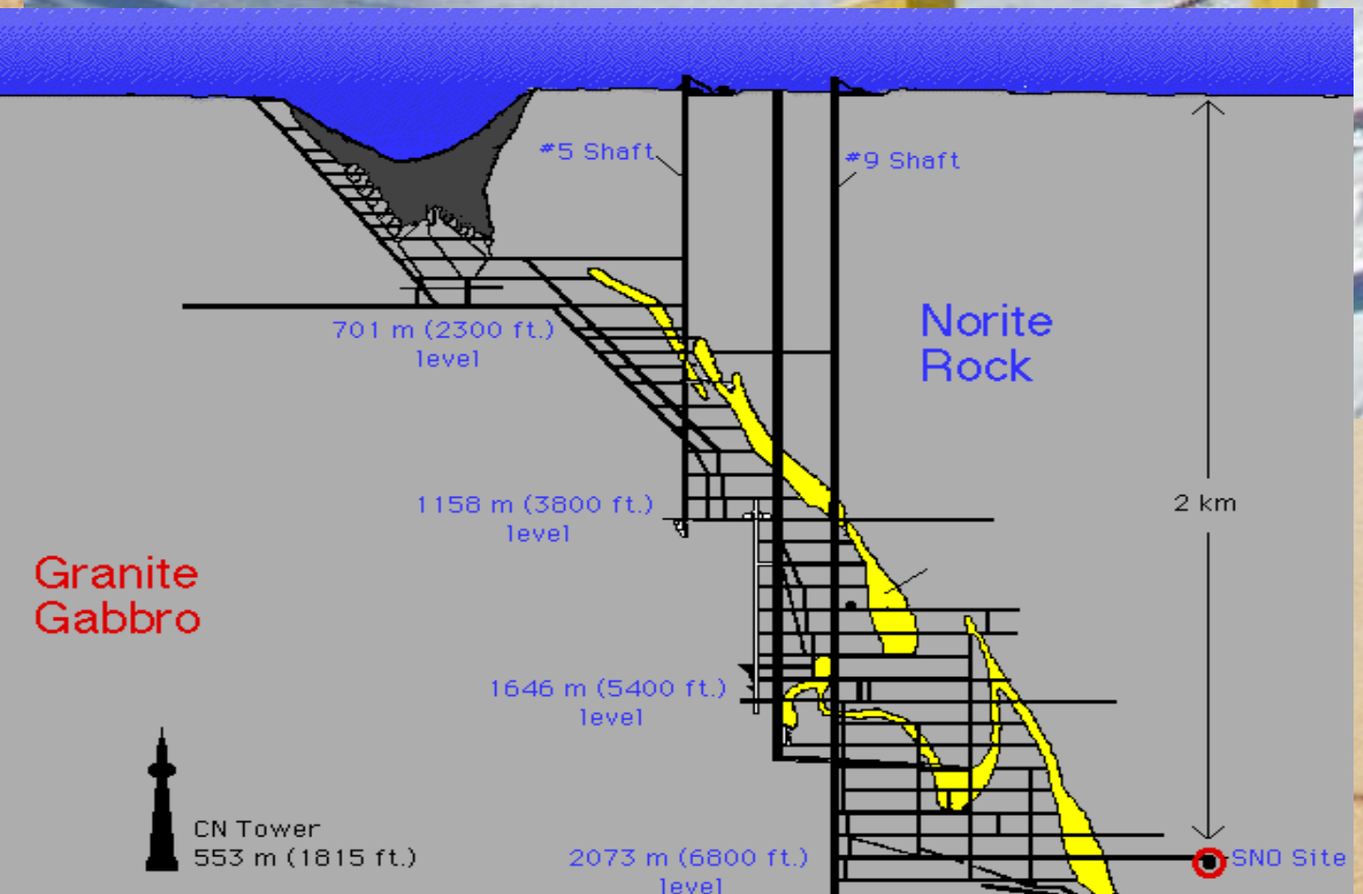
A Diverse Instrument for Neutrino Research within the SNOLAB Underground facility

New underground facility

SNOLAB
MINING FOR KNOWLEDGE
CREUSER POUR TROUVER... L'EXCELLENCE

SNO+

Creighton Mine



2km underground

Active nickel mine

Northern Ontario

SNO+ collaboration

University of Alberta

A. Baliek, P. Gorel, A. Hallin, M. Hedayatipoor, C. Krauss, Z. Petriw, L. Sibley, K. Singh, J. Sokoup.

Amstrong Atlantic State University

J. Secrest

Black Hills State University

K. Keeters

Brookhaven National Laboratory

W. Beriguette, S. Hans, L. HI, R. Rosero, M. Yeh, Y. Williamson

University of California, Berkeley / LBNL

F. Descamps, K. Kamdin, K. Haghighi, G. Orebi Gann, O. Wasalski

Dresden University of Technology

N. Barros, V. Lozza, B. von Krosigk, F. Krger, P. Schrock, K. Zuber

Laurentian University

D. Chauhan, E.D. Hallman, C. Kraus, T. Shantz, C. Virtue

University of Leeds

S. Bradbury, J. Rose

LIP Lisbon and Coimbra

S. Andringa, J. Carvalho, L. Gurriana, A. Maio, J. Maneira.

University of Liverpool

N. McCauley

University of North Carolina at Chapel Hill

M.Howe, J. Wilkerson

Oxford University

S. Biller, I. Coulter, N. Jelley, K. Majumdar, A. Reichold, M. Schwendener

University of Pennsylvania

E. Beier, R. Bonventre, W.J. Heintzelman, S. Grullon, J. Klein, P. Keener, A. Mastbaum, T. Shokair, R. Van Berg

Queen Mary, University of London

A. Back, F. Di Lodovico, P. Jones, J. Wilson

Queen's University

S. Asahi, M. Boulay, M. Chen, K. Clark, N. Fatemi-Ghomi, P.J. Harvey, C. Hearns, A. McDonald, A. Noble, T. Sonley, E. O'Sullivan, P. Skensved, I. Takashi

SNOLAB

C. Beaudoin, G. Bellehumeur, O. Chkvorets, B. Cleveland, F. Duncan, R. Ford, N. Gagnon, C. Jillings, S. Korte, I. Lawson, T. O'Malley, M. Schumaker, E. Vazquaz-Jauregui

University of Sheffield

J. McMillan

University of Sussex

E. Falk, J. Hartnell, G. Lefeuvre, M. Mottram, S. Peeters, J. Sinclair, J. Waterfield, R. White

TRIUMF

R. Helmer

University of Washington

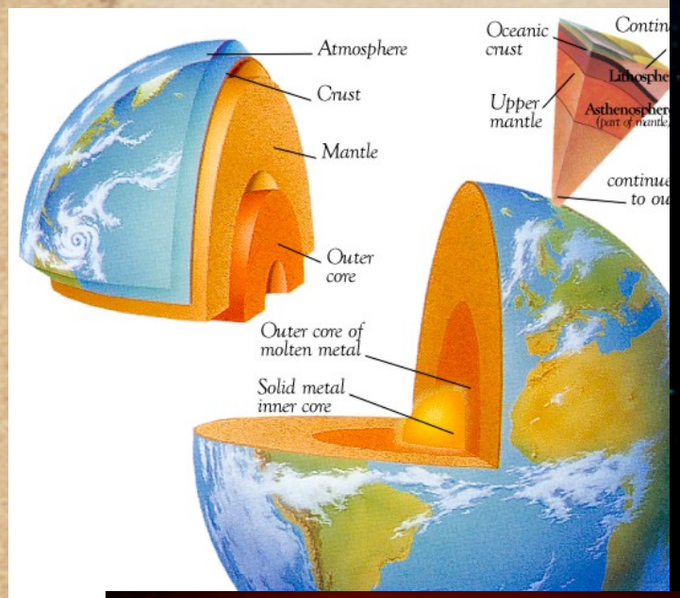
S. Enomoto, J. Kaspar, J. Nance, D. Scislowski, N. Tolich, H. Wan Chan Tseung

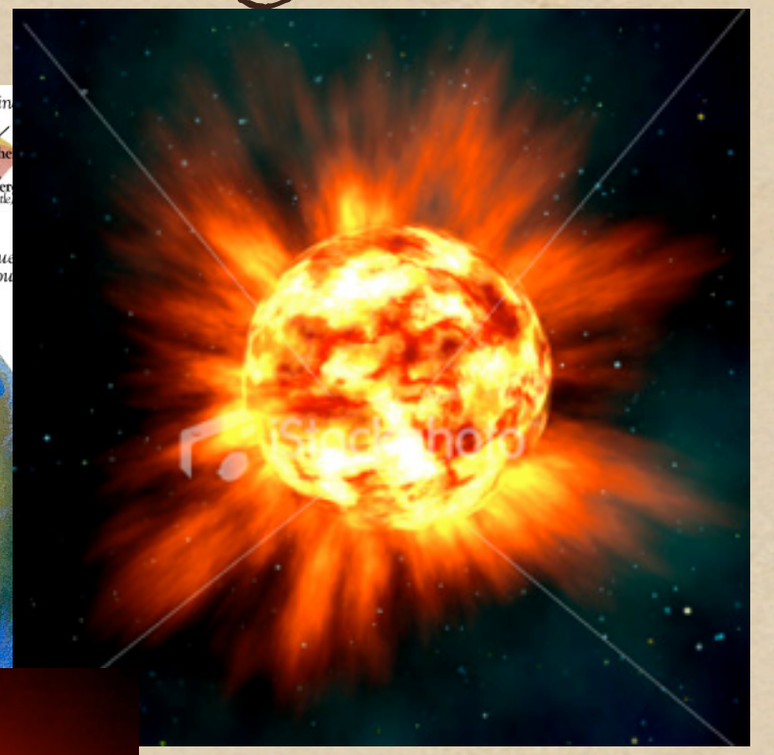
Overview

- The SNO+ Experiment
- SNO+ Physics goals

SNO+ Physics Programme

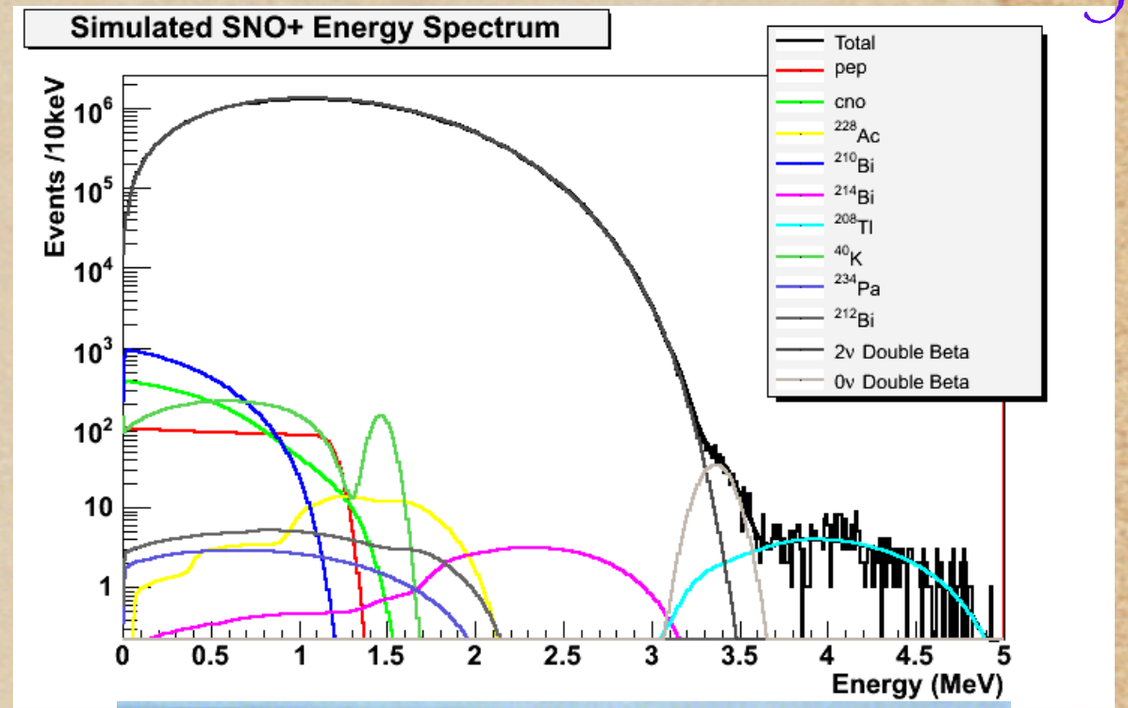
Geo neutrinos

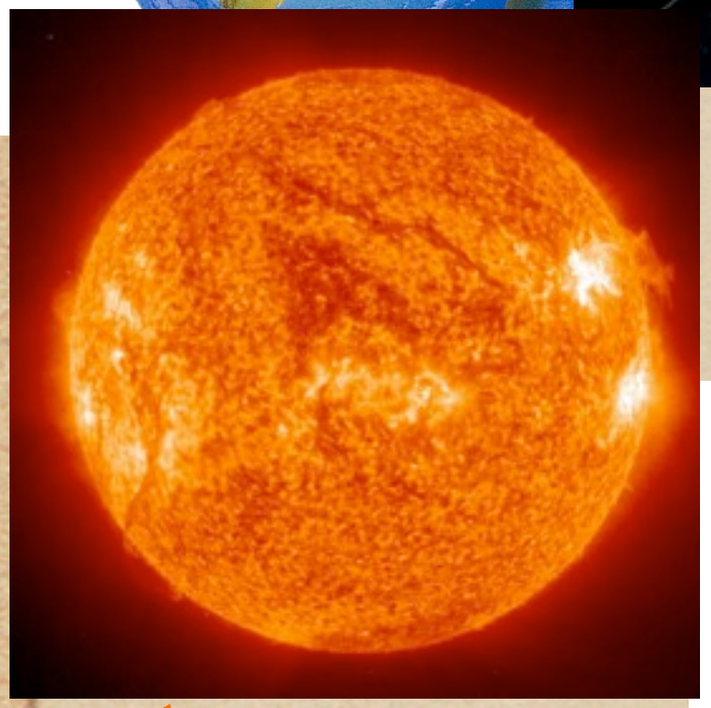




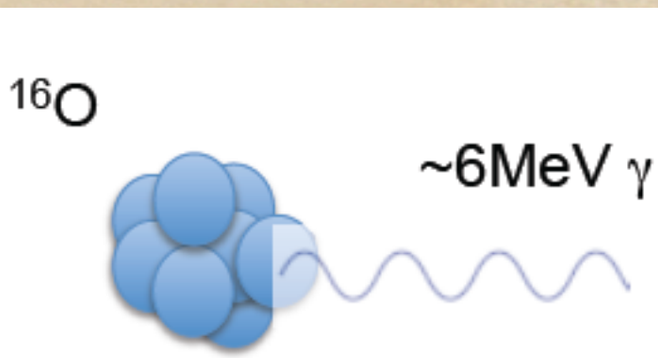
Supernova neutrinos

Neutrinoless double beta decay





Solar neutrinos



Reactor neutrinos

Invisible modes of nucleon decay

Solar Neutrinos

“For 35 years people said to me: `John, we just don’t understand the Sun well enough to be making claims about the fundamental nature of neutrinos, so we shouldn’t waste time with all these solar neutrino experiments.’

Then the SNO results came out.

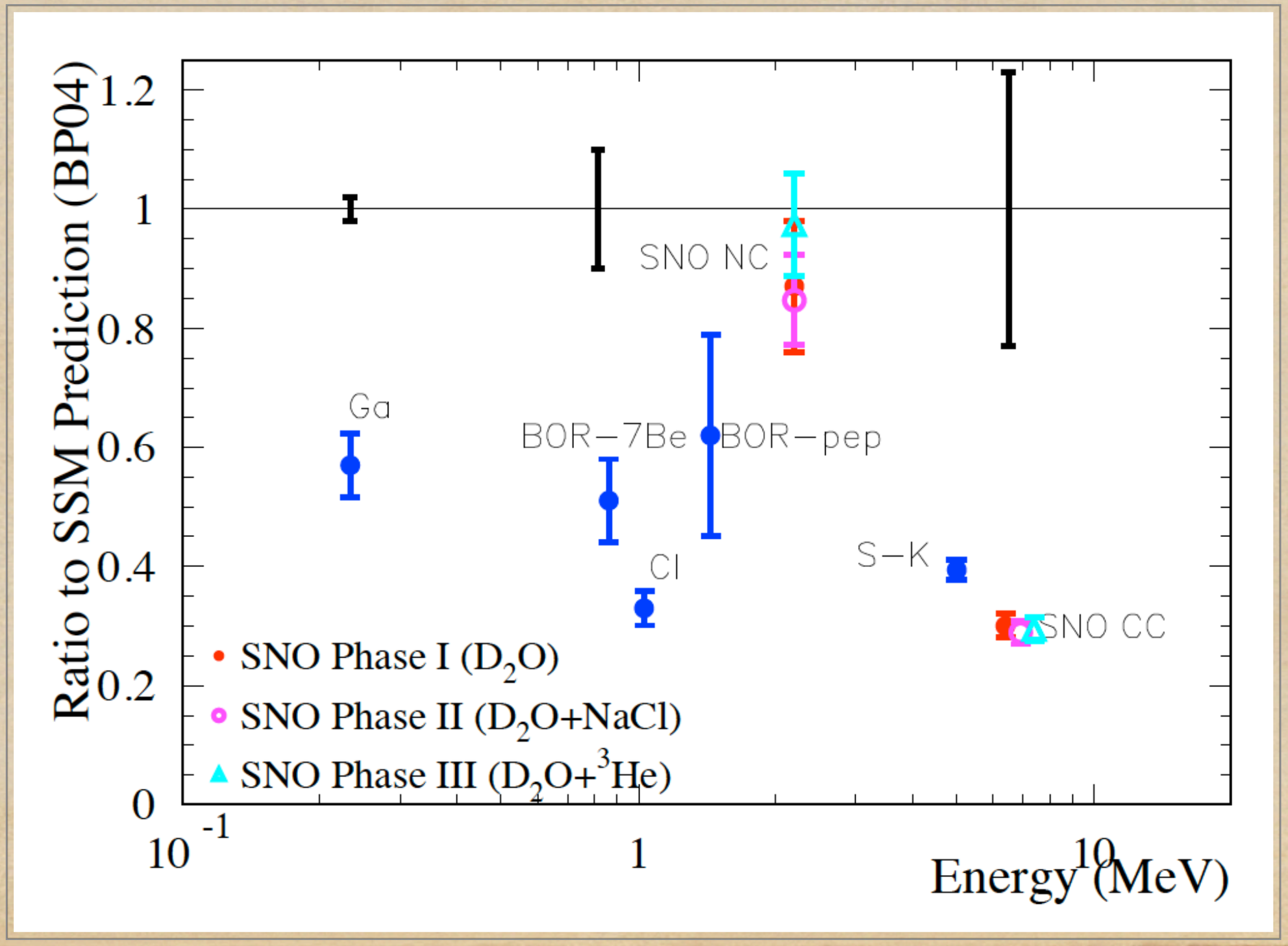
And the next day people said to me, `Well, John, we obviously understand the Sun perfectly well! No need for any more of these solar neutrino experiments.’”

--- John Bahcall, 2003

Overview

- The SNO+ Experiment
- SNO+ Physics goals
- Solar Neutrinos at SNO+

Solar Neutrino Oscillation



The Road Forward

- What the Sun can tell us about neutrinos
  - Precision pep flux
  - Low-energy ^{8}B spectrum

  } Search for new physics in transition region

  - Day/Night asymmetry measurement — Confirm MSW

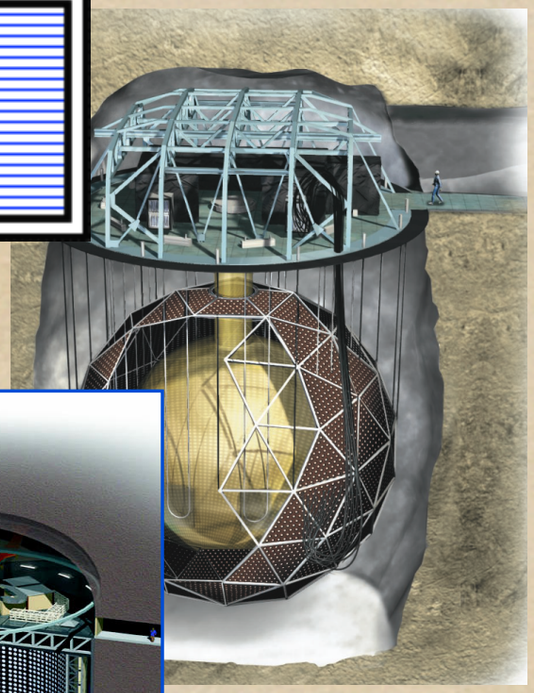
- What neutrinos can tell us about the Sun
  - CNO flux measurement — Resolve solar metallicity
  - Direct pp measurement — Luminosity constraint

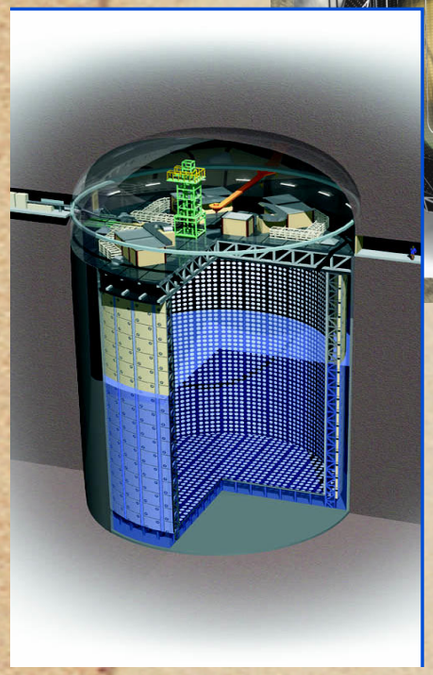
"Gold ring of solar neutrino physics & astronomy"

--- John Bahcall

Experiments

Water Cherenkov





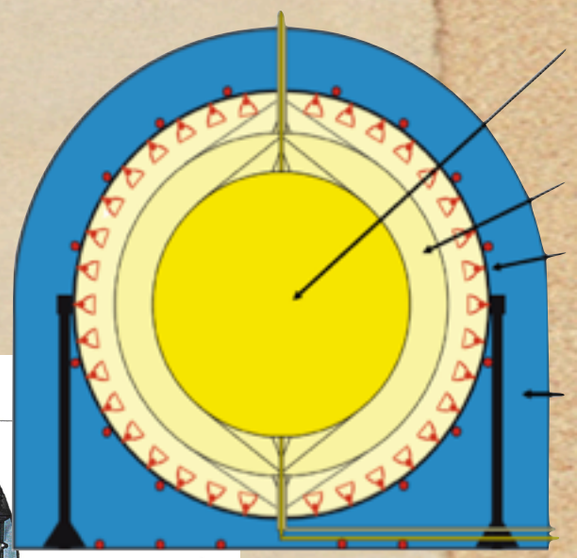
SNO

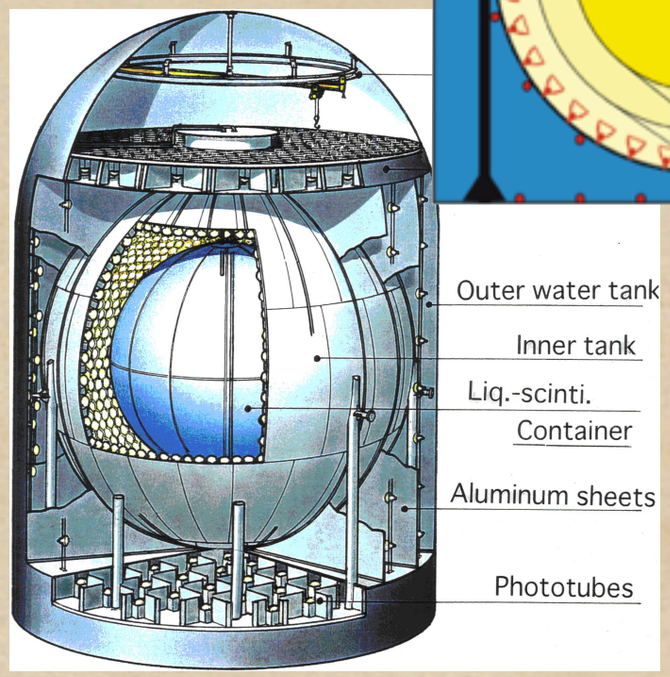
SuperK

Liquid Scintillator

Borexino

KamLAND





Radiochemical

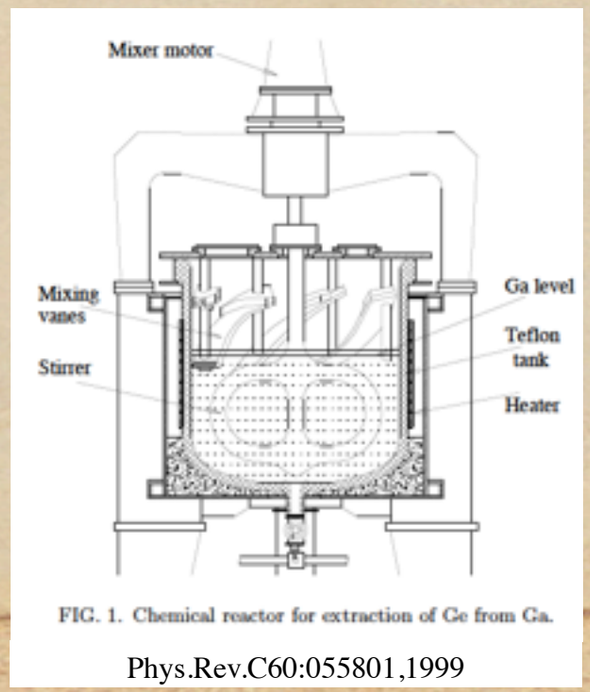


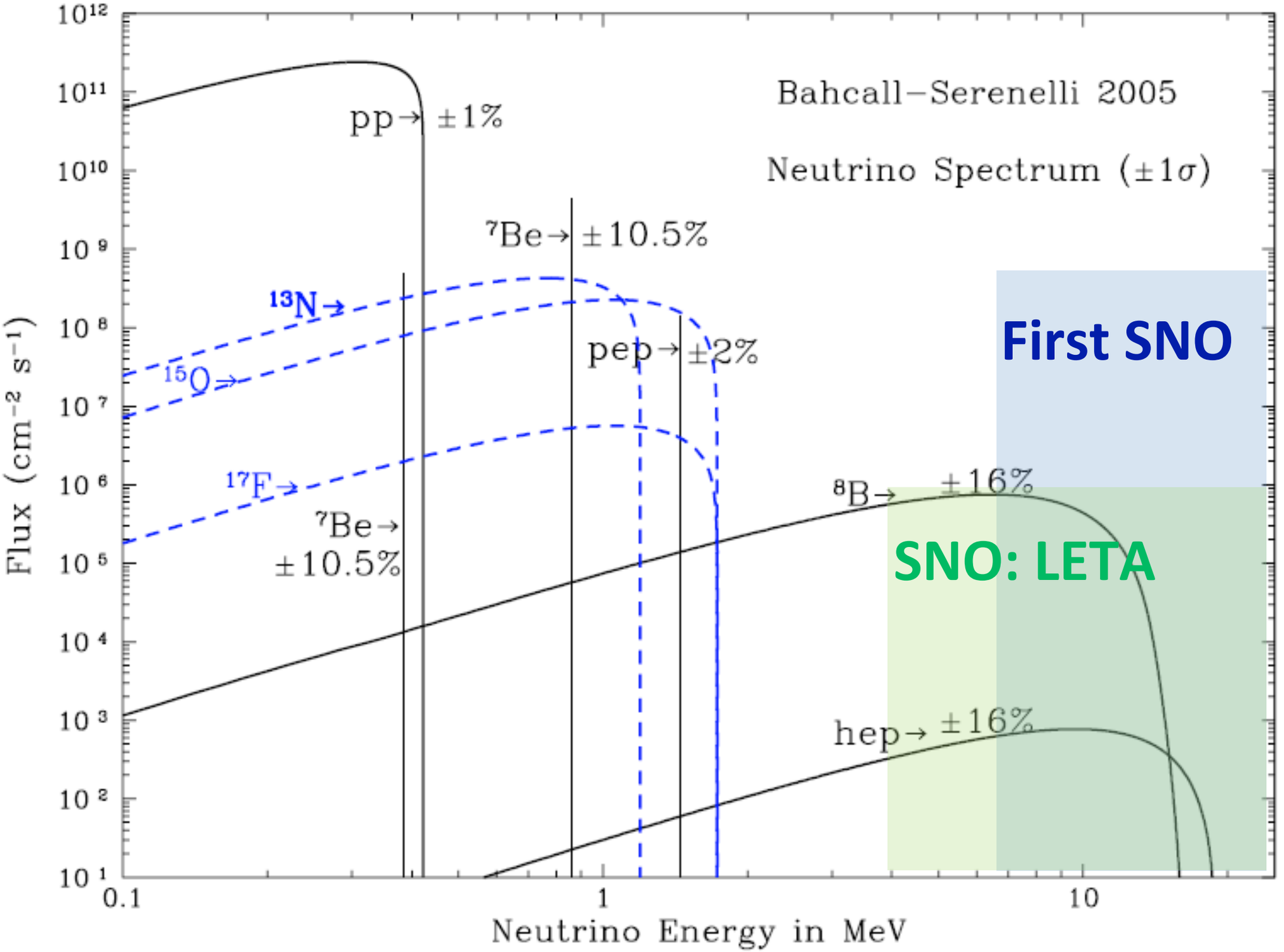
FIG. 1. Chemical reactor for extraction of Ge from Ga.

Phys.Rev.C60:055801,1999

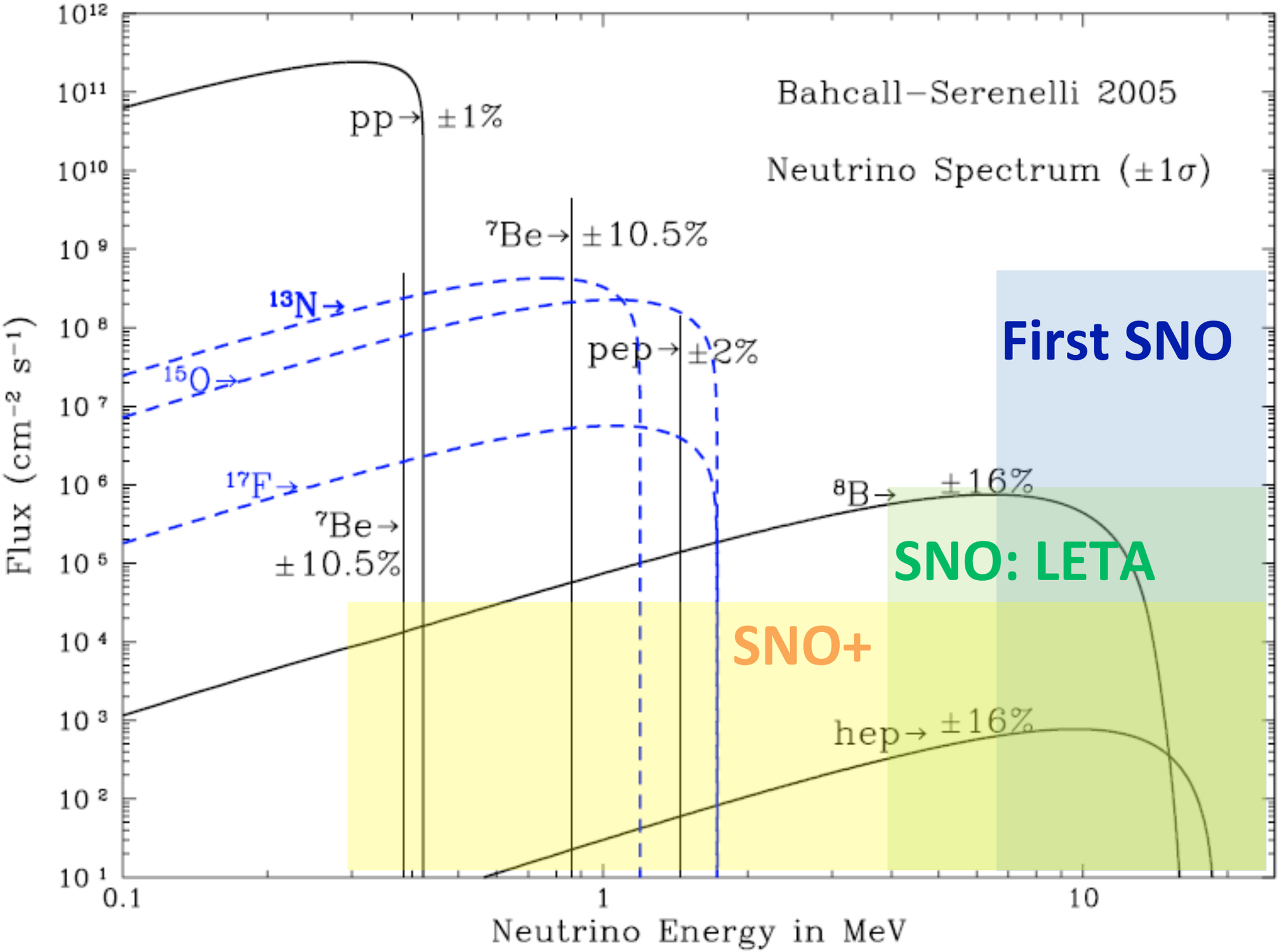
SAGE

The only fully-funded, new experiment is SNO+

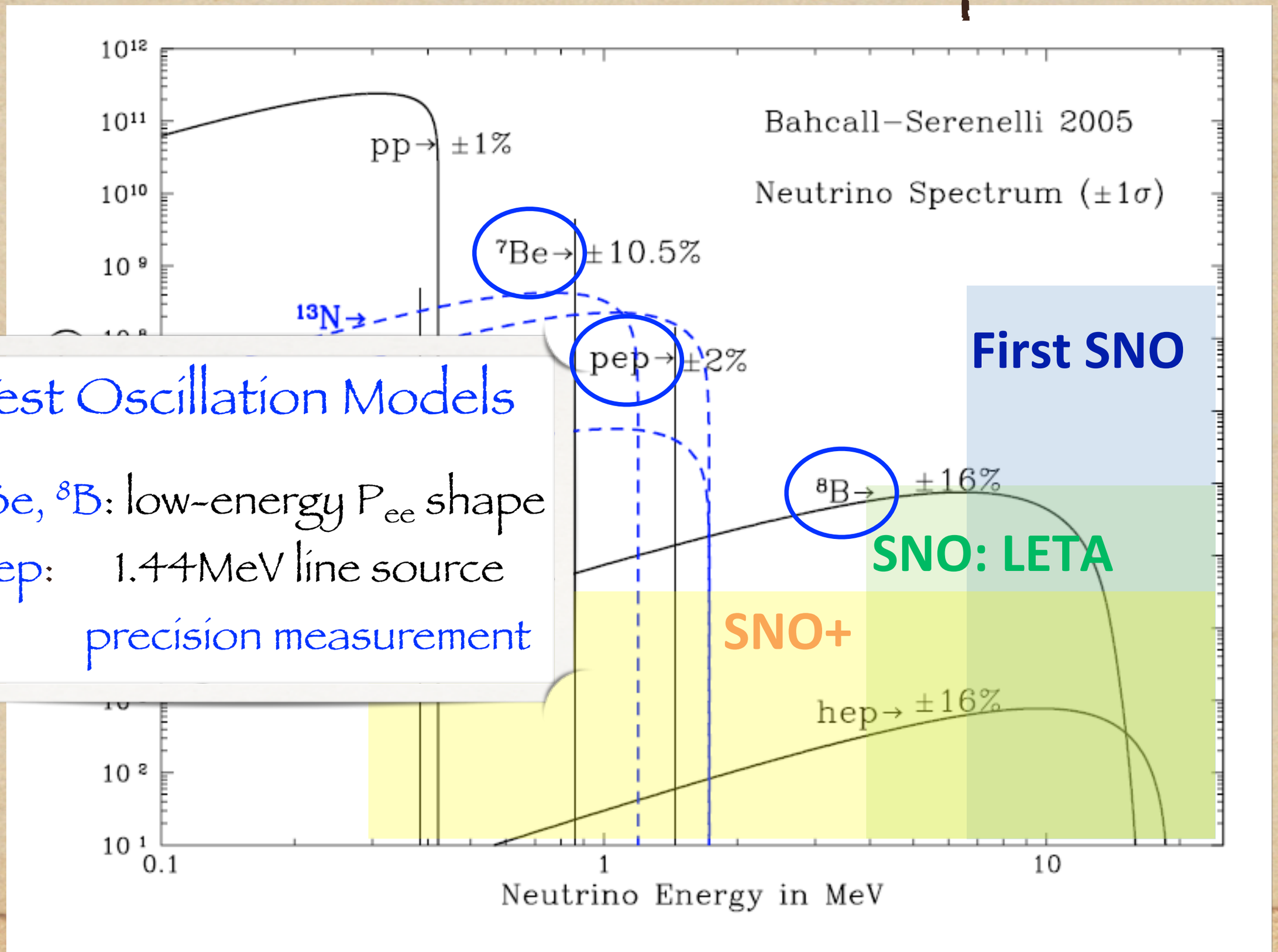
Solar ν Status



SNO+ Solar ν Prospects



SNO+ Solar ν Prospects



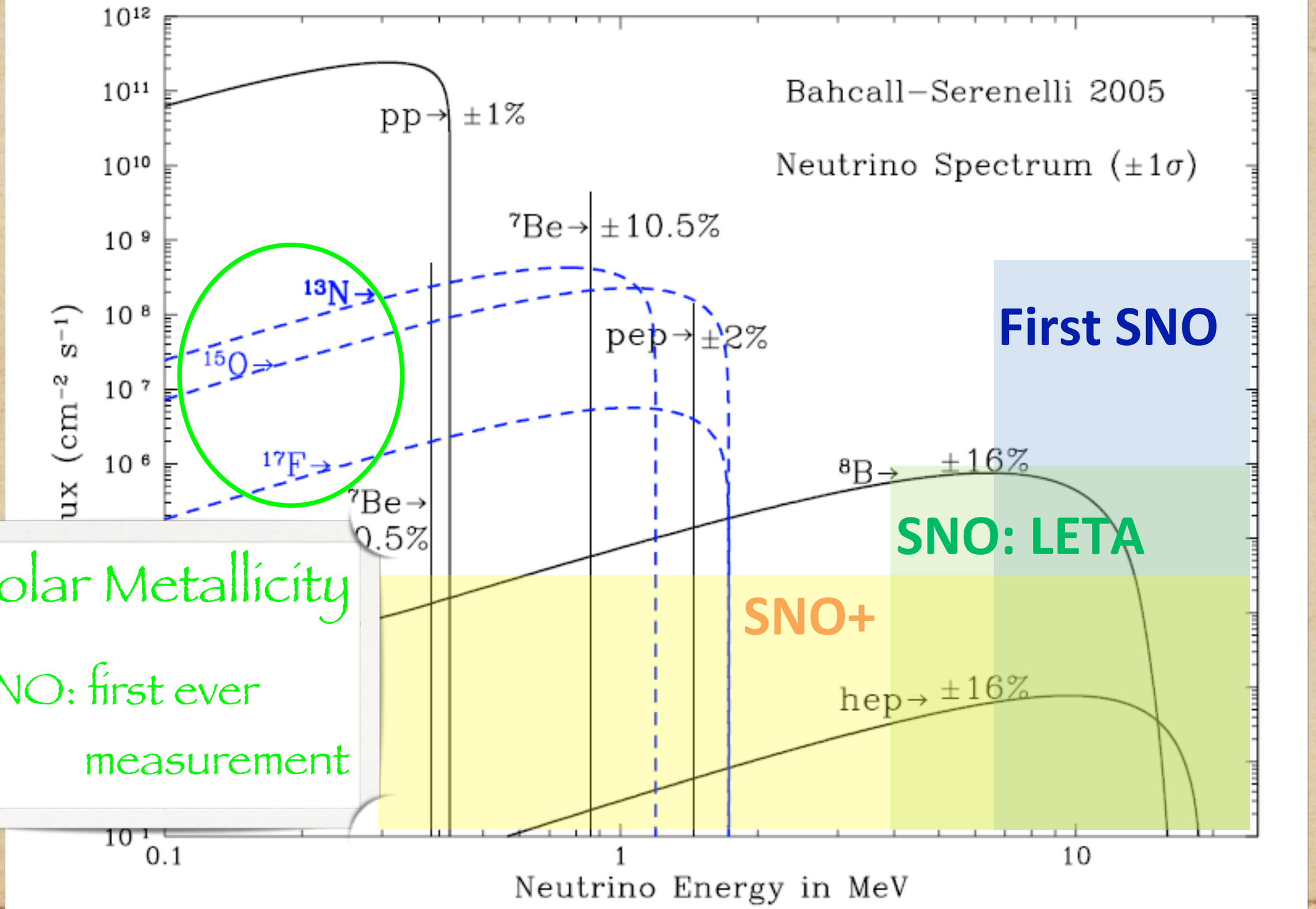
Test Oscillation Models

^{7}Be, ^{8}B: low-energy P_{ee} shape

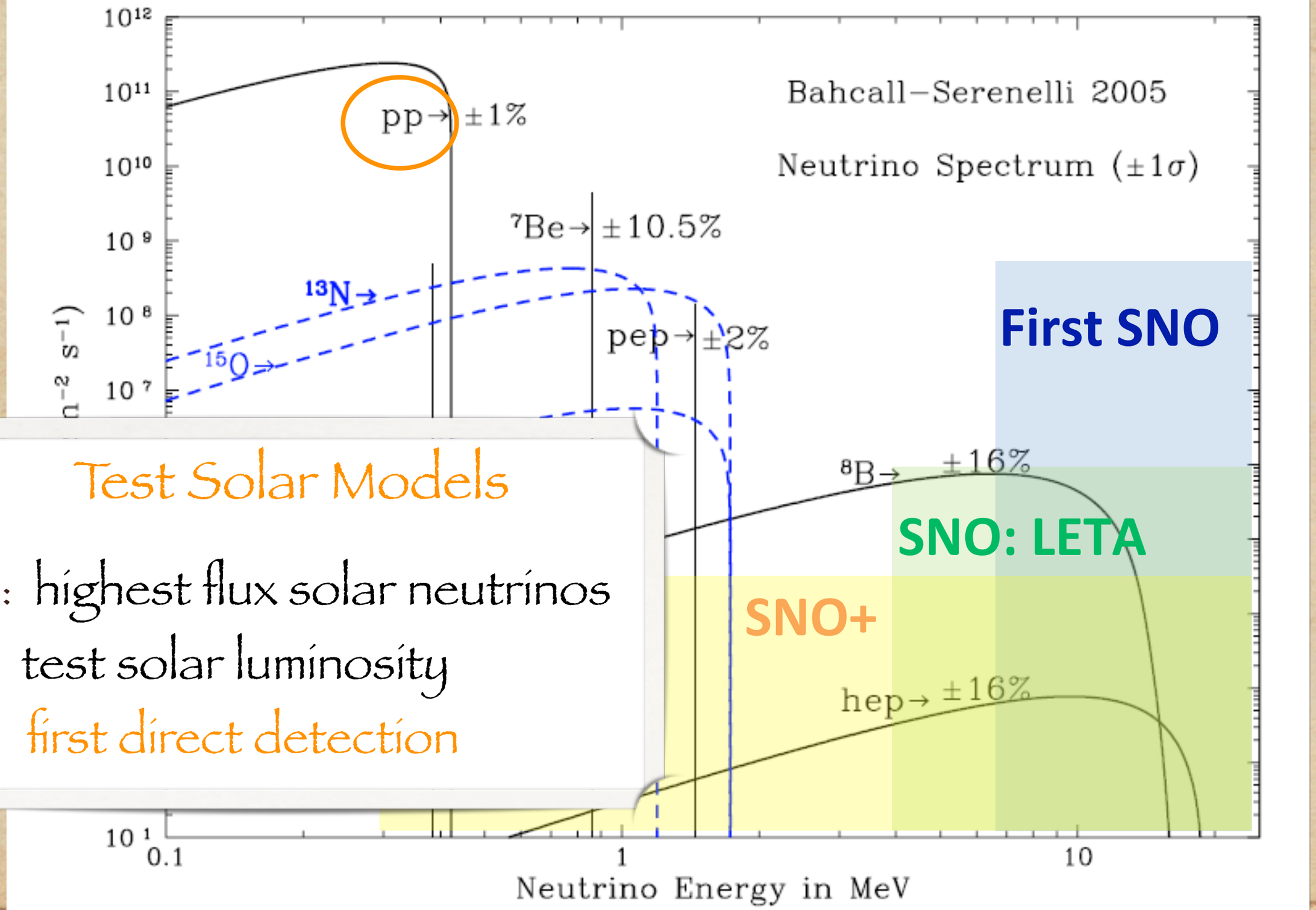
pep: 1.44MeV line source

precision measurement

SNO+ Solar ν Prospects



SNO+ Solar ν Prospects



Test Solar Models

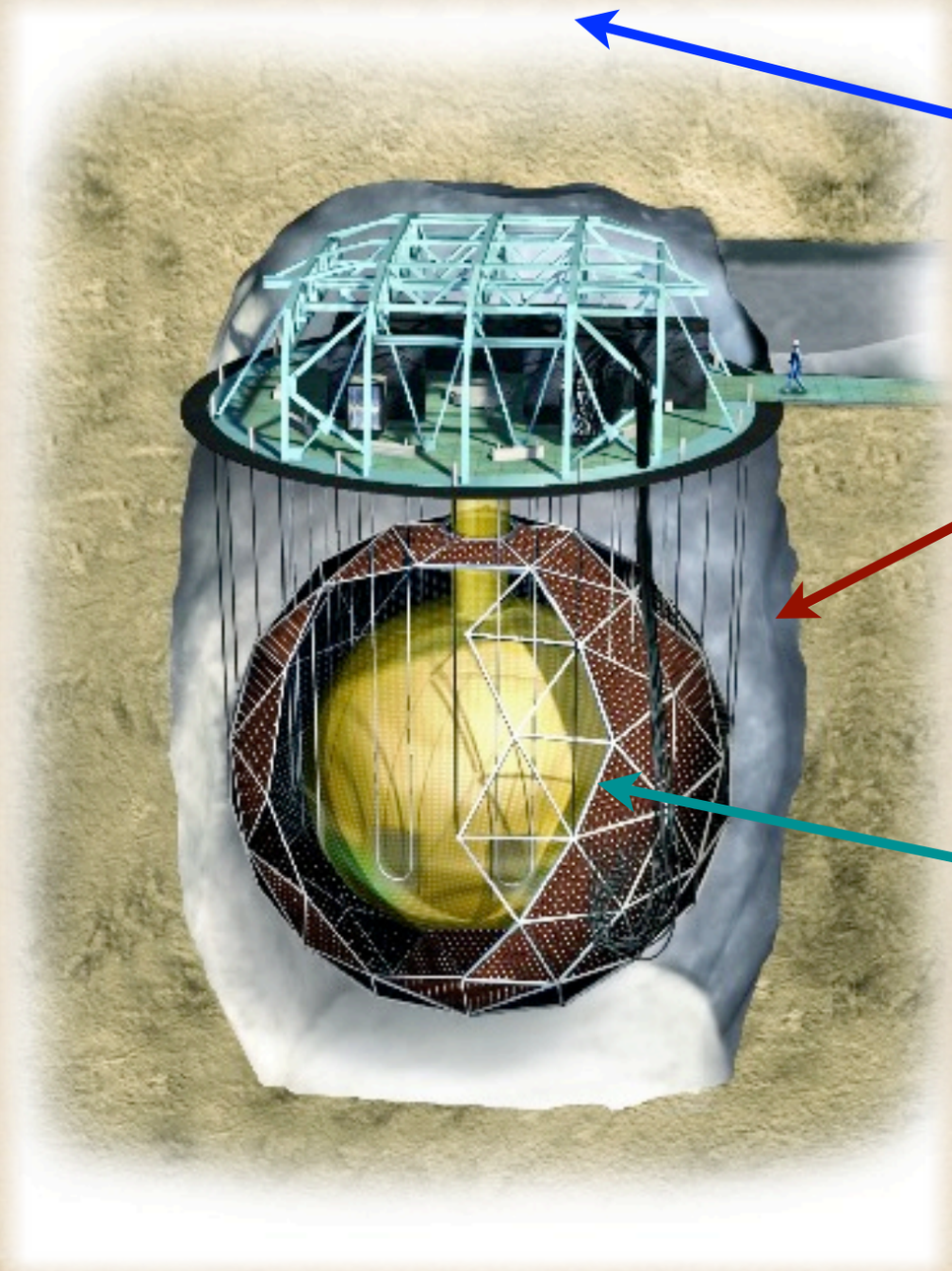
pp: highest flux solar neutrinos

test solar luminosity

first direct detection

SNO+ Backgrounds

- ^{39}Ar
- ^{210}Bi
- ^{11}C
- ^{14}C
- ^{40}K
- ^{85}Kr
- ^{210}Pb
- ^{210}Po
- U chain
- Th chain

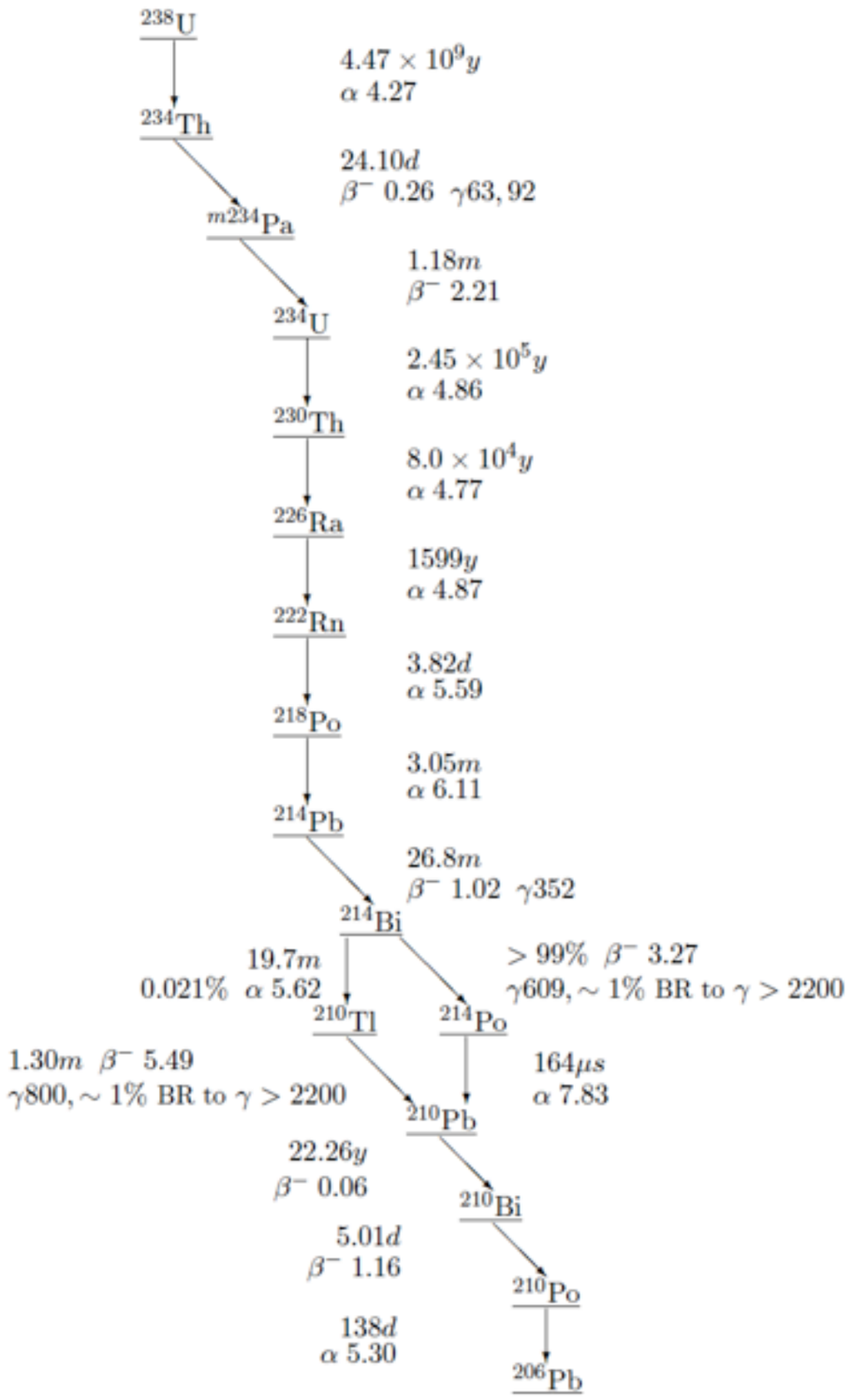


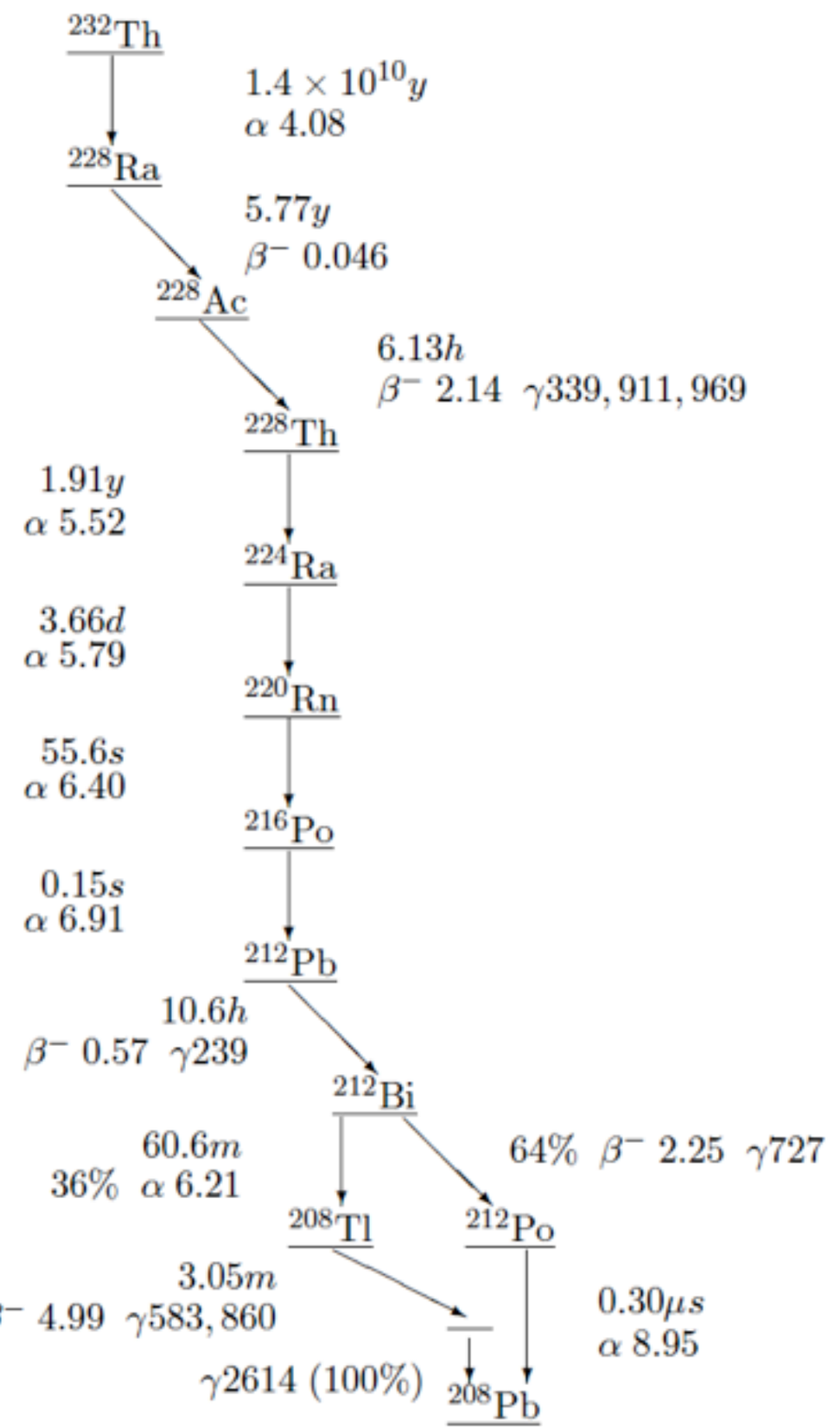
Cosmogenic
e.g. ^{11}C

External
AV, PMTs,
H_2O, ropes

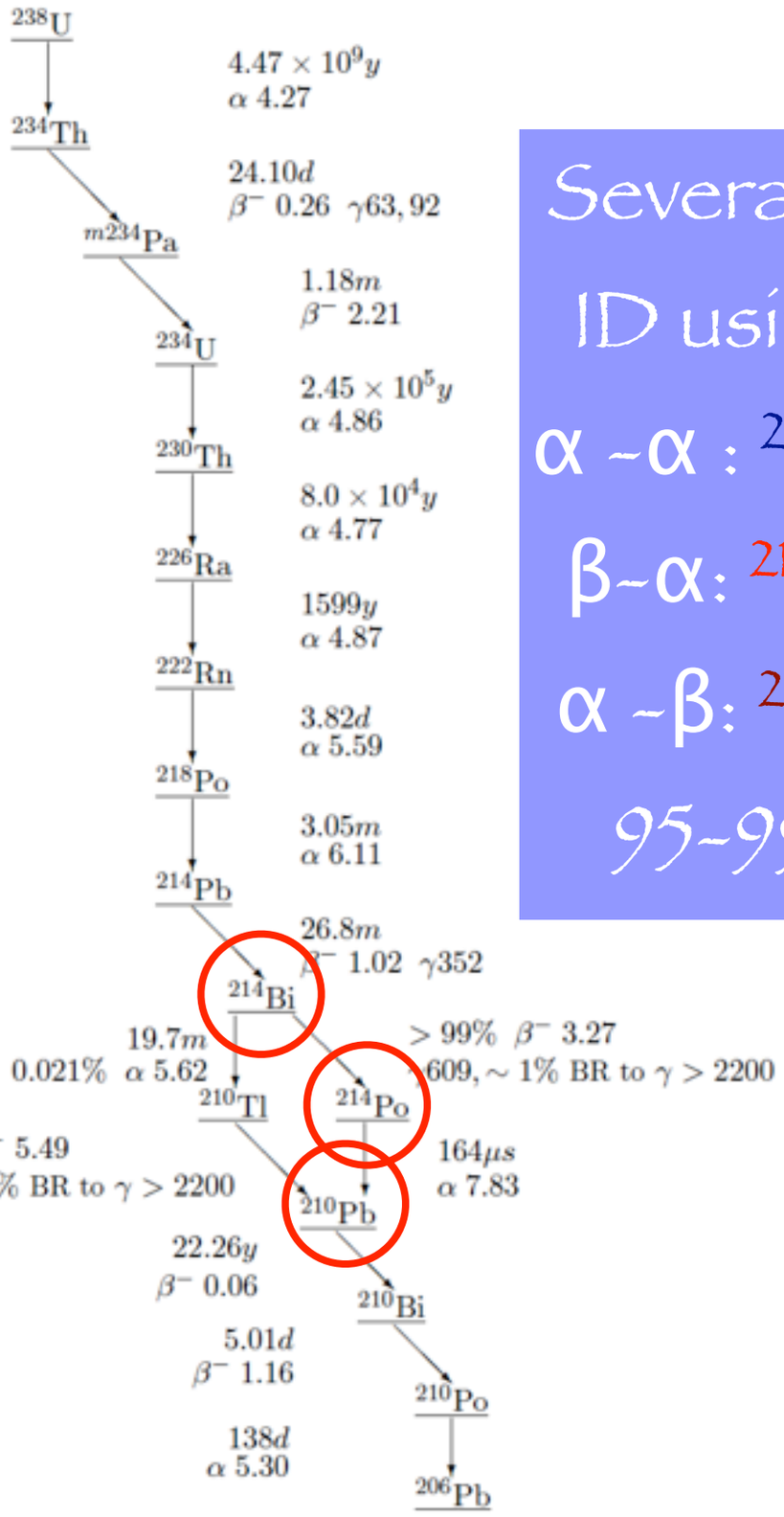
Internal
LS, AV leaching,
internal ropes

Background Mitigation





Background Mitigation



Several α, β emissions

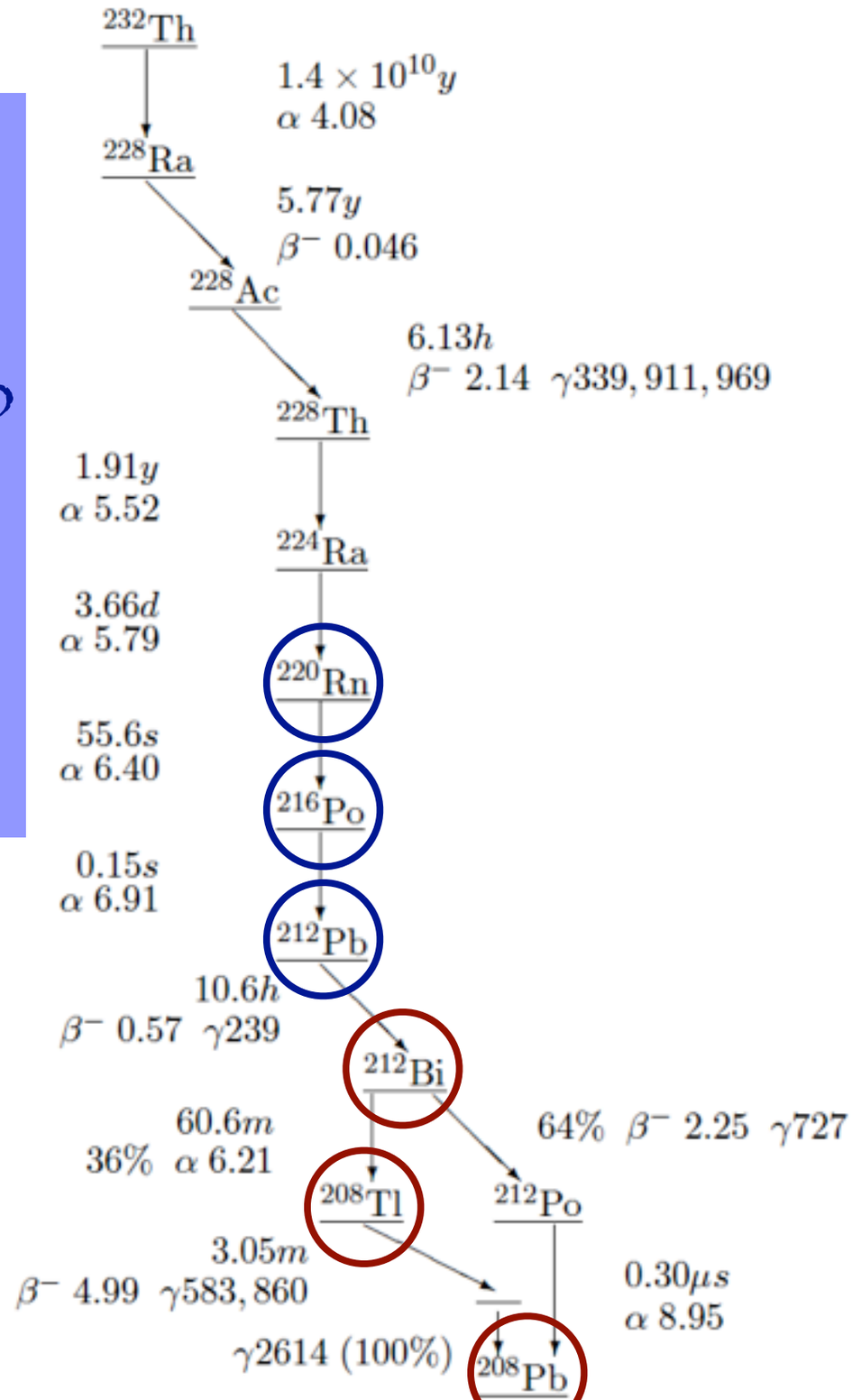
ID using coincidence

α -α : ^{220}Rn-^{216}Po-^{212}Pb

β-α: ^{214}Bi-^{214}Po-^{210}Pb

α -β: ^{212}Bi-^{208}Tl-^{208}Pb

95-99.9% rejection



SNO+ Advantages: Depth

^{11}C produced by cosmic μ hitting organic molecules

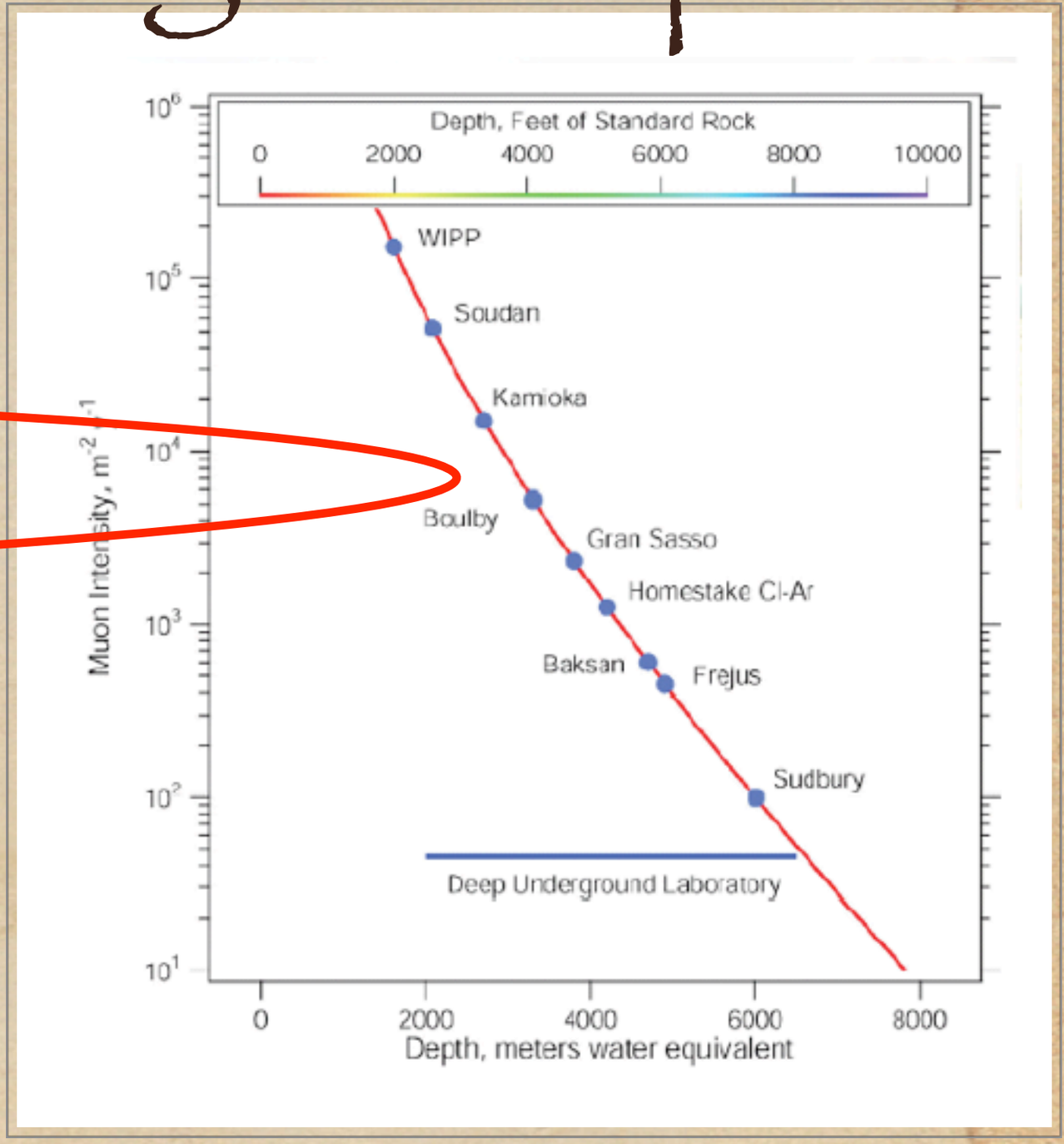
KamLAND: 2700 mwe

Borexino: 3500 mwe

SNO+: 6080 mwe

/100

/600



SNO+ Advantages: Depth

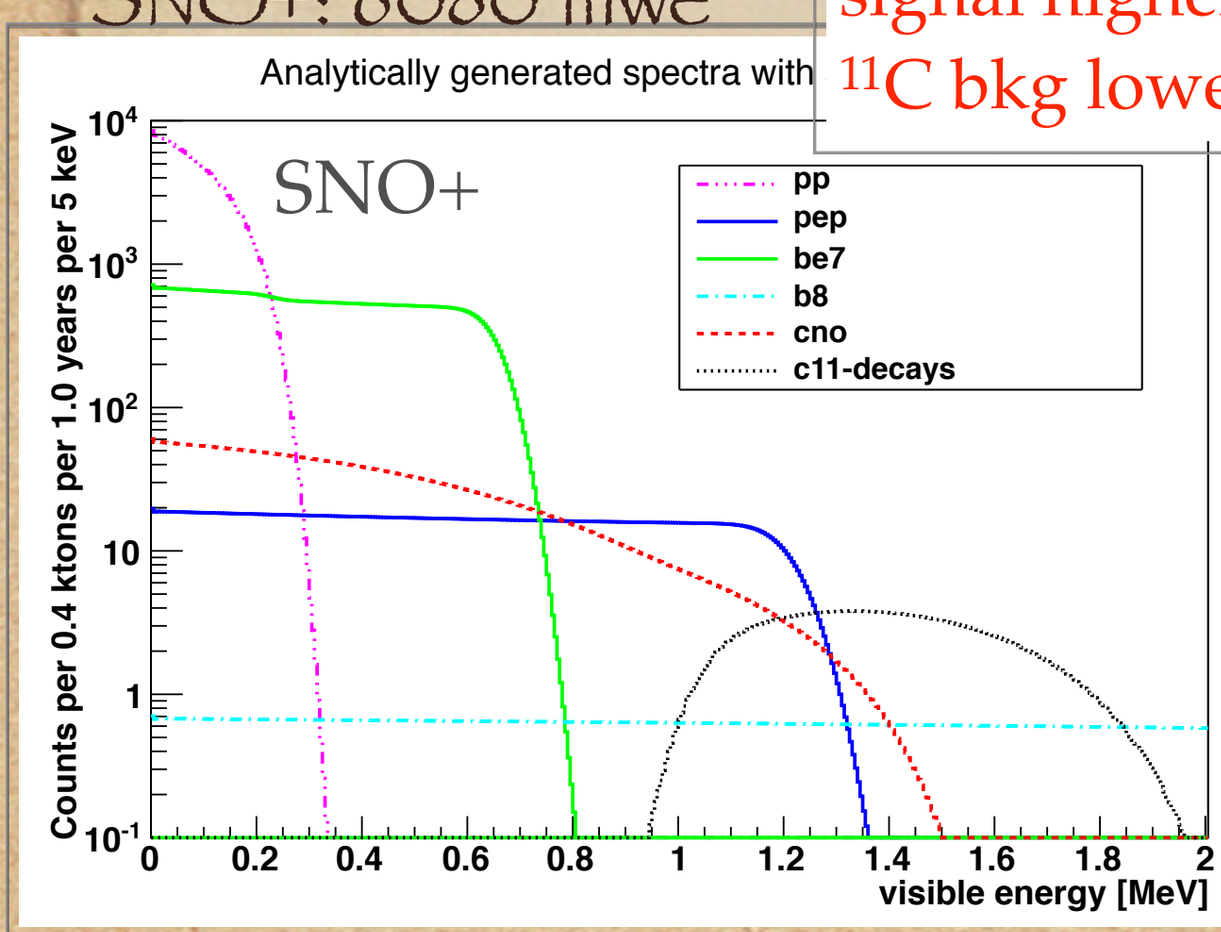
^{11}C produced by cosmic μ hitting organic molecules

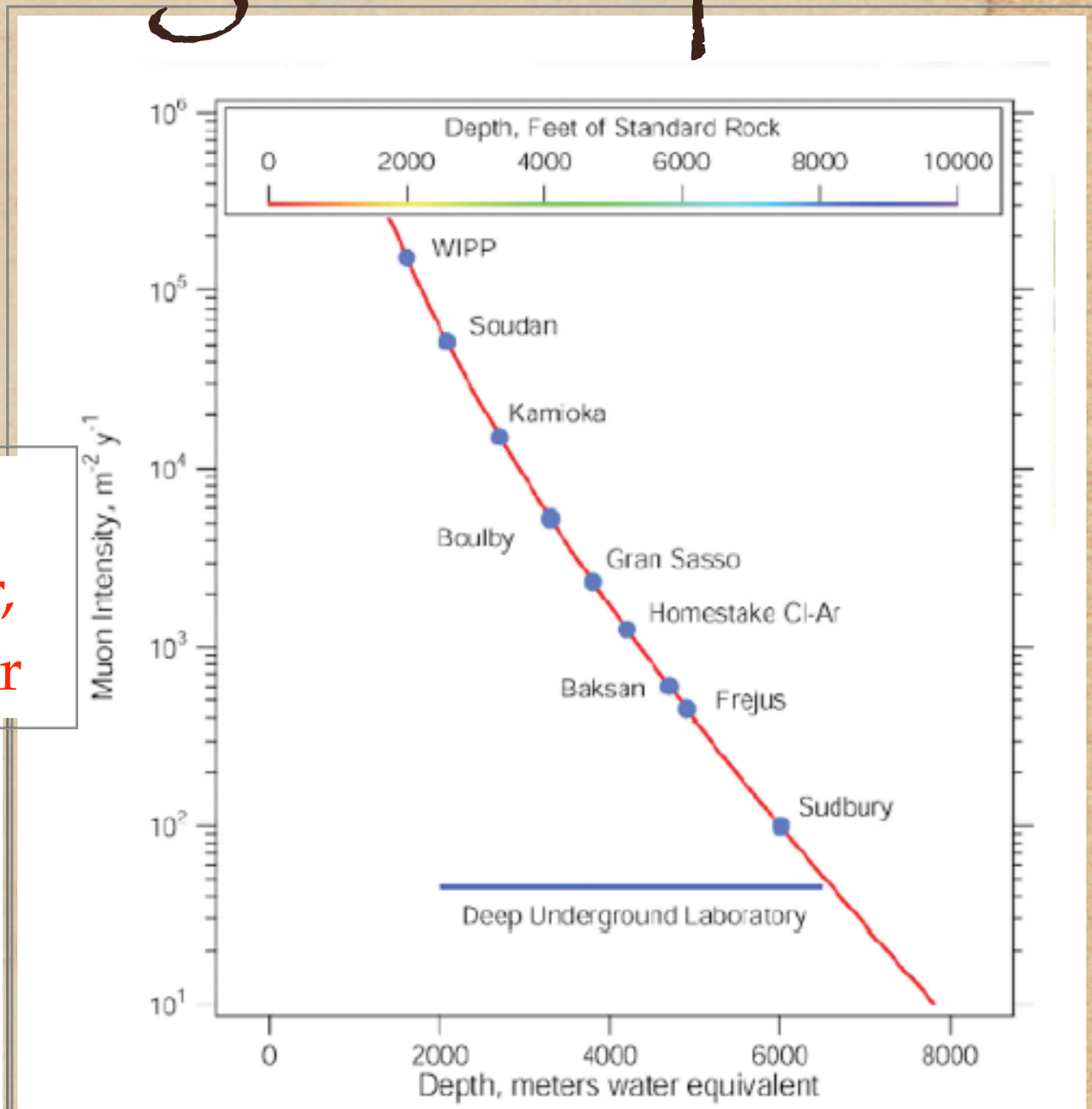
KamLAND: 2700 mwe

Borexino: 3500 mwe

SNO+: 6080 mwe

pep (& pp!) signal higher, ^{11}C bkg lower

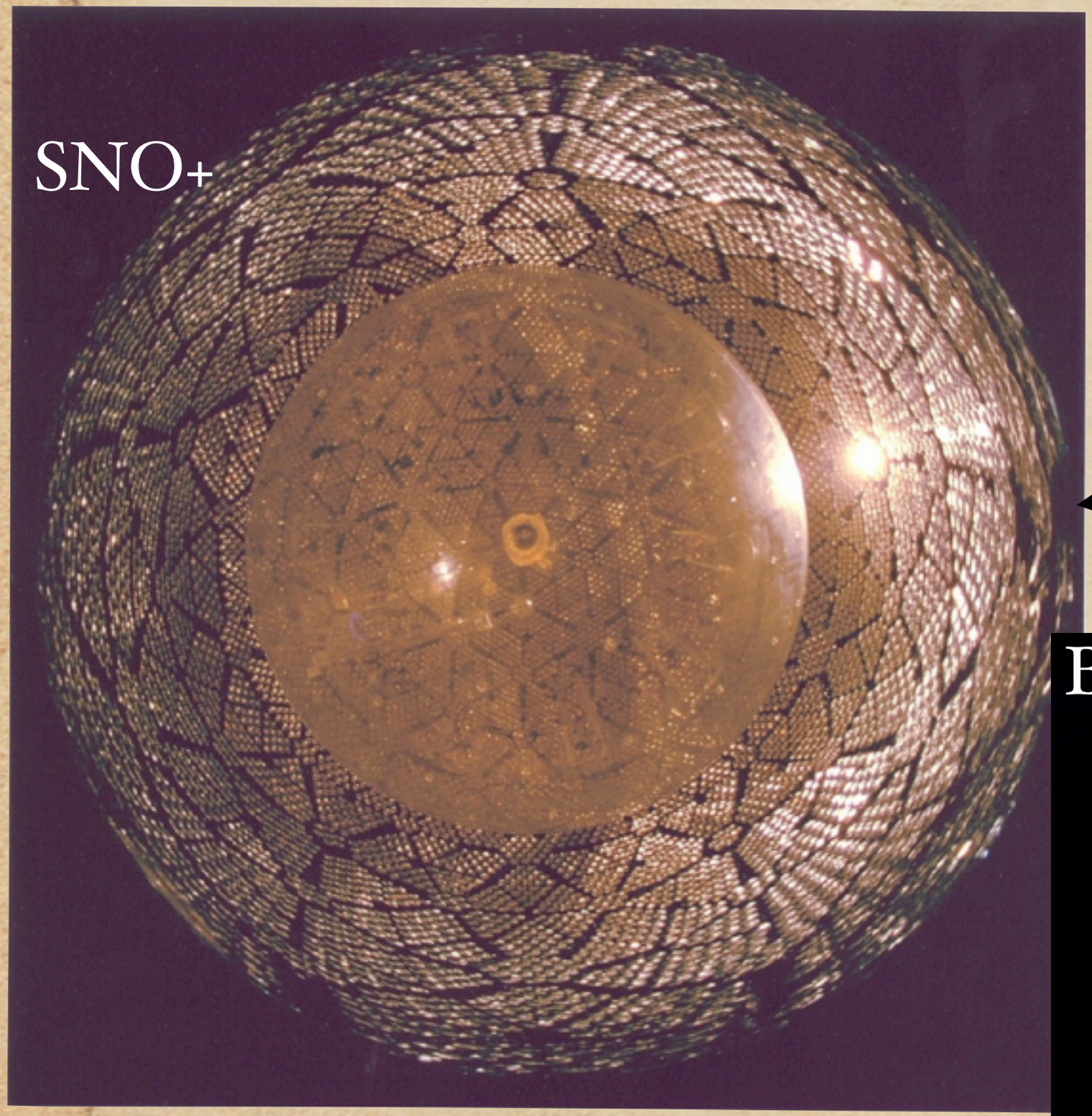




3-fold coincidence cut for 11C rejection

91% rejection, 52% signal loss

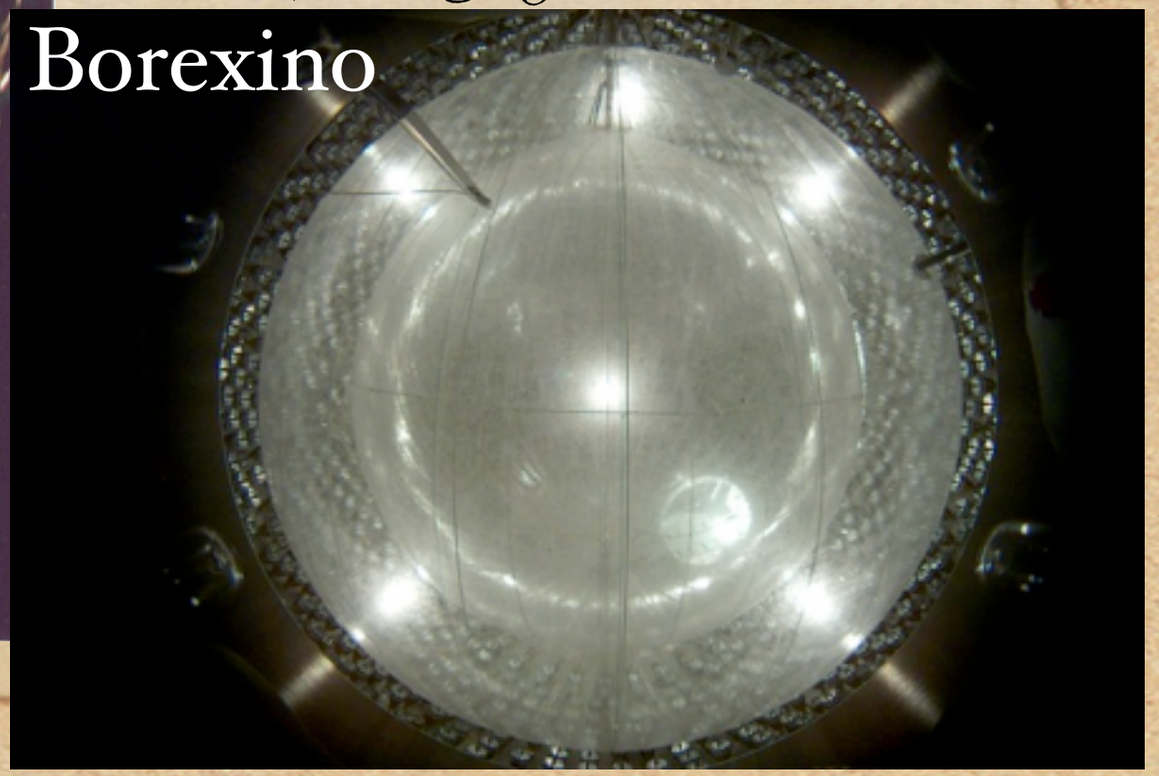
Statistics, Statistics, Statistics



1. Energy resolution:
~2200 vs ~9500 PMTs

2. Size:
278 vs 780ton scintillator
71 vs 400 fiducial

roughly to scale



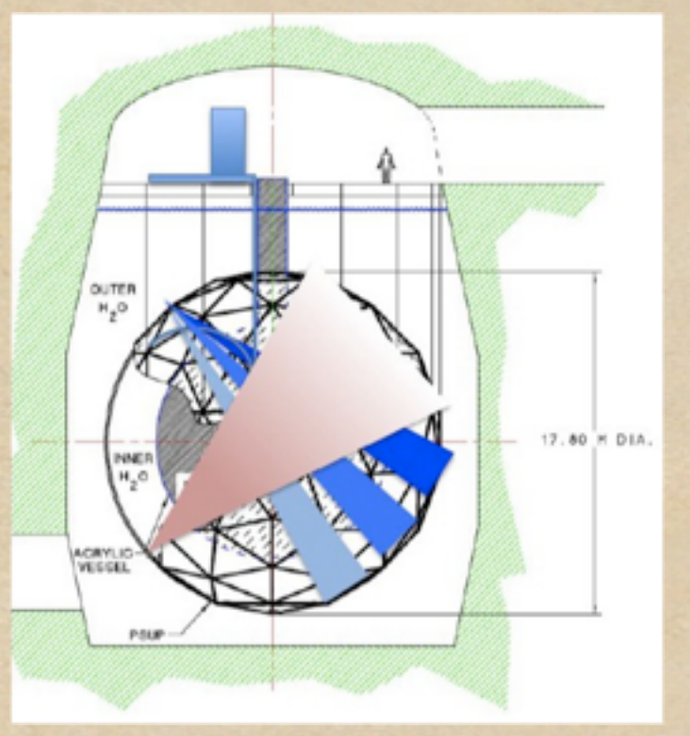
Calibration Programme

Source	AmBe	^{90}Y	^{65}Zn	^{60}Co	^{57}Co	^{24}Na	^{48}Sc	^{8}Li	^{16}N
Particle	n, γ	β	γ	γ	γ	γ	γ	β	γ
Energy(MeV)	4.4(γ)	2.2	1.1	2.5	0.122	4.1	3.3	10	6.1

- Comprehensive source list
- Minimalist deployment plan (risk 222Rn contam)
- Camera system for source positioning
- Plus optical sources

Optical Calibration

Light injection (ELLIE)

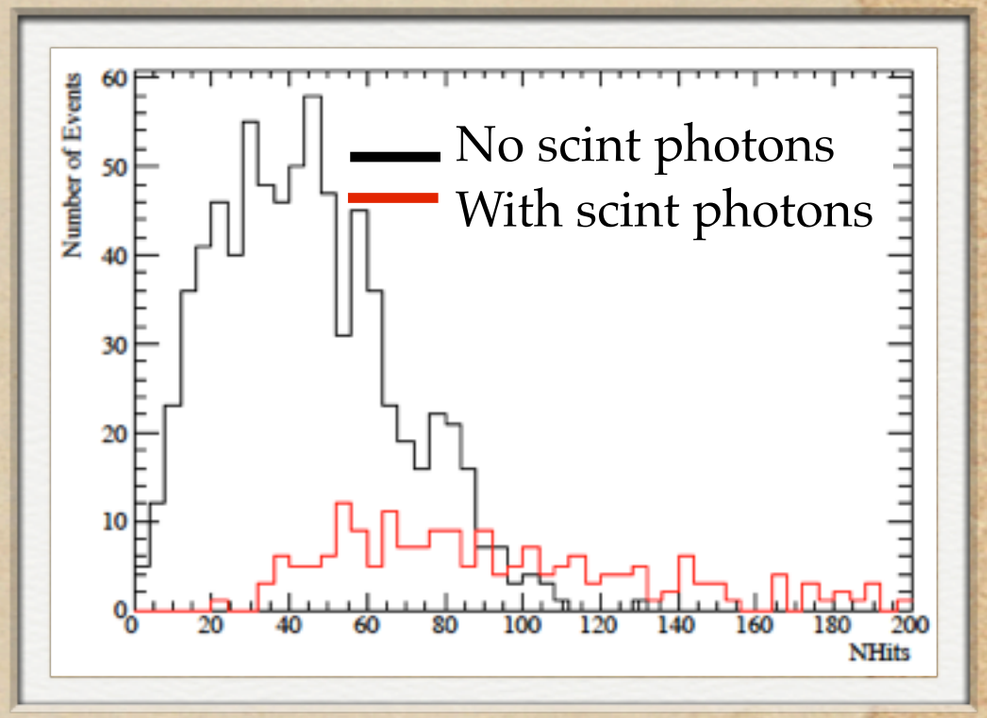


92 external injection points

Laserball

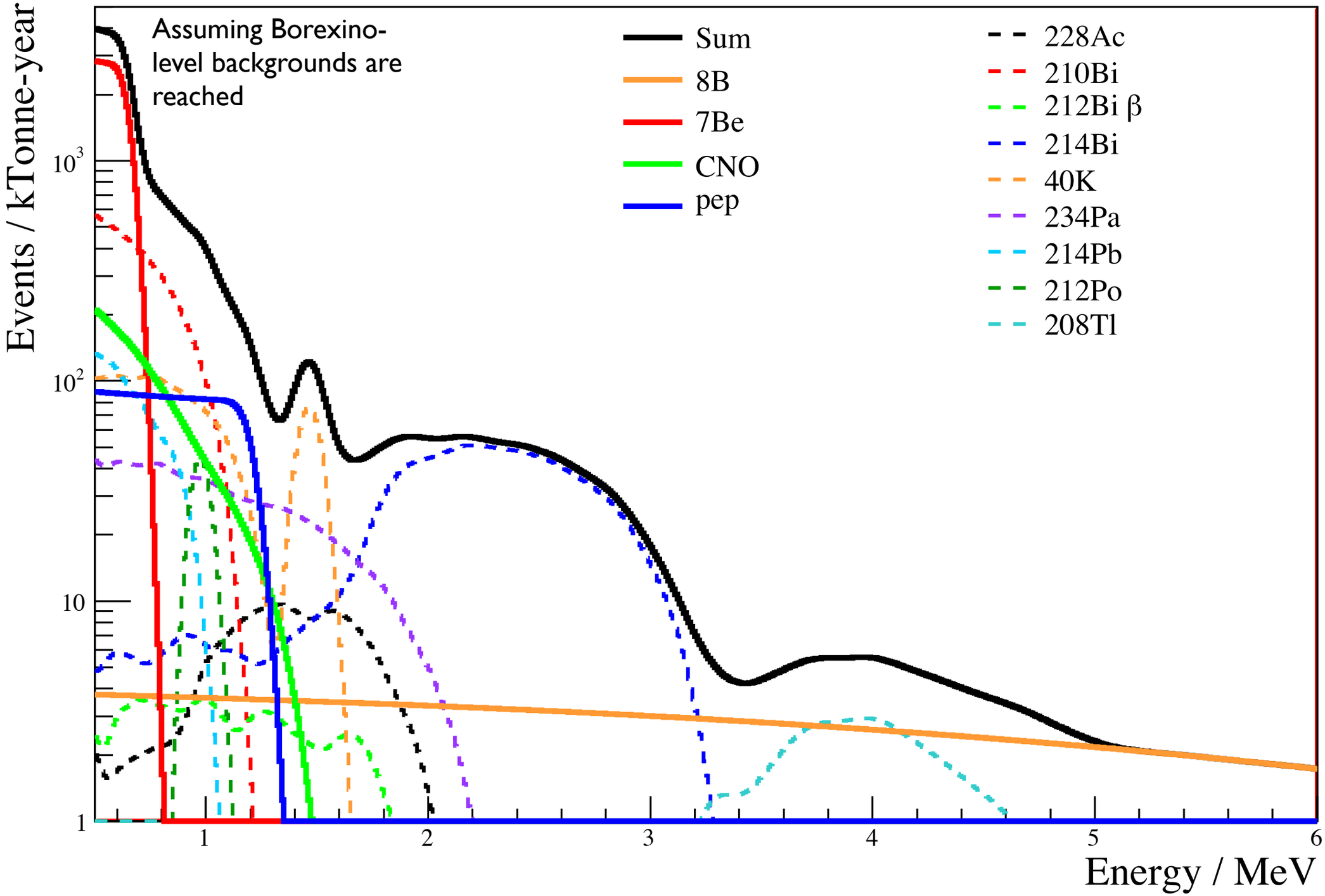
Internal src (Used by SNO)

Cherenkov

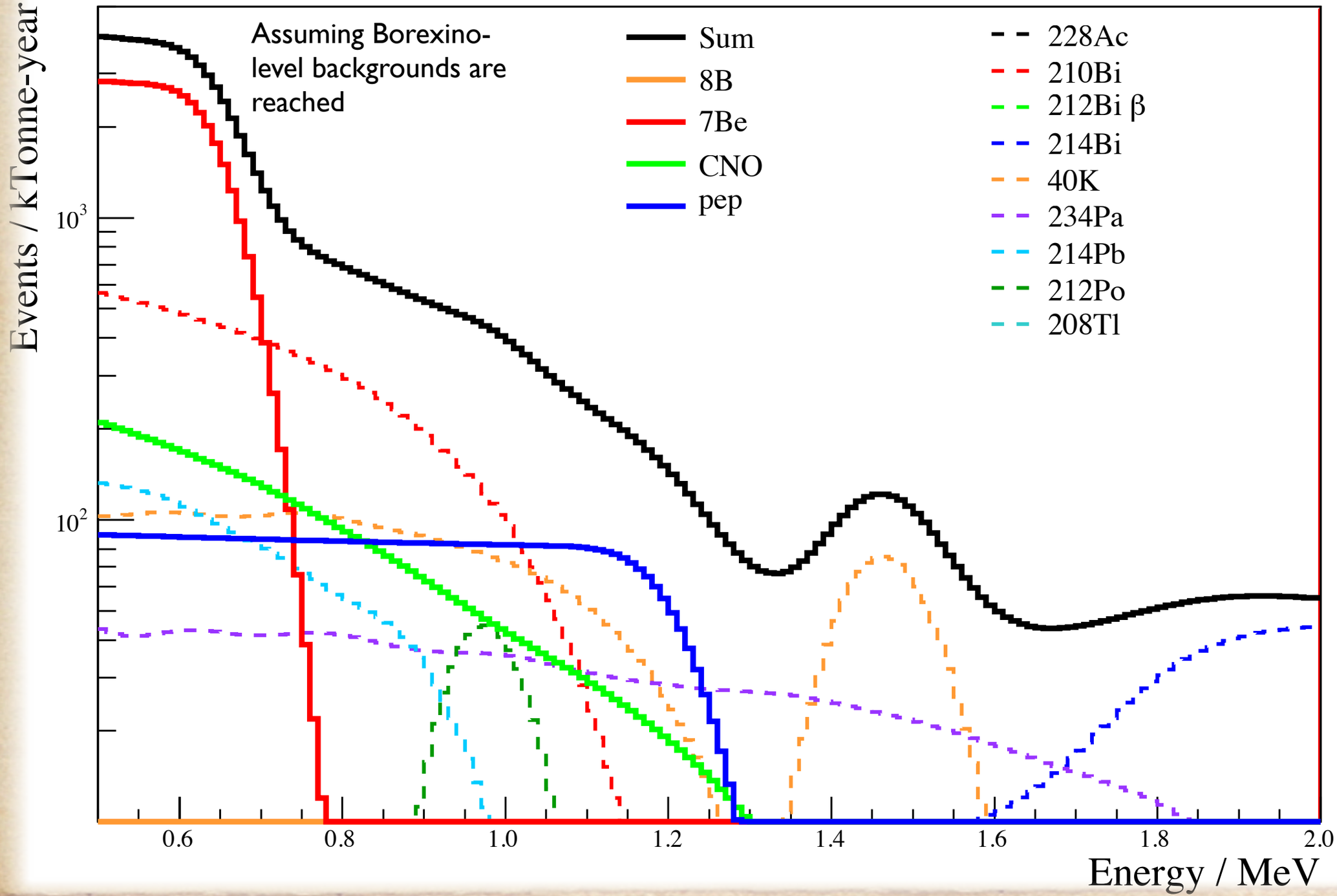


Absolute optical calibration

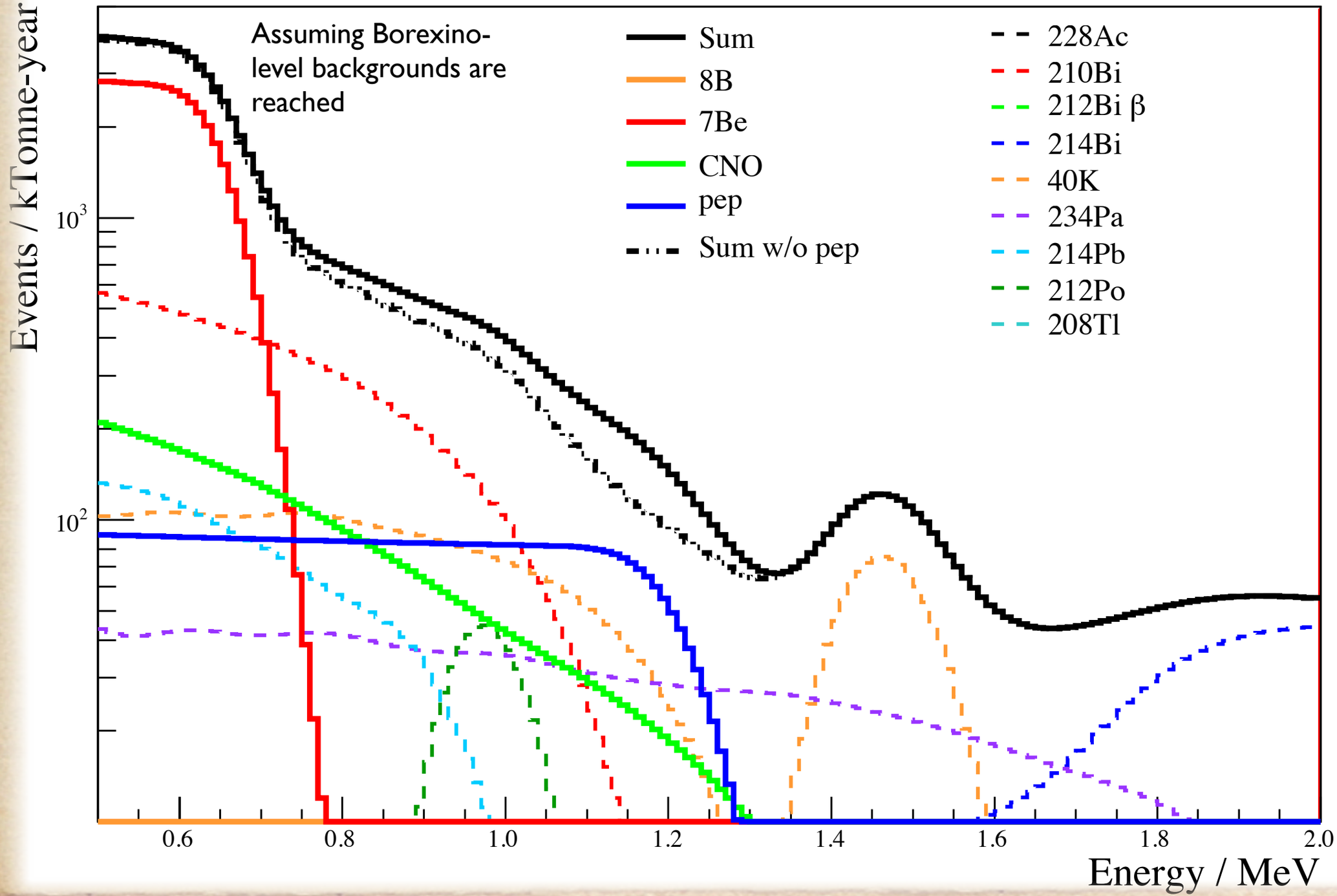
SNO+ Solar ν Signals



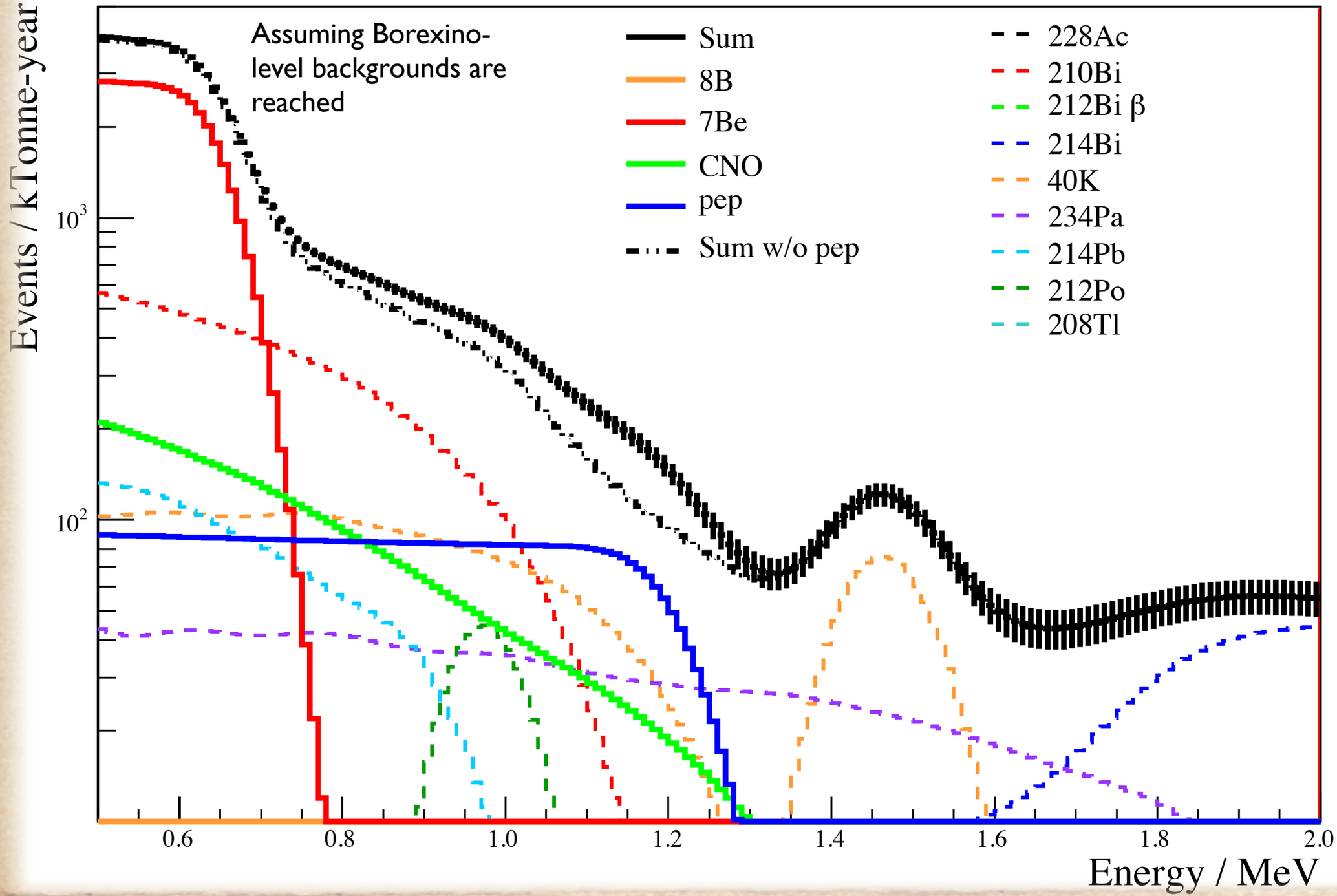
SNO+ Low Energy Solar ν



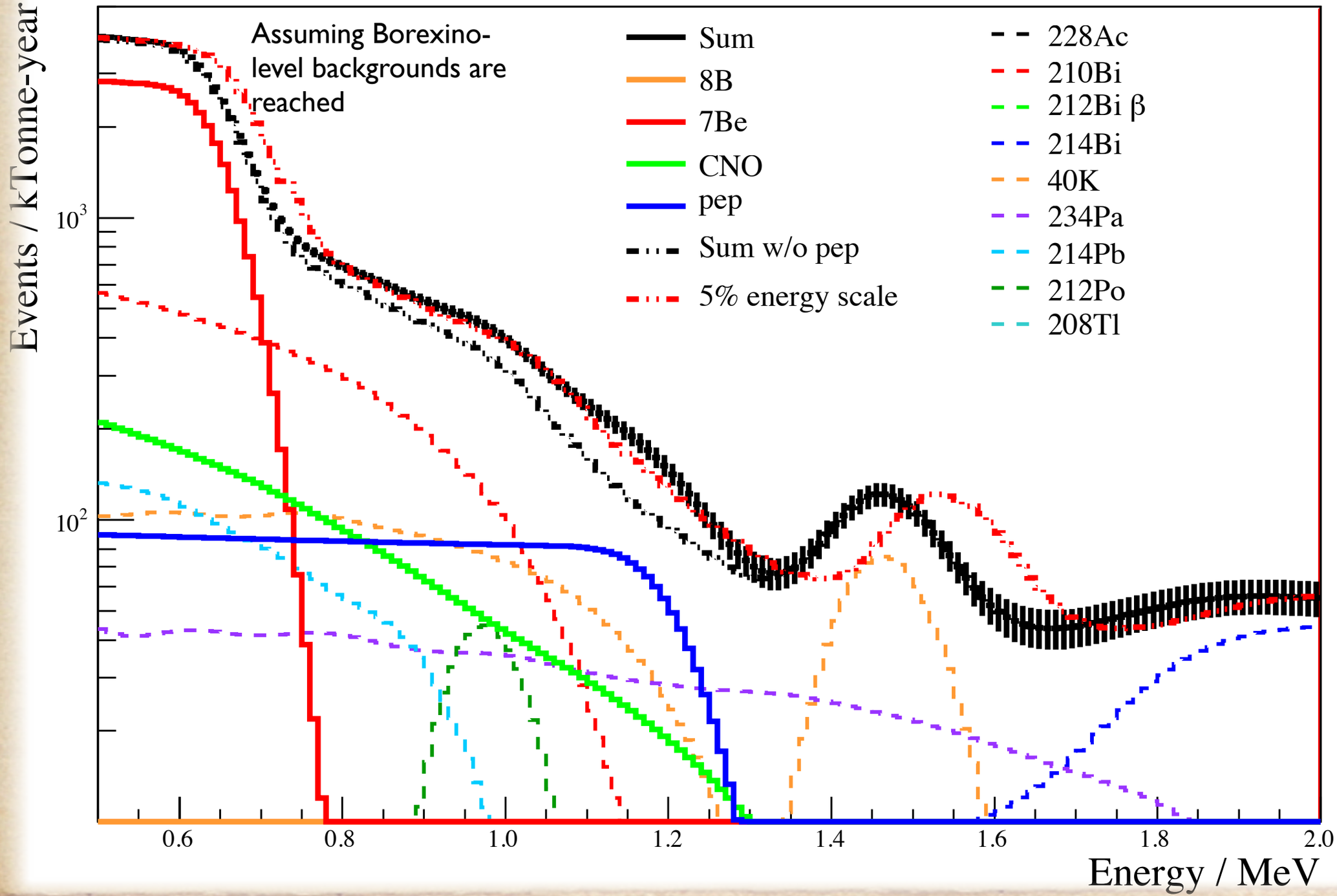
SNO+ Low Energy Solar ν



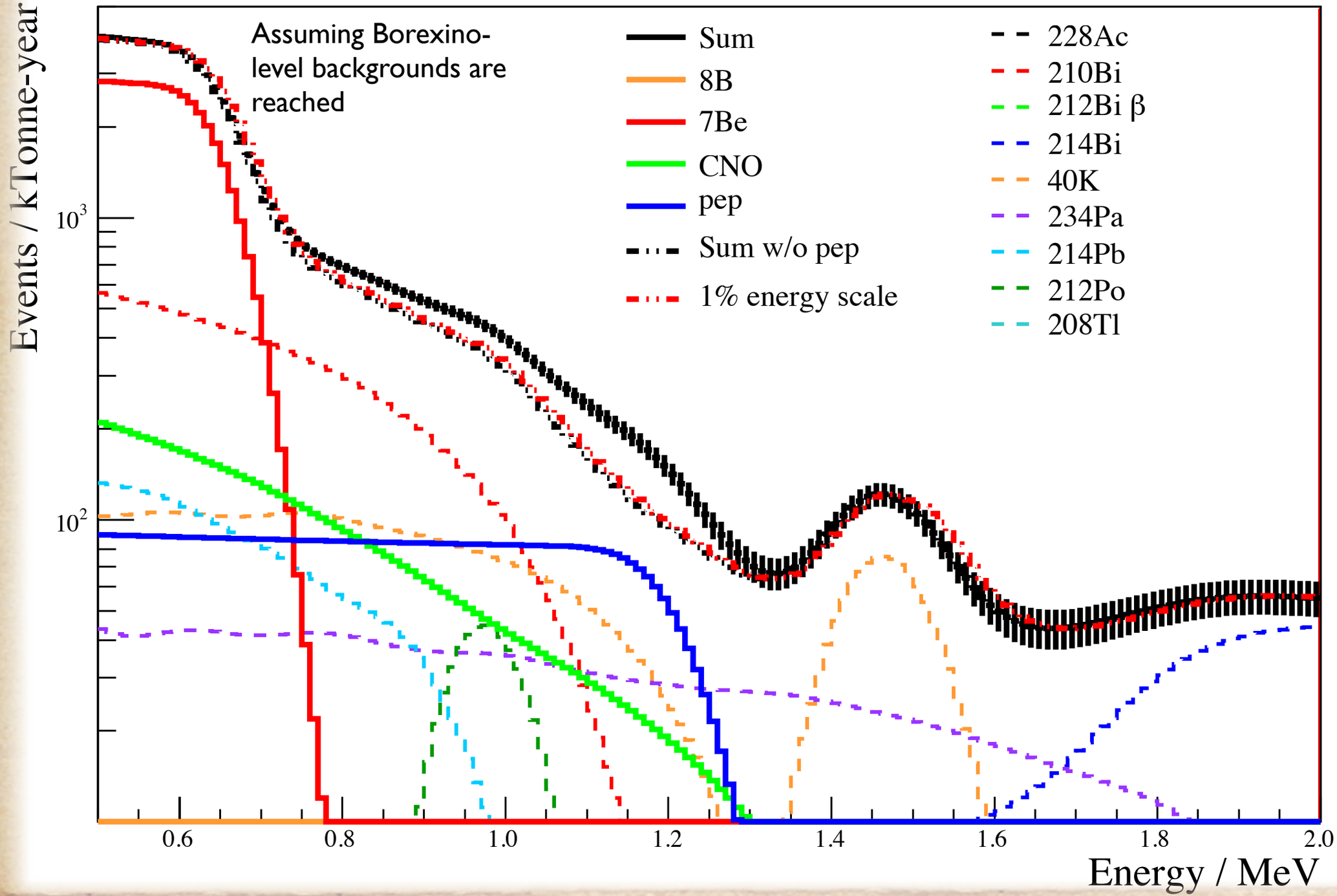
SNO+ Low Energy Solar ν



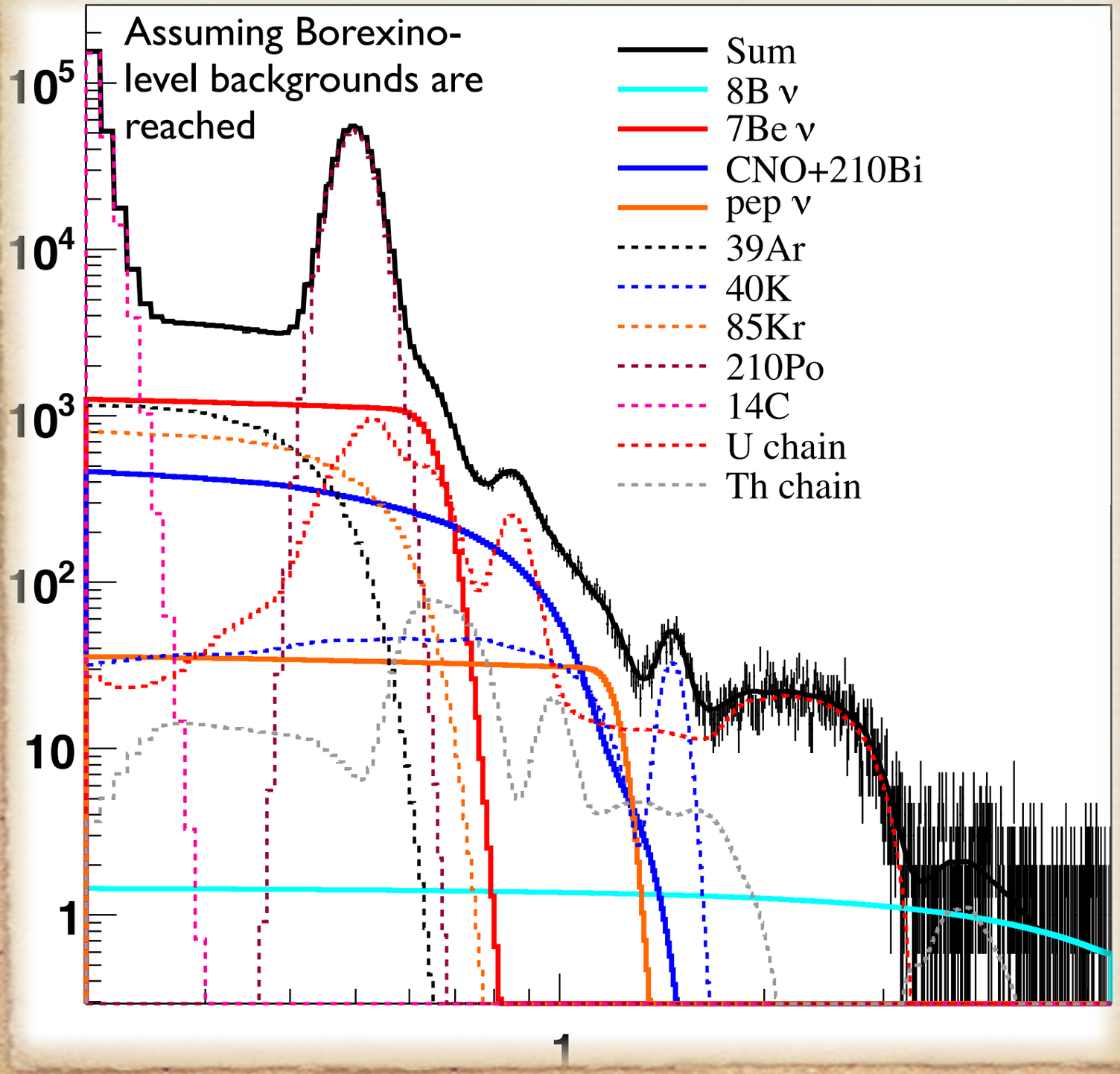
SNO+ Low Energy Solar ν



SNO+ Low Energy Solar ν

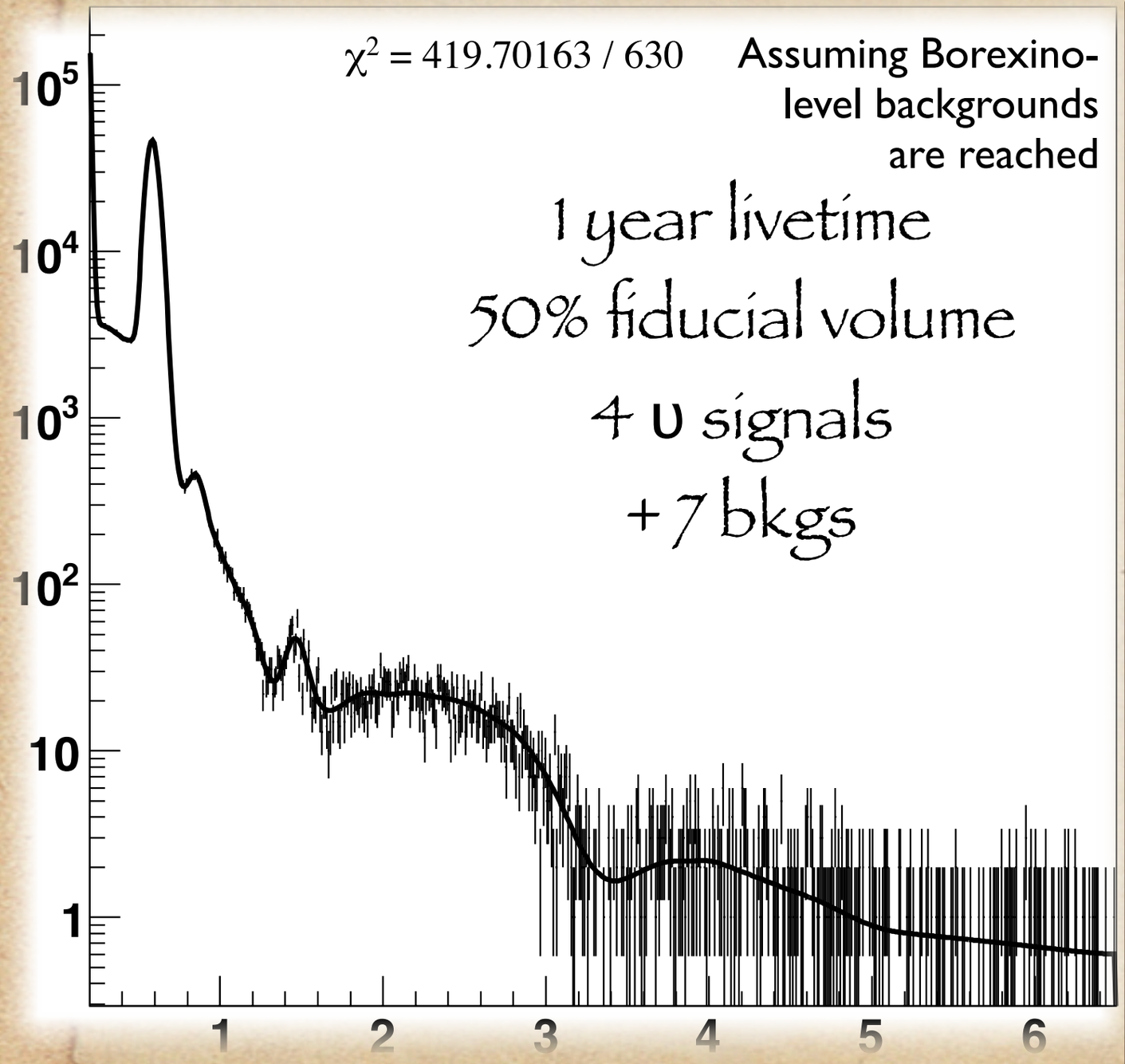


SNO+ Sensitivity Studies



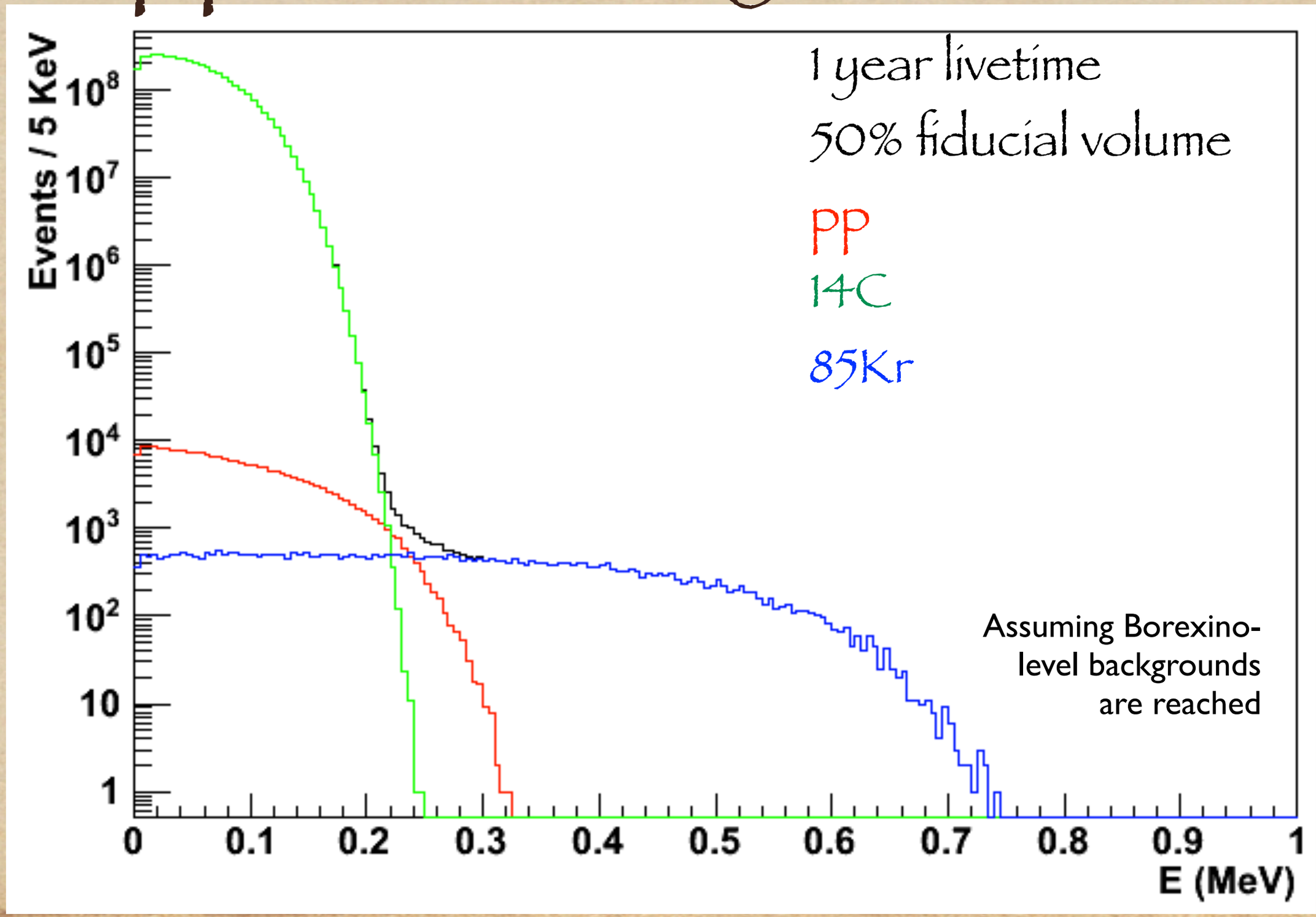
- 4 ν signals
- 30 bkgs
- Th chain eqm
- U chain semi-eqm
- Extended max L fit
- 50% fid vol
- Target bkgs
- Energy scale / resn studies
- Stat dominated

SNO+ Sensitivity Studies

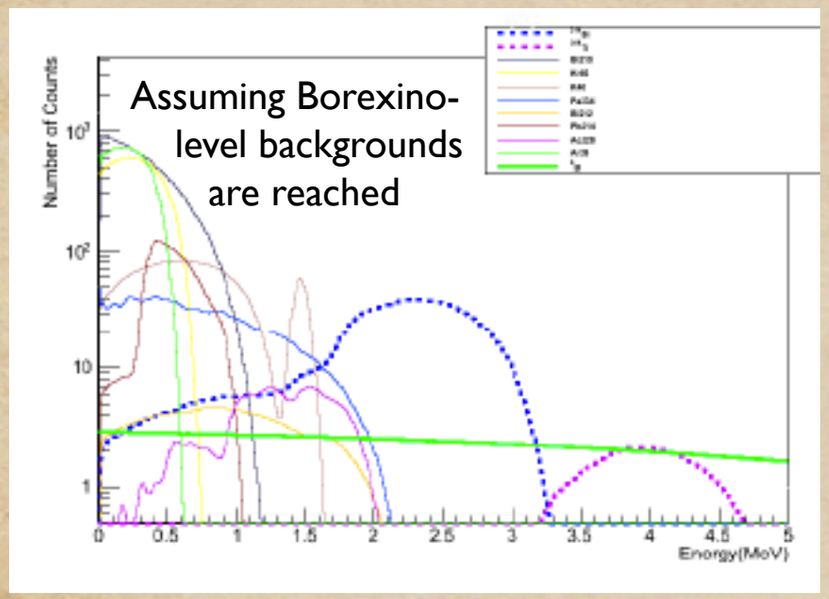


(stat)	1 yr	2 yrs
pep	9.1%	6.5%
8B	7.5%	5.4%
7Be	4%	2.8%
PP	A few % ?	
CNO	~15 % ?	
	Assuming Borexino-level bkgs are reached	

pp Sensitivity Studies



^{8}B Sensitivity Studies



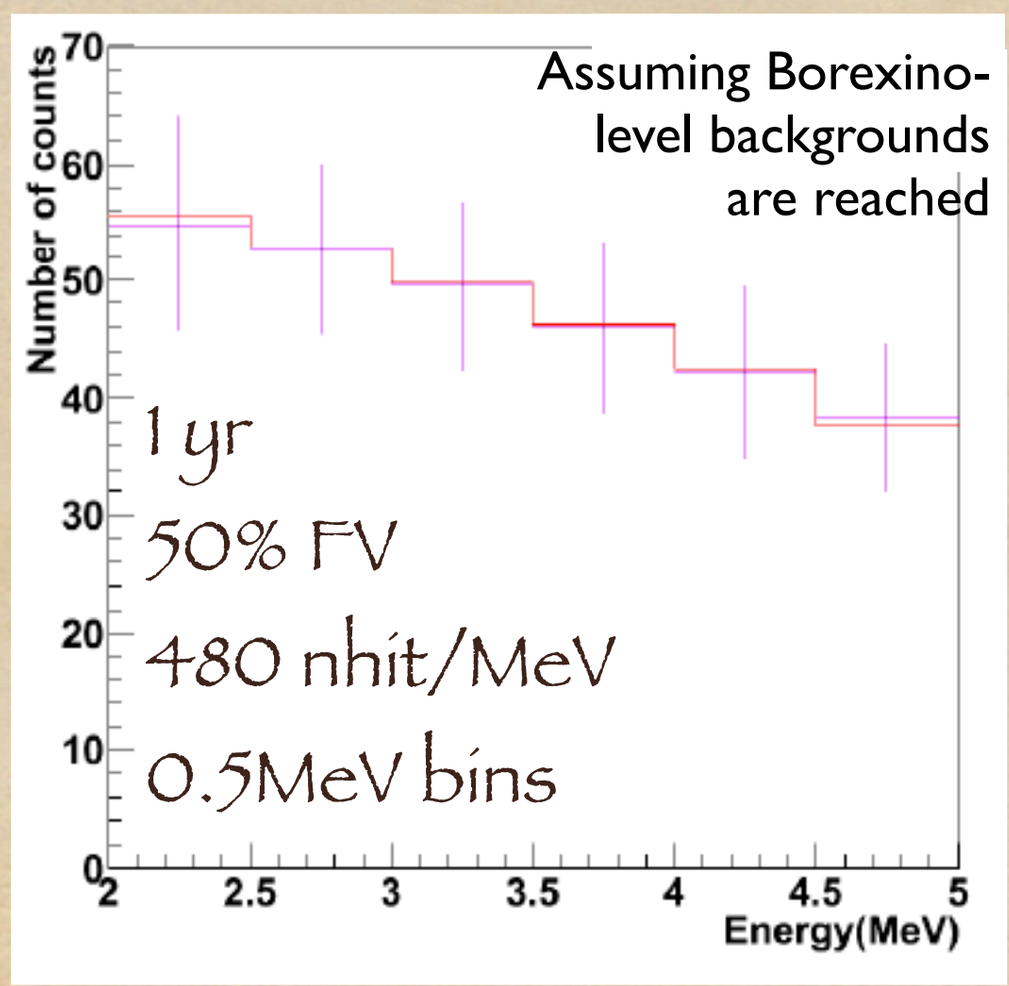
- Region of low background

- Assume:

  99.8% ^{214}Bi rejection,

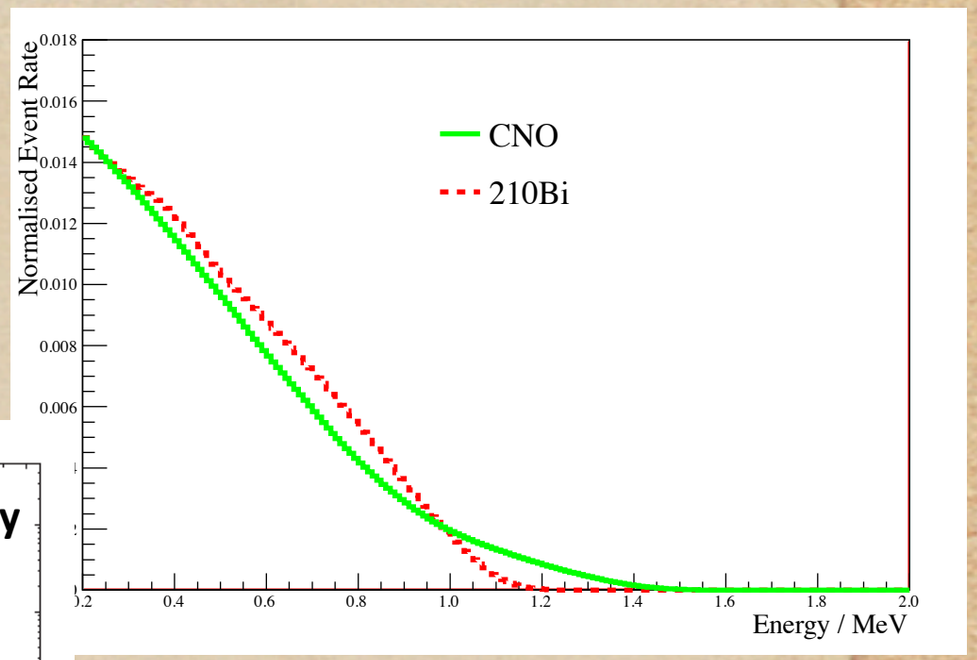
  90% ^{208}Tl rejection

- 40% constraint



CNO Sensitivity Studies

- Hard to separate CNO / ^{210}Bi
- Time-spectrum analysis



210Pb

Beta decays (22.3y)

210Bi

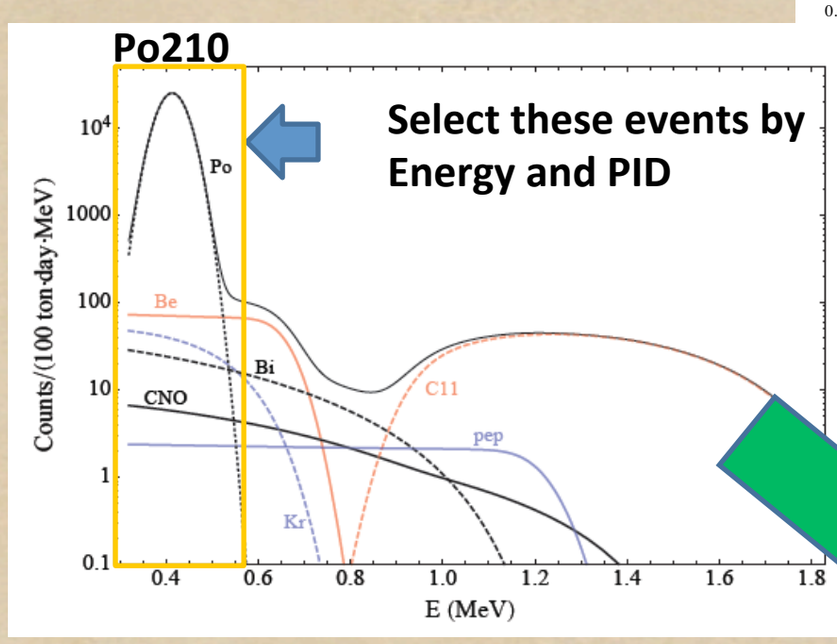
Beta decays (5d)

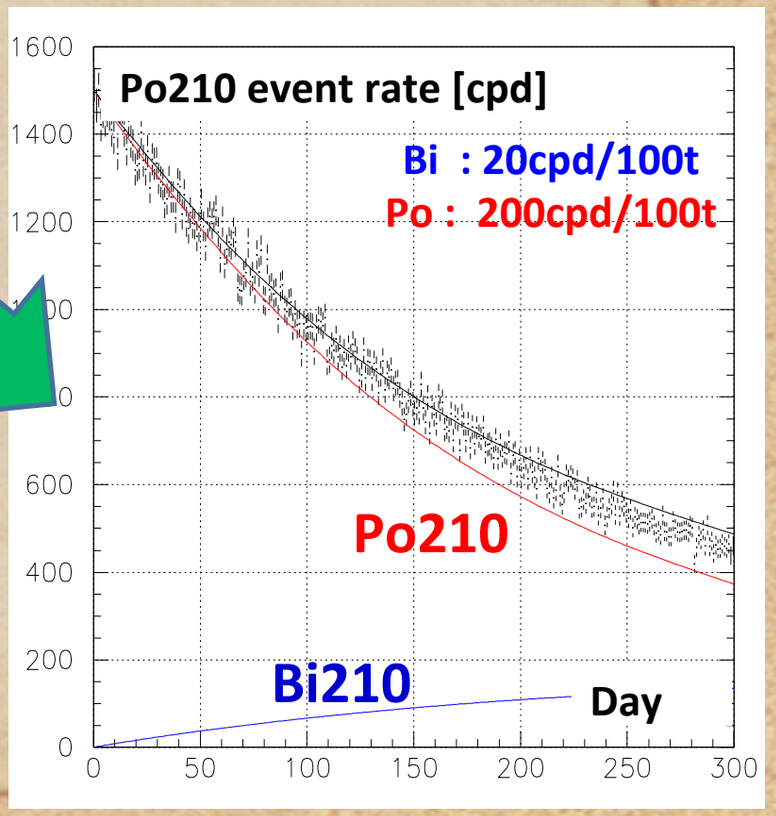
BG

210Po

Alpha decays (138d)

206Pb



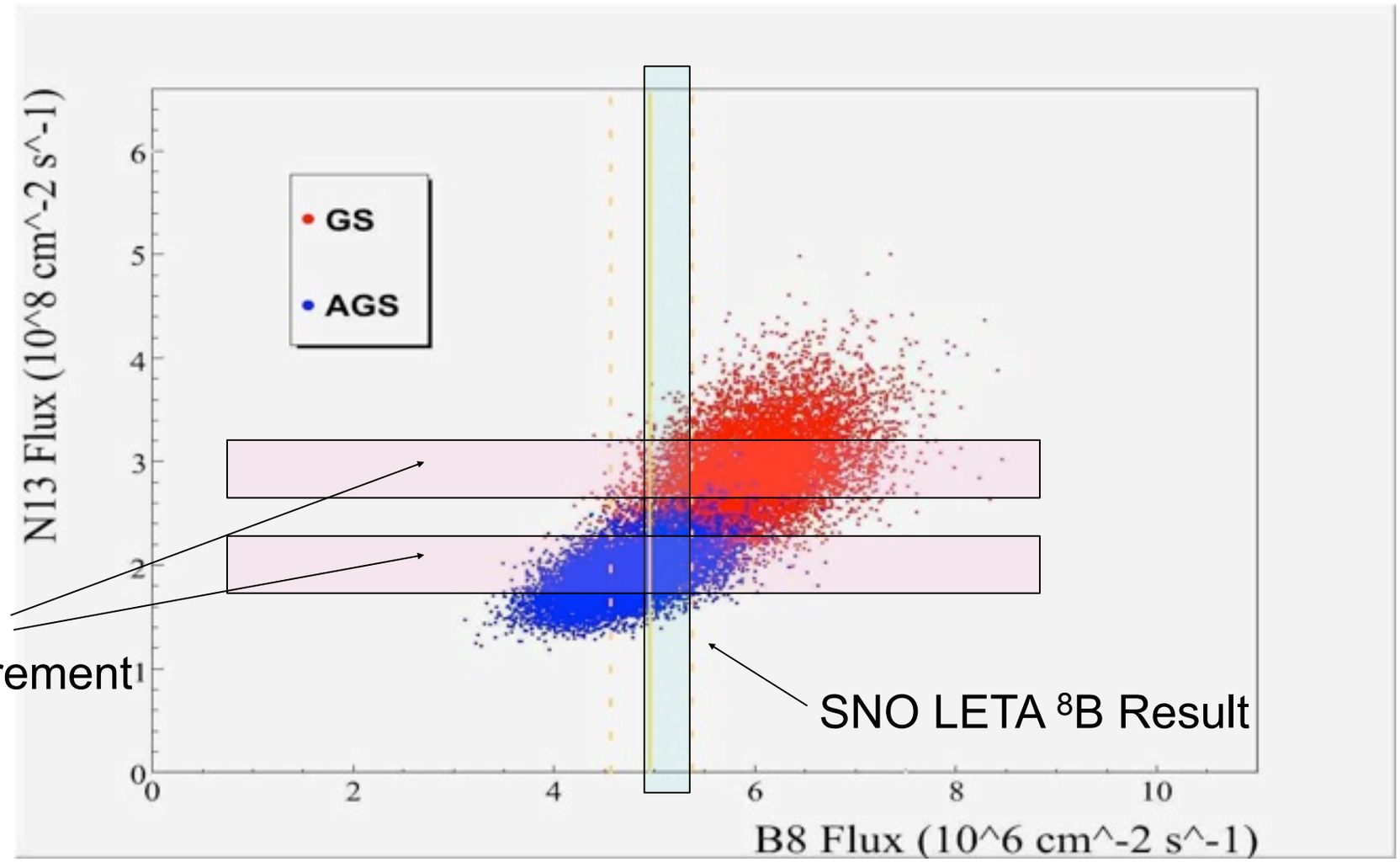


$$N_{Po}(t+dt) = N_{Po}(t) - \lambda_{Po} N_{Po}(t) + \lambda_{Bi} N_{Bi}(t)$$

Count this!! & Analyze its Time spectrum

SNO + SNO+

SNO + SNO+



M. Chen

SNO+ Solar Prospects

- SNO+ has decided to prioritise 0νββ
- Radon daughters have accumulated on the surface of the AV over the last few years in a significant way. If these leach into the scintillator, the purification system has the capability to remove them.
- However, depending on the actual leach rate, that removal might be inefficient and the ^{210}Bi levels in the scintillator too high for a pep/CNO solar neutrino measurement without further mitigation.
- Mitigation could include enhancing online scintillator purification, draining the detector and sanding the AV surface to remove radon daughters, or deploying a bag.
- 0νββ and low-energy ^{8}B solar neutrino measurements are not affected by these backgrounds

Overview

- The SNO+ Experiment
- SNO+ Physics goals
- Solar Neutrinos at SNO+
- SNO+ Status and Outlook

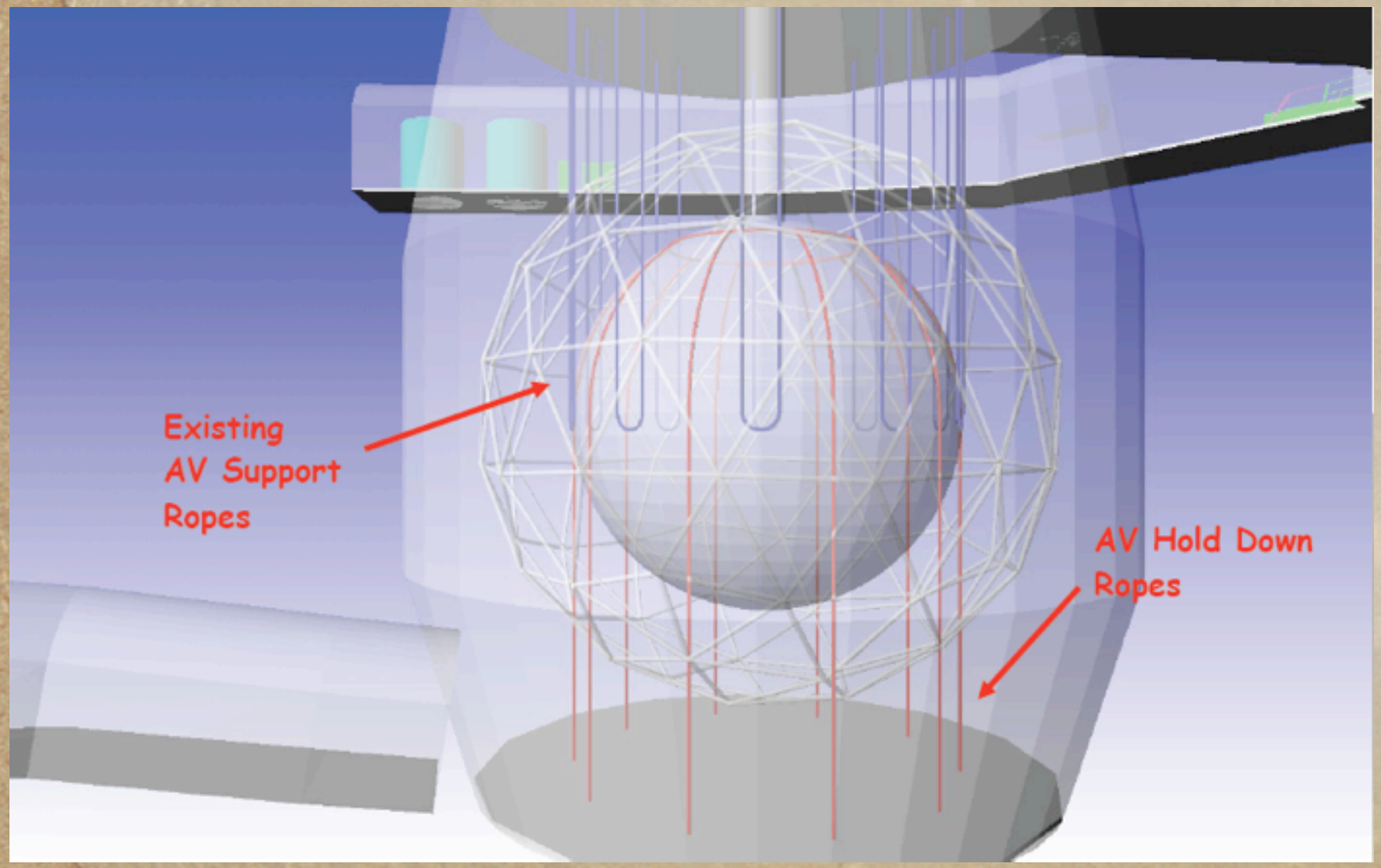
SNO+ Status

Highlights

SNO+ Status

Highlights

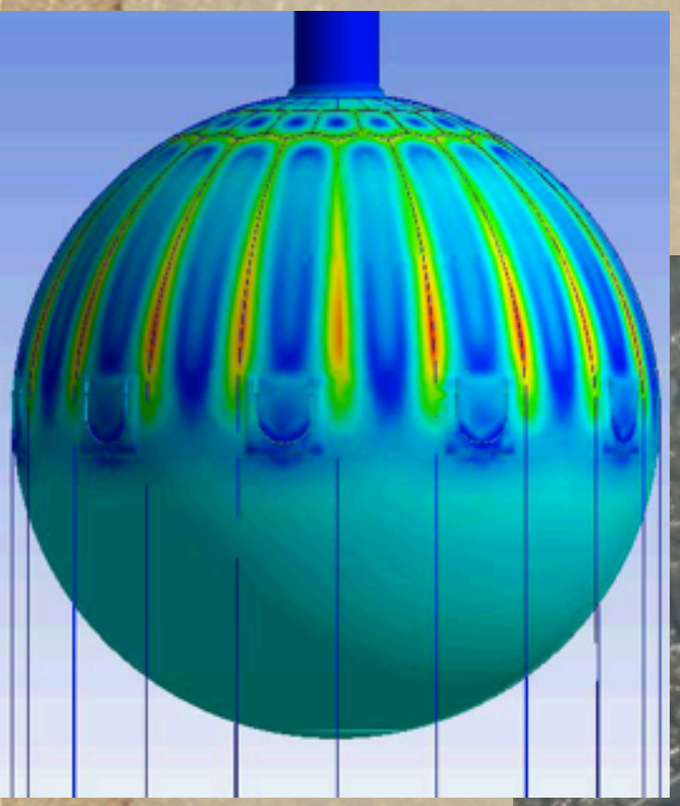
- Rope net installation



SNO+ Status

Highlights

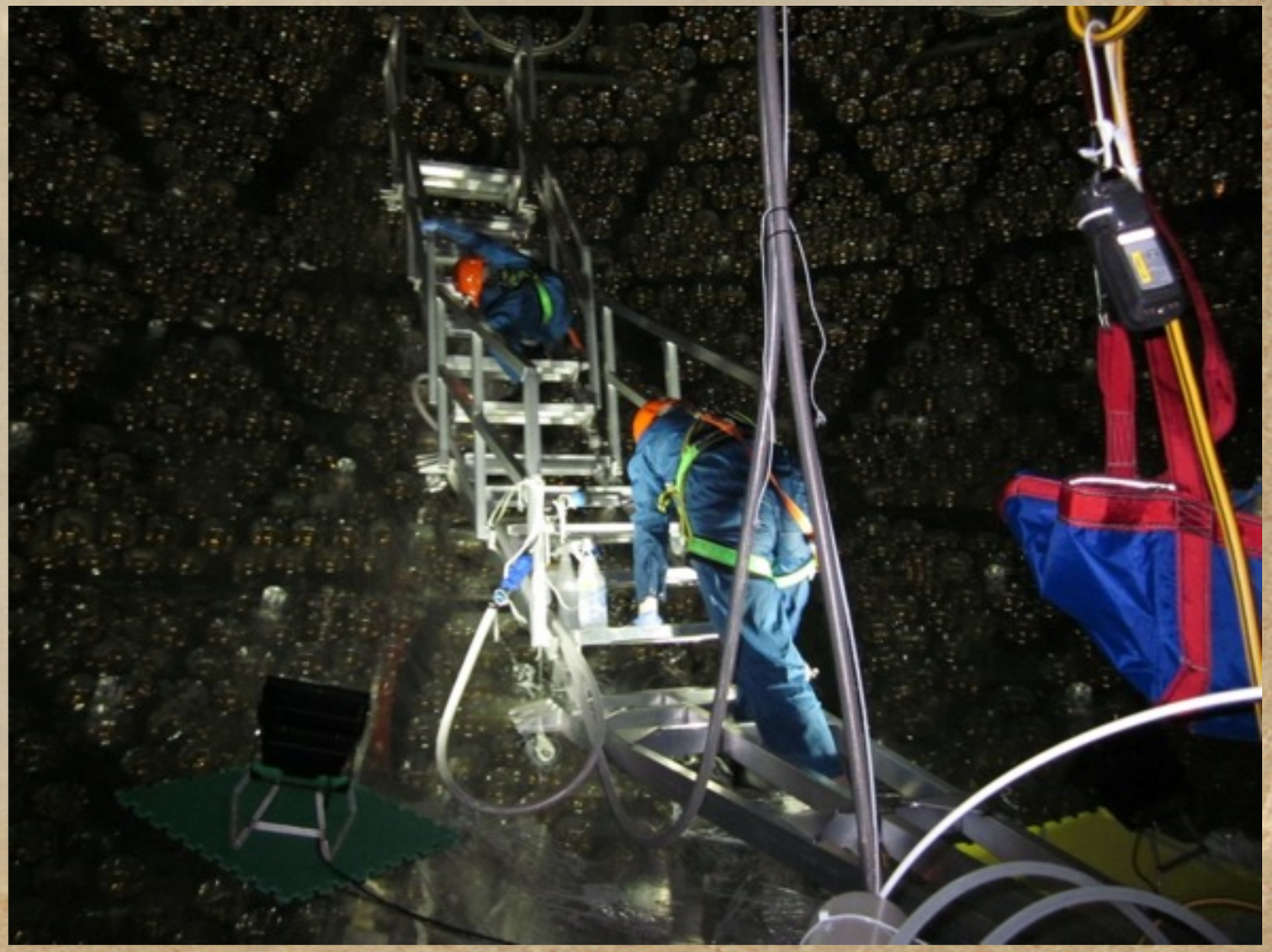
- Rope net installation complete



SNO+ Status

Highlights

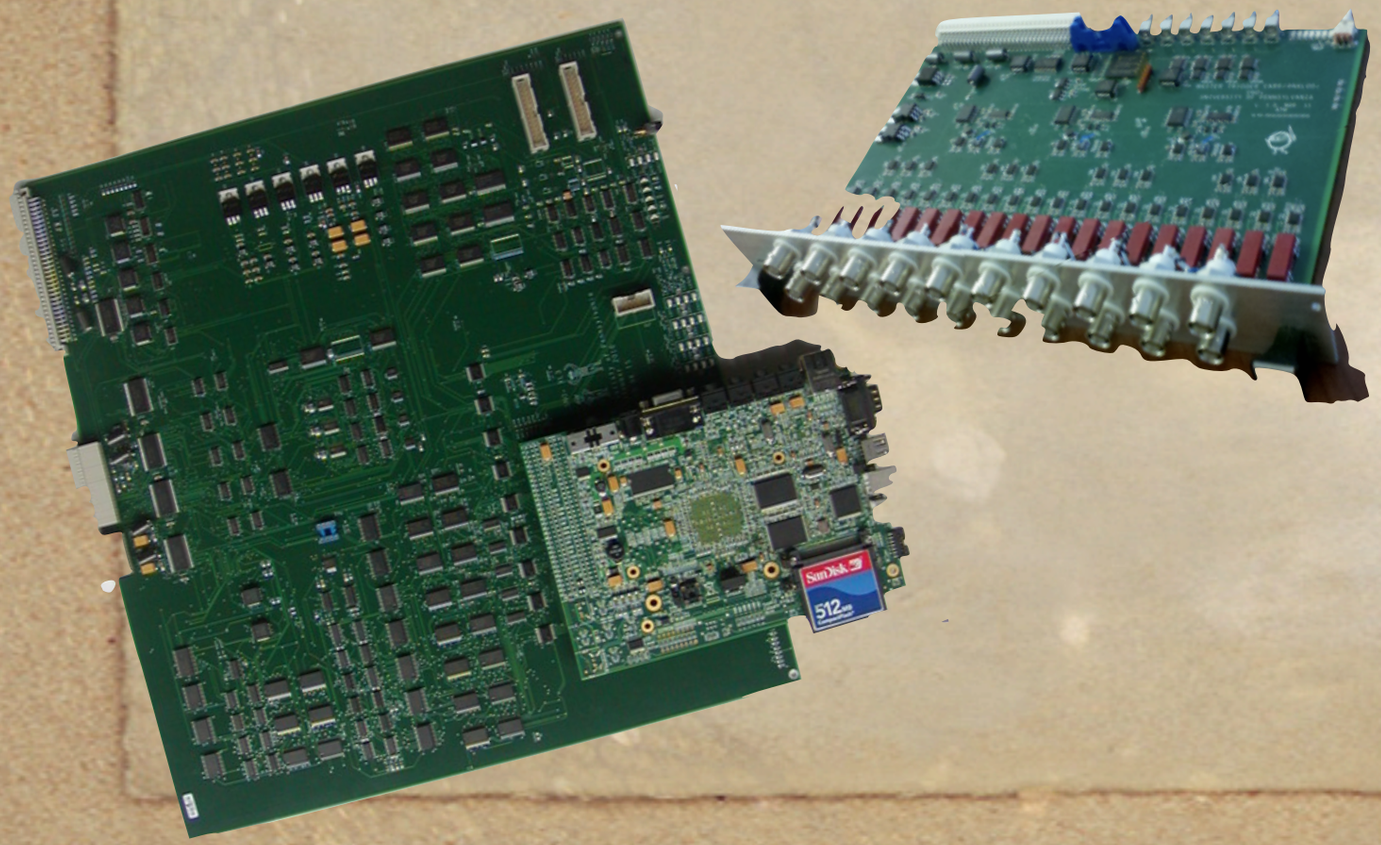
- Rope net installation complete
- Cleaning underway

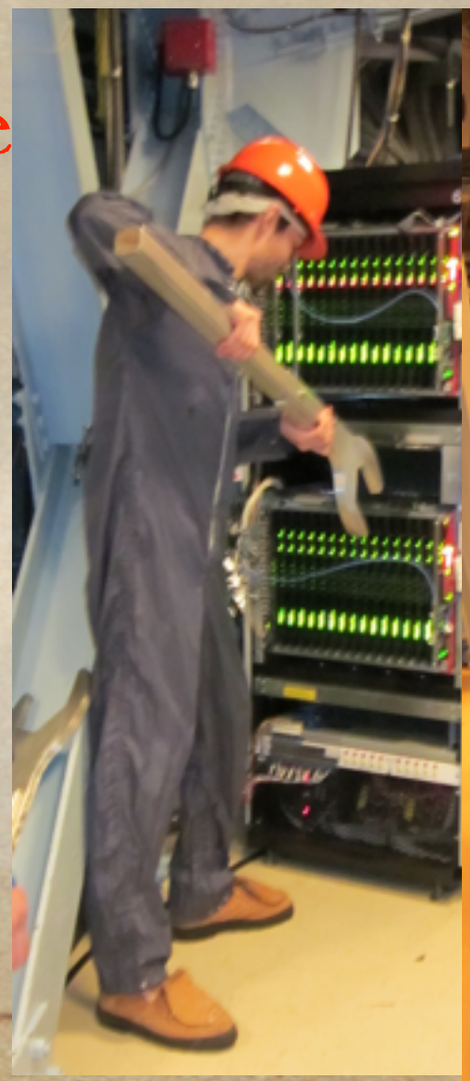


SNO+ Status

Highlights

- Rope net installation complete
- Cleaning underway
- Electronics upgrade complete





SNO+ Status

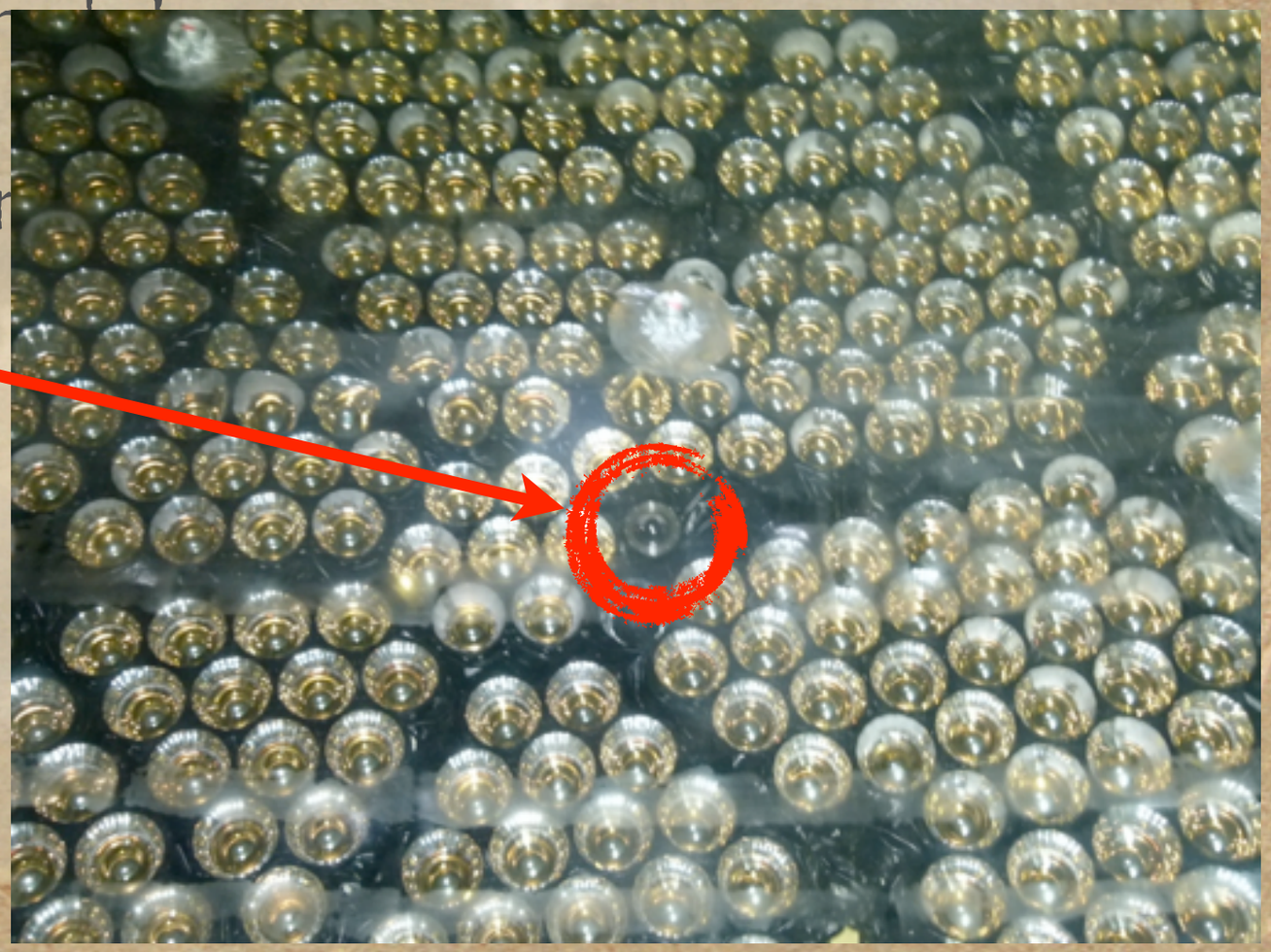
Highlights

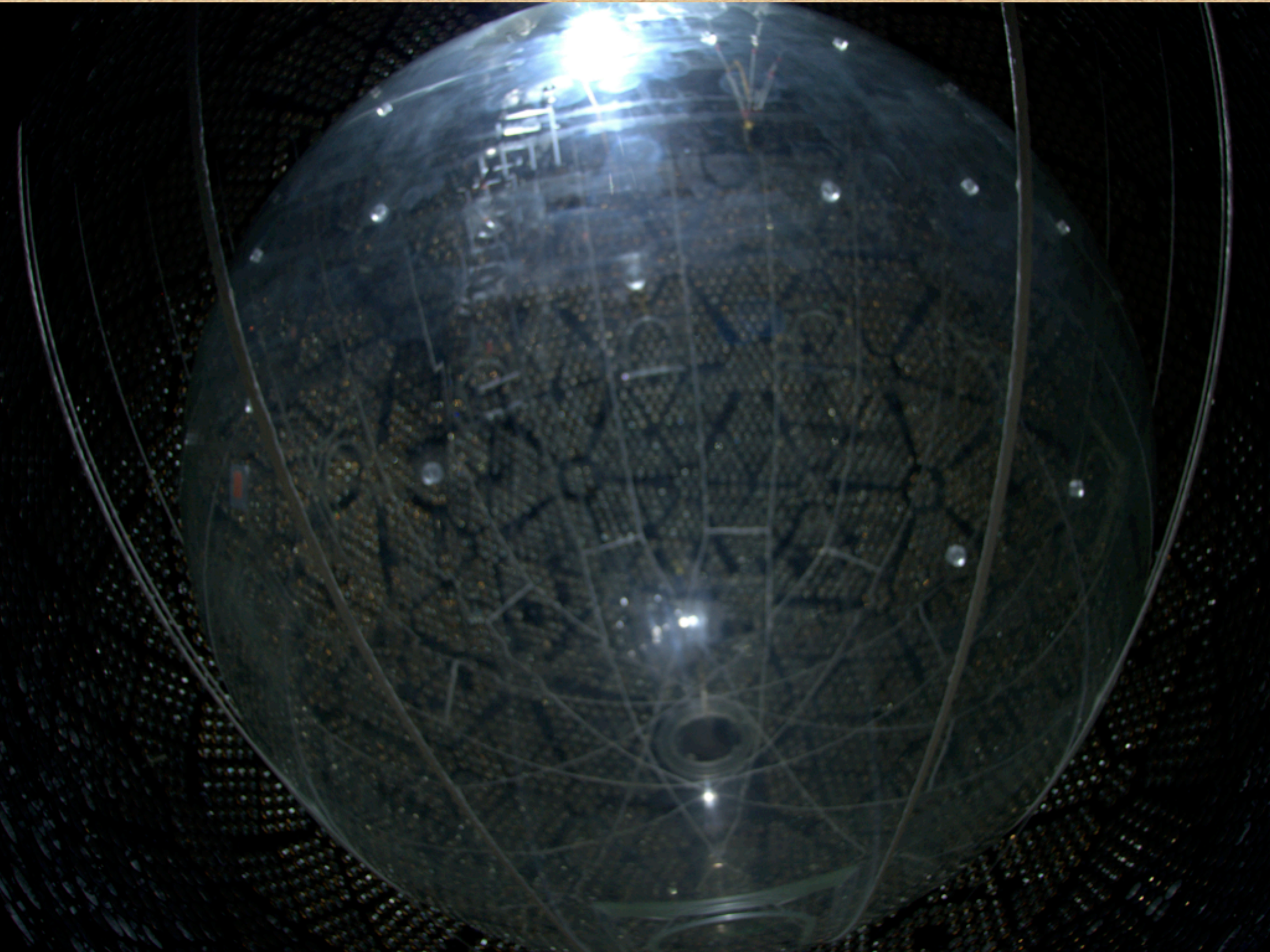
- Rope net installation complete
- Cleaning underway
- Electronics upgrade complete
- Successful 'air-fill' running

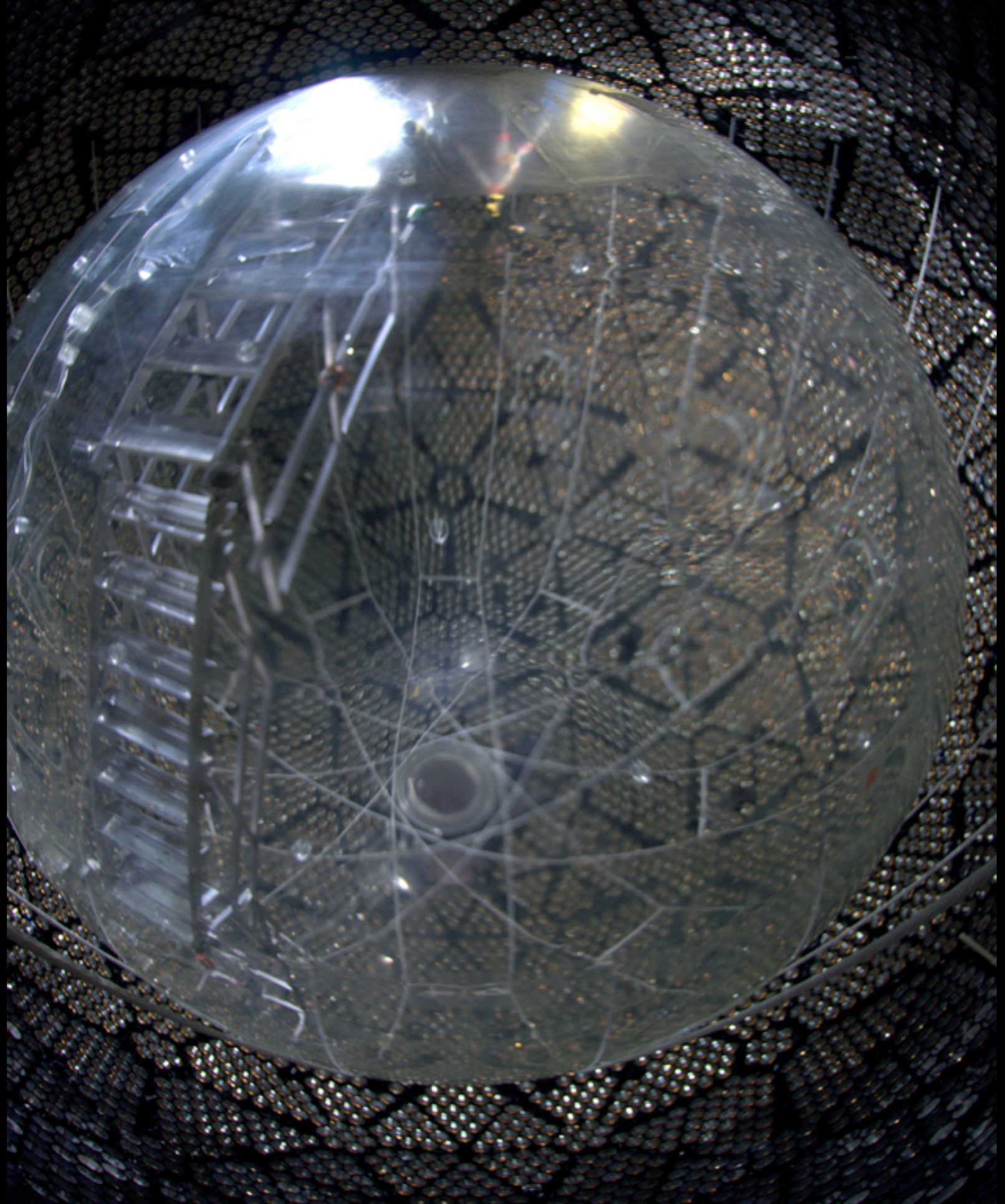
SNO+ Status

Highlights

- Rope net installation complete
- Cleaning underway
- Electronics upgrade com
- Successful 'air-fill' runnin
- Cameras installed







SNO+ Status

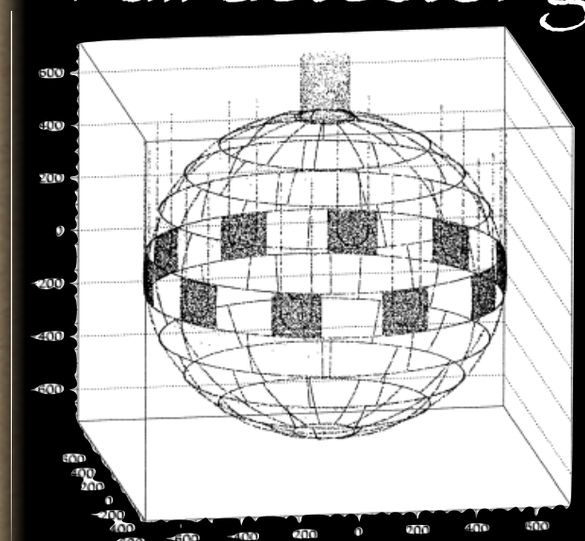
Highlights

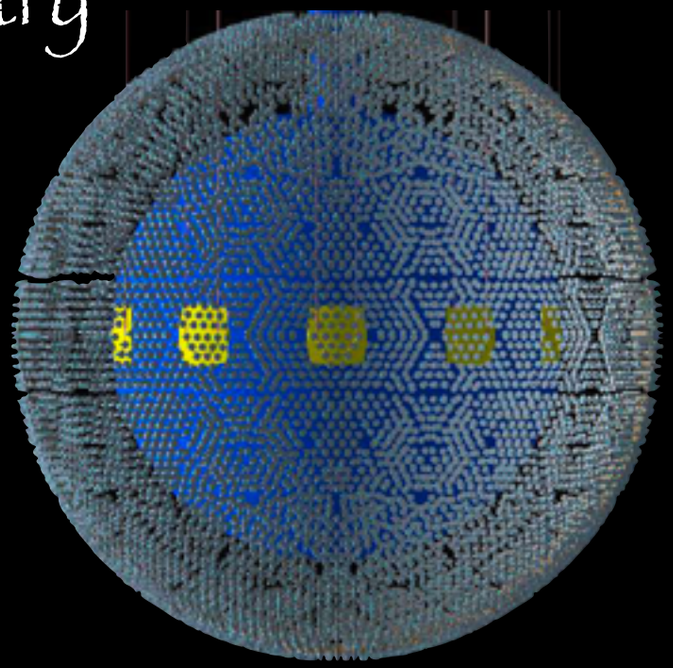
- Rope net installation complete
- Cleaning underway
- Electronics upgrade complete
- Successful 'air-fill' running
- Cameras installed
- 1/3 ELLIE fibres installed

Bundling at surface: March 2012

Analysis: Simulation

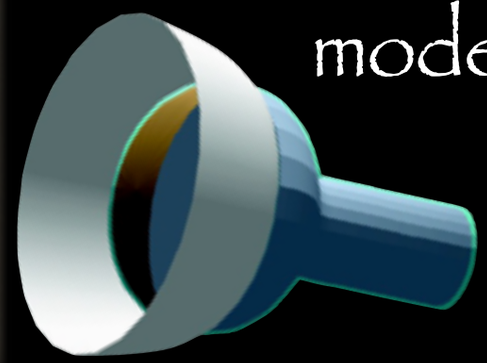
Full detector geometry

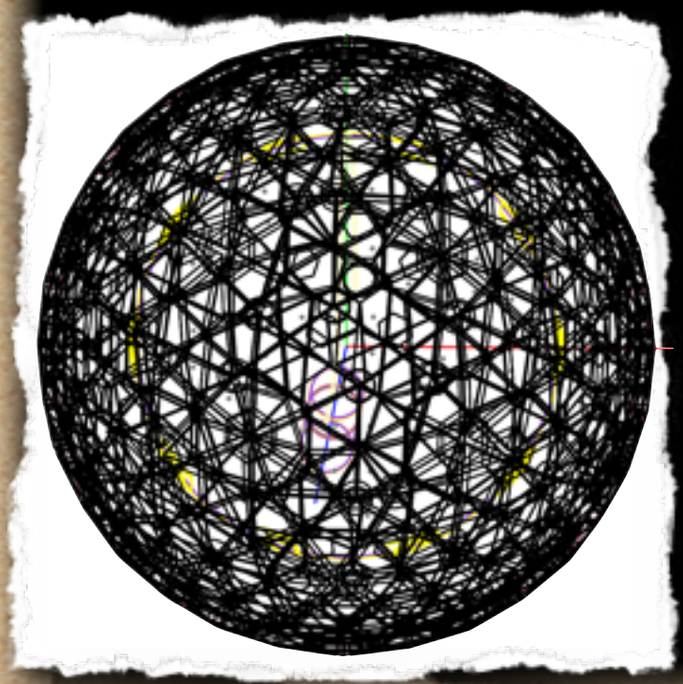


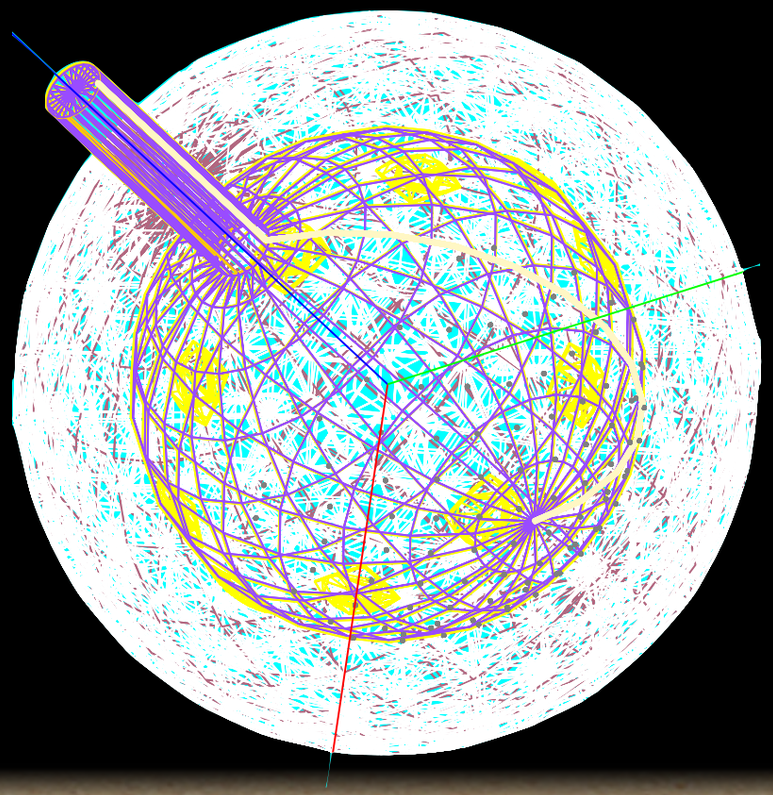


Full optical photon tracking

PMT + Concentrator model







Calibration sources

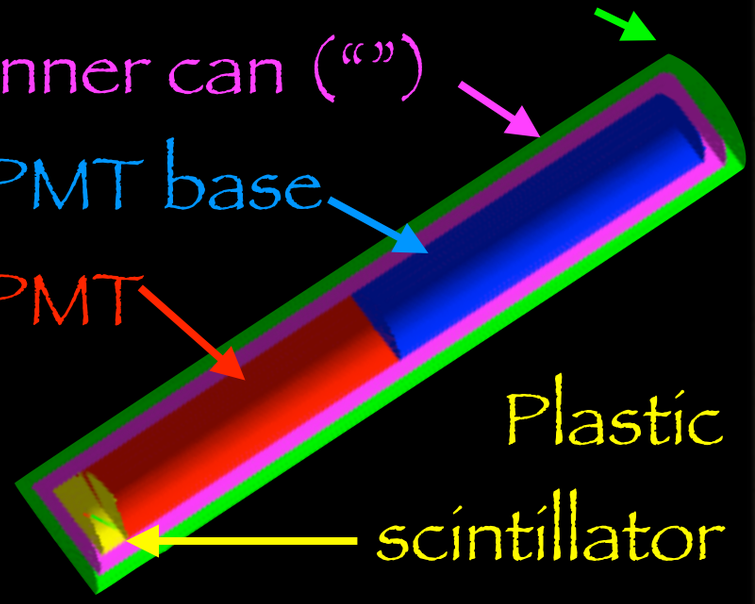
Outer can (delrin)

Inner can (“”)

PMT base

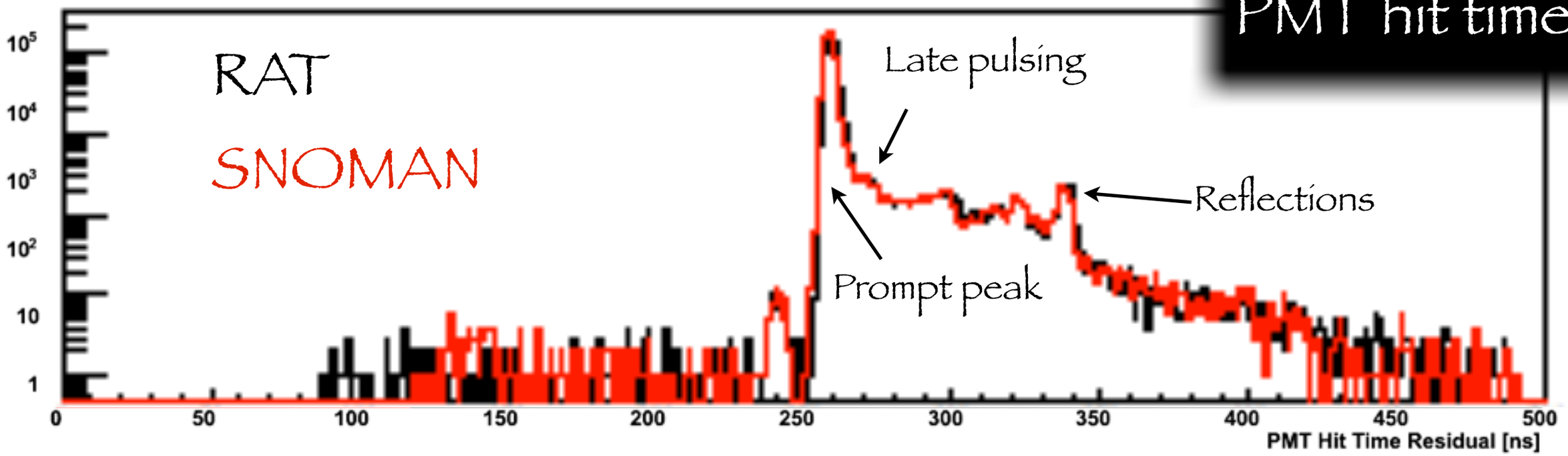
PMT

Plastic scintillator

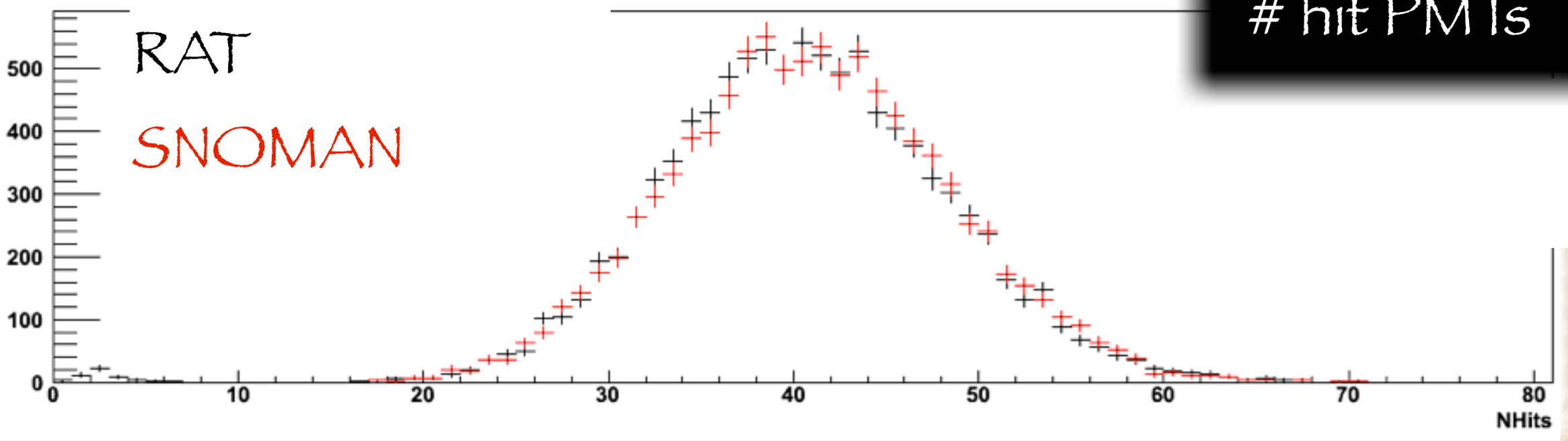


Analysis: Verification

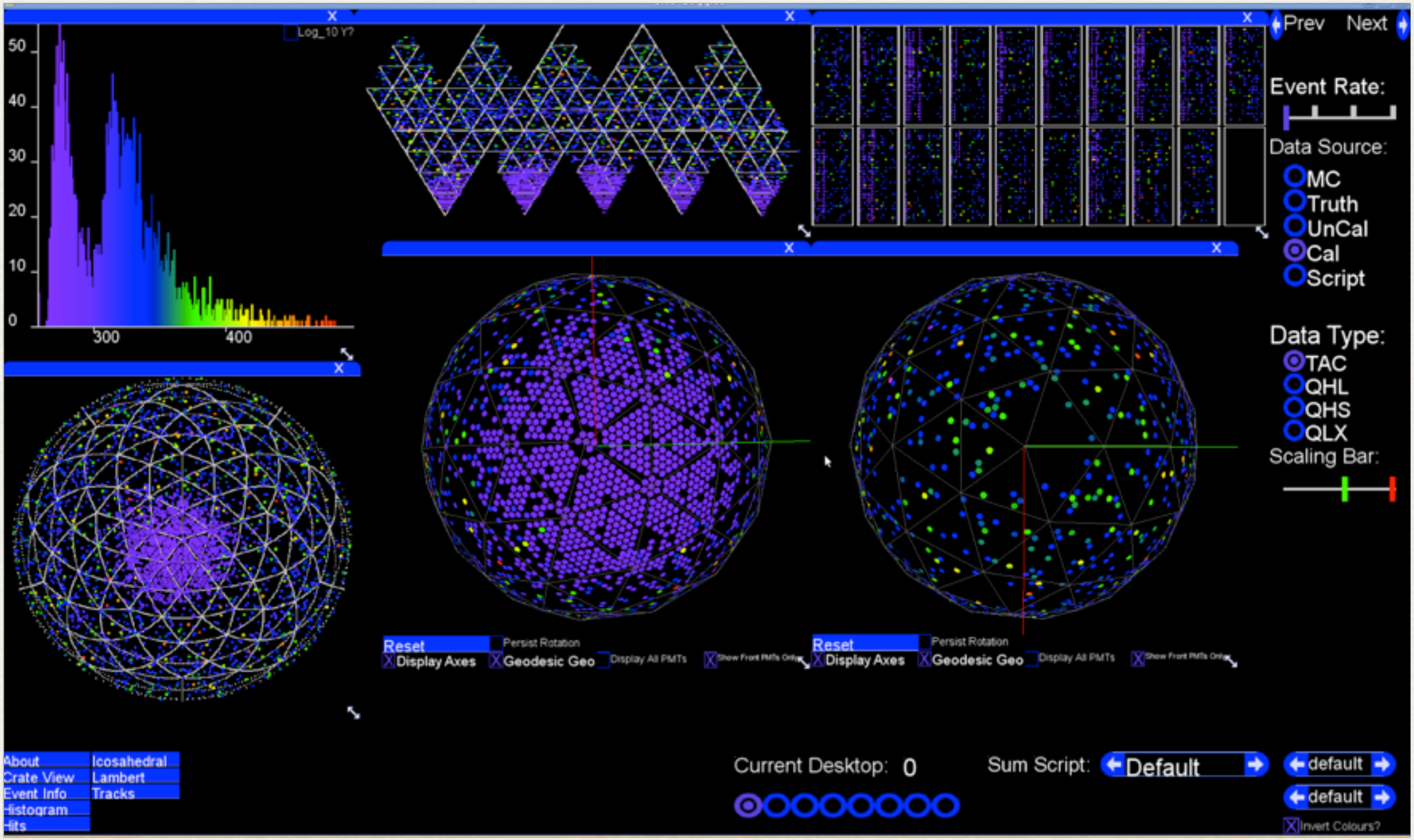
PMT hit time



hit PMTs

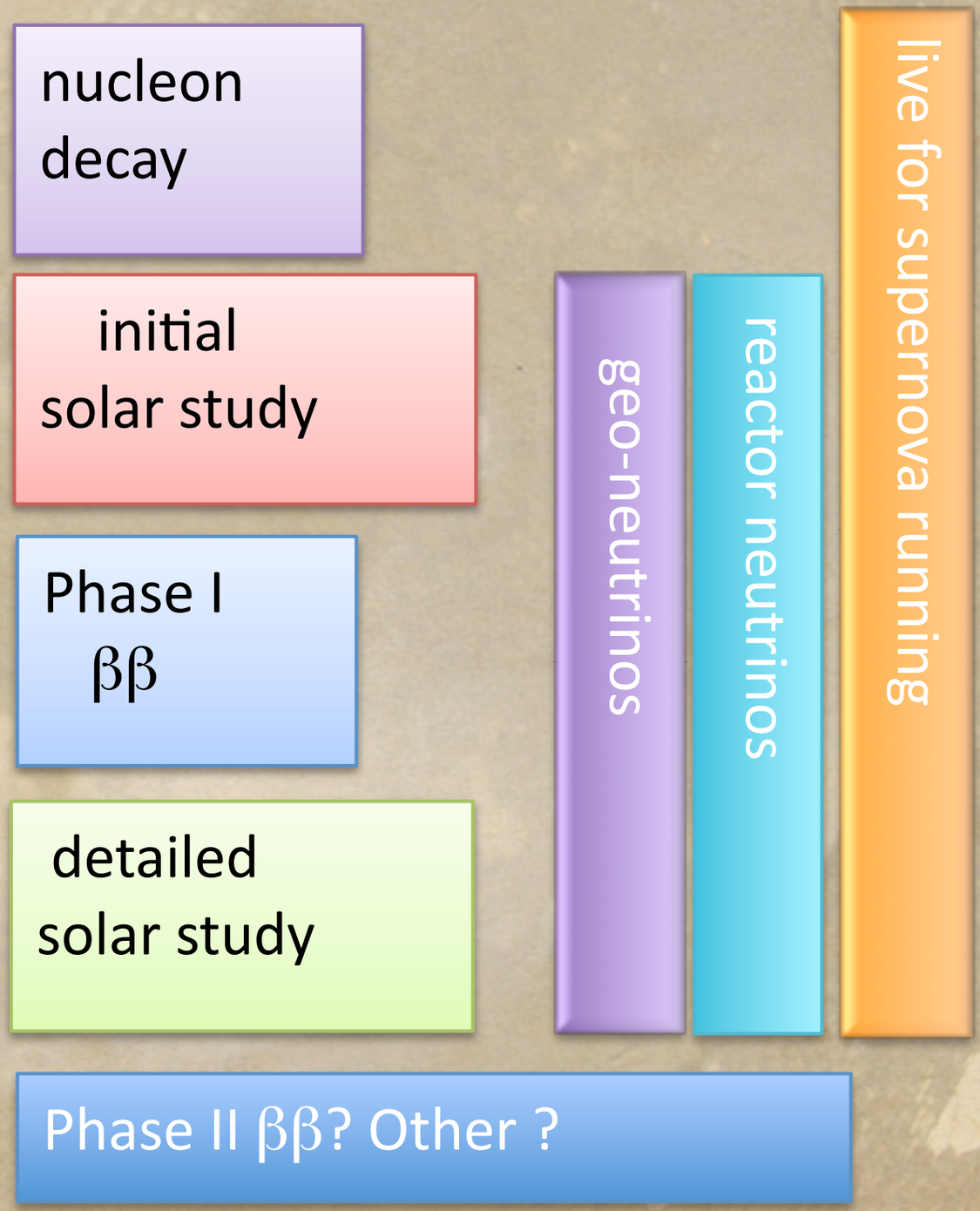


Analysis: Tools



Physics Plan

- SNO+
  - Light Water running (Mar 2013)
  - Scintillator run (Mar 2014)
  - Nd-loaded scintillator (Oct 2014?)
  - Pure scintillator (II) (2017?)



Thank you for
your attention

Back-up slides

0νββ WITH SNO+

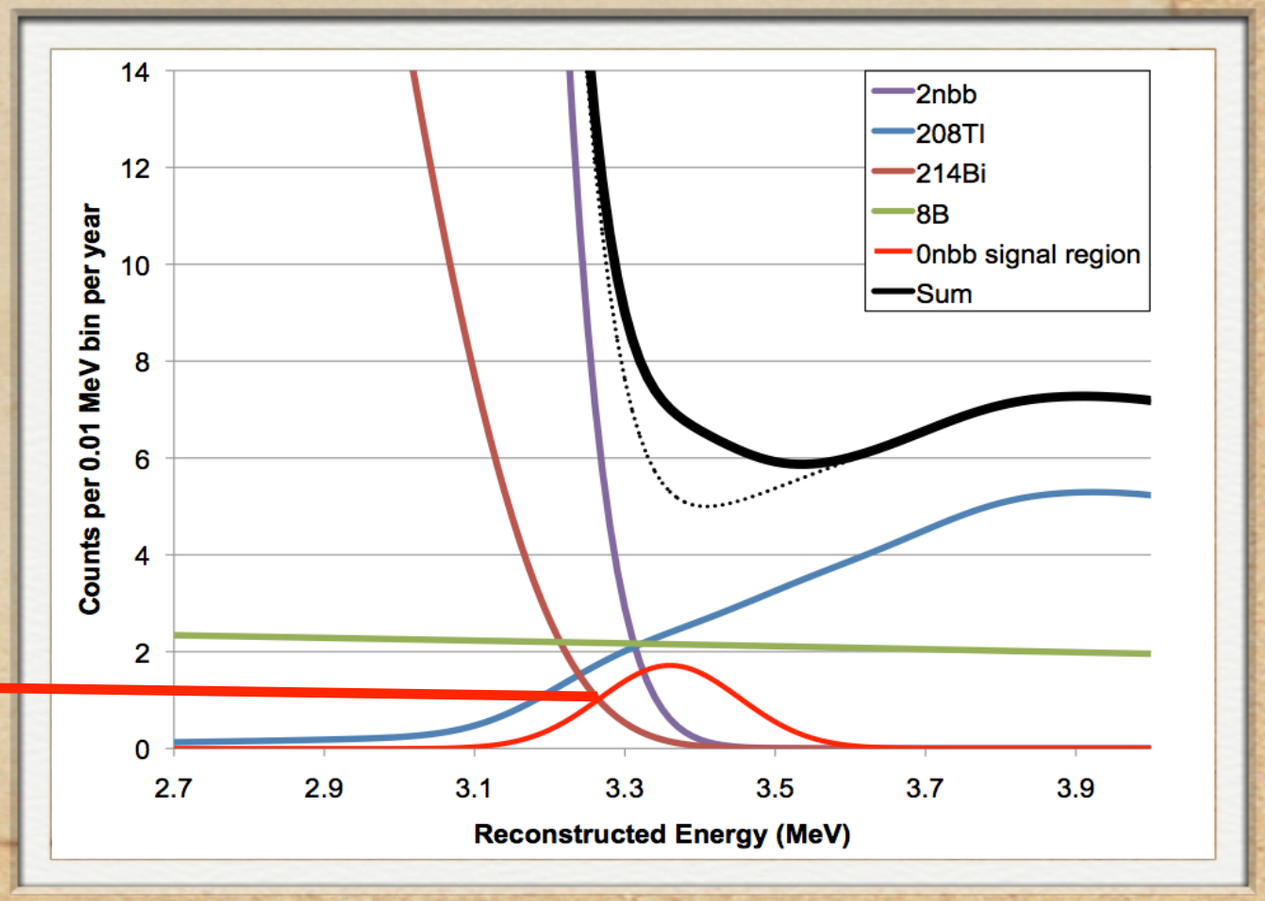
$$\Gamma = (T_{\frac{1}{2}})^{-1} = G_{0\nu}|M_{0\nu}|^2\langle m_\nu\rangle^2$$

Isotope	$Q_{\beta\beta}$	Natural abundance	$\lvert M_{0\nu}\rvert$	$\lvert G_{0\nu}\rvert^{-1}$ (10^{25} y eV^2)	$T^{0\nu}_{1/2}$ (10^{27} y)	$N_{0\nu}$ / $N_{0\nu}$ (Ge)
^{150}Nd	3.37 MeV	5.6%	1.85 ± 0.55	0.13	0.15	3.3

Sense and Sensitivity of ββ expts: arxiv/1010.5112

- Large
- Low bkg (deep, clean)
- Source in / source out
- Well defined background model

0νββ signal



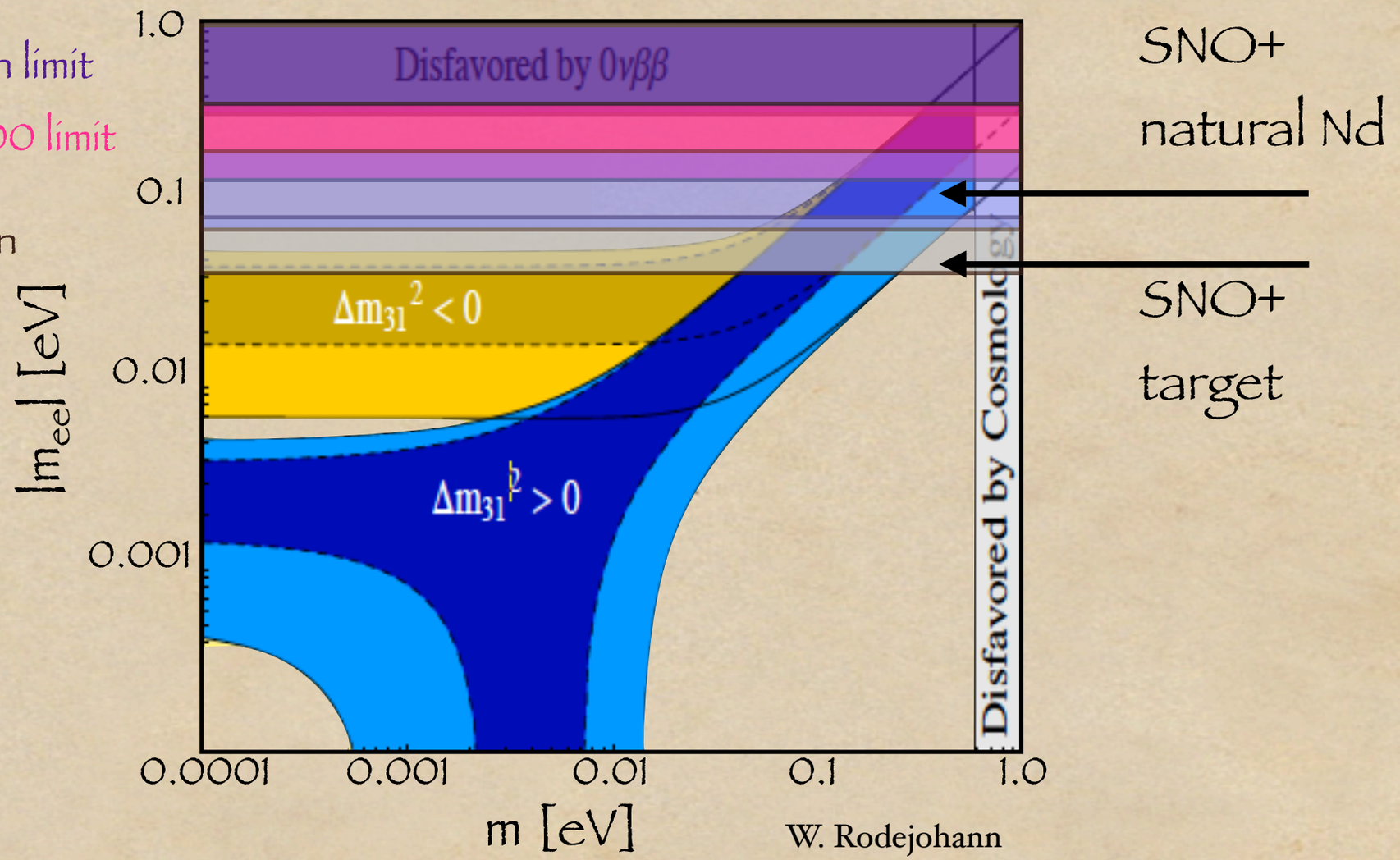
Status of the Field

KL-Zen limit

EXO-200 limit

MJD projection

CUORE projection



SNO+ natural Nd

SNO+ target