SNO+: A detector for neutrinoless double beta decay, low energy solar neutrinos, and geo-neutrinos.

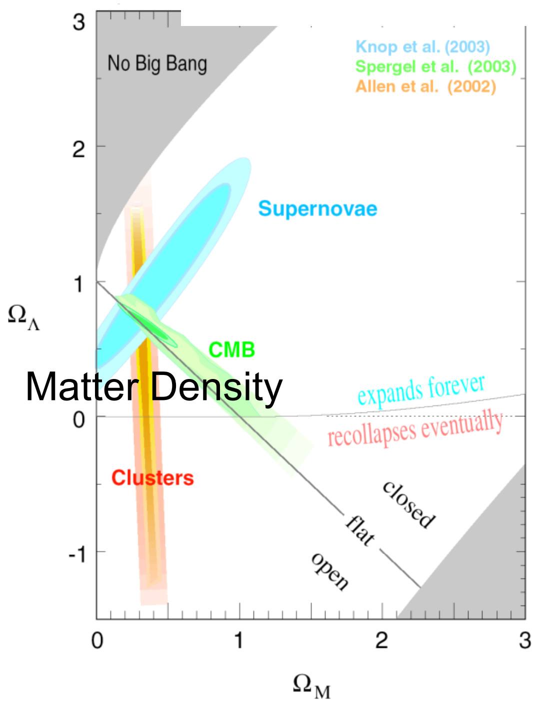
Aksel Hallin

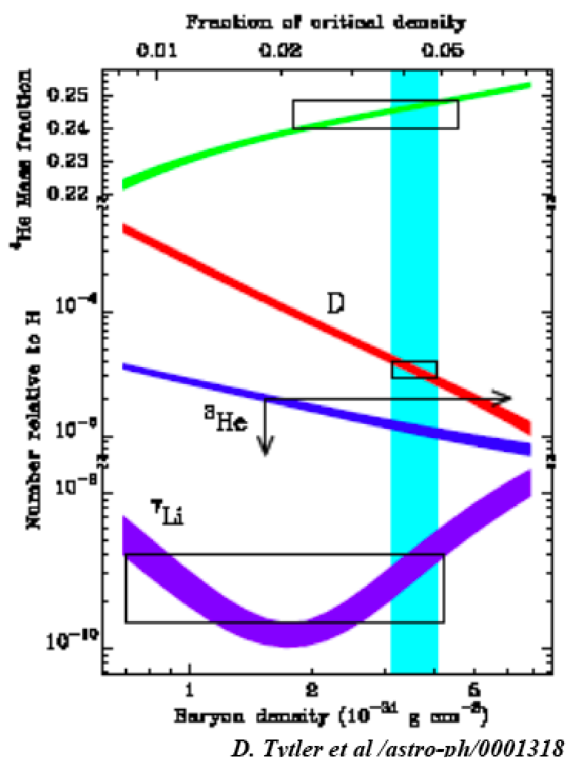
June 13, 2008

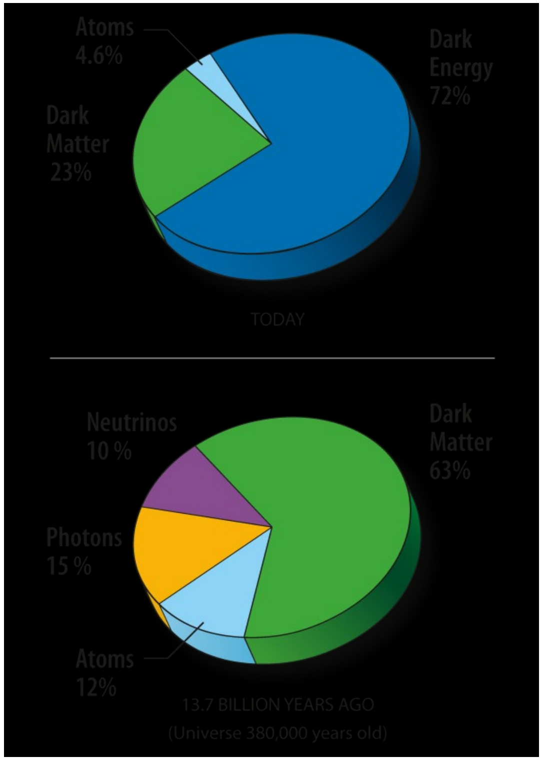
The Universe

$$\Omega_o = 1.02 \pm 0.02$$
$$\Omega_M = 0.27 \pm 0.04$$
$$\Omega_\Lambda = 0.73 \pm 0.04$$

$$\Omega_{BBN} = 0.044 \pm 0.004$$







$$\Omega_M - \Omega_{BNN} \approx 0.226 \pm 0.06$$

Figure 1. The mass composition of the Universe, from http://map.gsfc.nasa.gov/media/080998/080998_Universe_Content

Astroparticle physics is summarized neatly by the study

Connecting Quarks with the Cosmos: Eleven Science Questions for the New Century

1. **What is the dark matter**? ◄**SNOLAB**
2. What is the nature of the dark energy?
3. **How did the universe begin?** ◄**SNOLAB**
4. Did Einstein have the last word on gravity?
5. **What are the masses of the neutrinos, and how have they shaped the evolution of the universe?** ◄ **SNOLAB**
6. How do cosmic accelerators work and what are they accelerating?
7. Are protons unstable?
8. Are there new states of matter at exceedingly high density and temperature?
9. Are there additional spacetime dimensions?
10. **How were the elements from iron to uranium made?** ◄ **SNOLAB**
11. Is a new theory of matter and light needed at the highest energies?

A specific element of the third question is:

3b**. Why is the Universe made of matter and not antimatter and how did this asymmetry arise**? ◄ **SNOLAB**

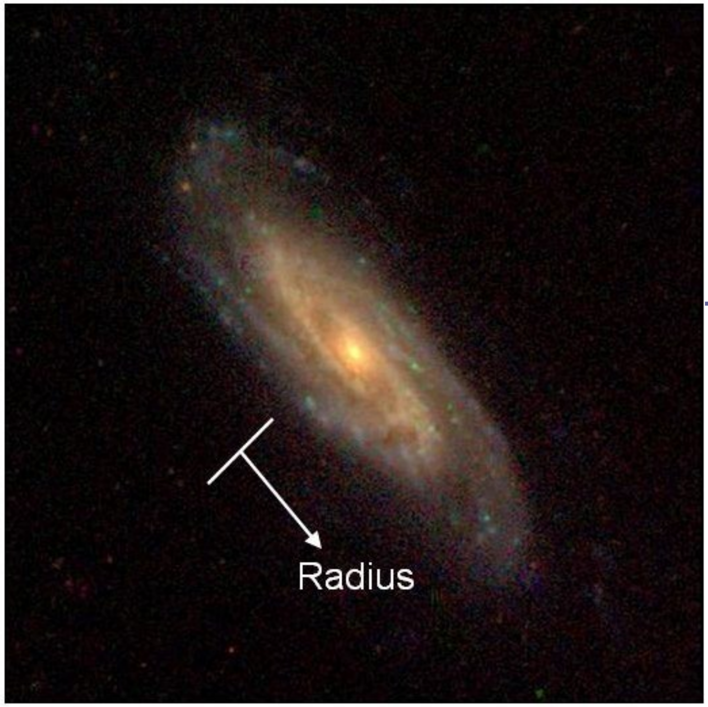
and a related element of the tenth question is:

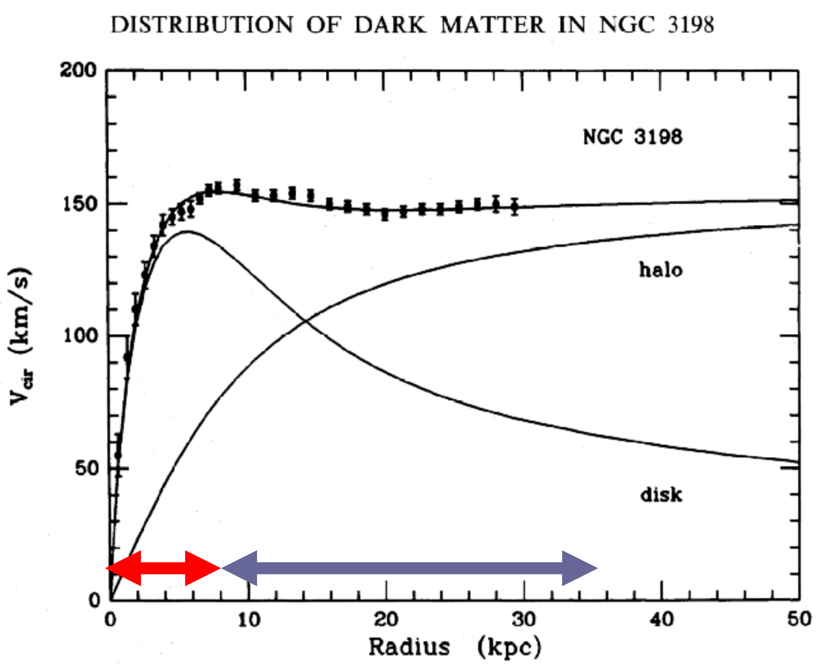
10b. **What role do neutrinos play in supernova explosions and how does this process affect the synthesis of heavy elements?** ◄ **SNOLAB**

Two main thrusts for SNOLAB science

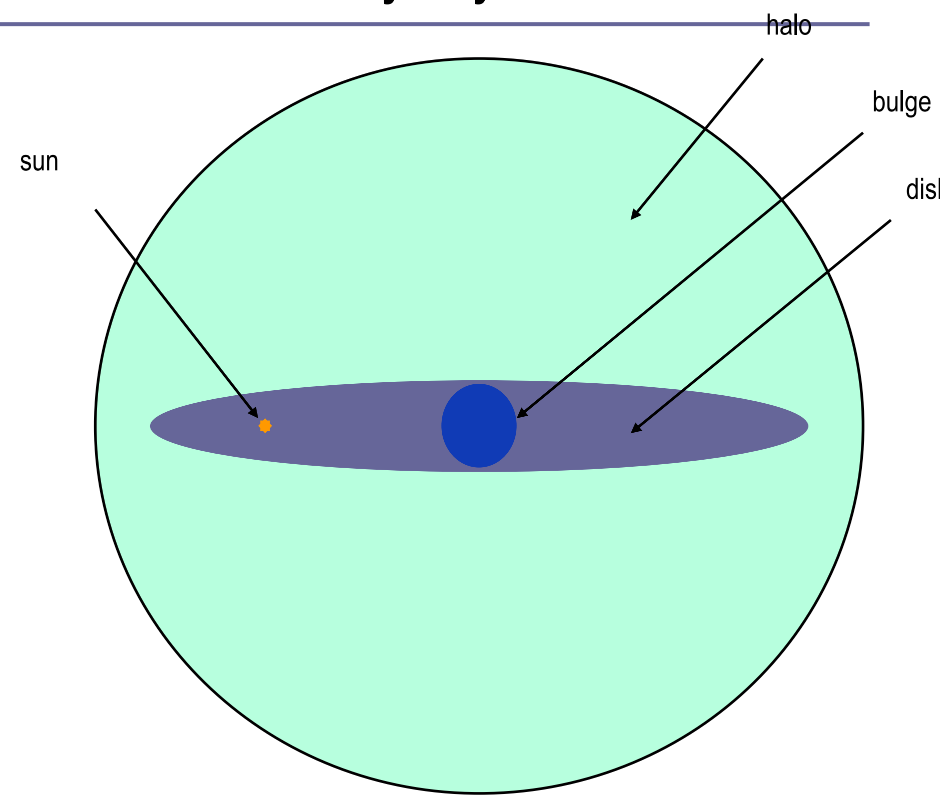
- What is the nature of Dark Matter?
  - Direct dark matter searches
- What are the character and interactions of neutrinos, and how do they affect cosmology and astrophysics?
  - Double beta decay (mass, are neutrinos their own antiparticles, leptogenesis?)
  - Solar neutrino interactions

Dark Matter

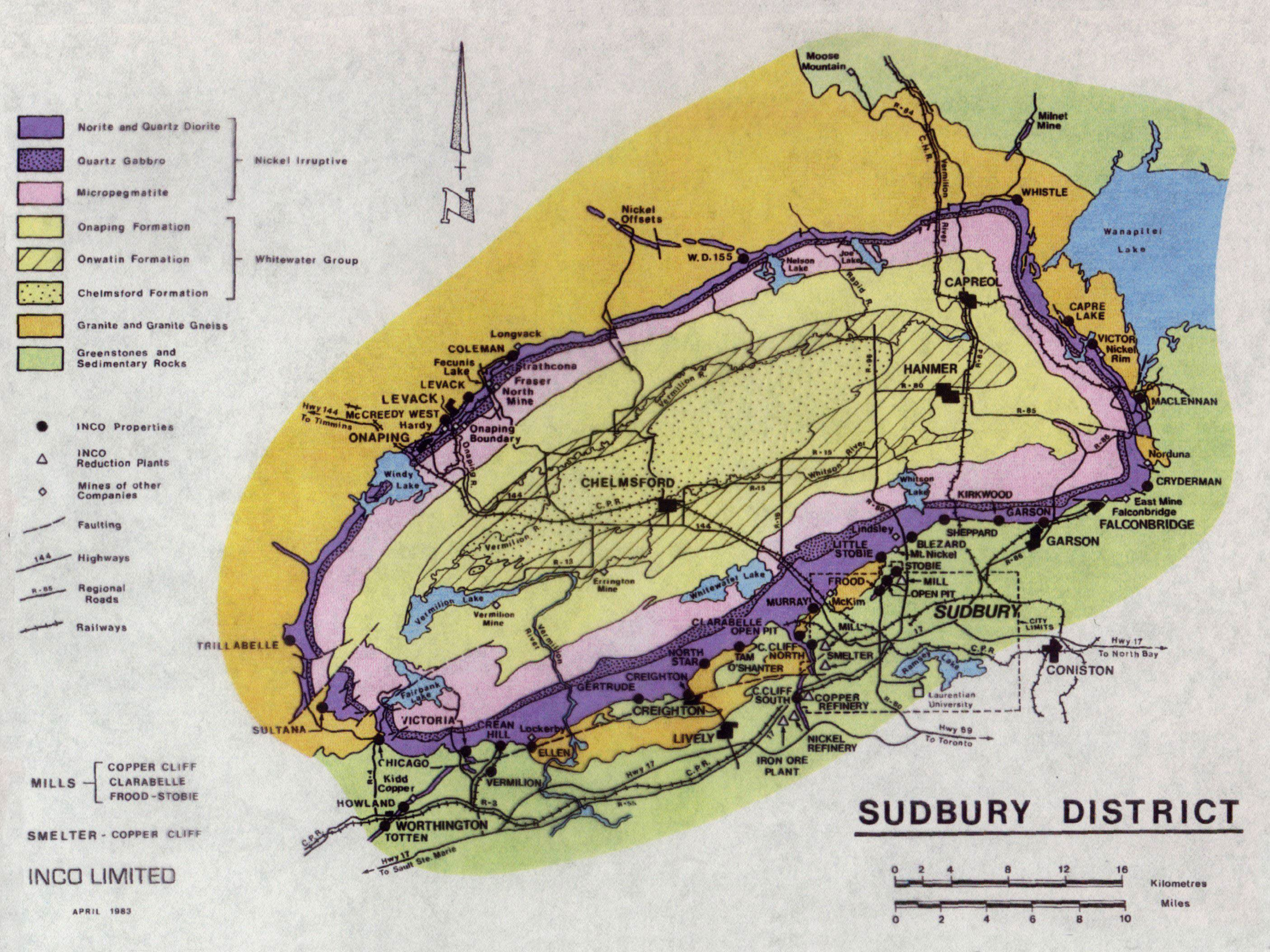




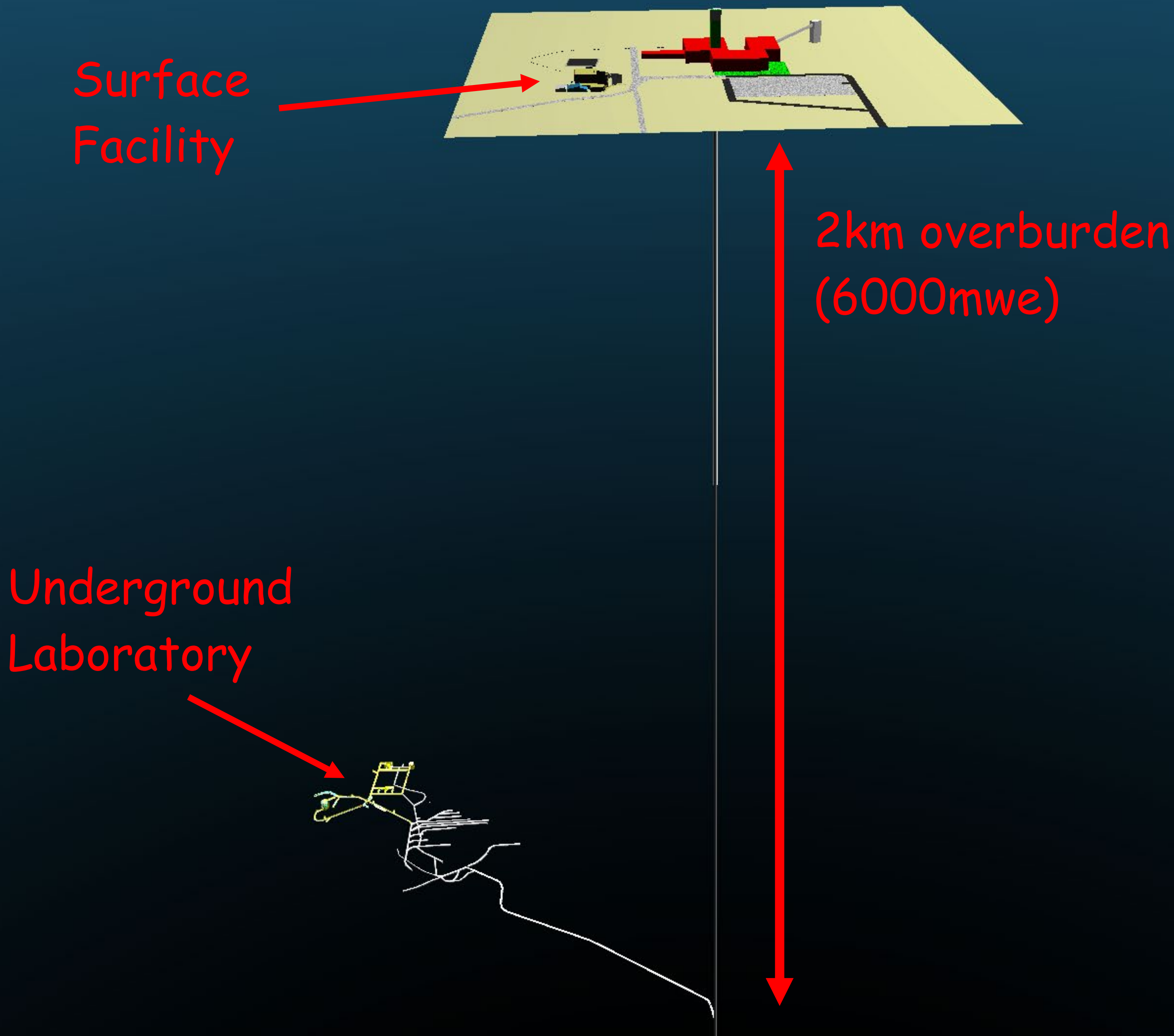
…the Milky Way




Sudbury
Toronto
Chicago
0 62mi

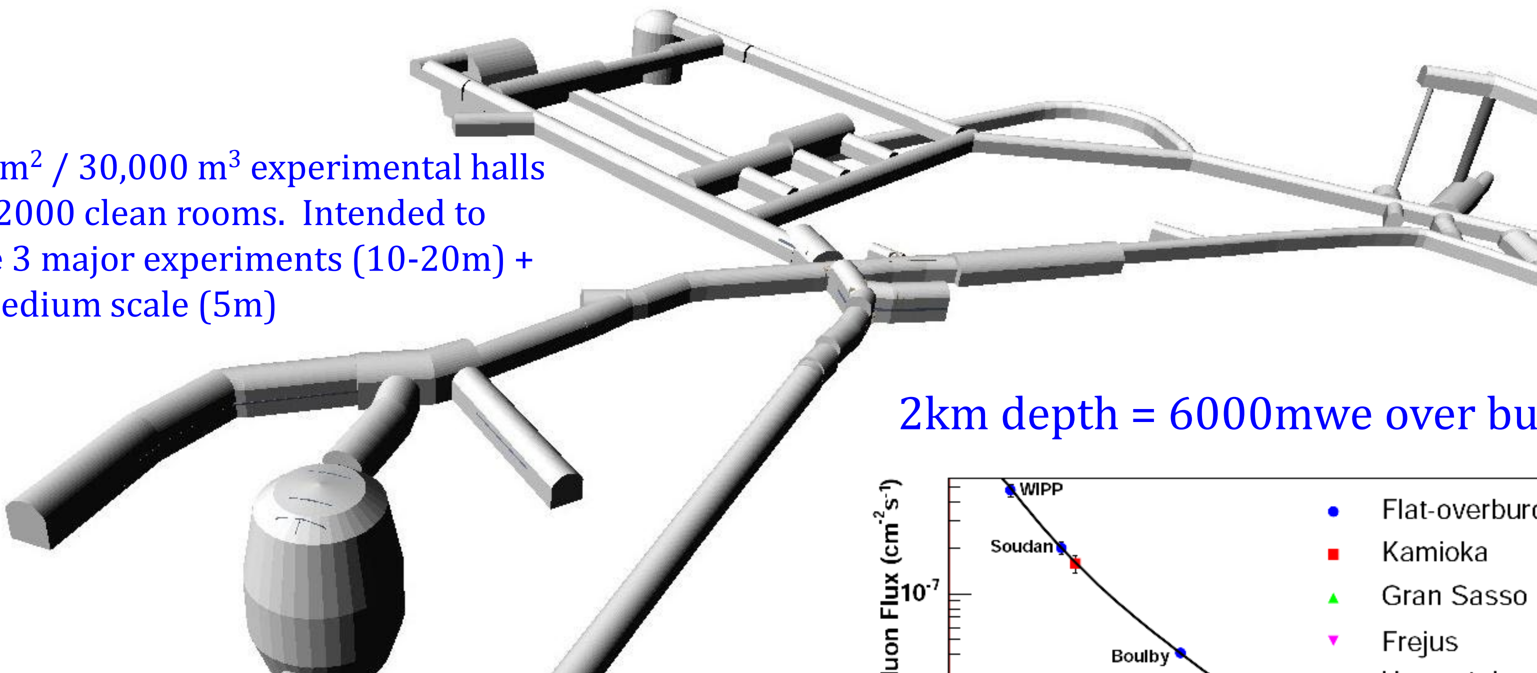


SUDBURY DISTRICT
Norite and Quartz Diorite
Quartz Gabbro
Micropegmatite
Nickel Irruptive
Onaping Formation
Onwatin Formation
Chelmsford Formation
Whitewater Group
Granite and Granite Gneiss
Greenstones and Sedimentary Rocks
INCO Properties
INCO Reduction Plants
Mines of other Companies
Faulting
Highways
Regional Roads
Railways
MILLS - COPPER CLIFF
CLARABELLE
FROOD-STOBIE
SMELTER - COPPER CLIFF
INCO LIMITED
APRIL 1983
N
Kilometres
0 2 4 8 12 16
Miles
0 2 4 6 8 10
Moose Mountain
Milnet Mine
WHISTLE
Wanapitei Lake
Nickel Offsets
W.D.155
Nelson Lake
Joe Lake
CAPREOL
CAPRE LAKE
VICTOR Nickel Rim
HANMER
MACLENNAN
Norduna
CRYDERMAN
East Mine Falconbridge
FALCONBRIDGE
GARSON
KIRKWOOD
SHEPPARD
Whitson Lake
Lindsley
BLEZARD
Mt. Nickel
STOBIE
LITTLE STOBIE
FROOD
MILL
OPEN PIT
McKim
MURRAY
SUDBURY
CITY LIMITS
CONISTON
Hwy 17 To North Bay
Ramsey Lake
Laurentian University
CLARABELLE OPEN PIT
C. CLIFF NORTH
TAM O'SHANTER
SMELTER
NORTH STAR
CREIGHTON
GERTRUDE
C. CLIFF SOUTH
COPPER REFINERY
LIVELY
NICKEL REFINERY
IRON ORE PLANT
Hwy 69 To Toronto
Hwy 17
C.P.R.
Lockerby
ELLEN
CREAN HILL
VICTORIA
Fairbank Lake
SULTANA
TRILLABELLE
CHICAGO
Kidd Copper
VERMILION
HOWLAND
WORTHINGTON
TOTTEN
Hwy 17 To Sault Ste. Marie
Longvack
COLEMAN
Fecunis Lake
Strathcona
LEVACK
Fraser
North Mine
Hwy 144 To Timmins
McCREEDY WEST
Hardy
ONAPING
Onaping Boundary
Windy Lake
CHELMSFORD
Vermilion Lake
Vermilion Mine
Errington Mine
Whitewater Lake
Vermilion River
Whitson River
Rapid R.
C.N.R.

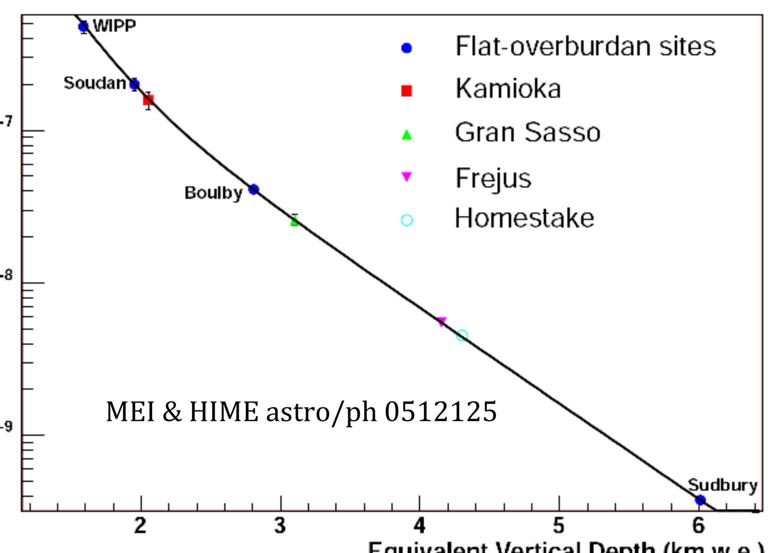

Surface Facility
2km overburden (6000mwe)
Underground Laboratory

SNOLAB Underground Facility

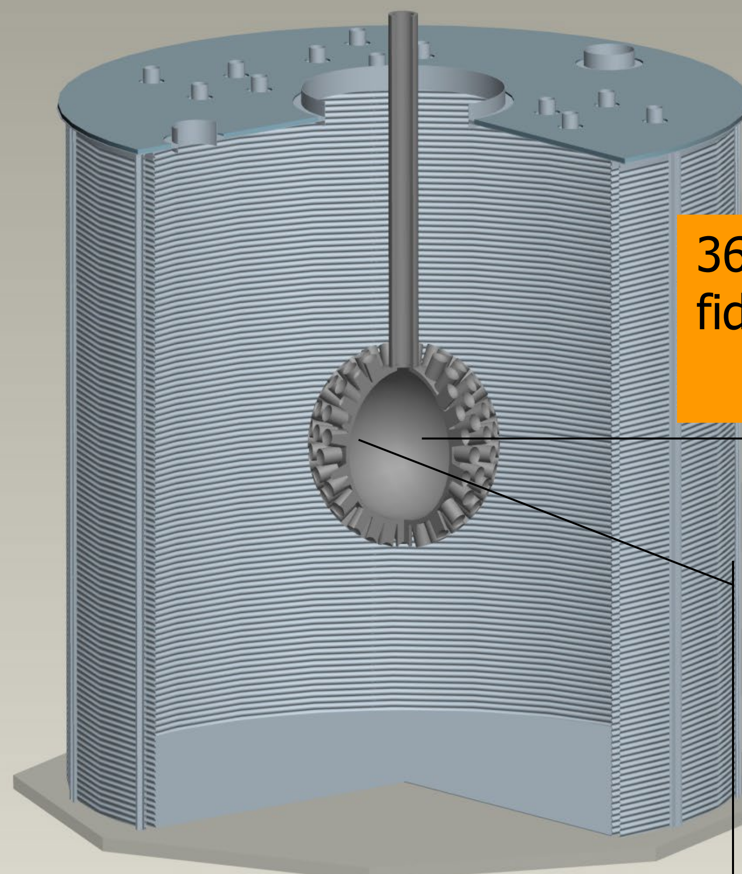
3,000m² / 30,000 m³ experimental halls class 2000 clean rooms. Intended to house 3 major experiments (10-20m) + 2-3 medium scale (5m)



2km depth = 6000mwe over burden

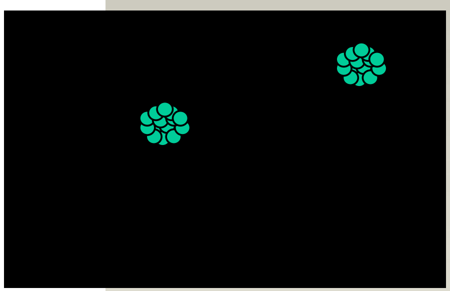


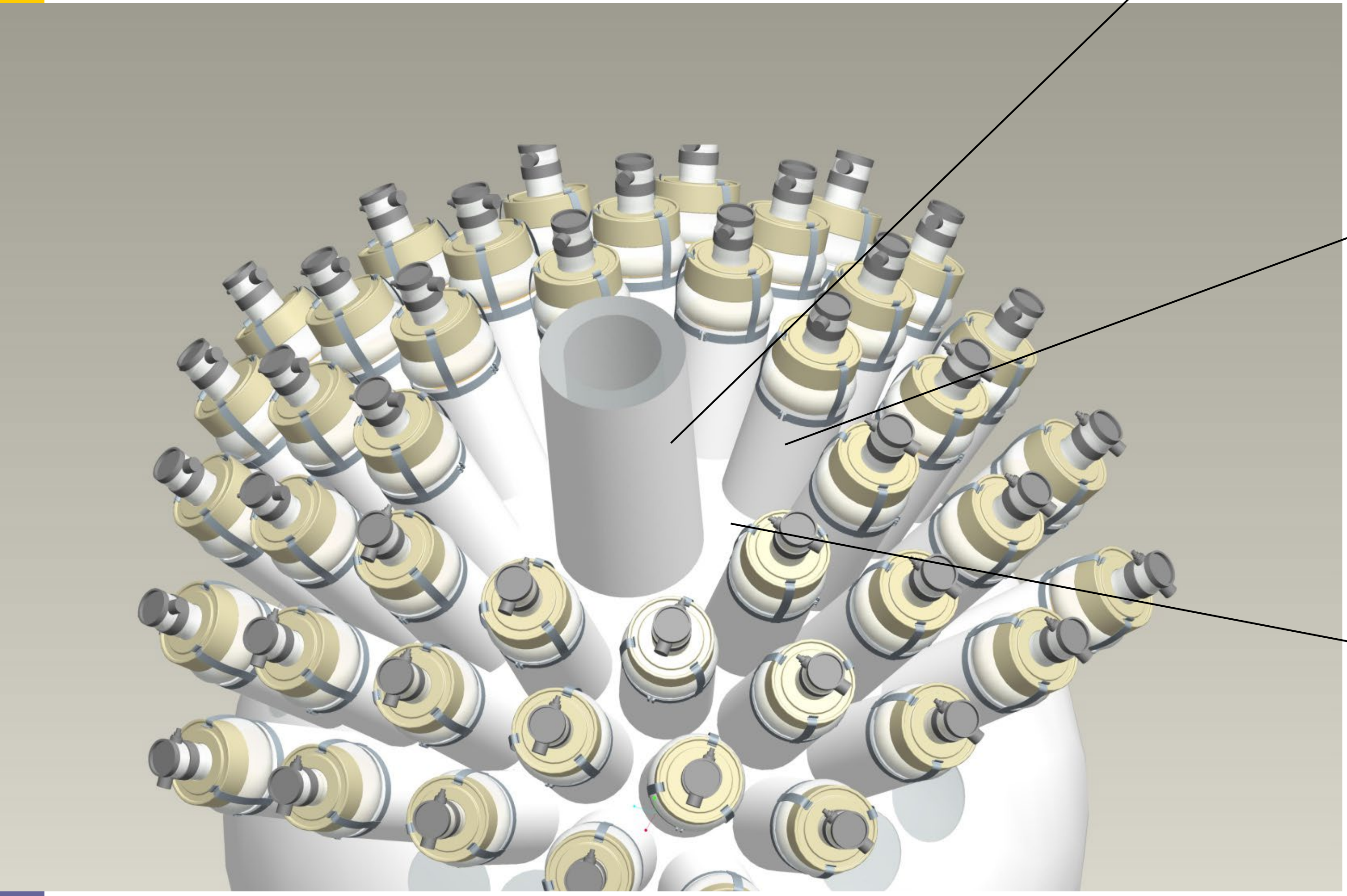
DEAP/Clean 3600 Detector

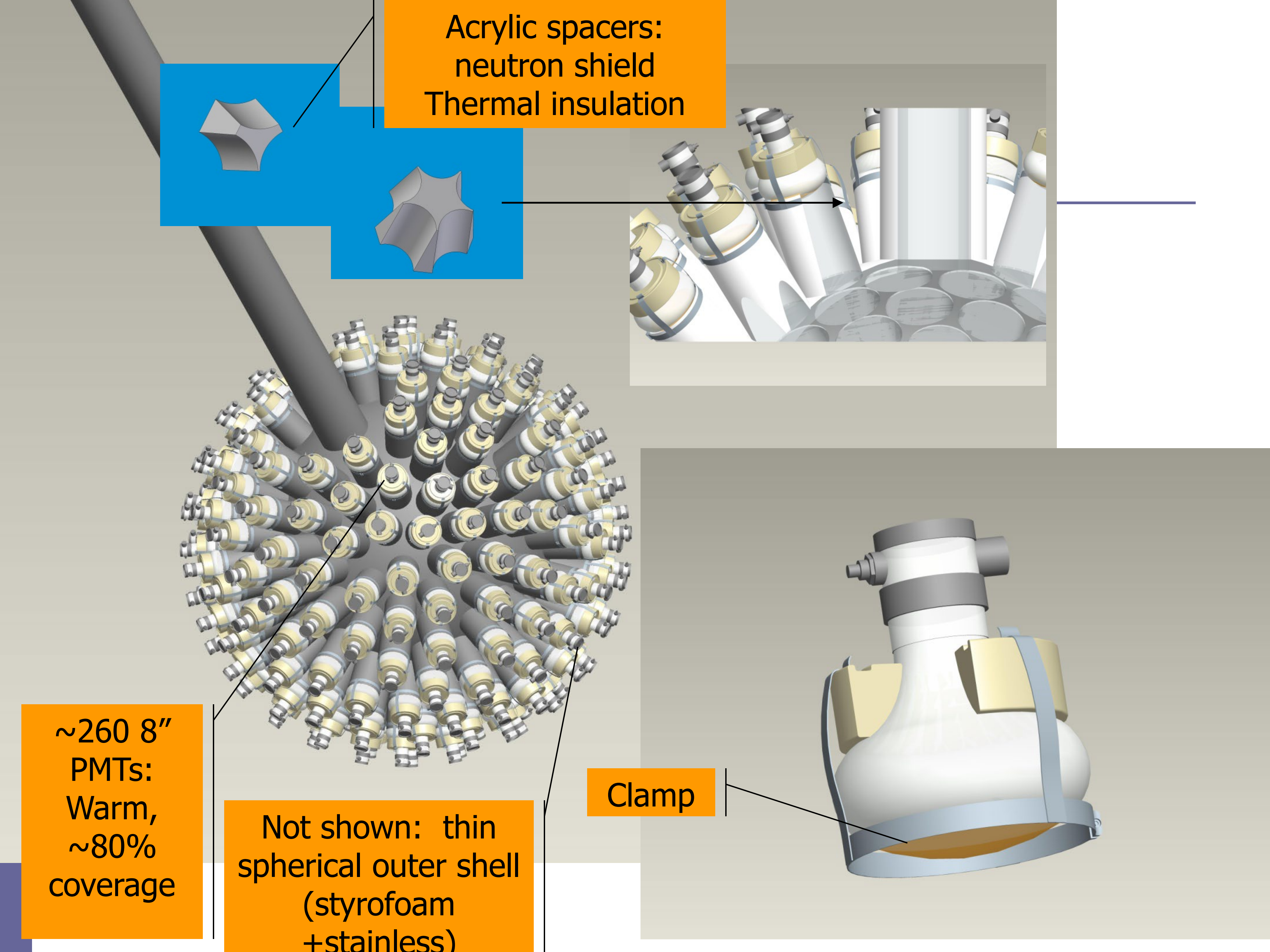


3600 kg LAr, 1000 kg fiducial

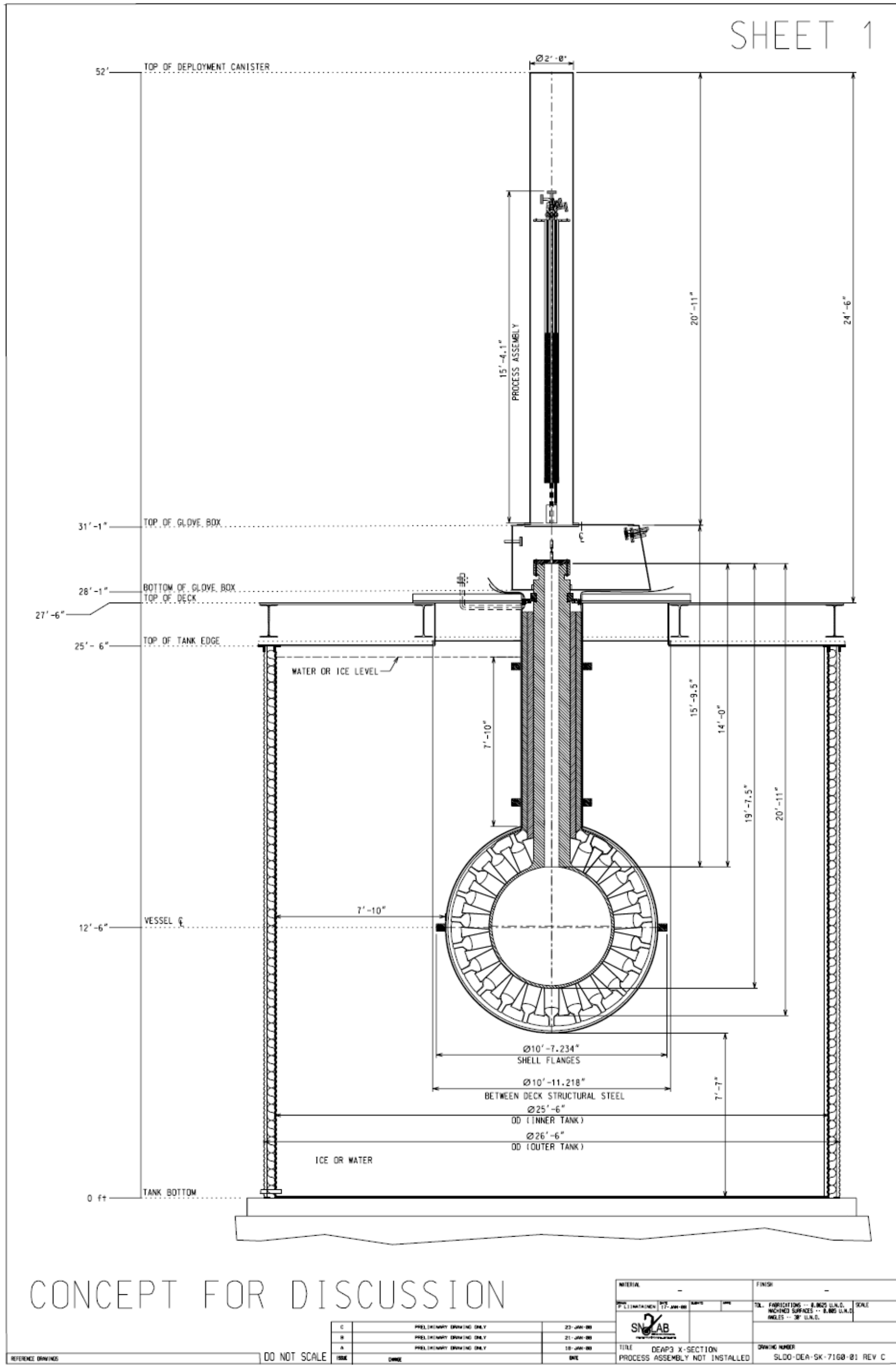
85 cm radius, 3.8 cm thick acrylic sphere: 100% of inside coated with TPB wavelength shifter
Radon barrier
Clean
Primary LAr containment

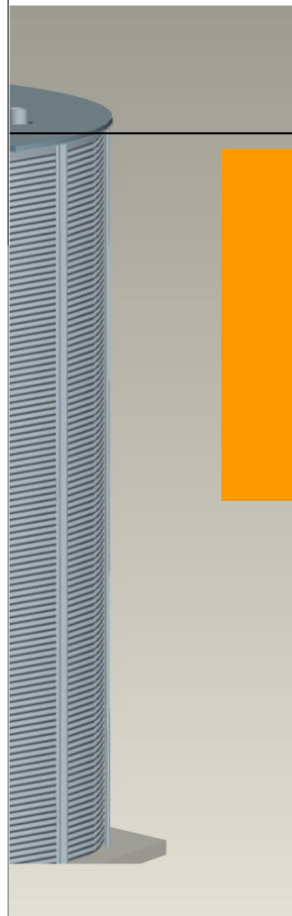



AV Neck,8” id 2” thick: Mechanical support, Access for process/cryogenic systems, calibration devices, thermal barrier
Acrylic Lightguide, Reflective outer coating: Light collection Neutron Shield Thermal insulation
Diffuse reflector on outside of acrylic vessel



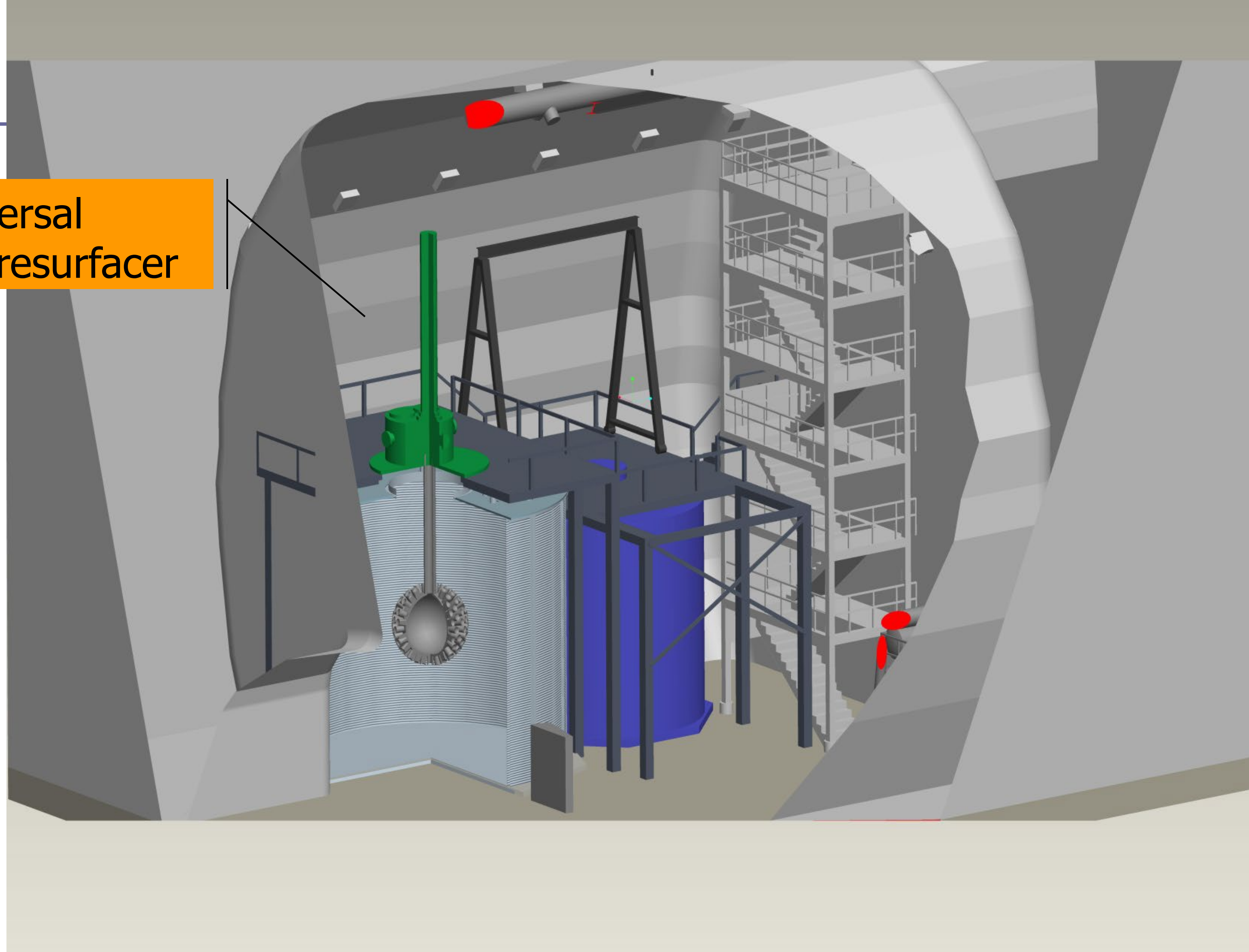
Acrylic spacers:
neutron shield
Thermal insulation
~260 8″
PMTs:
Warm,
~80%
coverage
Not shown: thin
spherical outer shell
(styrofoam
+stainless)
Clamp





Water:
Neutron, gamma shield
Muon veto
Thermal shield

CUT-AWAY VIEW INTO THE DETECTOR CAVERN

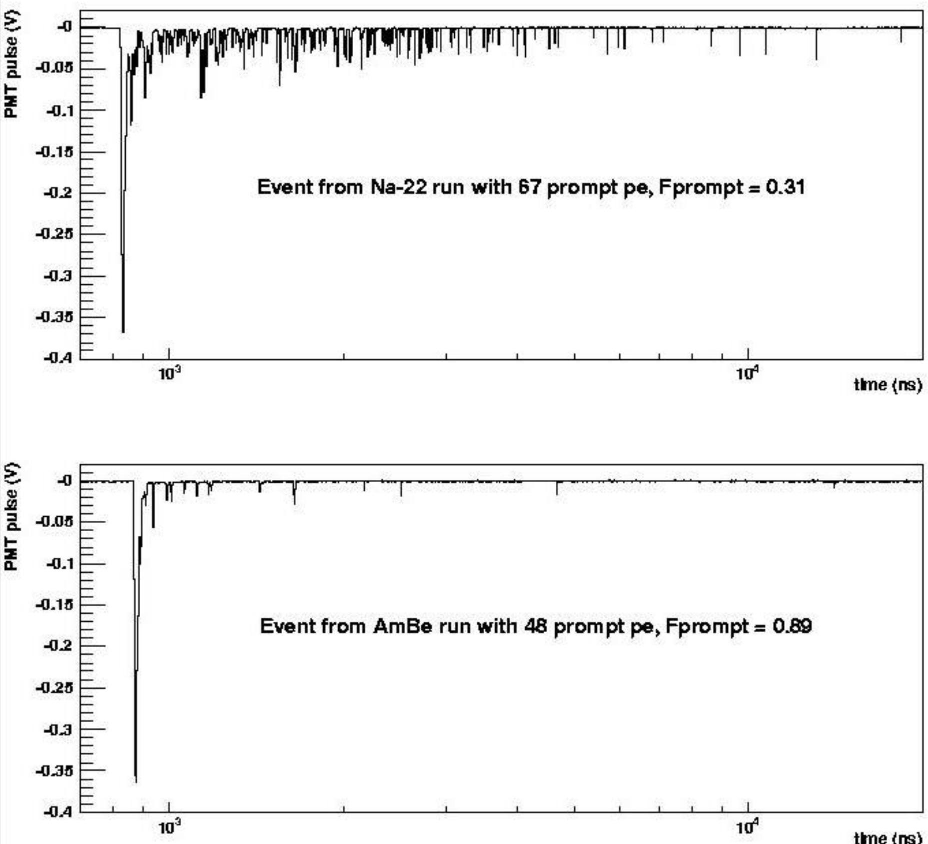


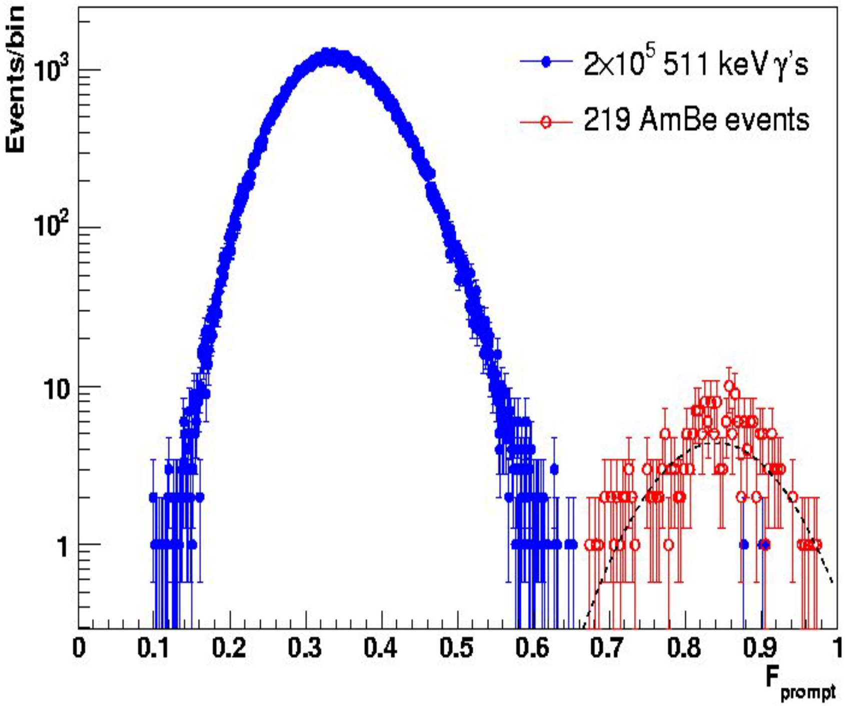
Backgrounds and the design

- Liquid circulation: to remove LAr contamination (no suspended particles > 8 microns)
- Acrylic vessel: allows radon isolation, resurfacing (need factor of ~1000 over "normal surfaces")
- Large FV, large light collection, 100% TPB, reflector on AV: to remove remaining surface recoils and for PSD
- Acrylic shield for neutrons
- Water shield/veto for muons

DEAP - Dark matter Experiment with Argon and Pulse-shape-discrimination

M.G.Boulay and A.Hime, Astroparticle Physics 25, 179 (2006)





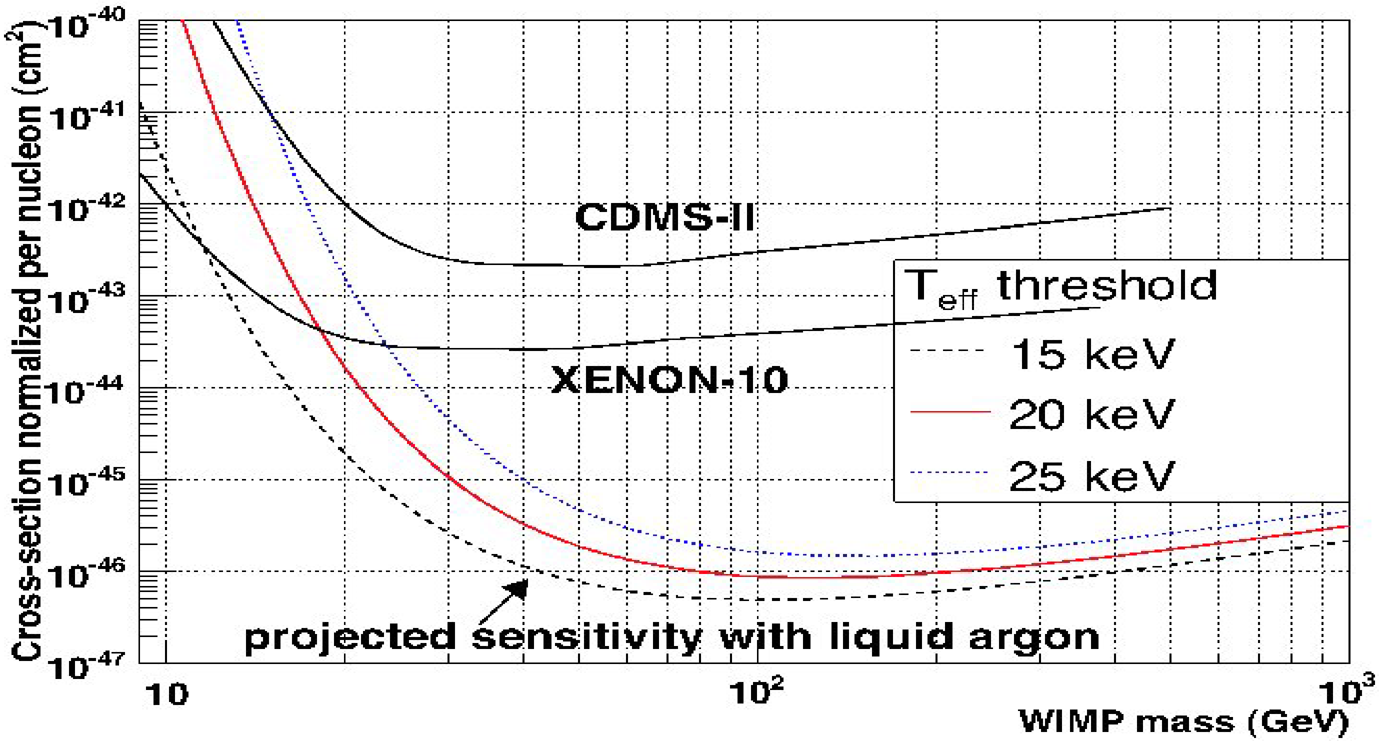
Concept Demonstrated Experimentally at LAN

DEAP-0

IV'rth SNOLAB Workshop, August (2005)

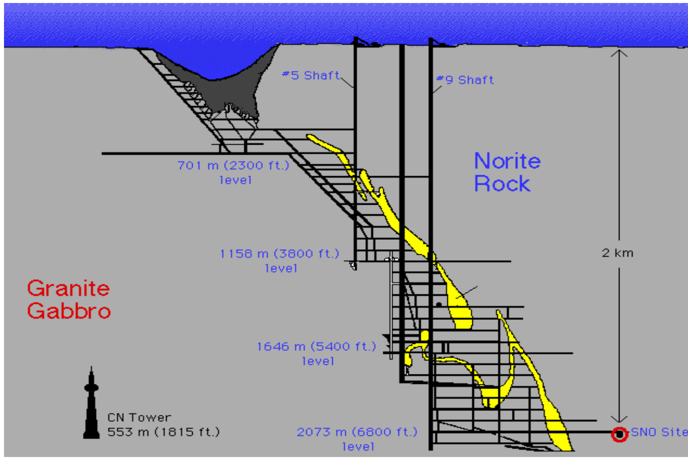
www.snolab2005.snolab.ca

WIMP Sensitivity with argon



For nominal threshold of 20 keV visible energy, 1000 kg LAr for 3 years is sensitive to 10^{-46} cm^2


Cube Hall



Sudbury Neutrino Observatory

1000 tonnes D_2O

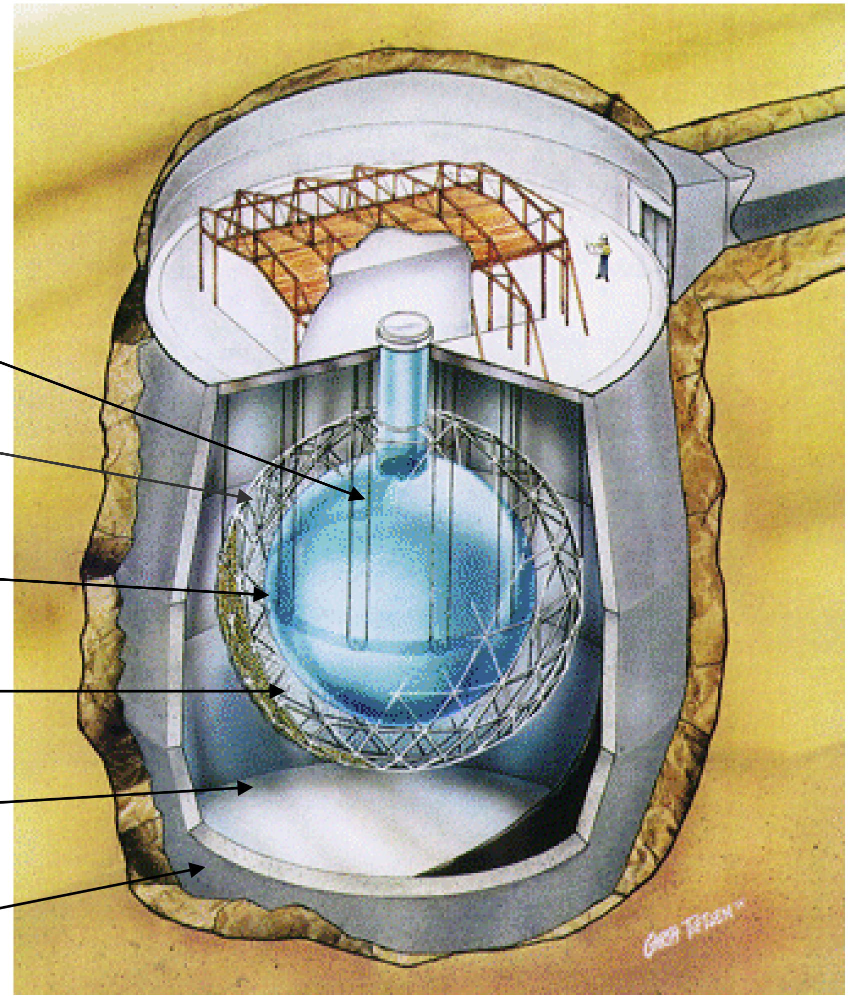
Support Structure for 9500 PMTs, 60% coverage

12 m Diameter Acrylic Vessel

1700 tonnes Inner Shielding H_2O

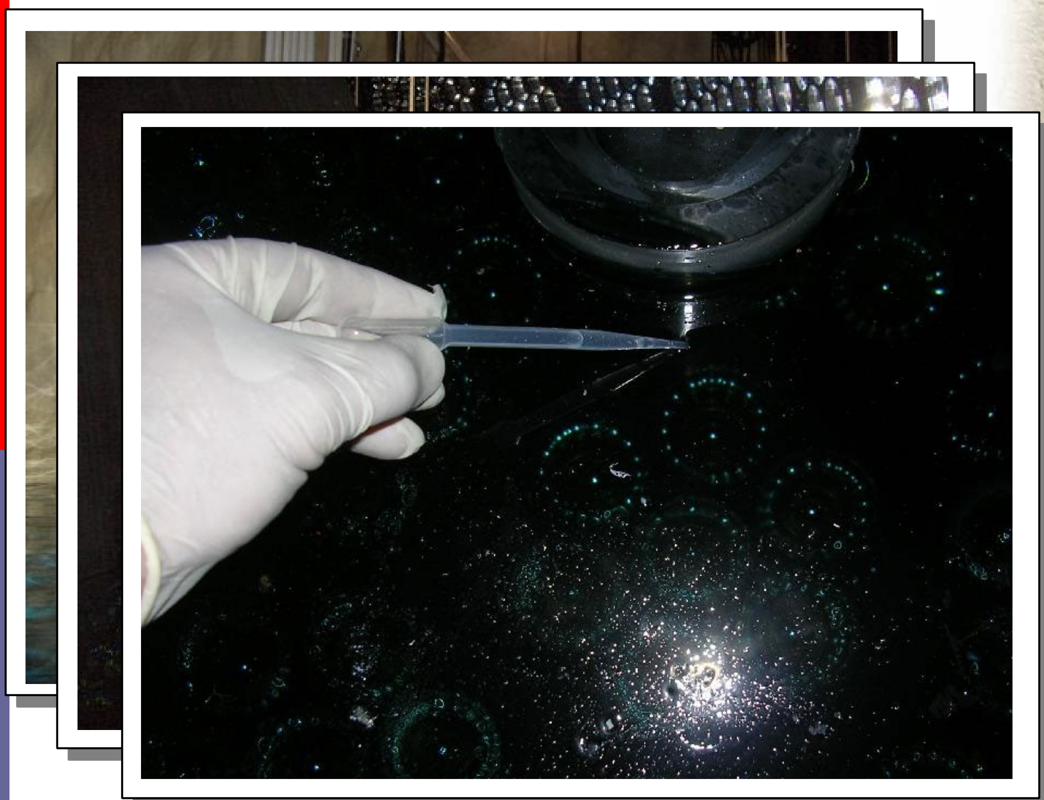
5300 tonnes Outer Shield H_2O

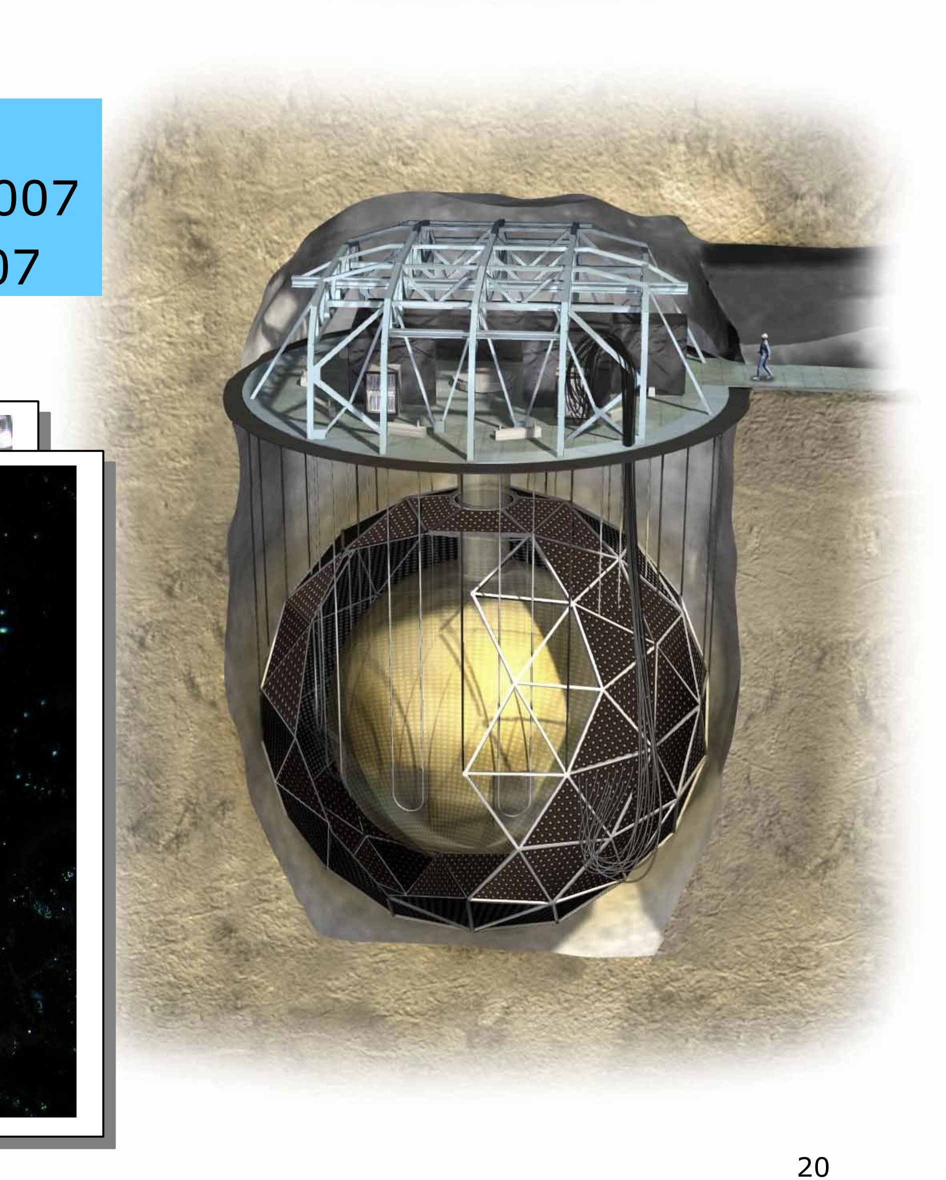
Urylon Liner and Radon Seal



SNO

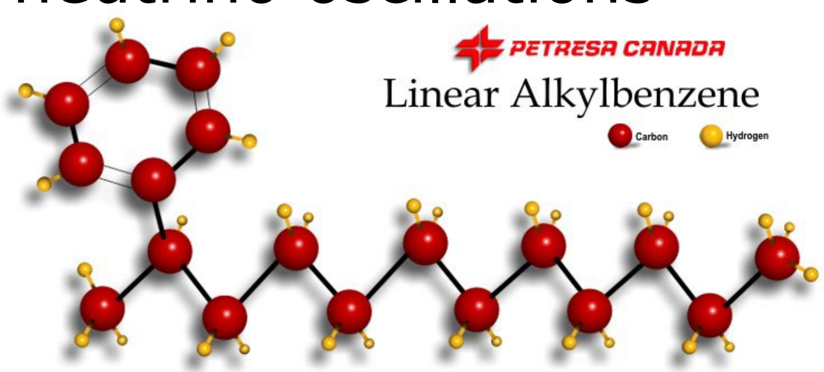
- Ended data taking 28 Nov 2006
- Most heavy water returned June 2007
- Finish decommissioning end of 2007





Fill with Liquid Scintillator

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



There has been remarkable progress in understanding *neutrinos*

U_{MNSP} Matrix

$$U = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix}$$

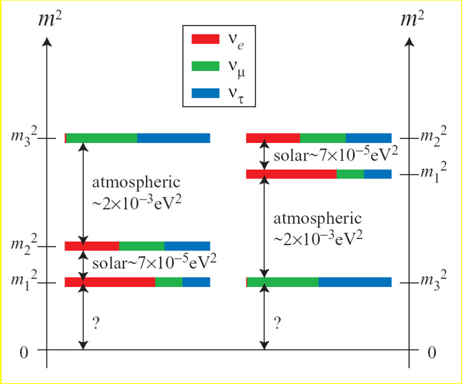
Additional CP Phases for Majorana Neutrinos

$$= \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix} \times \begin{pmatrix} \cos\theta_{13} & 0 & e^{-i\delta_{CP}}\sin\theta_{13} \\ 0 & 1 & 0 \\ -e^{i\delta_{CP}}\sin\theta_{13} & 0 & \cos\theta_{13} \end{pmatrix} \times \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \times \begin{pmatrix} 1 & 0 & 0 \\ 0 & e^{i\alpha/2} & 0 \\ 0 & 0 & e^{i\alpha/2+i\beta} \end{pmatrix}$$

$\theta_{23} \sim 45°$ $\quad$ $\tan^2\theta_{13} < 0.03$ at 90% CL $\quad$ $\theta_{12} \sim 32°$

We have also measured

$$\Delta m^2_{12} \text{ and } \Delta m^2_{23}$$



Values of θ_{13} & δ_{CP}?

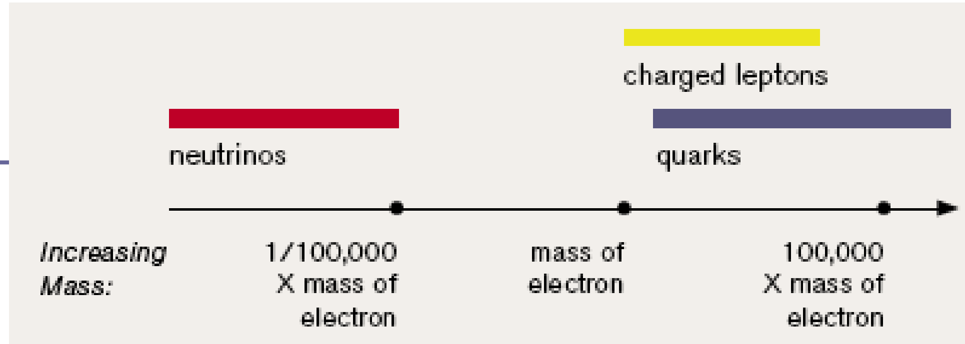
CP Violation in Neutrino Sector?

Leptogenesis & Matter-Antimatter Asymmetry in the Universe?

Are Neutrinos their own Antiparticles?

Neutrinos have emerged as among the most effective probes into the nature of higher unification, its symmetries and mass scales

Majorana Neutrino Mass & GUT Scale



$$m_\nu \ll m_\ell, m_q$$

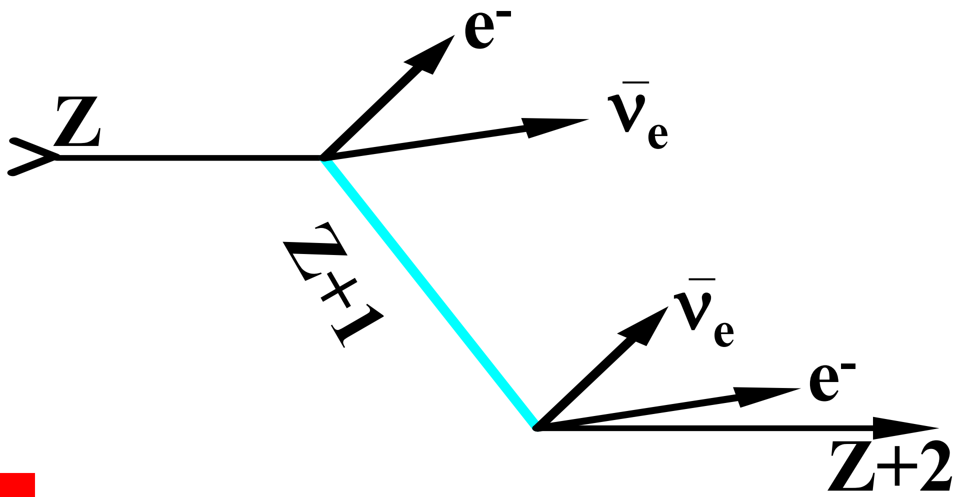
$m_D \sim 200$ GeV

$$m_\nu \propto \frac{m_D^2}{M_R}$$

$m_\nu \sim 0.01$ - 0.1 eV

Seesaw Mechanism

$M_R \sim 10^{15}$ GeV !

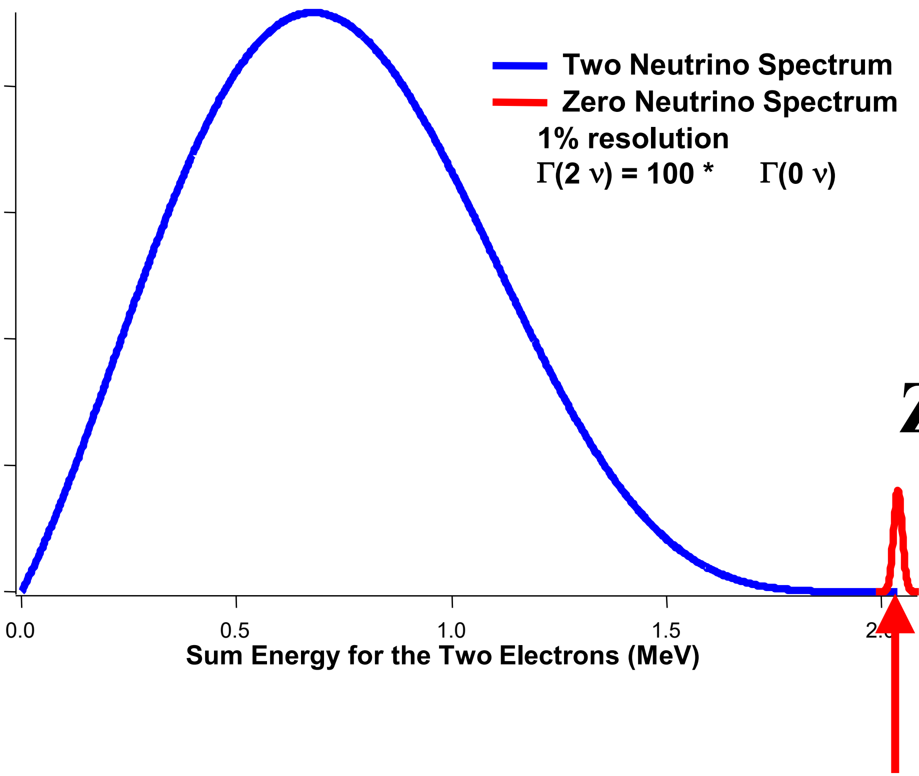


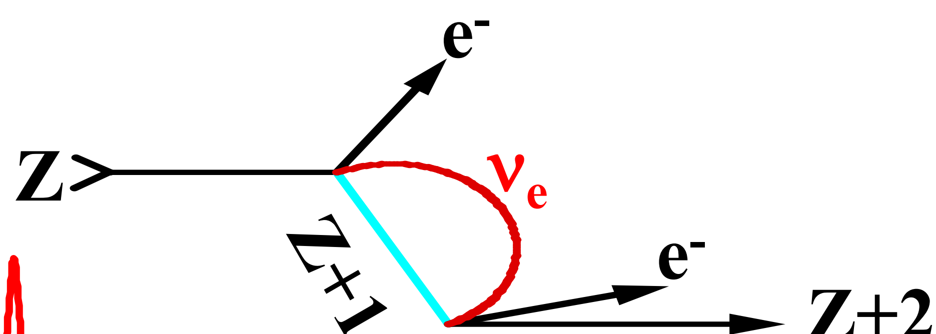
ββ Decay

Requires Massive Majorana Neutrino $\Delta L=2$

$$\Gamma_{0\nu} = G_{0\nu} \left| M_{0\nu} \right|^2 m_\nu^2$$

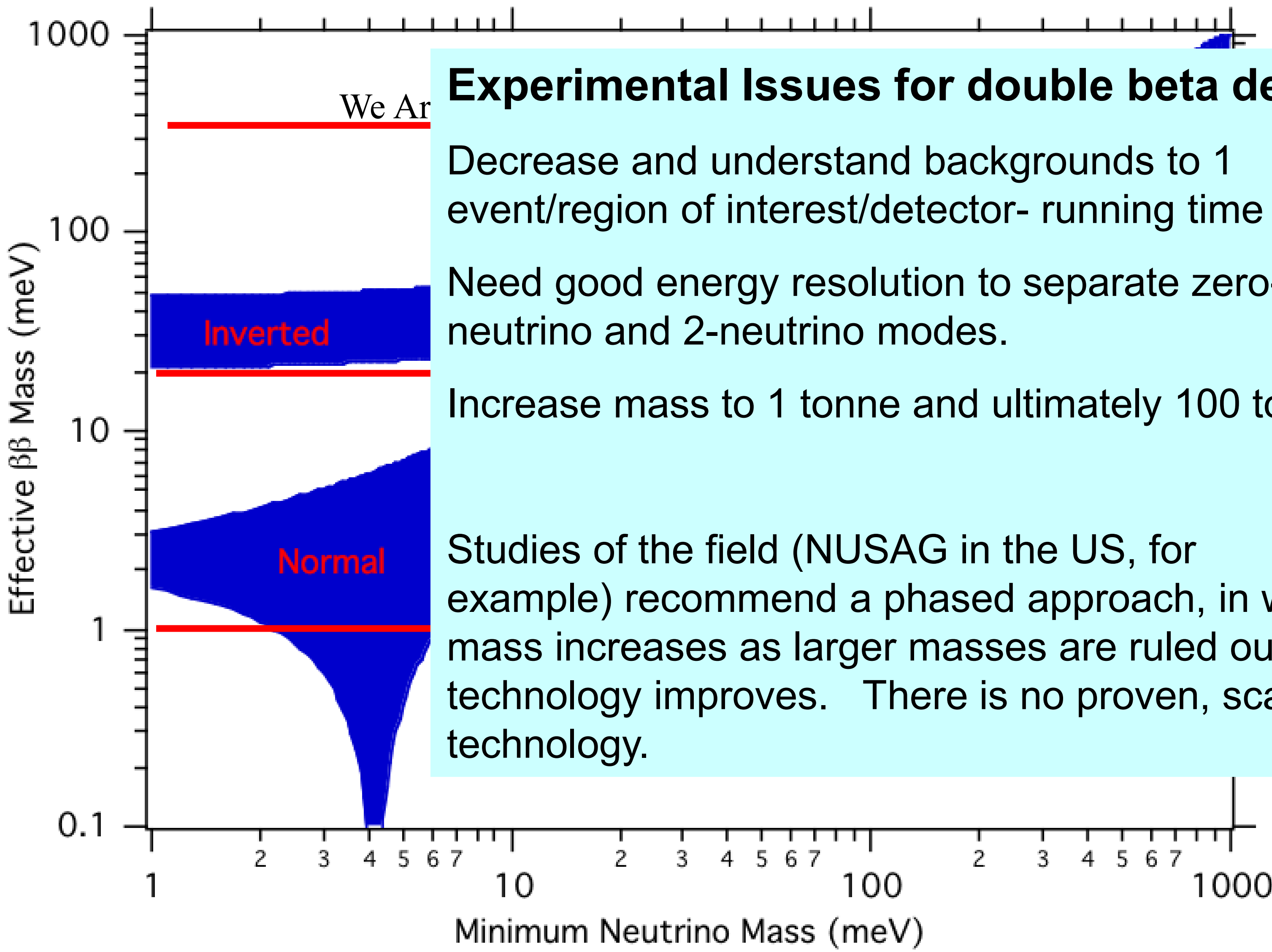
We learn $M_{0\nu}$ from nuclear physics





Endpoint Energy

Allowed Phase Space for a Majorana Neutrino Mass



Experimental Issues for double beta decay

Decrease and understand backgrounds to 1 event/region of interest/detector- running time

Need good energy resolution to separate zero-neutrino and 2-neutrino modes.

Increase mass to 1 tonne and ultimately 100 tonne.

Studies of the field (NUSAG in the US, for example) recommend a phased approach, in which mass increases as larger masses are ruled out and technology improves.   There is no proven, scalable technology.

^{76}Ge

^{5} yrs

^{6} yrs

^{7} yrs

^{8} yrs

^{9} yrs

SNO+ Double Beta Decay

- SNO+ with Nd-loaded liquid scintillator
  - …also called SNO++
- 0.1% Nd in 1000 tons of scintillator
  - with natural Nd corresponds to 56 kg of ^{150}Nd isotope
- sensitivity below 100 meV with natural Nd
- meters of ultra-low background self-shielding against gammas and neutrons
  - leads to well-defined background model
- liquid detector allows for additional *in-situ* purification
- possibility to enrich neodymium at French AVLIS facility

What Do Scintillators Offer?

- “economical” way to build a detector with a **large** amount of isotope
- several isotopes can be made into (or put in) a scintillator
- ultra-low background environment can be achieved (e.g. phototubes stand off from the scintillator, self-shielding of fiducial volume)
- with a liquid scintillator, possibility to purify *in-situ* to further reduce backgrounds

Why ^{150}Nd?

- 3.37 MeV endpoint (2nd highest of all $\beta\beta$ isotopes)
  - above most backgrounds from natural radioactivity
- largest phase space factor of all $\beta\beta$ isotopes
  - factor of 33 greater compared with ^{76}Ge
  - for the same effective Majorana neutrino mass, the $0\nu\beta\beta$ rate in ^{150}Nd is the fastest
- cost of $NdCl_3$ is \$86,000 for 1 ton (not expensive)
- upcoming experiments use Ge, Xe, Te; we can deploy a large and comparable amount of Nd

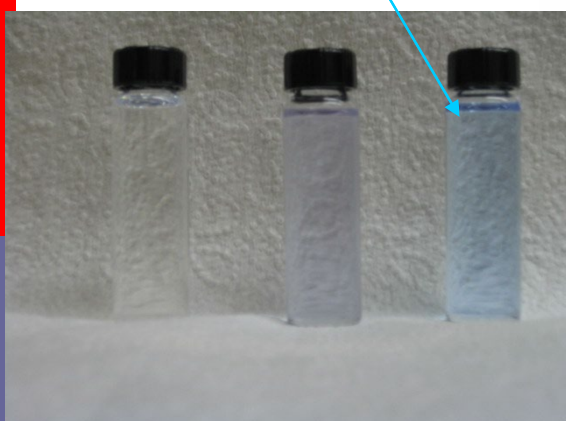
How Does ^{150}Nd Compare?

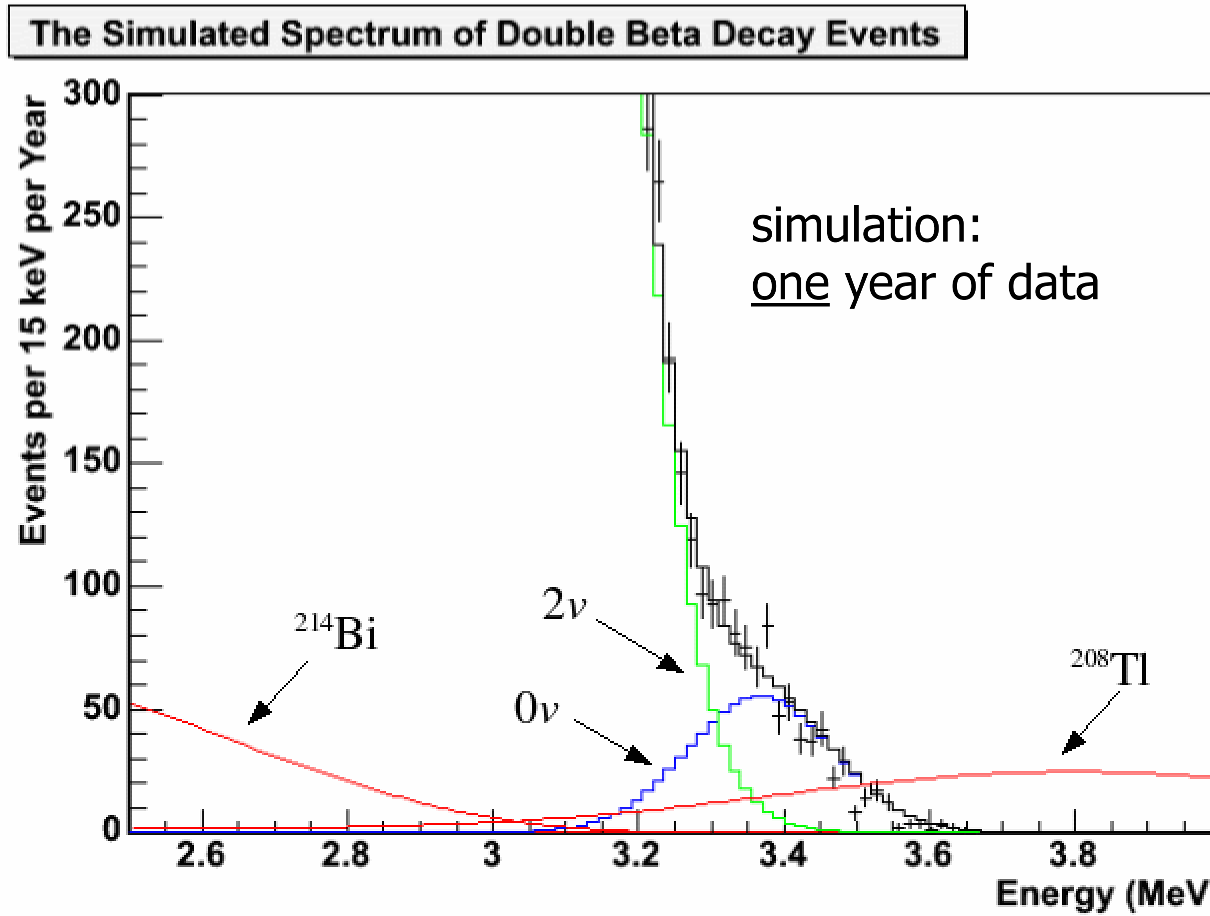
- 56 kg of ^{150}Nd is equivalent to:
- considering only the phase space factor
  - ~220 kg of ^{136}Xe
  - ~230 kg of ^{130}Te
  - ~950 kg of ^{76}Ge
- including QRPA matrix element calculations
  - ~1500 kg of ^{136}Xe
  - ~400 kg of ^{130}Te
  - ~570 kg of ^{76}Ge

thanks L. Simard and F. Piquemal

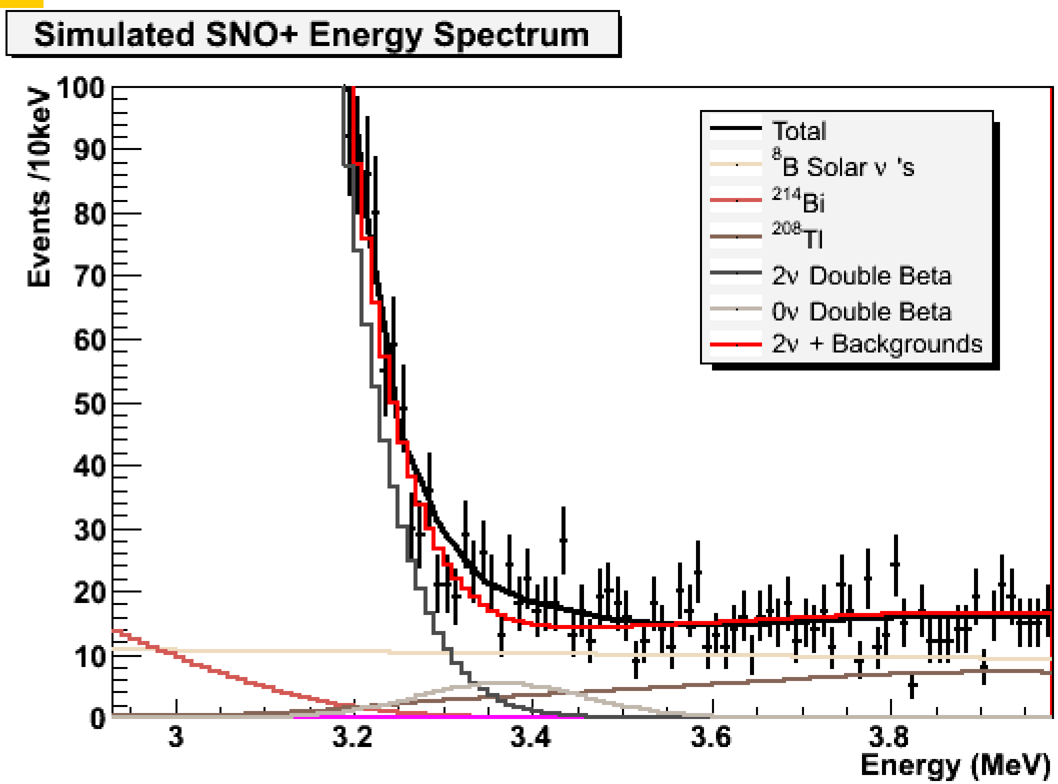
$0\nu\beta\beta$ Signal for $<m_\nu> = 0.150$ eV

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



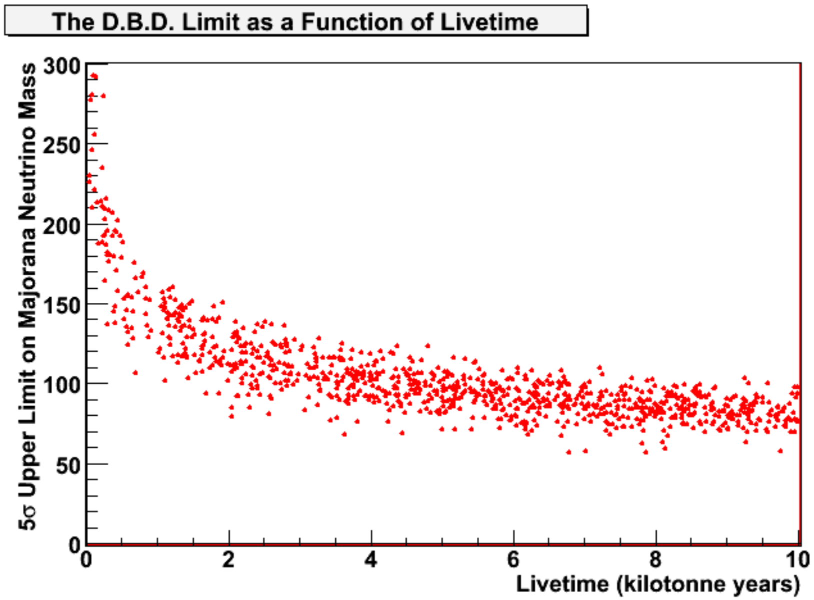


56 kg of ^{150}Nd and <m_ν> = 100 meV



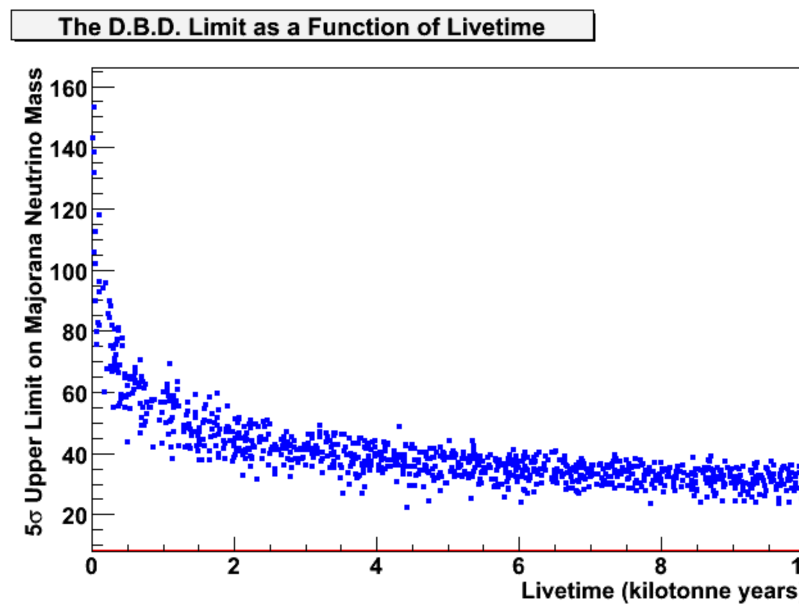
- 6.4% FWHM at Q-value
- 3 years livetime
  - U, Th at Borexino levels
  - 5σ sensitivity
  - note: the dominant background is ^{8}B solar neutrinos!
  - ^{214}Bi (from radon) is almost negligible
  - ^{212}Po-^{208}Tl tag (3 min) might be used to veto ^{208}Tl backgrounds; ^{212}Bi-^{212}Po (300 ns)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

Neutrino Mass Sensitivity



With natural Nd SNO+ is sensitive to effective neutrino masses as low as 100 meV.

With 10X enriched Nd our sensitivity extends to 40 meV.



^{150}Nd Scintillator Properties

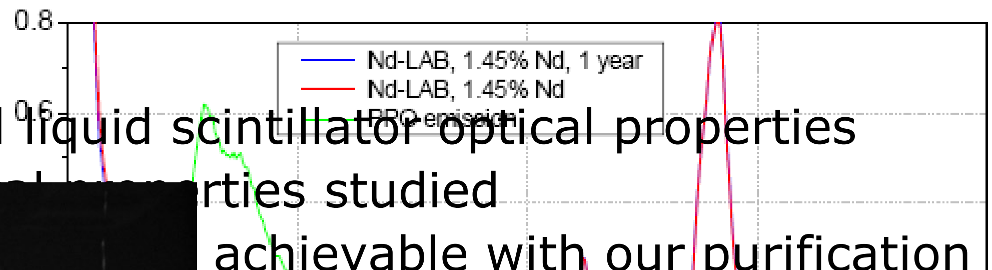
stable Nd-loaded liquid scintillator optical properties

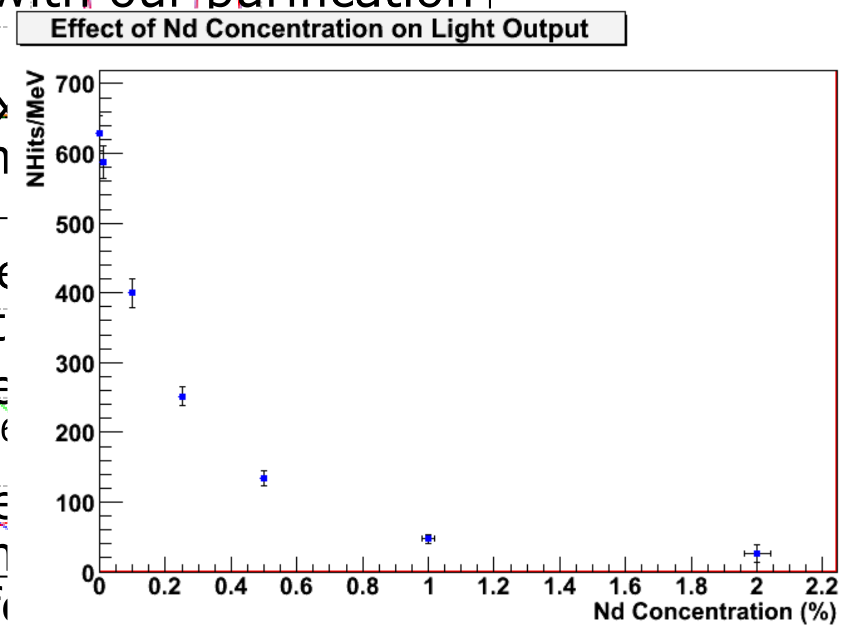
sc... rties studied

ta... achievable with our purification

te...

- ...he Nd carbox
  ...has ~10^6 tim
- ...have been de
  ...O_4 co-precipit
- ...tors of 10^5 re
  ...or Th and 10^6
- ...fied salted he
  ...e are the san
  ...en the transf
  further reduces impurities

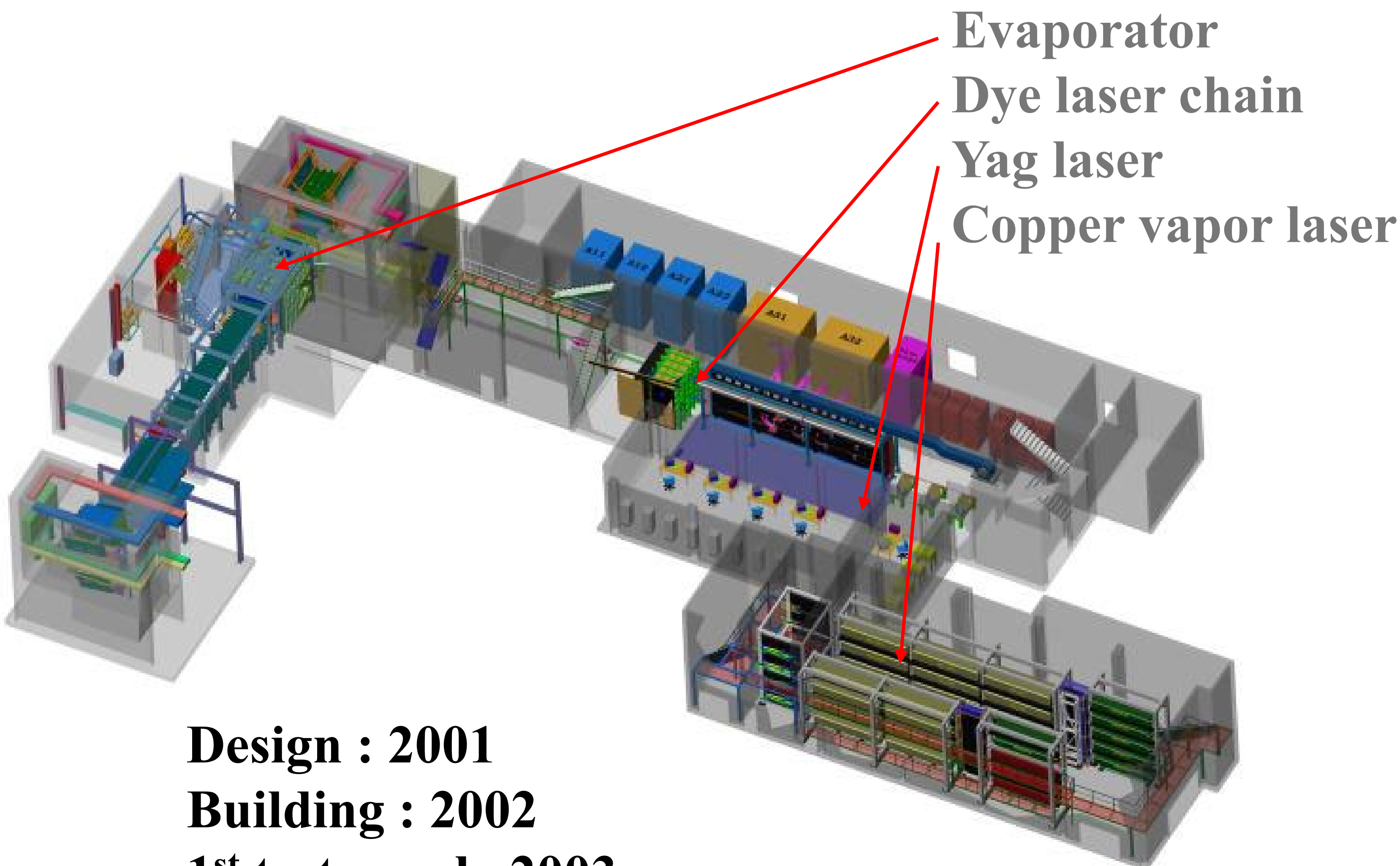




Nd-150 Consortium

- SuperNEMO and SNO+, MOON and DCBA are supporting efforts to maintain an existing French AVLIS facility that is capable of making 100’s of kg of enriched Nd
  - a facility that enriched 204 kg of U (from 0.7% to 2.5%) in several hundred hours

2000-2003 Program : Menphis facility



Design : 2001
Building : 2002
1st test : early 2003
1st full scale exp. : june 2003

AVLIS for ^{150}Nd is Known


Development of the laser isotope separation method (AVLIS) for obtaining weight amounts of highly enriched ^{150}Nd isotope

A.P. Babichev, I.S. Grigoriev, A.I. Grigoriev, A.P. Dorovskii, A.B. D'yachkov, S.K. Kovalevich, V.A. Kochetov, V.A. Kuznetsov, V.P. Labozin, A.V. Matrakhov, S.M. Mironov, S.A. Nikulin, A.V. Pesnya, N.I. Timofeev, V.A. Firsov, G.O. Tsvetkov, G.G. Shatalova

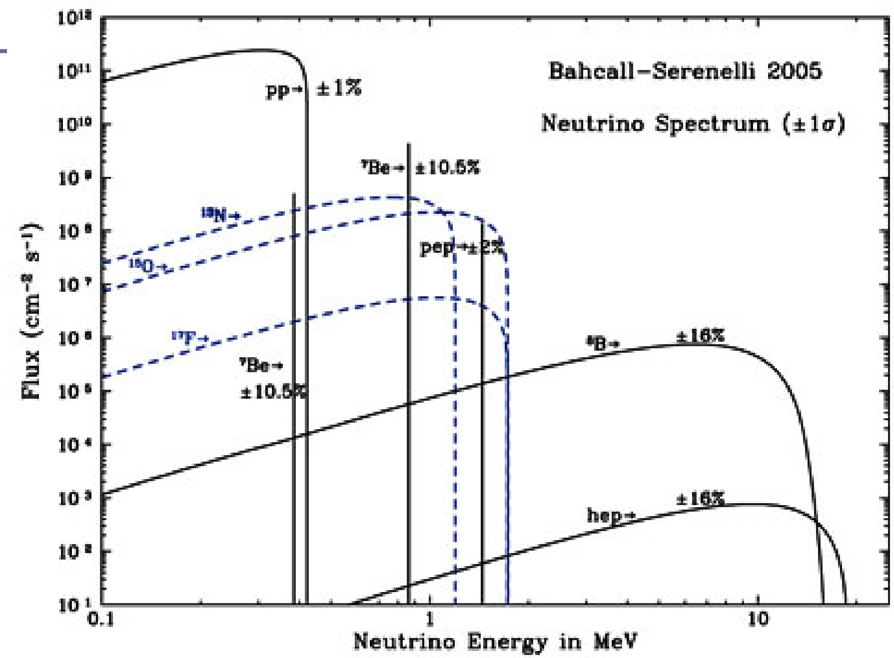
SNO+ Nd: Summary

- good sensitivity and very timely
- homogeneous liquid, well defined background model
  - large volume gives self-shielding
  - Q-value is above most backgrounds
    - thus "insensitive" to internal radon backgrounds
    - thus insensitive to "external" backgrounds (2.6 MeV γ)
- Th, Ra purification techniques are effective
- huge amounts of isotope, thus high statistics, can work for double beta decay search
  - requires exquisite calibration and knowledge of detector response

Low Energy Solar Neutrinos

- complete our understanding of neutrinos from the Sun

  pep, CNO, ^{7}Be, pp



p-p Solar Fusion Chain

$p + p \rightarrow {}^2H + e^+ + \nu_e$ $\quad$ $p + e^- + p \rightarrow {}^2H + \nu_e$

$^2H + p \rightarrow {}^3He + \gamma$

$^3He + {}^3He \rightarrow {}^4He + 2\,p$ $\quad$ $^3He + p \rightarrow {}^4He + e^+ + \nu_e$

$^3He + {}^4He \rightarrow {}^7Be + \gamma$

$^7Be + e^- \rightarrow {}^7Li + \gamma + \nu_e$ $\quad$ $^7Be + p \rightarrow {}^8B + \gamma$

$^7Li + p \rightarrow \alpha + \alpha$ $\quad$ $^8B \rightarrow 2\,\alpha + e^+ + \nu_e$

CNO Cycle

$^{12}C + p \rightarrow {}^{13}N + \gamma$ $\quad$ $^{13}N \rightarrow {}^{13}C + e^+ + \nu_e$

$^{13}C + p \rightarrow {}^{14}N + \gamma$

$^{14}N + p \rightarrow {}^{15}O + \gamma$ $\quad$ $^{15}O \rightarrow {}^{15}N + e^+ + \nu_e$

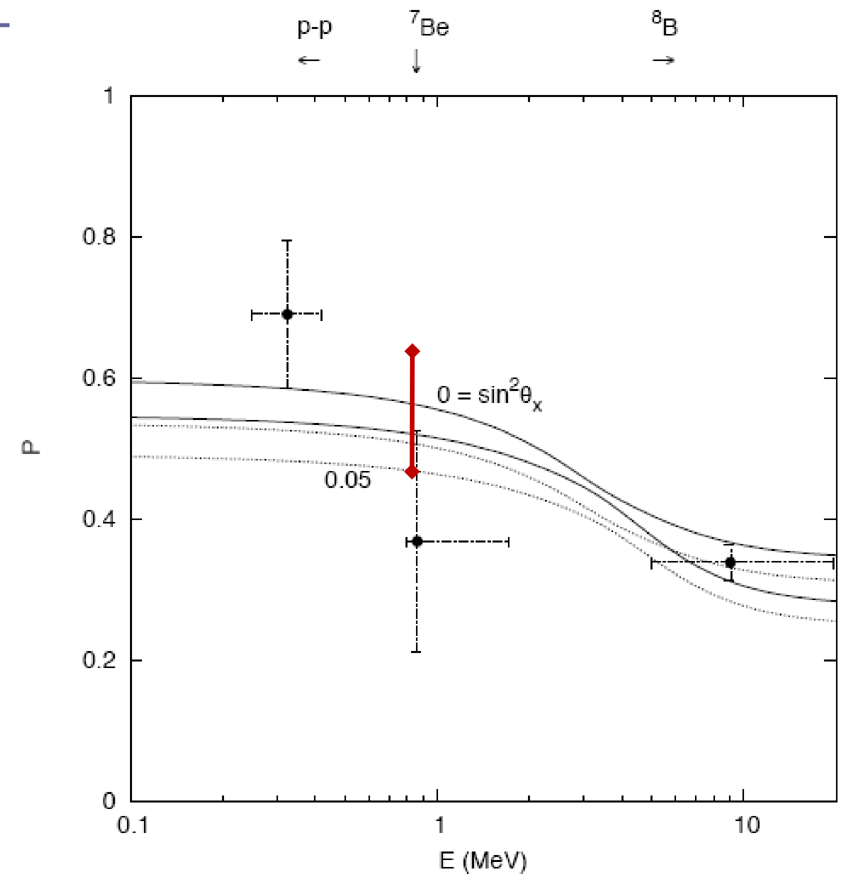
$^{15}N + p \rightarrow {}^{12}C + \alpha$

Ga, Cl and SNO Data – Distilled

deduce the survival probability
high energy: directly from SNO
medium energy: Cl minus high
low energy: Ga minus high, medium

we observe that the survival probability for solar neutrinos versus energy is not yet accurately determined from existing experiments

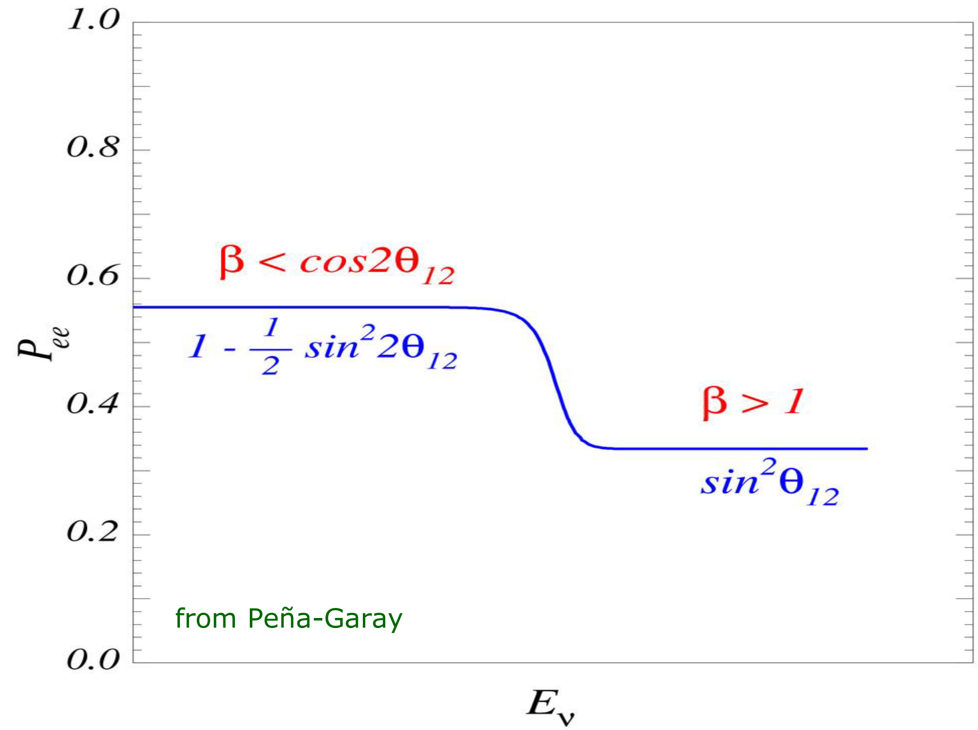
transition between vacuum and matter oscillations in the Sun has not been accurately determined



there is even some tension in existing low and medium data…

Neutrino-Matter Interaction

- best-fit oscillation parameters suggest MSW occurs
- but we have no direct evidence of MSW
  - day-night effect not observed
  - no spectral distortion for ^8B ν's
- testing the vacuum-matter transition is sensitive to new phy



for $\Delta m^2 = 8 \times 10^{-5}$ eV^2, $\theta = 34°$
N_e at the centre of the Sun $\rightarrow$
E is 1-2 MeV

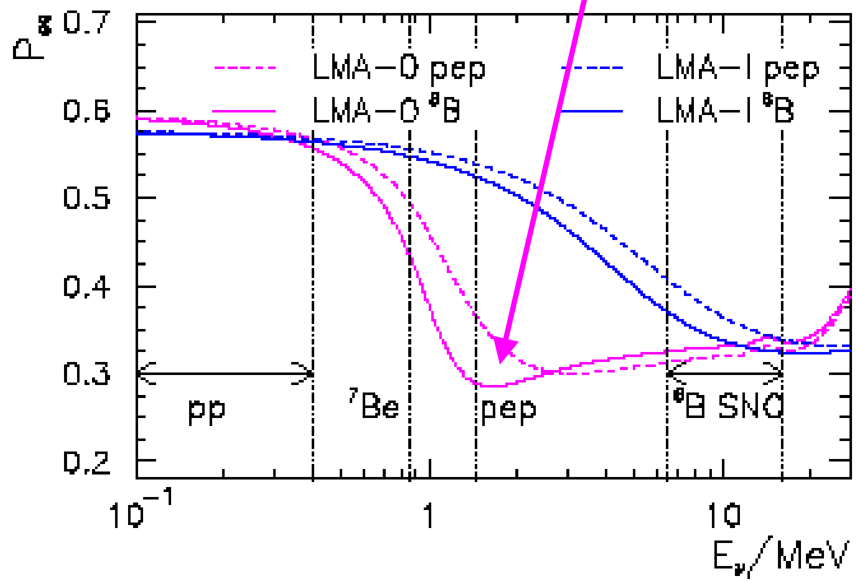
$$\begin{pmatrix} -\frac{\Delta m^2}{4E}\cos 2\theta + \sqrt{2}G_F N_e & \frac{\Delta m^2}{4E}\sin 2\theta \\ \frac{\Delta m^2}{4E}\sin 2\theta & \frac{\Delta m^2}{4E}\cos 2\theta \end{pmatrix}$$

Hamiltonian for neutrino propagation in the Sun

New Physics

- MSW is linear in G_F and limits from ν-scattering experiments ($\propto g^2$) aren't that restrictive
- oscillation solutions with NSI can fit existing solar and atmospheric neutrino data…NSI not currently constrained
- new *pep* solar ν data would reveal NSI

good fit with NSI



pep solar neutrinos are at the "sweet spot" to test for new physics

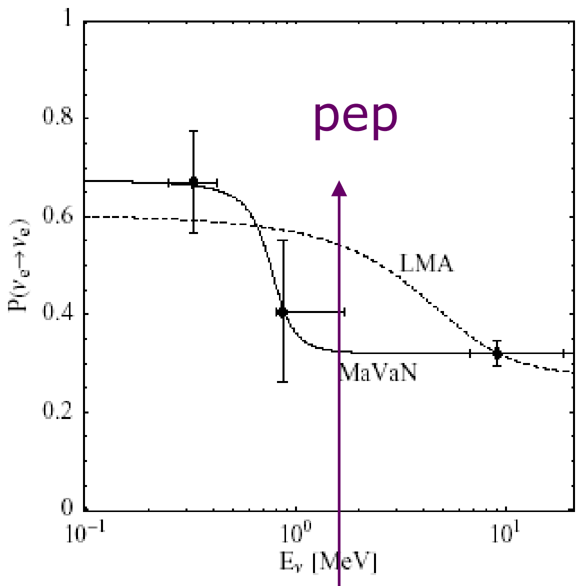
Friedland, Lunardini, Peña-Garay, hep-ph/0402266

Mass-Varying Neutrinos

- cosmological connection: mass scale of neutrinos and the mass scale of dark energy are similar
- postulating a scalar field and neutrino coupling results in neutrinos whose mass varies with the background field (e.g. of other neutrinos)

Fardon, Nelson, Weiner, hep-ph/0309800

- solar neutrinos affected?
- *pep* ν*: a* sensitive probe



Barger, Huber, Marfatia, hep-ph/0502196

The Standard Solar Model

Predicts ^{8}B neutrino fluxes well, but three experimental issues:

-Metallicity/opacity/helioseismology doesn't agree well
-"Weak young sun paradox"
-Lithium depleted by factor of 160

Bahcall, Pinsonneault, Basu,
THE ASTROPHYSICAL JOURNAL,
555:990È1012, 2001 July 10

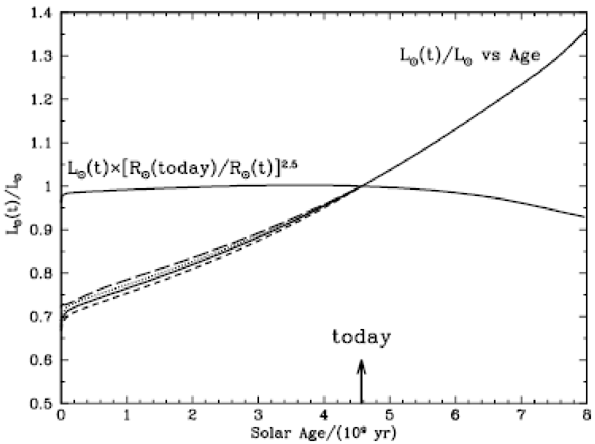
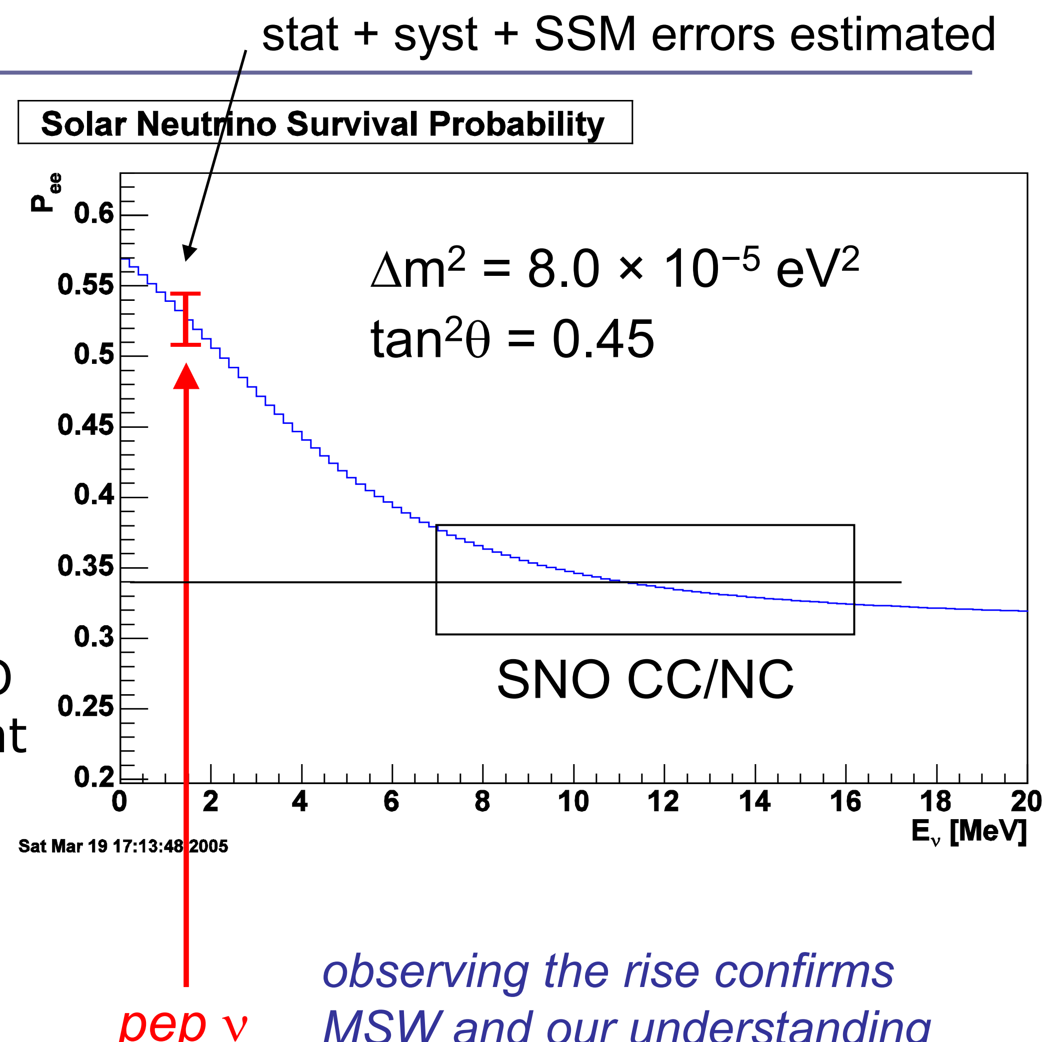


FIG. 2.—Normalized solar luminosity, $L_\odot(t)/L_\odot(\text{today})$, vs. solar age for the standard solar model (*solid curve*) and for three "deficient" solar models: the No Diffusion model (*dotted curve*), the $S_{34} = 0$ model (*short-dashed curve*), and the Mixed model (*long-dashed curve*). The luminosity evolution of the Sun is essentially the same in all solar models we have investigated, including deficient solar models. The rms deviation of the deviant models from the standard solar model luminosity is only 1% over the history of the Sun from the zero-age main sequence to the current epoch (see text for more details). The product $L_\odot(t)R_\odot(t)^{-2.5}$ varies by $\pm 4\%$ over the entire period from the zero-age main sequence to a solar age of 8×10^9 yr, while the solar luminosity itself varies by slightly more than a factor of 2 during this period. In the period between 4×10^9 and 8×10^9 yr, the relation $L_\odot(t) \propto R_\odot(t)^2$ is satisfied to $\pm 0.5\%$. The solar luminosity has increased by 48% from the zero-age main sequence to the present epoch. The present age of the Sun is indicated by an arrow at 4.59×10^9 yr. [*See the electronic edition of the Journal for a color version of this figure.*]

Why *pep* Solar Neutrinos?

SSM pep flux:
uncertainty ±1.5%

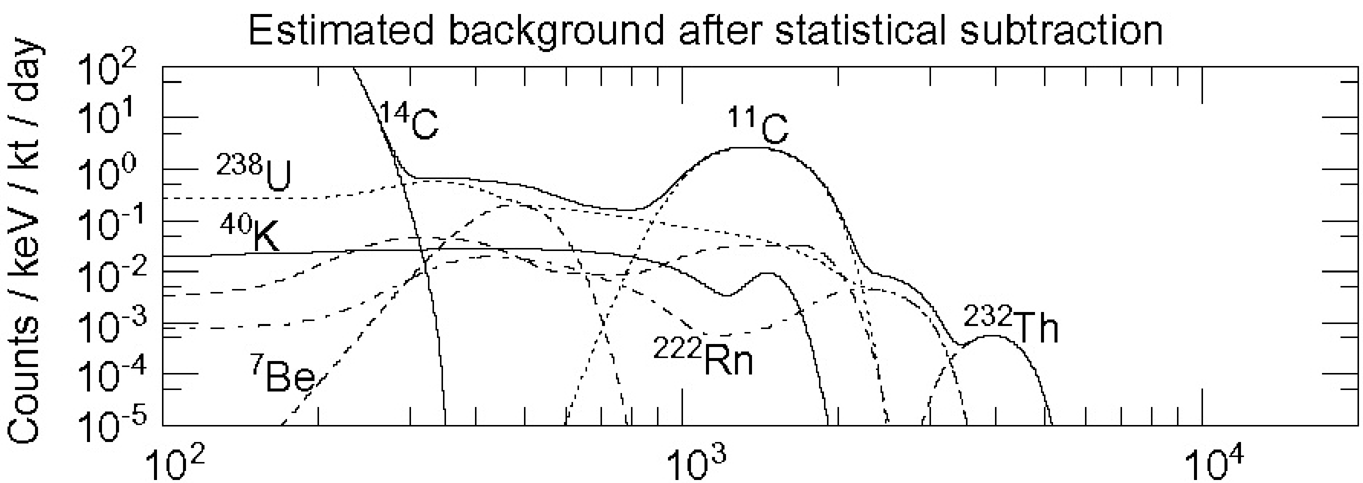
known source
known cross section (ν-e scattering)
→ measuring the rate gives the survival
probability
→ **precision test**
for neutrino physics with low energy solar neutrinos, have to achieve precision similar to SNO or better…it's no longer sufficient to just detect the neutrinos



pep solar neutrinos:
E_ν = 1.44 MeV
…are at the right energy to search for new physics

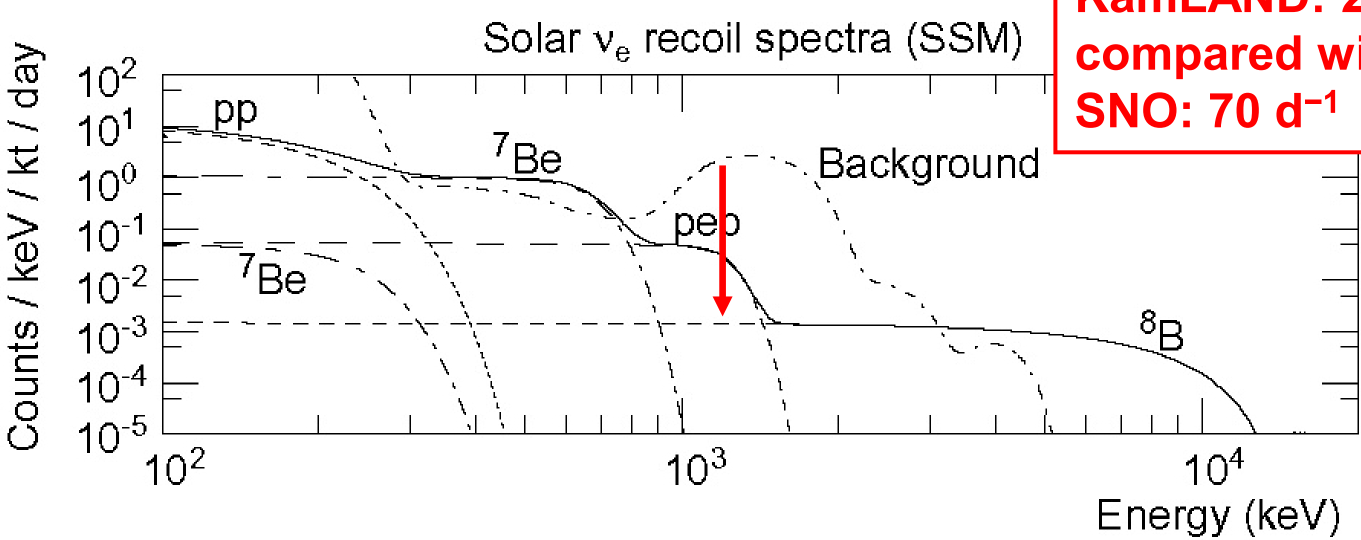
observing the rise confirms MSW and our understanding of solar neutrinos

^{11}C Cosmogenic Background



these plots from the KamLAND proposal

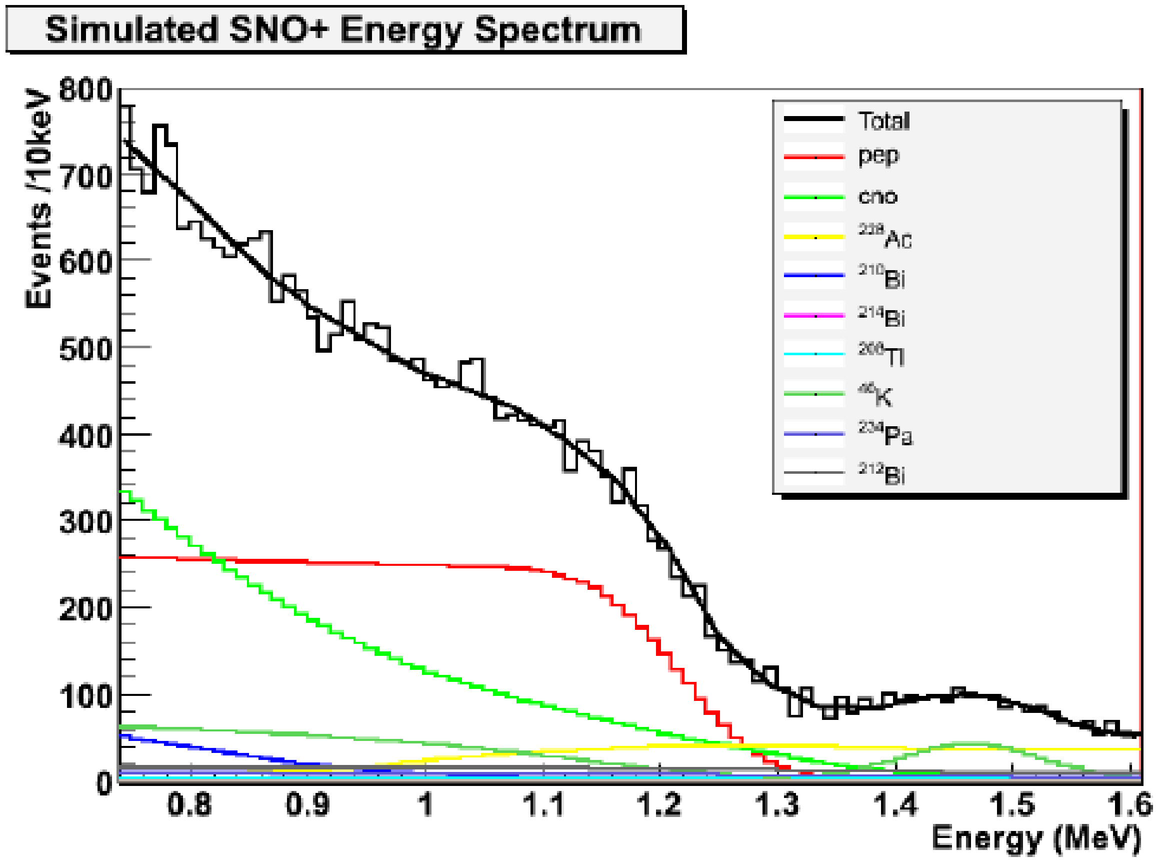
muon rate in KamLAND: 26,000 d^{-1} compared with SNO: 70 d^{-1}



Requirements for a Liquid Scintillator *pep* Solar ν Detector

- **depth**
  - to reduce/eliminate ^{11}C background
- **good light output** from the scintillator
  - studied the effect of varying the energy resolution; found not a steep dependence
- **radiopurity**
  - control of Rn exposure because of ^{210}Bi
  - eliminate ^{40}K internal contamination

Solar Signals with Backgrounds

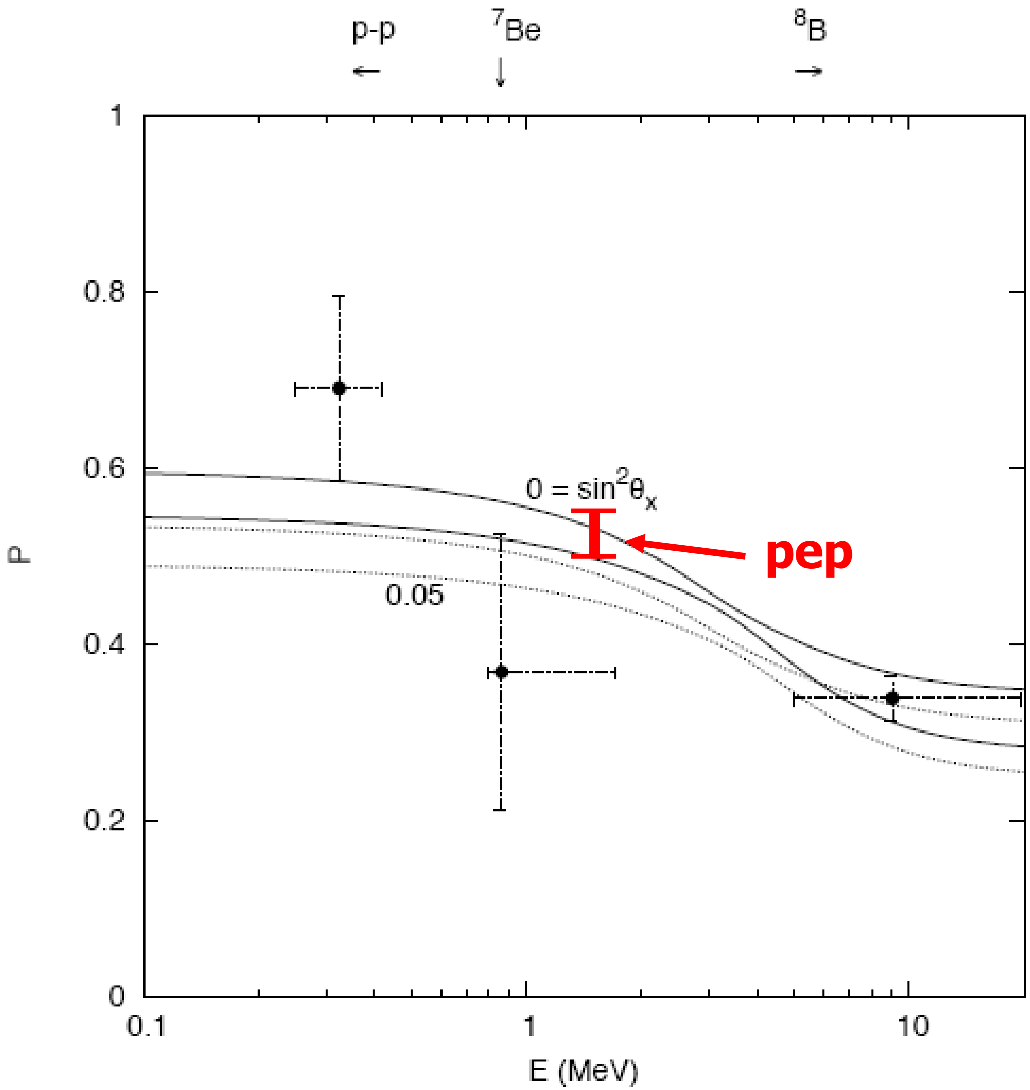


SNO+ Solar Neutrino Projected Capability

- with backgrounds at KamLAND levels
  - U, Th achieved
  - ^{210}Pb and ^{40}K post-purification KamLAND targets
  - external γ backgrounds
    - calculated based upon SNO external activities
    - fiducial volume 450 cm
- *pep* uncertainties
  - <±5% statistical (signal extraction from background)
  - ±3% systematic
  - ±1.5% SSM
  - e.g. it would be a measurement of the survival probability at 1.44 MeV of 0.55 ± 0.03

pep ν and θ_{13}

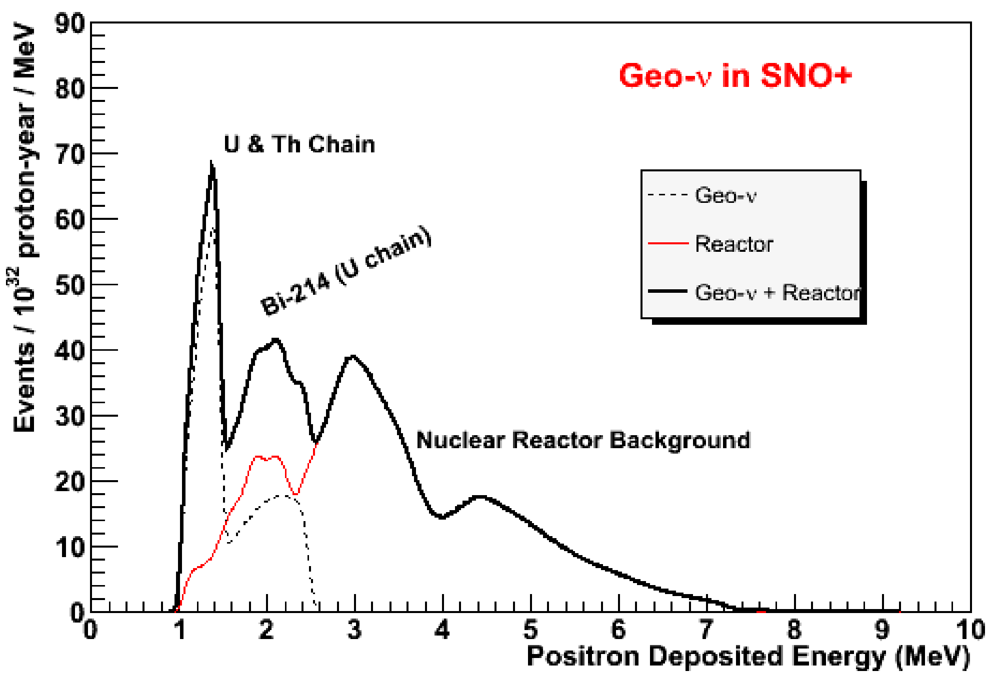
- solar neutrinos are complementary to long baseline and reactor experiments for θ_{13}
- hypothetical 5% stat. 3% syst. 1.5% SSM measurement
- has discriminating power for θ_{13}



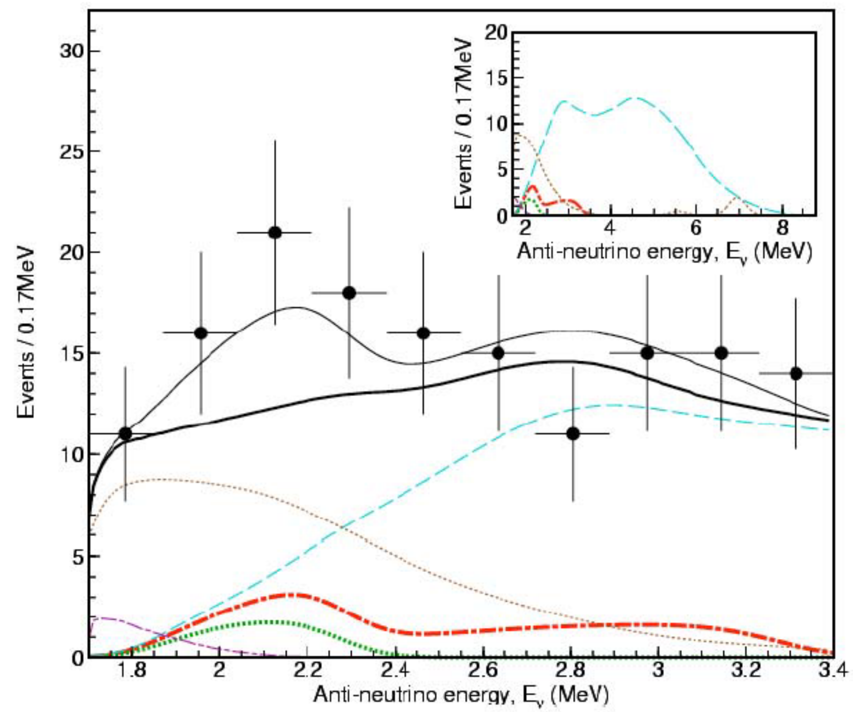
Geo-Neutrino Signal

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

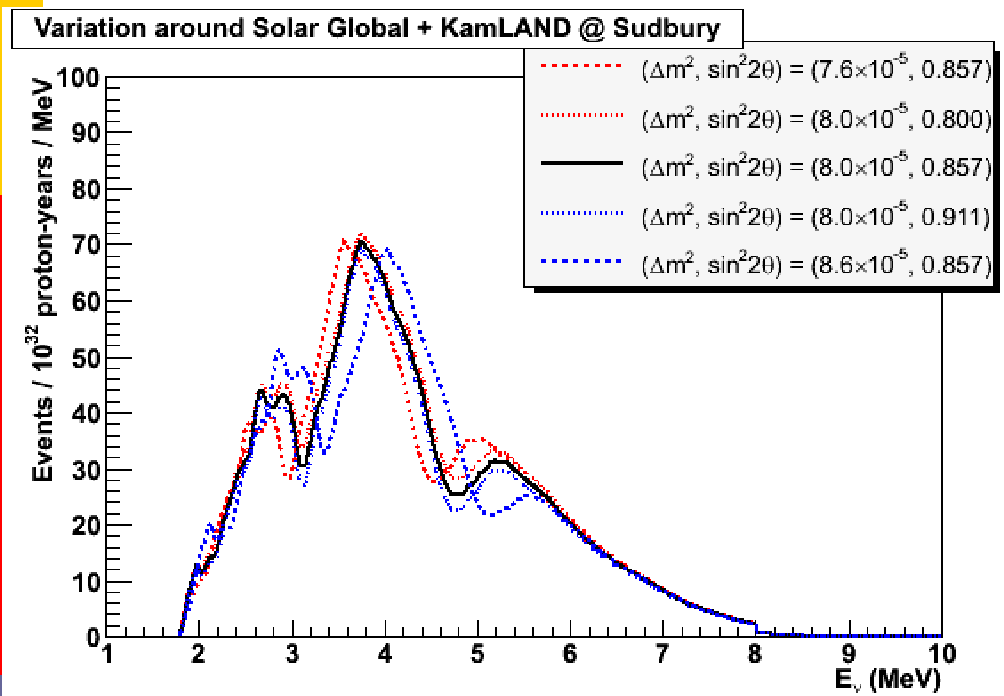


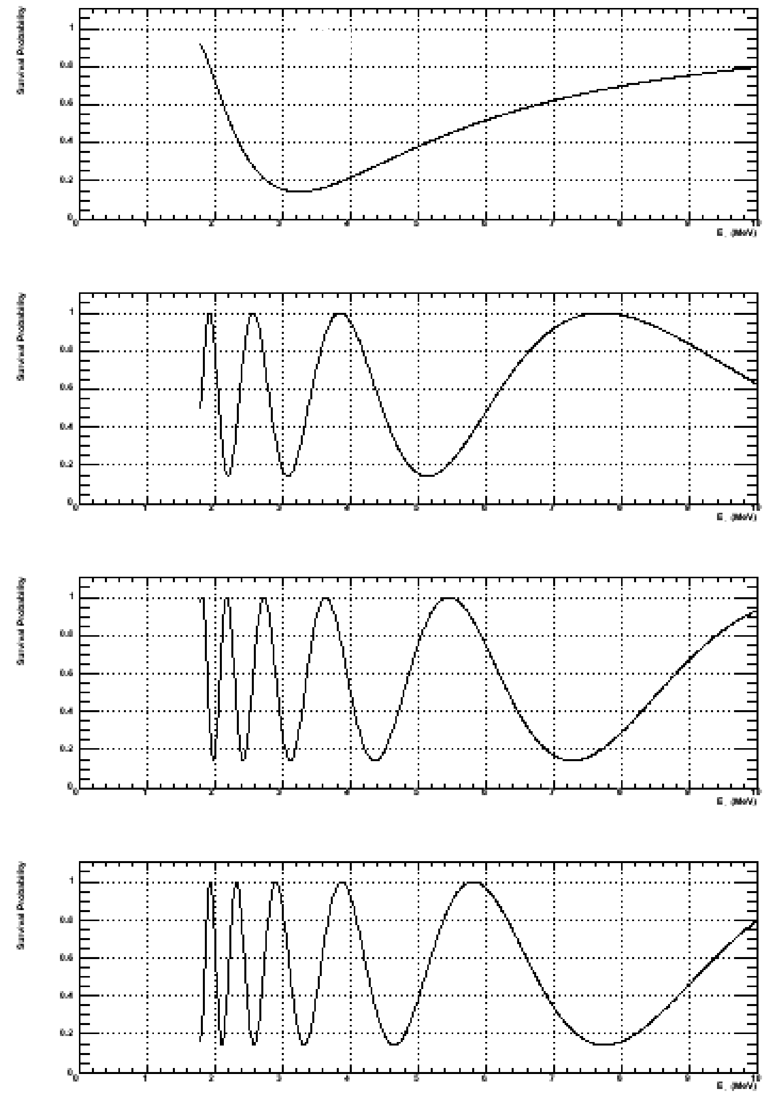
SNO+ geo-neutrinos and reactor background



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

Reactor Neutrino Oscillations





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

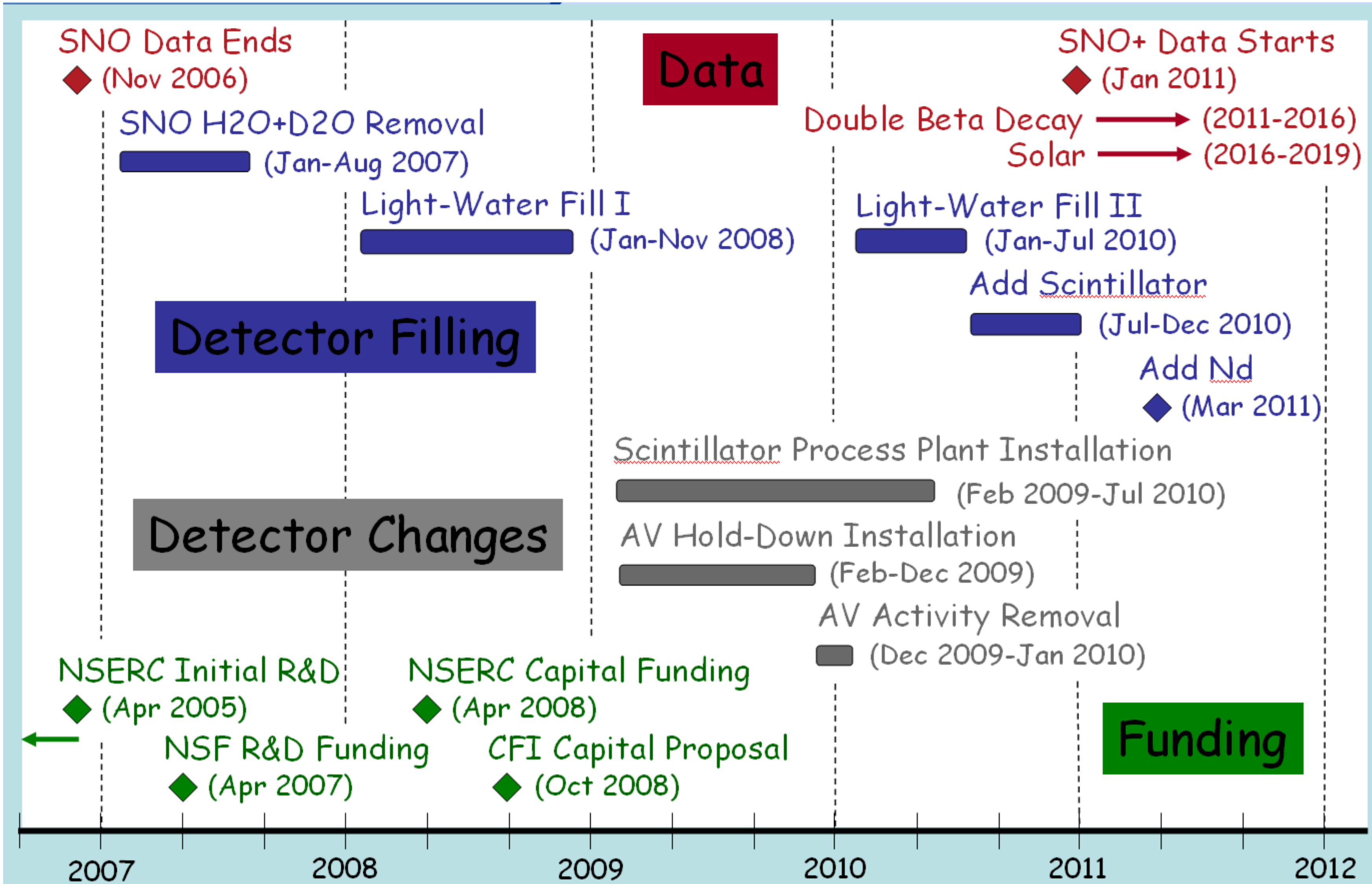
SN Neutrino Detection in SNO+

SNO+			vs. Super-Kamiokande	
CC:	$\overline{\nu}_e + p \rightarrow n + e^+$	(260) 41%	$\overline{\nu}_e + p \rightarrow n + e^+$	(7000) 91%
	$^{12}C(\nu_e, e)^{12}N$	(30) 4.7%		
	$^{12}C(\overline{\nu}_e, e^+)^{12}B$	(10) 1.5%		
NC:	$^{12}C(\nu_x, \nu_x)^{12}C^*$	(60) 9.3%	$^{16}O(\nu_x, \nu_x)^{16}O^*$	(410) 5%
	$\nu_x + p \rightarrow \nu_x + p$	(270) 42%		
ES:	$\nu_x + e \rightarrow \nu_x + e$	(12) 1.9%	$\nu_x + e \rightarrow \nu_x + e$	(300) 4%

Summary Points

- diverse and exciting neutrino physics
- SNO+ double beta decay is competitive and could be leading the field with an early start
- SNO+ is the most interesting solar neutrino experiment to be done post-SNO
- SNO+ geo-neutrinos will be a *Nature* publication of considerable popular science interest…for free!
- SNO+ reactor neutrino "oscillation dip moves as L/E" will be an easy *PRL* publication…for free!
- we have the required technical skills in our team
  - SNO+ includes KamLAND and Borexino members and experience
- we have proven SNO operations capability
- much of the development activity is straightforward engineering; nothing all that exotic is being proposed

SNO+ Schedule and Milestones



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