Neutrino physics with the SNO+ experiment

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Outline

- Introduction
- Double Beta Decay
- The SNO+ experiment
- Double Beta decay phase
- Neutrino Physics programme
- Conclusions

What we know:

-Neutrinos have mass

-Squared mass differences

Library of Congress

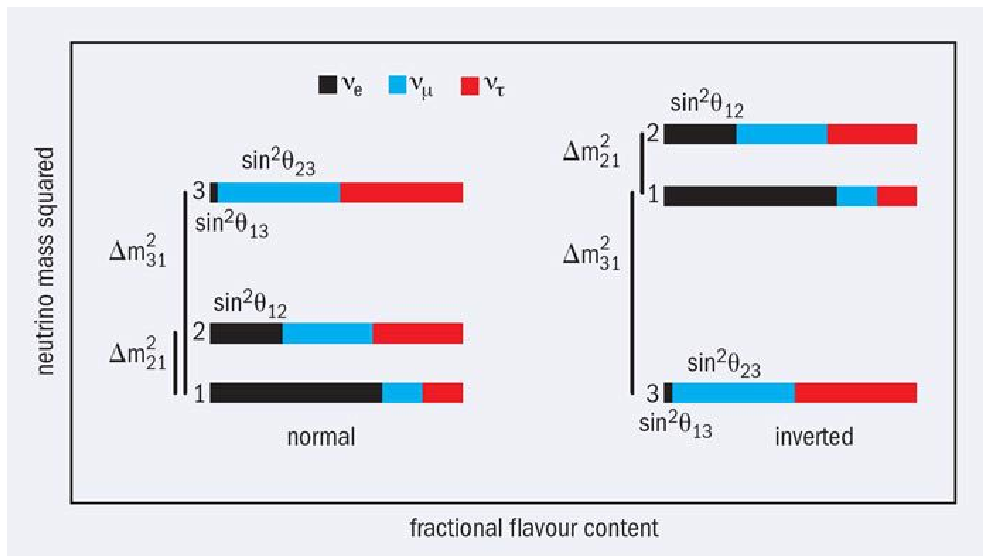
What we don't know:

-Absolute mass scale

-Mass hierarchy

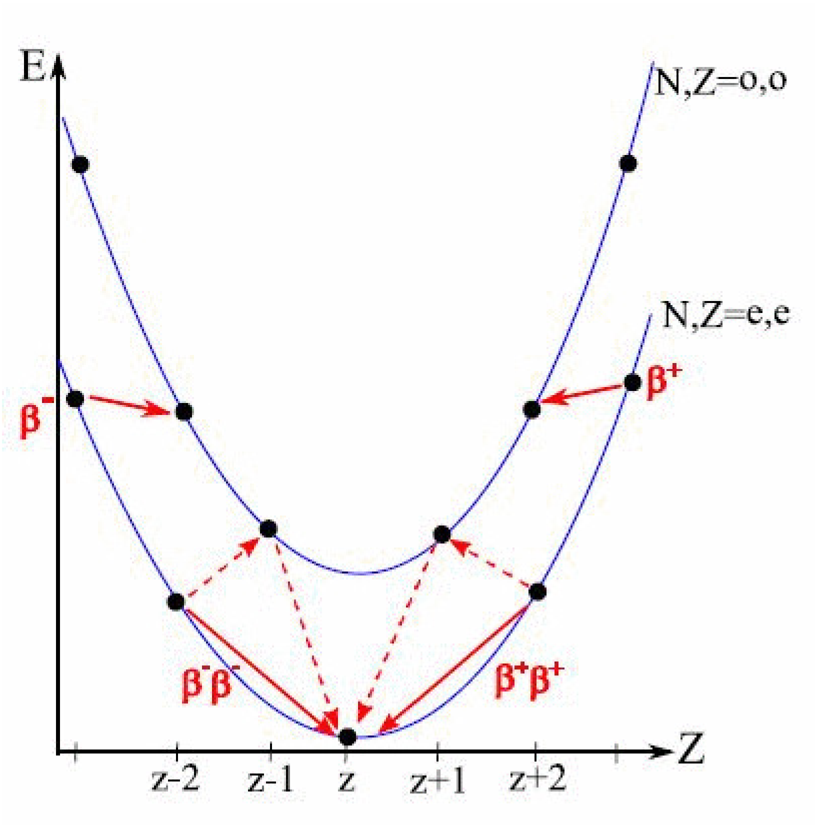
-Dirac vs Majorana

- Dirac neutrino (ΔL=0, $\nu \neq$ anti ν)
- Majorana neutrino (ΔL=2, $\nu =$ anti ν)

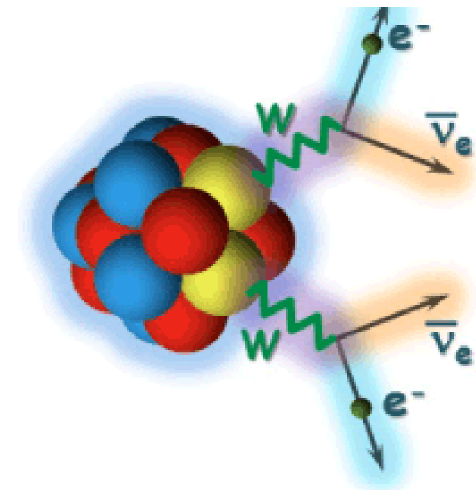


Double Beta Decay

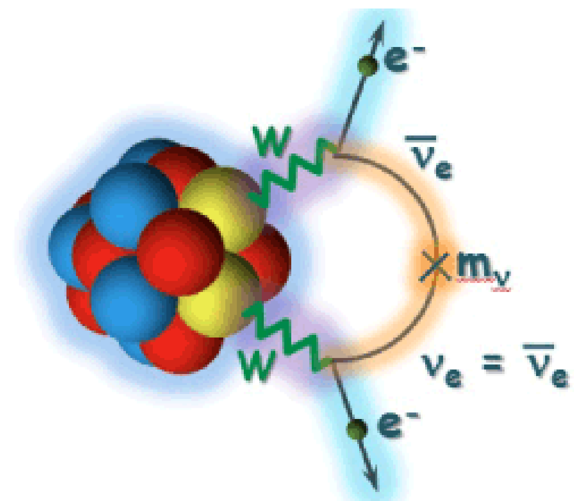
Beta decay
is energetically forbidden



- 35 isotopes in nature
- $T_{1/2} > 10^{20}$ yrs



$$(A, Z) \rightarrow (A+2, Z) + 2e^- + 2\bar{\nu}_e$$

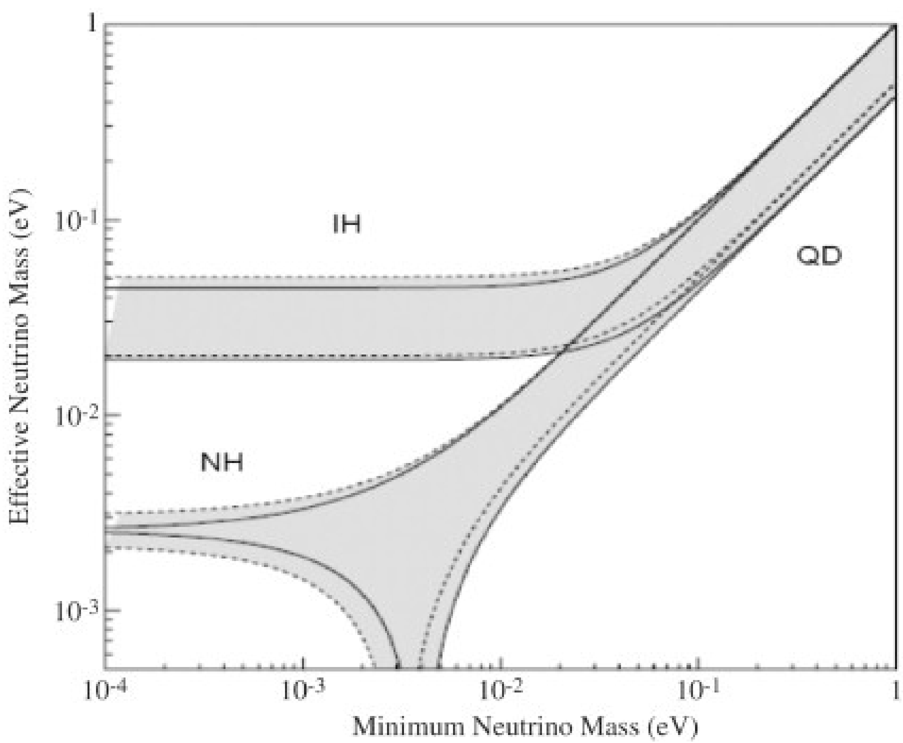


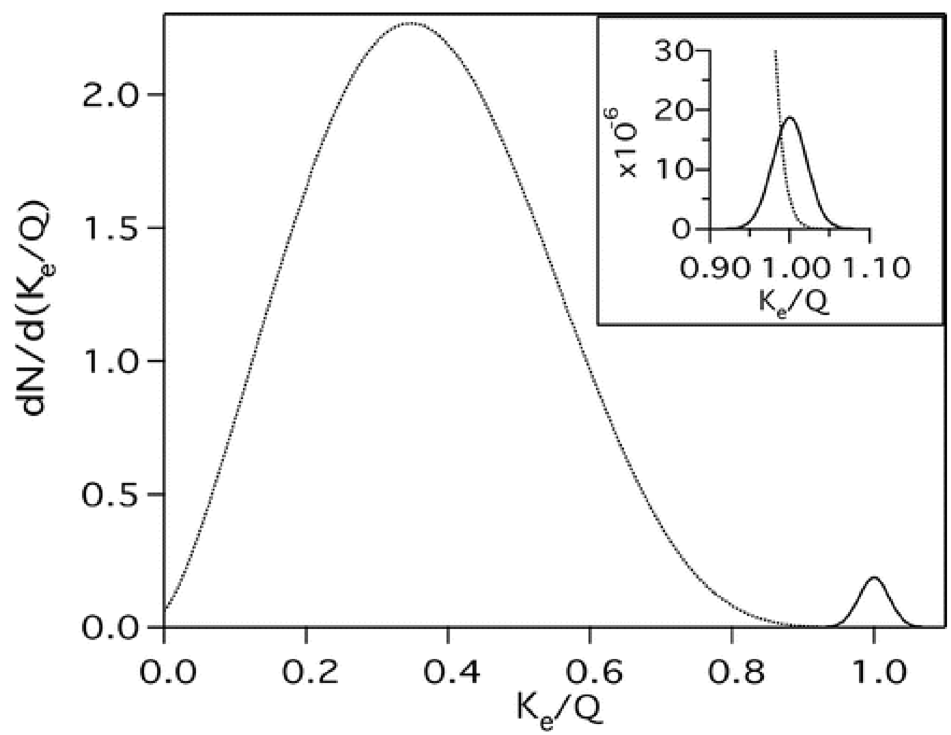
$$(A, Z) \rightarrow (A+2, Z) + 2e^-$$

Double Beta Decay

$$[T^{0\nu}_{1/2}]^{-1} = G^{0\nu}|\mathcal{M}^{0\nu}|^2\langle m_{\beta\beta}\rangle^2$$

- $G^{0\nu}$: Phase space factor
- $\mathcal{M}^{0\nu}$:Nuclear matrix element
- $\langle m_{\beta\beta}\rangle$: effective ν mass
  $\langle m_{\beta\beta}\rangle = \sum_i U^2_{ei} m_i$





$$[T^{0\nu}_{1/2}]^{-1} \propto \alpha\eta\sqrt{\frac{M\times t}{\Delta E\times B}}$$

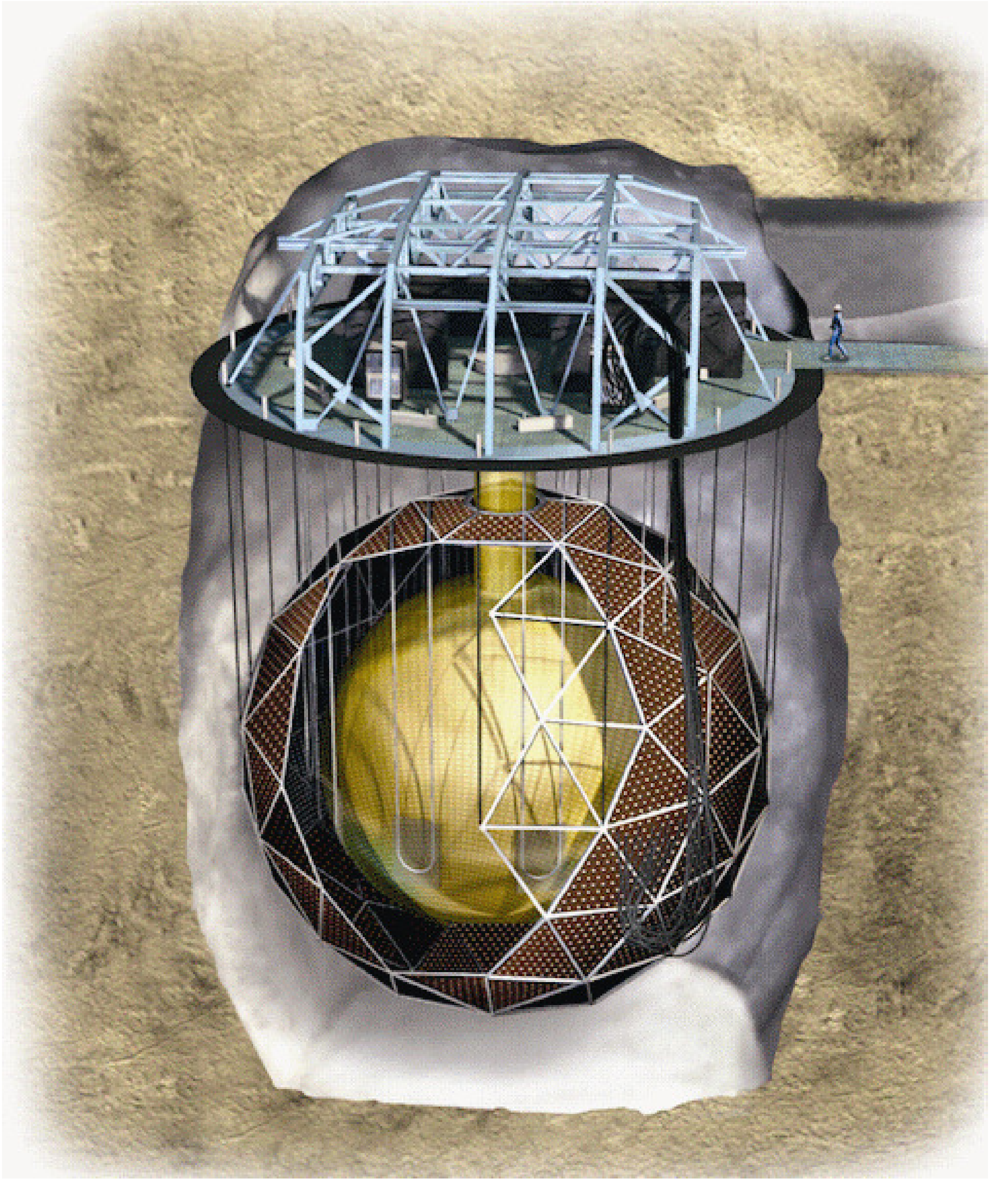
- isotopic abundance, efficiency
- high mass, long exposure
- low background, good energy resolution

SNO+ detector

2km underground @ SNOLAB

- Acrylic vessel
  $\phi = 12$ m
- Liquid scintillator
  780 tonnes
- 1700 tons H_2O inner
- 5700 tons H_2O outer
- 9500 PMTs

- Upgraded electronics
- Hold-down ropes system
- New calibration systems
- Scintillator plant



SNO+ Collaboration

Queen's University
University of Alberta
Laurentian University
SNOLAB
TRIUMF

BNL, AASU
Penn, UNC, BHSU
U. Washington
UC Berkeley/LBNL
Chicago, UC Davis

Oxford
Sussex
QMUL
Liverpool
Lancaster

LIP Lisboa
LIP Coimbra

TU Dresden

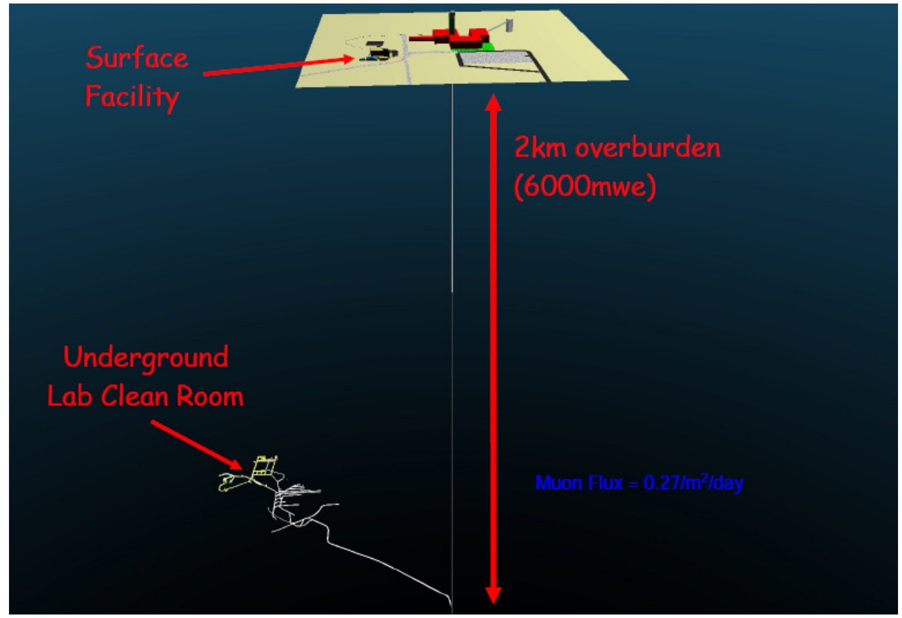
UNAM

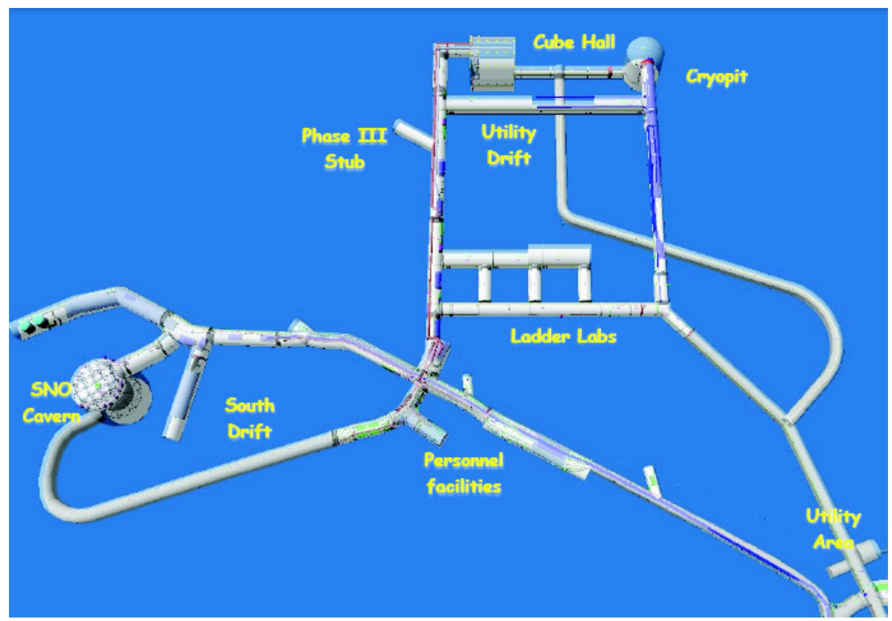
SNO+ at SNOLAB

SNOLAB

deepest and cleanest large-space international facility in the world

- **2 km underground near Sudbury, Ontario**
- **ultra-low radioactivity background environment Class 2000**
- **6000 m.w.e. overburden**
- **70 muons/day**
- **Physics programme focused on neutrino physics and direct dark matter searches**





SNO+ Physics Goals

- **Double beta decay with Tellurium**
- **Low energy solar neutrinos**
- **Geo-neutrinos**
- **Reactor neutrino oscillations**
- **Supernova neutrinos**
- **Nucleon decay**
- **Other exotic searches: axions**

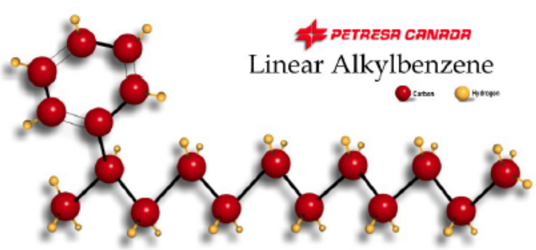
The top priority is a sensitive search for neutrinoless double-beta decay ($0\nu\beta\beta$) in ^{130}Te

Linear alkylbenzene (LAB) + 2,5-diphenyloxazole (PPO) fluor + Te

- Compatible with acrylic
- Inexpensive
- High light yield ($\sim 10000\gamma$/MeV)
- Safe
- Attenuation $\sim$ 20 m
- α/β timing discrimination

Properties:

- Density = 0.86 g/cm^3
- Flash point = 140 C
- Boiling point = 278-314 C



Double Beta Decay Phase

SNO+ Phase I
0.3% ^{nat}Te
($800\,kg$ ^{130}Te)

- High statistics
  (large mass)
- Low backgrounds
  (Fiducial cut, purification)
- source $\neq$ detector
- Reuse existing detector
  SNO inheritance
- Scalability
- Other isotopes

Why Tellurium?

- High abundance (34%)
- Relatively inexpensive compared
  to enriched isotope
- Favorable $|M^{2\nu}|/|M^{0\nu}|$
  $2\nu\beta\beta$ rate is relatively low
- No optical absorption lines
- Now loadable in scintillator:
  Te-LS prepared at BNL
  (light yield: $\sim 9400\gamma$/MeV)

Backgrounds

- Internal
  - Tellurium $2\nu\beta\beta$
  - Solar $^8B\nu$ ES
  - $(\alpha, n) + \gamma$
  - U/Th chains
    Scintillator and Tellurium
  - Cosmogenics
- External
  - PMTs
  - Acrylic vessel
  - Hold-up/down ropes
  - Water shielding

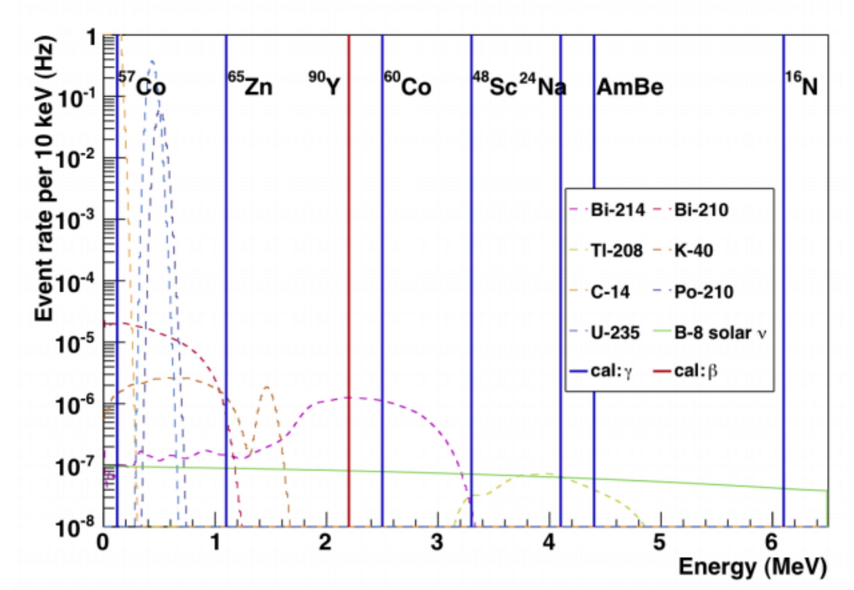
Purification

- Multistage distillation
  (to remove heavy metals,
  improves UV transparency)
- N_2/water vapor gas
  stripping
  (to remove Rn, Kr, Ar, O_2)
- Water extraction
  (to remove K, Ra, Bi)
- Metal scavenging
  (assay for solar phase)
  (to remove Ra, Bi, Pb)

- Th: 10^{-17} g/g
  ($\sim$ 3 cpd for ^{208}Tl and ^{228}Ac)
- U: 10^{-17} g/g ($\sim$ 9 cpd for ^{210,214}Bi)
- ^{40}K: 1.3 $\times 10^{-18}$ g/g
  ($\sim$ 23 cpd)
- ^{85}Kr, ^{39}Ar ($<$ 100 cpd)

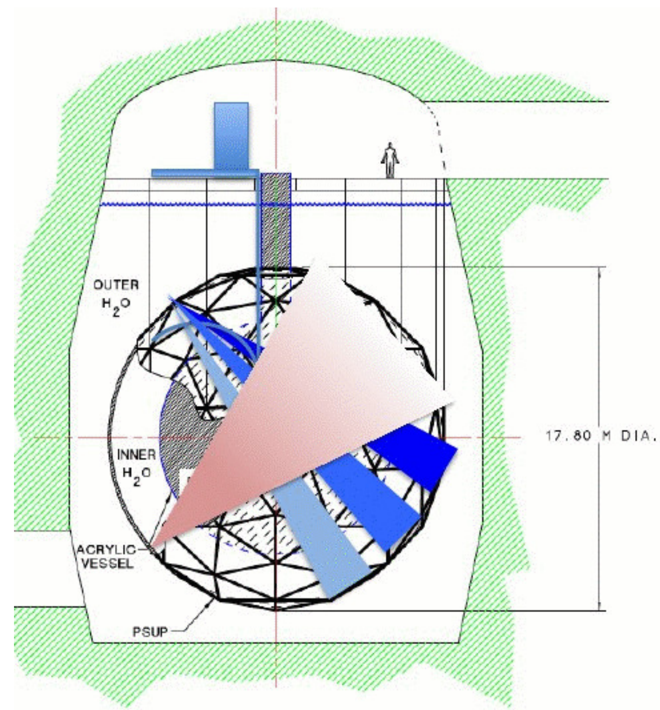
Detector response

Several calibration sources at different energies: AmBe, ^{65}Zn, ^{90}Y, ^{57,60}Co, ^{24}Na, ^{8}Li, ^{16}N

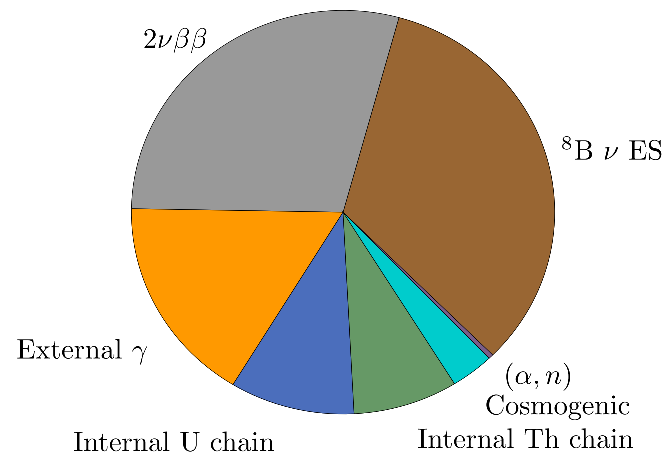


Optics

- **ELLIE:** Embedded LED Light Injection Entity
- **LED driven fibers mounted on the phototube sphere to monitor**
- **PMT timing calibration and gain**
- **Scattering and attenuation lengths**
- **Wavelength, opening angle, position, direction**

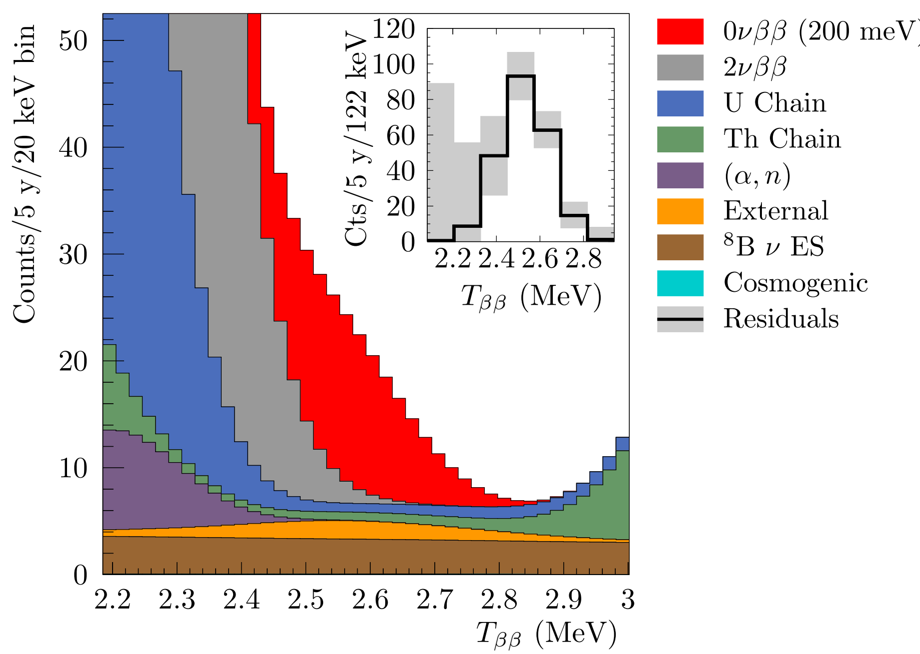


Double Beta Decay: Sensitivity



SNO+ $0\nu\beta\beta$ spectrum

- **5 years with 0.3% ^{nat}Te loading**
- **200 p.e./MeV**
  4.5% resolution at $Q_{\beta\beta}$
- **Fiducial volume: 3.5 m (20%)**
- **Energy window:**
  $-\sigma/2$ to$3\sigma/2$ around $Q_{\beta\beta}$
- **Assume BiPo tags 100% efficient for separate triggers**



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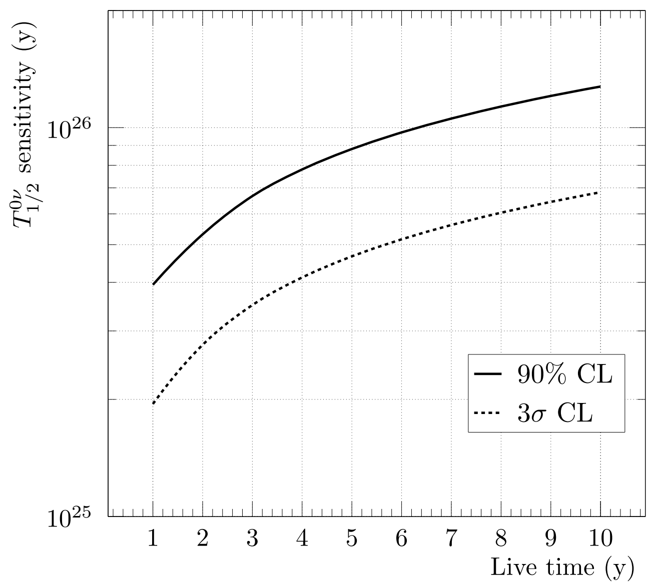
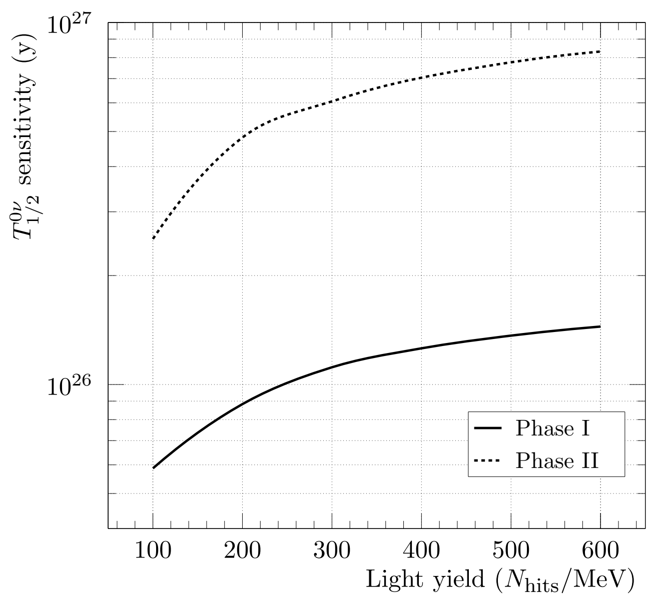


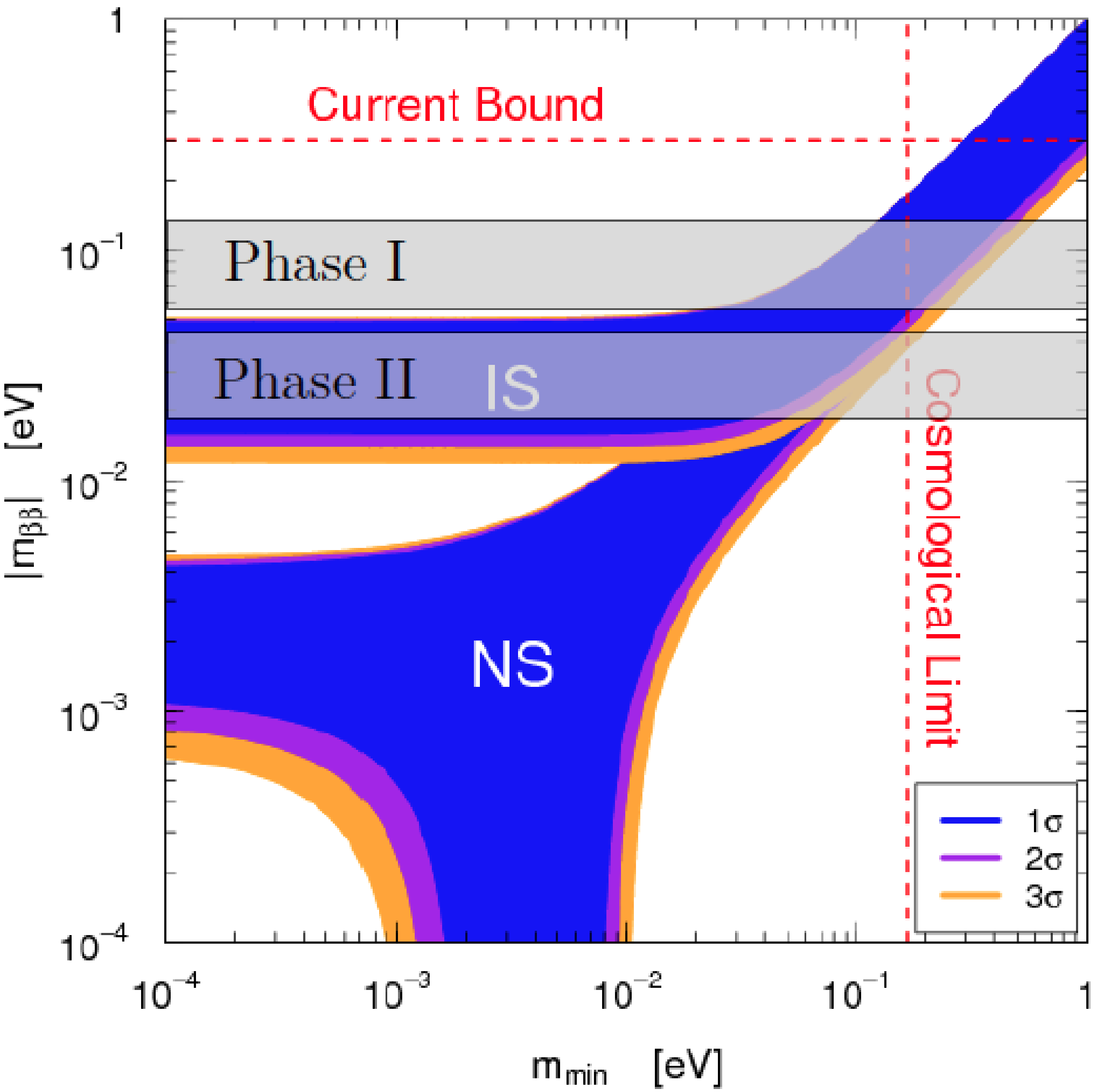


5 years:
$T_{1/2} = 9.84 \times 10^{25}$**yrs**
$m_{\beta\beta} = 66.5\, meV$
3 years:
$T_{1/2} = 4.27 \times 10^{25}$**yrs**
$m_{\beta\beta} = 101.0\, meV$
(90% C.L.)

- $M^{0\nu} = 4.03$ **(IBM-2)**
- $G^{0\nu} = 3.69 \times 10^{-14}$**/year**
- $g_A = 1.269$

Phase II:
3% ^{nat}**Te (8 tonnes** ^{130}**Te)**
450 p.e./MeV
3% energy resolution at $Q_{\beta\beta}$
$T_{1/2} = 8 \times 10^{26}$**yrs**
(90% C.L. in 5 years)

Sensitivity

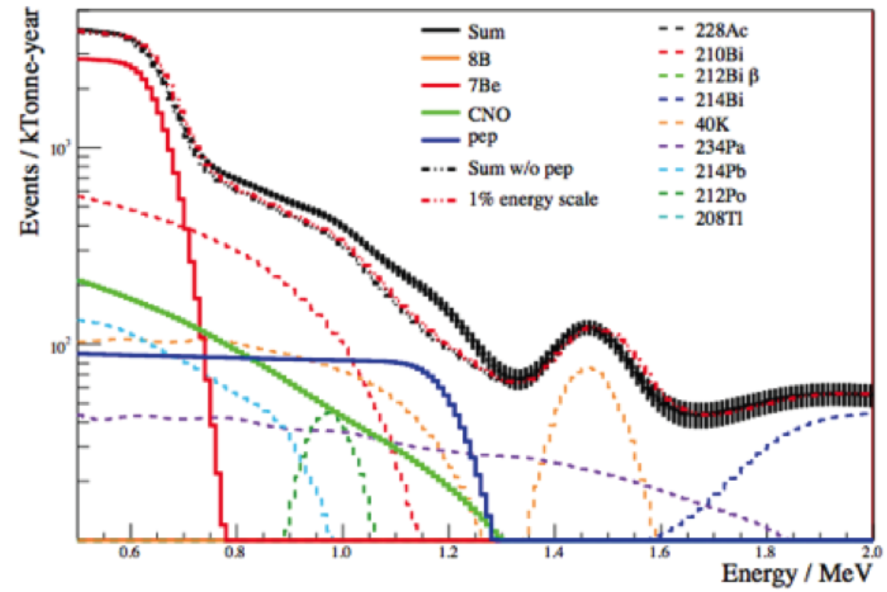


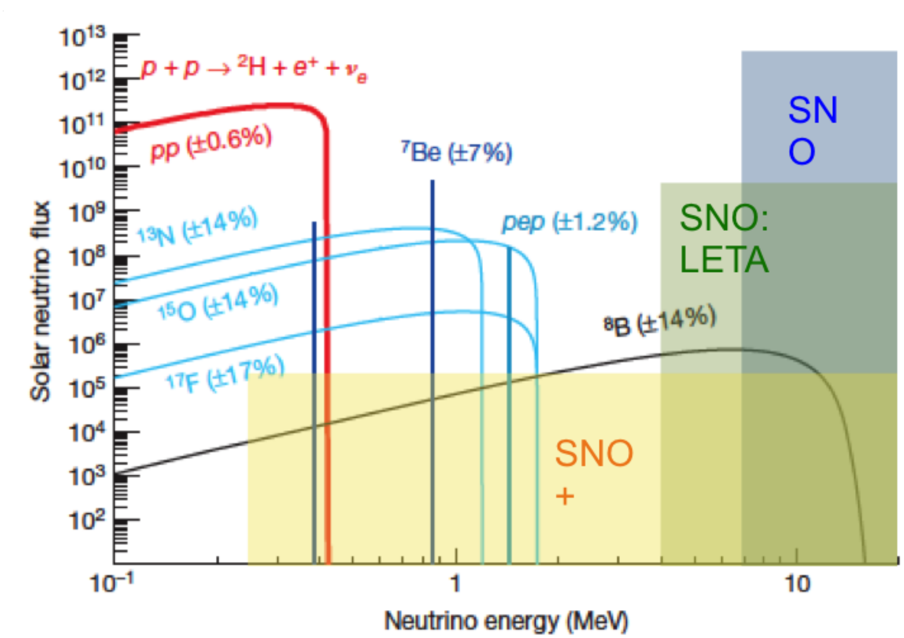
adapted from Bilenky & Giunti

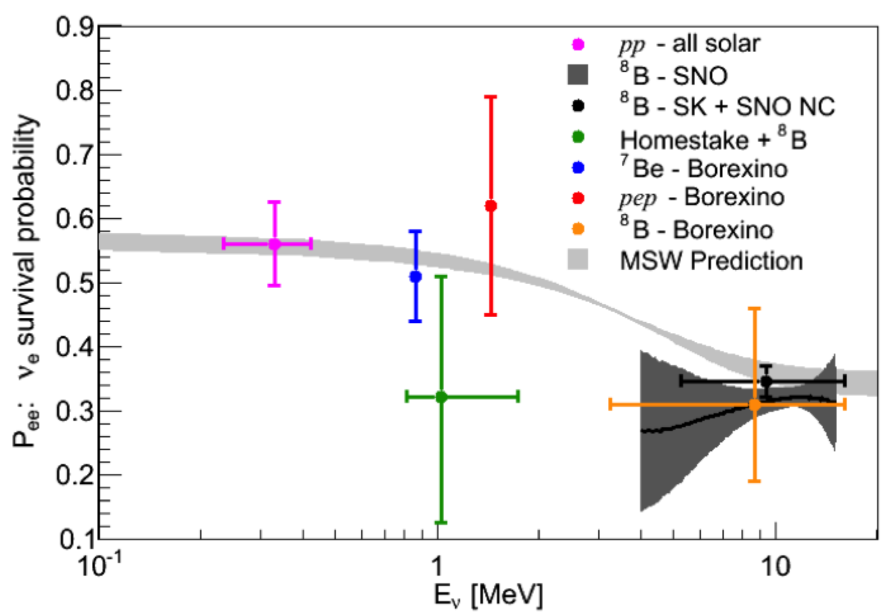
Solar Neutrinos

Precise measurement of low energy solar neutrinos

confirm that we understand the neutrino oscillation mechanism, how neutrinos interact with matter and know what happens inside the sun





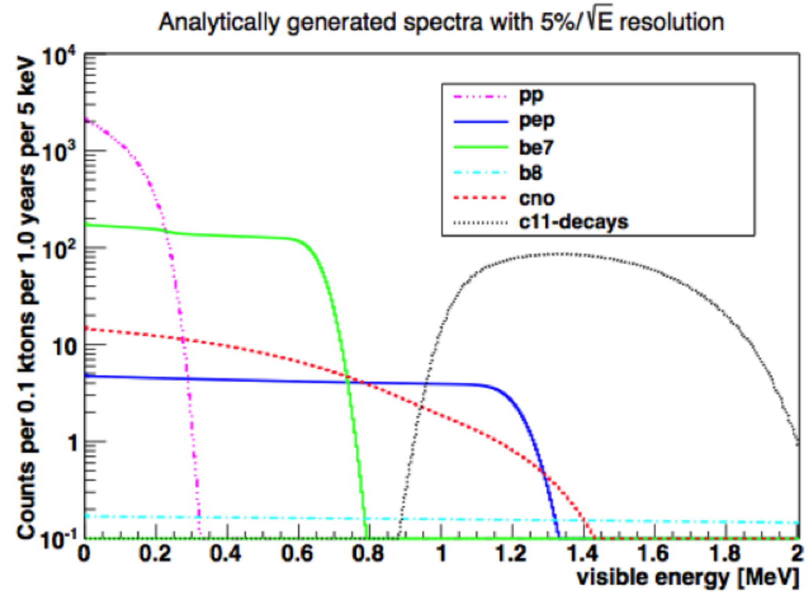


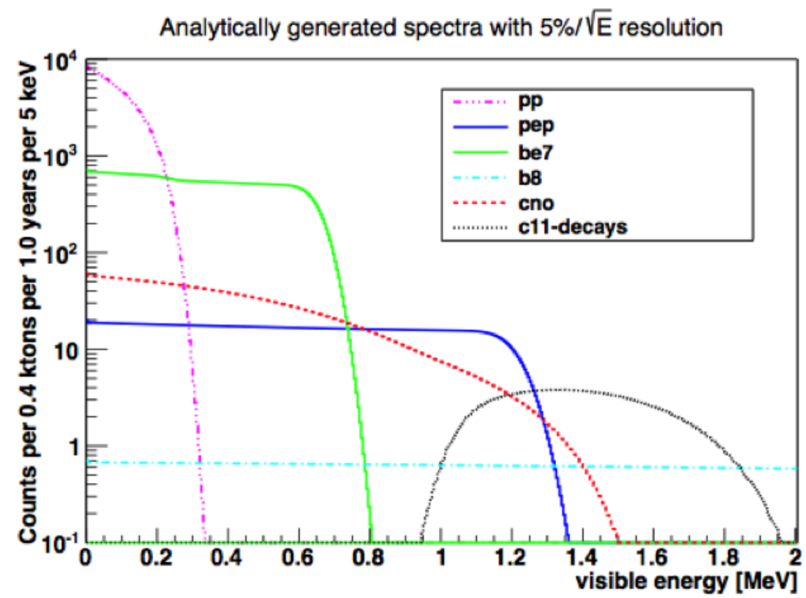
Low Energy Solar Neutrinos

Precise measurement of low energy solar neutrinos

- Solar neutrinos probe astrophysics and elementary particle physics models
- Solar metallicity (CNO)
- Neutrino oscillations (pep)

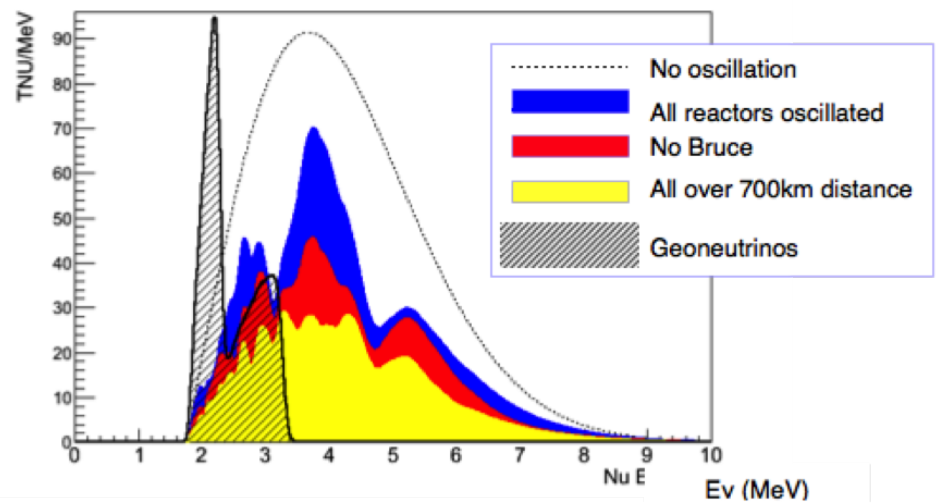
SNOLAB deeper than LNGS!

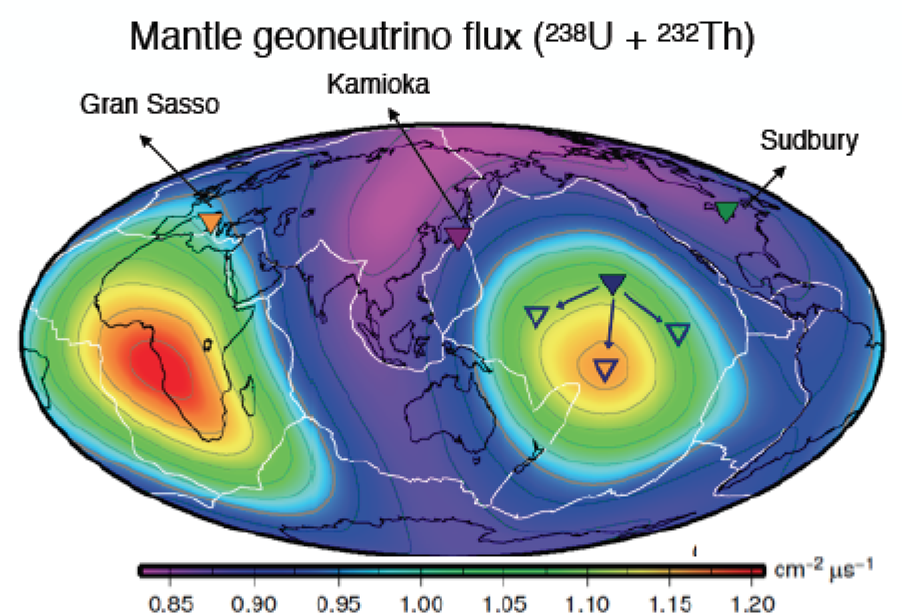




Detection through inverse beta decay (delayed coincidence)

- Geo
  - U, Th and K in Earth's crust and mantle
  - Investigate origin of the heat produced within Earth
  - Low reactor background: reactor/Geo ∼1.1
- Reactor
  - 3 nearby reactors dominate flux
  - Precision probe of neutrino oscillations



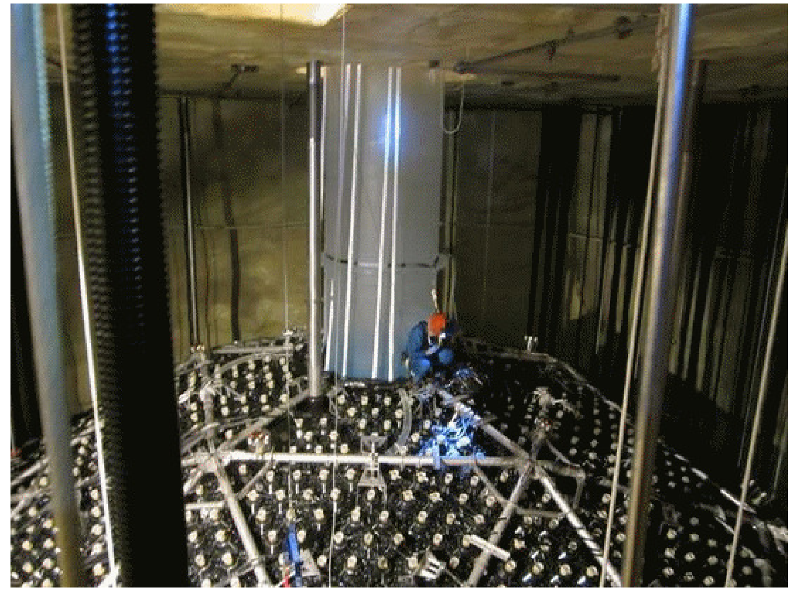


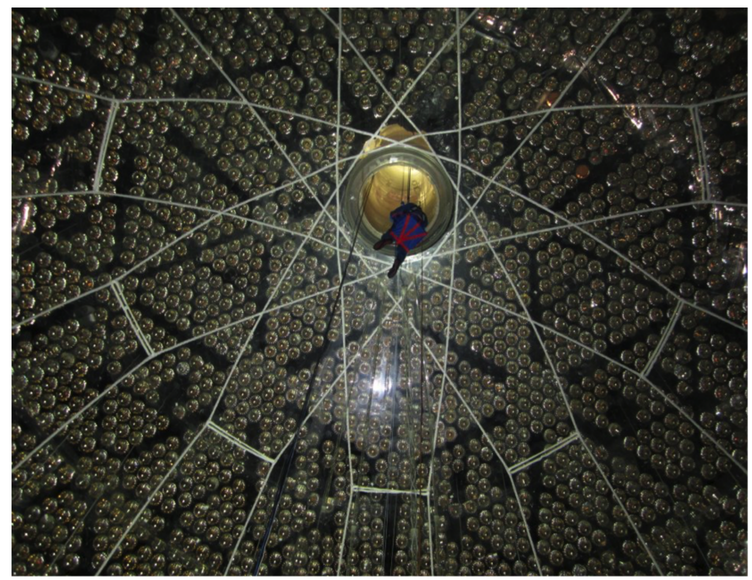
SNO+ Supernova Signal

Type II SN release ∼99% of their gravitational binding energy as ν's
Galactic supernovae estimated to happen once in ∼30 years
Neutrinos provide "early warning" of supernova for optical observations
Neutrinos provide information on neutrino oscillations, the supernova itself, cosmological parameters, etc.

- **Elastic scattering:**
  - 8 evts: $\nu_e + e^- \rightarrow \nu_e + e^-$
  - 3 evts: anti-$\nu_e + e^- \rightarrow$ anti-$\nu_e + e^-$
  - 4 evts: $\nu_{\mu,\tau} + e^- \rightarrow \nu_{\mu,\tau} + e^-$
  - 2 evts: anti-$\nu_{\mu,\tau} + e^- \rightarrow$ anti-$\nu_{\mu,\tau} + e^-$
- **Charged Current:**
  - 263 evts: anti-$\nu_e + p \rightarrow n + e^+$
  - 27 evts: $\nu_e + {}^{12}C \rightarrow {}^{12}N + e^-$
  - 7 evts: anti-$\nu_e + {}^{12}C \rightarrow {}^{12}B + e^+$
- **Neutral Current:**
  - 58 evts: $\nu_x + {}^{12}C \rightarrow {}^{12}C^*(15.11\text{MeV}) + \nu_x$
  - 273 evts: $\nu_x + p \rightarrow \nu_x + p$

SNO+ detector





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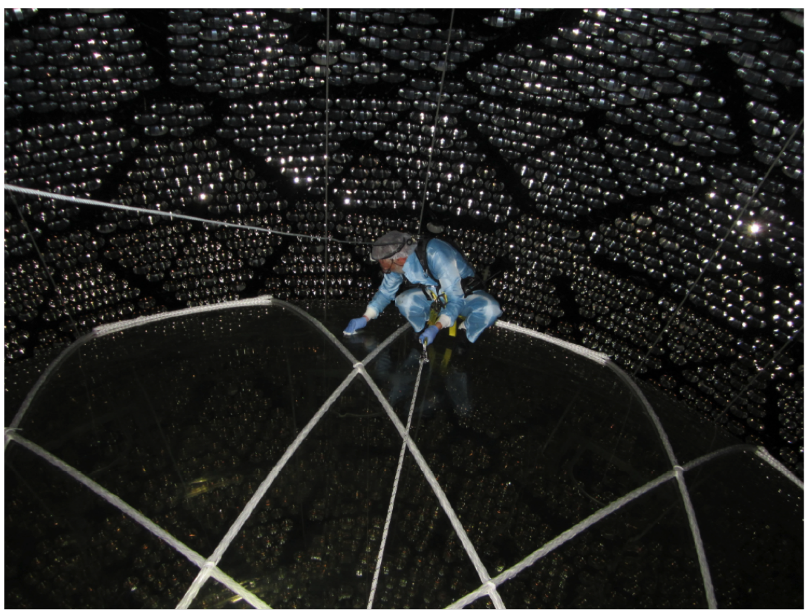

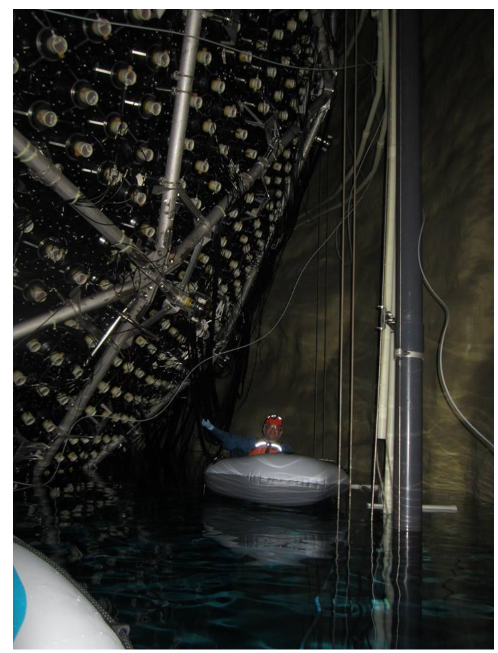

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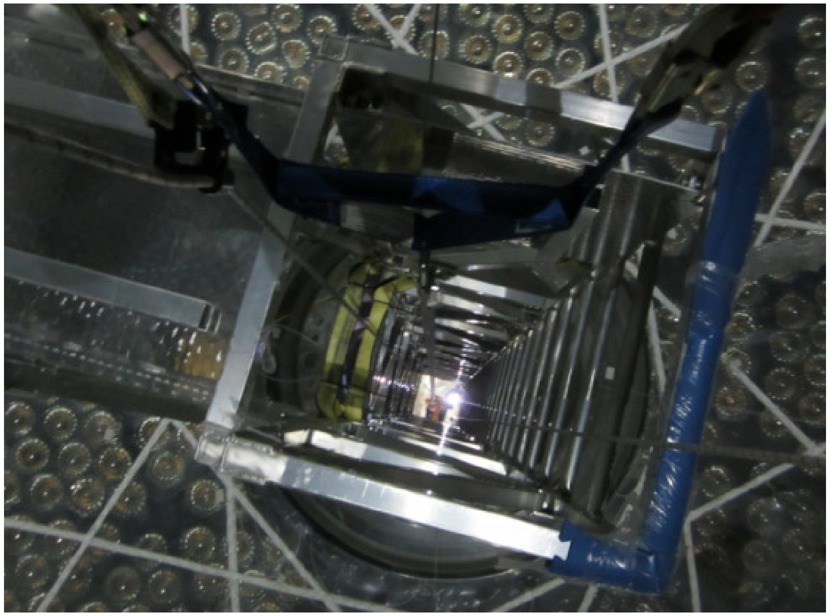

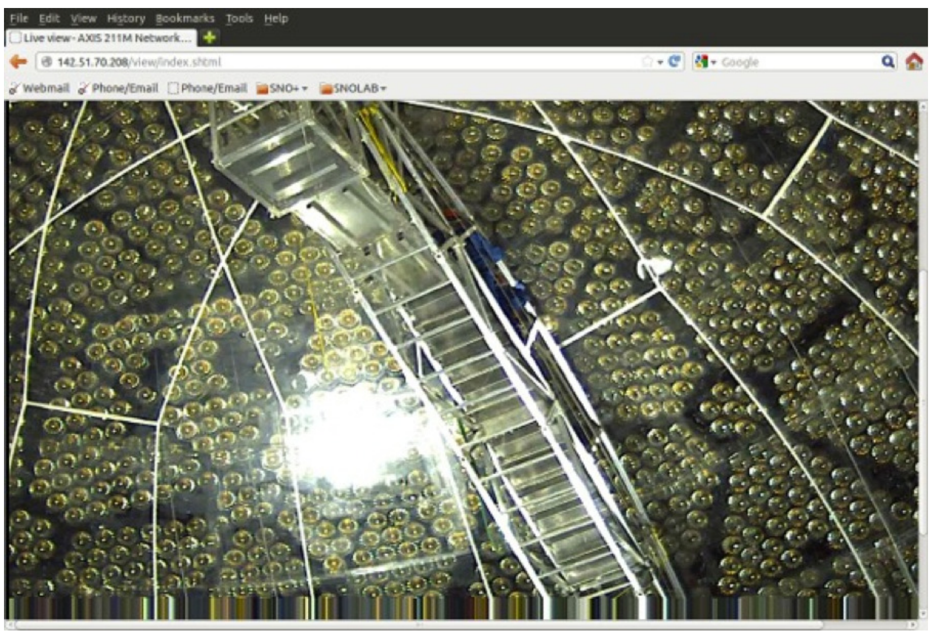

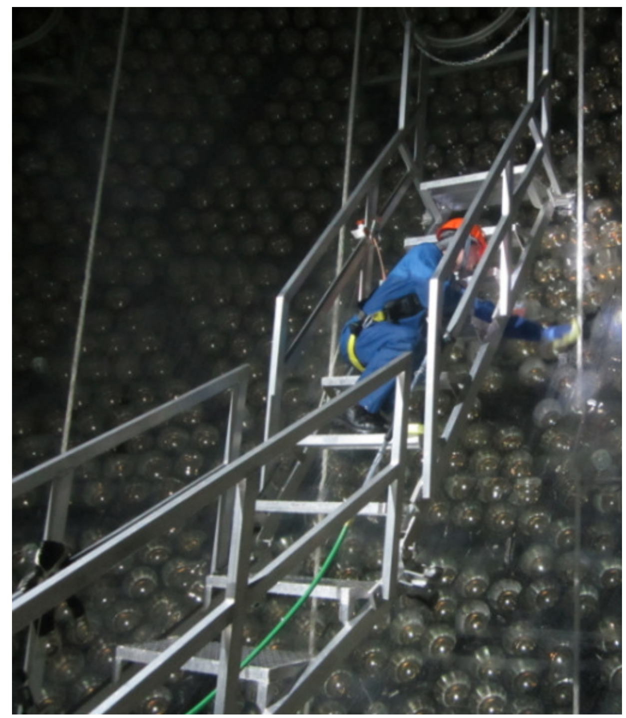

Status and plans

- **Current Status**
  - **Filling with water**
  - **Commissioning runs**
- **H2 2015: Water**
  - **Soak Rn daughters from the acrylic vessel**
  - **Calibrations, background measurements**
  - **Invisible nucleon decay search, supernova live**
- **H1 2016: Scintillator**
  - **Soak Rn daughters from the acrylic vessel**
  - **Calibrations, scintillator background measurements**
  - **Reactor antineutrino, geoneutrinos, solar neutrinos, supernova**
- **H2 2016: Te-loaded Scintillator**
  - **Neutrinoless double-beta decay search**
  - **Calibrations**
  - **Solar, reactor, geoneutrinos, supernova live**

Conclusions

SNO+ is a large liquid scintillator detector with a rich physics program

- **Priority on neutrinoless double beta decay (130-Tellurium)**
- **Invisible nucleon decay during water filling**
- **Also low-energy solar neutrinos, reactor and geo antineutrinos, supernova neutrinos, exotics like axions**

**Experiment is currently under construction,
with water data expected this year
scintillator fill and neutrinoless double beta decay in 2016**

Exciting neutrino physics just around the corner!

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IFUNAM is a new member since January 2015
enthusiastically approved by the SNO+ board