Neutrinoless Double Beta Decay Search with SNO+

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for the SNO+ Collaboration
University of Alberta

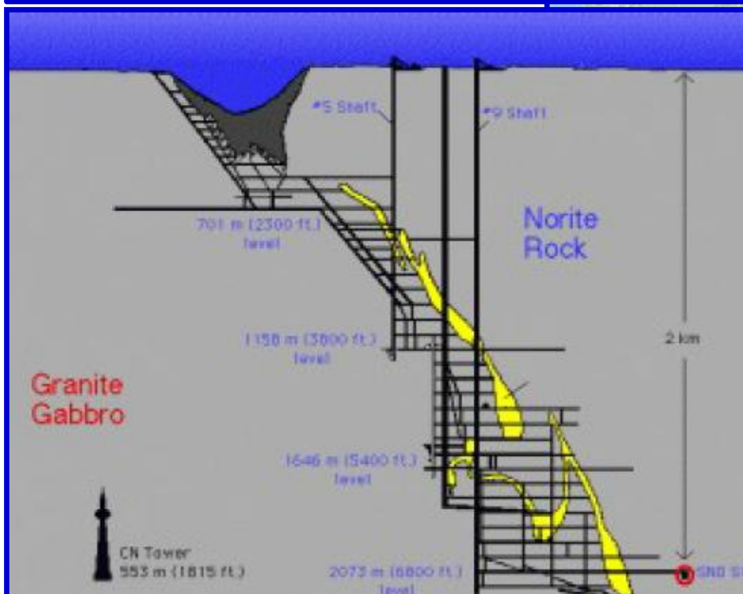
8th Nov. 2016

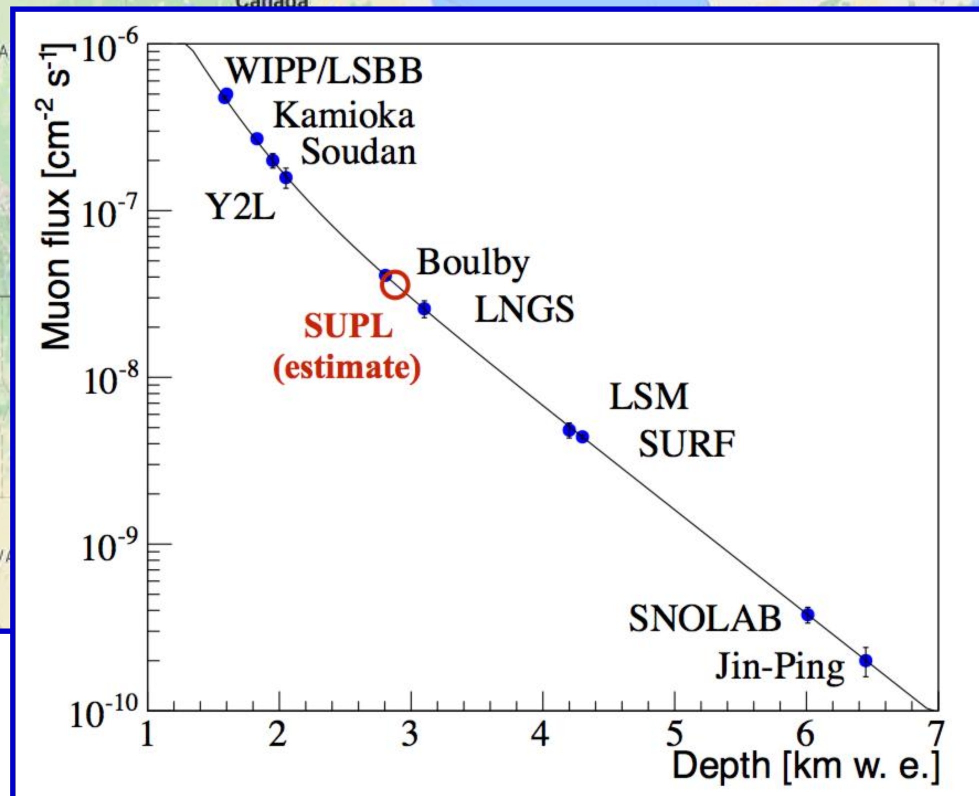
Location


SNOLAB


Hudson Bay
Canada
ALBERTA
MANITOBA
SASKATCHEWAN
NEWFOUNDLAND AND LABRADOR
ONTARIO
QUÉBEC
SNOLAB
Montreal
NB
PE
NOVA SCOTIA
MAINE
Toronto
VT
NH
MA
CT RI
NEW YORK
PENN
NJ
DE
MD
WEST VIRGINIA
VIRGINIA
KENTUCKY
OHIO
INDIANA
ILLINOIS
MICHIGAN
WISCONSIN
Chicago
IOWA
MISSOURI
KANSAS
NEBRASKA
MINNESOTA
NORTH DAKOTA
SOUTH DAKOTA
MONTANA
WYOMING
COLORADO
United States
UTAH
NEVADA
IDAHO
OREGON
WASHINGTON
an Francisco

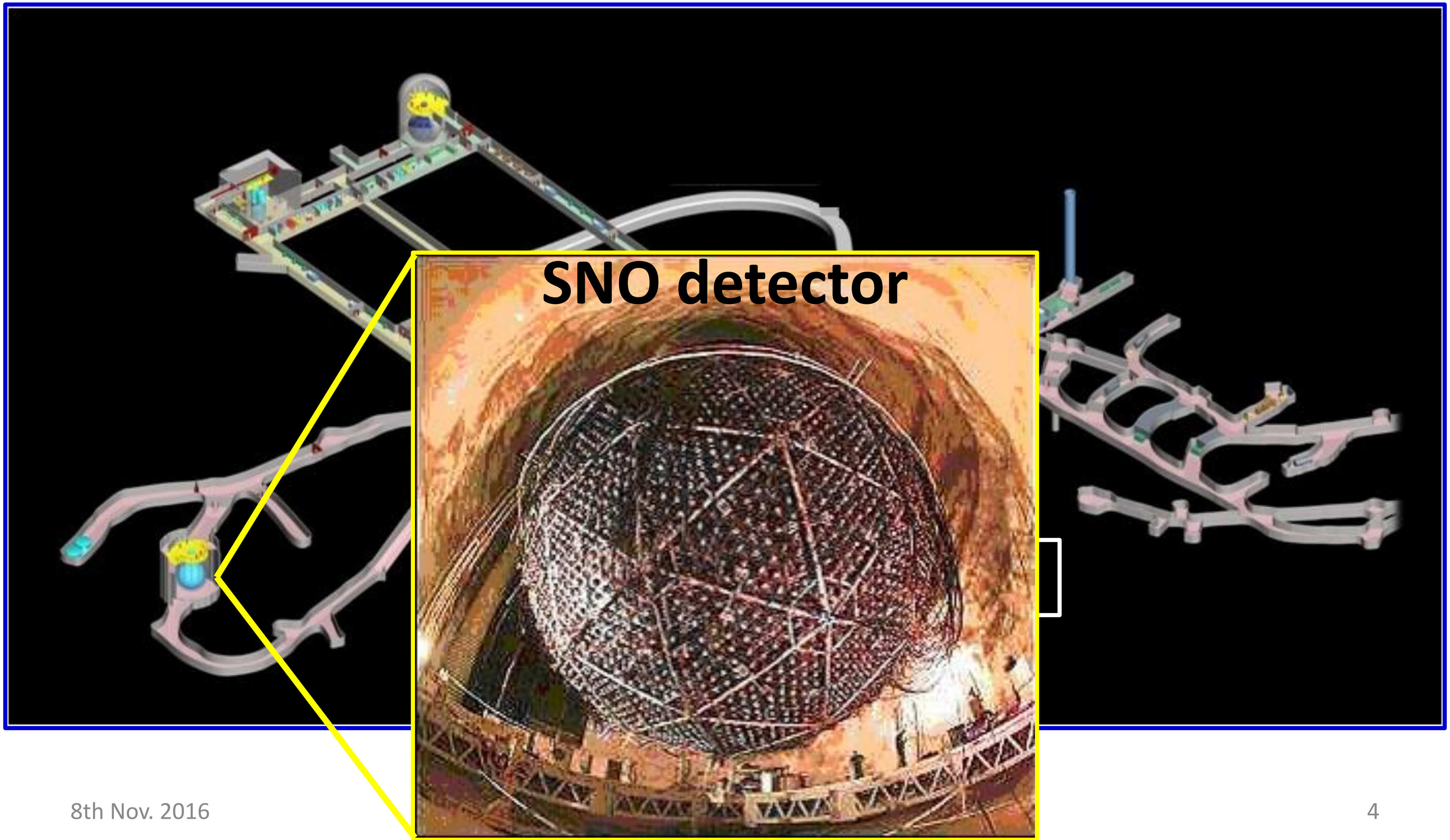
Location, 5890 mwe



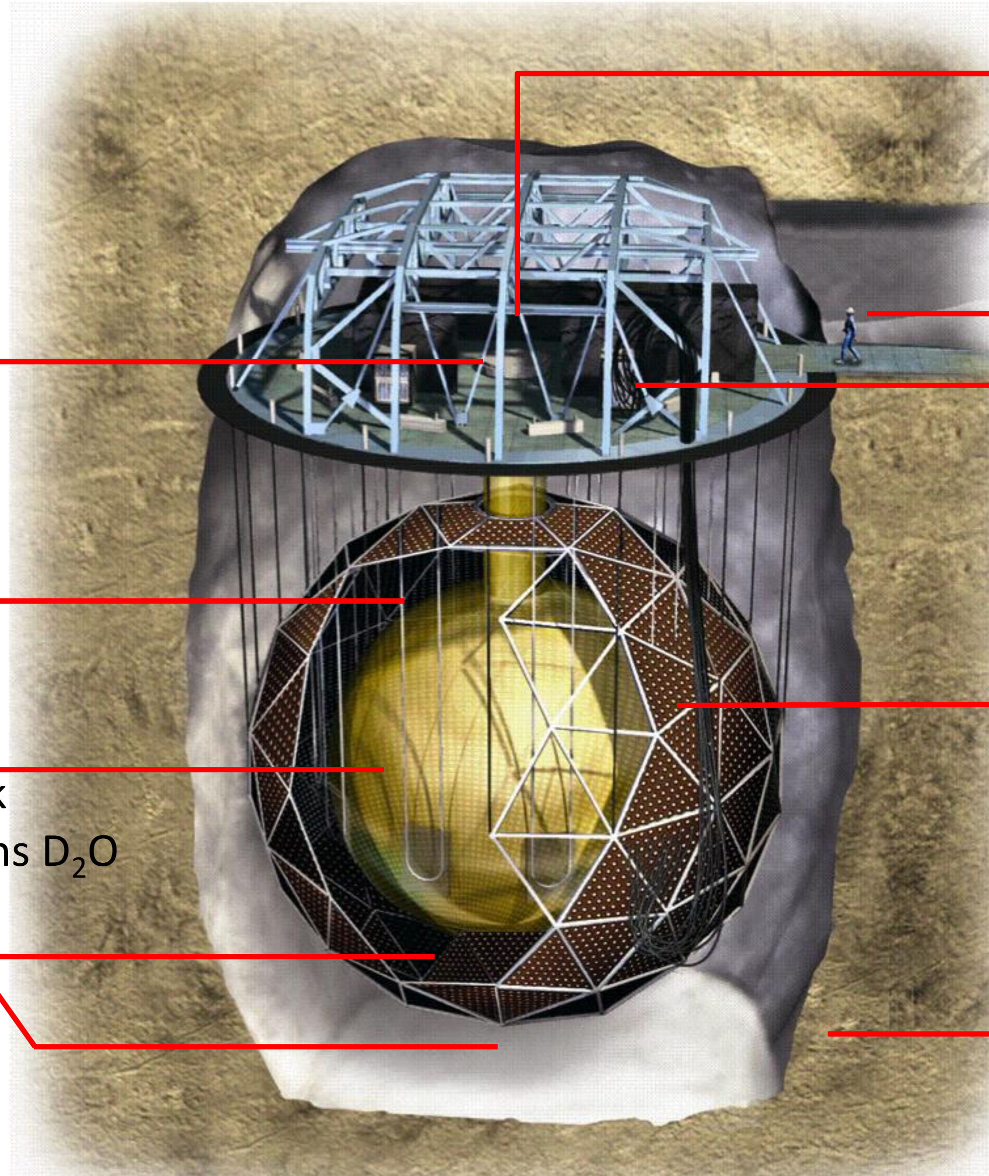


~63 muons/ day passing through the detector

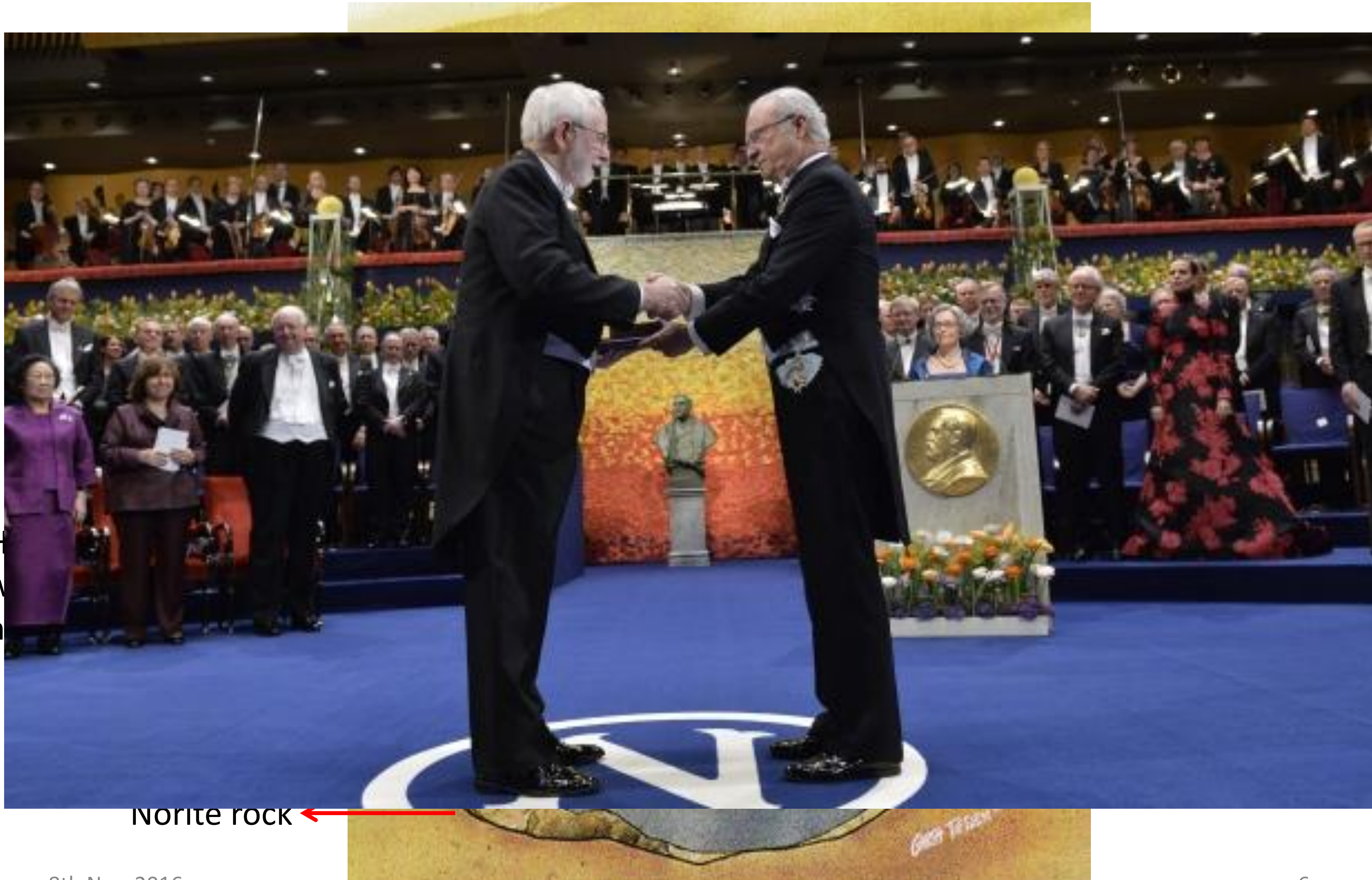
Clean Lab, 2 km Underground



SNO Detector



SNO Detector



Norite rock

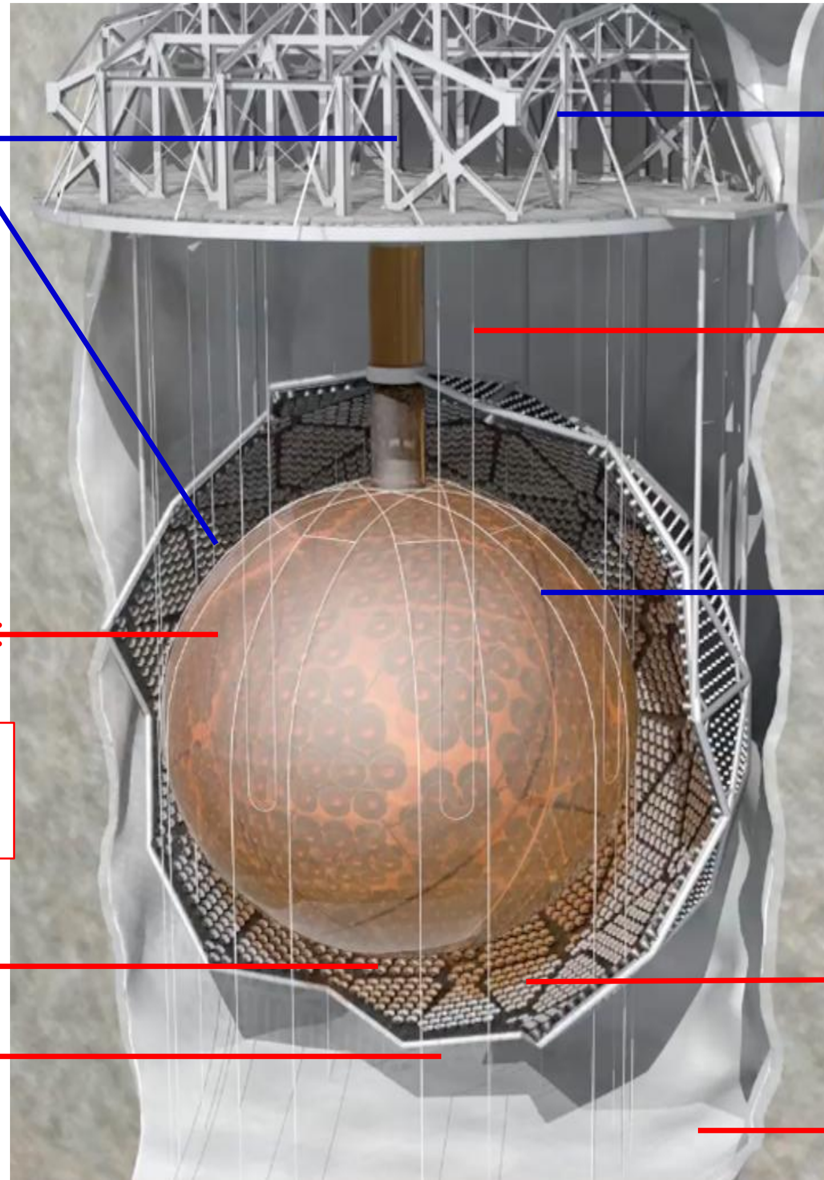
From SNO to SNO+

- SNO detector upgraded to observe Neutrinoless double beta decay
  - Replace heavy water with liquid scintillator (LS)
  - Scintillation in liquids produces about 50 times more light than Cherenkov emission
  - Lower energy threshold (well below 1 MeV) allows to achieve other physics goals
- Other Scientific goals
  - Solar Neutrinos from other reactions, antineutrinos from the Earth and nuclear reactors, Supernova neutrinos

SNO to SNO+, Detector upgrades

New Calibration system

Upgrades to the DAQ for higher rates



Hold-up ropes

Hold-down rope system to counteract buoyancy of the acrylic vessel

Acrylic Vessel 12 m diameter 5 cm thick was filled with ~ 1000 tons D_2O

will be filled with liq. scint. loaded with nat. ^{130}Te

Repaired damaged PMTs

PMT support structure (9300 PMTs) , 54% coverage

~7kT ultra-pure Water shield

Norite rock

University of Pennsylvania
University of Washington
Black Hills State University
Armstrong Atlantic University
University of Chicago
University of North Carolina
University of California – Berkeley
University of California - Davis
Brookhaven National Laboratory

University of Alberta
Queen's University
Laurentian University
TRIUMF
SNOLAB

Oxford University
University of Sussex
Liverpool University
Lancaster University
Queen Mary University of London

LIP Lisboa

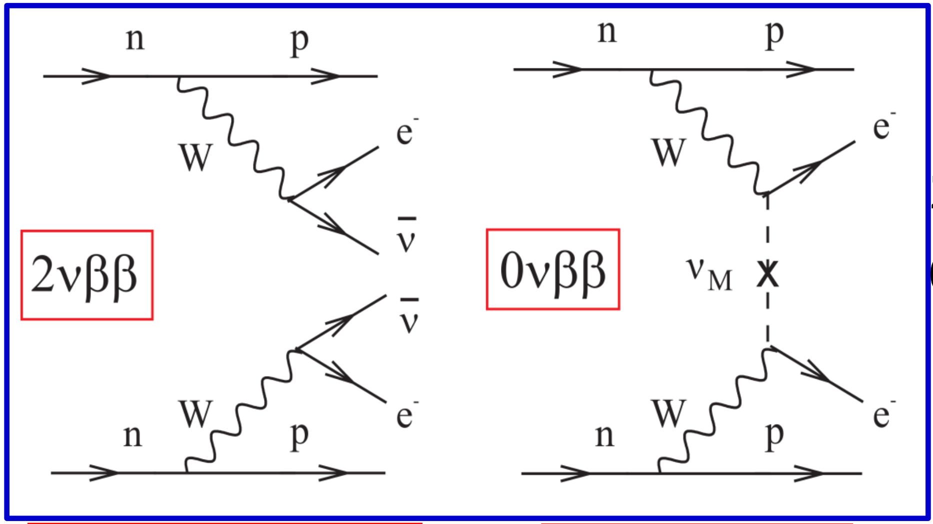
Technical University Dresden

Universidad Nacional Autonoma de Mexico

23 Institutions, 6 Countries, 120 Members

SNO+

Double Beta Decay Signature



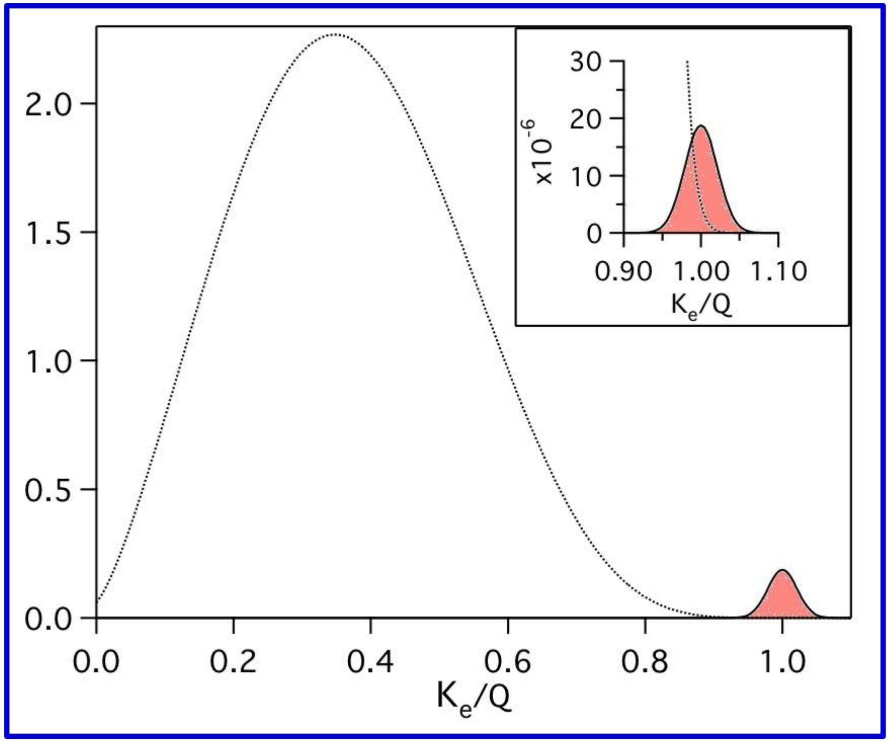
$$2\nu\beta\beta: (A,Z) \rightarrow (A,Z+2) + 2e^{-} + 2\nu \; ; \; \Delta L = 0$$

$$0\nu\beta\beta: (A,Z) \rightarrow (A,Z+2) + 2e^{-} \; ; \; \Delta L = 2 \rightarrow \nu = \bar{\nu}$$

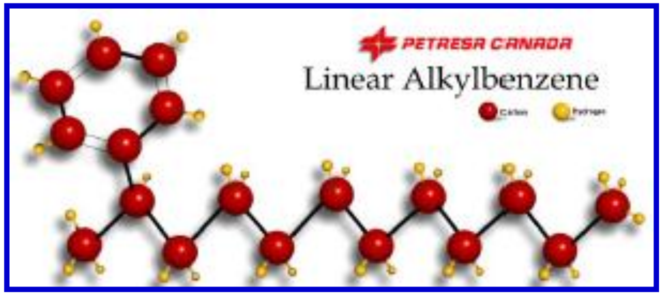
$T_{1/2}^{2\nu} \sim 10^{18} - 10^{21}\ \mathrm{y}$

$T_{1/2}^{0\nu} > 10^{25}\ \mathrm{y}$

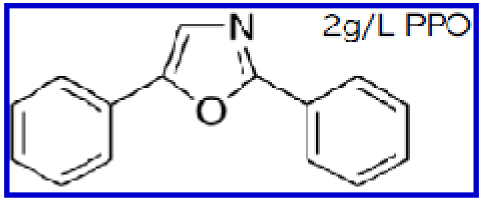
- Search for peak at the end of 2νββ spectrum
- Aim for low background, good energy resolution and large isotope mass



Liquid Scintillator Detector for $0\nu\beta\beta$ Measurement



- Chemically compatible with acrylic
- Low scattering and good optical transparency
- Low background environment
  - Self-shielding of scintillator
  - High purity - LS purification can be achieved by distillation
  - Fast Decay - Internal U/Th can be suppressed by beta-alpha rejection techniques
  - Huge external shielding
  - Phototubes (PMTs) removed by 2.4 m from scintillator



- Economical way to build a detector with scalable loading of $0\nu\beta\beta$ isotope
  - Trade off energy resolution for higher statistics
  - Fitting rather than bin counting is the tool of analysis to compensate for poorer energy resolution

Scintillator Purification Plant

LS Target Levels

^{85}Kr< 10^{-25} g/g

^{40}K < 10^{-18} g/g

^{39}Ar : 10^{-24} g/g

^{238}U-chain : 10^{-17} g/g

^{232}Th-Chain : 10^{-18} g/g

- **Water commissioning is complete, ready for scintillator commissioning**
- **Recirculation possible in 4 days**

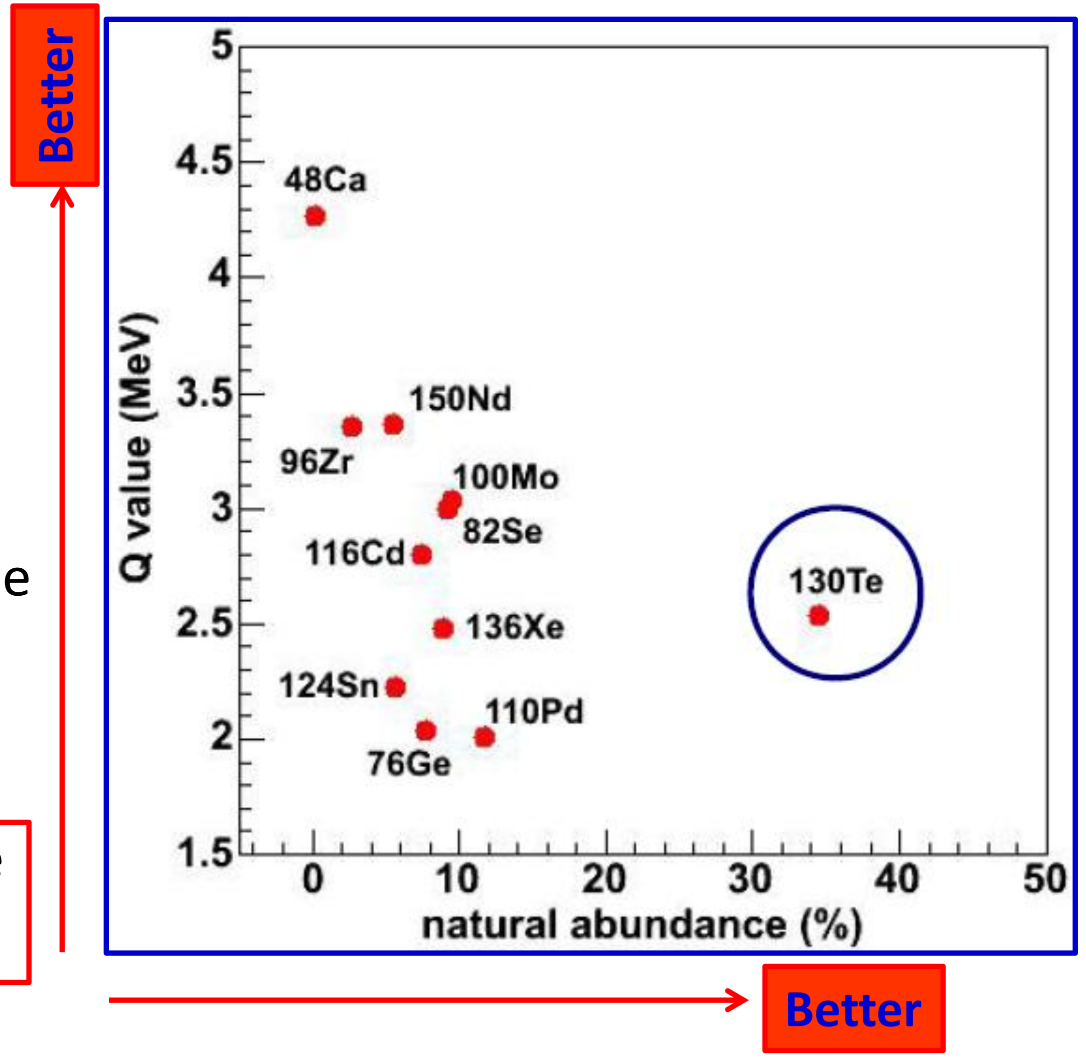
Industrial petrochemical plant built underground

- Multistage distillation (heavy metals & optical impurities)
- Pre-purification of PPO concentrated solution
- Steam/N2 stripping under vacuum (Rn, Ar, Kr, O_2 & water)
- Liq.-liq. extraction (water-LAB)
- Metal Scavengers (K,Pb, Bi, Ra)
- Microfiltration (fine particles)

Double Beta Isotope Selection

^{130}Te

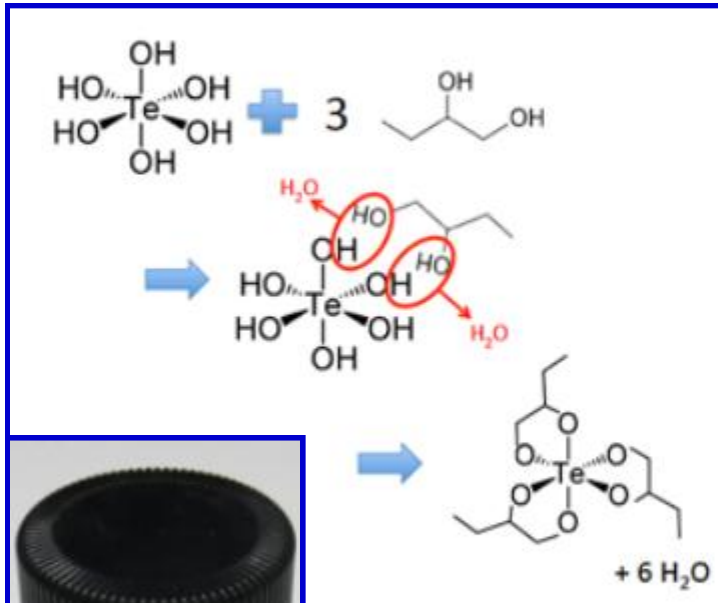
- High abundance (34%) in natural Te
- High $Q_{\beta\beta}$ = 2526.97 ± 0.23 keV
- Low backgrounds at high Q value
- High Q value increases phase space and decay rate
- One of the longest $2\nu\beta\beta$ lifetime
- Large abundance makes the scaling up cheaper

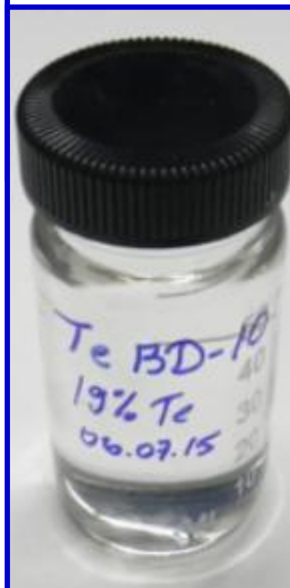


Loading ^{130}Te in LAB

- Successfully loaded nat. Te in LAB using Tellurium-butanediol complex (TeBD)
- First phase 0.5% nat. Te

  ~1300 kg of ^{130}Te will be deployed into liq. scint. (LAB+PPO+bisMSB)
- Stable and optically clear
  - No inherent absorption lines
- High light yield (~ 6,650 photons/MeV, ~ 400 p.e./MeV)
- Possibility of $\alpha-\beta$ separation





Tellurium Purification

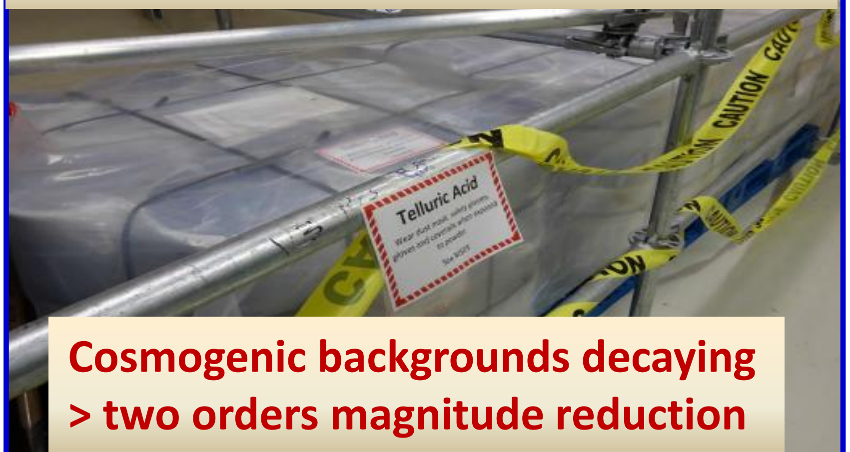
0.5% Tellurium-Diol Target levels:

1.3×10^{-15} g/g in ^{238}U (3×10^{-8} Bq/kg)

5×10^{-16} g/g in ^{232}Th (1.2×10^{-9} Bq/kg)

(raw Te ~10^{-11} g/g U/Th, 10^{-4} Bq/kg)

3.8 tons of $Te(OH)_6$ 0.3% Te loading



Cosmogenic backgrounds decaying
> two orders magnitude reduction

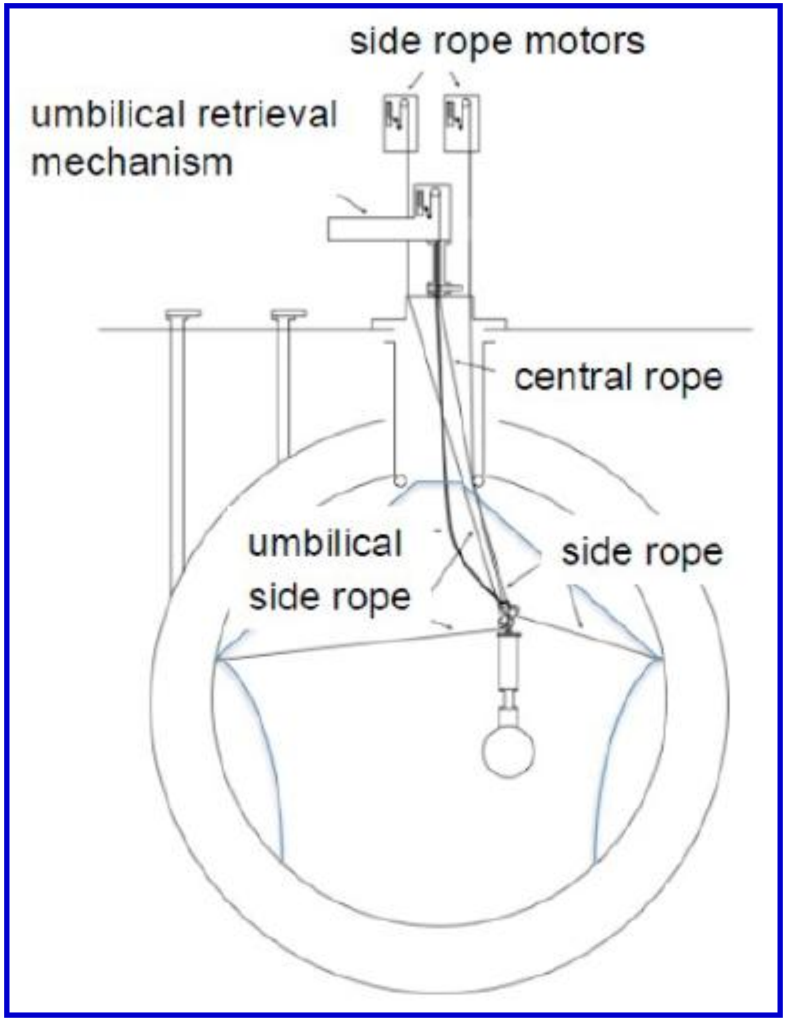
- 10kg pilot-scale plant operated successfully in June 2014
- Construction of full scale plant is ongoing
- 200 kg TeA/batch, ~50 working days to purify 8 tons

Te contamination in U/Th & can be cosmogenically activated (^{60}Co, ^{110m}Ag, ^{88}Y, ^{22}Na)

- Rejection needed 10^4 – 10^5 (V. Lozza and J. Petzoldt, Astropart. Phys., 61, 62-71, 2015
- New Technique developed at BNL

Calibration Sources

- Understanding the detector response in energy range (0.1-10) MeV
- Radioactive + optical sources
- Source deployment: minimum
- Some sources will be used only in water or scintillator phase



Source	Particle	Energy(MeV)	Tag
AmBe	n, γ	2.2, 4.4	Coincidence
16N	γ	6.1	Yes
24Na	γ	1.3, 2.7	Yes
48Sc	γ	1.0,1.2,1.3	No
57Co	γ	0.122	No
46Sc	γ ,γ	8.892, 1.120	Yes
90Y	β	2.4	No

Background Model

2νββ :

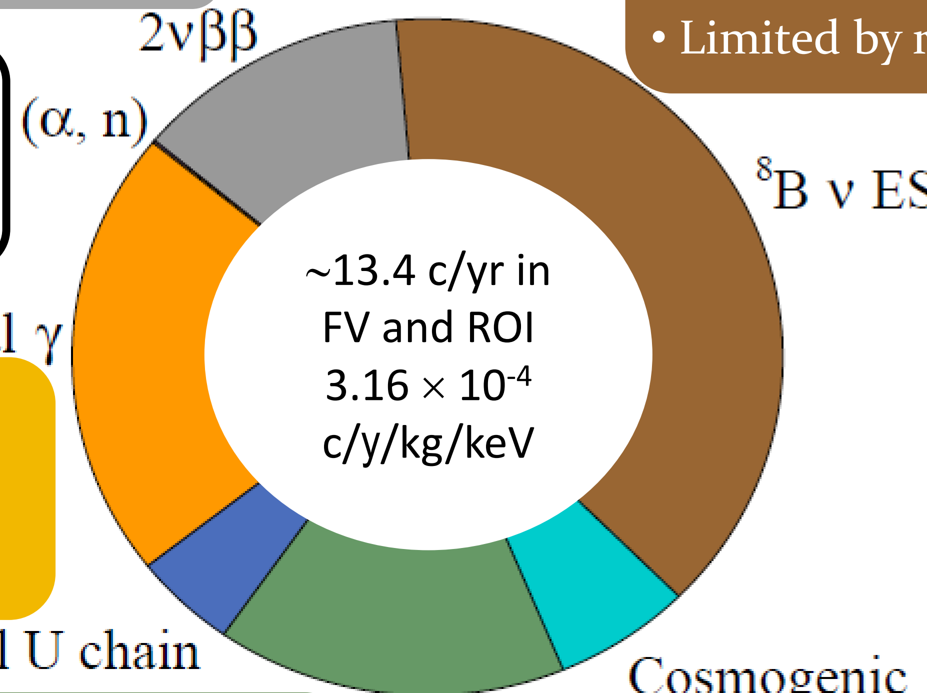
- Asymmetric ROI around 0νββ signal

^{8}B Solar Neutrinos :

- Flat Spectrum
- Constrained by SNO/ SK
- Limited by resolution

(α, n) :

- α - Capture on ^{13}C / ^{18}O
- delayed coincidence tagging



External gammas :

- AV, ropes, water, PMTs
- fiducial volume (20%) cut
- 50% rejection LH cut

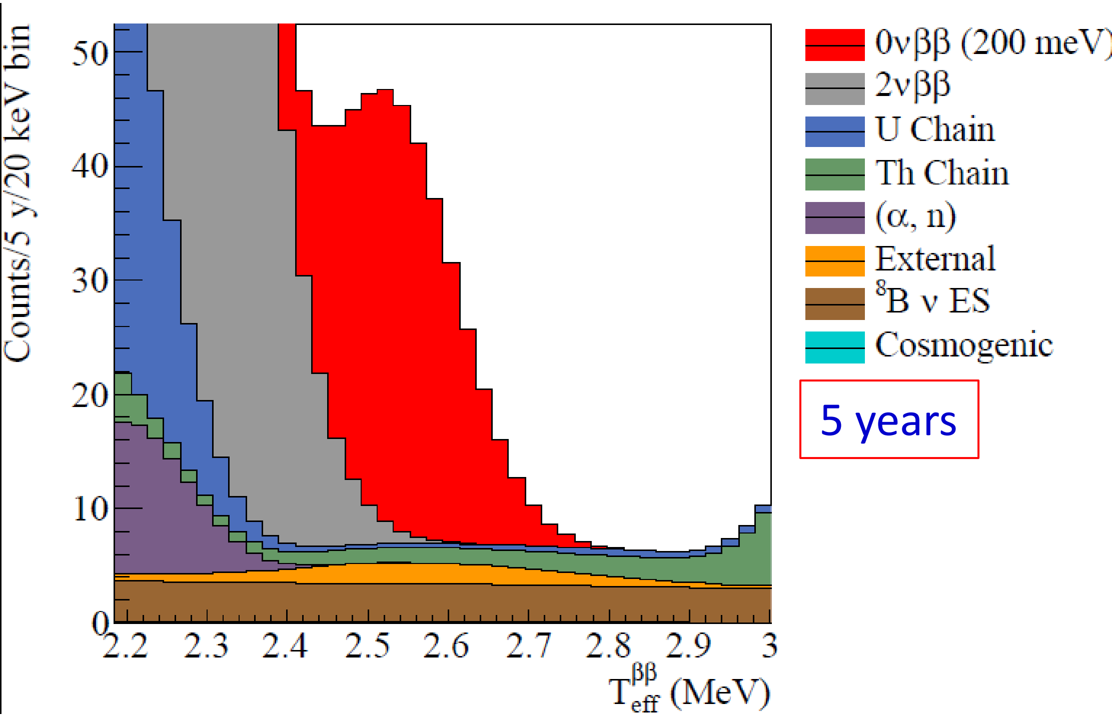
Internal U/Th Chain :

- ^{214}BiPo, ^{212}BiPo
- β–α delayed coincidence tagging
- In window trigger : x50 rejection
- Different trigger window: 100% rejection

Cosmogenic:

- ^{60}Co, ^{110m}Ag, ^{88}Y and ^{22}Na
- Mitigation: purification + "Cool Down" UG

SNO+ 0νββ Spectrum

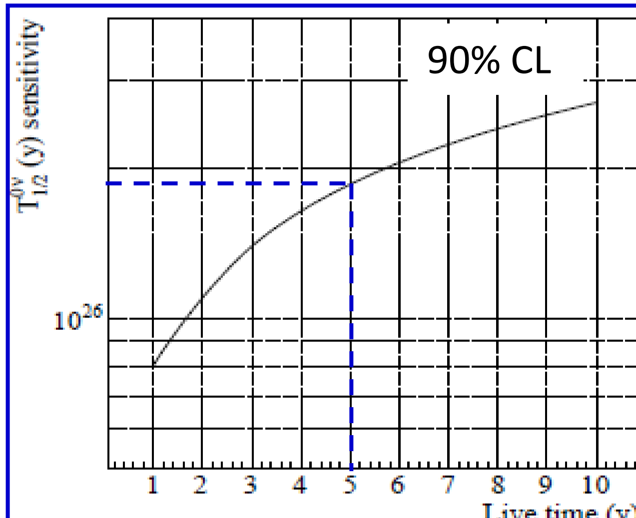


- LAB+PPO(2g/L) +bisMSB(15mg/L)
- 1300 kg ^{130}Te (0.5% by mass)
- 3.5 m (20%) FV cut
- 390 Nhits/ MeV (~4% ΔE)
- > 99.9% efficient ^{214}BiPo tag
- > 98% efficient of ^{212}BiPo tag
- Negligible cosmogenic isotopes

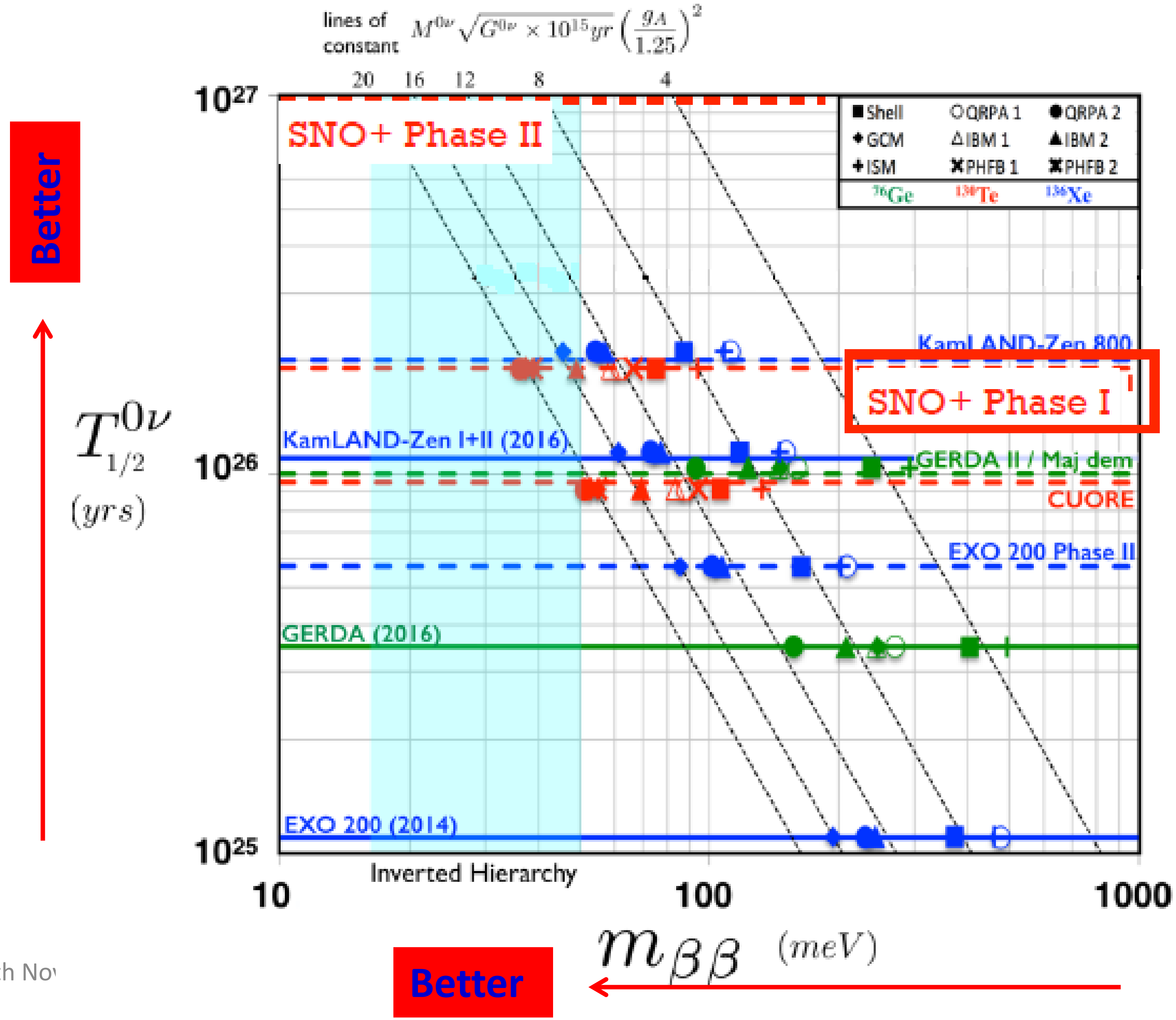
- NME = 4.03 (IBM-2)
- gA = 1.269
- G = 3.69 × 10^{-14} yr^{-1}

	1 year	5 years
$T_{1/2}$ [10^{26} yr]	0.80	1.94
mbb [meV]	75.2	38-92*

*NME range : 2.06 (ISM) – 4.98 (EDF)



Sensitivity for Neutrino Effective Mass



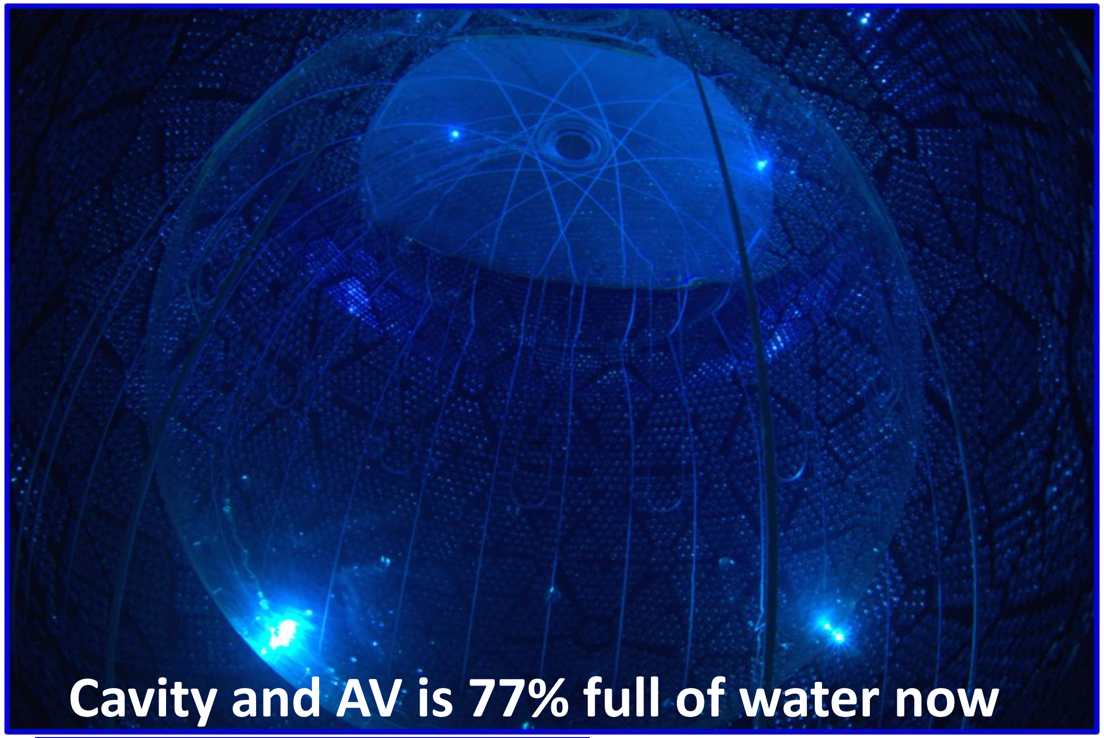
SNO+ Timeline and Physics

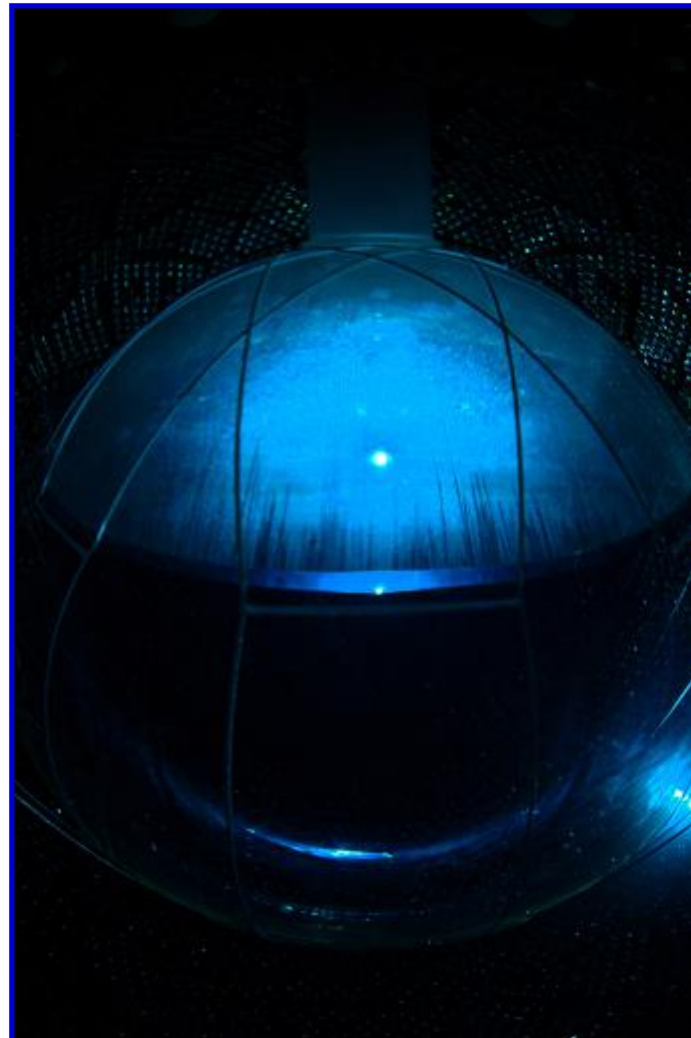
- Water Phase (Fall 2016)
- First LAB delivered on site (1^{st} week of Nov. 2016)
- Scintillator Phase (mid 2017)
- Te loaded ($0\nu\beta\beta$) Phase (2018)

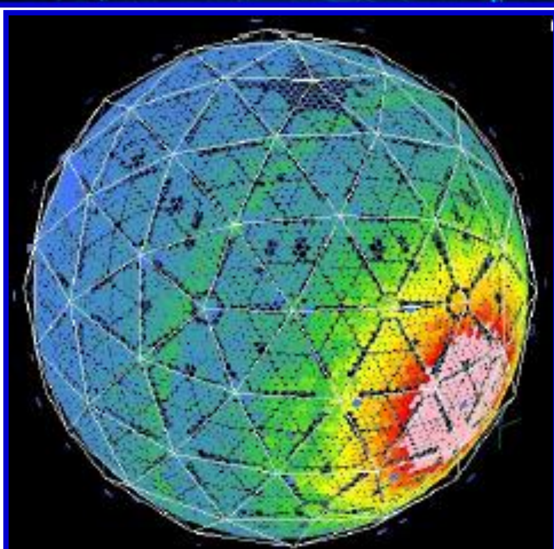
Goal	Water	Pure LS	^{130}Te-LS
$0\nu\beta\beta$			✗
^{8}B Solar Neutrinos		✗	✗
Low Energy Solar neutrinos		✗*	
Reactor & Geo-neutrinos		✗	✗
Exotics searches	✗	✗	✗
Supernova	✗	✗	✗

* After Te phase

Current Status







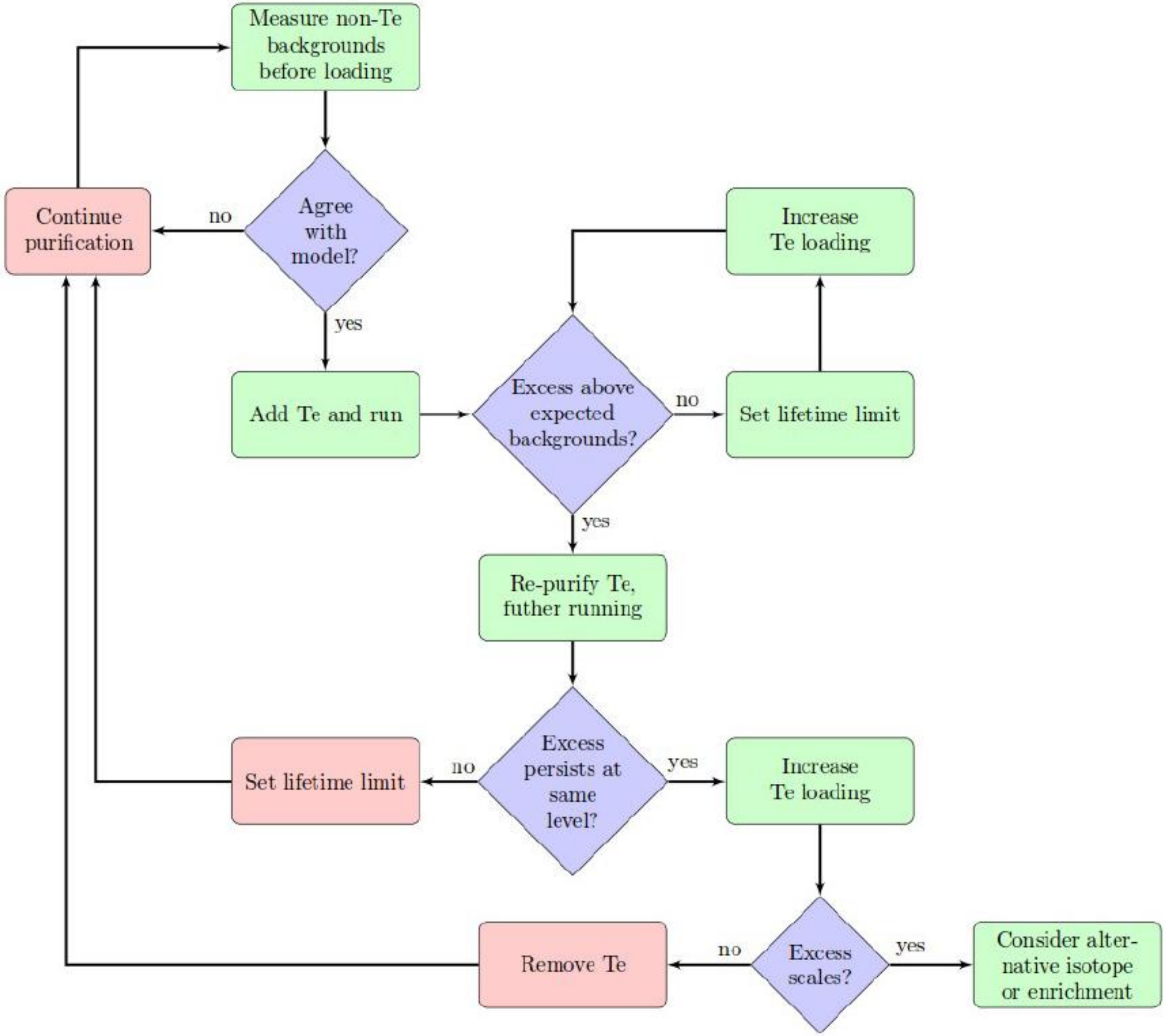
DAQ and optical calibration sources (external) are being commissioned

Conclusions and Outlook

- SNO+ is a multi-purpose neutrino liquid scintillator detector
  - The main goal is neutrinoless double beta search with ^{130}Te
- Developed purification and loading techniques for large amount of Tellurium in liquid scintillator
  - First phase with 0.5% Te (by mass), possibility of increased loading in future phase
- Background models developed using measured activities and optical properties
- Initial 0.5%Te loaded, 5 yr measurement $\rightarrow T_{1/2}^{0\nu\beta\beta} \sim 2\times10^{26}\, y$
  - Expect to reach top of the inverted hierarchy of neutrino masses and potentially better with higher loadings in phase II
- Progress on many fronts
  - AV rope systems, calibration systems, scintillator plant, Te purification plant ….
- Water phase data taking will start in Dec. 2016

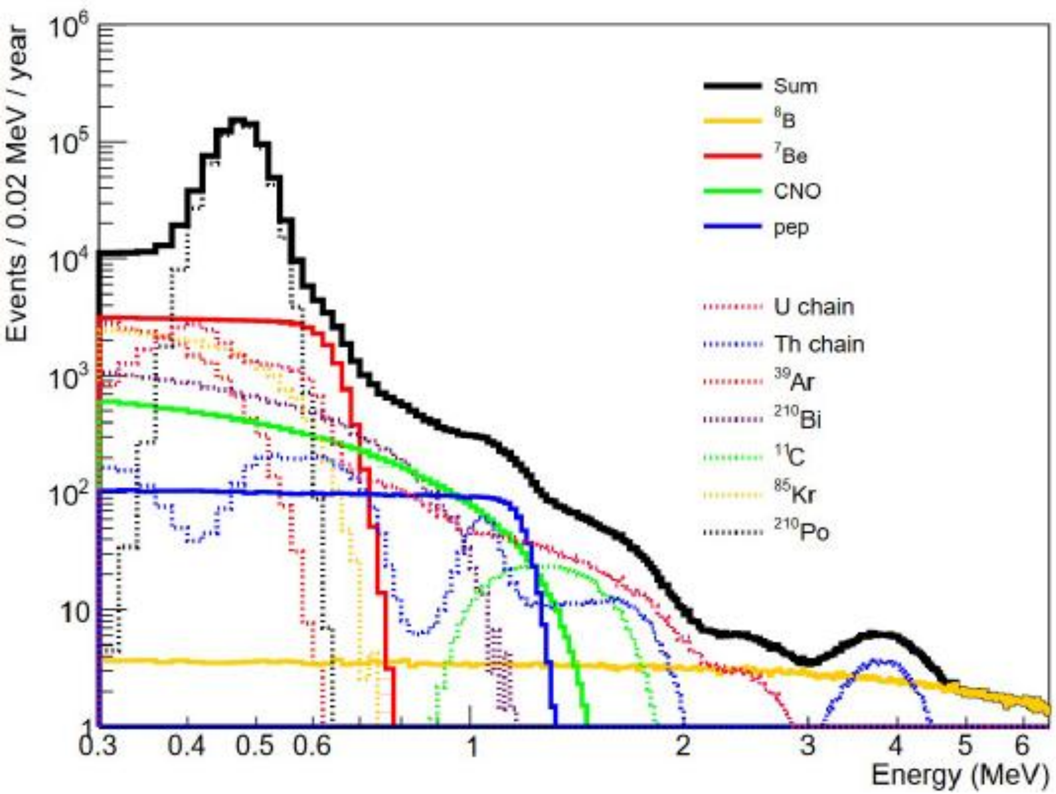
Backup Slides

Overall Logic



Solar Physics with SNO+

- SNO+ solar neutrino goal : pep/CNO and low energy ^{8}B neutrino measurement
  - Low 11C background (100 times deeper than Borexino)
  - Low energy threshold



Uncertainty on measured flux

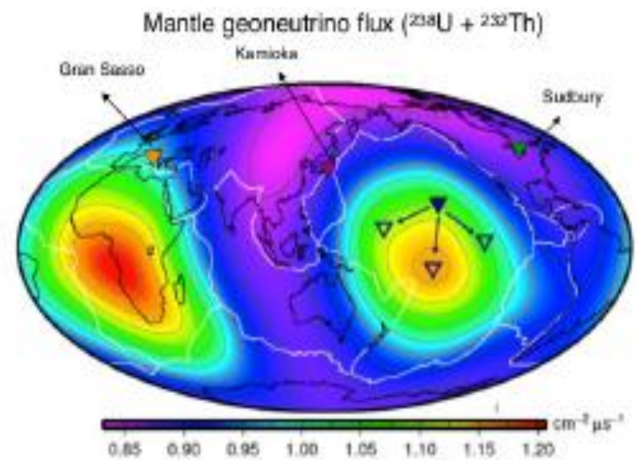
	6 months	12 months
8B	10%	7.1%
7Be	5.1%	3.3%
Pep	13%	8.9%
CNO+210Bi	6.5%	4.4%

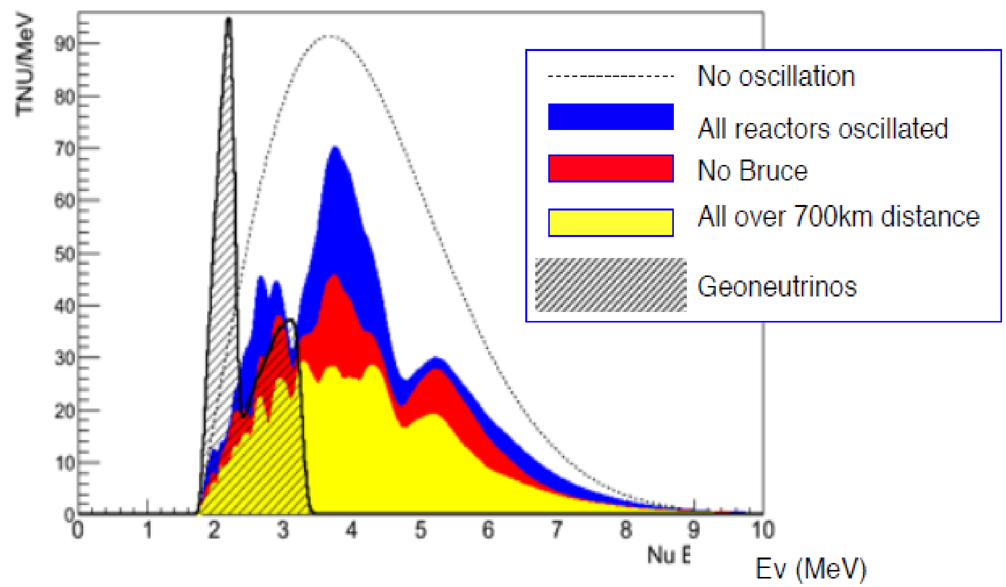
Assumptions :

- 400 Nhits/MeV
- FV = 5.5m
- 95% reduction of ^{214}Bi via delayed coincidence
- 95% reduction of ^{210}Po and ^{214}Po via alpha tagging
- 50% constraint on ^{85}Kr
- 25% on ^{232}Th-Chain
- 7% on ^{238}U-Chain

Antineutrinos with SNO+

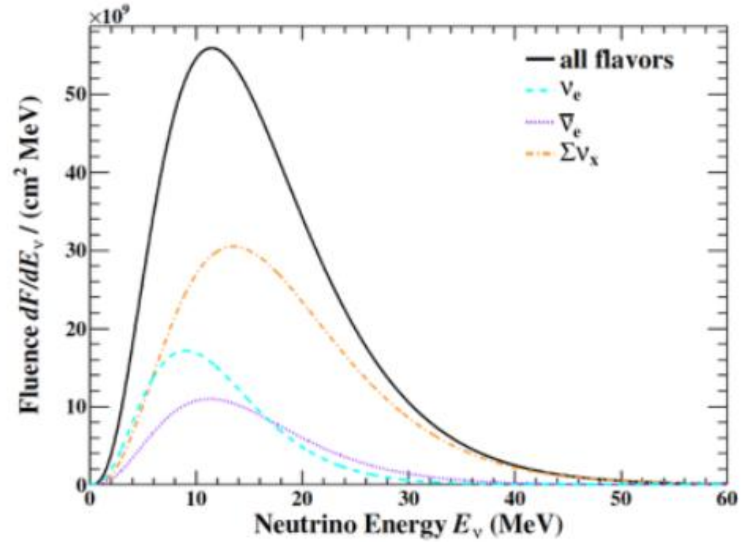
- Due to efficient neutron tagging (2.2 MeV γ) antineutrinos can be detected in all SNO+ phases
- Reactor Antineutrinos:
  - Oscillation parameters
  - 3 nearby reactors dominate flux
  - Very clear oscillation pattern for L/E ~ 100 km/MeV
- Geo Antineutrinos:
  - Investigate origin of radiogenic heat flow of the Earth
  - Geo:Reactor antineutrino flux is (1:1) in the energy range of 1.8-3.5 MeV
  - Up to now measured in KAMLAND and Borexino
  - Very well known geological structure in Sudbury





Supernova Neutrinos

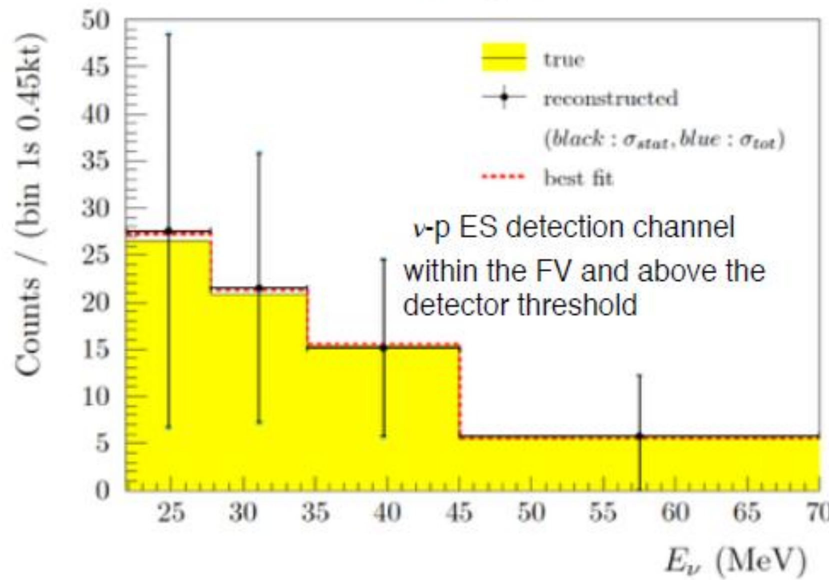
- p-ν elastic scattering events (in LAB)
- SNO+ will be part of SuperNova Early Warning System (SNEWS)
- Core-collapse supernovae: 99% of their gravitational binding energy released in the form of neutrinos



Assumptions: 10 kpc distance, 3 $\times 10^{53}$ erg of binding energy released in neutrinos, 5.5m FV, Mean energies 12 MeV for ν_e, 15 MeV for $\bar{\nu}_e$ And 18MeV for ν_x

Reaction	Number of Events
NC: $\nu + p \rightarrow \nu + p$	429.1 ± 12.0 [a]
CC: $\bar{\nu}_e + p \rightarrow n + e^+$	194.7 ± 1.0
CC: $\bar{\nu}_e + {}^{12}C \rightarrow {}^{12}B_{g.s.} + e^+$	7.0 ± 0.7
CC: $\nu_e + {}^{12}C \rightarrow {}^{12}N_{g.s.} + e^-$	2.7 ± 0.3
NC: $\nu + {}^{12}C \rightarrow {}^{12}C^*(15.1\,MeV) + \nu'$	43.8 ± 8.7
CC/NC: $\nu + {}^{12}C \rightarrow {}^{11}C$ or ${}^{11}B + X$	2.4 ± 0.5
ν–electron elastic scattering	13.1 [b]

[a] 118.9 ± 3.4 above a trigger threshold of 0.2 MeV visible energy.
[b] The Standard Model cross section uncertainty is $< 1\%$.



Te-Diol Complex and Optics