SNO+ Calibration Systems

Benjamin Tam (for the SNO+ Collaboration)
WNPPC 2018
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SNO+ Physics Programme

- **Neutrinoless Double Beta Decay**
- Low Energy Solar Neutrinos
- Geoneutrinos
- **Reactor Antineutrinos** **(← the next talk by Y. Liu!)**
- Supernova Neutrinos
- Invisible Nucleon Decay
- Axion-like Particle Searches

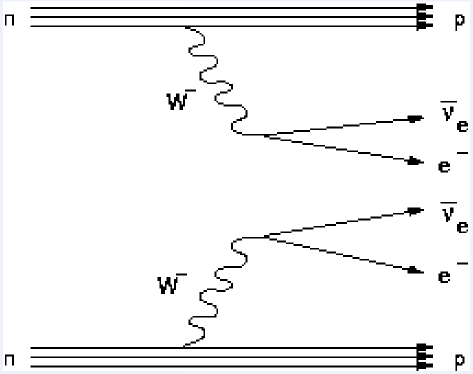
Double Beta Decay (1/2)

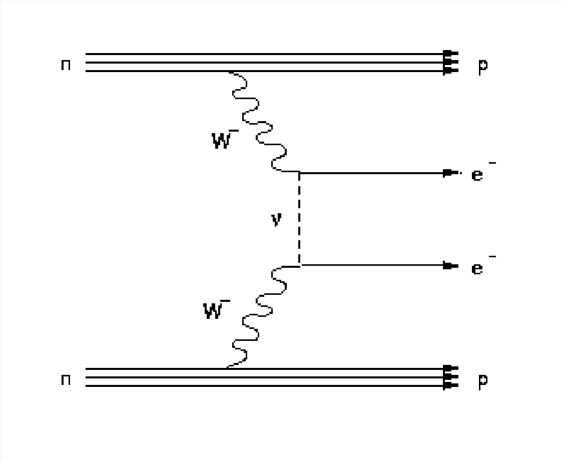
- Two Neutrino Double Beta Decay already observed

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

- Neutrinoless Double Beta Decay
    - Possible if neutrinos are Majorana

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

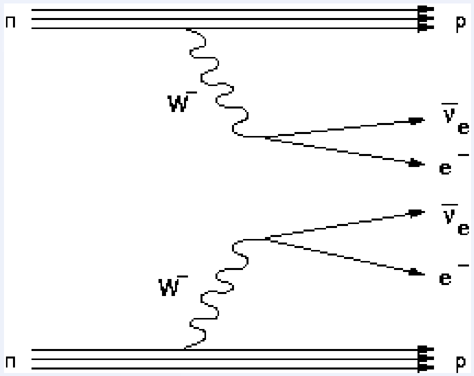


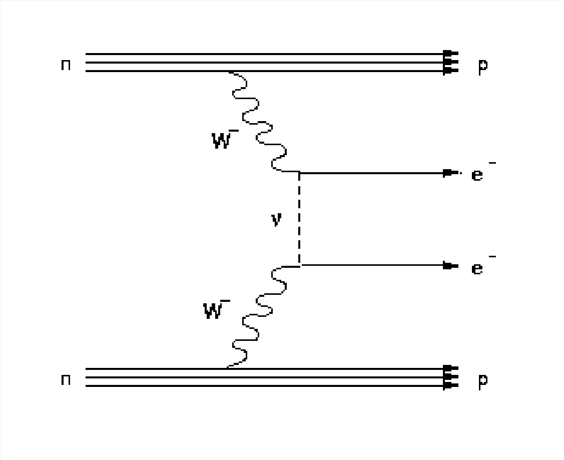


Nuclide	Half-life, 10^{21} years
^{48}Ca	$0.064^{+0.007}_{-0.006} \pm ^{+0.012}_{-0.009}$
^{76}Ge	1.926 ±0.094
^{78}Kr	$9.2^{+5.5}_{-2.6} \pm 1.3$
^{82}Se	0.096 ± 0.003 ± 0.010
^{96}Zr	0.0235 ± 0.0014 ± 0.0016
^{100}Mo	0.00693 ± 0.00004
	$0.69^{+0.10}_{-0.08} \pm 0.07$
^{116}Cd	0.028 ± 0.001 ± 0.003 $0.026^{+0.009}_{-0.005}$
^{128}Te	7200 ± 400 1800 ± 700
^{130}Te	0.82 ± 0.02 ± 0.06
^{136}Xe	2.165 ± 0.016 ± 0.059
^{130}Ba	(0.5 – 2.7)
^{150}Nd	$0.00911^{+0.00025}_{-0.00022} \pm 0.00063$
	$0.107^{+0.046}_{-0.026}$
^{238}U	2.0 ± 0.6

Double Beta Decay (2/2)

- Implications of Majorana Particles:
  - Leptogenesis
  - Absolute Neutrino Mass Scale
  - Predicted in some Grand Unified Theories





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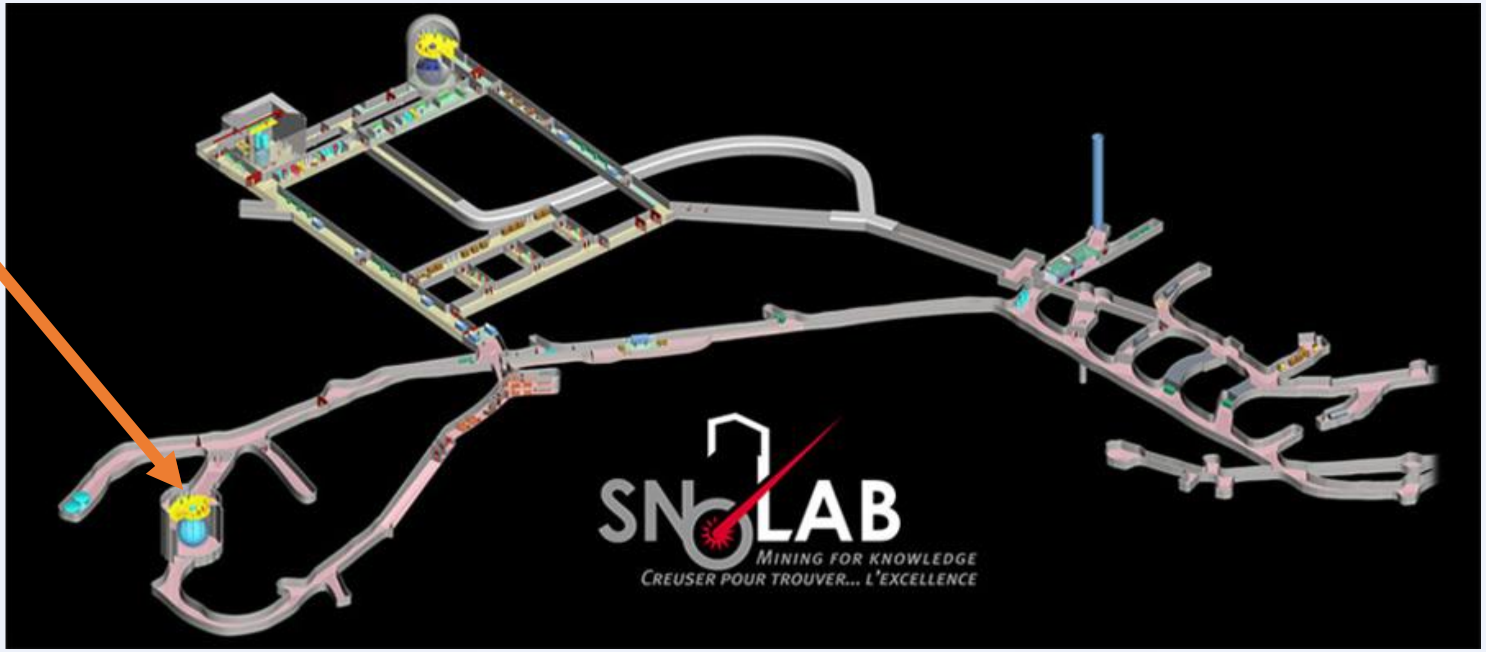
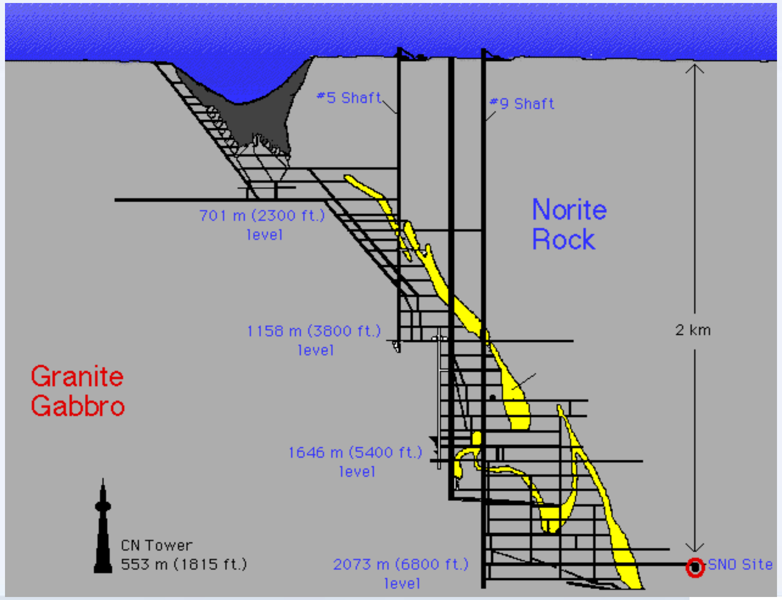
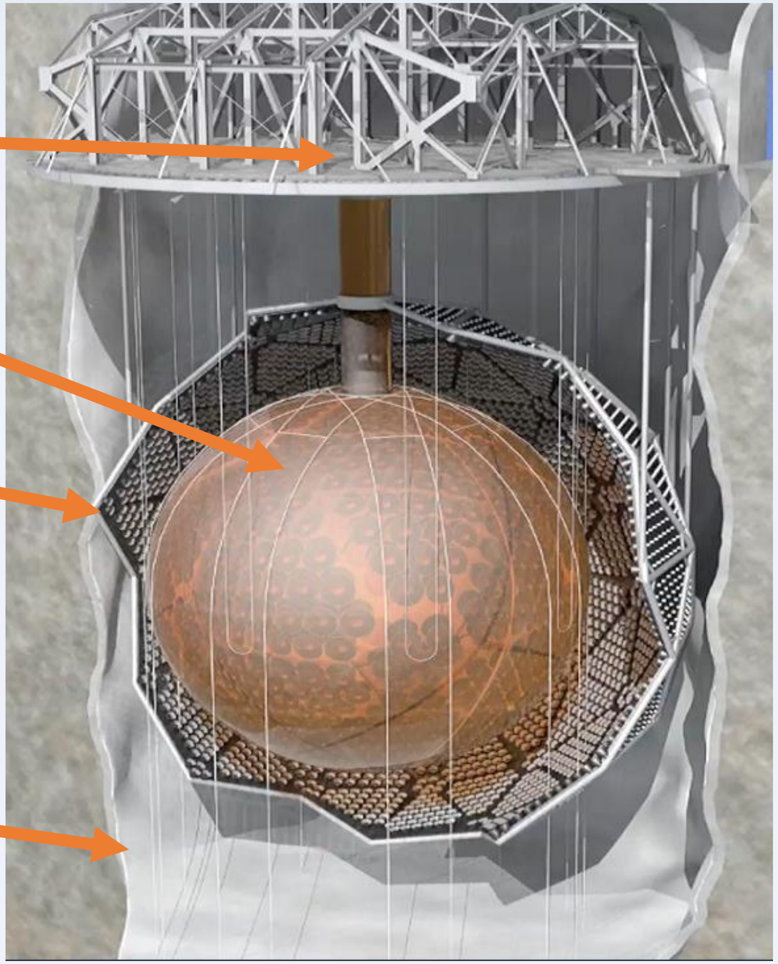
SNO+ Experiment (1/3)

- 780 tonne liquid scintillator experiment
- Located at SNOLAB





SNO+ Experiment (2/3)



Scintillator "Cocktail":

- Liquid Scintillator (Linear Alkylbenzene)
- Fluor (2,5-diphenyloxazole)
- 0.5% (By mass) Natural Te
  ~1300 kg ^{130}Te
  Double Beta Decay Isotope

SNO+ Experiment (3/3)

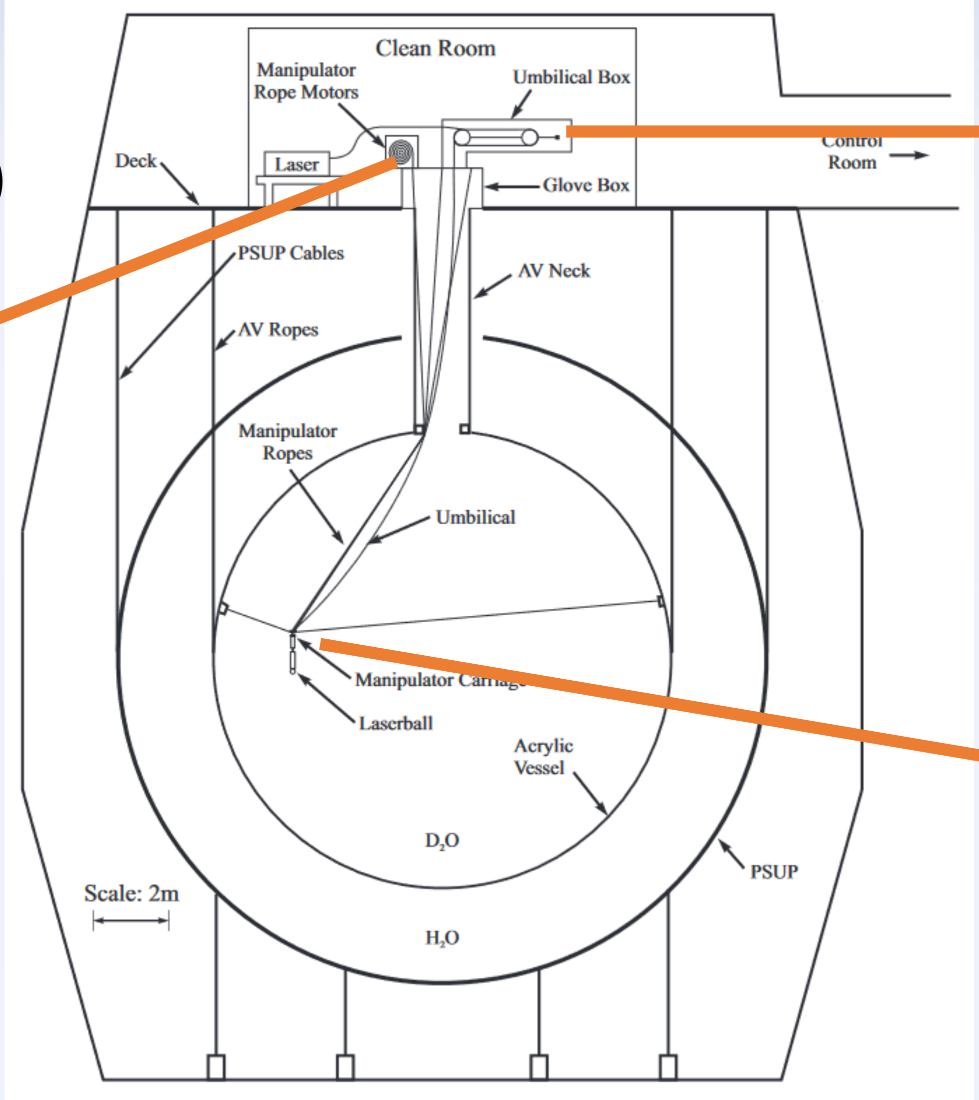
3 Phase Experiment:

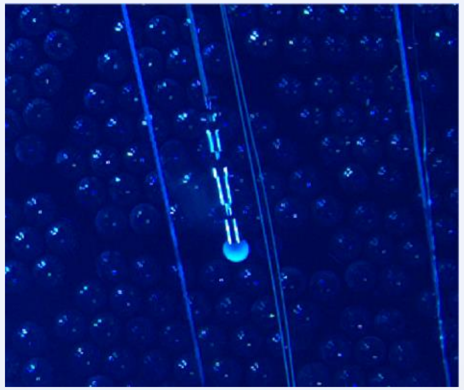
1. **Water Phase (Began 4 May 2017)**
2. Pure Scintillator Phase (Begins Summer 2018)
3. Te-Loaded Phase (Begins 2019)

Water Phase Goals:

- Reactor Antineutrinos
- Invisible Nucleon Decay
- External Background Analysis
- Commissioning of Calibration systems

Calibration Hardware (1/2)



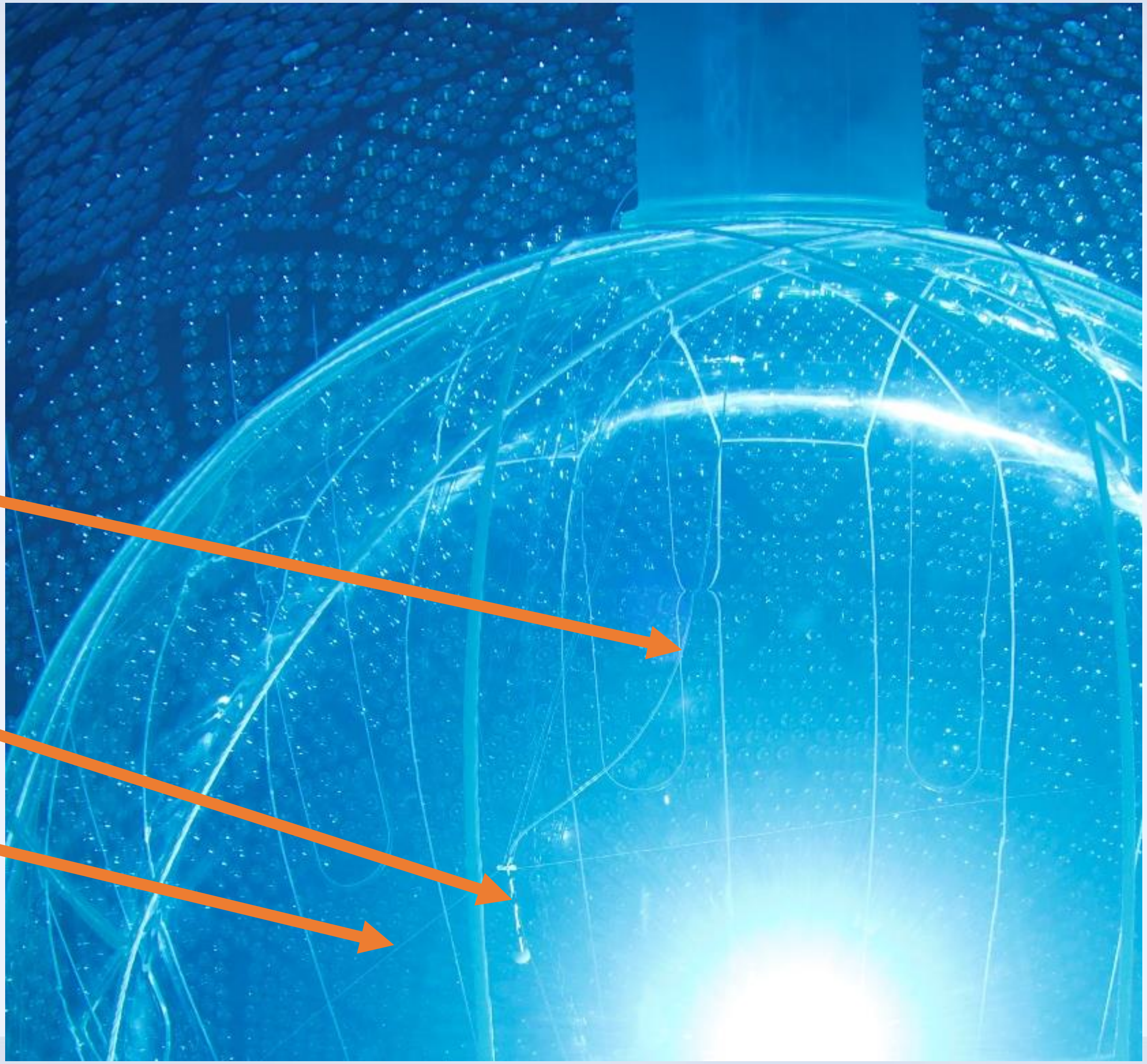


Calibration Hardware (2/2)

Umbilical

Source

Manipulator Ropes



Calibration Sources (1/4)

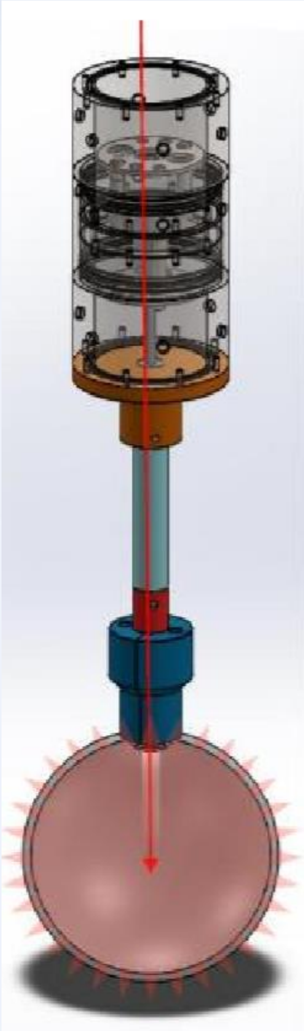
Deployed Sources:

- Light Diffusing Sphere "Laserball"
  - For PMT efficiency, timing, angular response, optical properties
- Radioactive Nitrogen-16 Source "N16"
  - For absolute energy measurements
- Americium-Beryllium Source "AmBe"
  - Additional energy measurements
  - Neutron Calibration (for Reactor Antineutrinos)

Calibration Sources (2/4)

Laserball:

- N_2 dye laser with six central wavelengths
  - $\lambda = 337, 365, 386, 421, 500, 620$nm
- Has multiple filters for varying intensity
- Light fed to quartz flask (white sphere)
- Light transferred using fibre optics in umbilical
- Produces approximately isotropic light



Calibration Sources (3/4)

N16: (1/2)

- ^{16}N undergoes beta decay:
  $^{16}N \rightarrow {}^{16}O + e + \overline{\nu} + \gamma$ (6.13 MeV)
- Source enclosure lined with plastic scintillator that captures the electron
  - Signal picked up by dedicated PMT inside source enclosure
- γ is emitted from source and picked up by detector

Calibration Sources (4/4)

N16: (2/2)

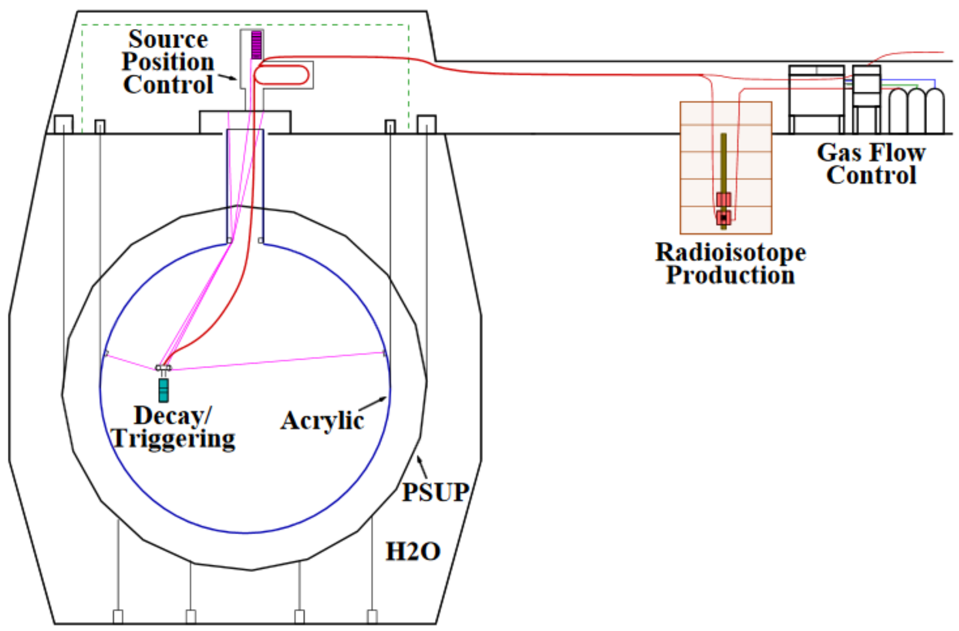
- ^{16}N produced by neutron activation of ^{16}O

  $^{16}O + n \rightarrow p + {}^{16}N$ ($\tau_{1/2} = 7.13s$)

- Neutron produced in DT generator

  $d + t \rightarrow n + {}^{4}He$

- CO_2 gas passed through DT generator
- ^{16}N gas sent to source via umbilical



Conclusions

- Laserball (PMT efficiency and relative energy calibration) used in conjecture with N16 (absolute energy calibration) to understand PMT responses.
- Calibration Systems successfully commissioned
- Also have deployed AmBe source for the SNO+ antineutrino campaign
  - That's the next talk…

Thanks!

University of Alberta
U.C. Berkeley
LBNL
Boston University
Brookhaven
University of Chicago
U.C. Davis
T.U. Dresden
Lancaster University
Laurentian University
LIP Lisbon
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Queen's University
Queen Mary University
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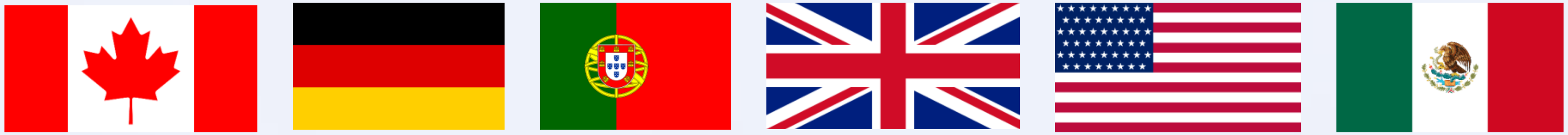
TRIUMF



Backup Slides

Invisible Nucleon Decay (1/2)

- Nucleon decay modes to final states where no visible energy is deposited

  eg. $n \rightarrow \nu\nu\nu$

- Predicted by some grand unified theories to explain baryogenesis

Existing Halflife Limits:

- SNO (^{16}O in Heavy Water): 2×10^{29} years
- KamLAND (^{12}C in LS): 5.8×10^{29} years

SNO+: Searching with ^{16}O in ultrapure water

Invisible Nucleon Decay (2/2)

Neutrons: $^{16}O \rightarrow {}^{15}O^{*} + n$

$^{15}O^{*} \rightarrow {}^{15}O + \gamma$ (6.18MeV) BR: 0.44

Protons: $^{16}O \rightarrow {}^{15}N^{*} + p$

$^{15}N^{*} \rightarrow {}^{15}N + \gamma$ (6.32MeV) BR: 0.41

- Idea is to detect signature γ without the corresponding particle
- Conservative Lifetime Estimate after 6 months at 90% C.L.:

$$\tau = \frac{N \times \varepsilon \times f_T}{S_{90\%}} = \begin{array}{l} 1.25 \times 10^{30} \text{ yrs (n)} \\ 1.38 \times 10^{30} \text{ yrs (p)} \end{array}$$

Decay source	Events in six months	$\cos\theta_{sun} > -0.8$ Cut
^{214}Bi	0	0
^{208}Tl	0.6	0.6
Solar-neutrinos	86.4	17.7
Reactor antineutrinos	1.5	1.3
External ^{214}Bi-^{208}Tl	9.2	8.9
Total	97.7	28.5
ϵ(n)	0.1089	0.1017
ϵ(p)	0.1264	0.1129

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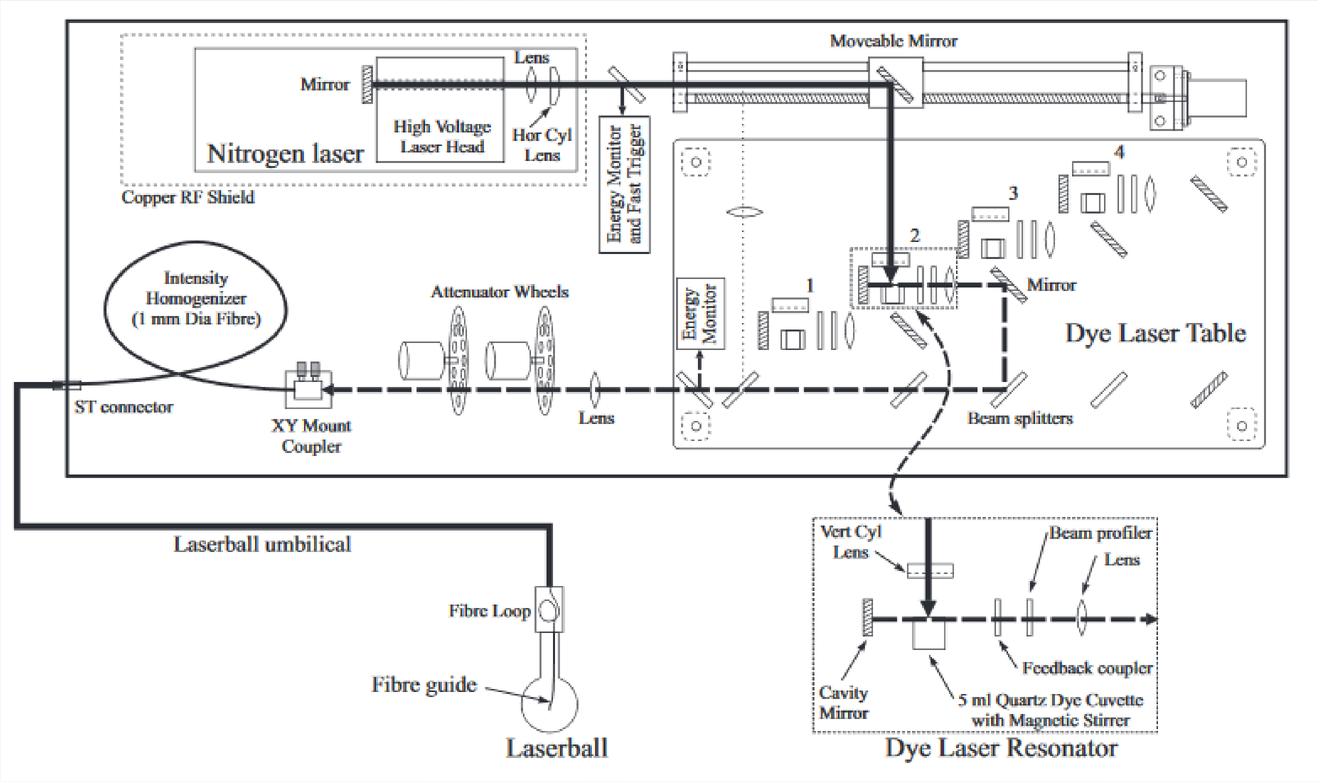
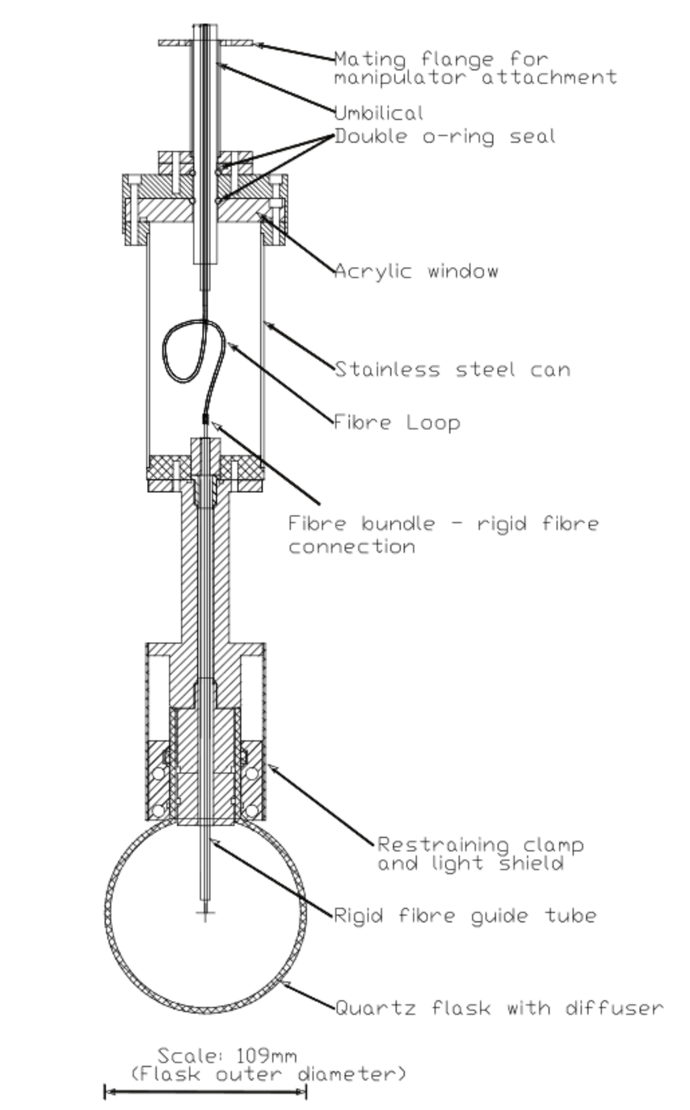
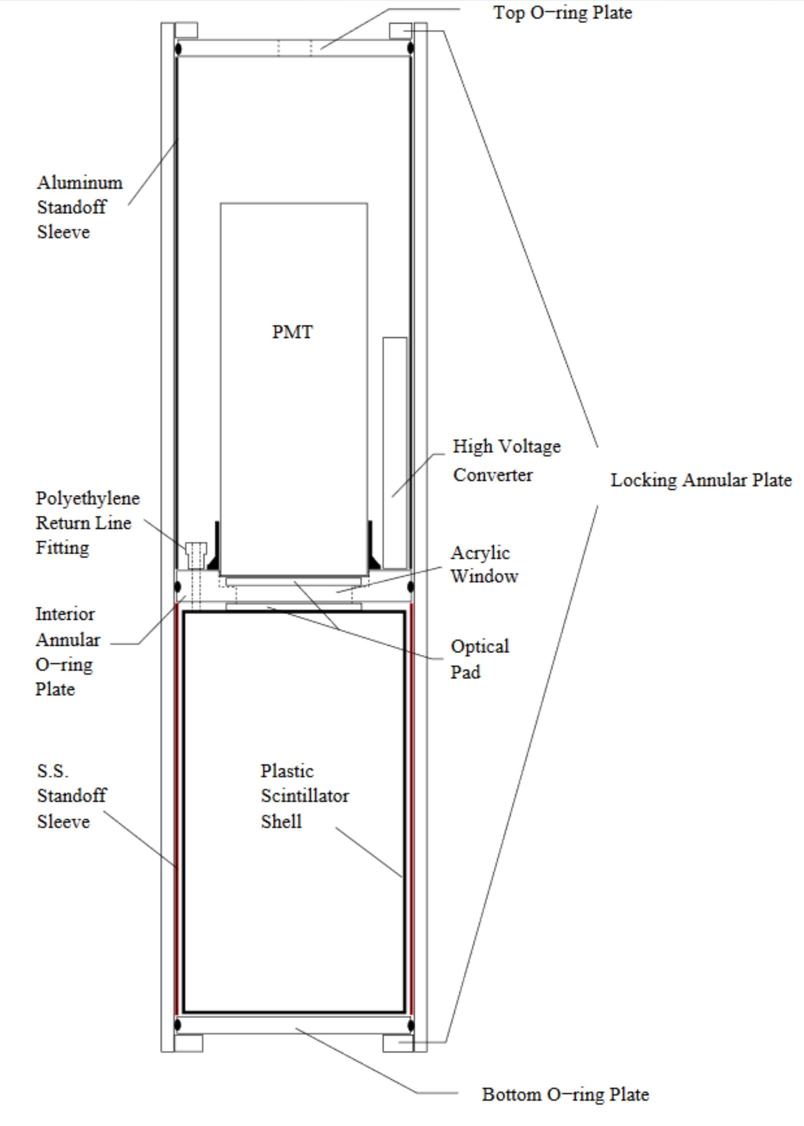
Cross-sectional view of the Laserball and laser system



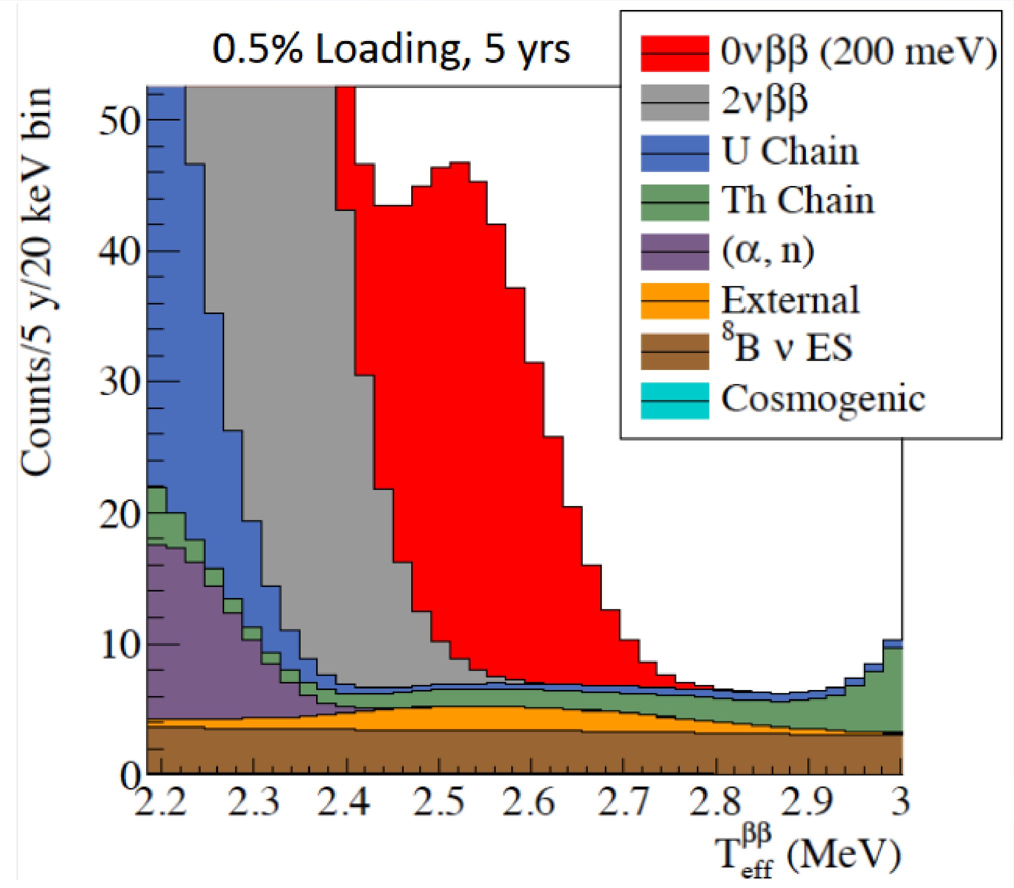


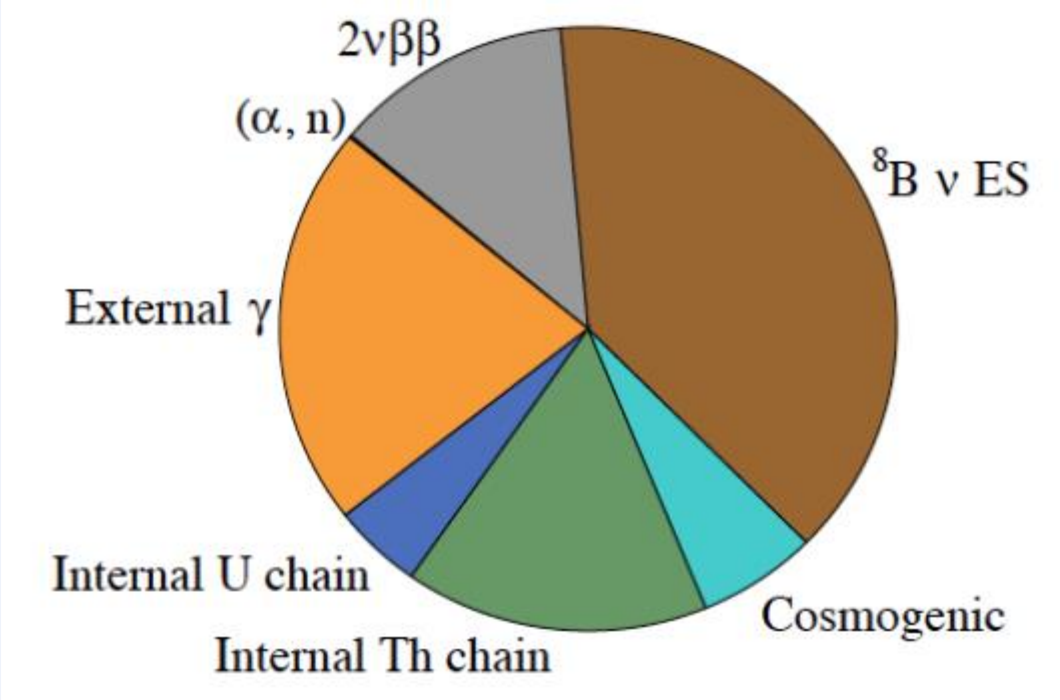
Cross sectional view and yield estimation parameters for N16

neutron flux	10^8 s^{-1}
cross section (σ)	35 mb [13]
Target Chamber pressure P_{tgt}	6.5 Atm
Target Chamber half height (h)	3.95 cm
Target Chamber inner radius (R_1)	2.32 cm
Target Chamber outer radius (R_2)	5.72 cm
Target Chamber volume (V_{tgt})	678 cm^3
Target Chamber gas density at 6.5 Atm (ρ)	3.52 x 10^{20} cm^{-3}
Main transfer line length (l_1)	43 m
Main transfer line area (A_1)	0.0793 cm^2
Intermediate transfer line pressure (P_{mid})	6.1 Atm
Umbilical transfer line length (l_2)	30 m
Umbilical transfer line area (A_2)	0.0455 cm^2
Decay Chamber volume (V_{dec})	1050 cm^3
Decay Chamber pressure (P_{dec})	4.05 Atm
Mass Flow Rate (Q)	230 Atm-cm^3 s^{-1}
^{16}N production yield (Y_n)	6.92x10^{-5} ^{16}N n^{-1}
Transfer efficiency (ϵ_{tgt})	34.8 %
Transfer efficiency (ϵ_{cap})	29.8 %
Decay Chamber efficiency (ϵ_{dec})	64.2 %
Total efficiency (ϵ_{tot})	6.7 %
Calculated Yield	460 s^{-1}



Expected Backgrounds





Te Loading in SNO+ Scintillator

- 0.5% by mass corresponding to 1333kg of 130Te
- Possibility to increase to percent level in future phases
- Te dissolved into liquid scintillator as an organometallic complex
  - Tellerium Butanediol created using Telluric Acid and 1,4-Butanediol