The SNO+ experiment: current status and prospect

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FOR THE SNO+ COLLABORATION

CAP 2020 CONGRESS - JUNE 8, 2020

Arthur B. McDonald Canadian Astroparticle Physics Research Institute

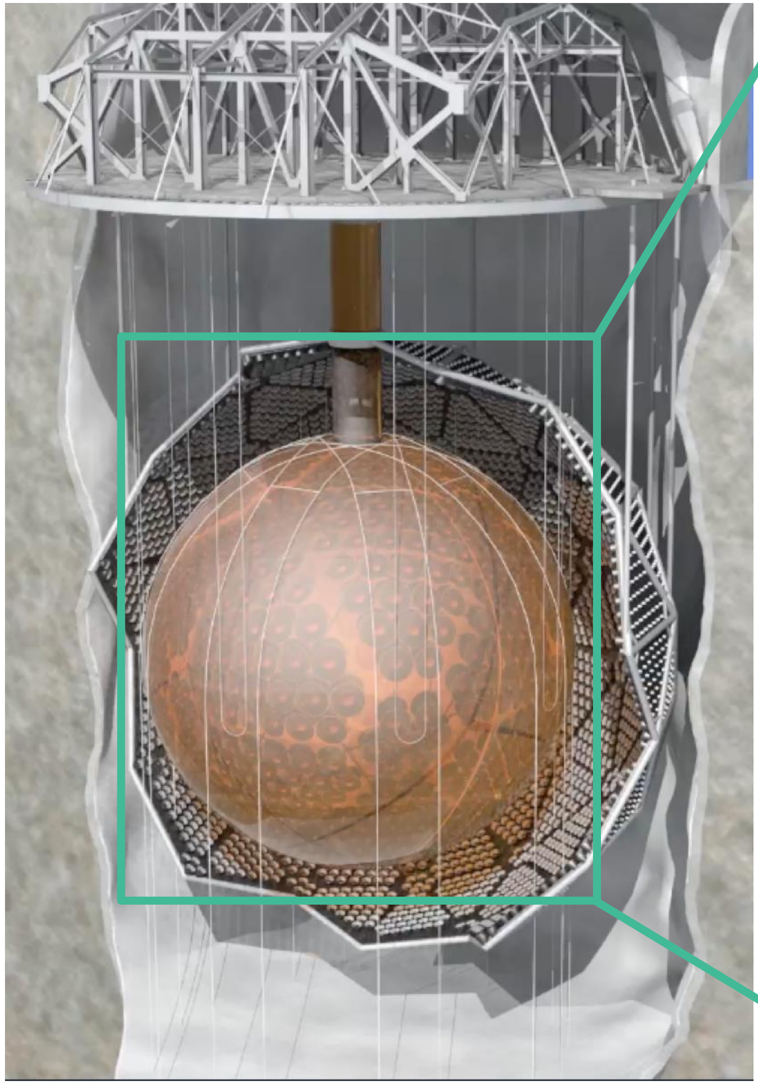
SNOLAB

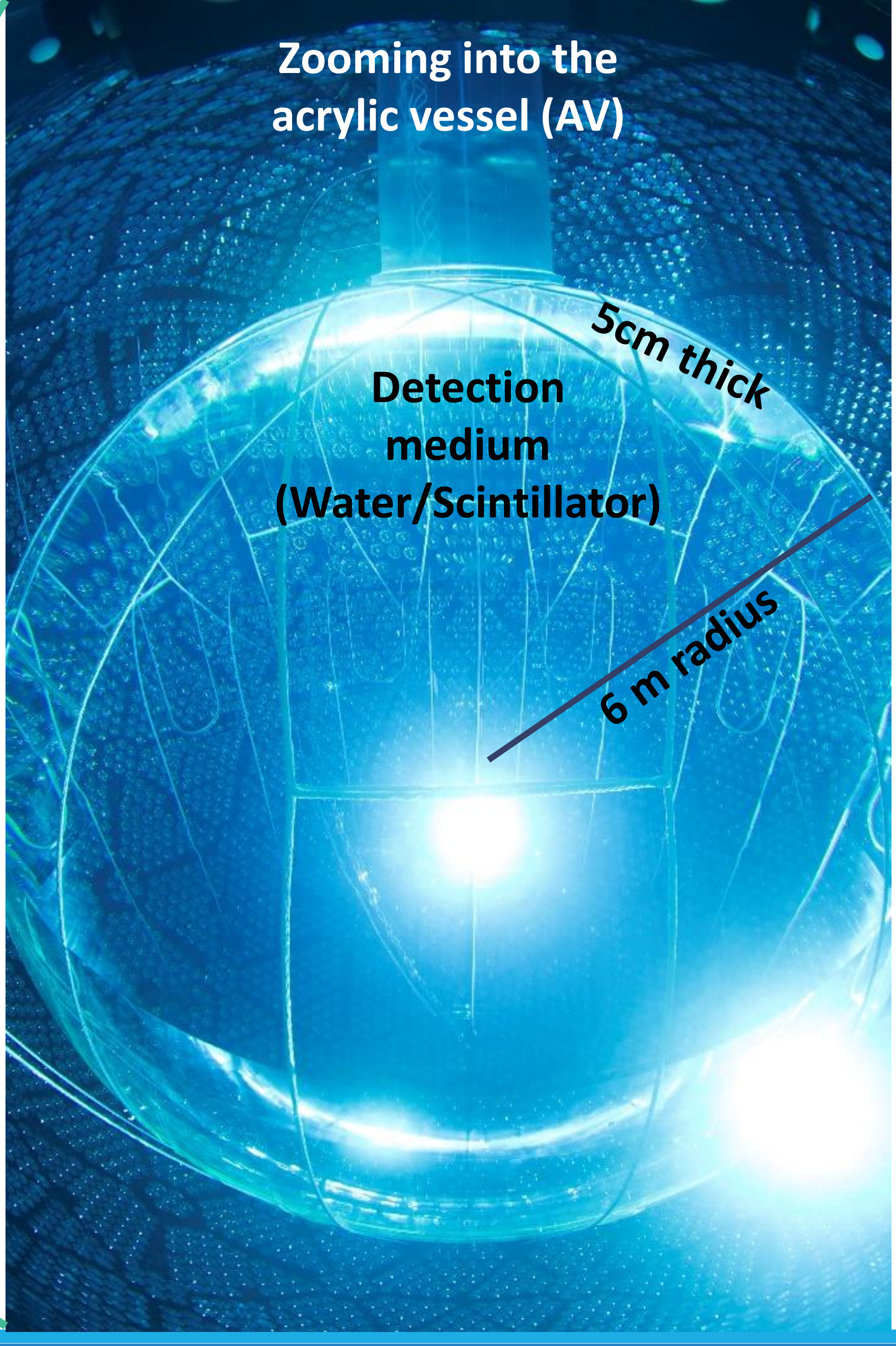
Laurentian University Université Laurentienne

Vale Creighton Mine
(Lively, Ontario)

SNOLAB

2km underground
(5.9 km.w.e.)





Vale Creighton Mine
(Lively, Ontario)

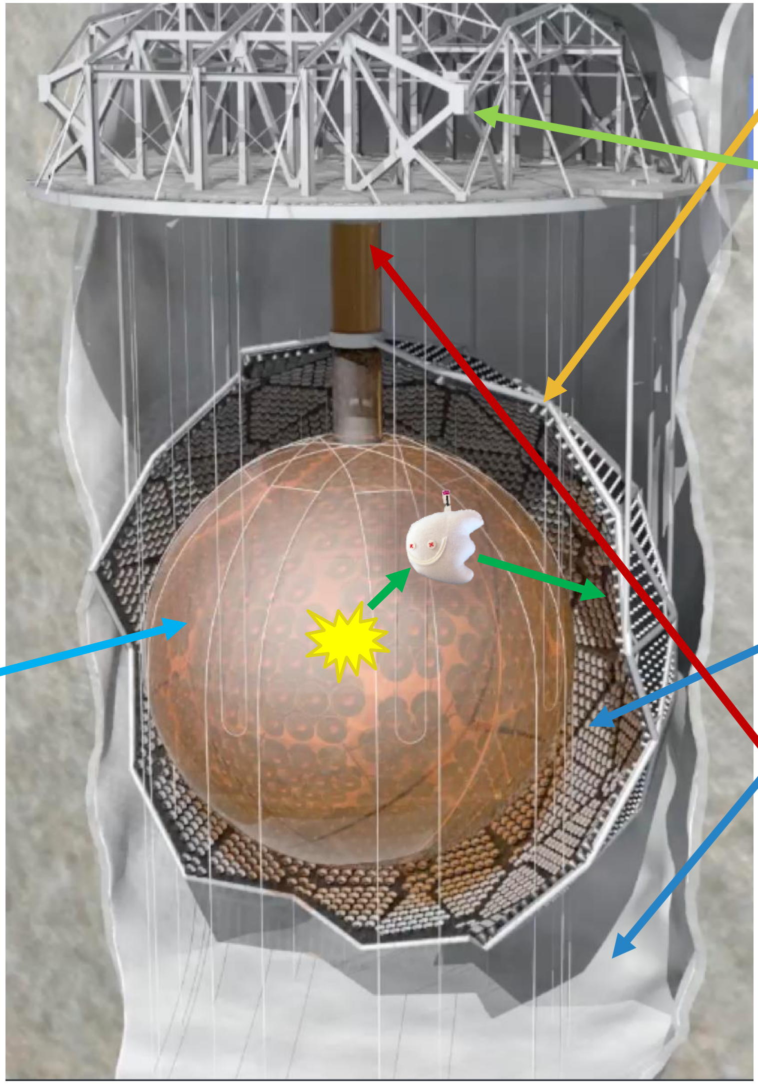
SNOLAB

2km underground
(5.9 km.w.e.)

~9300 photomultiplier tubes (PMTs)

- Mounted on support structure
- ~54% effective photocoverage

Upgraded **data acquisition system** to improve data readout



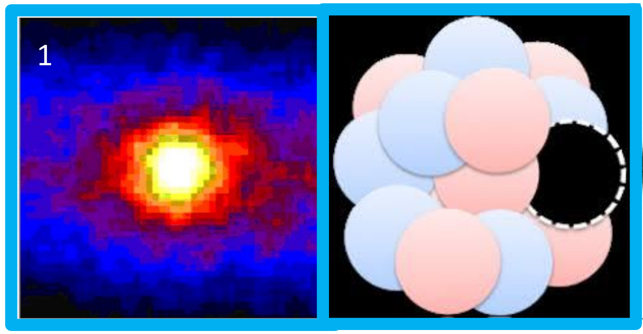
*Plush figure is from The Particle Zoo

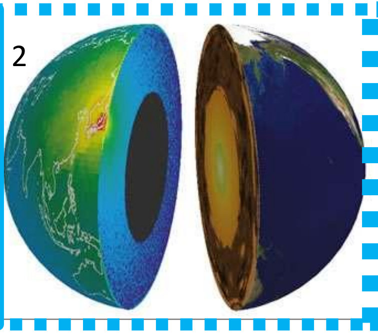
Acrylic vessel (AV)

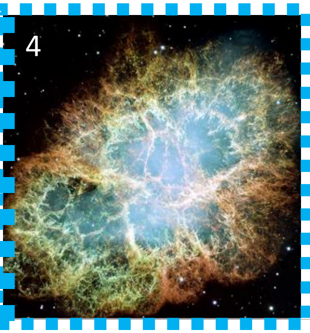
Water shielding

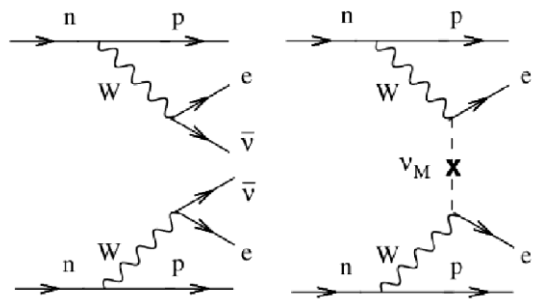
- 1.7 kt between AV and PMT support structure
  -> reduce background from PMT materials
- 5.3 kt between PMT support structure and cavity
  -> reduce background from rock wall

Sealed **cover gas** to reduce background from headspace volume









Water Phase

- ~900 t water
- Detector calibration
- External background measurements
- Measure the ^{8}B solar neutrino flux
- Search for nucleon decay to invisible modes
- **Measure neutron detection efficiency + thermal neutron-proton capture cross section**

Measurement of the ^{8}B solar neutrino flux in SNO+ with very low backgrounds

M. Anderson et al. (SNO+ Collaboration)

Consistent with matter enhanced neutrino oscillation & other solar neutrino flux measurements

Phys. Rev. D 99, 012012 (2019)

Search for invisible modes of nucleon decay in water with the SNO+ detector

M. Anderson et al. (The SNO+ Collaboration)
Phys. Rev. D 99, 032008 – Published 20 February 2019

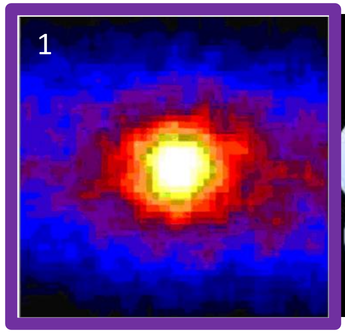
Set world-leading limit on invisible modes of proton decay

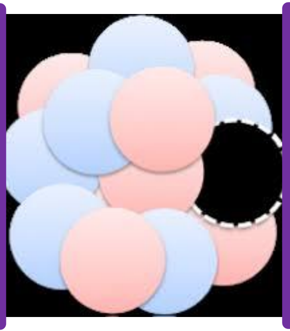
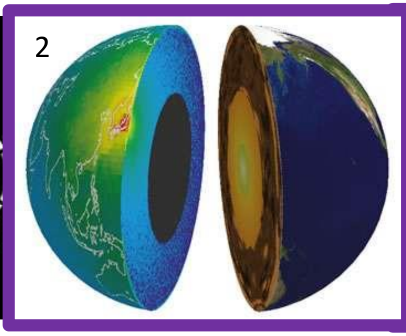
Phys. Rev. D 99, 032008 (2019)

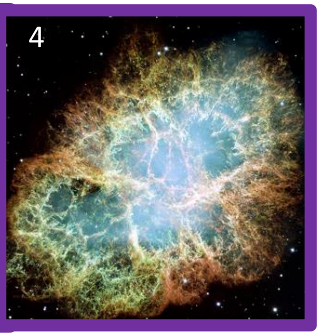
Scintillator (linear alkylbenzene, LAB) + PPO wavelength shifter Phase

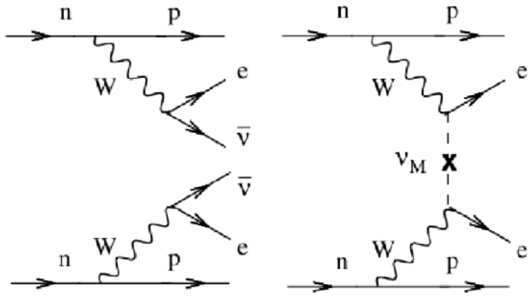
Scintillator + PPO + Tellurium Phase

[1]Super-Kamiokande Collaboration
[2]https://phys.org/news/2005-07-geoneutrinos-kamland.html
[3] https://nuclearsafety.gc.ca/
[4]NASA, ESA, J. Hester, A. Loll (ASU)



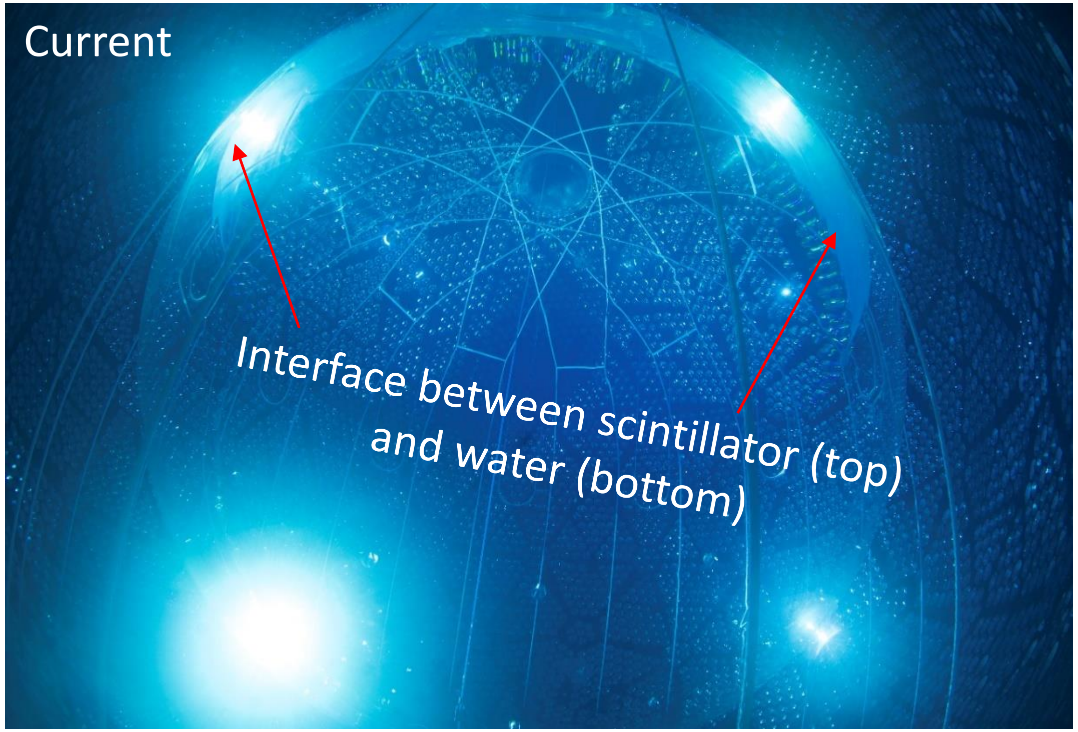




Water Phase

Scintillator (linear alkylbenzene, LAB) + PPO wavelength shifter Phase

- ~780 t of liquid scintillator; lower physics threshold
- Detector calibration
- Internal background measurements
- External background validation
- ❖ Low energy solar neutrinos (pep, CNO)
- ❖ Antineutrino detection – reactor & geo
- ❖ Supernova neutrinos physics



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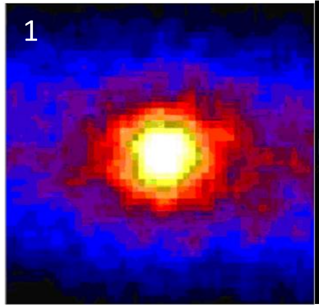
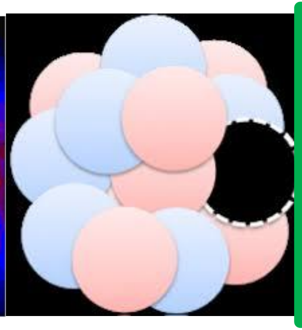
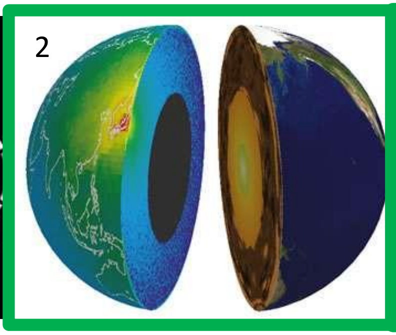
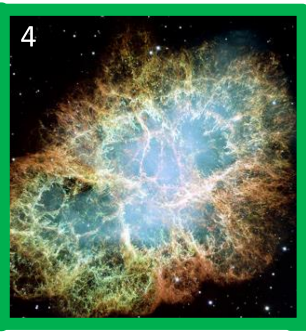
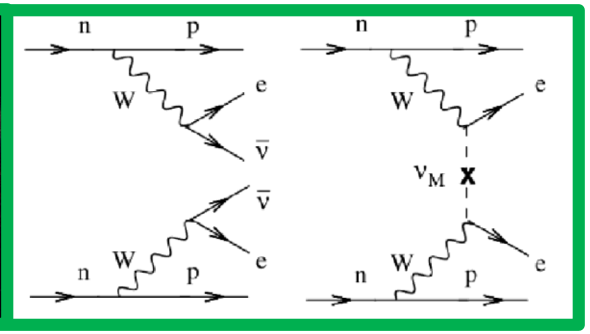










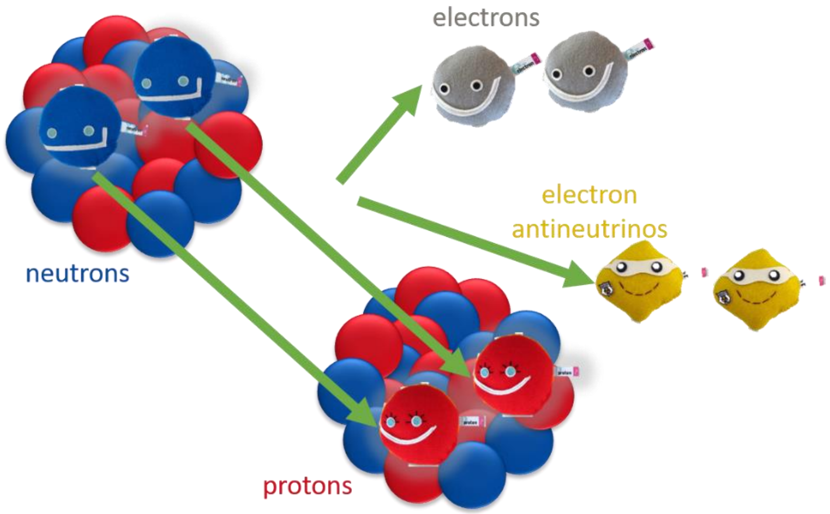
Water Phase

Scintillator (LAB) + PPO Phase

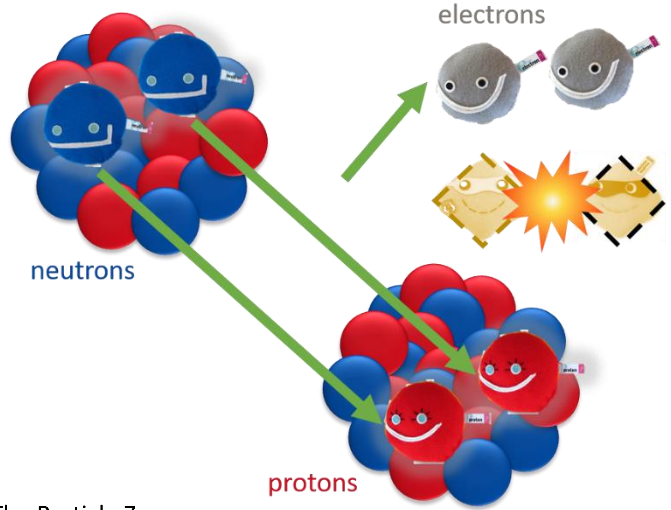
Scintillator + PPO + Tellurium Phase

- Neutrinoless double beta decay with ^{130}Te
  - Benefits of ^{130}Te:
    - Good Q-value (2.5 MeV)
    - High natural abundance (34%)
  - Observation of 0νββ
    - Proves neutrinos are Majorana particles
    - Demonstrates lepton number violation

Double beta decay (2νββ) lifetime measurement in ^{130}Te



Neutrinoless double beta decay (0νββ) search in ^{130}Te



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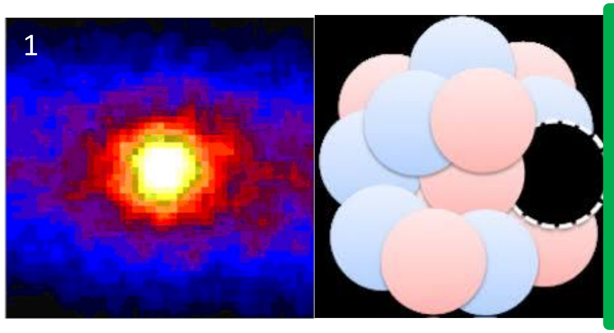
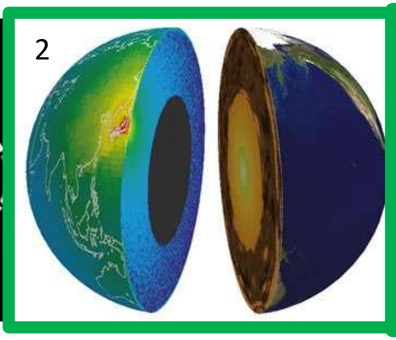
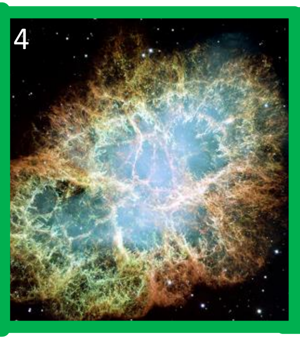
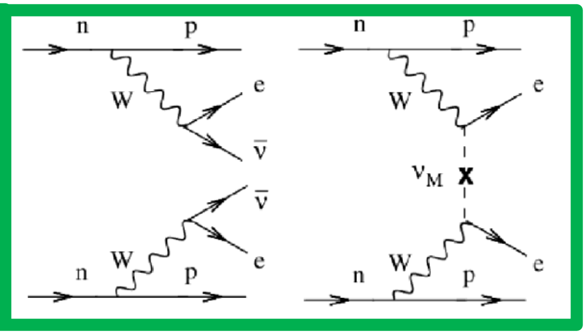








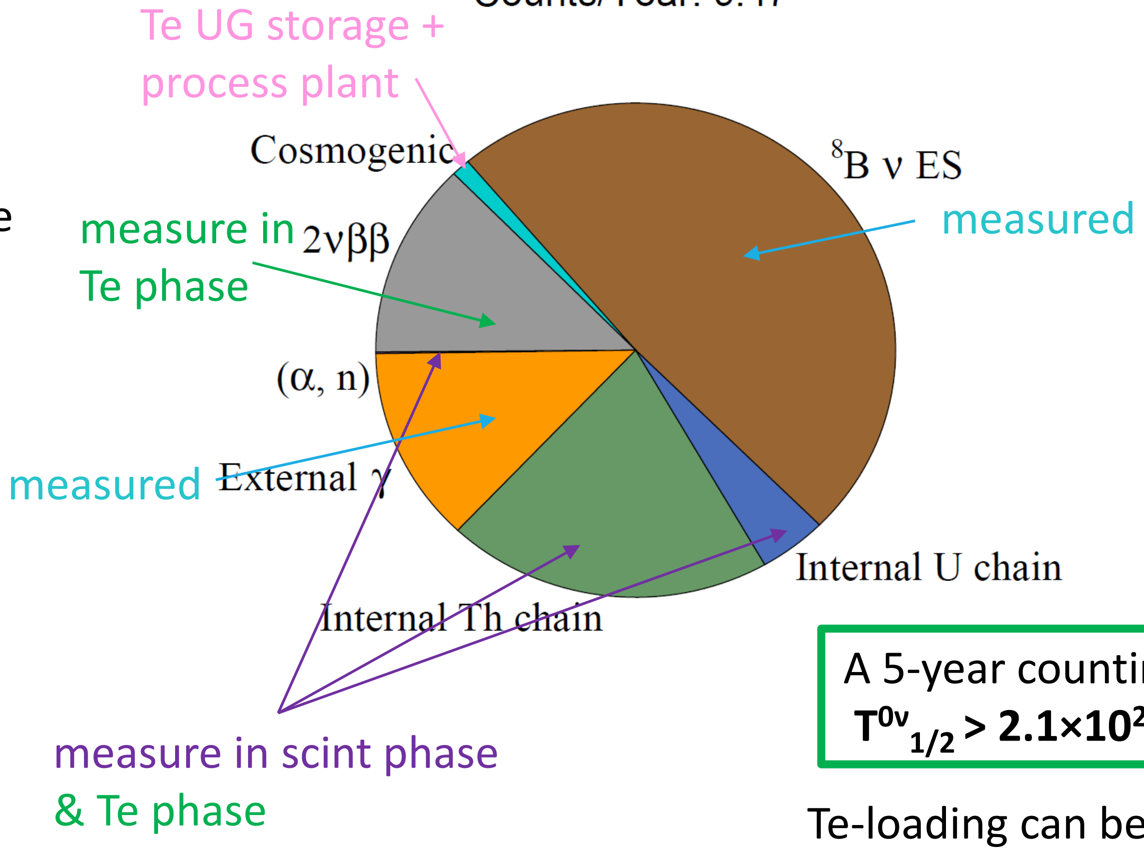
Water Phase

Scintillator (LAB) + PPO Phase

Scintillator + PPO + Tellurium Phase

- Neutrinoless double beta decay with ^{130}Te
  - Benefits of ^{130}Te:
    - Good Q-value (2.5 MeV)
    - High natural abundance (34%)
  - Observation of $0\nu\beta\beta$
    - Proves neutrinos are Majorana particles
    - Demonstrates lepton number violation

ROI: 2.42 - 2.56 MeV [-0.5σ - 1.5σ]
Counts/Year: 9.47



A 5-year counting analysis yields
$T^{0\nu}_{1/2} > 2.1\times10^{26}$ years (90% CL)

Te-loading can be increased by 4-8x

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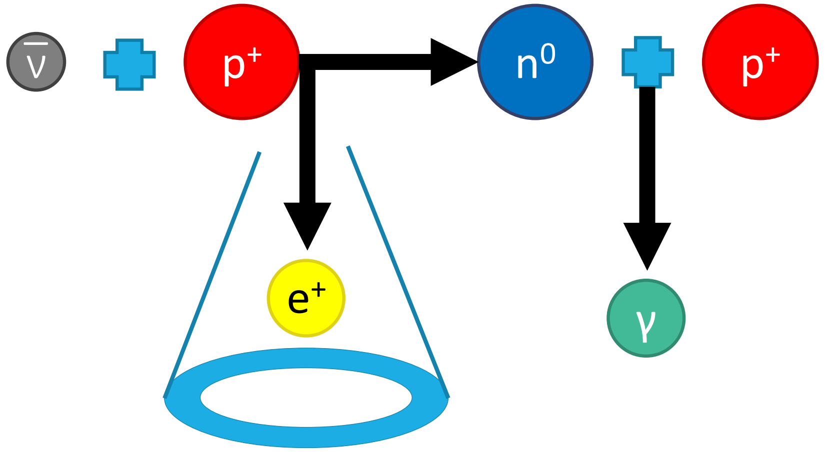
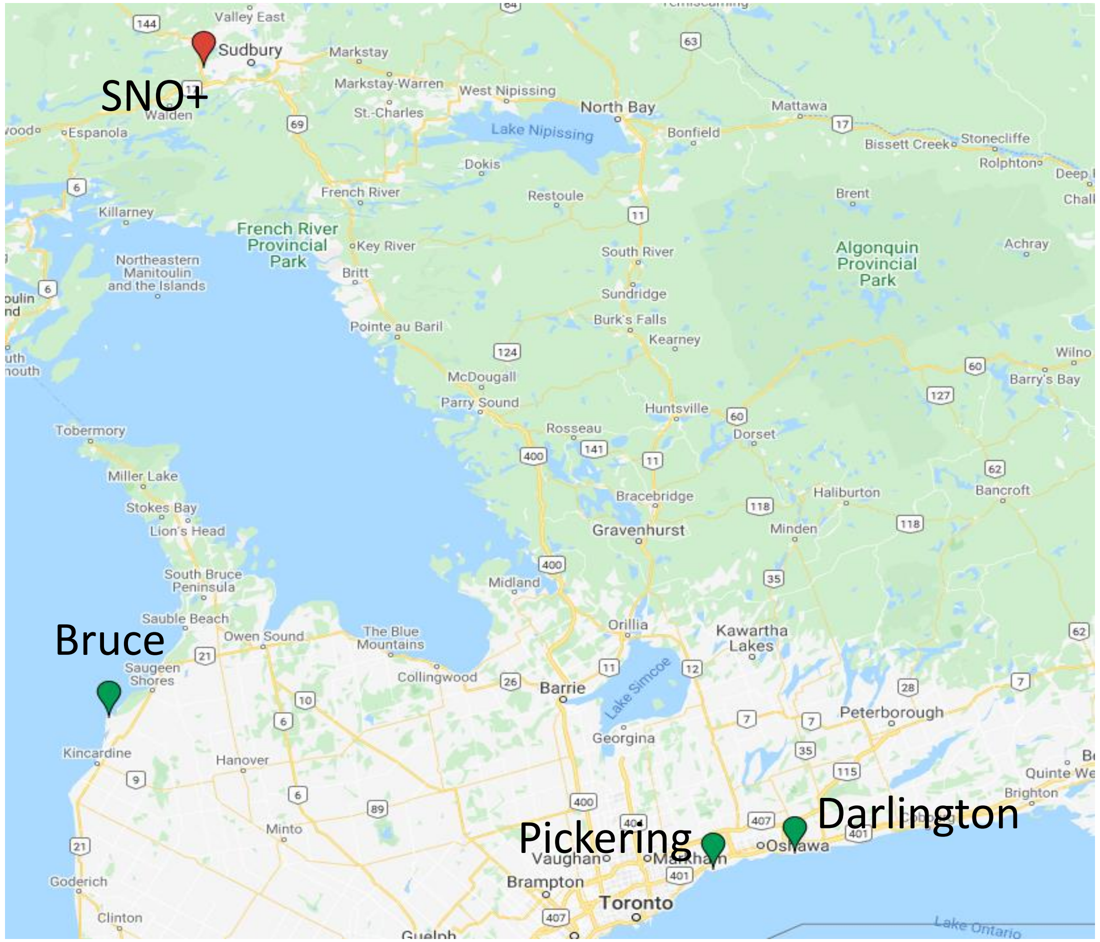
Antineutrinos: reactor and geo

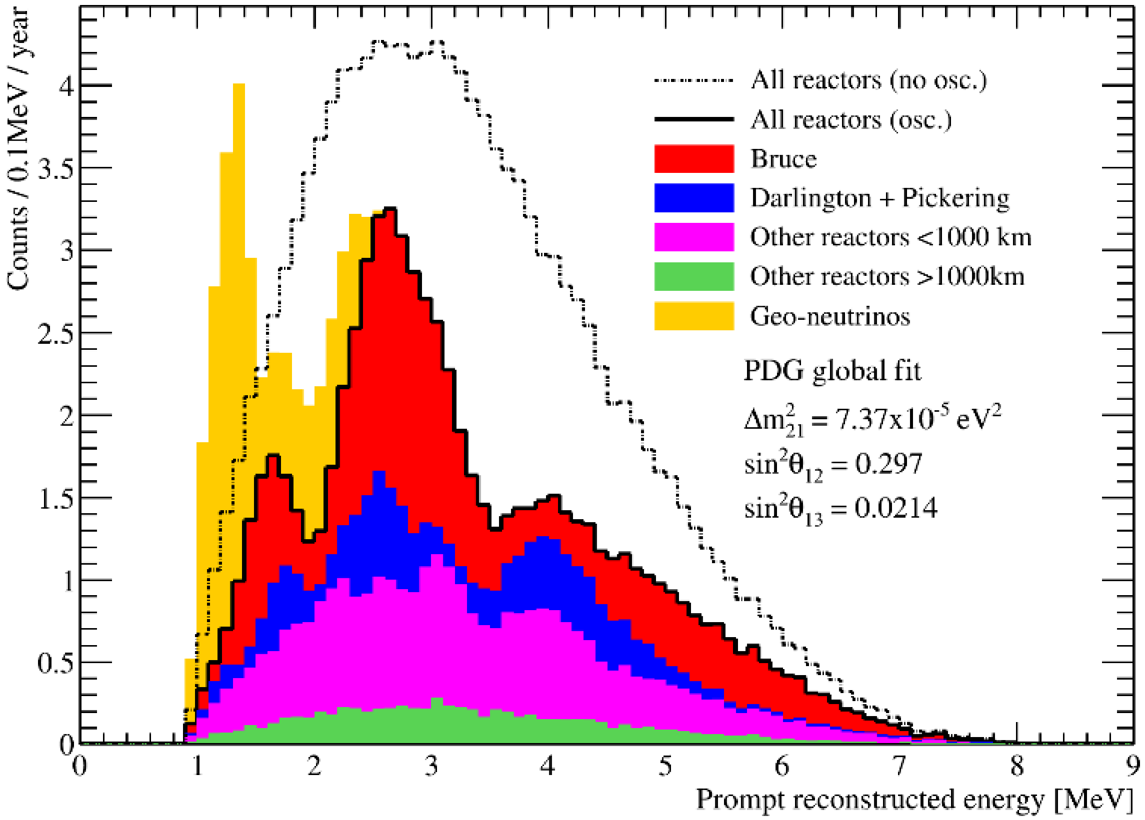
Detect reactor, geo-, and supernova antineutrinos with **Inverse Beta Decay** (IBD)



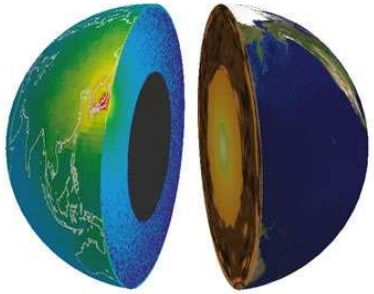
Antineutrinos: reactor and geo

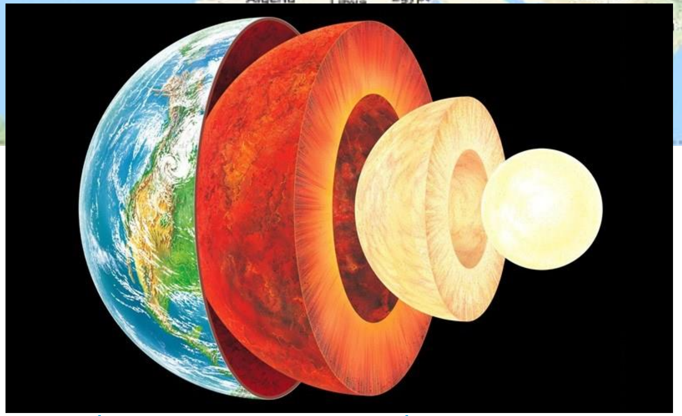


Prompt energy spectrum assuming PDG global fit Δm^2_{12}



Antineutrinos: reactor and geo

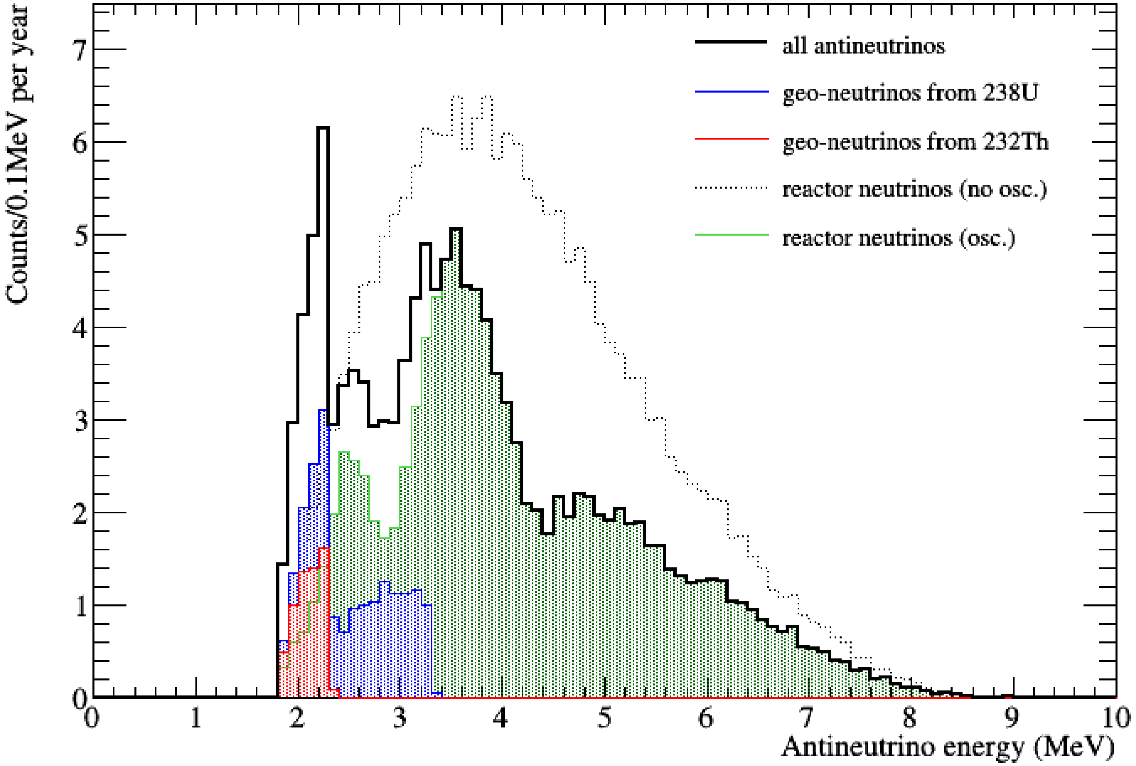




https://phys.org/

Radioactive isotopes in the Earth's mantle and crust β decay and release antineutrinos

Antineutrino energy spectrum with geoneutrino focus



Antineutrino detection in SNO+ water phase

Neutron capture efficiency is measured by deploying the **AmBe source**

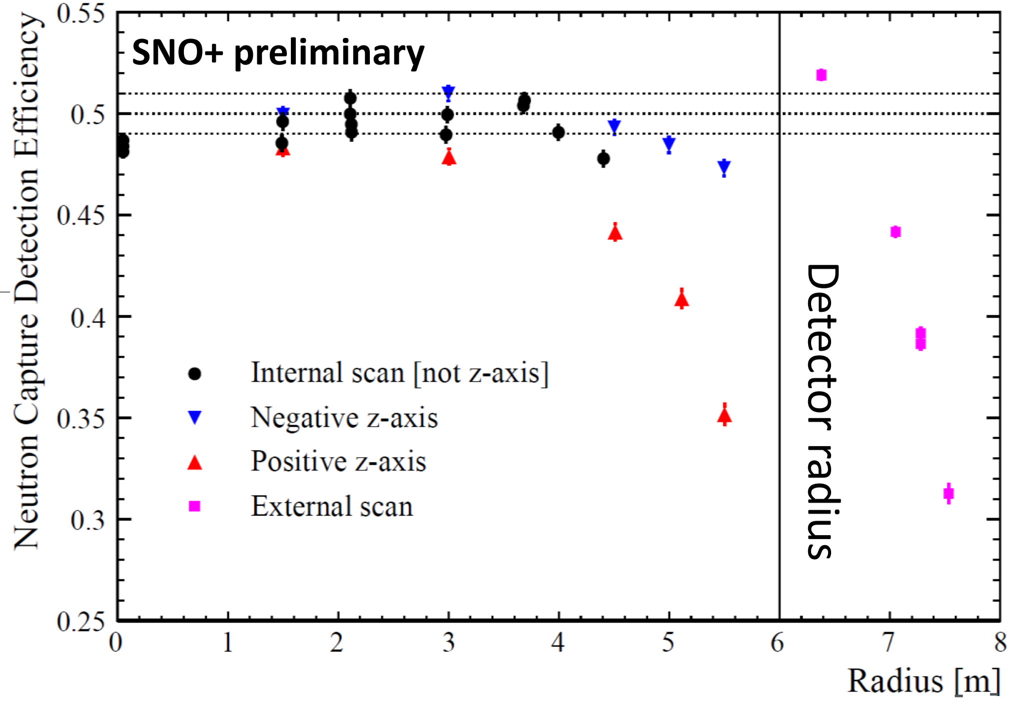
$\alpha + {}^{9}Be \rightarrow n + {}^{12}C$

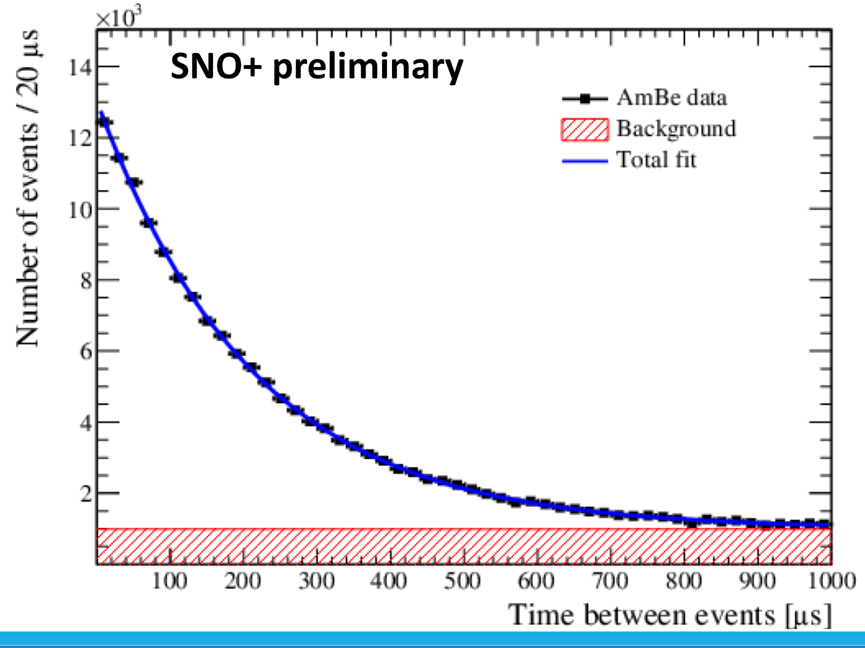
$\rightarrow n + {}^{12}C^*$

${}^{12}C^* \rightarrow {}^{12}C + 4.4\ \text{MeV}\ \gamma$ (prompt)

$n + {}^{1}H \rightarrow {}^{2}H + 2.2\ \text{MeV}\ \gamma$ (delayed)

} Coincidence provide a distinctive signature





Detection efficiency: 49.08±0.39%

Highest efficiency for neutron captures on hydrogen in water Cherenkov detectors

Neutron capture time constant

$\tau = 202.35^{+0.87}_{-0.76}\ \mu s$

$\sigma_{H,t} = (\tau\, v_{n,t}\, n_H)^{-1}$

$v_{n,t}$ ≡ thermal neutron velocity

n_H ≡ number density of hydrogen atoms

$\sigma_{H,t}$ ≡ thermal neutron-proton capture cross section

$\sigma_{H,t}$: $336.3^{+1.2}_{-1.5}$ mb

arXiv:2002.10351 (2020)

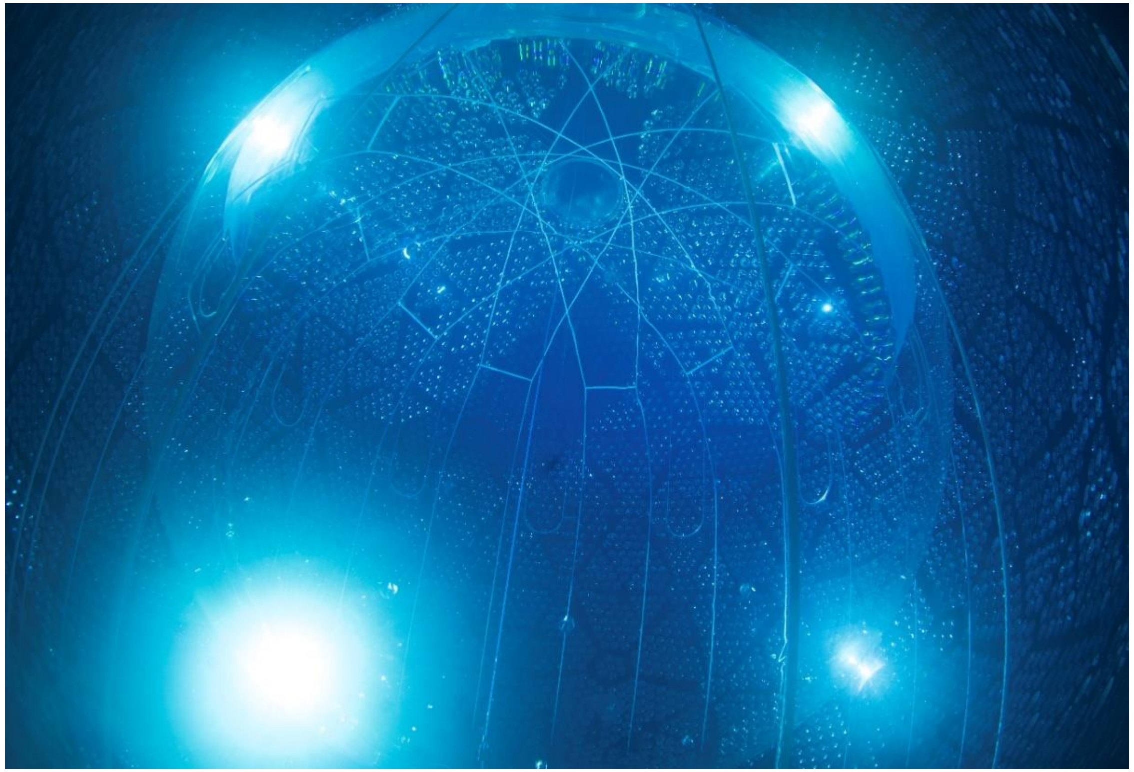
Current detector status

Scintillator+PPO Phase

- Scintillator+PPO fill on-going
  - See **Caroline Deluce**'s talk:
    "Towards Liquid Scintillator Phase of the SNO+ Neutrino Detector"
- Currently filled with 365t of LAB+PPO
- Scintillator background analyses on-going

Scintillator+PPO + Tellurium Phase

- Tellurium process plants in commissioning stage



Current water phase analysis status

Water Phase

- ✓ Physics papers with ultra-low background water data
  - ✓ Measured 8B solar neutrino flux with ultra-low background data Phys. Rev. D 99, 012012 (2019)
  - ✓ Set world-leading limit on invisible modes of proton decay Phys. Rev. D 99, 032008 (2019)
- ✓ Measure neutron detection efficiency + thermal neutron-proton capture cross section
- ✓ Measured external background, consistent with expectations

- Analysis ongoing and more papers in preparation
- Update existing analyses with
  - Higher statistics: additional 190.33 days
  - Completed optical calibration
  - Lower radon background