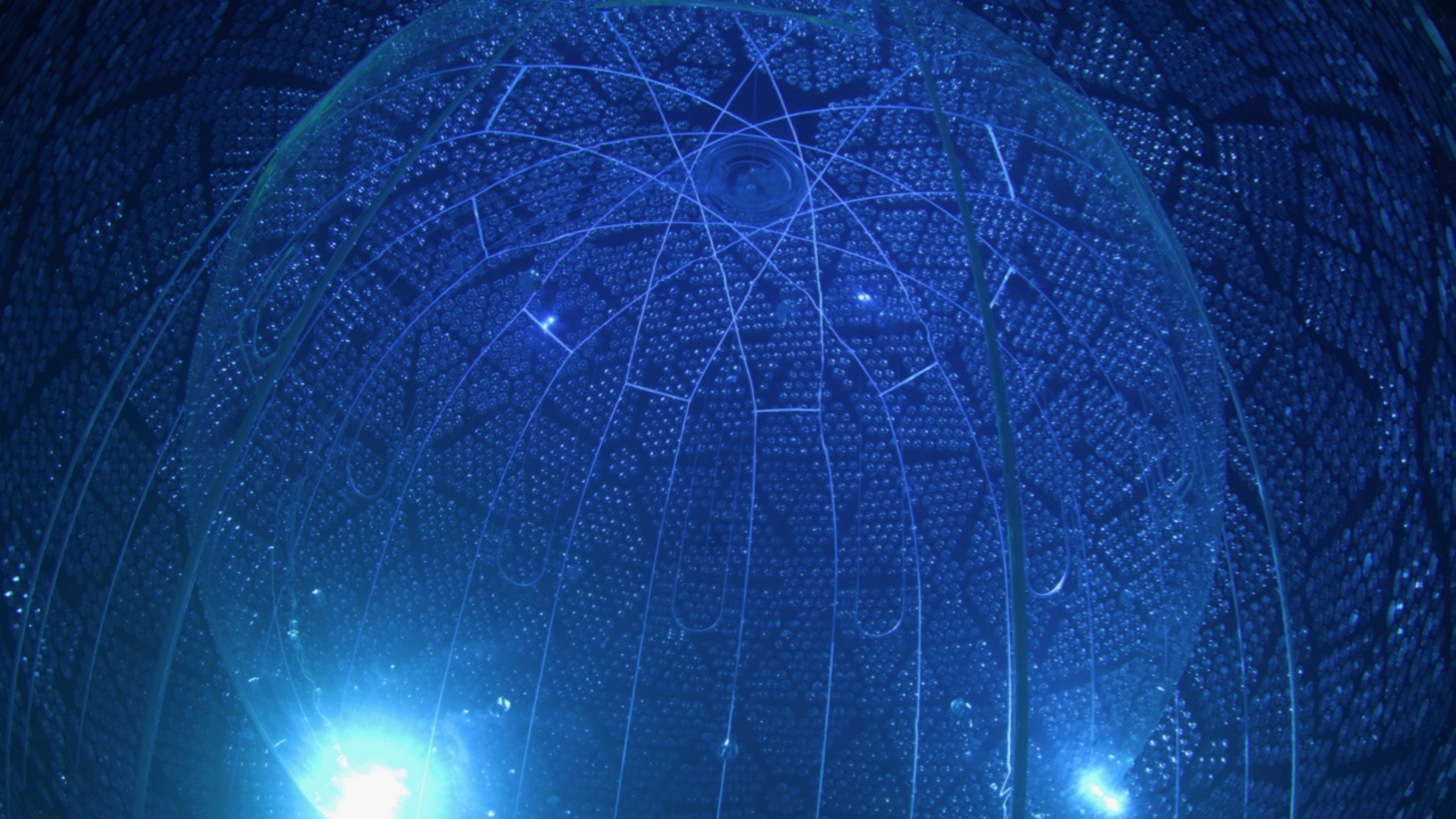
The
SNO+ Experiment
Neutrinoless Double Beta Decay Programme

Benjamin Tam (for the SNO+ Collaboration)
IOP Joint Meeting 2024
10 April 2024



SNO+

A multi-purpose neutrino experiment

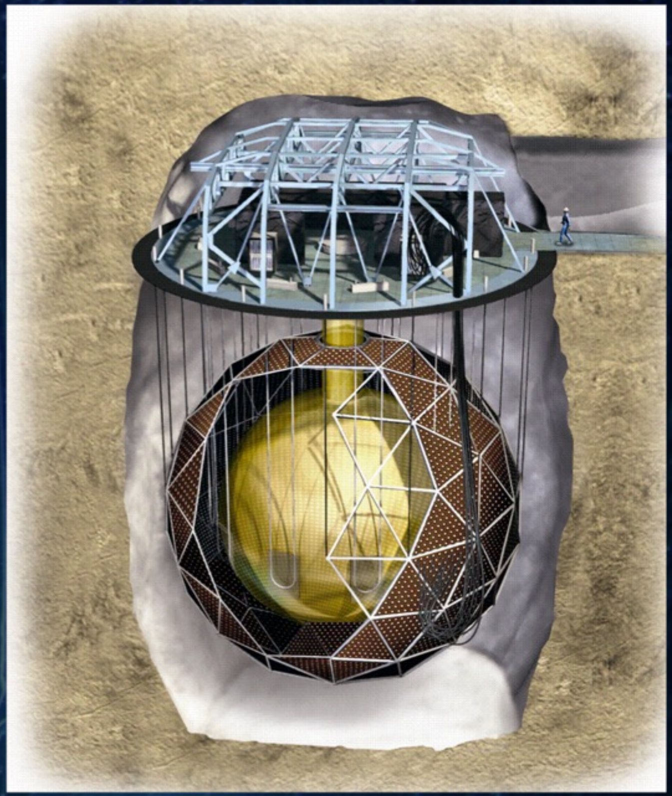
Successor to the Sudbury Neutrino Observatory

Inherited the main detector infrastructure:

- Primary detector body: a 12-m diameter Acrylic vessel
- Outer steel support structure, housing 9800 photomultiplier tubes
- Located 2km underground in the Canadian SNOLAB facility

Upgraded with liquid scintillator

- Better light yield



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Primary SNO+ Physics Goal

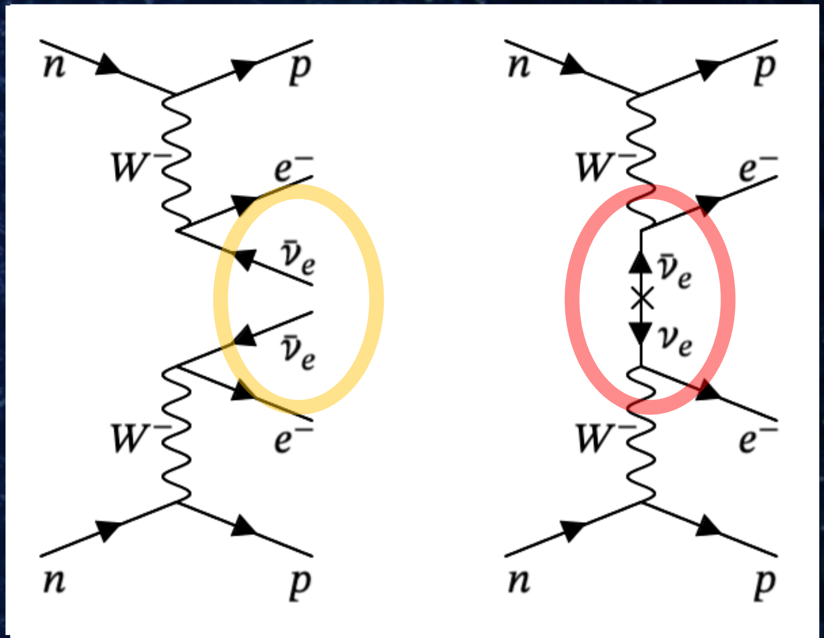
Determining if Neutrinos are Majorana Particles

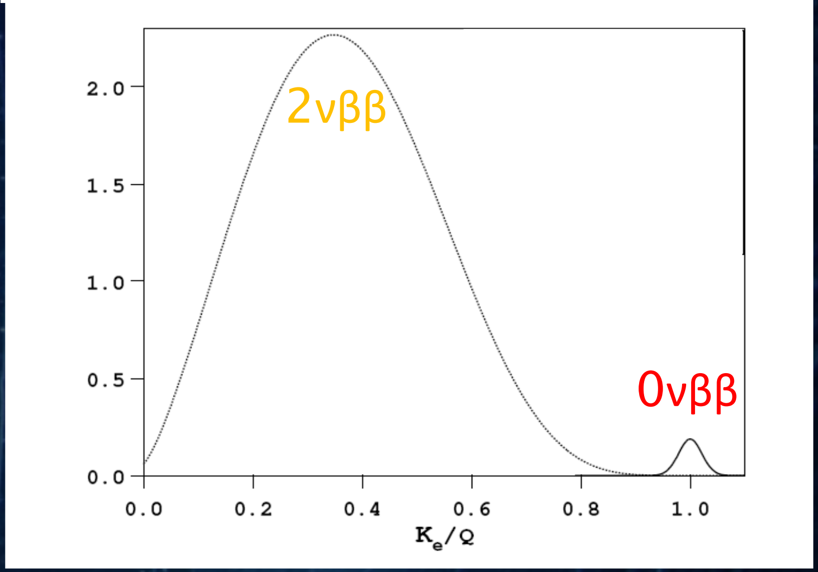
- Neutrinos and Antineutrinos would be the same particle
- Provides satisfying mass mechanism for neutrinos
  - And much more!

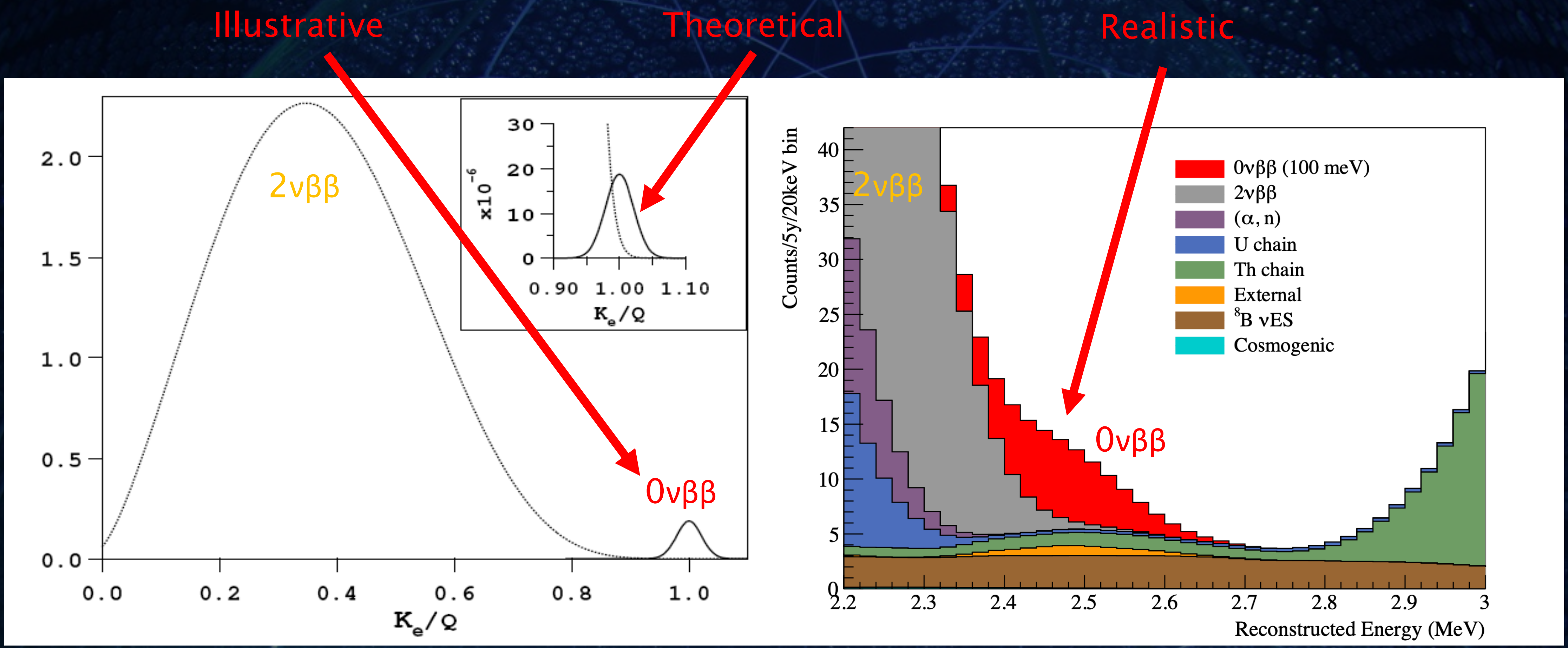
Experimental Methodology

Neutrinoless Double Beta Decay "0νββ"

- Two-neutrino double beta decay exists
  - Releases 2 neutrinos, 2 electrons
- If Majorana, the neutrino is exchanged virtually
  - Releases 0 neutrinos, 2 electrons
- Signature Signal: the measurement of both electrons







Main Experimental Challenge

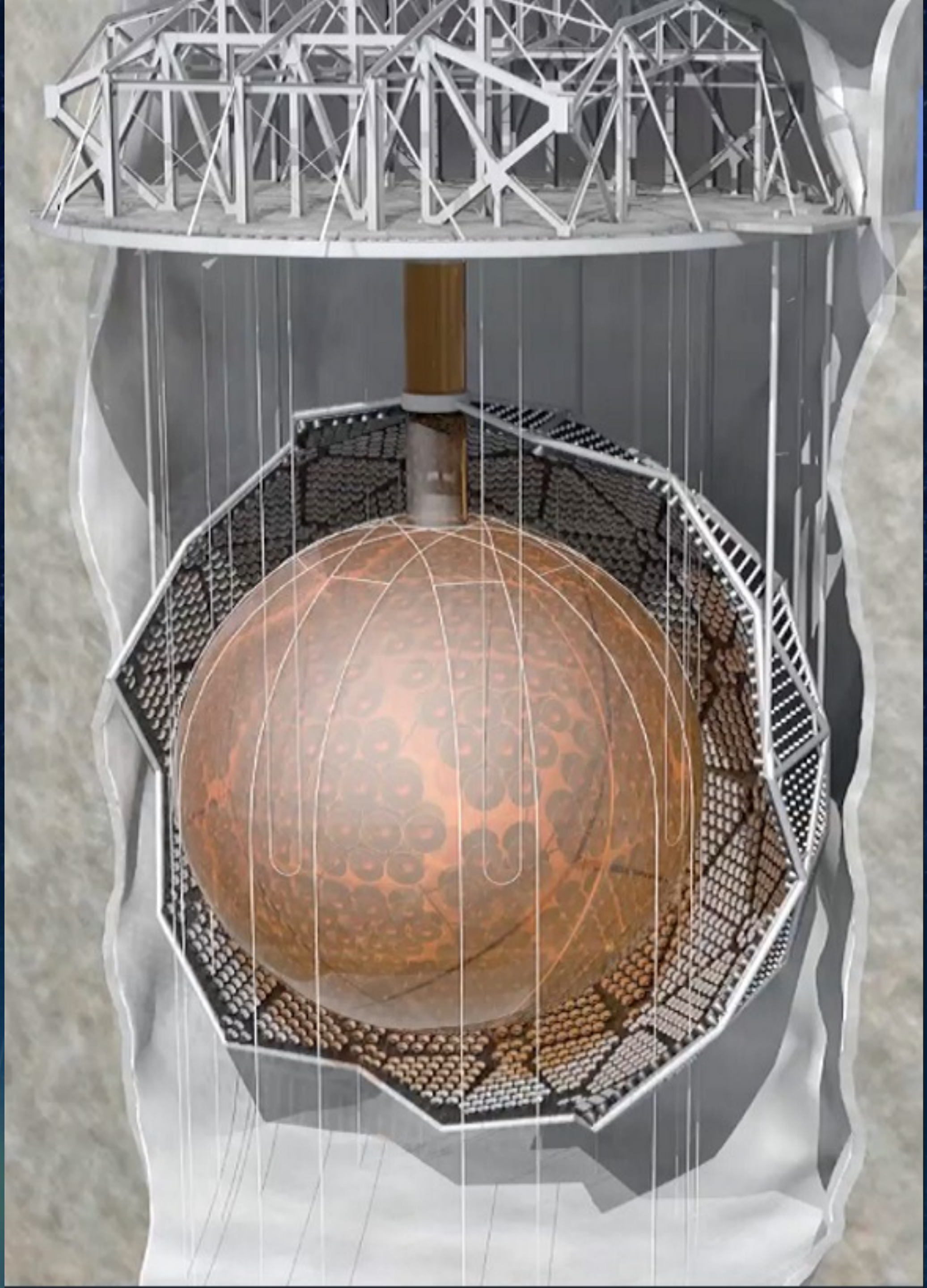
Suppressing Backgrounds through intense shielding and purification

Shielding

2070 m rock overburden
6010 m.w.e. (0.286±0.009 μ/m^2/d)

7000 m^3 external ultrapure water shielding

N_2 Cover Gas blanket across entire detector



Purification

Four chemical plants to treat the various internal and external media

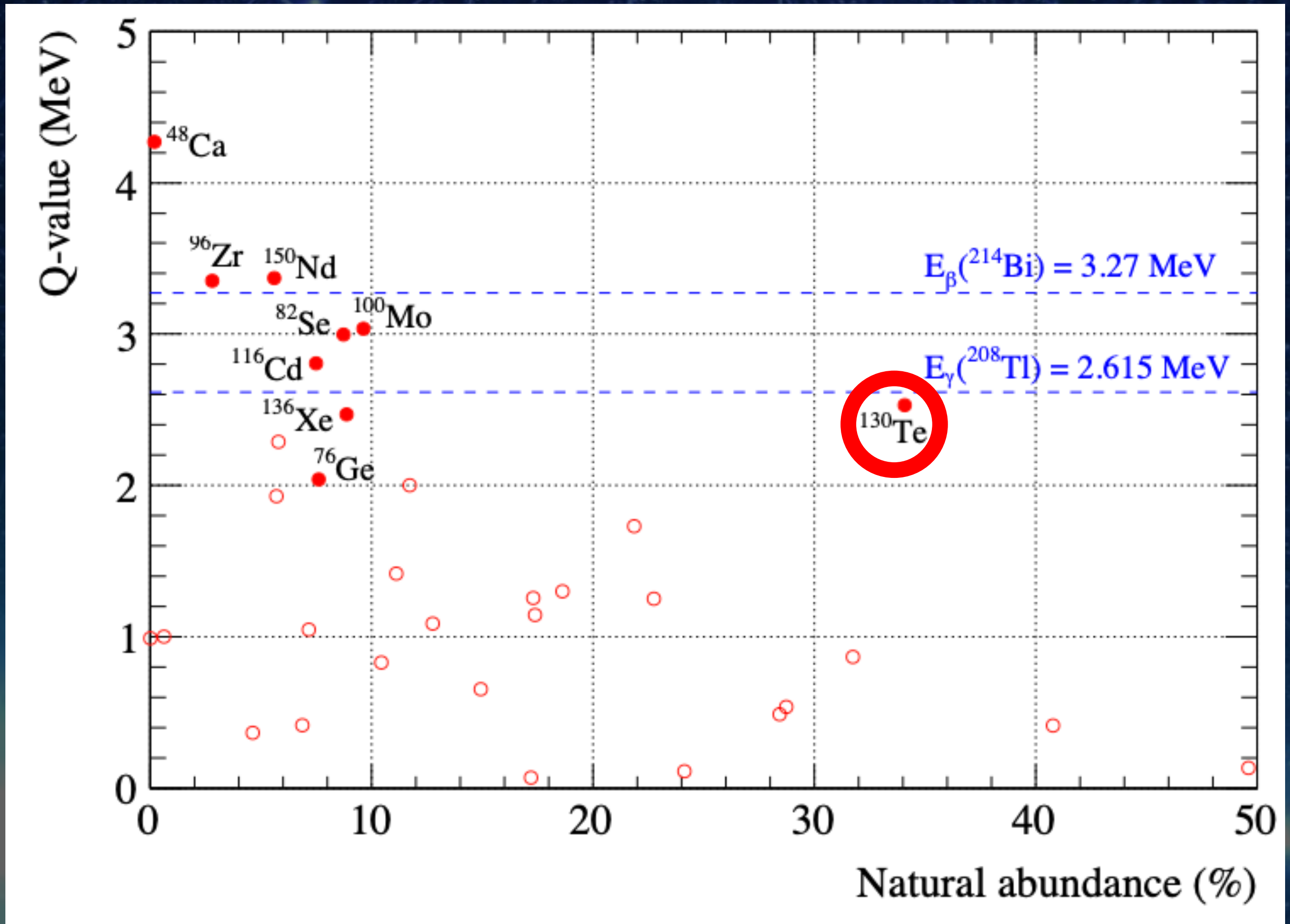
Vigorous QA campaign:
hourly chemical analysis during operations

Recirculation and repurification capabilities for internal and external media

Detector Hardware: JINST 16 P08059

The SNO+ 0νββ Strategy

- Improve sensitivity through a high isotope mass
- ^{130}Te chosen as isotope
  - High natural abundance → expensive enrichment unnecessary
  - Q-value of 2.53 MeV



The Road to 0νββ

Water Phase

May 2017 - July 2019

905 tonnes ultrapure Water

- Measure External Backgrounds
- Test calibration systems
- Achieve stable running of detector

→ Scintillator Fill →

Scintillator Phase

Started April 2022

780 tonnes liquid scintillator

- Quantify the backgrounds in the scintillator
- "Target out advantage"

→ Te Loading →

Tellurium Phase

Deployment 2025

780 tonnes liquid scintillator doped with >4 tonnes ^{nat}Te

- Begin the search for 0νββ

The Road to 0νββ

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Bonus!

Partial Fill

March – October 2020

365 tonnes liquid scintillator

- Preliminary look at the scintillator purity

The Road to 0νββ

Water Phase

May 2017 - July 2019

905 tonnes ultrapure Water

- Invisible Nucleon Decay
- Solar neutrinos
- Reactor anti-neutrinos
- Supernova neutrinos

Scintillator Fill →

Scintillator Phase

Started April 2022

780 tonnes liquid scintillator

- Solar neutrinos
- Reactor anti-neutrinos
- Geo-neutrinos
- Supernova neutrinos
- Light DM & MIMP DM
- Axion-like particles

Talk by James Page

Te Loading →

Tellurium Phase

Deployment 2025

780 tonnes liquid scintillator doped with >4 tonnes ^{nat}Te

- Scintillator Phase Physics Programme
- Neutrinoless double beta decay in ^{130}Te

Wide range of secondary physics capabilities!

SNO+ Liquid Scintillator

- Linear Alkylbenzene (LAB) + 2.2g/L Diphenyloxazole (PPO)
- Developed by SNO+, successfully used in Daya Bay, RENO, and others
- Compatible with acrylic and safer than other widespread liquid scintillators
- Purified using purpose-built purification plant
- Ultra-purity verified through extensive suite of hourly measurements during filling (~6000 samples analysed)

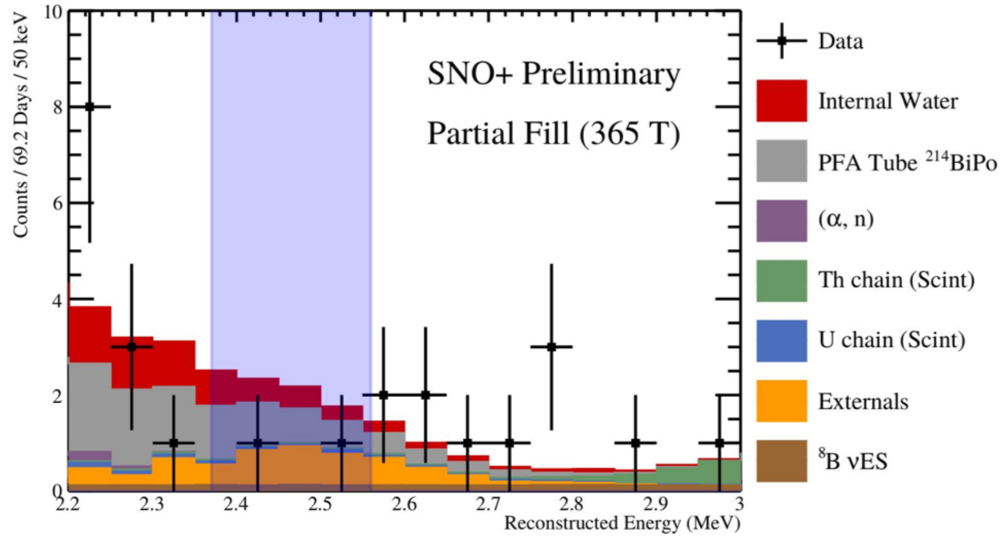
Scintillator Fill Completed
April 29, 2022

SNO+ Scintillator: JINST 16 P05009

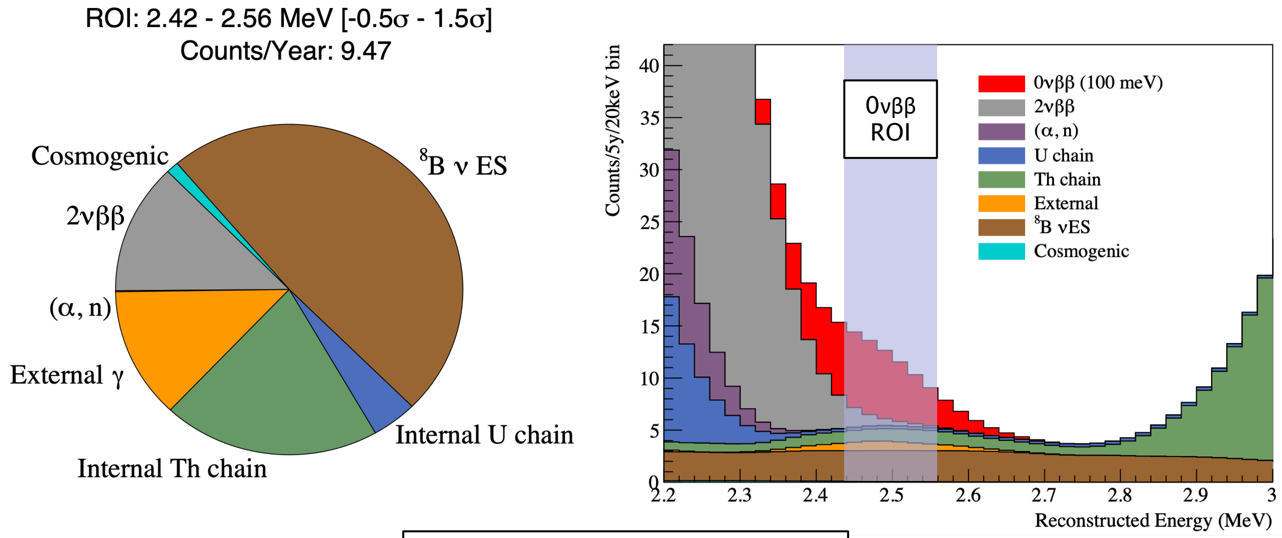
Target Out Analysis

Scintillator backgrounds can be understood prior to isotope deployment ("Target Out")

- Performed in partial fill
- Underway for scintillator phase
- Major SNO+ advantage not present in other 0νββ search techniques



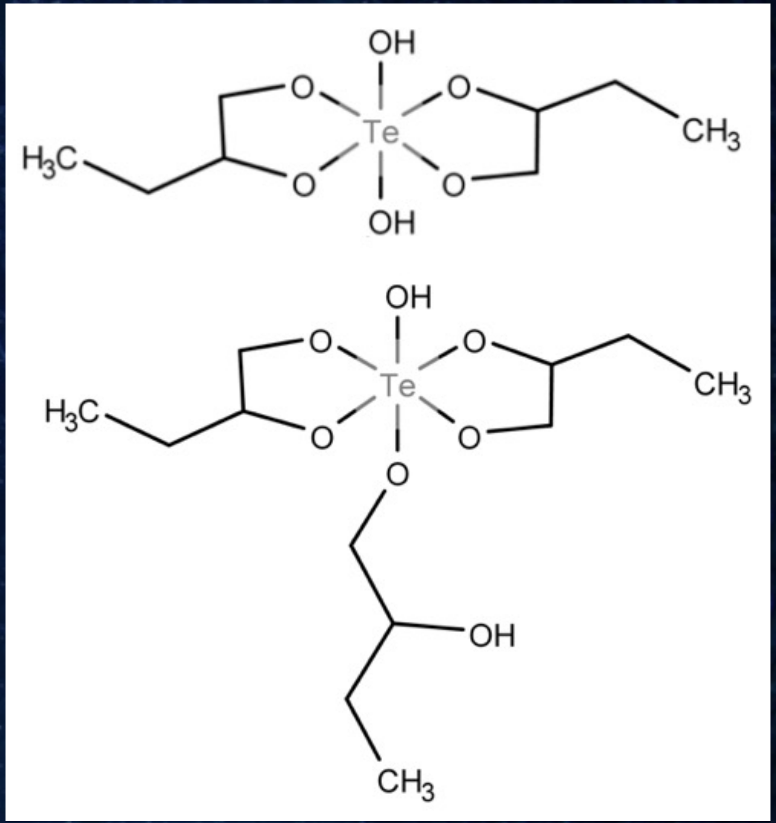
Partial Fill Target Out



Projected Tellurium Phase

Tellurium Loading of Scintillator

- Novel metal-loading technique to dope SNO+ LS with Te
  - Achieved by diolising telluric acid (TeA), forming Tellurium Butanediol (TeBD) that readily dissolves in LAB
  - Additives introduced to scintillator to improve light yield and stability
    - 1,4-Bis(2-methylstyryl)benzene (Bis-MSB)
    - Butylated Hydroxytoluene (BHT)
    - N,n-dimethyldodecylamine (DDA)



Final Detector Medium Composition:

904,000 L LAB

+ 2.2 g/L PPO

+ 2.2 mg/L bis-MSB

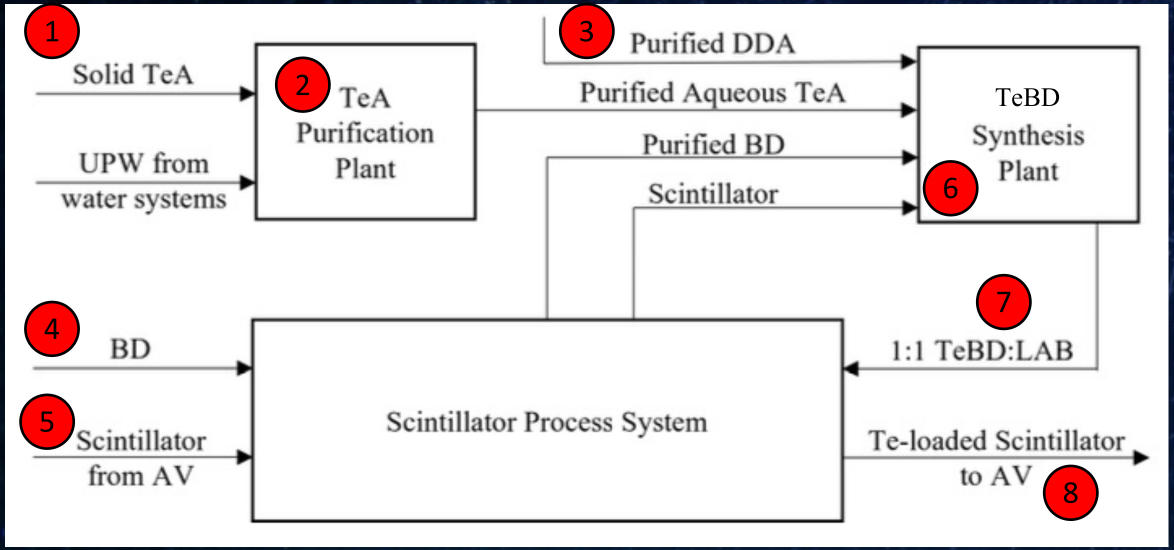
+ 6.5 mg/L BHT

+ DDA

+ TeBD

Tellurium Loading Technique: NIM A 1051:168204

Tellurium Purification & Deployment Plan

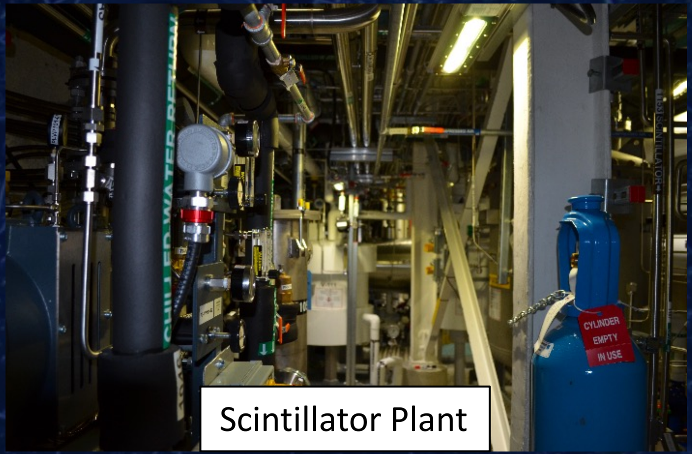


1. TeA brought underground for years to “cool off” cosmogenics
2. TeA purified in TeA Purification Plant
3. DDA purified in molecular still
4. BD purified in scintillator plant
5. Purified Scintillator taken from detector
6. TeBD synthesised in TeBD synthesis plant
7. TeBD diluted to desired concentration in the scintillator plant
8. Te-loaded scintillator added to the detector

Required Deployment Facilities

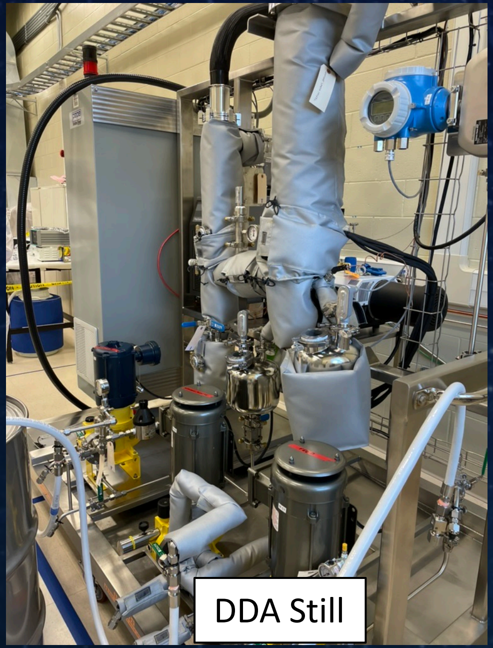
4 Chemical Plants Required:

- Scintillator Purification Plant
  - Built and commissioned
  - Used during scintillator fill
- TeA purification plant
  - Built and commissioned
  - Initial full-scale test started March 2024, near completion
- DDA Molecular Still
  - Built, currently commissioning
- TeBD Synthesis plant
  - Built, currently commissioning



Scintillator Plant

TeA Plant

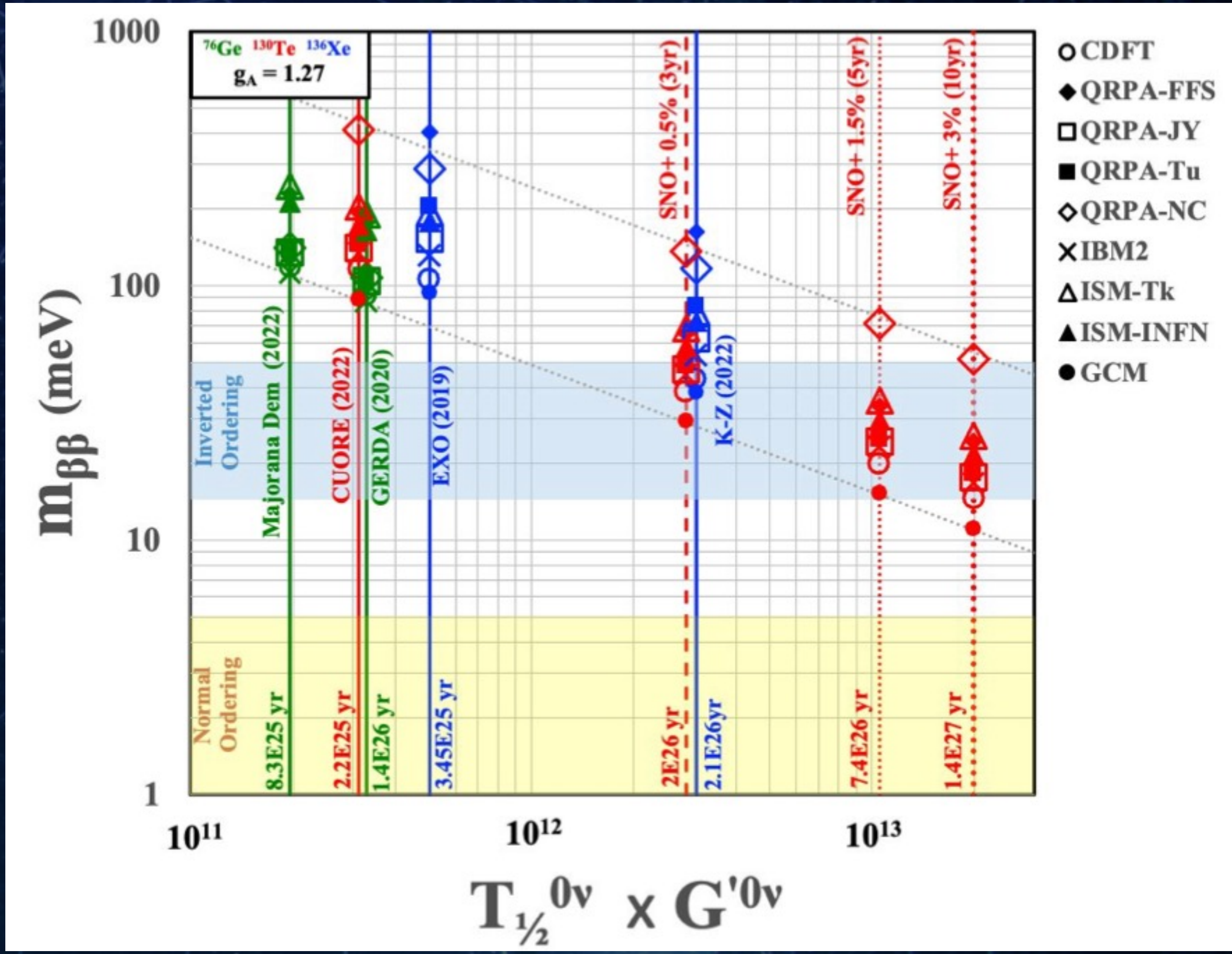


DDA Still

TeBD Synthesis Plant

SNO+ 0νββ Prospects

- Initial loading of 0.5% ^{nat}Te
  - ^{130}Te has a natural abundance of 34%
  - Corresponds to 1.3 tonnes ^{130}Te
- Tellurium deployment expected 2025
- Sensitive to $T^{0\nu}_{1/2} = 2 \times 10^{26}$ yr after 3 years data taking



SNO+ Advantages:

- Only planned tonne-scale search using Te
- Backgrounds can be well understood through target out analysis
- Highly and affordably scalable
  - Loading of up to 3% possible and planned
  - This would probe below inverted ordering space

SNO+ Tellurium Phase Coming Soon!

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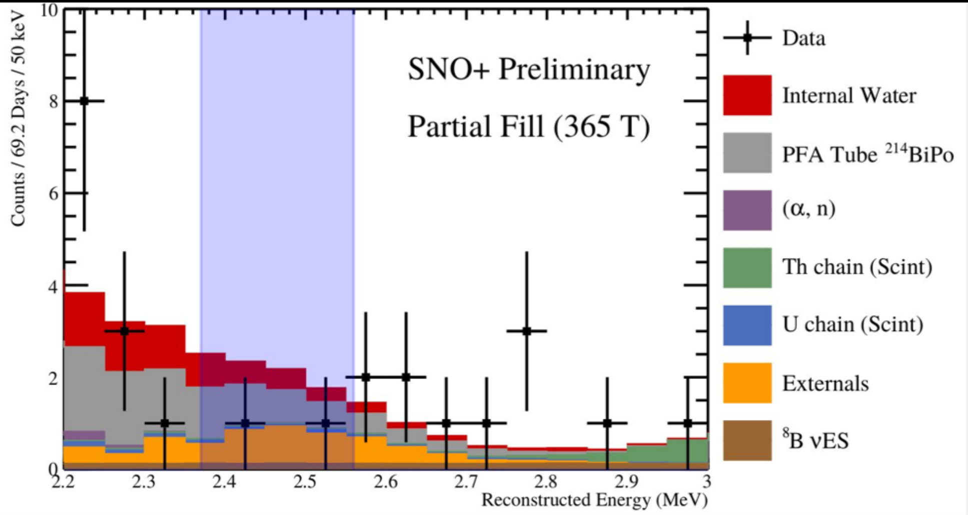
- All scintillator enhancements have been added
- All Te systems constructed, late stages of commissioning
- Initial demonstration of Te purification near completion
- Te Deployment planned for 2025!

Backups

Target Out (Partial Fill)



Background	Expected Counts in Partial Fill ROI
Internal Water	1.8
PFA Tube ^{214}BiPo	2.9
Externals	2.5
$(\alpha$, n)	0
Th Chain (Scint)	0.1
U Chain (Scint)	0.3
^{8}B νES	0.5
Total Backgrounds	8.0