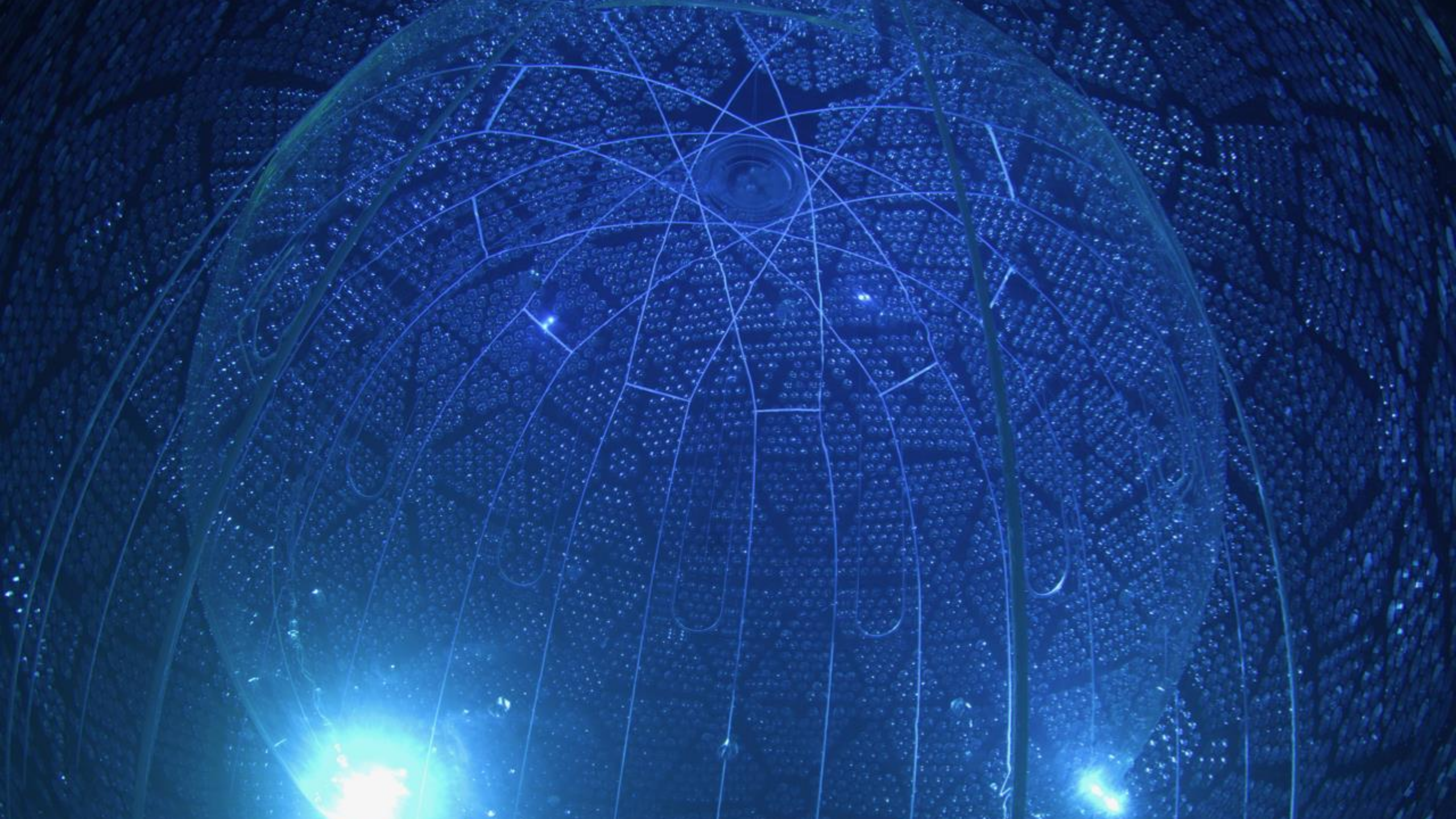
Status of the
SNO+ Experiment

Benjamin Tam (for the SNO+ Collaboration)
IOP Joint APP and HEPP Annual Conference
7 April 2025



A multi-purpose neutrino experiment

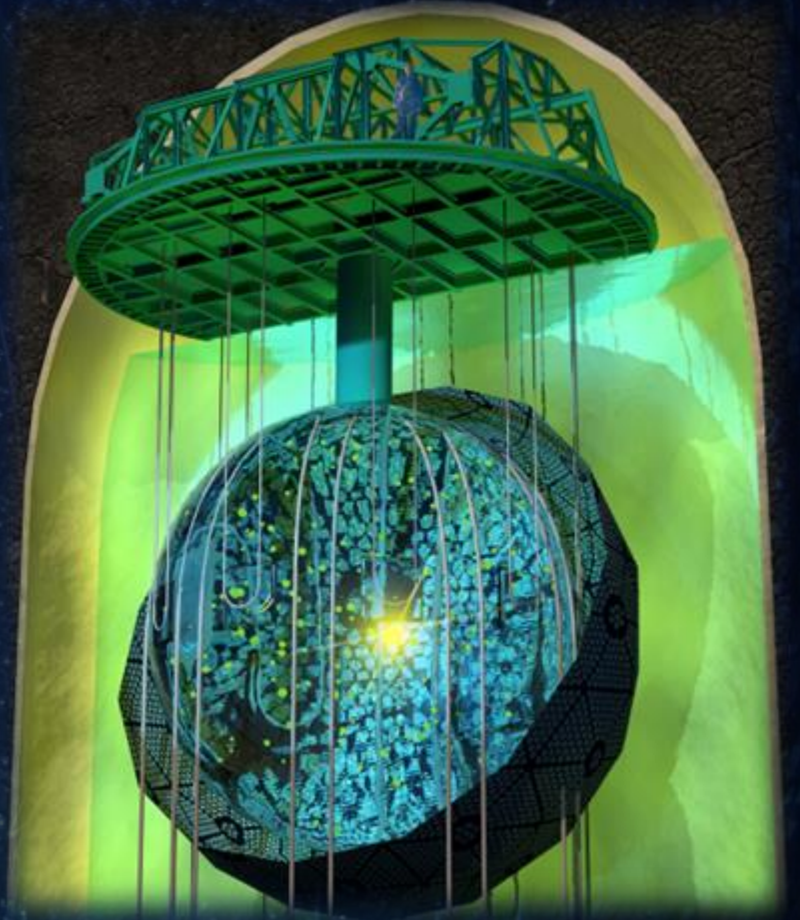
Successor to the Sudbury Neutrino Observatory

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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Queen's University
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SNOLAB
Shandong University
University of Sussex
TRIUMF

Primary SNO+ Physics Goal

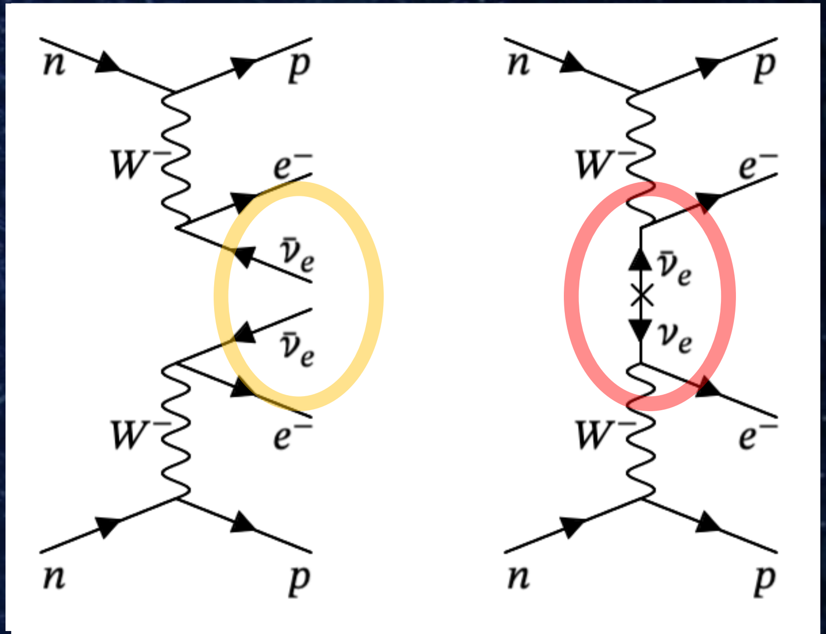
Determining if Neutrinos are Majorana Particles

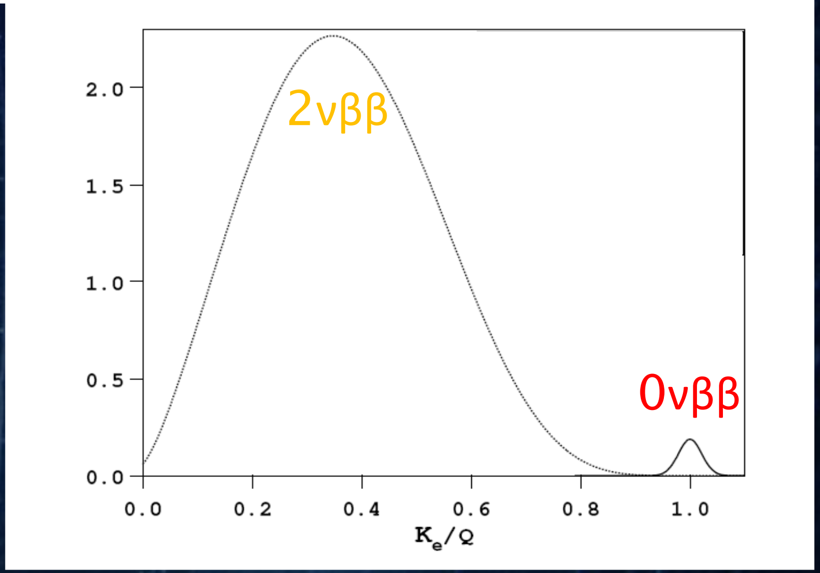
- Neutrinos and Antineutrinos would be the same particle
- Provides satisfying mass mechanism for neutrinos
  - And much more!

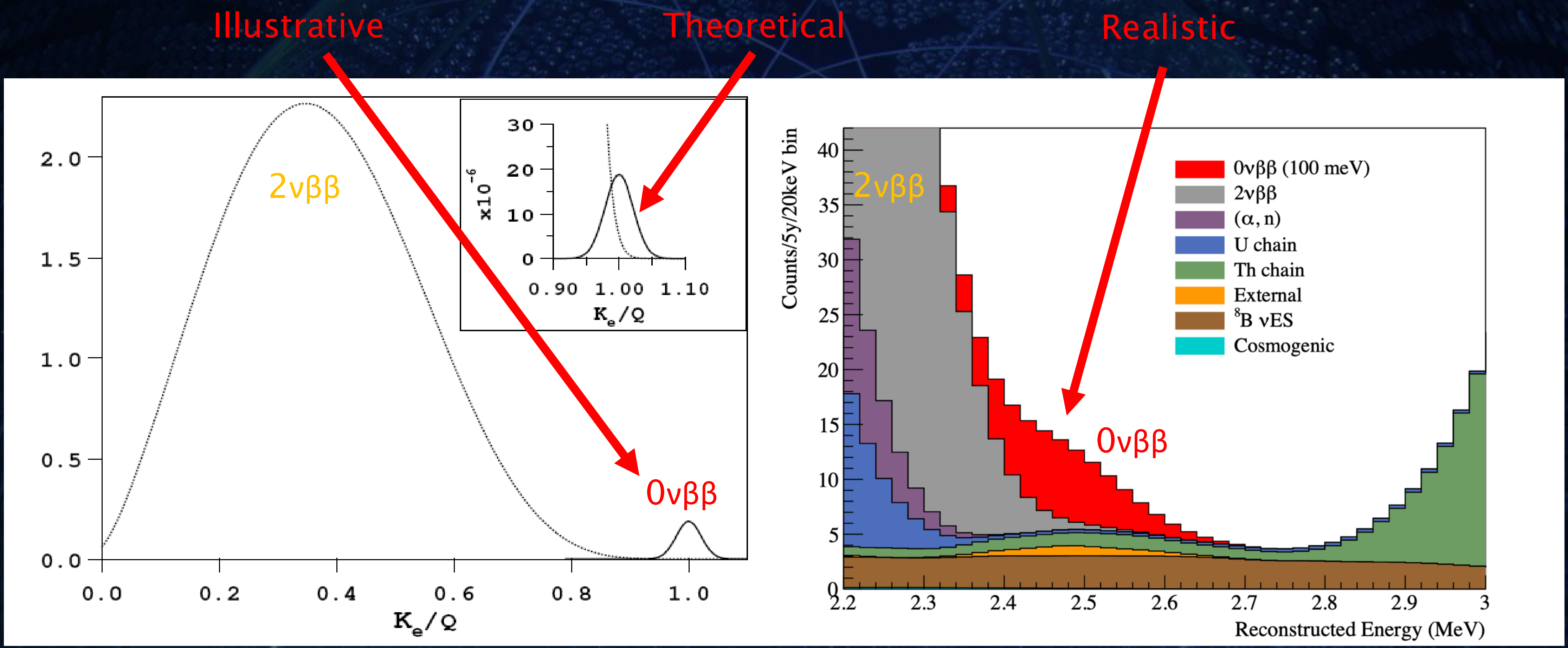
Experimental Methodology

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

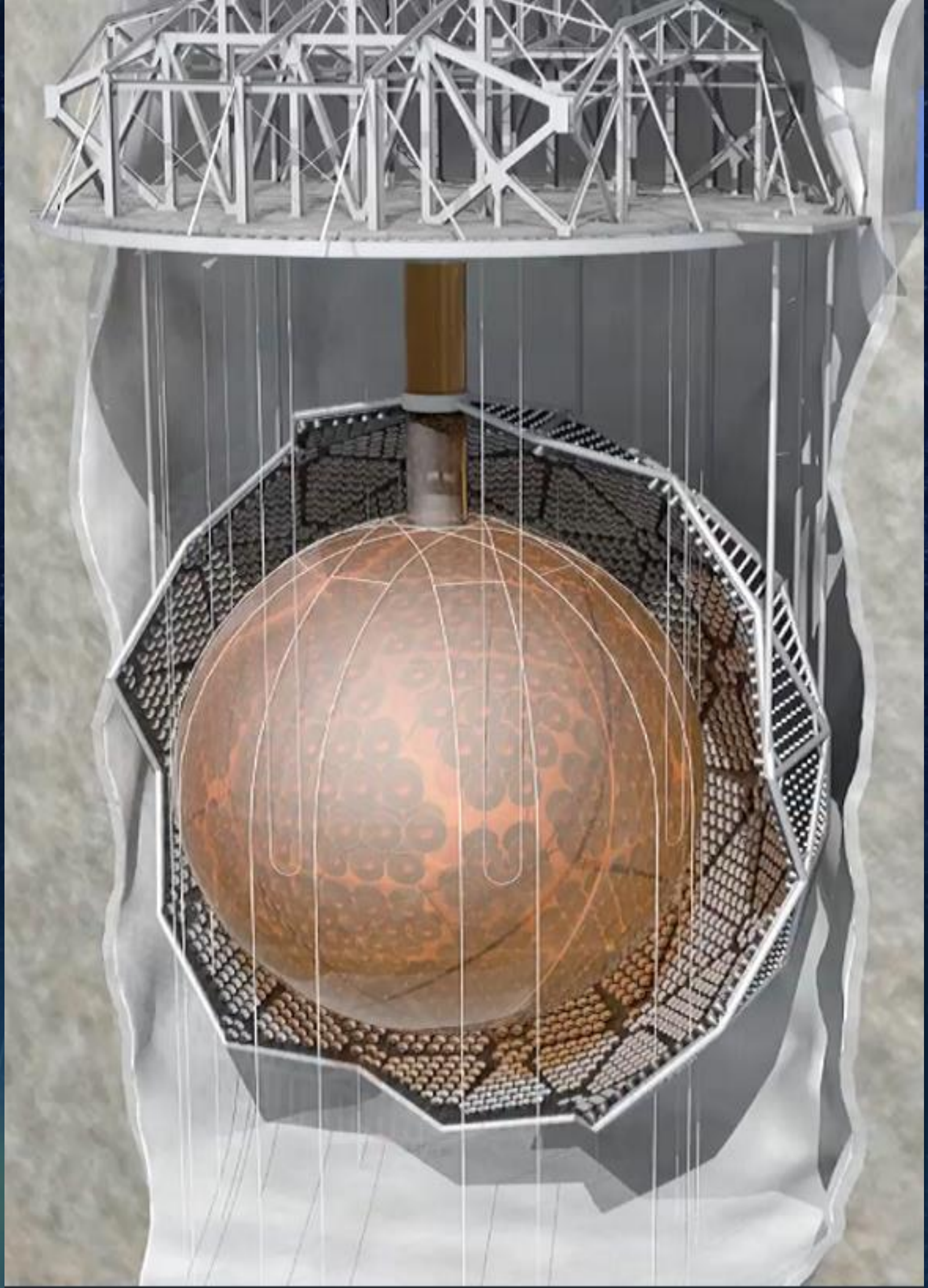
Suppressing Backgrounds through intense shielding and purification

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

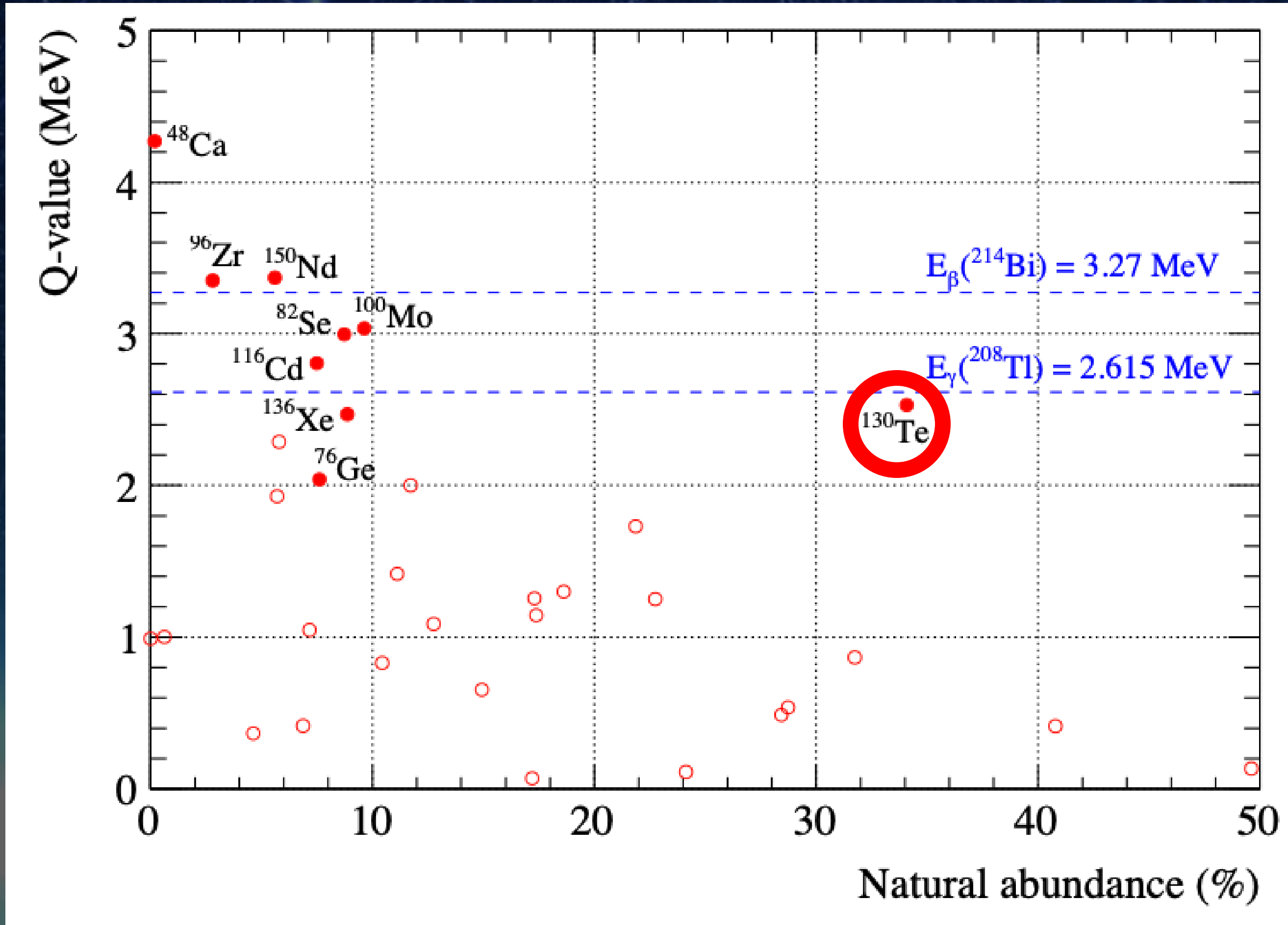
Vigorous QA campaign:
hourly chemical analysis during operations

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 Fill →

Water Phase

May 2017 - July 2019

904 tonnes water

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

Scintillator Fill →

Scintillator Phase

April 2022 – Dec 2023

780 tonnes scintillator

- Quantify the backgrounds in the scintillator

"Target-out Advantage"

Te Loading →

Tellurium Phase

Deployment 2025

Scintillator doped with tellurium

- Begin the Search for 0νββ
- Initial amount of tellurium: 0.5% by mass (1.3 tonnes ^{130}Te)

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Bonus!

Partial Fill

March – October 2020
365 tonnes liquid scintillator

- Preliminary look at the scintillator purity

Bonus!

Enhanced Scintillator Phase

Dec 2023 - Now

Additional reagents added to boost light yield and stability

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)
- Enhanced Scintillator Phase: light yield and stability further improved with later addition of 6.5mg/L BHT and 2.2mg/L bis-MSB

Enhanced scintillator phase currently underway


"The Last Sample"

SNO+ Scintillator: JINST 16 P05009

Tellurium Loading of Scintillator

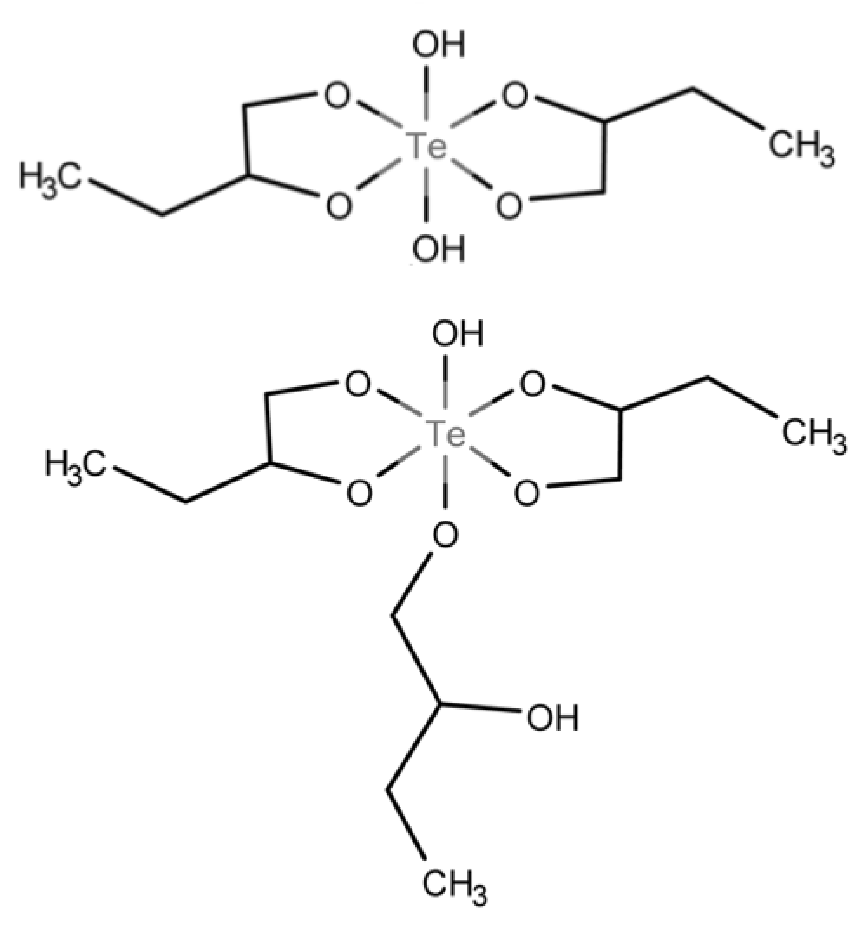
Newly developed method to load Te into LAB

- TeA (polar) is immiscible in LAB (non-polar)
- Aqueous telluric acid (TeA) is reacted with 1,2-Butanediol (BD) to create non-polar TeBD through condensation reaction:

$$\mathrm{TeA} + \mathrm{BD} \rightleftharpoons \mathrm{TeBD} + 2\mathrm{H_2O}$$

TeBD is unstable in the presence of water

- N,N-dimethyldodecylamine (DDA) added for stabilisation
- Explicitely demonstrated to be stable for more than 7 years in >78000ppm water (SNO+ detector has <5ppm water)
- To be added at a 0.25:1 molar ratio



Loading Technique: NIM.A. 1051 168204

Final Te-loaded scintillator cocktail

- Final composition has been determined
- Novel synthesis technique developed
  NIM.A. 1051 168204

CAS registered as # 2173121-84-9
"Tellurium, 1,2-butanediol hydroxy oxo complexes"

Initial deployment:

- 3.9 tonnes tellurium (0.5% by mass)
  (1.3 tonnes ^{130}Te)
- Plans to increase loading to 11.7 tonnes (1.5% by mass)
  (3.9 tonnes ^{130}Te)

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

Required Deployment Facilities

4 Chemical Plants Required

- Scintillator Purification Plant
  - For multistage distillation of BD
  - Used extensively for scintillator purification
  - Built, commissioned, extensively tested
- TeA purification plant
  - For pH and thermal recrystallisation of TeA
  - Initial full-scale test completed
  - Built and commissioned
- DDA Molecular Still
  - For thin-film distillation of DDA
  - Initial full-scale test completed
  - Built and commissioned
- TeBD Synthesis plant
  - TeBD created from purified TeA and TeBD
  - Built, currently commissioning

All facilities in undergoing final preparations for full-scale deployment later this year

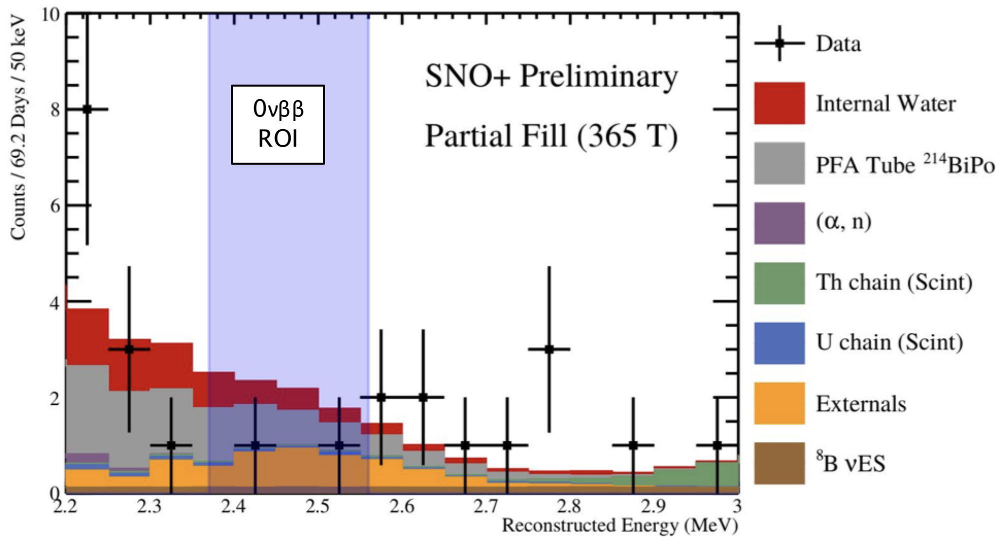
Target Out Advantage

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

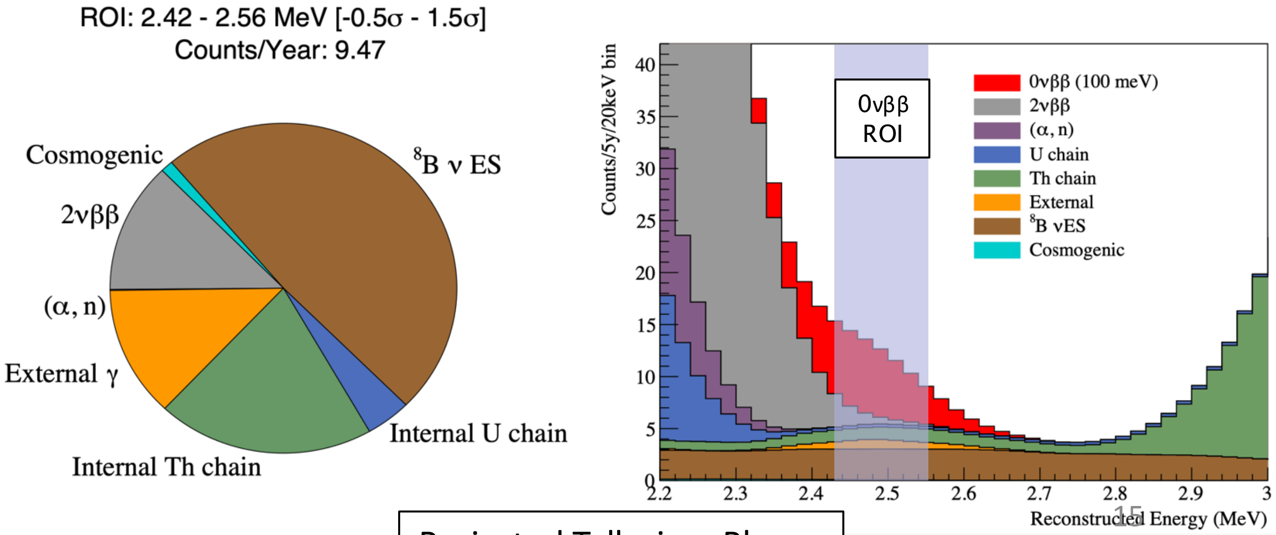
Major SNO+ advantage not present in other 0νββ search techniques

- Performed in partial fill phase
- Performed on preliminary scintillator phase
  - ^{238}U measured at (5.3±0.3)10^{-17} g/g
  - ^{232}Th measured at (5.7±0.3)10^{-17} g/g
- Being finalised for full scintillator phase
- Projected sensitivity of 2x10^{26} years after 3 year live time (90% C.L.)
  - Will exceed current world-leading measurement after 47 days of detector live time

Final sensitivity depends on purity achieved during Te Loading…



Partial Fill Target Out



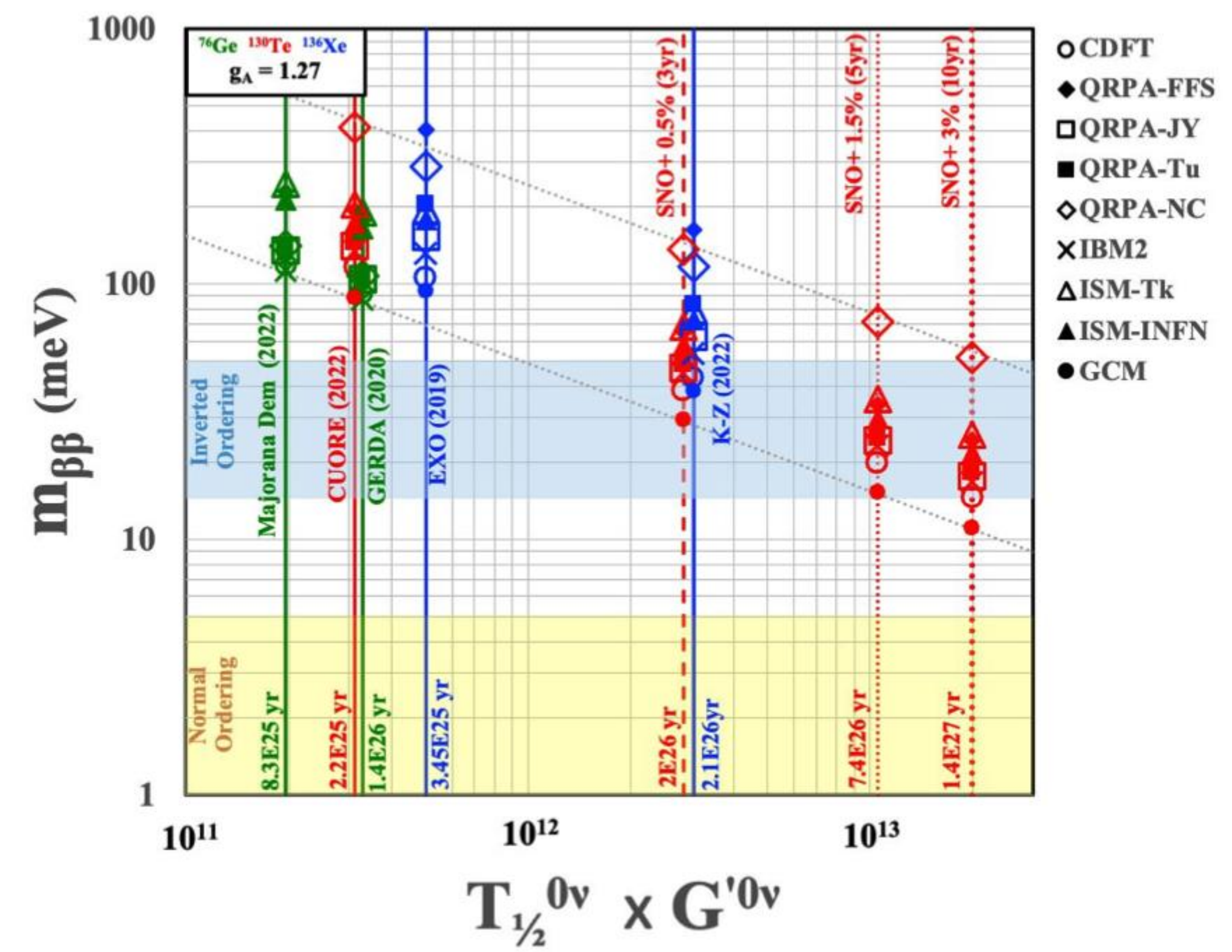
Projected Tellurium Phase

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

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



The Road to 0νββ

Water Fill → Scintillator Fill → Te Loading

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May 2017 - July 2019

904 tonnes water

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

Scintillator Phase

April 2022 – Dec 2023

780 tonnes scintillator

- Quantify the backgrounds in the scintillator
- Te loading method confirmed
- Te loading hardware constructed

Tellurium Phase

Deployment 2025

Scintillator doped with tellurium

- Begin the Search for 0νββ
- Initial amount of tellurium: 0.5% by mass (1.3 tonnes ^{130}Te)

Secondary Physics Capabilities

Water Fill →

Water Phase

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

Scintillator Fill →

Scintillator Phase

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

Te Loading →

Tellurium Phase

- $0\nu\beta\beta$
- Scintillator phase physics programme

Secondary Physics Capabilities

Water Fill → **Water Phase**
- Invisible Nucleon Decay
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Scintillator Fill → **Scintillator Phase**
- Solar Neutrinos
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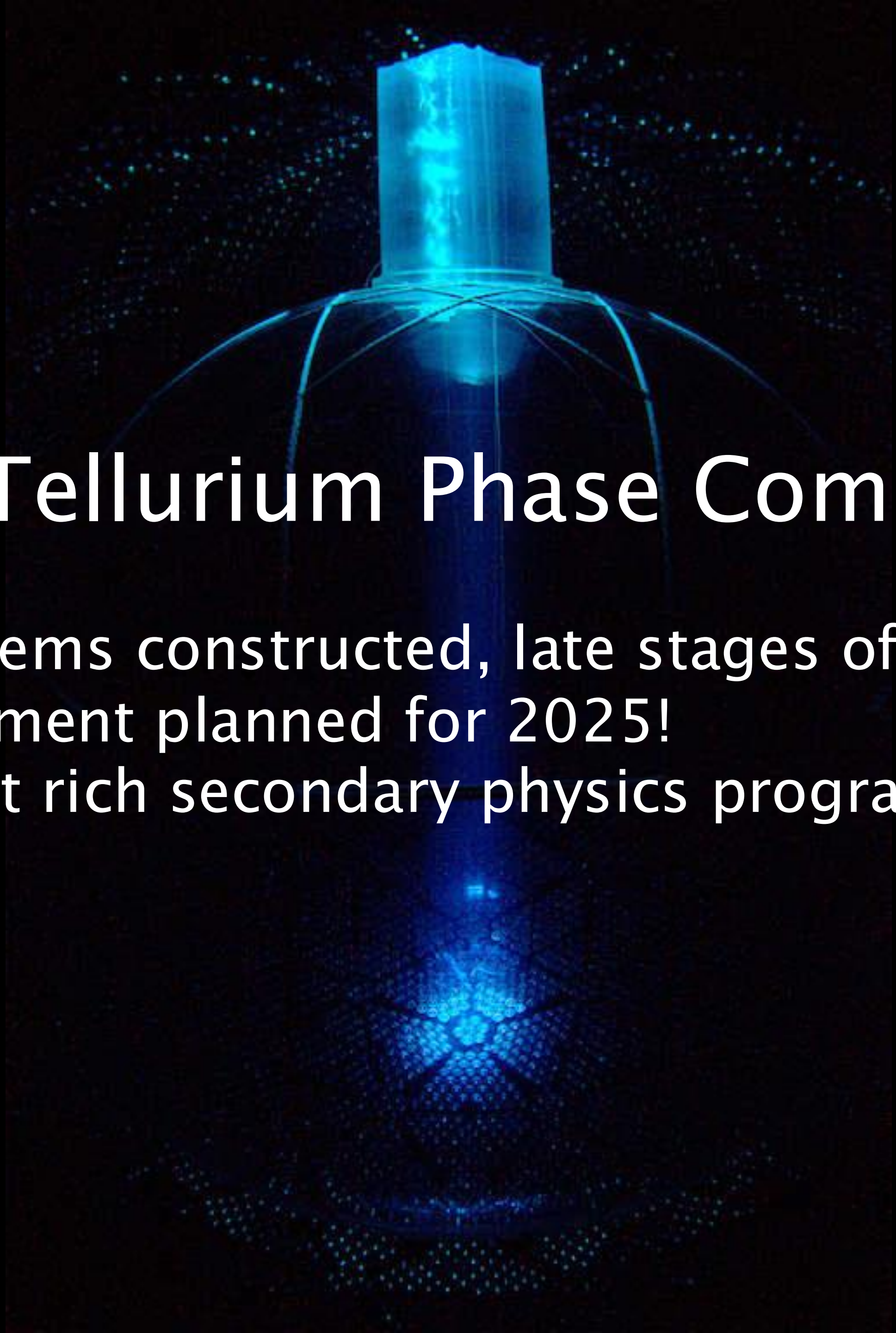
Te Loading → **Tellurium Phase**
- $0\nu\beta\beta$
- Scintillator phase physics programme

See my poster (#5)

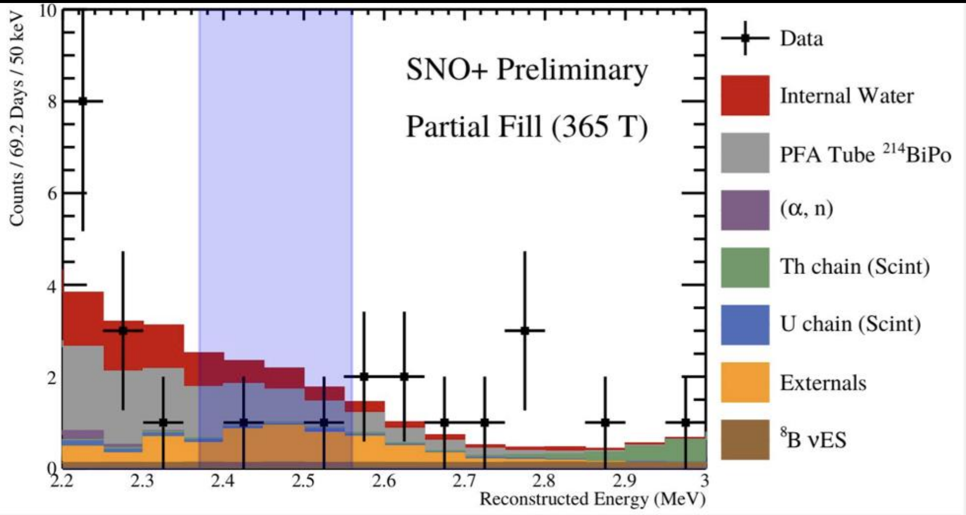


SNO+ Tellurium Phase Coming Soon!

- All Te systems constructed, late stages of commissioning
- Te Deployment planned for 2025!
- Concurrent rich secondary physics programme

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
(α, n)	0
Th Chain (Scint)	0.1
U Chain (Scint)	0.3
^{8}B νES	0.5
Total Backgrounds	8.0