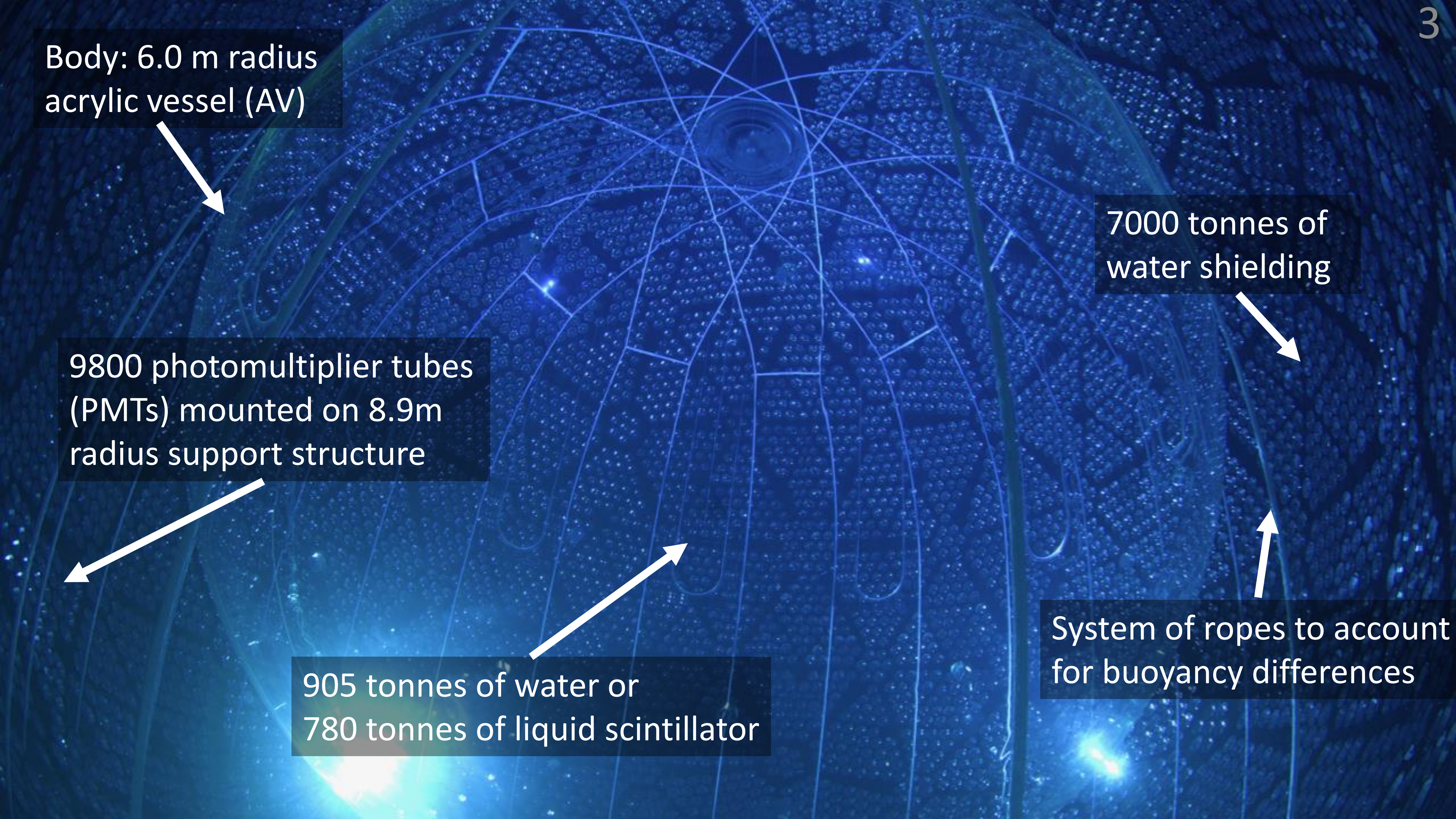
The
SNO+ Scintillator Fill

Benjamin Tam (for the SNO+ Collaboration)
WNPPC 2020
February 14, 2020


Body: 6.0 m radius
acrylic vessel (AV)
7000 tonnes of
water shielding
9800 photomultiplier tubes
(PMTs) mounted on 8.9m
radius support structure
905 tonnes of water or
780 tonnes of liquid scintillator
System of ropes to account
for buoyancy differences

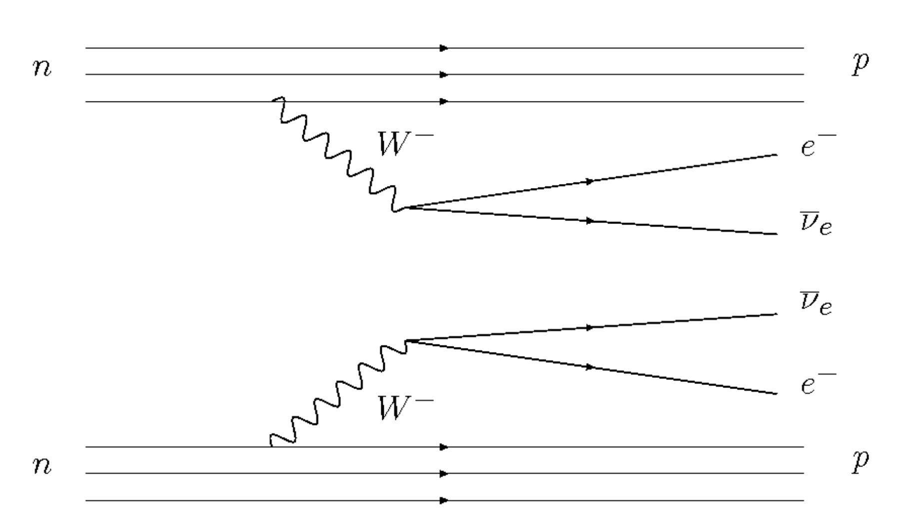
Three Operational Phases based on AV medium:

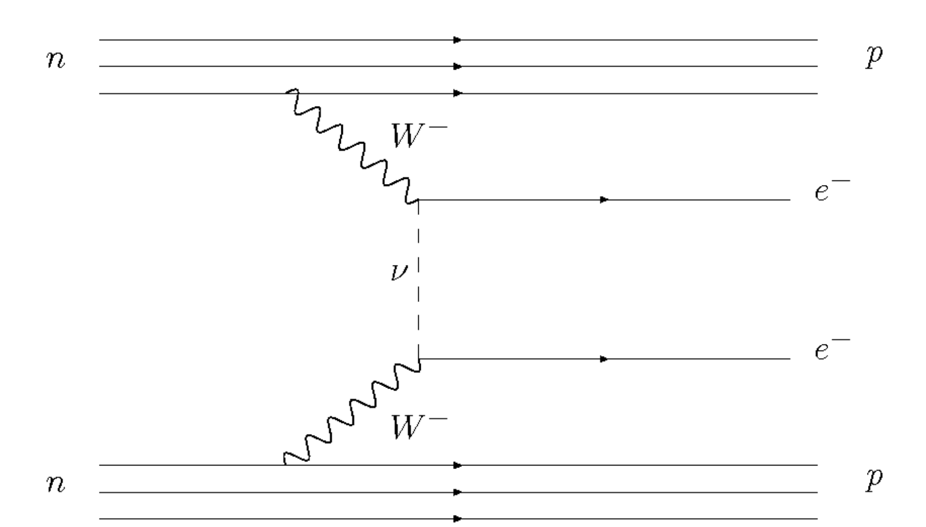
Phase	Medium	Physics Goals	Dates
1	Ultrapure Water	• Invisible Nucleon Decay search • Solar Neutrino Measurements • Supernova neutrinos • Axion-like particle search	• Operated May 2017 – July 2019
2	Liquid Scintillator	• Solar neutrino measurements • Reactor anti-neutrino measurements • Geo-neutrino measurements • Supernova neutrinos	• Commissioning started 2019 • Operation starting mid 2020
3	Tellurium-loaded Liquid Scintillator	• Neutrinoless double beta decay search in Tellurium 130* *Primary Physics Goal	• Commissioning starting 2020

Neutrinoless Double Beta Decay (0νββ)

- Uncharged massive particles can be their own anti-particle!

  "Majorana" particles (Not Dirac)
- Considerable range of implications from mass hierarchy to leptogenesis.
- Neutrinos are Majorana candidates
- 0νββ most viable way to probe for Majorana nature of neutrinos
- Possible in any isotope capable of 2νββ (standard model process)

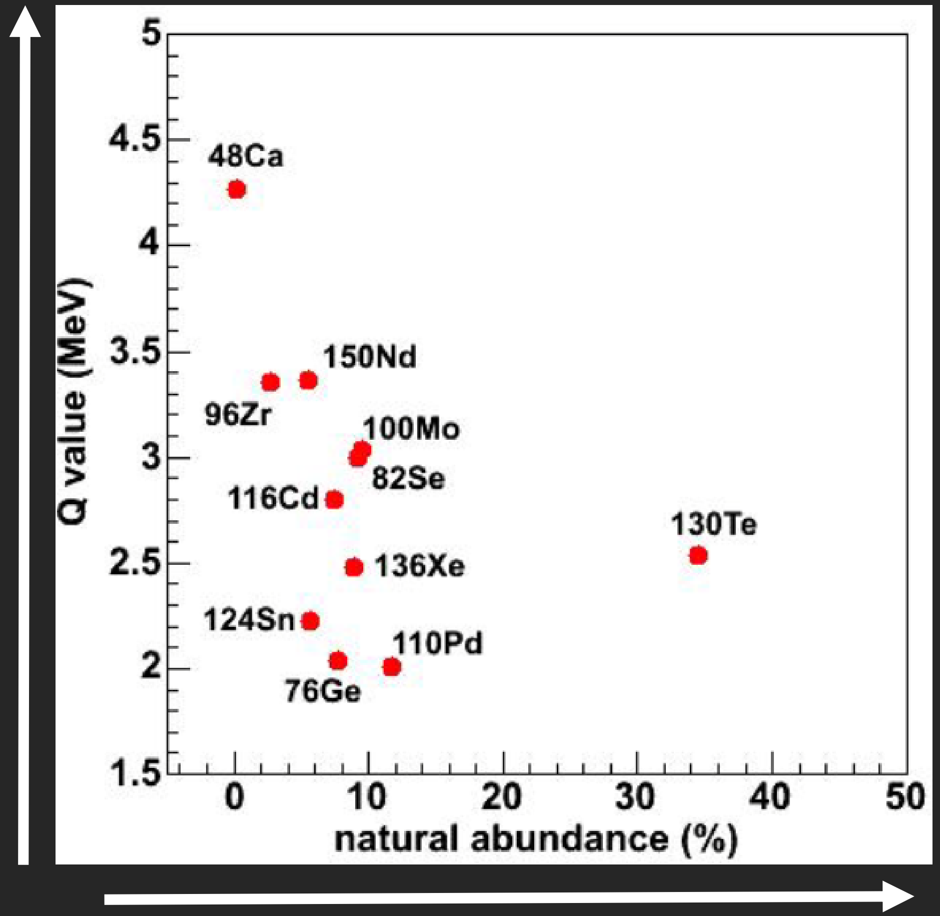




$0\nu\beta\beta$ Isotope

- Any isotope capable of $2\nu\beta\beta$ can undergo $0\nu\beta\beta$

Better
(Greater phase space
and lower backgrounds)

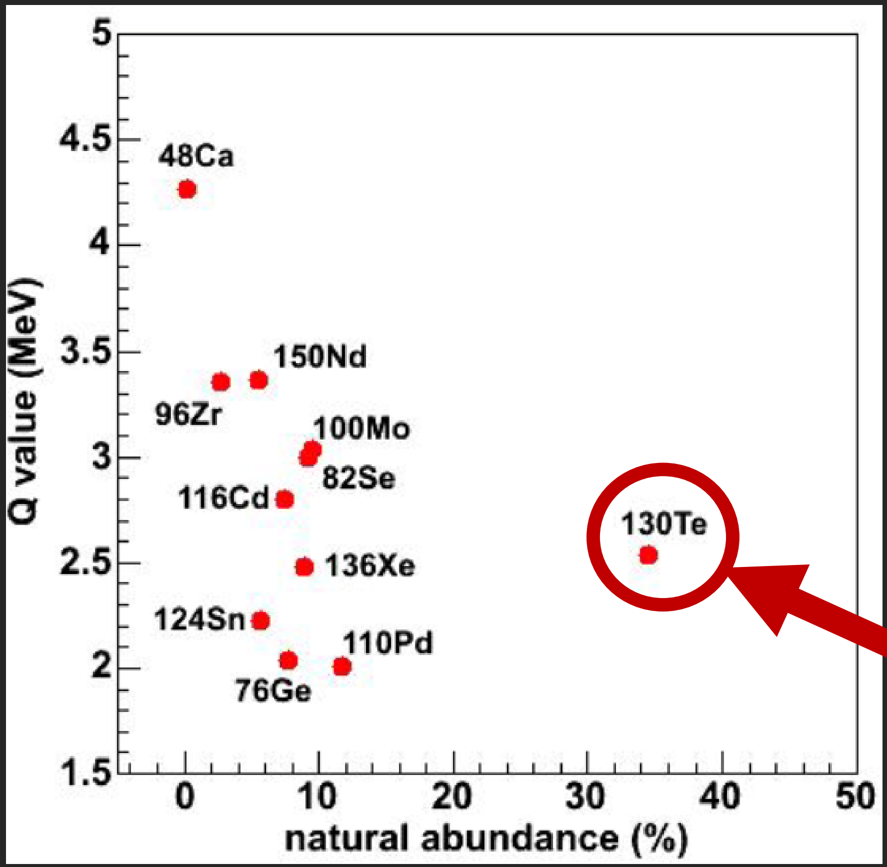


Bigger (cheaper)

0νββ Isotope

- Any isotope capable of 2νββ can undergo 0νββ

Better
(Greater phase space
and lower backgrounds)

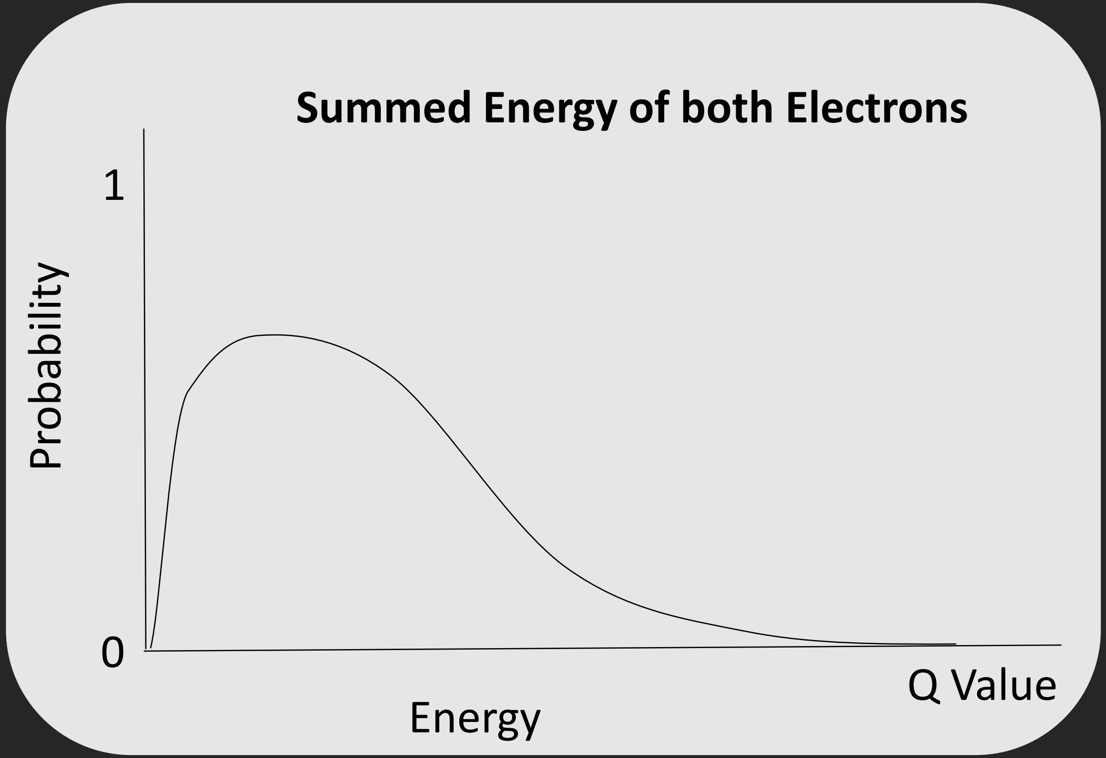


Loading goal of ~1300 kg ^{130}Te

Bigger (cheaper)

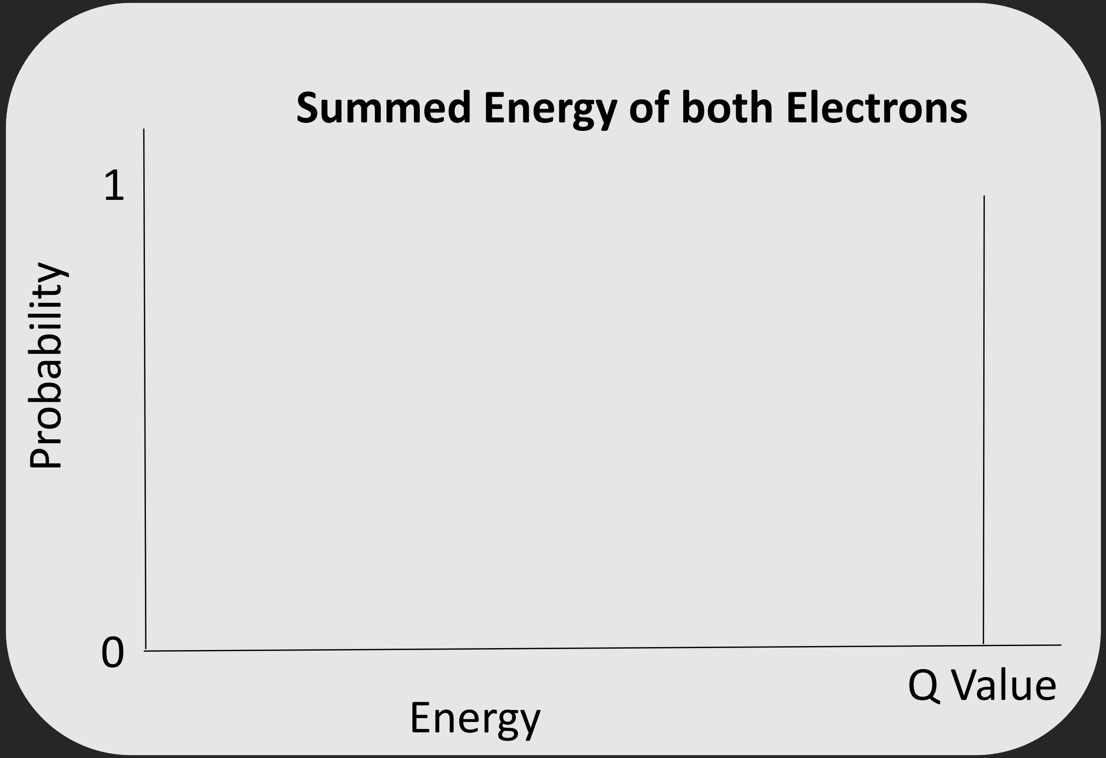
Double electron energy distribution

2νββ



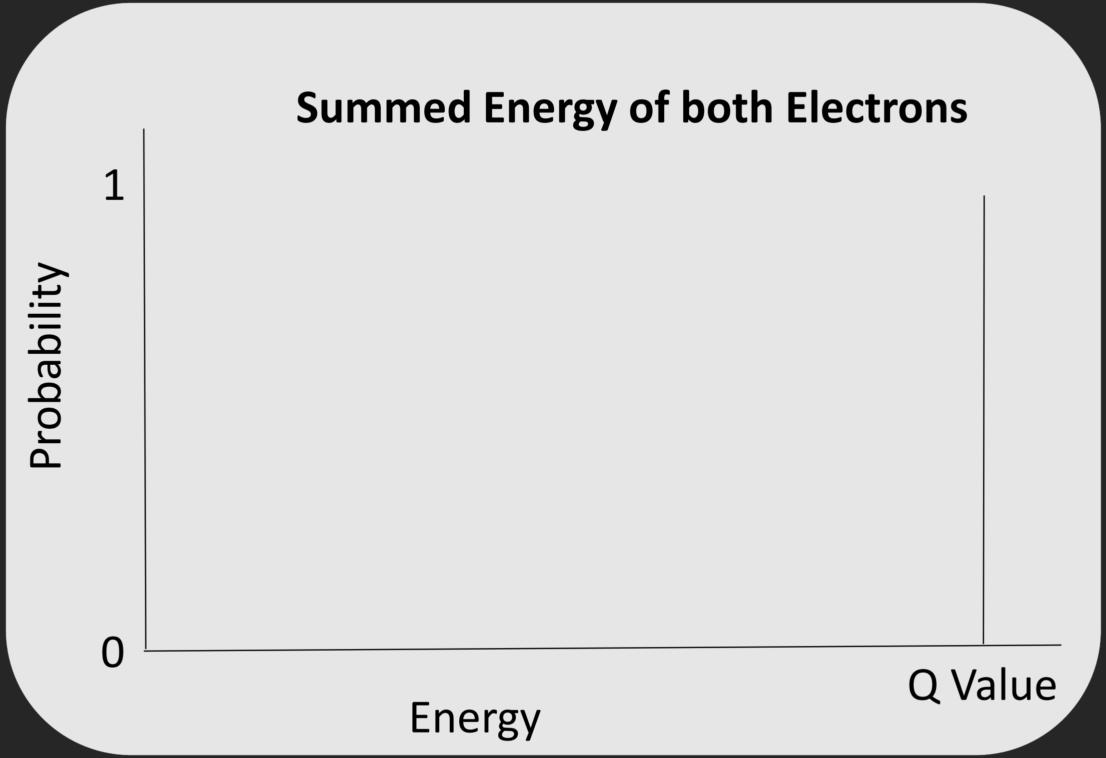
Double electron energy distribution

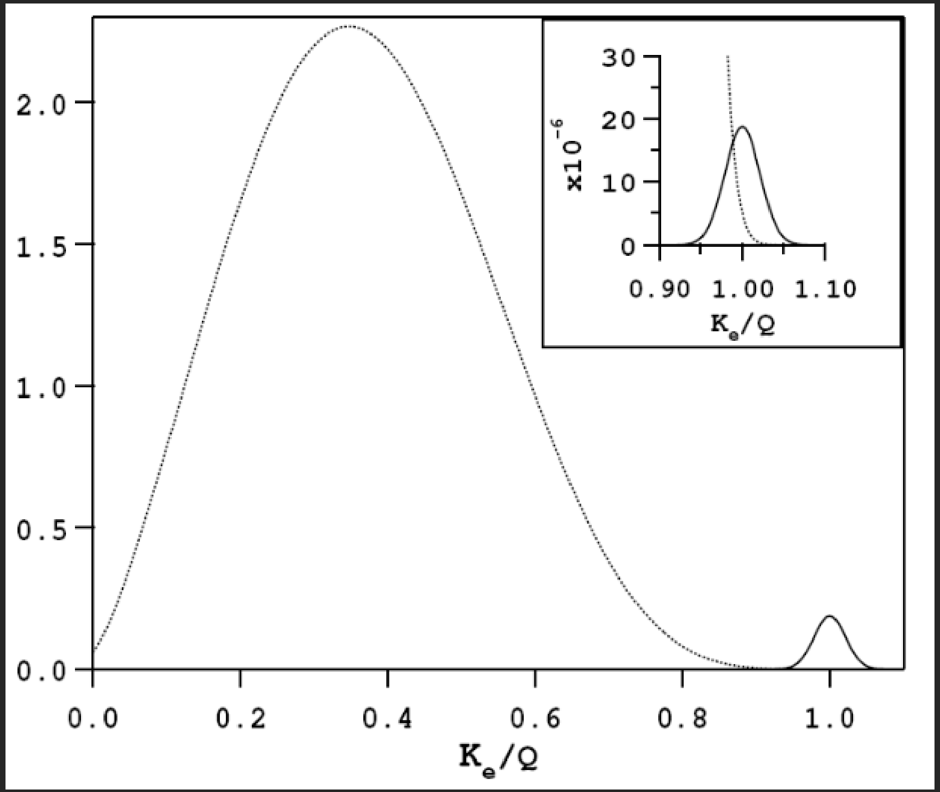
0νββ



Double electron energy distribution

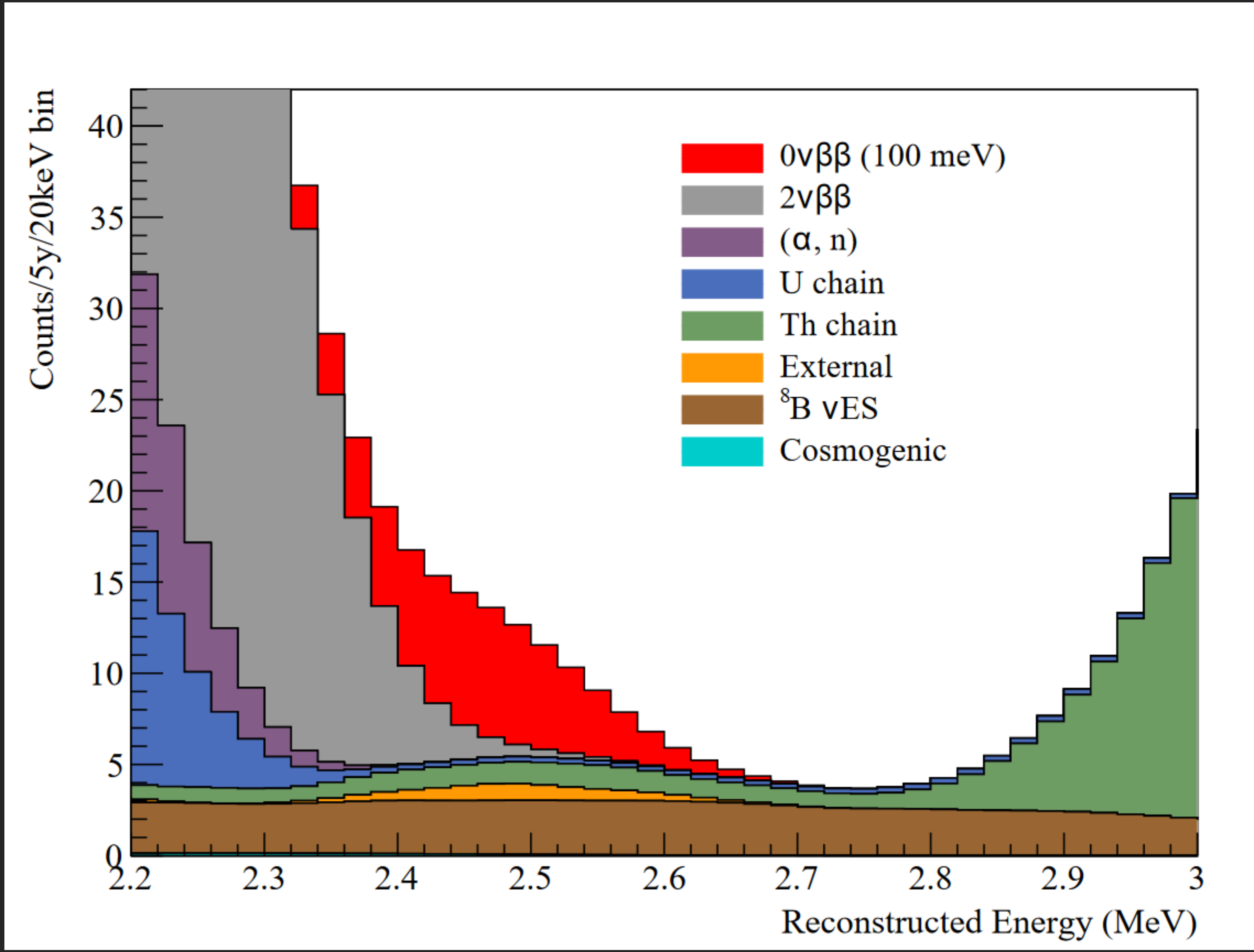
0νββ





0νββ is helicity suppressed, has a half-life >10^5 times longer than 2νββ

ROI Backgrounds Share



Simulated SNO+ Backgrounds in 0νββ ROI

SNO+ 0νββ Search Strategy

Strategy: Fill detector with a liquid scintillator loaded with dissolved ^{130}Te

Advantages:

- Huge target mass attainable (780 tonnes)
- Te loading can be scaled up relatively easily
- Liquid scintillator made of ultra-high-purity materials

Status: Filling with pure liquid scintillator, Te to be loaded after.

SNO+ 0νββ “Cocktail”

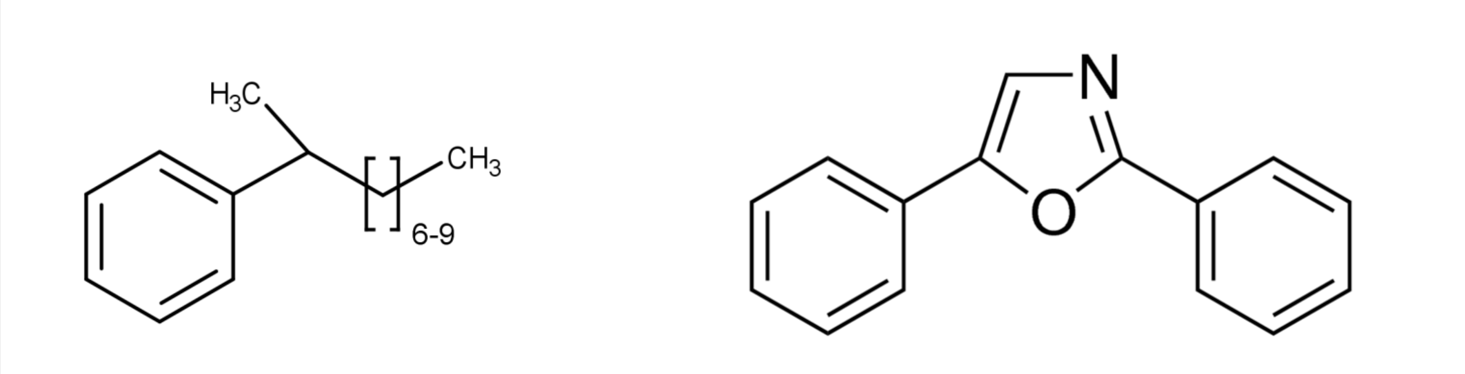
Tellurium Butanediol (TeBD) +

Dimethyldodecylamine (DDA) +

Liquid Scintillator

Liquid Scintillator

- Linear Alkylbenzene (LAB) + 2g/L Diphenyloxazole (PPO)



- Developed for SNO+, successfully used in Daya Bay and RENO
- >50x higher light yield than water
- LAB more compatible with acrylic and safer than other widespread liquid scintillators

Pseudocumene (PC) (Borexino, KamLAND)

Phenyl-o-xylyletane (PXE) (Double CHOOZ)

- PPO acts as a fluor emitting in the 325-420nm range

LAB Production and Purification

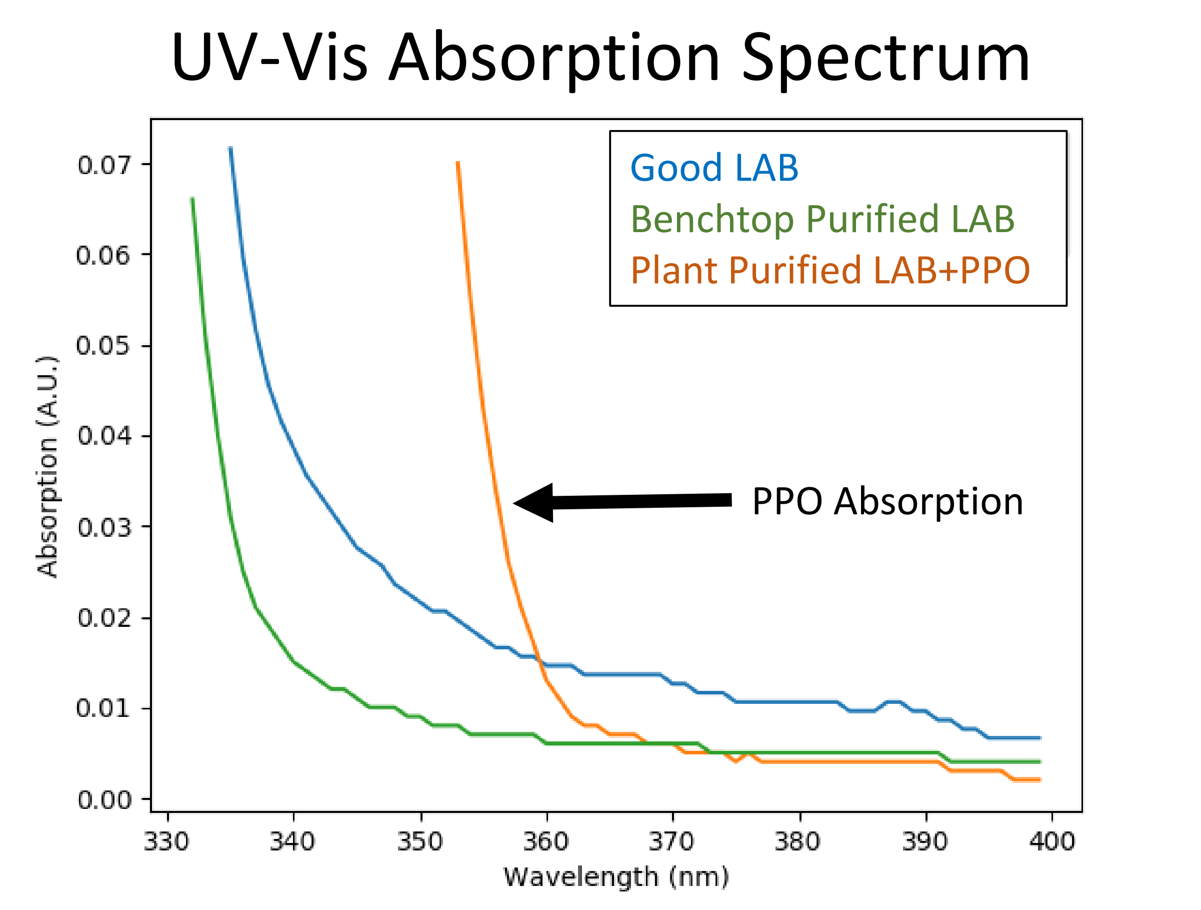
- LAB supplied at extreme quality standards from CEPSA Bécancour Québec
  - Each 20T shipment tested for UV-Vis, FTIR, water content, density, and turbidity to verify purity
- Shipped underground in passivated stainless steel railcars while under N_2 cover gas
- Further purified in underground scintillator purification plant
  - **Multi-stage distillation** removes lower volatility impurities including heavy metals and oxidized organics.
  - **N_2 and steam stripping** removes dissolved gases and volatile liquids

PPO Production and Purification

- Special high-quality “neutrino-grade”
- Mixed with purified LAB to a high concentration “master solution”
- Purified separately from LAB in the same scintillator purification plant
  - **N_2 stripping** removes dissolved gases and volatile liquids
  - **Multiple water extractions** removes ionic impurities
  - **Flash distillation** removes heavy metals and oxidized organics
- Mixed in-line with purified LAB to achieve desired concentration of 2g/L

Scintillator Quality Assessment

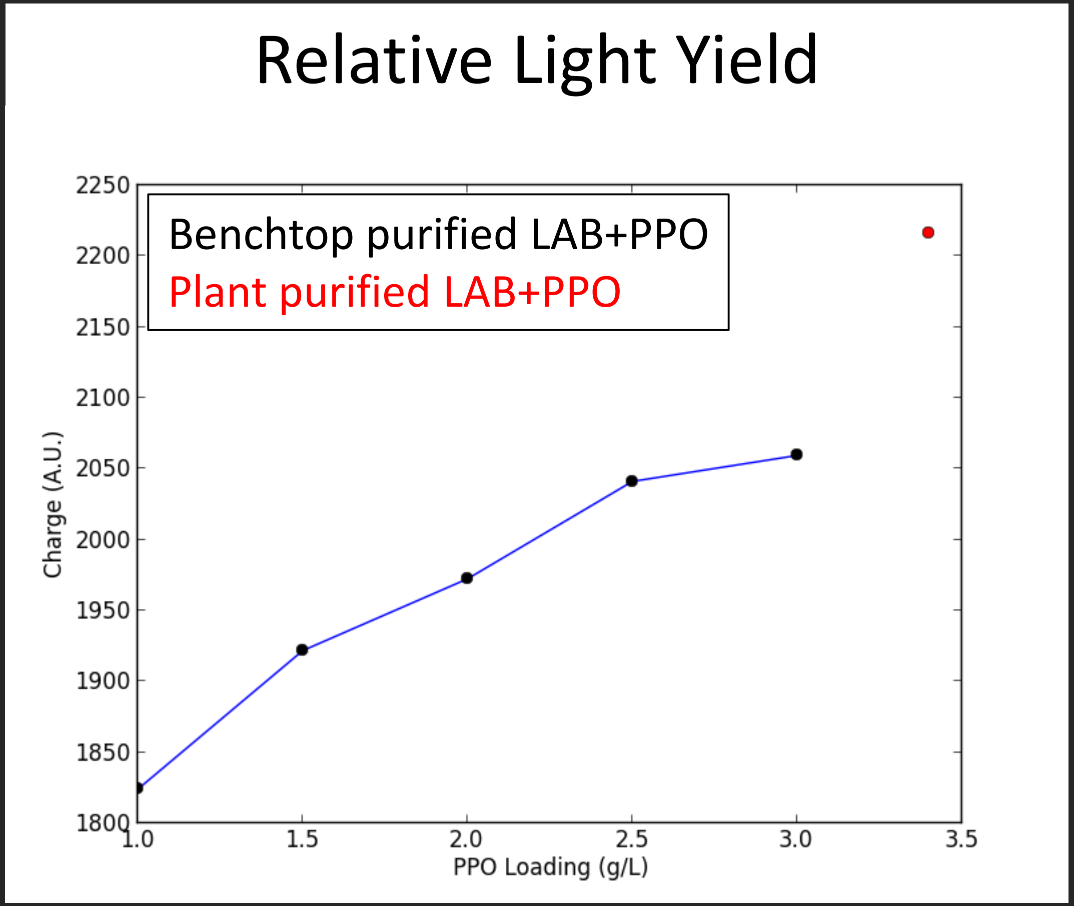
- Final scintillator passes through multiple 20-50nm filters before being sent into the detector
- LAB, Master Solution, and final scintillator accessed for quality hourly during purification plant operation and detector filling
  - **Nephelometry**: Assesses solid particulate contamination
  - **Densiometry**: Assesses liquid and dissolved contaminants
  - **UV-Vis Spectroscopy:** Assesses optical clarity, verifies PPO Concentration, proxy for radiopurity



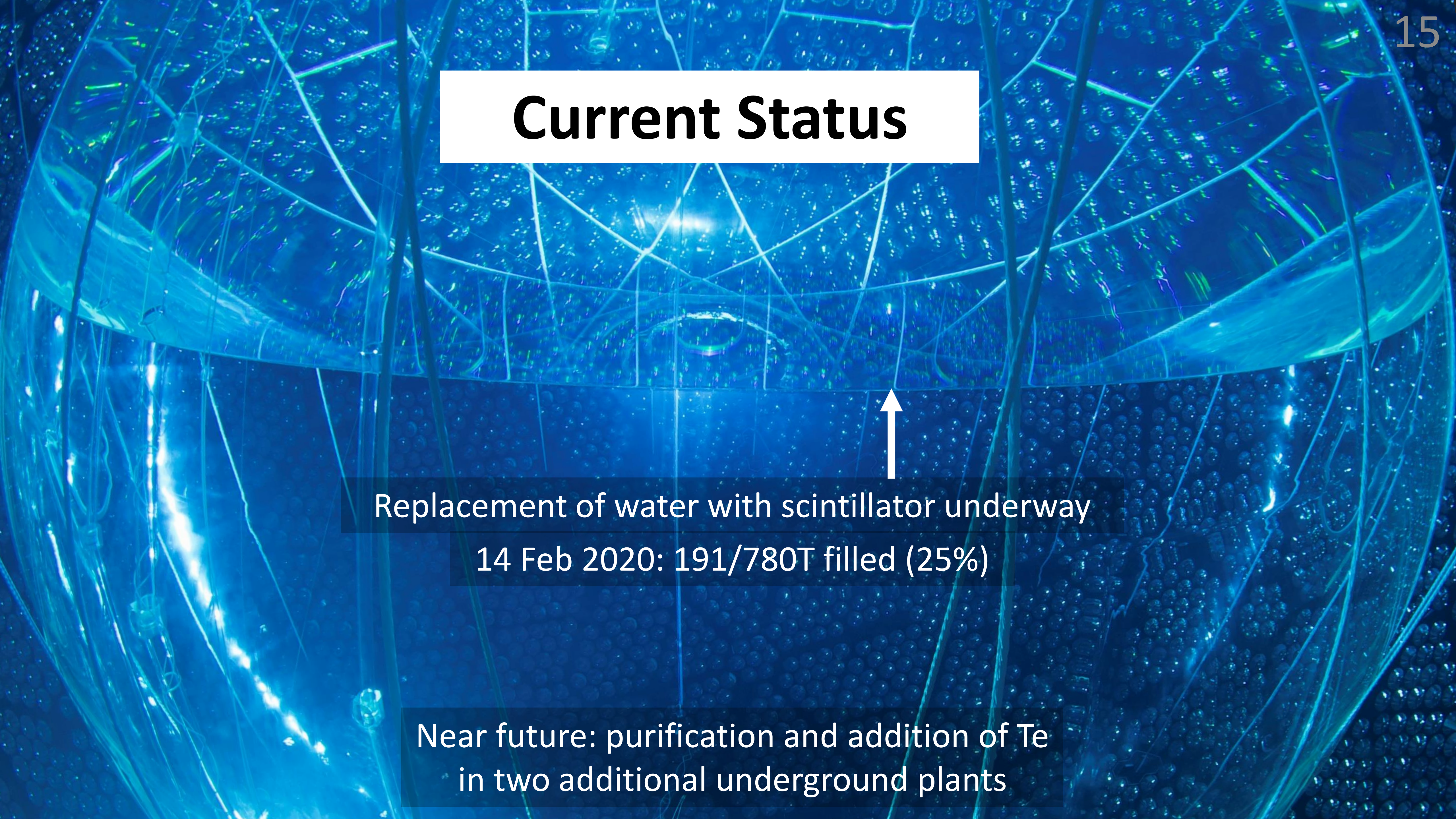
Scintillator Quality Assessment

- Further tests also regularly performed
  - **FTIR/XRF:** Accesses absorption for contaminants at non-UV/Vis wavelengths
  - **Neutron Activation:** Additional elemental concentration analysis
  - **Light yield:** Verified through a 6L 4-PMT detector

Quality Assessment team underground 24 hours every day for the duration of the detector scintillator filling campaign



Current Status



Replacement of water with scintillator underway

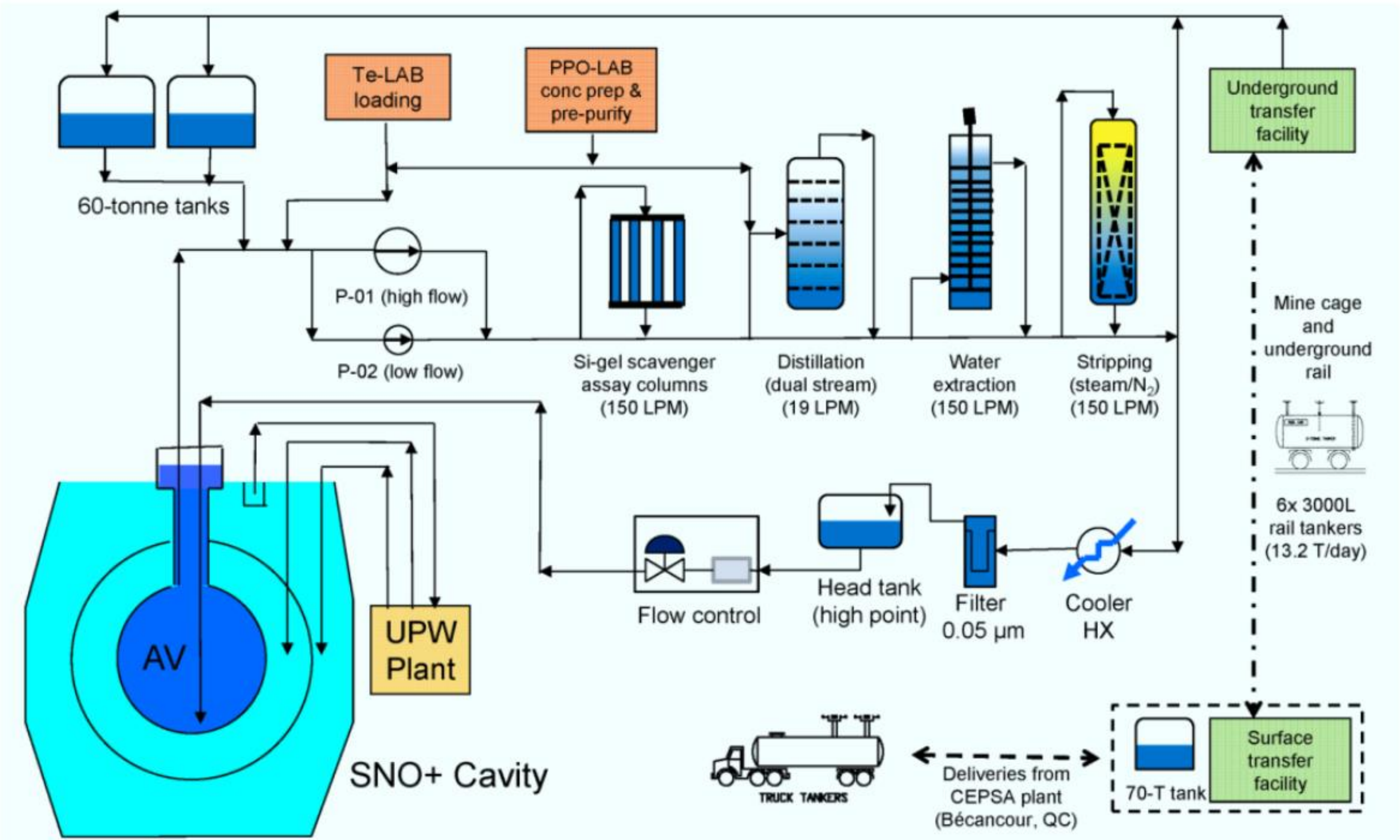
14 Feb 2020: 191/780T filled (25%)

Near future: purification and addition of Te
in two additional underground plants

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

LIP Coimbra
Kings College London
University of Liverpool
UNAM
University of Oxford
University of Pennsylvania
Queen’s University
Queen Mary University
SNOLAB
University of Sussex
TRIUMF

Backup Slides



Te-LAB loading
PPO-LAB conc prep & pre-purify
Underground transfer facility
60-tonne tanks
P-01 (high flow)
P-02 (low flow)
Si-gel scavenger assay columns (150 LPM)
Distillation (dual stream) (19 LPM)
Water extraction (150 LPM)
Stripping (steam/N_2) (150 LPM)
Mine cage and underground rail
6x 3000L rail tankers (13.2 T/day)
Flow control
Head tank (high point)
Filter 0.05 µm
Cooler HX
AV
UPW Plant
SNO+ Cavity
TRUCK TANKERS
Deliveries from CEPSA plant (Bécancour, QC)
70-T tank
Surface transfer facility

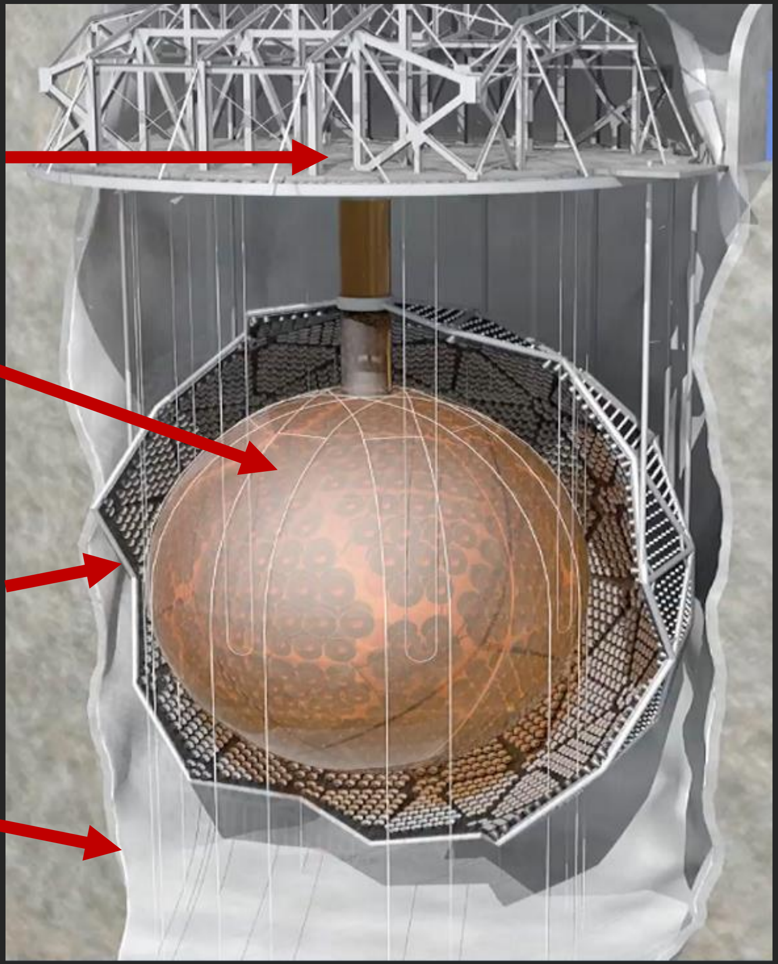
Contaminant Type	Distillation 220^{o}C @40 Torr	N2/Steam Stripping 100^{o}C	Water Extraction
Heavy Metals (radioactive)	Bi, K, Pb, Po, Ra, Th		U, Th, Ra, K, Pb
Dissolved Gases (radioactive)		Ar, Kr, O_2, Rn	
Oxidised Organics (Optical clarity)	Carboxyl groups, 1,4-benzoquinone		
Volatile Liquids (Optical clarity)		Residual water	

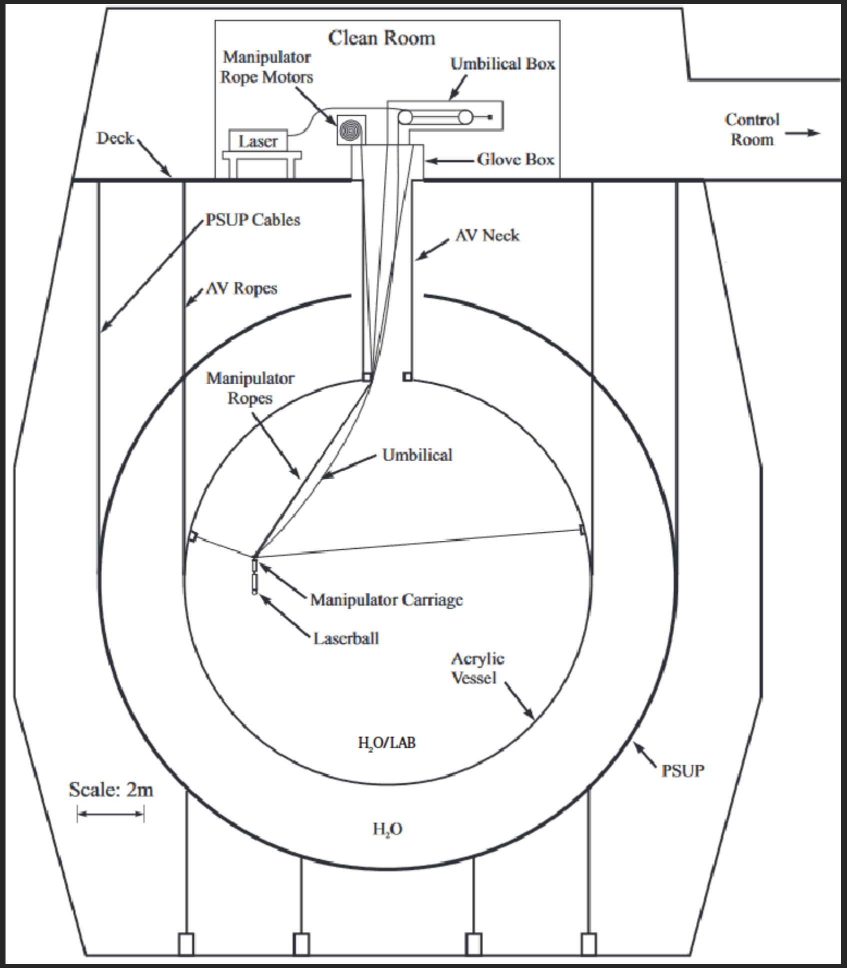
Deck Clean Room

Acrylic Vessel (AV)

PMT Support Structure (PSUP)

Cavity





Consequences of Majorana Neutrinos

- Violation of Lepton number conservation
- neutrino mass scale
- probing of neutrino hierarchy
- Supports some grand unified theories