Physics and Commissioning of the SNO+ experiment

Jack Dunger

EPS Venice 2017

LIP Coimbra
LIP Lisbon

Oxford University
Queen Mary, UoL
University of Liverpool
University of Sussex
University of Lancaster

SNOLAB
TRIUMF
University of Alberta
Queens University
Laurentian University

Brookhaven National Lab
Boston University
Norwich University
UoC, Berkley
UoC, Davis
Lawrence Berkeley Nat. Lab.
University of Chicago
University of Pennsylvania

TU Dresden

UNAM

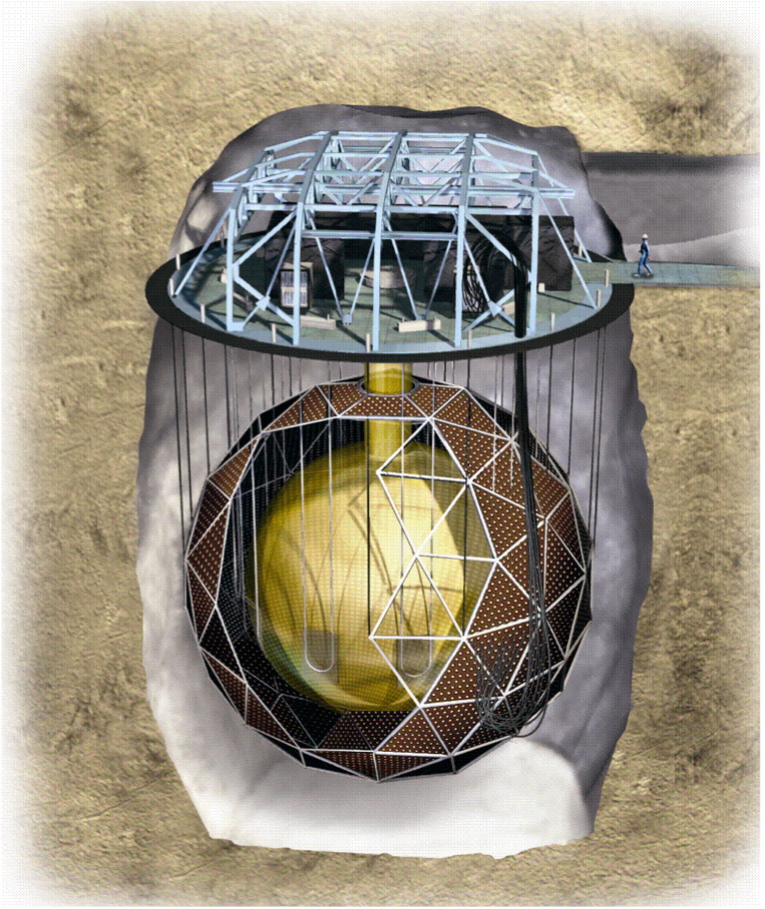
SNO+ Experiment

2km underground at SNOLAB, Sudbury

Upgrade the SNO detector to a liquid scintillator target

Multi-purpose neutrino/exotics detector:

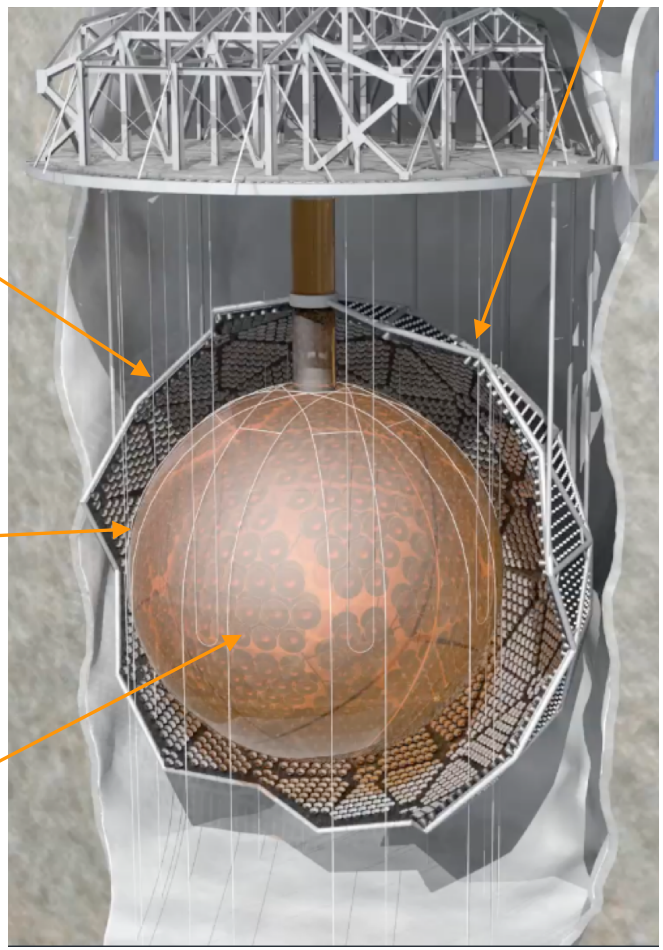
- Solar neutrinos
- Geo neutrinos
- Reactor neutrinos
- Supernova neutrinos



Primary goal: observation of neutrinoless double beta decay of ^{130}Te loaded into the scintillator volume

7 kt external water shielding

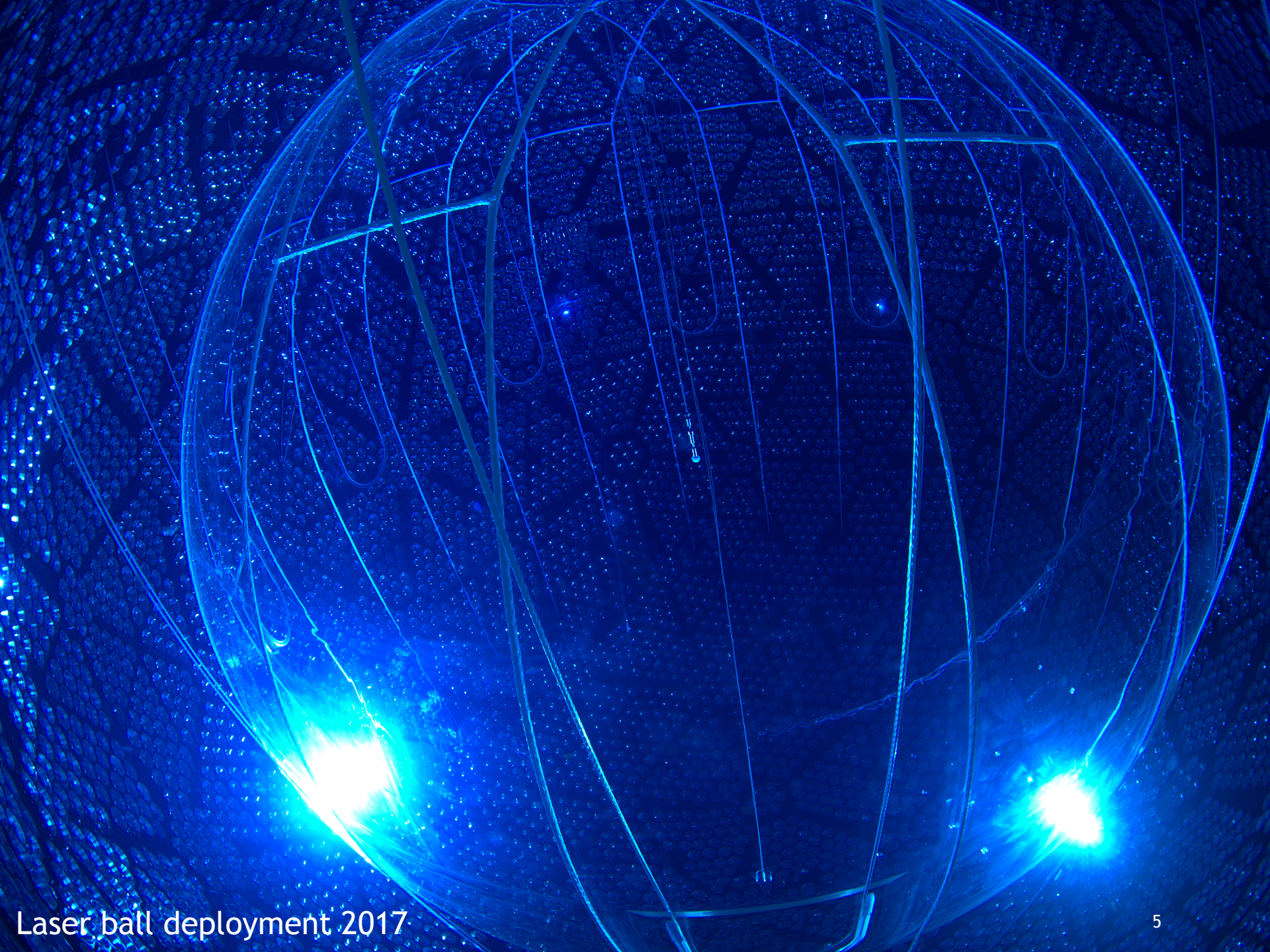
~9500 (8”) PMTs + concentrators
50% photocathode coverage



12 m
Acrylic vessel

~800 tonnes
water/pure scintillator/
Te loaded scintillator
target

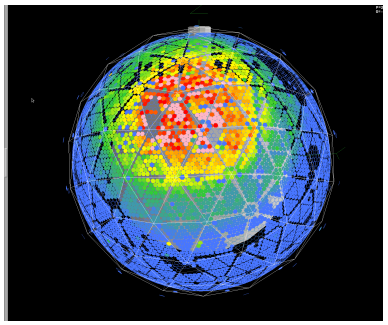
22 m



Laser ball deployment 2017

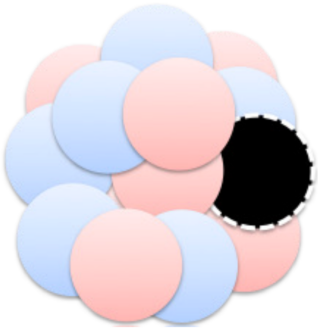
The Water Phase

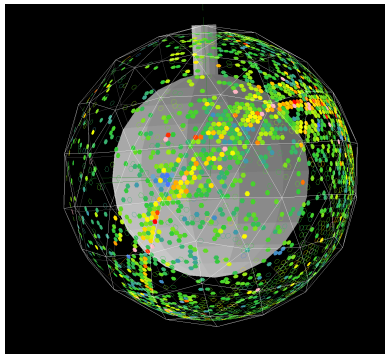
- Calibrations
  - PMT charge/time response
  - ^{16}N energy scale
  - Scattering/attenuation measurements
- Constraining external γ backgrounds

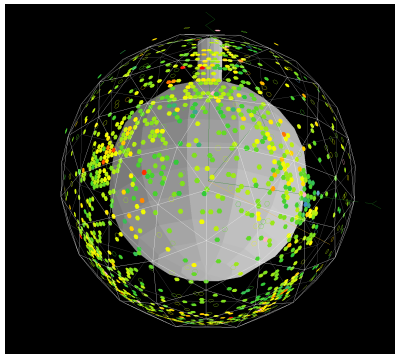


- Searching for invisible nucleon decay in ^{16}O
  e.g. $n \rightarrow 3\nu$

  —> Leading limit with 3 months live-time







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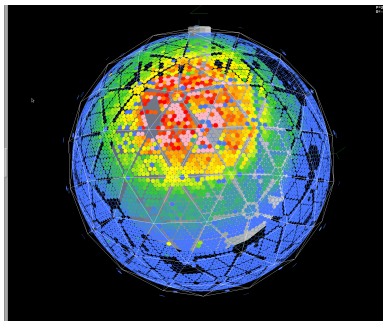

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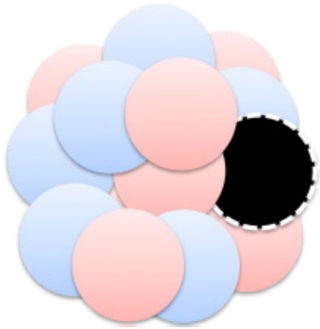
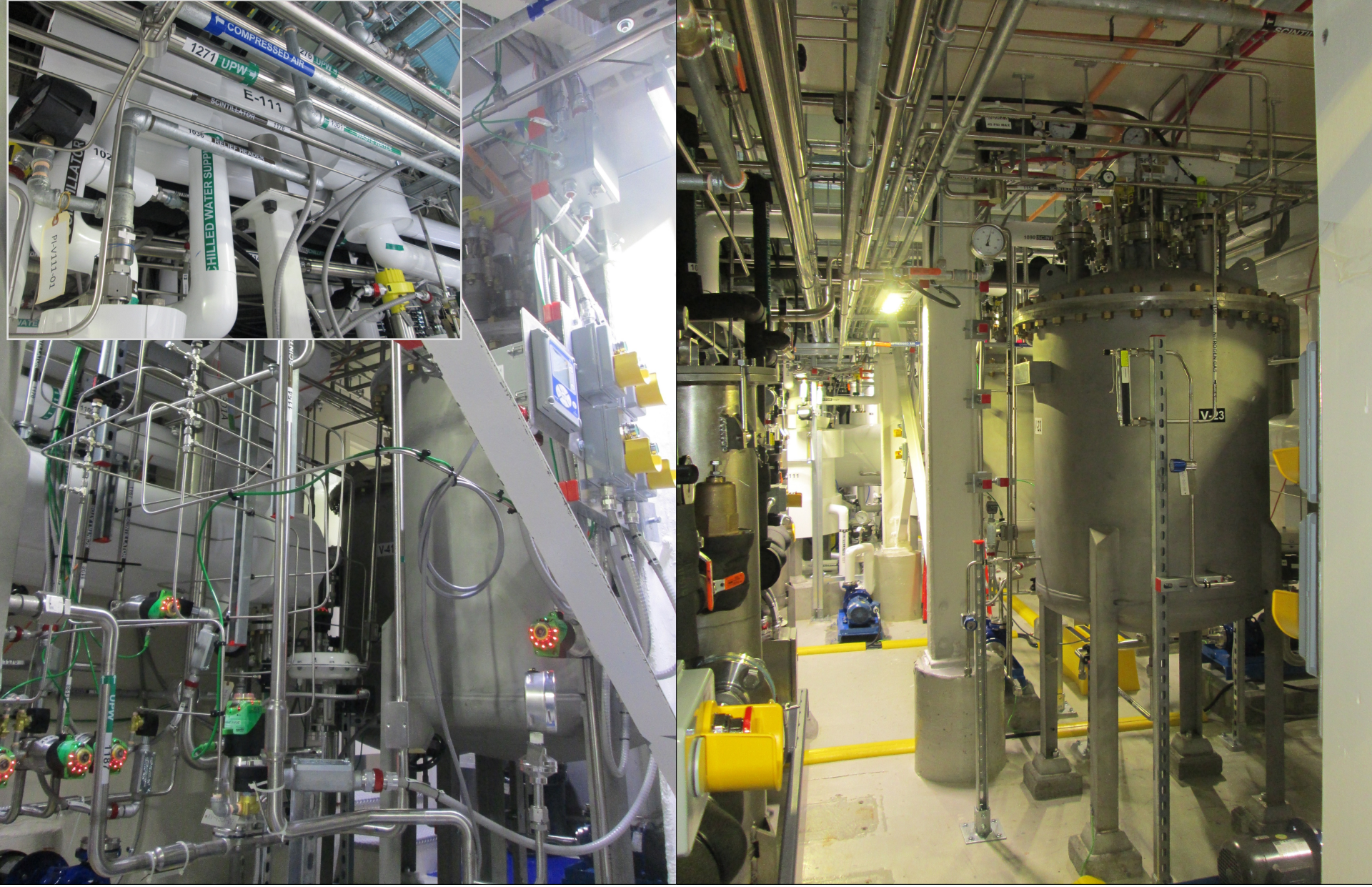


NP-10 “Data quality and run selection for the SNO+ experiment”
Elisabeth Falk



LAB purification plant commissioning underway for scintillator fill late 2017

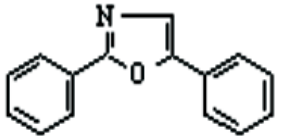
Water Cherenkov to Liquid Scintillator

Non-polar —> 1000x less U/Th g/g!

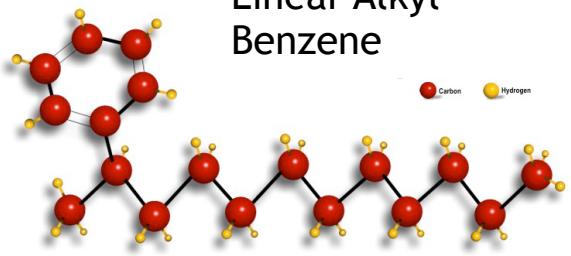
~50x more hits —> sub-MeV threshold,
few % √E/MeV resolution

Isotropic light, hides directional information

PPO fluor boosts efficiency



Linear Alkyl Benzene



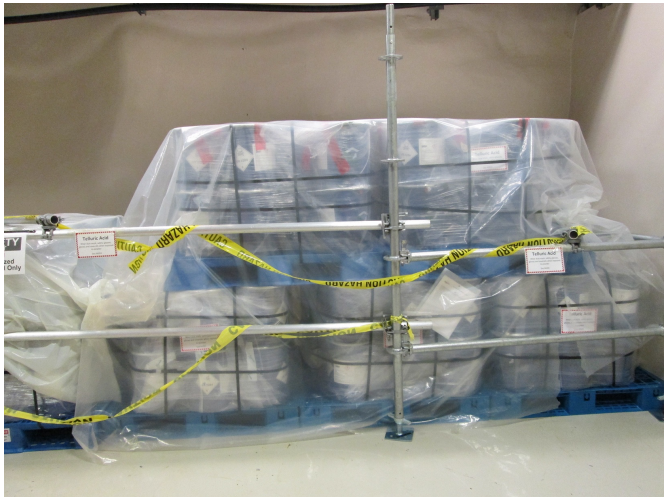
New U/G purification plant will deliver

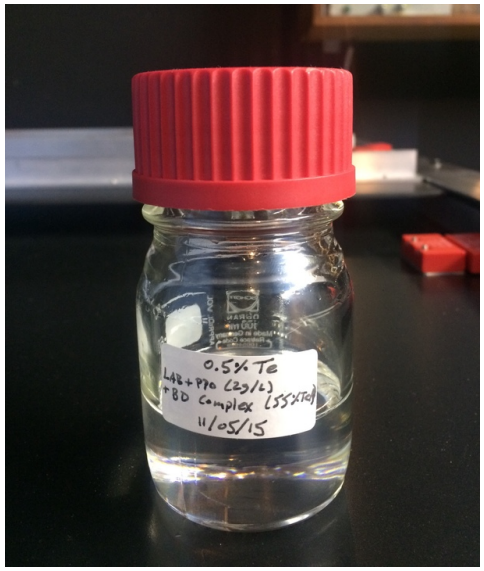
10^{-17} U/Th g/g_{LAB}

0νββ of ^{130}Te

SNO+ chooses ^{130}Te:

- High Q - 2.5MeV
- BiPo coincidence tag eliminates dominant radioactivity
- No light absorption in PMT acceptance window
- 34 % natural abundance
- Underground purification plant under construction





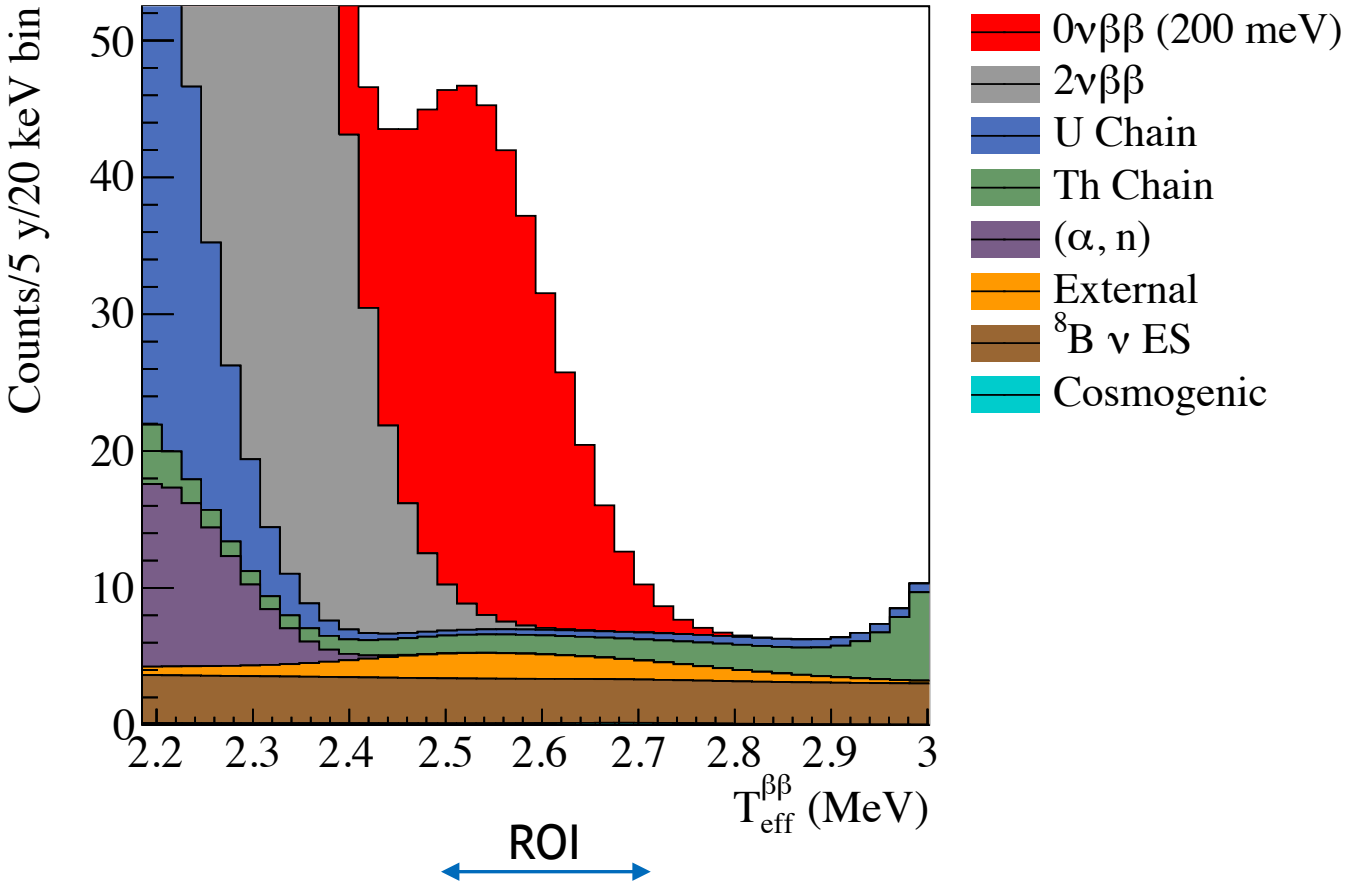
- Organometallic complex **TeBD**
- Soluble in LAB
- Very transparent
- Expect 500 p.e./MeV after quenching
- Loading target volume 2018

0.5% loading for Phase I
=
1.3 Tonnes ^{130}Te

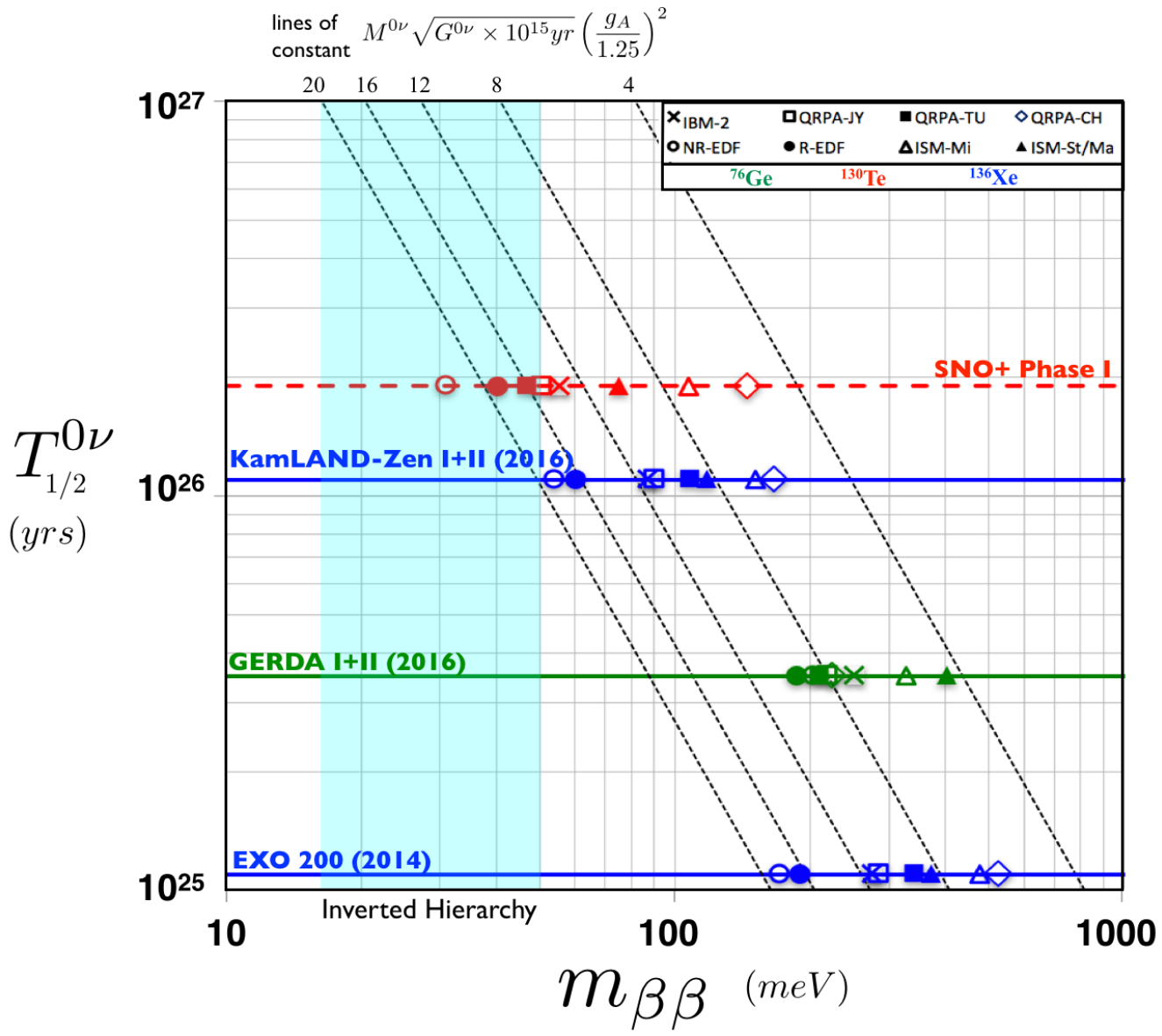
Sensitivity

13 counts/yr in ROI & Fiducial Volume

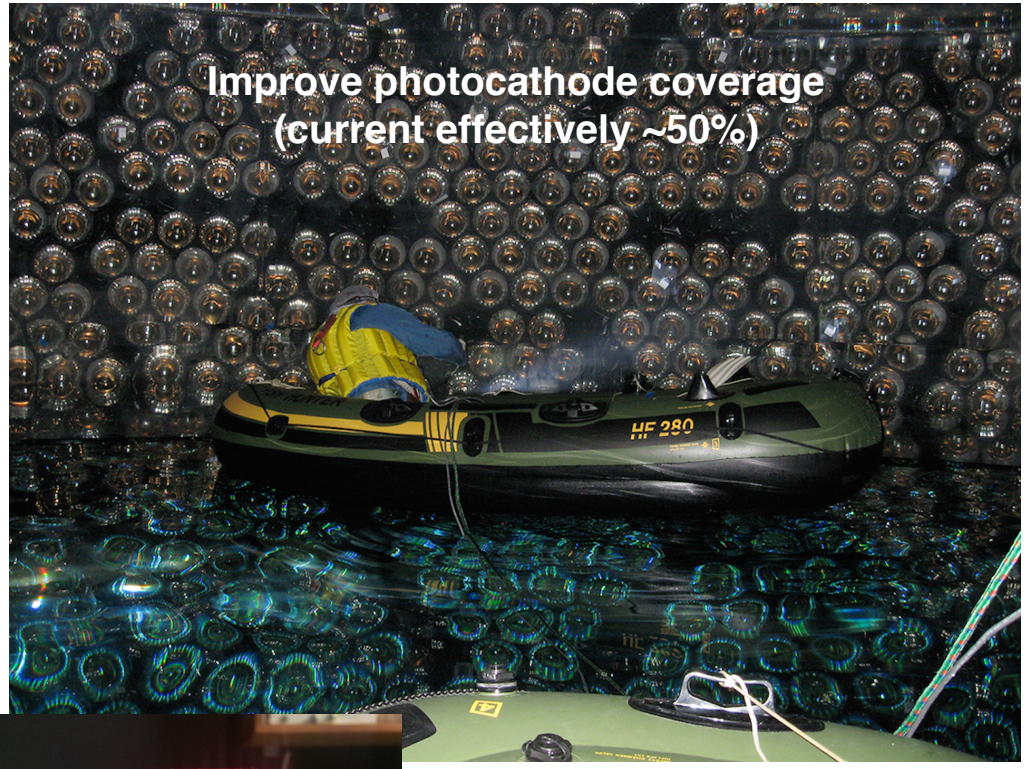
Livetime/yr	$T^{0\nu}_{1/2}$/yr	$m_{\beta\beta}$/meV
1	$8.0 \cdot 10^{25}$	75.2
5	$2.0 \cdot 10^{26}$	39.7



Sensitivity



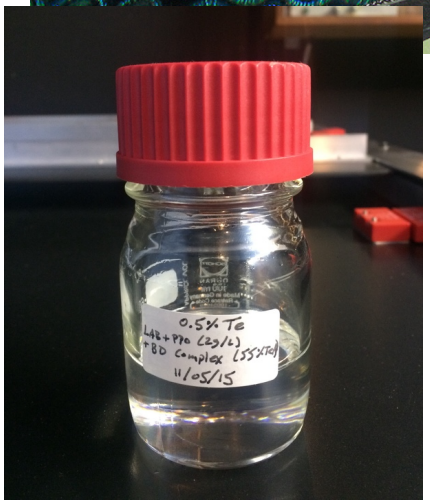
Phase II



Upgrade PMTs

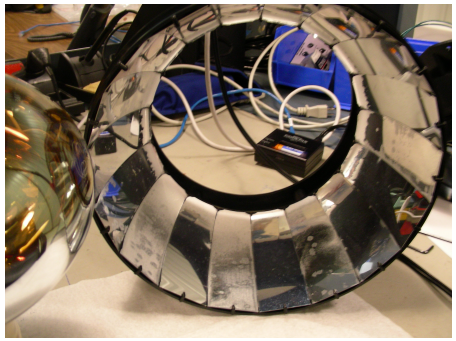
3x better collection!

Replace concentrators



Increase loading to % level

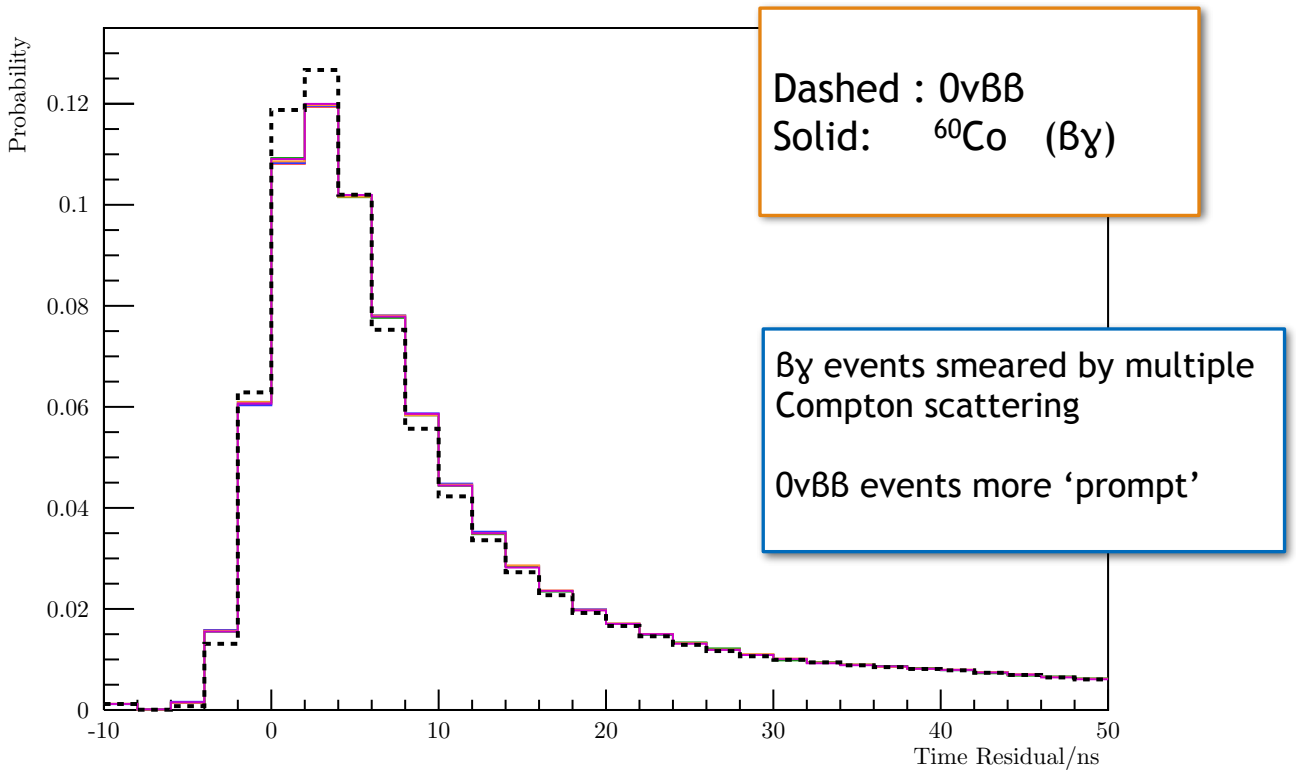
Aim to cover the inverted hierarchy

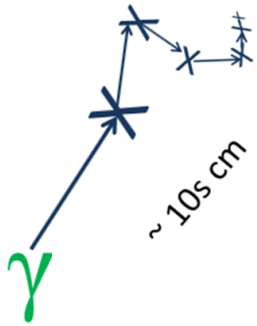


Multi-site Signatures

With scintillation light output and SNO+ collection:

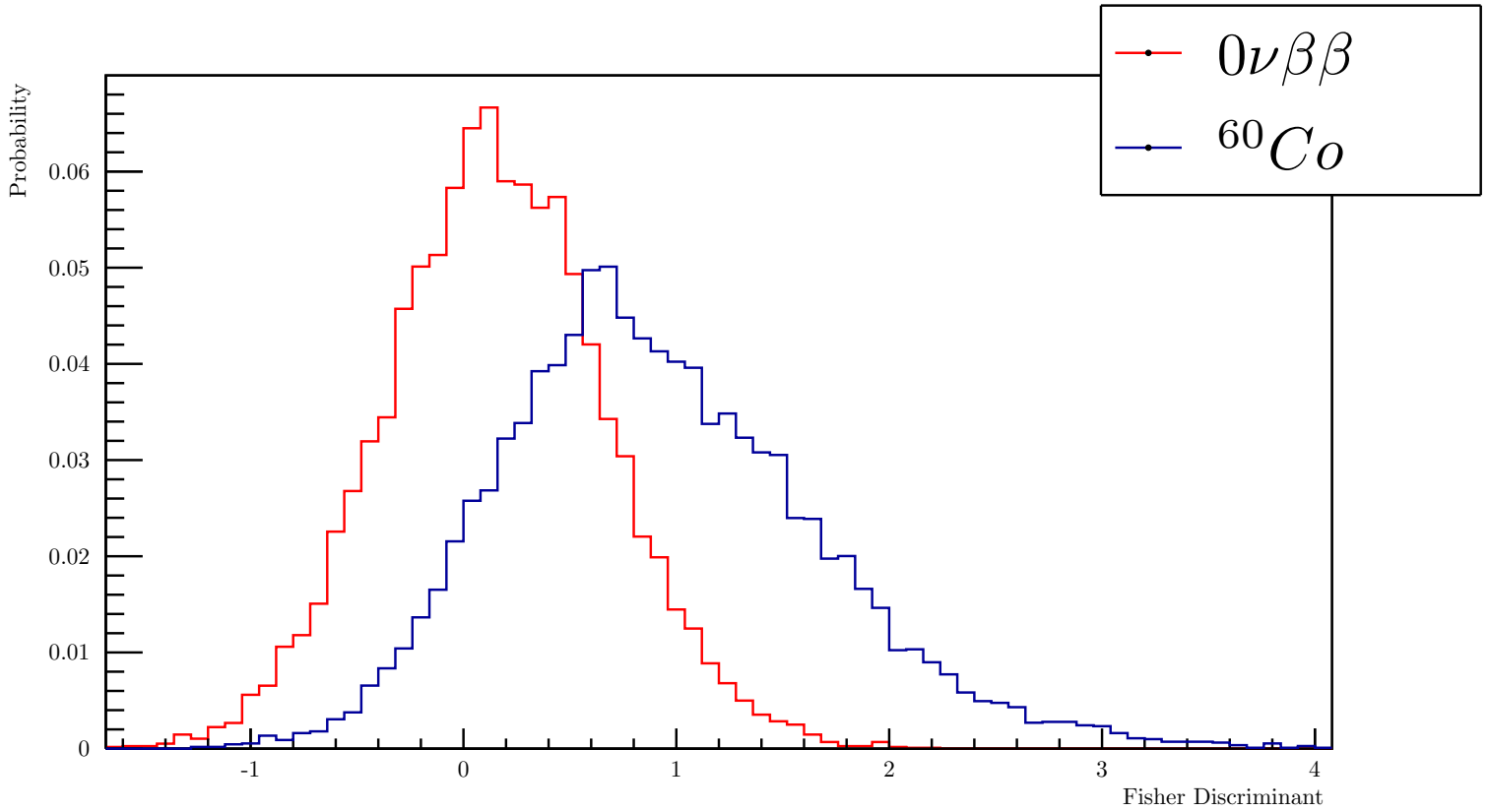
—> Statistically distinguish single/multi-site events in a kt scale detector





Multi-site Signatures - Cosmogenics

Important for e.g. ‘cosmogenic’ decays that can mimic a ßß signal



- Underground purification - 1000x reduction in such isotopes
- Multi-site signature allows for an in-situ constraint

Summary

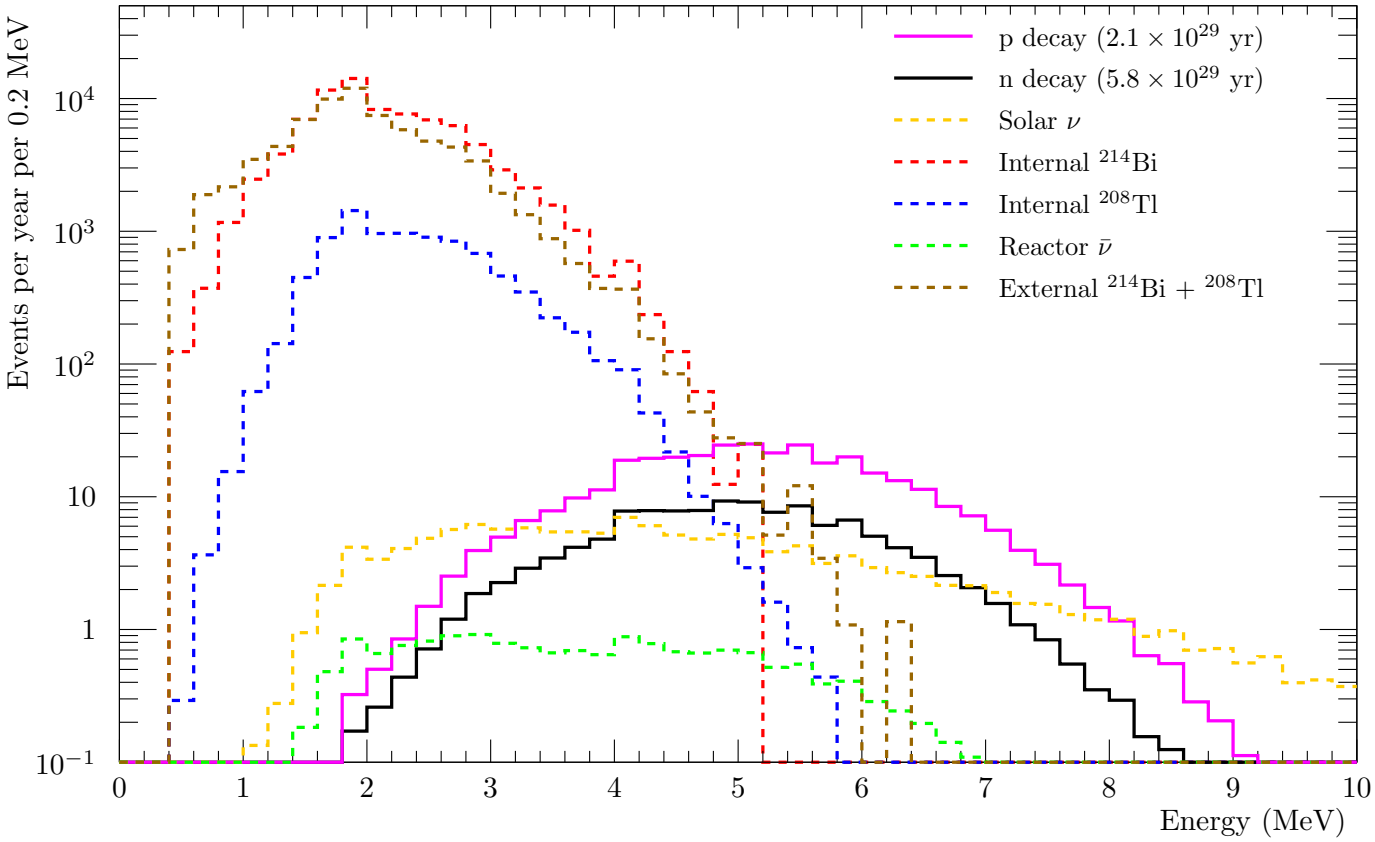
- SNO+ is taking water data
- Tellurium/scintillator and purification plants currently under installation/commissioning
- 5 years data covers the top of the inverted hierarchy, phase II can reach the bottom
- Single/multi-site discrimination in kt scale detectors is possible at SNO+ light levels


Thanks

Invisible Nucleon Decay

$n \rightarrow 3\nu$

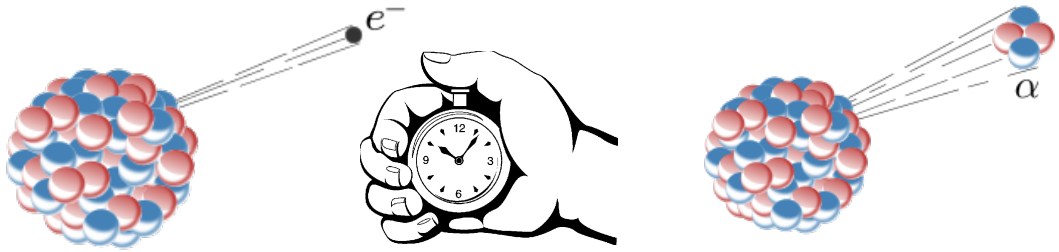
^{16}O -> $^{15}O^*$ / $^{15}N^*$ -> ^{15}O / ^{15}N + γ (6MeV)



- τ_n = 1.2 x 10^{30} years (current 5.8x10^{29})
- τ_p = 1.4 x 10^{30} years (current 2.1x10^{29})

BiPo Coincidences

^{21x}Bi



^{21x}Po

$$\tau_{214} = 164\mu\text{s} \qquad \tau_{212} = 299\text{ns}$$

Two triggers: Cut on energy, separation in time and space

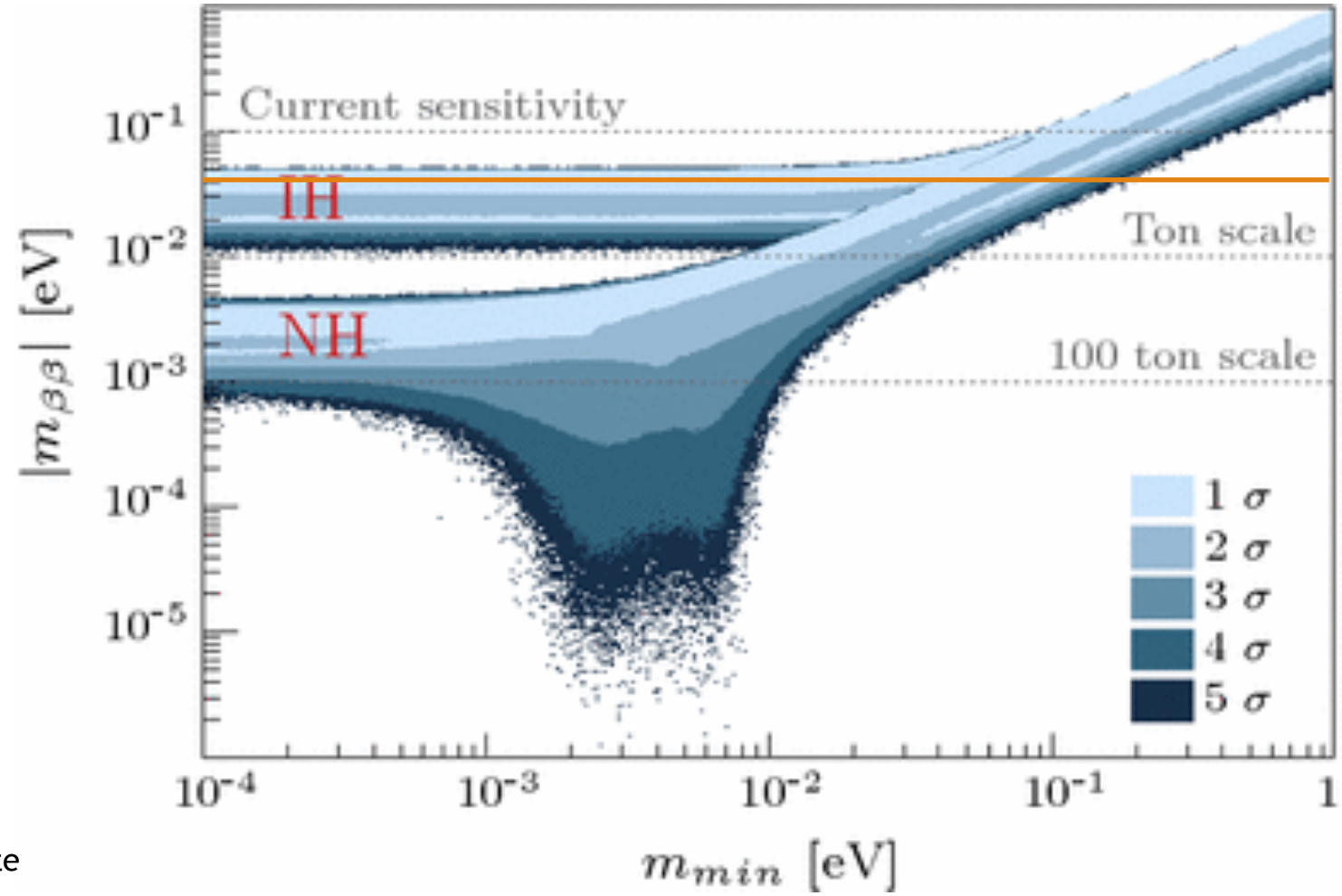
One trigger: α follower distorts ß scintillation pulse

Rejection Factor:

~ 5 x 10^5

in signal region

Mass Sensitivity



SNO+
Phase I

Slower rate

Lighter neutrinos

Mass Limit Assumptions

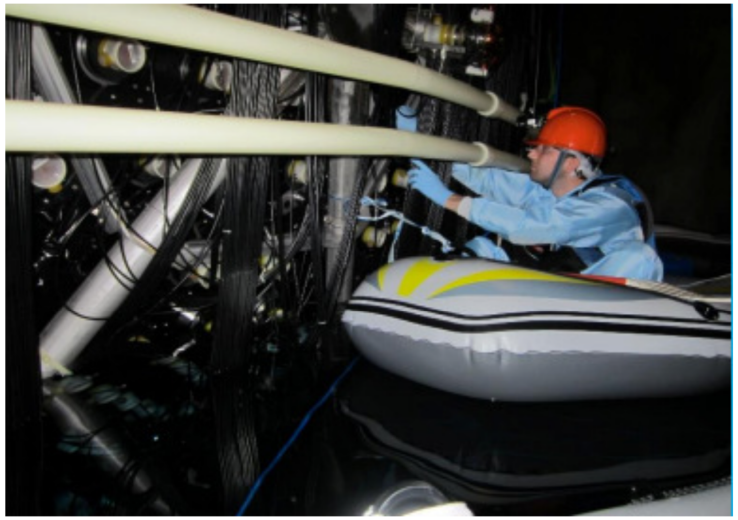
Livetime/yr	$T^{0\nu}_{1/2}$/yr	$m_{\beta\beta}$/meV
1	$8.0 \cdot 10^{25}$	75.2
5	$2.0 \cdot 10^{26}$	39.7

- IBM-2 model using the Miller-Spencer approach
- g_A = 1.269
- $m_{\beta\beta}$ range for 5 years: 38 - 92 meV

- 50% reduction of external radioactivity in fiducial volume from PSD
- 100% ^{21X}BiPo rejection with two triggers, 50x rejection on single trigger
- 25x reduction in α - n events from 18O and 13C

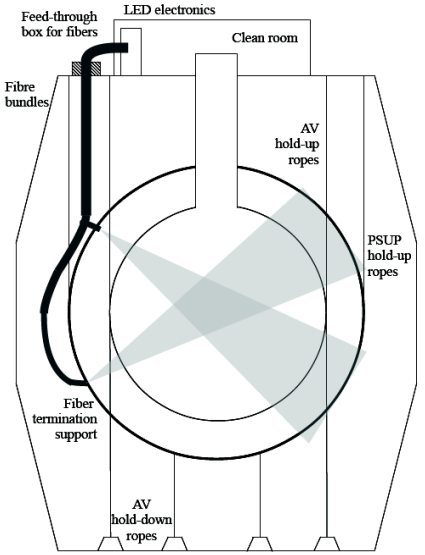
- Borexino U/Th levels in LAB
- Assumes TeBD has same U/Th as SNO internal water
- UG purification of Te
- 2 g/L PPO, 15mg/L bisMSB —> 390 hits/MeV

SNO to SNO+

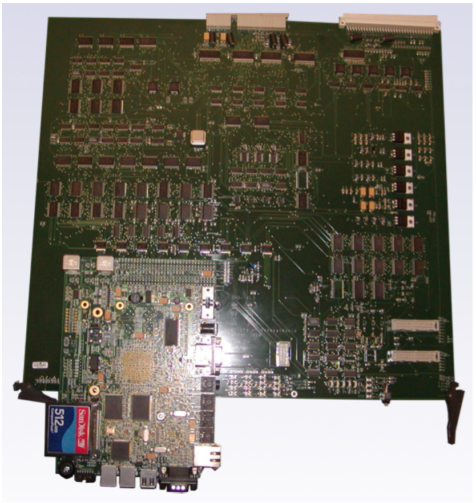


Cavity wall and PMT repairs

New embedded
optical calibration systems

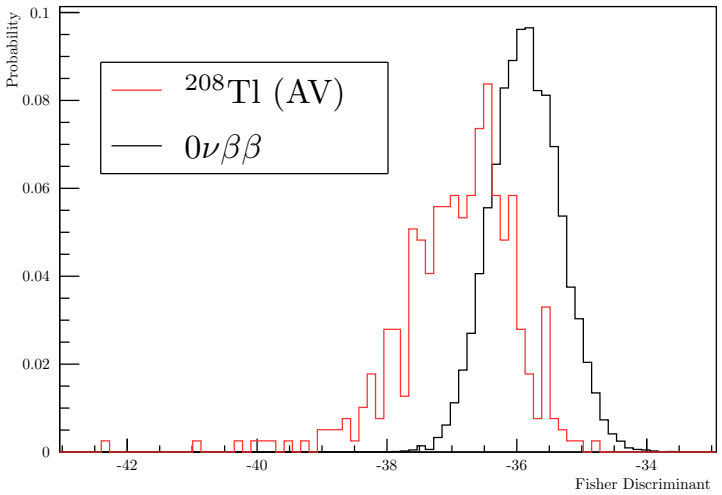


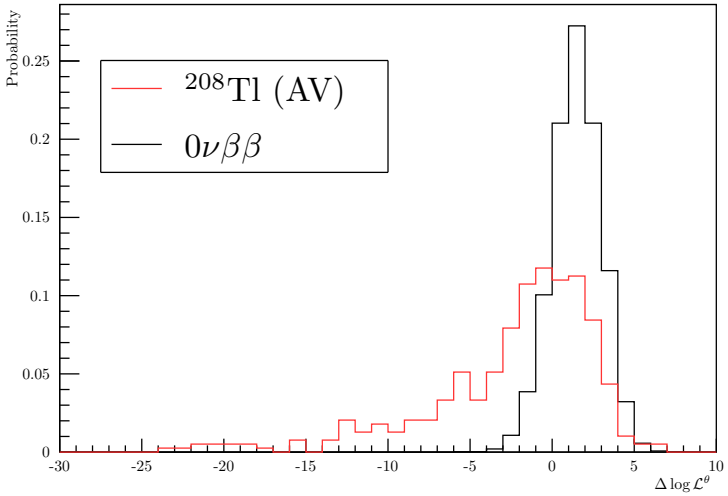
New rope system to offset
scintillator buoyancy



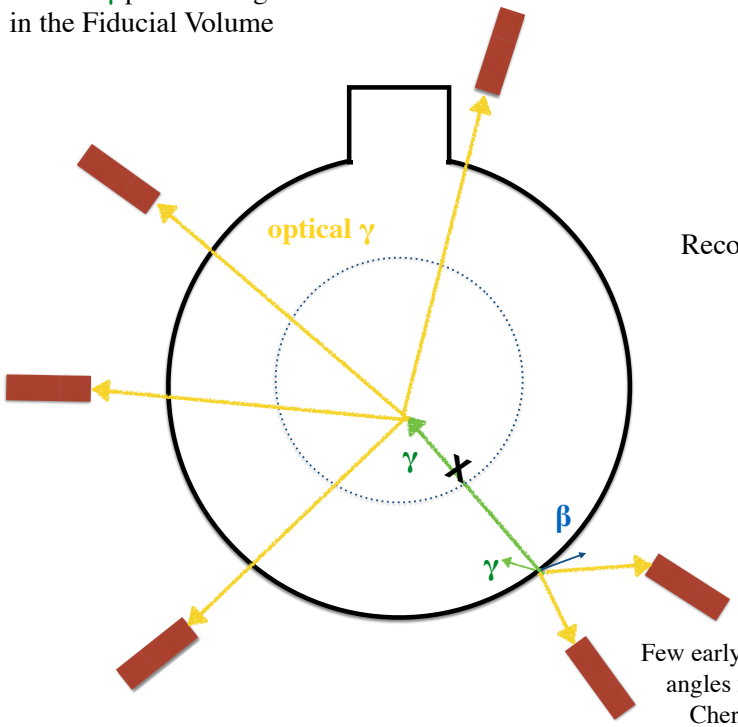
DAQ upgrades for increased
throughput

Multi-site signatures - External Radioactivity





2.6 MeV γ produces light in the Fiducial Volume



Reconstructs along γ track

Few early hits at small angles from Water Cherenkov or Scintillation

50% rejection
~1% sacrifice

Normal Hierarchy

For 1 event/yr $m_{\beta\beta}$ = 2.5meV

Isotope	tons of isotope for 1 ev/yr	equivalent natural tons	annual world production [5] (tons/yr)	natural elem. cost ($M)	enriched at $20/g ($M)
^{48}Ca	31.1	16380	2.4×10^{8}	2.6	622
^{76}Ge	58.2	746	118	1221	1164
^{82}Se	20.8	225	2000	39	416
^{96}Zr	21.4	763	1.4×10^{6}	27	427
^{100}Mo	12.2	127	2.5×10^{5}	4.4	244
^{110}Pd	26.0	221	207	5078	521
^{116}Cd	22.1	290	2.2×10^{4}	0.81	441
^{124}Sn	41.2	736	2.5×10^{5}	22	825
^{130}Te	23.6	68	~150	24	471
^{136}Xe	45.7	513	50	513	914
^{150}Nd	13.4	240	$\sim 10^{4}$	11	269

~ $1 billion Ge

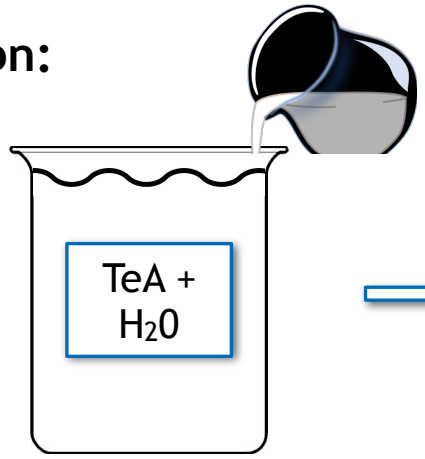
$ 24 million Te

~ $1 billion enriched Xe or 10x world production nat.

Steven D Biller - arXiv:1306.5654

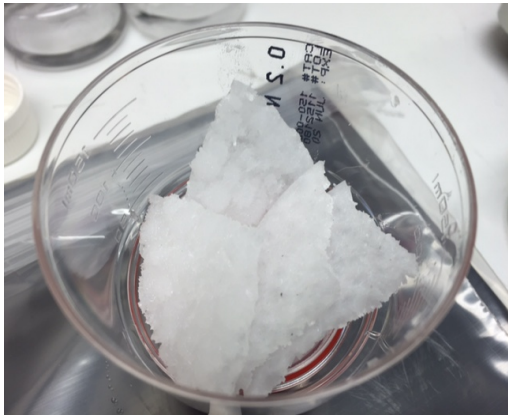
Tellurium Purification

A/G TeA purification:

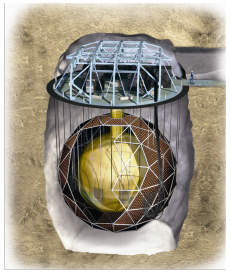


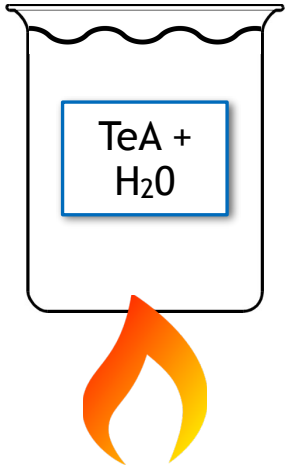
Nitric Acid

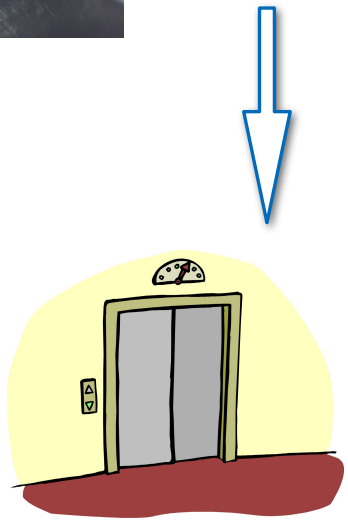
TeA Crystals



U/G TeA purification:



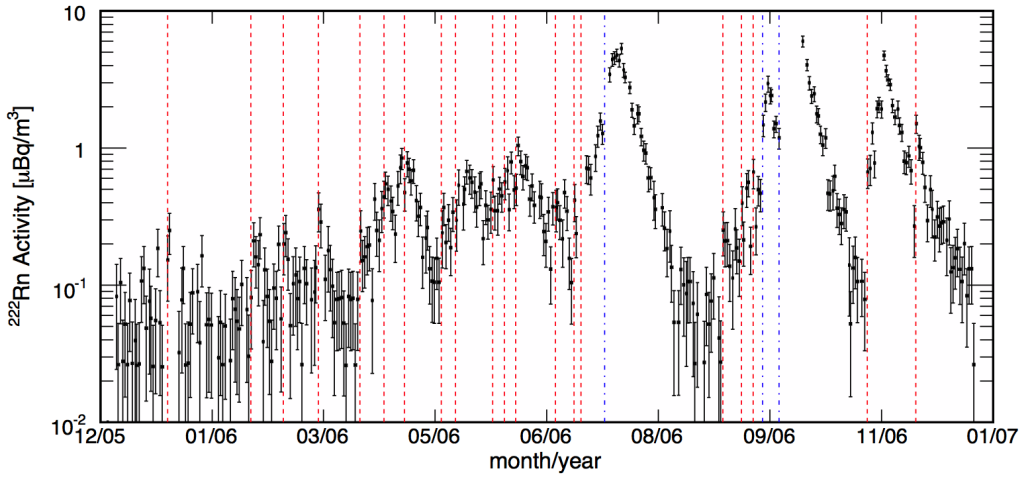




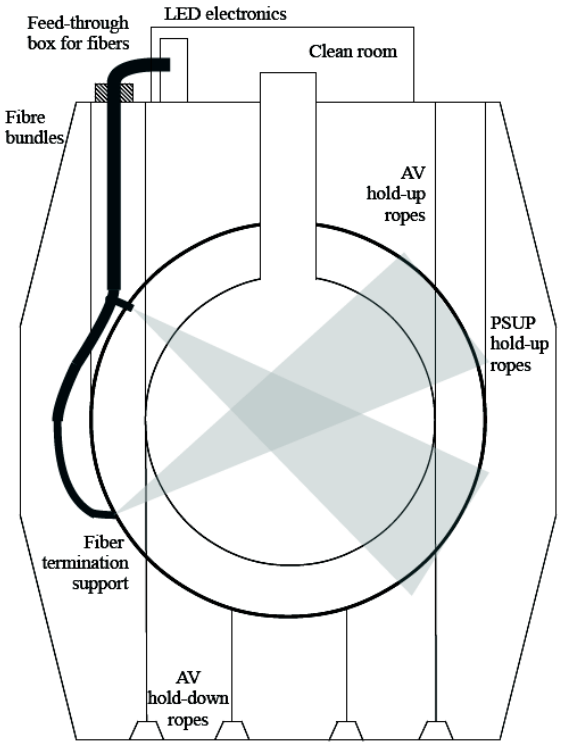
1000x impurity removal

ELLIE

Kamland ^{222}Rn contamination from source deployment



TELLIE: 91 fibres cover the whole detector with LED light for PMT calibrations



AMELLIE: Collimated LED light for attenuation measurement

SMELLIE: Multi-wavelength collimated laser light to measure scattering angle/length