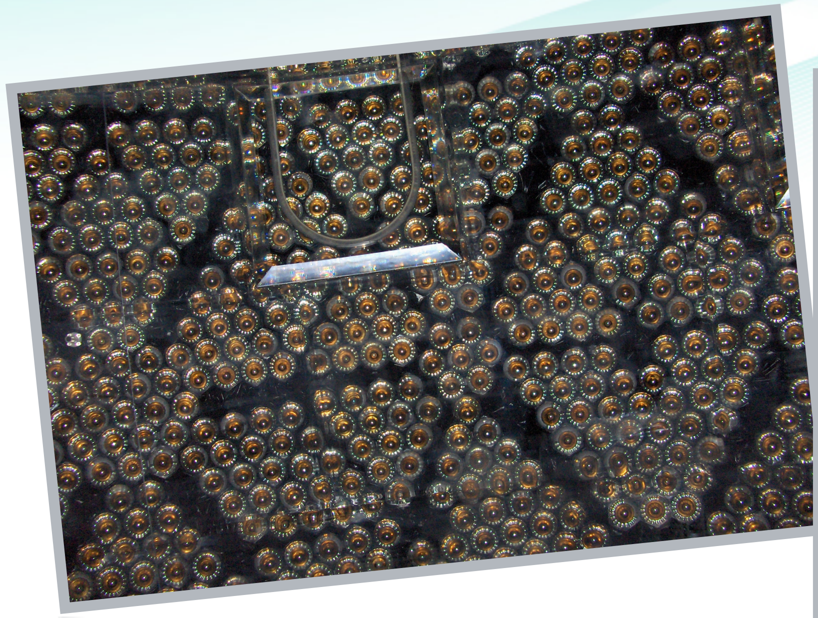
SNO+ Status and Double Beta Decay

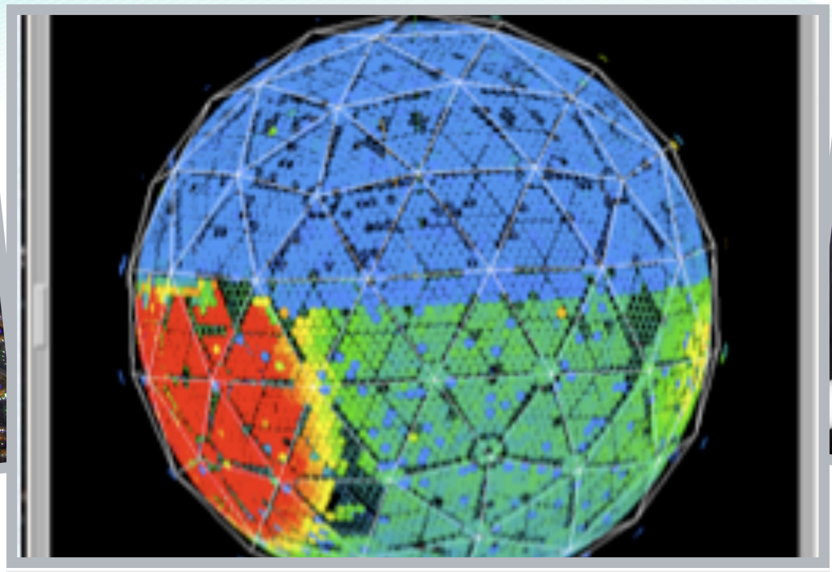
Christine Kraus

Queen's University, Laurentian University and SNOLAB

September 21st, Erice, Sicily, Italy



inside acrylic vessel, rope and PMTs



LED light in partially light water filled vessel

cavity wall, PMT HV cables and water

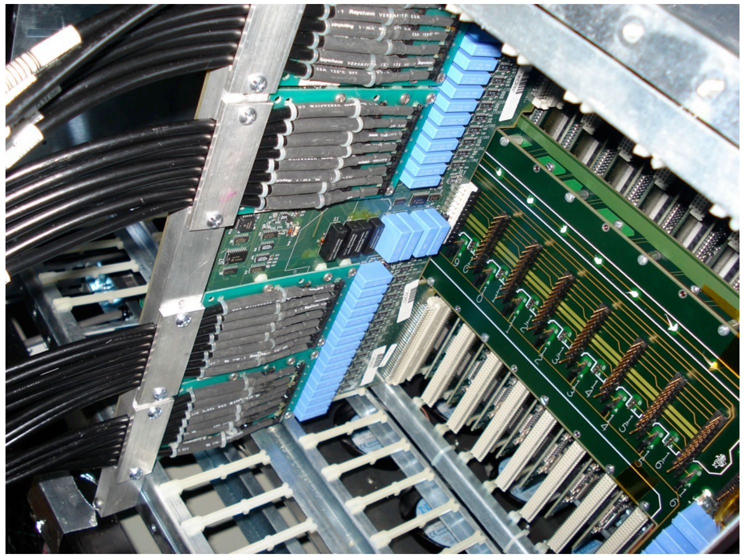
Outline

- *Introduction to the SNO+ experiment*
- *From SNO to SNO+*
- *Activities 2008-2010*
- *Double beta decay with SNO+*
- *First SNO+ data: "bucket measurements"*

giant, fuzzy ν's at SNO+
www.particlezoo.net/gallery.html

me in DCR

!!! fully funded, ready to go !!!



crate, HV connections

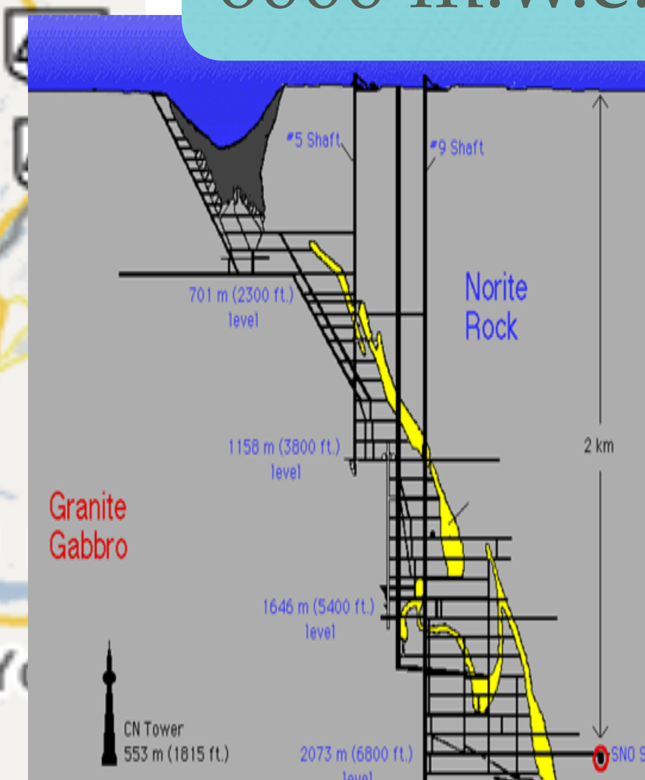
SNO+ is located at SNOLAB

300 km

Canada
Ontario
Sudbury
Creighton mine

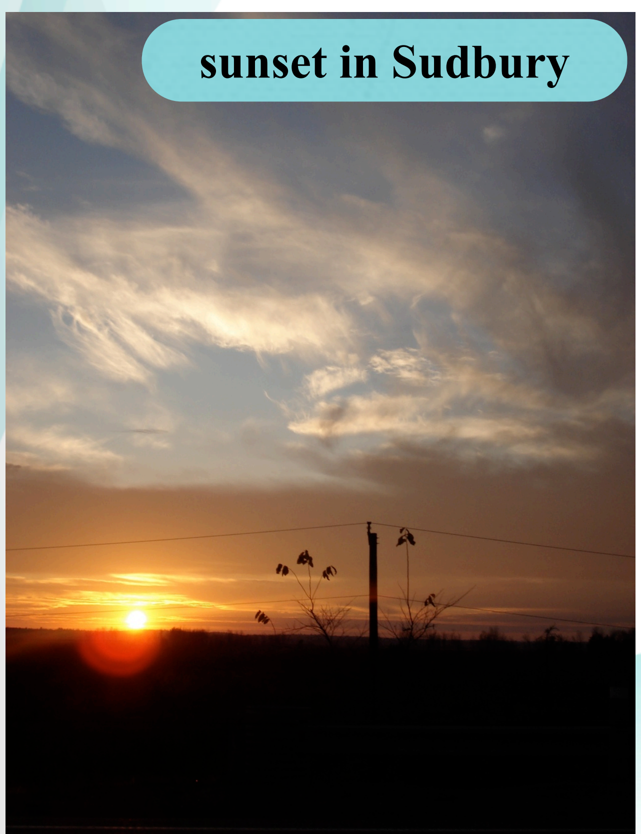
use existing SNO cavity

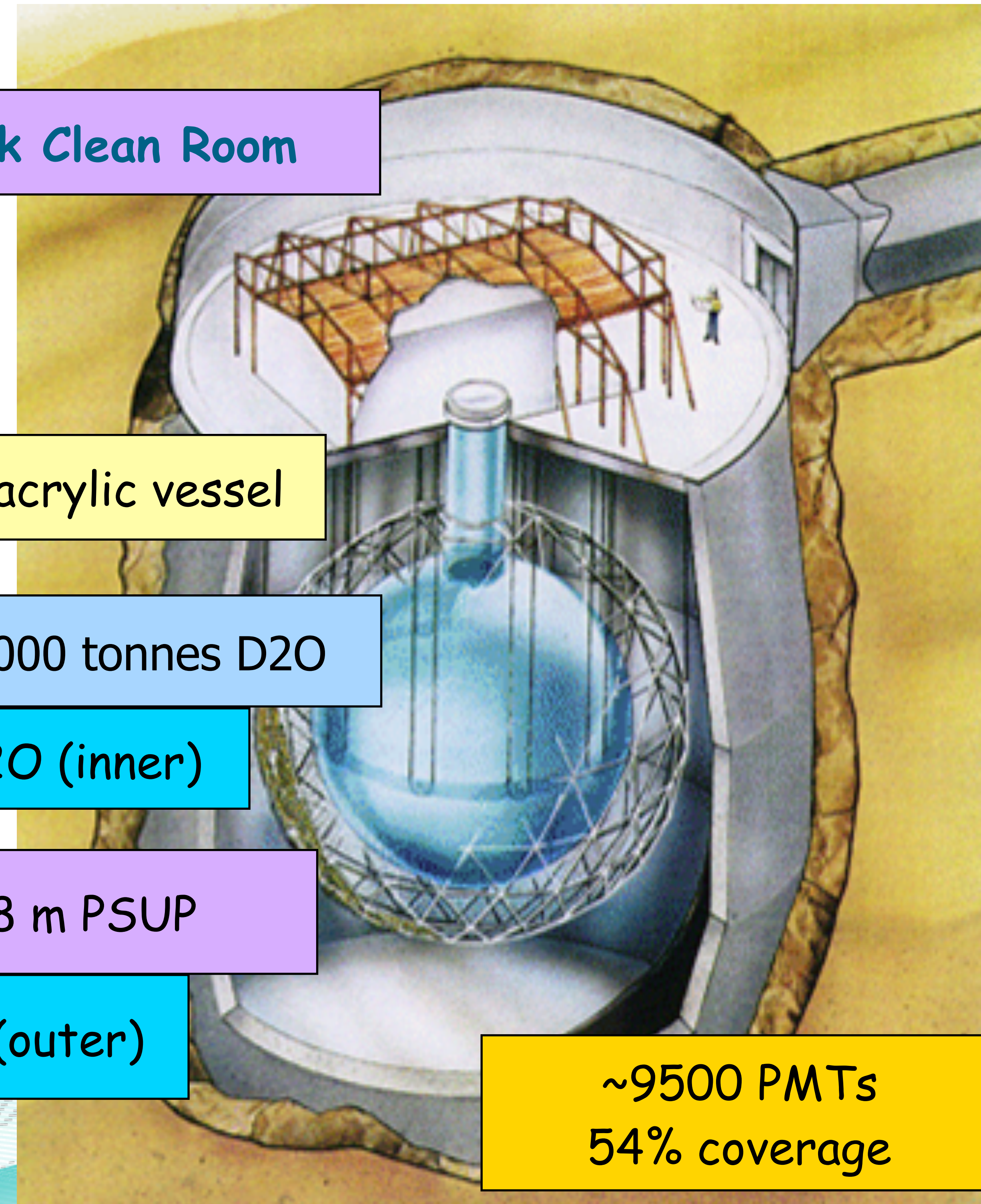
2 km or 6000 m.w.e.



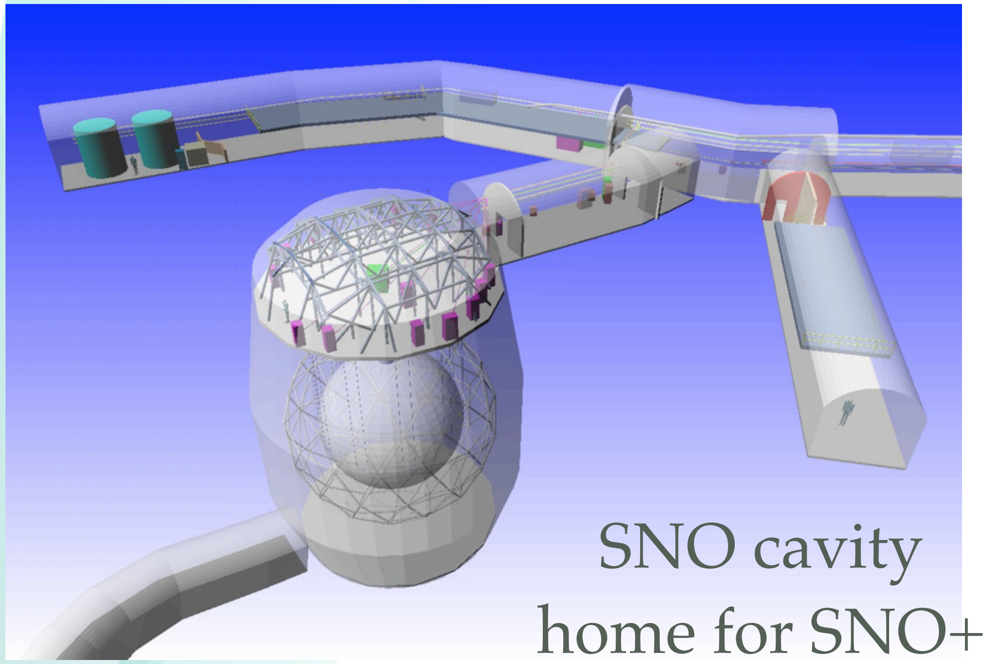
SNO detector

Acrylic vessel AV,
filled with 1000 tonnes
of heavy water:
1999-2006 data taking
in 3 phases

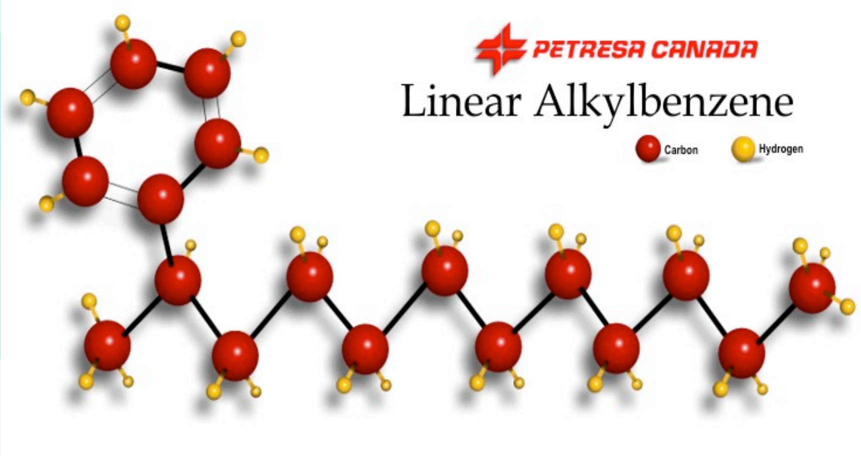




SNO +



SNO cavity
home for SNO+



- *Filling SNO acrylic vessel with liquid scintillator: Linear Alkyl Benzene = LAB and PPO*
- *Creating multi-purpose detector with rich physics program*
- *Nd loaded scintillator: double beta decay of ^{150}Nd*

Following topics: see S. Peeters

- *Solar neutrinos: pep and CNO*
- *Geo- and reactor-anti-neutrinos*
- *SN physics, SNEWS*

From SNO to SNO+

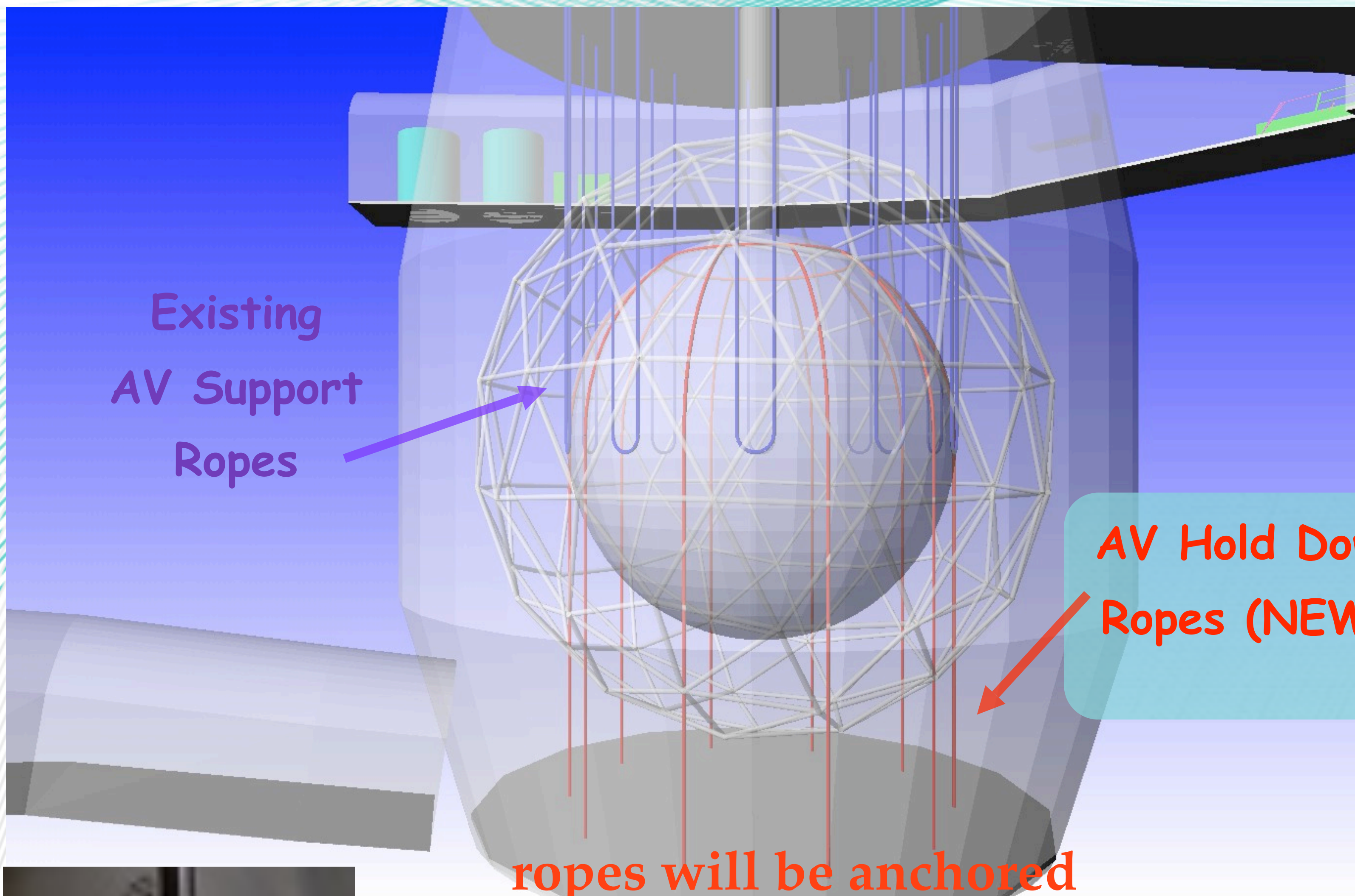
- *Suitable scintillator identified (acrylic compatible, safe: high flashpoint and low toxicity, cheap) --> next talk*
  → *buy and purify (purification system)*
- *Need to stop acrylic vessel from floating (LAB density is 0.86)*
  → *design (done), fabricate and install rope hold-down net*
- *Upgrades to electronics and DAQ - now higher event rates ...*
- *Radio-purity requirements are more stringent than in SNO*
  → *lower energy threshold --> ^{40}K now important (and other's)*
  also: careful material selection for radio-purity and compatibility
- *Need a new calibration system (next talk)*
  → *attached to acrylic vessel and absolutely sealed, no radon or oxygen*

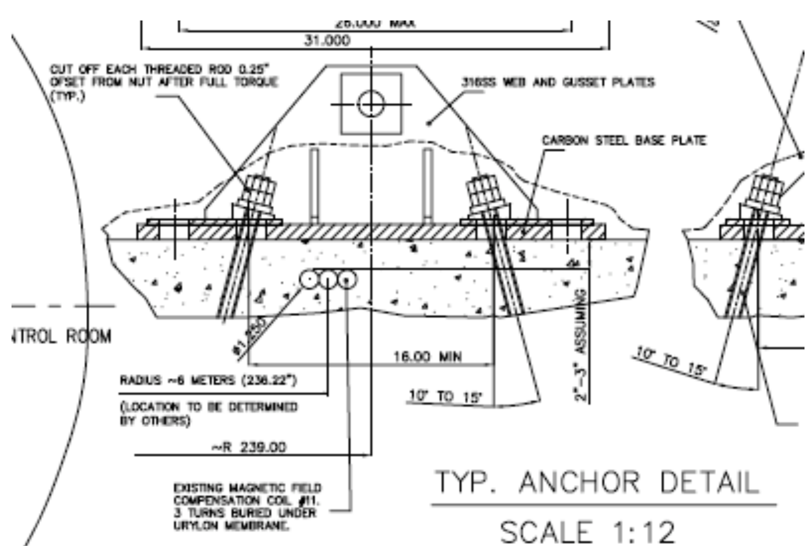
Neutrino interactions:

$\bar{\nu}_e + p \text{ --> } e^+ + n$

$\nu_x + e^- \text{ --> } \nu_x + e^-$

SNO+ hold down net



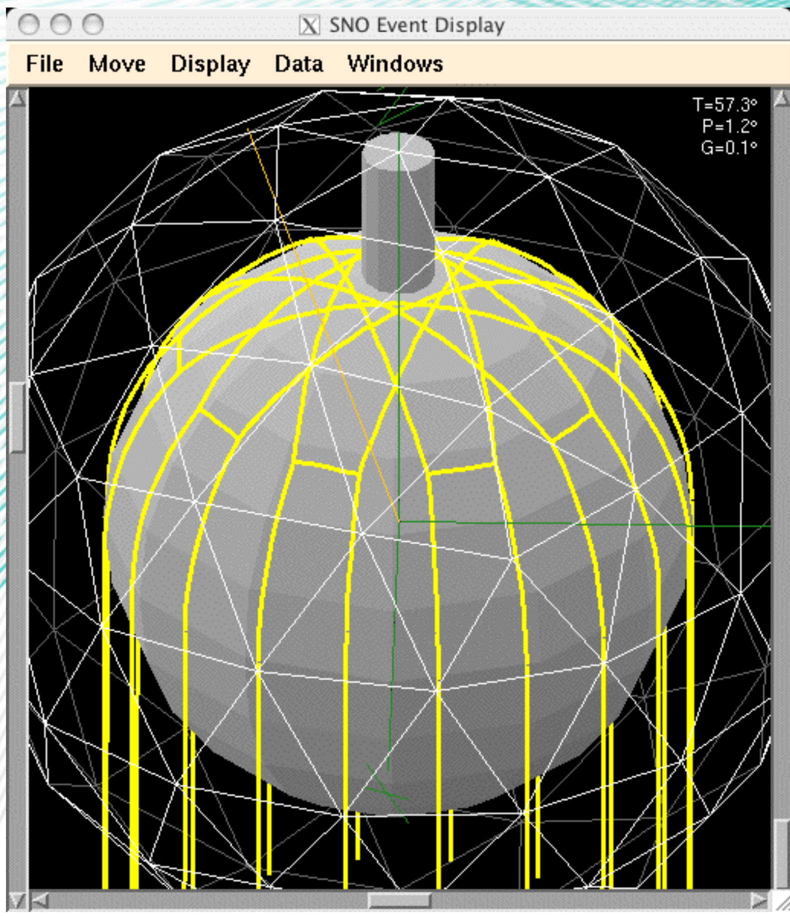


Existing AV ropes will be exchanged with new thinner rope. Tensylon is our candidate.

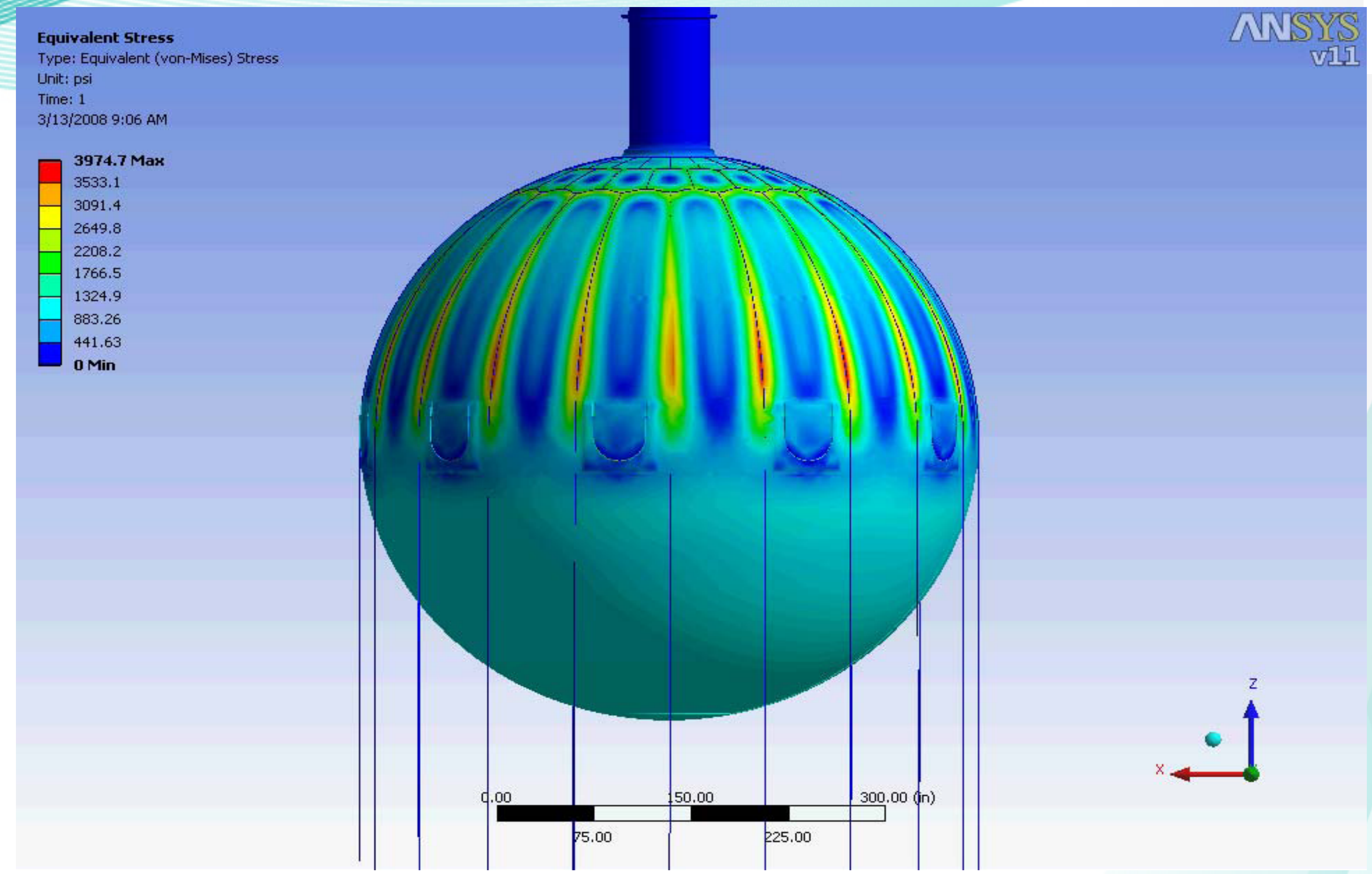
Significant reduction in ^{40}K levels

^{40}K level in Tensylon measured with UG Ge detector:
250 ± 130 ppb
~ factor 10 lower than Vectran (used for SNO)

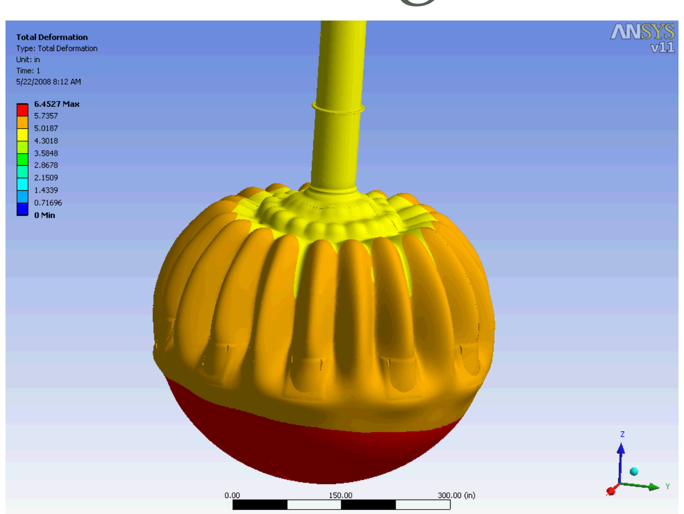
SNO+ rope net



actual conceptual design



FEA has been performed - no buckling, AV can handle stresses (below 600 psi)



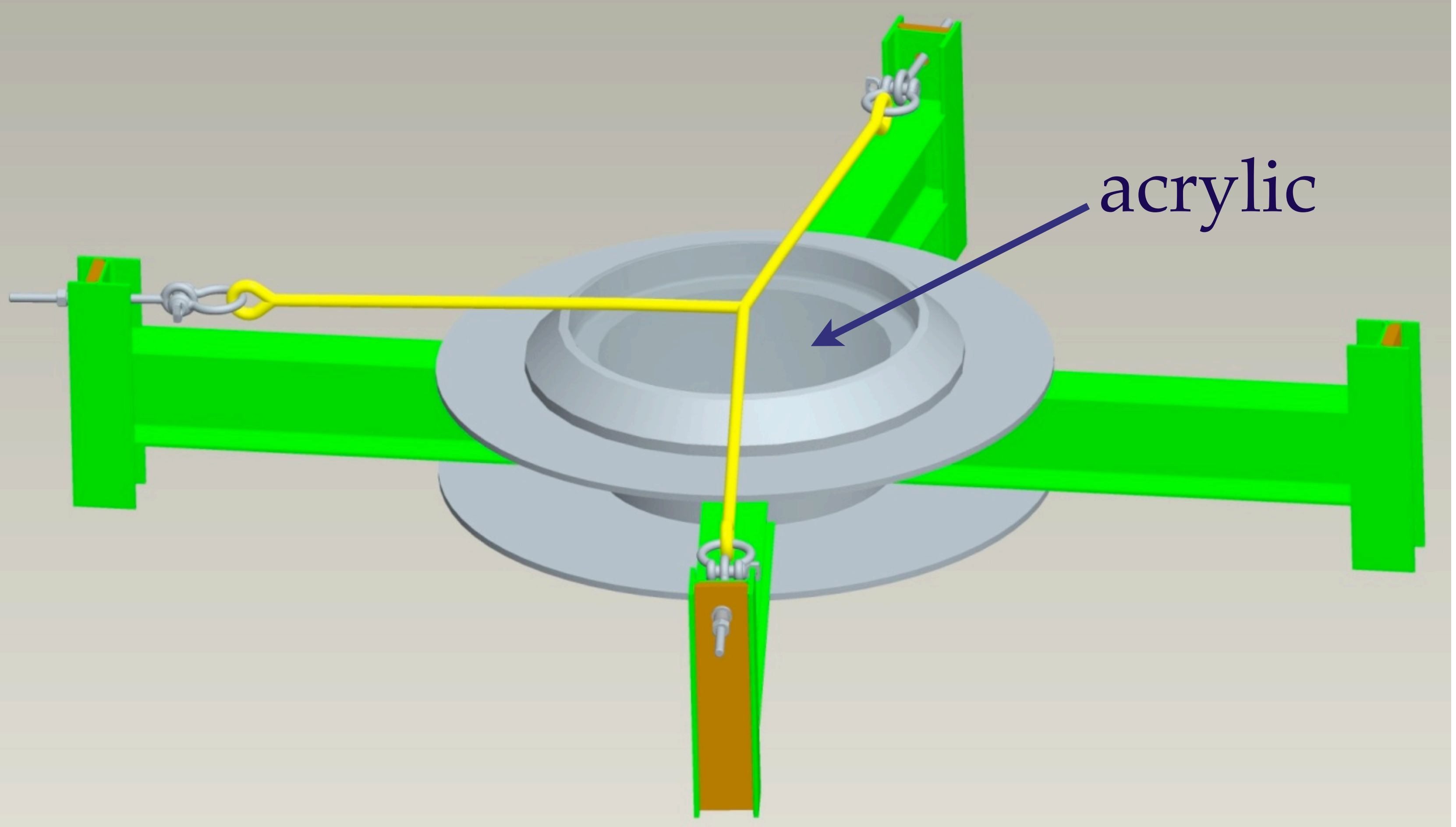
100x enhance to make effects visible

Re-certification of acrylic vessel: detailed inspection inside (boat) survey performed - how spherical is AV.

Left to do: rope over acrylic

parts are machined, test to be performed as soon as rope arrives

Rope over acrylic



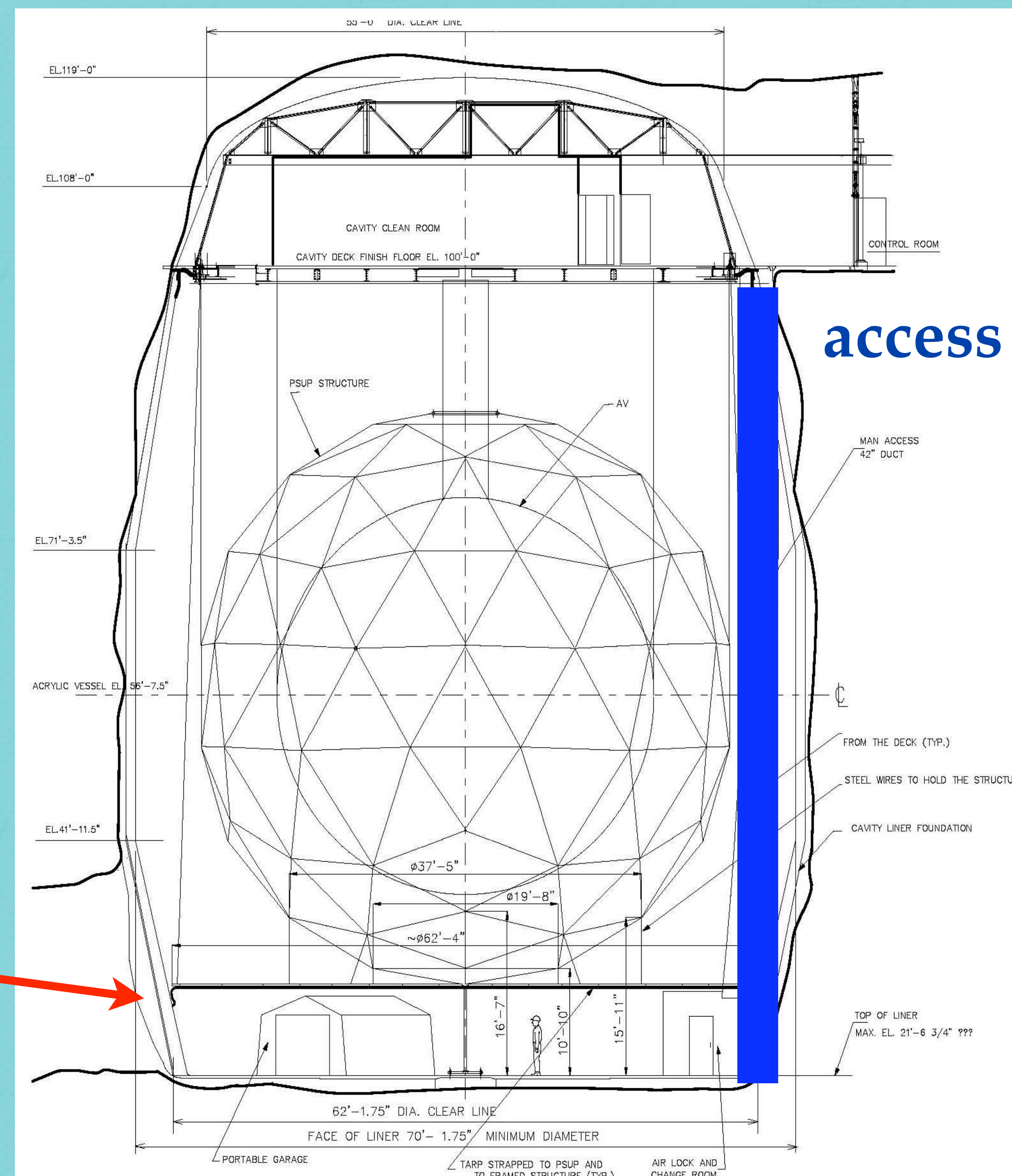
underway at University of Alberta

Preparations for cavity work

rope net needs to be anchored to the floor
--> drill 20 holes (~10 feet), grouting ...

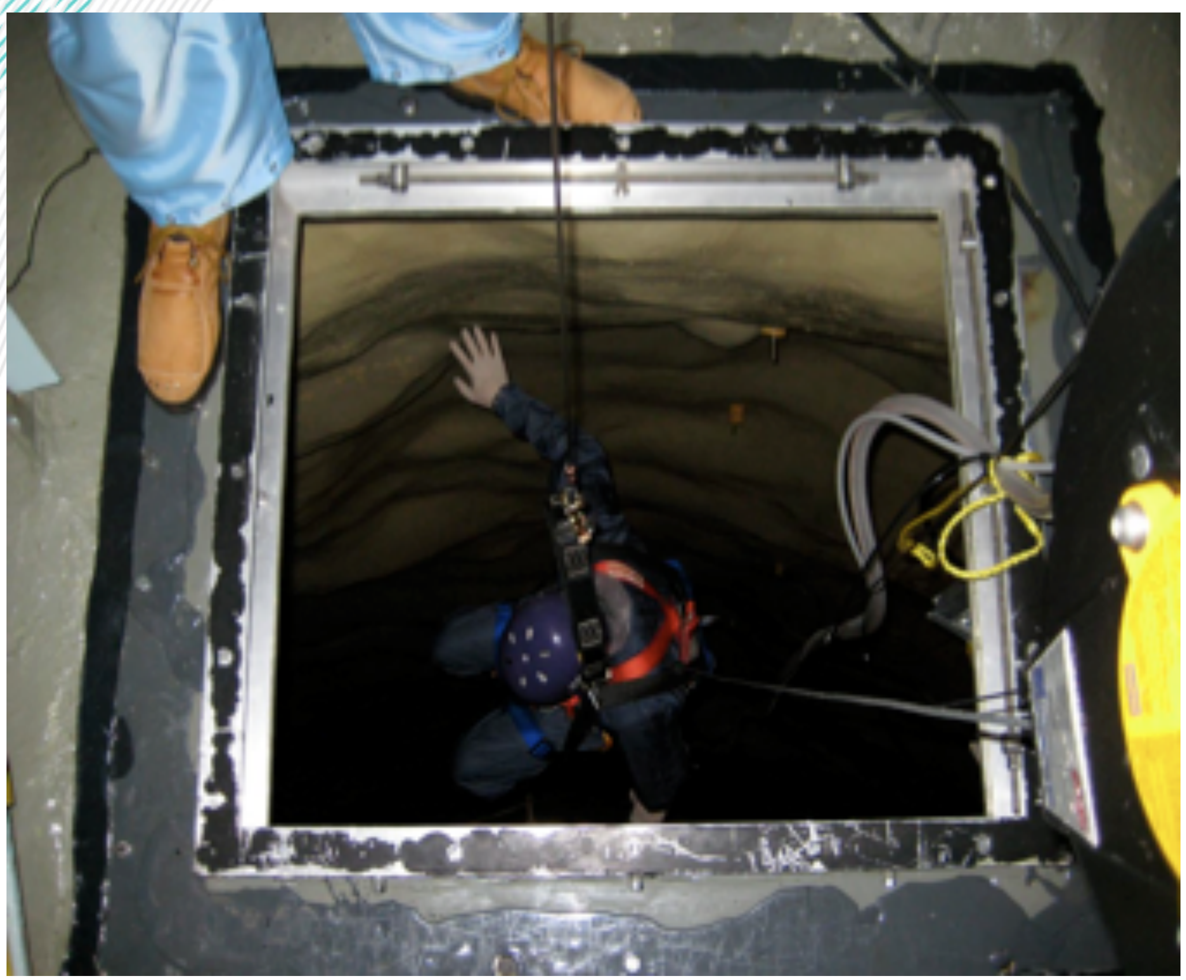
How can we keep the detector clean and safe?

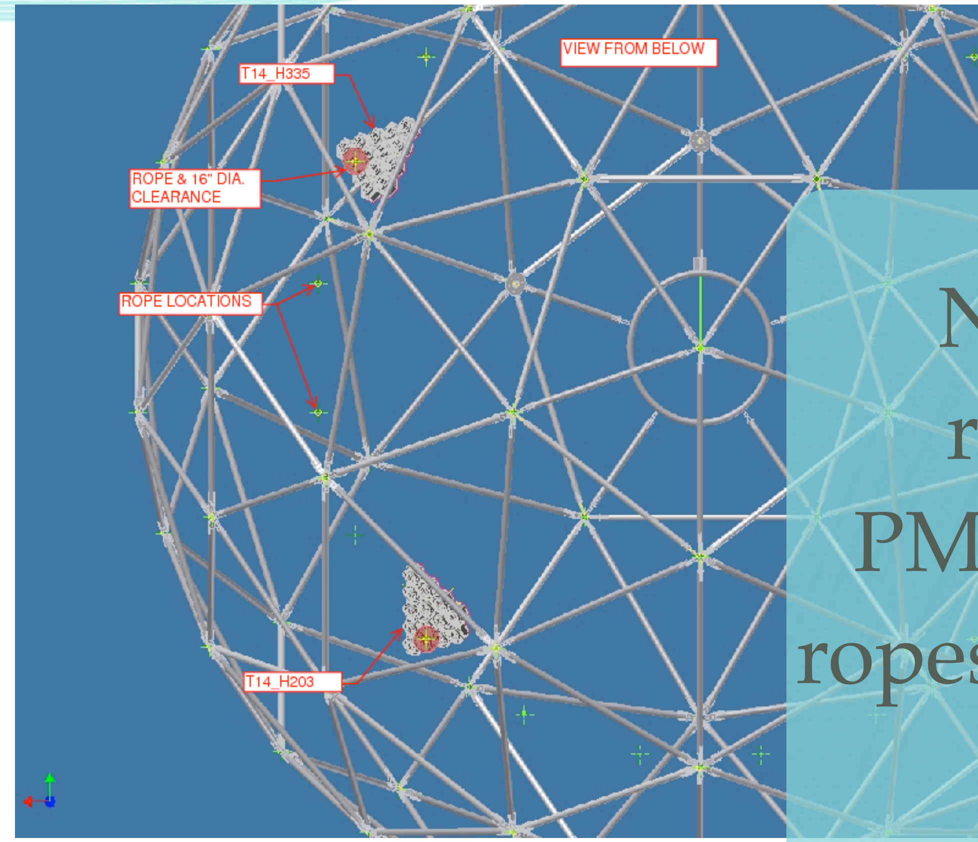
Separate work area from detector by an "umbrella"

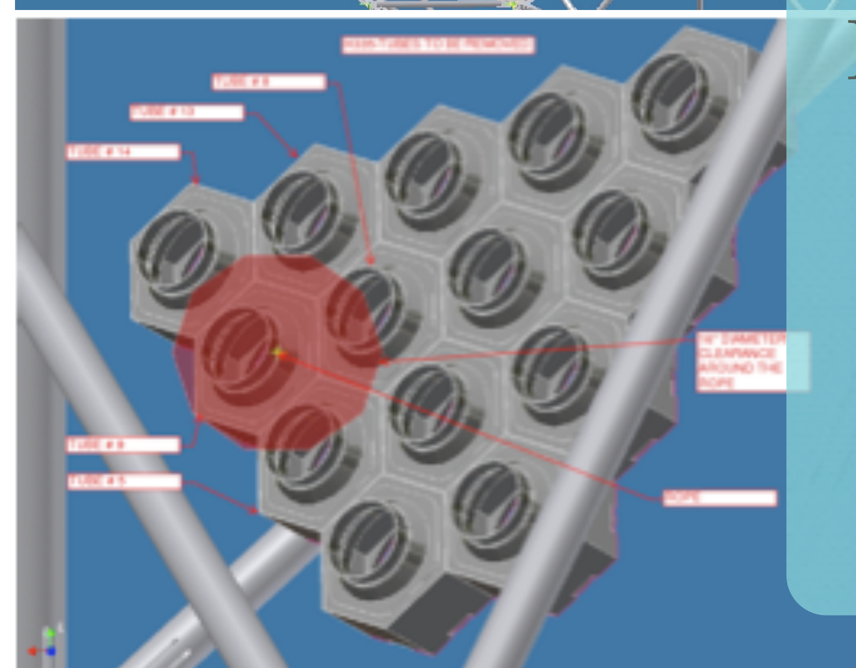


Access to cavity / AV

We use a bosun chair - people and material







Need to remove PMTs where ropes penetrate

May be used to replace some of the dead PMTs (<10%)

AV inspections

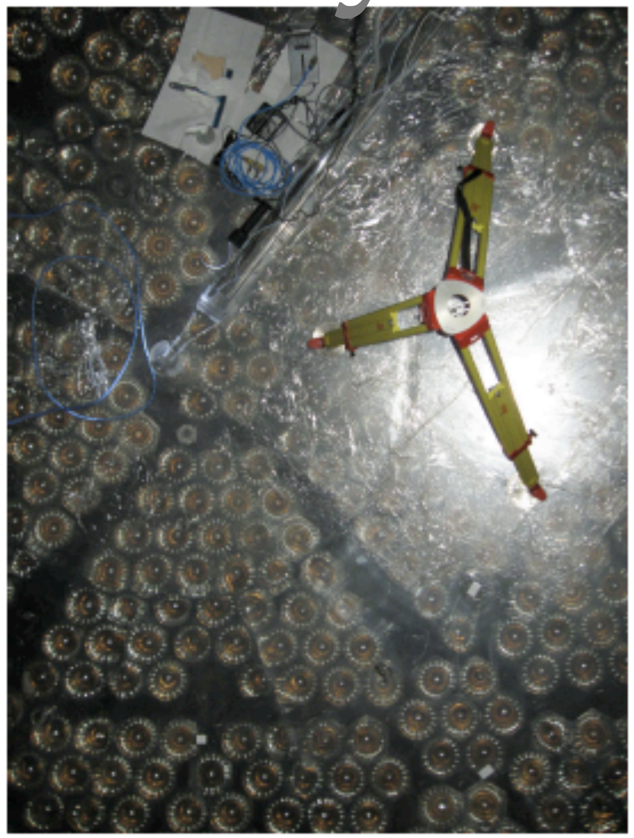
While draining the acrylic vessel with light water, we stopped every couple of feet and inspected every bond carefully. Targets for AV survey (~500) were attached as well.

11 expeditions between Nov 2008 and Jan 2009:
No crazing or deterioration of acrylic observed

Many inspections in cavity performed as well since 2007 (by boat and on the floor)

AV survey - May 2009

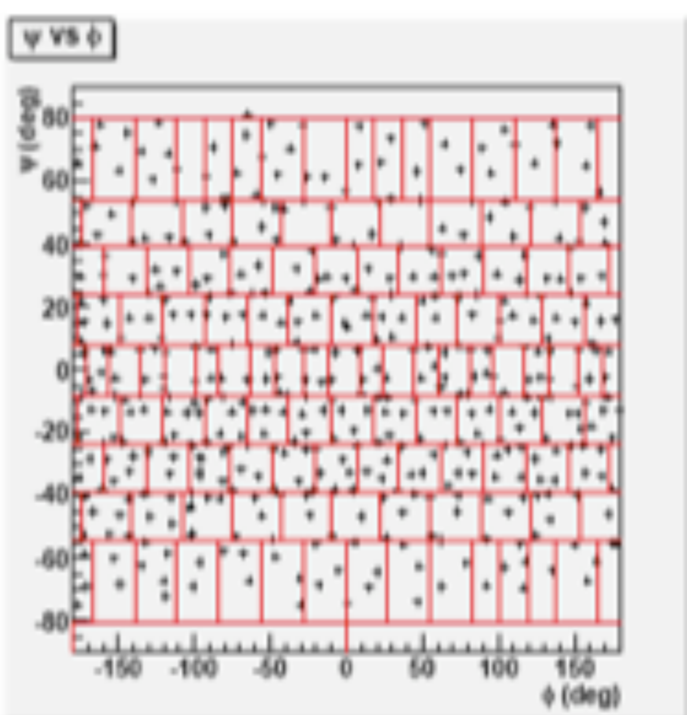
First Campaign

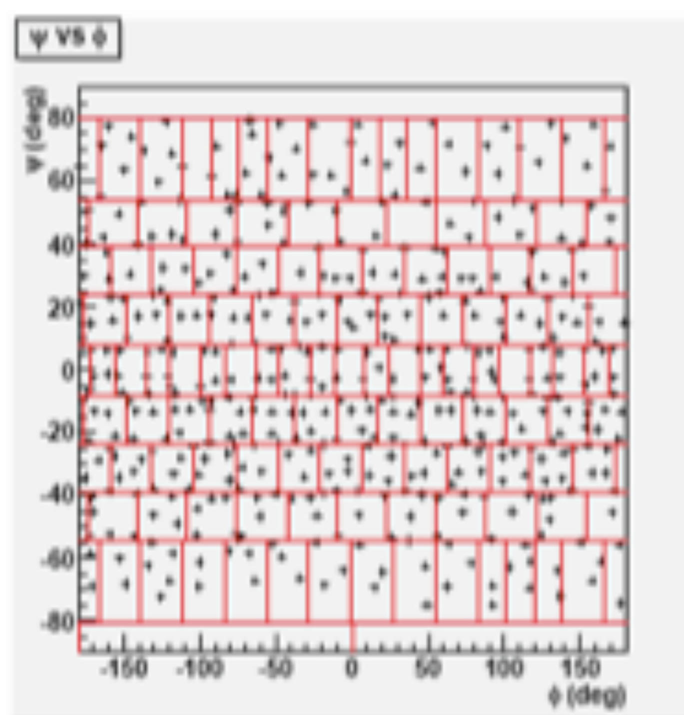


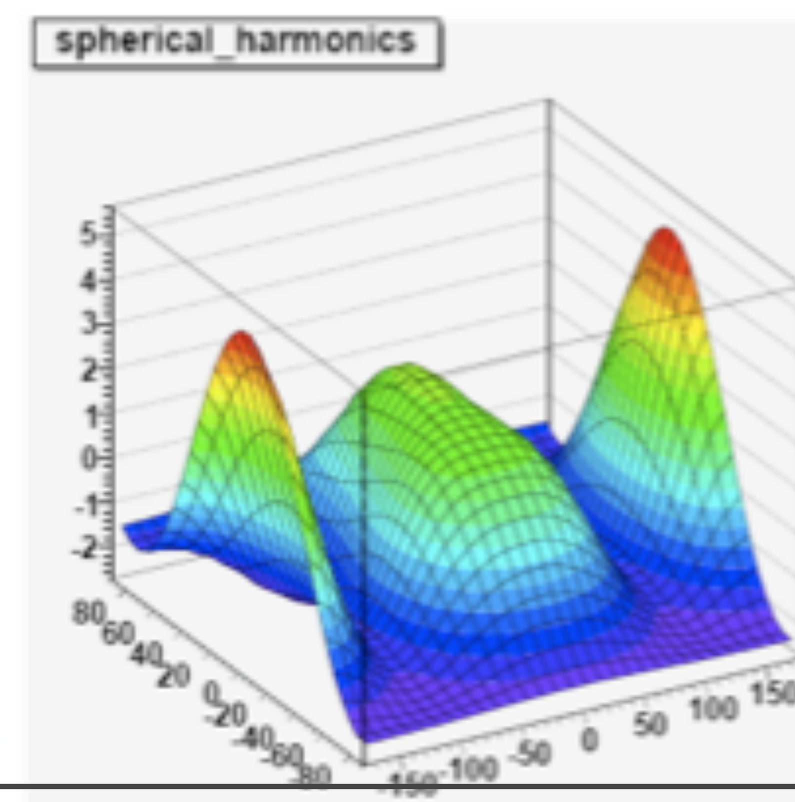
Second Campaign

2 campaigns
different tripod positions
in very good agreement

Combined result:
Radius = 601.142 ± 0.007 cm
As before: AV is spherical to better than 0.5″





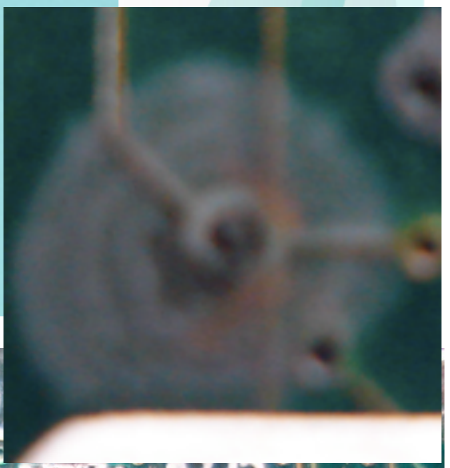


Use measured deviations in FEA; re-run stress and buckling analysis

SNO+ electronics upgrade

University of Pennsylvania, SNOLAB

Re-adjust short and long integration time to fit scintillator timing
replace crate to trigger communication board - network based
optimize for higher event rates
possibly hardware upgrades to further improve performance
clean all boards to get rid of "dark matter"



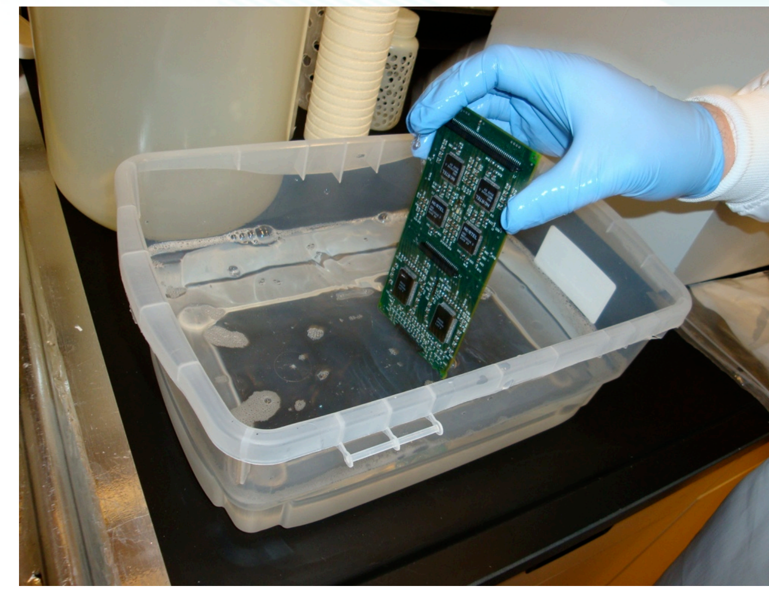
Experience from SNO:
electronics boards fail due to what we call "dark matter". Mine air contains H_2S that reacts with the boards. The deposited residue is conductive and not always visible.

Cleaning it off by hand improves the situation.
Problems clearly present during short light water running periods in 2007 and 2008

Dark Matter Cleaning

We defined and tested procedure that we will apply to every single electronics board (~1500) for the SNO+ detector

motherboards in cleaning solution and ultrasonic cleaner



daugther board - soap and water

drying in oven

SNO+ Double Beta Decay

Load the scintillator with ^{150}Nd as metallic-organic compound

Why Nd?

- 3.37 MeV endpoint (2^{nd} highest of all ββ isotopes)
  - above most backgrounds from natural radioactivity
- very large phase space factor of all ββ isotopes
  - 56 kg ^{150}Nd equivalent to (considering only the phase space)
    - ~220 kg of ^{136}Xe
    - ~230 kg of ^{130}Te
    - ~950 kg of ^{76}Ge
- isotopic abundance 5.6%

  0.1% w/w natural Nd-loaded liquid scintillator in 1000 tonnes has 56 kg of ^{150}Nd compared to 37 g in NEMO-III

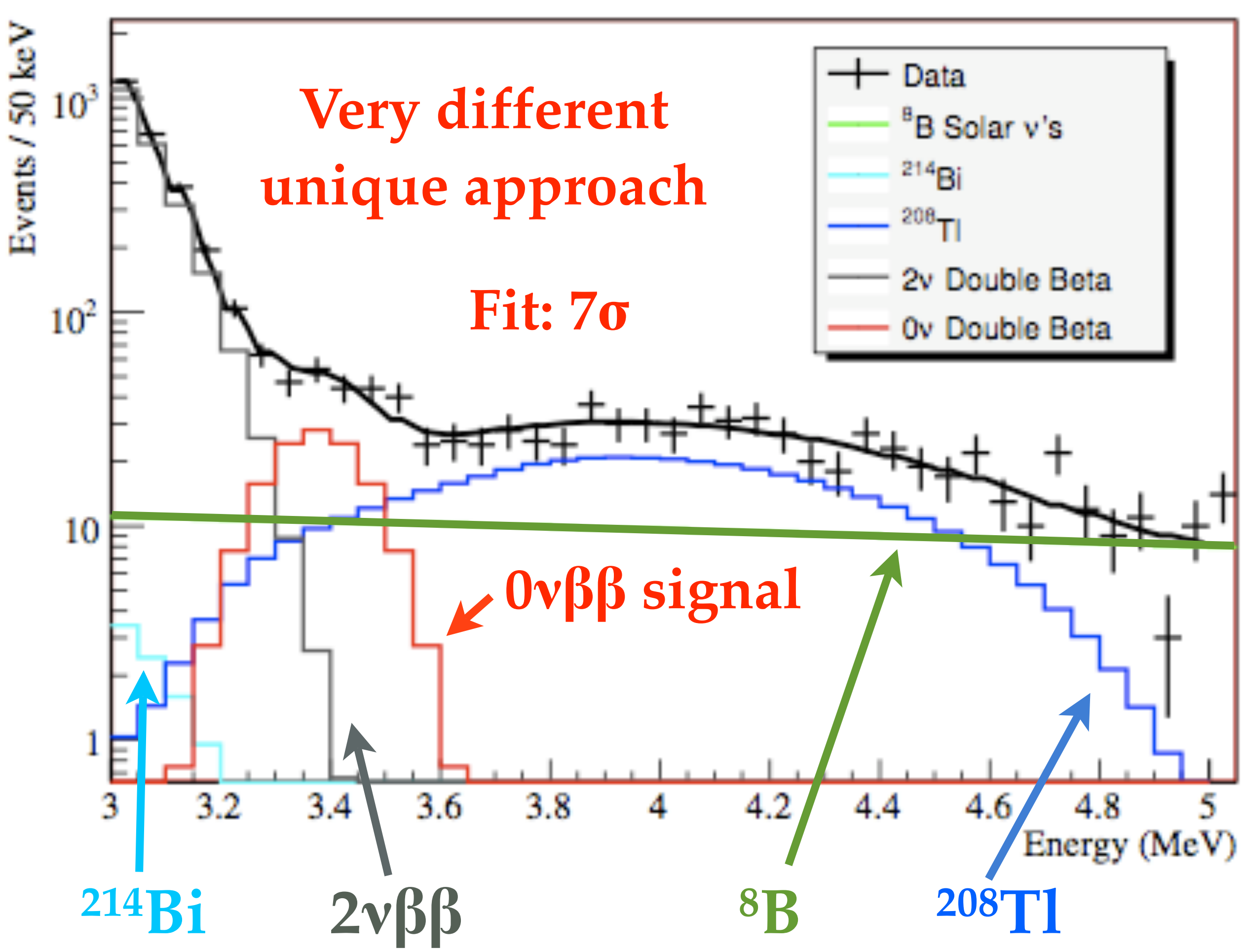
  0.1% is optically acceptable - still enough light
- cost $NdCl_3$ is $86,000 for 1 tonne
- 2νββ half life measured: (9.7 +/- 0.7 +/- 1.0) 10^{18} yr (NEMO III)
  favourable value *J. Phy. Conf. Ser. 173.012008 (2009)*

Energy Spectrum with Nd

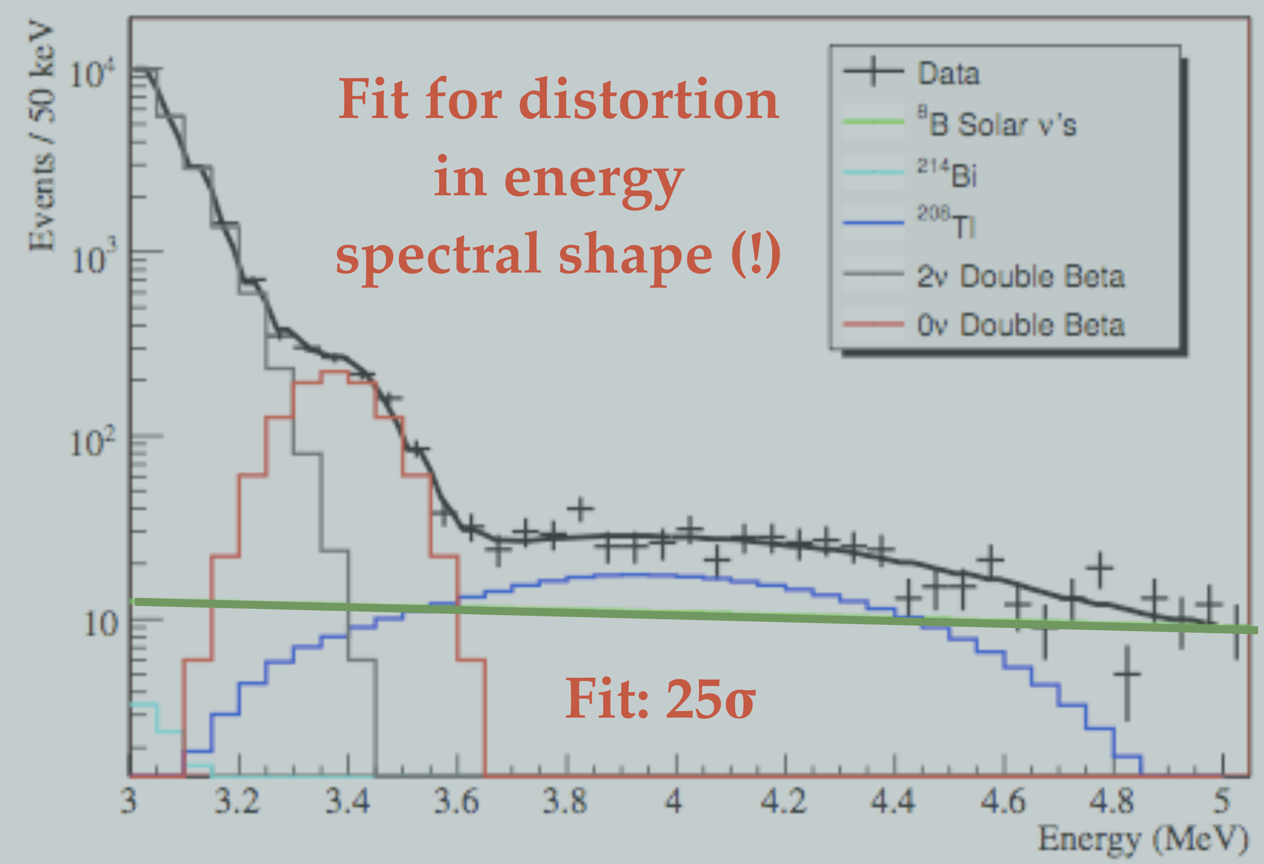
Note! Not counting "a-handful" of events, but fit for distortion in energy spectrum

Simulations assume: 1x10^{-17}g/g ^{242}Th, 1x10^{-18}g/g ^{238}U, gaussian energy distribution, 400 Nhit/MeV, well understood shapes, 1 kt*yr

56 kg Nd <m_ν> = 270meV



500 kg Nd ??

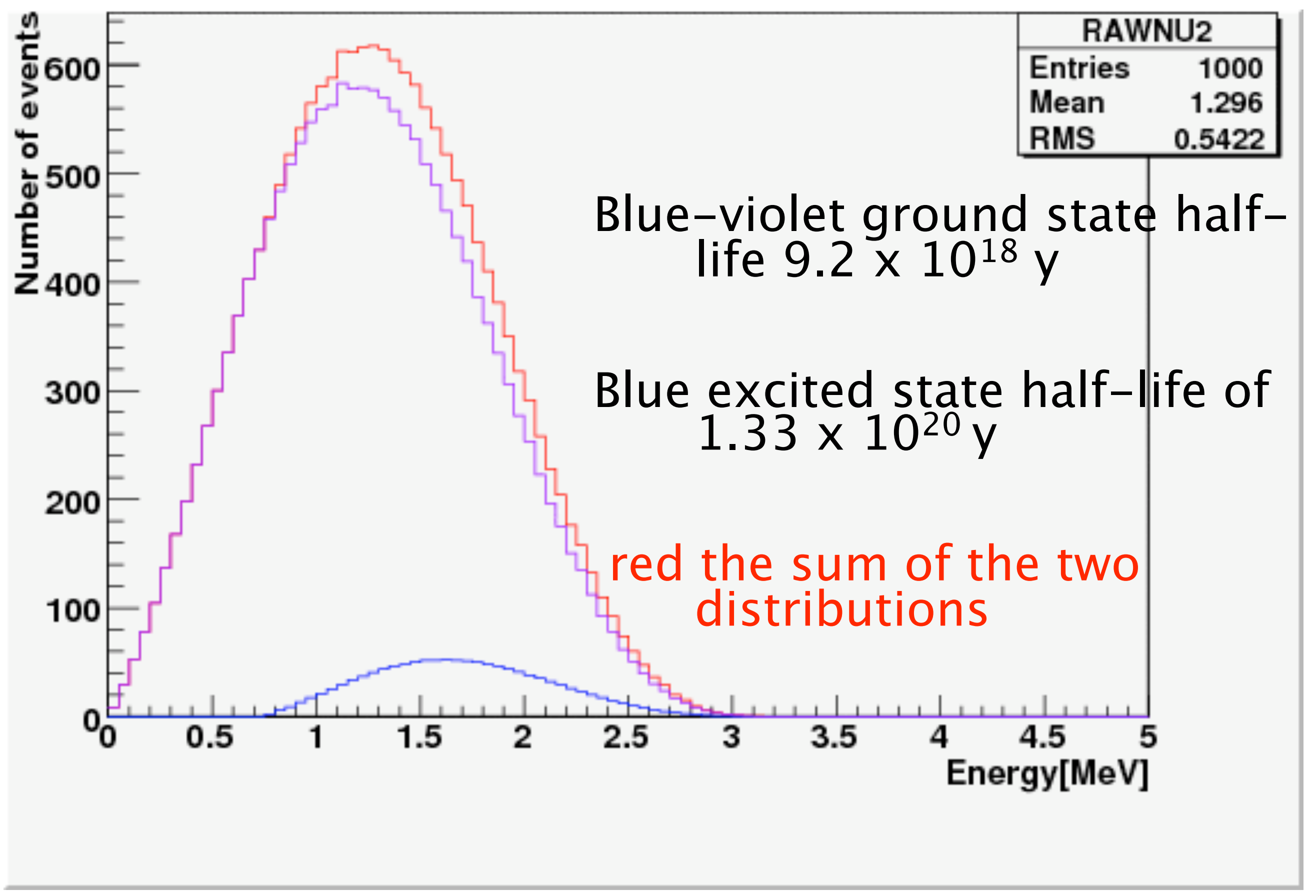


Note! SNO signal ^{8}B is the dominant background

Further sensitivity studies

Including excited states, other Nd isotopes (143-148), external backgrounds, electronic pile-up events

example: excited state



Nd internal backgrounds: Other rare earth components can cause pile-up events and distort the spectrum around the endpoint.

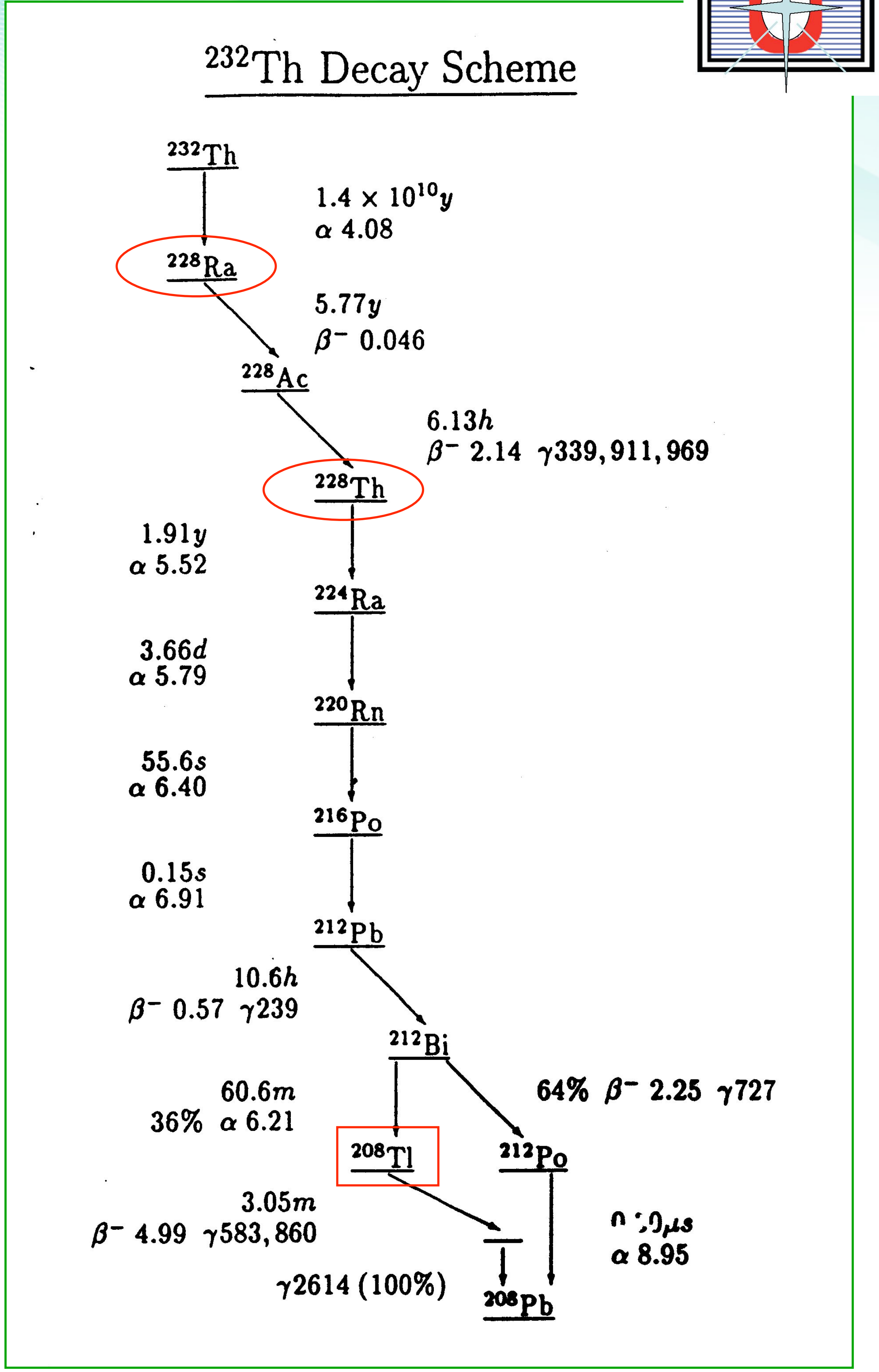
Located Nd that is low in the other rare earth measurements underway at SNOLAB.

Studies underway at Queen's University. Preliminary results show no significant influence on the resulting half life and sensitivity.

Nd radio-purity

- raw $NdCl_3$ salt measurement:
  - ^{228}Th at $32\pm25\times10^{-9}$ g ^{232}Th/gNd
- purification target:
  - ^{228}Th and ^{228}Ra in 10 tonnes of 10% Nd (in form of $NdCl_3$ salt) down to $<1\times10^{-14}$ g ^{232}Th/g Nd
- reduction factor of $>10^6$ required
- recall: SNO purified salted heavy water down to $\sim10^{-15}$ g/g level

Nd purification test at BNL and Queen's University look very promising



Tests at Queen's

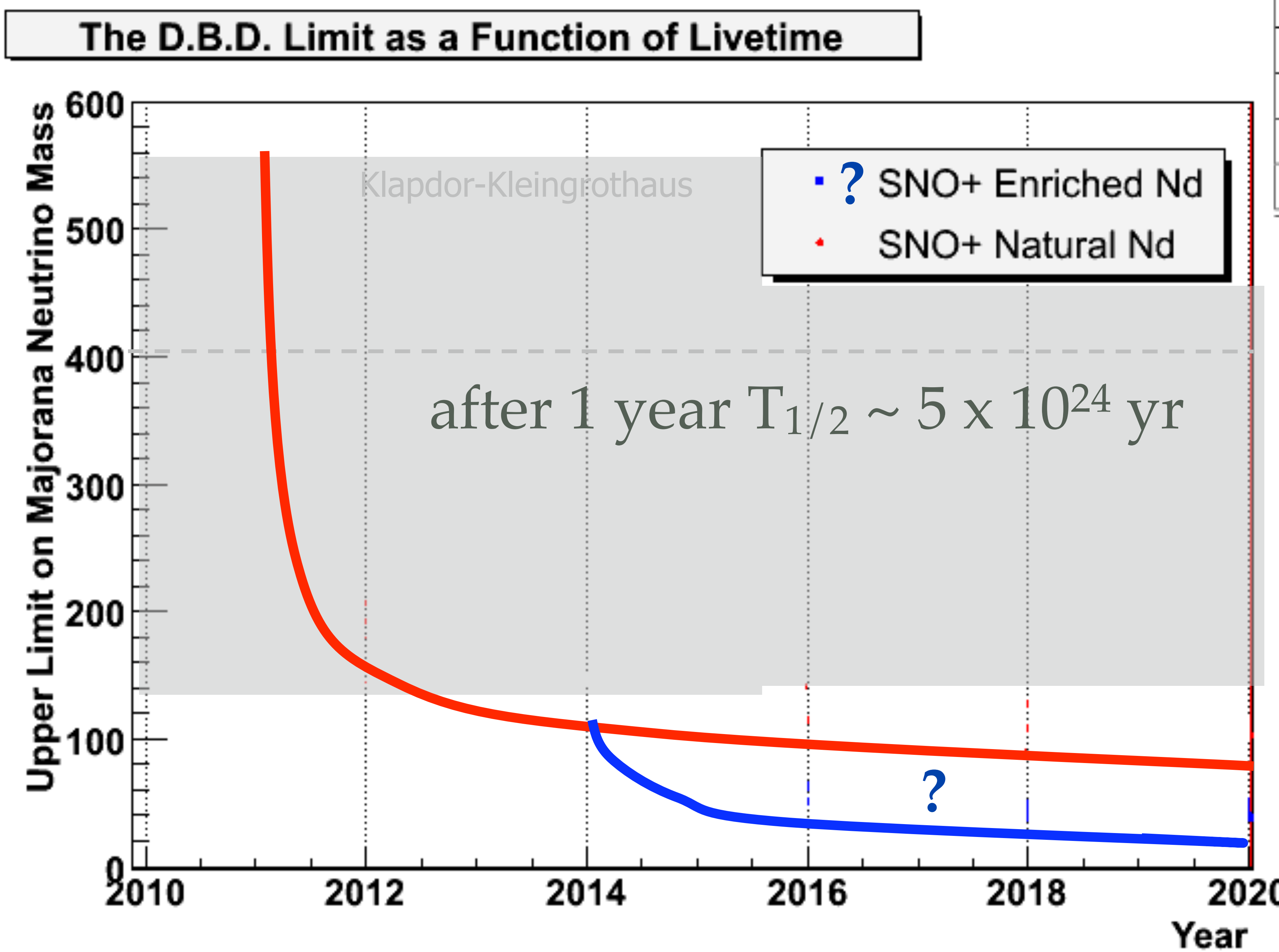
Spike Test Results: Extraction Efficiencies of Th and Ra in 10% $NdCl_3$ using HZrO (as in SNO) and $BaSO_4$

Purification method	Adsorbent Conc	Extraction efficiency 228Th	226Ra
	0.1 mg/g Zr	<5%	<10%
	0.44 mg/g Zr	99.06±0.22%	30.7±5.7%
HZrO mixed-in	**0.82 mg/g Zr**	**99.89±0.02%**	30.1±9.0%
BaSO4 mixed-in	1.0 mg/g Ba	9.5±4.7%	63.4±1.9%
	0.49 mg/g Ba	20.4±4.4%	97.2±0.2%
BaSO4 co-precipitation	**1.39 mg/g Ba**	62.8±2.3%	**99.89±0.03%**

Factor of 1000 purification per pass achieved for both Th and Ra!

SNO+ ββ sensitivity

Using main backgrounds, matrix element:



Calculation Method	$T^{0\nu}_{1/2}$ for $\langle m_\nu \rangle$ = 50meV
QRPA	1.0x10^{25}
RQRPA	2.0x10^{25}
RQRPA	2.0x10^{25}
RQRPA	(2.0 - 4.4)x10^{25}
QRPA	(1.6 - 3.5)x10^{25}
NSM	4.2x10^{26}

spread included

We are looking at possibilities to enrich Nd; AVLIS facility in France is no longer an option.

First SNO+ data

October 2008: inserted scintillator filled acrylic container (bucket) in light water filled acrylic vessel

bucket on source manipulator system

AmBe source mounted

3 different scintillator batches:
LAB + 2g/l PPO
raw, distilled and Nd loaded

GOALS achieved:

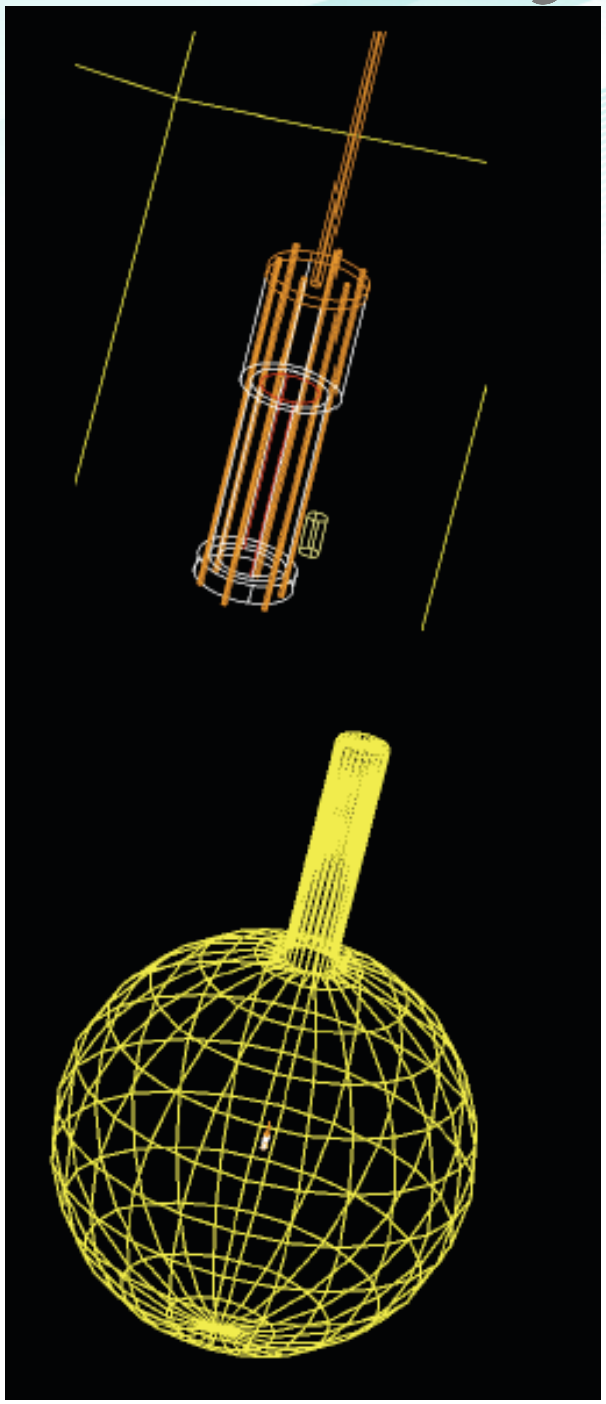
measured optical properties (light yield, birks constant)

Nd loaded scintillator creates enough light - similar light output

Good for simulation work
Comparison to bench top

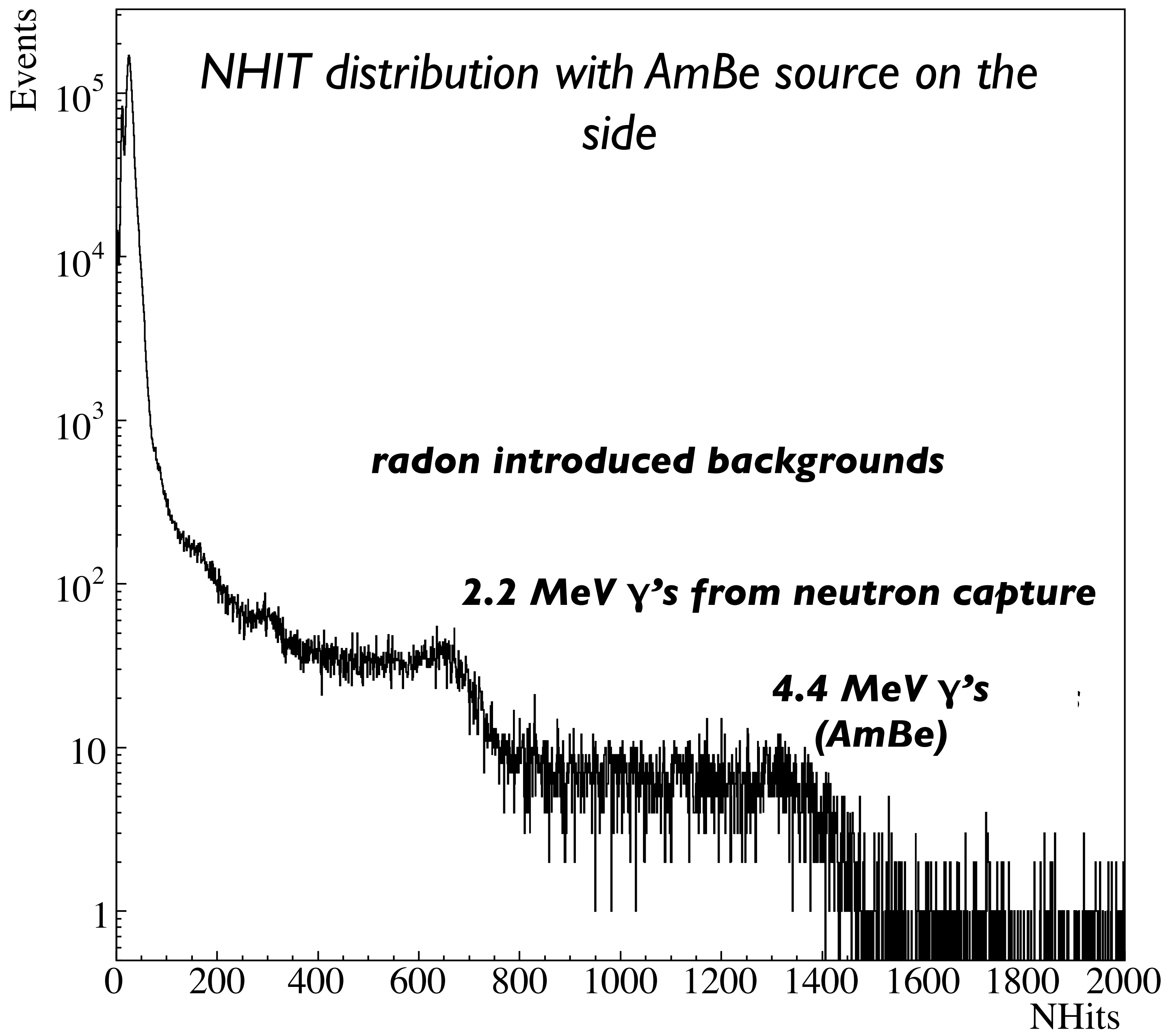
alpha-beta separation

Geometry - Spectrum



simulation: bucket and bucket inside AV

raw data: no cuts, energy ...



Conclusions

- *SNO+ is fully funded*
- *SNO+ has a rich physics program*
- *The transition phase from SNO to SNO+ is well underway*
- *Next steps: Work in the Cavity and AV (2009/2010)*
- *Working on simulations and analysis tools in parallel*
- *Start filling with scintillator in early 2011*

SNO+ collaboration (~70 people):

Canada: U. of Alberta, Laurentian U., Queen's U., SNOLAB (~30)

USA: AASU, BHSU, BNL, UNC, PENN, UW (~20)

Europe: LIP, Dresden, Leeds, Liverpool, Oxford, QMUL, Sussex (~20)

~ EXTRAS ~

Beta and double beta decay

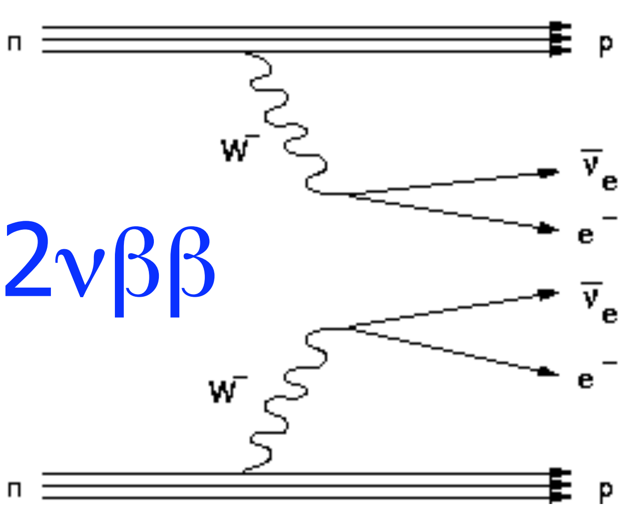
Beta decay

- $(A,Z) \rightarrow (A,Z+1) + e^- + \bar{\nu}_e$ β-decay
- $n \rightarrow p + e^- + \bar{\nu}_e$

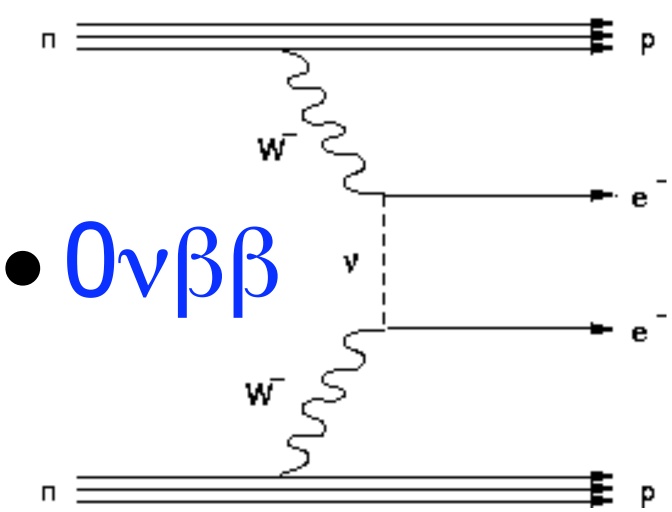
Double Beta decay

- $(A,Z) \rightarrow (A,Z+2) + 2e^- + 2\bar{\nu}_e$ 2νββ
- $(A,Z) \rightarrow (A,Z+2) + 2e^-$ 0νββ

- 2νββ



- 0νββ



ΔL=2 for 0νββ

Majorana pariticle

changing Z by two units while leaving A constant

SNO+ with ^{150}Nd

Endpoint at 3.37 MeV (second highest)

Halflife is (9.7 +/- 0.7 +/- 1.0) 10^{-18} yr (NEMO III)
natural abundance is 5.6%

0.1% loading is optically acceptable and corresponds to 56 kg

Measured quantity -- Halflife

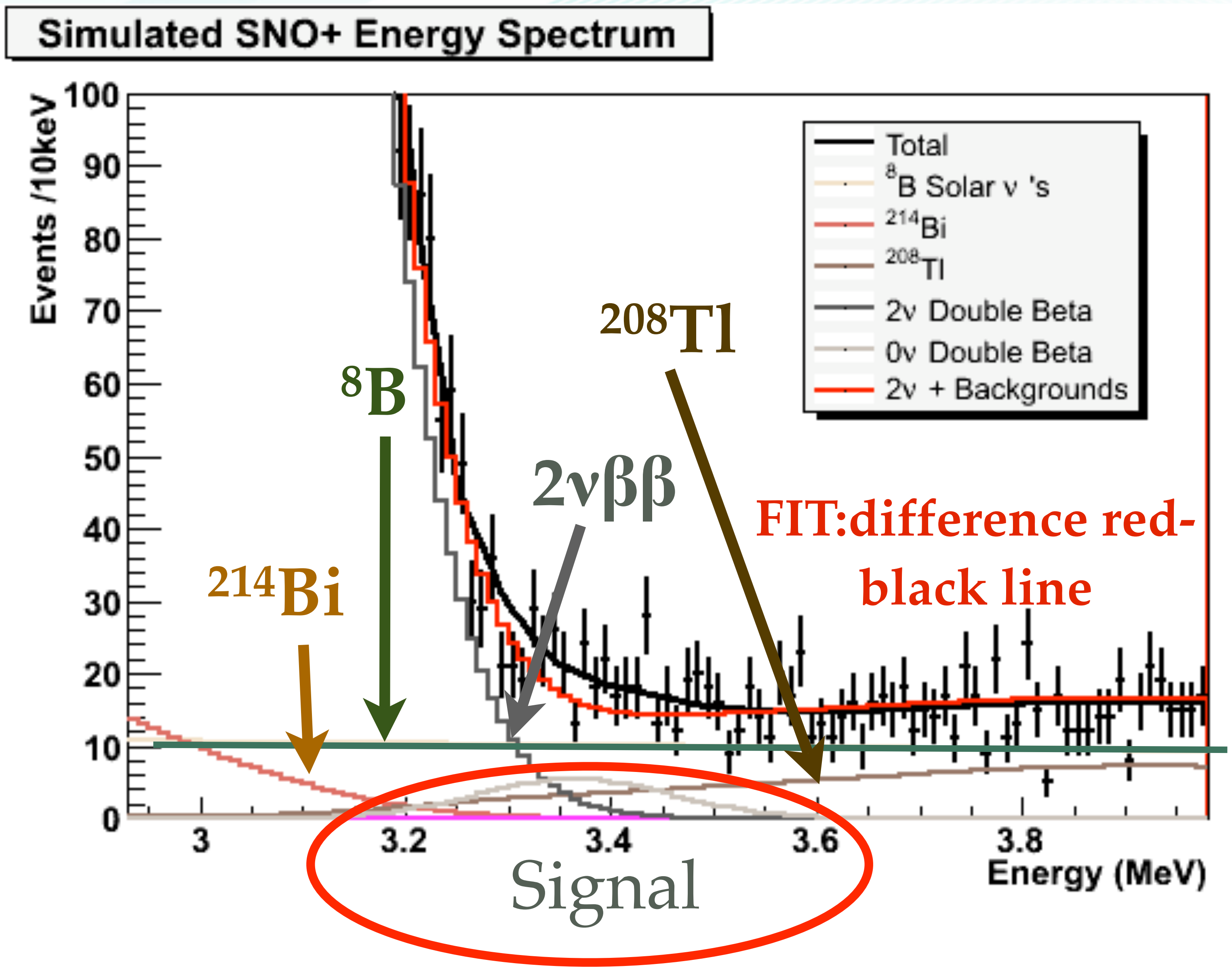
Quantity of interest
Effective Majorana neutrino mass

$$1 / T_{1/2} = PS * NME^{2} * (\langle m_{\nu} \rangle / m_{e})^{2}$$

Phase space integral
calculable

Nuclear transition matrix element (uncertainties from calculation, deformation)

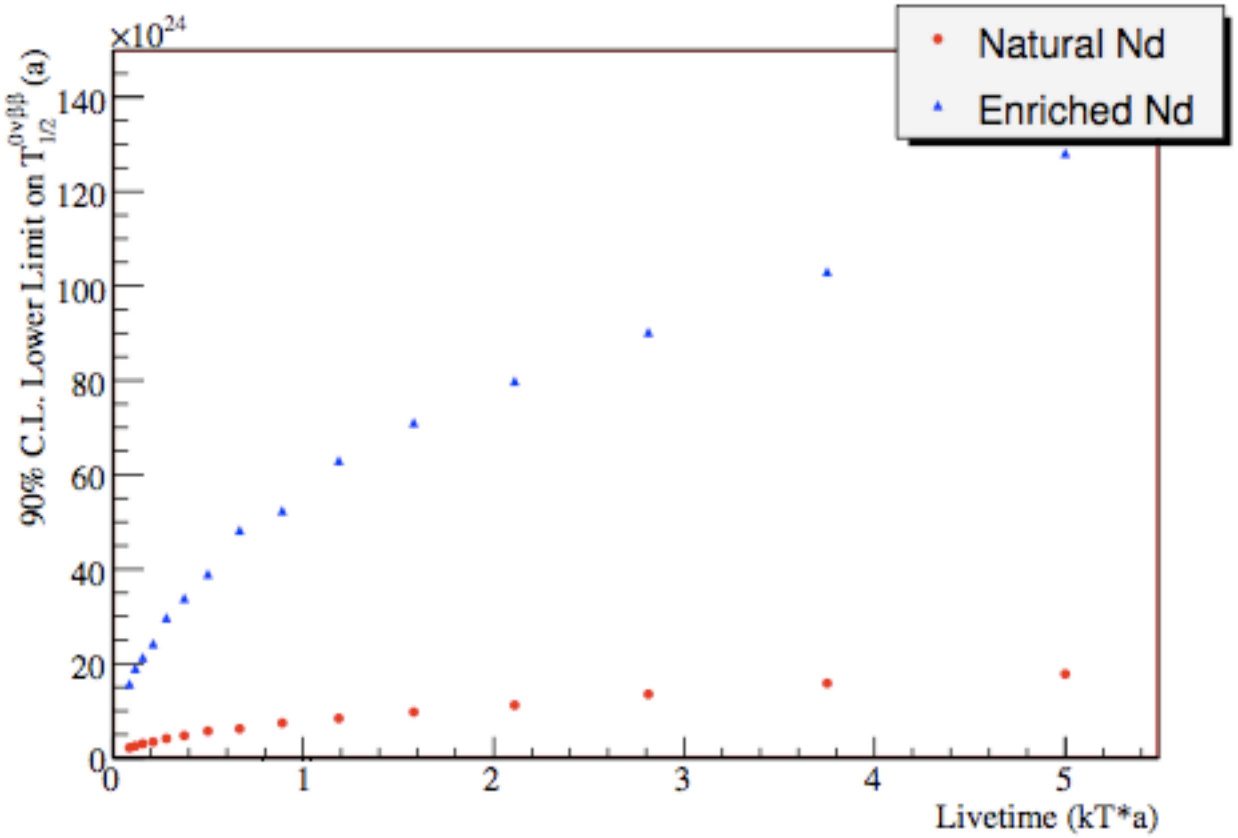
56 kg ^{150}Nd and <m_ν> = 100 meV



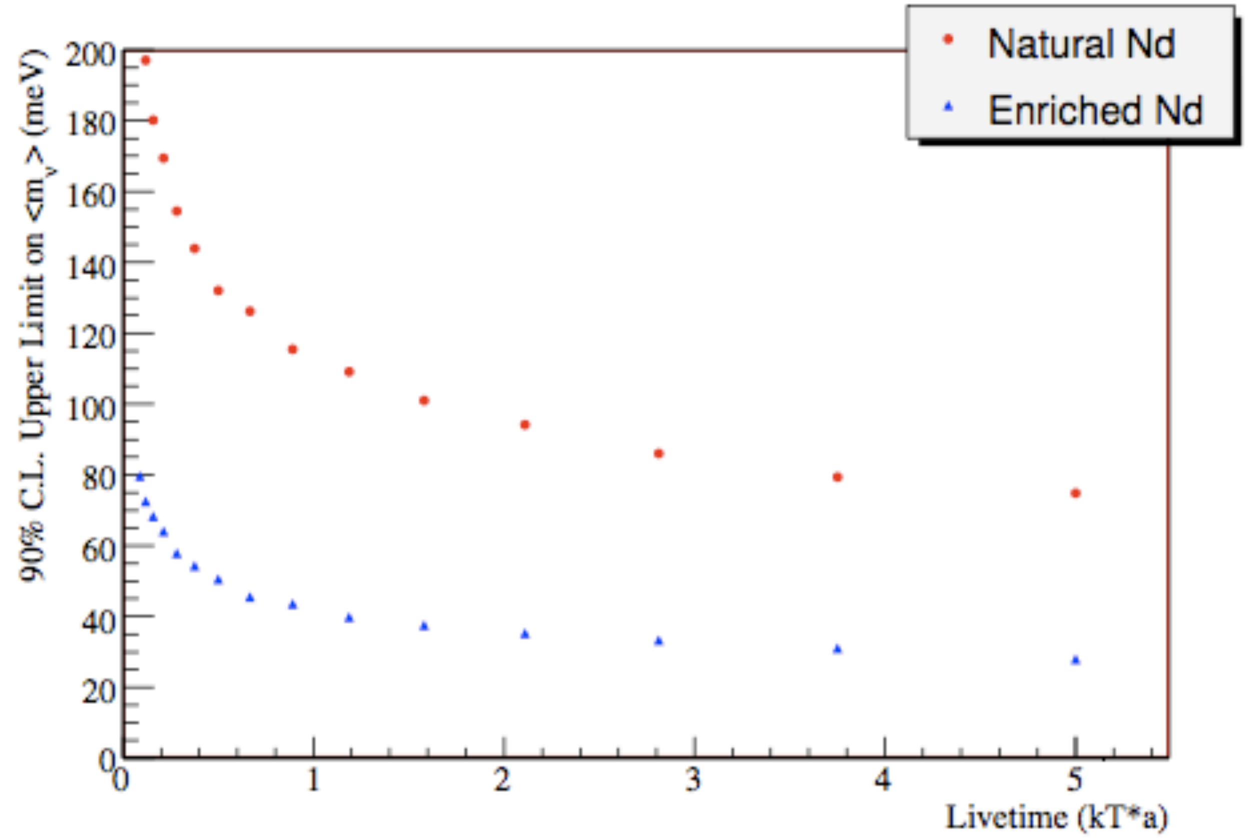
Main backgrounds:
2νββ, ^{8}B, ^{208}Tl, ^{214}Bi

- 6.4% FWHM at Q-value
- 3 years livetime
- U, Th at Borexino levels
- 5σ sensitivity
- note: the dominant background is ^{8}B solar neutrinos!
- ^{214}Bi (from radon) is almost negligible
- ^{212}Po-^{208}Tl tag (3 min) might be used to veto ^{208}Tl backgrounds;
- ^{212}Bi-^{212}Po (300 ns) events constrain the amount of ^{208}Tl

$T_{1/2}$ to $<m_\nu>$



(a) $T_{1/2}^{0\nu}$

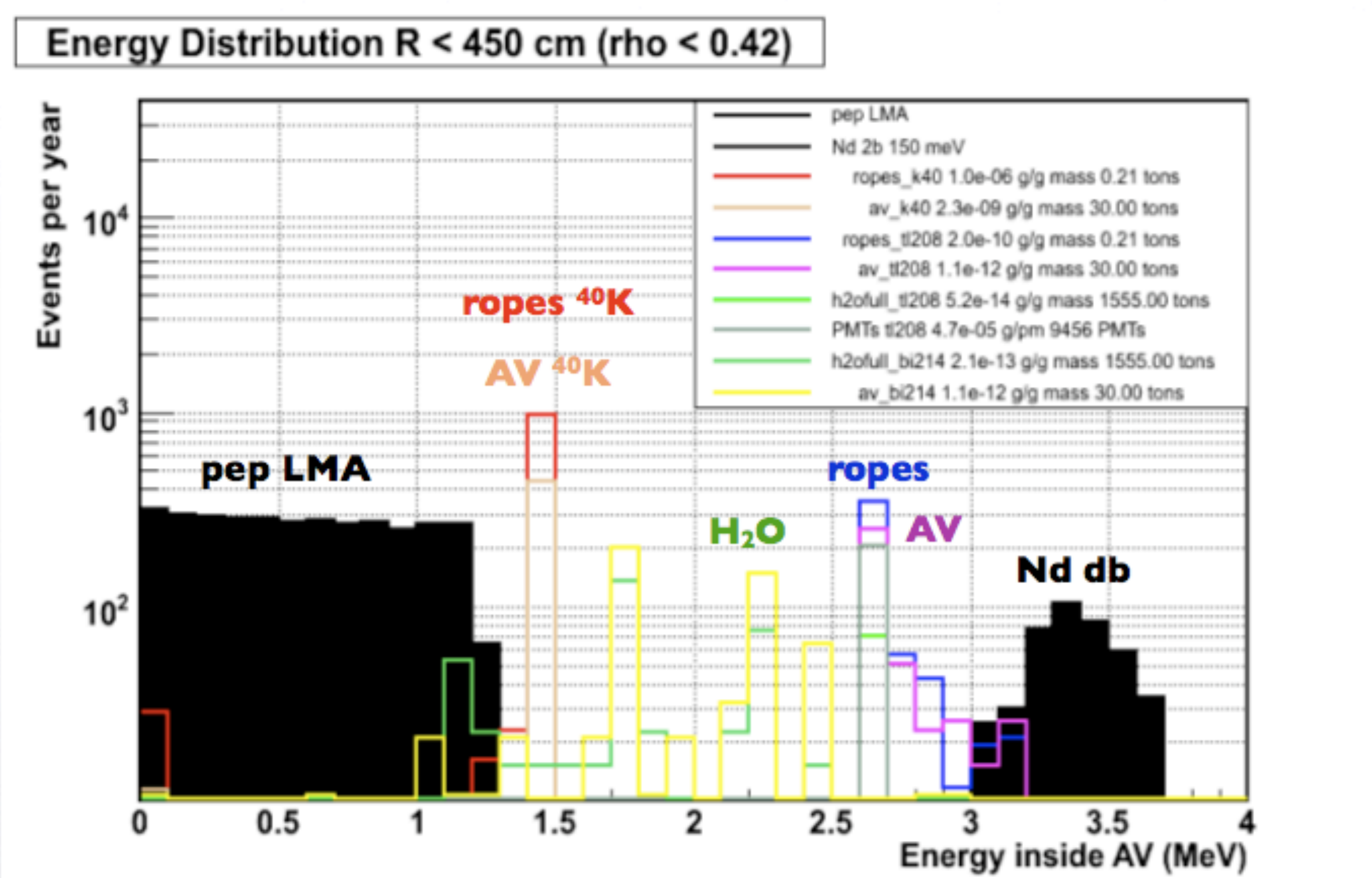


(b) $\langle m_\nu \rangle$

The baseline SNO+ $0\nu\beta\beta$ sensitivity as a function of live time. As SNO+ will have a real mass of 860kg, a fiducial volume cut that rejects events in ∼50% of the active volume, and will likely spend about 25% of its time performing calibrations and other maintenance tasks, it will take approximately three real years of running to accumulate one kT·a of data. Note that the range of variation in the ^{150}Nd matrix element calculations to date admit variation in the $\langle m_\nu \rangle$ curves shown in (b) within a factor of 2 lower and a factor of 3 higher. 1000 fake data sets were thrown and fitted in generating each point on the plots.

External bg for SNO+

Simulations give target values for materials used (!)



Simulations by Jose Maneira - LIP

- Ropes goal !
  - 1ppm nat–K
  - 200 ppt ^{238}U
  - 200 ppt ^{232}Th
- AV given !
  - 2.3 ppb nat–K
  - 1.1 ppt ^{238}U
  - 1.1 ppt ^{232}Th

Need to restrict fiducial volume !