# Progress and plans for the SNO+ double beta decay experiment

Nikolai Tolich

# SNO+

# Collaboration

- Armstrong Atlantic State University
- Black Hills State University
- Brookhaven National Laboratory
- University of California – Berkeley & Lawrence Berkeley National Laboratory
- University of Chicago
- University of North Carolina at Chapel Hill
- University of Pennsylvania
- University of Washington

- LIP Coimbra
- LIP Lisboa

- Oxford University
- Queen Mary, University of London
- University of Liverpool
- University of Sussex

- Laurentian University
- Queen's University
- SNOLAB
- TRIUMF
- University of Alberta

- Technical University of Dresden

# Detector

- SNO heavy water replaced by 780 tonnes of liquid scintillator
- 9000 PMTs
- 1500 + 5300 tons ultra-pure water shielding
- New rope net to hold down the 6m radius acrylic vessel
- 6800' underground in SNOLAB

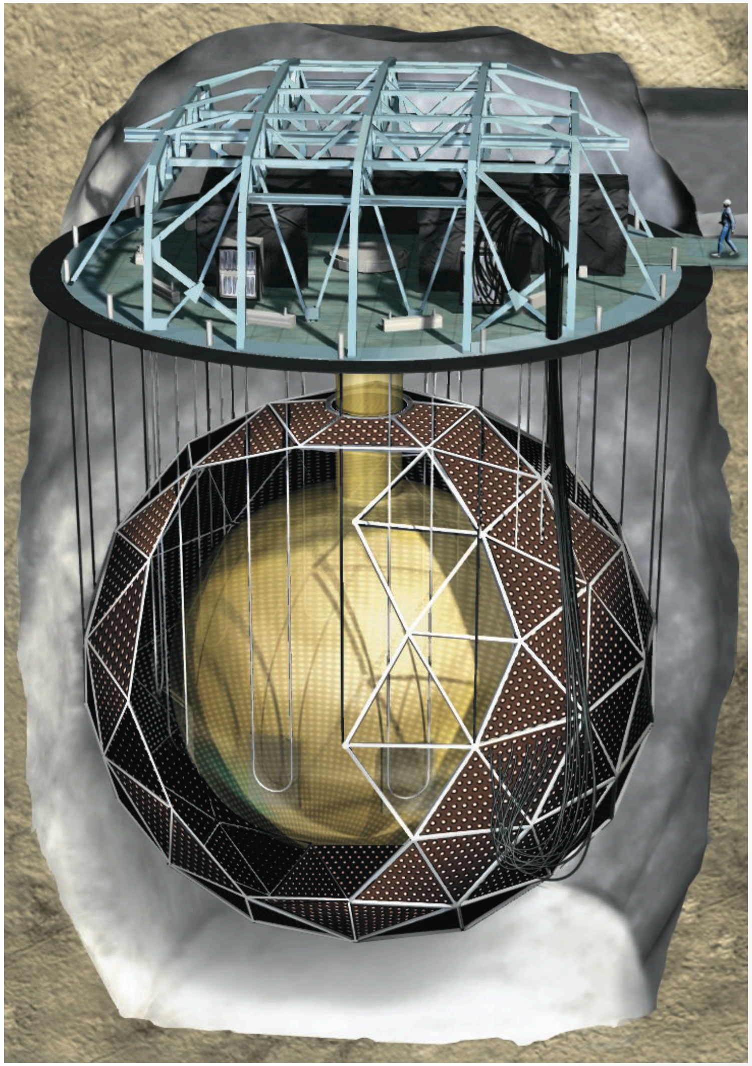
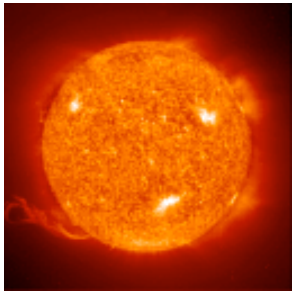
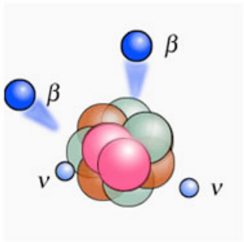


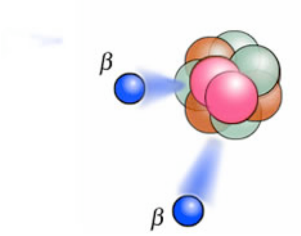
Image courtesy National Geographic

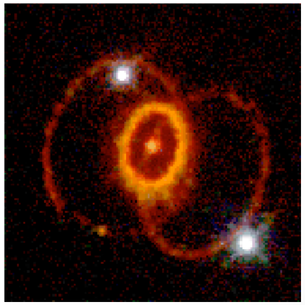
# SNO+ Physics

- Low Energy Solar Neutrinos
- Reactor Antineutrinos
- Geo-Neutrinos
- Supernova Neutrinos
- Neutrinoless Double Beta Decay



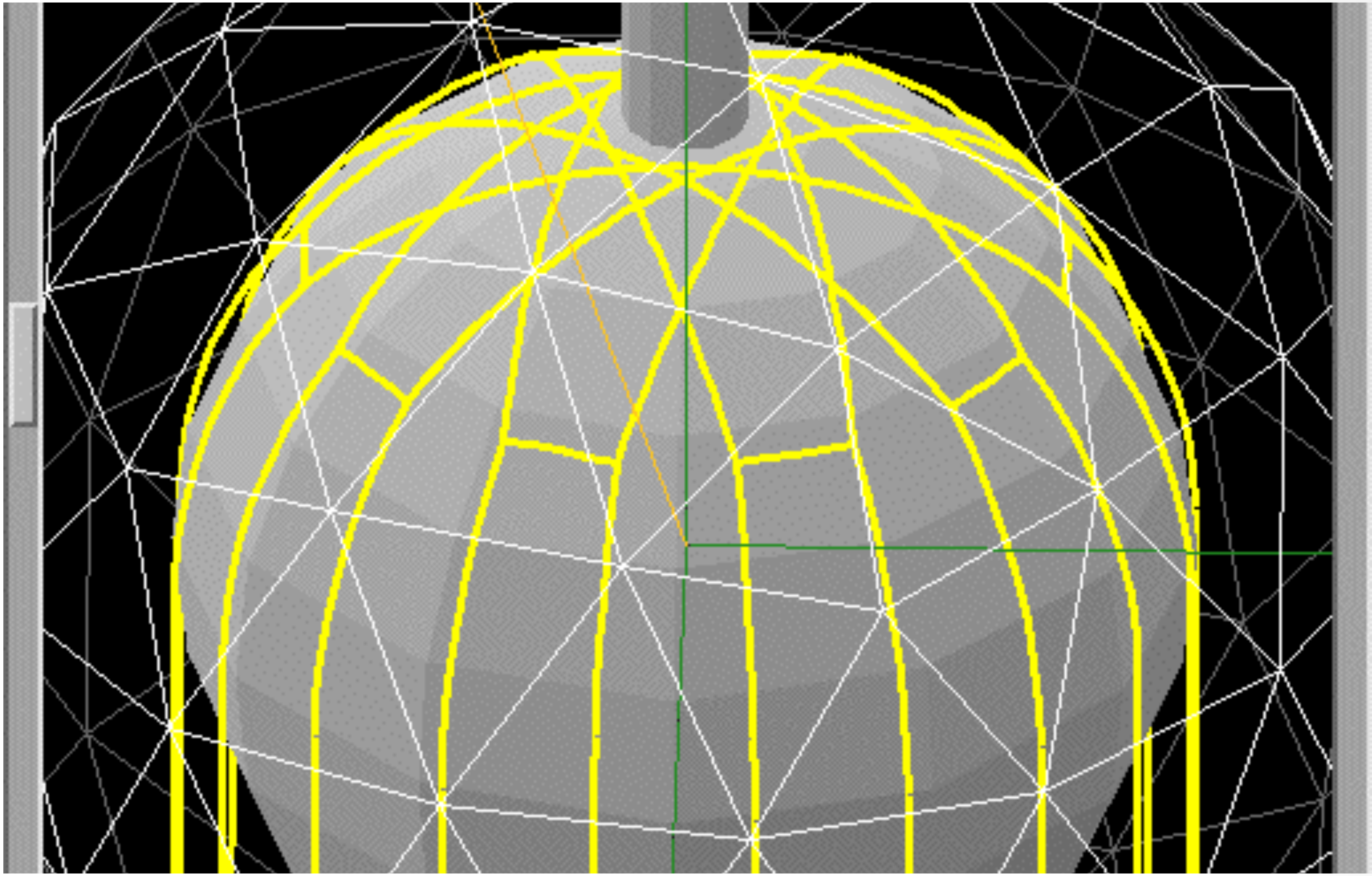


# SNO+ Status and Schedule

- Current: Construction phase
  - Install AV hold-down net
  - Upgrade electronics/DAQ
  - Clean Acrylic Vessel
  - Install scintillator purification system
  - Upgrade calibration/covergas system
- Summer 2013: Begin water fill
  - Buoyant test of hold-down net
  - Study backgrounds and nucleon decay
- Late 2013: Begin scintillator fill
  - Study backgrounds
- 2014: Add DBD isotope
- ~2017: Remove isotope, solar neutrino phase

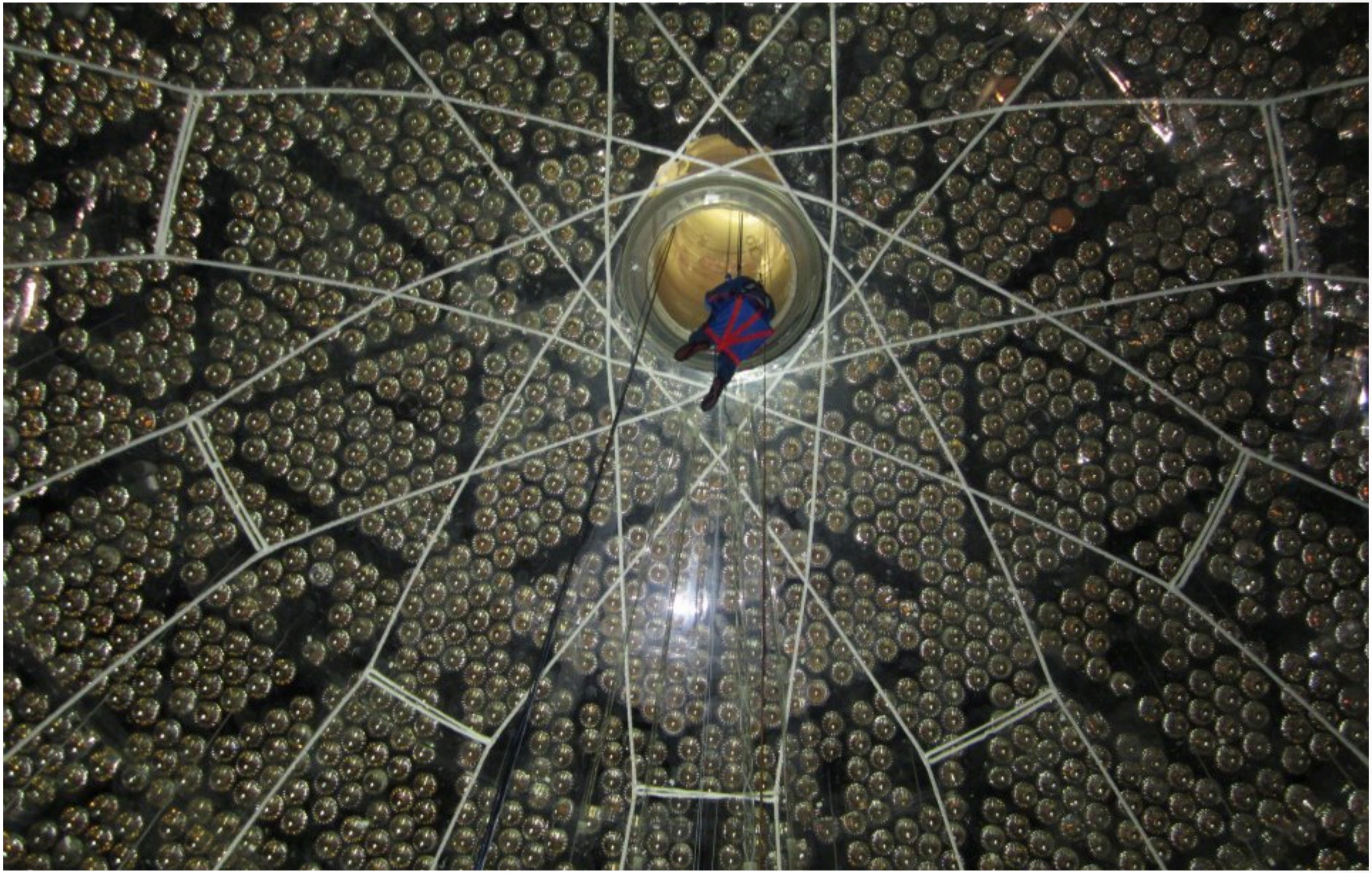


# Hold down net

Concept

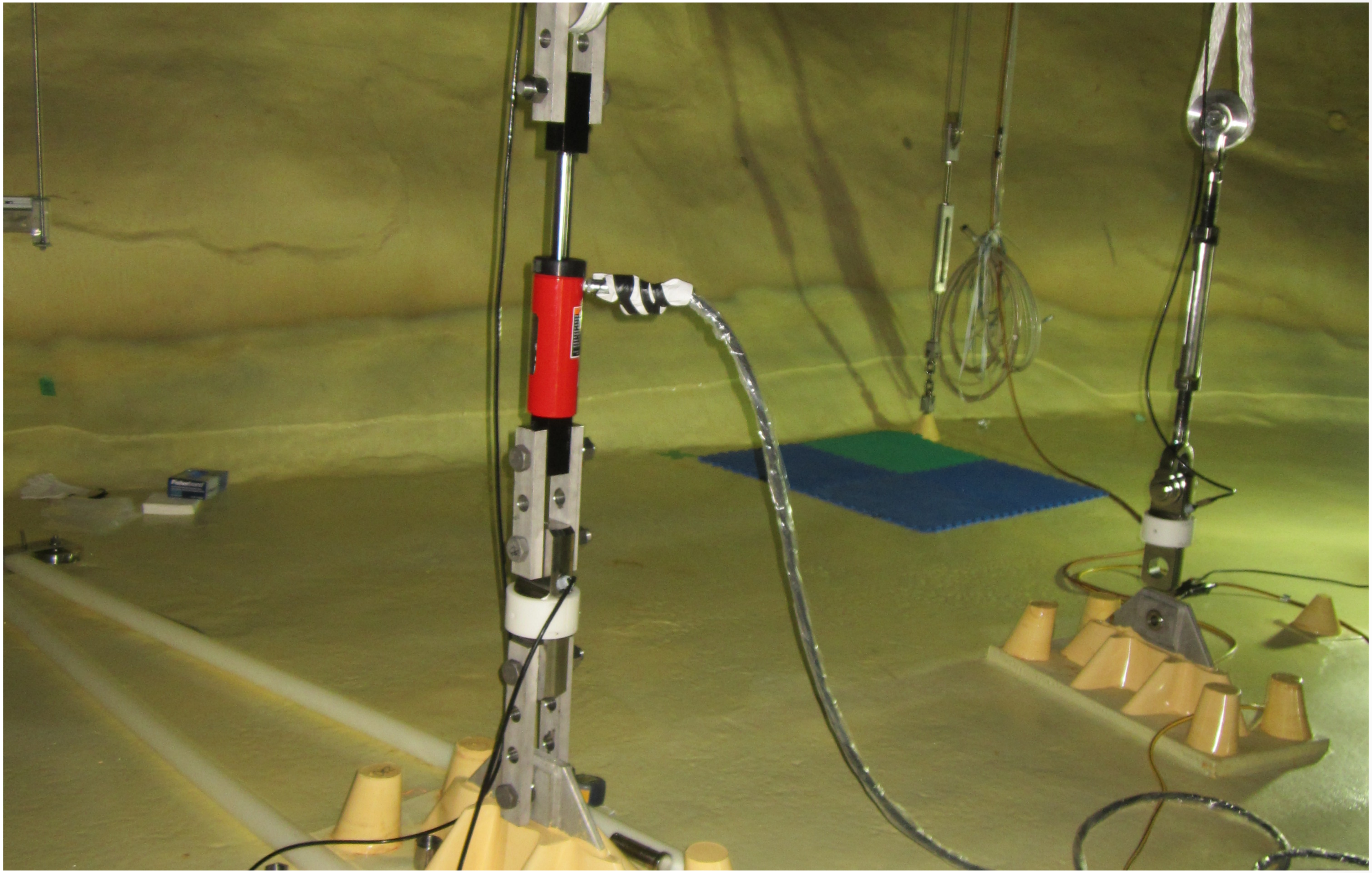
# Hold down net

Anchors and new floor liner



# Hold down net

Net installed



# Hold down net

Pre tensioned

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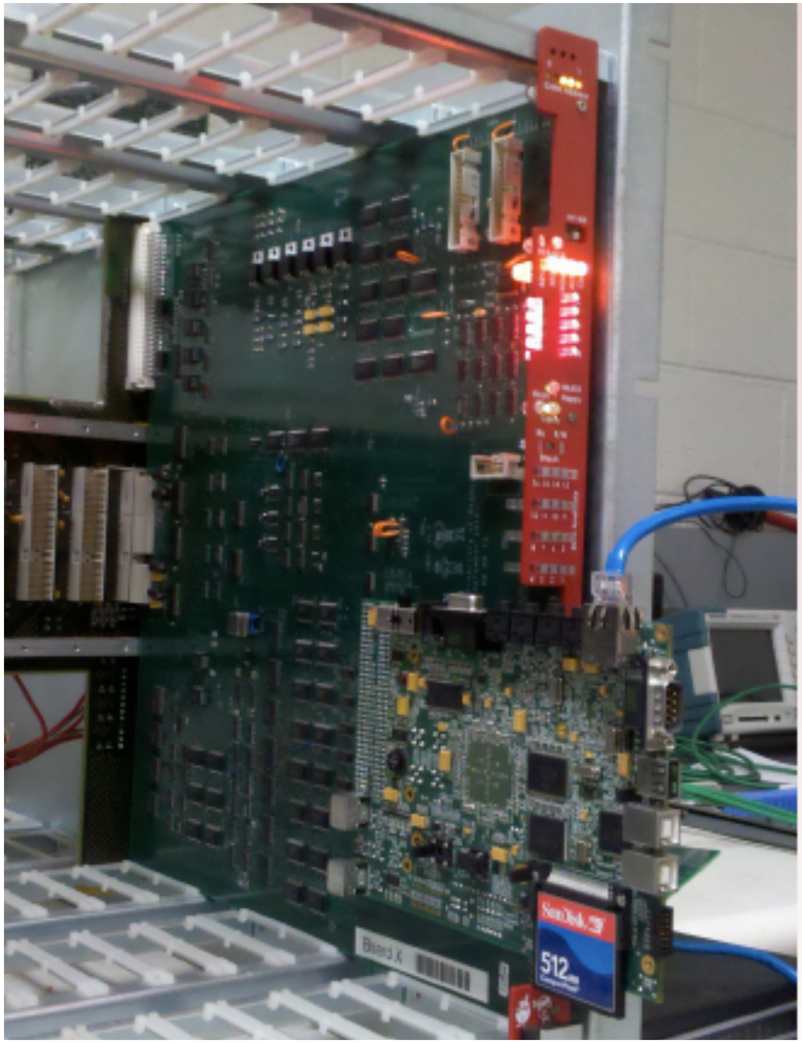
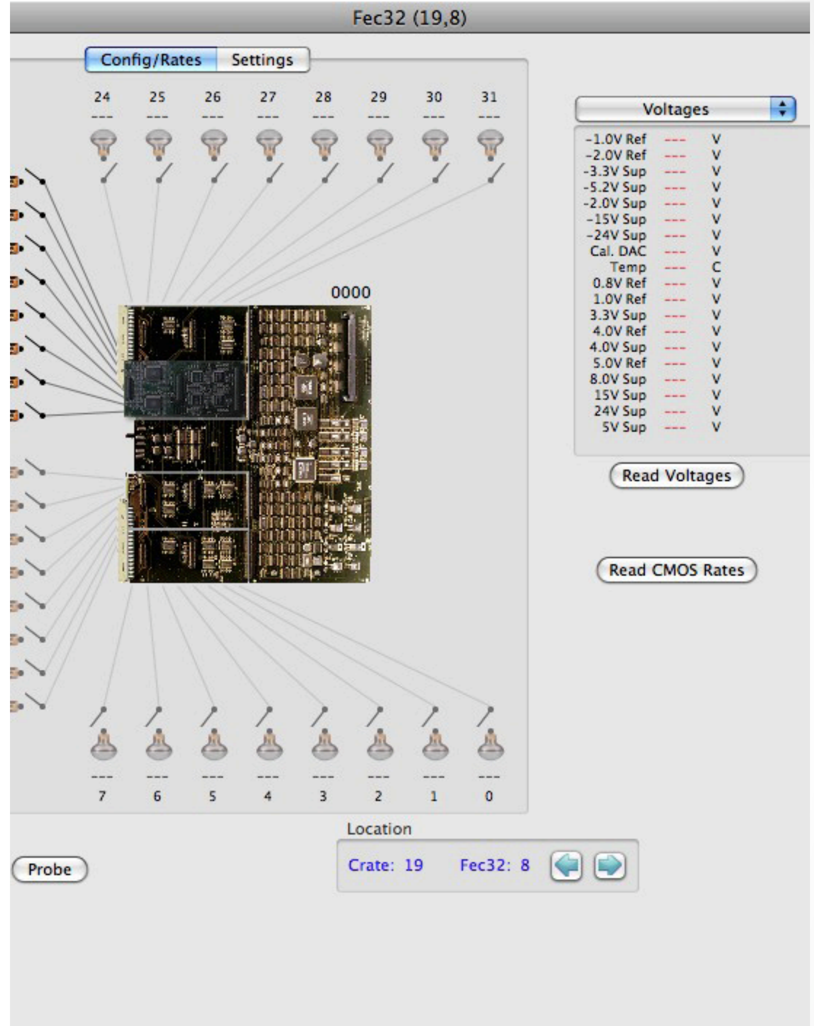
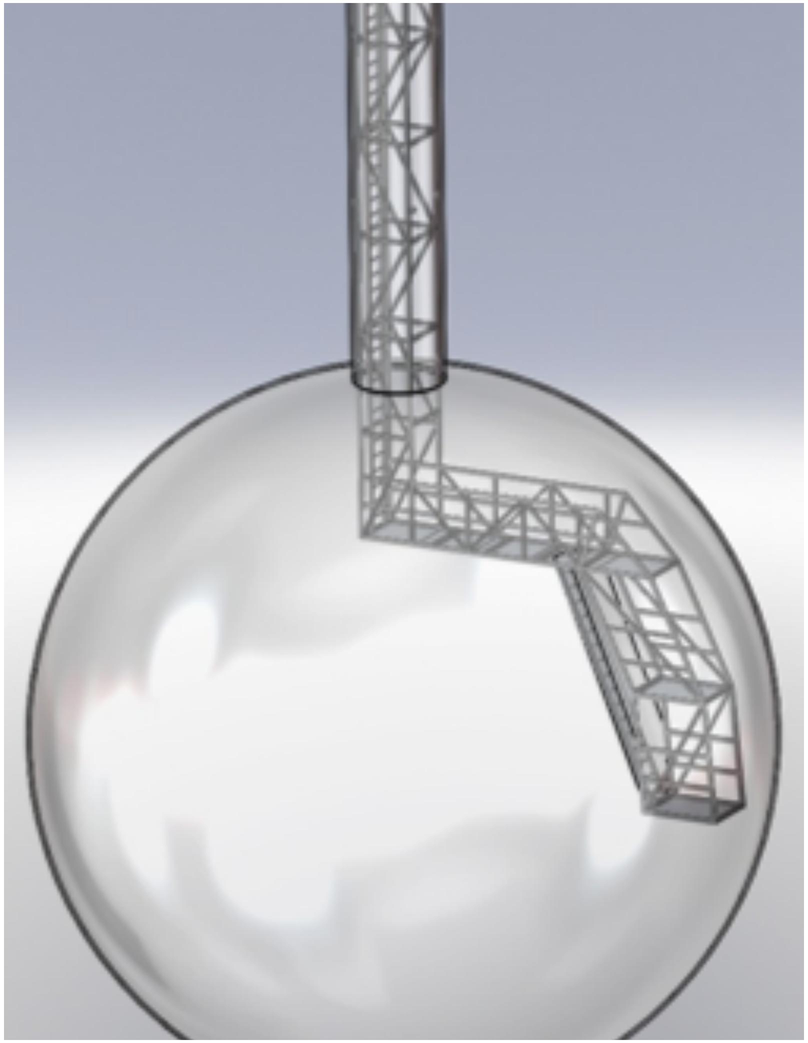


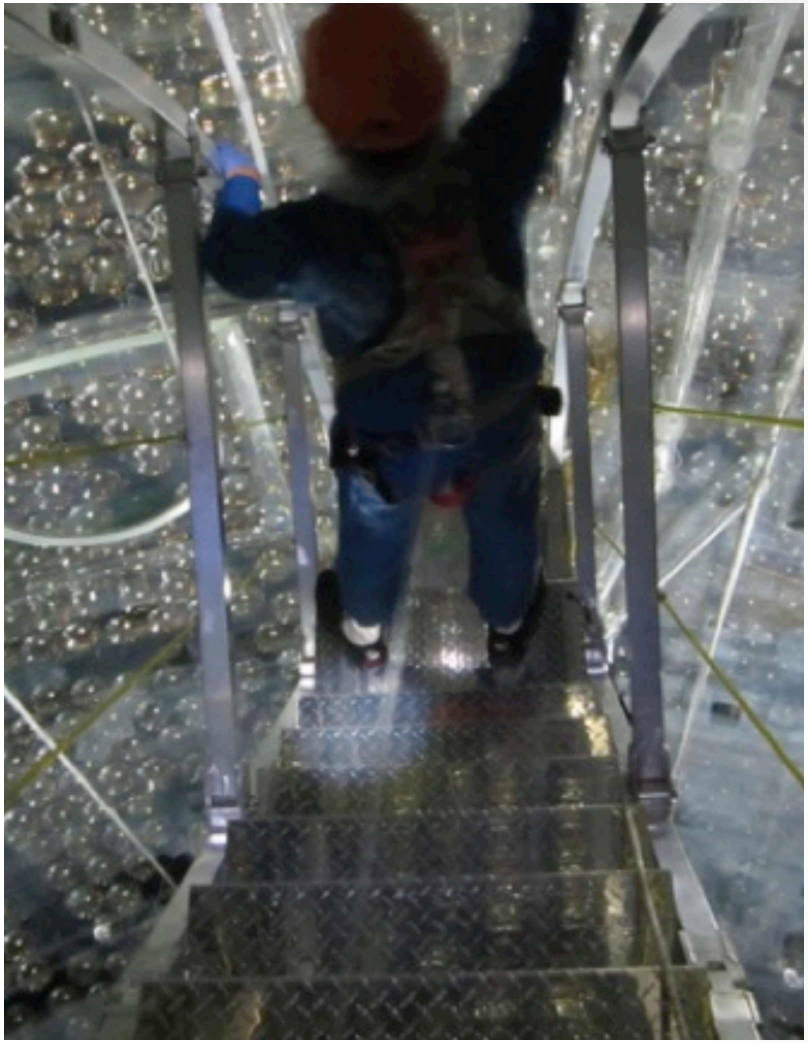



# Electronics/DAQ upgrades

Data rate ~100x greater than in SNO

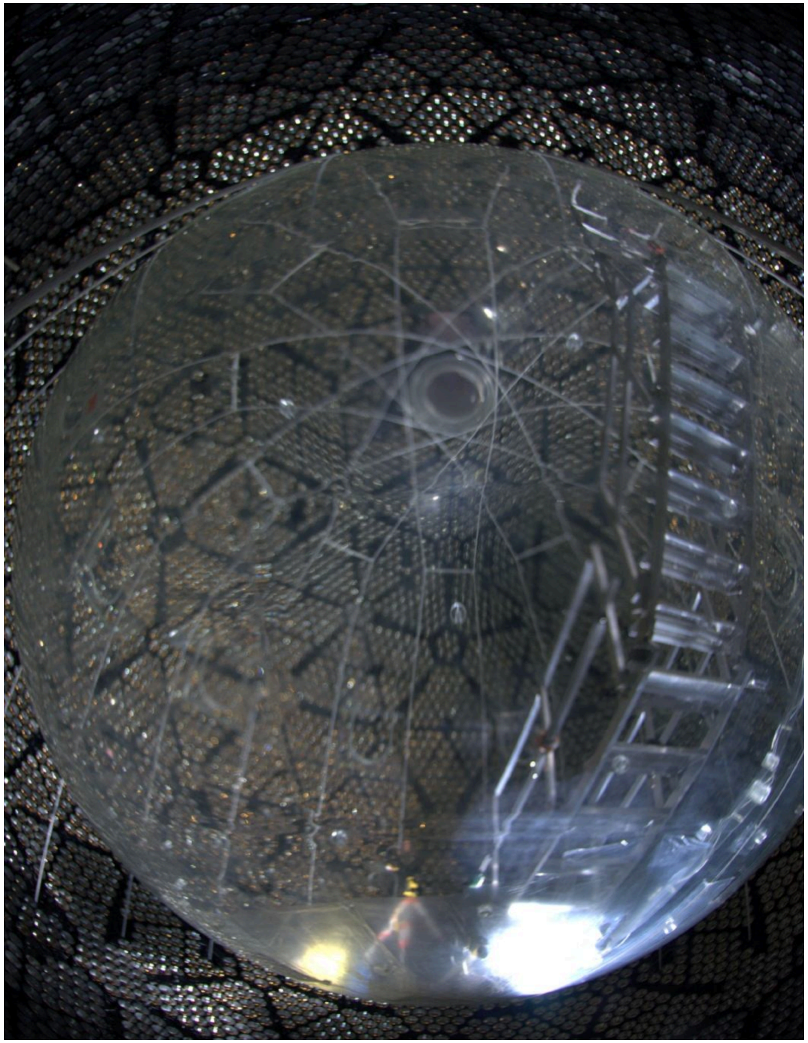
Demonstrated rates >15 MByte/s in air fill data





# Acrylic Vessel Cleaning

Upper hemisphere cleaned by suspended platform



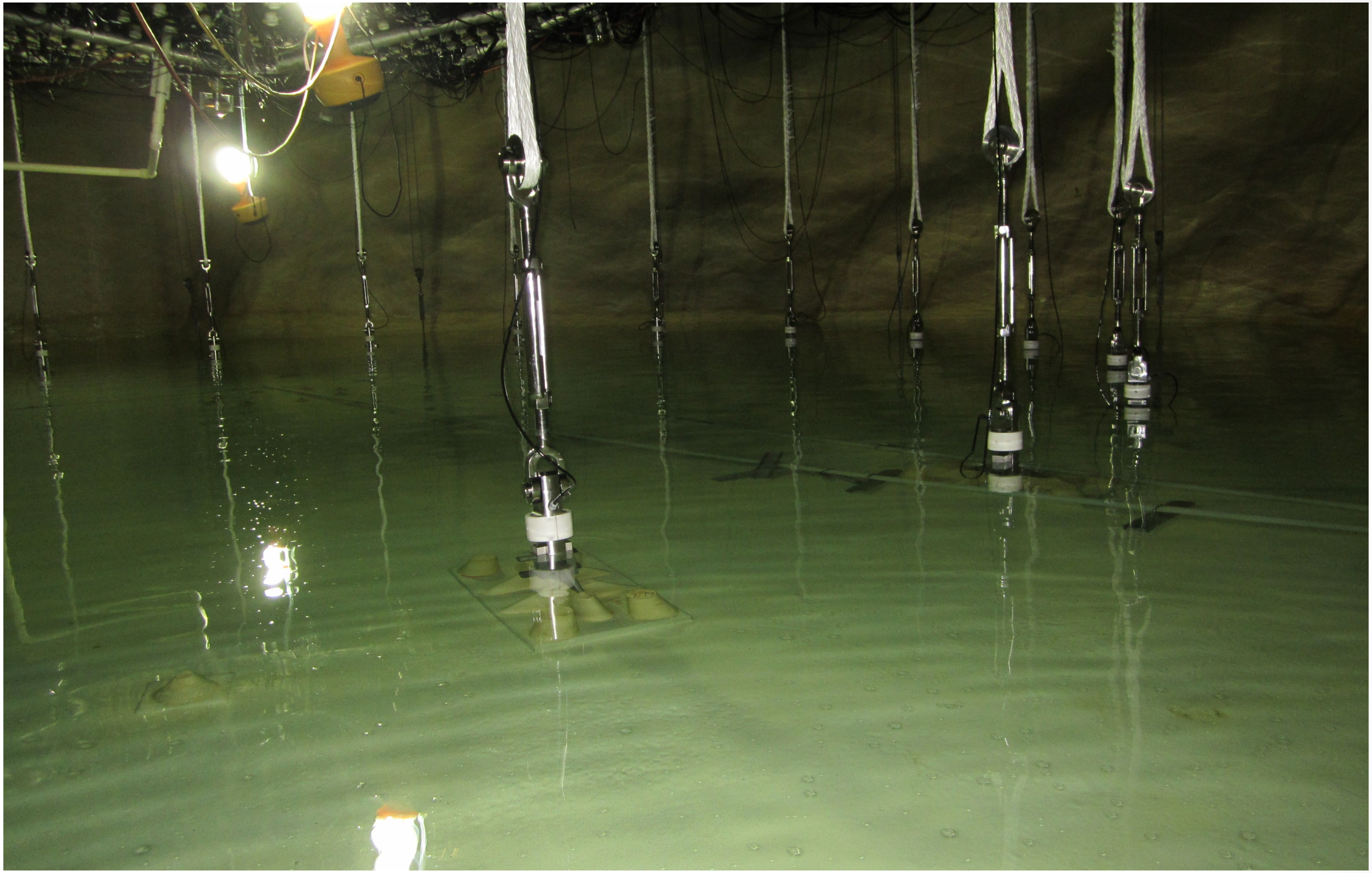
# Acrylic Vessel Cleaning

Lower hemisphere cleaned by rotating ladder

## Scintillator Process System

All process vessels underground at SNOLAB, leak checking underway

Good progress on civil construction



# Water Fill

Currently ~6’ of water in the bottom of cavity

Hold this level to practice circulation and purification, check new floor liner for leaks

# SNO+ Status and Schedule

- Current: Construction phase
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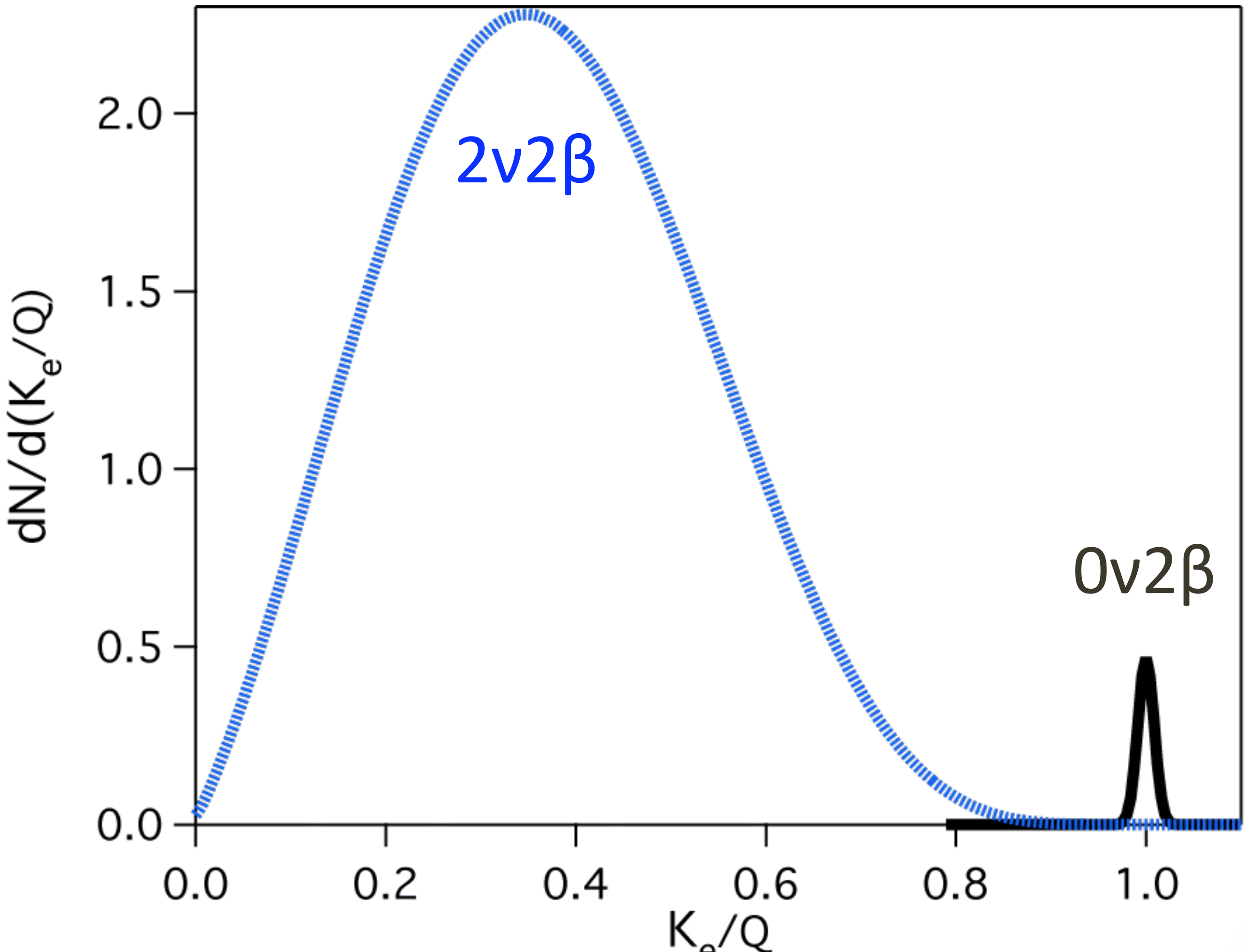
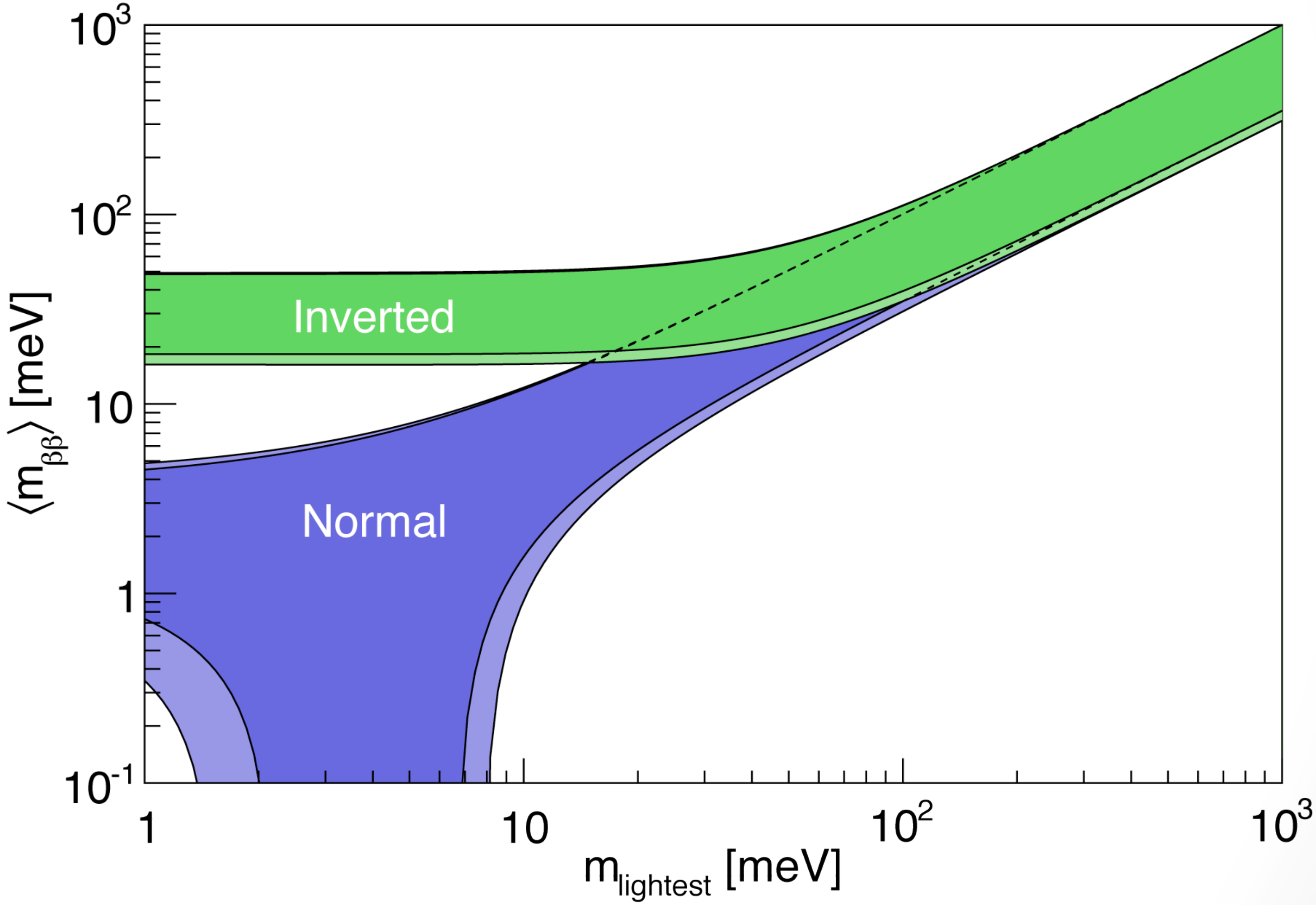
# $0\nu2\beta$

# Double Beta Decay Spectrum




arXiv:hep-ph/0611243

# Desired Sensitivity




Murayama, Schubert

# Sensitivity to $0\nu2\beta$ decay

- The following things are required to obtain good sensitivity:
  1. A short half-life for a given effective neutrino mass
     a. Large phase space factor, and/or
     b. Large matrix element
  2. A low background in your region of interest
     a. High Q value – less natural radioactivity backgrounds
     b. High ratio of $0\nu$ to $2\nu$ or good energy resolution – less $2\nu$ backgrounds
  3. A large number of atoms of your $0\nu2\beta$ decay isotope
     a. Low cost per mol of element
     b. Large number of isotope atoms
        - High natural abundance, or
        - Low cost to enrich, or
        - Low detector cost (detector is source), or
        - Detector unaffected by large amounts of element (source in detector)

# $0\nu2\beta$ isotopes

| | Part of 3b | | 1, 3 | | 2a | 2b |
|---|---|---|---|---|---|---|
| **Isotope** | **Abun. %** | **Half-life ×10$^{29}$ yr (2.5 meV)** | **element cost* ($M)** | **enriched cost*,** ($M)** | **Q (MeV)** | **0ν/2ν ×10$^{-8}$** |
| $^{48}$Ca | 0.19 | 2.70 | **2.6** | 622 | **4.27** | 0.016 |
| $^{76}$Ge | 7.8 | 3.18 | 1221 | 1164 | 2.04 | **0.55** |
| $^{82}$Se | 9.2 | 1.05 | **39** | 416 | 3.00 | 0.092 |
| $^{96}$Zr | 2.8 | 0.93 | **27** | 427 | **3.35** | 0.025 |
| $^{100}$Mo | 9.6 | 0.51 | **4.4** | 244 | 3.04 | 0.014 |
| $^{110}$Pd | 11.8 | 0.98 | 5078 | 521 | 2.00 | 0.16 |
| $^{116}$Cd | 7.6 | 0.79 | **0.81** | 441 | 2.81 | 0.035 |
| $^{124}$Sn | 5.6 | 1.38 | **22** | 825 | 2.29 | 0.072 |
| $^{130}$Te | 34.5 | 0.75 | **24** | 471 | 2.53 | **0.92** |
| $^{136}$Xe | 8.9 | 1.40 | 513 | 914 | 2.46 | **1.51** |
| $^{150}$Nd | 5.6 | 0.37 | **11** | 269 | **3.37** | 0.024 |

* for 1 event/yr
** assuming $20/g

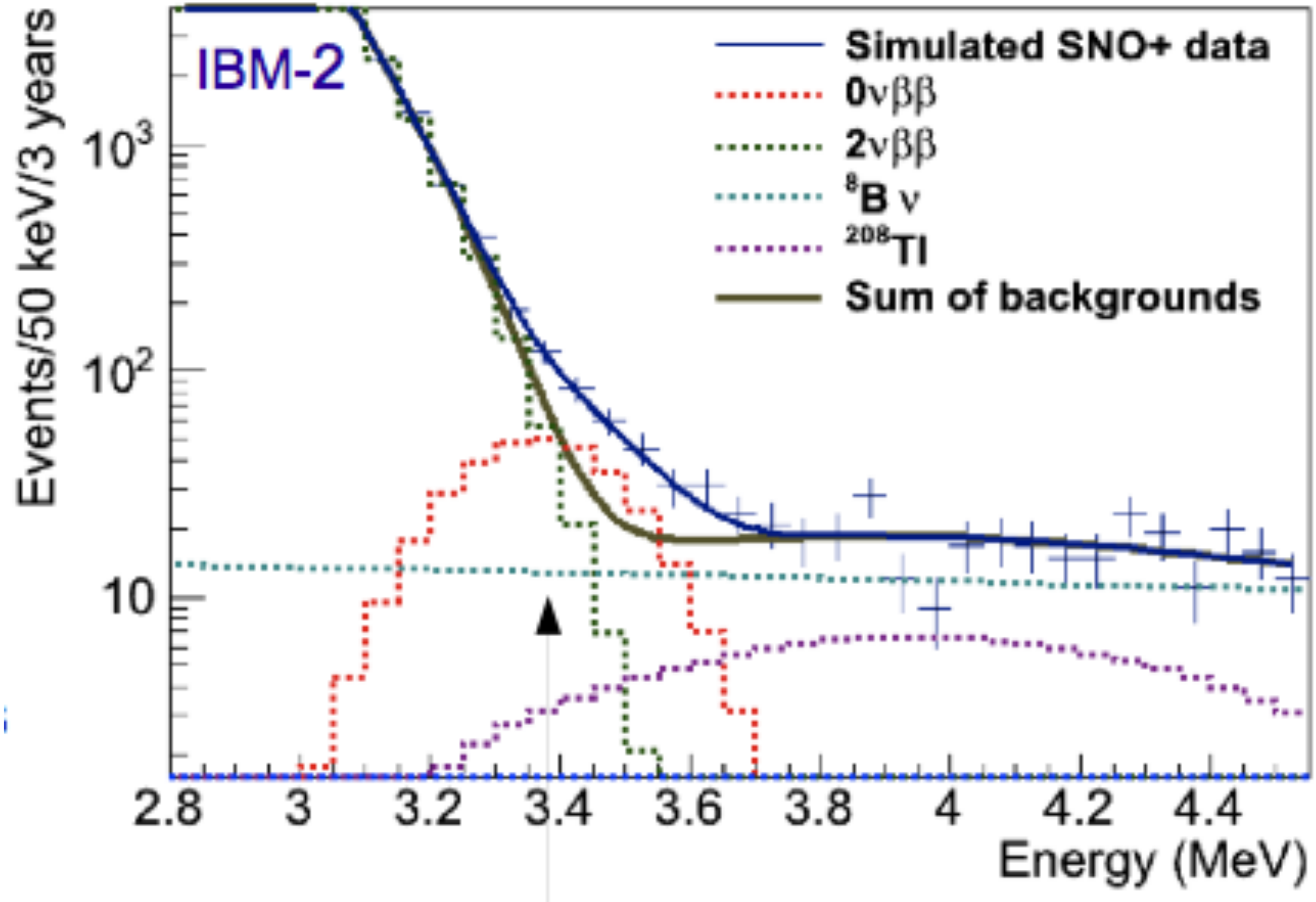
Biller, S. D., PRD **87**, 071301(R) (2013)

# SNO+ $0\nu2\beta$ isotope

# $^{150}$Nd – previous isotope

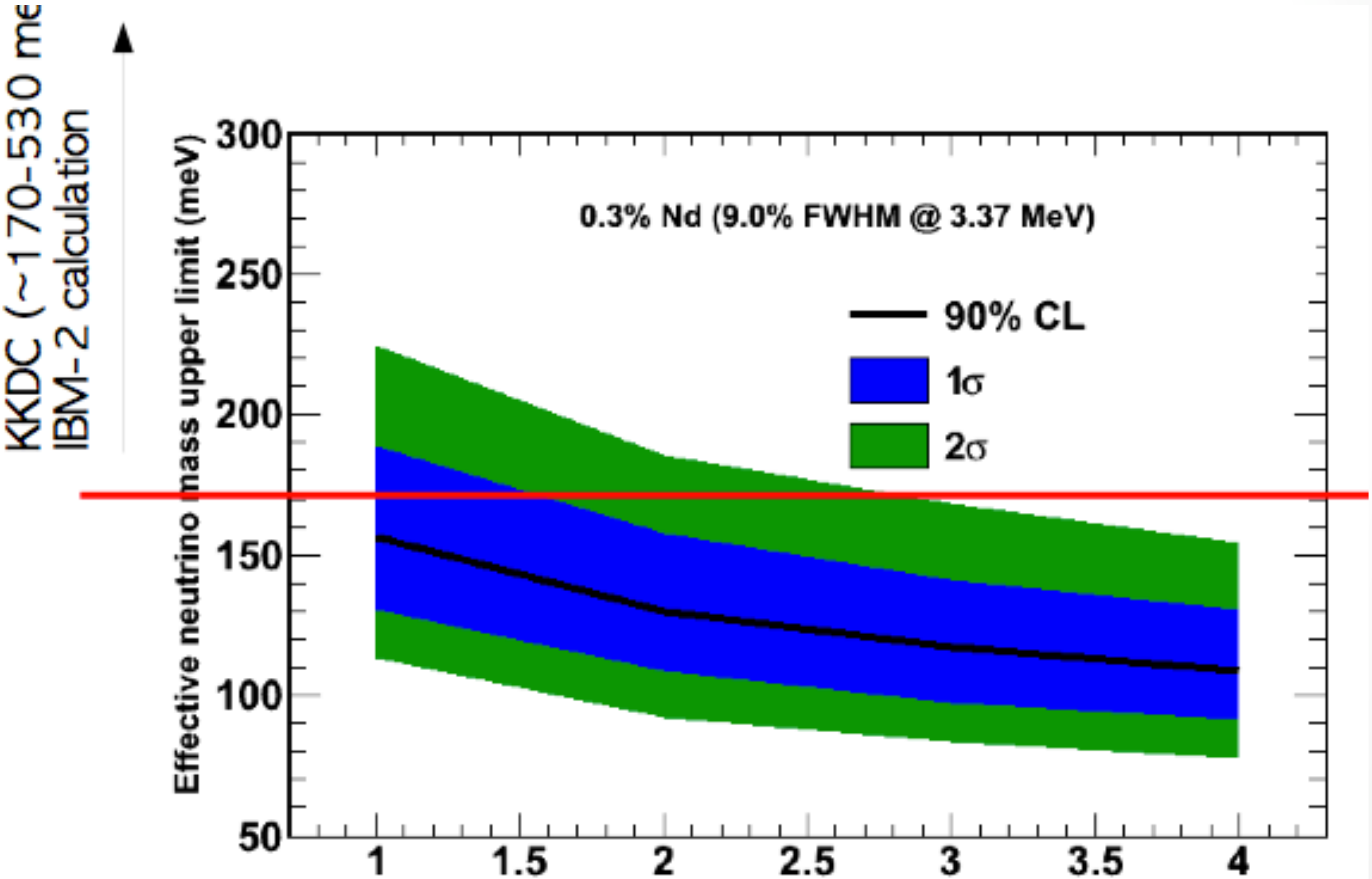
- Loading Nd into the SNO+ scintillator gives 140kg $^{150}$Nd at 0.3% loading of natural neodymium (limited by optics)
- Advantages
  - Cost effective (1 and 3a)
  - High Q value (2a)
- Disadvantages
  - Low 0*v*/2*v* (2b)
  - Relatively low abundance, no enrichment facility, $Nd^{3+}$ affects light output (3b)

# Expected Spectrum




2.4 live-years of data, 50% fiducial volume

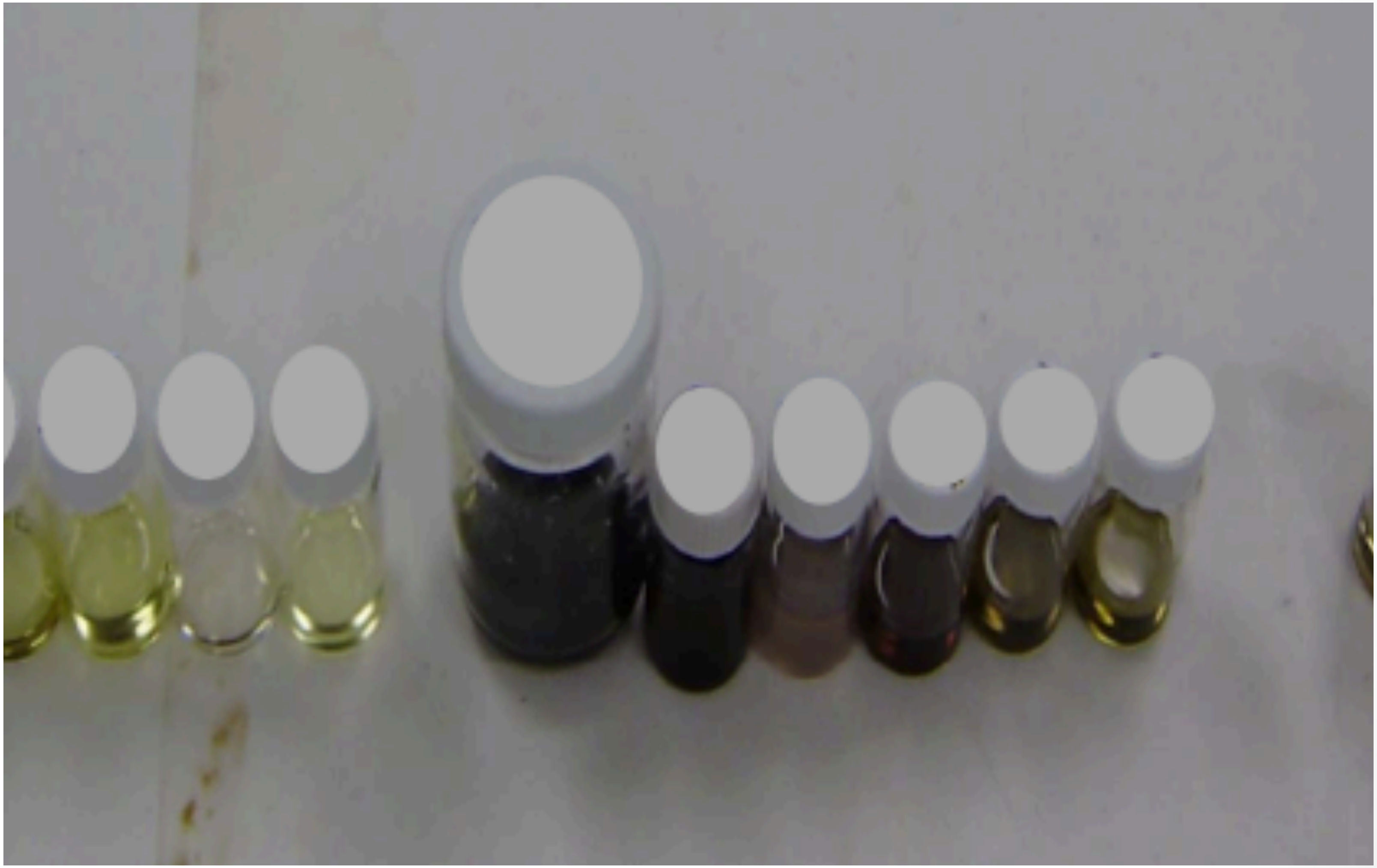
# Expected Sensitivity



# $^{130}$Te – current isotope

- Advantages
  - Cost effective (1 and 3a)
  - High 0*v*/2*v* (2b)
  - Relatively high abundance and light output not obviously affected by isotope of interest (3b)
- Disadvantages
  - Low Q value (2a)

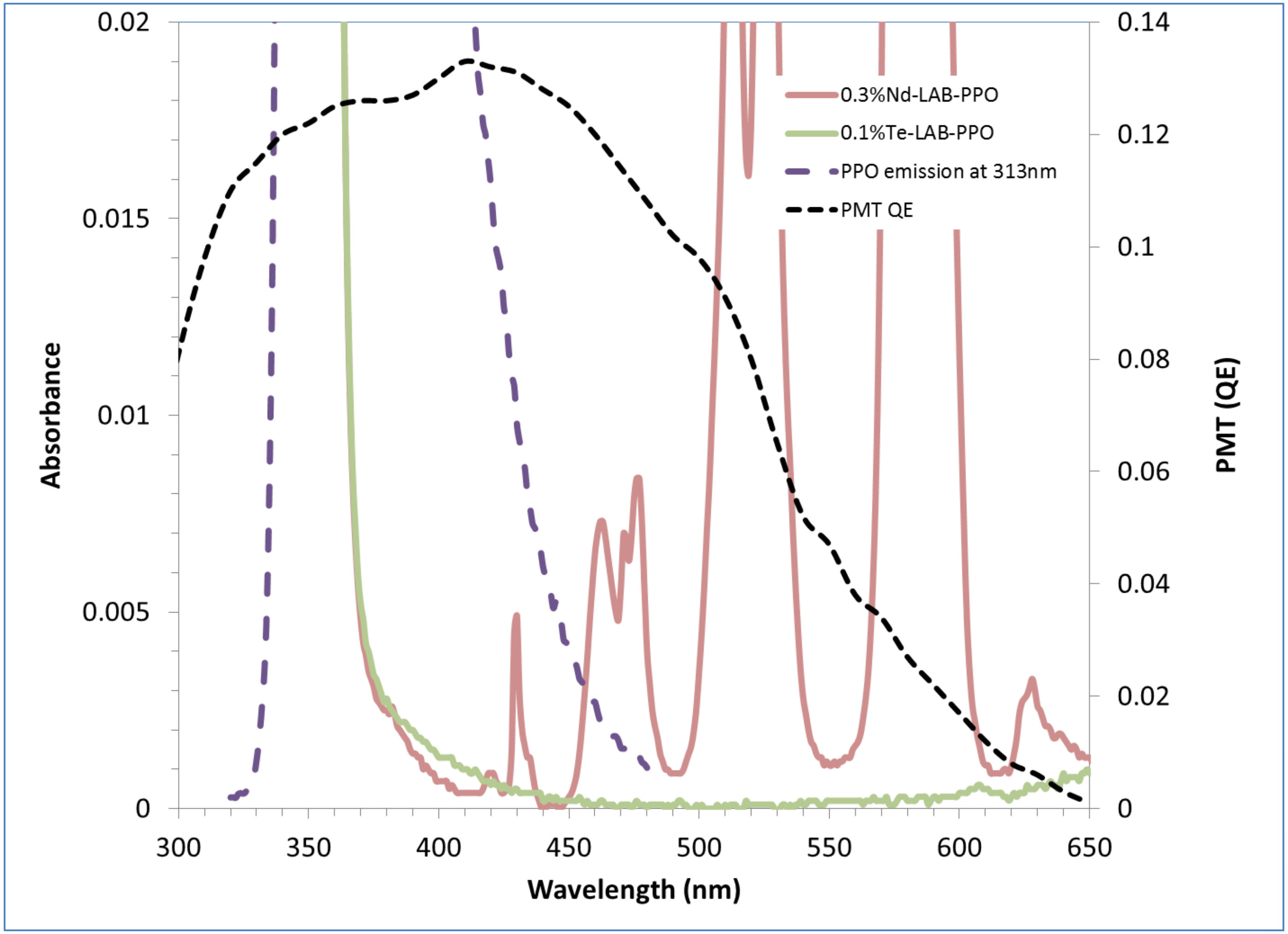
# Te Loaded “Scintillator”



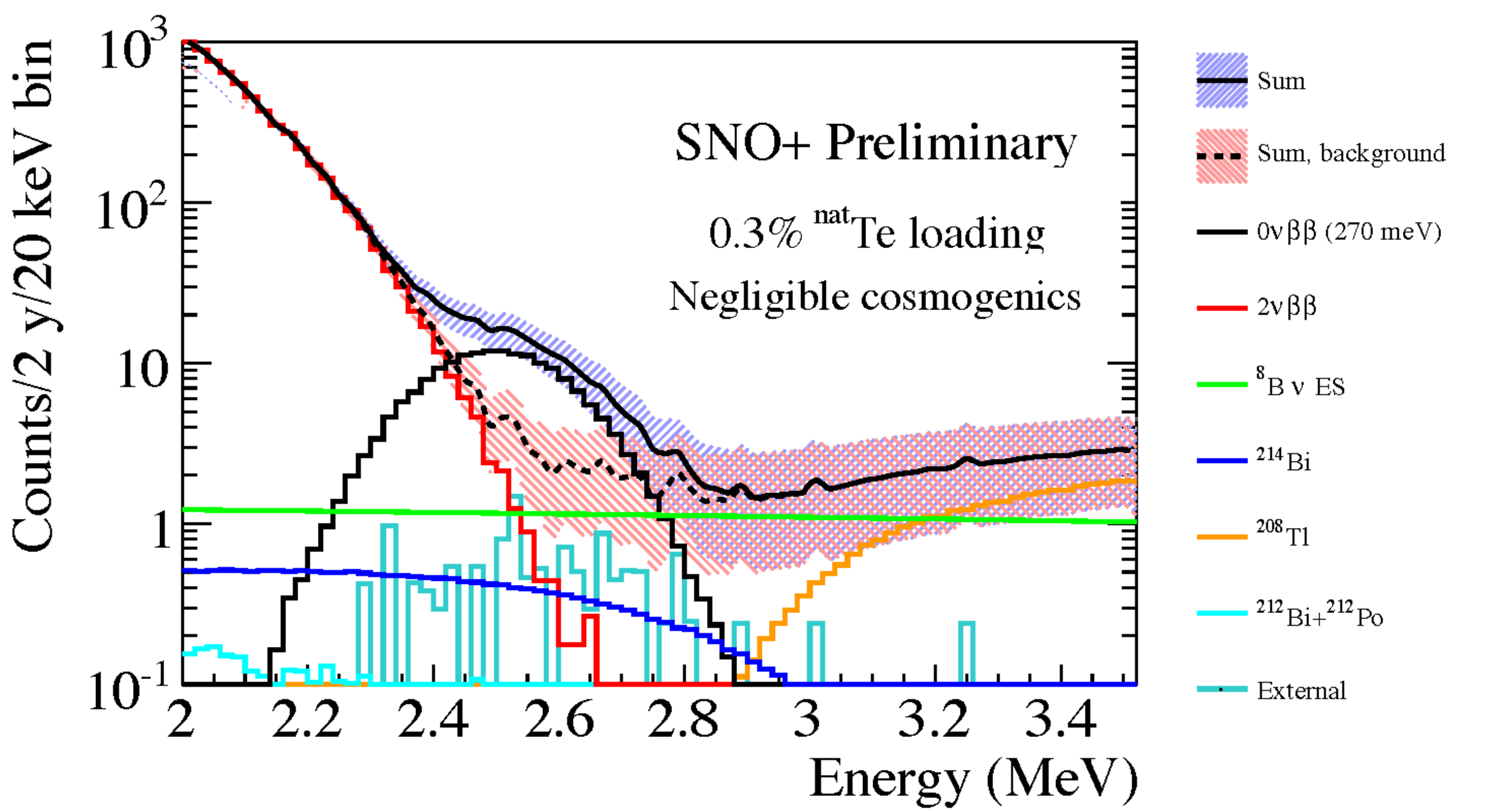
# Te Loaded Scintillator

- Developed stable Te-loaded LAB with good optical properties

# Light Absorption

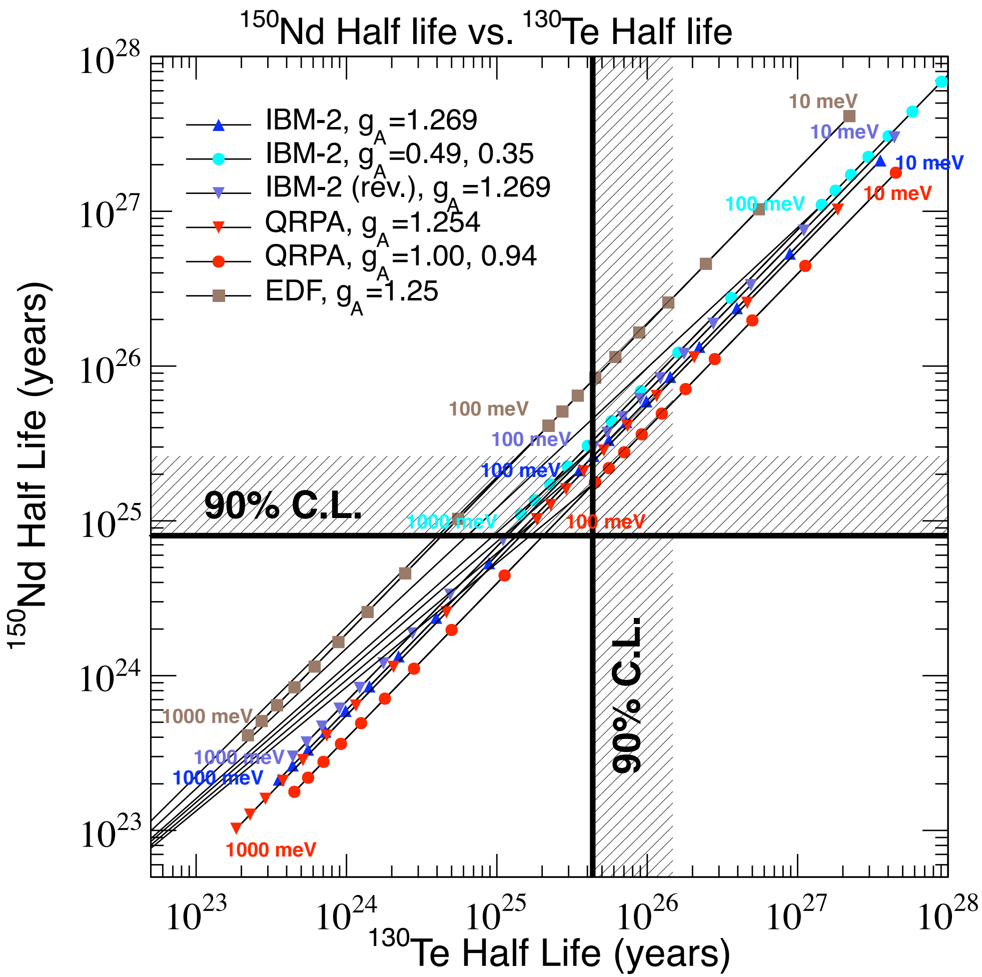


# Expected Spectrum




2 live-years of data, 20% fiducial volume

# $^{150}$Nd to $^{130}$Te comparison



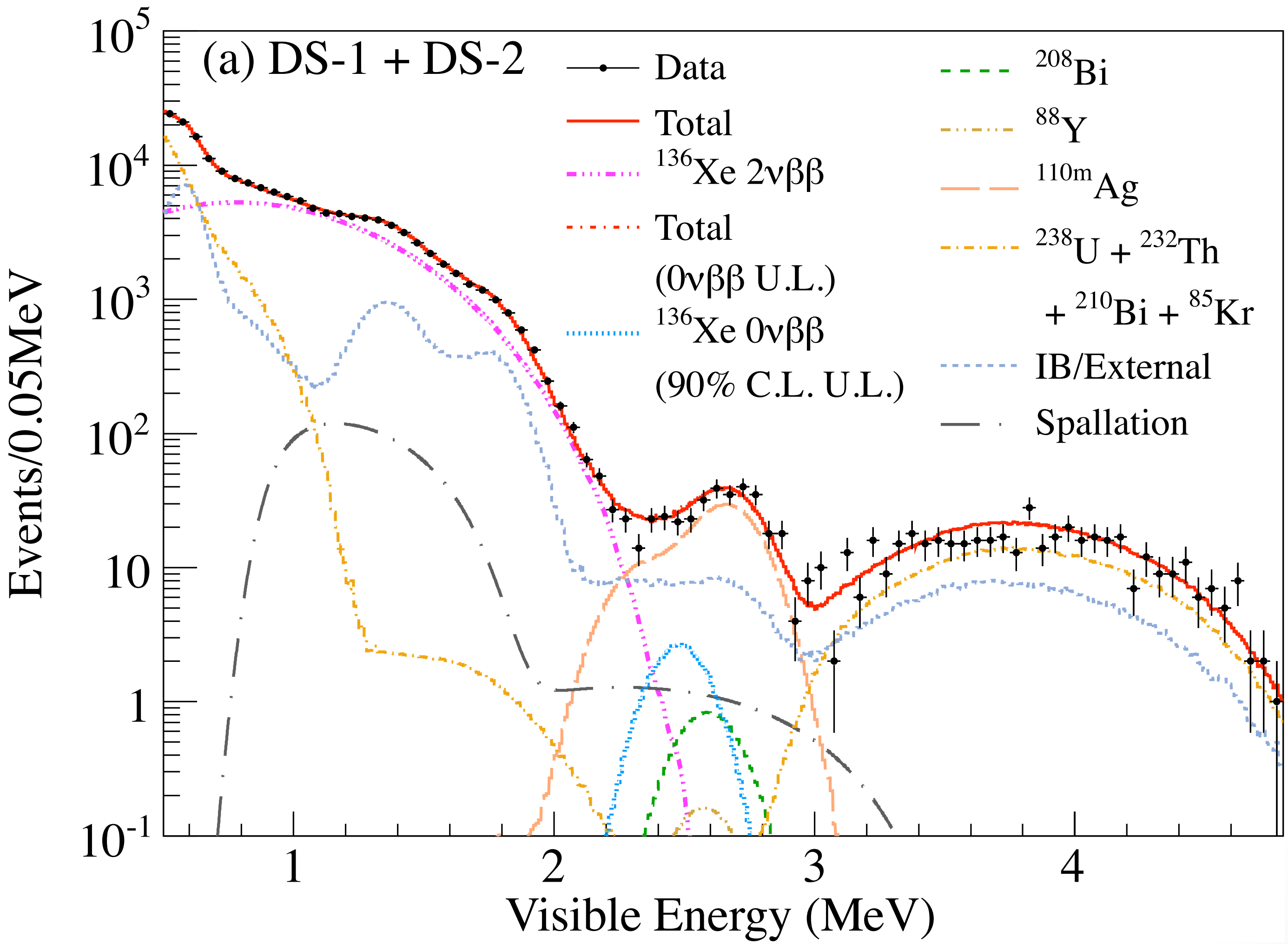

Te sensitivity 70-100 meV

# Backgrounds

# U/Th

- 2.53 MeV Te endpoint overlaps with $^{214}$Bi spectrum ($^{238}$U chain)
  - U-chain backgrounds in liquid scintillator can be extremely low (<2 decays/day/100T)
    - SNO+ has developed techniques to purify Te to acceptable U/Th levels
    - Working to develop purification of other required chemicals
  - $^{214}$Bi can be suppressed by more than a factor of 1000 using the 164μs $^{214}$Bi – $^{214}$Po delayed coincidence
- 2.6 MeV gamma from external $^{208}$Tl suppressed by fiducialization
  - Internal $^{208}$Tl at higher energy

# KamLAND-Xen




arXiv:1211.3863v2

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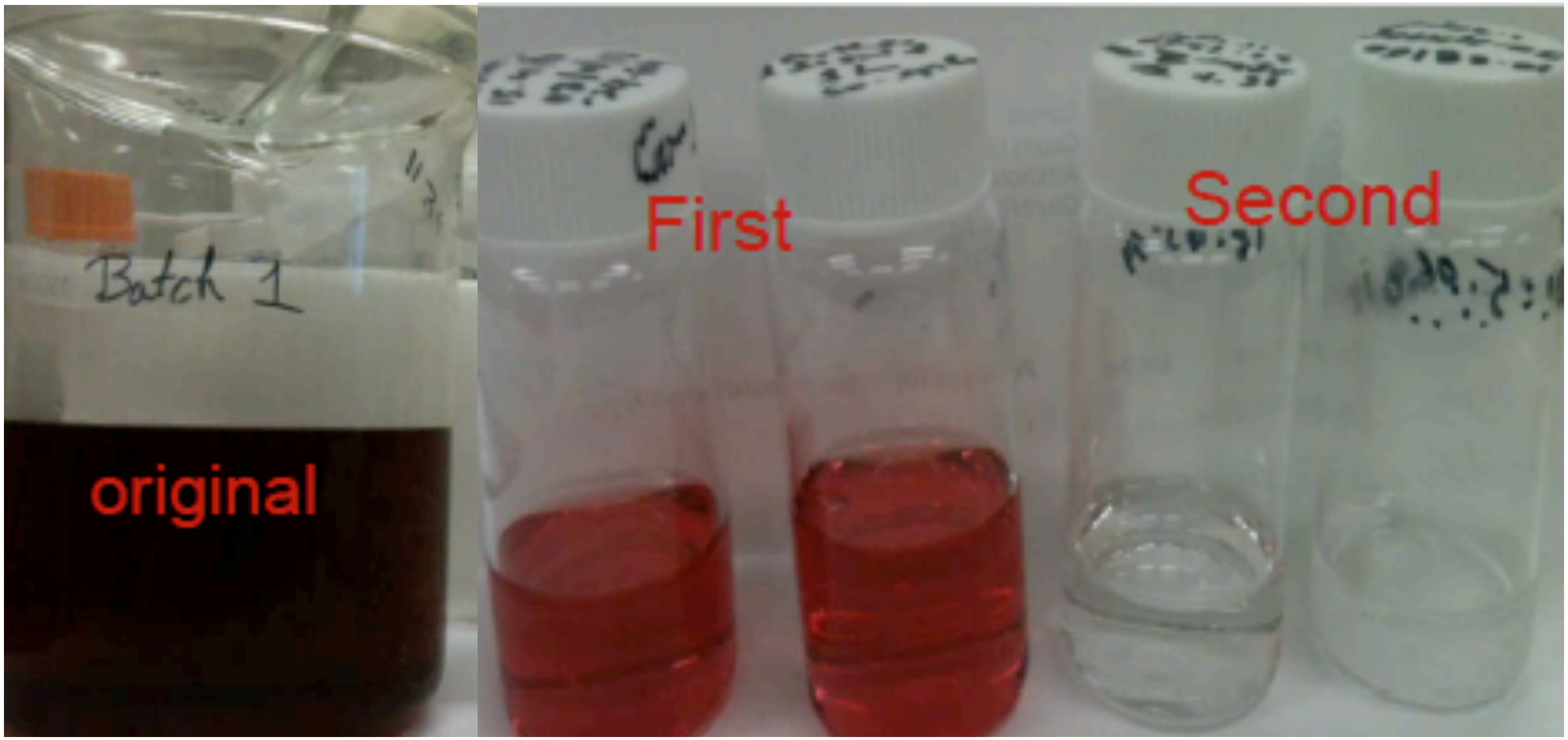
# Cosmogenic Backgrounds

- Half-life between 20 days and 1 billion years and mass number less than either 130 or 150
- Subsequent decay with Q value > 2 MeV
- In $^{130}$Te I identified:
  - $^{22}$Na, $^{26}$Al, $^{42}$Ar, $^{44}$Ti, $^{46}$Sc, $^{56}$Co, $^{58}$Co, $^{60}$Fe, $^{60}$Co, $^{68}$Ge, $^{82}$Sr, $^{84}$Rb, $^{88}$Y, $^{88}$Zr, $^{90}$Sr, $^{102}$Rh, $^{102m}$Rh, $^{106}$Ru, $^{110m}$Ag, $^{124}$Sb, and $^{126}$Sn
- In $^{150}$Nd I identified:
  - $^{26}$Al, $^{42}$Ar, $^{44}$Ti, $^{56}$Co, $^{82}$Sr, $^{88}$Y, $^{88}$Zr, $^{106}$Ru, $^{126}$Sn, $^{146}$Gd, and $^{148}$Eu

# Cosmogenic Purification



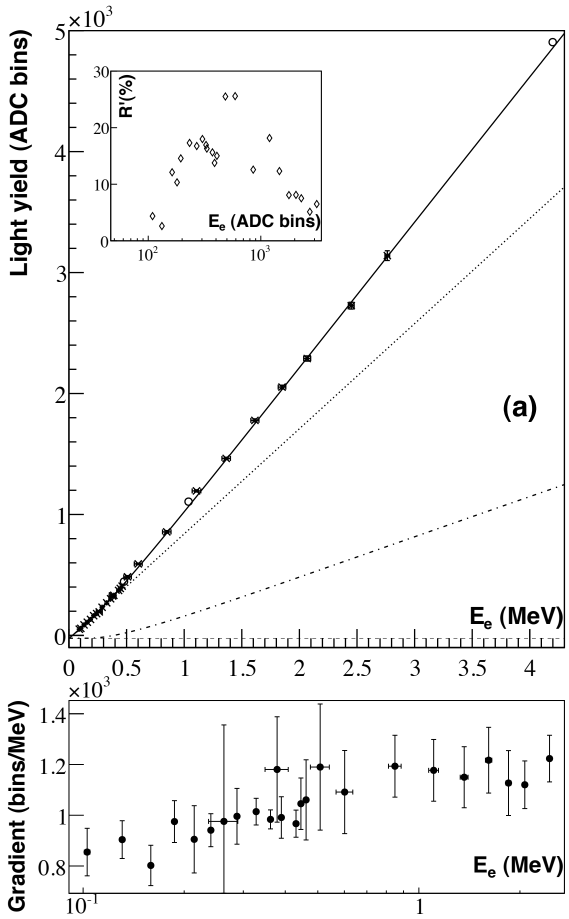

Demonstrated purification of approximately 1000 per pass
Regrowth of cosmogenics requires at least a “polishing” purification underground to obtain “zero” expected events

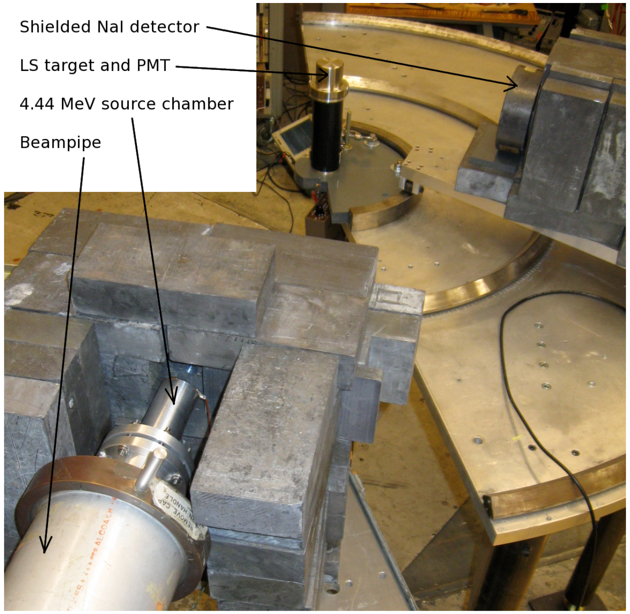
# Sensitivity vs Discovery

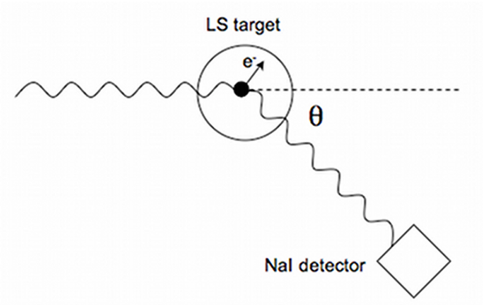
# Sensitivity vs Discovery

- An experiment can set an excellent limit if it does not see a peak
- If a peak is seen it needs to be demonstrated that it is not a background
- NEXT would have two distinct handles, which would allow one to determine if the energy peak is a background or not
- Minimum steps in SNO+
  - Observe peak
  - Purify
  - Observe that peak has not gone away
  - Spike with each background at a level comparable to the peak
  - Observe bigger peak
  - Purify
  - Observe original peak

# LAB Energy Linearity



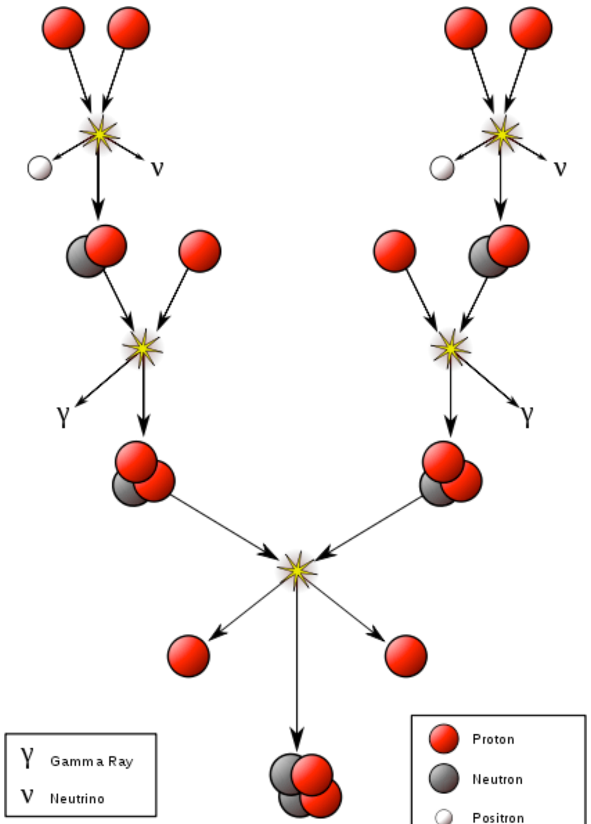




arXiv:1105.2101

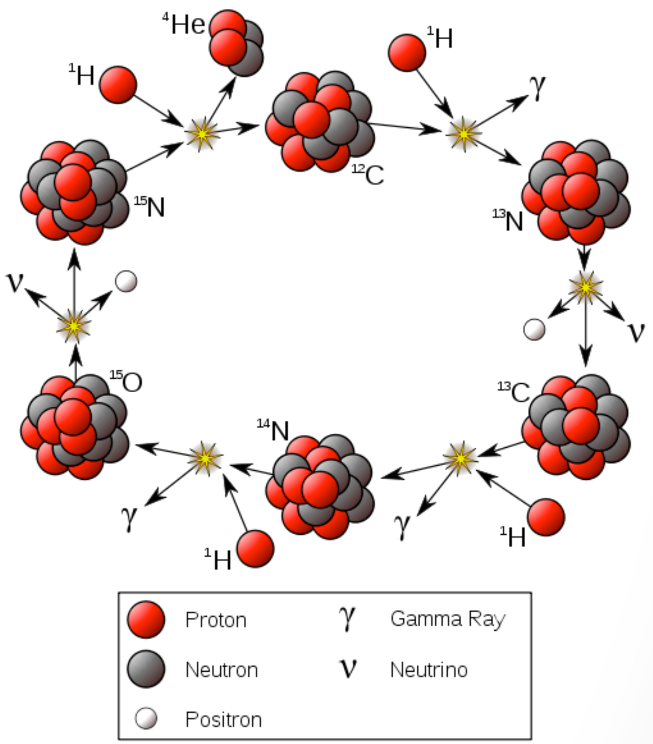
# Solar Neutrinos

# Solar Fusion ($4^1H \rightarrow {}^4He + 2e^+ + 2\nu_e$)

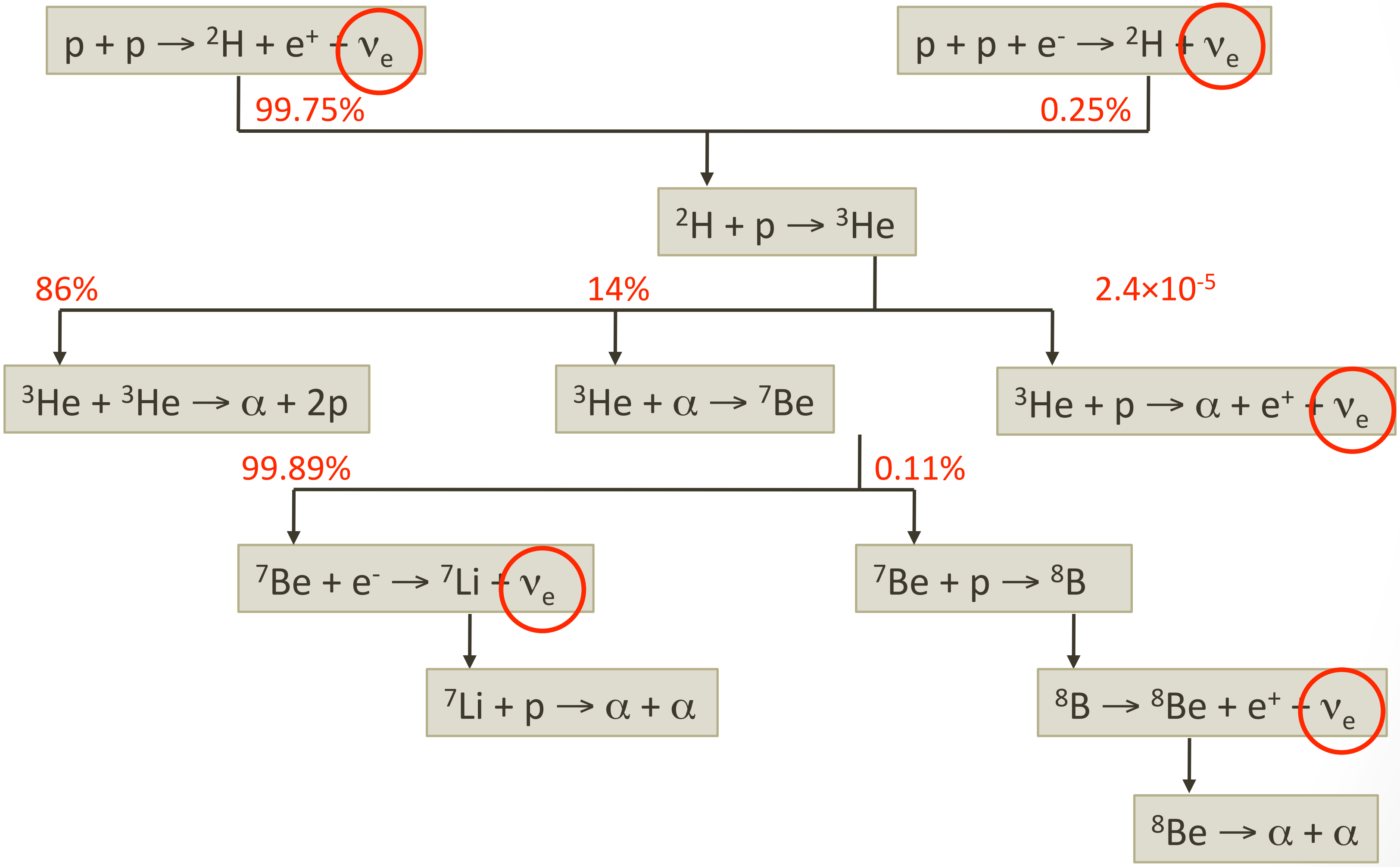
**PP fusion**



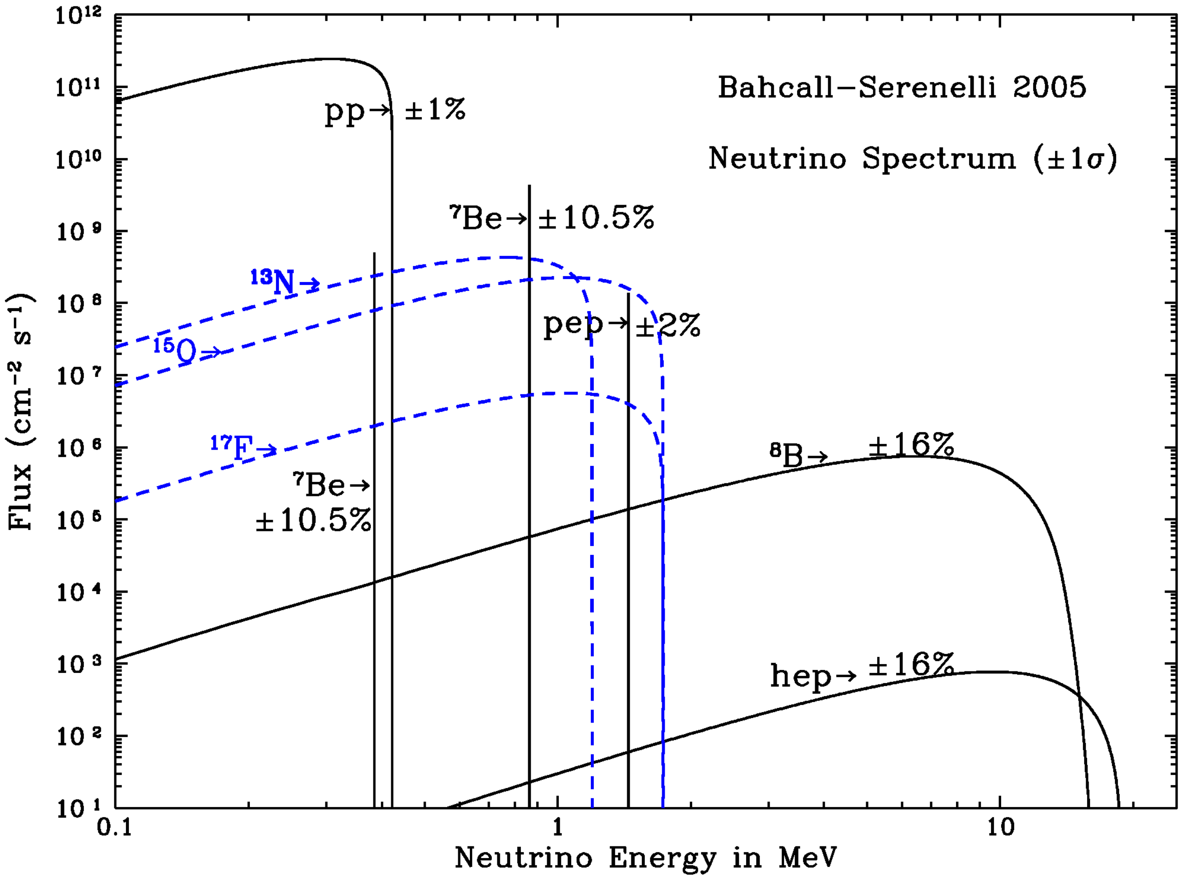

**CNO cycle**



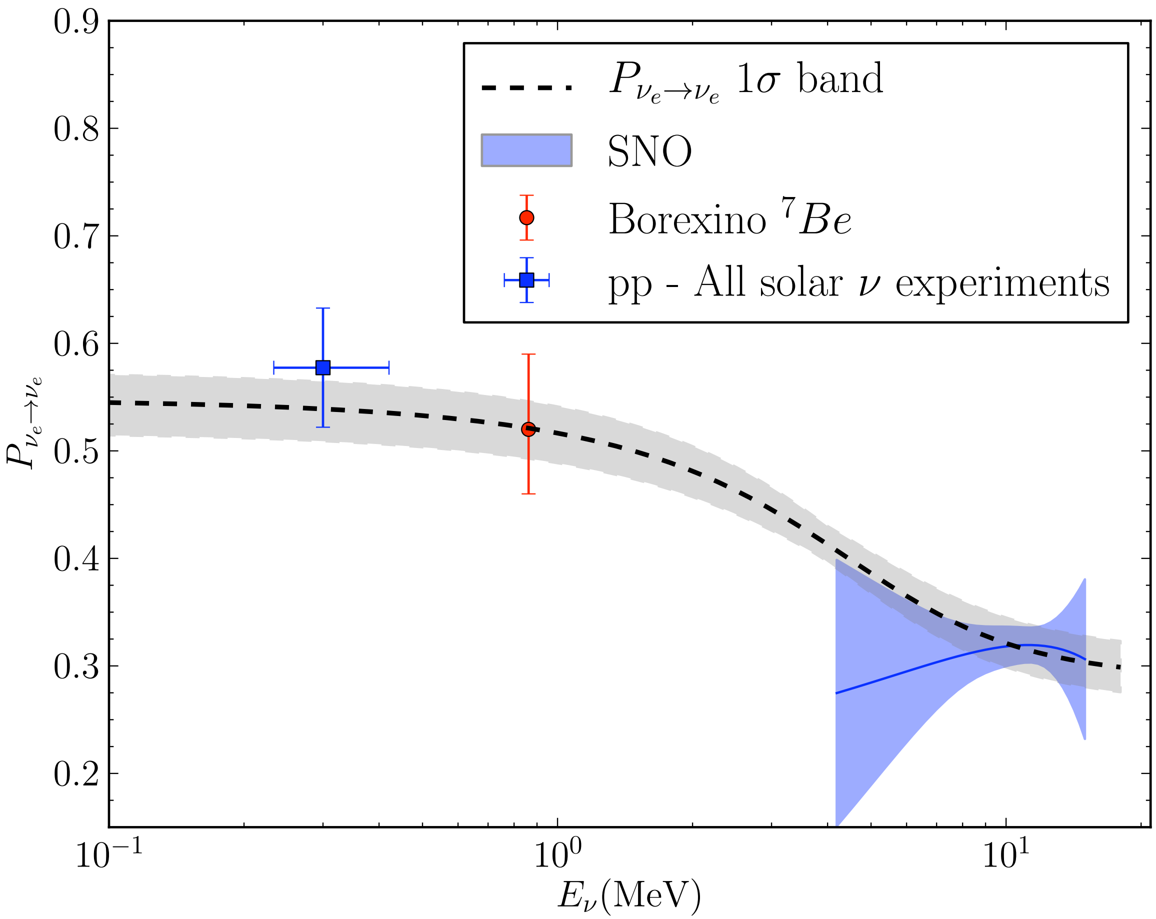
# Solar pp Chain Reactions



# Energy Spectrum



# *pep* Neutrinos




arXiv:1109.0763

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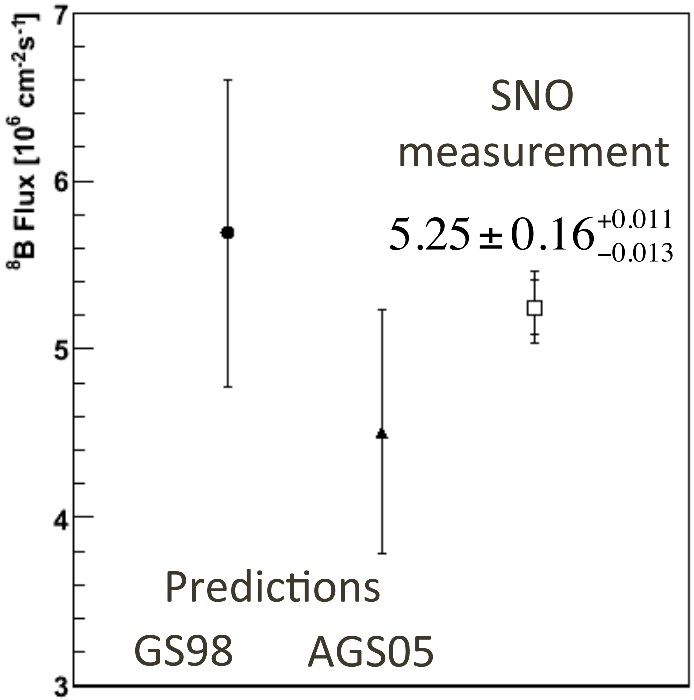
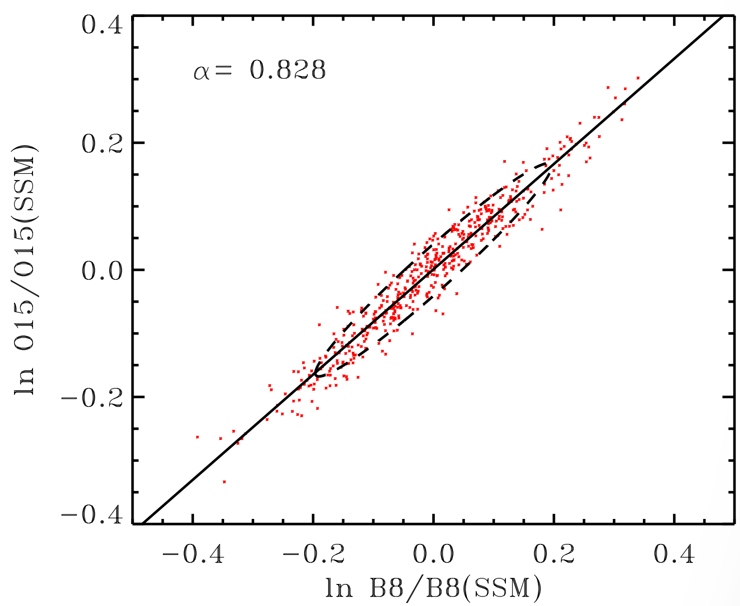
# CNO Neutrinos



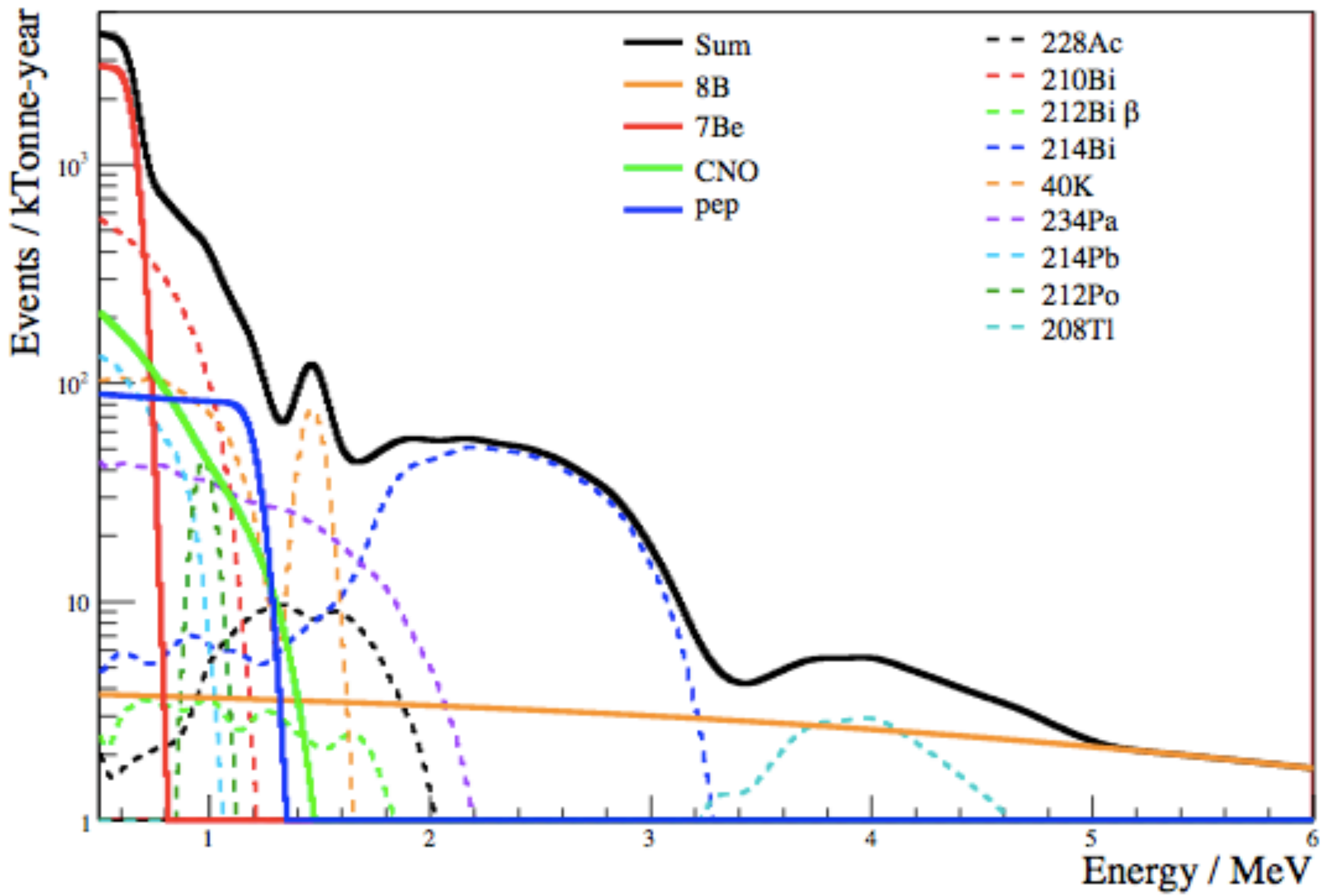

arXiv:0902.0036v1



# Official Statement

- SNO+ has decided to prioritize 0*ν2β*
- Radon daughters have accumulated on the surface of the AV over the last few years in a significant way. If these leach into the scintillator, the purification system has the capability to remove them.
- However, depending on the actual leach rate, that removal might be inefficient and the $^{210}$Bi levels in the scintillator too high for a pep/CNO solar neutrino measurement without further mitigation.
- Mitigation could include enhancing online scintillator purification, draining the detector and sanding the AV surface to remove radon daughters, or deploying a bag.
- 0*ν2β* and low---energy $^{8}$B solar neutrino measurements are not affected by these backgrounds

# SNO+ Energy Spectrum




Assumes Borexino background levels

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# Conclusions

- Te will not suffer from the $2\nu$ background
- We will have to be vigilant against all other backgrounds
- Sensitivity of 70 to 100 meV
- May be able to significantly increase loading without increasing backgrounds to cover the entire inverted hierarchy
- Potentially excellent solar neutrino detector, but that has been officially delayed