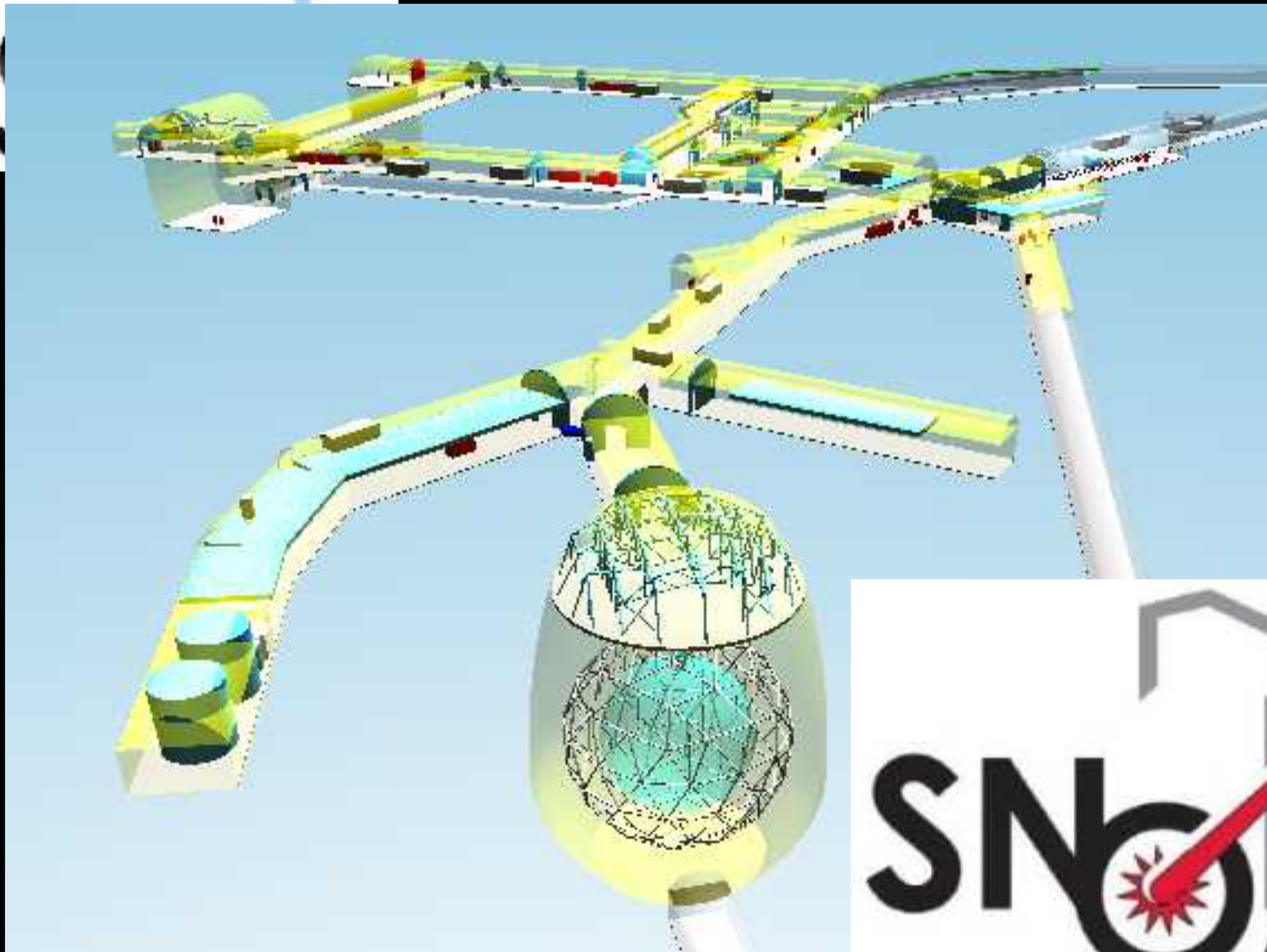
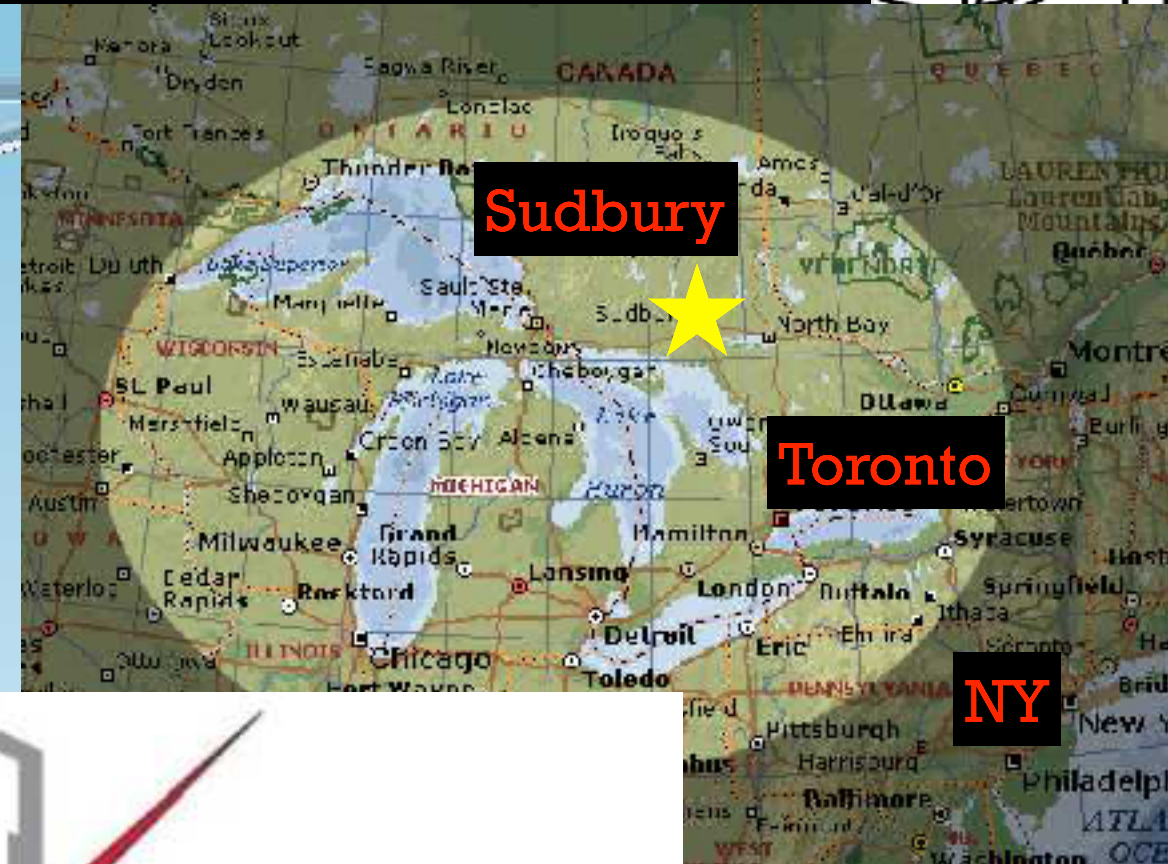
SNO+

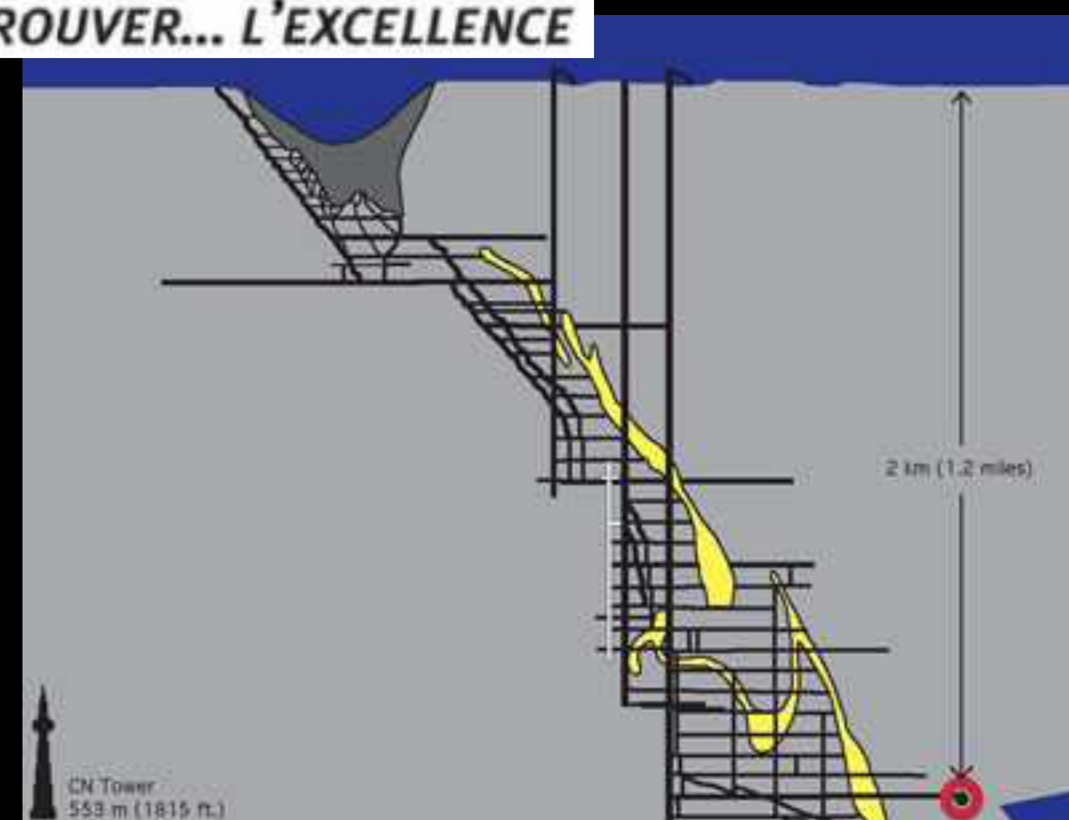
Sofia Andringa, Fernando Barão, Ana Sofia Inácio, Pedro Jorge, Amélia Maio, José Maneira, Stefan Nae, Gersende Prior, Valentina Lozza

Jornadas do LIP, Évora
February 17, 2018





SNOLAB
MINING FOR KNOWLEDGE
CREUSER POUR TROUVER... L'EXCELLENCE



Very deep (2 km, 6000 mwe),
very clean (class 2000 clean room)
underground laboratory
in Sudbury, Ontario, Canada

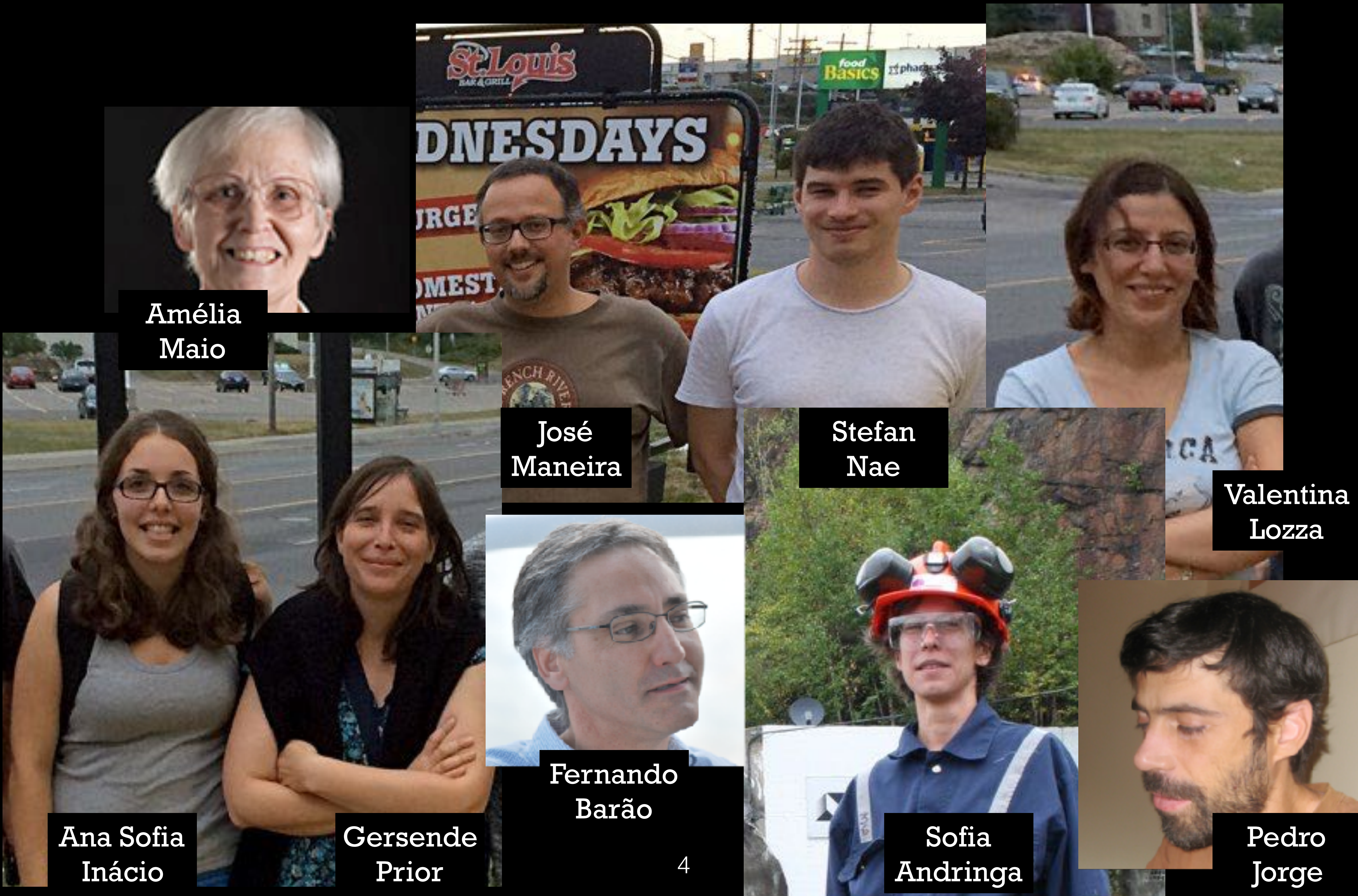
Ideal conditions for low background physics!

SNO+ Collaboration

- Armstrong Atlantic State University
- Boston University
- Brookhaven National Laboratory
- Lancaster University
- Laurentian University
- Lawrence Berkeley National Laboratory
- LIP Coimbra
- LIP Lisboa
- Oxford University
- Queen Mary, University of London
- Queen's University
- SNOLAB
- Technical University of Dresden
- TRIUMF
- Universidad Nacional Autonoma de Mexico
- University of Alberta
- University of California - Berkeley
- University of California - Davis
- University of Chicago
- University of Liverpool
- University of North Carolina at Chapel Hill
- University of Pennsylvania
- University of Sussex
- University of Washington

24 Institutes
6 countries
90 members

LIP Group


Amélia Maio
José Maneira
Stefan Nae
Valentina Lozza
Fernando Barão
Ana Sofia Inácio
Gersende Prior
Sofia Andringa
Pedro Jorge

SNO+ detector

780 tons of **liquid scintillator**

loaded with double-beta decay isotope (Te130)

contained in an **acrylic vessel (AV)** 12 m diameter

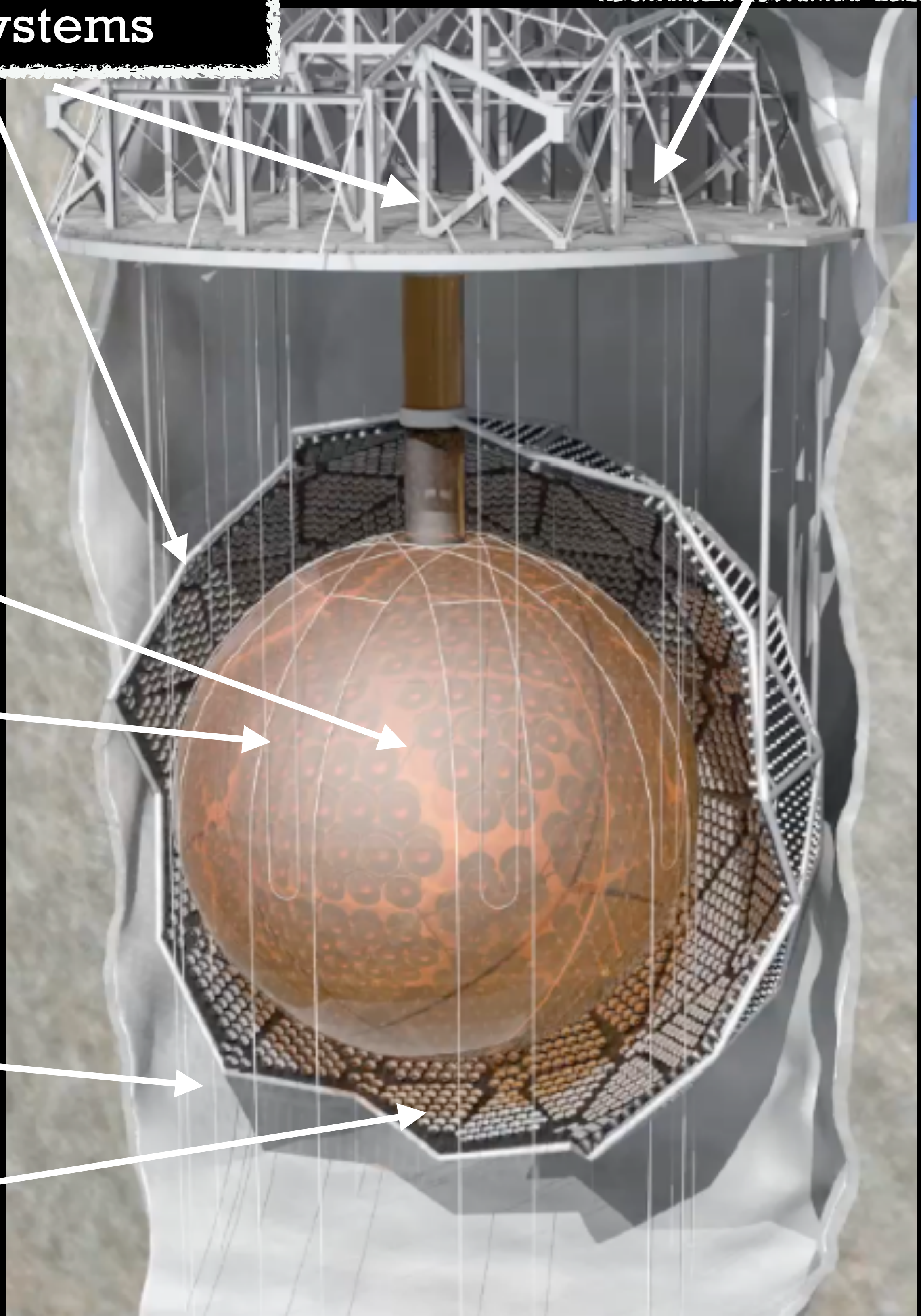
held-down by **new rope system**

shielded by 7 kt ultra-pure water

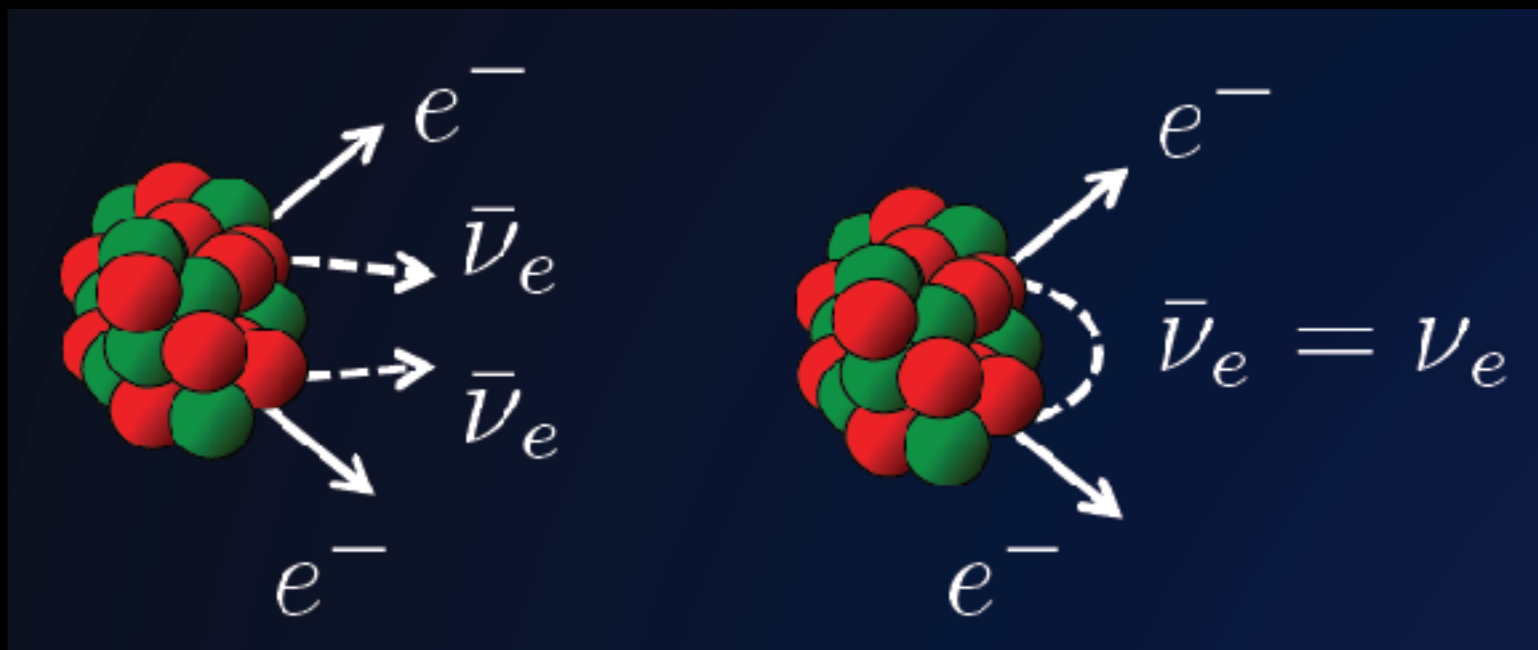
viewed by ~ **9300 PMTs** (8”) mounted on 17 m diam. structure

new calibration systems

new DAQ and readout cards



Neutrino-less double beta decay



- Only happens if neutrinos are of Majorana type
- Half-life depends on the neutrino mass

$$\frac{1}{T^{0\nu}_{1/2}} = G_{0\nu}|\mathcal{M}_\nu|^2 \left| \frac{m^\nu_{\rm ee}}{m_{\rm e}} \right|^2$$

Half-life

Nuclear Physics terms

Particle Physics term
Effective Majorana mass
Depends on masses m1, m2, m3
also on neutrino mixing parameters

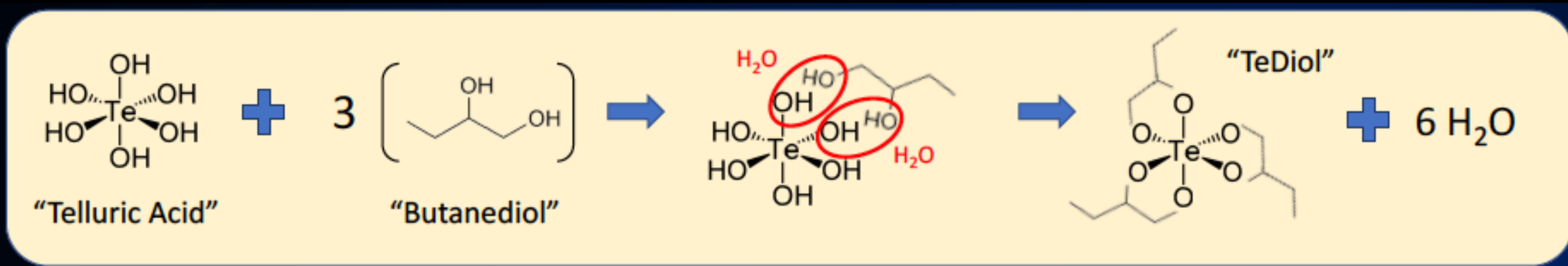
$$m^\nu_{\rm ee} = m_1 c^2_{12} c^2_{13} + m_2 s^2_{12} c^2_{13} e^{2i\alpha_2} + m_3 s^2_{13} e^{2i(\alpha_3+\delta)}$$

Neutrinoless double-beta decay search with Tellurium at SNO+

- Massive detector, provides self-shielding of external backgrounds
- Advantages of ^{130}Te
  - Large natural isotopic abundance (34%), so no enrichment needed to deploy tonne-scale of isotope
  - High half-life of 2ν mode: $T_{1/2}^{2\nu\beta\beta} = 7.0 \times 10^{20}$yr
- Liquid scintillator
  - can be purified on-line
  - loading can be changed
  - fast timing allows rejection of several time-correlated radioactivity backgrounds
  - strict control of backgrounds close to spectrum endpoint (2.53 MeV)

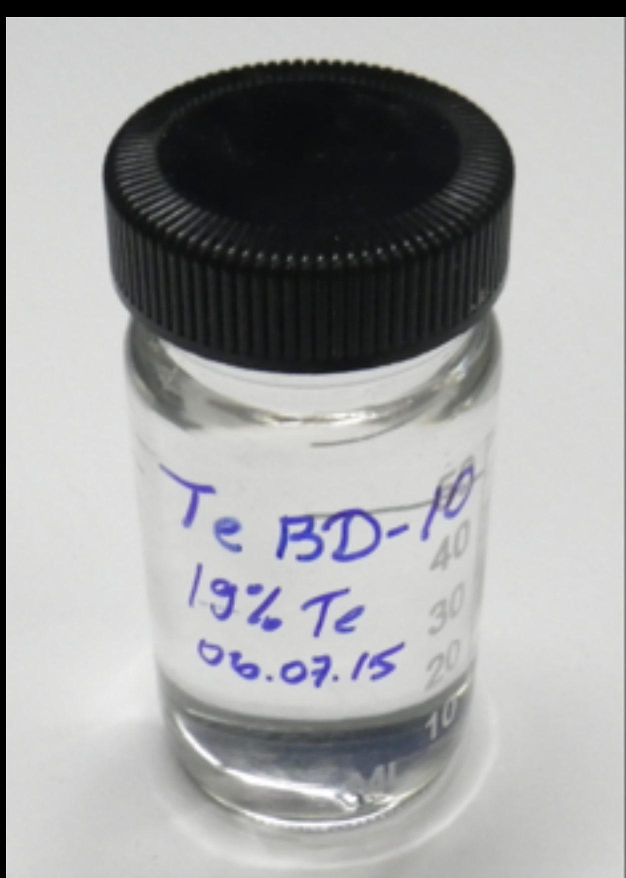
Tellurium-loading

- A bit of chemistry…



Telluric acid + 1,2 butane-diol

Tellurium-butanediol complex (TeBD)+ water (evaporate after synthesis)



TeBD very transparent and soluble in LAB liquid scintillator

Expect 400 p.e./MeV

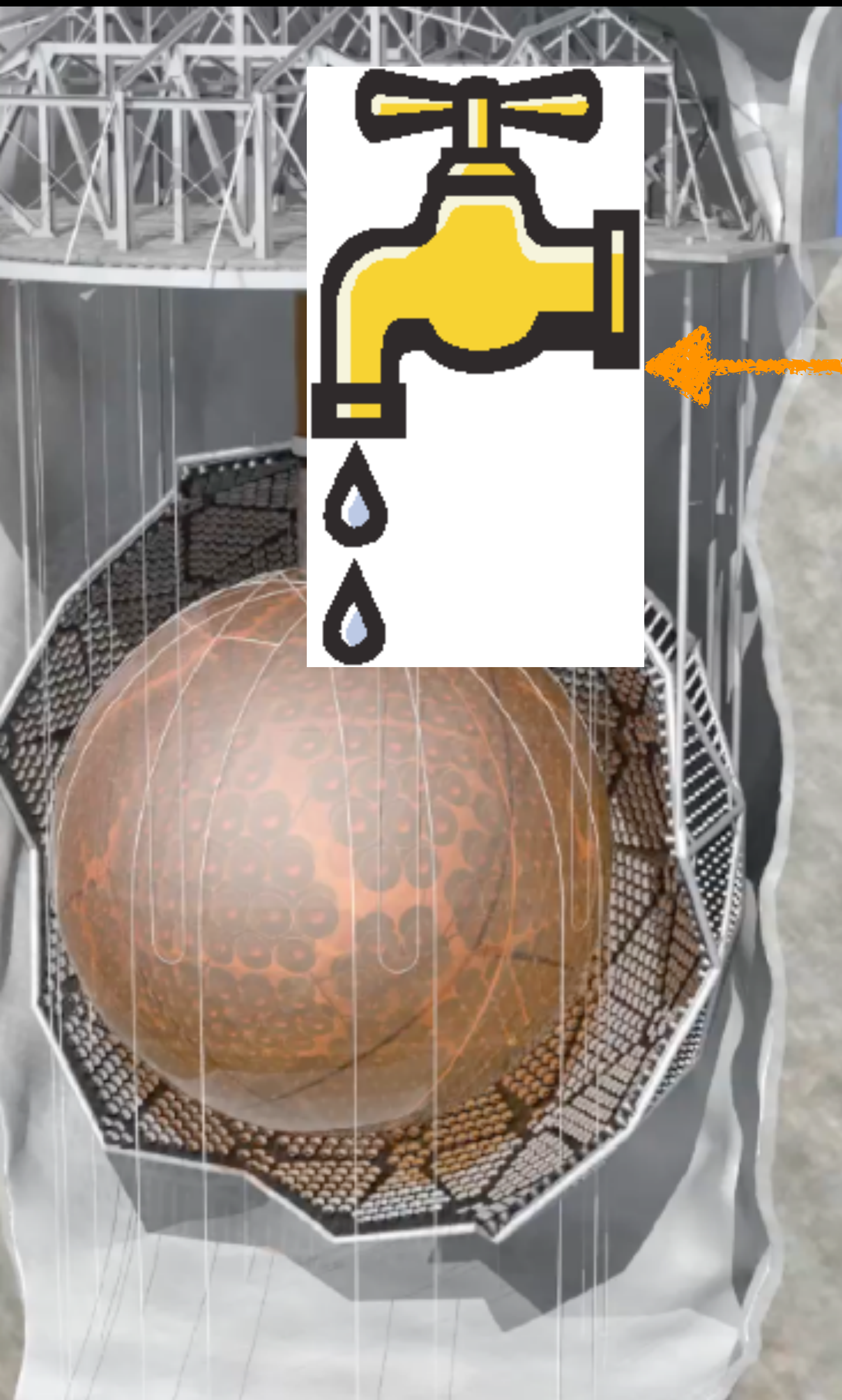
SNO+ phase I loading: 0.5 %
=
1333 kg of isotope

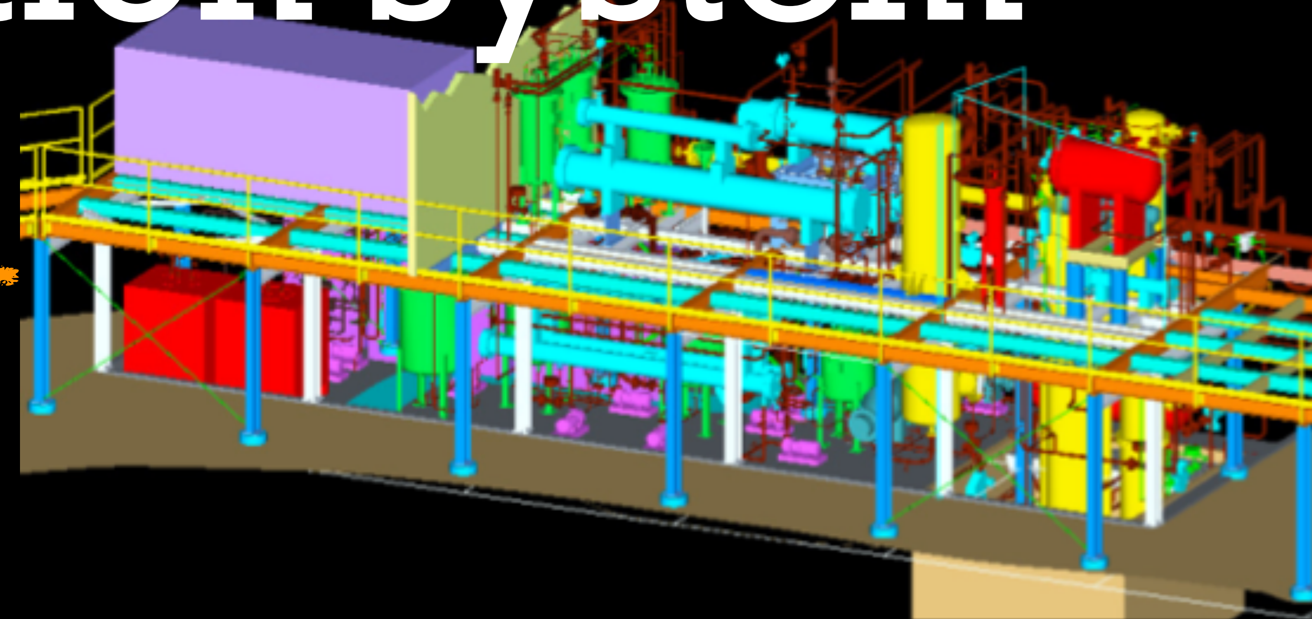
Tellurium

1.8 t underground

SNO+ Developments and Status

Purification system





Chemical plant
built underground!

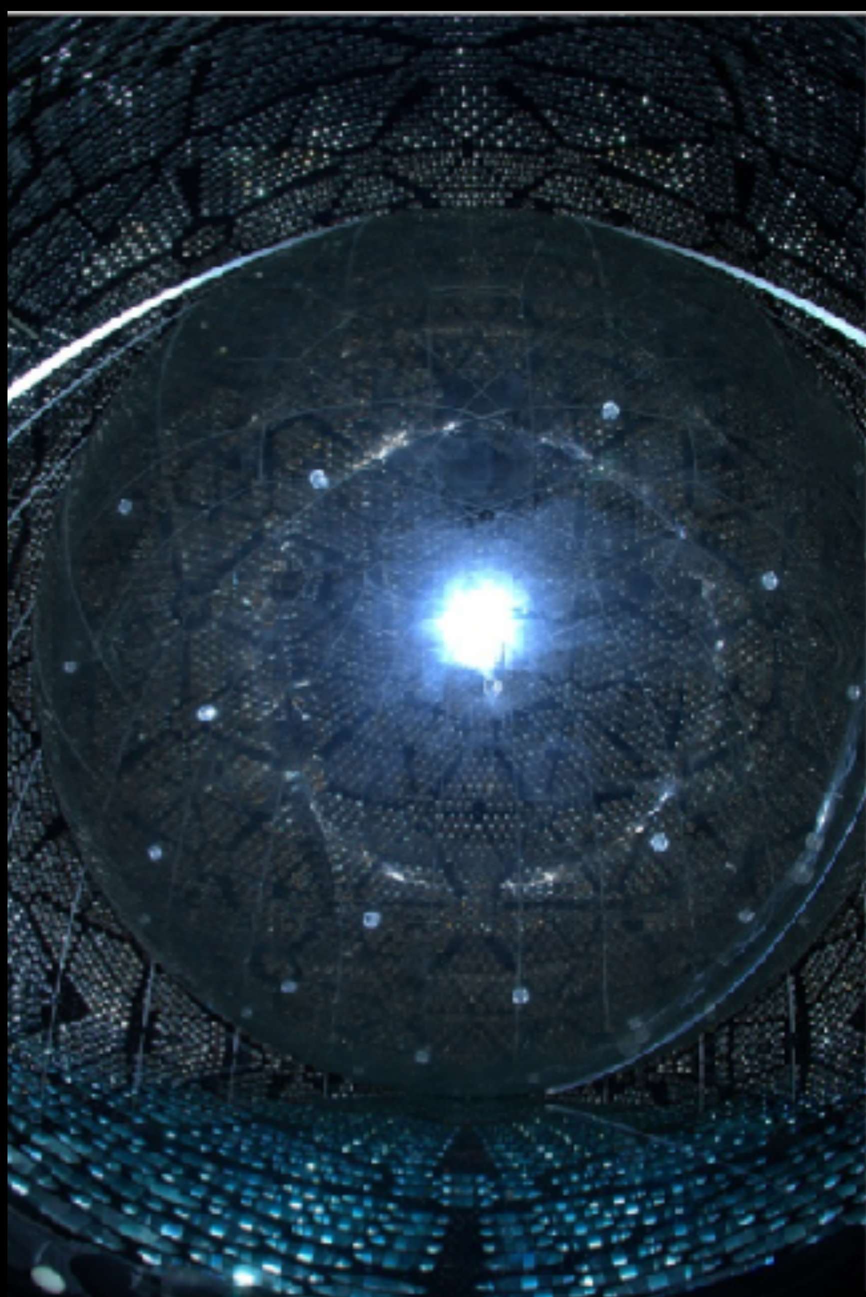
- distillation
- water extraction
- gas/vapor stripping

SNO+ Detector

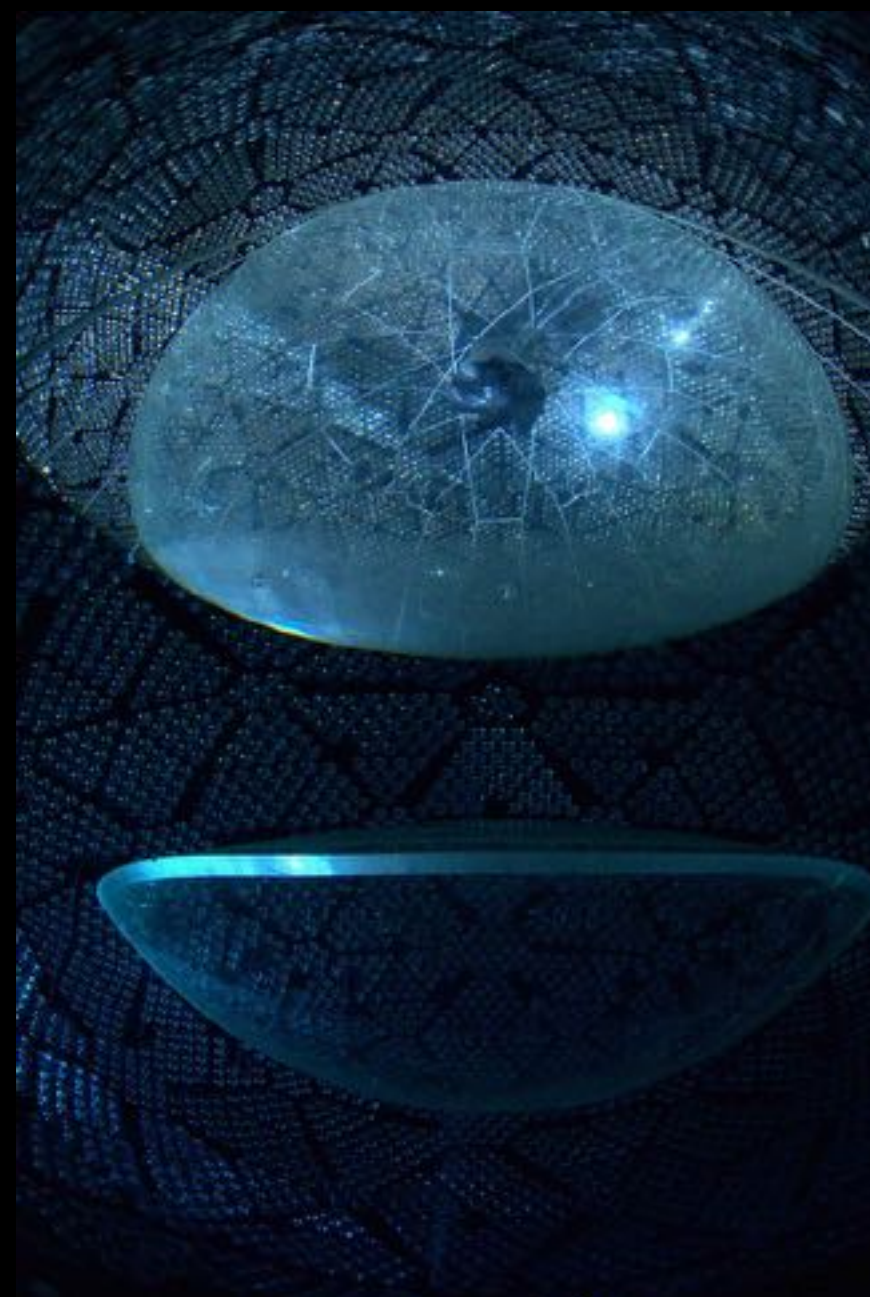
- PMTs
  - 9300 8' diameter (Hammamatsu)
  - Reflectors to increase collection
- Acrylic vessel
  - 5 cm thick
  - 6 m diameter

- New rope system
  - takes up buoyancy of scintillator
  - tested during water fill

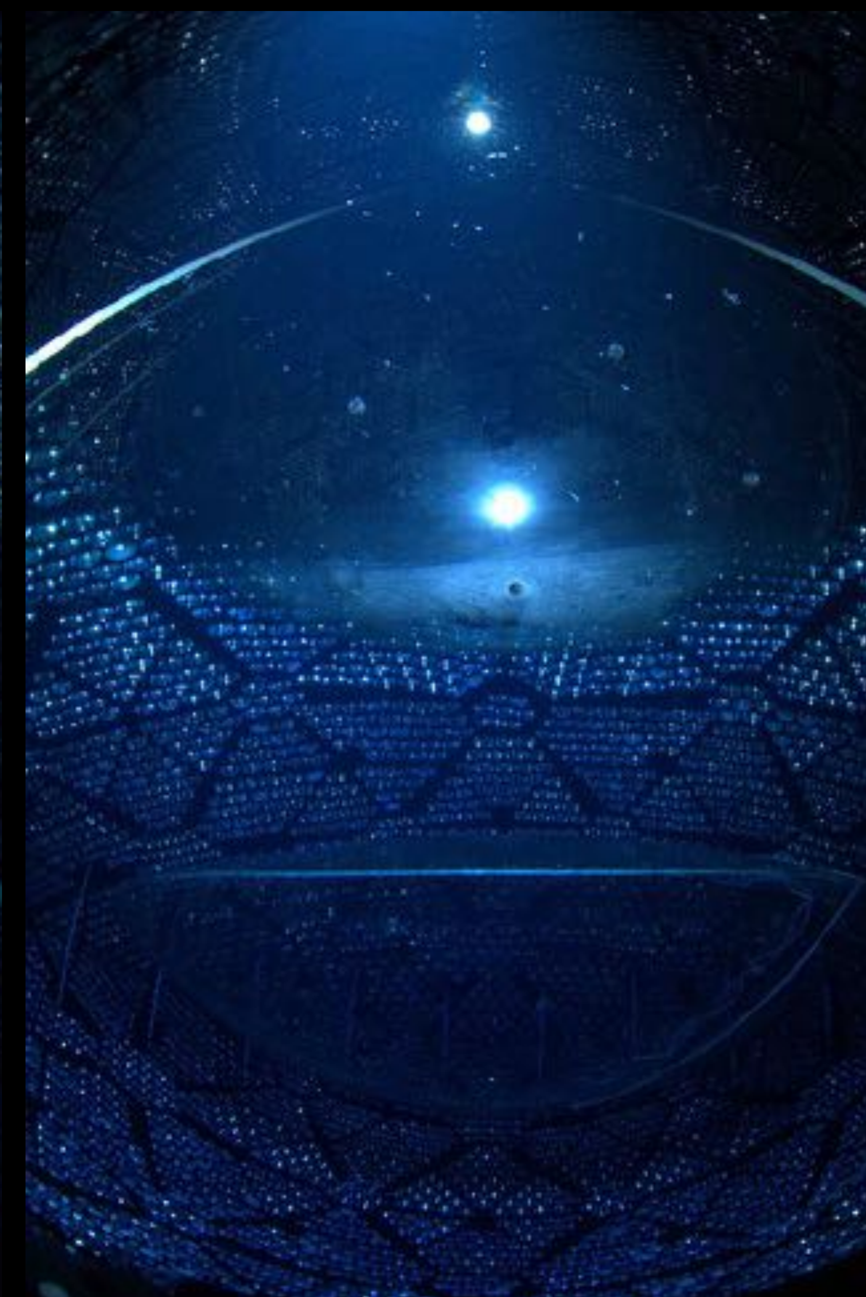
Water fill



Camera above water
Light above water

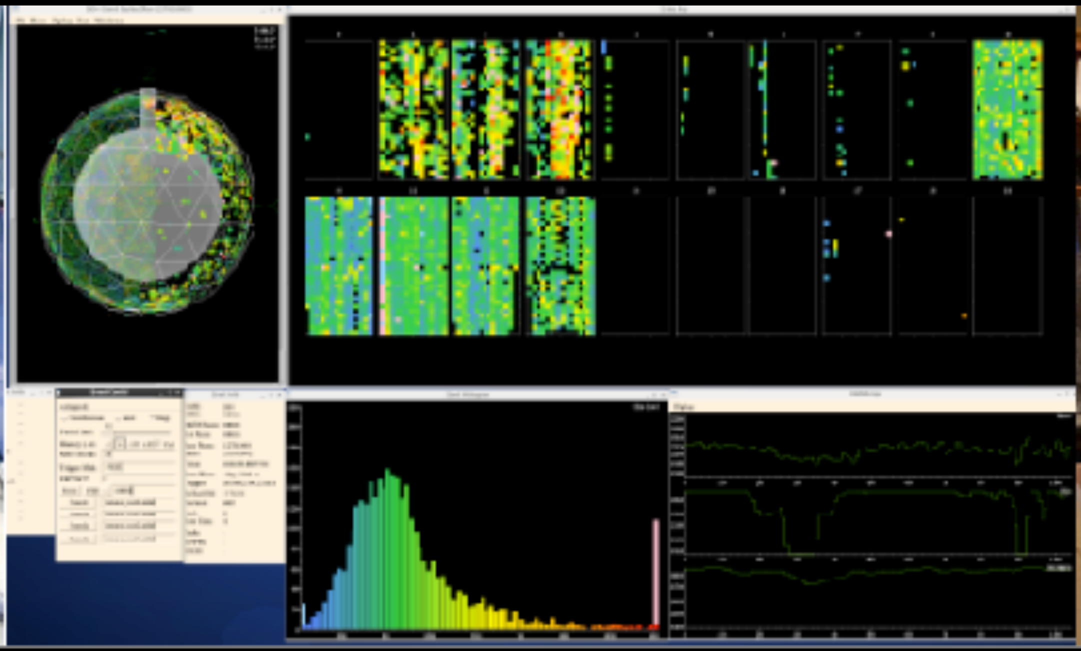


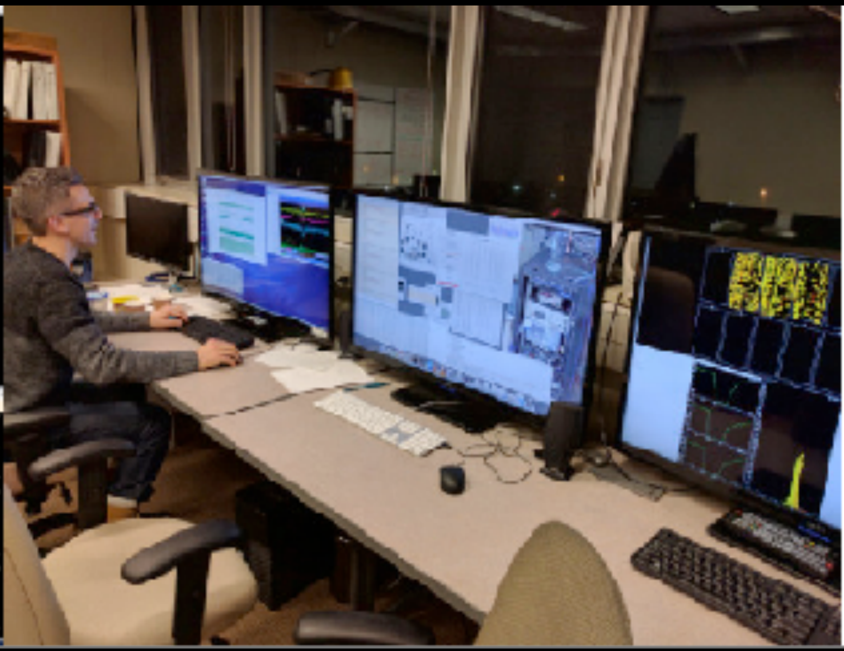
Camera below water
Light above water

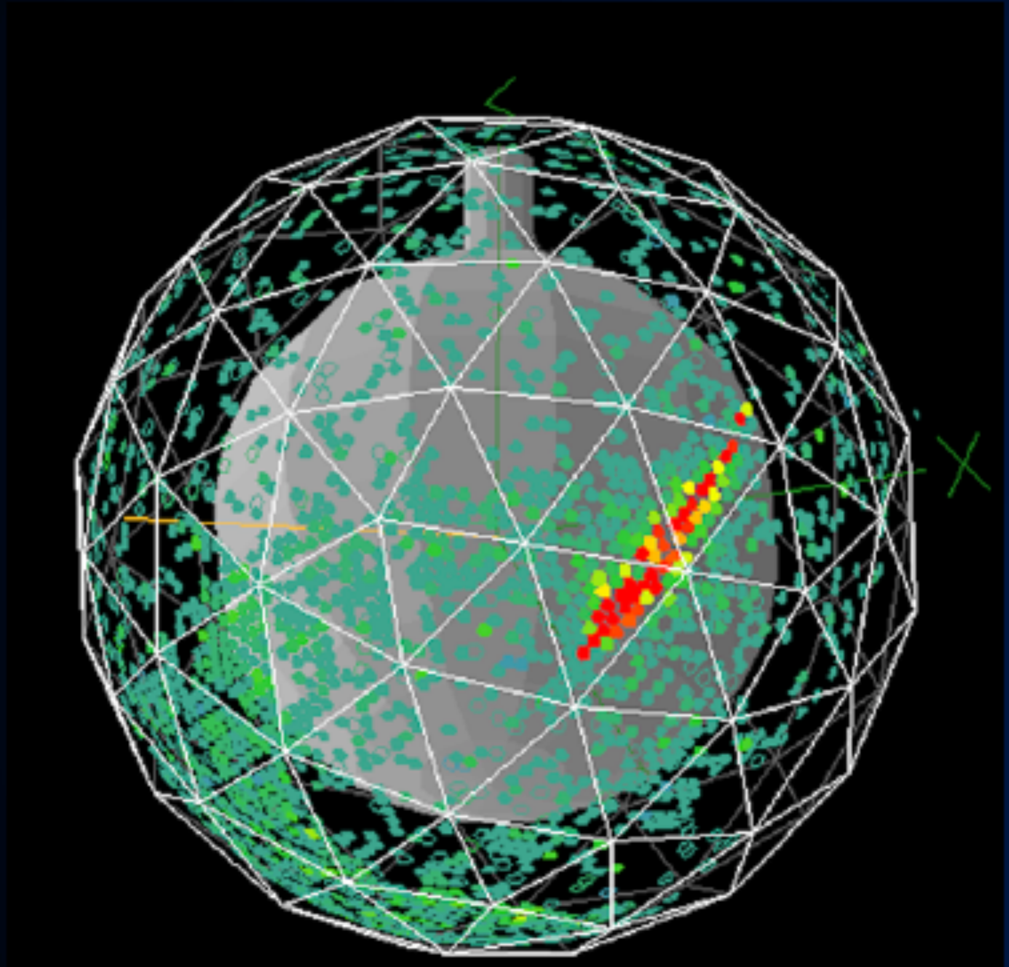


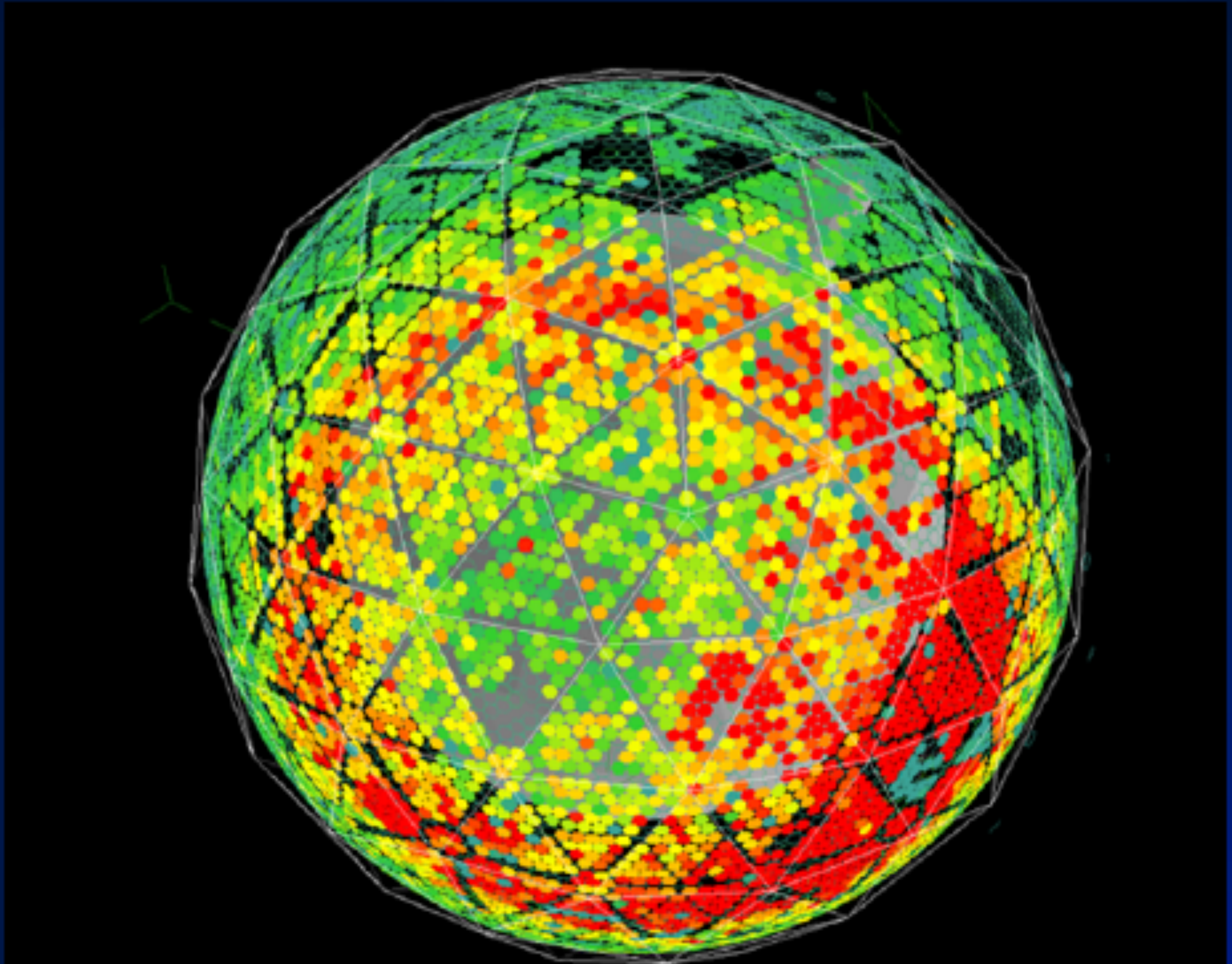
Camera below water
Light below water

Data-taking!





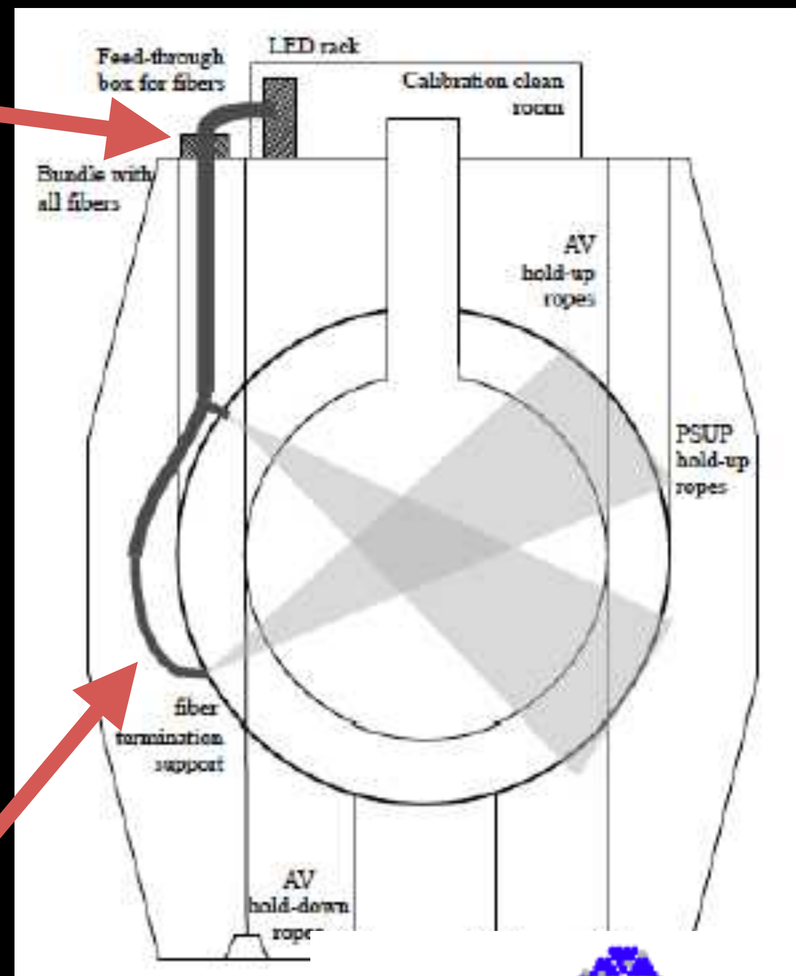

Muon candidate grazing the detector


Another muon candidate

LIP Contributions

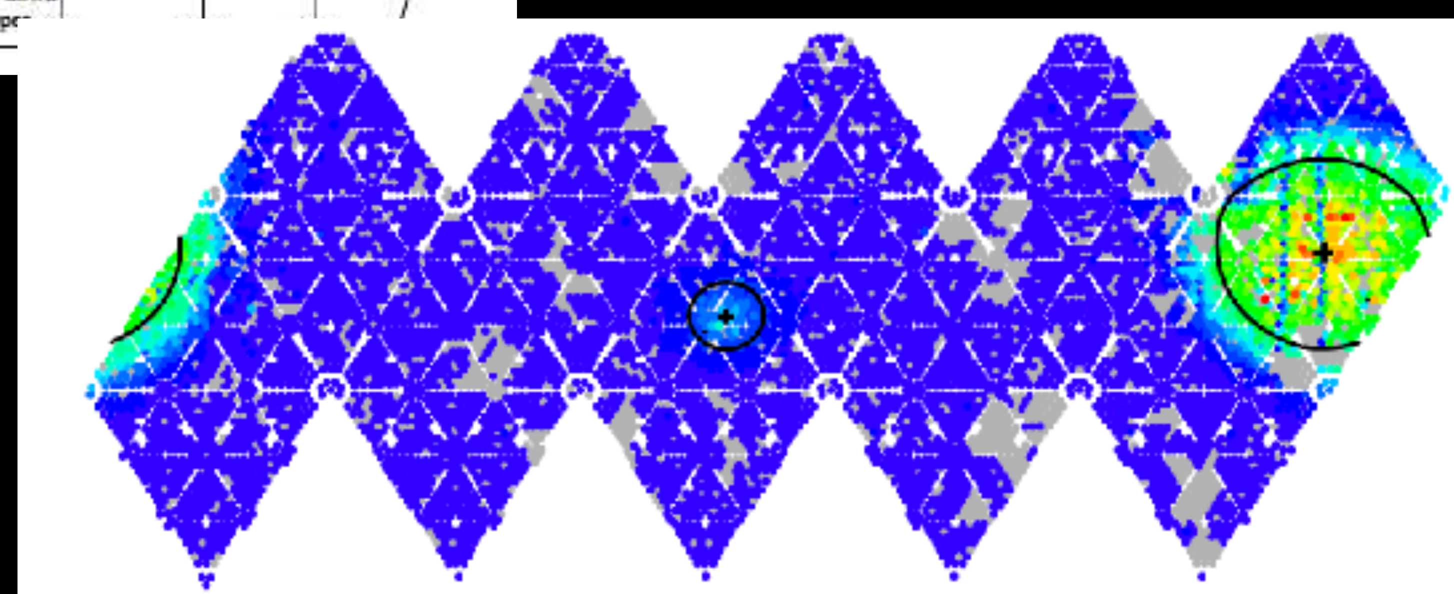
External Light Sources

- arXiv:1411.4830



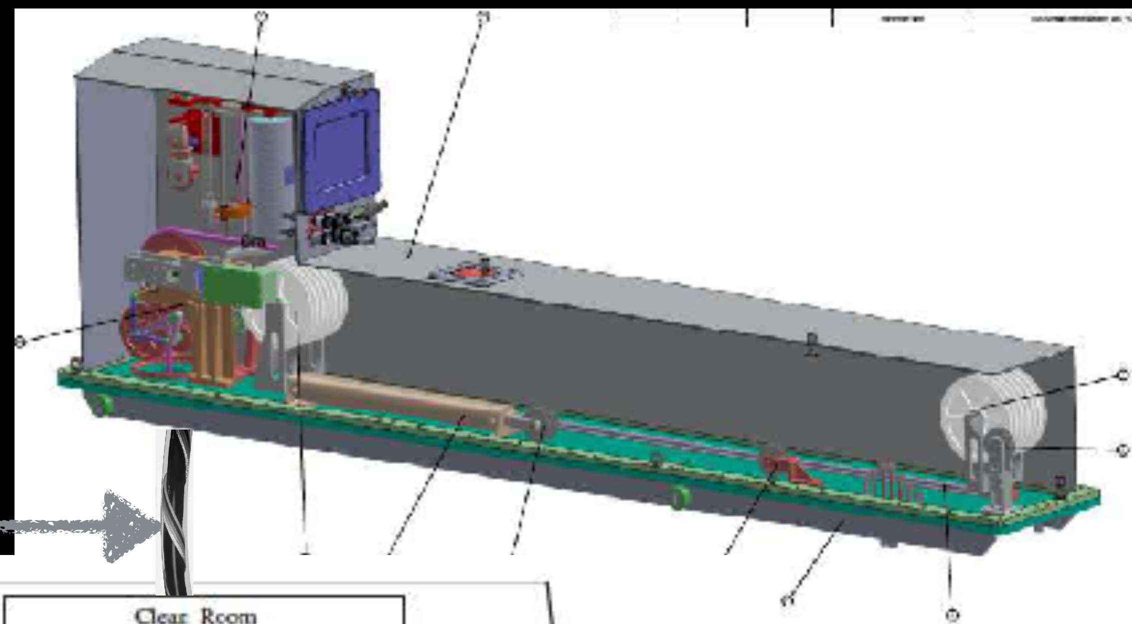
- LIP responsible for:
  - > 100 PMMA fibers
  - feed-throughs and mount points done at LIP-Coimbra
  - installation plan

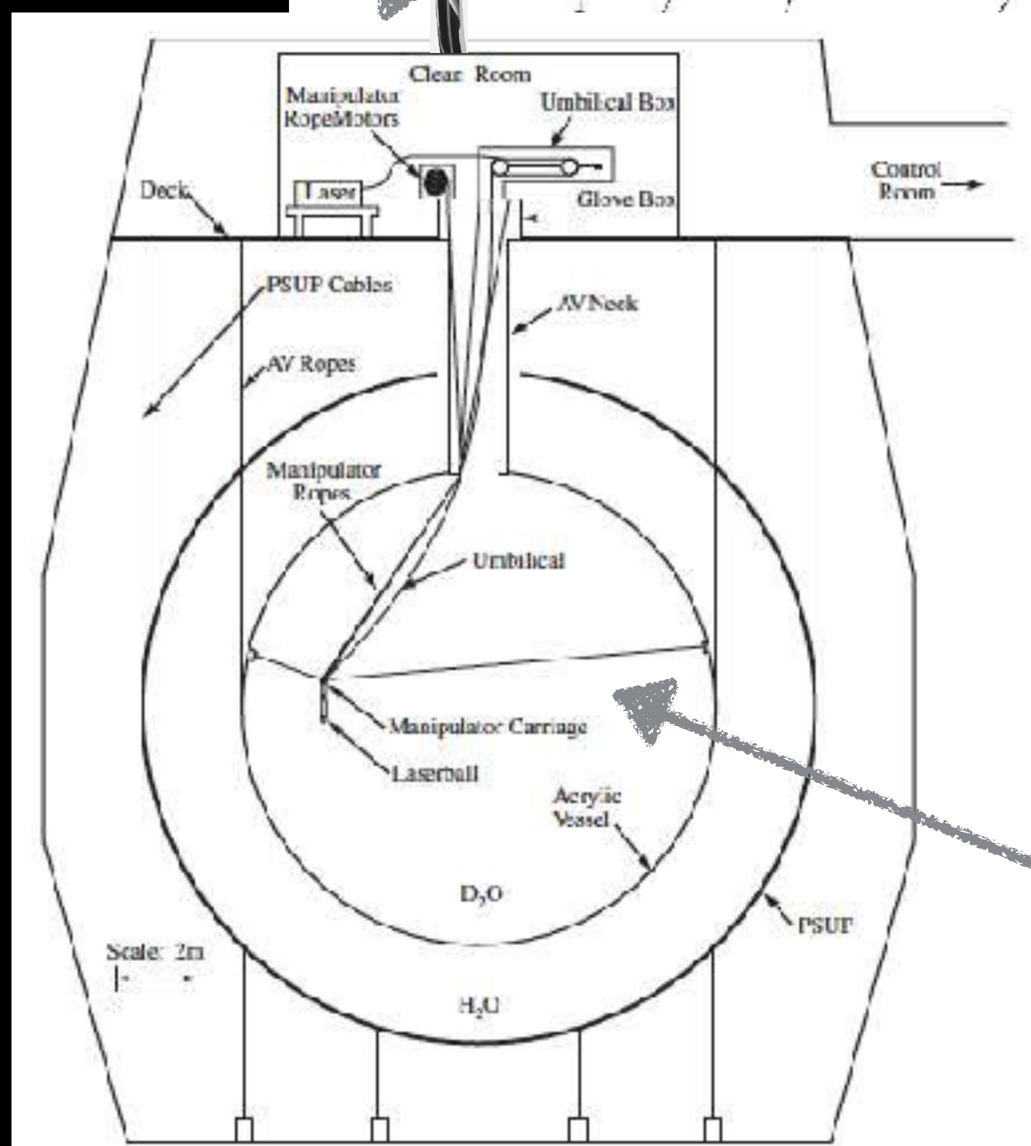
- Since 2016
  - completed installation
  - all channels working!



Internal calibration sources

Umbilical cable for fibers, elect. cables, gas tubes





Umbilical Retrieval Mechanism (LIP)
Move and control 26 meters of cable and rope, without letting Radon gas into the detector

Ropes for moving the source around

- Big Effort of Coimbra Workshop and Lab: Thanks!

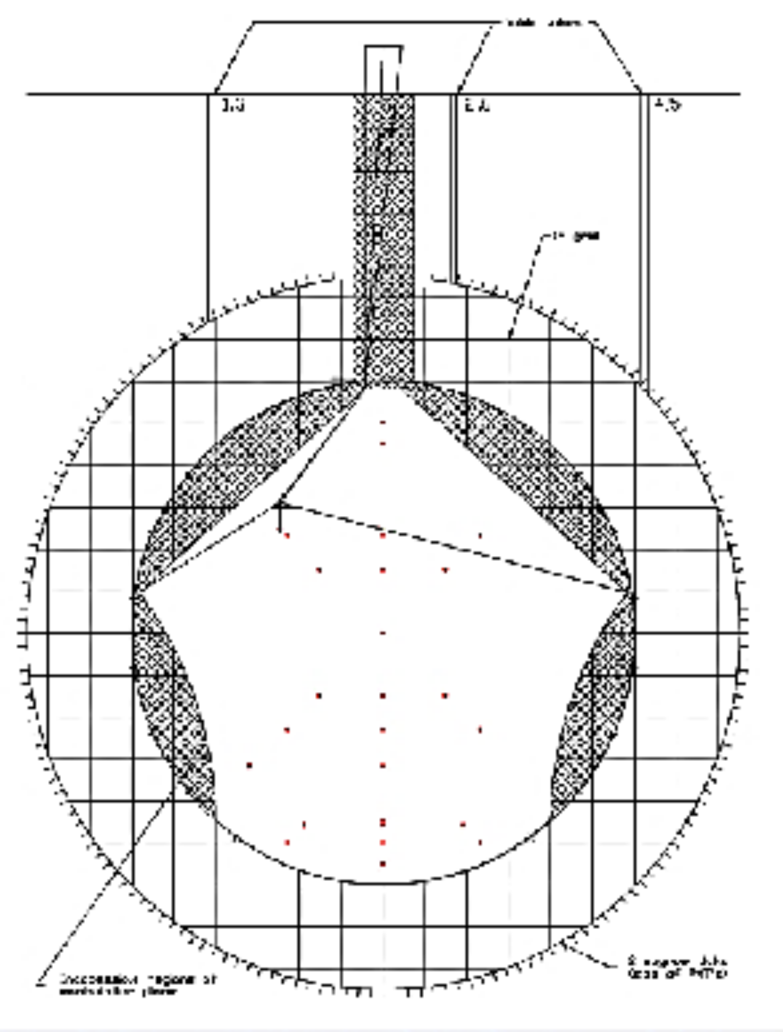
Coimbra, Sep. 2016

SNOLAB, Jan. 2017

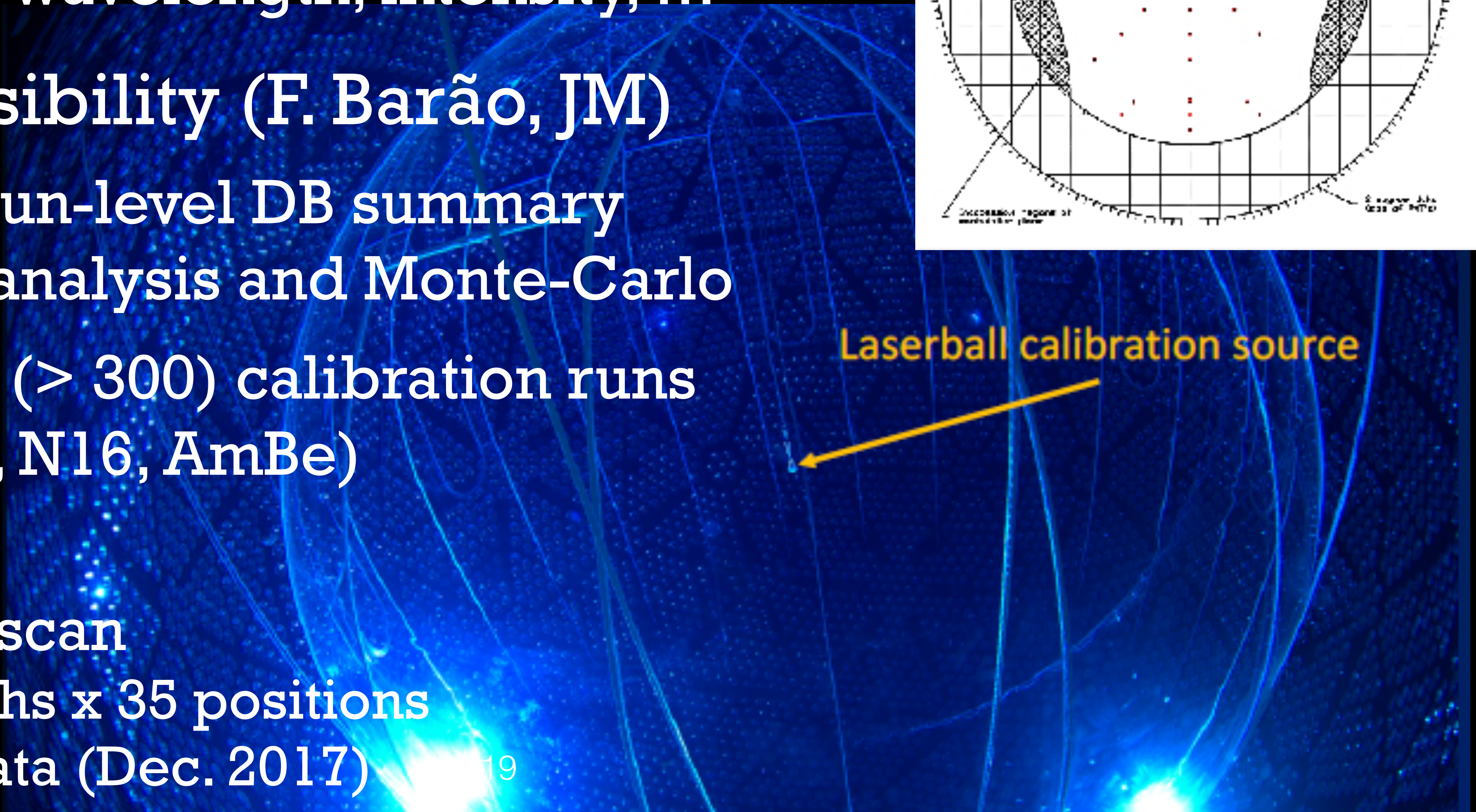
- Second system in construction, to be sent in 2018
- see A. Blanco this afternoon

Water phase calibration

- (using old SNO system)



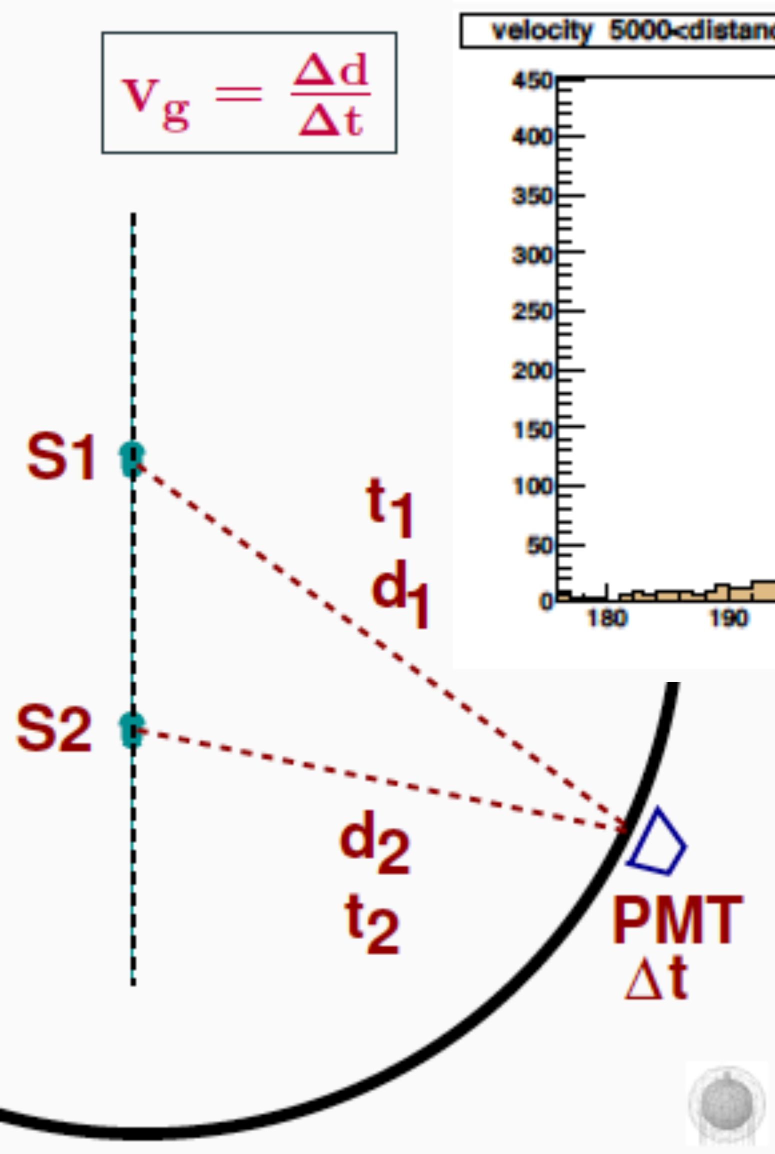
- Calibration hardware records data from source deployment
  - Source type, position, orientation, …
  - Laser rate, wavelength, intensity, …
- LIP responsibility (F. Barão, JM)
  - produce run-level DB summary tables for analysis and Monte-Carlo
  - used in all (> 300) calibration runs (Laserball, N16, AmBe)

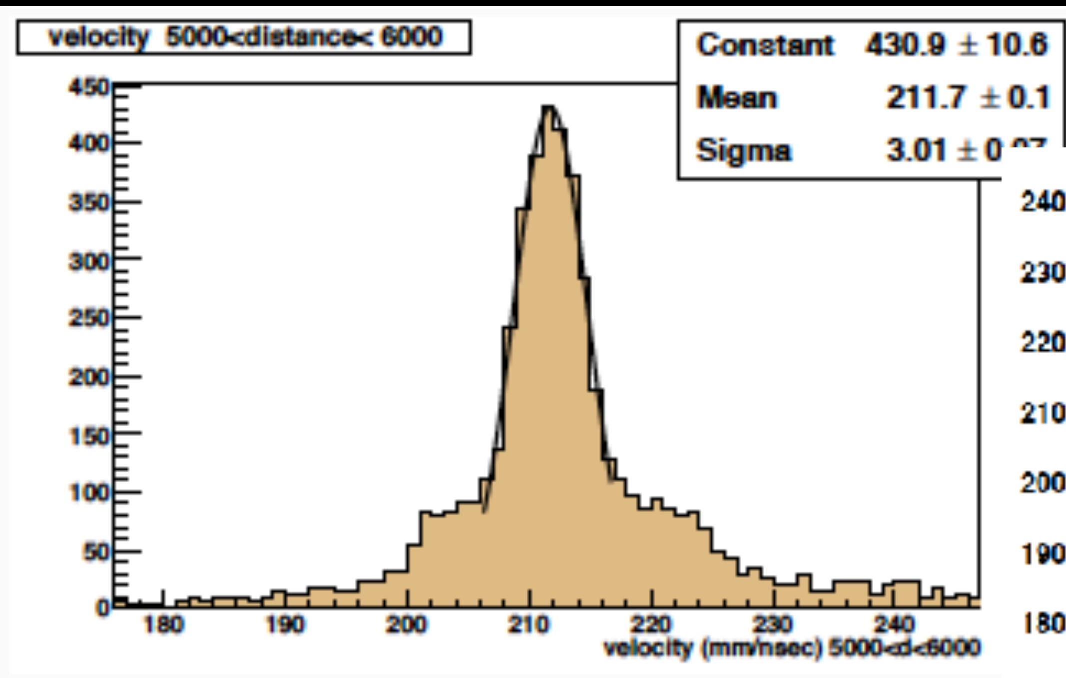


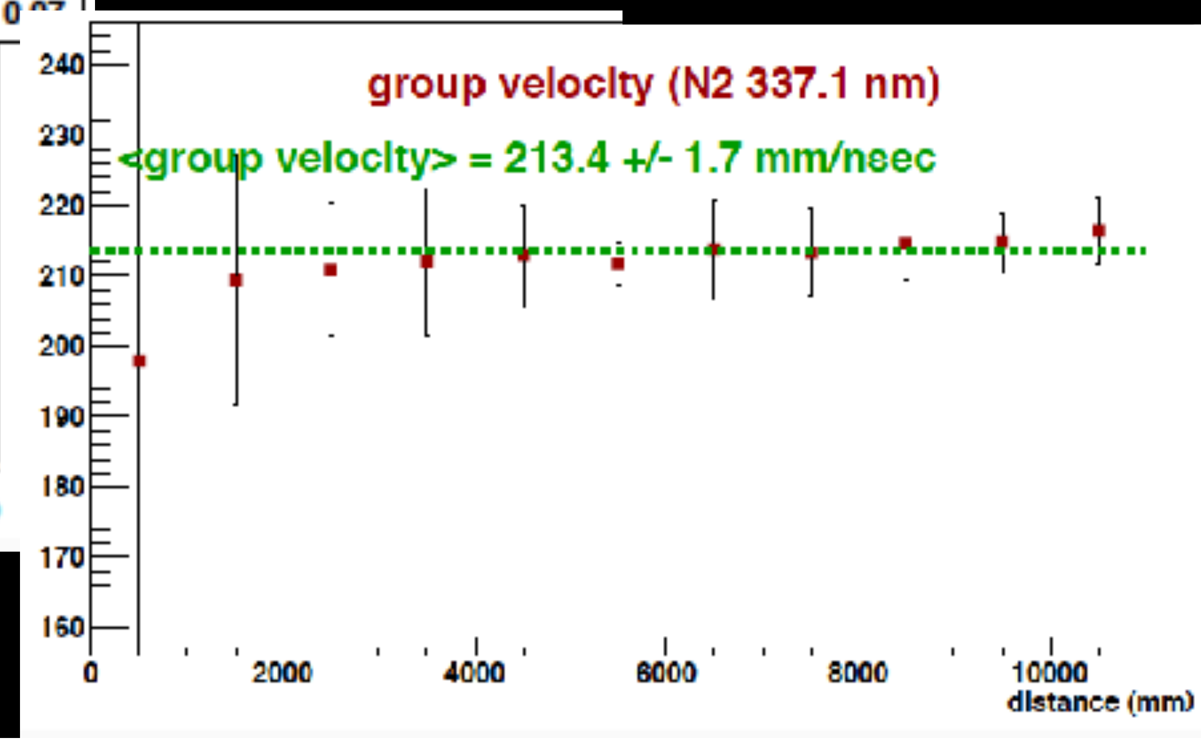
- Big laserball scan
  - 6 wavelengths x 35 positions
  - 1 week of data (Dec. 2017)

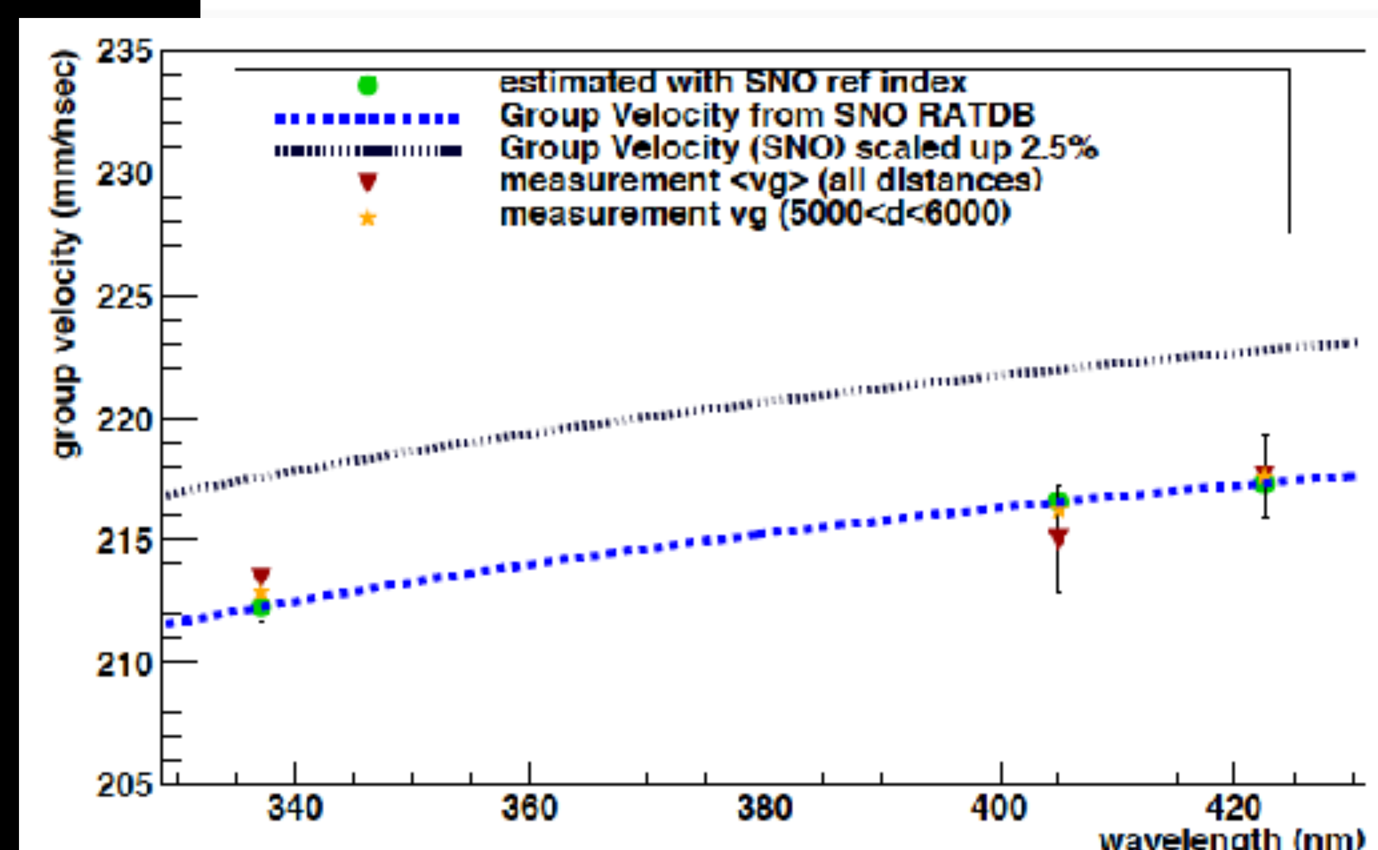
Group velocity check

- F. Barão, JM





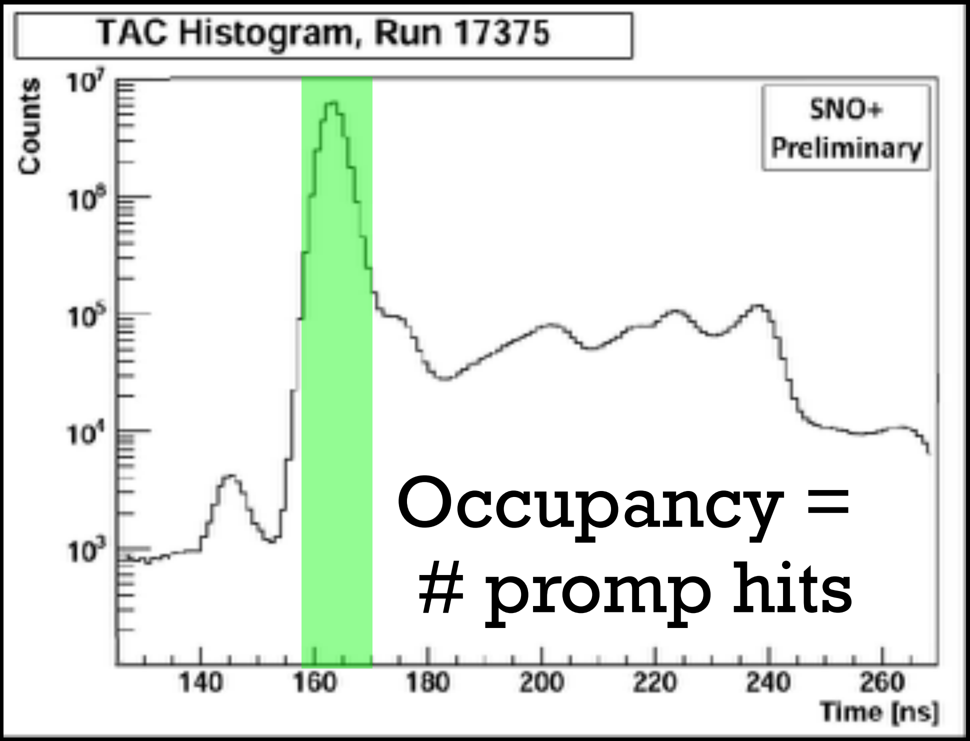


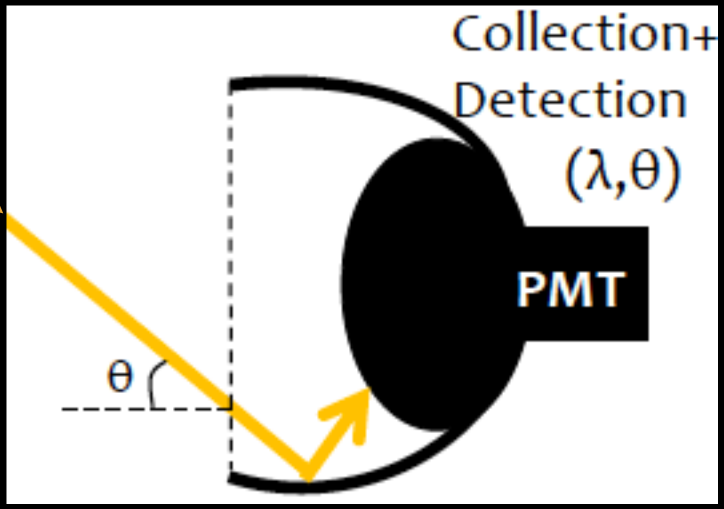


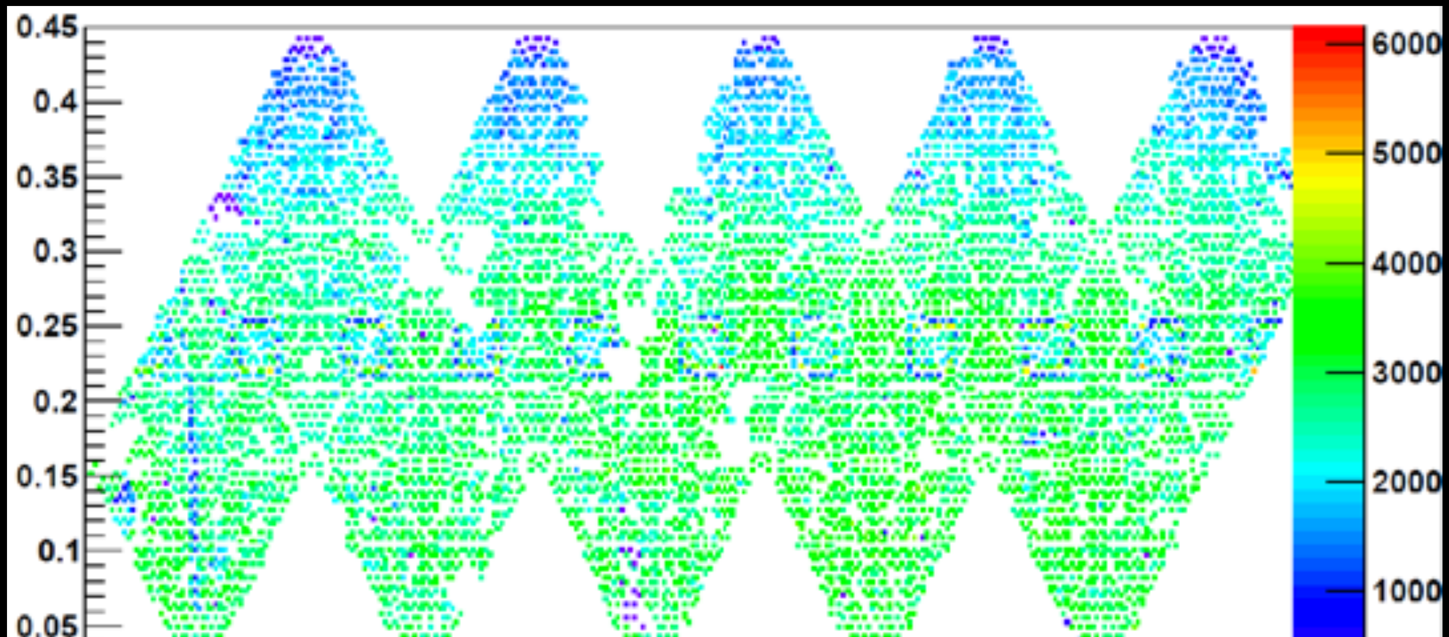
- Laserball vertical scan
  - position differences well-known
- Validated group velocity to better than 1%

Optical calibration

- Model occupancy as a function of source position and wavelength (remove shadows, etc)
- Fit water attenuation, source distribution, PMT response
  - follows reflectivity degradation -> to be used in scintillator phases







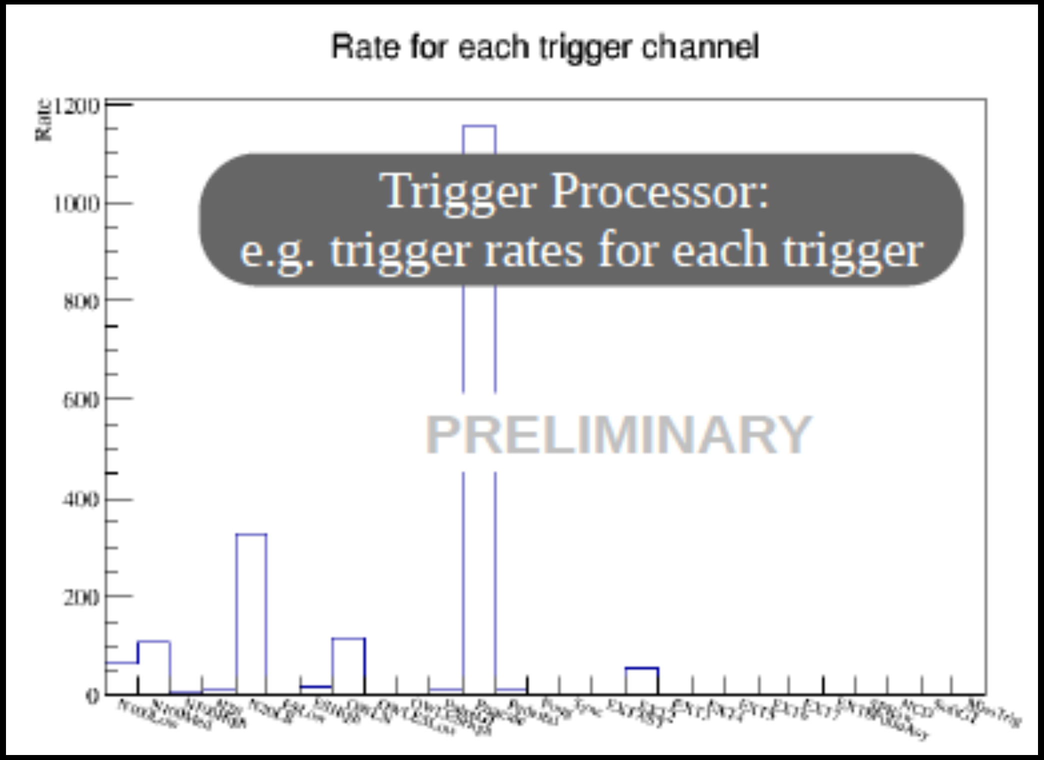
- See poster by Ana Sofia Inácio

LIP

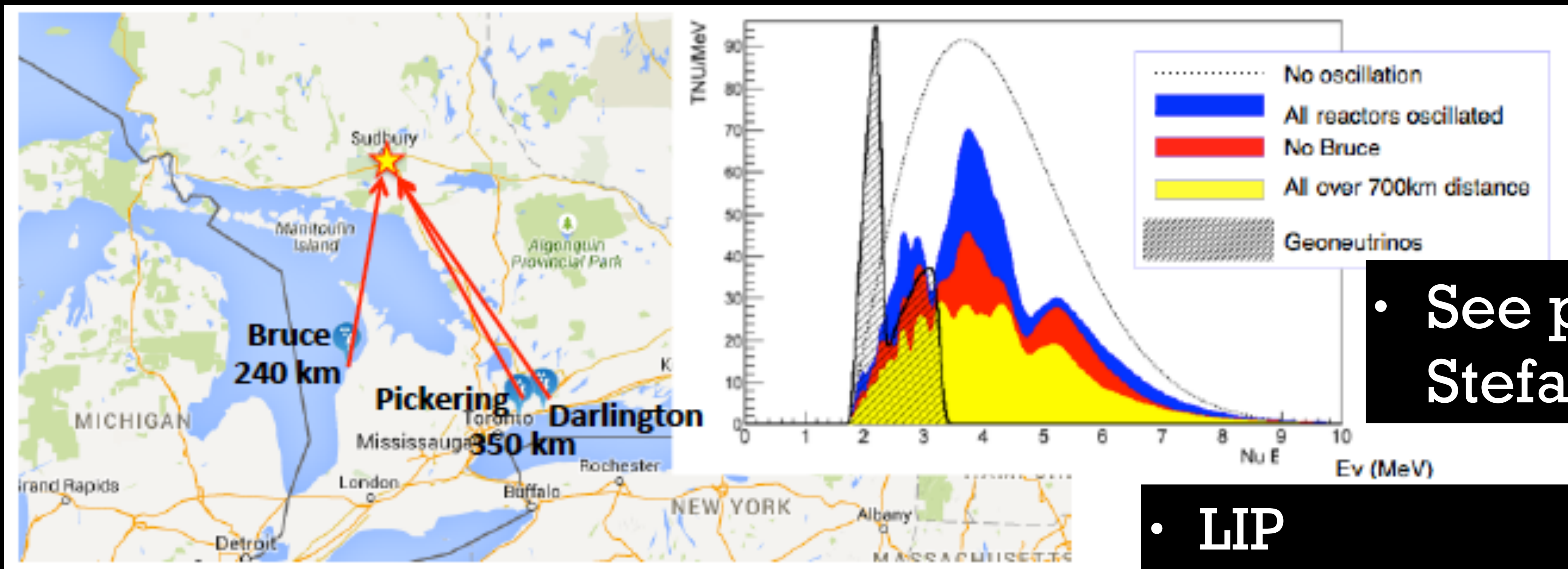
- JM, G. Prior working group conveners
- A.S. Inácio responsible for water phase laserball analysis

DQ/ Run Selection

- DQ low level
  - detector state/lab conditions
  - Ex.: HV nominal ? readout errors ?
- DQ high level, example checks:
  - Physics triggers OK?
  - Rates as expected ?
  - 10 MHz/50 MHz clocks agree ?
- Continuous data-taking 24/7 since > 1 yr
- Big job organizing the DQ checks, tuning the cuts, validating all runs
- LIP responsibilities
  - Gersende Prior Run Selection group leader
  - Stefan Nae RS analysis, DB browser



Reactor antineutrinos

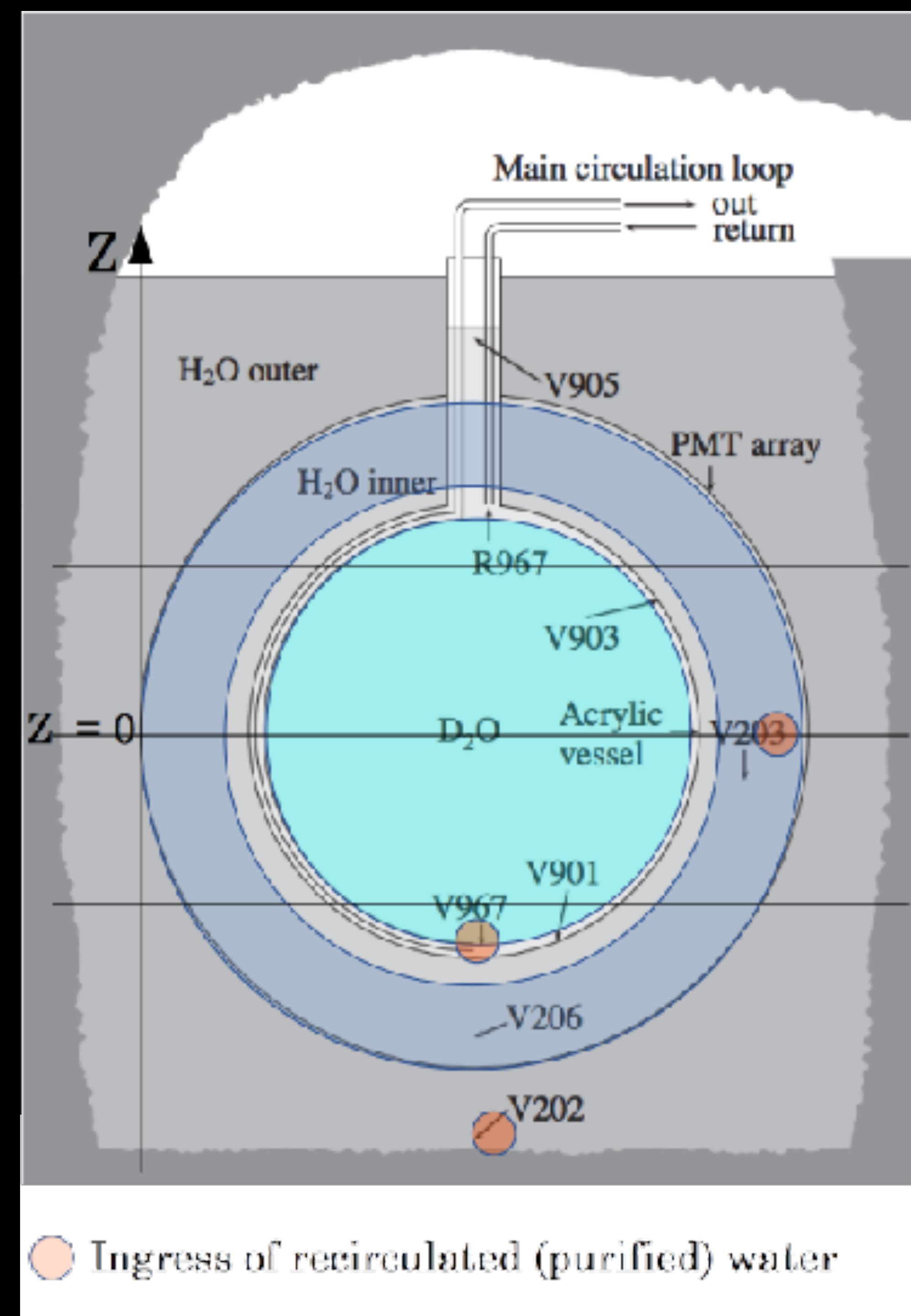


- See poster by Stefan Nae
- LIP
  - Sofia Andringa working group convener
- Currently focusing on water phase
  - never done with “normal” triggers in unloaded water Cherenkov detector
  - what data periods have good triggers/low bg ?
  - optimizing coincidence selection cuts
  - neutron efficiency calibration with AmBe source, Jan. 2018
  - currently analyzing the data, that mimics antinu signal

Water Backgrounds

- Identify "hot" regions, potential causes
- Daily data analysis by Valentina to monitor time evolution in ≠ zones, cross-check with re-circulation flow
- Identified issues with circulation routes, trigger settings
- Define cuts for nucleon decay analysis

- LIP responsibility
  - Valentina Lozza Backgrounds group leader



Next milestones

- Detector
  - Continue water phase calibrations & physics
  - Scintillator fill
  - Pure scintillator commissioning phase
  - Mix Tellurium in
  - Tellurium-loaded phase starts

2018

2019

- Scintillator plant
  - Commission scintillator plant
  - Install Telluric acid purification
  - Install diol purification

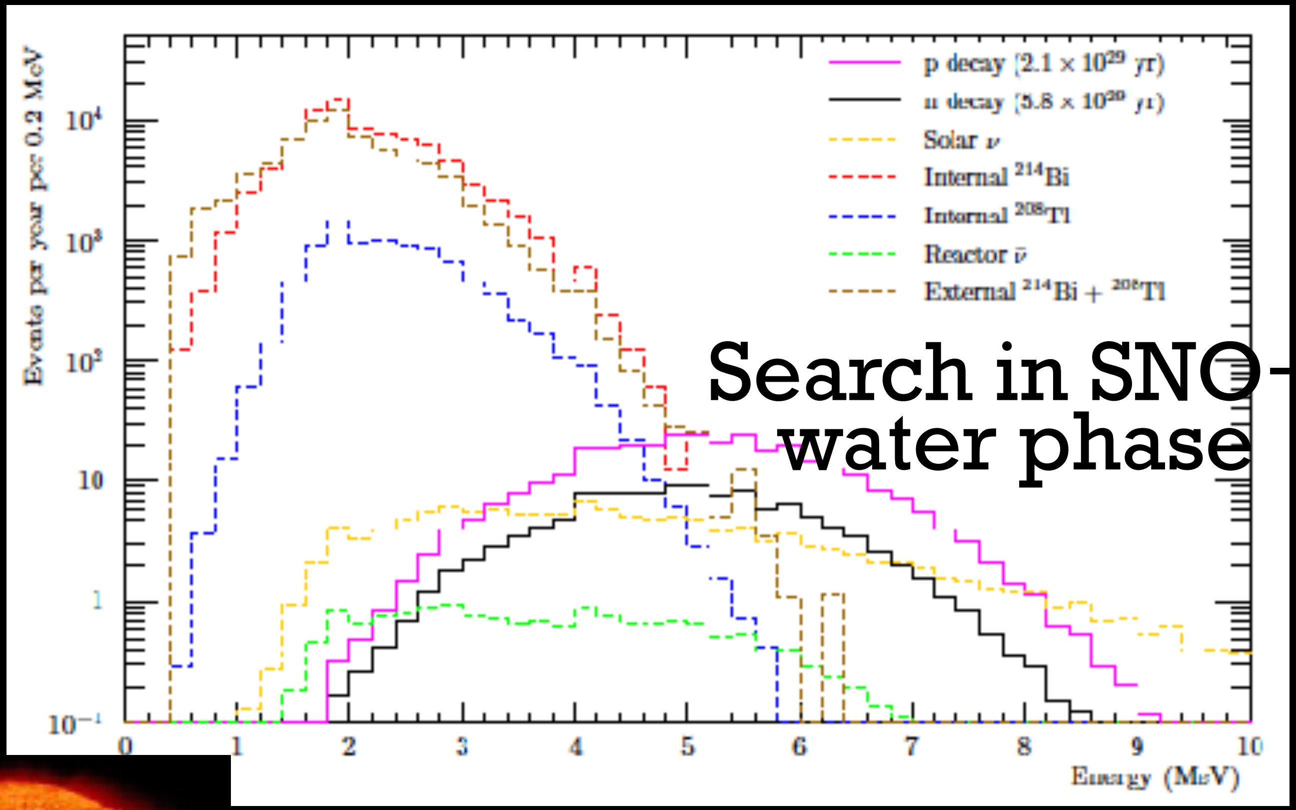
Physics in water and pure scintillator phases

- Invisible nucleon decay

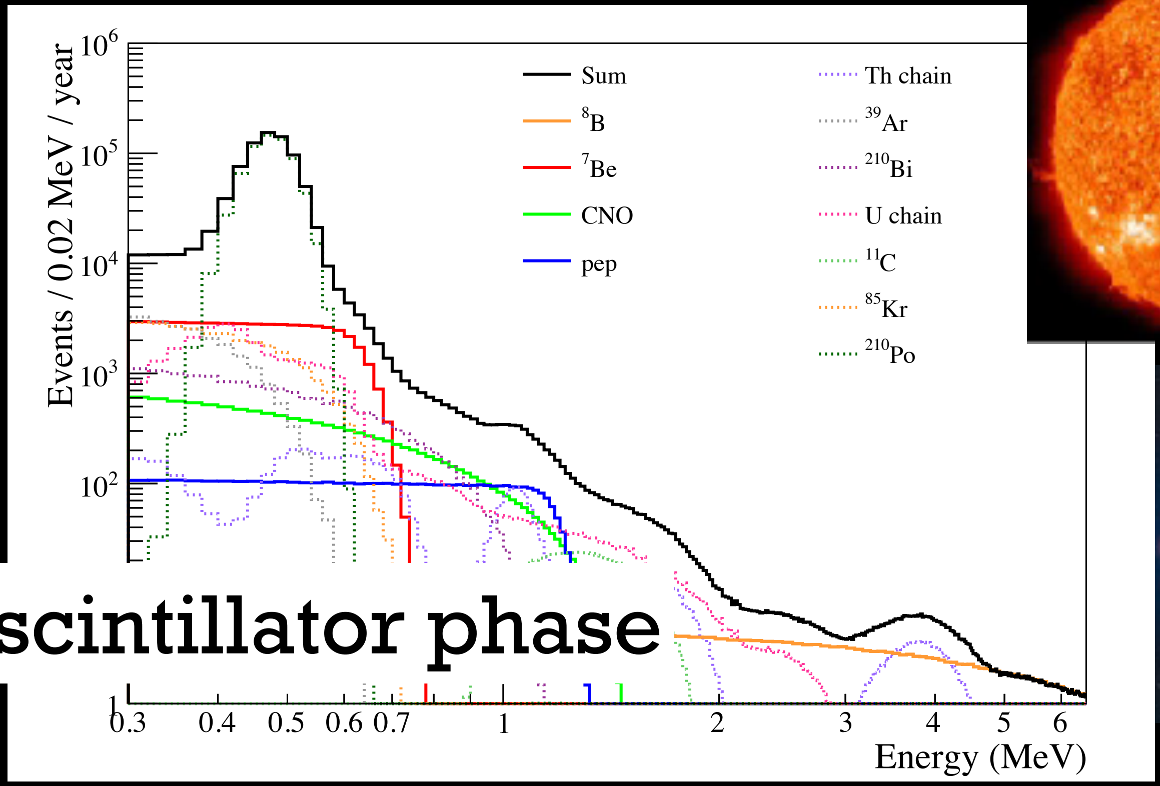
$$n \to \nu\nu\nu$$
$$p \to \nu\nu\, \text{x}$$

- leaves unstable nuclei

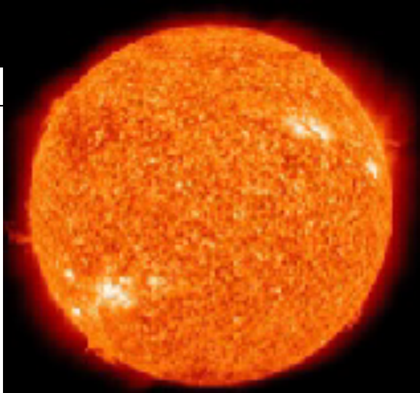
$$^{16}\text{O} \to {}^{15}\text{O}^* \to \sim 6\ \text{MeV}\ \gamma$$
$$({}^{15}\text{N}^* \to \sim 6\ \text{MeV}\ \gamma)$$



Search in SNO+ water phase



scintillator phase



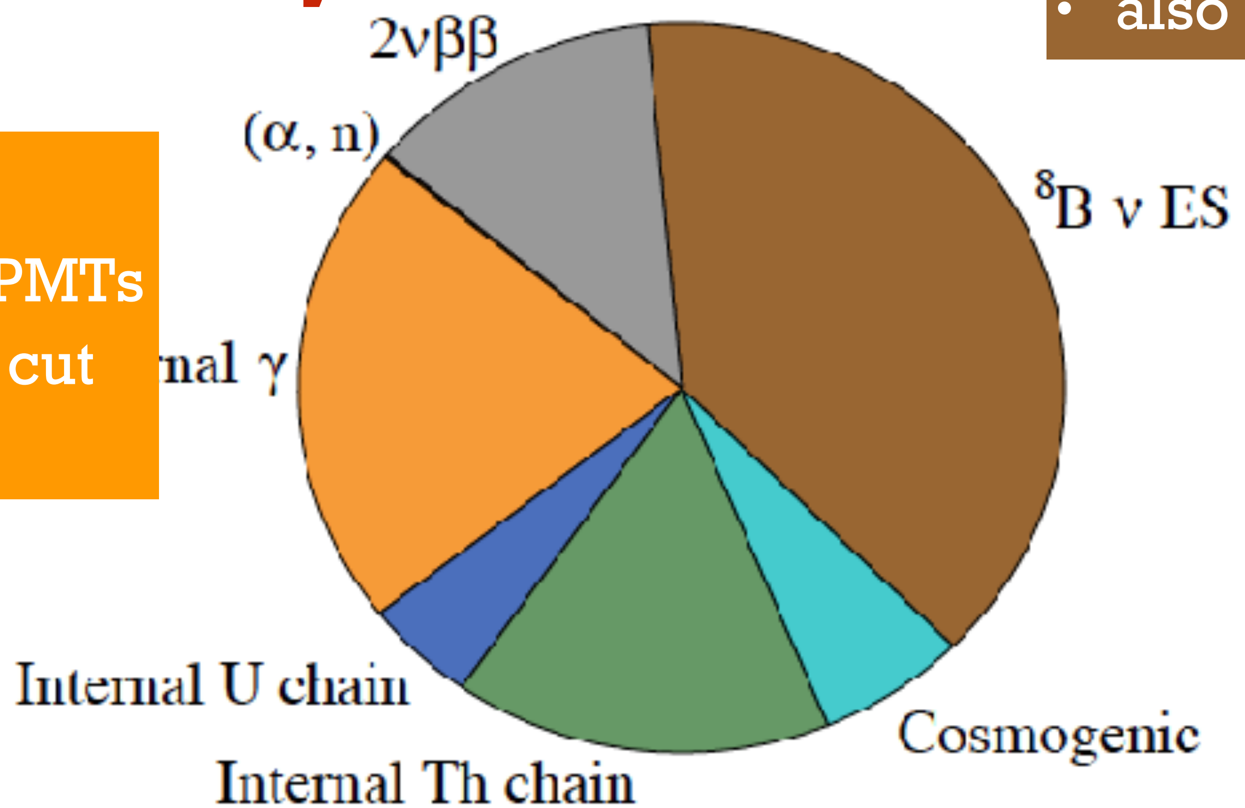
- Solar neutrinos
  - search for non-standard oscillations
  - constrain solar models
- Supernovae neutrinos
  - low threshold interesting for ν-proton scattering

Backgrounds for 0νββ search

Two neutrino mode 2νββ:
- asymmetric ROI around the 0νββ signal
- limited by energy resolution

^{8}B solar neutrinos:
- flat spectrum
- constrained by SNO/SK data
- also limited by resolution

14 ev/yr in FV and ROI



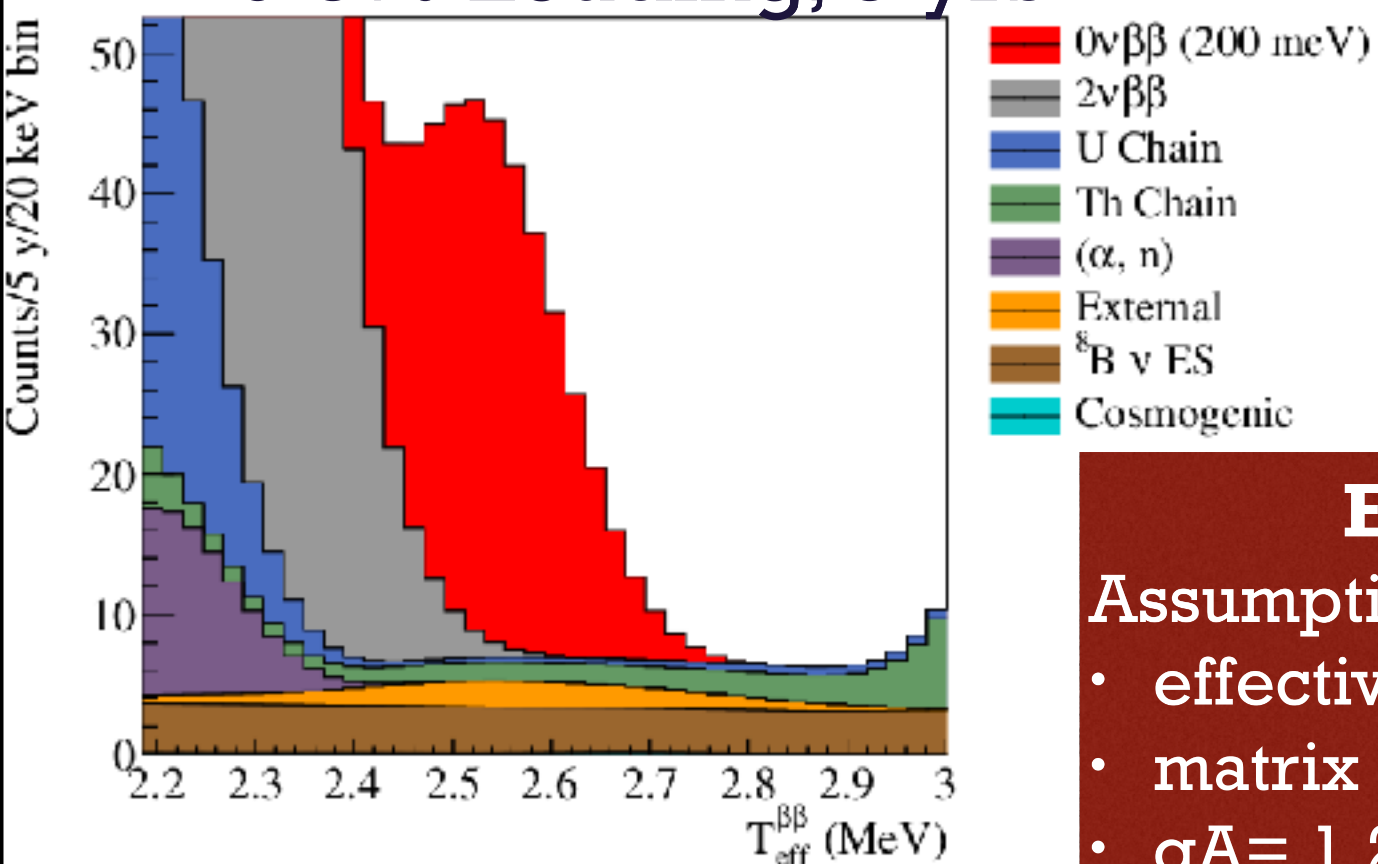
External gammas:
- from AV, ropes, water, PMTs
- fiducial volume (20%) cut
- requires good timing

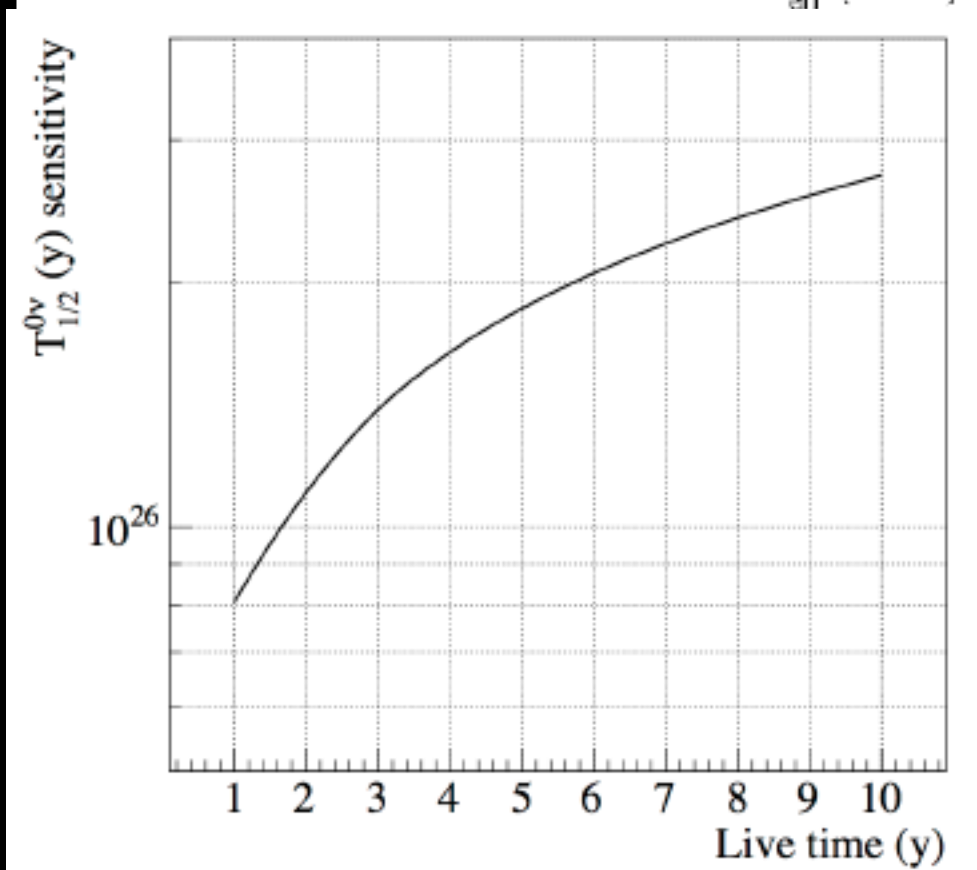
Internal U/Th chain
- betas from ^{214}BiPo, ^{212}BiPo
- tagged with β-α time-correlations
- same trigger window: x50 rejection
- different trigger window: 100% rejection

Cosmogenics:
- ^{124}Sb, ^{60}Co, ^{110m}Ag, ^{88}Y, ^{22}Na
- reduced by purification and "cool-down" UG storage
- Below 1 ev/yr in ROI/FV

Sensitivity

0.5% Loading, 5 yrs.





Expected spectrum for 5 yrs.

Assumptions (theory):

- effective ν mass: 100 meV
- matrix element = 4.03 (IBM-2)
- gA= 1.269, G = 3.69×10^{-14} yr^{-1}

Assumptions (expt.):

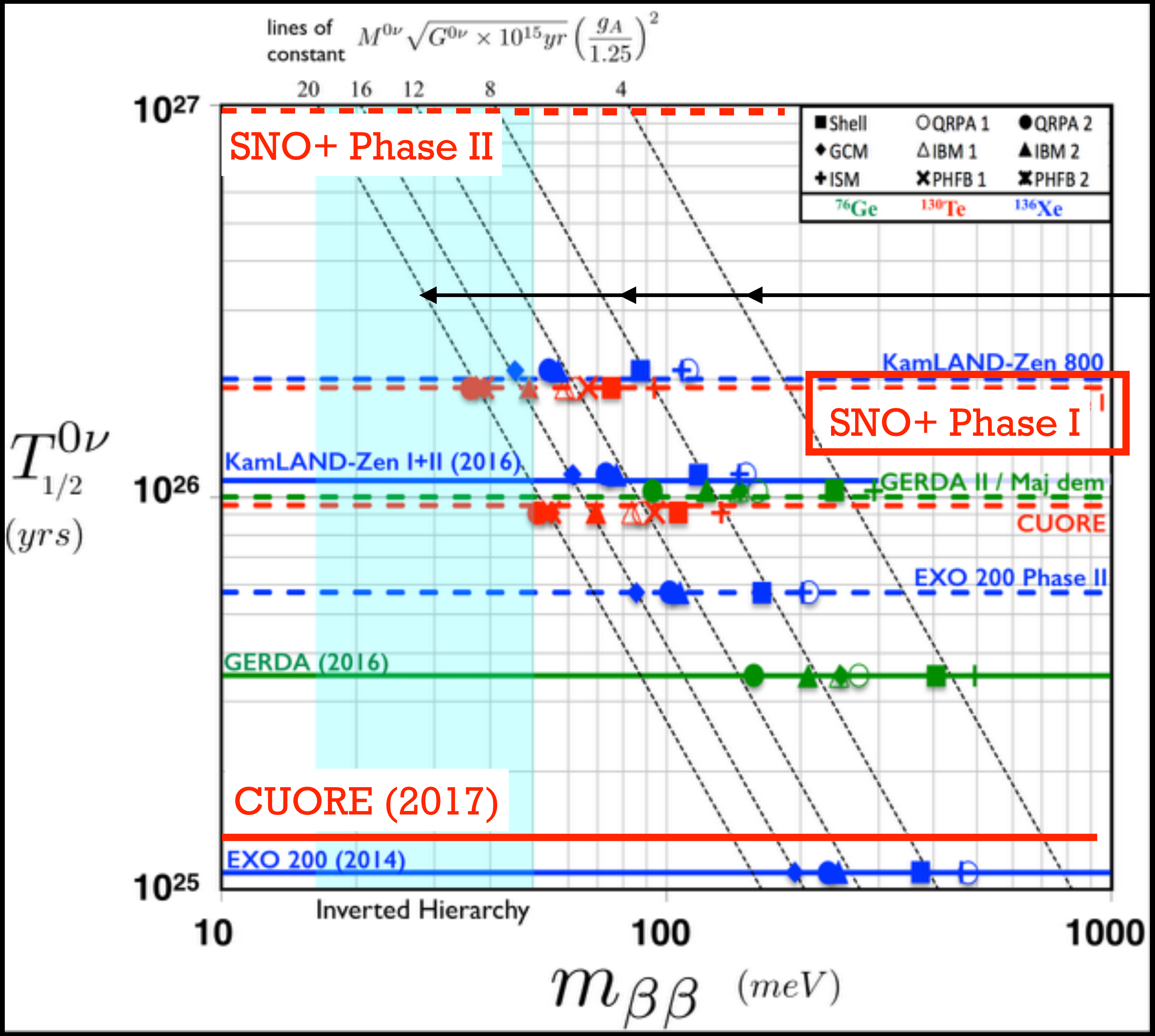
- 0.5% ^{nat}Te loading
- R < 3.5 m (FV= 20%)
- > 99.99% (98%) rejection of ^{214}BiPo (^{212}BiPo)
- light yield 390 Nhits/MeV

$T_{1/2} \geq 2 \times 10^{26}$ yr (90% CL, 5 yr)

$m_{\beta\beta} \approx 40 - 90$ meV

Comparison with other experiments

Higher $T_{1/2}$ is better



We don't know which of the nuclear models (diagonal lines) is best.

Large uncertainties.

Need experiments with different isotopes!

Lower $m_{\beta\beta}$ is better

Summary and outlook

- SNO+: large amounts of Tellurium in liquid scintillator
  - Expect to reach the top of the inverted hierarchy, with 0.5%, and potentially better with higher loadings in Phase II
- Progress on many fronts: taking water data!
- LIP participation since the beginning, and growing
  - Calibration systems, analysis methods
  - Data quality; selection of good physics runs
  - Characterizing backgrounds from radioactivity: external gammas, correlated decays, cosmogenics
  - Antineutrino search: neutron response in scintillator and water
- Looking also for future experiments
  - considering participating in DUNE, long-baseline neutrino oscillation experiment with beam from Fermilab

SNO+ Outlook

- Detector full with water, and taking data!
  - Busy with analysis, calibrations…
  - Soon, scintillator data and then Tellurium!

Acknowledgements

This work was partially funded by Fundação para a Ciência e a Tecnologia (FCT, Portugal) through the following project grants:

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- EXPL/FIS-NUC/1557/2013
- IF/00863/2013/CP1172/CT0006
- PTDC/FIS/115281/2009

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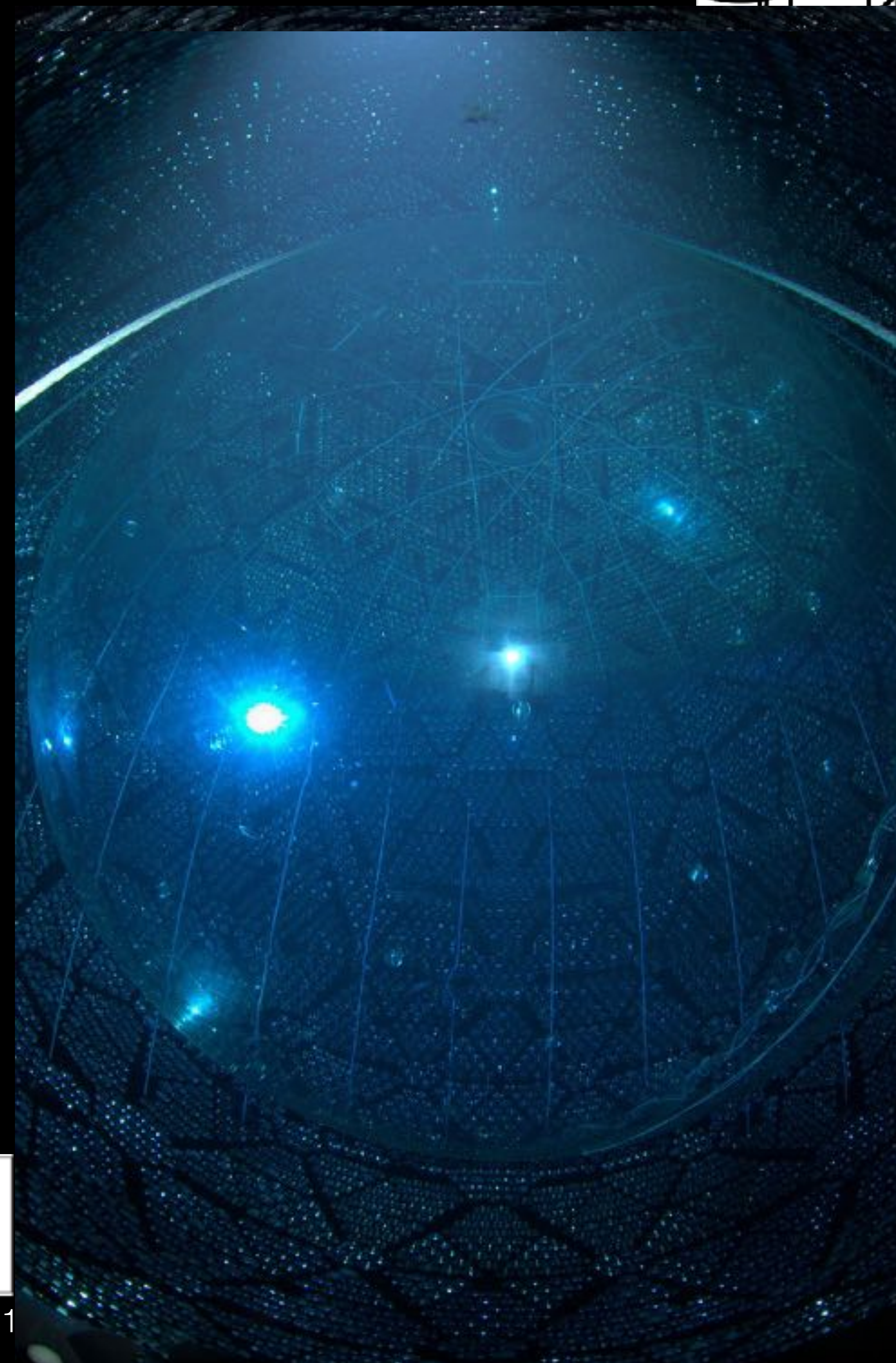
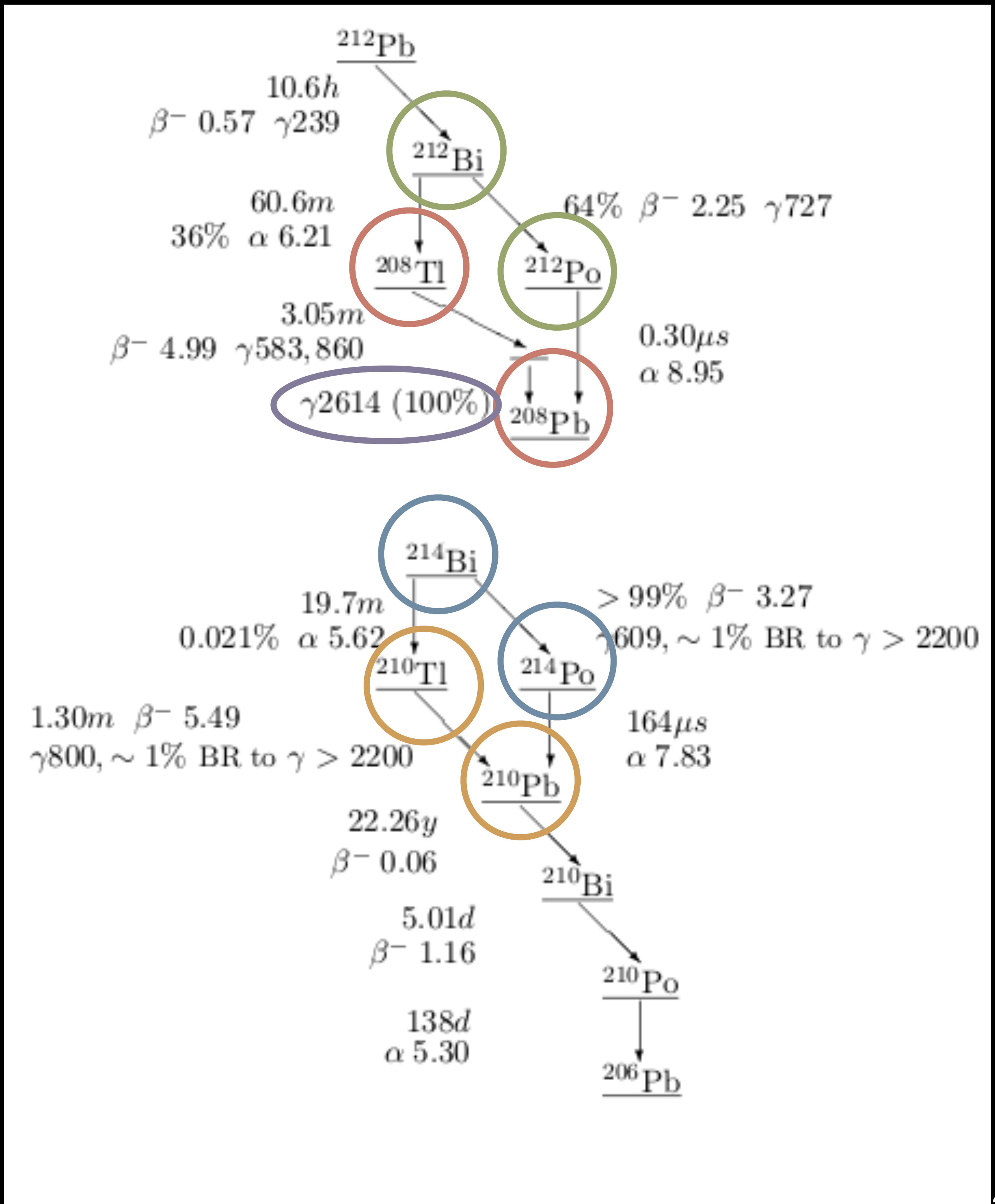
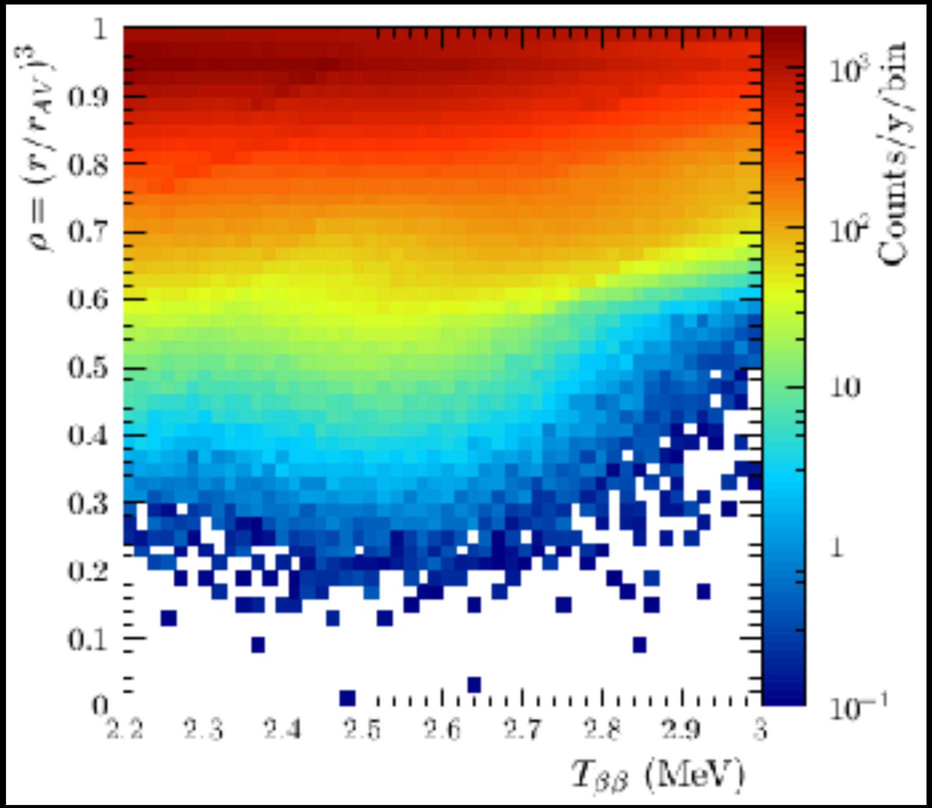


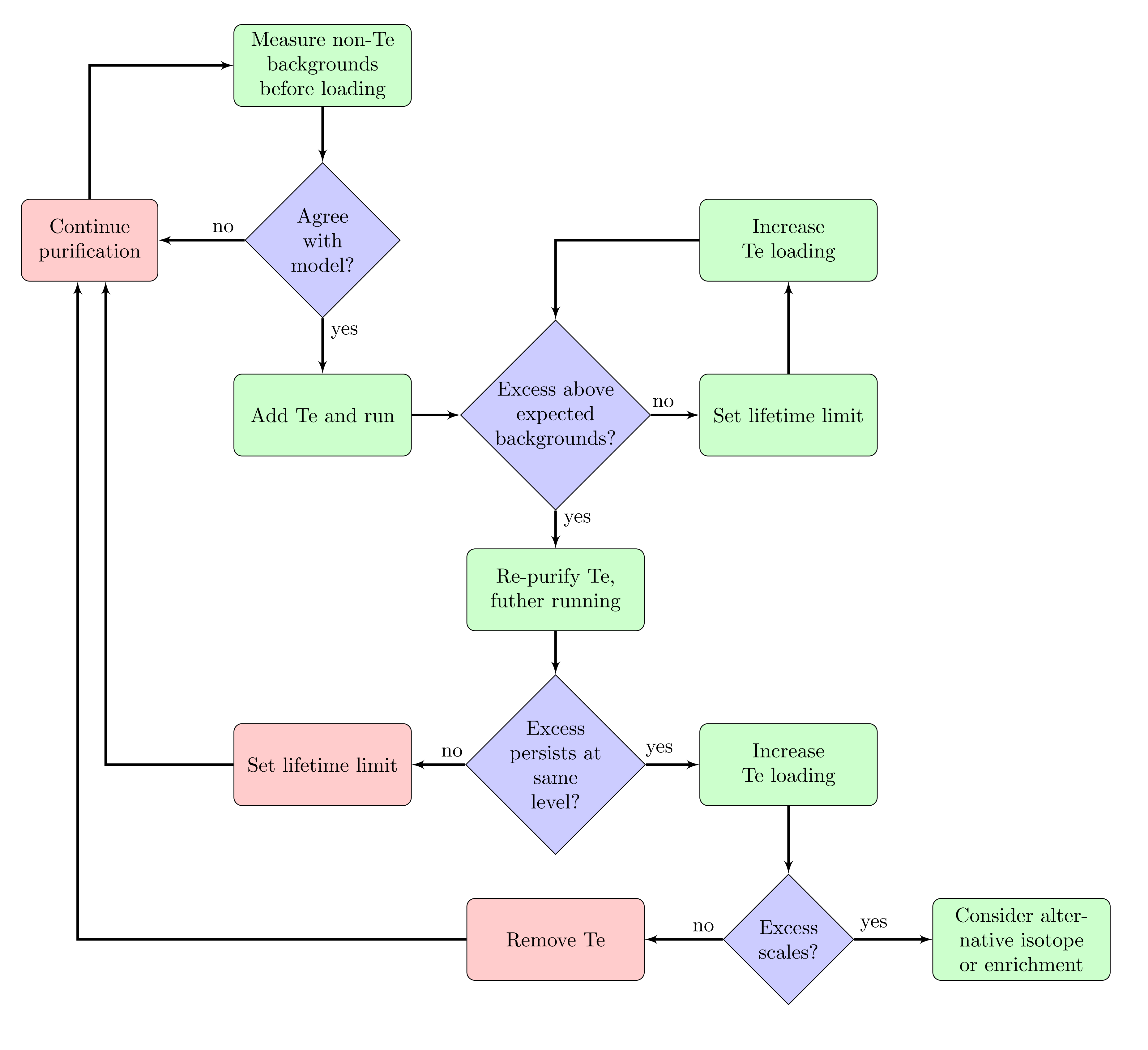
Extra slides

Int./Ext. Backgrounds



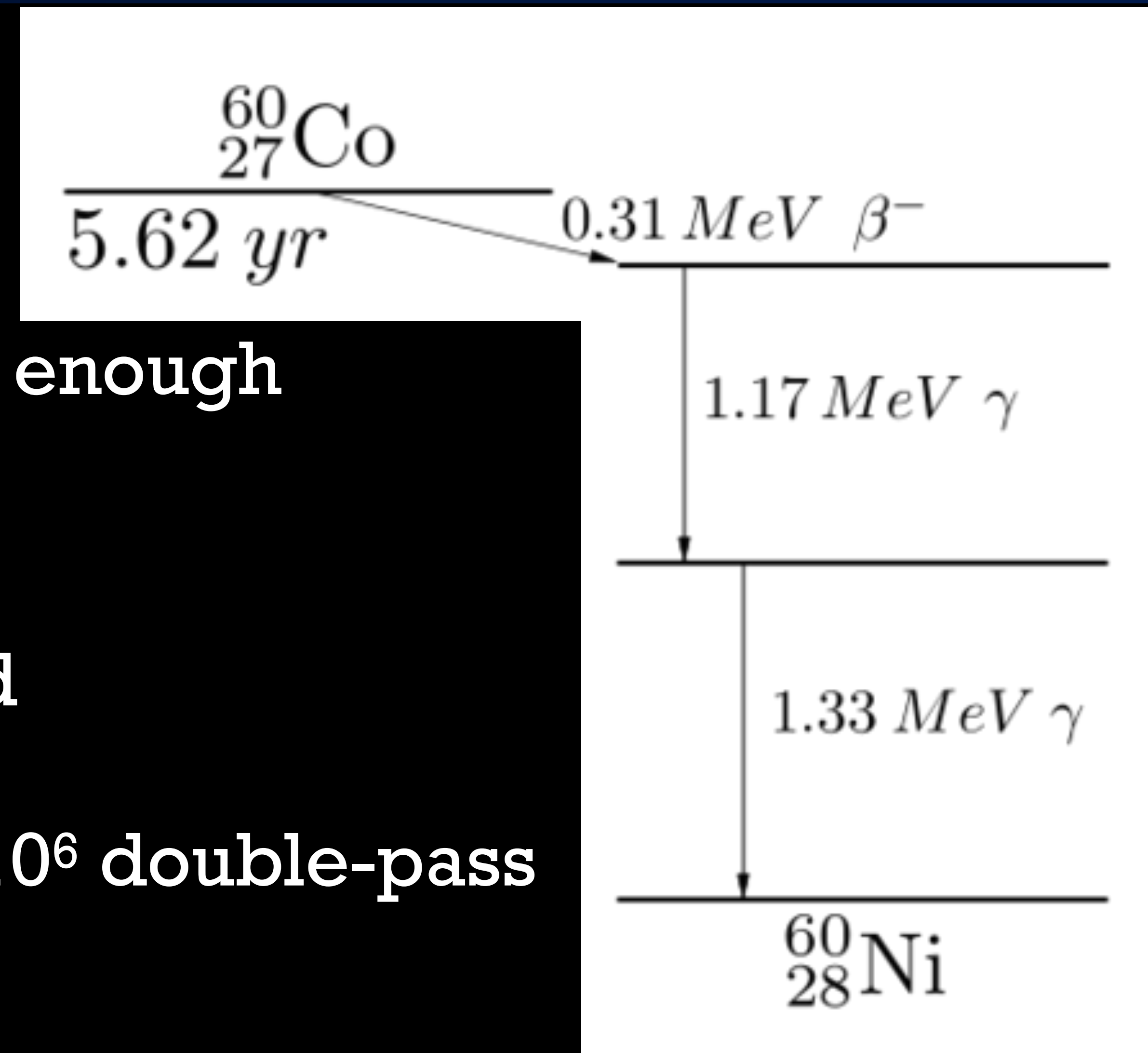


What if we see a bump?



Tellurium purification

V. Lozza and J. Petzoldt, Cosmogenic activation of a natural tellurium target, Astroparticle Physics 61 (2015) 62-71.

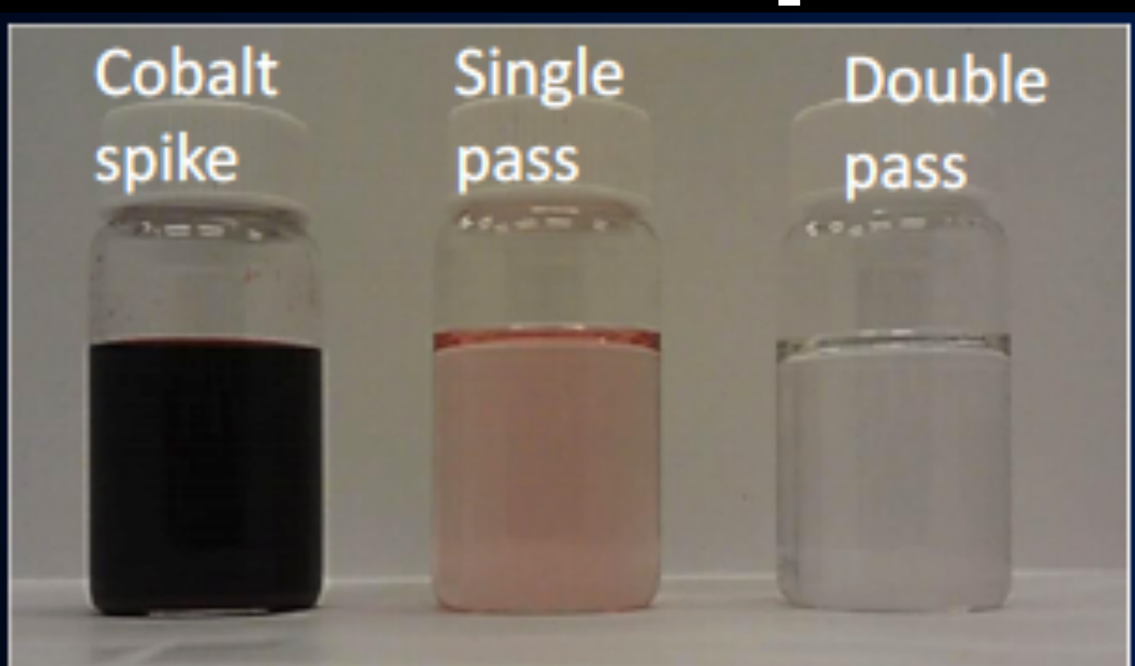


Activation of Tellurium by cosmic rays produces isotopes w/ decays close to DBD peak and w/ long half-lives:

- "Cooling down" UG helps, but is not enough

<u>Purification Method:</u>

- dissolve Te-acid in water, filter
- force re-crystallization, w/ nitric acid
- pump away liquid, rinse
- Cobalt efficiency: 10^2-10^3 per pass, 10^6 double-pass
- done UG to avoid quick build-up



S. Hans et al., NIMA795 (2015) 132-139

Pilot plant: 10 kg
Now building full scale:
200 kg per batch

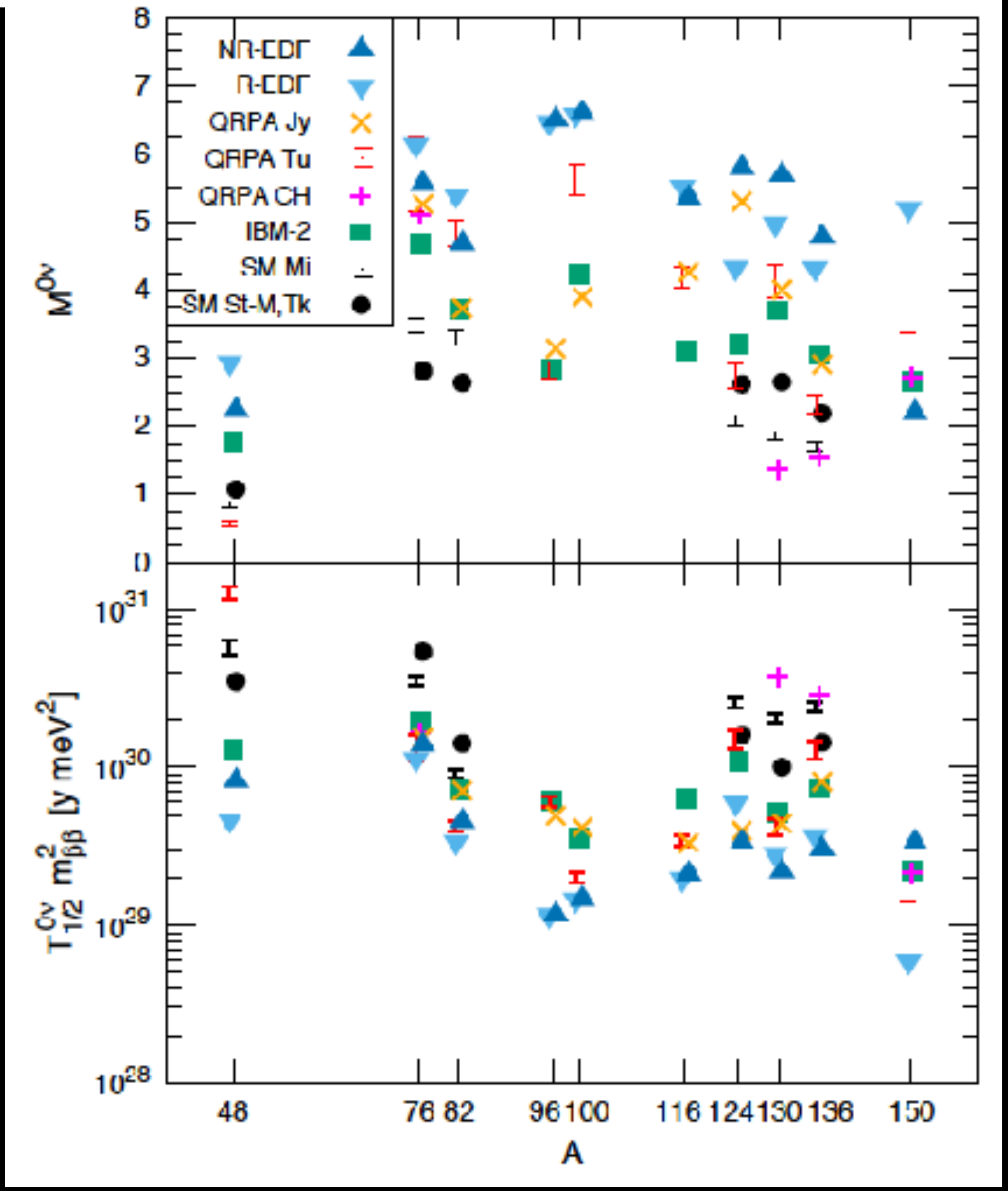
From half-life to $m_{\beta\beta}$

$$m^{\nu}_{ee} = m_1 c^2_{12} c^2_{13} + m_2 s^2_{12} c^2_{13} e^{2i\alpha_2} + m_3 s^2_{13} e^{2i(\alpha_3+\delta)}$$

$$\frac{1}{T^{0\nu}_{1/2}} = \boxed{G_{0\nu} |\mathcal{M}_\nu|^2} \left| \frac{m^{\nu}_{ee}}{m_e} \right|^2$$

Half-life

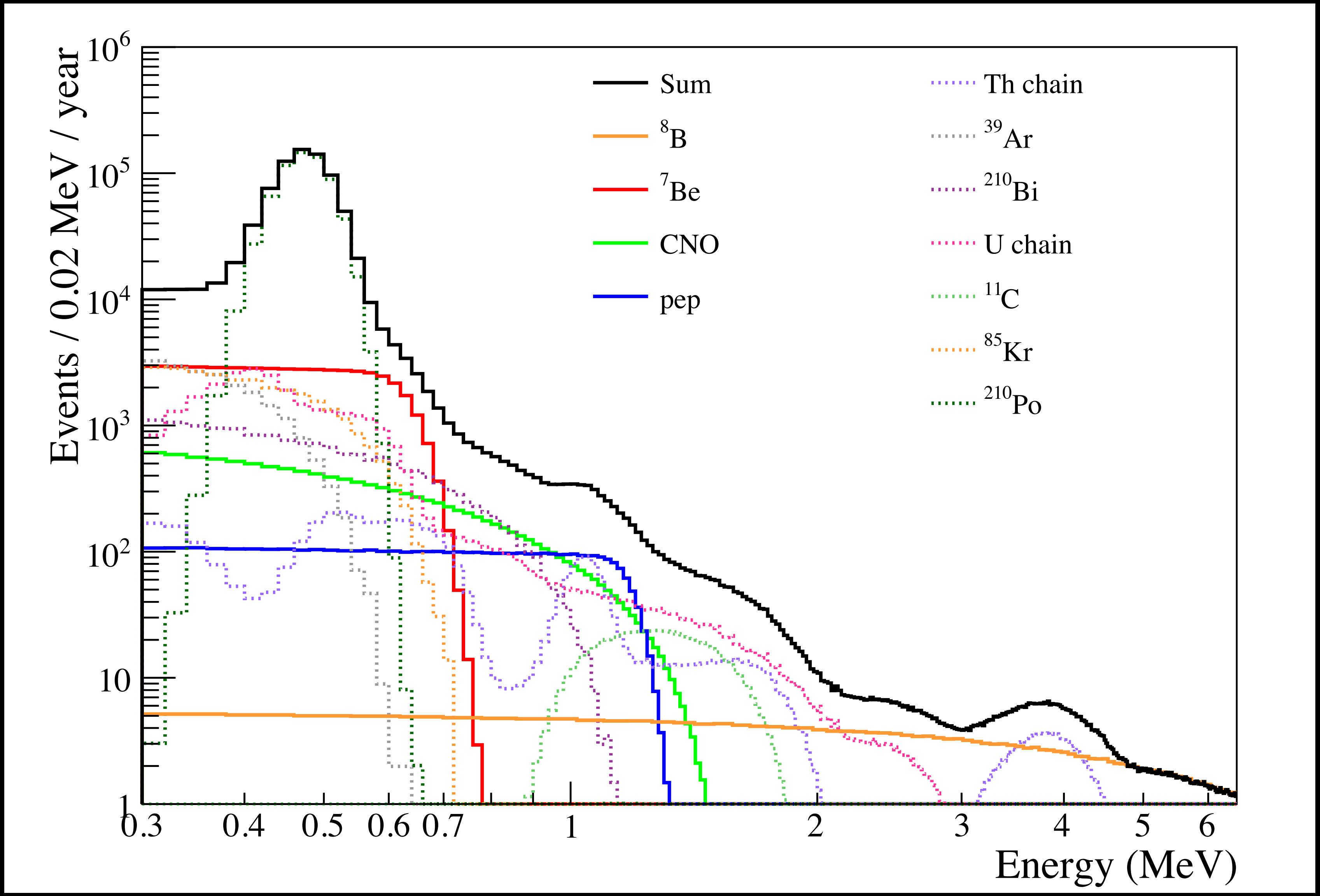
Nuclear Physics terms



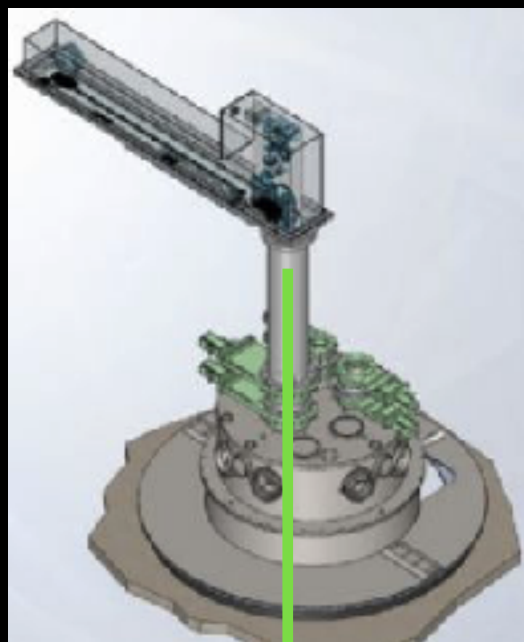
Wide variation in nuclear matrix element predictions
Essential to measure with several isotopes

arXiv:1610.06548

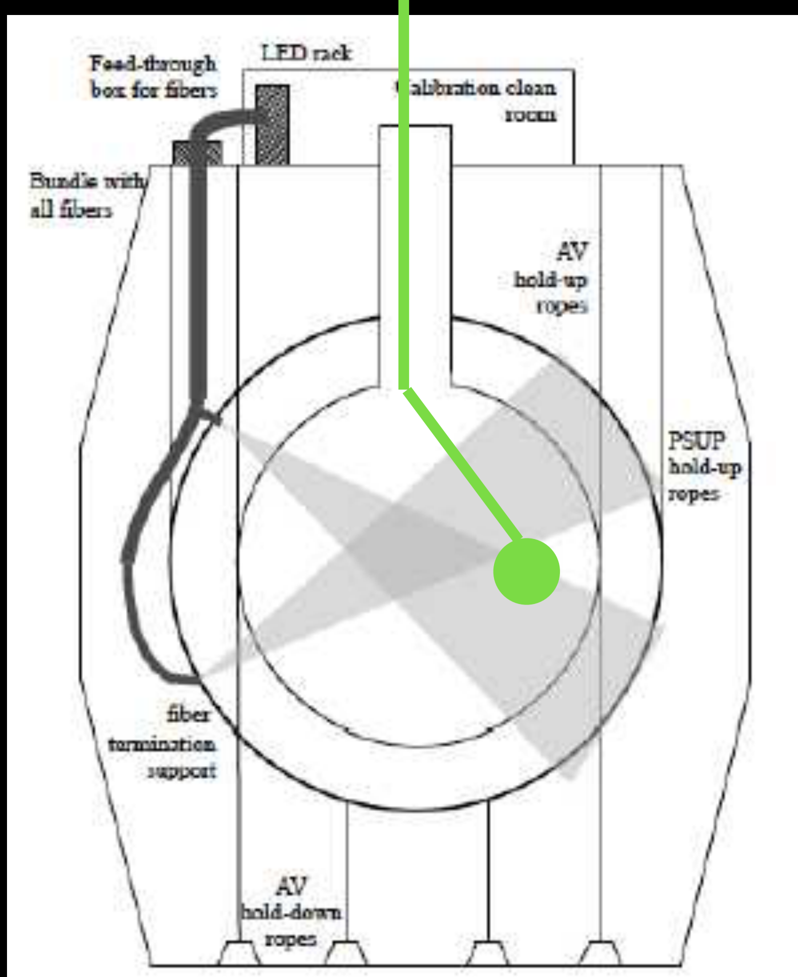
Solar spectrum



Calibration overview



- Types of sources
  - radioactive (gamma, neutron) or optical (lasers, LEDs)
- But avoid introducing radioactivity!



- Two approaches
  - external light sources (fibers) for frequent use
  - sources inside the AV. Very careful material selection and sealing of mechanism

TABLE 1: Calibration sources that are considered for use by the SNO+ experiment.

Source	AmBe	^{60}Co	^{57}Co	^{24}Na	^{48}Sc	^{16}N	^{220}Rn/^{222}Rn
Radiation	n, γ	γ	γ	γ	γ	γ	α, β, γ
Energy [MeV]	2.2, 4.4 (γ)	2.5 (sum)	0.122	4.1 (sum)	3.3 (sum)	6.1	various