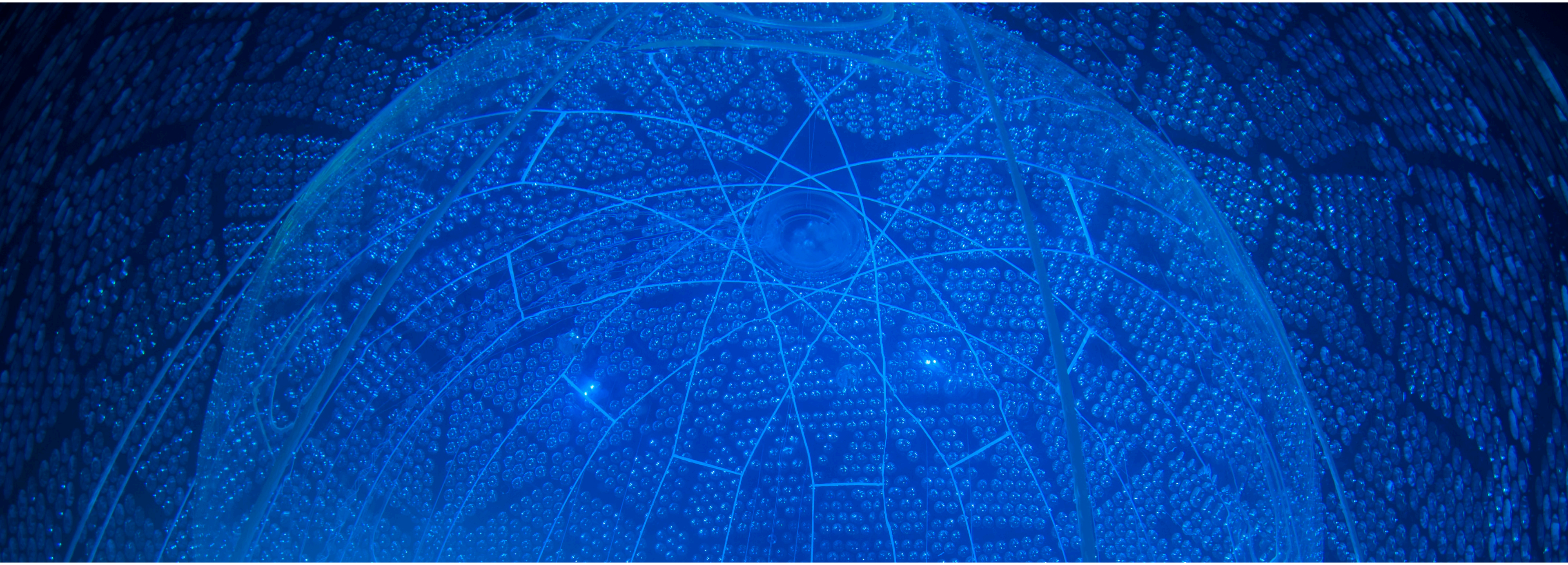
The Search for Neutrinoless Double-Beta Decay at SNO+



Meng Luo,
for the SNO+ Collaboration
31 July 2019

APS | DIVISION OF PARTICLES & FIELDS

SNO+

SNO+ Collaboration

Univ. of Alberta, Laurentian Univ., Queen's Univ., SNOLAB, TRIUMF

UC Berkeley/LBNL, Boston Univ., BNL, Univ. of Chicago, UC Davis, Univ. of Pennsylvania

Lancaster Univ., Univ. of Liverpool, Univ. of Oxford, QMUL, Univ. of Sussex, King's College London

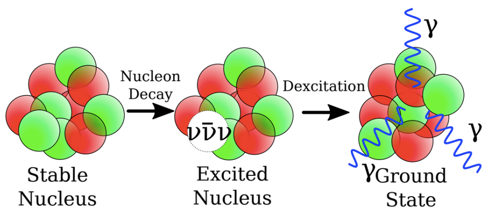
Laboratório de Instrumentação e Física Experimental de Partículas (LIP)

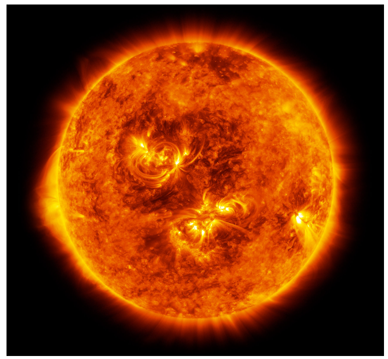
Technische Universität Dresden

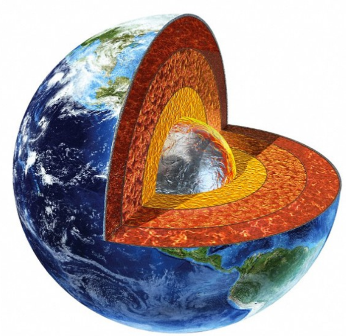
Universidad Nacional Autónoma de México

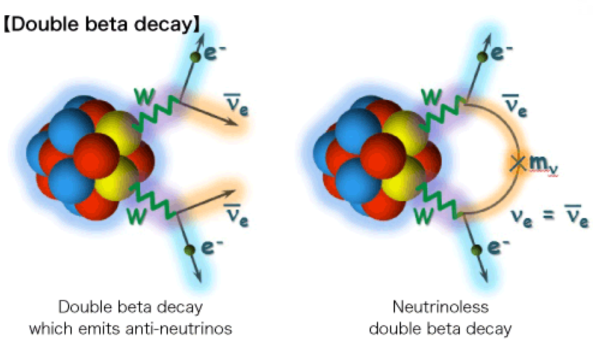
The SNO+ Experiment

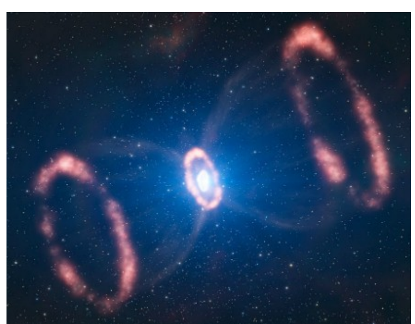
A Multi-Purpose Particle Experiment









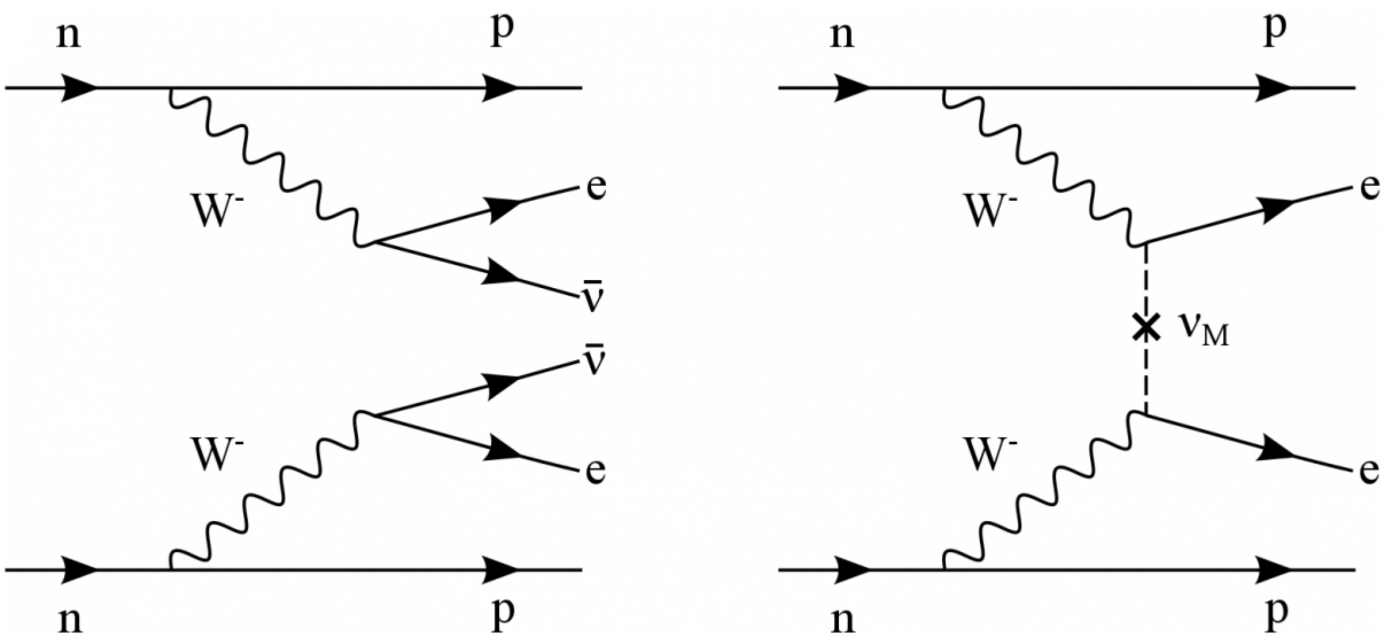


- **One experiment, lots of physics**
  - **Water Phase** (2017-18)
    - Nucleon decay (published!)
    - ^{8}B solar ν (published!)
    - Reactor anti-ν
    - Detector calibration
    - Background measurement
  - **Scintillator Phase** (2019)
    - Low energy solar ν
    - Geo and reactor anti-ν
    - Background measurement
  - **Te+scintillator Phase** (2020 -)
    - $0\nu\beta\beta$ search with ^{130}Te
    - $t_{1/2}$ measurement of $2\nu\beta\beta$
    - Geo and reactor anti-ν
  - Supernova ν in all phases!

Adapted from Morgan Askins, DNP 18 and wwwkm.phys.sci.osaka-u.ac.jp

0νββ Decay

The Hunt for No Neutrinos



Double-Beta Decay

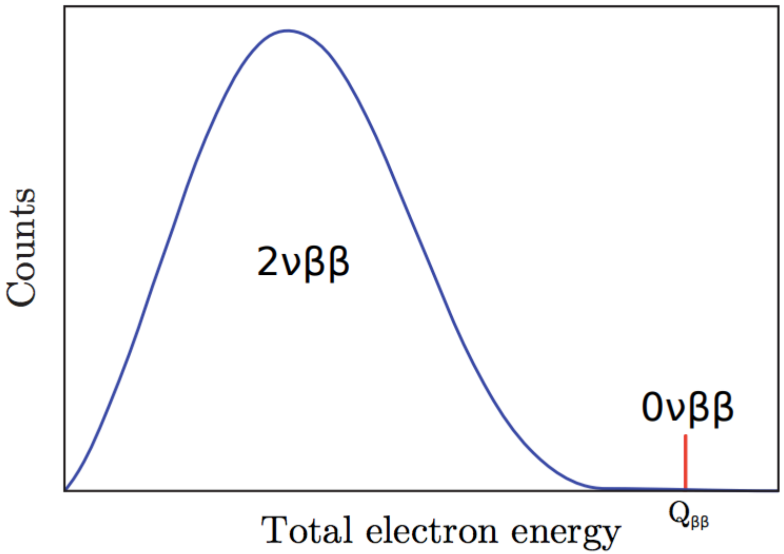
- **SM process ($t_{1/2}$~ 10^{21} yr)**
- **Observed from several isotopes**
- **Energetically favored over β decay**

Neutrinoless Double-Beta Decay

- **Non-SM process ($t_{1/2}$> 10^{25} yr)**
- **Only possible if *ν* is Majorana fermion**

0νββ Decay

The Hunt for No Neutrinos



Isotope	η isotopic abundance (%)	$Q_{\beta\beta}$ [MeV]
^{48}Ca	0.187	4.263
^{76}Ge	7.8	2.039
^{82}Se	9.2	2.998
^{96}Zr	2.8	3.348
^{100}Mo	9.6	3.035
^{116}Cd	7.6	2.813
^{130}Te	34.08	2.527
^{136}Xe	8.9	2.459
^{150}Nd	5.6	3.371

Signal Signature

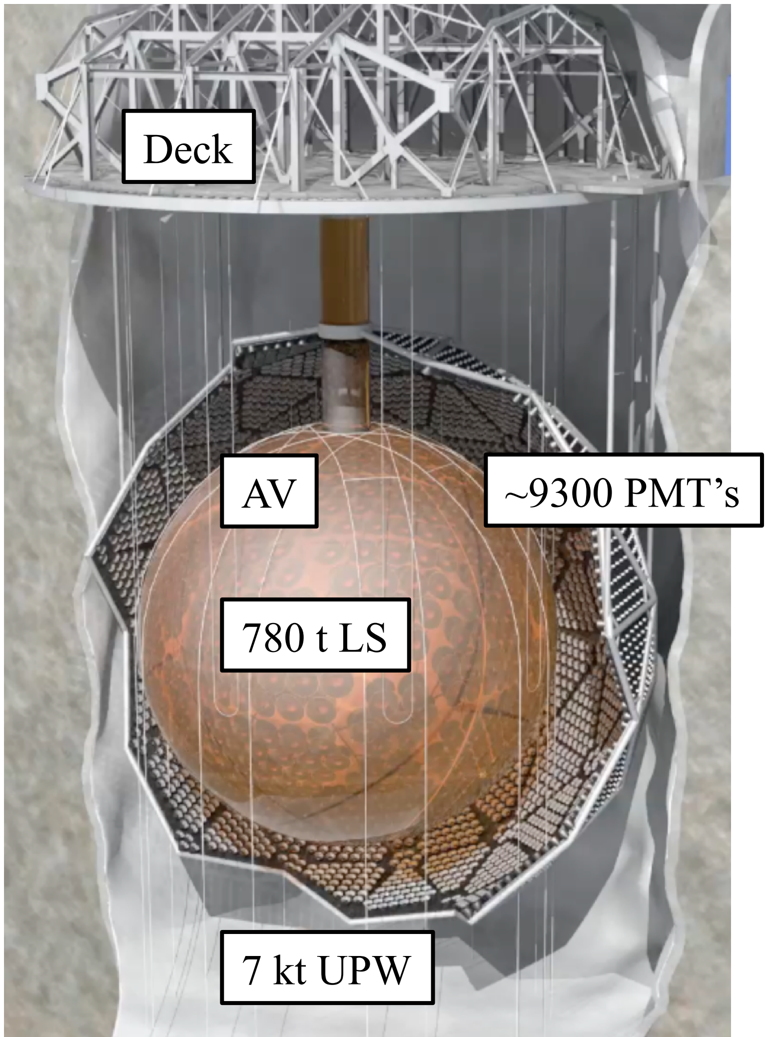
- Monoenergetic peak at $Q_{\beta\beta}$
- Need good energy resolution
- Need low background level

Choice of Isotope

- Two important parameters: η and $Q_{\beta\beta}$
- High $Q_{\beta\beta}$: avoid natural radioactivity
- High η: 0νββ decay is extremely rare

Figure and table from Dell'Oro S, Marcocci S, Viel M, Vissani F. *Adv. High Energy Phys*. 2016:2162659 (2016)

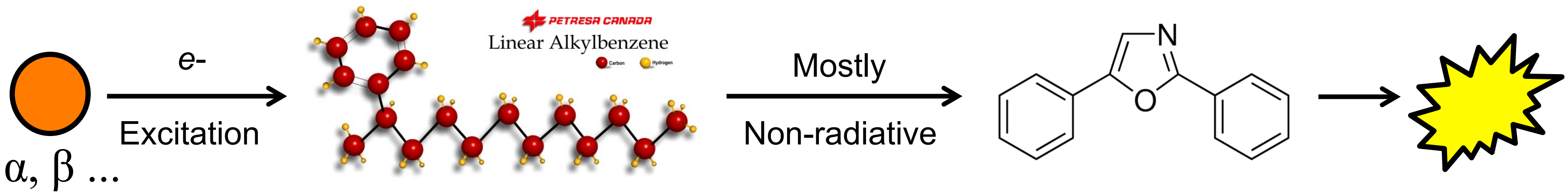
The SNO+ Experiment
Detector Overview



- **Located in SNOLAB, ON, Canada**
- **~ 2 km undergroud (~ 6 km.w.e)**
- **Low cosmic μ^- rate (~ 3 / hr)**
- **Class-2000 clean room**
- **Reuses SNO detector with some "+'s"**
    - Upgraded DAQ and electronics
    - New hold-down ropes
    - New calibration system
    - New scintillator plant
    - New Te purification & synthesis plant

Liquid Scintillator

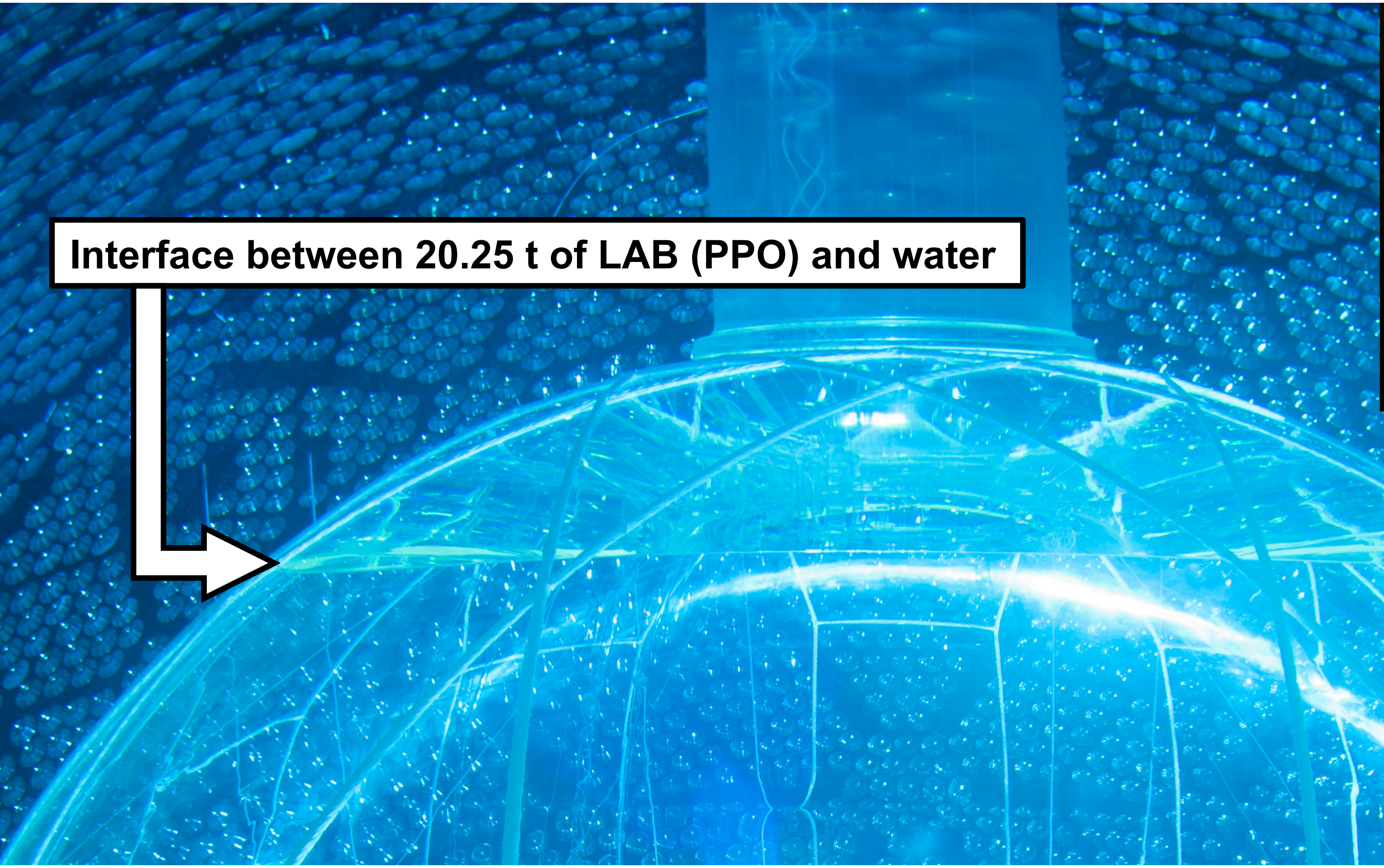
Let there be light!

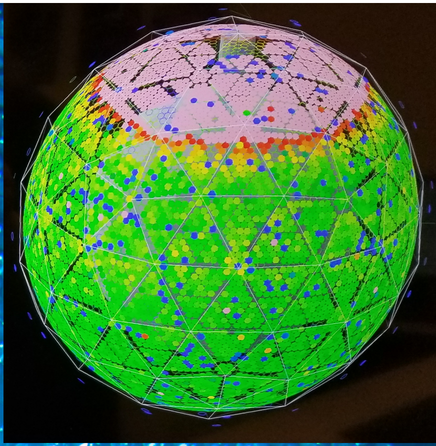


LAB (solvent) **PPO** (fluor, 2 g/L)

- **High light yield**: ~ 10000 photons/MeV ~ 550 PMT hits/MeV
- **Great transparency**: attenuation length ~ 20 m
- **Compatibility with acrylic**
- **α/β pulse shape discrimination**
- **Low toxicity**
- **Affordability**

Scintillator Phase
In Action!





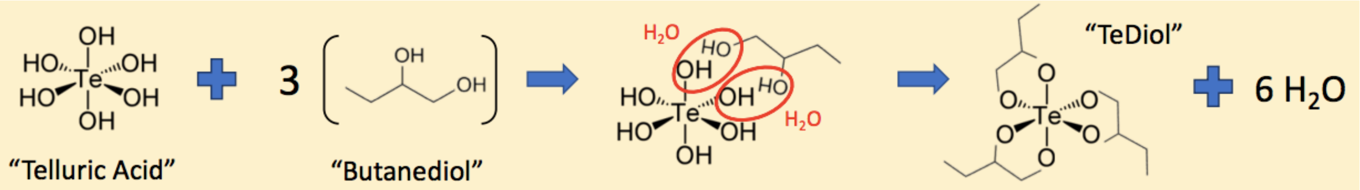
0νββ Decay at SNO+

Te-Loaded Scintillator

SNO+ Phase I: 0.5% natural Te (1.33 t ^{130}Te)

The Cocktail:

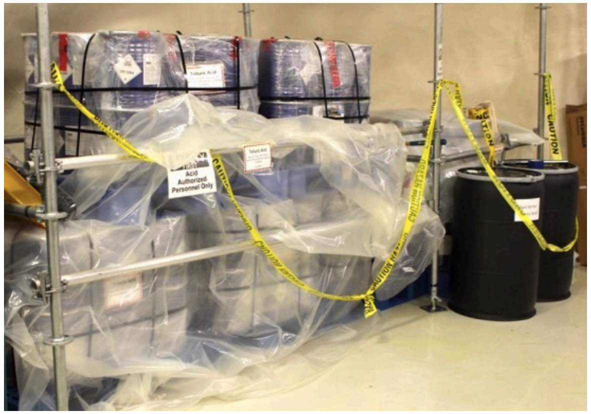
- LAB + PPO (2 g/L) + bis-MSB (15 mg/L) + Te-ButaneDiol + DDA



- ~ 4 tons of TeA has been "cooling" underground since 2015.
- TeA purification and TeDiol synthesis plants commissioning now.
- Good optical transparency and light yield: ~ 460 PMT hits/MeV

Key Advantages of SNO+

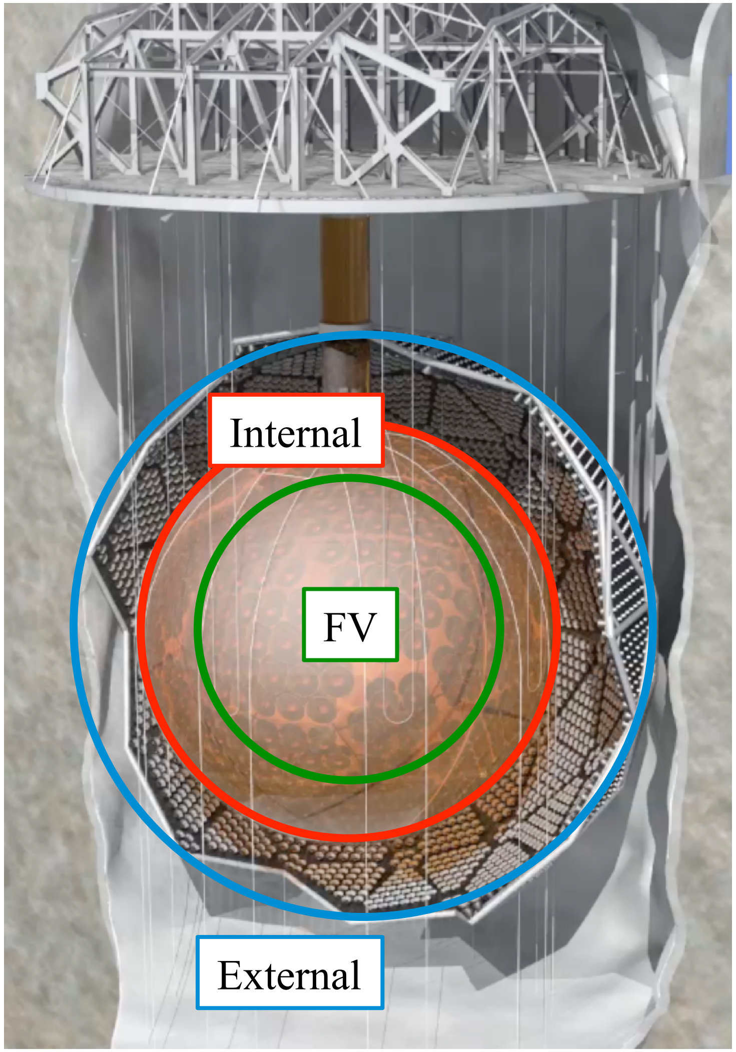
- High statistics
- Scalability
- No need for enrichment
- Low backgrounds
  - Fiducialization
  - Purification



Adapted from Christopher Grant, DBD 18.

Backgrounds

And Where to Find Them



Internal

- $2\nu\beta\beta$
- Solar ^{8}B ν
- ^{238}U and ^{232}Th-chain
- (α,n) reaction on ^{13}C or ^{18}O
- Cosmogenics

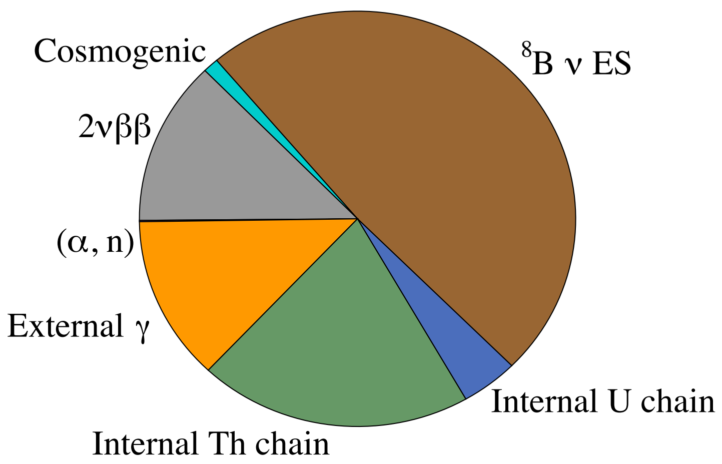
External

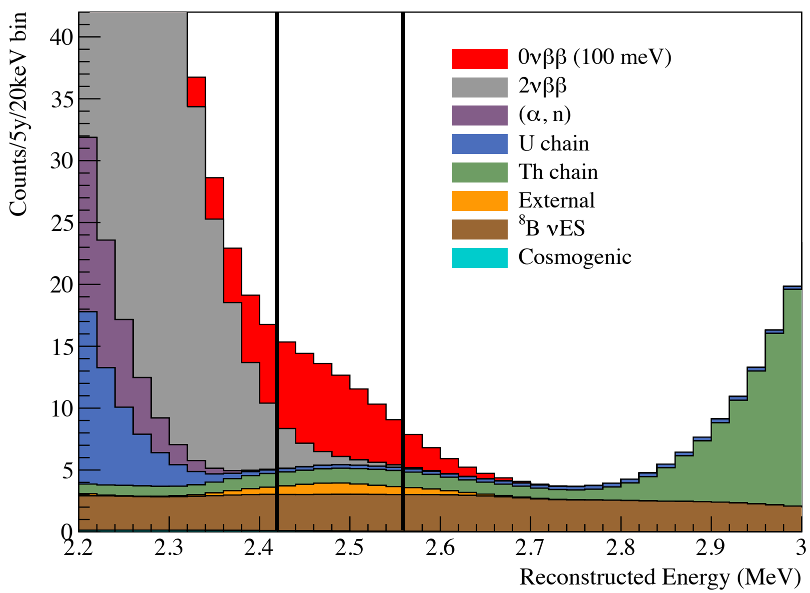
- PMT's
- Acrylic vessel
- Hold-down & hold-up ropes
- Water shielding

Backgrounds

And How to Reduce Them

ROI: 2.42 - 2.56 MeV [-0.5σ - 1.5σ]
Counts/Year: 9.47





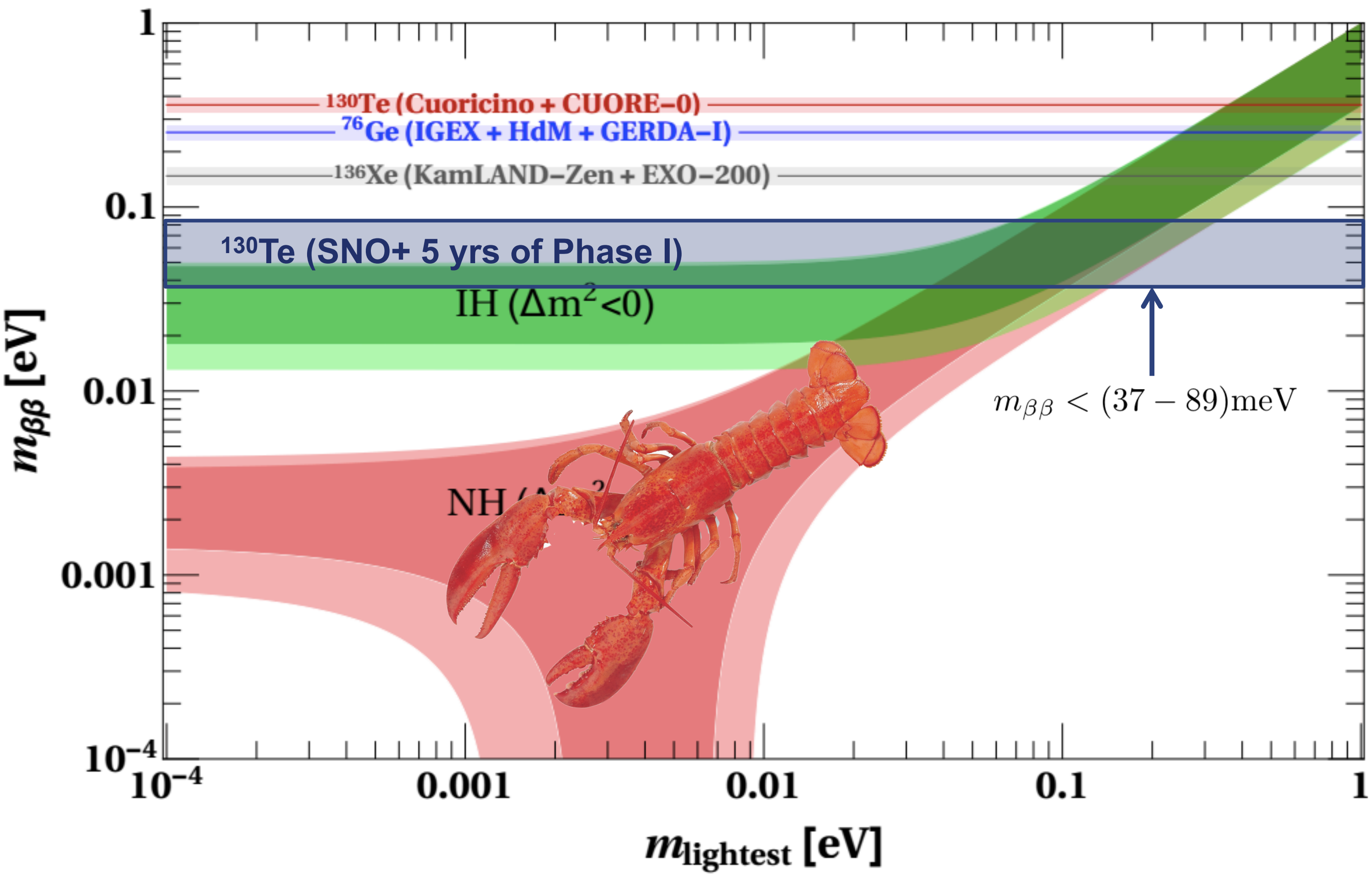
- **^{8}B:**
  - **Source term measured. Directionality in scintillator?**
- **Internals:**
  - **Measurement before Te loading. PSD of BiPo.**
- **Externals:**
  - **Measured in water phase. Fiducialization.**
- **2νββ:**
  - **Improve light yield for better energy resolution.**
- **Cosmogenic:**
  - **Purification, underground "cooling."**

- 5 years of Phase I
- Fiducial radius: 3.3 m
- **0νββ decay half-life sensitiyity:**

$$T^{0\nu}_{1/2} > 2.1 \times 10^{26}\ \text{yr}\ (90\%\ \text{C.L.})$$

The "Lobster" Plot

Probing the mass hierarchy

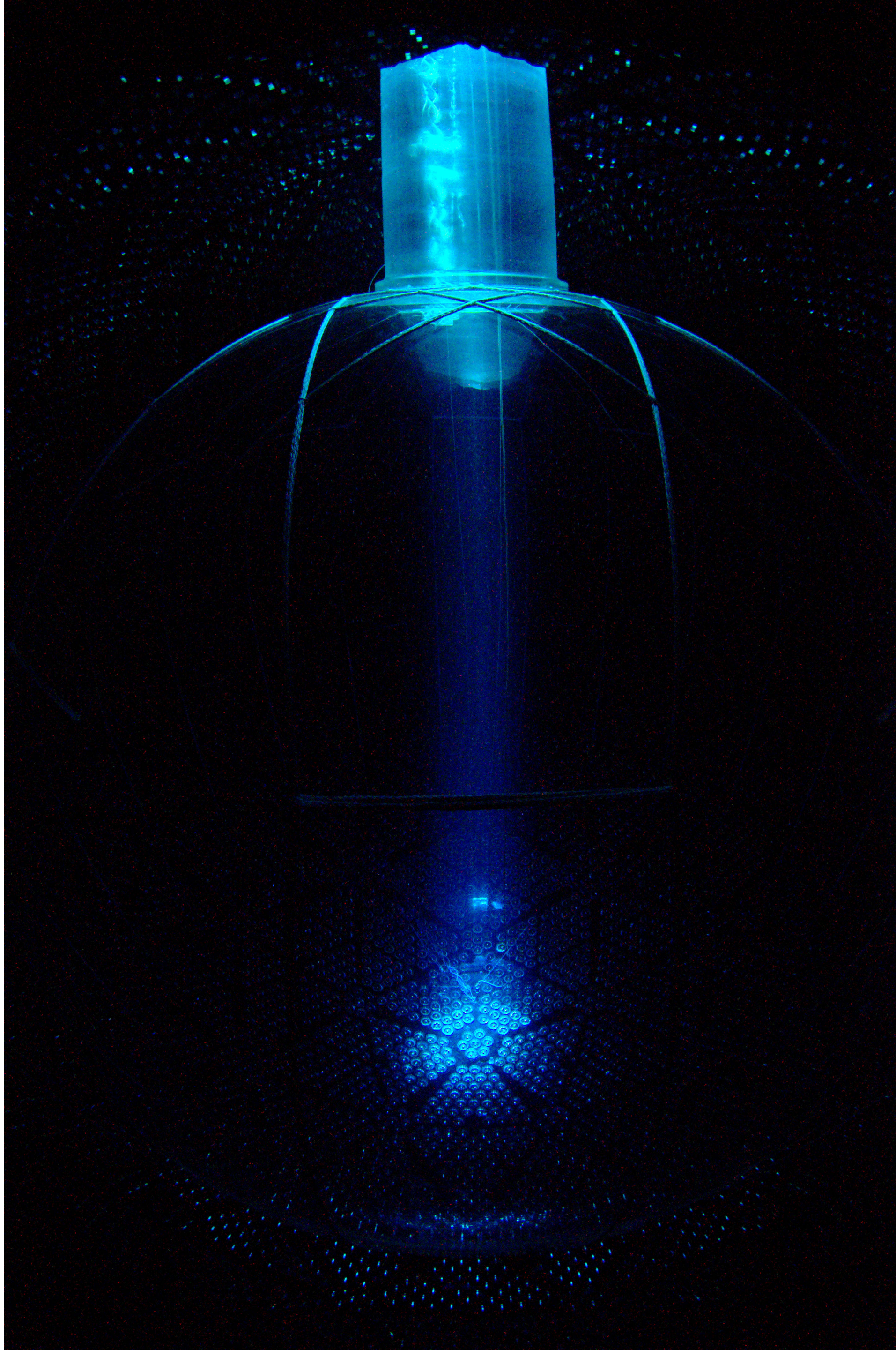


Adapted from Dell'Oro S, Marcocci S, Viel M, Vissani F. *Adv. High Energy Phys*. 2016:2162659 (2016)

Summary

Take-Home Messages

- **SNO+ has finished water phase and published the physics results.**
- **SNO+ is currently filling with scintillator and will start Te loading next year to search for 0νββ decay.**
- **SNO+ Phase I will perform a competitive measurement of 0νββ decay with ^{130}Te.**
- **SNO+ Phase II is currently under active R&D for higher sensitivity**
  - Higher Te loading (4% ~ 10.6 t ^{130}Te)
  - Upgrade PMT array, concentrators
  - Using a balloon vessel
  - …

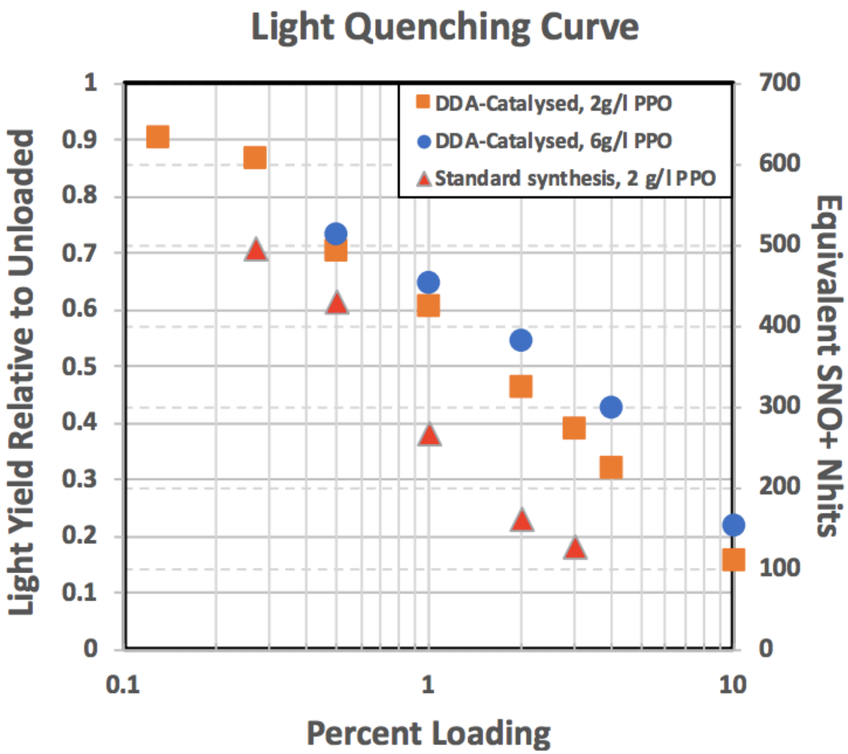


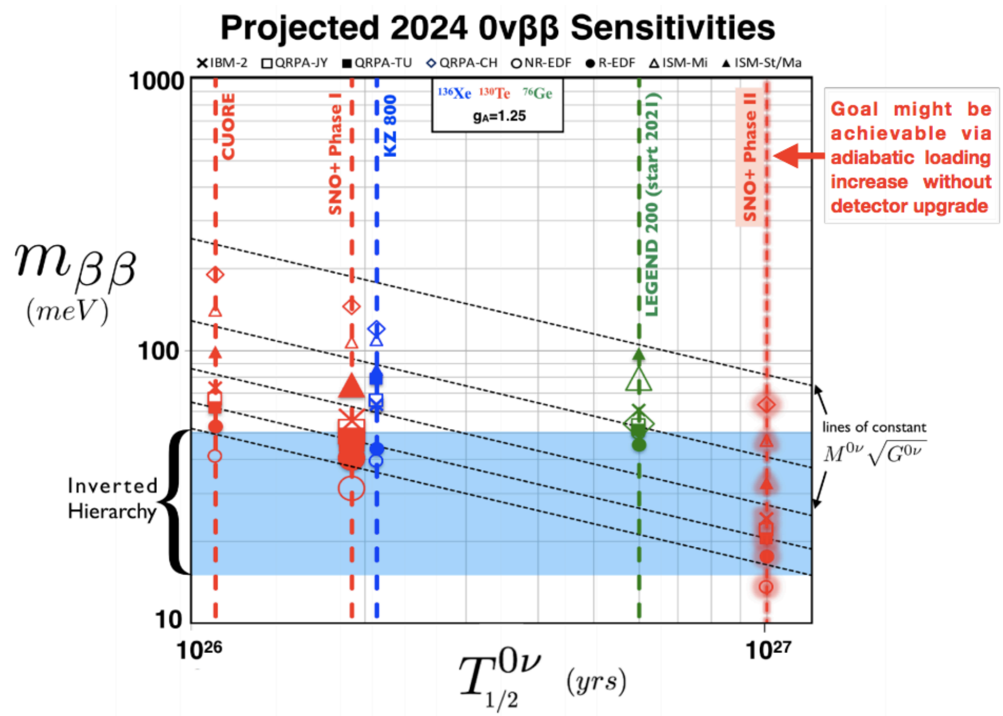

Thank you!
SNO+ Experiment
Sudbury, ON, Canada
SNO+ Collaboration

Backup Slides

Future Prospect

SNO+ Phase II





Neutrino Mass

Bonus from 0νββ Decay Search

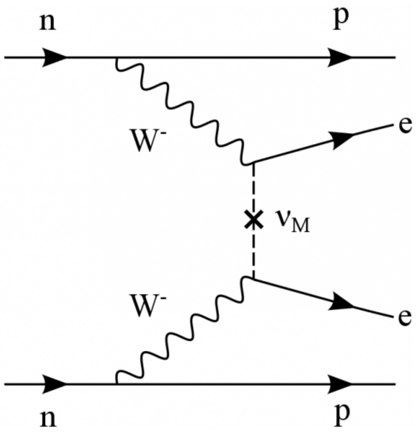
- For the 0νββ experiments, the observable is $t^{1/2}$. With Fermi's golden rule:

$$[t^{1/2}]^{-1} = G_{0\nu}\,|\mathcal{M}|^2\,|f(m_i, U_{ei})|^2$$

$$f(m_i, U_{ei}) \equiv \frac{m_{\beta\beta}}{m_e}$$

$m_{\beta\beta}$ is known as the "**effective Majorana mass**."

$$m_{\beta\beta} = \left| \sum_{i=1,2,3} e^{i\xi_i}\,|U_{ei}^2|\,m_i \right|$$



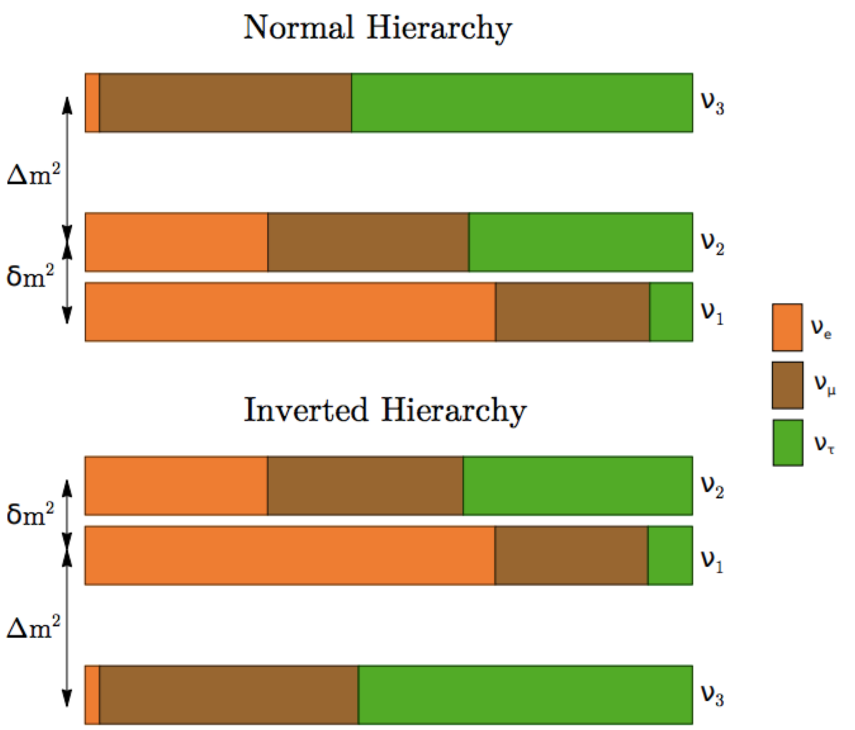
Mass Hierarchy

The ordering matters

- The oscillation experiments can only measure Δm^2.

$$P_{\alpha\to\beta,\alpha\neq\beta} = \sin^2(2\theta)\sin^2\left(\frac{\Delta m^2 L}{4E}\right)$$

- Up to now, we have only determined the sign of δm^2_{21}. Thus, we don't know the ranking of m_3 relative to $m_{1,2}$



$$\begin{bmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{bmatrix} = \begin{bmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{bmatrix} \begin{bmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{bmatrix}$$

$$m_{\beta\beta} = \left| \sum_{i=1,2,3} \mathrm{e}^{i\xi_i} \, |U^2_{\mathrm{e}i}| \, m_i \right|$$

Figure from Dell'Oro S, Marcocci S, Viel M, Vissani F. *Adv. High Energy Phys*. 2016:2162659 (2016)