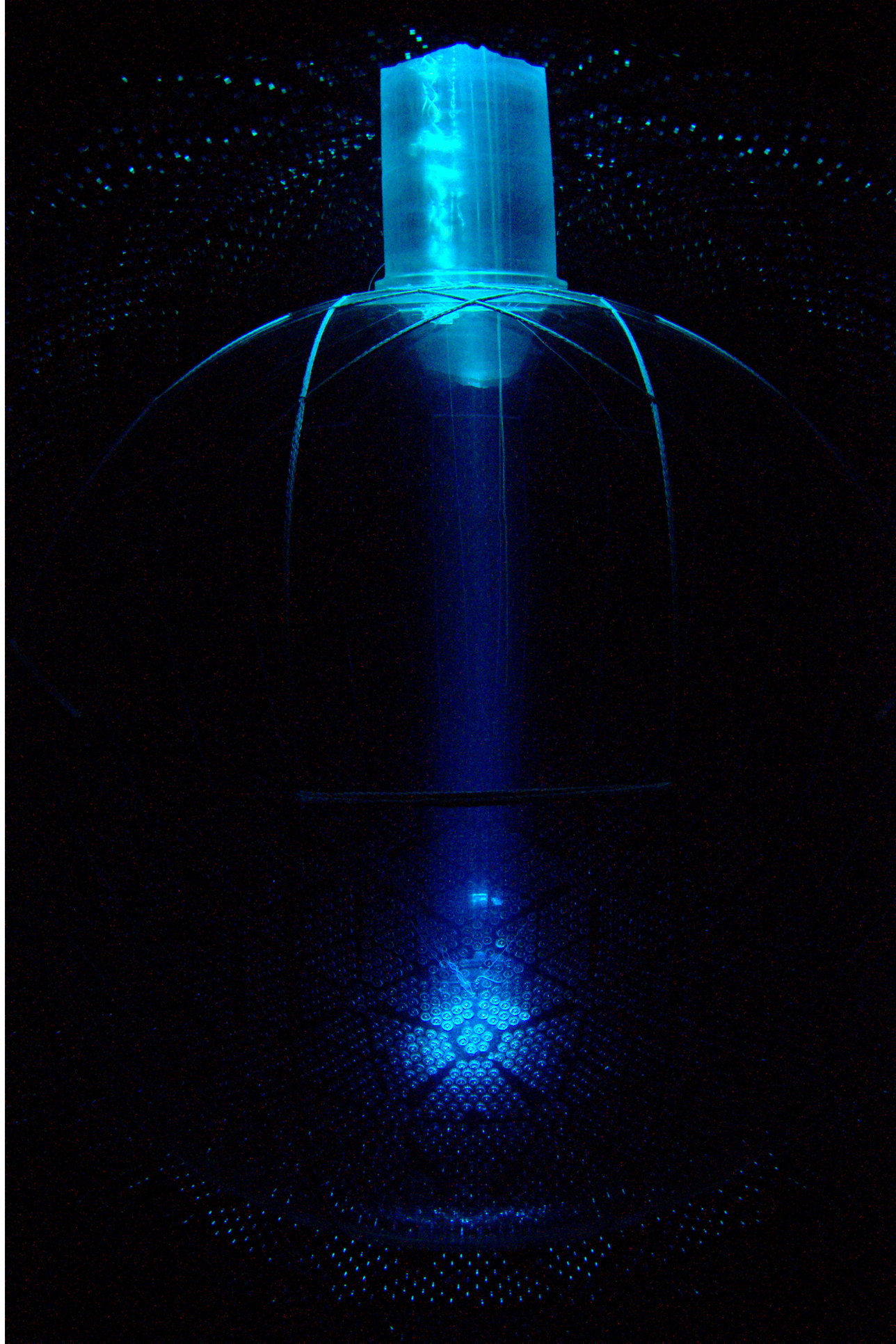
IPP Town Hall for the Long Range Plan

July 15, 2020

Mark Chen
for the SNO+ Collaboration

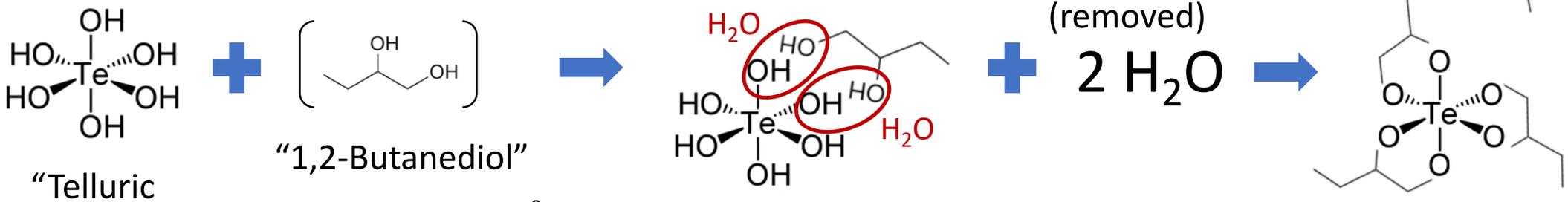
Queen's University
Canadian Institute for Advanced Research

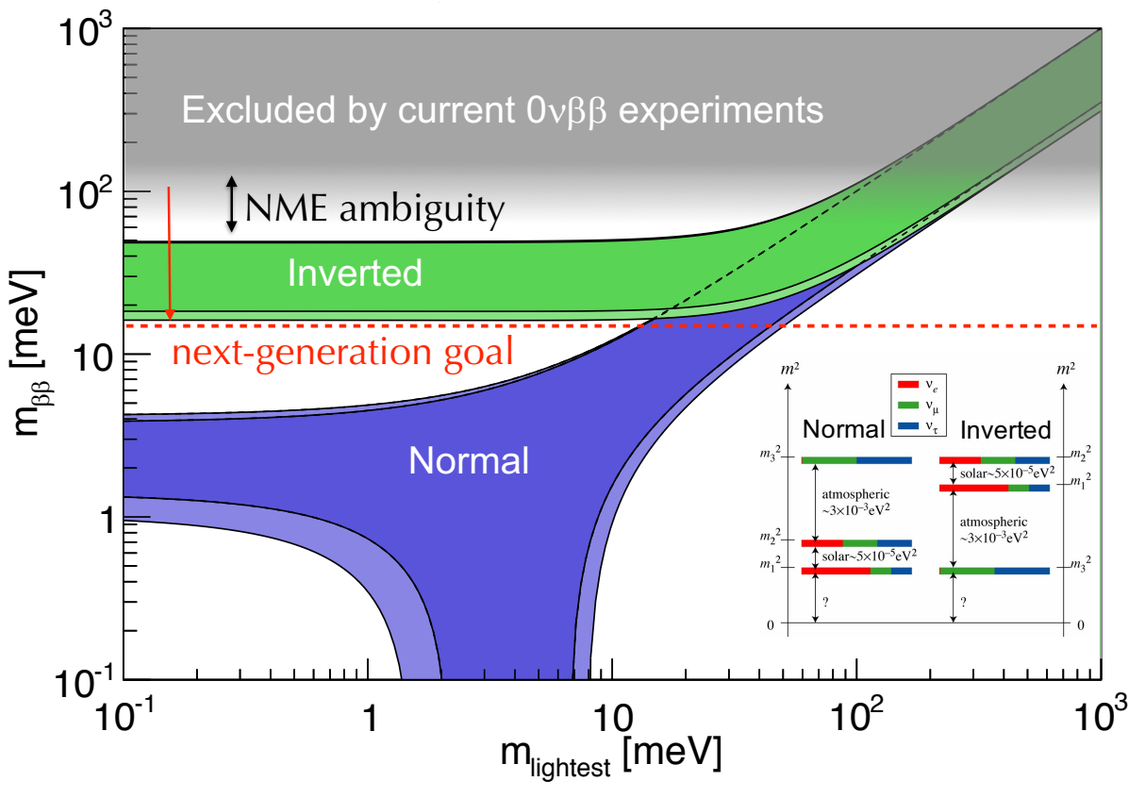


SNO+ Neutrinoless Double Beta Decay with Tellurium-Loaded Liquid Scintillator

Principal goal: economical, scalable approach to $0\nu\beta\beta$; achieving sensitivity to $m_{\beta\beta}$ in the parameter space corresponding to the Inverted Neutrino Mass Ordering…*and beyond*

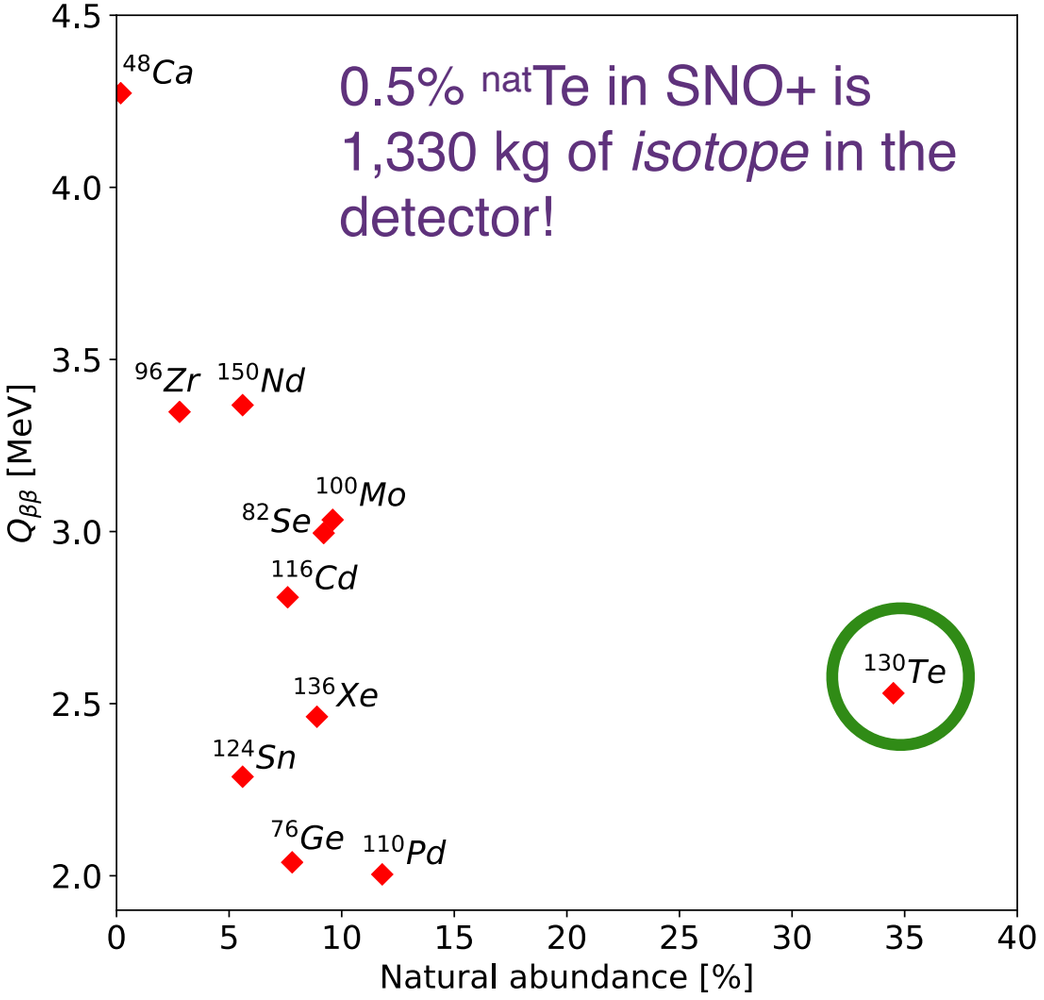
^{130}Te has 34% natural abundance = no costly isotopic enrichment req'd



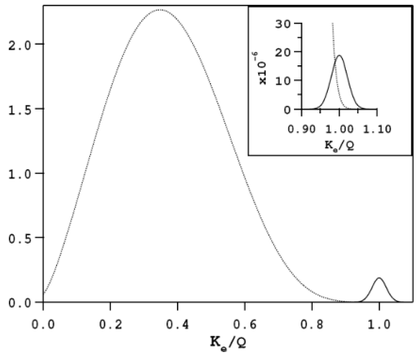


from J. Detwiler talk, Neutrino 2020

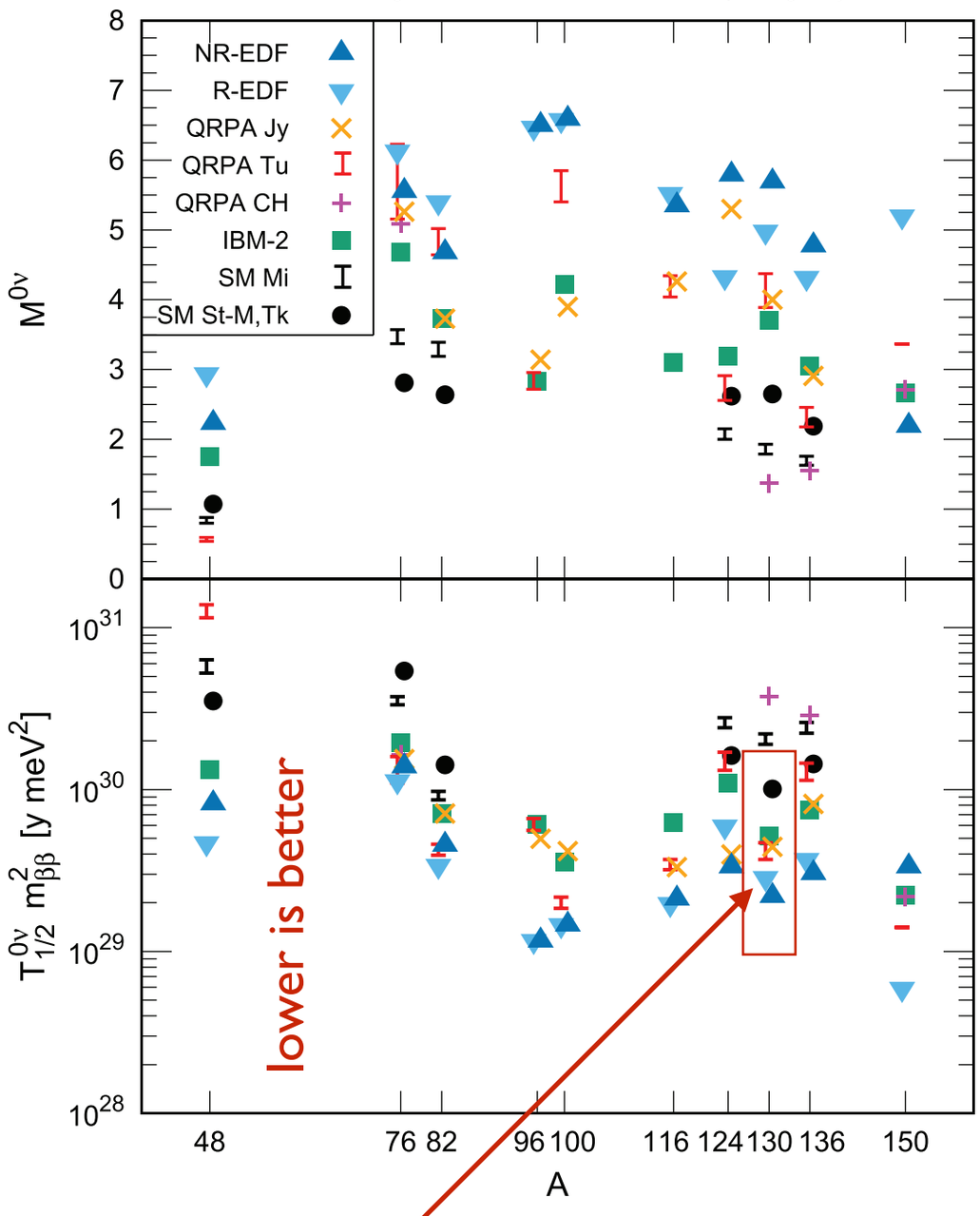
Tellurium for Double Beta Decay



^{130}Te & ^{136}Xe have the smallest 2νββ/0νββ ratio



Jonathan Engel and Javier Menéndez 2017 *Rep. Prog. Phys.* **80** 046301



Favourable $G_{0\nu}(Q,Z)\,|M_{0\nu}|^2$

Thoughts on Future NLDBD Sensitivity
(for all experiments)

- Signal / Background
  - an affordable way to deploy a *large* quantity of isotope is required to reach non-degenerate “Normal Mass Ordering” sensitivity
- “Background Index” = counts/keV/kg/yr
  - to improve backgrounds, one can improve
    - “keV” energy resolution – SNO+ has increased the light yield of the TeLS in recent R&D
    - “counts/kg-yr” – low radioactivity techniques have been developed by SNO+ with underground purification of tellurium just getting started → potential for future improvement
    - two-electron (single site) signal topology to suppress backgrounds – many experiments have event classifiers like single-site/multi-site discrimination, including SNO+ (also Cherenkov/scintillation separation R&D)
    - tagging the DBD daughter nucleus – an interesting capability being developed by nEXO and NEXT

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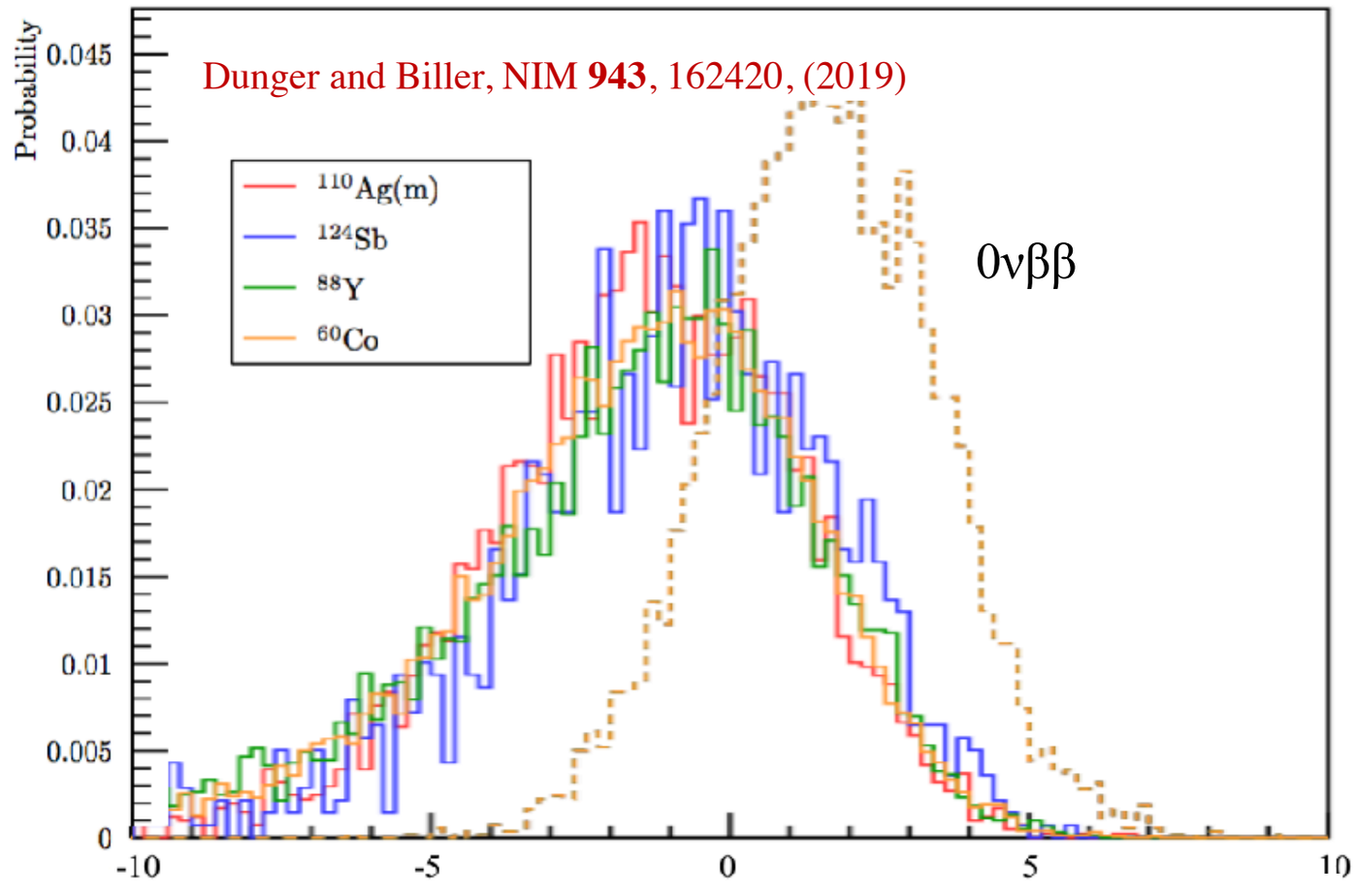

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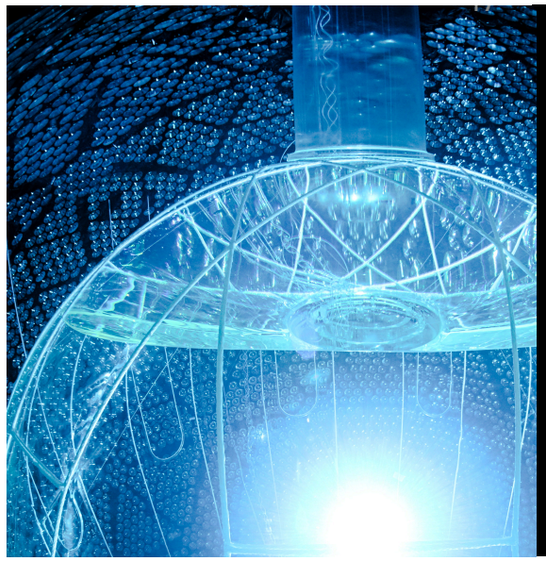
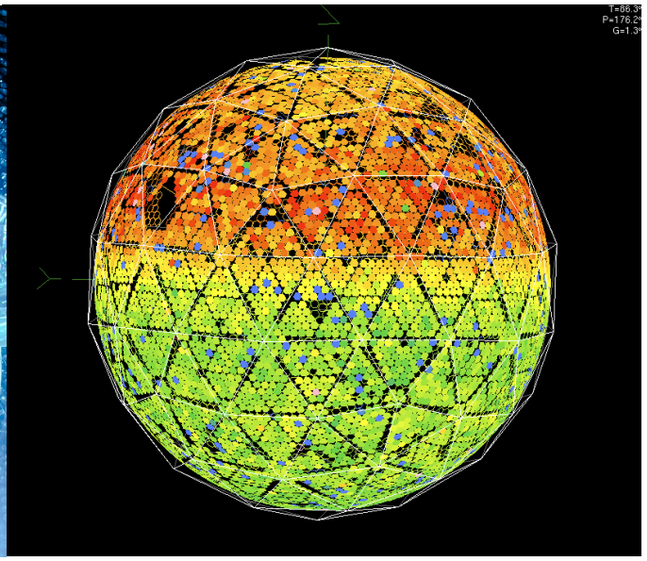
SNO+

Phase I Status





Scintillator fill paused halfway due to COVID-19

LS purification and filling was progressing well

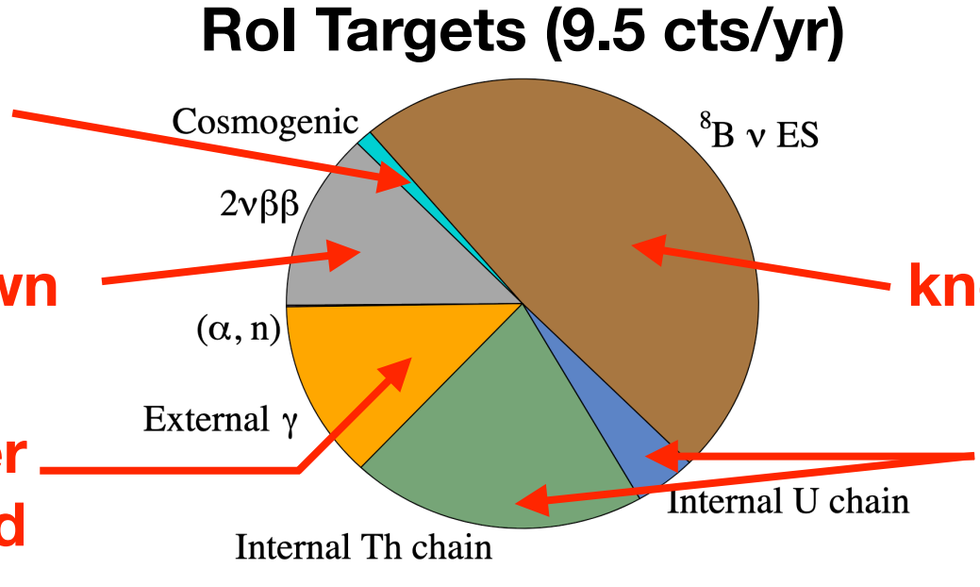
Tellurium purification and loading systems completed: undergoing commissioning

Measured unloaded LS light levels at or above expectation

can be verified with multi-site analysis
(NIM 943, 162420, 2019)

known

constrained by water data: target achieved



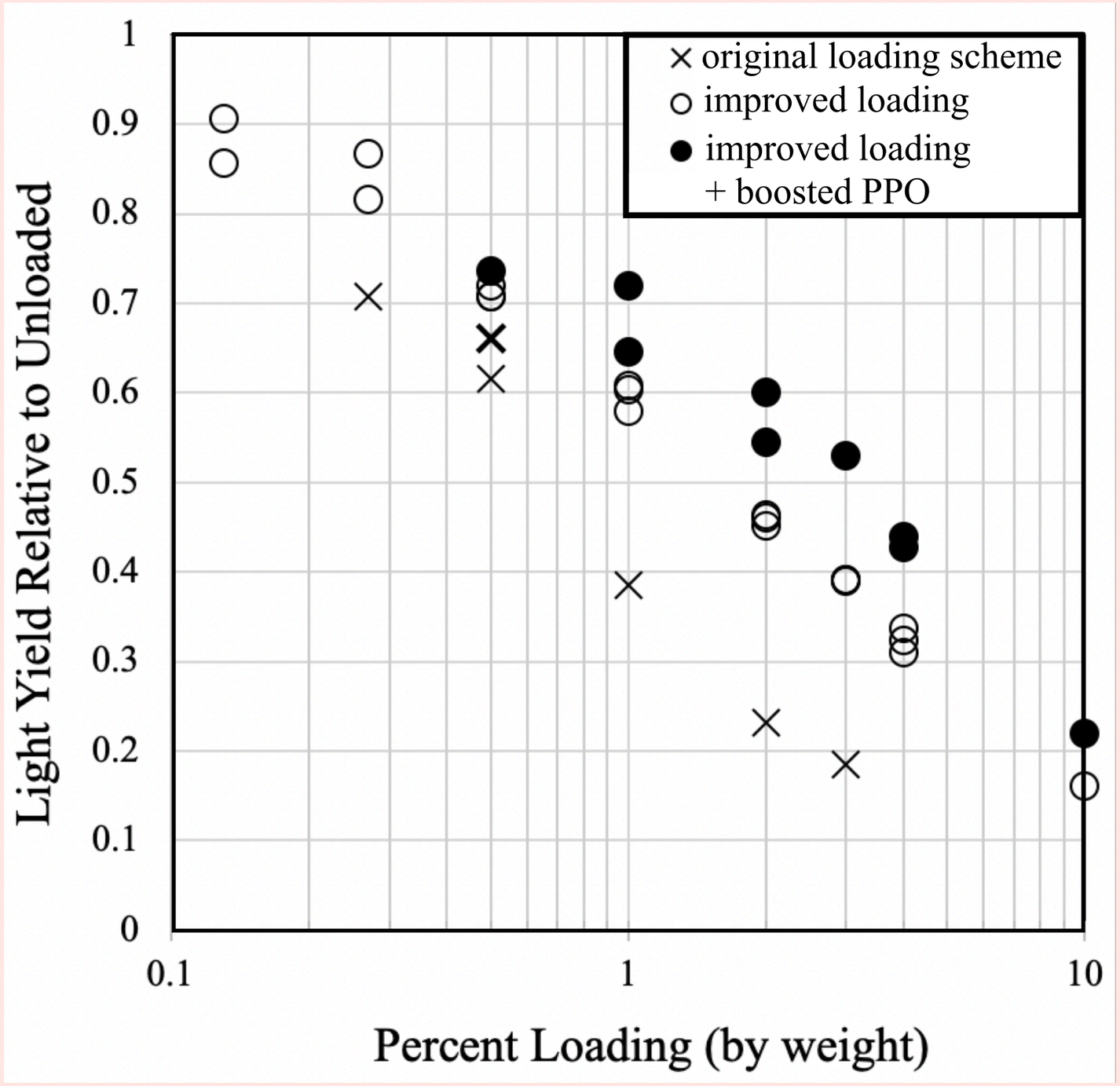
known

scint data: target achieved, awaiting Te data

Phase II Progress:

Te-loading technology now achieves levels of several percent with improved light yield - can use existing SNO+ Phase I Te loading systems (now being commissioned)

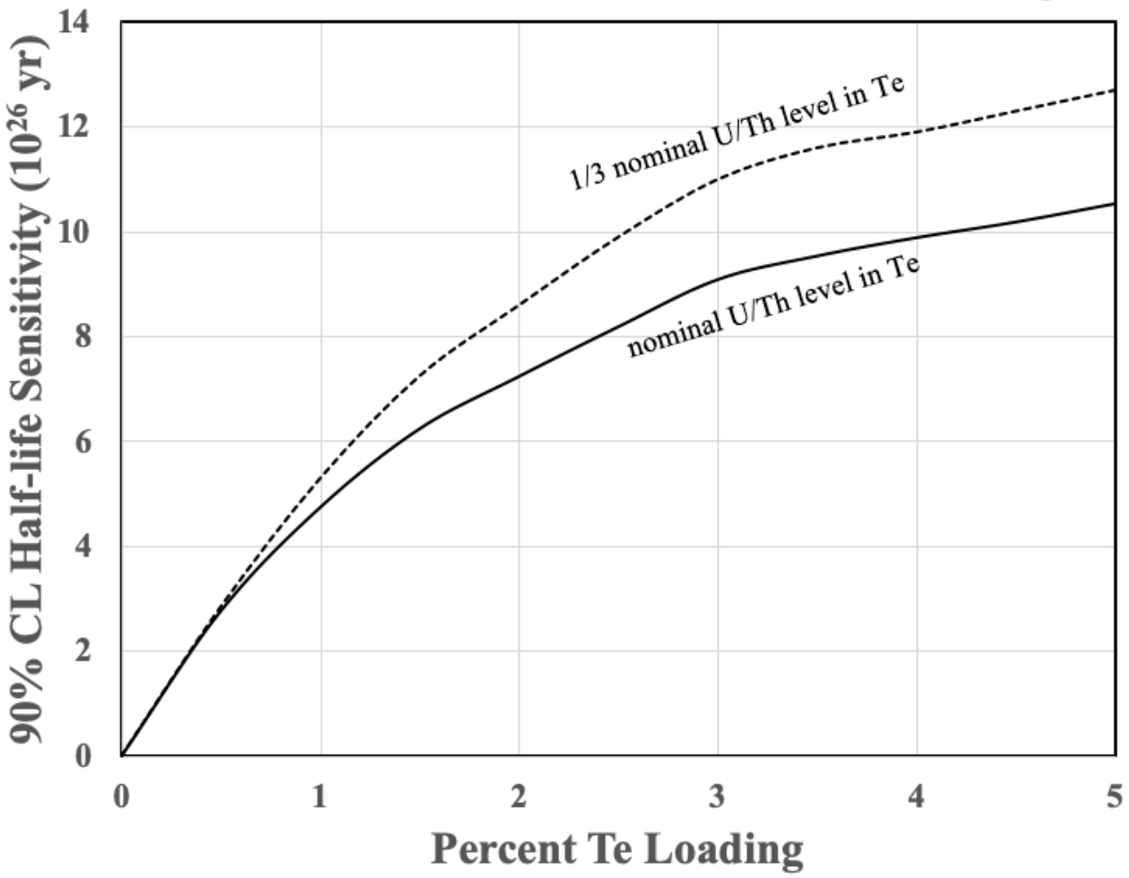
Scintillator samples with several percent Te are stable on the timescales of years



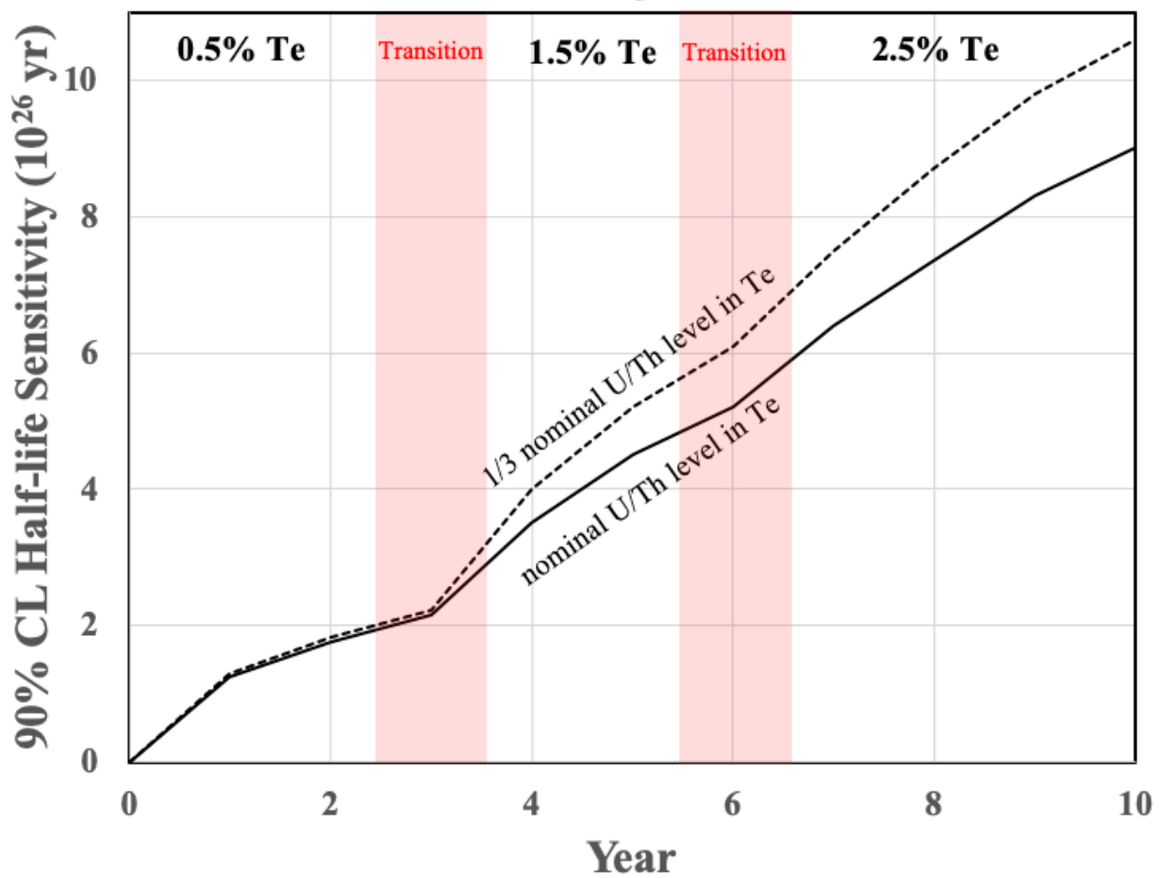
The cost of additional loading is **~$2M per tonne of 0νββ isotope**, which is 1-2 orders of magnitude less expensive than any other approach!

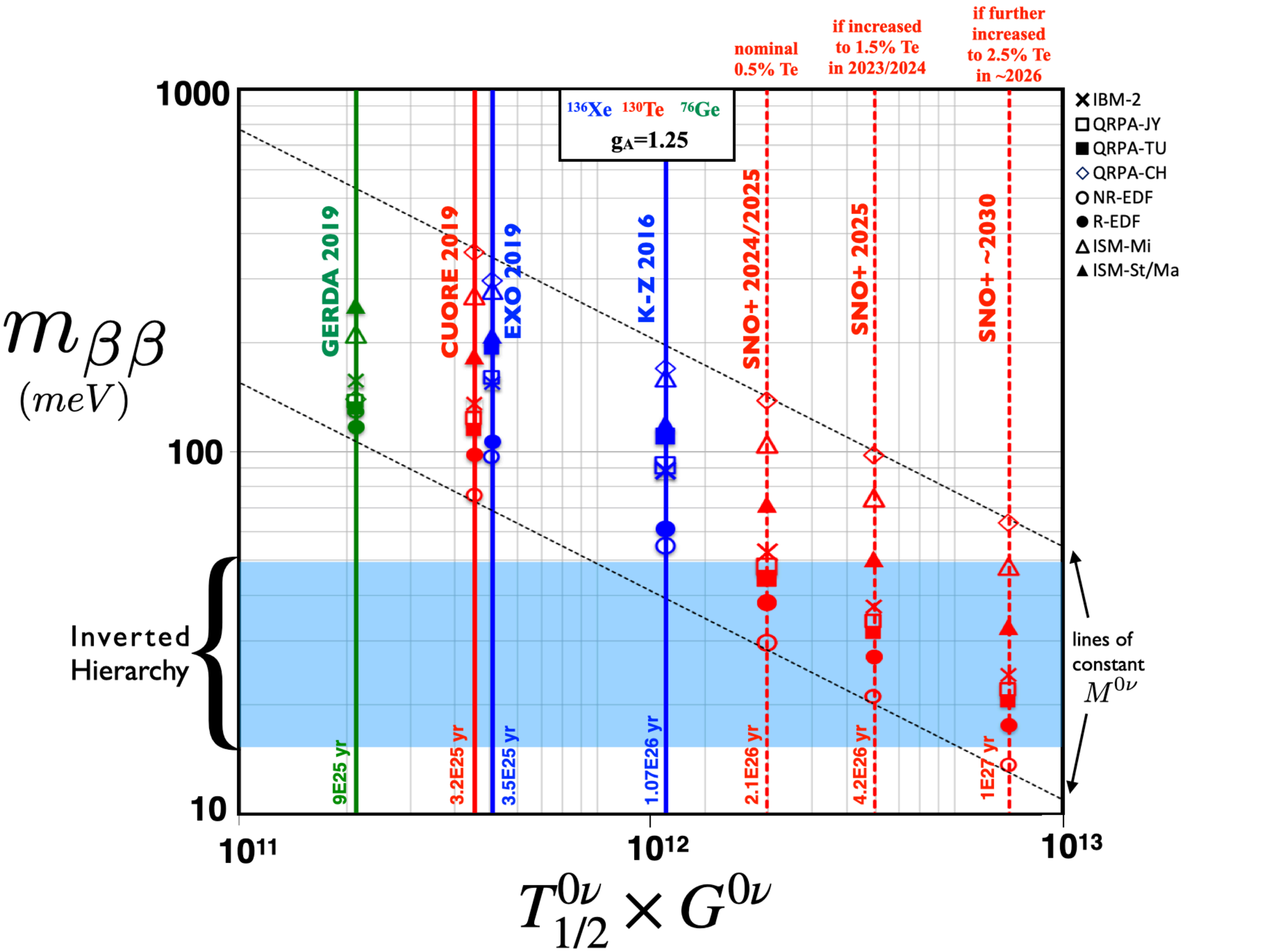
Technology looks economically viable for significant scale-up in future experiment to pursue discovery-level sensitivity beyond the Inverted Ordering range of $m_{\beta\beta}$ parameter space

SNO+ Phase II
5yr Half-life Sensitivity vs Loading



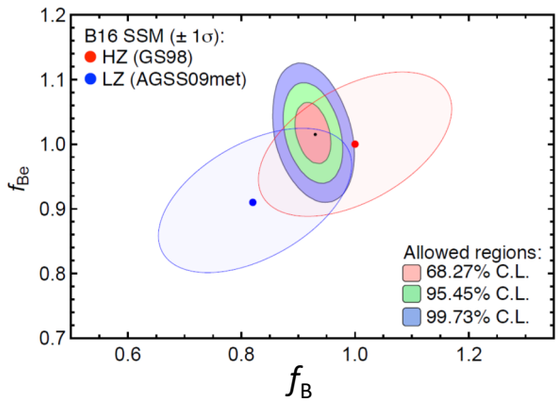
SNO+ Phased Loading Plan
(no detector upgrades required)

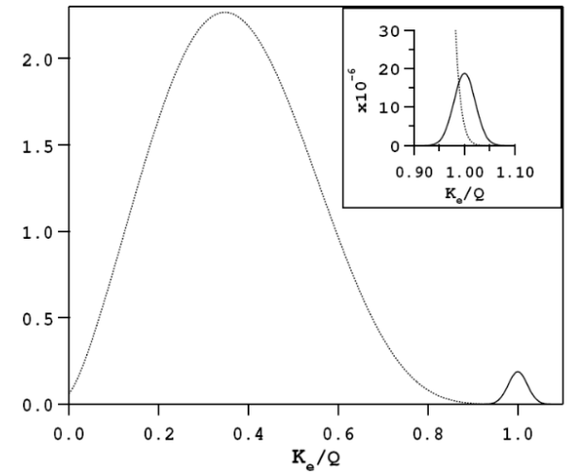


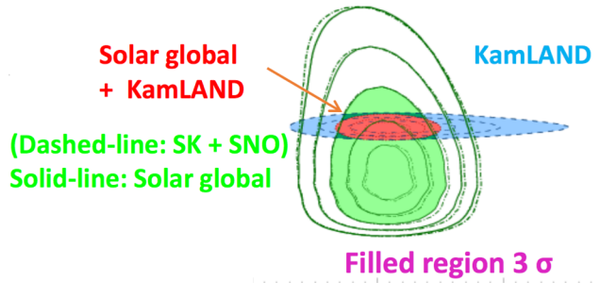

nominal 0.5% Te
if increased to 1.5% Te in 2023/2024
if further increased to 2.5% Te in ~2026
^{136}Xe ^{130}Te ^{76}Ge
g_A=1.25
GERDA 2019
CUORE 2019
EXO 2019
K-Z 2016
SNO+ 2024/2025
SNO+ 2025
SNO+ ~2030
IBM-2
QRPA-JY
QRPA-TU
QRPA-CH
NR-EDF
R-EDF
ISM-Mi
ISM-St/Ma
9E25 yr
3.2E25 yr
3.5E25 yr
1.07E26 yr
2.1E26 yr
4.2E26 yr
1E27 yr
Inverted Hierarchy
lines of constant $M^{0\nu}$
1000
100
10
10^{11}
10^{12}
10^{13}
$m_{\beta\beta}$ (meV)
$T^{0\nu}_{1/2} \times G^{0\nu}$
New Physics Sensitivity: Phase-Space Weighted Half-Life

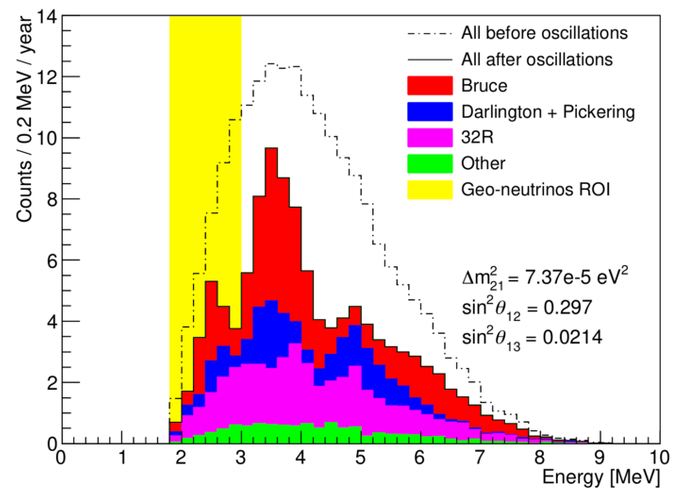
SNO+ Physics Program

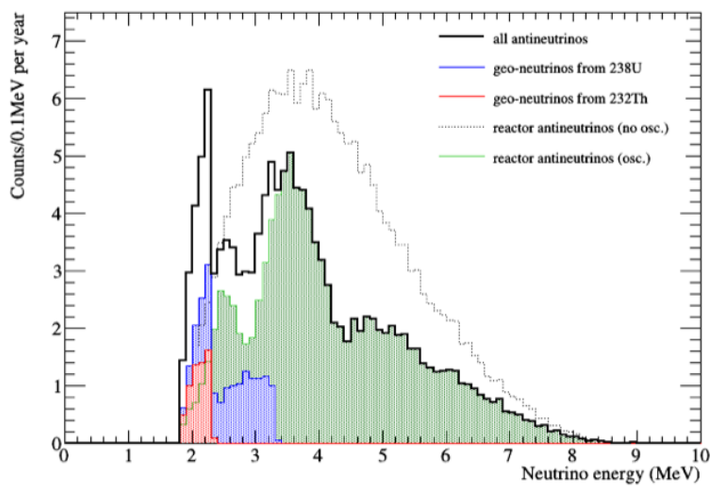
- Neutrinoless double beta decay
- Solar neutrinos
- Reactor antineutrinos
- Geo neutrinos
- Supernova neutrinos
- Nucleon decay

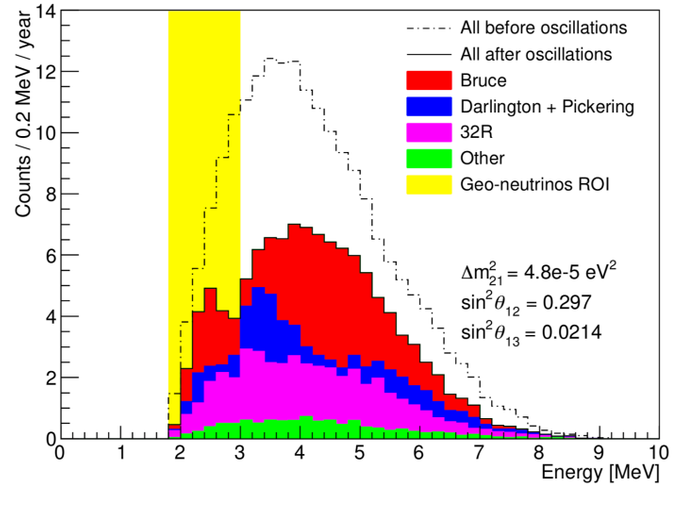












“Physics and Other Research Goals”

- (asked for by Mike) Other research goals include:
  - Purification of tellurium to remarkably low levels of trace impurities, at the tonne-scale, underground!
  - Earth Sciences: geo neutrino measurement adds to knowledge of radiogenic heat power in the deep Earth and tests models of bulk Earth chemical composition

Summary – SNO+ Long Range Plans

- SNO+ Water Phase finished
  - 3 physics results published
  - another 2-3 physics results to follow
- Filling with liquid scintillator resumes when COVID-19 restrictions ease
- Physics results from scintillator partial fill
- Physics results from unloaded scintillator:
  - solar neutrinos?
  - reactor and geo antineutrinos (brief duration)
- Purify Te, synthesize TeDiol and add to the detector: starts the SNO+ double beta decay Phase I
  - reactor and geo antineutrinos also during Te DBD Phase
  - ^{8}B solar neutrinos down to $Q_{\beta\beta}$ endpoint also

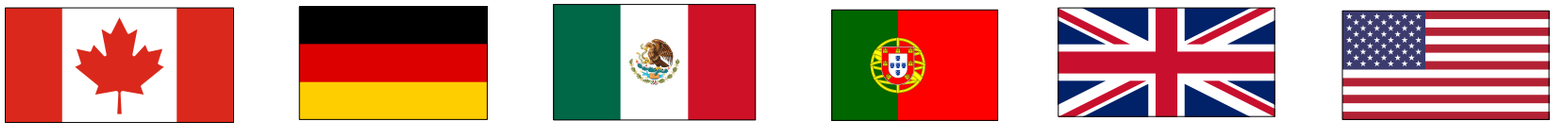
Several $M procurement of Te and chemicals req'd

- Evaluation of Te DBD technique and prospects → procurement of more Te and butanediol, operation of Te process systems to gradually increase loading
  - adjust LS cocktail to further boost light yield (no more R&D needed)

SNO+ Collaboration

60 Canadian collaborators
+72 International collaborators
13 Canadian MSc and PhD students
10 Canadian postdocs/RAs

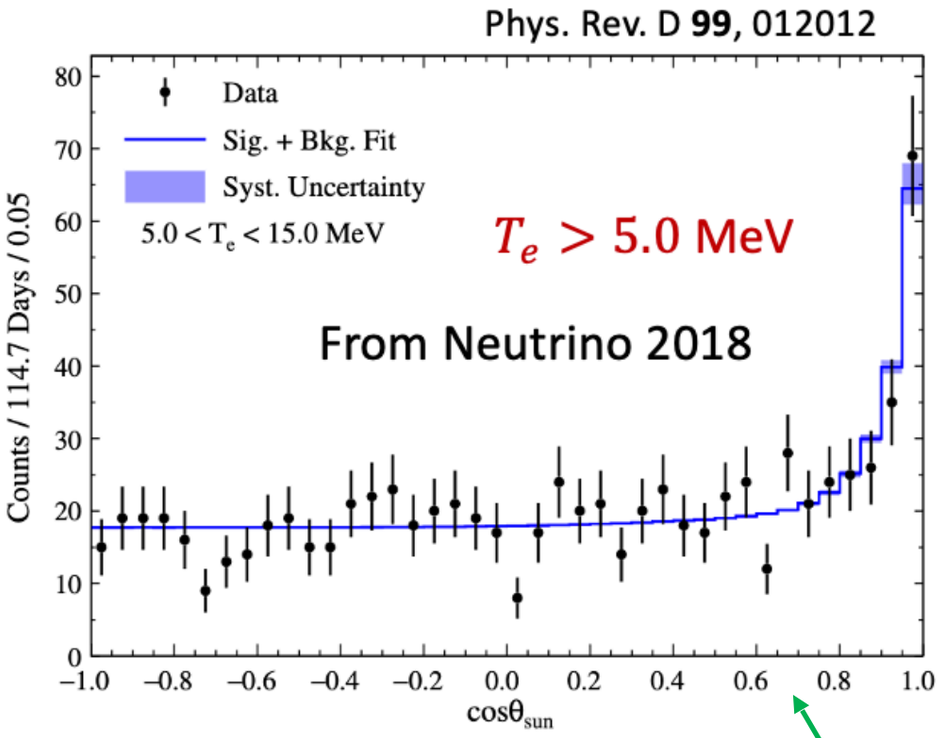
Univ. of Alberta
UC Berkeley / Lawrence Berkeley National Lab
Boston Univ.
Brookhaven National Lab
Univ. of Chicago
UC Davis
Technical Univ. of Dresden
IPP
King's College London
Lancaster Univ.
Laurentian Univ.
LIP Lisbon and Coimbra
Univ. of Liverpool
UNAM
Univ. of Oxford
Univ. of Pennsylvania
Queen's Univ.
Queen Mary Univ. of London
SNOLAB
Univ. of Sussex
TRIUMF



Backup Slides

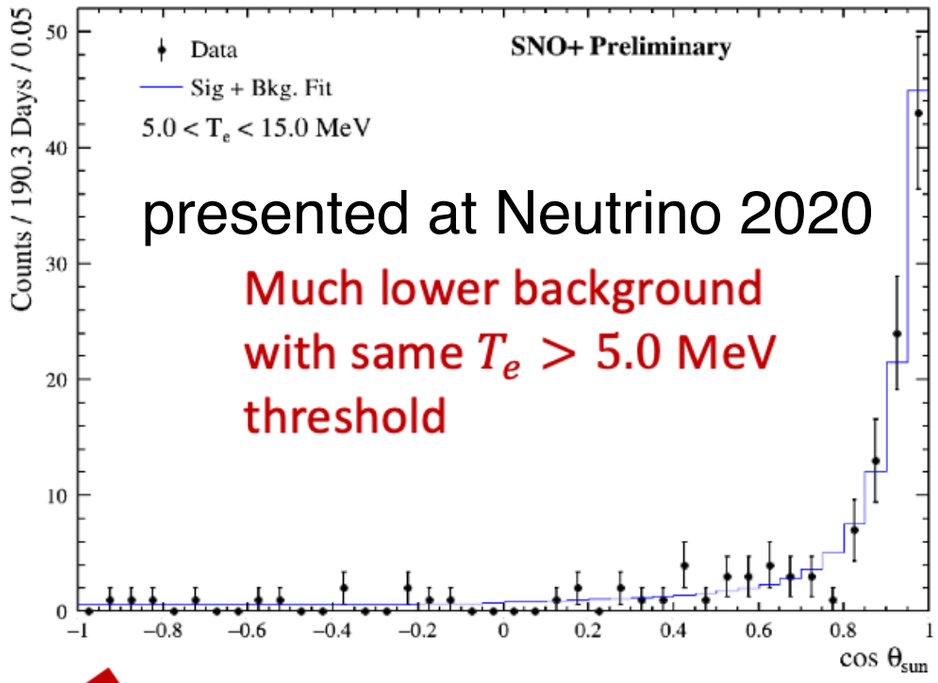
^{8}B SOLAR NEUTRINOS MEASURED BY SNO+ WITH VERY LOW BACKGROUNDS

NOW *EVEN* LOWER BACKGROUNDS

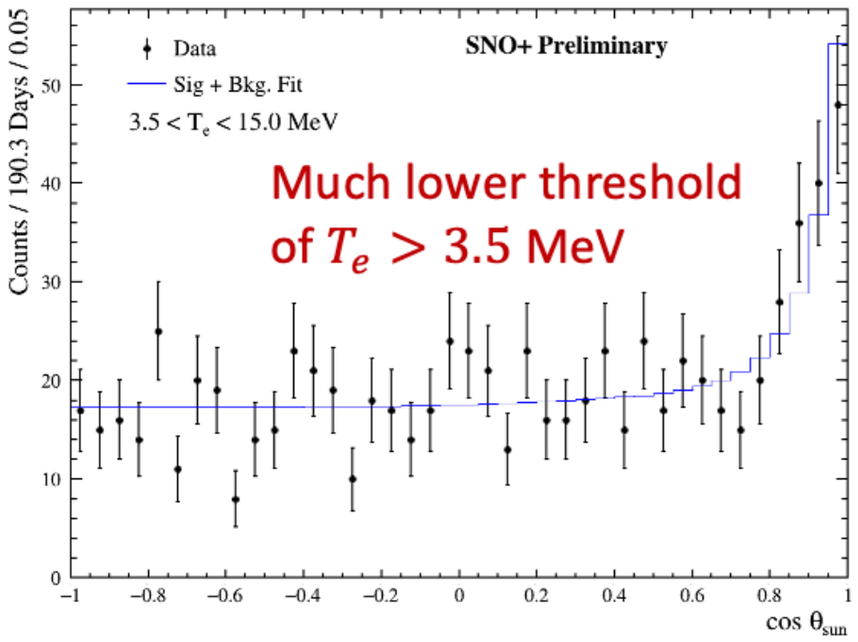


M. Anderson et al., (SNO+ Collaboration), "Measurement of the ^{8}B solar neutrino flux with very low backgrounds", Physical Review D **99**, 012012 (2019)

NEW



NEW



new solar neutrino analysis with lower backgrounds and energy threshold being completed…