Neutrinoless Double Beta Decay Phase of the SNO+ Experiment

IOP Joint APP and HEPP Annual Conference
8 April 2019

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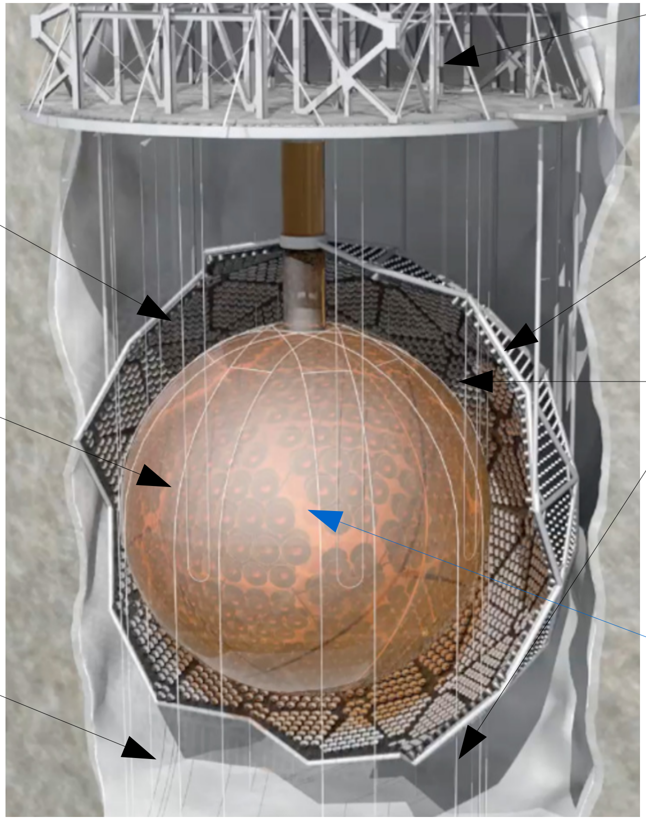
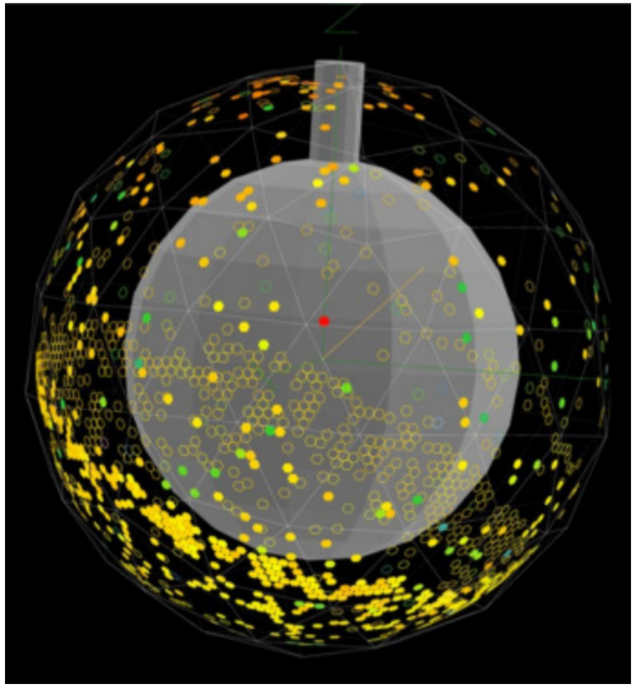
UNIVERSITY OF OXFORD

SNO+

SNO+

Multipurpose neutrino detector in Sudbury, Canada

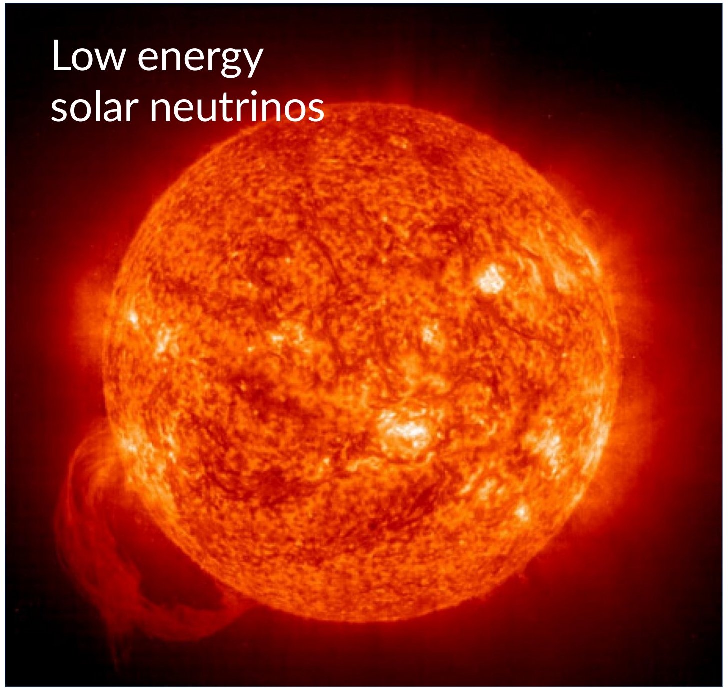




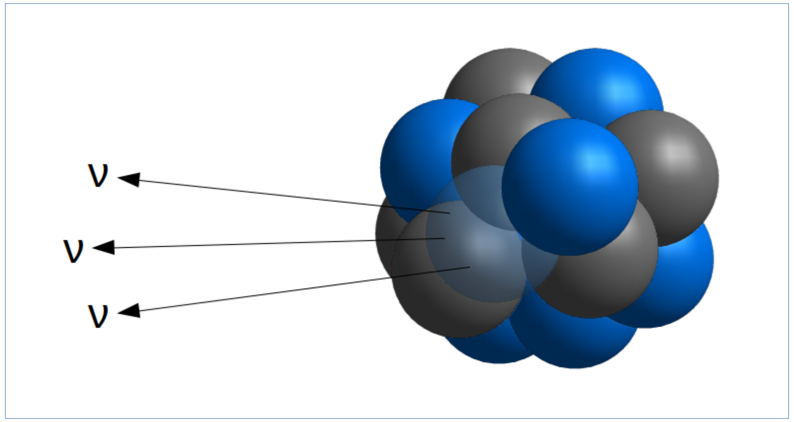
Timeline

Water phase: Finished
Pure scintillator phase: Filling ongoing
Tellurium phase: Loading starts early 2020

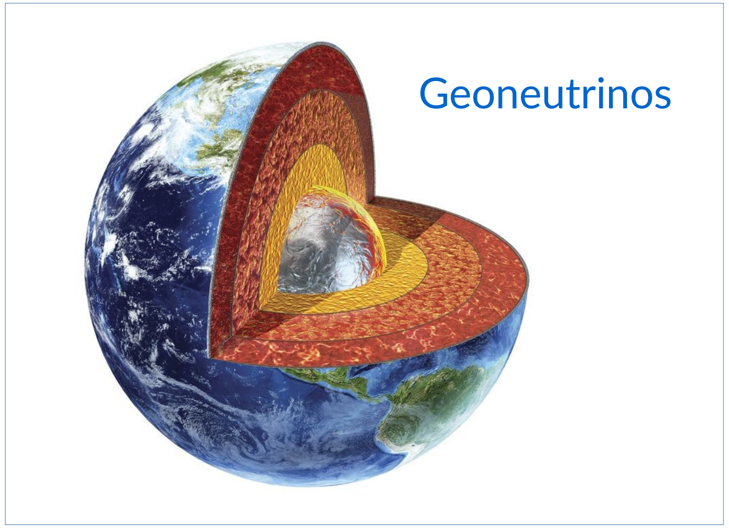
SNO+ Physics

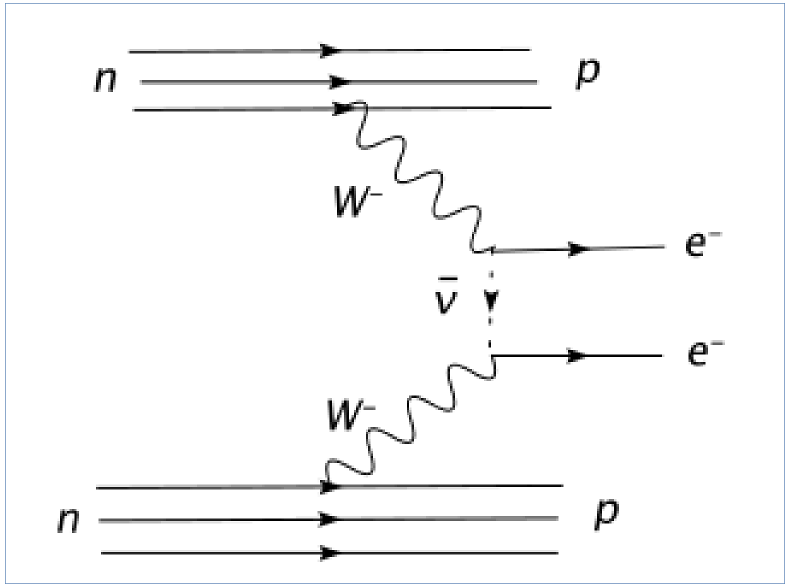



Reactor antineutrinos

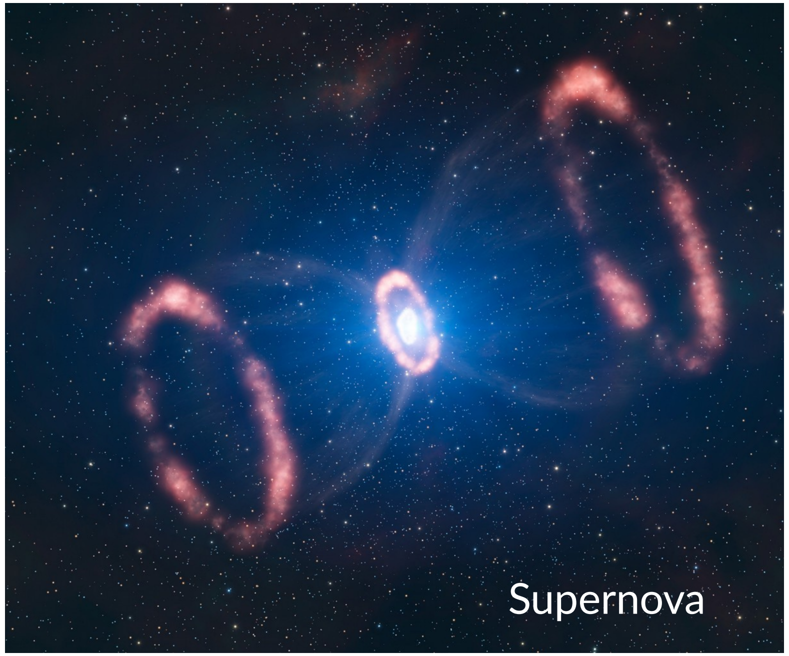


Invisible nucleon decay
+ other exotic physics



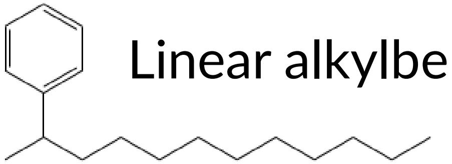


Neutrinoless double beta decay



Tellurium loaded scintillator

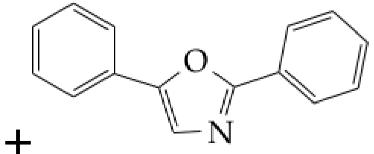
Requirements: High light yield, radiopurity, long term stability, material compatibility, safety...



Linear alkylbenzene (LAB)

+

2g/L 2,5-diphenyloxazole (PPO)

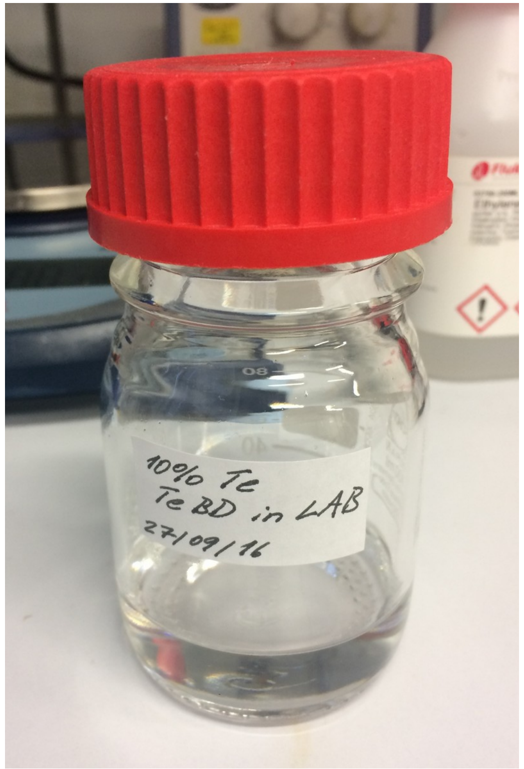


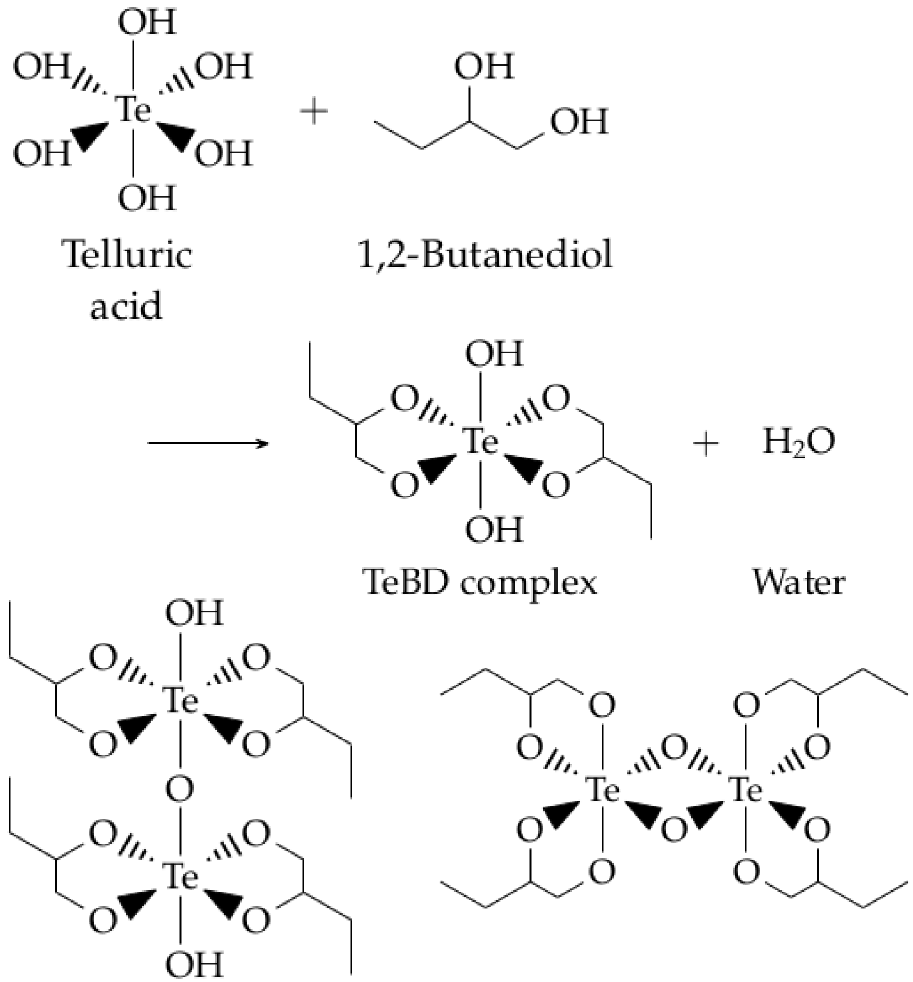
+

Tellurium-butanediol (TeBD)

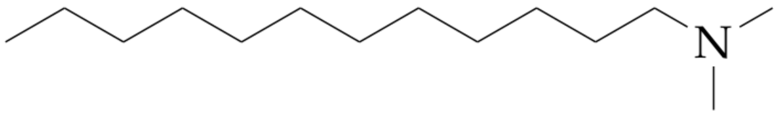
+

N,N-dimethyldodecylamine
(DDA, 0.5 molar DDA:Te)





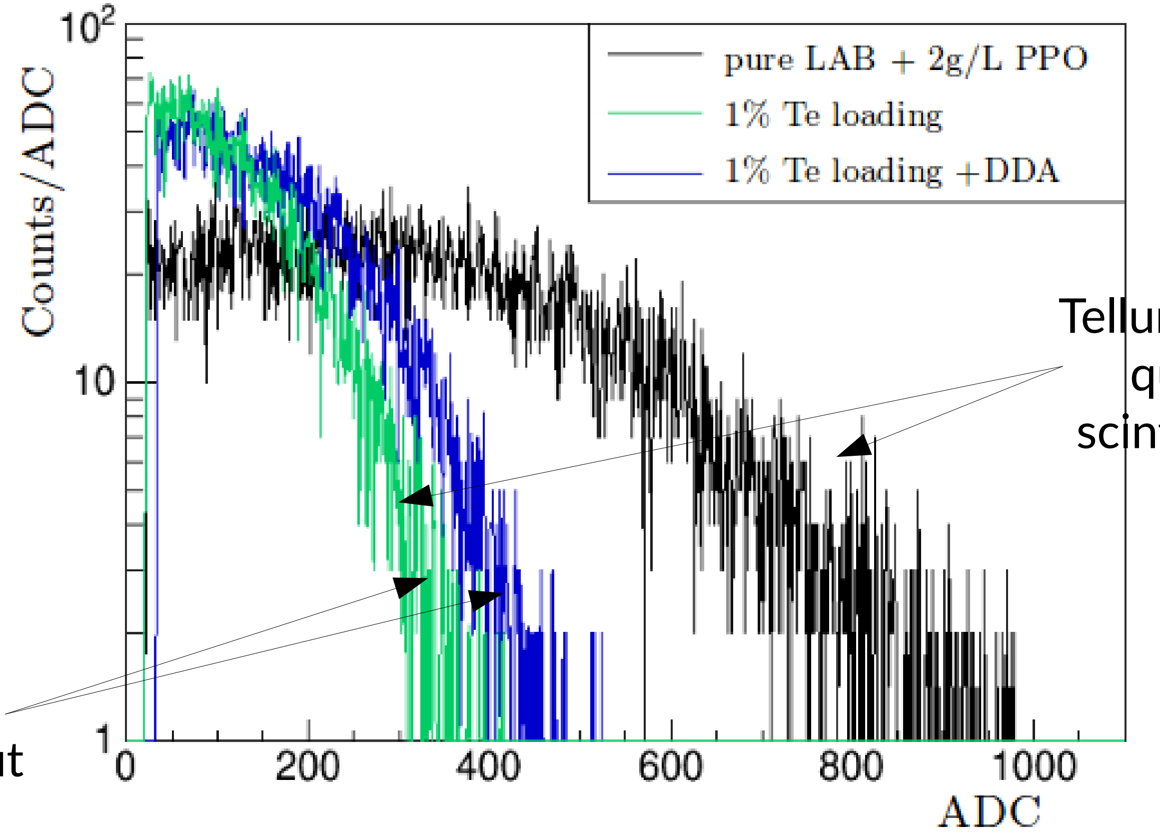
Amine addition – light yield



N,N-Dimethyldodecylamine

Advantages:
Helps stabilise TeBD in LAB
Safe for underground handling
Increases light yield by ~15%
Improves resistance against water

DDA neutralises TeBD mixture and forms an ionic association with the complex to solubilise in LAB

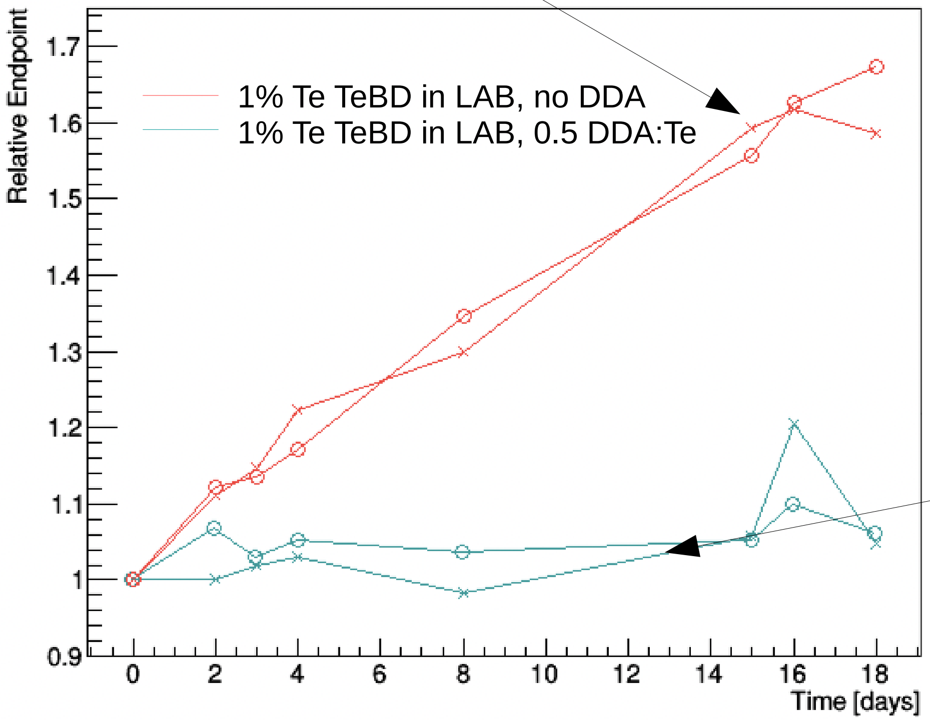


Tellurium loading quenches scintillator light

DDA offsets Te quenching to some extent
0.5 molar ratio chosen to optimise light output

Amine addition – water resistance

Water association can cause phase separation in samples without DDA - Te effectively falling out of solution decreases quenching and hence LY increases over time

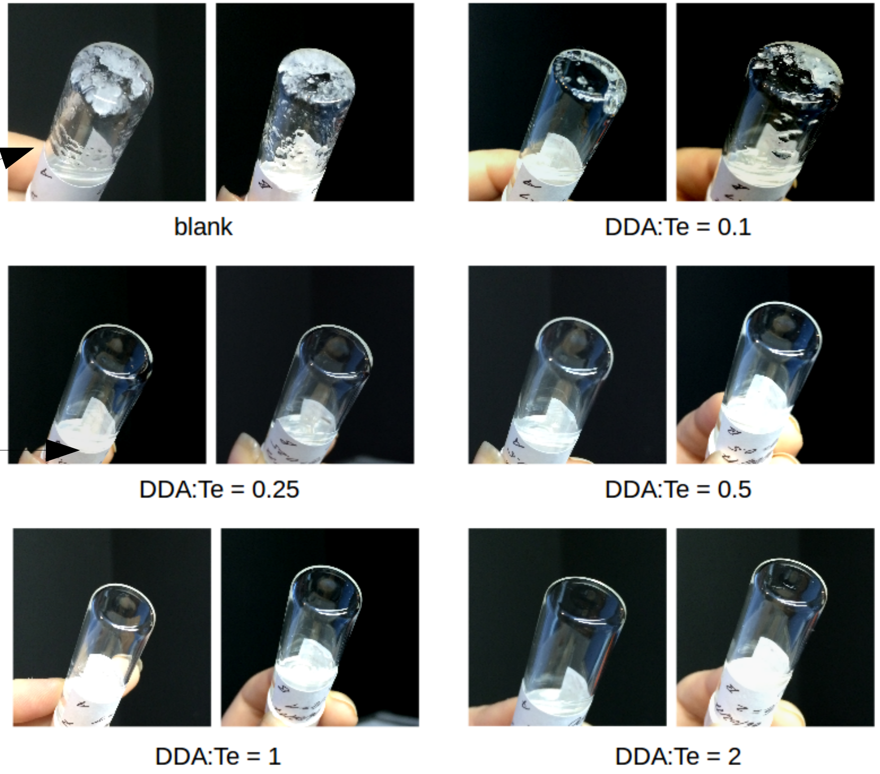


Flake formation in samples without DDA upon **extreme humidity exposure**

No flake formation observed in any samples with DDA:Te>0.25 molar

Light yield remains stable over time with DDA

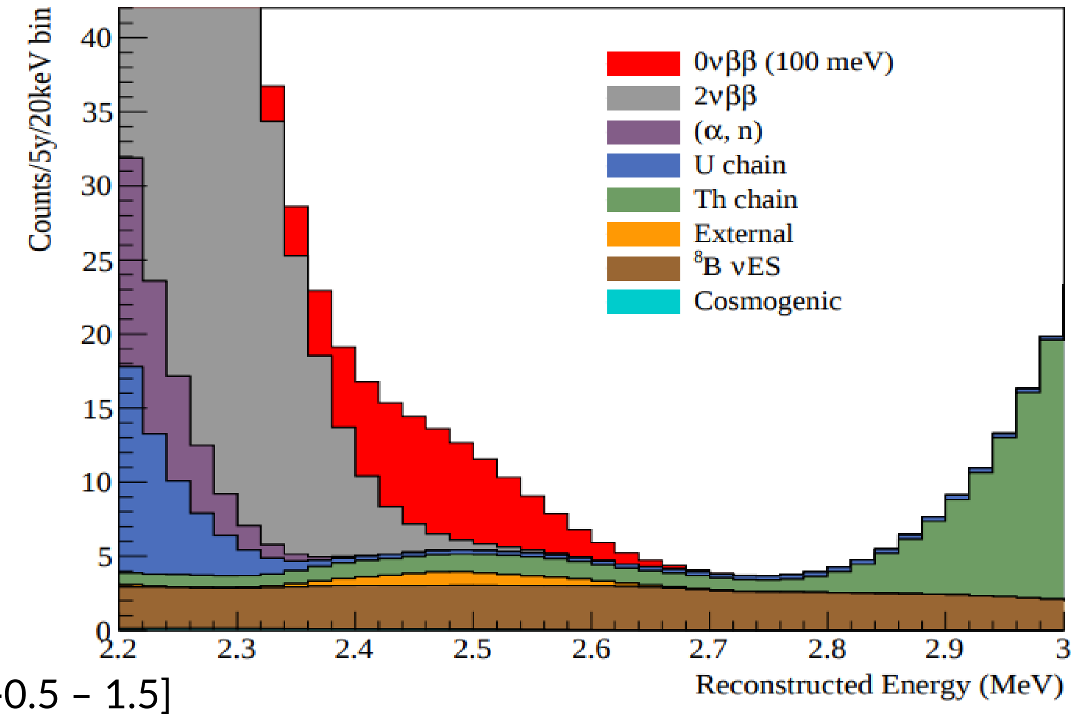
2 yrs after humidity exposure

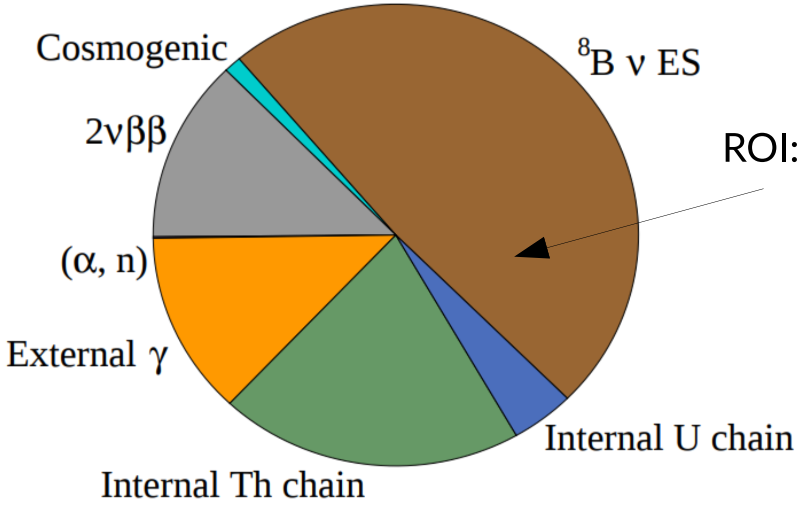


DDA reduces oligomerisation into longer Te chains improving its long term stability in humid conditions

0νββ in Phase I

Tellurium 130
High Q value (2.5 MeV)
High natural abundance (34 %)
Long 2νββ half-life (7.9x10^{20} yrs)
Light yield of 460 PMT hits/MeV
with loading technique





ROI: 2.42-2.56 MeV [-0.5 – 1.5]
Fiducial Volume: 3.3 m

Counting analysis
9.47 counts/yr → $T_{1/2}$ > 2.1x10^{26} yrs
after 5 yrs with 0.5 % Te (Phase I)

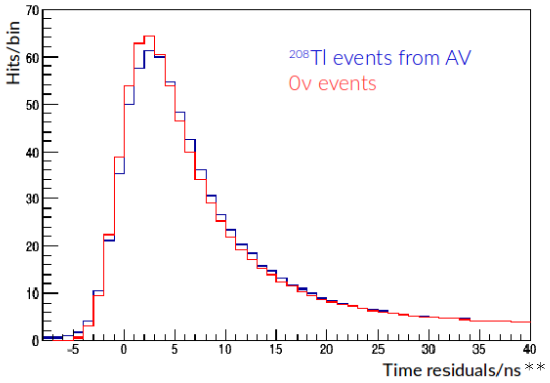
0νββ analysis

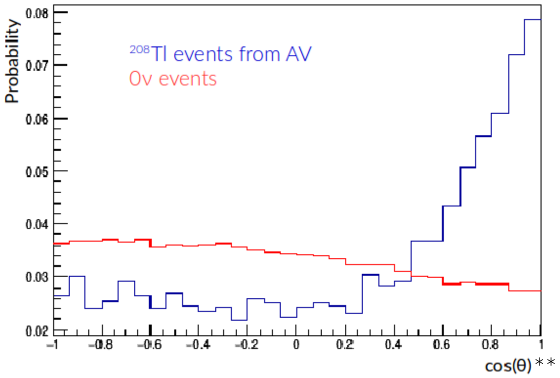
Likelihood analysis development

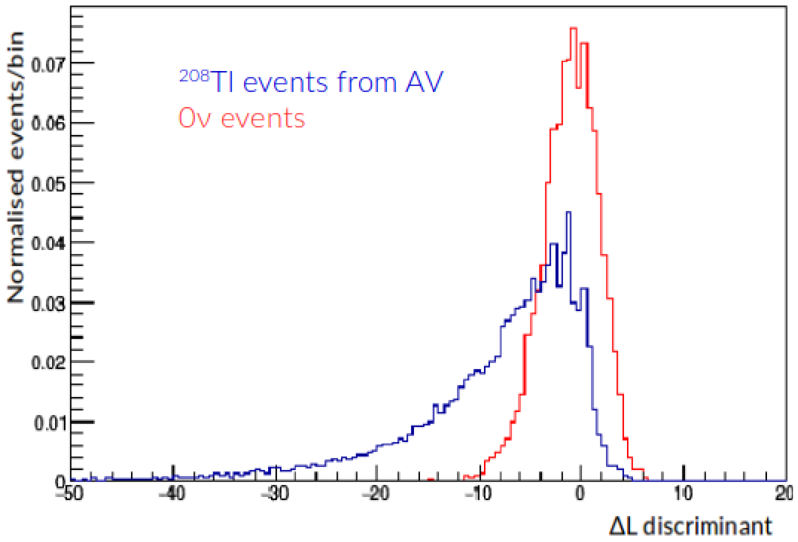
Can improve sensitivity by fitting the overall distribution
Binned log likelihood as test statistics
Markov Chain Monte Carlo optimiser
~30 background normalisations floated in the fit

Currently a 2D fit in energy and R^3
Planned extension to more dimensions using **timing and topological background discrimination***

*Dunger, Biller: "Multi-site Event Discrimination in Large Liquid Scintillation Detectors" 2019 (arXiv:1904.00440)







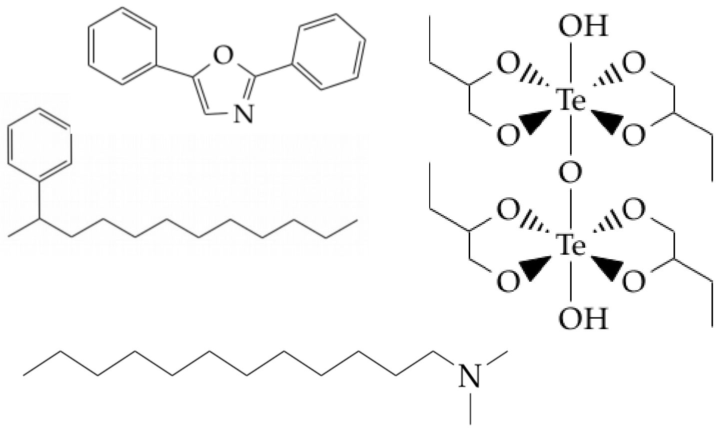
**Time residuals = $t_{hit} - t_{fit} - t_{tof}$
θ = angle between reconstructed position and hit PMT

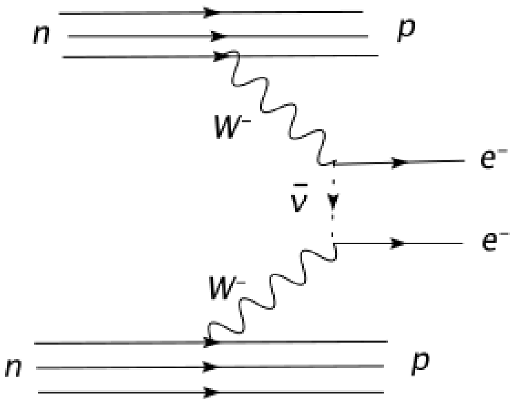
Summary

SNO+ deploys a novel technique for Tellurium loading into organic scintillator

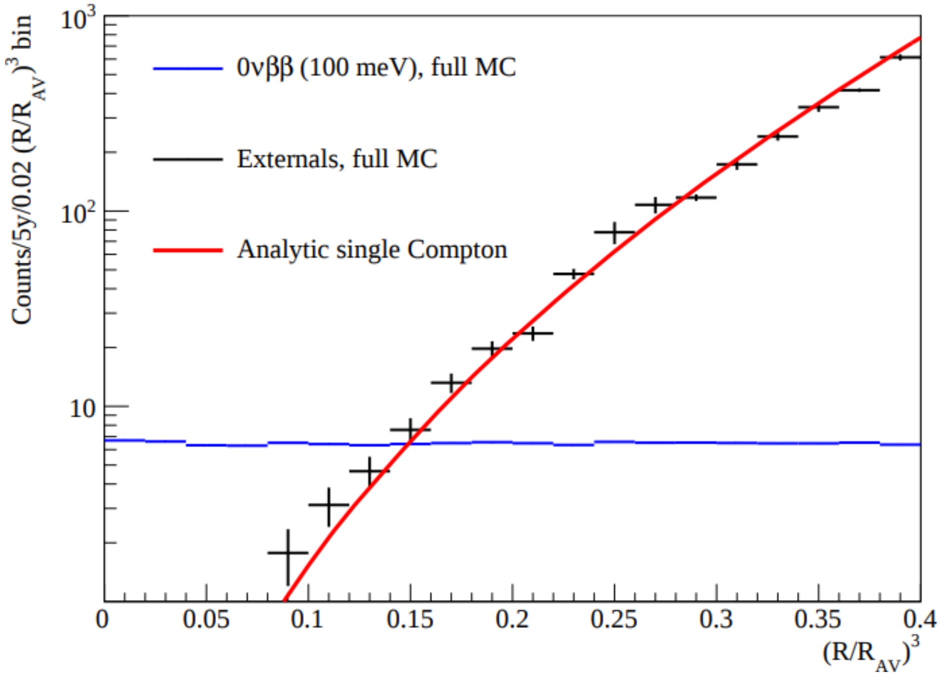
Addition of DDA improves properties of loaded scintillator mixture (light yield and water attack resistance)

SNO+ will have world leading sensitivity to $0\nu\beta\beta$ in ^{130}Te

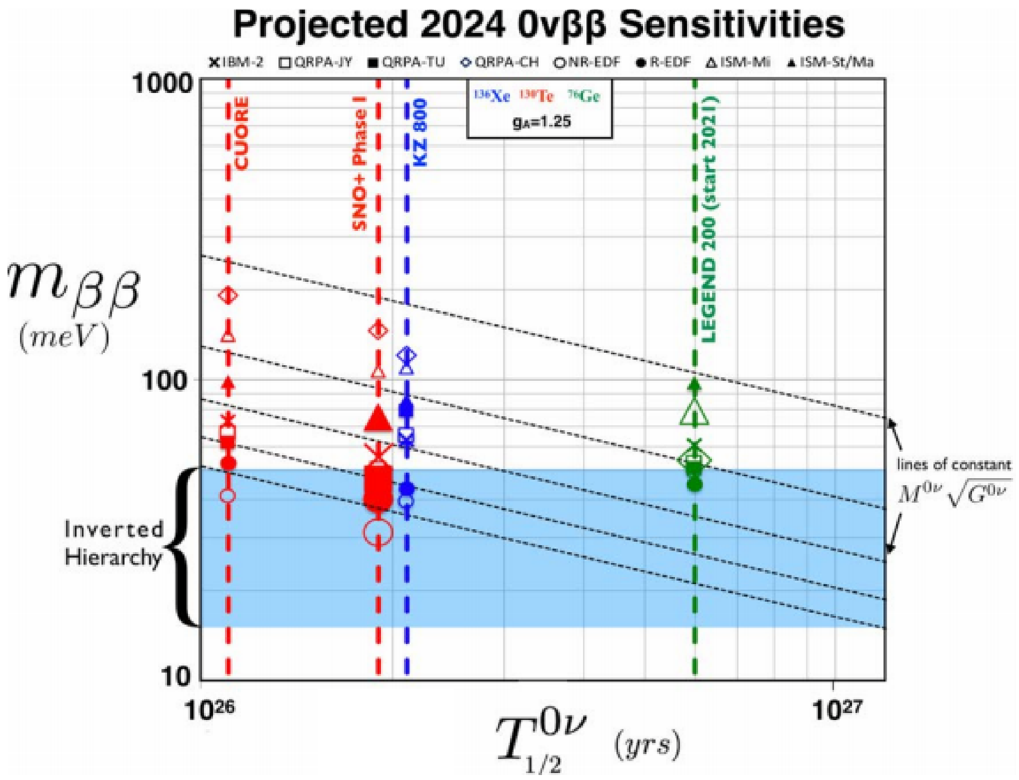




Back up



10^3
10^2
10
0 0.05 0.1 0.15 0.2 0.25 0.3 0.35 0.4
$(R/R_{AV})^3$
Counts/5y/0.02 $(R/R_{AV})^3$ bin
$0\nu\beta\beta$ (100 meV), full MC
Externals, full MC
Analytic single Compton



Projected 2024 0νββ Sensitivities
IBM-2 QRPA-JY QRPA-TU QRPA-CH NR-EDF R-EDF ISM-Mi ISM-St/Ma
^{136}Xe ^{130}Te ^{76}Ge
g_A=1.25
CUORE
SNO+ Phase I
KZ 800
LEGEND 200 (start 2021)
1000
100
10
$m_{\beta\beta}$ (meV)
Inverted Hierarchy
lines of constant $M^{0\nu}\sqrt{G^{0\nu}}$
10^{26}
10^{27}
$T^{0\nu}_{1/2}$ (yrs)