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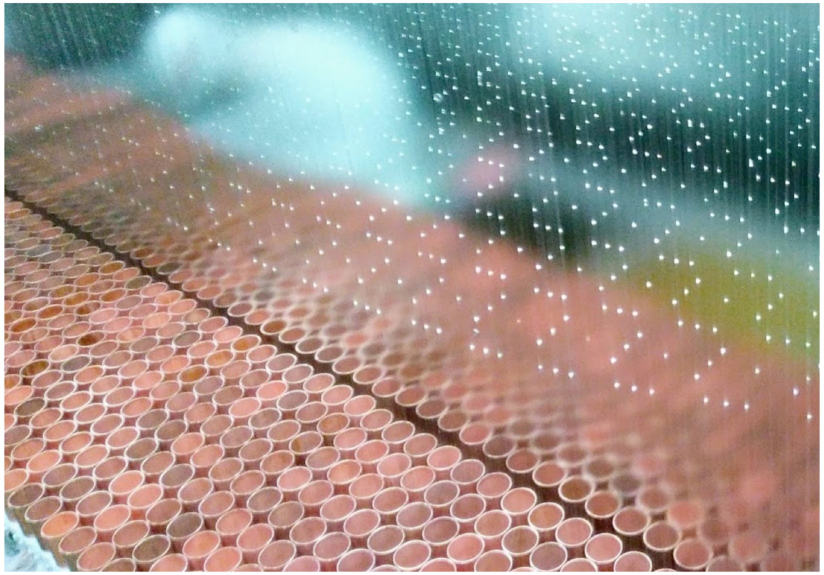
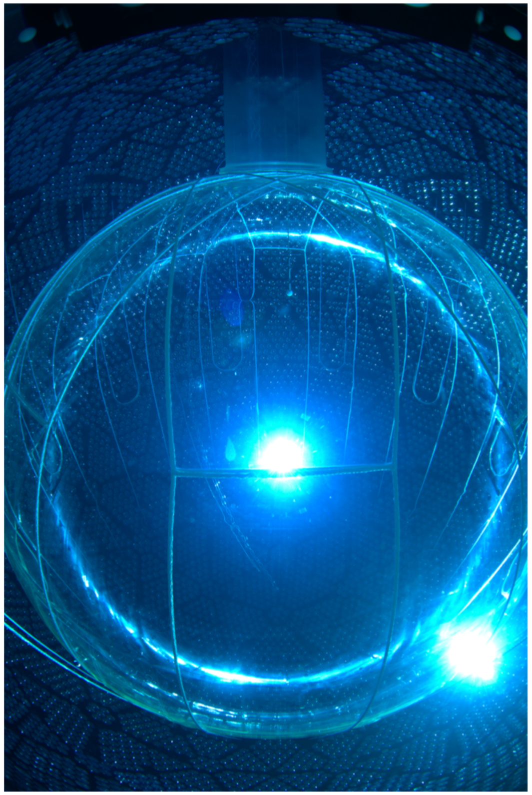
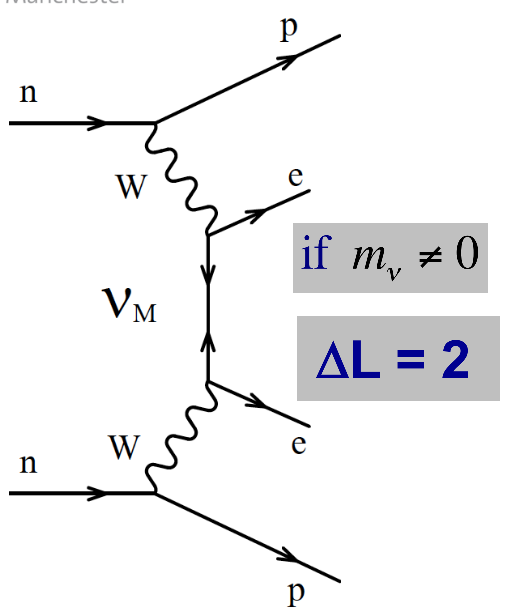
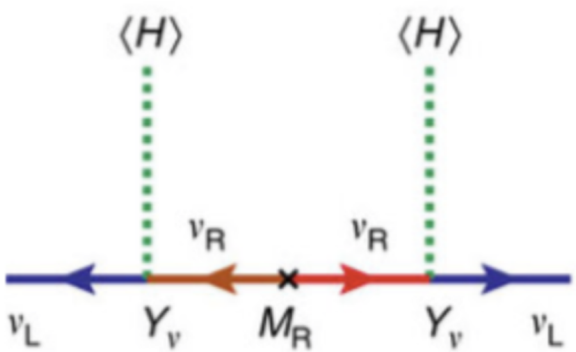
Neutrinoless double-beta decay

Justin Evans









(image credit: T. Ohlsson et al., Nat. Comm.)

0νββ

Majorana or Dirac nature of neutrino

Lepton flavour violation

Absolute neutrino mass

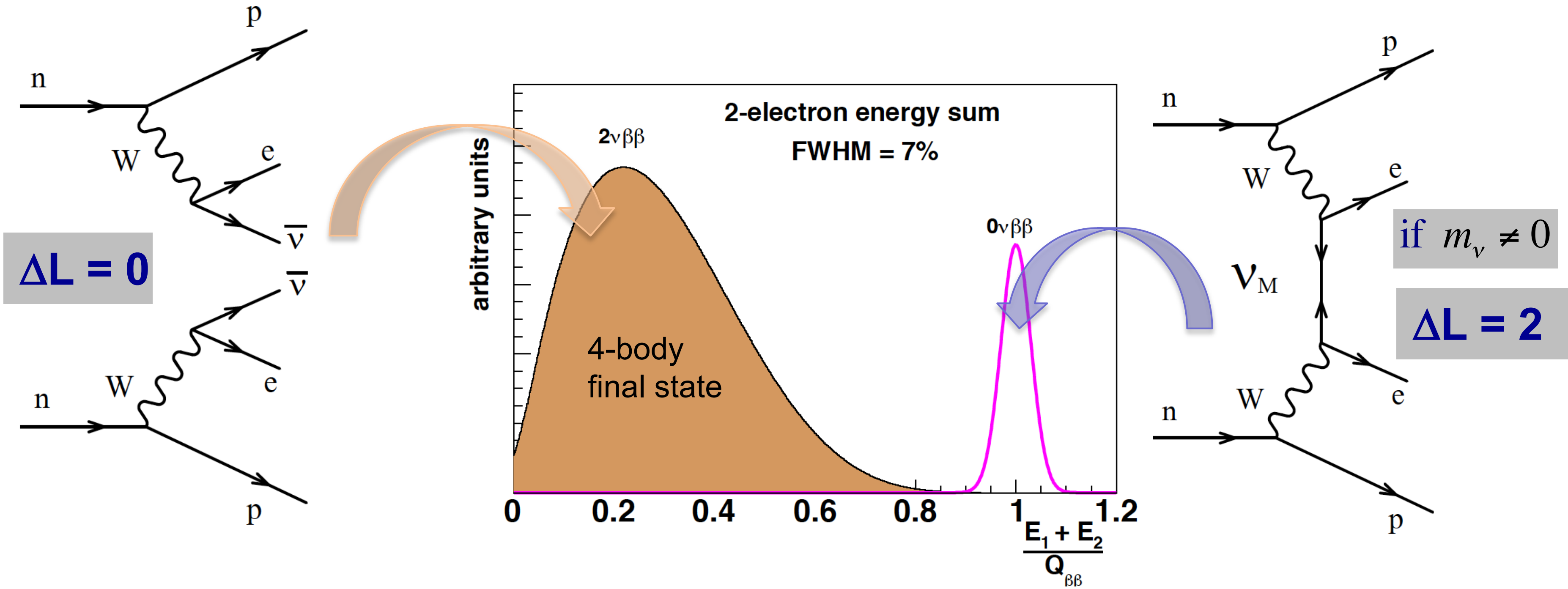
Seesaw models

- Natural explanation for suppression of neutrino masses

Probe of exotic physics

- Majorons
- Right-handed currents
- SUSY
- …

0νββ



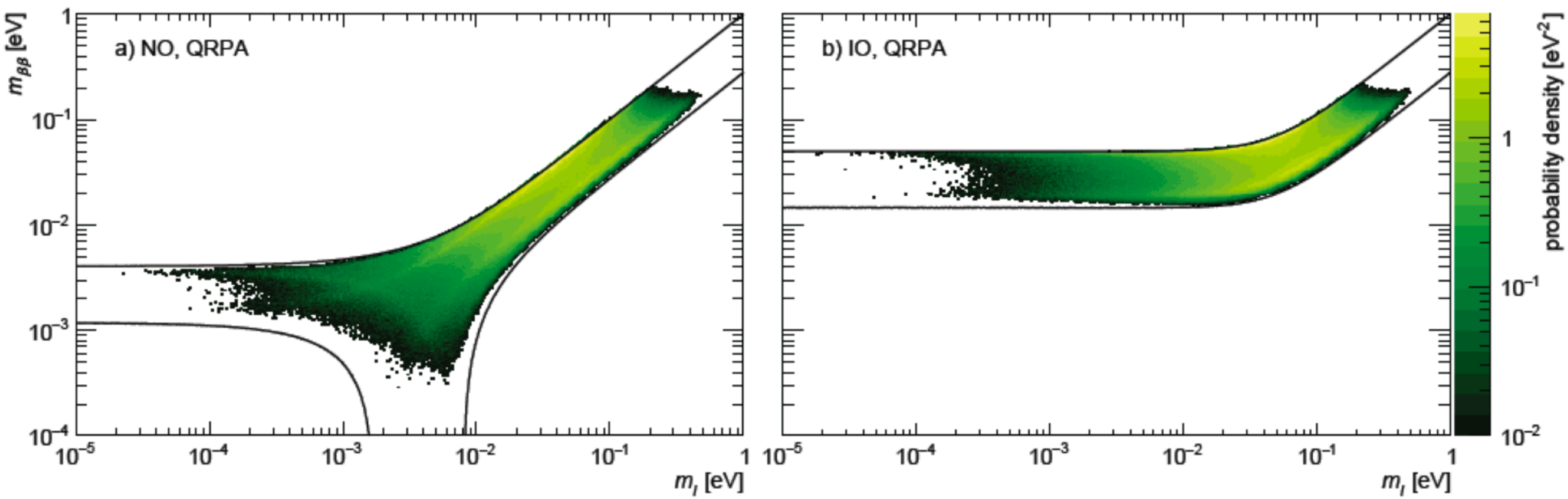
An experimental and theoretical challenge

- Energy resolution
- Background suppression
- Isotope mass
- Nuclear matrix elements

The global picture

From Agostini, Benato & Detwiler, Phys. Rev. D **96**, 053001 (2017)

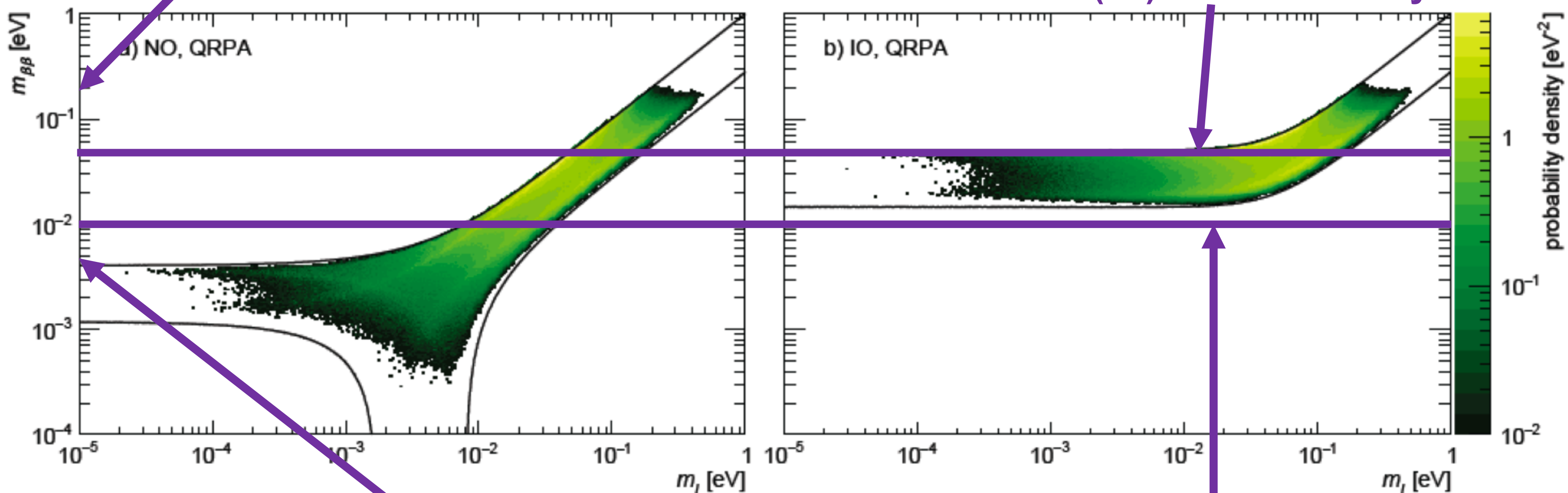
- Assume a logarithmic prior on the neutrino mass
- Assume a flat prior on the mixing angles and phases



The global picture

Current published limits are around here
$T_{1/2} \sim 10^{25}$ yr

Current experiments can get to here
$T_{1/2} = 10^{26}$-10^{27} yr
O(10) counts / ton / y

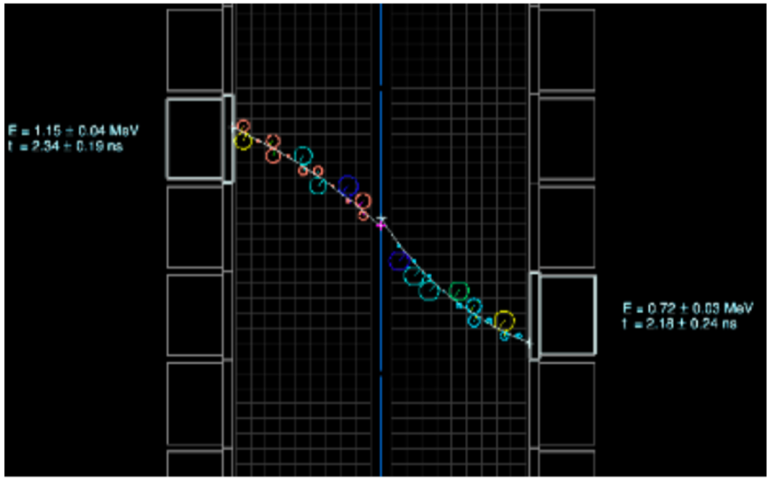


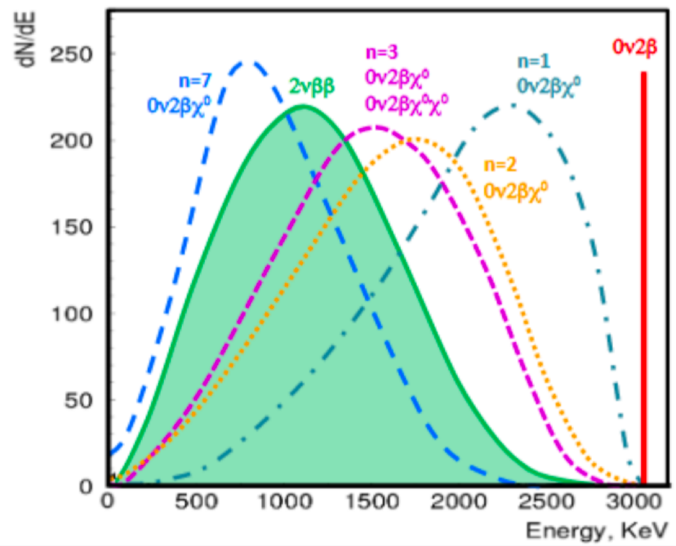
This corresponds to
$T_{1/2} = 10^{28}$-10^{29} yr
O(0.1) counts / ton / y

The next generation (15-20 years) should get us here
$T_{1/2} = 10^{27}$-10^{28} yr
O(1) counts / ton / y

- Excellent discovery potential, even in the case of normal ordering

SuperNEMO





One of the few experiments where source ≠ detector

- Full topological reconstruction
- Modular
- Can investigate multiple isotopes

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SuperNEMO Demonstrator Module

All detector modules delivered underground (LSM)

Half of the detector (tracker + calorimeter) fully integrated

- First events seen from half-detector commissioning

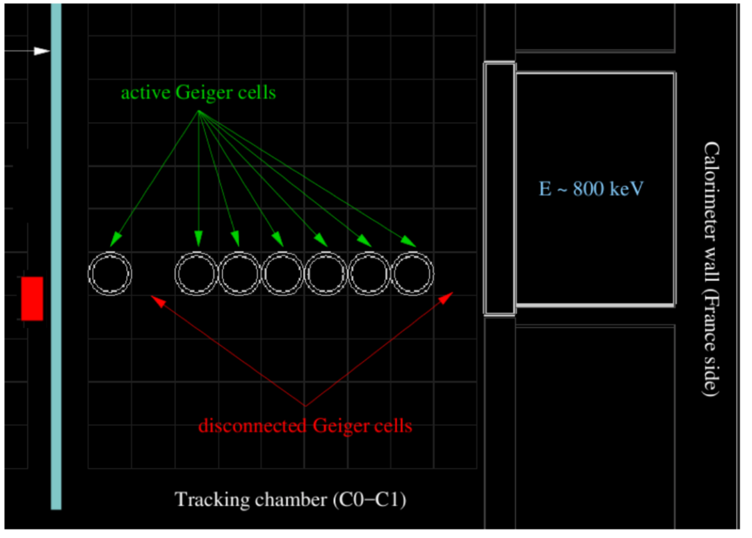
^{82}Se source foil (6.3 kg) production completed

- Installation happening this summer

Reliant on CG funding to exploit this major UK investment

Broad physics programme

- $\langle m_\nu \rangle < 0.16\text{–}0.4$ eV; $T_{1/2} > 6\times10^{24}$
- Exotic $0\nu\beta\beta$ mechanisms
- $2\nu\beta\beta$ SSD/HSD discrimination at 5σ
- Probe of g_A
- Lorenz invariance violation
- Additional isotopes – ^{150}Nd and ^{48}Ca
- $0\nu4\beta$



SNO+

Load liquid scintillator with 0.5% natural Te

- High abundance of ^{130}Te – no enrichment necessary

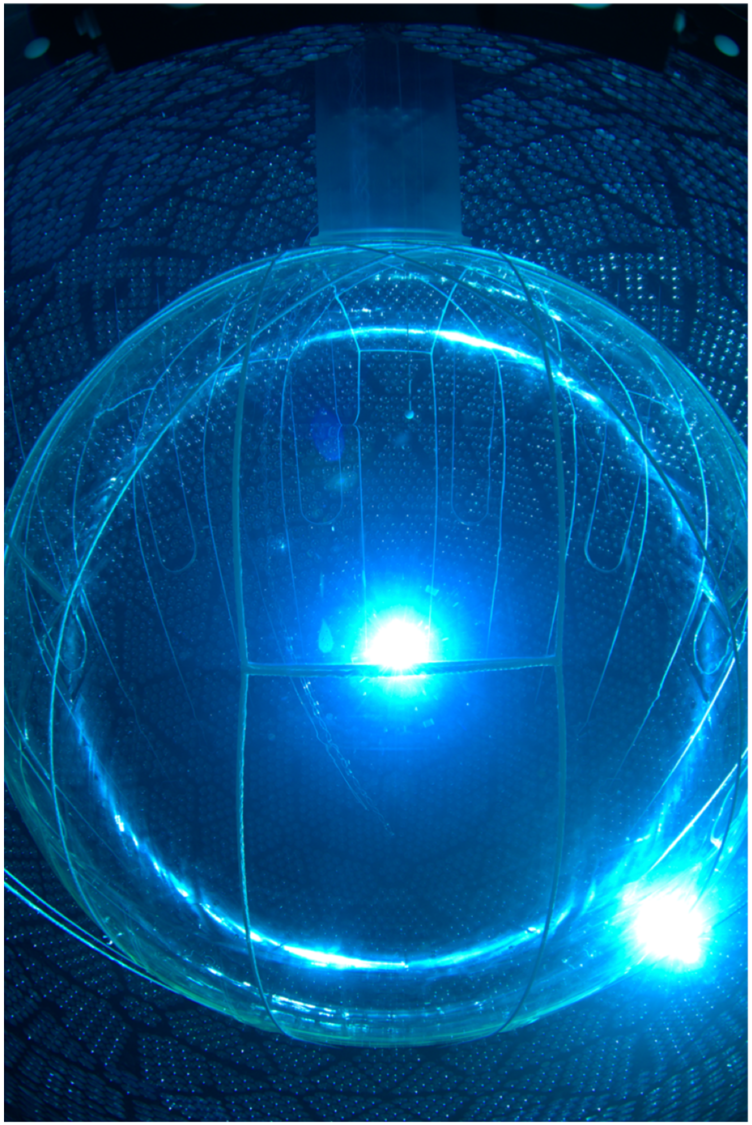
$0\nu\beta\beta$: $T_{1/2} > 1.9\times10^{26}$ yr

Solar neutrinos

Geoneutrinos

Reactor antineutrinos

Nucleon decay



SNO+

Data-taking with water began in May 2017

- Measurements of external backgrounds and solar neutrinos

Scintillator purification plant is being commissioned

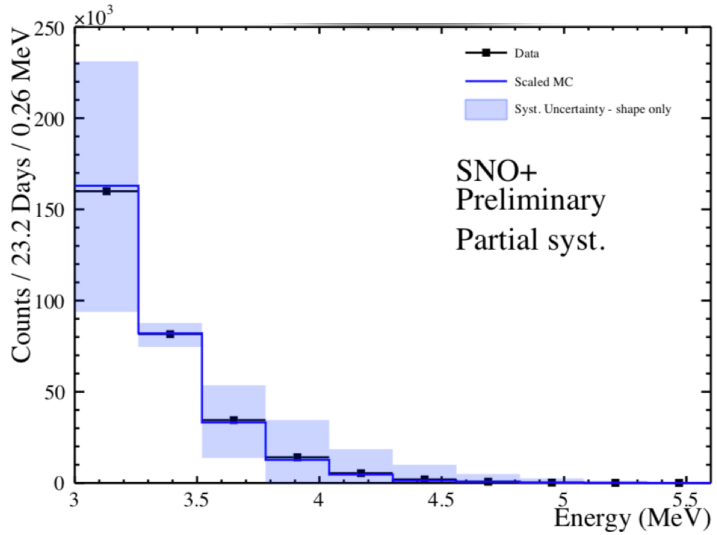
- Scintillator fill starts this month

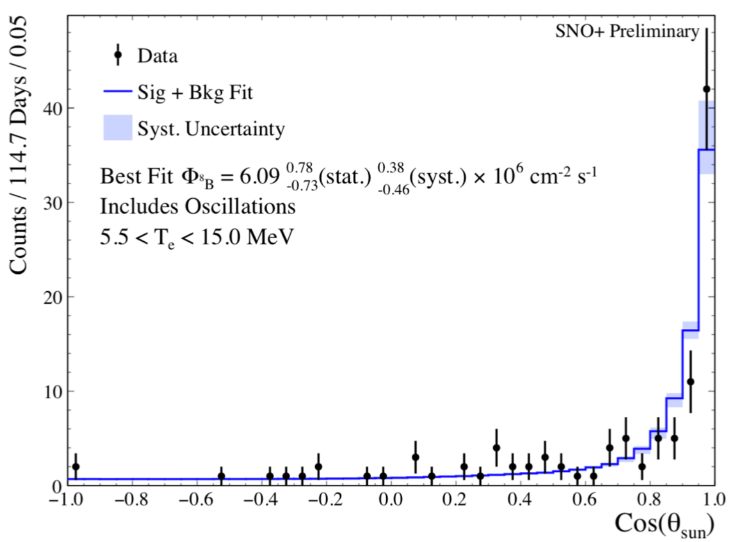
Building of the Te-butanediol synthesis plant is underway

- TeA has been stored underground for more than 2 years

Te loading in spring 2019

Reliant on CG funding for exploitation





SuperNEMO future directions

In case of discovery, SuperNEMO is the best way to characterize $0\nu\beta\beta$

- Full topological reconstruction

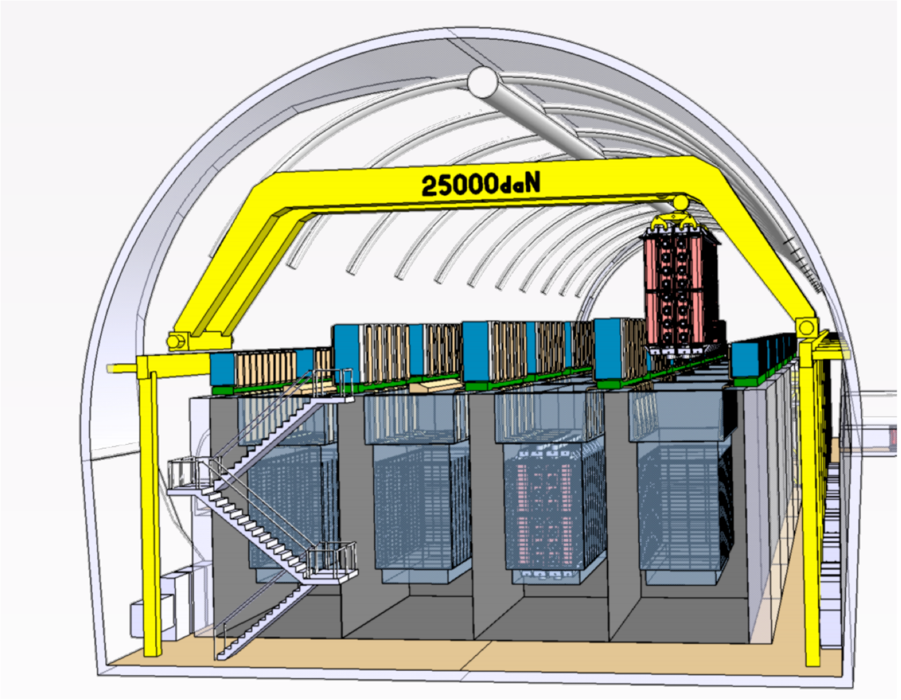
Modular; multiple isotopes; excellent background rejection

15-20 modules for 100 kg isotope

- $T_{1/2} \sim 1\text{x}10^{26}$ yr
- Can confirm and characterise a signal in any of the current experiments

€2.5M / module

- Expensive to extrapolate beyond 100 kg, to probe $T_{1/2} \sim 10^{27}$-10^{28} yr
- R&D is ongoing into cost-reduction



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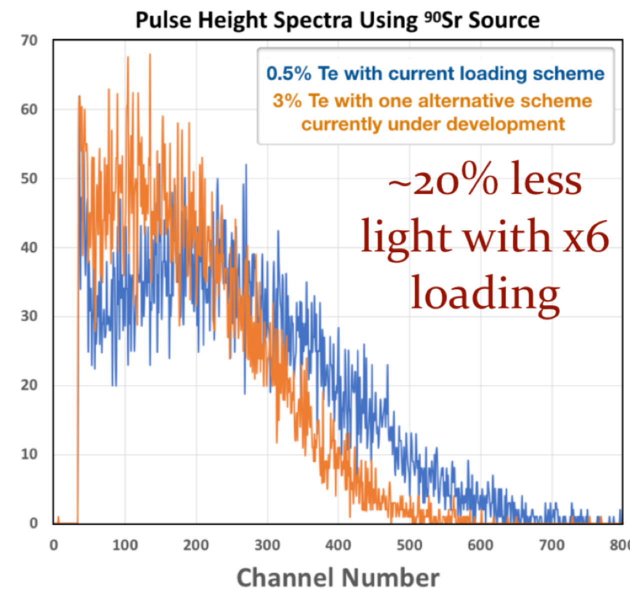
SNO+ future directions

Increase Te loading to 1–3%

- Ambition to reach a ton of isotope ($T_{1/2} > 10^{27}$ yr)
- Challenge is to maintain the light yield



New PMTs with 34% QE

New light concentrators

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UK expertise

UK 0νββ has extensive low-background expertise

- Which also benefits the dark-matter community

High-purity germanium detectors at Boulby

UCL-developed RnCL, sensitive to 40 μBq / m^3

Second RnCL being built at RAL for cryogenic temperatures

UCL has ICP-MS facilities for ppq sensitivity

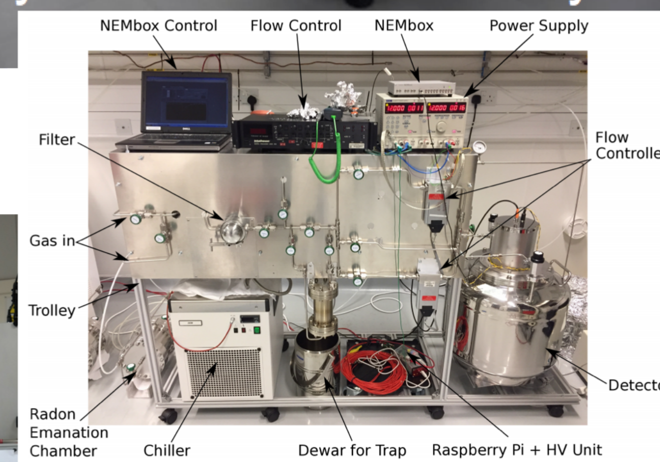
Boulby has surface-alpha measurement facilities

- UK can provide screening across the decay chain with all the major techniques

Discussions with colleagues in Latin America about how to pass on our expertise

World's best-resolution large plastic calorimeter

- Now being used for proton-therapy beam calibration



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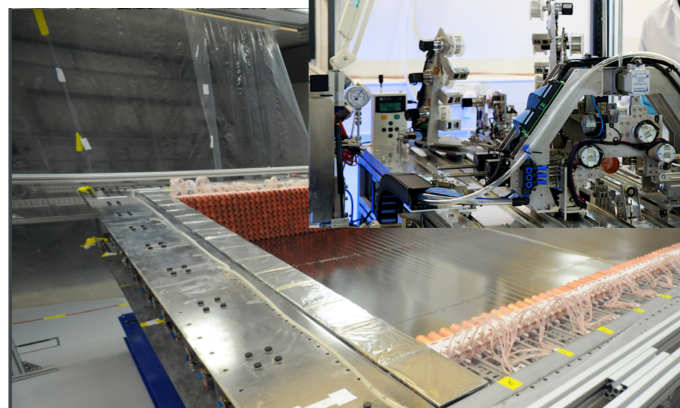
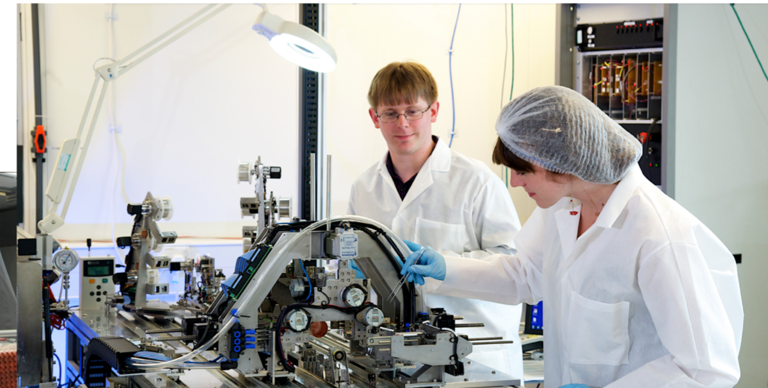
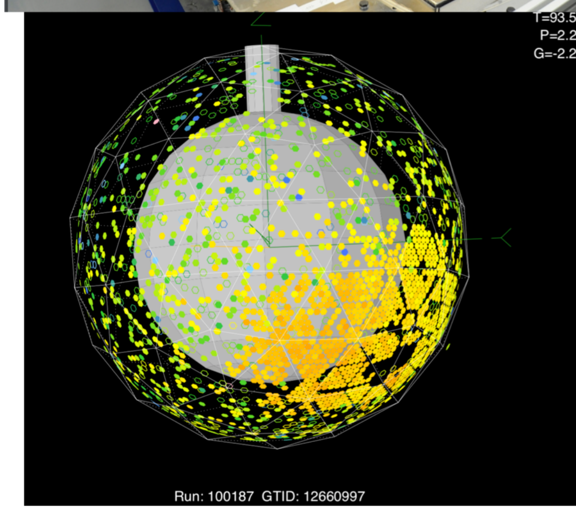
UK leadership

- Two spokespeople of SuperNEMO
- Pioneered tellurium loading in SNO+
- Built the SuperNEMO tracking detector
- Provided calibration devices for SNO+







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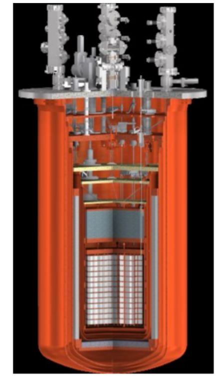
The global future



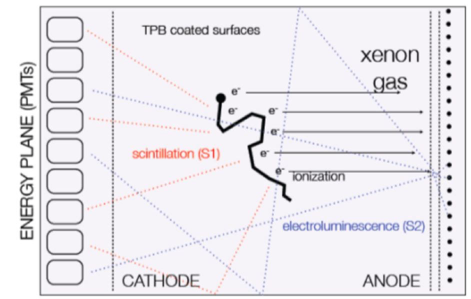
(This is not a comprehensive list of projects.)

Majorana & GERDA → LEGEND Ge

CUORE → CUPID Te

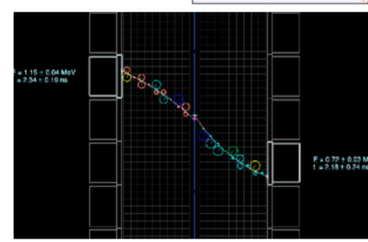
EXO → nEXO
PANDA
NEXT
KamLAND-Zen → KamLAND2-Zen

} Xe



SNO+ Te

SuperNEMO Multiple isotopes



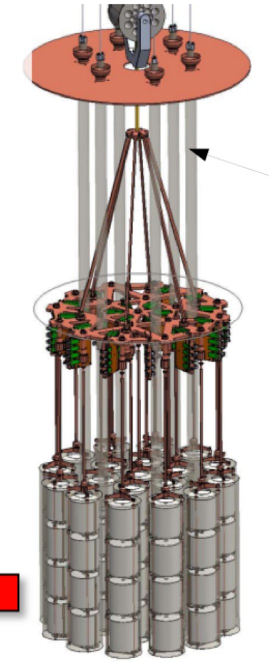
- In Europe, ApPEC states 0νββ is a high priority, and aims to converge on a roadmap for the next-generation experiments by 2020
- 2013 CERN strategy: "In the coming years, CERN should seek a closer collaboration with ApPEC on detector R&D with a view to maintaining the community' s capability for unique projects in this field"
- In the US, a down-select is underway to maximize support for a single large project

Large Enriched Germanium Experiment for $0\nu\beta\beta$ Decay

- ^{76}Ge experiments have demonstrated world-leading sensitivity : GERDA and Majorana Demonstrator (MJD).
- Only GERDA & KamLAND-Zen setting limits at 10^{26} yrs.
- A clear path to discovery :
  - 10^{27} yrs : [175-200] kg; bkg reduction factor 3.
  - 10^{28} yrs : 1 tonne; further bkg reduction factor 6.
- Key performance requirements very plausible :
  - GERDA & MJD reach similar performance already with highly complementary shielding, readout etc.

Current GERDA array

LEGEND-200 in GERDA cryostat. Deployment 2021.



LEGEND

- Collaboration formed in 2016.
- UK invited to join based on :
  - HPGe expertise (in nuclear physics community).
  - Low background screening capability.
- Currently UCL, Liverpool & Lancaster have expressed interest & are participating at low level.
  - Strong UK participation/leadership are possible.

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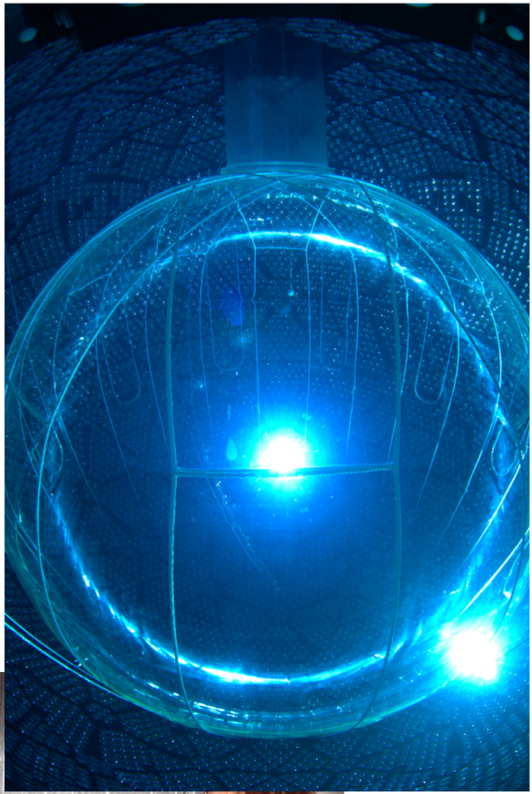
UK ambition



We are moving into the exploitation phases of both SNO+ and SuperNEMO

- Reliant on the PPGP providing CG funding for exploitation of our investments, and to deliver M&O responsibilities

Now is the time to define the UK's future direction

- We must consolidate as a community to ensure maximum impact

Boulby is a world-leading facility for radiopurity assays

- Investment here ensures UK leadership whatever the technological choices

Existing UK-led technologies are vital to the future of the field

- As we exploit the existing phases of SuperNEMO and SNO+ we will learn a lot
- Support is vital to define and realise the next phases

UK is actively scoping out future options to ensure we are setting world-leading limits