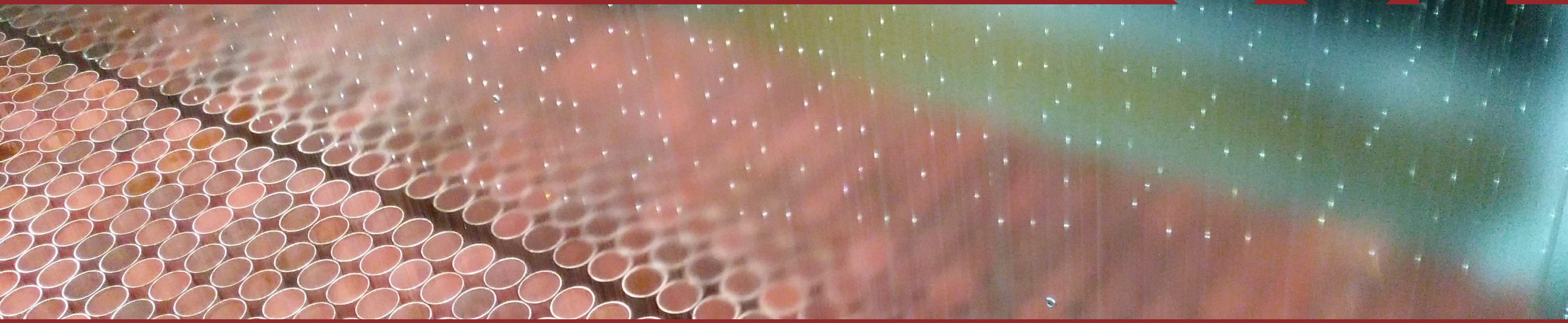


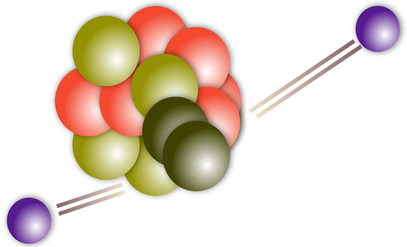
Status of the SuperNEMO ββ-decay experiment

Cheryl Patrick, UCL

IOP APP/HEPP Conference, March 26-28, 2018

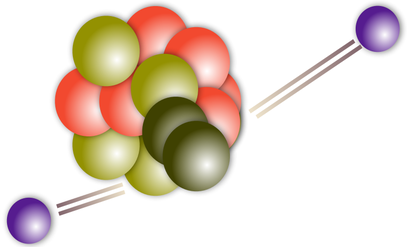
SuperNEMO in one slide

SuperNEMO in one slide



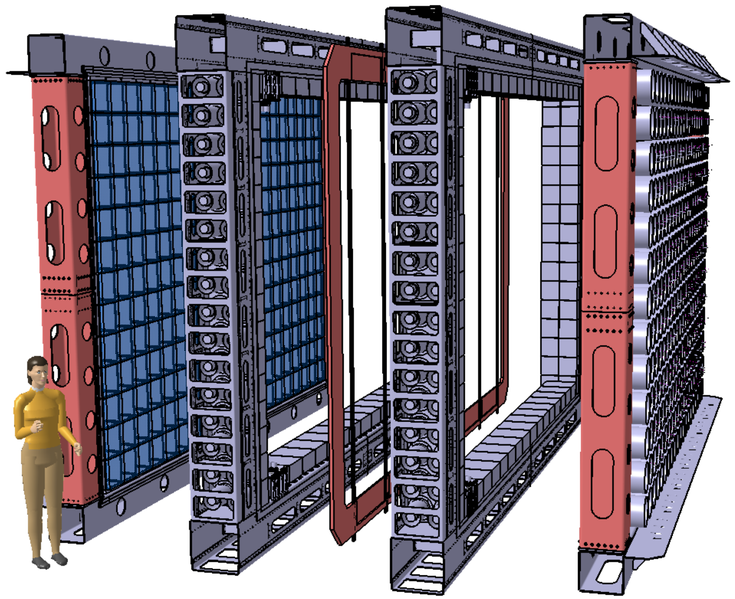
- neutrinoless double-beta decay experiment

SuperNEMO in one slide

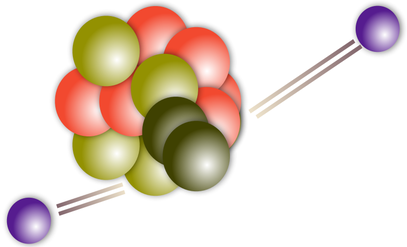


- neutrinoless double-beta decay experiment

- unique tracker-calorimeter architecture
- ultra-low backgrounds



SuperNEMO in one slide



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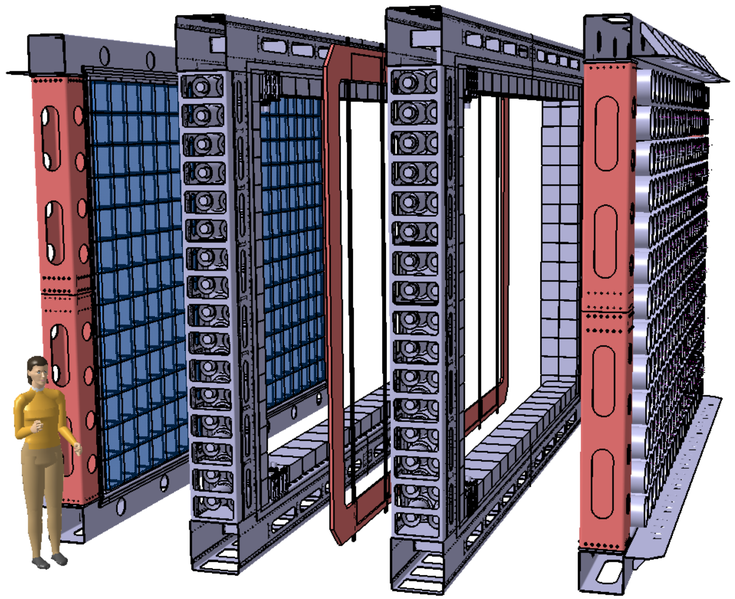

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- under construction at LSM, France

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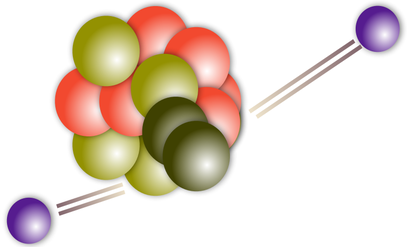

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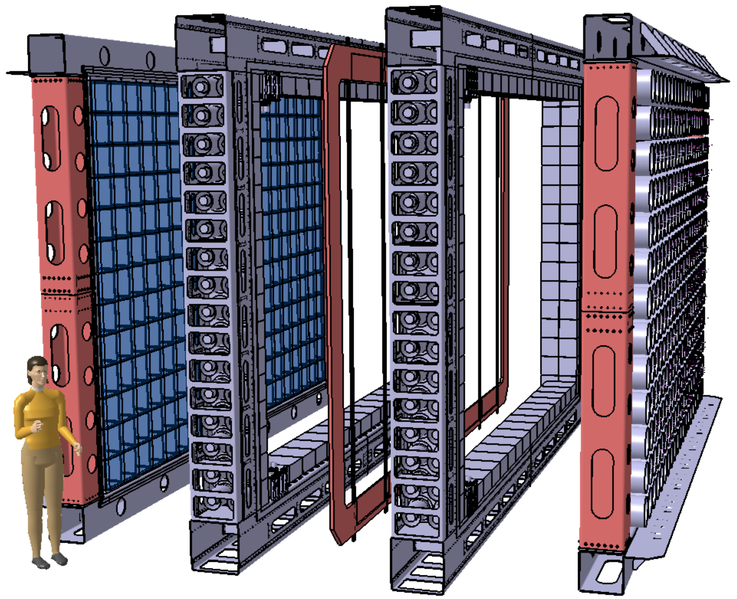
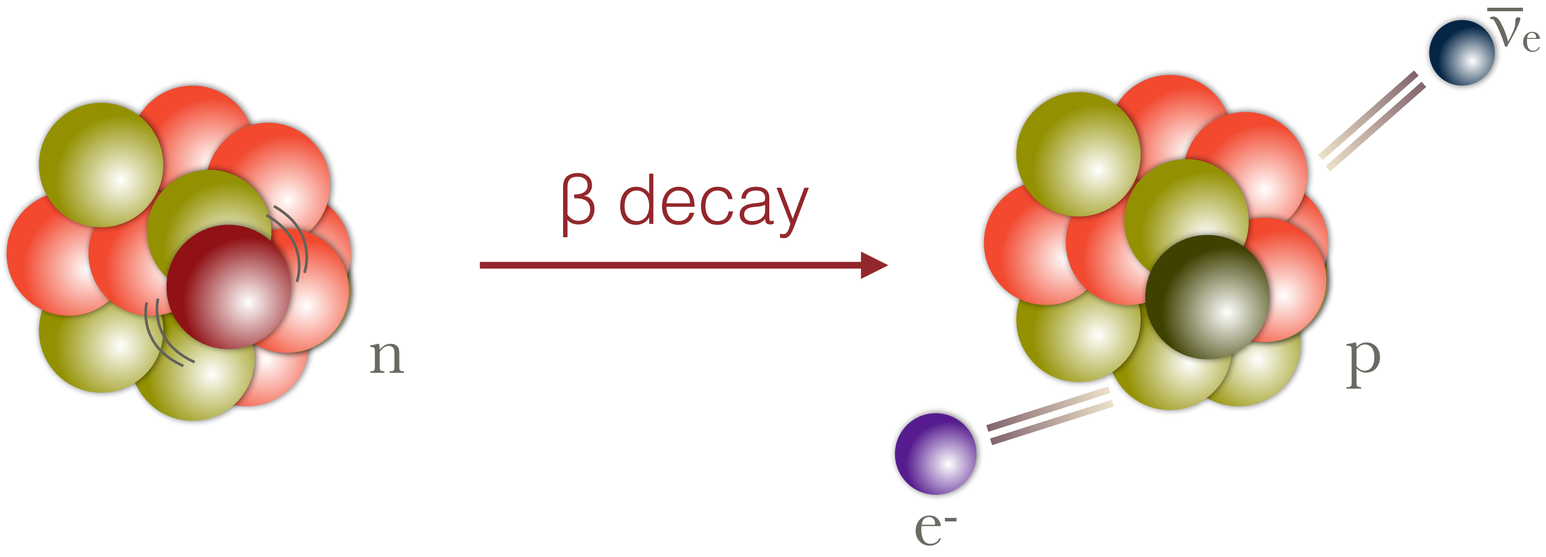
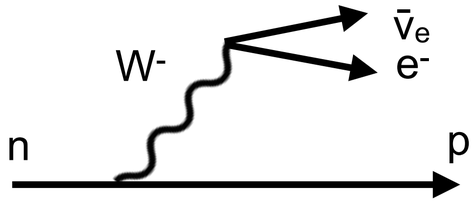


- unique tracker-calorimeter architecture
- ultra-low backgrounds

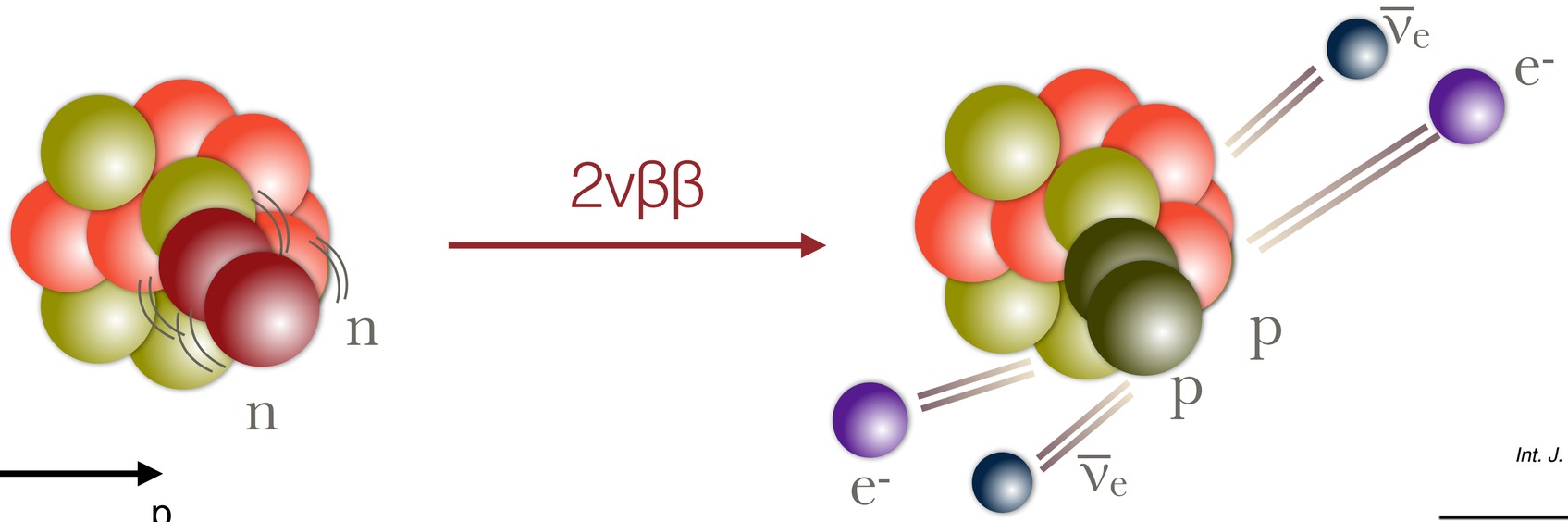
- under construction at LSM, France
- first data this year

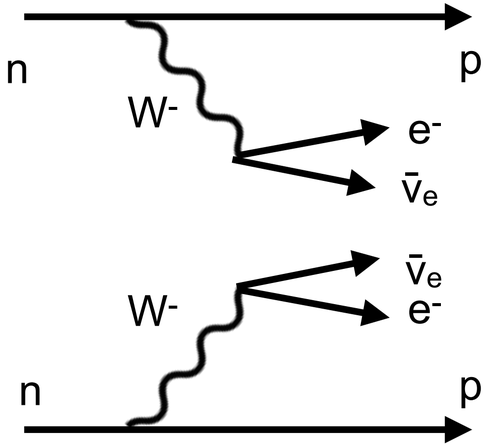
beta decay



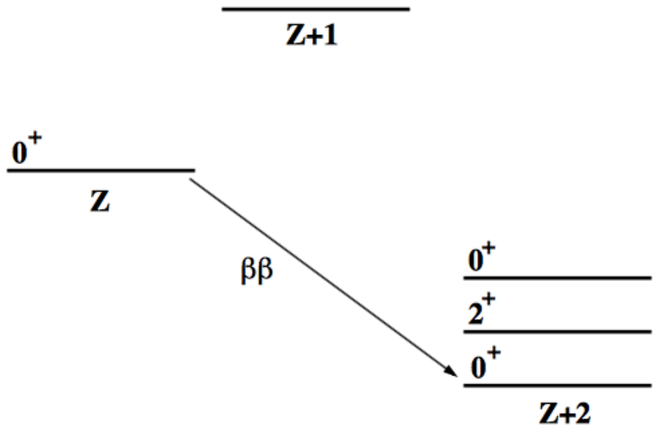


double-beta decay

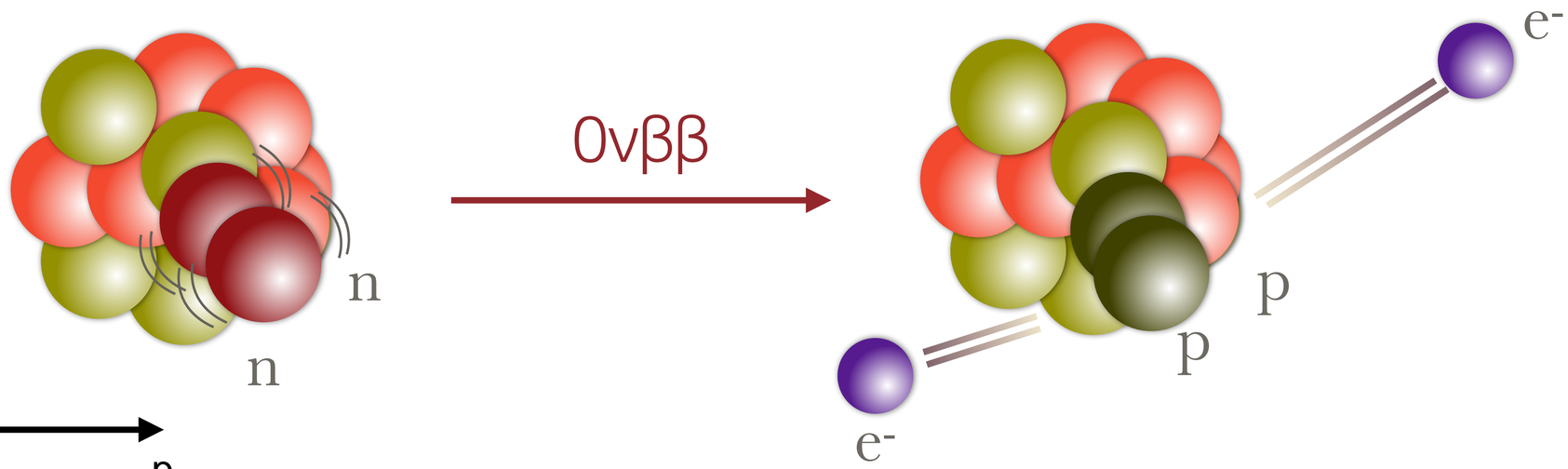


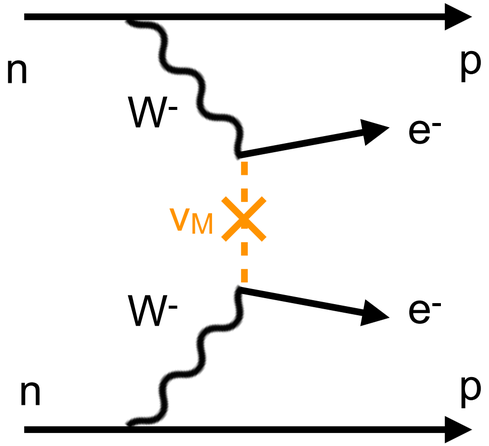


Int. J. Mod. Phys. E Vol. 25, 1630007 (2016)



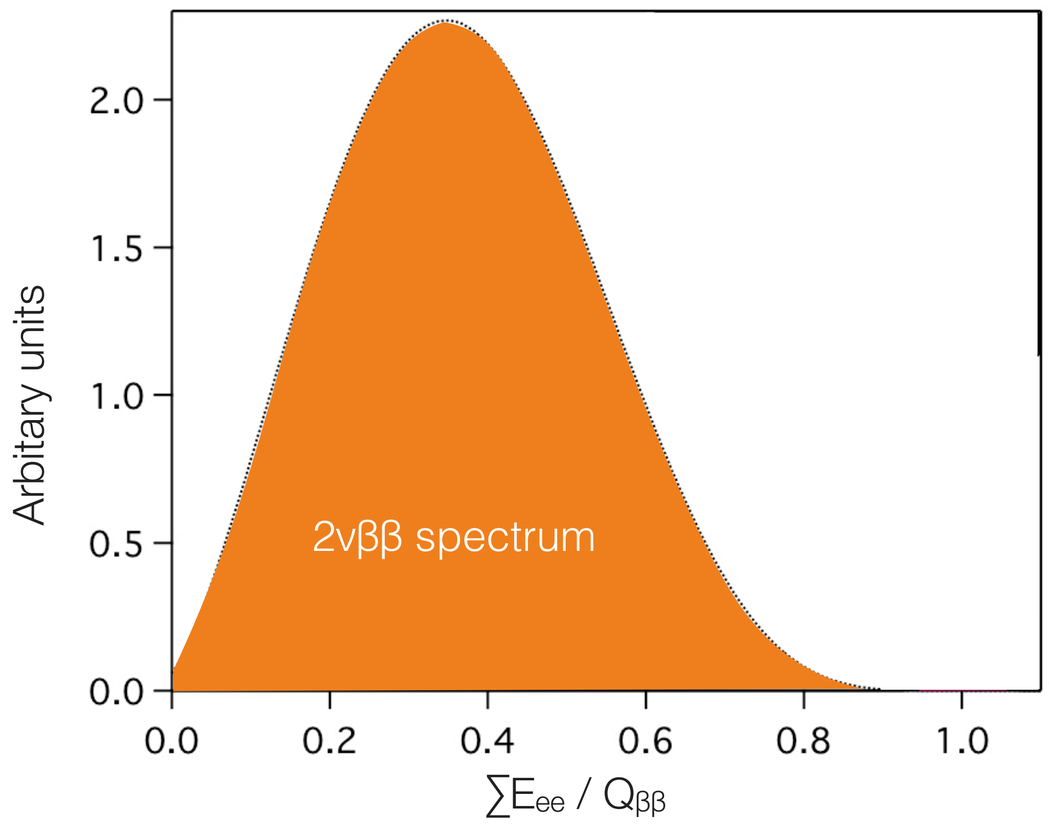
Neutrinoless double-beta decay





Neutrino must be Majorana (ν=ν̄)

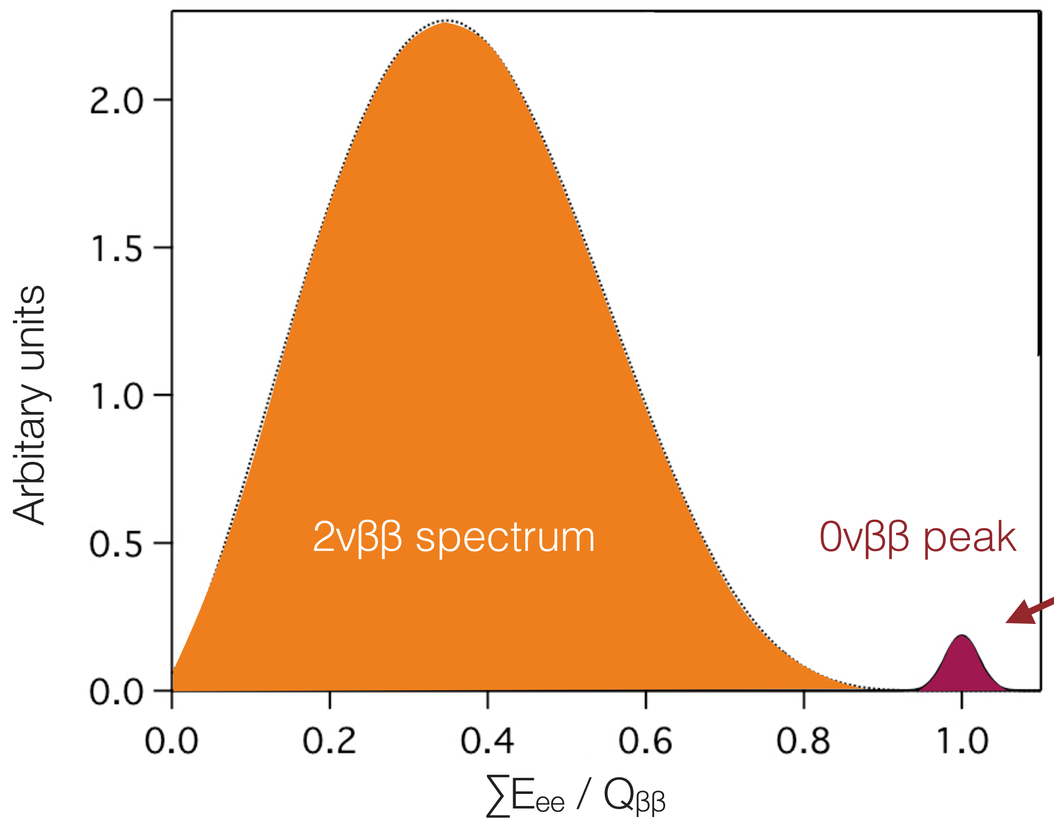
So how does this look?



Summed 2-electron energy as fraction of ββ decay energy

Some fraction of energy goes to neutrinos

So how does this look?



No neutrinos means all energy goes to electrons (smeared in reconstruction)

Summed 2-electron energy as fraction of ββ decay energy

NEMO-3 - the slightly-less-super NEMO

NEMO-3 tracker-calorimeter detector (2003-2011)

- 2νββ measurements and 0νββ limits for several isotopes
  - **^{100}Mo** (Phys. Rev. Let. 95, 182302)
  - **^{150}Nd** (Phys. Rev. D 94, 072003)
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  - **^{96}Zr** (Nucl.Phys.A847:168-179)
  - **^{82}Se** (coming soon)
- Quadruple beta decay limit (Phys. Rev. Lett. 119, 041801)

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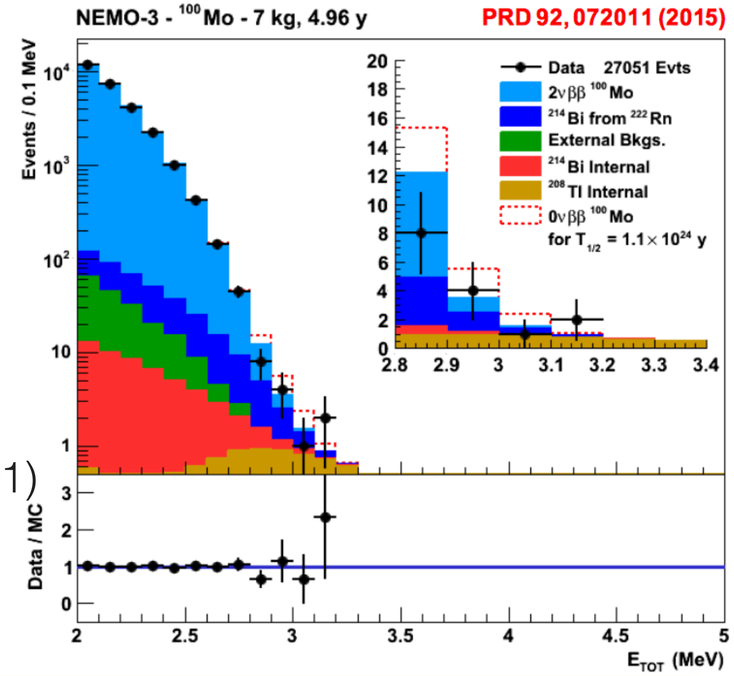


^{100}Mo

2νββ:

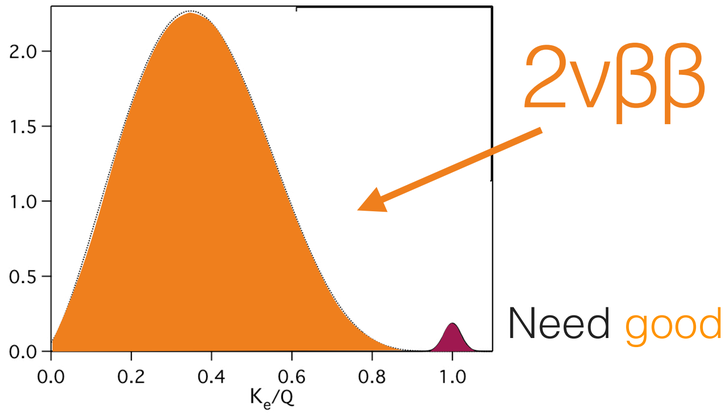
$T_{1/2}$ = 7.1 ± 0.02 (stat) ± 0.54 (sys) x 10^{18} yr

0νββ:

$T_{1/2}$ > 1.1x 10^{24} years

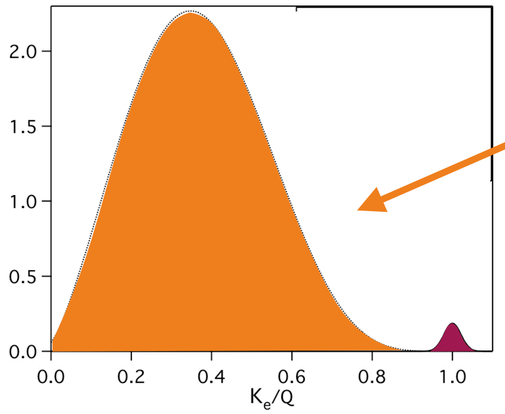
$\langle m_\nu \rangle$ < 0.33 - 0.62 eV *Phys. Rev. Let. 95, 182302*

Backgrounds to 0νββ: 2νββ



Need good energy resolution

Backgrounds to 0νββ: 2νββ



2νββ

Need good energy resolution

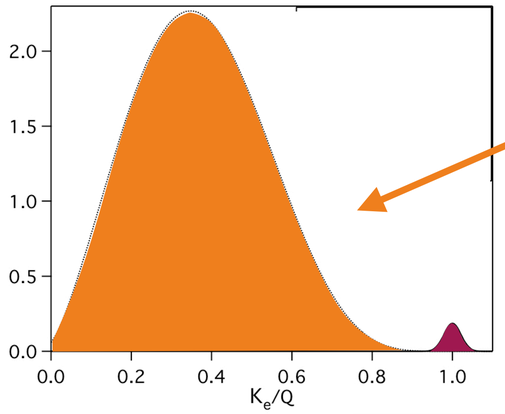
Optical module = polystyrene scintillator block + 8" radiopure PMT

Energy Resolution: 8% FWHM (1MeV)
twice as good as NEMO-3

Time resolution: 400ps (1MeV)

Nucl.Inst.Meth. A 868 98-108

Backgrounds to 0νββ: 2νββ



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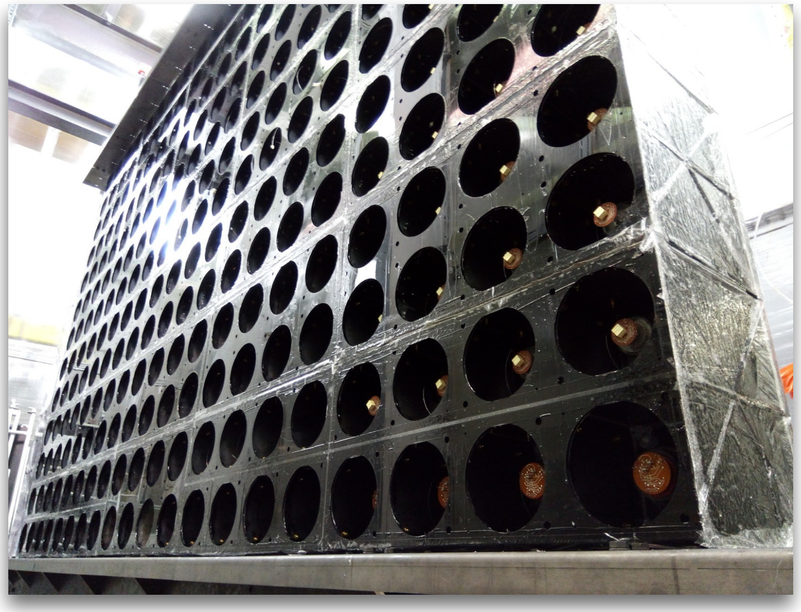
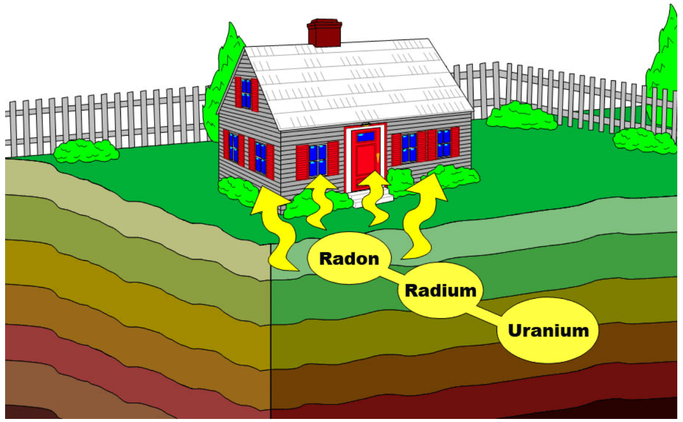


Main calorimeter walls: 520 optical modules

With side, top and bottoms: 712 modules total

Backgrounds to 0νββ: Radon and natural radioactivity



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- β-emitting daughters in detector and ββ source can mimic ββ
- 4-pronged attack…

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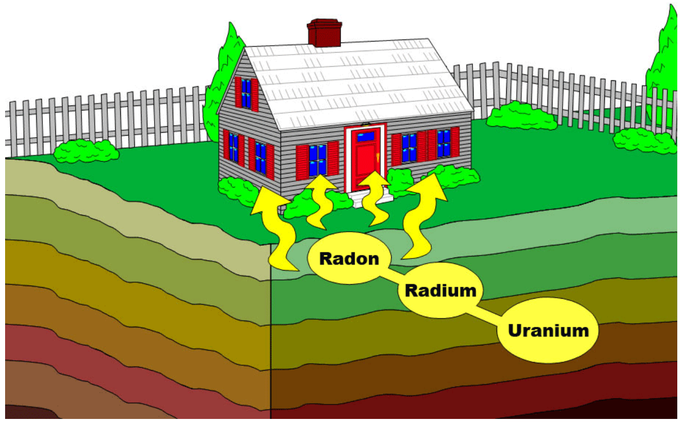

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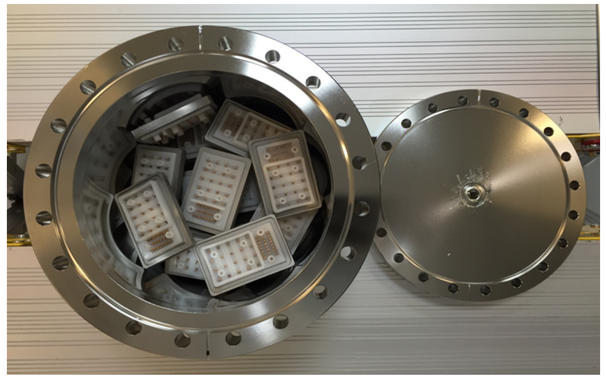
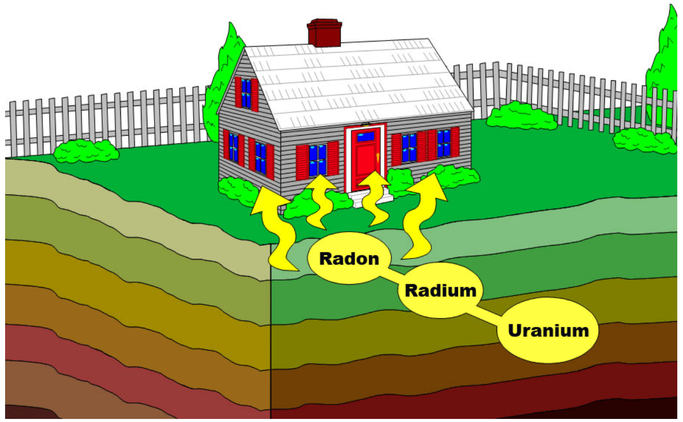


See Fang Xie's talk

Backgrounds to 0νββ: Radon and natural radioactivity



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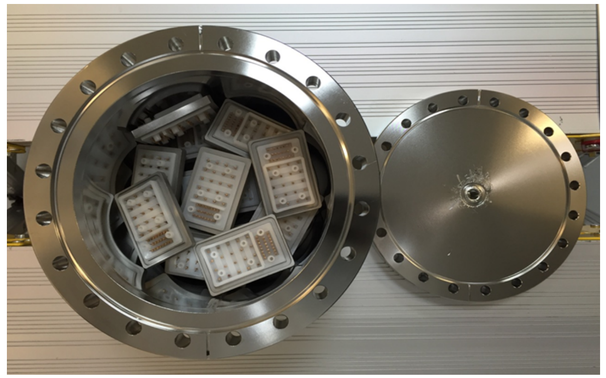

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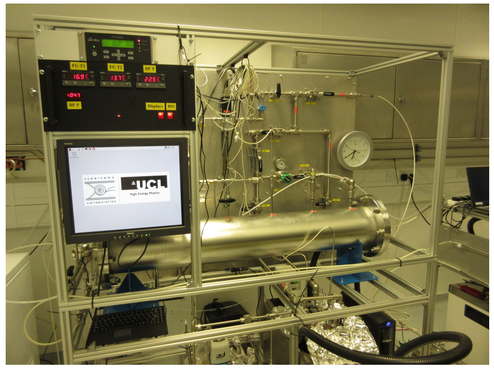
2) Flow gas through detector



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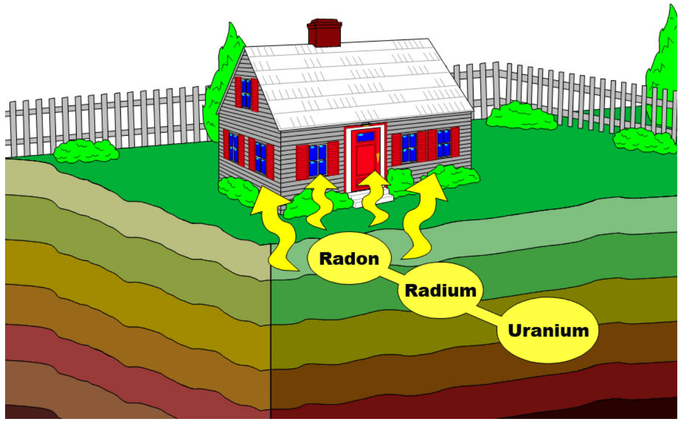

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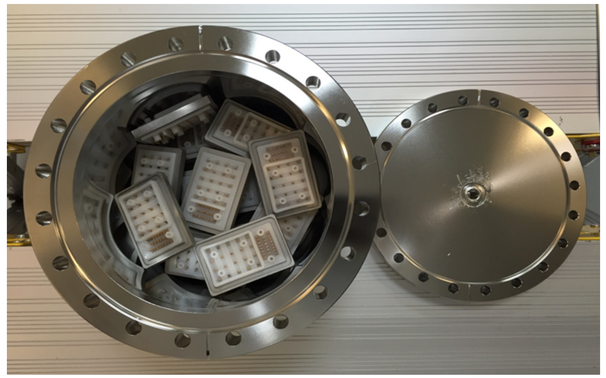

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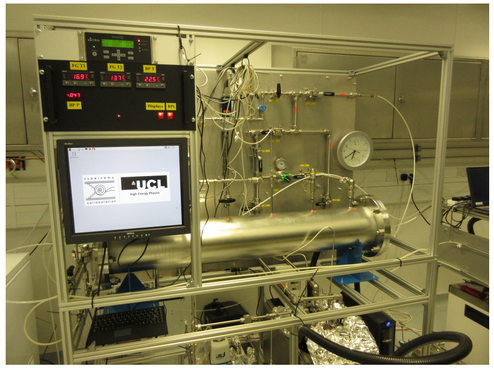
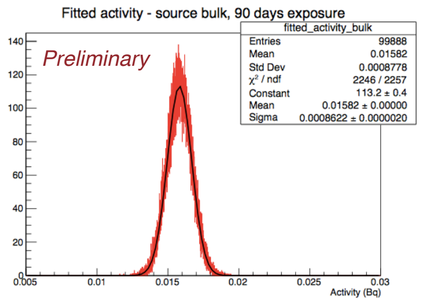


3) Measure background activities



See Lauren Dawson's talk

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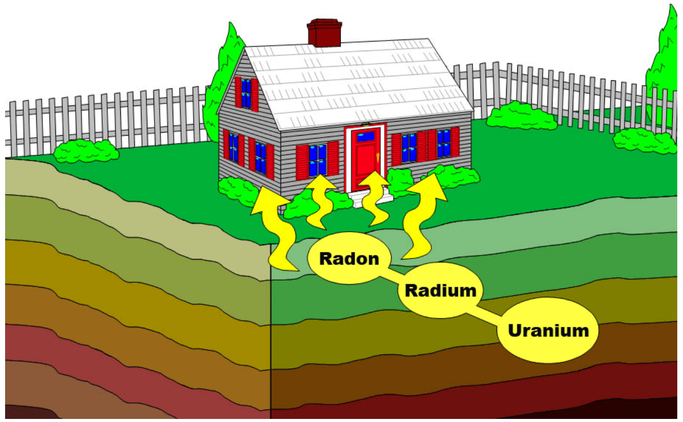

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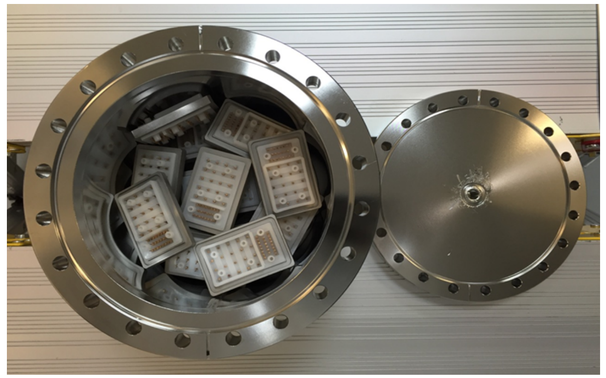

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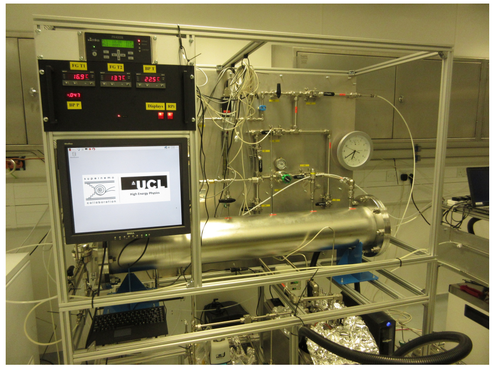

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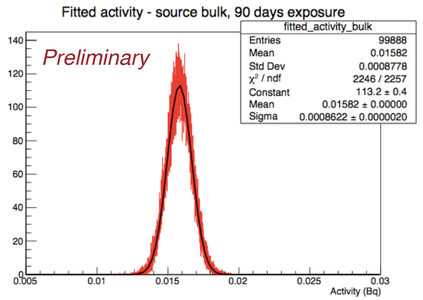
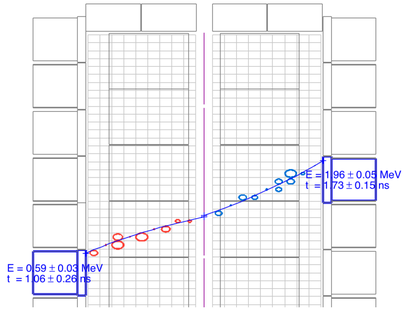


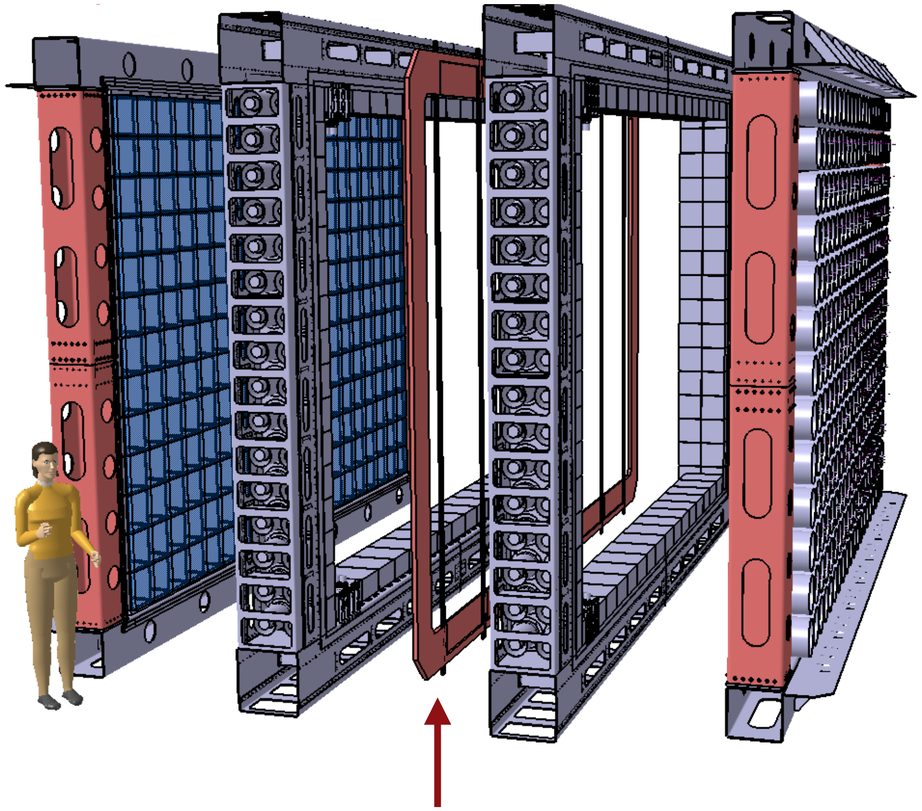
See Lauren Dawson's talk

4) Clever topological cuts



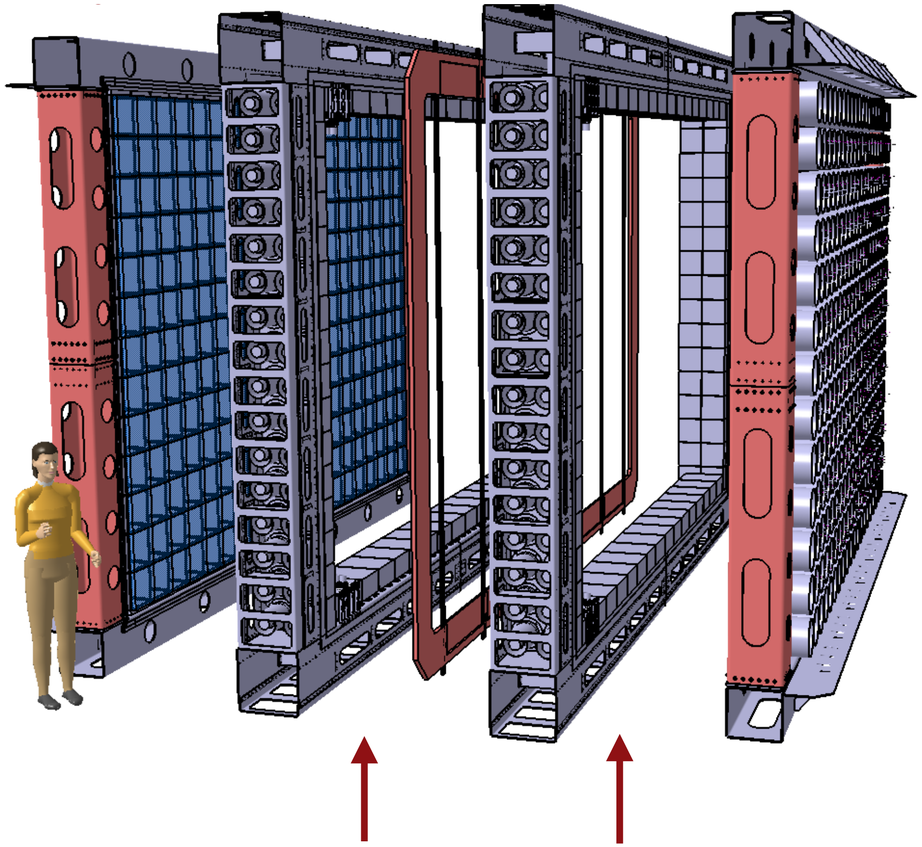
- Tracker reconstructs particles' paths
- Magnetic field for charge information
- Calorimeter timing identifies their origin

The SuperNEMO demonstrator



Source frame holding strips of ββ emitter (^{82}Se)

The SuperNEMO demonstrator



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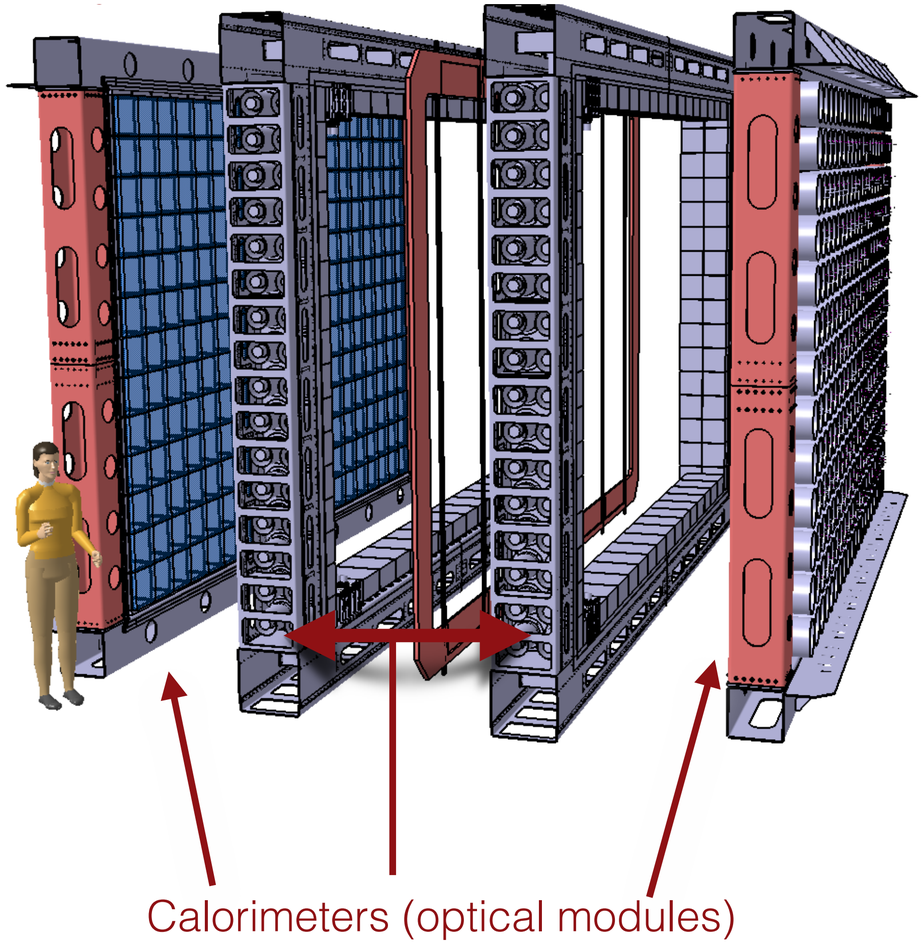
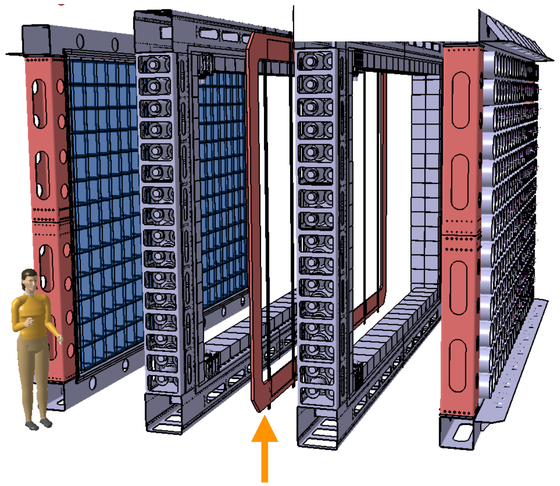


ββ Sources

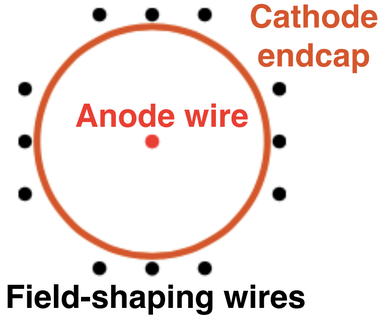


- 7kg of ββ emitter (^{82}Se)
- Enriched selenium mixed with PVA in Mylar wrapper
- Purified with distillation / chromatography / chemical precipitation
- BiPo detector confirmed ^{208}Tl and ^{214}Bi contamination at few μBq/kg levels
- Ready to hang at LSM

JINST 12 (2017) P06002

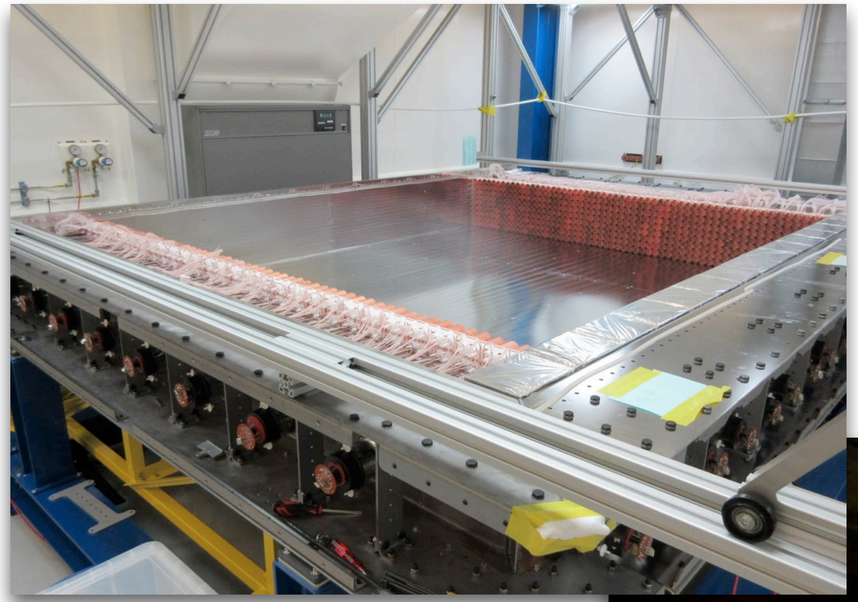
Wire trackers

2034 drift cells wired in Manchester
To run in Geiger mode



Installed into 4 C-shaped tracker sections at MSSL (UCL);
C-sections commissioned and tested for radon

Wire trackers

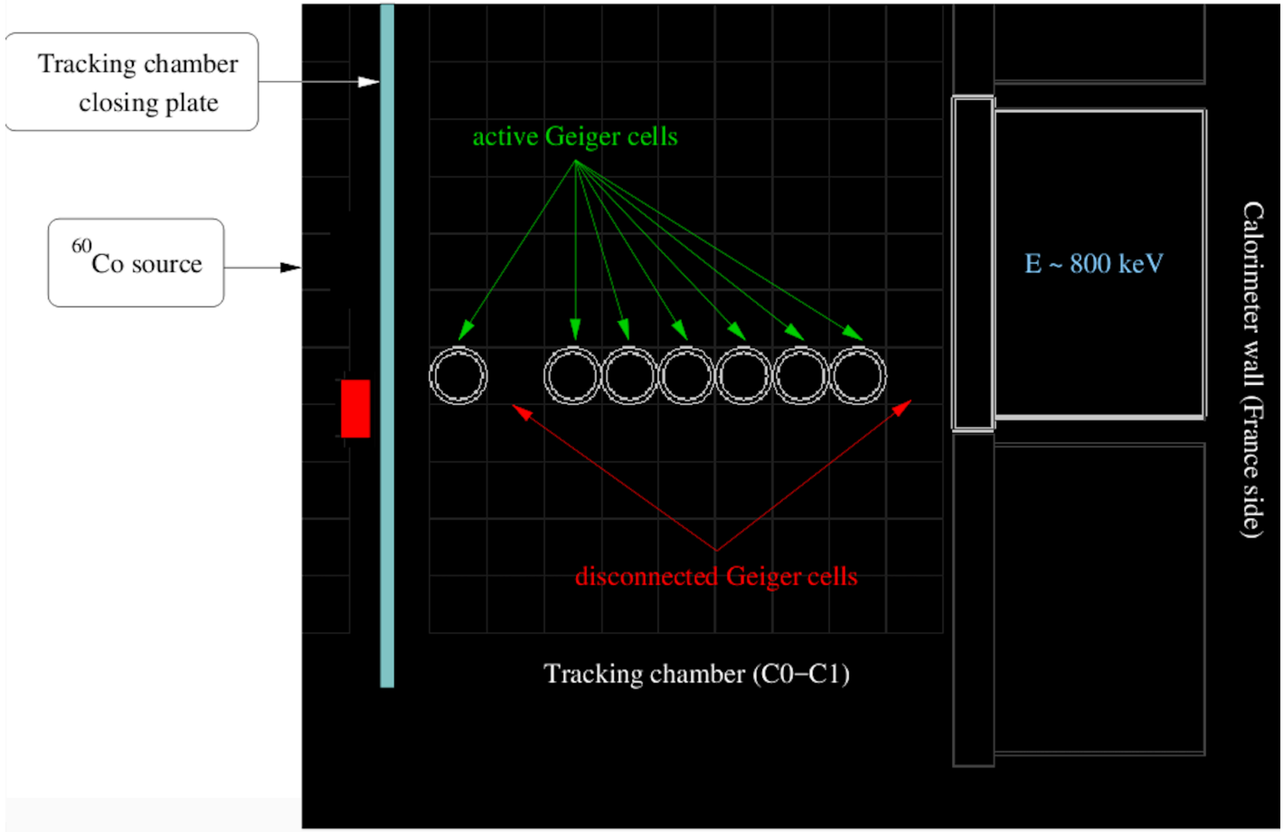


Completed C-section ready for shipping

In the Fréjus tunnel, approaching LSM

Pairs of C-sections joined and attached to a calorimeter wall

Half-detector status

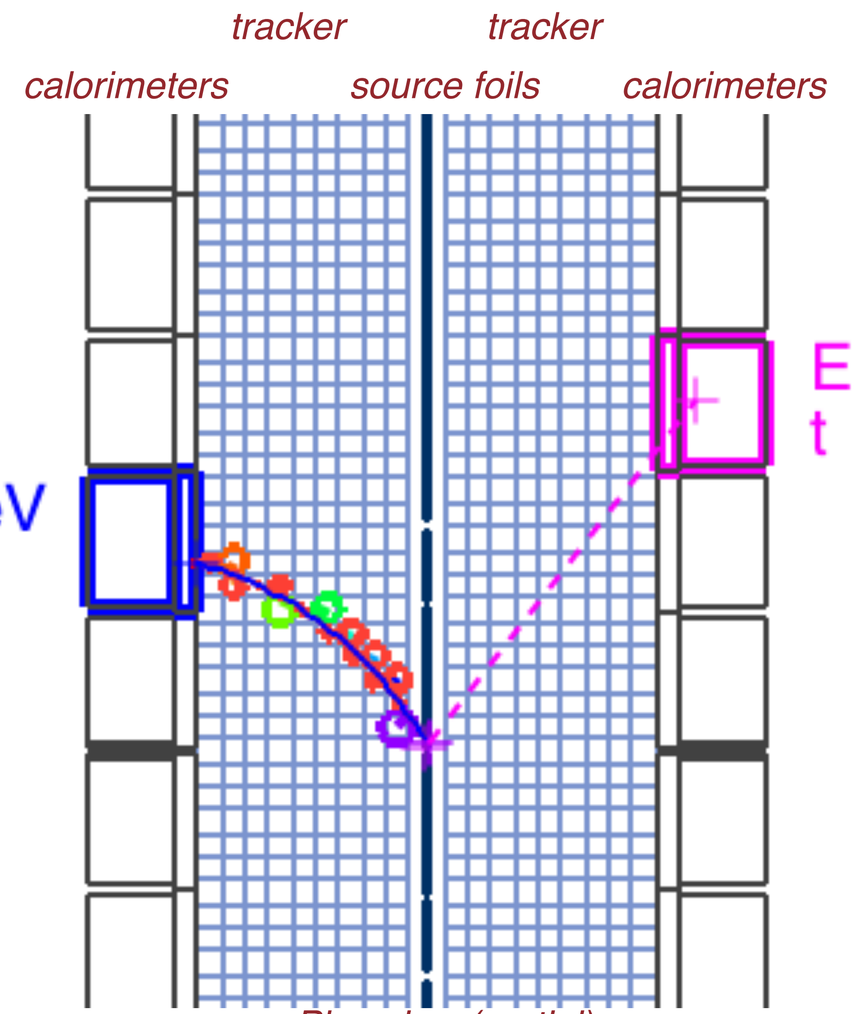


2017: half-detector commissioning with cobalt-60 source

Half-detector opened and awaiting source frame attachment

Reconstruction

Falaise reconstruction software can identify:



Plan view (partial)

$E = 0.77 \pm 0.03$ MeV
$t = 3.31 \pm 0.23$ ns

electrons

Track with negative curvature, intercepting a calorimeter

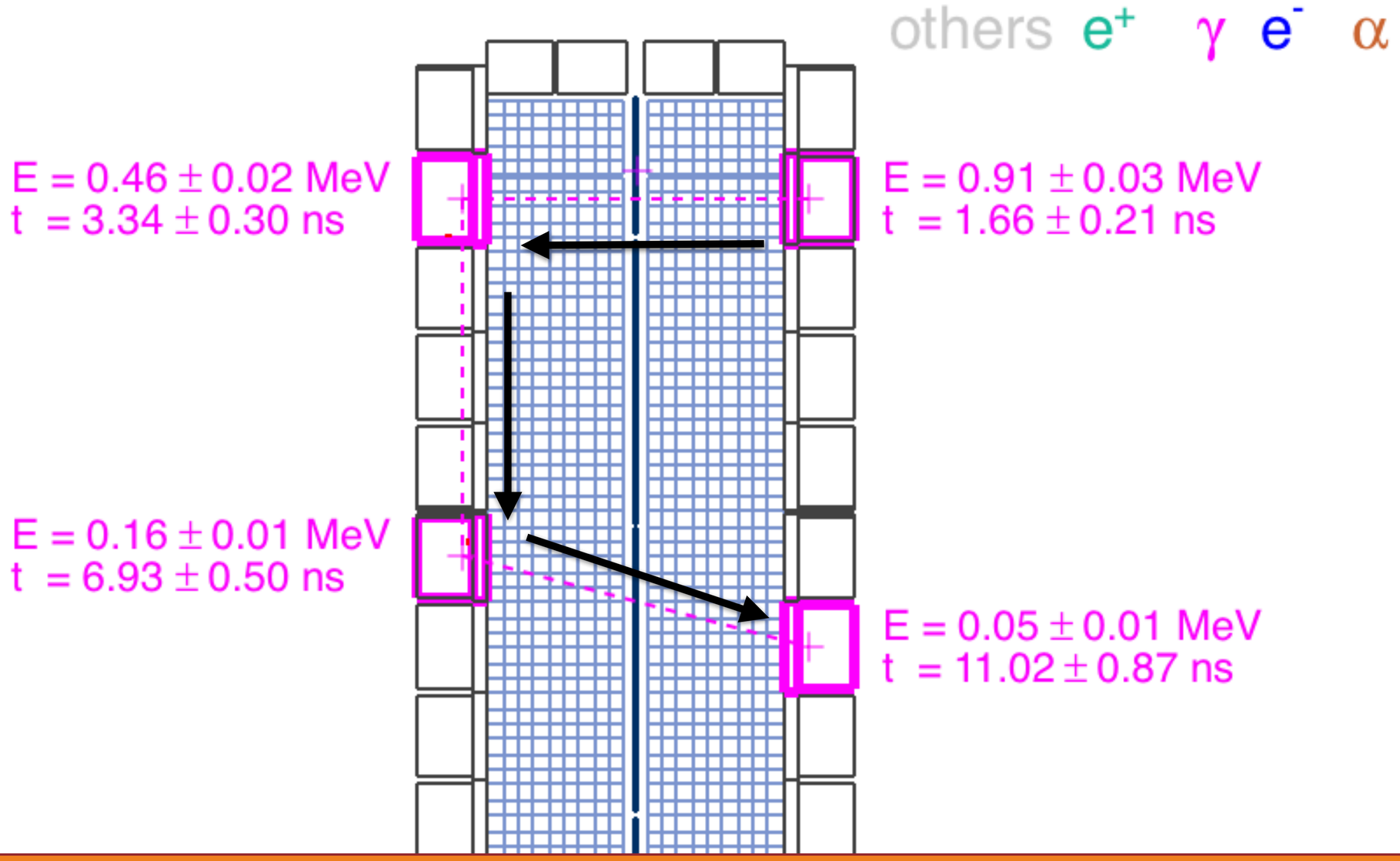
$E = 0.43 \pm 0.02$ MeV
$t = 5.37 \pm 0.31$ ns

and gammas

Isolated calorimeter hits

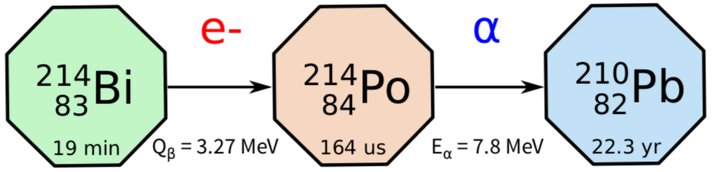
Reconstruction

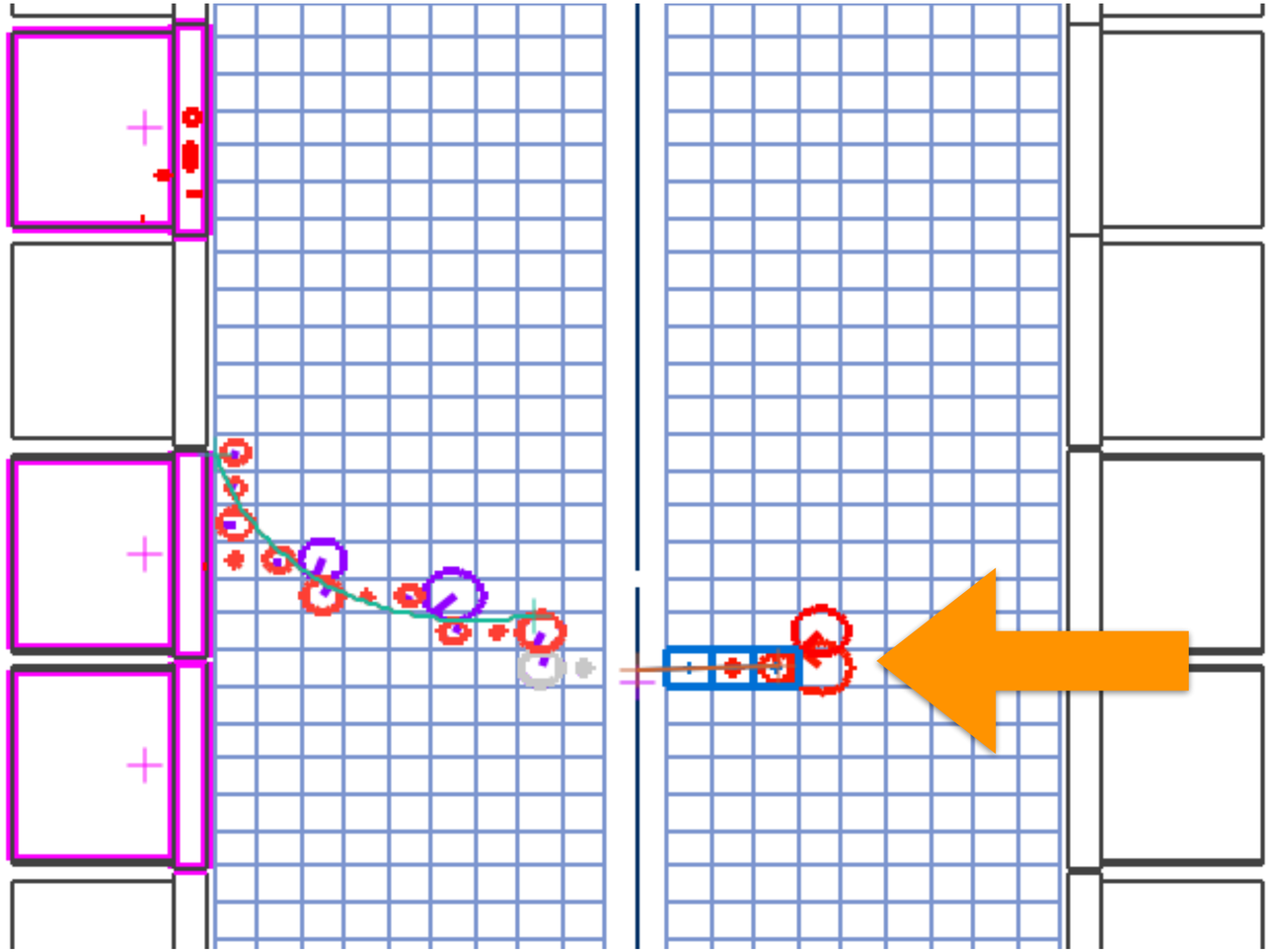
Timing information can group isolated calorimeter hits that could come from the same gamma



Reconstruction

Short, straight tracks a few μs after an electron are characteristic of alpha particles from ^{214}Bi-^{214}Po decays

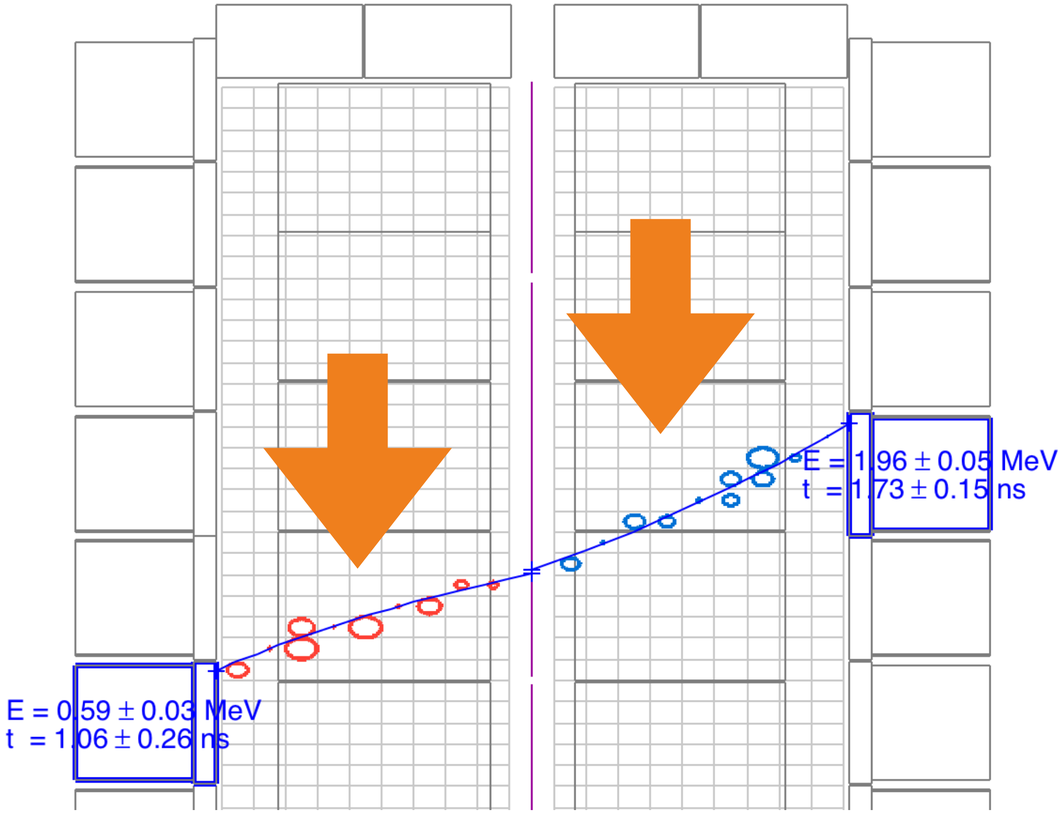




Demonstrator sensitivity

ββ events are characterised by

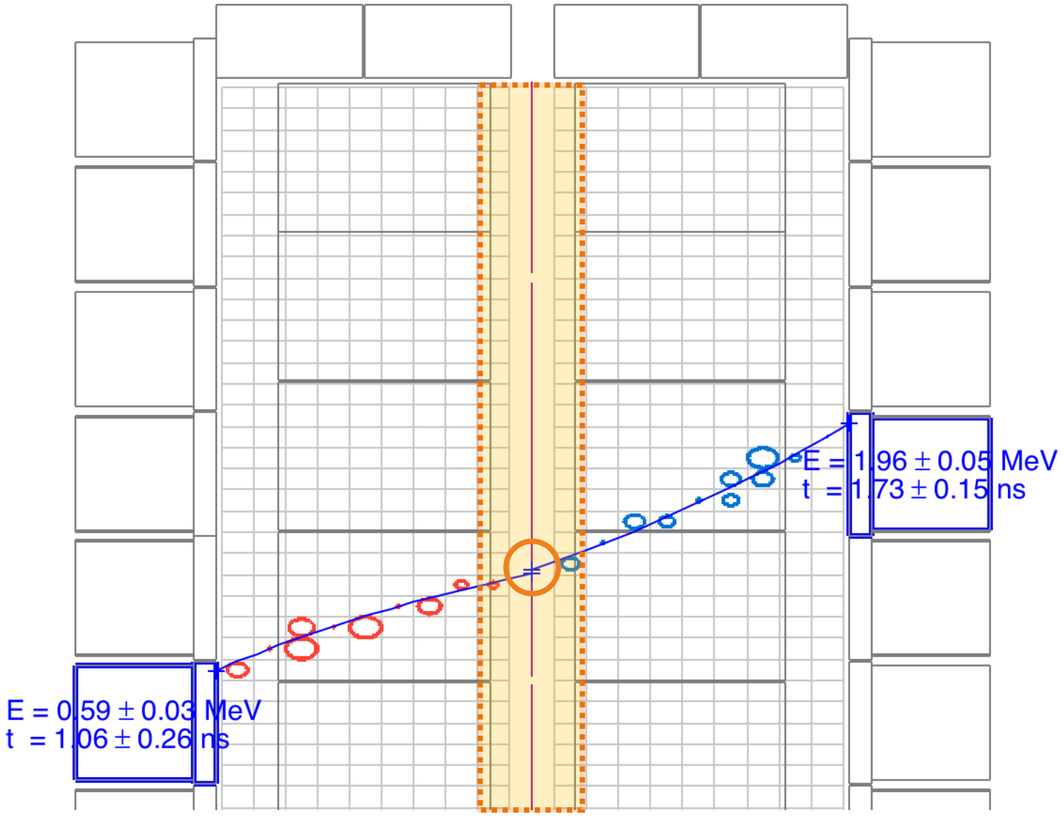
- Two electron-like tracks (negative curvature, associated calorimeter)



Demonstrator sensitivity

ββ events are characterised by

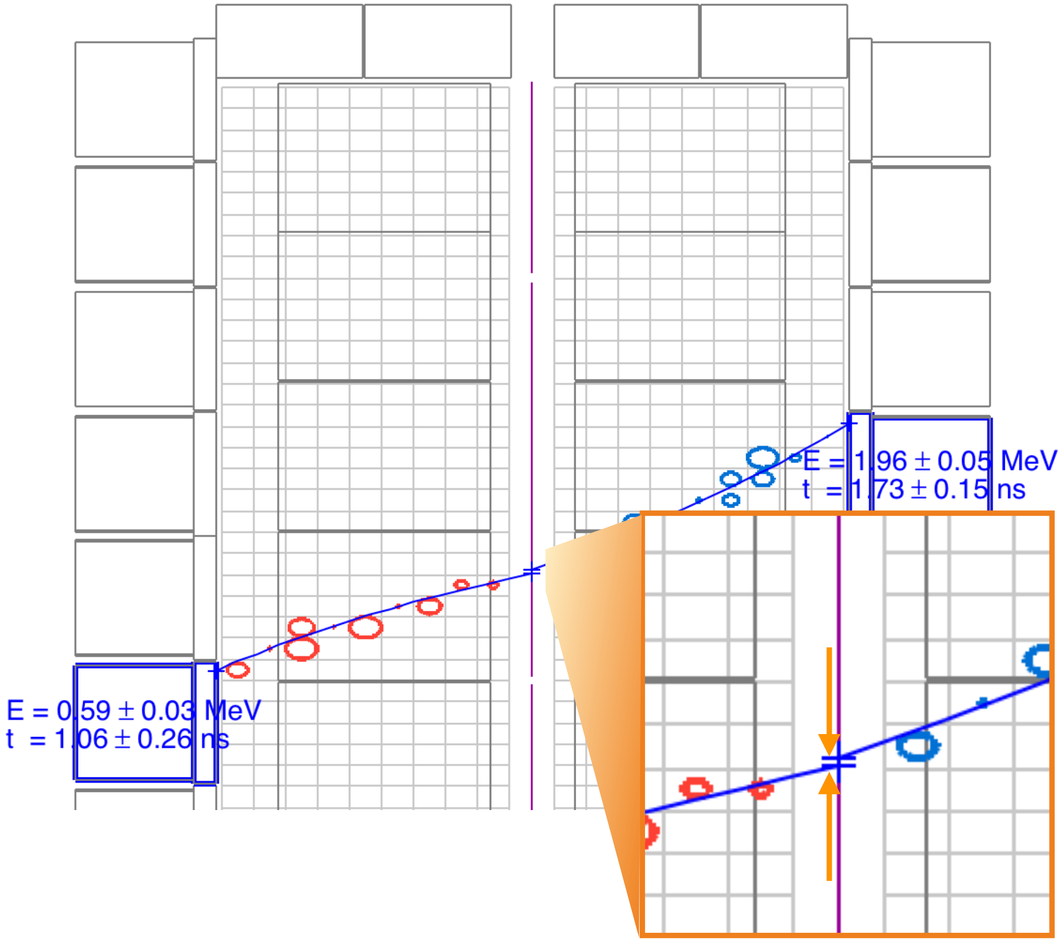
- Two electron-like tracks (negative curvature, associated calorimeter)
- A combined vertex on the source foil



Demonstrator sensitivity

ββ events are characterised by

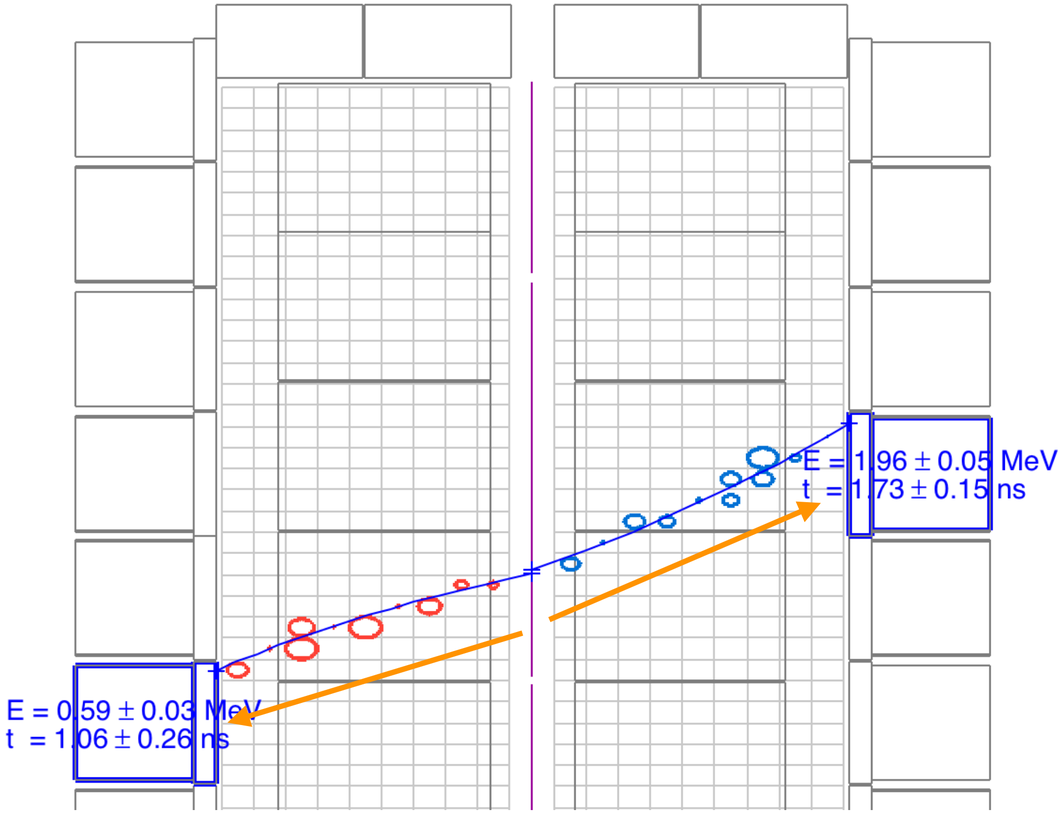
- Two electron-like tracks (negative curvature, associated calorimeter)
- A combined vertex on the source foil
- Vertex separation < 7cm parallel and 6 cm perpendicular to wires



Demonstrator sensitivity

ββ events are characterised by

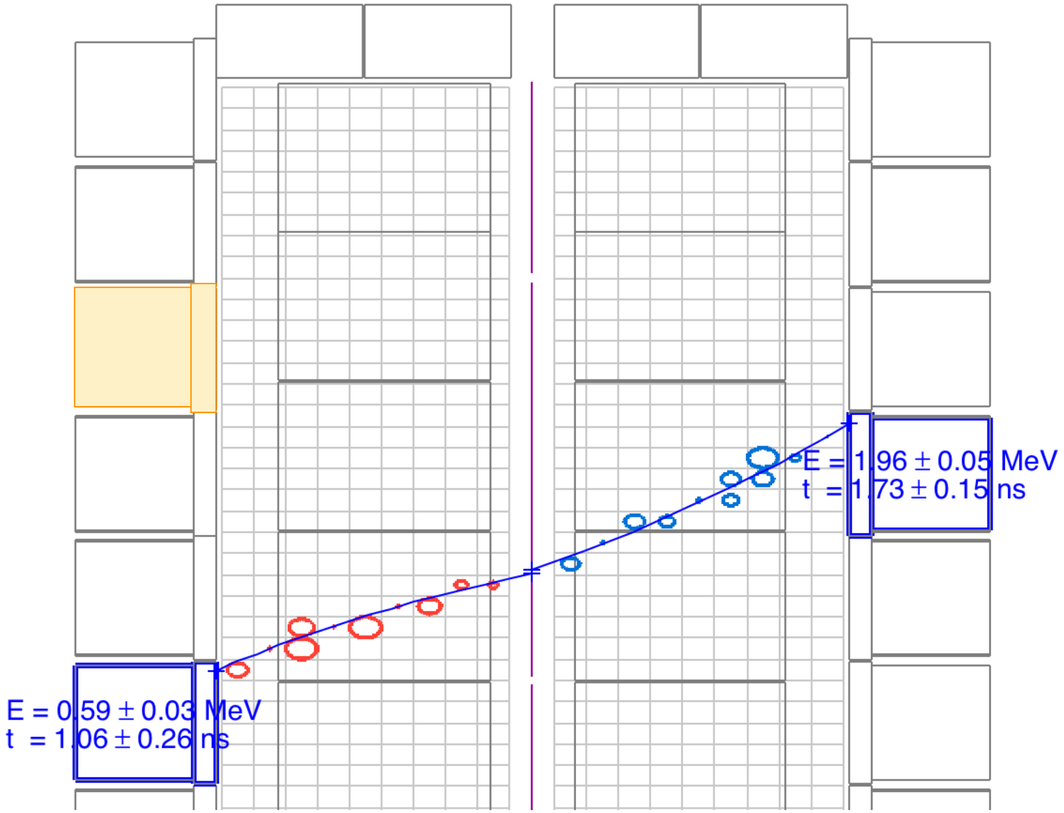
- Two electron-like tracks (negative curvature, associated calorimeter)
- A combined vertex on the source foil
- Vertex separation < 7cm parallel and 6 cm perpendicular to wires
- Internal probability > 4%



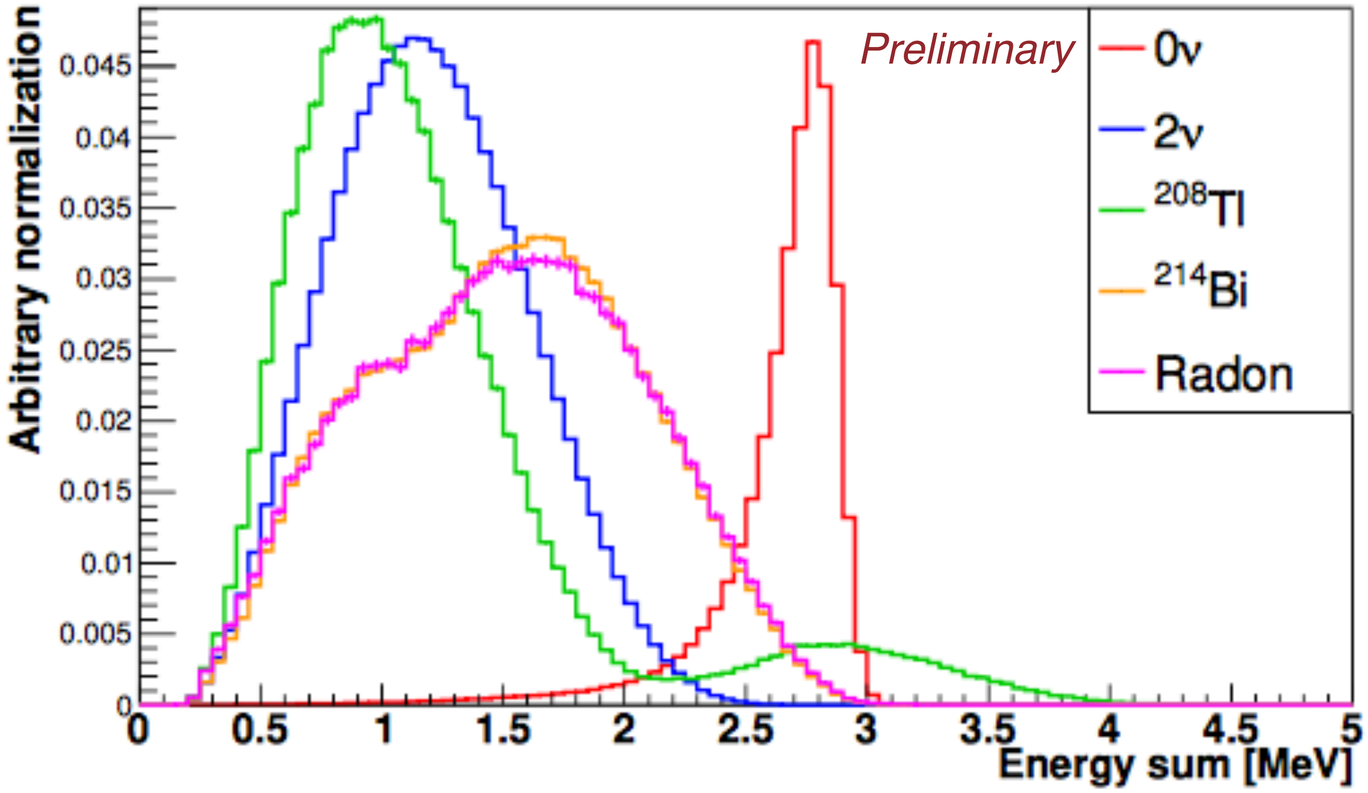
Demonstrator sensitivity

ββ events are characterised by

- Two electron-like tracks (negative curvature, associated calorimeter)
- A combined vertex on the source foil
- Vertex separation < 7cm parallel and 6 cm perpendicular to wires
- Internal probability > 4%
- No unassociated (gamma-like) hits



Demonstrator sensitivity



Summed 2-electron energy is best distribution to separate signal from background

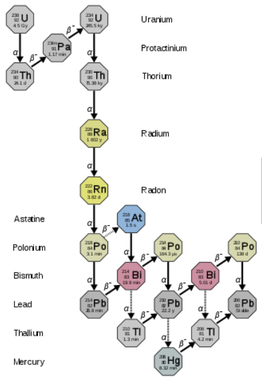
Using a boosted decision tree, we can improve sensitivity by including other variables (angle between tracks, individual electron energies, internal/external probability, vertex separation…)

$T_{1/2} > 5.85 \times 10^{24}$ years (90% C.L)

For 7kg of ^{82}Se (demonstrator) and 2.5 years' exposure

Other analyses

Background measurements

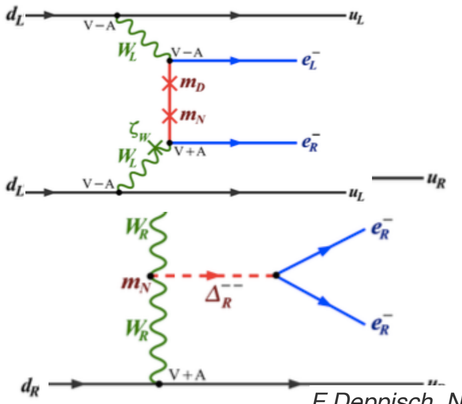


Radon

Foil contamination

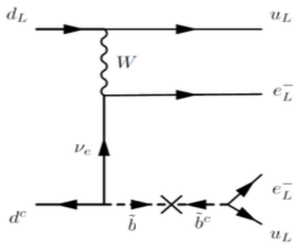
External background rates

Alternative 0νββ mechanisms



Majorons

L-R symmetry



SUSY

Leptoquarks

F Deppisch, NuPhys 2016

2νββ measurements

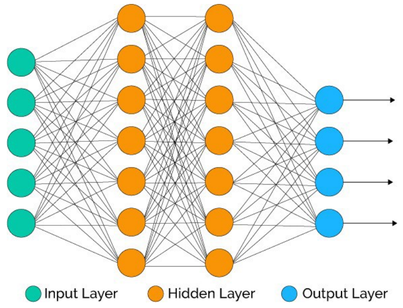
SSD

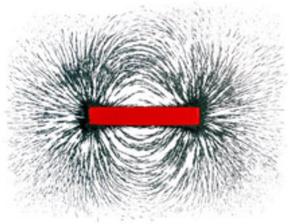
HSD

Improved simulation and techniques

Optical simulations

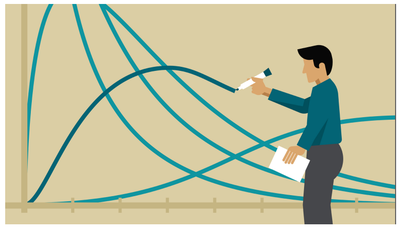
Machine learning techniques



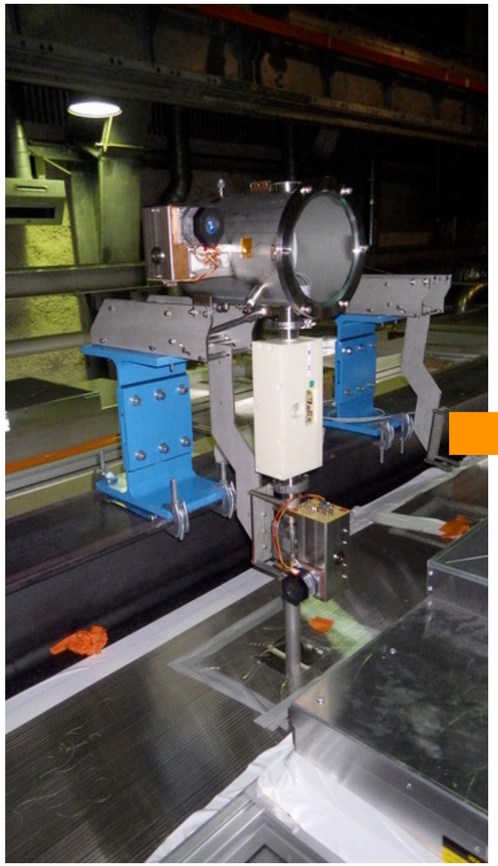


Magnetic field mapping

Statistical techniques

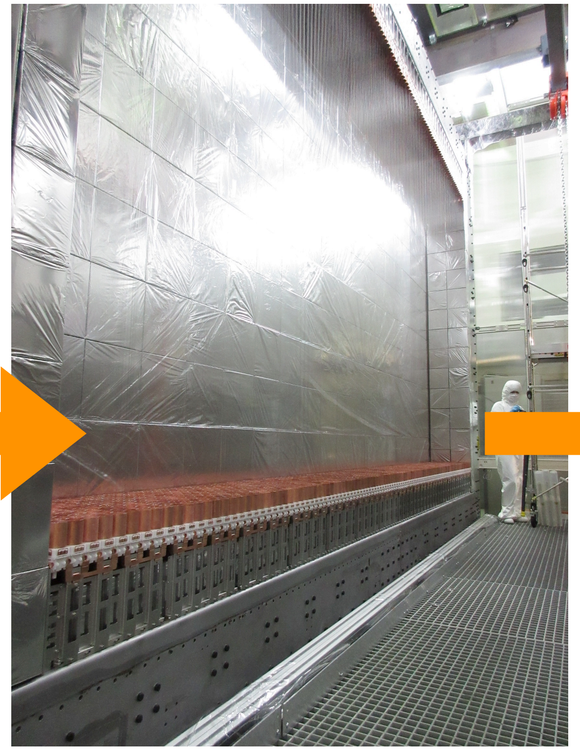


Next steps



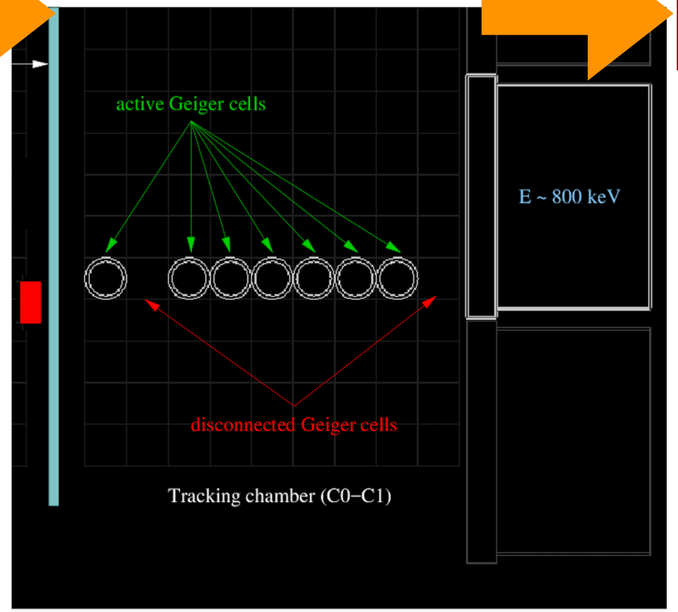
Validate calibration system

Install source foils (April/May)



Close the detector

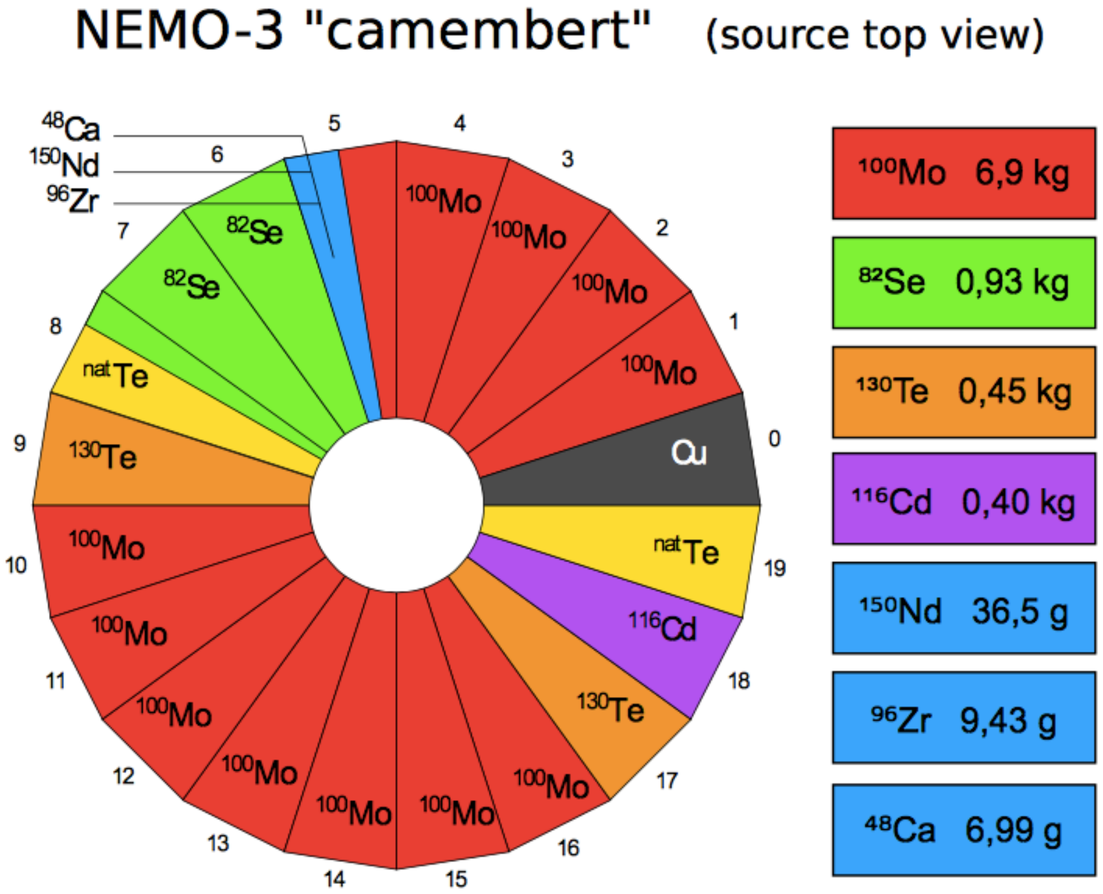
Commissioning
Calibration
Monte Carlo challenge



FIRST DATA!

Long-term plans

- Other isotopes

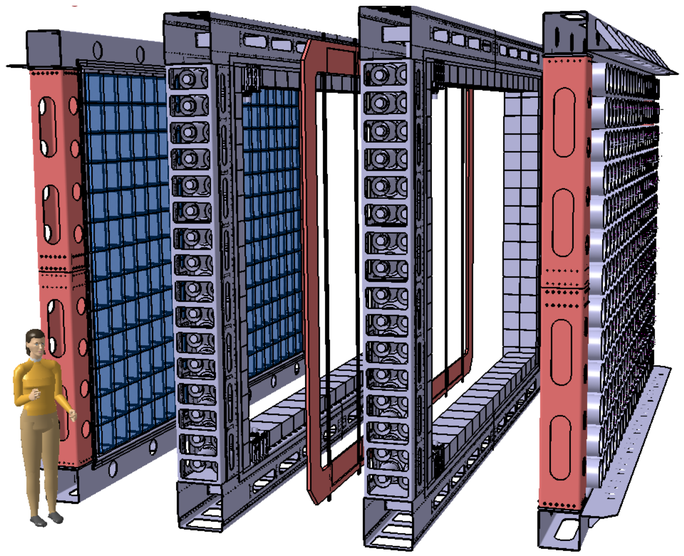


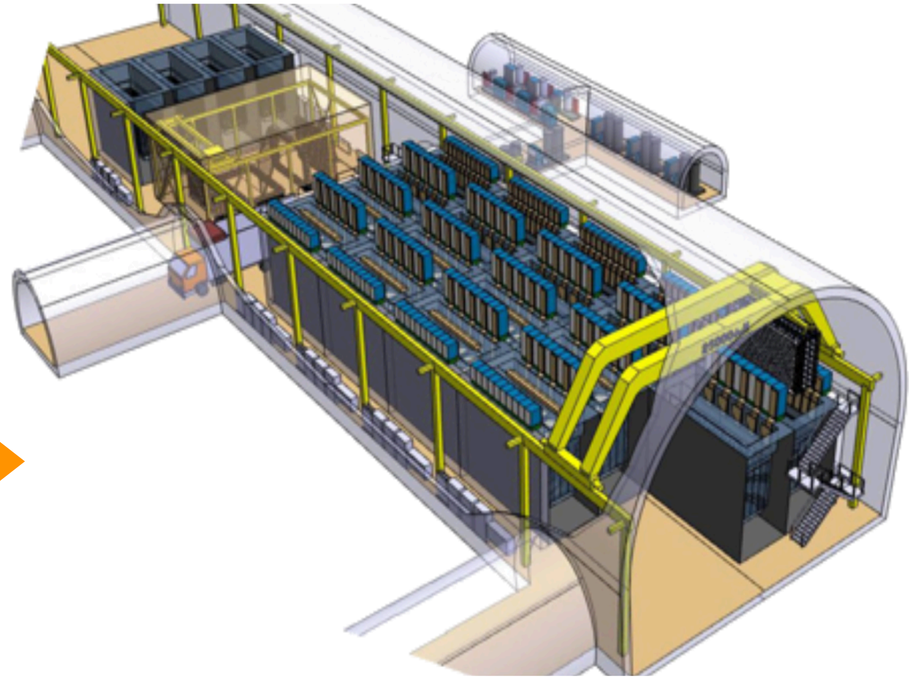
NEMO-3 studied 7 of the 13 observed ββ isotopes

SuperNEMO's design allows us to exchange the ^{82}Se source foils for foils of other materials

Long-term plans

- Other isotopes
- Full SuperNEMO





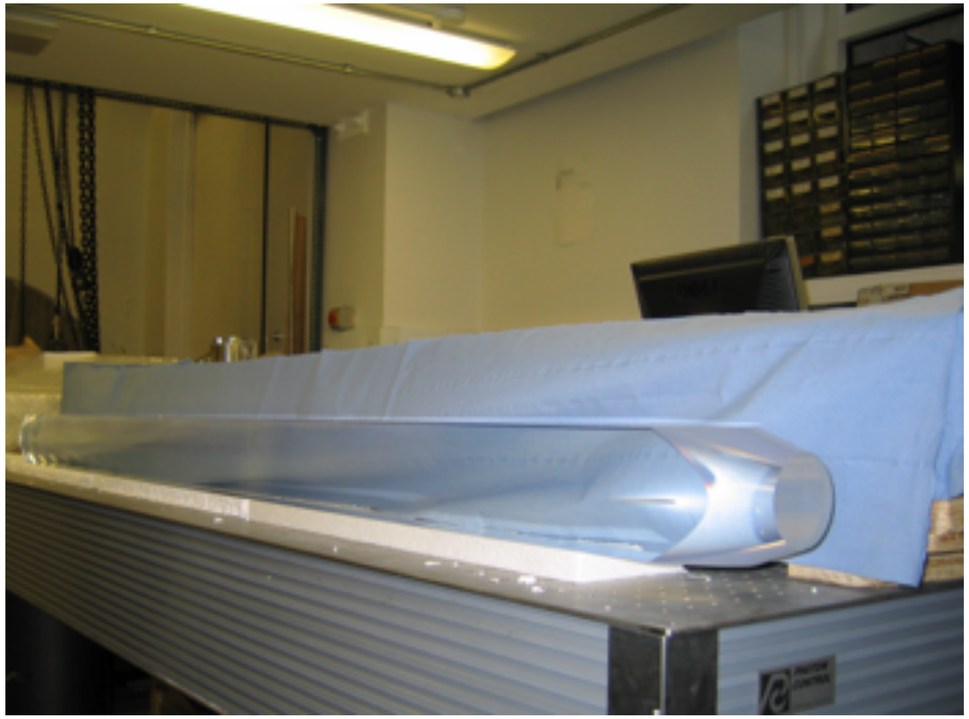
A proposed 20-module full SuperNEMO detector improves our sensitivity to

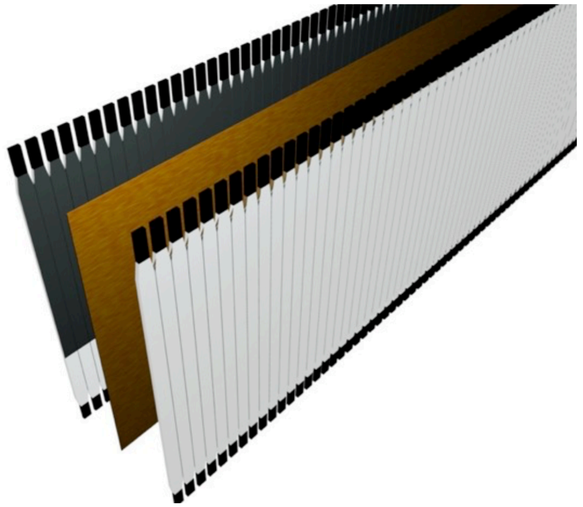
$T_{1/2} > 10^{26}$ years; $\langle m_\nu \rangle < 50\text{-}100$ meV

For 100kg of ^{82}Se and 5 years' exposure

Long-term plans

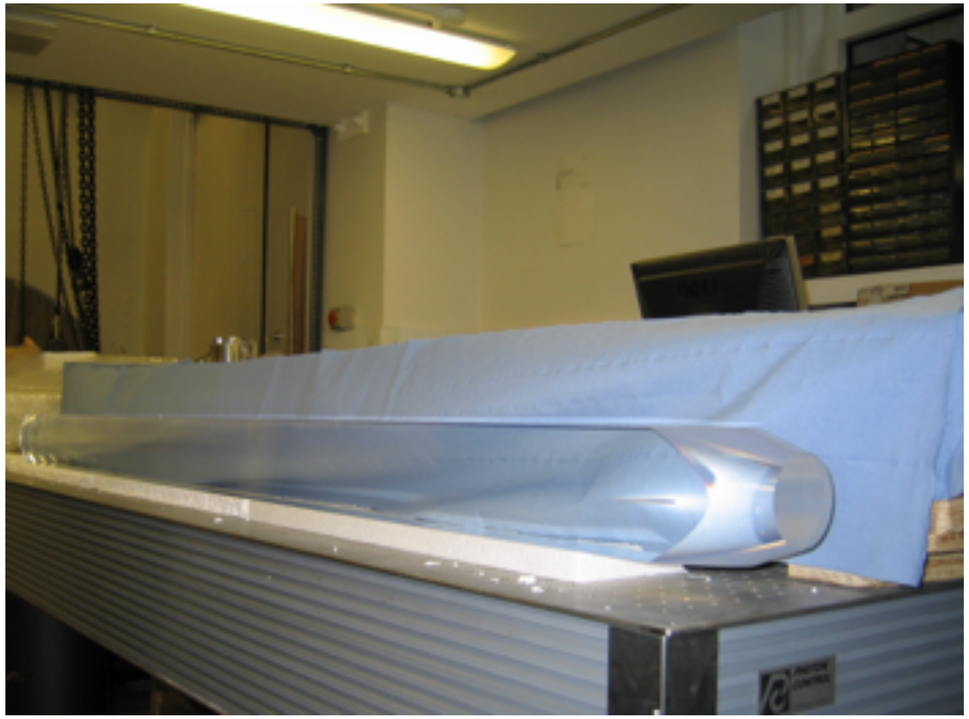
- Other isotopes
- Full SuperNEMO
- Detector R&D:
  - scintillator bars

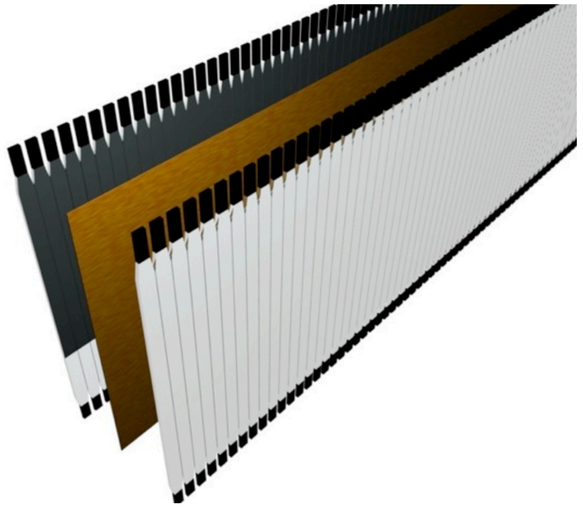


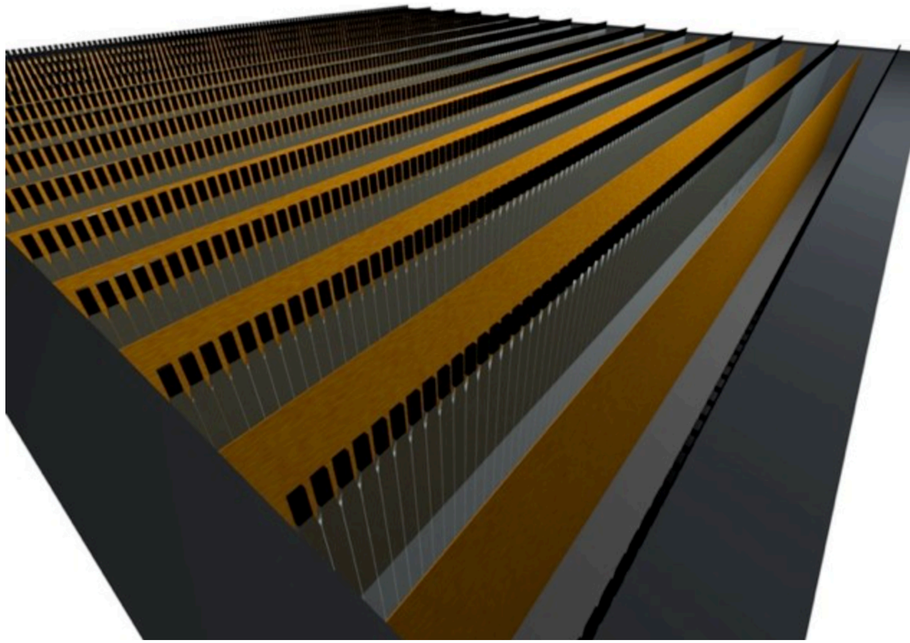


Long-term plans

- Other isotopes
- Full SuperNEMO
- Detector R&D:
  - scintillator bars



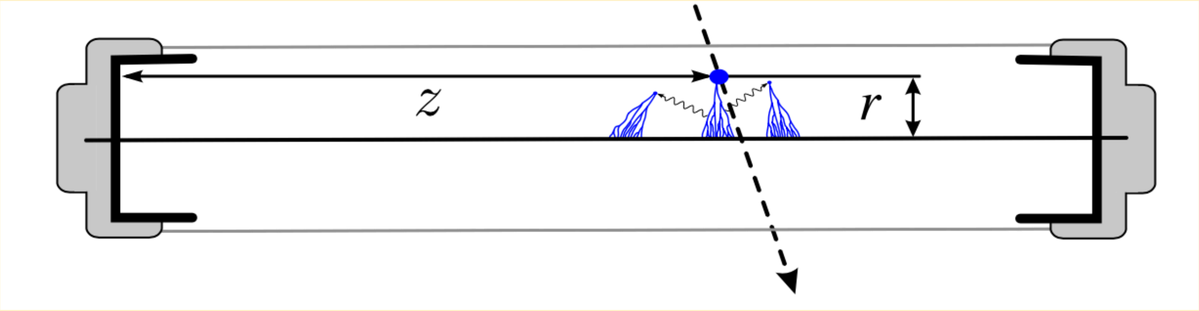




- Walls of 2m scintillator bars sandwiched between tracker layers = good background rejection?
- Fewer PMTs - save ££ and radioactivity
- Easier to build
- But can we maintain our energy & time resolution?

Long-term plans

- Other isotopes
- Full SuperNEMO
- Detector R&D:
  - scintillator bars
  - tracker improvements



- SuperNEMO's tracker cells operate in the Geiger regime (electron avalanche saturated, independent of ionisation)
- Could we use proportional mode and measure the ionisation energy?

Long-term plans

- Other isotopes
- Full SuperNEMO
- Detector R&D:
  - scintillator bars
  - tracker improvements

Goal: an improved SuperNEMO that is

- extensible,
- compact and
- inexpensive,
- and retains the performance of the demonstrator