Tracking-based experiments in Double Beta Decay

Outline

- Why tracking?
- NEMO-3 - RESULTS!
- SuperNEMO
- Gaseous Xe experiments
  - EXO-gas
  - NEXT
- DCBA

Ruben Saakyan

University College London

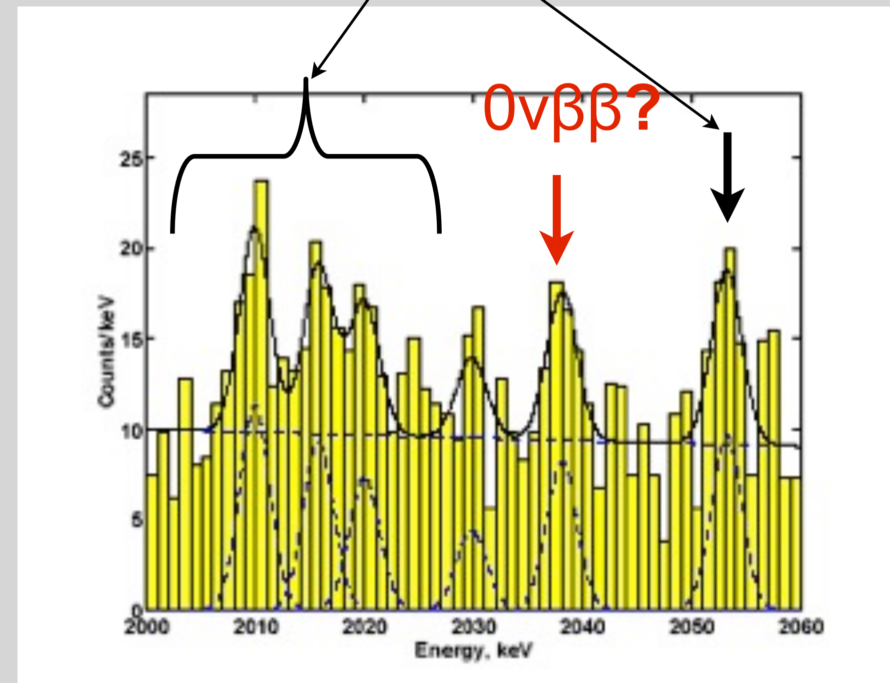
Neutrino 2010

Athens, 16 June 2010

How do we know it is ββ?

- ☑ $E_{e1} + E_{e2} = Q_{\beta\beta}$ (for 0ν)

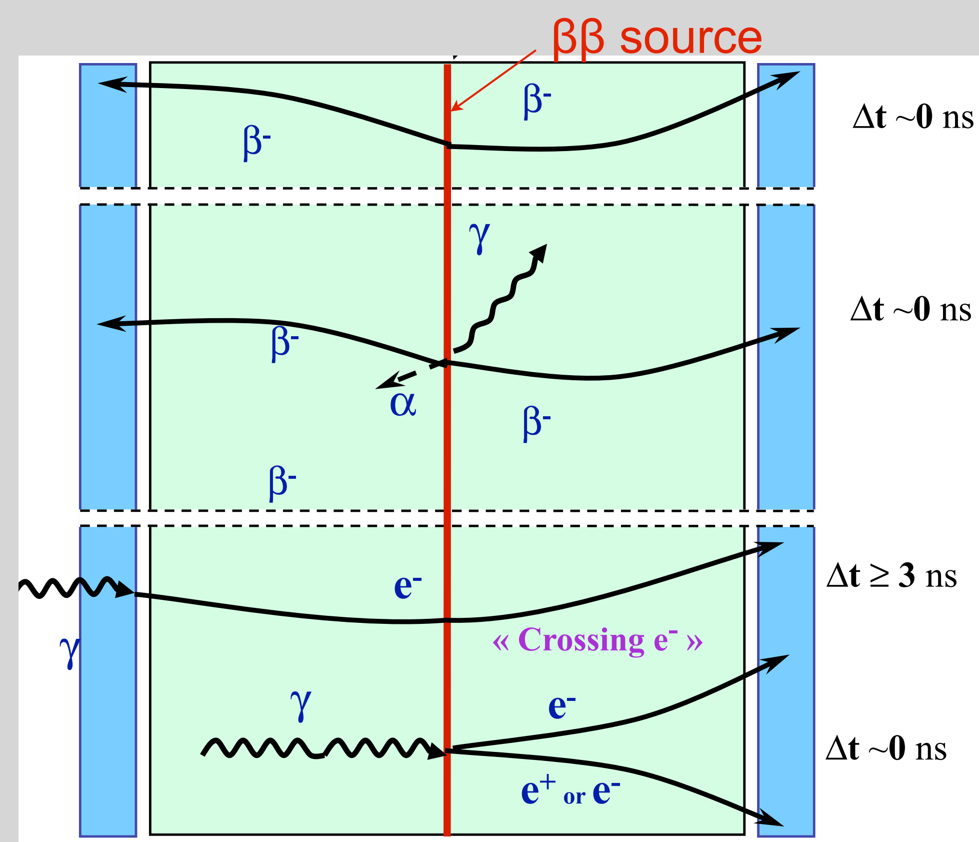
Calorimeter only



HPGe spectrum (KK claim)

- ☑ **Several** observables
- ☑ Two **electrons**
- ☑ **Coincident**
- ☑ From the **same vertex**
- ☑ **Angular** distributions between two electrons

Tracking

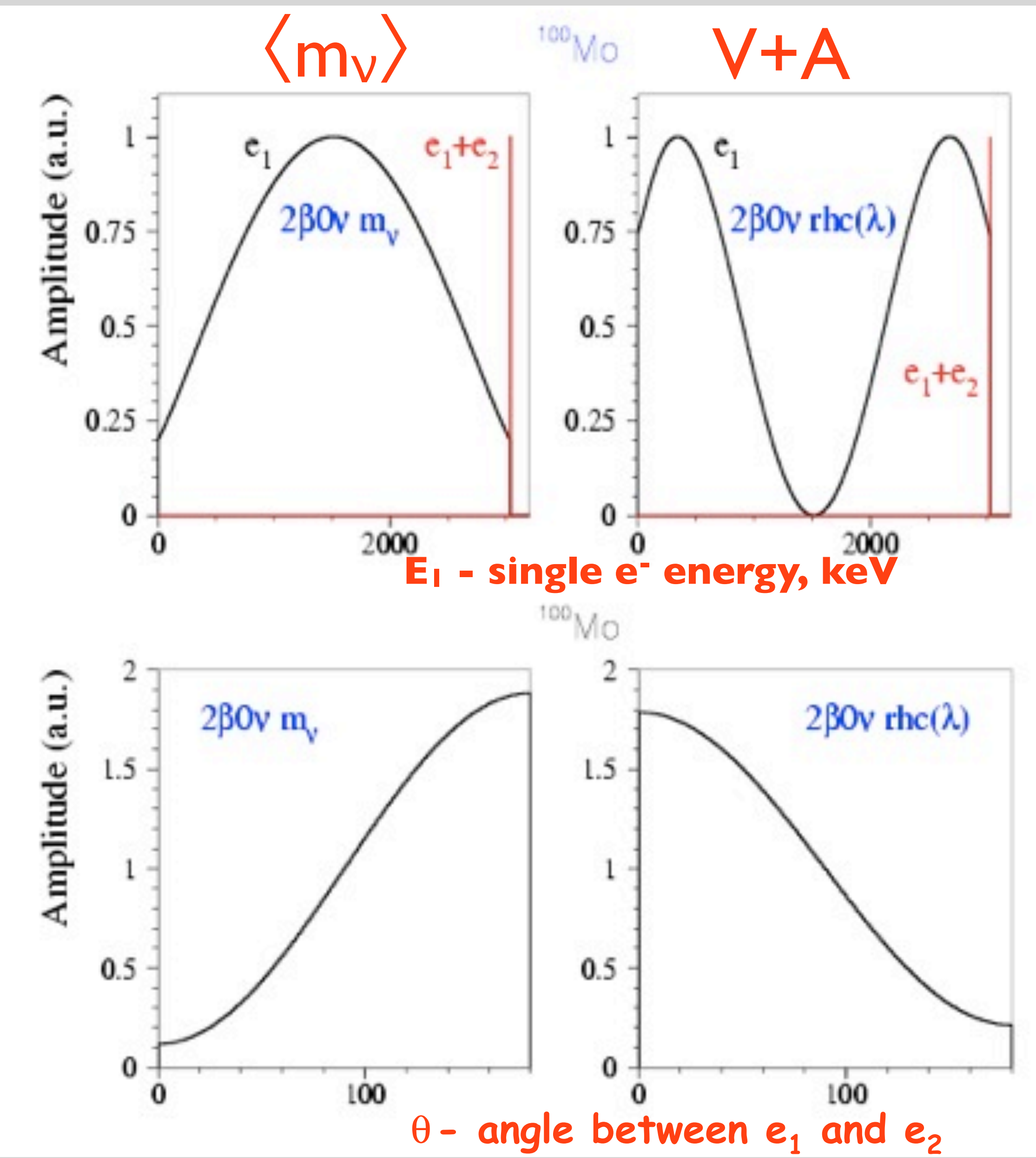


Tracko-Calo, e.g. NEMO3/SuperNEMO

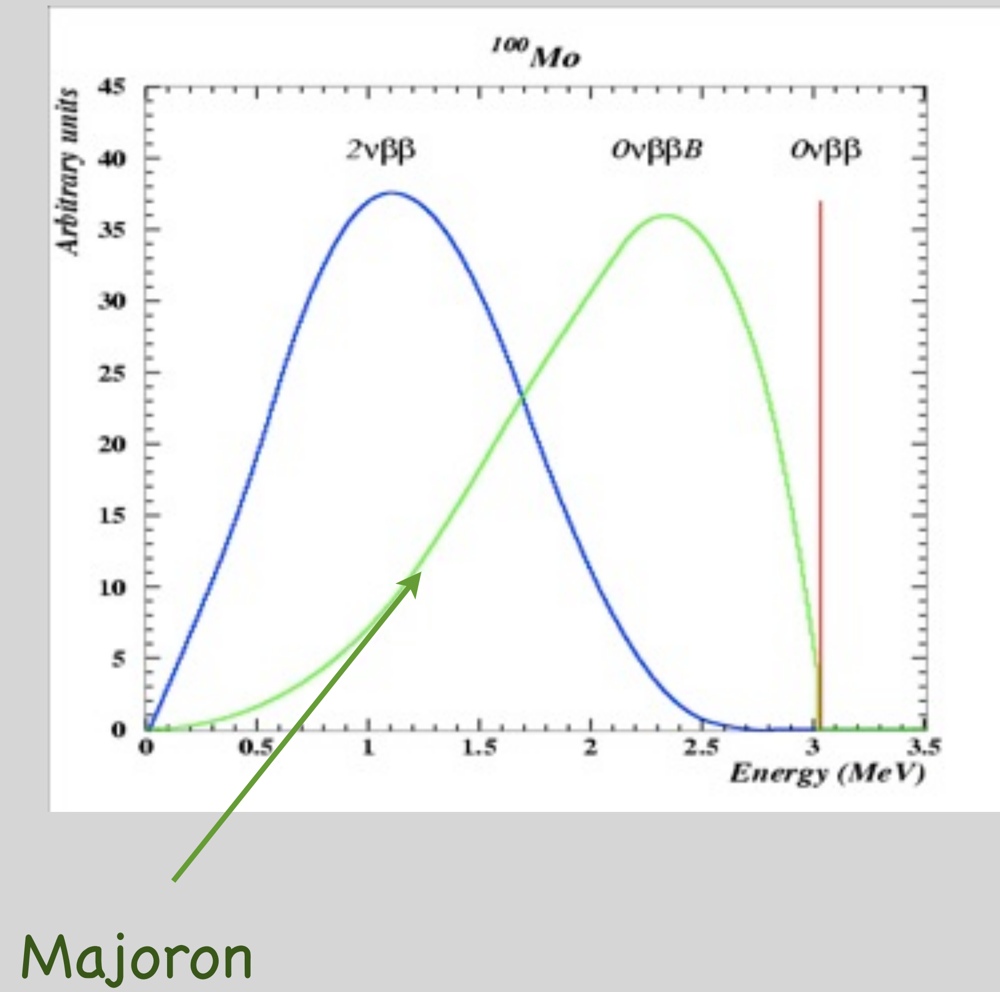
Open-minded search for any 0νββ mechanism

$$\frac{1}{T^{0\nu}_{1/2}} = G^{0\nu}(Q_{\beta\beta},Z)\left|M^{0\nu}\right|^2 \eta^2$$

η can be due to $\langle m_\nu \rangle$,V+A, Majoron, SUSY, H^- or a combination of them



Topology can be used to disentangle underlying physics mechanism

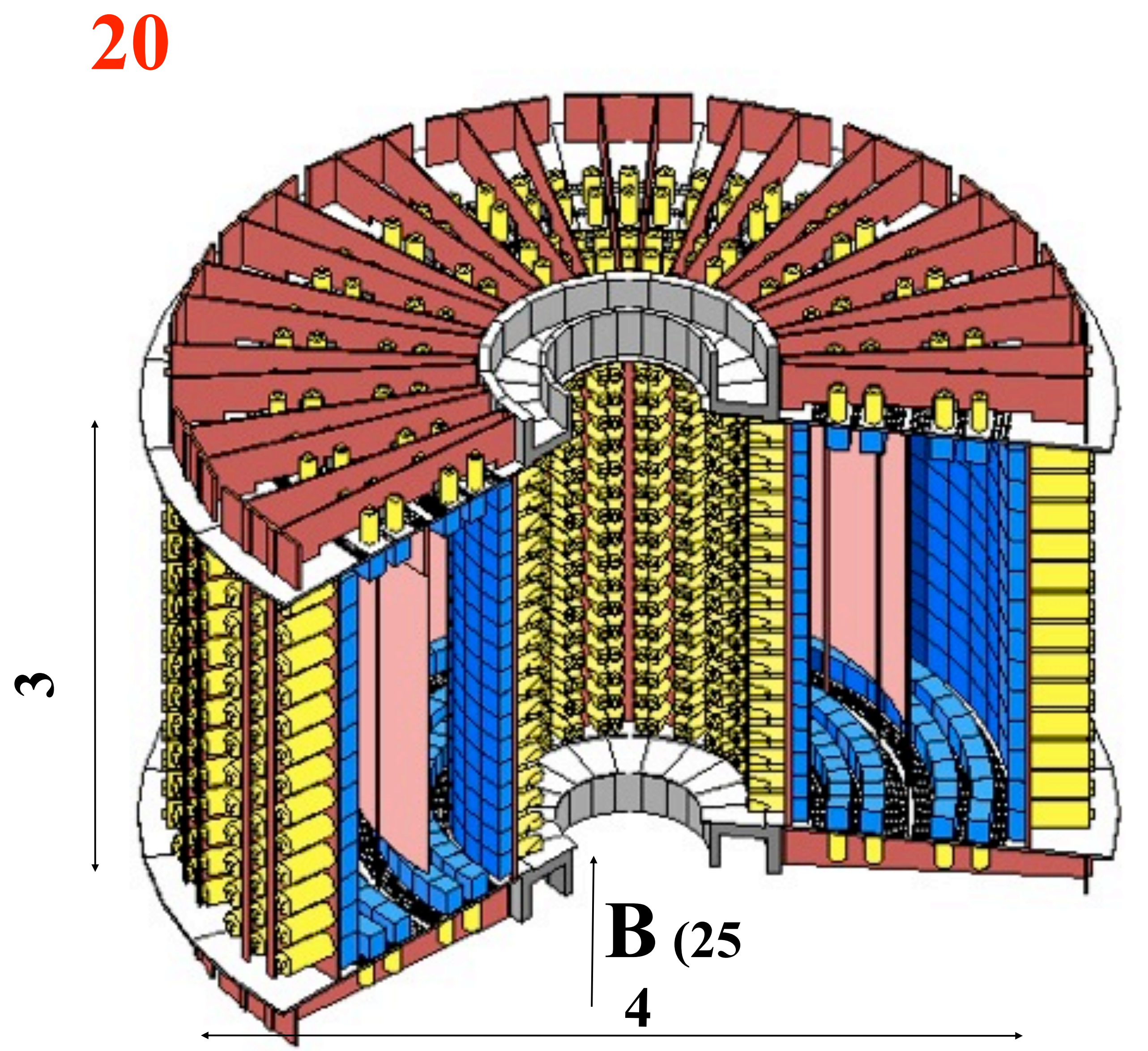


Topology detection is a more sensitive method for phenomena with continuous spectra, e.g. 2νββ, 0νββB (Majoron)

Neutrino Ettore Majorana Observatory

The NEMO-3 detector

Modane Underground Laboratory : 4800 m.w.e.



Source: 10 kg of ββ isotopes

7kg of ^{100}Mo, 1kg of ^{82}Se + smaller quantities of ^{130}Te, ^{116}Cd, ^{48}Ca, ^{96}Zr, ^{150}Nd

Tracking detector:

drift wire chamber operating in Geiger mode (6180 cells)

Gas: He + 4% ethyl alcohol + 1% Ar + 0.1% H_2O

Calorimeter:

1940 plastic scintillators coupled to low radioactivity PMTs

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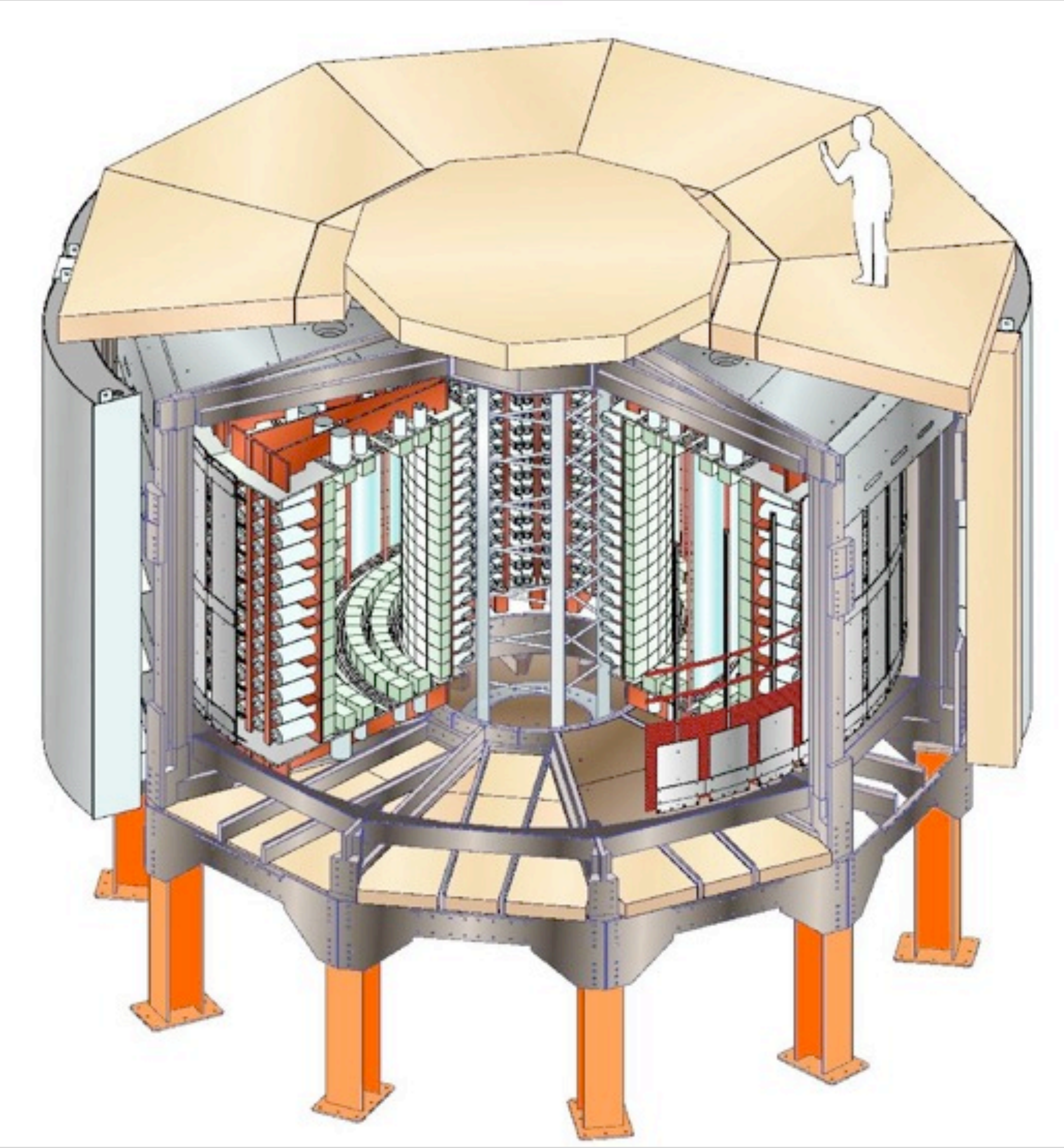

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cylindrical, S = 20 m^2, e ~ 60 mg/cm^2

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Magnetic field: 25 Gauss

Gamma shield: Pure Iron (e = 18 cm)

Neutron shield: 30 cm water (ext. wall)

40 cm wood (top and bottom)

(since march 2004: water + boron)

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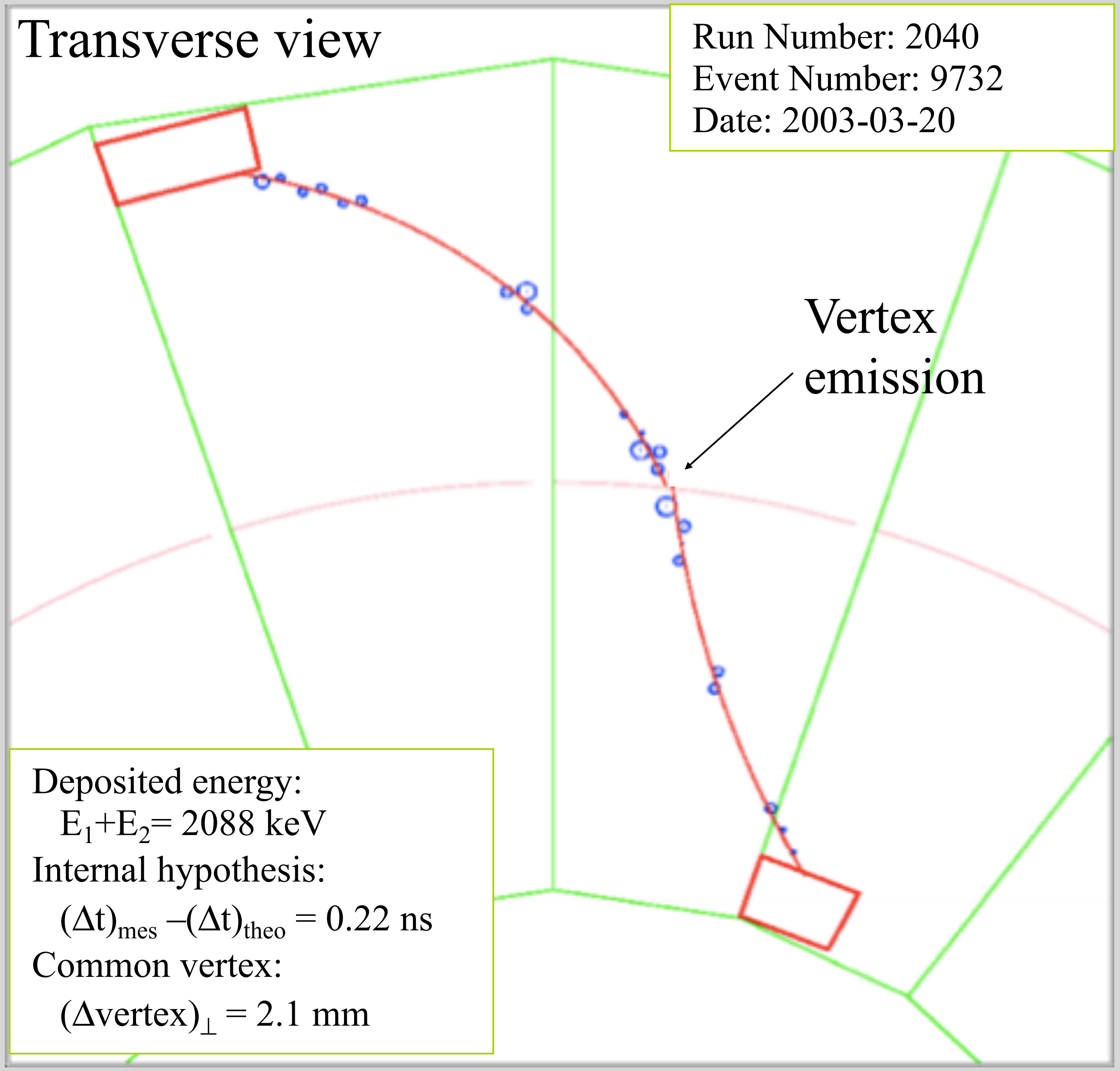
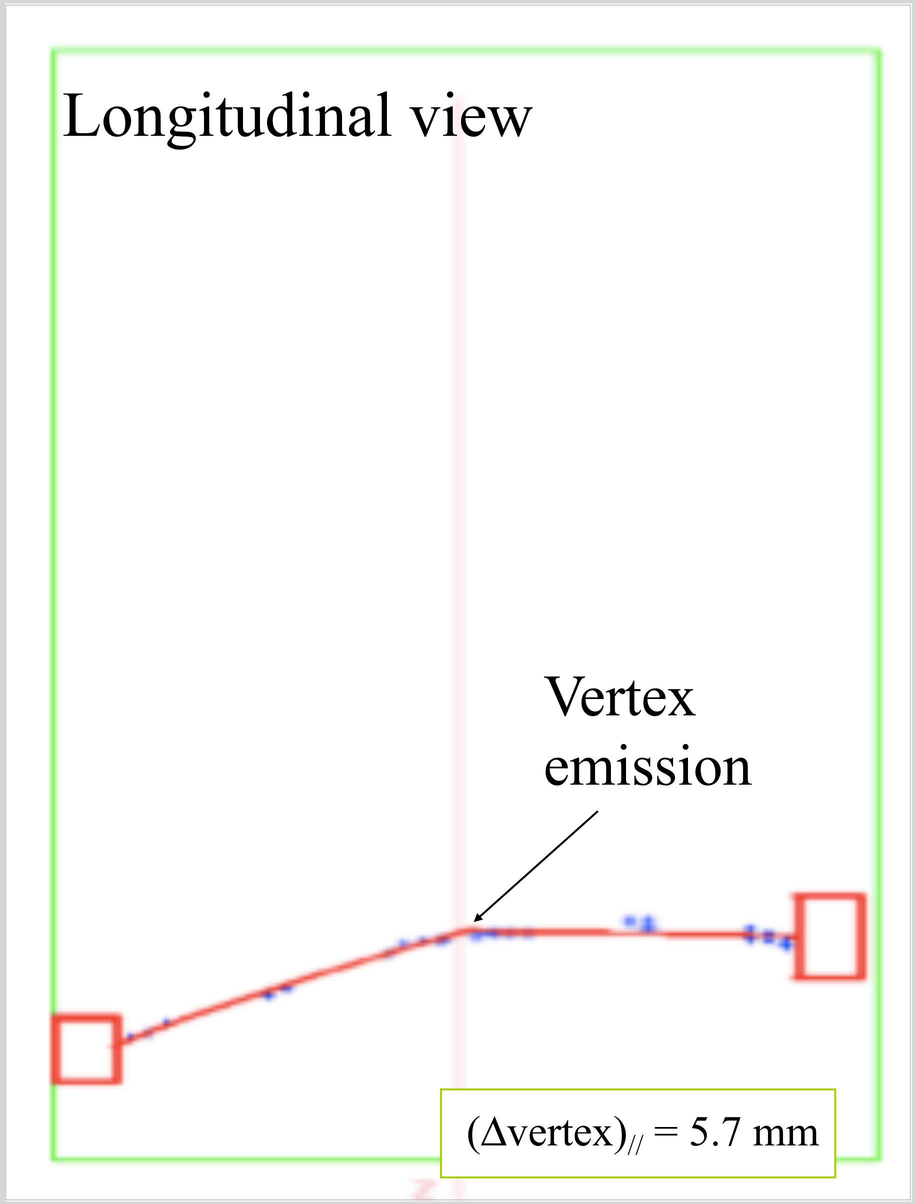
Radon-free air around the detector

- Phase I(Feb 2003 - Oct. 2004): High Radon
- Phase II(Dec 2004 - Now): Low Radon

(Radon cont. reduced by factor 6)

ββ events in NEMO3





Trigger: 1 PM > 150 keV

3 Geiger hits (2 neighbour layers + 1)

Trigger Rate ~ 5.5 Hz

ββ evts: 1 event every 2 minutes

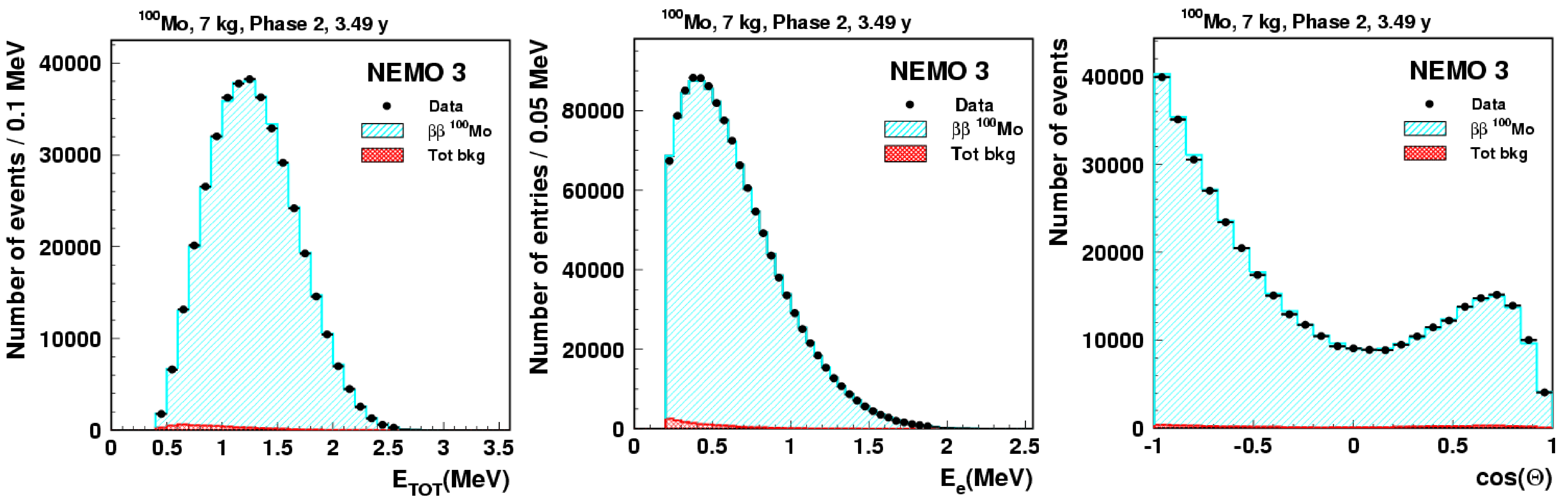
Backgrounds are measured using event topology and timing to produce a background model for ββ

NIM A606 (2009) 449-465.

See poster by B. Pahlka!

NEMO-3 **Results**

^{100}Mo (7kg), $2\nu\beta\beta$



$T_{1/2}(2\nu) = [7.17 \pm 0.01(stat) \pm 0.54(sys)] \times 10^{18}$ yr ⇒ ~3.5 yr, Phase II (low Rn), S/B = 76

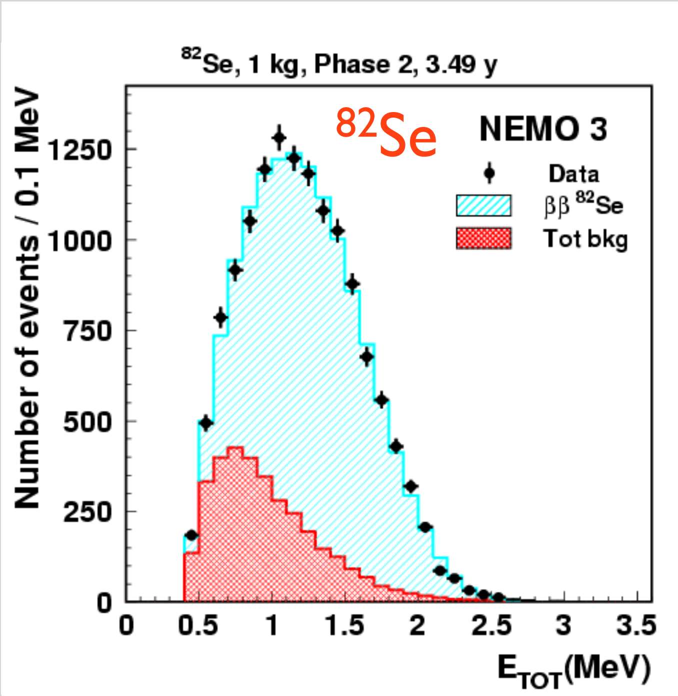
$M^{2\nu}(^{100}Mo) = 0.126 \pm 0.006$

to be compared with earlier published in PRL 95 (182302) 2005:

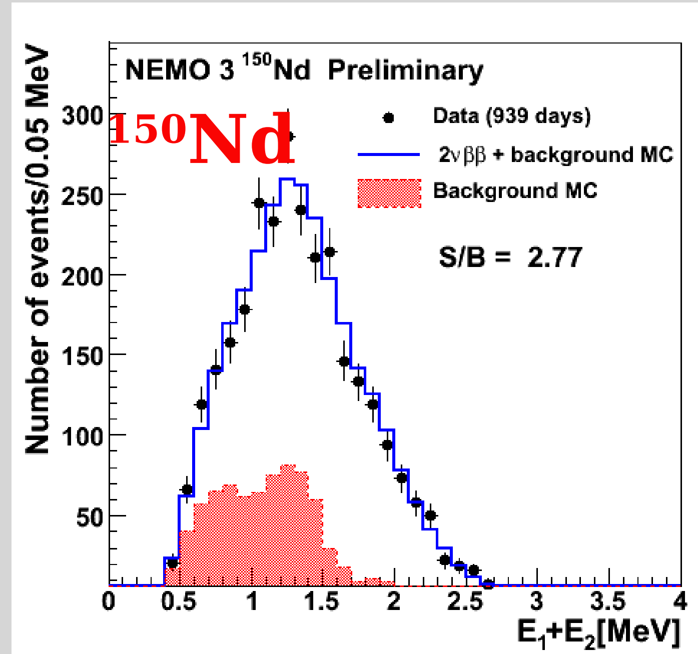
$T_{1/2}(2\nu) = [7.11 \pm 0.02(stat) \pm 0.54(sys)] \times 10^{18}$ yr ⇒ ~1 yr, Phase I, S/B = 40

NEMO-3 to run until Nov'10. Special runs to improve systematics.

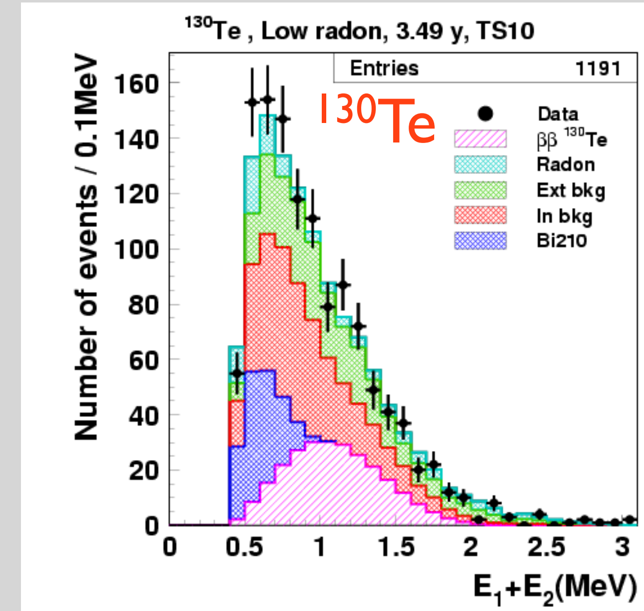
2νββ results for other isotopes (preliminary)



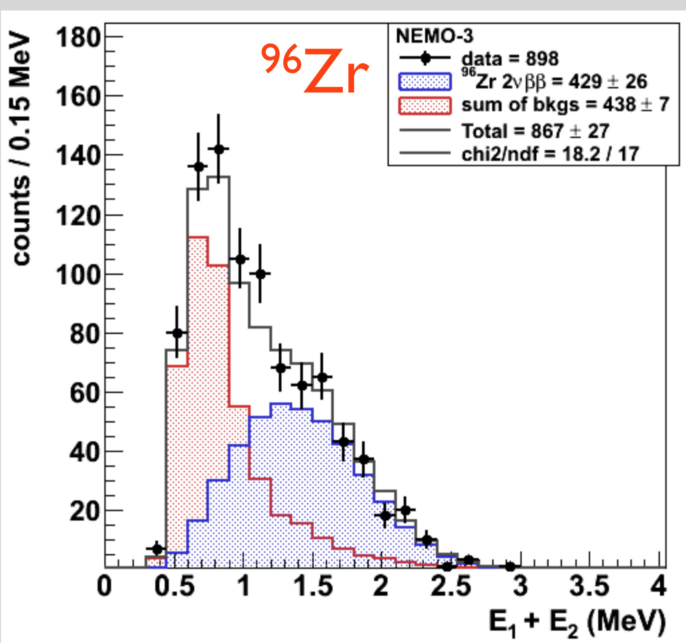
[9.6±0.1(stat)±1.0(sys)]×10^{19} yr
$M^{2\nu}$=0.049±0.004



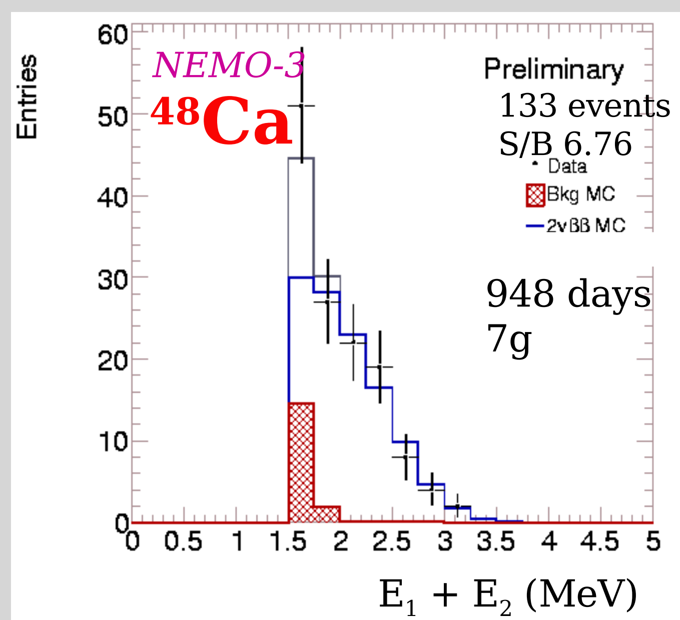
[9.20±0.25(stat)±0.63(sys)]×10^{18} yr
$M^{2\nu}$=0.030±0.002



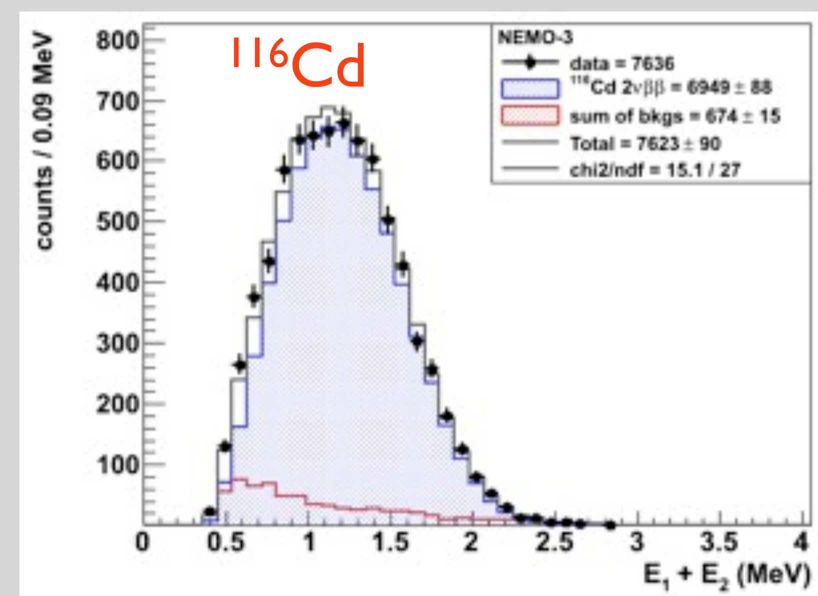
[$7.0^{+1.0}_{-0.8}$(stat) $^{+1.1}_{-0.9}$(sys)]×10^{20} yr
$M^{2\nu}$=0.0173±0.0025



[2.35±0.14(stat)±0.16(sys)]×10^{19} yr
$M^{2\nu}$=0.049±0.002



[$4.4^{+0.5}_{-0.4}$(stat)±0.4(sys)]×10^{19} yr
$M^{2\nu}$=0.0238±0.0015

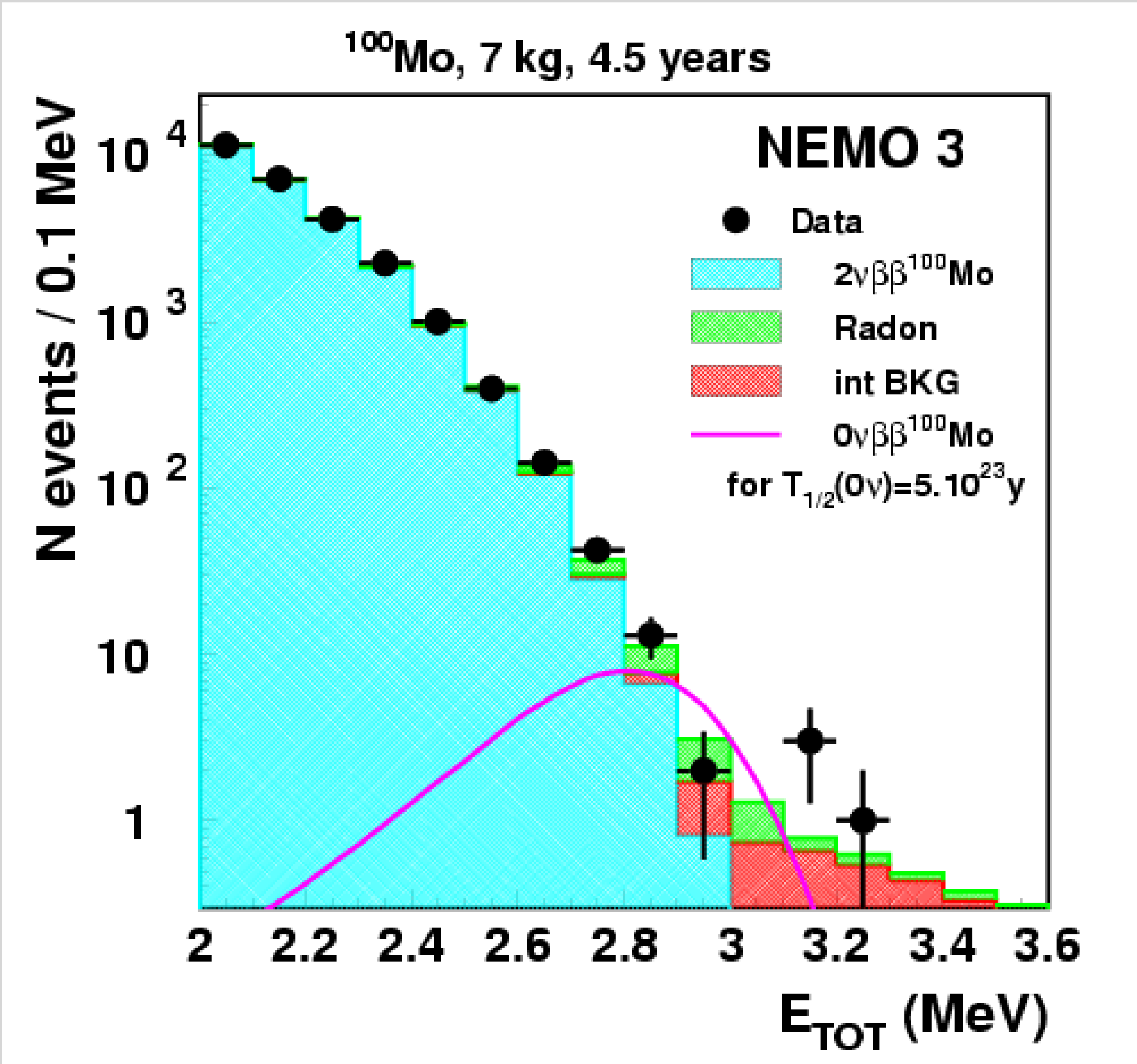


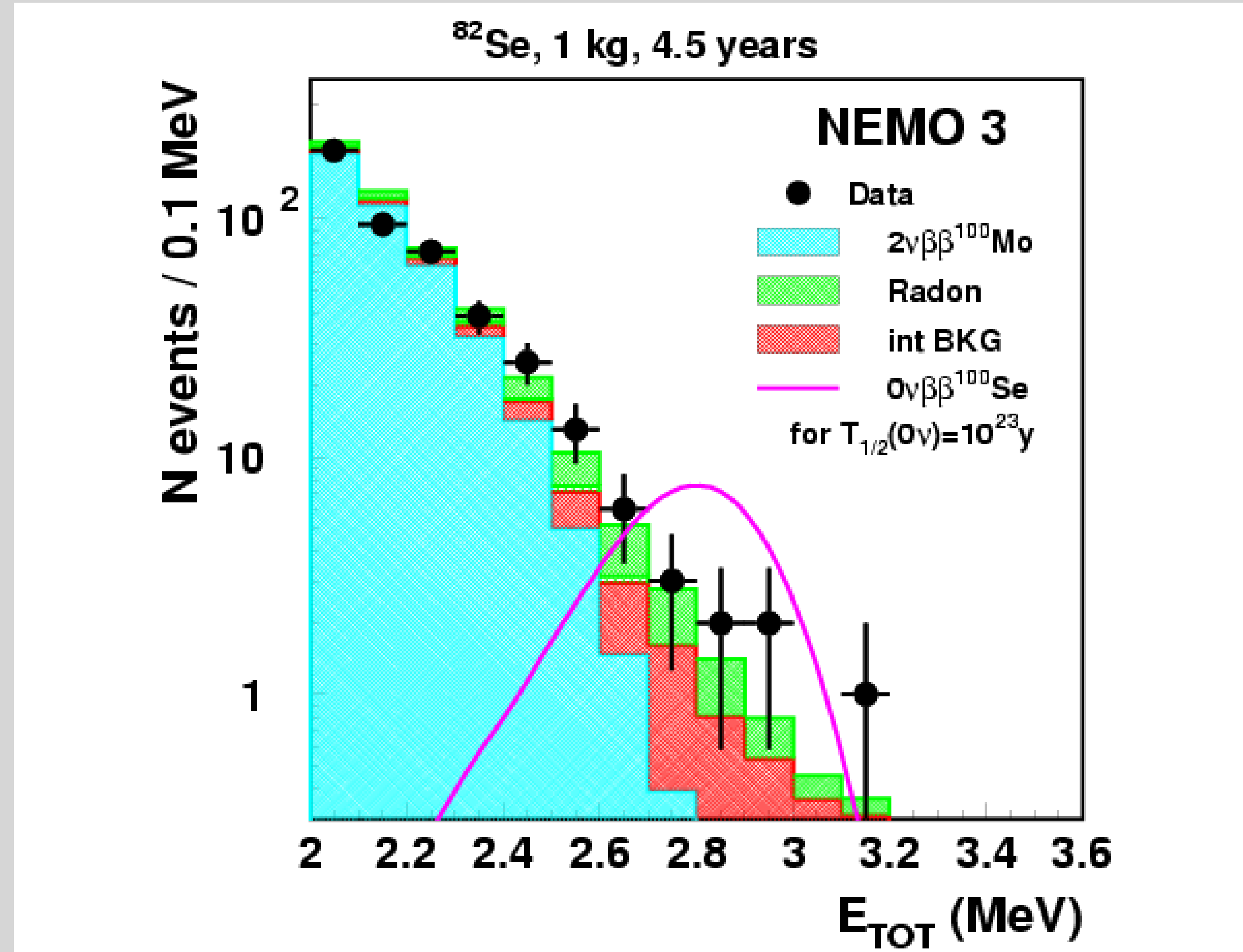
[2.88±0.04(stat)±0.16(sys)]×10^{19} yr
$M^{2\nu}$=0.0685±0.0025

Many more results available. Excited states, 0ν for different mechanisms and isotopes

See poster by B. Pahlka

0νββ for ^{100}Mo(~7kg) and ^{82}Se (~1kg)





[2.8-3.2] MeV: DATA = 18; MC = 16.4±1.4

$T_{1/2}(0\nu) > 1.0\times10^{24}$ yr at 90%CL

$\langle m_\nu \rangle < (0.47 - 0.96)$ eV

[2.6-3.2] MeV: DATA = 14; MC = 10.9±1.3

$T_{1/2}(0\nu) > 3.2\times10^{23}$ yr at 90%CL

$\langle m_\nu \rangle < (0.94 - 2.5)$ eV

V+A: $T_{1/2}(0\nu) > 5.4\times10^{23}$ yr at 90%CL
Majoron: $T_{1/2}(0\nu) > 2.1\times10^{22}$ yr at 90%CL

$\lambda < 1.4\times10^{-6}$
$g_{ee} < 0.5\times10^{-4}$ World's best result!

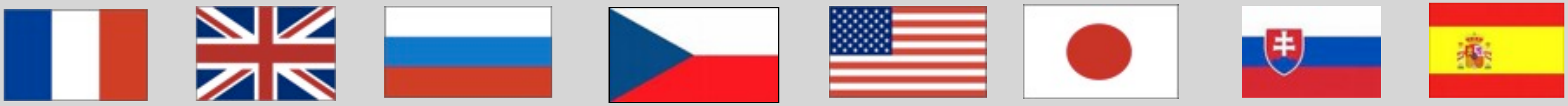
From NEMO-3 to SuperNEMO

NEMO-3		SuperNEMO
^{100}Mo	isotope	^{82}Se or other
7 kg	isotope mass M	100+ kg
18 %	efficiency ε	~ 30 %
^{208}Tl: ~ 100 μBq/kg ^{214}Bi: < 300 μBq/kg Rn: 5 mBq/m^3	internal contaminations ^{208}Tl and ^{214}Bi in the $\beta\beta$ foil Rn in the tracker	^{208}Tl ≤ 2 μBq/kg *if ^{82}Se*: ^{214}Bi ≤ 10 μBq/kg Rn ≤ 0.15 mBq/m^3
8% @ 3MeV	energy resolution (FWHM)	4% @ 3 MeV

$T_{1/2}(\beta\beta0\nu) > 2 \times 10^{24}$ y
$\langle m_\nu \rangle < 0.3 – 0.9$ eV

$T_{1/2}(\beta\beta0\nu) > 1 \times 10^{26}$ y
$\langle m_\nu \rangle < 0.04 - 0.11$ eV

SuperNEMO (~100 people)



Planar and **modular** design:

~ 100 kg of enriched isotopes (20 modules x 5 kg)

1 module:

Source (~40 mg/cm^2)   4 x 2.7 m^2

^{82}Se first but almost any isotope possible

(^{82}Se: High $Q_{\beta\beta}$, long $T_{1/2}(2\nu)$,

proven enrichment technology)

^{150}Nd, ^{48}Ca being looked at

Tracking : drift chamber ~2000 cells

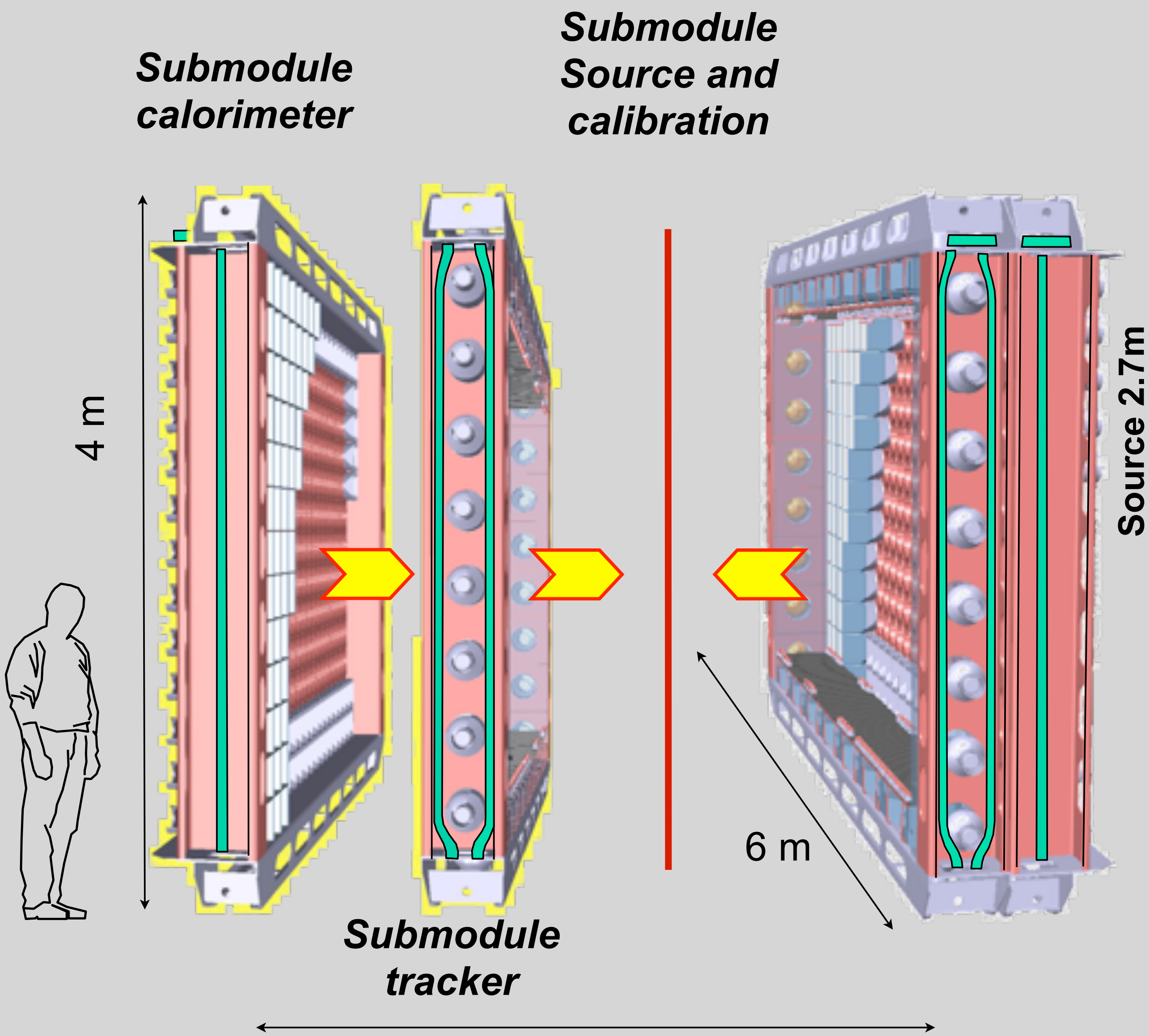
in Geiger mode

Calorimeter: scintillators + PMTs

550 PMTs + scint. blocks

Modules surrounded by water

passive shielding

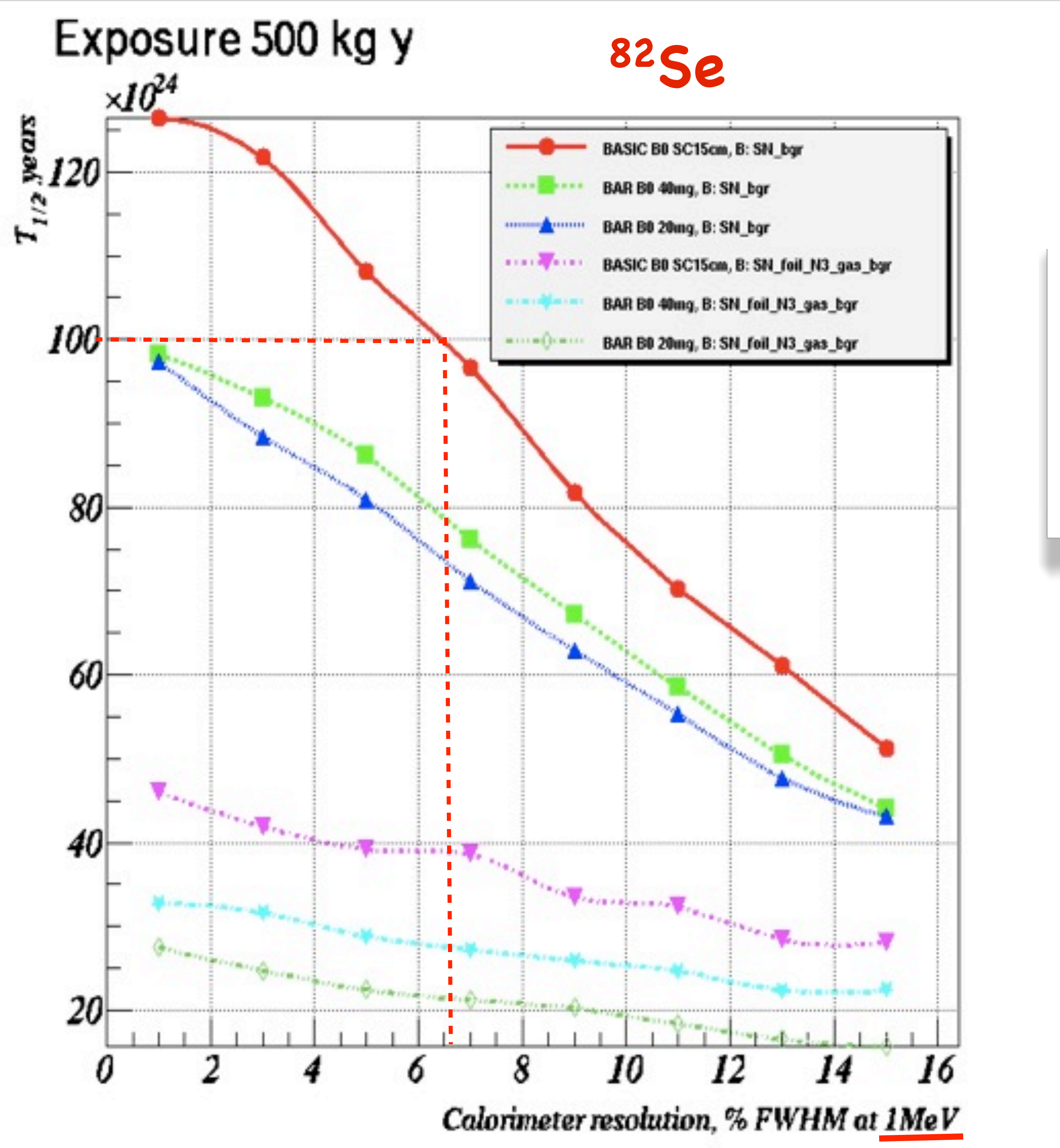


2 m (assembled, ~0.5m between source and calorimeter)

Physics Studies

Full chain of GEANT-4 based software + detector effects

+ NEMO3 experience



5 yr with 100kg of ^{82}Se:

$T_{1/2} > 10^{26}$ yr, $\langle m_\nu \rangle < 50$-$100$ meV at 90%CL

with target detector parameters

Much more than 1 result!

- Other mechanisms: V+A, Majoron, etc
- Disentangling $\langle m_\nu \rangle$ and V+A:
  arXiv: 1005.1241
- $\beta\beta0\nu$(and 2ν) to excited states

See SuperNEMO poster by F. Nova

ββ Source (^{82}Se)

Enrichment

100 kg by centrifugation is feasible

Foil production: 40-50 mg/cm^2

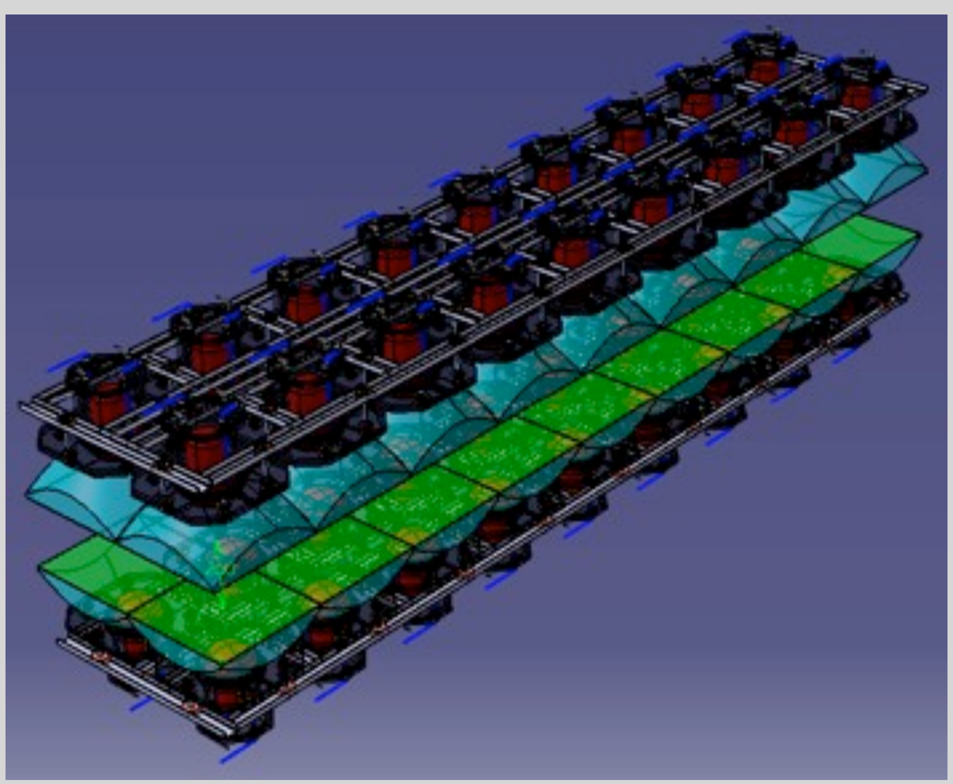
NEMO-3 “composite” foil

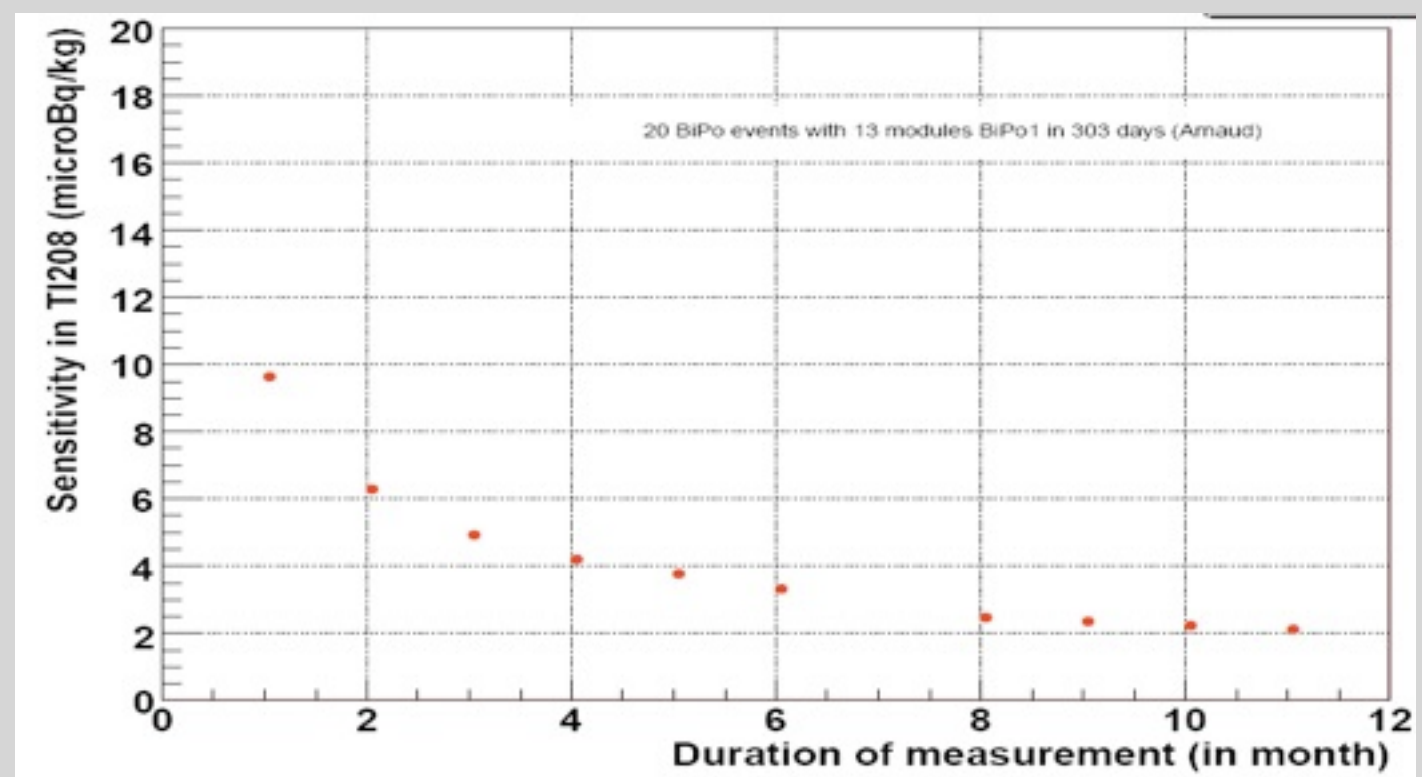
Other methods being explored

Radio-purity: ^{208}Tl < 2 μBq/kg, ^{214}Bi < 10 μBq/kg

Chemical and physical purification methods

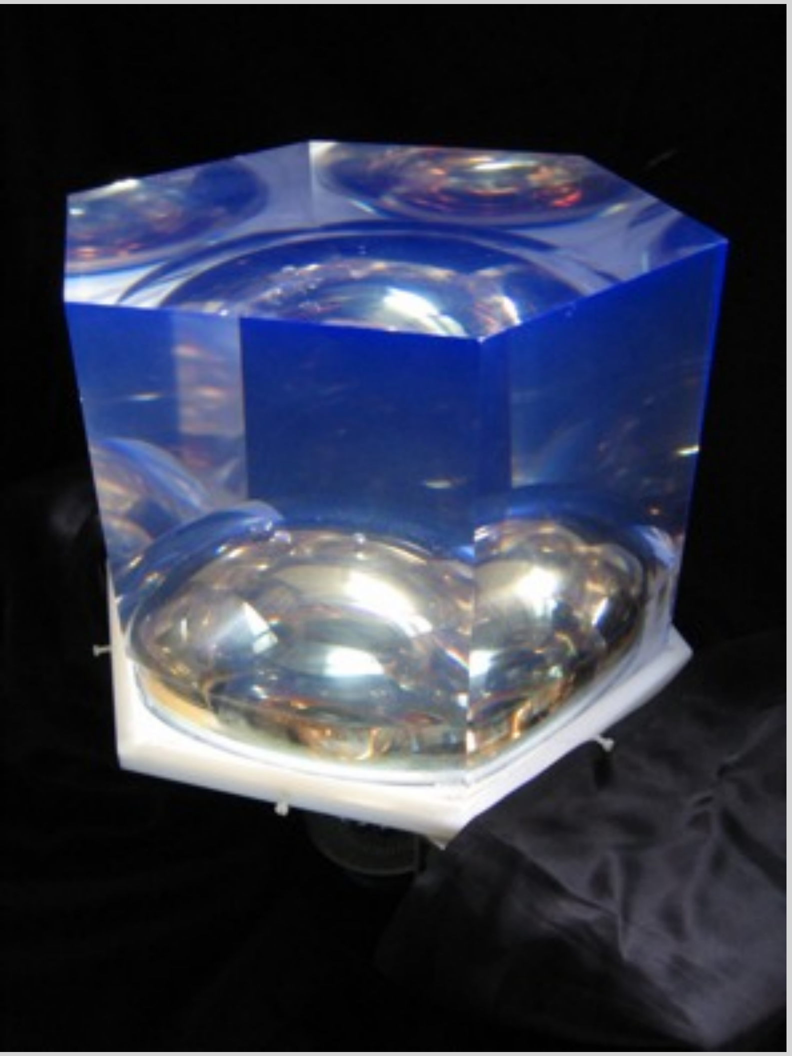
Dedicated BiPo detector to measure these levels





See SuperNEMO poster by F. Nova

Calorimeter R&D



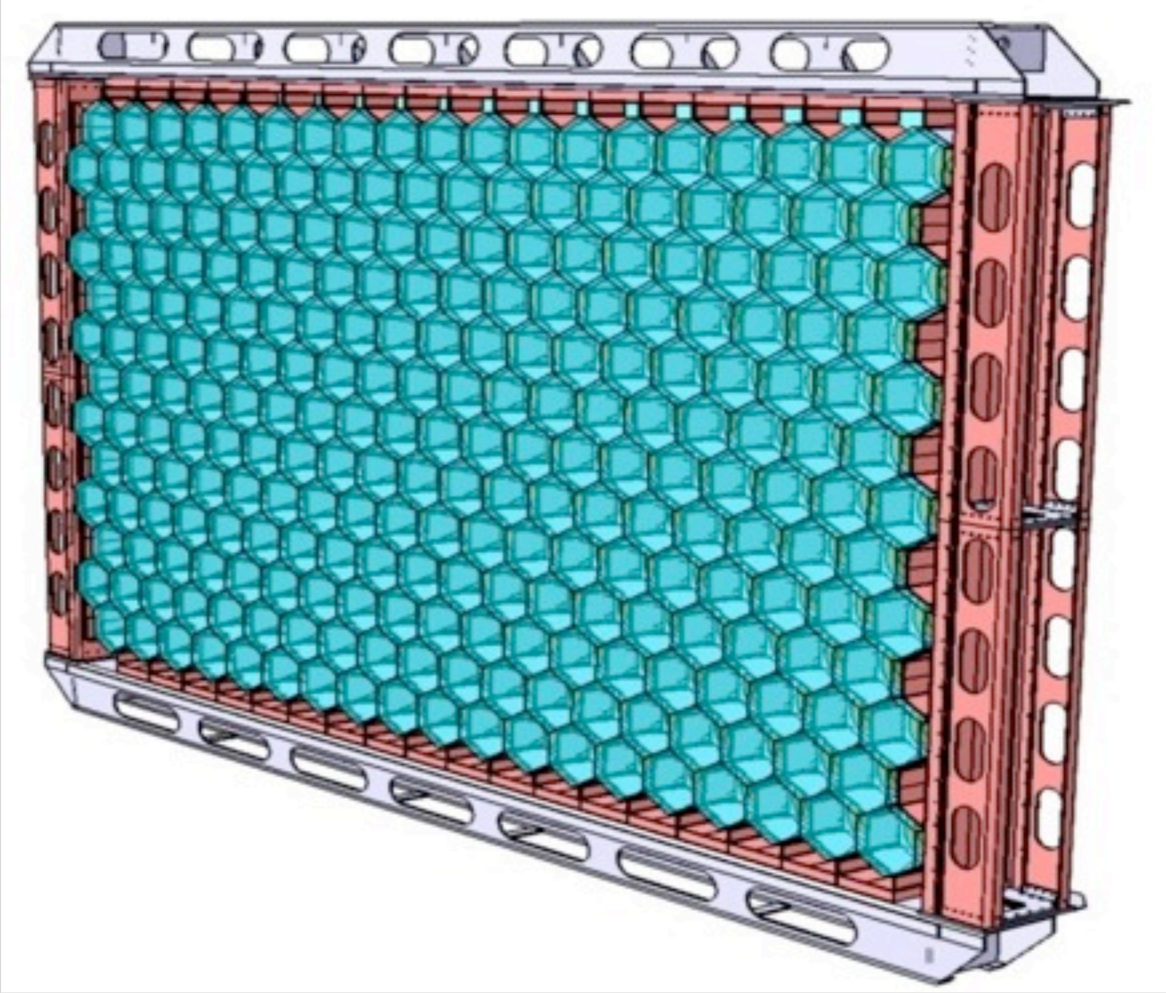
Large R&D effort to improve energy and time resolution

Scintillator

- Material
- Shape
- Size
- Coating

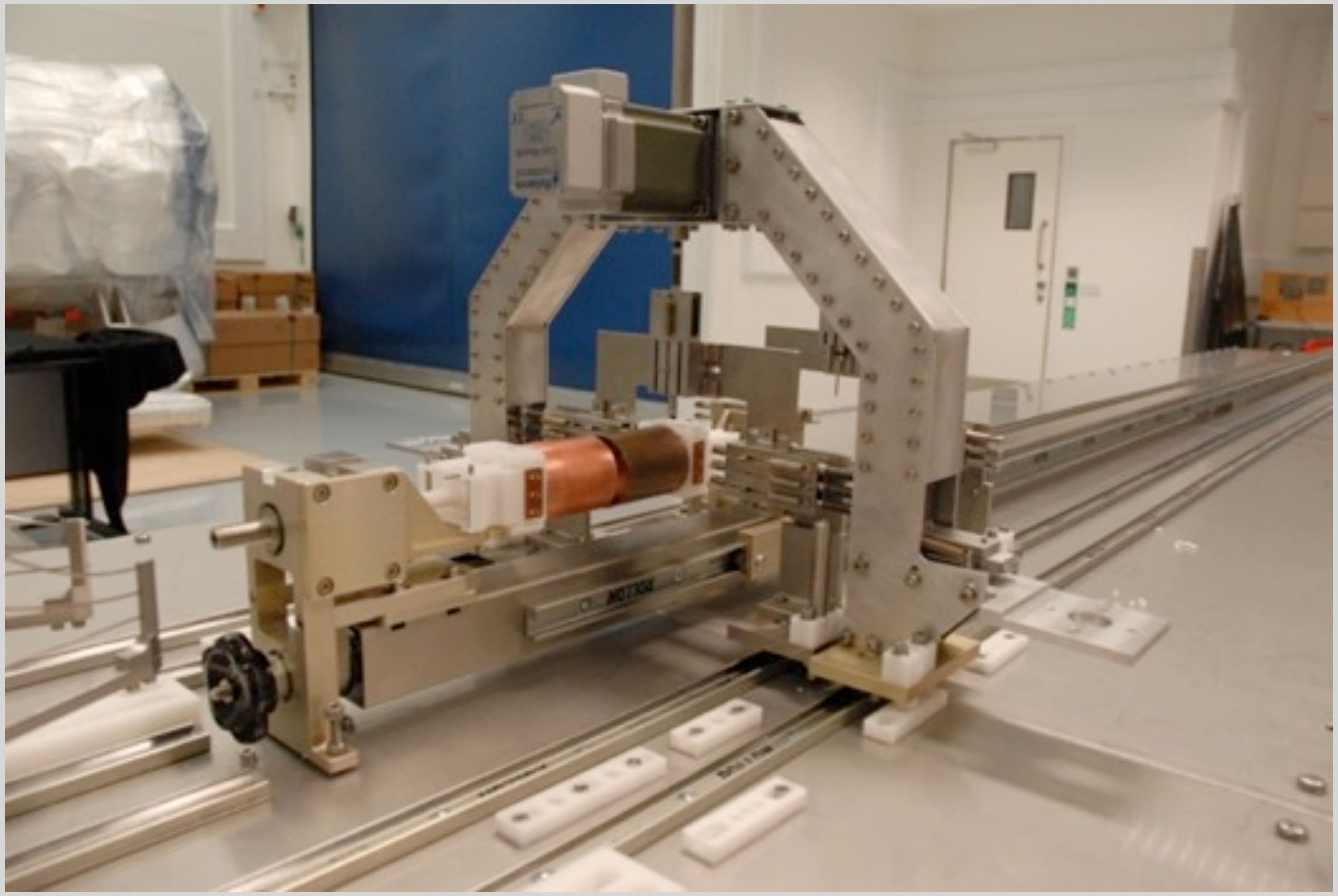
PMT

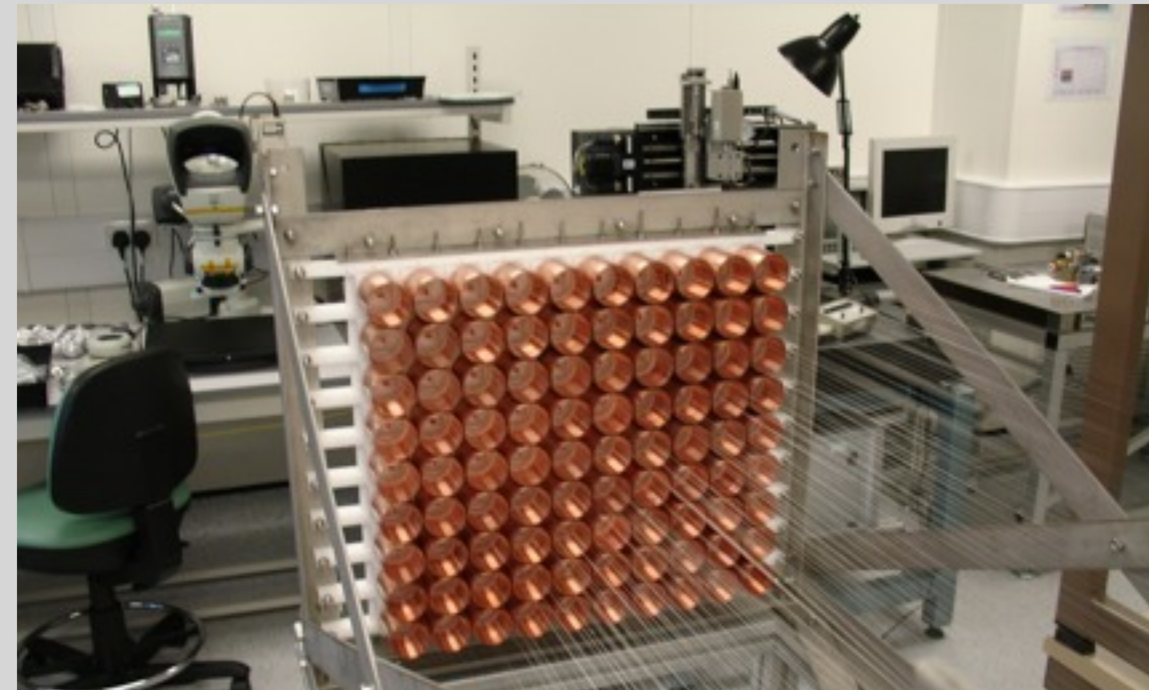
- QE
- Uniformity
- Collection efficiency
- Radiopurity

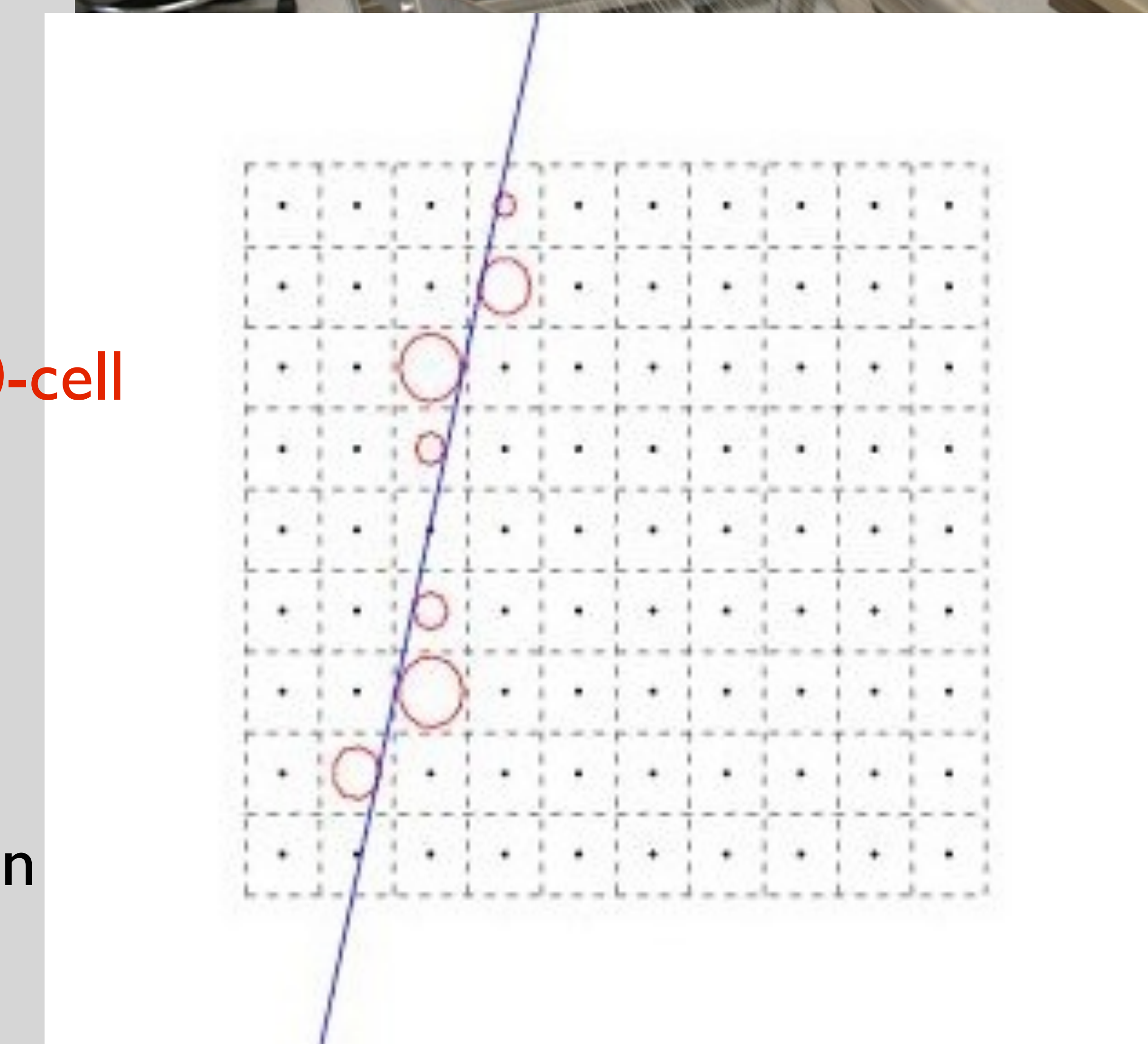


Required resolution demonstrated with 28cm Hex block (≥10cm thick) directly coupled to 8" PMT → **FWHM = 4% @ $Q_{\beta\beta}$ = 3 MeV**

Tracker R&D







- Basic cell design developed and verified with 90-cell prototype
- Mechanical model of automated wiring robot
- Cosmic muon data collected.
  Required performance demonstrated
  - 0.7mm transverse, 1cm longitudinal resolution
  - Cells efficiency >98%

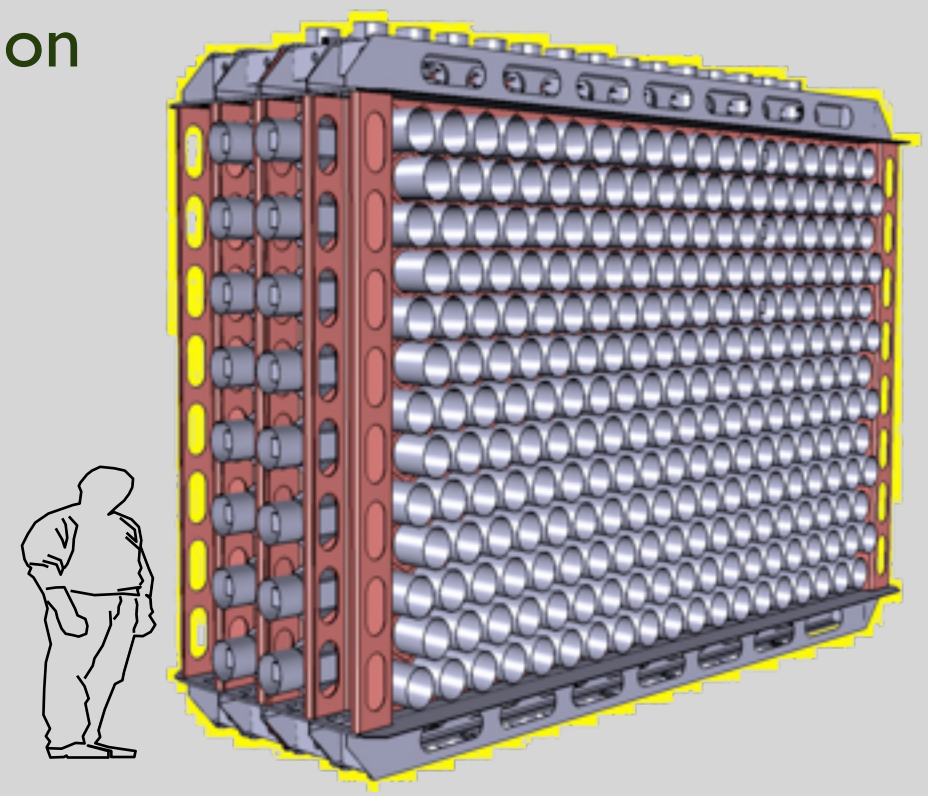
From R&D to construction
1st SuperNEMO module - **Demonstrator**

Goals

- Demonstrate feasibility of large scale mass production
- To measure backgrounds especially from radon emanation
  - Only possible with a realistic super-module
- To finalise detector design
- To produce a competitive physics measurement

↓

0.3 expected bkg events in 2.8 - 3.2 MeV
with 7kg of ^{82}Se in 2 yr



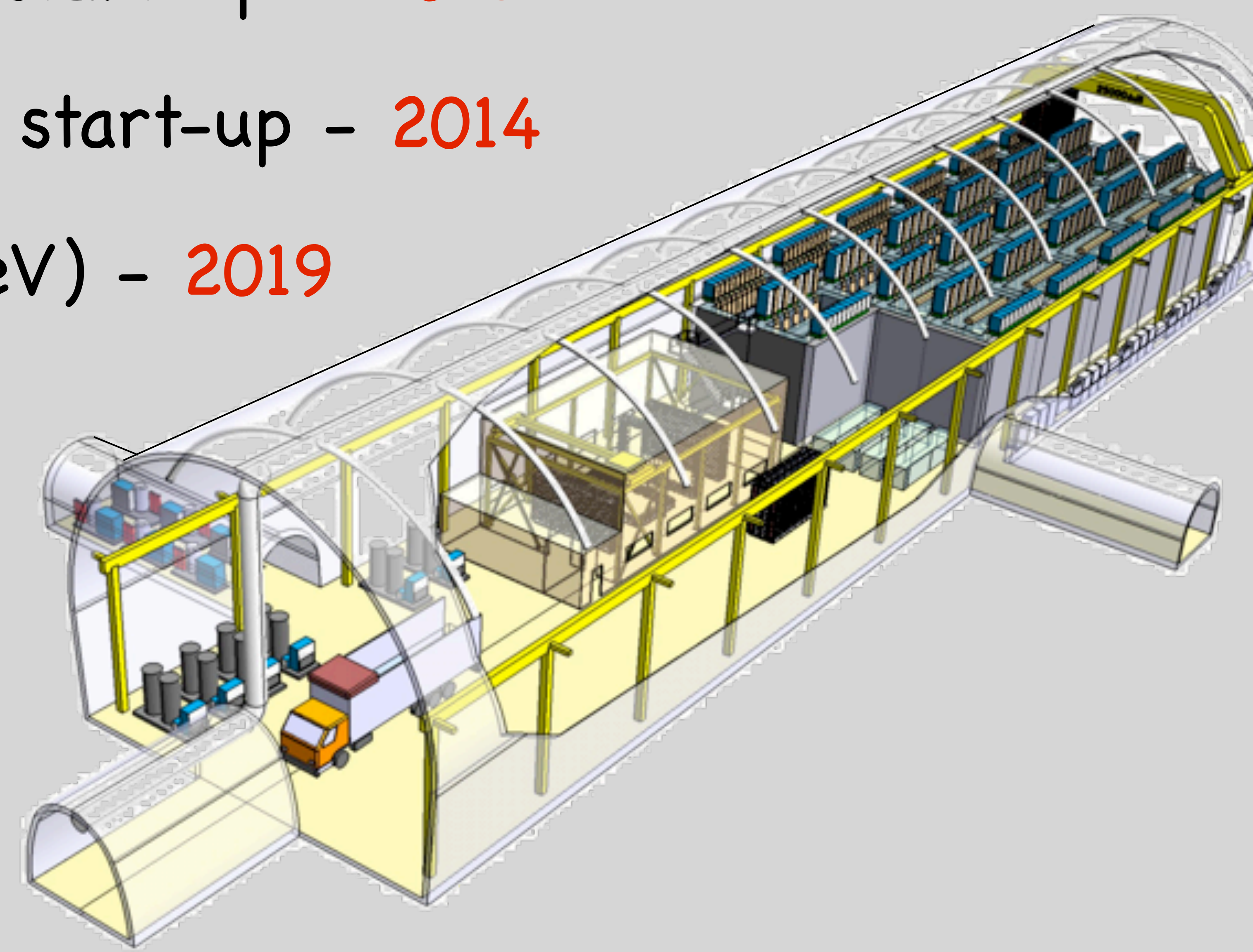
Sensitivity by 2015: $6.5 \cdot 10^{24}$ yr (90% CL)

Equivalent to $\mathbf{3 \cdot 10^{25}}$ **yr** for ^{76}Ge (using phase space ratio only)

or ~4 expected "golden events" if KK claim is correct

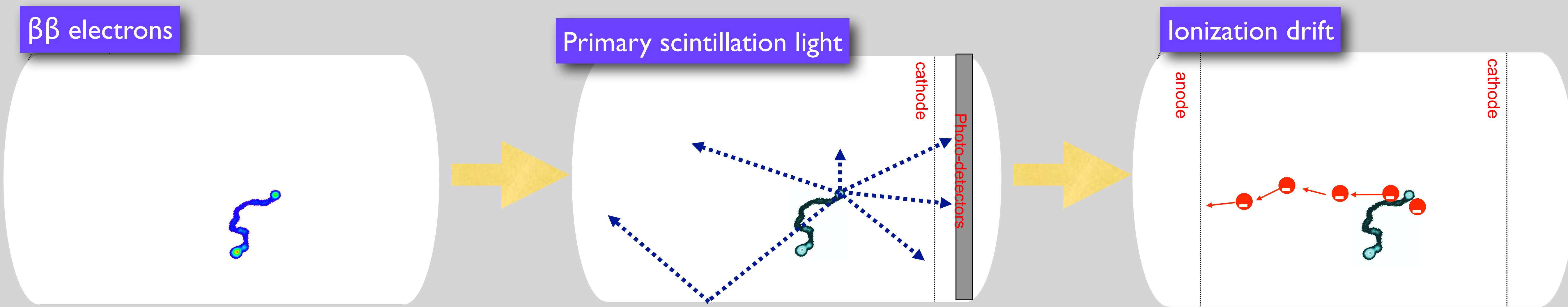
SuperNEMO schedule highlights

- NEMO-3 decommissioning - early 2011
- Demonstrator construction - 2010-2012
- Demonstrator physics run start-up - 2013
- Full detector construction start-up - 2014
- Target sensitivity (~0.05 eV) - 2019

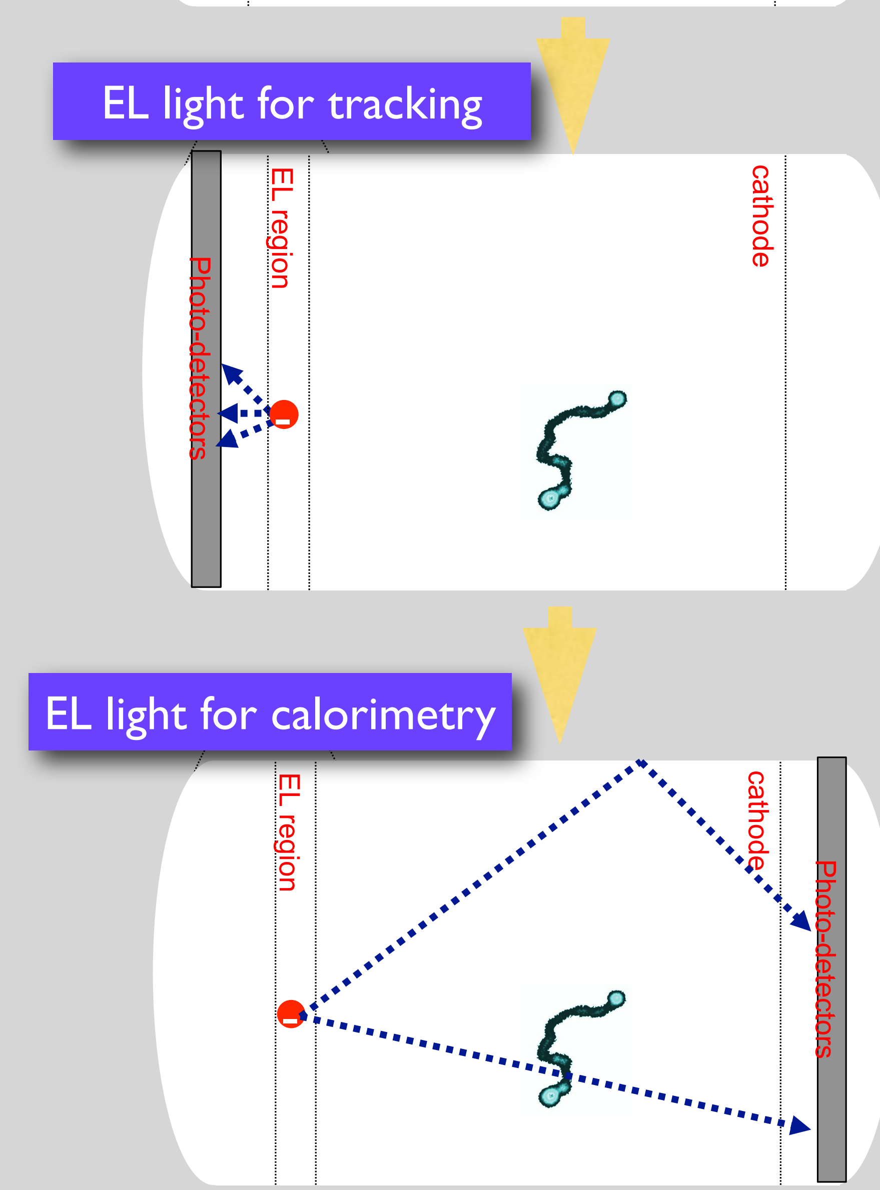


KK claim to be verified with Demonstrator by 2015

High Pressure ^{136}Xe TPC.



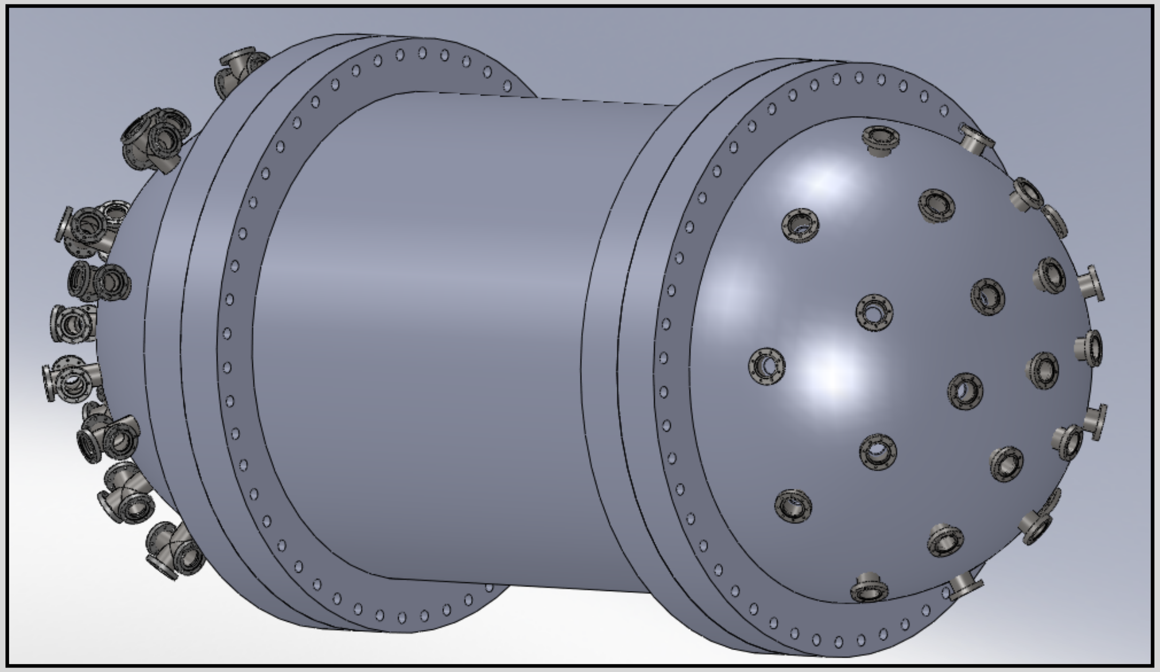
- **Baseline concept:**
  - Primary scintillation light for t_0
  - Electroluminescent (EL) light for tracking, “PID” and calorimetry
  - Single drift volume, photosensors at endcaps



- **Alternatives being explored:**
  - Charge avalanche gain via Micromegas
  - Dual drift volume, instrumented barrel
- **Difficulties**
  - Multiple scattering in HPXe is large
  - In pure Xe diffusion is significant
  - δ-rays, bremsstrahlung

NEXT - Neutrino Experiment with a Xenon TPC

A 10 bar TPC



- **R&D underway with small-scale prototypes:**
  - Studies of primary and secondary scintillation
  - Energy resolution in Xe with Micromegas
- **Schedule:**

  2010: preparation of site in LSC (Canfranc)

  2011: first prototype operating in LSC

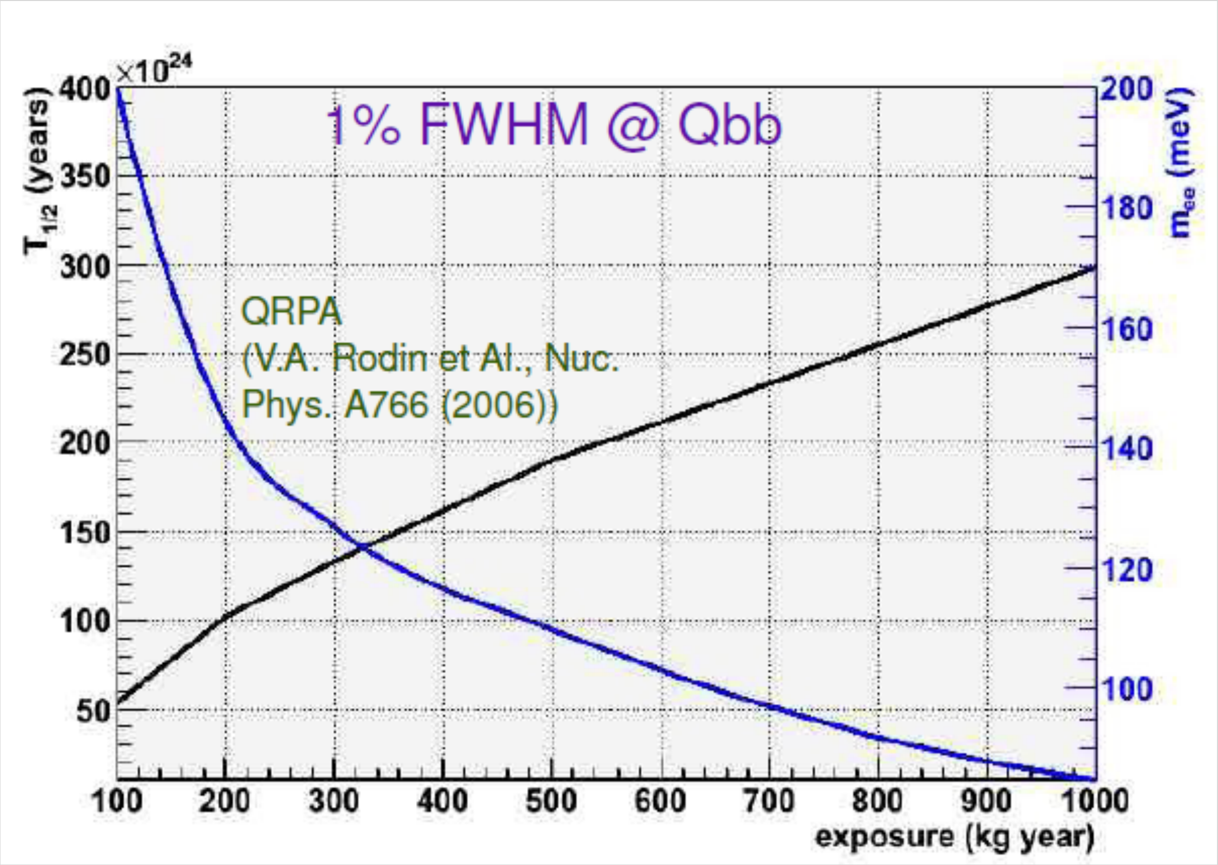
  2012: NEXT-100 construction (~100 kg of ^{136}Xe)

  2013: NEXT-100 commissioning

- **Assumptions:**
  - 0.1 mBq/kg vessel
  - 100 mBq from readouts
  - Minimum set of cuts on ββ topology
  - δE/E = 1% (FWHM)
- **Sensitivity** **(500 kg·yr, 90% CL):**

$T_{1/2}^{0\nu} = 1.8\cdot 10^{26}$ yr ⇒ $m_{\beta\beta} = 110$ meV

See NEXT poster by T. Dafni



Plots courtesy of NEXT collaboration

EXO-Gas (^{136}Xe)

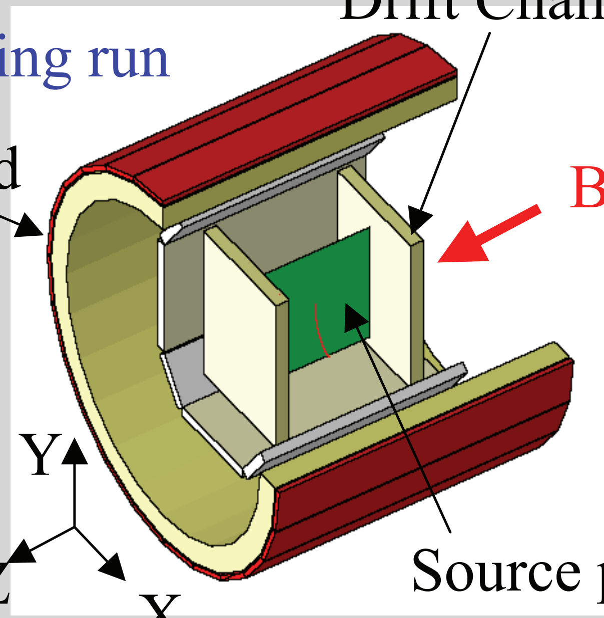
- EXO-Gas is building a tracking TPC using an Electroluminescence (EL) readout
- Will operate in pure xenon (ie no quench)
- Part of a prototype to complement studies of barium tagging for decays in gas
- Further activity depends on results of EXO-200

Chamber for studying energy resolution in gaseous Xe at Carleton

Drift Chamber Beta Ray Analyser

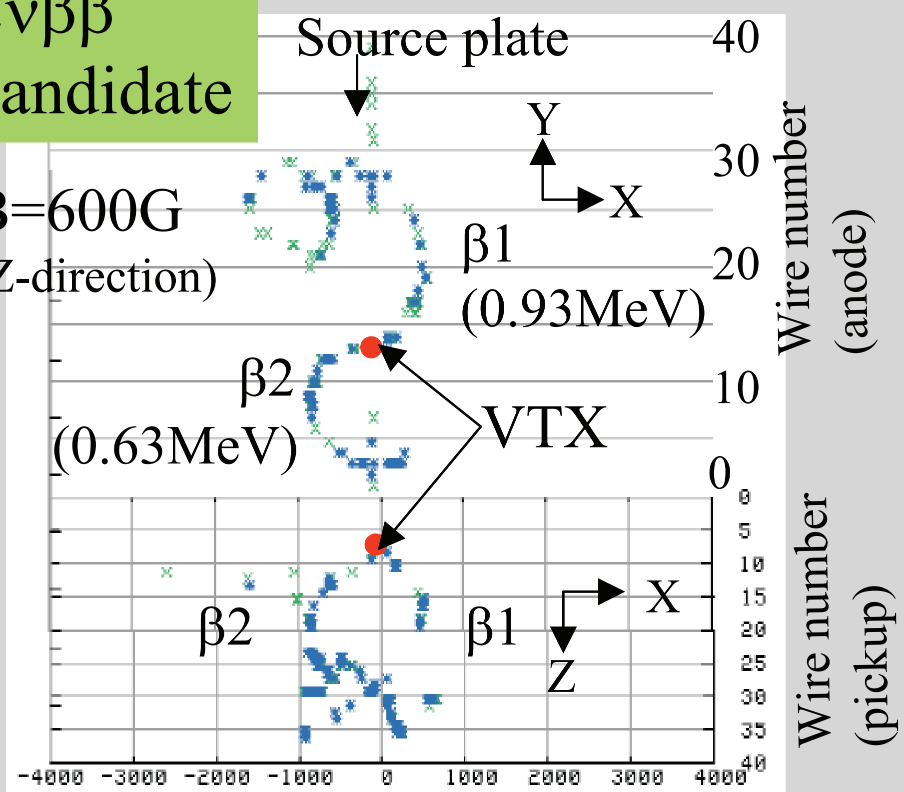
DCBA Experiment

DCBA-T2
engineering run



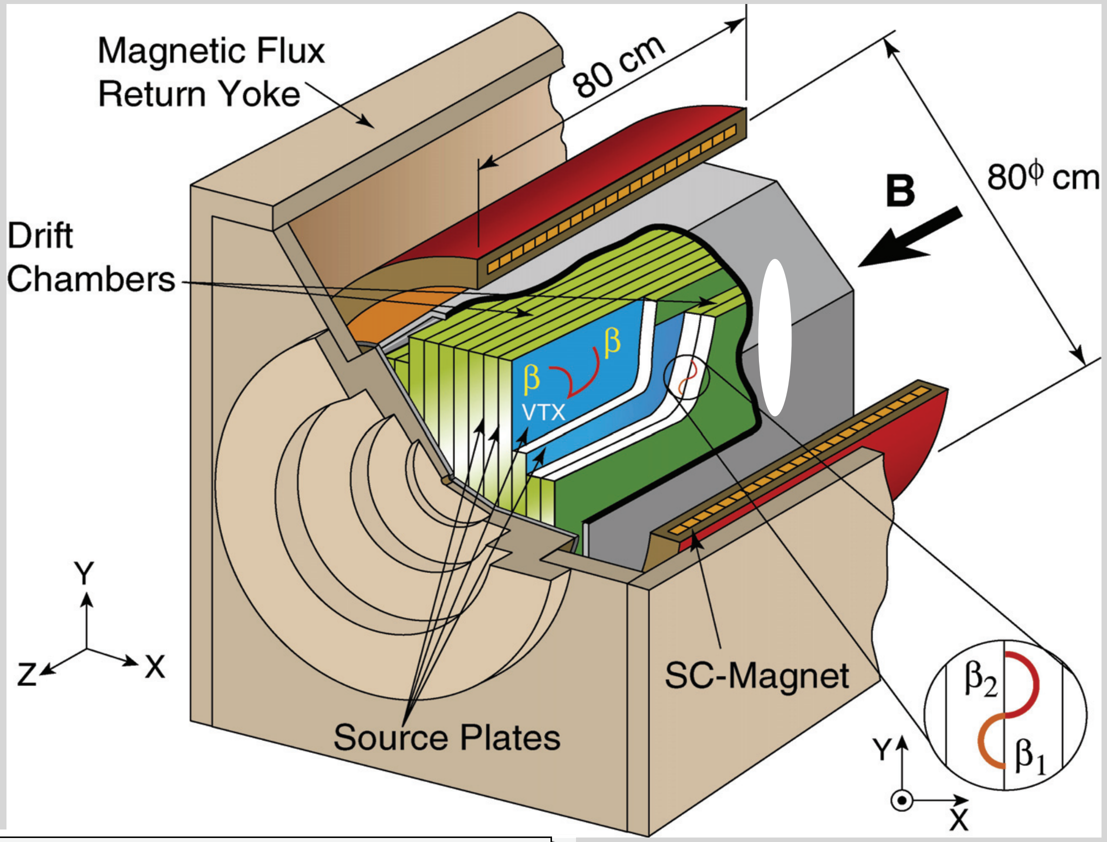
2νββ candidate

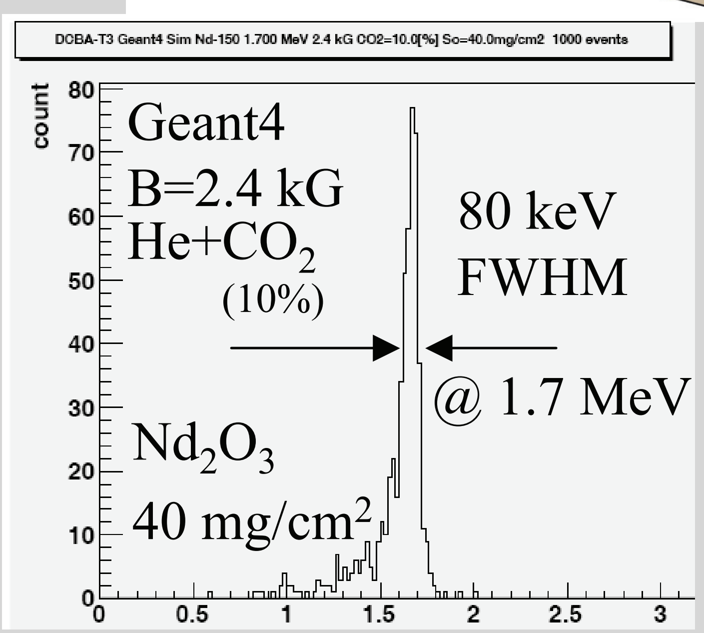
B=600G
(Z-direction)



See poster by N. Ishihara

DCBA-T3 under construction





Corresponding
ΔE/E
=3.4% (FWHM)
at Q of ^{150}Nd
(=3.37 MeV)

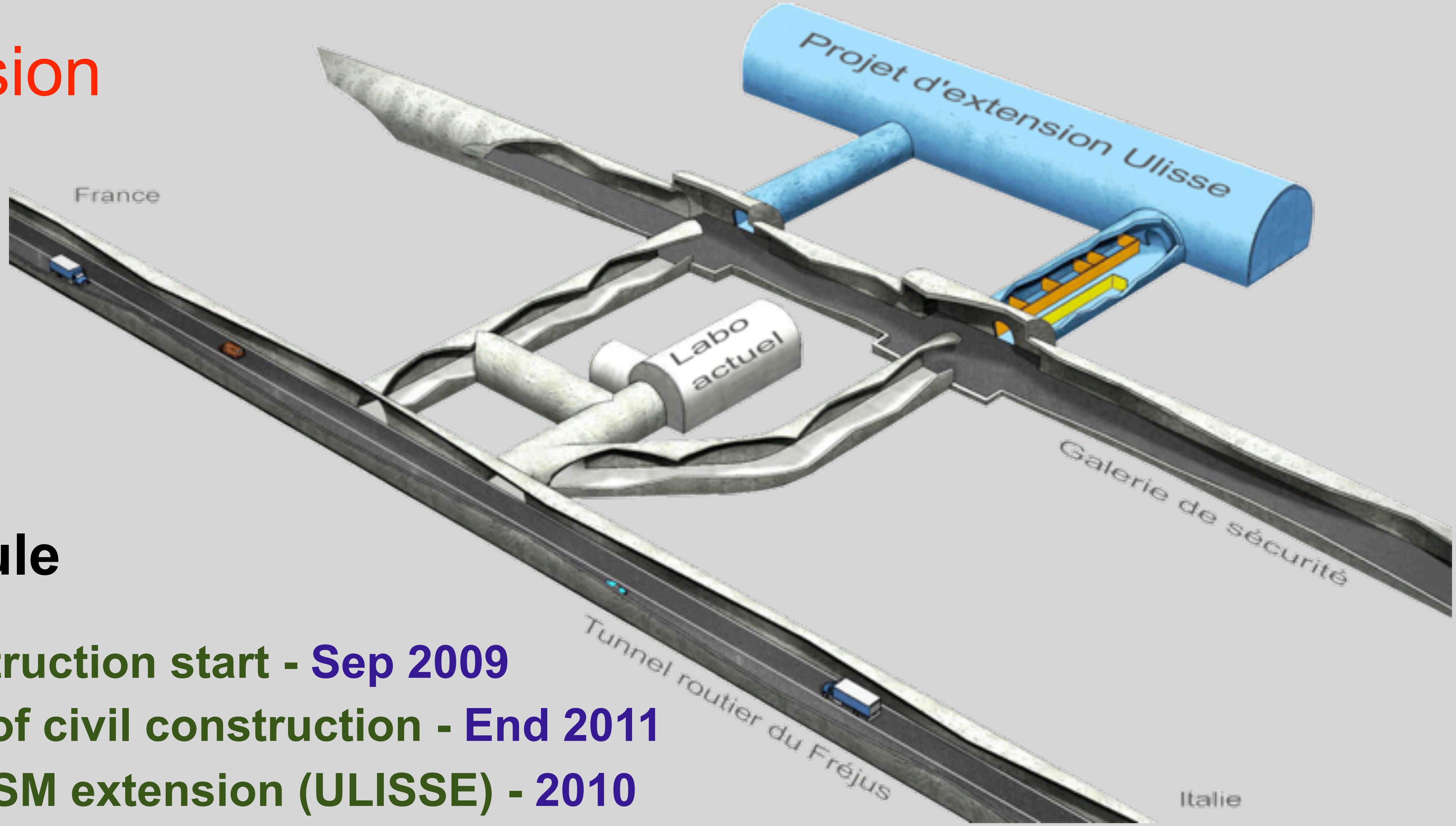
Plots courtesy of DCBA collaboration

Concluding Remarks

- Tracking-based experiments:
  - Have competitive sensitivity
    NEMO-3: $T_{1/2}$ (^{100}Mo) > 10^{24} yr
    - $\langle m_\nu \rangle$ < ~0.5 eV, g_{ee} < 0.5×10^{-4}, λ < 1.4×10^{-6}
  - Provide a unique and powerful background rejection
  - Look for a smoking gun evidence of the process
  - May shed light on physics mechanism
- Next 5-10 yrs will see "the claim" tested and reach the benchmark sensitivity of 0.05 eV

BACKUP

LSM Extension



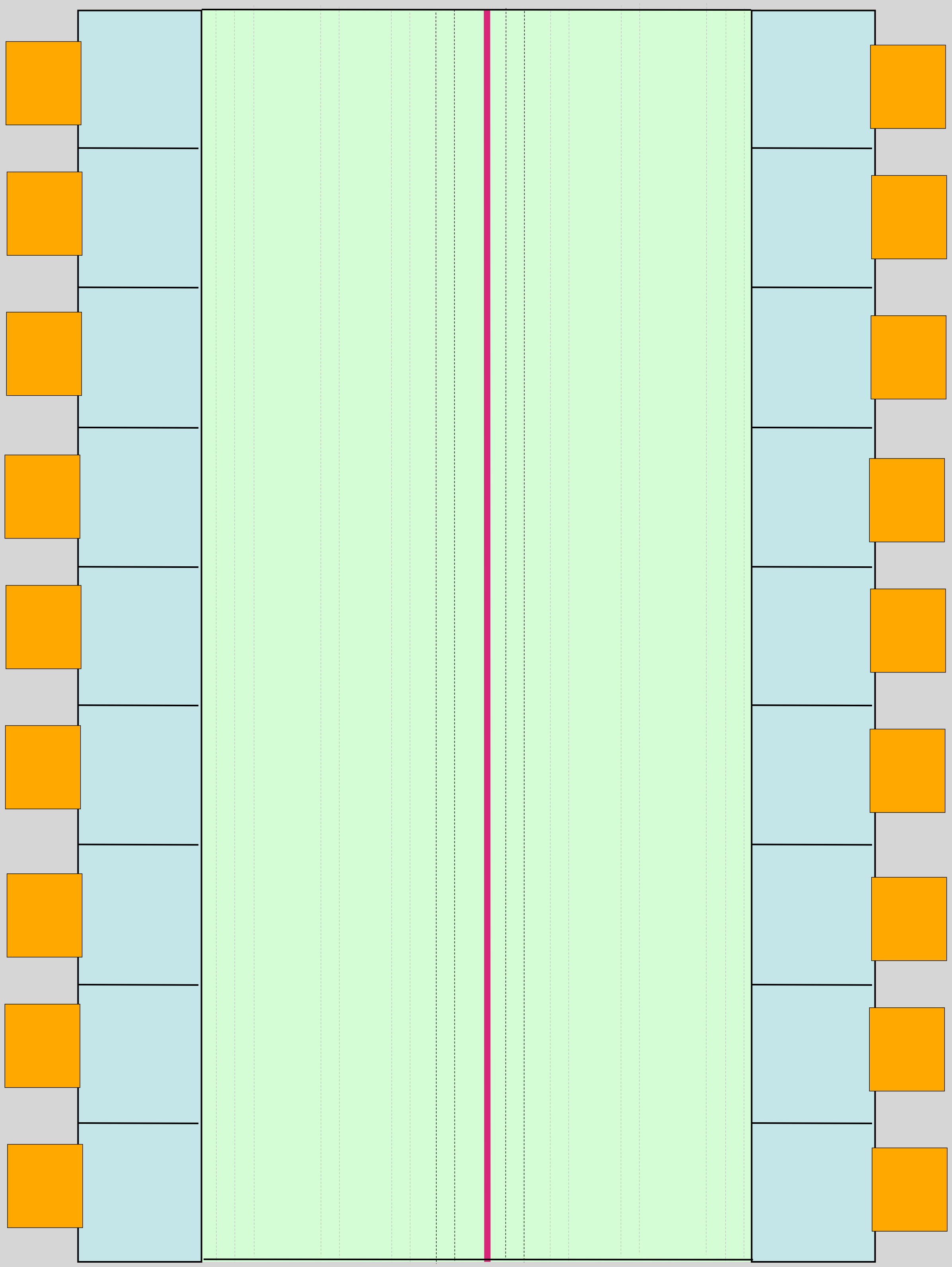
Schedule

- **Safety tunnel construction start - Sep 2009**
- **Safety tunnel, end of civil construction - End 2011**
- **Detailed study of LSM extension (ULISSE) - 2010**
- **Deadline for final decision/money commitment - May 2011**
- **Excavation of new Lab completed - mid-2012**
- **Outfitting completed, Lab ready to host experiments - 2013**

Minimal scenario: 45,000m^3 (100m long), 12M€ excavation + 3M€ outfitting

2^d ULISSE workshop in October. 11 LOIs received.

NEMO-3 Backgrounds for ββ



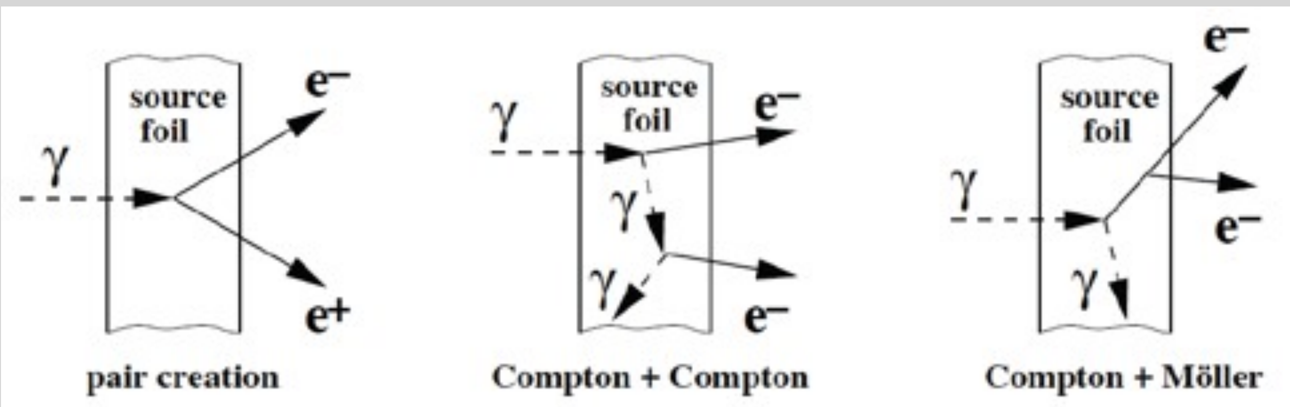
NEMO-3 Backgrounds for ββ

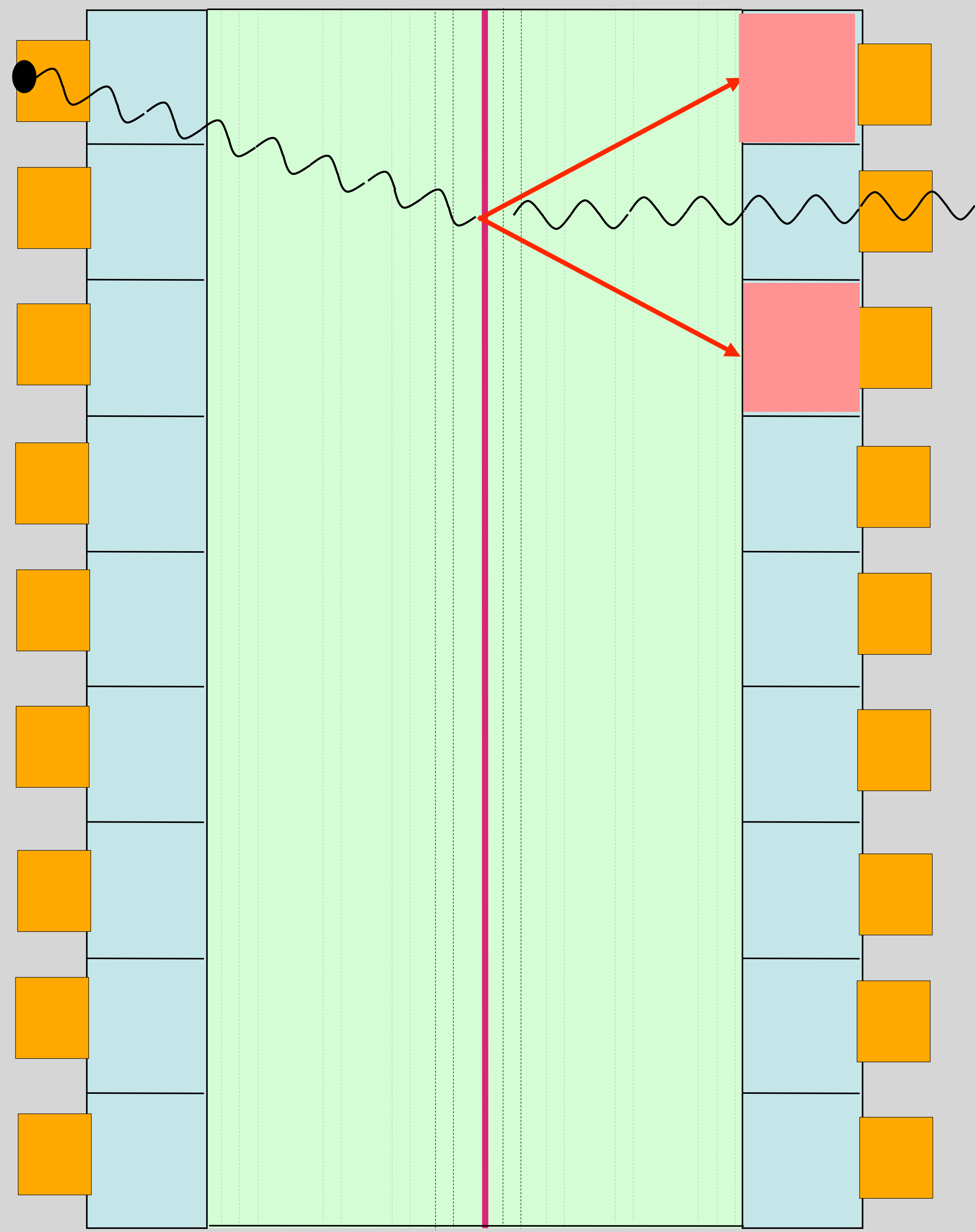
- **External** γ (if the γ is not detected in the scintillators)

  Origin: natural radioactivity of the detector or neutrons

  Main bkg for ββ2ν but negligeable for ββ0ν

  (^{100}Mo and ^{82}Se $Q_{\beta\beta}$~ 3 MeV > Eγ(^{208}Tl) ~ 2.6 MeV)





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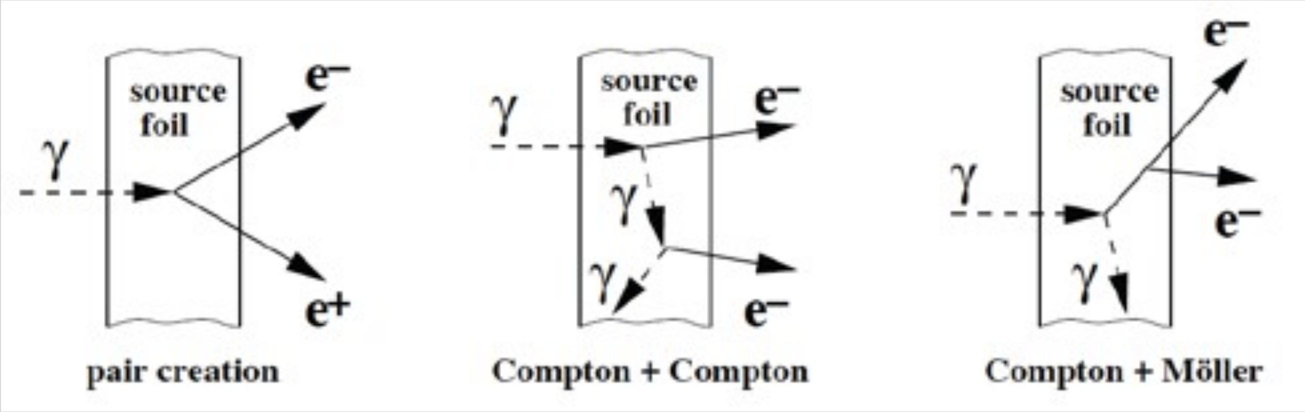
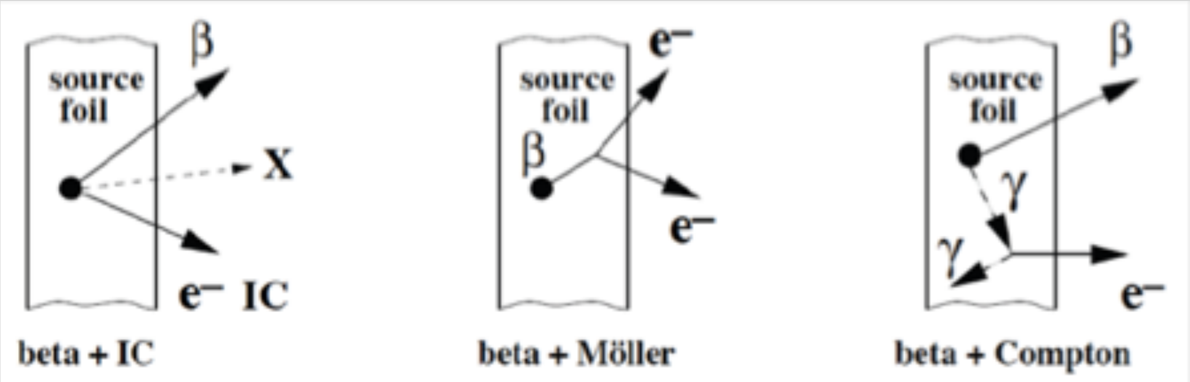
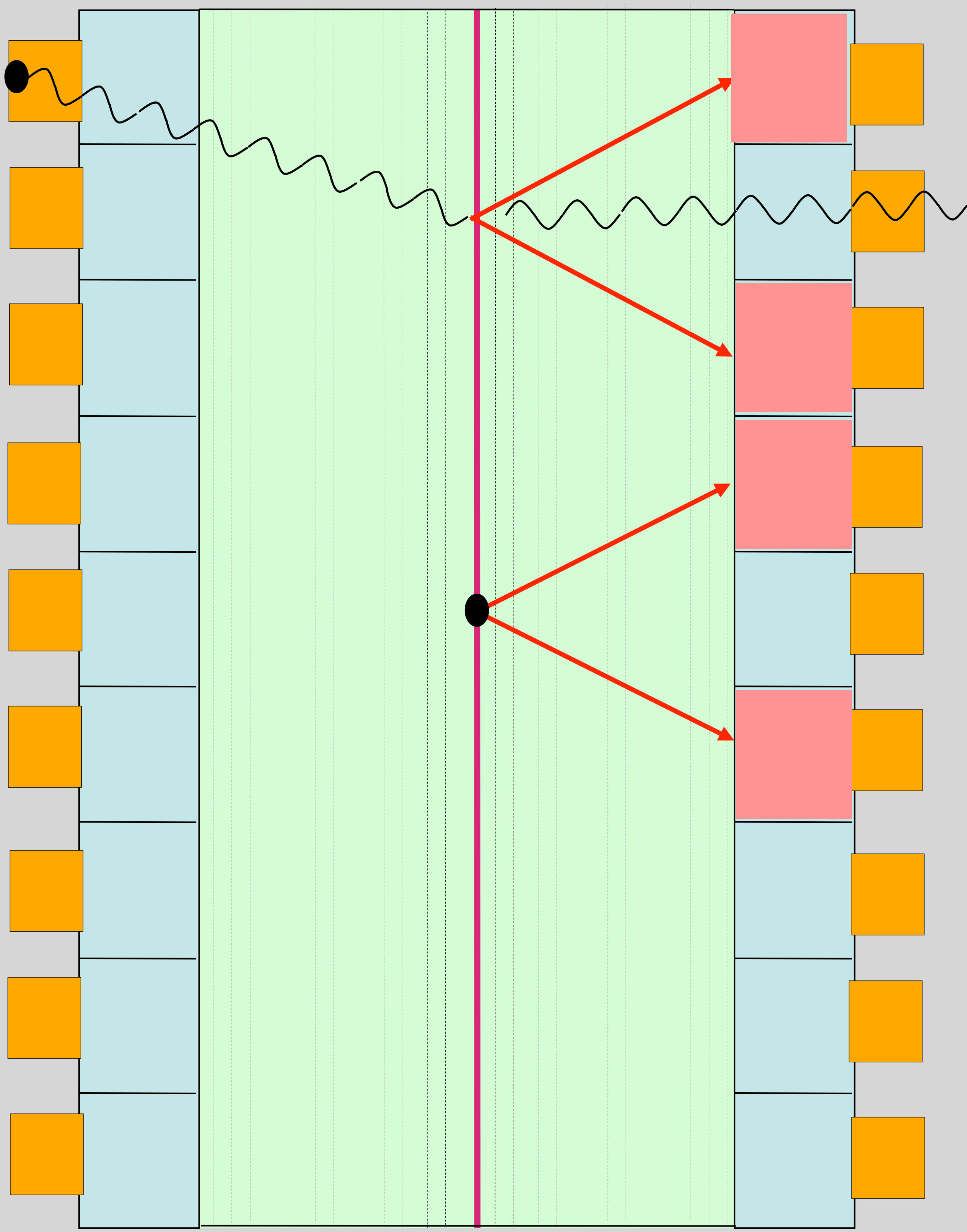


- **^{232}Th (^{208}Tl) and ^{238}U (^{214}Bi) contamination inside the ββ source foil**





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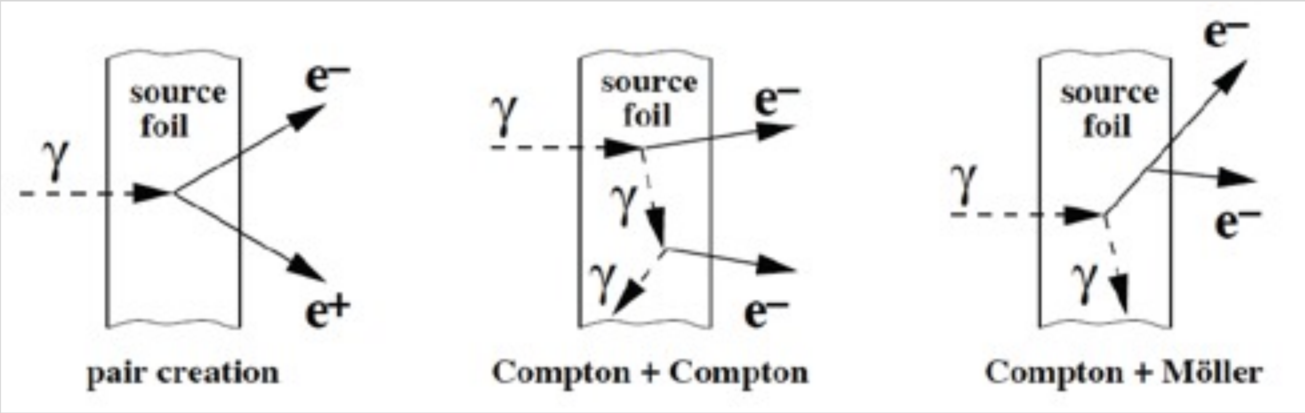

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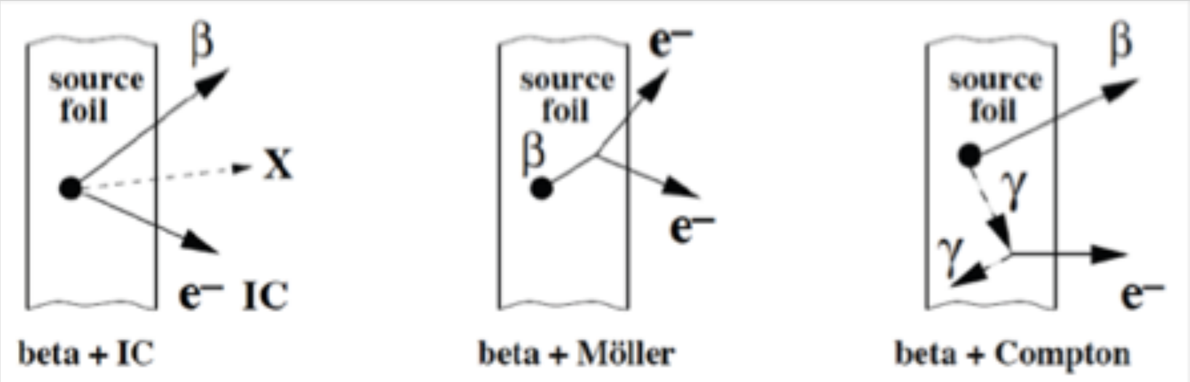
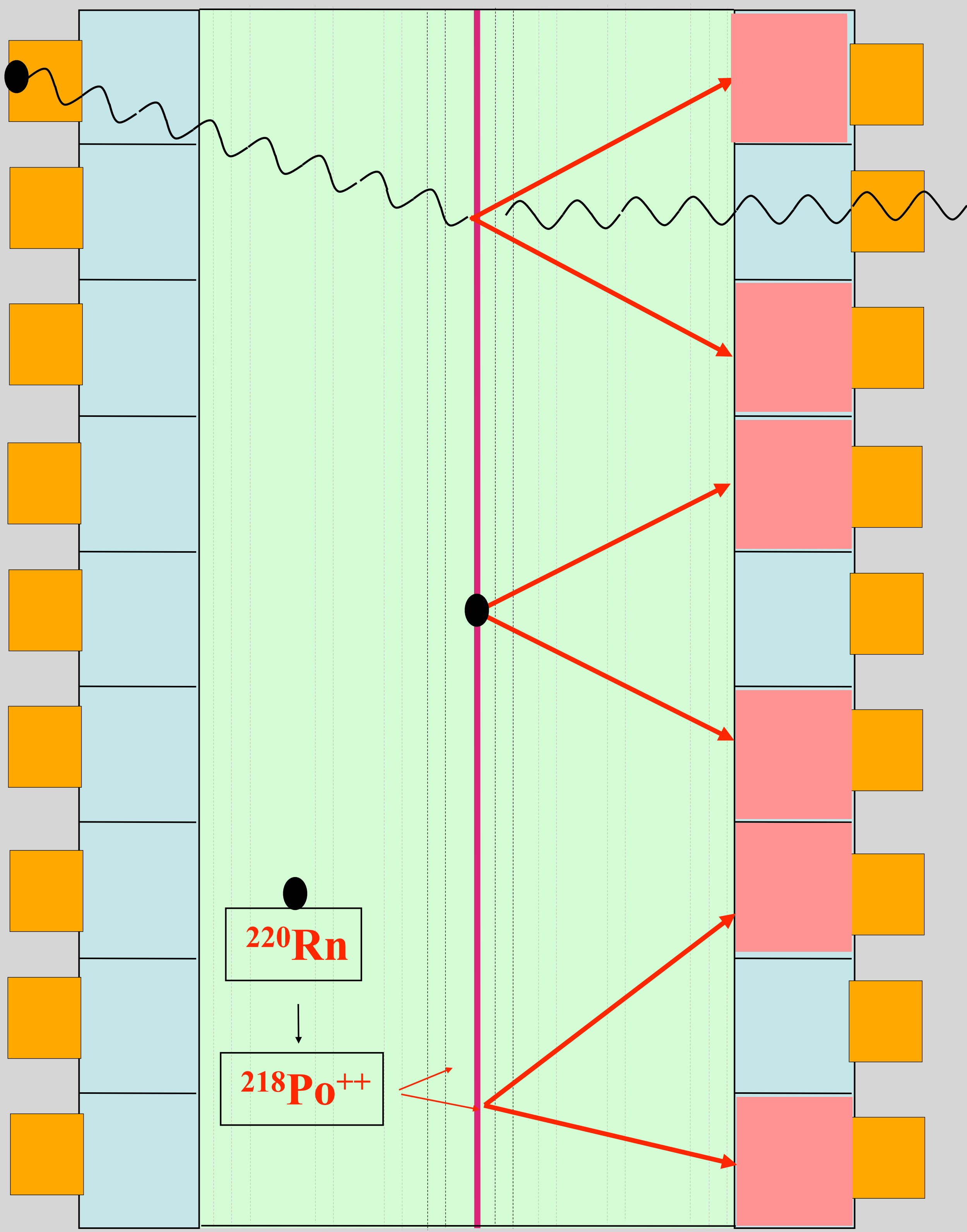


- **Radon (^{214}Bi) inside the tracking detector**
  - deposits on the wire near the ββ foil
  - deposits on the surface of the ββ foil



NEMO-3 Backgrounds for ββ

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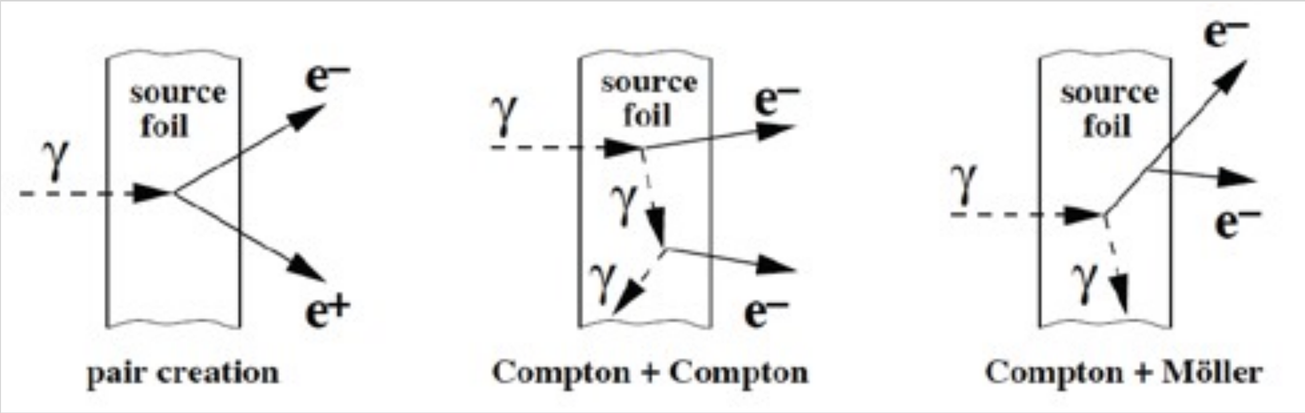

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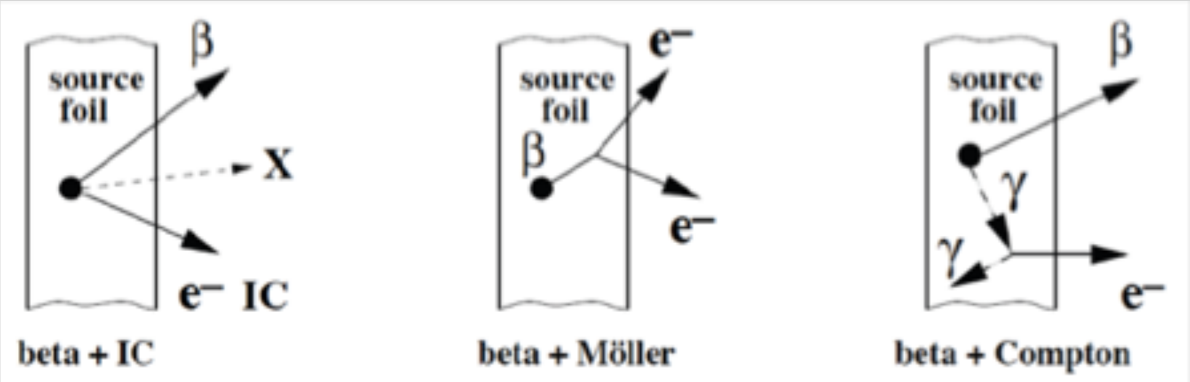

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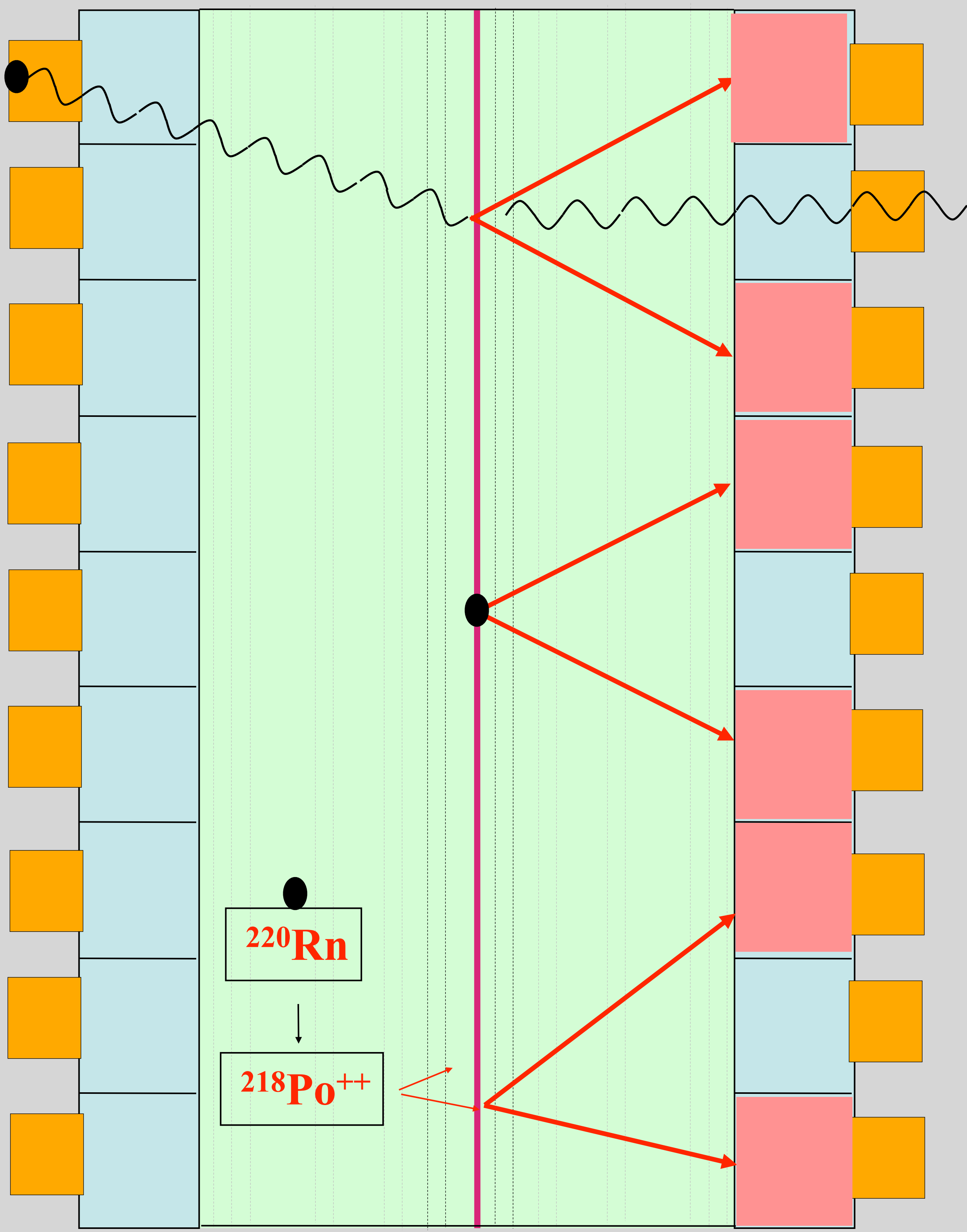
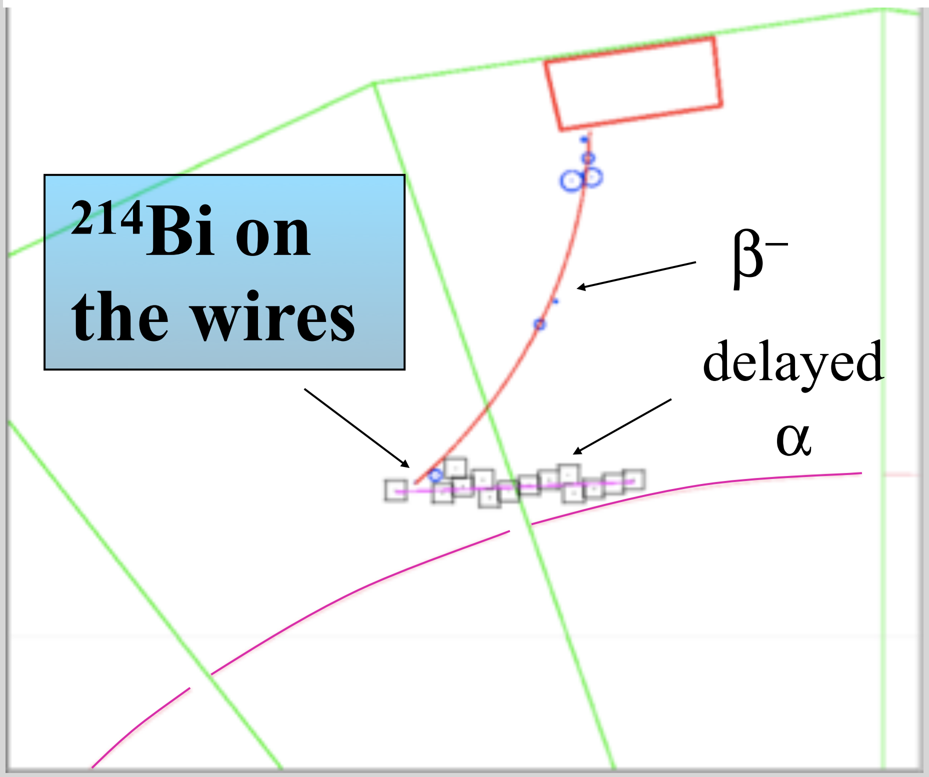


Each bkg is measured using the NEMO-3 data

Example: Radon inside the tracking detector

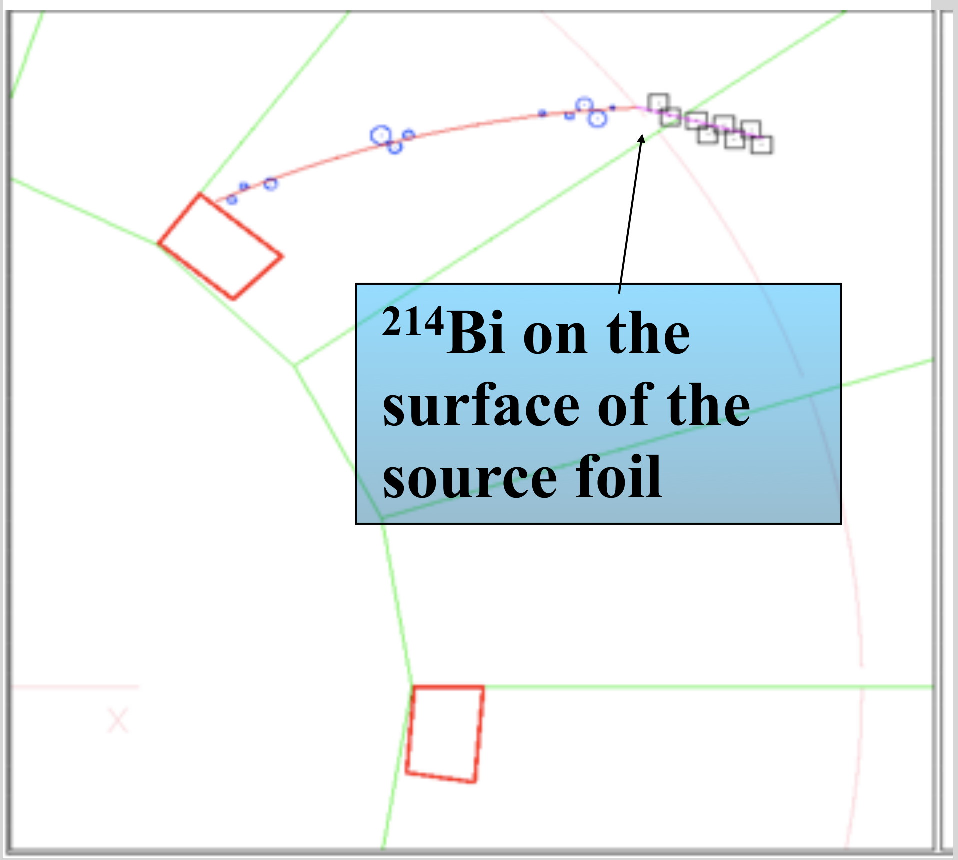
$^{214}\mathrm{Bi} \xrightarrow{\beta} {}^{214}\mathrm{Po} \xrightarrow[(164\ \mu s)]{\alpha} {}^{210}\mathrm{Pb}$



Example: Radon inside the tracking detector

$^{214}Bi \xrightarrow{\beta} {}^{214}Po \xrightarrow{\alpha} {}^{210}Pb$

(164 μs)



Example: Radon inside the tracking detector

$^{214}Bi \xrightarrow{\beta} {}^{214}Po \xrightarrow{\alpha} {}^{210}Pb$

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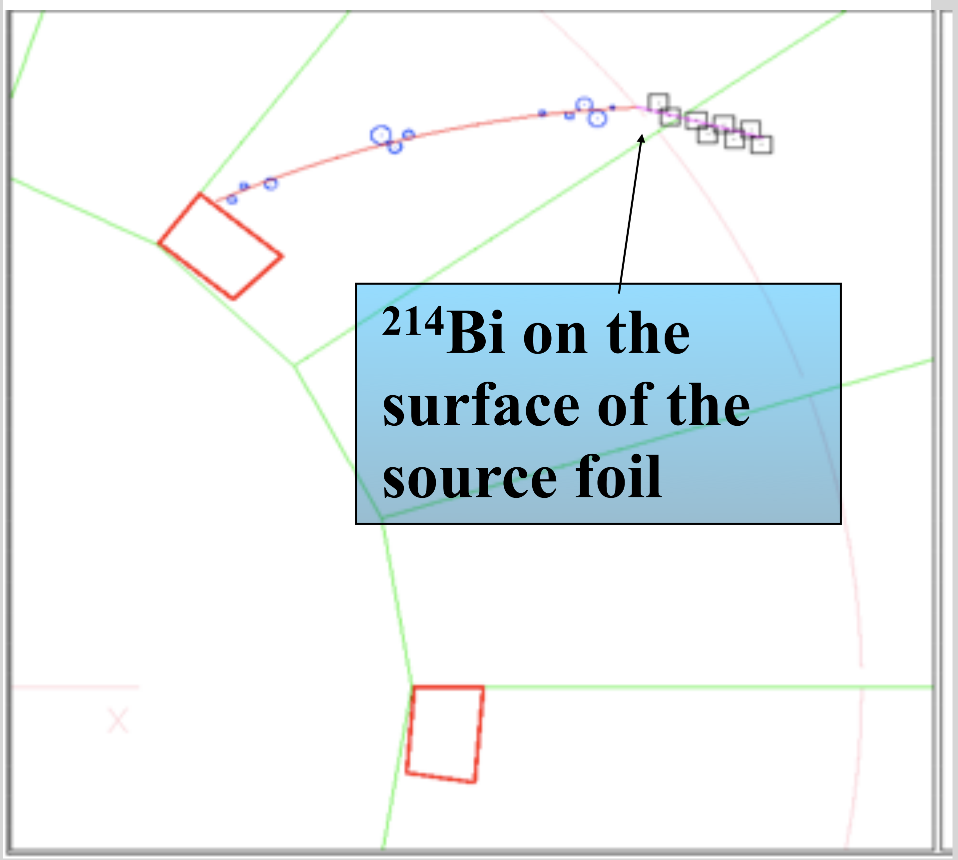
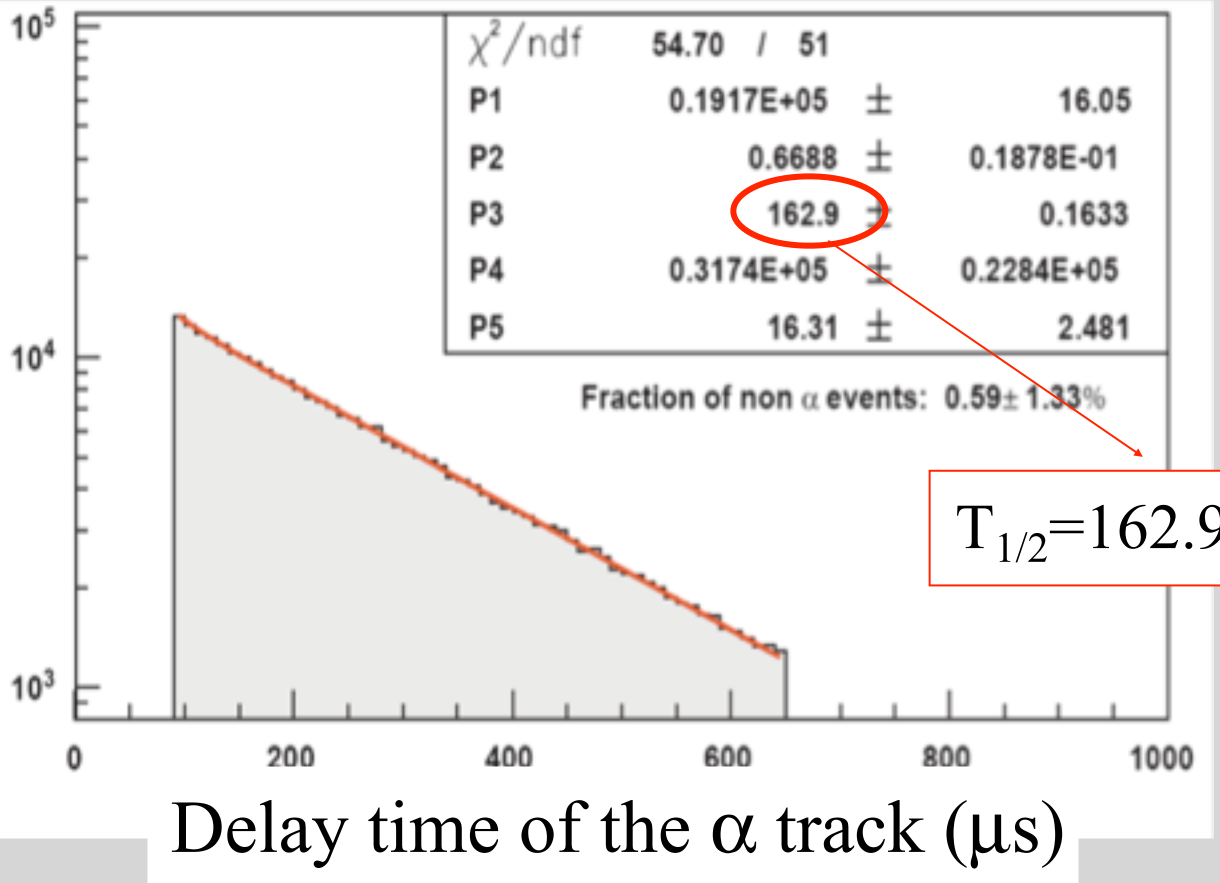


Pure sample of $^{214}Bi - {}^{214}Po$ events



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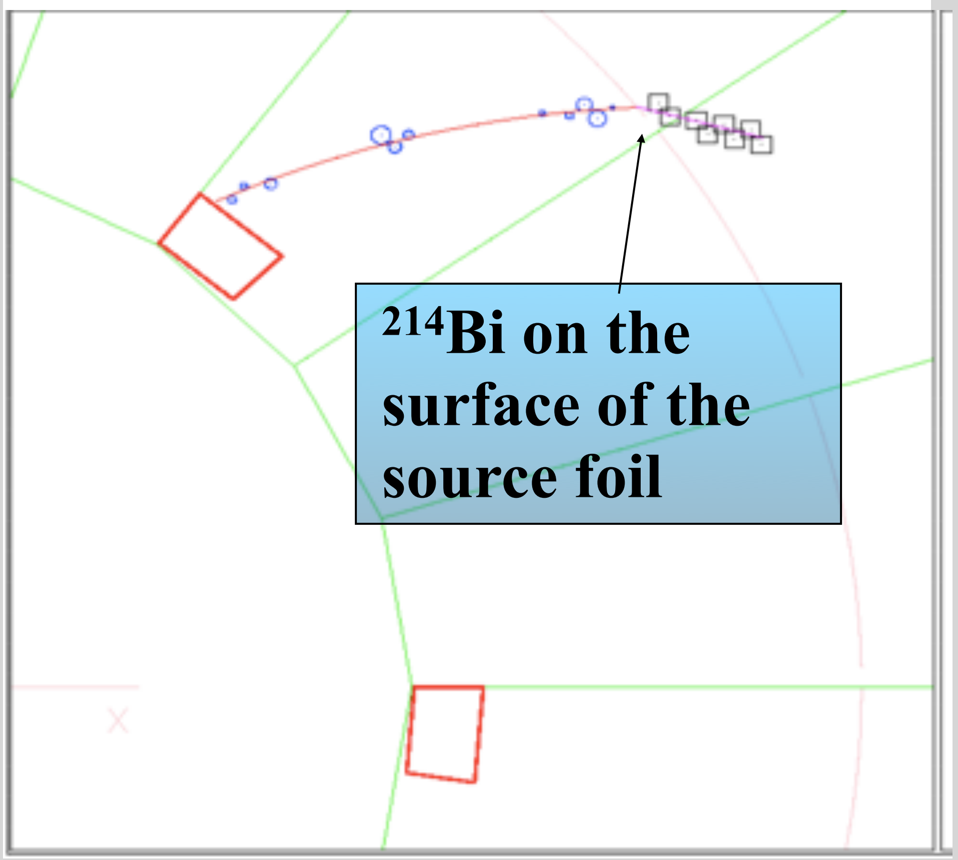

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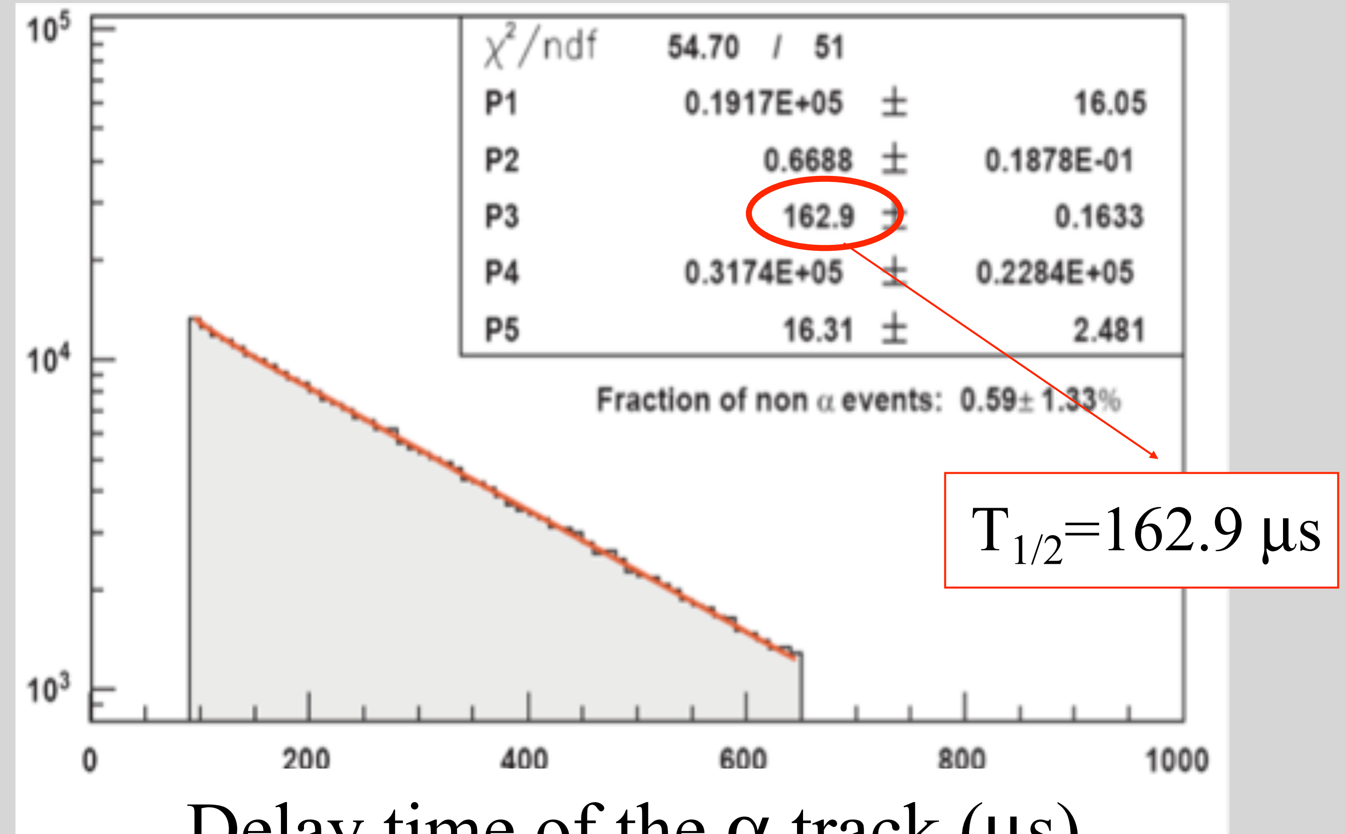
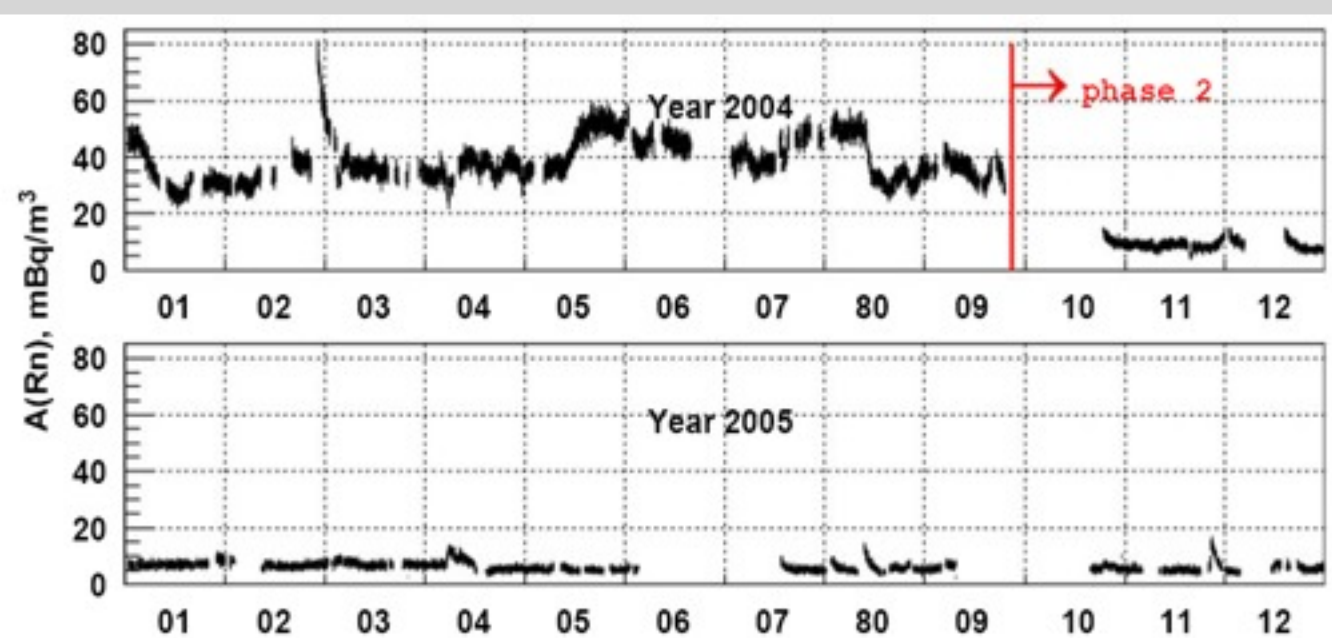


Delay time of the α track (µs)

Monitoring of the Radon bkg every day



- Phase 1: Feb. 2003 → Sept. 2004
  Radon Contamination
- Phase 2: Dec. 2004 → Today
  A (Radon) ≈ 5 mBq/m³

$0\nu\beta\beta$ experiment is about BKG suppression!

detector efficiency — mass — live time

$$T_{1/2}(90\%CL) > N_A \frac{\varepsilon \ln 2}{n_{90} A} \sqrt{\frac{M\,T}{b\,\Delta E}}$$

b: bkg / (keV kg yr) in window ΔE

n_{90}: $N_{excluded}$ for 90% CL

Current best calorimeters (bolometers, Ge):

b = 0.2 counts/(keV kg yr) ΔE = 5 keV

bΔE = 1 c/kg yr

Next generation calorimeters (CUORE, GERDA):

b = 0.01 counts/(keV kg yr) ΔE = 5 keV

bΔE = 0.05 c/kg yr

(both: $\Delta E/E$ = 0.2%)

Current topological (NEMO3)

b = 0.002 counts/(keV kg yr) ΔE = 250 keV $\Delta E/E$ = 8%

bΔE = 0.5 c /kg yr

Next generation topological (SuperNEMO)

b = 5×10^{-5} counts/(keV kg yr) ΔE = 150 keV $\Delta E/E$ = 4%

bΔE= 0.0075 c/kg yr

"Dream" scenario for calorimeters:

b = 0.001 counts/(keV kg yr) ΔE = 5 keV $\Delta E/E$ = 0.2%

bΔE = 0.005 c/kg yr