Sensitivities to BSM physics with SuperNEMO

Maros Petro, Collaboration meeting 2026, UK

OUTLINE

- Simulation Setup
- Background model
- Sensitivities – 1D ROI
- Sensitivities – ND ROI

Simulation Setup

- Falaise 5.1.7 version
- 12% FWHM for all main wall OMs
- No simRC at this point (I did not remove faulty OMs)
- Use of Cimrman Module for tracking [1]
- Magnetic field off
- Realistic flat source foil
- Aegir module used for generation of BSM not in Decay0

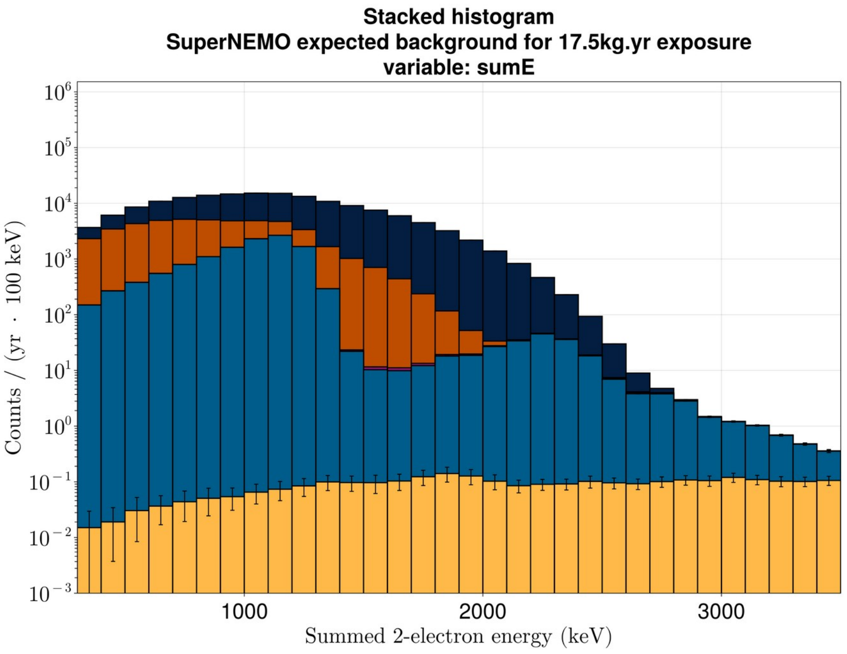
[1] https://github.com/SuperNEMO-DBD/CimrmanModule/tree/main

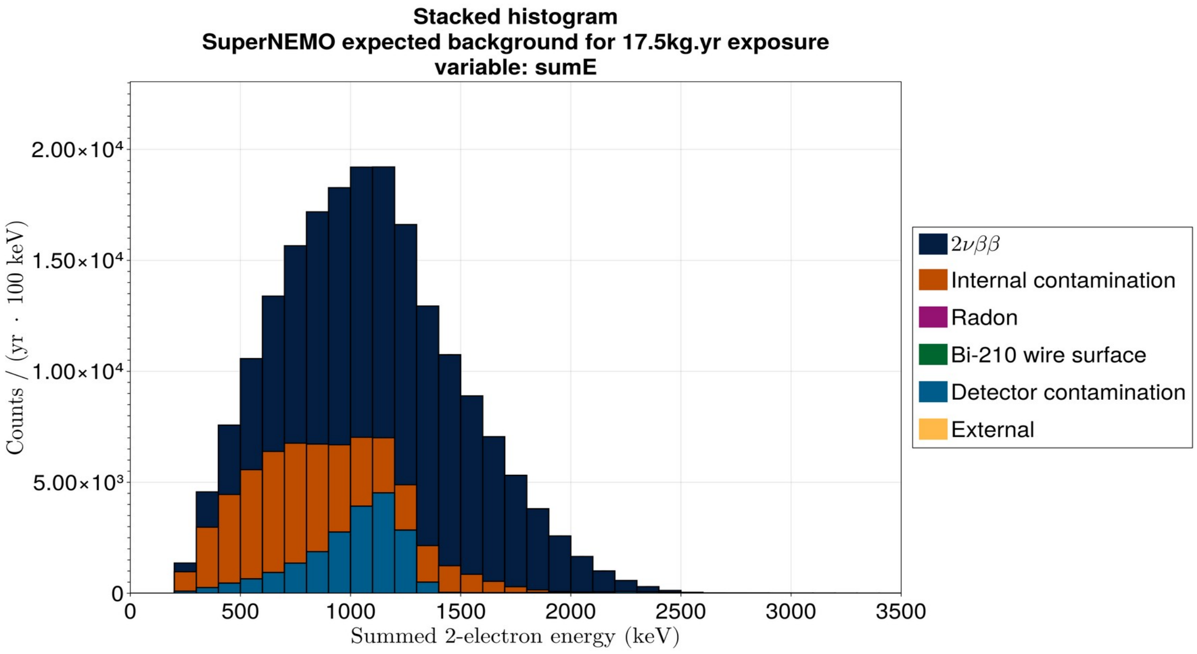
Background model

- Estimated background for 17.5 kgyr exposure
- Using the following activities
- What is the weight of 5'' PMT? 5'' Scintilator?
- External gammas from Xalbat (measurements before iron shielding so I added extra factor of 500)
- Neutrons should be 1/3rd according to Sam's new measurements

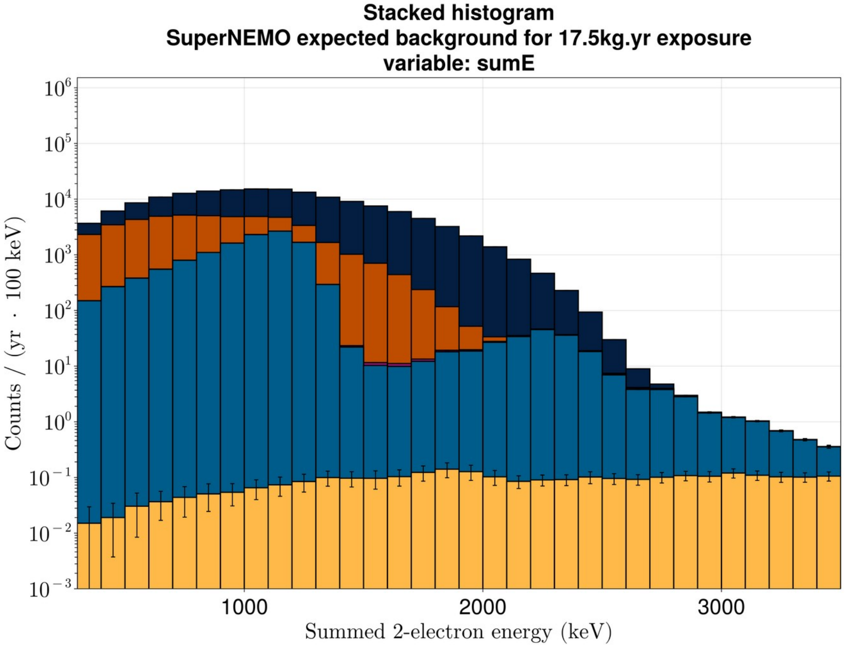
Source	Activity / Flux	Scaling factor s	Reference
$2\nu\beta\beta$	1.86 mBq/kg	~~6.25 kg~~ 6.11kg	[76]
^{214}Bi	10 µBq/kg	6.25 kg	[77]
^{208}Tl	2 µBq/kg	6.25 kg	[77]
^{40}K	(58.7 ± 0.1) mBq/kg	6.25 kg	[78]
^{234m}Pa	(17.3 ± 0.1) mBq/kg	6.25 kg	[78]
Radon gas	150 µBq/m^3	15 m^3	[77]
Photomultiplier tubes (PMTs)			
^{40}K (8" PMT)	0.95 Bq/PMT	440 PMTs	[83]
^{40}K (5" PMT)	0.53 Bq/PMT	272 PMTs	[83]
^{214}Bi (8" PMT)	0.32 Bq/PMT	440 PMTs	[83]
^{214}Bi (5" PMT)	0.24 Bq/PMT	272 PMTs	[83]
^{208}Tl (8" PMT)	0.26 Bq/PMT	440 PMTs	[83]
^{208}Tl (5" PMT)	0.039 Bq/PMT	272 PMTs	[83]
8" Plastic scintillators (~10 kg each)			
^{214}Bi	0.3 mBq/kg	440 kg	[84]
^{40}K	2.2 mBq/kg	440 kg	[84]
External γ radiation			
^{214}Bi	0.5 Bq	$\sim 500^{-1}$ shielding factor	[79]
^{208}Tl	2.4 Bq	$\sim 500^{-1}$ shielding factor	[79]
^{40}K	1.2 Bq	$\sim 500^{-1}$ shielding factor	[79]
neutrons			
thermal	1.2 ~~3.6~~ µn/s/cm^2	-	[80]
fast	2.2 ~~6.59~~ µn/s/cm^2	-	[82]

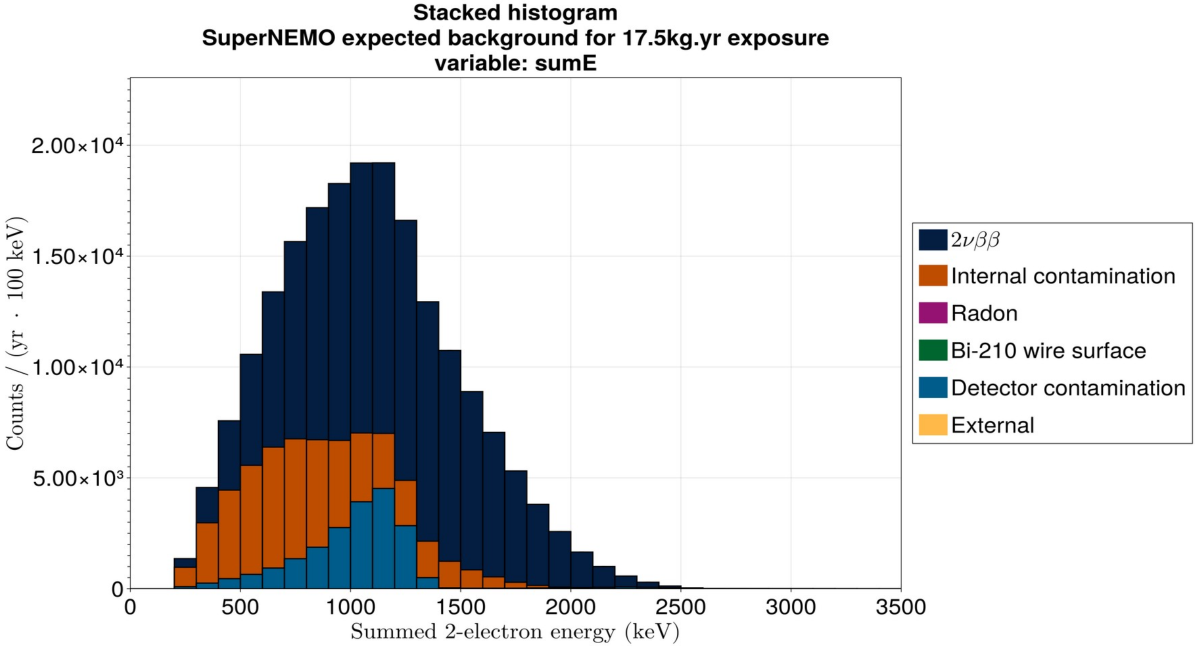
Background model





Background model





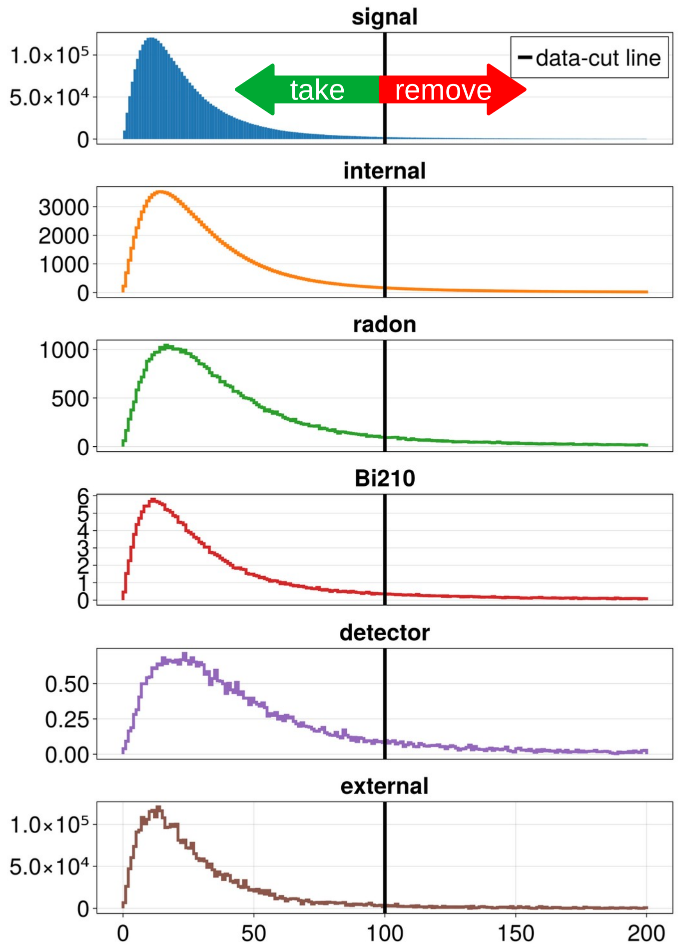
Data cuts used:
2 charged tracks + 2 foil vertices + 2 associated calohits
+ **Pint > 4% + Pext < 1%** + vertex < 100mm

Sensitivities 1D

$$T^{0\nu}_{1/2}(E_l, E_u) \propto \frac{\varepsilon(E_l, E_u)}{\mathcal{S}(\bar{b}(E_l, E_u))}.$$

- In traditional sensitivity approach we look at the individual distributions of each measurable and try to find a data-cut that maximizes signal-to-background

Distributions of 2D vertex distance

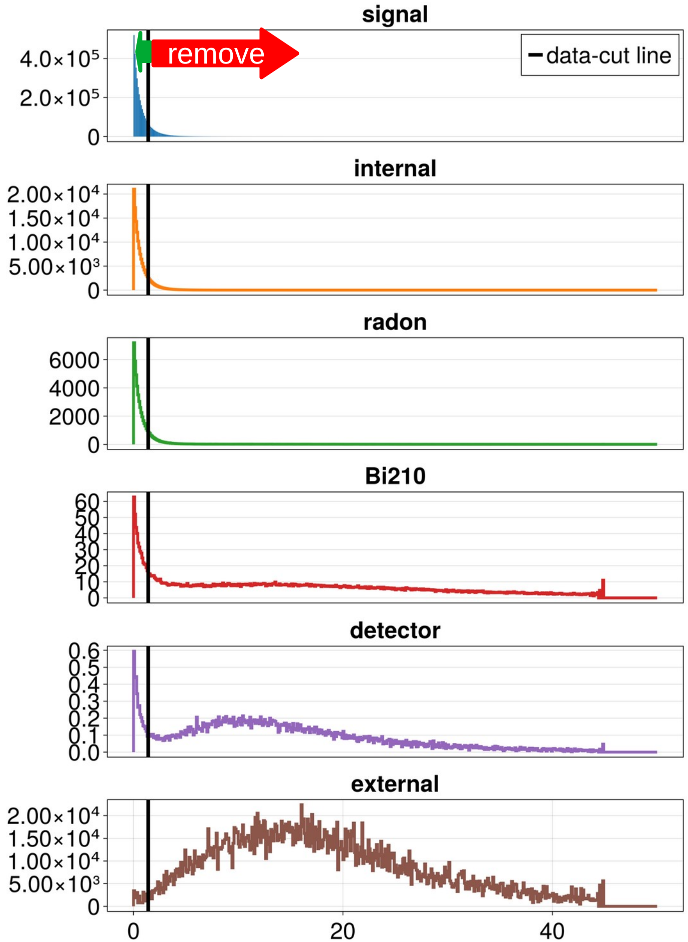


Sensitivities 1D

$$T^{0\nu}_{1/2}(E_l, E_u) \propto \frac{\varepsilon(E_l, E_u)}{\mathcal{S}(\bar{b}(E_l, E_u))}.$$

- In traditional sensitivity approach we look at the individual distributions of each measurable and try to find a data-cut that maximizes signal-to-background

Distributions of log(P_int)

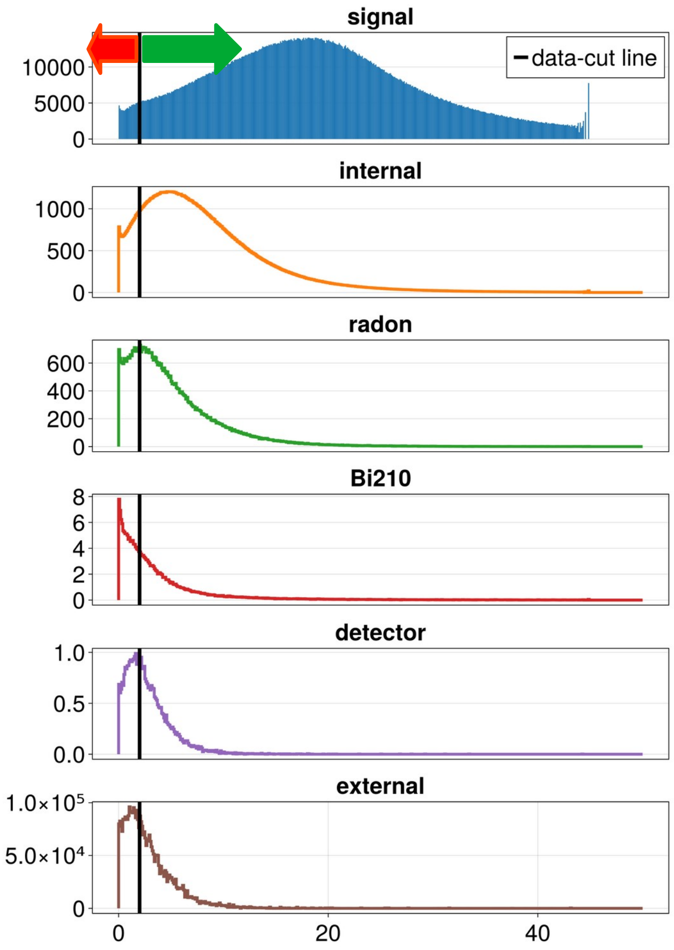


Sensitivities 1D

$$T^{0\nu}_{1/2}(E_l, E_u) \propto \frac{\varepsilon(E_l, E_u)}{\mathcal{S}(\bar{b}(E_l, E_u))}.$$

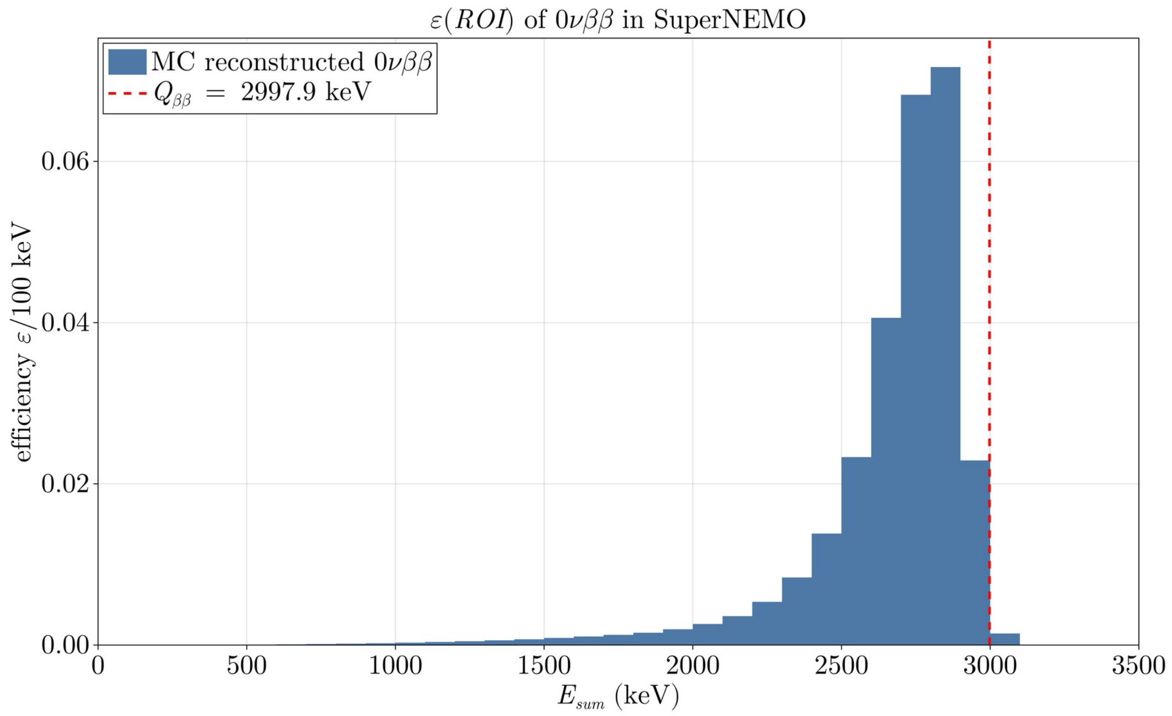
- In traditional sensitivity approach we look at the individual distributions of each measurable and try to find a data-cut that maximizes signal-to-background

Distributions of log(P_ext)



Sensitivities 1D

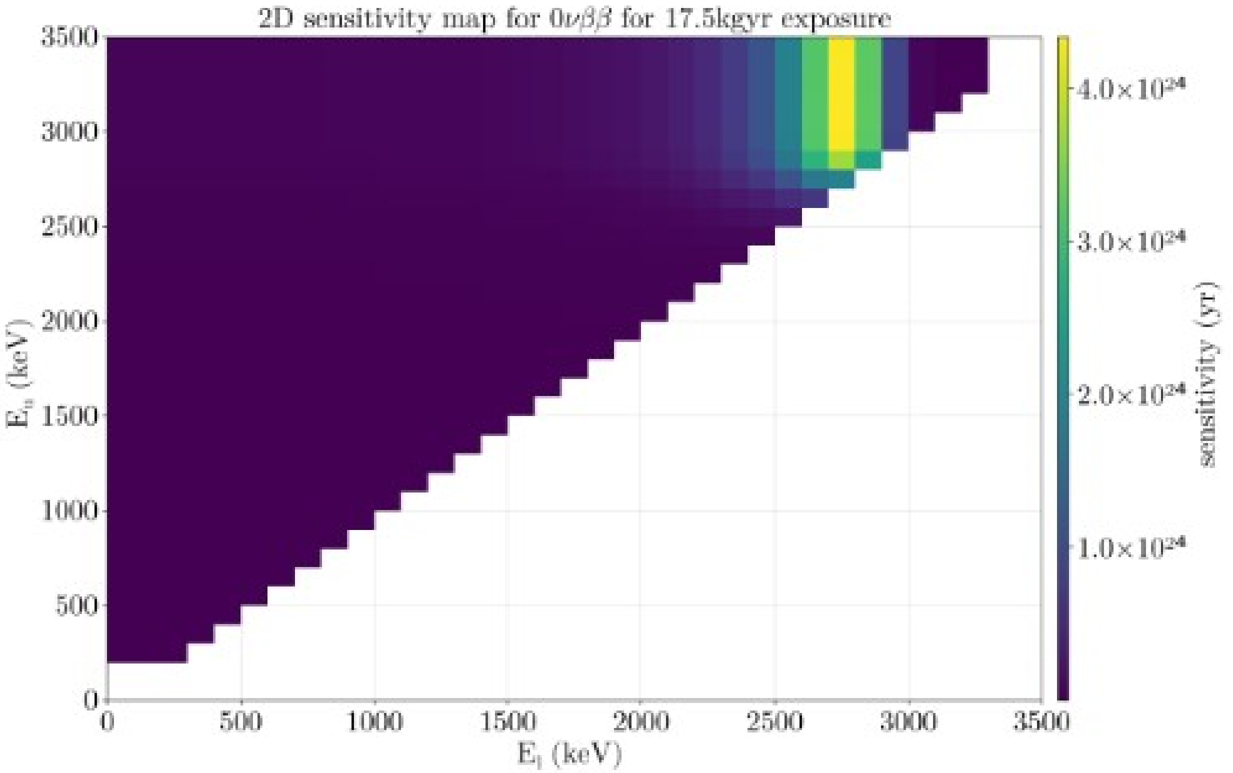
- Data cuts as shown in the background slide
- ROIs for E_sum:
  - **0nubb: 2700 – 3000 keV**
  - 0nubbM1: 2500 – 3000 keV
  - 0nubbM2: 1300 – 3000 keV
  - 2nubb RH: 0 – 2700 keV
- Radon acitivities:
  - Target – 150 uBq/m3
  - Bad – 2 mBq/m3
  - Middle – 0.6 uBq/m3
  - Optimistic – 0.2 uBq/m3



Sensitivities ND

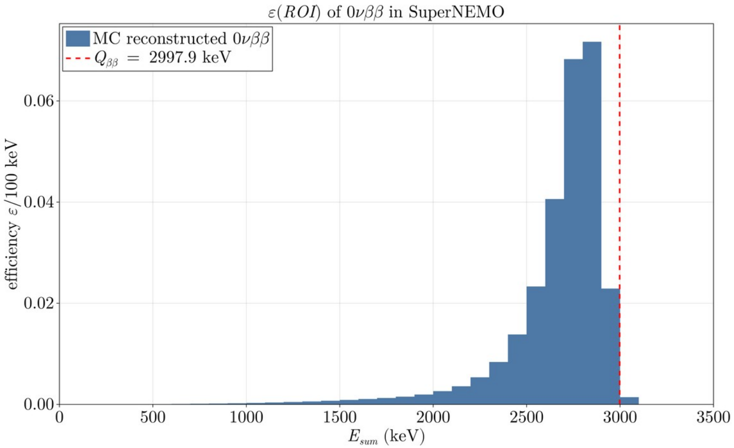
$$T^{0\nu}_{1/2}(E_l, E_u) \propto \frac{\varepsilon(E_l, E_u)}{\mathcal{S}(\bar{b}(E_l, E_u))}.$$

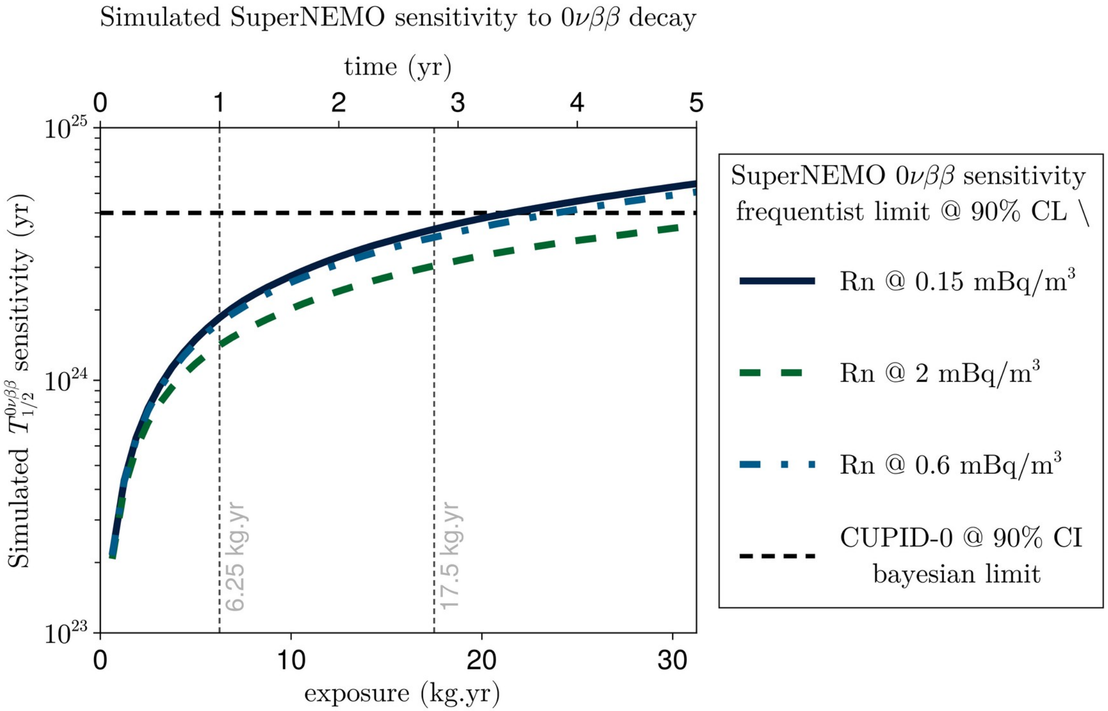
- In traditional sensitivity approach we look at the individual distributions of each measureable and try to find a data-cut that maximizes signal-to-background
- **After data-cuts are applied**, calculate sensitivity per ROI, find max



Sensitivities 1D - 0nubb

1D ROI	$(2700-3000)$keV
efficiency	0.163
backgrounds	1.46 cts
sensitivity	4.03×10^{24}yr (17.5kgy)

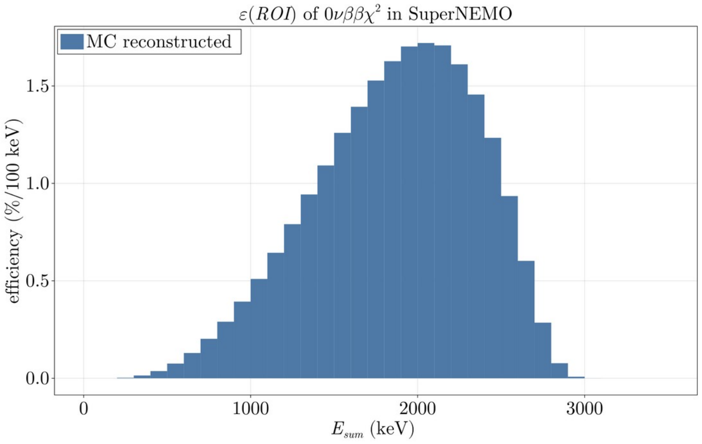


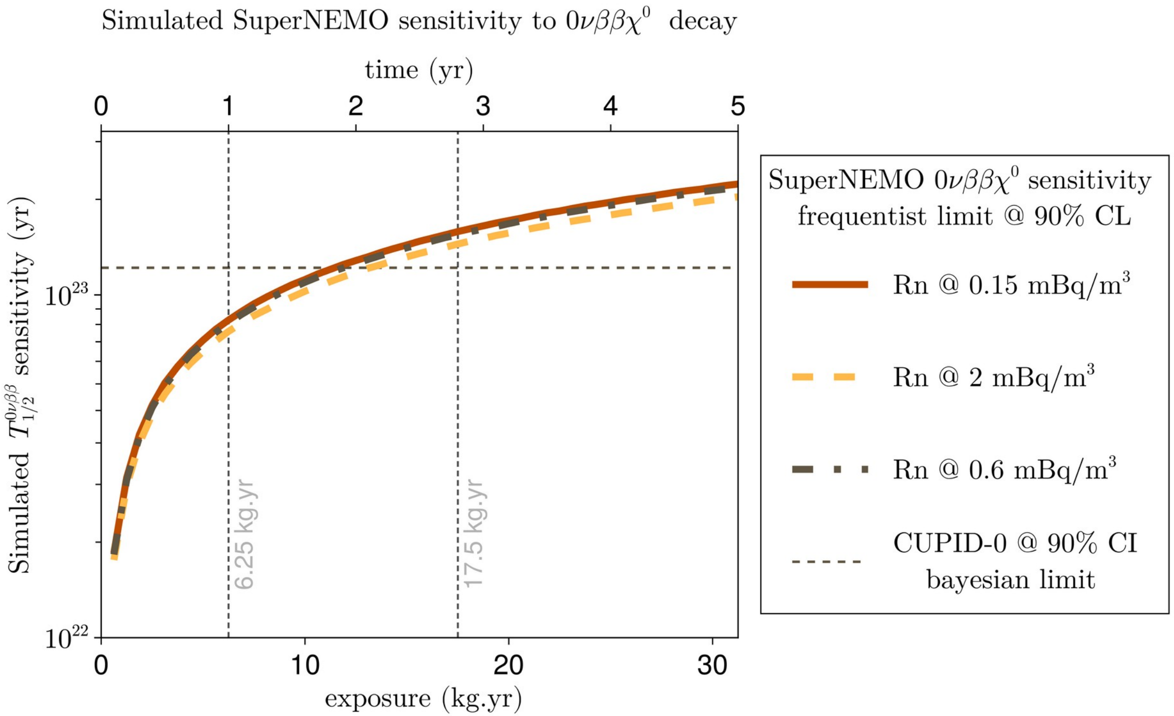


Sensitivities 1D - 0nubbM1

1D ROI	$(2500-3000)$keV
efficiency	0.019
backgrounds	31.2 cts
sensitivity	1.56×10^{23}yr (17.5kgy)

Table 6.6: $0\nu\beta\beta\chi^0$ sensitivity for target radon



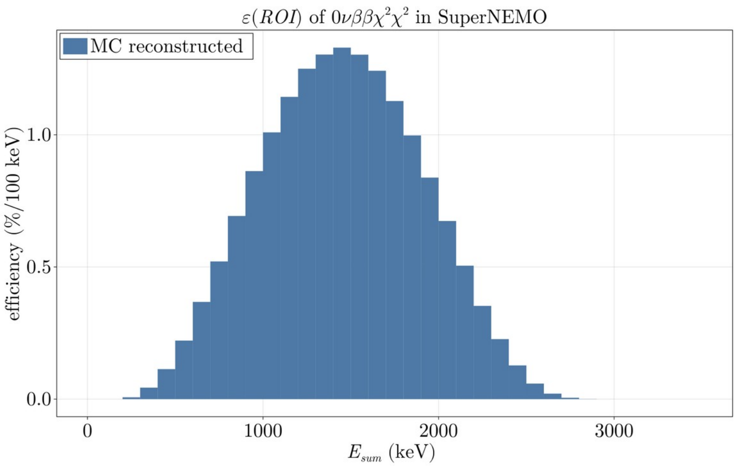


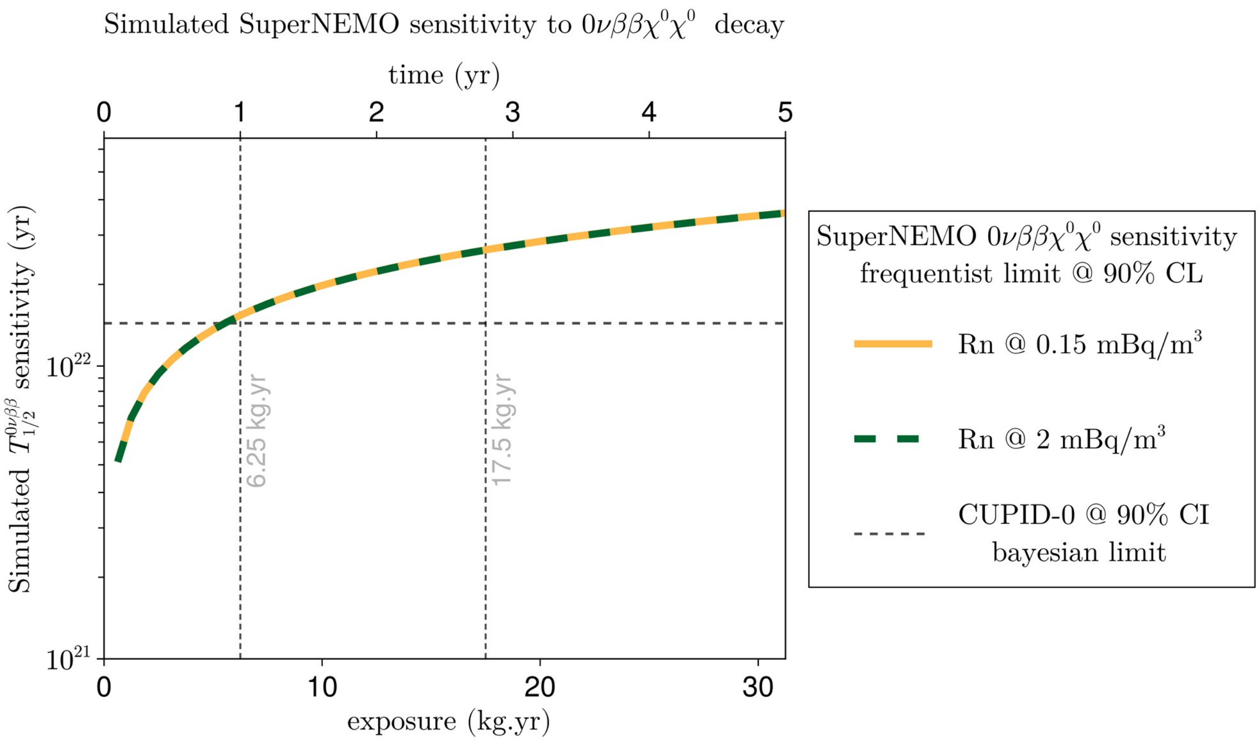
https://www.sciencedirect.com/science/article/pii/0370269381900113
https://arxiv.org/abs/hep-ph/9412365

Sensitivities 1D - 0nubbM2

1D ROI	$(1300 - 3000)$keV
efficiency	0.101
backgrounds	47090 cts
sensitivity	2.52×10^{22}yr (17.5kgy)

Table 6.7: $0\nu\beta\beta\chi^0\chi^0$ sensitivity for target radon



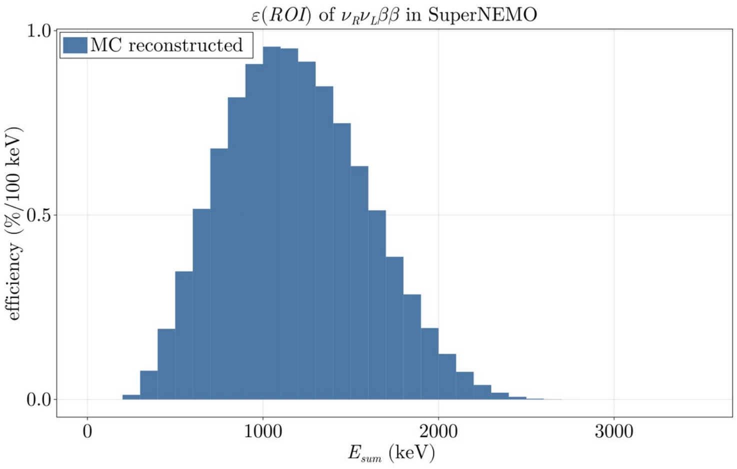


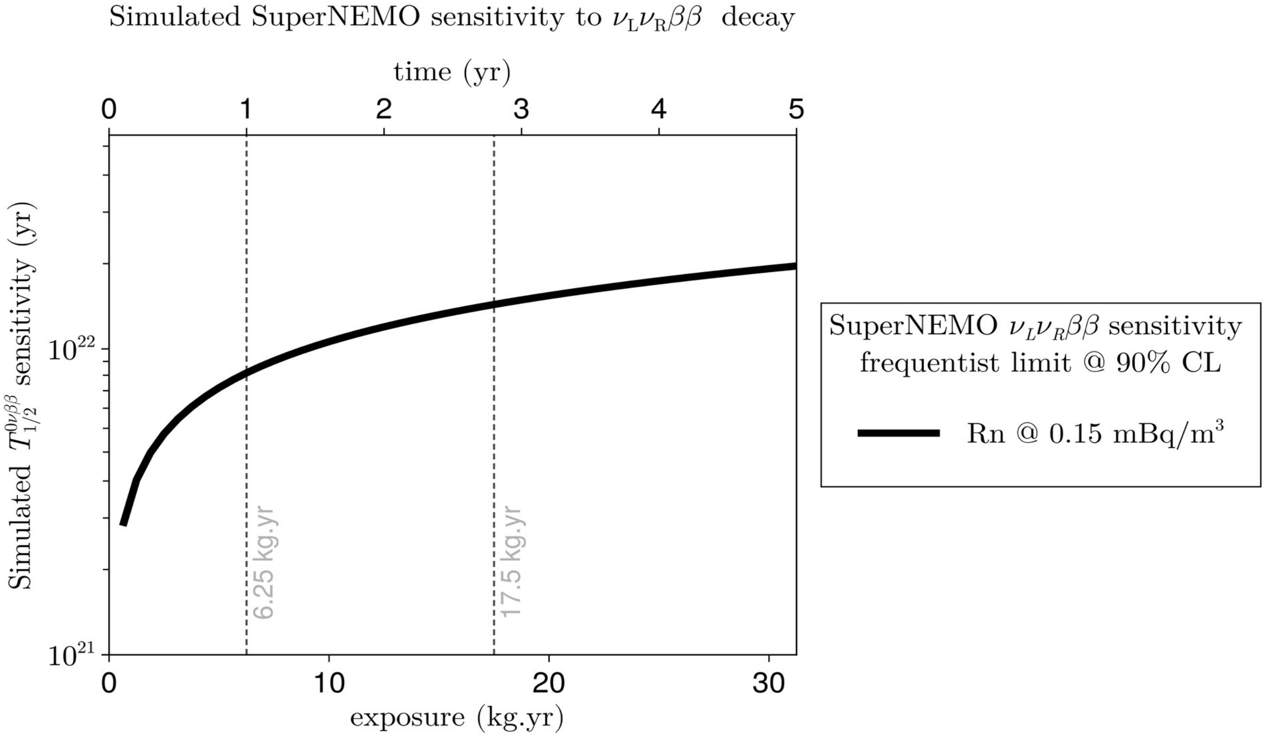
https://www.sciencedirect.com/science/article/pii/037026938190011З
https://arxiv.org/abs/hep-ph/9412365

Sensitivities 1D – 2nubb RH

1D ROI	$(0-2700)$keV
efficiency	0.103
backgrounds	156000 cts
sensitivity	1.41×10^{22}yr (17.5kgy)
ϵ	~ 0.007

Table 6.8: $\nu_R\nu_L\beta\beta$ sensitivity for target radon





Ref - https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.125.171801

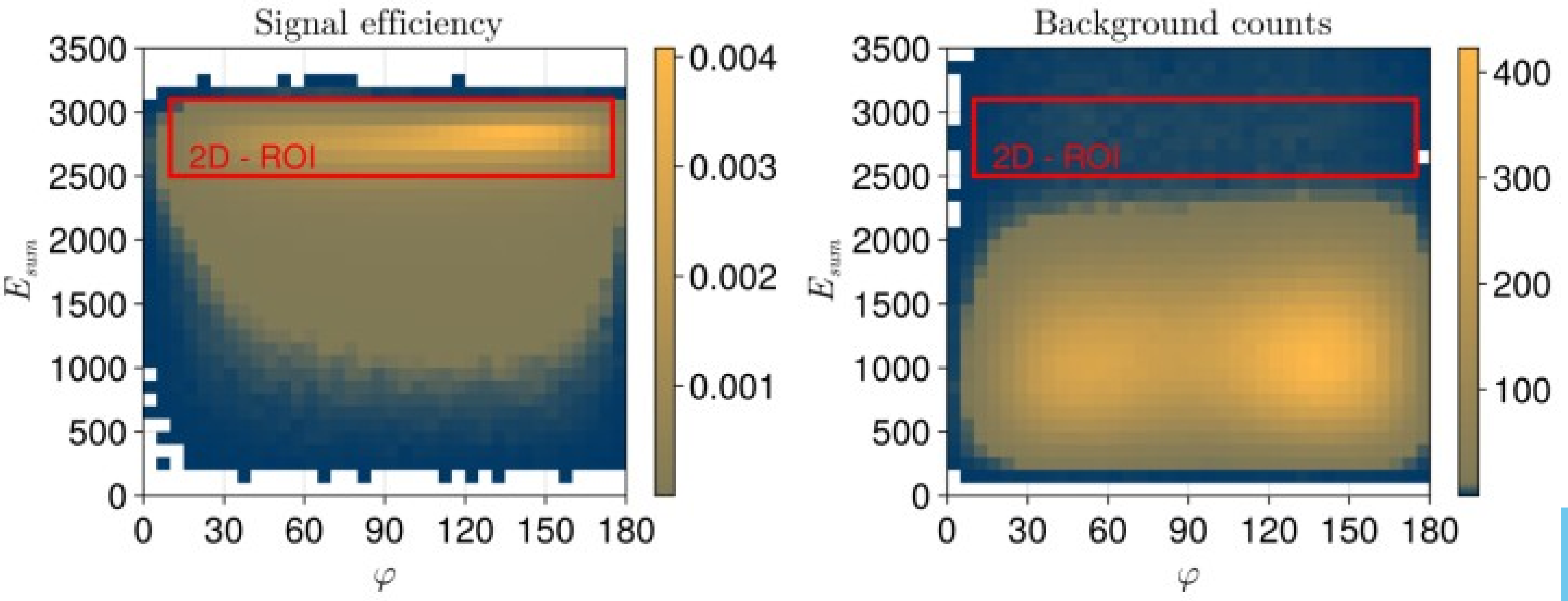
Sensitivities ND

$$T^{0\nu}_{1/2}(E_l, E_u) \propto \frac{\varepsilon(E_l, E_u)}{\mathcal{S}(\bar{b}(E_l, E_u))}. \quad \Rightarrow \quad T^{0\nu}_{1/2}(\Theta_l^{(1)}, \Theta_u^{(1)}, \Theta_l^{(2)}, \Theta_u^{(2)}, \ldots) \propto \frac{\varepsilon(\Theta_l^{(1)}, \Theta_u^{(1)}, \Theta_l^{(2)}, \Theta_u^{(2)}, \ldots)}{\mathcal{S}\left(\bar{b}(\Theta_l^{(1)}, \Theta_u^{(1)}, \Theta_l^{(2)}, \Theta_u^{(2)}, \ldots)\right)}.$$

- In 1D approach, we select data-cuts **first,** then optimize ROI (i.e.E_sum) to find best sensitivity!
- In ND approach, we optimize the data-cuts **while** optimizing sensitivity!

Sensitivities ND

$$T^{0\nu}_{1/2}(E_l, E_u) \propto \frac{\varepsilon(E_l, E_u)}{\mathcal{S}(\bar{b}(E_l, E_u))}. \quad \Rightarrow \quad T^{0\nu}_{1/2}(\Theta_l^{(1)}, \Theta_u^{(1)}, \Theta_l^{(2)}, \Theta_u^{(2)}, \dots) \propto \frac{\varepsilon\left(\Theta_l^{(1)}, \Theta_u^{(1)}, \Theta_l^{(2)}, \Theta_u^{(2)}, \dots\right)}{\mathcal{S}\left(\bar{b}(\Theta_l^{(1)}, \Theta_u^{(1)}, \Theta_l^{(2)}, \Theta_u^{(2)}, \dots)\right)}.$$



Sensitivities ND

0nubb ND sensitivity for **target radon**

φ	$(5-180)^\circ$
E_{sum}	$(2700-3000)\mathrm{keV}$
2D vertex distance r	$(0-150)\mathrm{mm}$
Δy	$(0-150)\mathrm{mm}$
Δz	$(0-150)\mathrm{mm}$
P_{int}	≥ 0.001
P_{ext}	≤ 0.1
track length l	$(0-2500)\mathrm{mm}$
efficiency	0.19
backgrounds	1.81 cts
sensitivity	$4.24 \times 10^{24}\mathrm{yr}$ (17.5kgy)

Table 6.8: ND $0\nu\beta\beta$ sensitivity for target radon

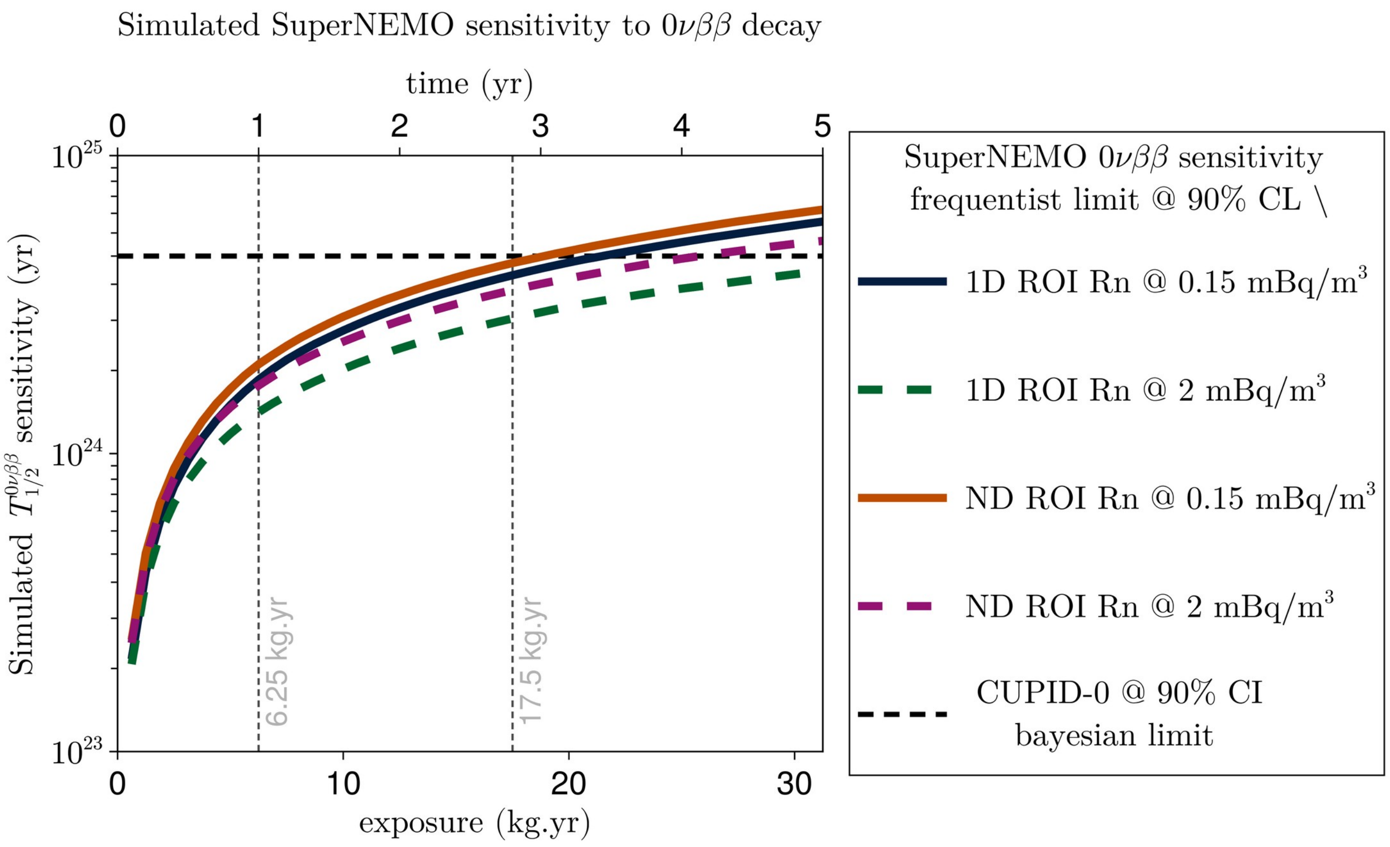
0nubb ND sensitivity for **high radon**

φ	$(15-180)^\circ$
E_{sum}	$(2700-3000)\mathrm{keV}$
r	$(0-80)\mathrm{mm}$
Δy	$(0-70)\mathrm{mm}$
Δz	$(0-90)\mathrm{mm}$
P_{int}	≥ 0.001
P_{ext}	≤ 0.1
l	$(0-2000)\mathrm{mm}$
efficiency	0.19
backgrounds	3.71 cts
sensitivity	$3.51 \times 10^{24}\mathrm{yr}$ (17.5kgy)

Table 6.9: ND $0\nu\beta\beta$ sensitivity for high radon $2\,\mathrm{mBq/m^3}$

Sensitivities ND

- Target radon:
  - 5% increase
- Bad radon (2mBq/m3):
  - 21% increase
  - More room to optimize!



Conclusion

- We need a very precise list of background sources, activities, amounts
- Time of flight is very powerful for external sources (duh.)
- Using traditional 1D approach, we are close to world bests
- ND approach should take us there
  - But it is expensive (computationally, statistically)
  - More powerful for **bad radon** (vertex and length cuts become important)
  - Can be tailored for each process!
- TO DOs:
  - Bayesian sensitivities (~3 days of calculations on CC)
  - Full ND optimization for all signal processes
  - Finish thesis and compile all results there...stay tuned
  - Produce 2el spectra with Filip’s tracking + cimrman for phase0 + phase1?

Backup

Background composition Esum<3500 keV

- Target radon

source	counts in ROI	% budget
bb2nu	110305.0 ± 33.0	70.83
Bi214	10.95 ± 0.02	0.01
K40	13505.0 ± 67.0	8.67
Pa234m	20152.0 ± 44.0	12.94
Tl208	1.29 ± 0.0	0
Bi210 wire surface	1.54 ± 0.06	0
Radon	260.6 ± 2.7	0.17
PMT Bi214	18.0 ± 5.0	0.01
PMT K40	11300.0 ± 2100.0	7.26
PMT Tl208	96.0 ± 96.0	0
Scintilator Bi214	3.6 ± 2.1	0.06
Scintilator K40	61.0 ± 23.0	0
external Tl208	0.64 ± 0.05	0.04
external Bi214	0.12 ± 0.01	0
external K40	0.17 ± 0.02	0
fast neutrons	2.4 ± 0.27	0
thermal neutrons	0.13 ± 0.08	0
Total	155700.0 ± 2100.0	0
		100

Background composition for 1D ROI

TARGET radon

Background composition		
source	**counts in ROI**	**% budget**
bb2nu	0.86 ± 0.09	59.31
Bi214	0.08 ± 0.0	5.52
Tl208	0.03 ± 0.0	2.07
Radon	0.14 ± 0.02	9.66
External gamma	0.01 ± 0.01	0.69
Fast neutrons	0.33 ± 0.12	22.76
Total	1.45 ± 0.15	100

Radon 2mBq/m3

Background composition		
source	**counts in ROI**	**% budget**
bb2nu	0.86 ± 0.09	26.63
Bi214	0.08 ± 0.0	2.48
Tl208	0.03 ± 0.0	0.93
Radon	1.92 ± 0.23	59.44
External gamma	0.01 ± 0.01	0.31
Fast neutrons	0.33 ± 0.12	10.22
Total	3.23 ± 0.27	100

Radon 0.6mBq/m3

source	**counts in ROI**	**% budget**
bb2nu	0.86 ± 0.09	45.5
Bi214	0.08 ± 0.0	4.23
Tl208	0.03 ± 0.0	1.59
Radon	0.58 ± 0.07	30.69
External gamma	0.01 ± 0.01	0.53
Fast neutrons	0.33 ± 0.12	17.46
Total	1.89 ± 0.17	100

ND background composition 0nubb

TARGET radon

Background composition		
source	**counts in ROI**	**% budget**
bb2nu	1.02	0.56
internal	0.14	0.08
radon	0.24	0.13
external	0.43	0.23
	1.83	

Radon 2mBq/m3

Background composition		
source	**counts in ROI**	**% budget**
bb2nu	1.00	0.27
internal	0.13	0.04
radon	2.25	0.60
external	0.34	0.09
	3.71	

Bad radon background