Status of SuperNEMO

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The neutrino-less double beta decay

2vββ decay: $(A,Z) \rightarrow (A,Z+2) + 2e^{-} + 2\bar{\nu}_e$

- 2nd order process allowed in the SM
- Single β decay forbidden (energy & angular momentum)

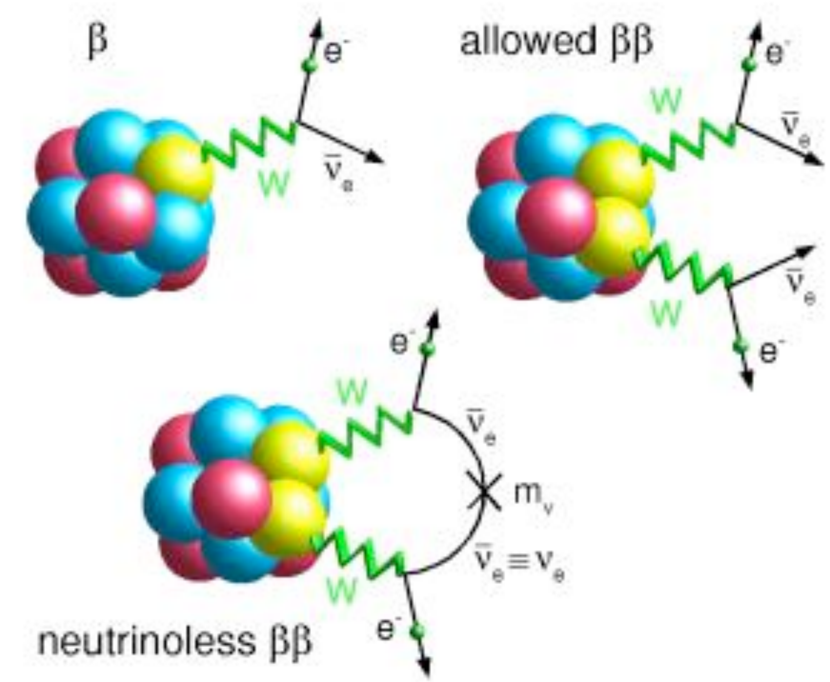
0vββ decay: $(A,Z) \rightarrow (A,Z+2) + 2e^{-}$

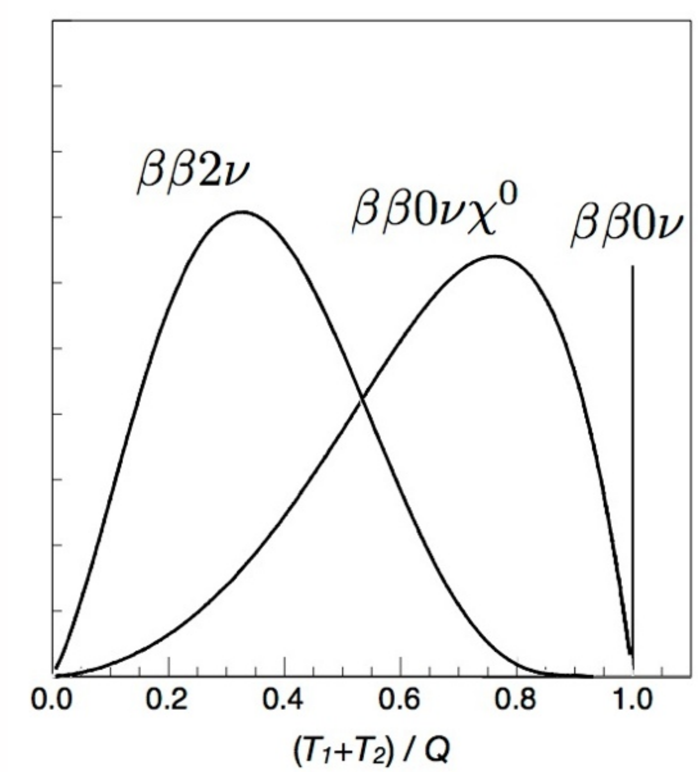
- process forbidden in the SM

$$(T^{0\nu}_{1/2})^{-1} = G_{0\nu}(Q_{\beta\beta},Z)|M_{0\nu}|^2\eta^2$$

- Light Majorana neutrino exchange
- Right-handed current (V+A), SUSY, 1 Majoron, etc.

Different event topology in the final state





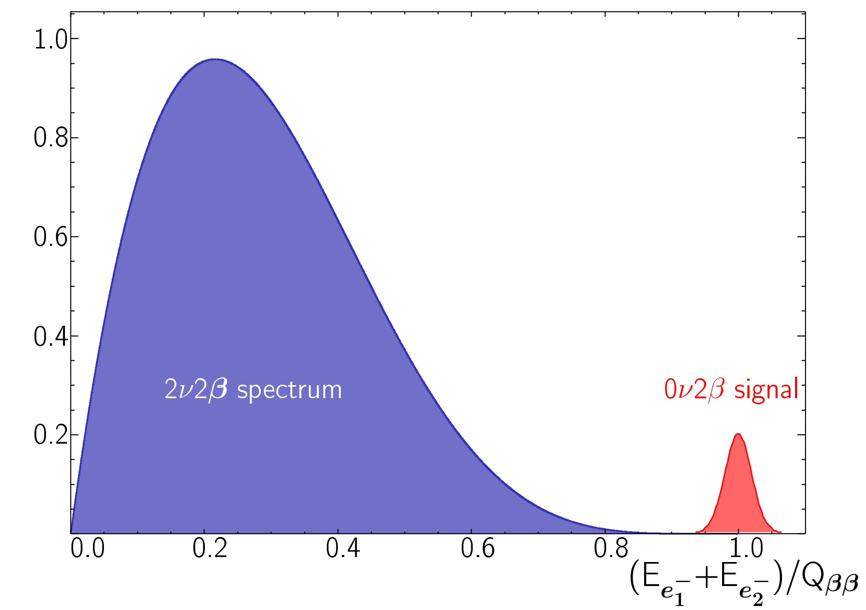
Searching for 0vββ process

Measure the 2 e⁻ energy spectrum

- 2vββ signature → Broad spectrum
- 0vββ signal signature → Peak @ $Q_{\beta\beta}$

If no signal → set a limit on half life

$$T^{0\nu}_{1/2} > \frac{N_A \ln 2}{n_\sigma} \times \frac{\epsilon}{A} \times \sqrt{\frac{M \times t}{B \times \Delta E}}$$

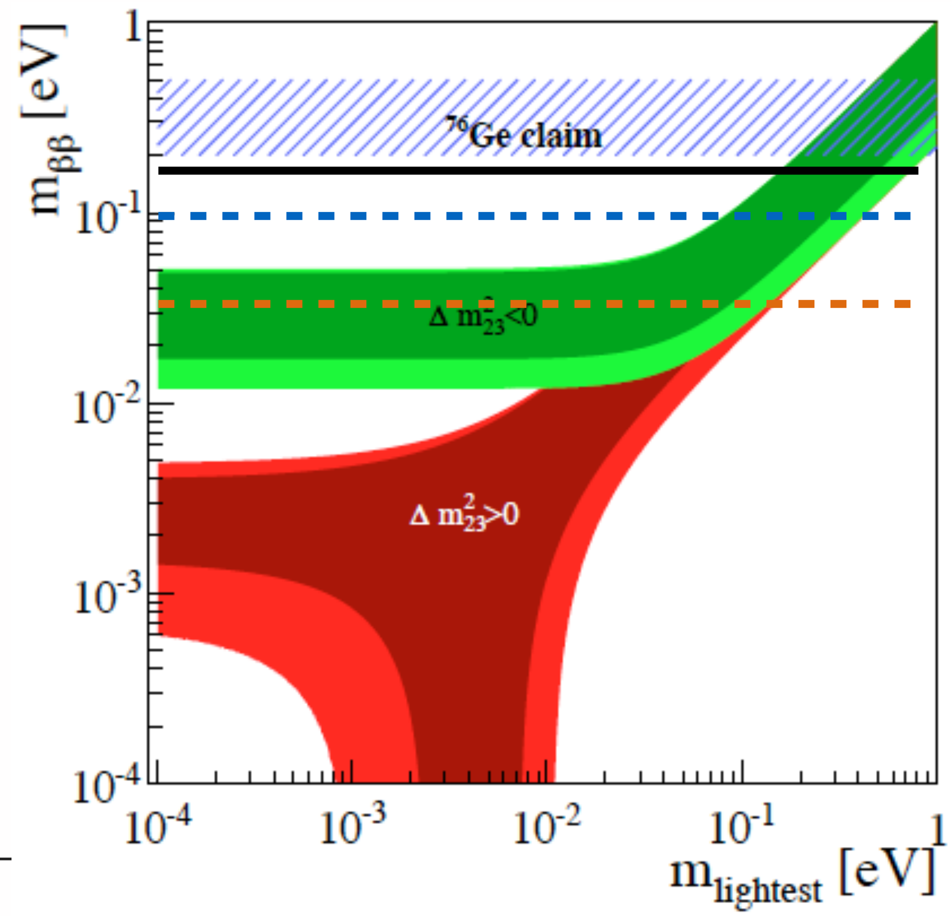


5 years time scale:

- M ~ 10 - 50 kg of ββ isotope
- Background level 10^{-3} cts. /(keV kg y)

10 years time scale:

- M ~ 100 kg - 1t of ββ isotope
- Background level 10^{-4} cts. /(keV kg y)

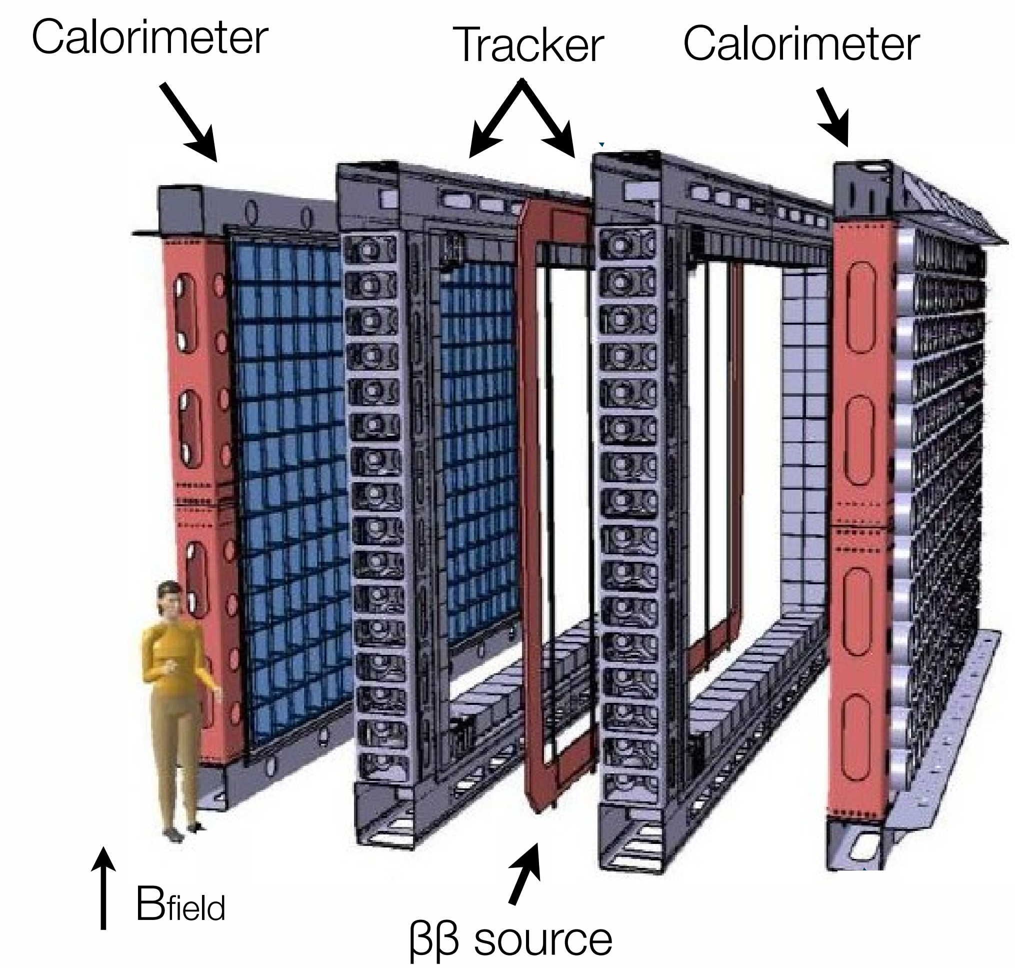


SuperNEMO: toward the new generation

Extrapolate a well known technique (NEMO-3):

- 100 kg of ββ emitter in 20 detection module
- Approach Inverted Hierarchy region

	NEMO-3	SuperNEMO
Efficiency	18%	~30%
Isotope	7 kg ^{100}Mo	~100 kg ^{82}Se (^{150}Nd, ^{48}Ca)
Exposure	35 kg y	~500 kg y
Energy res.	8% @ 3 MeV	4% @ 3 MeV
^{208-}Tl (source)	~100 μBq/kg	< 2 μBq/kg
^{214}Bi (source)	~ 300 μBq/kg	< 10 μBq/kg
Rn (in tracker)	5 mBq/m^3	0.15 mBq/m^3
$T_{1/2}$	10^{24} y	10^{26} y
$\langle m_\nu \rangle$	0.31 - 0.79 eV	0.04 - 0.1 eV



A challenge under many aspects:

- R&D program in the past years almost completed!
- Next step: Demonstrator module

SuperNEMO: the demonstrator module

One SuperNEMO module → 7 kg ^{82}Se running ~2.5 y

- To be installed @ LSM (replacing NEMO-3)

Match SuperNEMO requirements

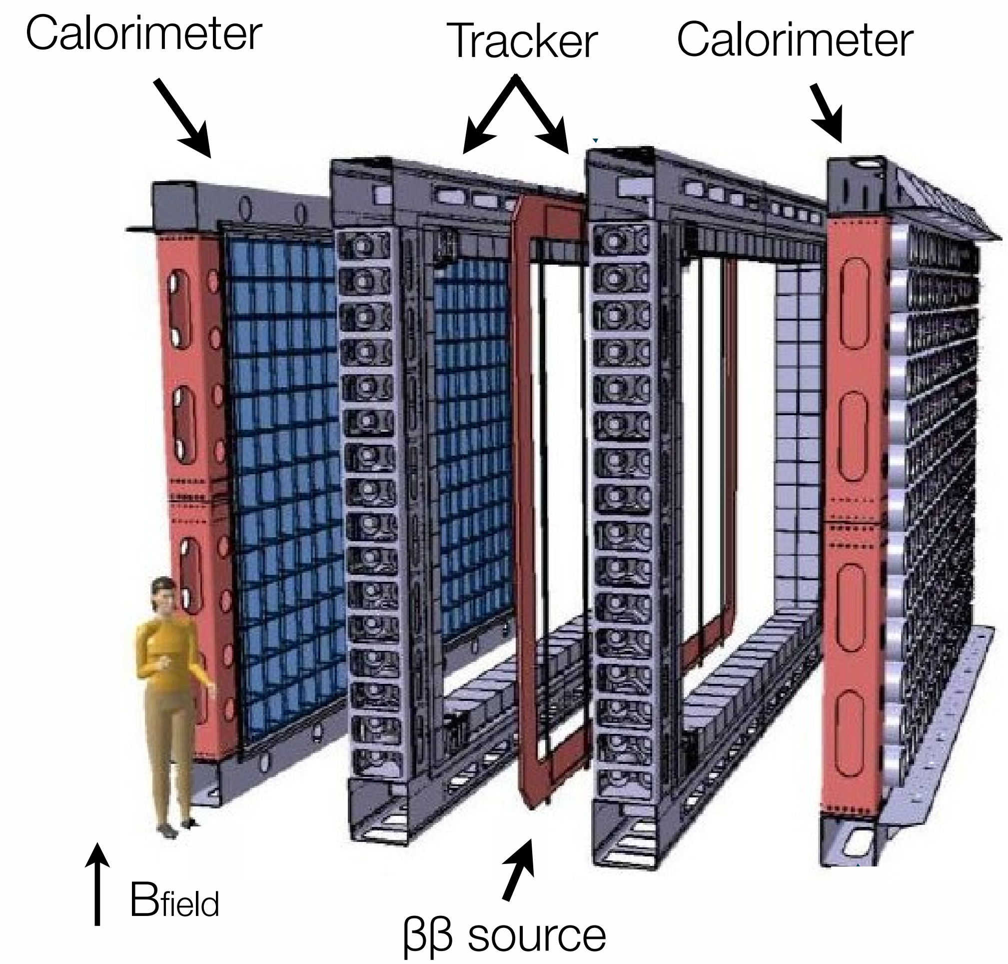
- Background level ~ 10^{-4} cts./(keV kg y)
- Background free at high energy (^{150}Nd)

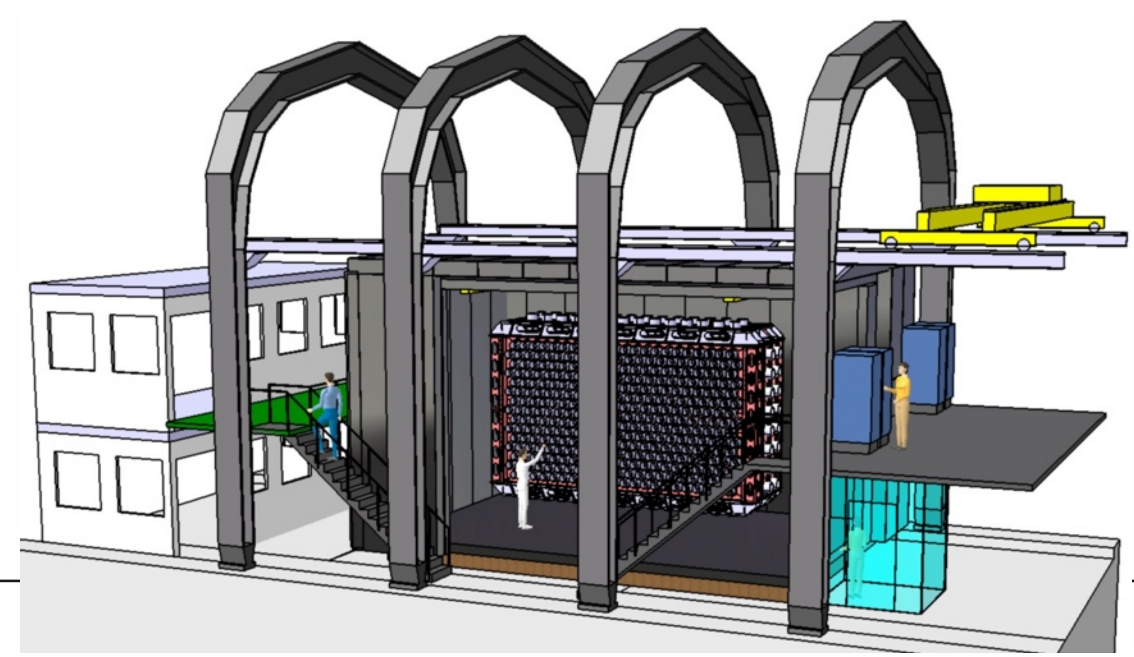
Reach NEMO-3 (^{100}Mo) sensitivity in 4.5 months

- Sensitivity: $\langle m_\nu \rangle$ ~ 0.20 - 0.40 eV

Schedule:

- Calorimeter & tracker under production
- Installation & commissioning in 2015
- First physics data by the end of 2015!





Contribution from the labex

Contribution from the labex

Technical activities LAPP/LSM

- R&D and production of ^{82}Se foil source
- Development of the Slow Control system
- Chemical Se purification in collaboration with JINR (Dubna)

Physics studies

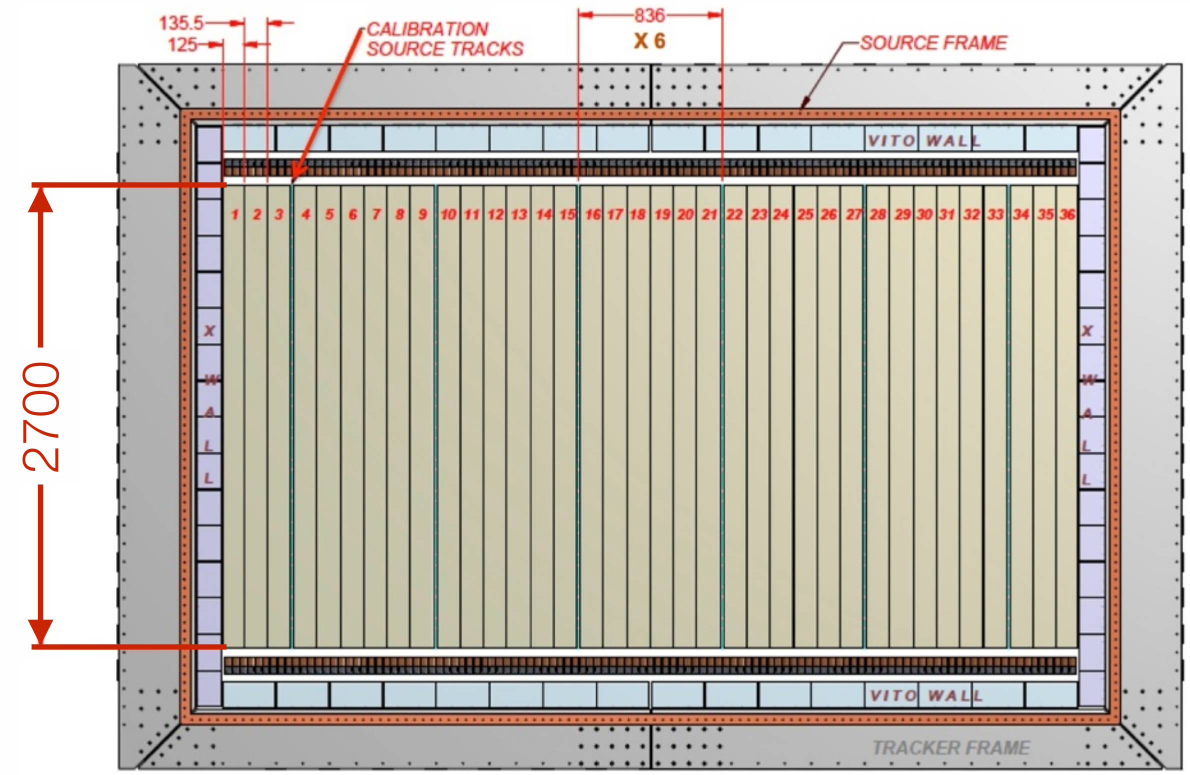
- Simulation/Sensitivity studies
- NEMO-3 Data analysis

The next step

- Detector installation + commissioning + running (2014 - 2016)
- Physics data analysis (2015 - 2016)

SuperNEMO: the source foil

- About 37 foils installed on the source frame in the detector center
- ^{82}Se powder mixed with PVA glue + nylon mechanical support
- 5.56 kg of enriched ^{82}Se, negotiation ongoing for the remaining 1.5 kg
- 400g of ^{Nat}Se purified with chemical chromatography for radio-purity measurement (LSM & Dubna)

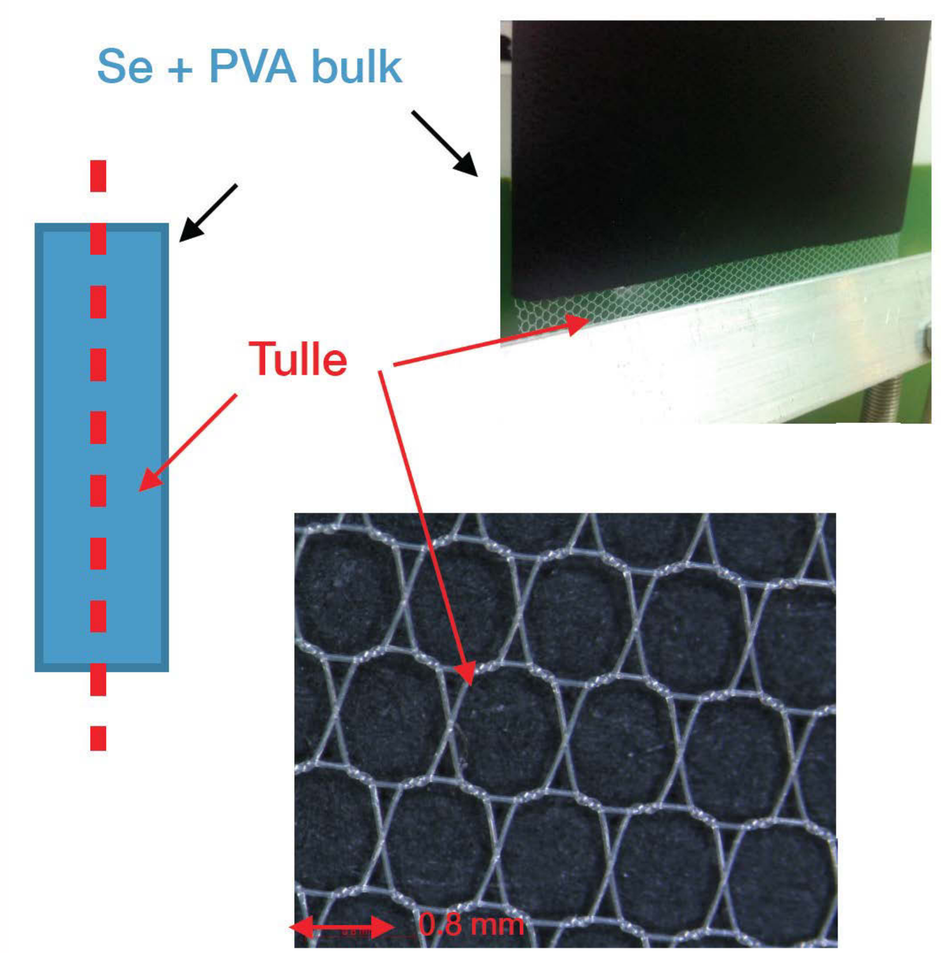


Limits on foil contamination in ^{208}Tl (2 µBq/kg) and ^{214}Bi (10 µBq/kg) are challenging

Foil source production @ LAPP

A. Remoto, D. Duchesneau, J.M. Dubois, A. Jeremie, T. Le Noblet

- LAPP is in charge for the production of 1/2 of the source for the Demonstrator
- A new design is proposed: light nylon fabric (tulle) as internal foil support
- Foil production protocol is defined. All the tools are ready! Improving the technique with practice…
- All materials to be used in foil production have been defined.
- Radio-purity measurements have been performed (collaboration with LSM, LAL and LSC - Canfranc)



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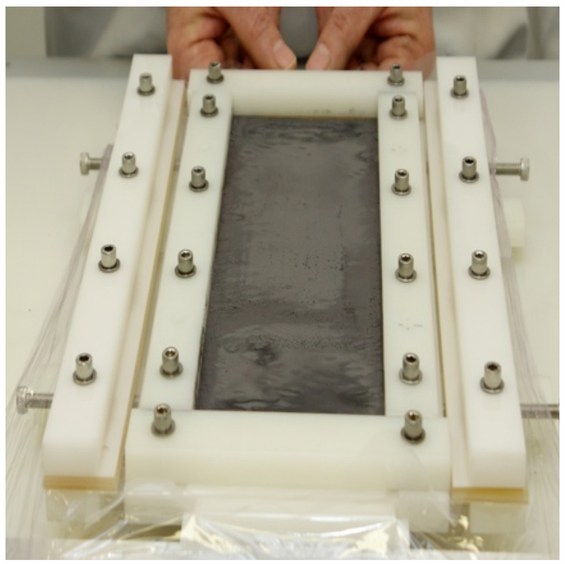
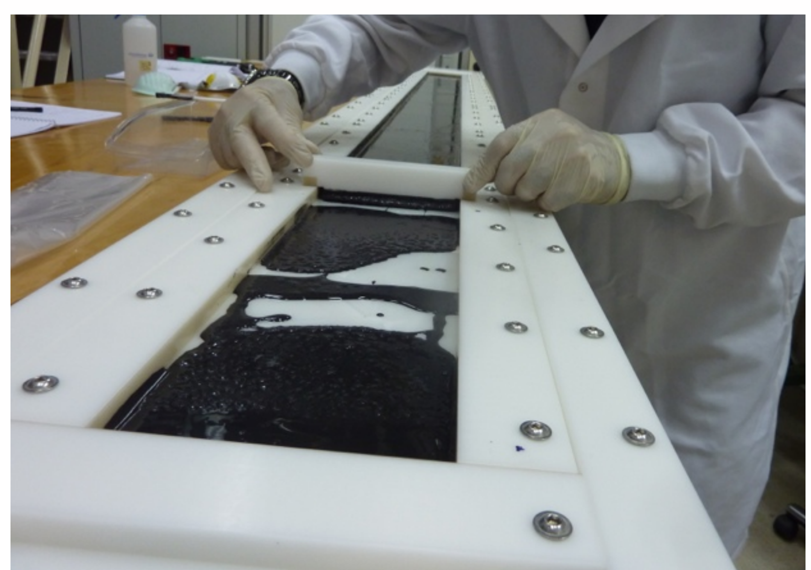


Where we were last year

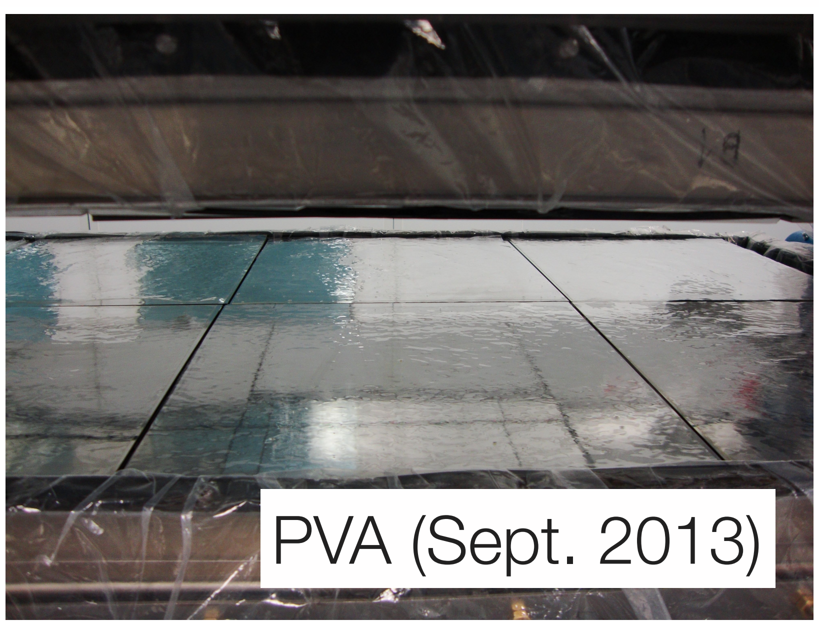
Where we are now

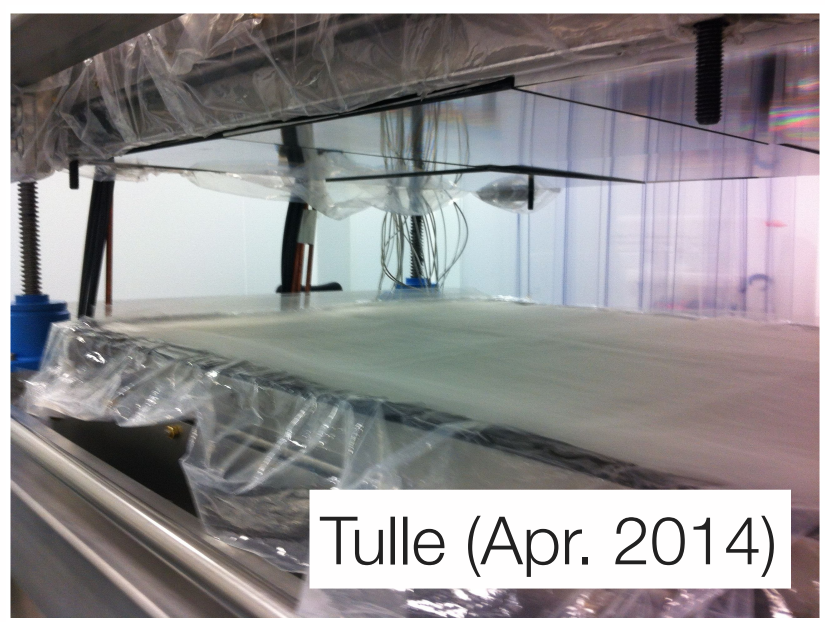


Material radio-purity

A. Remoto, D. Duchesneau, J.M. Dubois, A. Jeremie, T. Le Noblet

Material	Density	A(214-Bi)		A(208-Tl)	
	[g/cm3]	Limit	Measured value @ 90% C.L.	Limit	Measured value @ 90% C.L.
		[uBq/kg]	[uBq/kg]	[uBq/kg]	[uBq/kg]
82-Se	3.20	10	jan. 2015	2	jan. 2015
Polyvinyl alcohol	1.30	100	[532; 1094] ± 77	20	<65
Nylon6-6 (tulle)	1	714	[274.51 – 681.25] ± 48.25	143	[222.25 – 407.42] ± 31.65


PVA (Sept. 2013)


Tulle (Apr. 2014)


82-Se (now)

Material radio-purity

A. Remoto, D. Duchesneau, J.M. Dubois, A. Jeremie, T. Le Noblet

Material	Density [g/cm3]	A(214-Bi) Limit [uBq/kg]	A(214-Bi) Measured value @ 90% C.L. [uBq/kg]	A(208-Tl) Limit [uBq/kg]	A(208-Tl) Measured value @ 90% C.L. [uBq/kg]
82-Se	3.20	10	jan. 2015	2	jan. 2015
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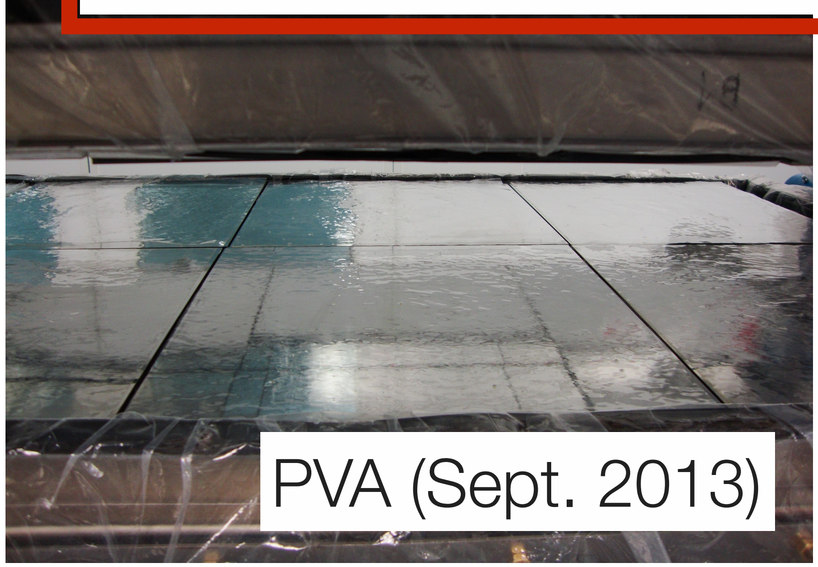
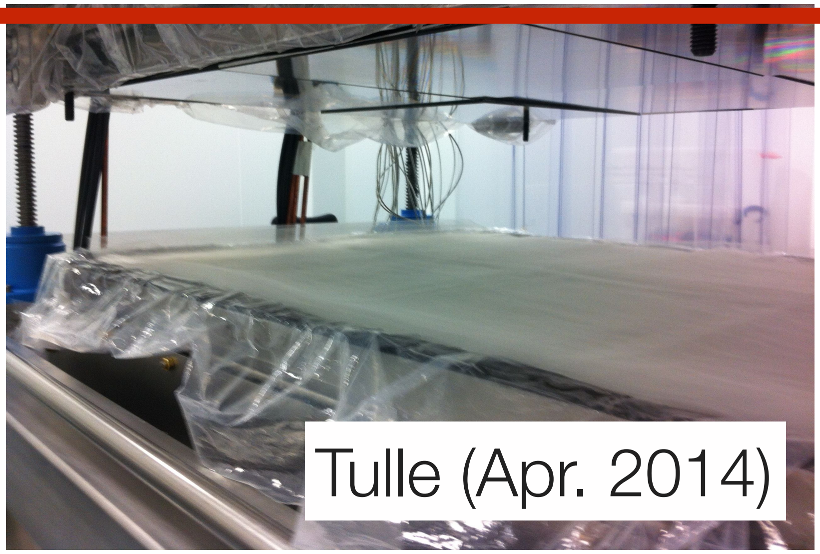
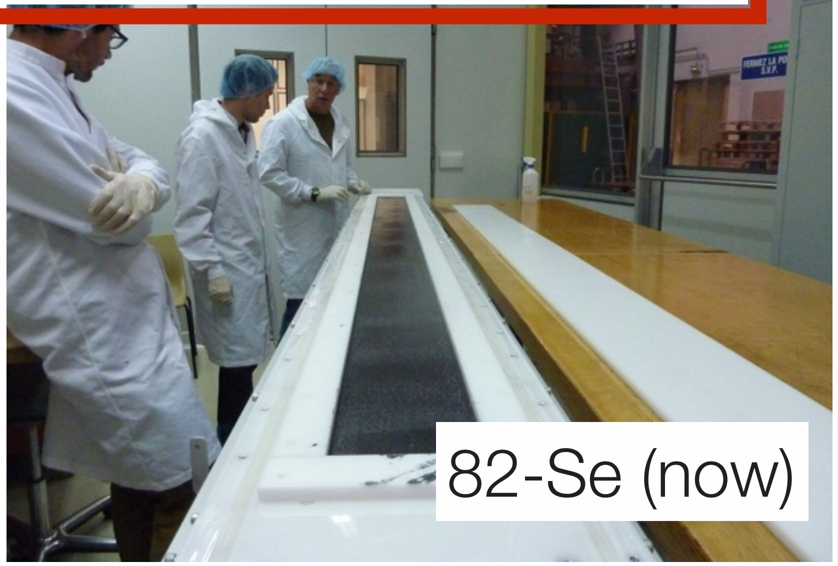
Contamination during sample production: there is room for improvement


PVA (Sept. 2013)


Tulle (Apr. 2014)


82-Se (now)

Material radio-purity

A. Remoto, D. Duchesneau, J.M. Dubois, A. Jeremie, T. Le Noblet

Material	Density [g/cm3]	A(214-Bi) Limit [uBq/kg]	A(214-Bi) Measured value @ 90% C.L. [uBq/kg]	A(208-Tl) Limit [uBq/kg]	A(208-Tl) Measured value @ 90% C.L. [uBq/kg]
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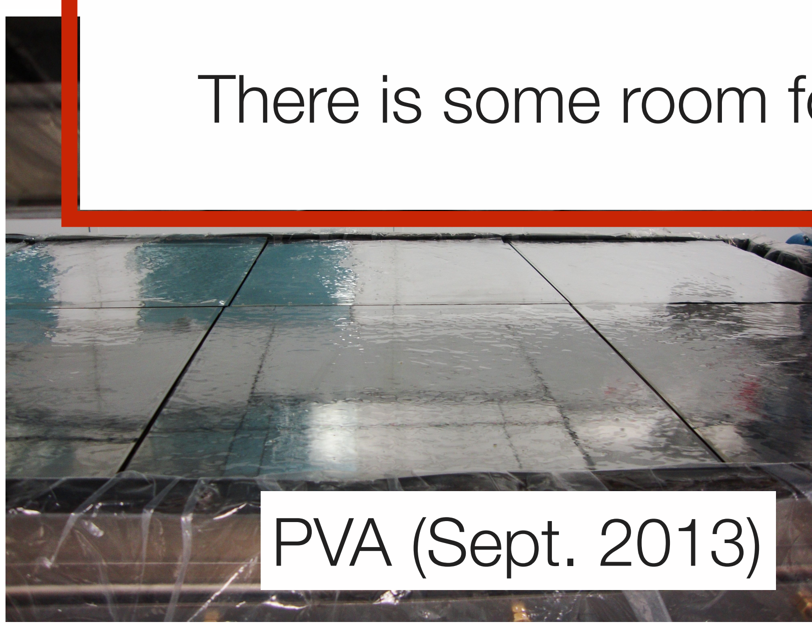
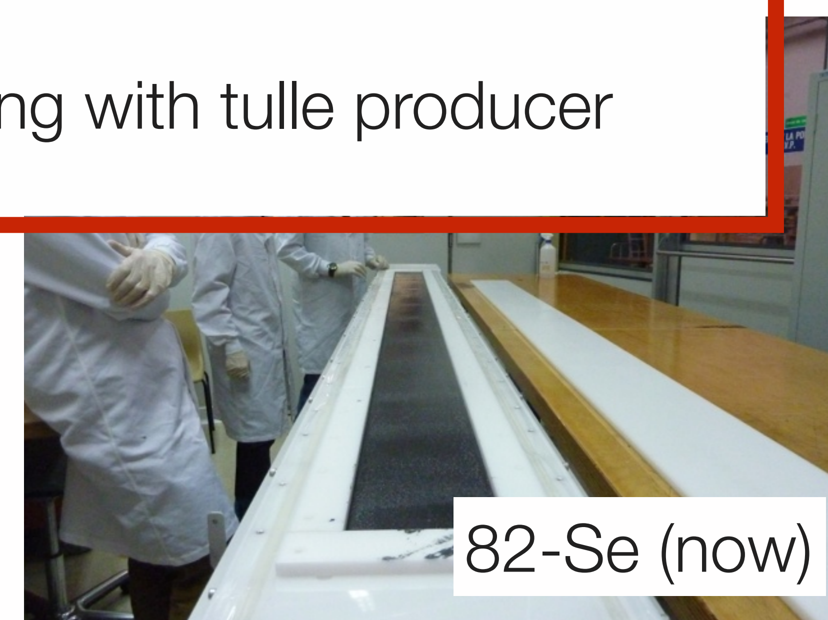
There is some room for improvement: discussion ongoing with tulle producer

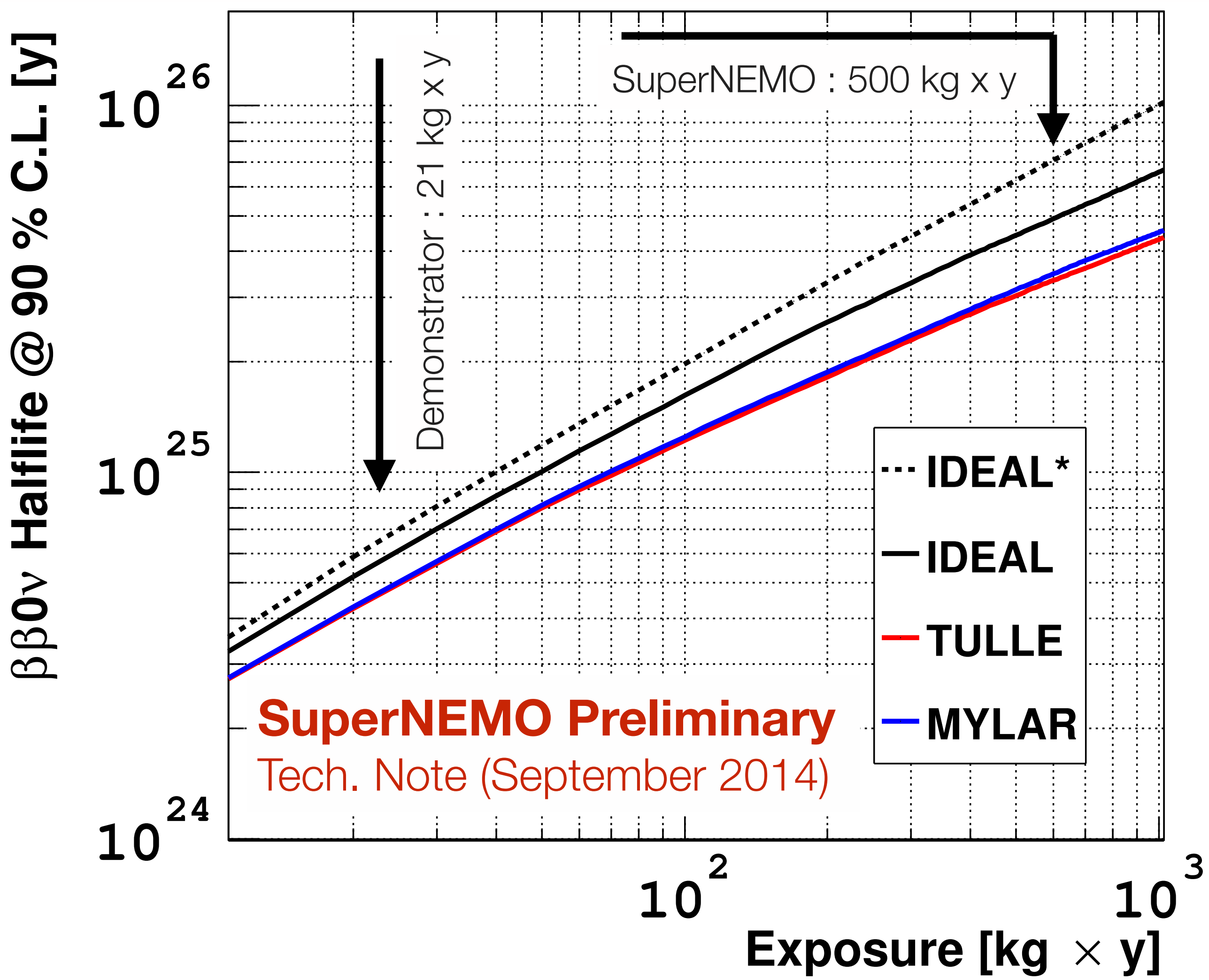

PVA (Sept. 2013)


Tulle (Apr. 2014)


82-Se (now)

Sensitivity studies

A. Remoto, T. Le Noblet, D. Duchesneau

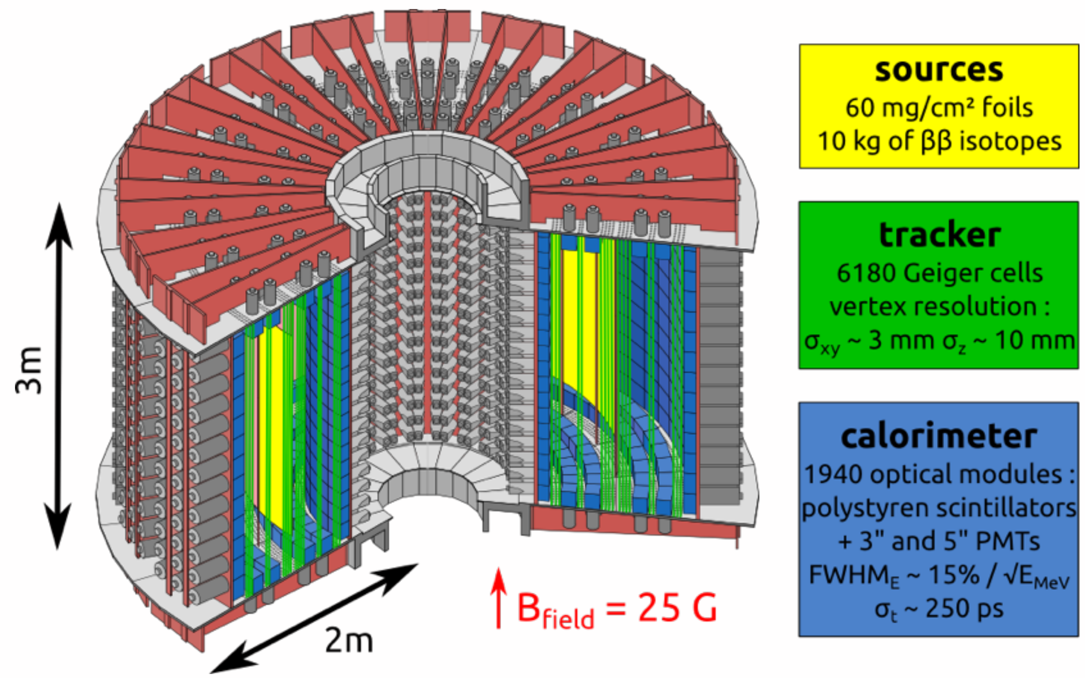


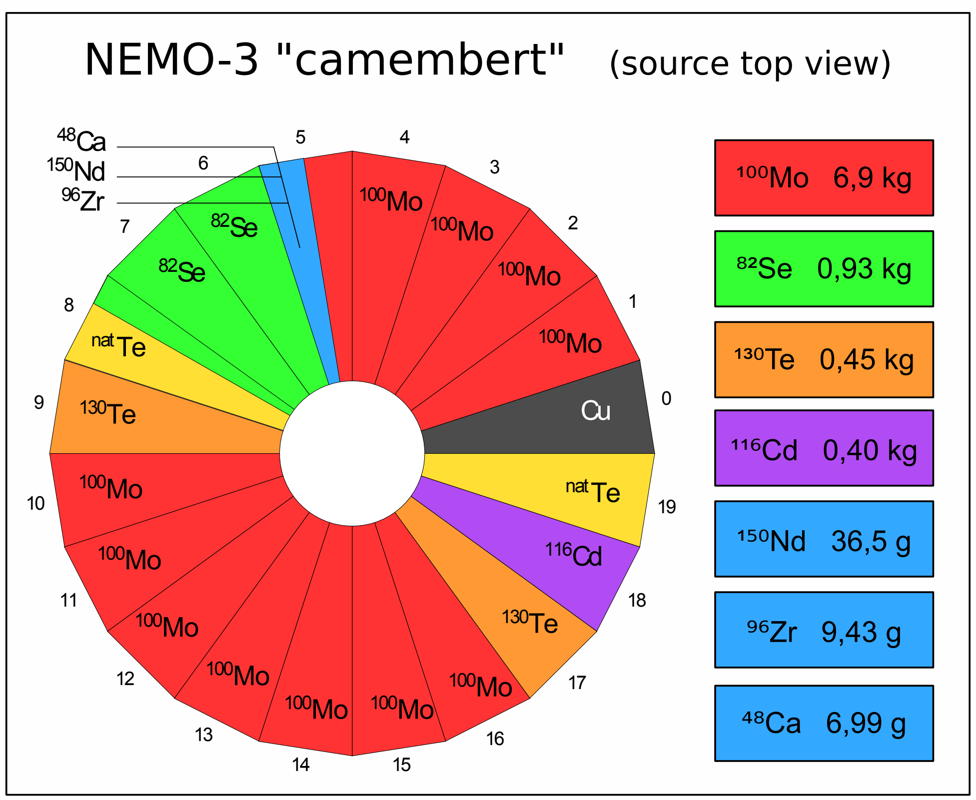
- Sensitivity study comparing different design of the source foil
- Results from recent radio-purity measurements taken into account
- LAPP proposal provide compatible performance with alternative design
- T. Le Noblet M2 stage, March-July 2014 (currently Ph.D. student)
- Most recent sensitivity study available in the collaboration
- Other relevant contribution on simulations and reconstruction chain

NEMO-3 analysis : ^{116}Cd

A. Remoto

- NEMO-3 observed 10kg of different ββ isotopes from February 2003 to January 2011
- Results among the most competitive to date
- Final analysis for all the isotopes ongoing



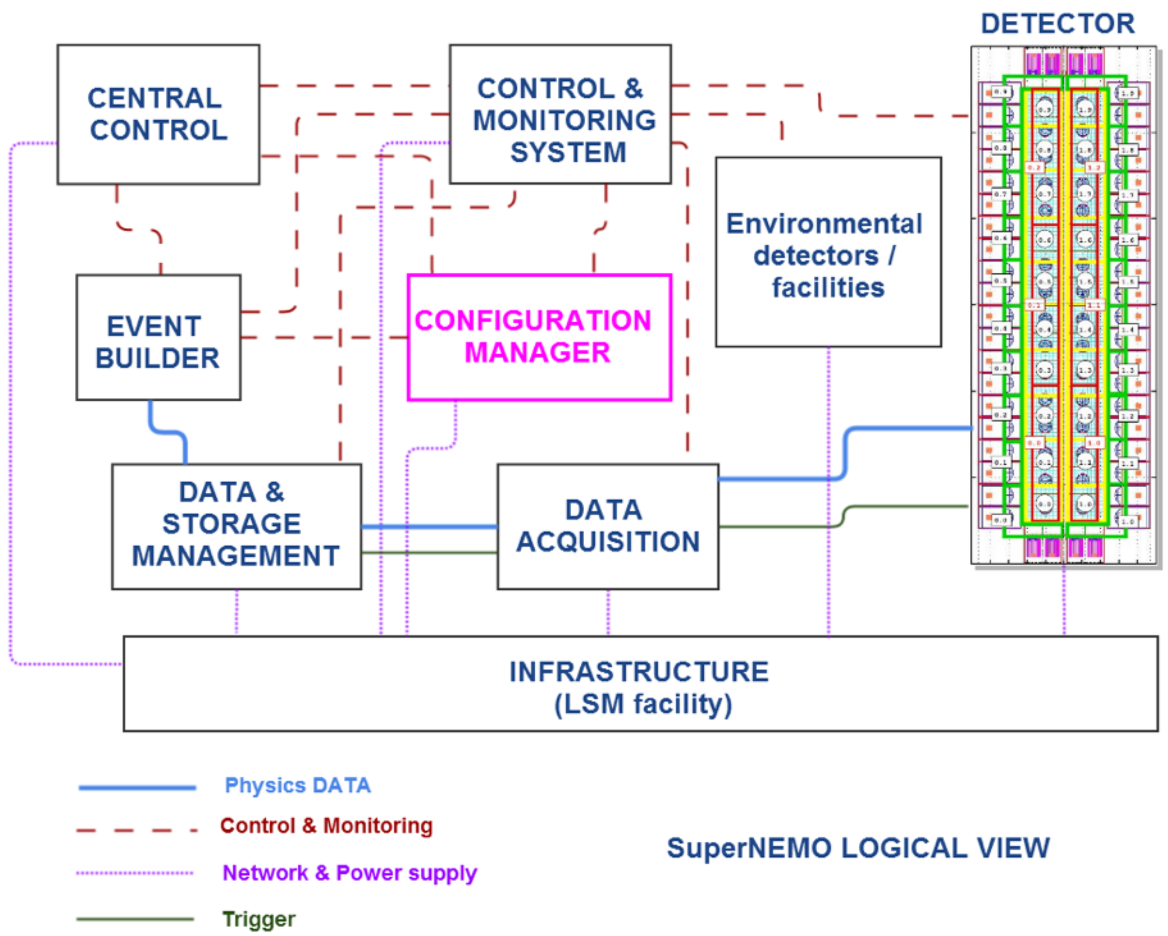


- 100-Mo (full stat.) published on Phys. Rev. D. 89.111101 (2014). Enigmass labs among the authors
- Full stat. for ^{82}Se, ^{48}Ca, ^{150}Nd published soon
- I've recently join the analysis effort being in charge of the ^{116}Cd analysis. Publication in 2015…

Control & Monitoring system

E. Chabanne, D. Duchesneau, T. Le Flour, S. Lieunard, J.L. Panazol

- Control/monitor environmental parameters, detector subsystems (local & remote)
- Operate heterogeneous devices
- Technical choice common with CTA project
- Take advantage of existing experience



- Status:
  - Collecting interface Control Document (ICD) from different sub-system
  - Control & command use case definition (for each sub-system)
  - First mock up of coil power supply to test remote control & monitoring

Conclusions

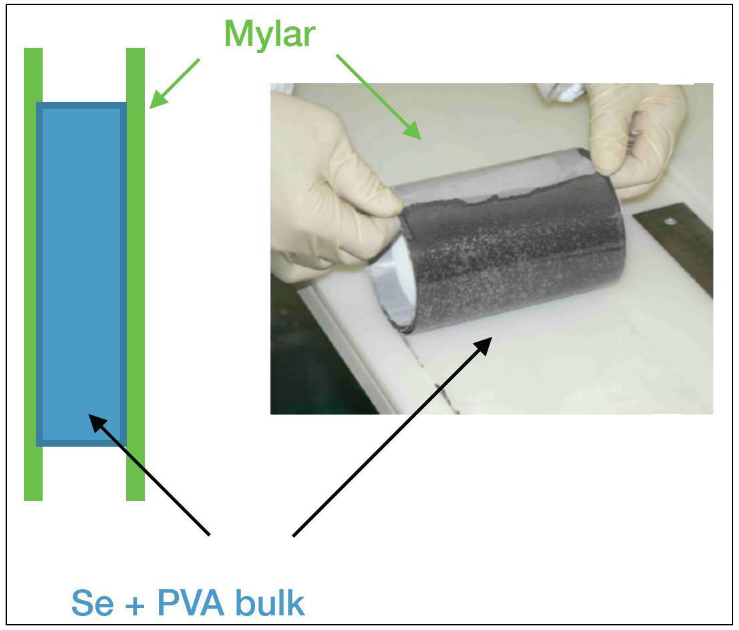
- SuperNEMO activities developed within the ENIGMASS Labex are well advanced
- The activities are expected to be ready by the end of 2015, in time for the demonstrator installation/commissioning/running
- Publication dedicated to the activities under development at LAPP/LSM are envisaged in the coming years (3 papers expected)

- The SuperNEMO group @ LAPP is growing: T. Le Noblet — Ph.D. student till 2017
- Conferences: Talk @ NOW 2014 (Otranto) & Poster @ Nu2014 (Boston)
- K. Lang U. Texas (MINOS+ spokesperson, chair of the SuperNEMO source foil package) in sabbatical year @ LAPP since July 2014

Backups

Sensitivity studies

Source foil design

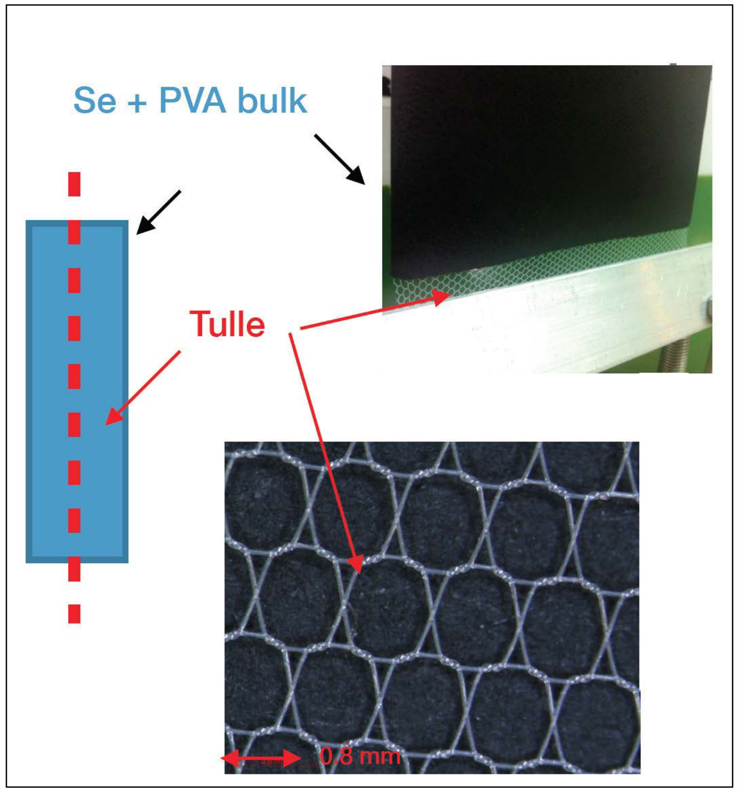


MYLAR

- Based on the design used in NEMO-3
- ^{82}Se + PVA (5% - 10%) + 2 mylar backing film
- 12 μm mylar film micro-perforated under an ion beam
- Surface density ~1.6 mg/cm^2

TULLE

- New conception design
- ^{82}Se + PVA (10%) + inner tulle (nylon6-6) mesh
- 100 μm bobbinet tulle with hexagonal weave
- Surface density ~0.7 mg/cm^2



Foil parametrisation

- IDEAL : Se + 5 % PVA
- TULLE : Se + 10 % PVA + 1.2 % nylon
- MYLAR : Se + 5 % PVA + 2 mylar films

Design	f_{Se} [–]	f_{PVA} [–]	$f_{Support}$ [–]	a [mg/cm^2]	ρ [g/cm^3]	t [μm]
IDEAL	0.95	0.05	0.00	52.5	3.11	169
TULLE	0.888	0.10	0.012	56.3	2.98	189
MYLAR	0.95	0.05	–	$52.5_b + 3.2_f$	$3.11_b + 1.4_f$	$169_b + 24_f$

- Foil activity estimated as:

$$A = \sum_i \frac{f_i}{f_{Se}} \times A_i$$

Design	f_{Se}/f_{Se} [–]	f_{PVA}/f_{Se} [–]	$f_{Support}/f_{Se}$ [–]	A(^{214}Bi) [μBq/kg]	A(^{208}Tl) [μBq/kg]
IDEAL	1	0.053	0.000	62.0	3.4
TULLE	1	0.113	0.014	154.9	12.7
MYLAR	1	0.053	0.068	$62.0_b + 111.6_f$	$3.4_b + 15.6_f$

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- Tulle is considered uniformly distributed in the foil bulk

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- Tulle is considered uniformly distributed in the foil bulk
- The mylar layers are accounted separately from the source bulk

R.O.I. method

The sensitivity is defined as a limit on the decay half-life

Constant depending on the material

Exposure : 7 kg x 3 y

$$T^{0\nu}_{1/2} > \frac{N_A \ln 2}{W} \times \frac{\epsilon \times M \times T}{\mathcal{S}(b)}$$

Signal selection efficiency:

$$\epsilon_i(E_{Low}; E_{Up}) = \frac{1}{N} \int_{E_{Low}}^{E_{Up}} \frac{\mathrm{d}N}{\mathrm{d}E} \mathrm{d}E$$

Average upper limit on the number of signal events for a given mean expected background level

Optimise the R.O.I. on order to **maximise the ε/S(b) ratio**

Event generation

- Using Falaise-legacy + SNAnalysis
- Generate ββ0v, ββ2v, ^{208}Tl and ^{214}Bi, consider the $2e^-$ channel only
- Simple event selection: 2 calo hits associated to 2 negative tracks with vertex on foil
- MYLAR design: ^{208}Tl and ^{214}Bi events generated also in the film

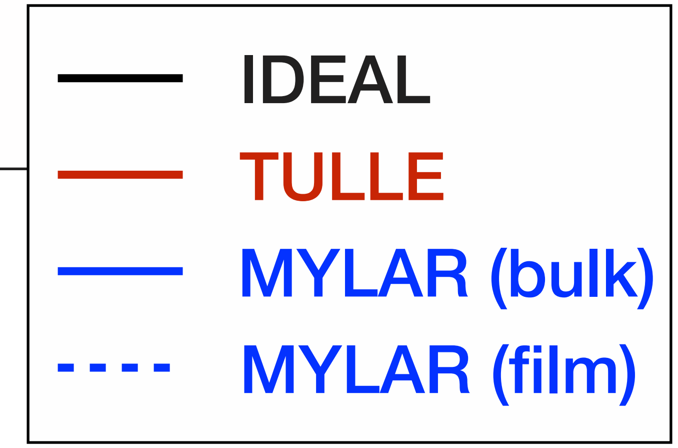
# of generated events

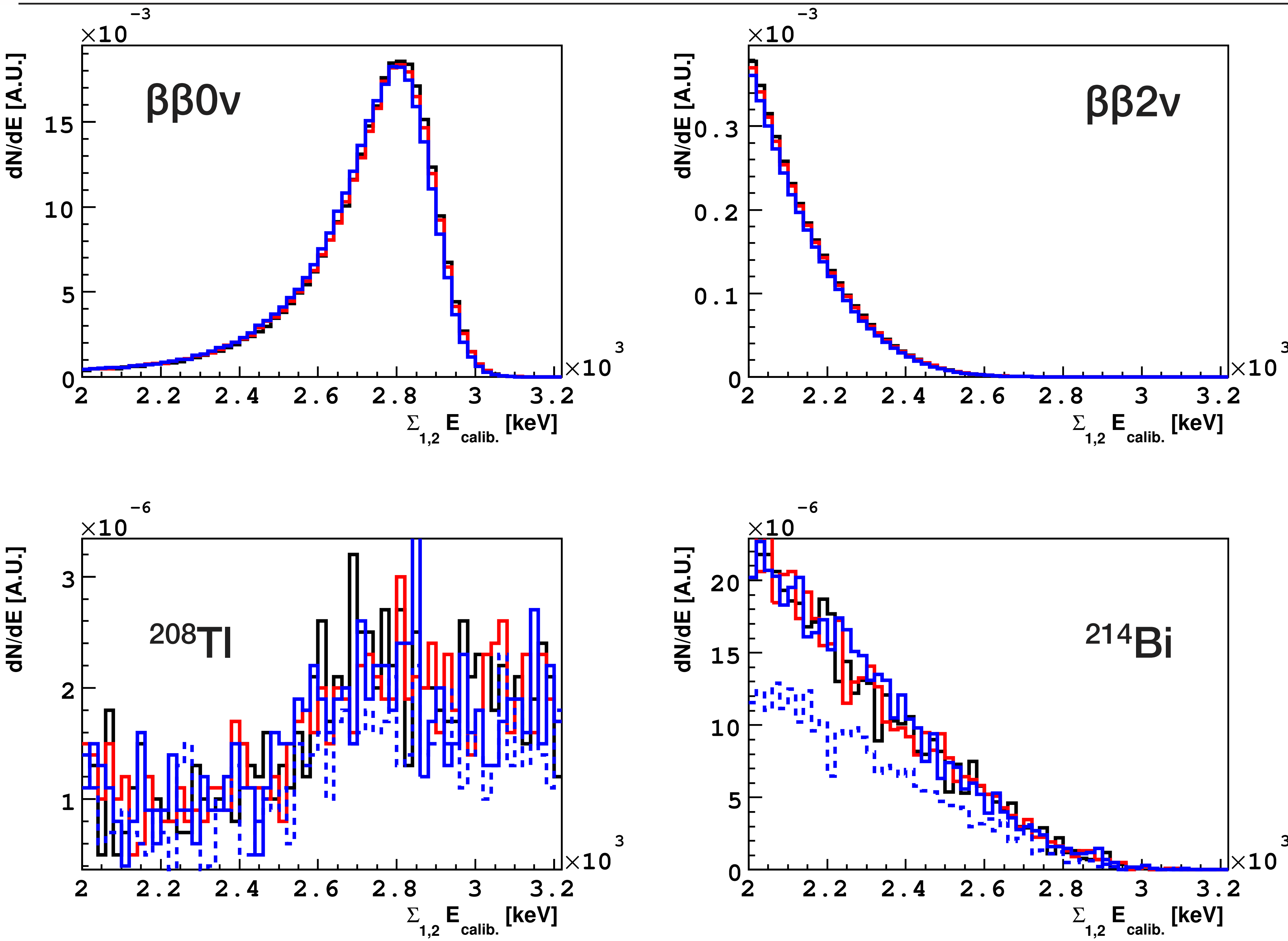
Design	$\beta\beta0\nu$	$\beta\beta2\nu$	^{208}Tl	^{214}Bi
IDEAL	10^6	10^7	10^7	10^7
TULLE	10^6	10^7	10^7	10^7
MYLAR				
(bulk)	10^6	10^7	10^7	10^7
(film)			10^7	10^7

Statistical uncertainties:

- ~0.2 % for ββ0v & ββ2v
- ~3 - 5 % for ^{208}Tl and ^{214}Bi
- ×2 lower than NEMO-3 syst. uncertainty

$2e^-$ energy distribution





2e⁻ energy distributions do not strongly depend on the foil design

$2e^-$ selection efficiency in [2.0; 3.2] MeV

Design	$\epsilon_{0\nu}$ [%]	$\epsilon_{2\nu}$ $\times 10^{-2}$ [%]	ϵ_{Tl} $\times 10^{-2}$ [%]	ϵ_{Bi} $\times 10^{-2}$ [%]
IDEAL	29.01±0.05	33.64±0.04	0.99±0.03	4.3±0.1
TULLE	28.84±0.04	33.05±0.04	0.95±0.03	4.4±0.1
MYLAR (bulk)	28.86±0.04	31.75±0.04	0.92±0.03	4.5±0.1
MYLAR (film)			0.73±0.03	2.7±0.1

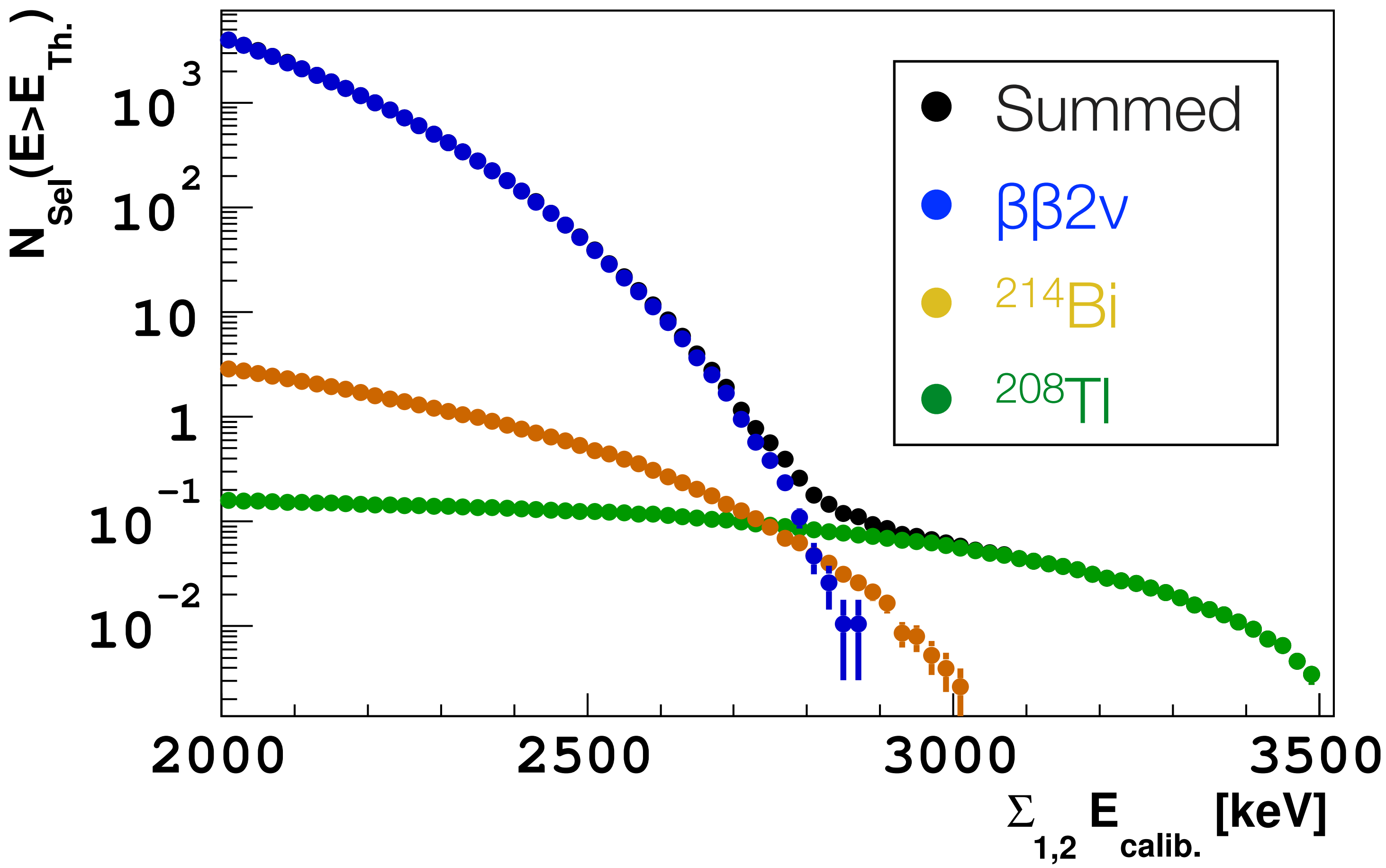
- Overall decrease of the event selection efficiencies for ββ0v and ββ2v
  - Due to increased foil thickness
  - Effect more important for ββ2v in the MYLAR design (at low energies)
- No significant decrease for ^{208}Tl and ^{214}Bi

Estimated background level

IDEAL* design

- Se + 5 % PVA (IDEAL)
- A(^{214}Bi) = 10 uBq/kg
- A(^{208}Tl) = 2 uBq/kg

Cumulative background distribution



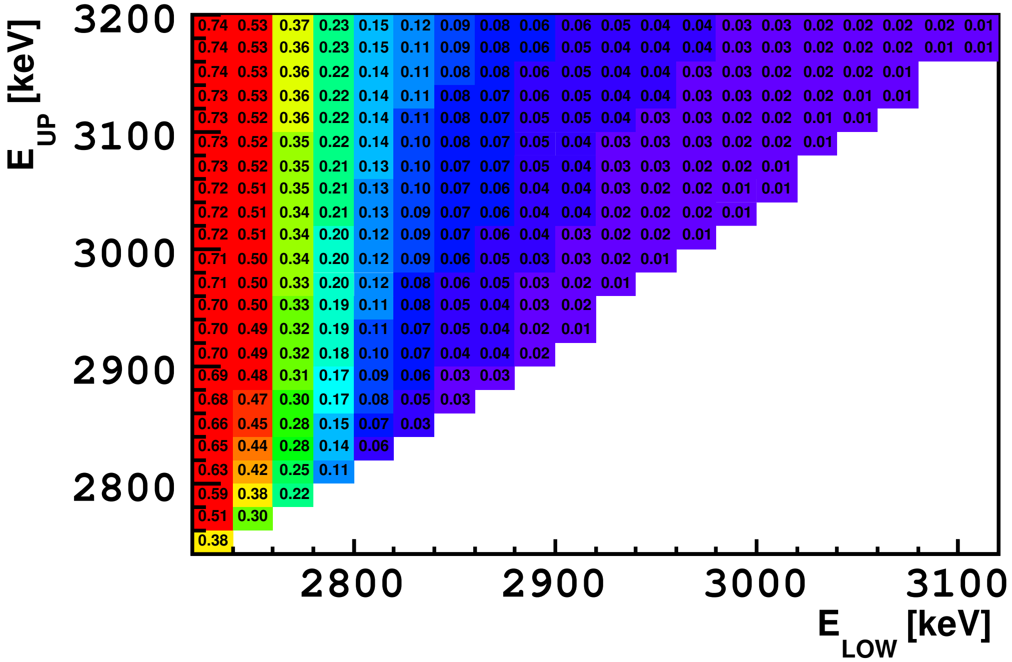
$$N_{2\nu} = \frac{N_A \ln 2}{W} \times \frac{\epsilon_{2\nu} \times M \times T}{T^{2\nu}_{1/2}}$$
$$N_{214Bi} = A_{214Bi} \times \epsilon_{214Bi} \times M \times T$$
$$N_{208Tl} = A_{208Tl} \times \epsilon_{208Tl} \times M \times T$$

Move only the lower edge of the R.O.I. [E_{Low}; 3.5] MeV

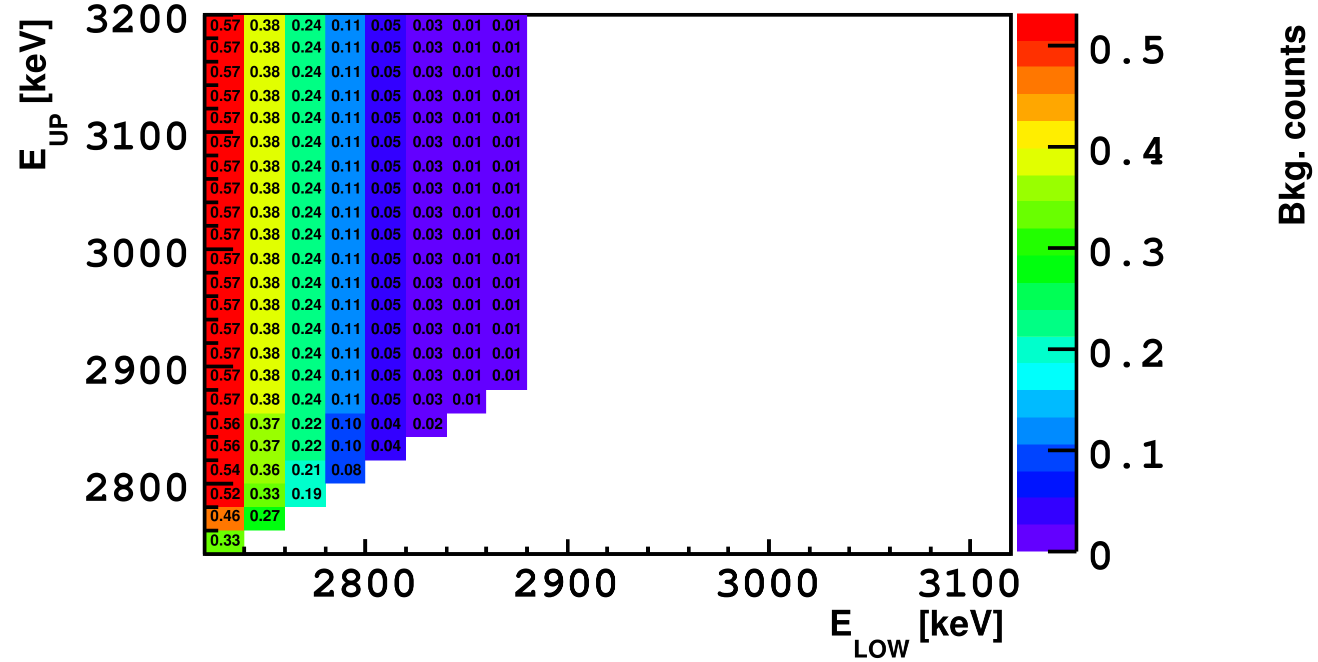
We can move both edges…

Estimated background level

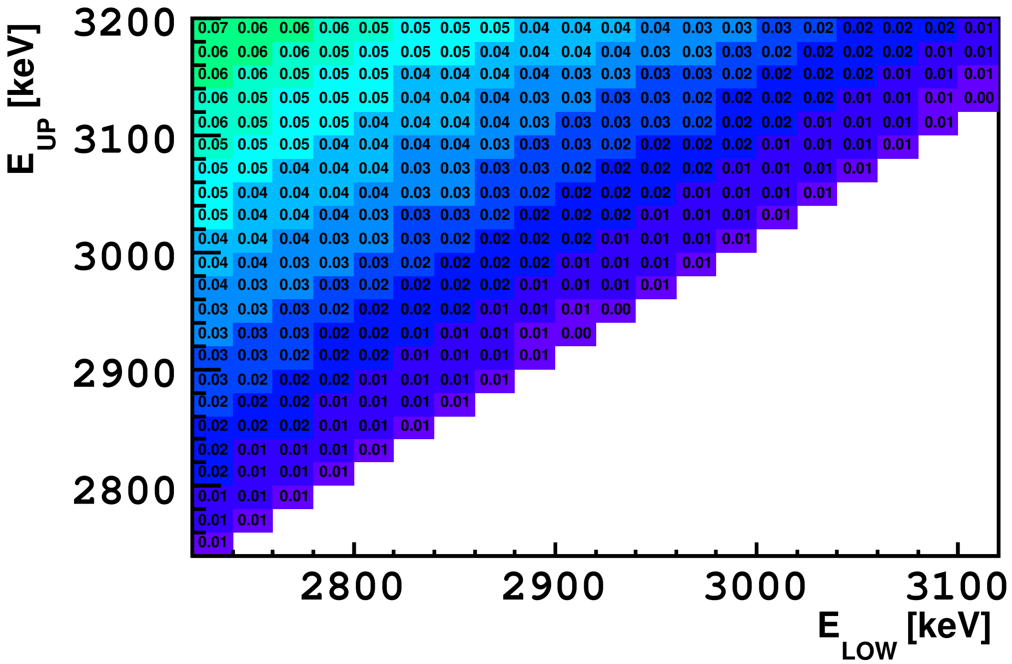
Summed background counts



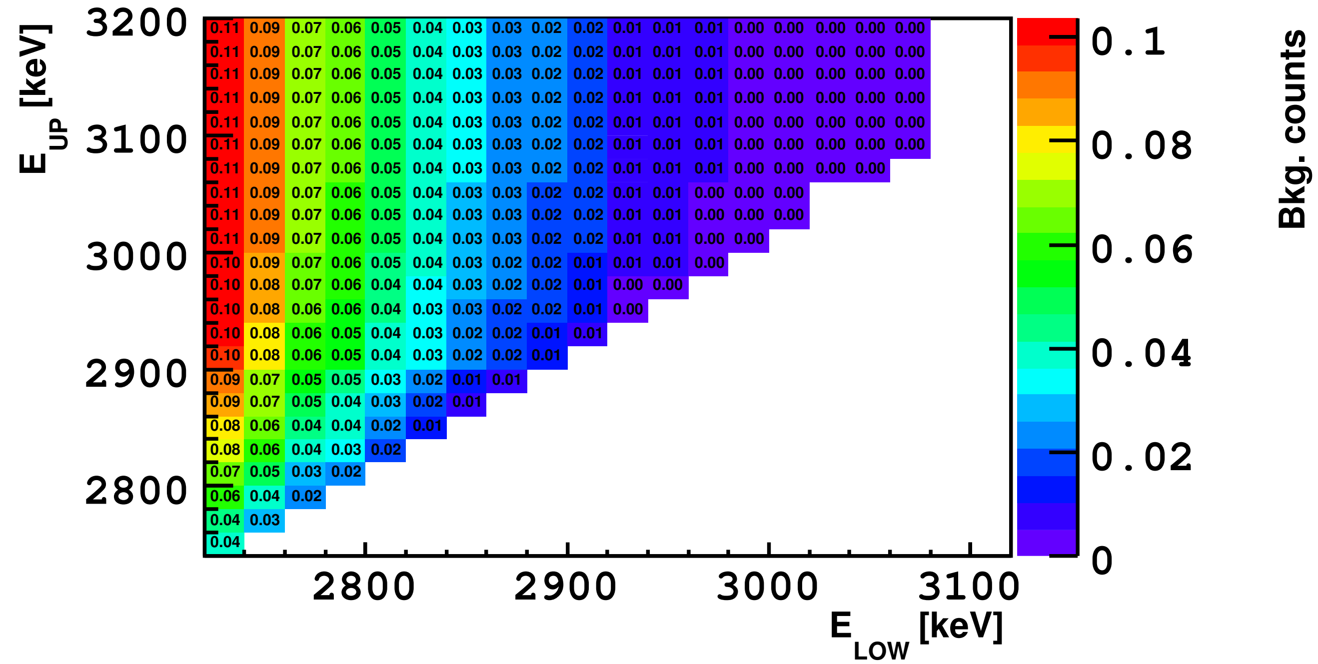
ββ2ν counts



Tl208 counts



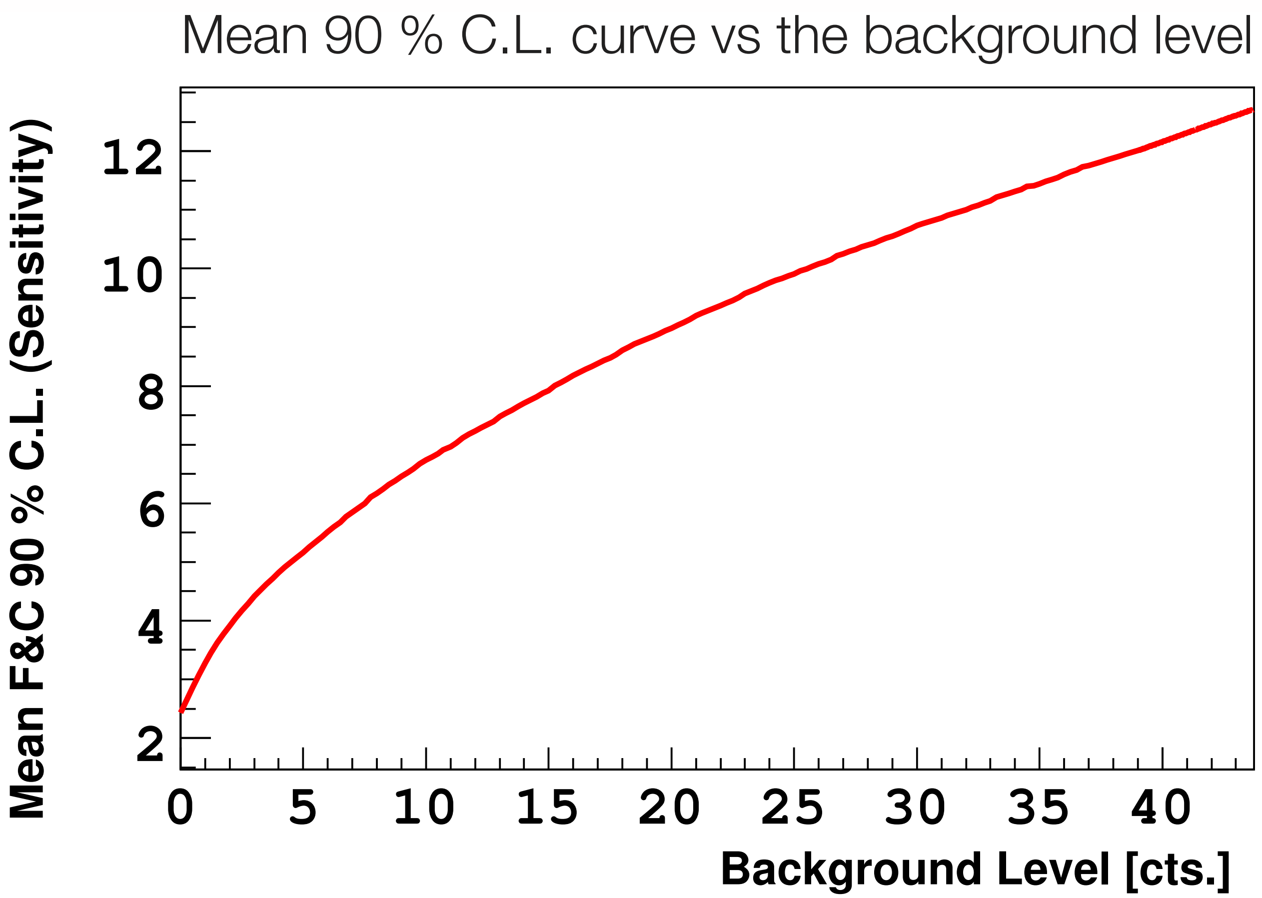
Bi214 counts



The Feldman & Cousins 90% C.L.

Sensitivity: Average upper limit on the number of signal events that would be obtained by an ensemble of identical replicas of such experiment, each one with the same mean expected background and no true signal

[Phys.Rev.D57:3873-3889,1998] and [JCAP 1106:007,2011]



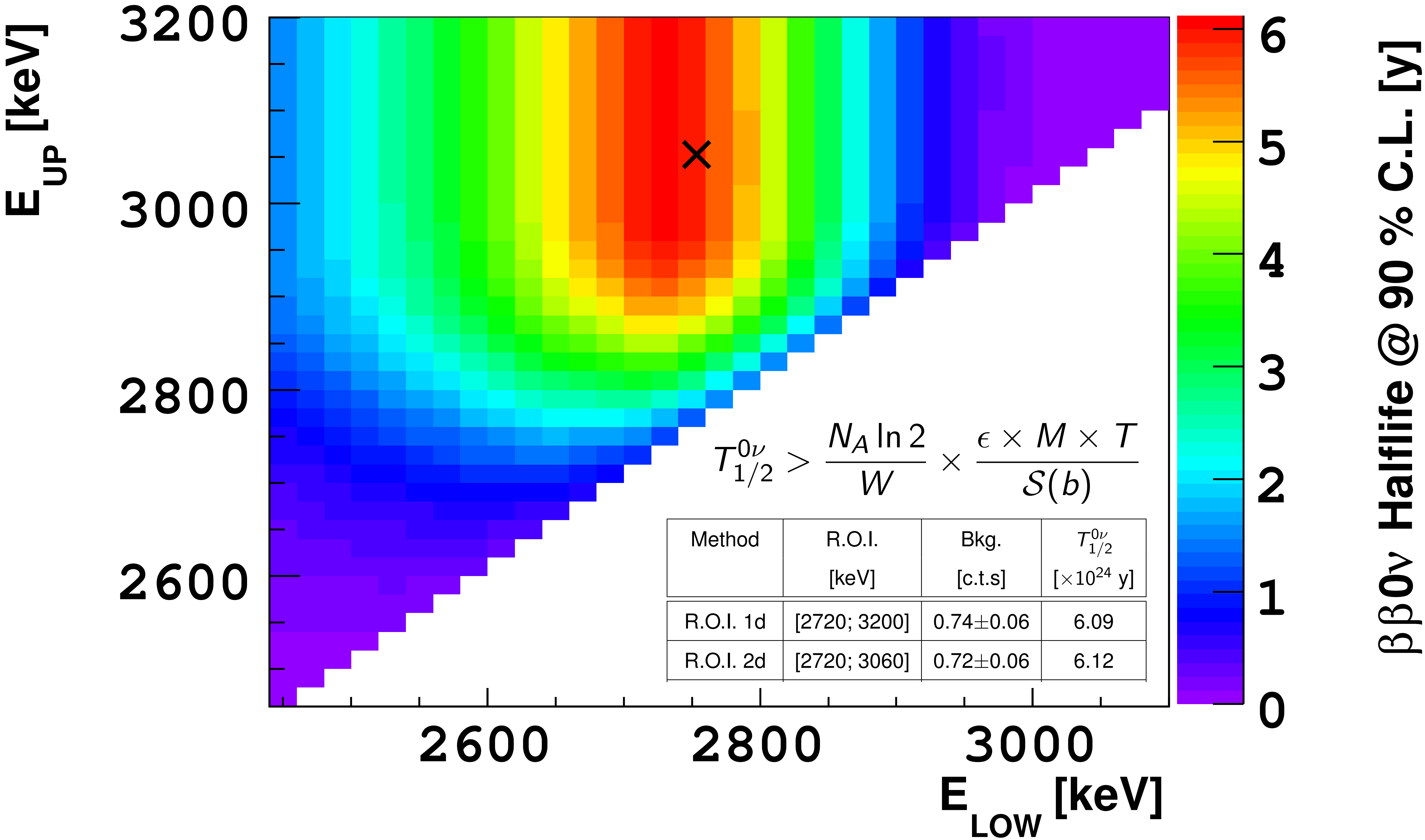
$$\mathcal{S}(b) \equiv E[\mathcal{U}(n|b)] = \sum_{n=0}^{\infty} \mathcal{P}(n;b) \times \mathcal{U}(n|b)$$

Feldman & Cousins upper limit for the signal **n** and the mean predicted background **b**

Follow classical limit for large background:

$$\mathcal{S}(b) \propto a \times \sqrt{b},$$

Sensitivity scan

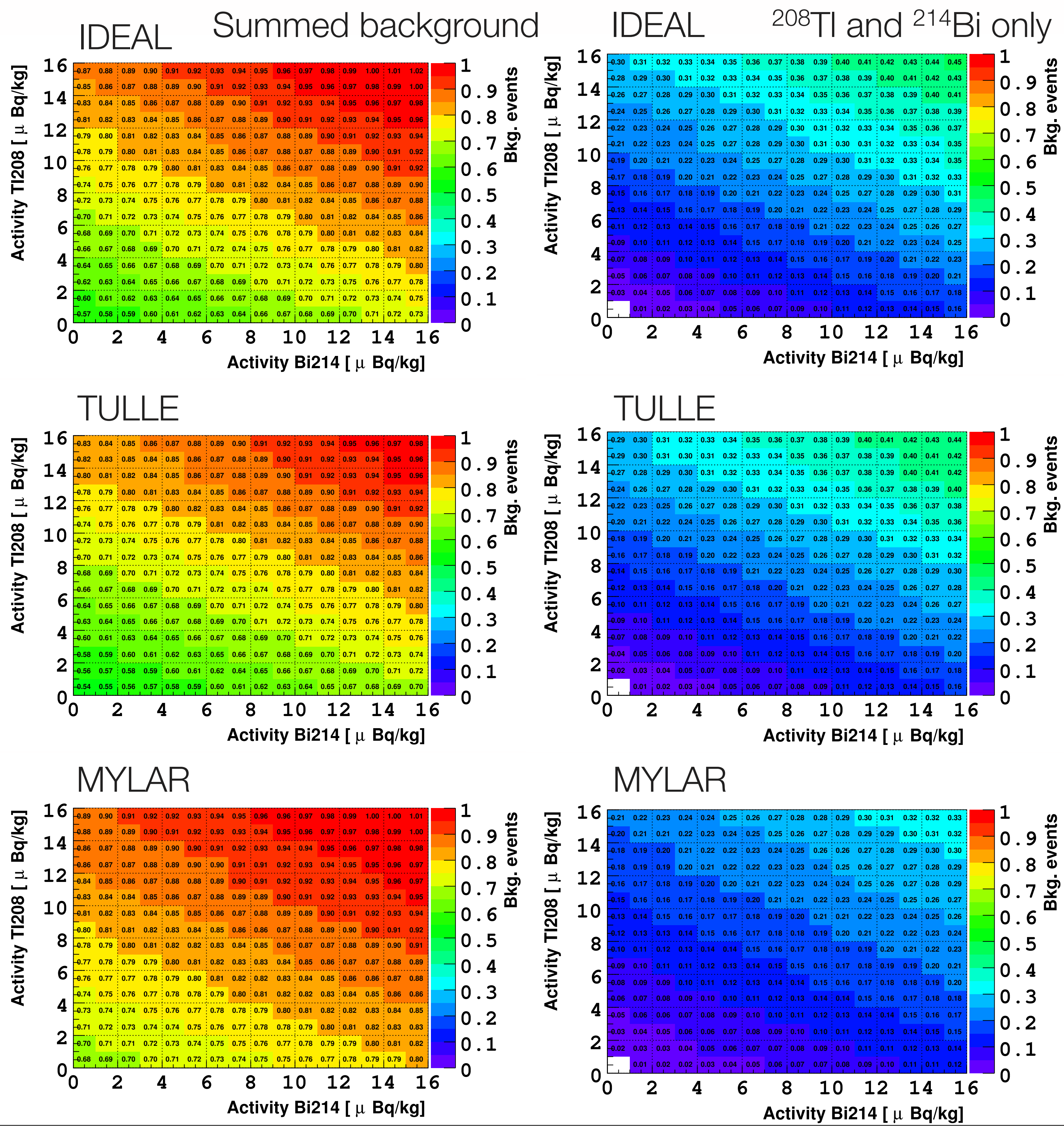


$$T_{1/2}^{0\nu} > \frac{N_A \ln 2}{W} \times \frac{\epsilon \times M \times T}{\mathcal{S}(b)}$$

Method	R.O.I. [keV]	Bkg. [c.t.s]	$T_{1/2}^{0\nu}$ [$\times 10^{24}$ y]
R.O.I. 1d	[2720; 3200]	0.74±0.06	6.09
R.O.I. 2d	[2720; 3060]	0.72±0.06	6.12

Background counts vs activity

- Activity in [0 ; 15] μBq/kg
- Optimised R.O.I.
- Exposure : 7 kg x 3 y
- Compatible background level among designs
- At target radio-purity level:
  - ~0.15 cts. in ^{208}Tl and ^{214}Bi



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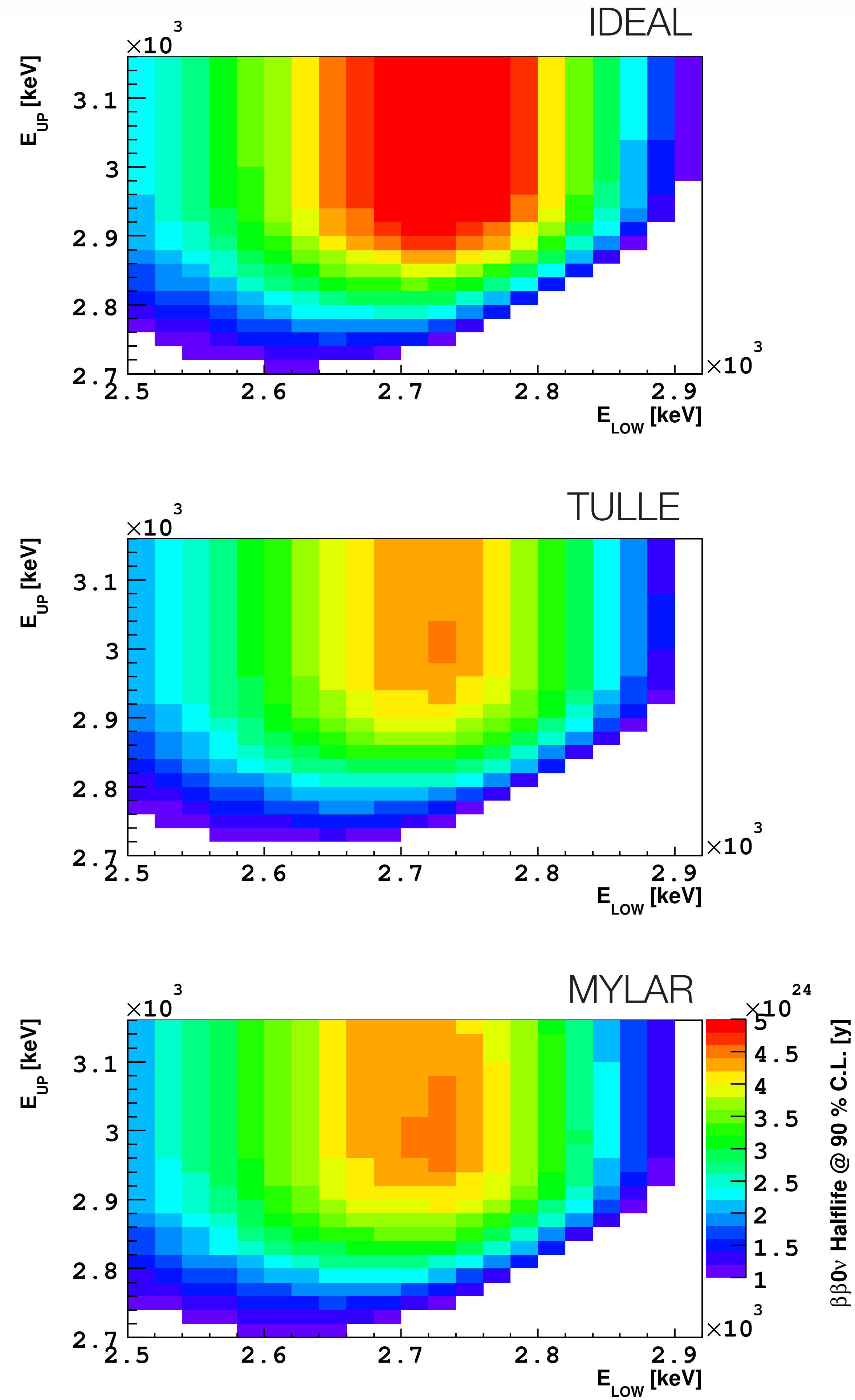
Performance comparison

- IDEAL — TULLE — MYLAR
  - Account for measured contamination
- IDEAL*
  - A_{214Bi} = 10 μBq/kg ; A_{208Tl} = 2 μBq/kg
- <18 % (TULLE) ; <16 % (MYLAR) w.r.t. (IDEAL)
- TULLE and mylar compatible within ~3 %

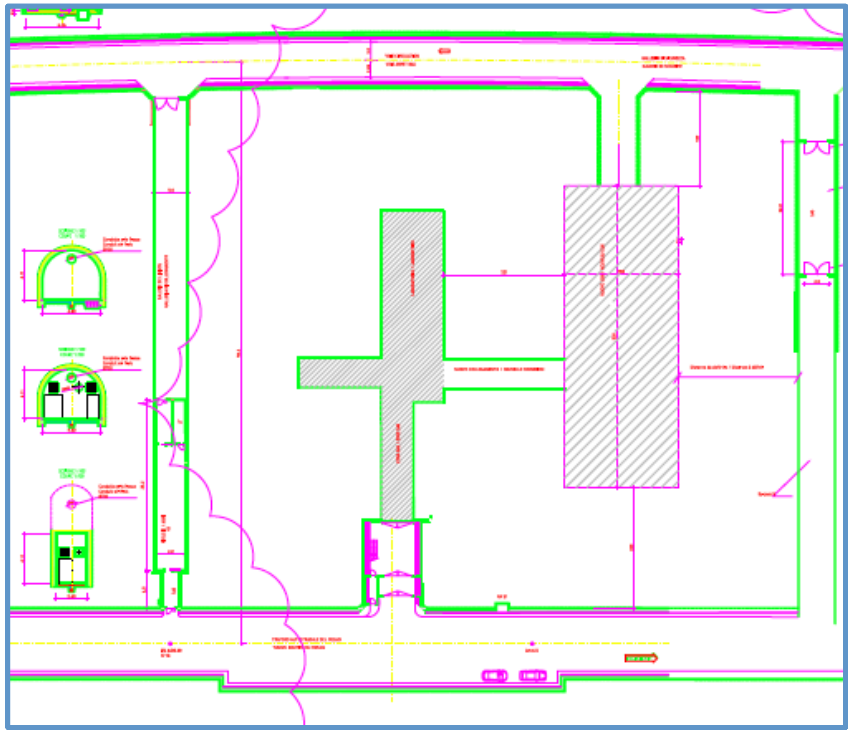
Design	R.O.I. [keV]	$\epsilon_{0\nu}$ [%]	bkg. [cts.]	$T^{0\nu}_{1/2}$ [$\times 10^{24}$ y]
*IDEAL**	[2720; 3060]	17.44±0.04	0.7±0.1	6.12
IDEAL	[2720; 3060]	17.44±0.04	1.3±0.1	5.34
TULLE	[2720; 3020]	16.98±0.04	2.4±0.1	4.40
MYLAR	[2720; 3000]	16.44±0.04	2.1±0.1	4.50

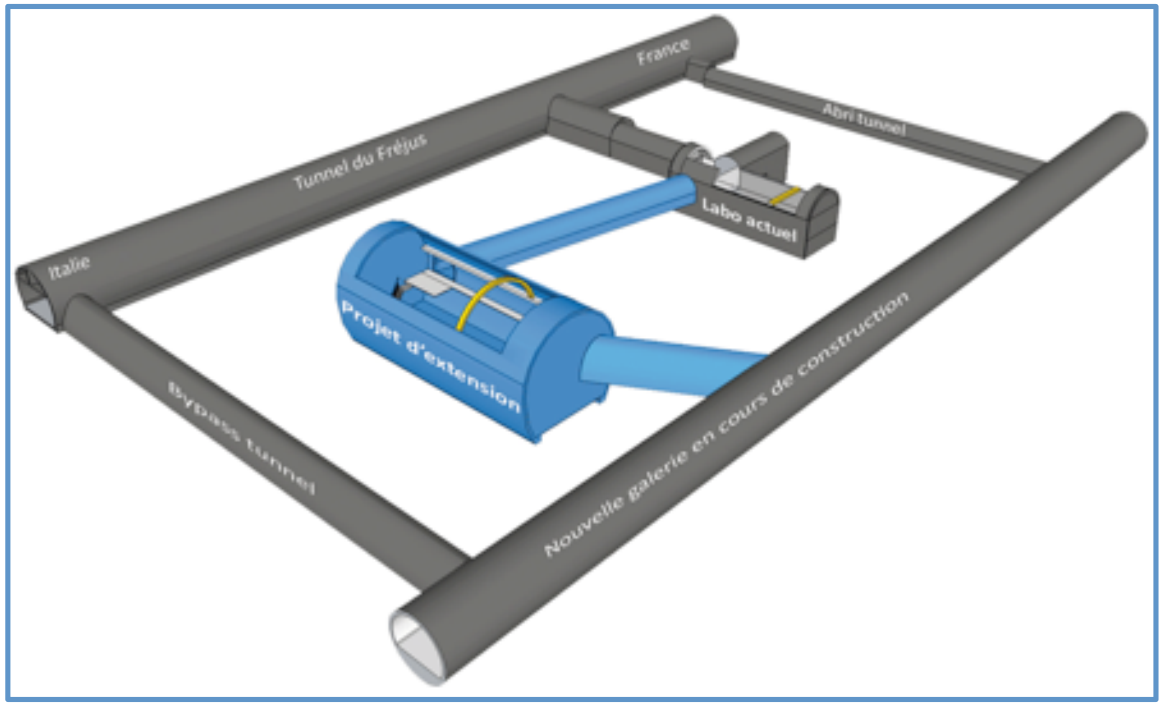


Alberto Remoto

Friday, 28 November 14

Projet final : 14 000 m³ (X4 LSM actuel)





Cavité: Longueur 40 m, Largeur 18 m, Hauteur 16 m

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Financement travaux: CNRS, Région et CG73

Consultation entreprise pour savoir si le coût de réalisation est dans l'enveloppe Budgétaire

Calendrier creusement si financement obtenu mi 2015 – mi-2016