R2D2
Radioactivity constraints

Numbers are taken from our sensitivity study publication: **JINST 13 (2018) no.01, P01009**

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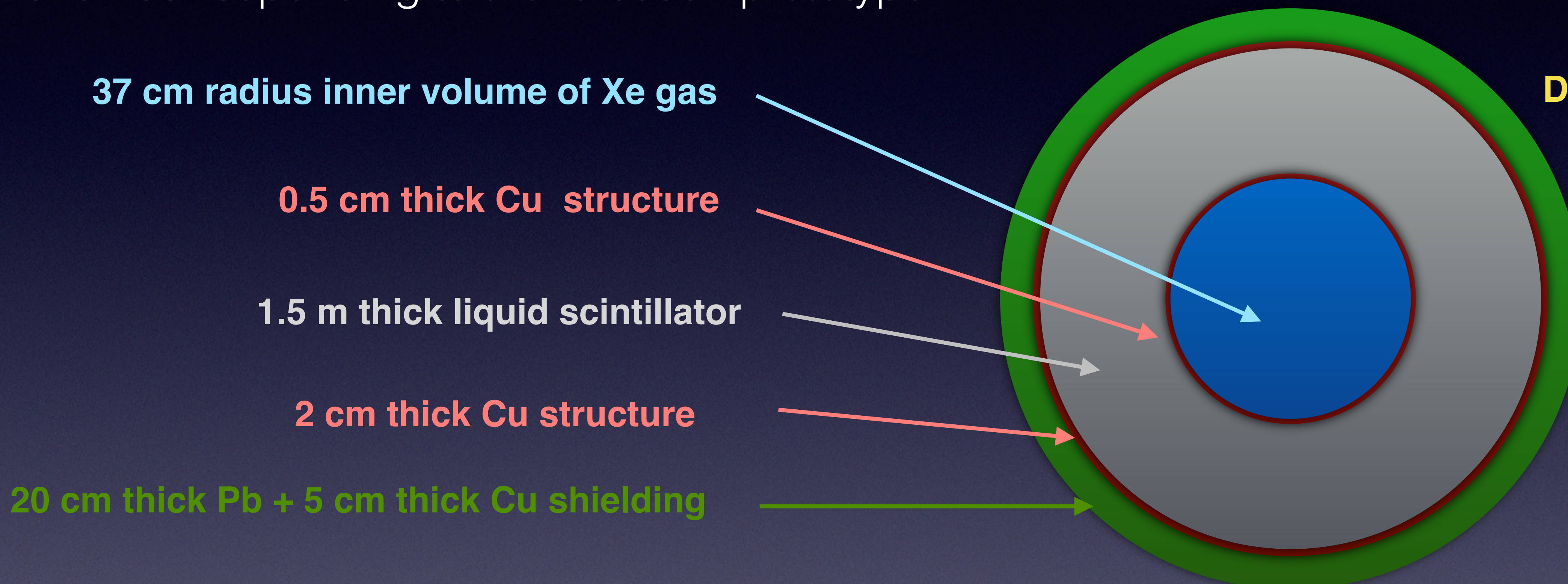
NEWS-G Collaboration Meeting

Grenoble - 13/6/2019

Prototype 2

Sensitivity studies

- We developed a **full Monte Carlo simulation** to assess our capability to reject background and to evaluate the possible sensitivity on the searched signal.
- We considered a geometry including active and passive veto and a small mass of 50 kg of xenon corresponding to the foreseen prototype.



Drawing not in scale

Xenon active volume	**Liquid scintillator volume**	**Shielding volume**
Mass of 50 kg	Thickness of 1.5 m	20 cm Lead
Radius of 37 cm	Assumed to be LAB	5 cm Copper
Pressure of 40 bar		

This choice, based on the results of a pressure and radius scan, is driven by the need of containing at least 80% of the $\beta\beta0\nu$ electrons.

The thickness is chosen in order to have a background rate below 0.1 events per year from the ^{208}Tl contamination of the liquid scintillator vessel.

The choice was made to match the shielding used in measurements performed at LSM to have a reliable and less complicated MC.

Background from the sphere

- The number are computed for a Copper with an activity of 10 μBq/kg.
- They are reduced with a smaller ROI of $Q_{\beta\beta}$ ± 0.6%.

Source	Events in ROI ($Q_{\beta\beta}$ ± 1.5%)	+ LS cut (Energy in LS< 200 keV)	+ Rmin cut (Rmin< 36 cm)	+ ΔR cut (ΔR< 5 cm)
^{60}Co	6.9 ± 0.1	6.9 ± 0.1	6.9 ± 0.1	0.8 ± 0.1
^{232}Th chain	28.0 ± 0.8	4.6 ± 0.3	3.7 ± 0.3	0.8 ± 0.1
^{238}U chain	9.3 ± 0.2	8.8 ± 0.2	7.5 ± 0.2	3.0 ± 0.1
$\beta\beta0\nu$	82.1% ± 0.3%	82.1% ± 0.3%	81.9% ± 0.3%	76.2% ± 0.3%

Background from the LS vessel

- The liquid scintillator has to be thick enough to avoid background from LS vessel.
- The vessel is 2 cm thick Copper.

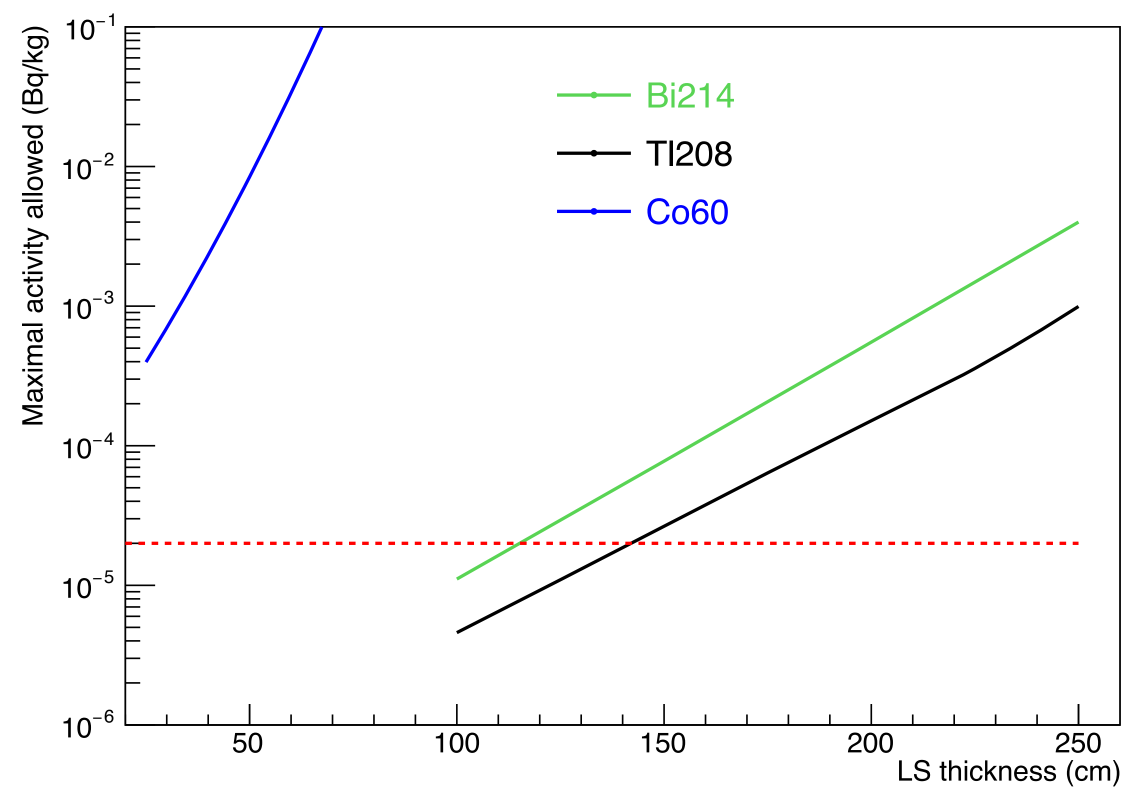


Figure 9: *Maximal allowed activity of ^{214}Bi (green), ^{208}Tl (black) and ^{60}Co (blue) in Bq/kg as a function of the liquid scintillator thickness to have 0.1 background events (after all cuts) per year in the 50 kg Xenon active volume. The dashed red line represents a limit of 20 μBk/kg.*

External Gammas

- Spectrum and rate taken from measurements at LSM: H. Ohsumi *et al.* [NEMO Collaboration], Nucl. Instrum. Meth. A **482**, 832 (2002).

- The most critical energy range given the rate is 1.7-4 MeV.

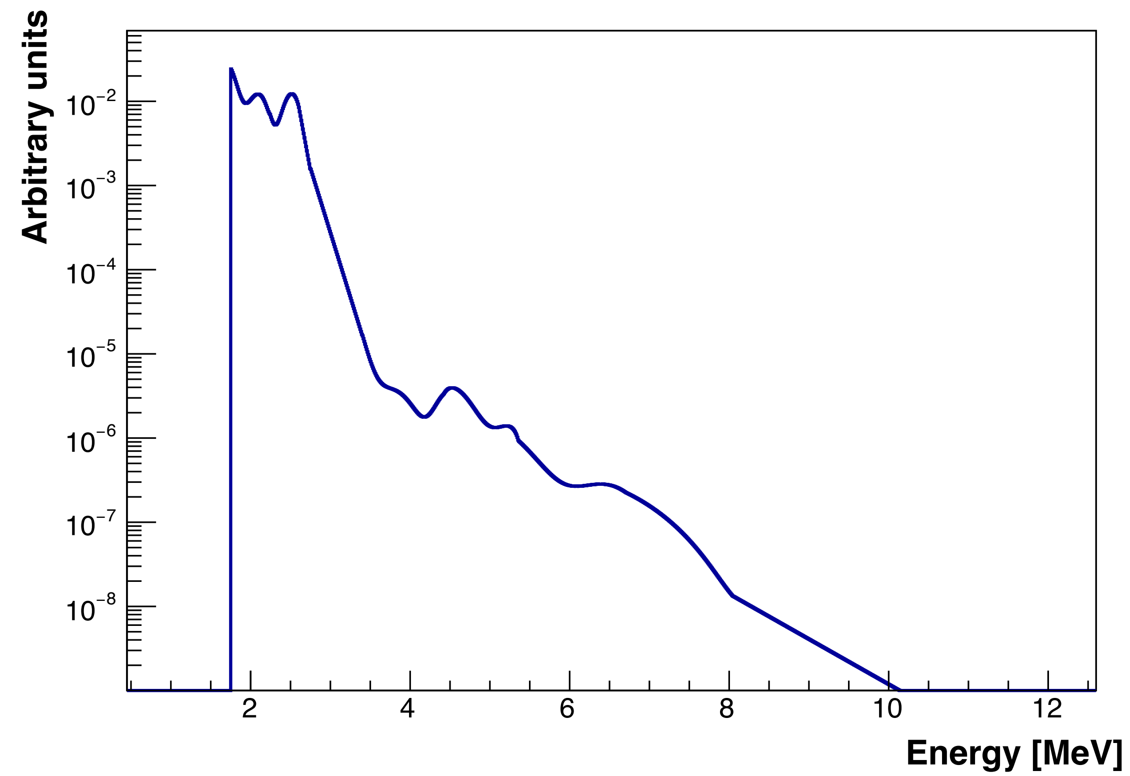


Figure 10: *External gamma background spectrum in arbitrary units taken from Ref. [15].*

Shielding	Events per year
No shielding	20250 ± 4700
(5 cm Cu + 10 cm Pb)	27 ± 6
(5 cm Cu + 10 cm Pb) + 5 cm Pb	1.5 ± 0.4
(5 cm Cu + 10 cm Pb) + 10 cm Pb	0.12 ± 0.03

Table 2: *Number of external gamma background events per year, in the energy region 1.7–4 MeV, for different shieldings. The shielding quoted in parentheses is accounted for in the total rate determination, whereas the one quoted outside the parentheses is directly implemented in the MC as an additional spherical layer.*

Neutrons

- Neutrons capture giving gammas are already accounted for. We then considered high energy neutrons giving proton recoils and neutron captures on Xenon.
- In a conservative way we did not consider Xenon enrichment. The background is negligible.

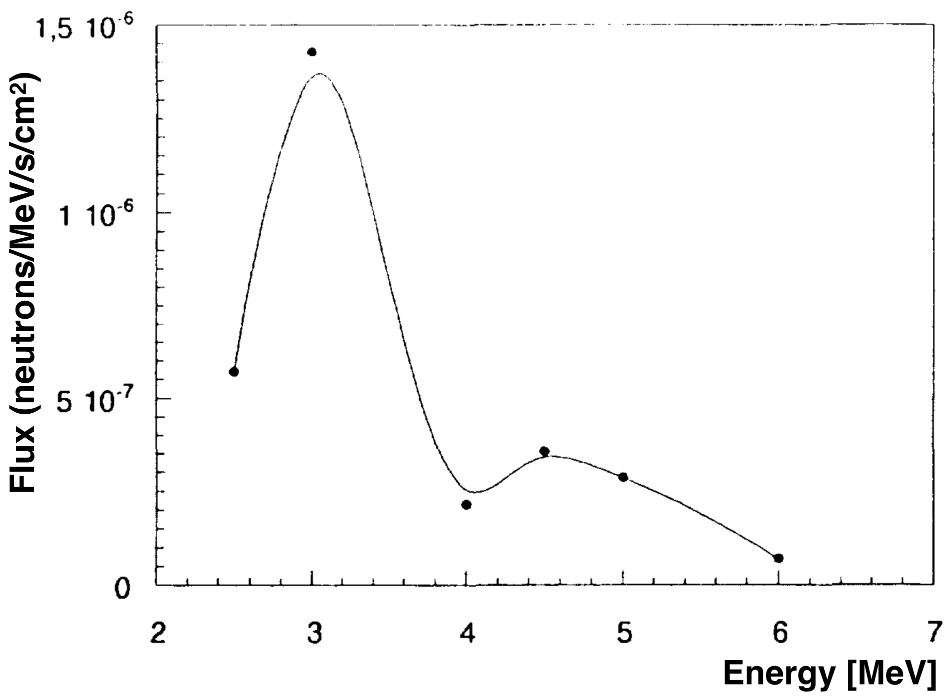


Figure 11: *External neutron flux measured at LSM taken from Ref. [16].*

Isotope	Fraction of isotope abundance	Fraction of captures	Mean number of gammas	Mean total gamma energy
^{128}Xe	1.91%	0.3%	5.5	6.9 MeV
^{129}Xe	26.4%	21.5%	9.5	9.2 MeV
^{130}Xe	4.07%	0.6%	6.4	6.6 MeV
^{131}Xe	21.23%	77.0%	4.1	7.1 MeV
^{132}Xe	26.91%	0.4%	4.8	6.4 MeV
^{134}Xe	10.44%	0.1%	6	6.4 MeV
^{136}Xe	9.04%	0.1%	2.1	4.0 MeV

Table 3: *Results obtained from the GEANT4 simulation on the fraction of neutron absorption on each Xenon isotope normalized to the total number of absorptions. The mean number of gammas emitted and the mean total energy are also given.*

Radon

- Considering that we want a background below 0.1 events per year the constraint on Rn in the **Xenon** volume is **50 μBq/kg** or equivalently **12 mBq/m^3**.
- In the liquid scintillator the constraint is given by the rate of trigger. To be below 1 Hz we need **5 μBq/kg**. (in KamLAND a factor of 100 better was achieved).
- We also have to consider the surface deposition and rate of Pb210. Limited by the trigger rate we need an activity better than **2 μBq/cm^2**. In CUORE and at LSM a factor of 10 better was achieved.

Summary

Constraint	Reason
Copper Xenon vessel activity below 10 μBq/kg	Background from the Xenon vessel at the level of 1 event per year in 50 kg
Liquid scintillator thickness of at least 150 cm Copper/stainless steel liquid scintillator vessel activity below 25 μBq/kg	Reduce the background from the liquid scintillator vessel below the level of 0.1 events per year in 50 kg
Lead shielding of at least 25 cm	Reduce the background from external gammas below the level of 0.1 events per year in 50 kg Reduce the trigger rate in LS due to low energy external gamma below the level of 1 Hz
Radon activity in Xenon volume below 50 μBq/kg	Reduce the background from Radon below the level of 0.1 events per year in 50 kg
Radon activity in LS volume below 5 μBq/kg	Reduce the trigger rate in LS due to Radon below the level of 1 Hz
Lead activity on LS vessel surface below 2 μBq/cm^2	Reduce the trigger rate in LS due to ^{210}Pb below the level of 1 Hz

Table 7: *Major constraints on the detector setup arisen from the presented studies.*