BACKGROUND REDUCTION FOR GERMANIUM DOUBLE BETA DECAY DETECTORS

Héctor Gómez Maluenda. University of Zaragoza.

hgomez@unizar.es

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OUTLINE

- Motivations.
- Simulation features.
- Granularity.
- Segmentation.
- Spatial Resolution & Pulse Shape Analysis.
- Estimation of counting rates.
- $0\nu\beta\beta$ Events.
- Summary & Conclusions.
- Outlook.

MOTIVATIONS

- New generation of **neutrinoless double beta decay** experiments using enriched germanium detectors need to reach a background level of **~10^{-3} c/(keV kg y)** in the Region of Interest to have the expected sensitivity.

- Three main contributions in 2.0-2.1 MeV region:

  Internal contamination of **^{60}Co** and **^{68}Ge** due to cosmogenic activation of germanium crystals.

  External **2614.5 keV** gammas coming from ^{232}Th chain.

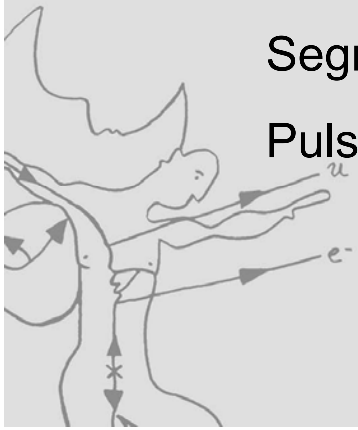
- Need to study the optimal configuration for the mass and the distribution of the germanium detectors and to quantify the background reduction that can be reached using different techniques:

  Granularity of the experiment.

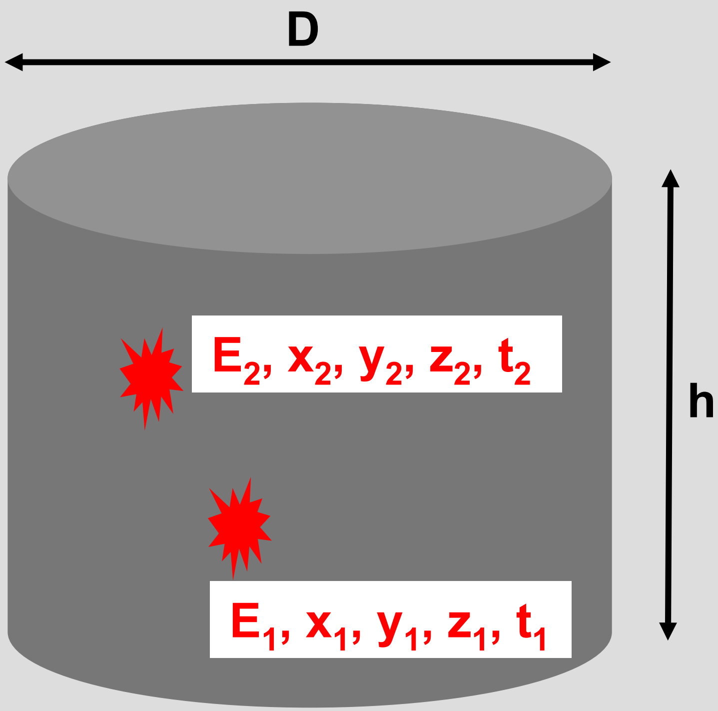
  Segmentation of the crystal.

  Pulse Shape Analysis (PSA).

} **SIMULATION**



SIMULATION FEATURES



Cylindrical detectors (D=h).

Natural Germanium.

Masses between 0.1 and 4 kg.

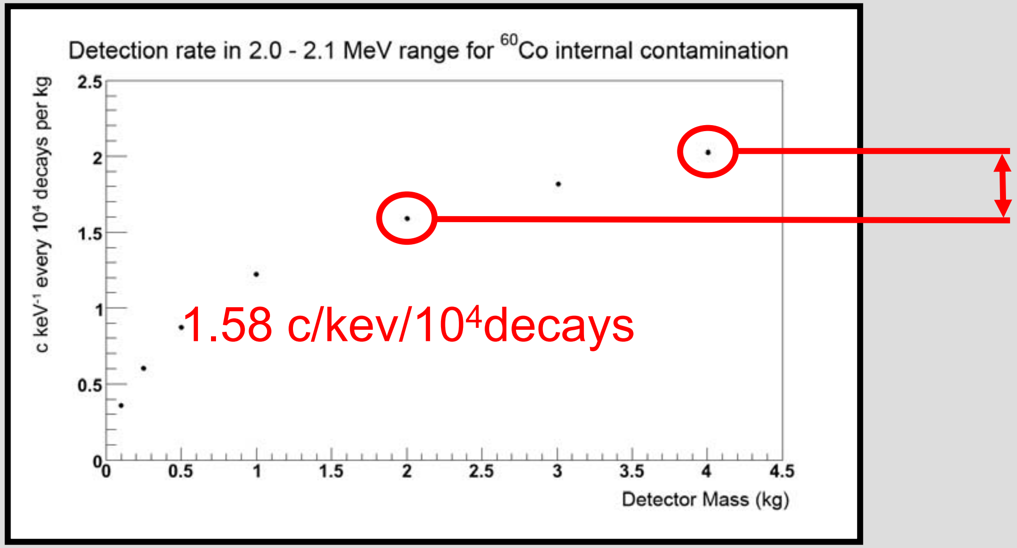
Neither cryostat nor shielding.

Standard GEANT4 models.

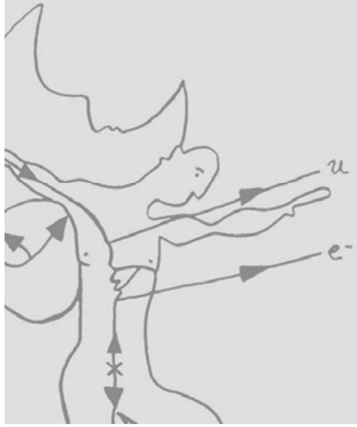
Position, Energy and Time of each interaction produced in an event have been registered. → **Possibility of different analysis.**

GRANULARITY

What could be the optimal mass of the detectors that build the whole experiment to have a background level as low as possible?



28% more events registered in the RoI in a 4 kg detector than in a 2 kg one for ^{60}Co internal contamination.



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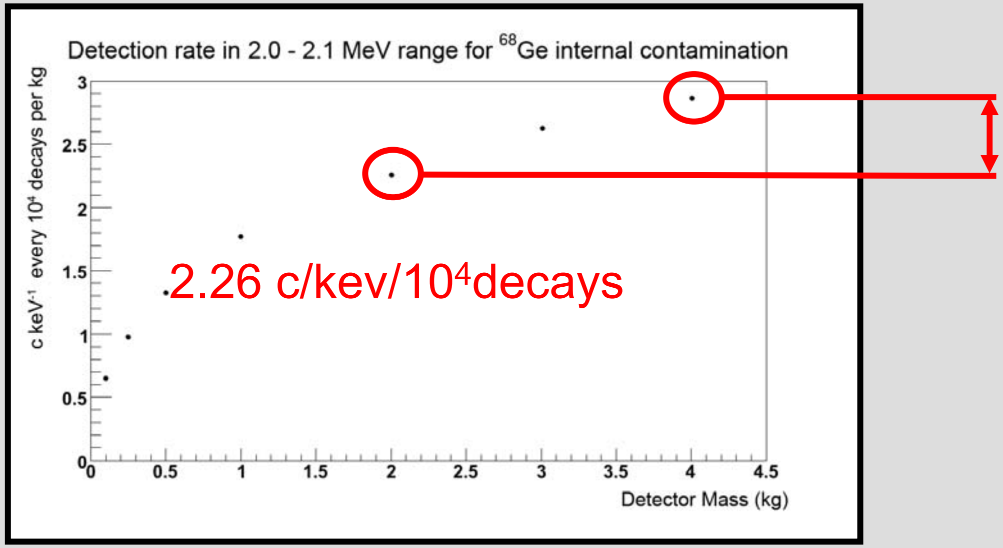
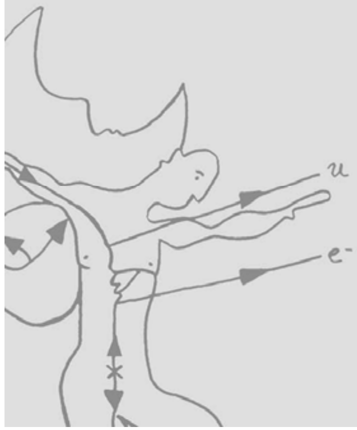


26% more events registered in the RoI in a 4 kg detector than in a 2 kg one for ^{68}Ge internal contamination.



GRANULARITY

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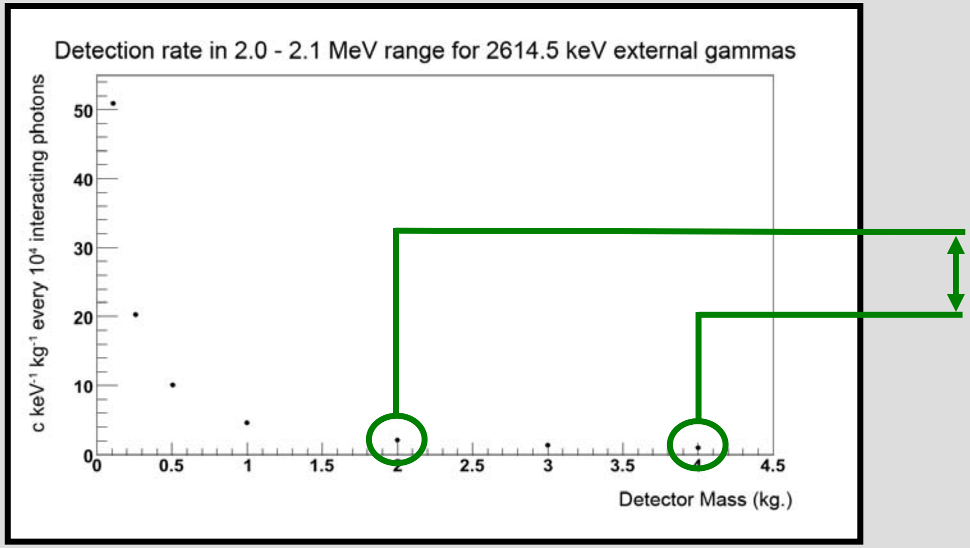


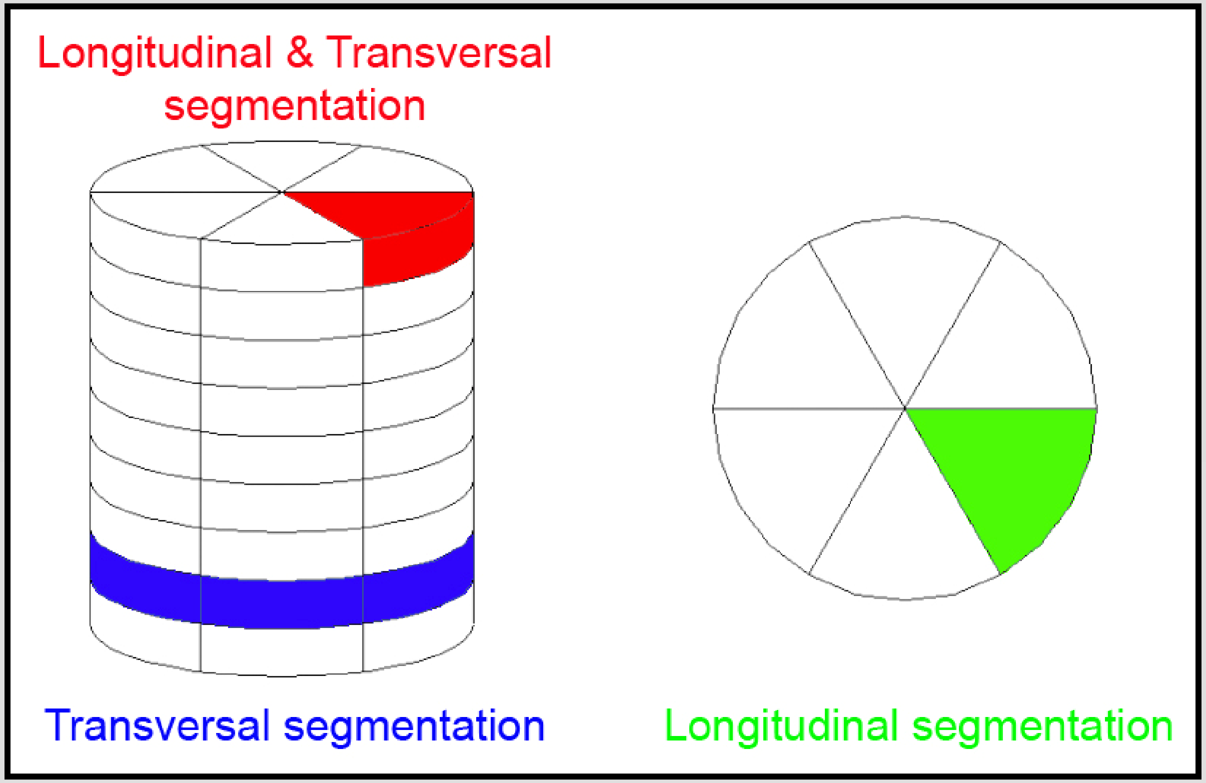
54% less events registered in the RoI in a 4 kg detector than in a 2 kg one for 2614.5 keV external photons.

OPTIMAL MASS OF THE COMPONENT DETECTORS DEPENDS ON WHAT KIND OF BACKGROUND EVENTS WE WANT TO REDUCE.

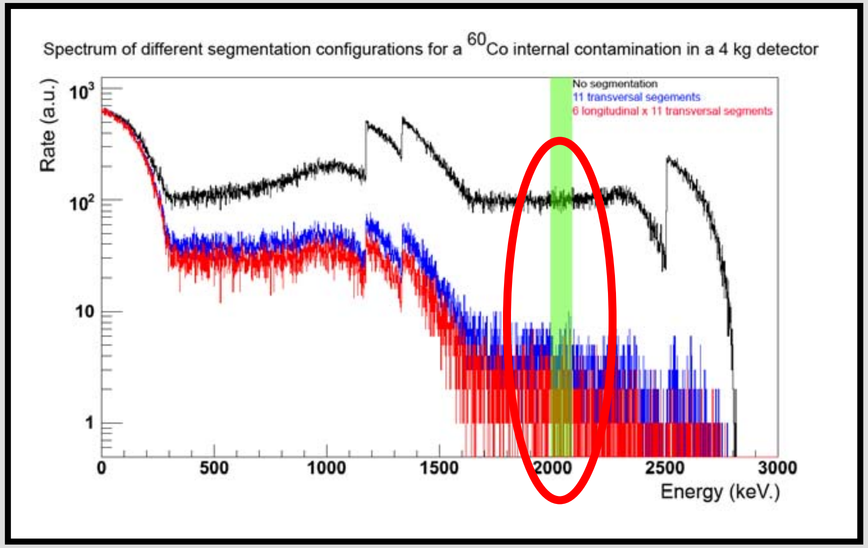
SEGMENTATION

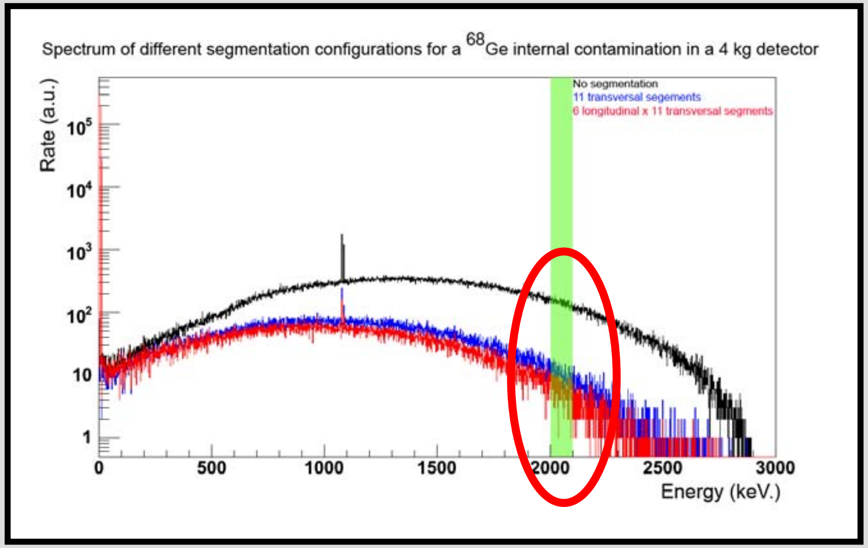
How much can we reduce the background by segmentation of crystals and anticoincidence techniques?

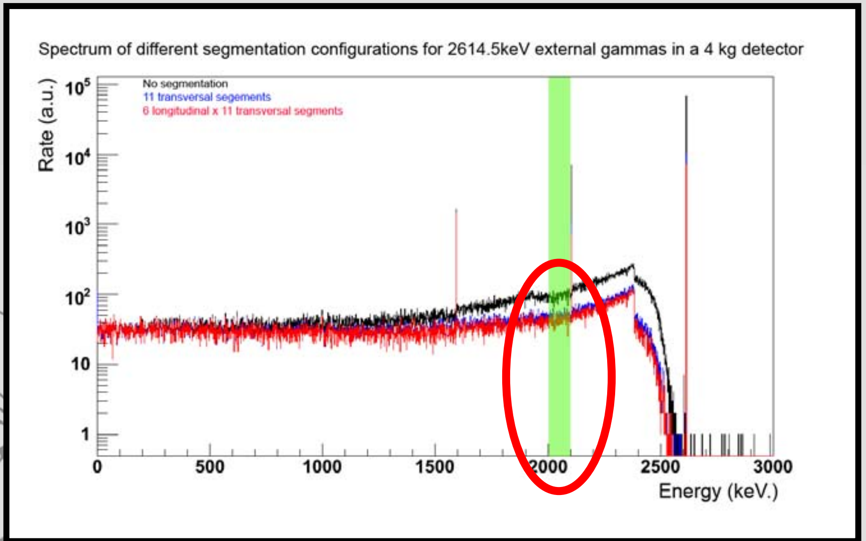
SEGMENTATION SCHEME:



SEGMENTATION







Up to **98 out of 100** background events coming from ^{60}Co internal contamination can be rejected applying segmentation and anticoincidence techniques.

95 out of 100 events from ^{68}Ge and **more than a half** from 2614.5 keV gammas can be also rejected.

SEGMENTATION

SUMMARY FOR OTHER SEGMENTATION SCHEMES

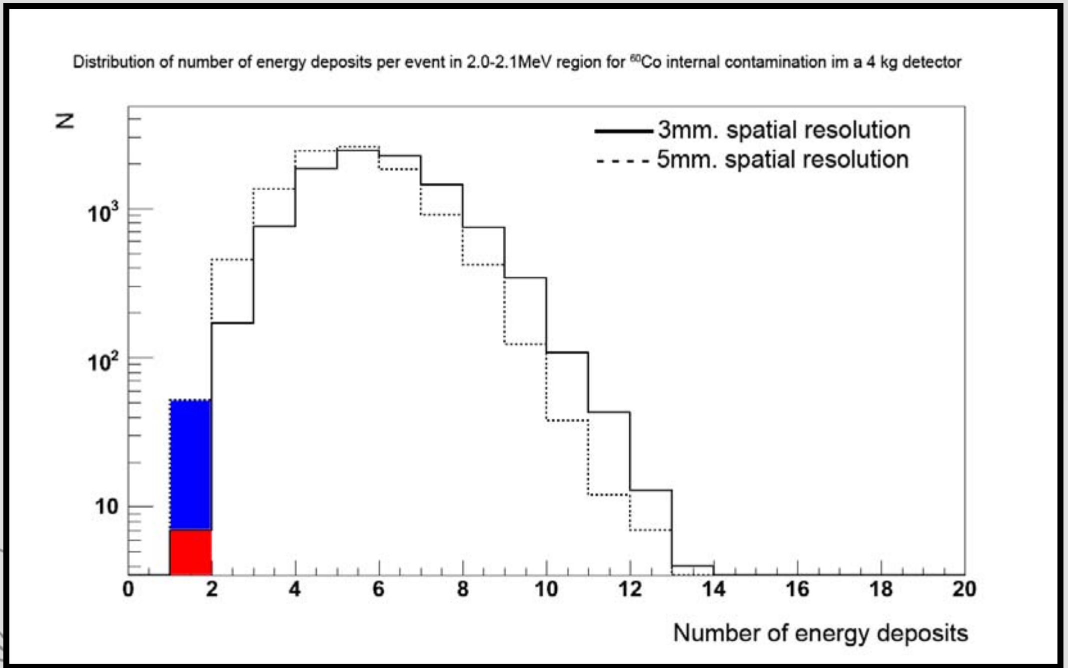
Percentage of rejected events in 2-2.1 MeV region by segmentation and anticoincidence techniques.

	2 kg				4 kg			
	7 planes	9 planes	7 planes & 6 sectors	9 planes & 6 sectors	9 planes	11 planes	9 planes & 6 sectors	11 planes & 6 sectors
^{60}Co	**92.4**	**95.6**	**97.0**	**98.2**	**94.9**	**96.7**	**97.6**	**98.4**
^{68}Ge	**86.1**	**90.7**	**93.2**	**95.1**	**89.8**	**92.7**	**94.2**	**95.8**
2614.5 keV gammas	**40.6**	**44.4**	**48.6**	**51.0**	**45.4**	**49.4**	**52.4**	**55.1**

SPATIAL RESOLUTION & PSA

➢ Spatial resolution of the detectors, obtained by the analysis of the registered pulses, allows to differentiate background “multisite” events from real DBD “monosite” events.

➢ Current techniques can locate an energy deposit with an accuracy between 2.5 and 5.4 mm. **(Kröll, Bazzacco. NIM A 565 (2006) 691-703)**



· 4 kg Detector:

0.1% of background events coming from ^{60}Co internal contamination are “monosite” if a **3 mm** spatial resolution is assumed.

The value is **0.5%** if the spatial resolution is **5 mm**.

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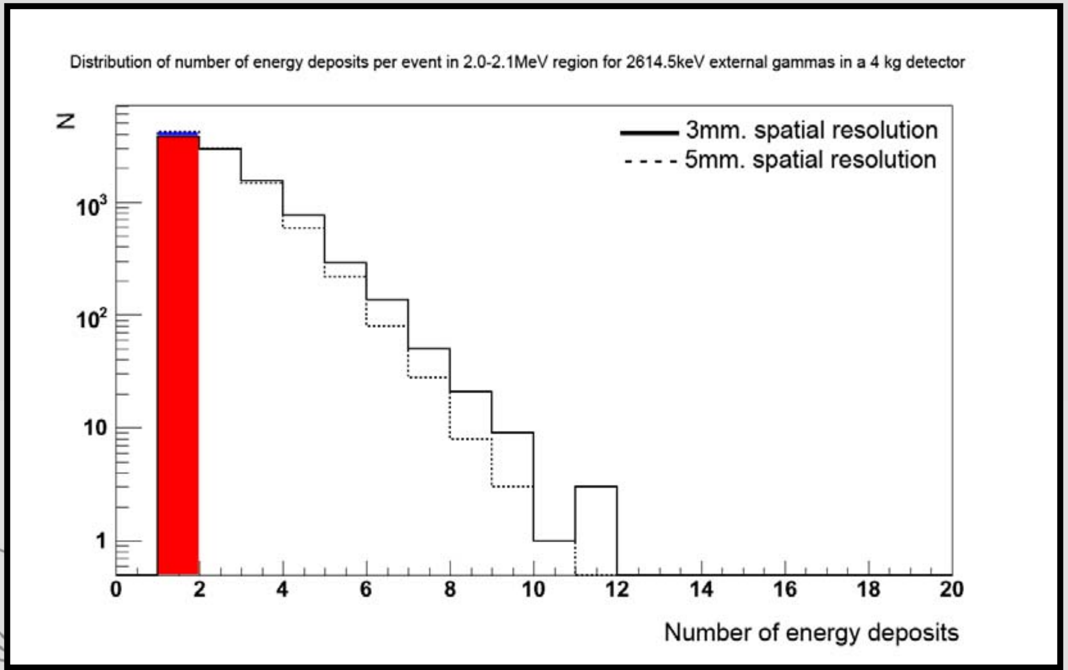

The distribution is quite different for the external 2614.5 keV contamination.

3 mm. → 39.7% "monosite".

5 mm. → 45.5% "monosite".

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	Percentage of “monosite” events in 2-2.1 MeV region assuming different spatial resolutions.			
	2 kg		4 kg	
	3 mm resolution	5 mm resolution	3 mm resolution	5 mm resolution
^{60}Co	**0.3**	**1.0**	**0.1**	**0.5**
^{68}Ge	**1.1**	**3.0**	**0.8**	**2.2**
2614.5 keV gammas	**44.4**	**48.8**	**39.7**	**45.5**

COUNTING RATES

- To estimate the raw background is necessary to make some **hypothesis**:

- **COSMOGENIC ACTIVATION OF THE CRYSTAL:**
  - ^{60}Co: 5 kg^{-1} d^{-1} of Production Rate and 30 d of Exposure Time.
  - ^{68}Ge: 2 configurations

    a) 1 kg^{-1} d^{-1} of Production Rate, 180 d of Exposure Time and 180 d of Cooling Time.

    b) 10 kg^{-1} d^{-1} of Production Rate, 180 d of Exposure Time and 730 d of Cooling Time.

- **EXTERNAL CONTAMINATION:**
  - Environmental flux of 2614.5 keV photons: **0.1 cm^{-2} s^{-1}** (based on LSC meas.).

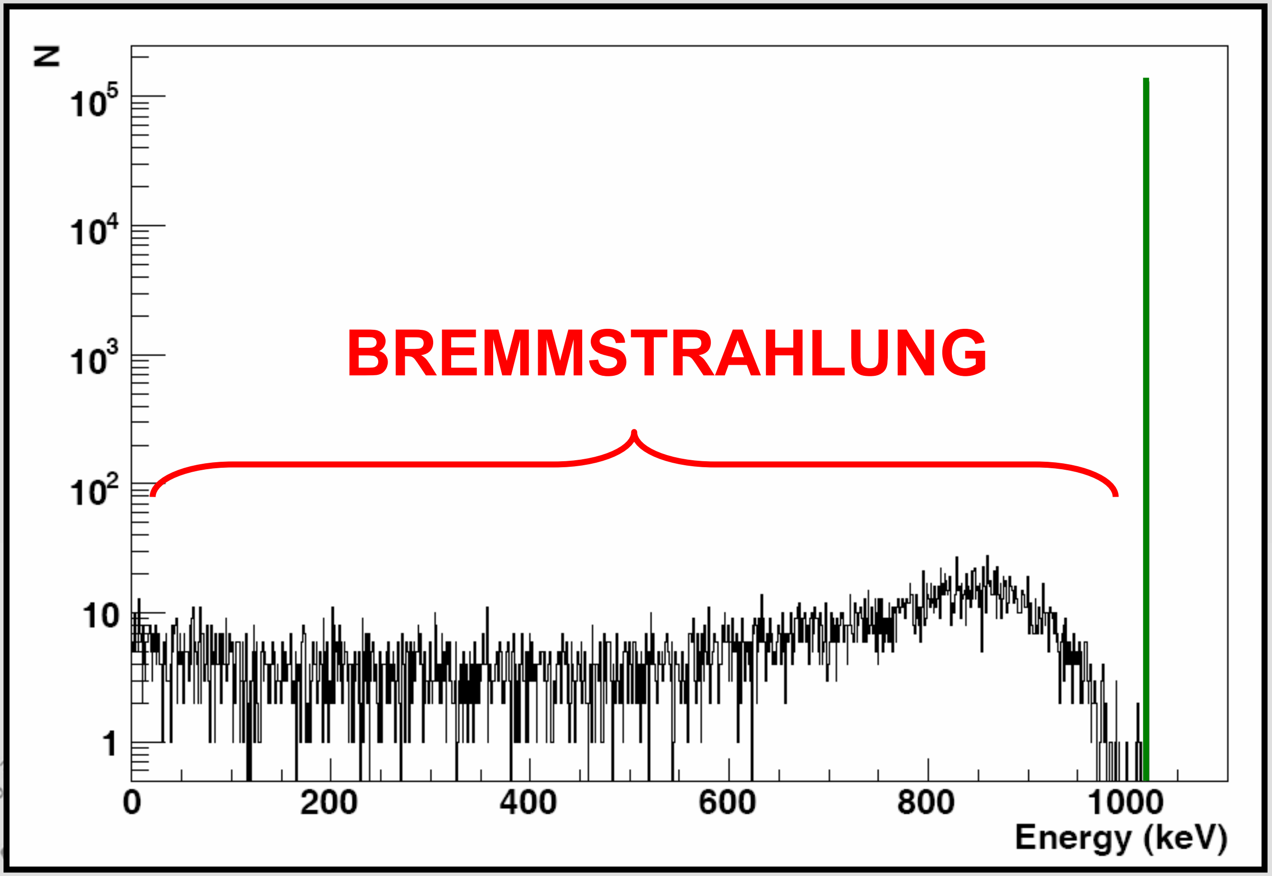
- **INTRINSIC CONTAMINATION OF LEAD:**
  - ^{232}Th Activity: **1 μBq kg^{-1}** (as starting value).

COUNTING RATES

	Estimates of counting rates R (c keV^{-1} kg^{-1} y^{-1}) in the 2-2.1 MeV region of interest					
	2 kg			4 kg		
	raw	9 planes & 6 sectors	Segmented PSA	raw	11 planes & 6 sectors	Segmented PSA
^{60}Co	**$2.9x10^{-3}$**	**$5.2x10^{-5}$**	**$8.7x10^{-6}$**	**$3.7x10^{-3}$**	**$6.0x10^{-5}$**	**$3.7x10^{-6}$**
^{68}Ge (a)	**$1.2x10^{-2}$**	**$6.1x10^{-4}$**	**$1.4x10^{-4}$**	**$1.6x10^{-2}$**	**$6.8x10^{-4}$**	**$1.3x10^{-4}$**
^{68}Ge (b)	**$3.1x10^{-2}$**	**$1.5x10^{-3}$**	**$3.4x10^{-4}$**	**$3.9x10^{-2}$**	**$1.7x10^{-3}$**	**$3.1x10^{-4}$**
External 2614.5 keV 30 cm Pb	**$3.0x10^{-2}$**	**$1.5x10^{-2}$**	**$1.3x10^{-2}$**	**$2.4x10^{-2}$**	**$1.1x10^{-2}$**	**$9.4x10^{-3}$**
External 2614.5 keV 40 cm Pb	**$2.6x10^{-4}$**	**$1.3x10^{-4}$**	**$1.1x10^{-4}$**	**$2.1x10^{-4}$**	**$9.3x10^{-5}$**	**$8.3x10^{-5}$**
Intrinsic 2614.5 keV in lead	**$2.8x10^{-3}$**	**$1.4x10^{-3}$**	**$1.2x10^{-3}$**	**$2.2x10^{-3}$**	**$9.9x10^{-4}$**	**$8.8x10^{-4}$**
BEST TOTAL	**$1.8x10^{-2}$**	**$2.1x10^{-3}$**	**$1.5x10^{-3}$**	**$2.2x10^{-2}$**	**$1.8x10^{-3}$**	**$1.1x10^{-3}$**

0νββ EVENTS

- A "single" energy deposit of 2040 keV is expected as 0νββ signal.
- There are cases where not all the energy is collected.



0νββ EVENTS

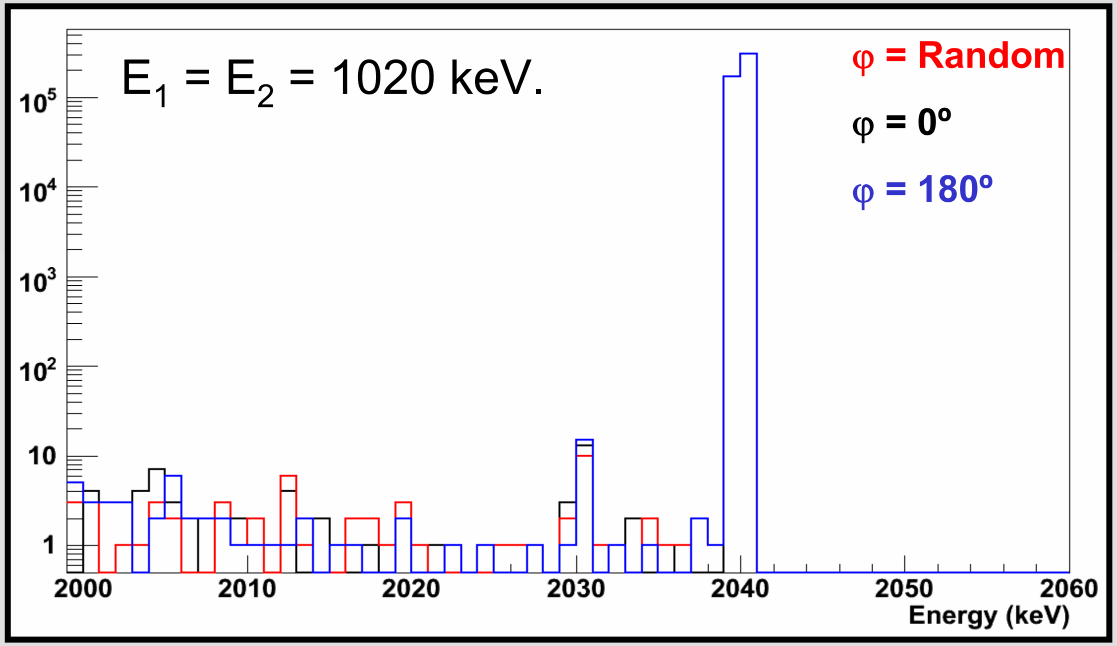
How many 0νββ events can we lose due to Bremmstrahlung?

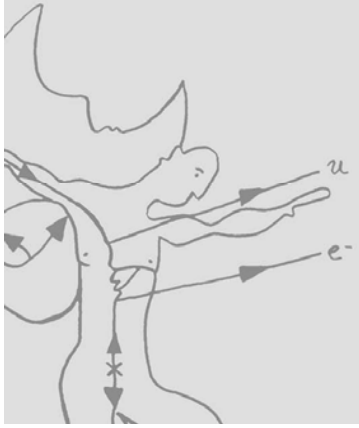
➢Simulation of 2 electrons from the same point:

$(x_0, y_0, z_0, E_1, E_2, \varphi)$

φ → Random angle is good to obtain a first estimation.

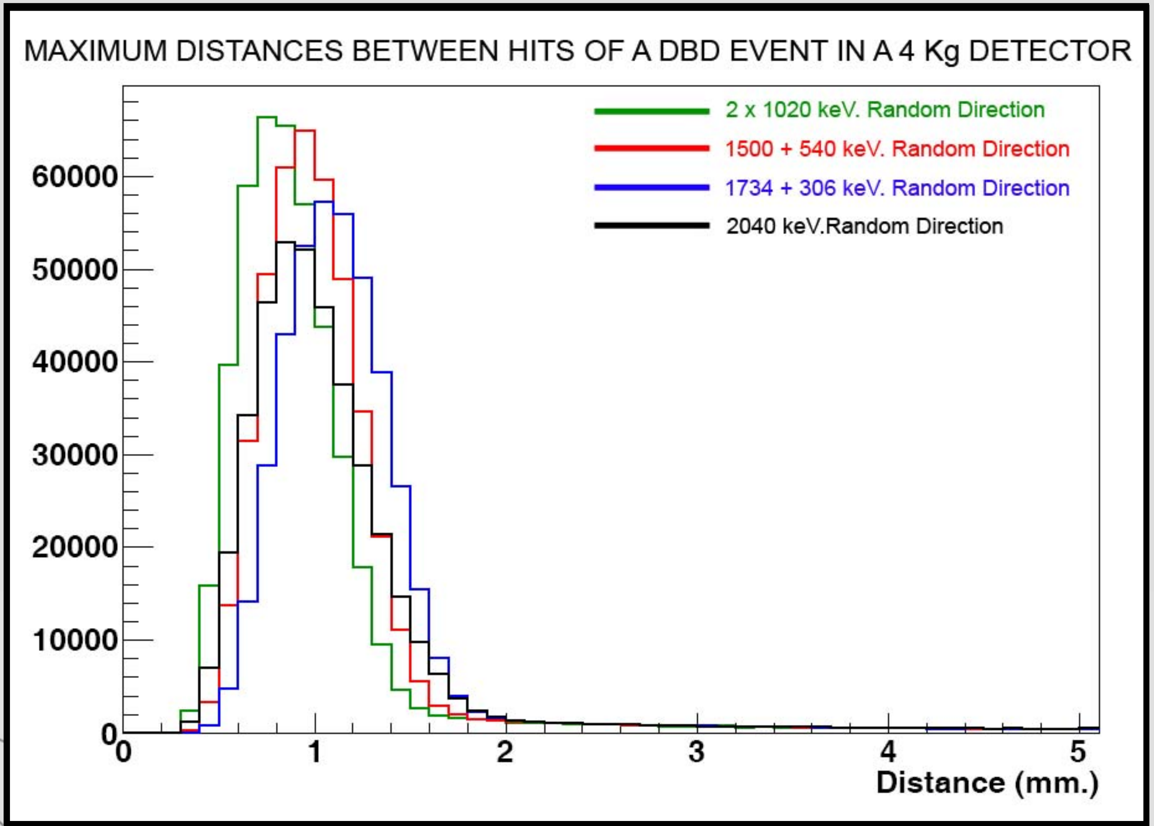
E_1, E_2 → $E_1 + E_2 = 2040$ keV





0νββ EVENTS

Distribution of the maximum distance between hits of an event is interesting for further analysis.



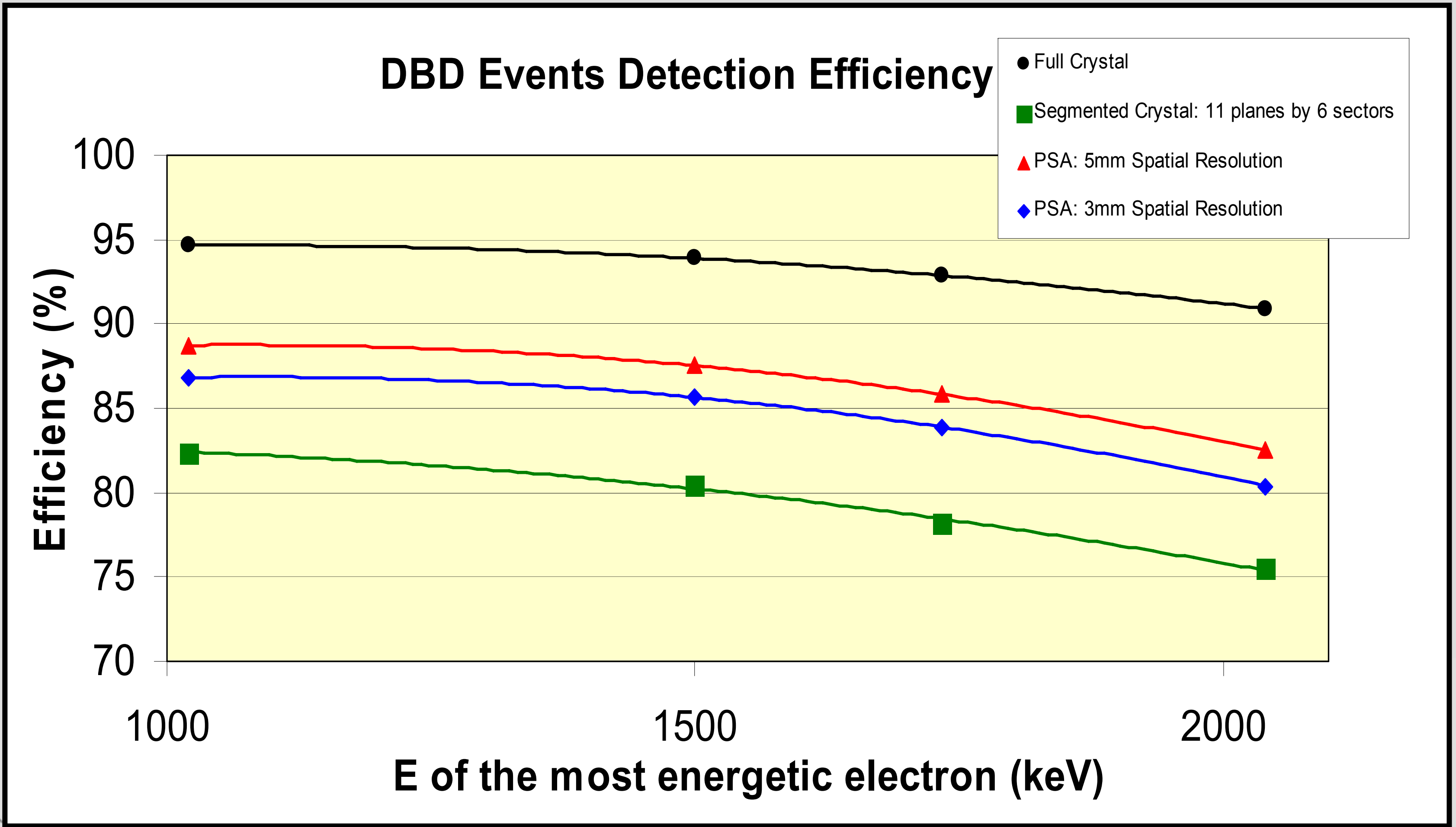
Most of the events have a maximum “interdistance” below 5 mm.

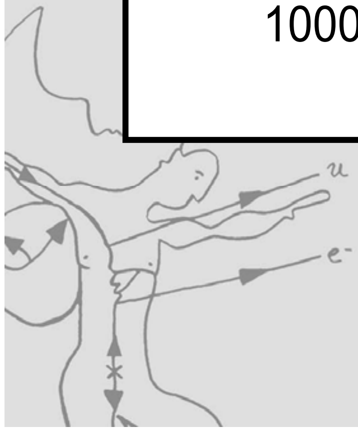
MONOSITE EVENTS FOR PSA.

0νββ EVENTS

	DETECTION EFFICIENCY OF 0νββ EVENTS IN A 4 kg DETECTOR						
	Full Crystal	Segmentation				PSA	
		9 planes	11 planes	9 planes 6 sectors	11 planes 6 sectors	3 mm	5 mm
2 x 1020 keV. Rand. Dir	**94.66**	**86.38**	**84.83**	**83.68**	**82.37**	**86.83**	**88.74**
1500 + 540 keV. Rand. Dir.	**93.91**	**84.84**	**83.13**	**82.00**	**80.47**	**85.64**	**87.52**
1734 + 306 keV. Rand. Dir.	**92.85**	**82.86**	**80.97**	**79.83**	**78.17**	**83.89**	**85.84**
2040 keV Rand. Dir.	**90.91**	**80.10**	**78.32**	**77.02**	**75.47**	**80.39**	**82.53**

0νββ EVENTS

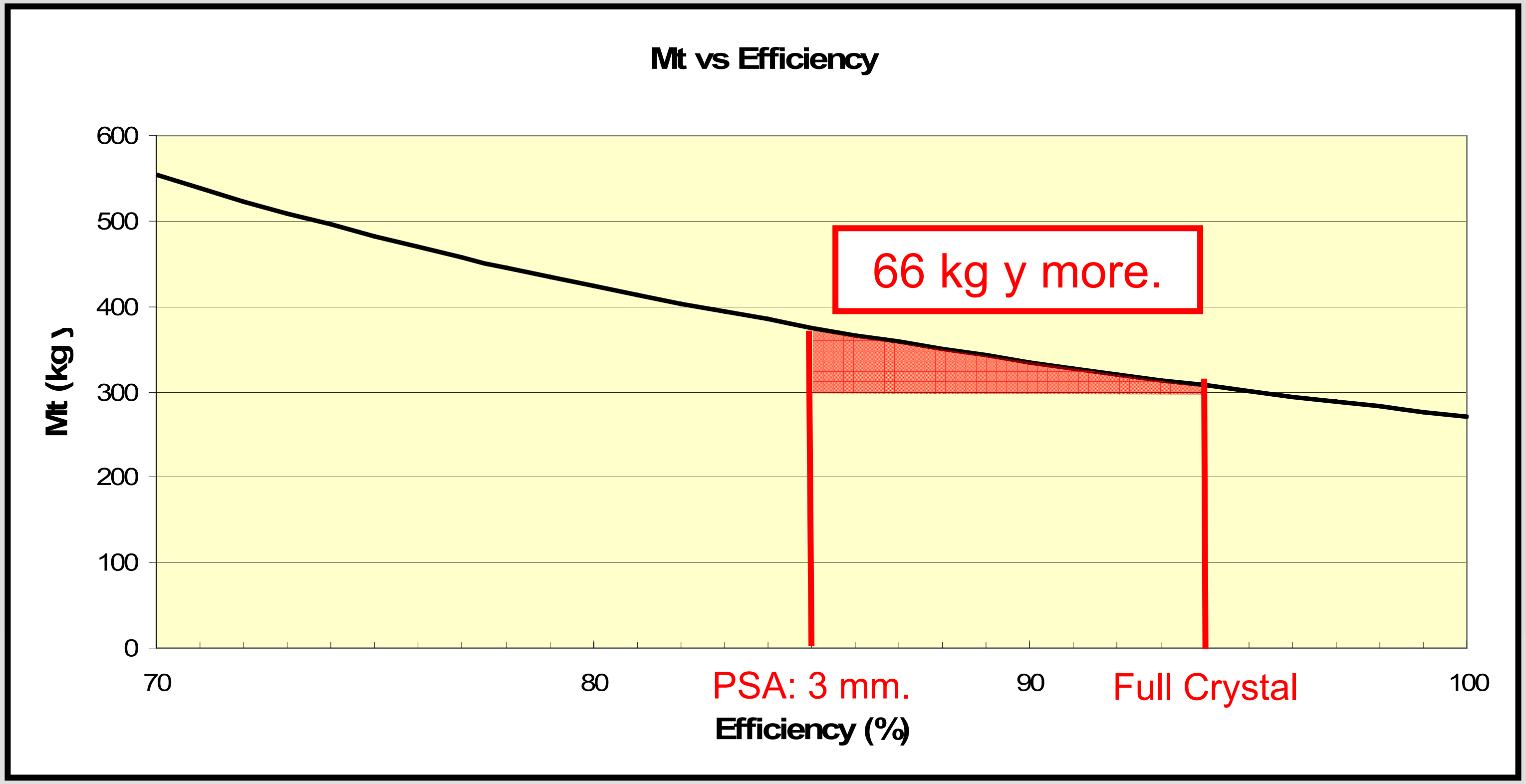


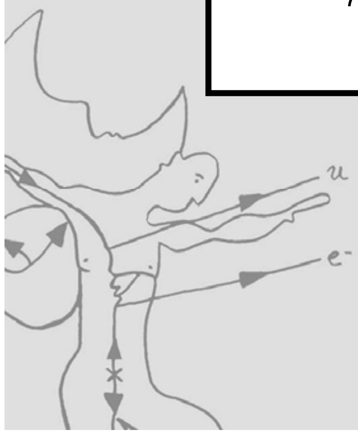


$$\varepsilon = aE^2 + bE + c$$

0νββ EVENTS

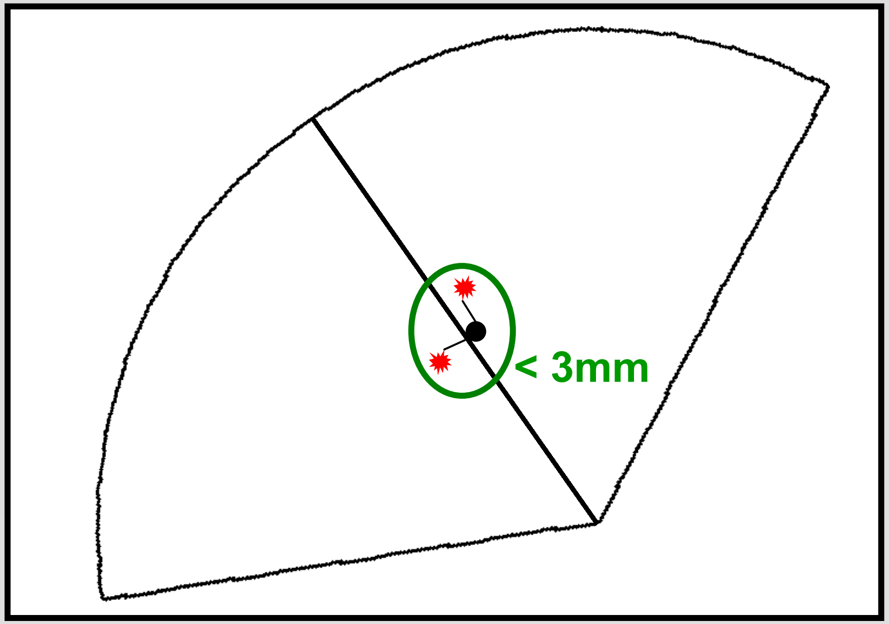
The importance of the efficiency.





0νββ EVENTS

A particular case: **Border events**



Anticoincidence between segments rejects these events.

PSA considers these events as MONOSITE

SUMMARY & CONCLUSIONS I

➢ Final background level of **10^{-3} c keV^{-1} kg^{-1} y^{-1}** using 2 kg or 4 kg detectors:

- Combination of some background reduction techniques.
- Appropriate contamination levels in the used components.

➢ Massive detectors are better in order to reject background events coming from external sources but worse for internal one.

➢ Background events coming from internal contamination of the crystal can be mostly rejected applying PSA and segmentation techniques.

➢ All these techniques have to be applied optimizing the efficiency of $0\nu\beta\beta$ events detection.

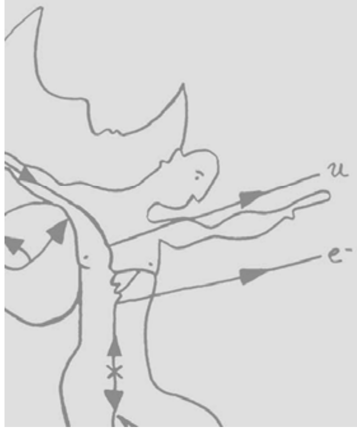
SUMMARY & CONCLUSIONS II

- It´s necessary to find ways to have a raw background level as low as possible:

  - Crystal growth and storage underground in order to avoid cosmogenic activation.

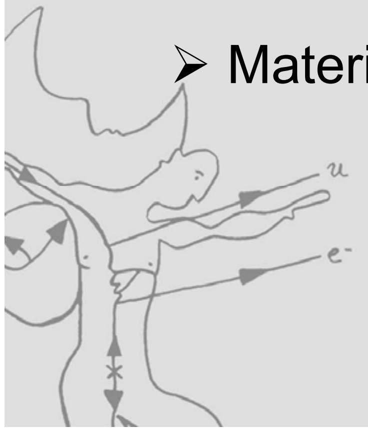
  - Use of radiopure materials for the cryostat and build the shielding.

- All the techniques to reduce the background level are quite conventional and can be done right now.



OUTLOOK

- Study of other background sources (neutrons…).
- Estimation of a final value of the efficiency for $0\nu\beta\beta$ events detection.
- Development of a PSA system.
- Design and development of a natural germanium prototype to be installed at Canfranc Underground Laboratory.
    - Underground electroformed copper cryostat.
    - Segmentation configuration.
    - Acquisition system.
    - Design and construction of the shielding for the prototype.
    - Materials selection.



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