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The β^- decay station at Orsay : BEDO

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Outline

- Nuclear structure study

- the β^- decay

- Production of radioactive beam in ALTO

- BEDO : BEta Decay at Orsay

- Performances

- Improvement

- Conclusion

Nuclear Structure study

In order to study the structure of a nuclei, we need to excite the nuclei.
Different technics are used :

- nuclear reaction : transfer reaction, fission, fusion …
- nuclear decay : β decay, α decay, βn decay …

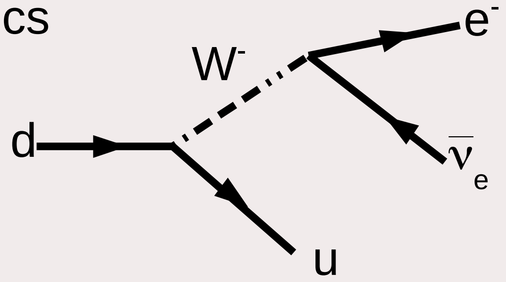
The ground state of a nucleus only gives information about the mass.

A small remember about the energy scale in nuclear physics :

- exited states in a nucleus : between tens of keV and tens of MeV
- beam : from few keV until 350 AMeV (AMeV = MeV per nucleons)

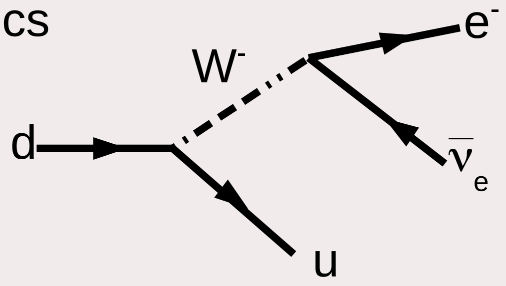
The β decay

Elementary particle physics



The β decay

Elementary particle physics

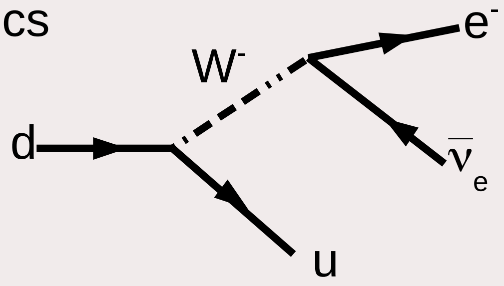


« Elementary » nuclear physics

$$n \rightarrow p + e^- + \bar{\nu}_e$$

The β decay

Elementary particle physics



« Elementary » nuclear physics

$$n \rightarrow p + e^- + \bar{\nu}_e$$

Nuclear physics

$${}^{A}_{Z}X_{N} \rightarrow {}^{A}_{Z+1}Y^{*}_{N-1} + e^- + \bar{\nu}_e \rightarrow {}^{A}_{Z+1}Y_{N-1} + \gamma + e^- + \bar{\nu}_e$$

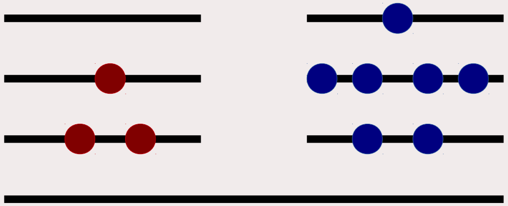
Why do we still study β decay ?

$${}^{A}_{Z}X_{N} \rightarrow {}^{A}_{Z+1}Y_{N-1}^{*} + e^{-} + \bar{\nu}_{e} \rightarrow {}^{A}_{Z+1}Y_{N-1} + \gamma + e^{-} + \bar{\nu}_{e}$$

Why do we still study β decay ?

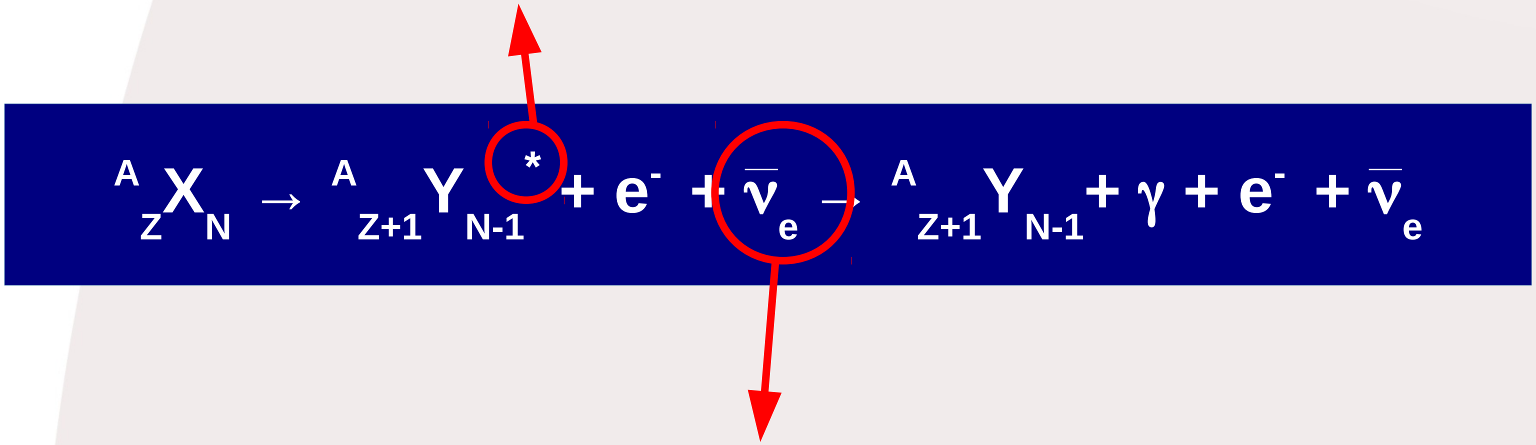
Effects due to strong interaction

$$ {}^{A}_{Z}X_{N} \rightarrow {}^{A}_{Z+1}Y_{N-1}^{*} + e^{-} + \bar{\nu}_{e} \rightarrow {}^{A}_{Z+1}Y_{N-1} + \gamma + e^{-} + \bar{\nu}_{e} $$



^{10}Li

Why do we still study β decay ?



Effects due to strong interaction

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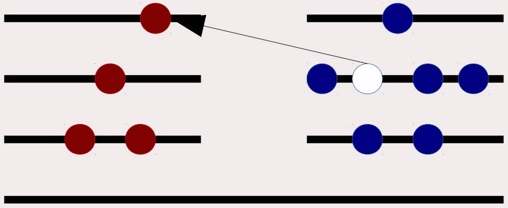
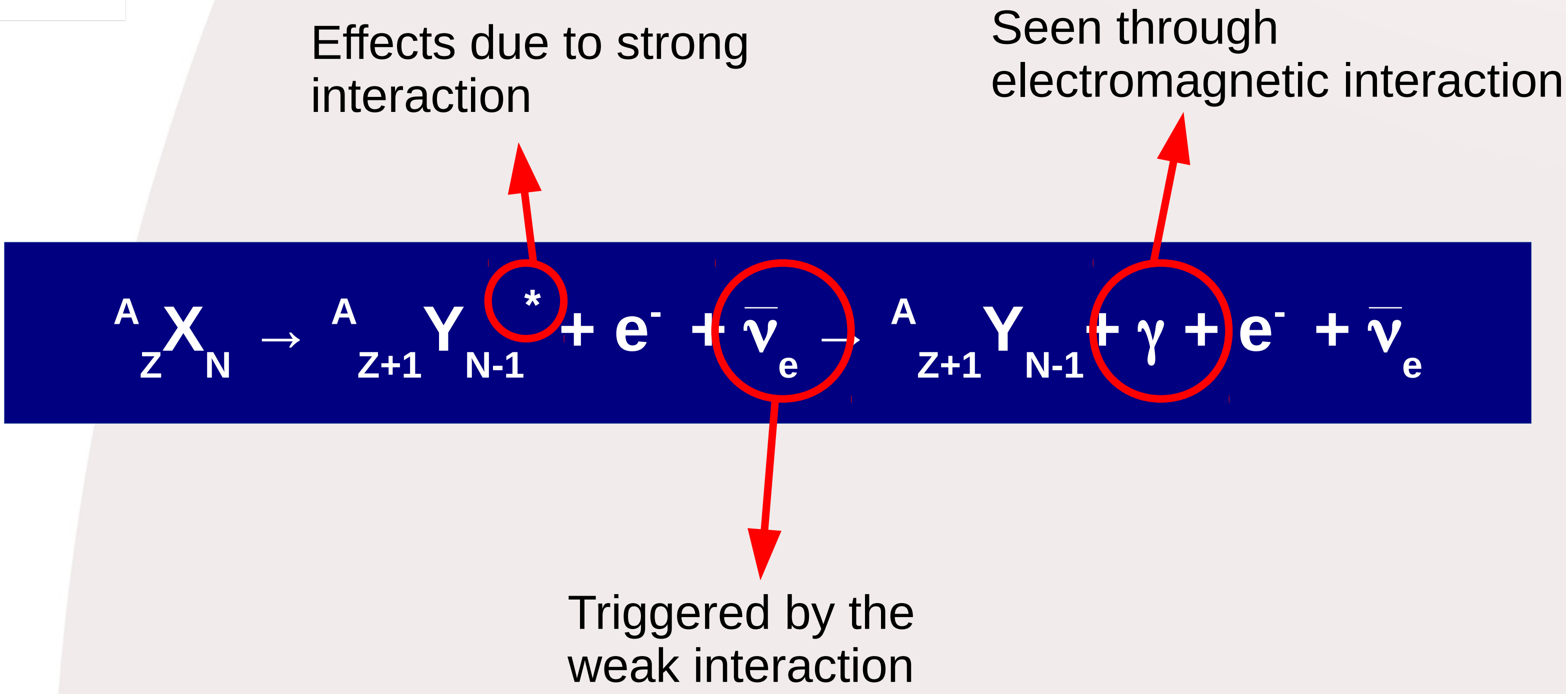
Triggered by the weak interaction



${}^{10}Be^{*}$

Why do we still study β decay ?

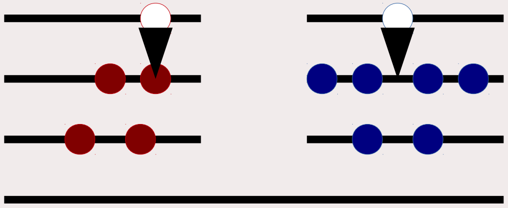


Effects due to strong interaction

Seen through electromagnetic interaction

$${}^{A}_{Z}X_{N} \rightarrow {}^{A}_{Z+1}Y^{*}_{N-1} + e^{-} + \bar{\nu}_{e} \rightarrow {}^{A}_{Z+1}Y_{N-1} + \gamma + e^{-} + \bar{\nu}_{e}$$

Triggered by the weak interaction



^{10}Be

Why do we still study β decay ?

The weak interaction is well known in the case of standard model but in the nuclei, its effects change :

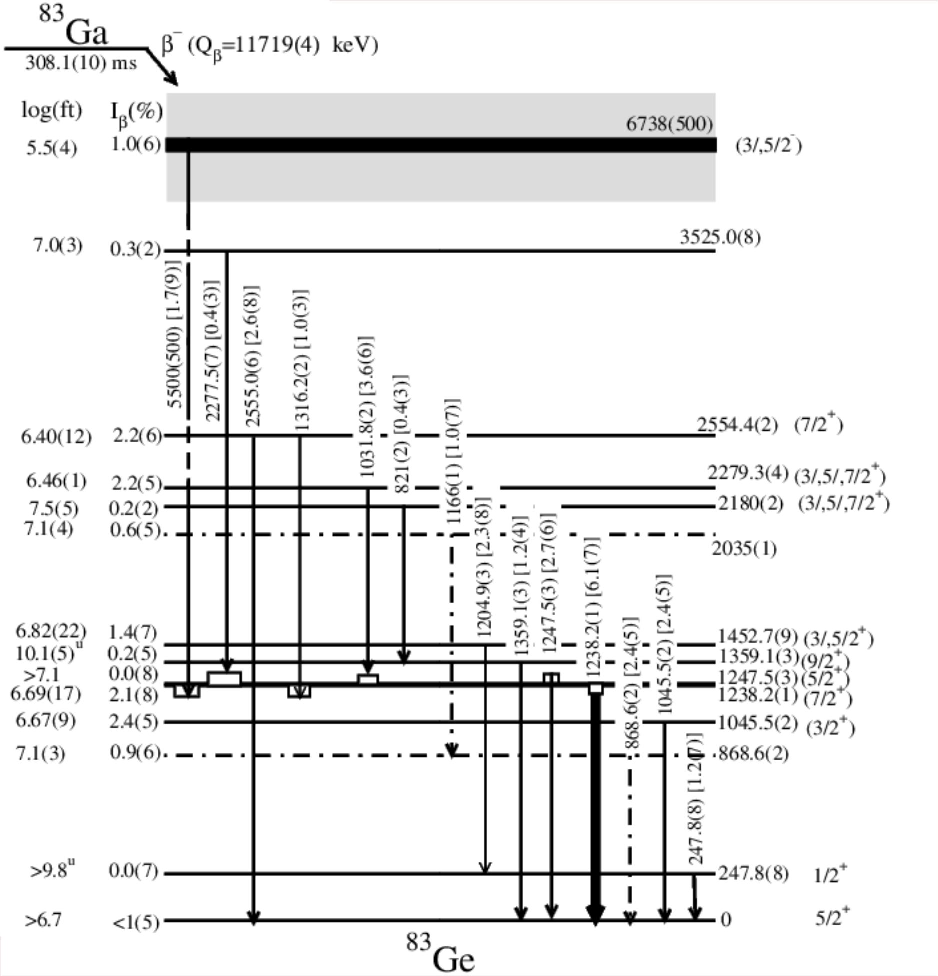
- Just binding a proton to the neutron (not stable) gives a stable nuclei : deuterium

- Typical time of weak interaction is less than 10^{-11}s but nuclei can have half life of thousands years (^{14}C).

- The nuclear shell model hamiltonian depends on the isospin projection and when a neutron is changed into a proton the isospin projection of the concerned nucleon is changed so the mean field acting on the other nucleon changes so effects can appear : nuclear resonnances, excitation, monopole drift …

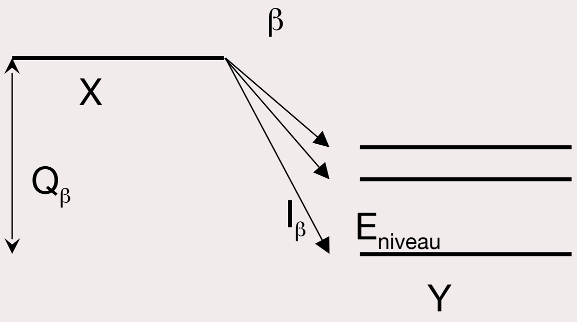
So β decay is a phenomenon allowing to study the strong interaction through electromagnetic interaction trigerred by weak interaction

How do we study nuclear structure trought β decay ?

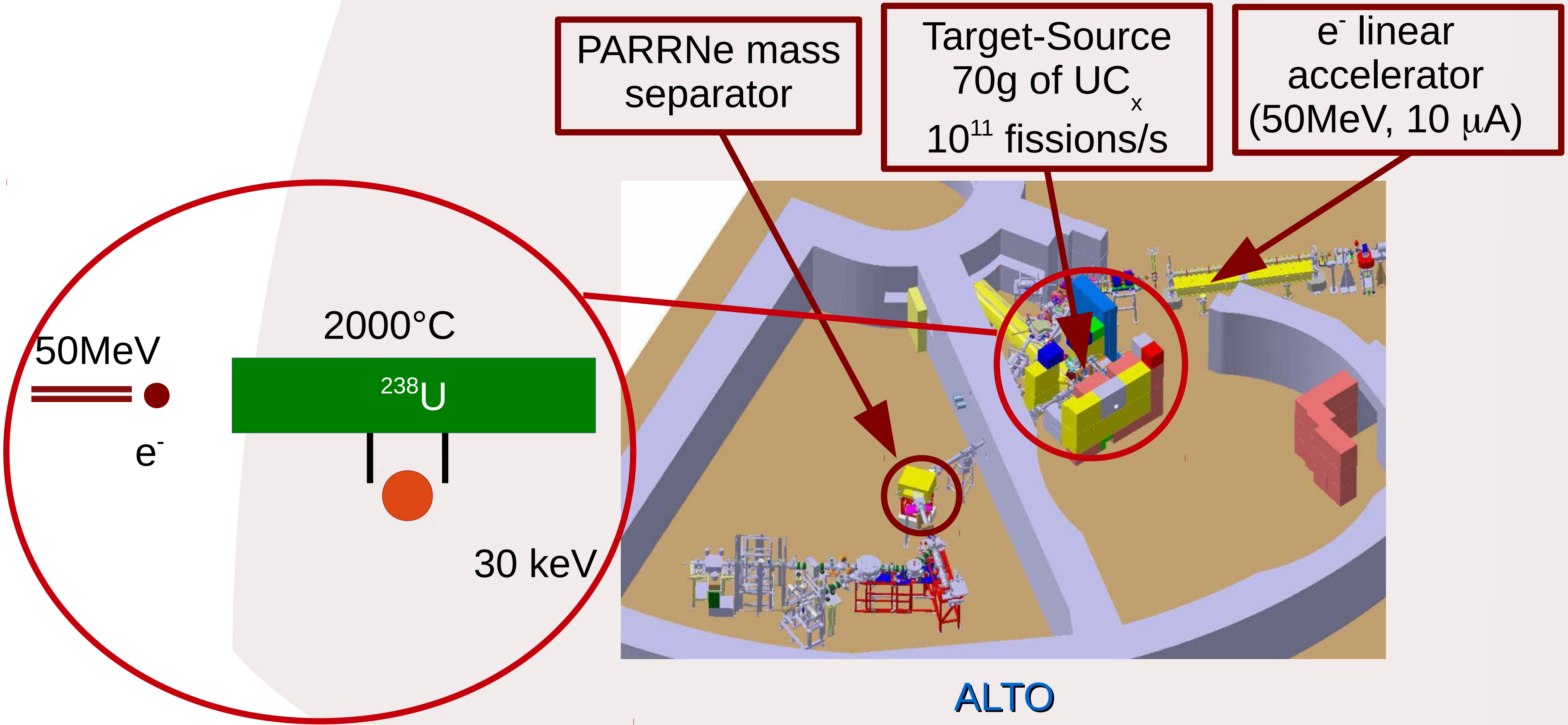


C. Delafosse et al., preliminary results

Type de transition	L	GT		$log(ft)$
		ΔJ	$\Delta\pi$	
Permise	0	0,1	non	<6
$1^{ère}$ interdite	1	0,1,2	oui	6-10
$2^{ème}$ interdite	2	1,2,3	non	10-13



Production of radioactive nuclei in ALTO



PARRNe mass separator

Target-Source
70g of UC_x
10^{11} fissions/s

e^- linear accelerator (50MeV, 10 μA)

50MeV

e^-

2000°C

^{238}U

30 keV

ALTO
(Accélérateur Linéaire – Tandem d'Orsay)

A β decay detector : what do we need ?

$$ {}^{A}_{Z}X_{N} \rightarrow {}^{A}_{Z+1}Y_{N-1}^{*} + e^{-} + \overline{\nu}_{e} \rightarrow {}^{A}_{Z+1}Y_{N-1} + \gamma + e^{-} + \overline{\nu}_{e} $$

A β decay detector : what do we need ?

$$ {}^{A}_{Z}X_{N} \rightarrow {}^{A}_{Z+1}Y_{N-1}^{*} \boxed{+ e^{-}} + \bar{\nu}_{e} \rightarrow {}^{A}_{Z+1}Y_{N-1} + \gamma + e^{-} + \bar{\nu}_{e} $$

An electron detector : the detection of an electron will be a time reference of the decay.

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An electron detector : the detection of an electron will be a time reference of the decay.

The photon energy are the signature of the daughter nuclei (Y), so we need high precision photon detector (10 keV < E < 10 MeV)

The neutrino is hardly detectable and useless for our study of beta decay !

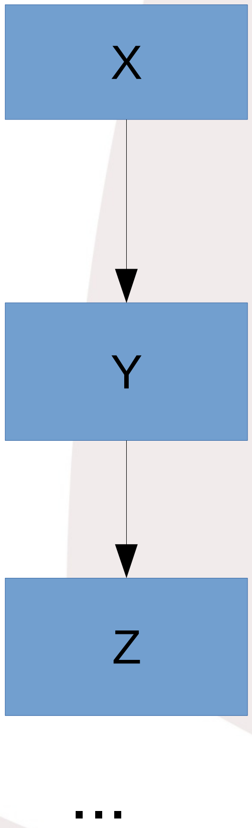
BEDO : Multiple detector

Constrains :

- Avoid long lived descendants activities !
- Have a good beta efficiency
- Have a good gamma efficiency and energy resolution
- Have clean spectra

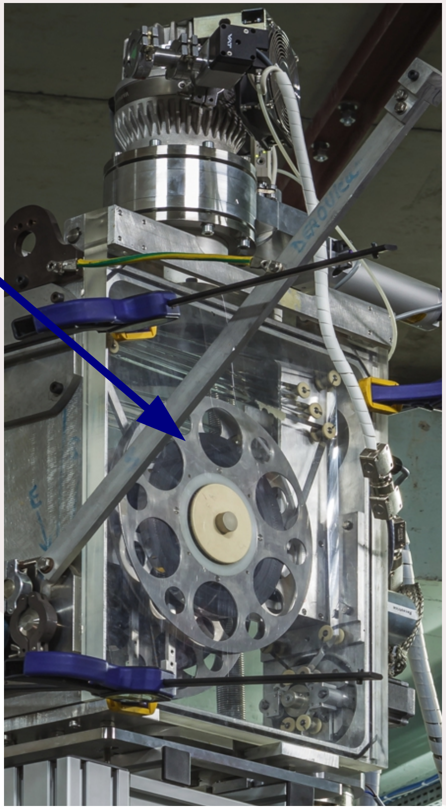
BEDO : Multiple detector

#1 Avoid long lived descendant activities

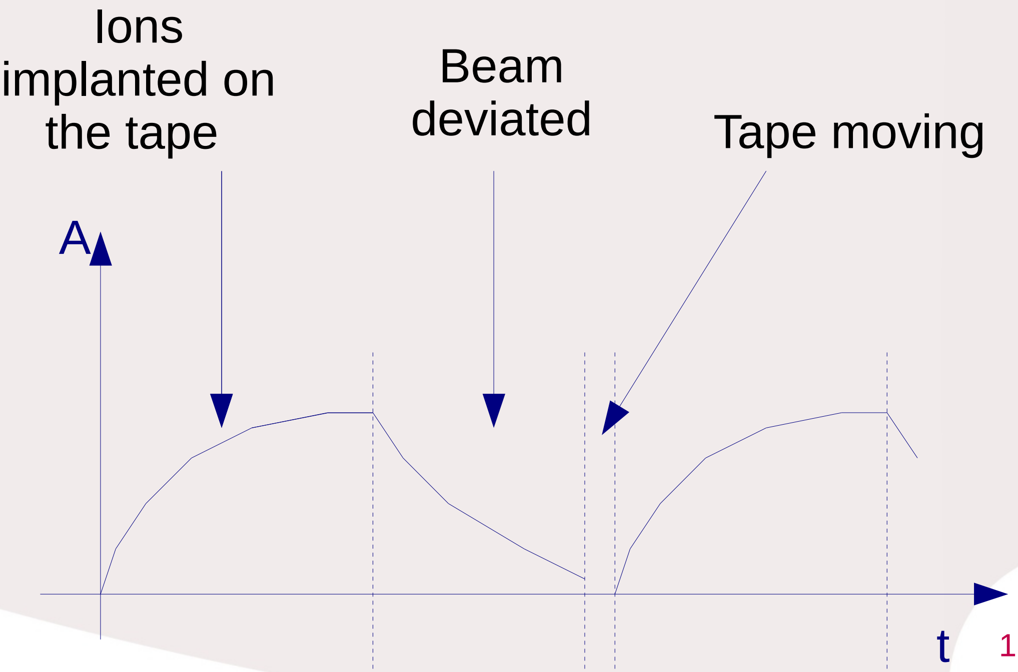


#1 Avoid long lived descendant activities

Solution : moveable aluminium coated mylar tape



Double wheels



Ions implanted on the tape

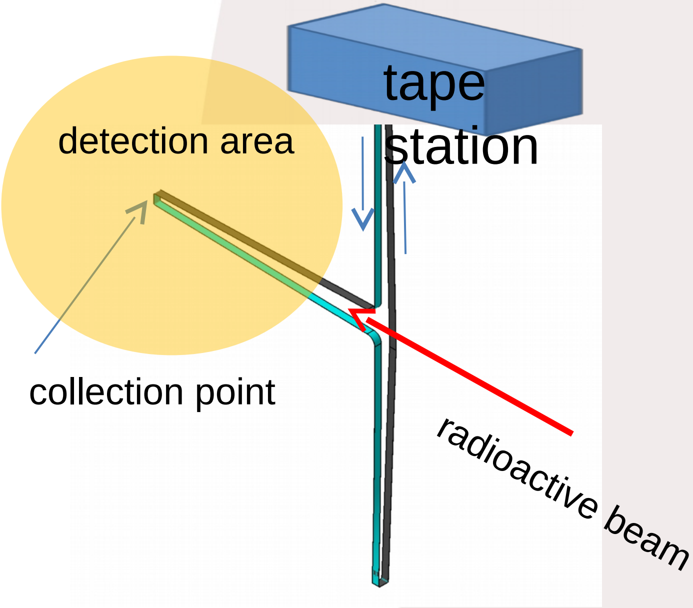
Beam deviated

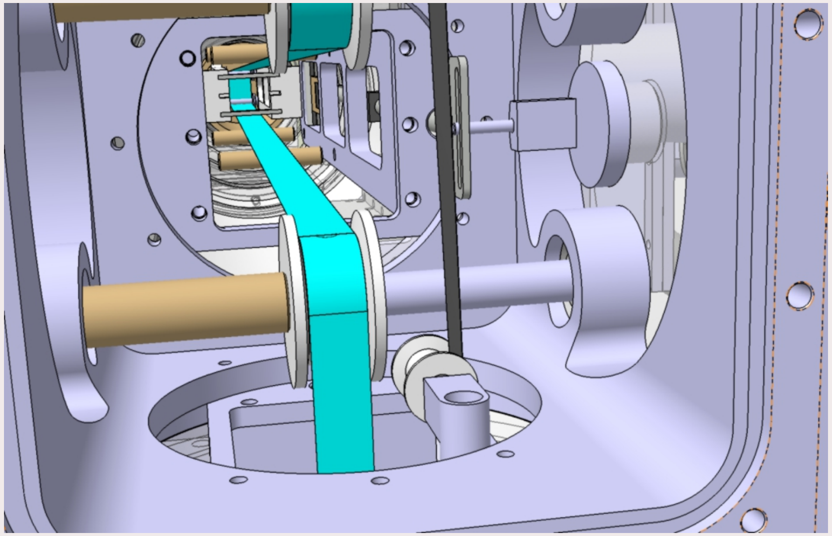
Tape moving

BEDO : Multiple detector

#1 Avoid long lived descendant activities

Solution : moveable aluminium coated mylar tape





BEDO : Multiple detector

#2 Detection of electrons

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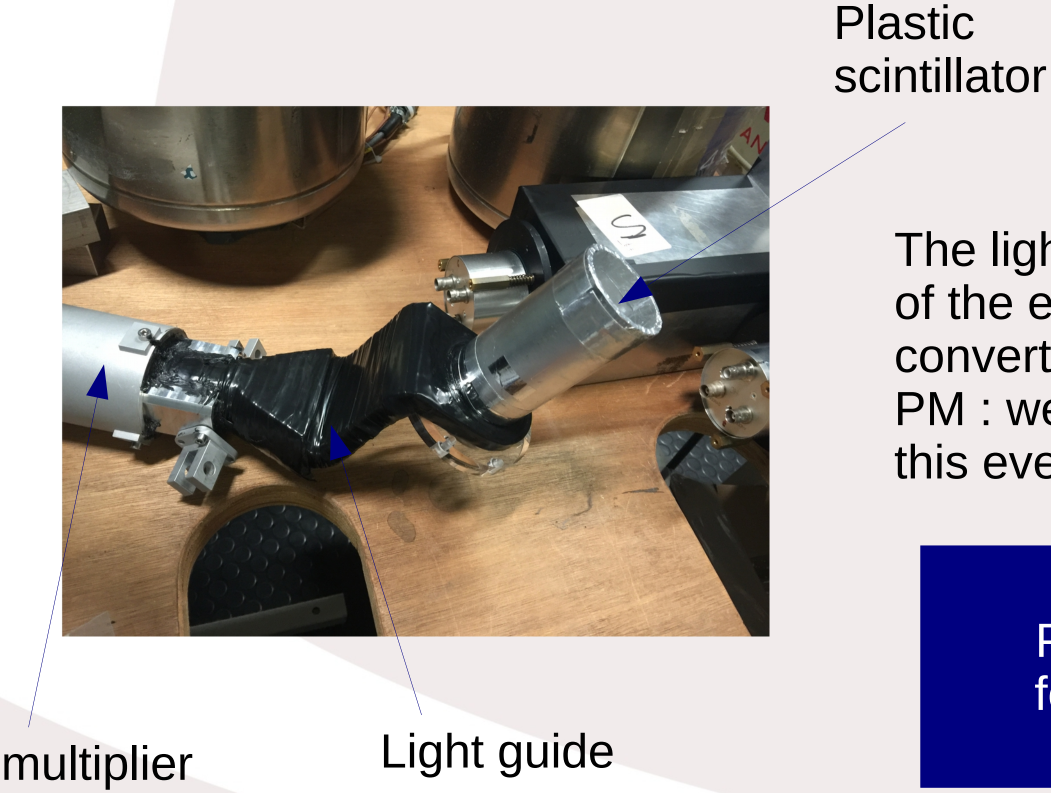
Solution : A plastic cylinder


Plastic
scintillator

photomultiplier

Light guide

The light coming from the interaction of the electron in the plastic will be converted in an electric signal by the PM : we save the absolute time of this event.

Placed around the tape
for an efficiency of 60 %

BEDO : Multiple detector

#2 Detection of gammas

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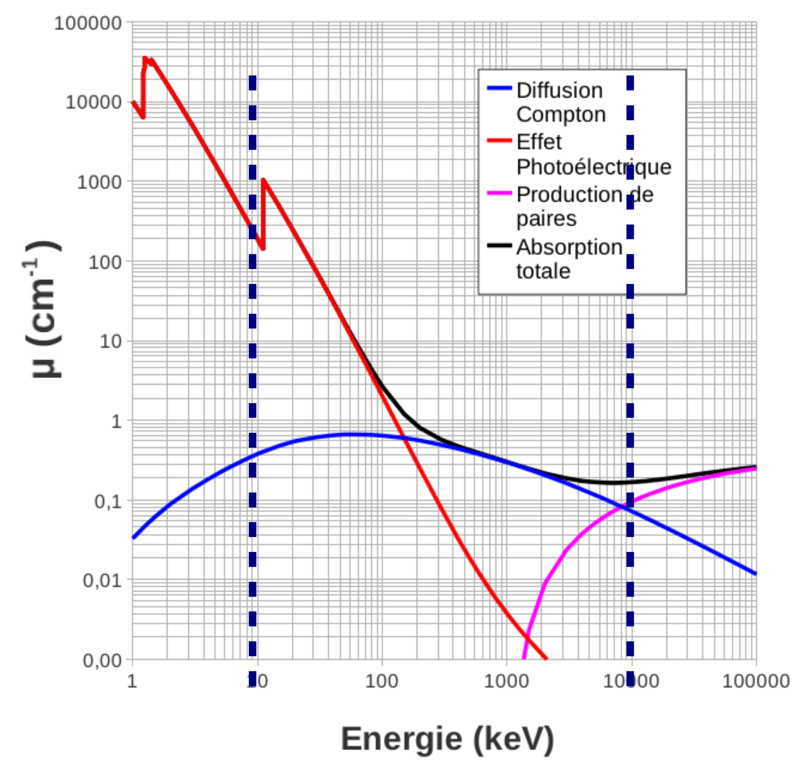
Solution : HPGe detectors

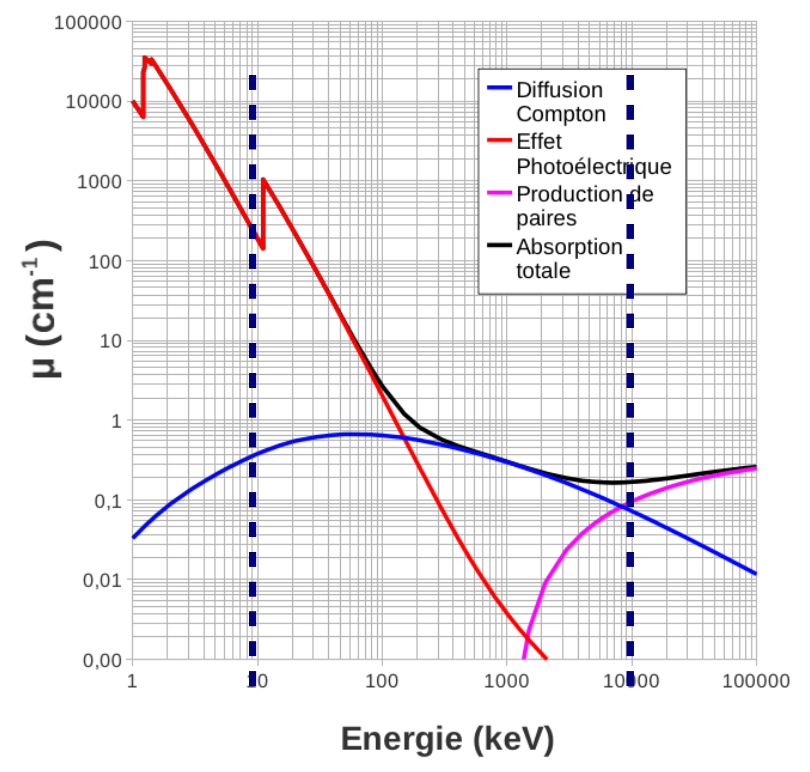


Why HPGe :
Ge crystal is the highest Z semi-conductor

BEDO : Multiple detector

#2 Detection of gammas

Solution : HPGe detectors



Why HPGe :
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Good efficiency

BEDO : Multiple detector

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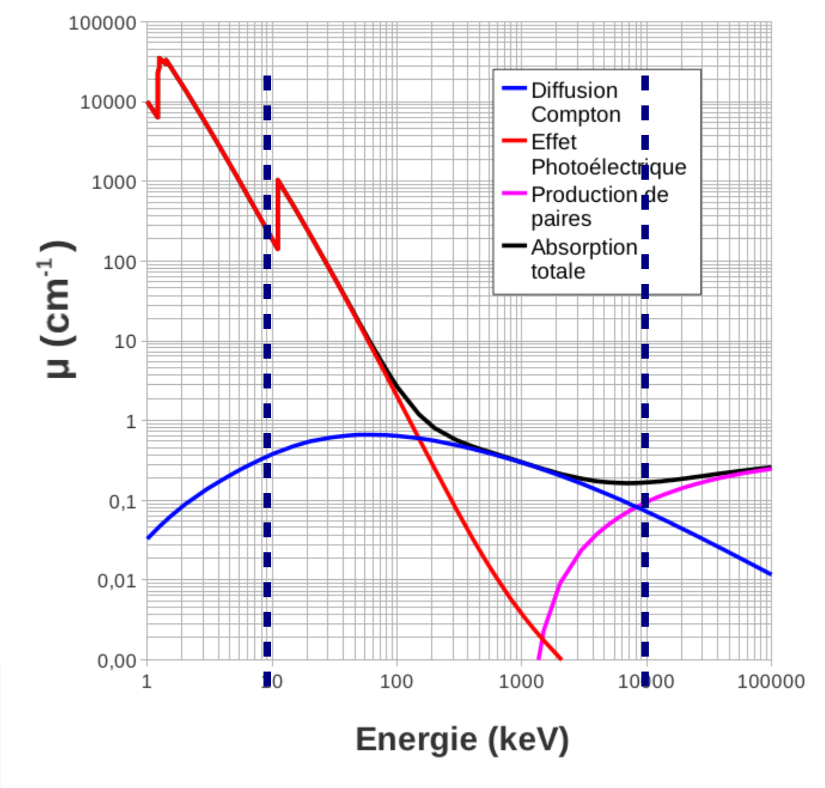
Solution : HPGe detectors



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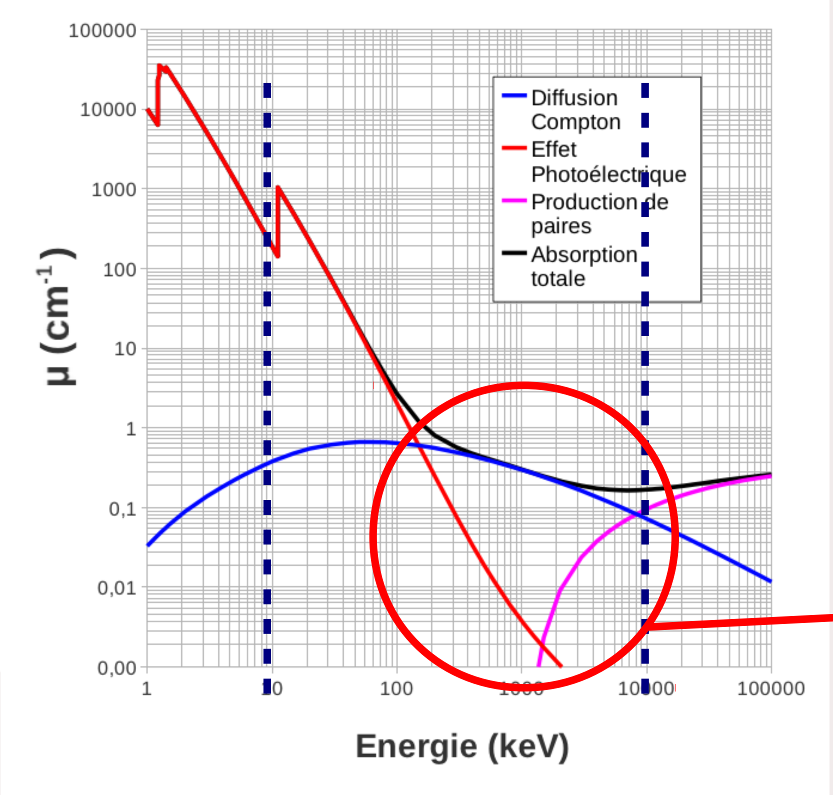
#2 Detection of gammas

Solution : HPGe detectors



Why HPGe :
Ge crystal is the highest Z semi-conductor

Good efficiency

Good resolution

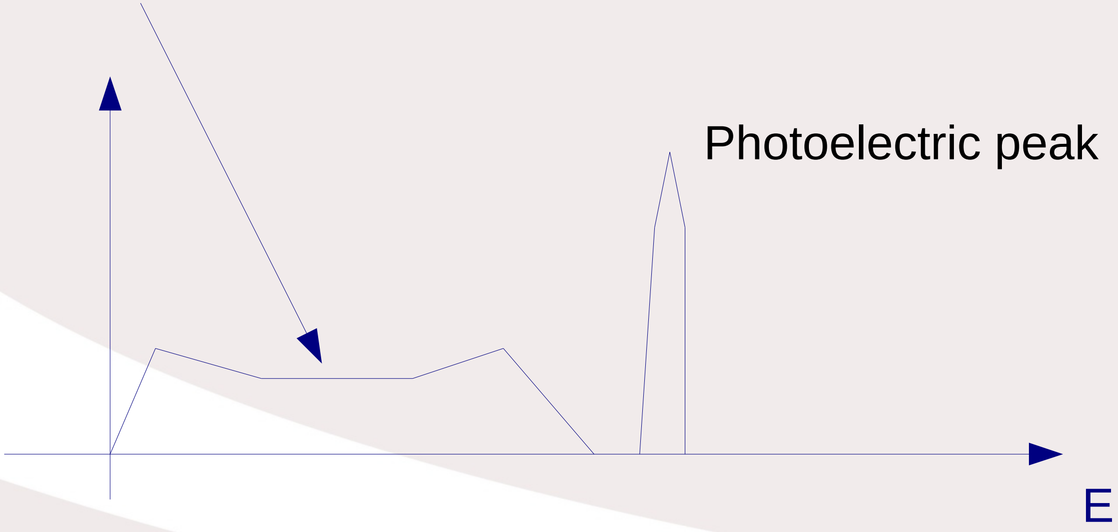
Problem : in the nuclear physic energy scale, the photon-matter interactions are dominated by Compton effect

Compton effect

The photon gives a part of its energy to an electron in the crystal and the rest of the energy is release by the emission of another photon.

1st case : the secondary photon deposit its energy in the crystal (the measured energy is still the energy of the photon : add a count in the photoelectric peak)

2nd case : the secondary photon goes out of the crystal (the measured energy is not the energy of the photon : creation of the so-called Compton plateau)



Photoelectric peak

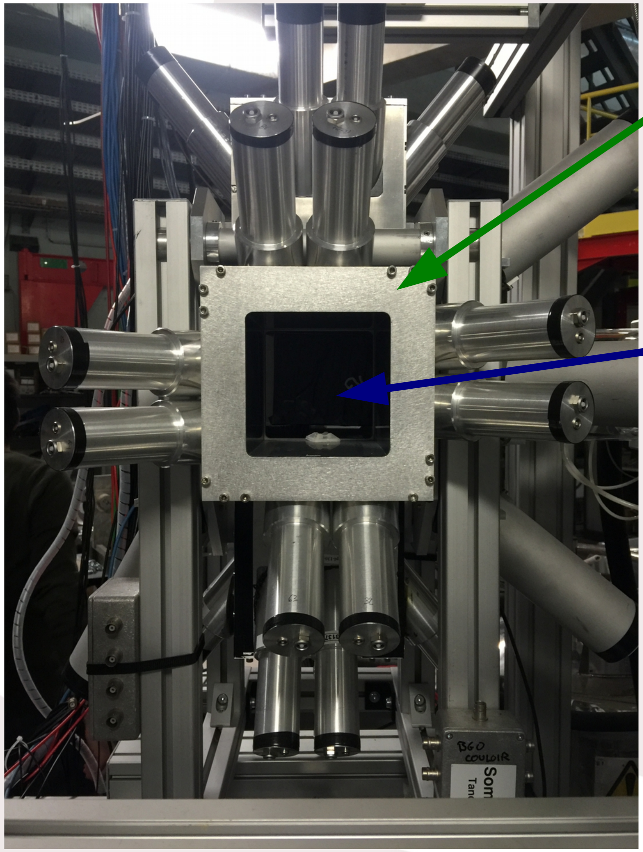
BEDO : Multiple detector

#3 Have clean spectra (reduce the Compton plateau)

2 possibilities :
- Anti-Compton shield
- Add-Back procedure

#3 Have clean spectra (reduce the Compton plateau)

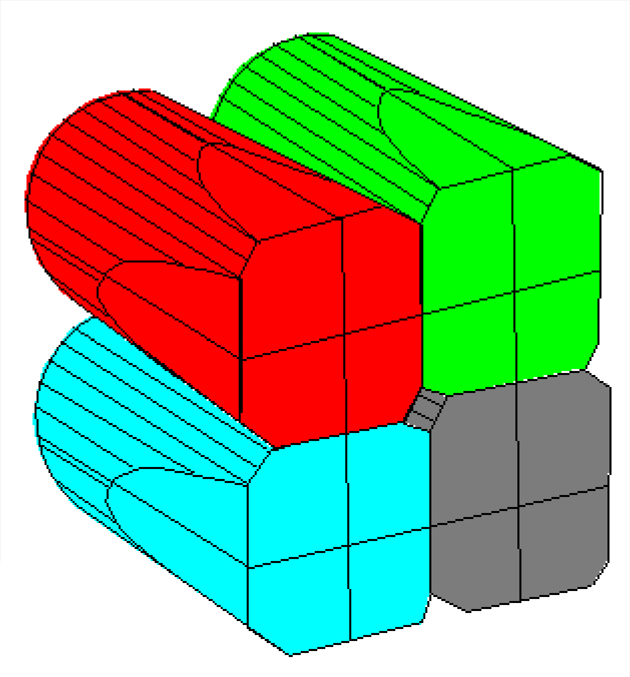
Solution 1 : BGO shields



BGO crystals surrunding the Ge crystal. BGO is a very efficient scintillator (but with a poor resolution) so if the secondary photon goes out of the Ge crystal it will be detected in the BGO : by coincidences between BGO and Ge we can remove a part of the Compton plateau

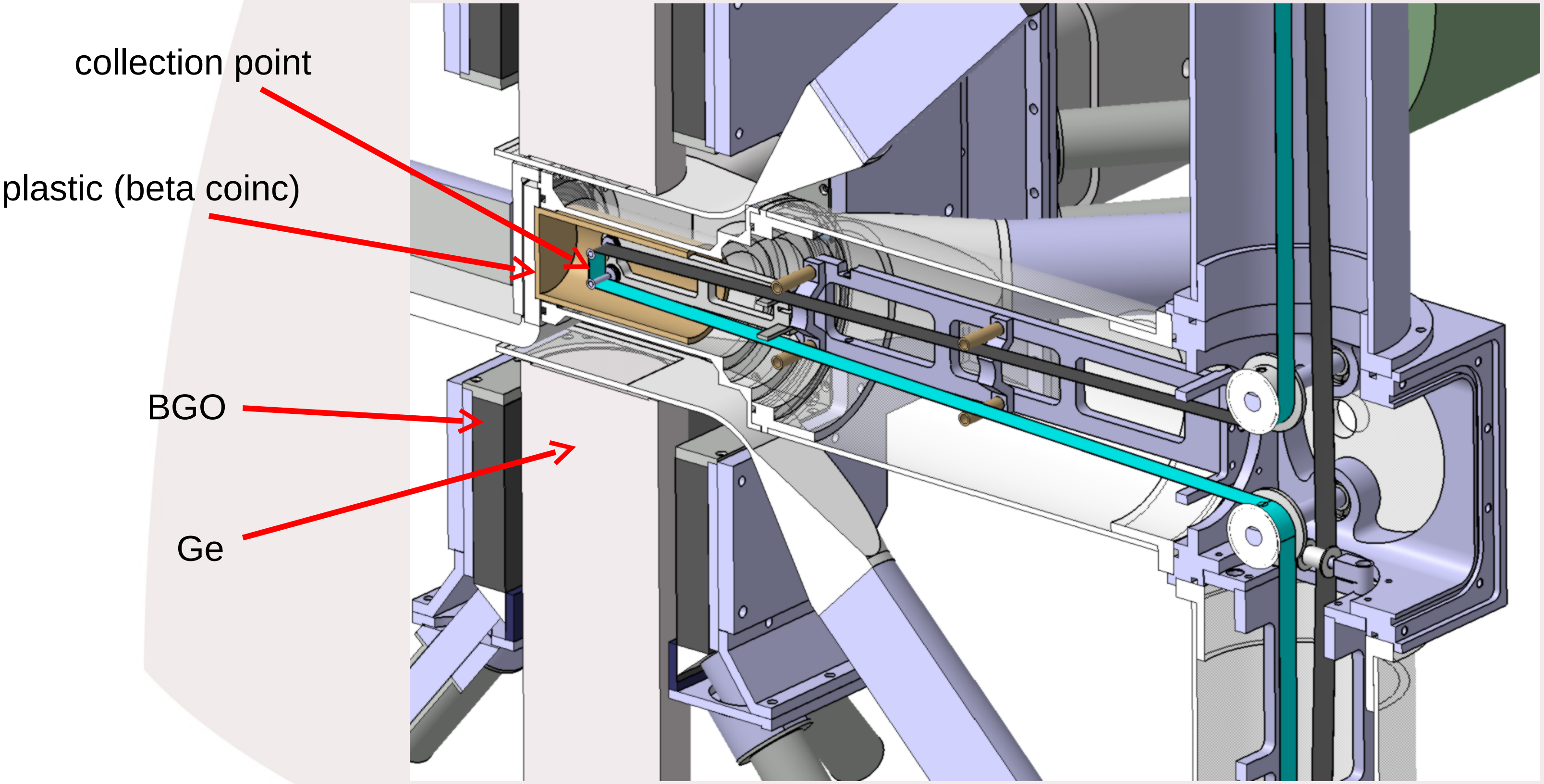
#3 Have clean spectra (reduce the Compton plateau)

Solution 2 : Clover



We place 4 HPGe crystals in the same detector so if a secondary gamma escape for one of the crystal, it can be detected in a second one. So, if two detectors are triggered in a typical time window, we can add the two measured energies, that is the AddBack procedure

BEDO : Multiple detector



BEDO performances : β decay of ^{83}Ga

Z	79Kr	80Kr	81Kr	82Kr	83Kr	84Kr	85Kr	86Kr	87Kr	88Kr	89Kr	90Kr	91Kr	92Kr	93Kr	94Kr	95Kr
	78Br	79Br	80Br	81Br	82Br	83Br	84Br	85Br	86Br	87Br	88Br	89Br	90Br	91Br	92Br	93Br	94Br
34	77Se	78Se	79Se	80Se	81Se	82Se	83Se	84Se	85Se	86Se	87Se	88Se	89Se	90Se	91Se	92Se	93Se
	76As	77As	78As	79As	80As	81As	82As	83As	84As	85As	86As	87As	88As	89As	90As	91As	92As
32	75Ge	76Ge	77Ge	78Ge	79Ge	80Ge	81Ge	82Ge	83Ge	84Ge	85Ge	86Ge	87Ge	88Ge	89Ge	90Ge	
	74Ga	75Ga	76Ga	77Ga	78Ga	79Ga	80Ga	81Ga	82Ga	3Ga	84Ga	85Ga	86Ga	87Ga			
30	73Zn	74Zn	75Zn	76Zn	77Zn	78Zn	79Zn	80Zn	81Zn	82Zn	83Zn	84Zn	85Zn				
	72Cu	73Cu	74Cu	75Cu	76Cu	77Cu	78Cu	79Cu	80Cu	81Cu	82Cu						
28	71Ni	72Ni	73Ni	74Ni	75Ni	76Ni	77Ni	78Ni	79Ni								
	43		45		47		49		51		53		55		57		N

$$^{83}_{31}\mathrm{Ga}_{52} \rightarrow {}^{83}_{32}\mathrm{Ge}_{51}^{*} + e^{-} + \bar{\nu}_e$$

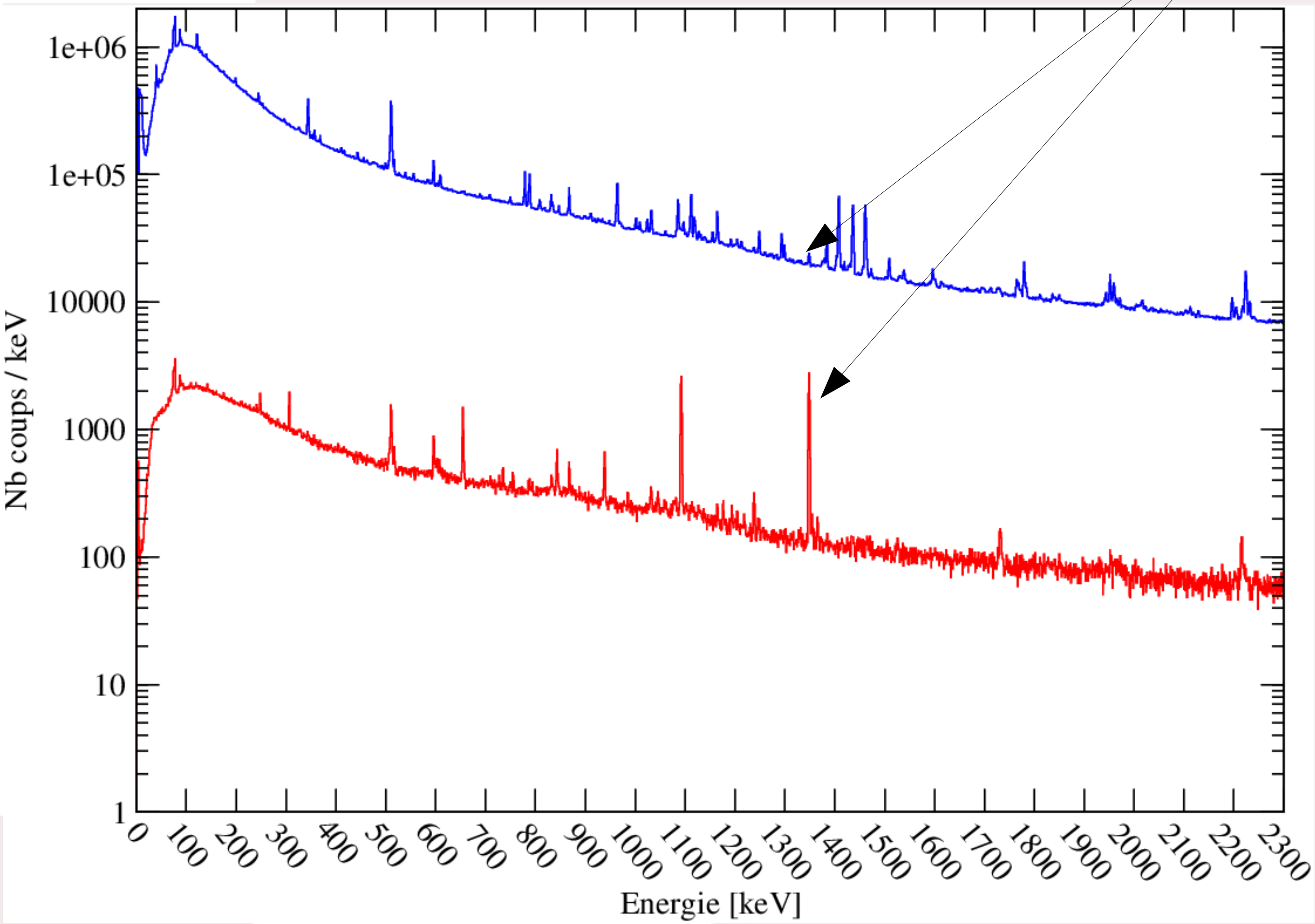
$$^{83}_{32}\mathrm{Ge}_{51}^{*} \rightarrow {}^{82}_{32}\mathrm{Ge}_{51} + e^{-} + \bar{\nu}_e + n + \gamma \ (85\ \%)$$

$$^{83}_{32}\mathrm{Ge}_{51}^{*} \rightarrow {}^{83}_{32}\mathrm{Ge}_{51} + e^{-} + \bar{\nu}_e + \gamma \ (15\%)$$

BEDO performances : β decay of ^{83}Ga

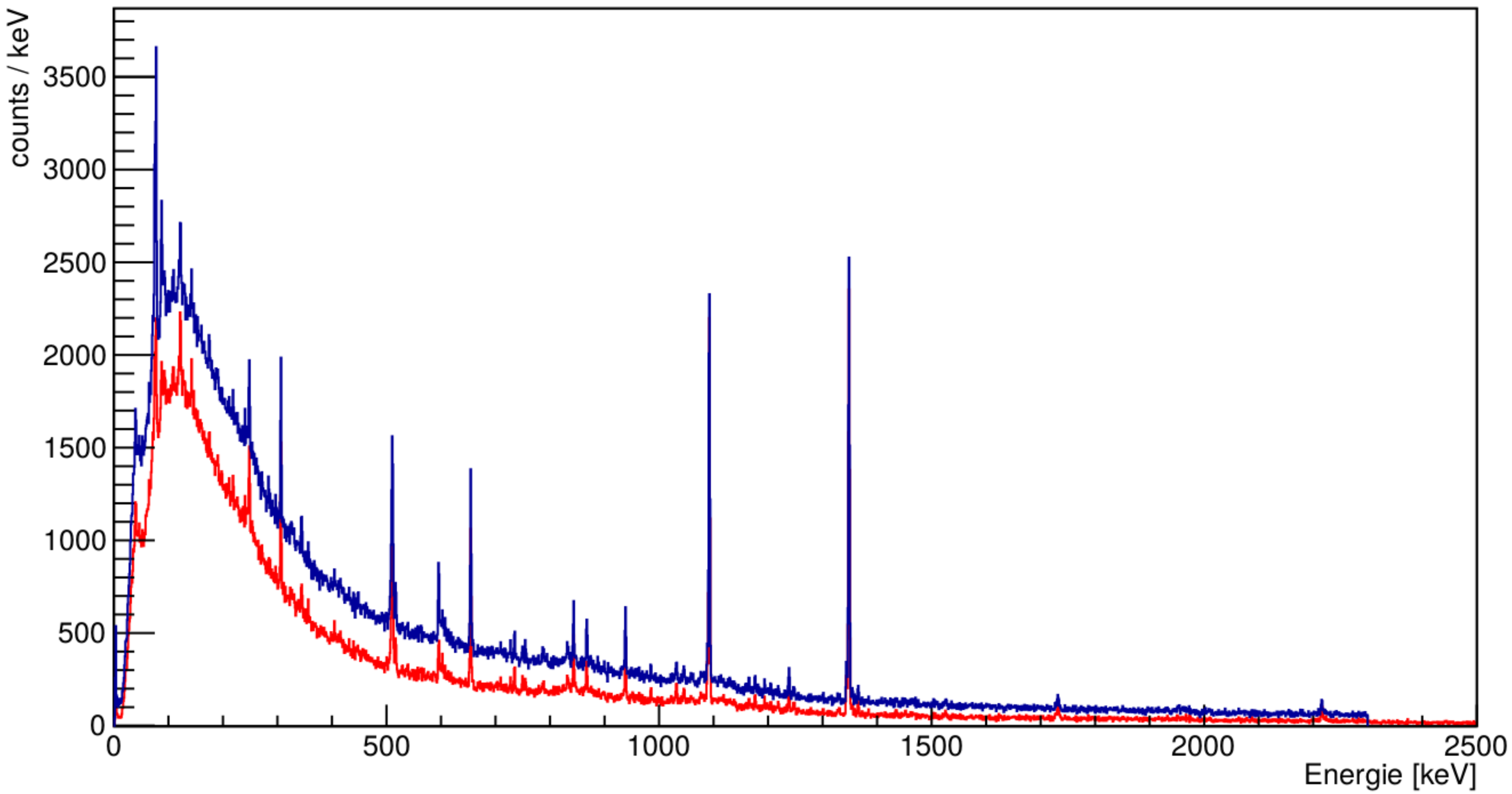
#1 Beta gamma coincidences

More intense transition in the decay



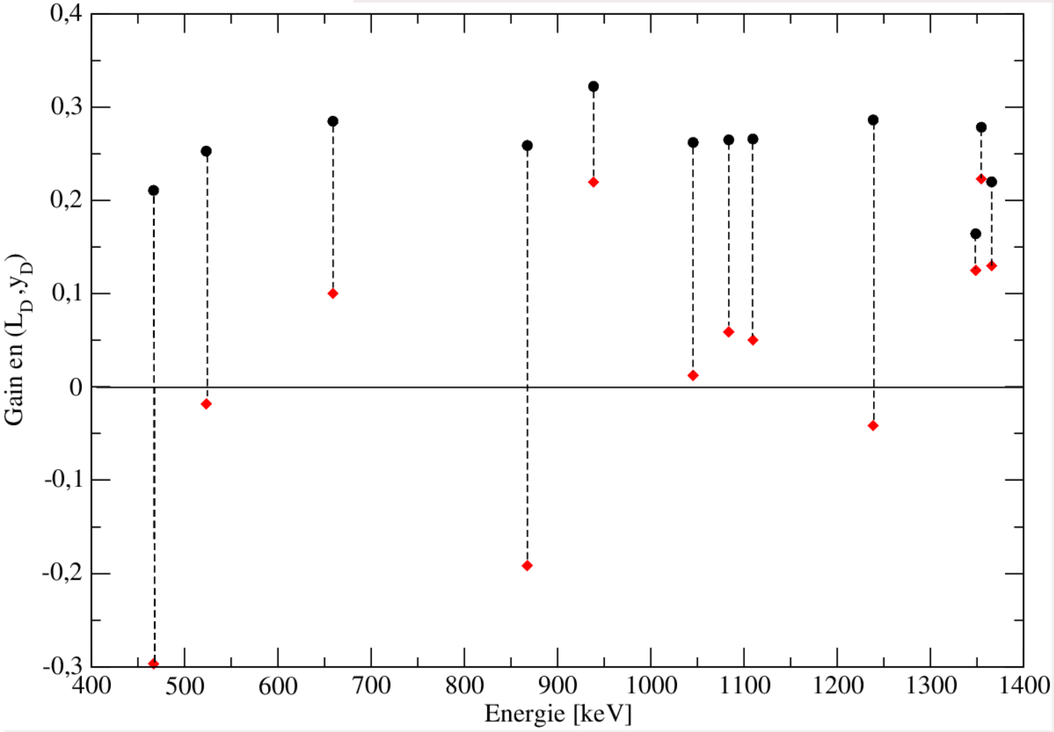
BEDO performances : β decay of ^{83}Ga

#2 Compton rejection



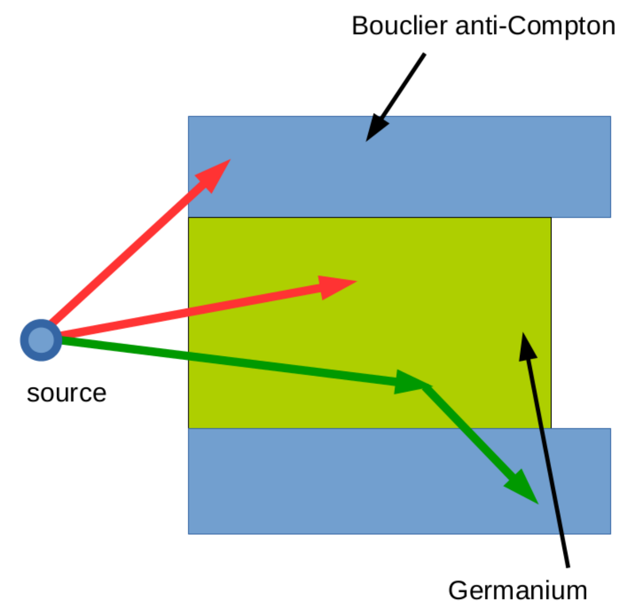
BEDO performances : β decay of ^{83}Ga

#2 Compton rejection



L_D = detection limit = nb of counts needed to consider a peak

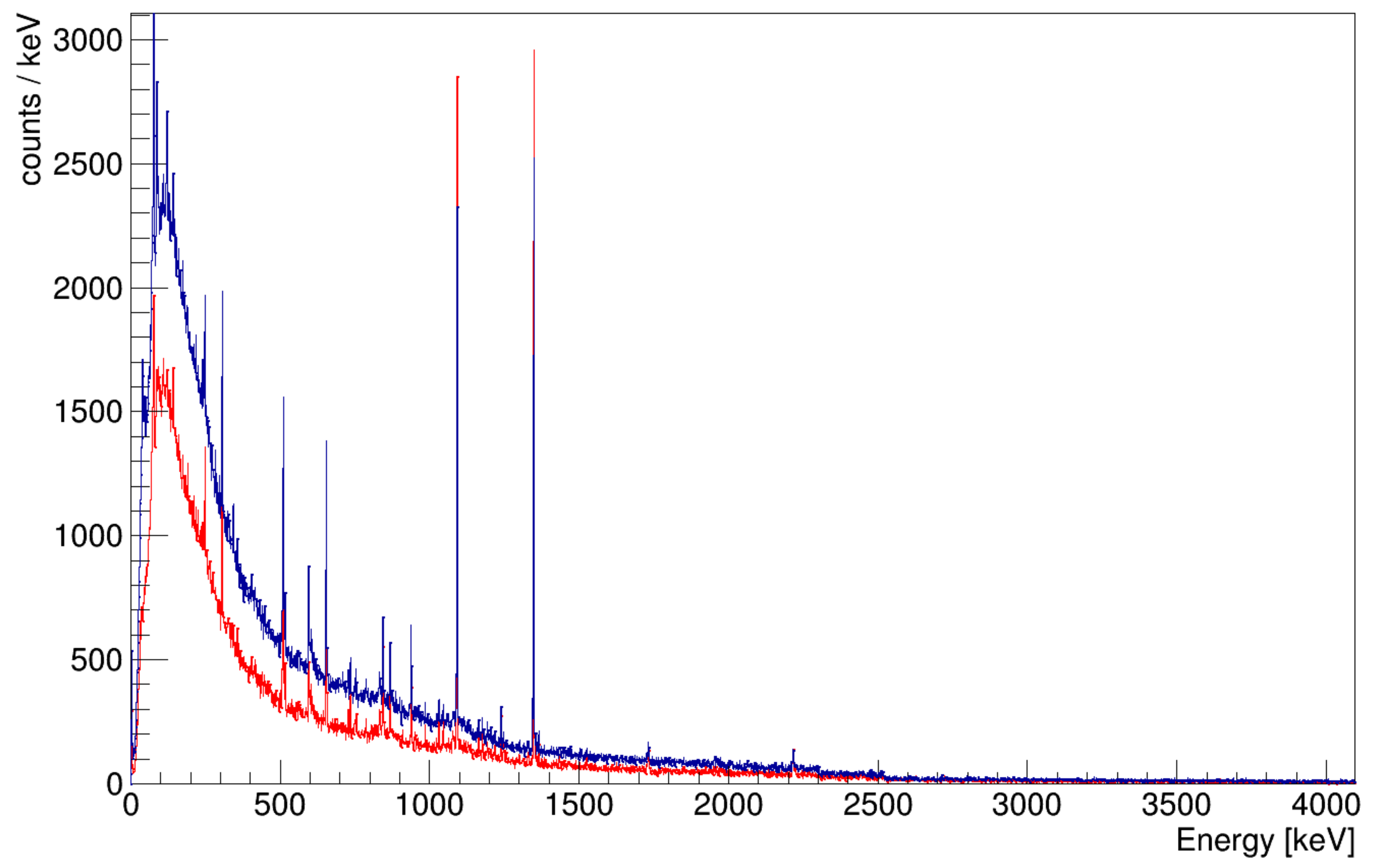
y_D = minimum detectable yield



Gain in y_D < gain in L_D because of real coincidence between BGO and Ge from two gammas emitted by the source

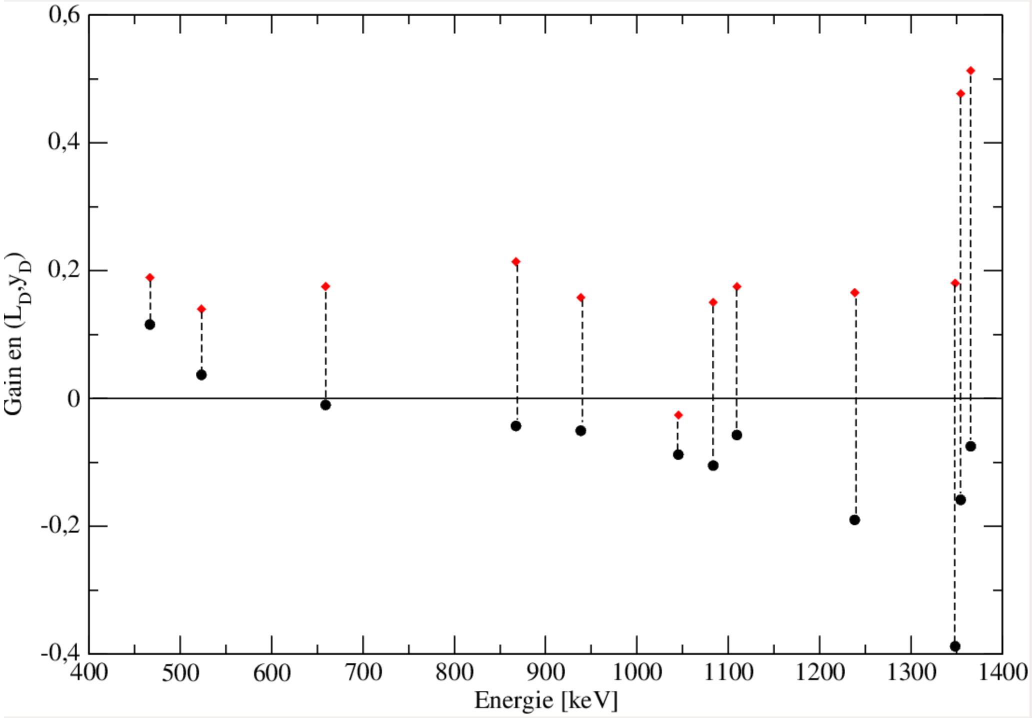
BEDO performances : β decay of ^{83}Ga

#2 AddBack procedure



BEDO performances : β decay of ^{83}Ga

#2 AddBack procedure



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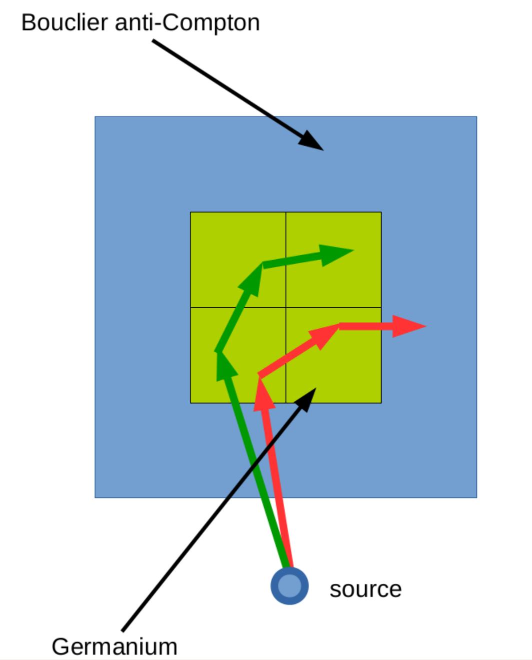
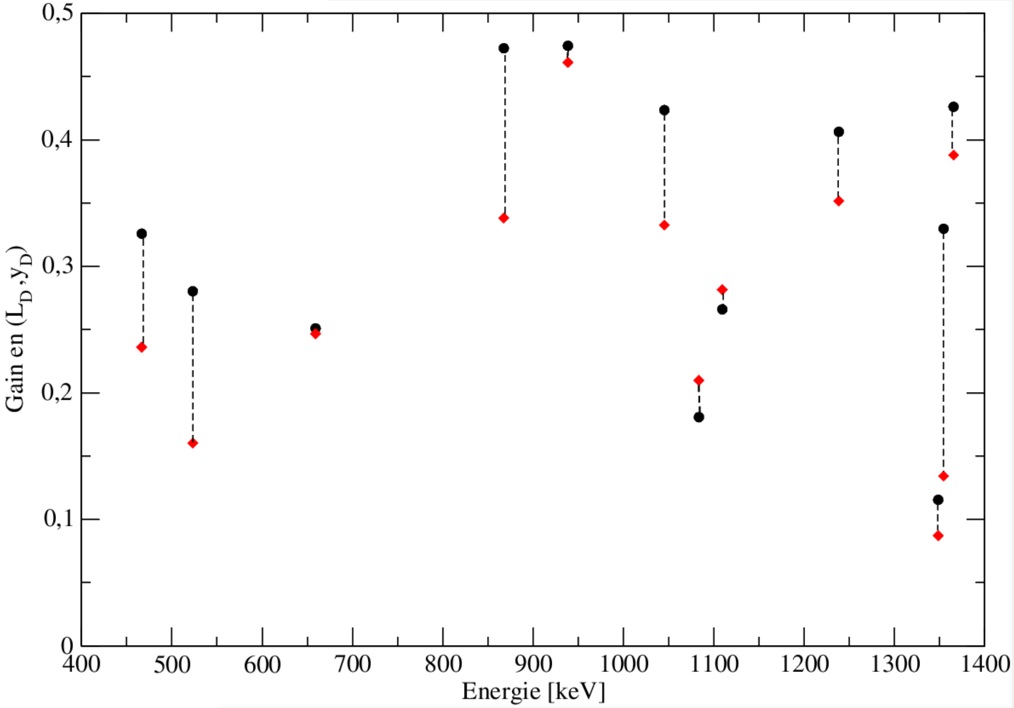


Gain in y_D < gain in L_D because it adds reconstructed counts in photopeak.

But gain in L_D <0 because badly reconstructed energies are added in the background at higher energy.

#2 AddBack procedure and Compton rejection



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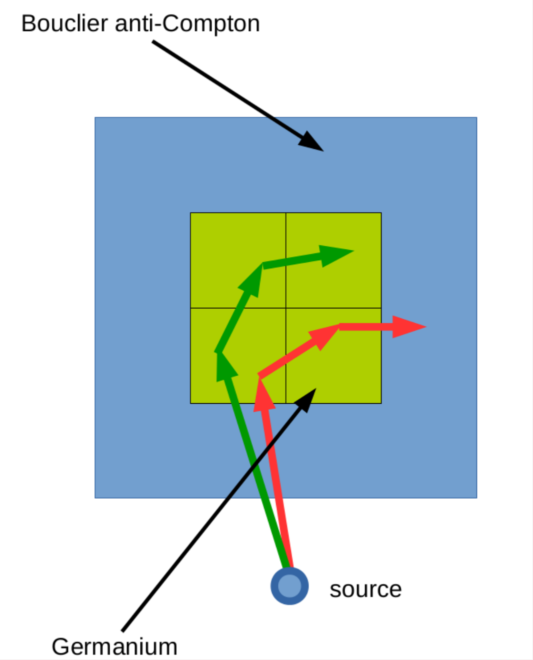
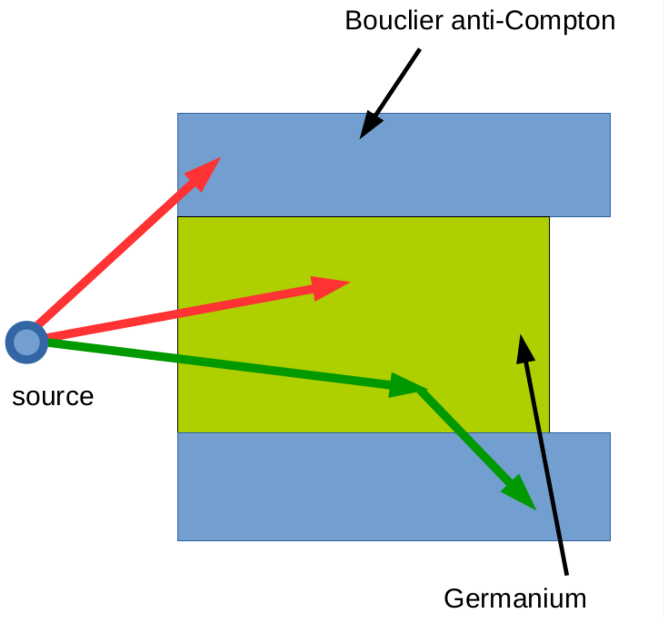


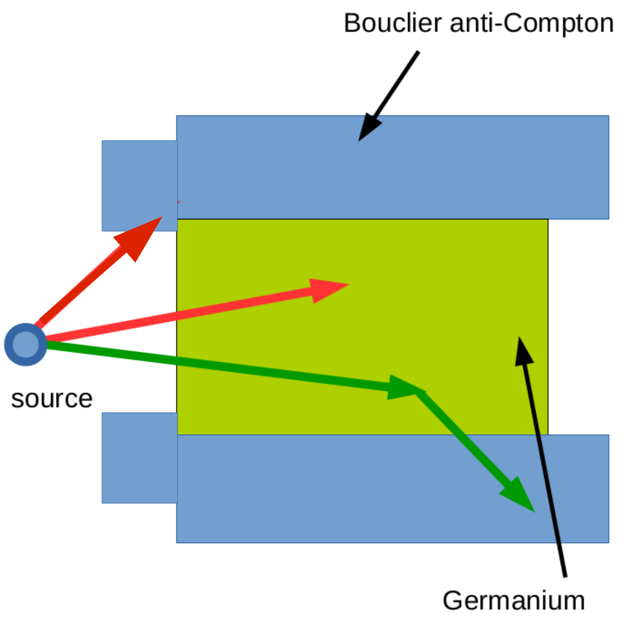
We have the same problem than with Compton rejection alone but the gain in y_D is positive

Improvement



In order to avoid the red case : one can shield the shield, i.e. one put another efficient crystal between the source and the shield.

Improvement



In order to avoid the red case : one can shield the shield, i.e. one put another efficient crystal between the source and the shield.

Test will be done in June 2017

BEDO Collaboration

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Thanks for your attention !