Structure and shape evolution in neutron-rich Zn and Ga isotopes towards the N=50 shell closure : data analysis

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June 20, 2024

Table of contents

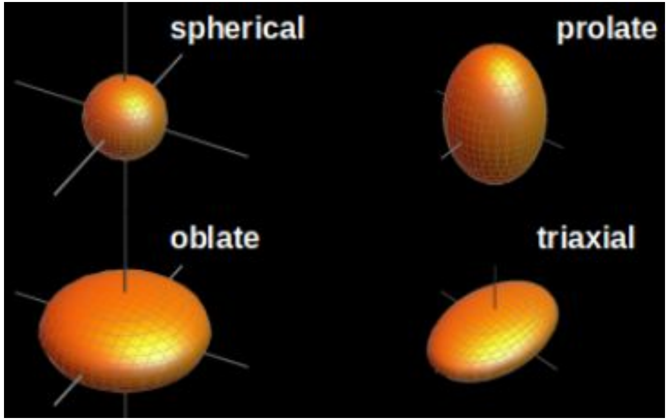
I) Introduction

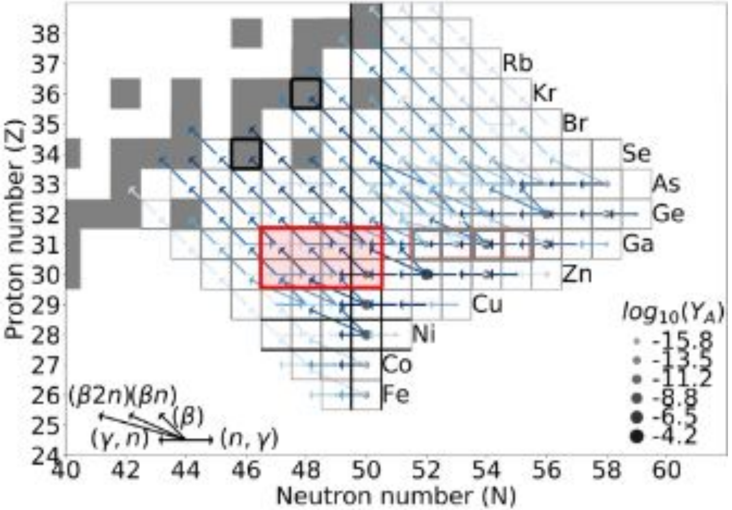
- Preliminary work for the study of exotic $_{30}Zn$ and $_{31}Ga$ isotopes
- Create the tools necessary for the data analysis
- Implementation of *add-back* and *Compton suppression* techniques

II) Theoretical motivations

- Investigate shape transition in exotic $_{30}$Zn and $_{31}$Ga nuclei

- $_{30}$Zn and $_{31}$Ga isotopes part of the astrophysical r-process

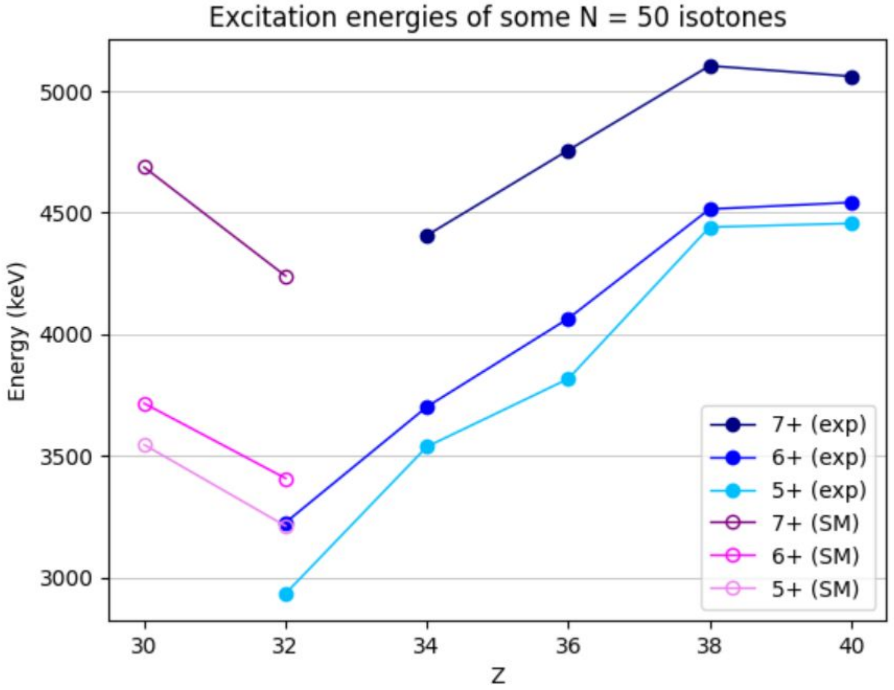




M. P. Reiter *et al.* PRC 101, 025803 (2020)

II) Theoretical motivations

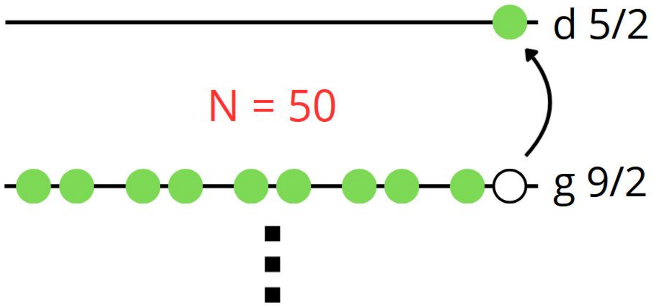
- Gain information on the doubly-magic ^{78}Ni (Z = 28)

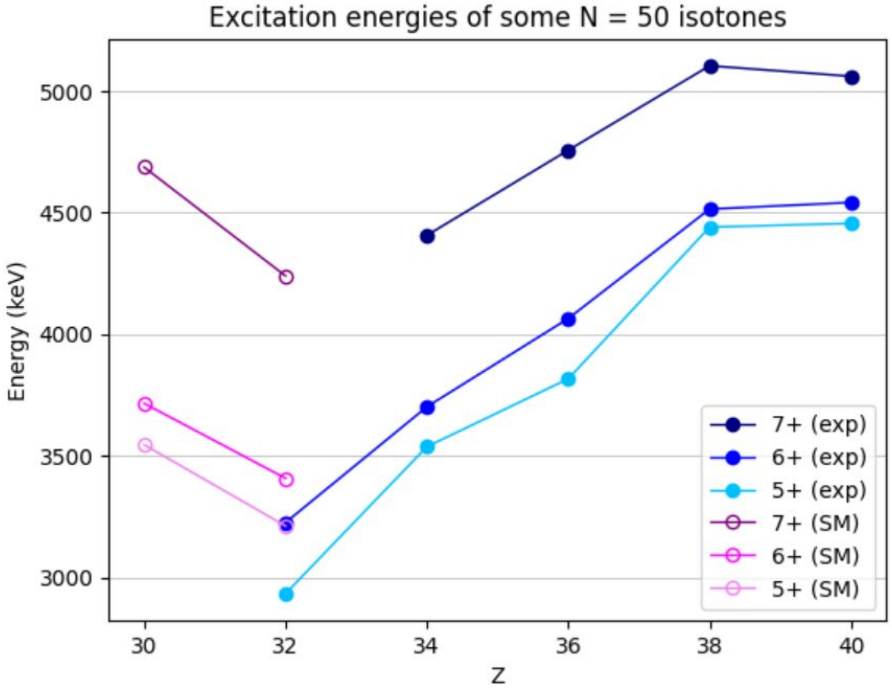


Measured energies of the first 5+, 6+ and 7+ excited states in N = 50 isotones

II) Theoretical motivations

- Gain information on the doubly-magic ^{78}Ni
- First 5+, 6+ and 7+ states in ^{80}Zn : excite neutrons above N = 50





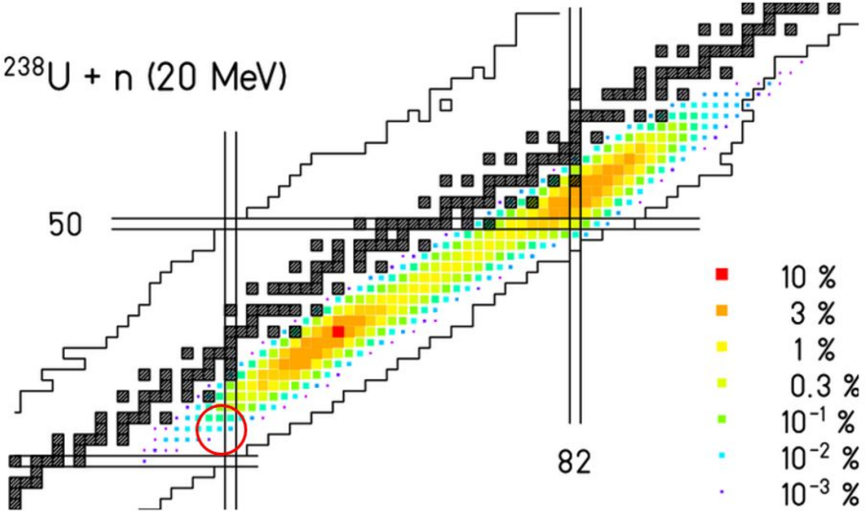
Measured energies of the first 5+, 6+ and 7+ excited states in N = 50 isotones

II) Fusion-fission reaction

- ${}_{30}$Zn and ${}_{31}$Ga nuclei produced by the fusion-fission reaction n + ^{238}U → FF + xn

- ${}_{30}$Zn and ${}_{31}$Ga have a very low production yield

- 200 different nuclei created → contaminant gamma-rays



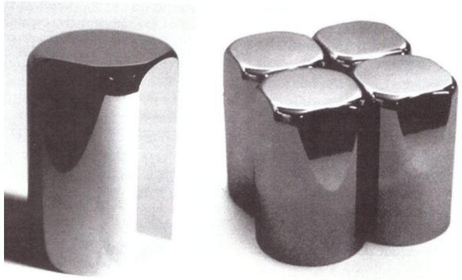
Produced nuclei from the fission of ^{238}U

Schmidt *et al.* PR Special Topics 10. 014701 (2007)

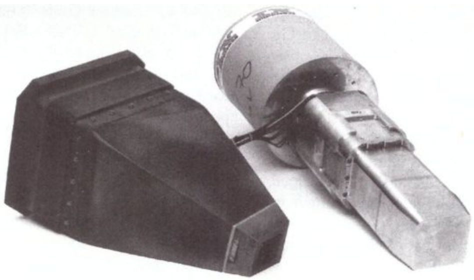
II) Experimental setup - nuball

- HPGe for energy resolution, $LaBr_3$ for time resolution

- BGO shields to reduce the Compton background



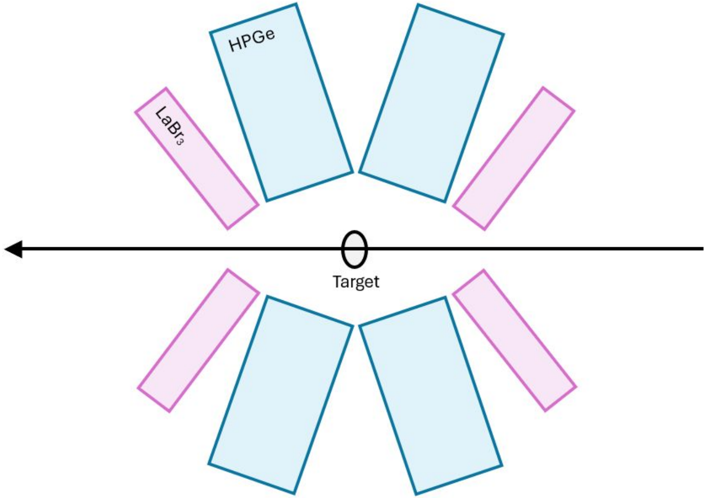
Single HPGe crystal and 4 crystals in a clover

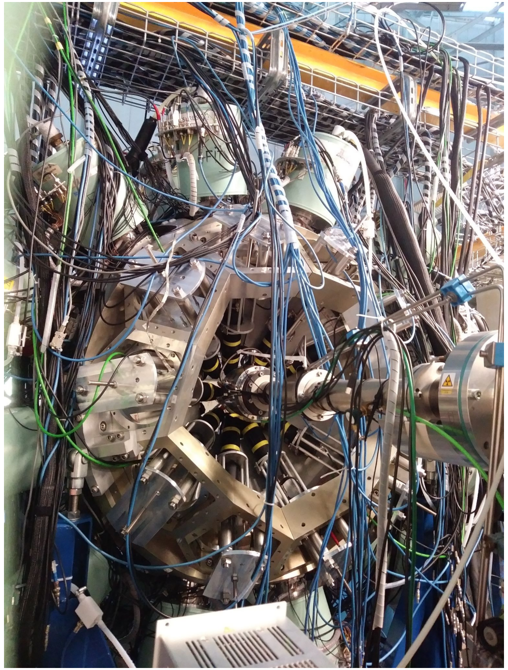


The BGO shield of the clover next to it

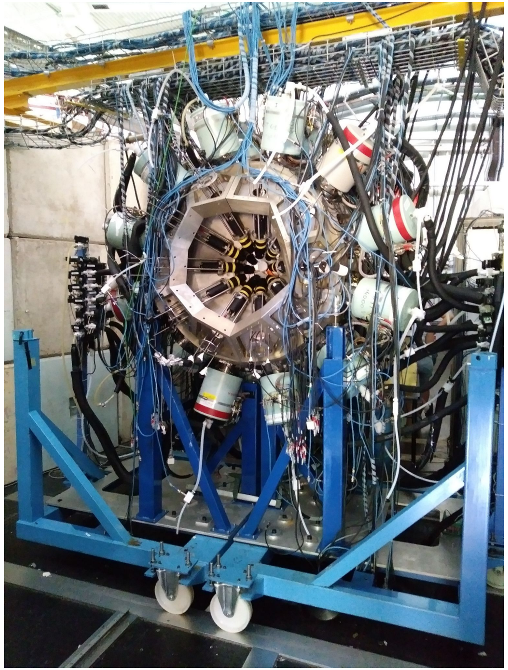
II) Experimental setup - nuball

- 2 rings of 12 clovers each
- 2 rings of 10 $LaBr_3$ each





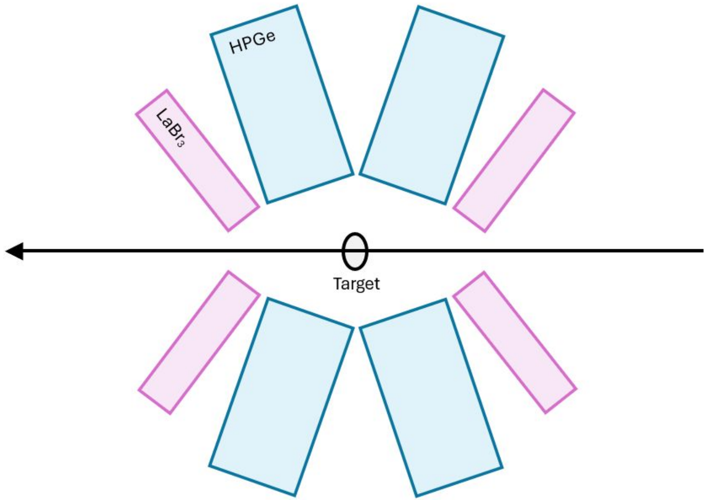
Upstream view

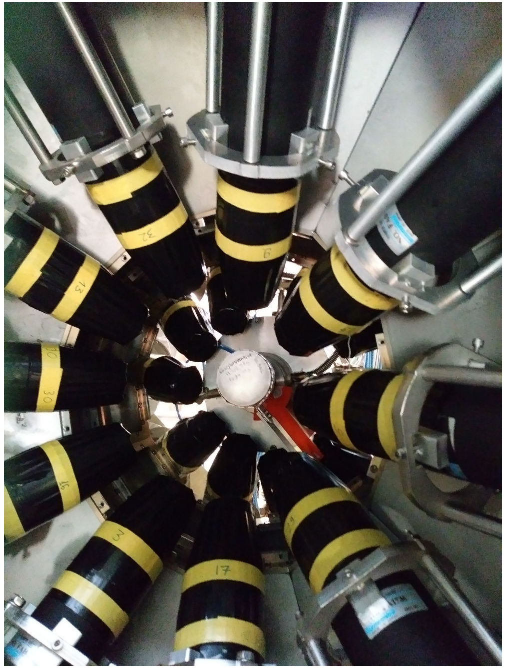


Downstream view

II) Experimental setup - nuball

- 2 rings of 12 clovers each
- 2 rings of 10 $LaBr_3$ each





$LaBr_3$ rings

Clover rings

III) BGO shielding

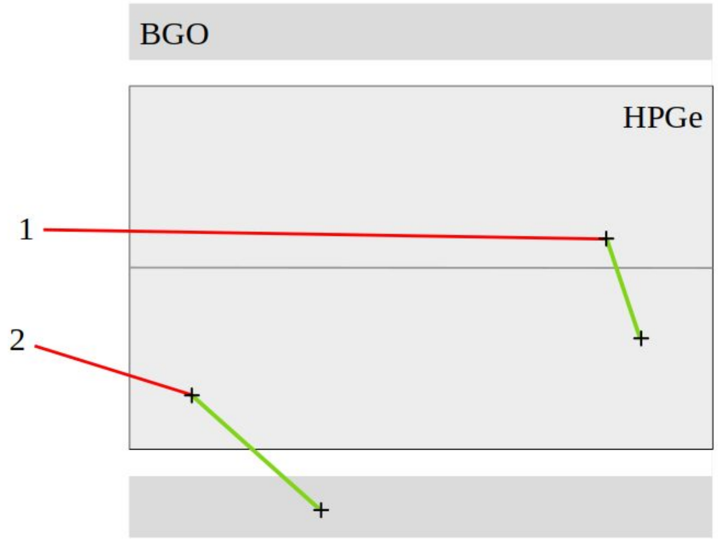
- Two main interactions :

- photoelectric effect dominates until 140 keV

- Compton scattering dominates beyond

- Use of BGO shields to reduce the Compton background

→ discard photons having a BGO hit

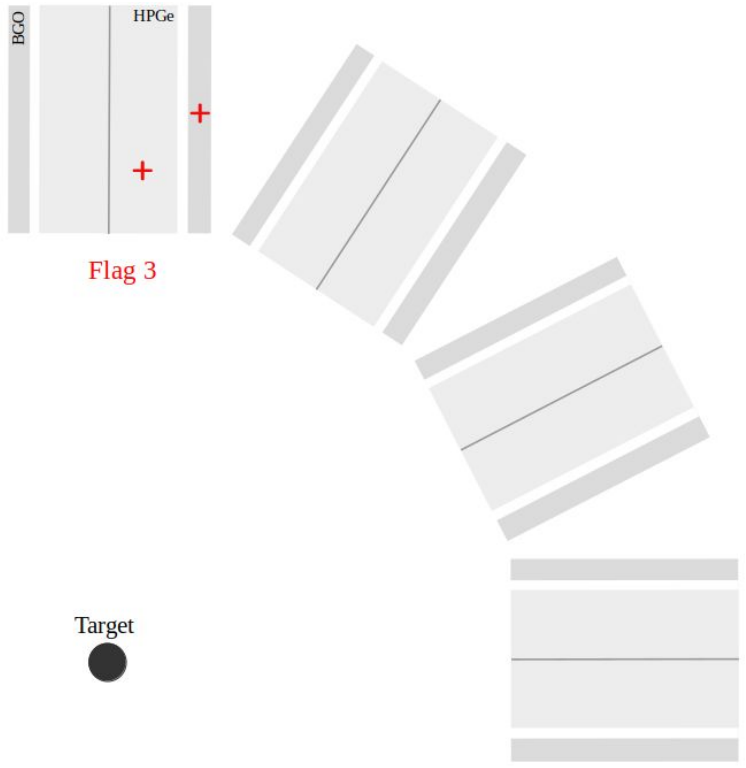


2 photon interactions in a Compton-shielded clover

III) Event classification

- Flag system : when both HPGe and BGO hit were registered in

- the same detector : flag 3 - not clean

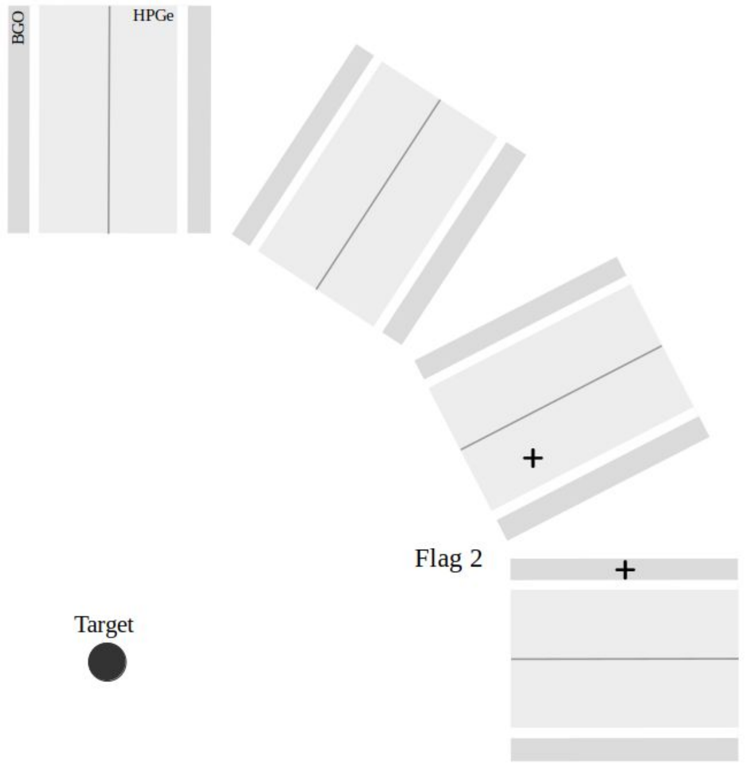


III) Event classification

- Flag system : when both HPGe and BGO hit were registered in

- the same detector : flag 3 - not clean

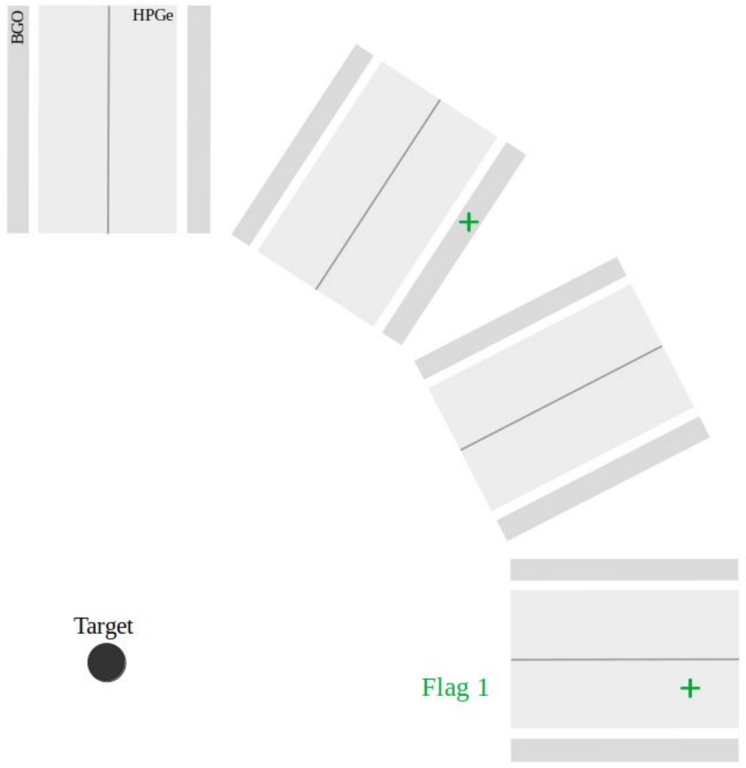
- 2 neighboring detectors : flag 2 - maybe clean



III) Event classification

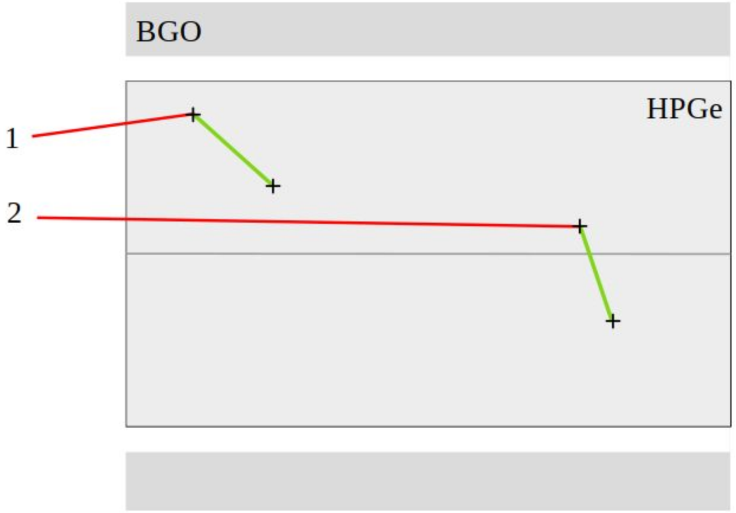
- Flag system : when both HPGe and BGO hit were registered in

- the same detector : flag 3 - not clean
- 2 neighboring detectors : flag 2 - maybe clean
- 2 non-neighboring detectors : flag 1 - clean



III) Event classification

- Add-back method to recover the total energy of the photon



- In the sorted data tree :

- energy
- flag

- Reaction runs :

- 78% flag 1
- 11% flag 2
- 11% flag 3

III) Cubix analysis

https://cubix.in2p3.fr, Jérémie Dudouet

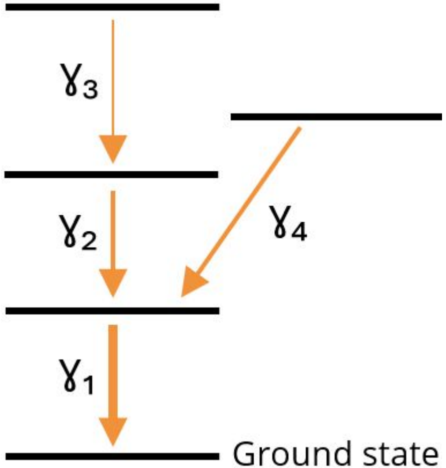
- Build 2D and 3D gamma coincidence matrices

III) Cubix analysis

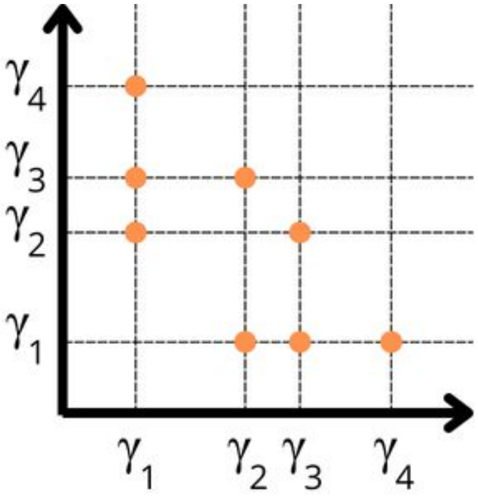
https://cubix.in2p3.fr, Jérémie Dudouet

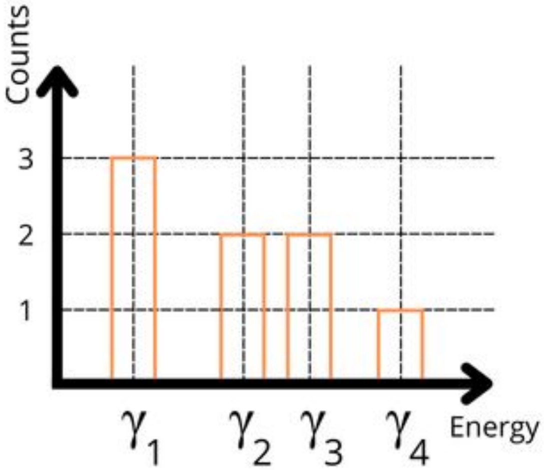
- Build 2D and 3D gamma coincidence matrices

Part of a level scheme with 4 transitions



Filling (middle) and total projection (right) of a 2D gamma coincidence matrix

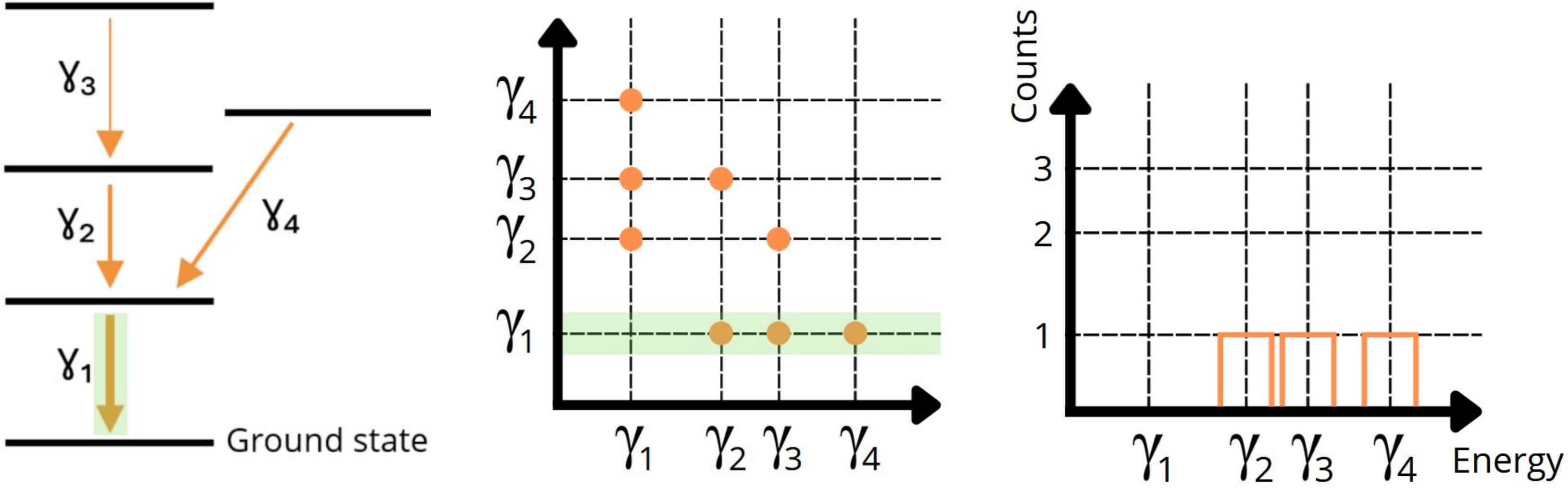




III) Cubix analysis

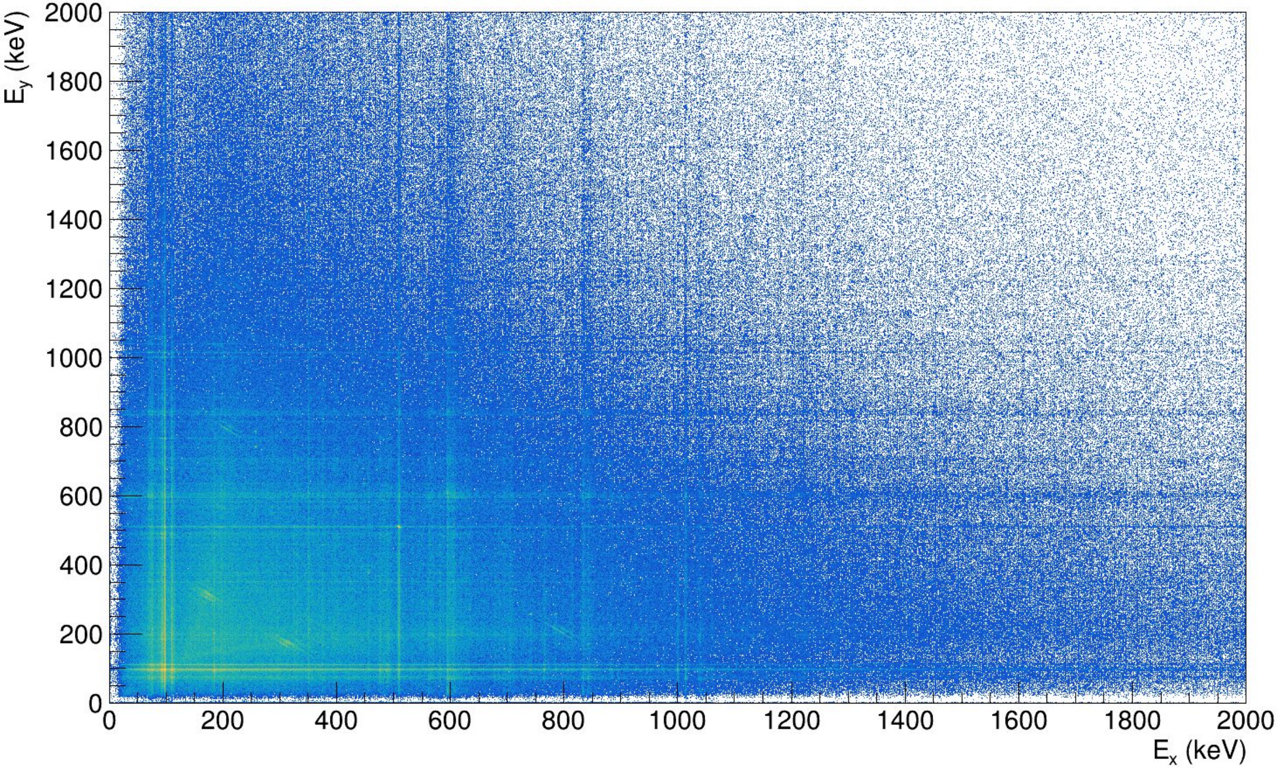
- Use one or multiple *gates* to identify gamma in coincidence

Choice of a gate (middle) and projection of the 2D matrix along that gate (right)



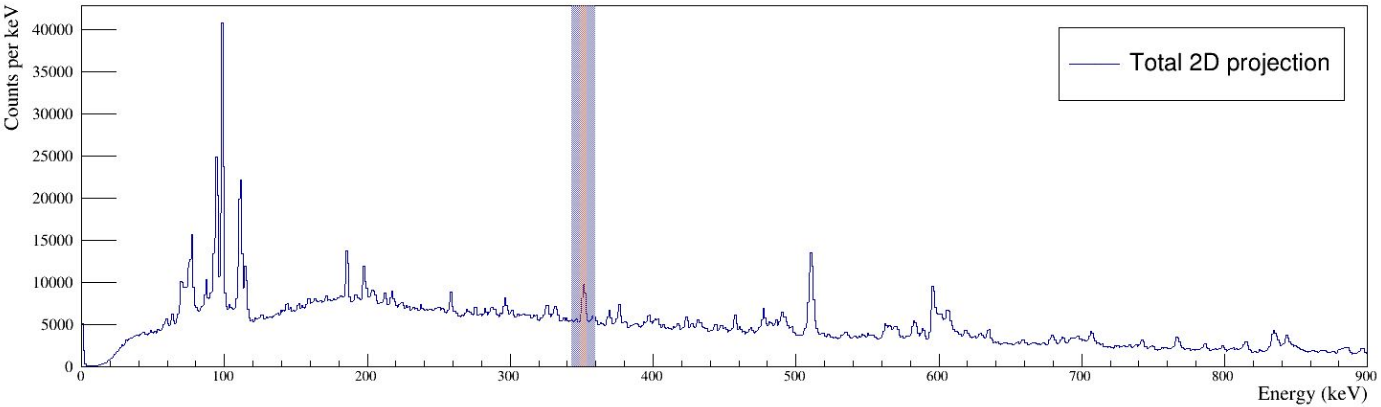
III) Cubix analysis

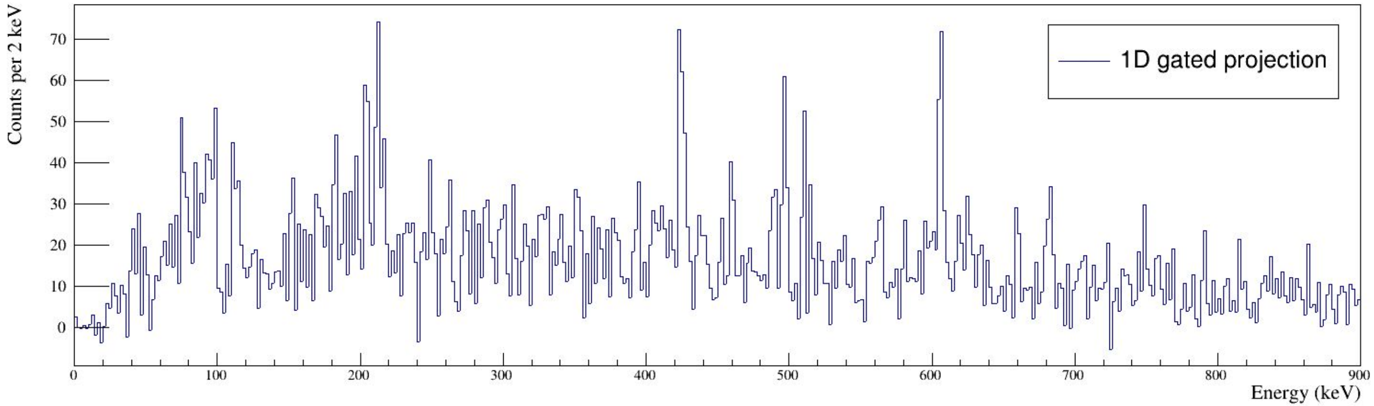
2D gamma coincidence matrix



III) Cubix analysis

Total projection (top) and projection along a gate (bottom) of a 2D gamma coincidence matrix

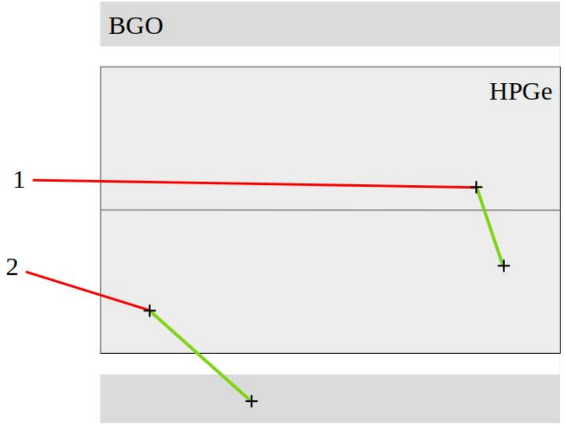


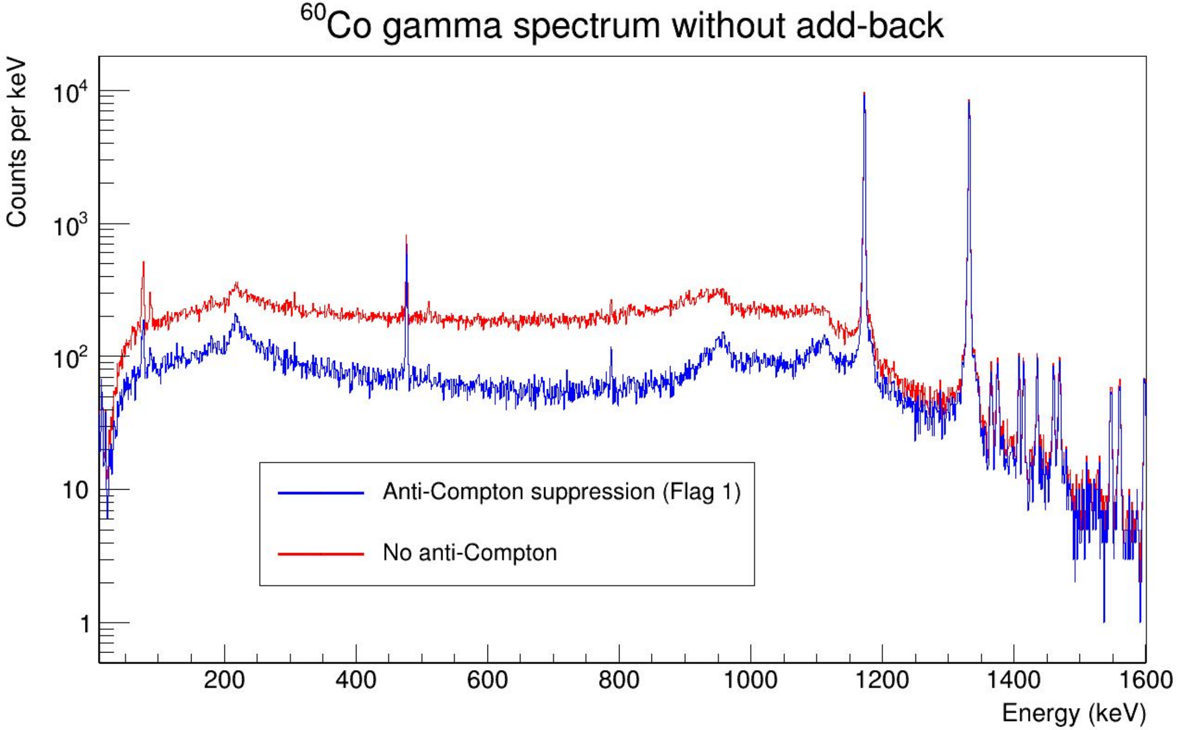


IV) Event classification results

- Effects of anti-Compton :

- photopeak area : -4.2 %
- background area : -54 %



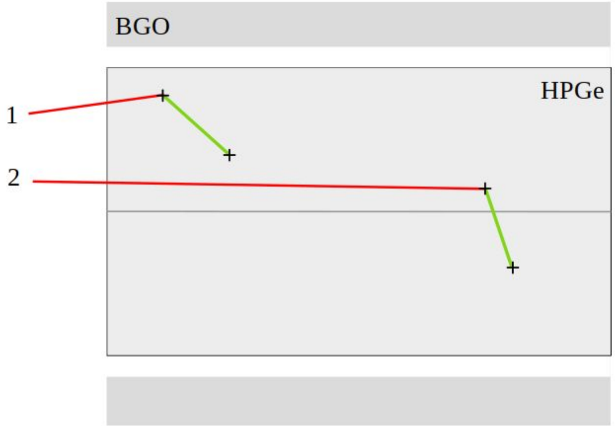


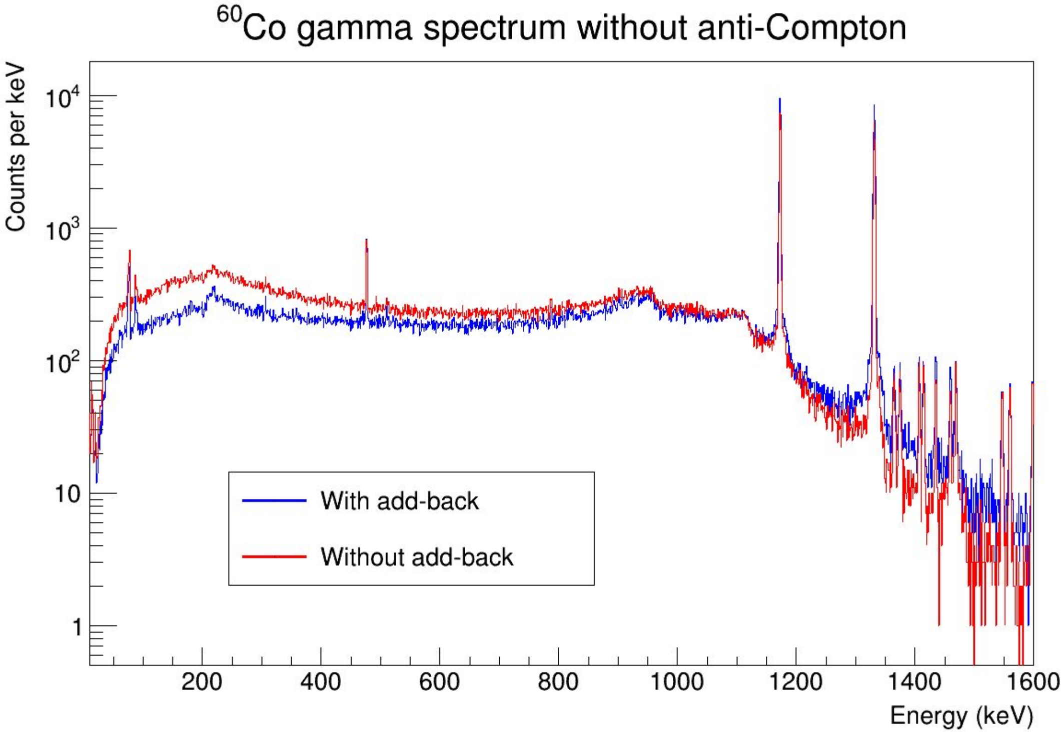
Gamma spectrum without add-back and with or without anti-Compton for ^{60}Co

IV) Event classification results

- Effects of add-back :

- photopeak area : +40 %
- background area : -23 %



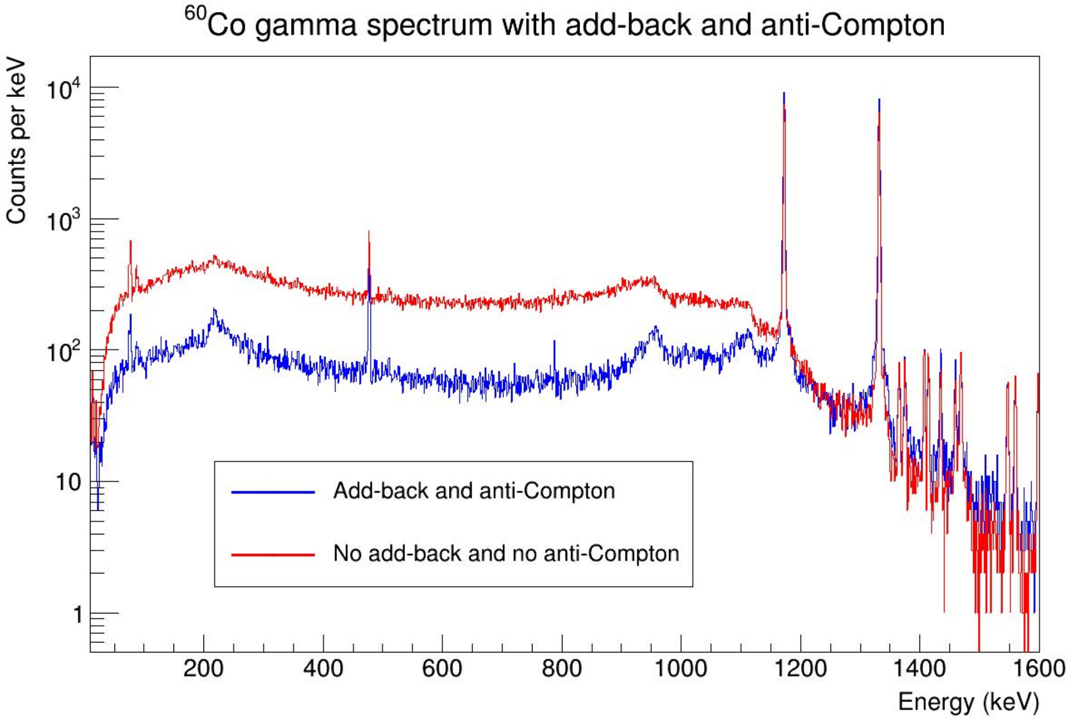


Gamma spectrum without anti-Compton and with or without add-back for ^{60}Co

IV) Event classification results

- Combined effects of anti-Compton and add-back :

Situation	Only AC	Only AB	Both AC and AB
Photopeak area	-4.2 %	+40 %	**+34 %**
BG area	-54 %	-23 %	**-71 %**

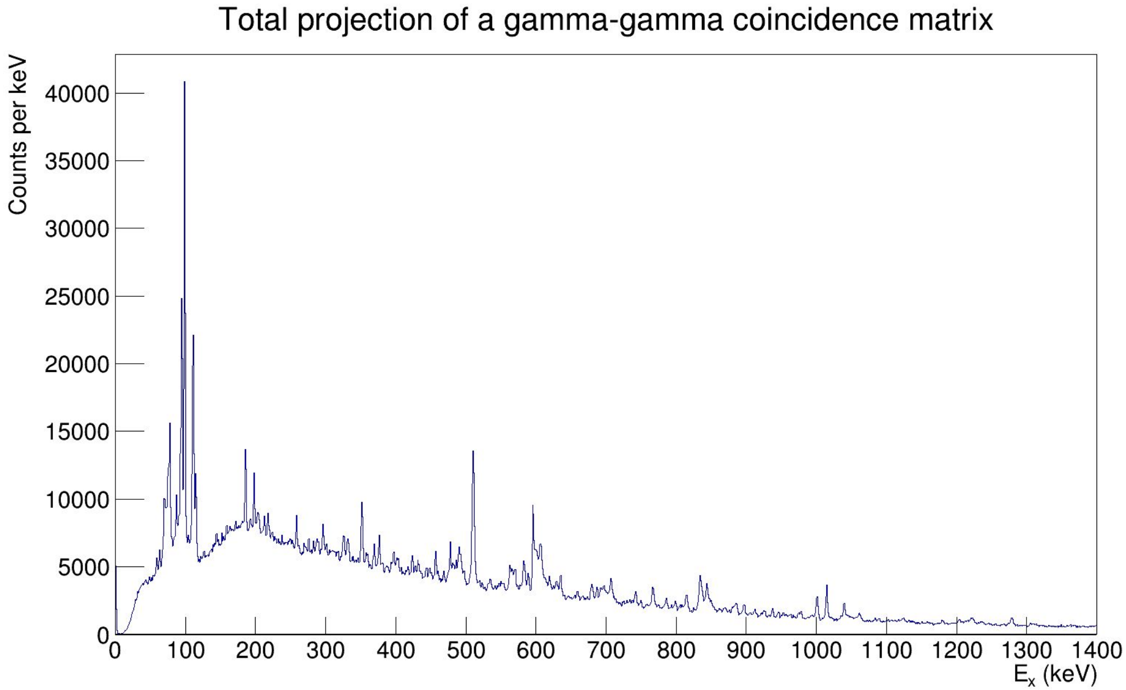


Gamma spectrum with or without add-back and anti-Compton for ^{60}Co

IV) Data analysis results

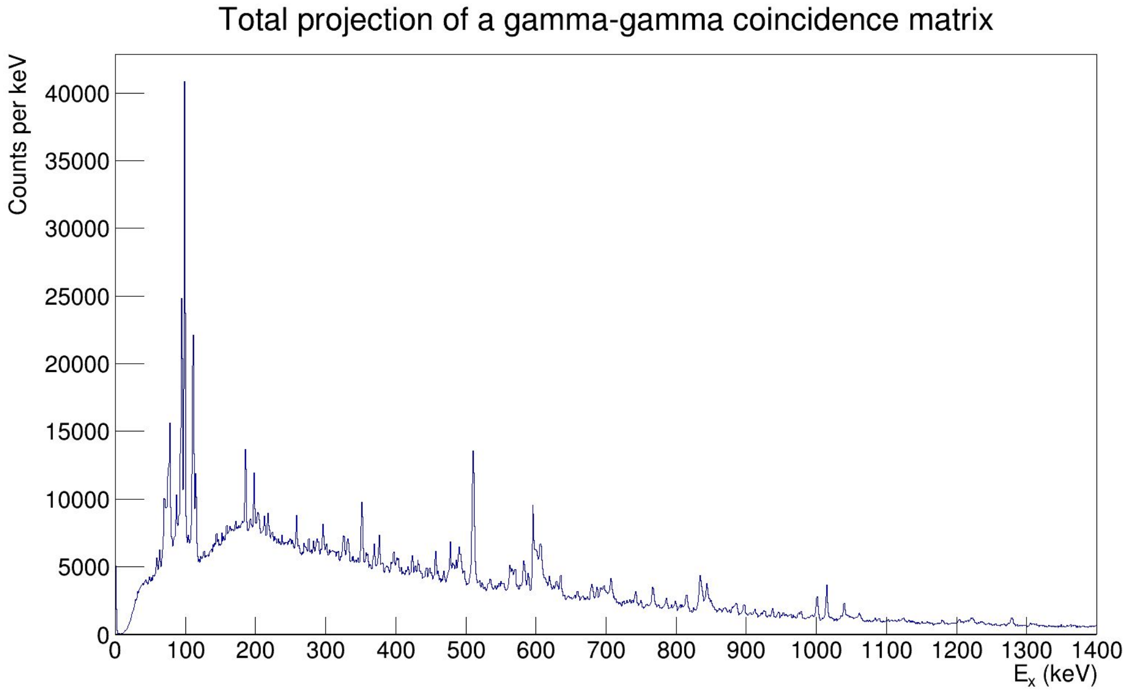
- Goal : reproduce literature results with 2D matrices

- Built with reaction data



IV) Data analysis results

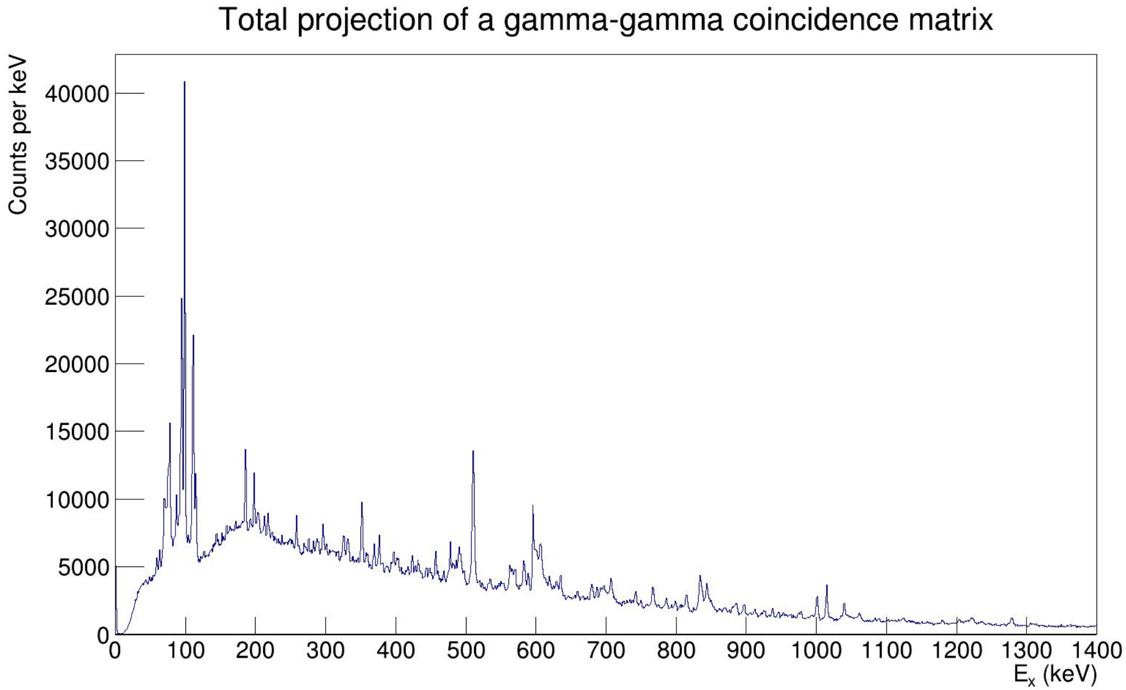
- Goal : reproduce literature results with 2D matrices
- Built with reaction data
- Gate to identify a fission fragments pair



IV) Data analysis results

- Goal : reproduce literature results with 2D matrices
- Built with reaction data
- Gate to identify a fission fragments pair

→ too many contaminant nuclei in 2D



IV) Data analysis results

- Triple gamma coincidences techniques

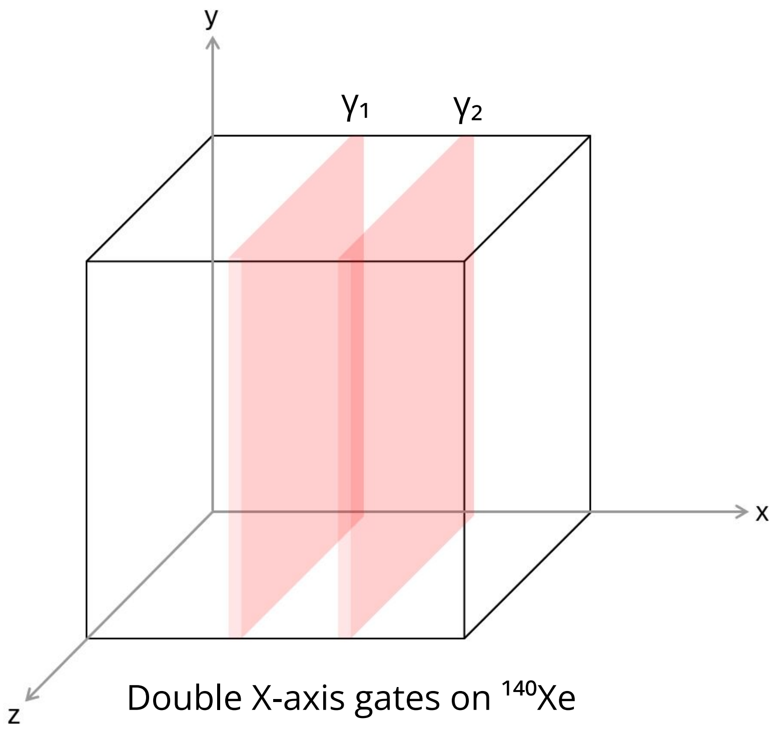
- ^{140}Xe - ^{96}Sr FF pair as a benchmark case :
  well produced and known in the literature

- Use of multiple *gates* to identify
  gamma transitions

IV) Data analysis results

- Double X-axis gates on two ^{140}Xe peaks

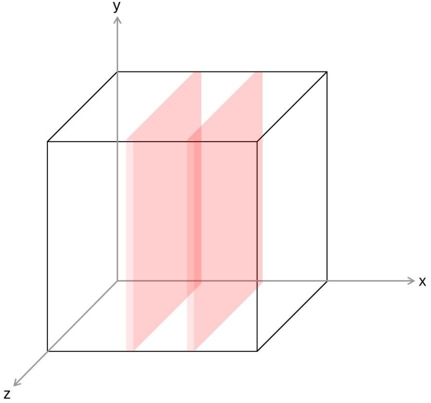
→ increased statistics but risk of contamination

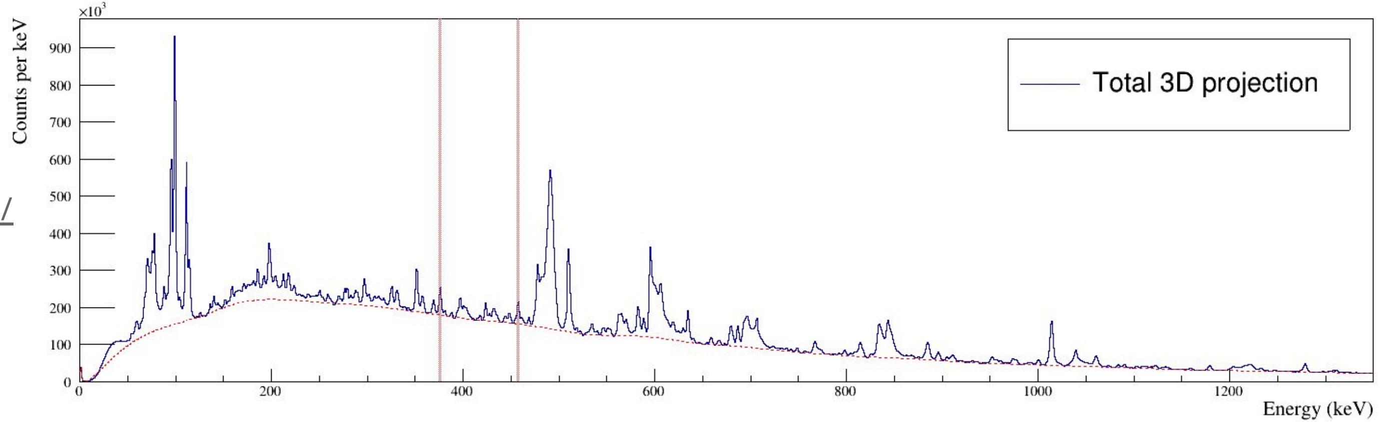


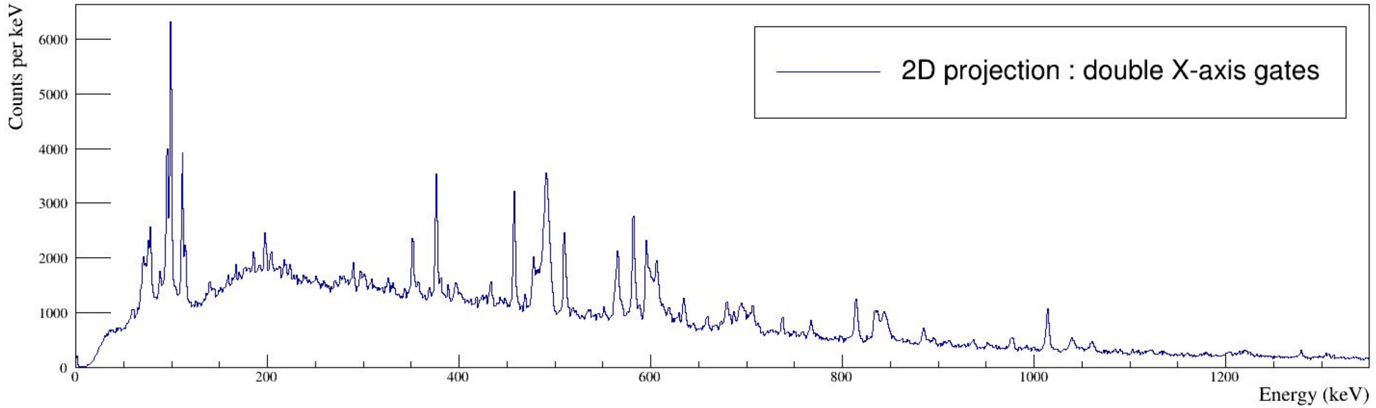
Double X-axis gates on ^{140}Xe

IV) Data analysis results

NuDat 3 :
https://www.nndc.bnl.gov/nudat3/



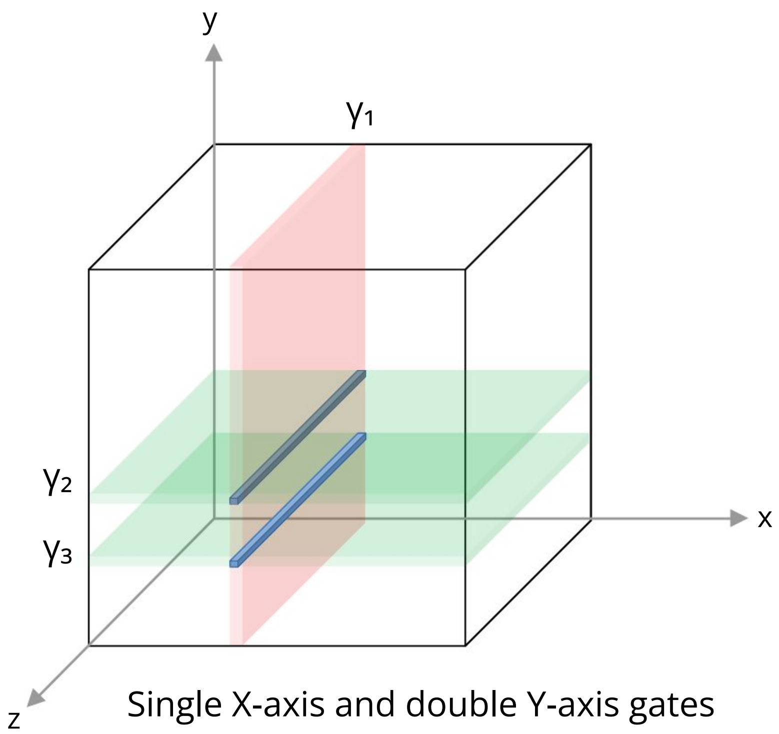




IV) Data analysis results

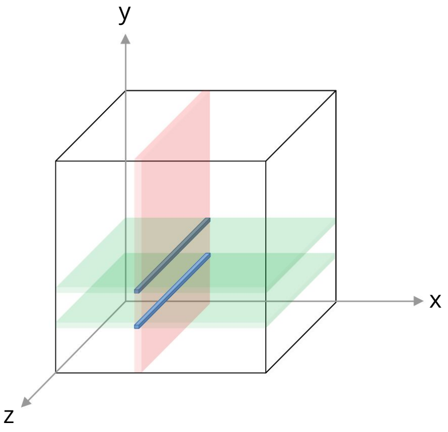
- Single X-axis gate on ^{140}Xe and double Y-axis gates on ^{96}Sr

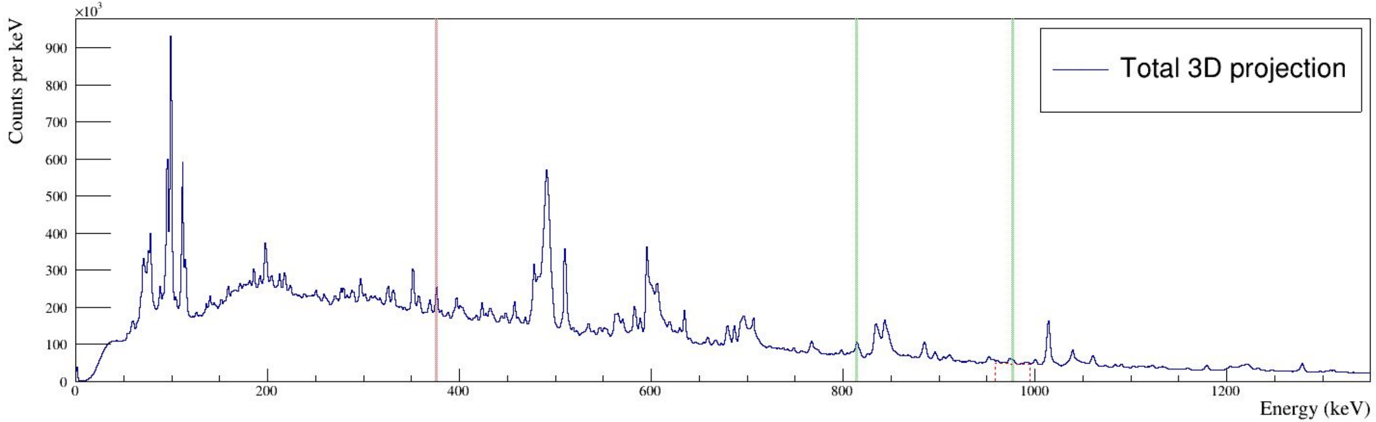
→ lower statistics but cleaner spectrum

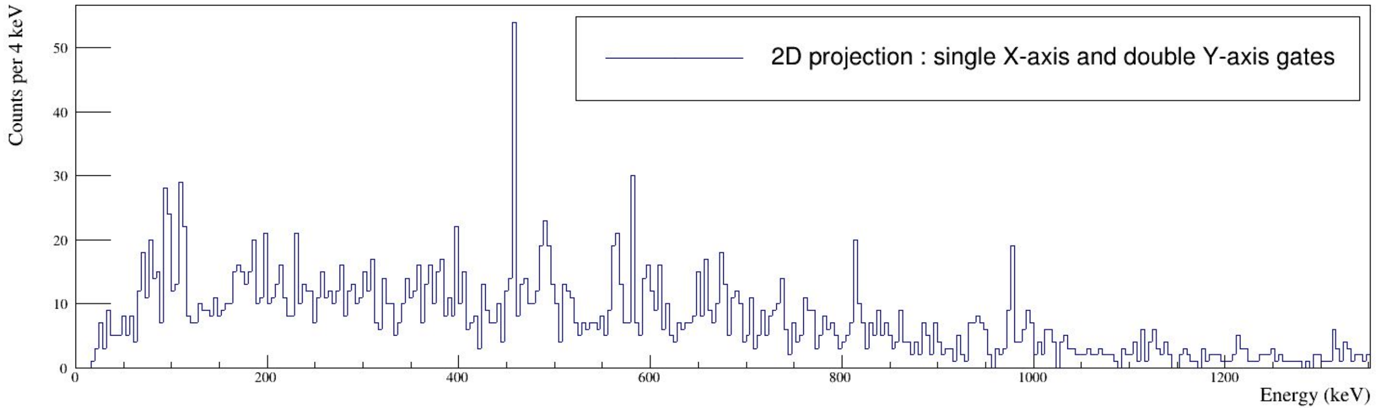


Single X-axis and double Y-axis gates

IV) Data analysis results







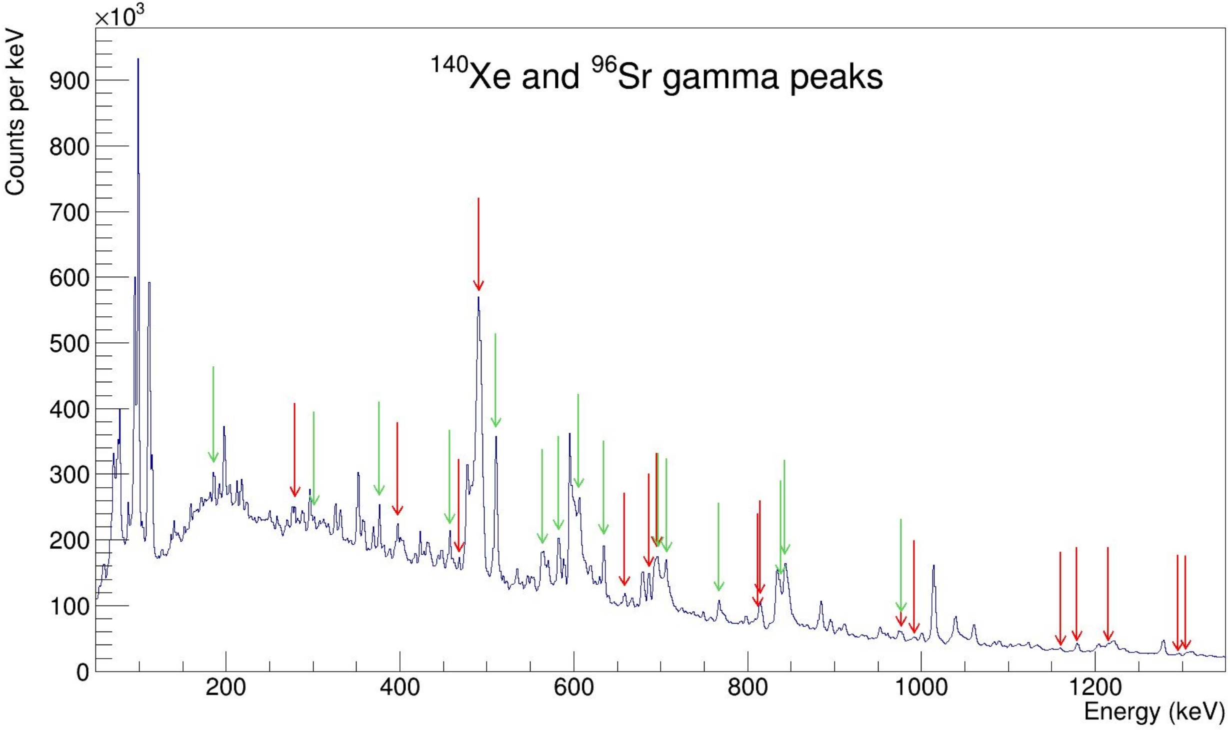
IV) Data analysis results

- Green arrows : ^{140}Xe

→ 15 gamma transitions

- Red arrows : ^{96}Sr

→ **16 gamma transitions identified with a triple coincidence matrix**



V) Conclusion

- Sorting code with the anti-Compton and add-back techniques combining :

- a Compton background reduction of 71 %

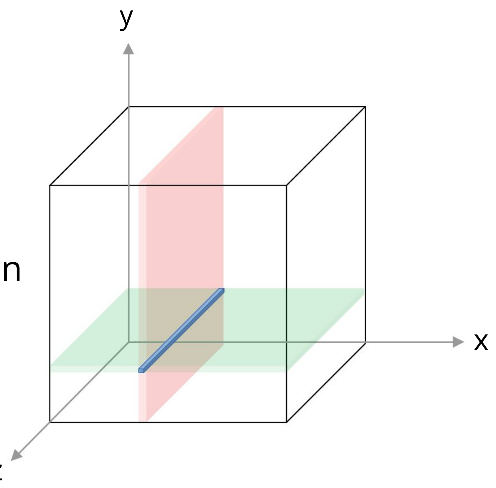
- a total absorption peak area increase of 34 %

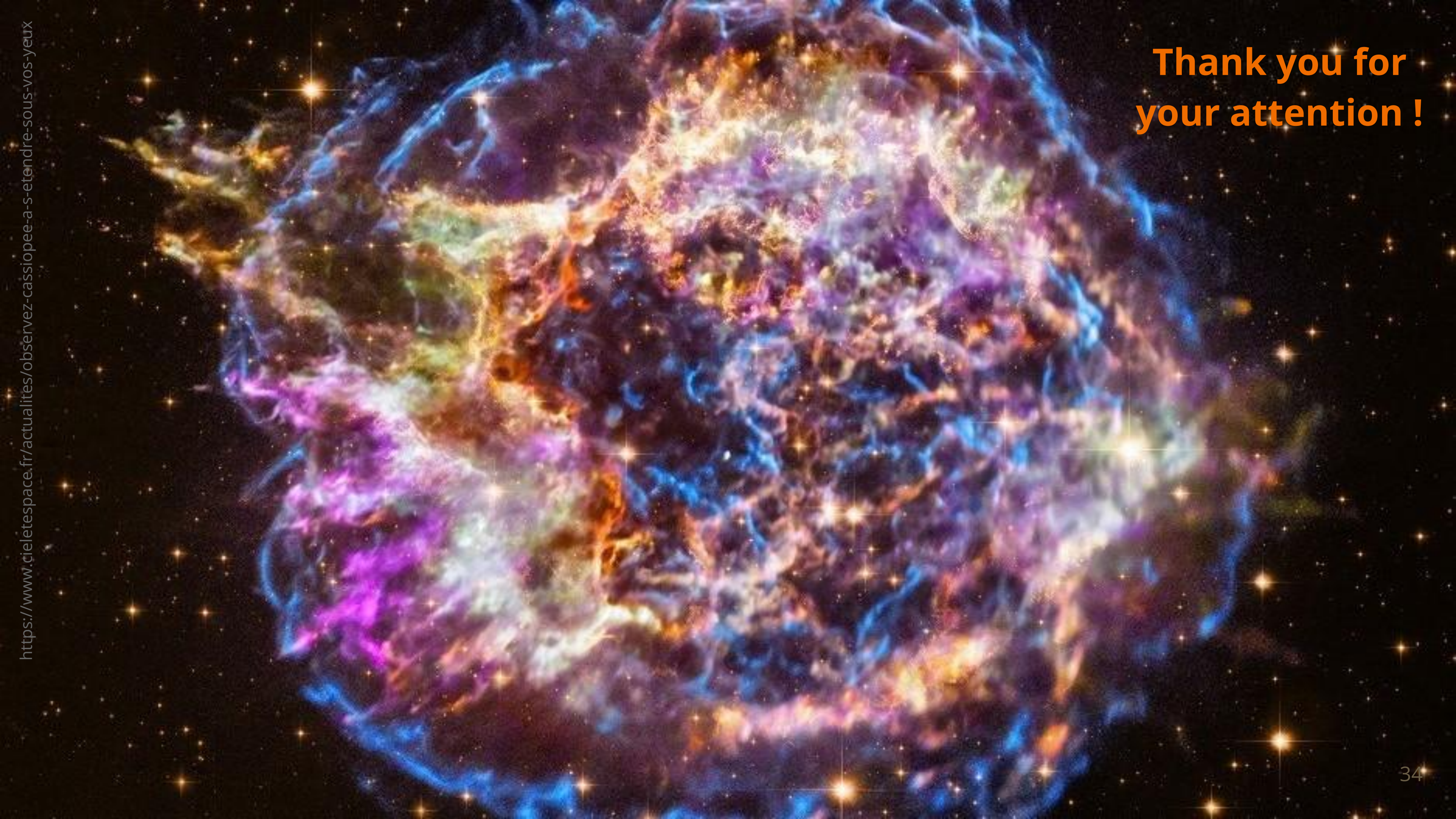
- Identification of transitions from the ^{140}Xe - ^{96}Sr fission fragments pair validating triple-coincidence techniques

- Next step : reproduce the level scheme of the ^{140}Xe - ^{96}Sr pair

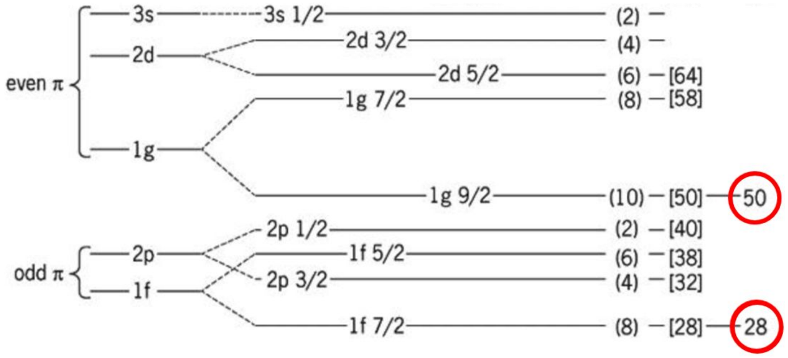
- Identify Zn nuclei and construct their level schemes

Double gates on ^{96}Sr peaks

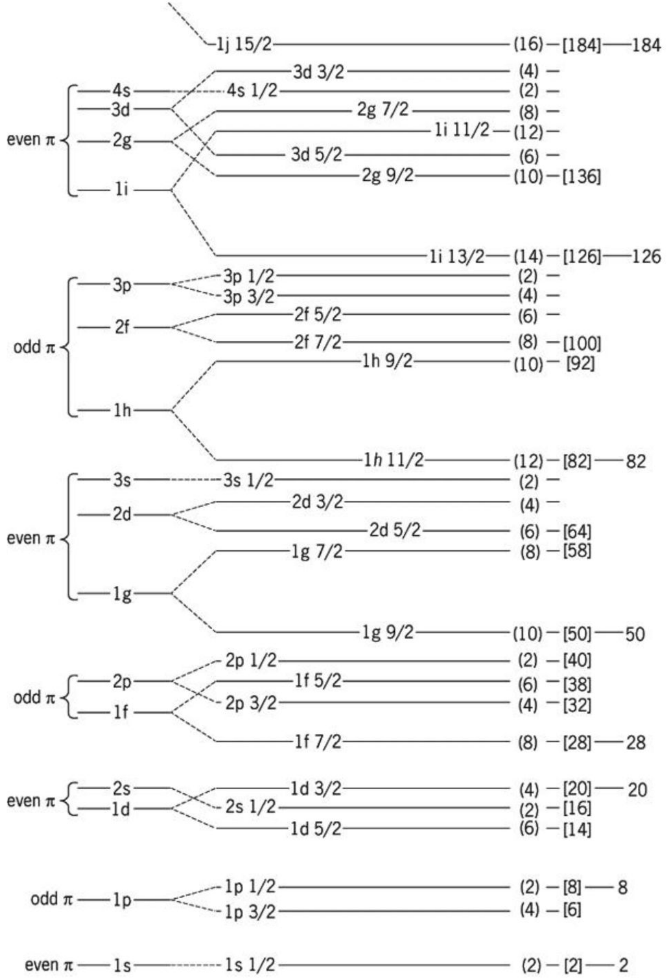



Thank you for
your attention !
https://www.cieletespace.fr/actualites/observez-cassiopee-a-s-etendre-sous-vos-yeux

Shell model



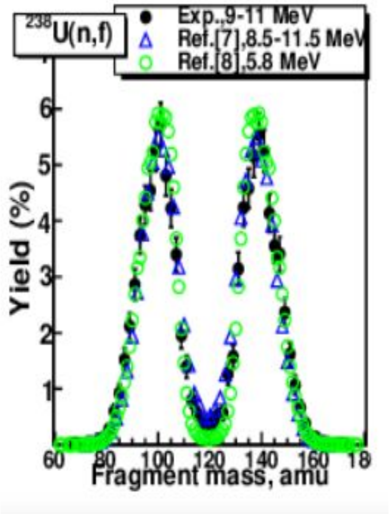
even π
3s
2d
1g
3s 1/2
2d 3/2
2d 5/2
1g 7/2
1g 9/2
(2)
(4)
(6) — [64]
(8) — [58]
(10) — [50] — 50
odd π
2p
1f
2p 1/2
1f 5/2
2p 3/2
1f 7/2
(2) — [40]
(6) — [38]
(4) — [32]
(8) — [28] — 28



1j 15/2 — (16) — [184] — 184
even π
4s
3d
2g
1i
3d 3/2 — (4)
4s 1/2 — (2)
2g 7/2 — (8)
1i 11/2 — (12)
3d 5/2 — (6)
2g 9/2 — (10) — [136]
1i 13/2 — (14) — [126] — 126
odd π
3p
2f
1h
3p 1/2 — (2)
3p 3/2 — (4)
2f 5/2 — (6)
2f 7/2 — (8) — [100]
1h 9/2 — (10) — [92]
1h 11/2 — (12) — [82] — 82
even π
3s
2d
1g
3s 1/2 — (2)
2d 3/2 — (4)
2d 5/2 — (6) — [64]
1g 7/2 — (8) — [58]
1g 9/2 — (10) — [50] — 50
odd π
2p
1f
2p 1/2 — (2) — [40]
1f 5/2 — (6) — [38]
2p 3/2 — (4) — [32]
1f 7/2 — (8) — [28] — 28
even π
2s
1d
1d 3/2 — (4) — [20] — 20
2s 1/2 — (2) — [16]
1d 5/2 — (6) — [14]
odd π — 1p
1p 1/2 — (2) — [8] — 8
1p 3/2 — (4) — [6]
even π — 1s
1s 1/2 — (2) — [2] — 2

Fission fragments mass number distribution

- Two peaks : A = 100 and A = 140



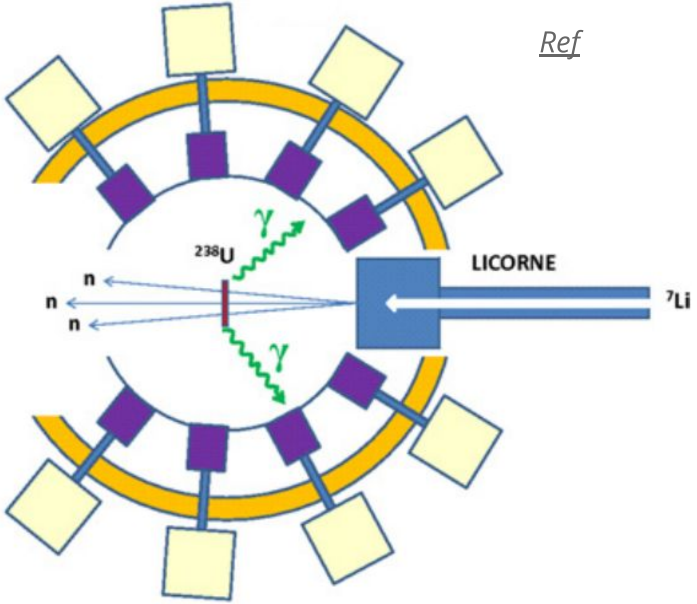
II) LICORNE

- Inverse kinematics reaction p (^{7}Li, ^{7}Be) n offers a natural focusing of the beam (at forward angles)

- Advantages :

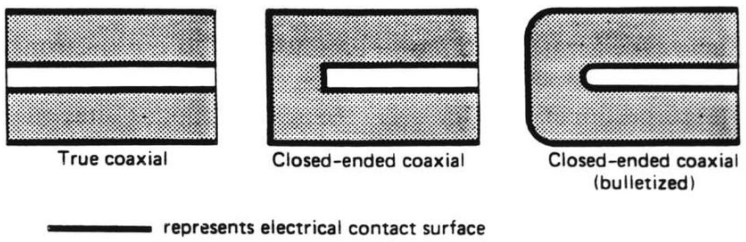
- neutron flux increased by a factor 25 - 100
- neutron background reduced at most angles
- possibility to place detectors adjacent to the neutron source

Ref



LICORNE beam with one ring of HPGe detectors

HPGe crystal

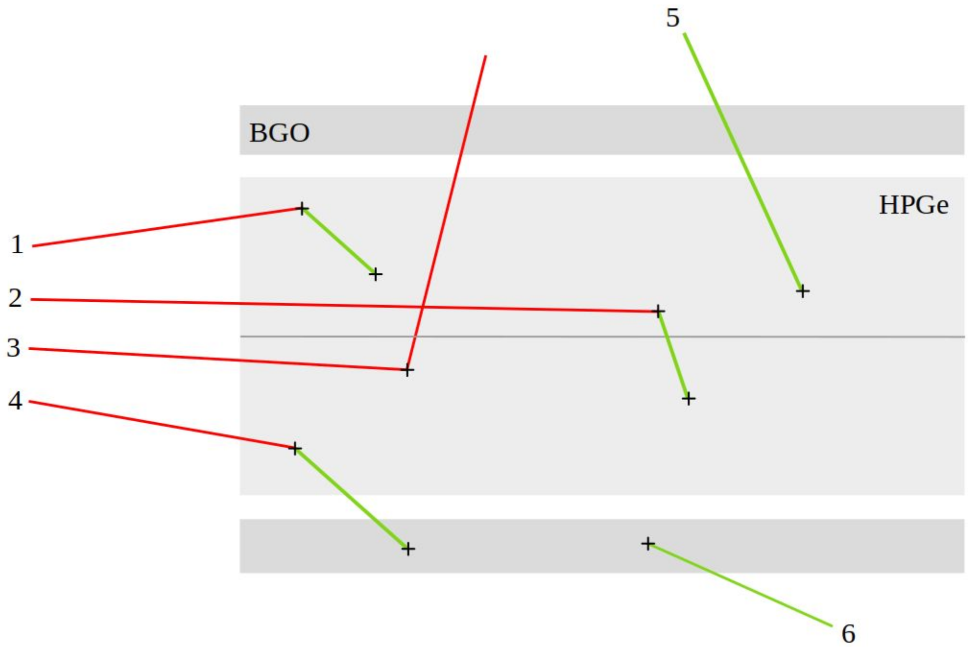


The closed-ended coaxial bulletized HPGe used in the experiment

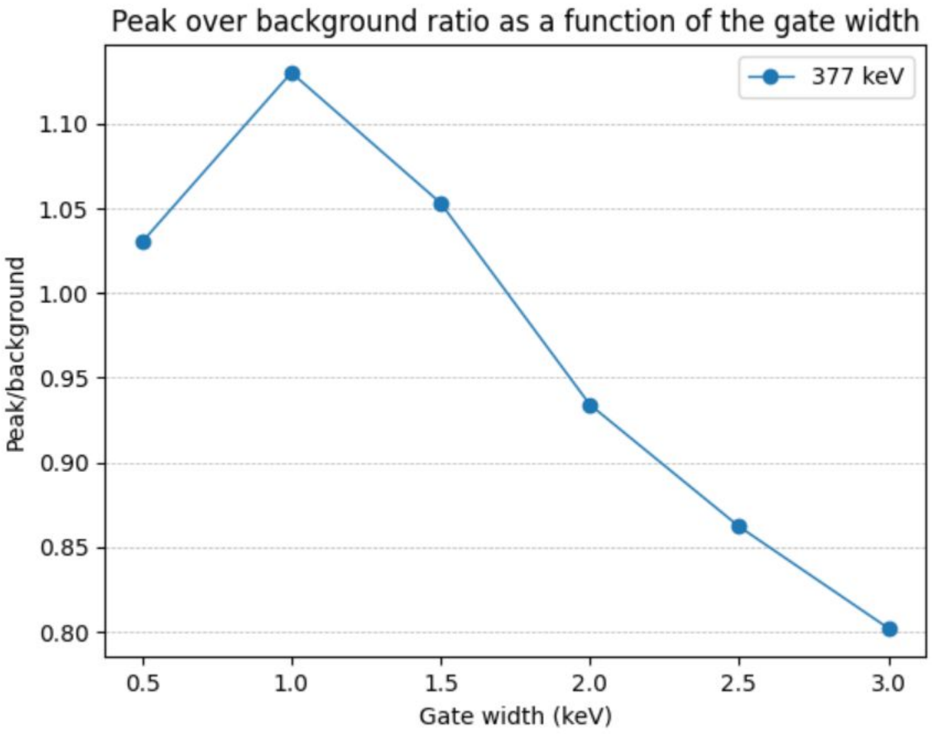
III) Event classification

- Event = set of photons, hit = interaction of a photon in a detector

Photon	HPGe hit	BGO hit	Clean ?
1	✔	✘	Yes
2	✔	✘	Yes
3	✔	✘	Yes
4	✔	✔	No
5	✔	✘	Yes
6	✘	✔	No



Gate choice



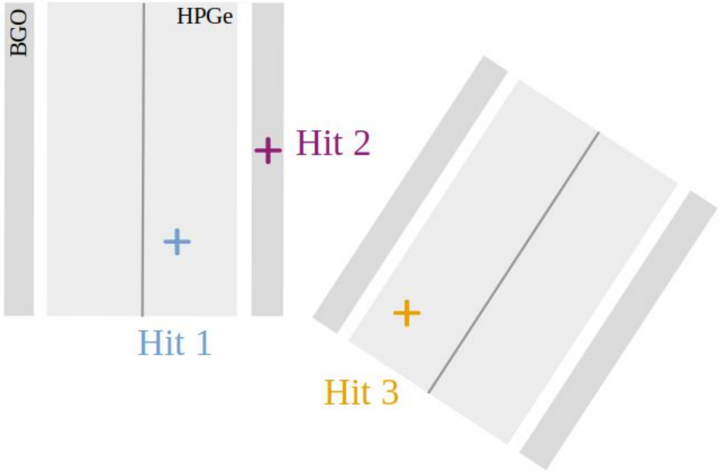
Peak over background ratio as a function of the gate width
377 keV
Peak/background
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.5
1.0
1.5
2.0
2.5
3.0
Gate width (keV)

V) Perspectives

- Limit : no way of discarding photons doing only Compton scattering

- Improvement to the flag system :

- before : hit 1 not clean, hit 3 possibly clean
- after : hit 1 not clean, hit 3 clean



Three hits in two adjacent clovers