Search for Electron Capture of ^{176}Lu with a LYSO scintillator

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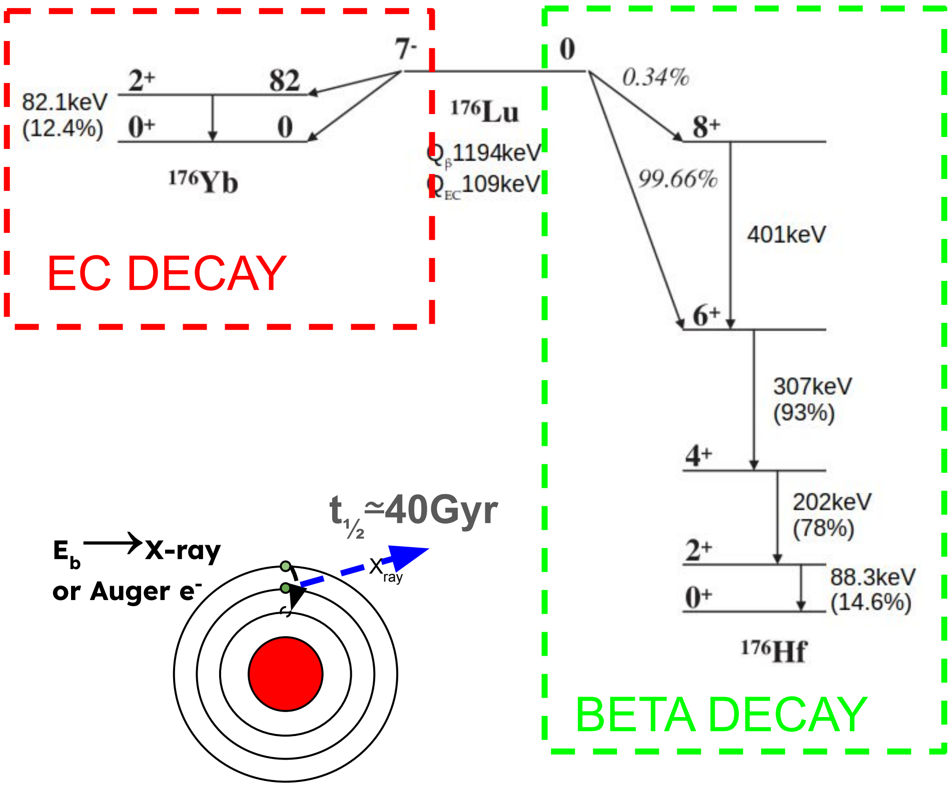
Electron Capture of ^{176}Lu

- ^{176}Lu → β- decay to ^{176}Hf (~38 Gyr)
- Potentially unstable under EC (measured ^{40}K, ^{50}V and ^{138}La, missing ^{23}Te, ^{176}Lu and ^{180}Ta*)

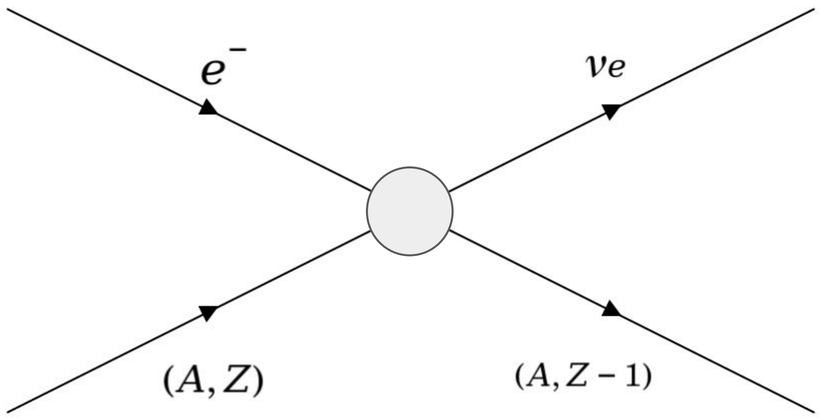
- Lu/Hf ratio is an isotopic clock
- ^{176}Lu/^{175}Lu s-process thermometer in studies of stellar nucleosynthesis
- 7th and 5th forbidden decays (never been detected) the experimental investigation is a test for hypothetical violations of the Standard Model



Previous searches for the ^{176}Lu EC decay were performed by using a passive Lutetium source coupled to a HP-Ge detector.

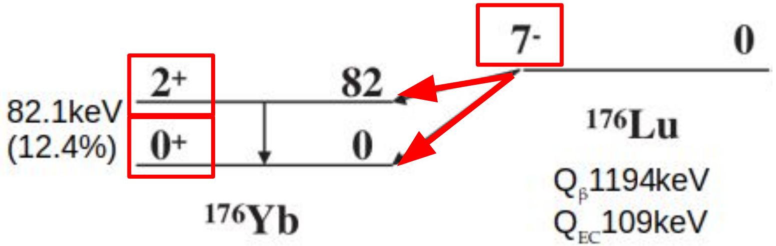
EC decay: pure EC decay and forbiddenness

Electron capture is a process where a proton-rich nuclei absorbs an electron and emits a neutrino. Considering the nucleus size and the ν energy, it is very hard that the ν carries away more than ½ħ



The Forbiddenness of a EC decay is related to the jump total angular momentum and parity.

$$I_i = I_f + L + S$$

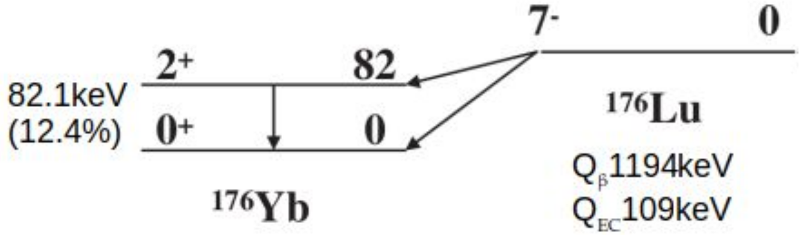


^{176}Lu EC decay is 7th or 5th forbidden!

EC decay: visible energy in EC

Example: EC decay to 2^+ ^{176}Yb (the less forbidden).

Signature of this transition is the 82 keV gamma from ^{176}Yb relaxation.



In addition:

$Q' = (Q_{EC} - E_{\gamma 82}) = 27$ keV (k-shell capture not allowed)

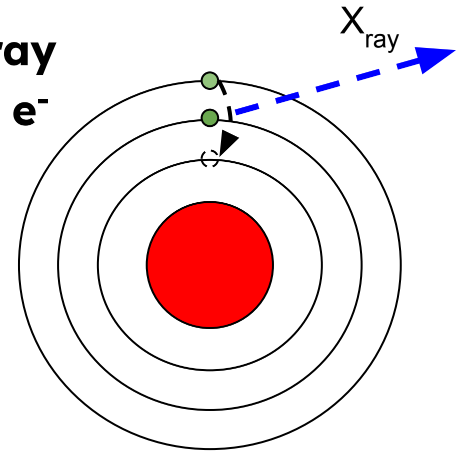
VISIBLE ENERGY in this decay:

- Pure EC decay (discrete energies):

$$Q - E_\nu = E_{\gamma 82} + E_b < 82+10.5 \text{ keV}$$

E_b (L shell edge)

$E_b \rightarrow$ X-ray or Auger e^-



Detector: LYSO as active ^{176}Lu source

LYSO (Lutetium-yttrium oxyorthosilicate) scintillator coupled with a PMT in coincidence with a HP-Ge detector.
Expected β-decay activity: 40Bq/g

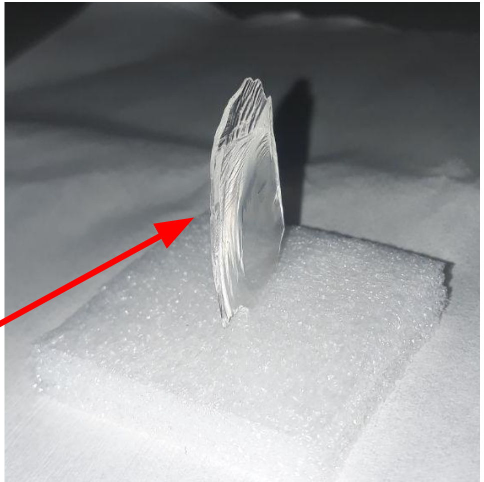
The thin source geometry allows 82keV photon to escape the crystal and to be detected in a nearby HP-Ge.

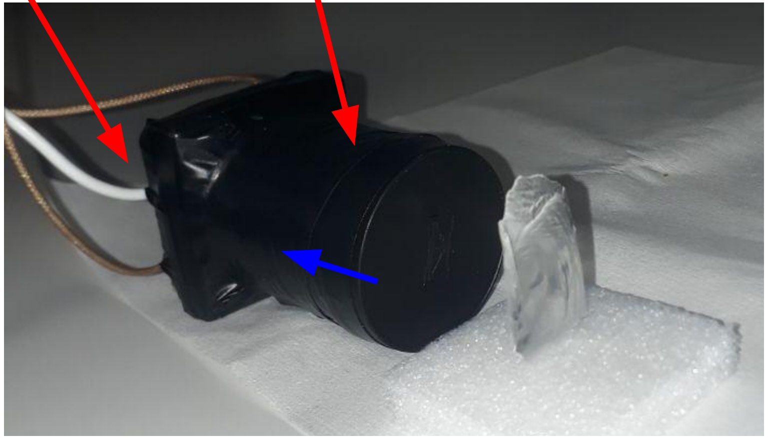
LYSO measures X-rays and Auger e$^-$ from the filling process of the vacancy or the possible radiative photons.

Active ^{176}Lu source:
powerful rejection of β decay bkg.

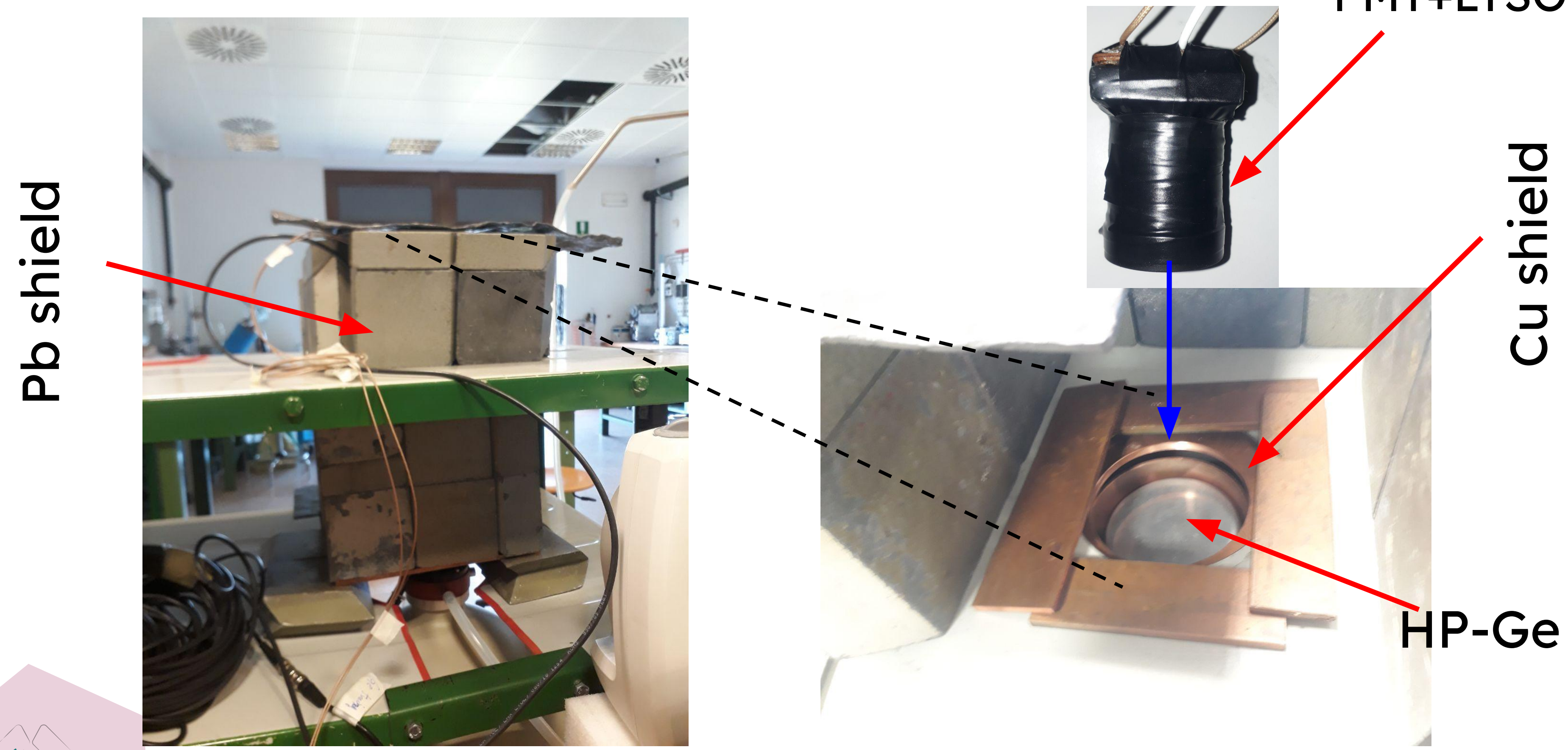
LYSO (7.9 gr)

Hamamatsu R5946 PMT

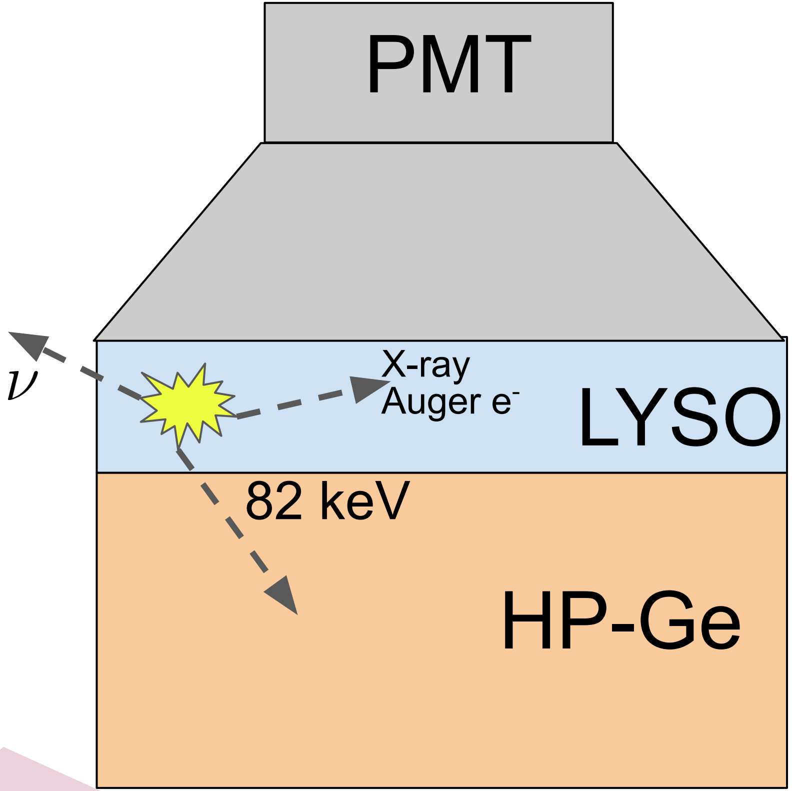


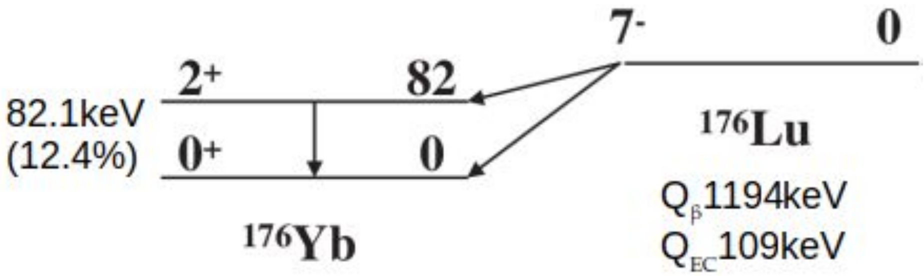


Detector: setup@INFN-TIFPA



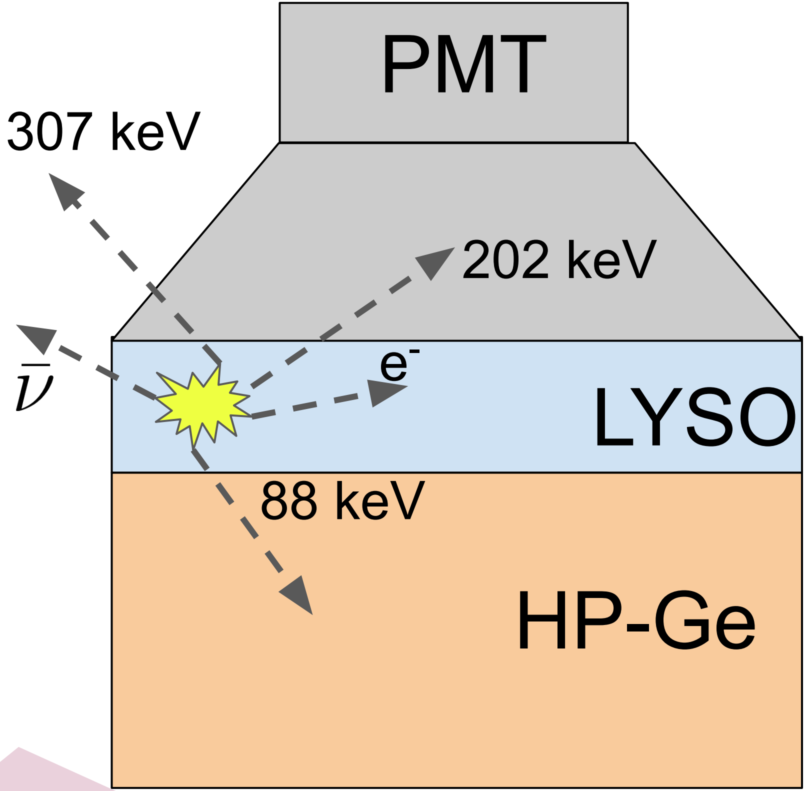
Signal topology: 2^+Yb EC decay (5th forbidden)



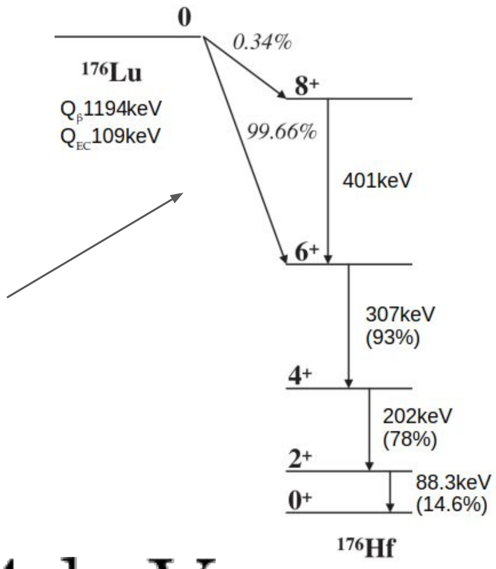


$$Q_{EC} = 109 \text{ keV}$$
$$E_{Ge} = 82 \text{ keV}$$
$$E_{LYSO} < 27 \text{ keV}$$

Example of background: β⁻ decay



β-decay provides a bkg identified by “large” energy released in LYSO

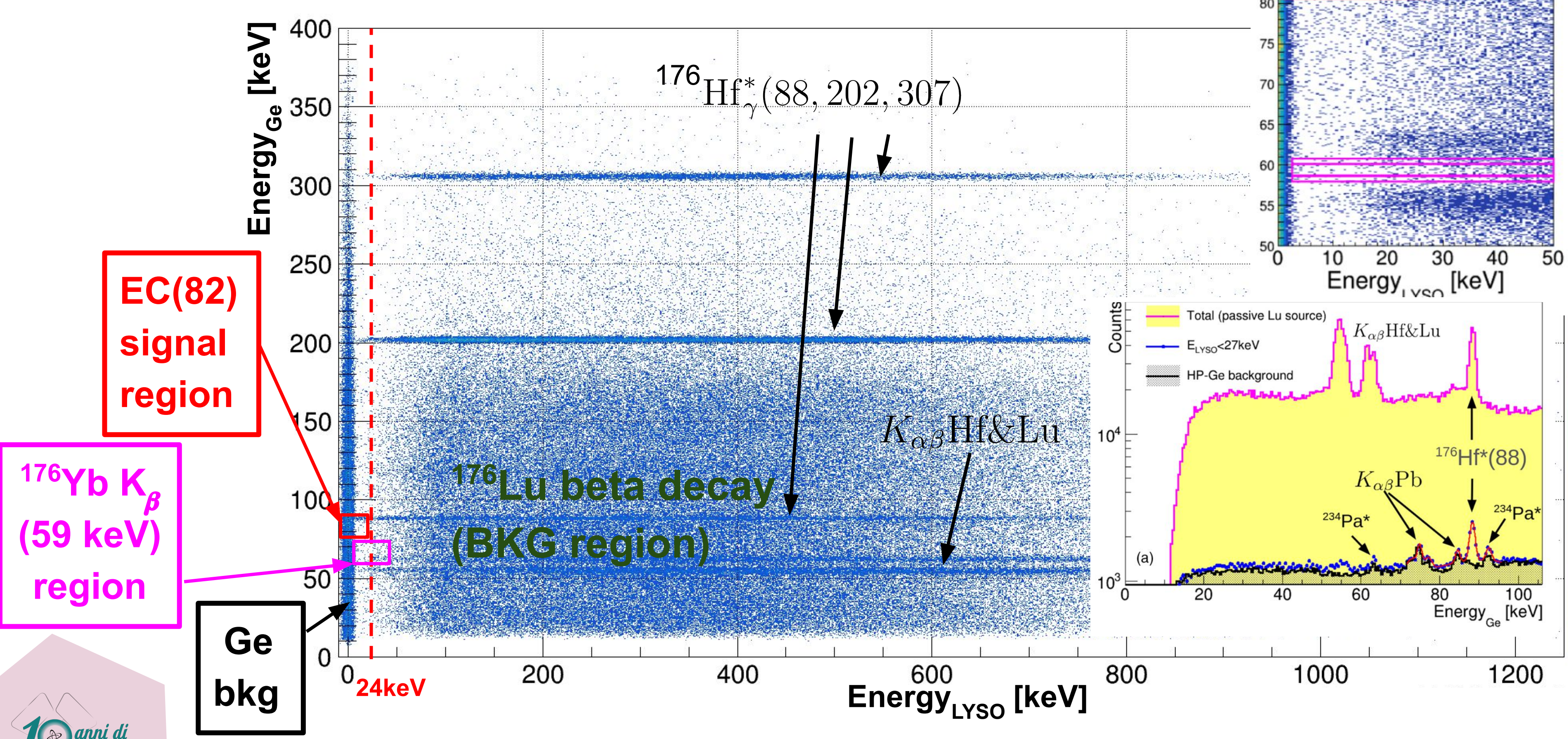


$$Q_\beta = 1194 \text{ keV}$$

$$E_{Ge} = 88 \text{ keV}$$

$$E_{LYSO} \approx 400 \text{ keV}$$

Two-dimensional spectrum of ^{176}Lu



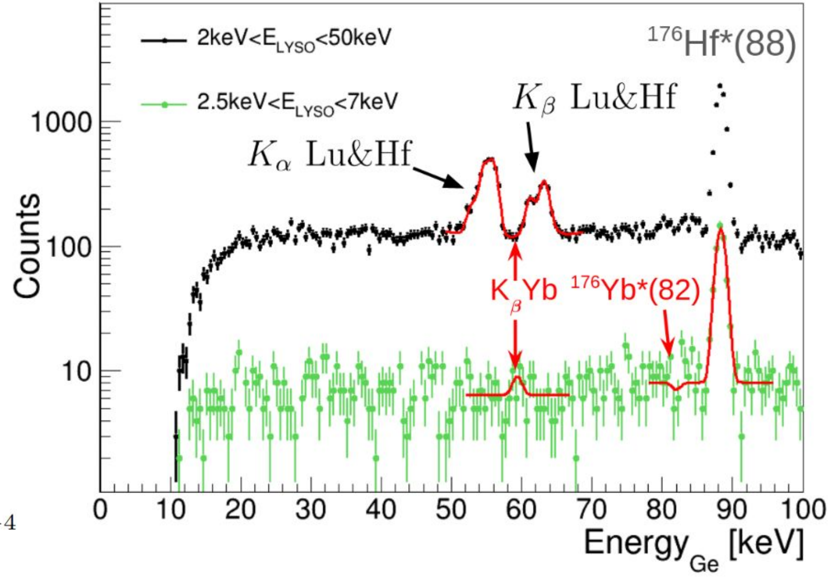
Results

No evidence for $^{176}Yb^{*}$ 82.1 keV γ-ray and 59.3 keV K_β x-ray was found.

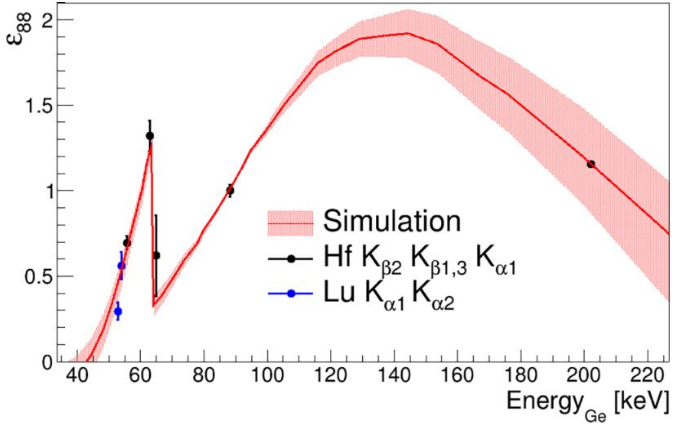
Upper limit on number of events $N_{82} < 38 \pm 105$ provides an upper limit on the EC branching fraction:

$$B_{82} = \frac{(1+\alpha_T^{82})N_{82}/\varepsilon_{88}}{(1+\alpha_T^{88})N_{88}} < 2.6 \times 10^{-3} \quad B_{59} = \frac{N_{59}/(\varepsilon_{59}\varepsilon_{88}\varepsilon_{sel})}{(1+\alpha_T^{88})N_{88}} < 6 \times 10^{-4}$$

α_T^{82}=7.06, α_T^{88}=5.86 total electron conversion coefficients



Detection efficiency, ε_{88}, (relative to 88 keV) for x/γ rays emitted by the LYSO source. The behavior is due to self-absorption of the LYSO crystal (63.3-keV Lu k-edge) combined with detection efficiency of the GC2020 HP-Ge



Conclusions

- Active source technique: LYSO as detector
- Background reduction (^{176}Lu β-decay and the HP-Ge intrinsic/external)

- No evidence for the EC process.
- Depending on the particular EC channel, we set upper limits to the ^{176}Lu EC branching fraction

- Estimations are 3-30 better than what obtained with previous measurements.

Electron capture channel	Branching ratio limit (95% C.L.)	Previous limit (68% C.L.) [5]
$1s$ EC + 59 keV	0.035%	0.36%
$1s$ REC + 59 keV	0.029%	
L EC + 82 keV	0.024%	0.45%
$L/3s$ REC + 82 keV	0.026%	
$n_{>3s}$ REC + 82 keV	0.028%	
$3p$ REC + 82 keV	0.036%	
$3s/3p$ EC + 82 keV	0.027%	
$3d$ EC + 82 keV	0.038%	
Any + 82 keV	0.26%	

https://doi.org/10.1103/PhysRevC.107.045504
https://doi.org/10.1051/epjconf/202329001002