NUSPIN 2017
26-29 June 2017
GSI
Europe/Berlin timezone

Investigation of internal background of ^{7}Li and ^{6}Li enriched CLYC scintillators

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Outline

- ✓ Scintillators detectors for nuclear physics
- ✓ Elpasolite crystals – Why they are so interesting?
- ✓ Neutron detection capability
- ✓ Internal background in different CLYC scintillators and in a CLLB(C) samples
- ✓ Internal background can affect nuclear physics experiment?
- ✓ Conclusions

Scintillators for nuclear physics experiments

Detector requirements:

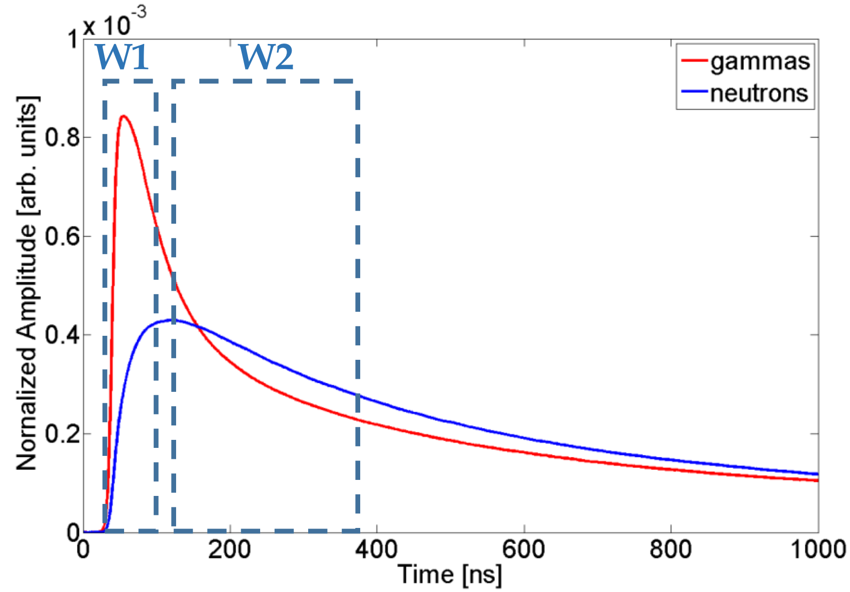
- ✓ Measurement of high energy gamma rays (~ 15 MeV) → Good efficiency
- ✓ Good Time resolution
- ✓ Imaging properties to reduce Doppler Broadening
- ✓ Energy resolution is not mandatory but very useful for:
  - calibration
  - measurement and studies of discrete structures
- ✓ Possibility to discriminate between gamma rays and neutrons using TOF and PSD

Scintillators are the best candidates for this kind of experiments

Material	Light Yield [ph/MeV]	Emission λ_{max} [nm]	En. Res. at 662 keV [%]	Density [g/cm^2]	Principal decay time [ns]
NaI:Tl	38000	415	6-7	3.7	230
CsI:Tl	52000	540	6-7	4.5	1000
$LaBr_3$:Ce	63000	360	3	5.1	17
CLLB:Ce	60000	410	2.9	4.2	55, ~ 270
CLYC:Ce	20000	390	4	3.3	1 CVL 50, ~1000

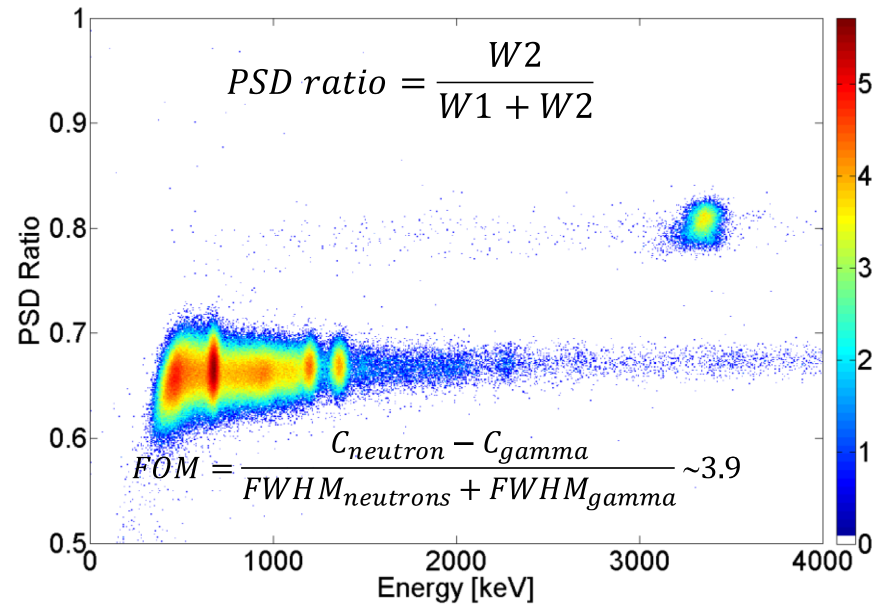
Elpasolite scintillators

The elpasolite crystals were developed approximately 10 years ago.
Excellent performances in terms of **gamma and neutron detection**.
Examples: CLLB:Ce ($Cs_2LiLaBr_6$:Ce), CLLC:Ce ($Cs_2LiLaCl_6$:Ce) and CLYC:Ce (Cs_2LiYCl_6:Ce)



Characteristics:

- ✓ High **energy and time resolution**
- ✓ Neutron-gamma **pulse shape discrimination** capability
- ✓ High **proportionality**
- ✓ High **efficiency** for gamma and neutrons
- ✓ High **light yield**
- ✓ **Low cost**



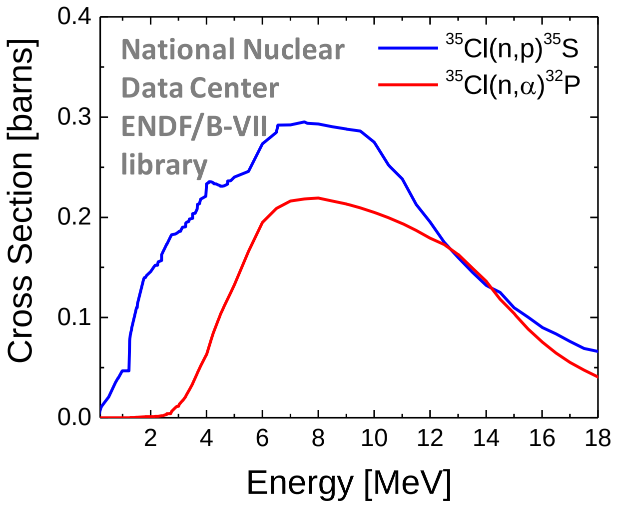
PSD is based on the difference in the scintillation decay response to gamma and neutrons.

Neutron detection

Fast neutrons:

- ✓ $^{35}Cl(n,p)^{35}S$ → Q-value = 0.6 MeV σ ≈ 0.2 barns at E_n = 3 MeV
- ✓ $^{35}Cl(n,\alpha)^{32}P$ → Q-value = 0.9 MeV σ ≈ 0.01 barns at E_n = 3 MeV

$E_{p/\alpha} = (E_n + Q)\, q_{p/\alpha}$ → p or α energy is linearly related to n energy → CLYC is a neutron spectrometer



E_n > 6 MeV other reaction channels on detectors isotopes → not easy neutron spectroscopy

The kinetic energy of the neutrons can be measured via:

1) Time of Flight (TOF) techniques.
2) The energy signal

Thermal neutrons:

- ✓ $^{6}Li(n,\alpha)t$ → Q-value = 4.78 MeV σ = 940 barns at E_n = 0.025 eV.

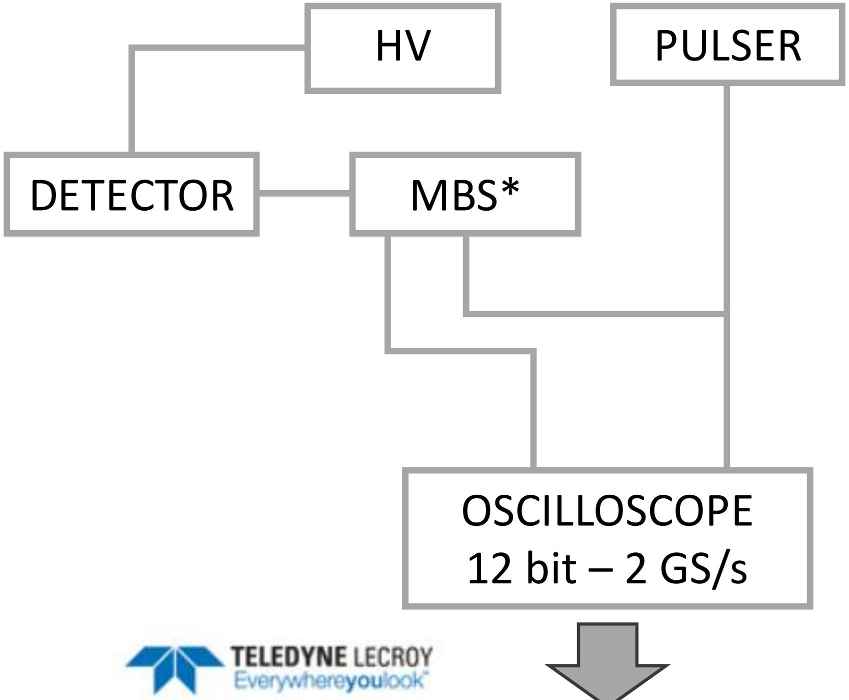
To fast thermal detection:
^{6}Li (^{6}Li = 95%) enriched CLYC → CLYC-6

1 CLYC-6 1'' x 1''
1 CLLB(C) 1'' x 1''

To fast neutron detection:
^{7}Li (^{7}Li > 99%) enriched CLYC→ CLYC-7

1 CLYC-7 1'' x 1''
1 CLYC-7 2'' x 2''
1 CLYC-7 2'' x 2''

Internal background measurements

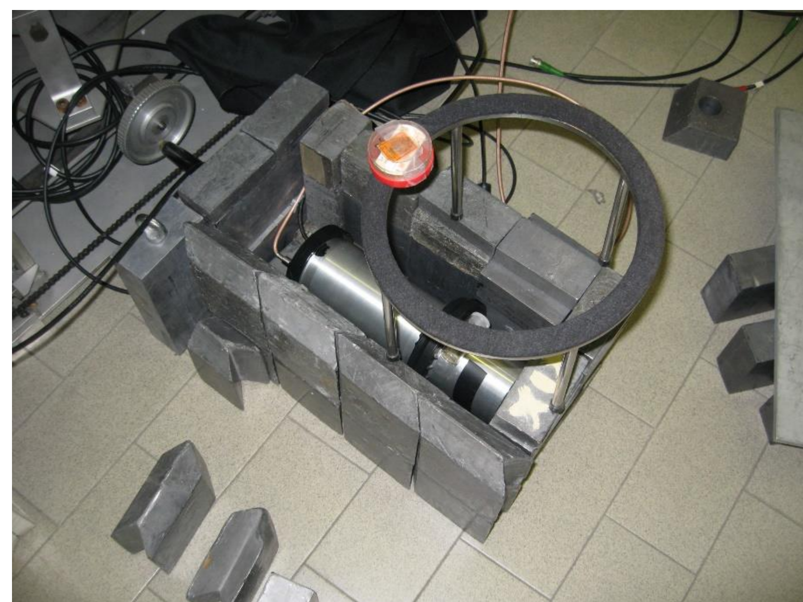


The detectors were placed inside a lead shield. The shield was changed from 5 cm up to 10 cm.

Calibration run with sources (^{137}Cs and ^{60}Co)

Data with and without shield were compared.

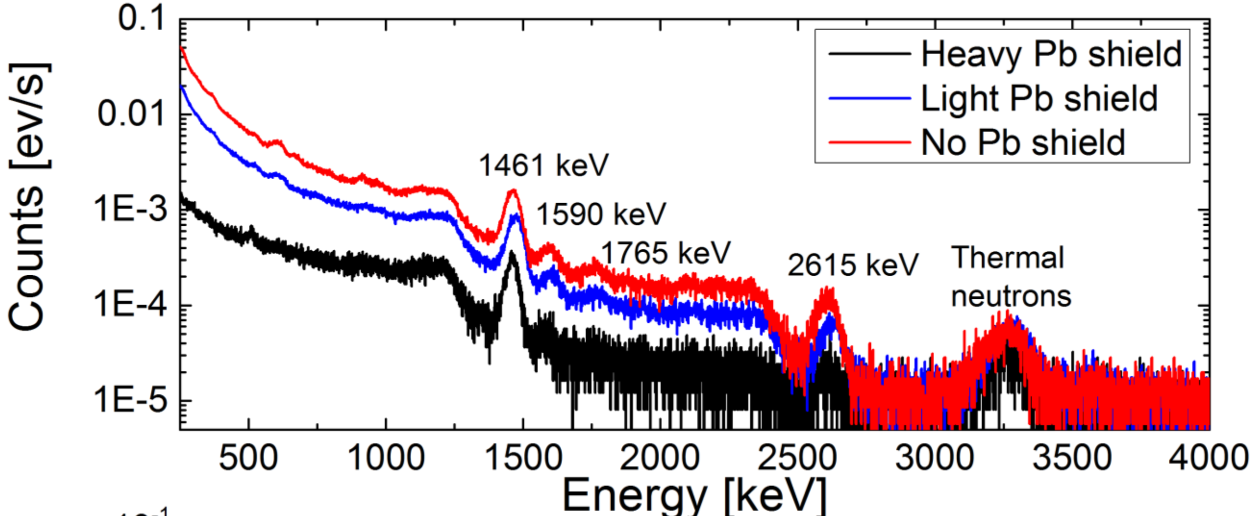
The measurements runs for few days.

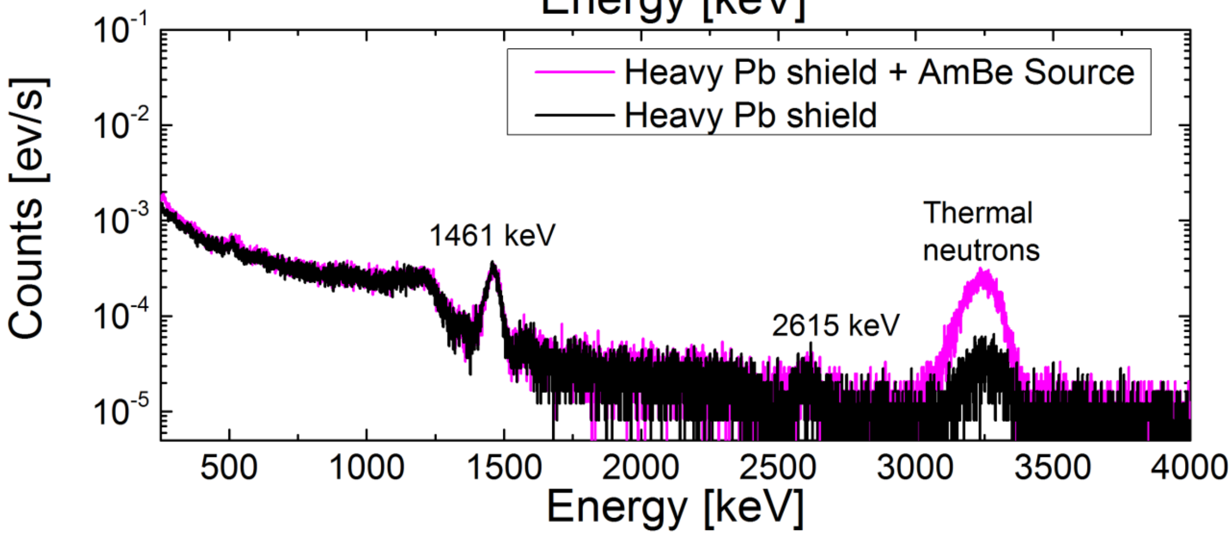


* Developed in Milan for CLYC scintillators

Internal Radiation

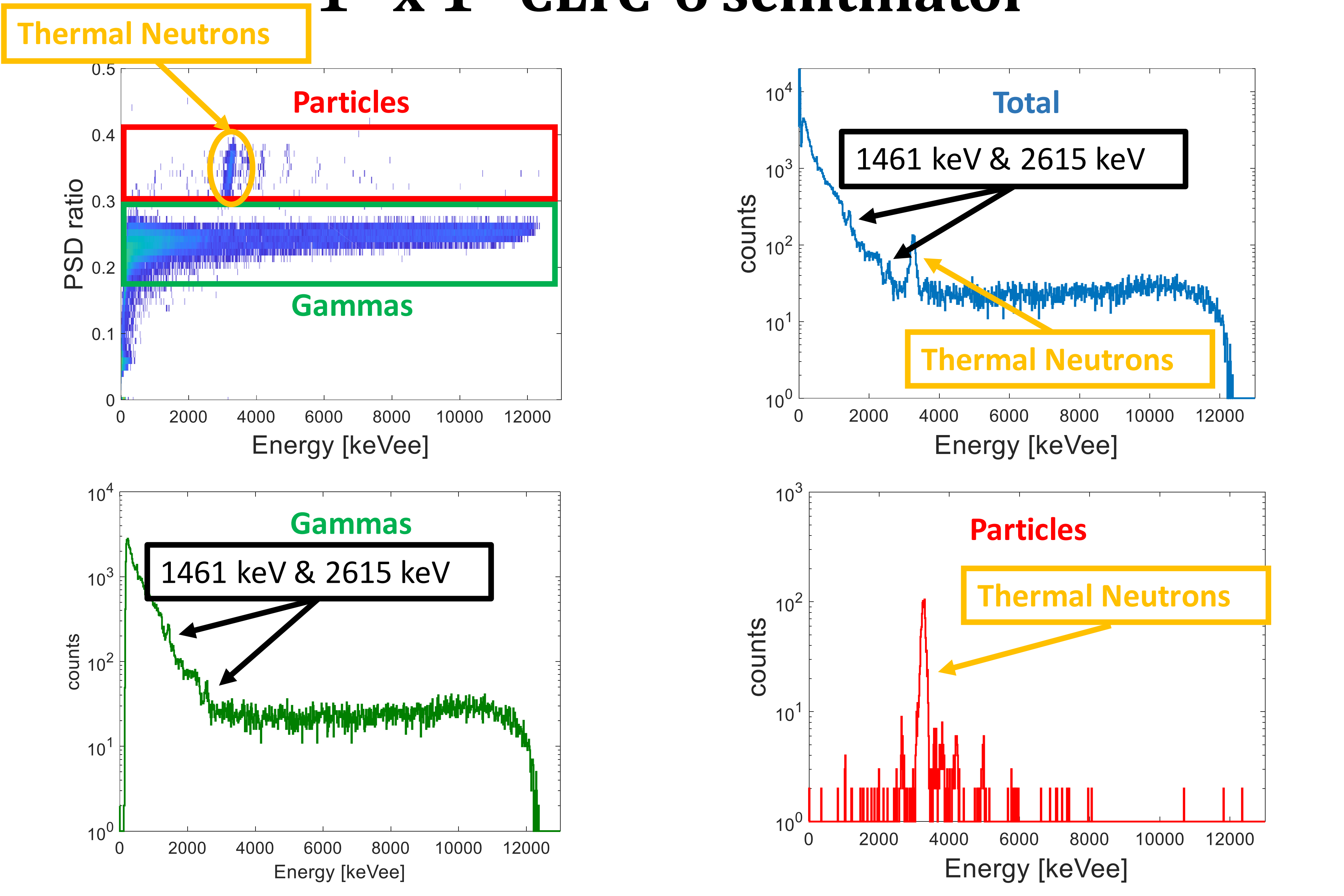
Measurements performed in Milan using a 95% enriched ^{6}Li 1”x1” CLYC:Ce scintillator



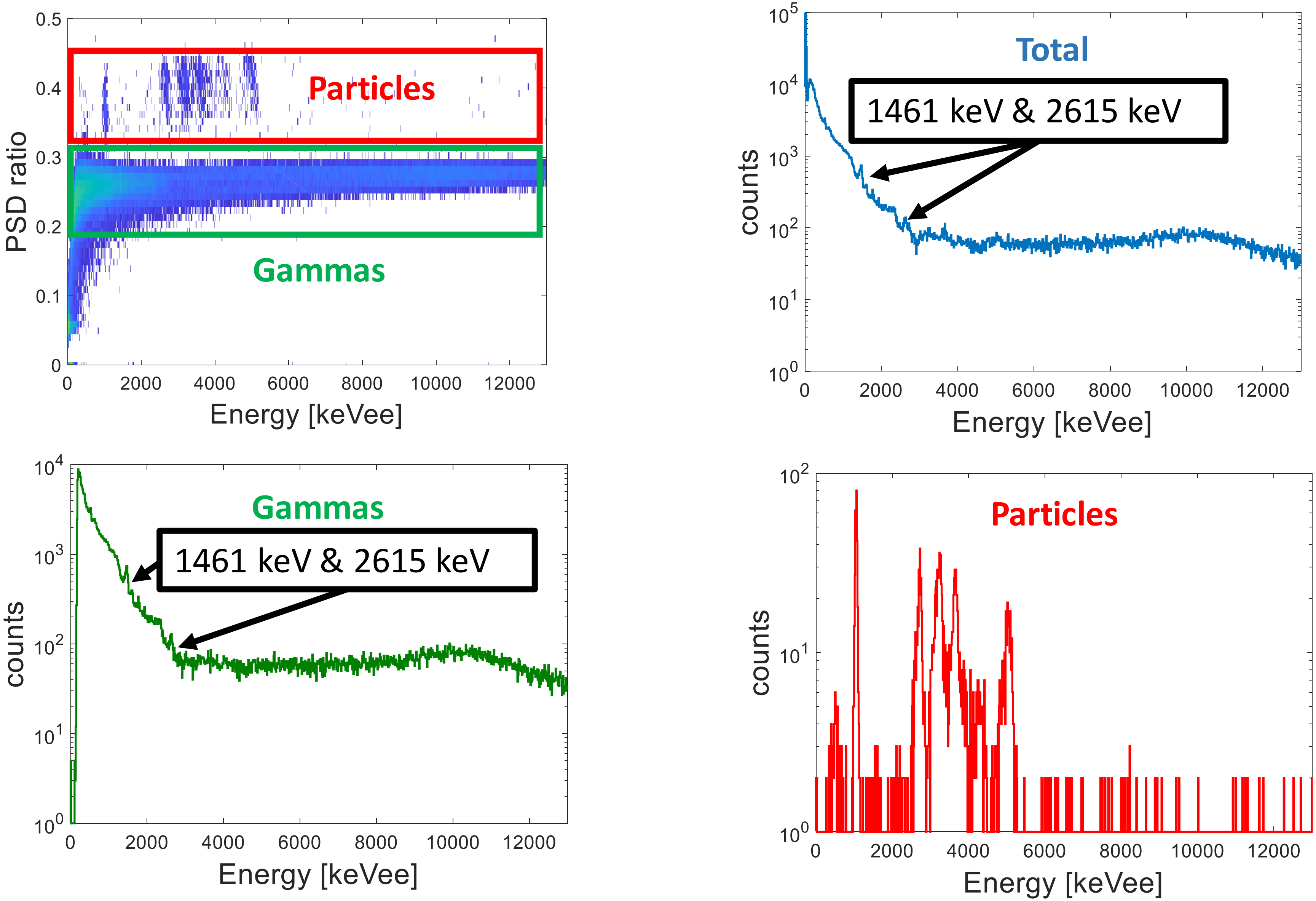


- ✓ The **internal radiation** is practically **absent** in CLYC:Ce.
- ✓ Internal radiation is not affected by any kind of shield.
- ✓ The internal radiation is weaker that **0.02 events/cm³**
- ✓ **Thermal Neutrons** are weakly affected by the Pb shield

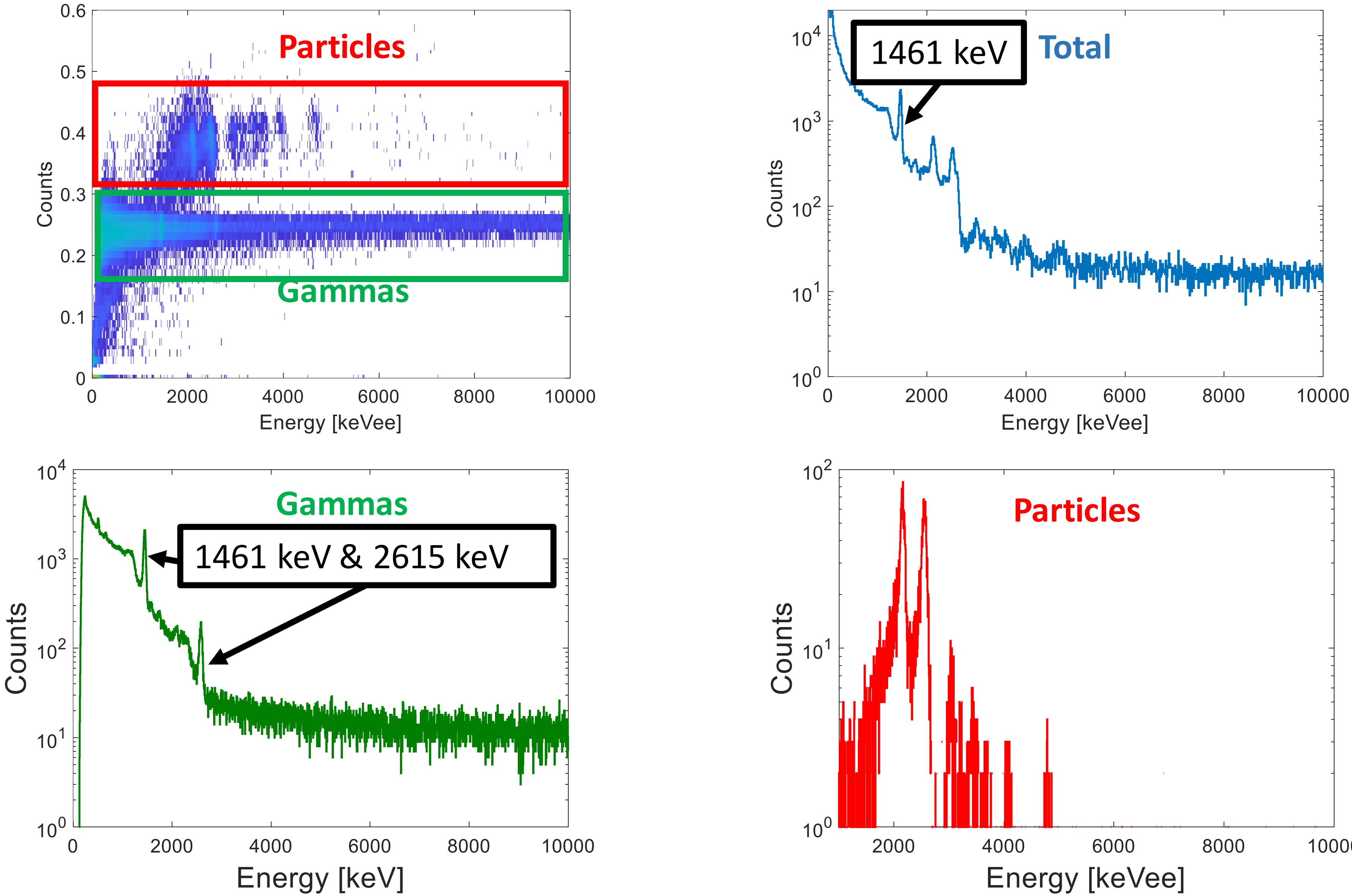
1” x 1” CLYC-6 scintillator



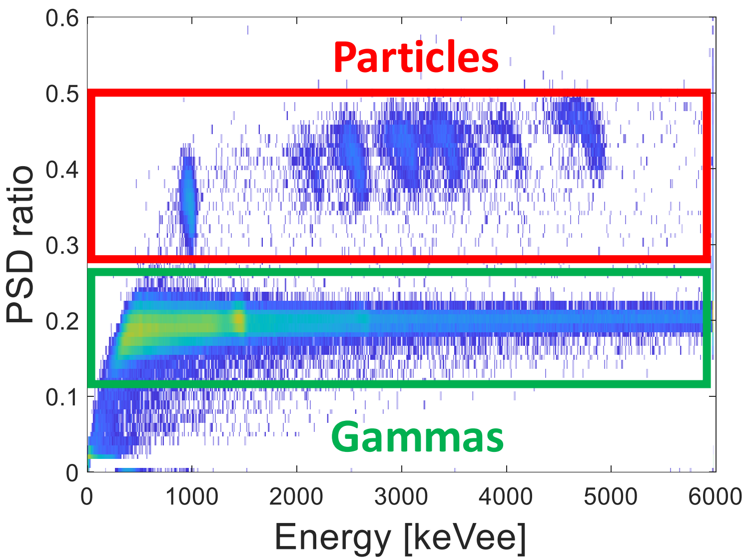
1” x 1” CLYC-7 scintillator

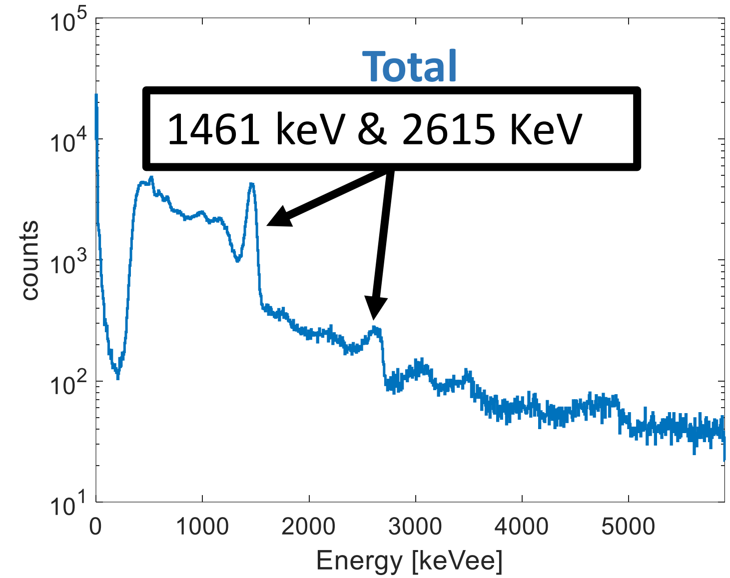


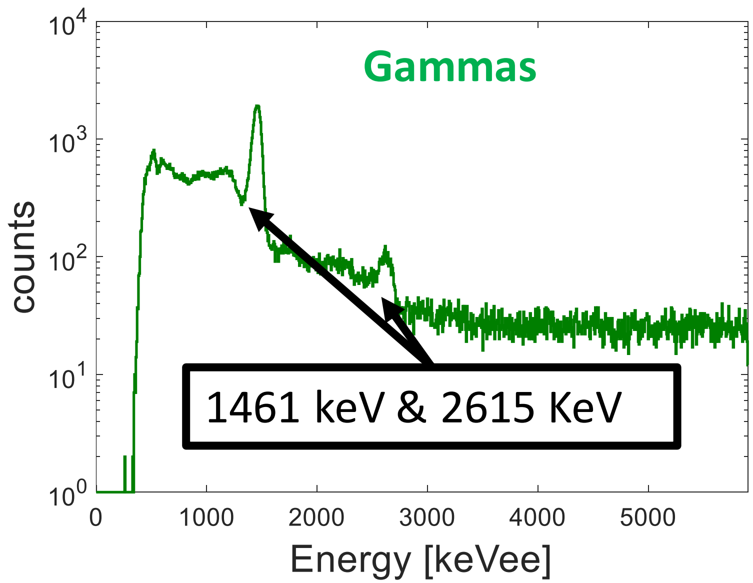
2” x 2” CLYC-7 scintillator

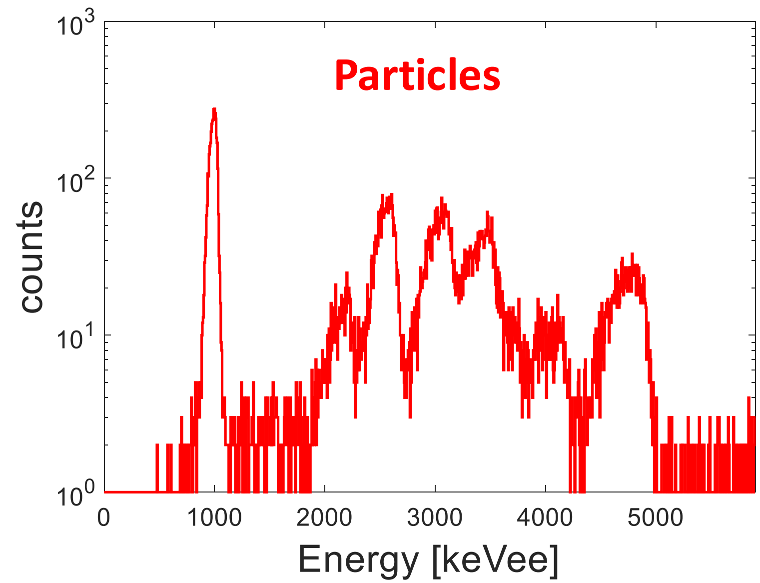


3” x 3” CLYC-7 scintillator

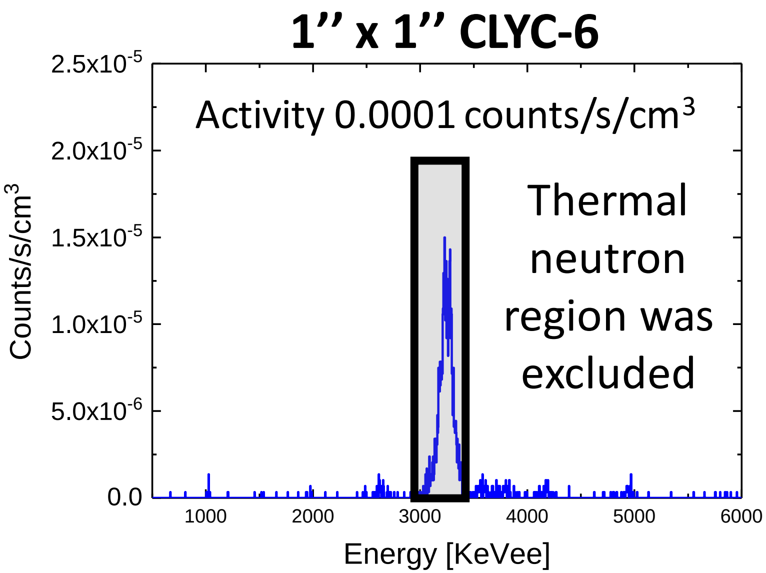


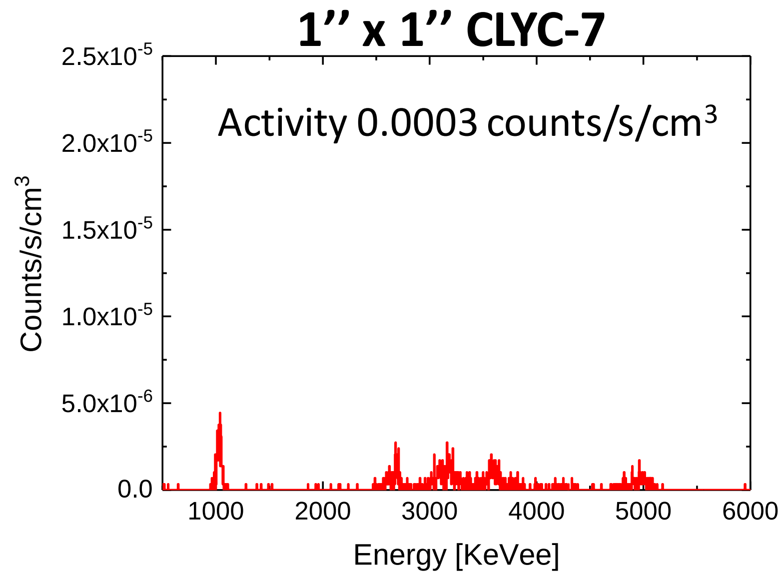


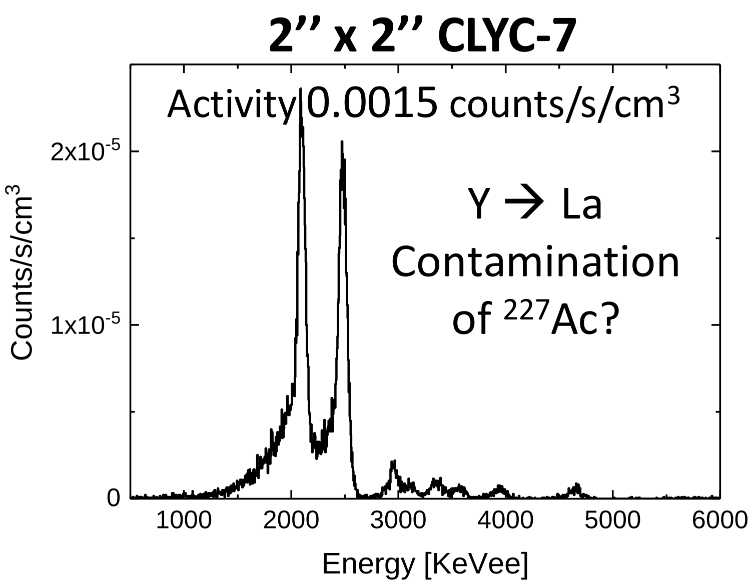


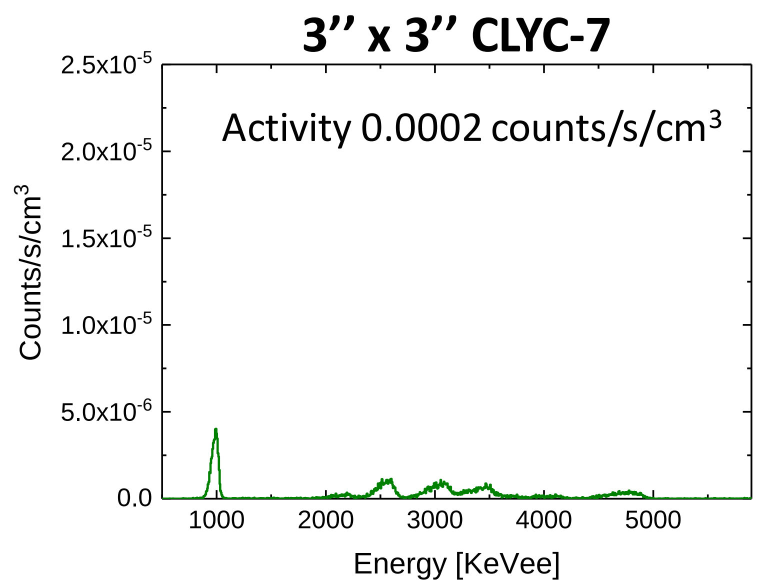


How much is the particle internal activity?





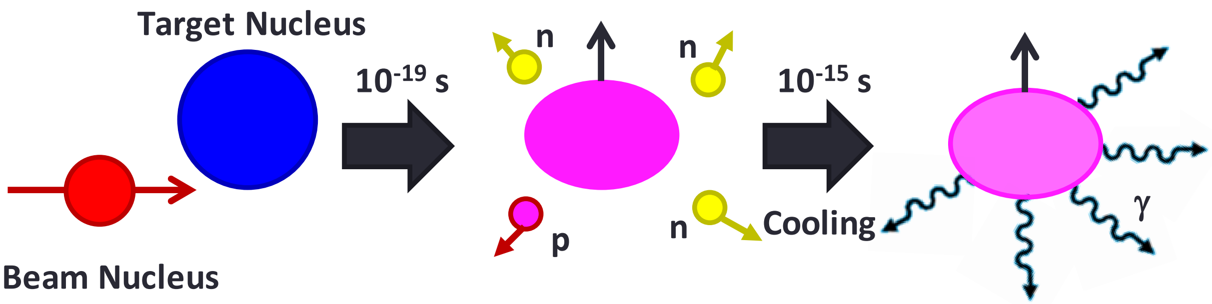




Internal background in nuclear physics experiments

A tool to study nuclear structure properties is the gamma decay of GDR (Giant Dipole Resonance).

GDR can be built on excited nucleus (usually fusion-evaporation reaction and compound nucleus) or on ground state.



Neutron Flux [n/s]	Neutron detected in the 2'' x 2 '' CLYC [n/s/keV/cm^3]*
10^1	2.18 10^{-5}
10^2	2.18 10^{-4}
10^3	2.18 10^{-3}
10^4	2.18 10^{-2}
10^5	2.18 10^{-1}
10^6	2.18 10^0
10^7	2.18 10^1
10^8	2.18 10^2

Max number of background events is 5 10^{-6} n/s/keV/cm^3 for the 2'' x 2'' CLYC.

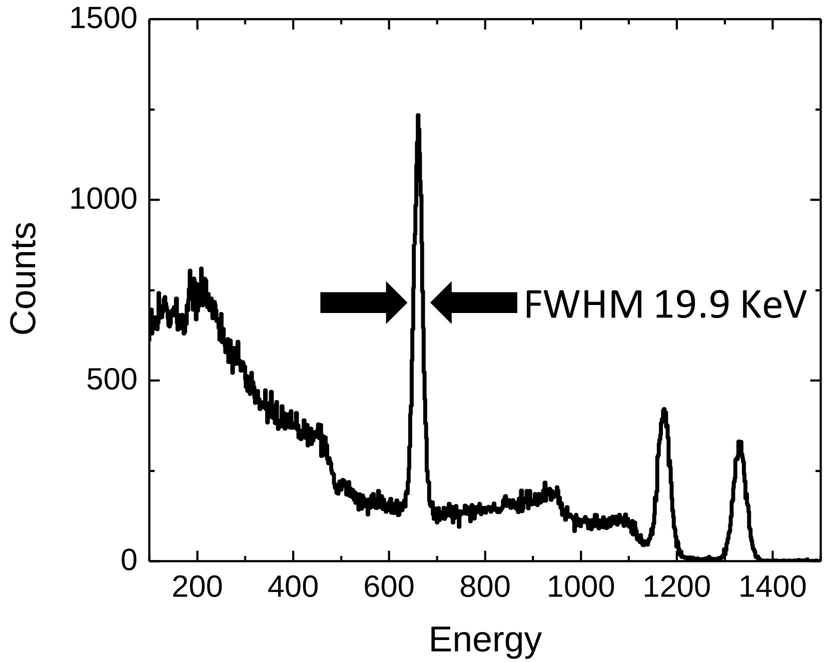
To have a good subtraction of the background, it has to be at least 10 times smaller than the neutron events.

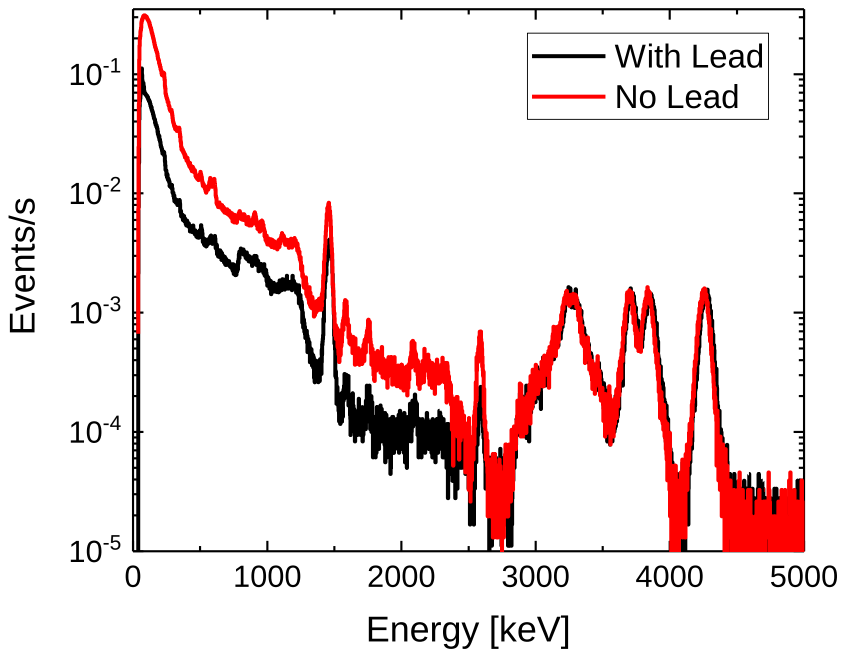
To satisfy this condition the neutron flux has to be around 10^2 n/s. → the flux is in the order of the flux of fusion-evaporation reactions (10^2 – 10^3 n/s).

* The neutron efficiency was estimated from the values measured for 1'' x 1'' CLYC-7 detector

CLLB(C) internal background

- ✓ Density of 4.2 g/cm^3, light yield of 60 ph/keV, high linearity.
- ✓ ^{6}Li enriched
- ✓ Excellent Energy resolution at 622 keV 3%.
- ✓ Possibility to perform **gamma and neutron discrimination**.
- ✓ ^{35}Cl ions to detect and perform neutron spectroscopy





- ✓ The **internal radiation** due to the presence of La.
- ✓ Alpha Internal radiation is not affected by the shield.
- ✓ The internal radiation is weaker comparable with $LaBr_3$:Ce internal radiation

Conclusion

- ✓ The elpasolite crystals are suitable for nuclear physics experiments, in particular CLYC and CLLB(C) scintillators
- ✓ The internal background was measured for 4 different CLYC samples
  - ✓ 1’’ x 1’’ CLYC-6: activity 0.0001 counts/s/cm^3
  - ✓ 1’’ x 1’’ CLYC-7: activity 0.0003 counts/s/cm^3
  - ✓ 2’’ x 2’’ CLYC-7: activity 0.0015 counts/s/cm^3
  - ✓ 3’’ x 3’’ CLYC-7: activity 0.0002 counts/s/cm^3
- ✓ The internal activity is at least 10 times smaller than the neutron flux in nuclear physics experiments.
- ✓ The CLLB(C) energy resolution was measured.
- ✓ The first measurement on the CLLB(C) internal background was performed.

Acknowledgments

N. Blasi[1], S. Brambilla[1], F. Camera[1,2], A. Mentana[1,2], B. Million[1], and S. Riboldi[1,2].

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THANK YOU FOR THE ATTENTION