Study of elpasolite crystals for neutron/gamma spectroscopy

-First measurements with CLYC:Ce-

I.Zeghni, C.Delafosse

IJCLab/CNRS-IN2P3/Univ. Paris-Saclay

Current detection techniques

Helium-3 Based Detectors

TETRA - France

Neutron spectrometers

D. Testov et al. Nucl. Instrum . Methods Phys. Res. Sect Accel. Spectrometers Detect. Assoc. Equip., vol 815, pp. 96-103, Apr.2016

- Advantages :
  - High capture cross-section for thermal neutrons
  - Precise neutron counting through destructive detection
  - Gamma transparency
  - No threshold
- Drawbacks :
  - Loss of neutron energy information
  - Dependence on helium-3:
  - Very expensive and rare
  - Limited availability due to geopolitical constraints
  - Slow thermalisation (30µs)

Gamma spectrometers

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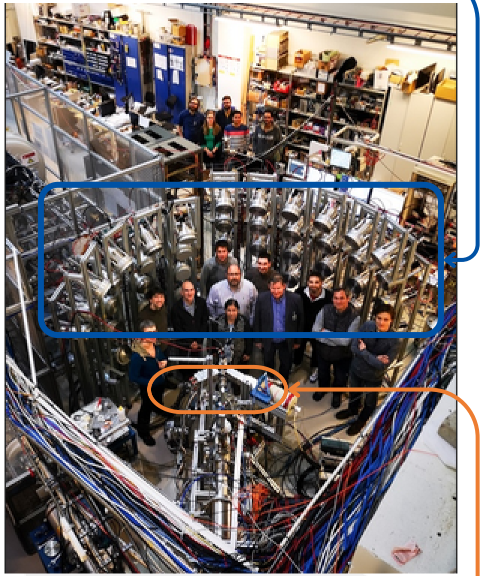
Organic Scintillator Detectors

MONSTER - Finland



T. Martínez et al. MONSTER, Nuclear Data Sheets Vol 120, p.78-80, June 2014

- Advantages :
  - Neutron energy determination through Time-of-Flight measurements
- Drawbacks :
  - Relatively high energy thresholds
  - Low efficiency due to large source-detector distance
  - Significant detector cross-talk caused by neutron scattering
  - Use of hazardous liquid scintillators (BC537):
  - Sensitive to gamma rays (discrimination with PSA)

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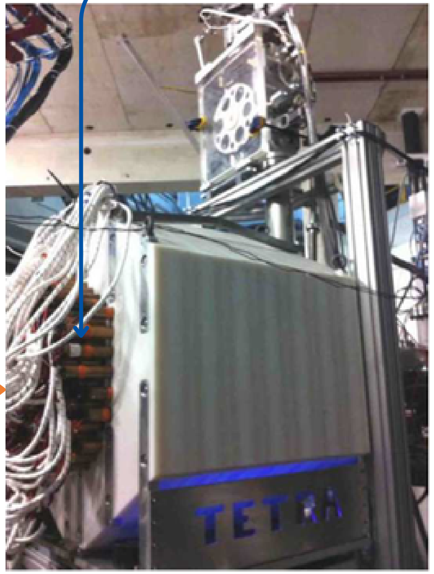

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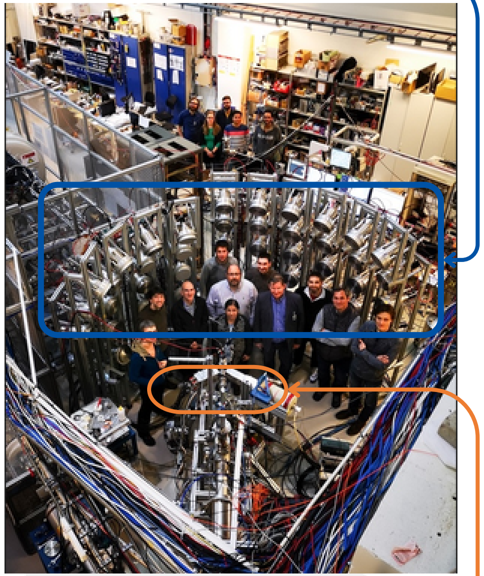

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Gamma spectrometers

The SENSE project aims to develop a compact hybrid detector based on chlorine-containing elpasolite crystals for simultaneous neutron and γ-ray spectroscopy, enabling efficient neutron spectroscopy without time-of-flight techniques

- Advantages :
  - Destructive detection of both thermal (if contains 6Li) and/or fast neutrons (if contains 35Cl)
  - Simultaneous γ-ray detection
  - Neutron/γ discrimination through pulse shape analysis
  - Inorganic and solid

- Drawbacks :
  - Hydroscopic → Must be sealed and encapsulated in aluminum
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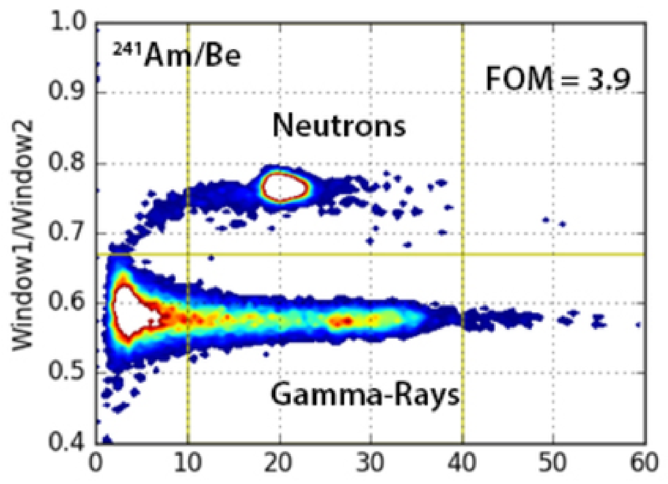
- The choice is oriented toward **CLYC:Ce** for the following reasons :
  - Zeff = 54
  - Scintillant with a Light Yield of 20,000 ph/MeV (NaI : 40,000 ph/Mev)
  - 2 channel for neutron capture with Cl : Cl(n,p)S & Cl(n,α)P
  - Very good PSD for neutron/gamma discrimination
  - Possibility to grow large crystals



PSD ratio - RMD crystals CLYC datasheet

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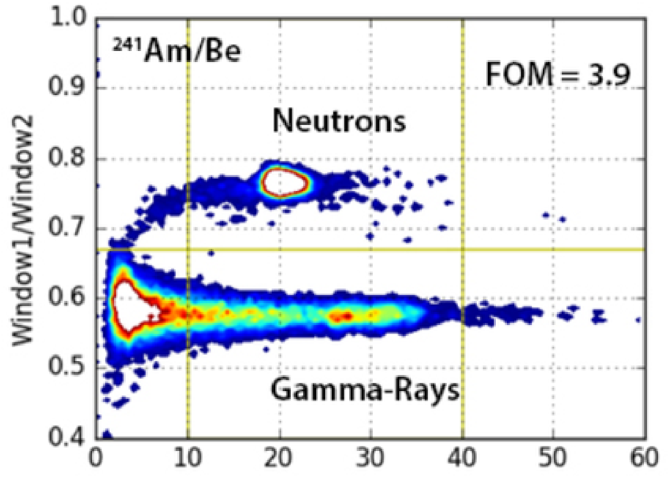
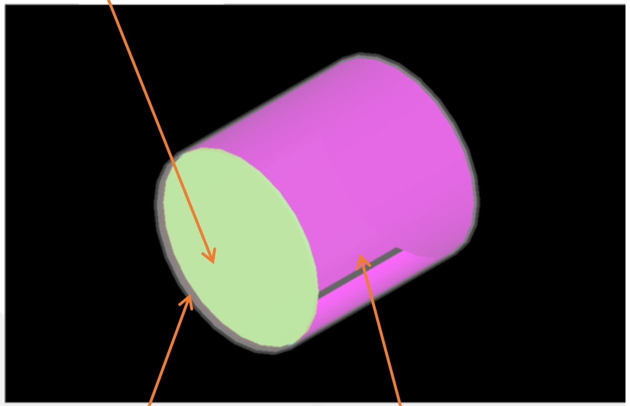
GOAL : Characterize the performance of CLYC:Ce in term of energy resolution and detetction efficiency for both neutrons and gammas in the range 100keV to 10MeV



PSD ratio - RMD crystals CLYC datasheet

- The study begins with the benchmark of a well known elpasolite crystal : **CLLB:Ce** ($Cs_2LiLaBr_6$:Ce)

Simulations with GEANT4



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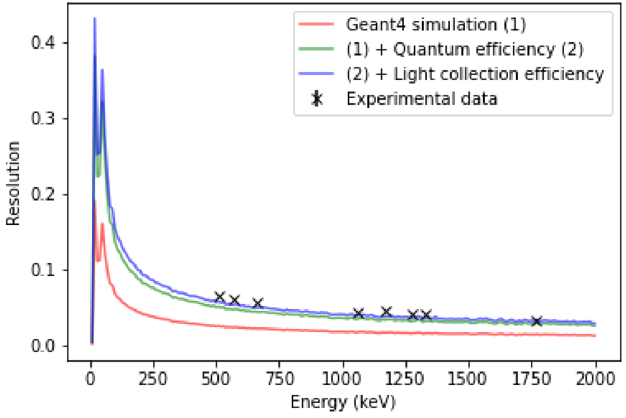
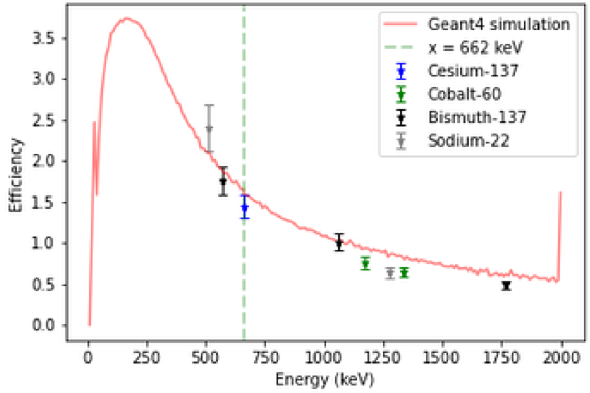
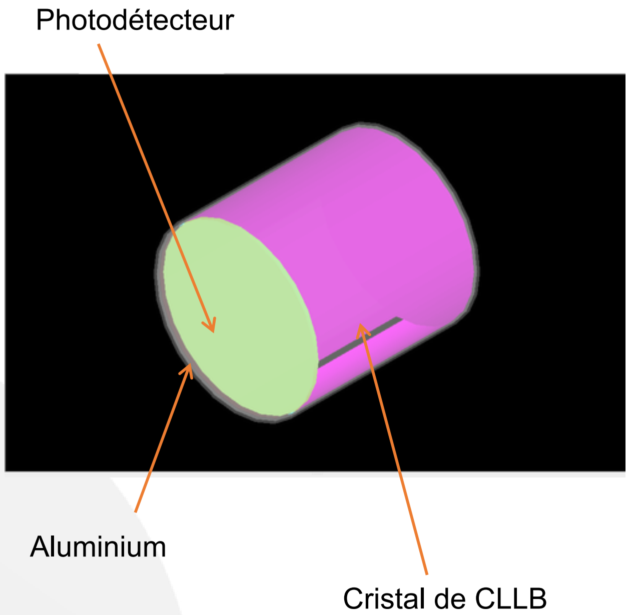


Resolution



Efficiency

Simulations with GEANT4



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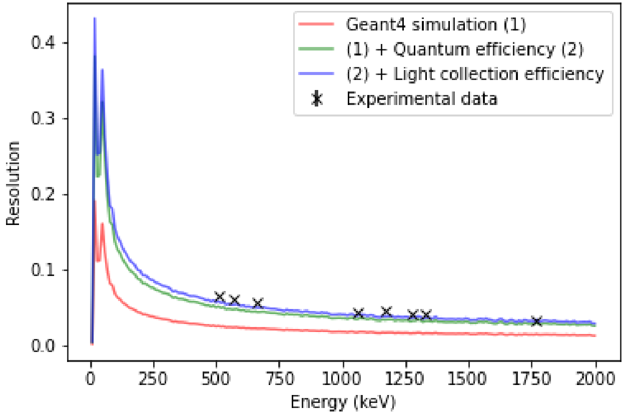

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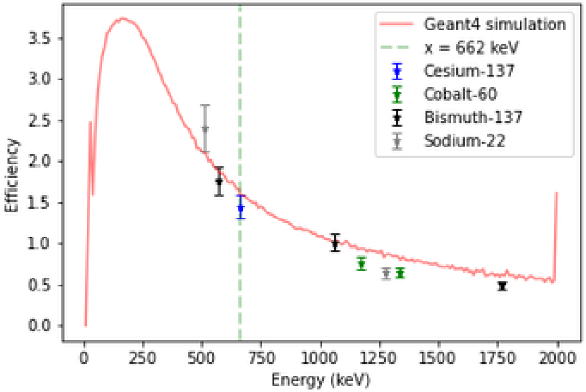

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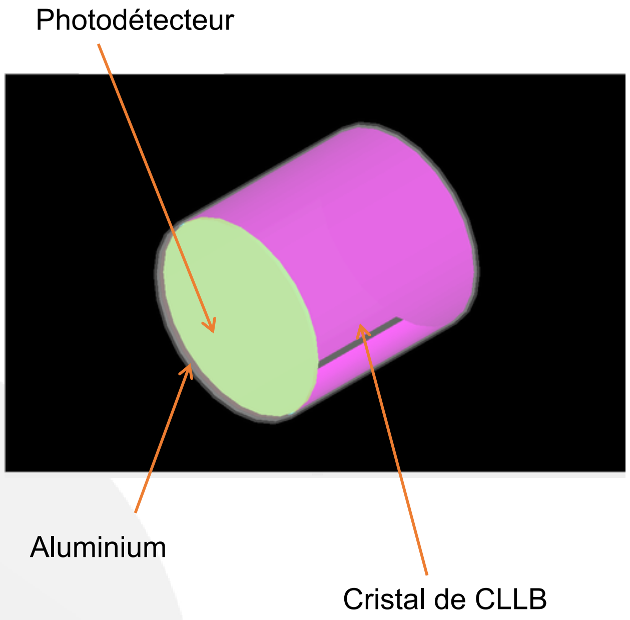
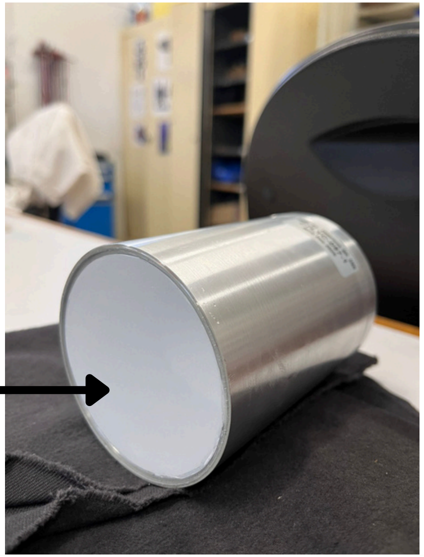
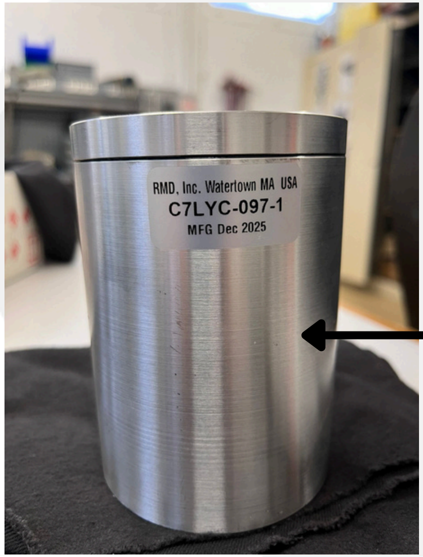


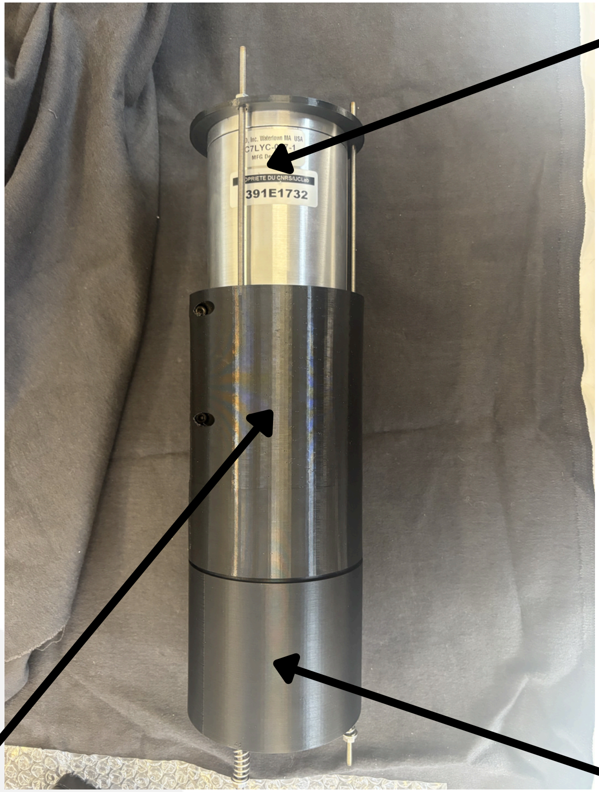
Good agreement between simulation and experiments for CLLB.

- The crystal was ordered at RMD inc.
- The dimension are the following
  - Radius of 3 inches
  - Lenght of 4 inches
- Encapsulated with reflector inside aluminum
- Quartz window for waterproofing sealing





CLYC



Photomutliplier Tube
(Hamamatsu R594)

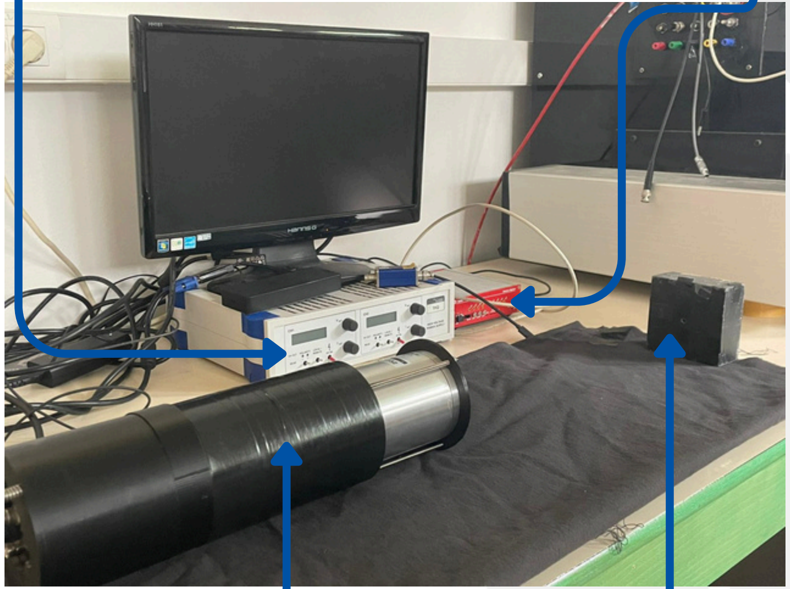
Many thanks to M.IMRE, B.MATHON, C.DOMINGOS for the conception and V.CHAUMAT for the dividor

Homemade Tension dividor

Experimental setup

High voltage set at
U = -1500V

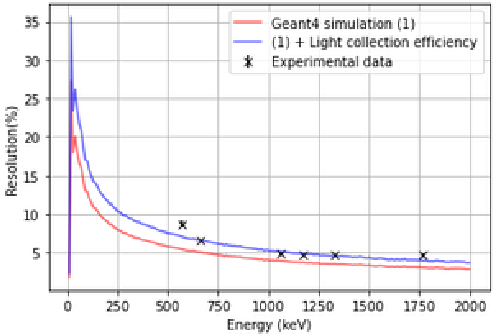
DAQ CAEN DT5730
12 bits/ 500MHz

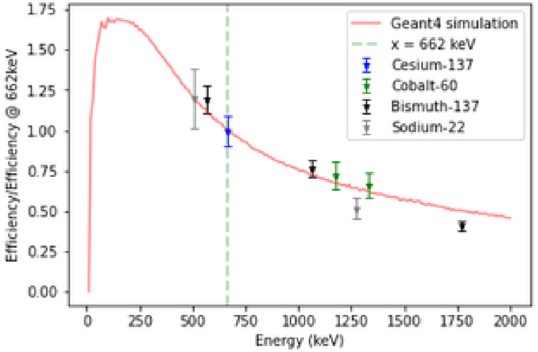


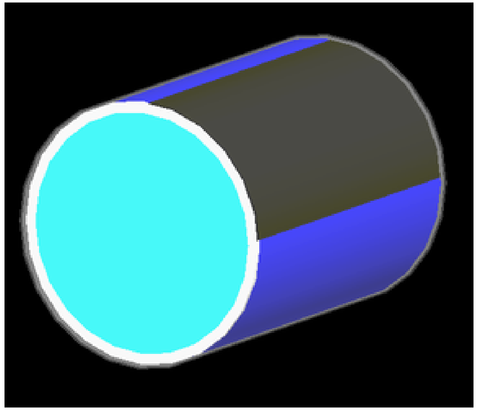
CLYC + PMT
HAMAMATSU R594

Radioactive source behind
Lead for collimation

Comparaison with Simulations



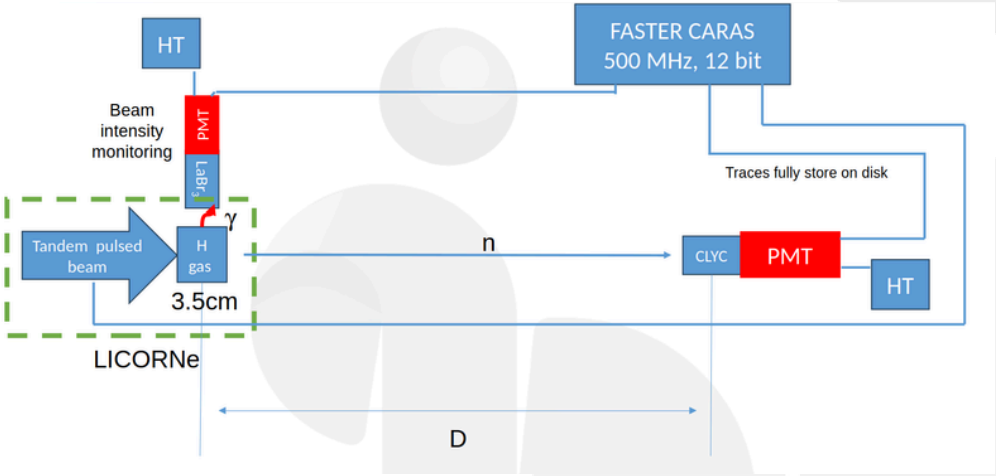


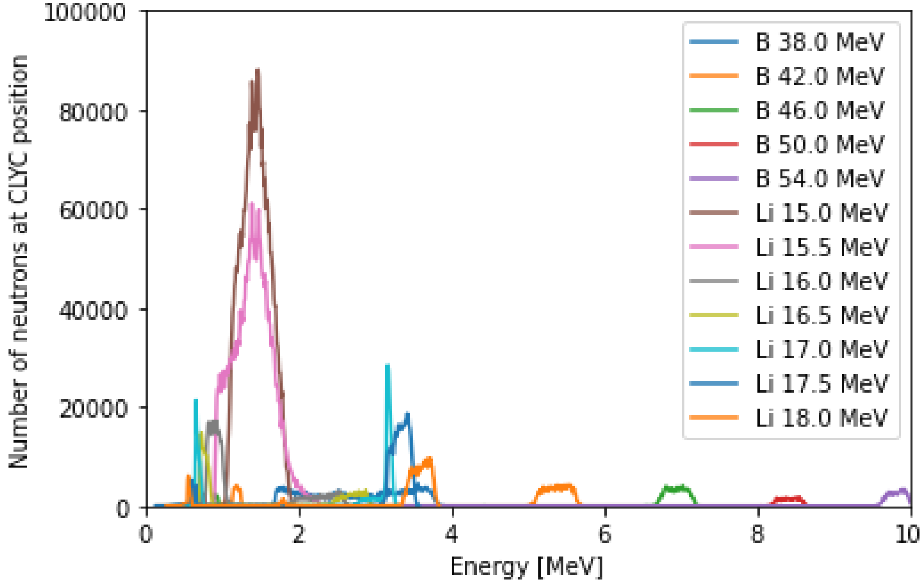


We are looking for an optical grease that is transparent in the 200-500 nm range, if someone has one, please contact me : isaac.zeghni@ijclab.in2p3.fr

- Neutron part difficult to tackle (neutron capture cross section badly implemented in Geant4) at these energies
- Need of experimental data for comparison

Simulation performed by M.Lebois based on the work presented in L. Qi's PhD thesis (Université Paris Saclay)

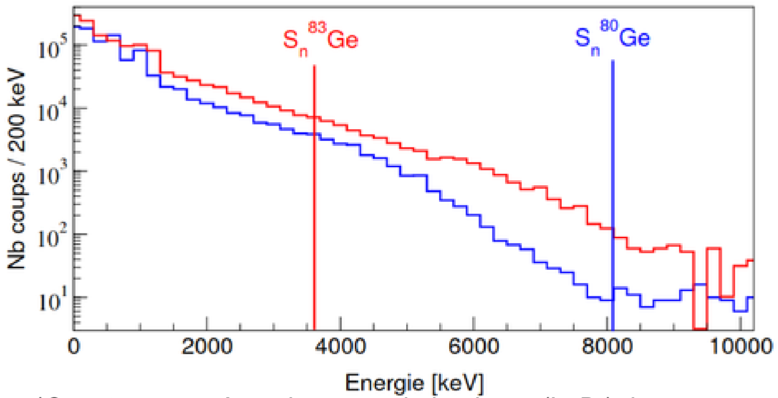




Proposal accepted by ALTO PAC 2026 to be performed by the end of the year!

- To conclude, after benchmarking with CLLB:Ce, The CLYC:Ce crystal has been studied through simulations, compared with experimental data.
- So far, there is a good agreement between simulations and experiments for gamma interactions.
- Soon, the study will be focused on neutrons interactions through PSD using LICORNe at ALTO.

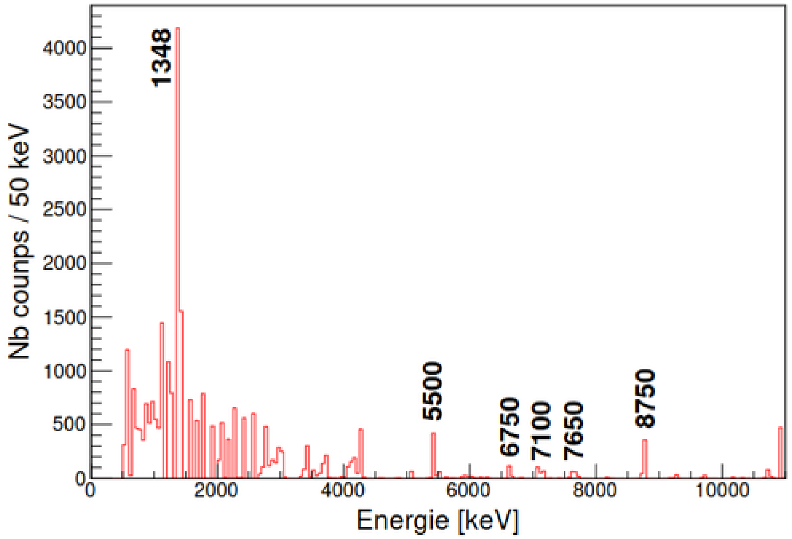
The response function describes how a detector responds to an incident particle of a given energy. It gives the probability distribution of measured signals produced by particle of known energy.



**Spectre mesuré par bromure de lanthane (LaBr) issus de la décroissance du 83Ga*

RESPONSE FUNCTION

DECONVOLUTION



A.Gottardo et al. - PLB 772C, pp. 359-362 (2017)

Special thanks to all who have contributed to this project so far

I.Zeghni
C.Delafosse
G.Hull
V.Chaumat
T.Cornet
M.Lebois
M.Imre

MERCI POUR VOTRE ATTENTION !

S.Olmo
B.Mathon
C.Domingues Goncalves
B.Geoffroy
N.Bleibleih
R.Mahema

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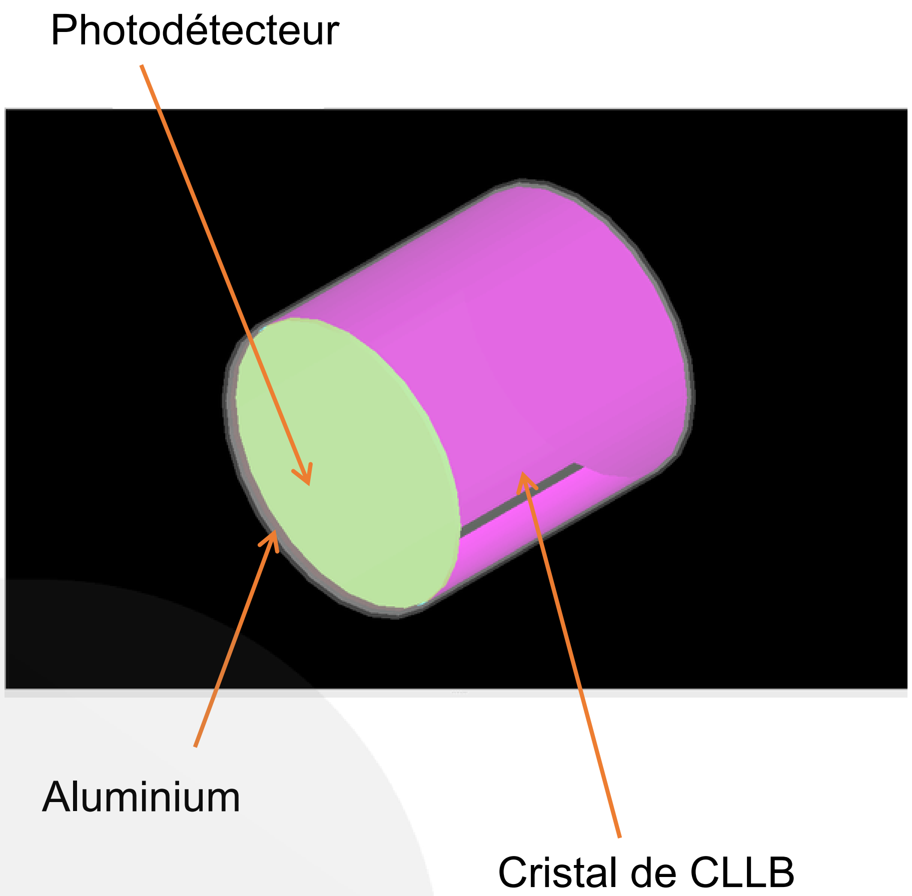
BACK UP

- Modélisation du cristal (CLLB, protection en aluminium et surface réfléchissante) et d'un photodétecteur
- Simulations de 10,000 photons gammas monoénergétiques, pour des énergies allant de 10 keV et 2 MeV, avec un pas de 10 keV
- Utilisation du multithreading pour accélérer les calculs
- PhysicsList optiques prenant en compte les paramètres du cristal introduit précédemment
- Données enregistrées:
  - Nombre de photons détectés
  - Energie déposée
  - Temps d'arrivée des photons sur le photodétecteur
  - Type de particule (uniquement gamma pour l'instant)



PhysicsList utilisés (Merci à Emile Cantacuzène)

- Interactions électromagnétiques : *G4EMPenelopePhysics*
- Hadroniques :
  - *G4HadronElasticPhysicsHP* (Interaction neutrons thermiques/cristal)
  - *G4HadronPhysicsQGSP_BIC_HP* (Neutrons thermiques ET rapides)
- Radioactivité et désintégration :
  - *G4DecayPhysics*
  - *G4RadioactiveDecayPhysics* (Décrit la désintégration beta dans la source)
- Optique :
  - *G4OpticalPhysics* (Production et transport des photons dans le scintillateur(réflexion, transmission, absorption etc…) et la collecte sur la photocathode.)
  - *GammaNuclearPhysics* (Interactions des photons avec les noyaux du cristal)
- Ions :
  - *G4IonElasticPhysics* (Collision élastique avec des ions lourd)
  - *G4IonPhysicsXS* (Interaction des ions optimisé pour la détection)