Instrumentation Physics Cases and for EURISOL-DF, the next step towards EURISOL

New Materials

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Outline:

- Old and New Inorganic Scintillators, test, measurements and R&D:
  - LaBr3:Ce, LaBr3:Ce:Sr+
  - Elpasolite - CLYC - CLLBC
  - CeBr3
- Conclusions

Sorry in advance if I did not cite all the works and R&D activity which have been done so far

Important

In this talk we concentrate on scintillators. HPGe detector or in general solid state detectors will not be discussed. Semiconductor detectors have an energy resolution which will never be reached by scintillators (because of the energy gap, the conversion light-electrons, Fano factor, …)

First Generation 'old' scintillators

NaI ⇒ acceptable energy resolution, strong non linearity in energy, bad time resolution
BaF2 ⇒ bad energy resolution, excellent time resolution
BGO ⇒ bad energy resolution, bad time resolution, excellent efficiency
CsI ⇒ good for the measurement of light charged particles
…………………………………………………………………..

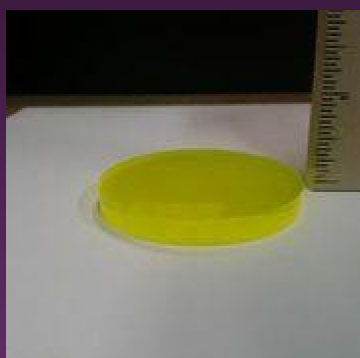
Second Generation 'almost new or new' scintillators

Lanthanum Halide ⇒ LaBr3:Ce, LaCl3:Ce
New Matherials: ⇒ SrI2:Eu, CeBr3
Elpasolide : ⇒ CLYC, CLLB, CLLBC, CLLC
Ceramic ⇒ GYGAG
……………………………………………………………………

Third Generation scintillators

Co Doped LaBr3:Ce - Sr++
……………. TLYC ……………… ?

Material	Light Yield [ph/MeV]	Emission λ_{max} [nm]	En. Res. at 662 keV [%]	Density [g/cm^2]	Pricipal 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
SrI_2:Eu	80000	480	3-4	4.6	1500
$CeBr_3$	45000	370	<5%	5.2	17
GYGAG:Ce	40000	540	<5%	5.8	250
CLYC:Ce	20000	390	4	3.3	1 CVL 50, ~1000



Now there are, in addition to the one listed above, some new materials (CLLB, CLLBC, LaBr3:Ce-Sr)

LaBr3:Ce:Sr was borrowed from St.Gobain

Picture done in Milano

Lanthanum Halide: LaBr3:Ce Detectors

It was discovered in 2001 in Delft
It is now a rather 'known' scintillator detector
- it is in Knoll book !

Several arrays have been designed

- HECTOR+
- FATIMA
- PARIS, CALIFA
- OSCAR
- ALBA
- LaBr3:Ce in
  - ROSPHERE and ELI-NP
  - Darmstadt LaBr3:Ce array
  - HIγS array
- ....

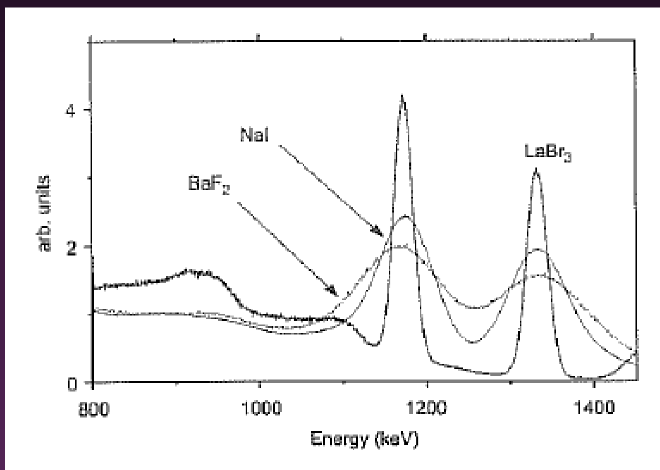
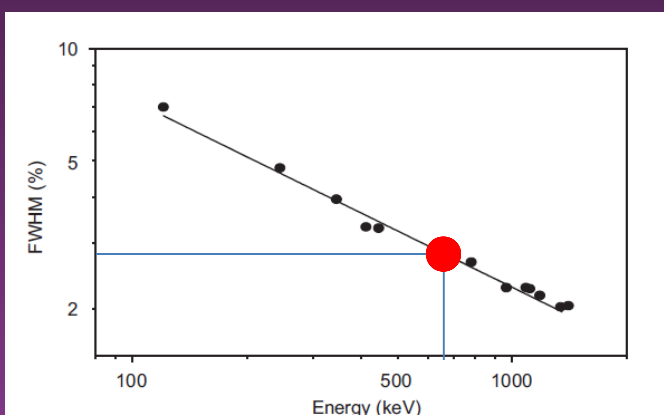


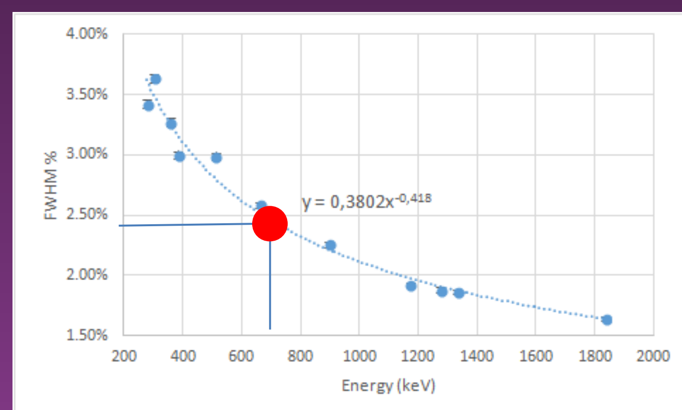
Figure 8.14 Comparison of the ^{60}Co pulse height spectrum measured with 1-inch × 1-inch $LaBr_3$, NaI, and BaF_2 (From Nicolini et al.[215]).

E.V.D. van Loef et al.
Appl. Phys. Lett. 79(2001)1573

R. Nicolini et al.
NIM A582>(2007)554



LaBr3:Ce
R. Nicolini et al. NIM A582(2007)554



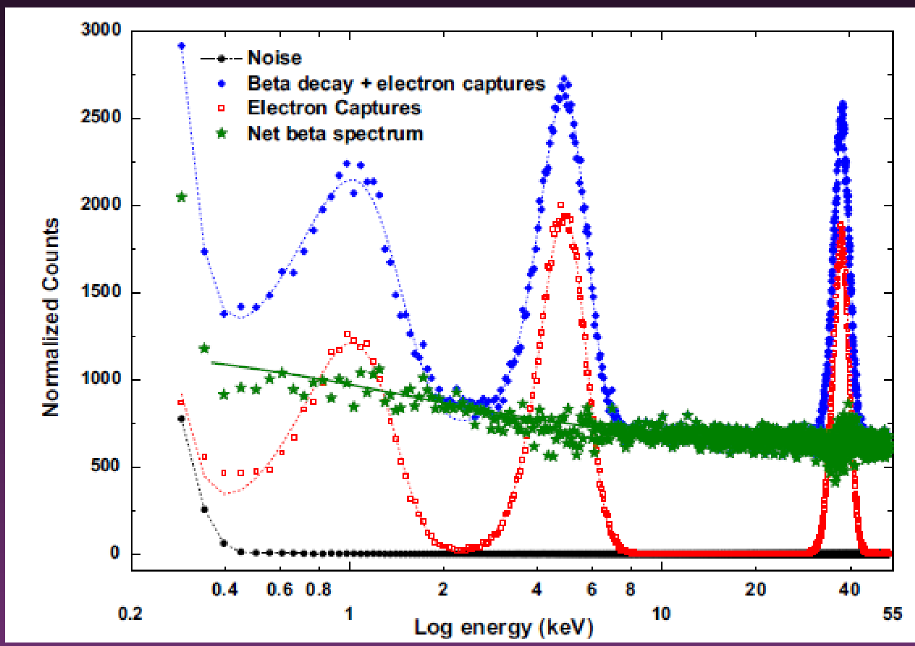
LaBr3:Ce-Sr+ - Thanks to St.Gobain which borrowed us a sample
G. Colombi – private communications

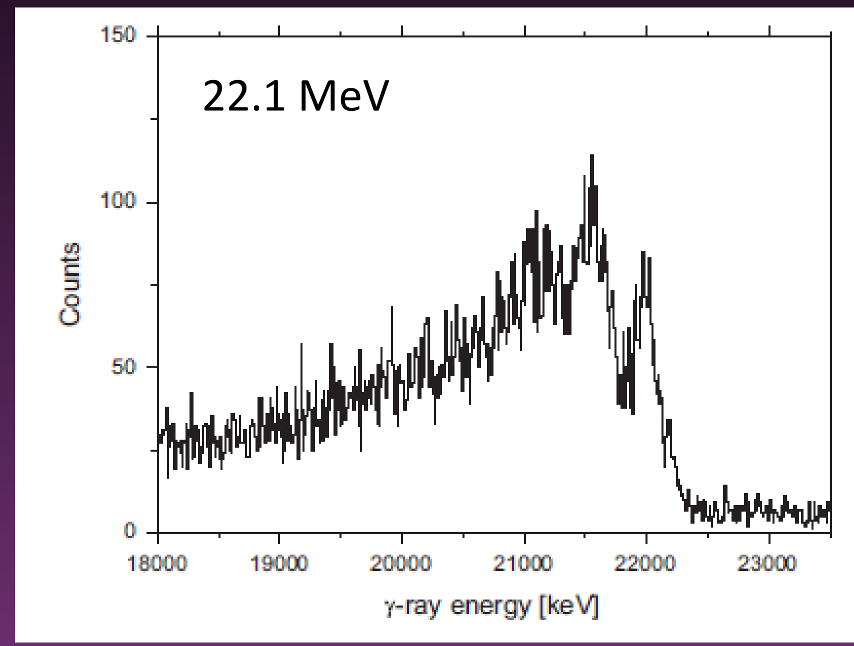
There is something new
Co-Doped LaBr3:Ce
LaBr3:Ce-Sr+
B390 (St.Gobain)

Better energy Resolution
PSD Possible

Lanthanum Halide: LaBr3:Ce Detectors

LaBr3:Ce detectors provide, at the same time, clean spectroscopic information from a few tens of keV up to tens of MeV, being furthermore able to clearly separate the full energy peak from the first escape one. This is particularly true for large volume detectors which have Full Energy Peak efficiency for high energy γ-rays



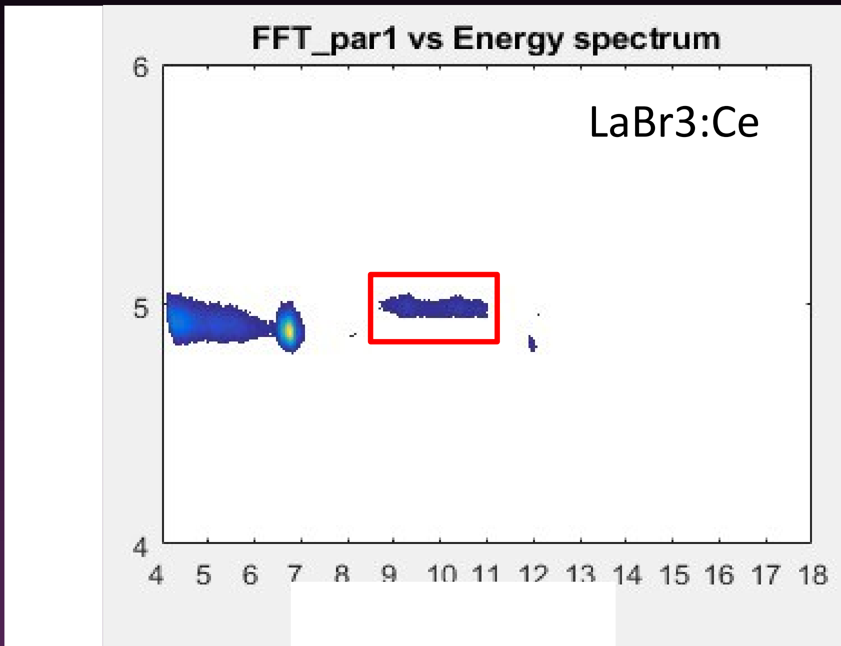


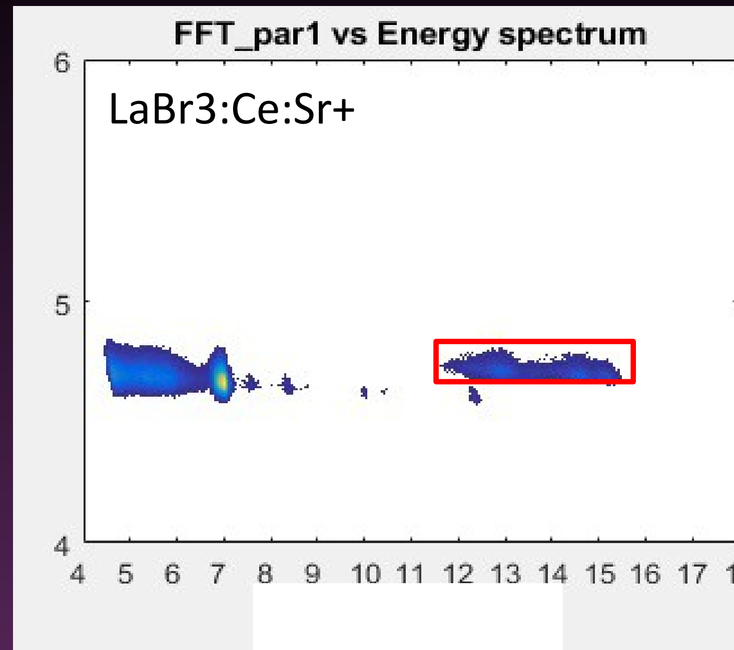
3”x3” LaBr3:Ce
F.G.A. Quarati et al. Appl. Rad. and Iso. 108(2016)30

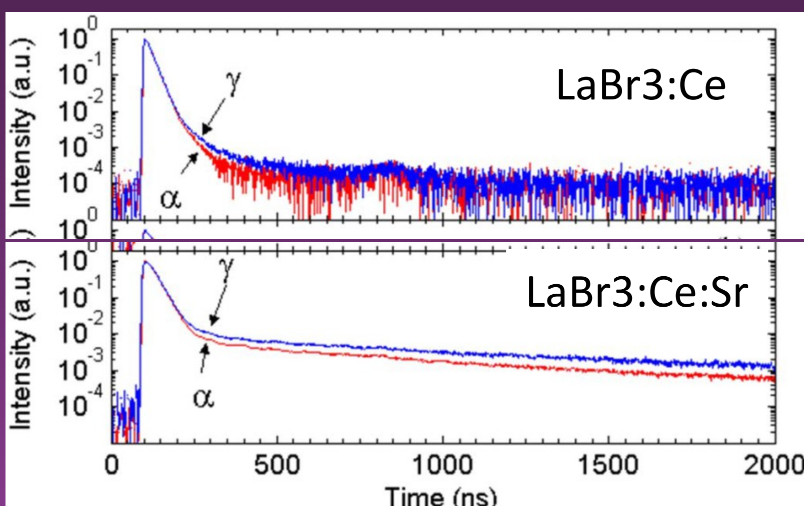
3.5” x 8” LaBr3:Ce
A. Giaz et alk et al. NIM A 729(2013)910

PMT non linearity and in-homogeneity in large volume crystals might limit the energy resolution to 0.5-1%. Intrinsic LaBr3:Ce non linearity may affect energy resolution for $E\gamma$ < 100 keV

R&D on LaBr3:Ce Detectors + Co-Doped
PSD Properties





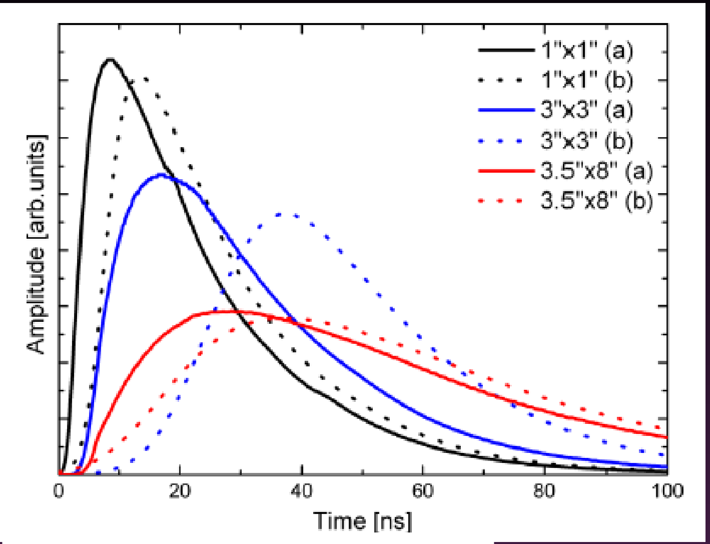


Thanks to St.Gobain -

LaBr3:Ce and LaBr3:Ce:Sr+ PSD might be capable to discriminate alpha internal background (especially for LaBr3:Ce:Sr+)

- F. Crespi et al. NIMA 602(2009)520
- Yang et al IEEE-TNS 63(2016)416
- G. Colombi, S.Capra e G.Gosta private communications

R&D on Lanthanum Halide: LaBr3:Ce Detectors



A.Giaz et al. NIM-A729(2013)910–921

a – detector size –Hamamatsu H6533 PMT (0.7 ns risetime)

b – PMT induced effect

In general, the larger is the PMT the ‘slower’ is its time response.

LaBr3:Ce (whatever is the size) has a time resolution < 2 ns

Extremely fast timing (FWHM < 300 ps) might be very difficult to achieve with large volume (i.e. 3” x 3”) LaBr3:Ce

Small LaBr3:Ce Detectors $\Rightarrow$ excellent time performances

- They can be used for lifetime measurement
    - ΔT = 50 ps
  - See N. Marginean et al. Eur. Phys. J. A 46, 329–336 (2010)
    - A very fast tube is needed (XP20D0) - M. Moszynski et al. A 567 (2006) 31–3
    - Energy resolution is not optimized (3.6% at 511 keV)

- Fast Timing It is a very powerful technique applied in several experiment in ROSPHERE, FATIMA array was designed for that. The important aspect is an highly tuned and well maintained array of small LaBr3:Ce

Therefore:

LaBr3:Ce (and probably Co-Doped LaBr3:Ce:Sr) Detectors

- They can do, in a much better way, the work of NaI scintillators
  - large volumes (we have 9x20 cm crystals)
  - good energy resolution (at low and high γ-ray energy)
  - very fast (fast signals and excellent time resolution)

- But
  - Weak PSD properties
  - No neutron spectroscopy is possible
  - 'strong' internal activity
  - Cost

Elpasolite scintillators: CLYC, CLLC, CLLB and CLLBC

- The elpasolite crystals were discovered approximately 10 years ago.
- Excellent performances in terms of **gamma and neutron detection**.

They are Gamma and Neutron detectors:

- High **energy and time resolution**
- Neutron-gamma PSD capability
- High **linearity**

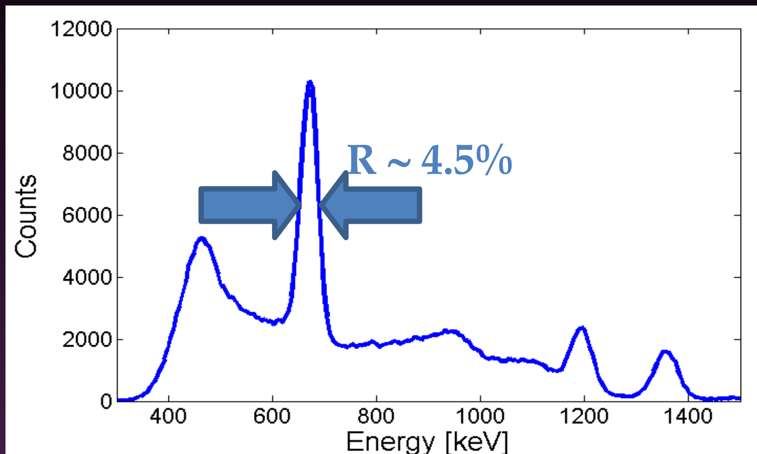
CLYC is commercially available up to 3″ x 3″

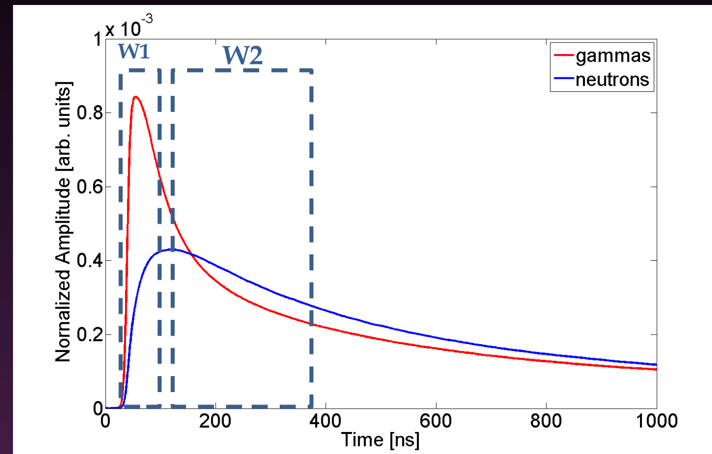
CLLB is commercially available up to 1.5 " x 1.5″

CLLBC is commercially available up to 1" x 1″

	CLYC	CLLC	CLLB	CLLBC
Density [g/cm^2]	3.3	3.5	4.2	4.2
Emission [nm]	290 CVL 390 Ce^+	290 CVL 400 Ce^+	410 Ce^+	410 nn
Decay Time [ns]	1 CVL 50,~1000	1 CVL 60, ≤ 400	55, ≤ 270	
Light yield [ph/MeV]	20000	35000	45000	45000
Light yield [n/MeV]	70000	110000		140000
En. Res. at 662 keV [%]	4	3.4	2.9	3.3%
PSD	Excellent	Excellent	Possible	Yes

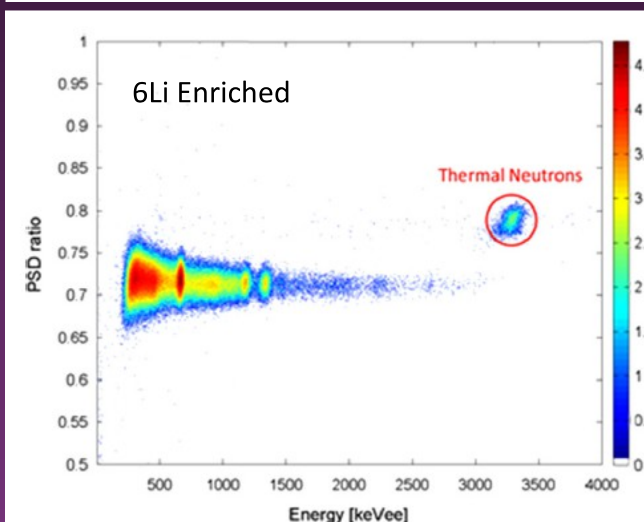
CLYC ($Cs_2LiYCl_6:Ce^{3+}$) scintillator

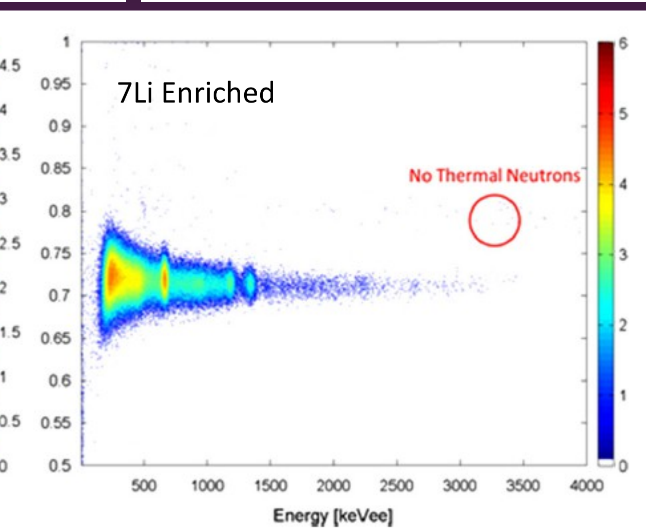




Good resolution:
Better than NaI
Worst than LaBr3

PSD
Possible





Thermal Neutrons:

- ✓ 6Li (n,α)t
  - Q-value = 4.78 MeV

Fast Neutrons

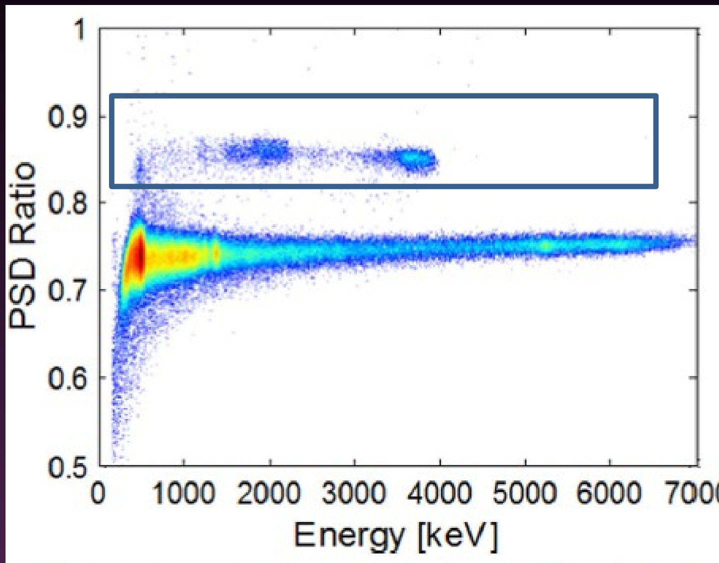
- ✓ 35Cl(n,p)35S
  - Q-value = 0.6 MeV
- ✓ 35Cl(n,α)32P
  - Q-value = 0.9 MeV

$E_{p/\alpha}=(E_n + Q)\, q_{p/\alpha}$ $\Rightarrow$ Fast n spectroscopy

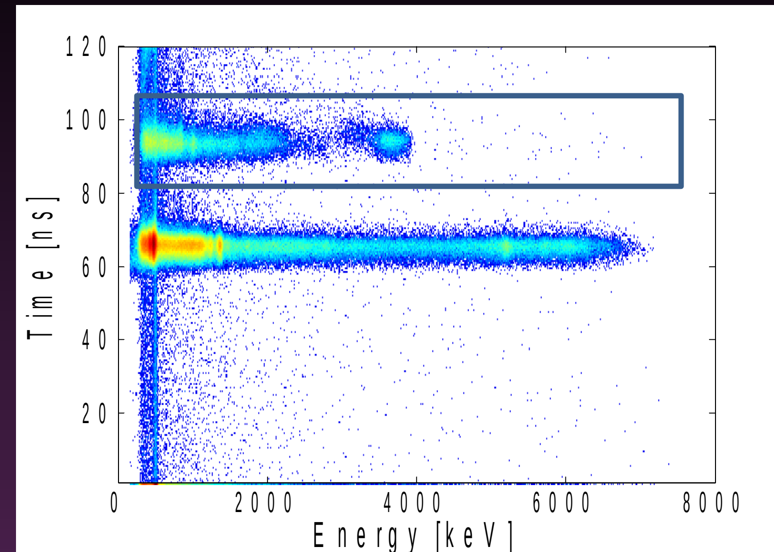
En < 6 MeV not to have 3 body channels

A.Giaz et al. NIM A825(2016)51 and A.Giaz et al. NIM A810(2016)132

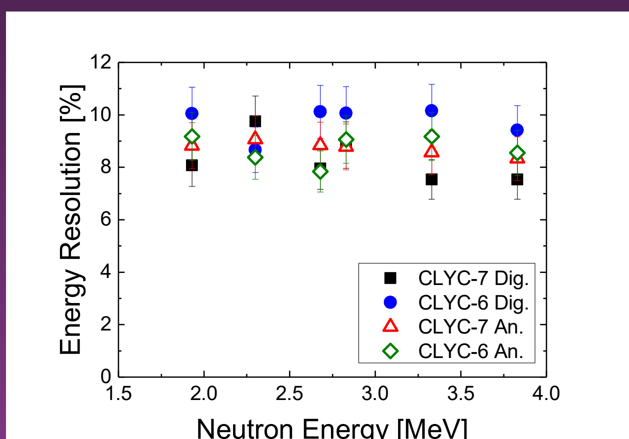
Fast Neutron Spectroscopy

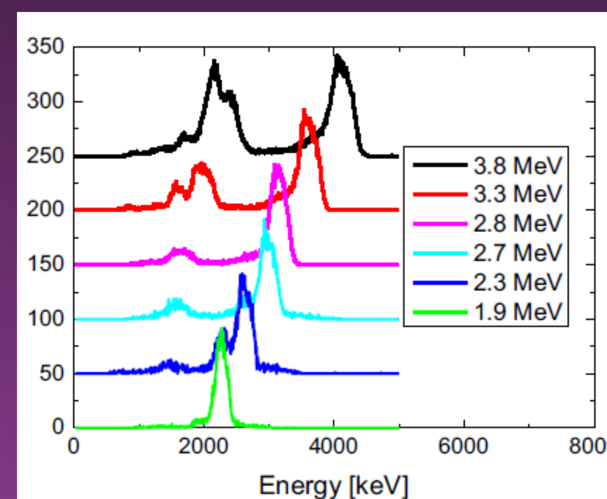


PSD Ratio vs Energy in CLYC (keVee)



TOF vs Energy in CLYC (keVee)





Energy spectra of Neutrons

A.Giaz et al. NIM A825(2016)51 e A.Giaz et al. NIM A810(2016)132

Therefore:

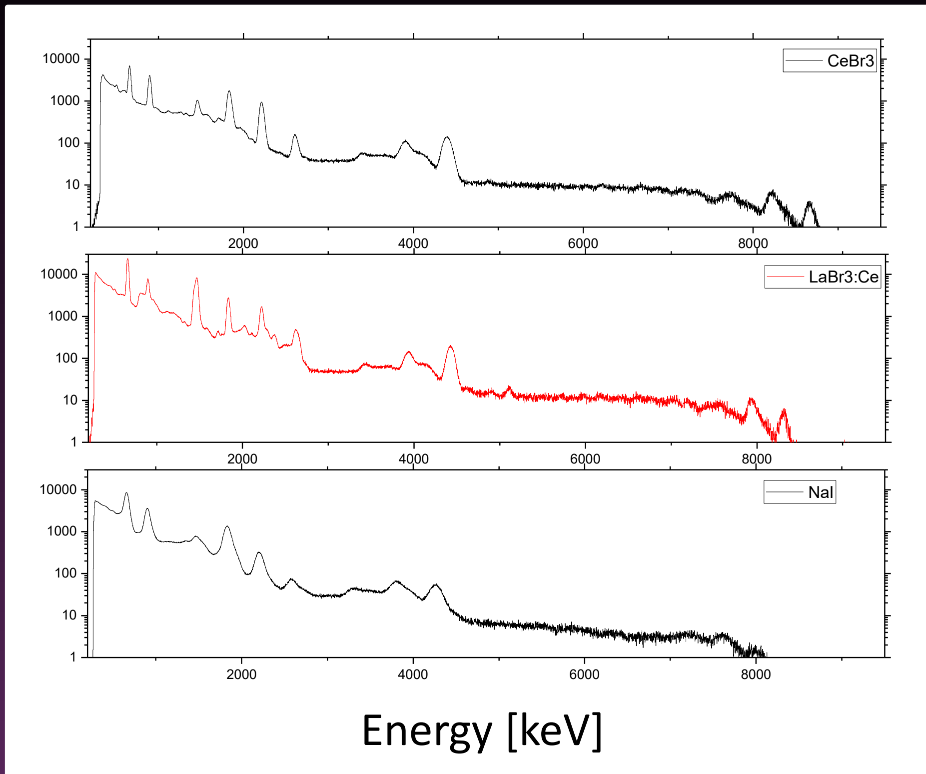
CLYC (and perhaps other ‘Elpasolite’) Detectors

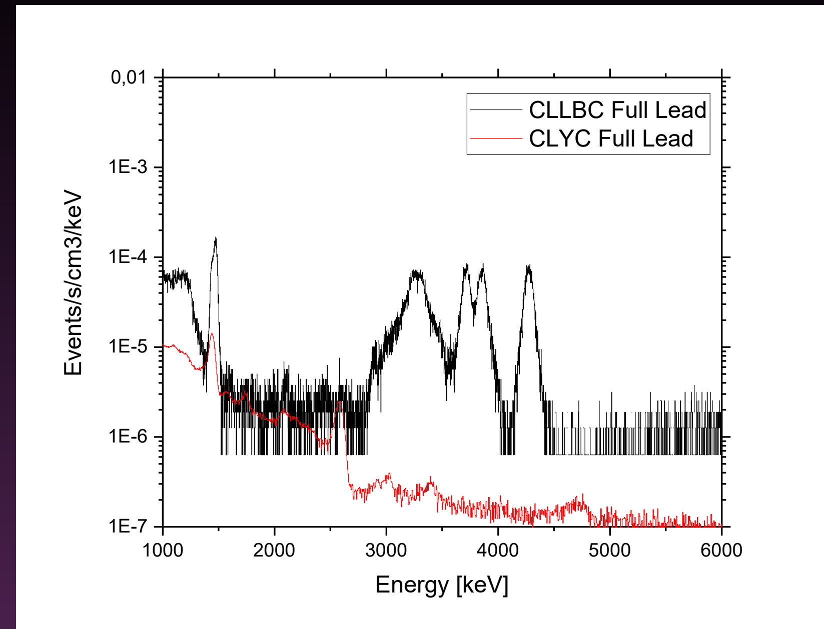
- they can do the same work of LaBr3:Ce
- LaBr3:Ce can perform a little better job for γ-rays

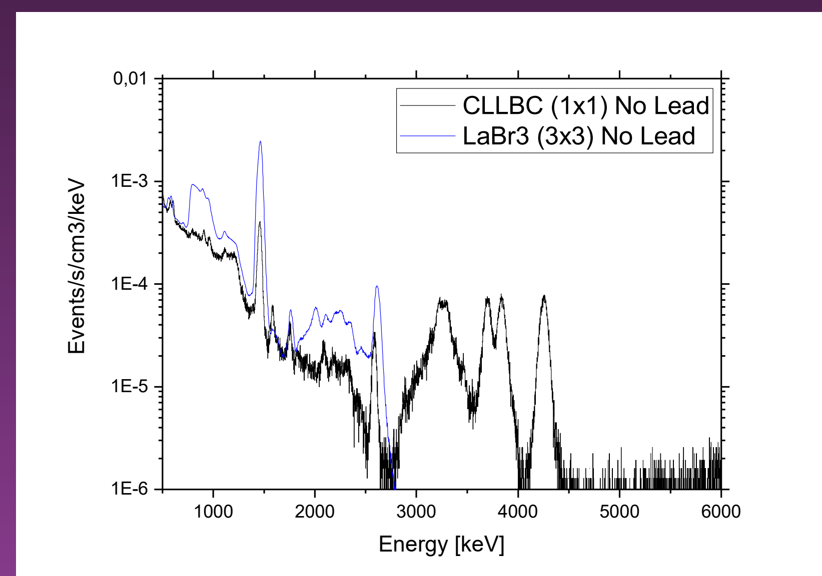
- But
  - Strong PSD properties
  - CLYC-6 is sensitive mainly to thermal neutrons
  - CLYC-7 is sensitive only fast neutrons
    - neutron spectroscopy is possible
    - may be that CLYC could identify also p,D,T,alpha
  - Very weak internal activity
  - Cost

LaBr3:Ce - CeBr3 – NaI (3"x3")

CLLBC scintillator







CeBr3 has an energy resolution a little worser than LaBr3:Ce but has no 138La internal background

The internal radiation of CLLBC is comparable to that of LaBr3:Ce

Internal radiation of CLYC is extremely low if compared to LaBr3:Ce

Conclusions

- **In this talk we concentrate on scintillator new materials**

Semiconductor detectors have an energy resolution which will never be reached by scintillators (because of the energy gap, the conversion light-electrons, Fano factor, …)

- **Scintillators should be used with HPGe or when HPGe cannot be used (when efficiency, timing and count rate is an important issue)**
  - Large volumes are needed
  - Nanosecond (or better) time resolution is needed
  - Large count rate are expected
  - Good (not excellent) energy resolution is needed
  - Neutron Spectroscopy
  - Total Price and detector maintenance is an issue

- **Scintillators world is rapidly evolving and several new materials arrived, arrive and will arrive on the market**

Thank you for the attention