GDS
GDS Topical Meeting: GDS coupling to auxiliary detection systems
25-27 January 2017 *INFN Laboratori Nazionali di Legnaro*
Europe/Rome timezone

A new scintillator detector for nuclear physics experiments: the CLYC scintillator

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Outline

- ✓ Characterization measurements on new scintillators (SrI_2, $CeBr_3$, CLYC)
- ✓ CLYC
  - Enrichment with ^{6}Li (Thermal and fast neutrons)
  - Enrichment with ^{7}Li (fast neutrons)
  - Measurements with monochromatic fast neutrons
  - Neutron energy resolution from PSD
  - Continuous neutron spectra
- ✓ Co Doped $LaBr_3$:Ce, CLLB and CLLBC crystals
- ✓ LaBr3:Ce with SIPM
- ✓ Summary

Scintillators in nuclear physics experiments

Detector requirements:

- ✓ Measurement of low and high energy gamma rays (0.1 - 15 MeV) → Good efficiency
- ✓ Good Time resolution
  - background rejection
  - TOF measurements
- ✓ 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

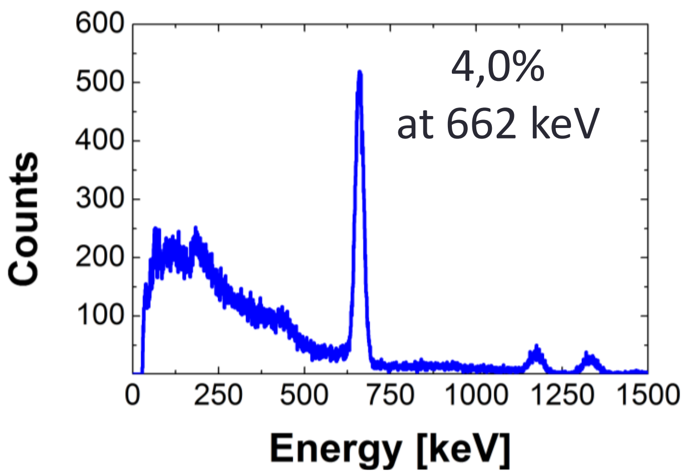
Material	Light Yield [ph/MeV]	Emission λ_{max} [nm]	En. Res. at 662 keV [%]	Density [g/cm^2]	Principal decay time [ns]
NaI:Tl	38000	415	6-7	3.7	230
CsI:Tl	52000	540	6-7	4.5	1000
$LaBr_3$:Ce	63000	360	3	5.1	17
SrI_2:Eu	80000	480	3-4	4.6	1500
$CeBr_3$	45000	370	~4	5.2	17
GYGAG	40000	540	<5	5.8	250
CLYC:Ce	20000	390	4	3.3	1 CVL 50, ~1000

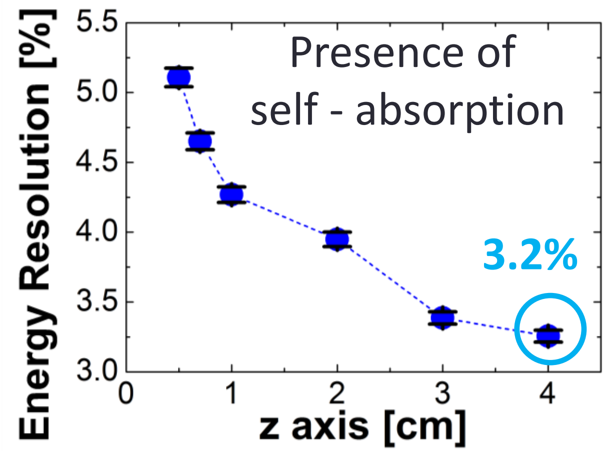
The SrI_2:Eu scintillator (2'' x 2'')

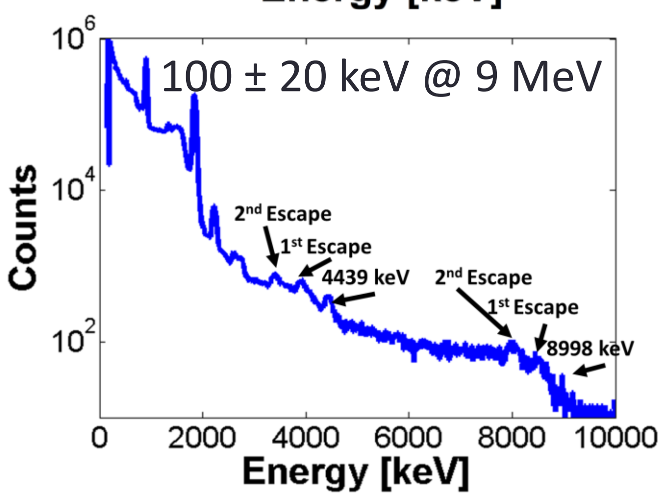
A. Giaz et al., NIM A 804, (2015), 212

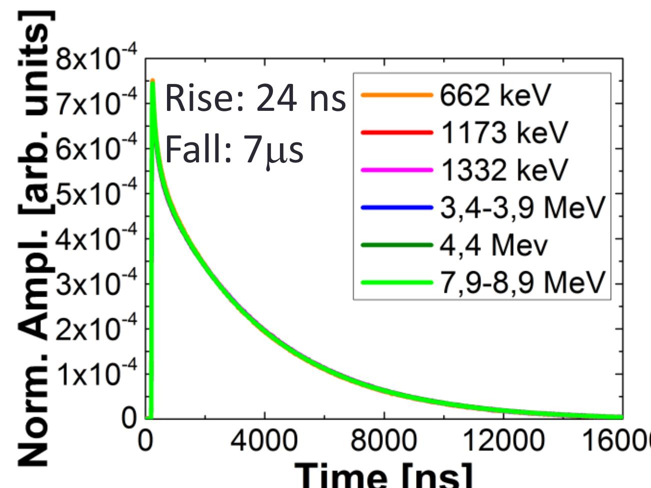
Characterization measurements:
- ✓ Energy resolution up to 9 MeV
- ✓ Crystal scan along the three axes
- ✓ Study of the signal shape

- Energy resolution of ~ 3.2% at 662 keV
- Slow detector (fall time ~ 7 μs)
- Large volume crystals (2'' x 2'') available
- Self absorption







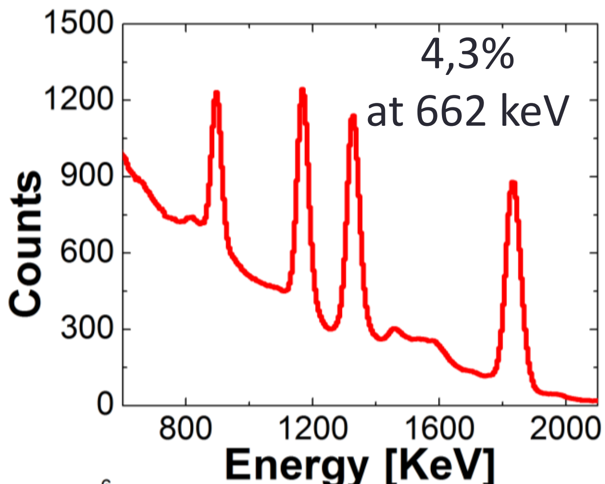


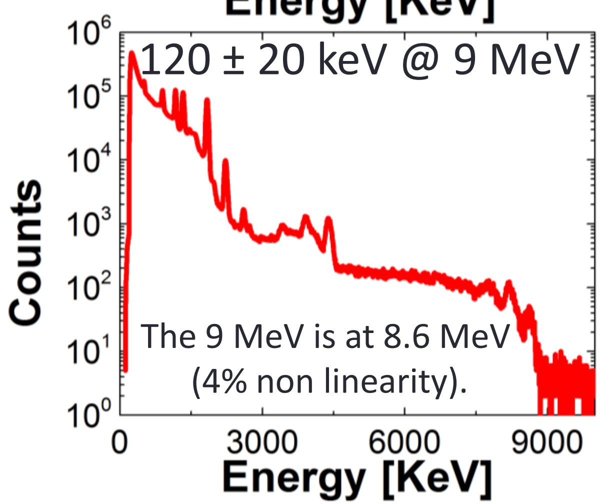
The $CeBr_3$ scintillator (2'' x 3'')

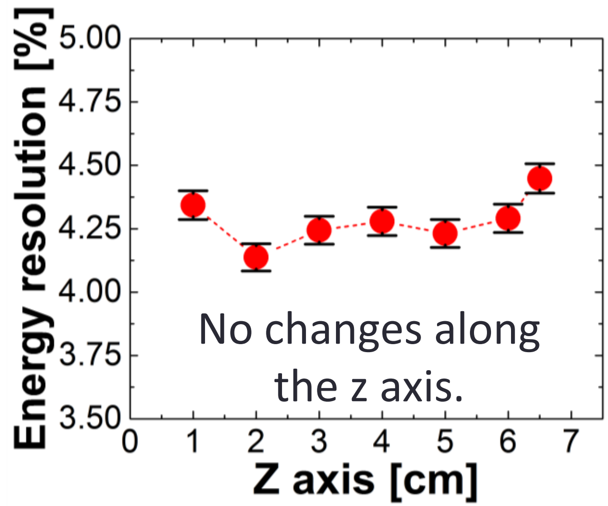
A. Giaz et al., NIM A 804, (2015), 212

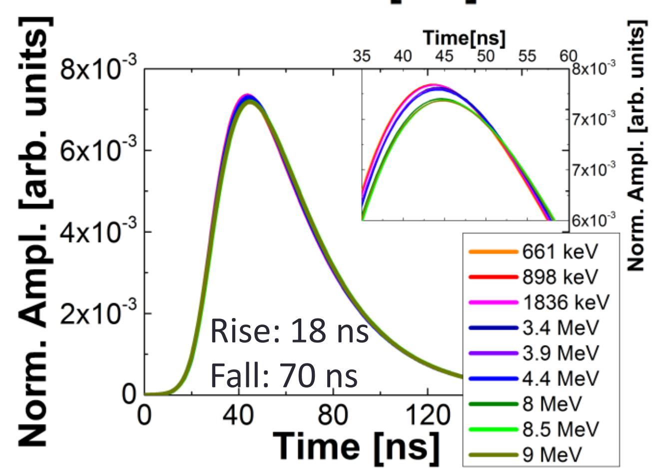
Characterization measurements:
- ✓ Energy resolution up to 9 MeV
- ✓ Crystal scan along the three axes
- ✓ Study of the signal shape

- Energy resolution of ~ 3.5% at 662 keV
- Very similar to $LaBr_3$:Ce
- Large volume crystals (3'' x 3'') available
- No internal activity

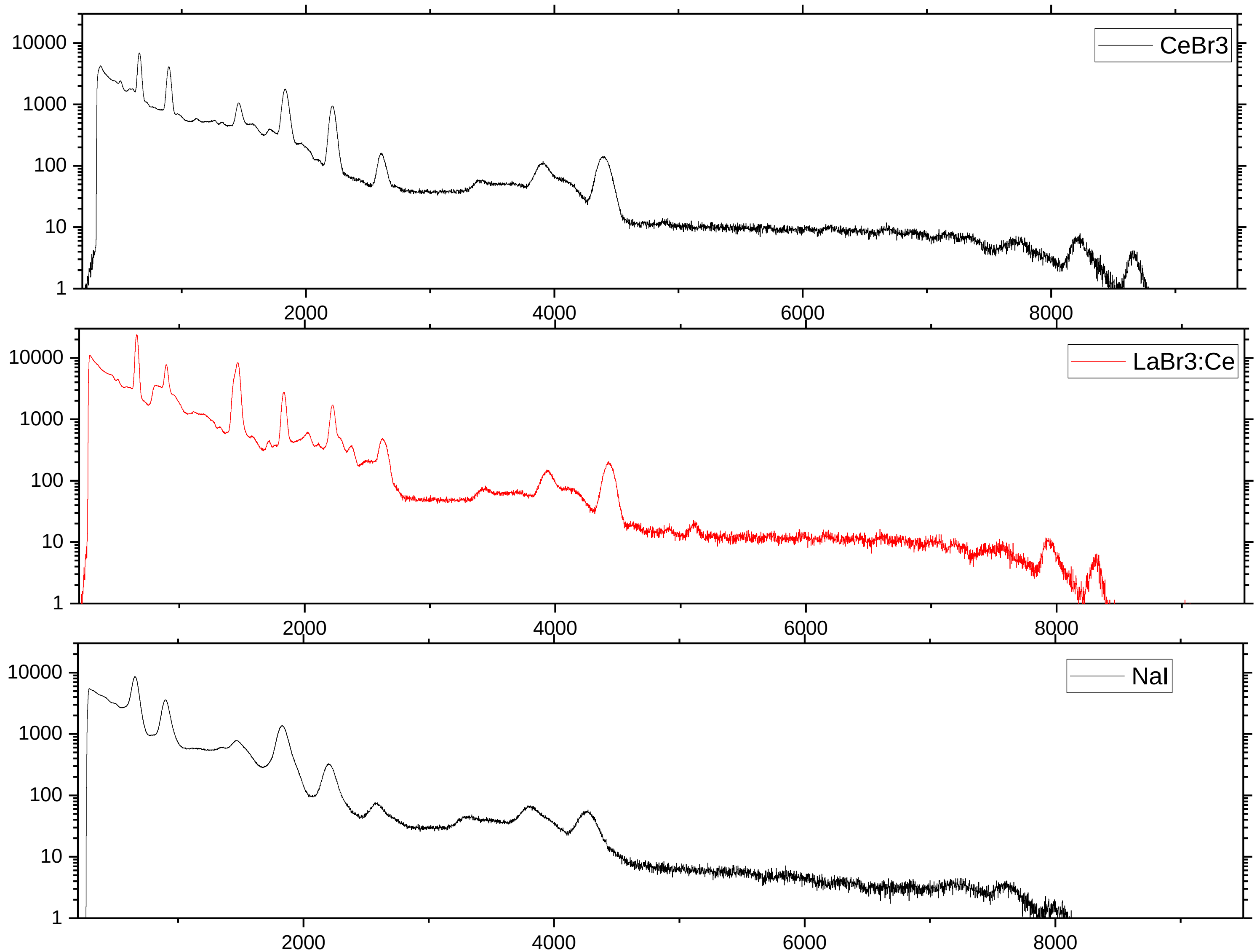








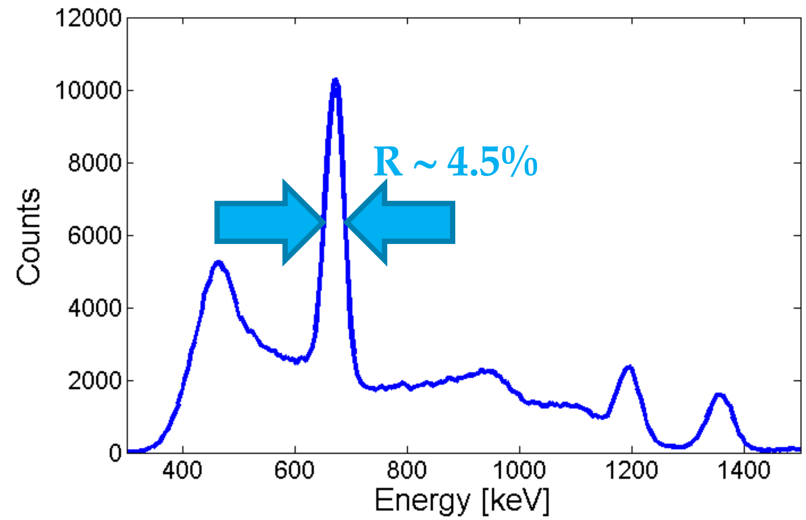
The $CeBr_3$ scintillator (3'' x 3'')

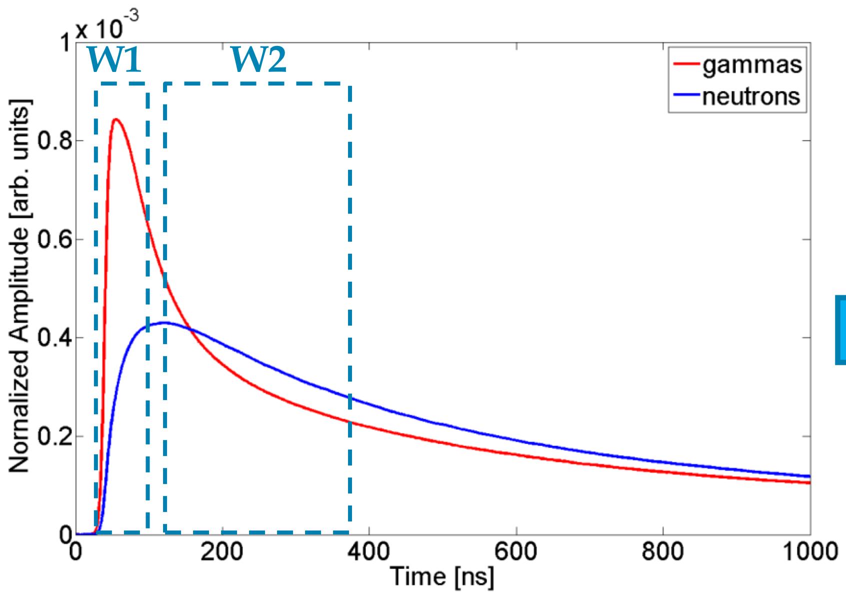


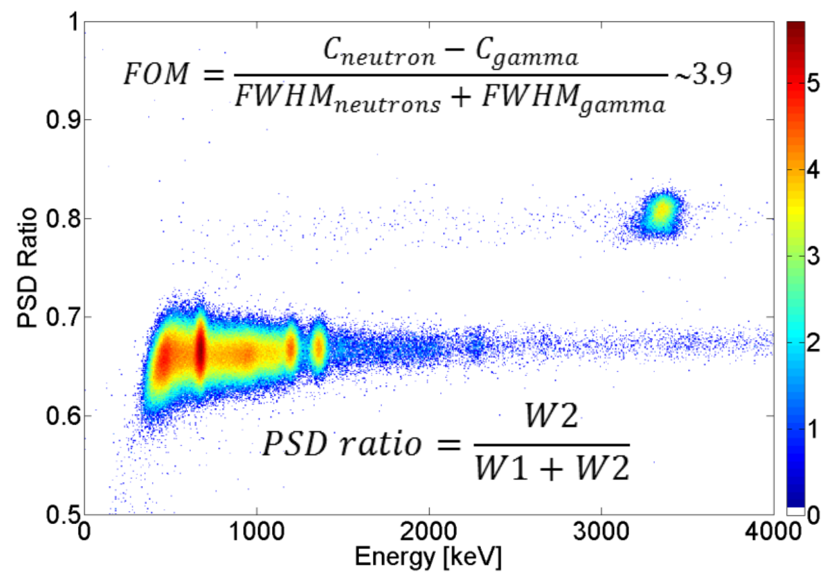
The CLYC scintillator ($Cs_2LiYCl_6:Ce^{3+}$)

The CLYC crystals were developed approximately 10 years ago.

- ✓ Density of 3.3 g/cm^3,
- ✓ light yield of 20 ph/keV
- ✓ high linearity, especially at low energy.
- ✓ Energy resolution at 622 keV < 5%
- ✓ time resolution of 1.5 ns.
- ✓ Excellent neutron gamma discrimation.







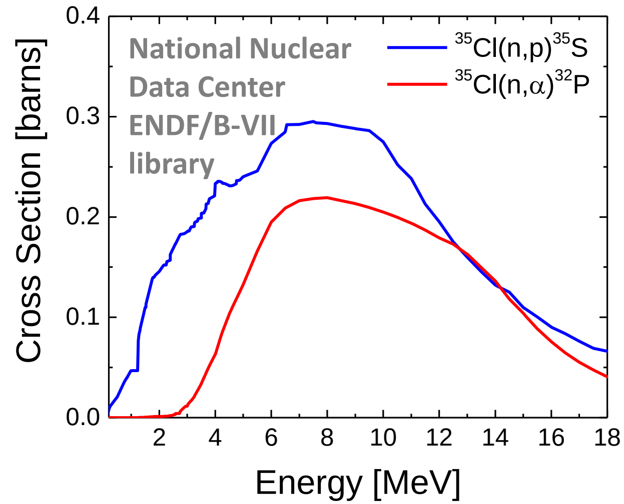
Neutron detection

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



Thermal neutrons:

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

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

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

The kinetic energy of the neutrons can be measured via:

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

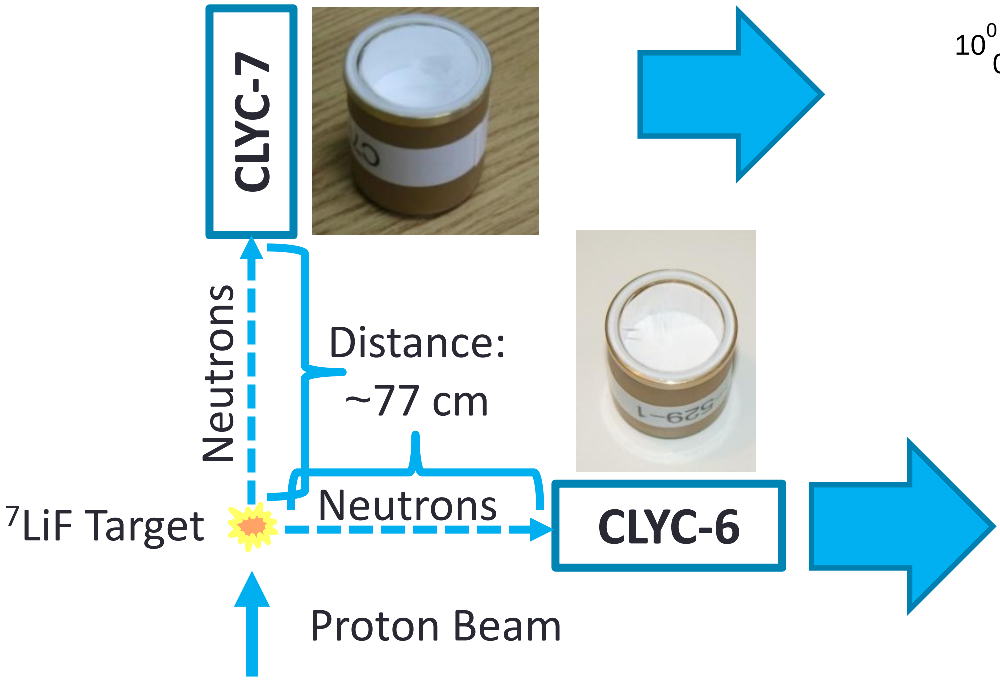
Two measurements:

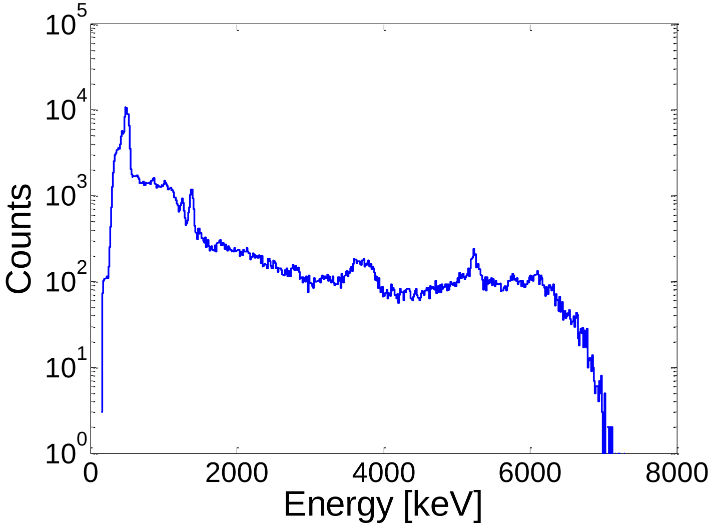
✓ Monochromatic neutrons
✓ Continuous neutron spectrum of an $^{241}Am/^{9}Be$ source

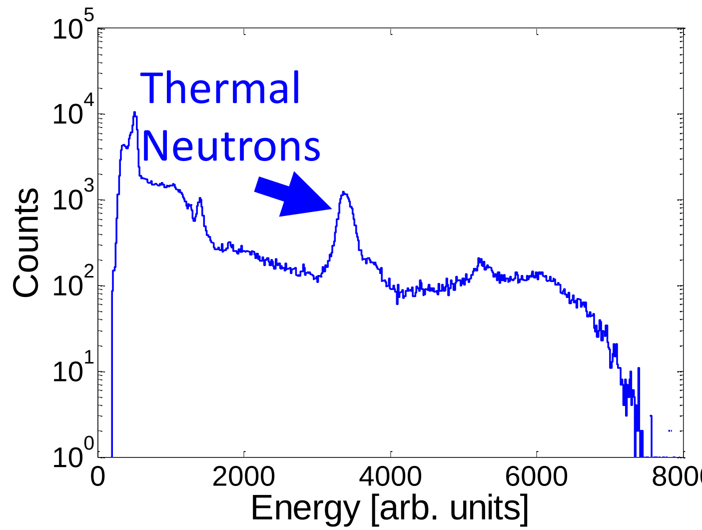
Fast Neutron Detection with CLYC

A. Giaz et al., NIM A 825, (2016), 51

Proton Energy [MeV]	Detector Angle	Neutron Energy [MeV]
5.5	0°	3.83
5	0°	3.33
4.5	0°	2.83
5.5	90°	2.68
5	90°	2.30
4.5	90°	1.93







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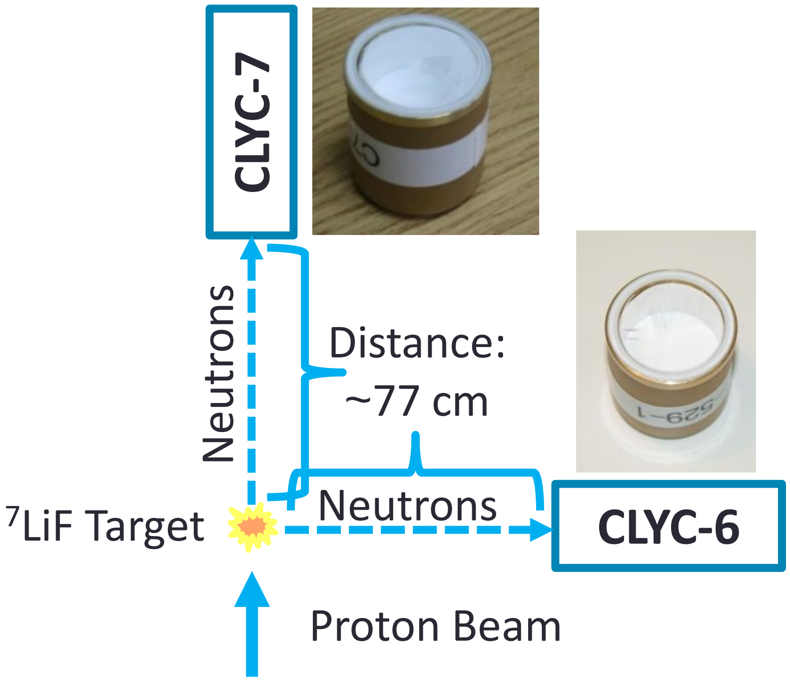
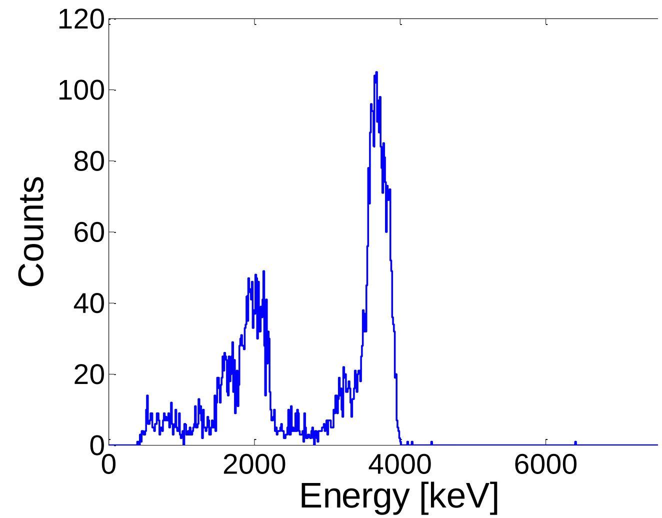
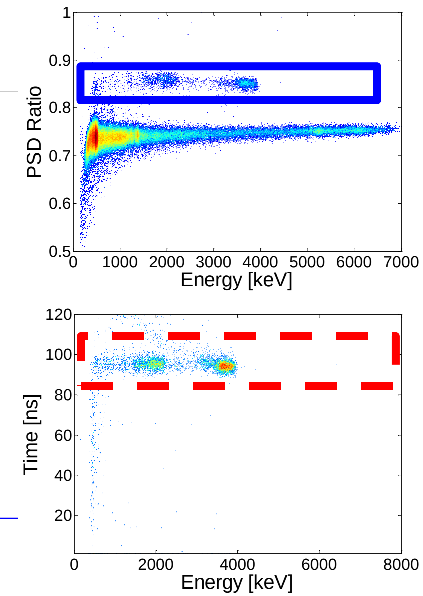
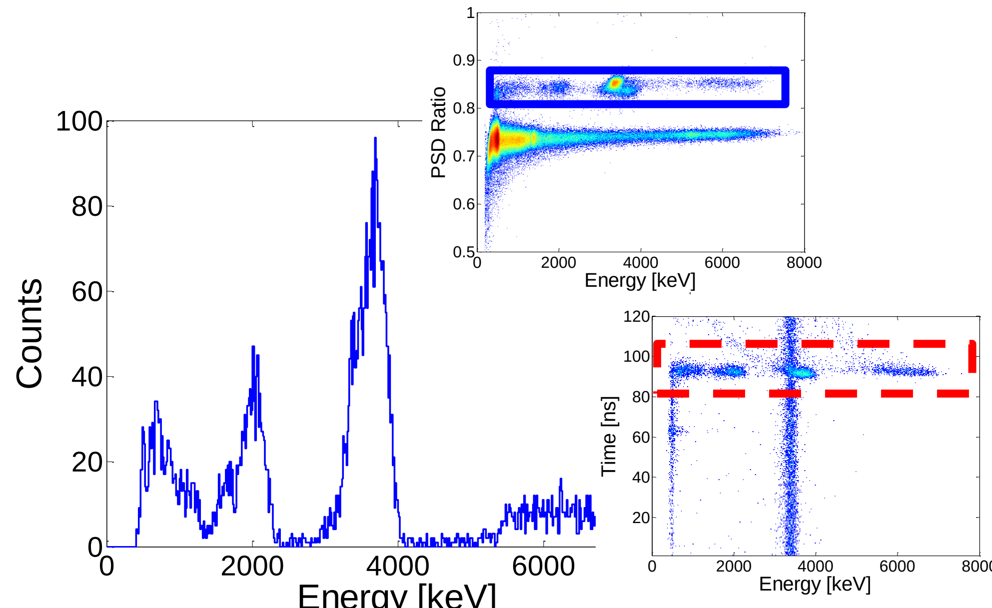


A. Giaz et al., NIM A 825, (2016), 51







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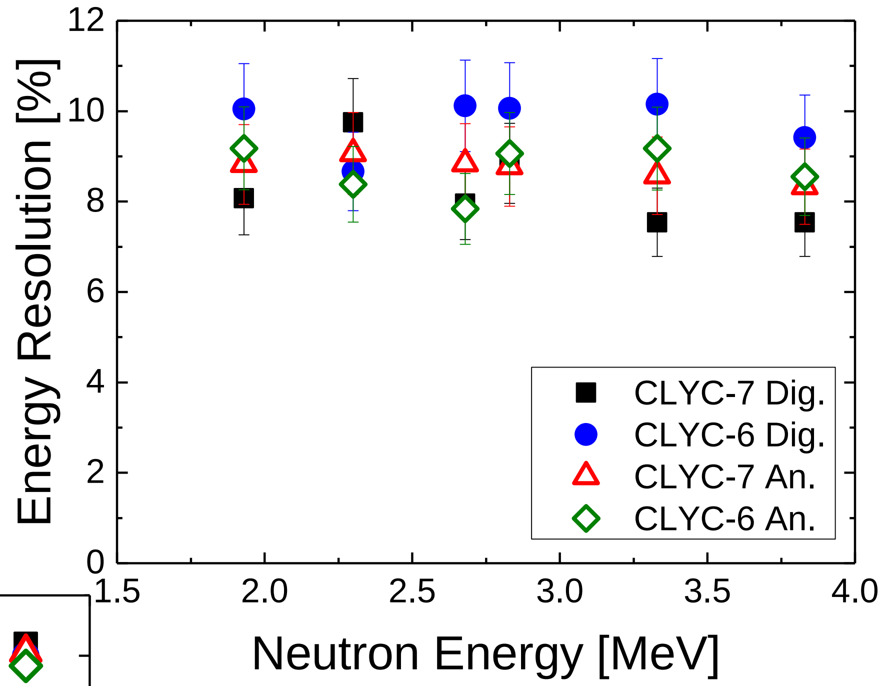
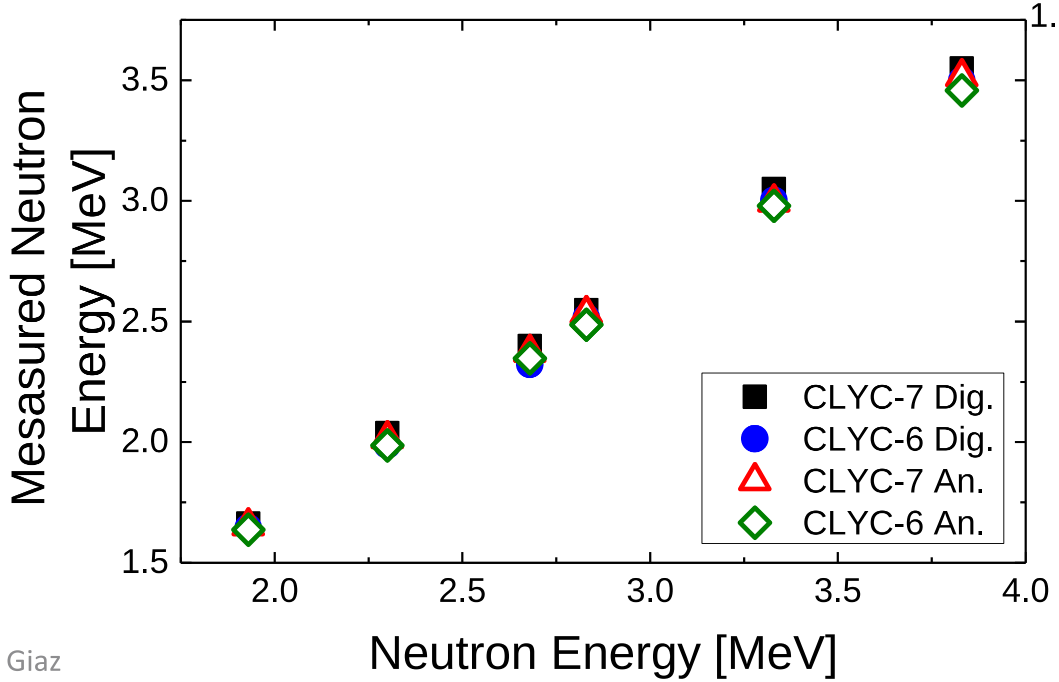




The energy of the outgoing proton is linearly related to the energy of the incoming neutron.

$$E_n = E_{mis}/q - Q$$

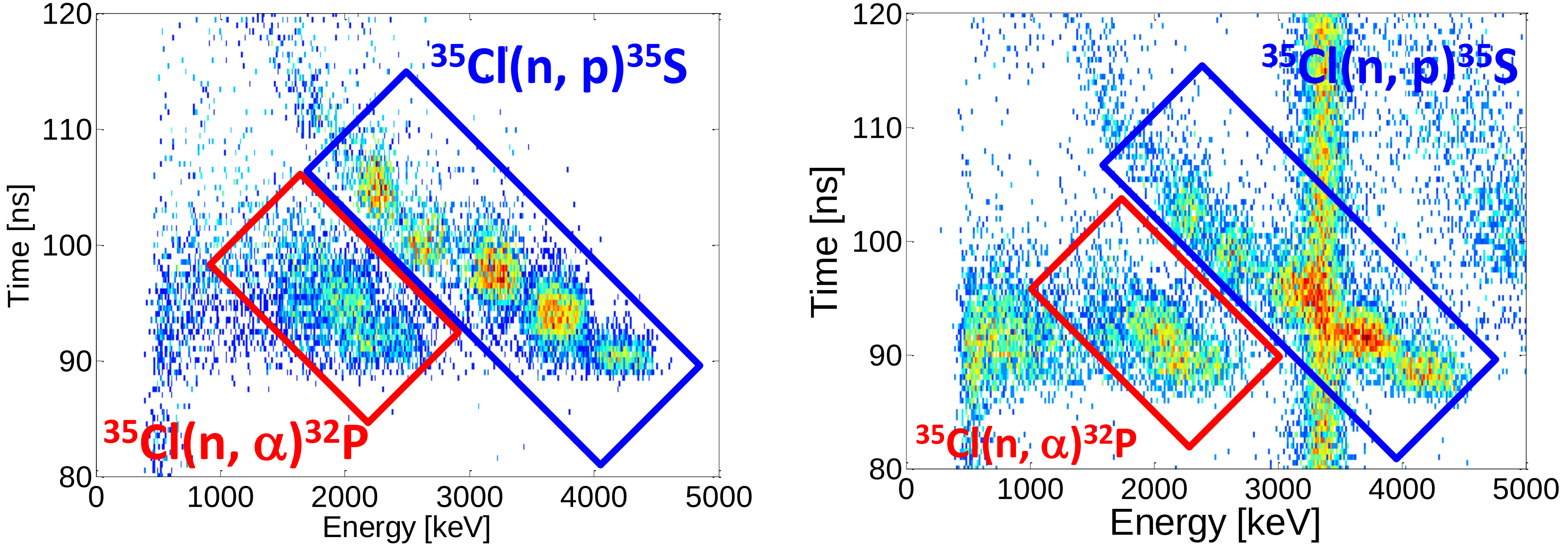
A. Giaz et al., NIM A 825, (2016), 51

Continuous neutron spectra

A continuous neutron spectra can be measured using the time vs energy matrices (gated on PSD).
The blue region includes contribution of $^{35}Cl(n,p)^{35}S$ reaction only

Note:
PDS identify an incoming neutron but not its energy
TOF identify a neutron or a delayed γ-ray

Using both information it is possible to identify a neutron and to measure its energy



A. Giaz et al., NIM 825, (2016), 51

$^{241}Am/^{9}Be$ Source

$^{241}Am/^{9}Be$ source:

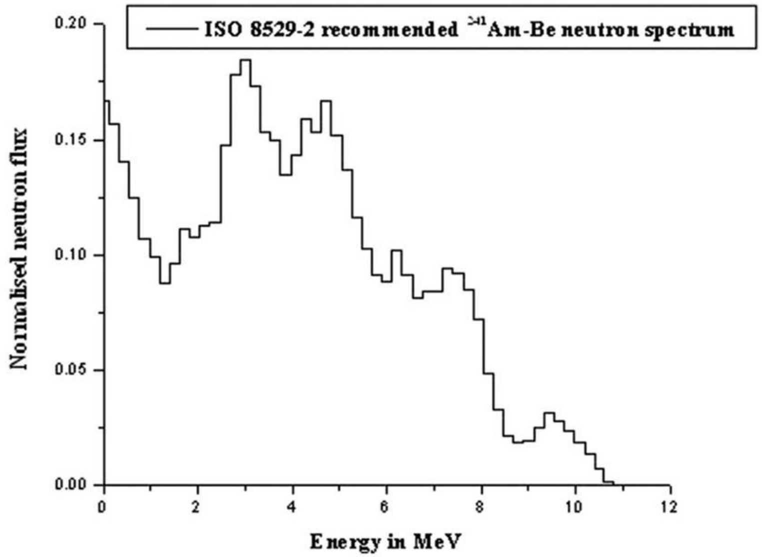
$^{241}Am \rightarrow {}^{237}Np + \alpha$ ($E_\alpha \sim 5.5$ MeV)

$\alpha + {}^{9}Be \rightarrow {}^{13}C$ (Q = 5.7 MeV)

$^{13}C \rightarrow n + {}^{12}C$ ($E_n < 11.2$ MeV)

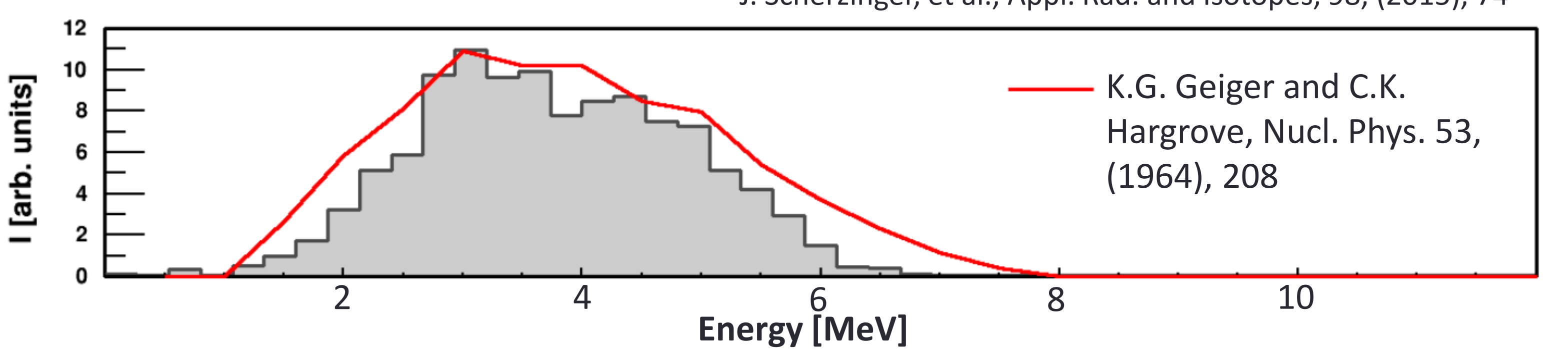
^{12}C can be in different states:

- ✓ Ground state : Q = 5.7 MeV
- ✓ **1st excited state: Q = 1.3 MeV, $E_\gamma = 4.439$ MeV**
- ✓ 2nd excited state: $E_{th} = 2.8$ MeV $E_\gamma = 7.654$ MeV
- ✓ 3rd excited state: $E_{th} = 5.7$ MeV $E_\gamma = 9.641$ MeV

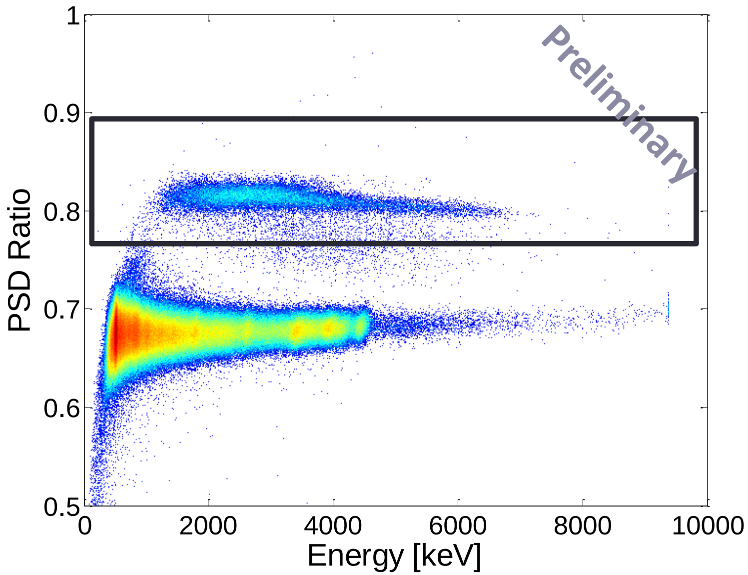


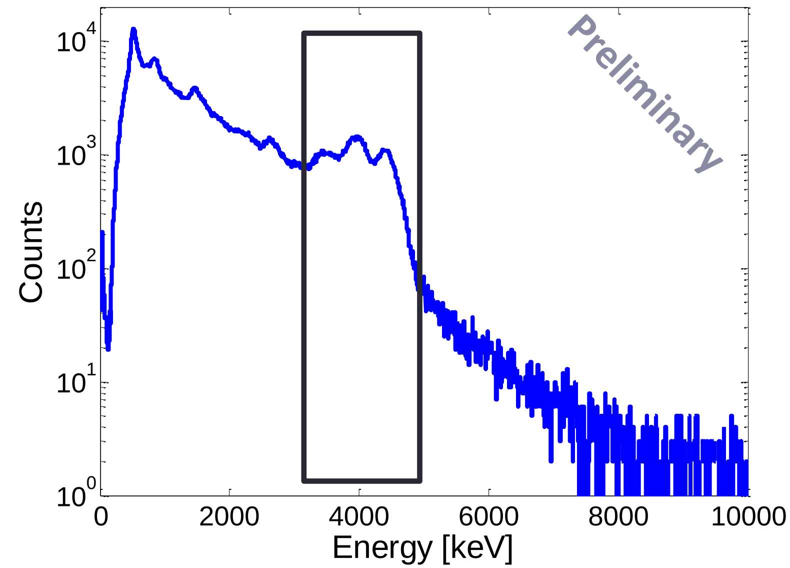
Neutron spectra measured in coincidence with a 4.439 MeV γ ray using the TOF technique.

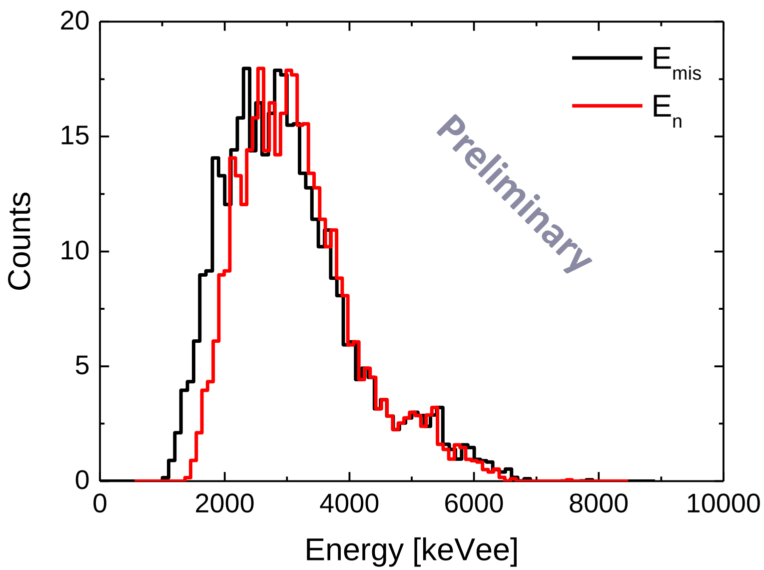
J. Scherzinger, et al., Appl. Rad. and Isotopes, 98, (2015), 74



Measurement of the $^{241}Am/^{9}Be$ spectrum







PDS to separate neutrons from gammas.

$E_n = E_{mis}/q - Q$

E_n < 7 MeV: dominant reaction is $^{35}Cl(n,p)^{35}S$ till E_n < 4 MeV , for higher energies it is necessary to separate different contributions. → using TOF techniques.

New Scintillators

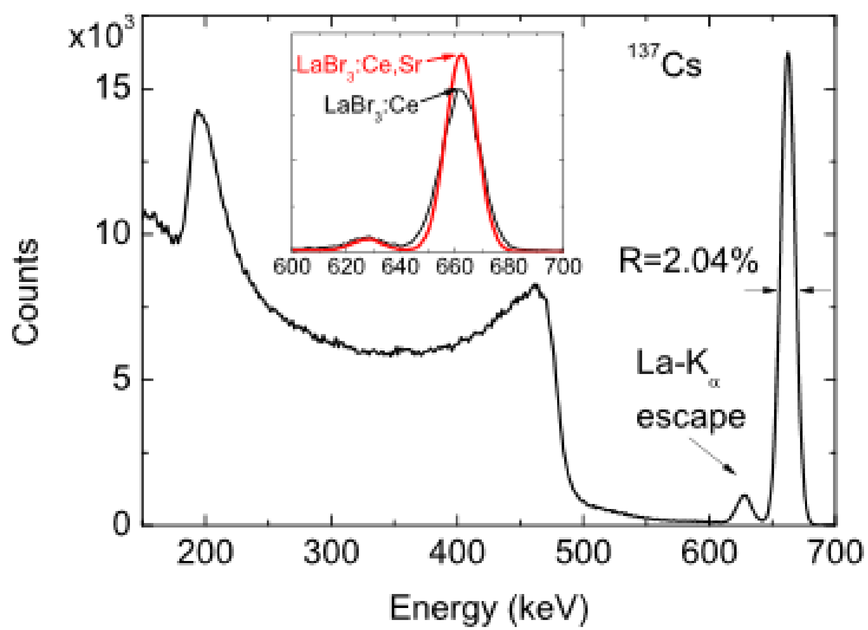
New scintillator materials are available in small size (ENSAR2-PASPAG Project)

Material	Light Yield [ph/MeV]	Emission λ_{max} [nm]	En. Res. at 662 keV [%]	Density [g/cm^2]
NaI:Tl	38000	415	6-7	3.7
CLYC:Ce	20000	390	> 4	3.3
CLLBC:Ce	45000	410	< 3	4.1
CLLB:Ce	55000	410	< 3	4.2

CLYC $\Rightarrow$ Cs_2LiYCl_6 CLLB $\Rightarrow$ $Cs_2LiLaBr_6$
CLLBC $\Rightarrow$ $Cs_2LiLa(Br,Cl)_6$
These new crystals are available since few months
CLYC 3”x3” is available since 2016 only

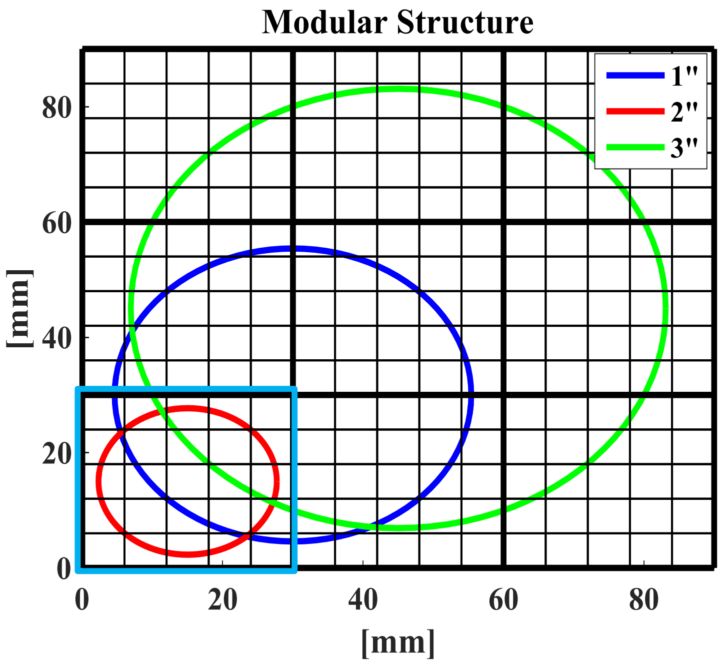
Co-doped $LaBr_3$:Ce

- Co-doping should improve the linearity at low energy
- Co doping should improve energy resolution
- No large volume detectors available (maybe first in 2017)



Alekhin et al. J. Appl. Phys. 113, 224904 (2013)

New sensors- Large Area SIPM

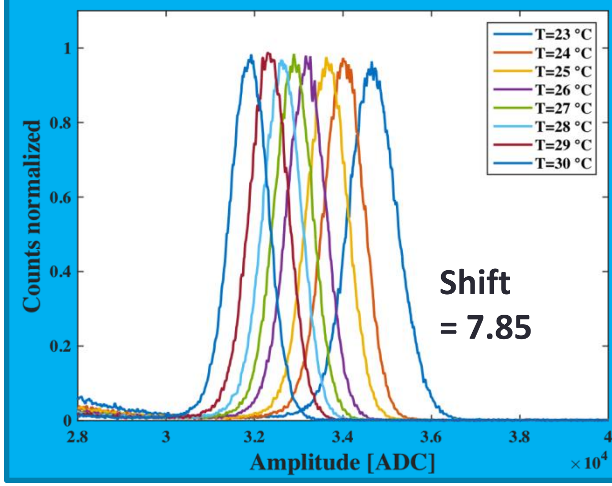


Individual SiPM properties:

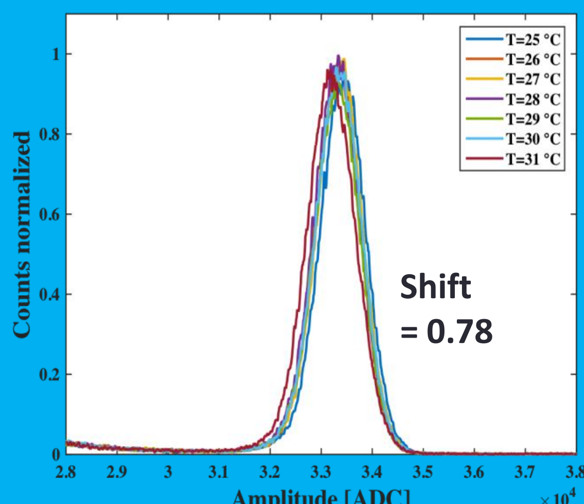
- ✓ Technology: NUV-HD produced by FBK
- ✓ Active area: 6 x 6 mm^2 (39600 mcells)
- ✓ Microcells size: 30 x 30 mm^2
- ✓ Cell density: 1100 $mcells/mm^2$
- ✓ FF (Fill Factor): 77%
- ✓ PDE (Particle Detection Efficiency (con FF)) (@380 nm, Vov = 6V): 43.5%
- ✓ DCR (Dark Counr Rate) (Vov = 6V): 68 $kcps/mm^2$
- ✓ ENF (Excess Noise Factor): 1.19

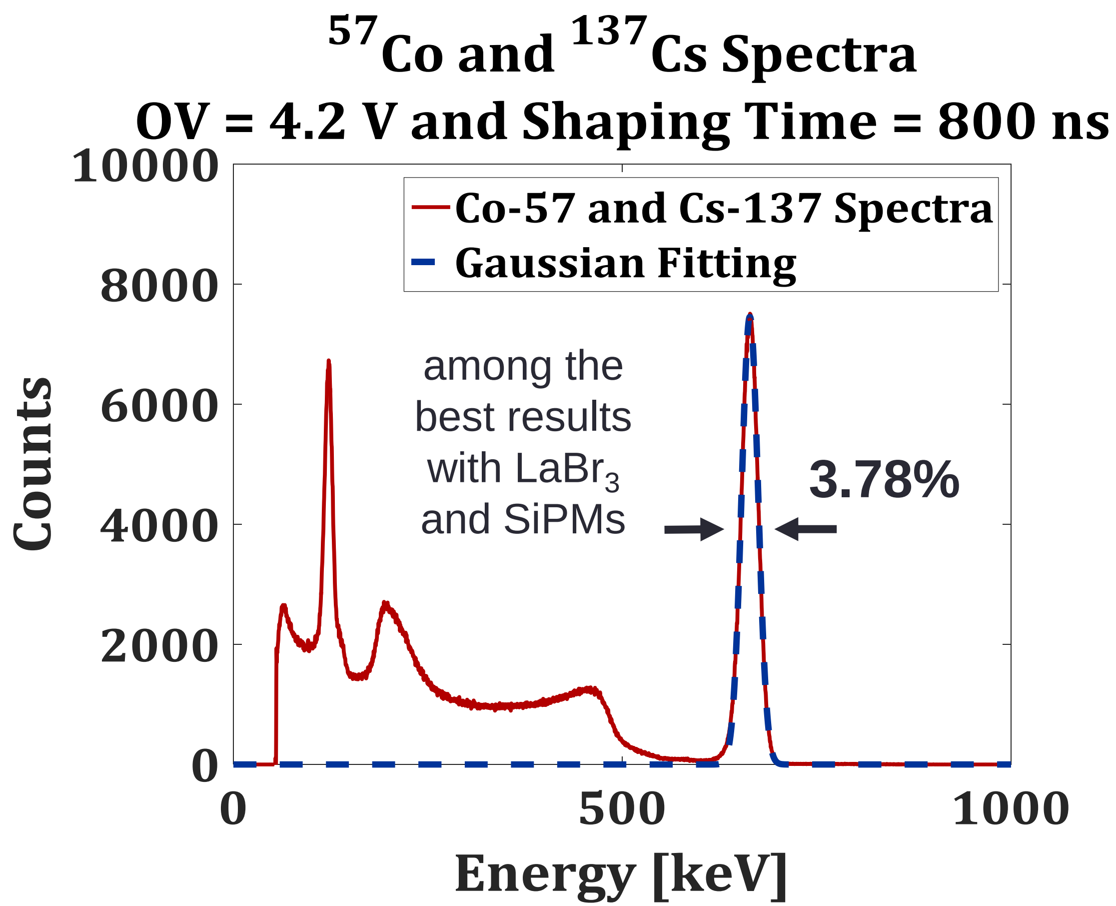
LaBr3:Ce (2'' x 2'') coupled to SiPM

Without gain stabilization



With gain stabilization





Results can be improved:

There were 4 cells (6 mm x 6 mm) not working

$LaBr_3$ not in the center to cover the least possible of these 4 cells.

New arrays in production at FBK

Conclusions

Several new scintillators are or will be soon on the market

- CLLB, CLLBC CoDoped $LaBr_3$:Ce, CLYC, $CeBr_3$, SrI_2, ….
- Their detailed performances are not fully known
- Several studies on CLYC were done and will be done
  - Energy Resolution and PSD
  - Neutron spectroscopy
  - Continuous neutron spectra

R&D on light sensor (SiPM) for spectroscopy is starting

THANK YOU FOR THE ATTENTION