New Scintillator detectors for nuclear physics experiments

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Outline

- ✓ Introduction
  - Nuclear physics experiments
  - Scintillator detectors in nuclear physics experiments
- ✓ Characterization measurements on scintillators
  - SrI_2:Eu
  - $CrBr_3$
  - GYGAG:Ce
- ✓ Measurements of neutron spectra with CLYC scintillator
  - Monochromatic neutrons
  - Neutrons from ^{241}Am/^{9}Be source
- ✓ Summary: advantages and disadvantages of each scintillator

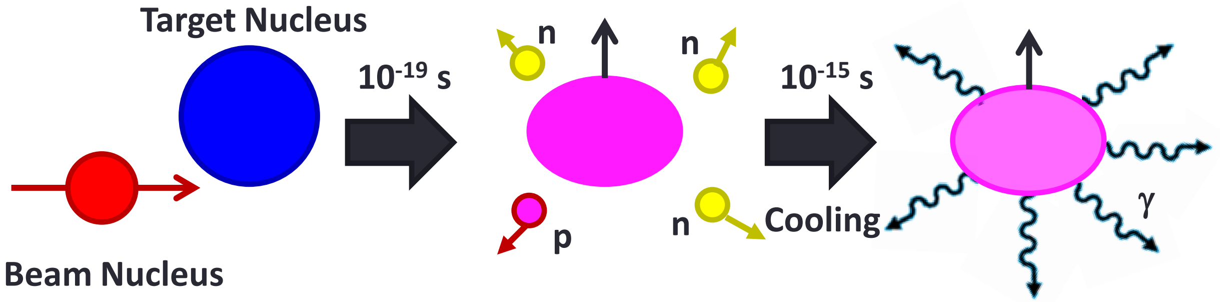
Nuclear physics experiments

Nuclear physics experiments, especially with radioactive beams allows to explore unknown mass regions.

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.

Fusion evaporation reaction



GDR and neutron evaporation branching ratio is 10^{-3}

From the GDR built on excited nuclei:

- ✓ Nuclear shape and deformation
- ✓ Fusion dynamics → dynamical dipole
- ✓ Isospin mixing measurement (CKM-matrix – V_{ud} term)
- ✓ Thermal fluctuations

Scintillators in 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
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

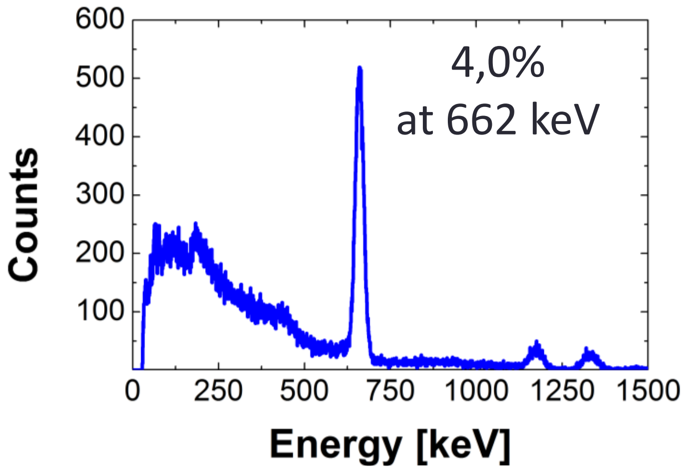
- Energy resolution of ~ 3.2% at 662 keV
- Slow detector (fall time ~ 7 μs)
- Large volume crystals (2'' x 2'') available
- Self absorption

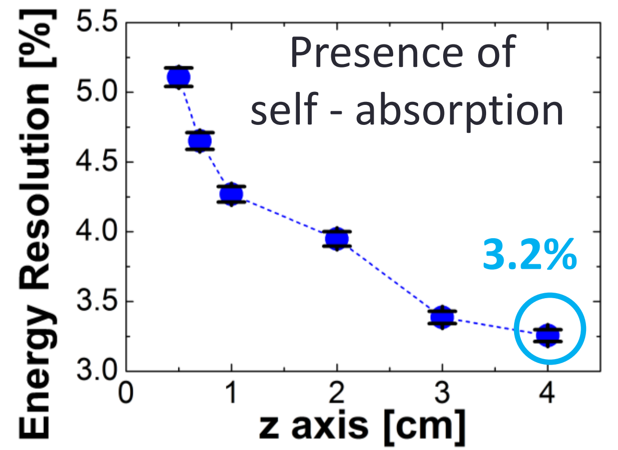
Characterization measurements:

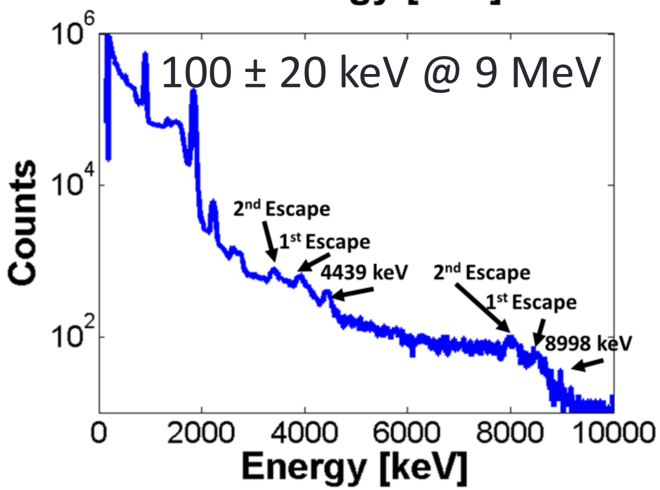
✓ Energy resolution up to 9 MeV

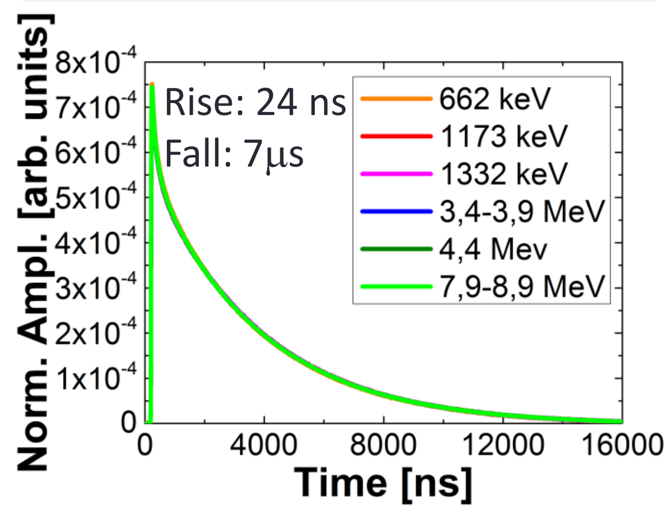
✓ Crystal scan along the three axes

✓ Study of the signal shape









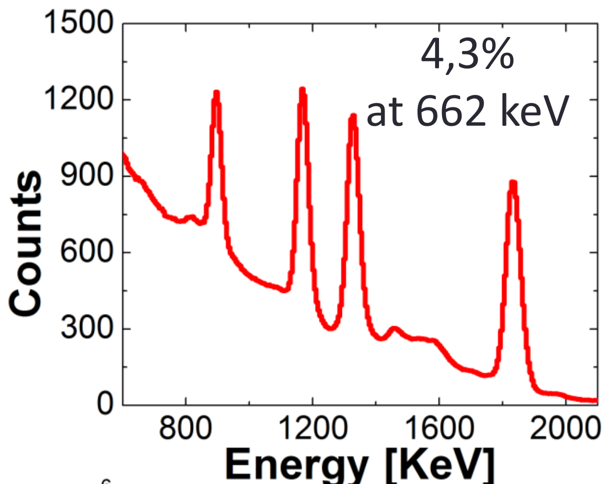
The $CeBr_3$ scintillator (2'' x 3'')

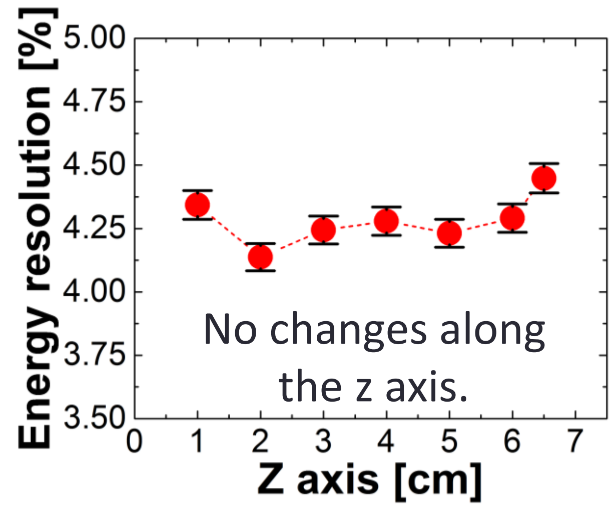
A. Giaz et al., NIM A 804, (2015), 212

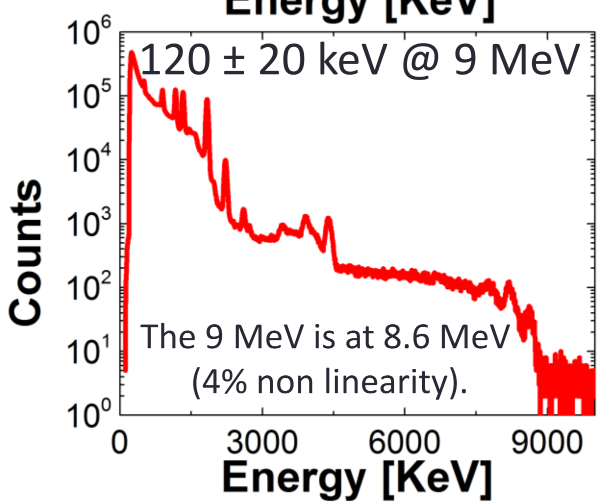
- Energy resolution of ~ 3.5% at 662 keV
- Very similar to $LaBr_3$:Ce
- Large volume crystals (3'' x 3'') available
- No internal activity

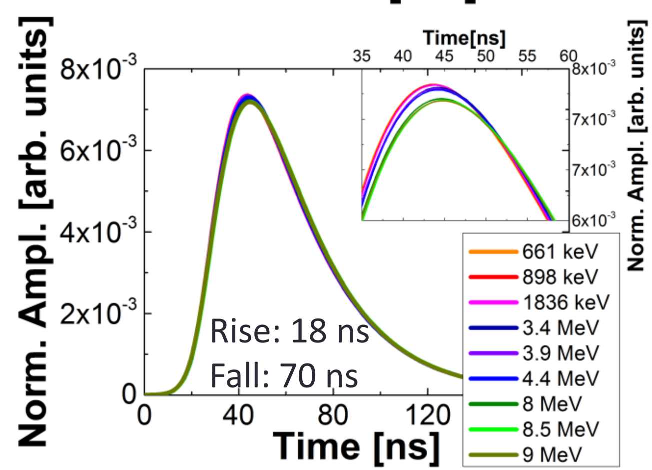
Characterization measurements:

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









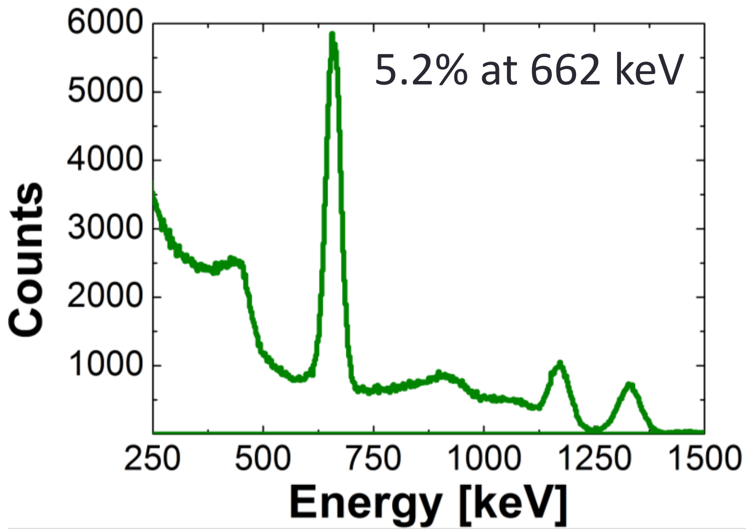
The GYGAG:Ce Scitillator (2'' x 0.7'')

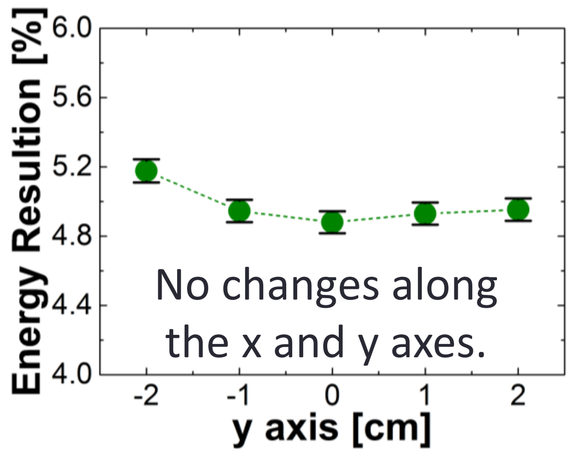
A. Giaz et al., NIM A 804, (2015), 212

- Energy resolution of ~ 4.0 % at 662 keV
- emission wave length 530 nm (yellow)
- No commercially available
- Ceramic detector: any size and shape

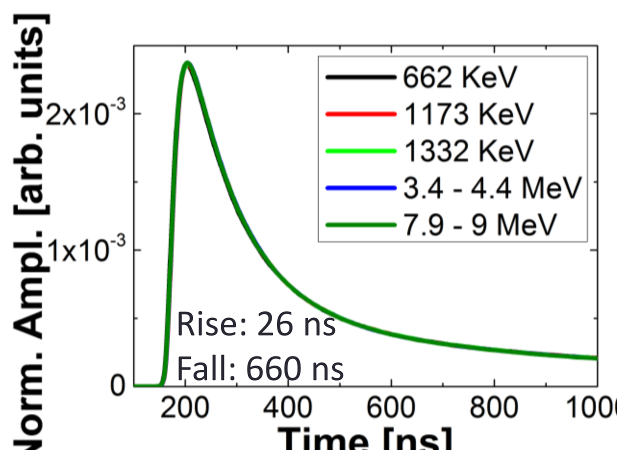
Characterization measurements:

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





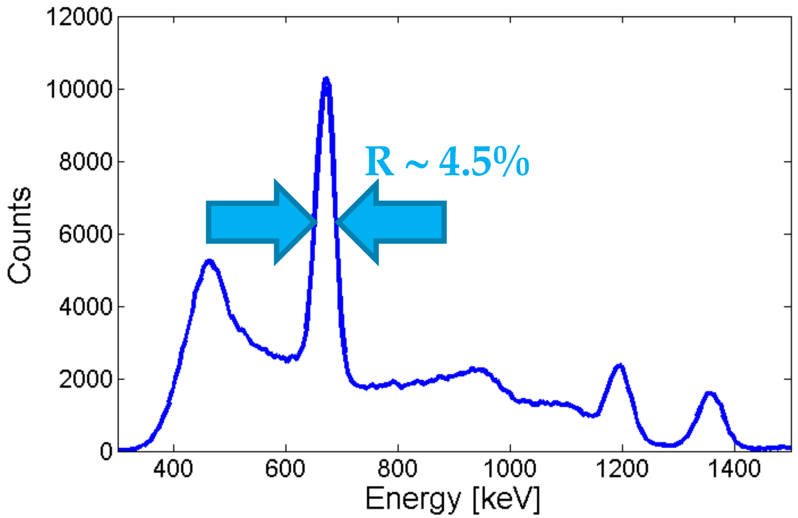
Photocathode optimized for the blue region.
A sensor optimized for yellow light will provide a better resolution (SiPM).

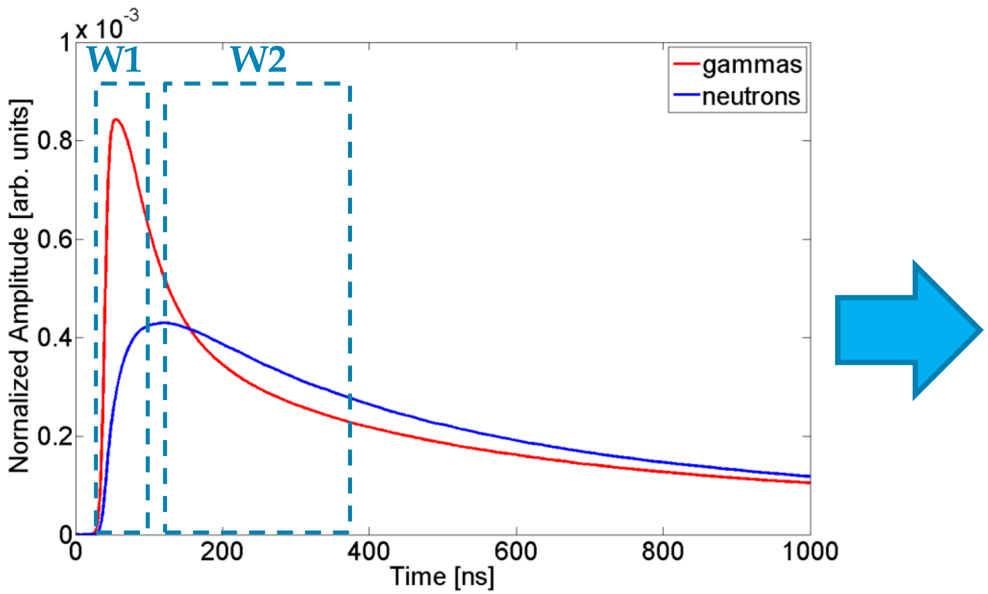


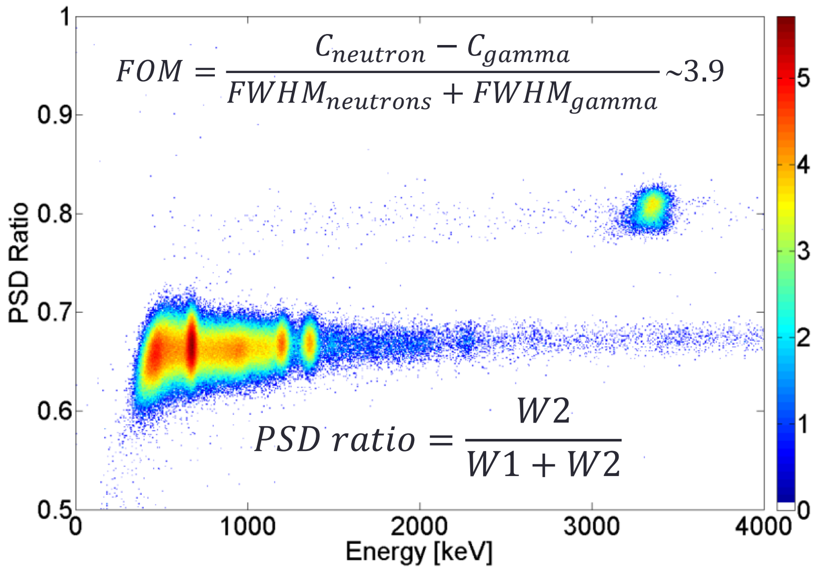
The CLYC scintillator ($Cs_2LiYCl_6:Ce^{3+}$)

The elpasolite crystals (CLYC, CLLC, CLLB, TLYC and TLLB) were developed approximately 10 years ago. CLYC:Ce (Cs_2LiYCl_6:Ce) belongs to this class of scintillators.

- ✓ 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% and time resolution of 1.5 ns.
- ✓ Excellent performances in terms of gamma and neutron detection.





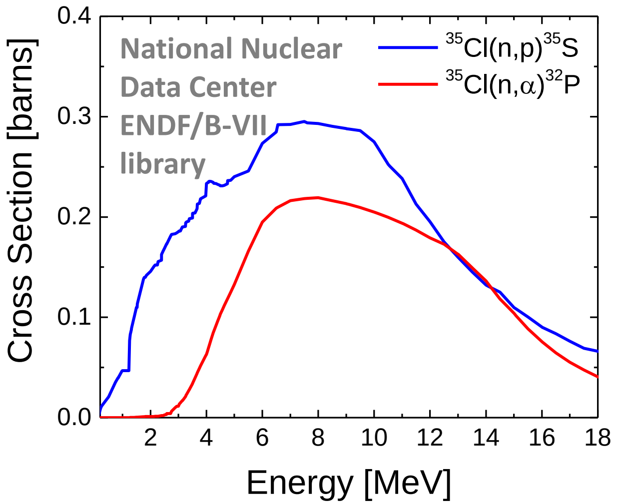


Neutron detection

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 fast 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]
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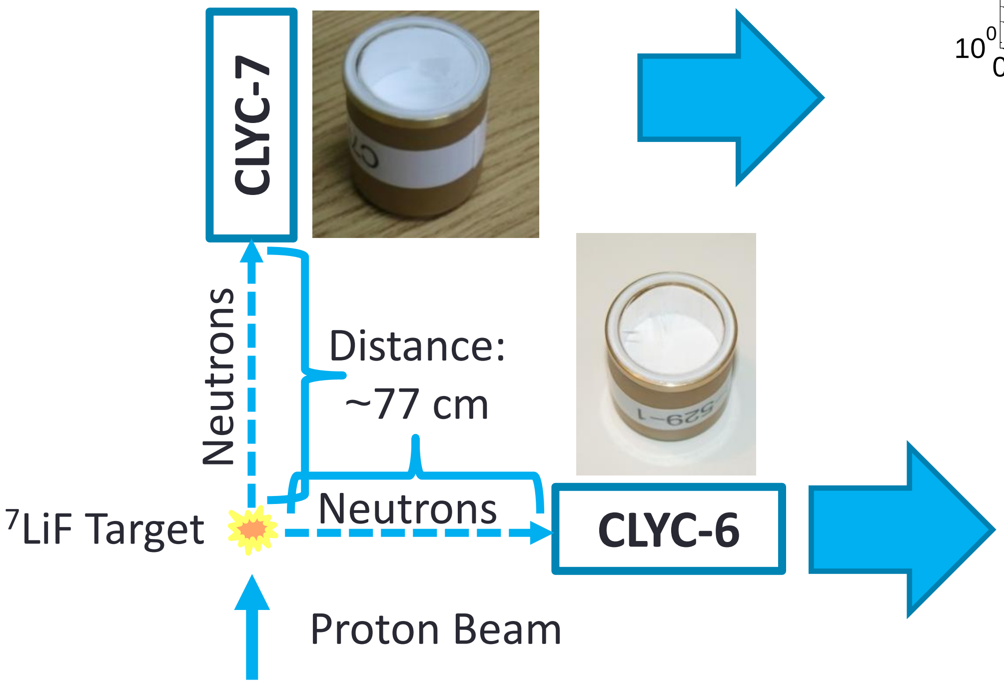

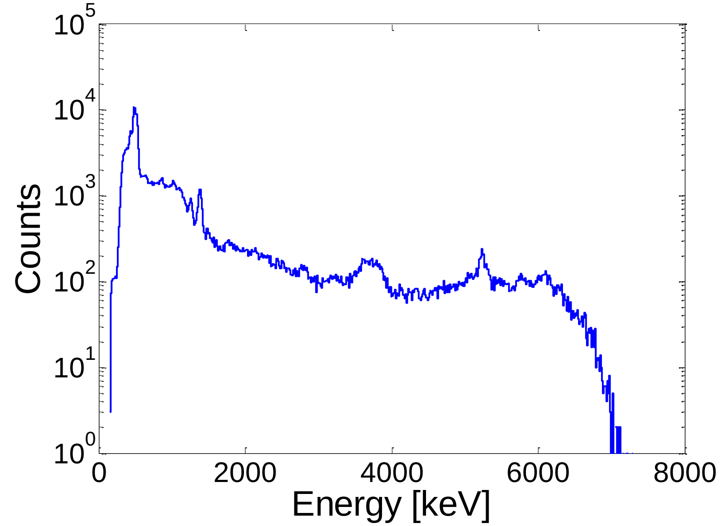

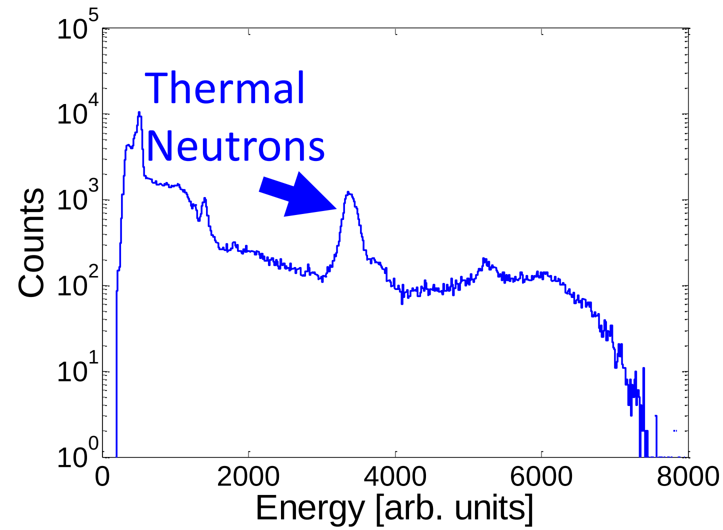

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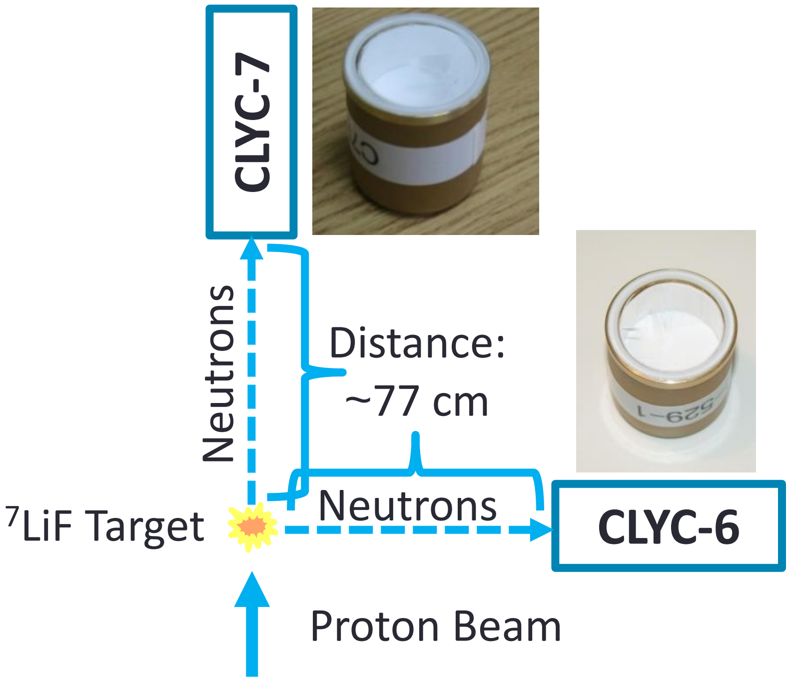
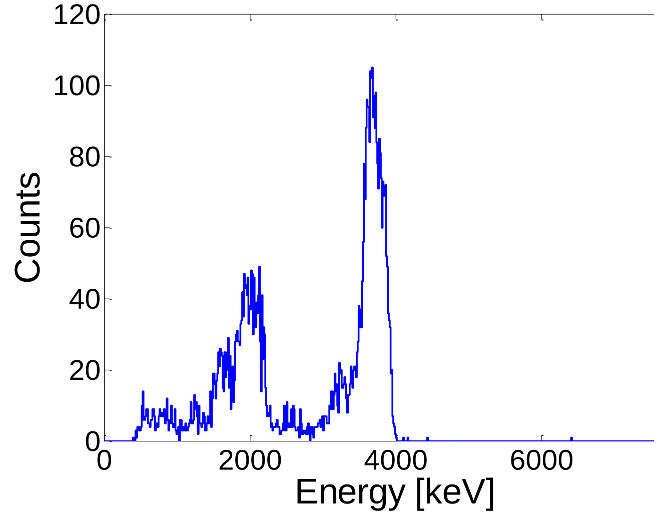
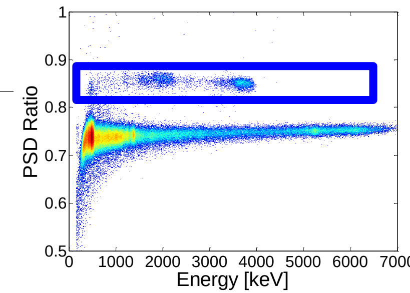
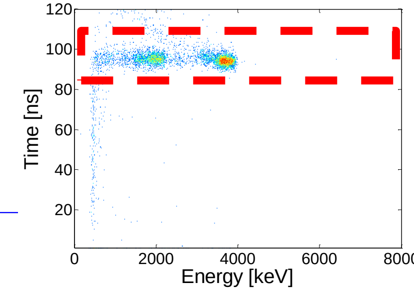
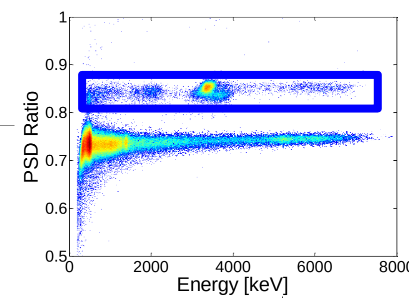


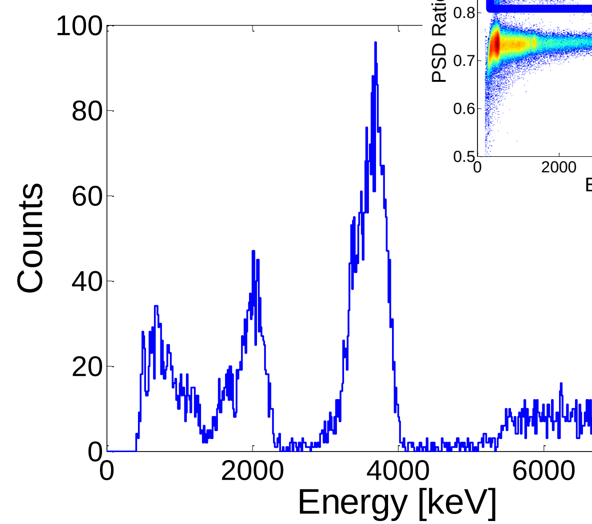
A. Giaz et al., NIM A 825, (2016), 51

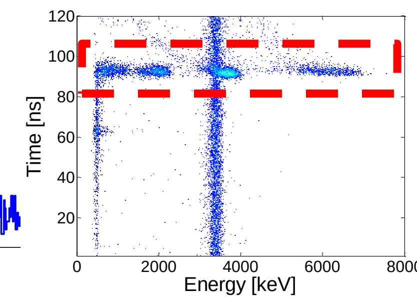










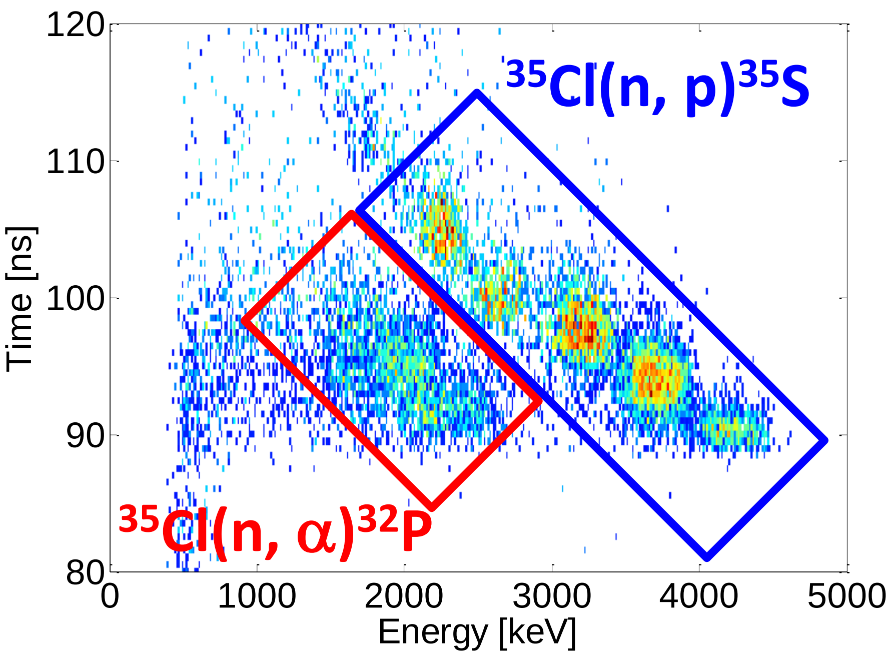


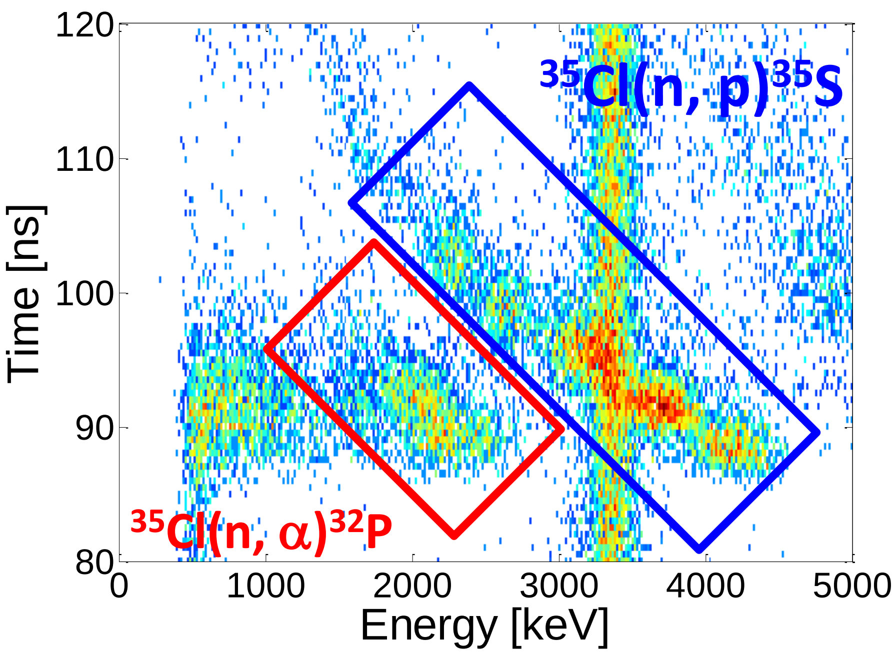
Continuous neutron spectra

To simulate a continuous neutron spectra the time vs energy matrices (gated on PSD) of the different measured energies were summed.

The pictures show that is possible to separate the contribution of the two different reactions.

The red region includes both the contribution of $^{35}Cl(n,\alpha)^{32}P$ reaction and both $^{35}Cl(n,p)^{35}S^*$ reaction (1st excited state energy = 1572 keV)





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

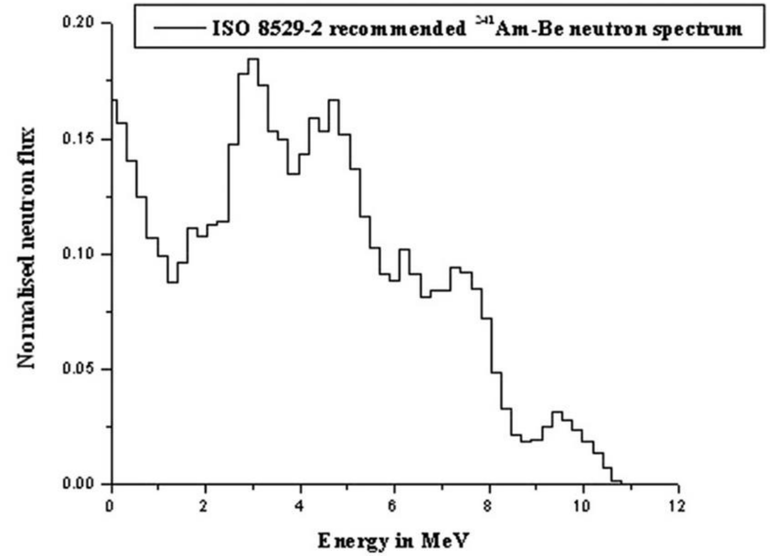
$^{241}Am/^{9}Be$ Source

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

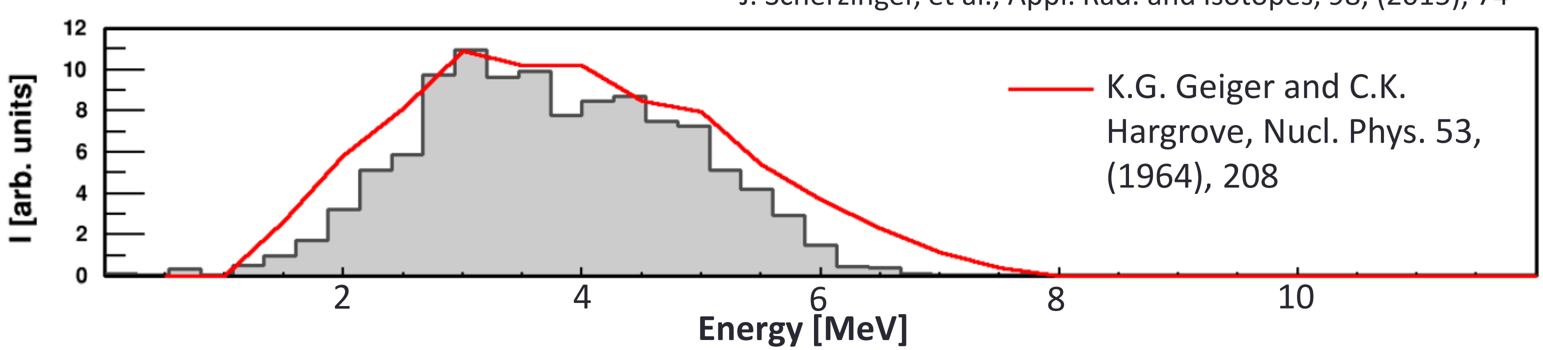


^{12}C can be in different states:

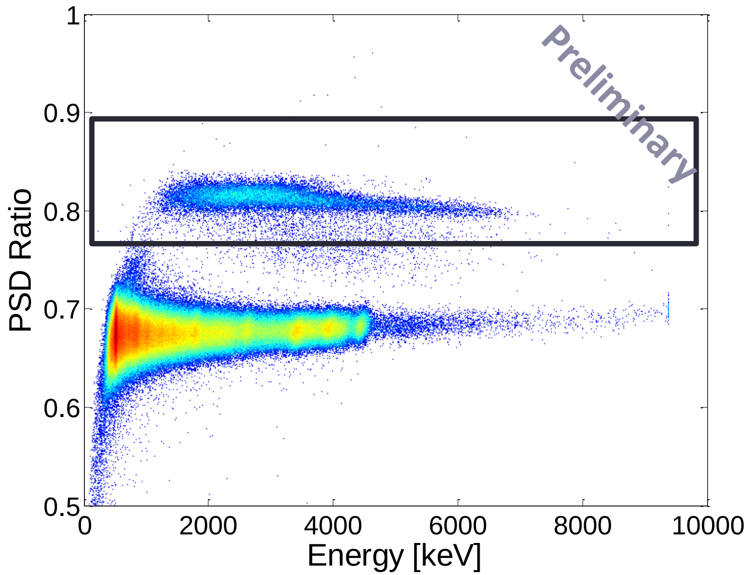
- ✓ Ground state : Q = 5.7 MeV
- ✓ **1st excited state: Q = 1.3 MeV, E_γ = 4.439 MeV**
- ✓ 2nd excited state: E_{th} = 2.8 MeV E_γ = 7.654 MeV
- ✓ 3rd excited state: E_{th} = 5.7 MeV E_γ = 9.641 MeV

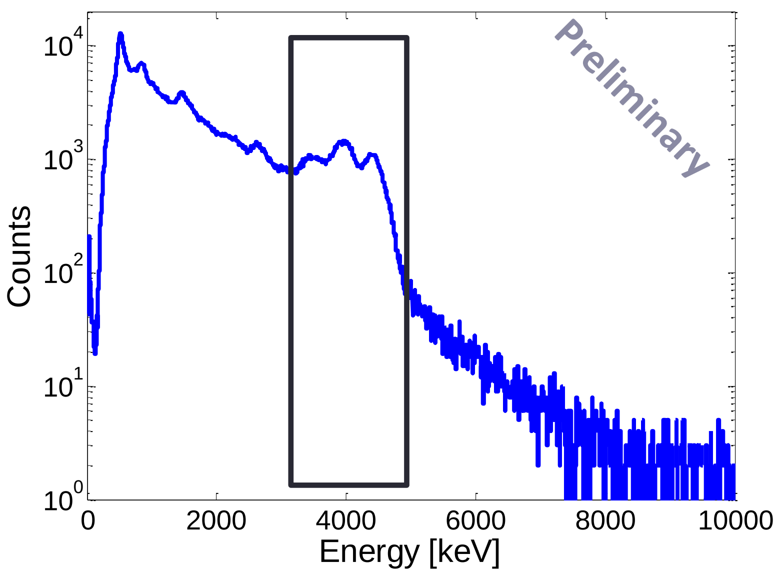
Neutron spectra measured in coincidence with a 4.439 MeV γ ray using the TOF technique.

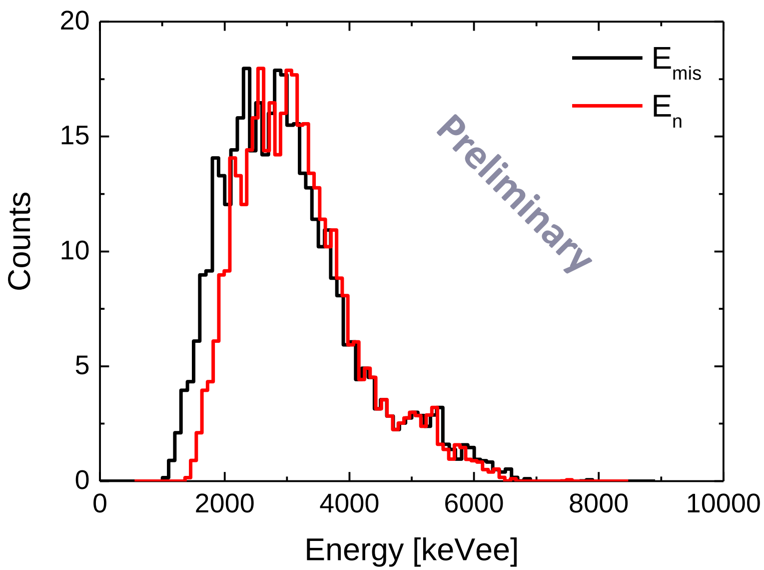
J. Scherzinger, et al., Appl. Rad. and Isotopes, 98, (2015), 74



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.

Summary

- $LaBr_3$:Ce
  - ✓ Most used, large volume detector available (3.5'' x 8''), fast scintillator, good energy and time resolution, good efficiency
  - X Huge internal activity
- SrI_2:Eu
  - ✓ Large volume detector available (2'' x 2''), good energy resolution
  - X Self-absorption → better to have small crystals, slow scintillator → no high rate experiment
- CeBr
  - ✓ Similar to LaBr3:Ce, fast scintillator, good energy resolution and time resolution, no internal activity
  - X Energy resolution slightly worse than $LaBr_3$:Ce
- GYGAG:Ce
  - ✓ Ceramic scintillator, possibility to built it in every shape and dimension, good energy resolution
  - X Samples not yet available
- CLYC:Ce
  - ✓ Large volume detector available (3'' x 3''), good energy and time resolution, possibility to discriminate and measure gamma rays and neutrons
  - X Low density and low light yield, two component of signals (long tails)

Thank you for the attention!

Slide di back up

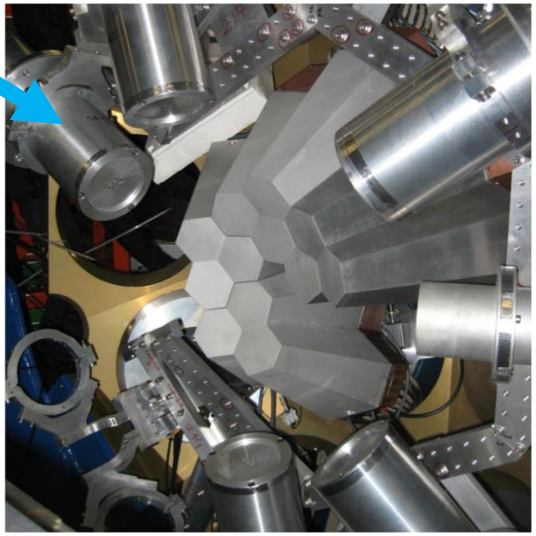
The $LaBr_3:Ce$ scintillator

- Energy resolution of 2.7% at 662 keV
- Fast detector (time resolution ~ 300 ps)
- Good efficiency $\rho = 5.1\ g/cm^3$
- Good linearity at low energy
- Large volume crystals (3.5'' x 8'') available
- Internal activity

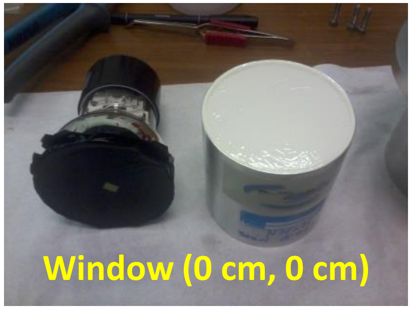
Characterization work already done → Arrays of $LaBr_3:Ce$

Example of arrays with $LaBr_3:Ce$:

- HECTOR+
- OSCAR
- PARIS

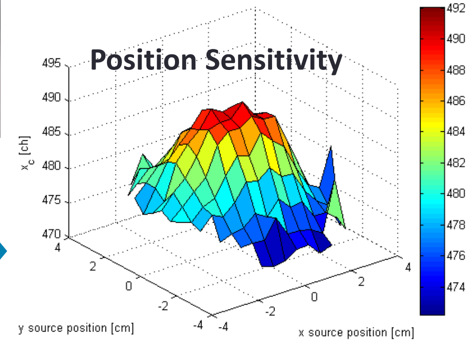


Position sensitivity with $LaBr_3:Ce$



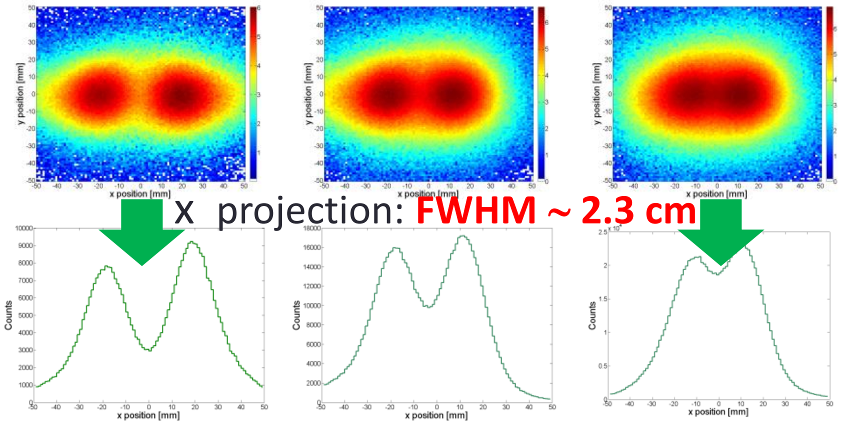
Shield PMT with collimated source

Position of the centroid



Position reconstruction on event by event

Distance 4 cm | Distance 3 cm | Distance 2 cm



X projection: **FWHM ~ 2.3 cm**

A. Giaz et al., NIM A 772, (2015), 103 & N. Blasi et al., NIM A 839 (2016), 23.

Fast Neutron Detection with CLYC

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

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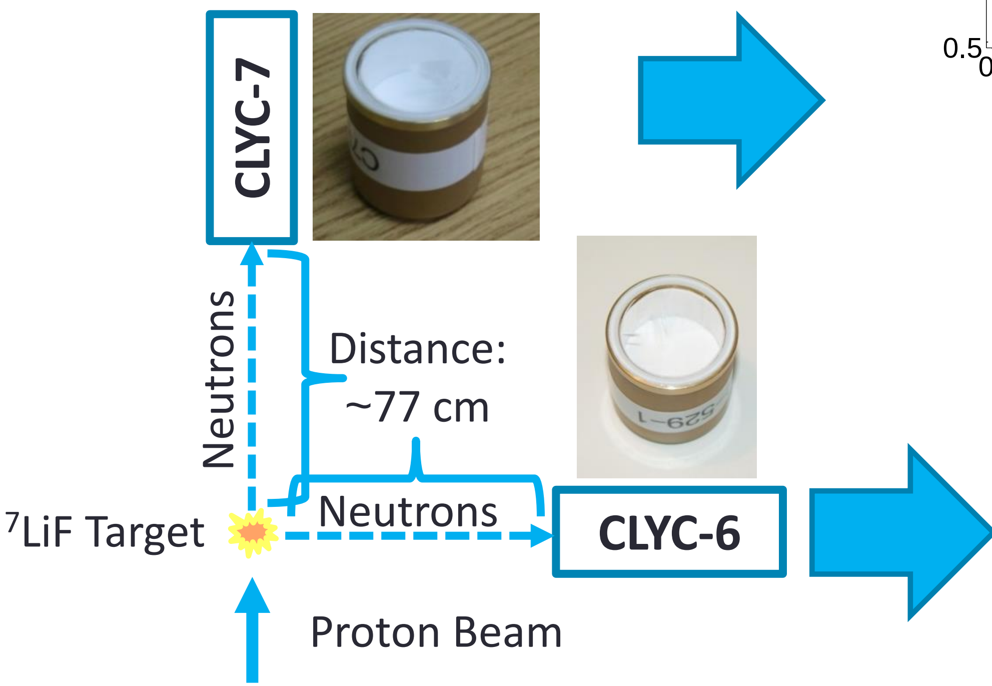

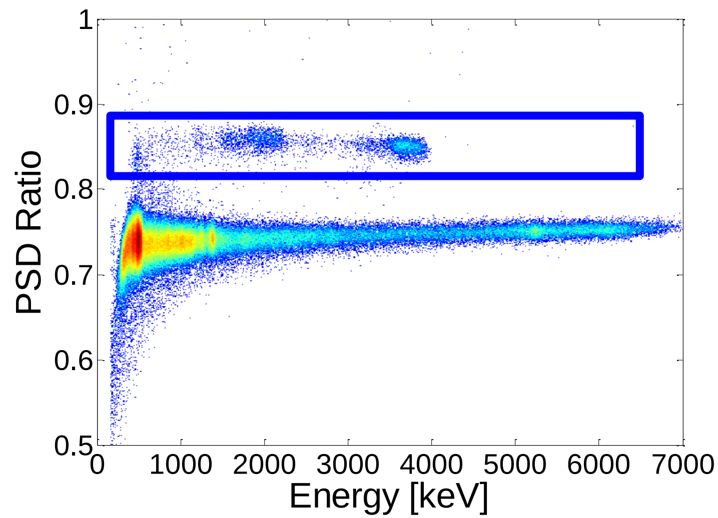

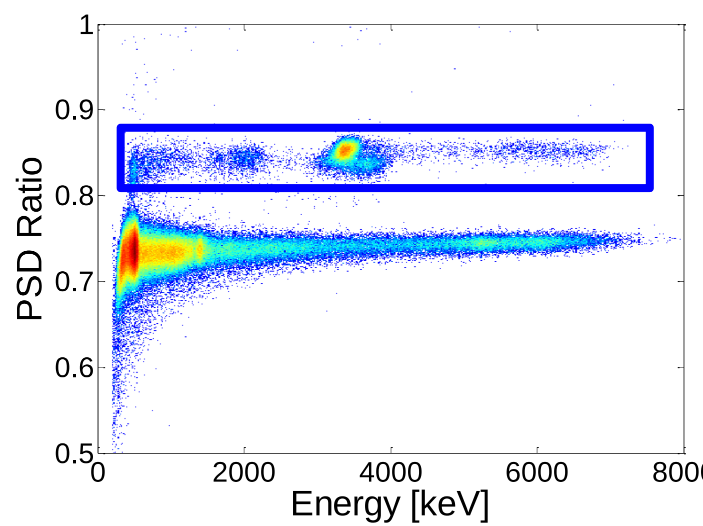

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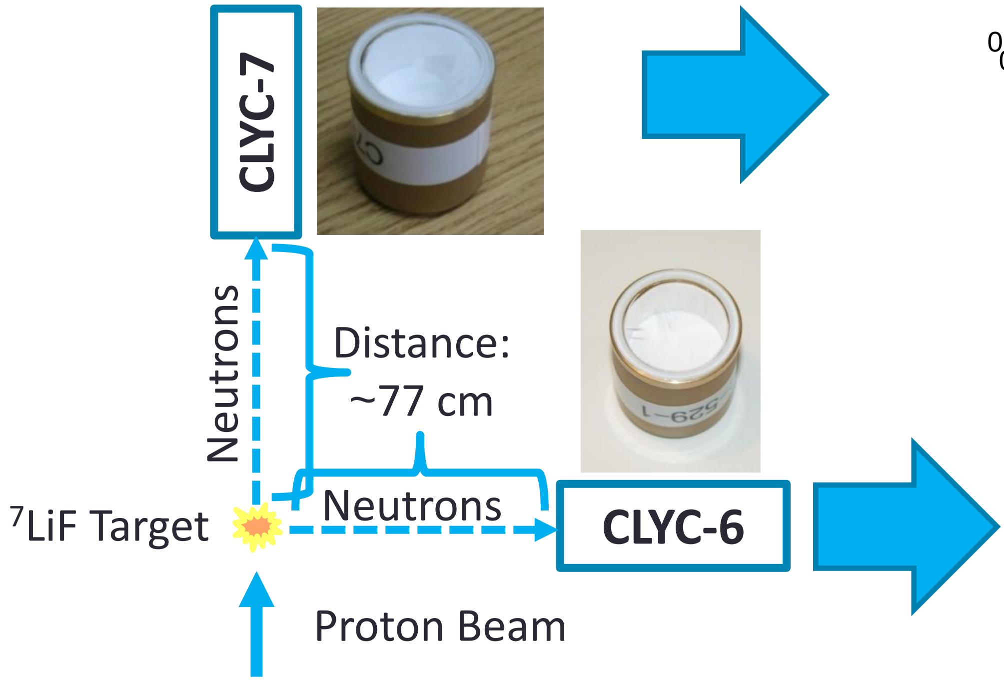

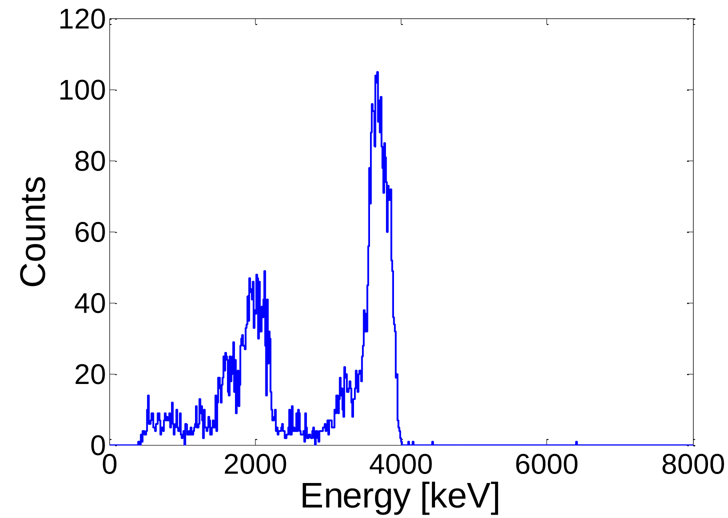

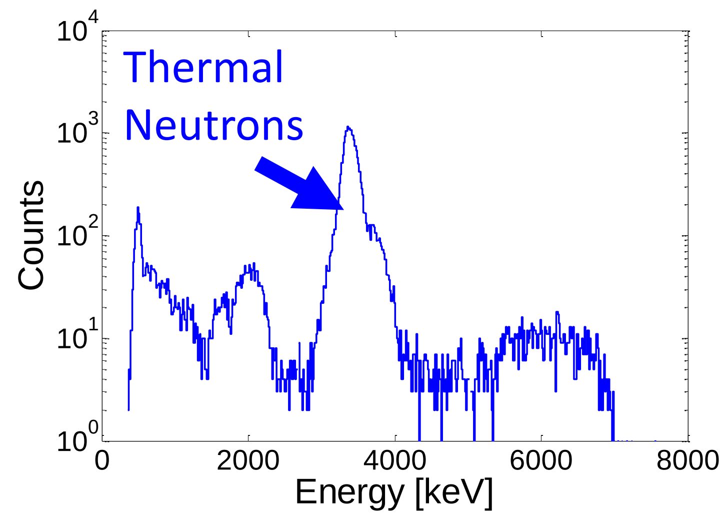

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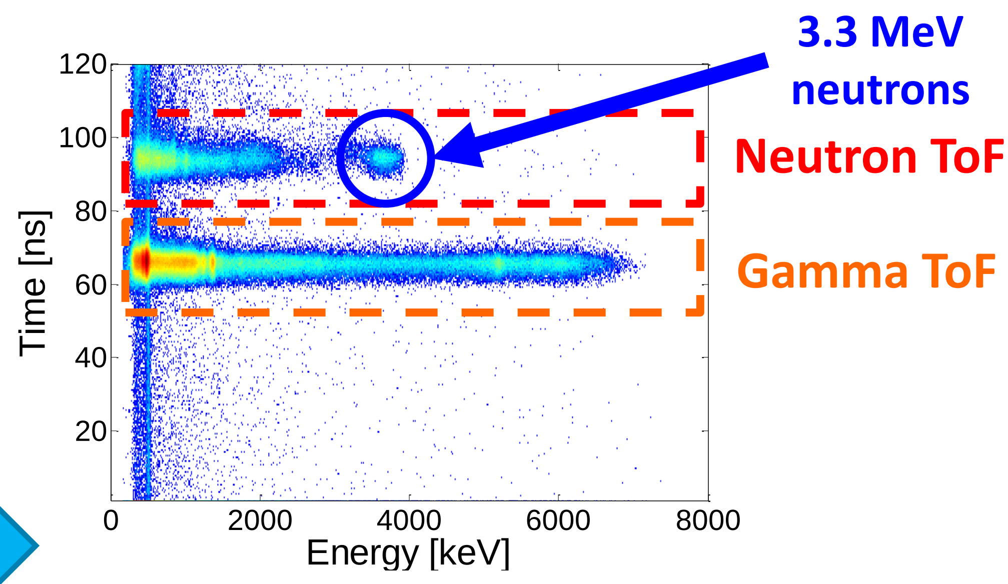

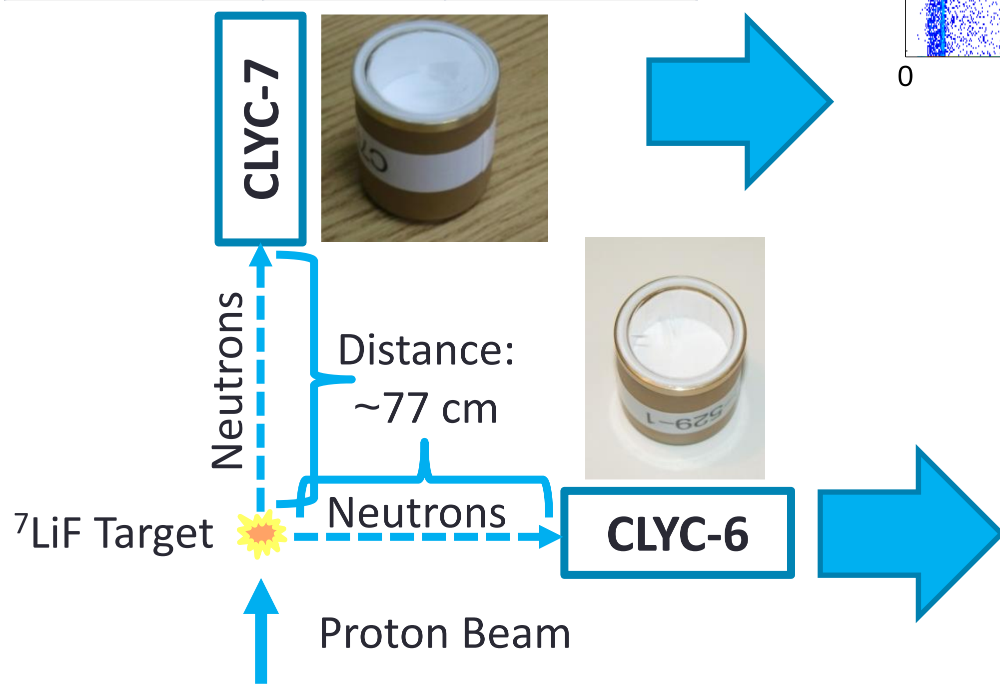

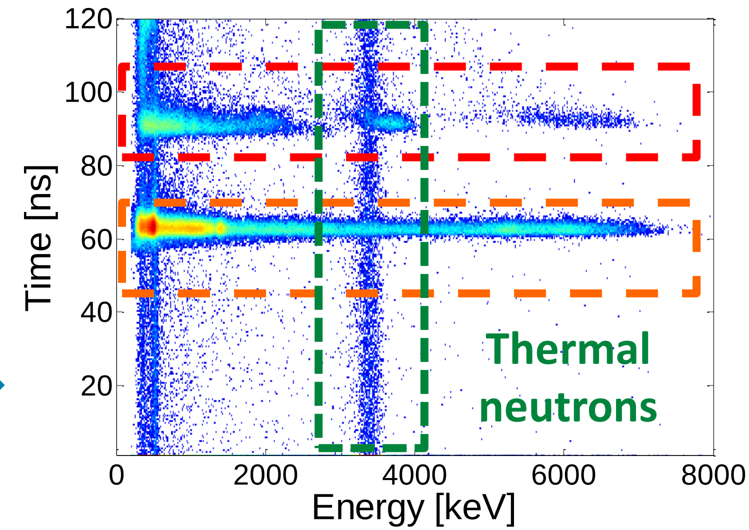

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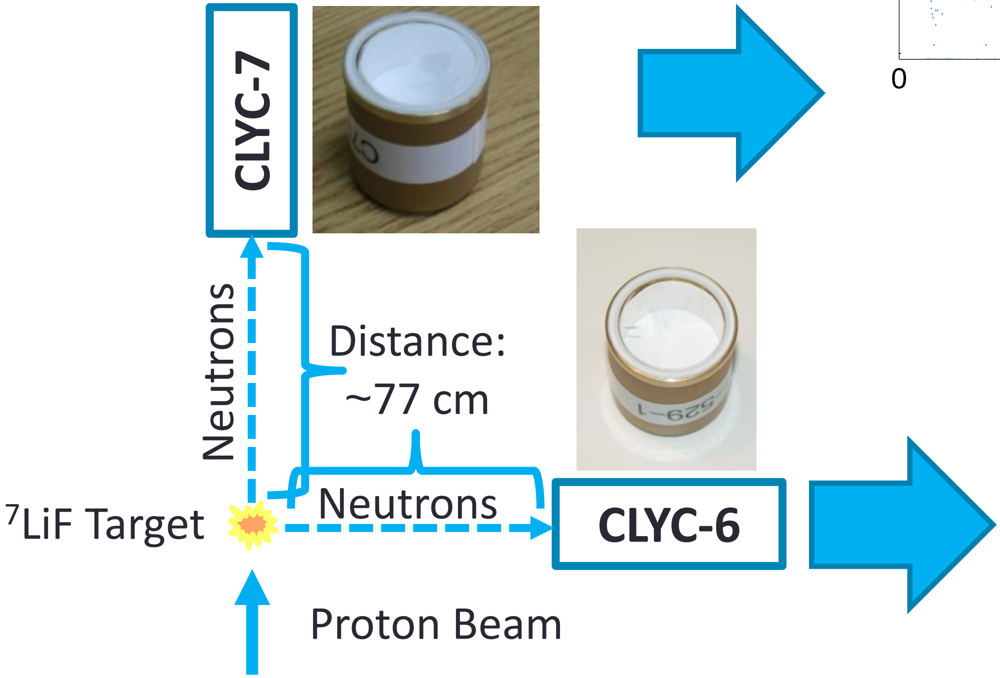
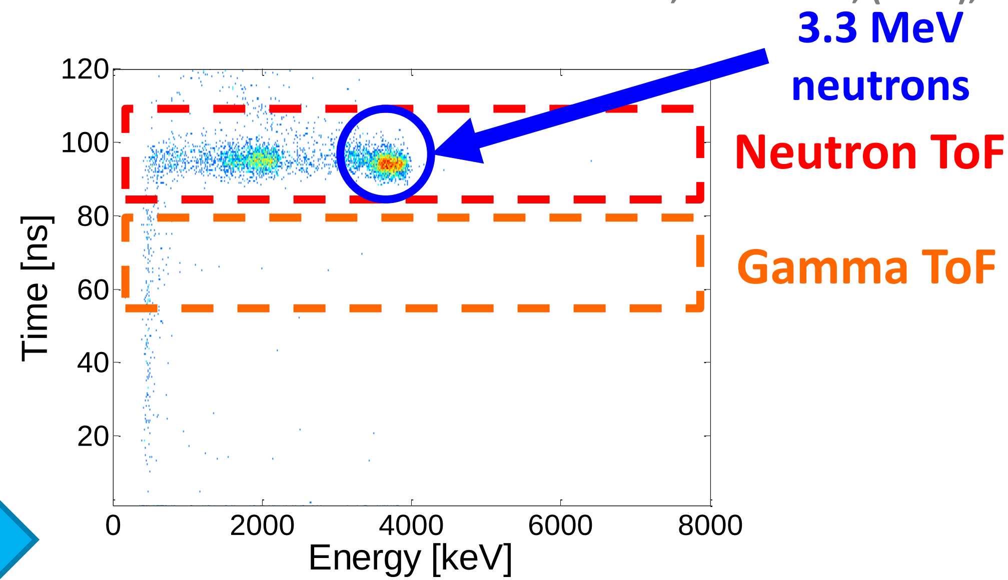
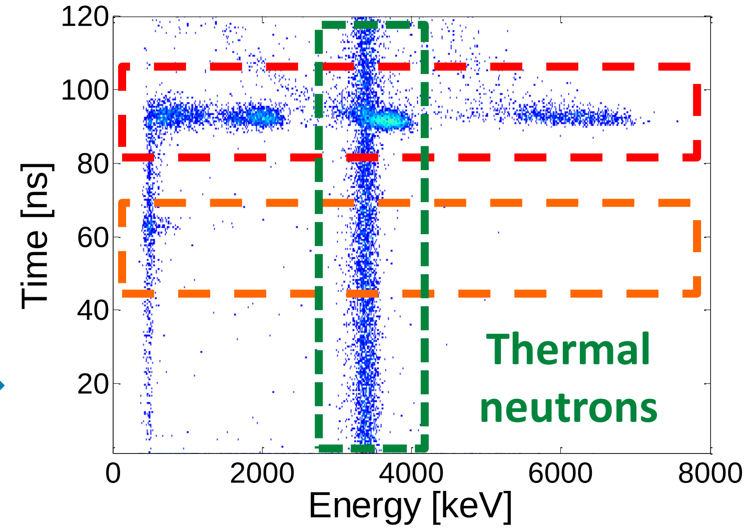
4.5	90°	1.93







CeBr$_3$ – LaBr$_3$:Ce – NaI:Tl (3'' x 3'')