Stilbene-based neutron TOF-spectrometer

Anh Mai

ACCULINNA group, FLNR, JINR

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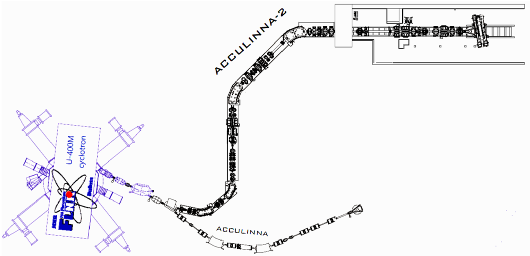
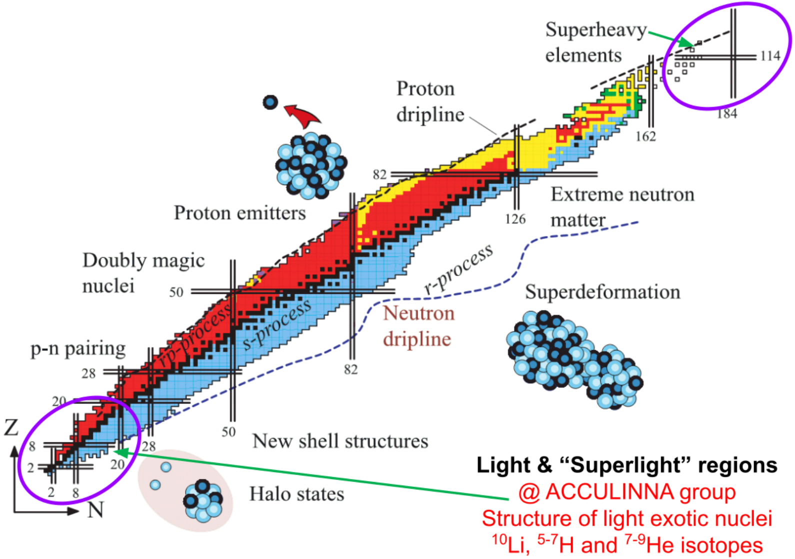
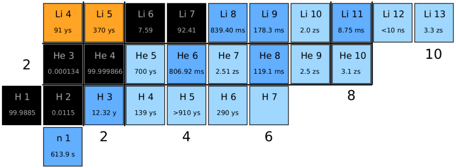
for fundamental and applied physics
25 February 2025, Catania



Main areas of interest at FLNR at nuclide chart



Motivation



Measurement of correlations,
⇒ detection of **neutrons** in coincidences with charged reaction products is needed.

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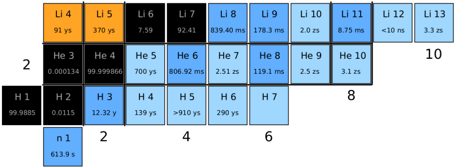

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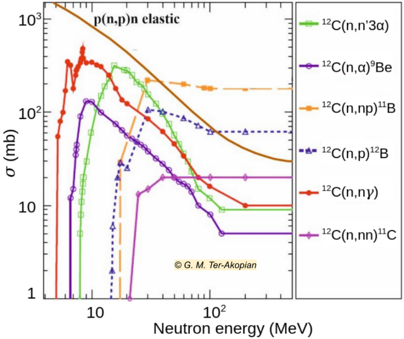


Neutron-matter interaction cross-sections in accordance with different neutron energies

Stilbene crystals:

- high luminescence efficiency
- fast response time
- crystalline and solid
  $\rightarrow$ high durability, non-flammable
- greatly sensitive to neutrons
  $\rightarrow$ well-suited in our range
- excellent $n - \gamma$ **discrimination**

$\Rightarrow$ Stilbene was implemented @ ACCULINNA-2.

Stilbene based neutron spectrometer

The neutron spectrometer assembly @ ACCULINNA-2

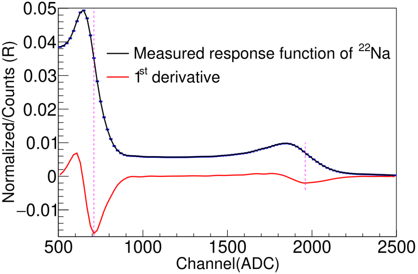
- unsettled incident neutron energy - scintillator response correlation $\rightarrow$ TOF method is applied,
- undesirable γ-background $\rightarrow \mathrm{n} - \gamma$ separation performance,
- light output is non-linear and different for diverse particles,
- neutron registration efficiency

$\Rightarrow$ The characterization of neutron TOF spectrometer, where amplitude and time resolution, $\mathrm{n} - \gamma$ discrimination, light output response and detection efficiency were investigated.

1. Gamma measurements

Amplitude calibration

An example of Compton edge (CE)
from stilbene scintillator using $^{22}\mathrm{Na}$ source



$$E_{CE} = E_\gamma\left(1 - \frac{1}{1+\frac{2E_\gamma}{m_e c^2}}\right)$$

$\Rightarrow$ 1st derivative of measured response combined with GEANT4 simulation for precise CE determination

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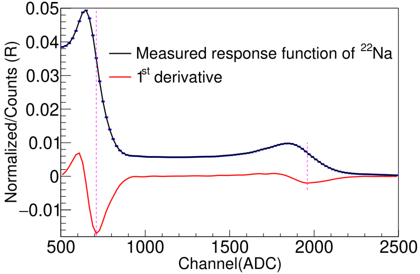

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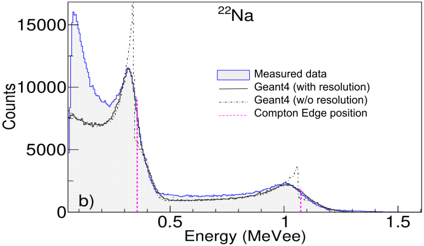
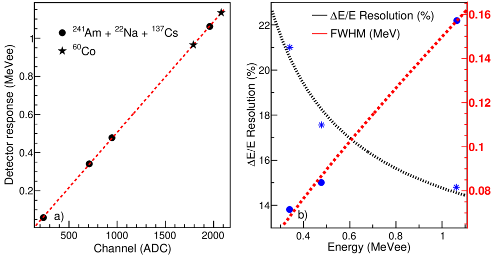
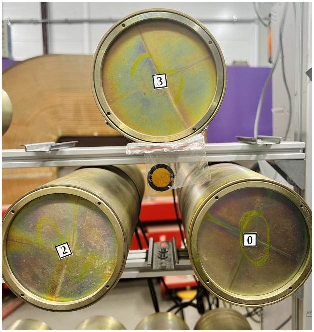




Time resolution

$\gamma - \gamma$ coincidence measurement



$$\sigma_1^2 = \frac{1}{2}(\sigma_{12}^2 + \sigma_{13}^2 - \sigma_{23}^2)$$

$$\sigma_2^2 = \frac{1}{2}(\sigma_{12}^2 - \sigma_{13}^2 + \sigma_{23}^2)$$

$$\sigma_3^2 = \frac{1}{2}(-\sigma_{12}^2 + \sigma_{13}^2 + \sigma_{23}^2)$$

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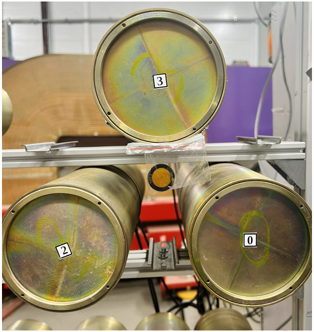

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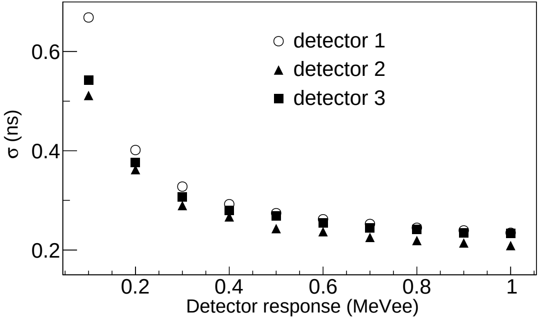
Time resolution relies upon the amplitude signal



→ different range of data derives from disparate signal sizes,

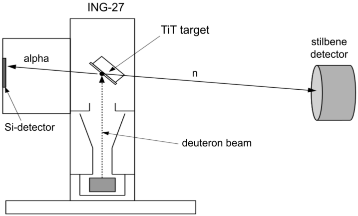
→ low-energy events are associated with the registration of rescattered γ-quanta.

2. Neutron measurement

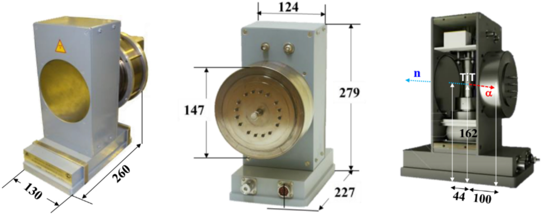
ING-27 DT neutron generator

The experimental schematic of

DT-reaction



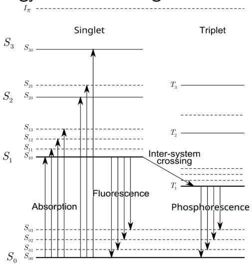
ING-27 dimensions (mm) in experiment



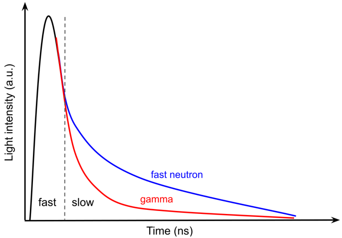
- a deuteron-beam @ 100 keV bombards a thin titanium-tritium TiT target by means of $d + t \to \alpha + n$ fusion reaction to produce 14-MeV neutrons,
- the neutron generator has an intensity up to 10^8 n/s in 4π,
- α-particles were registered by a 64-pixel (8 $\times$ 8 strip) DSSD @ 100 mm from the target,
- stilbene was placed at a distance of 15 cm for neutron detection.

Neutron-gamma discrimination

The scintillation process by means of π-electronic energy levels of an organic molecule



Timing signals for gamma and neutron in the scintillator



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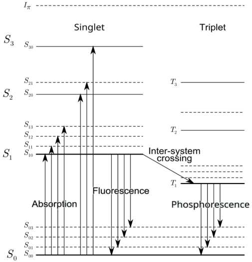

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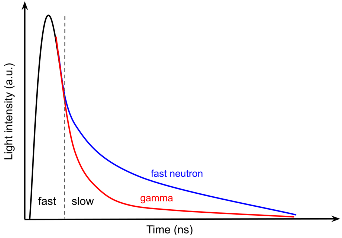
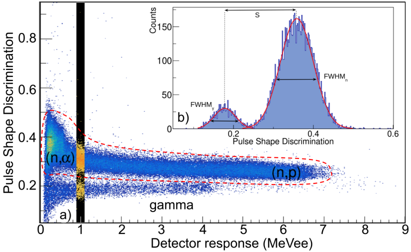
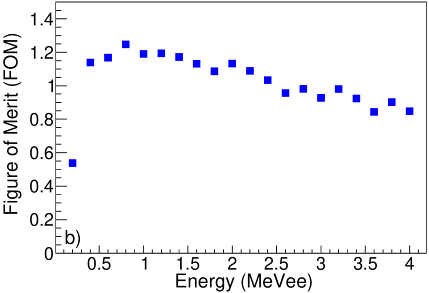


Illustration of neutron-gamma separation by Pulse Shape Analysis from the 14-MeV neutron generator.

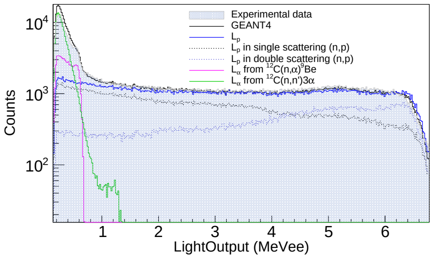




Light output response in organic scintillator

Neutron interaction with stilbene scintillator

leads to a large number of different processes



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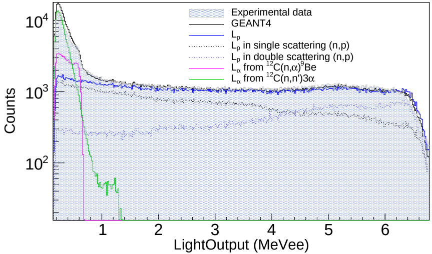
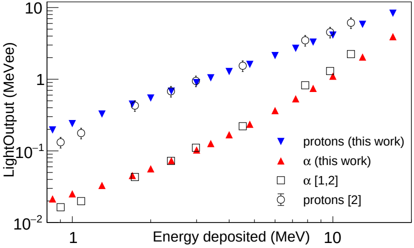


Light output response of stilbene scintillator to protons and alpha particles



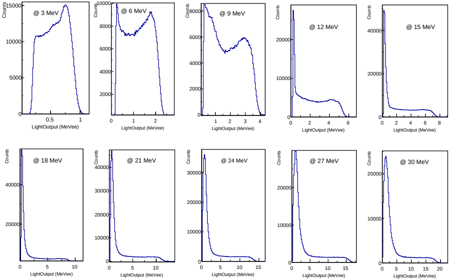
→ Chiefly, protons and α-particles produce the main light in the stilbene detector,
→ The response of proton + α-particles was simulated and reconstructed with measured data, and compared with other works,
→ Knowing the proton-response is the key to determine the incoming neutron energy.

[1] V. Verbinski et al., Nucl. Instrum. Methods 65 (1), 8–25 (1968).
[2] R.L. Craun and D.L. Smith, Nucl. Instrum. Methods 80, 239–244 (1970).

Neutron registration efficiency

The calculated response in the stilbene detector

to various incident neutron energies



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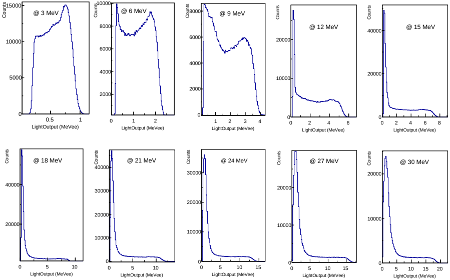
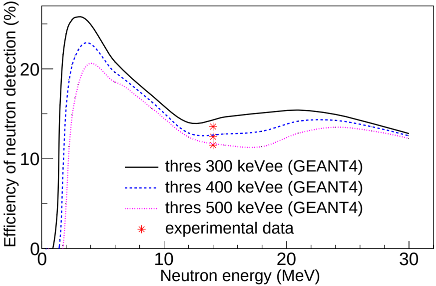
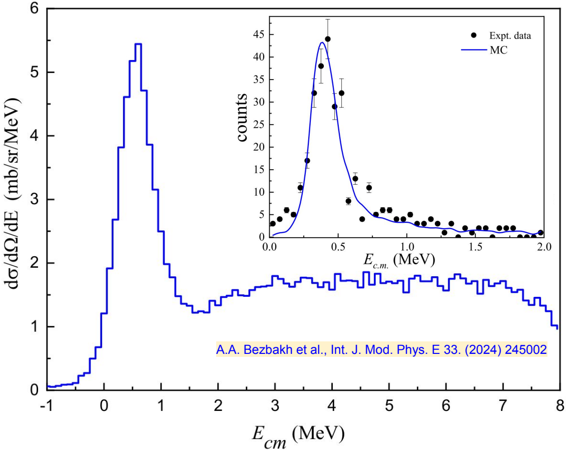


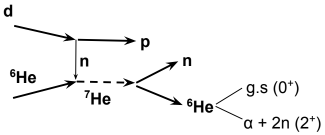
The measured and calculated neutron efficiency in the energy range of 3-30 MeV



→ Measured data at 14 MeV was in a good agreement with GEANT4 simulation, thus neutron registration can be estimated in other energy ranges from 3-30 MeV.

Applications @ ACCULINNA-2





p-^{6}He-n final state coincidences
full kinematics reconstruction

⇩

Improved instrumental resolution
~140 keV (FWHM)
that is comparable to the resonance intrinsic width @ ^{7}He g.s (1p, $J^{\pi} = 3/2^{-}$)

→ Latest results of ^{7}He population have demonstrated the contribution of neutron detection that significantly improved the overall experimental resolution in full kinematical measurements of charged reaction products in coincidence with neutrons.

Conclusions

- The performance of stilbene based modular neutron spectrometer @ ACCULINNA-2 was characterized in this work: amplitude and time resolution, neutron/gamma separation performance and detection efficiency in the detector,
- With such characteristics, our stilbene scintillators are fast enough for neutron energy measurements by using ToF technique and become advantageous for our study of resonance states of various neutron-rich nuclei like $^{5-7}\mathrm{H}, ^{7,9}\mathrm{He}$ and $^{10}\mathrm{Li}$, ...

Much appreciated for your attention.!