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Letter of Intent to the ISOLDE and Neutron Time-of-Flight Committee

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Response of stilbene scintillator to (n,n) and (n,n') reaction channel in TOF experiments

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Abstract: We propose to study the performances of an array of 8 stilbene scintillators in a n+^{12}C experiment at EAR1, with the aim of proving that the setup is suitable for (n,n) and (n,n') measurements. This investigation is a follow up of a previous Letter of Intent (LoI) concerning the experimental study of stilbene detectors performed at EAR2. We look forward to assess, for the first time at n_TOF, the possibility to measure (n,n) and (n,n') reaction channels on the basis of the results achieved at EAR2, thus potentially extending the range of cross section investigation at n_TOF in the framework of the challenges and goals up to the end of Run 3, supporting the n_TOF long term plan.

Requested protons: 6×10^{17} protons on target
Experimental Area: EAR1

1 Introduction

In a previous Letter of Intent (LoI) [1], the n_TOF Collaboration has proposed to study the performances of trans-stilbene organic scintillators (stilbene), and the deuterated version (stilbene-d_{12}) [2], as a potential replacement of conventional C_6D_6 liquid scintillator (i.e. for (n,γ) measurements). The test was performed at EAR2, and several stilbene detectors were studied. Among them, four units of cylindrical stilbene scintillators, 25.4 mm in diameter, 25.4 mm long (1 inch x 1 inch) produced by Inrad Optics US (Scintinel) were used. Fig. 1 shows the setup of the test of LoI [1]. The 4 modules described above and of interest for this LoI are the ones housed in carbon fiber cylinders and positioned at 90° and 135° with respect to the neutron beam. They are coupled to Hamamatsu R7378A photomultipliers (synthetic silica window), powered by Sens-Tech PS1807 ultra compact active voltage dividers with DC-DC converters.

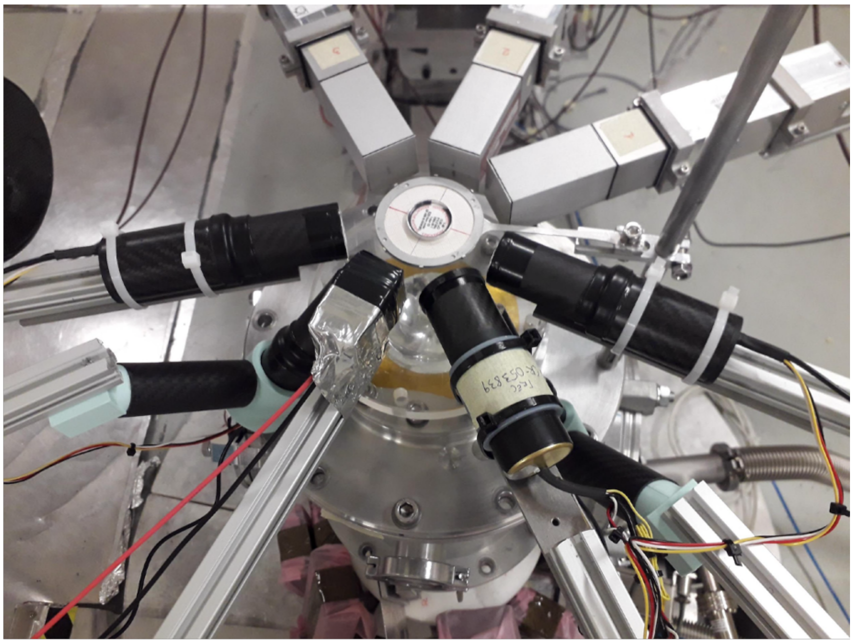

Figure 1: Configuration for the study of stilbene scintillators proposed in the previous Letter of Intent in Ref. [1]. The detectors of interest for the present LoI are the ones housed in carbon fiber cylinders, and positioned at 90° and 135° with respect to the beam line.

That test was focusing at studying the response of the modules in order to provide the full technical specifications with respect the EAR2 neutron beam (n-TOF dynamics and γ-flash), namely: the response to the γ-flash, the gain stability as a function of the counting rate conditions, the neutron-γ discrimination capability, etc. The overall detector performances were assessed by measuring n+^{197}Au, n+^{12}C, n+^{56}Fe samples and empty-sample, providing also precise calibrations by standard γ-ray sources and Americium–Berillium (Am–Be) mixed neutron γ source.
A good n-γ discrimination was obtained with the Am–Be source by using the well-established pulse shape discrimination (PSD) technique (τ_1 = 4.3 ns and τ_2 = 30 ns

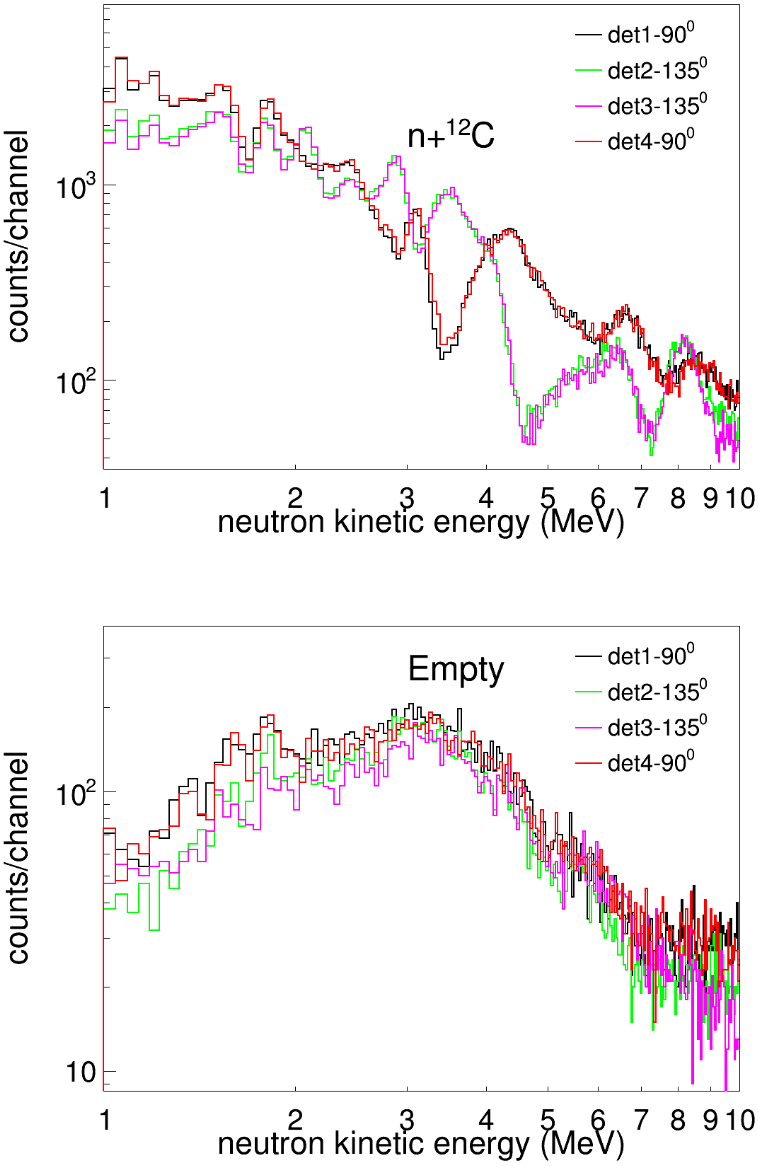

Figure 2: Detector counts as a function of the neutron kinetic energy for n+^{12}C (upper panel) and empty frame (lower panel) at two different laboratory angles, 90° and 135°, with respect to the neutron beam direction. A 400 keV threshold to the deposited energy and PSD condition for neutron selection were applied. Beam high intensity pulses were used. According to the detector angular position, different structures can be observed at around 3 MeV when measuring with the ^{12}C target. It was verified that the background (empty frame) was structurless.

being the decay times of scintillation light emission in stilbene). The discrimination threshold on deposited energy was estimated to be slightly greater than 200 keV for γ rays. When operating with the neutron beam, several experimental complications arise.

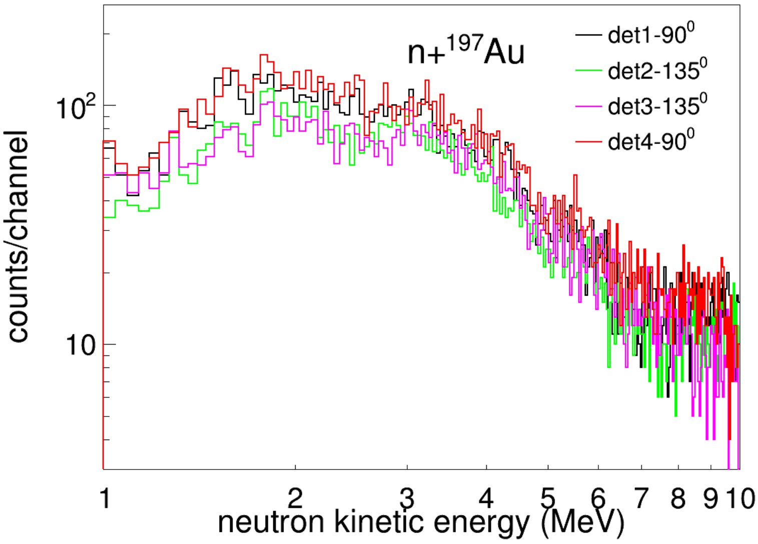

Figure 3: Detector counts as a function of the neutron kinetic energy for d n+^{197}Au at two different angles. Structures present at around 3 MeV during the n+^{12}C measurement were not observed in case of n+^{197}Au. Same selection conditions applied in Fig. 2 are used.

In fact, only neutrons with energy approximately greater than a few hundreds of keV can produce a signal in the detector. Therefore, the relevant time-of-flight interval for detecting scattered neutrons is between 200 and 2000 ns after the γ–flash. In this region the recovery of the detector after the γ-flash takes place, and the detector baseline oscillates. In addition, the compressed TOF dynamic range in EAR2 results in a large number of events in this reduced TOF region. As a result, the n/γ discrimination capability of the detector becomes exceedingly complicated as the neutron energy increases. Moreover, a large part of the signals must be rejected because of signal pileup, which hinders a fine control of the PSD technique. Nevertheless, from the analysis of the data collected in the test, promising results were obtained, see Fig. 2 and Fig. 3 where TOF was converted to neutron kinetic energy.
In fact, by selecting events attributable to neutron, i.e. elastically scattered by the sample, we observe different structures in the TOF spectrum of the n+^{12}C measurement at different angles (Fig. 2), fully consistent between detectors and with the expected structures in the cross section Fig. 4. While structures were not observed in the same energy range for n+^{197}Au reaction (Fig. 2).

2 Working plan

Focusing to the objective of implementing a setup to perform (n,n) and (n,n') measurements LoI [3], carbon represents an excellent sample for the proposed study. The ^{12}C(n,n) cross section features narrow and broad resonances between 2 and 4 MeV (see Fig. 4),

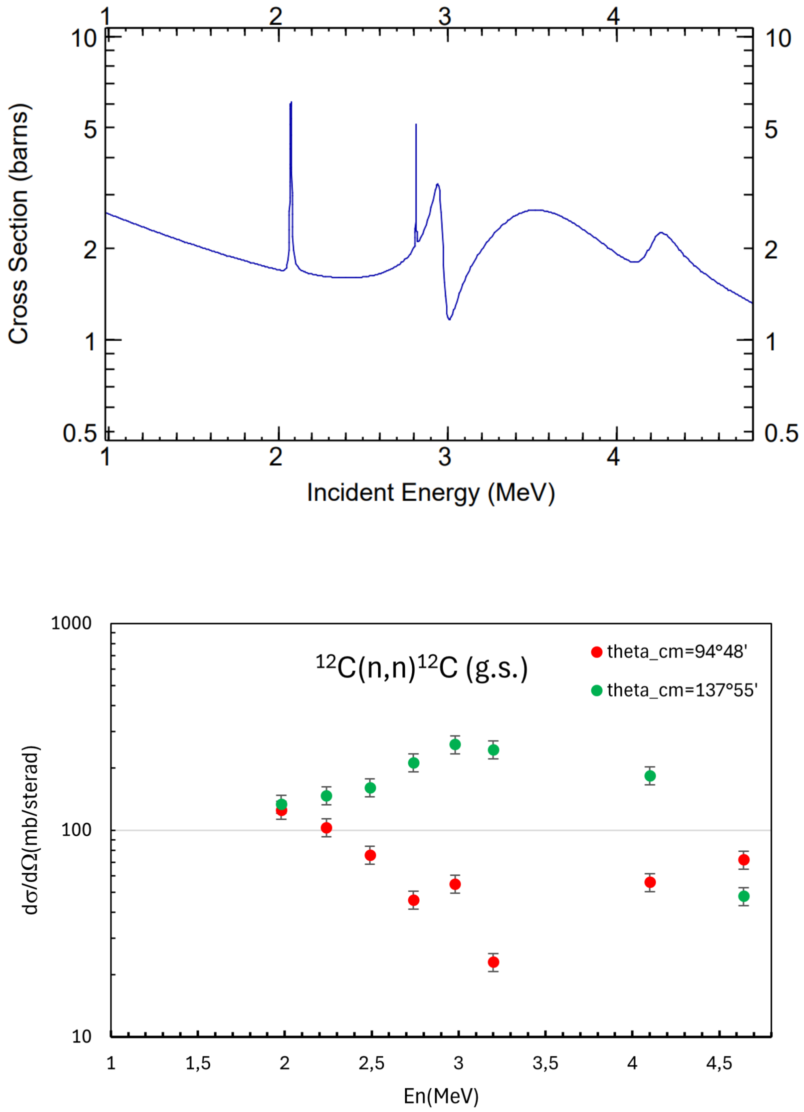

Figure 4: Total cross section for n+^{12}C elastic scattering from [6] (upper panel). Differential cross section for n+^{12}C elastic scattering measured at two different center of mass angles by [7] (bottom panel).

while the ^{12}C(n,n') reaction channel opens at 4.44 MeV. Moreover the ^{12}C(n,n) cross section exhibit angular distribution (see Fig. 5) that can be investigated by this study. This would represent the first experimental evidence establishing the possibility for n_TOF to measure (n,n) and (n,n') reaction channels in the 1-20 MeV energy range, enforcing the capability of the n_TOF facility to approach new physical scenarios, leading in the medium term to perform n-γ and γ-γ correlation measurements by a setup providing large solid angle coverage.
As mentioned above, the previous LoI [1] was focused on the (n,γ) reaction channel, and therefore the experimental setup was optimized for relatively small neutron kinetic

energy. On the other hand, the region of interest for (n,n) and (n,n') reaction channel can be found at higher energy. Therefore, we propose to perform a dedicated measurement test at EAR1, where the 10-time larger dynamic TOF range results in a TOF region of interest between 2 and 20 μs. The advantages of running the test at EAR1 are notable: reduced effect of the γ-flash and reduced pile-up probability, as well as a better energy resolution (with respect to EAR2).

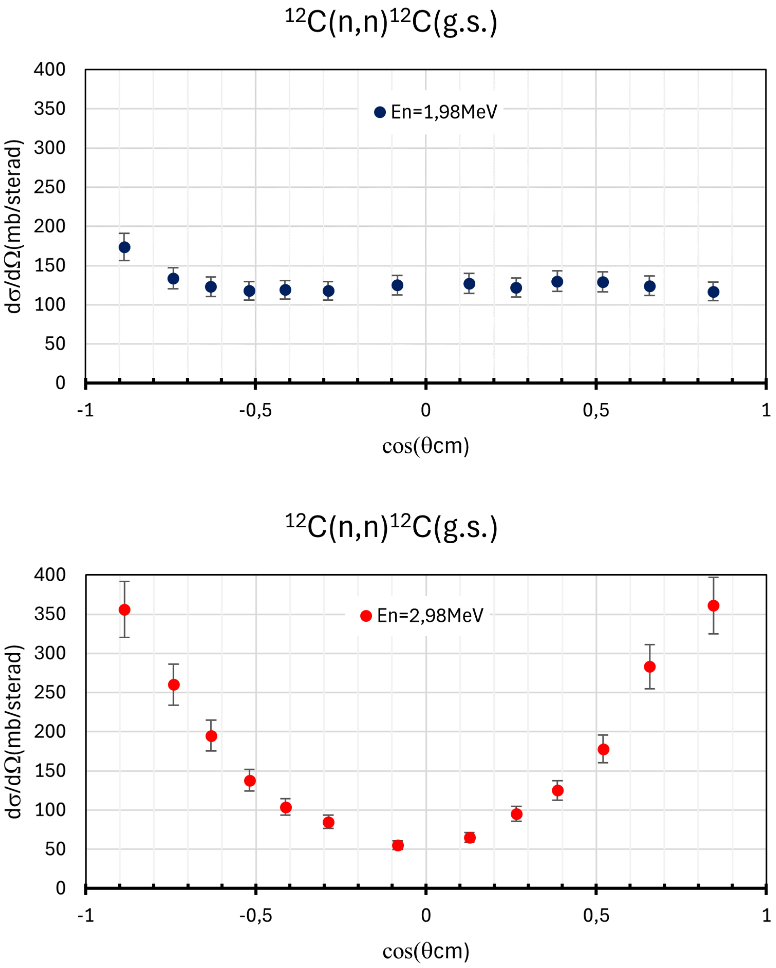

Figure 5: Angular distributions for n+^{12}C elastic scattering measured by [7] at two different neutron energies.

In addition to the four stilbene scintillators mentioned above, we will provide an additional set of 4 modules (INFN-CT) with the same geometry and readout system, embedding stilbene scintillator by PROTEUS-US. Presently, an array of 8 stilbene scintillators is available for the experiment and fully characterized in terms of gamma response and PSD capability. By this array of scintillators positioned at different angles with respect to the beam line we can investigate the possibility to exploit them for: (n,n) reaction channel study (e.g. Ref. [4]) and correlated $n-\gamma$ angular distributions (e.g. Ref. [5]).
We propose to use 5.0×10^{17} protons on target for n+^{12}C and 1.0×10^{17} protons on target

for a measurement by the same detection setup and an empty-sample on the beam to evaluate and subtract the background.
The requested number of protons was calculated on the basis of the n+^{12}C cross sections available in literature and by using a carbon sample of 2×10^{-3} at/b. The corresponding number of (n,n) reactions events in the energy range between 1 and 10 MeV will be $\approx 10^7$. Considering the detection efficiency of the detection setup, the calculated detection rate will allow to clearly disentangle the cross-section structures between 1 and 10 MeV.

Summary of requested protons: 6×10^{17}.

References

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[6] D. A. Brown, *et al.*, ENDF/B-VIII.0: The 8th Major Release of the Nuclear Reaction Data Library with CIELO-project Cross Sections, New Standards and Thermal Scattering Data, Nucl. Data Sheets **148** (2018) 1

[7] F. Demanins, *et al.*, Elastic scattering of fast neutrons by Li-6 and C-12 between 1.98 Mev and 4.64 MeV, INFN Reports / Low Energy Physics Series, **73/2** (1973)

Appendix

DESCRIPTION OF THE PROPOSED EXPERIMENT

Part of the experiment	Design and manufacturing
SIMON	☒ To be used without any modification ☐ To be modified
Stilbene scintillators and detector holders	☐ Standard equipment supplied by a manufacturer ☒ CERN/collaboration responsible for the design and/or manufacturing

HAZARDS GENERATED BY THE EXPERIMENT
Additional hazard from flexible or transported equipment to the CERN site:

Domain	Hazards/Hazardous Activities		Description
Mechanical Safety	Pressure	☐	[pressure] [bar], [volume][l]
	Vacuum	☐	
	Machine tools	☐	
	Mechanical energy (moving parts)	☐	
	Hot/Cold surfaces	☐	
Cryogenic Safety	Cryogenic fluid	☐	[fluid] [m3]
Electrical Safety	Electrical equipment and installations	☐	[voltage] [V], [current] [A]
	High Voltage equipment	☐	[voltage] [V]
Chemical Safety	CMR (carcinogens, mutagens and toxic to reproduction)	☐	[fluid], [quantity]
	Toxic/Irritant	☐	[fluid], [quantity]
	Corrosive	☐	[fluid], [quantity]
	Oxidizing	☐	[fluid], [quantity]
	Flammable/Potentially explosive atmospheres	☐	[fluid], [quantity]
	Dangerous for the environment	☐	[fluid], [quantity]
Non-ionizing radiation Safety	Laser	☐	[laser], [class]
	UV light	☐	
	Magnetic field	☐	[magnetic field] [T]
Workplace	Excessive noise	☐	
	Working outside normal working hours	☐	
	Working at height (climbing platforms)	☐	
	Outdoor activities	☐	
Fire Safety	Ignition sources	☐	
	Combustible Materials	☐	
	Hot Work (e.g. welding, grinding)	☐	
Other hazards			