EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Addendum to Proposal INTC-P-406 to the ISOLDE and Neutron Time-of-Flight Committee

Silicon strip detector test for ^{26}Al($n,p/\alpha$) measurements at neutron energies above 150 keV, relevant for ^{26}Al production in massive stars

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Abstract: ^{26}Al(n,p) and ^{26}Al(n,α) are key destruction reactions of the cosmic γ-ray emitter ^{26}Al in massive stars. The n_TOF collaboration has recently measured these reactions at EAR-2 and published cross sections up to neutron energies of about 150 keV, resolving discrepancies of previous measurements and thereby improving uncertainties of stellar reaction rates at low temperatures, most relevant to Asymptotic Giant Branch stars. A new spallation target recently installed at n_TOF led to an improvement in neutron beam characteristics. We propose to test our silicon strip detector system at EAR-2 to establish if these improved conditions would enable a measurement of ^{26}Al(n,p) and ^{26}Al(n,α) reactions up to 500 keV. This would allow to determine the ^{26}Al destruction rates in massive stars, which are the major source of ^{26}Al in our galaxy.

Requested protons: 1×10^{17} protons on target
Experimental Area: EAR2

The presence of the radioactive isotope ^{26}Al ($T_{1/2} = 7 \times 10^5$ y) in our galaxy is proof that nucleosynthesis is an ongoing process [1]. ^{26}Al can be detected by its characteristic γ-ray emission, and its abundance and distribution in our galaxy can give clues about star formation rates and stellar explosion mechanisms. ^{26}Al is mainly produced in massive stars, and ejected into the interstellar medium by stellar winds and during the later Core Collapse Supernova explosion (CCSNe). The neutron destruction reactions ^{26}Al(n,p) and ^{26}Al(n,α) have been identified as having a high impact on ^{26}Al yields [2]. This motivated a recent measurement of these reactions at the n_TOF EAR-2 facility, which allowed us to determine stellar reaction rates with high accuracy, resolving discrepancies between previous data [3, 4]. Cross sections were measured up to neutron energies of about 150 keV, which allowed us to constrain stellar reaction rates relevant for ^{26}Al abundances (and associated isotopic signatures in meteoritic grains) in Asymptotic Giant Branch stars; a paper about the astrophysical impact of these results is in preparation [5]. For ^{26}Al originating from massive stars, the cross section should also be known at higher energies, for example, cross sections up to 500 keV completely constrain the reaction rate at carbon shell burning temperatures of around 1 GK. There is only one measurement of the ^{26}Al(n,p) cross section corresponding to the relevant stellar temperature range for massive stars [6], which has been obtained using the activation technique at a neutron energy around 300 keV. Hence, a measurement of the energy dependent cross section up to about 500 keV neutron energy is essential to decrease uncertainties in ^{26}Al destruction rates in massive stars.

The upper limit of 150 keV neutron energy of the n_TOF experiment was due to presence of a large prompt signal induced by the proton beam hitting the spallation target (called γ-flash). The effect of this signal is illustrated in Figure 1, which shows the Flash-ADC signal trace of the preamplifier output from one neutron bunch (the data accquistion is started by a PS accelerator trigger, and then continuously records the detector output for the duration of the neutron bunch). From Fig. 1 we see that neutrons are produced around 10μs after the acquisition started, inducing a large signal in the preamplifier with a rise time of a few μs (marked with a red, bold arrow). With increasing time, neutrons of decreasing energy arrive in the experimental area, and may produce α particles via (n,α) reactions. These result in much smaller signals in the detectors, indicated by the black arrows at times of 20, 50 and 70 μs. The much higher amplitude caused by the γ-flash compared to the α signals preclude an analysis of detector signals for the first few μs.

During the recent long shutdown at CERN, a new spallation target has been installed at n_TOF which offers a prospect to greatly improve the detector response for such a measurement. The previous experiment had to be performed with a large beam collimator to maximise counting statistics. With the new target, the neutron flux is about 50 % higher in the keV region (see Fig. 2), which allows us to perform the measurement using a smaller beam collimator, while maintaining similar counting statistics. Silicon detectors can be placed well outside the neutron beam, and we expect a reduced response to the γ-flash as a consequence. In addition, Fig. 2 also demonstrates that the absorption dips in the flux in the tens of keV region are significantly smaller. This is particularly important for the case of ^{26}Al, since the main ^{26}Al+n resonances are located at these neutron energies (and statistics in the last experiment were limited due to these dips).

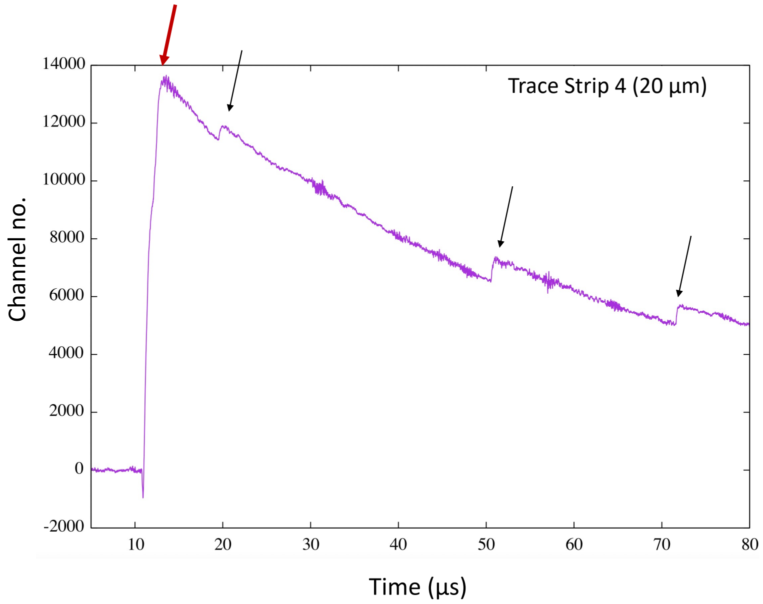

Figure 1: Preamplifier signal trace recorded with one strip of the thin 20μm detector. The neutron bunch is produced at around 10 μs, inducing a large signal (red bold arrow). The signals of interest at around 20, 50 and 70 μs are much smaller in amplitude (black arrows).

We plan to test the performance of our existing silicon strip detector system under those new and improved conditions. We will measure the well established reference reactions ^{10}B(n, α) and ^{6}Li(n, t), and perform runs without a sample in the reaction chamber to determine the level of background. A small adjustment to the existing setup will enable us to vary the distance between detector and neutron beam centre, to establish if the background would decrease significantly when moving the detector further away from the beam centre. We also plan to quantify the difference in the backgrounds for the different silicon strip detector thicknesses, i.e. 20 μm and 300 μm. In total we request 1×10^{17} protons on target.

Summary of requested protons: 1×10^{17} protons on target

References

[1] R. Diehl, H. Halloin, K. Kretschmer, G. G. Lichti, V. Schönfelder, A. W. Strong, A. Kienlin, W. Wang, P. Jean, J. Knödlseder, J.-P. Roques, G. Weidenspointner, S. Schanne, D. H. Hartmann, C. Winkler and C. Wunderer, Nature (London) **439**, 45 (2006).

[2] C. Iliadis, A. Champagne, A. Chieffi, M. Limongi, Astrophys. J. Suppl. S. **193**, 16 (2011).

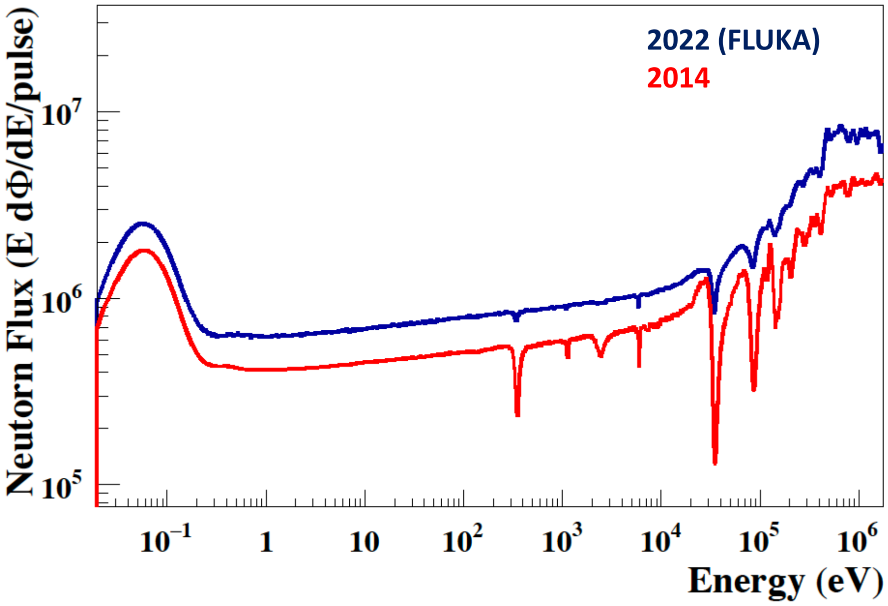

Figure 2: Comparison of the neutron flux with small beam collimation between 'old' (2014) and 'new' spallation target (2022). The neutron flux overall increases, and absorption dips in the keV region due to aluminium in the beamline are significantly reduced.

[3] C. Lederer-Woods, *et al.* (n_TOF Collaboration), Physical Review C**104**, L022803 (2021).

[4] C. Lederer-Woods, *et al.* (n_TOF Collaboration), Physical Review C**104**, L032803 (2021).

[5] U. Battino, C. Lederer-Woods, *et al.*, *in preparation*, (2022).

[6] H.P. Trautvetter, H.W. Becker, U. Heinemann, L. Buchmann, C. Rolfs, F. Käppeler, M. Baumann, H. Freiesleben, H.J. Lütke-Stetzkamp, P. Geltenbort, and F. Gönnewein, Z. Phys. A **323**, 1 (1986).

Appendix

DESCRIPTION OF THE PROPOSED EXPERIMENT

Please describe here below the main parts of your experimental set-up:

Part of the experiment	Design and manufacturing
If relevant, write here the name of the fixed installation you will be using [SiTe-EDI: Silicon Telescope setup used in P-406 (present at CERN)]	☒ To be used without any modification ☐ To be modified
Modified detector holder	☐ Standard equipment supplied by a manufacturer ☒ CERN/collaboration responsible for the design and/or manufacturing
[insert lines if needed]	

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, etc.)	☐	
	Outdoor activities	☐	

Fire Safety	Ignition sources	☐	
	Combustible Materials	☐	
	Hot Work (e.g. welding, grinding)	☐	
Other hazards			