EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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

Development of a passive low cost and scalable solid state detector for spatially resolved neutron measurements

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Abstract:

This proposal seeks to advance development of novel neutron detectors as well as to perform a useful measurement for the n_TOF collaboration. The University of Dallas in conjunction with the n_TOF collaboration propose to measure the neutron beam profile at EAR2 utilizing multiple Neutron Intercepting System on a Chip (NISoC) devices. These solid-state detectors have micron-scale spatial resolution and have previously measured a neutron beam profile at a TRIGA reactor. Furthermore, as these devices do not require power or external connections while collecting data, they may be employed in future uses where space and/or power is a constraint. As this detector technology relies on the ^{10}B(n,α) reaction, this measurement will characterize the thermal component of the n_TOF EAR2 flux.

Requested protons: $5{\times}10^{17}$ protons on target
Experimental Area: EAR2

Neutron Intercepting System on a Chip (NISoC) devices are based on nonvolatile solid-state architectures which allow data collection and preservation without power. A transistor spacing of 90 nm provides for micron-scale spatial resolution with roughly one billion pixels per device. NISoC detectors are relevant to any application wherein measuring the neutron fluence is critical with a minimal setup. When the data is analyzed offline, NISoC detectors require neither power nor digitization, meaning that no cables or electronics must be present beyond individual detector chips. As these devices are produced in modern semiconductor fabrication facilities in quantities of 10,000 chips per lot and at a cost of individual euros per device, NISoC has the potential to make neutron detector more affordable and widespread. This has particular interest to the nuclear non-proliferation community, but also has application to oil and gas exploration, dosimetry, and neutron radiography.

The University of Dallas has previously measured a thermal and epithermal neutron beam profile at TRIGA with multiple NISoC devices as documented in [1]. Current prototypes are packaged as individual electronics chips, providing a large coverage area (of several cm^2) with small inactive regions when tiled together. Furthermore, each prototype detector has two blocks of charge storage elements, creating the structure shown in Fig. 1 for a 4×4 array. Future focal plane arrays of NISoC devices will provide the same spatial resolution removing dead space. However, they will not be available until 2024 or 2025.

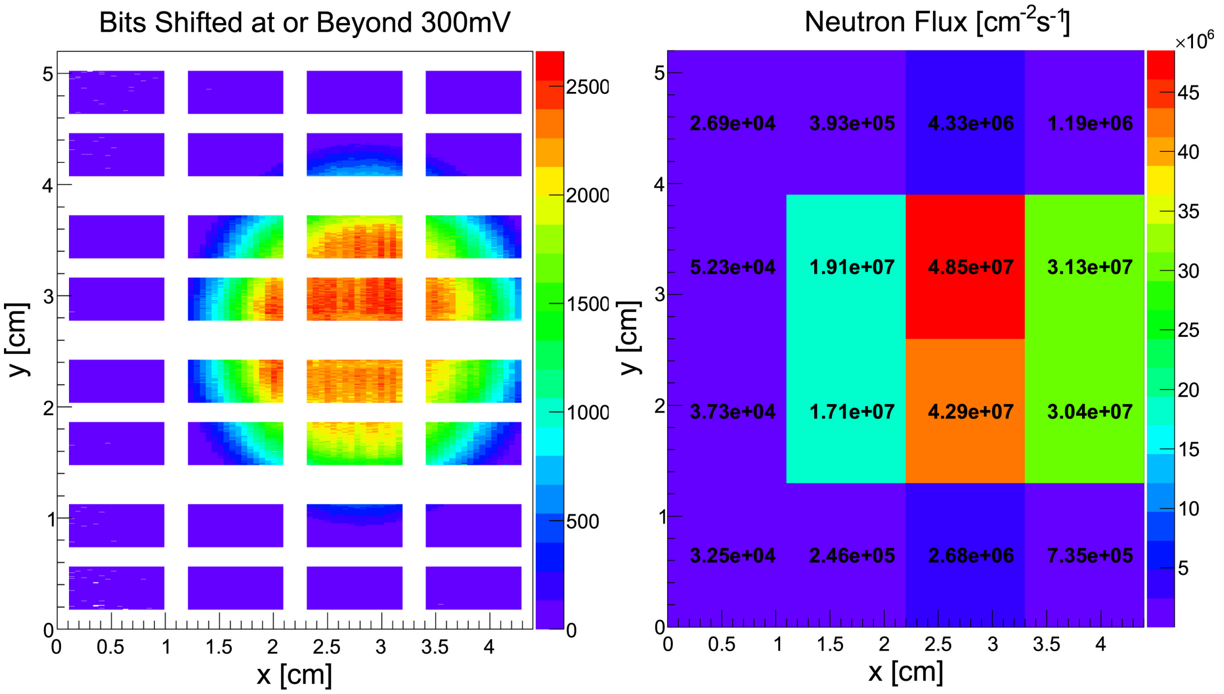

Figure 1: Left: Neutrons incident on a 4×4 array of NISoC devices at a thermal neutron beamline. The number of bits with a voltage shift beyond 300 mV is plotted over physical location within a fixture [1]. Each pixel within the plot represents 2^{20} bits. Right: The flux computed by neutron activation analysis for each of the 16 gold foils at the same location along the beam. The identical order-of-magnitude variations in the NISoC devices and gold foils serve as a preliminary validation of NISoC linearity.

Measurements

The reaction on which NISoC detectors function is ^{10}B(n,α)^{7}Li. A layer of borated glass is manufactured on top of the NISoC transistors. As the ^{7}Li and α are emitted back-to-back, one of these highly ionizing nuclei passes through the charge-sensitive transistors. The expected count rates of NISoC devices within the EAR2 beam [2] were simulated using an approximate NISoC device geometry and EAR2 beam flux [3, 4] as can be seen in Fig. 2. The sensitive region of the NISoC devices were simulated as a uniform 14mm×22mm×3μm volume which is 8% natural boron and 92% natural silicon.

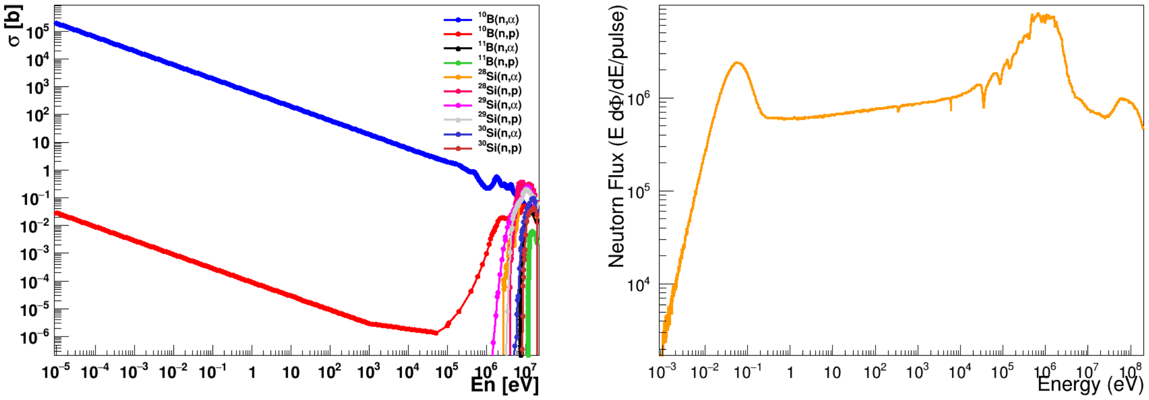

Figure 2: Left: Neutron interaction cross sections from ENDF/B-VIII.0 relevant for simulating the detector response. Right: The neutron fluence at EAR2 target position (19.53 m).

The devices are calibrated at a certain voltage level before exposure to the beam. The charged particles from the ^{10}B(n,α)^{7}Li reactions interacting with the chip decrease this voltage which is read out after the irradiation. Calibration and readout is done using custom electronics. The readout consists of four modules: interface, analog, control, and power (Figure 3). The interface module interfaces with a particular NISoC device, including power and signal conditioning and an FPGA for data processing; the analog module generates a variable DC reference voltage with μV precision and high temperature stability; the control module manages all other modules and external communications, and features a high-performance microcontroller with USB and Ethernet connectivity; the power module provides power supplies and protection to the rest of the system. The n_TOF collaboration currently possesses a previous iteration of this readout which is a factor of 8 slower. This new architecture unlocks the high-precision scans and quick turnaround times needed for future work. It is also an extensible platform that can easily accommodate the physical and electrical requirements of future NISoC prototypes.

The expected counts per nominal pulse as a function of energy is plotted in Fig. 4. Owing to the characteristic peak of thermal neutrons present in the EAR2 flux combined with the '1/v' ^{10}B interaction cross section, the measurement will be dominated by thermal

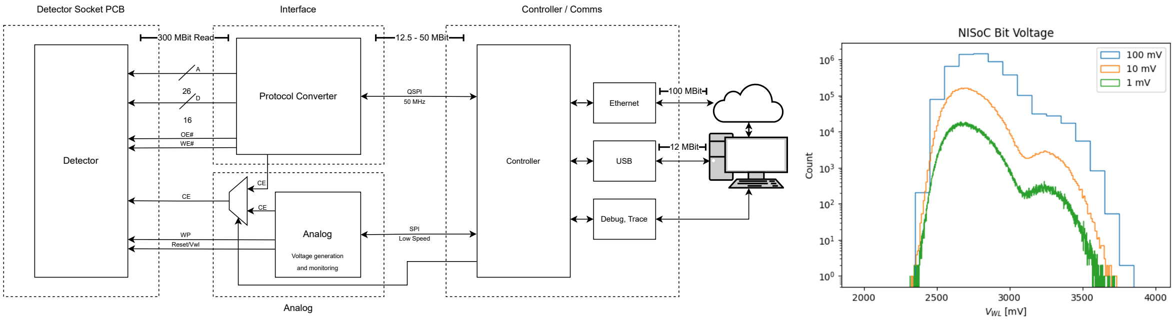

Figure 3: Left: A circuit schematic of the improved NISoC readout boards. Each dashed block is a different physical board which can be seamlessly upgraded. Right: A sweep of NISoC transistor voltages with 100 mV (blue), 10 mV (yellow), and 1 mV (green) resolutions. The higher resolution scans are now possible with the increased precision and speed of the new boards.

neutrons. Furthermore, other reactions beyond ^{10}B(n,α) in either boron or silicon can be neglected. However, n_TOF EAR2 allows the use of several different neutron filters, for example a sheet of Cadmium with a thickness of 0.5 mm at a distance of about 10 m from the spallation target. Cadmium has step-like neutron cross-section at around 0.3 eV, see right panel of Fig. 4, which allows to absorb all the neutrons with lower energies and therefore allows to investigate detector response and beam profile beyond the thermal fraction of the neutron beam.

To study the linearity behaviour of the detectors, a handful of individual devices will be exposed to the center of the beam and removed and analyzed at different time intervals corresponding to different neutron fluences. To confirm the predicted count rates with and

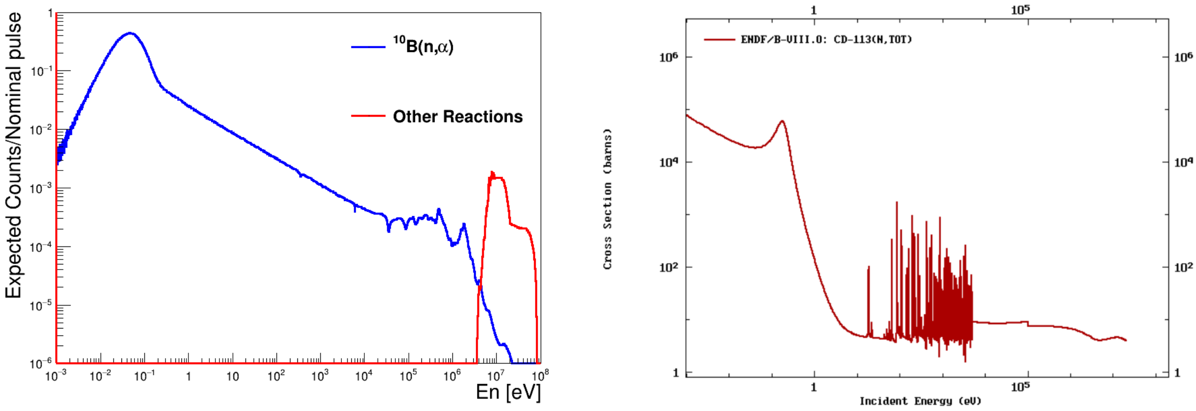

Figure 4: Left: The expected counts per bin and chip per nominal pulse resulting from the ^{10}B(n,α) reaction (blue) and all other reactions (red). Right: The total neutron cross section of ^{113}Cd.

without filter and their linearity, 2.5×10^{17} protons are requested towards this goal. Based on these preliminary results, a 3×4 array of NISoC devices will be assembled to cover a 6.0 cm × 5.8 cm area. This exposure time will depend on the results of the count rate studies and other operational priorities, but is nominally requested to be 2.5×10^{17} protons. Additionally, the results obtained will be compared with previous studies of the EAR2 neutron beam profile [5, 6], helping to reduce systematic uncertainties associated to this quantity.

Summary

2.5×10^{17} protons on target are requested for linearity studies and neutron spectrum filtering with individual devices and 2.5×10^{17} protons on target for the beam profile measurement with an array of devices for a total of 5.0×10^{17} protons on target.

Summary of requested protons: 5×10^{17} protons.

References

[1] T. Hossain et al., Nucl. Instr. Meth. A 1012 (2021) 165577

[2] C. Weiss et al., Nucl. Instr. Meth. A 799 (2015), 21, 90–98

[3] M. Sabate-Gilarte, PhD thesis (2017)

[4] M. Sabate-Gilarte, Eur. Phys. J. A (2017) 53: 210

[5] F. Suljik, CERN student note (2017)

[6] Y.H. Chen, EPJ Web Conf. Volume 146, 2017

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 [Name fixed/present n_TOF installation:	☒ To be used without any modification ☐ To be modified
If relevant, describe here the name of the flexible/transported equipment you will bring to CERN from your Institute **University of Dallas**: • 16×NISoC devices as described in the main text • Custom low voltage read-out system	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, etc.)	☐	
	Outdoor activities	☐	
Fire Safety	Ignition sources	☐	
	Combustible Materials	☐	
	Hot Work (e.g. welding, grinding)	☐	
Other hazards			