EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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

Multiple Argon Experiments at n_TOF (the MArEX initiative)

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S. Andringa[1], M. Bacak[2], Y. Bezawada[4], J. Boissevain[5], D. Cano-Ott[3], N. Carrara[4], A. Casanovas[2], S. Gollapinni[5], J. Huang[4], W. Johnson[10], A. Junghans[11], A. Losko[12], V. Lozza[1], A. Manna[6,7], P. Mastinu[8], E. Mendoza[3], A. Mengoni[9,7], M. Mulhearn[4], E. Pantic[4], E. Renner[5], D. Rivera[5], T. Stomatopolous[5], R. Svoboda[4], A. S. Tremsin[13], J. Ullmann[5], J. Wang[10], T. Zhu[4] and The n_TOF Collaboration

[1] *LIP, 1649-003 Lisbon*
[2] *CERN, CH-1211 Geneva*
[3] *CIEMAT, 28040 Madrid*
[4] *University of California at Davis, Physics Department, Davis, CA 95616*
[5] *Physics Division, Los Alamos National Lab, Los Alamos, NM 87545*
[6] *Department of Physics and Astronomy, University of Bologna, Via Irnerio 46, 40127 Bologna*
[7] *INFN, Sezione di Bologna, Viale Berti-Pichat 6/2, 40127 Bologna*
[8] *INFN, Laboratori Nazionali di Legnaro, 35020 Legnaro, Padova*
[9] *ENEA, Via Martiri di Monte Sole 4, 40129 Bologna*
[10] *South Dakota School of Mines, Deparment of Physics, Rapid City, SD 57701*
[11] *Helmholtz-Zentrum Dresden-Rossendorf, D-01328 Dresden*
[12] *Forschungs-Neutronenquelle Heinz Maier-Leibnitz, 85748, Garching, Germany*
[13] *University of California at Berkeley, Berkeley, CA, USA*

Spokespersons: Alberto Mengoni [alberto.mengoni@cern.ch] and Robert Svoboda [rsvoboda@physics.ucdavis.edu]
Technical coordinator: O. Aberle [oliver.aberle@cern.ch]

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Abstract: A program of measurements at n_TOF, part of the Multiple Argon Experiments (MArEX) initiative, is introduced. A first set of test measurements, on solid and gas targets, is proposed, necessary for a proper design of the setups for both, transmission as well as capture determination of the accurate neutron interaction cross section data on Argon, for various applications for large-scale particle physics detectors.

Requested protons: 3.4×10^{18} protons (2.7×10^{18} for EAR1 and 0.7×10^{18} for EAR2)
Experimental Area: EAR1 and EAR2

1 Introduction

The n_TOF and the ARTIE[1] collaborations have expressed interest in developing liquid argon (LAr) and/or gaseous argon (GAr) transmission experiments at their facilities, as part of a larger effort for understanding neutron propagation and capture in argon. These efforts are of interest to the particle physics and nuclear physics communities, since liquid argon has now become a ubiquitous detector material for neutrinos (DUNE, SBND, ICARUS, MicroBooNE), dark matter (DarkSide), and others. In spite of this interest, nuclear interactions on liquid argon have not been well studied.

While some of the physical quantities necessary to reconstruct the neutron cross sections for various reaction channels are quoted with small uncertainties (see for example neutron widths of resonances in ^{40}Ar [1]), others are only available as evaluated guesses (see the capture widths in the same reference [1]). Of particular interest is the minimum of the neutron scattering cross section, close to the 76.5 keV s-wave resonance of ^{40}Ar, for which the scattering length (mean-free-path) of neutrons can reach several kilometers on gaseous material and several tens of meters in LAr. In addition, the neutron total cross section in the energy range of 50-100 MeV has not been measured at all on argon, and the data above 100 MeV (as measured by the MiniCAPTAIN experiment) has large error bars and deviates from major evaluated nuclear data libraries (i.e. ENDF/B-VIII.0) evaluation by a factor of two. A serious effort is therefore called for improving the necessary basic nuclear data for neutron interaction with Argon.

Thus far, this effort has been preceded only by a precision measure of the neutron capture cross section at eV energies by the ACED[2] experiment [2], and a preliminary measurement of the total cross section in the 20-70 keV region by ARTIE [3] at LANSCE.

In this letter of intent we outline a first set of measurements at n_TOF, to provide the necessary characterization of detection systems, background conditions and target preparation, for planning accurate measurements on the main reaction channels (transmission and capture) for neutron interactions on gaseous argon. In this respect, this initiative, the *Multiple Argon Experiments* (MArEX) initiative, can be viewed also as preparatory for building a liquid argon infrastructure, for direct measurements on the material used in large-scale particle physics detectors.

2 n_TOF MArEX Demonstrators

Transmission is determined through the formula

$$T(E) = \frac{N_{\rm in}(E) - B_{\rm in}(E)}{N_{\rm out}(E) - B_{\rm out}(E)} \frac{Q_{\rm out}}{Q_{\rm in}}, \tag{1}$$

where "in" and "out" refer to target-in and target-out respectively, $N_\alpha(E)$ is the number of counts measured for energy bin E, $B_\alpha(E)$ is the number of background counts and $Q_{\rm out}/Q_{\rm in}$ is a normalization for the two beams.

[1] Argon Resonant Transmission Interaction Experiment

[2] Argon Capture Experiement at DANCE

Solid Demonstrators — As a test the feasibility of transmission measurements at n_TOF, we propose to measure the cross-section of several well studied materials, such as gold, aluminum and carbon, which are readily available. Aluminum is present in the beam line, making it an ideal filter material for studying backgrounds for a transmission measurement. Aluminum has several large resonances in the region of interest, which can be utilized in the black resonance technique for characterizing backgrounds. The cross section on carbon is mostly flat in the region of interest and is also the main material used in the construction of the SCUBA tanks discussed below.

SCUBA Demonstrator — To test whether transmission experiments on LAr are feasible at n_TOF (e.g. seeing whether or not the background rate is too high for a measurement to be competitive) we propose to use a gas target, since this would be much cheaper to build and would allow us to measure cross sections at much higher energies. A liquid argon target would require a remote cryogenic infrastructure be built at the facility, which could be done as part of the larger effort if the gas target is successful. A gas target simplifies the design of both the target and the remote system and a demonstrator can be built using simple off-the-shelf parts, such as SCUBA tanks.

SCUBA tanks rated at 300 atm are available in a variety of sizes, from 2 liters (36.9 cm length) to 13 liters (54.5 cm length) capacities. The tanks are made from carbon fiber and are pressure certified (European PED 2014/68/UE, CE mark).

Using a 36.9 $\pm$ 0.5 cm tank, 2 liters capacity, held at 300 atm[3], we find a column density of about .297 atoms per barn. Using this column density, a lower and upper bound on cross section sensitivity (assuming a transmission rate of 90% and 10% respectively) can be found. The table below gives bounds for various capacities (all for 300 atm Ar pressure).

Capacity [liters]	Column Density [at/b]	Lower Bound [b]	Upper Bound [b]
2	0.297	0.35	7.75
6	0.387	0.27	5.95
13	0.439	0.24	5.24

Table 1: Upper and lower bounds on cross section visibility determined by the pressure of the gas in the SCUBA tank. Density, and hence column density, are linear in pressure. The upper and lower bound are calculated by assuming 10% and 90% transmission values for the upper and lower bounds respectively. The 10% and 90% numbers are chosen due to insensitivity to differences in cross section for transmission values at or around one or zero.

[3]Density can be found through the ideal gas formula,

$$\rho = \frac{MP}{RT}, \tag{2}$$

where M is the molar mass, P is the pressure, R is the ideal gas constant and T is the temperature.

Detector	Converter reaction	Converter density (μg/cm^2)	(at/barn)	detector efficiency	Dimension (diameter)
μmegas	^{235}U(n,f)	469.2	1.2E-6	0.9	70 mm
μmegas	^{10}B(n,α)	19.6 (^{10}B$_4$C)	1.5E-5	0.9	100 mm
SiMon	^{6}Li(n,t)	600 (^{6}LiF)	1.4E-5	0.2	60 x 60 mm^2
Li-glass	^{6}Li(n,t)	6.4 mm (LiG)	1.1E-2	1.0	76 x 76 x 6.4 mm^3
MCP	^{10}B(n,α)	1 mm (B-Glass)	2.0E-4	1.0	28 x 28 x 1 mm^3

Table 2: Potential detection setups with standard sample sizes.

3 Transmission measurement setup

In principle a total cross section (or transmission) measurement is similar to a neutron flux measurement, performed twice: with and without the Argon target. The proposed measurement is based on the efficient neutron detection over a broad energy range from eV to several hundreds of keV which is commonly achieved by using neutron converter reactions, for example ^{235}U(n,f), ^{10}B(n,α) and ^{6}Li(n,t). The n_TOF flux commissioning campaigns use several detectors coupled with neutron converters, for example μmegas with ^{235}U and ^{10}B converters and n_TOF's silicon neutron beam monitor using a ^{6}LiF converter. All those detectors require sufficiently thin samples to allow the charged particles to reach the sensitive volume of the detector. The neutron detection efficiency scales with the number of converting nuclei exposed to the beam, their cross-section and the detector efficiency, see the summary in Table 2.

In the main neutron energy region of interest, up to several hundreds of keV, the standard detectors used at n_TOF for neutron flux measurements, as mentioned above, are not well suitable because all converting reactions have a similar cross-section from 10 to $\approx$ 500 keV. The only way to increase the efficiency is to increase the number of atoms per barn (at/barn) by adding more samples. To reach sufficient count rates the number of samples quickly out scales pragmatic numbers of thin samples.

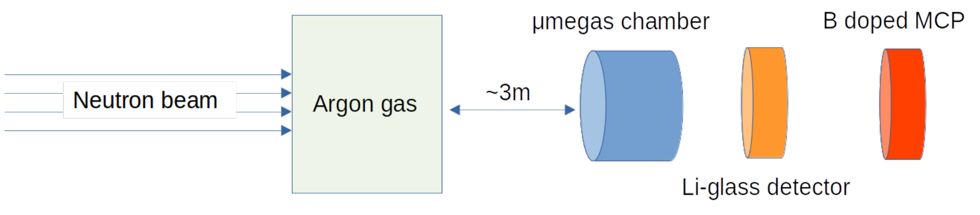

Figure 1: A schematic view of the proposed sample and detector.

Therefore, for the low energy region, we will use a commercial Li-Glass (LiG) detector that achieves a neutron detection efficiency of a few percent below a few hundreds of keV by increasing its thickness. The detector is considered as a standard detection system for total cross-section measurements but cannot be used at higher energies due to γ-flash implications.

To cover the high energy region, from several hundreds of keV to tens or even hundreds of MeV, the only useful converter reaction due to its cross section is ^{235}U(n,f), thus we will employ a μmegas detector loaded with the ^{235}U samples available at n_TOF (total thickness: 700 μgr/cm^2).

The proposed setup will look similar to the sketch in Figure 1, where in addition to the μmegas and Li-Glass detector, the use of a high efficiency ^{10}B doped multi channel plate (MCP) detector [4] and a neutron imaging detector [5, 6, 7] is foreseen. The advantage compared to the "single pixel" LiG detector is the Timepix based readout in both systems which allows higher count rates due to readout segmentation. As the converting layer, i.e. the scintillator, in the imaging detector is not directly coupled in the system, it can be exchanged easily. That gives the advantage to exchange a low neutron energy scintillator (based on ^{6}Li) with a plastic scintillator that would allow a measurement in the high neutron energy via neutron-proton scattering. Furthermore, the imaging detectors provide neutron-γ discrimination. To further reduce systematic effects from scattered neutrons the detection setup will be placed several meters downstream of the transmission sample. The LiG and MCP detectors will be placed at as much distance as possible with respect to the μmegas detector to avoid cross-talk and systematics due to the neutrons generated by ^{235}U(n,f).

The expected transmission spectrum through 36.9 cm Argon gas at 300 atm and the scuba tank (1.2 cm carbon fiber + 0.2 cm $C_{10}H_8O_4$) with the LiG detector and 1.5×10^{18} protons is shown in Figure 2.

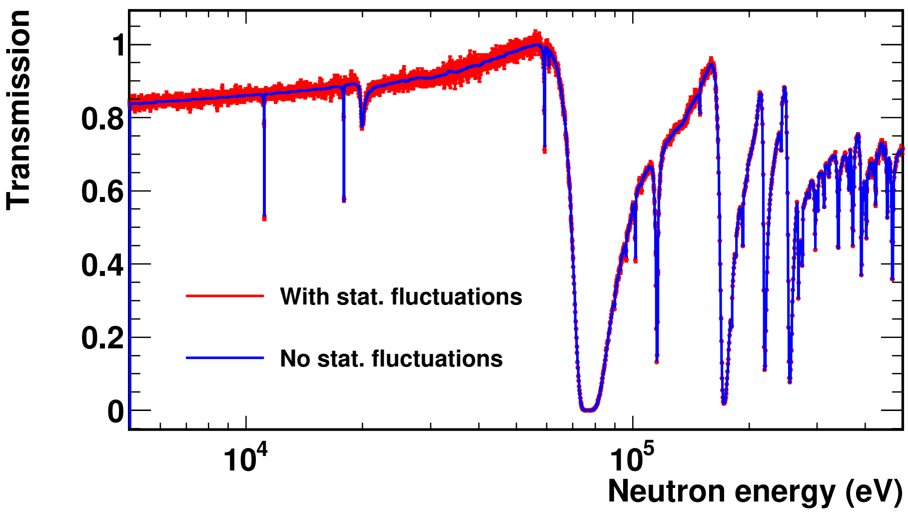

Figure 2: Neutron transmission through 0.297 at/b ^{nat}Ar predicted by ENDF/B-VIII.0, with (red) and without (blue) modelling the statistical fluctuations. In both cases the n_TOF EAR1 resolution function has been modelled. To model the statistical fluctuations we have considered the LiG detector efficiency, the effect of the scuba tank, and 1.5×10^{18} protons in 1000 bins per decade equally distributed between the measurement with and without sample.

4 A capture measurement

In addition to the transmission measurement, a neutron capture cross section measurement can be envisaged for providing additional physical information on the neutron interaction with Argon in the energy region of interest here. In fact, a full parametrization of the neutron resonances in Ar require their gamma-ray widths in addition to the neutron widths. Given the experience gained in the development of a ^{3}He gas-target for the X17 measurement [8], a small carbon fiber container that can sustain high pressure has been developed. The one which we plan to use for a test capture measurement consists of a cylinder, 2.5 cm radius and 5.0 cm length, with two semi-spheres of radius 2.5 cm at the extremes. The expected count rates for standard EAR1 and EAR2 capture setups are

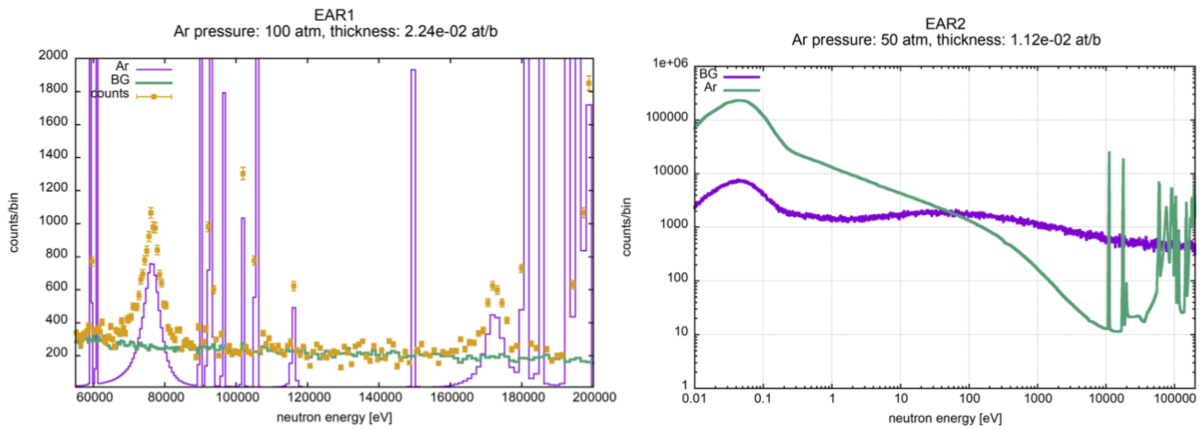

Figure 3: Count rate estimate for the capture measurement in EAR1 (left panel, 5×10^{17} protons) and EAR2 (right panel, 5×10^{17} protons). The focus of the EAR1 plot is on the 76.5 keV s-wave resonance, while for EAR2, the full range is shown in which a good signal/BG ratio is clearly visible at thermal energies, even with an Ar gas pressure of 50 atm.

shown in Figure 3. For the EAR1 measurement, we plan to use the standard capture setup with 4 C_6D_6 detectors, while for the EAR2 measurement, we will use the array of 9 sTED detectors (segmented C_6D_6 setup [9]). For the capture measurement, the estimated number of protons necessary to reach the statistics shown in Figure 3 is 7×10^{17} for both areas (note the lower pressure set for EAR2), including the beam-time requested for the measurement of the empty containers.

5 Summary

We propose to perform test measurements of the total cross-section of natural Argon gas in a transmission setup up to a few 100 keV. A combination of several detectors will be employed to guarantee high efficiency and data quality. The availability of a commercial container, i.e. carbon fiber scuba tank, and the relatively easy handling of the inert Argon gas under high pressure make it a good candidate for a first transmission measurement with gaseous targets performed at n_TOF. For the transmission measurement campaign we request 2×10^{18} protons of which 0.75×10^{18} protons will go the measurement with and without sample each, and an additional 0.5×10^{18} protons will be dedicated to black

resonance filter measurements to estimate the neutron background.
For capture, tests measurements in both EAR1 as well as EAR2 will be performed, with a specially developed gas-cell and standard detection setups. A lower pressure is estimated to be sufficient to perform the capture measurements, which will require 7×10^{17} for each experimental area.

Summary of requested protons: 27×10^{17} protons for EAR1 and 7×10^{17} for EAR2.

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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
uMegas detectors	☒ To be used without any modification ☐ To be modified
Li-glass detector and boron doped MCP [Part 1 of experiment/ equipment]	☒ Standard equipment supplied by a manufacturer ☐ CERN/collaboration responsible for the design and/or manufacturing
[Part 2 of experiment/ equipment]	☐ 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: 300 [atm], volume: 2[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			