FIRST RESULTS FROM THE ARGON RESONANT TRANSPORT INTERACTION EXPERIMENT



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ARTIE Physics Goals

- Precisely measure the region of low cross-section at 57keV in the n+Ar⁴⁰ cross-section using a neutron beam with time of flight (TOF) spectroscopy.
- Evaluated Nuclear Data Library (ENDF) points to lower crosssection at 57 keV but the Winters b et al. measurement did not observe it.
- Unclear where the discrepancy is coming from and if it is within the experimental uncertainty.
- 57keV neutrons interaction length in liquid argon (natural abundances of isotopes) is 30 m while Winter et al. gives 5 m.



ARTIE Physics Motivation: Help the science of DUNE

Regions of small n-Ar cross section are important for reliable predictions of transportation and shielding of neutrons in a large-scale LAr-based *v* experiments such as DUNE.

- Neutrons from *v* interactions might exit the detector volume and affect the energy resolution. At which rate?
- Background neutrons from detector components and the surrounding rock might enter from the outside. To which penetration depth?
- Will externally-produced neutrons for the calibration of detector probe deep enough?



So a more precise cross section measurement is needed.

ARTIE setup at Lujan Neutron Scattering Center@LANL

ARTIE data taken using 63.8 m neutron flight path.



Neutron flux in flight path 13

Neutrons are produced via spallation reactions caused by 800 MeV proton beam (@20Hz and 80μ A) impinging on W-target and passed through a liquid hydrogen moderator .

Current was monitored during the data taking and was used as a quality cut. Proton beam pulse provides a start time for each event.





Liquid-hydrogen moderator delays neutrons

Moderator induces a time delay to neutrons. Modeled via Monte Carlo simulation (Moderator Response Function) that gives fractional time delay ($\delta T/T$) for 10 m flight path.



ARTIE flight path in the ROI (30-70keV), time delay is ~1-2% with a spread of about 10% about the mean (accounted in systematics).

Neutron flux in flight path 13

After a moderator, a Cadmium filter near the ARTIE target is used to suppress slow neutron flux below 0.5 eV. It reduces DAQ dead-time and background from slow neutrons aliasing as high energy neutrons.



ARTIE target effective column density of 3.3 atoms/b

ARTIE contains LAr with natural abundance of isotopes at atmospheric pressure using a foam-insulated open-dewar design.

LAr target is 1.68m long and 2.5cm in diameter (» beam size) providing an effective column density of 3.3 atoms/b. ARTIE is nearly opaque to neutrons at energies far from low cross section region \Rightarrow ROI is 30-70keV



2" thick brass cylinders with 6 mm holes in the center were used to collimate the beam.

TOF detector

Neutrons are detected by a ⁶Li-glass scintillator detector coupled to two 5" PMTs: $n+6Li \rightarrow 4He+3H$, Q=4.78MeV.

Both PMTs were required to have pulses within a 100 ns coincidence window.

For each event DAQ recorded a timestamp (used to calculate kinetic energy) and integrated charge (Q).





Energy calibration via resonance lines

- Identify TOF peaks of known resonances of aluminum and cadmium present in the path line and their ENDF energies.
- Correct their measured TOF by subtracting median of simulated moderator time delay for a provisional path length based on measurements.
- Perform linear fit with two energy independent parameters to account for additional time delays and residual difference between the actual and simulated moderator response (t_{fit} , L_{fit}).



Cross section via target in/target out data



Dominant background late- arriving high-energy beam neutrons that have undergone multiple scattering

Background estimation using large resonances

Look at events in the TOF region (as close as possible to the ROI) where material in beam line has an expected black or almost black resonance and assume measured events are background related.



Estimation of Target-in density@LANL

ARTIE target has boil of rate of 1.56L/h so a small fraction of GAr is present in LAr runs. Target-in density measured at UC Davis after the beam data.

 $M = M_0 + (\rho_{in@UCD} - \rho_{air})V(h)$

Simultaneous measurement of mass M via precision scale and liquid height h during the boil off allows for extraction of target-in density at UCD. Correct it for altitude of LANL.

Mass of empty apparatus M_0 measured via precision scale and volume V(h) measured with known amounts of water.

$$\rho_{in} = 1.318 \pm 0.017 kg/L$$



Target-in density is 5.9% lower than the nominal density.

Largest systematic uncertainties

Despite flushing target's end-cap windows with dry gases, a thin layer of ice formed on the Kapton windows over the course of many hours.

Target was warmed up to allow the ice to melt. Data immediately before (thickest ice layer) and after (windows are free of ice) warming up were analyzed to determine 0.3mm maximum ice thickness.

2m of the flight path is under	Systematic Uncertainty	PAR UNCERTANTY (%)	σ UNCERTANTY (%)
the air.	Overall beam	±1.1	±1
Local weather conditions	stability		
induced a variation of 0.4% in	Filling period	-5	-3.1
the neutron flux reaching	stability		
TOF detector.	Target-in density	±1.3	±1.3
	Ice build up	-3.8	-2.4

Analysis cross-check: Transmission for Carbon



Good agreement between the measured and simulated transmission with $\chi^2/\text{NDF} = 2.7/6$ in the ROI.

Carbon Spattering Target by K. J. Lesker 99.999% purity attached to the target with GAr. 15

Neutron-argon total cross section in the ROI



Total uncertainty increased around Al resonance. Al is present in the path line.

Summary and outlook

- Neutrons scattering in Ar influence the design and performance of the DUNE detector, and can affect other LAr-based large scale rare event search experiments.
- ARTIE experiment was designed to have a thick target (large column density) to precisely measure small n-Ar scattering cross-section in the region around 57keV in order to cross check previous measurement and ENDF evaluation.
- ARTIE measurement of the total cross section as a function of energy confirms the existence of a small cross-section at 57keV in agreement with the ENDF evaluation.
- ARTIE measurement will be used in simulations for the development and optimization of neutron-based detector calibration system, as well as signal and background modeling for the DUNE experiment.

Thank you







Extra Slides

Run quality cut and beam-target alignment

Data was collected during a two week period, with most runs being LAr or GAr fill.

For LAr runs during the re-fill (once per h)₄₆₀me cold vapor gas would cool the brass collimator causing misalignment and drop in event rate (independent of the neutron energy). These periods are excluded (12% of data loss) ₅₀This₀₆ut aggounds fog₅₃ 12%₀₀data loss for liquid argon runs and introduces a ~5% 350 time from runser tain ties in the neutron flux.



Good data were selected excluding periods where DAQ had problems or the neutron beam was unstable.

ARTIE energy resolution ~3% in ROI

Two main factors affect energy resolution $\delta E/E$

- Incident proton pulse width (triangular shape) is the dominant
- Moderator function response asymmetric spread

