ARTIE: Measuring the 57keV neutron cross-section of liquid argon

APS Far West Section

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Understanding Neutrons For DUNE Is Crucial

• DUNE, an upcoming international long-baseline neutrino experiment
  • Utilizes a Liquid Argon (LAr) time-projection chamber (TPC) to explore neutrino physics

• Understanding neutron transport in LAr is important:
  • Neutron Shielding
    • How far will neutrons penetrate the active volume?
  • Calibration
    • Can we inject neutrons into the volume?
  • Neutrino Physics
    • Neutrons can be a product of neutrino interaction events, such as in supernovae
Why ARTIE?

• Current understanding of the total cross section of argon is contested between theory (ENDF) and experiment (Winters et al)
  - Winters used gaseous argon (0.2 atoms/b) to cover a wide energy range
    - Perhaps not sensitive enough to detect the 57keV anti-resonance!

• Argon Resonance Transport Interaction Experiment aims to resolve this discrepancy at 57keV
  - At 3.5 atoms/b, we are 15x more sensitive at 57keV!

<table>
<thead>
<tr>
<th>Neutron Energy [keV]</th>
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<tbody>
<tr>
<td>20</td>
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<tr>
<td>$10^{-3}$</td>
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<td>$10^{-2}$</td>
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<table>
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<tr>
<th>$\sigma_{\text{tot}}$ [b]</th>
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<tr>
<td>ENDF natural Ar</td>
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<td>Winters</td>
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| Winters | 0.2 atoms/b | T=0.984 | T=0.998 |
| ARTIE   | 3.5 atoms/b | T=0.76  | T=0.97  |
How do we measure n cross sections?

- Place a target in the beam line and neutrons not scattered will reach the detector.
- We know the flight path length, so then time-of-flight (TOF) determines the energy.
- Turns into a counting experiment, per \(i_{th}\) energy bin!

The total cross section in an \(i_{th}\) energy bin is

\[
\sigma_i = \frac{-\ln(T_i)}{n}
\]

\(T_i\): transmission coefficient  
\(n\): target density [atoms/barn]

\[
T_i \approx \frac{N_{in}}{N_{out}}
\]

\(N_{in}\) and \(N_{out}\) are the number of observed neutrons with the target in or out

\[
n = \frac{d \, N_A}{m_A \, 10^{-24} \, \rho}
\]

d: length of target  
\(\rho\): density  
\(N_A\): Avogadro’s number  
\(m_A\): molar mass
ARTIE at LANL

• ARTIE utilized neutron flight path 13 at LANSCE, at Los Alamos National Laboratory (LANL)

ARTIE Target Specifications
• 168cm long, 1” diam. cylindrical target of 99.99% pure LAr
• Foam jacket insulation, LAr reservoirs, and thin Kapton windows along the beamline
Problems

• Many corrections during data analysis need to be considered
  • Target density
  • Afterpulsing
  • Deadtime
  • Background subtraction
  • Misalignment
  • Atmospheric effects

• I will primarily discuss:
  • Evaluating the target density
  • Deadtime corrections
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- Target density
- Afterpulsing
- Deadtime
- Background subtraction
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- Deadtime corrections
As previously seen, the ARTIE target is not pressurized or vacuum sealed

• Therefore the LAr will constantly boil, this is problematic

Cross Section given by:

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• More gas means lower density, \( \rho \), which will reduce the cross section
  • Need to evaluate this effective density
A side experiment to find the effective density was done back at UCDavis.

Target sits on precision scale, filled with LAr, and is allowed to boil off naturally.
- Mass and liquid level are recorded via camera and then reviewed later.

Given mass of empty target and volume, we can then work out the density

$$\rho_{\text{target}} = \rho_{\text{LAr}} \frac{V_{\text{tot}} - V_{\text{GAr}}}{V_{\text{tot}}}$$

- $$\rho_{\text{target}} = 1.318 \text{ kg/L} \pm 0.008 \text{ (stat)} \pm 0.015 \text{ (sys)}$$
- Approx 7% GAr
Systematics: Missed Neutrons

• What happens when neutron events arrive too close together?
  • A problem!
• Our DAQ is insensitive, or dead, for approximately 220ns after it acquires a pulse
  • Our TOF spectra must then be corrected for
• Using an analytical “Bowman” correction, we can move through bin-by-bin and correct for the deadtime losses
  • For the worst-case scenario, GAr, it never exceeded 1%
• To verify, a Monte Carlo was constructed and agreed w/n 0.5%

\[
N_c(I) = \frac{N_o(I)}{N_b} \left\{ -\ln \left(1 - \frac{N_o(I)/N_b}{\sum_{J=J_0}^{I-1} N_o(J)/N_b} \right) \right\}
\]
Preliminary Results

• The ARTIE experiment is coming to a close

• Systematics are being finalized and validated
  • Barring a few corrections, preliminary results are presented here

• Paper under preparation, expect an arXiv submission in about 4 weeks!
Questions?

ARTIE target installed: Leon Pickard (right)

FP13 Beam line, downstream

Prof. Mike Mulhearn (left), Prof. Bob. Svoboda (right) with the Li6 detector (behind)

Part of the ARTIE Crew at LANL: me(left), Prof. Bob Svoboda (right), Prof. Sofia Andriga (top)
Backup: Missed Neutrons

![Diagram showing missed neutron events]

- What happens when neutron events arrive too close together?
- A problem!
- Once the integration window is triggered, our DAQ does not record the arrival times of any additional pulses within the window. They are technically recorded via the charge integration, but their time information is lost.

Thus we miss some neutron events.

**Diagram: 200ns Integration Window**

- **BLUE:** first neutron event
- **RED:** second neutron event

- PMT #1
- PMT #2

- Time