LArIAT
Liquid Argon TPC In A Testbeam
Charged Pion-Ar total interaction cross-section

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On behalf of the LArIAT Collaboration

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What is LArIAT?

- LArIAT is a 170 liters of LArTPC designed for calibrating detector response in a charged particle beam.

- Main motivation is to execute a comprehensive program to characterize LArTPC performance in the energy range relevant to both the Short-Baseline (µBooNE, SBND, ICARUS) and Long-Baseline (DUNE) neutrino experiments.

LArIAT: Liquid Argon In A Testbeam
Scale of LArIAT

- One 10kT DUNE LArTPC Module (18m x 19m x 66m)

LArIAT TPC (0.25 tons)
(0.4 m x 0.47 m x 0.9 m)
Small detector but Rich Physics goal!
Why LArIAT?

- **Physics Goals:**
  - Hadron-Ar interaction cross sections
  - Study of nuclear effects in Ar
  - $e/\gamma$ shower identification
  - Particle sign determination in the absence of a magnetic field utilizing topology (e.g. decay vs capture).
  - Geant4 validation

- **R&D Goals:**
  - Ionization and scintillation light studies
  - Optimization of particle ID techniques
  - LArTPC event reconstruction
Where is LArIAT?
Particle interaction in LAr produces ionization and scintillation light.

Prompt light emission (read out by PMT's) starts the clock.

Electrons drifts to the anode (Ar$^+$ ion drifts to the cathode).

Electron induces charge on the wire.

Tracks are reconstructed from the wire signals.
LArIAT Beamline

Primary Target (Al)

Primary 120 GeV $p$

Tunable 8 – 64 GeV Beam

Secondary Target (Cu)

Tertiary Beamline & LArIAT TPC

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Tertiary Beamline

Cu target

Secondary beam 8-64 GeV π⁺

Multi-wire proportional chambers (MWPCs)

Time of flight scintillators

Aerogel counters

Cryostat & TPC

Cosmic Paddles

Bending dipole magnets

μ punch-through paddles

μ range stack

Secondary beam 8-64 GeV π⁺
- **Goal:** Momentum reconstruction before entering TPC.

- Difference of the angle between the tracks determines the momentum.
Time of Flight

- TOF separates $\mu/\pi/e$ from protons and kaons.
- The timing readout of TOF and MWPC can separate particle ID($\mu/\pi/e$, $p$, $K$)

$\Delta t$ between DSTOF and USTOF V1751 hits
Run: 4295; Total number of spills: 100

- We know the particle ID and momentum before it enters the TPC.
Cryostat and TPC

- LArIAT uses refurbished ArgoNeuT TPC.
  - 2 Readout Planes
  - 240 wires/plane +/- 60°, 4mm pitch
  - Drift field 500 V/cm

- Light Collection system:
  - Wavelength shifting reflector foils to shift the scintillation light into visible spectrum. (William Foreman's talk)

- Signal to noise ratio:
  - Run 1 : 50:1
  - Run 2 : 70:1
LArIAT Event!

- LArIAT Run I: 9 weeks of data (May 1, 2015 – July 4, 2015)

- LArIAT Run II has just finished taking data (Feb 17, 2016 to end of July 2016)

- 2D views from LArIAT on-line event display

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Interesting Events

Pion Production Candidate

Beam Direction  
LArIAT Data

Pion - Elastic Scattering Candidate

Beam Direction  
LArIAT Data

Pion - Charge Exchange Candidate

Beam Direction  
LArIAT Data

Pion - Inelastic Scattering Candidate

Beam Direction  
LArIAT Data
First Total $\pi^-$-Ar Cross Section Result

Preliminary!
Measuring the Cross-section

Thin Sliced Method

- Using the granularity of the LArTPC, we have treated the wire-to-wire spacing as a series of “thin-slab” targets.

- The probability of pion interaction can be written as

\[
\frac{N_{\text{interacting}}}{N_{\text{Incident}}} = P_{\text{Interacting}} = 1 - e^{-\sigma n z}
\]

Where \(\sigma\) is the cross-section per nucleon, \(z\) is the depth of the slab and \(n\) is the density of the slab.

- Thus we can write the pion cross-section as a function of energy as

\[
P_{\text{Interacting}} = 1 - \left(1 - \sigma n \delta z + \ldots\right)
\]

\[
\sigma(E) \approx \frac{1}{nz} P_{\text{Interacting}} = \frac{1}{nz} \frac{N_{\text{interacting}}}{N_{\text{Incident}}}
\]
Event selection

- We have a wire chamber track (with an initial kinetic energy) matched to a TPC track, we follow that TPC track in slices.
  - For each slice we ask: “Is this the end of the track?”
  - **NO**: Calculate the kinetic energy at this point and put that in our “incident” histogram.
  - **Yes**: Calculate the kinetic energy at this point and put that in our both “interacting” and “incident” histogram.

\[
KE_{\text{Interaction}} = KE_i - \sum_{i=0}^{n\text{Spts}} dE/dX_i \times \text{Pitch}_i
\]

\[\frac{1}{nZ}\]
Reminder: Cross-section still contains capture and decay process, we are in a process of removing those from our sample.
Conclusion

- First analysis from LArIAT:
  - Total Pion cross section on argon never before measured.

- Next steps for the analysis:
  - Treatment of pion capture and decay processes
  - Investigating the use of other beamline detectors to improve the sample purity.

- More analyses to come from LArIAT:
  - Exclusive $\pi$-Ar absorption and charge exchange channels as well as elastic, inelastic all are underway.
    - All of the above for $\pi^+$'s as well
    - Kaon (Total and possibly exclusive channels analysis)(Elena Gramellini's Poster #708)
    - proton, etc...

- $e/\gamma$, muon sign determination, scintillation light studies.

Run II (Feb-Jul 2016) has produced 5 times more statistics! Stay tuned!
Thank you
Backup Slides
LArTPC working principles

Why Ar?

- **Dense** (40% more dense than water)
- **Abundant** (1% of the atmosphere)
- **Ionizes easily** (55,000 events/cm)
- **High electron lifetime**
- **Lots of scintillation light**

Credit: Ben Jones (UTA) for image

This difference between the energy levels is why LAr is transparent to the scintillation light it produces.
Energy window

FTBF Low Energy Tune

FTBF High Energy Tune

32 GeV $\pi^-$ on Target, +100 A Magnet Current

LAriAT Preliminary
Cross-section results from Geant4 so far

![Graph showing cross-section results from Geant4](image-url)
# Event sample

<table>
<thead>
<tr>
<th>Event Sample</th>
<th>Number of Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi^-$ Data Candidate Sample</td>
<td>32,064</td>
</tr>
<tr>
<td>$\pi/\mu/e$ ID</td>
<td>15,448</td>
</tr>
<tr>
<td>Requiring an upstream TPC Track within $z &lt; 2$ cm</td>
<td>14,330</td>
</tr>
<tr>
<td>$&lt; 4$ tracks in the first $z &lt; 14$ cm</td>
<td>9,281</td>
</tr>
<tr>
<td>Wire Chamber / TPC Track Matching</td>
<td>2,864</td>
</tr>
<tr>
<td>Shower Rejection Filter</td>
<td>2,290</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Beam Composition (%)</th>
<th>$\pi^-$</th>
<th>$e^-$</th>
<th>$\gamma$</th>
<th>$\mu^-$</th>
<th>$K^-$</th>
<th>$\bar{p}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>48.4</td>
<td>40.9</td>
<td>8.5</td>
<td>2.2</td>
<td>0.035</td>
<td>0.007</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Selection Efficiency</th>
<th>$\pi$</th>
<th>$e$</th>
<th>$\mu$</th>
<th>$\gamma$</th>
<th>$K^-$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>74.5%</td>
<td>3.6%</td>
<td>90.0%</td>
<td>0.9%</td>
<td>70.6%</td>
</tr>
</tbody>
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Energy Correction

\[ KE_i = \sqrt{p^2 + m^2_\pi} - m_\pi - E_{\text{Flat}} \]

Gaussian Fit from 35 – 55 MeV

\[
\begin{align*}
\chi^2 / \text{ndf} & = 319.3 / 17 \\
\text{Constant} & = 3962 \pm 22.3 \\
\text{Mean} & = 43.1 \pm 0.1 \\
\text{Sigma} & = 7.635 \pm 0.068
\end{align*}
\]
Aerogel Cherenkov detector

- Aerogel distinguishes pions from muons.
  - In a particular momentum range the aerogels will produce cherenkov light differently for pion and muon.
  - Before reaching the TPC we could know the incident momentum, charge, particle ID.
  - We have not used aerogel information in our cross-section analysis, but currently we are investigating.
Muon range stack is for the improvement of Particle ID for through going pions and muons.

- A segmented block of steel with scintillator bars and PMTs.
- Muons will penetrate further than pions.
- Match this activity to the rest of the beamline and the TPC.