LArIAT Liquid Argon TPC in a Test Beam

Data Acquisition and Trigger

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on behalf of
The LArIAT Collaboration

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The LArIAT Experiment

- Repurposed ArgoNeut cryostat and time projection chamber TPC
- Tertiary beam from the Fermilab Main Injector, historic MCenter beam line
- Many species: $\mu \pi \gamma e p K$
- Momentum range from 0.2 GeV to 1.5 GeV
- Answer the question: How to identify particles in liquid argon?
- Unlike in $\nu$ beams, we ID the particle prior to entering the detector and cross reference in the TPC
- Nuclear cross sections & more
- Data taking 2015, 2016, 2017...
The LArIAT Time Projection Chamber

- Two 60° sense wire planes give 2 spatial coordinates
- Drift time gives third dimension 3D tracks
- 480 sense wires
- 25 kV Cathode plane
- 500 V/cm E field
- 350μs max electron drift time
- Cold preamps yield improved S/N ~ 70:1
- Digitization in the warm, 12 bits every 128 ns (variable)
DAQ: Top View of Detector Elements

Five independent asynchronous readout systems

- Cu target
- Secondary beam 8-64 GeV $\pi^\pm$
- Multi-wire proportional chambers (MWPCs)
- Bending dipole magnets
- FTBF TDCs 1.2ns
- V1751 1ns
- V1740 128ns
- WUT 15psec
- $\mu$ range stack
- $\mu$ punch-through paddles
- Several independent detector systems with specialty readout and independent clocks

Tasks:
“Configure, Trigger, Readout, Build and Write”
Beam and DAQ+Trigger Timing

Fermilab’s Beam Complex super cycles is 60.5 seconds

4.2 seconds of slow spill to switch-yard and test beam*

Rest of time beam sent to NuMI and BNB Neutrino beam lines

* Slow spill subject to reposition in super-cycle time line

Normally $T = 30$ seconds, adjustable via software

$00$ All systems and data fragments synchronized to $00$ start of each super cycle

BEAMON and COSMICON are inputs to trigger
Requirements & Solutions

- Have 4.2 second window beam spill + up to 50 seconds collection cosmic rays every 60.5 second super cycle
- *Cannot* read every sample without custom readout hardware and $$$
- Must have triggered system handle ~ 100 – 200 triggers/spill
  - ~ 3 Mb data per trigger, TPC data alone
- TPC Data volume dominates requirements
  - ~ 350 μsec max drift time, plus padding = 393 μsec
  - Ideally 128 nsec sample time, 256 nsec adequate, 512 ns if needed
  - 480 wires to readout, no zero suppression, two bytes per channel per sample (12 bit ADC)
- Found solution with CAEN V1740 64 channel waveform digitizer
  - High density 6U VME, single width – need 8 cards
  - Required new “decimation” in firmware to slow 16 nsec to 128 nsec ...
  - Large buffers can store 64, 128, 256 events, depending on T width
CAEN V1740 VME Crate

V1740 Crate prior to analog hookup
Note daisy-chained digitizer clock
Chained optical link for configuration and readout
Common trigger and reset $00 inputs from fanouts
First board in chain provides master clock, downstream clocks

phase adjusted to < 150 ps skew

V1740s constantly digitizing to circular buffer
On receipt of trigger, copy buffer to memory location
Ready immediately for subsequent trigger
Beam line and Light Collection

• Light collection (ToF, Aerogel, LCS) have much faster time scales
  – ~ 10’s of nsec
  – 2 × CAEN V1751, eight channels each, 1 nsec sampling
  – Typical wave form width 28 μsec
  – Specially modified for 200 mV scale (single photo-electrons)
  – Read via CAEN CONET optical link to A3818 PCI bridge
  – For precision ToF hit timing use WUT Wave Union TDC, resolution ~ 15 psec
  – Read via VME via PCI bridge

• Wire Chambers with max drift ~ μsec
  – Use established Hansen readout supported by FTBF staff
  – Have 1.17 nsec granularity, independent clock
  – Multi-hit TDCs, four chambers, (x,y) (128,128) 1024 channels
  – Spill stored entirely in on-board buffers, collated to central controller
  – Read at end of spill by main Lariat DAQ over ethernet

• TPC contra mundum
  – Two very different time scales ➔ fast and slow triggers!
Details of LArIAT DAQ Readout Data Flow
Several external sources read and collated by single event builder “DAQ PC”

Data packaged per spill into artDAQ fragment and saved in art / LArSoft compatible root data files
DAQ Software

• “KISS” – Keep It Simple, Stupid!
• No Quixotic GUI developments, *nunca*!
• Configure system via human readable XML text files
  – One per subsystem, store entirety in data stream and LArIAT database every run in structured form
  – Easy to include, exclude components and tweak their setting
  – Expert access only, shifters do not access
• To start a run, simply type “go” at the prompt
  – Yes, it’s really that easy!
• Display run status in a single easy-to-use web page
  – No, it doesn’t really count as a GUI
• Use artDAQ framework to produce art and LArSoft compatible root file output
  – See J. Freeman’s talk from Monday for artDAQ details
• Already reusing techniques, code, classes for SBND BNB experiment
LArIAT Run Status

Simple, succinct table indicating all pertinent DAQ and Trigger quantities showing the run is proceeding apace.
Data Archiving

- DAQ closes data file and signals archiver to pick up file
- dCache/enStore/PNFS: Archiving/file serving process
- SAM: Cataloging / description / metadata process
- Uses standard Fermilab FTS file transport service
- Data files easily retrievable via simple SAM queries

R. Johnson, J. St. John

![Files completed chart](chart.png)
**Challenge: Cross-Detector Synchronization**

Difference in nominal times between beam line wire chambers and TPC light readout

\[
\Delta t \text{ between V1751 and MWPC recorded trigger times}
\]

Run: 2982; Spill: 3

\[
\text{slope: } 28.78071 \mu s/s
\]

**CHALLENGE:** Subsystems with separate acquisition clocks must be aligned in the data

Time matching between wire chambers and ToF PMTs

Note both offset and slope corrections

Stability improved with time, but still significant macroscope variations

After the fact synchronization can be achieved in the absence of common clocks

J. Ho
Challenge: Front End Configuration Upsets

Our most serious data collection problem was corruption of the front end preamp configurations, wreaking havoc with gains, filter times, offsets.

Take ASIC upset time as basis and look for closest LAr fill time.

Careful DAQ error logging and work with cryo group led to high correlation with LAr refills, noise induced on sense wires by liquid motion most likely.

Workaround: Have DAQ reinitialize front end after every spill.
Challenge: Search to Stamp Out noise

All detectors subject to various noise source – need fast, nimble tools to search and destroy: e.g. flexible pulse injection and wave form display

Stress test – all but one channel pulsing, note cross-talk pick-up at sharp rising and falling edges (cyan wave form should be zero)

Coherent noise – correlated or anticorrelated noise across adjacent channels

CAEN, LArIAT, D. Shooltz
LArIAT Trigger

• Several detectors means several possible trigger sources

• With long TPC time scale, fast light time scale:
  – Fast Trigger: Readout light, wire chamber, ToF, AeroGel (on V1751s), plus Wire Chambers’ TDCs
  – Delayed Trigger: Readout TPC, one readout window later
  – Allows time to veto TPC readout in case of pile-up or halo, saves bandwidth
  – Also allows intra-drift trigger, e.g. Michel electrons, more info

• Need flexible, programmable trigger
  – Implement trigger logic and scalers on user-programmable CAEN V1495 VME based FPGA card
  – Think CDF Fred or CMS GL1T, unusual for test beam
  – Configurable and readable over VME bus
  – Serves as final logic for several crates of NIM logic discriminating many detector signals
  – Provides prescale function to reduce high rate triggers

M. Kordosky, M. Stephens, J. Zhu
CAEN V1495 Card in situ, prior to cabling
Three 32 bit built-in logic I/O ports
One optional NIM input module

- 32 Trigger Input, twisted pair ECL (NIM to ECL)
- Reset Input on $00
- Fast and Delayed Trigger Output
- Trigger Counter and Trigger Path Identifier
  Send to V1740 for latching on trigger
  (synchronization check)
# 16 Typical Trigger Inputs

Above inputs can be specific in up to 16 trigger output paths, required ON or OFF.

<table>
<thead>
<tr>
<th>Input</th>
<th>Source</th>
<th>Input</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>WC1</td>
<td>Wire chamber up stream</td>
<td>HALO</td>
<td>Beam halo counters</td>
</tr>
<tr>
<td>WC2</td>
<td>Wire chamber 2</td>
<td>PULSER</td>
<td>Hardware pulser, testing</td>
</tr>
<tr>
<td>WC3</td>
<td>Wire chamber 3</td>
<td>COSMICON</td>
<td>Cosmic post-beam gate</td>
</tr>
<tr>
<td>WCC *</td>
<td>Wire chamber majority logic</td>
<td>COSMIC</td>
<td>Cosmic paddles</td>
</tr>
<tr>
<td>BEAMON</td>
<td>Spill beam gate</td>
<td>LARRY</td>
<td>Cosmic trigger with light</td>
</tr>
<tr>
<td>USTOF</td>
<td>Upstream Time of Flight</td>
<td>MICHEL</td>
<td>Michel electron</td>
</tr>
<tr>
<td>DSTOF</td>
<td>Downstream Time of Flight</td>
<td>LARSCINT</td>
<td>LAr scintillation light</td>
</tr>
<tr>
<td>PUNCH</td>
<td>Punch-through counter</td>
<td>MURS</td>
<td>Muon Range Stack</td>
</tr>
</tbody>
</table>

* WC exceptionally has majority logic, 3 / 4

Delayed trigger VETO uses same input logics with opposite logic.

All logic stored in LArIAT database available for offline use.
**Typical Trigger Output Paths**

Run 6373, near end of LArIAT Run 1 when things were quite stable
With 866 spills, > 14 hour run

<table>
<thead>
<tr>
<th>Path</th>
<th>Trigger Requirements ON</th>
<th>Required OFF</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>BEAMON+USTOF+DSTOF+WCC</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>BEAMON+USTOF+DSTOF+WCC+PUNCH+MURS</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>BEAMON+USTOF+DSTOF+WCC+PUNCH</td>
<td>-MURS</td>
</tr>
<tr>
<td>4</td>
<td>BEAMON+USTOF+DSTOF+WCC+MURS</td>
<td>-PUNCH</td>
</tr>
<tr>
<td>5</td>
<td>COSMIC</td>
<td>-BEAMON</td>
</tr>
<tr>
<td>6</td>
<td>LARRY</td>
<td>-BEAMON</td>
</tr>
</tbody>
</table>

The delayed trigger VETO function was not normally required but remains available for run 3 in 2017
Thanks!

Both physics and technical knowledge already benefiting future neutrino experiments
Run 1 2015, Run 2 2016
Looking forward to run 3 in 2017 with new sense planes and more

This talk represents hard work from many people on LArIAT

LArIAT: The little detector with a big heart, out standing in the field
Backup Slides
LArIAT Readout Kernel

- Configuration and Readout factorized by C++ classes per subsystem, using OO inheritance to simplify coding
  - Each subsystem class outputs Lariat specific data fragments
- Main LariatReadout class conducts configuration and readout
  - Monitors triggers via interrupts and polling
  - Watches for spill status in order to cleanup and end and restart
- LArIAT kernel wrapped into *ArtDaq* Boardreader class
  - Lariat_generator extends LariatReadout
  - Wraps all Lariat specific fragments into one *ArtDaq* Fragment per spill
  - Converts raw binary to Root object readable by Art and LArSoft
LArIAT Data Fragments

Class names and contents, produced by LariatReadout, defined in shared online and offline package 
*LariatFragments*

**V1740Fragment**
- TPC wires’ wave forms
- Trigger hit timing digital wave form
- Muon Range Stack

**V1751Fragment**
- ToF, AeroGel, Light Collection (PMTs, SiPMS)

**V1495Fragment**
- Trigger counters and configuration

**TriggerFragment**
- Pipeline of all trigger input pattern, including time stamps

**WUTFragment**
- High precision ToF hit times

**TDCFragment**
- Beam wire chambers’ hit times

NB: At this level, each fragment is *asynchronous* to the others and time slicing takes place down stream (see later talk). At readout time, all fragments from one spill are concatenated into one ArtDaq Fragment. See backup slides for synchronization demonstration.
• Demand for online computing modest but critical
• One 8 core for configuration, readout, archiving
  – Install CAEN A3818 four channel optical bridge (large)
  – Locally cache at least one week of data (more in reality)
• One 8 core for online data quality monitoring
  – Need one minute feedback for beam and detector conditions
  – Redundant power, redundant disk (thanks, SLAM group!)
• Hot backups for each function
• Two thin gateways for access
• Strong firewall to access main DAQ, DQM per FNAL and DoE security requirements (unusual for test beam)
Simplified Trigger Logic

- 32 arbitrary external NIM inputs on the left
- Input latch and counters at 100 MHz × 2
- 16 coincidence logic units trigger paths
- OR of paths indicates fast trigger
- Delay, plus NOT VETO indicates delayed trigger
- Record triggers + times in FIFO for VME readout
Real Time Data Quality Monitoring

As always, fast, real-time data quality monitoring (DQM) critical to successful experiment operations.

As data are taken, raw data are *rsynced* to dedicate DQM server from DAQ.

Data are analyzed and plots produced, viewable in sophisticated web interface, example to the left.

J. Ho