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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Online Computing Track 1.5, Contribution 546
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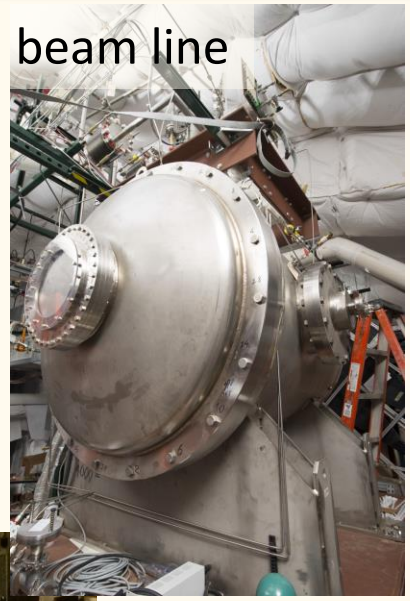
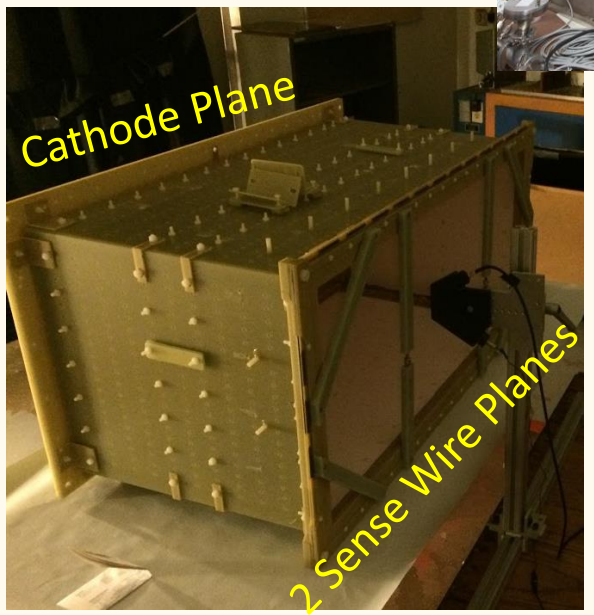
The LArIAT Experiment

- Repurposed ArgoNeut cryostat and time projection chamber TPC
- Tertiary beam from the Fermilab Main Injector, historic MCenter beam line
- Many species: μ π γ 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 ν 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…

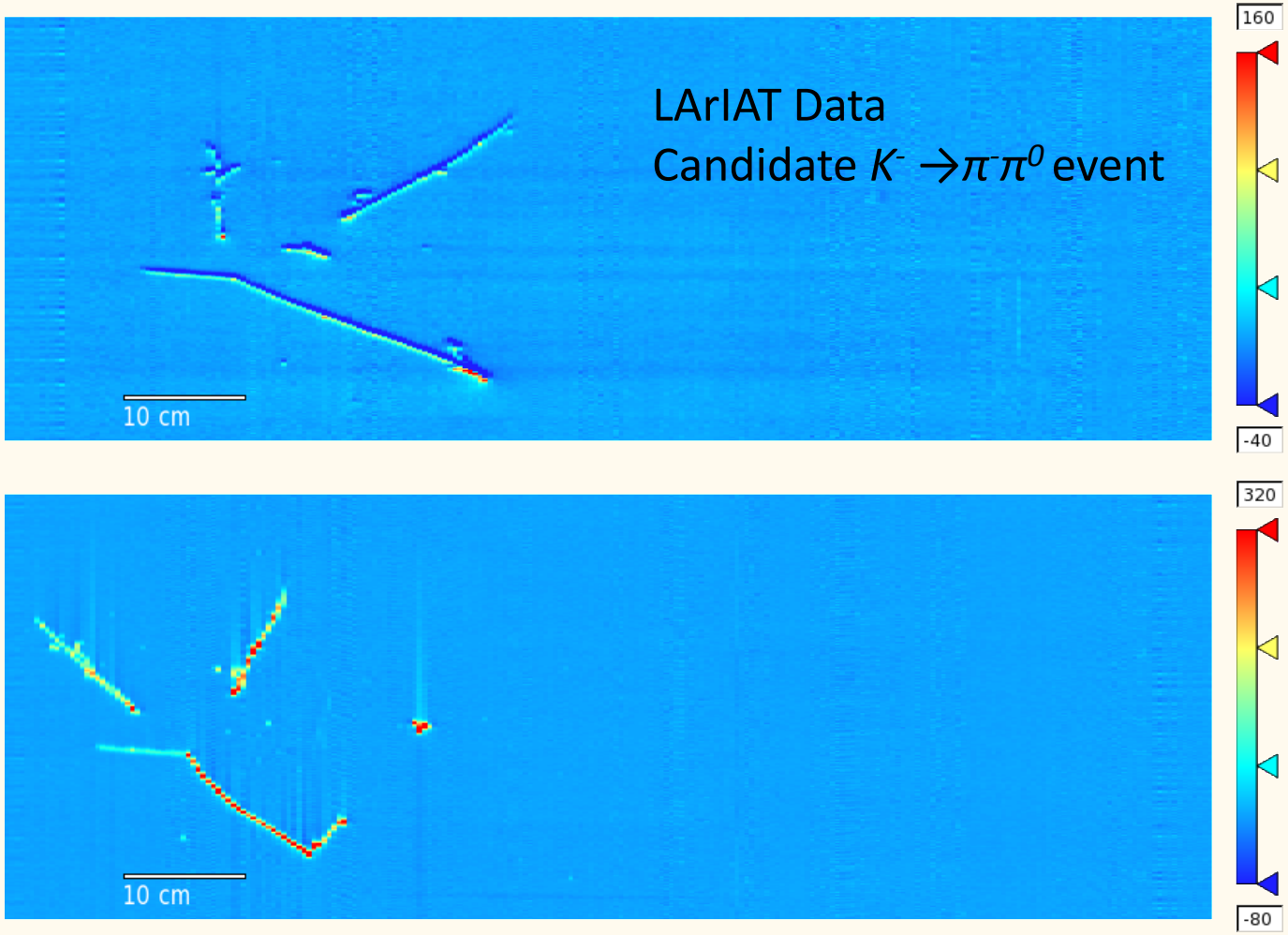
Cryostat in beam line



TPC, before installation

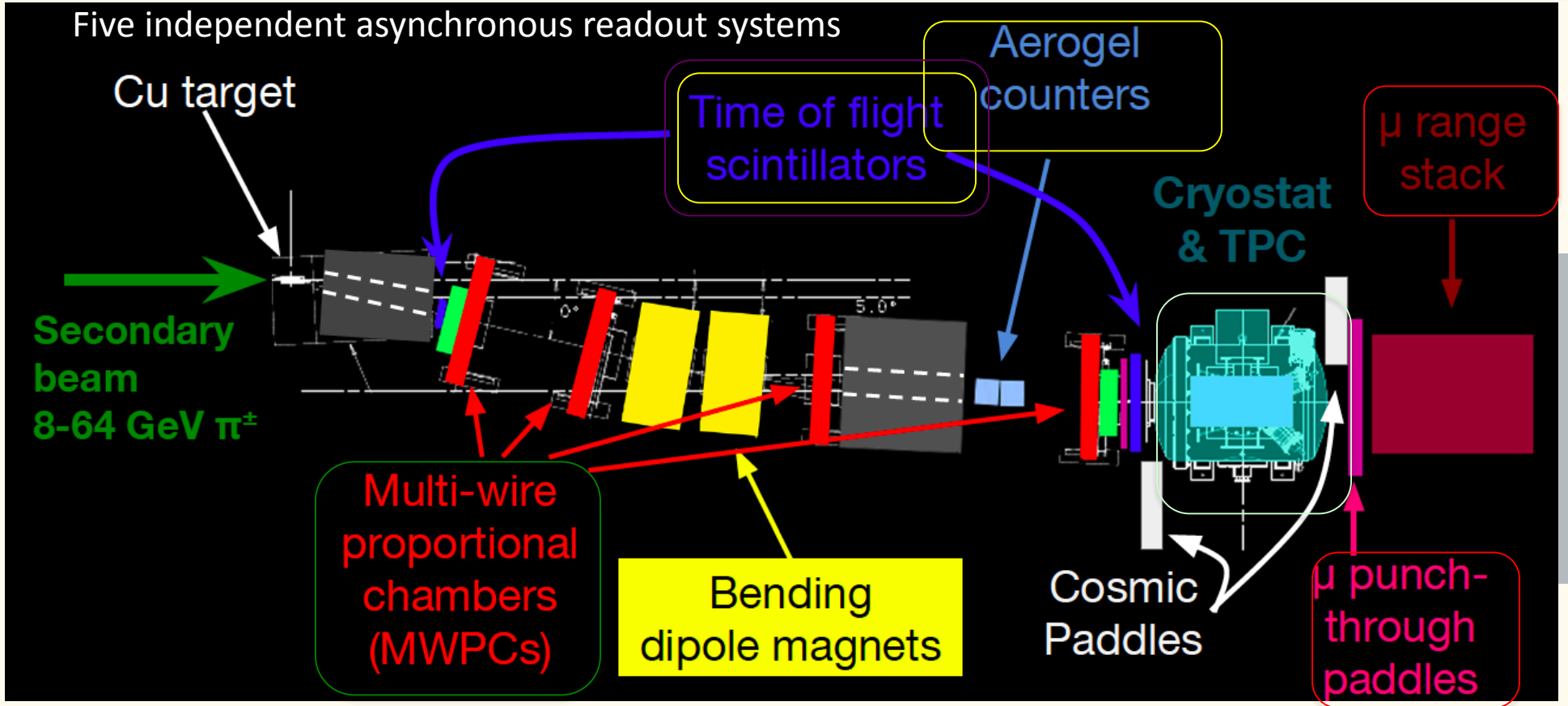


The LArIAT Time Projection Chamber



- 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



Several independent detector systems with specialty readout and independent clocks

FTBF TDCs 1.2ns

V1751 1nsec

V1740 128nsec

V1740 128ns

WUT 15psec

Tasks:
"Configure, Trigger, Readout, Build and Write"

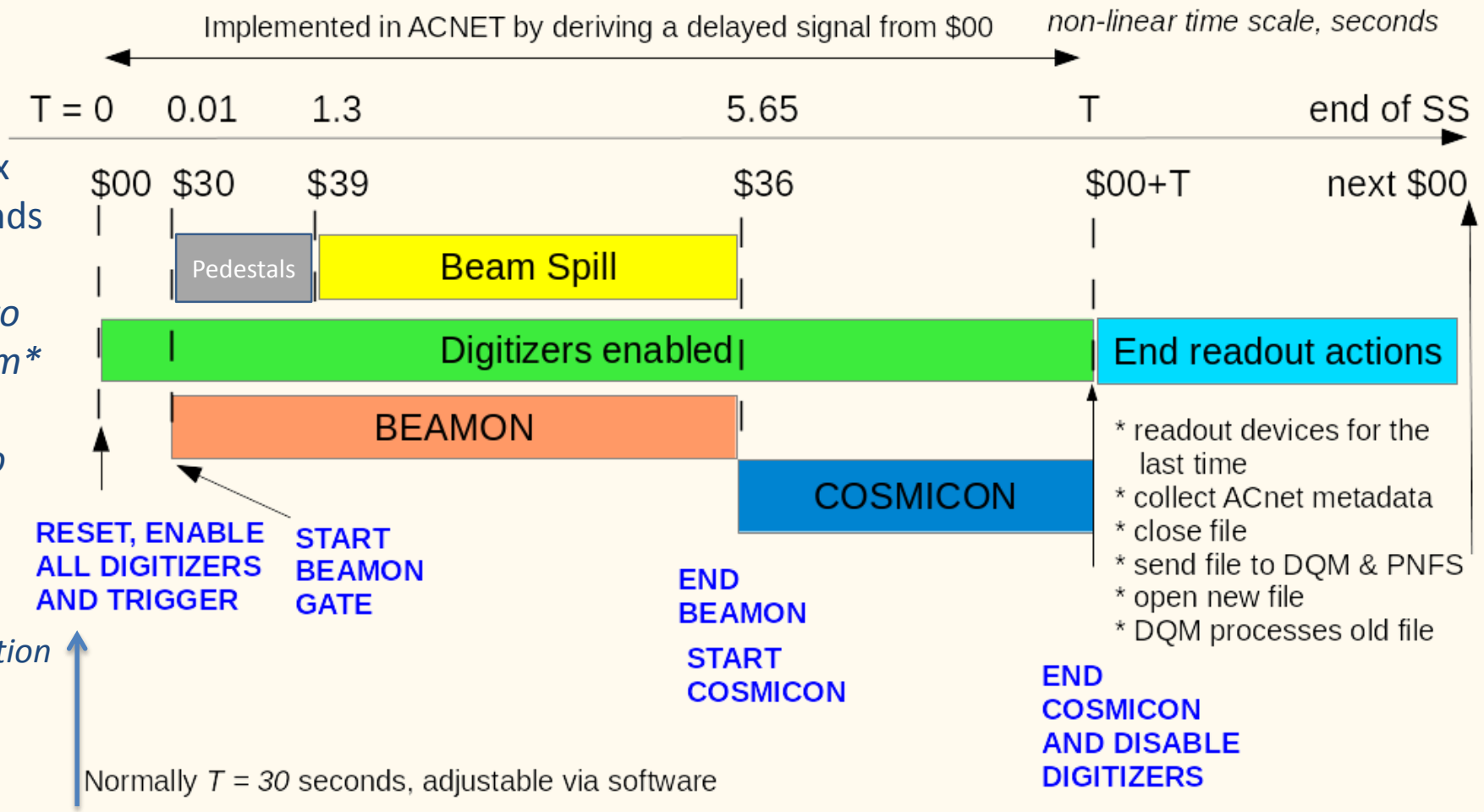
Beam and DAQ+Trigger Timing

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*



$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 wave form 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

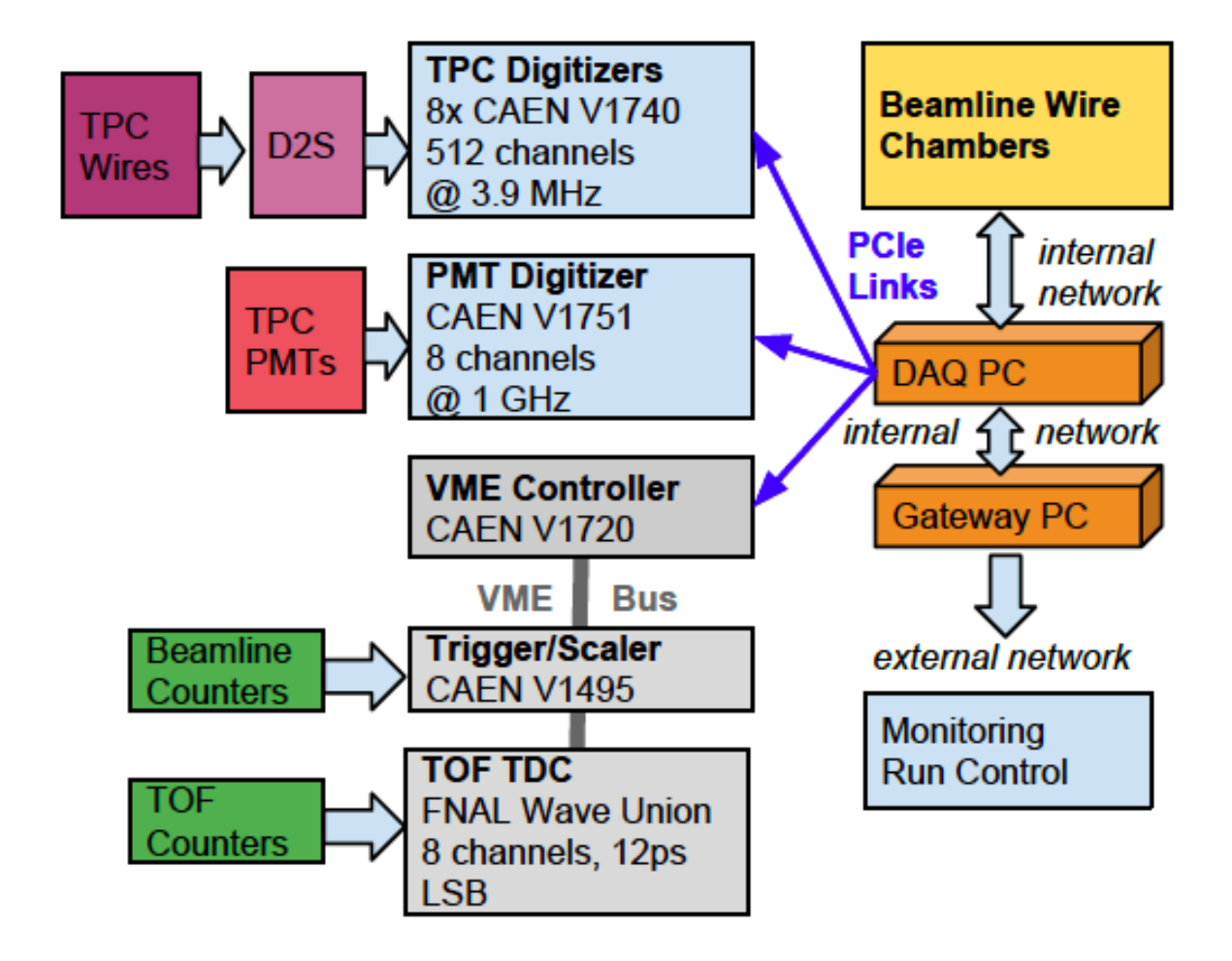
A3818

- 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

WUT

- TPC *contra mundum*
  - Two very different time scales ➔ fast and slow triggers!

Data Flow Diagram



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

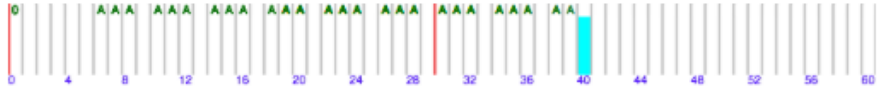
DAQ Software

- *"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

lariat-wbm.fnal.gov

LArIAT Run Status



Run	6099	Spill	160
V1740 Run Triggers	815	V1740 Spill Triggers	4
V1751 Run Triggers	1241	V1751 Spill Triggers	18
SpillActive	0	RunActive	1
MCenter Energy	15.998 GeV	MCenter Intensity	7.74E9 ppp
MC7SC1	1.406E5 Cnts	MC7 Magnet	0.031 amps [59.998 amps]
DiskSpaceUsed, %	38.86	SuperCycle Time	40.533 SEC
LAr Temperature	90.6 degK	LAr Level	4.636 InAr
Time	2015.06.11-17:31:00	Complete Files Waiting	1
Components	V1740 V1751 V2781 V1495 TDC WUT LARASIC		

Trigger Inputs

WC1IGNOREME	6602	WC2IGNOREME	5046
WC3IGNOREME	2562	WCCOINC3OF4	1925
BEAMON	1	USTOF	8401
DSTOF	1834	PUNCH	20667
HALO	4749	PULSER	293
COSMICON	1	COSMIC	966
PILEUP	757	MICHEL	2797
LARSCINT	17795	MURS	6170

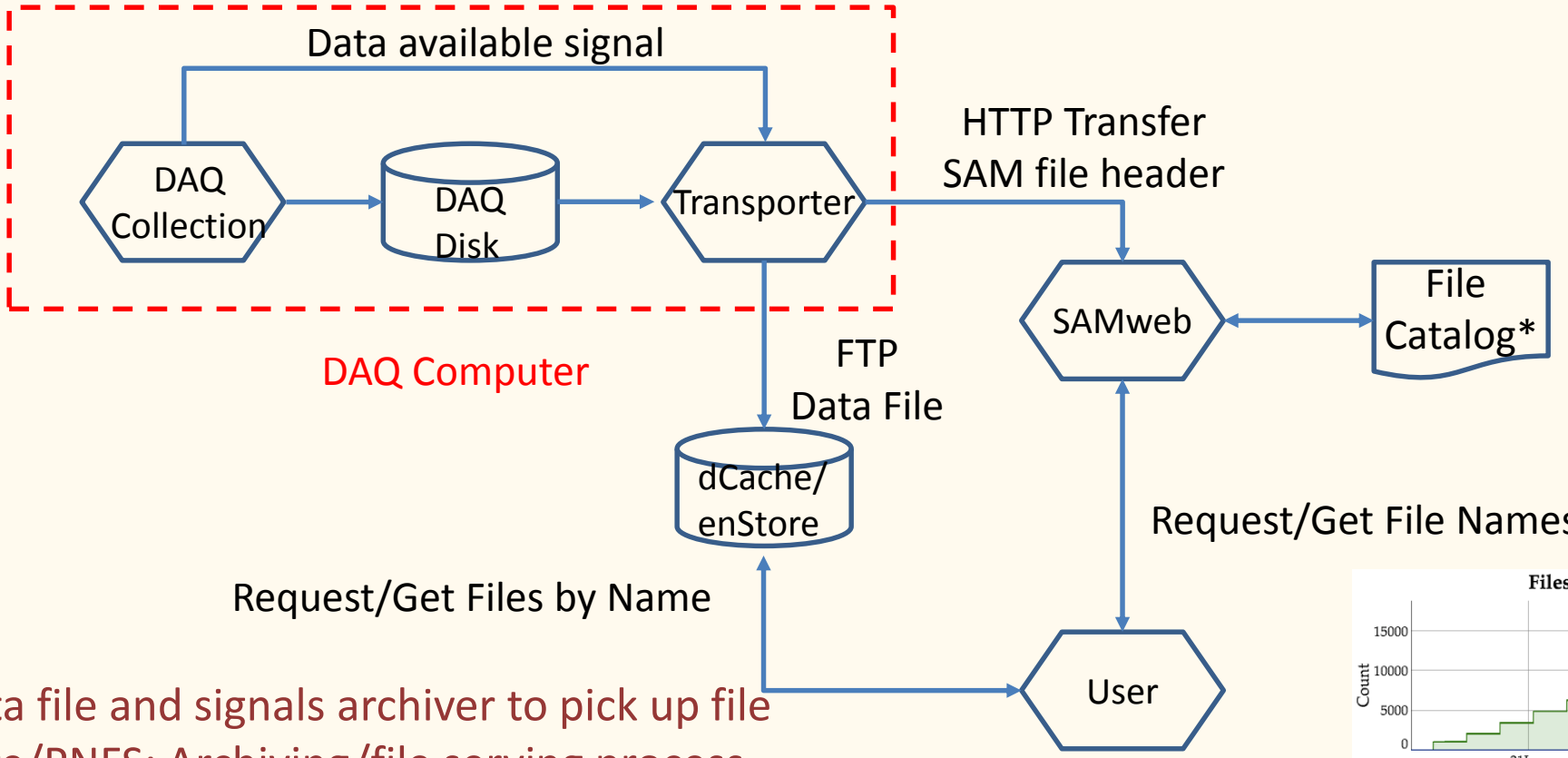
Trigger Output Paths

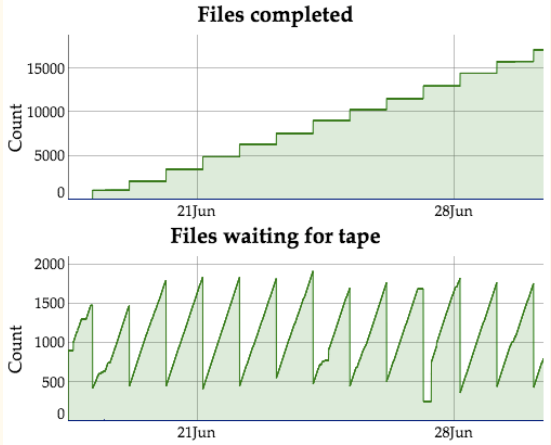
BEAMON USTOF DSTOF WCCOINC3OF4 ~ PUNCH MURS	16	BEAMON USTOF DSTOF WCCOINC3OF4 PUNCH MURS ~	7
BEAMON USTOF DSTOF WCCOINC3OF4 PUNCH ~ MURS	14	BEAMON USTOF DSTOF WCCOINC3OF4 MURS ~ PUNCH	3
COSMICON COSMIC ~	0	MICHEL ~ BEAMON	6

Veto Output Paths

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

Data Archiving

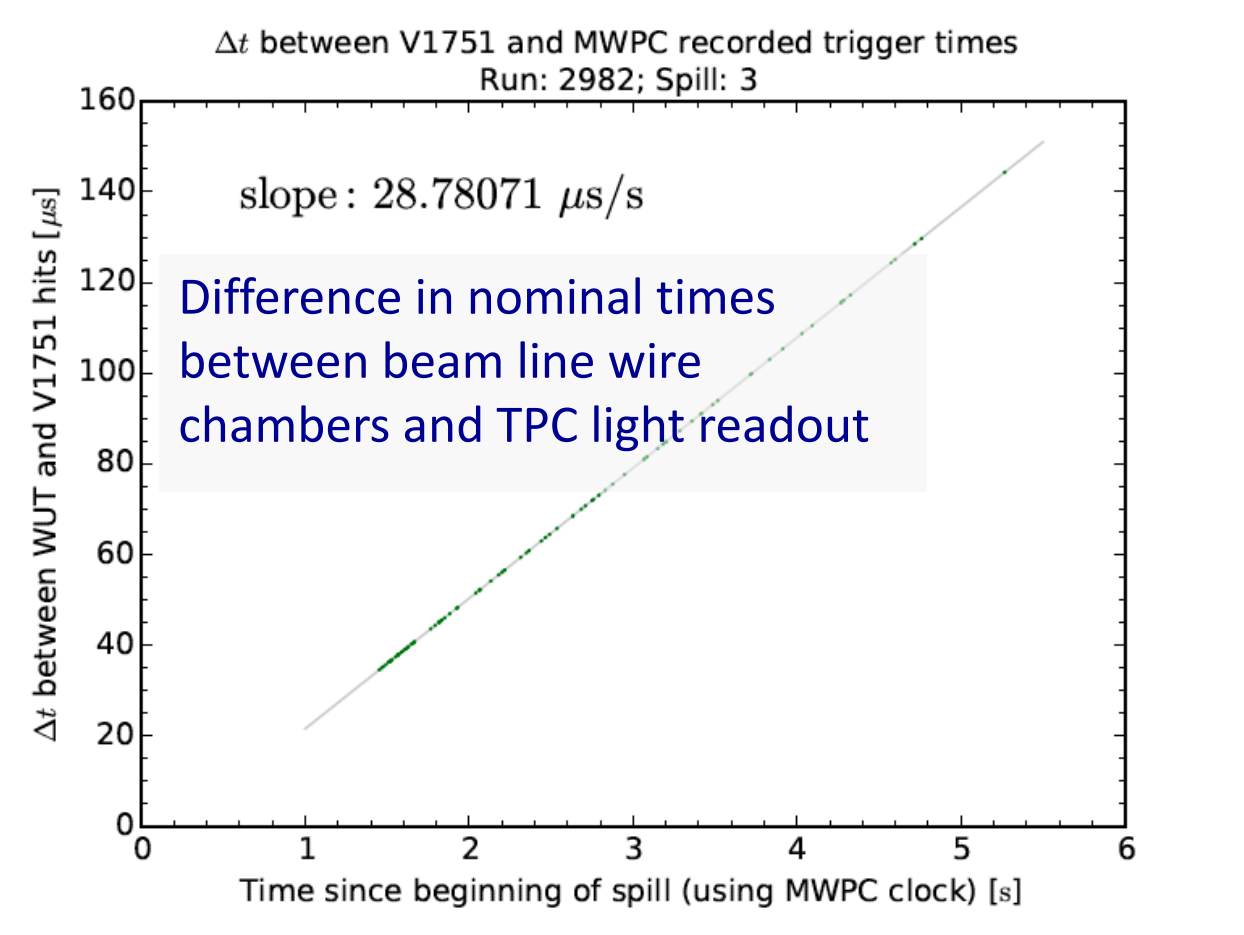


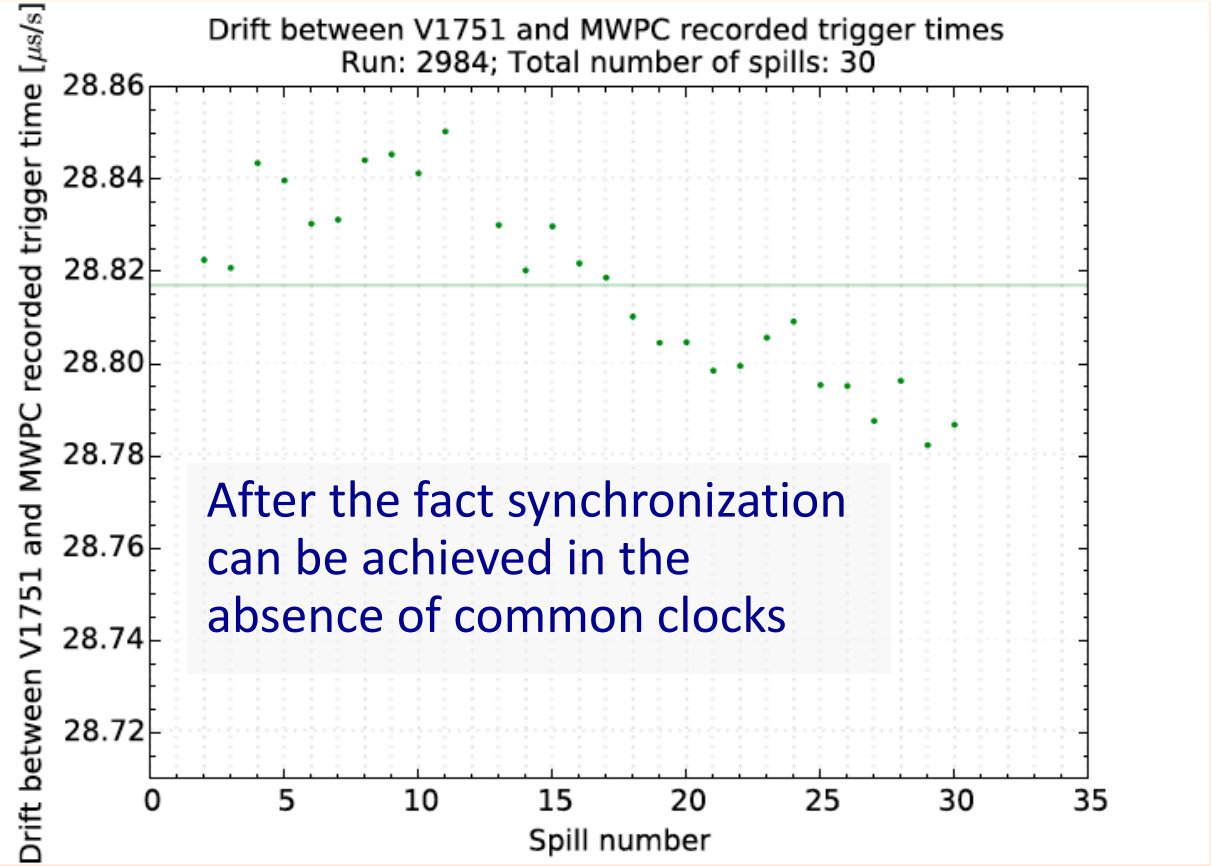


- DAQ closes data file and signals archiver to pick up file
- dCache/enStore/PNFS: Archiving/file serving process
- SAM: Cataloging / description / metadata process
- Uses standard Fermilab FTS file transport service
- Data files easily retrievable via simple SAM queries

R. Johnson, J. St. John

Challenge: Cross-Detector Synchronization



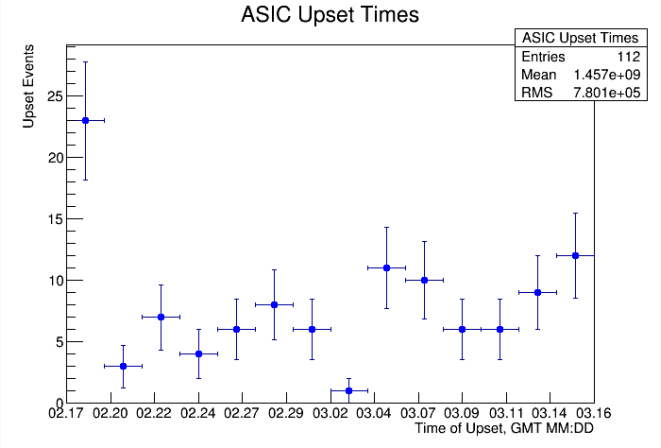


J. Ho

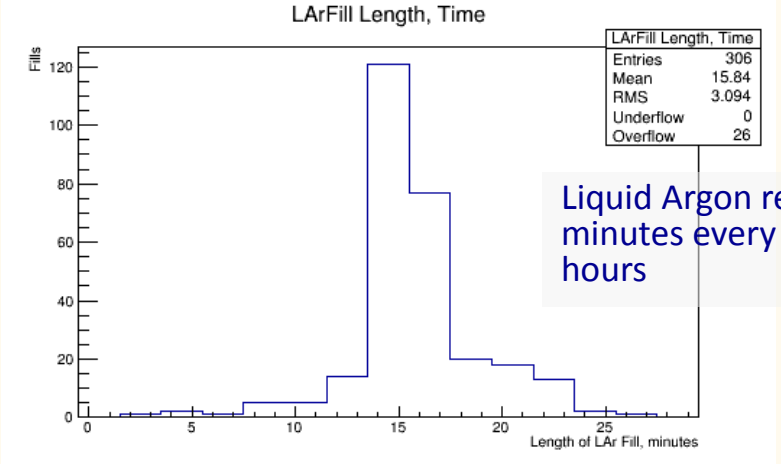
CHALLENGE: Subsystems with separate acquisition clocks must be aligned in the data

Time matching between wire chambers and ToF PMTs
Note *both* offset and slope corrections
Stability improved with time, but still significant macroscope variations

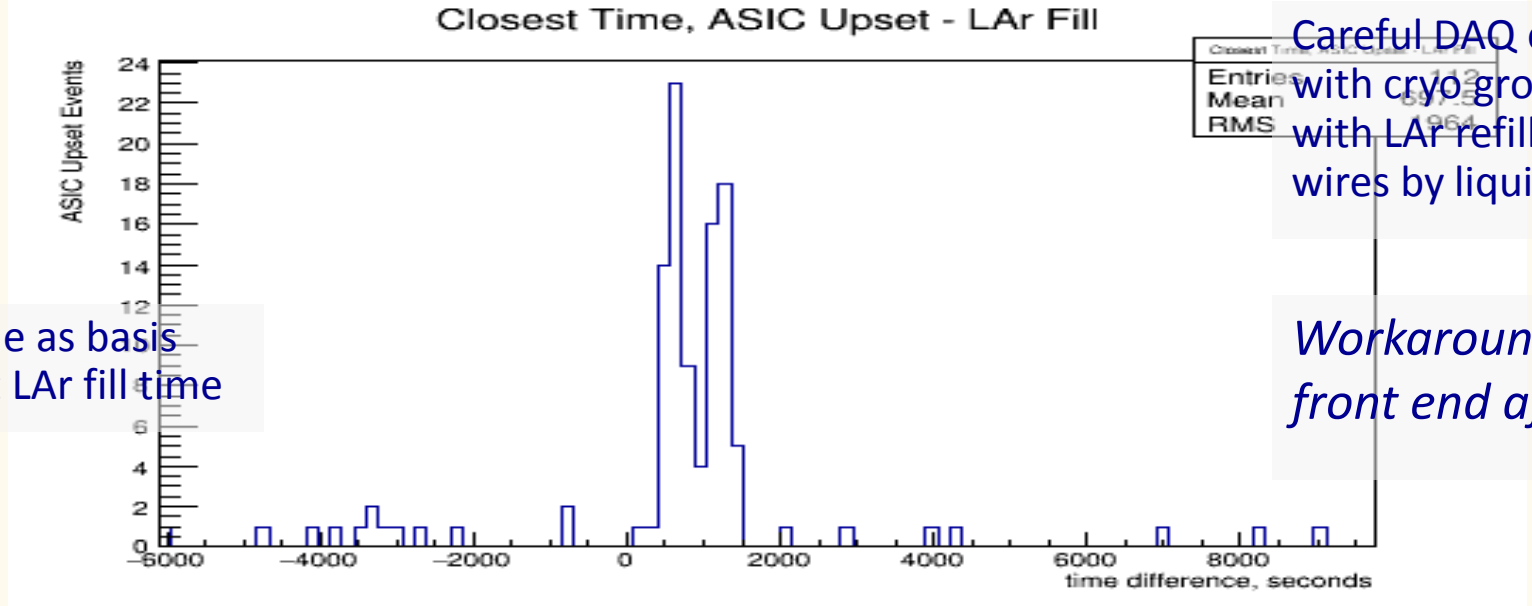
Challenge: Front End Configuration Upsets



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



Liquid Argon refills 15 minutes every 3 or 4 hours

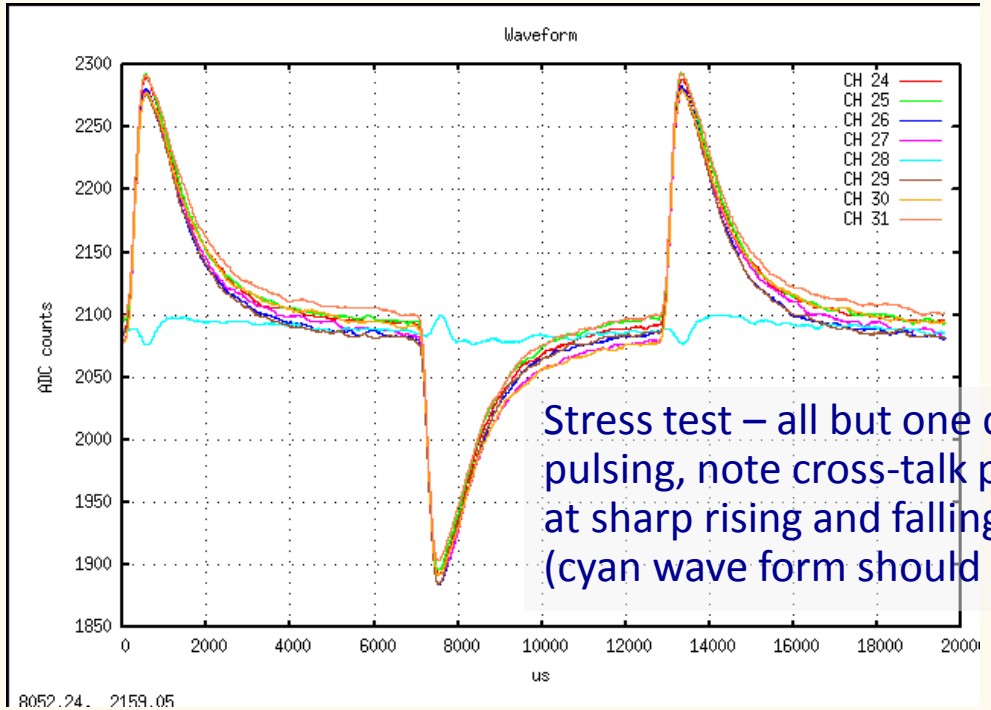


Careful DAQ error logging and work with cryo group led to high correlation with LAr refills, noise induced on sense wires by liquid motion most likely

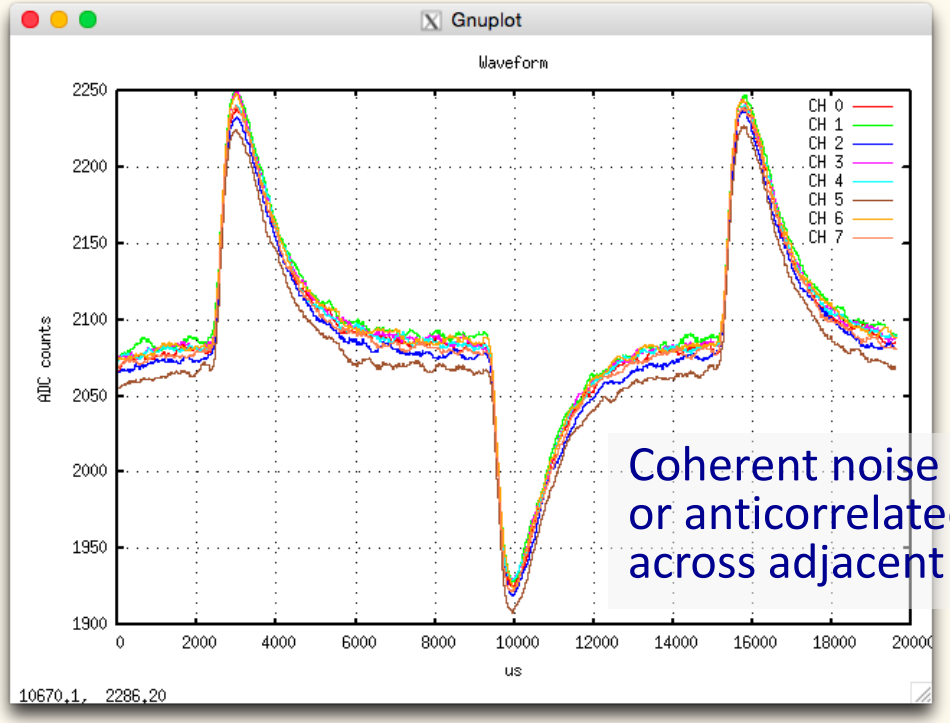
Take ASIC upset time as basis and look for closest LAr fill time

Workaround: Have DAQ reinitialize front end after every spill

Challenge: Search to Stamp Out noise



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

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

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

V1495 Trigger Card

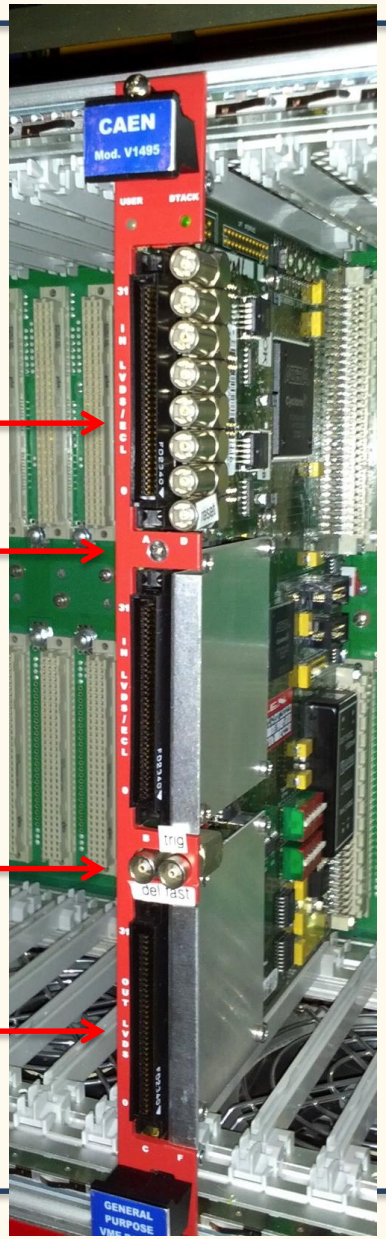
CAEN V1495 Card in situ, prior to cabling
Three 32 bit built-in logic I/O ports
One optional NIM input module

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

Delayed trigger VETO uses same input logics with opposite logic

All logic stored in LArIAT database available for offline use

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

* WC exceptionally has majority logic, 3 / 4

Typical Trigger Output Paths

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

Path	Trigger Requirements ON	Required OFF
1	BEAMON+USTOF+DSTOF+WCC	
2	BEAMON+USTOF+DSTOF+WCC+PUNCH+MURS	
3	BEAMON+USTOF+DSTOF+WCC+PUNCH	-MURS
4	BEAMON+USTOF+DSTOF+WCC+MURS	-PUNCH
5	COSMIC	-BEAMON
6	LARRY	-BEAMON

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

DAQ Software, Details

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

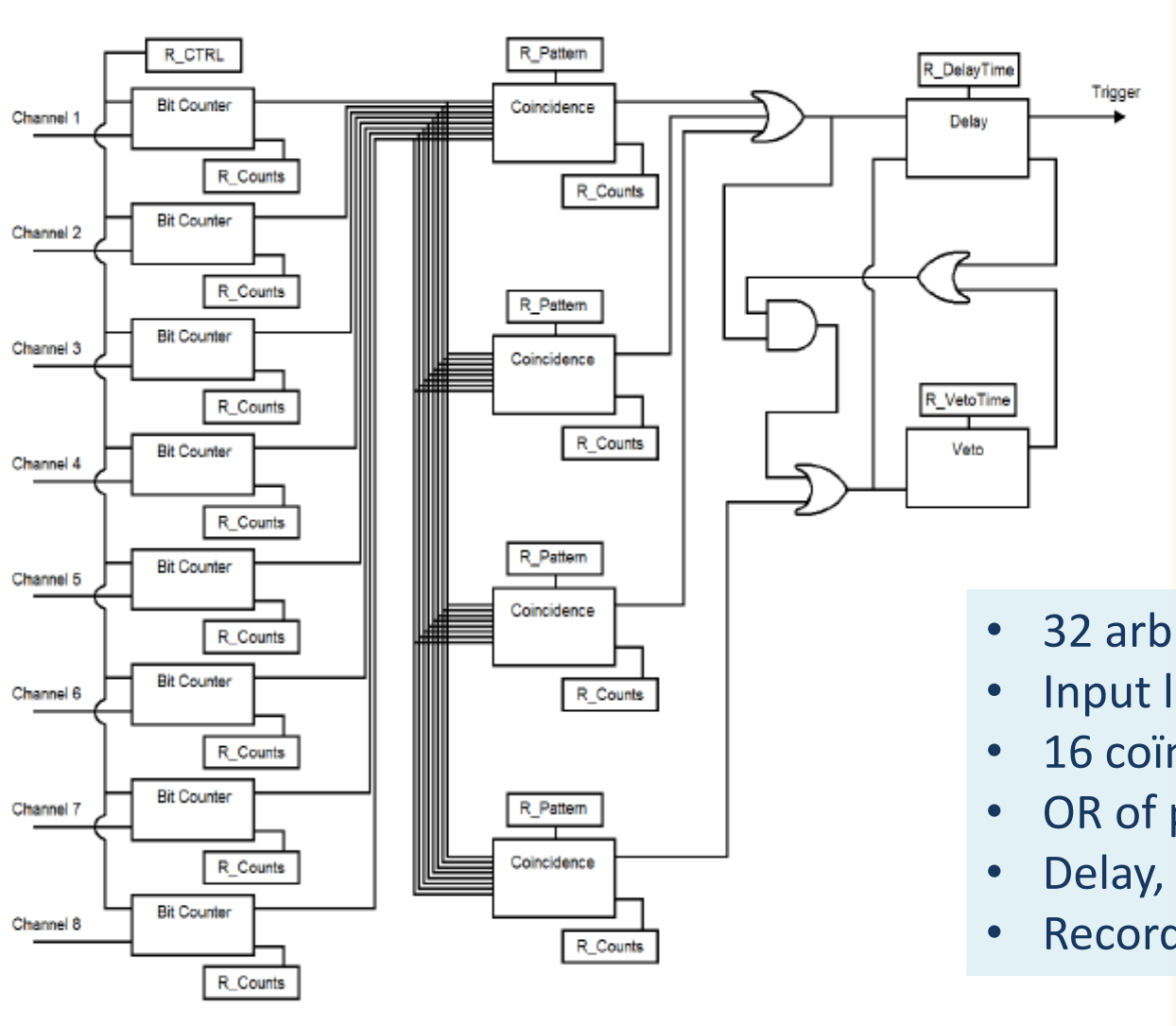
- Beam wire chambers' hit times

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.

Online Computing

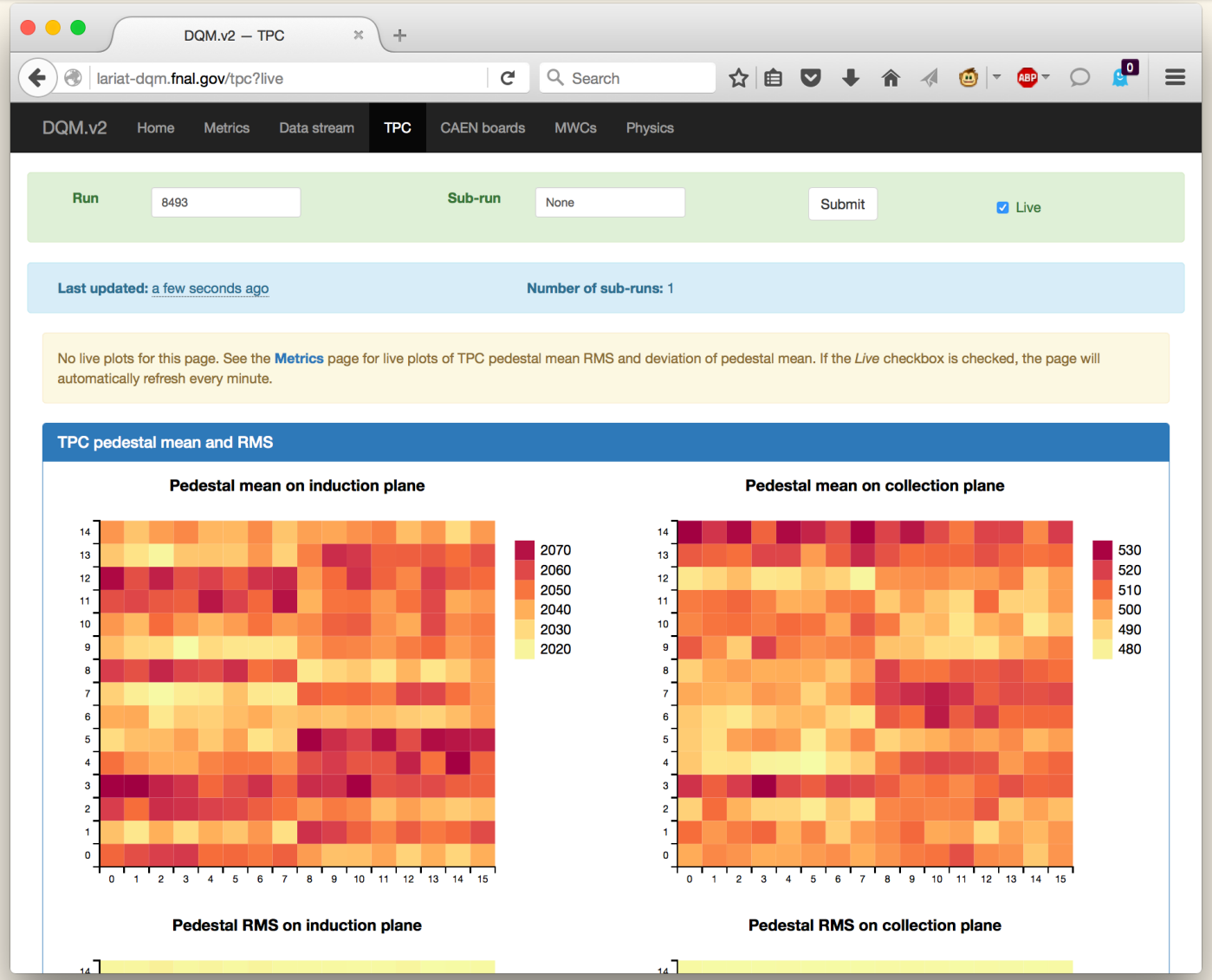
- Demand for online computing modest but critical
- One 8 core for configuration, readout, archiving
  - Install CAEN A3818 four channel optical bridge (large)
  - Locally cache at least one week of data (more in reality)
- One 8 core for *online* data quality monitoring
  - Need one minute feedback 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 coïncidence 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