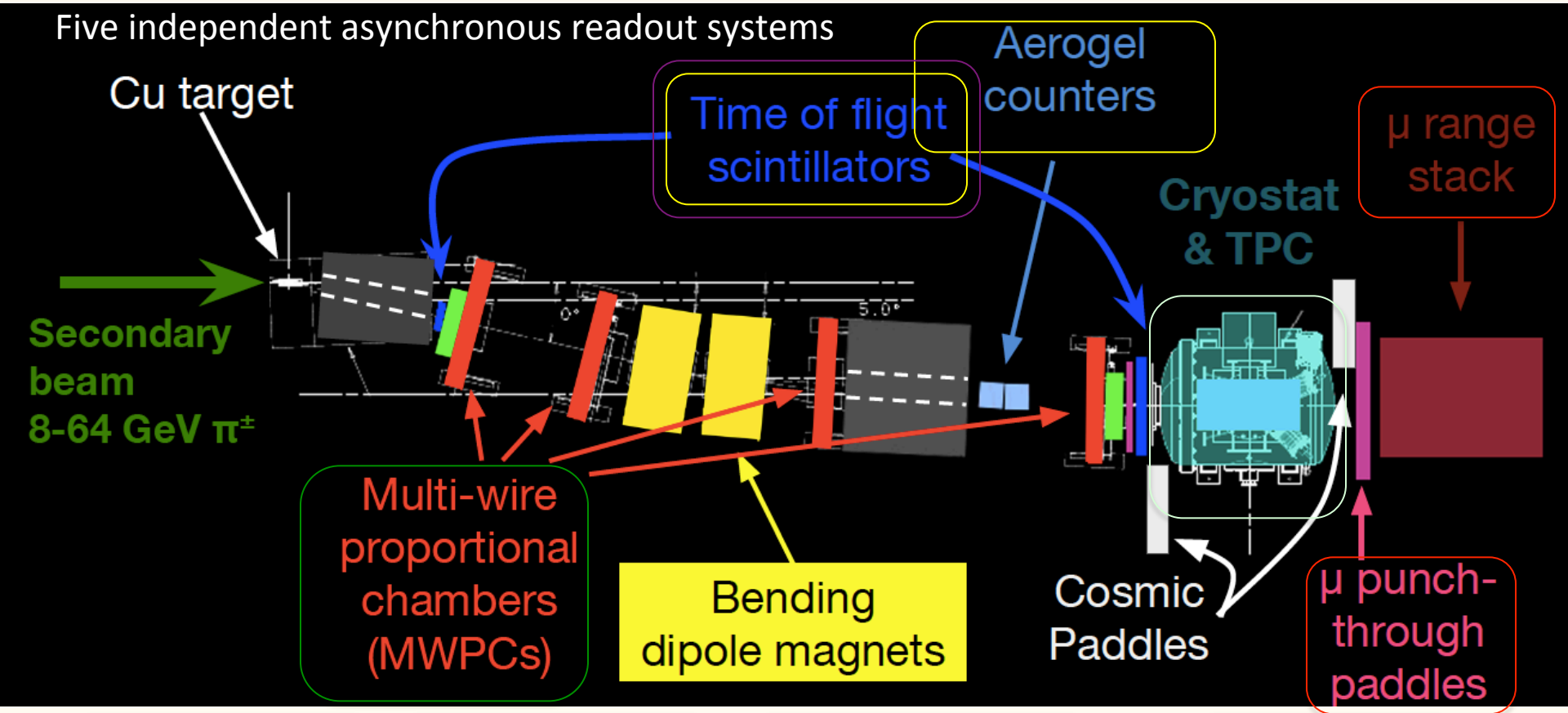
LArIAT T-1034 Operational Readiness Review

Data Acquisition and Trigger

William Badgett
Fermilab

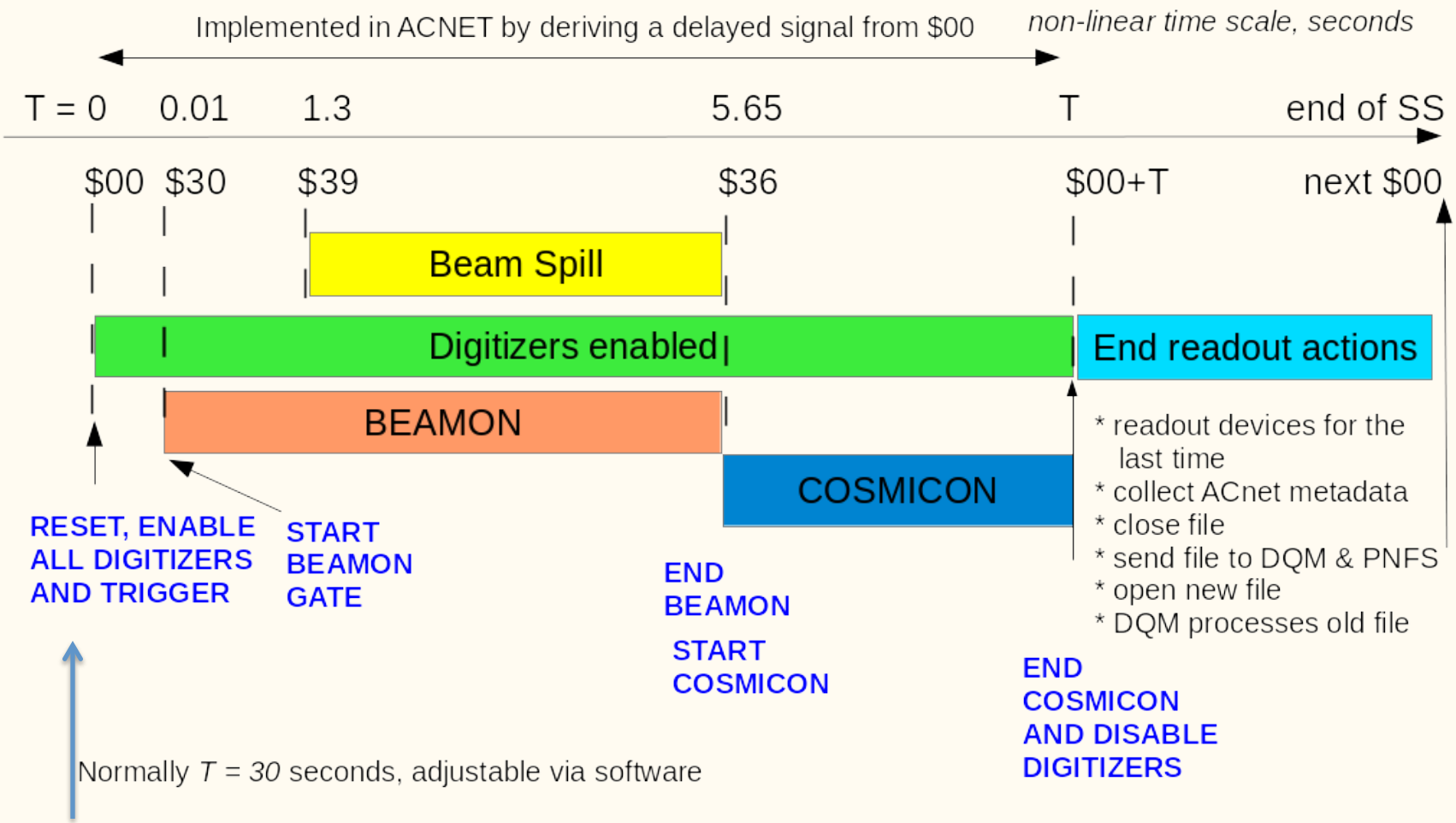
on behalf of
The LArIAT Collaboration

DAQ Top View



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

Beam and DAQ+Trigger Timing



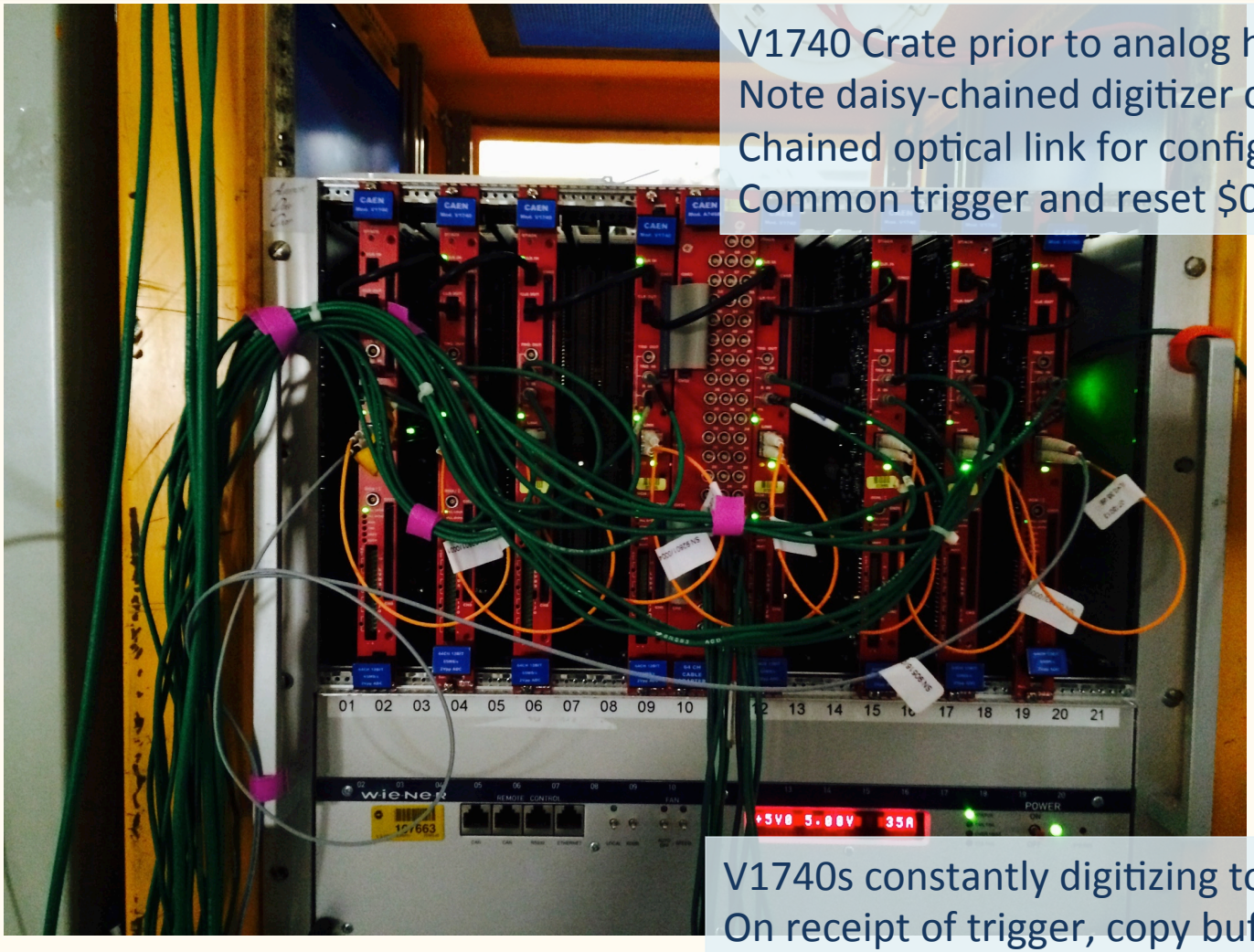
$00 *All systems and data fragments synchronized to $00 start of each super cycle*

BEAMON and COSMICON are inputs to trigger

Requirements & Solutions

- Have 4.2 second window beam spill + 24 seconds cosmics every 60 second super cycle
- *Cannot* read every sample without custom readout hw $$$
- Must have triggered system handle ~ 100 – 200 triggers/spill
- 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
- 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

V1740s constantly digitizing to circular buffer
On receipt of trigger, copy buffer to memory location
Ready immediately for subsequent trigger

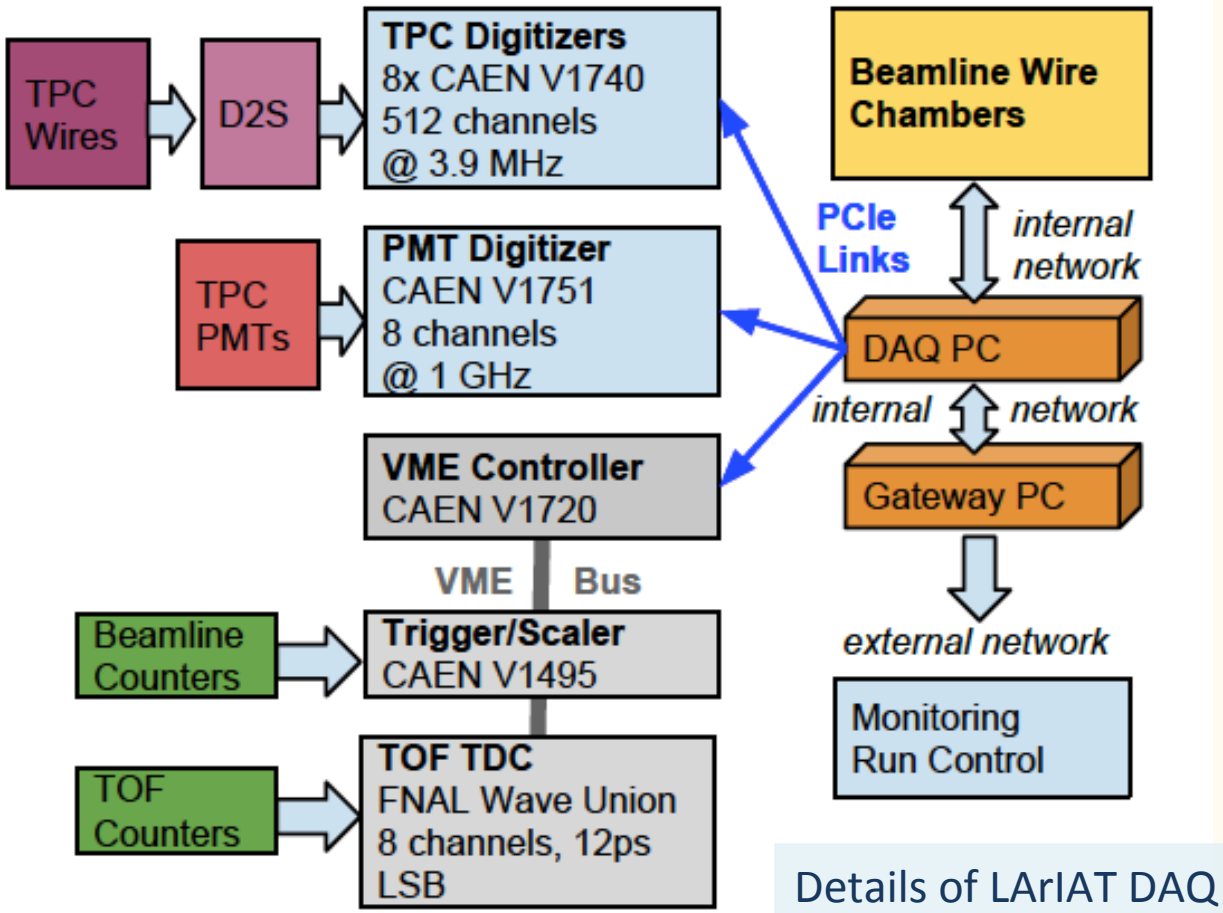
Beam line and Light Collection

- 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!

Data Flow Diagram



Details of LArIAT DAQ Readout Data Flow
Several external sources read and collated by single event builder “DAQ PC”

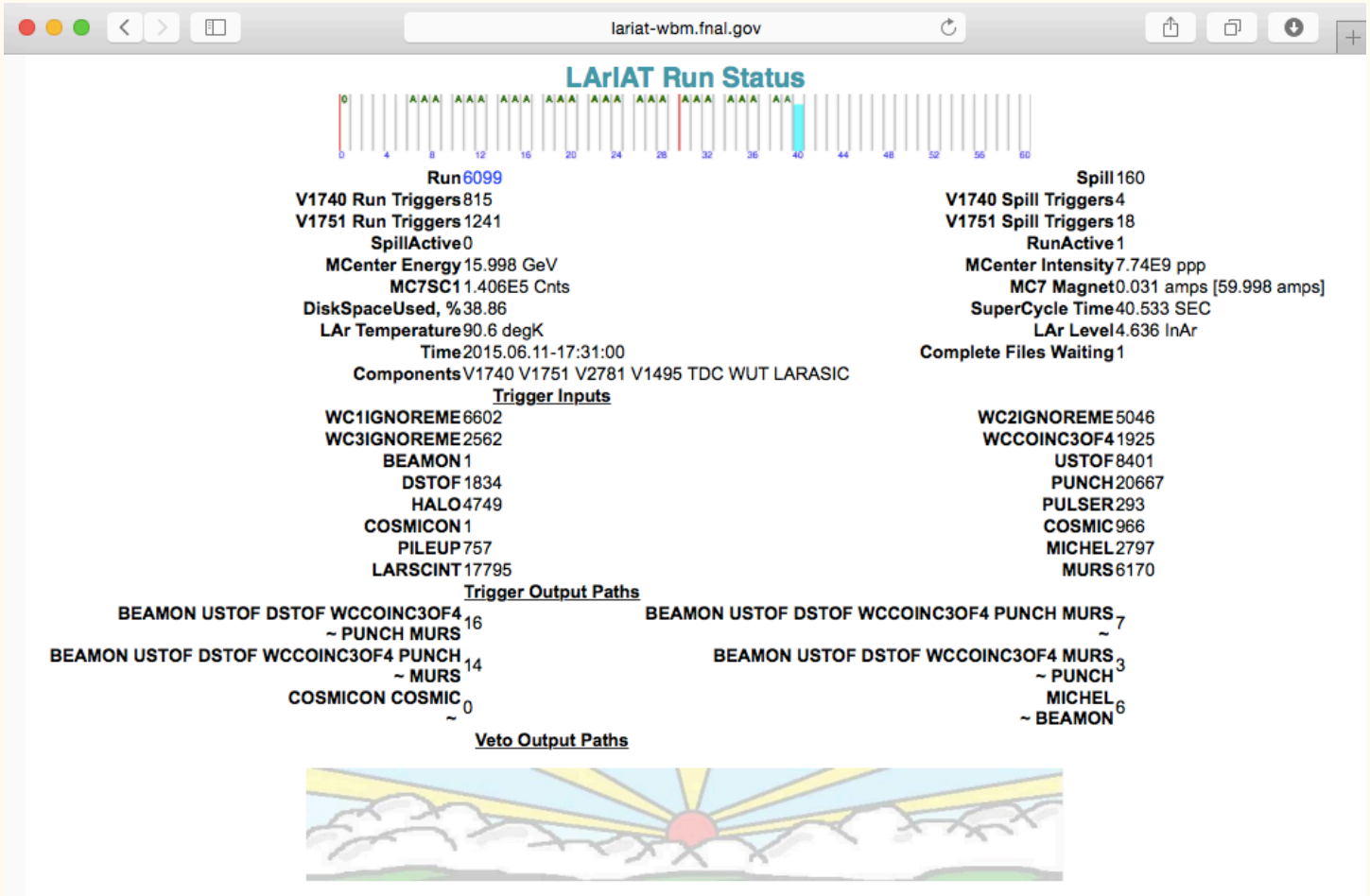
Online Computing

- 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)

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

LArIAT Run Status



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

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

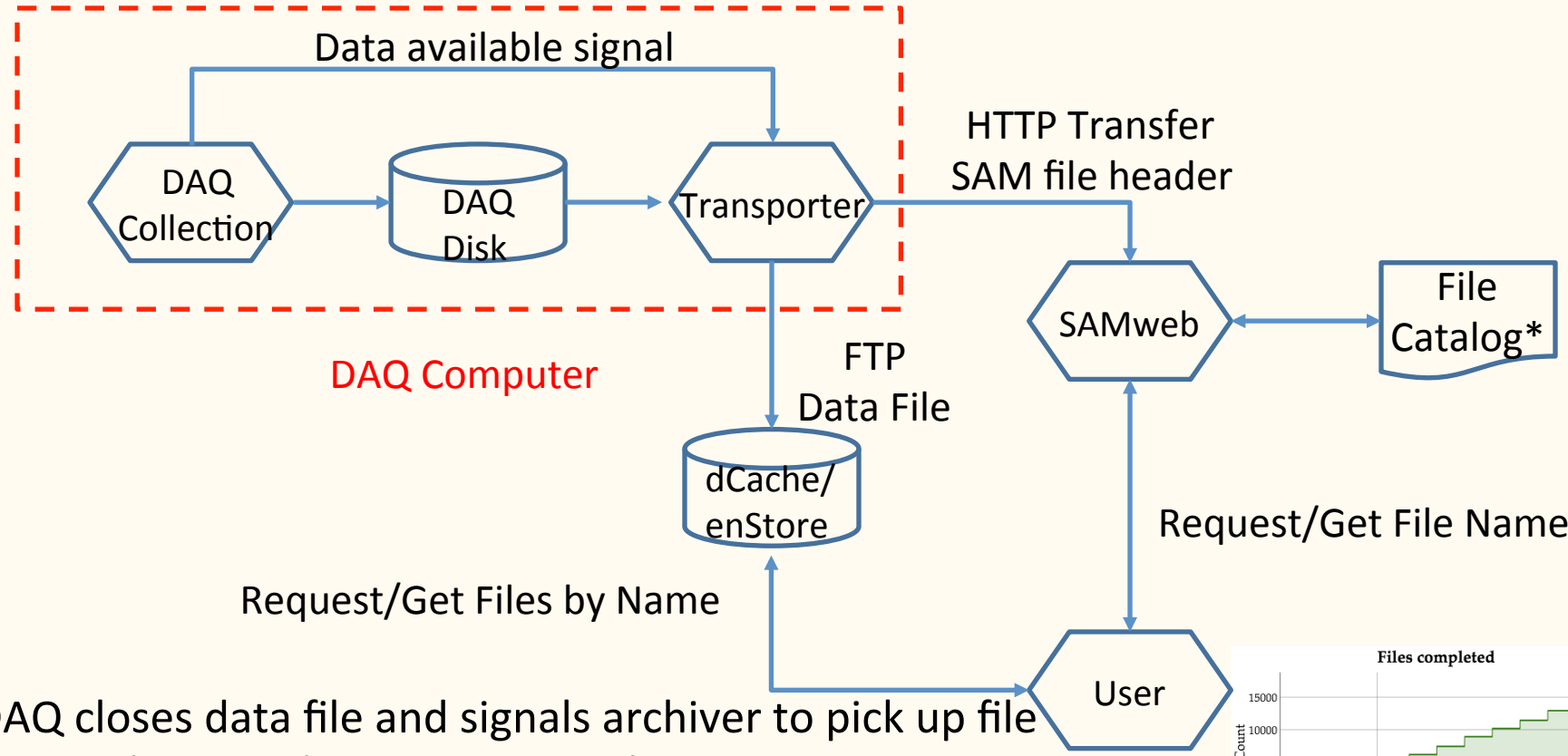
TriggerFragment
- Pipeline of all trigger input pattern, including time stamps

WUTFragment
- High precision ToF hit times

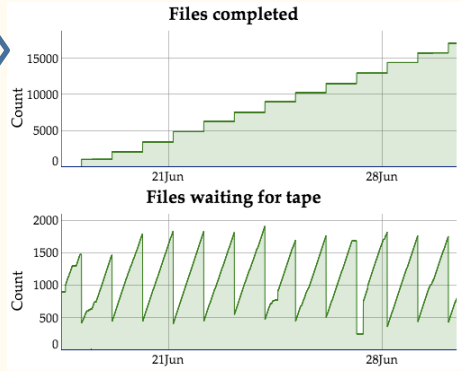
TDCFragment
- Beam wire chambers' hit times

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.

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



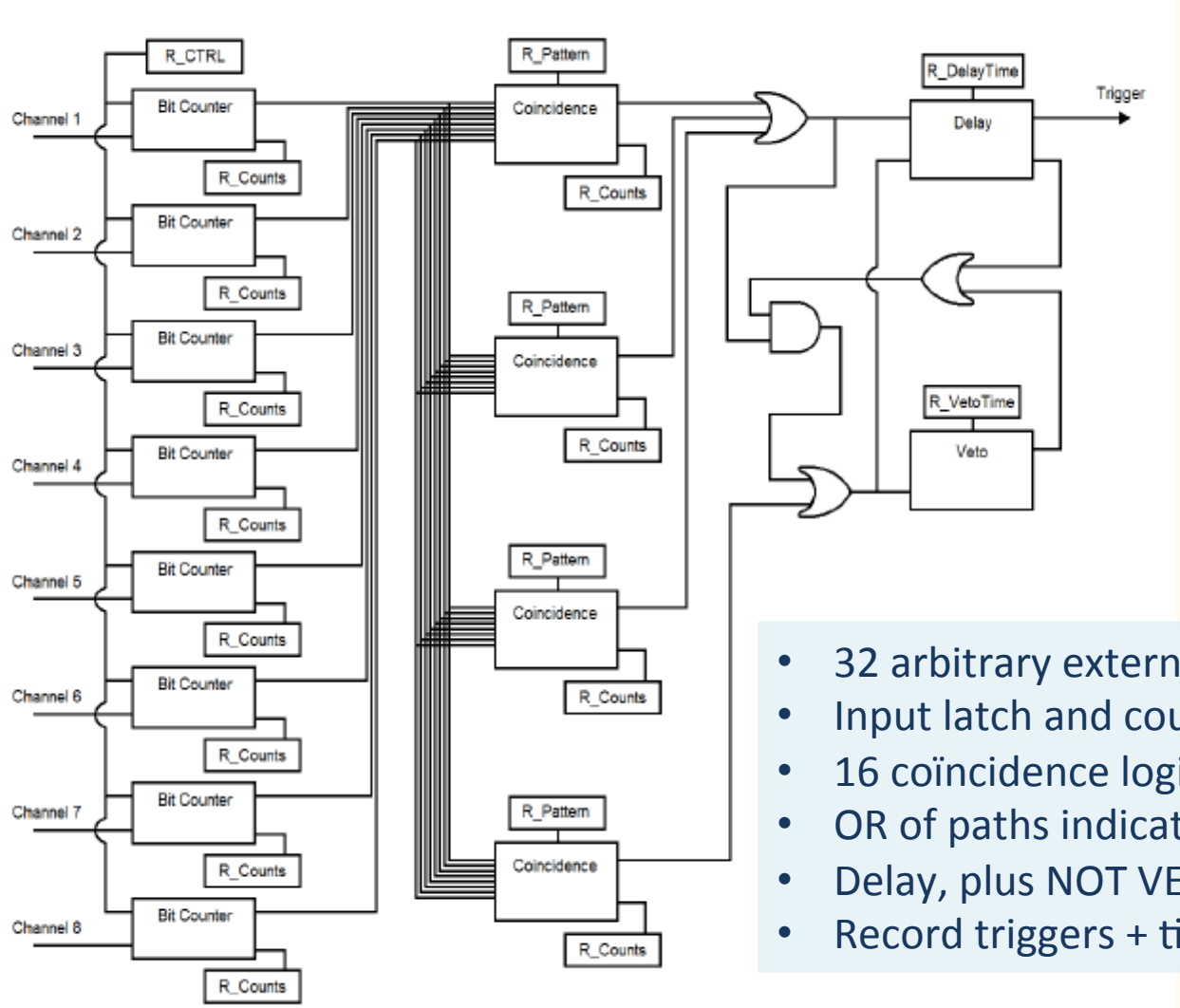
DAQ Hiccups in Run 1

- Getting new and existing futures on the CAEN digitizers involved months of iterative debugging and fixes
  - Most issues solved prior to Run 1
- Remaining issues, CAEN V1740 and V1751 digitizers
  - Occasional event counter mismatches, expect BUSY mechanism to help
  - Pedestal jumps on V1751s – "ameliorated" by register retries
  - Found unexpected V1740 post-trigger dead-time – fixed by CAEN
  - Rare readout hang-ups < 0.1%
- Wire Chamber TDC readout
  - Occasional loss of configuration registers
  - Regular failure of basic data sanity checks, data nonsense
  - Text based interfaced to TDC controller not reliable – losing bytes

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

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

V1495 Trigger Card

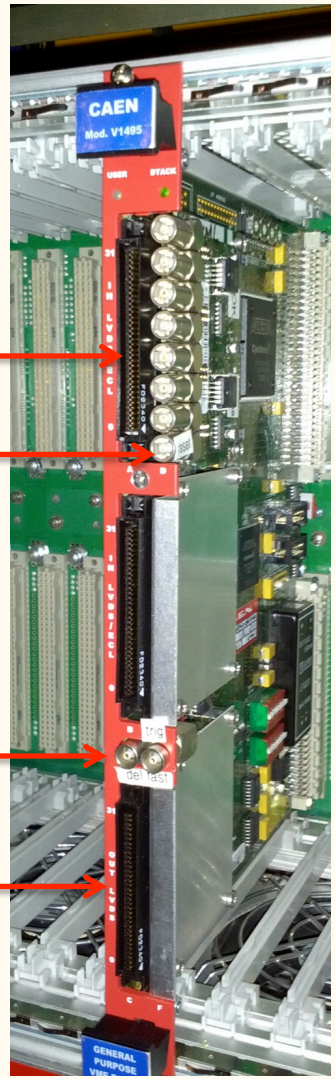
CAEN V1495 Card in situ, prior to cabling
Three 32 bit built-in logic I/O ports
One optional NIM input module

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

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

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

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
Run 2 we will use a BUSY function in the VETO logic

Trigger Running Experience

- Generally excellent reliability and functionality
  - Firmware code often difficult to understand – most problems related to us not understanding the logic
  - Flaws with the PCI to VME bridge had already been worked out by CMS a while back
- Implementing upgrades during shutdown
  - Adding 16 additional trigger input for a total of 32, since we were over-subscribed at 16
  - Adding adjustable software-controllable pulser logic
  - Capability to pre-scale one or more trigger paths – useful for background studies with high rate triggers à la colliders

Backup Slides

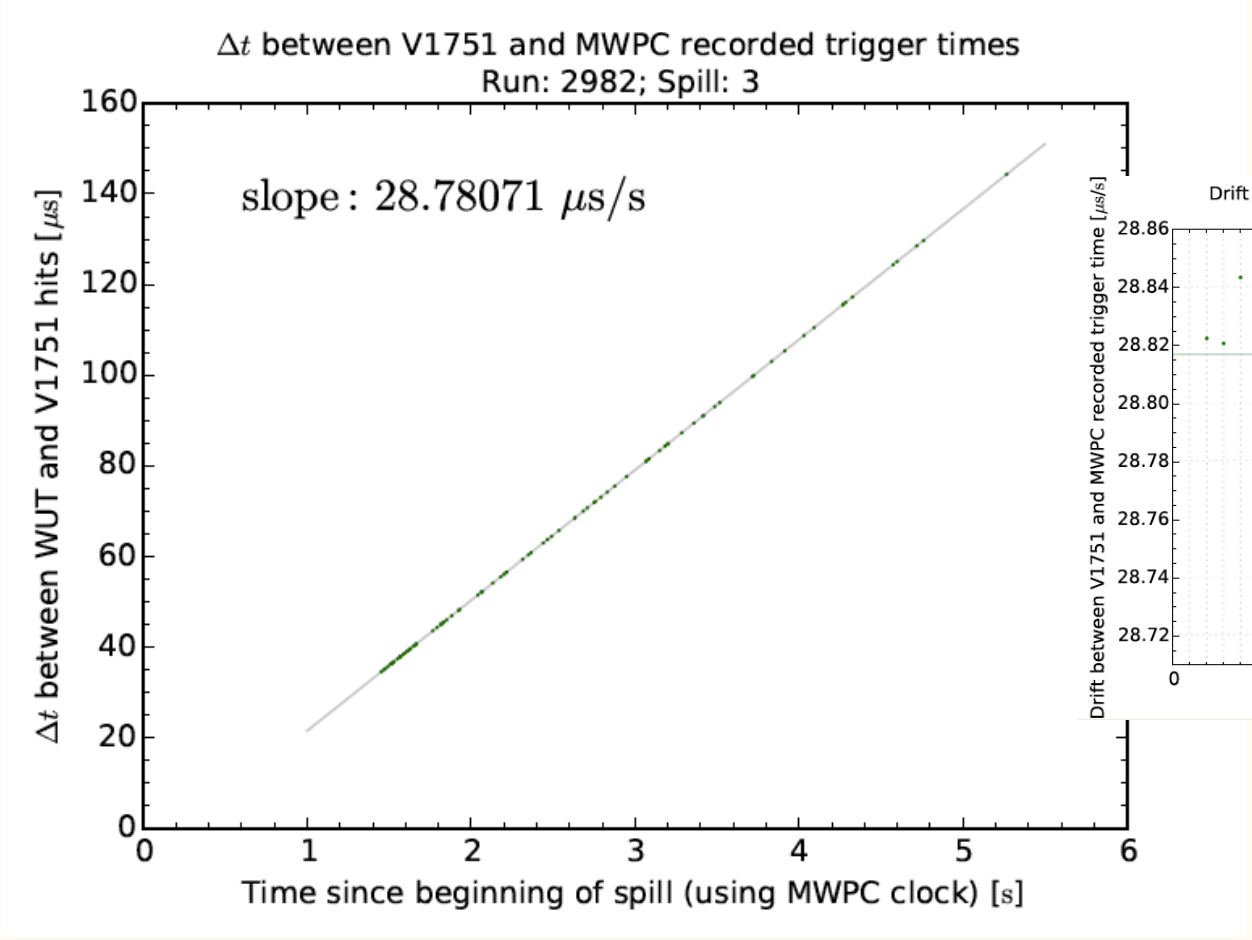
Hardware Spares

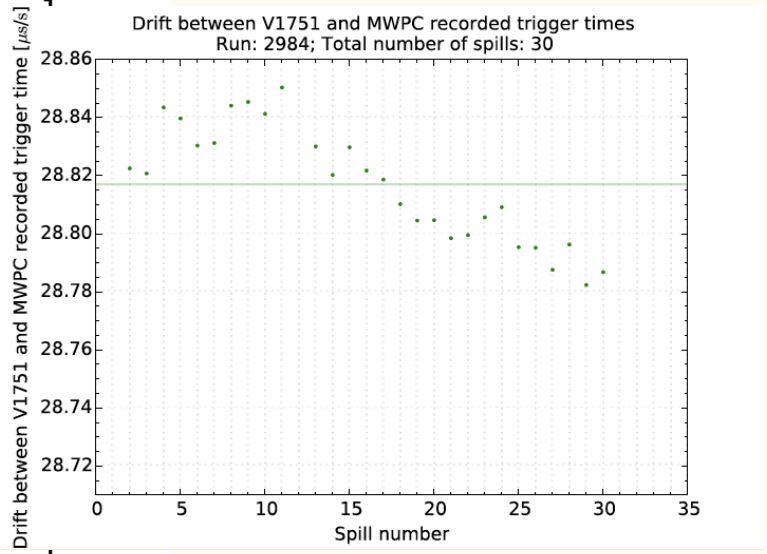
Detector	Digitizer	In System	Spares
TPC	CAEN V1740	8	0
μ Range Stack +	CAEN V1740	1	0
Light collection + ToF	CAEN V1751	2	0
High res ToF	WUT	1	0+
Trigger	CAEN V1495	1	0
VME Master	CAEN V2718	1	0
PCI-VME Bridge	CAEN A3818	1	1

There may be money for spares in FY16

VME Crate	Spare	Spare
TPC and μRS+	Wiener VME64x	One chassis, no power supply
ToF, Light, Trigger	CAEN VME64x	One spare CAEN with power supply

Cross-Detector Synchronization





Time matching between wire chambers and ToF PMTs
Note offset and slope corrections
Stability improved with time