The D0 RunII Trigger

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Run I Trigger

- Old Run I system consisted of three major levels of triggering:
  - L0 – scintillator trigger
  - L1 – hardware trigger based on fast sums from calorimeter and muon detectors
  - L3 – software trigger running on a farm of ~50 processors
- L2 trigger added later
  - Refined electron candidates in calorimeter
  - Finer granularity hardware information from muon detector
- L1/L2 accept rate was 150Hz
  - Event size of 450kB

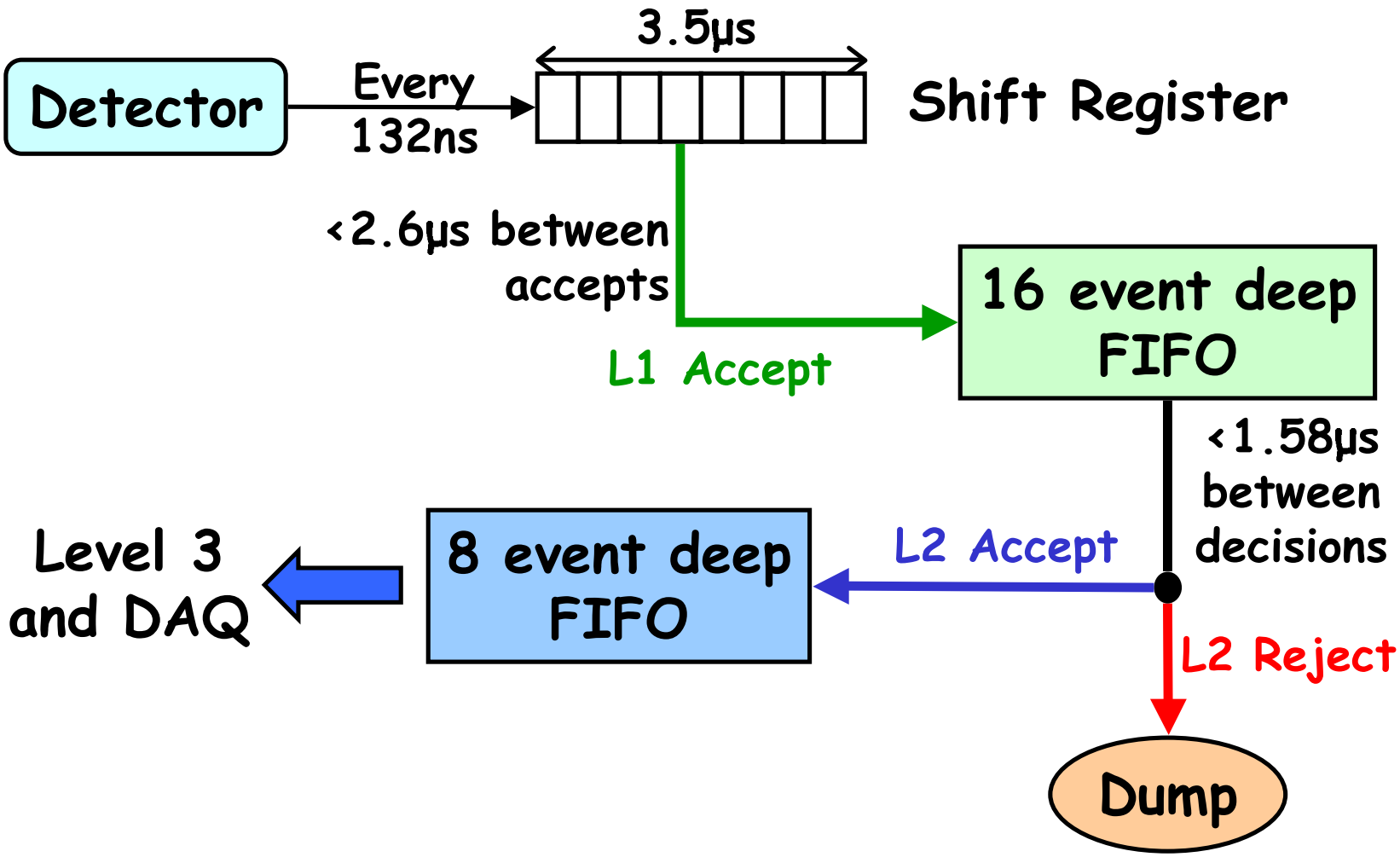
Run II Upgrade

- For Run II the Tevatron has been significantly upgraded
  - Ten fold increase in luminosity to $2 \times 10^{32} cm^{-2} s^{-1}$
  - Beam crossing interval reduced to 132ns (compared to 4μs in Run I)
- …and so has the DØ detector
  - Inner 2T superconducting solenoid
  - New tracking detectors
    - Silicon, Fibre Tracker and Pre-shower
  - Upgraded muon detector

Run II Trigger Upgrade

- Trigger needed to be significantly upgraded to meet the challenge:
  - Include tracking information from new detectors
  - Expand the L2 trigger to examine all triggers and to have detector specific pre-processing engines
  - Increase the bandwidth and processing power of the L3 workstation farm

Triggered Readout



Level 1 Trigger

- Run II L1 trigger includes information from new tracking subdetectors
  - Central Fibre Tracker (CFT)
  - Central Pre-Shower (CPS)
  - Forward Pre-Shower (FPS)
- …as well as the Run I systems
  - Calorimeter (CAL)
  - Muon (MUO)
- L1 trigger hardware framework manages all the different systems

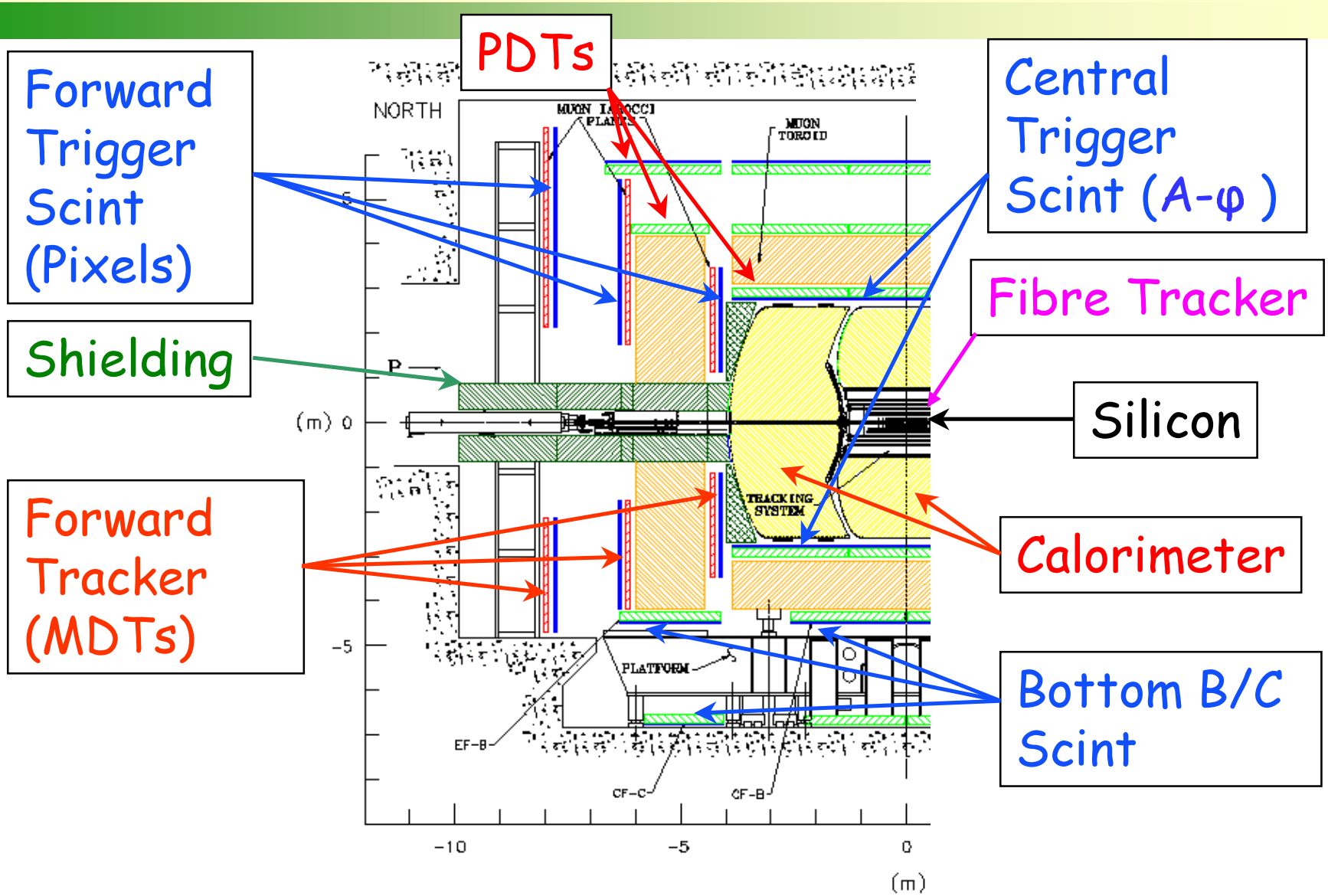
Level 1 Overview

- L1 Trigger uses a pipelined architecture
  - Each system's data is clocked into a 3.5μs long memory
  - L1 trigger has this long (3.5μs) to decide whether to trigger
- Trigger decision a two stage process
  - Each L1 system sends terms (bits) to the framework every 132ns (7MHz)
  - Framework ANDs (+limited OR) these to give 128 trigger bits
  - If any bits are set generate a L1 accept

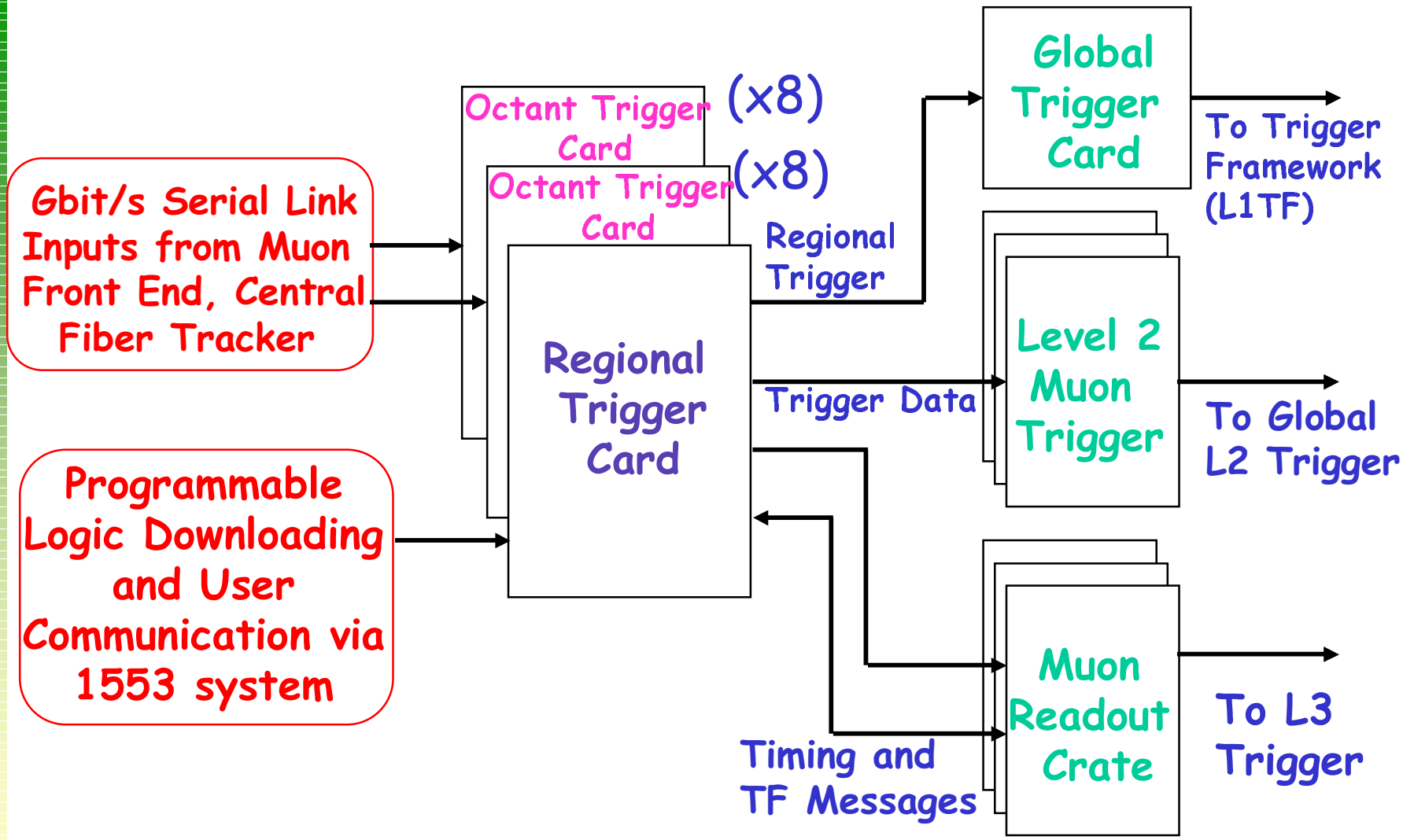
Muon Detector

- Muon detector divided into 3 regions
  - Central ($|\eta|<1.0$)
  - Forward ($1.0<|\eta|<2.0$) [North and South]
- Each region has three layers of counters (A,B and C)
  - Only the A layer is inside iron toroid
- Each layer consists of drift tubes
  - A has 4 decks, B and C have 3 decks
  - A and C layers also have scintillator
- Trigger creates "centroids" for each layers
  - Centroids combined with scintillator and Fibre tracker data to give muons

Muon Detector



L1 Muon Electronics



L1 Muon Outputs

- Output to L1 Framework is 32 bits
  - Selected from 256 possible terms at start of run (these terms don't change)
- Terms can select various criteria
  - PT threshold (2,4,7 or 11 GeV/c)
  - η region (|η|<1, |η|<1.5, |η|<2)
  - Quality: Loose or Tight
  - Muon multiplicity
- Remaining data buffered for output to L2 (16 buffers) and L3 (8 buffers)

L1 Calorimeter

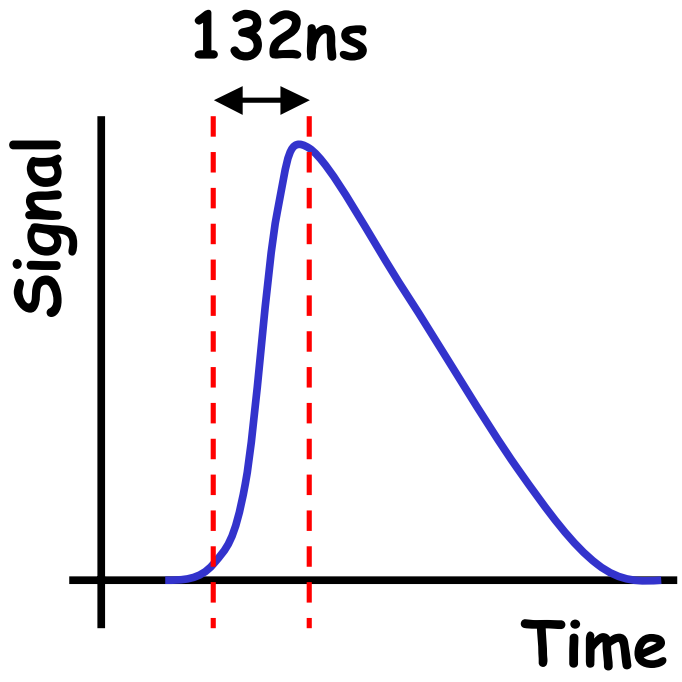
- L1 calorimeter trigger groups calorimeter cells into "Trigger Towers"
  - 1280 towers in total (40η x 32φ)
  - Each has an EM and Hadronic energy
- Triggering performed using "reference sets"
  - Reference set is a set of thresholds for every trigger tower
  - 4 EM reference sets (+seed mask for L2)
  - 4 EM+Hadronic reference sets (+L2 seed mask)
- Each reference set has 4 count thresholds
  - Sets a bit if more than N cells above reference

L1 Calorimeter

- Other triggers possible
  - Total EM and EM+Hadronic energy thresholds
  - Vector summed missing E_T thresholds
- Quadrant triggers on 2 EM and 2 EM+Hadronic reference sets
  - 1 or more towers in a given quadrant
  - 2 or more towers in a given quadrant
- Out of all these possible triggers only 32 wired to the L1 framework

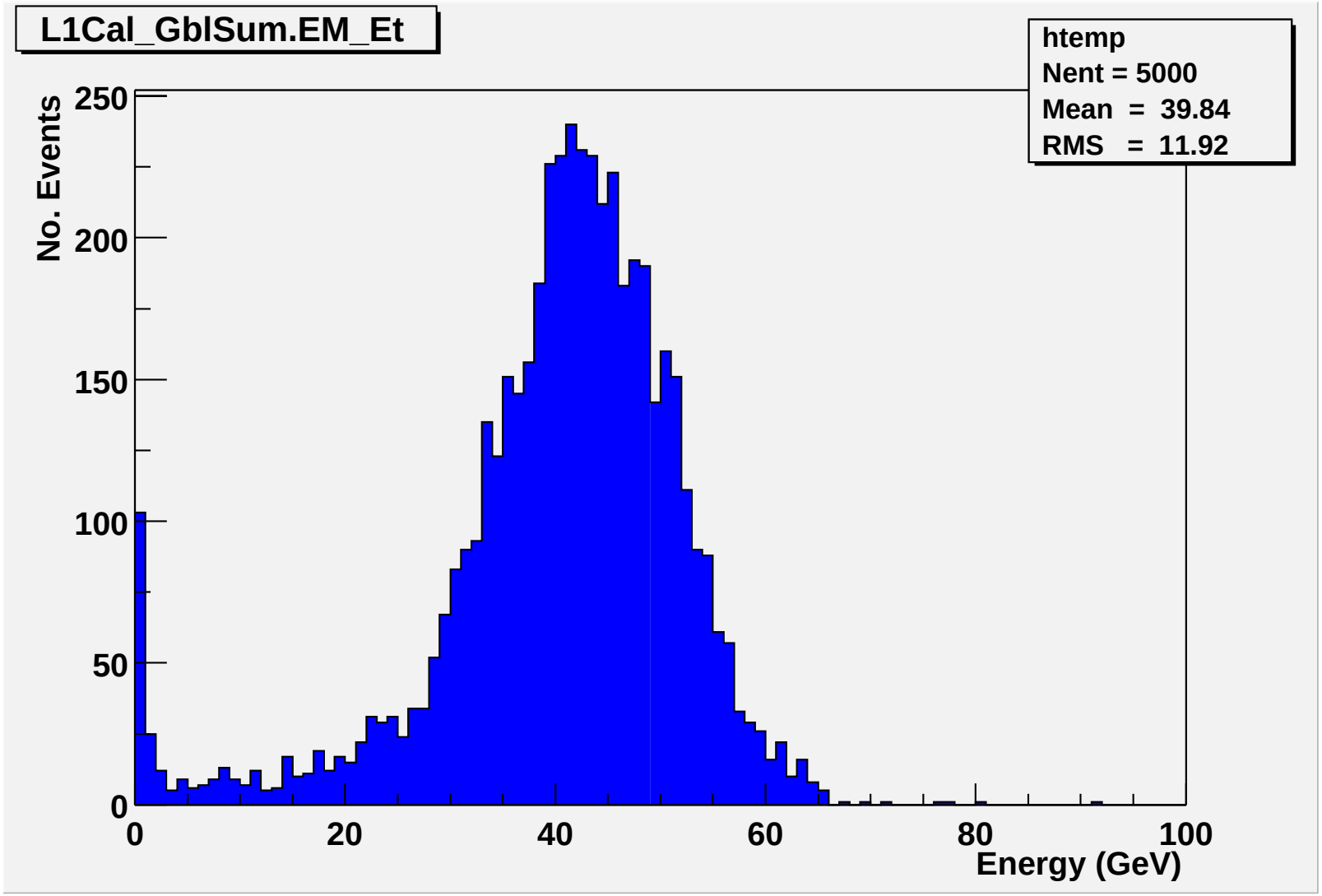
L1Cal Timing Resolution

- Potential difficulty in Run II is cross talk between beam crossings
  - Signal rise time ~132ns
  - Could loose ~1% of signal/ns…or worse trigger on the wrong crossing

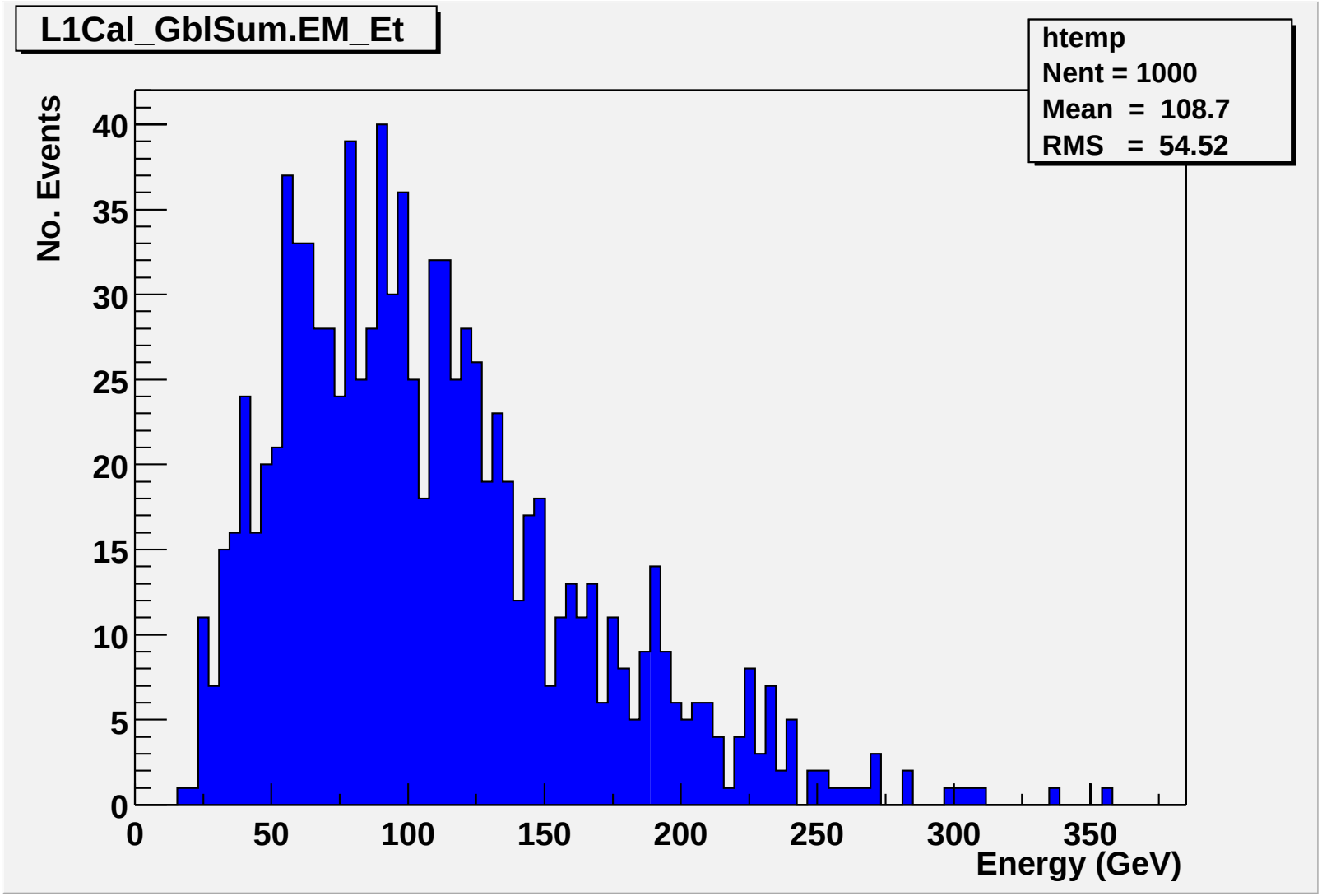


- Caused by 400ns drift time in Argon

Single 50GeV e^- EM E_T



ttbar EM E_T


L1Cal_GblSum.EM_Et
htemp
Nent = 1000
Mean = 108.7
RMS = 54.52
No. Events
0
5
10
15
20
25
30
35
40
0
50
100
150
200
250
300
350
Energy (GeV)

L1 CFT+CPS

- Axial Central Fibre Tracker (CFT) and Central Pre-Shower (CPS) triggers are integrated
  - CFT uses FPGA electronics to perform tracking in 4 p_T bins
  - Tracks are then matched to clusters
- CPS stereo layers are not included
  - Not used in L1, only processed for readout to L2 Pre-Shower Pre-processor

L1CPS/CFT Trigger Terms

- L1 CFT/CPS sends 64 trigger terms to L1 framework, formed from:
  - No. clusters without tracks
  - No. tracks as functions of:
    - Charge
    - p_T bin
    - Association (or lack thereof) with a high or low threshold pre-shower cluster
  - Occupancy level of the detector
  - Total p_T
  - φ sector with highest p_T

L1 Forward Pre-Shower

- FPS has extra "mip" layer in front of the converter
  - Makes up for no tracking
- 32 terms provided to L1 framework
  - Count of clusters as a function of:
    - High/Low shower threshold
    - Match with mip layer hit
    - Stereo layer (u or v)
- U/V layer association only performed for L2 readout
  - Clusters truncated and need to ensure at least one u/v cluster readout per calorimeter tower

Level 2 Trigger

- The level 2 trigger has a two stage design
  - Pre-processors format and sort L1 data
  - Global processor correlates information across the whole detector
- Input rate (L1 accepts) of 10kHz
  - Nominal 100μs processing budget/stage
- Output rate (L2 accepts) of 1kHz
- Required to respond to events in same order they are received
  - Workstation farm not useful given this constraint
  - Use single, powerful processors: Compaq Alpha

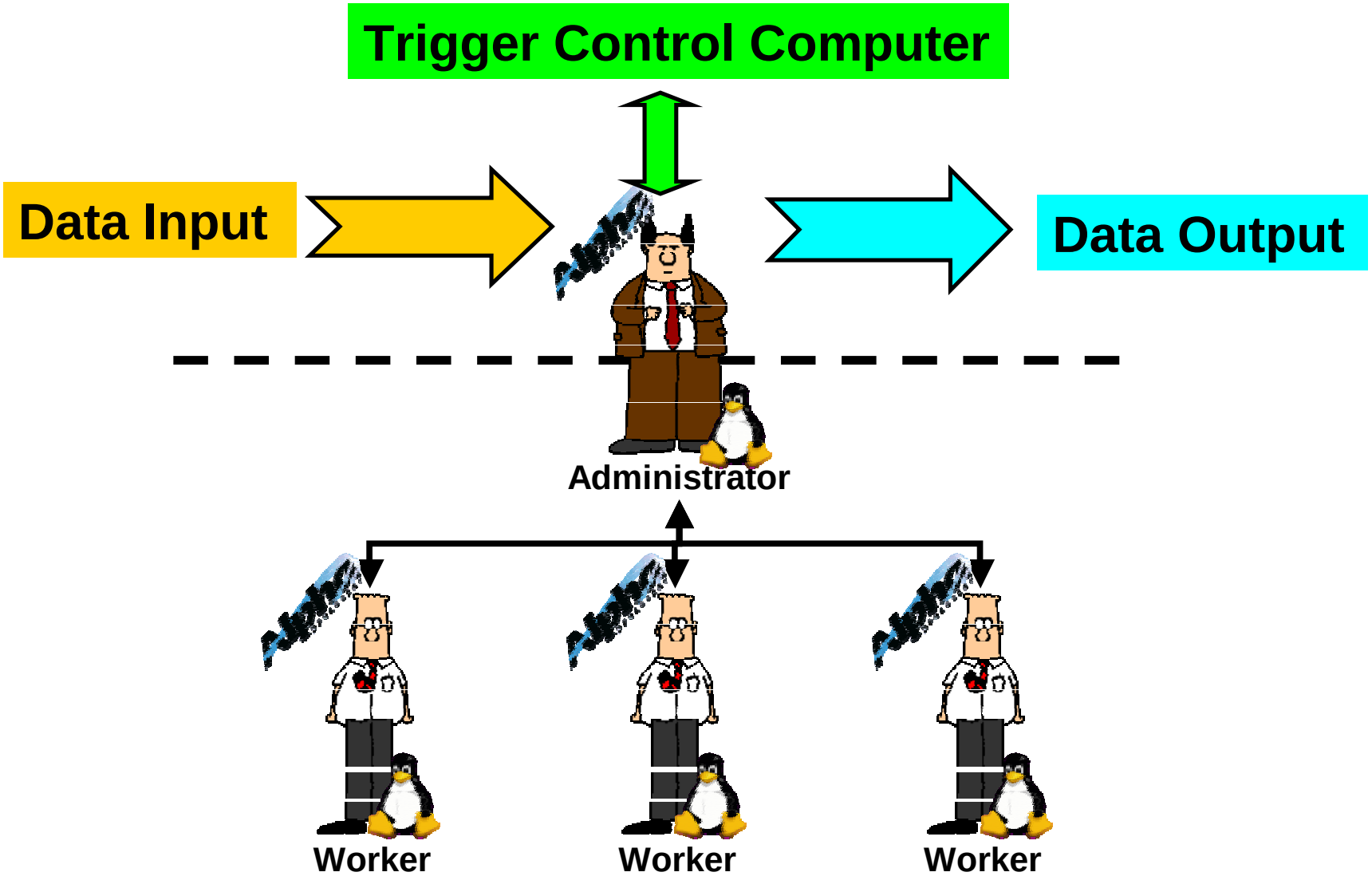
Level 2 Crate

- Each L2 pre-processor and global has a single crate
  - Administrator Alpha Board
  - One (or more) worker Alpha Boards
  - Input card which broadcasts data to all Alpha boards in the crate
  - VME Buffer Driver (VBD) card to send data to L3
- Each crate has two backplanes
  - VME64 for Physics (VIPA)
  - MagicBus (320MB/s, 128bit custom bus)

Level 2 Alphas

- Two types of Alpha: Administrator and Worker
- Administrator
  - Controls all external data paths
    - L1/L2PP inputs
    - L3 output
    - Control path to Trigger Control Computer
  - Does parity and data integrity checks
  - Only one Administrator per crate
- Worker
  - Processes event data
  - Mulitple workers allowed in each crate
    - Duplicate or different functionality

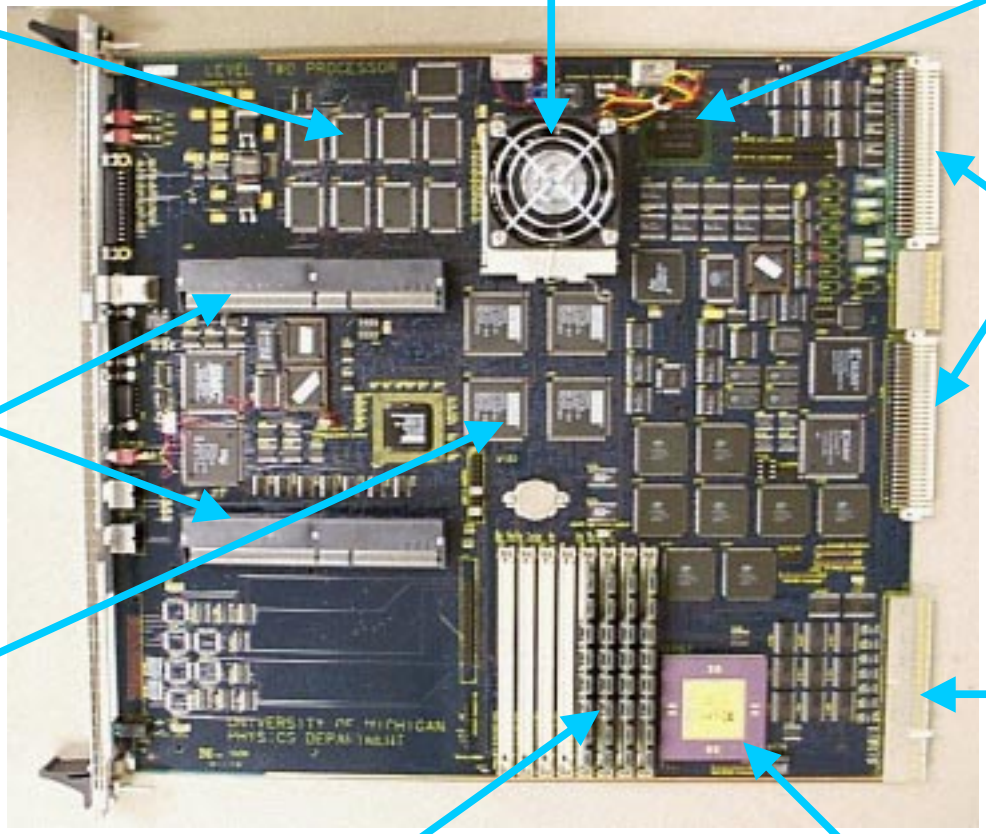
Alphas in a Crate



Alpha Processor Card

- Alpha processor card is based on digital PC164 motherboard
  - 500MHz Alpha CPU
  - 128MB memory
  - On board hard and floppy disks
  - Two PCI slots e.g. for Network card
- Interfaced to both backplanes
  - PCI-VME by Universe II chip
  - PCI-MBus by custom FPGAs
    - Broadcast interface for data input
    - Programmed IO for Alpha-Alpha messages

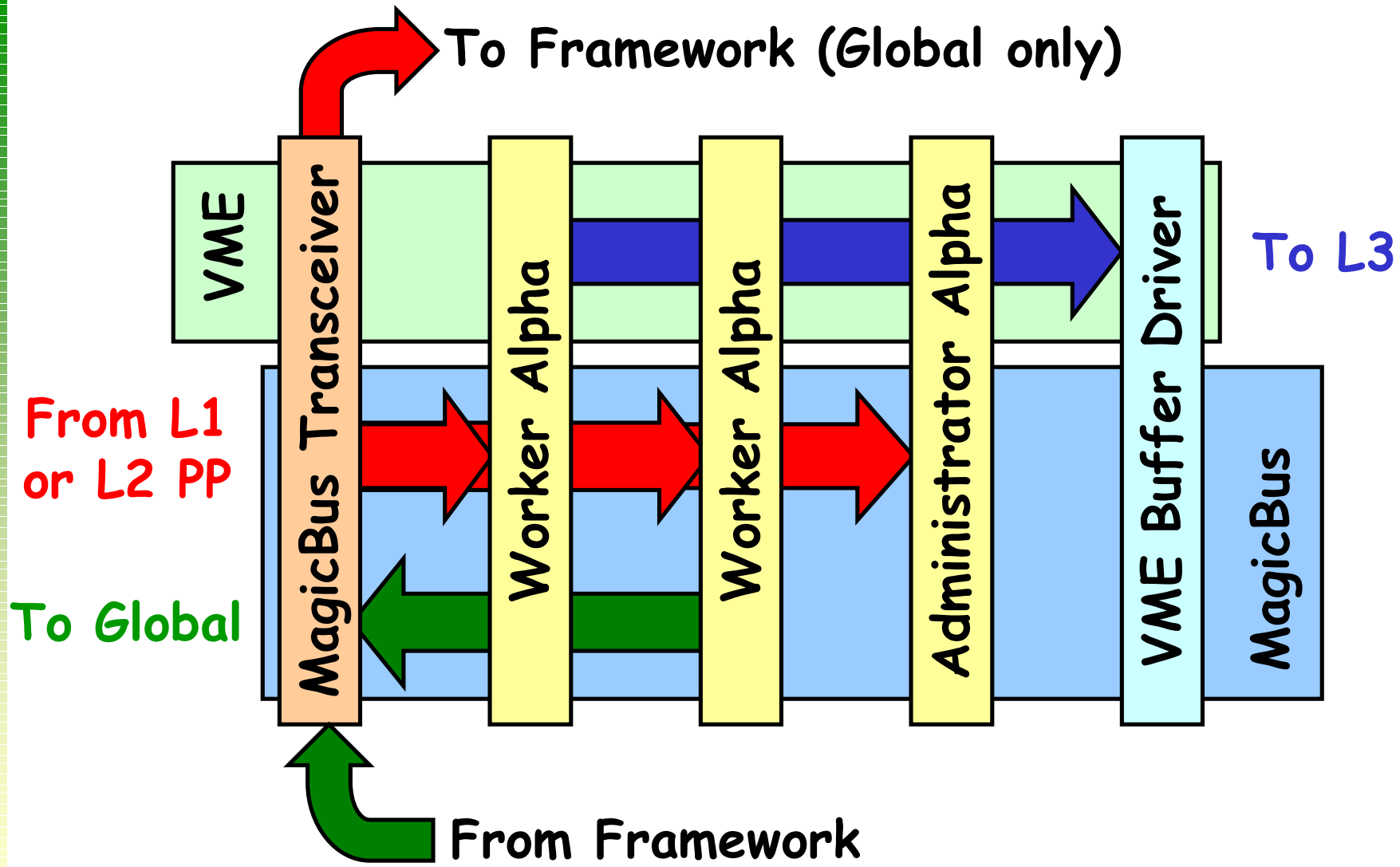
Alpha Processor



Magic Bus Transceiver

- The L2 Jack-of-all-trades!
  - Receives L1 input data and broadcasts it to all the Alphas in the crate
  - Receives output data from pre-processors and sends it to Global
  - Sends 128 L2 trigger bits from Global to the trigger framework
  - Sends commands from the trigger framework to the Administrator Alpha
- Data is sent via MBus
- Control/Setup via VME

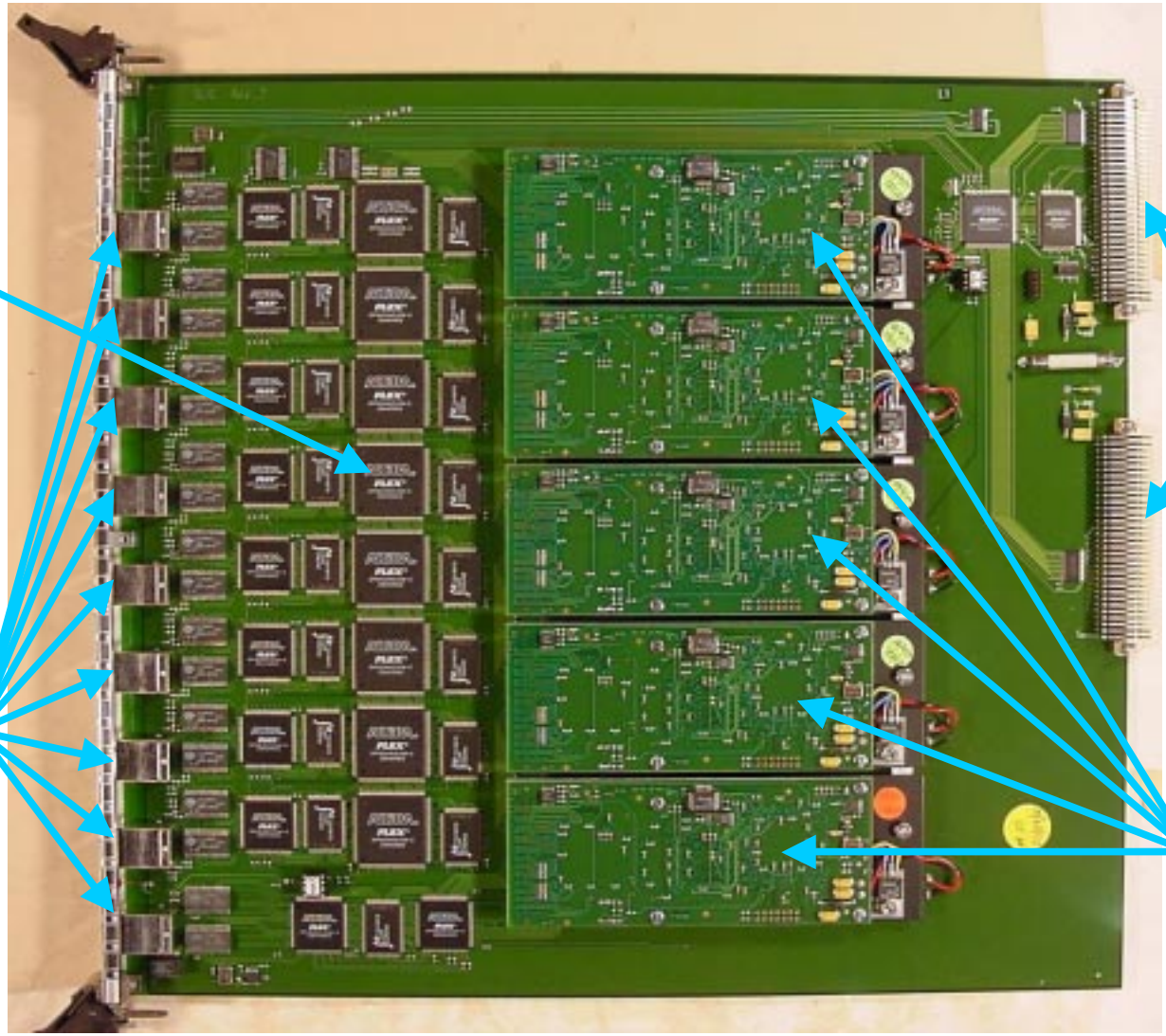
Level 2 Dataflow



Muon Pre-Processor

- Muon PP is only L2 system to process the full readout data
- Achieved using Second Level Input Converter (SLIC) cards
  - Process front end data and output results to MBT card
  - 5 DSPs to process (4) the input data and format (1) the output data
  - More computing power that Alpha board (each DSP has 1600mips!) but a lot harder to program

The SLIC



Calorimeter Pre-Processor

- Calorimeter has three different types of workers
  - Electromagnetic, Jet and Missing E_T
- Input data are
  - Trigger tower energies from L1CAL
  - EM and Hadronic seed masks
- Performs a clustering algorithm and outputs results to Global
  - EM clusters
  - Jet clusters
  - Missing E_T

Pre-Shower Pre-Processor

- Receives cluster information from
  - Axial and stereo CPS
  - Stereo FPS (u and v layers)
- Clusters received as fibre channels
  - Must be converted into η/φ coordinates for Global (to match Cal)
- Finally clusters are ordered in η/φ to reduce CPU time taken in global when matching with other subdetectors

CFT Pre-Processor

- Receives tracks from L1 CFT trigger
  - Sorts and possibly truncates the tracks before outputting to Global
- Output to Global
  - Tracks sorted by P_T
  - Tracks sorted by impact parameter
- Will also receive track data from the L2 Silicon Tracking Trigger when it comes online

L2 Silicon Tracking Trigger

- A silicon preprocessor is now planned to be included in L2
  - Will arrive ~1 year after start of run
- Processes Silicon detector data
  - Improves tracking resolution
  - Provides vertex information
- Design uses custom-built hardware
  - Data enters standard L2 system through the CFT pre-processor to provide a standard interface to Global

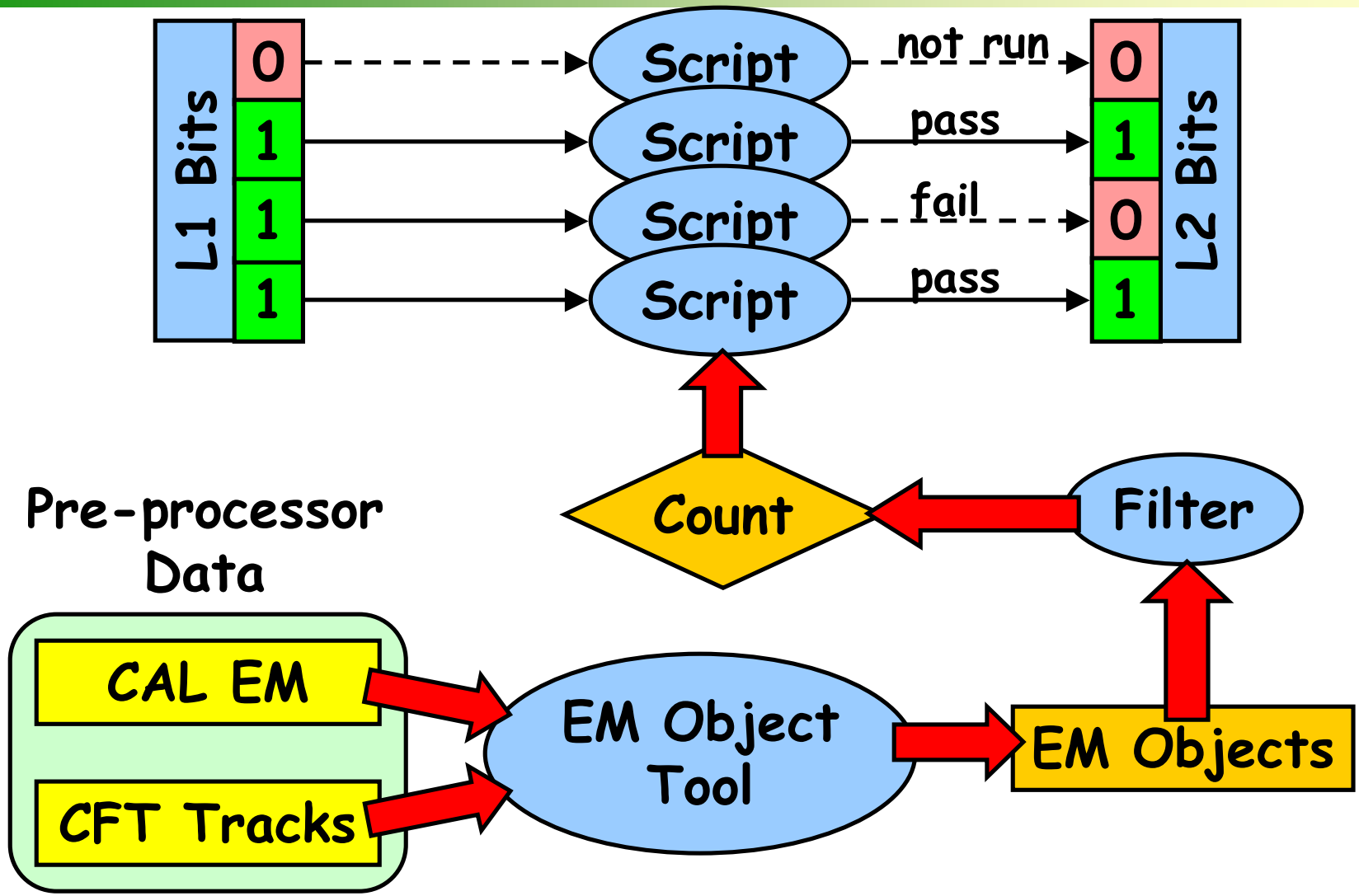
L2 Software

- Alpha boards run Linux/Alpha (RedHat 6.2) with a hacked kernel
  - low level interrupt handler
  - Physical memory allocator for DMA
- Code is all written in C++
  - C and Assembly give no appreciable performance boost
  - Restrictions on allowed C++ constructs
    - No dynamic memory, no STL, no RTTI and no exceptions
- All this needed to reach ~50-100μs time budget

Level 2 Global

- Global processor assembles pre-processor data into physics objects by "Tools"
  - Tools exist for EM objects, jets, muons, masses and, eventually, possibly taus
- Output of tools used by "Filters" to select objects meeting certain criteria
- Each set L1 bit runs a script
  - Each script runs one or more filters
  - If sufficient objects pass each filter then the script itself passes
  - Passed scripts set their corresponding L2 bit and hence will cause an L2 accept

L2 Global


L1 Bits
0
1
1
1
Script
Script
Script
Script
not run
pass
fail
pass
0
1
0
1
L2 Bits
Count
Filter
Pre-processor Data
CAL EM
CFT Tracks
EM Object Tool
EM Objects

Global Electron EMfraction

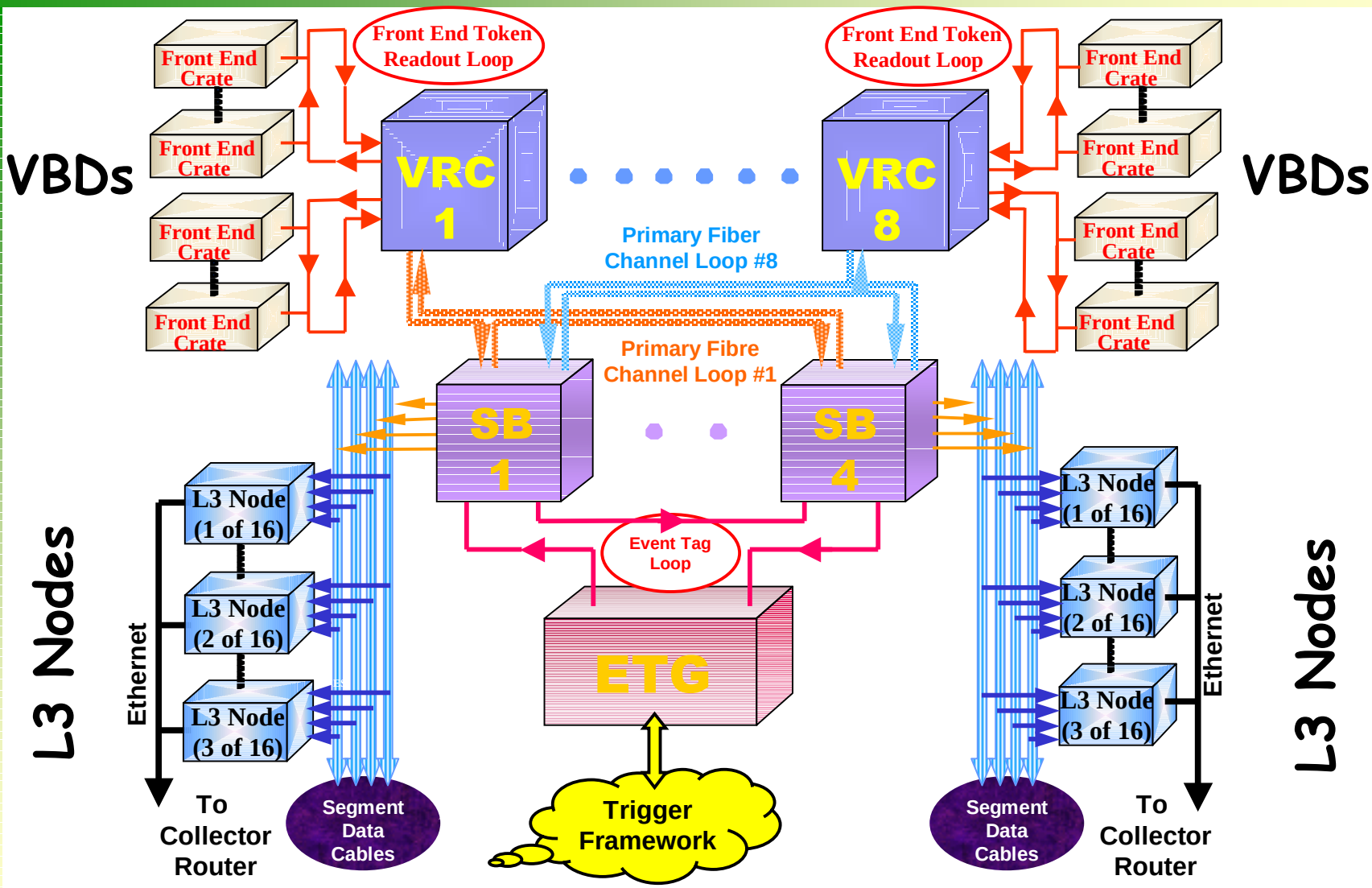
Level 3 Trigger

- L3 is the only trigger stage where the full detector readout is available
  - L3 system also acts as the DAQ, writing data over the network to tape
- Data reaches L3 from VBD cards
  - VBDs are readout by VRCs (VME Readout Controllers)
  - VRCs send the data to Segment Controllers
  - Segment controllers send the data to the 16 attached workstation nodes

Level 3 Dataflow

- When a L2 accept is received all crates write data to a VBD
  - Contains 8 L3 output buffers
- VME readout controller (VRC) then reads this data into the L3 system
  - VRCs use a token ring mechanism, rate is controlled by limiting new tokens
  - Each VRC reads up to 8 crates on two token rings (16 crates in total)
- VRCs then send this data to segment controllers
  - Data then sent to one or more of the 16 attached processing nodes

L3 Hardware


VBDs
Front End Crate
Front End Crate
Front End Crate
Front End Crate
Front End Token Readout Loop
VRC 1
Front End Token Readout Loop
VRC 8
Front End Crate
Front End Crate
Front End Crate
Front End Crate
VBDs
Primary Fiber Channel Loop #8
Primary Fibre Channel Loop #1
SB 1
SB 4
L3 Nodes
L3 Node (1 of 16)
L3 Node (2 of 16)
L3 Node (3 of 16)
Ethernet
Event Tag Loop
ETG
L3 Node (1 of 16)
L3 Node (2 of 16)
L3 Node (3 of 16)
Ethernet
L3 Nodes
To Collector Router
Segment Data Cables
Trigger Framework
Segment Data Cables
To Collector Router

L3 Processor Nodes

- Processor farm now useful since events can be processed in any order
- Each node has the same setup
  - 4 processor Intel machine
  - Runs Windows NT
  - Processed data output over ethernet
- Data arrives into a multi-port memory card in a VME crate
  - Data moved into CPU's memory by DMA transfer over a PCI-VME bridge

L3 Software

- L3 filter process has similar design principles to L2 global worker
  - Multiple scripts associated with every L2 trigger bit
  - Tools process and present data
  - Filters cut the data presented by tools
  - Scripts use filters to decide whether to pass the event
- Significantly larger time budget
  - ~100ms/event (>1000 times L2 budget!)

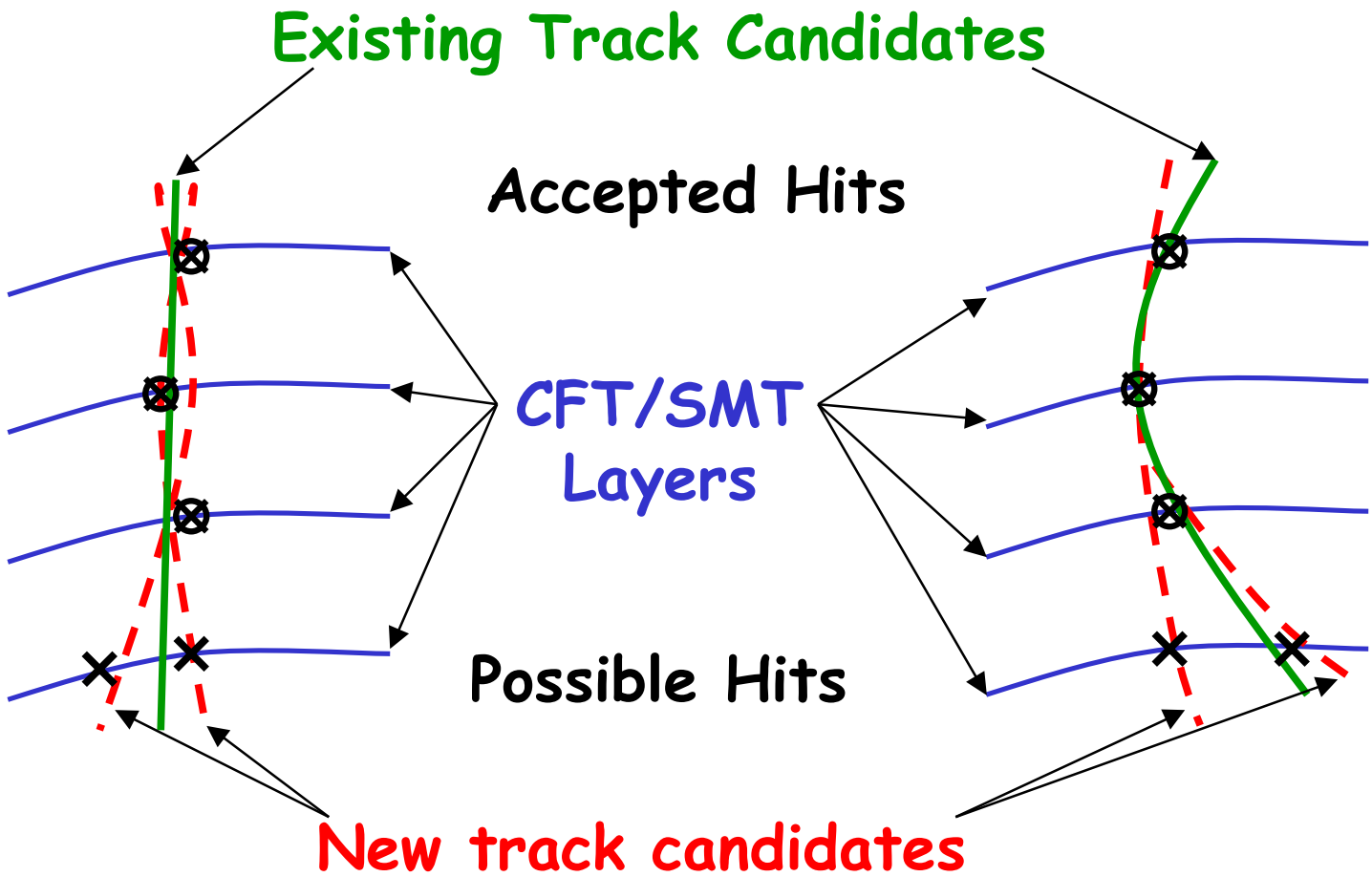
L3 Tracking

- L3 has two tracking packages
  - Global tracking (CFT + SMT)
  - CFT Tracking
- Both use similar techniques but:
  - CFT only tracking considerably faster than using CFT+SMT
  - CFT enough for some physics topics
    - e.g. J/ψ has 2 low p_T tracks

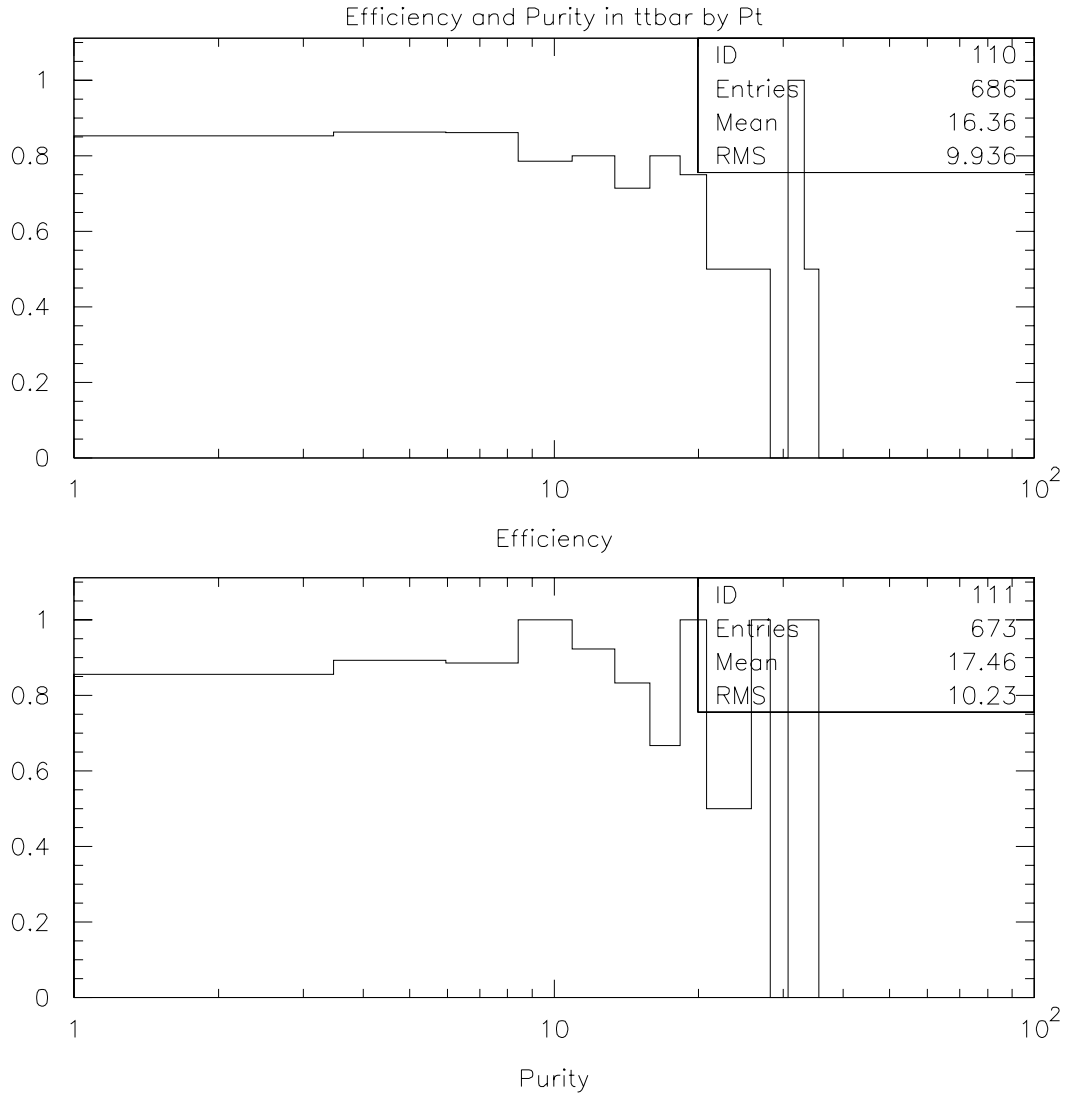
Global Tracking

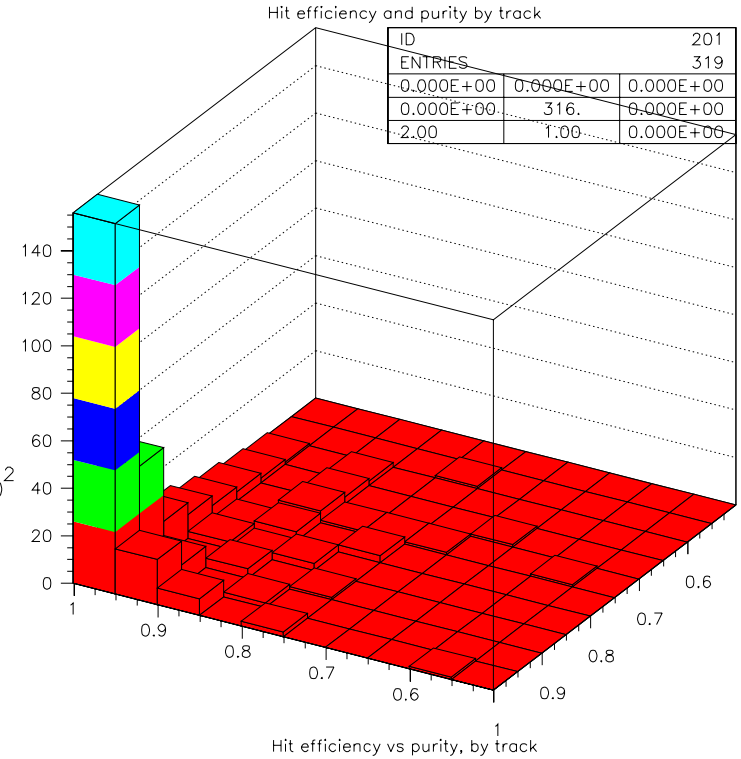
- Global tracker capable of both axial and stereo tracking
  - Uses SMT to improve resolution and fake rejection
- Axial tracking starts at the outer radius of the CFT and works in
  - Only 'n' closest hits considered along with no hit (currently n=2)
    - 'no hit' has a built-in χ^2 penalty
  - 'm' best track candidates are kept per layer (currently m=2)

Projecting to a New Layer

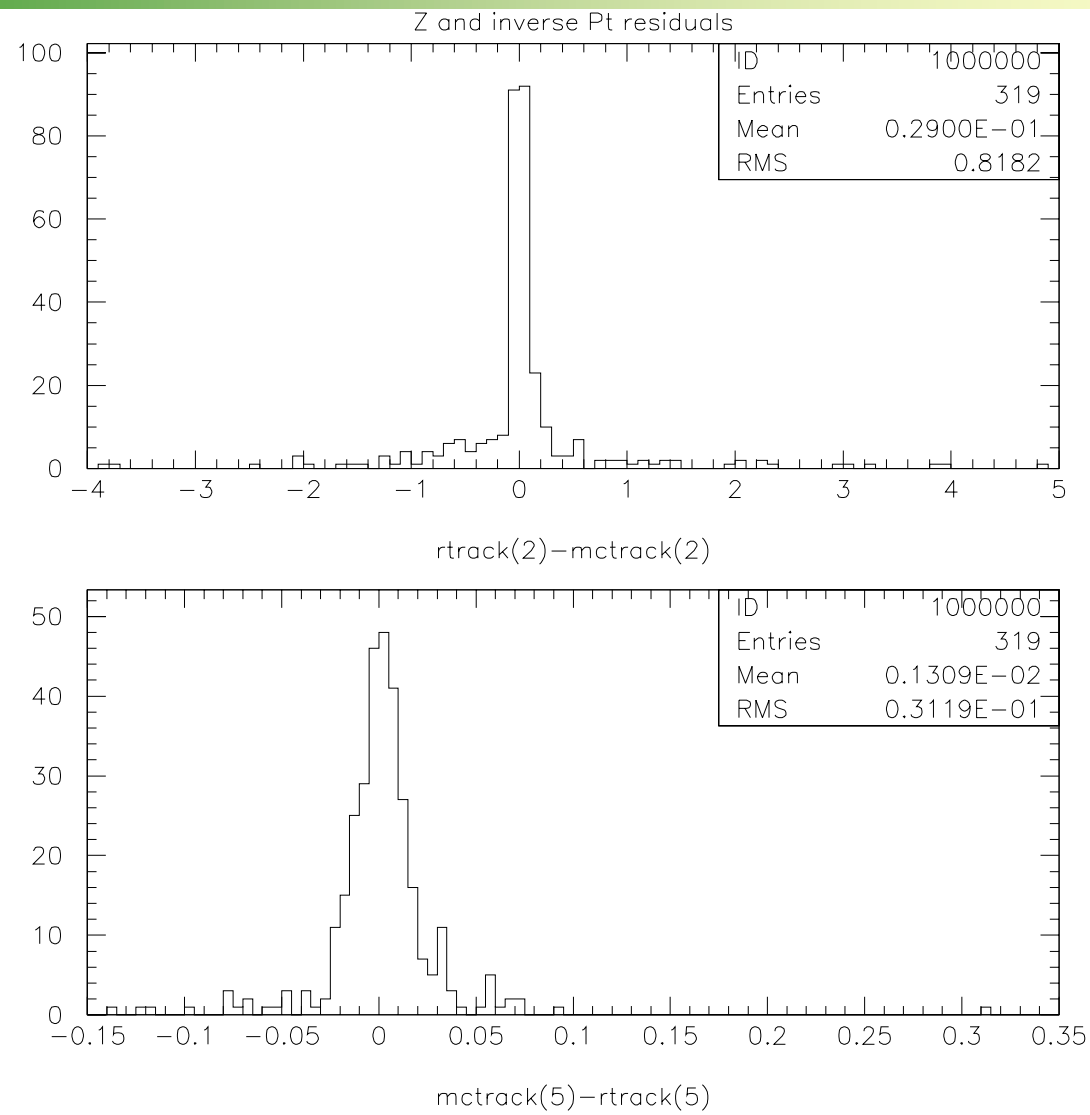


Efficiency and Purity



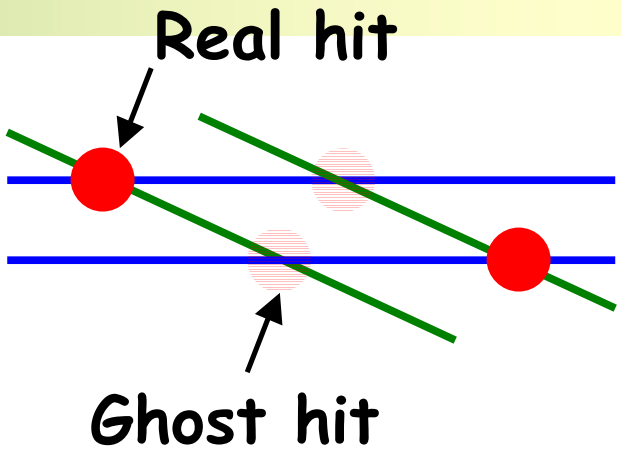


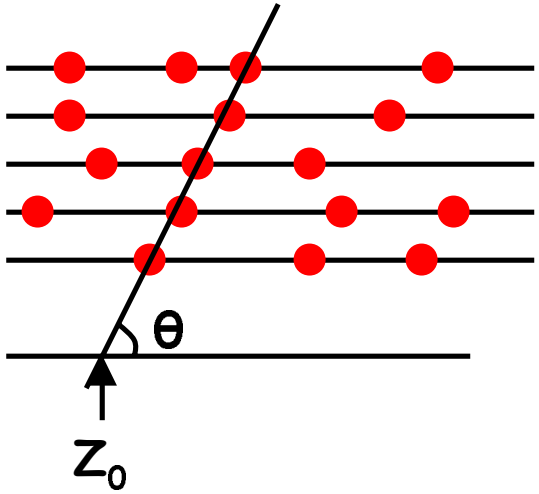
Residuals


Z and inverse Pt residuals
ID 1000000
Entries 319
Mean 0.2900E−01
RMS 0.8182
rtrack(2)−mctrack(2)
ID 1000000
Entries 319
Mean 0.1309E−02
RMS 0.3119E−01
mctrack(5)−rtrack(5)

Stereo Tracking

- Stereo tracks are found starting with the intersections of axial and stereo fibres
  - Many ghost hits included
- For each cluster a range Z_0 and θ values are possible
  - Allowed values give a straight line on Z_0,tan(θ) plane
  - Entries are added to a histogram and peaks correspond to stereo tracks





Trigger Simulation

- Simulation of the trigger is being developed
  - Trigger verification: did the trigger do what we think it should?
  - Studies of efficiencies and rates
- L1 requires specially written code to simulate the hardware
- L2 and L3 use online code compiled inside the offline framework
  - Allows code development without needing the online hardware

L1 Status

- L1 Framework in place and operating for almost a year
  - Some debugging work still going on
- L1 Calorimeter hardware still in place from Run I
  - Hasn't been powered up yet
- Entire L1 Muon trigger chain works
  - Awaiting arrival of full electronics
- L1 CFT/CPS firmware being written

L2 Hardware Status

- Alpha board production run complete but manufacturing problems
  - Attempting to fix each board
  - Looking at doing a second production run
  - Bring forward upgrade schedule
- MBT cards in final production run
  - Firmware nearly complete
- SLIC cards
  - Production complete
  - Firmware/Software being developed

L2 Software Status

- Linux up and running on the Alpha
  - Low level drivers being completed as hardware becomes available
- Pre-processor and Global algorithms already in Trigger Simulation
  - Initial versions running and being debugged

L3 Status

- L3 filter framework up and running!
- Currently being debugged
  - Error conditions not handled properly
- Several tools functioning
  - Muon unpacking
    - Needs factor ~10 speed increase!
  - Calorimeter unpacking & calibration
  - Silicon unpacking
    - Well tested and robust
    - Needs factor ~2 speed increase