DØ Level 1 Trigger

Presented for the D-Zero collaboration by

Dan Edmunds
Michigan State University,
East Lansing, Michigan, USA

10-th INTERNATIONAL CONFERENCE
ON INSTRUMENTATION FOR COLLIDING BEAM PHYSICS

Budker Institute of Nuclear Physics
Siberian Branch of Russian Academy of Science
Novosibirsk, Russia

5 March 2008

Outline

- Introduction
  - Fermilab
  - DZero
  - Triggering at D-Zero
- L1 Trigger Sub-Systems
- Trigger Framework
- Serial Command Link
- Control of the TFW
- Monitoring of the TFW
- Online Luminosity Measurement
- Conclusion

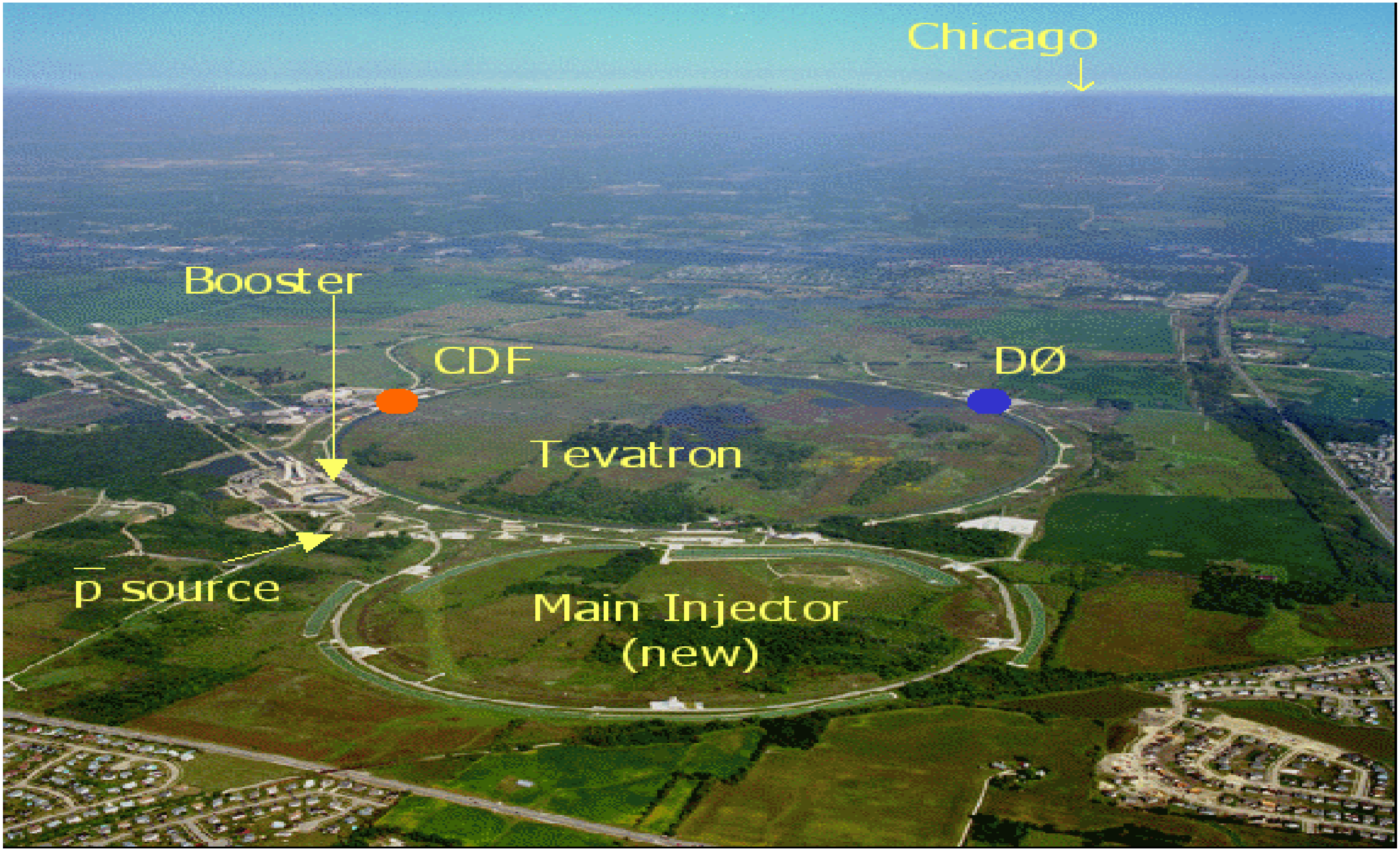
Disclaimer

- This will NOT be a Physics talk but rather a more **technical talk** concentrating on the **design concepts** and implementation of the D-Zero Level 1 Trigger System.

- Technical Expertise: MSU was part of the original proposal and has been leading the overall design of the DØ Level 1 Trigger:
  - Run I: L1 Trigger Framework, L1Cal, & L1.5
  - Run IIa: New L1/L2 Framework & upgraded L1Cal
  - Run IIb: New L1Cal (with Saclay & Columbia)
  - Continuing: Operation and Maintenance

- Introduction
  - Fermilab
  - DZero
  - Triggering at D-Zero
- L1 Trigger Sub-Systems
- Trigger Framework
- Serial Command Link
- Control of the TFW
- Monitoring of the TFW
- Online Luminosity Measurement
- Conclusion

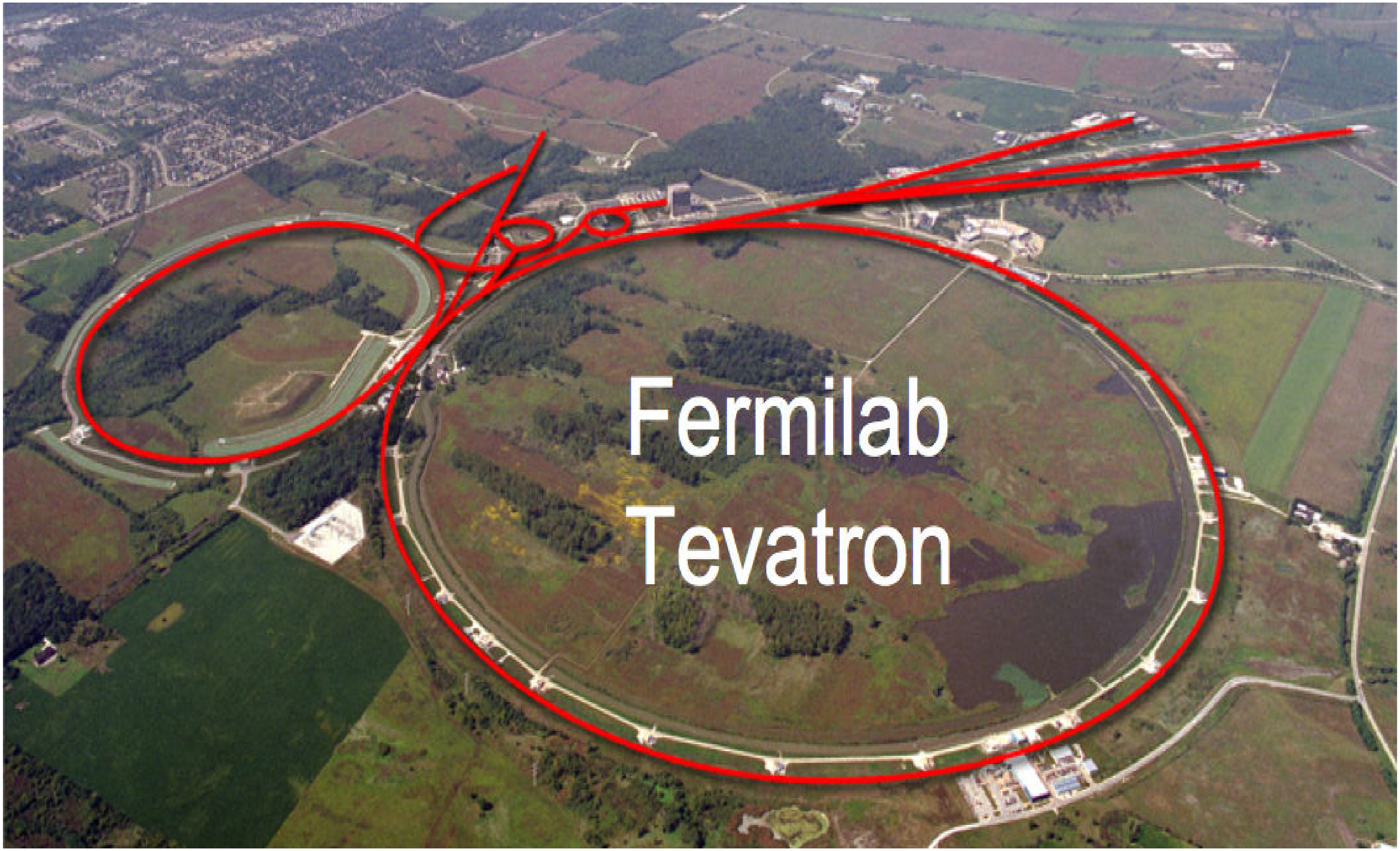
Fermilab


Chicago
Booster
CDF
DØ
Tevatron
$\overline{p}$ source
Main Injector
(new)

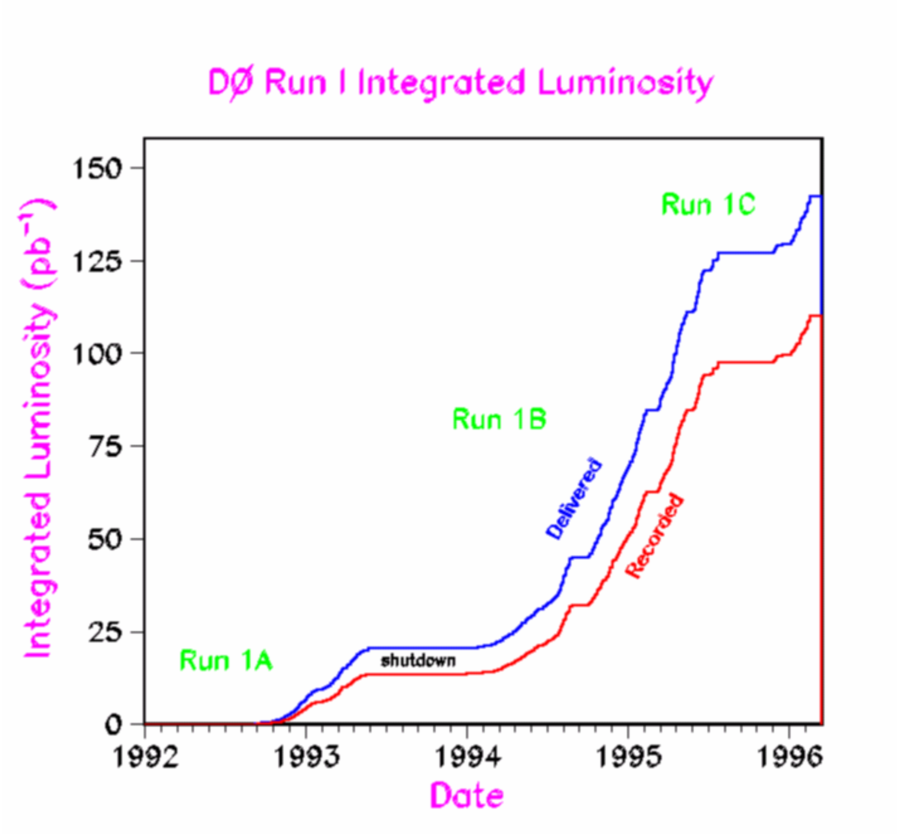
Fermilab

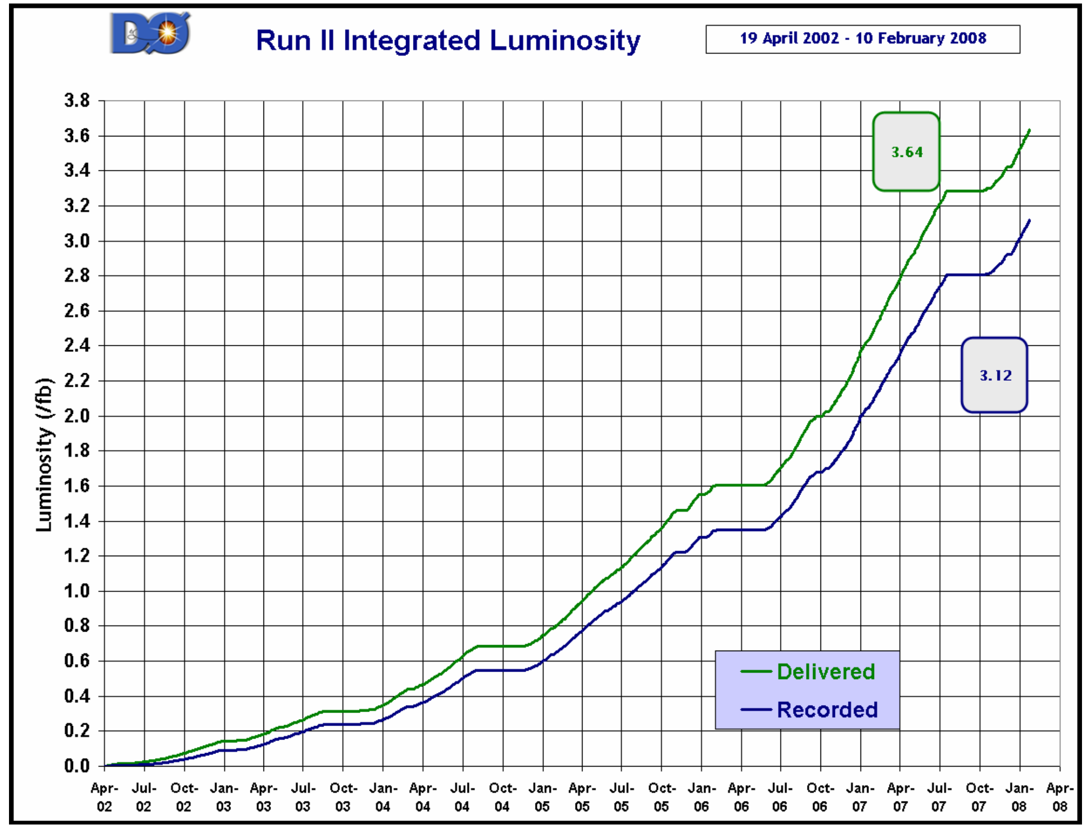
- Fermi National Laboratory
  - Near Chicago, Illinois, USA
  - Tevatron Collider 2 km in diameter
  - Proton-Antiproton collisions
  - New Main Injector for Run II in 2001
  - 36 Beam Crossings per turn, 396 ns apart
  - Center-of-mass energy 1.96 TeV
  - Instantaneous Luminosity $>10^{32}$ cm^{-2} s^{-1}

Fermilab



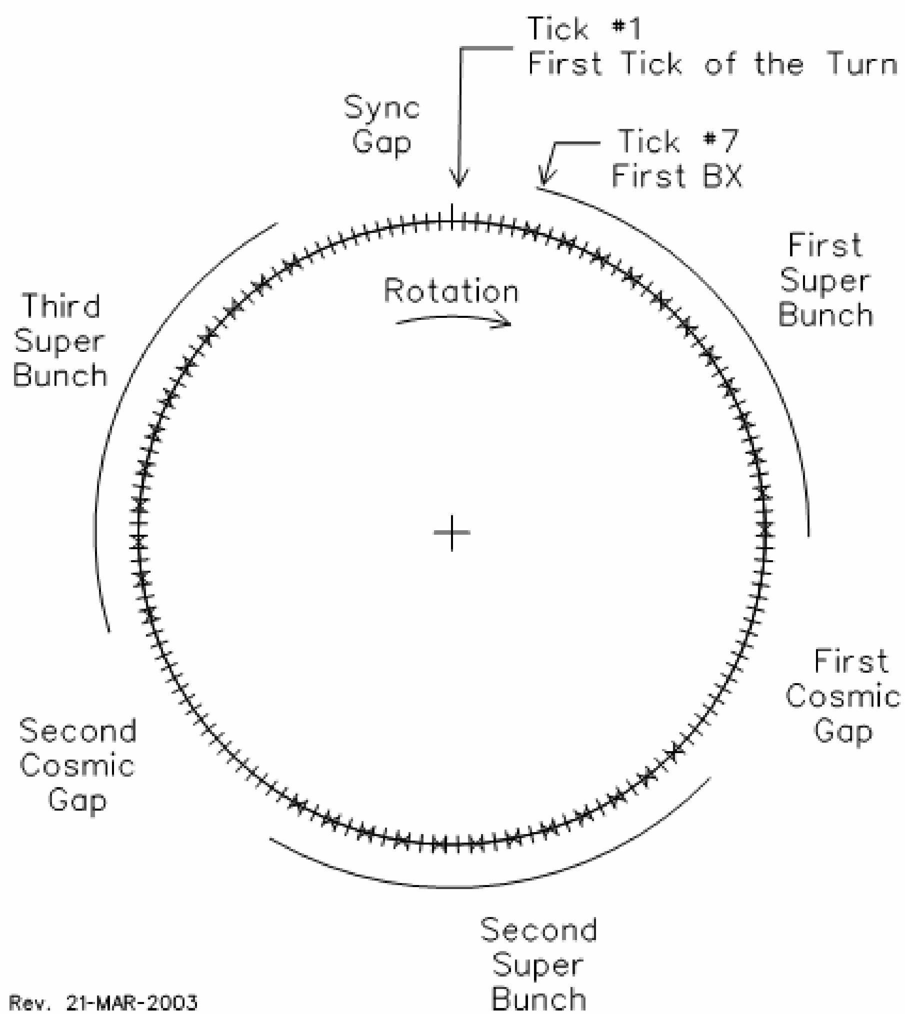
Fermilab: Integrated Luminosity





- Run II is Integrating Luminosity at a rate equaling all of Run I every ~3-4 weeks

Run II Beam Structure



TeV RF = 53.104 MHz
Period = 18.83 nsec
1113 Cycles of TeV RF per Turn
RF Cycle == RF Bucket

BX == TeV Beam Crossing

Accelerator BX's can be no closer than once every 7 RF Buckets.
Accelerator BX's spaced an integer number of 7 RF Bucket periods.

7 RF Buckets == 1 Tick
7 x 18.8 nsec = 132 nsec = 1 Tick
Ticks in a Turn are numbered 1:159
Tick rate = 7.59 MHz

In Run IIA there are 36 BX's per Turn
3 Super Bunches of 12 BX's each
During a Super Bunch there is a BX every 3 Ticks.
3 fold symmetry:
B0 = CDF, D0, F0 = TeV RF

Chronology

- DZero experiment
  - Proposed in 1983; first data recorded in 1992
    - Focus: high mass states, large Pt phenomena.
  - Run I: Discovery of the Top Quark in 1995
  - Run II: new Central Tracker with Magnetic Field, Silicon Microstrip, Scintillating Fiber, new Trigger Framework and readout electronics (2001).
  - Run IIb: new inner layer for Silicon Tracker, and new L1Cal (2006).
  - Recently: e.g. Discovery of "triple-scoop" baryon Ξ_b

D-Zero Collaboration

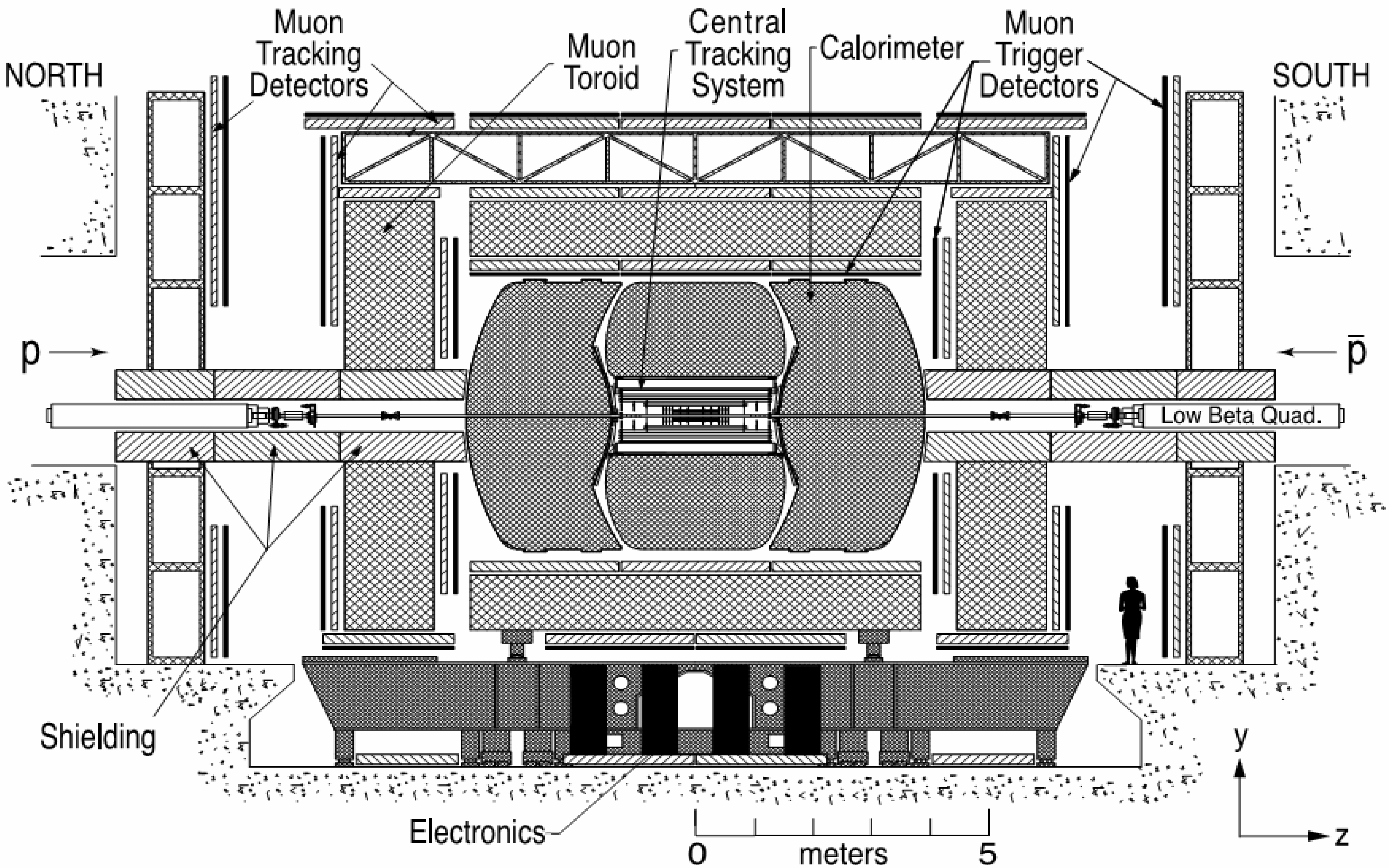
D-Zero Collaboration

- > 600 on Author List
- From > 80 Institutions
- In 18 countries

D-Zero Detector

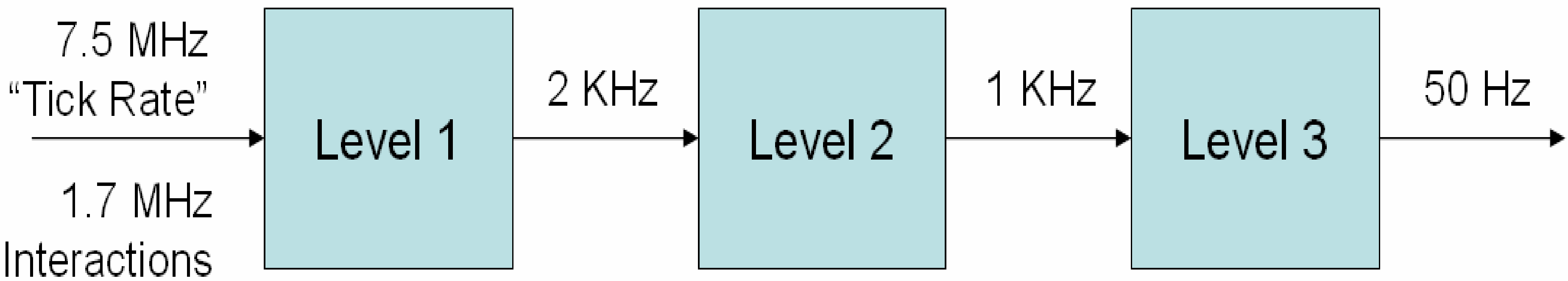
- Three major subsystems:
  - Central Tracking detectors
  - Uranium/Liquid-Argon Calorimeters
  - Muon spectrometer.

D-Zero Detector(s)



Triggering at D-Zero

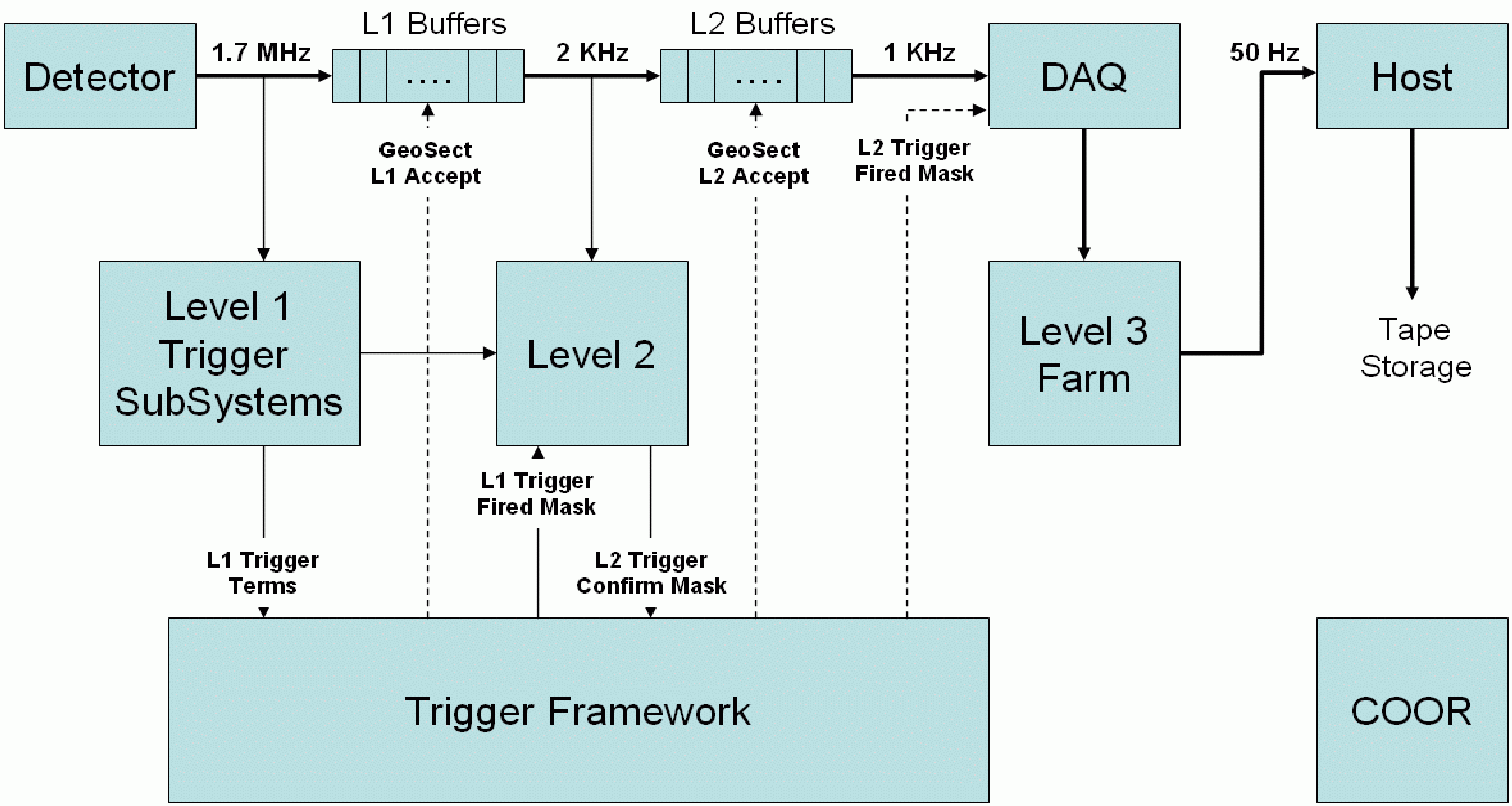
- Three Levels of Triggering



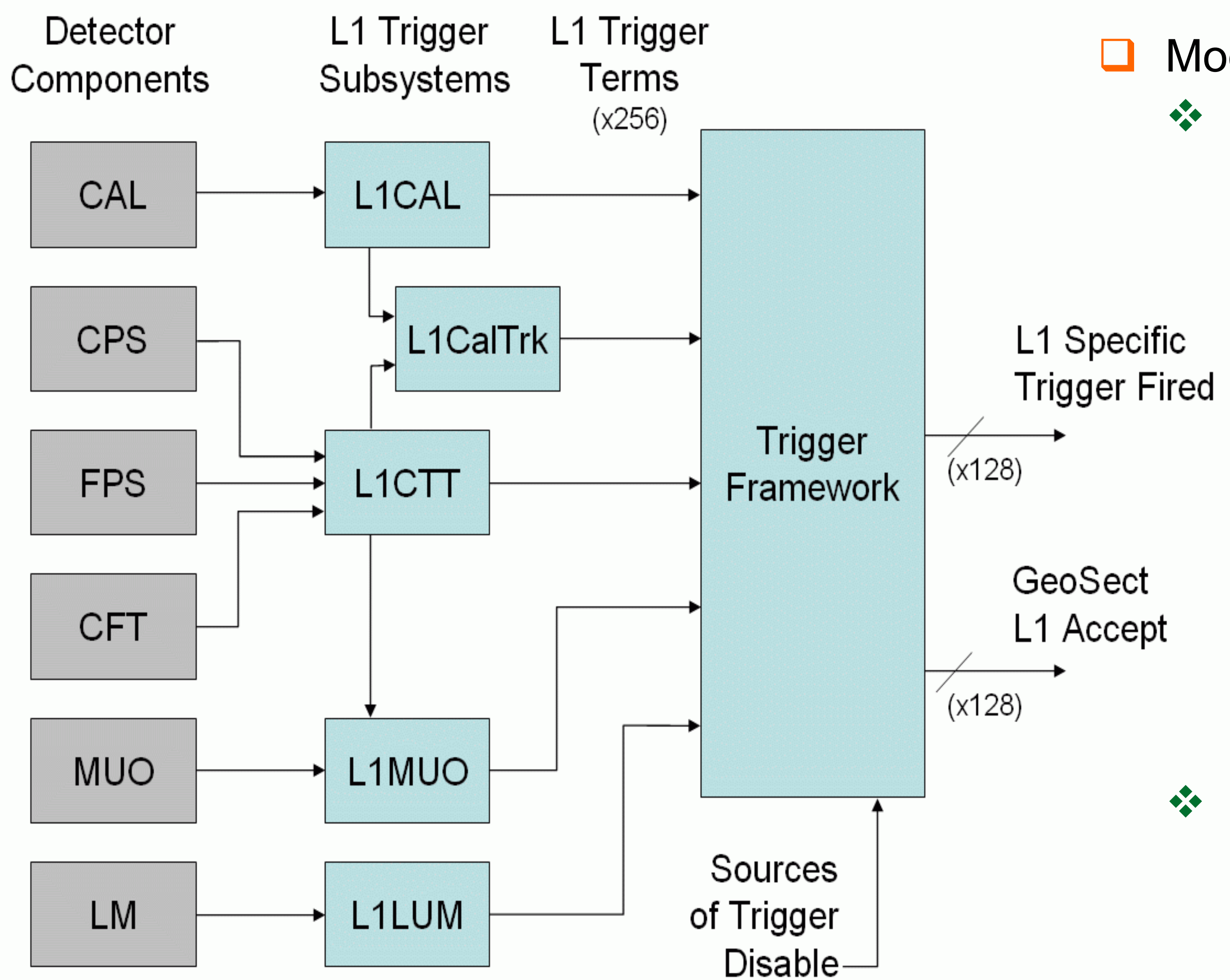
Each L1 SubSystem use:	Each L2 Processor use:	L3 Processor Farm use:
•Special Signal From its Detector Front-Ends	•Special Signal From Detector Front-Ends •Signals from L1 SubSystem	•Full readout From Detector •Data from L1 and L2

Triggering at D-Zero

- Event Data Path

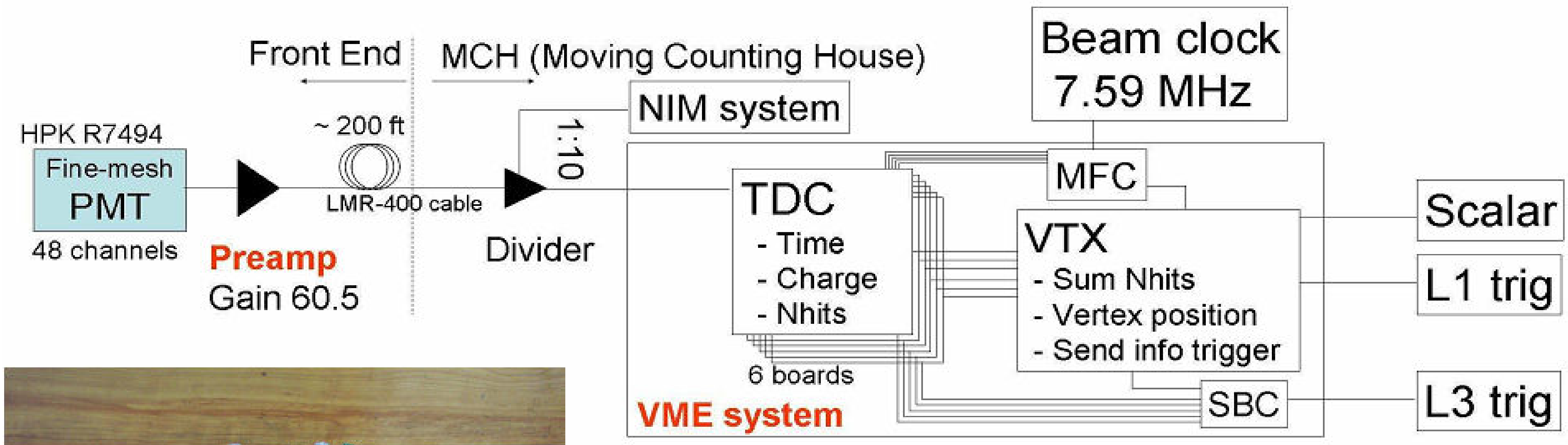


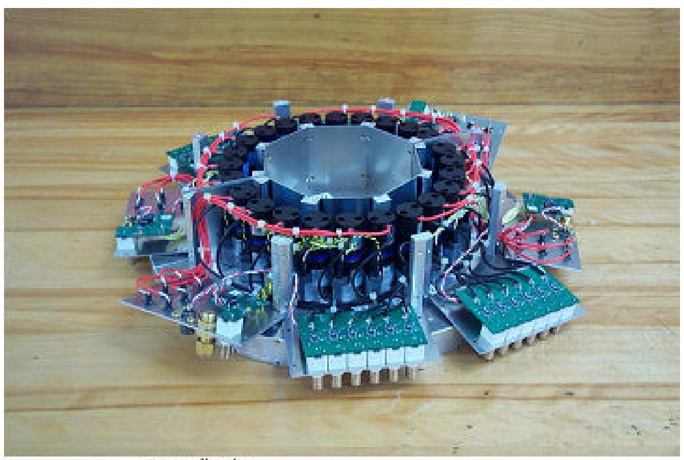
D-Zero Level 1 Trigger

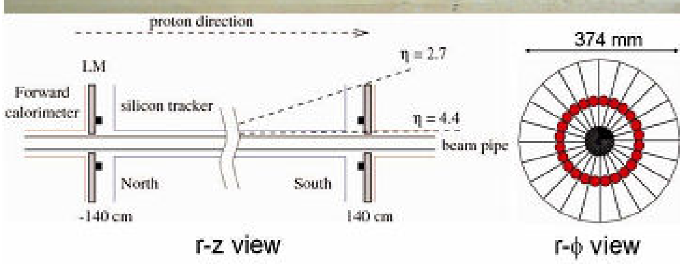


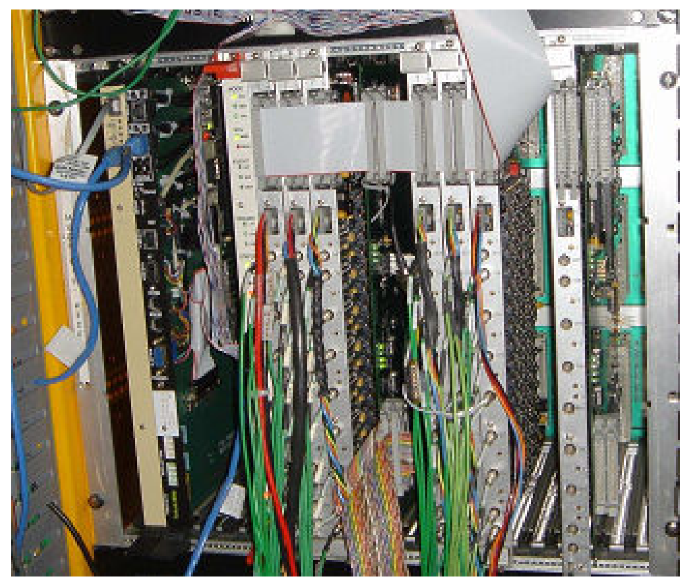
- Modular Design
  - L1 Trigger Subsystems do **not** directly cause triggers
  - Partitionable Triggering and Readout

L1 Trigger Sub-Systems : Luminosity









L1 Trigger Sub-Systems : Luminosity

- References:
  - LM upgrade:
    - IEEE NSS conference record and Fermilab conference note

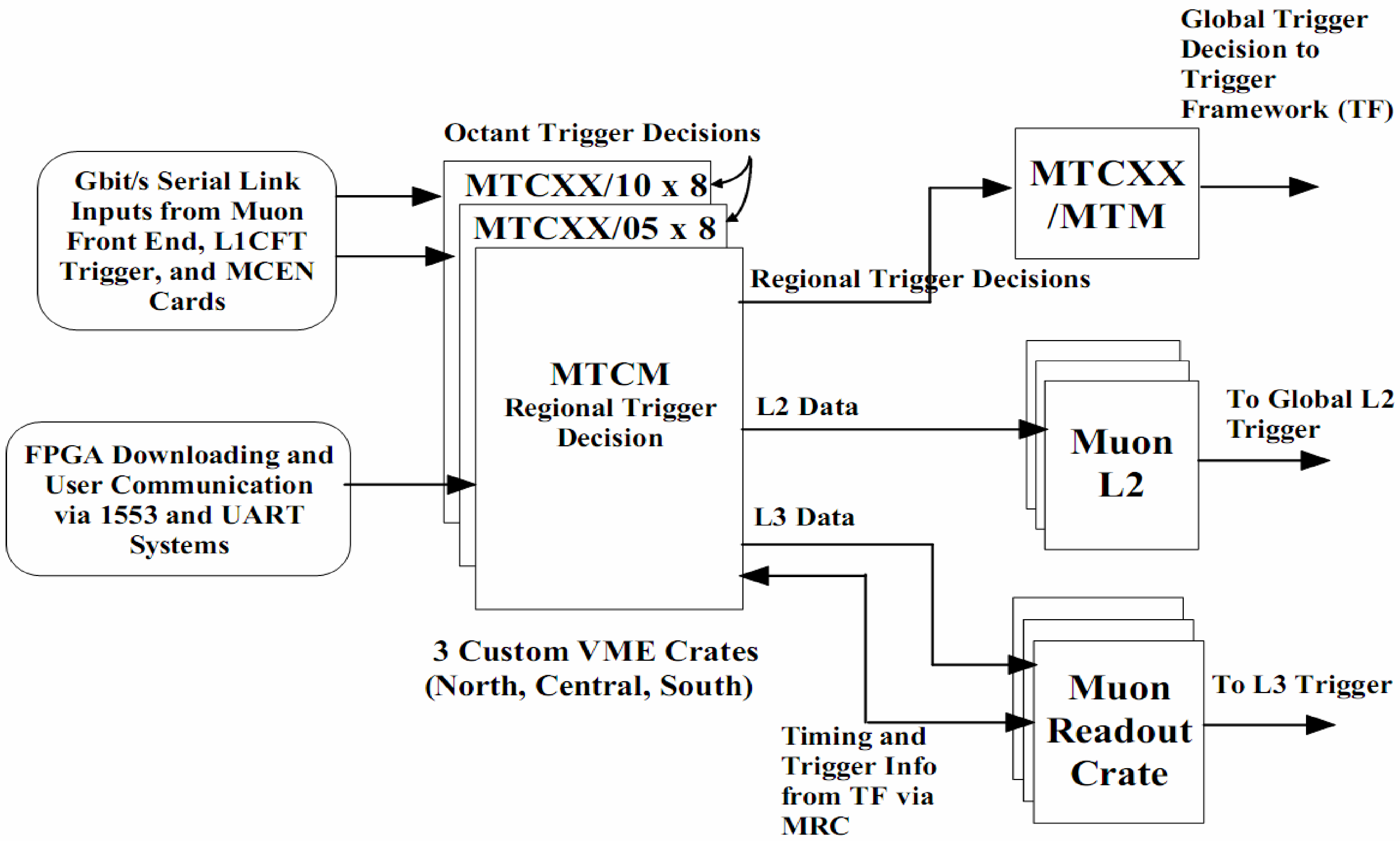
      Upgrade of the D0 luminosity monitor readout system.

      By D0 Collaboration (John Anderson et al.). FERMILAB-CONF-06-470-E, Dec 2006. 4pp. Prepared for 2006 IEEE Nuclear Science Symposium (NSS), Medical Imaging Conference (MIC) and 15th International Room Temperature Semiconductor Detector Workshop, San Diego, California, 29 Oct - 4 Nov 2006.
  - Run II LM:
    - Publication as well as a Fermilab conference note

      The D0 Run II luminosity monitor.

      By D0 Collaboration (Chyi-Chang Miao for the collaboration). FERMILAB-CONF-98-395-E, Dec 1998. 8pp. To be published in the proceedings of 6th International Conference on Advanced Technology and Particle Physics, Villa Olmo, Italy, 5-9 Oct 1998. Published in Nucl.Phys.Proc.Suppl.78:342-347,1999.

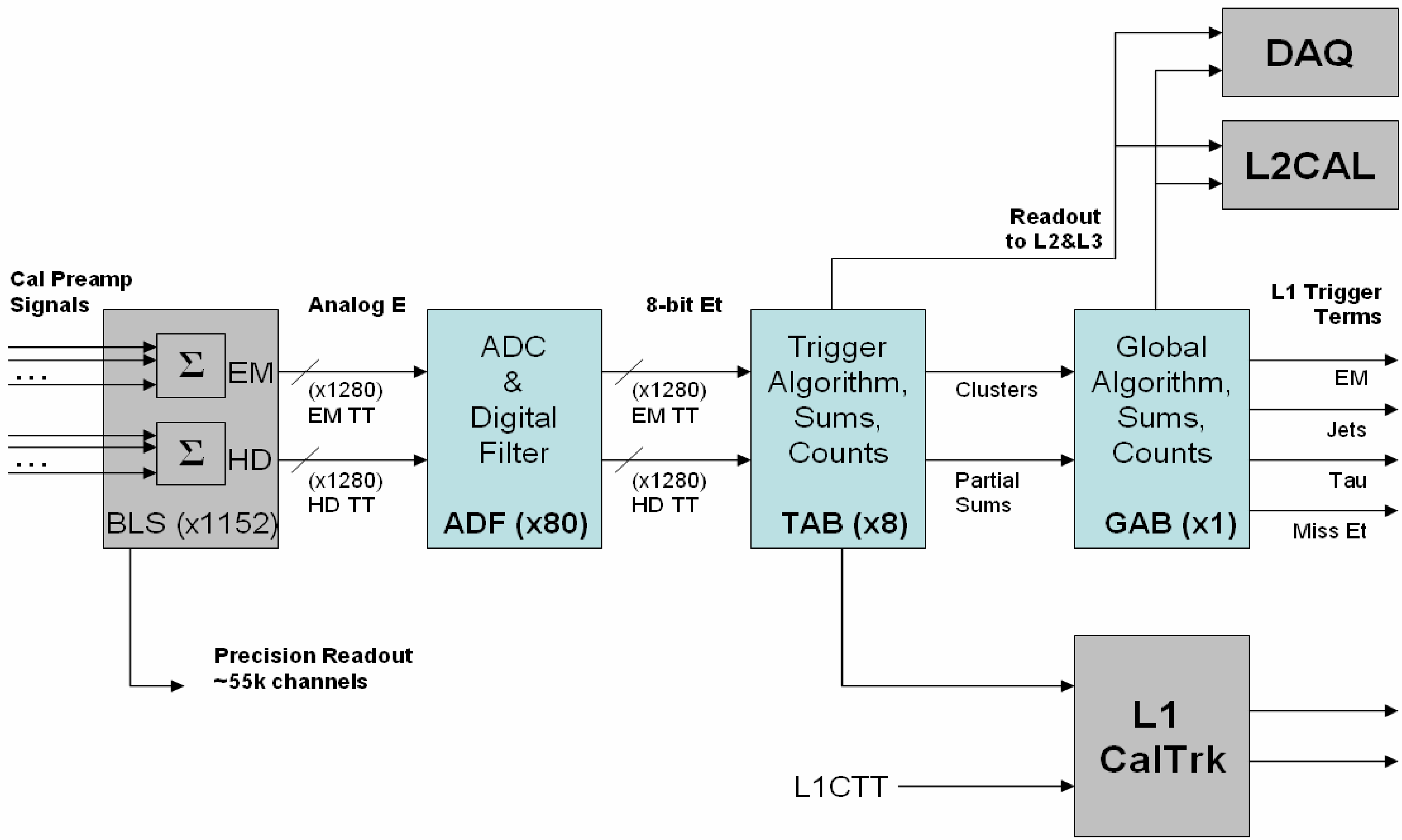
L1 Trigger Sub-Systems : L1Muon



L1 Trigger Sub-Systems : L1Muon

- References:
  - http://www-d0online.fnal.gov/www/groups/calmuo/
  - http://atlas.physics.arizona.edu/~johns/l1muo/l1muo-top.htm

L1 Trigger Sub-System: L1Cal

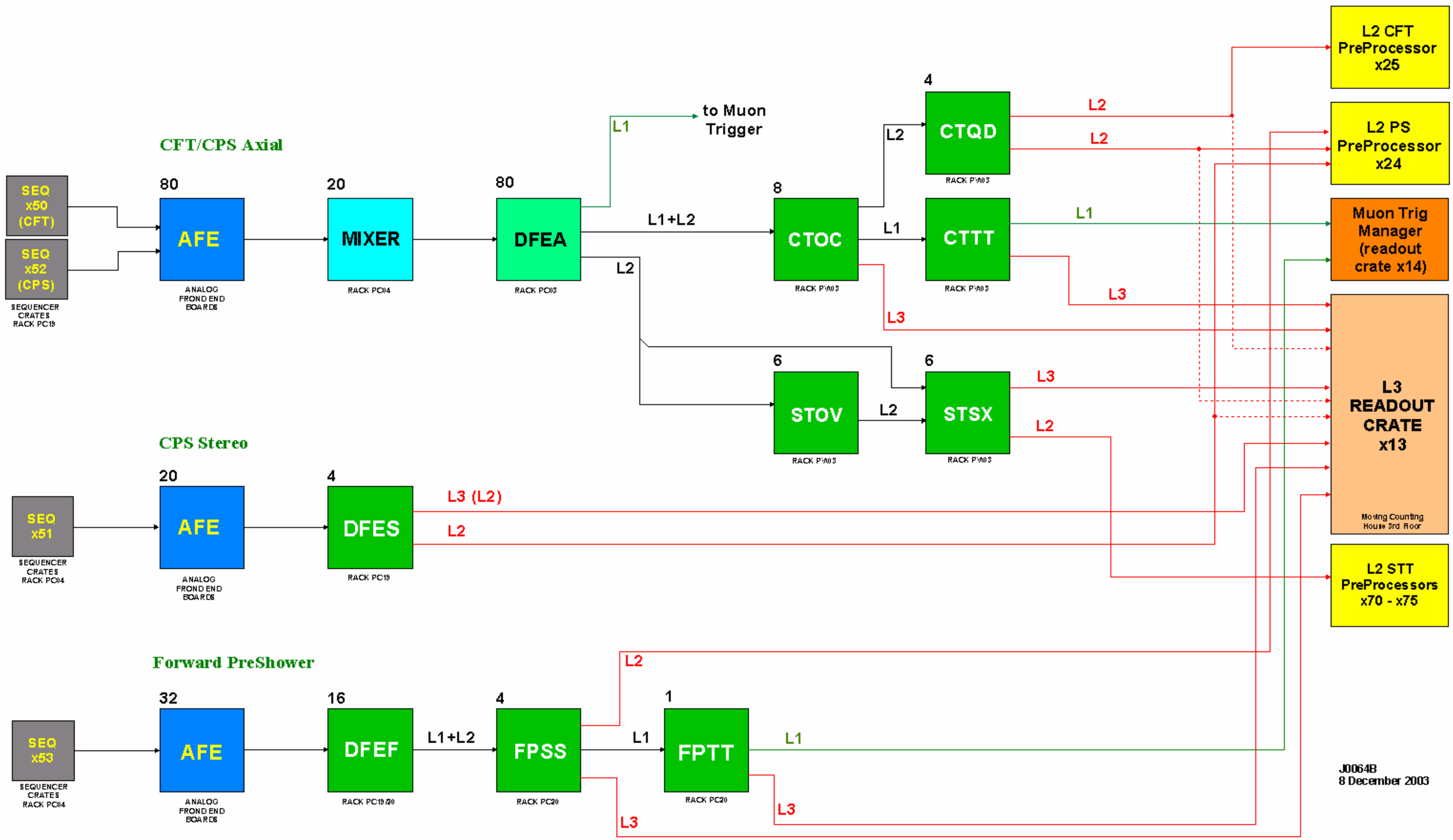


L1 Trigger Sub-System: L1Cal

- Example of Trigger Term sent to the Trigger Framework
  - CSWEM(2,10.,3.2) : >= 2 Electron, >=10 GeV, |eta|<=3.2
  - CSWEI(1,16.,3.2) : >=1 Isolated EM, >=16 GeV, |eta|<=3.2
  - CSWJT(1,20.,3.2) : >=1 Jet, >=20 GeV, |eta|<=3.2
  - CSWMET(24.) : Missing Et >= 24 GeV

- References:
  - http://www.nevis.columbia.edu/~evans/l1cal/

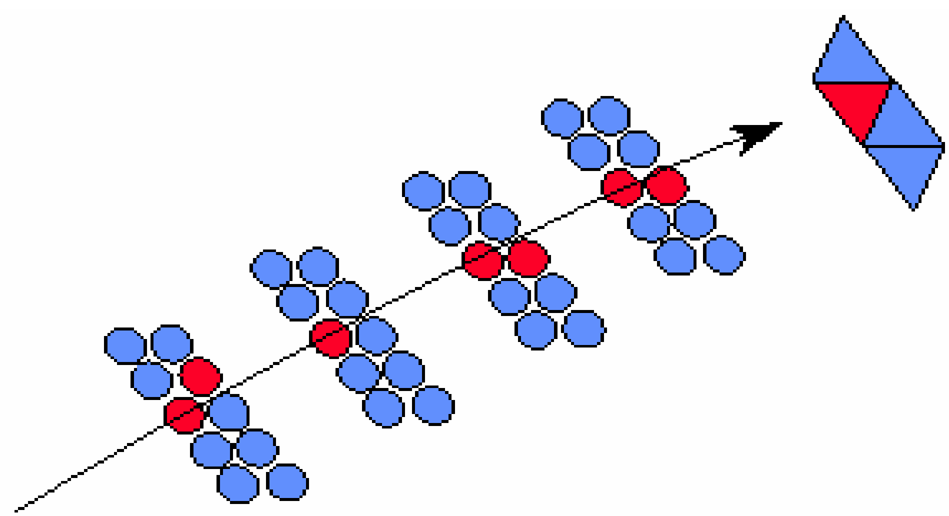
L1 Trigger Sub-System: L1CTT



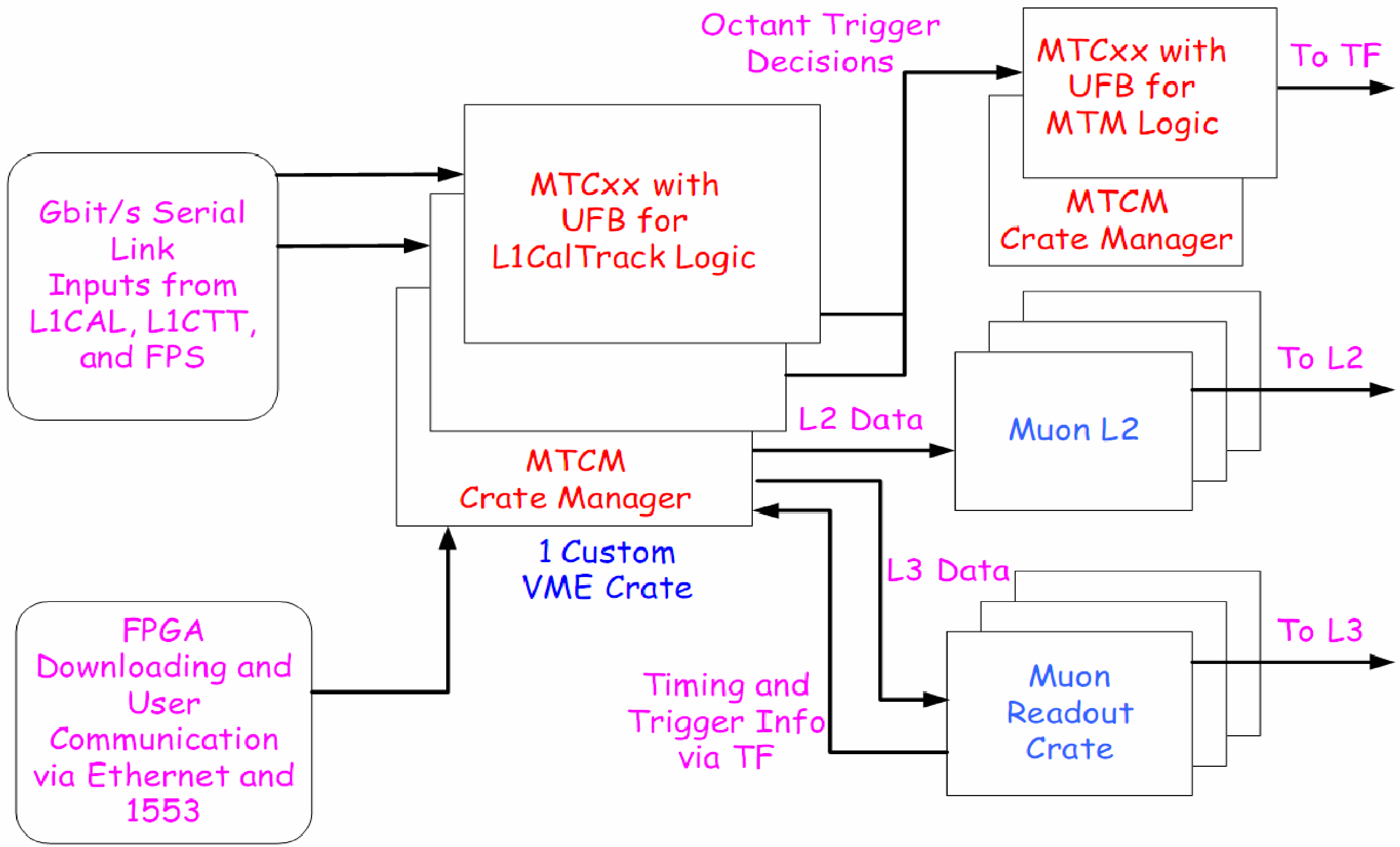
L1 Trigger Sub-System: L1CTT

- Tracking Trigger:
  - Send all axial fibers (plus central and forward preshower) to gate arrays
  - Detect if a fiber combination is consistent with preset Pt thresholds
  - Also tags: Track, Isolated Track, Electron, …

- Reference:
  - http://www-d0online.fnal.gov/www/groups/cft/CTT/online/ctt_main.html



L1 Trigger Sub-System: L1Cal-Track

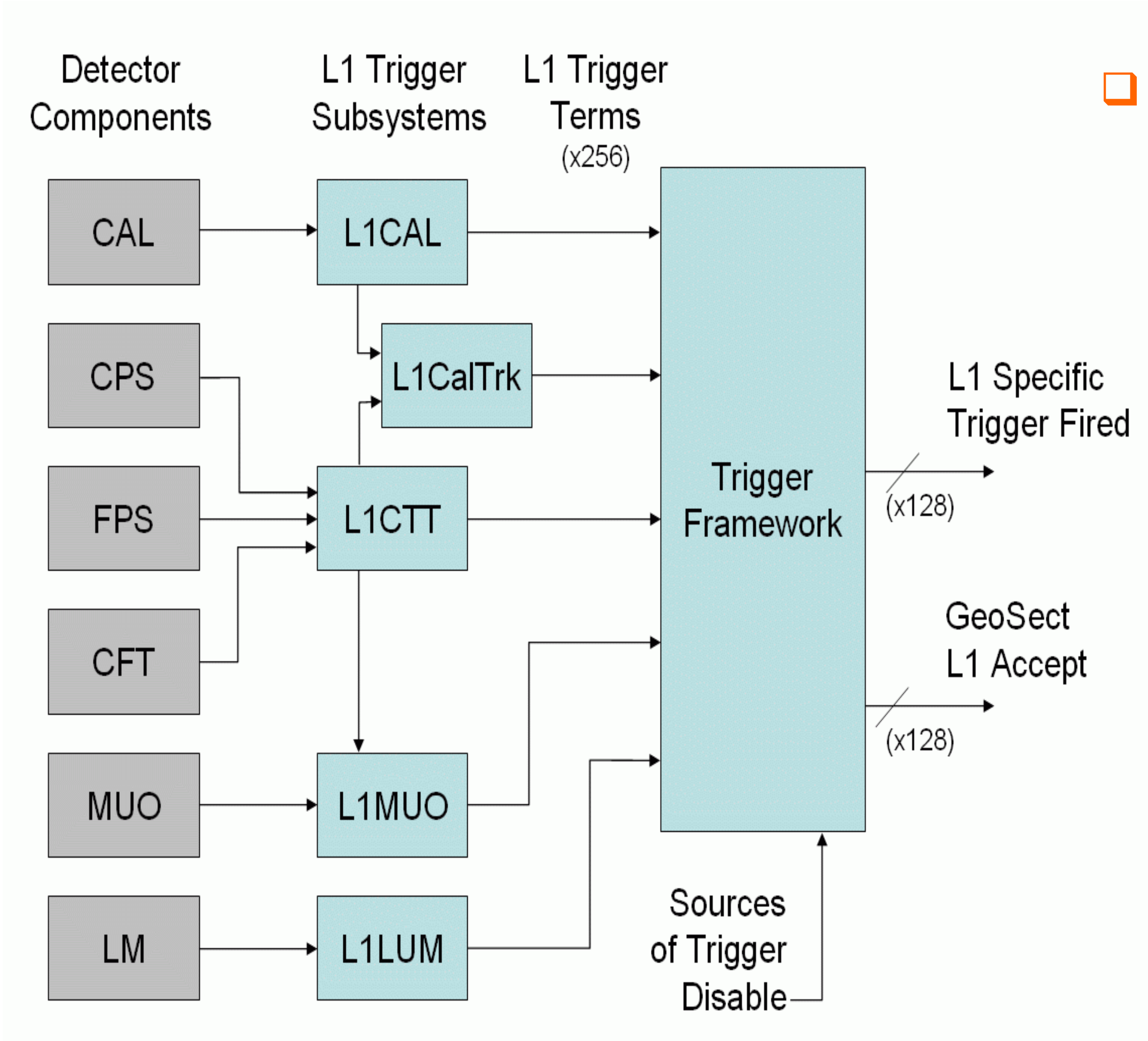


L1 Trigger Sub-System: L1Cal-Track

- Reference:
  - http://atlas.physics.arizona.edu/~johns/l1muo
    /l1caltrack/l1caltrack-top.htm

- Introduction
  - Fermilab
  - DZero
  - Triggering at D-Zero
- L1 Trigger Sub-Systems
- **Trigger Framework**
- Serial Command Link
- Control of the TFW
- Monitoring of the TFW
- Online Luminosity Measurement
- Conclusion

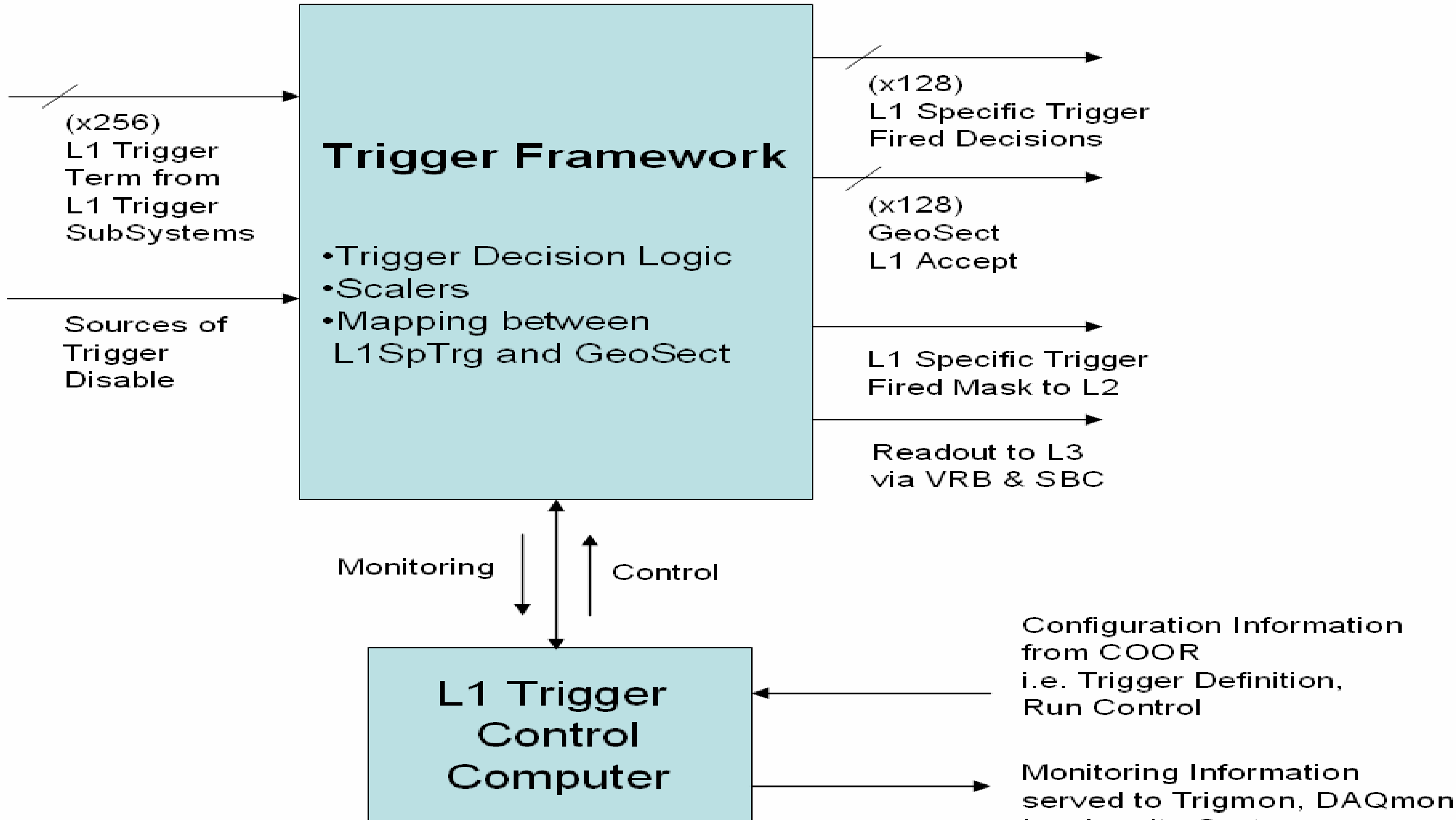
D-Zero Level 1 Trigger



- Modular Design
  - L1 Trigger Subsystems do **not** directly cause triggers
  - Partitionable Triggering and Readout

Trigger Framework

- Level 1 Functionalities of the TFW

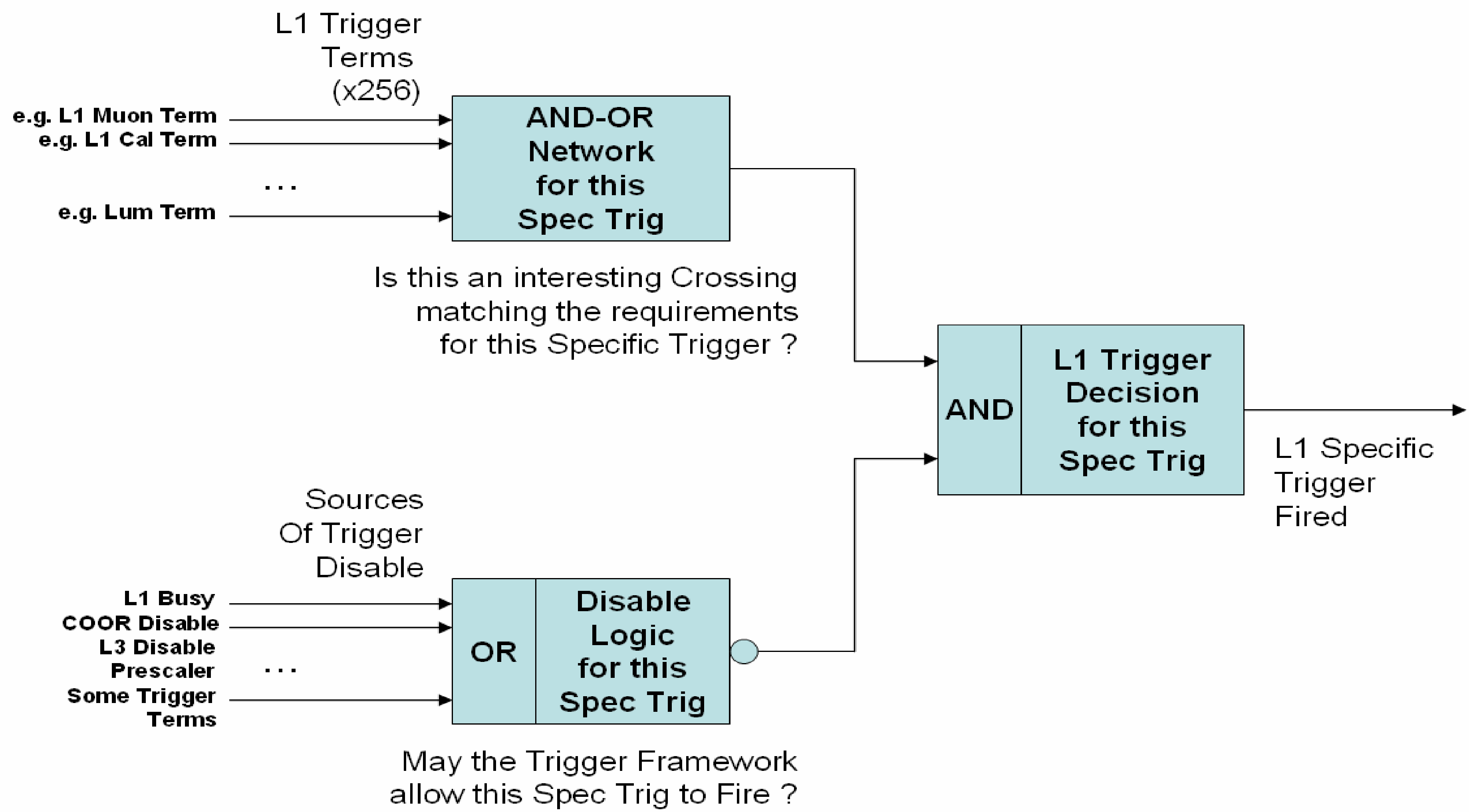


Trigger Framework

- A typical L1 Trigger would include, e.g:
  - Some L1 Trigger Terms
    - Require L1CTT ‘TTK(1,3.)‘ i.e. >= 1 Track >= 3 GeV
    - Require L1CAL ‘CSWEM(1,4.,3.2)’ i.e. >= 1 Electron >= 4 GeV
    - Require L1MUO 'mu1ptxattx‘ ie. >=1 muon with tight scint requirement
    - Require 'live_accel_bx‘
  - Some Technical Terms
    - Veto ‘skip_next_n_0‘ i.e. skip 8 crossings after each L1 Accept
    - Veto 'caltc00‘ i.e. stay away from Calorimeter pulser
  - A List of crates to be readout
  - A Prescale ratio

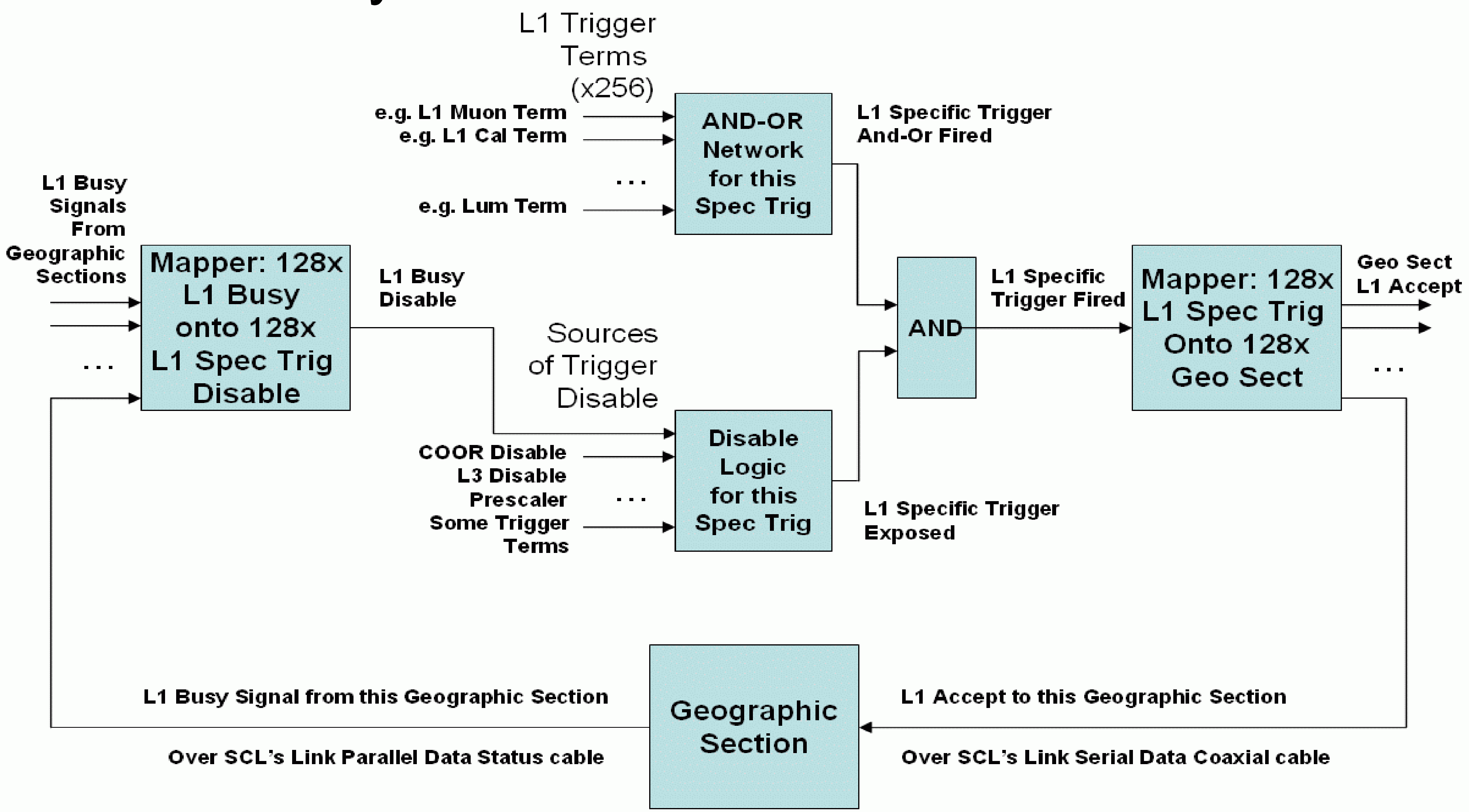
Trigger Framework

❑ Forming Trigger Decisions



Trigger Framework

- The DAQ System can "throttle" itself



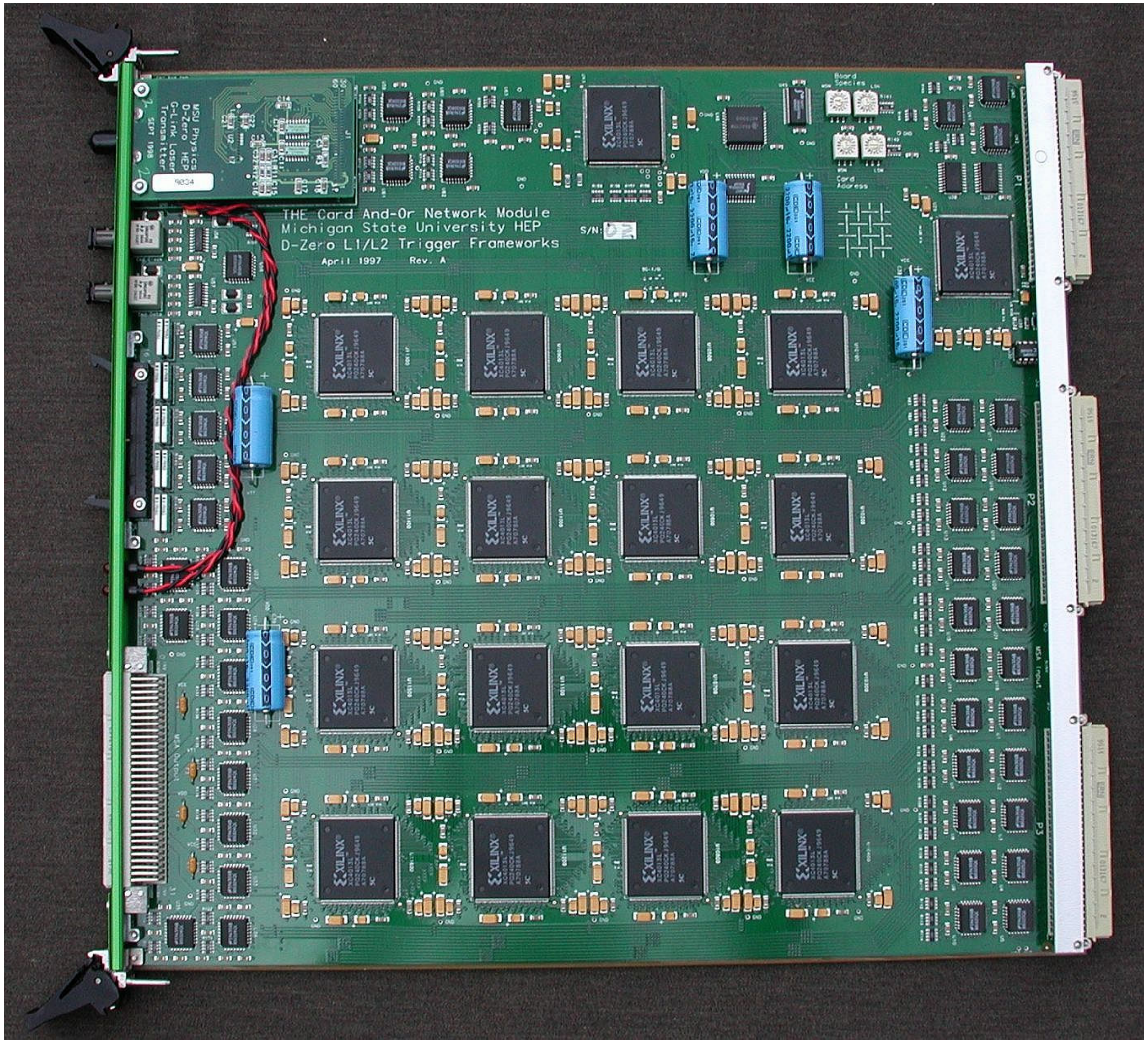
Trigger Framework

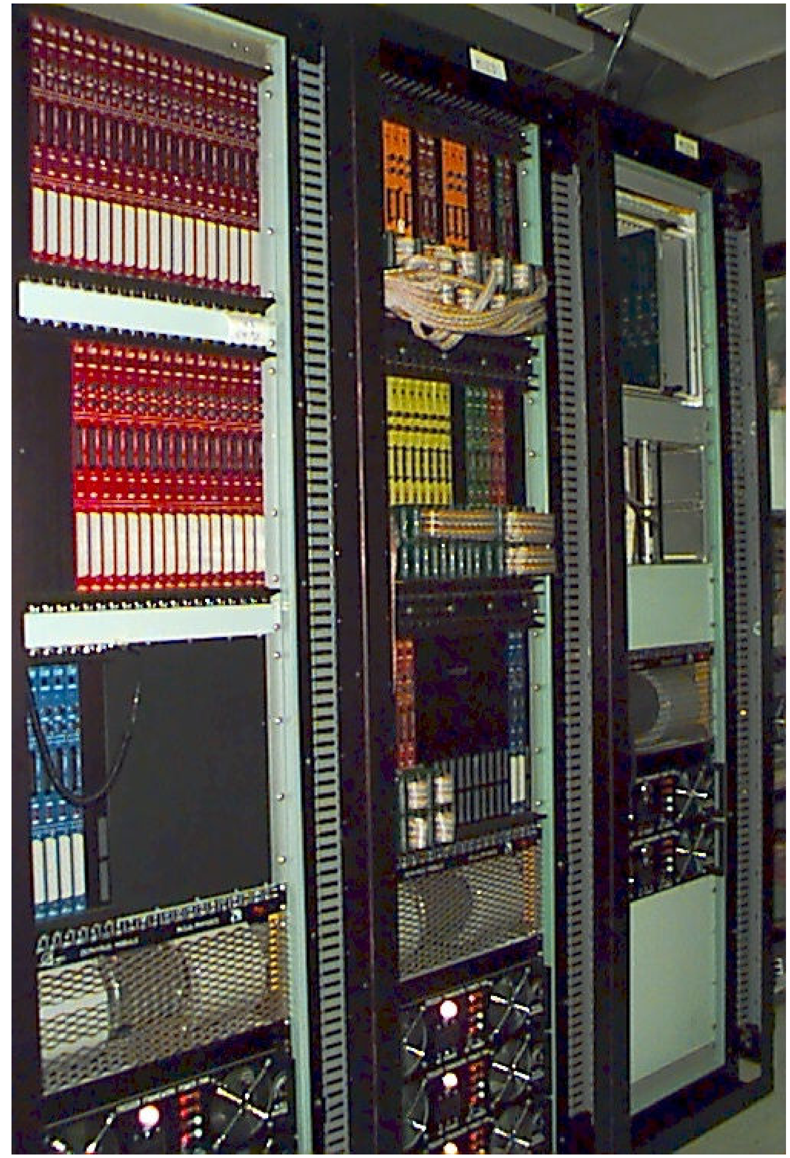
- 256 Input **Trigger Terms** available
  - use ~175 for data taking with beam
- 128 **Geographic Sections**
  - use ~80 for data taking with beam
- 128 **Specific Triggers** available
  - use ~120 for data taking with beam
  - Different types
    - Physics
    - zero bias
    - monitoring
    - diagnostics

Trigger Framework

- The Trigger Framework itself reads out
  - Pass information to L3 system
    - e.g. Event Number
  - Includes all inputs, outputs, states
    - e.g. Mask of Specific Trigger Fired for this event
  - Includes information about adjacent BXs
    - e.g. state of L1 Trigger Terms for previous and next crossings
  - Allow verification of TFW internal operation
  - Cross-reference with other subsystems

Trigger Framework



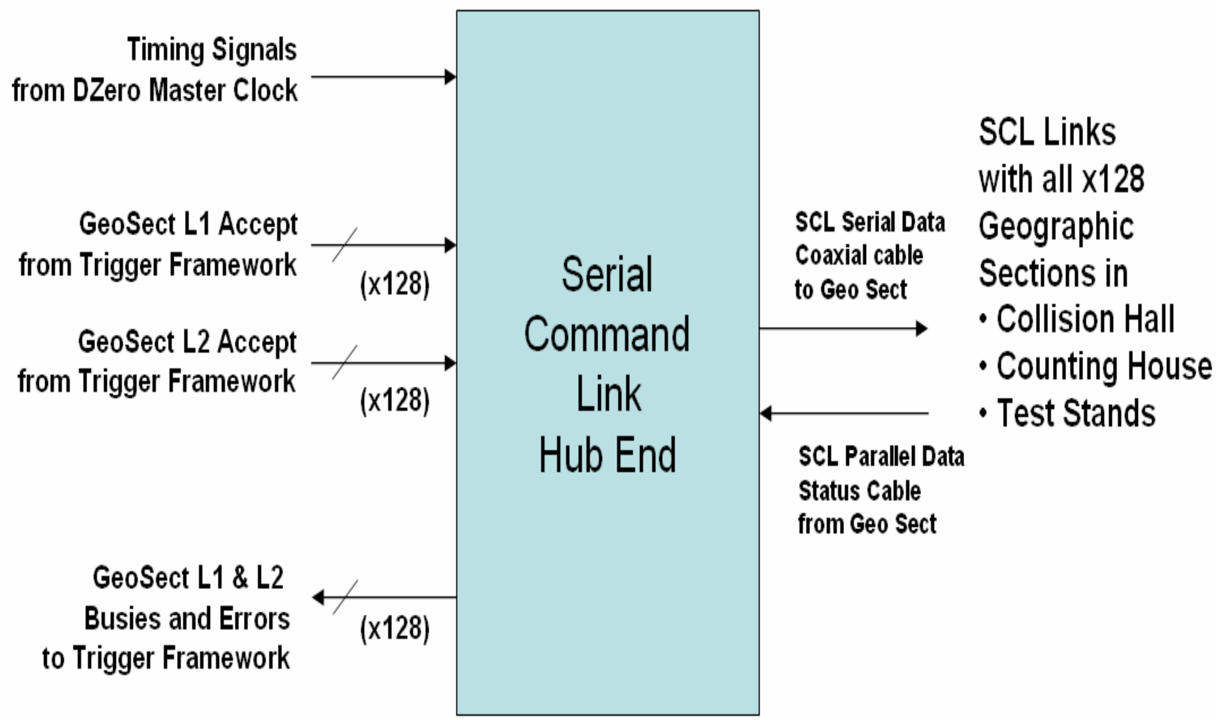


- Introduction
  - Fermilab
  - DZero
  - Triggering at D-Zero
- L1 Trigger Sub-Systems
- Trigger Framework
- **Serial Command Link**
- Control of the TFW
- Monitoring of the TFW
- Online Luminosity Measurement
- Conclusion

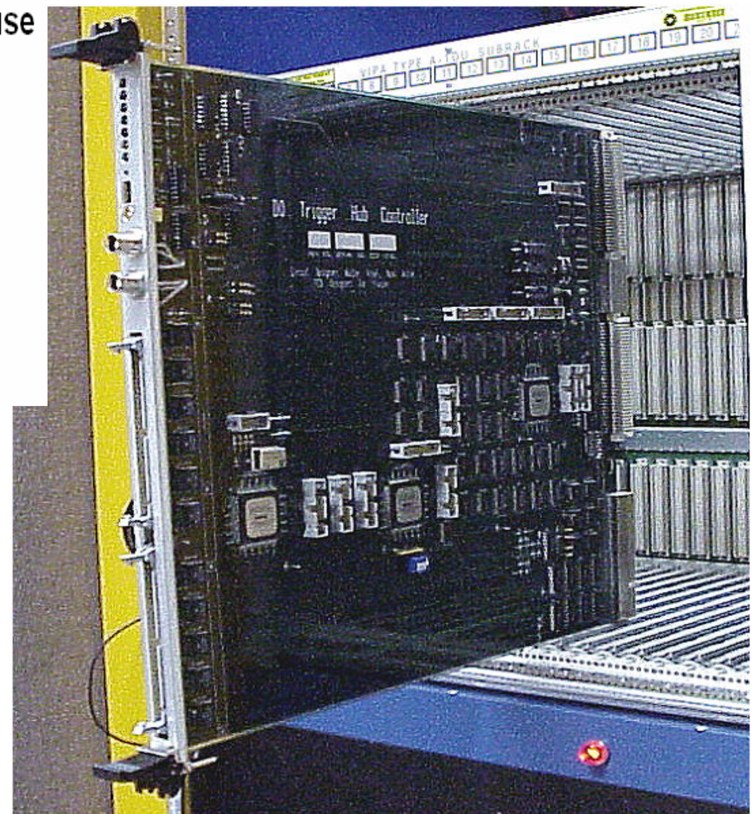
SCL = Serial Command Link

- Design idea: Common hardware path carrying all the information a Geographic Section needs to operate in the Run II Trigger/DAQ environment.
- SCL Hub End is hosted in the Trigger Framework
  - Sends to each GeoSect:
    - Timing Information from DZero Master Clock
    - L1/L2 Trigger Decisions from Trigger Framework
    - Initialization requests
  - Receives from all GeoSect and concentrates:
    - L1 and L2 Busy signals
    - L1 and L2 Error signals
    - Initialization Acknowledgement

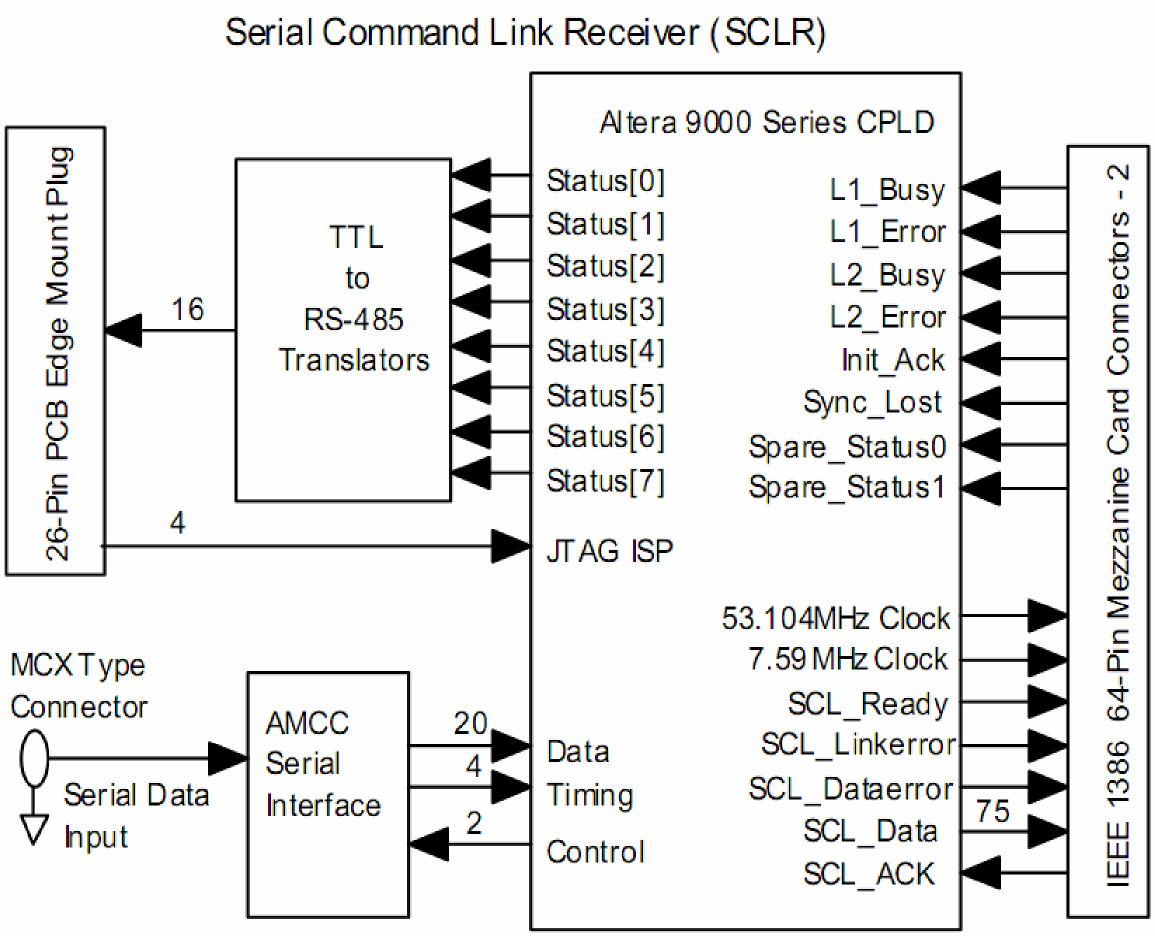
SCL : Hub End

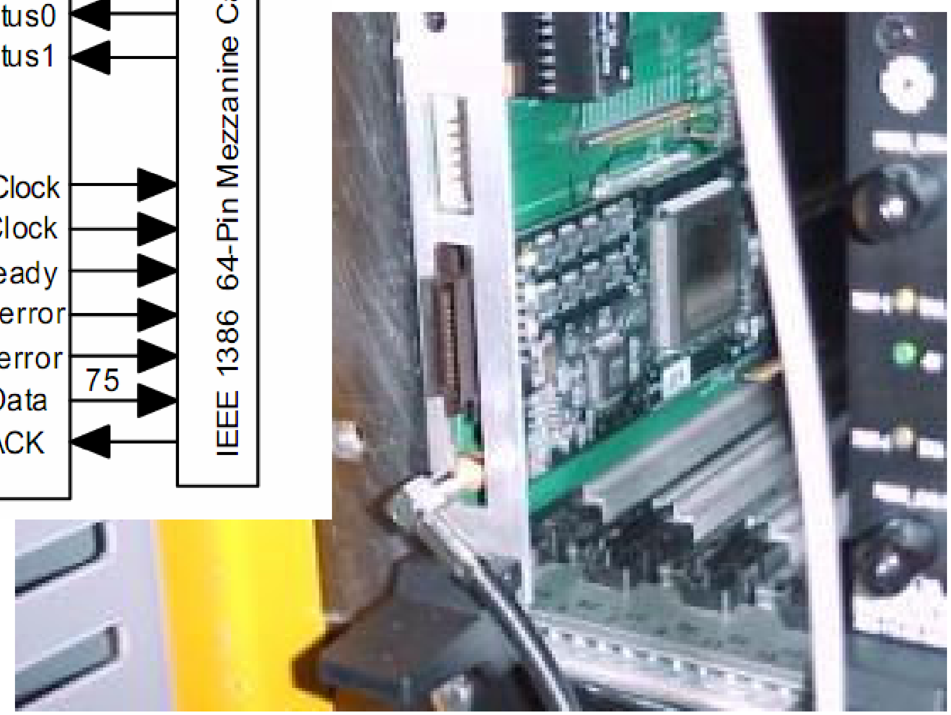


Timing Signals from DZero Master Clock
GeoSect L1 Accept from Trigger Framework
(x128)
GeoSect L2 Accept from Trigger Framework
(x128)
GeoSect L1 & L2 Busies and Errors to Trigger Framework
(x128)
Serial Command Link Hub End
SCL Serial Data Coaxial cable to Geo Sect
SCL Parallel Data Status Cable from Geo Sect
SCL Links with all x128 Geographic Sections in
• Collision Hall
• Counting House
• Test Stands



SCL : Receiver Mezzanine





Serial Command Link

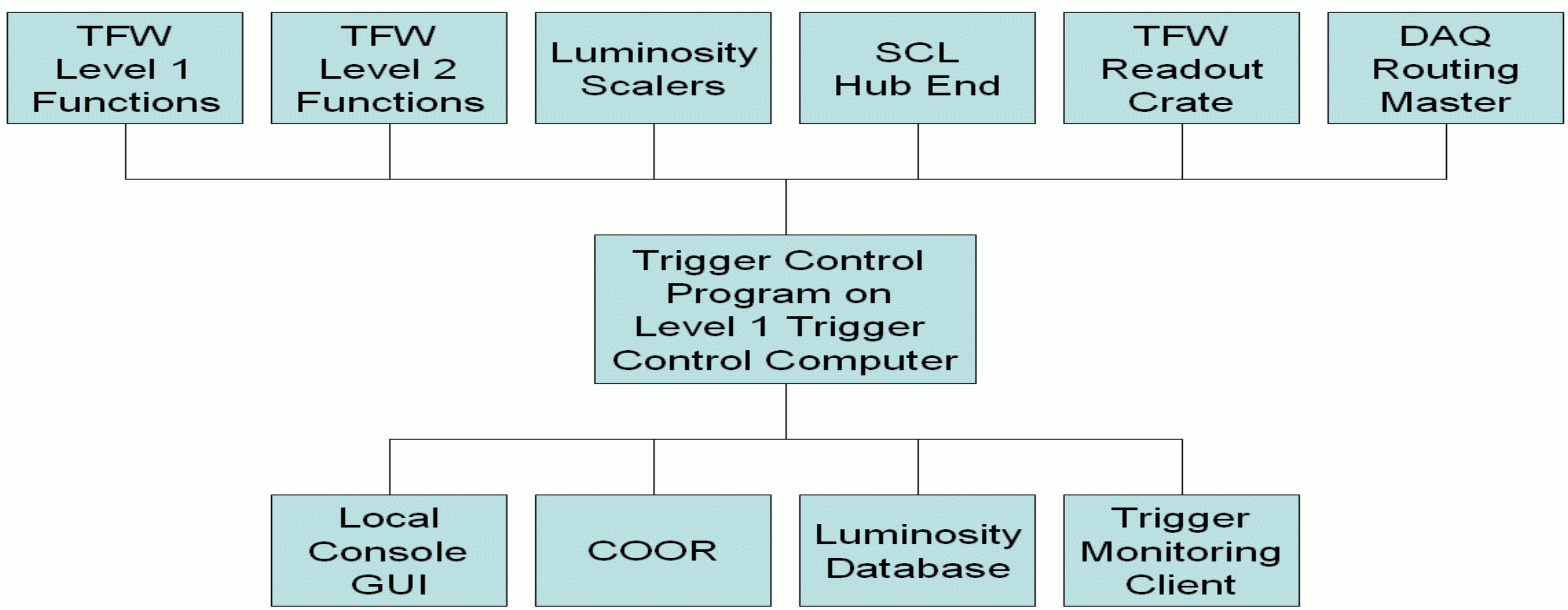
- Connect to Geographic Sections of different types
  - Most readout, some used for synchronization
  - Some on platform, some in Counting House
  - Some used for Test Stands

- References:
  - http://www-ese.fnal.gov/d0trig
  - http://www.pa.msu.edu/hep/d0/l1/scl.html

- Introduction
  - Fermilab
  - DZero
  - Triggering at D-Zero
- L1 Trigger Sub-Systems
- Trigger Framework
- Serial Command Link
- **Control of the TFW**
- Monitoring of the TFW
- Online Luminosity Measurement
- Conclusion

Control of the TFW

- COOR is the experiment coordinator program
- Trigger Control Computer (L1TCC) hides the complexity of the hardware from rest of experiment.
  - COOR and L1TCC communicate at high level.
  - Pick the Interface at triggering resources; where cleanest



Control of the TFW

- COOR makes requests and L1TCC complies
  - All messages are acknowledged
    - Success/Failure
  - COOR requests are incremental
    - i.e. not full context in every message
- "Trigger Programming" in three phases
  - Configuration of FPGA Firmware (at power up)
  - Initialization (including before each store)
    - Check health status of all resources
    - Forget all history
    - Bring to defined default state for COOR control
  - Run-Time programming (for physics running or tests)
    - Managed by Trigger Board (for physics)
    - Controlled through COOR

Control of the TFW

- Trigger Control Software
  - Object-oriented implementation with generic procedures used for:
    - COOR messages
    - Tests and diagnostics
    - Interactive expert commands (via GUI)
  - All communications & all actions are logged
    - with time stamps.
  - Check previous content of a register before changing its content, check again after
    - Not relying solely on VME IO cycle completion

- Introduction
  - Fermilab
  - DZero
  - Triggering at D-Zero
- L1 Trigger Sub-Systems
- Trigger Framework
- Serial Command Link
- Control of the TFW
- **Monitoring of the TFW**
- Online Luminosity Measurement
- Conclusion

Monitoring of the TFW

- Provides monitoring of Triggering & DAQ for the whole experiment
- Monitor Trigger Resources
- Diagnose sources of problems
- Data may be displayed in different forms
  - Rates
  - Percentages
  - Counts
  - States

Monitoring of the TFW

- Hardware assistance:
  - TFW hardware is built to simultaneously "capture" monitoring information in all parts of the TFW
  - L1TCC later reads out this snapshot over VME
- Beam Crossing counter captured in snapshot provides accurate Time Base for scaler increments:
  - Can tell ~100.0% apart from exactly 100%
  - And tell ~0.0% from exactly never

Monitoring of the TFW

- Get a fresh snapshot of monitoring information about once every 5 seconds (including the precise Beam Crossing counter for time reference)
  - Get information from triggered BXs, when possible
  - Force the capture of fresh contemporary data when DAQ is stuck, to be able locate the source of the problem
- L1TCC only captures monitoring information
- L1TCC serves monitoring data to Monitoring Clients
  - Calculate increments, rates, percentages
  - Display, Graph, Log
  - Automatically diagnose problems, take action
  - Post on the web
    - http://www.pa.msu.edu/hep/d0/l1/tcc/trigmon_snapshot_frame.html
    - http://www-d0online.fnal.gov/www/groups/tm/daqrates/current_store.html

- Introduction
  - Fermilab
  - DZero
  - Triggering at D-Zero
- L1 Trigger Sub-Systems
- Trigger Framework
- Serial Command Link
- Control of the TFW
- Monitoring of the TFW
- **Online Luminosity Measurement**
- Conclusion

Instrumenting & Monitoring
Online Luminosity for each L1 Trigger

- First: need a Luminosity Monitor signal
  - cf. other DZero talk

- Now need to instrument this signal to be able to derive:
  - Delivered and Recorded Beam Luminosity
  - Instantaneous and Integrated Luminosity
  - Individual Luminosity that each L1 Specific Trigger has been exposed to

How Luminosity is Measured for each L1 Trigger

- Luminosity Monitor must be instrumented separately for each bunch
  - Non linear math = compute each bunch separately, then sum
  - Non linear math = must maintain good time resolution
- Luminosity Monitor must be instrumented separately for each Specific Trigger
  - Specific Triggers enabled (exposed) for different crossings
- D-Zero could thus have
  - 128 x 159 = 20k scalers
- For comparison: Atlas could have
  - 256 x 3564 = 900k scalers

How Luminosity is Measured for each L1 Trigger

- Reducing the number of luminosity scalers:
  - Differentiate Correlated vs Non-Correlated sources of disable
    - Some sources may not treat all crossing evenly
    - e.g. a larger bunch may cause more L1 Accept, and dead-time can thus “shadow” following bunches
  - Form Exposure Groups for L1 Specific Triggers with common sources of correlated disable
    - Geographic Section Disable (L1 busy after Trigger Accept)
    - Some Global Disable (e.g. skip next crossing after L1 Accept)
    - Some And-Or Exposure Restrictions (e.g. Live Crossing)
  - Individual Specific Trigger in each Exposure Group may still have independent sources of de-correlated disable
    - COOR Enable
    - Prescaler (after careful implementation of a duty cycle prescaler)
    - Level 2 Disable (not fixed delay from L1 Accept)
    - Level 3 Disable (no fixed delay)

How Luminosity is Measured for each L1 Trigger

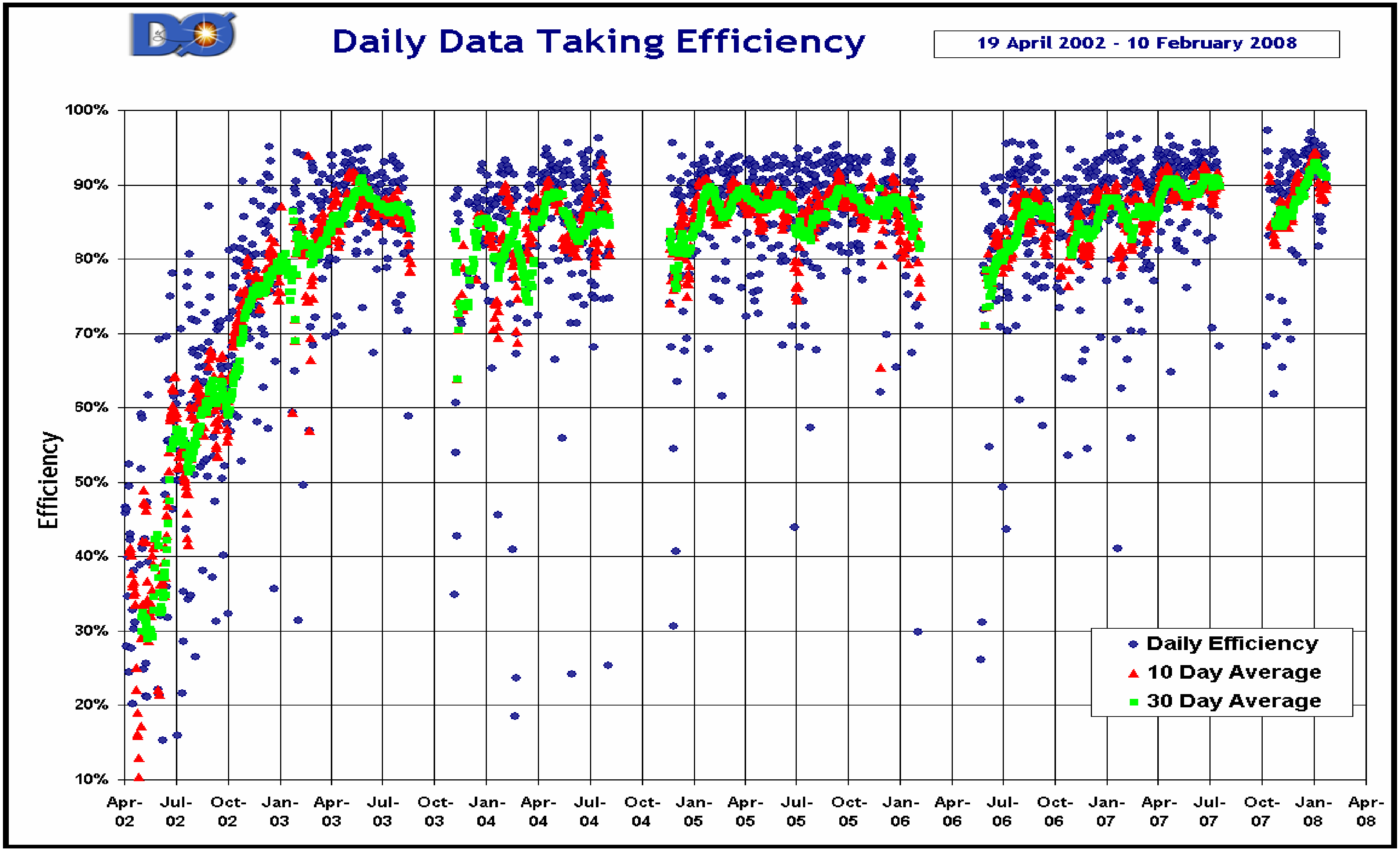
- Fully instrument up to 8 separate Exposure Groups
  - 8 x 159 = 1.3k scalers
- Instrument the de-correlated contribution for each Specific Trigger
  - Applied as a correction to the Exposure Group the Specific Trigger belongs to
- Luminosity information recorded at Luminosity Blocks boundaries with unique IDs
  - every minute, or when run conditions change
- End up with individual measurements for the "Exposed Luminosity" of all 128 L1 Spec Triggers

Instrumenting & Monitoring
Online Luminosity for each L1 Trigger

- Summary for the L1 Trigger designer:
  1. All Luminosity quantities must be instrumented "per bunch"
  2. Classify sources of L1 Trigger disable in 2 types:
     - Correlated to Bunch Luminosities
     - Non-Correlated to Bunch Luminosities
       - ✓ design Prescaler functionality to be non-correlated (duty ratio prescalers)
  3. Form Exposure Groups of L1 Triggers having common Correlated sources of disable, and instrument each Exposure Group with a set of per bunch scalers
  4. Instrument non-correlated disable for each L1 Trigger
  5. Divide beam time into Luminosity Blocks (time segments)
  6. For each Luminosity Block, compute correlated Exposure Group luminosities, and scale down by non-correlated fraction to obtain individual L1 Trigger luminosities.

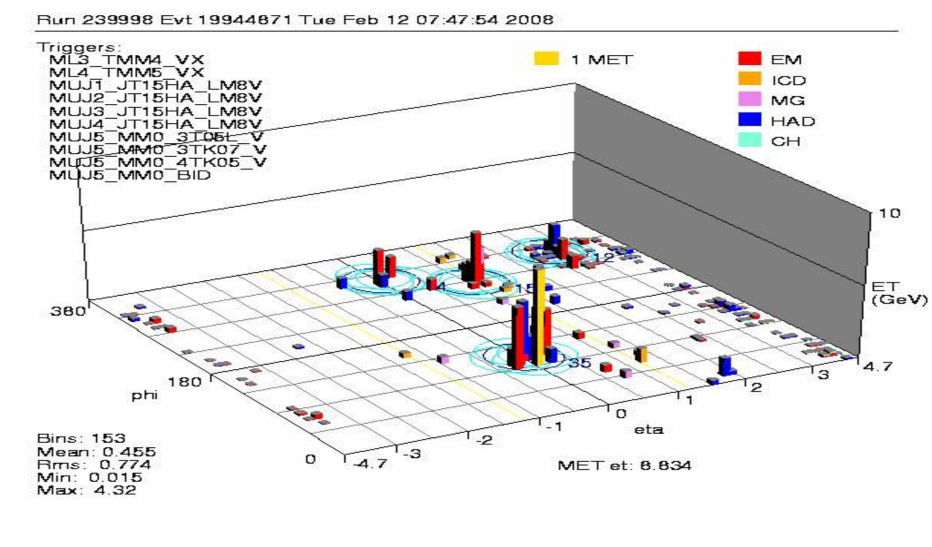
- Introduction
  - Fermilab
  - DZero
  - Triggering at D-Zero
- L1 Trigger Sub-Systems
- Trigger Framework
- Serial Command Link
- Control of the TFW
- Monitoring of the TFW
- Online Luminosity Measurement
- **Conclusion**

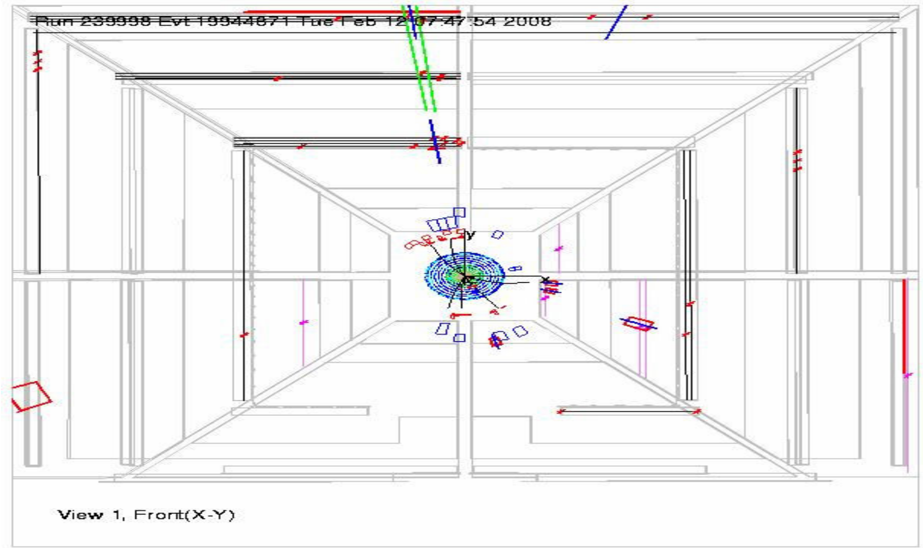
Conclusion

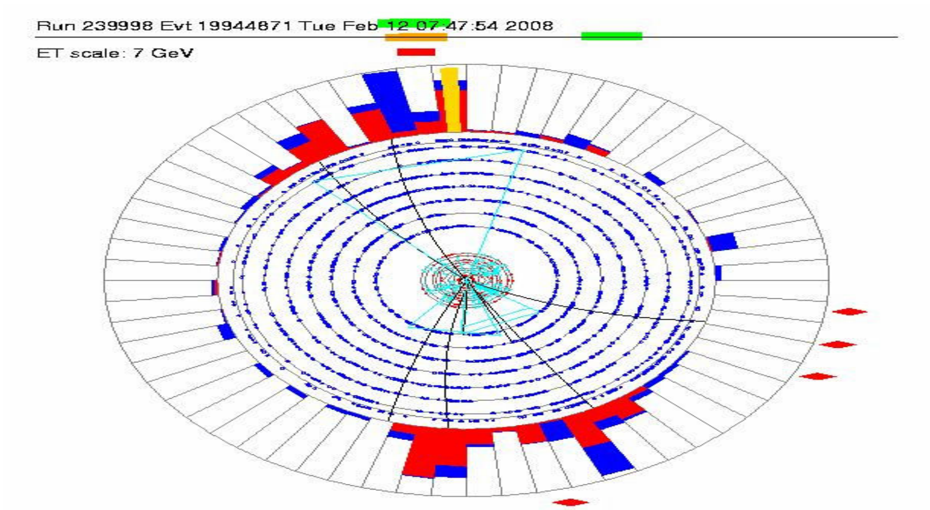


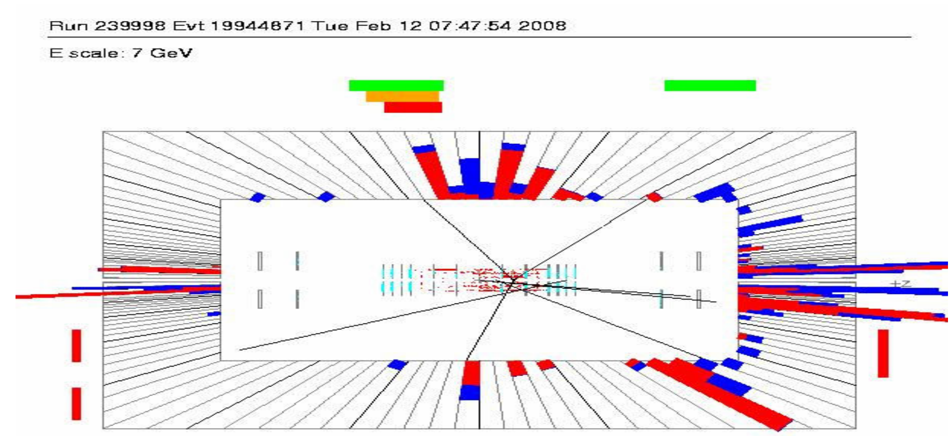
Daily Data Taking Efficiency
19 April 2002 - 10 February 2008
Efficiency
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
Apr-02
Jul-02
Oct-02
Jan-03
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
Jul-04
Oct-04
Jan-05
Apr-05
Jul-05
Oct-05
Jan-06
Apr-06
Jul-06
Oct-06
Jan-07
Apr-07
Jul-07
Oct-07
Jan-08
Apr-08
Daily Efficiency
10 Day Average
30 Day Average

Live Events Online
www.fnal.gov/pub/now/live_events/dzero_live.html



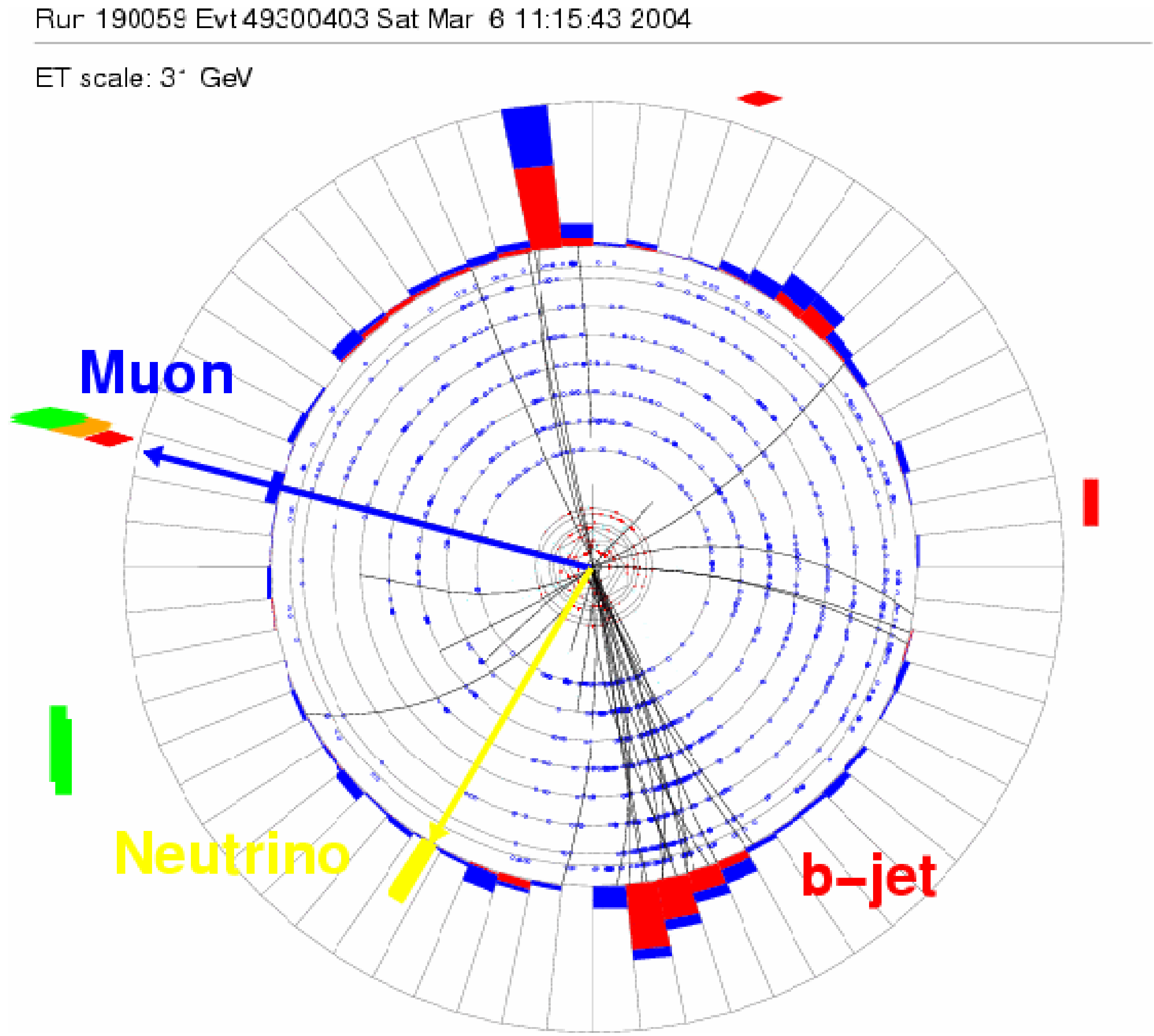






Conclusion

- A Single Top Candidate



Conclusion

- RunII hardware in operation since 2001
- First RunII Collisions in April 2001
- Expect to run through 2009 and maybe 2010
- Over 3 fb^{-1} of integrated luminosity recorded
- Potential for 8-9 fb^{-1} by end of 2010

Thank you

- Contact: edmunds@pa.msu.edu
- http://www.pa.msu.edu/hep/d0/l1/