



Operation and Performance of the CMS Level-1 Trigger During 7 TeV Collisions



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TIPP 2011

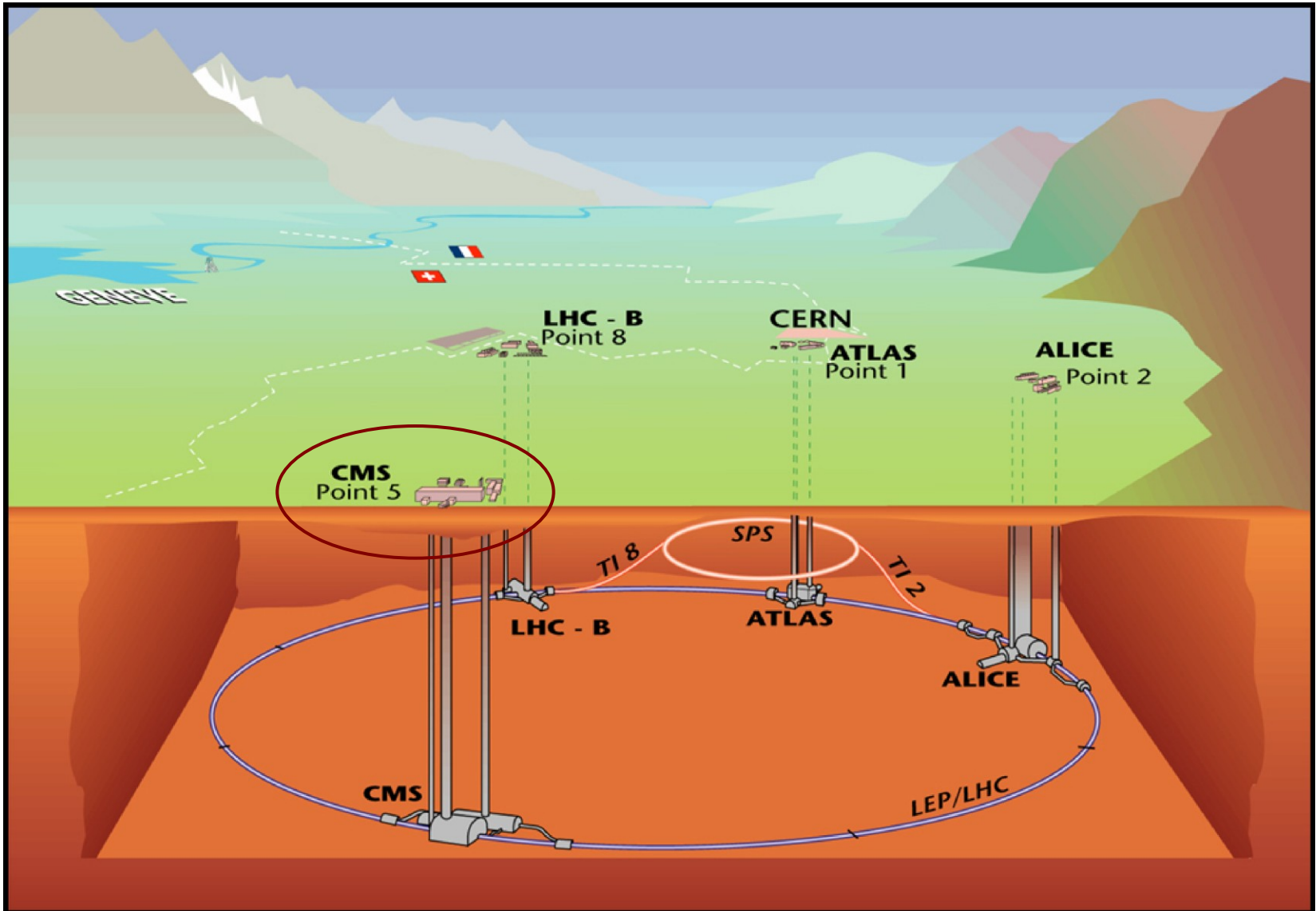
Thursday, June 9, 2011

The pdf file of this talk is available at:

<https://indico.cern.ch/contributionDisplay.py?contribId=73&sessionId=19&confId=102998>



The Large Hadron Collider





LHC p-p Collisions Operations 2010-2011

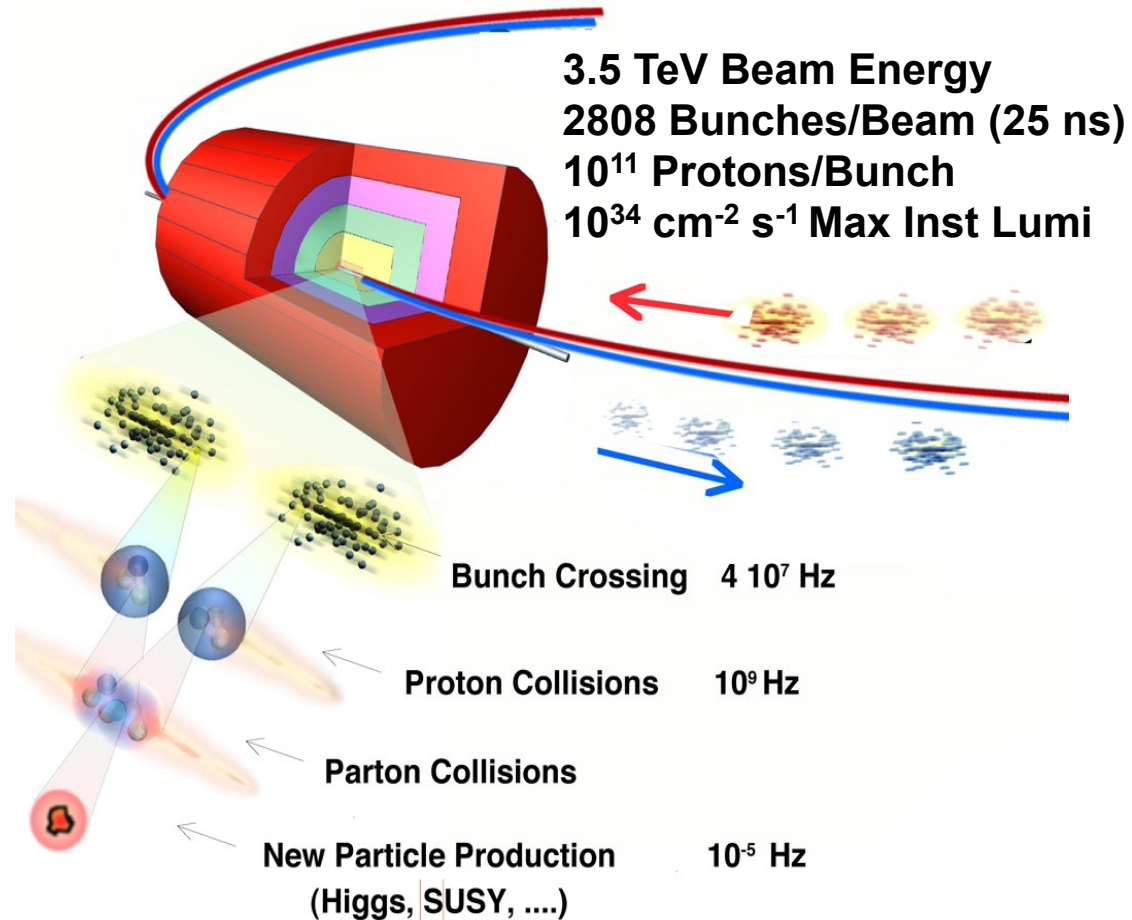


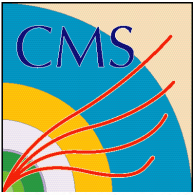
2010: $\sqrt{s} = 7 \text{ TeV}$

- **Peak Instantaneous Luminosity:**
 $> 2 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$

2011: $\sqrt{s} = 7 \text{ TeV}$

- **Peak Instantaneous Luminosity:**
 $1.23 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$
(1042 colliding at CMS)
- **And increasing!**
- **This year a maximum of ~1404 bunches/beam in LHC (50 ns spacing)**
- **Possible to gain some additional inst. lumi (intensity, β^* , emittance, etc)**





CMS Detector



SUPERCONDUCTING COIL

CALORIMETERS
ECAL Scintillating PbWO₄ Crystals

HCAL Plastic scintillator
brass sandwich

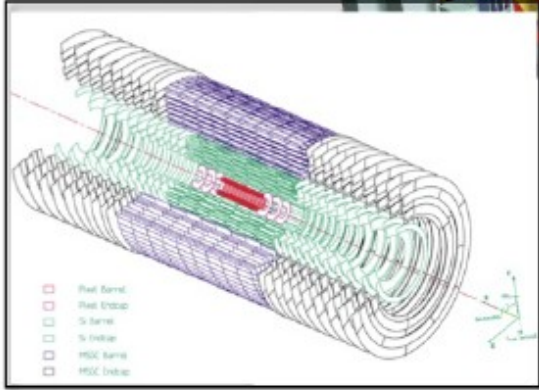
IRON YOKE

MUON ENDCAPS

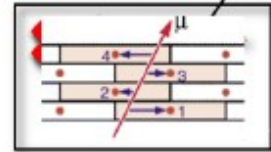
MUON BARREL

Total weight : 12,500 t
Overall diameter : 15 m
Overall length : 21.6 m
Magnetic field : 4 Tesla*

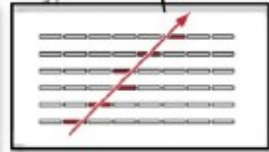
TRACKERS



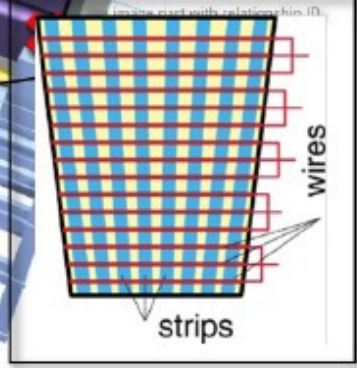
Silicon Microstrips
Pixels



Drift Tube Chambers (DT)

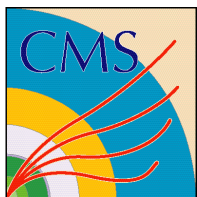


Resistive Plate Chambers (RPC)

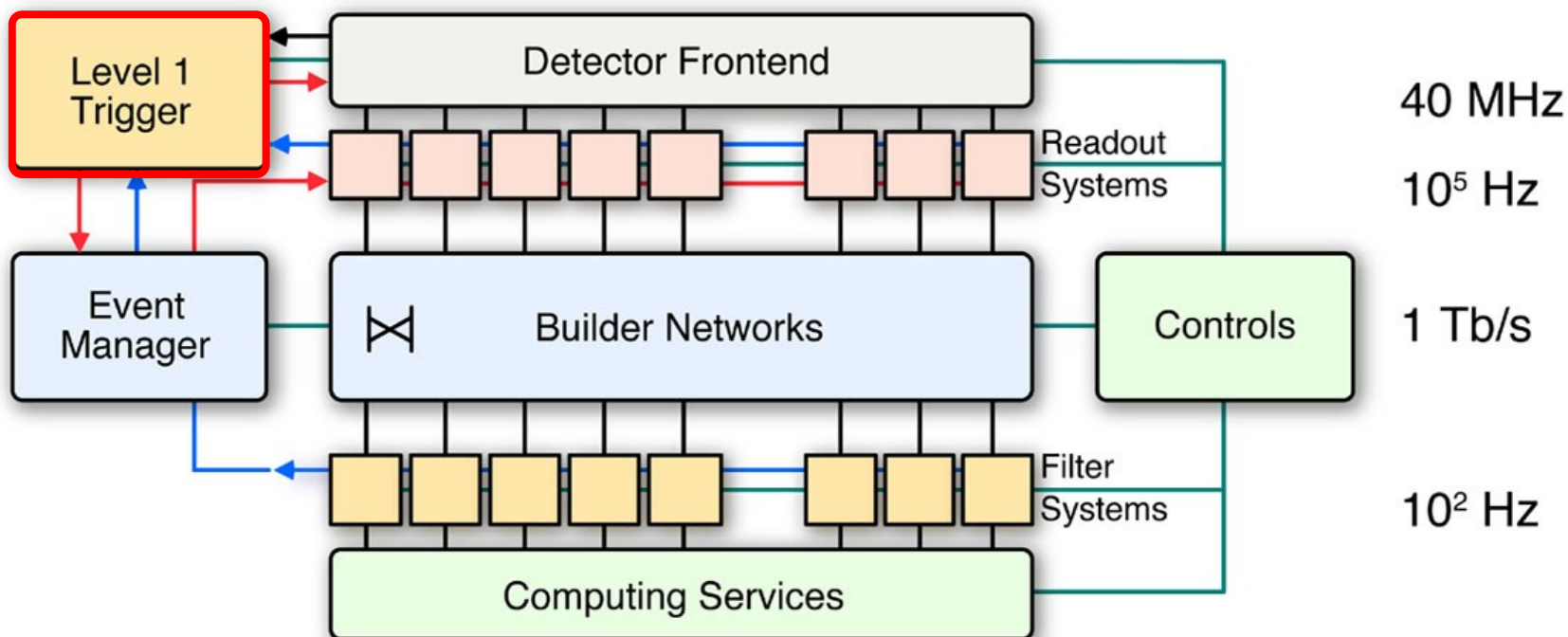


Cathode Strip Chambers (CSC)
Resistive Plate Chambers (RPC)

***Actually 3.8 T**

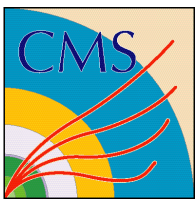


CMS Trigger & DAQ Systems



Level-1 Trigger

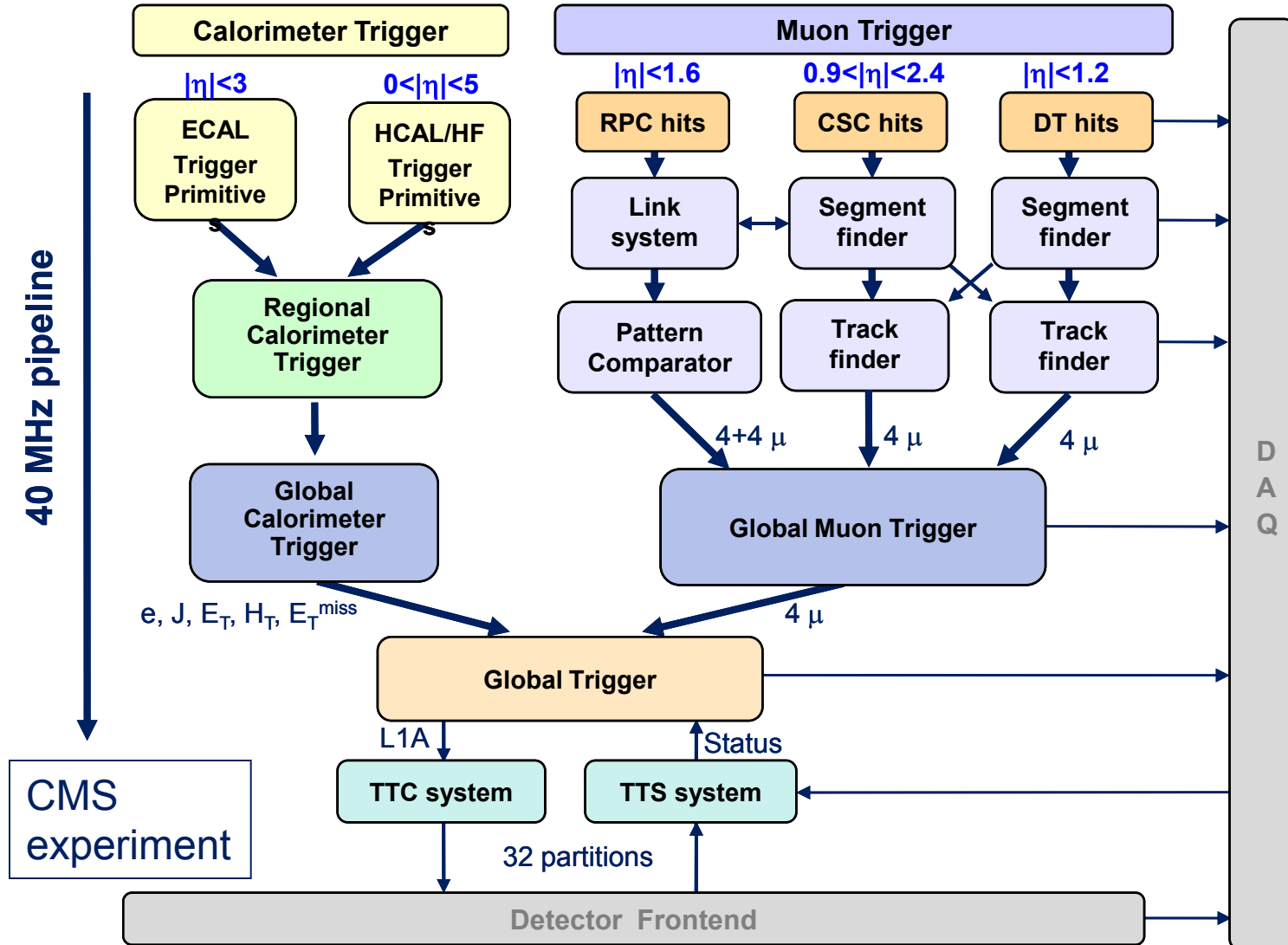
- LHC beam crossing rate is 40 MHz & at full Luminosity of $10^{34} \text{ cm}^{-2}\text{s}^{-1}$ yields 10^9 collisions/s
- Reduce to ~ 300 kHz output to High Level Trigger and keep high- P_T physics
- Pipelined at 40 MHz for dead time free operation
- Latency of only $3.2 \mu\text{sec}$ for collection, decision, propagation



The CMS Level-1 Trigger

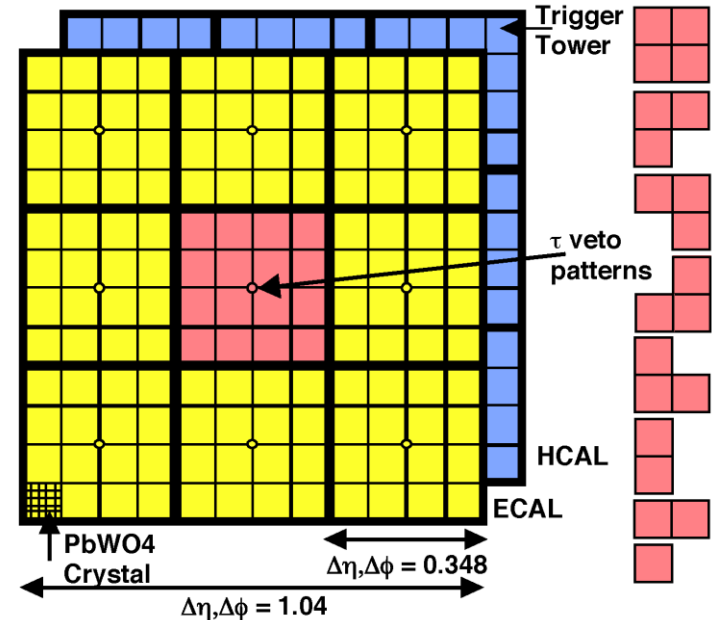
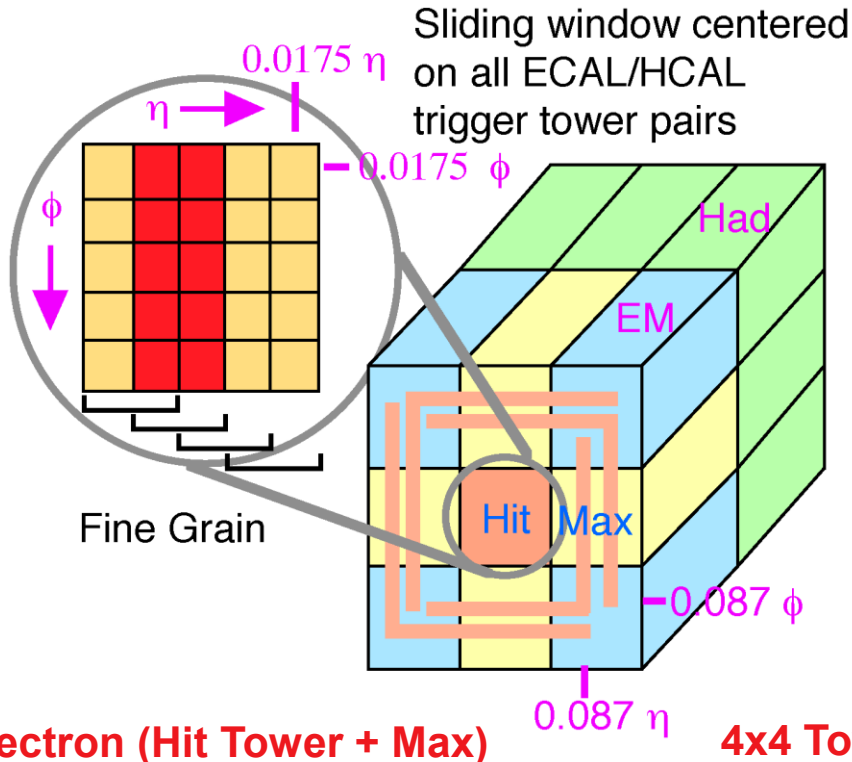


Calorimeter, muon, and beam monitoring (not shown) systems participate in CMS L1





e/ γ and Jet Algorithms



Electron (Hit Tower + Max)

- 2-tower ΣE_T + Hit tower H/E
- Hit tower 2x5-crystal strips >90% of E_T in 5x5 (Fine Grain)

Isolated Electron (3x3 Tower)

- Quiet neighbors: all towers pass Fine Grain & H/E
- One "L" of 5 EM $E_T < \text{Thr.}$

4x4 Tower sums from RCT to GCT

Jet or τE_T

- 12x12 trig. tower ΣE_T sliding in 4x4 steps w/central 4x4 $E_T > \text{others}$

τ : isolated narrow energy deposits

- Energy spread outside τ veto pattern sets veto
- Jet $\equiv \tau$ if all 9 4x4 region τ vetoes off

GCT uses tower sums for E_T, ME_T jets for H_T, MH_T

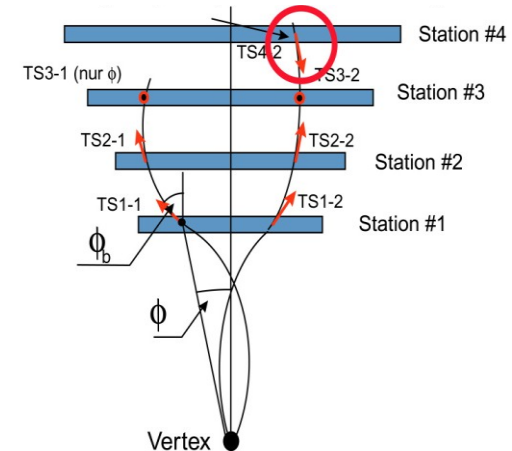
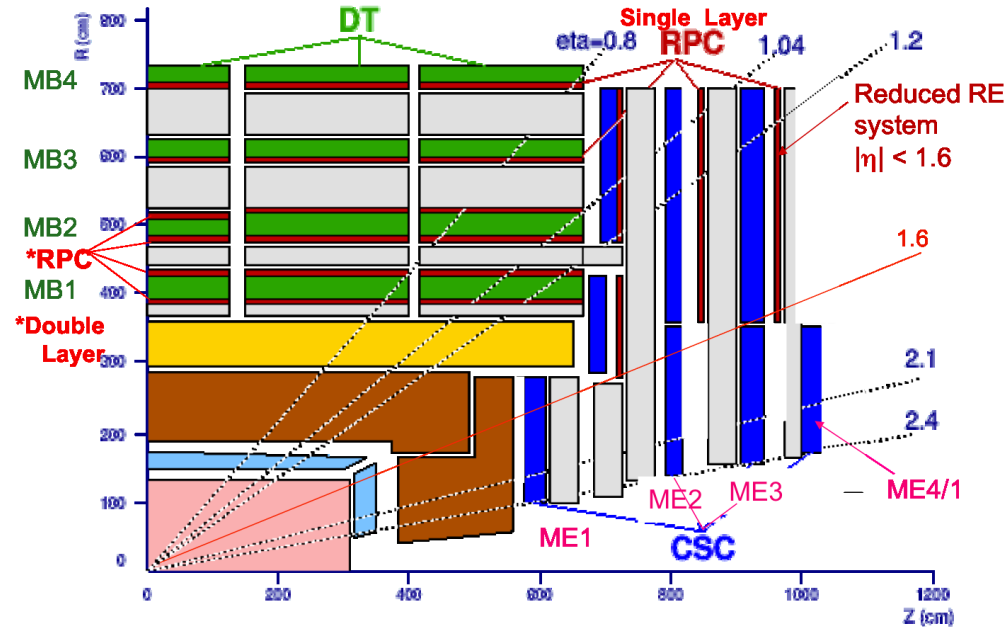


Muon Trigger



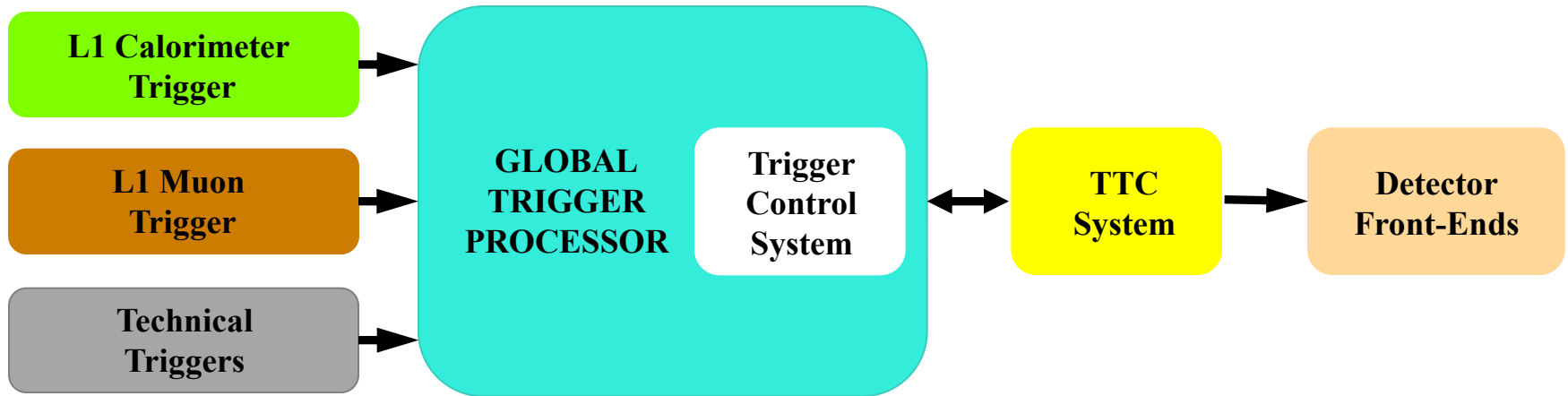
Muon Trigger

- 3 muon detectors to $|\eta| < 2.4$
- Drift Tubes
 - Track Segment ID and Track Finder
- Cathode Strip Chambers
 - Track Segment ID and Track Finder
- Resistive Plate Chambers
 - Pattern Matching
- 4 candidates per subsystem to Global Muon Trigger
- Global Muon Trigger sorts, removes duplicates, 4 top candidates to Global Trigger
- Track building at 40 MHz!





Global Trigger



Receives Trigger Objects:

- 4 forward and 4 central jets, 4 τ -jets, 4 isolated and 4 non-isolated e/γ , total E_T , missing E_T , H_T and position information from GCT
- 4 μ with position, sign, and quality information from GMT

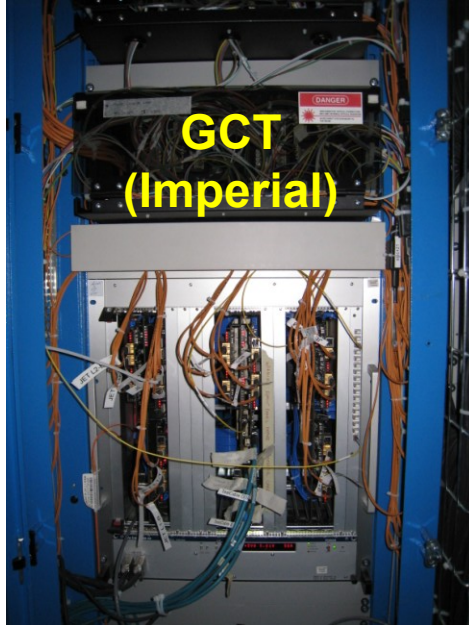
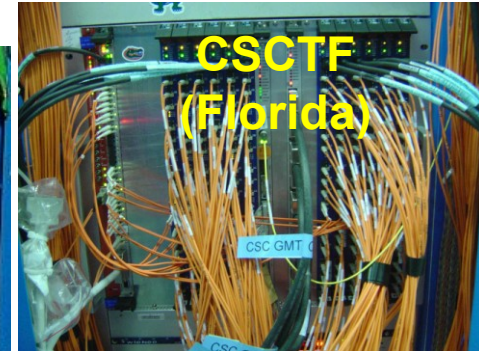
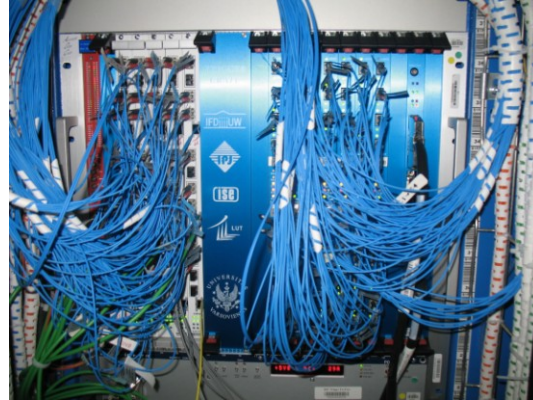
Different conditions (thresholds, topological cuts) can be combined to make 128 physics triggers

Forwards Level-1 Accept to DAQ and Trigger Timing and Control (TTC) system for read-out of the detector front-end electronics

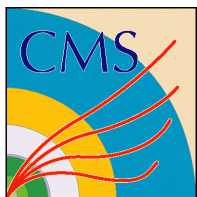
L1 Trigger Custom Hardware



RPC PaC
(Warsaw)



- Hundreds of boards
- Thousands of:
 - ASICs
 - FPGAs
 - Copper Cables
 - Optical Fibers
 - (Wo)man hours



Operating the Trigger: L1 Online Tools and Trigger Supervisor



L1 Online Page

- Browser interface for trigger shifters and experts
- Access to configuration tools
- Monitors status of TS processes
- Displays Trigger Rate, Key type, etc.
- Real time alerts and alarms

Trigger Supervisor (TS)

- Online software framework to configure, test, operate, monitor, and communicate among trigger systems
 - Individual subsystems and a central cell interacting via SOAP commands
 - Interface to CMS Run Control
 - System configuration via a pre-defined key for data taking, internal tests, and multi-system interconnection tests
- Accesses DBs for configuration including channel masking
- Provides feedback after transitions
- Monitoring Information and alerts

Home Tools DataBase Monitoring Documentation Online Software LHC Report a bug Contacts

Run 165238
 I1_hit_collisions/v95 - LHC - PHYSICS RANDOM CALIBRATION
 30 min 34 sec - 982.0 Hz

CENTRAL TTC MI GT GCT RCT GMT CSCTF RPC OTTF DT

Shifter Reminder (Changed Tue May 17 at 14:00)
 Changes to this Shifter Reminder should be done ALWAYS in agreement with the Trigger Field Manager.
 As of today, new Run Setting needs to be loaded into the L1_HLT key if the number of bunches changes. Check here <https://cmswbn.web.cern.ch/cmswbn>

Central Cell

Now Displaying Configuration

Transitions: [stop] [suspend] [Reset]

AutoMode [bool]
 CLOCK_TYPE [string] LHC
 DCS_LHC_Flags [string] ES_HV_ON&
 FEDVector [string] 0806180&2
 L1_KEY [string] L1_2011051
 ML_KEY [string] beam1-man
 Run Number [unsigned long] 165238
 TSC_KEY [string] TSC_201105
 TTCVector [string] 3333233333
 Rags [string]

Reply

```
enable[* GT] CSCTF DT OTTF GCT GMT GT MI RCT RETRI RPC:
DT: Sent.
DTTF: Sent.
GCT: Sent.
GMT: Sent.
MI: Sent.
RCT: Sent.
RETRI: Sent.
RPC: Sent.
GT: [wait for CSCTF: success=1 DT:***** success=1 DTTF: success=1 GCT:*****
#---CSCTF.enable----
#---DT.enable----
Transition 'enable' started in workers: 'YB+1_DW' 'YB+1_UP' 'YB+2_DW' 'YB+2_UP' 'YB-1_DW' 'YB-1_U'
```

Monitoring Panel Error Analysis Export Alarms
 Wed May 18 13:32:47 2011 (RCT back, RCT Monitoring Explained)
 FED mask read:
 QPLL Lock Status: OK
 TTC Error Bit on MasterClockCrate: OK

Cell	Sub	Link	Phase	Cell	Sub	Link	Phase	Cell	Sub	Link	Phase	Cell	Sub	Link	Phase	Cell	Sub	Link	Phase	Cell	Sub	Link	Phase	
RC0	RC0	RC0	RC0	RC0	RC0	RC0	RC0	RC0	RC0	RC0	RC0	RC0	RC0	RC0	RC0	RC0	RC0	RC0	RC0	RC0	RC0	RC0	RC0	RC0
RC1	RC1	RC1	RC1	RC1	RC1	RC1	RC1	RC1	RC1	RC1	RC1	RC1	RC1	RC1	RC1	RC1	RC1	RC1	RC1	RC1	RC1	RC1	RC1	RC1
RC2	RC2	RC2	RC2	RC2	RC2	RC2	RC2	RC2	RC2	RC2	RC2	RC2	RC2	RC2	RC2	RC2	RC2	RC2	RC2	RC2	RC2	RC2	RC2	RC2
RC3	RC3	RC3	RC3	RC3	RC3	RC3	RC3	RC3	RC3	RC3	RC3	RC3	RC3	RC3	RC3	RC3	RC3	RC3	RC3	RC3	RC3	RC3	RC3	RC3
RC4	RC4	RC4	RC4	RC4	RC4	RC4	RC4	RC4	RC4	RC4	RC4	RC4	RC4	RC4	RC4	RC4	RC4	RC4	RC4	RC4	RC4	RC4	RC4	RC4
RC5	RC5	RC5	RC5	RC5	RC5	RC5	RC5	RC5	RC5	RC5	RC5	RC5	RC5	RC5	RC5	RC5	RC5	RC5	RC5	RC5	RC5	RC5	RC5	RC5
RC6	RC6	RC6	RC6	RC6	RC6	RC6	RC6	RC6	RC6	RC6	RC6	RC6	RC6	RC6	RC6	RC6	RC6	RC6	RC6	RC6	RC6	RC6	RC6	RC6
JSC	JSC	JSC	JSC	JSC	JSC	JSC	JSC	JSC	JSC	JSC	JSC	JSC	JSC	JSC	JSC	JSC	JSC	JSC	JSC	JSC	JSC	JSC	JSC	JSC

Monitoring

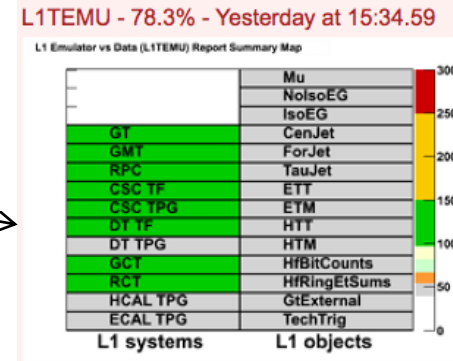
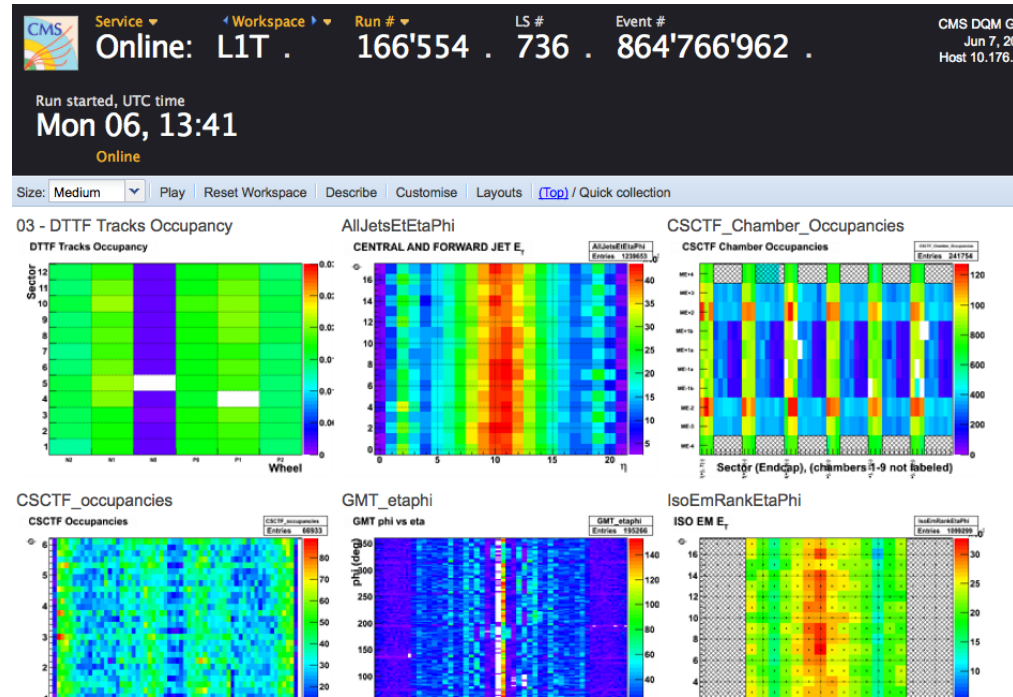


Monitoring the Trigger: Data Quality



Data Quality Monitoring (DQM)

- Updated in real time
- Data delivered at ~Hz
- L1 Trigger Summary Page has selected histograms for trigger shifter
 - More detailed expert-level plots also available
- Old runs available
- Comparison with reference histograms possible
- Real time check of Data with SW emulator
 - Simple summary for CMS DQM shifter
 - Used for run validation





First Collisions



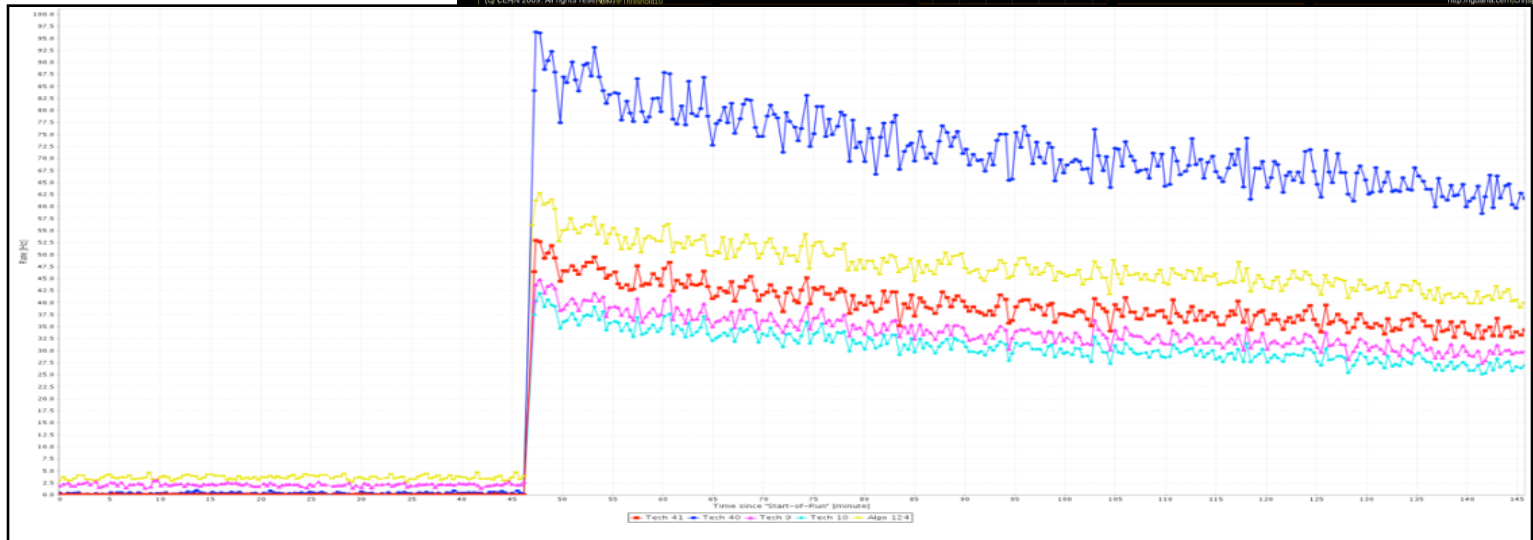
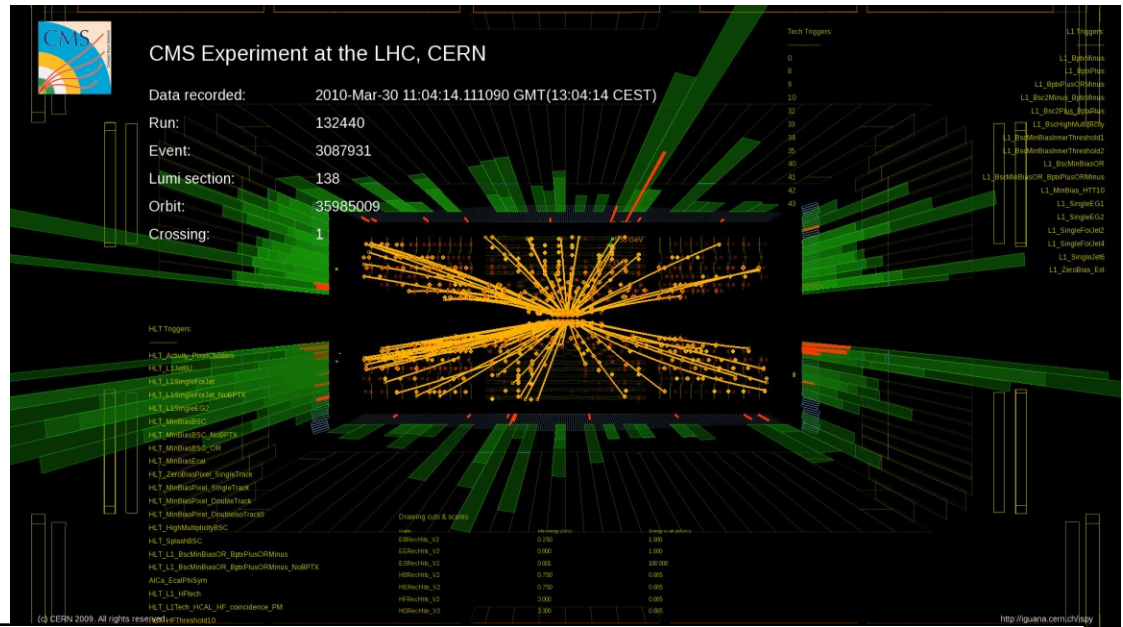
Tuesday March 30, 2010

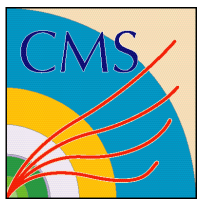
12:58

$L \sim 10^{27} \text{ cm}^{-2} \text{ s}^{-1}$

~ 60Hz Collision Rate

Time to optimize the trigger synchronization!





2010: Commissioning Synchronizing the Trigger



Collision products take longer to get to outer part of detector

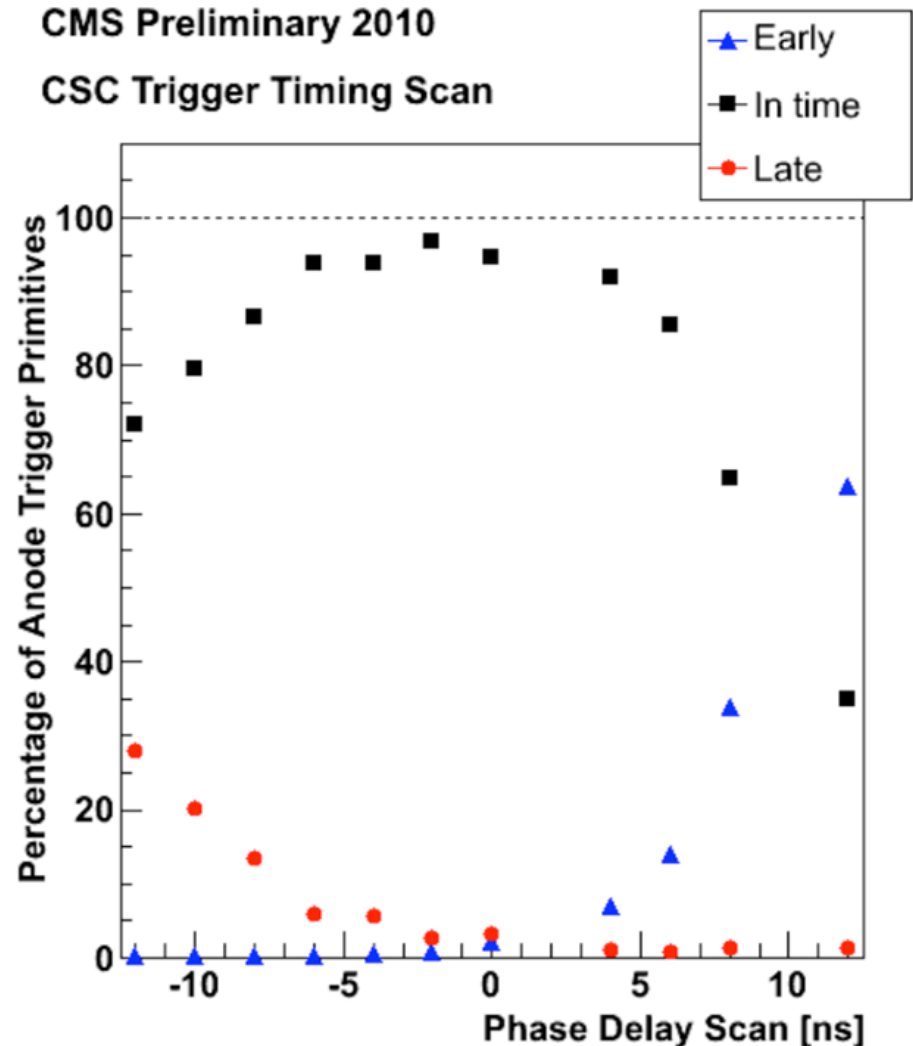
- e.g. to reach CSC takes longer than ECAL

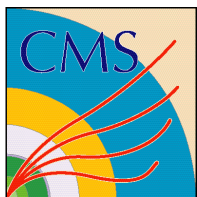
Take into account many different cable lengths

- Even within a sub-detector

First runs only a Minimum-Bias Trigger (Beam Scintillator Counter)

- Take data with a number of delays
- Find the best alignment between subsystem (CSC shown) and Minimum-Bias Trigger
- Repeated for each Trigger subsystem
- Cross-checks available in DQM



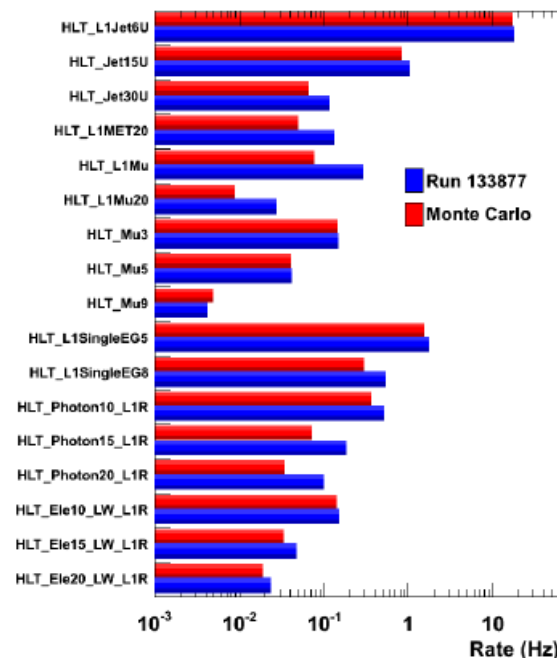
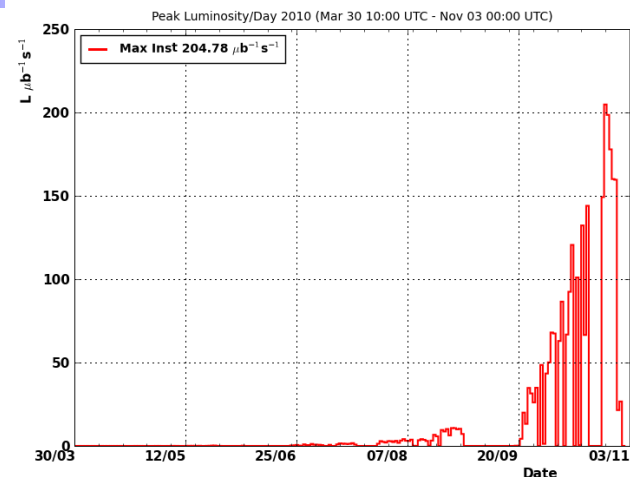


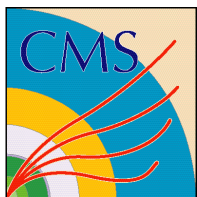
2010: Operational Challenge Rates



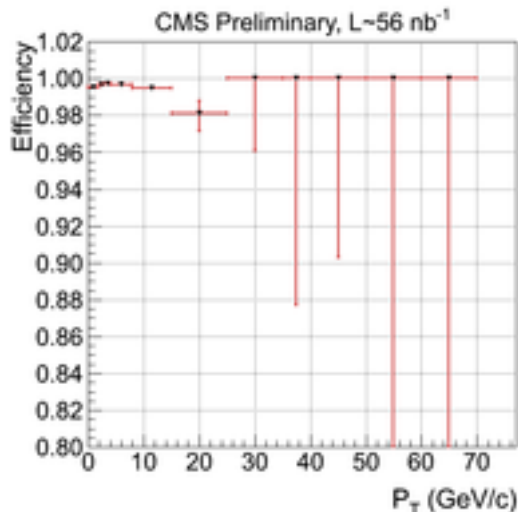
Final month of 2010 p-p running, max inst. lumi rapidly increased to $2 \cdot 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$

- No longer relying on Minimum Bias but a full menu of physics object triggers
- L1 works with the HLT to maintain a sustainable HLT stored data rate
 - Up to 65 kHz in, $\sim 400 \text{ Hz}$ out
- New L1 & HLT configurations and menus:
 - Higher thresh. L1 Triggers for HLT seeds
 - Prescaling at L1 and HLT to reduce rates
 - Several prescale “sets” to allow as much data to tape as possible
 - Lumi decreases \rightarrow change set of prescales, keep rate about the same
- Possible to predict output rates with MC
- Must take into account other factors
 - Cosmic backgrounds, pile-up effects, detector effects, etc.



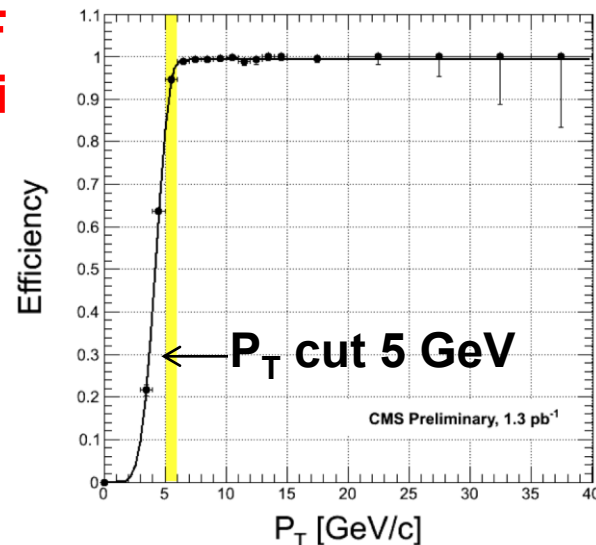


2010 Trigger Efficiencies

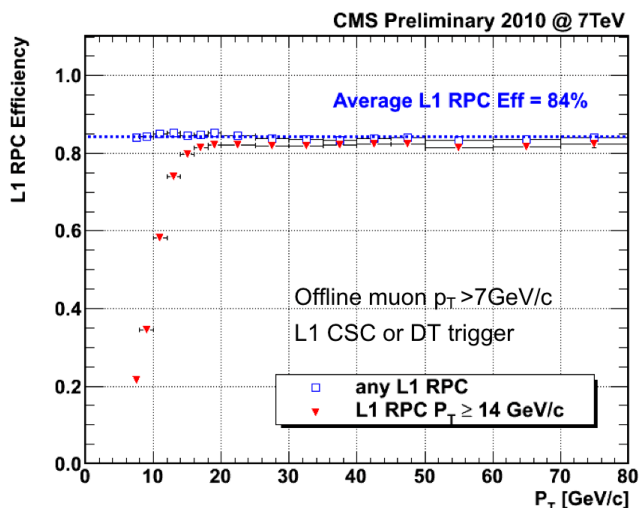


**CSCTF
Global
Muons**

**DTTF
J/psi**

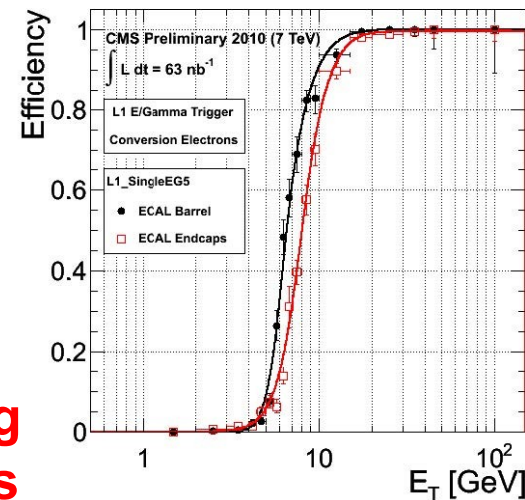


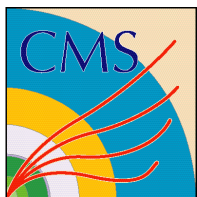
**Good Trigger
Performance
During First
LHC Run**



**RPC
Global
Muons**

**Cal Trig
Electrons**



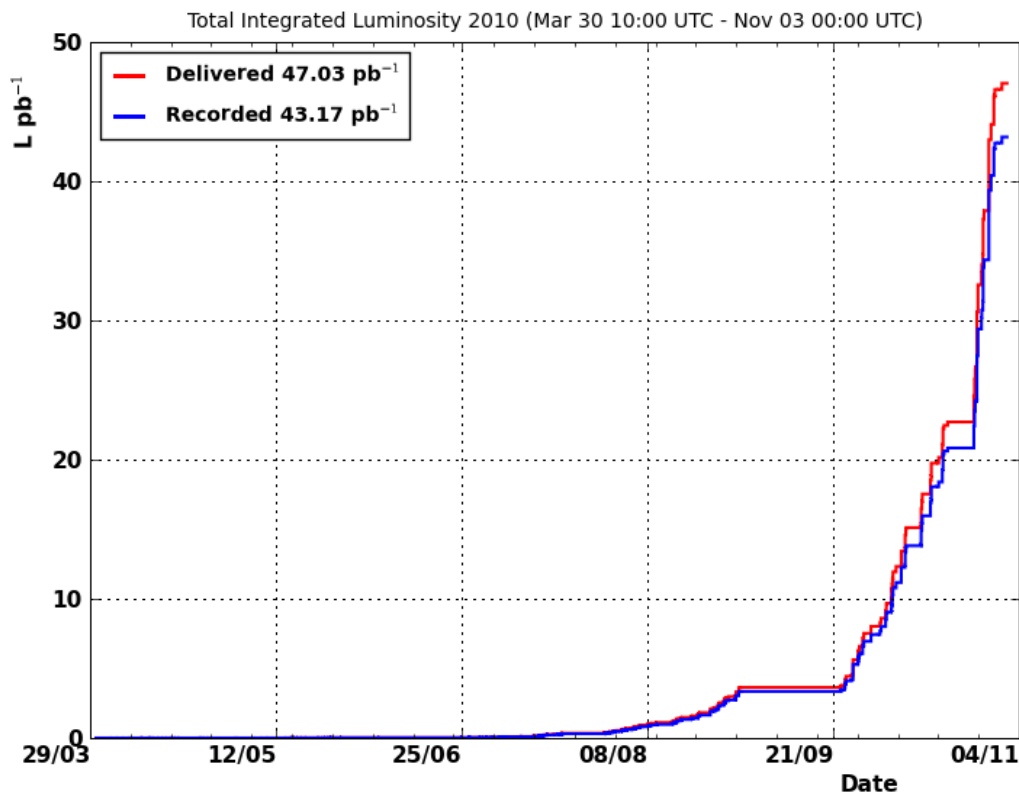


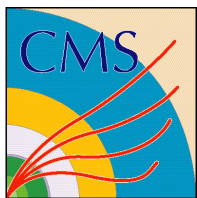
Achieved in 2010



End of 2010 p-p run:

- 43 pb^{-1} data taken
- Maximum sustained L1 rate of ~ 65 kHz
 - 368b – 348 colliding at CMS, 150ns spacing
 - Up to ~ 5.5 pb^{-1} in a single fill
- Good setup, startup, and performance of L1 Trigger





2011: Operations Controlling the Rates



LHC has been steadily increasing instantaneous luminosity delivered to the experiments in 2011

- Well beyond what was delivered in 2010
- How to best control rates while keeping physics? A few examples of what the L1 Trigger can do:
- e/γ triggers
 - Energy corrections to improve resolution
 - Correct L1 at tower level using MC generated objects
 - Corrections dependent on η
 - ECAL Spike Killing
 - Energy deposited by heavily ionizing particles in ECAL barrel single-crystal avalanche photodiodes look like very energetic isolated e/γ candidates
 - Check crystals around suspect spike for energy and zero if isolated to a single crystal
 - Fine Grain (FG) and $E_{T,HCAL}/E_{T,ECAL}$ (H/E) vetoes for e/γ
 - Apply to tower with max E_T

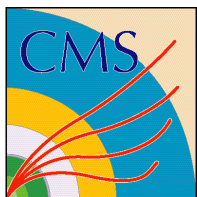


2011: Operations

Controlling the Rates



- Isolation (not yet used)
 - Narrow energy deposit around the tower with Max E_T and no towers with FG and H/E Veto set
- Jet triggers
 - Improve the resolution with jet energy corrections
 - Correct online jets to MC Truth
 - Correction matrix in η and p_T applied to jets
- Muon triggers
 - Improve ghost busting
 - Muon tracking algorithms may find fake “ghost” muons due to detector geometry or timing effects, e.g. cracks between chambers, drift time, etc.
 - Difficult, but each sub-detector has their own
 - Improve pattern recognition
 - Require more layers in pattern matching
 - RPC now uses 4/6 layers instead of 3/6
- Continue to develop the L1-HLT menus with prescale sets
 - Must anticipate physics groups’ needs as beam conditions change



2011: Operations Avoiding pre-triggers



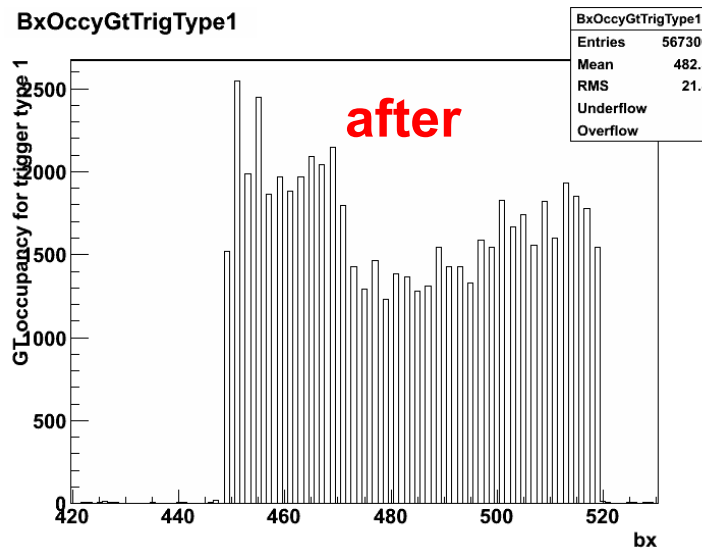
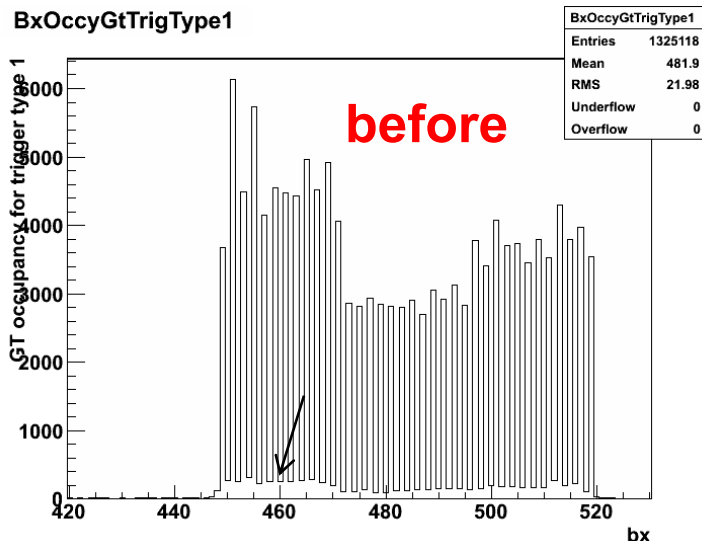
Problem:

- Triggers are pre-firing at about ~5% of the time

Can we avoid this source of inefficiency?

- CMS BPTX_AND Trigger
 - AND of two precision electrostatic beam pick-ups
 - Provides colliding bunch structure in CMS for every fill
- Copy, reduce delay by 1 BX and shorten signal to ~20ns
- Use it as veto on pre-triggers
- But it vetoes the slow particle (HSCP) trigger (BX+1) when the bunch spacing is 50 ns!

How to fix this? (Next Slide)





2011: Operations Trigger on HSCPs



Heavy Stable Charged Particles (HSCPs) take as much as 2 BX to exit the detector

- Look for late signal in muon triggers
- But preBPTX veto during 50 ns bunch spacing vetoes these!

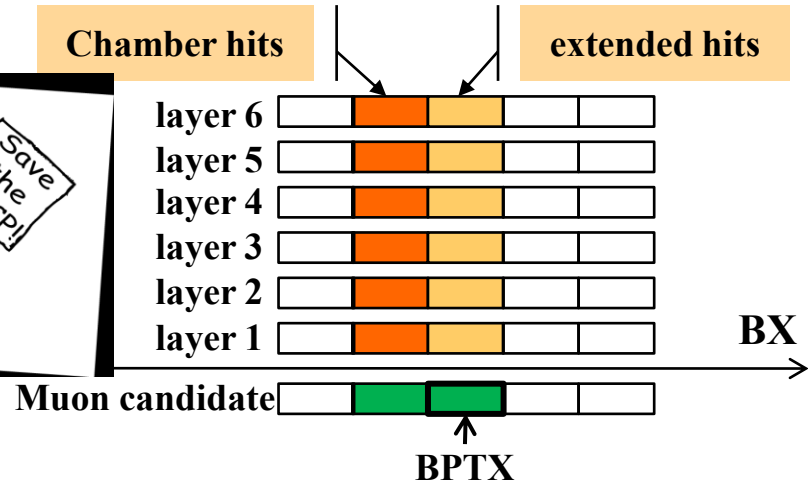


RPC Trigger can extend detector signal to 2 BX

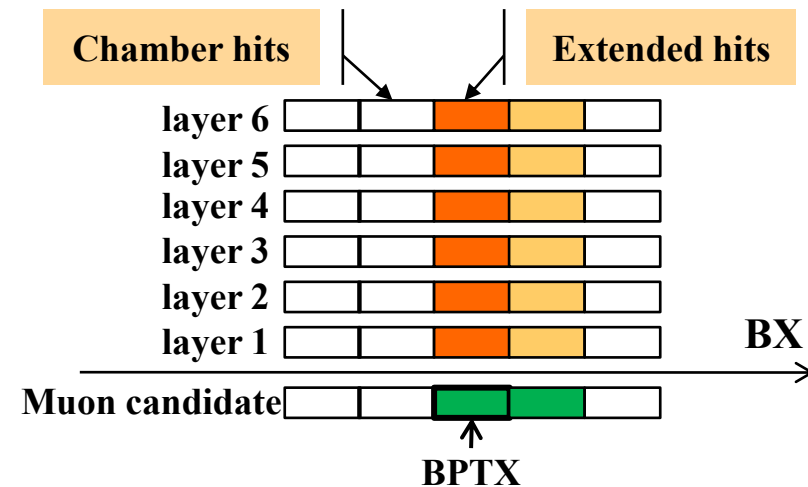
- Reduce RPC delay into GMT by 1 BX
- preBPTX will veto early in-time muons
- In-time muons still captured with collision BX
- HSCPs aligned with collision BX
- Create special HLT path to keep slow particles (the BXid will be +1 wrt to Tracker, for example).

HSCPs Triggering!

In-time muon



HSCP



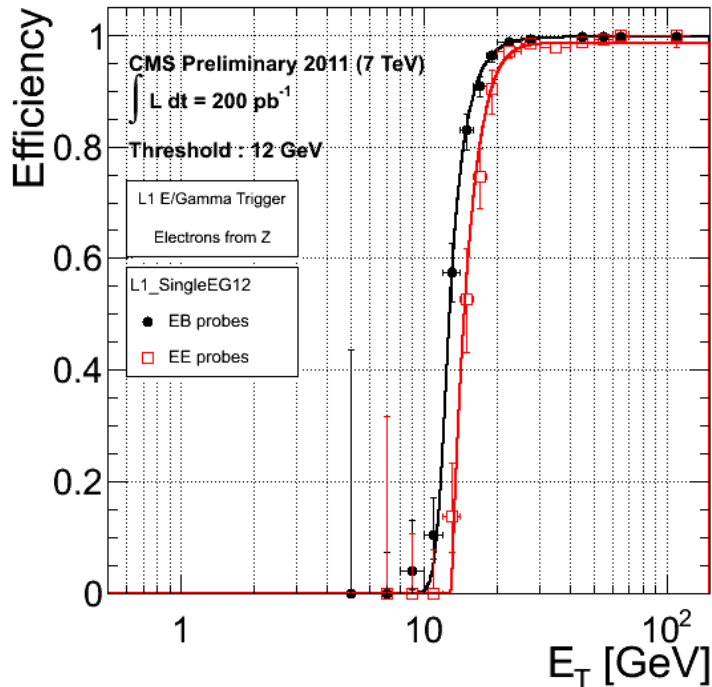


2011 Trigger Performance

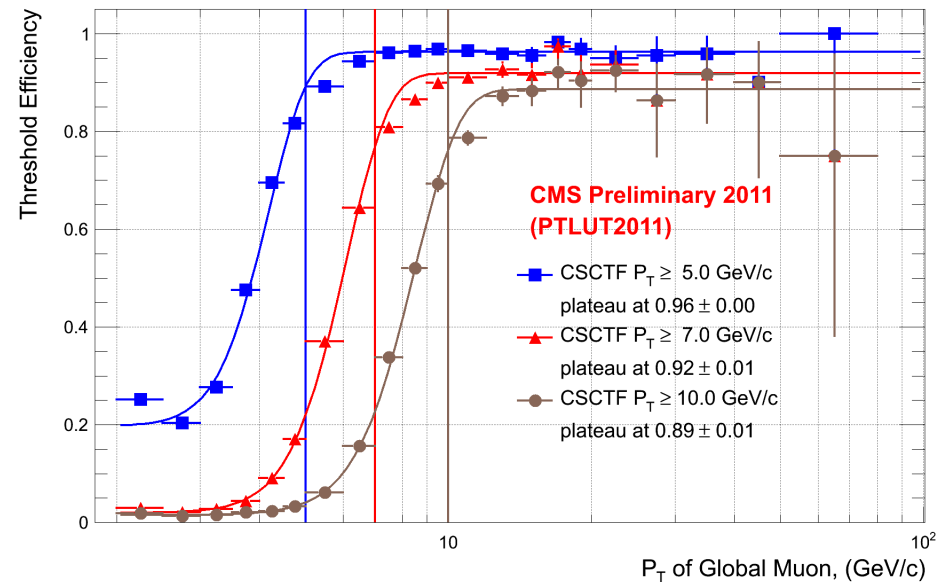


Hot off the presses!

L1 $e/\gamma > 12$ GeV (Calo Trig)



CSCTF Global Muons





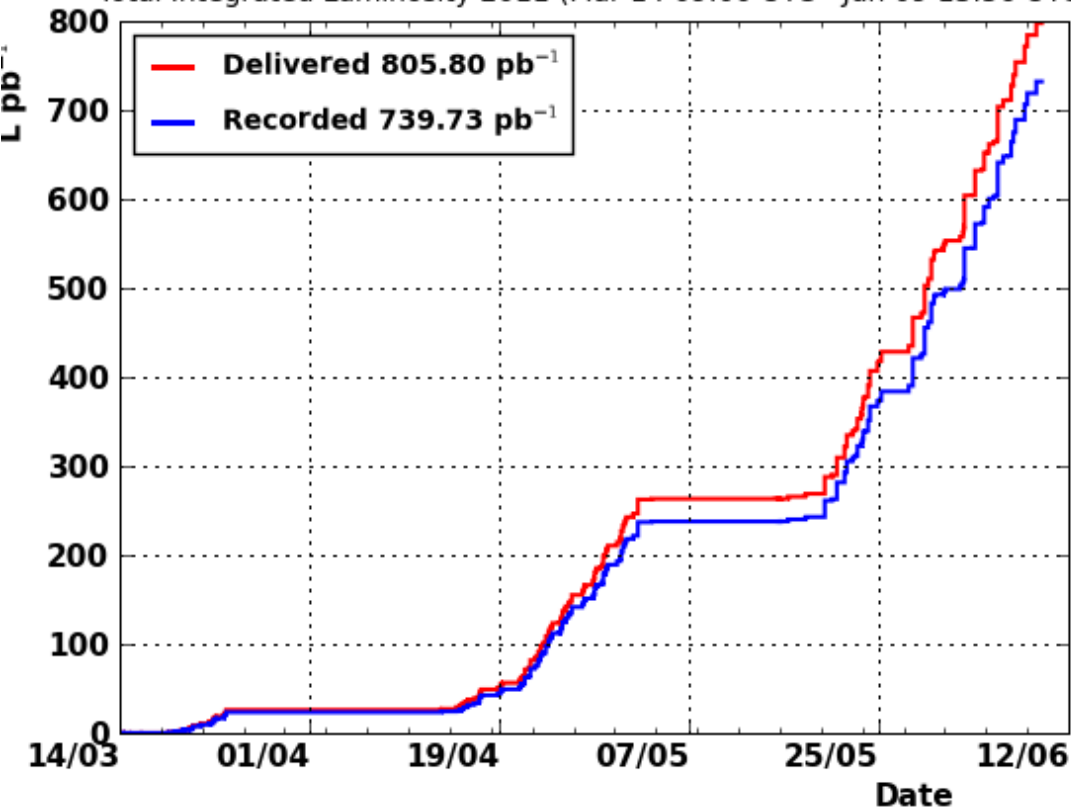
Halfway through 2011

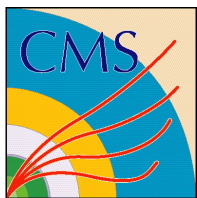


Middle of 2011 p-p run:

- $\sim 740 \text{ pb}^{-1}$ data taken
- Maximum sustained L1 rate of $\sim 65 \text{ kHz}$
 - 1104b with 1042 colliding at CMS, 50ns spacing
 - $\sim 45 \text{ pb}^{-1}$ recorded in a single fill

Total Integrated Luminosity 2011 (Mar 14 09:00 UTC - Jun 09 13:56 UTC)





Conclusions



CMS L1 Trigger is performing well

- 2010 and 2011 not without its challenges
- **Complex system, in Hardware and Software**
 - Excellent pool of experts
 - Problems addressed in a timely manner

LHC still increasing the luminosity

- **Will still stress system, both detectors and triggers**
 - Must remain diligent, even if luminosity stabilizes
- **Expect L1 Menus to continue evolving**
 - Physics results may dictate changes instead of lumi
- **Challenge to balance physics needs with rate limitations**
 - L1T must continue to work with HLT

Looking forward to lots of interesting physics results!