CMS L1 Trigger

Commissioning with cosmic rays

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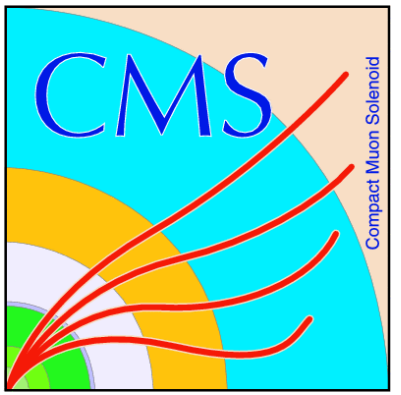
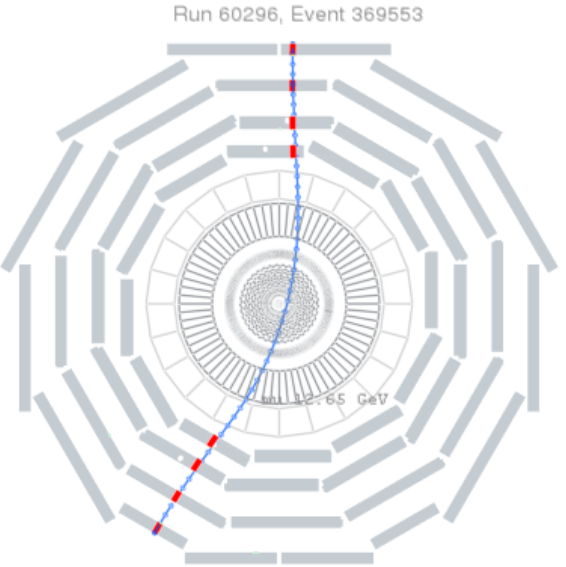
for the CMS Collaboration

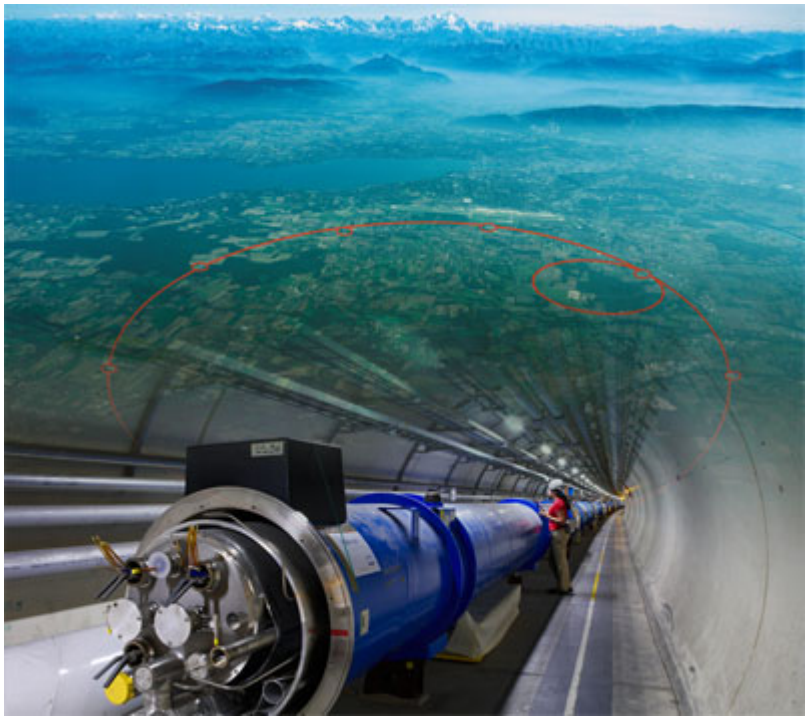


Outline

- LHC and CMS
- Two levels of CMS trigger: L1 and HLT
- Cosmic ray runs
- Results from cosmic ray runs
  - *L1 trigger emulator studies*
  - *synchronization of L1 triggers*
  - *efficiencies of L1 triggers*
  - *resolutions of L1 triggers*
- Synchronization from LHC beam
- Summary

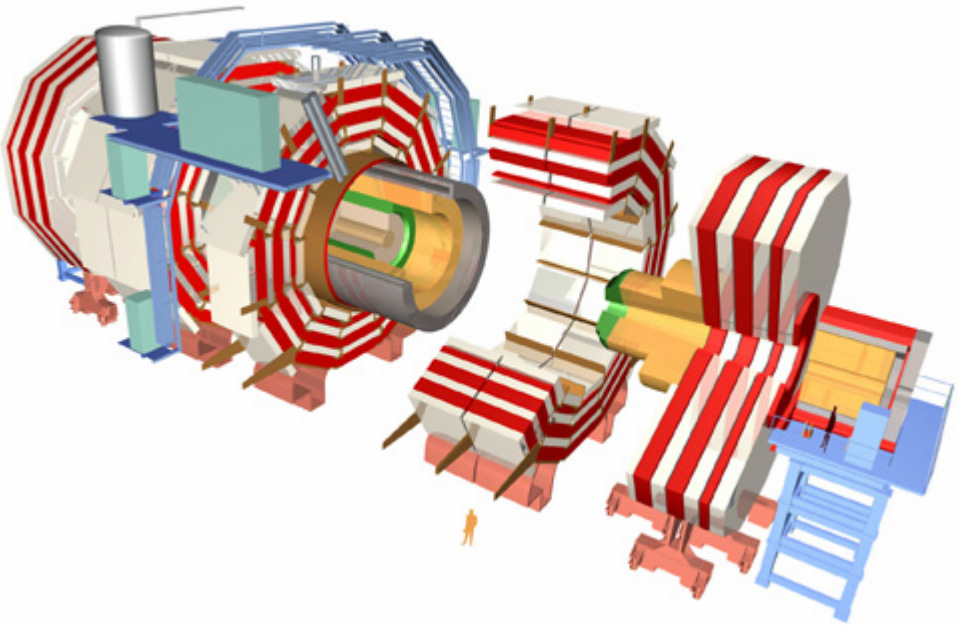


LHC and CMS



LHC (Large Hadron Collider)

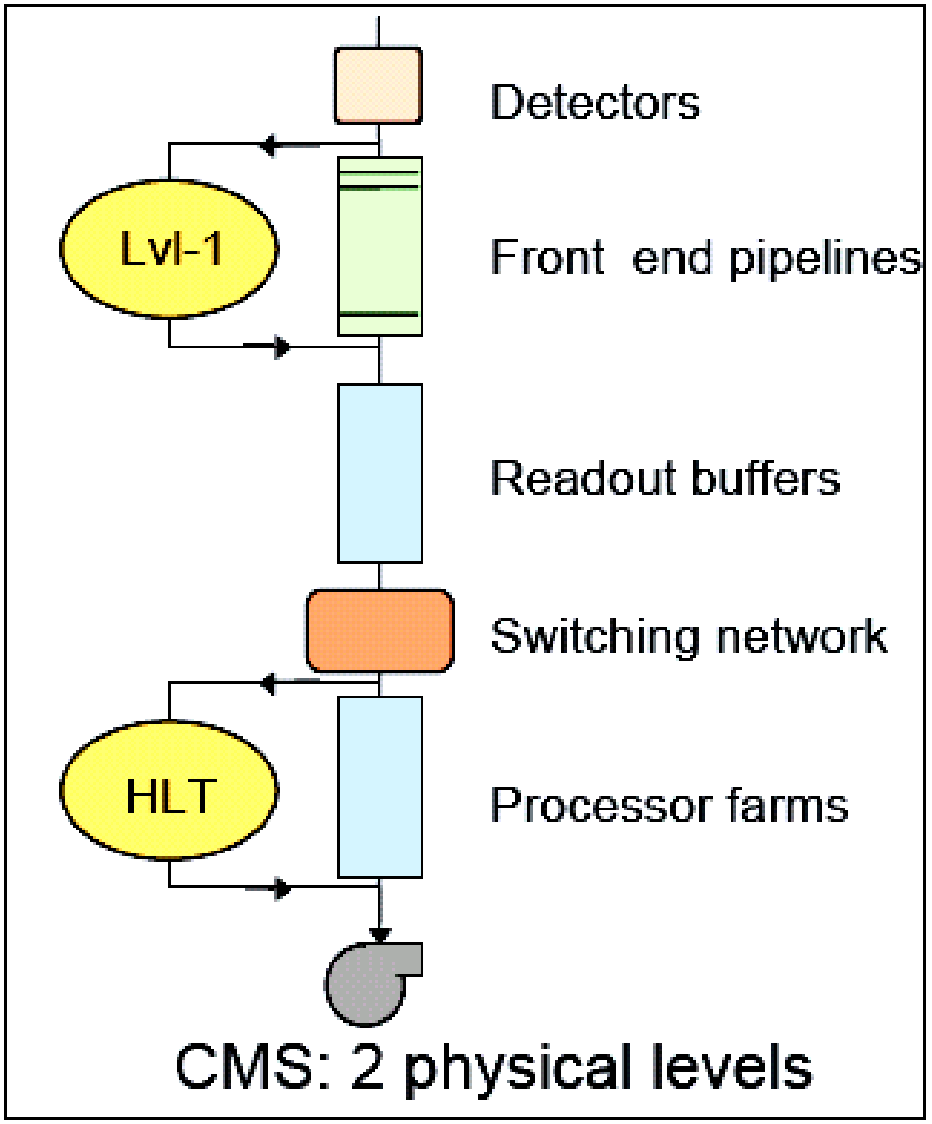
- collides protons to protons with 14 TeV design center-of-mass energy
- first beams circulated in September 2008
- expected first collisions: end of 2009



CMS (Compact Muon Solenoid)

- multi-purpose experiment
- tracker, electromagnetic and hadronic calorimeters, and muon detectors

L1 and HLT trigger

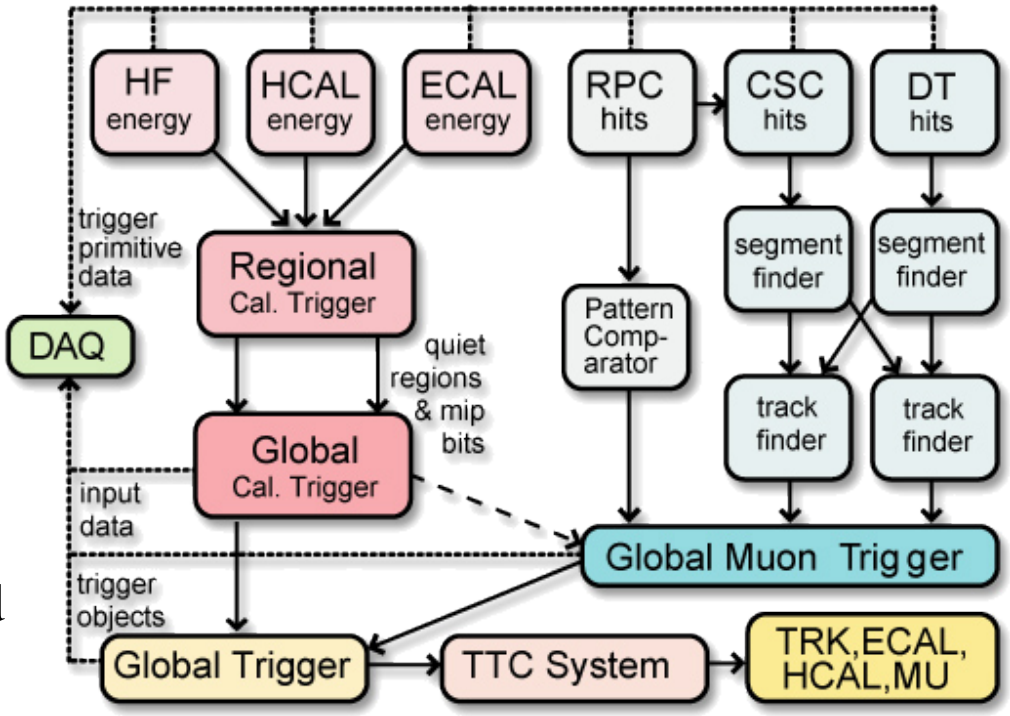


CMS Trigger system consists of two levels:

- **Level-1 trigger (L1)**
  - *input rate: 1 GHz*
  - *output rate: 100 kHz*
  - *custom made hardware processors*
- **High Level trigger (HLT)**
  - *input rate: 100 kHz*
  - *output rate: 100 Hz*
  - *PC farm using reconstruction software and event filters similar to the offline analysis*

L1 trigger

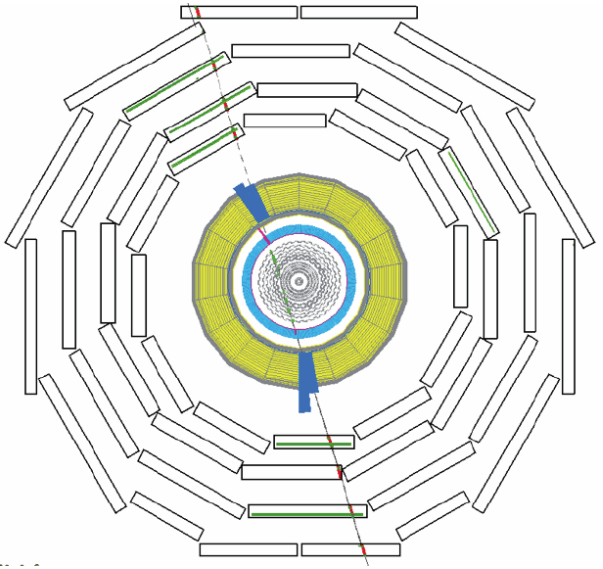
- The L1 trigger is based on the calorimeter and muon detectors
- At L1 we trigger on:
  - *4 highest E_T $e^{\pm}/\gamma$*
  - *4 highest E_T central jets*
  - *4 highest E_T forward jets*
  - *4 highest E_T tau-jets*
  - *4 highest P_T muons*
- For each of these objects the rapidity, η, and φ are also transmitted to GT so HLT can seed on them
- In addition we trigger on
  - *inclusive triggers: E_T, ME_T, H_T, MH_T*
  - *minimum-bias and zero-bias*

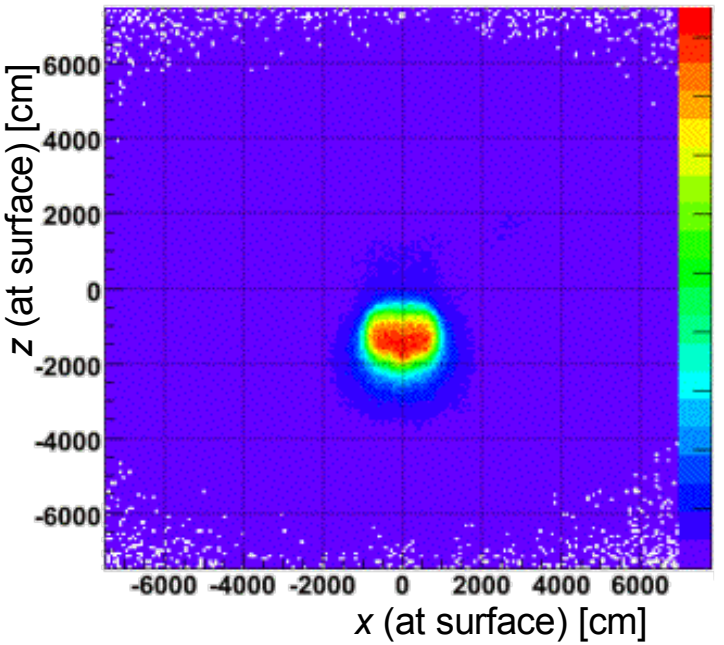


- 3.2 μs latency
  - *cable propagation leaves 1 μs for processing*

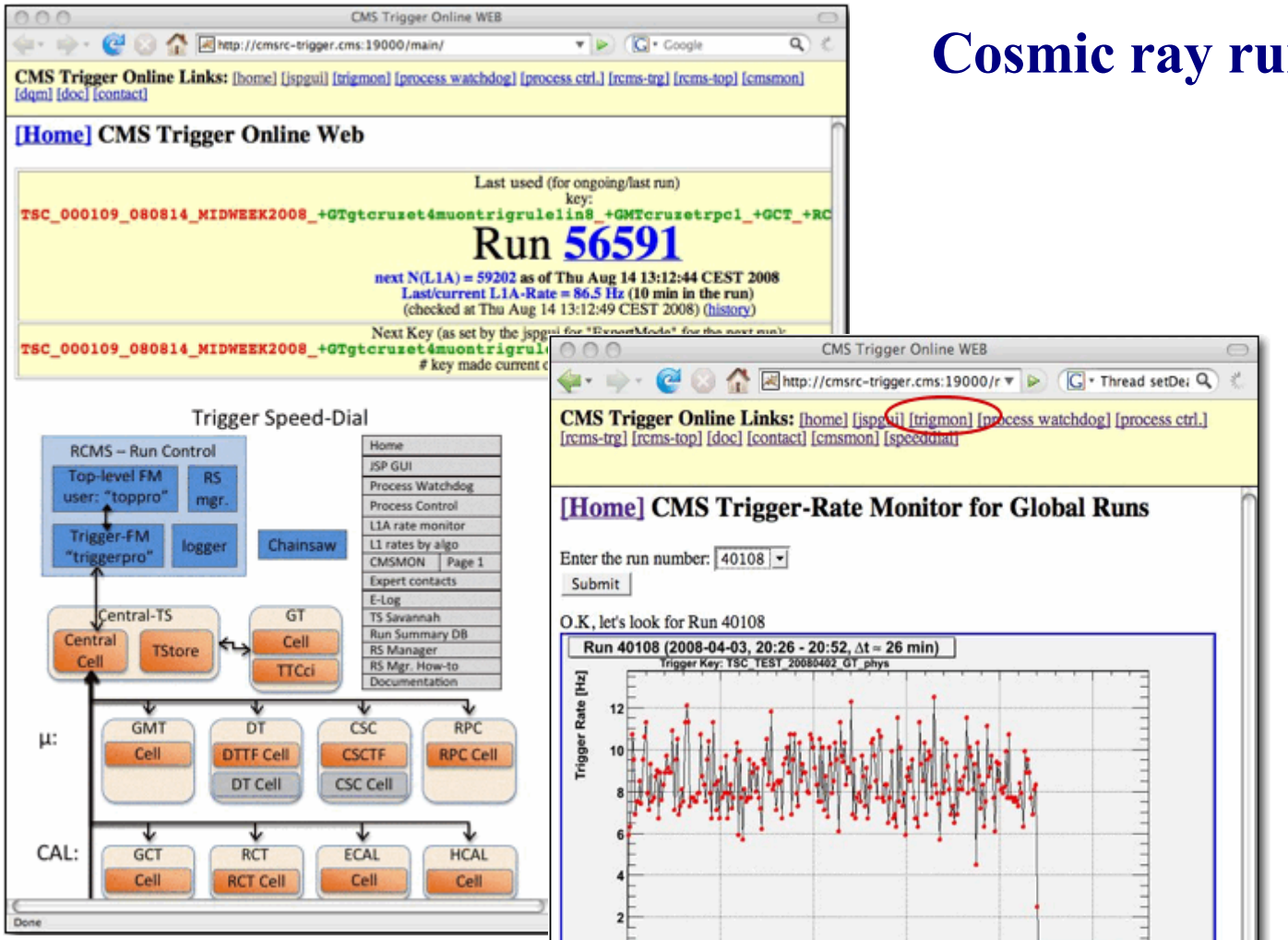
Cosmic ray runs

- CMS has collected over 300 million cosmic ray events
  - *without good trigger, only very low chances to see cosmic ray muons or high-E_T "jets" or "electrons"*
- Cosmic ray runs help preparing for physics running
  - *synchronization between trigger and data*
  - *trigger rates from cosmic rays and from noise*
  - *trigger efficiencies*
  - *resolutions between trigger and reconstructed objects*





Trigger shifter monitoring tools



Cosmic ray runs are good opportunity to test and improve

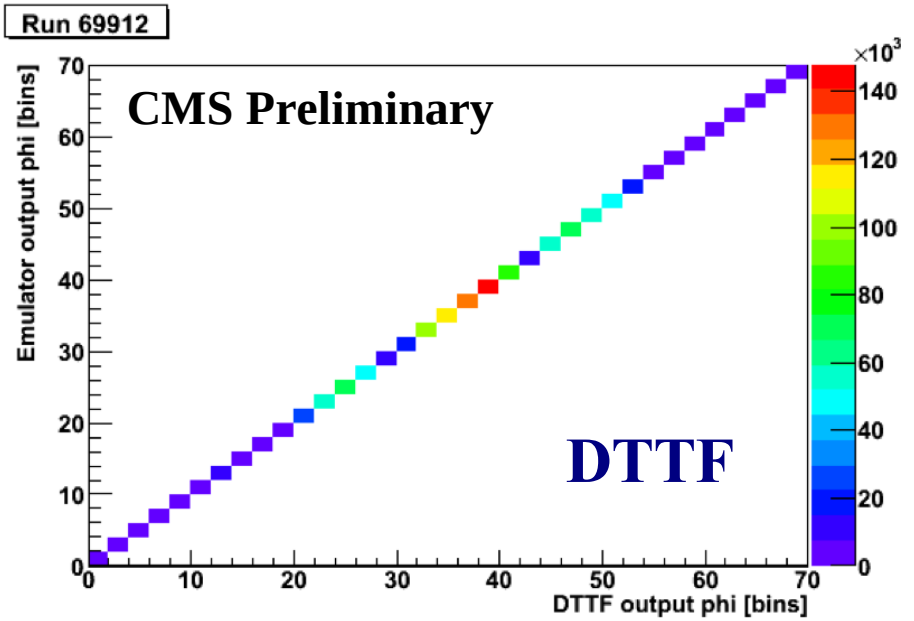
- *online software*
- *trigger monitoring tools*
- *train people for real data taking*

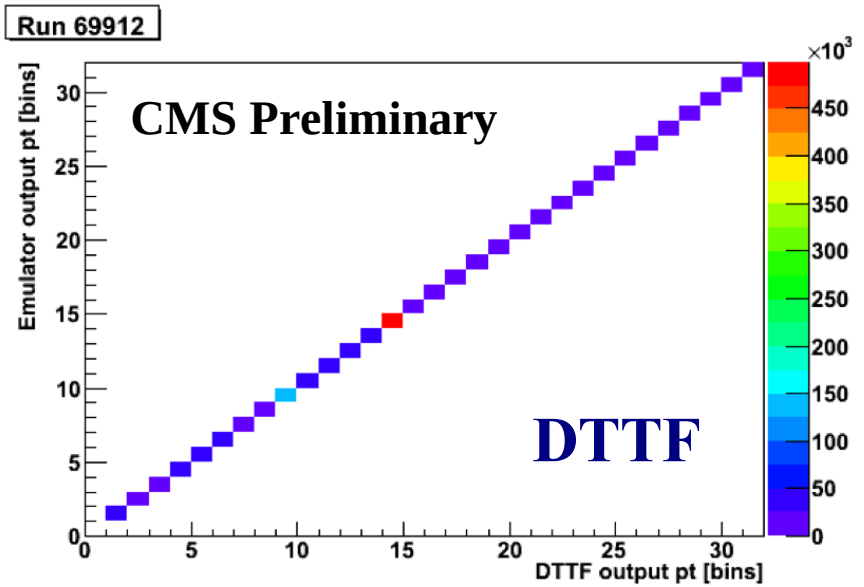
L1 trigger emulator

L1 trigger emulator

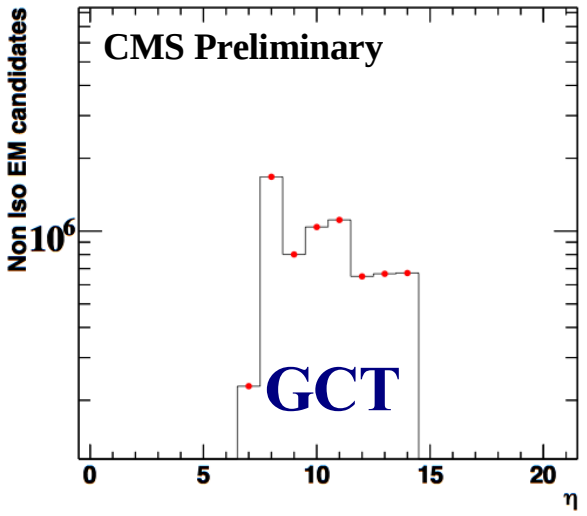
- Software that emulates bit by bit the L1 trigger subsystems
  - *it uses the same input as hardware*
  - *it produces the same output as hardware, with identical format*
  - *it uses the same configuration as the hardware*

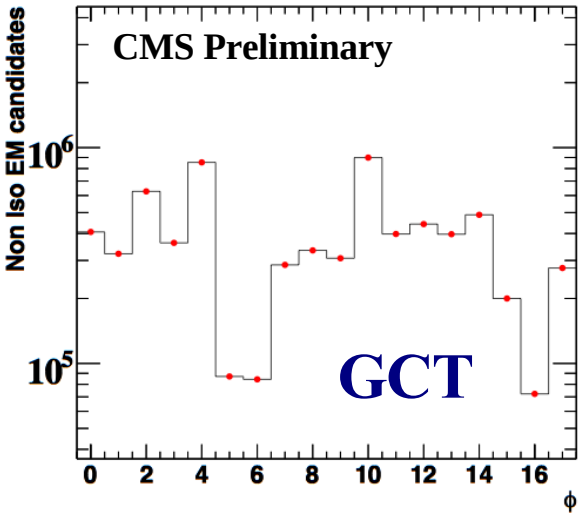
- **Excellent agreement between data and emulator**

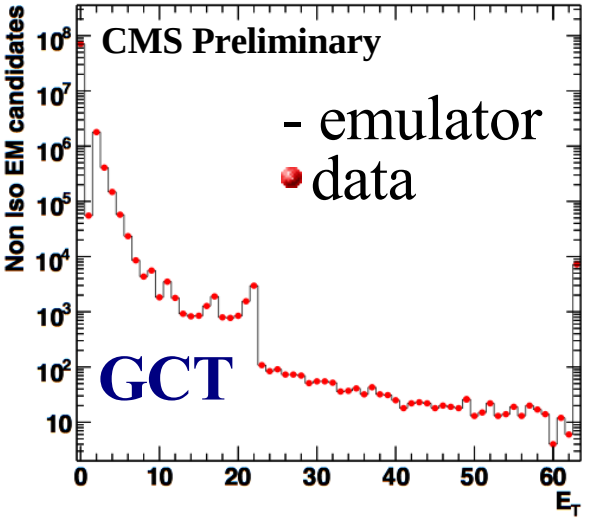


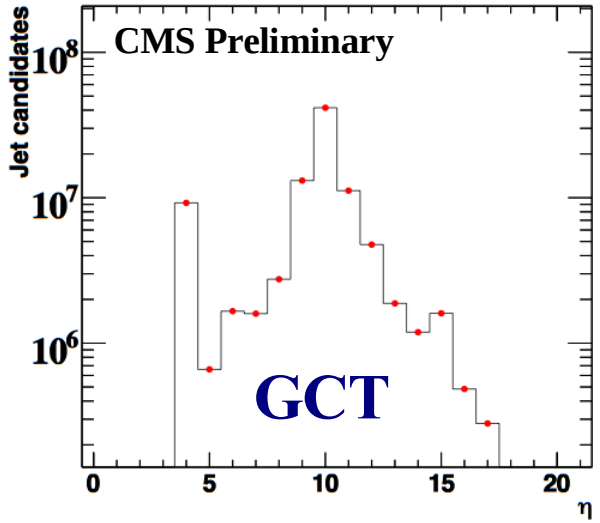


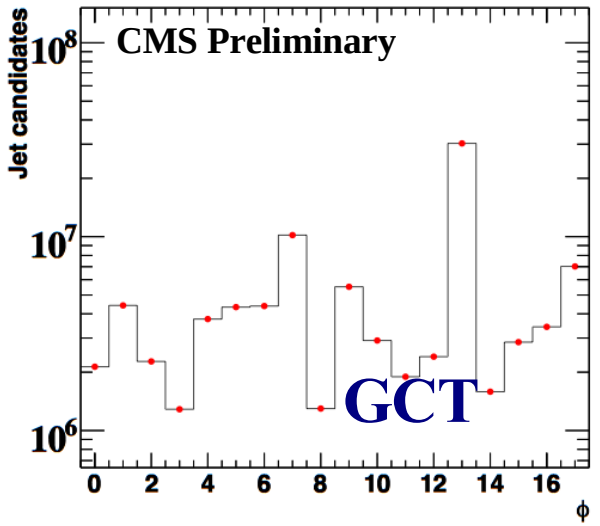
L1 trigger emulator continued

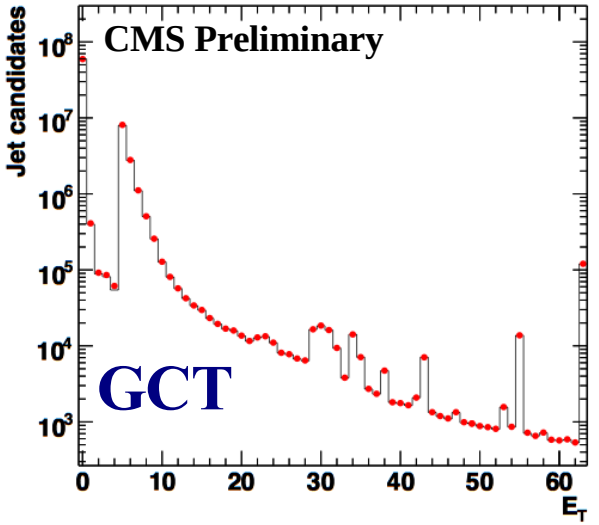










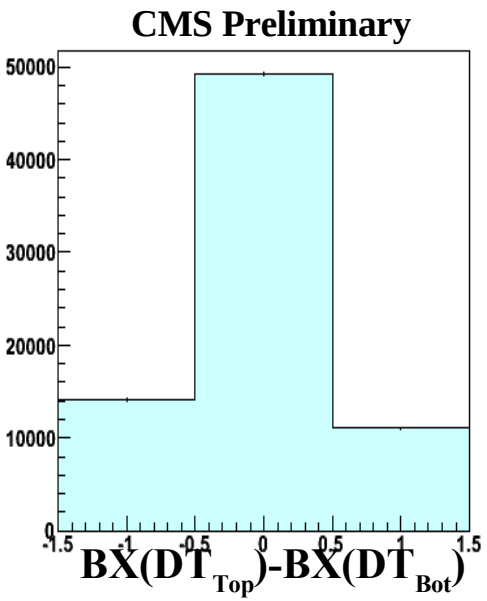


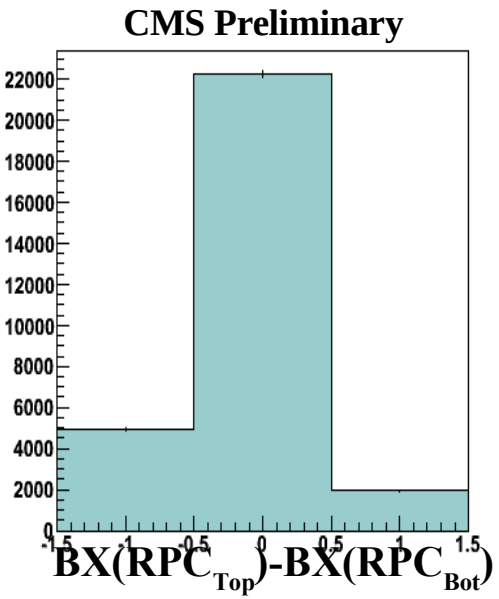
Note: the GCT data is mainly noise, thus the structures are not important!

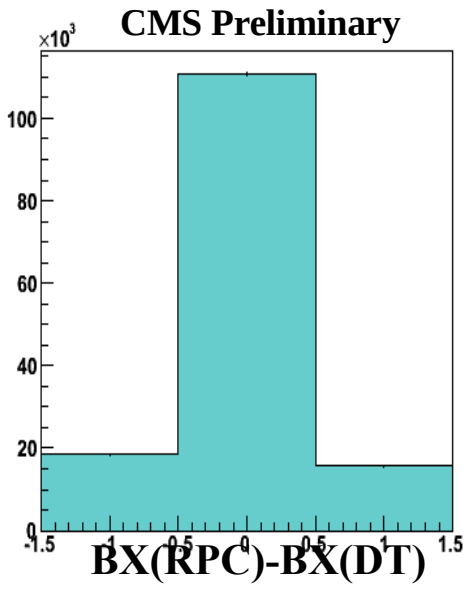
Synchronization of muon triggers

Bunch crossing differences between L1 muon candidates created by the same cosmic muon

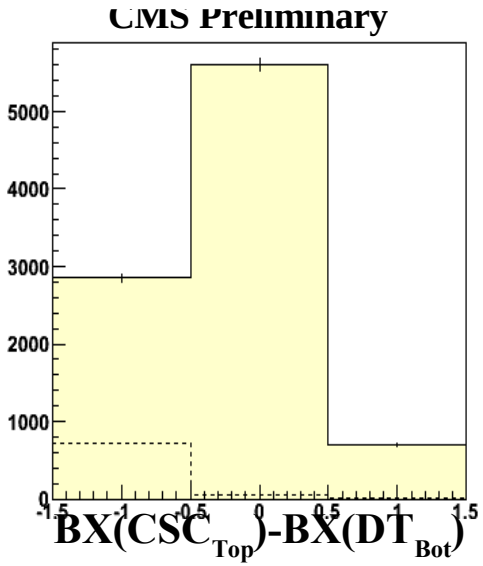
- *synchronization as good as one can expect from cosmic rays*

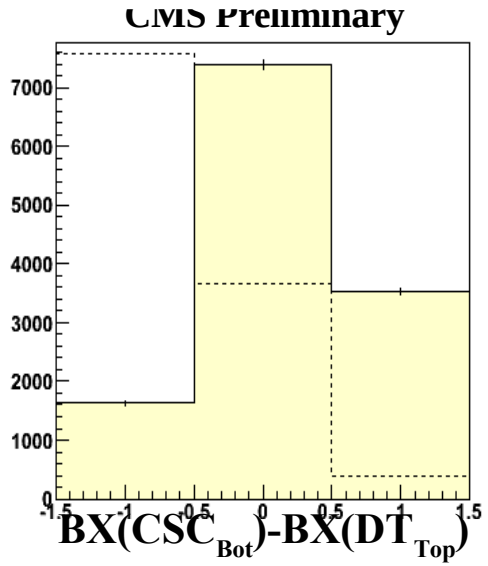






- *CSC trigger timing: dashed line shows the situation before last modification*

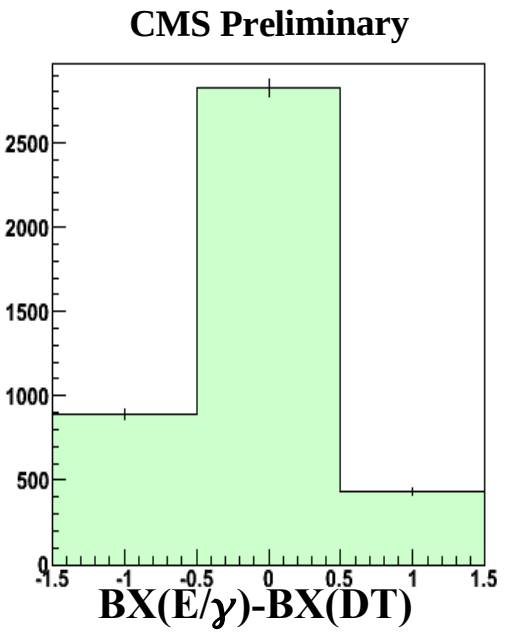


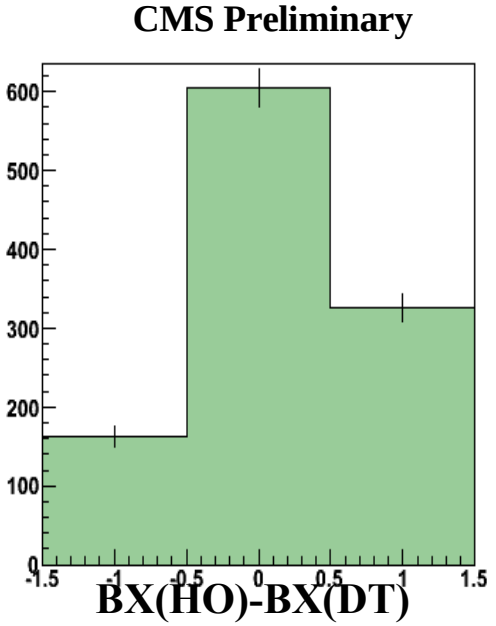


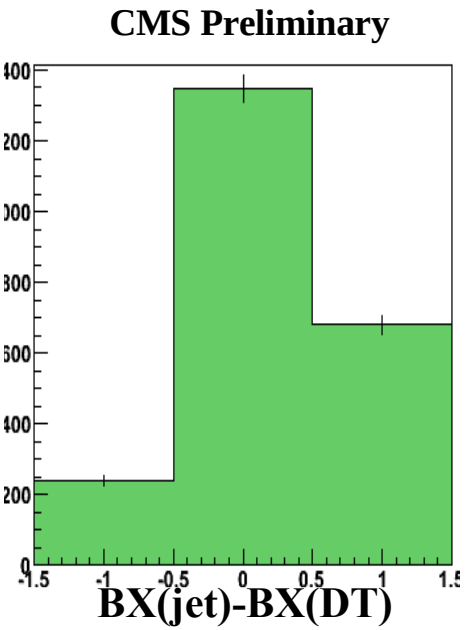
Synchronization between L1 muon and CALO triggers

Bunch crossing differences between L1 muon candidates and calorimeter triggers

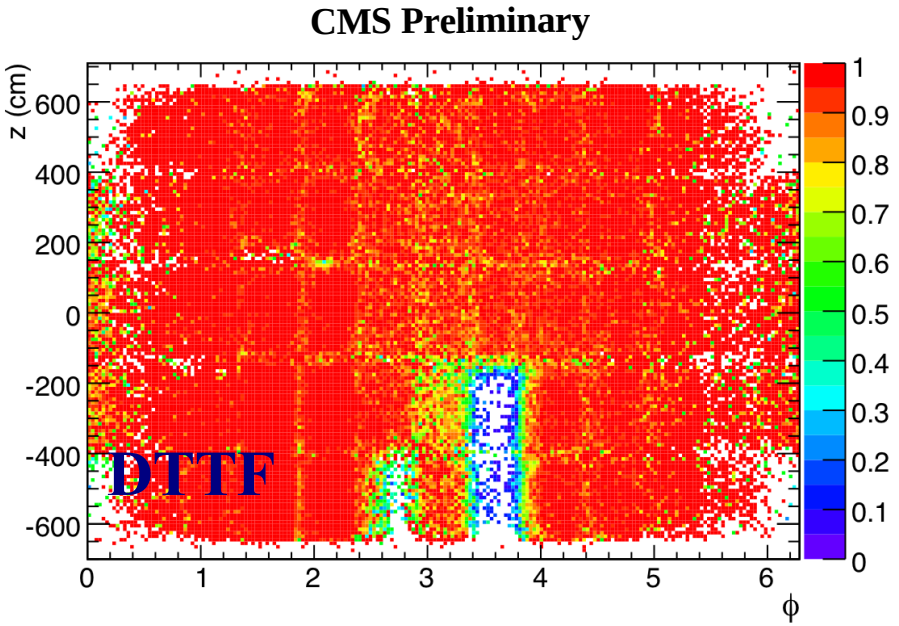
- *synchronization as good as one can expect from cosmic rays*







Efficiency of muon triggers

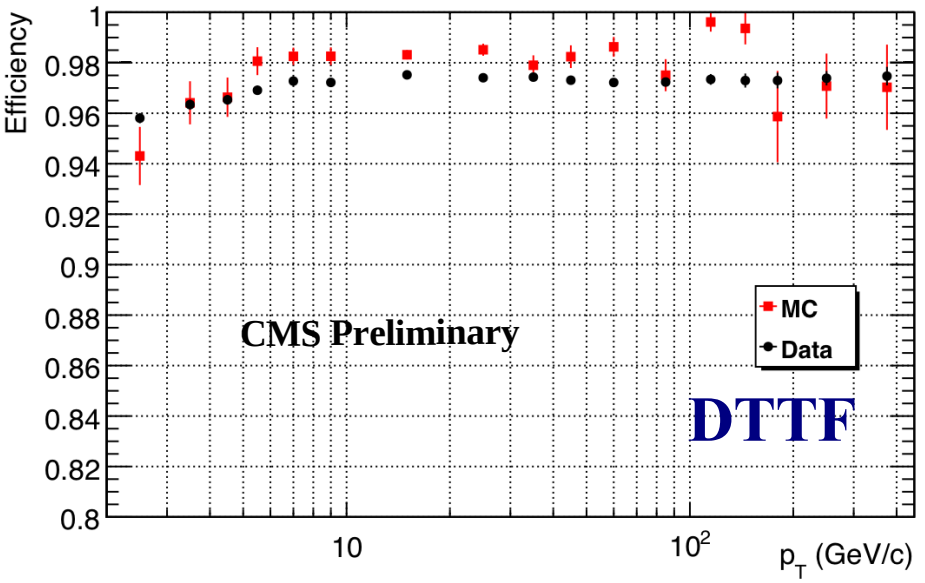


DTTF trigger efficiency

- trigger efficiency wrt stand-alone tracks
- holes: sectors masked due to hardware problems

DTTF trigger efficiency vs p_T

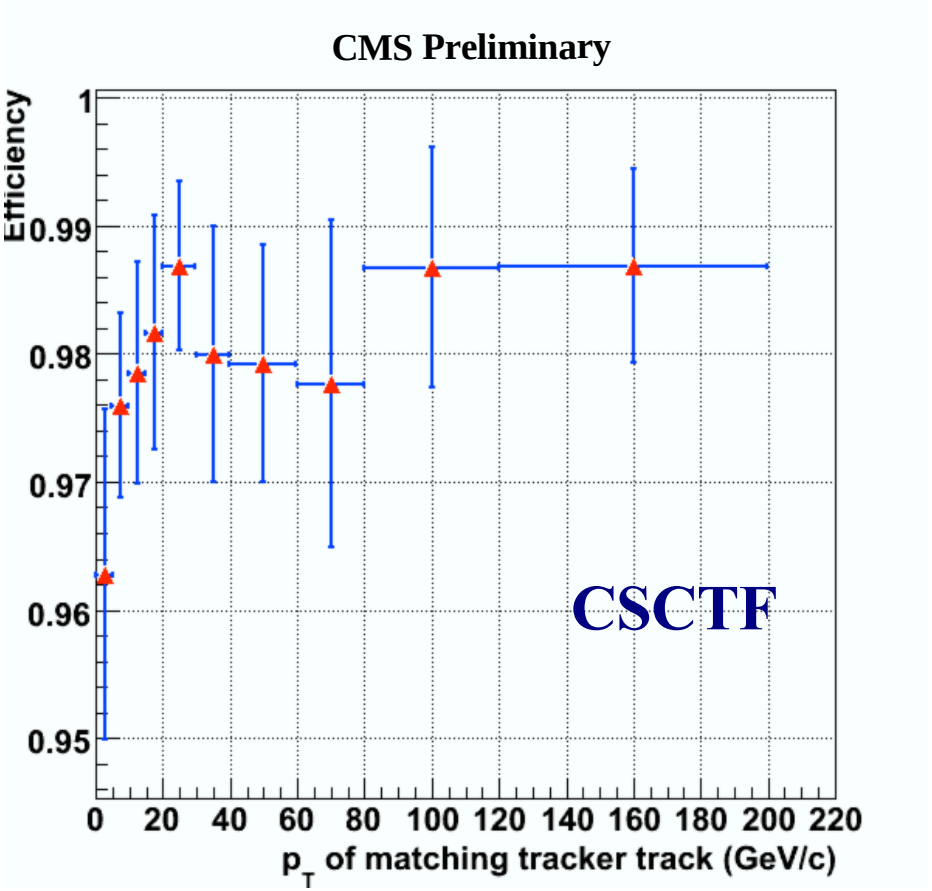
- masked sectors removed
- good agreement between data and MC



Efficiency of muon triggers continued

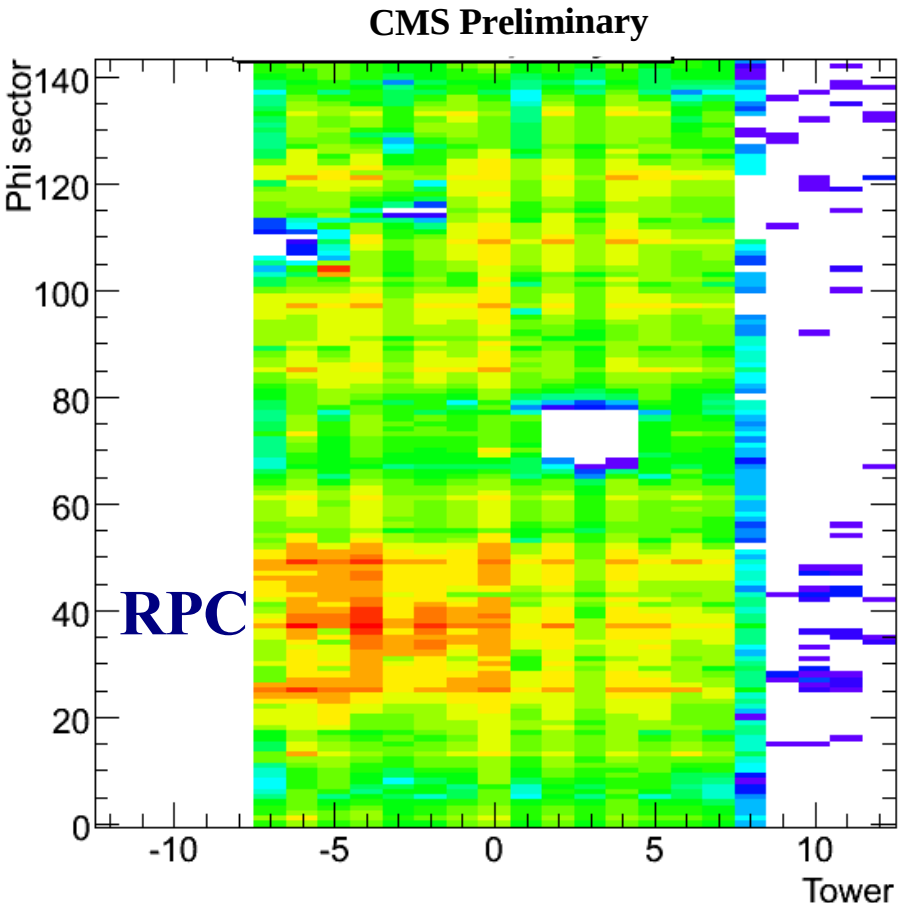
CSCTF efficiency

- tracker track extrapolated to endcap
- look for matching CSC trigger with 2 or more stations in coincidence

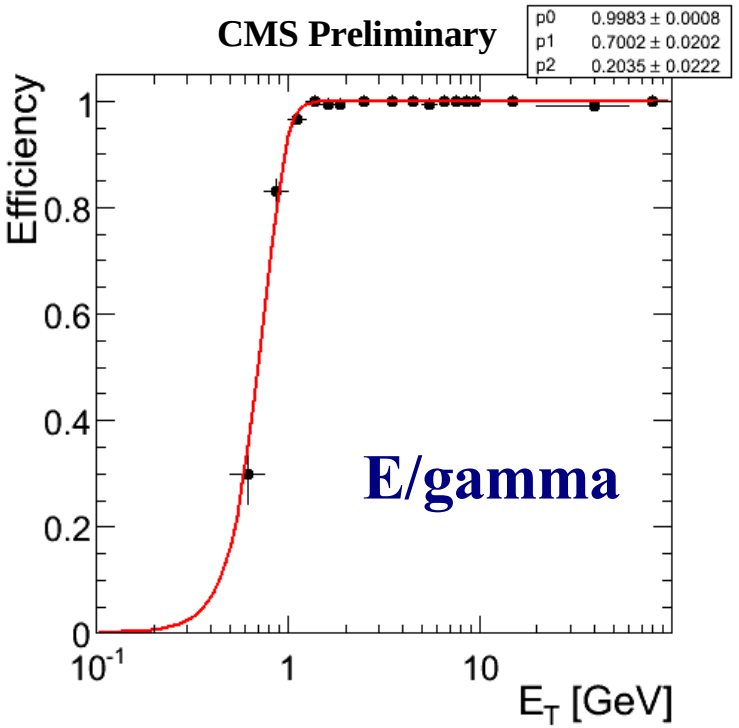


RPC occupancy

- during 2008 cosmic ray run
- endcaps fully ready in 2009 runs



Efficiency of CALO triggers

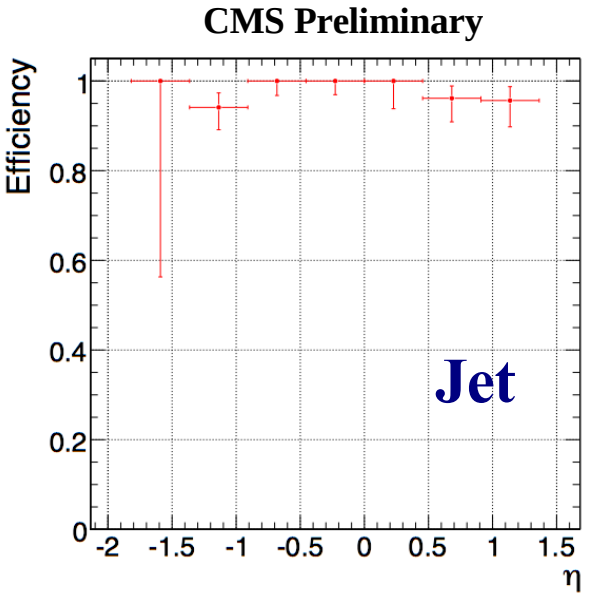


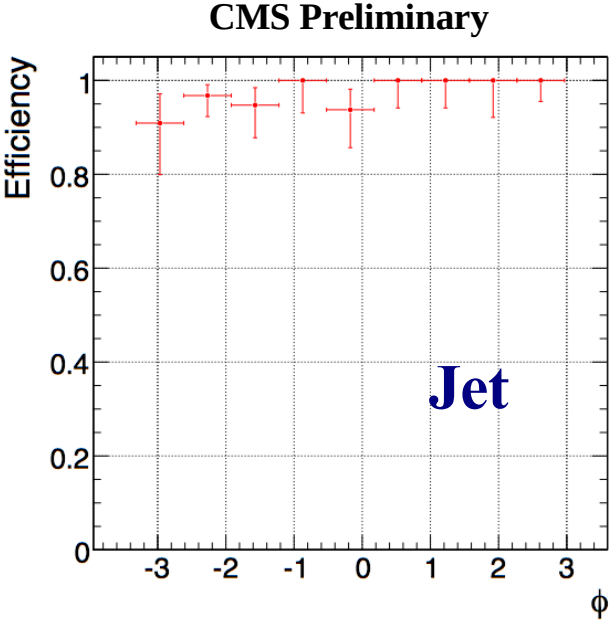
E/gamma trigger efficiency turning curve

- muon triggered events
- reconstructed muon passing close to ECAL supercluster

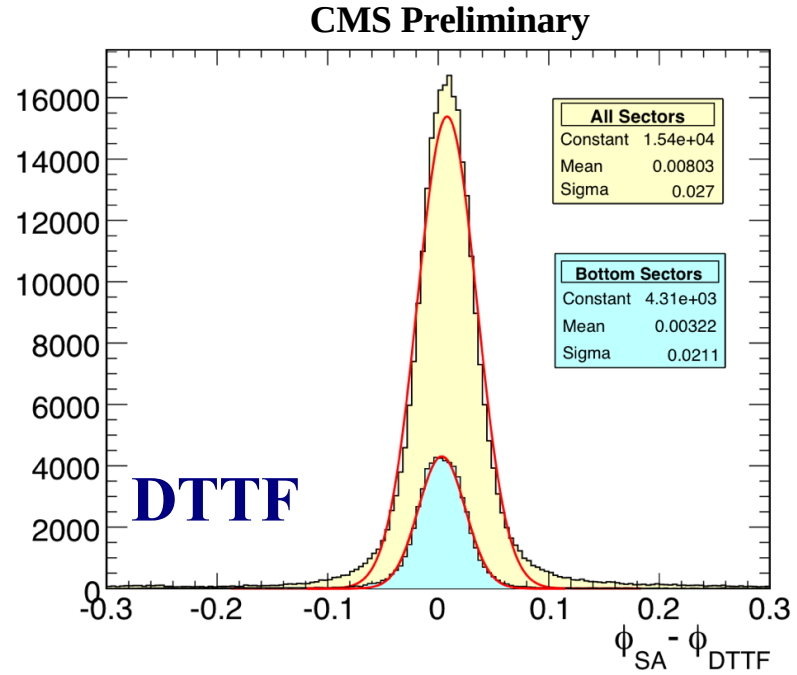
Jet trigger efficiency

- E/gamma triggered events
  - *mainly noise with large electromagnetic fraction*





Muon phi, eta resolution

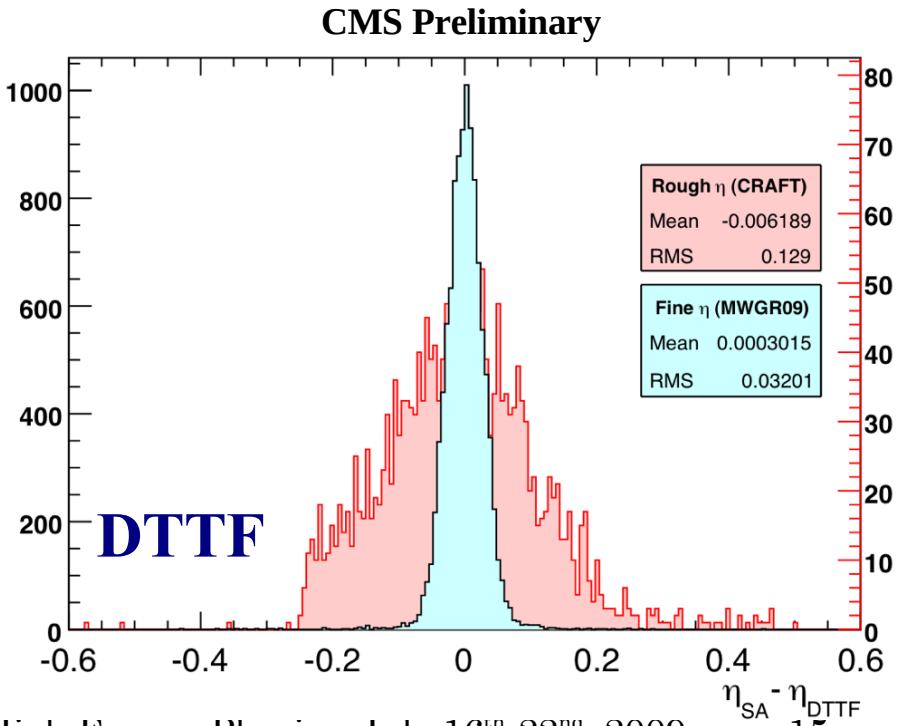


DTTF phi resolution

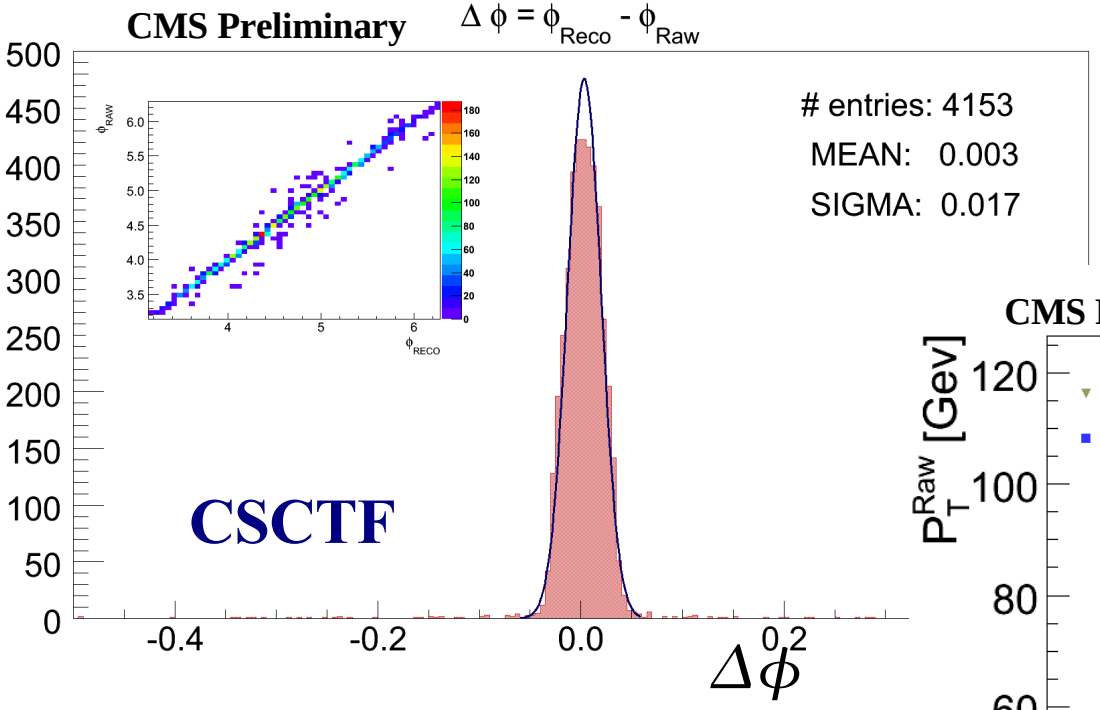
- difference wrt stand-alone track
- bottom sectors: LHC-like muon direction
  - *observed sigma=0.021*
  - *expected sigma~0.02*

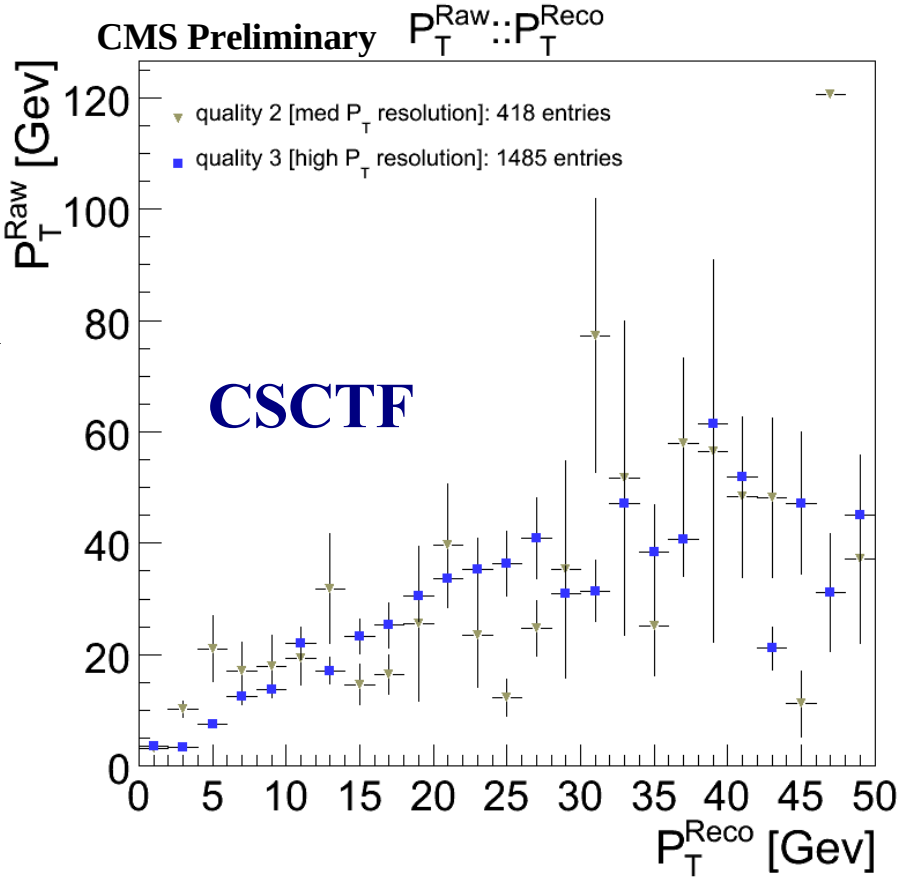
DTTF eta resolution

- difference wrt stand-alone track
- red plot: eta TF not fully operational in 2008 running
- blue plot: commissioned eta TF in 2009 running



Muon phi, p_T resolutions continued





CSCTF resolutions

- require a muon on both top and bottom part of the detector
- compare the muon on bottom part to reconstructed track

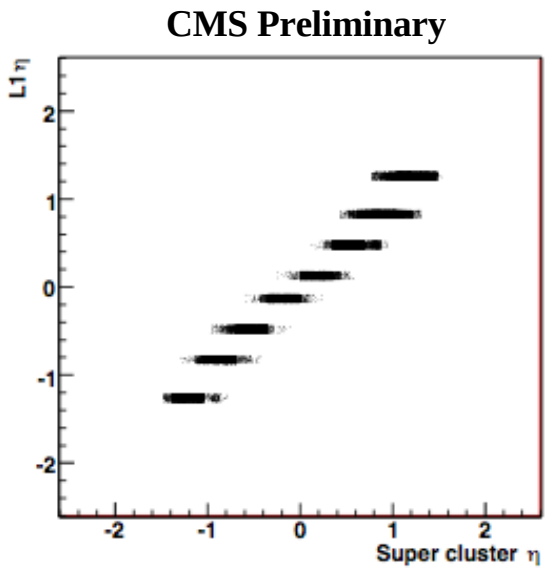
E/gamma eta, phi resolution

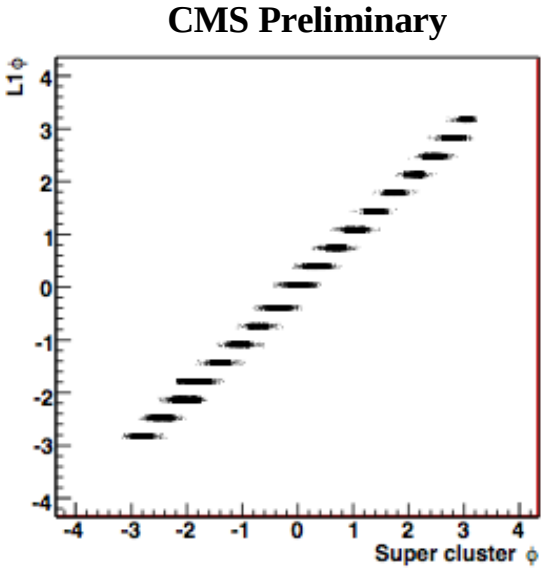
Eta, phi correlations

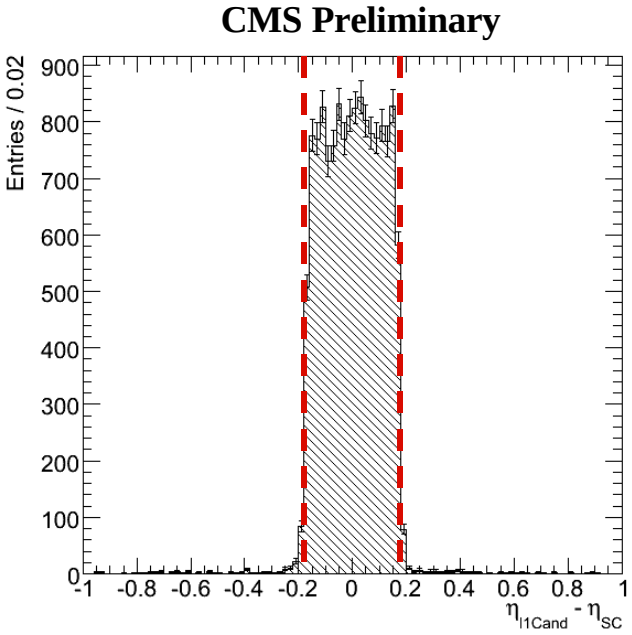
- L1 trigger object matched to closest reconstructed super cluster

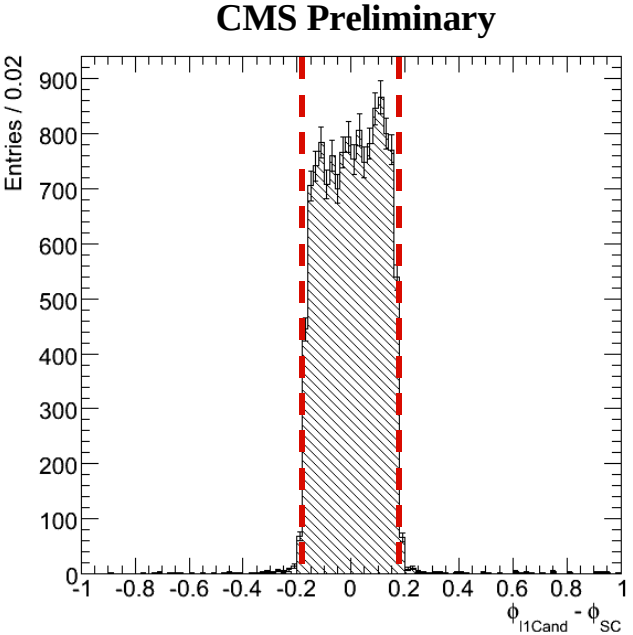
Eta, phi resolutions

- muon triggered events
- reconstructed muon close to super cluster
- granularity of L1 e/gamma trigger: 0.35x0.35
  - *resolution width as expected*









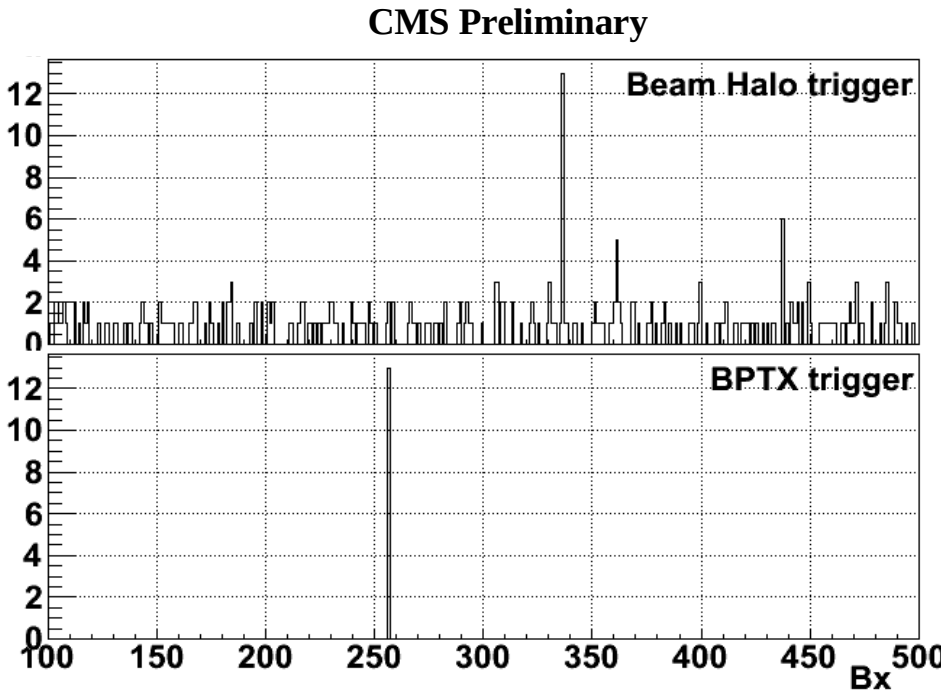
L1 synchronization to LHC beam

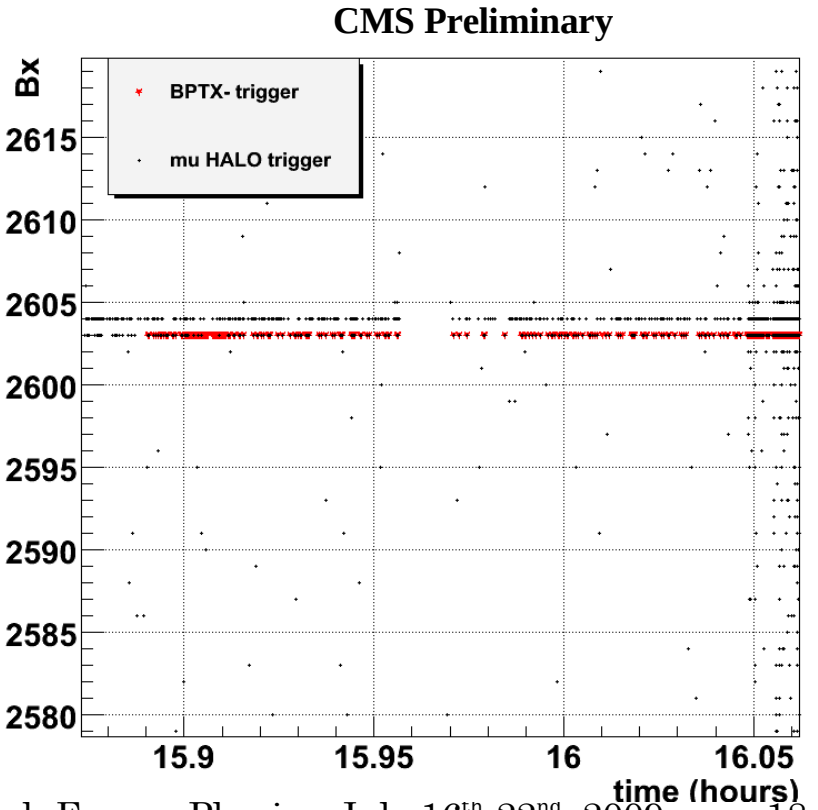
Beam splash events

- *measurement of the time delay between the Beam Pickup (BPTX) trigger and previously synchronized CSC beam halo trigger*

Circulating beams

- *synchronization of BPTX trigger with CSC halo trigger*
- *CSC beam halo spread into two BX due to imperfect internal synchronization (cosmic data limitation)*



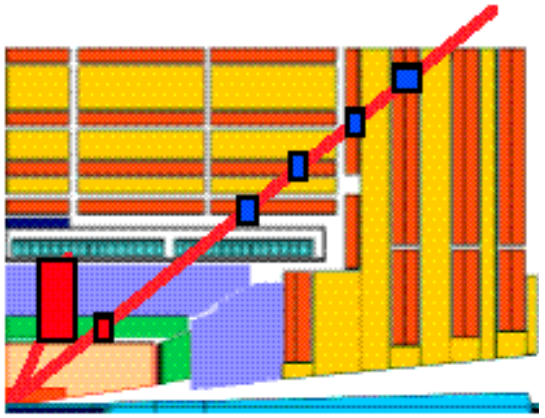


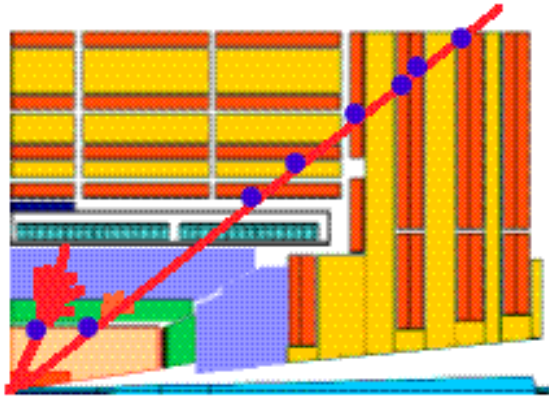
Summary

- **Experience from cosmic ray runs has proved that L1 trigger runs stably and reliably**
- **We have performed several analysis from the L1 trigger data from cosmic rays**
  - *L1 trigger emulator studies*
  - *synchronization of L1 triggers*
  - *efficiencies of L1 triggers*
  - *resolutions of L1 triggers*
    - **Results show good performance of the L1 trigger**
- **CMS L1 trigger is ready and looking forward to collision data**

Backup

HLT trigger





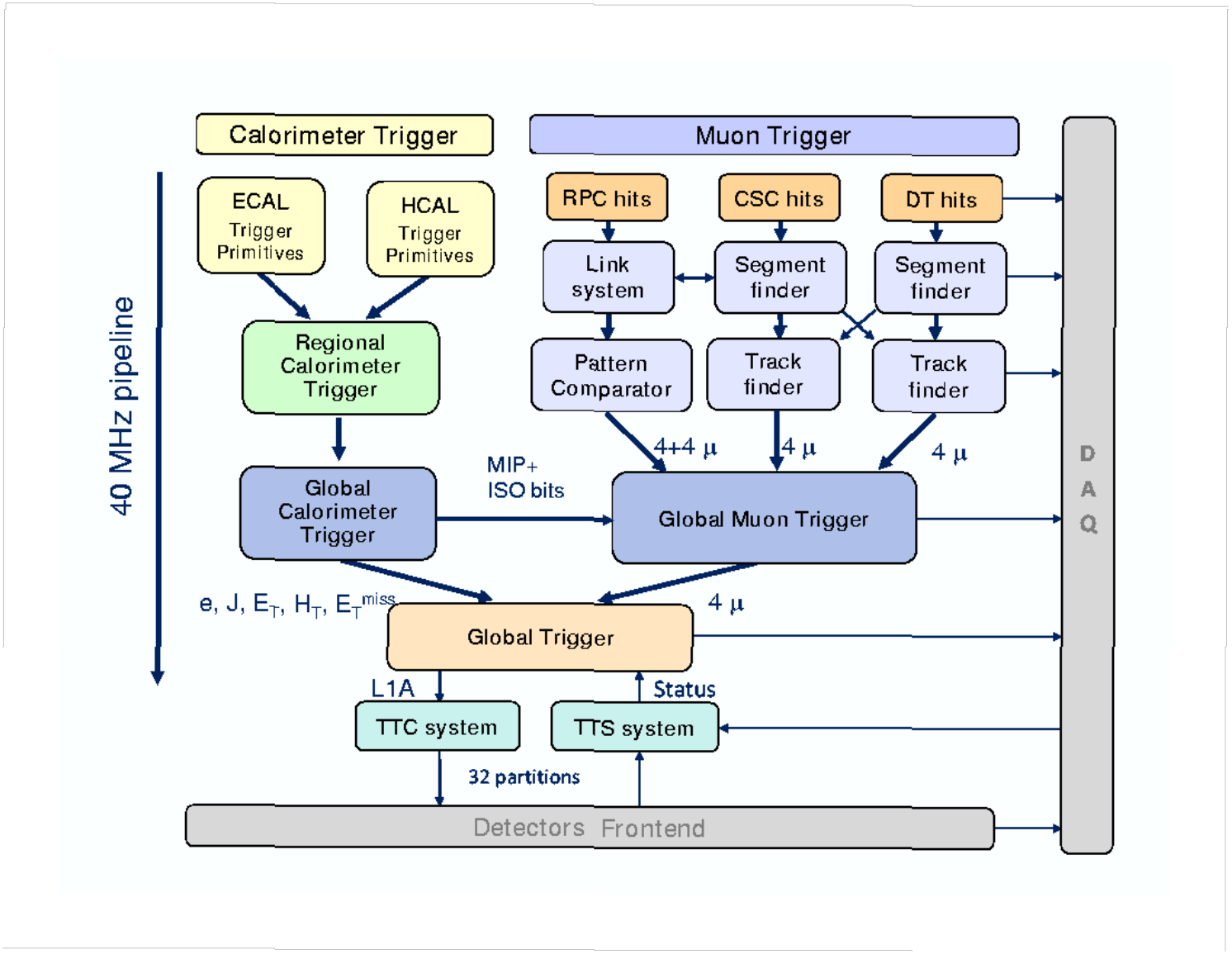
Purely software based
- *runs on a farm of commercial PCs*

Less strict time constraints than L1 trigger
- *average processing time 40 ms*

Algorithms executed in order of increasing complexity
- *Finer granularity precise measurements*
- *Clean particle signatures*
- *Kinematics, effective mass cuts and event topologies*
- *Track reconstruction and detector matching*
- *Event reconstruction and analysis*

Execution of path stopped unless evidence for signal is found

L1 trigger


Calorimeter Trigger
Muon Trigger
ECAL Trigger Primitives
HCAL Trigger Primitives
RPC hits
CSC hits
DT hits
Link system
Segment finder
Segment finder
Regional Calorimeter Trigger
Pattern Comparator
Track finder
Track finder
40 MHz pipeline
4+4 μ
4 μ
4 μ
MIP+ ISO bits
Global Calorimeter Trigger
Global Muon Trigger
DAQ
e, J, E_T, H_T, E_T^{miss}
4 μ
Global Trigger
L1A
Status
TTC system
TTS system
32 partitions
Detectors Frontend