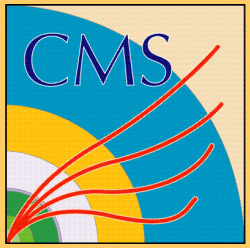


The CMS LEVEL 1 TRIGGER SYSTEM

FUNCTIONALITY and PERFORMANCE

Herbert ROHRINGER

on behalf of CMS

CMS TWO-LEVEL TRIGGER CONCEPT

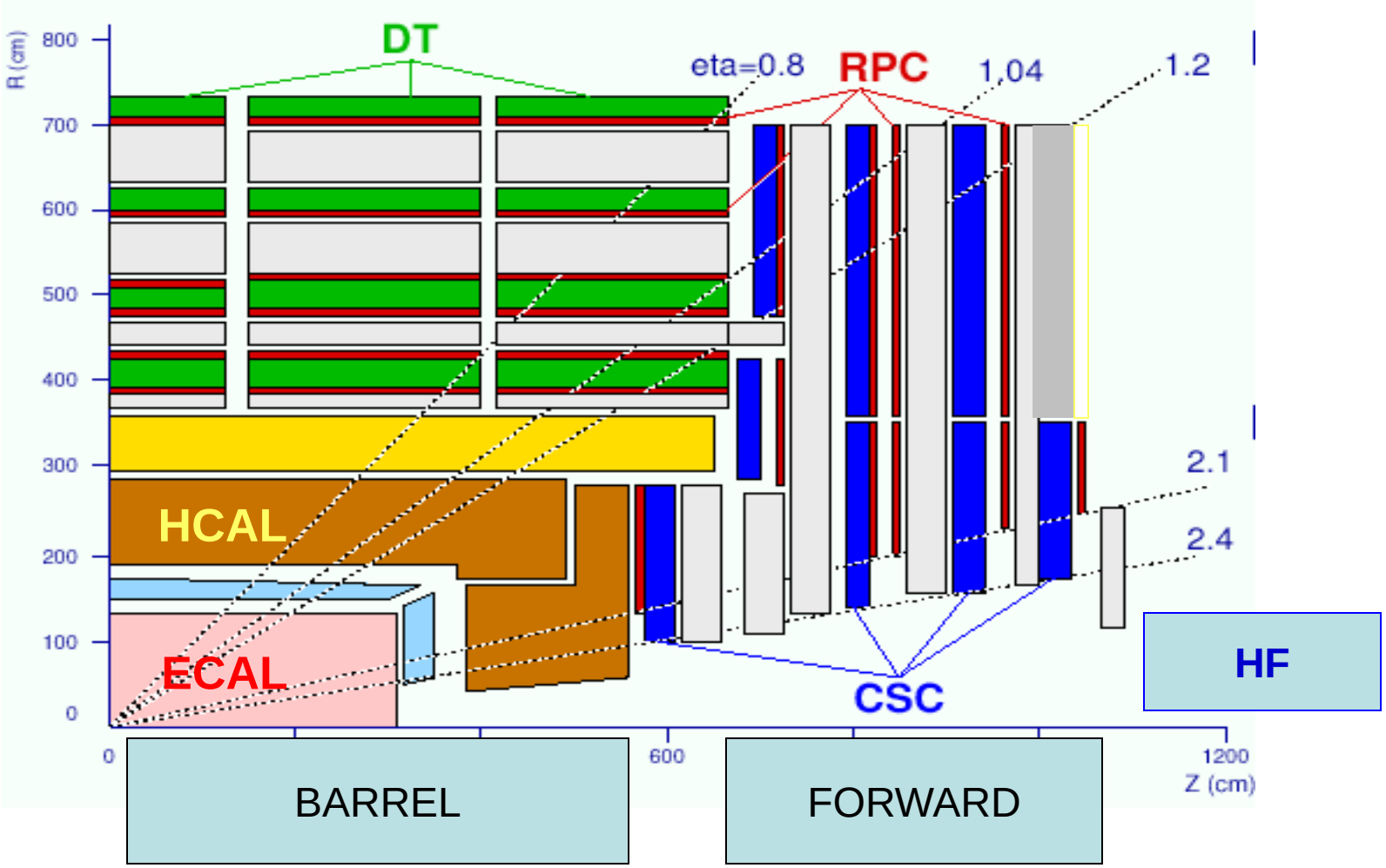
- **LEVEL 1** has to reduce the LHC bunch crossing rate from 40 MHz -> 100 kHz
  - hardware based fast decision logic
  - uses only coarse data - e.g. "best " 4 trigger objects from MUON SYSTEMS and CALORIMETERS
  - works in "pipeline" mode
  - simple algorithms running in parallel applied
  - Central Trigger Control System & Trigger Supervisor
  - if trigger decision positive -> **L1Accept** **Latency 4 μs**

- **Meanwhile full detector data are stored in ring buffers**

- **If L1Accept -> High Level Trigger HLT** - has to reduce 100 kHz -> O(100 Hz)
  - uses full detector data (including tracker data)
  - event processing with programs running in a computer farm ("FILTER FARM")
    reconstructs muons, electrons/gammas, jets, E_t,….
    evaluates TRIGGER PATHS, seeded by previously found trigger objects
  - **subdivides** processed data in **data streams** according to physics needs, calibration, data quality, ...

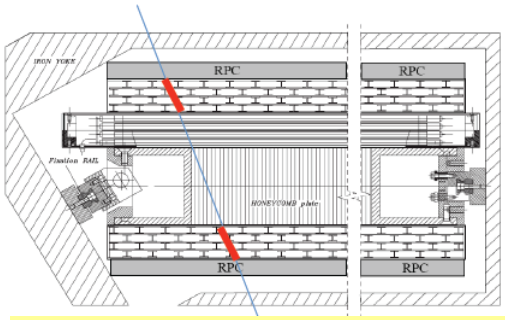
computing time < 40 msec >

TRIGGER COMPONENTS

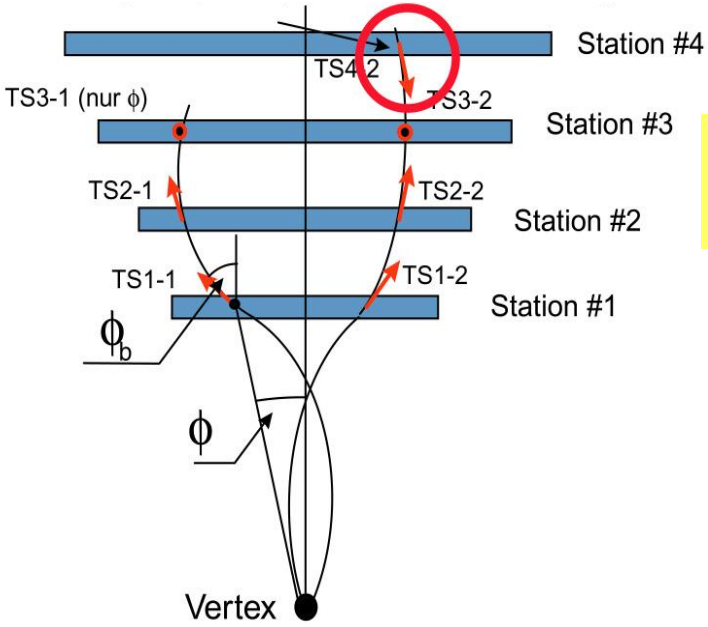


MUON TRIGGER TRACK FINDING

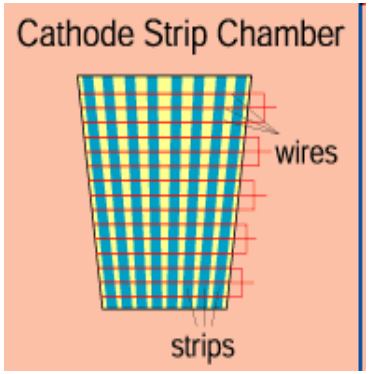
DT MUON STATION

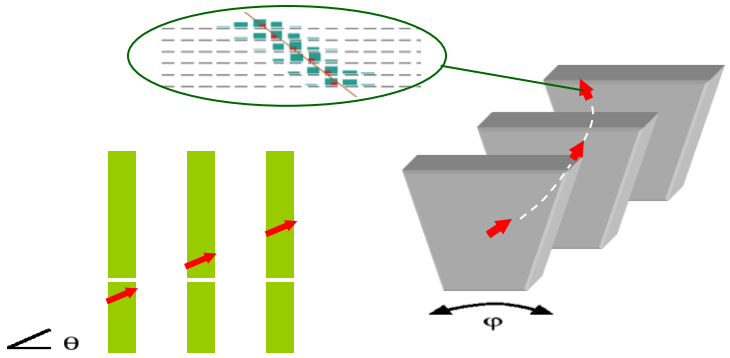


Local Segment Finder



CSC trigger



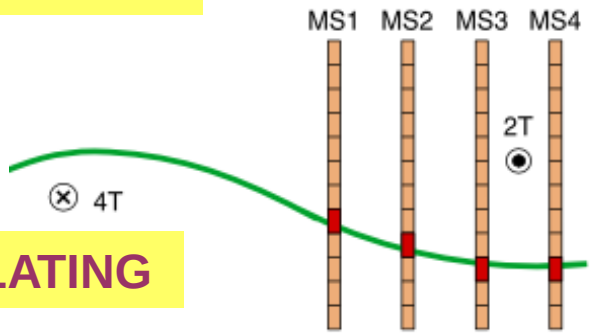


Anode strips

Cathode wires

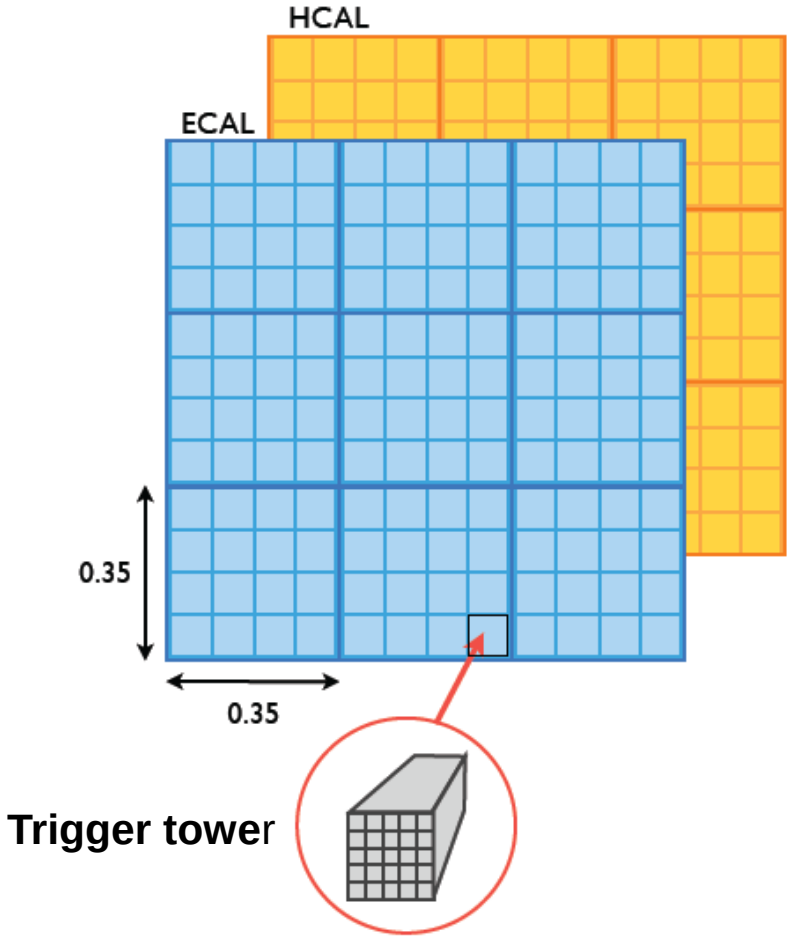
TRACK EXTRAPOLATION

RPC trigger



TEMPLATING

JET - TAU - ELECTRON TRIGGER



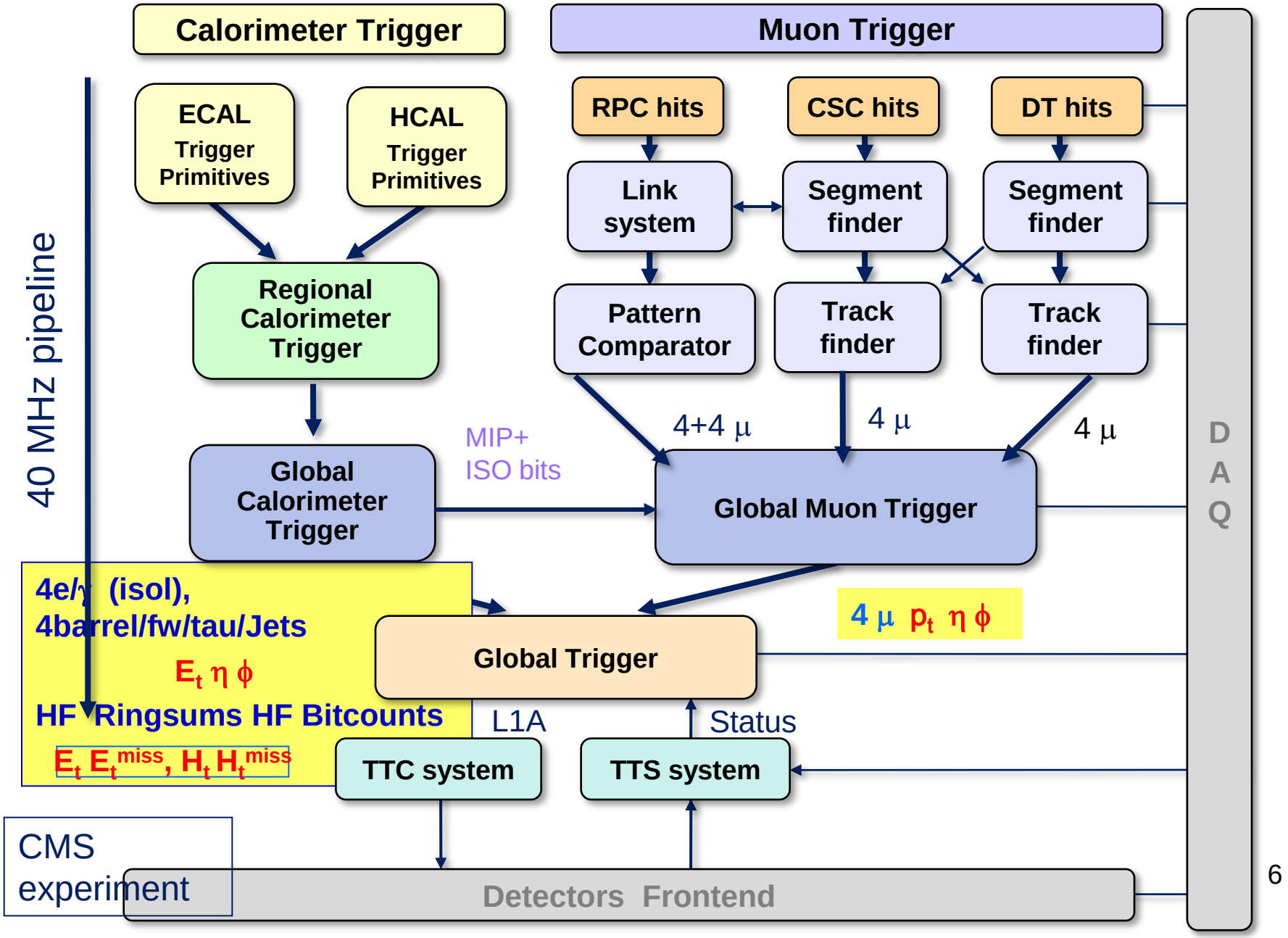
Trigger objects come from **Trigger towers**

E_t is summed up over regions of 4 x 4 Trigger towers

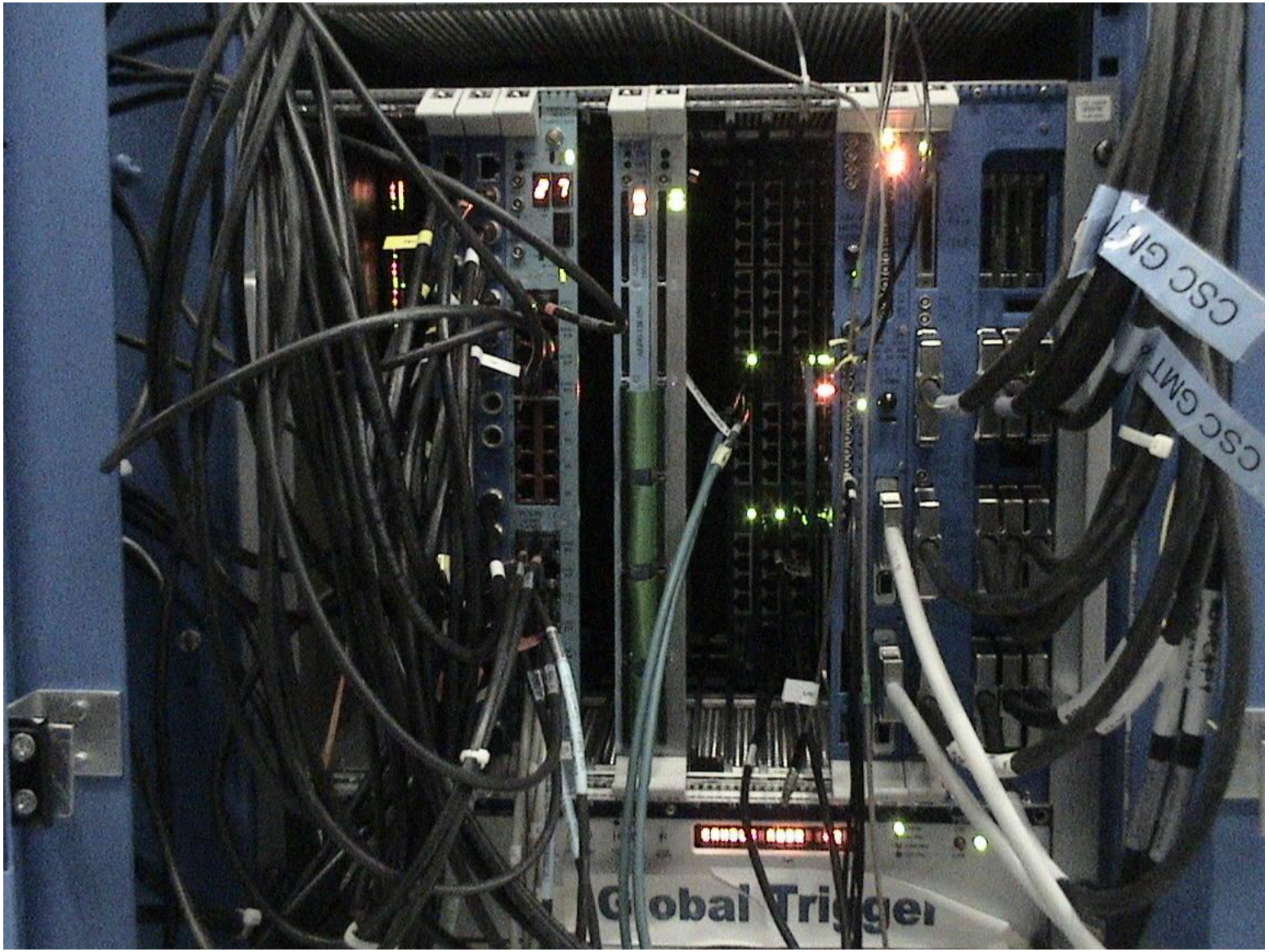
e/γ candidates : peak search in substrips of ECAL towers

jet finding : peak search via sliding windows using coarse regions of Trigger towers

LEVEL-1 TRIGGER ARCHITECTURE



GLOBAL TRIGGER HARDWARE



Trigger capability

- Physics trigger

  versatile chaining of conditions on trigger objects [e/γ,jets,μ] to form algorithms
  - requiring p_t/E_t thresholds, ranges in η, ϕ , charge - for single and multiobjects
  - correlations between 2 trigger objects

  up to **128 algorithms** are evaluated in parallel

  preset conditions for different luminosities - dynamical change is in testing

  preset trigger tables for fast loading

  on request fast change of thresholds possible

  firmware change (new/changed algorithms)

- Calibration + independent testing

- Triggers "in between" for long-lived particles

L1 TRIGGER DECISION

- **Evaluation** of at most **128 physics algorithms**
  and **64 direct trigger signals** from LHC beamcounters, CMS beam scintillators ….
- **final OR** with masking and prescaling –> **L1Accept**
- Hardware trigger decision can be checked during later HLT processing
- for limitations of instantaneous rate : **Trigger rules** :
  e.g . NO triggers in two consecutive bunch crossings allowed
- L1Accept transmitted to subdetectors to **start readout of full data** in the detector ring buffers for HLT
- Transmit trigger data to HLT

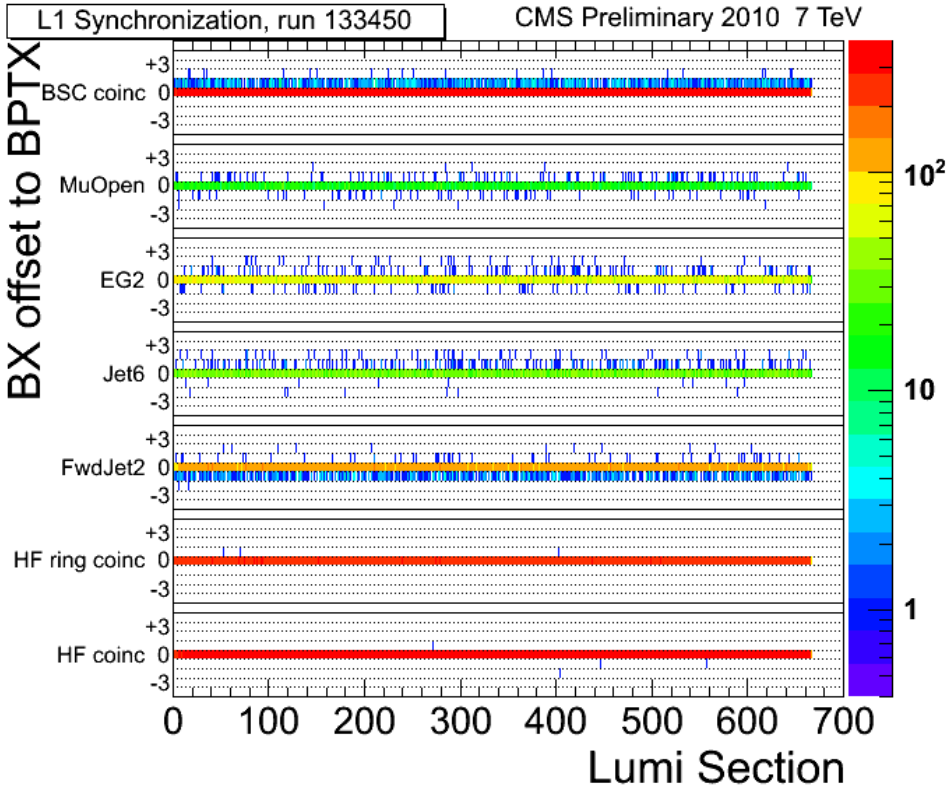
COLLISION TRIGGER

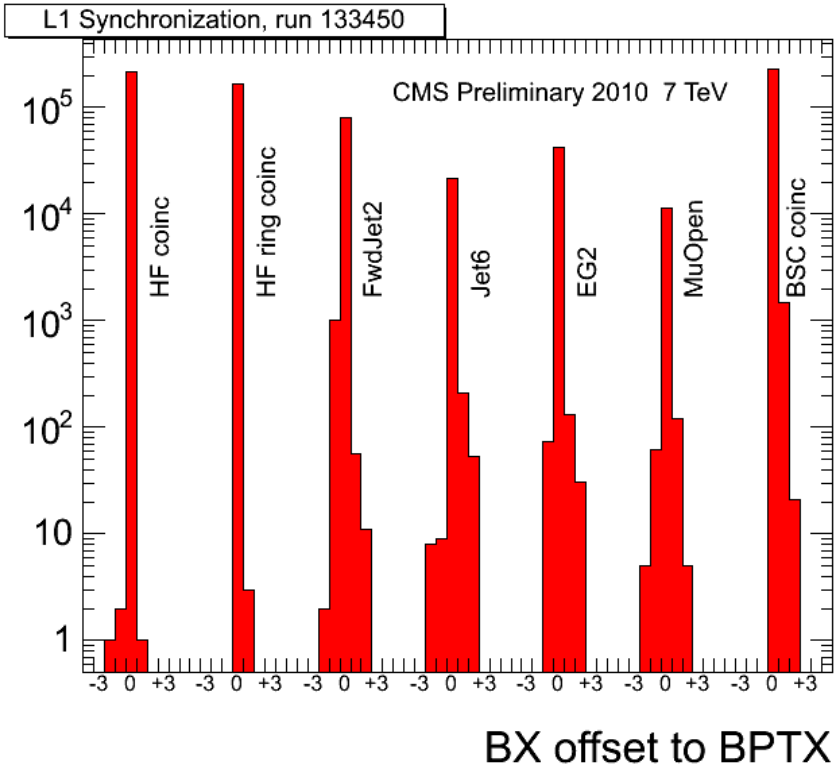
- **BPTX** beam pickup far from CMS - very loose
  → **ZeroBias**
- **Beam szintillators** + **HF** somethings happens
  → **MinBias**
- **Gradually enabling of**
  - Calorimeter and muon trigger with luminosity
- **Minimum bias prescaling**
- **BPTX prescaling** to prevent resonant frequency of wire bonds of tracker readout
- **Physics Triggers** active for triggerselection and rate reduction

TRIGGER COMMISSIONING and RESULTS from COLLISIONS

- **SYNCHRONISATION** of trigger signals
  - between trigger components
  - to LHC bunch crossing
  - important testing was done during Cosmic Runs in 2006, 2008,2009
- **STABILITY**
- **QUALITY**
- **EFFICIENCY**

L1 Synchronisation Summary





Minimum bias events passing BSC coincidence trigger, high threshold

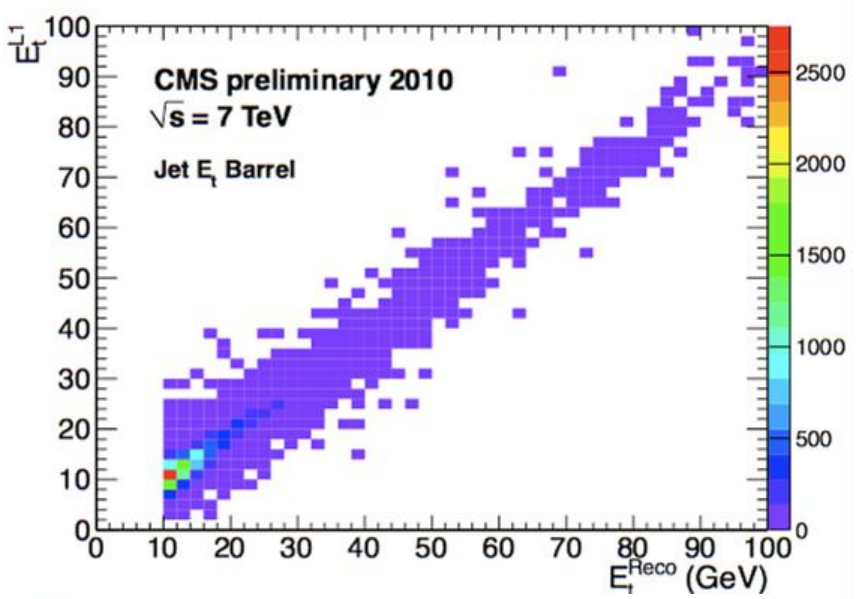
- Plots show time of calorimeter, muon and BSC triggers wrt BPTX trigger (in units of BX)
  - As function of Lumi Section (left), and integrated over all Lumi Sections (right)
- No noise/anomalous signal cleaning

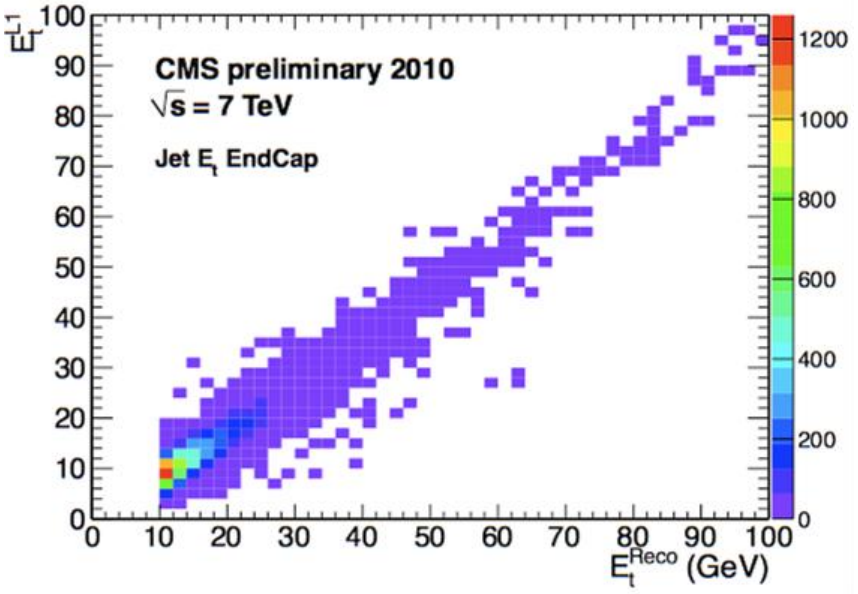
L1 Jets E_t vs Offline Jets E_t^{reco}

- **Leading L1 jet**

  matched to offline

  reco jet within cone $\Delta R < 0.5$
- $|\eta|^{reco} < 2.6$
- $E_t^{reco} > 10$ GeV
- Minimum Bias events



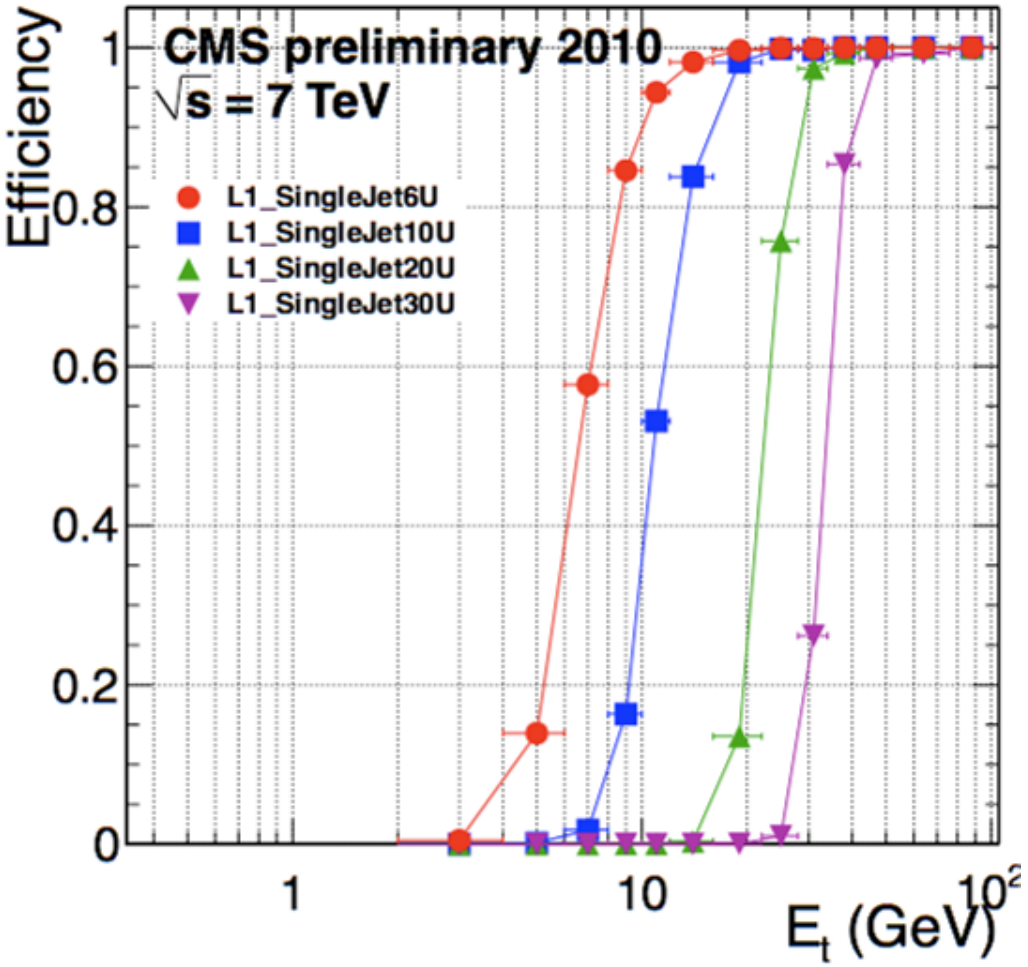


L1 Jet Efficiency

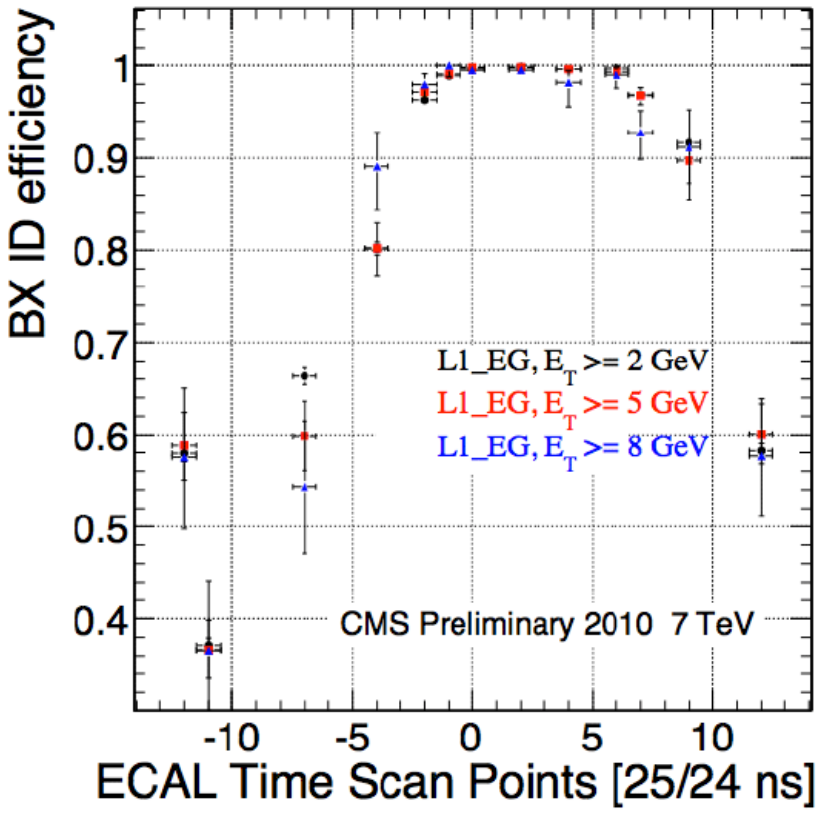
- **Efficiency as function of offline jet E_t^{reco}**

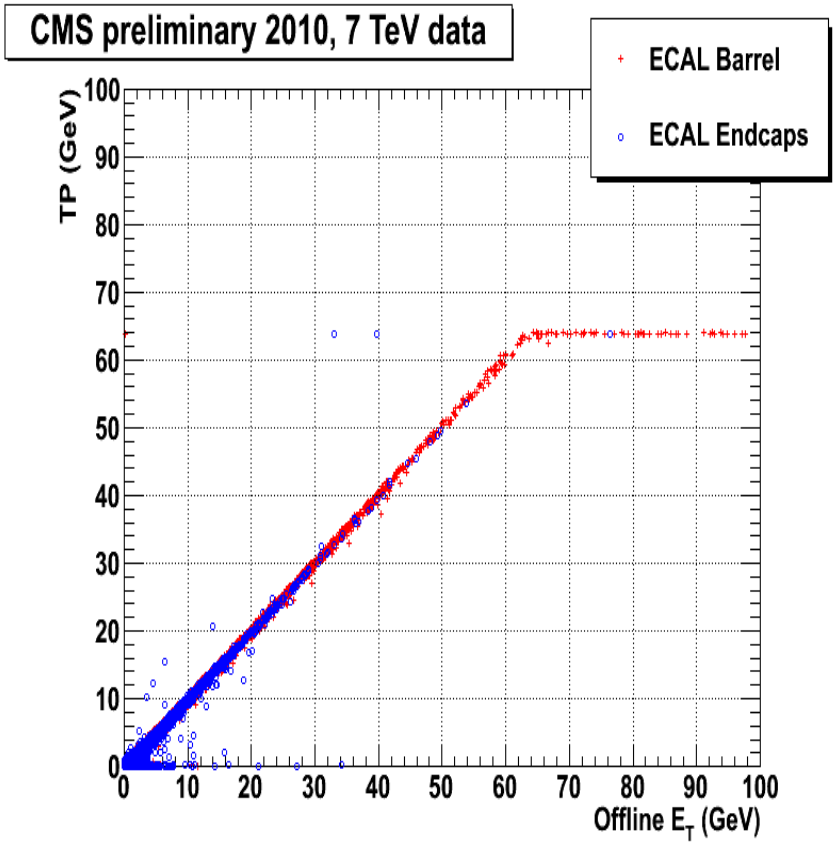
  for L1 jet E_t 6,10,20,30 GeV

  - **Leading offline reco jet matched to a L1 jet**
  - **with $\Delta R < 0.5$**
  - **$E_t^{reco} > 10$ GeV**
  - **$|\eta|^{reco} < 2.6$**
  - **Minimum Bias events**



Ecal commissioning



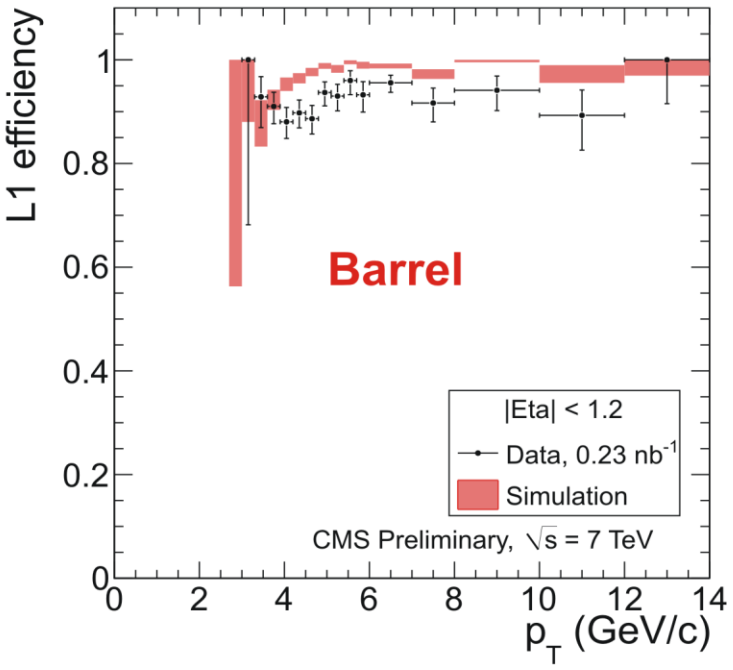


BUNCH CROSSING vs **signal efficiency**
SYNCHRONISATION

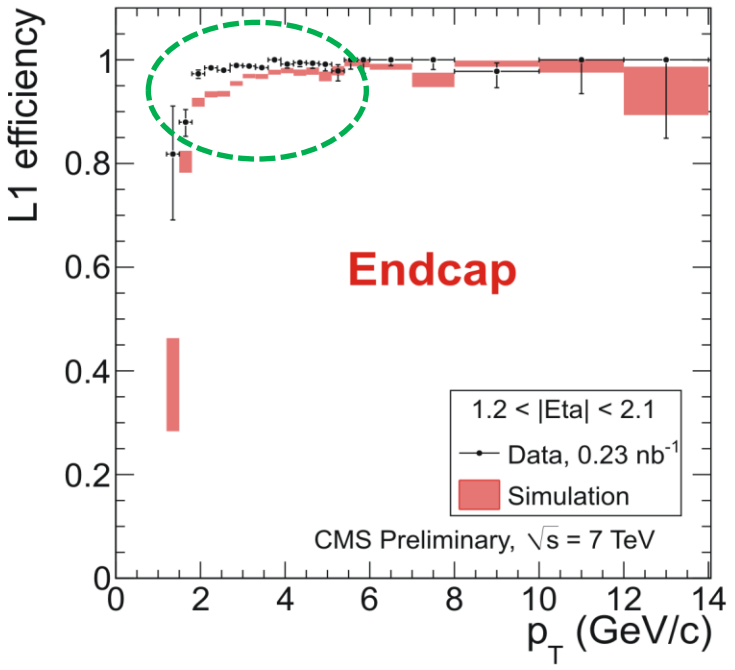
Trigger E_t vs Reco E_t

L1 / Tight Muon EFFICIENCY

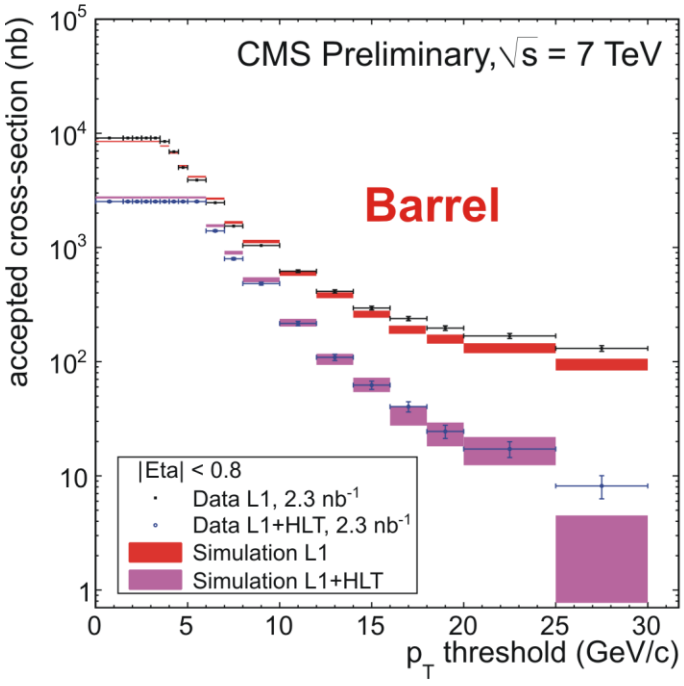
Plateau efficiency
~5% low in barrel

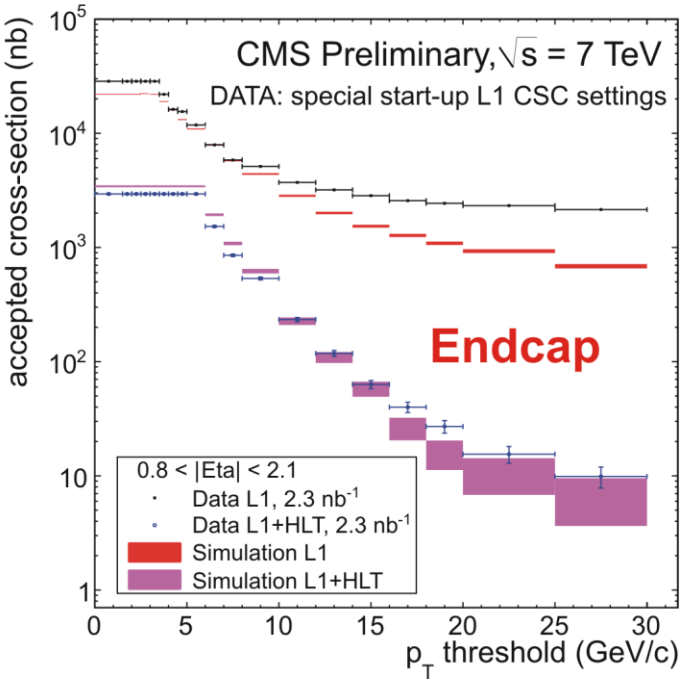


More efficient, due to
CSC singles in data



MUON L1 and HLT Trigger Rates





Good agreement in barrel (no CSC)

Endcap: difference expected due to special CSC startup trigger (single CSC chamber hits), not emulated in standard MC

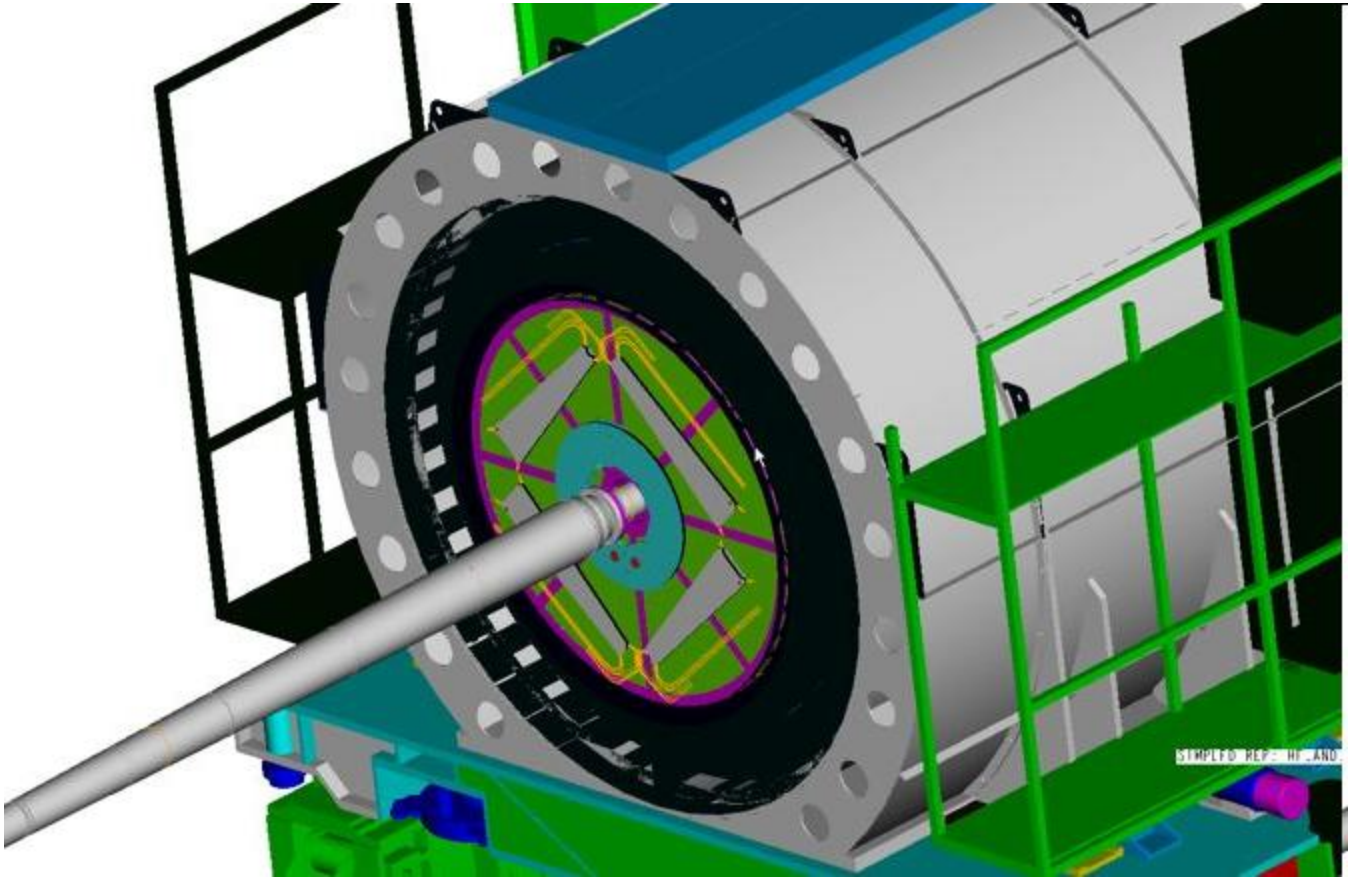
CONCLUSIONS

- CMS L1 is running smoothly
- L1 input is a good seeding for HLT
- Gradually “active triggering” deployed with increasing Luminosity
- The L1 capability not yet fully used

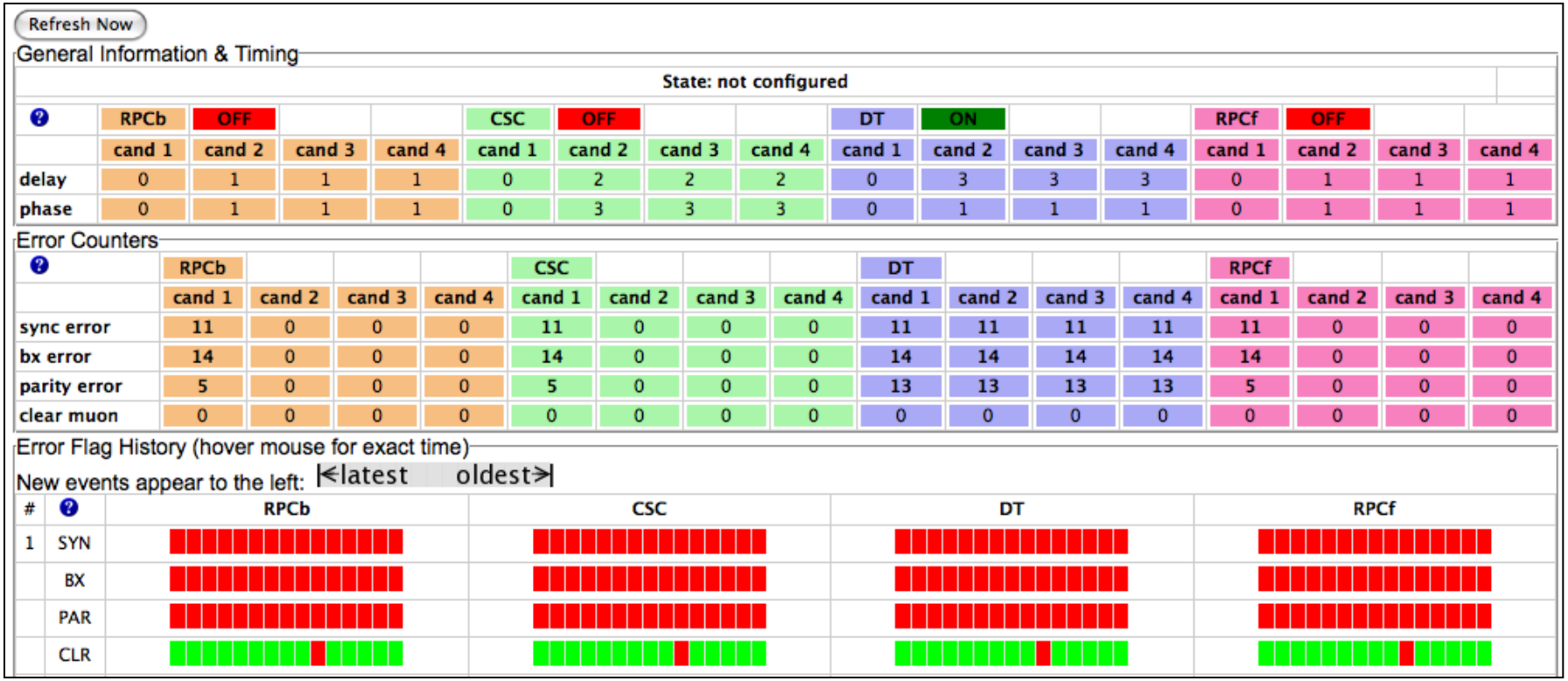
  (trigger with angular correlations ..)
- L1 designers looking forward to show “more goodies”

BACKUP SLIDES

BEAM SCINTILLATOR BSC



STEERING CONSOLE



Refresh Now

General Information & Timing

State: not configured

	RPCb	OFF			CSC	OFF			DT	ON			RPCf	OFF		
	cand 1	cand 2	cand 3	cand 4	cand 1	cand 2	cand 3	cand 4	cand 1	cand 2	cand 3	cand 4	cand 1	cand 2	cand 3	cand 4
delay	0	1	1	1	0	2	2	2	0	3	3	3	0	1	1	1
phase	0	1	1	1	0	3	3	3	0	1	1	1	0	1	1	1

Error Counters

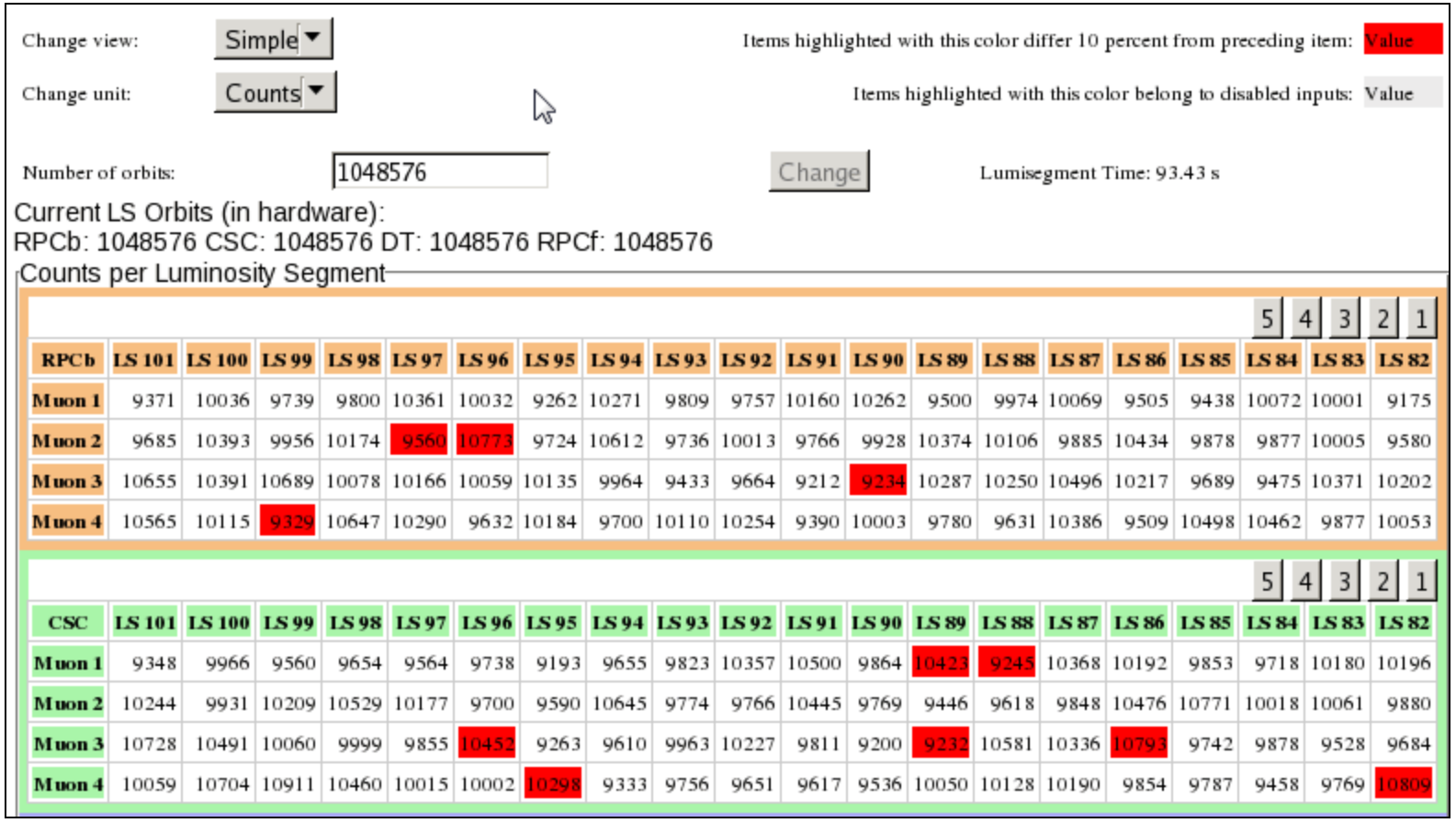
	RPCb				CSC				DT				RPCf			
	cand 1	cand 2	cand 3	cand 4	cand 1	cand 2	cand 3	cand 4	cand 1	cand 2	cand 3	cand 4	cand 1	cand 2	cand 3	cand 4
sync error	11	0	0	0	11	0	0	0	11	11	11	11	11	0	0	0
bx error	14	0	0	0	14	0	0	0	14	14	14	14	14	0	0	0
parity error	5	0	0	0	5	0	0	0	13	13	13	13	5	0	0	0
clear muon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Error Flag History (hover mouse for exact time)

New events appear to the left: |<latest oldest>|

#		RPCb	CSC	DT	RPCf
1	SYN				
	BX				
	PAR				
	CLR				

STEERING CONSOLE



Change view: Simple

Change unit: Counts

Items highlighted with this color differ 10 percent from preceding item: Value

Items highlighted with this color belong to disabled inputs: Value

Number of orbits: 1048576 Change

Lumisegment Time: 93.43 s

Current LS Orbits (in hardware):
RPCb: 1048576 CSC: 1048576 DT: 1048576 RPCf: 1048576

Counts per Luminosity Segment

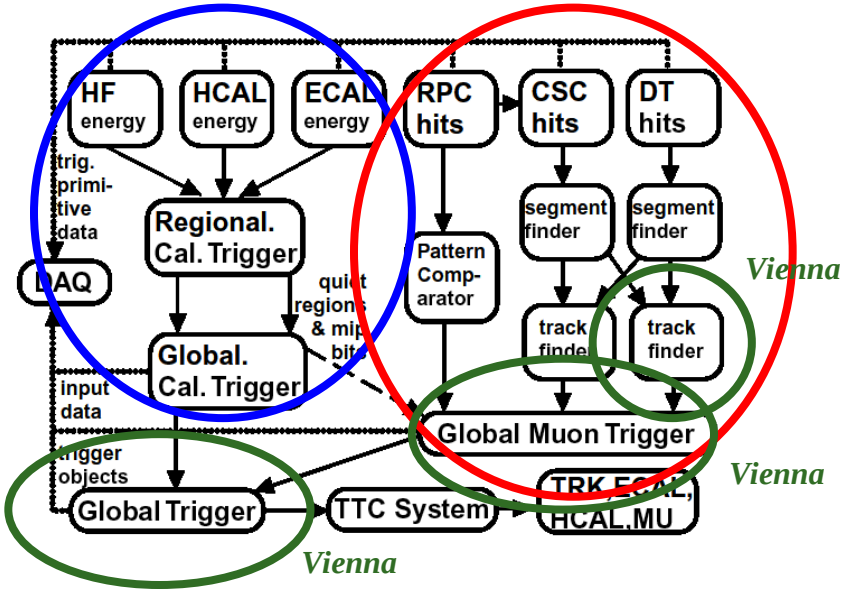
5 4 3 2 1

RPCb	LS 101	LS 100	LS 99	LS 98	LS 97	LS 96	LS 95	LS 94	LS 93	LS 92	LS 91	LS 90	LS 89	LS 88	LS 87	LS 86	LS 85	LS 84	LS 83	LS 82
Muon 1	9371	10036	9739	9800	10361	10032	9262	10271	9809	9757	10160	10262	9500	9974	10069	9505	9438	10072	10001	9175
Muon 2	9685	10393	9956	10174	9560	10773	9724	10612	9736	10013	9766	9928	10374	10106	9885	10434	9878	9877	10005	9580
Muon 3	10655	10391	10689	10078	10166	10059	10135	9964	9433	9664	9212	9234	10287	10250	10496	10217	9689	9475	10371	10202
Muon 4	10565	10115	9329	10647	10290	9632	10184	9700	10110	10254	9390	10003	9780	9631	10386	9509	10498	10462	9877	10053

5 4 3 2 1

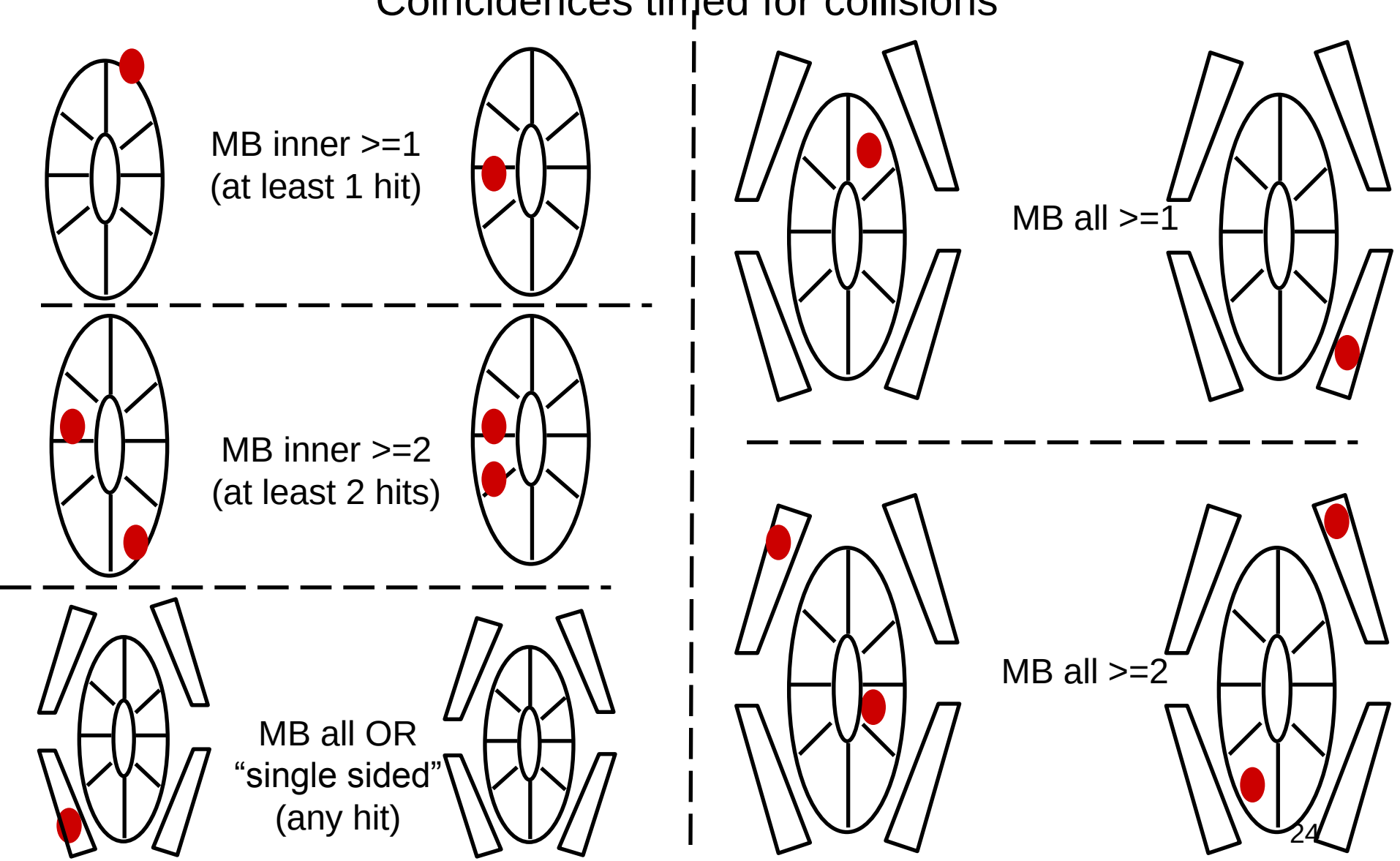
CSC	LS 101	LS 100	LS 99	LS 98	LS 97	LS 96	LS 95	LS 94	LS 93	LS 92	LS 91	LS 90	LS 89	LS 88	LS 87	LS 86	LS 85	LS 84	LS 83	LS 82
Muon 1	9348	9966	9560	9654	9564	9738	9193	9655	9823	10357	10500	9864	10423	9245	10368	10192	9853	9718	10180	10196
Muon 2	10244	9931	10209	10529	10177	9700	9590	10645	9774	9766	10445	9769	9446	9618	9848	10476	10771	10018	10061	9880
Muon 3	10728	10491	10060	9999	9855	10452	9263	9610	9963	10227	9811	9200	9232	10581	10336	10793	9742	9878	9528	9684
Muon 4	10059	10704	10911	10460	10015	10002	10298	9333	9756	9651	9617	9536	10050	10128	10190	9854	9787	9458	9769	10809

structure of the CMS Level-1 trigger



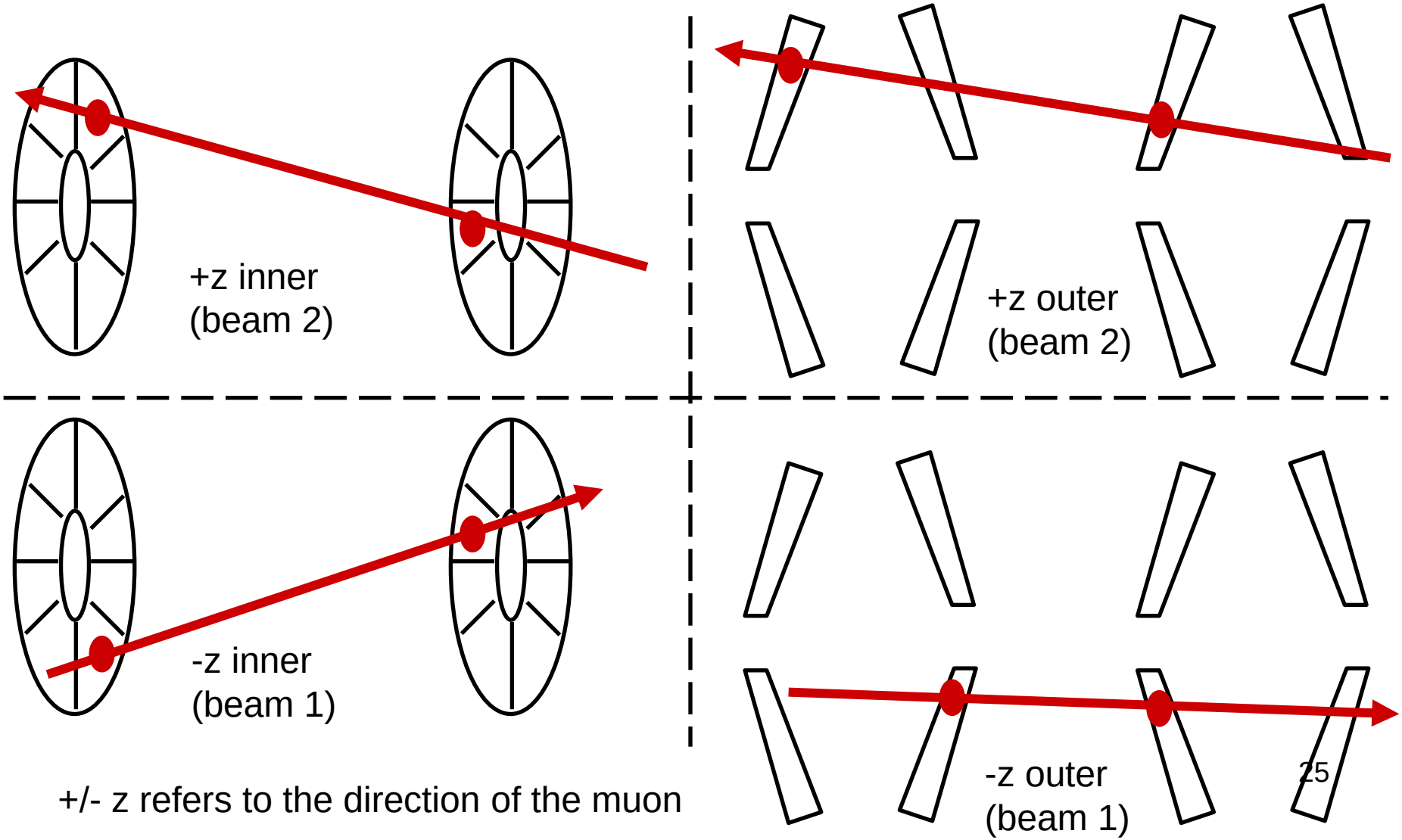
Minimum bias triggers

Coincidences timed for collisions

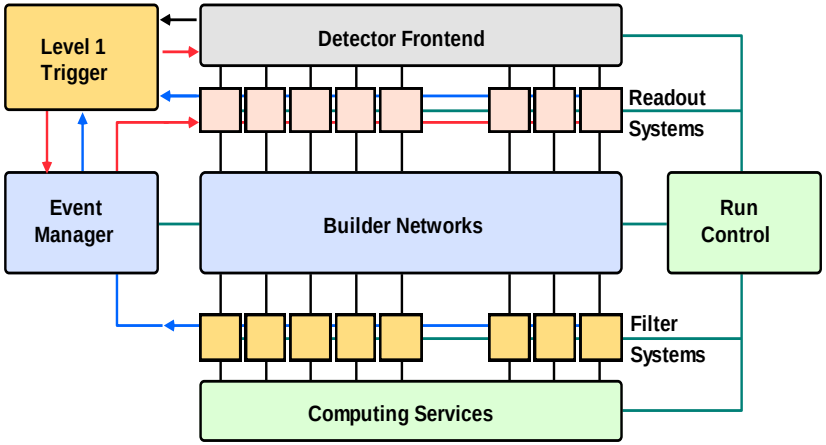


Beam halo triggers

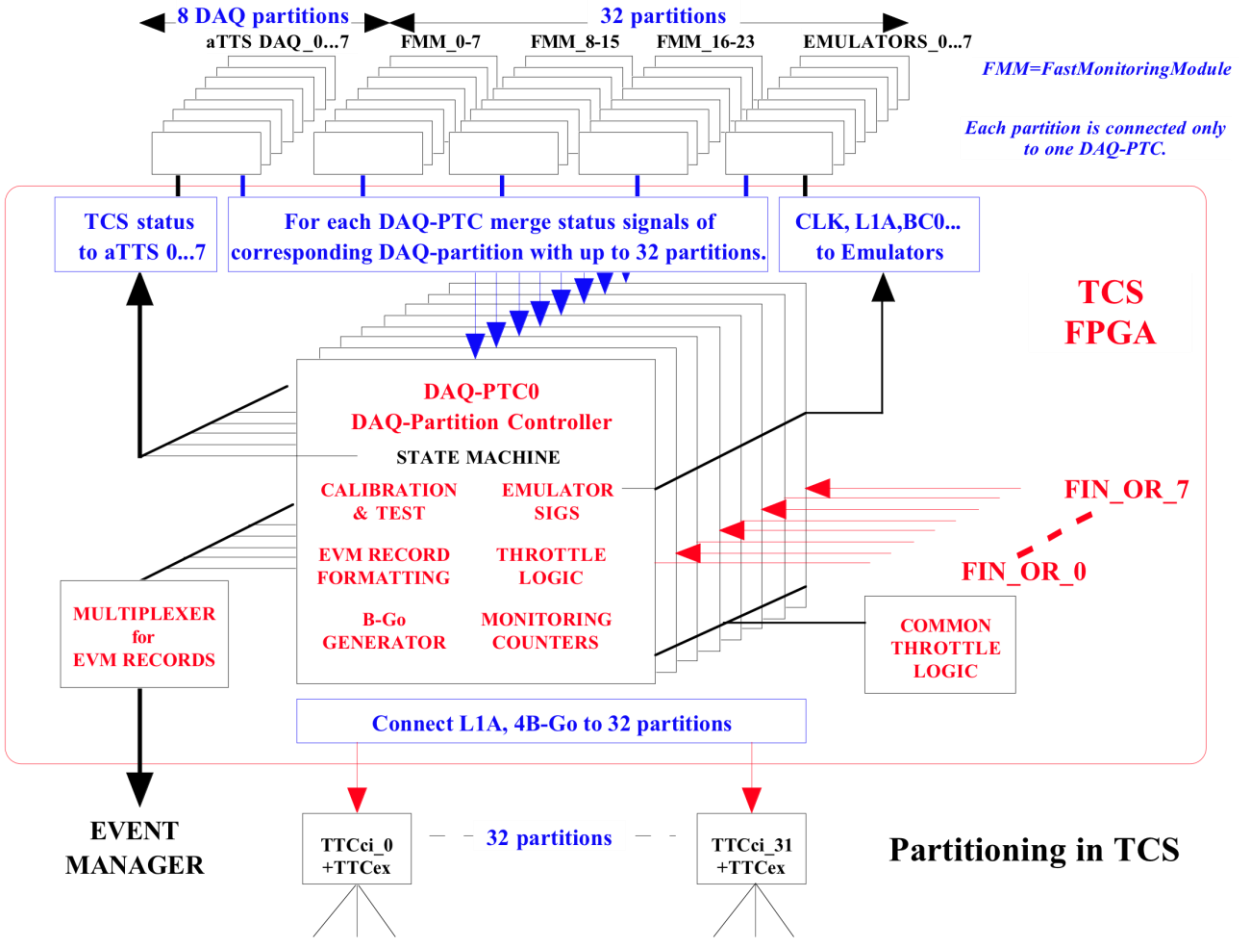
Coincidence: at least 1 hit each side, in any segment, w/in 40 ns timed for muons moving with *c*



+/- z refers to the direction of the muon

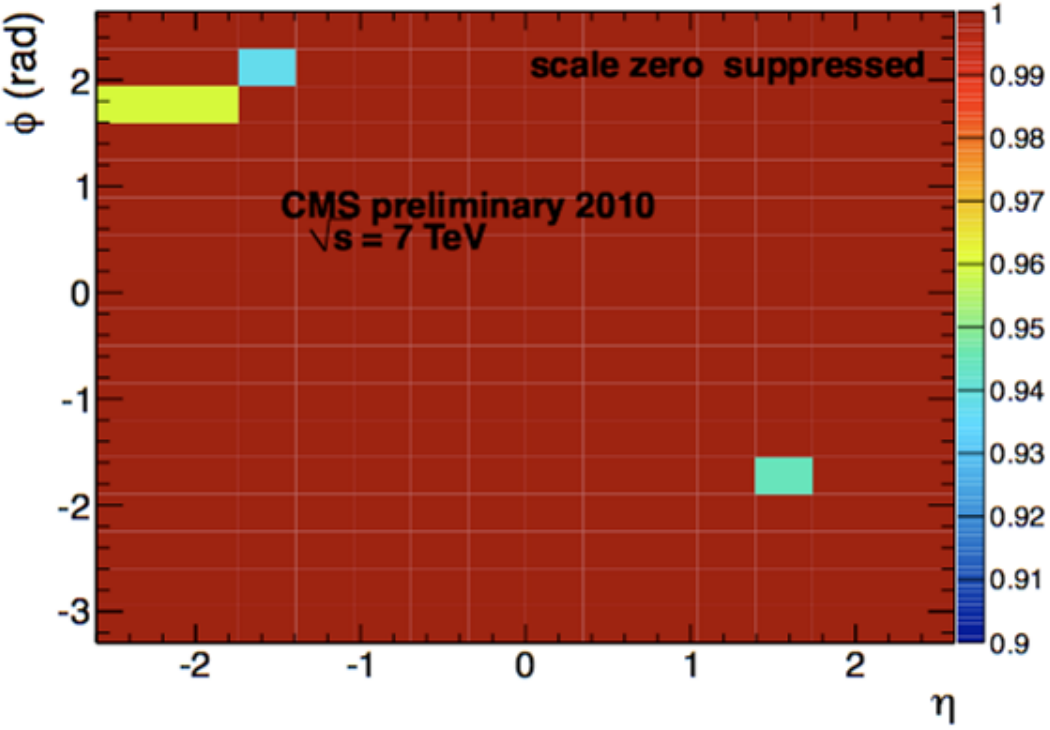


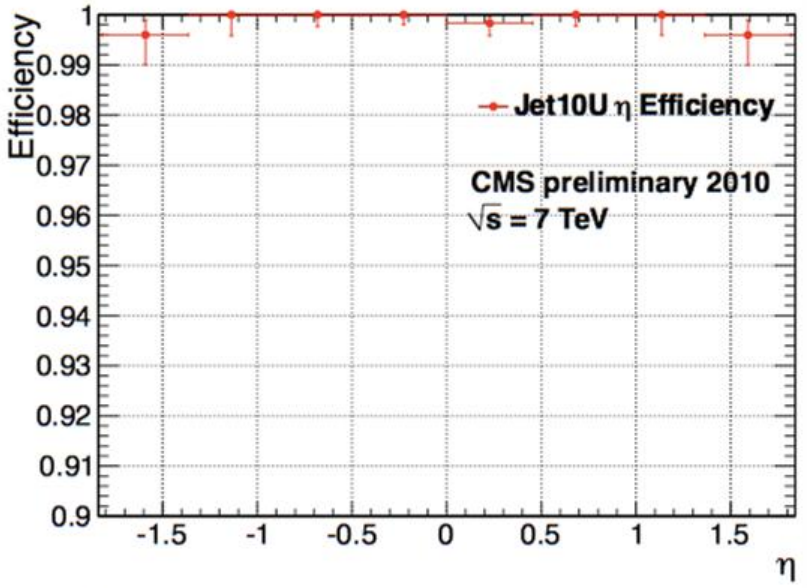
Level-1 Maximum trigger rate	100 kHz	No. Readout Units	- 512
System efficiency	98%	No. Builder Units	- 512
Event Flow Control	- 10^6 Mssg/s	No. Filter Unit	- n x 512
Builder network (512x512 port)	• 500-1000 Gb/s	No. (C&D) Network ports	- 10000
Event filter computing power	- 5 10^6 MIPS	No. programmable units	- 10000

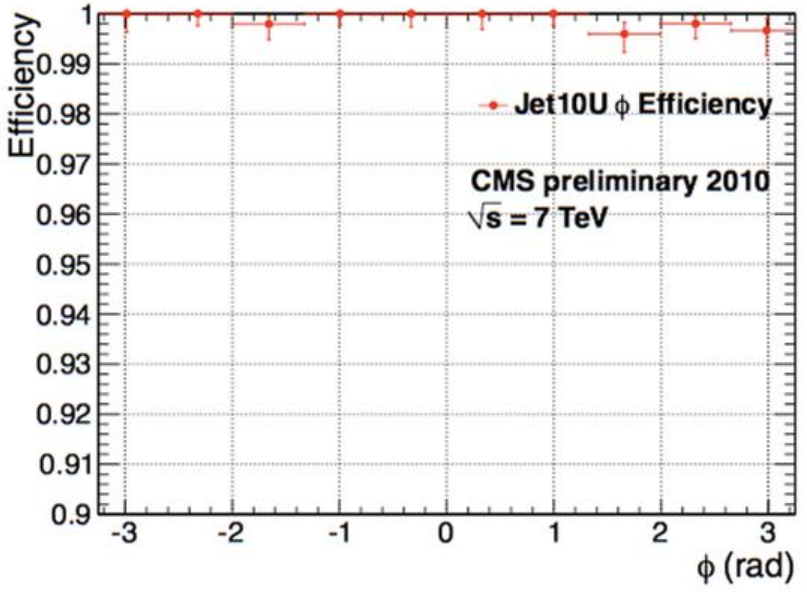

8 DAQ partitions
32 partitions
aTTS DAQ_0...7
FMM_0-7
FMM_8-15
FMM_16-23
EMULATORS_0...7
FMM=FastMonitoringModule
Each partition is connected only to one DAQ-PTC.
TCS status to aTTS 0...7
For each DAQ-PTC merge status signals of corresponding DAQ-partition with up to 32 partitions.
CLK, L1A,BC0... to Emulators
TCS FPGA
DAQ-PTC0
DAQ-Partition Controller
STATE MACHINE
CALIBRATION & TEST
EMULATOR SIGS
EVM RECORD FORMATTING
THROTTLE LOGIC
B-Go GENERATOR
MONITORING COUNTERS
FIN_OR_7
FIN_OR_0
MULTIPLEXER for EVM RECORDS
COMMON THROTTLE LOGIC
Connect L1A, 4B-Go to 32 partitions
EVENT MANAGER
TTCci_0 +TTCex
32 partitions
TTCci_31 +TTCex
Partitioning in TCS

1 Jet Efficiency

- Contact : Bryn Mathias (Bryn.Mathias@cern







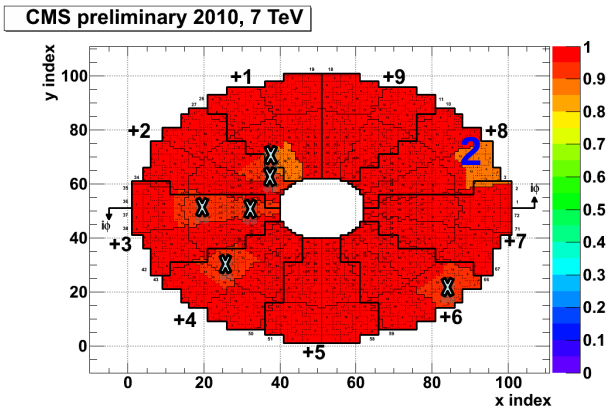
L1 EG5 geometrical efficiency on superclusters (E_T > 15 GeV)

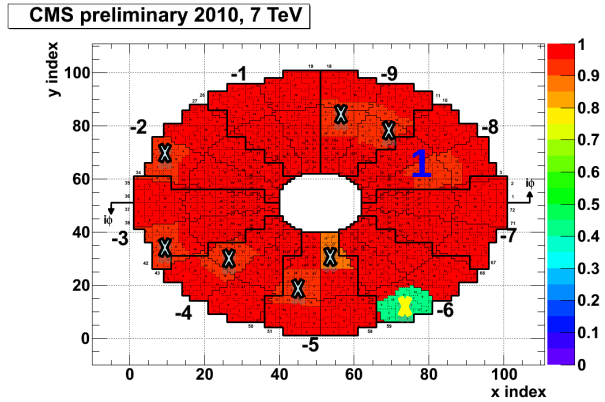
Efficiency by trigger region (1 region = 4x4 Trigger Towers)

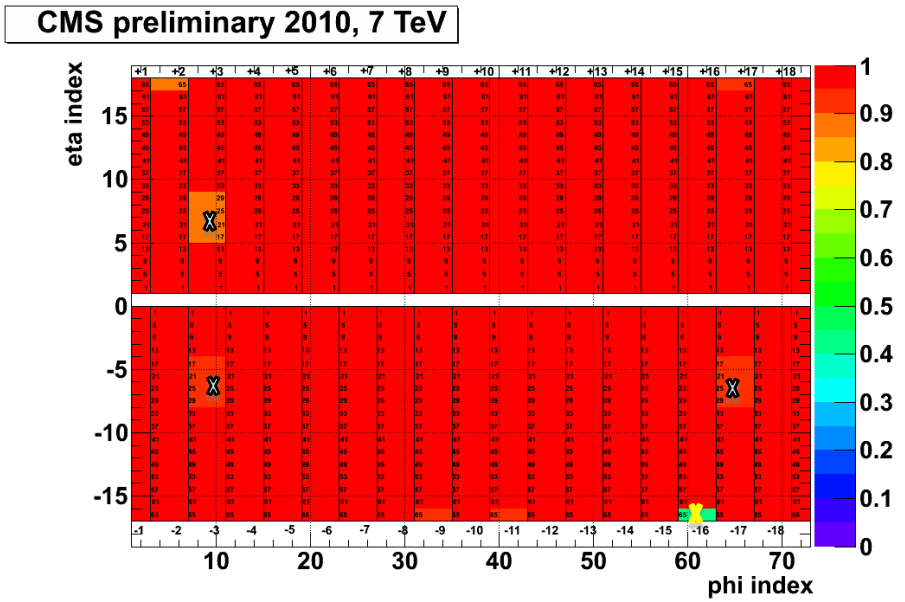
- Contact: Clémentine Broutin
  Clementine.Broutin@cern.ch

- Calorimeter geometry
  - 1 tower = 5x5 crystals
  - 1 region = 4x4 towers

- Inefficiencies :







Masks at ECAL level: 1+ towers masked
Masks at RCT level: half region

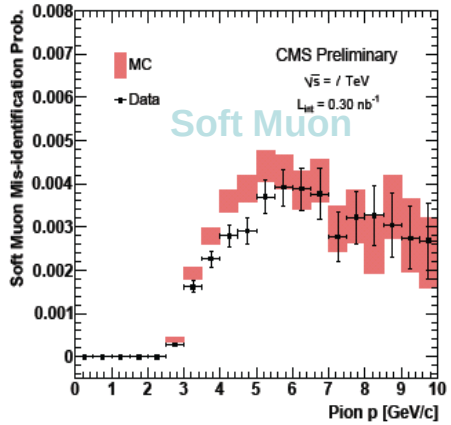
Remaining inefficient regions:
1. Blank tower for ECAL
2. ?

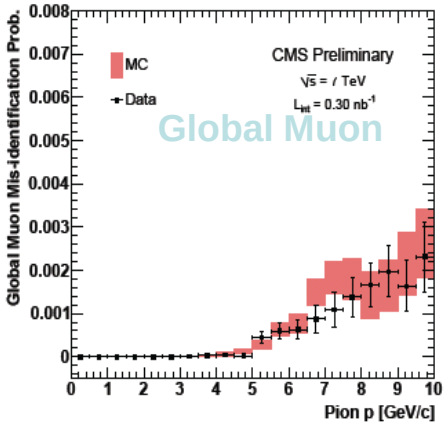
Rate vs momentum

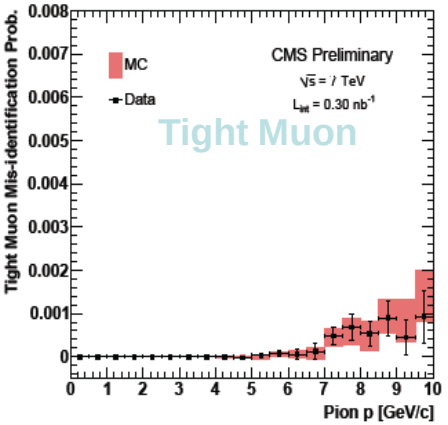
PIONS

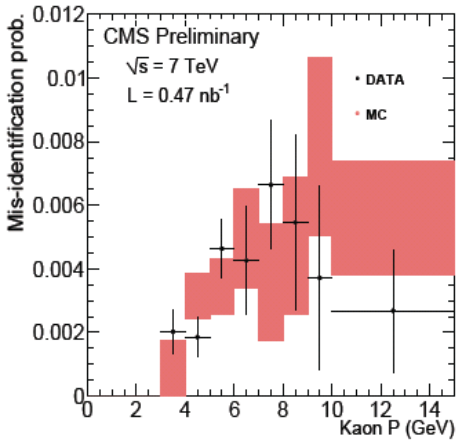
KAONS

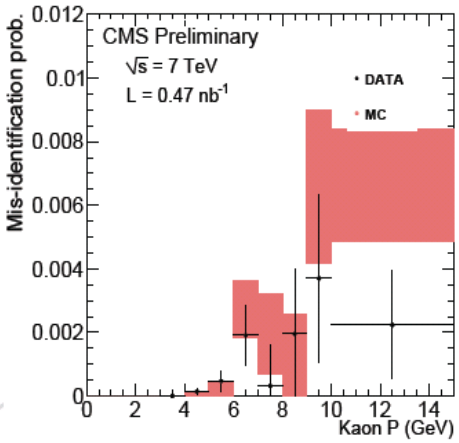
PROTONS

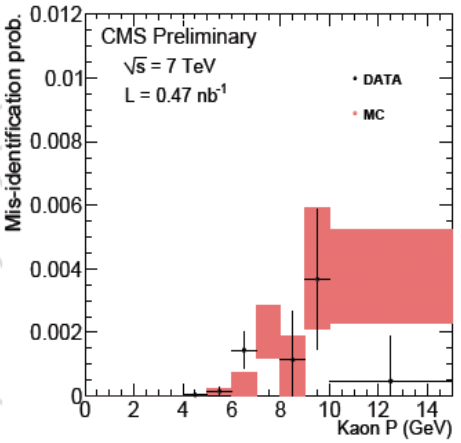


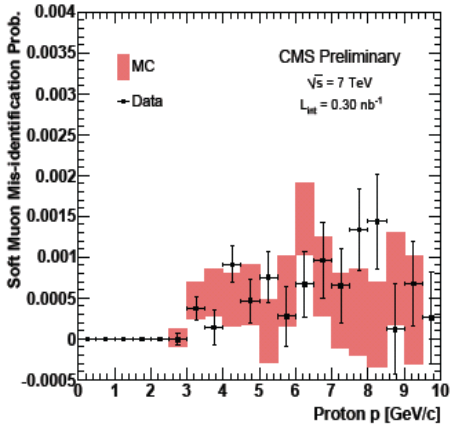


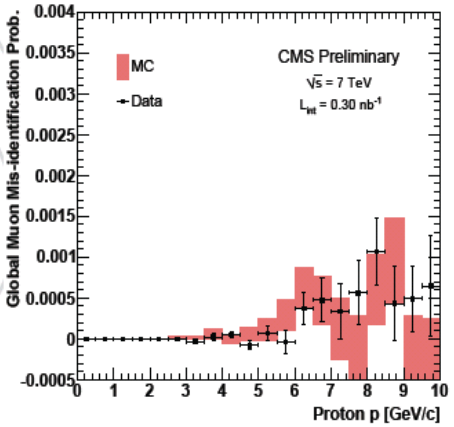


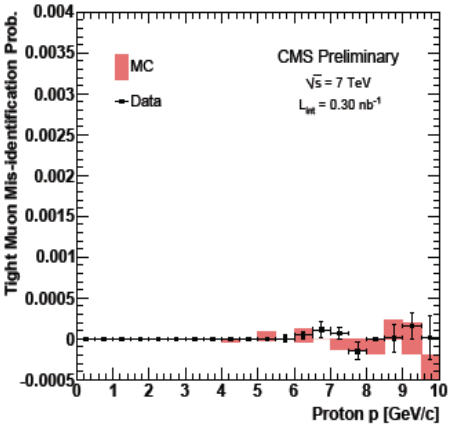










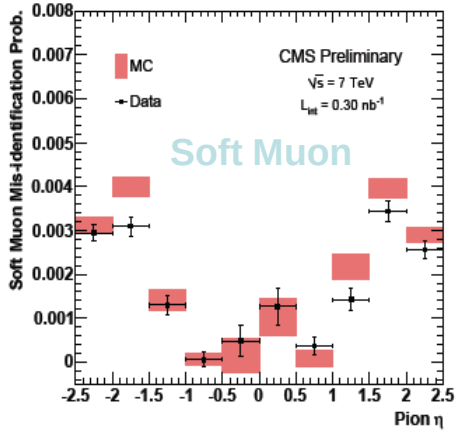


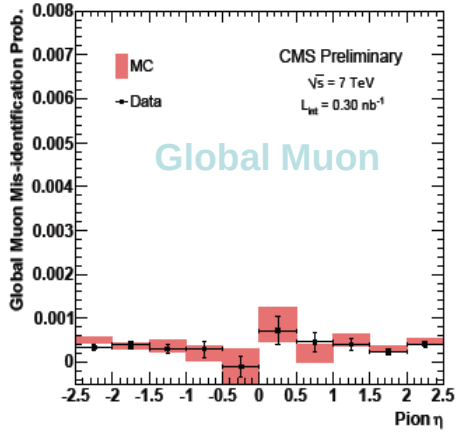
Rate vs η

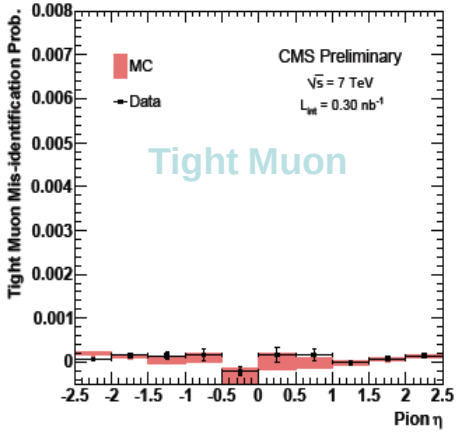
PIONS

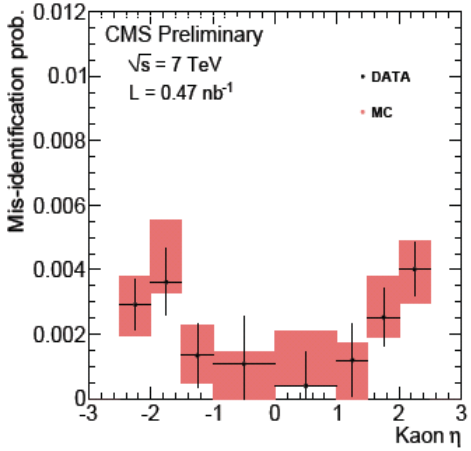
KAONS

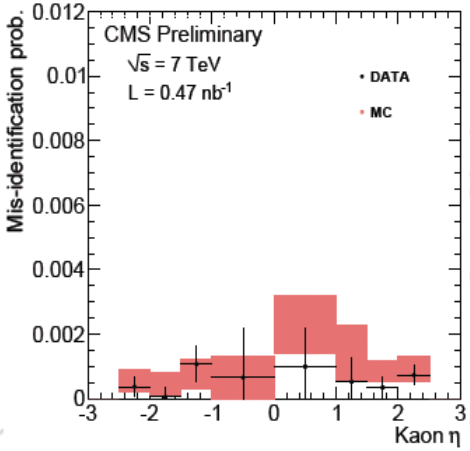
PROTONS

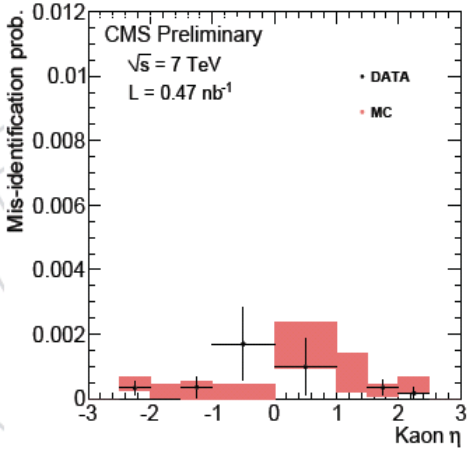


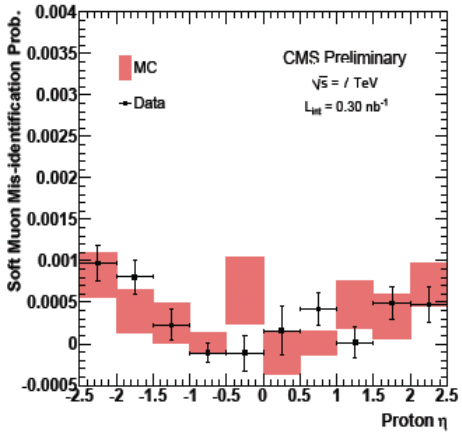


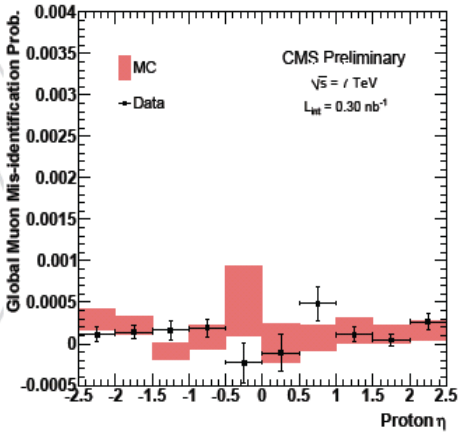


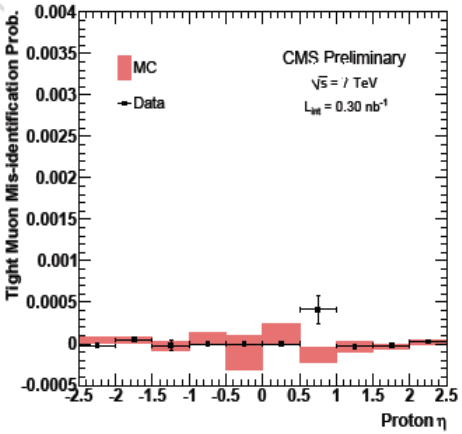




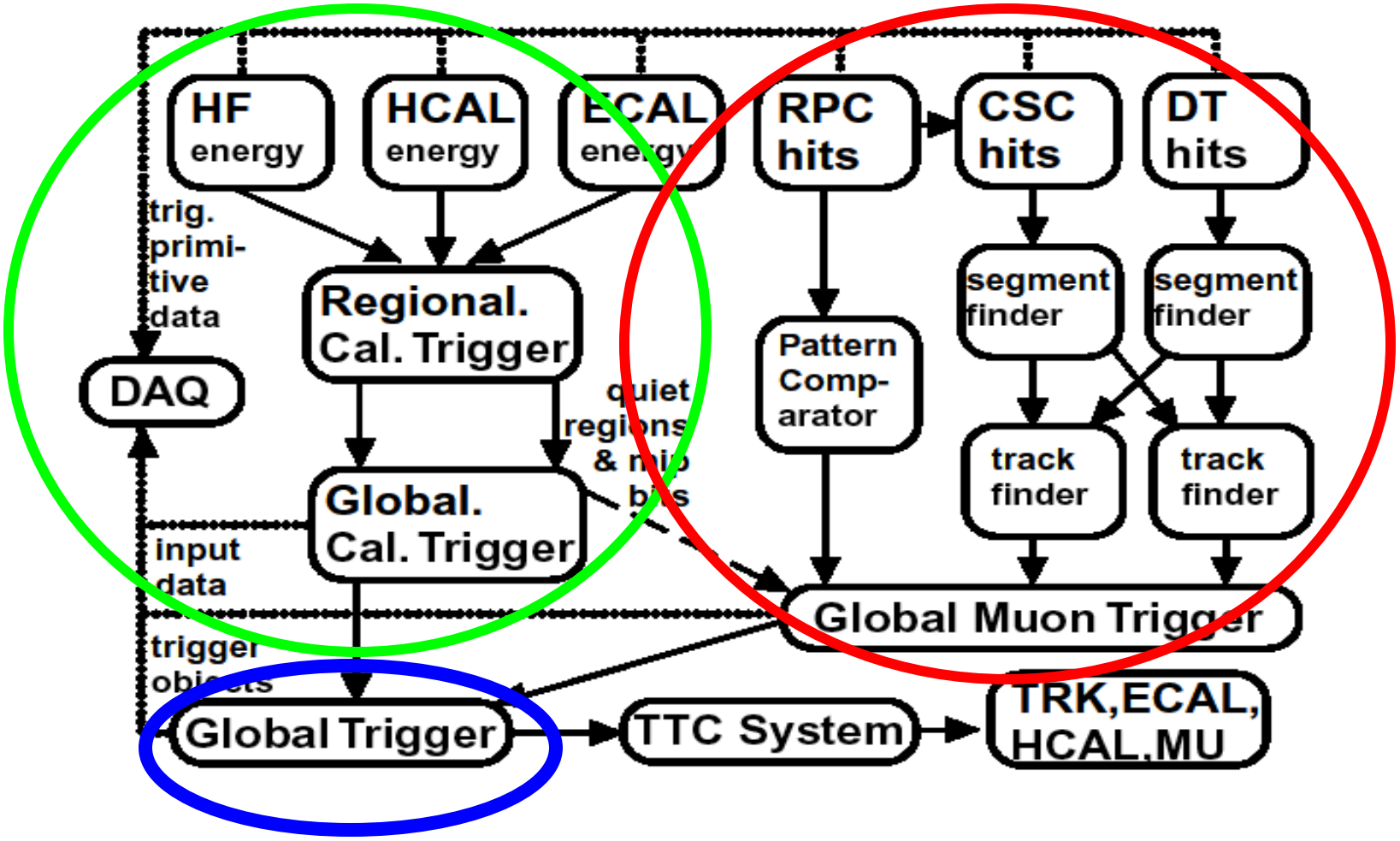




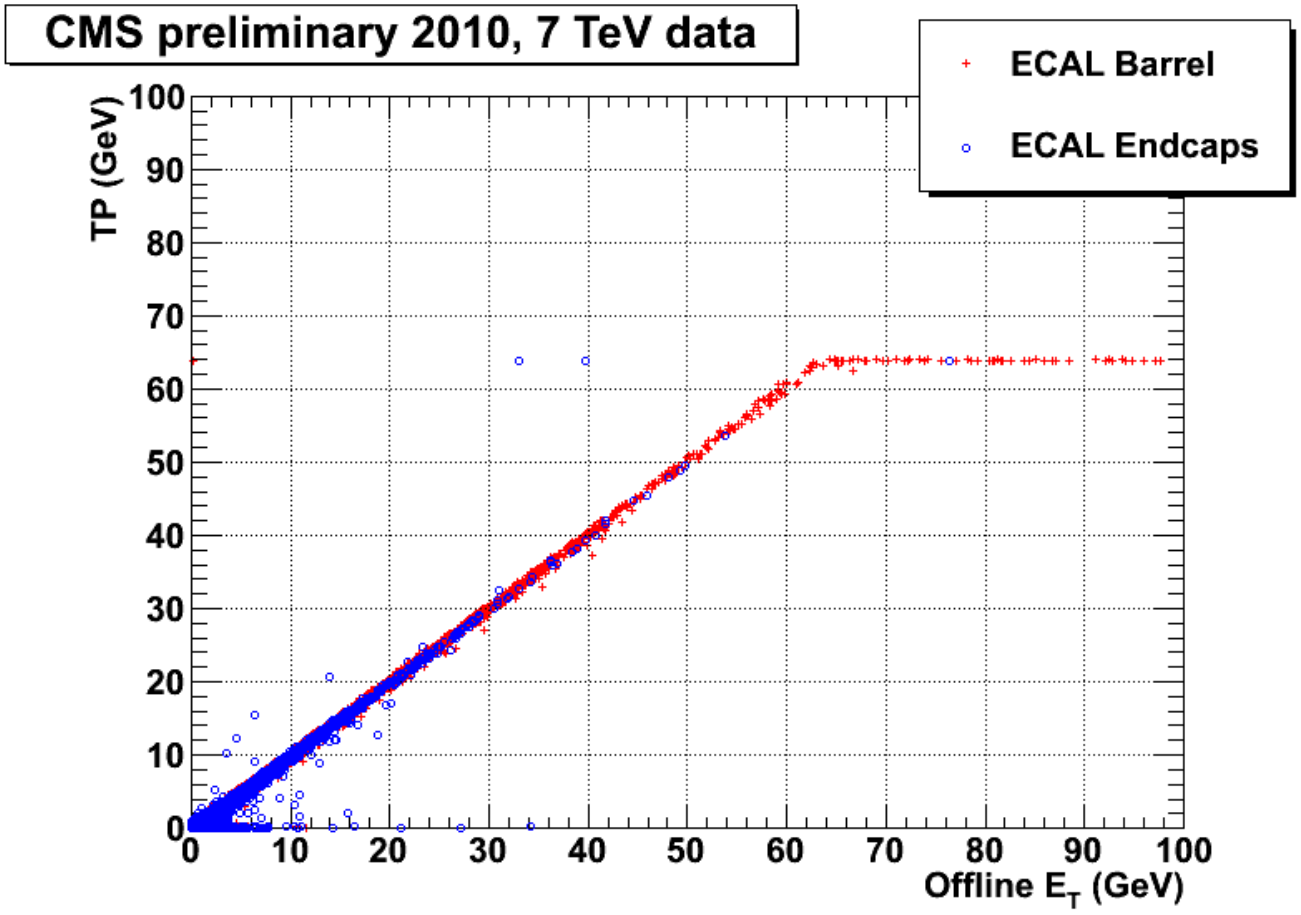




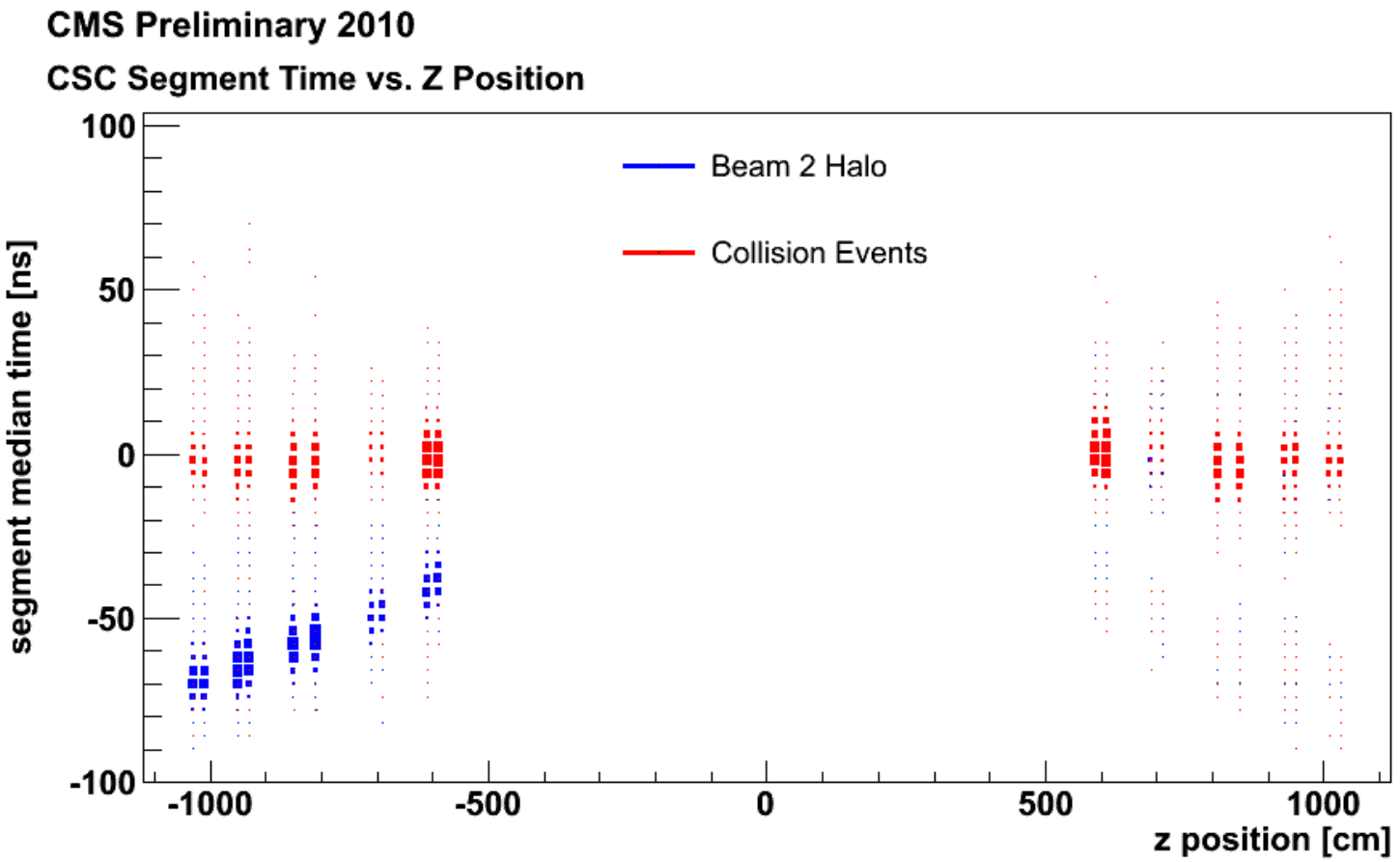
TRIGGER ARCHITECTURE



Ecal tp _ reco


CMS preliminary 2010, 7 TeV data
ECAL Barrel
ECAL Endcaps
TP (GeV)
Offline E_T (GeV)
0
10
20
30
40
50
60
70
80
90
100

DISTINGUISH BEAMHALO & COLLISIONS



TRIGGER FLOW

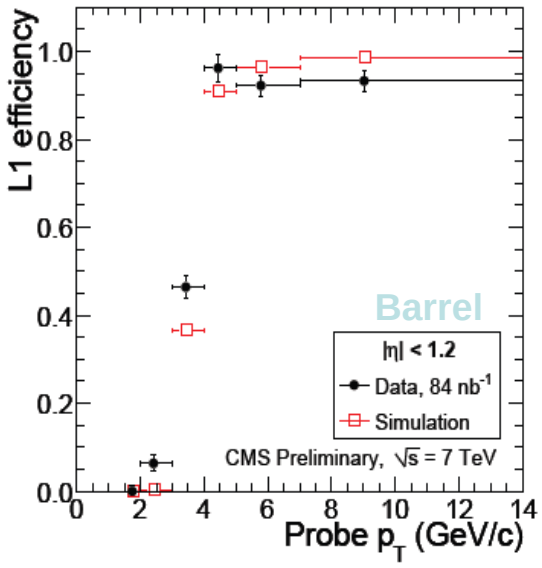
- L1 Trigger Control SYSTEM
- Control delivery of L1 accepts depends on status of detector read out systems and Dataacquisition system

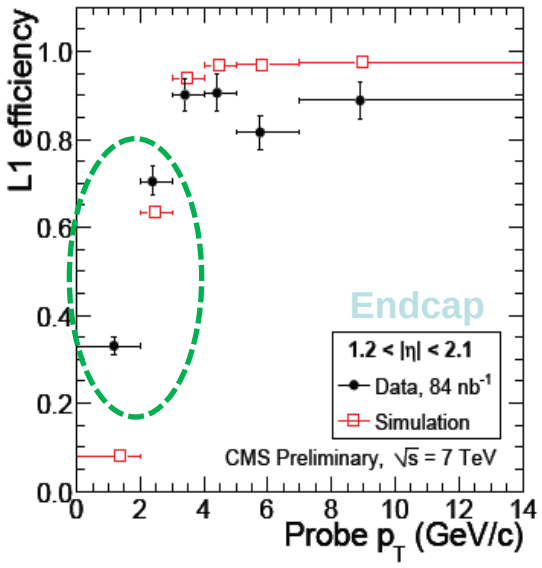
TCS partionioning :

- Trigger groups can work independently
- Trigger superviser setting up & controlling

Tag and Probe "absolute" trigger efficiencies

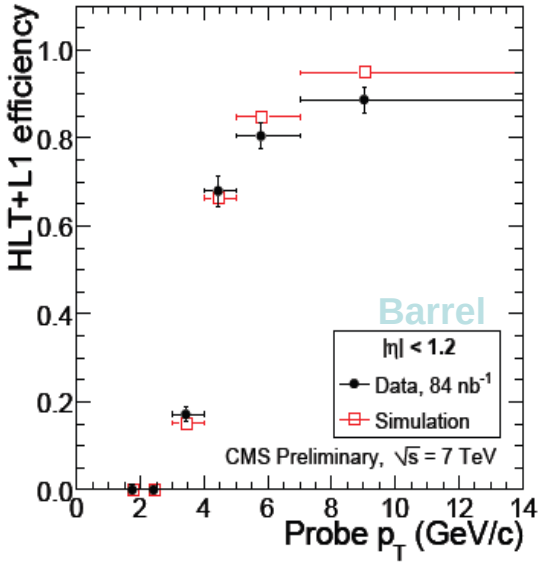
L1MuOpen

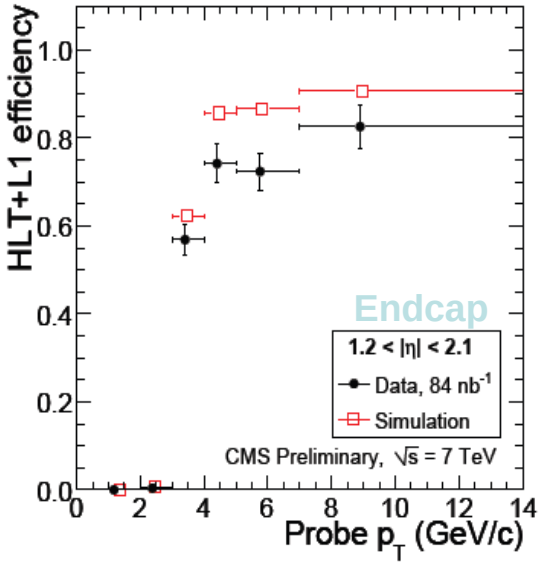




Plateau efficiency
~5% low in barrel
~10% low in endcap?

L1 + HLT_Mu3





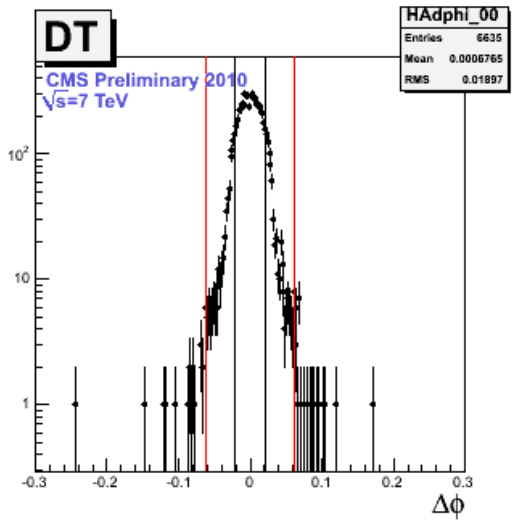
Difference at low pT expected, due to special start-up settings L1 CSC trigger (singles), not in included in the standard MC emulation

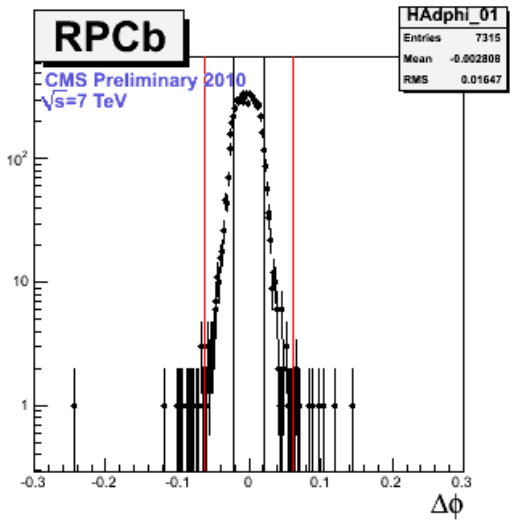
Muon Trigger spatial ϕ resolutions and GMT matching

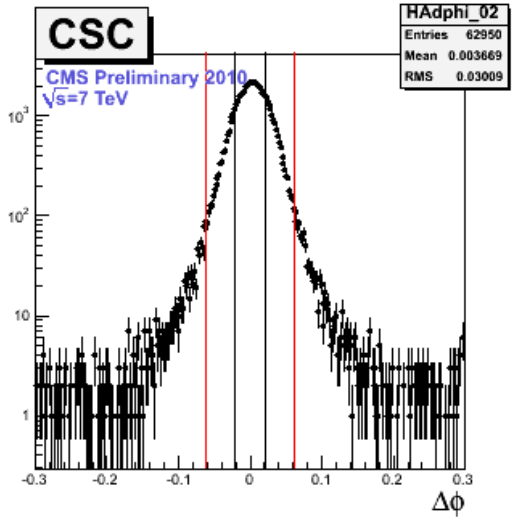
Comparison between the ϕ position of the subsystem's L1 candidate and ϕ extrapolated from the reconstructed muons.

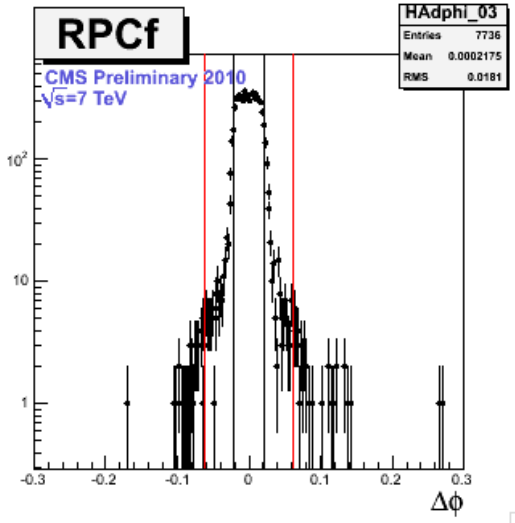
Black lines = 1 trigger bin
Red lines = GMT matching window

CSC tails in ϕ
- Found a bug in firmware, wrong ϕ assignment on low quality tracks
- Bug reproduced by emulator
- New firmware to be deployed ~ next week







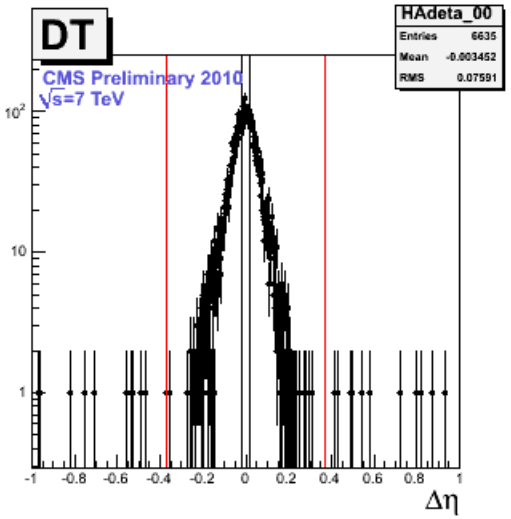


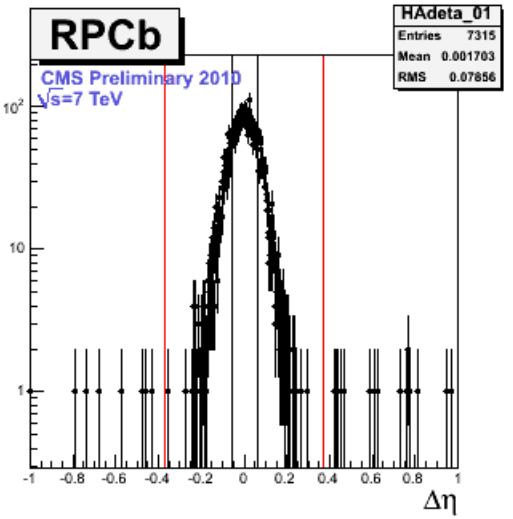
Muon Trigger η spatial resolutions and GMT matching

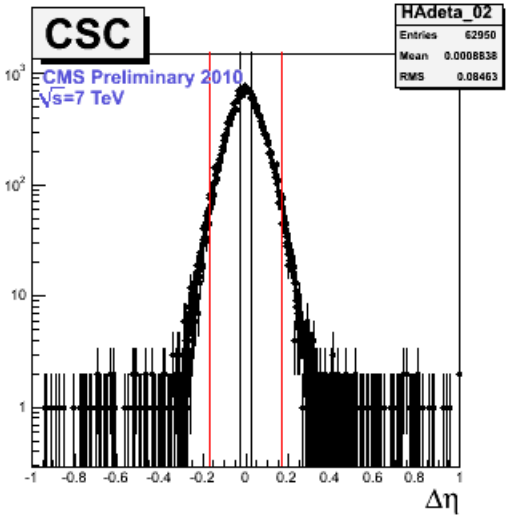
Comparison between the η position of the subsystem's L1 candidate and η extrapolated from the reconstructed muons.

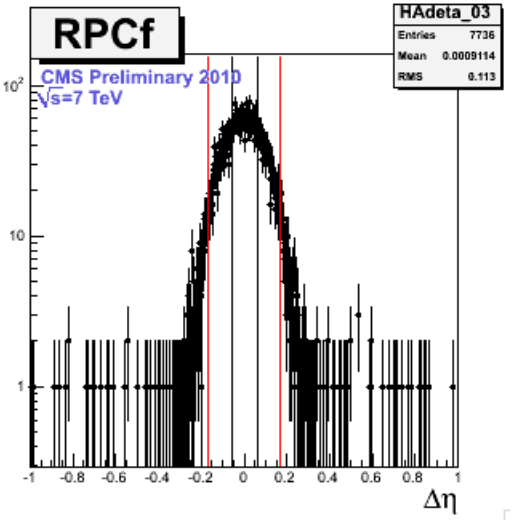
Black lines = 1 trigger bin
Red lines = GMT matching window

Large width in CSC, RPCf η distribution due intricacies of the L1 assignment vs simple reco extrapolation used
- In fact, CSC-RPCf matching in r is good, see next slide









TRIGGER ARCHITECTURE

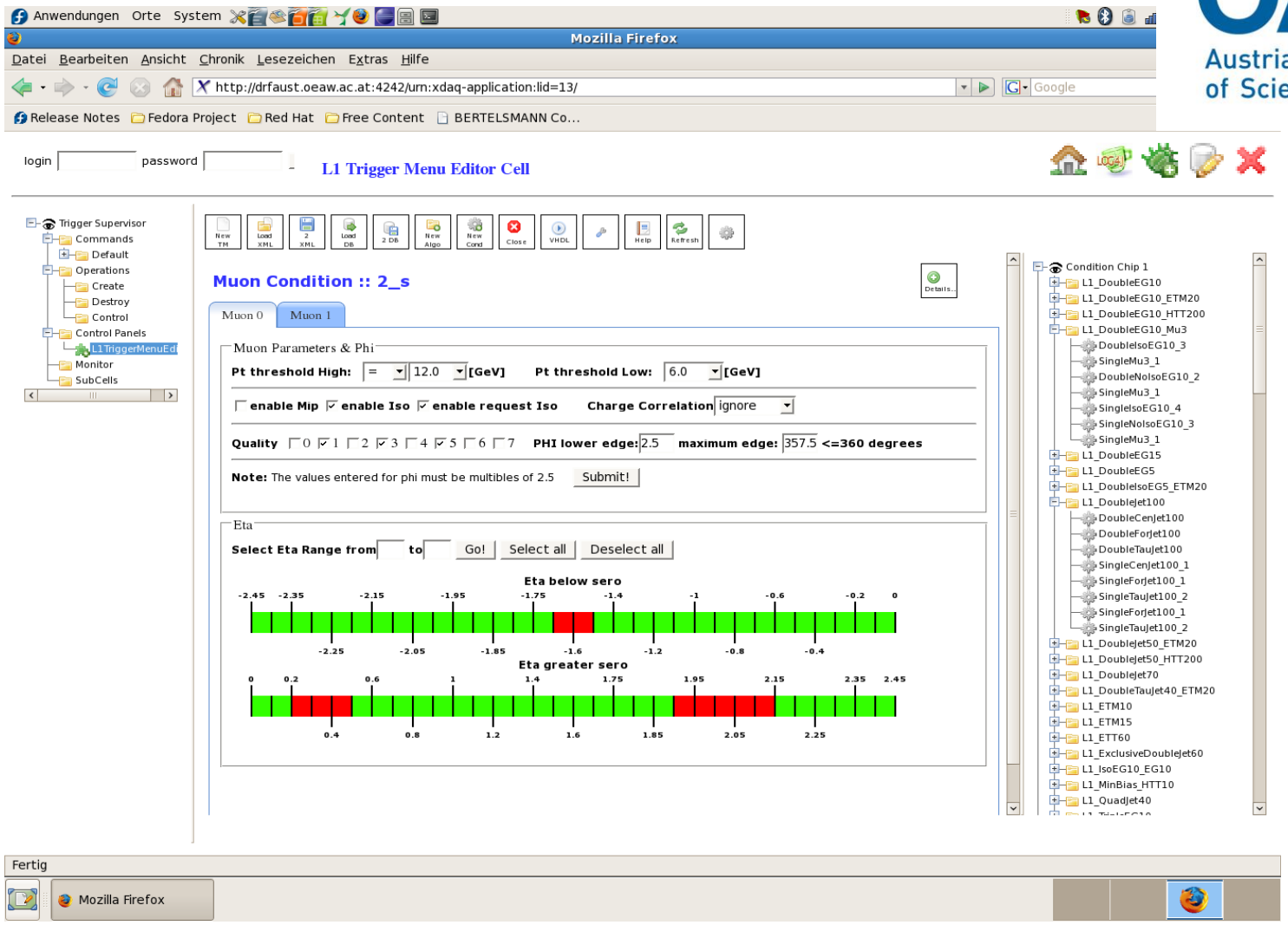
Muon Ecal HCAL HF form the TRIGGERSYSTEM

each component produces **Triggerprimitives** in local detectorpart
regional detectorparts -> **global** detector
→ barrel muon system has 12 sectors
each superlayer of a muon chamber gives candidates
each MUONSTATION = SECTOR gives at most 2 muon candidates
from 12 sectors -> select 4 muons
-> FWD muon system -> 4 muons
-> RPC muon system -> 4 muons
-> GLOBAL MUON TRIGGER
(programmable) combination -> 4 final (best) triggermuons

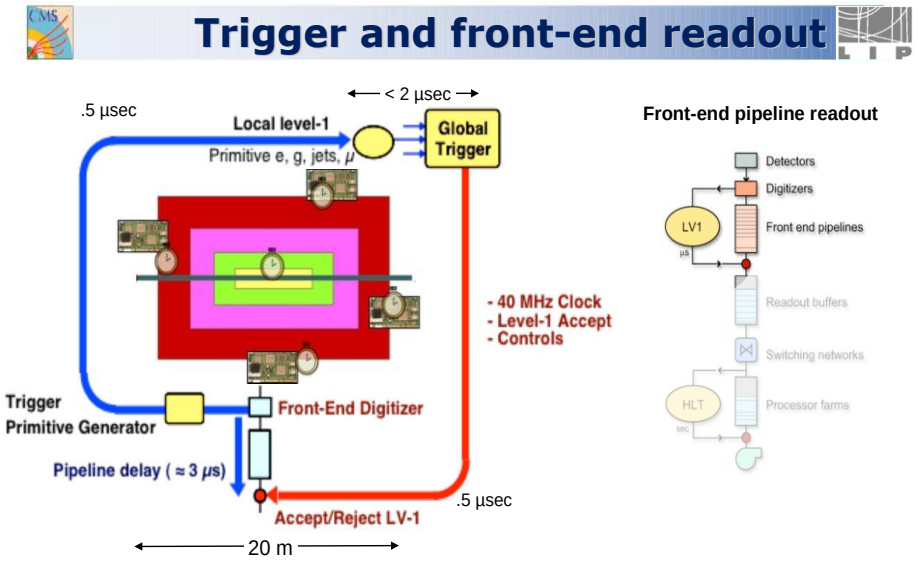
GLOBAL TRIGGER uses these Triggerobjects
synchronizes Muon & Calo & HF + …inputs

Electronics realizations are
ASICS Application specific integrated circuits
FPGA Field programmable gate arrays
steering Firmware (interestingly stable since years)
calculates Algorithm in the Hardware
used to load the algorithm, which are setup by GUI, in the Hardware

TRIGGER MENUS GUI



TRIGGER FLOW

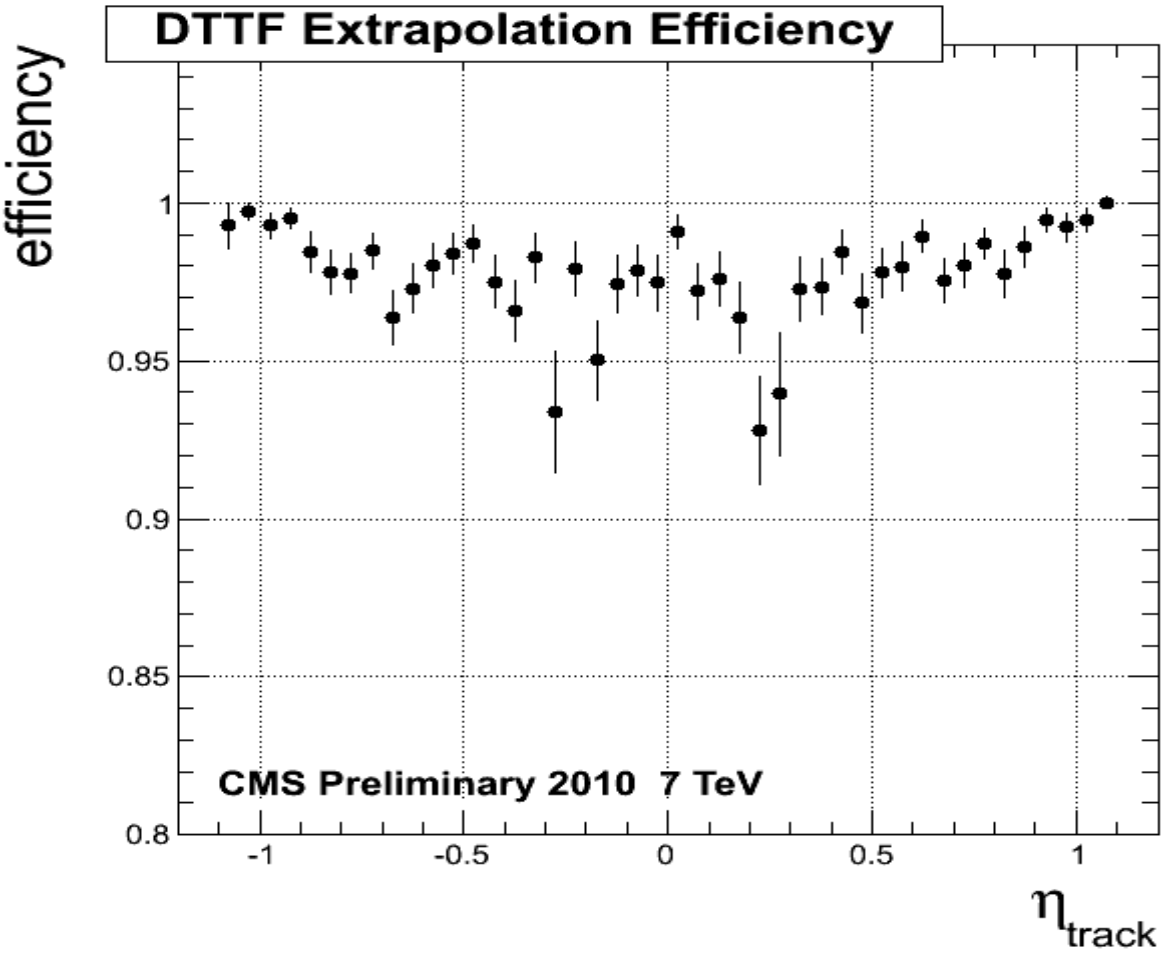


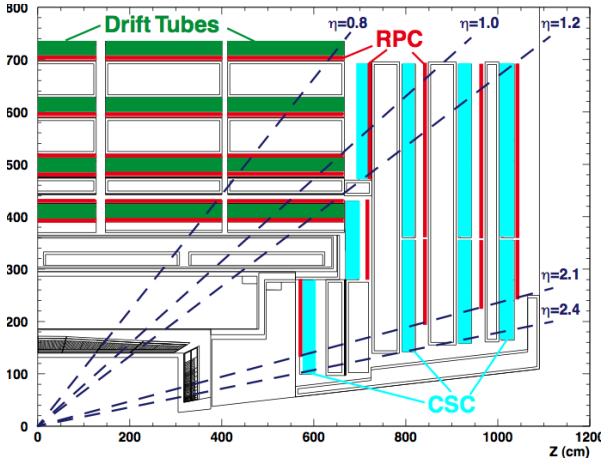
- 40 MHz digitizers and pipeline readout buffers (~ 3 µs)
- 40 MHz Level-1 trigger (massive parallel pipelined processors)
- High precision (~ 100ps) timing, trigger and control distribution

COSMIC RUN RATES

- L1_Single Mu Open just a muon candidate 300 Hz
- L1_Single EG1 E/g candidate Et > 1 GeV 23 Hz
- L1_SIngleJet10 single jet with Et > 10 GeV 140 Hz

DTTF Extrapolation Efficiency

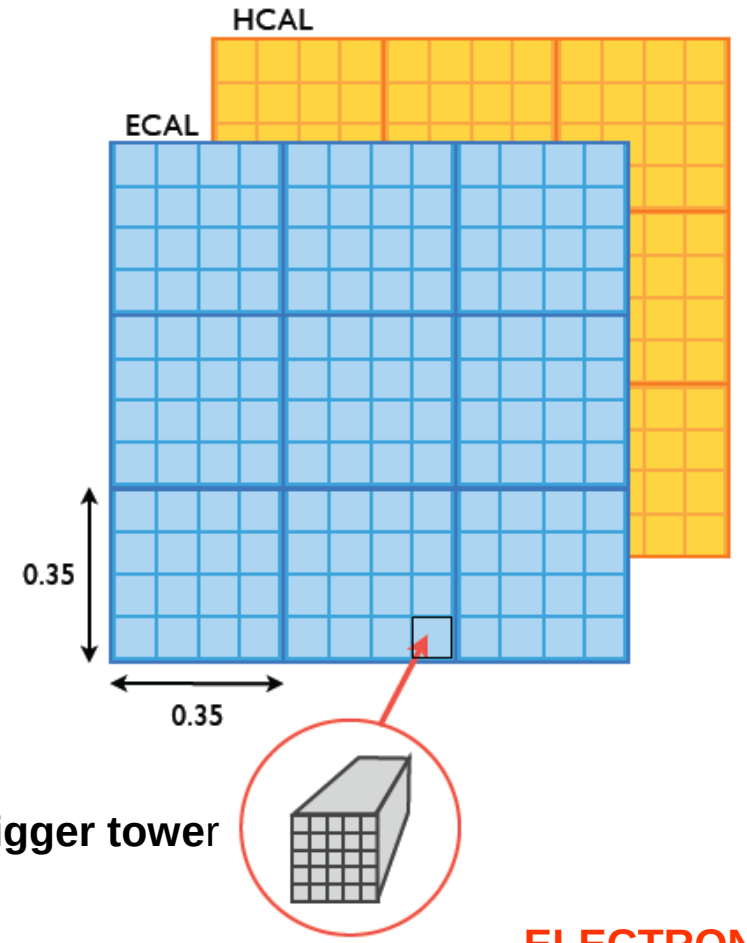




NOTE:
DTTF extrapolations were tuned using CRAFT superpointing muons. The “calibration point” was then set to an extrapolation efficiency of 95%

In the plot, the DTTF Extrapolation efficiency (DTTF efficiency wrt “triggerable events”) vs Eta is shown.
About the auxiliary picture: to explain the range in eta where the DTTF is efficient.
The DTTF receives Trigger Segments from the CSC trigger system to build trigger track candidates in the “overlap” region.
This connection was commissioned with early data, in particular the relative synchronization between DT and CSC was tun
Without good CSC->DT stub exchange, the DTTF efficiency drop would start at η ~0.8

JET - TAU –ELECTRON TRIGGER



E_t

- Sliding window
  - 12x12 ECAL+HCAL trigger towers
  - Slides by 4x4 steps
  - Central 4x4 Et sum > neighbours
  - -5 < eta < 5
- Tau classification (-3 < eta < 3)
  - "Tau veto" bit for each 4x4
  - Veto if energy is outside tau pattern
  - Tau jet requires all 9 vetoes off
- Tau patterns :

ELECTRON finding in substrips of ECAL Towers

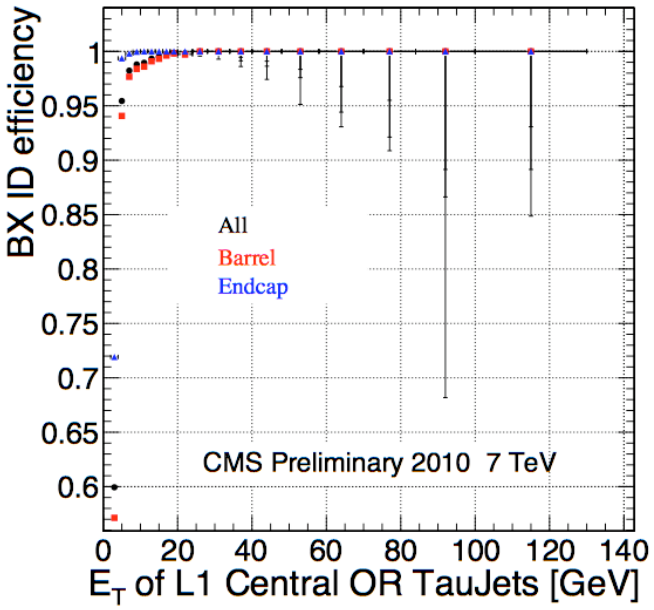
JET FINDING search in 3*3 TRIGGER REGIONS = 4x4 trigger towers

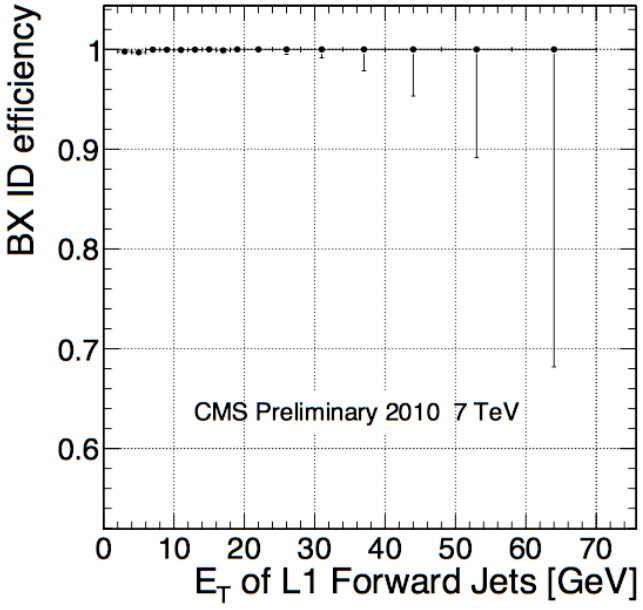
SYNCHRONISATION

- The detector signals have to be synchronized to the correct bx – and time differences corrected by delays

  “pre/post firing” - harm consecutive triggers
- how big can the time window be ?
- should be stable in time

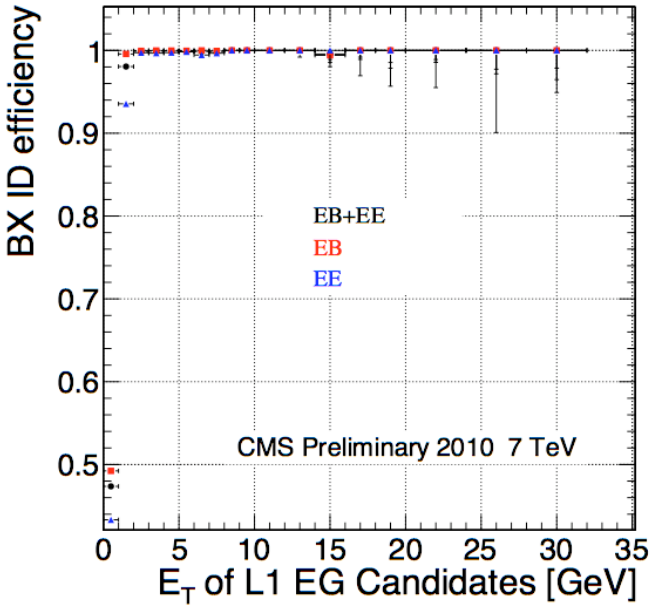
L1 BX ID Efficiency - Jets & E/Gamma





Anomolous signals from ECAL, HF removed

Noise pollutes BX ID efficiency at low Et values



- Sample of min bias events
  - Triggered by BSC coincidence, with good vertex and no scraping
- **Fraction of candidates that are in time with bunch-crossing (BPTX) trigger**
  - **Plotted as function of L1 assigned E_t**
  - **Denominator is N L1 candidates within +/-2 BX of BPTX trigge**

L1 EG efficiency for electrons

For **L1 Electron 5 GEV Threshold**
L1 Electron 8 GEV Threshold

- **EG trigger efficiency for electrons from conversion electrons**
- Two η ranges shown:
  - **Barrel, endcaps**