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The CMS Muon Trigger

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for the CMS collaboration

Outline

- Introduction
- The Compact Muon Solenoid detector
- The CMS Muon system
- Trigger and Data Acquisition system
- Level-1 Muon Trigger
- High Level Trigger strategy
- Summary

Introduction

Interactions/s:

- Lum = 10^{34} $cm^{-2}s^{-1}$ = 10^{7} mb^{-1} Hz
- $\sigma_{inel}(pp)$ = 70 mb
- Interaction Rate, R = 7×10^{8} Hz

Events/ beam crossing:

- Δt = 25 ns = 2.5×10^{-8} s
- Interactions/crossing = 17.5

Not all proton bunches are full:

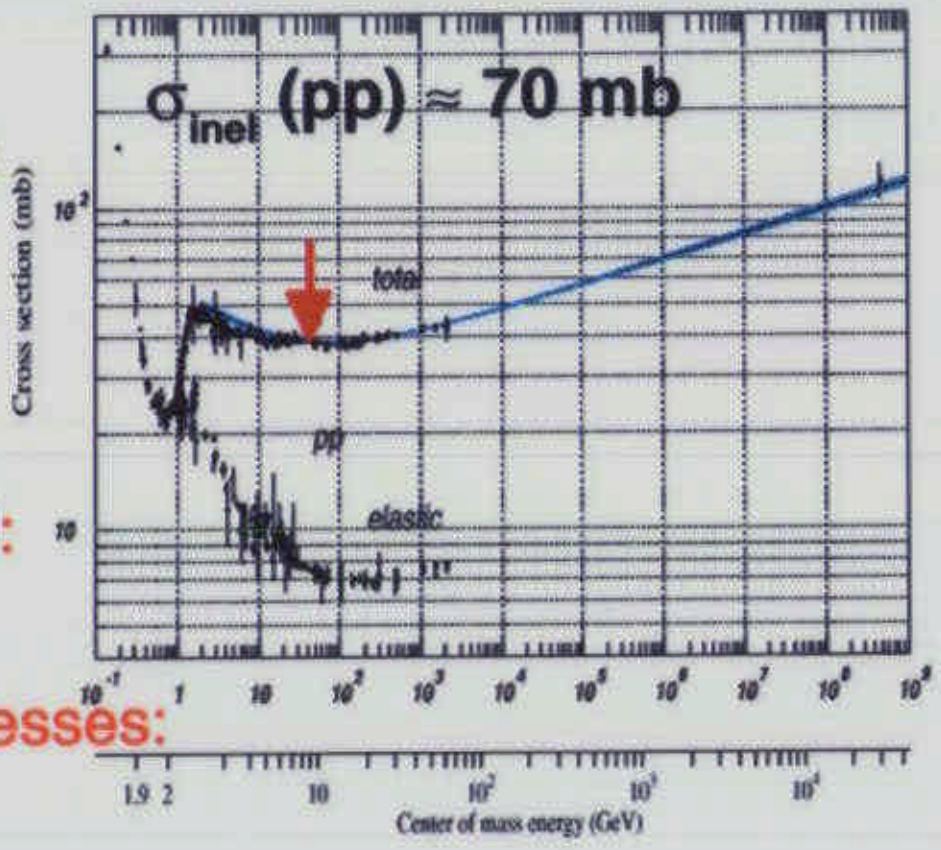
- (2835/3564)
- Events/"active" crossing = 23

Cross-section of physics processes:

- inelastic: 10^{9} Hz
- $W \rightarrow l\,\nu$: 10^{2} Hz
- $t\bar{t}$ production: 10 Hz
- Higgs (600 GeV) : 10^{-2} Hz

Selection needed: $1:10^{10\text{-}11}$

- before branching fractions...



LHC Challenges

- Number of channels ≈ $O(10^7)$
  → need huge number of connections
- ~20 interactions every 25 ns
  → need information superhighway
- Calorimeter information should correspond to tracker info
  → need to synchronize detector elements to 25 ns
- In some cases: Detector signal > 25 ns
  → integrate more than one bunch crossing's worth of information
- In some cases: Time Of Flight > 25 ns
  → need to identify bunch crossing...
- Can store data at ≈100 Hz
  → need to reject most interactions
- It's On-Line (cannot go back and recover events)
  → need to monitor selection

The CMS Detector

SUPERCONDUCTING COIL

CALORIMETERS

ECAL Scintillating $PbWO_4$ Crystals

HCAL Plastic scintillator copper sandwich

IRON YOKE

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

TRACKERs

Silicon Microstrips
Pixels

MUON BARREL

Drift Tube Chambers (DT)

Resistive Plate Chambers (RPC)

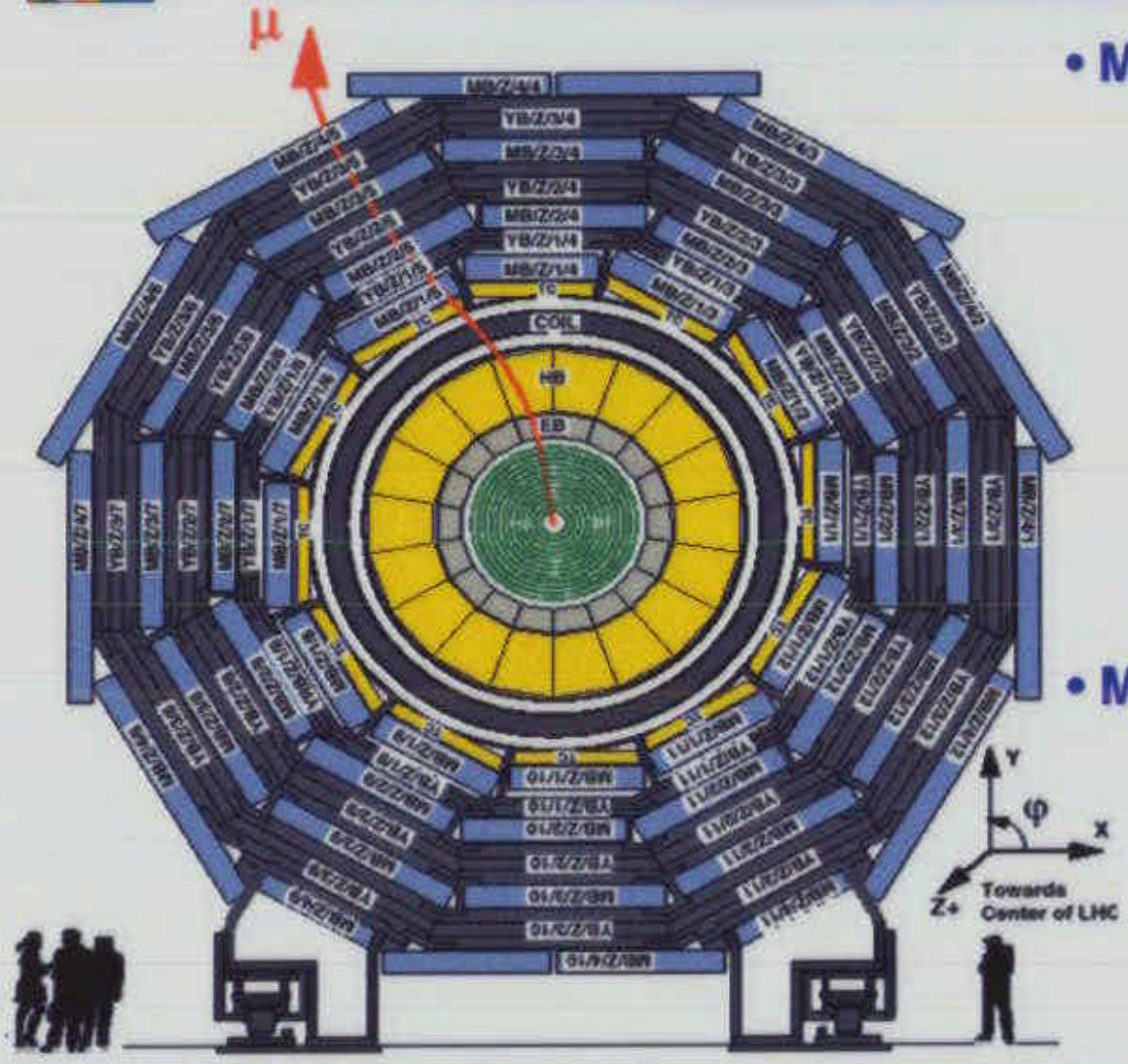
MUON ENDCAPS

wires

strips

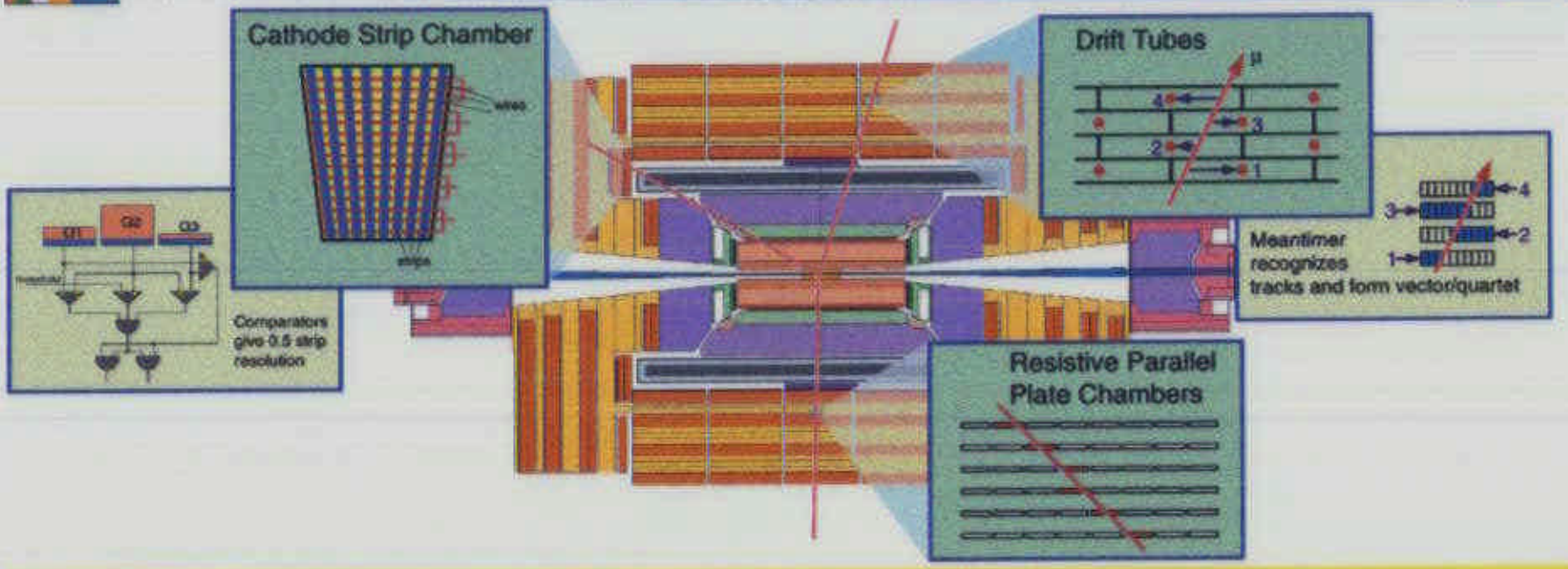
Cathode Strip Chambers (CSC)
Resistive Plate Chambers (RPC)

Muon System



- **Muon Barrel**
  - Four layers of Drift Tube chambers with Bunch crossing identification capability (DTBX)
  - Resistive Plate Chambers to detect muon hits for triggering purpose (RPC)
- **Muon Endcap**
  - Cathode Strip Chambers (CSC) up to $|\eta| < 2.4$
  - Resistive Plate Chambers (RPC) up to $|\eta| < 2.1$

Muon Detectors



Three types of gaseous particle detectors for muon identification:

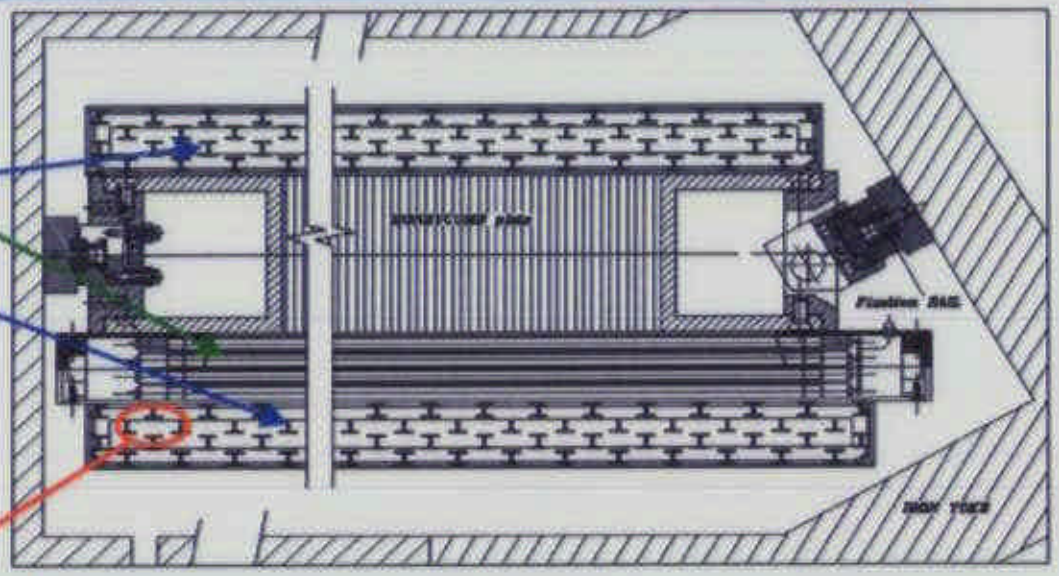
- Drift Tubes (DT) in the central barrel region
- Cathode Strip Chambers (CSC) in the endcap region
- Resistive Plate Chambers (RPC) in both the barrel and endcaps

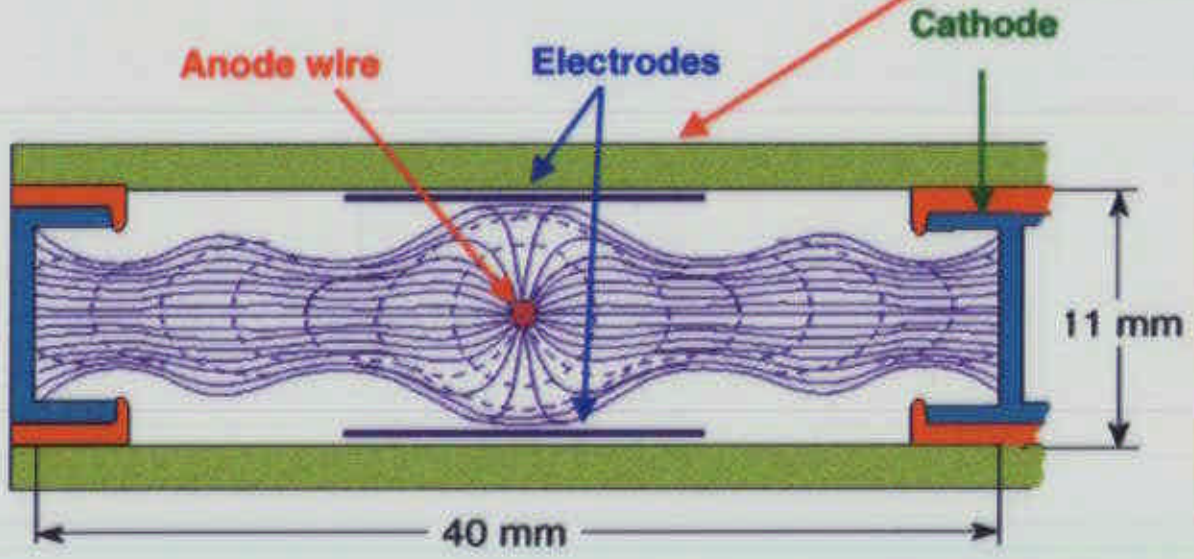
The DT and CSC detectors are used to obtain a precise measurement of the position and thus the momentum of the muons, whereas the RPC chambers are dedicated to providing fast information for the Level-1 trigger

Muon DT Chambers

Each DT Chamber comprises
4 layers of DT cells in r-φ, 4 in r-z and
further 4 in r-φ

(No r-z layer in the fourth station)

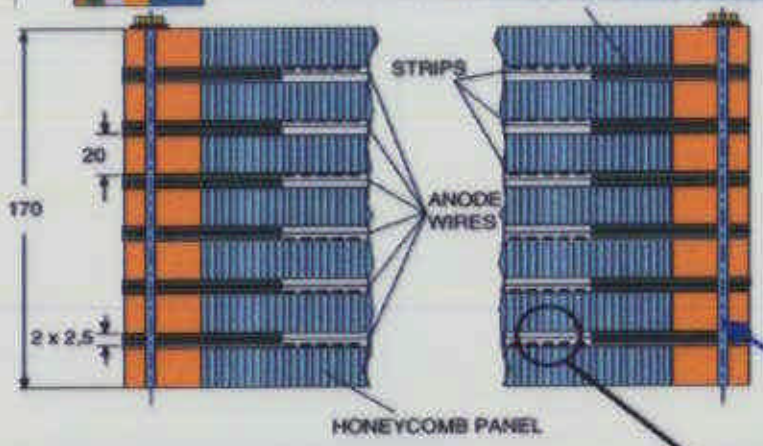




Nominal Operating Parameters

• Nominal Mixture	Ar - CO_2 (85% -15%)
• Nominal voltages	strips at 1800V, wires at 3600, I-Beams at -1800V
•Gain (nominal)	9.10^4
•Typical charge	1pC

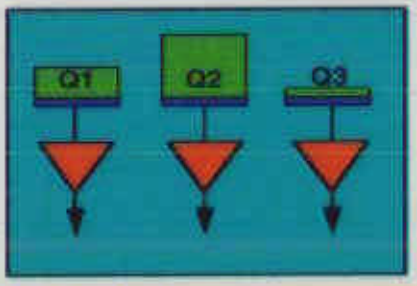
Muon Endcap Stations

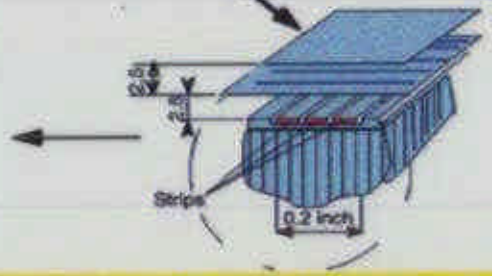


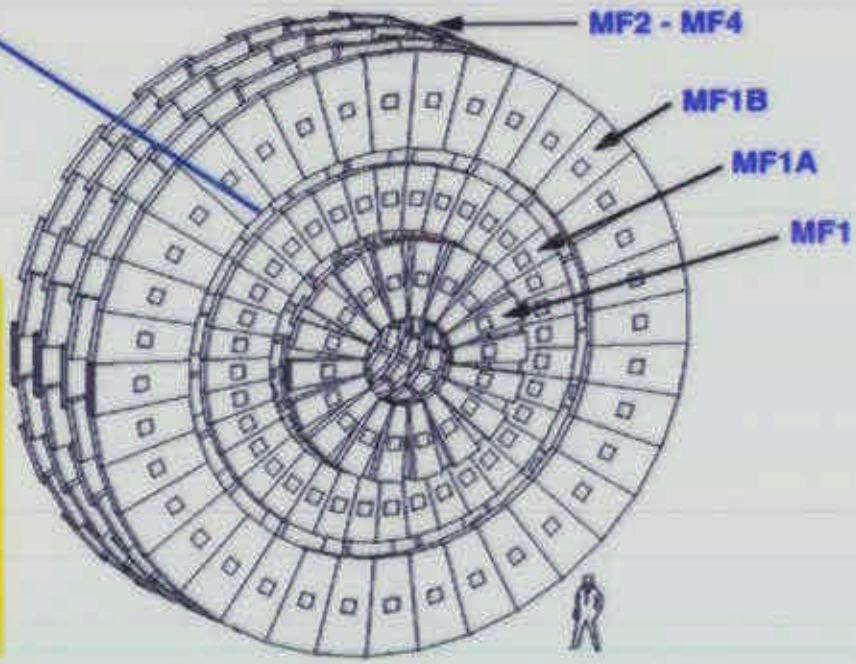
4 Endcap Stations each comprising

6 layers of CSCs with strip and anode wire readout

- Coordinate in bending plane is precisely measured by interpolation of induced charge on strips (σ=63.4 μm)
- Nominal mixture: Ar -CO_2 -CF_4 (30% 50%20%)





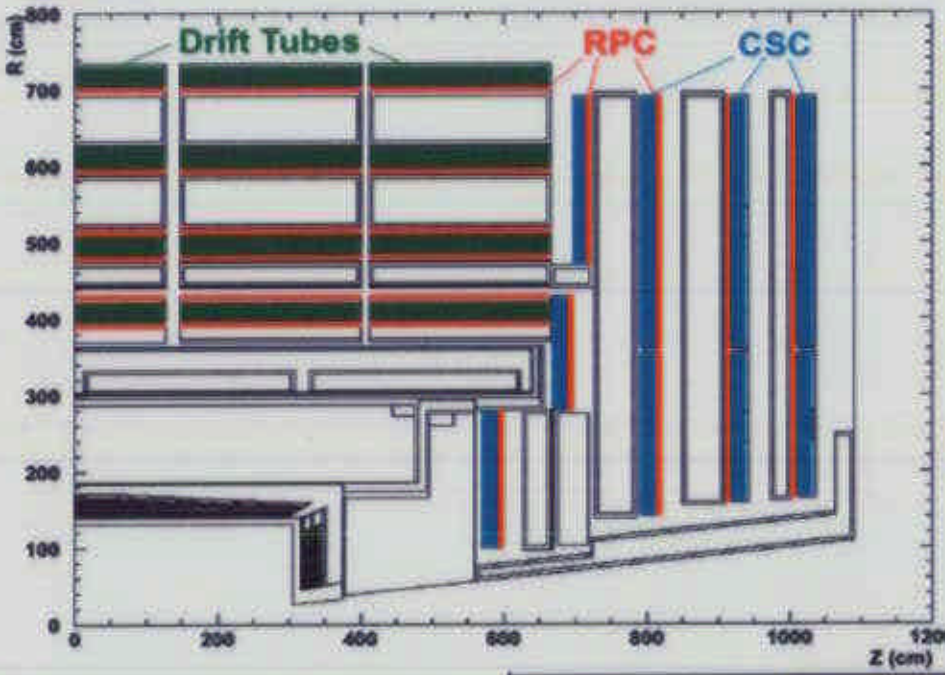


CSC stations are arranged in 4 disks of chambers

Inner rings have 18 CSCs each covering 20°. Outer rings have 36 CSCs covering 10° each

Position of the stations is optimized for best momentum resolution

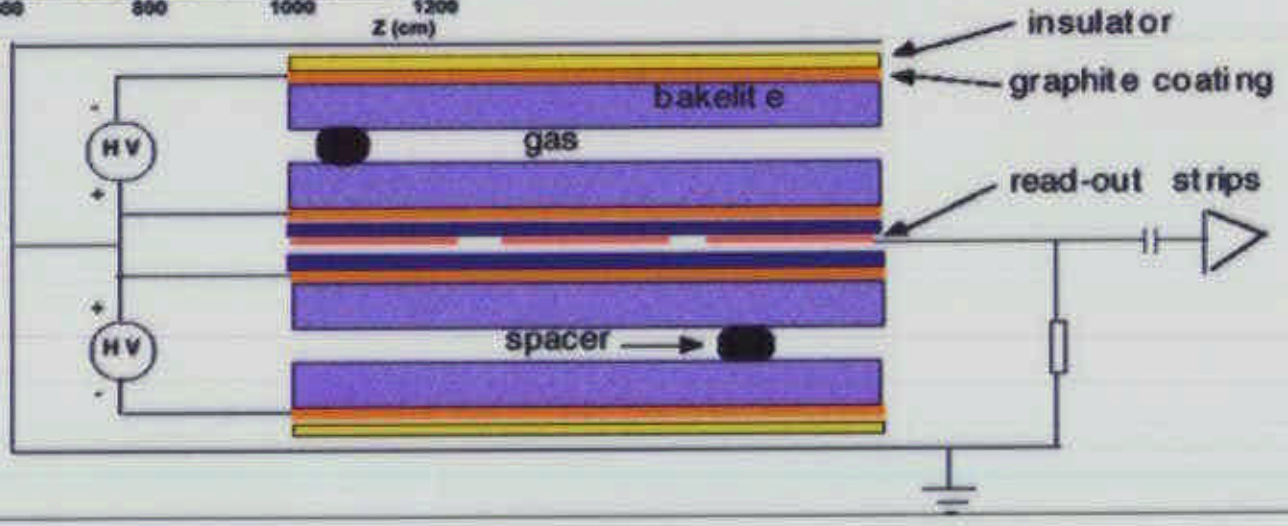
Resistive Plate Chambers



Dedicated trigger detector, with
fast timing response

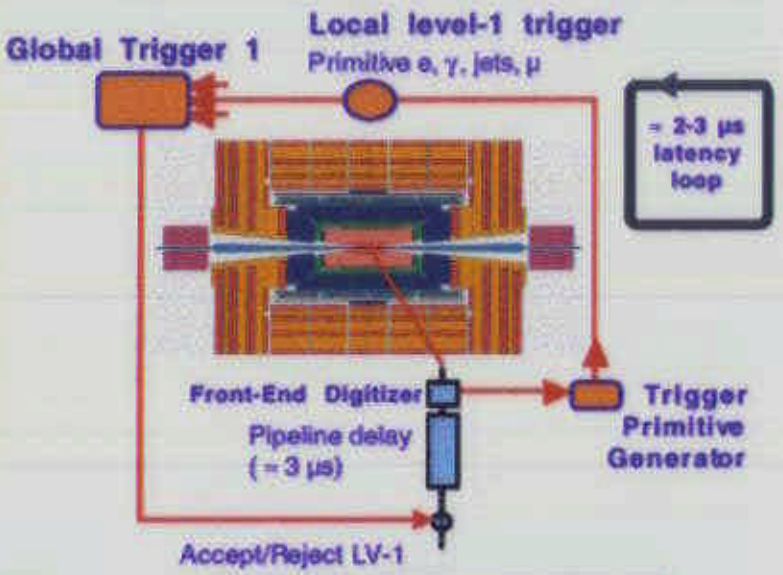
Basic functions:

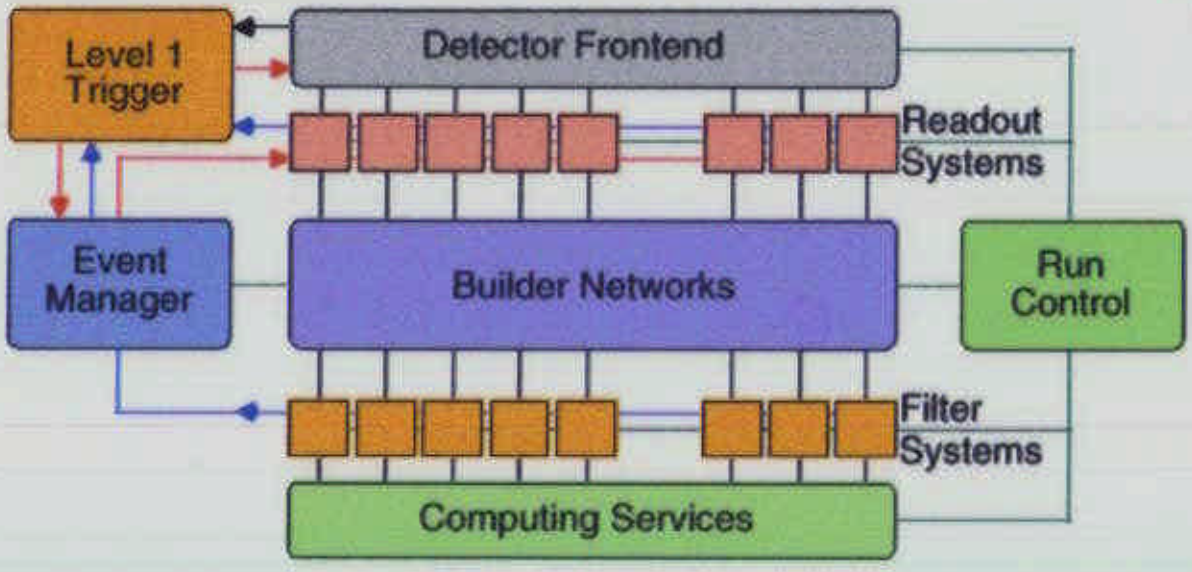
- identify candidate muon track
- assignment of bunch crossing to the candidate track(s)
- estimate their transverse momenta

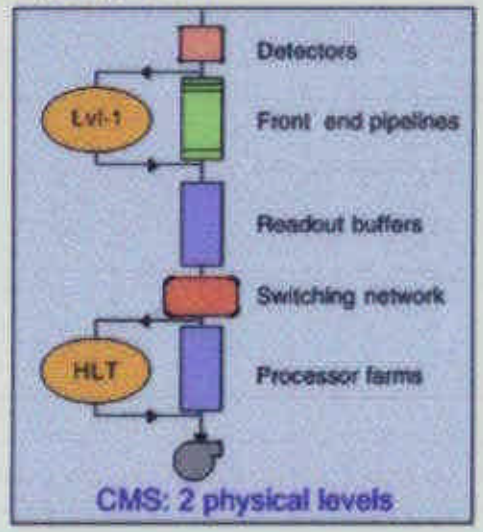


Trigger & DAQ

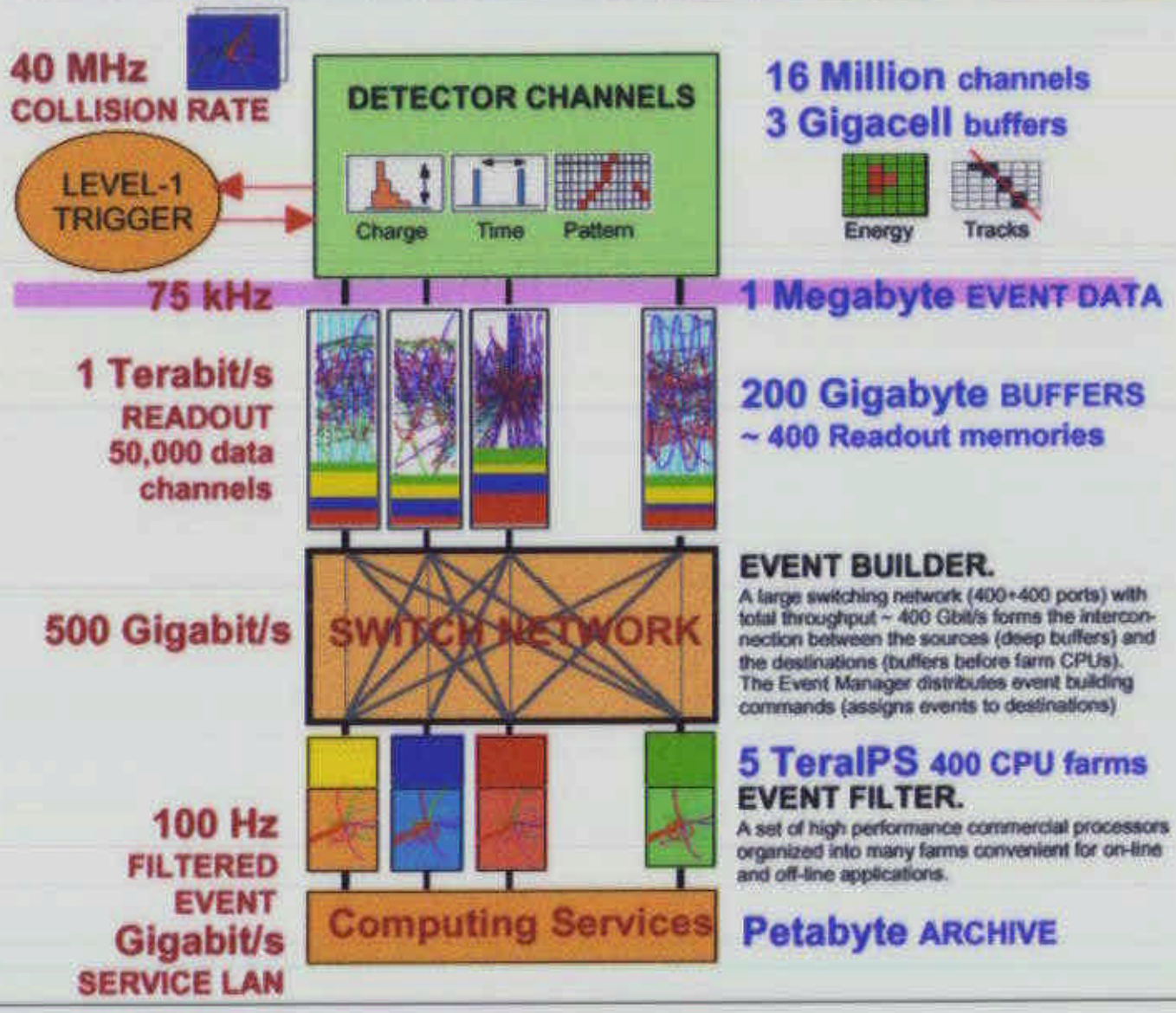
Collision rate	40 MHz
Level-1 Maximum Trigger rate	75 kHz
Average event size	~ 1 Mbyte
No. of In-Out Units (200-5000 Byte/event)	1000
Event Builder (512-512 switch) bandwidth	~ 500 Gbit/s
Event filter computing power	~ 5 10^8 MIPS
Data production	~ Tbyte/day
No. of readout crates	~ 300
No. of electronics boards	~ 10000







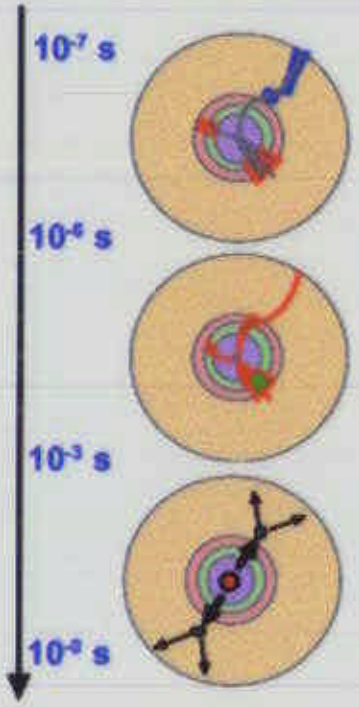
Data Acquisition



Trigger

Must reduce 1 GHz of input interactions to 100 Hz

Do it in steps/ successive approximations: *multi-level trigger*



Collision rate 10^9 Hz
Channel data sampling at 40 MHz

Level-1 selected events 10^5 Hz
Particle identification (High p, e, μ, jets, missing E_T)
- Local pattern recognition
- Energy evaluation on prompt macro-granular information

Level-2 selected events 10^3 Hz
Clean particle signature (Z, W, ..)
- Finer granularity precise measurement
- Kinematics, effective mass cuts and event topology
- Track reconstruction and detector matching

Level-3 events to tape 10..100 Hz
Physics process identification
- Event reconstruction and analysis

L1 :

- only calorimeter & muon information
- special-purpose hardware for trigger processors (ASICs, FPGAs, etc)
- must work dead time free
- processing logic: 25 ns pipelined system
- ~500 ns latency
- output rate : 75 kHz

L2 :

- only calorimeter & muon information
- no tracker data yet
- finer granularity, precise measurement
- detector matching
- hardware: processor farm
- output rate: <10 kHz

Level-1 Muon Trigger

Task of the L1 Muon Trigger:

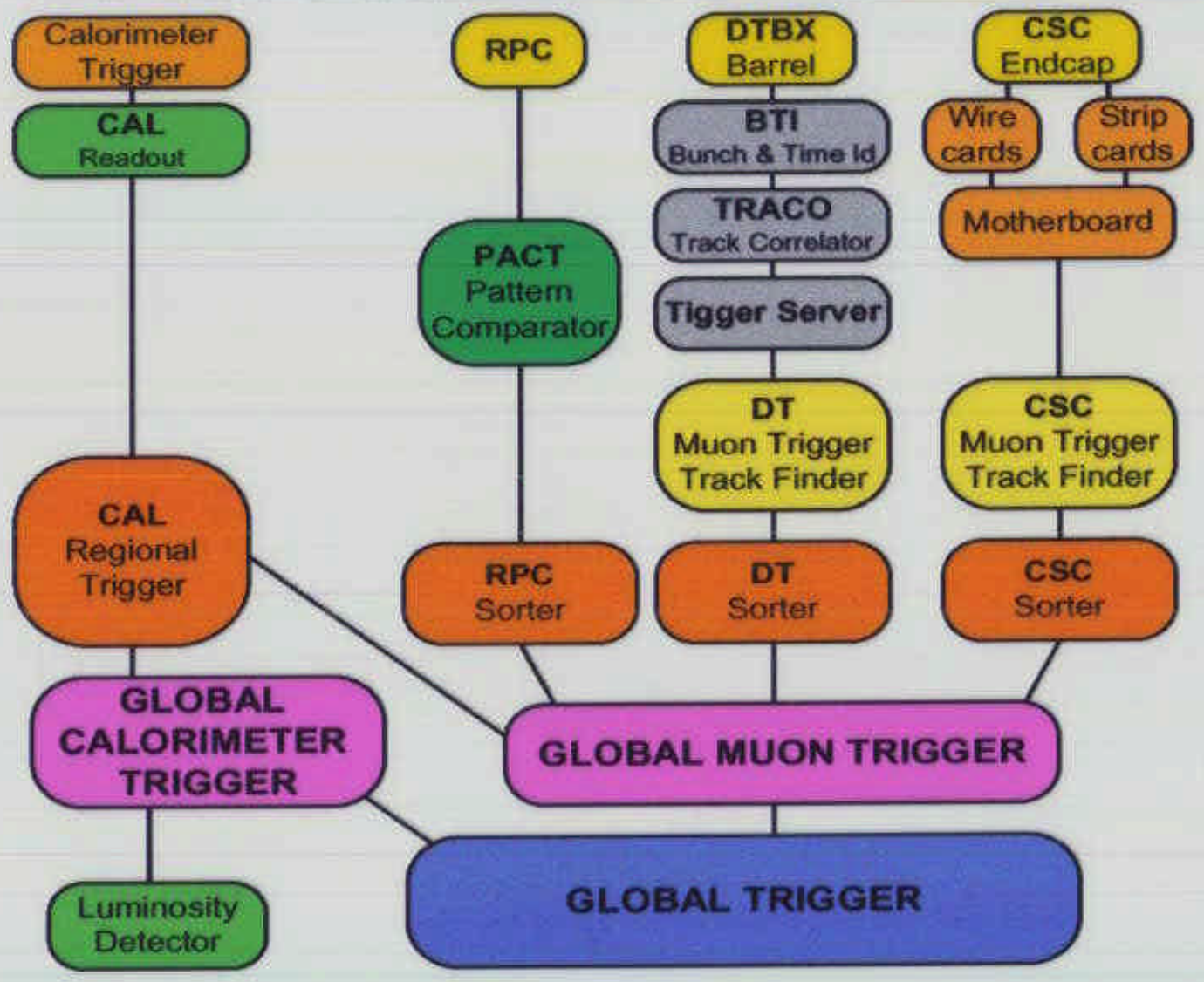
- muon identification
- transverse momentum measurement
- bunch crossing identification

Basic requirements:

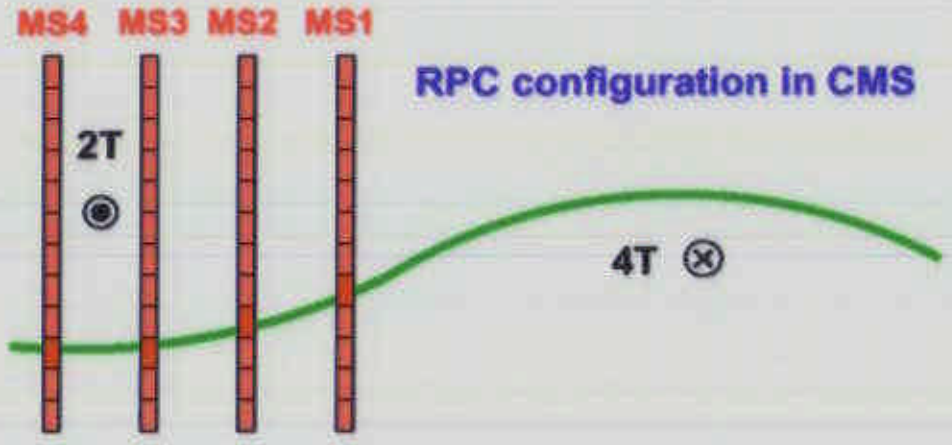
- geometrical coverage: up to $|\eta| = 2.4$
- latency: $< 3.2\ \mu s$ (128 bx)
- trigger dead time: not allowed
- maximal output rate: < 15 kHz for luminosities $< 10^{34}\ s^{-1}cm^{-2}$
- trigger thresholds are fully programmable
- background rejection: trigger rate due to background should not exceed the rate of prompt muons from heavy quark decays
- low pt reach: should be limited only by muon energy loss in the calorimeters
- Isolation: transverse energy Et deposited in each calorimeter region of $\Delta\phi \times \Delta\eta = 0.35 \times 0.35$ around a muon is compared with a threshold
- output to the Global Trigger: up to 4 highest pt muons in each event

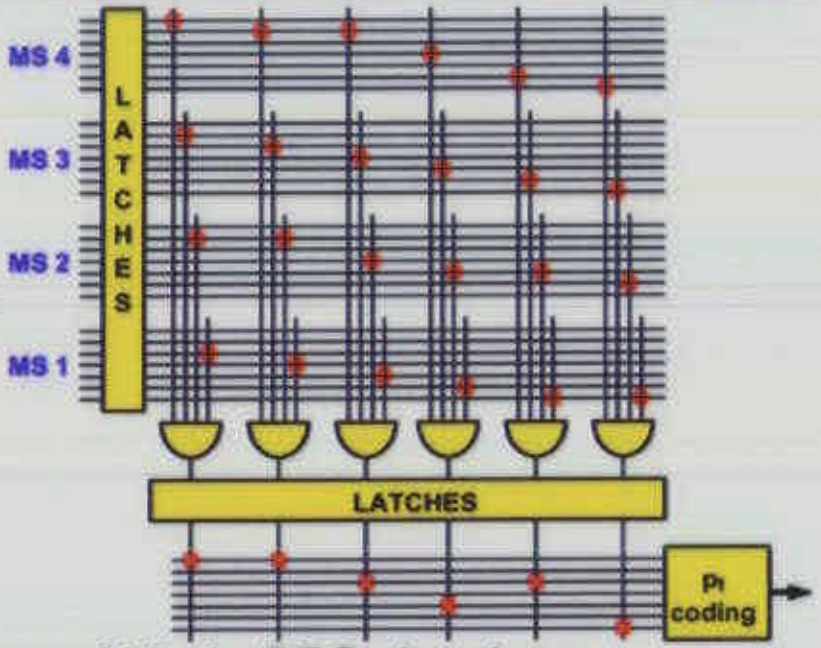
- **Nominal L1 rate (75 kHz) is shared equally between muon and calorimeter triggers**
- **Further a safety factor of 3 to account for the limited reliability of rate predictions**

Level-1 Trigger



RPC Trigger





Principle: based on spatial and time coincidence of hits in RPC chambers. Pattern of hit strips is compared to predefined patterns corresponding to various p_t values.

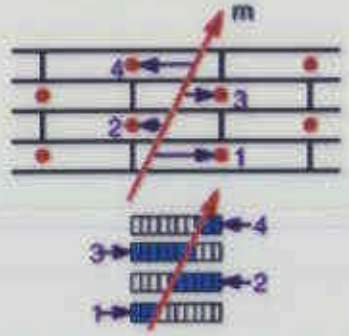
Trigger primitives: Hits from RPC chambers

Output: 8 muon candidates : 4 from barrel region and 4 from endcaps (pt, charge, η, φ, quality)

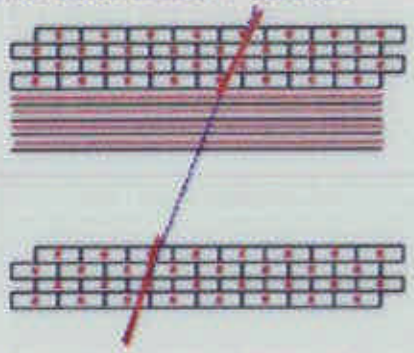
Hardware implementation: Front end chip and PAC (Pattern Comparator): ASICs

Drift Tube & CSC Trigger

Drift Tubes

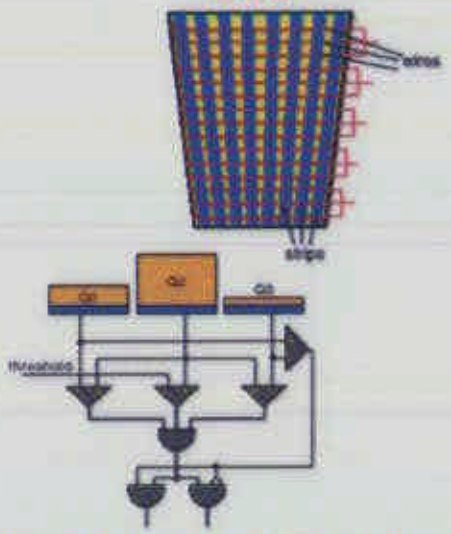


Meantimers recognize tracks and form vector / quartet.



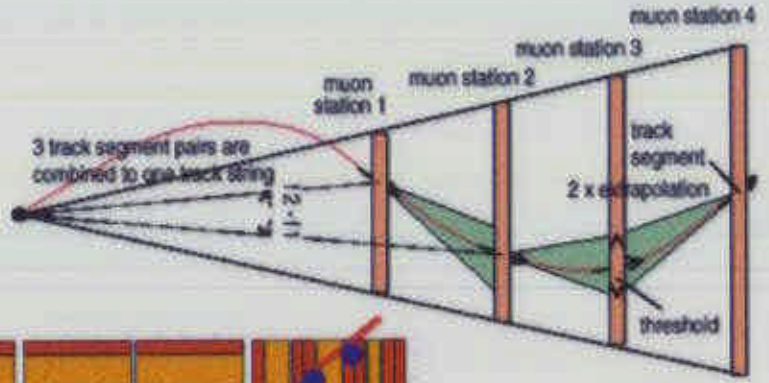
Correlator combines them into one vector / station.

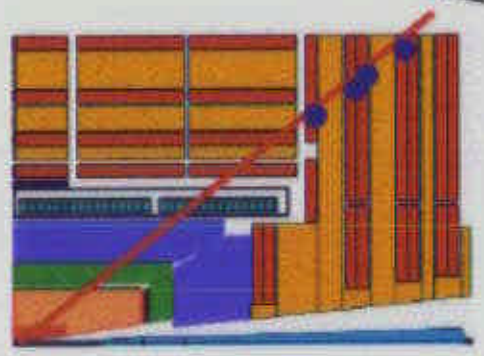
CSC



Comparators give 1/2-strip resol.

Hit strips of 6 layers form a vector.





- Extrapolation: using look-up tables
- Track Assembler: link track segment-pairs to tracks, cancel out fakes
- Assignment: pt (5 bits), charge, η (6 bits) , φ(8 bits), quality (3 bits)

Hardware implementation:

ASICs for Trigger Primitive Generators
FPGAs for Track Finder processors

Global Muon Trigger

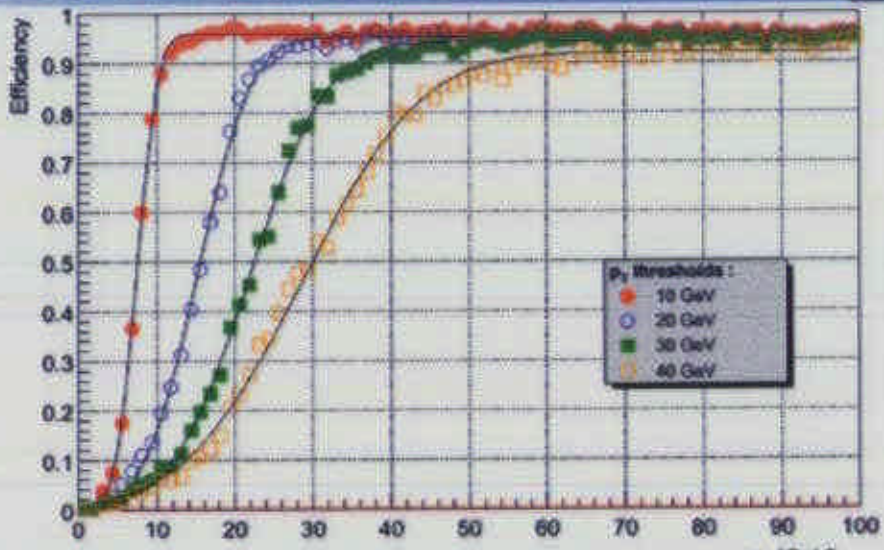
Task:

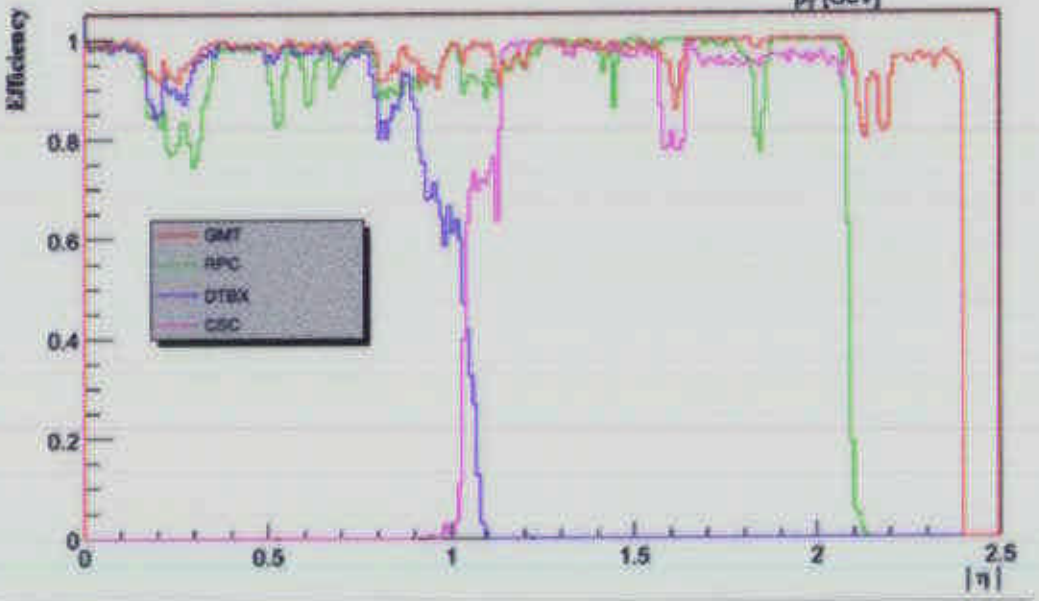
- combine the results from the RPC, CSC and DT triggers
- try to match muon candidates from different trigger systems
- make use of complementarity of the 3 sub-systems
- improve overall trigger efficiency and rate capability
- assign muon isolation
- deliver the 4 best (highest p_t, best quality) muons to the Global Trigger

P_t resolution:

- 18% barrel
- 35% endcaps

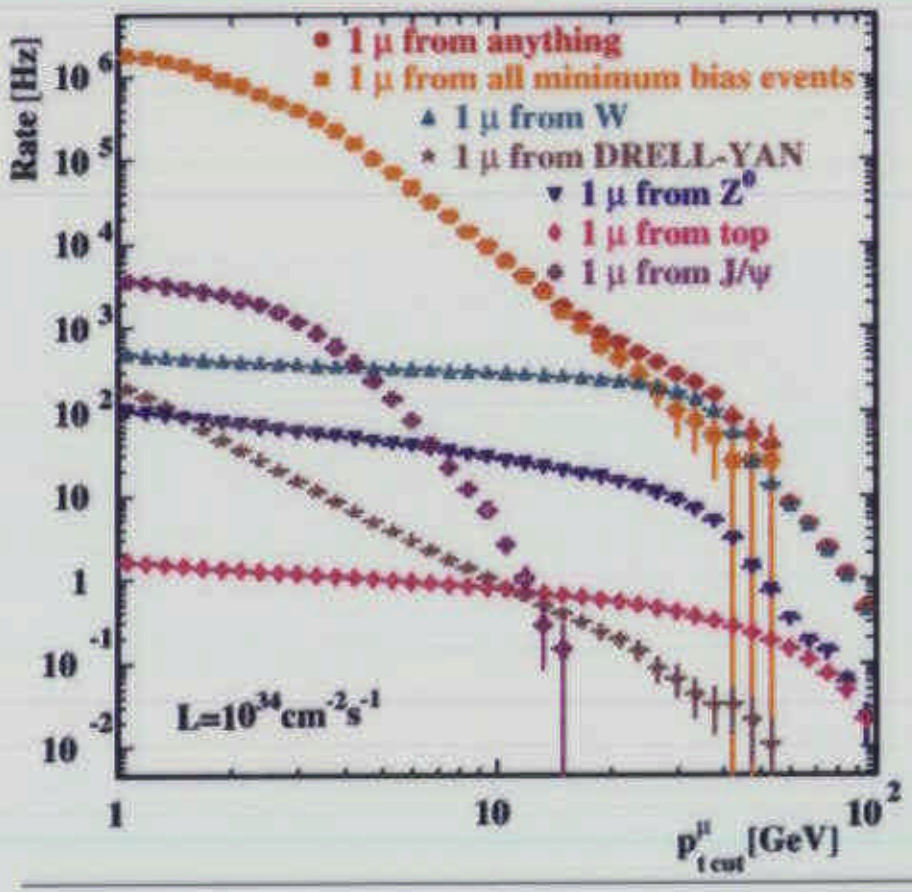
Efficiency: ~ 97%

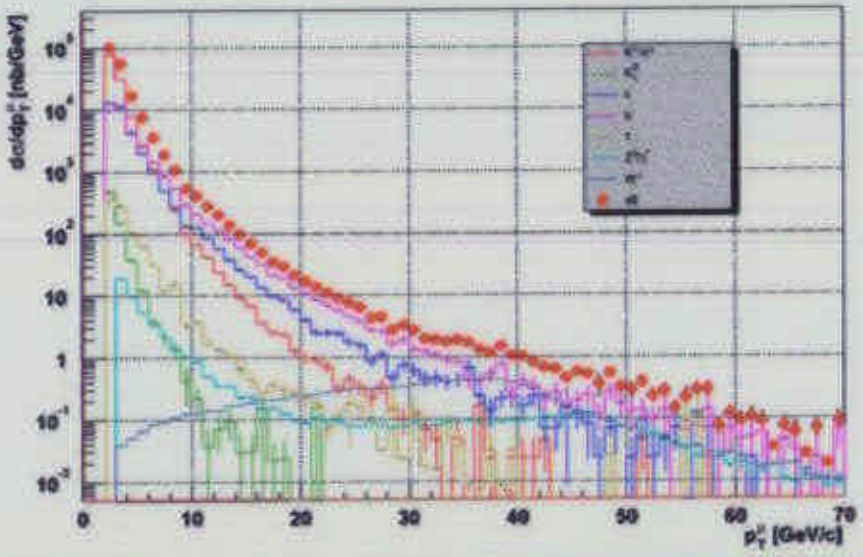




Trigger Rates

- The rate is dominated by π,K decays up to 4 GeV and by b-, c-quark decays from 4 to 25 GeV
- The trigger rate can be adjusted by moving the threshold in a wide range of p_t
- Two muon event rates are 2 orders of magnitude lower





trigger	trigger threshold	rate
1 μ	20 GeV	8 kHz
2 μ	4, 4 GeV	1.5 kHz
1μ + X	4 GeV	5.5 kHz

HLT

Strategy for High Level Trigger:

filtering in steps

- local muon reconstruction (with L1 seed)
- redefine p_t measurement
- propagate muon to interaction point
- reject fake L1 muons
- reduce non-prompt muon contribution
- check muon isolation

- L2 p_t resolution: 10% barrel, 20% endcaps
- L2 reduction: factor ~10
- L2 efficiency: ~96%

- **at L3 bring in tracker data**
- **match muons with tracker**

Summary

- Online event selection at the LHC is a challenge
- CMS will have a multi-level trigger system
- L1 Trigger Technical Design Report to be submitted by the end of 2000
- Prototypes of almost all L1 Trigger components have been build and tested
- The CMS L1 Muon Trigger is robust
- L2 trigger strategy has been developed and tested