CMS Muon Systems

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Note: Unless otherwise stated figures come from the CMS Outreach Webpage.

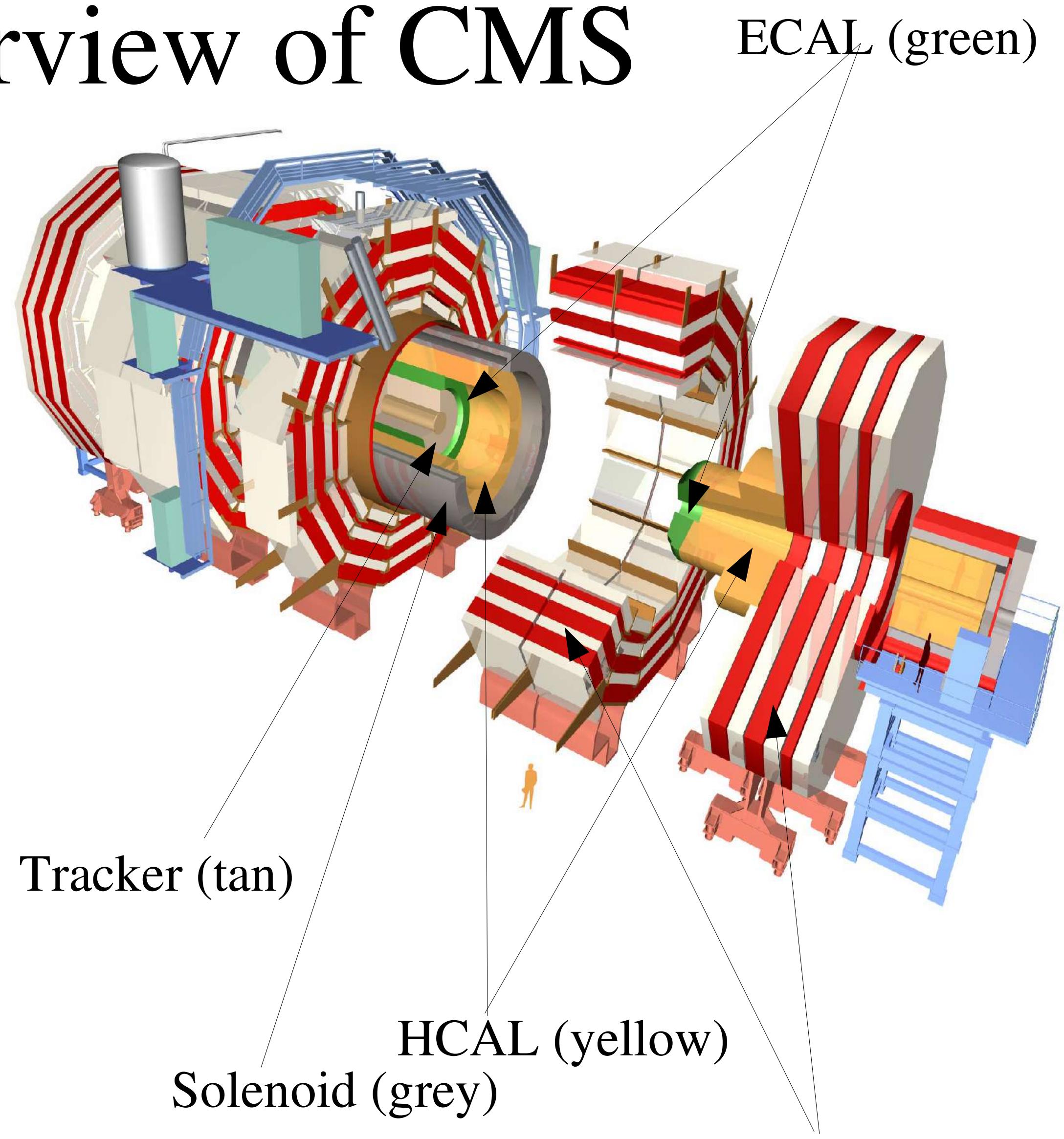
Outline

- CMS and the Muon Chambers
  - barrel, DT
  - endcap, CSC
  - RPC
  - Trigger (quick)
- Backgrounds
  - Types
    - Punchthroughs
    - Decays in flight
  - Muon Isolation

Quick Overview of CMS

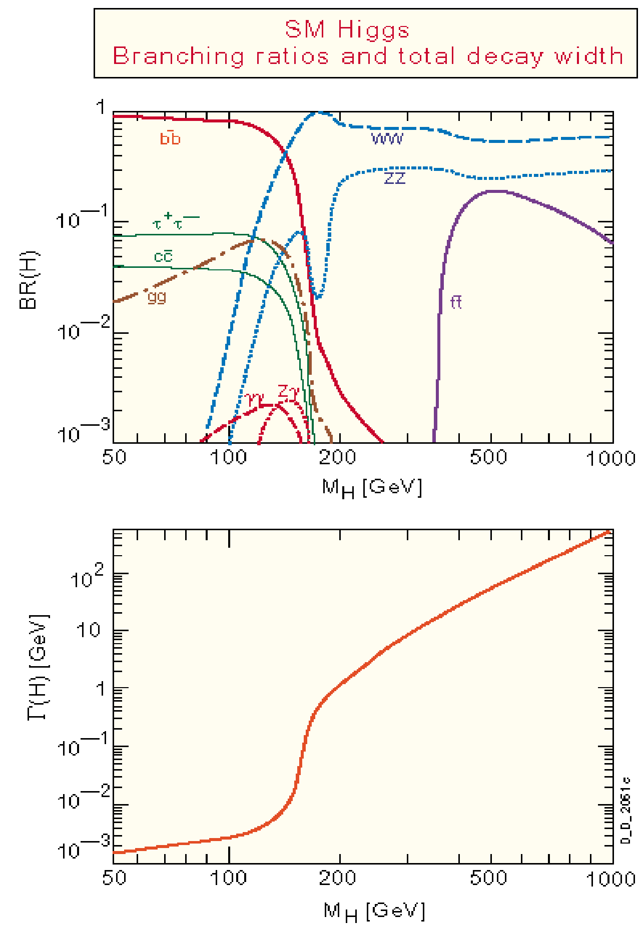
- CMS stands for Compact **Muon** Solenoid

- Consists of:
  - a tracker for accurately measuring momentum of charged particles
  - an electromagnetic and hadronic calorimeter for measuring deposited energy
  - a solenoidal magnet
  - a large muon chamber located within the return flux of the magnet, can precisly measure muon momentum



Why are Muons So Important?

- The purpose of LHC and CMS is to discover new physics at the electroweak scale.
  - May come in the form of Higgs, Z', SUSY particles, gravitons, etc.
  - These particles can decay into hadronic jets, leptons or a combination of both.
  - Leptons, such as the muon, offer a "clean" signal, i.e. the leptons are easy to tag and reconstruct their 4-vectors as opposed to jets which leave a broad energy deposit in the HCAL.
  - Therefore, we need a muon system that can easily identify muons and run in an LHC environment.

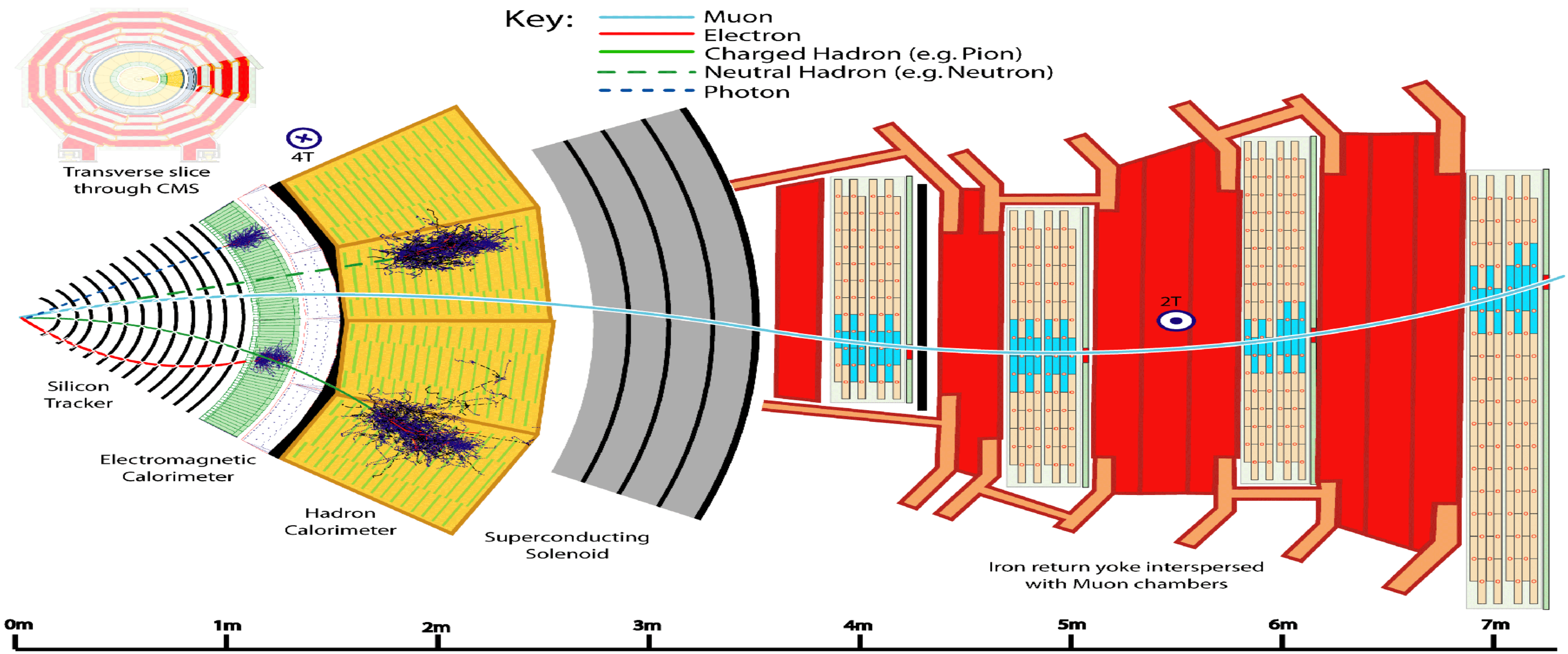


Nearly all of these particles can decay leptonically into a pair of muons. We need good muon identification over a wide range of momenta and eta.

Requirements

- There are three purposes for the muon system.
  - muon identification
  - muon trigger
  - muon momentum measurment
- The requirements of the system are dependent on the physics goals and the nature of the LHC environment.
- In order to achieve those goals at the LHC the had to look at the following things:
  - amount of material before the muon chamber
  - beam crossing ID
  - pT resolution at the 1% level for at 10GeV and at the 10% level for 1TeV
  - charge assignment

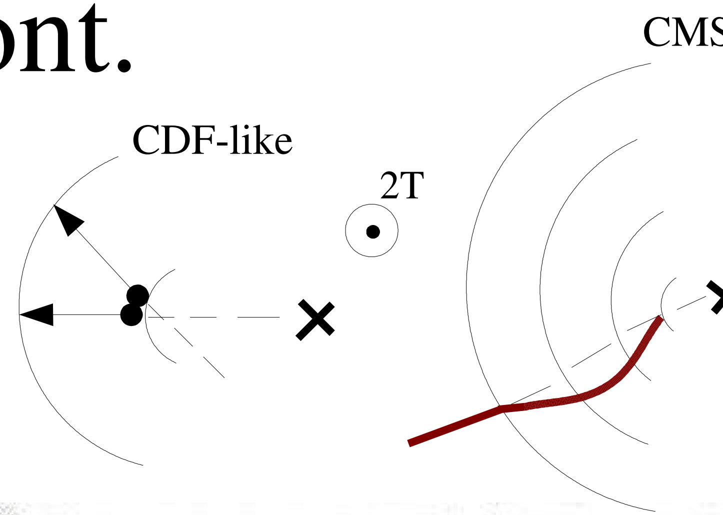
How is CMS's Muon System Different?

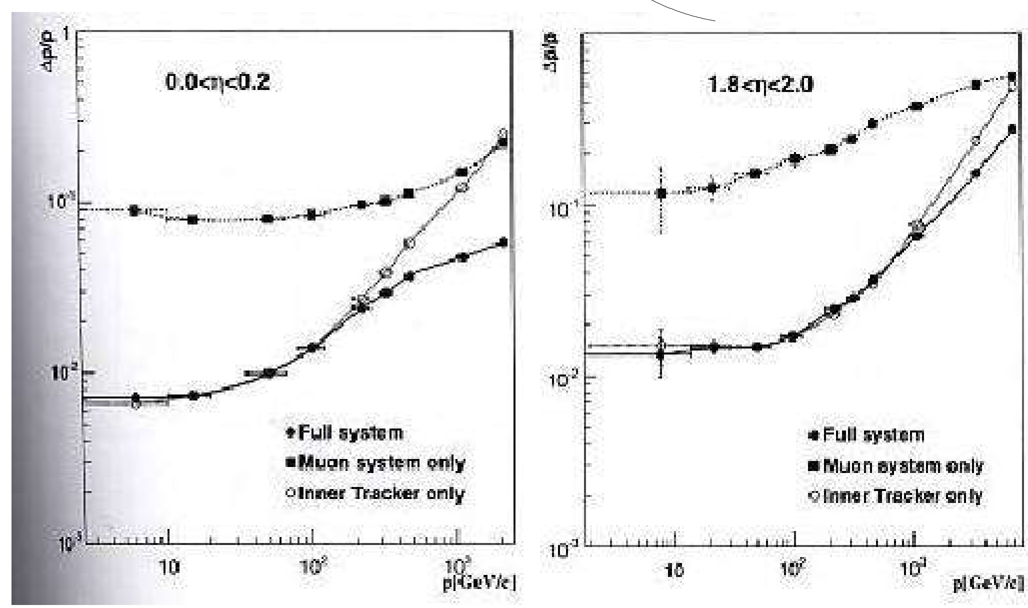


- CMS has decided to put their muon chambers within the return yoke for the magnetic field. This gives them the advantage over detectors like CDF in that they can measure the muons' momentum not only in the tracker but in the muon chamber as well.

How is the Muon System Different? cont.

- In detectors where the muon system is located outside of the return flux, only the original direction of the muon can be determined by noting that $\oint \vec{B}\cdot d\vec{l}=0$ if the muon has completely left the magnetic field.
- CMS utilises this in it's last muon station as well as a momentum measurement in both the tracker and muon chambers to get a better resolution by requiring the muon track in the last station point to the interaction point.

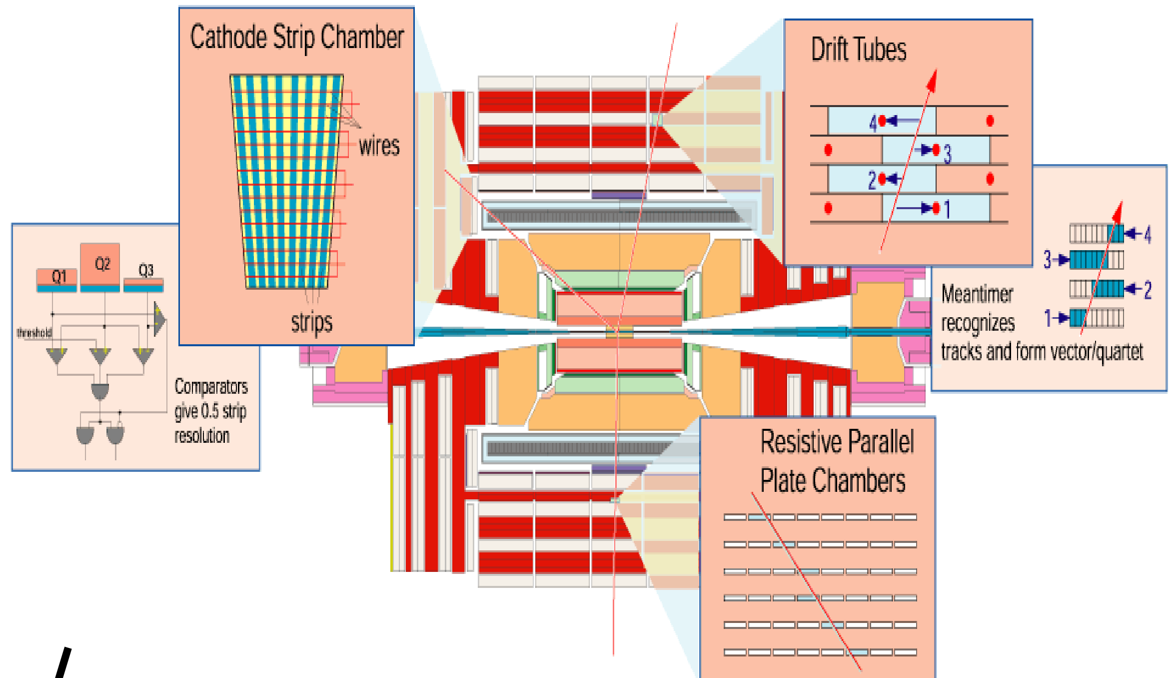


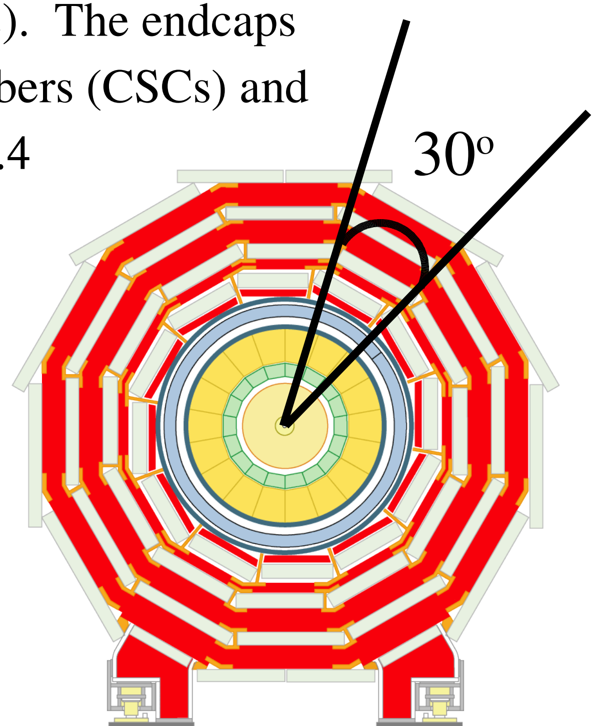


Here Full system impies using the muon system, the tracker and making sure the last track points to the interaction point. (Figure from CMS TDR 8.1 Detector Performance and Software Vol I)

Muon Chambers Layout

- The muon system is composed of 4 concentric shells sandwiched between iron return yoke in the barrel and 8 (4 per side) round endcap plates. Each shell and plate is composed of 12 sectors which cover 30^o in ϕ.
- The barrel ($|\eta|<1.2$) uses drift tube (DTs) chambers as well as resistive plate chambers (RPCs). The endcaps use cathod strip chambers (CSCs) and RPCs and cover $|\eta|<2.4$

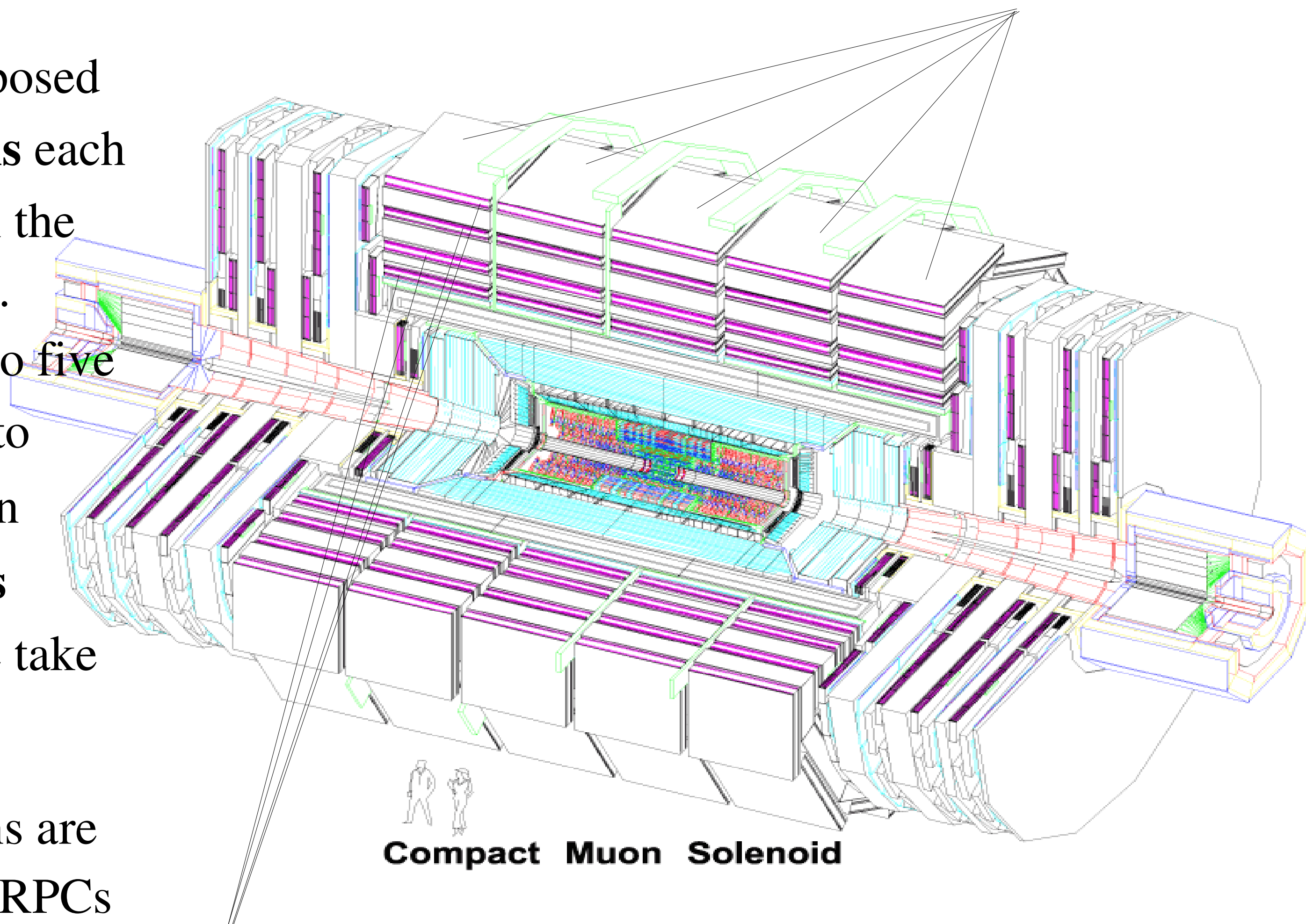




This combination is used because DTs and CSCs provide accurate position measurments but have a large lag time. On the other hand RPCs have a very accurate time measurment and short response. The trigger combines information from all three and provides efficient rejection of background.

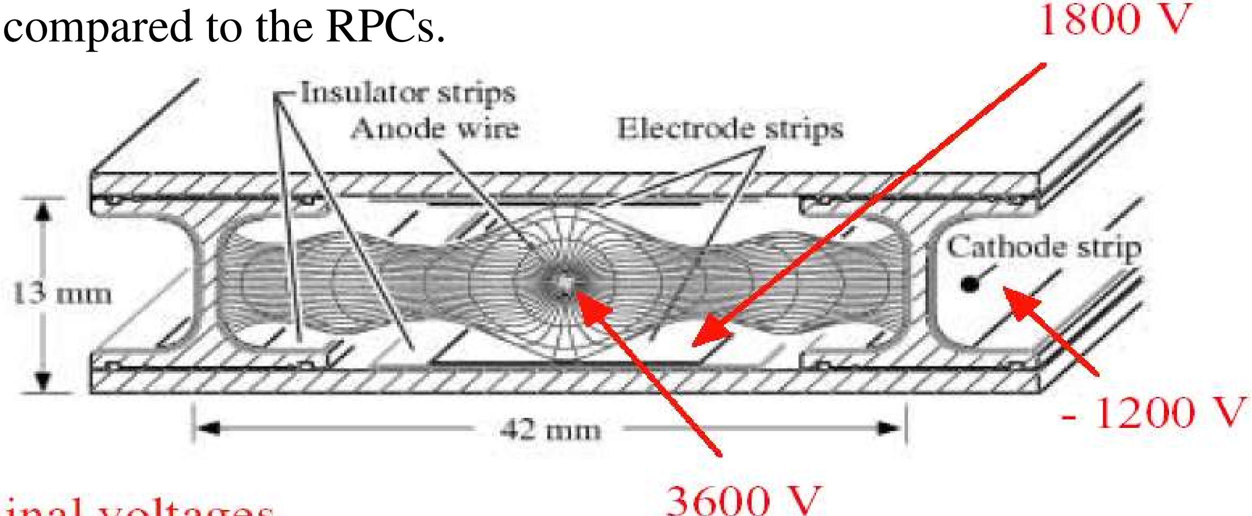
Barrel Detector and DTs

- The barrel system is composed of four cylindrical **stations** each with 250 chambers within the return yoke of the magnet. Each station is divided into five **wheels** labelled YB-2 up to YB+2. Each **wheel** is then segmented into 12 **sectors** which as discussed before take up 30^o in phi.
- The two innermost stations are sandwiches of DTs and 2 RPCs while the two outermost DTs are coupled to 1 RPC.



Drift Tube Chambers

- Drift tubes were chosen for the barrel region because in this region the magnetic field is uniform and contained withing the iron return yoke of the magnet.
- Ea. tube is 42mm wide and 13mm tall and contains an Ar(85%) + CO_2(15%) mixture.
- Voltages are applied to the outside of the outside of the tube in order to shape the electric field on the inside.
- When a particle passes through the chamber it liberates electrons which are accelerated along the field lines to the wire. Position is measured by calculating the migration time and using the drift velocity of electrons through the gas mixture. This gives a space resolution of ~ 100µm
- Due to the large drift time for the DTs, triggering at a high pace is more difficult than compared to the RPCs.



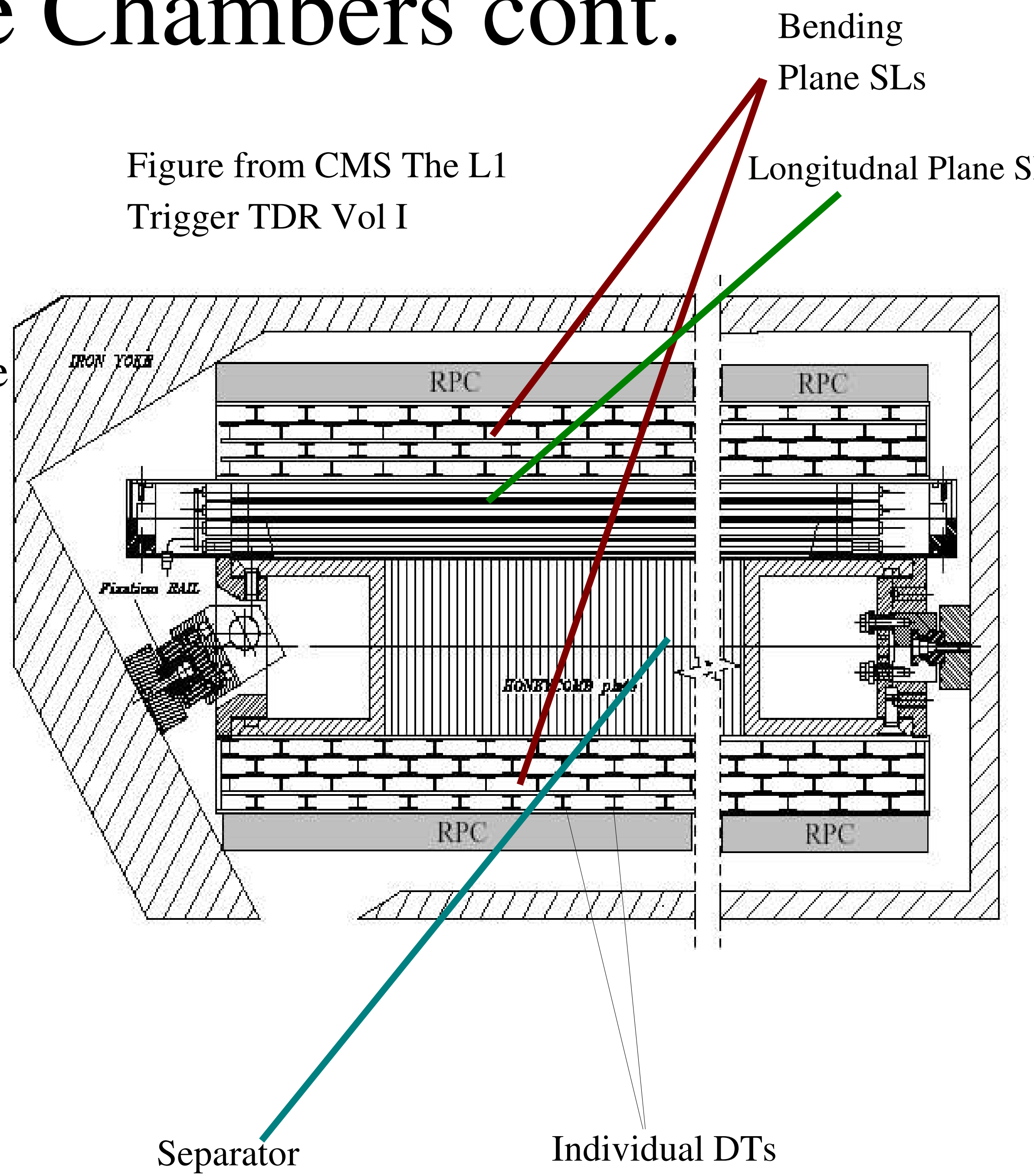
Nominal voltages

Figure from P. Giacomelli of INFN Bologna, UCR *CMS Muon Detector-VCI 2000*
From the CMS Muon Chambers Outreach webpage.

Drift Tube Chambers cont.

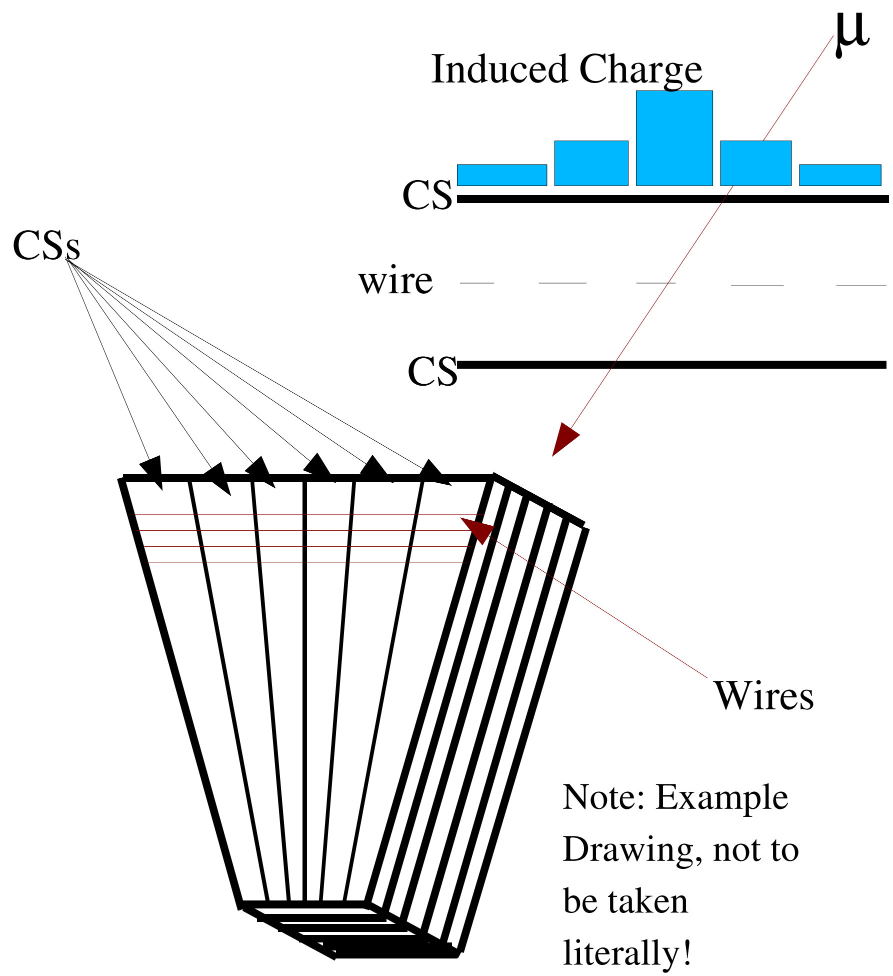
- Each DT module is composed of 3 superlayers (SL) which are split into four layers of staggered drift tubes. Two SLs make measurements in the ϕ direction (bending plane) while the other makes a measurement in the θ direction (longitudinal plane).
- The two bending plane SLs are separated by a 20cm thick honeycomb Al separator which provides a lever arm in the bending plane which is useful for triggering purposes to get some space between hits.

Figure from CMS The L1 Trigger TDR Vol I



Endcaps and CSCs

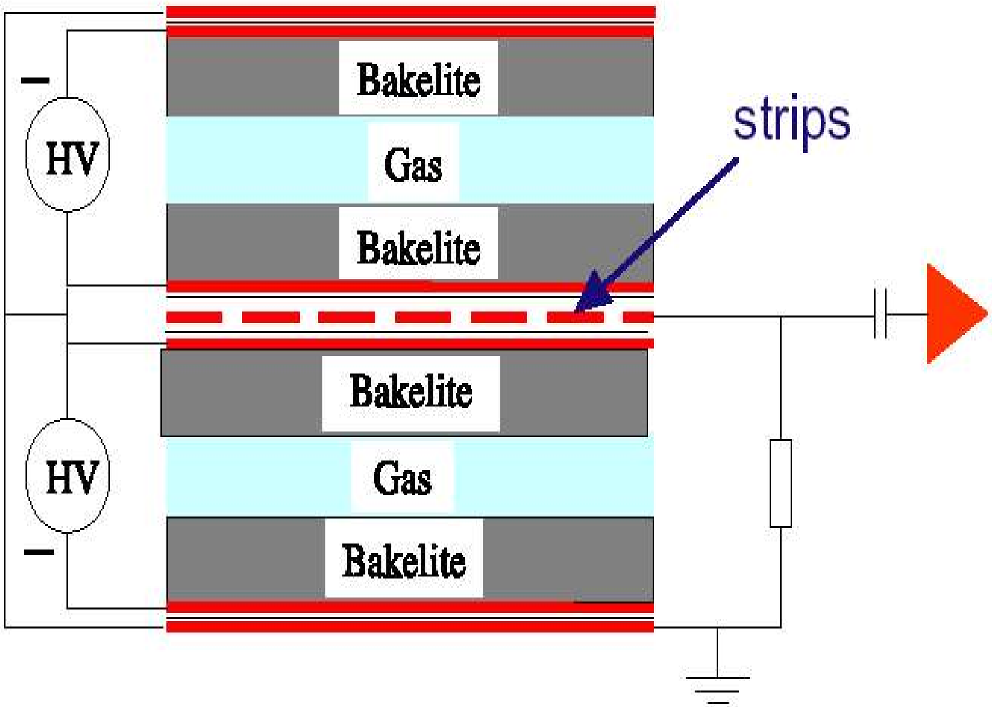
- The CSCs are trapezoidal multiwire proportional chambers.
- When a muon passes through the chamber it ionizes the gas within the chamber. An avalanche of charge then builds up on the wire and a charge is then induced on the strips.
- A position is read by extrapolating the amount of charge induced on several strips. A position resolution of 80-450μm/layer, with 6 layers per chamber is possible.
- Like DTs, CSCs have a good position resolution but a poorer response in time.



Wires are perpendicular to the strips except for the chambers in ME1/1 where due to high magnetic field effects the wires are tilted at an angle of 25°

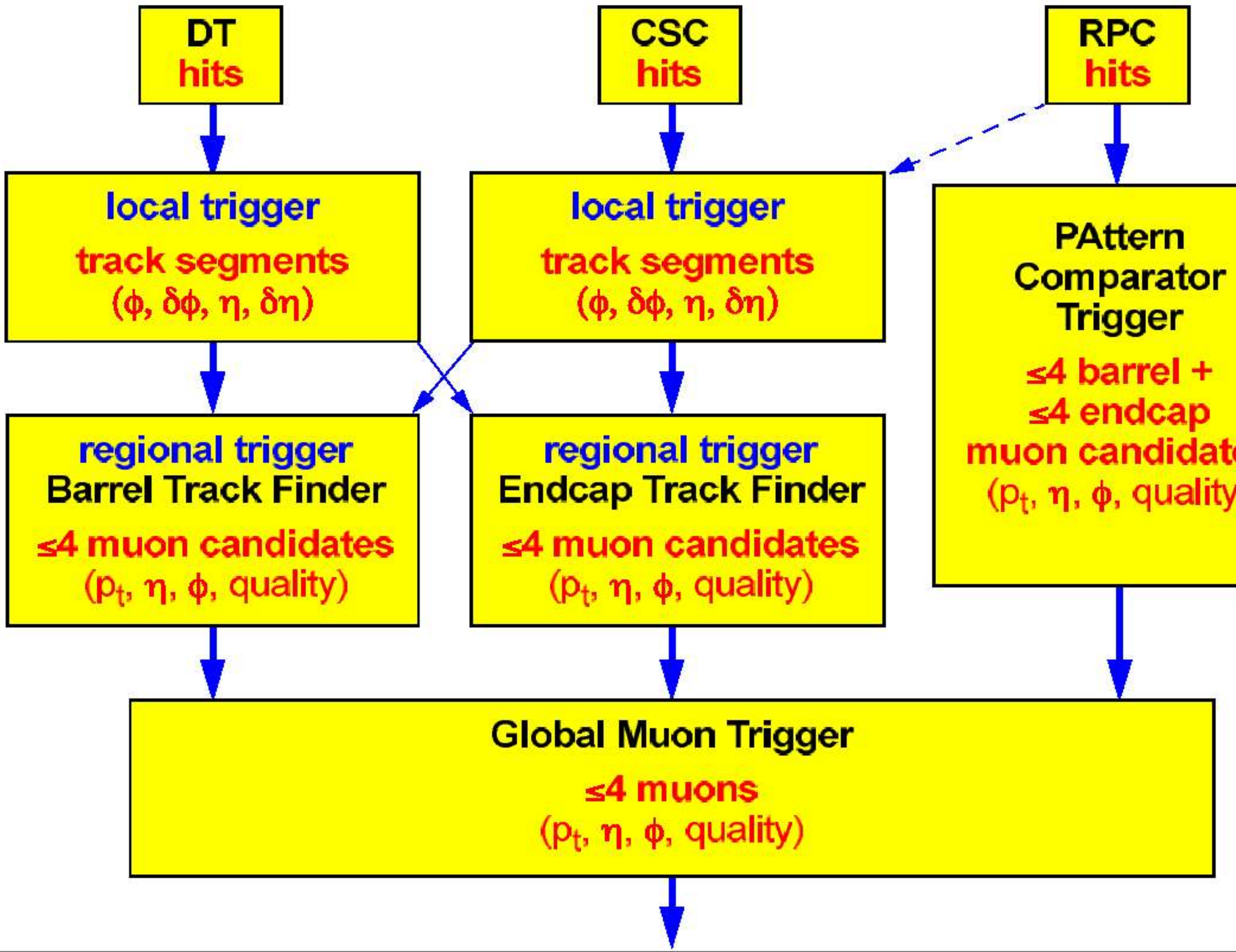
RPCs

- As mentioned before, interspersed between the DTs and CSCs are RPCs covering essential the same area.
- Redundancy offers an additional and complementary trigger.
- RPCs have faster response time (~3ns time resolution) than DTs and CSCs and have a different sensitivity to background. The three triggers signals will run in parallel until they are combined in the Global Muon Trigger.



Picture from P. Giacomelli's 2000 Talk on Muon Detector

Quick Overview of Trigger



Picture from P. Giacomelli's 2000 Talk on Muon Detector (and Trigger TDR)

Summary of Detector

Detector	Drift Tubes	Cathode Strip Chambers	Resistive Plate	
Function	Tracking p_T trigger BXID	Tracking p_T trigger BXID	BXID p_T trigger Resolve tracking ambiguities	
η region	0.0 - 1.3	0.9 - 2.4	0.0 - 2.1	
Stations	4	4	Barrel 6	Endcap 4
Layers	RΦ 8, Z 4	6	2	
Chambers	250	540	360	252
Channels	195000	Strips 273024 Wire groups 210816	80640	80642
Spatial resolution (σ)	per wire 250 µm RΦ (6/8 pts) 100 µm Z (3/4 pts) 150 µm	RΦ (6 pts) 75 µm (outer CSCs) 150 µm R(6pts) $(15\text{-}50)/\sqrt{72}$ µm	Cell size	
Time resolution	5 ns	6 ns	3 ns	
Within 20 ns window	> 98% (station) no parallel B field	> 92% (station)	98%	

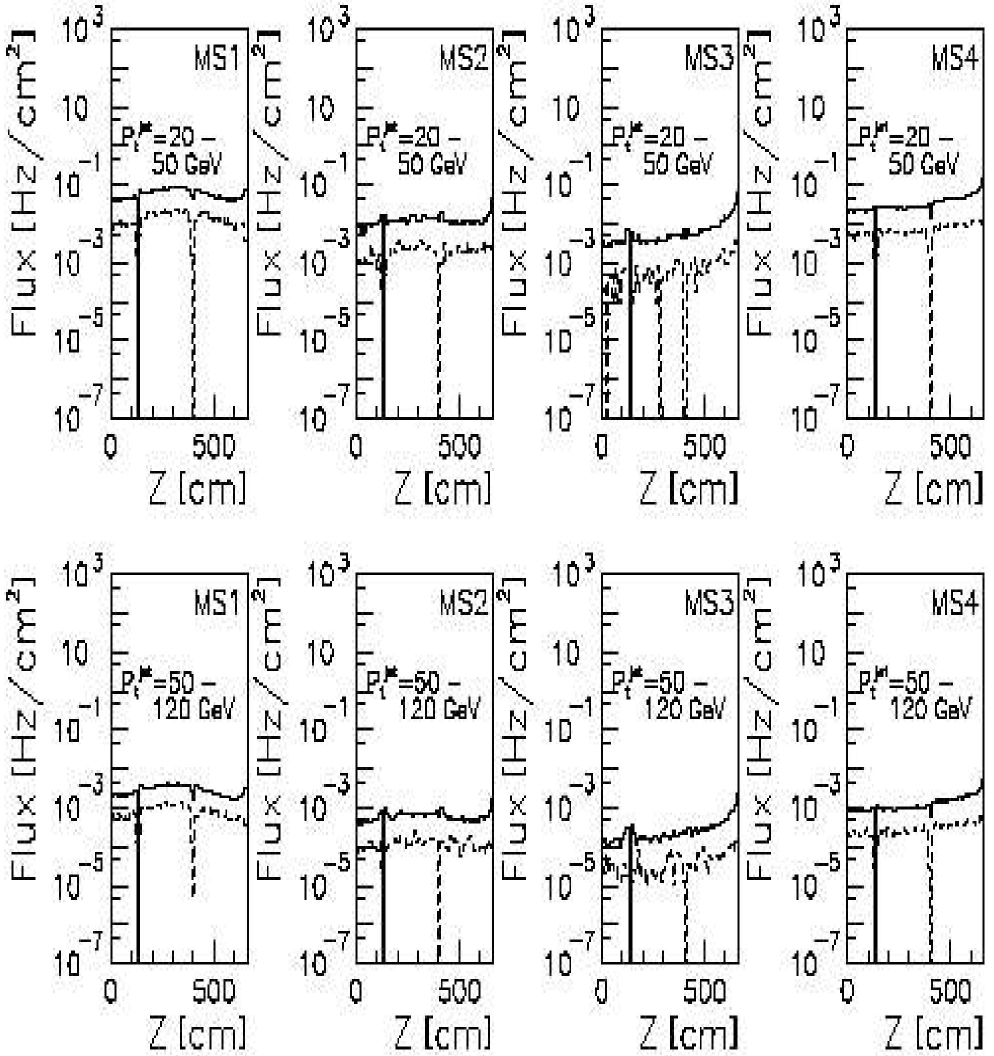
Table from Muon TDR

Background

- Before we discuss backgrounds we should define what are sources of “good” muons. Good muons are muons that a products of heavy particles such as W, Z, H as well as new physics particles such as SUSY particles, W',Z' and gravitons.
  - these muons have high pT and are isolated from jets
- There are four dominant backgrounds to “good” muons at LHC.
  - Decays in flight, i.e. c- and b-quark decays, π and K decays.
  - Hadronic punchthrough
  - muon bremsstrahlung, δ-rays
  - absorbtion of thermal neutrons from hadronic showers -> photons-> e's
    - these electrons have a low low energy and are mostly absorbed in the aluminum plating of the DTs.

Punchthrough

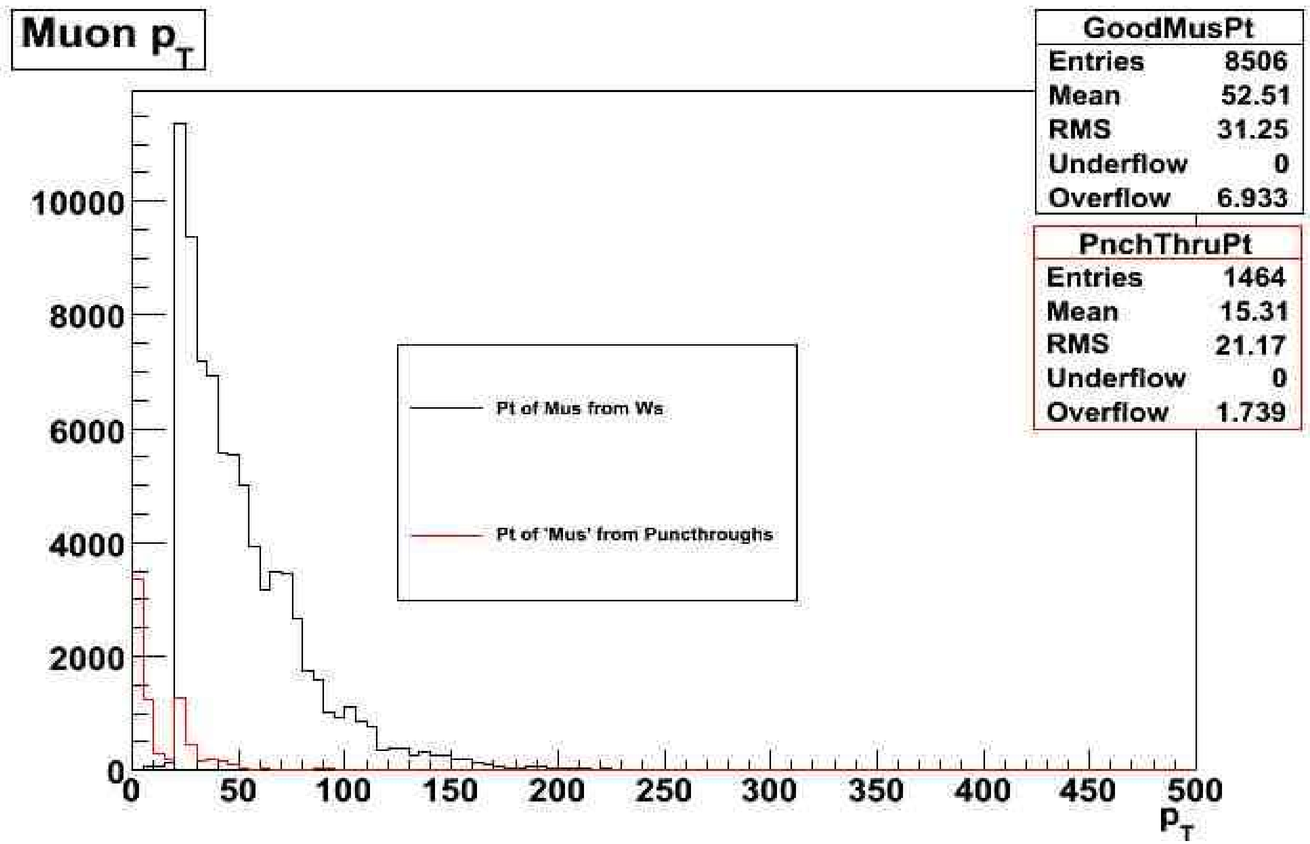
- What are punchthroughs?
  - Punchthrough particles are charged hadrons which make it through the calorimeters, solenoid and shielding and enter the muon chamber.
  - Although there is on average 11-15λ front of the muon chambers hadrons produced at the end of a shower will have only 1λ or 2λ to get through before they reach the muon chamber
- Where are punchthroughs?
  - Due to the extended HCAL-barrel, tv absorber plates and a 20cm thick iroi "tail catcher" means that punchthrough effects are largest at higher eta.



A. Benvenuti and V. Genchev, **CMS NOTE 1998/052**

How Do We Deal with Punchthroughs?

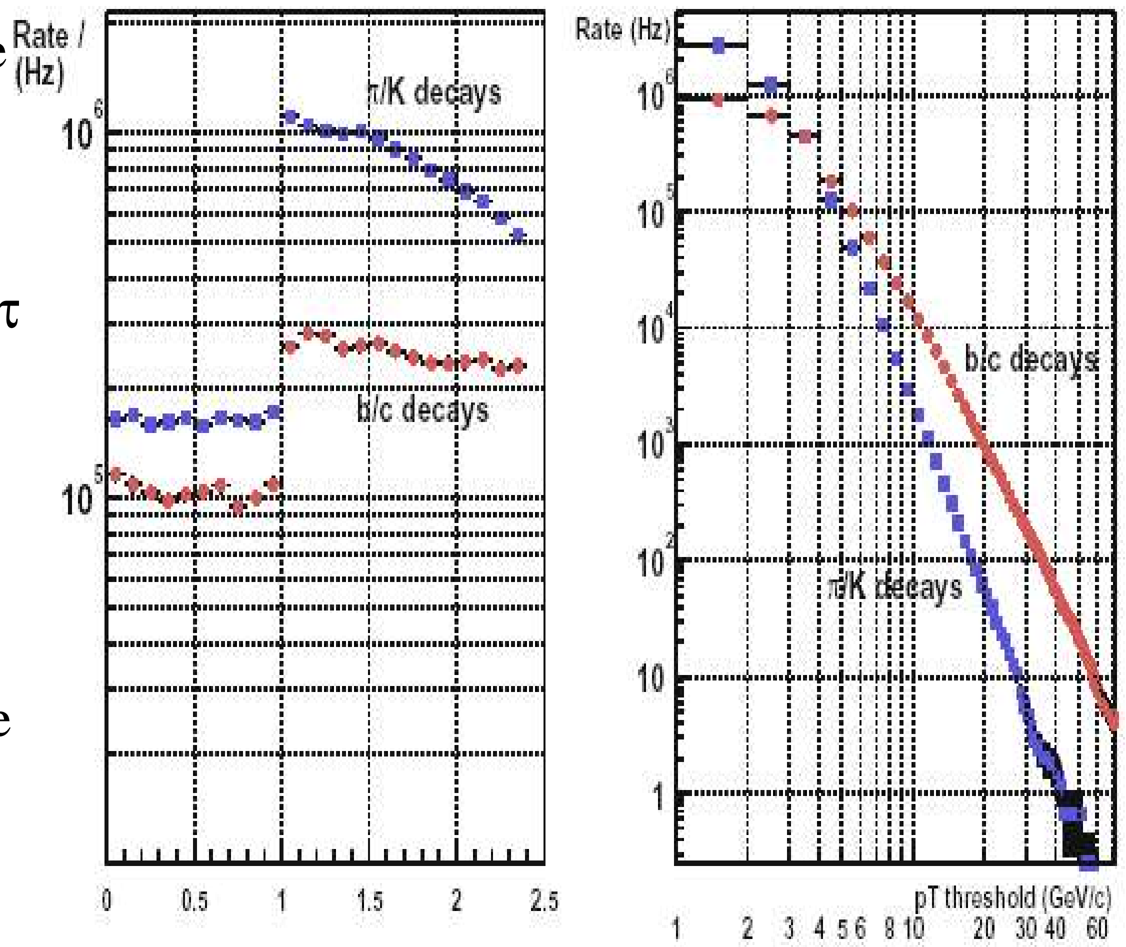
- Notice that punchthroughs are a small portion of total muons. Because of their low energy and their association with jets (we'll get to this) we can require a hit in the final muon station to cut this background out.



W+jets sample scaled to $1fb^{-1}$

“Unprompt” Real Muons

- These are real muons from decay in flight of kaons and pions.
- Tend to dominate the background at the <4GeV pT range.
- Compared to Ws and Zs (and c's and b's) where $c\tau \approx 1$cm, $c\tau(K) \approx 3.7$m and $c\tau \approx 7.8$m
- Using the fact that the track in the last muon station will not point to the interaction point and an accurate measurement of the muon's pT from the muon chambers and tracker we can exclude these backgrounds.

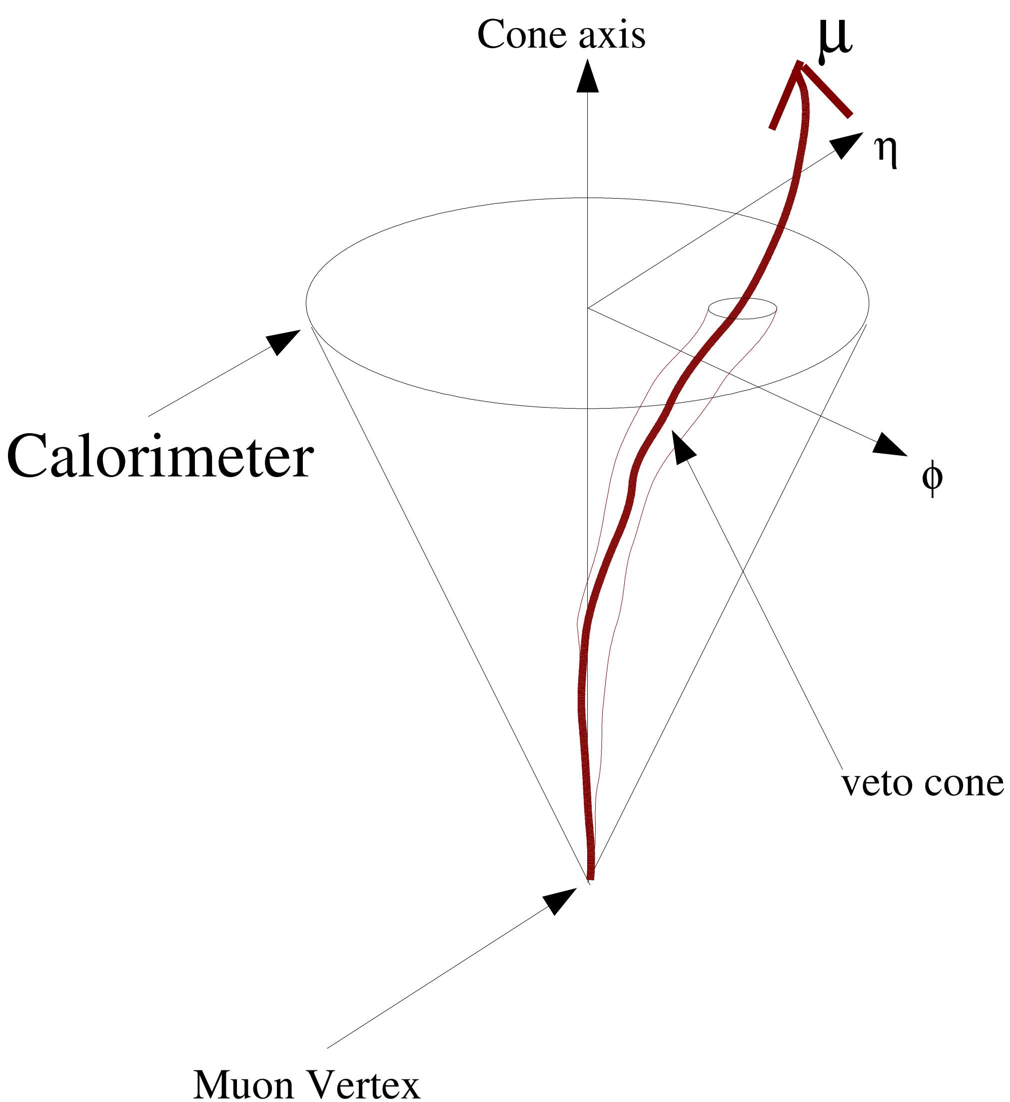


Prompt Muon Background and Isolation

- One of the more difficult backgrounds are prompt muons from c- and b-quark decays. These processes dominate the background at the 1μ and 2μ rate for a wide range of pT values (see CMS Note 2000/067).
- The difficulty come from these being real muons that point back to the interaction vertex with higher pT than other backgrounds.
- One major difference is that these muons are produced inside jets.
  - If we can isolate muons that don't have a jet cone associated with them then we can cut out a lot of this background.

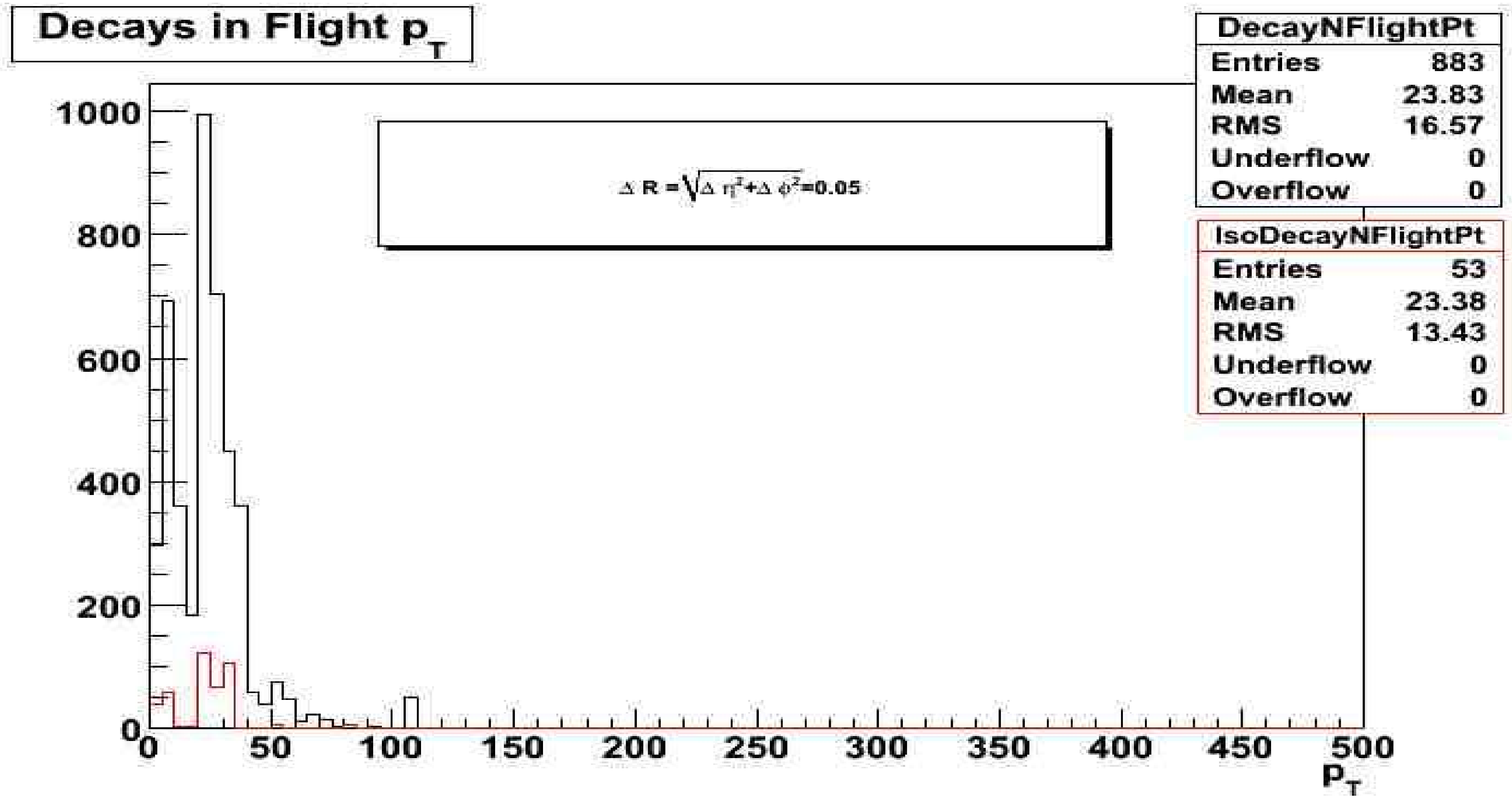
Isolation

- How does it work?
  - From the four possible muon candidates from the Global Muon Trigger an η-ϕ is defined in the calorimeter.
  - A muon is isolated if all the bits are quiet in an η-ϕ cone around the muon.
  - The energy deposited by the muon in the calorimeter, the veto, is subtracted out to give a stronger isolation.



Of course all of this can be done using the tracker as well.

What are the effects of isolation?



W+jets, scaled to $1fb^{-1}$

Points to take away:

- CMS has it's muon chambers within the return yoke of the magnet.
  - this allows for measurements of the muon's pT in both the tracker and the muon chambers.
  - Good resolution and eliminate background.
- The detector uses a redundant system of DTs, CSCs and RPCs to get a good position resolution along with an accurate BX ID and fast triggering.
- Of the major backgrounds, prompt muon decay from c's and b's is the most difficult.
  - Muon isolation is a powerful tool that helps tag muons from heavy, interesting particles from those associated with jets.