The CMS Muon System

Description, status and MTCC results

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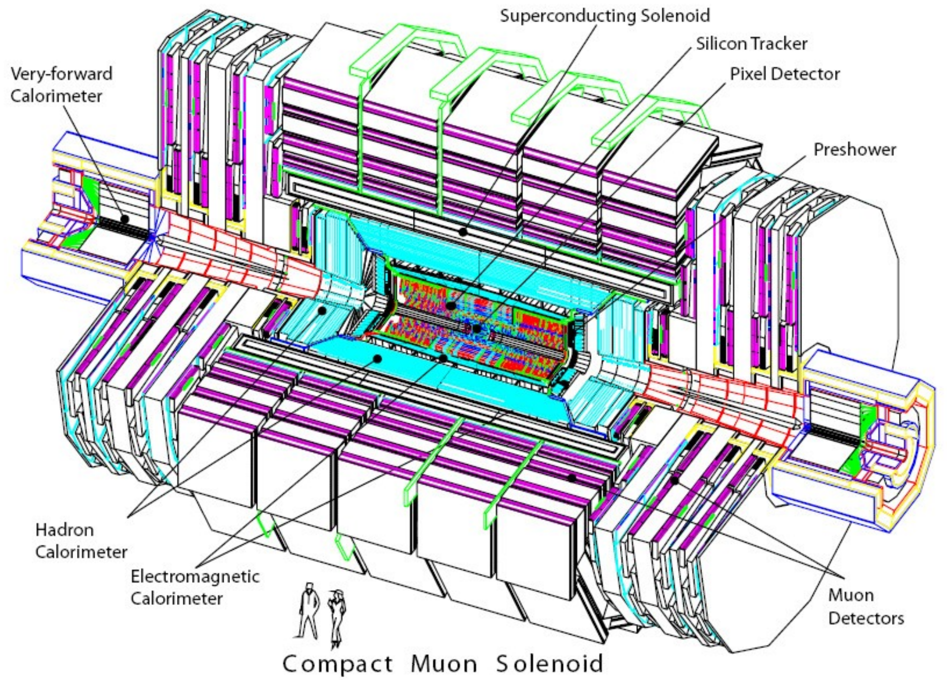
on behalf of the CMS Muon System

2007 European Physics Conference
Manchester, 20th July 2007

CMS at a glance

Length: 21.6 m
Diameter: 14.6 m
12500 Tons

Tomorrow:
Status and commissioning of CMS (C. Wultz)



Tracker@ -20ºC
Pixel: σ=10(20) μm $r\Phi$ (z)
Strip Tracker: μstrips Silicon
σ TIB~20 μm,TOB~40 μm

Solenoid: Superconductor 4T
L=13 m, ∅5.9 m
Magnetic Field **returns** through iron yoke

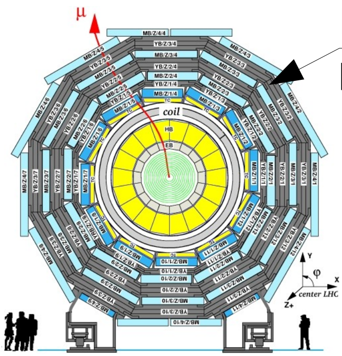
Trigger:
Approx. 20 ev/bx @ L=10^{34}/cm^{2}s
ν_{bx}=*40Mhz ⇒ 10^9 ev/s*
L1 FPGAs,ASICs, 312 μs
output rate *100 kHz*
Decision photon,e,μ,jets > p_T cuts
HLT output 100 ev/s
Reduction info, farm CPUs

ECAL: $PbWO_4$ crystals, short χ_0 and fast response, but low light yield
Intrinsic gain photodetectors: Silicon APD barrel,VPT for EE
Electrons: *σ(E)/E~0.5-1% (E>20 GeV)*

HCAL: Brass+plastic scint. tiles readout by WLS+CF
Hadronization leaks after magnet caught by scint **H**adron **O**uter (barrel)
HCAL Energy resolution: Pions *σ(E)/E~20%@50 GeV, ~15%(E>100 GeV)*

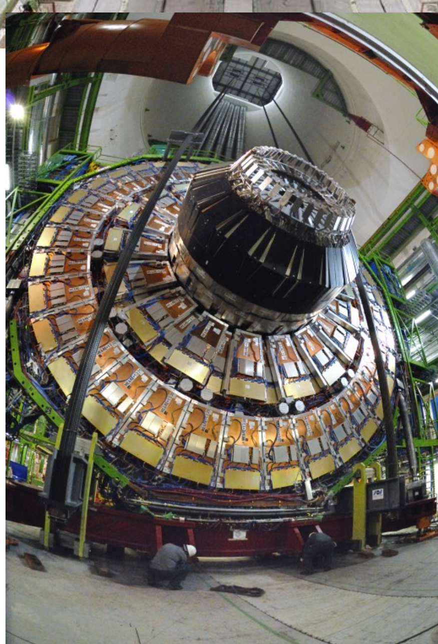
Muon System: key for trigger. 250 DTs, 540 CSCs, 912 RPCs
Moderate p_T resolution (comp. tracker)
Barrel: $|\eta|<1.2$, *low* B *uniform*, R(μ)≤ *1 Hz/cm²*, R(n bkgd)=*1-10 Hz/cm²*
Endcaps: $0.9<|\eta|<2.4$, *B upto 3.5T*, R(μ)≤ *200 Hz/cm²*, R(n bkgd)<*1kHz/cm²*
Barrel-Endcap overlap in $0.9<|\eta|<1.2$
RPC: σ_t~*1 ns, identification bx*

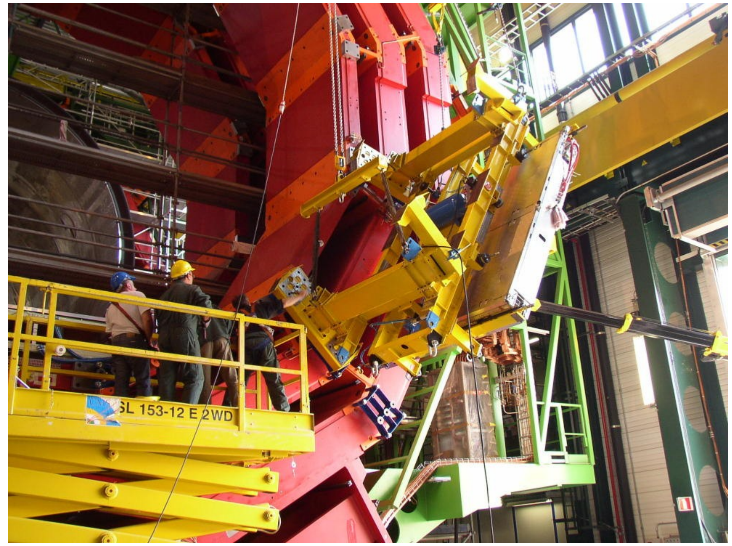
From sketches to reality



Muon System by 2002

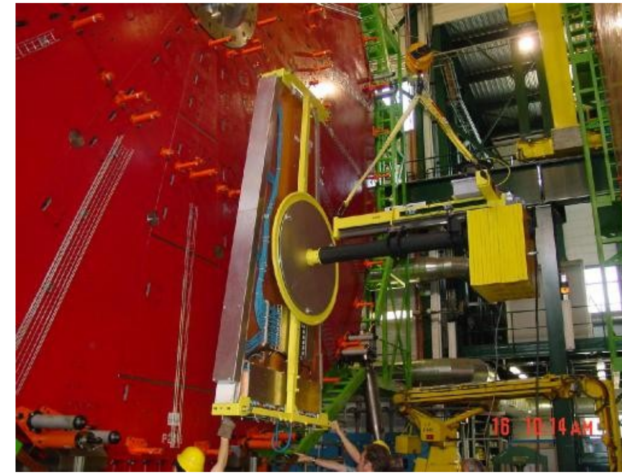
2007 in the cavern





First DT installed

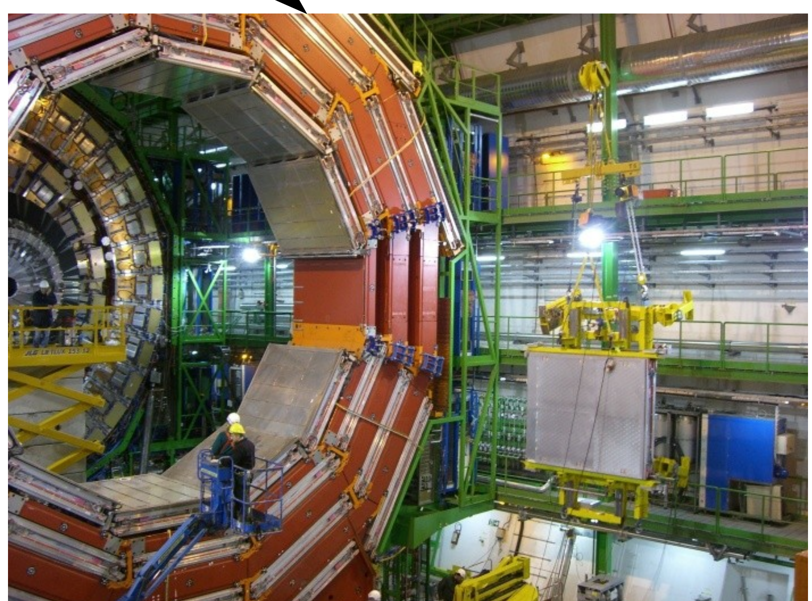
2004



First CSC installed

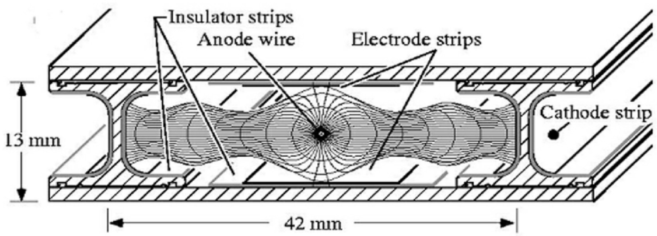
2003

Last DTs installed



Last CSC installed

MUON Drift Tubes CHAMBERS

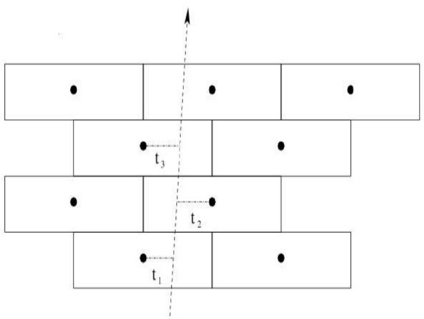


Ar/CO2~85/15%

Voltages (3600,1800,-1200)V

Cell resolution~250 µm

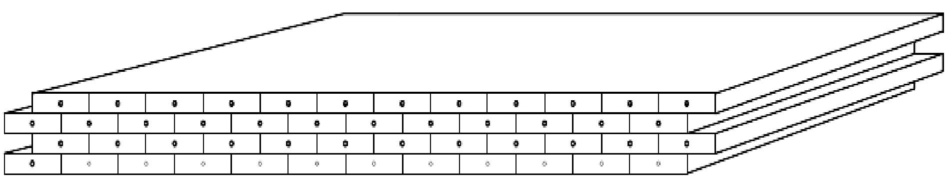
Cell nonlinearity 100-150 µm

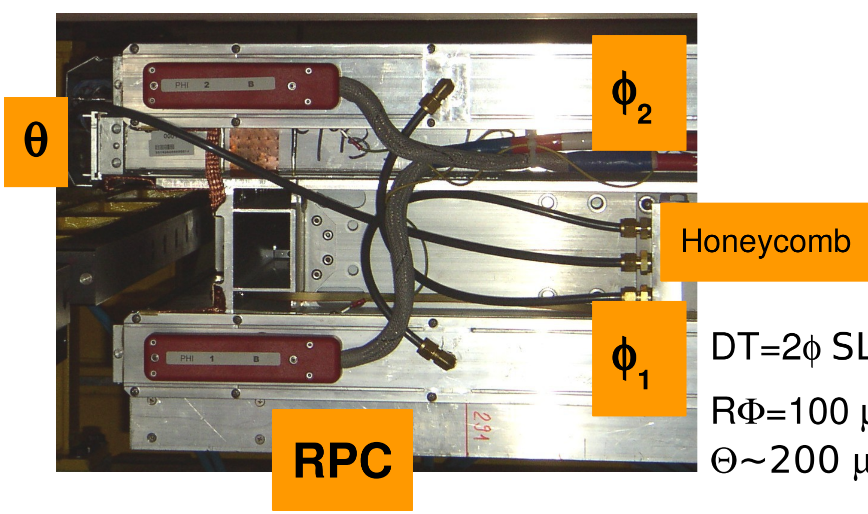


$$T_{max}=t_2+\frac{t_1+t_3}{2}$$

T_{max}~380 ns

$$v_{drift}=\frac{2.1}{T_{max}}\approx 54\,\mu m/ns$$



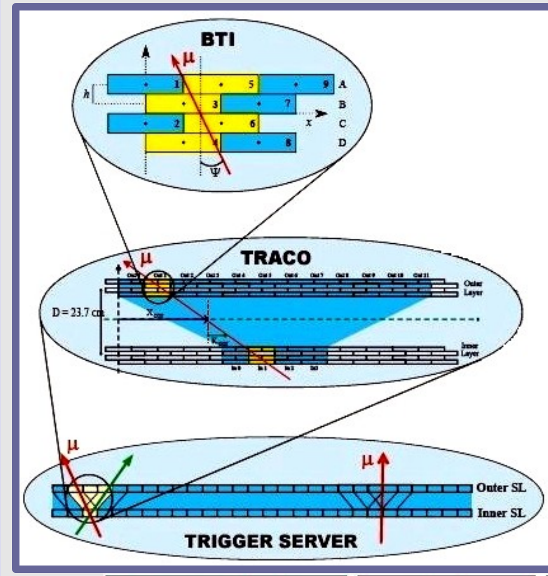


DT=2ϕ SL (+θ SL)

RΦ=100 µm

Θ~200 µm

On board Tr/RO electronics

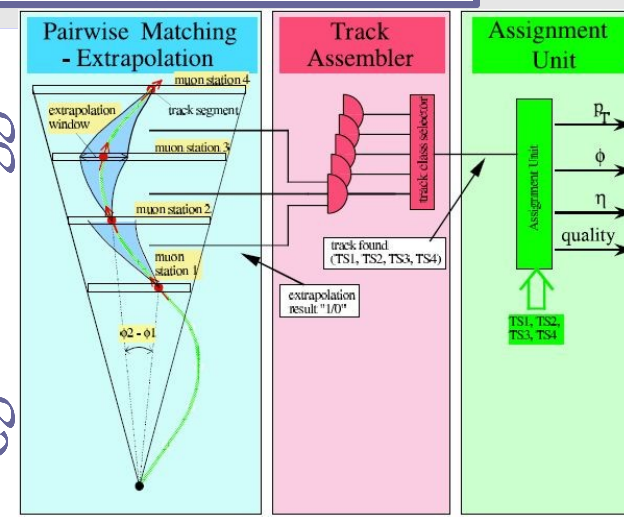


Bx identification
Track parameters
Segment quality

Φ improvement
Ghost supression

2 candidates selection

Regional Trigger



❶ Muons best measured by tracker

❷ Muon system main task is identification

❸ L1 trigger uses muons from muon system (cannot wait for tracker reconstruction)

Cathode Strip Chambers

See also: Poster by I. Vorobiev

MW proportional chambers: 6 anode wires planes interleaved between 7 cathode panels.

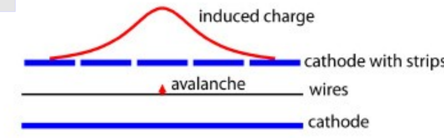
Chambers are 10° or 20° (Φ).

Wires: measure R coord. Strips Φ coord. Wires are 3.2 mm spaced.

Ar(40%)/CO_2(50%)/CF_4(10%) 3.6kV

ME1/1 specifics (under 4T). 2.9kV, 2.5 mm wire spacing, 29° wire tilt to compensate lorentz force

Work at high rates under non-uniform B



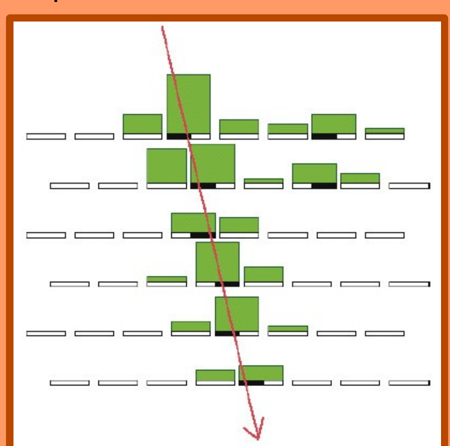
Φ coordinate by interpolation of charges in strips

Comparators identify hit position/layer with ½ strip accuracy (working on triads of strips)

Cathode Front- End Board

❶ TMB (1/chamber in peripheral crates) searches for patterns across layers

Up to 2 patterns/bx

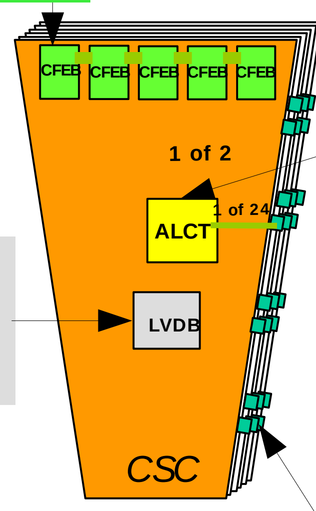


❷ Matches up to 2 ALCTxCLCT / bx

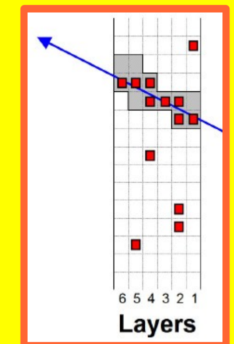
Muon Port Card (1/9 chambers) sorts out 2d-LCTs

Finds best 3 candidates and forwards them to Track Finder

LV Distribution Board



Anode LCT Board



Hit

Predef. pattern

ALCT performs (every 25 ns) FPGA based pattern search of muons coming from IP

Pattern demands at least 4 planes present

Upto 2 patterns/bx

ALCT are already trigger primitives

Anode Front- End Board

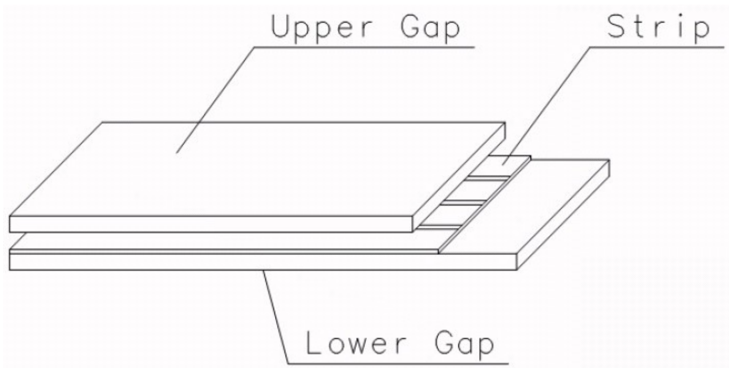
16 channel amplifier discriminator ASIC

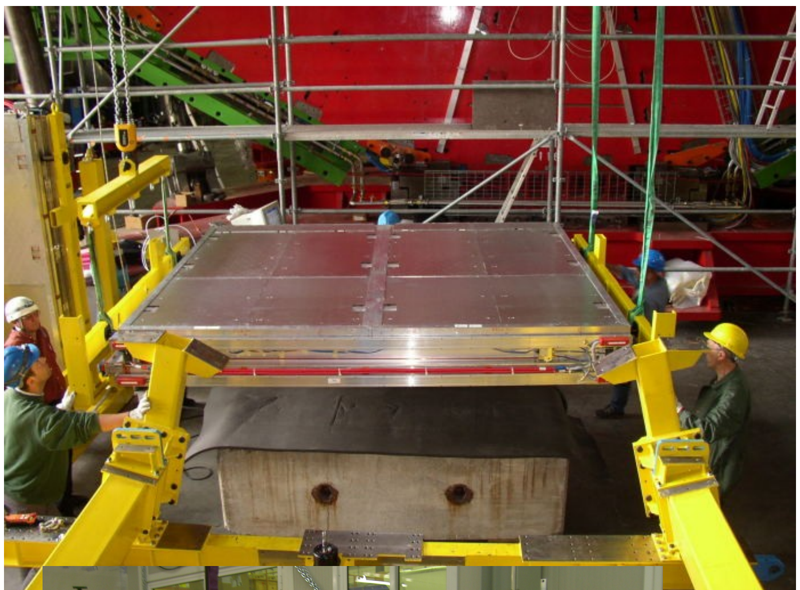
Depending on chamber size, there are 12 to 42

Wire signal gives fast information with rough spatial resolution O(mm)

Precise rΦ spatial measurement =100-240 µm/plane

Resistive Plate Chambers





Layout:

RPCs are gaseous parallel-plate detectors with excellent time resolution ~1.5 ns, used for BX identification (spatial resolution~cm)

RPCs consist of two gaps, operated in avalanche mode, with common pick-up strips in the middle.

One gap= Two "2 mm thick" bakelite plates, 2 mm spaced
Inner side painted with graphite, outer side insulated with Mylar
HV=10kV

Closed loop gas operation

Operated with 96.2% ($C_2H_2F_4$), 3.5% iC_4H_{10}, 0.3% SF_6

Water vapour added to keep 45% relative humidity⇒ avoids changes of the bakelite resistivity

Layout

Barrel: stations 1 and 2 have 2 layers of RPCs,
stations 3 and 4 only one each. Strips parallel to beam.

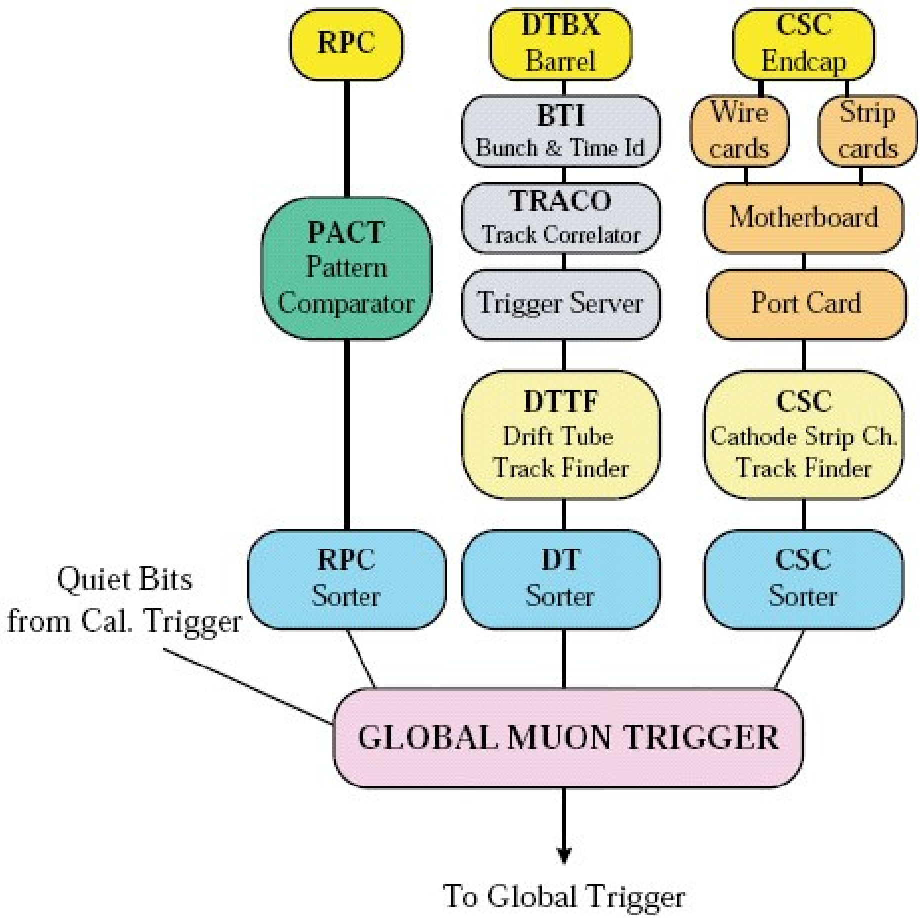
Endcaps: 3 rings, 4 layers (though innermost ring and RE4/* staged)

Electonics:

FE boards amplify and discriminate signals (16 strips/FEB)
LB (around the detector) synchronize the signals with the 40Mhz clock and transmit them to trigger electronics in USC.

Hits from all stations collected by comparator logic. If they are aligned along a possible muon track, a p_T value is assigned and quality information is added

L1 trigger system



Note: GMT also receives 2 bits (isolation and compatibility with MIP) from cal. triggers
This info is attached to the GMT and forwarded to GT

DTs & CSCs

First process the info from each chamber locally

One vector (position and angle) / chamber·muon is delivered

Vectors from different stations collected by Track Finders, tailored to form a track and assigned p_T

Up to 4 best (highest p_T,quality) muons/system sent to GMT

RPCs

4 highest pT muons for barrel and 4 highest for endcaps are selected

Global Muon Trigger

Redundant system:
either RPCs and/or DTs (CSCs) in the barrel (endcaps)
can be used to trigger

GMT receives the best 4+4 muons from DT+CSC and combines them with the 4+4 candidates from RPC
Matching of candidates based on proximity in (η,Φ) space
Case of matching⇒parameters combined for max precision
No matching⇒candidates are ranked (pT,quality,η) and sent to GT

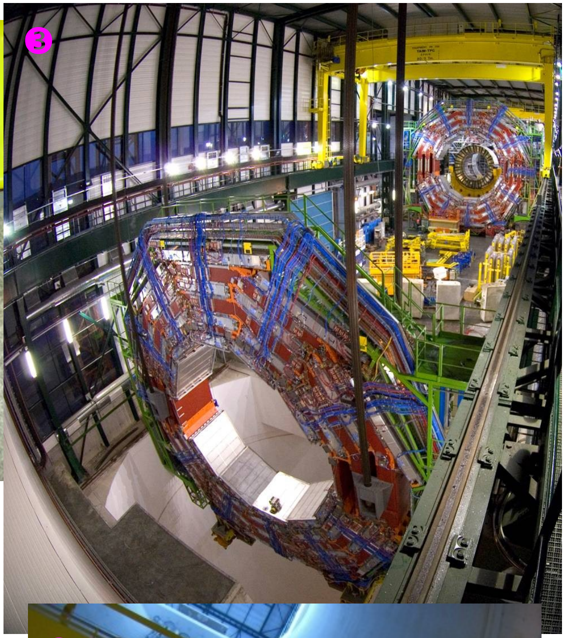
Barrel Status

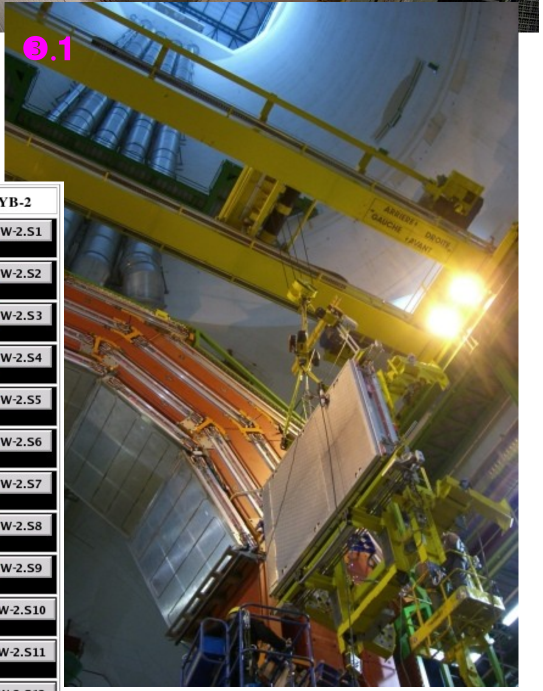
Chambers:

❶ All chambers ISR-precommissioned, installed and recommissioned

❷ All chambers equipped with MiniCrates (RO/trigger electronics)

❸ 8 DTs (horizontal) not installed (gantry cables) are then installed in UX5 (❸.1)





Wheels:

❹ 3@cavern: YB2/YB1/YB0
2@surface: YB-1, YB-2

❺ Wheels are >70% cabled (HV,LV,Tr/RO,DCS fibers,TTC fibers) and then lowered

❻ After cabling, wheels are sector commissioned from chambers up to tower electronics:

- YB-2 expected end of August (surface)
- YB-1 Sect. Comm. done (under.)
- YB0 75% sect. Comm. (under.)
- YB+1 expected beginning August (under.)
- YB+2 expected end of September (under.) (slowed down by shortage of LV supplies)

Sector	YB+2	YB+1	YB0	YB-1	YB-2
1	W2.S1	W1.S1	W0.S1	W-1.S1	W-2.S1
2	W2.S2	W1.S2	W0.S2	W-1.S2	W-2.S2
3	W2.S3	W1.S3	W0.S3	W-1.S3	W-2.S3
4	W2.S4	W1.S4	W0.S4	W-1.S4	W-2.S4
5	W2.S5	W1.S5	W0.S5	W-1.S5	W-2.S5
6	W2.S6	W1.S6	W0.S6	W-1.S6	W-2.S6
7	W2.S7	W1.S7	W0.S7	W-1.S7	W-2.S7
8	W2.S8	W1.S8	W0.S8	W-1.S8	W-2.S8
9	W2.S9	W1.S9	W0.S9	W-1.S9	W-2.S9
10	W2.S10	W1.S10	W0.S10	W-1.S10	W-2.S10
11	W2.S11	W1.S11	W0.S11	W-1.S11	W-2.S11
12	W2.S12	W1.S12	W0.S12	W-1.S12	W-2.S12

Underground Surface

http://dt-sx5.web.cern.ch/dt-s

Electronics

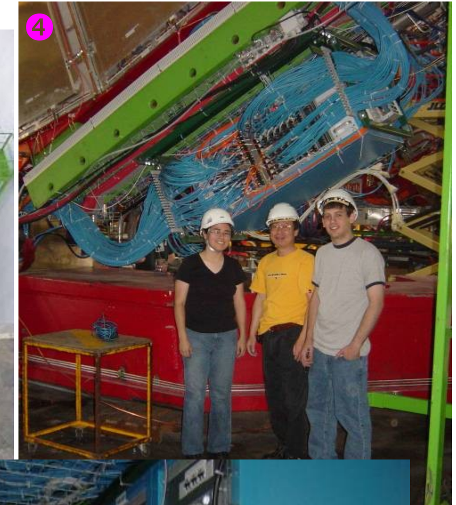
LV suppliers are late

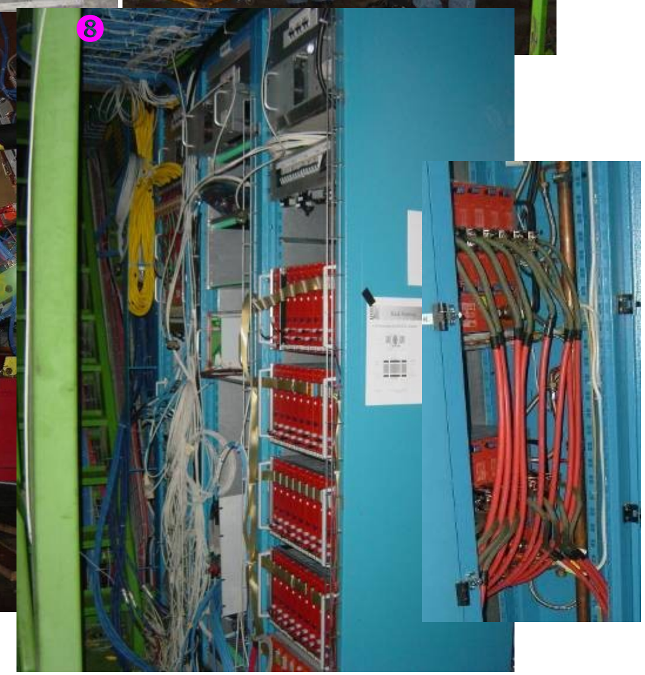
Cooling

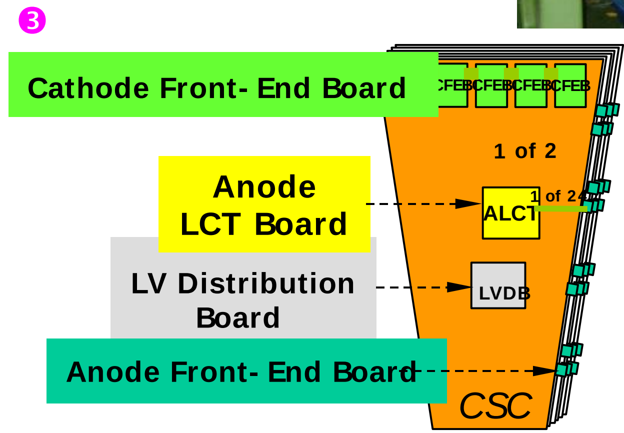
LV rack cooling requires more study

Endcap Status

- ❶ Started CMS heavy lowering (YE2,YE1)
- ❷ All chambers (468) mounted
- ❸ All on chamber electronics installed and commissioned
- ❹ All peripheral crates and electronics from discs in UX5 commissioned
- ❺ Services UX5 still being installed
- ❻ Commissioning in SX5 continues
- ❼ Slice test in UX5
- ❽ 15%HV system commissioned (rest is pretested&installed)
- ❾ LV system almost finished
- ❿ Gas and cooling connections done
- ⓫ Completed rack installation
- ⓬ Complete eMu commissioning Nov15?







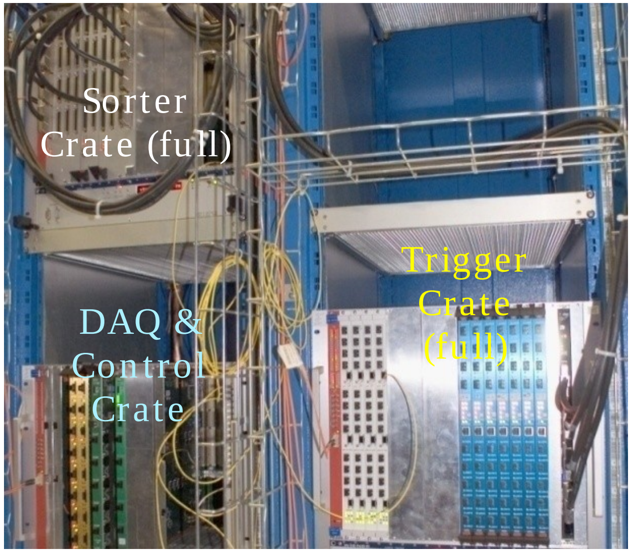
RPC Status

❶ Barrel and forward (except RE-3) chambers installed,
cabled and precommissioned (=gas tightness, HV/LV tests) done

❷ Barrel: HV wrong connectorization (firm's pitfall) obliged to replace HV cables. Work ongoing

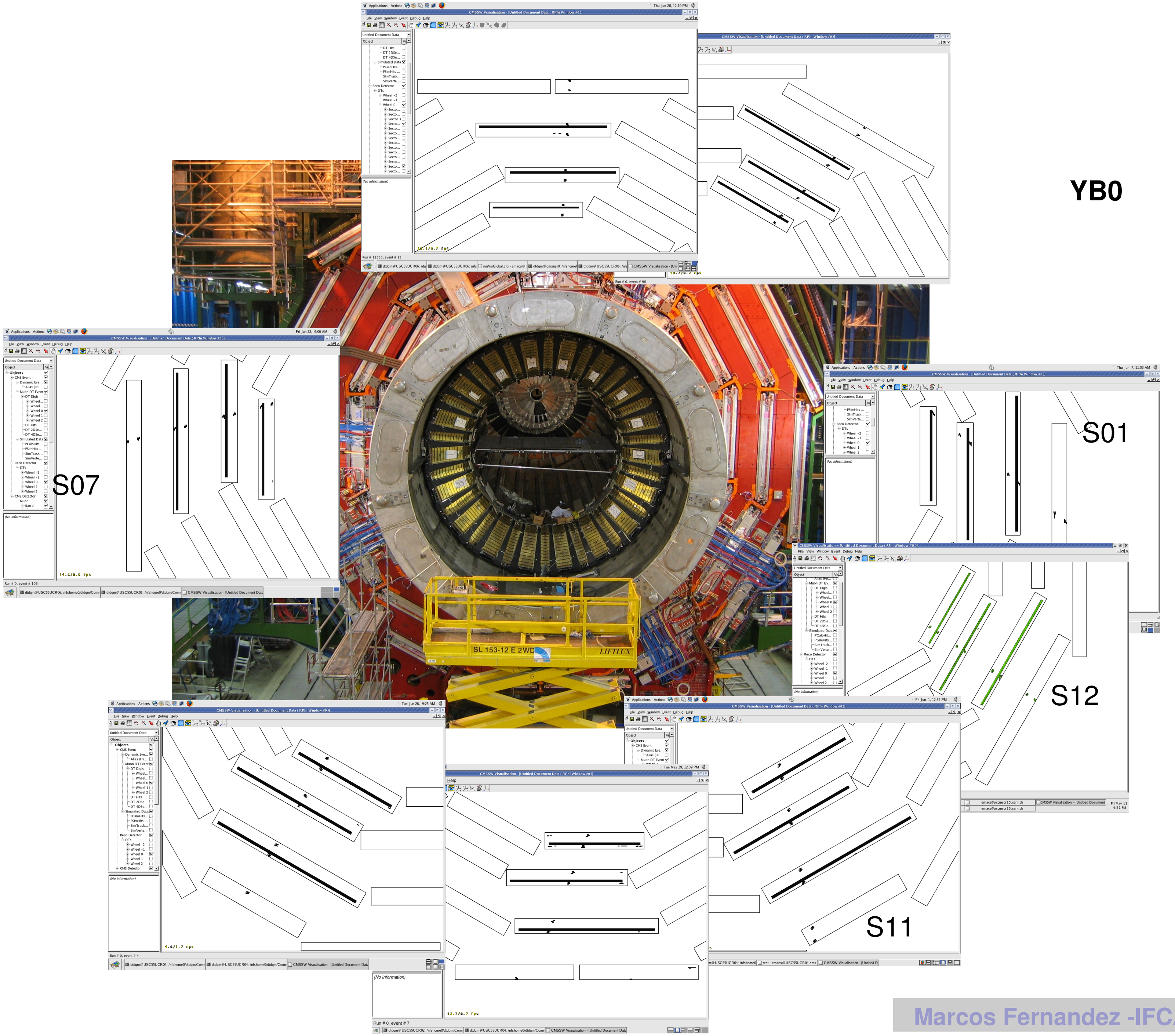
❸ Barrel full commissioning done by Feb 08.
Forward full commissioning done by Nov 07

❹ One Trigger Crate installed in USC and fully equipped is used for commissioning. Rest of Trigger Boards components delivered early August and will be assembled by September



❺ Long term gas tests showed correlation of gas parameters (humidity, purity), with dark current in some chambers. Tests carried out and solution expected in 2 months time

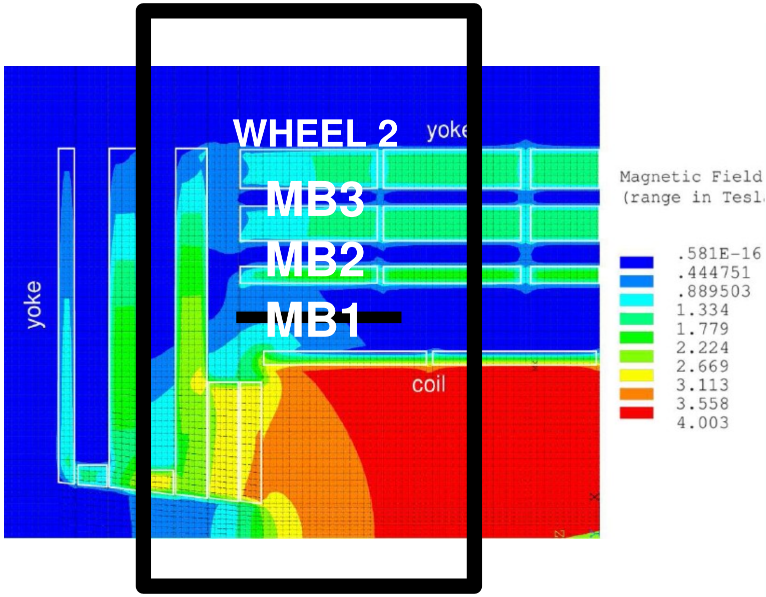
First Muons seen underground

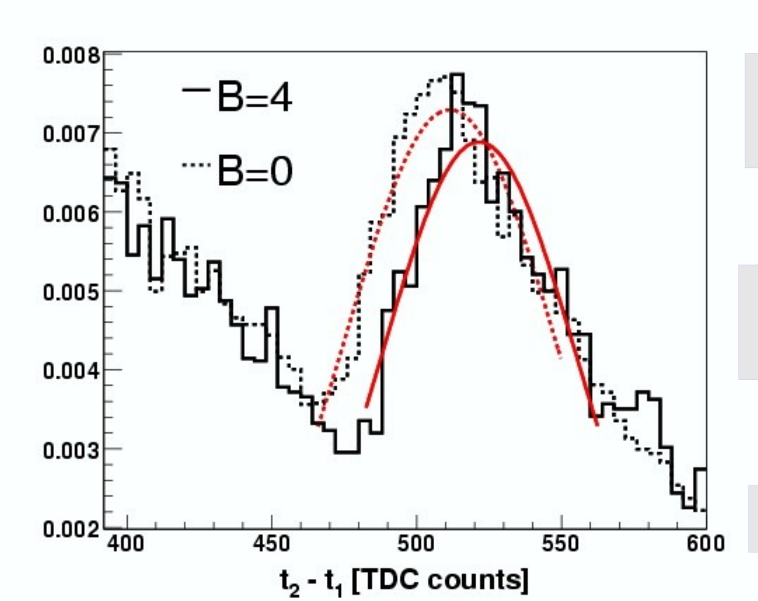


See also tomorrow:
First cosmic data taking
with CMS
(H. Sakulin)

Selected MTCC muon results …

Drift velocity and Magnetic field





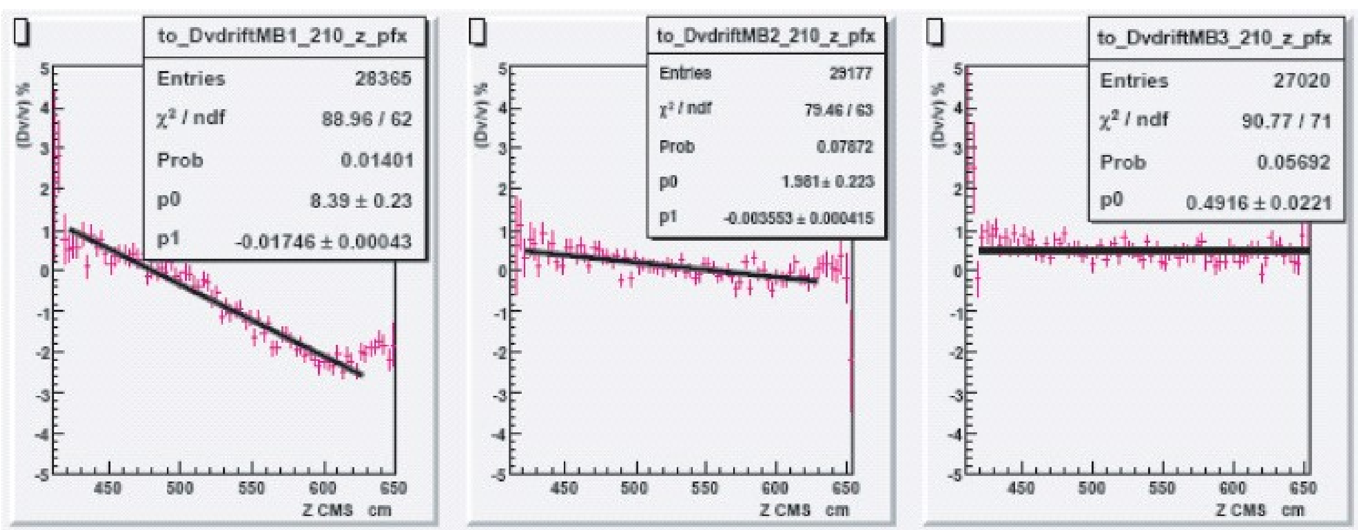
Photons produced near wire by the avalanche

↓

Some of them reach the cathode and produce P.E. effect

↓

Time(2^{ary}e-)-Time(1^{ary} e-)=Tmax



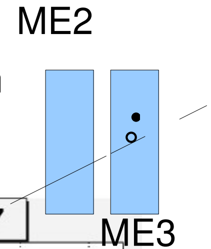
MB1 Wheel 2 | MB2 Wheel 2 | MB3 Wheel 2

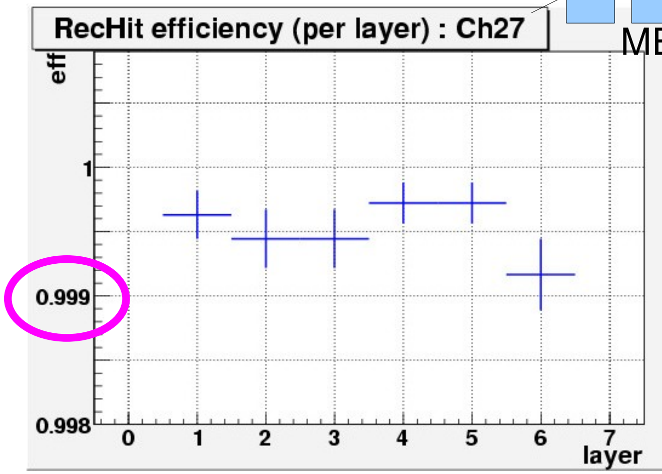
– Increased drift time implies change of v_{drift}

– v_{drift} decreases 3% at 4T for MB1 in wheel 2

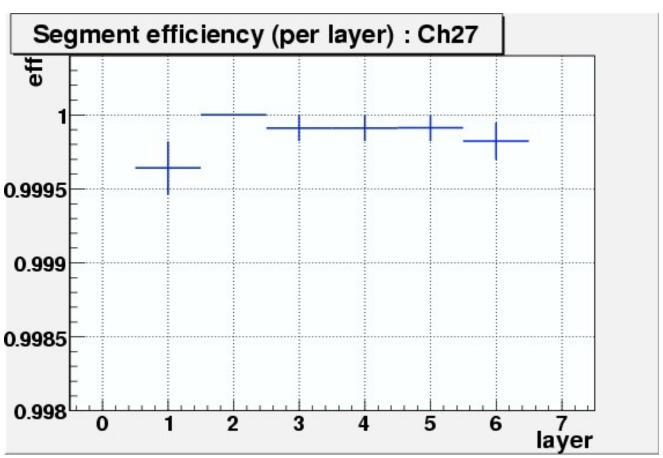
– Negligible effect in YB0/YB±1

1) Eff. to record a hit in a given layer in a given chamber





2) Eff. to place a hit in a segment

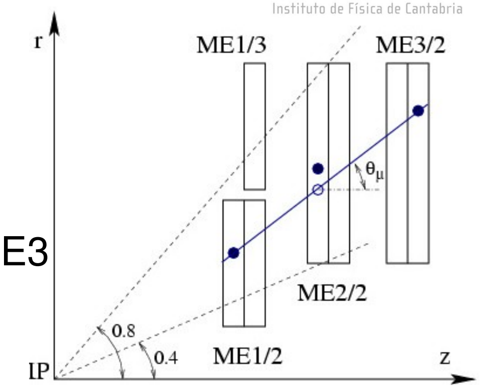


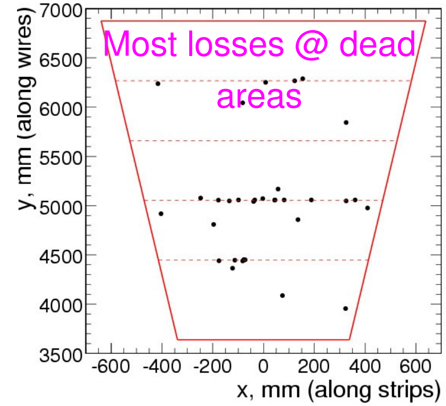
3) Eff. to find 2d-LCT (Anode and Cathode)

Sample:

IP-like muons reconstructed by ME1&ME3

ME2 not in trigger

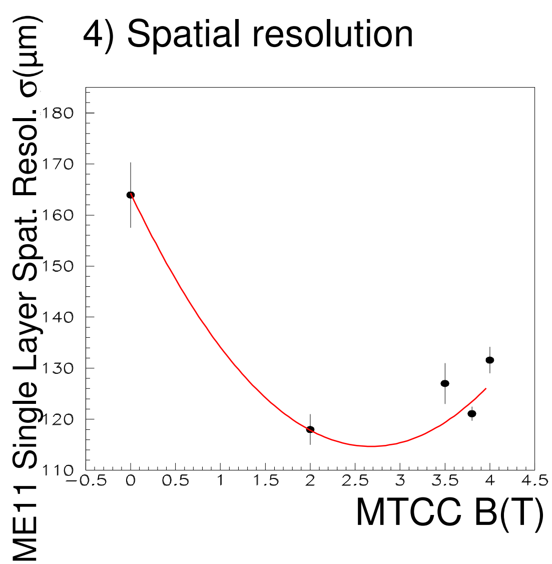




MISSED at ME2 (statistics for 6 chambers)

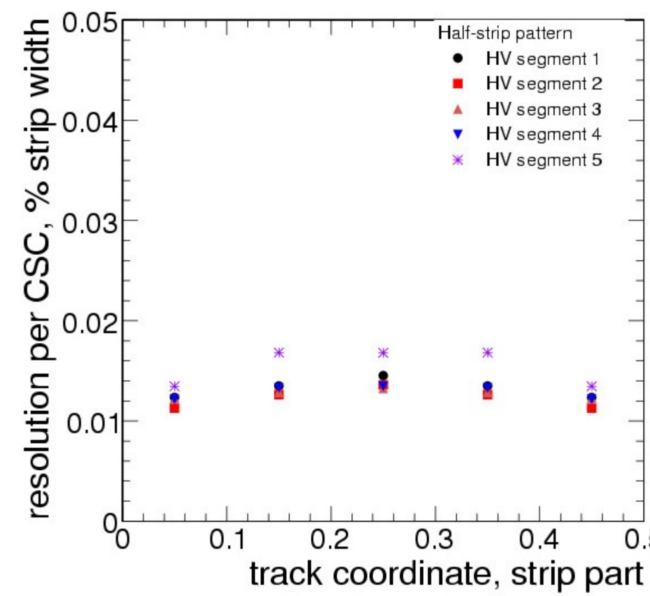
32 / 7376=99.6±0.1%(stat.) @ 3.6 kV

4) Spatial resolution

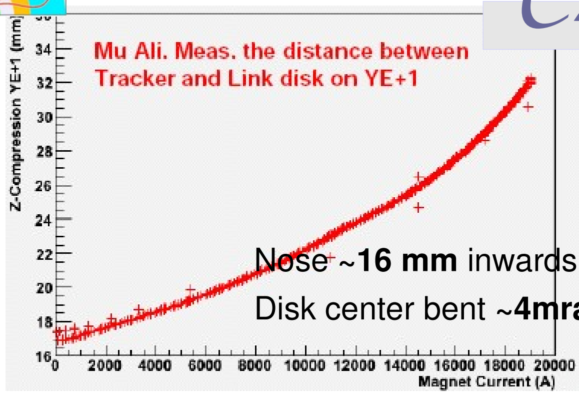


5) HLT: Hit reconstruction algorithm

It does not need any fitting or calibrations, only charges between neighbouring strips

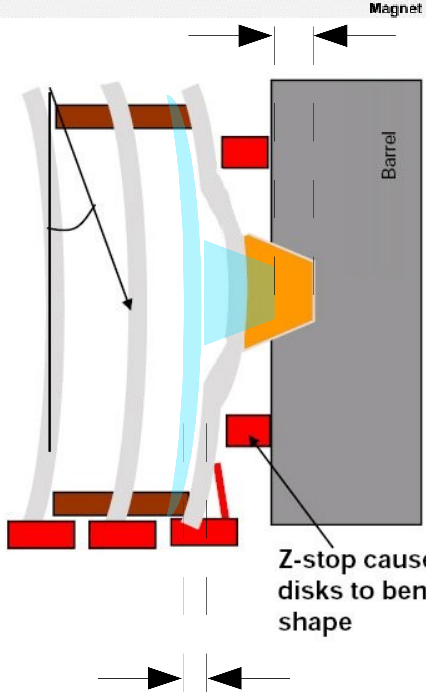


CMS magnet-induced "walks"

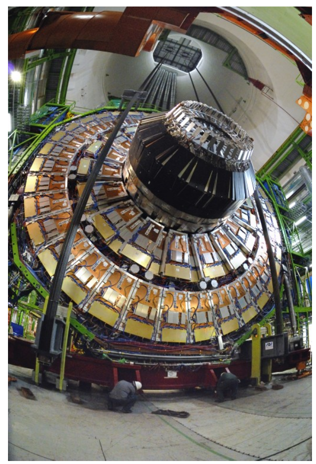


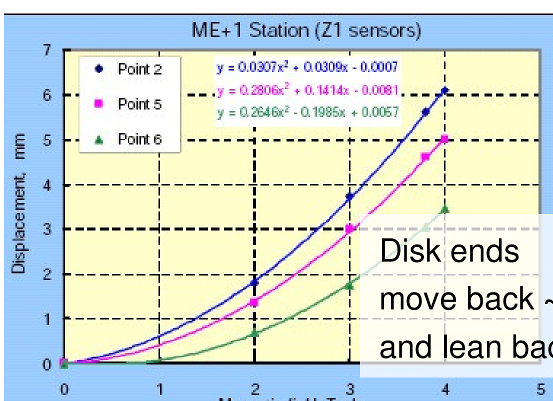
Nose ~**16 mm** inwards

Disk center bent ~**4mrad**



Z-stop cause the endcap disks to bend into a cone shape

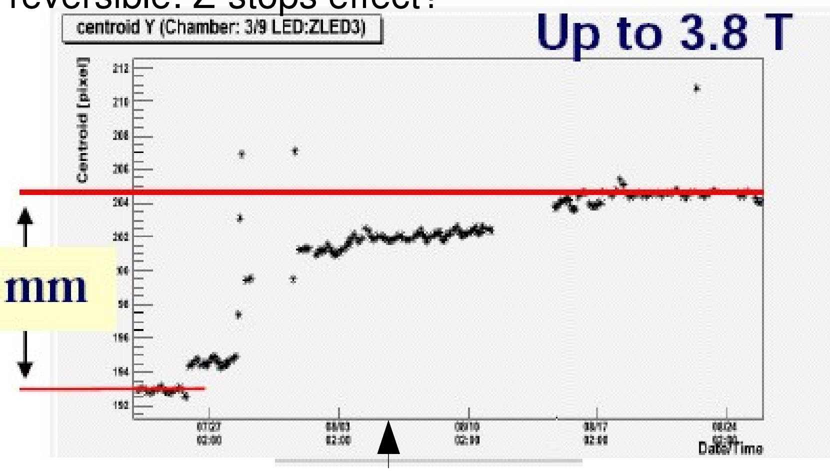




Disk ends move back ~**6 mm** and lean back ~**2.5mrad**

Distance YB2-YB0 (measured at B=0T) changed after magnet was powered at B=3.8T

Not reversible: Z-stops effect?

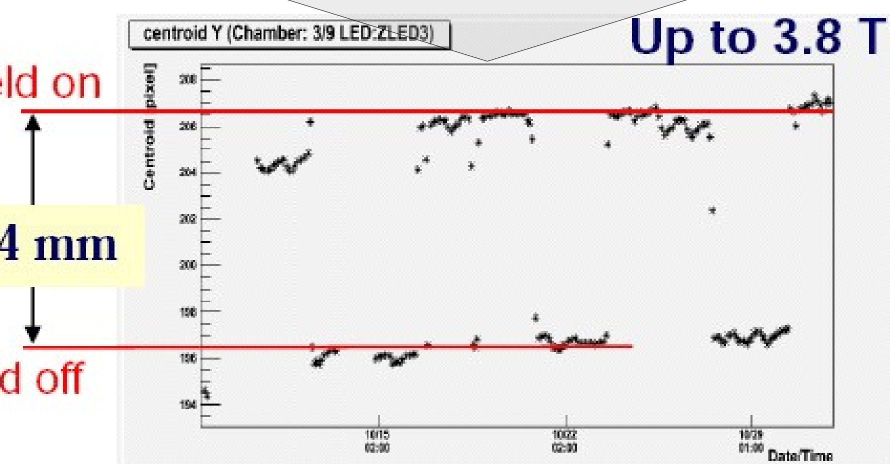


2.7 mm

B=0T (start of MTCC)

B=0T (end of MTCC)

CMS is open & closed again



Field on

2.4 mm

Field off

"Accordion" effect

Summary

CMS descent, installation and commissioning continues, as we speak

The muon system in CMS is redundant and highly efficient. It is used for L1 trigger
Combines fast detectors (RPCs) with precise spatial resolution devices (DTs in the barrel, CSC in the endcaps)

<u>Status snapshot:</u>

Barrel: after all Dts have been commissioned in surface, sector commissioning proceeds underground (40% accomplished)
Endcaps: Commissioning completion expected for November, 15%HV finished
RPCs: forward (barrel) commissioning finished by Nov. 07 (Feb08). Long term gas tests ongoing

<u>MTCC snapshot:</u>

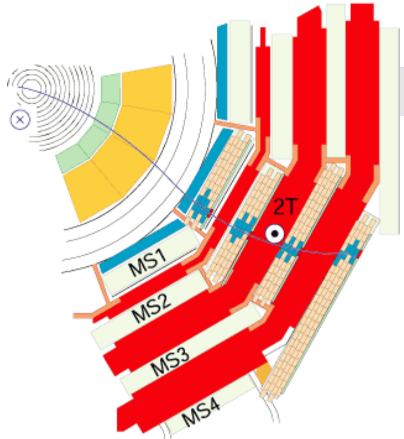
Muon system provided trigger to the experiment. Synchronization of the detectors studied for first time
Drift velocity decrease of 3% (as expected) seen for B=4T for innermost station in outermost wheels
New developments as the HLT algorithm developed along the MTCC

See also 2 other hardware talks (C. Wultz and H. Sakulin) tomorrow

Plots taken from following sources:
CSC Status: B. Paul Padley; DT Status: M. Dallavalle;RPC Status: A. Colaleo
DT results: Marco Zanetti, MTCC report
CSC results: MTCC report
Alignment : MTCC report and A. Calderon

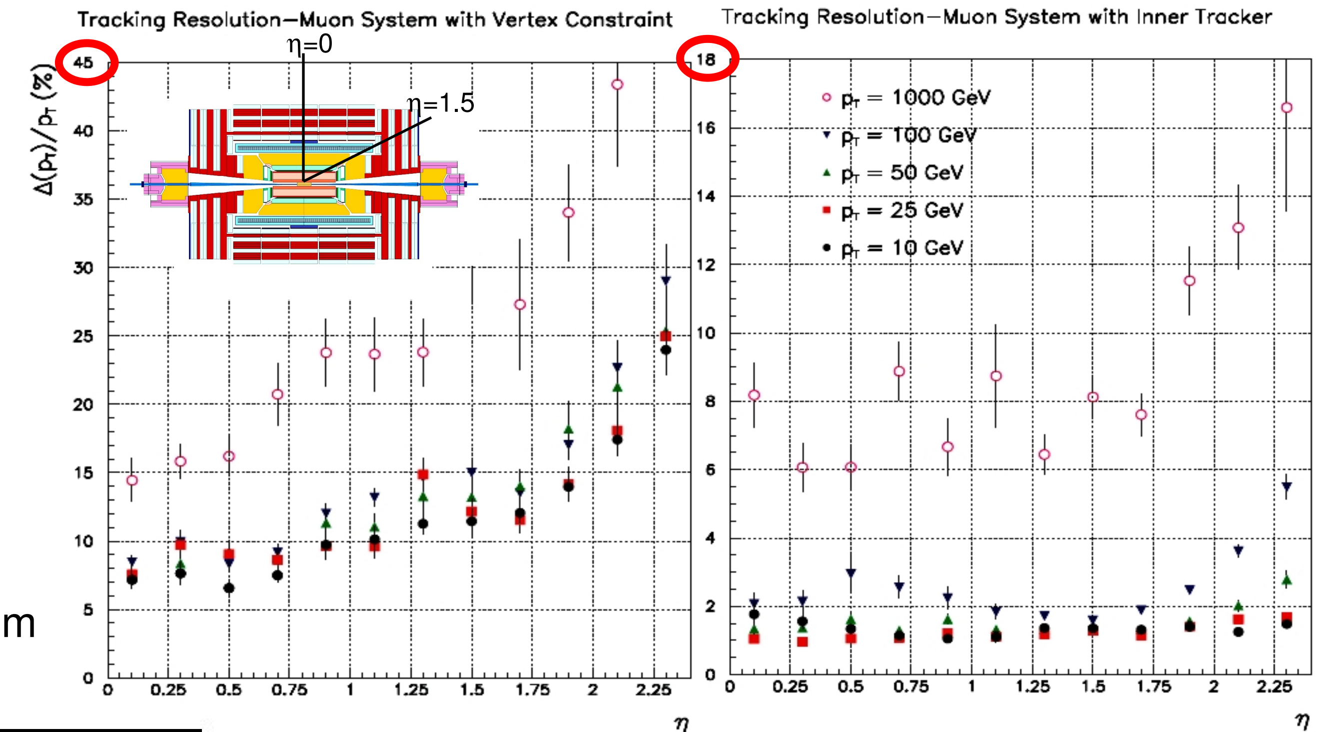
Backup …

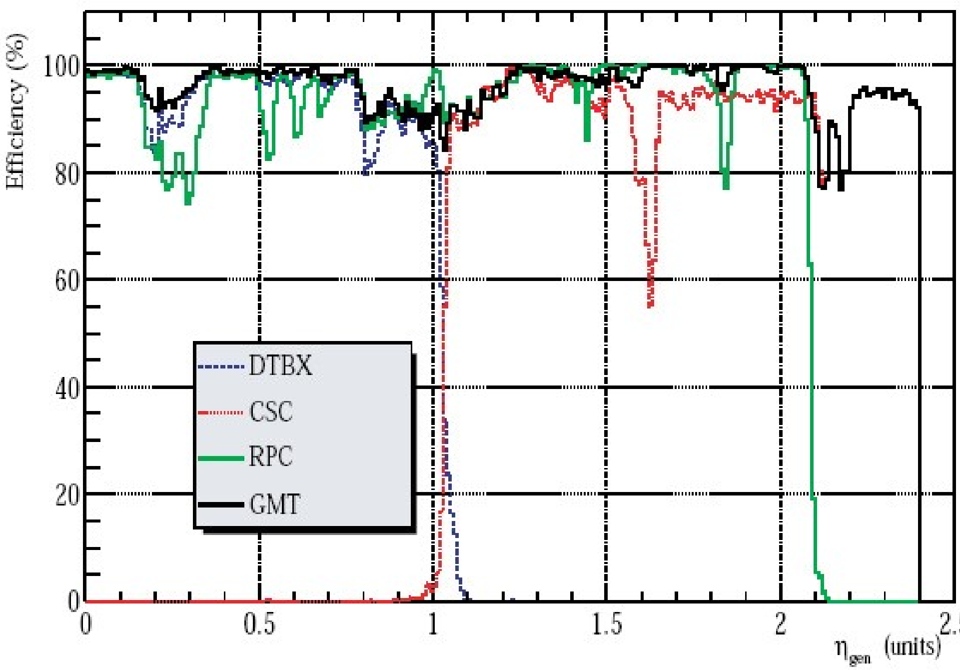
Muon measurement, performance and efficiency



Muons measured
in 3 different ways
(central muons with enough p_T):

1) In the Inner Tracker
2) With the muon system
3) Inner Tracker+ Muon System





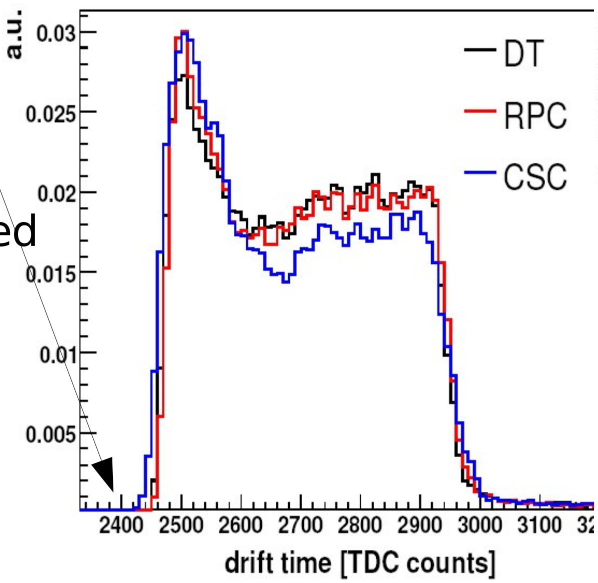
Efficiency=Prob. of finding at least 1 muon of any pT for events where 1 muon was generated

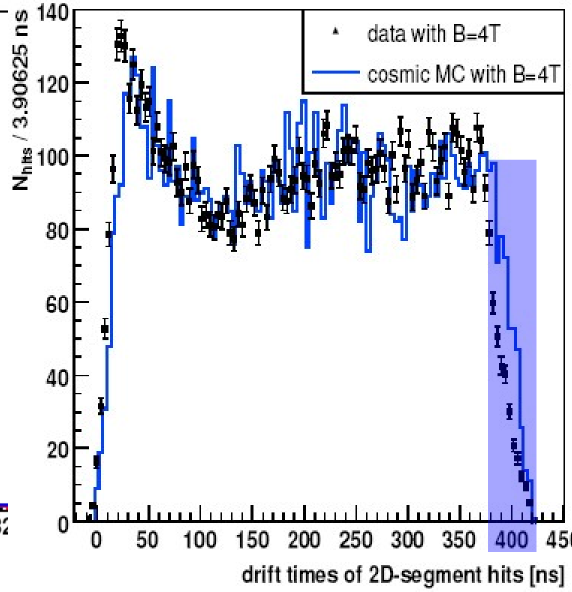
- GMT improves efficiency in all range.
- Gaps come from geometric acceptance: partially recovered by GMT due to complementarity of RPC wrt DT/CSC
- 2.1< |η|<2.4 no RPC available

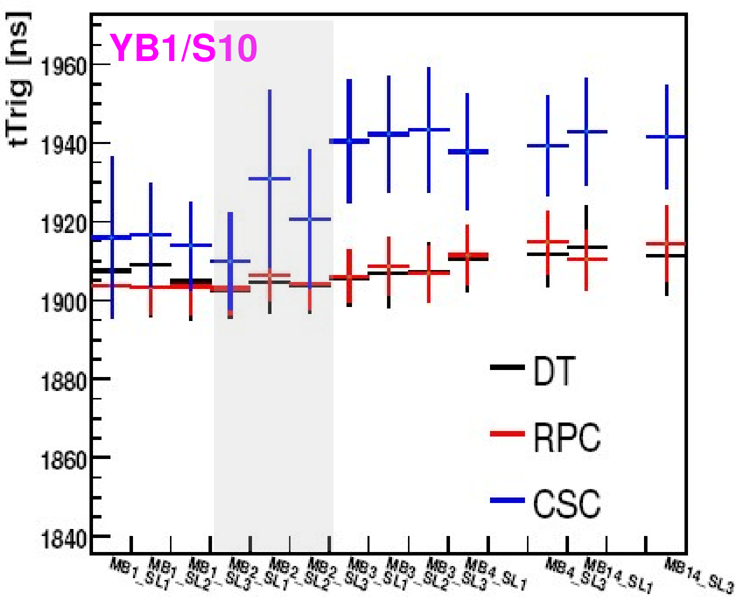
MTCC: MUON subsystems SYNCHRONIZATION

$x_{hit}=v_{Drift}(t_{TDC}-t_{Trig});x_{hit}=0 \Rightarrow t_{TDC}=0,\ t_{Trig}\neq 0$ (latency)

– Time pedestal smeared by signal produced along the whole wire, and the timing of the muons (25 ns bunched in LHC, or random in cosmics)



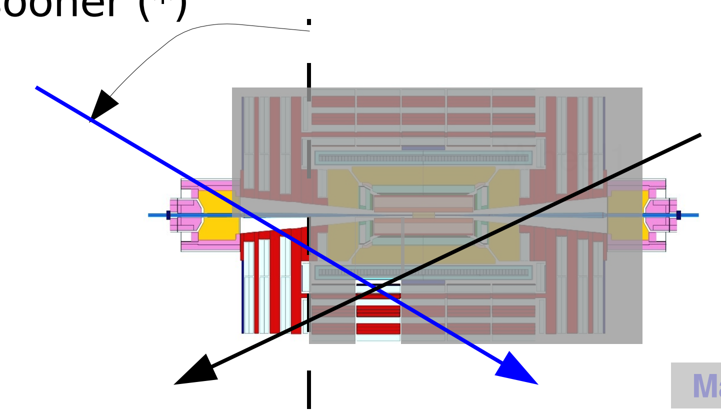




(*) trigger works in common stop mode

– Different trigger sources, different pedestals
– Good RPC and DT synchronization.
Poorer CSC synchro. wrt DT suffers from cosmics inclination. Some triggers will appear in diferenent BX

MB2/W1(CSC triggering) crossed mainly by muons 1st coming from CSC chambers. L1A from CSC arrives sooner (*)



Cosmics:

$$\frac{dN}{d\Omega}\approx\cos^2(\Theta)$$

MTCC

DT Hit Resolution

σ_{Ttrig}~7 ns⇔390 µm > cell resolution

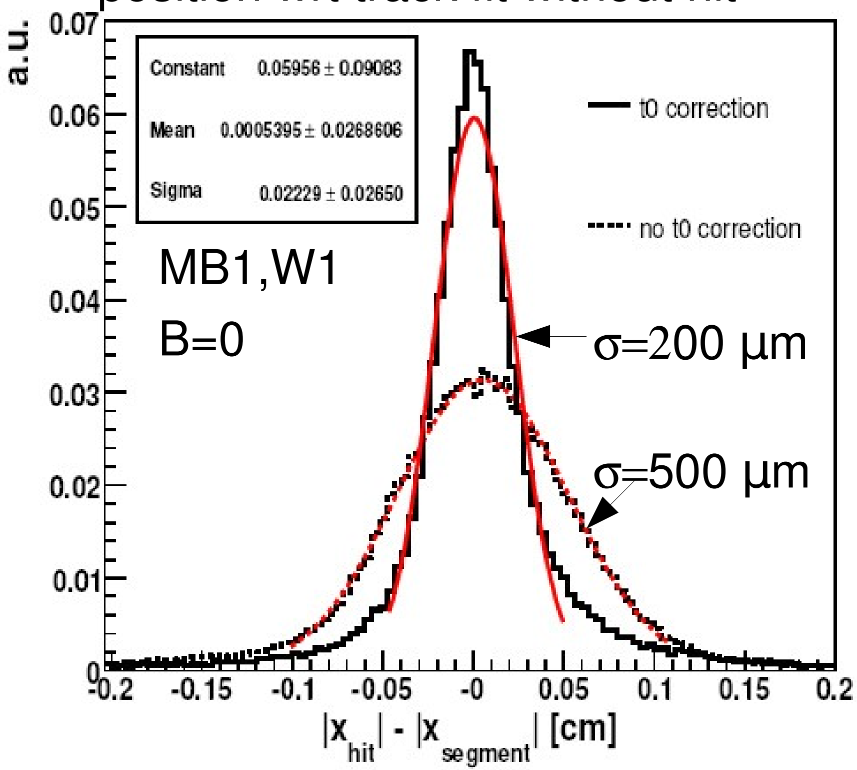
NEW event by event Ttrig correction :

8 meas/track

⇓

T_{trig}, v_{drift} , slope,intercept
fitted event by event

Residuals comparing measured hit position wrt track fit without hit



DT Momentum Resolution

Poor synchronization (non-bunched) cosmic rays leads to degraded p_T resolution

CMS design $\Delta p_T/p_T$~10%