Calibration of the Barrel Muon Drift Tubes System in CMS

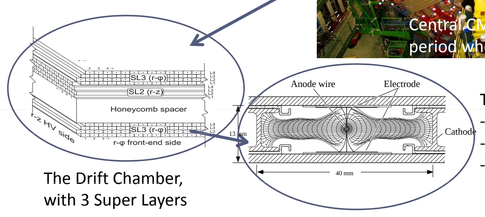
Silvia Maselli – INFN Torino, Italy
on behalf of CMS Collaboration

Introduction

Drift Tubes Detector

The Compact Muon Solenoid is a general purpose proton-proton detector designed to run at the Large Hadron Collider.

- Dimensions: Weight: 12500 tons, Diameter: 15m, Length: 21.6m
- Magnetic field: 4 Tesla (3.8T at start-up)
- Tracker and calorimeters inside the superconducting solenoid
- **Muon detector in the return yoke**
- Barrel + 2 Endcaps + forward detectors



The Drift Chamber, with 3 Super Layers

The elementary Drift Cell:
-Anode Wire +3.6 kV
- Cathode -1.2kV
-Electrode Strip +1.8kV

The Drift Tube System in CMS is a tracking detector.

The experimental signal:
Drift Time of the electrons which migrate to the anode wire
Measure of time-space relationship

The precise knowledge of the Drift Time and of the Drift Velocity requires an accurate calibration of the DT System.

The goal of the Calibration procedure is to determine:
- Time Pedestal from the TDC measurement -> Drift Time
- Estimate the Drift Velocity

Calibration of the Drift Tube System

Time Synchronization

The time measured by TDC contains the Drift Time + other contributions:

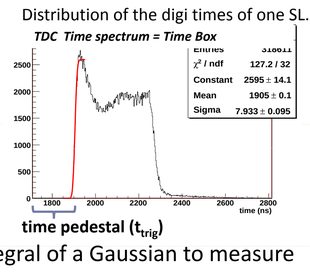
$$t_{TDC} = t_0^{pulses} + t.o.f. + t_{prop} + t_{offset} + t_{drift}$$

$$t_{trig} = t_{mean} - k\times\sigma(t_{mean})$$

Time Pedestal definition ➡ t_{trig} definition

t_{TDC} TDC measurement
t_0^{pulses} interchannel synchronization
t.o.f. Time of Flight of the muon from the IP to the cell
t_{prop} propagation time of the signal along the anode wire
t_{offset} trigger latency
t_{drift} drift time
t_{trig} Time Pedestal correction
t_{mean} inflexion point of the rising edge
$\sigma(t_{mean})$ width of the fit to the rising edge of the Time Box

Distribution of the digi times of one SL.



The Method:
The rising edge is fitted with the integral of a Gaussian to measure the pedestal of the drift time.

The Time Pedestal is related to the inflexion point of the rising edge through a **k** factor that is tuned by requiring the minimization of residuals on the reconstructed hit position.

The Time Pedestal Calibration is computed with Super Layer granularity

Drift Velocity Calibration

Time Pedestal depends on the Drift Velocity used in reconstruction.

Drift Velocity depends on: gas purity, temperature, pressure; electrostatic configuration within cell } Hardware monitoring

Effective Drift Velocity influenced by impact angle and magnetic field.

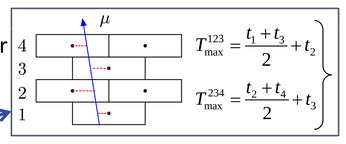
Two possible algorithm:
- parameterized Drift Velocity
- linear constant Drift Velocity choosing proper granularity within detector

In the present analysis a linear constant Drift Velocity is assumed.

The Method:
Mean Timer technique to estimate the Maximum Drift Time

T_{Max} computed with the Mean Timer technique. Different formula for different pattern.

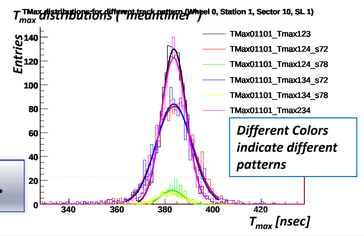
The most simple case:



$$T_{max}^{123} = \frac{t_1+t_3}{2} + t_2$$

$$T_{max}^{234} = \frac{t_2+t_4}{2} + t_3$$

$<T_{Max}>$, $<\sigma_{TMax}>$ computed as weighted mean of each formula

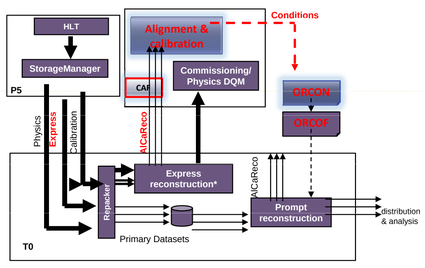


Vdrift = L/2 * 1/<Tmax>

Resolution = $\sqrt{2/3}$ Vdrift * $<\sigma_{TMax}>$

Prompt Calibration Work Flow

Requirements: robust, automated, short latency procedure



The Calibration constants are computed at the CERN Analysis Facility (CAF) a dedicated cluster for fast analysis/calibration with a fast access to data Disk storage.

The Constants are Validated at CAF and transferred to the experiment Online DB (Oracle Back-end Pool-ORA which Serves HLT trigger - ORCON) and streamed to the offline DB (Oracle Back-end Pool-ORA Serves offline reco at Tier0 - ORCOFF) .

10-20 % of total bandwidth are used as calibration data input.
A Data reduction processed by the Central CMS Computing Facility (Tier0) skims the event content (Alignment and Calibration Streams - AlCaReco) e.g. for Muon Calibration the Muon Digitations product are saved.

Results

Two main steps in commissioning the Drift Tube calibration procedures:
Proof-of-principle with Simulation Data: 2008 Computing Software and Analysis challenge (CSA08)
Real Cosmic Data: Cosmic Run At Four Tesla (CRAFT)

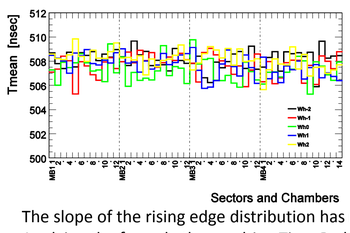
CSA08 results

Simulated Events: Computing Software and Analysis challenge (CSA08)

For the first time, a full-scale challenge with large statistics under conditions similar to LHC startup.
Full complexity of end-to-end workflows daily, database operations, constants validation.

21M Leptons (mostly from b/c + W/Z):
S43: 6 days with 43 × 43 bunch configuration with luminosity L = 2×10^{30}
S156: 6 days with 156 × 156 bunch configuration with luminosity L=2×10^{31}

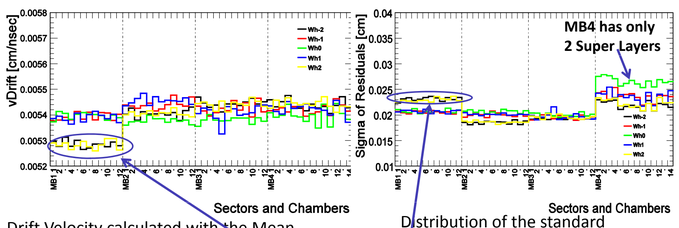
Time Pedestal Calibration



Mean value of rising edge of the Time Box:
- Time Of Flight from the interaction point is already subtracted.
- An average value ~ 507 nsec is shown, consistent to the input time pedestal added to the drift time at simulation level
- Fluctuation due to time of propagation of the signal along the wire (~2 nsec)

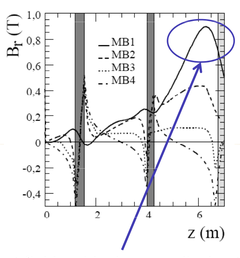
The slope of the rising edge distribution has resulted to be on average ~3 nsec
Applying the formula the resulting Time Pedestal value is closed to the one used at simulation production.

Drift Velocity Calibration



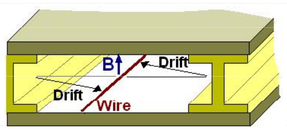
Drift Velocity calculated with the Mean Timer technique.

Distribution of the standard deviation of the residuals directly proportional to the hit resolution



The path length increases
➔ Drift velocity "apparently" decreases

Sketch of the effect of B perpendicular to the wire on the Drift path



Magnet field residual perpendicular to wire is present in some of the Drift Tube chambers

The real life: Cosmic Run At Four Tesla (CRAFT)

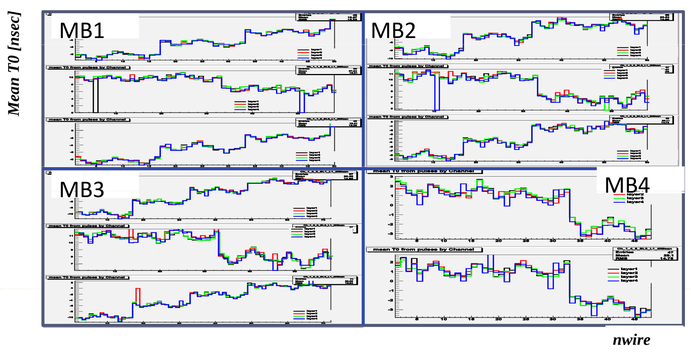
Drift Tube Calibration with Real Data:
- Interchannel Synchronization
- Noise Calibration
- Time Pedestal Calibration
- Drift Velocity Calibration

$$t_{TDC} = t_0^{pulses} + t.o.f. + t_{prop} + t_{offset} + t_{drift}$$

$$t_{trig} = t_{mean} - k\times\sigma(t_{mean})$$

Interchannel Synchronization

- Inter-channel synchronization is the signal path length to the readout electronics.
- It is computed within each chamber with a wire granularity
- Test Pulse events are injected to FE electronics, acquisition during Abort Gap (~1MB/sec)
- Special stream of calibrations events are foreseen



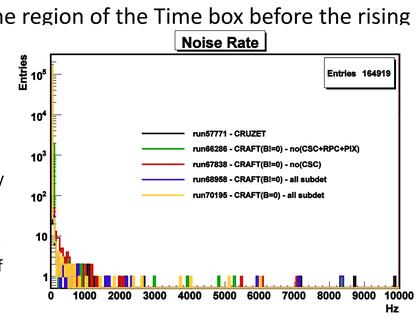
The trend of the graphs shows stepping functions which reproduce the distance of the FE boards in each chamber from its centre.
Maximum Interchannel sync. correction ~10 nsec.

Noise Calibration

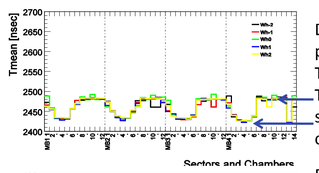
Very low number of noisy cells ≈ 20 in the whole DT system - < 1‰

Noise calibration has the role to "clean" the Time Box distribution before fitting the rising edge to find the Time Pedestals.
Noisy cells:
-have hits registered in the region of the Time box before the rising edge.
- have rate > 500 Hz.

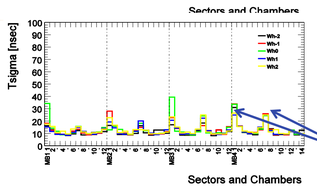
Noise in the Drift Tube System results to be:
-Stable for all data taking period
- Not influenced by B field, and by the presence of other detectors
- concentrated in more internal chambers (MB1)
- concentrated in the extremity of the cell layers



Time Pedestal Calibration



Distribution of the mean of the inflexion point of the fit to the rising edge of the Time Box.
The difference of values between above sectors a below sectors explained by Time of Flight of Cosmics.

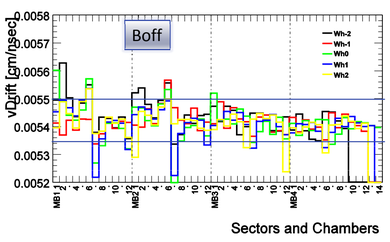


Distribution of the slope of the rising edge of the Time Box.
The contribution of the slope is ~ 10 nsec which depends from the distribution of the arrival time of cosmics.
The vertical sectors:
- do not participate to the trigger
- have more inclined and worse defined tracks
- have lower statistics

The Time Pedestal Calibration is obtained from this expression with k=-0.7 obtained minimizing the reconstruction residuals.

$$t_{trig} = t_{mean} - k\times\sigma(t_{mean})$$

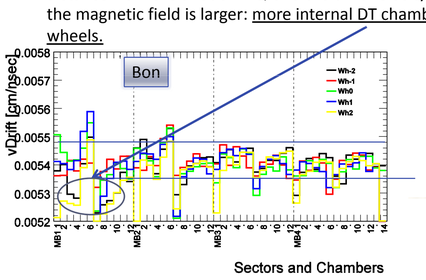
Drift Velocity Calibration



With no magnetic field, and not counting for the experimental uncertainties, an approximate constant value of 54.3 μm/nsec is observed.
Fluctuation are originating from:
- vertical Super-Layers
- Super-Layers out of data acquisition
- uncertainties in the arrival time of cosmics
- Cell non linearity

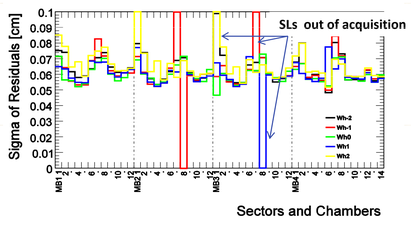
Two main sources of Drift Tubes non linearity: { Angle of tracks, Magnetic field

Both contributions are evident computing the residuals as a function of the distance from the anode wire, and the drift velocity where the residuals of the magnetic field is larger: more internal DT chambers (MB1) for the outer wheels.



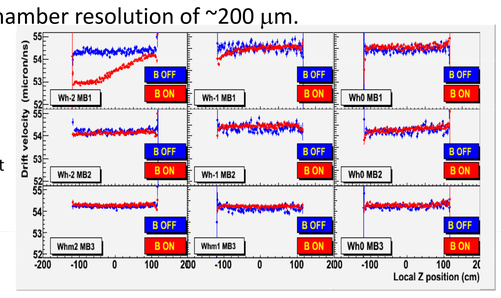
The Validation of the Calibration procedure is performed computing the residuals on the reconstructed distances from the wire. They contain the convolution of arrival time of cosmics and the cells non-linearity.

CMS is not designed for cosmics!
Cosmics have random arrival time while CMS trigger designed for bunched muons (40 MHz) with fixed t.o.f. → additional smearing of (25/√12) ns ≈ 400 μm



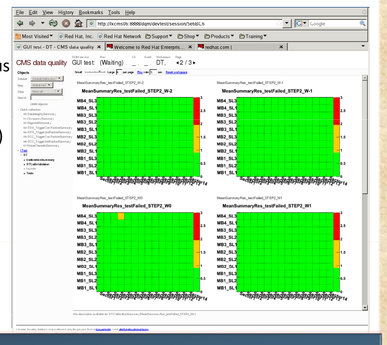
The distribution of the σ of the residuals for the triggering sectors is an indication of the resolution obtained at the pattern recognition level which shows a value of 550 μm.
A straight line fit leaving as additional free parameters the drift velocity and the time of passage of the muon provides the expected chamber resolution of ~200 μm.

The fit provides also a better refined linear constant value of the drift velocity. The most internal chambers (MB1) of the outer wheels show a lower value .

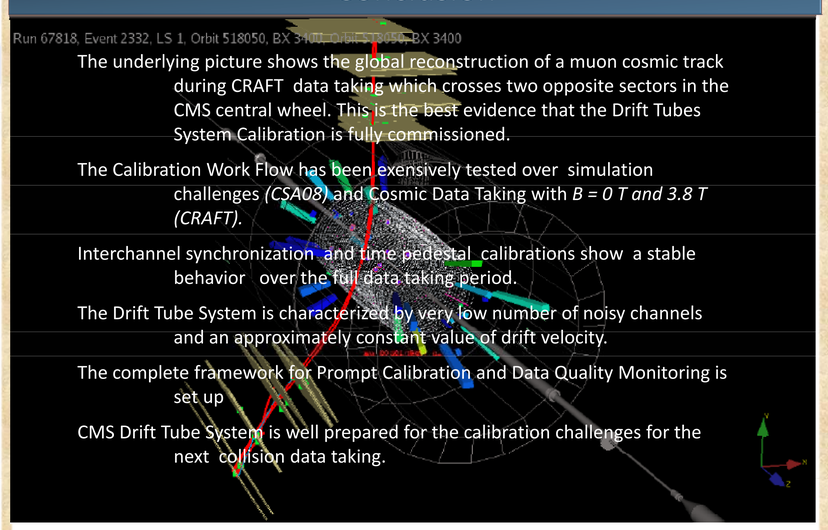


Data Quality Monitoring for DT Calibration

- Successful completion of the constants validation does not ensure the output of the Calibration is reasonable with regard to previous versions.
- Monitoring histograms are created and collected in the Data Quality Monitoring (DQM) infrastructure of CMS.
- This tool provide the experts with all the information necessary to validate the new release and receive quality feedback within a short time.



Conclusion



The underlying picture shows the global reconstruction of a muon cosmic track during CRAFT data taking which crosses two opposite sectors in the CMS central wheel. This is the best evidence that the Drift Tubes System Calibration is fully commissioned.

The Calibration Work Flow has been exensively tested over simulation challenges *(CSA08)* and Cosmic Data Taking with *B = 0 T and 3.8 T (CRAFT).*

Interchannel synchronization and time pedestal calibrations show a stable behavior over the full data taking period.

The Drift Tube System is characterized by very low number of noisy channels and an approximately constant value of drift velocity.

The complete framework for Prompt Calibration and Data Quality Monitoring is set up

CMS Drift Tube System is well prepared for the calibration challenges for the next collision data taking.

Silvia Maselli: Maselli@to.infn.it