# Pixel Upgrade for the CMS Detector at the Large Hadron Collider

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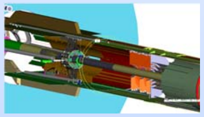
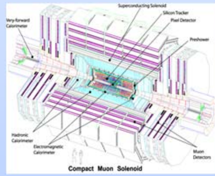
## CMS Detector



### Introduction

The basis of this research is designated around the Compact Muon Solenoid (CMS) experiment at the Large Hadron Collider. This massive, yet relatively small, detector consists of several layers to track different types of particles in a collision. This apparatus uses a 13m x 7m solenoid magnet which produces a magnetic field of approximately 4 Tesla, to bend the path of the particle so that its momentum can be measured. This momentum is crucial to our understanding of the events at the time of the actual collision. A tracker is necessary to record this information so it can, then, be analyzed.

**The Tracker:** Colliding bunches of protons first encounter the silicon tracker consisting of 13 layers at the center region and 14 layers at the end caps. This tracker measures the trajectories of individual particles and then matches them to their origins.




**The Electromagnetic Calorimeter:** the next layer consists of lead tungstate crystals and is designed to stop and measure the energies of electrons and photons.

**The Hadronic Calorimeter:** This layer consists of brass or steel layers containing plastic scintillator tiles and is designed to measure the energy of individual hadrons and to allow the identification of missing energy events.

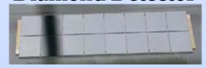
**The Solenoid Magnet:** This enormous magnet uses its field to curve the track of the particles and allows for the measurement of their charge/mass ratio.

**The Muon Detector:** This layer consists of three parts: drift tubes, which measure the precise trajectory in the central barrel region; cathode strip chambers, which have the same function, but are located at the end caps; and resistive plate chambers, which provides a quick signal when the muon passes through the detector.

## CMS Readout Boards

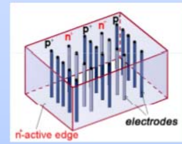

- Planes constructed from current CMS technology
- 4 Sets of X and Y planes allow for adjustable telescope geometry
- 6 or 8 Read Out Chips for X and Y oriented planes

## Diamond Detector



- Fast readout compared with silicon detectors
- Currently used in CDF and ATLAS
- Radiation hardening increases lifetime and reliability along the beam-pipe

## 3D Detector




- Provide 3D particle track information
- Allow for reconstruction of secondary vertices from β and τ decays
- Efficient power consumption
- Currently being used in ATLAS

- Several other prospects under going test and analysis
- Detectors are tested at Fermilab Meson facility
- Diamond Detector (Torino)
- 3D silicon detector (Purdue)

## Radiation Hardness

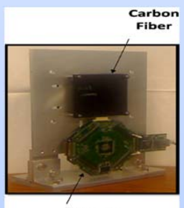
- When pixel detectors are exposed to the high energy produced in the CMS and ATLAS experiments their specific properties gradually change as a result of radiation damage, which:
- Alters energy levels of silicon atoms
- Changes effective carrier concentration
- Changes voltage and current characteristics
- Increases leakage currents

These factors lead to a loss of resolution and efficiency

- Radiation hardened sensors undergo a process which makes them more resistant to these effects
- The result is a pixel chip which is more reliable under the high radiation environment associated with the close proximity to the beam pipe

## Captan Boards

- Each pixel plane has a dedicated processing board
- Boards perform Analog to Digital Conversion "ADC" at various speeds
- Equipped with Gigabit Ethernet Port for fast readout
- Operate at 3.8 V
- Can be linked to the test device for data acquisition

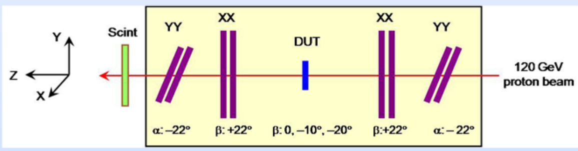



### Runtime Parameters

(Value estimates from last run)

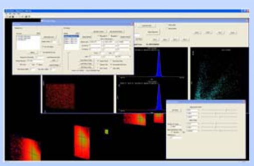
- Trigger voltage 1-1.1 kV
- Trigger Delay 8ns
- Plane geometry
  - X-plane angle α
  - Y- plane angle β
- DUT threshold Voltage VTH
- DUT testing angle β

## Telescope Setup




- Telescope dimensions 17 cm x 17 cm x 86.8 cm
- DUT Mounted on a rotatable Data Acquisition Unit
- 8 CMS PSI46 readout chips are located upstream and stream from the DUT
- Planes tilted to 22° to produce charge sharing for improved hit precision
- DUT and adjustable Telescope planes allow for variable telescope geometry
- Scintillation trigger located upstream for early particle detection

## Testing Procedure/Online Analysis



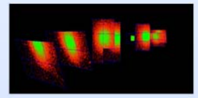
### Procedure Outline

- Predetermine trigger threshold in test run trials
- 10 minute runs for each study of interest
- Data integrity is checked using 3D viewer
- Beam should appear centered in planes
- Data collected from each run is merged into software structures to represent complete events
- Runs are generated as various parameters on the DUT are changed such as β and VTH
- Each test run is given a unique run number
- Further analysis is carried out offline to asses DUT performance

### Advanced GUI

- Voltage and current monitoring
- Incorporated Network monitoring
- Easy access and control of run parameters
- Auto calibration of planes and DUT
- 3D Visualizer for integrity data monitoring and beam alignment

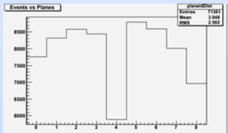
## Alignment



- Performed both online and offline
- The beams must share a common center, used as a reference point..in plane frame
- Alignment is made by one adjusting a single plane parameter at a time.
- This is repeated for each plane to produce optimal plane geometry
- Optimal fit parameters are stored in XML configuration files for use during analysis

## Event Building

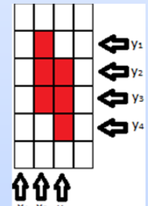
- Events are generated as the particle crosses the sensor plane
- Organized by plane and location
- Coordinates recorded locally by pixel row and column
- Locations are used to produce hit maps




Events detected per plane

## Clustering

- Cluster plane coordinates given by $x_i$, $y_i$
- Clusters refer to isolated groups of pixel events
- Pixel events are used to calculate weighted charge center for clusters
- This is done for X and Y projections



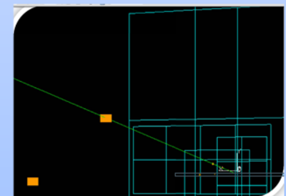

$$\bar{x}_i = \frac{\sum Q_i x_i}{\sum Q_i}$$

$$\bar{y}_i = \frac{\sum Q_i y_i}{\sum Q_i}$$

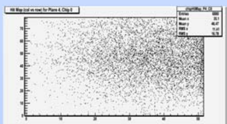
## Track Reconstruction

$$x_{proj} = \Delta z * b_{xi} + a_{xi}$$
$$y_{proj} = \Delta z * b_{yi} + a_{yi}$$
$$\chi^2 = \sum_n \left( \left( \frac{R_i}{\sigma_i} \right)^2 \right)$$

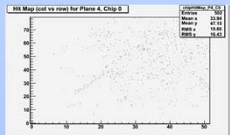
- Clusters on each plane $x_i$, $y_i$ coordinates
- Points corresponding to minimum chi error are used to reconstruct track



## Events Dependence On Voltage



Hits recorded at VC = 350V



Hits recorded at VC = 250V


## Calculating Residuals

Reconstructed tracks are used to project the accepted crossing point of the particle when it reaches the Downstream DUT coordinate

$$x_{residual} = x_{rec} - x_{proj}$$
$$y_{residual} = y_{rec} - y_{proj}$$

Thanks to Enver Alagoz