Cornell University
Laboratory for
Elementary-Particle Physics

The Status and Performance of the CMS Pixel Detector

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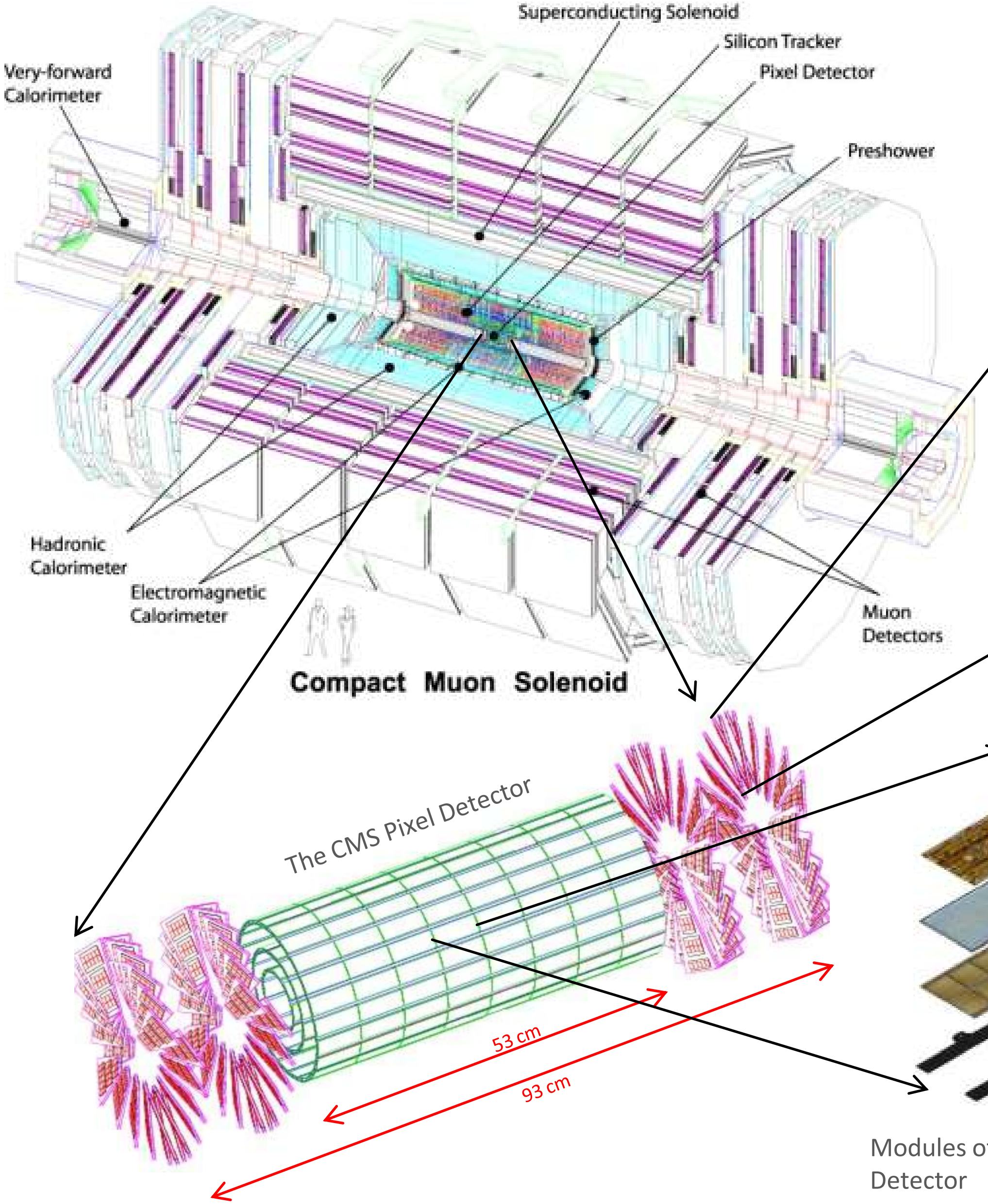
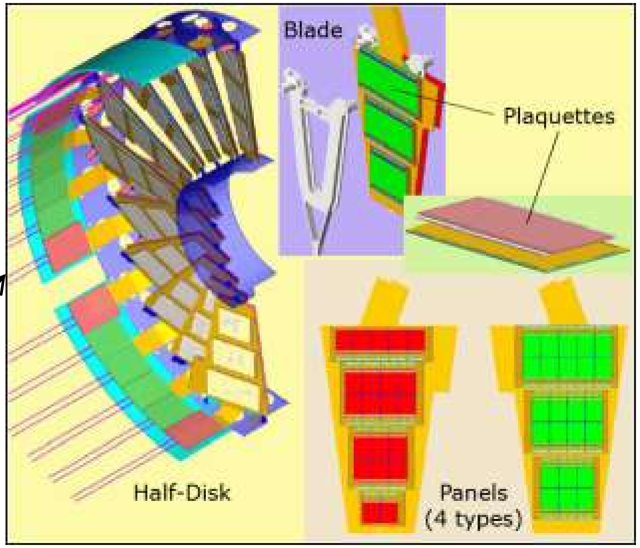
on behalf of the CMS Pixels team

Contents

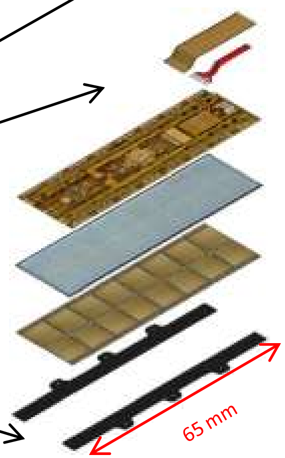
12 March 2009

The Pixel Detector in the Compact Muon Solenoid





Panels of the Forward Pixel Detector



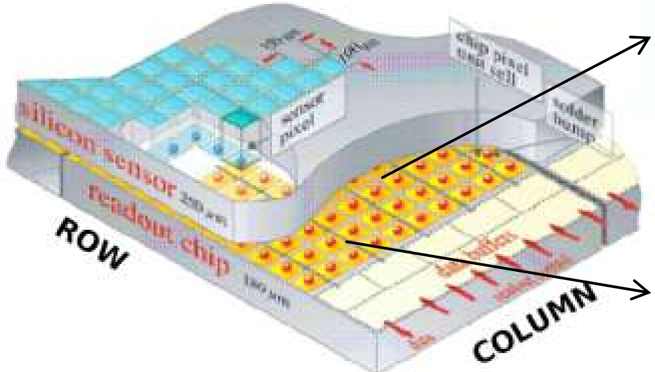
Modules of the Barrel Pixel Detector

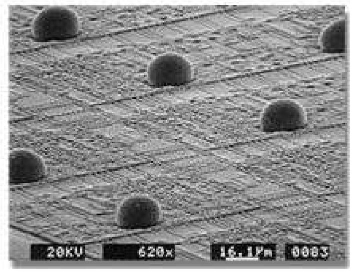
- Forward Pixel Detector (**FPix**) has two disks on each side at 34.5 cm and 46.5 cm
- FPix has 672 modules

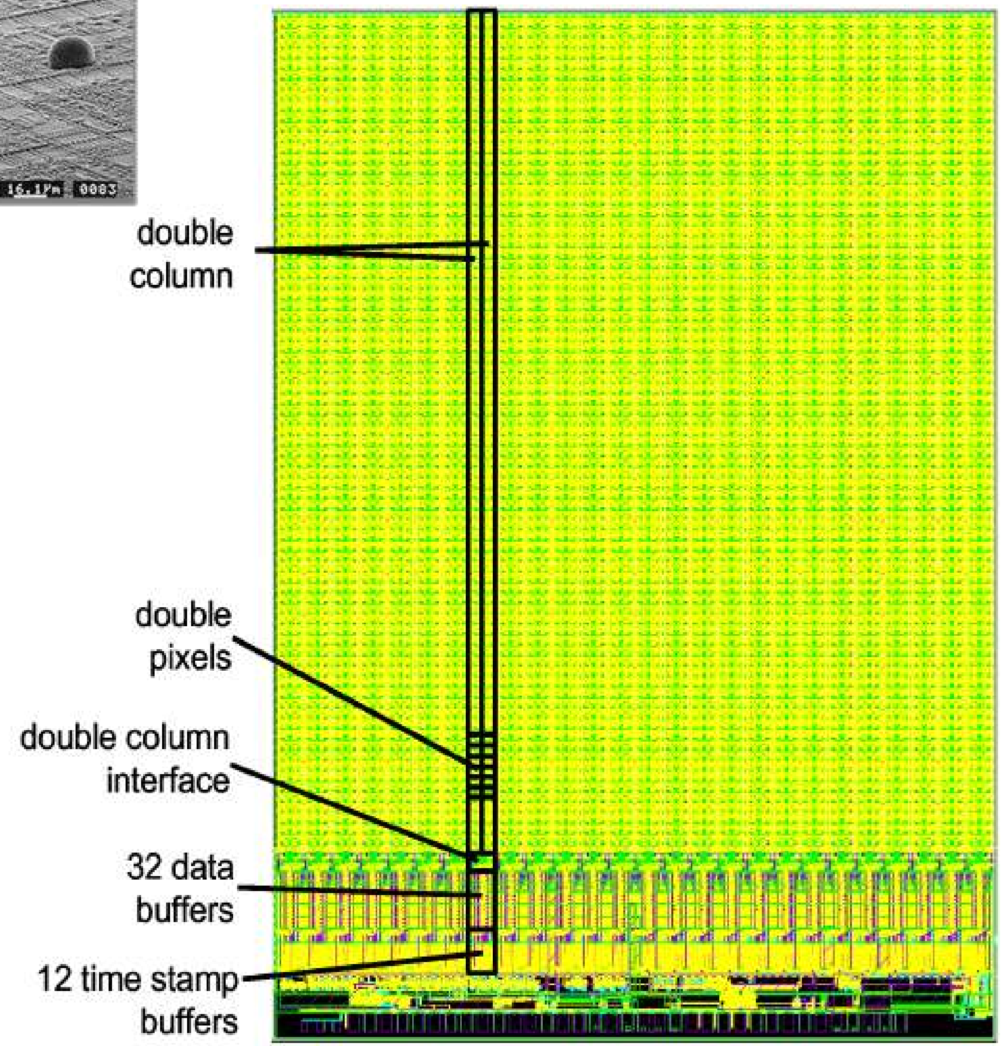
- Barrel Pixel Detector (**BPix**) has 3 layers of radii 4.3 cm, 7.2 cm and 11.0 cm
- BPix has 768 modules

- Total of ~**15,840 Readout Chips**

The Pixel Sensor and the Read Out Chip







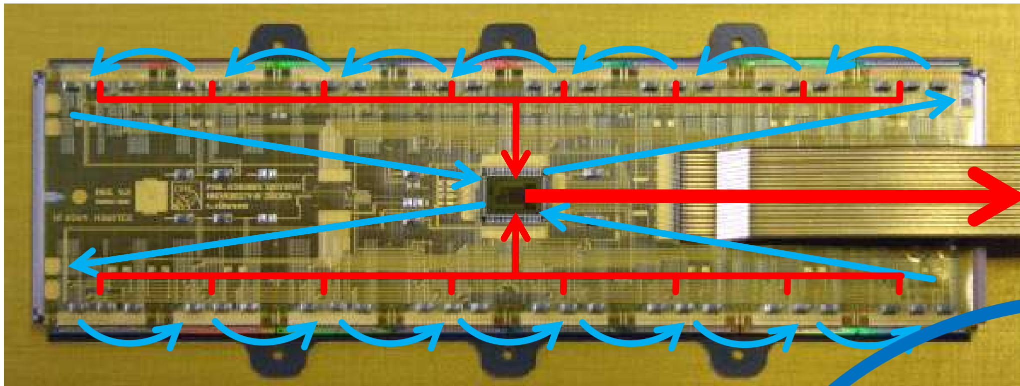
•ReadOut Chip (ROC) bump bonded sensor pixels.

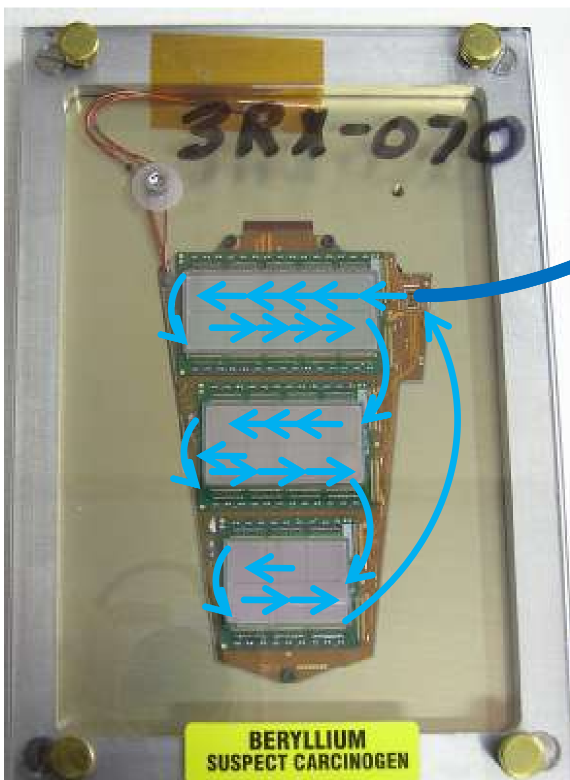
•52   80 = 4160 pixels per ROC
•15,840 ROCs
•66 million pixels

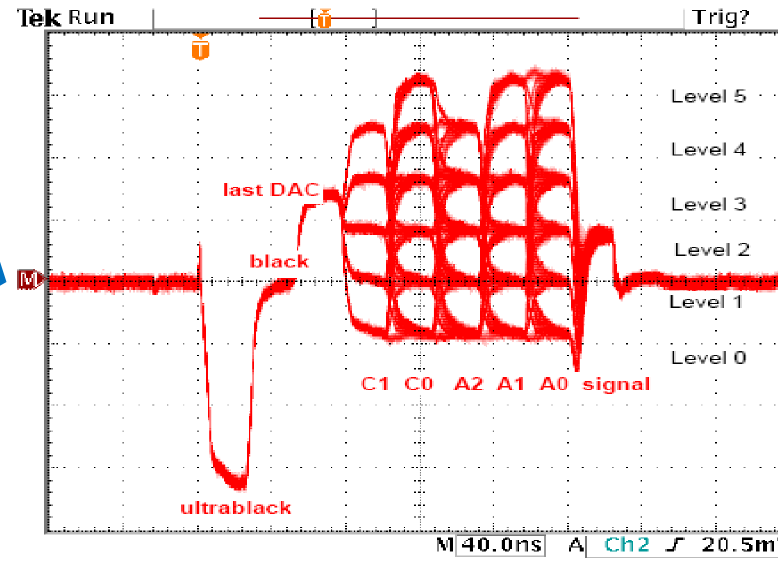
•Automatic zero-suppression

•Each pixel has a programmable threshold (adjusting this is called *trimming*)

Forward and Barrel Pixel Analog Readout





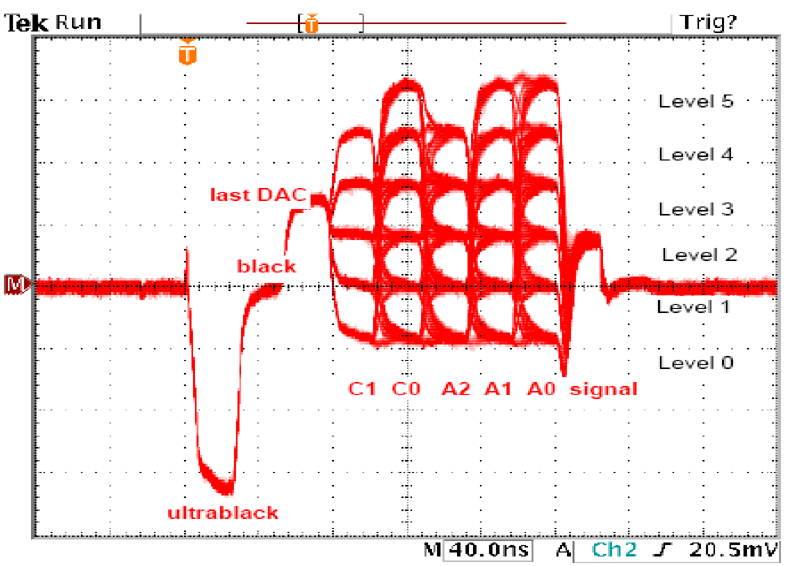


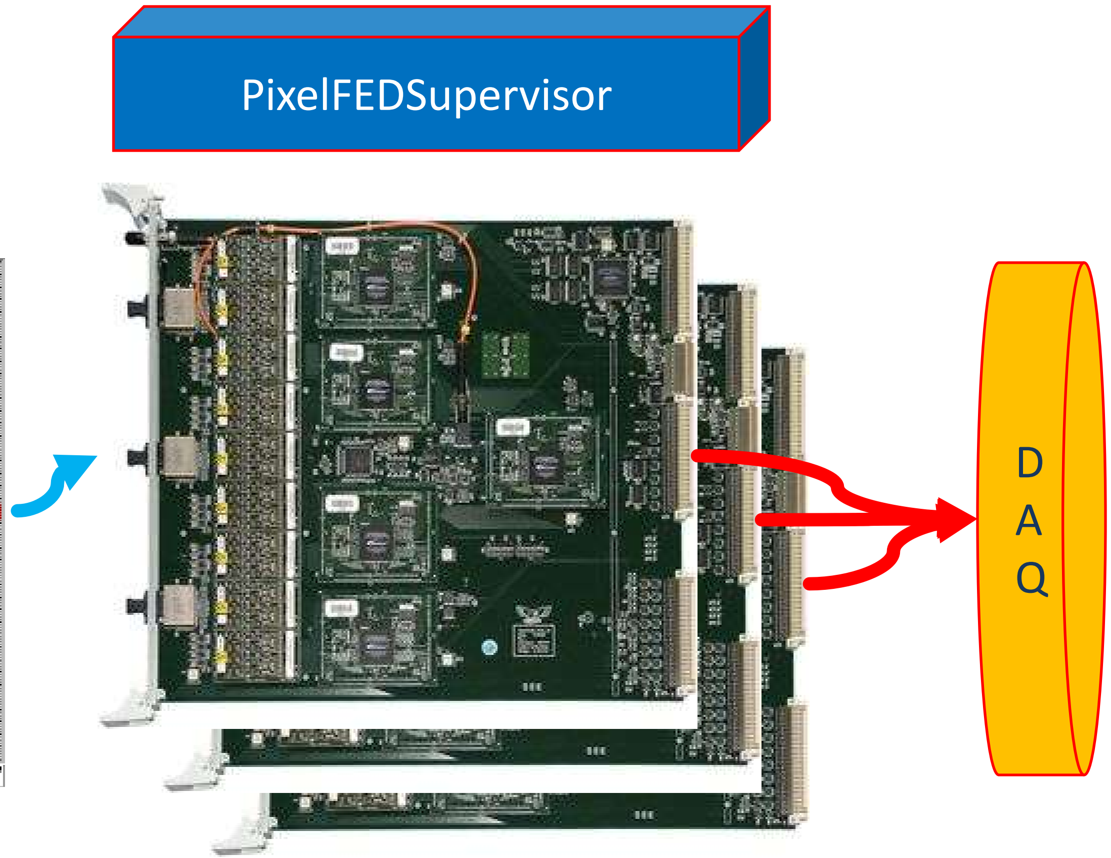
•On receiving a L1 trigger, the Token Bit Manager (TBM) initiates a Chinese-whisper of “token bits” that instruct each ROC to send its hit data to the TBM

•The signal from the TBM is electrical and analog. It encodes the ROC #, row and column and charge deposit of each pixel hit

•The electrical signal from the TBM is converted to optical by the Analog-Optical Hybrid (AOH)

Digitization of Analog Readout with the Front End Driver





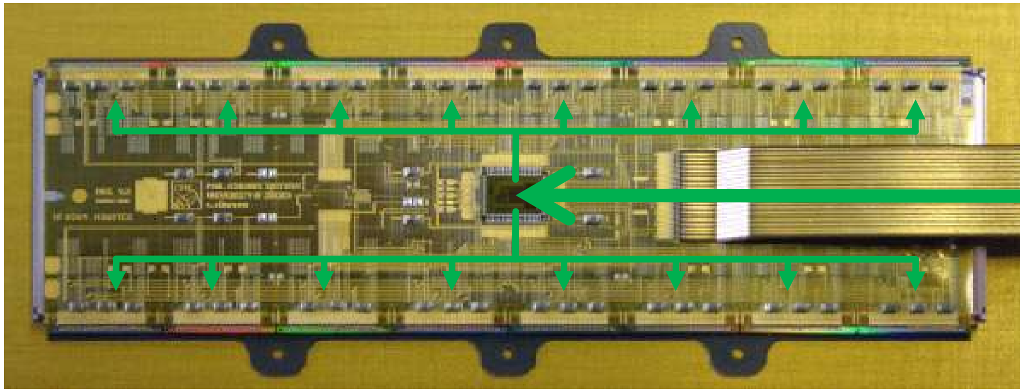
•Pixel Front End Driver (FED) digitizes analog signals given the level thresholds for decoding.

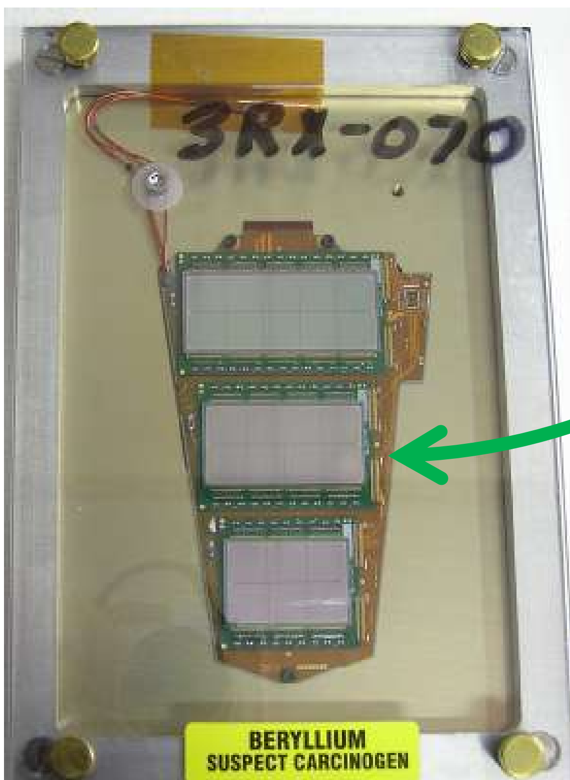
•One crate of FED boards is controlled by one PixelFEDSupervisor application. 40 FEDs in Pixels.

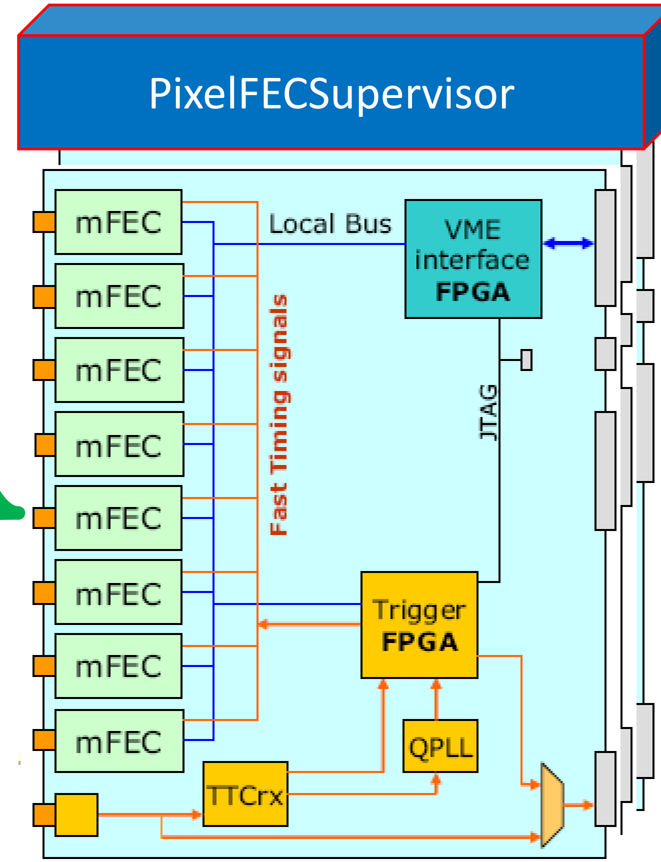
•FEDs send digitized data down S-Link cables to the Data Acquisition System (DAQ).

•FED data may also be read out via VME by the PixelFEDSupervisor.

Barrel and Forward Pixel Programming Chain





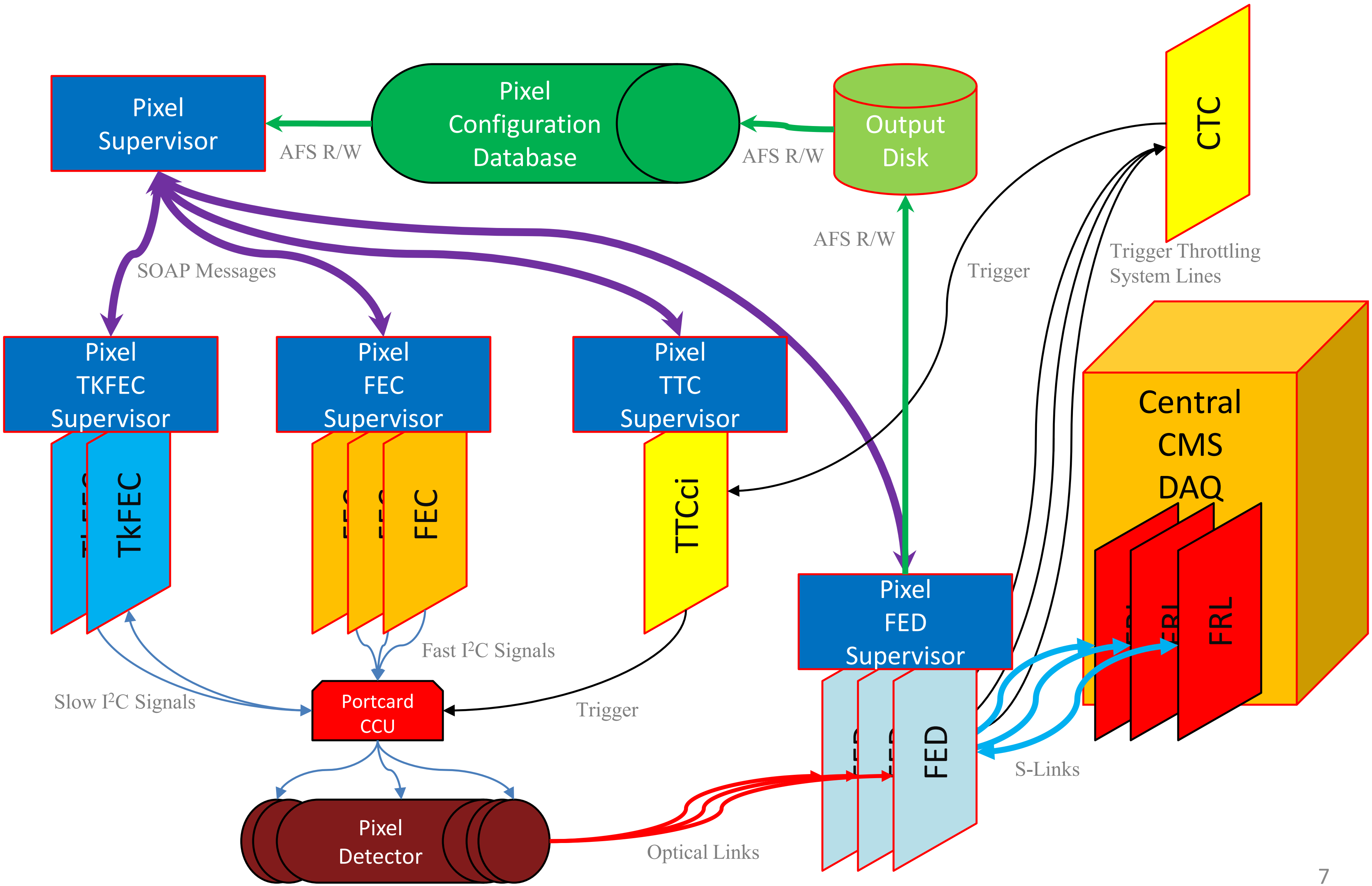


•Control signals consist of

1. Clock & L1 Trigger
2. I^{2}C Commands for programming

•Using I^{2}C commands we can program various DACs on each ROC, set trim bits on each pixel and inject charges for calibration purposes.

Pixel Data Acquisition Software



Lowering the Barrel Pixels into the Cavern

Inserting the Barrel Pixels into CMS

Quick Checkout of the Barrel Pixels

1 week

•The BPix was lowered into the cavern on 23 July 2008

•Installed cooling, power cables, optical fiber connections

•Quick Checkout using standalone software developed at PSI was used to quickly check communication with the BPix. The following were tested:

- •Clock and trigger distribution.
- •Front end programmability
- •Quality of readout Signals
- •Bias connections.

•Done by 29 July 2008

•FPix given the green light for installation

Inserting the Forward Pixels into CMS

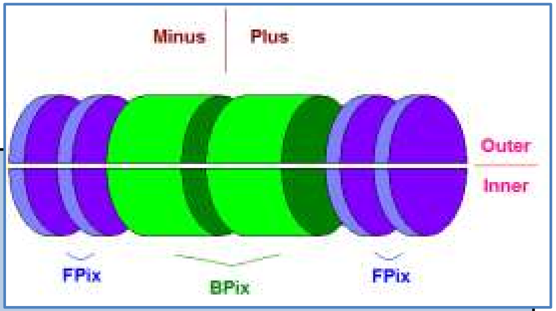
The FPix being slid in with the BPix in place.

Synchronous insertion of the inner and outer half-cylinders.

Cabling and cooling after insertion

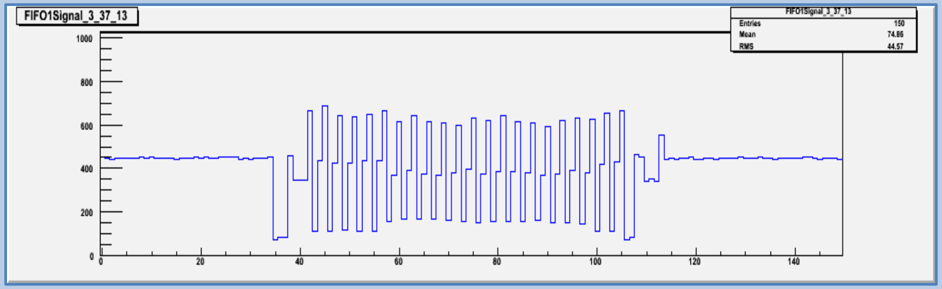
Viola, Monsieur!

Quick Checkout of the Forward Pixels



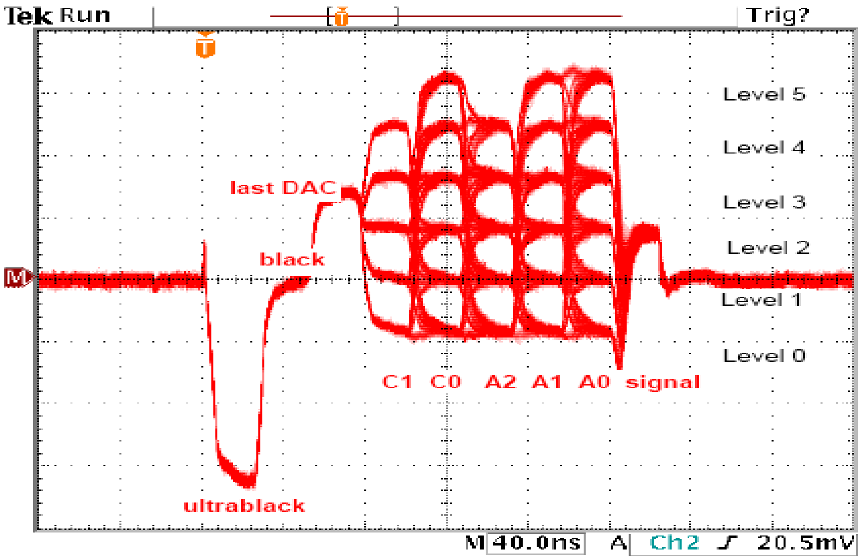
1 week

- FPix services connected by 31st July 2008
- Quick Checkout using Pixel Data Acquisition Software one Half Cylinder at a time:
  - Ensure correct mapping of the data fibers
  - Appropriate change of drawn current on configuring the Readout Chips
  - Stable baseline of the TBM analog signal (*FEDBaselineCalibration*)



- Some panels required cleaning of the optical fiber. Baselines stabilized.
- CMS Pixel Detector closed on 7th August 2008

Address Levels Calibration during Second Commissioning Phase



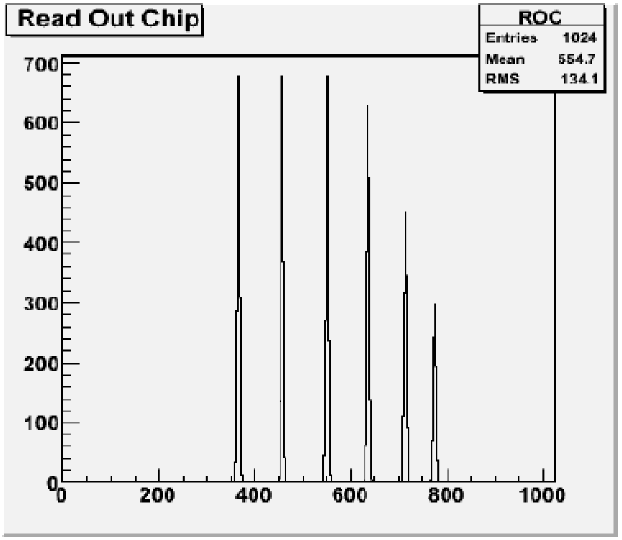
The analog signal from the TBM

Address Levels Calibration

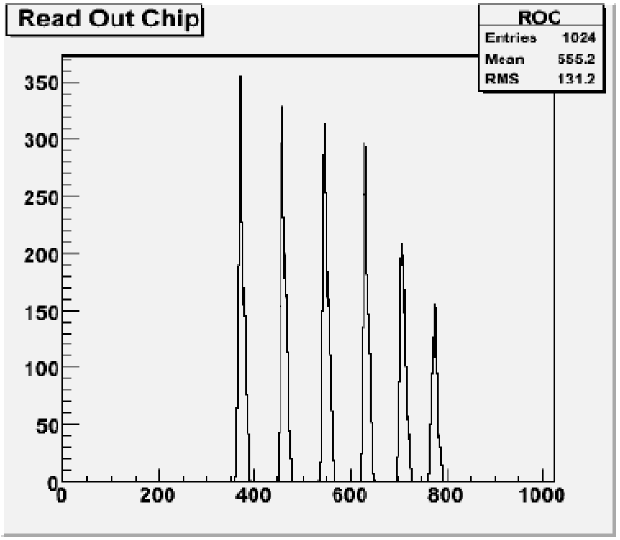
For the FED to decode the analog output of the TBM, it must know the address level thresholds.

Address level peaks may get smeared out when:
- The FED samples the signal at the wrong time
- The baseline is jittery due to unclean optical fibers

Good separation: rms is ~2.5 ADC



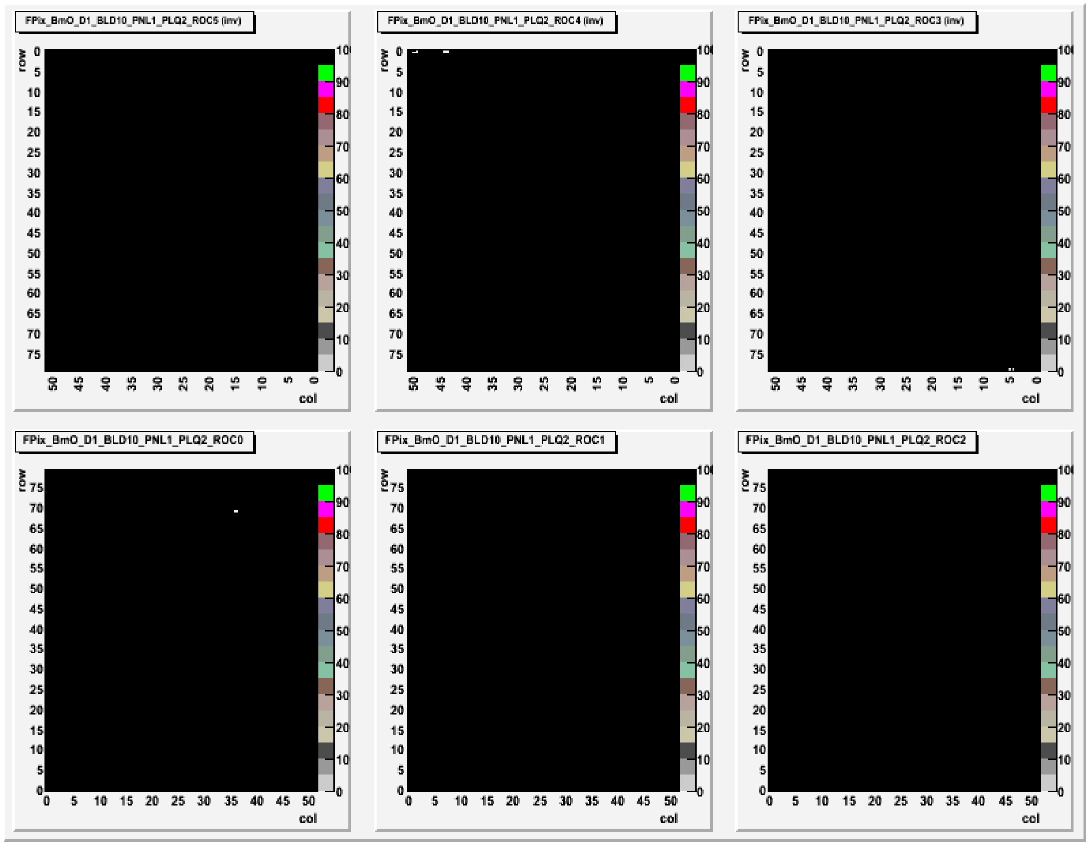
Poor separation: rms is >5 ADC



Pixel Alive Scan during Second Commissioning Phase

Pixel Alive

Inject charge repeatedly into each pixel and see how often they respond.
Build up an efficiency map and identify defective pixels.



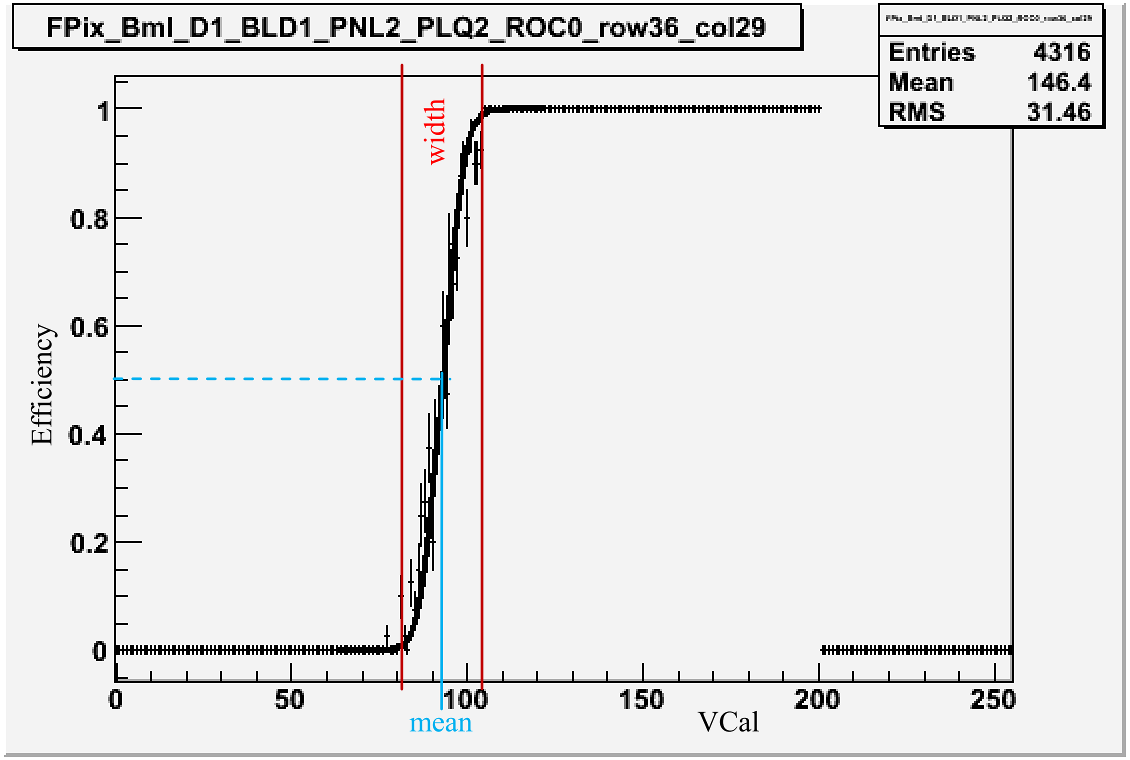
Dead Pixels

0.010% of BPix
0.015% of FPix

S-Curve Calibration during Second Commissioning Phase

S-Curve Calibration

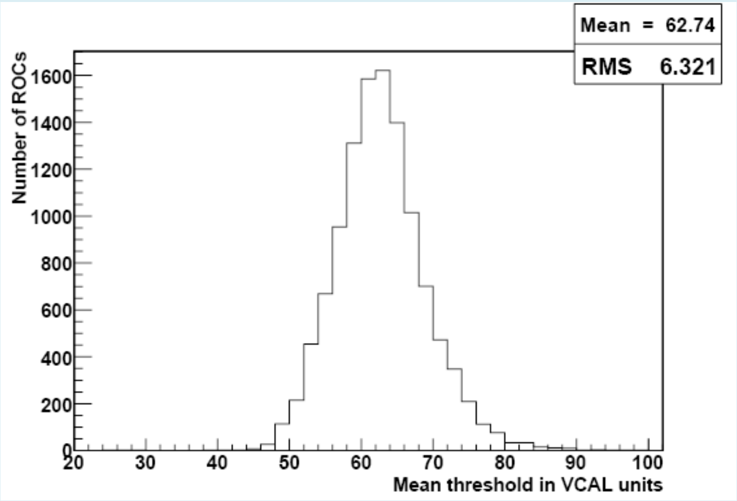
The charge injected into each pixel for calibration, governed by *VCal*, is varied.
The efficiency of pixel response against the change in *VCal* gives us an S-Curve



•The *VCal* corresponding to 50% efficiency is the **threshold** of response.
•The width of the turn-on region is a measure of the pixel's **noise**.

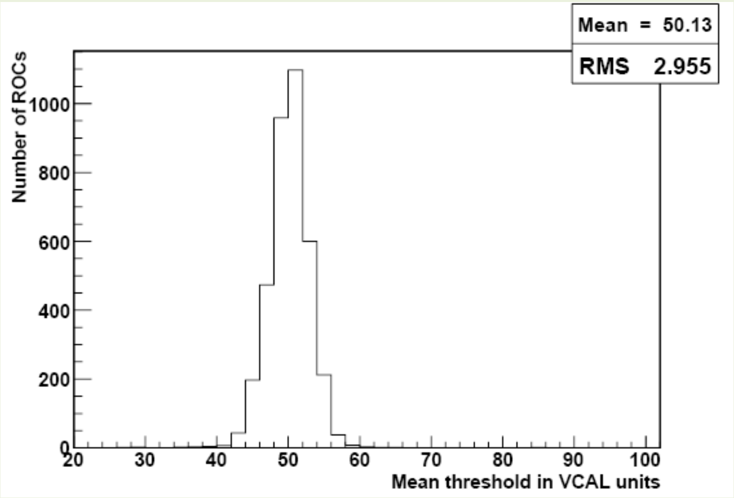
•One unit of *VCal* is roughly **65 electrons**.

Pixel Thresholds from S-Curves during Second Commissioning Phase



Threshold distribution for *un-trimmed* Barrel Pixels.

Mean corresponds to ~**3690 e$^-$**

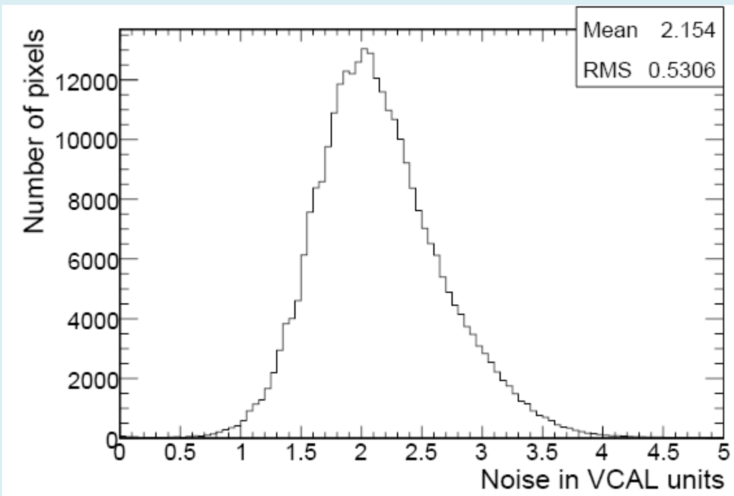


Threshold distribution for *trimmed* Forward Pixels.

Mean corresponds to **2870 e$^-$**

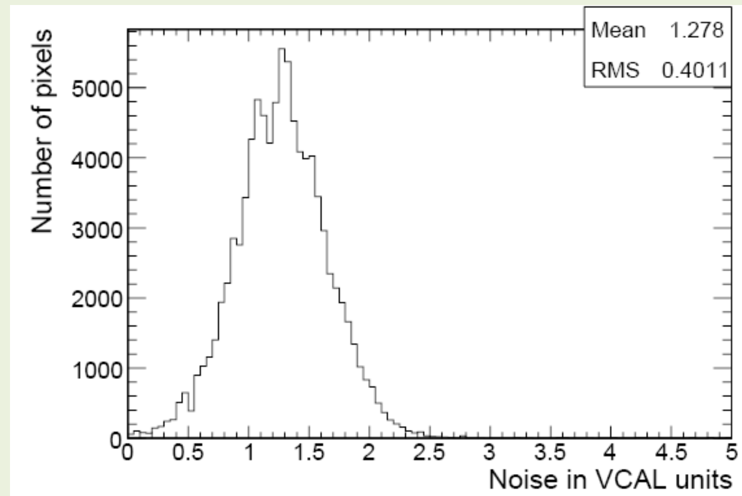
Threshold well below the minimum ionizing particle ~22,000 e$^-$

Pixel Noise from S-Curves during Second Commissioning Phase



Noise distribution for the Barrel Pixels.

Mean corresponds to **141 e$^-$**



Noise distribution for the Forward Pixels.

Mean corresponds to **85 e$^-$**

Level of noise does not significantly degrade response of the detector

Results of the Second Phase of Commissioning

1 week

4 days

•Physical access to the Pixel Detector lost on the 7^{th} of August 2008

•In the FPix, 260 ROCs are not performing. 6% of the FPix is out of action
(135 ROCs shorted digital voltage, 101 ROCs lost bias voltage, 24 ROCs have low signal)

•In the BPix, 100 ROCs are not performing. 0.87% of the BPix is out of action

•Of the remaining FPix pixels, 0.015% are dead and masked out
•Of the remaining BPix pixels, 0.010% are dead and masked out

•0.0005% of the pixels are masked out as noisy

•The integration between DAQ and DCS required for semi-automatic power-up was tested and established as conventional procedure.

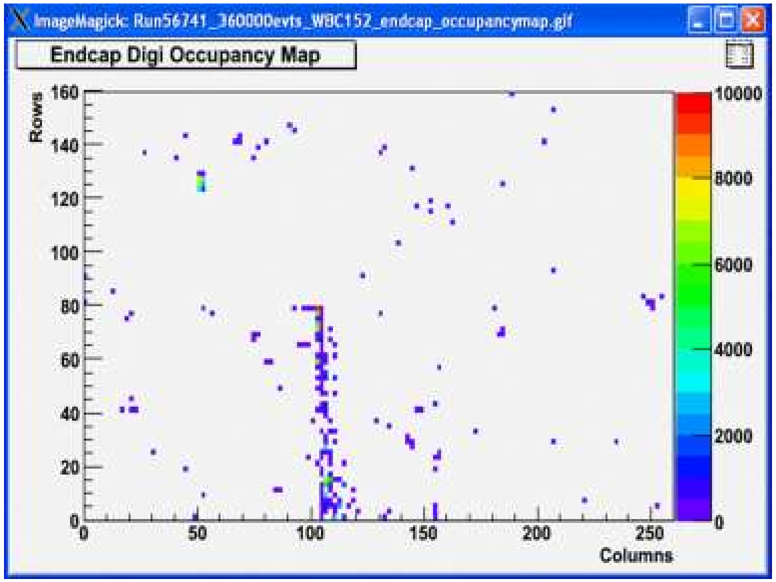
•The FPix participated in a mid-week global run on the 13^{th} – 14^{th} of August 2008

•FPix roughly time-aligned with cosmics

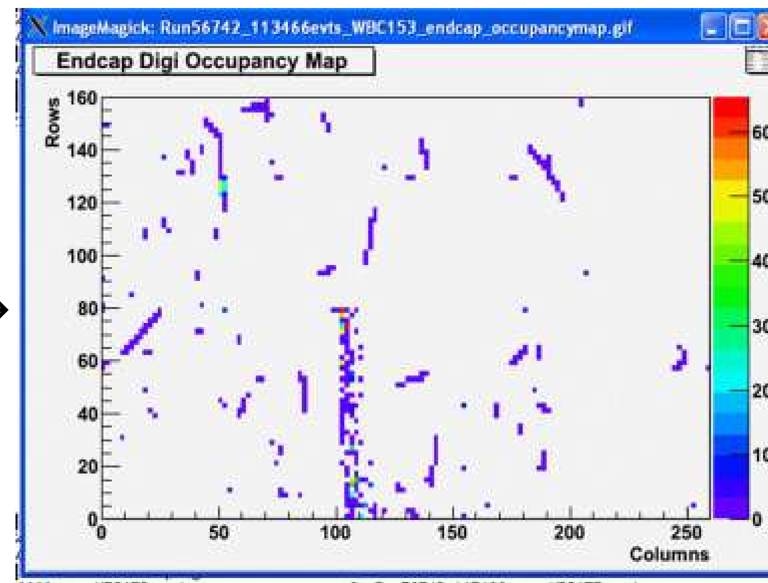
•FPix and BPix functioned as one detector under CMS Run Control between18^{th} – 25^{th} of August 2008 (CRUZET 4)

Time Alignment in the Third Phase of Commissioning & Global Run

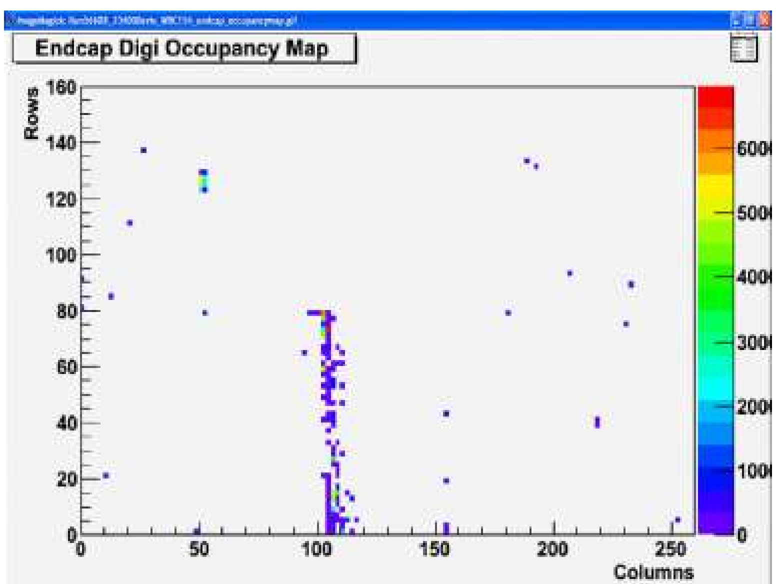
The Final Stage of Time Alignment in the FPix with Cosmics



← Misaligned (No Tracks)



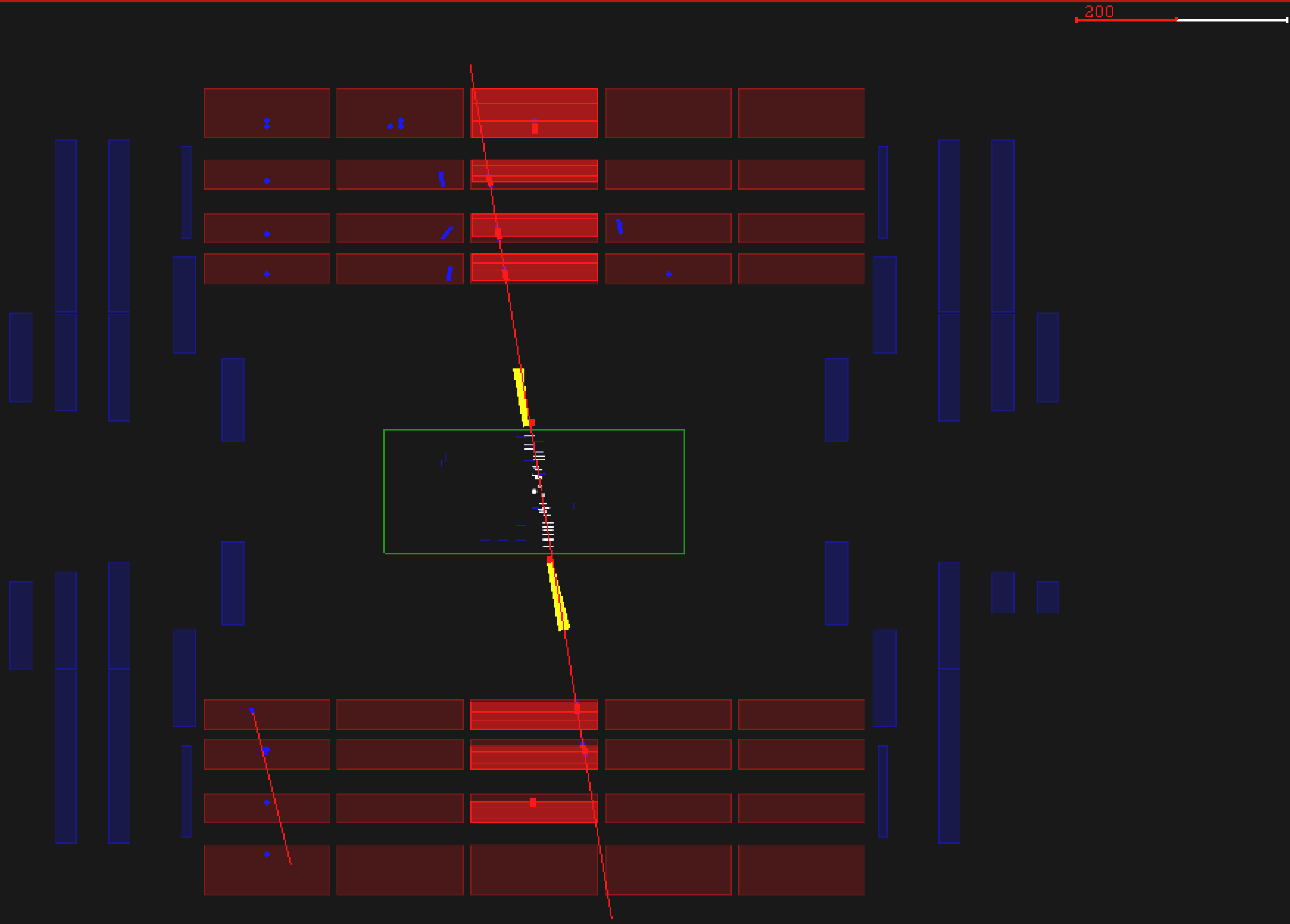
Aligned → (Tracks!)



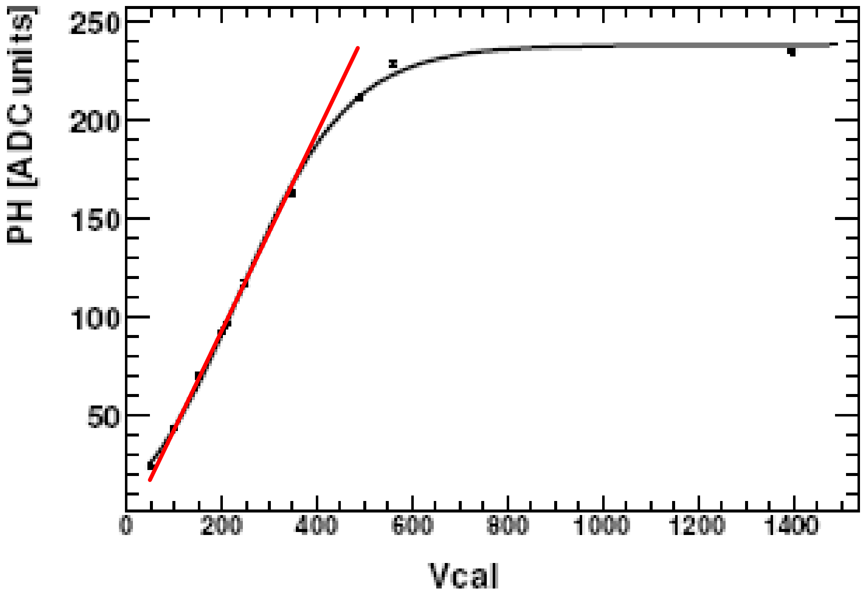
← Misaligned (No Tracks)

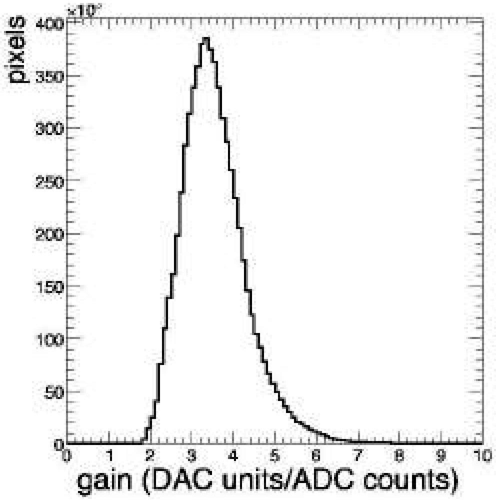
Hot pixels at the edge of a module

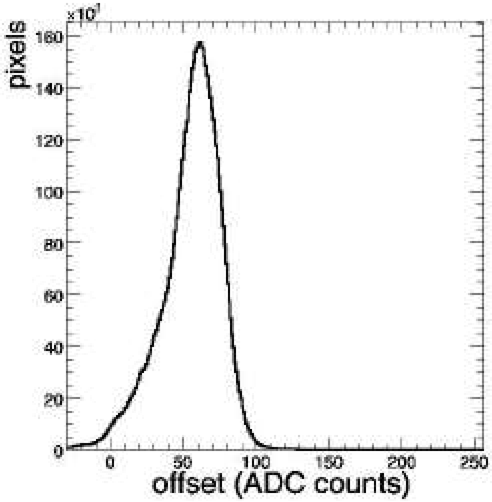
Cosmics in CRUZET 4



Gain Calibration







Gain Calibration

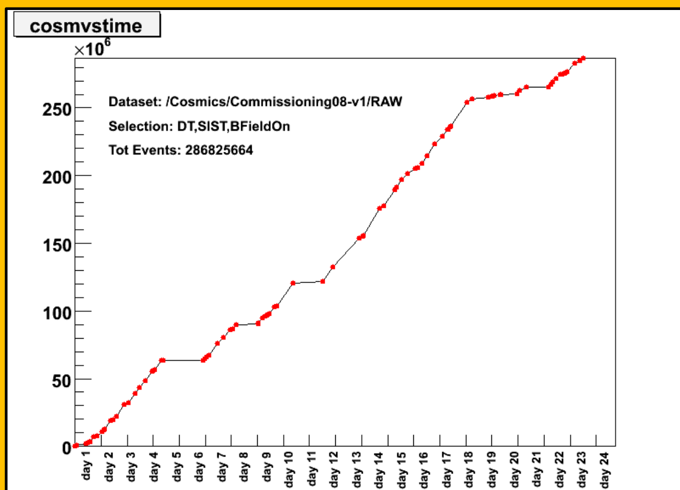
The charge injected into each pixel for calibration, governed by *VCal*, is varied.

The pulse height in ADC counts plotted against the *VCal* gives us the Gain Curve

- **Linear fit** between the Pulse Height read out by the FED and the charge in *VCal* units or electrons it represents.
- Mean of slope = 3.6 (DAC/ADC)
- Offset = 55 ADC
- Used for **calculating charge deposited** in clusters (position average)

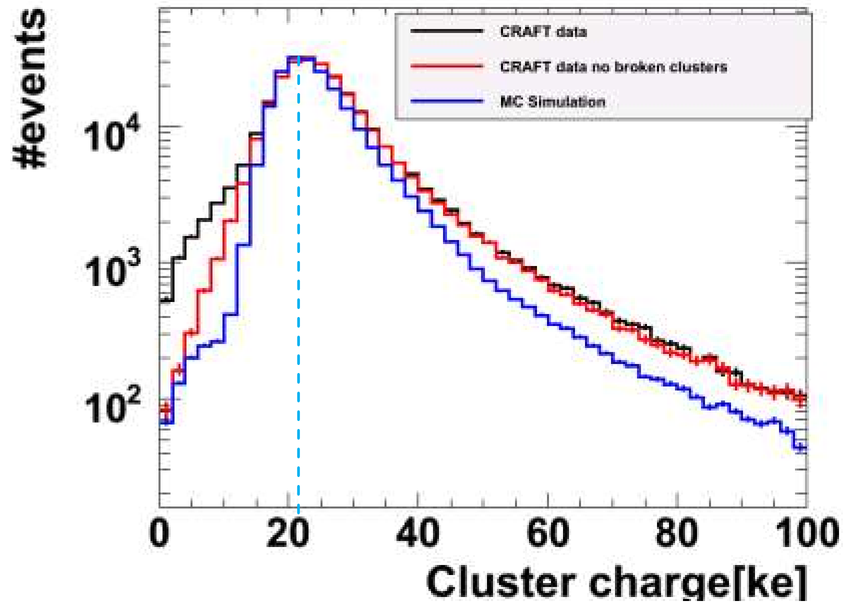
Charge Collection

•CRAFT (Cosmic Run at Four Tesla) at 3.8 T took about 370 million events.

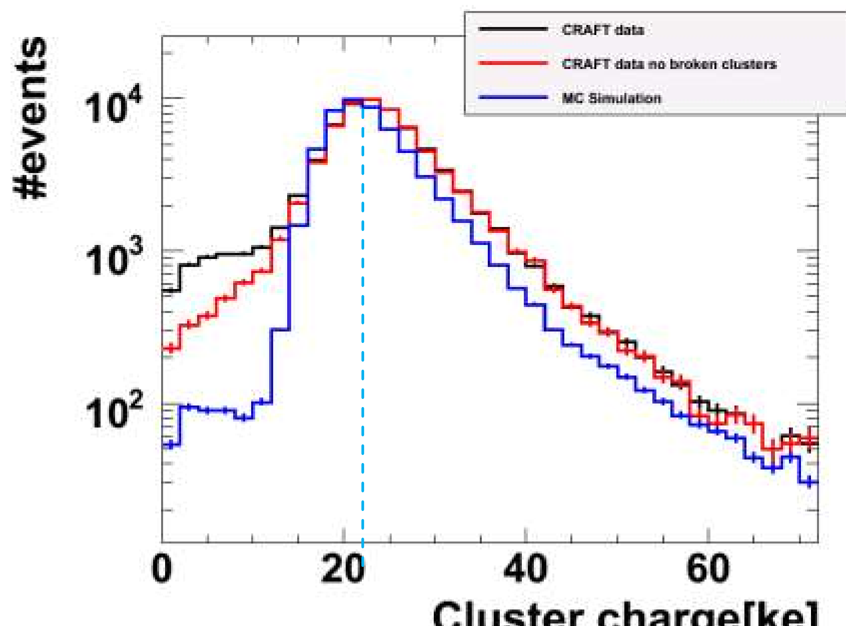


•80,000 tracks recorded through the Pixel Detector

•Cluster charge normalized to 285 μm gives a **Landau distribution with peak at ~ 22,000 e$^-$**

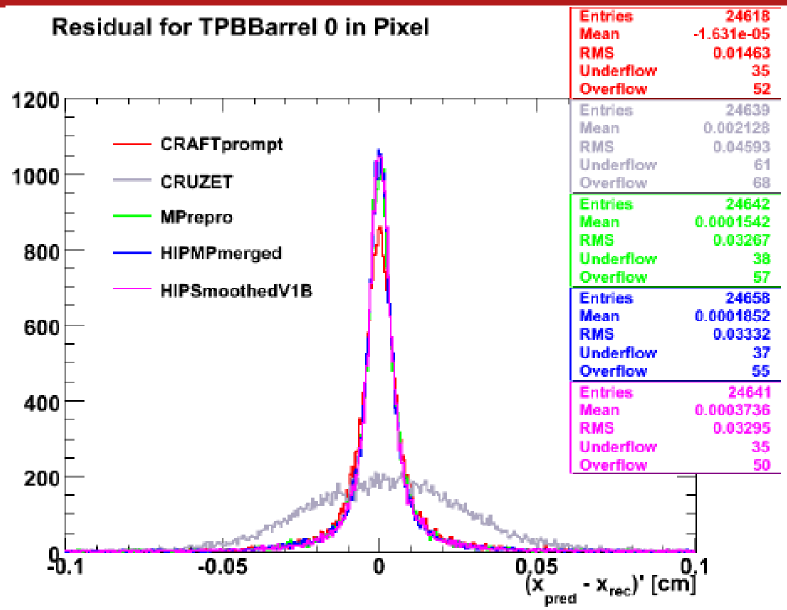


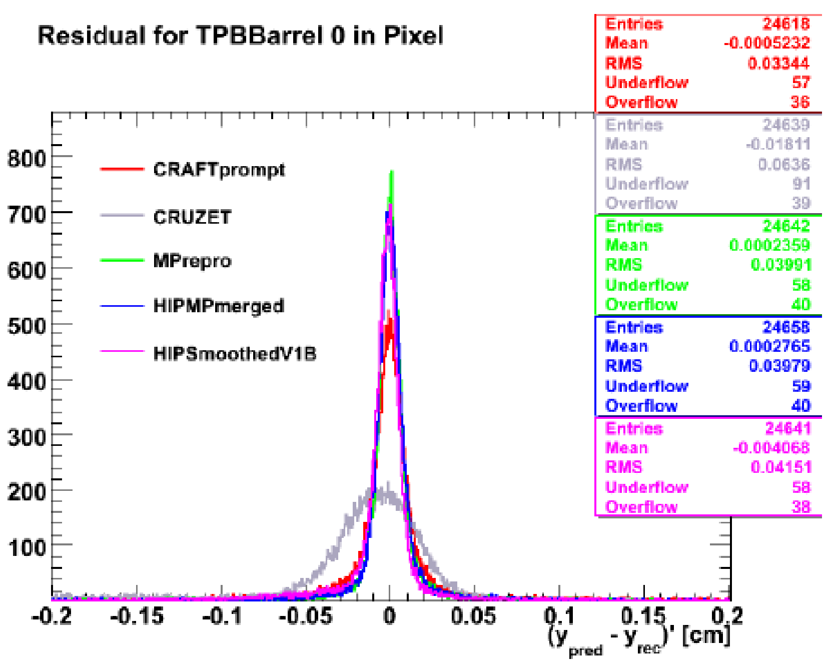
Barrel Pixels



Forward Pixels

Track Quality after Rough Alignment





- Barrel Pixels aligned at module level

- **CRUZET** is the nominal geometry

- **CRAFT-HIP** and **CRAFT-MP** are two alignment algorithms applied to the CRAFT data

- Significant narrowing of track residuals

Conclusions

•The CMS Pixel Detector was installed successfully within a very tight schedule (days!)

•Commissioned in two weeks

•Participated in Cosmic Run at Zero Tesla (CRUZET 4) as one detector.

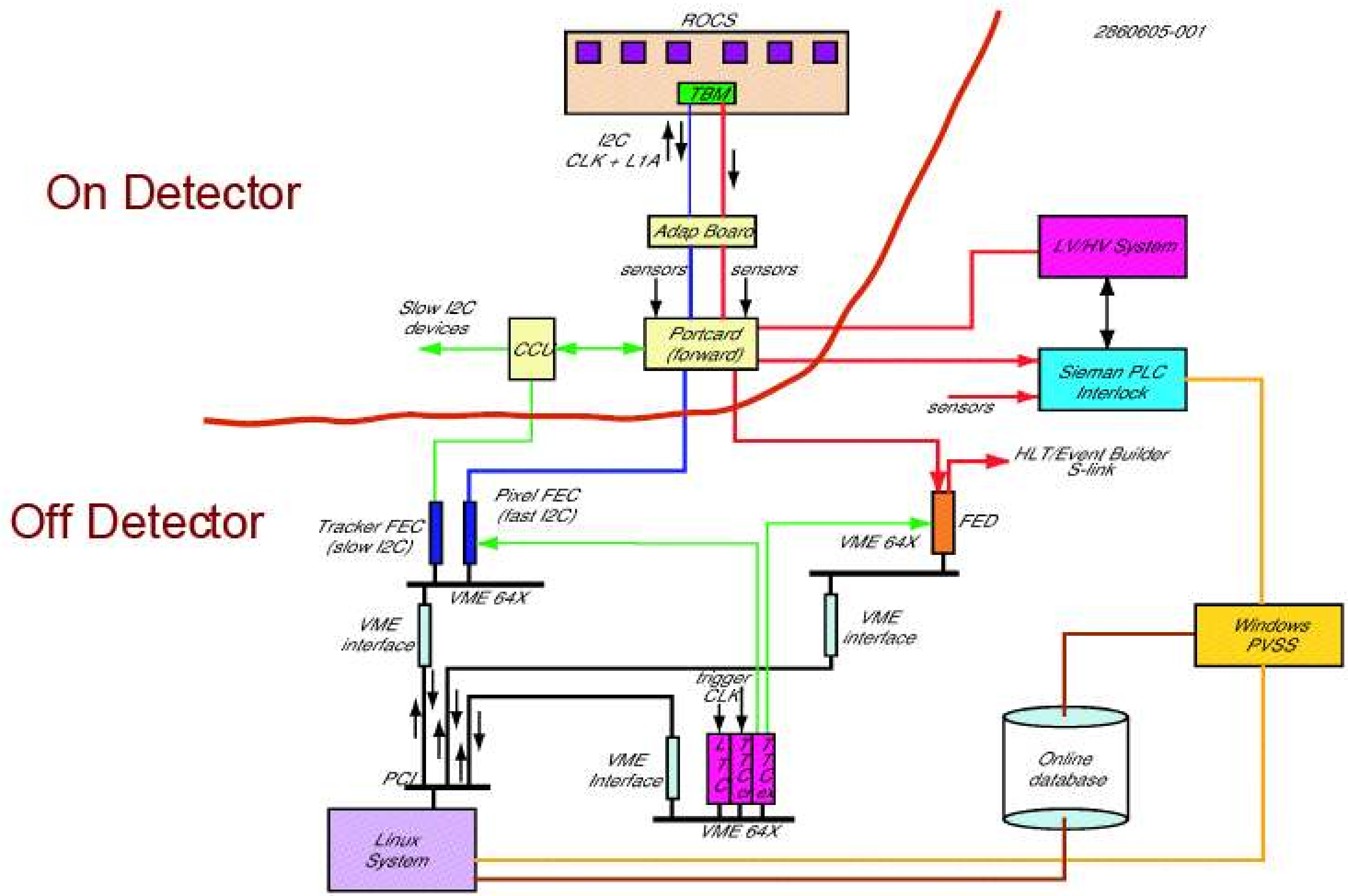
•Participated in Cosmic Run at Four Tesla (CRAFT 3.8 T) as one detector. Data collected is being used for performance studies and alignment.

•6% of the Forward Pixel Detector is damaged. It is being taken out and repaired over the 2008-2009 winter shutdown.

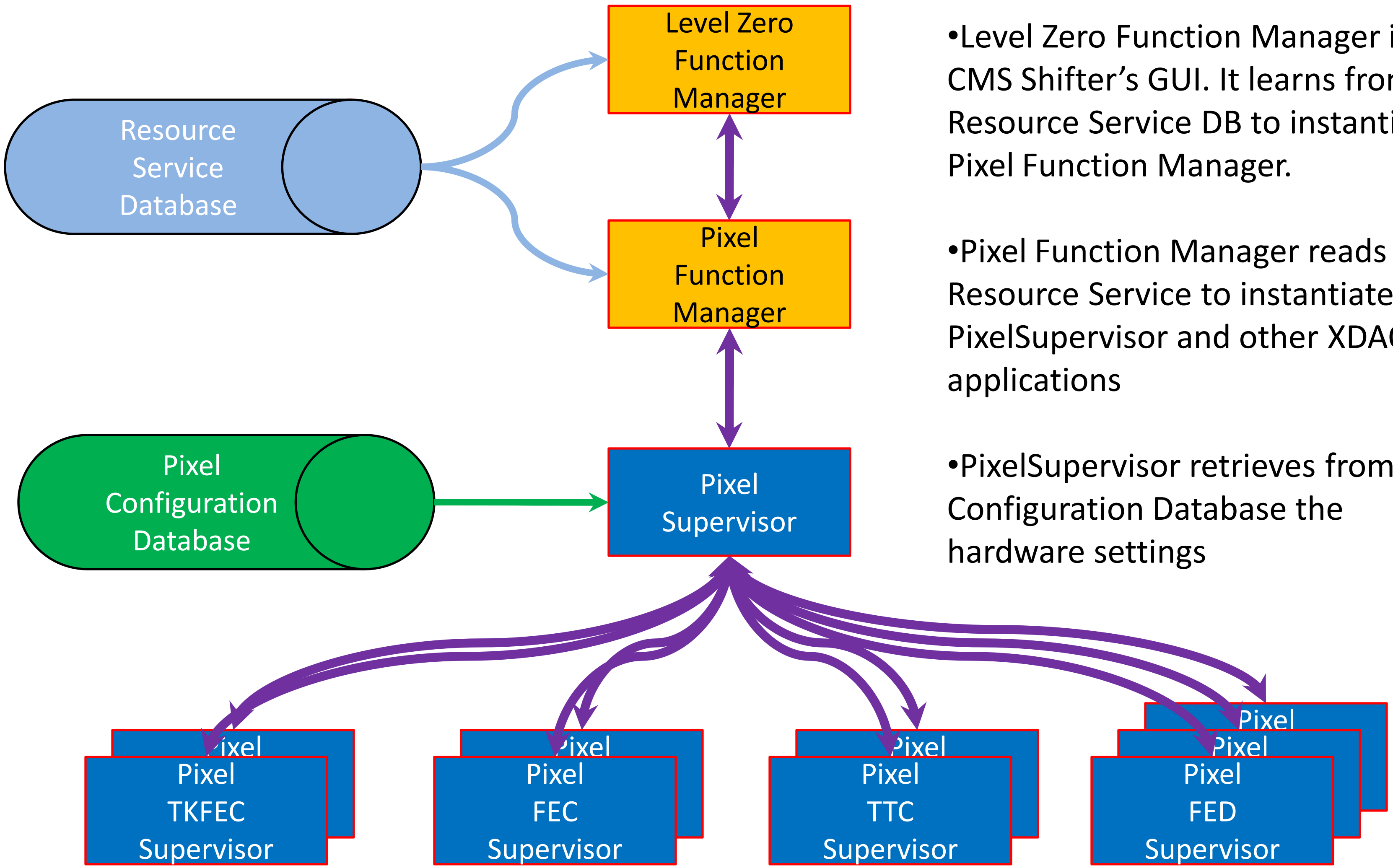
•Should be optimally ready for data taking in Spring 2009

Backup Slides

Pixel Control and Readout

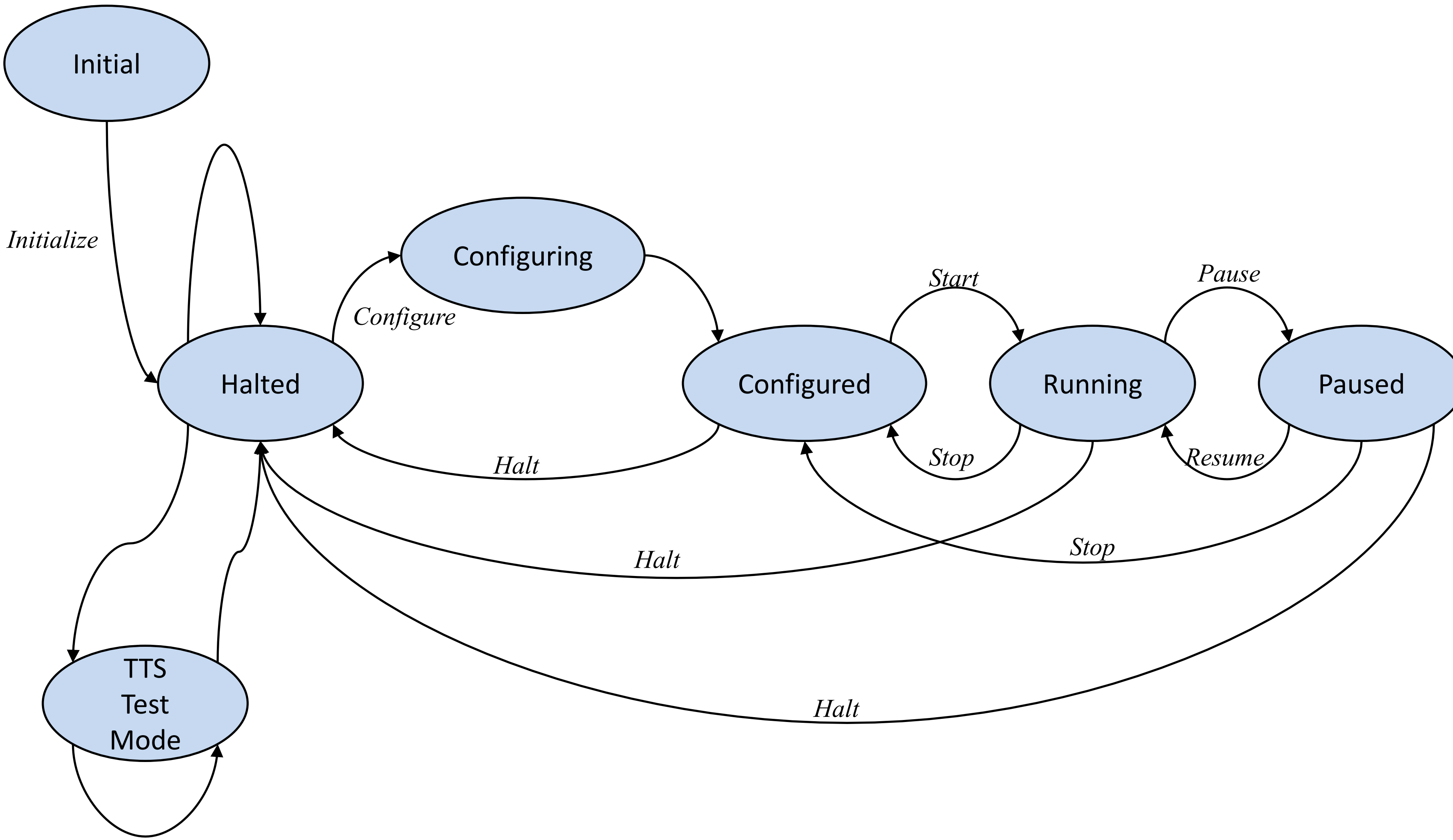


Pixel Online Software within the Run Control Framework

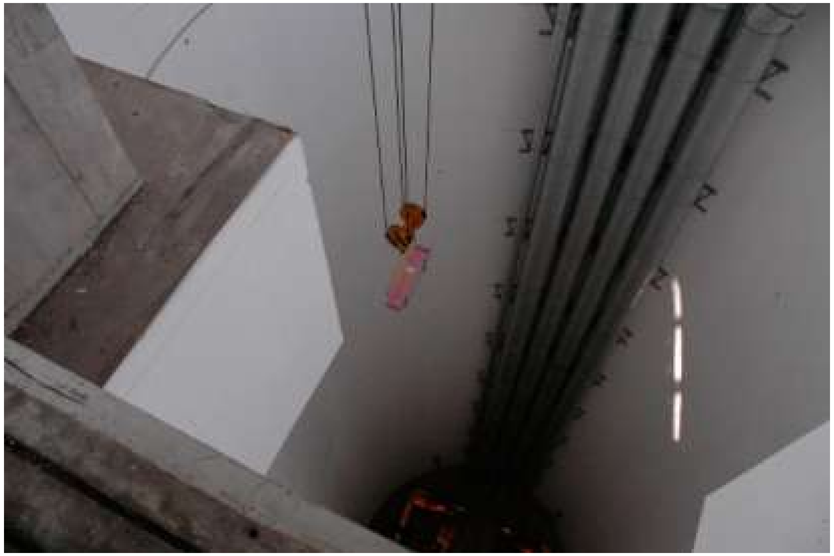


- Level Zero Function Manager is the CMS Shifter's GUI. It learns from the Resource Service DB to instantiate a Pixel Function Manager.
- Pixel Function Manager reads from Resource Service to instantiate PixelSupervisor and other XDAQ applications
- PixelSupervisor retrieves from Pixel Configuration Database the hardware settings

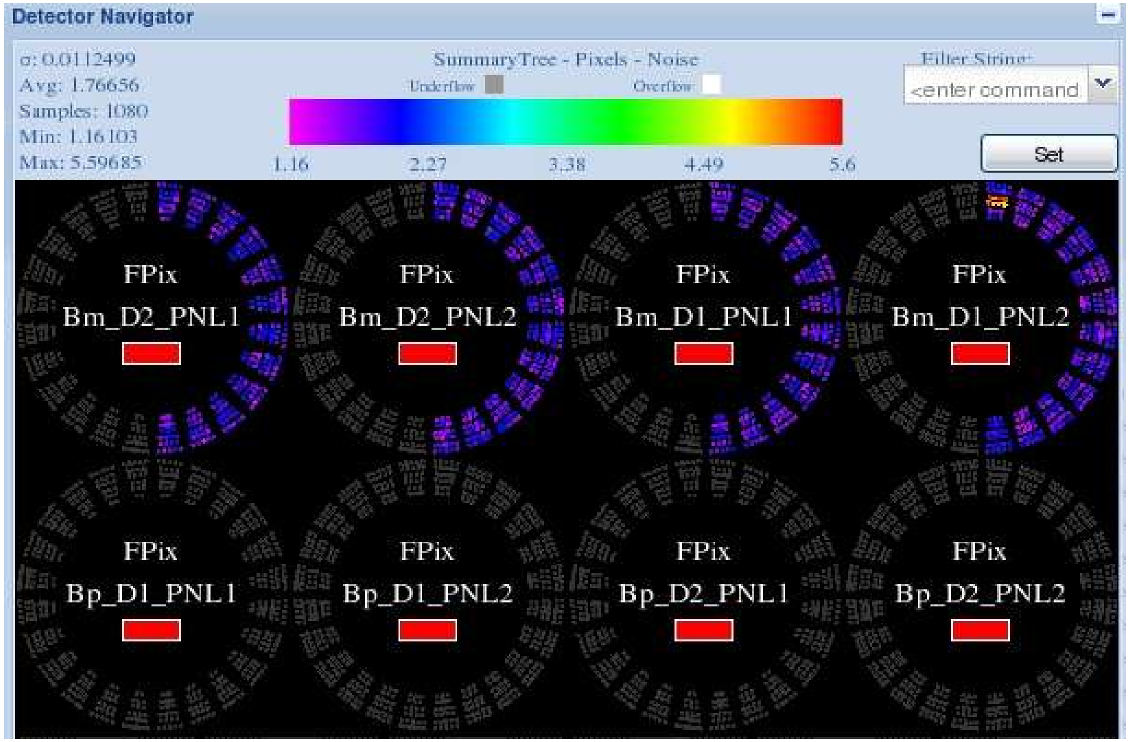
Finite State Machine Structure of PixelSupervisor

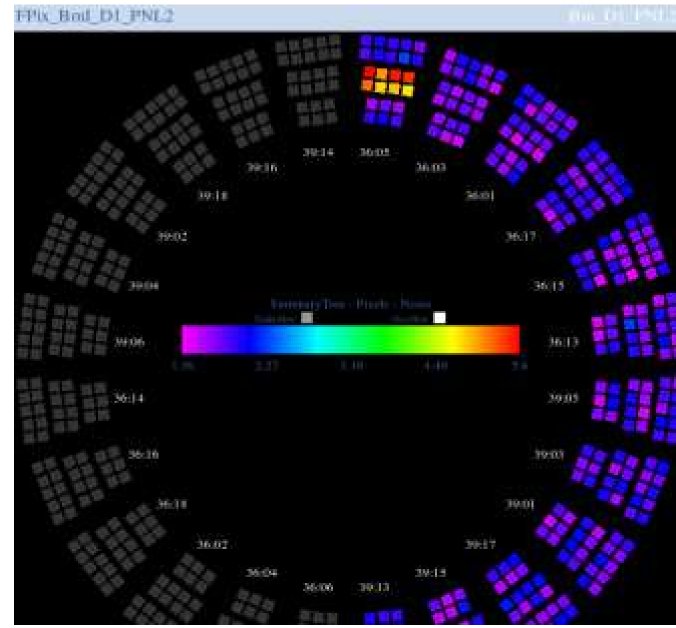


Lowering the Forward Pixels into the Cavern



Commissioning Phase II – S-Curve Calibration

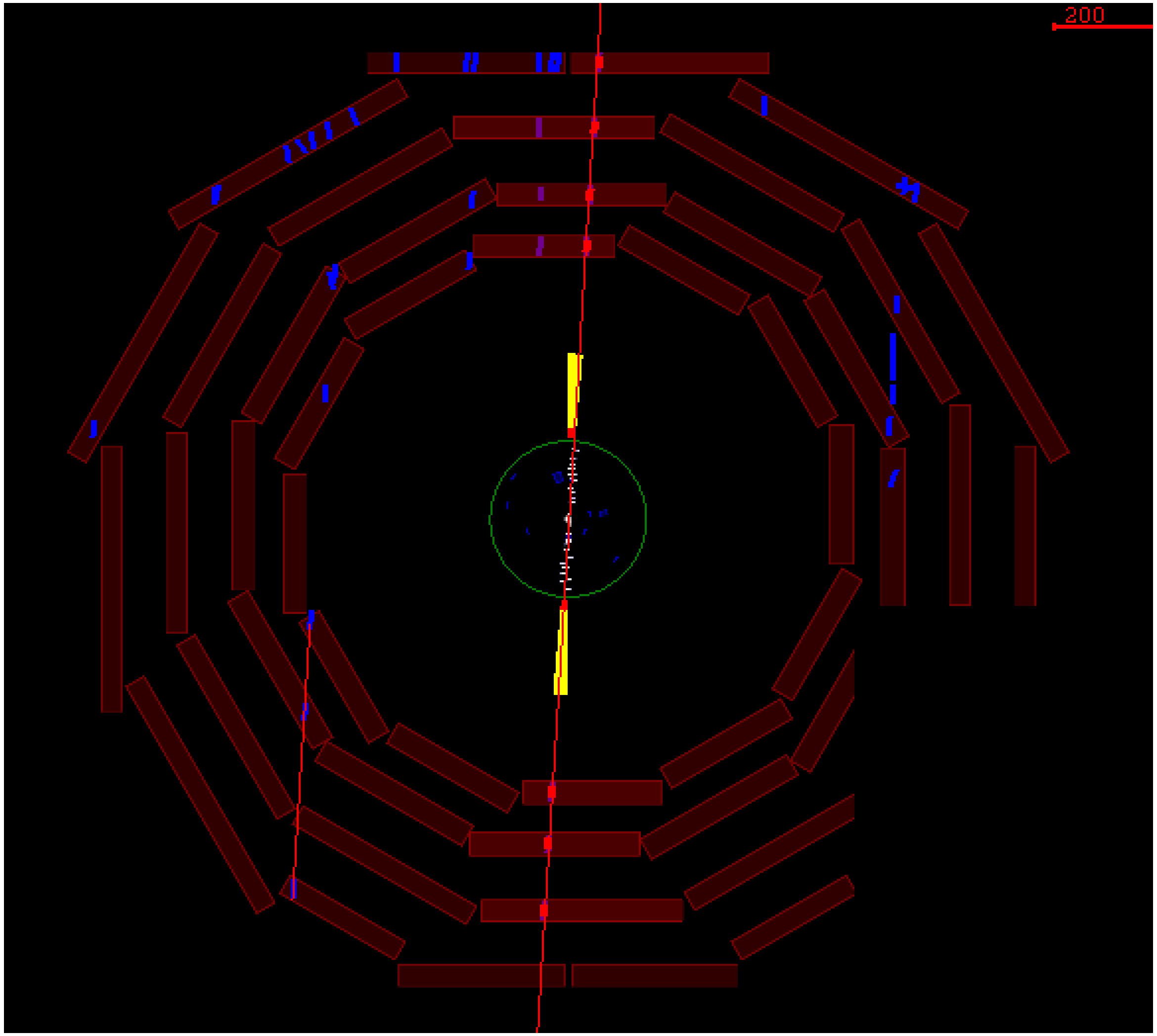




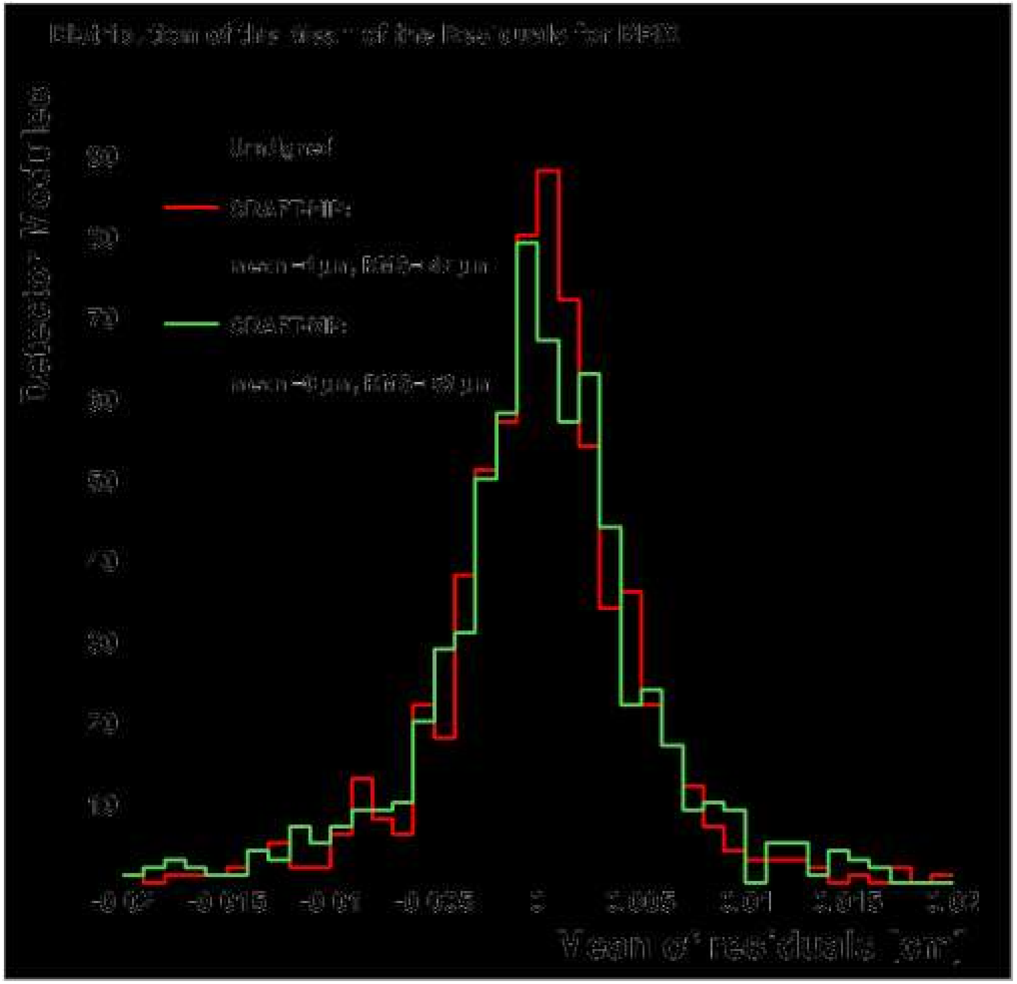
An S-Curve Showing the Broken High Voltage Wirebond

- *BmI_D1_PNL2* had been noted through inspection to have a broken high-voltage wirebond

Cosmics in CRUZET 4



Track Quality after Rough Alignment



- Barrel Pixels aligned at module level
- **Unaligned** is the nominal geometry
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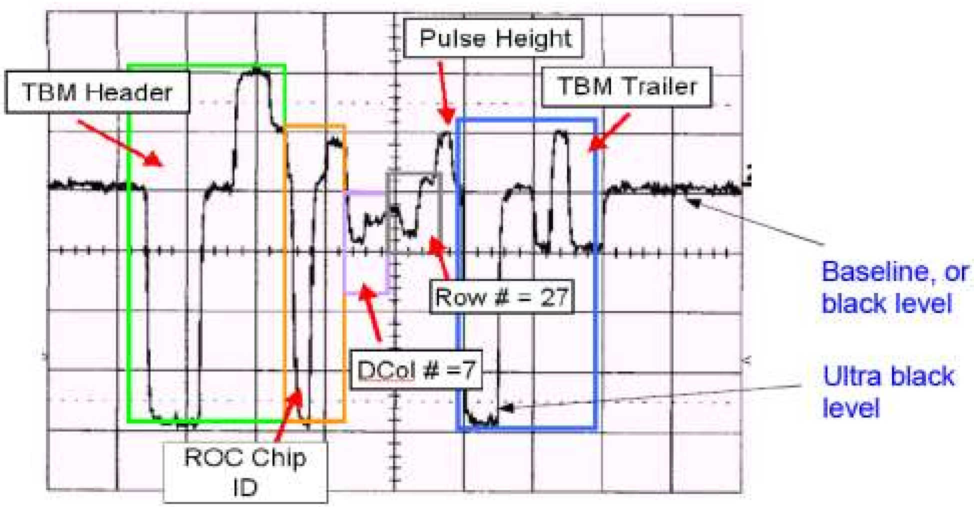
Commissioning Phase II – Address Levels Calibration



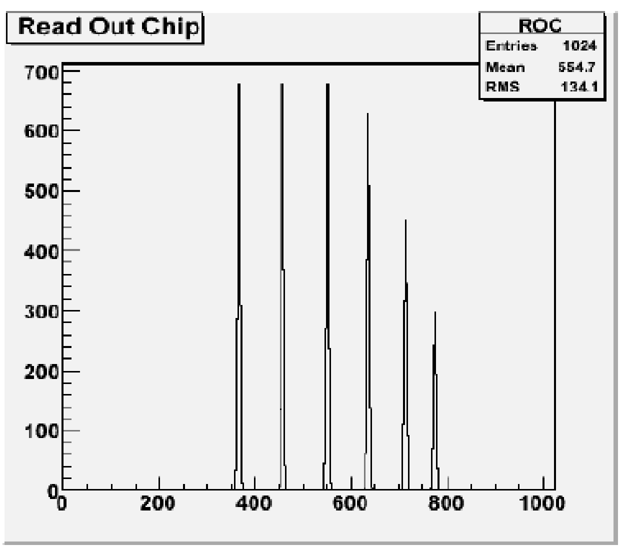
The analog signal from the TBM

Address Levels Calibration

For the FED to decode the analog output of the TBM, it must know the address level thresholds.

Address level peaks may get smeared out when:
- The FED samples the signal at the wrong time
- The baseline is jittery due to unclean optical fibers

Good separation: rms is ~2.5 ADC



Poor separation: rms is >5 ADC