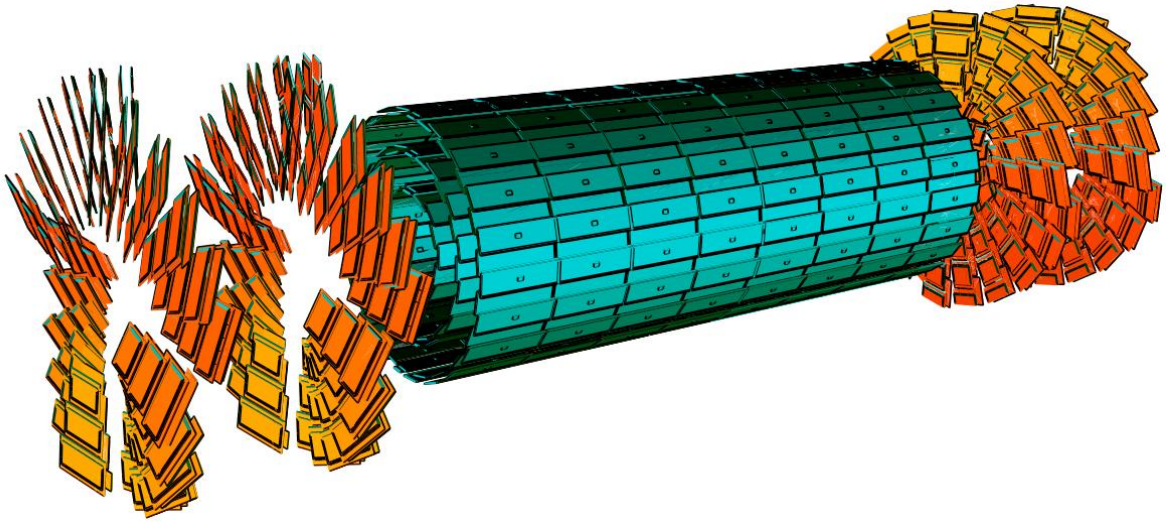
Status of the CMS Pixel Detector

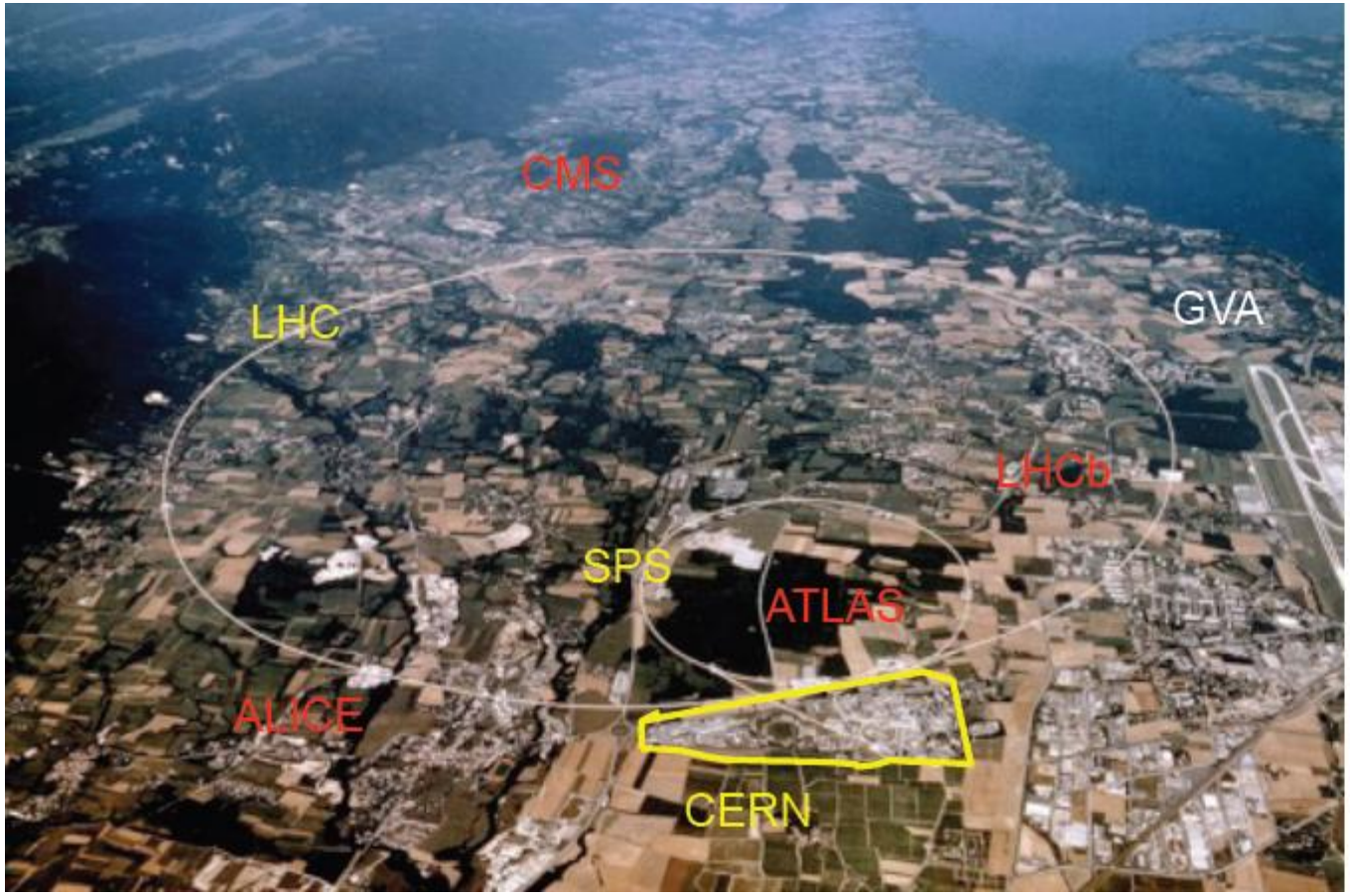
G. Bolla, bolla@cern.ch

PURDUE UNIVERSITY

For the CMS Pixel Group



LHC: The Large Hadron Collider

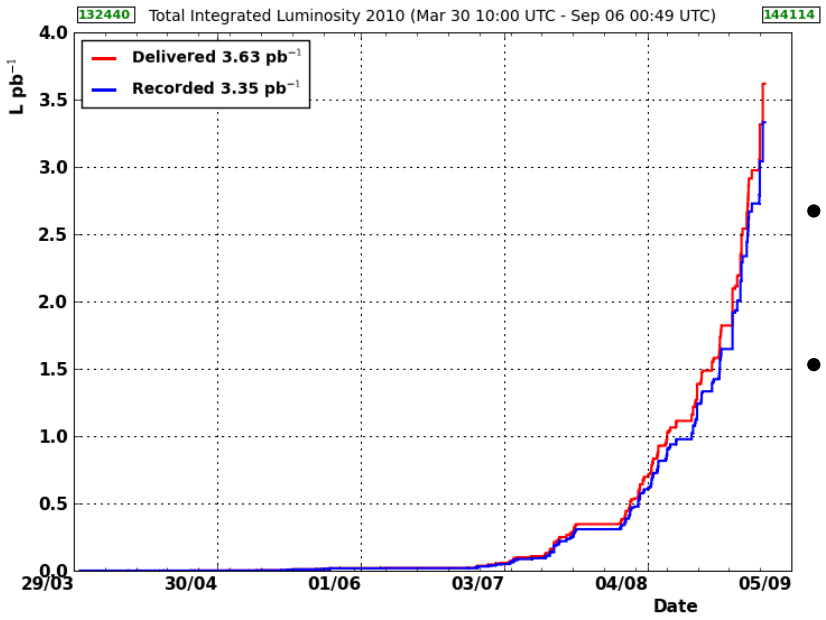


LHC Design Parameters:
p-p collider:
$\sqrt{s}$ =14 TeV
$L=10^{34}\ cm^{-2}s^{-1}$
Also Heavy Ion:
Pb-Pb at 5.5 TeV
$L=10^{27}\ cm^{-2}s^{-1}$

Startup Scenario 2010 – 2011
- $\sqrt{s}$=7 TeV
- Long Physics Run $L_{peak}=10^{32}cm^{-2}s^{-1}$

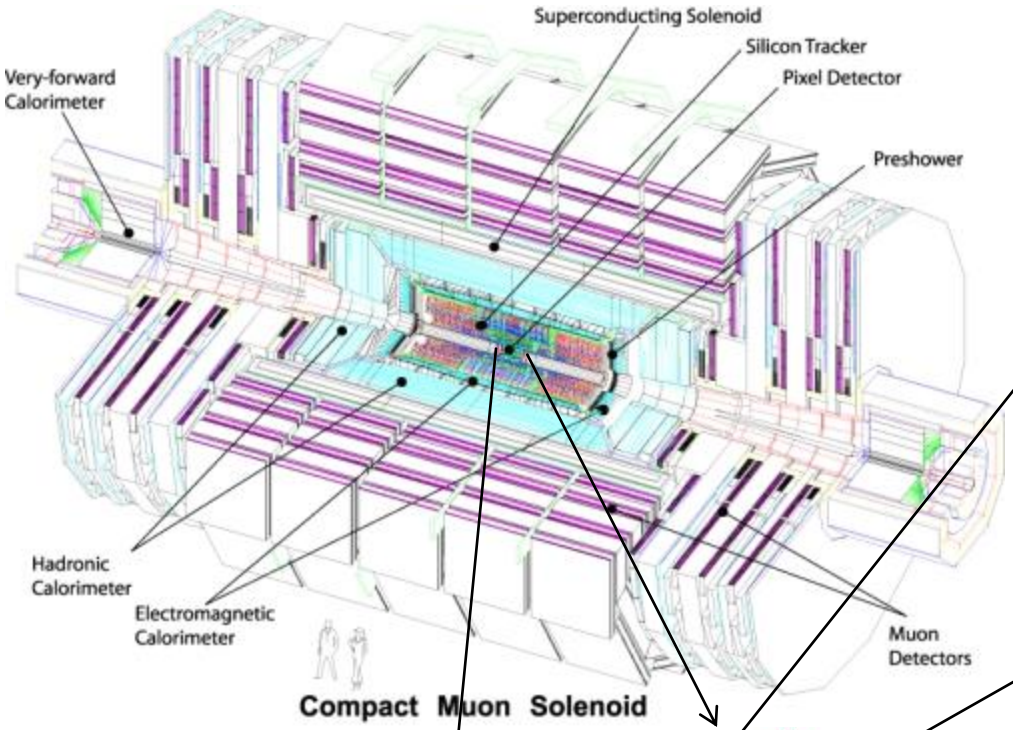
CMS and Pixel: some important dates

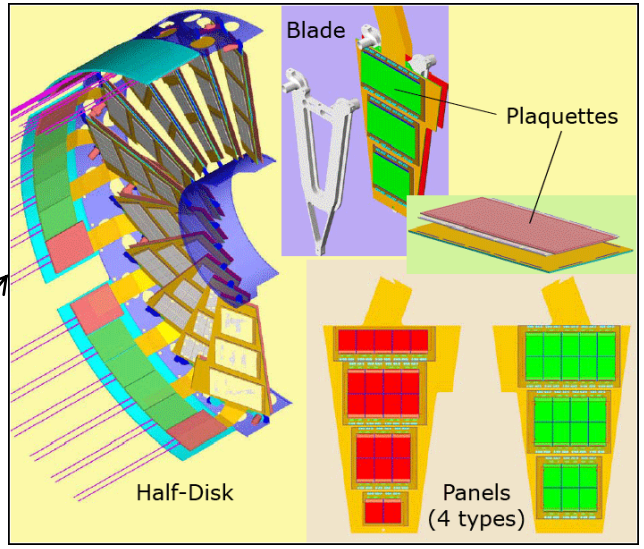
- July/August 2008
  - Pixel Installation in the CMS experiment.
- March/April 2009
  - FPIX Extraction/repair/re-installation
- December 2009
  - Collisions at 900 Gev and 2.36 TeV
- March 30th 2010
  - First collisions at 7 TeV



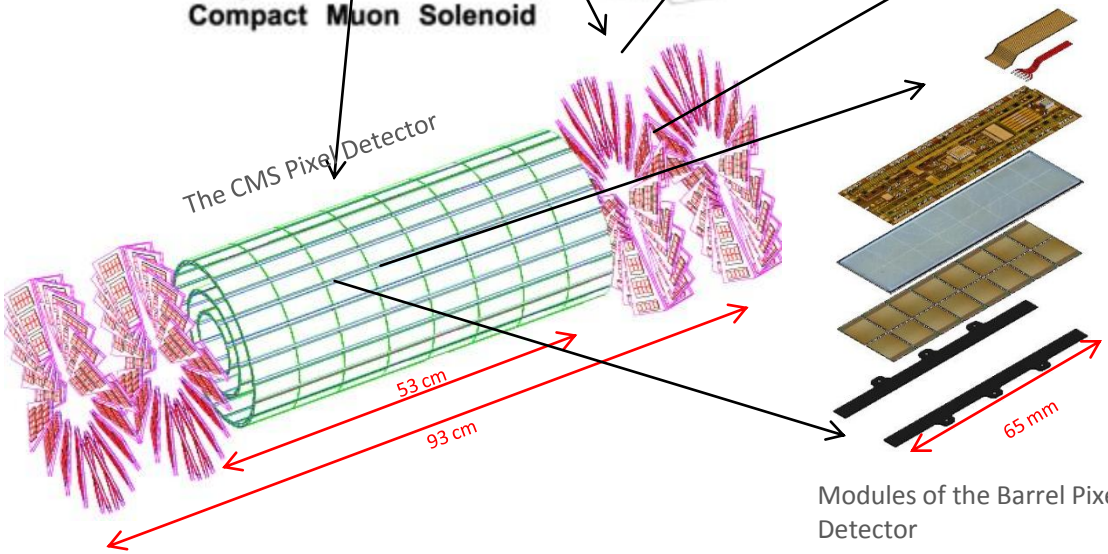
- Today
  - ~3.5 pb^{-1} delivered
- And next:
  - 40-50 pb^{-1} by the end of the year
  - 1 fb^{-1} by the end of 2011

System overview





Panels of the Forward Pixel Detector



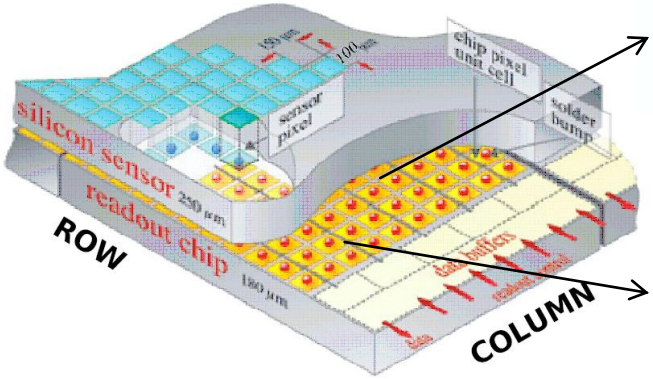
Modules of the Barrel Pixel Detector

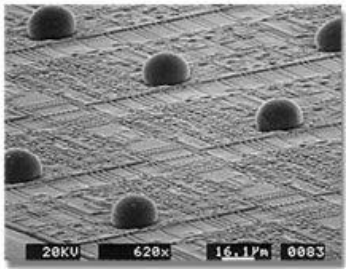
- Forward Pixel Detector (**FPix**) has two disks on each side at 34.5 cm and 46.5 cm
- FPix has 672 modules

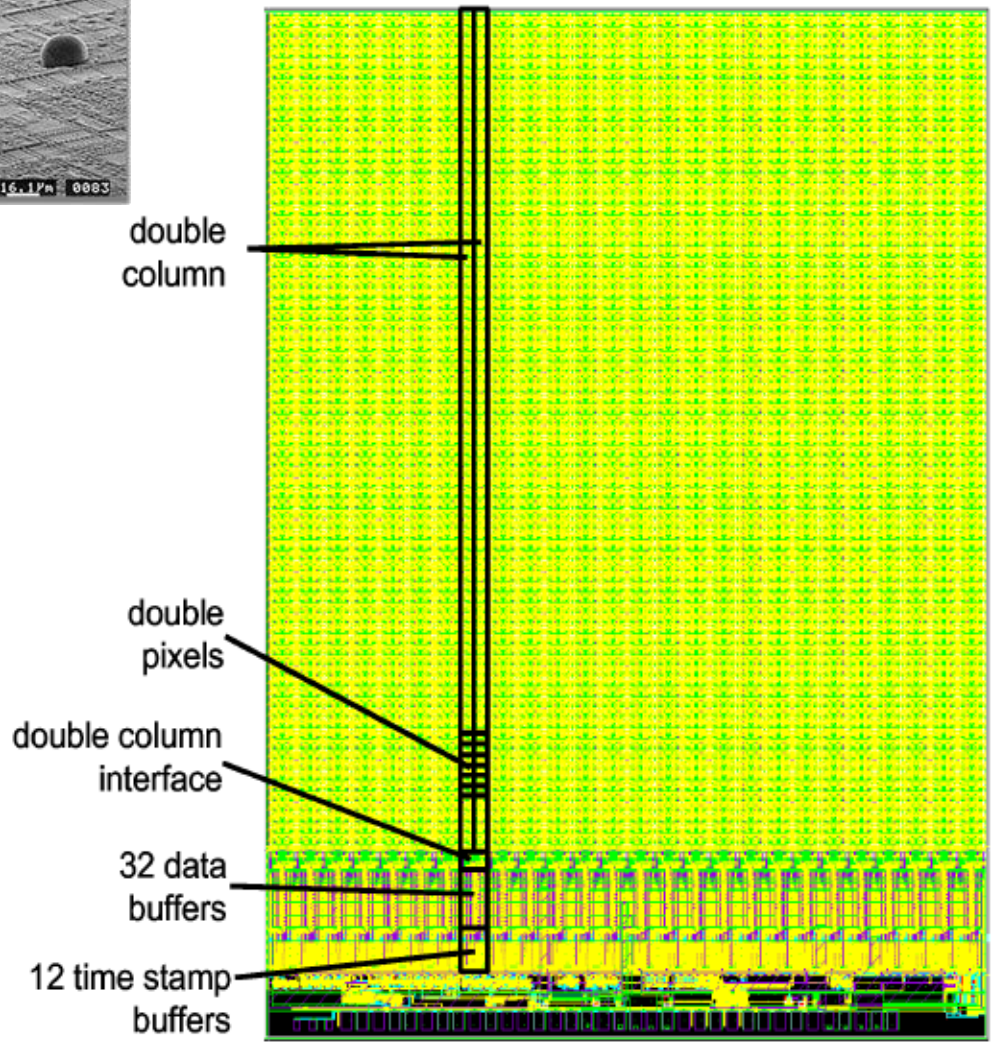
- Barrel Pixel Detector (**BPix**) has 3 layers of radii 4.3 cm, 7.2 cm and 11.0 cm
- BPix has 768 modules

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

The core of the system (sensor and readout chip)

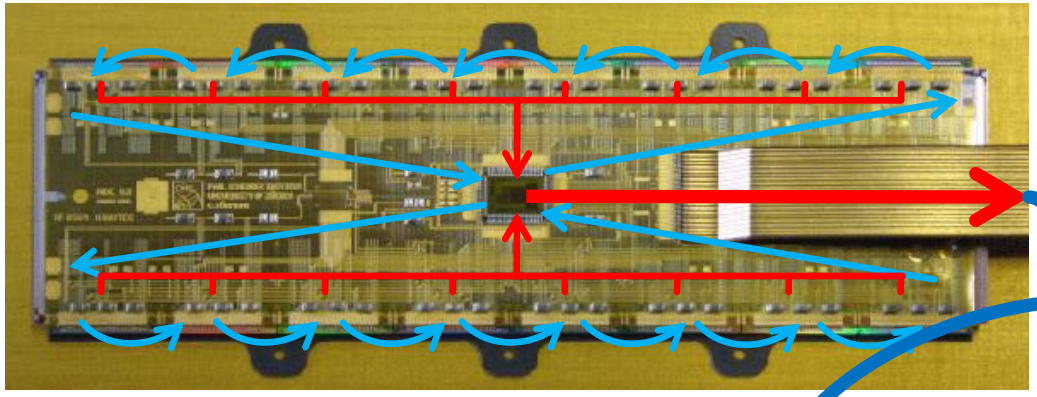


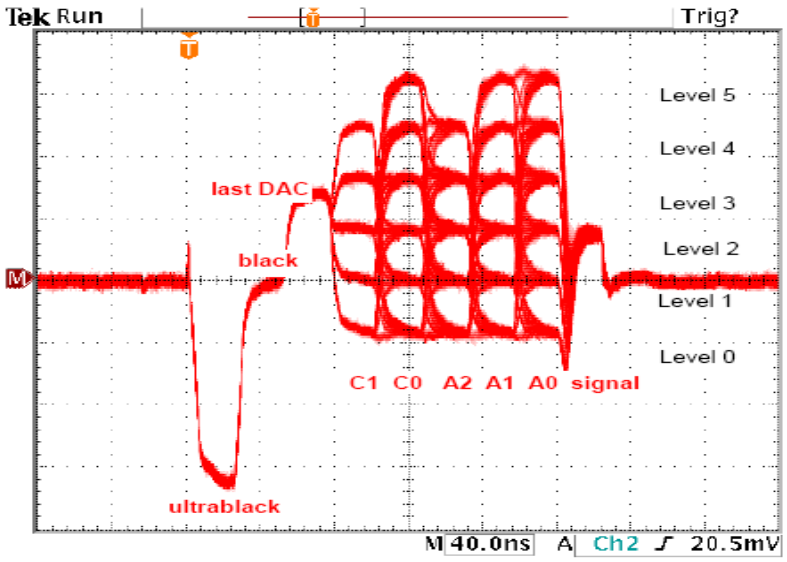


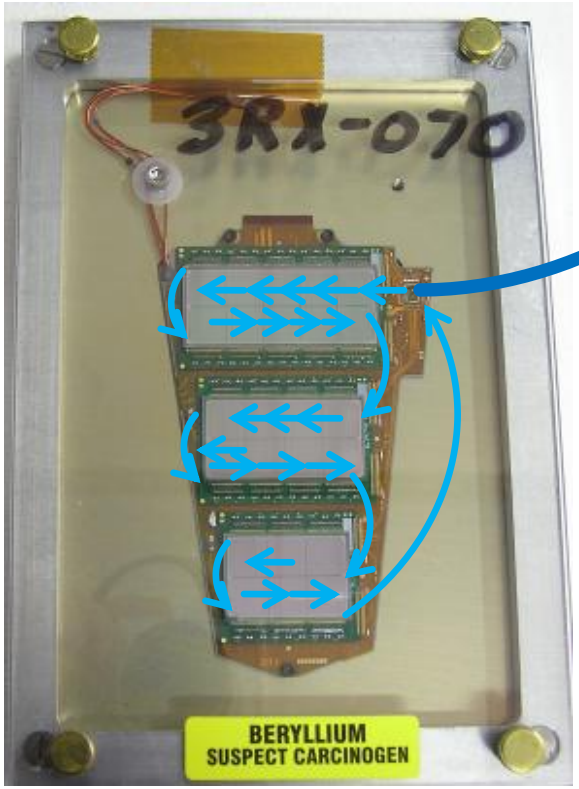


- **ReadOut Chip (ROC) bump bonded sensor pixels.**
- **52 80 = 4160 pixels per ROC**
- **15,840 ROCs**
- **66 million pixels**
- **zero-suppressed output**
- **Each ROC can be tuned (DAC)**
- **Each pixel has a programmable threshold (adjusting this is called *trimming*)**

Module readout





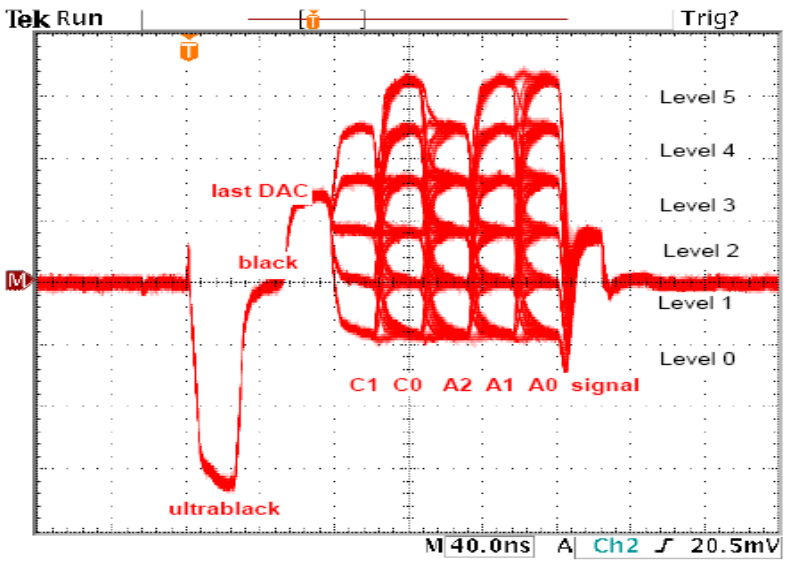


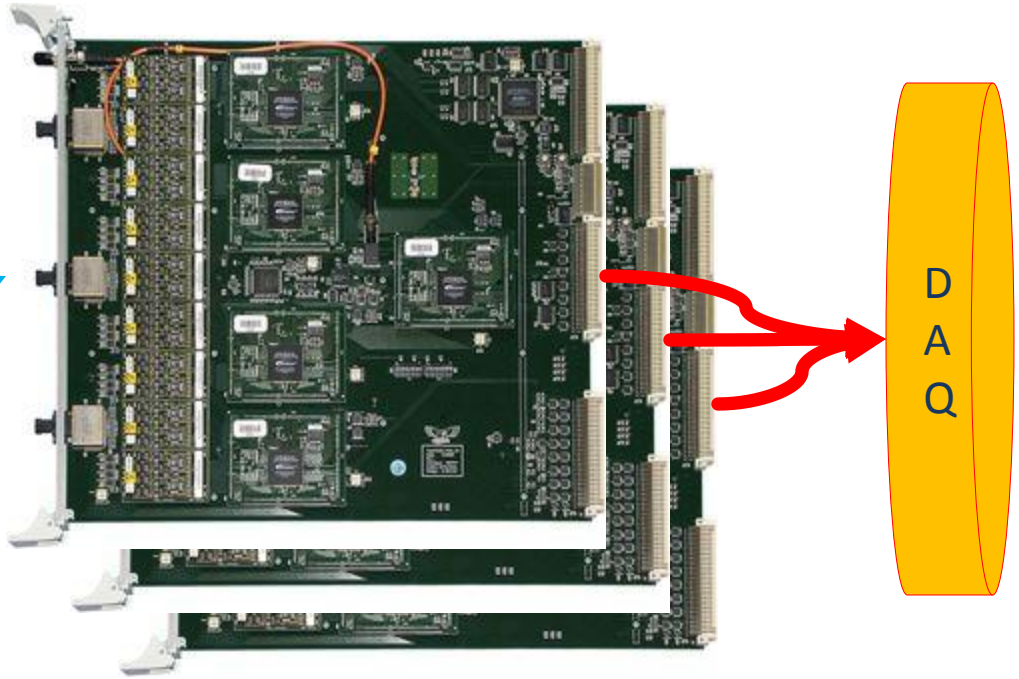
- On receiving a L1 trigger, the Token Bit Manager (TBM) initiates a Chinese-whisper of "token bits" that instruct each ROC to send its hit data to the TBM

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

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

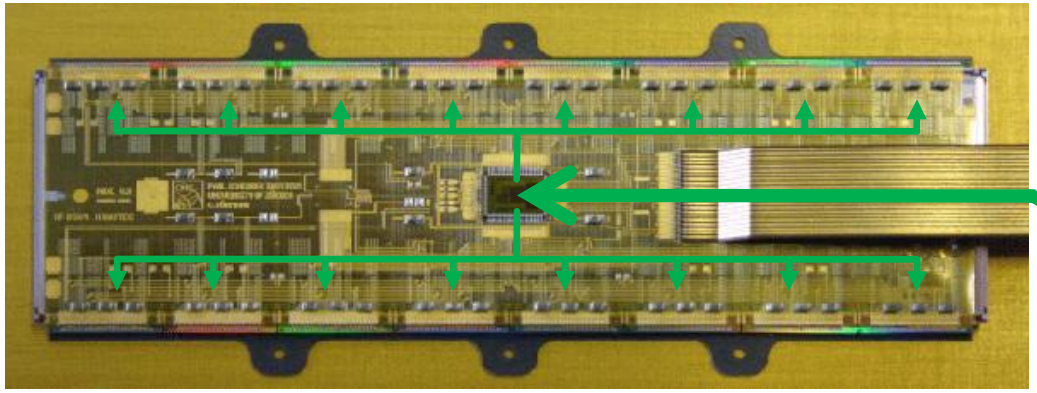
Digitizer and data readout

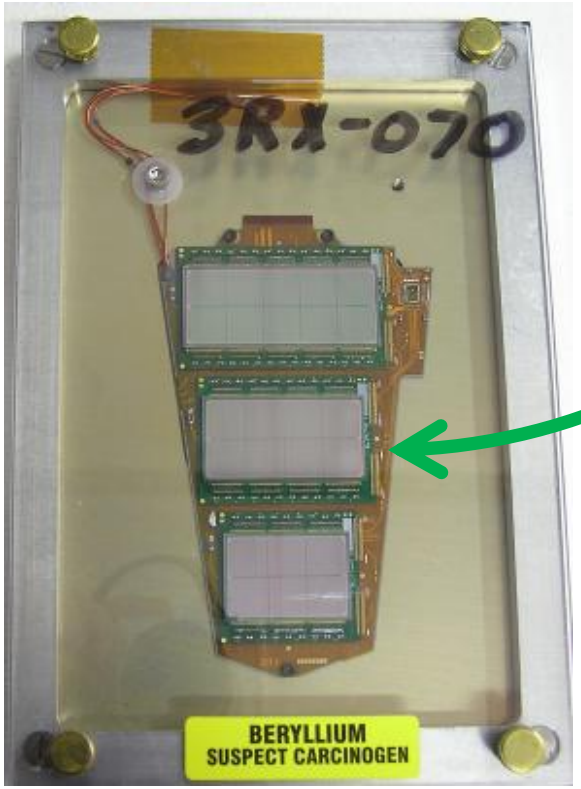


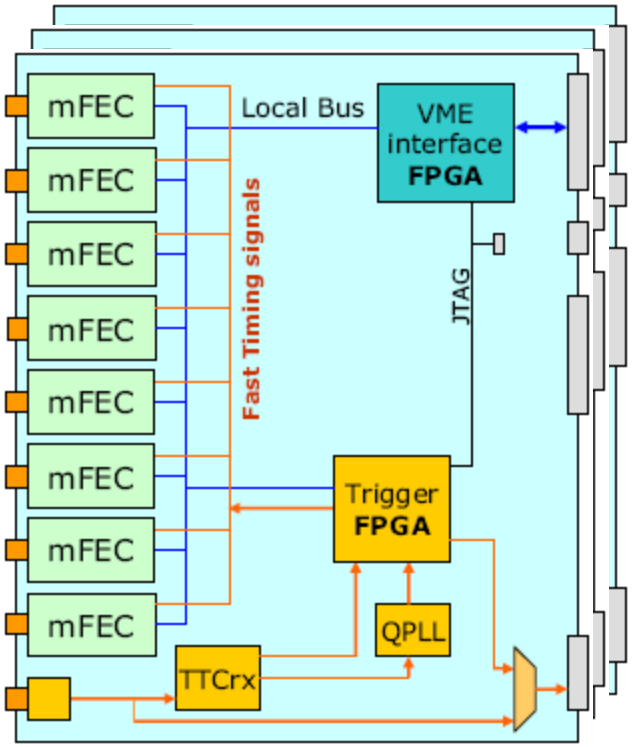


- Pixel Front End Driver (FED) digitizes analog signals given the level thresholds for decoding.
- One crate of FED boards is controlled by one PixelFEDSupervisor application.
  - 3 crates for a total of 40 FEDs in Pixels.
- FEDs send digitized data down S-Link cables to the Data Acquisition System (DAQ).
- FED data may also be read out via VME by the PixelFEDSupervisor.
  - Diagnostic informations

Controller





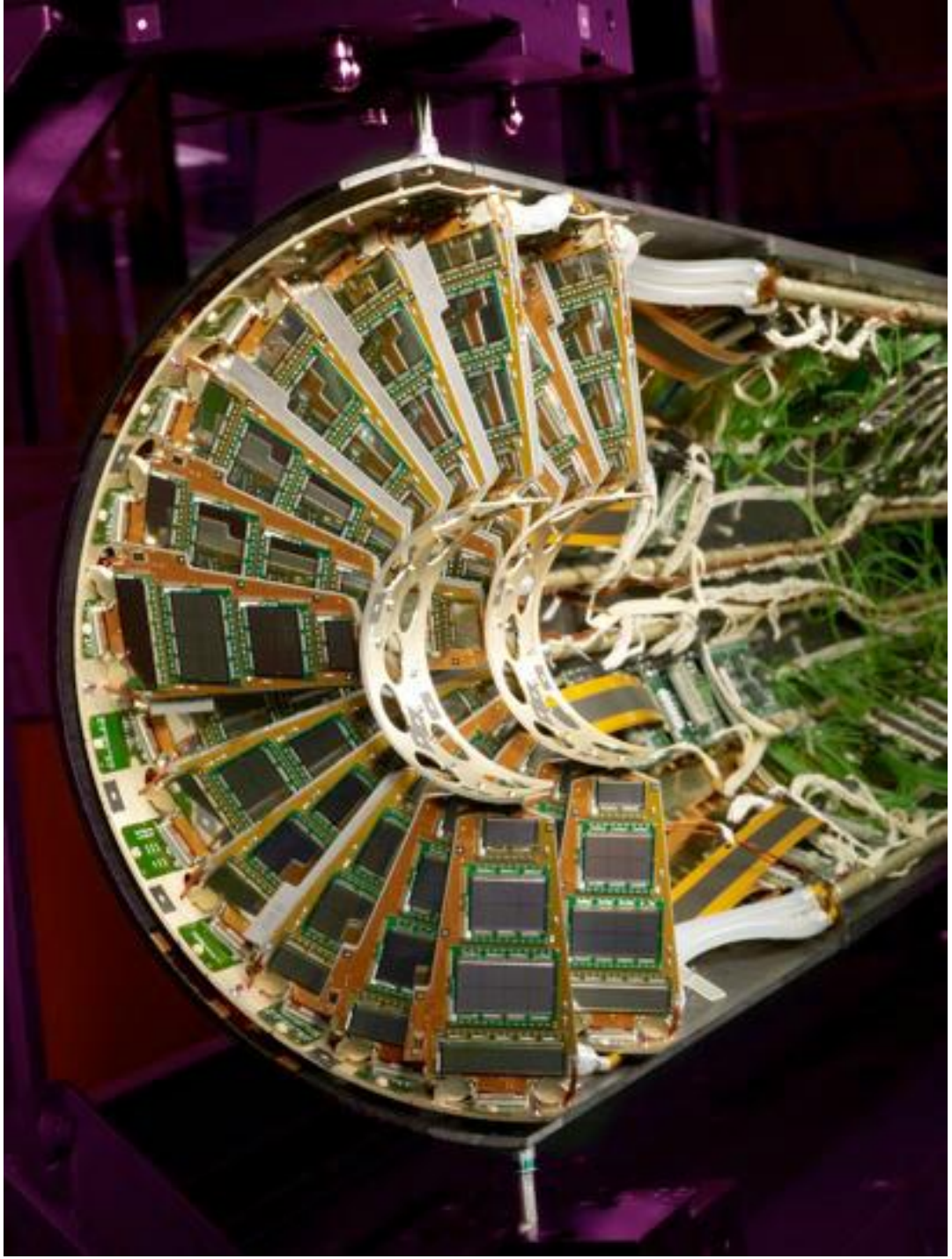


- Control signals consist of
  1. Clock & L1 Trigger
  2. I^2C Commands for programming

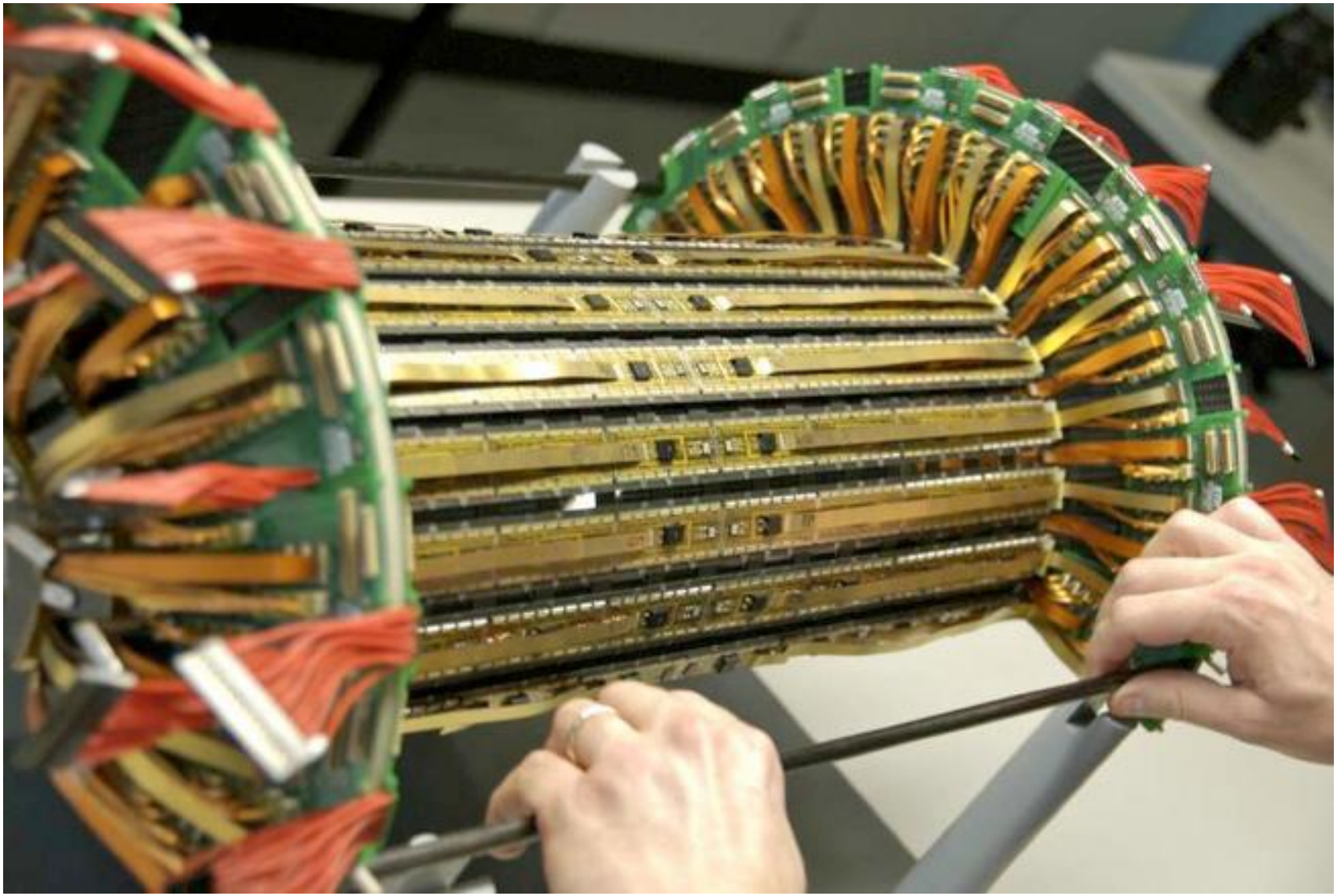
- Using I^2C commands we can program various DACs on each ROC, set trim bits on each pixel and inject charges for calibration purposes.

PURDUE UNIVERSITY

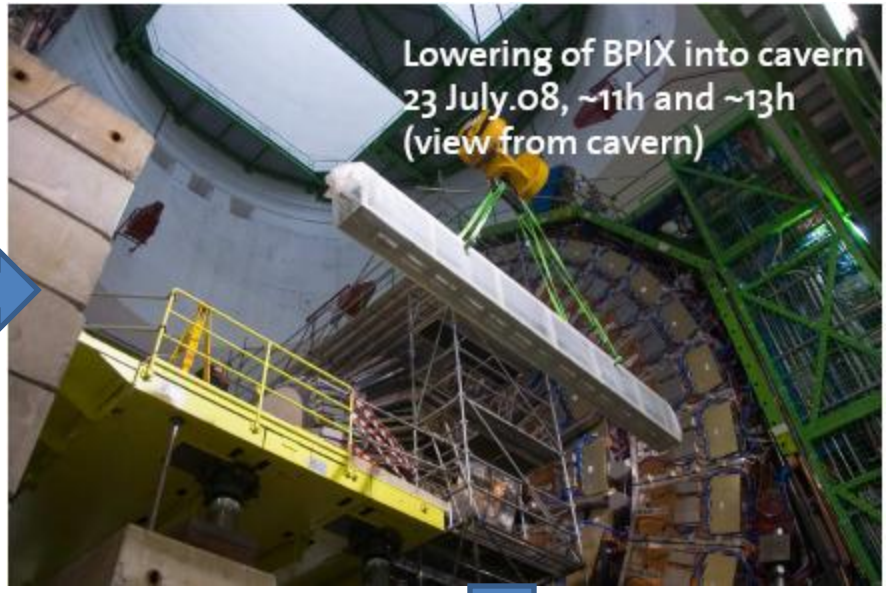
CMS Pixel Disks



CMS Pixel Barrel



Installation in CMS

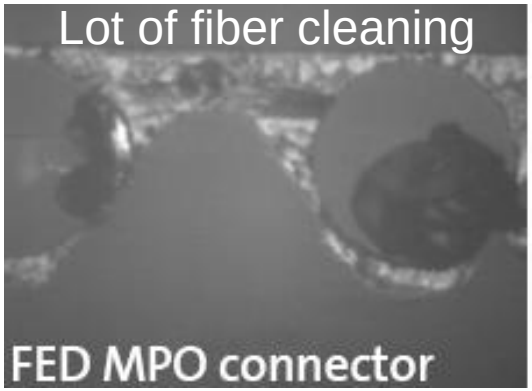


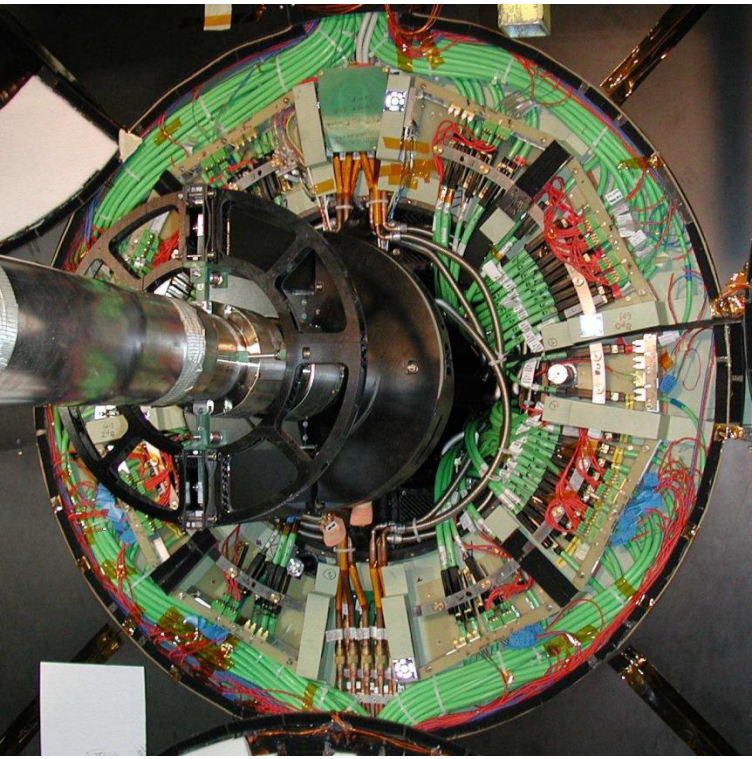
Installation

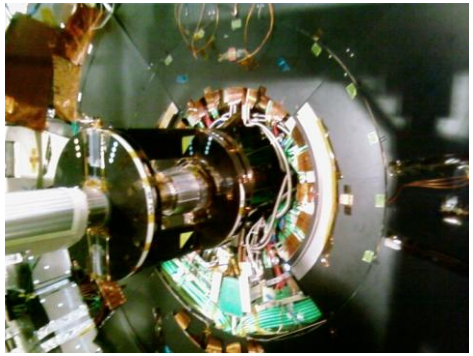
- Systems (BPIX and FPIX) slide on pre-build rails into the strip tracker bore.
- System latches in final position.
- Procedural process to the minimal detail.

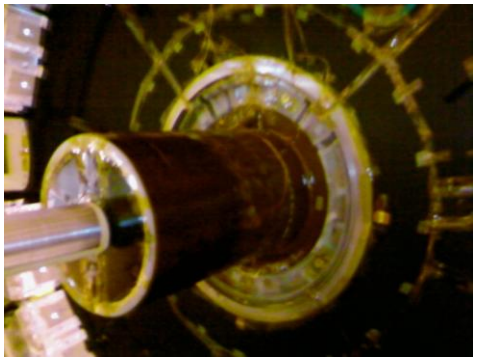
Timeline (less than a couple of weeks total)

- Barrel Pixel (5 working days)
  - July 23th lowered in the cavern
  - July 29 green light for the insertion of the FPIX
- Forward Pixel
  - Lowered install and connected in 1 working day/side

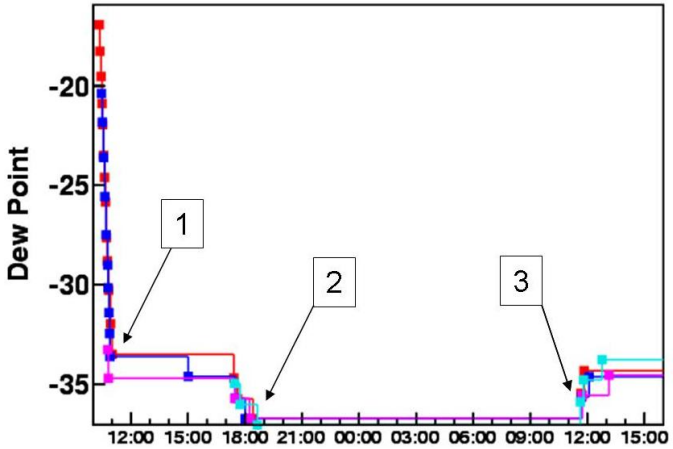






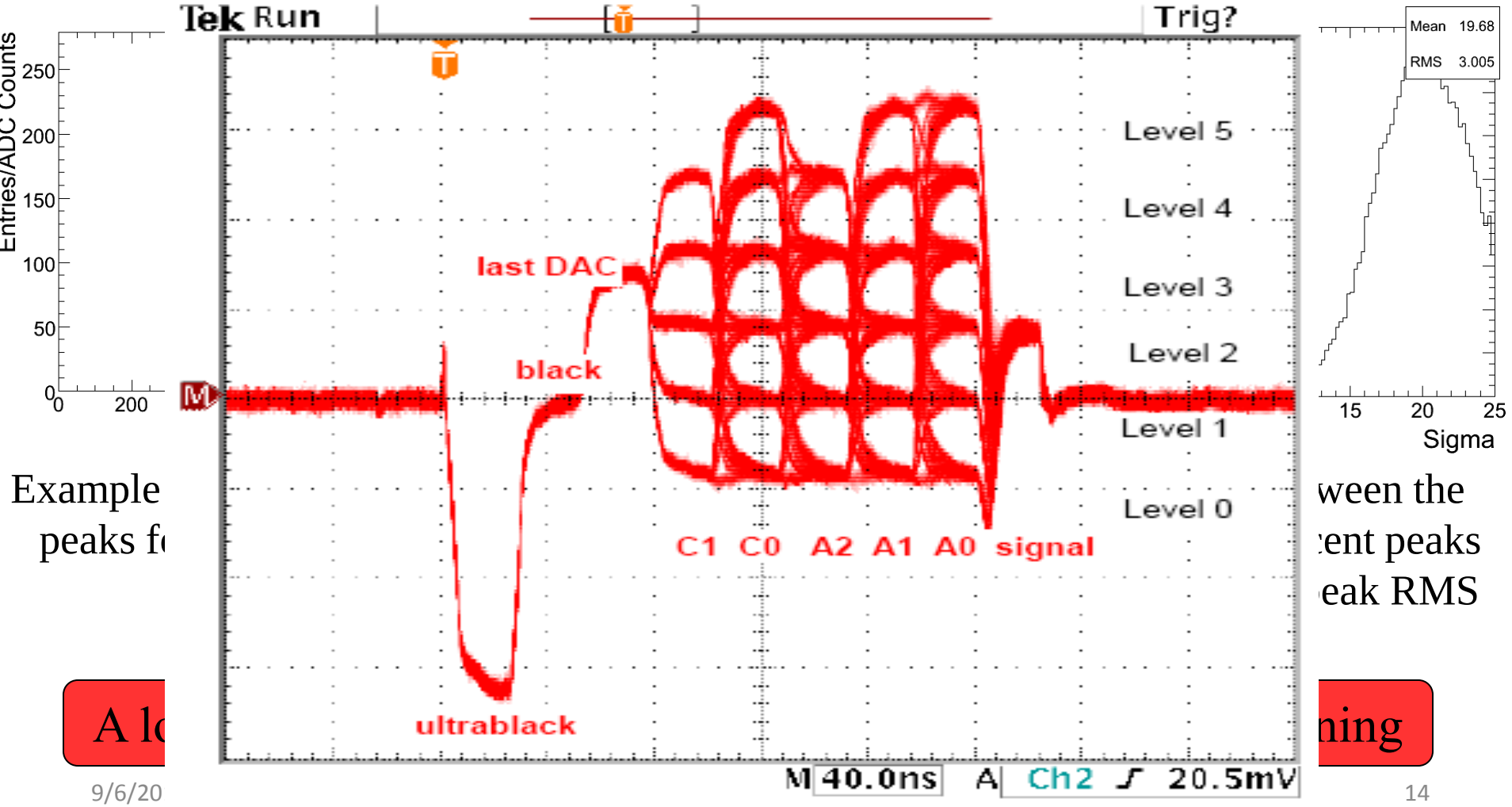


Final touch: a humidity seal to keep the detector dry



Calibrations (addresses)

For each pixel hit, the address is encoded with a 6 level scheme over 5 clock cycles, the 6th one giving the charge.



Example

peaks f

ween the

ent peaks

eak RMS

A l

ning

Final numbers of defects by the end of 2008

	Pixels	Lost on surface	Lost later	Total	Single Pixels
Barrel Layers	48M	0.35%	0.52%	0.87%	0.01%
Forward disks	18M	0.00%	6.00%	6.00%	<0.1%

2008/2009 Winter shutdown

Decided to pull out the Forward Pixel detector to understand/repair the faulty 6%

- Already partially diagnosed in situ
  - One LV short
  - One HV short
  - One broken wirebond during insertion

Repairs

- Two major problem to be solved:
- A HV to GND short
  - A single wire had its insulation cracked during installation and was touching the grounded carbon fiber structure surrounding it.
    - All other wires checked for this failure and no other action needed
- A LV short
  - Associated with bad crimping.
    - All cables on all four Half Cylinders were measured and re-crimped (if needed)

- **A number of connectors at the Filter Board end of the cables was replaced and new resistance measurements taken**

mOhm	-Z2, 1.4		-Z2, 1.2		-Z2, 2.2		-Z2, 1.3	
	before	after	before	after	before	after	before	after
Va+	30.1	28.6	54.2	28.3	29.8	27.2	32.5	29.5
Va-	33.3	28.6	86.9	31.7	30.6	26.1	30.6	28.6
Vd+	43.7	28.2	31.6	29.6	34.2	27.1	33.8	28.8
Vd-	33.5	28.3	37.4	28.6	26.5	26.6	44.9	28.6

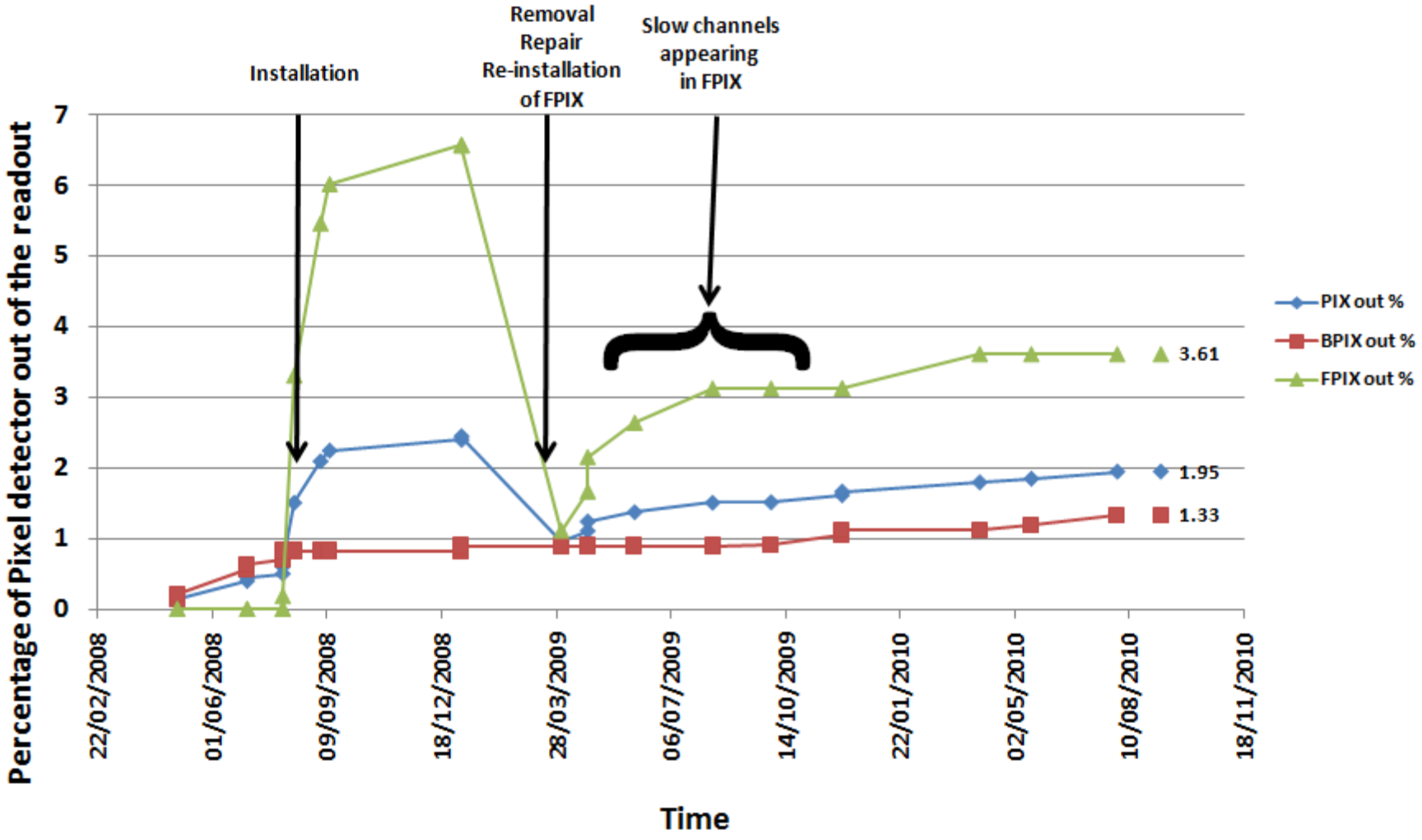
mOhm	-Z2, 2.3		-Z1, 2.4		-Z1, 1.2		-Z2, 1.3	
	before	after	before	after	before	after	before	after
Va+	52.3	27.7	55.1	27.6	33.1	28.8		
Va-	21.5	26.4	26.5	26.3	29.4	28.8		
Vd+	28.4	26.4	26.9	26.9	35.7	29.8		
Vd-	33.1	26.8	26.4	26.1	33.2	29.4		

FPIX Extraction/maintenance/repair/re-insertion

- Other achievements
  - Replaced silicon cooling hoses
    - Max pressure raised from 1.7 barg to 2.5 barg
  - Installed new humidity sensors
    - HS2000 sensors to cross-calibrate the existing HMX
  - Replaced back-feet on the Half Cylinders
    - Easier to remove/re-install
  - Implement cold-fingers for the AOH
    - Improve the thermal stability of the Analog Opto Hybrids
    - Allows longer time of data-taking without recalibrating the optical baseline
    - Reduce the consequences of the thermal coupling between pixel and the surroundings (TIB).
- The system was designed for “fast” insertion and removal.
  - Potential for yearly beam pipe bakeout procedure
  - We have proven that within three months we can get the job done from beginning to end.

CMS Pixel detector status

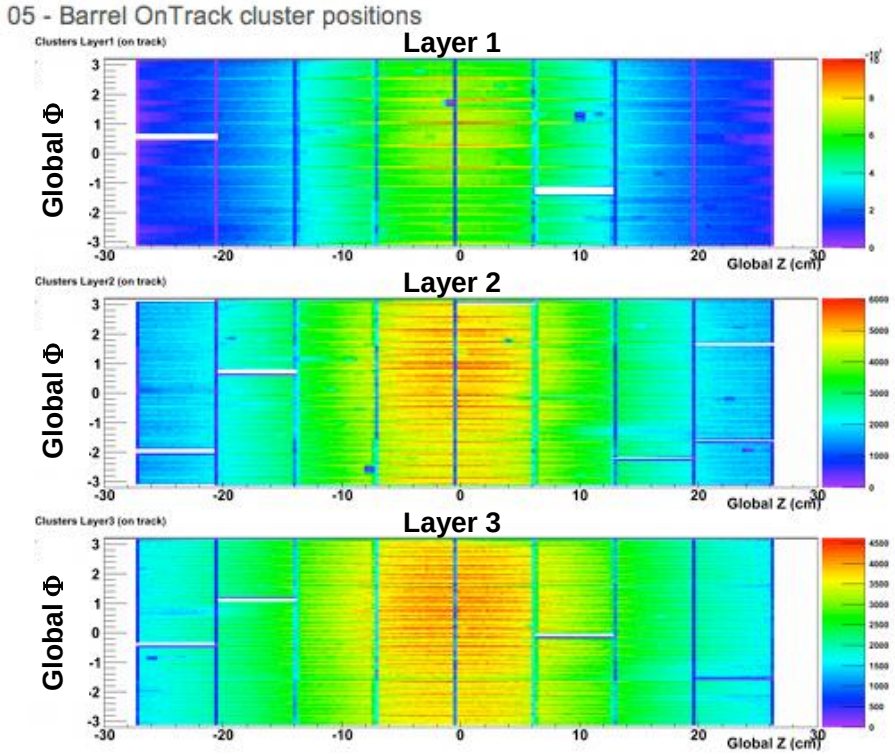
98% of the detector is taking data with the experiment.

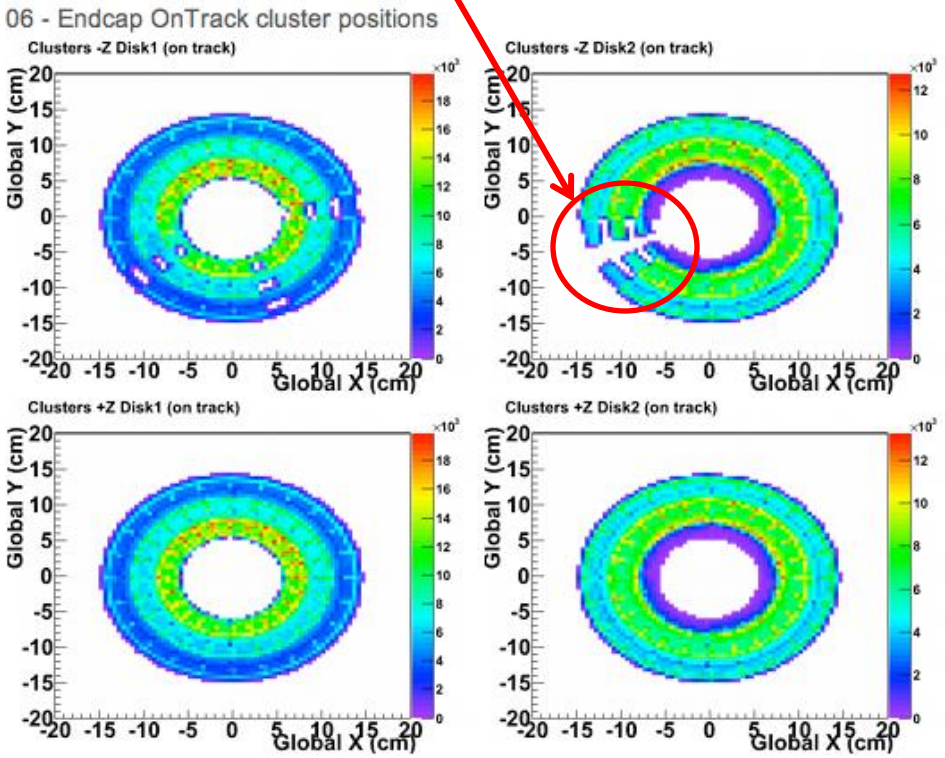


CMS Pixel detector status

DQM: Data Quality Monitor
Cluster on track maps. The maps show the location of the disabled modules.

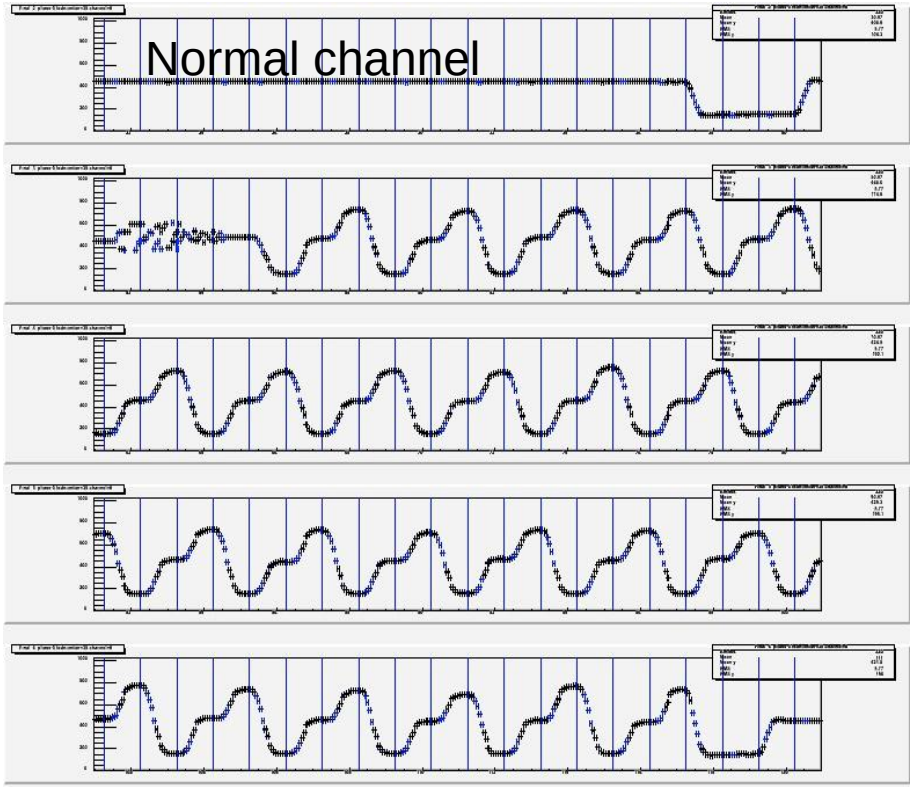
Location of “slow” channels

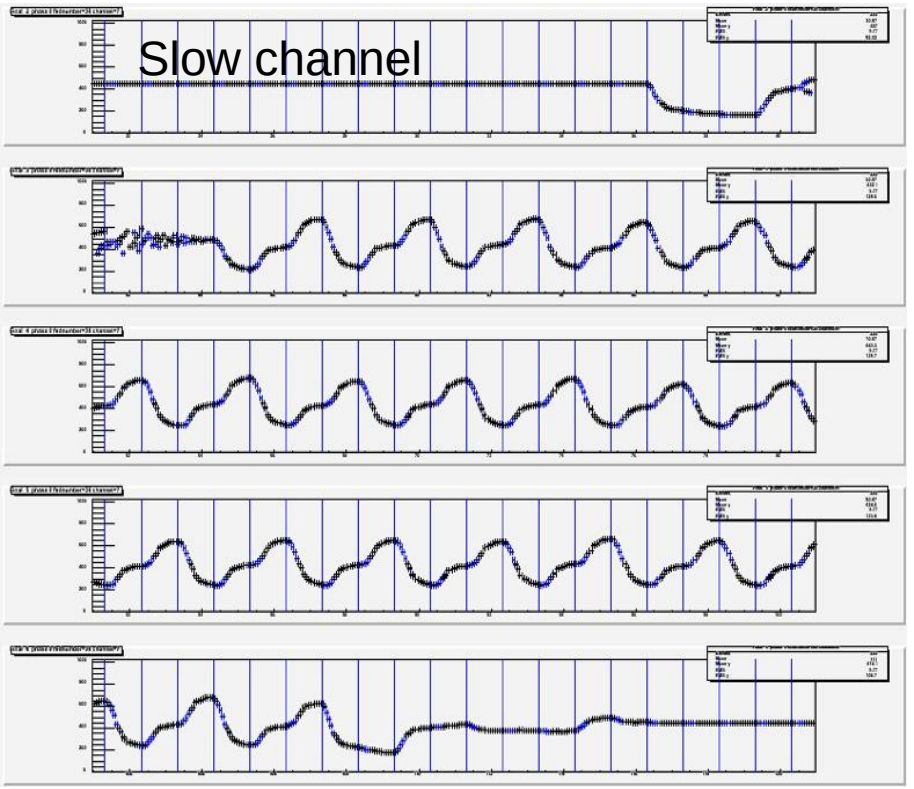




The “slow” channels

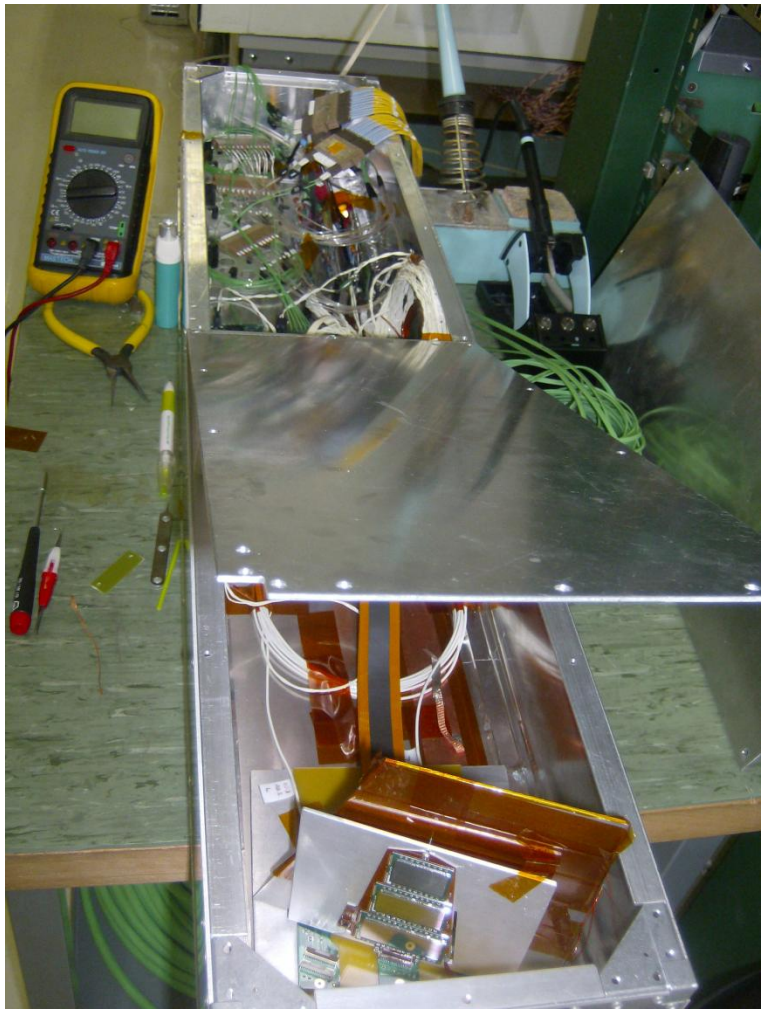
- **75% of the FPIX failures suffer from the same symptoms.**
  - **Low rise-time of the analog output signal.**
- **It is impossible to separate the address levels (Undecodable information)**
- **The CMS pixel system was inserted in CMS last summer**





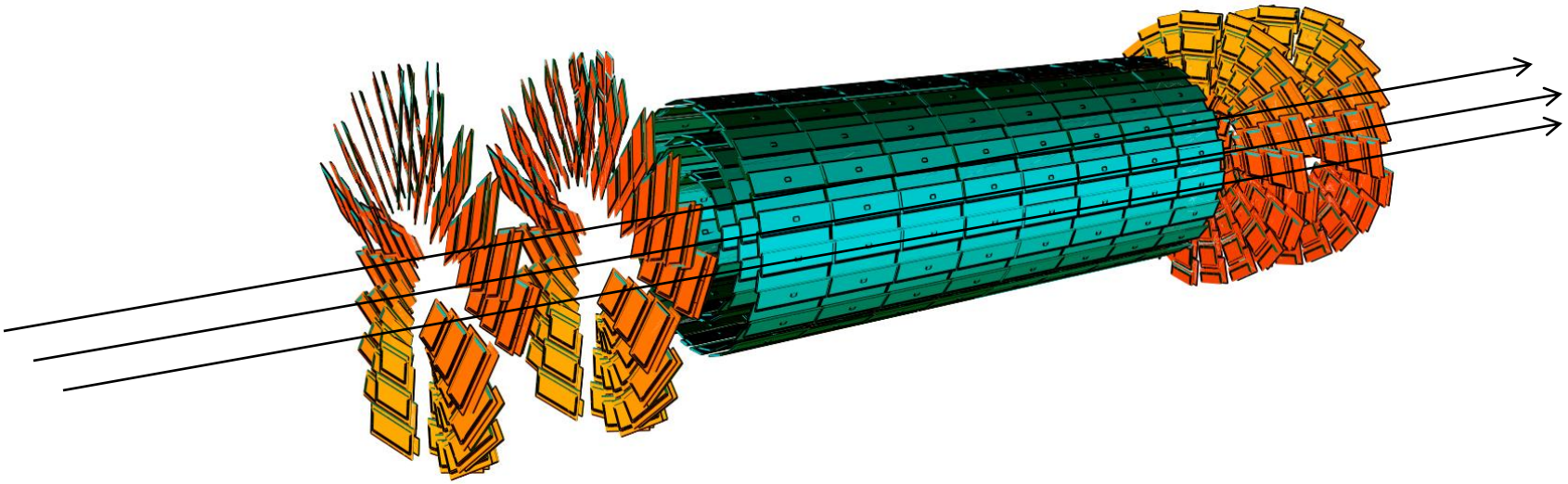
The “slow” channels (2)

- Long list of tests performed in the lab with spare components
- We managed to generate a long list of scenarios to be investigated
  - but none of them reproduce the symptoms as measured in the experiment.
- We are now trying to deal with the problem in situ
  - developing FED firmware modifications to:
    - measure the rise-time on the fly event by event from the TBM header (3 clock cycles long)
    - Event by event apply the measured correction to the address levels.
- Also considering removal/diagnose/repair of the FPIX MINUS during the 2012 shutdown.



Operational issues 1: Beam-gas interactions

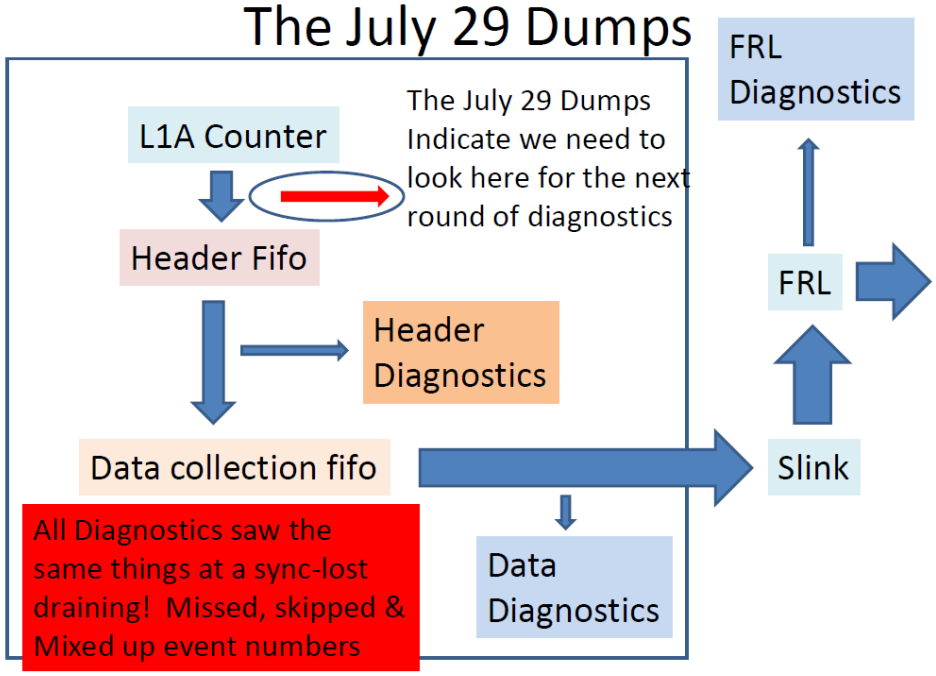
- **Beam gas interactions in the straight session of the LHC close to the experiment generates shower of particles that enter the pixel detector along the beam line.**
  - **Large number of pixel above threshold in the barrel if the track hits the sensor**
  - **Visible since early 900 GeV collisions (and even with single bunches passing by).**
  - **Implemented new FED firmware to dump the long events and holdoff triggers.**
    - **More details in Ben's talk**



- **A poster on Beam Background at CMS By Steffen Muller later during the week**

Operational issues 2: Data corruption in the FED

- In the last 5 months the Beam conditions changed by few orders of magnitude
  - Instantaneous luminosity from E27 to E31 (last week)
  - From 1 up to 38 bunches colliding at CMS
- L1 Trigger rates in the experiment grew accordingly from some to ~70-100 KHz.
- In the early summer it became evident that some data corruption was taking place inside the pixel FEDs (probably a coincidence that it started to show up with the firmware changes implemented to deal with the Beam background events).

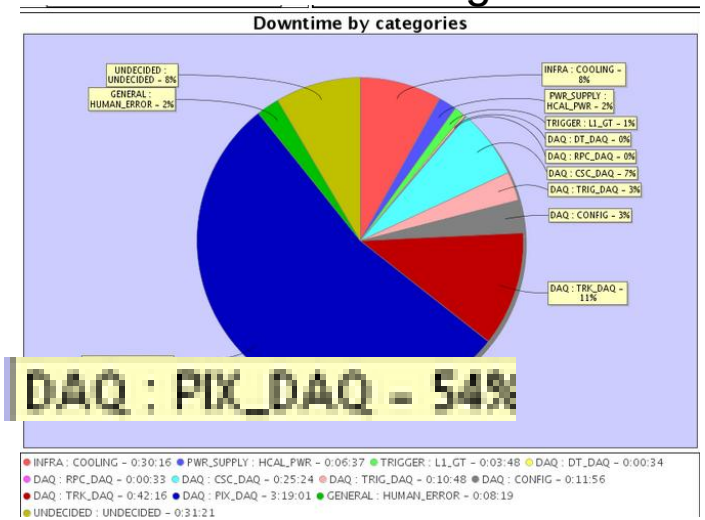


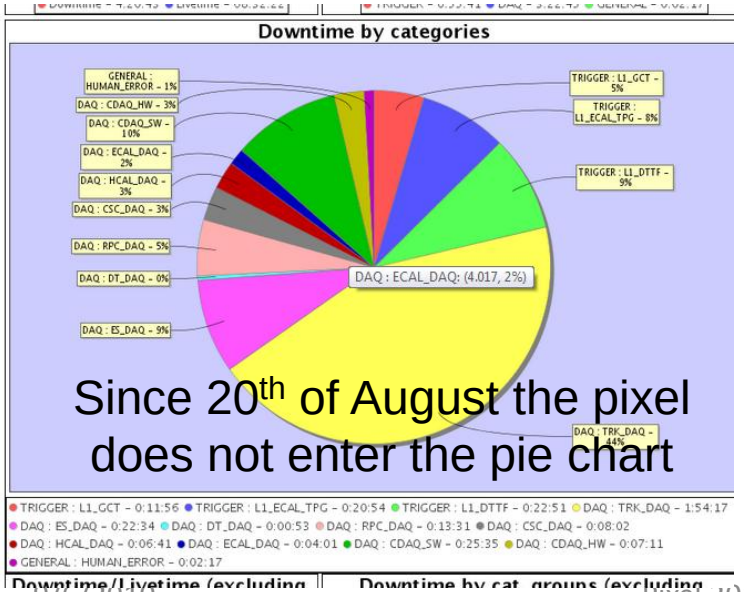
- For the first 6-7 weeks the problem was visible only during data taking with collisions.
  - Not visible with random triggers (but no data coming from the detector).
- Managed to reproduce the symptoms outside of stable beam by taking data with the HV OFF.
  - Sensor not depleted
  - Huge noise
  - Several pixel above thresholds

Operational issues 2: Data corruption in the FED

- **CMS runs with efficiency bigger than 90%.**
- **The major source of inefficiency was the data corruption in the pixel FEDs**
  - **Event number out of order is an error that the DAQ does not forgive and the run is to be stopped and restarted (some 5 minutes loss)**
  - **Rate of the error: once every 3-4 hours depending on the trigger rates.**

First week of August



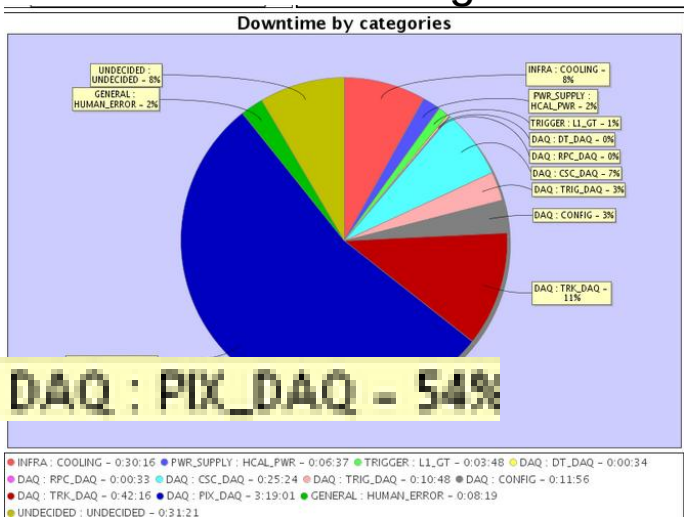


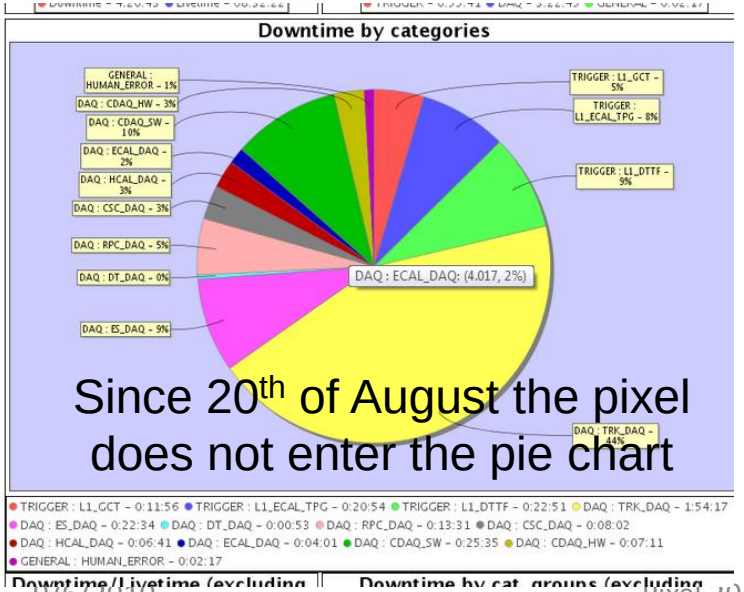
- **Problem was solve by acting again on the pixel FED firmware.**
  - **Small modification to the logic**
  - **<u>Signal conditioning</u>**
    - **Lower current of the output drivers**
    - **Low slew rate setting for the fpga**

Operational issues 2: Data corruption in the FED

- **CMS runs with efficiency bigger than 90%.**
- **The major source of inefficiency was the data corruption in the pixel FEDs**
  - **Event number out of order is an error that the DAQ does not forgive and the run is to be stopped and restarted (some 5 minutes loss)**
  - **Rate of the error: once every 3-4 hours depending on the trigger rates.**

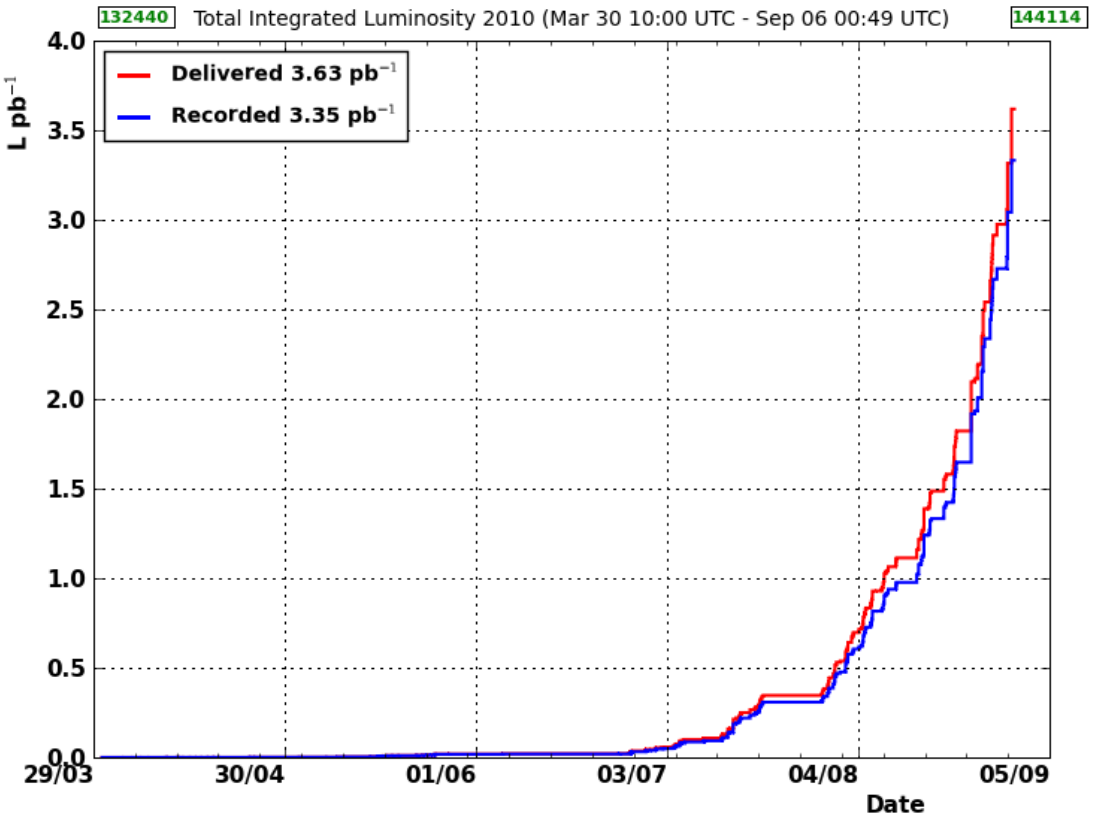
First week of August





- **Problem was solve by acting again on the pixel FED firmware.**
  - **Small modification to the logic**
  - **<u>Signal conditioning</u>**
    - **Lower current of the output drivers**
    - **Low slew rate setting for the fpga**

Impact on data quality



The experiment collected 3.35 pb^{-1} of the 3.63 delivered (efficiency little higher than 90%).

The offline data certification process declared 4.8 nb^{-1} Bad due to pixel data quality

about 0.15 %

- Two more talks on the quality of the data.
  - Urs: Offline calibrations
  - Mauro: Tracking and Vertexing

Final remarks

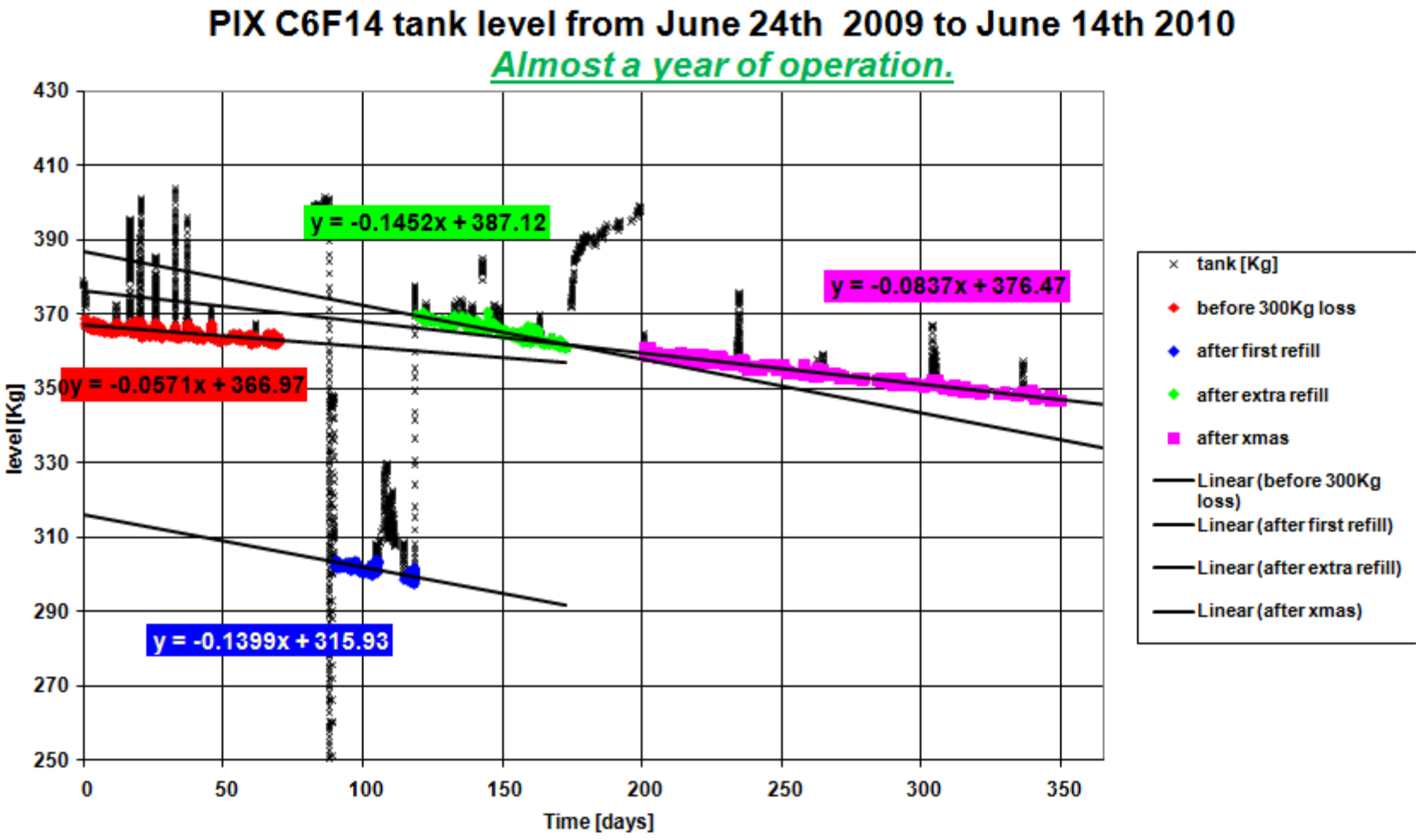
- The hardware of the pixel detector is in good shape for the 2010-2011 run at LHC.
- It was demonstrated that the detector can be extracted/maintained/reinserted in a few months.
- Some issues with collision operations were encountered and resolved.
- More fun on the data quality and performance in other presentations.

Spare slides

Infrastructure

- CAEN system:
  - Last two modules were replaced in:
    - Detector power (4603): July 14th 2009
    - Control power (4602): May 27th 2009
  - It is quite challenging to keep personnel trained for efficient access/maintenance with such small failure rate.
    - Pasquale/Gino/Bill are ready.
    - Enough spares in hand.
- VME and online computing
  - Nothing to report on the hardware: Stable condition
    - Listening carefully at the problem reported by other sub-detectors
      - VME-PC optical communication boards
  - Online computing → Ben presentation later

Pixel infrastructure: cooling



Pixel infrastructure: cooling-2

- **Stable good performance since refurbishment (early 2009).**
  - **Leak rate is negligible: No refill needed for the next 7-8 years**
  - **Recalibrated the Temperature sensors of the cooling plant.**
    - **Solved a long lasting mystery (3.4 degrees warmer detector than expected)**
- **Still Running at 7.4 deg C (coolant temperature)**
  - **What if the luminosity delivered exceed (by far) expectations and we accumulate *sizeable* radiation damage?**
    - **Can we go colder with the existing system?**
    - **Paola (CMS cooling coordinator) calculated that the present cooling system is compatible with sub-zero operation (Down to -5 -10 deg C).**
      - **Pixel is a small load for the C6F14 system**
    - **This assumes no changes in the operating temperature of the other tracker components (Strips).)**

Cooling incident

One of the SS corrugated flexible hoses was pinched and leaked visibly
Spotted in two hours due to the beam pipe survey.
Hose repaired by Atelier Central
Leak tested with Helium at 5 barg
Reinstalled on 04/09
Flow re-established within a few hours
By that time everything but FPIX BpI were already checked out