CMS Pixel Status

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On behalf of the CMS Collaboration

Pixel 2012, Inawashiro (Japan), September 3rd 2012

Outline

- The LHC and the CMS experiment;
- The CMS Pixel Detector;
- Operations during the first 3 years of data taking;
- Calibrations;
- Performance;
- Conclusions.

The Large Hadron Collider

Design parameters:

p-p:

$\sqrt{s}$ = 14 TeV

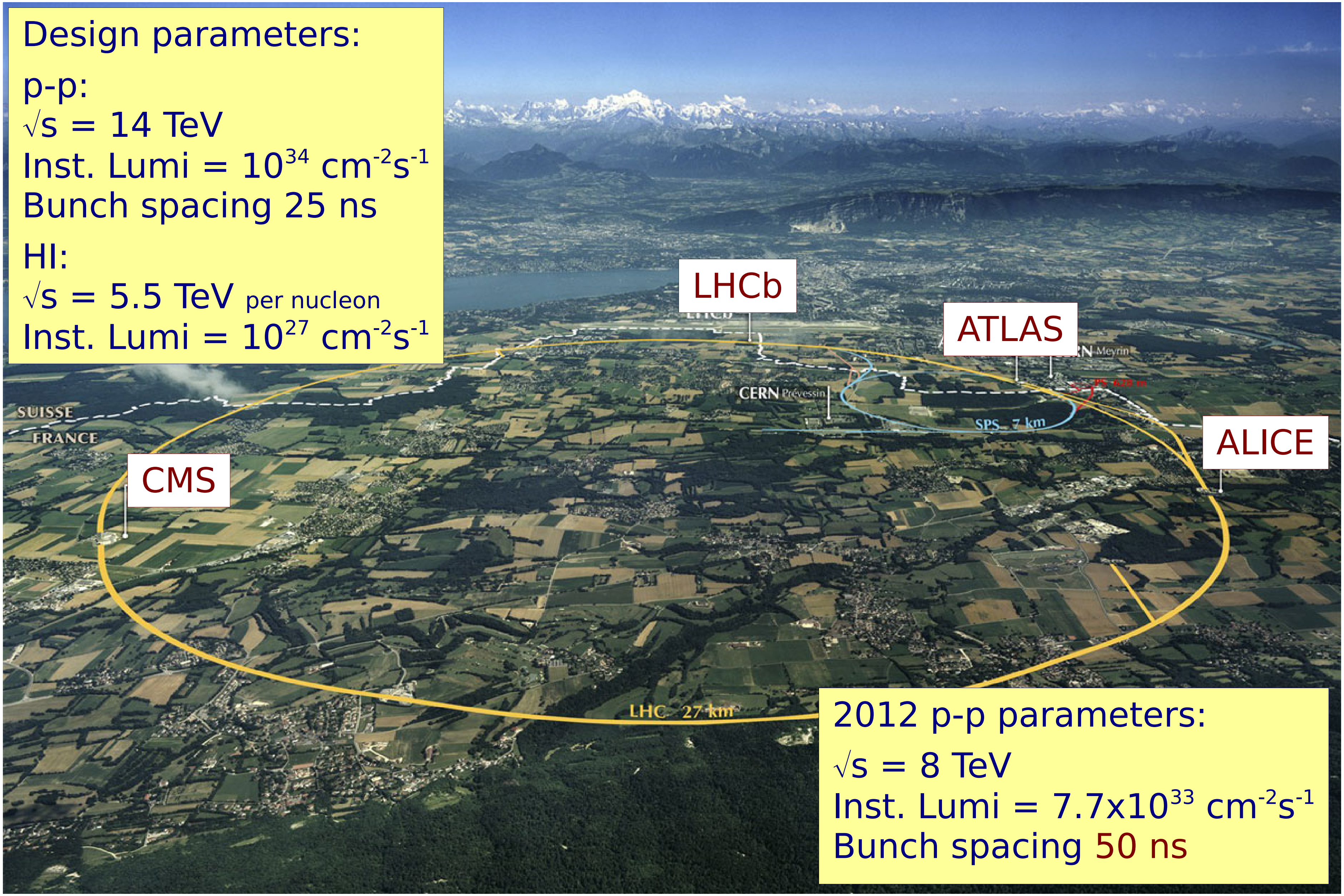
Inst. Lumi = 10^{34} $cm^{-2}s^{-1}$

Bunch spacing 25 ns

HI:

$\sqrt{s}$ = 5.5 TeV per nucleon

Inst. Lumi = 10^{27} $cm^{-2}s^{-1}$



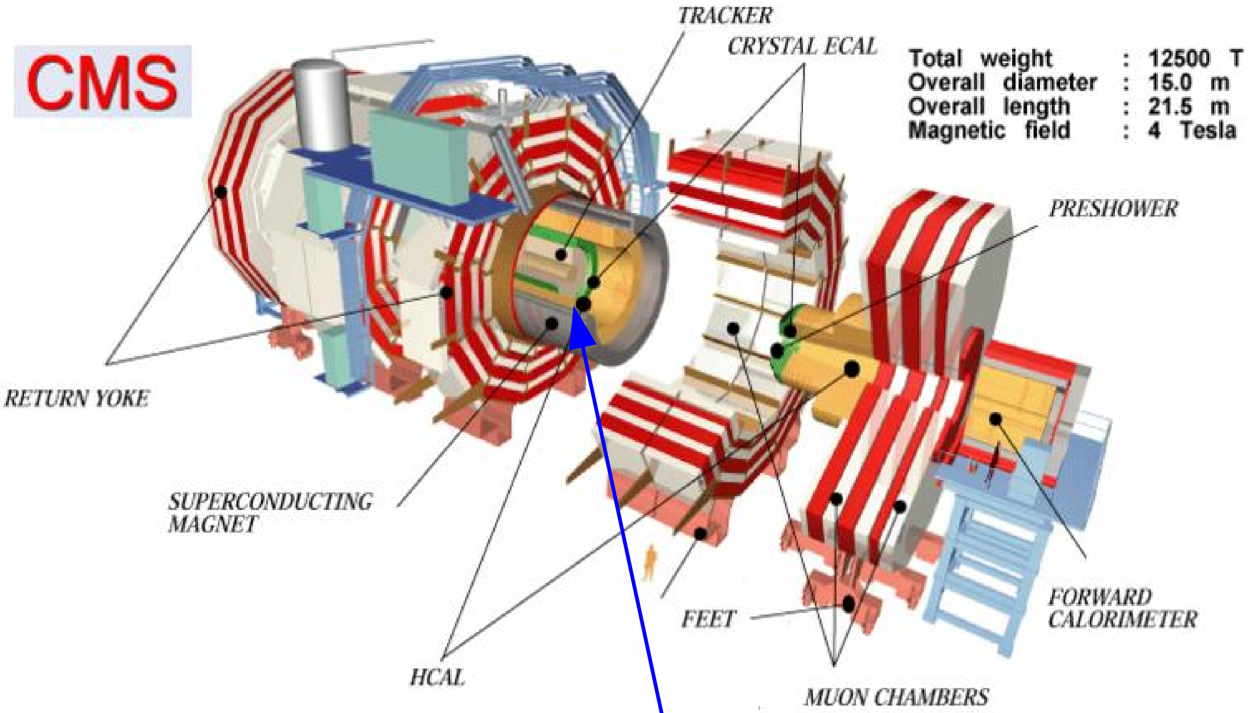
2012 p-p parameters:

$\sqrt{s}$ = 8 TeV

Inst. Lumi = 7.7×10^{33} $cm^{-2}s^{-1}$

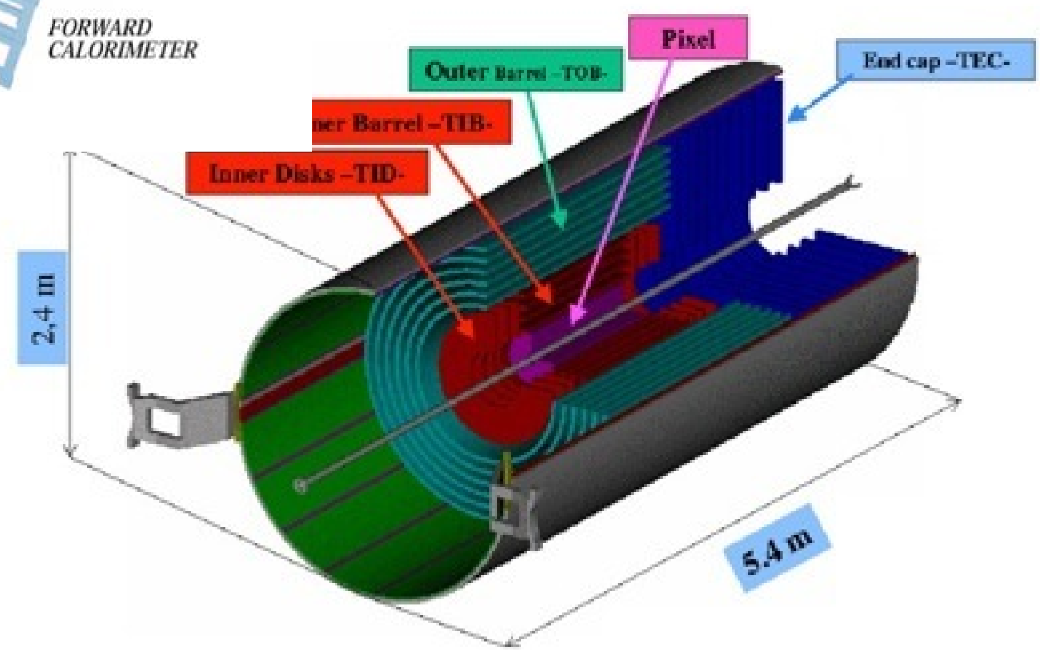
Bunch spacing 50 ns

The CMS experiment



General purpose detector

Vast physics programme: Higgs, top, B, QCD, Heavy Ion, and searches for SUSY, exotica, ...

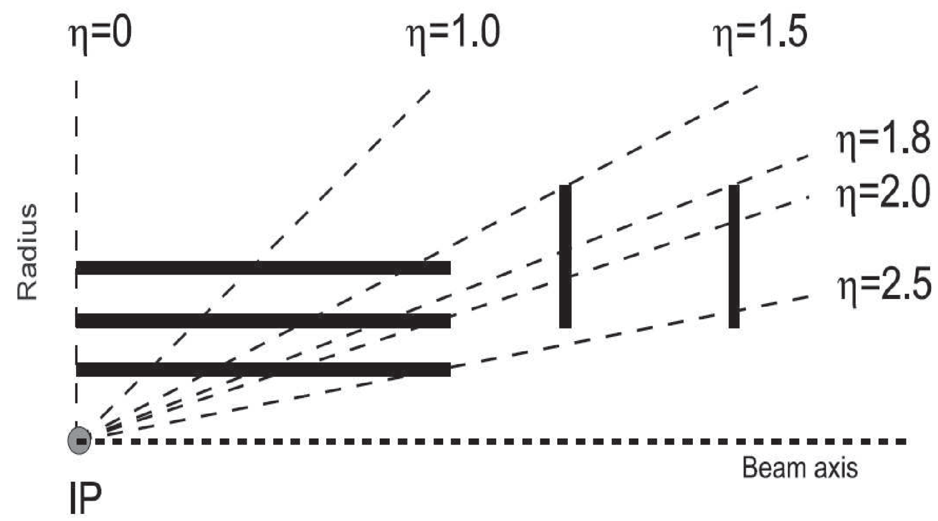


Very good data-taking efficiency: overall ~93%

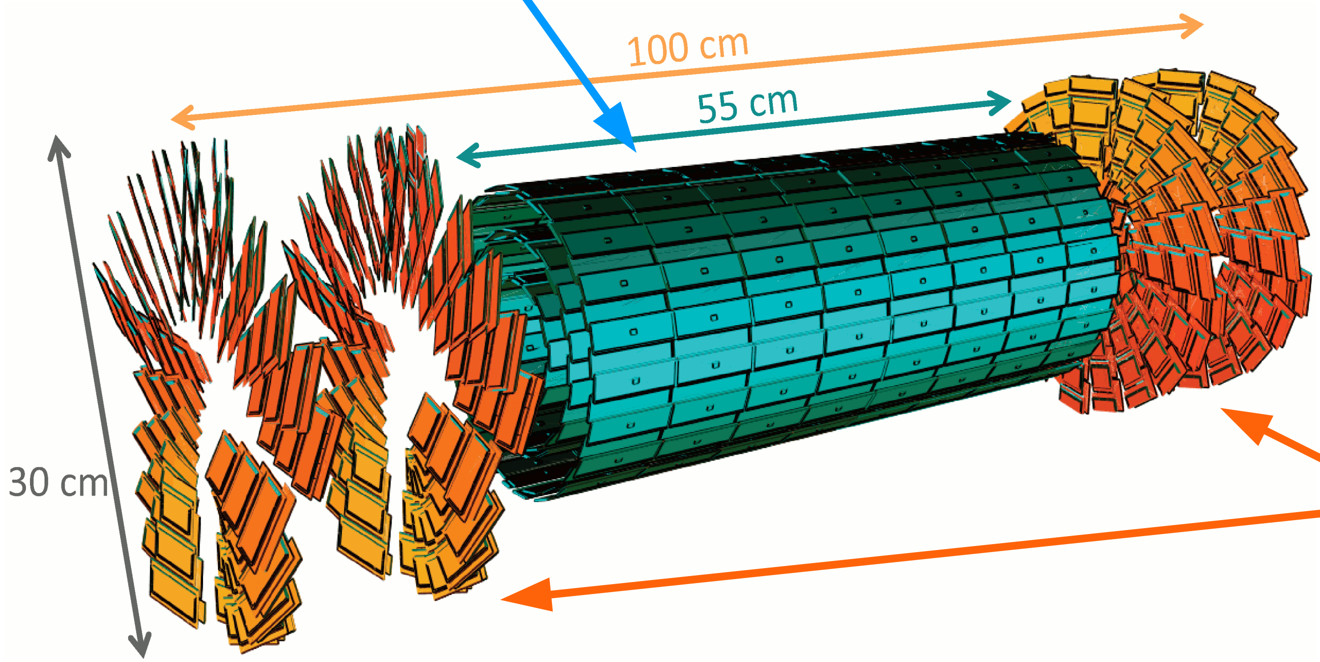
The CMS Pixel Detector

Pixel Barrel (BPix):

3 layers (56 cm long) placed at
r = 4.3, 7.2, 11.0 cm
48M pixels, 11520 ROCs
1120 readout links



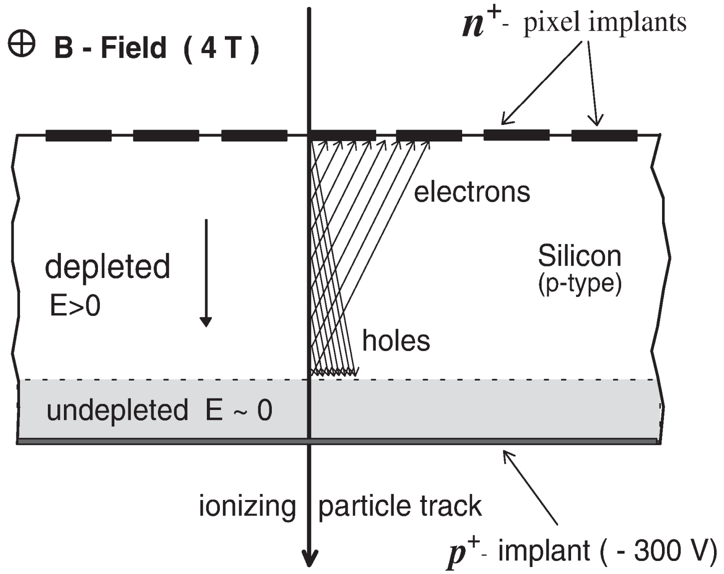
Excellent (good) tracking efficiency up to η = 2.0 (2.5)

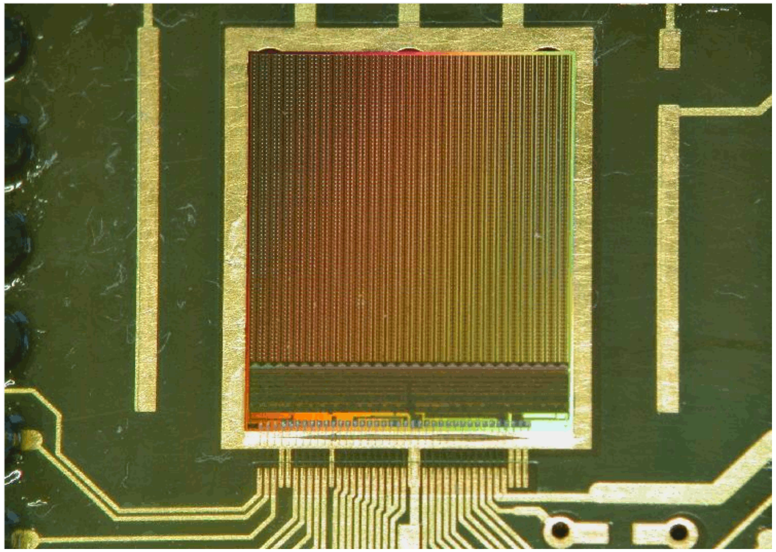


Pixel Endcap (FPix):

4 disks placed at
z = ±34.5, ±46.5 cm
inner (outer) radius = 6 (15) cm
18M pixels, 4320 ROCs,
192 readout links

Sensor and ROC



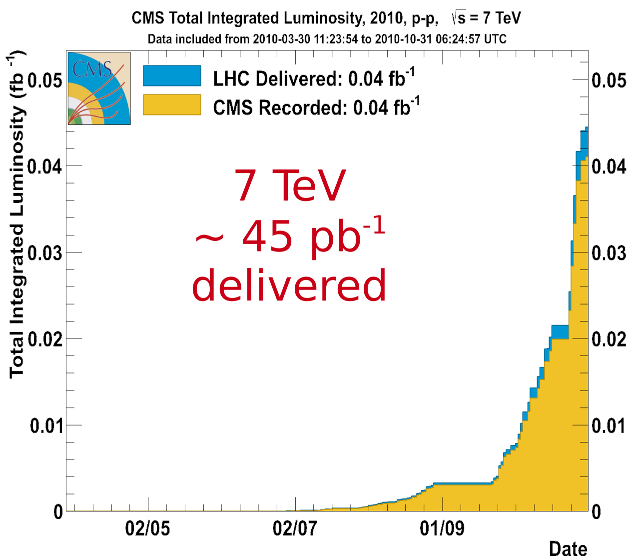


- n-in-n silicon sensors;
- Each sensor has 52 x 80 = 4160 pixels;
- Pixel size: 100μm x 150μm;
- The ReadOut Chip (ROC) was designed by PSI and manufactured by IBM;
- Automatic zero-suppression;
- 26 DACs to regulate settings, each pixel has a 4-bit DAC for fine adjustments (trimming);
- Double-column drain architecture:
  - Hits buffered till trigger decision;
  - Single 25ns-wide bunch-crossing readout;

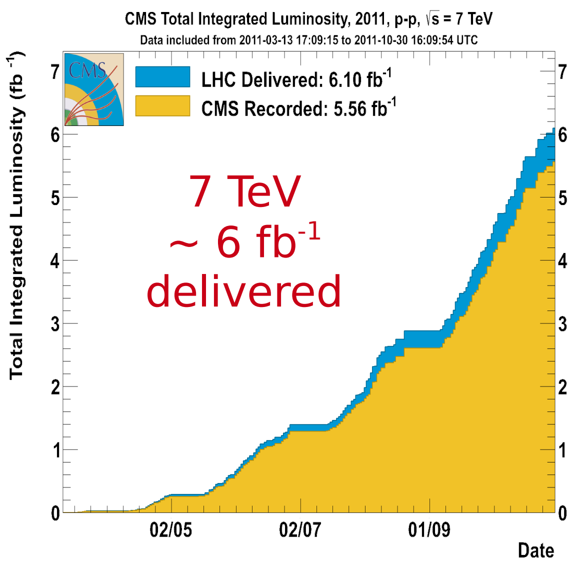
Data taking

- The detector was installed in the Summer 2008;
- Taken out in the 2008/2009 shutdown for small repairs and ameliorations;
- Operating normally during the 2009-2012 run;
- The instantaneous luminosity varied by several orders of magnitude: $\sim 10^{27} - 7.7 \times 10^{33}$;
- Currently contributing no more than a few % of the overall CMS downtime.

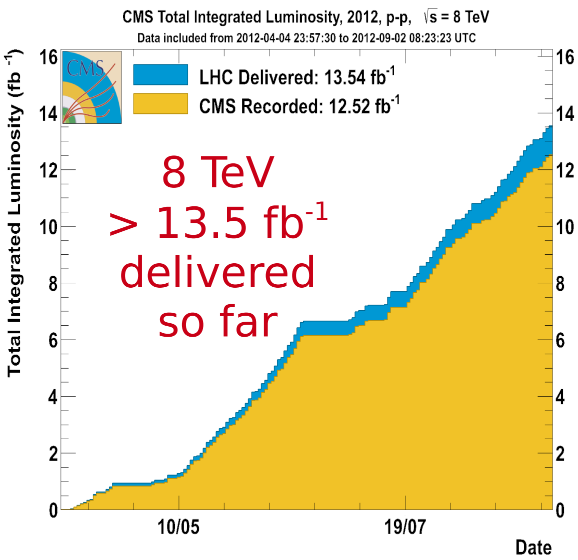
2010



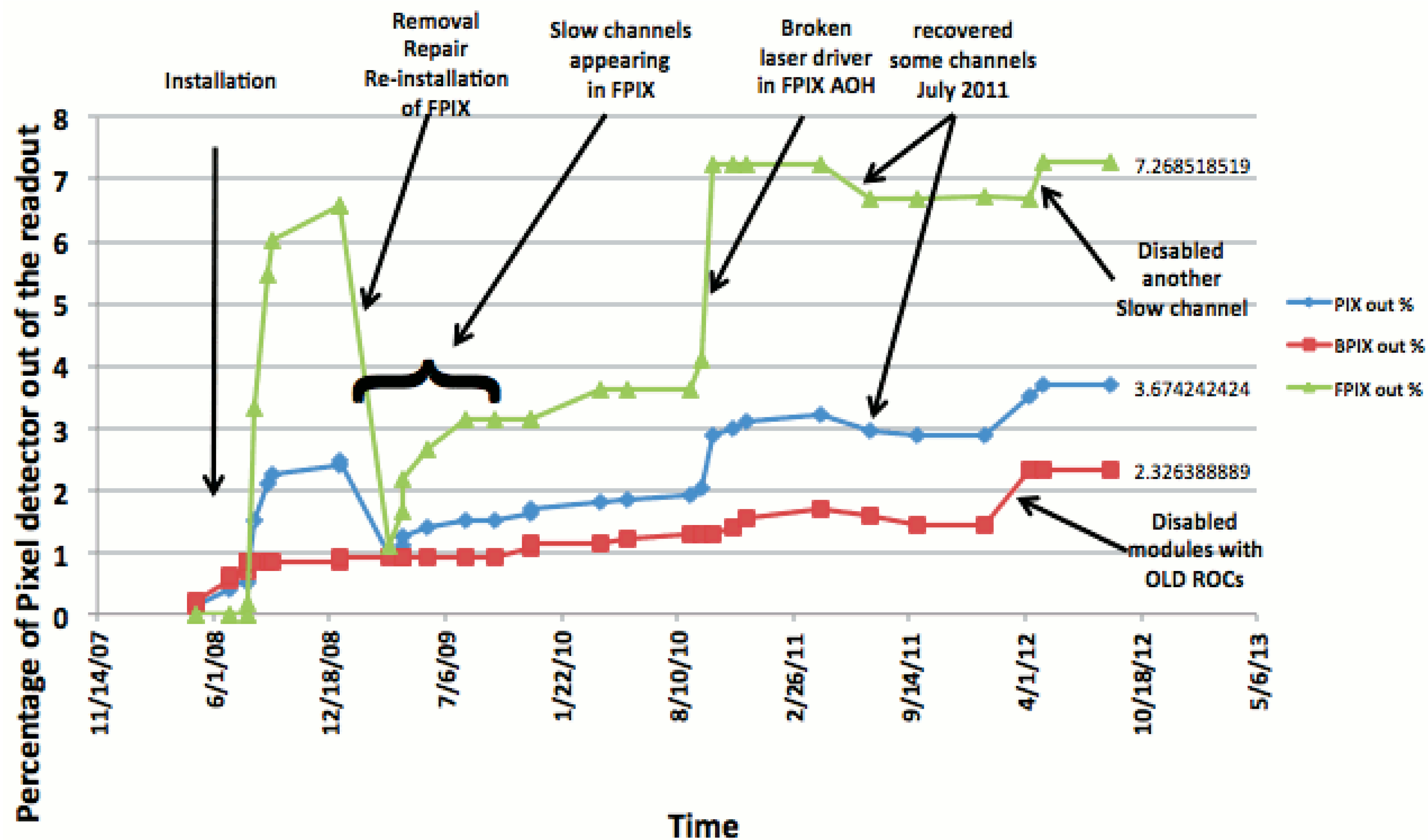
2011



2012

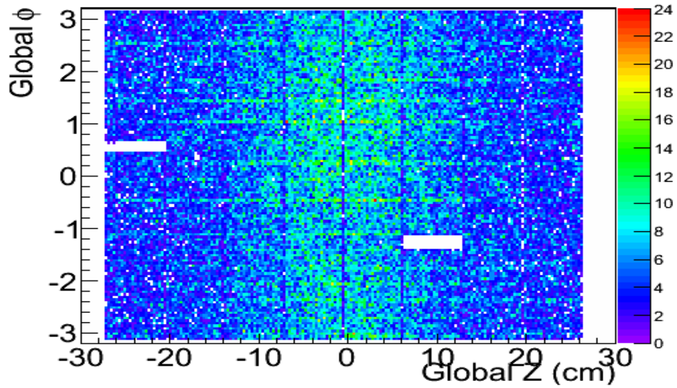


Detector Status

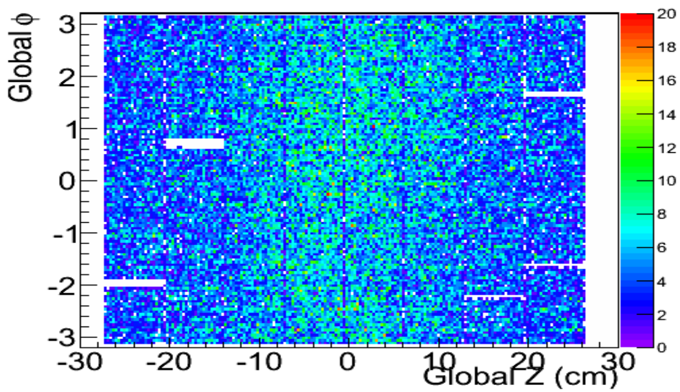


Detector Status

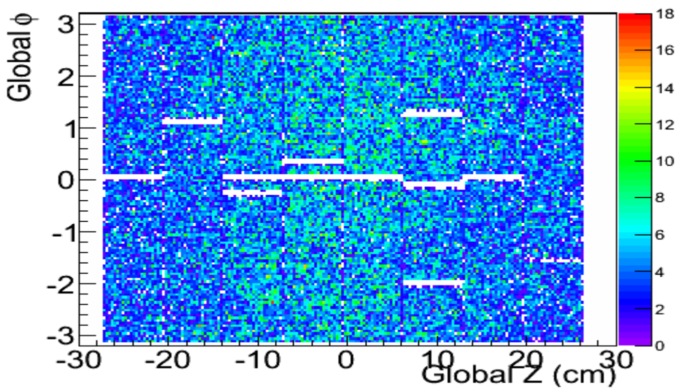
BPix layer 1



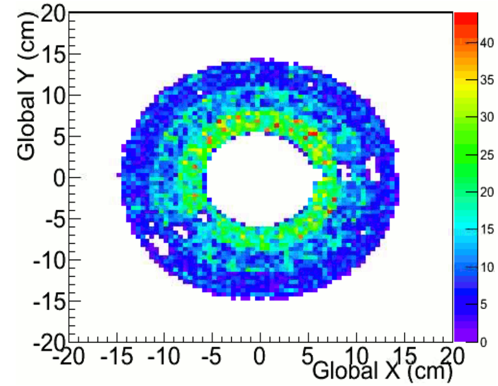
BPix layer 2



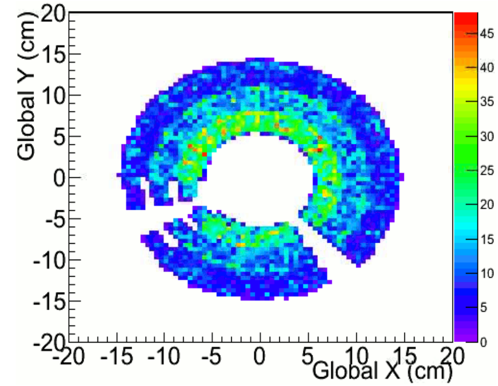
BPix layer 3



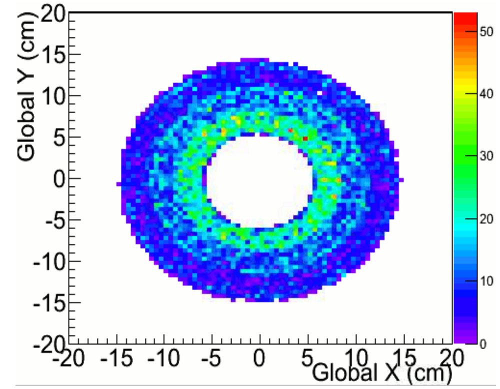
FPix minus D1



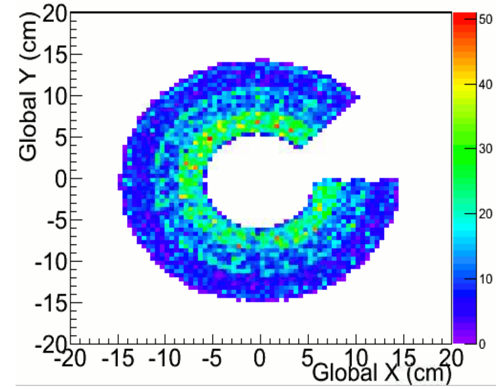
FPix minus D2



FPix plus D1

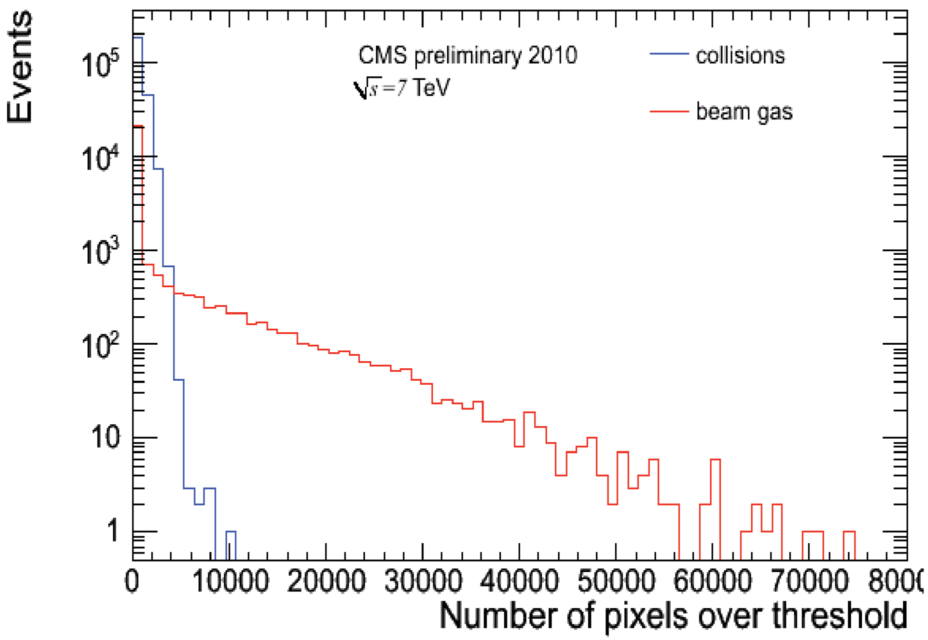


FPix plus D2



Beam gas events

- Major issue during 2010, significant source of downtime during the first year;
- Interaction of beams with gas molecules can produce particles that fly along the beam direction;
- These particles can graze along BPix modules, creating a large number of hits;

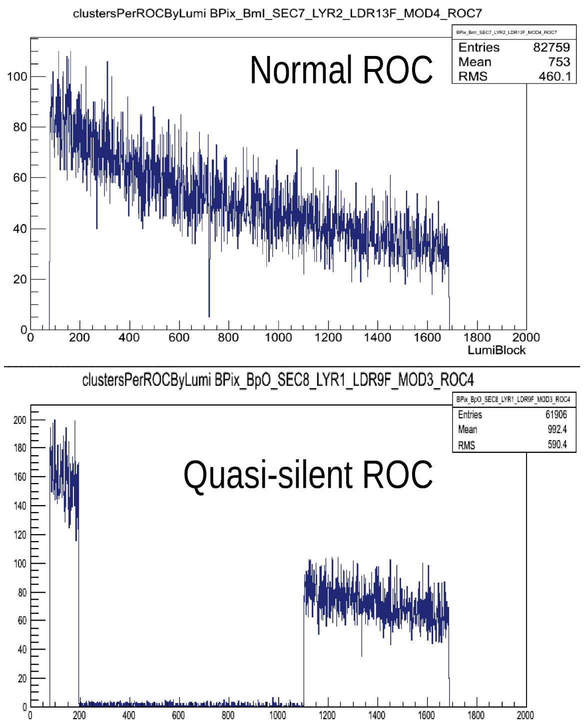


- One particular FED channel will have a very high occupancy;
- Solved with the implementation of the "busy mechanism": triggers are stopped to allow the channel(s) to catch up;
- During the Winter Stop 2011/2012, a non conformity in one of the joints between two elements of the machine 18.5 m from the interaction point was fixed. This caused bad vacuum and high deadtime from the Pixel in 2011.

SEU recovery

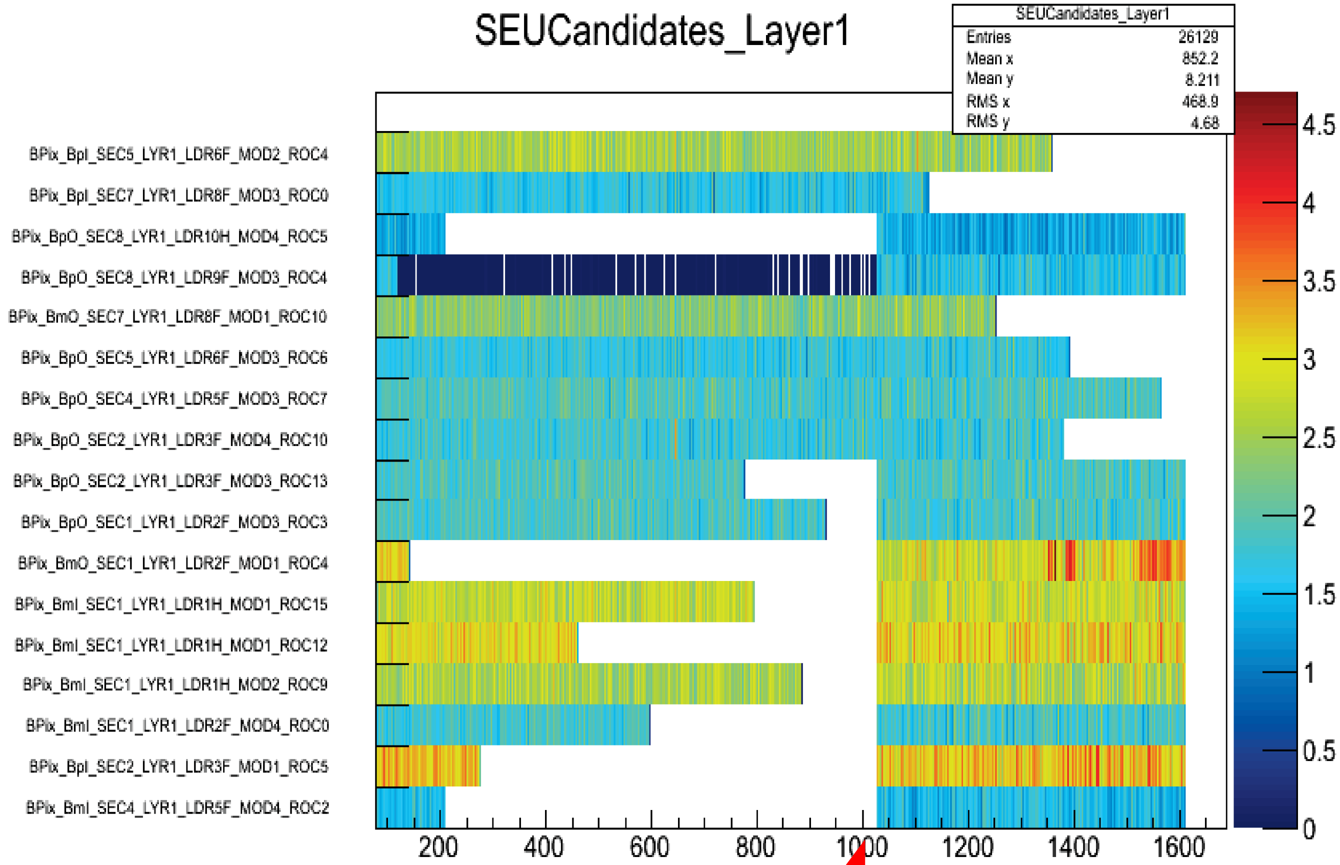
- Single Event Upset (SEU) events refer to a bit flip in memory, generally caused by ionization from charged particle tracks;
- SEU events may interrupt data-taking or degrade the quality of the data;
- With the increase of luminosity, SEU's are becoming more and more of an issue, so these need to be addressed efficiently;
- SEU's can affect the detector at different granularities:
  1) Single pixel: not an issue, FEDs can handle the associated error;
  2) ROC, module, portcard: this is detrimental for data taking and needs to be addressed;
- When an SEU is detected, the Pixel Online Software sends a request to the central DAQ, which stops the trigger, and allows the reprogramming of the ROC registers, DACs, and portcards for the whole detector;
- The whole procedure takes only a few seconds.

SEU recovery



time →

Due to SEUs, some ROCs become “silent” or “quasi-silent”, till they are reprogrammed again



SEU recovery

SEU recovery

Two complementary mechanisms are in place to detect SEU's:

1) Monitoring for OFF channels:

- The FED shuts a channel off in case of a number of consecutive timeouts happen. If the channel is not recovered after 3 tries, the mechanism leaves the channel off;

2) Searching for Out-of-Synch (OOS) errors:

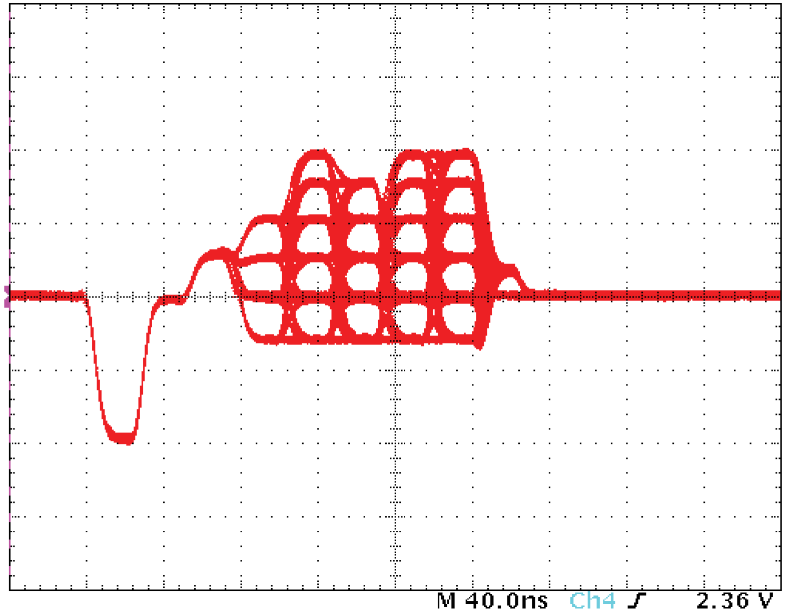
- If X OOS errors happen in a period of Y events, the recovery mechanism is triggered;
- We have found that the optimal parameters are (X,Y) = (8, 100,000)

These mechanisms have been proven to work reliably and significantly reduce the downtime of the experiment.

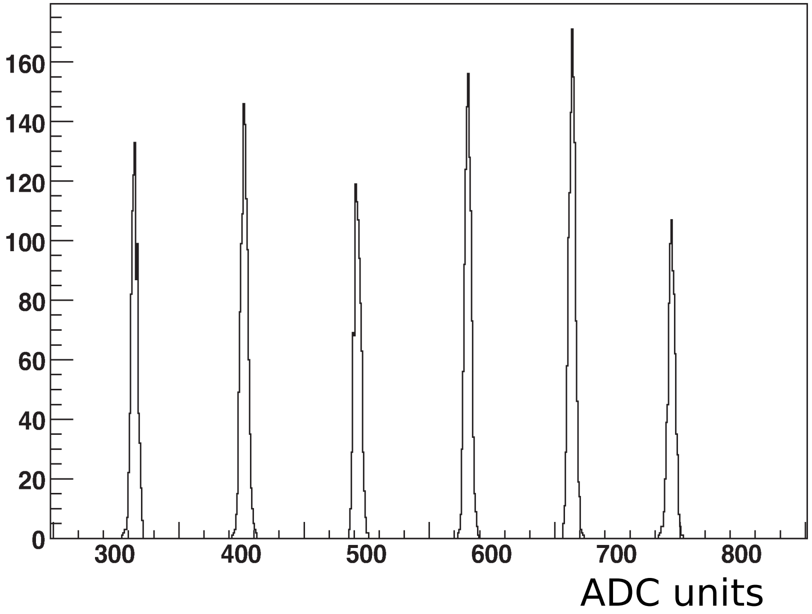
We are also considering ideas to take into account SEUs in offline reconstruction in order to improve tracking.

Weekly Calibrations

- FED baseline calibration:
  - Adjusts the optical receiver in order to take the “black” level in the middle of the ADC range;
  - This is very sensitive to temperature variations;
  - An automatic baseline correction takes care of small fluctuations of the baseline;



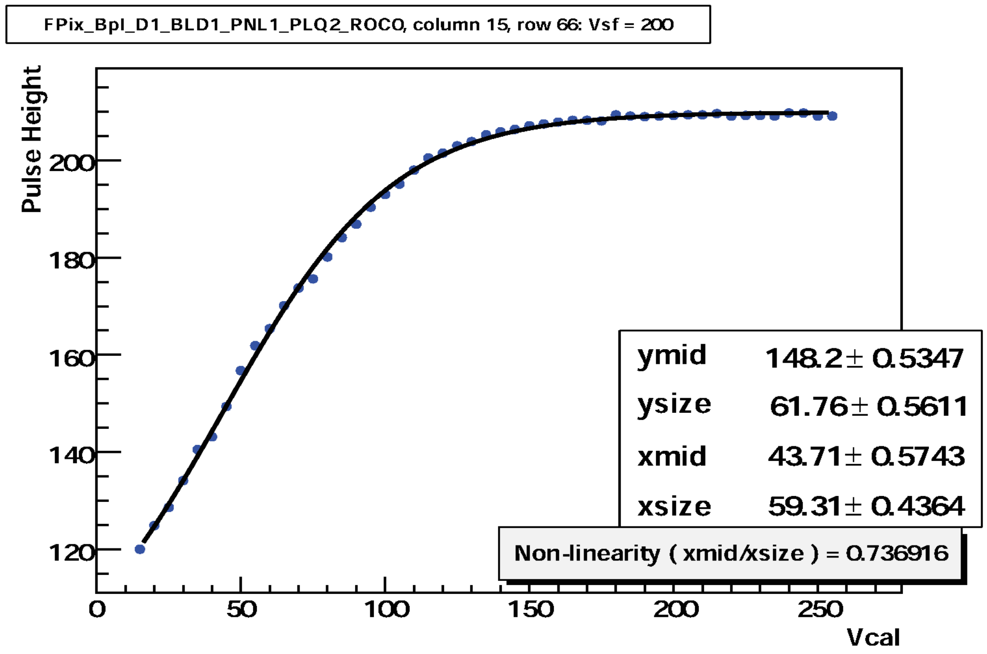
- Address Levels calibration:
  - Determines the values used by the FED to decode pixel addresses;
  - For most ROCs the 6 levels are very well separated and stable in time.



Weekly Calibrations

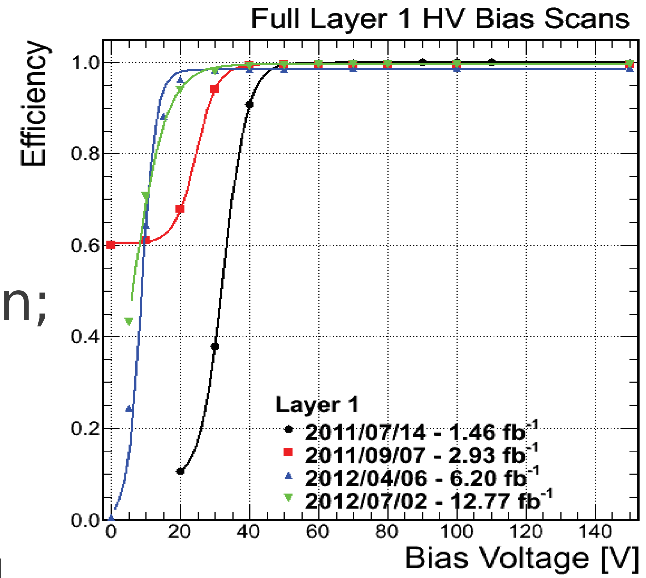
- SCurve calibration:
  - Measurement of the efficiency vs injected charge;
  - Used to determine noise and threshold levels of each pixel;
- Gain Calibration:
  - Measurement of ADC values vs injected charge;
  - Determines the linearity of the response for each pixel;

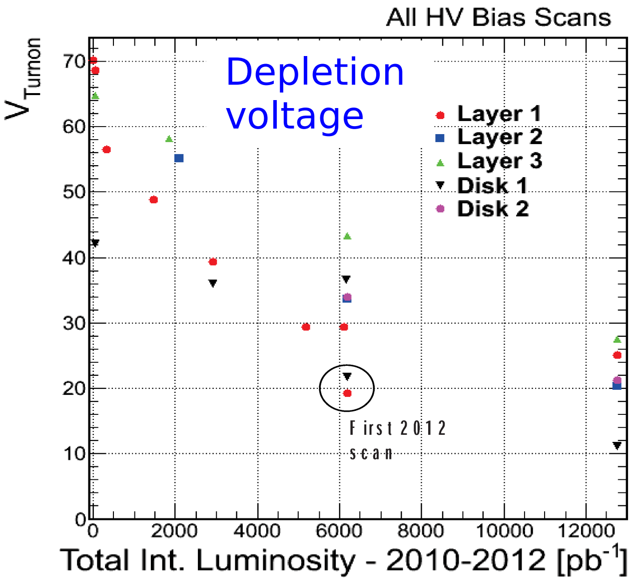
These calibrations are run weekly, mostly as a check, on a subset of pixels. A full Gain Calibration on all pixels is run every ~6 months to update the constants to be used in offline reconstruction.



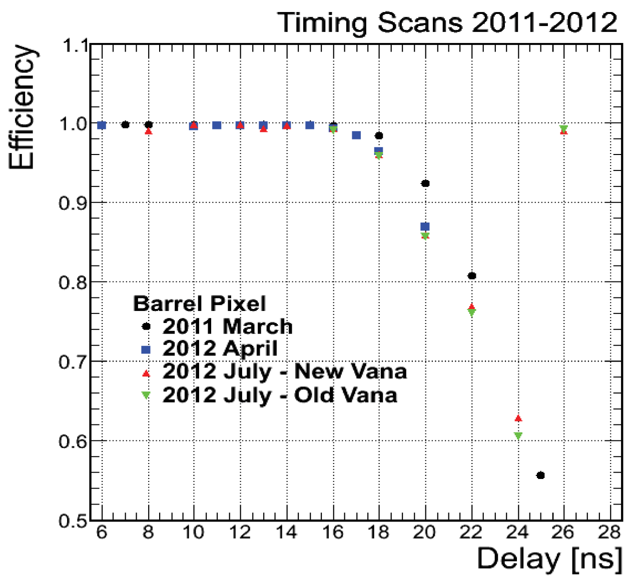
Bias and Timing scans

- Pixel Bias Scan:
  - Done once every 1-2 months to monitor the evolution of sensors as we accumulate radiation;
  - Can be done on a full layer/disk during low-luminosity runs, or on few non-overlapping modules during normal running (negligible impact on data quality);



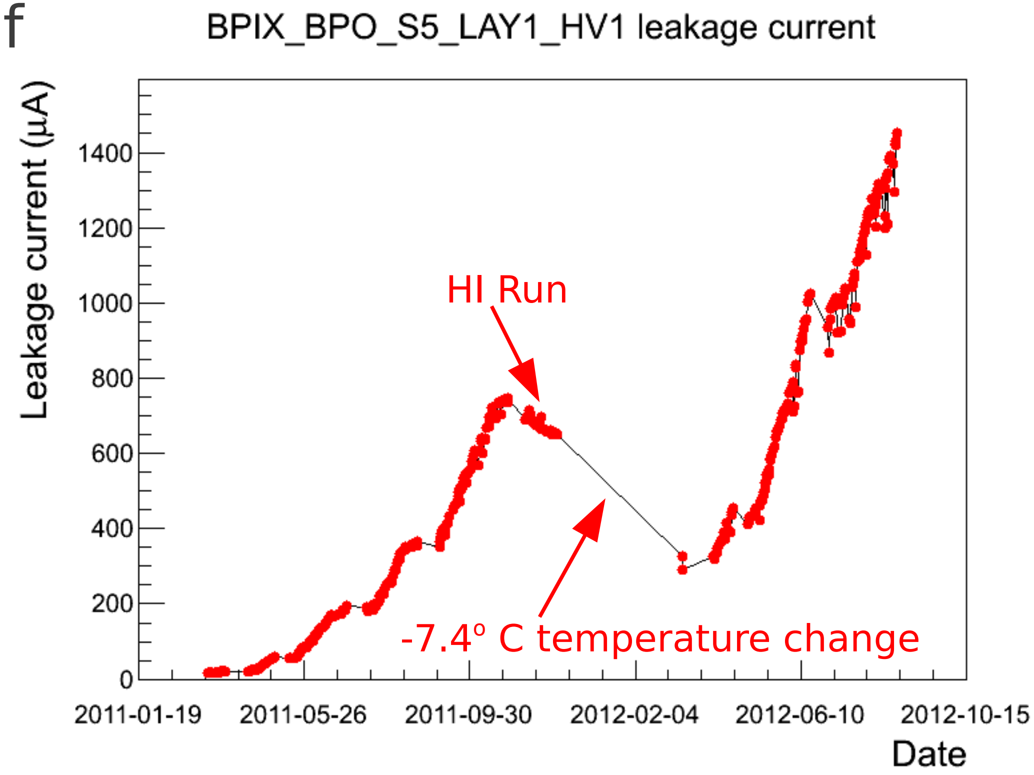


- Timing scan:
  - Performed to check that the delay settings put us well within the plateau of efficiency;
  - This is done less often (a couple times per year), and when significant changes to some relevant settings are made.



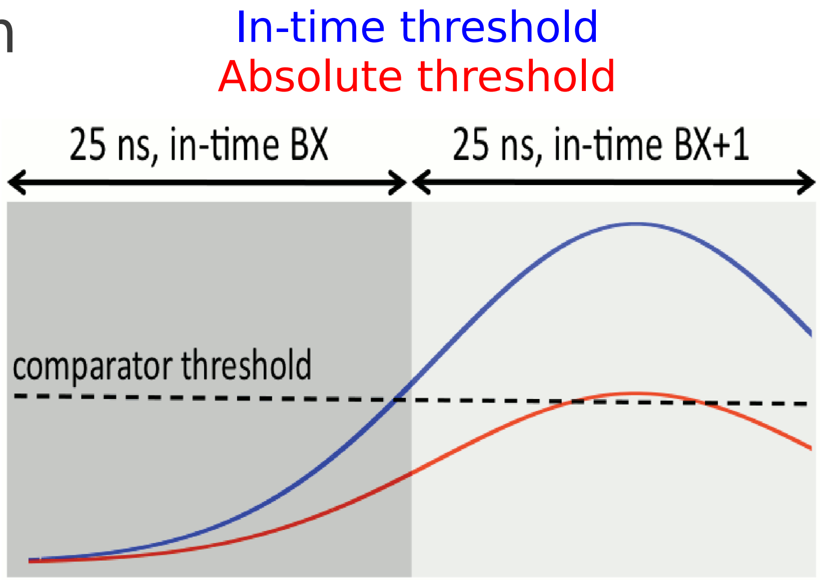
Recalibration for low temperature

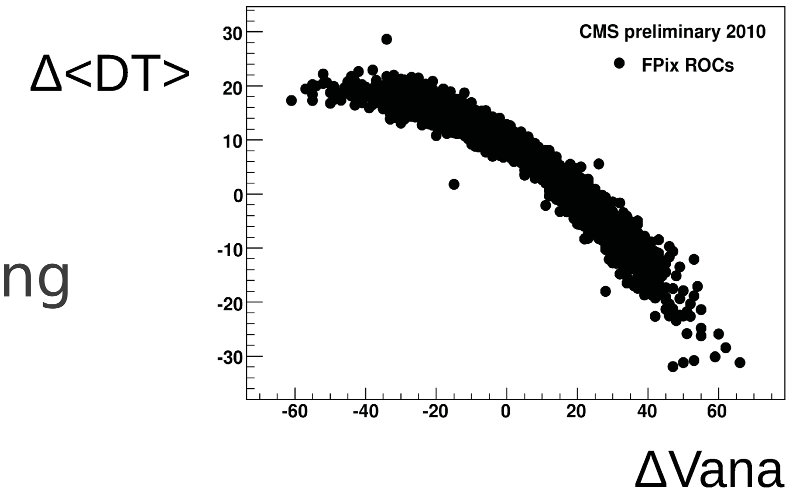
- We started running the detector setting the coolant temperature at +7.4° Celsius (the sensor is actually ~10° warmer);
- As we accumulate radiation, the leakage current in the sensor increases;
- The obvious way to reduce the leakage currents is by lowering the temperature of the detector (we gain a factor 2 every 7.4°);
- Due to the imperfect sealing of the Pixel volume, currently we cannot run the detector at the design temperature of -20° C;
- The lowest safe temperature we can run at is 0° C;
- We recalibrated the detector for running at 0° C during the 2011/2012 Winter stop.



Recalibration for low temperature

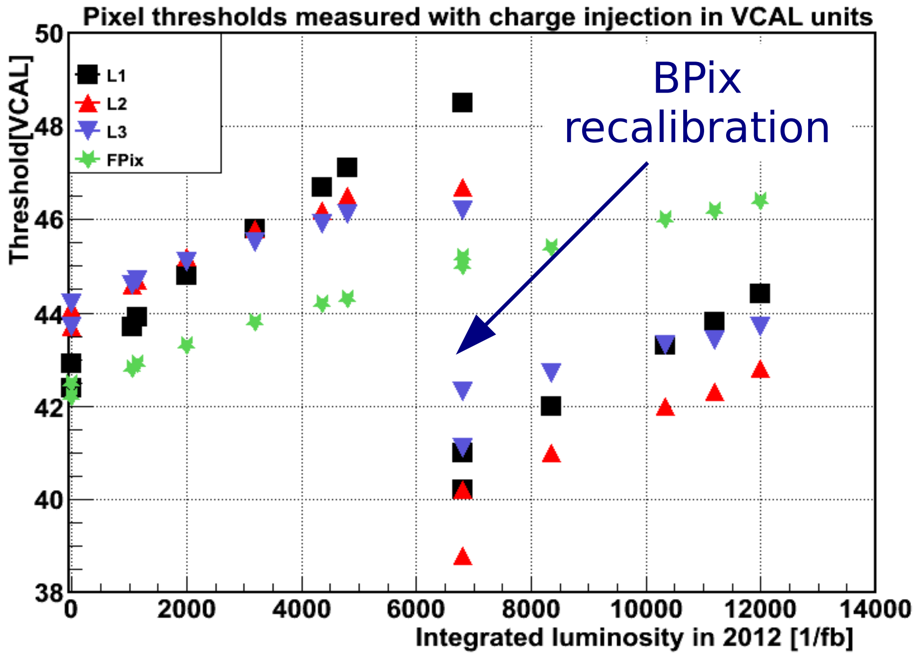
- A big part of the recalibration program is devoted to the setting of the analog voltage of the ROCs (Vana);
- This influences the “timewalk” DT, that is the difference between the “in-time” and “absolute” thresholds;
- Ideally, we would want to have the smallest possible DT, but this translates into high values of Vana and high currents in the chips;
- The setting has to be made so that we are comfortably away from the tripping limits of the power supplies;
- Following this, the process of minimizing thresholds ROC by ROC can be done.





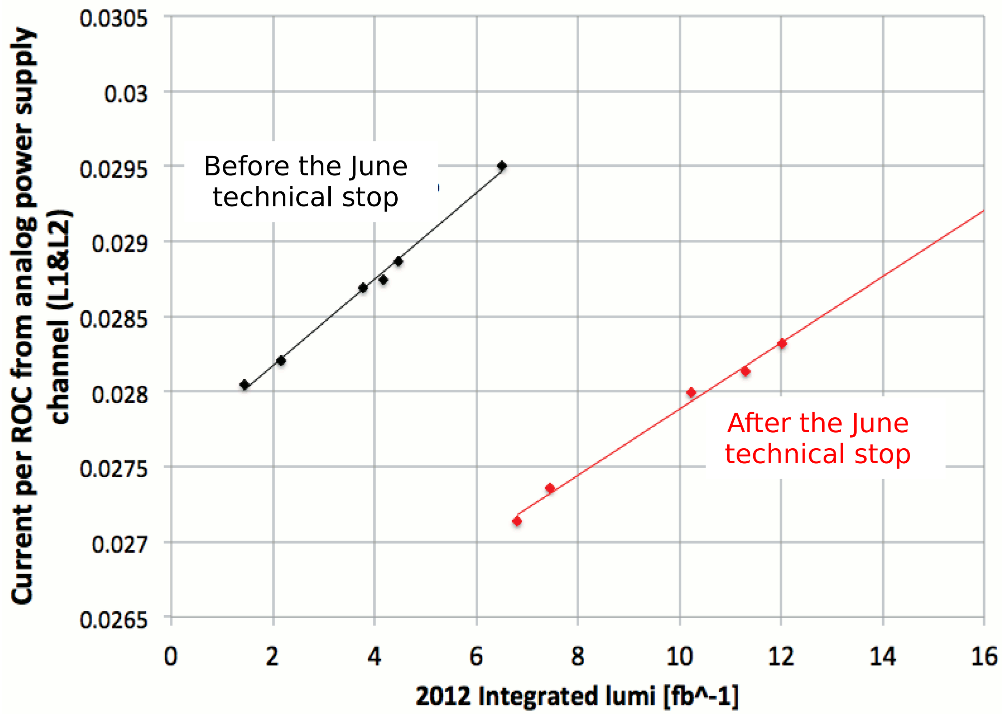
Effects of radiation

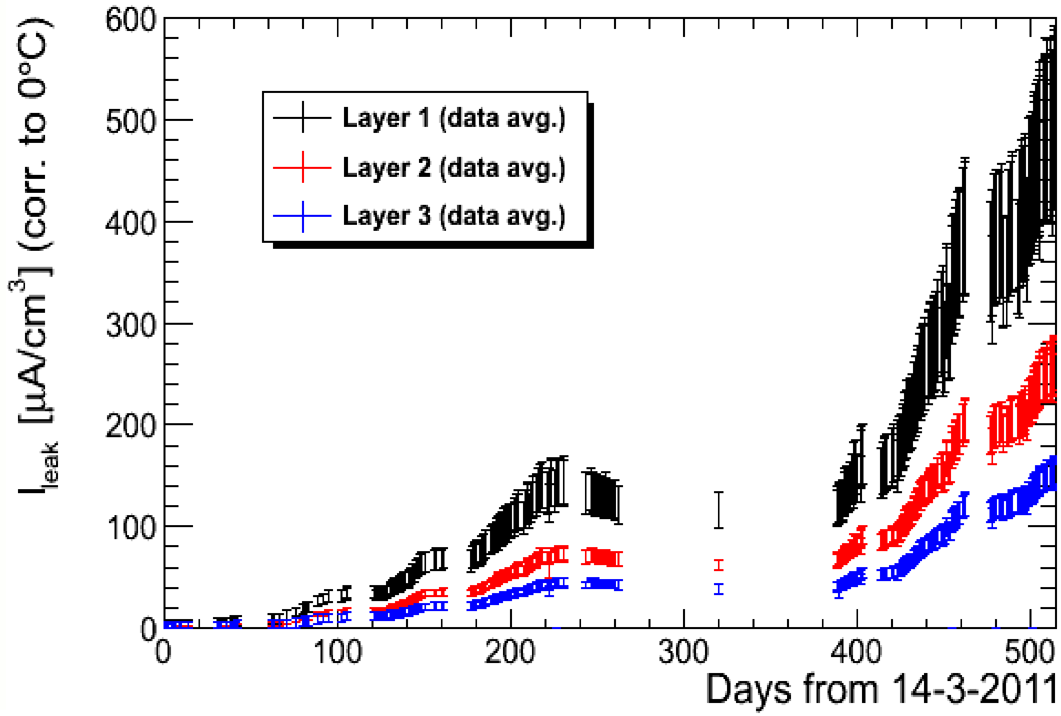
- We have observed a linear increase of the thresholds and the analog current in the ROCs as a function of the integrated luminosity;
- This effect is expected to plateau at some point, but so far the behavior is quite linear;
- The increase of the analog current brought some sectors of BPix close to the tripping threshold;
- During the June LHC technical stop, we lowered Vana on BPix and ran again the procedure to optimize the thresholds (mostly to recover a small fraction of the ROCs affected by the change);
- This procedure will be repeated, if necessary during the next technical stops.



Typical thresholds: ~2500-3000 electrons
1 Vcal unit = ~66 electrons

Effects of radiation

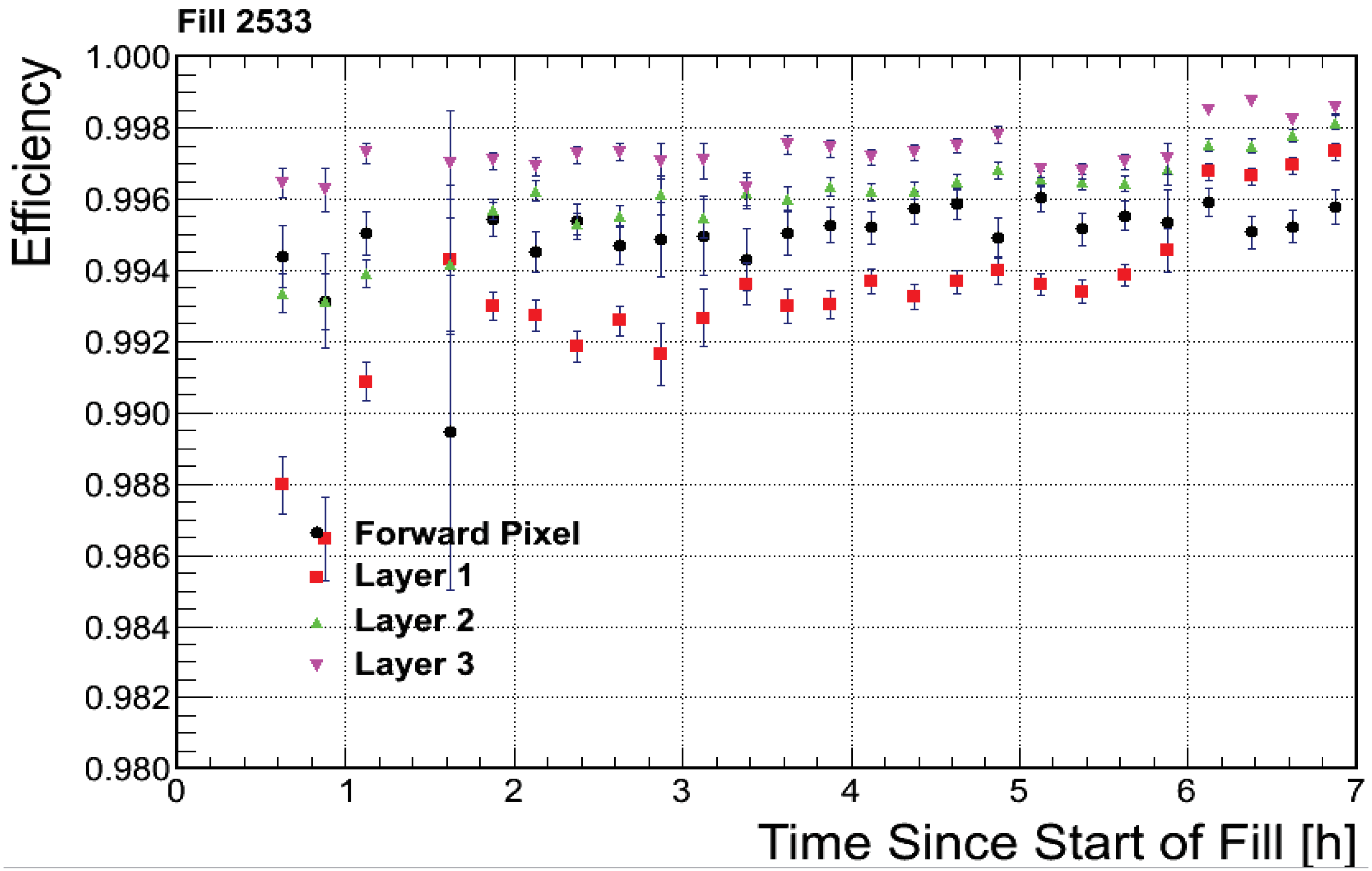




Example of analog current for one BPix power supply as a function of the integrated luminosity.
The step down is the effect of the recalibration performed during the June technical stop.
The slope is slowly improving (going towards "saturation")

Evolution of the leakage current in BPix, corrected to 0° C.
The behavior is in reasonable agreement with the model prediction.

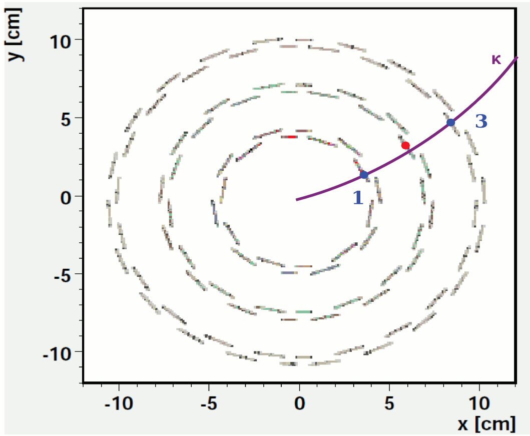
Pixel Efficiency

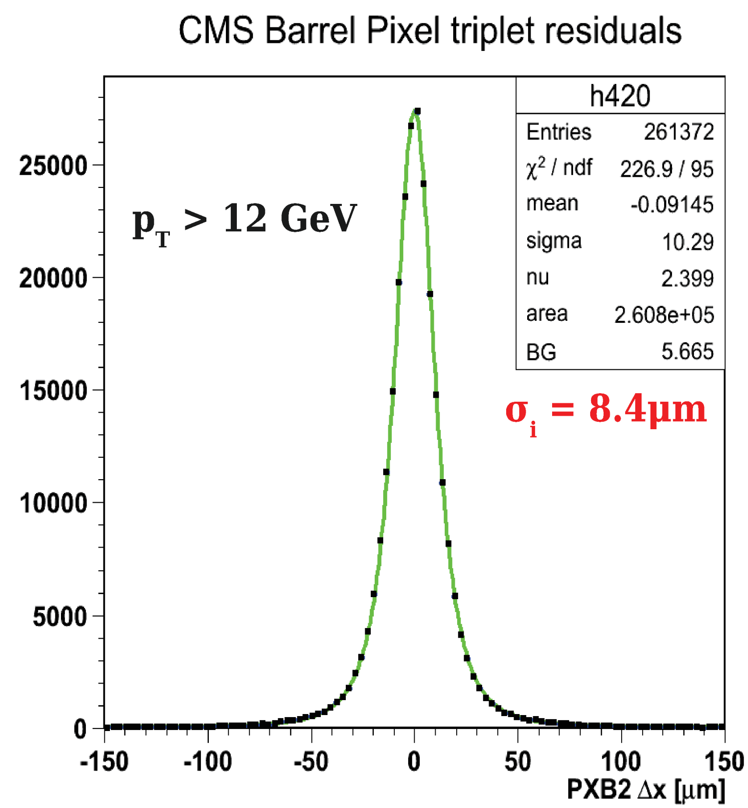


Pixel hit efficiency in general > 99%.
Some dependence (a fraction of %) on the instantaneous luminosity (due to occupancy).

Pixel Hit Resolution

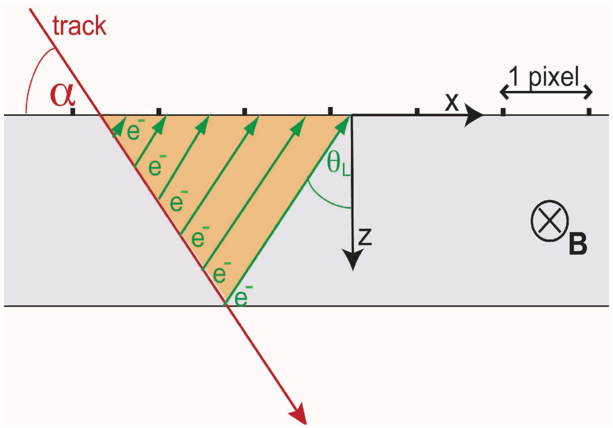
- The Pixel Hit Resolution is measured using the “triplet method”;
- Tracks with three hits in the barrel are selected;
- Redefinition of tracks:
  - Curvature is taken from the full Tracker;
  - Position and angles from layers 1 and 3;
- The track is interpolated to layer 2 and the residual between the track and the actual hit is measured;
- Measurements of the resolution using the “overlap method” give consistent results.

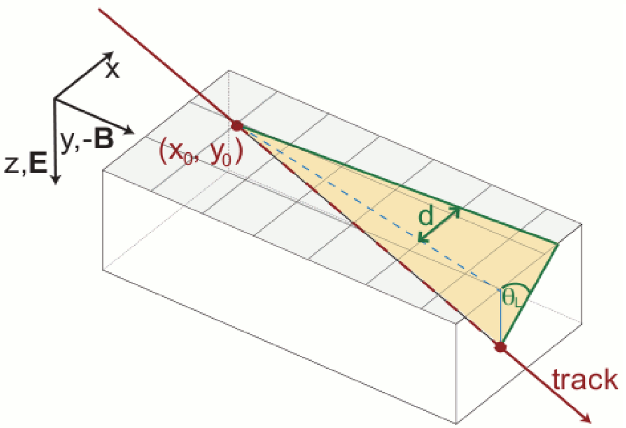


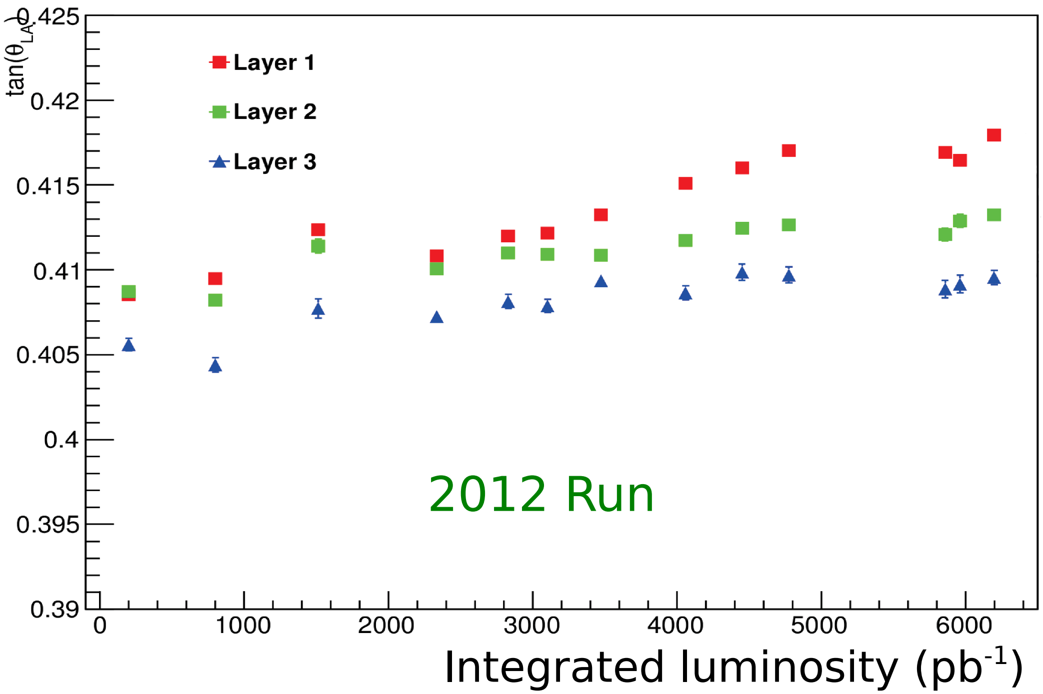


Lorentz Angle

- The Lorentz shift spreads the charge over more pixels (improving resolution);
- We measure the Lorentz Angle with the "grazing method": we take well reconstructed tracks and measure the drift of electrons vs production depth;
- In general good agreement with MC;



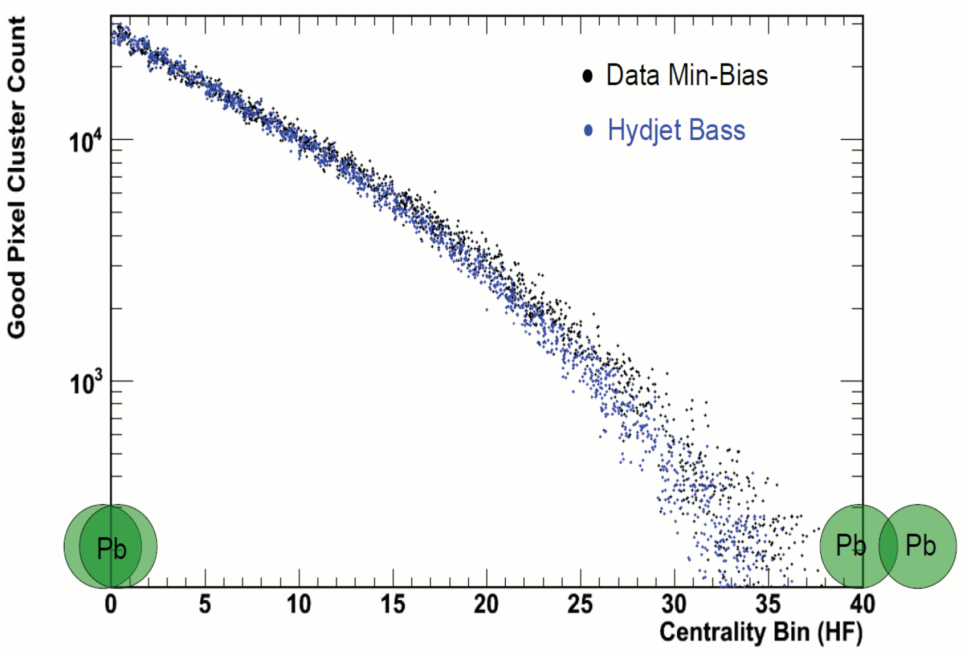




- Still to be understood:
  - Forward backward asymmetry;
  - Dependence of LA vs integrated luminosity.

Heavy Ions Run

- Very different challenges wrt p-p:
  - Much bigger event size;
  - Much lower collision rate;
- Pb-Pb data-taking (2011 Run):
  - $\sqrt{s}$ = 2.76 TeV;
  - Inst. Lumi ~5 x 10^{26} cm^{-2} s^{-1};
  - Integrated Lumi: ~160 μb;



- Buffer sizes in FED's need to be adjusted for track multiplicities ~2 orders of magnitude higher than in p-p;
- No significant problems encountered during the HI runs in 2010 and 2011, the performance appear to be identical to those of p-p collisions;
- At the beginning of 2013, the LHC will deliver p-Pb collisions.

Plans for the shutdown

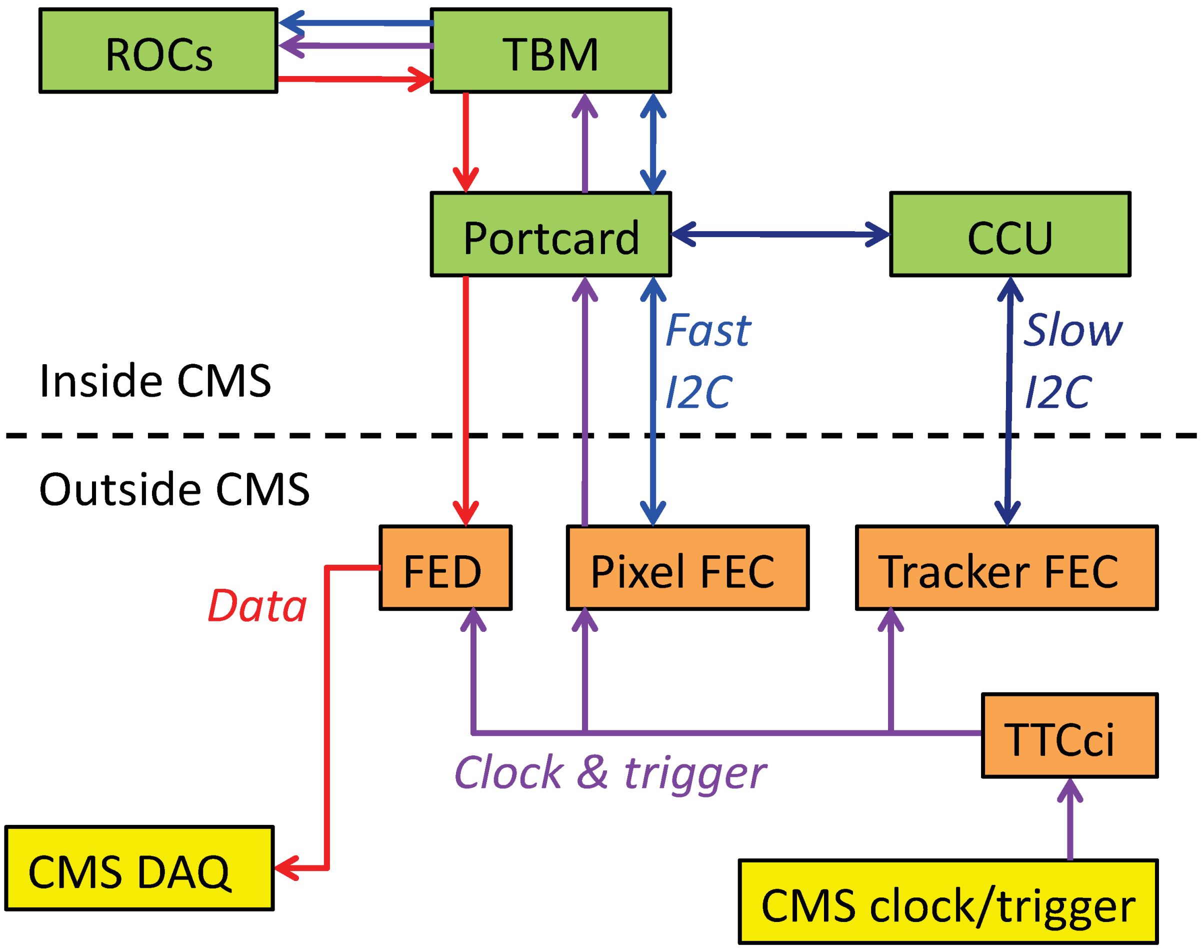
- In Spring 2013, after the Heavy Ion run is finished, the Pixel detector will be extracted from CMS and brought to surface;
- Repairs will likely bring back to life most of the channels currently excluded from the data-taking;
- In the meantime, work to improve the sealing of the Pixel volume will be performed, allowing the detector to run at the design temperature of -20° C (for the coolant);
- The detector will be inserted back at the beginning of 2014 and will be re-calibrated for the new environment conditions.

Conclusions

- In the first three years of LHC running, the Pixel detector has performed very well;
- Overall the infrastructure is very stable and the detector is contributing to a small fraction of the CMS downtime;
- The performance in efficiency and resolution matches the design expectations;
- We are monitoring the evolution of the detector as it absorbs more and more radiation;
- We are looking forward to a successful end of 2012 run and more years of data-taking after the first long shutdown of the LHC.

Backup Slides

Pixel DAQ



- 40 MHz analog readout:
  - Pulse height;
  - Pixel address;
- On receiving the L1 trigger, the Token Bit Manager (TBM) reads in sequence the ROCs it controls;
- The electrical TBM signal is converted to optical;
- Front End Driver (FED):
  - Receives optical signal;
  - Digitizes it and sends it to CMS DAQ.

Beam gas events

Solutions:

1) Discard the events coming when one FED channel is in timeout. This works fine, but at the price of having significant data loss when trigger rate is high;
2) "Busy mechanism": after a settable number of timeouts (we have been using 4), we stop the triggers;

The second mechanism has been proven to work well, with very small deadtime for the experiment.

Developed and deployed a "low slew rate" FED firmware to cope with data corruption arising from some particular channels (in part related to the busy mechanism).

Slow channels

- Many FPix failures have this symptom: slow rise time of the analog signal, causing the separation of the address levels to fail;
- Work is ongoing on developing a firmware capable to handle this.