# Operational experience and performance of the CMS pixel detector during the first LHC beams

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On behalf of the CMS Collaboration

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- The CMS pixel system and operating conditions
- Detector present status
- Calibrations
- Performance with first LHC beams
- Conclusions

# The CMS Pixel System

- Total pixel area: 1 $m^2$ ---- 66 M pixels ----
- 3 barrel layers at 4.3, 7.3, 10.2cm; 53cm length
- 4 disks from 4.8 to 14.4 cm radius
- 3-hit coverage for tracks $|\eta|<2.2$

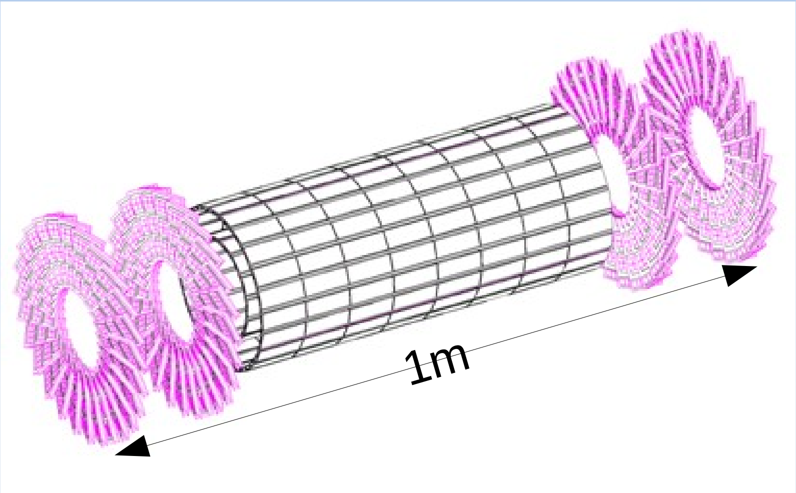
  2-hit coverage for tracks $|\eta|<2.5$
- Si Sensors: n on n, 150 x 100 μm pixels

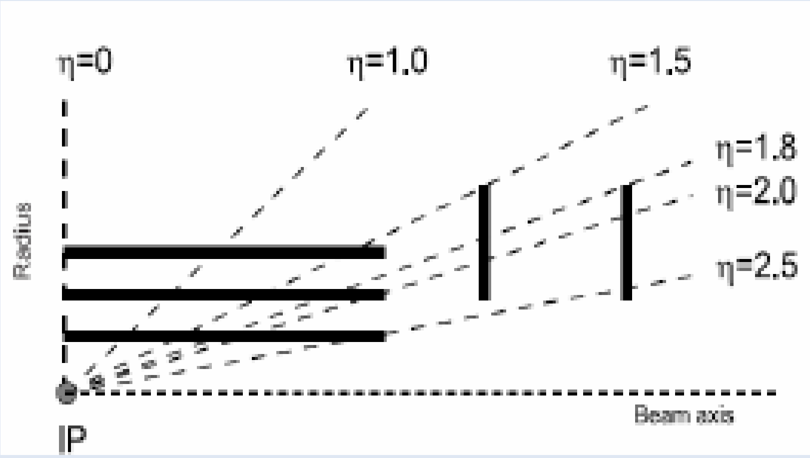
  285-270 μm thick (BPIX/FPIX)

  p-spray BPIX and p-stop FPIX
- PSI-46 Read Out Chips (ROC)

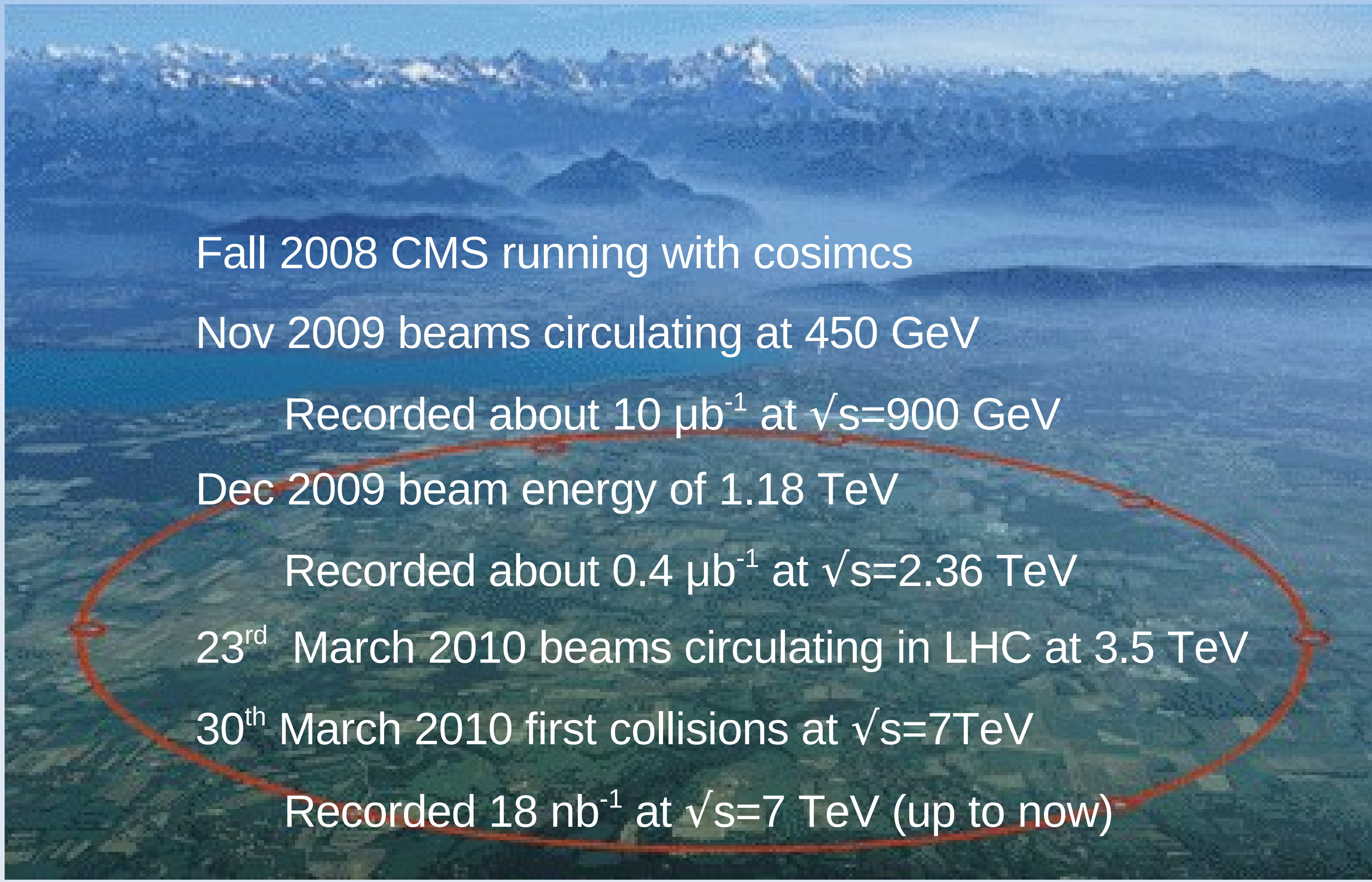
**10 years of design, construction and commissioning.**

**Installation in Summer 2008**



# Cosmics and LHC first beams



Fall 2008 CMS running with cosimcs

Nov 2009 beams circulating at 450 GeV

- Recorded about 10 $\mu b^{-1}$ at $\sqrt{s}$=900 GeV

Dec 2009 beam energy of 1.18 TeV

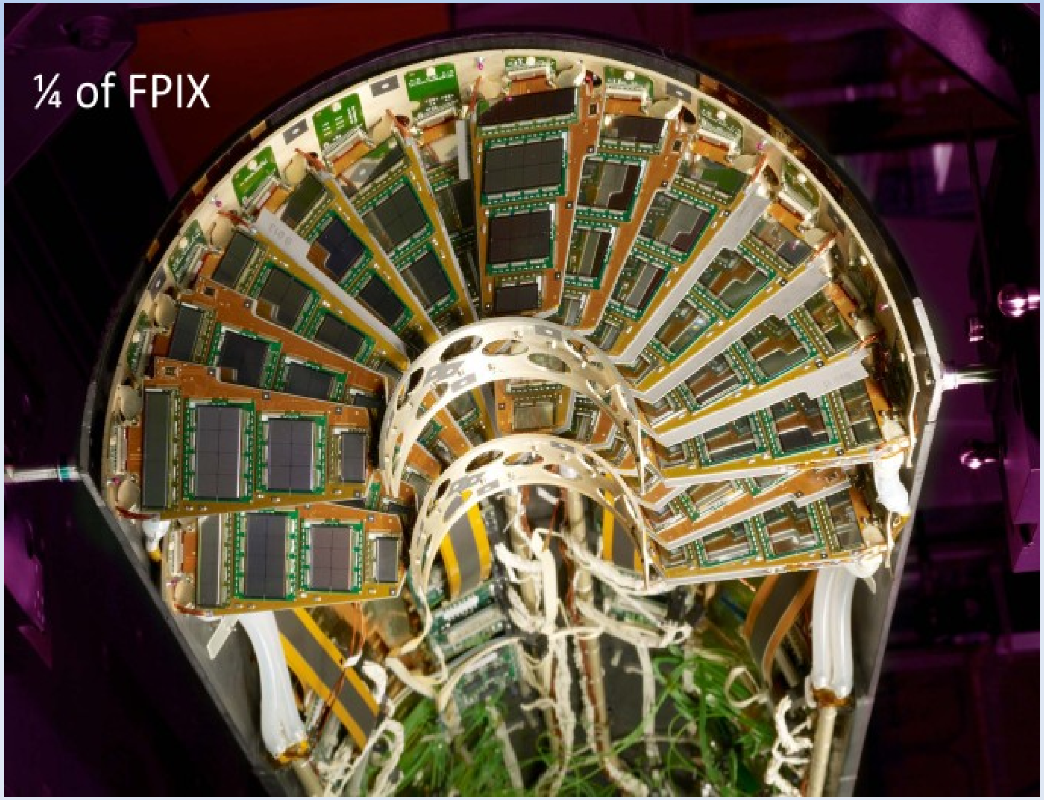
- Recorded about 0.4 $\mu b^{-1}$ at $\sqrt{s}$=2.36 TeV

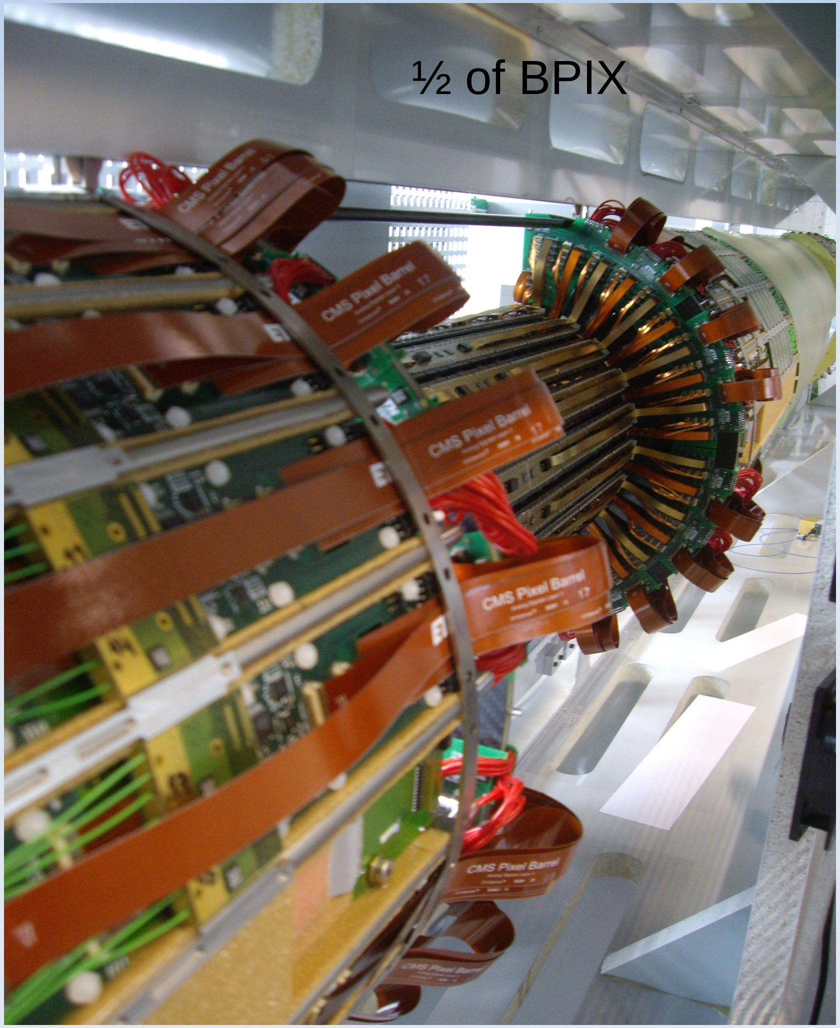
23rd March 2010 beams circulating in LHC at 3.5 TeV

30th March 2010 first collisions at $\sqrt{s}$=7TeV

- Recorded 18 $nb^{-1}$ at $\sqrt{s}$=7 TeV (up to now)

# The CMS Pixel System




$V_{bias}$ = 150V BPIX / 300V FPIX
Coolant temperature 7.4$^0$C
Sensor temperatures ~ coolant +6$^0$C

# Detector status

- 2008 insertion of the pixel detector into CMS

  - Calibration/cosmic running
- Spring 2009 extraction of the FPIX, recovered 5%, re-insertion

  - re-calibration, cosmic running and first beams
- 2010 running at $\sqrt{s}$=7TeV

- **98.4%** of the pixel detector is in operation (99% of BPIX, 96.9% of FPIX )
- Dead modules, excluded from the read out, mainly due to:
  - broken wire bonds
  - missing HV connections
  - no\slow analog readout
- Most failures are present since installation

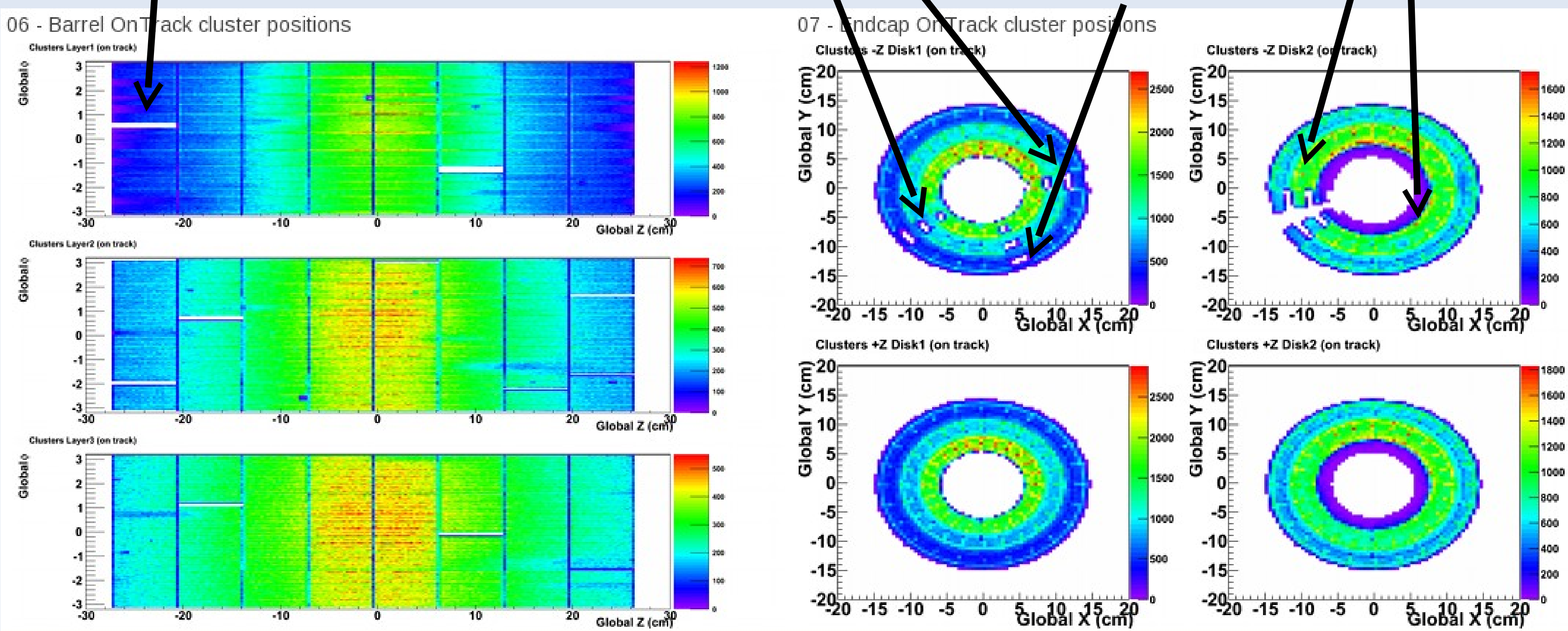
# Detector Status: maps

2 panels with low/missing analog output

4 panels with slow rise time
Plus a 5th one that is intermittent

Latest failure (0.1%)

Single ROC problem recoverable



# Detector status: dead pixels

- Dead pixels due to:

  (a) ROC pixel cells which do not work for some reason (known from module tests)

  (b) Si-sensor cells which do not work

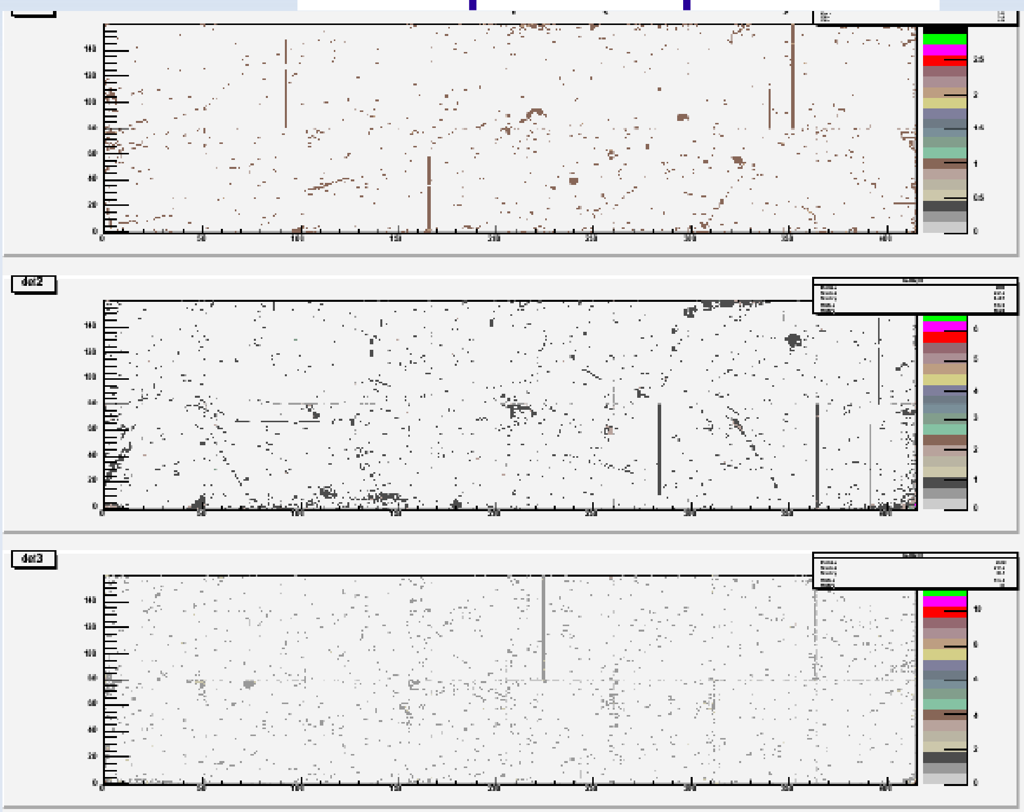
  (c) The bump-bond between the ROC and sensor is broken

Dead pixel maps:

- only modules in the read out
- all modules superimposed on ONE single module per Layer
- includes masked pixels, double column

| | |
|---|---|
| Layer 1 | $1.8\times10^{-4}$ |
| Layer 2 | $1.9\times10^{-4}$ |
| Layer 3 | $1.2\times10^{-4}$ |

**Dead pixel map in BPIX**



Layer 1
1752 dead
12/module

Layer 2
2967 dead
8.4/module

Layer 3
2624 dead
5.7/module

Runs: 134721, 132602, 143477

# Detector calibration

- with calibration runs:
  - Standard DAQ parameter calibration
  - ADC gain and pedestal determination: convert the pixel charge measurements from ADC counts --> charge units
  - absolute threshold optimization

- with cosmic runs and colliding beams:
  - Spatial alignment
  - Timing alignment
  - Effective threshold evaluation
  - Lorentz angle measurements

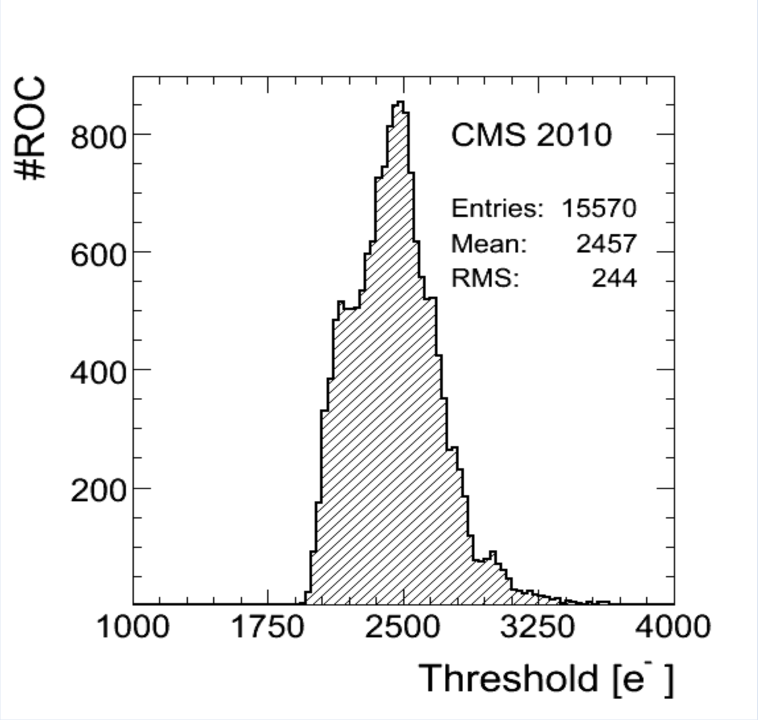
# Absolute threshold optimization

- Pixel detector more sensitive to smaller charges
  - Reduce the mean and the spread of the comparator thresholds (Vthr) from the values used during the module tests and 2008 cosmic runs.
  - Iterative procedure, using lower and lower internal calibration signals (Vcal) and measuring the Vthr at which the pixels are still 100% efficienct
  - Trim bits are used to equalize pixel to pixel Vthr variation

Mean absolute threshold value of 2457e-

REMARK: Due to time walk the minimum hit signal that fires the discriminator threshold in time with the trigger bunch crossing is higher (~800e-) than the absolute threshold

In-time threshold can be evaluated comparing data/MC

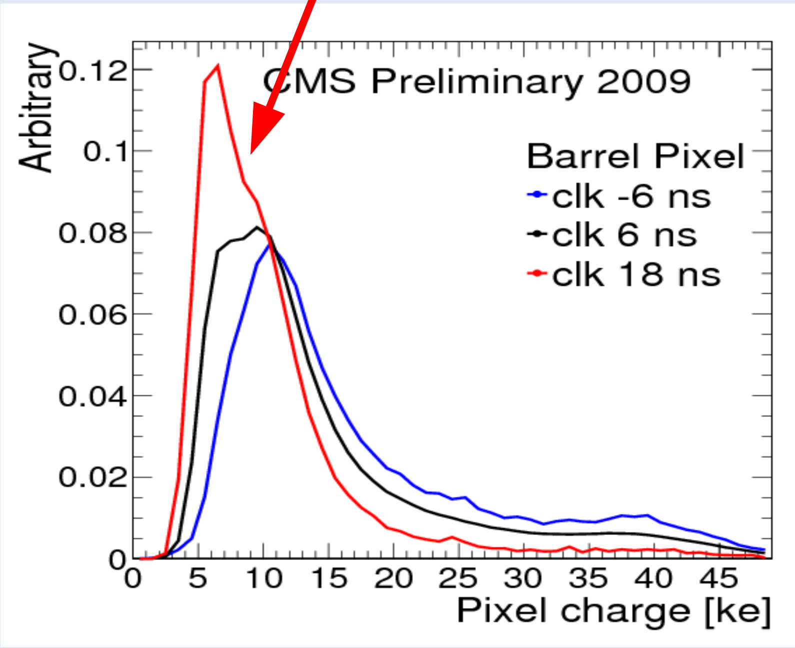


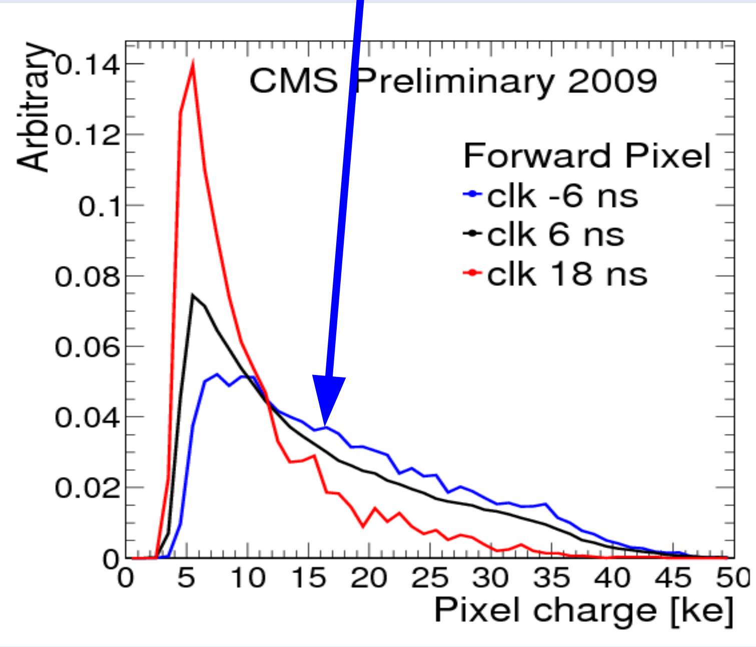
# Timing alignment

- First timing alignment: equalization of pixel module delays measuring the length of the optical fibers, cables
- Coarse scan of the pixel detector latency in steps of 25ns measuring the pixel hit efficiency with cosmic tracks
- Fine adjustment (steps of 6ns) of the clock phase vs trigger signal with first beams (2009): optimal clock phase maximizes cluster charge and size

**Too late: loss of highest charges**

**Too early: loss of small charges**



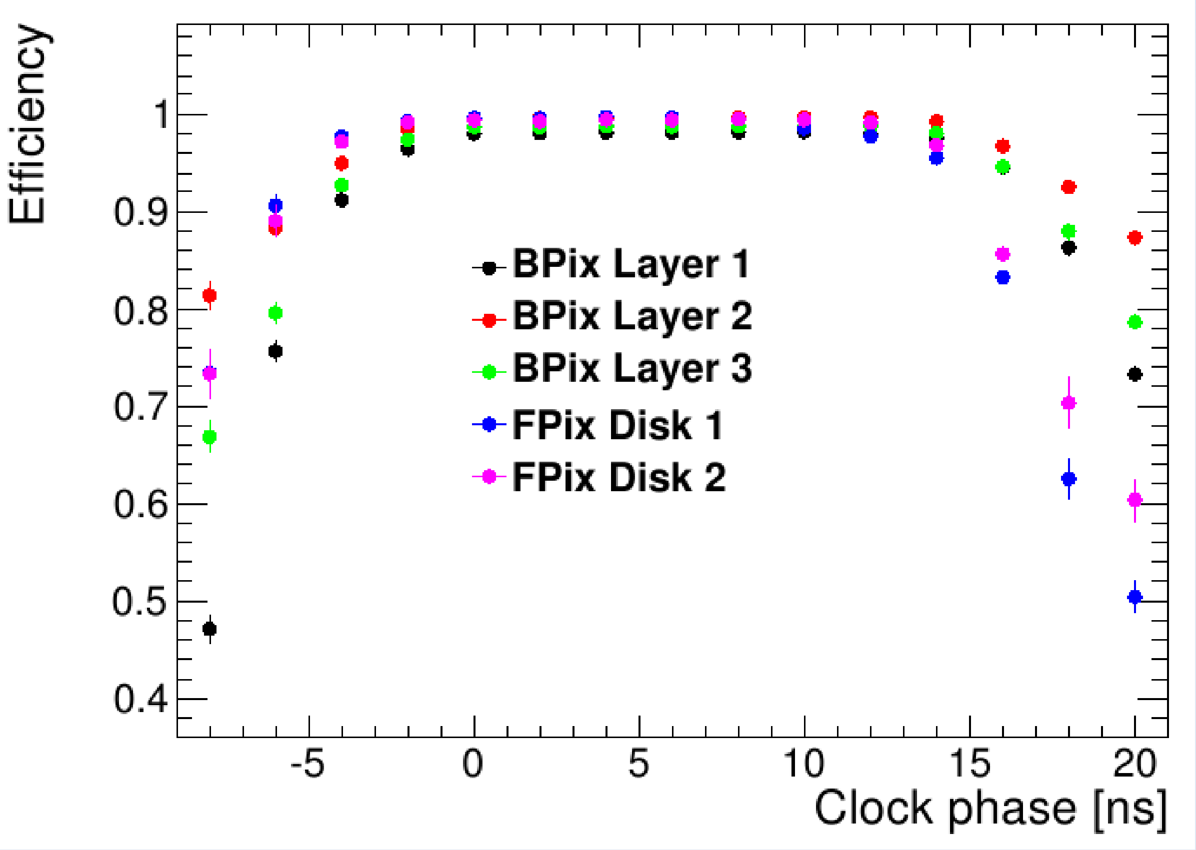

+6ns optimizes the different quantities!

# Timing alignment

- More accurate timing optimization with efficiency measurements @ 7TeV (2010)
  - BPIX to be delayed by additional 2ns vs FPIX

Delay: FPIX 8ns
BPIX 10ns

Efficiency vs delay



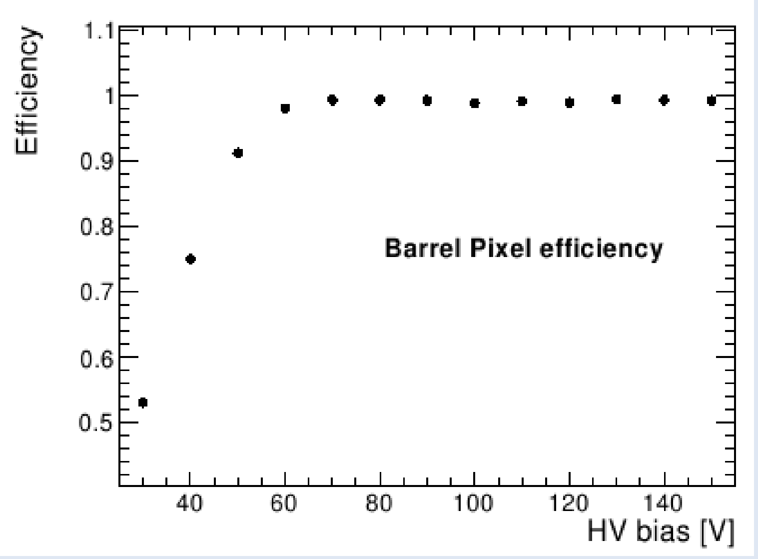
- A bias scan check for data at 7TeV
  - Hit efficiency vs $V_{bias}$
    - Hit detection efficiency -> extrapolating a track to the pixel sensor to check a compatible hit (valid hit)
    - $\varepsilon = \Sigma \text{valid} / \Sigma(\text{expected})$

Over 99% @ $V_{bias}$

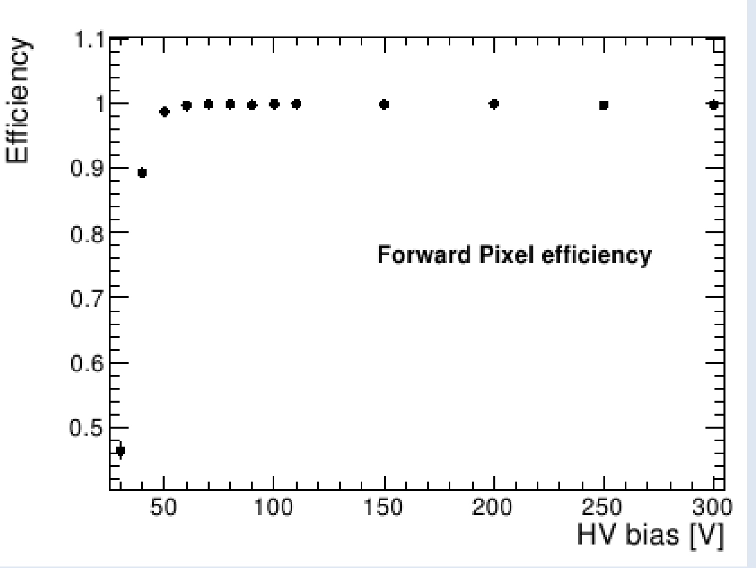
$V_{bias}$ = 150V BPIX

$V_{bias}$ = 300V FPIX

**Hit Efficiency in BPIX**

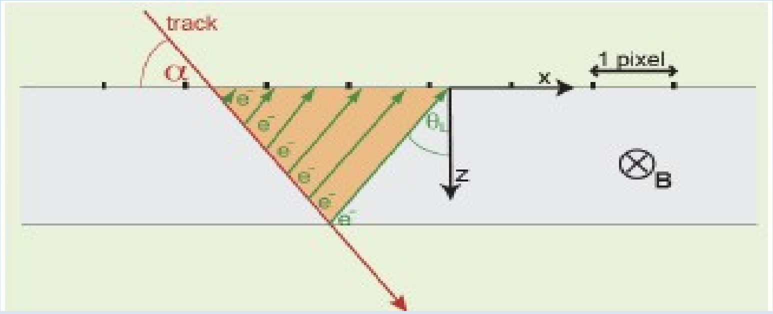



**Hit Efficiency in FPIX**



# Lorentz Angle

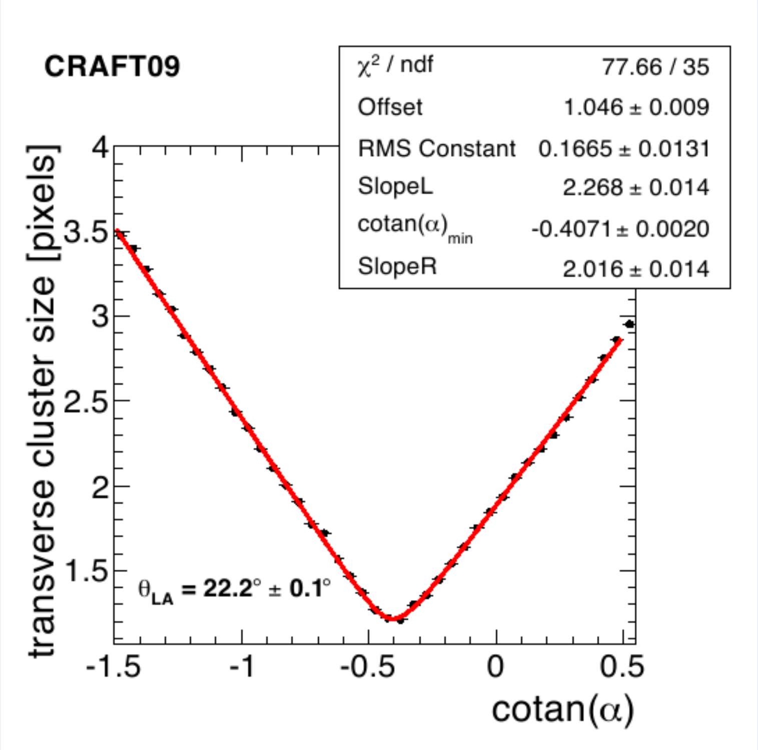
- Measure the Lorentz Angle ($\Theta_{LA}$) with two methods.
  - n-in-n pixels and large B -> Lorenz drift of the carriers along x direction in the barrel
  - Measure of $\Theta_{LA}$ to correct hit position.




## (1) minimum cluster size (cosmics)

- the charge spread over neighboring pixels depends on α (track incident angle)
- minimum cluster size for charges produced along the drift direction: $\cot\alpha_{min} = \tan\theta_{LA}$

$$\boxed{\Theta_{LA} = 22.2 + 0.1^0}$$

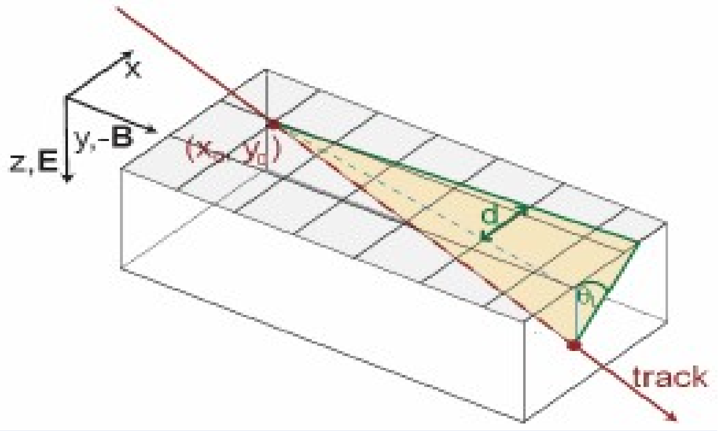



*this method is not suitable for collision data where 80° < α < 100°*

# Lorentz Angle

## (2) grazing angle method (collision data in BPIX)

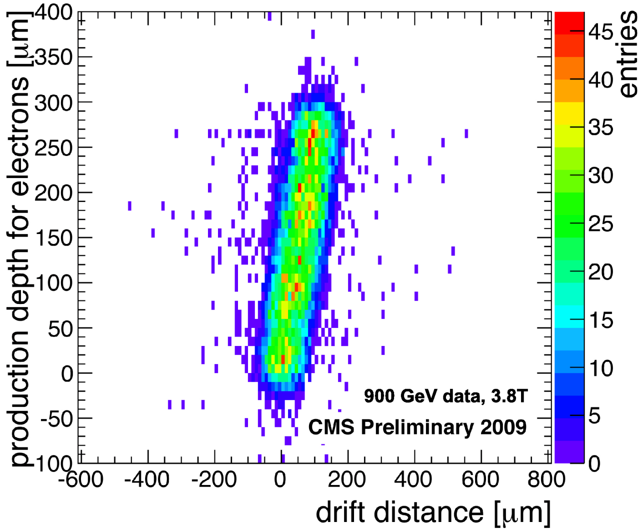
- use well reconstructed tracks so that the path through the detector is known
- for each pixel in a cluster determine the drift distance in x from the track (*d*)
- averaging over many tracks: evaluate *d* vs depth
- slope of the linear fit --> $\Theta_{LA}$
- long clusters in y needed -> select tracks with shallow impact ("grazing") angle

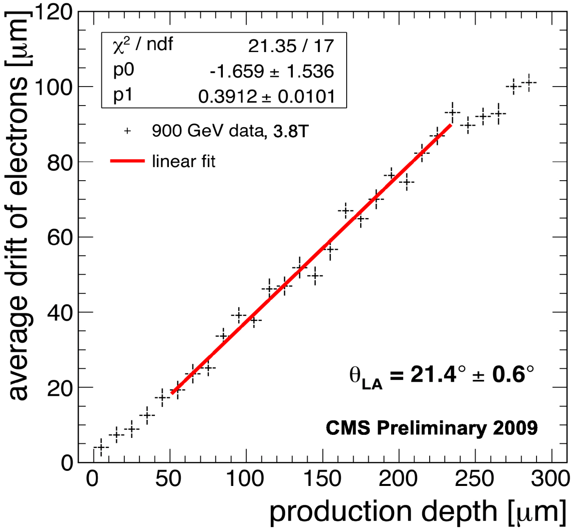



$$\Theta_{LA} = 21.4 + 0.6^0$$

*The results from collision data and cosmic data agree !!!*

**$\sqrt{s}$=900GeV B=3.8Tesla**

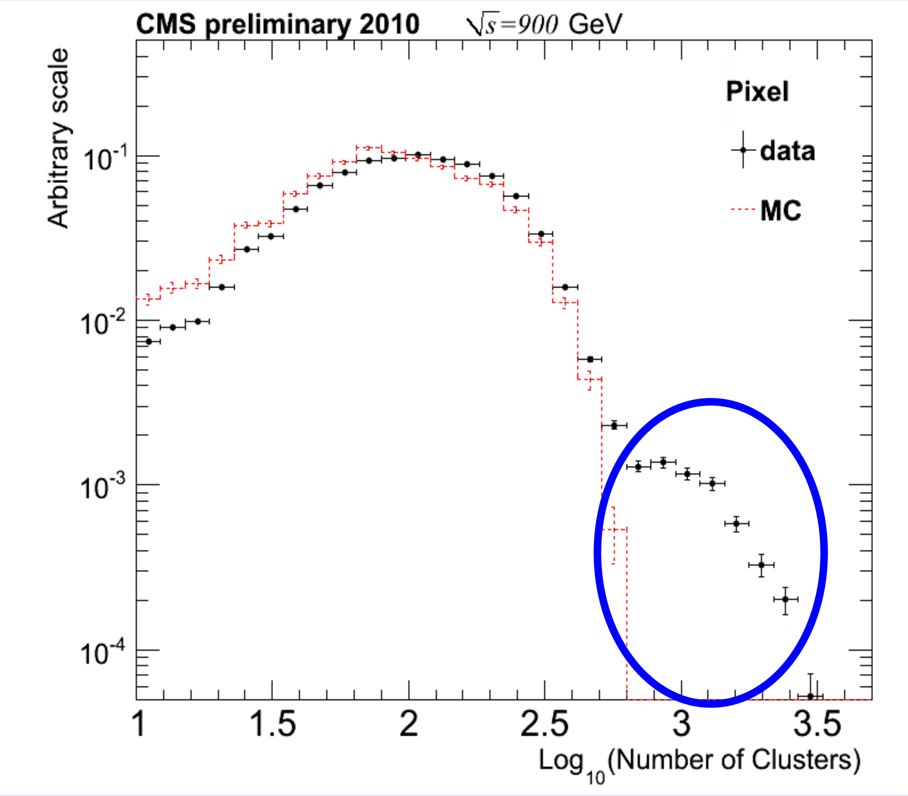


# Performance: Pixel cluster multiplicity

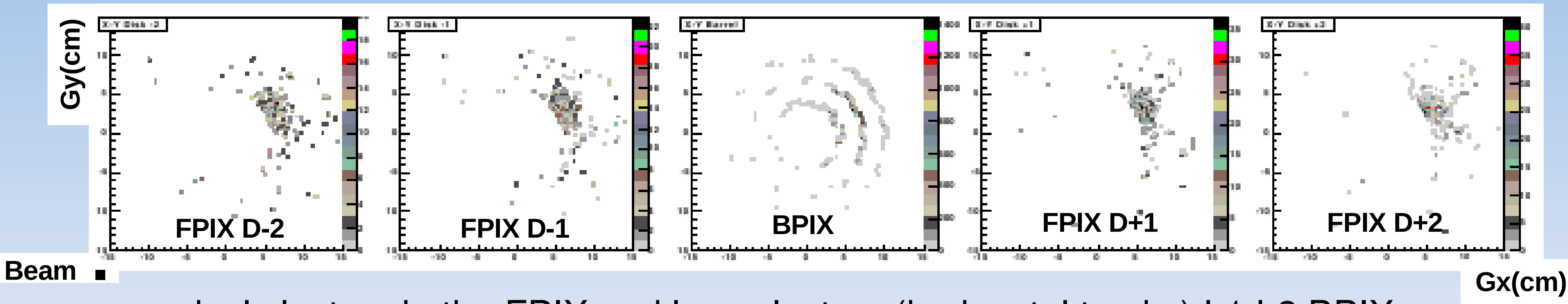
- Number of pixel clusters in minbias events @900GeV
- Data compared with PYTHIA MC event generator(*)
- Good agreement BUT excess of large multiplicity events
- High occupancy events observed since

  the first collisions
- large multiplicity of pixels in a cluster, clusters, tracks and bad quality reconstructed tracks

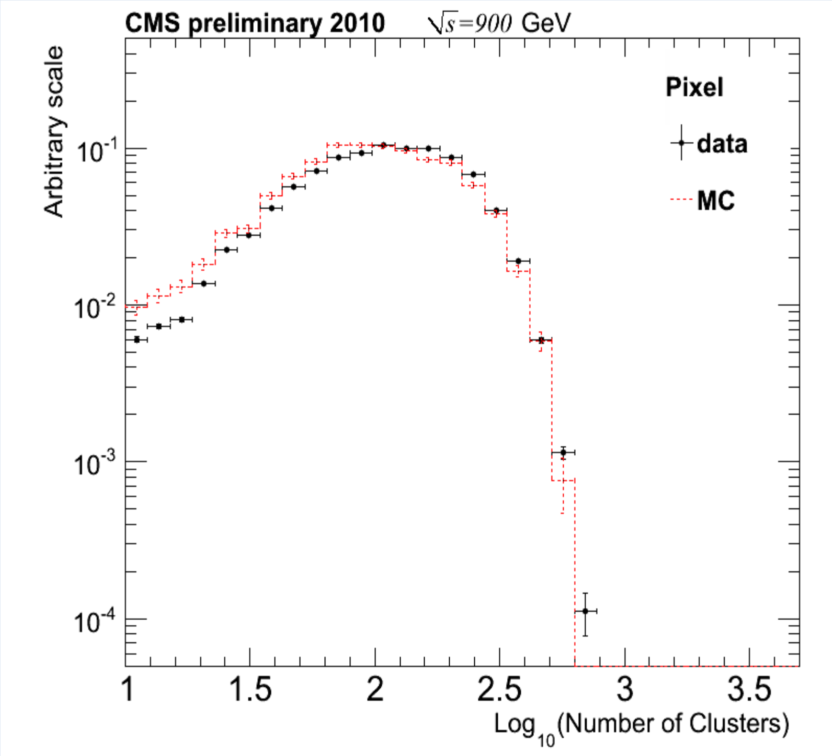



(*) *A. Moraes, C. Buttar and I. Dawson. European Physics Journal C, 50 (2007) 435*

# Background events



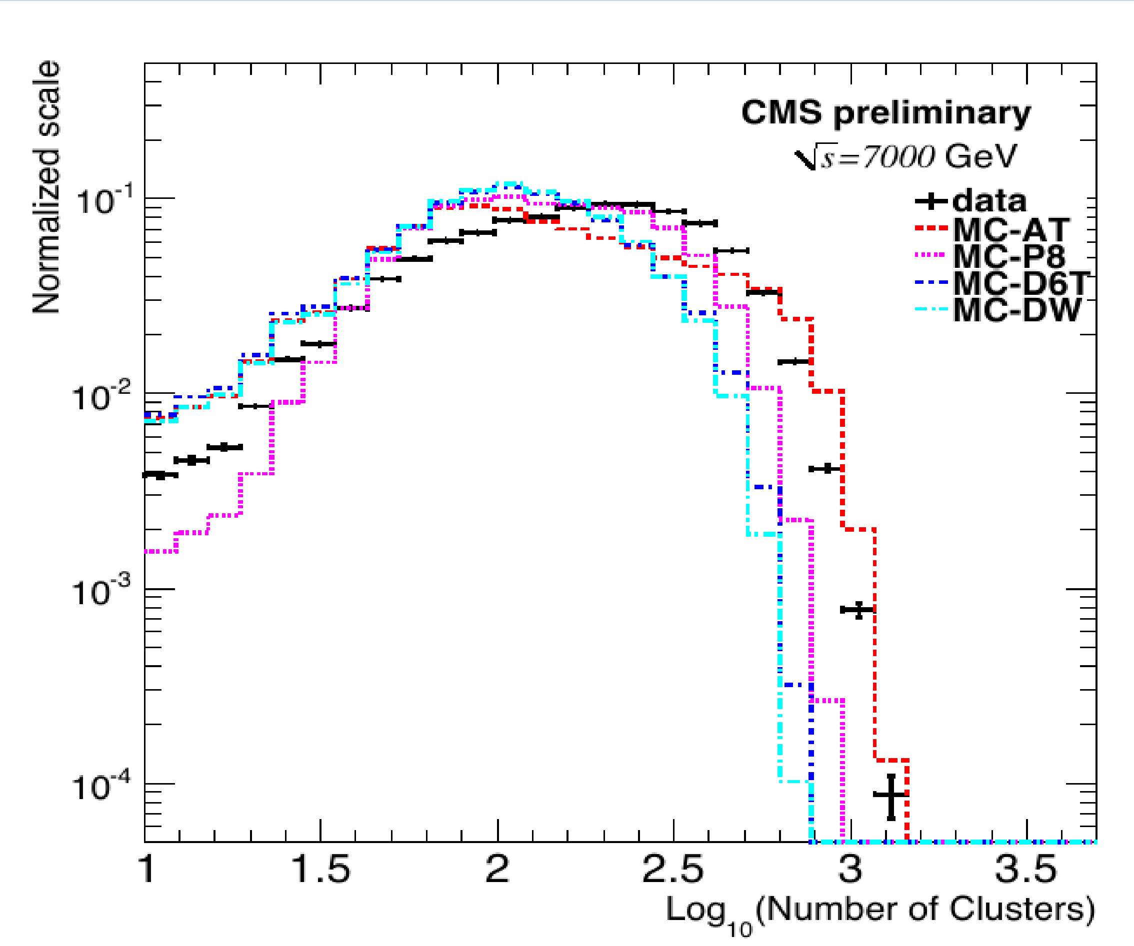

- many pixel clusters in the FPIX and long clusters (horizontal tracks) L1 L2 BPIX
- source of these events could be beam-gas interactions in the vicinity the interaction point or satellite collisions.
- large event size >1Kpixels/FEDch. -> in error cascade (overflow, timeout, loss of synchronization) -> FED firmware upgraded to automatic resync




Beam-gas trigger veto or combined cuts on cluster shape, track quality, and good vertexing requirements efficiently remove background

# Performance: Cluster multiplicity

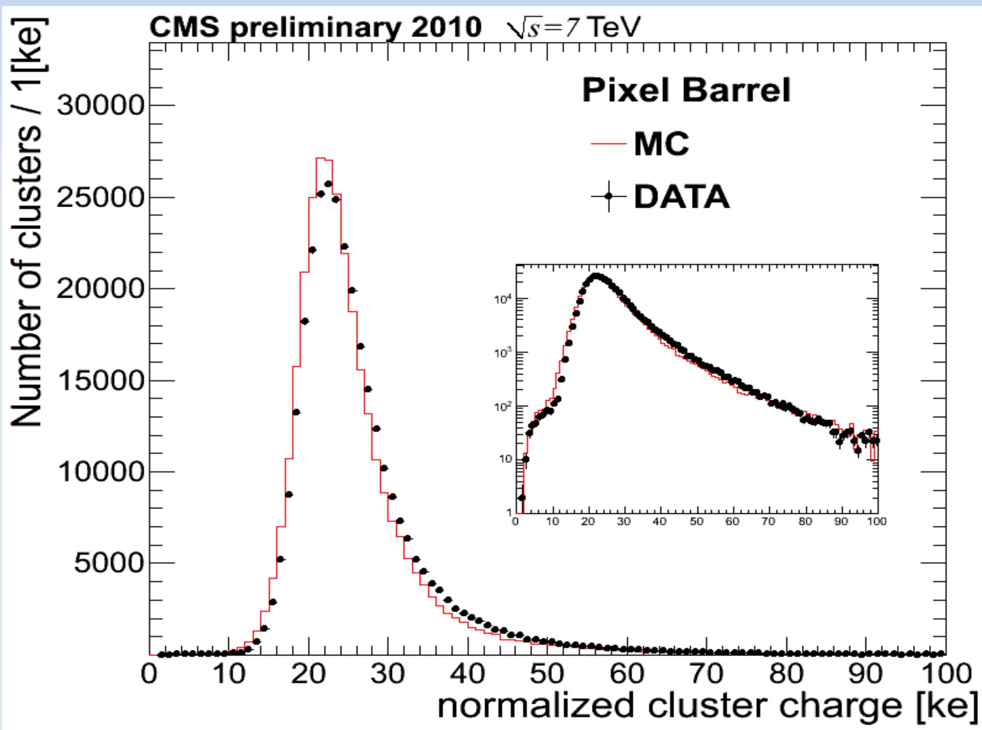
- Number of clusters measured in the pixel detector in minbias events @ 7TeV
- Different MC tuning compared

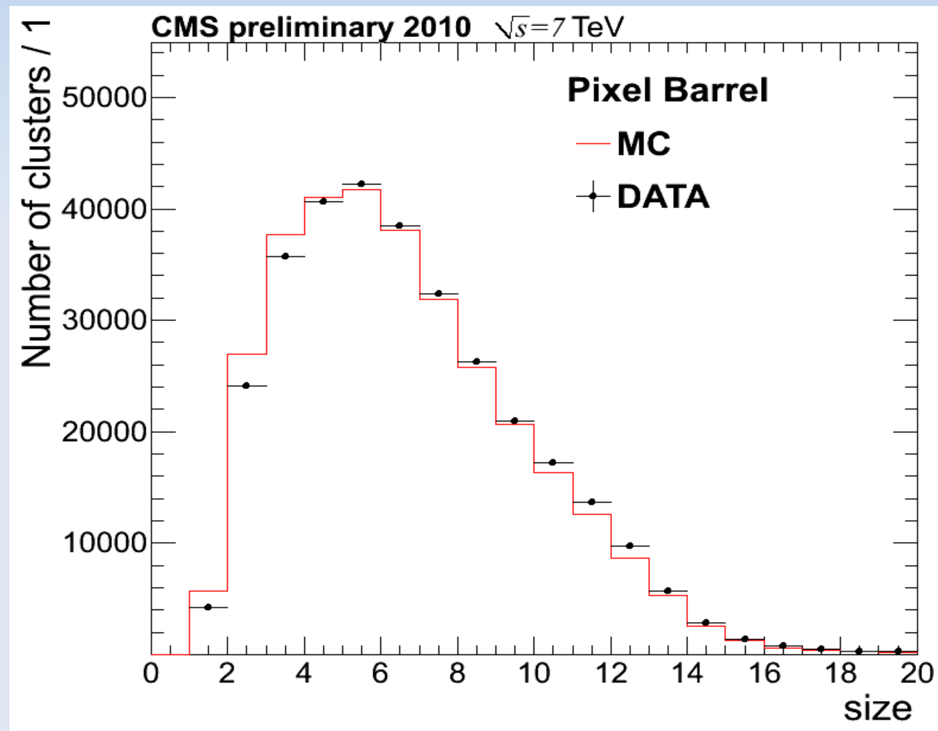



- Data and MC in good agreement @ 0.9, 2.36, 7 TeV
- Discrepancies depend on MC tuning
- No single tuning which satisfies the comparison at all energies and cluster multiplicities

# Performance – Data / MC

- Normalized cluster charge and size distribution in barrel and endcaps @ 7TeV
  - Charge scaled by track path length in the pixel sensor to the sensor thickness



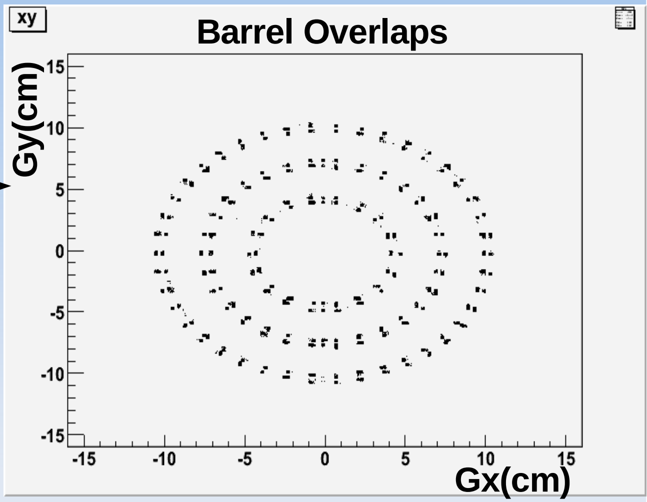

Nice agreement with data and good description also in tails

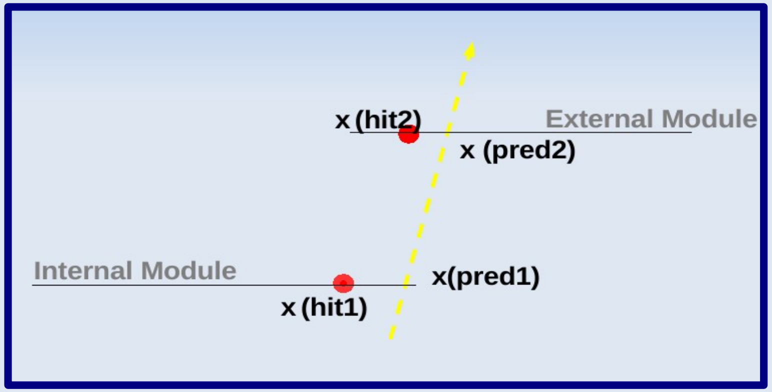
Good description by MC!
discrepancy for small cluster sizes <4
Need further improvement in the MC par.

# Performance – Hit Resolution

Intrinsic position resolution measured for the barrel in the overlapping regions:

- Select tracks $p_t$>2.5GeV/c with two hits in the same layer
  - $\Delta x_{hit}$ =x(hit1) – x(hit2) *measured hit difference*
  - $\Delta x_{pred}$ =x(pred1) – x(pred2) *predicted hit difference*
  - dd = $\Delta x_{hit} - \Delta x_{pred}$ *double difference*
  - $\sigma(dd)^2 = \sigma(\Delta x_{hit})^2 + \sigma(\Delta x_{pred})^2$
    - $\sigma(\Delta x_{hit})^2 = 2\,\boldsymbol{\sigma(x_{hit})}^2$ *same resolution both modules*
    - $\sigma(\Delta x_{pred})^2$ *includes MS and rotational misalignment*




*Extrapolated track excluding the layer under study*

- Advantages of overlap method:
  - $\sigma(\Delta x_{pred})$ more precise than $\sigma(x_{pred})$
  - extrapolation of tracks over short distances (~1cm)
  - σ(dd) independent on translational misalignment

# Performance – Hit Resolution

- Use overlap regions at least 20 tracks
- big pixels at the edge excluded
- Resolution evaluated both in x (top plot) and y (bottom plot)

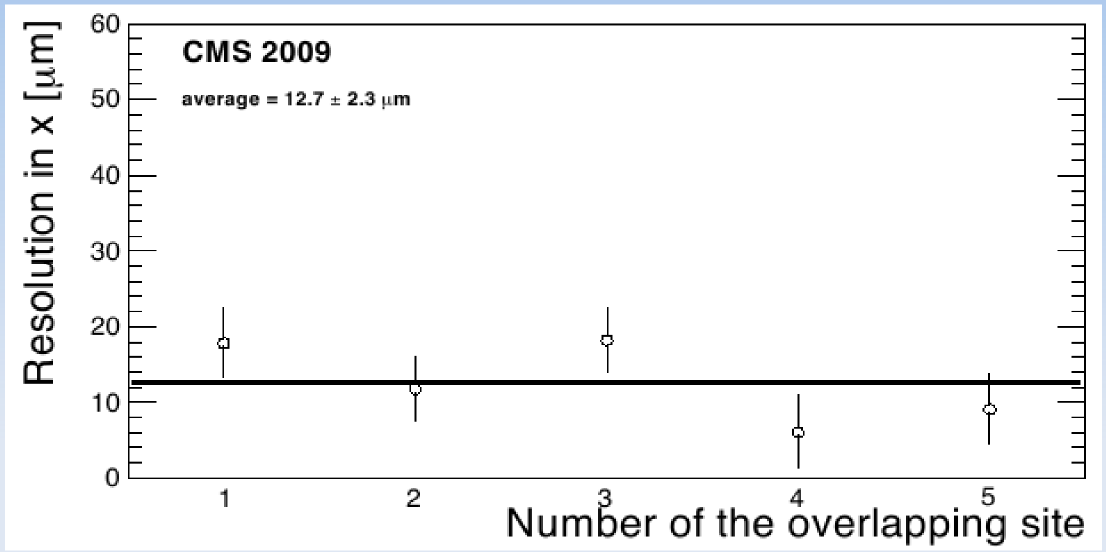
12.7 ± 2.3 μm along X
28.1 ± 1.9 μm along Y

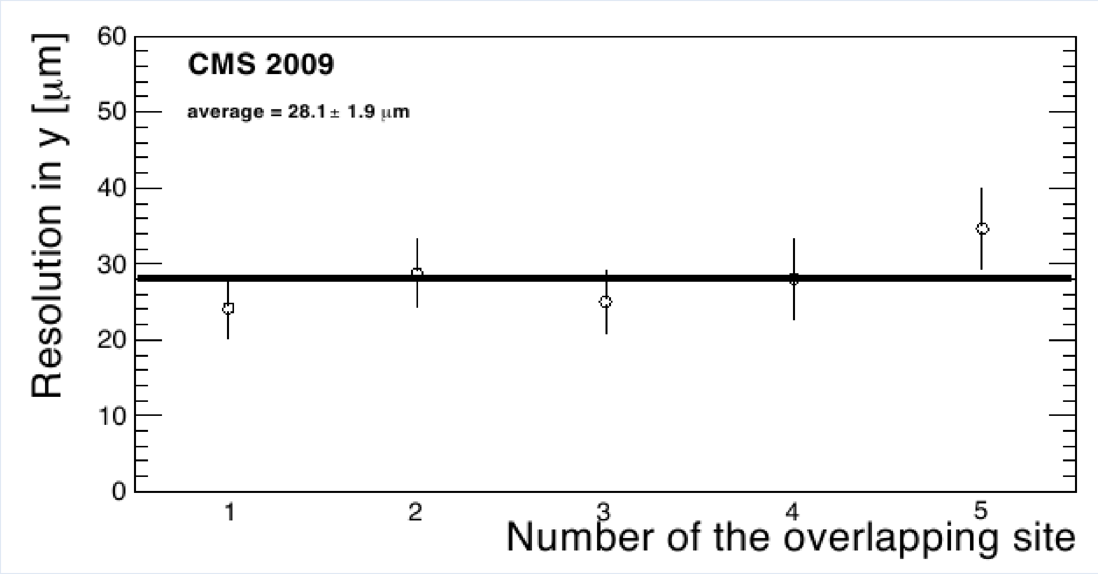
Simulation:
14.1 ± 0.5 μm along X
24.1 ± 0.2 μm along Y

Good agreement between data and simulation

More statistics needed with high luminosity runs!

Study the dependence on the track pt



# Conclusions

- The pixel detector has been commissioned with cosmic muons and first beam collisions
  - Timing adjustment
  - Lorentz angle
  - Absolute threshold
- Overall 66M channels, 98.4% detector is operational
- Pixel detector performance with data at 0.9, 2.36, 7 TeV collisions:
  - data-MC comparison: good agreement -> detector behavior well under control
  - efficient removal of background events
  - detection efficiency over 99%
  - hit resolution 12.7μm along X 28.1μm along Y

**Ready for physics analysis with LHC data !**

# Backup slides

# In-time threshold

Small pulse (blue) reaches a given threshold value later than large pulse (red)

- **Time Walk** is difference in time to reach the same threshold
- **Effective in-time threshold** corresponds to the minimum signal that fires the discriminator threshold in time with the trigger bunch crossing
- Smaller signal will be associated to the wrong bunch crossing
- In-time thr ~ 800e- + Absolute thr

**Intime thr =**
**Absolute thr =**