Operation of the CMS Pixel Detector

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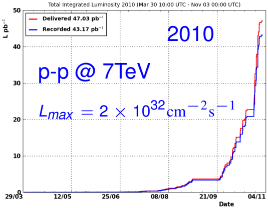
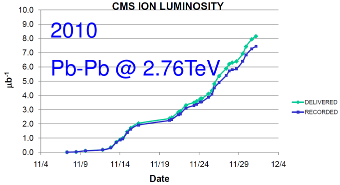
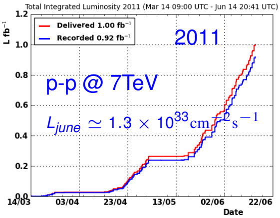
Outline

- The CMS Pixel Detector
- Operation of the Pixel Detector
- On-line and off-line calibrations
- Performance of the Pixel Detector
- Conclusions







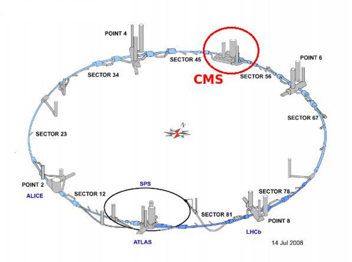
CMS Pixel Detector, Vertex10

- (Re)Startup Scenario 2010 – 2011
  - √s=7 TeV
  - Long Physics Run $L_{peak}=10^{32}cm^{-2}s^{-1}$
    - Integrated L = 1000 pb^{-1} goal

Fewer intense bunches 1E11 p/bunch
Pile up from multiple pp interactions
$\langle N_{int} \rangle \sim$ 2-3

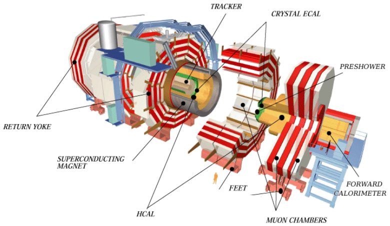
7 June 2010 CMS Pixels - Karl.Ecklund@rice.edu

CMS at LHC



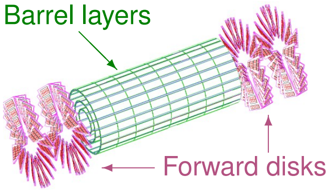
LHC:

- $27\ km$ ring, 1232 superconducting ($1.9\ K$) dipoles
- $p-p$ collider, $7\ TeV$ each beam
- nominal luminosity $10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$, rate $40\ MHz$



CMS:

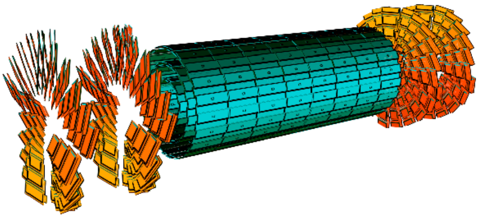
- Length $22\ m$, diameter $15\ m$, weight $12.5\,\mathrm{kton}$
- Magnetic field $3.8\,\mathrm{Tesla}$

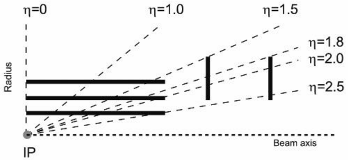


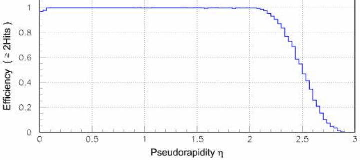
Pixel Detector:

- Barrel layers: $l = 53\ cm$, $R = 4.2,\ 7.3,\ 11\ cm$
- Forward disks: $z = 34.5, 46.5\ cm$, $R = 6 \div 15\ cm$
- Area $\sim 1.1\ m^2$, 66M channels

CMS Pixel Detector I







CMS Pixel Detector built of:

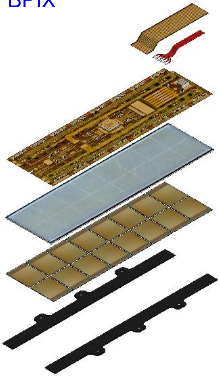
- BPix: 768 modules, 11520 ROCs, 48 Mpixels
- FPix: 192 panels, 4320 ROCs, 18Mpixels

Rapidity coverage:

- with 3 pixel hits up to $|\eta|$=2.1
- with 2 pixel hits within 2.1<$|\eta|$<2.5

CMS Pixel Detector II

BPIX



Cables: signal&power

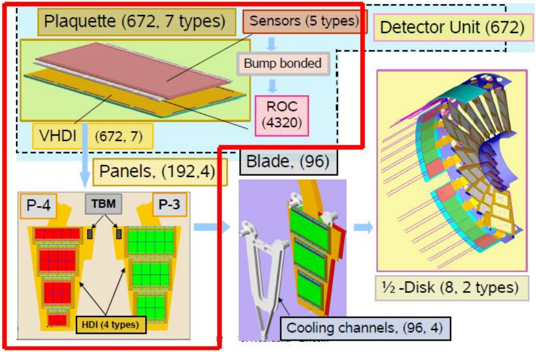
HDI print with TBM

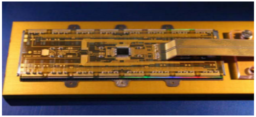
Si sensor

16 ROCs

Base strips: Si_3N_4

FPIX

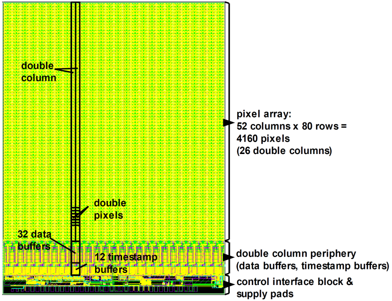


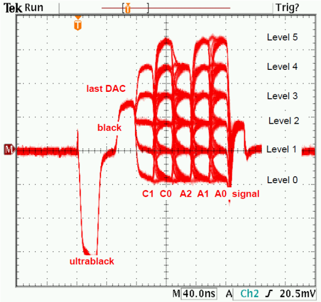


- BPix has 2 module designs: 16ROCs and 8 ROCs
- FPix has 7 plaquette designs: 2-10 ROCs

Readout Chip

- ROC designed by PSI, manufactured by IBM
  - 0.25 μm process, $\sim$1.3 million transistors
- ROC size: 8$\times$ 8mm^2
  - 4160 pixels of 100$\times$150 μm^2 in $r\phi \times z$ (CMS coordinates)
- 26 adjustable DACs per ROC, 4 trim bits per pixel
- Double column drain architecture
- 40 MHz analog readout: analog PH and pixel address



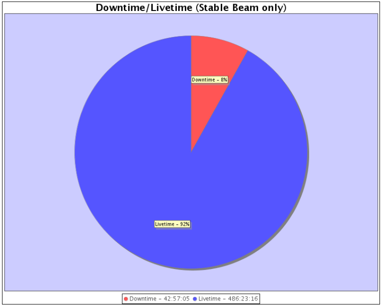


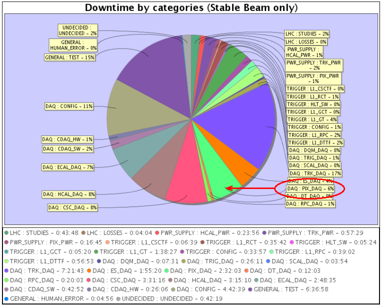
Infrastructure

- Cooling
  - coolant T=+7.4°C. Cooling was stable in 2010/11, no problems observed
  - in 2012 we may run at -10°C continuously, successful tests at this temperature done in January
  - humidity problem observed later in February (to be solved during winter stop, details see later)
- Power
  - stable running in 2010/11, no major problems observed
  - one remote sensing wire lost that affected 8 BPix modules
- Electronics
  - hardware was very stable in 2010/11
  - firmware have been modified several time to deal with different problems: 1) high multiplicity events from beam-gas background, 2) internal noise of mezzanine card (corrupted readout), 3) heavy ion events handling

Pixel operation

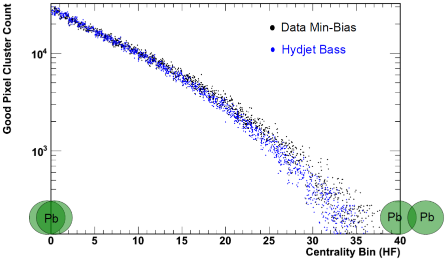
- CMS downtime since restart in March 2011:
  - CMS efficient 92% of time
  - Pixel detector contributes 6% of the total inefficiency
  - In Spring 2010: contributed 11% of the total inefficiency
- HI collisions in Nov-Dec 2010:
  - CMS efficient 94% of time
  - Pixel detector contributes 5% of the total inefficiency

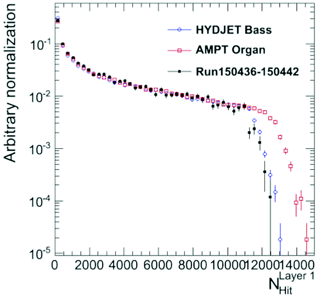




Operation in HI collisions

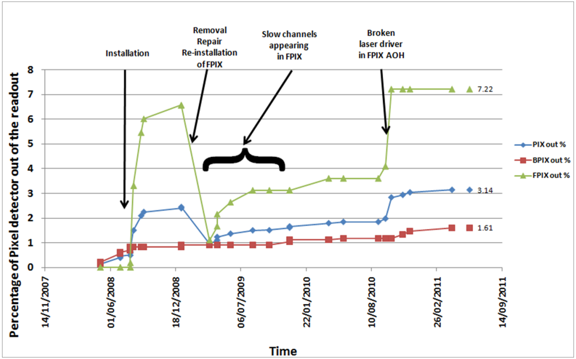
- Pb-Pb collisions in CMS
  - $\sqrt{s} = 2.76$ TeV
  - luminosity $\simeq 3 \times 10^{25}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ for 128×128 bunches
  - minimum bias collision rate 150Hz
- Major differences between p-p and HI
  - much higher multiplicity (but uniform!)
  - much lower collision/trigger rate
- To cope with larger event size FEDs buffer size increased
- NO problems observed with pixel detector operation in HI collisions
- Pixel performance appeared identical to p-p collisions





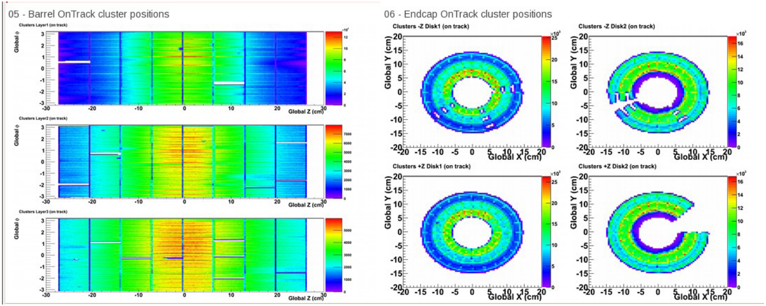
Pixel detector status I

- The whole Pixel detector: **96.9%** functional ROCs
  - FPix **92.8%**: 4320-312=4008 functional ROCs
  - BPix **98.4%**: 11520-186=11334 functional ROCs
- Total 'dead' random pixels : $<2\times10^{-4}$ in functional ROCs
  - about 6K ($\sim 10^{-4}$) inefficient pixel found with internal calibration
  - about 700 ($\sim 10^{-5}$) 'noisy' pixel (masked) found in cosmic ray data



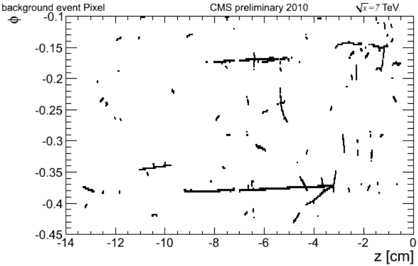
Pixel detector status II

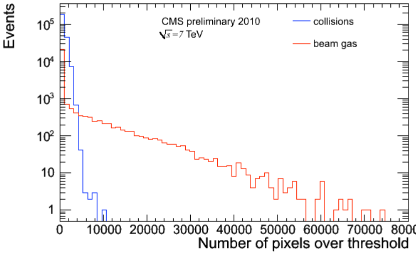
- Major problems in BPix:
  - single ROC problems: some recoverable
  - broken wires: not recoverable
  - token lost: not recoverable
- Major problems in FPix:
  - bad address levels due to slow signal rise time: recoverable in FED FW
  - no communication with optical transmitter: recoverable if CMS open



Beam-gas background I

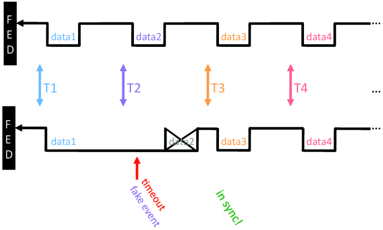
- What is beam-background events:
  - showers of particles that graze the detector along the beam axis (z)
  - occur coincident with bunch crossings
  - consistent with beam-gas interactions in the beam pipe
  - lead to a huge occupancy in BPix (but concentrated in 1 out of 36 FED channels)
  - impose challenges to maintaining event synchronization, especially at high trigger rates

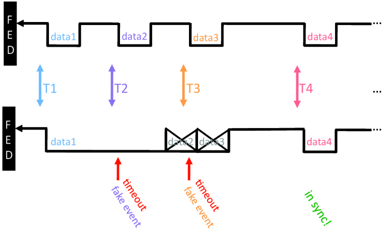




Beam-gas background II

- Where is a problem:
  - beam-gas event is large and can block FED(s) for long time
  - next event comes at NOT expected time (later)
  - FED(s) stays out of synchronization (timeout sent to CMS DAQ)
- Solution:
  1. drop the event(s) that not arrive when expected (event 'data2')
  2. if N (tunable) consecutive timeouts, stop CMS trigger, so FED can resynchronize itself



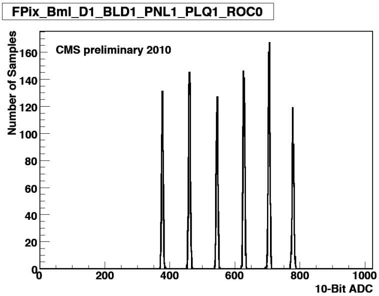


Operational temperature

- At certain moment we want T be lower, e.g. -10°C
  - detector need to be re-calibrated (DAC settings)
  - test has been done in January: not completed due to lack of time
  - later, in February, observed the RH problem (interlock due to high RH)
- 'Humidity problem'
  - it was not observed before winter 2010/11 stop
  - RH rises when CMS magnet is switched on (above 2-2.5T)
  - one side of detectors affected more than other
- Possible explanation and actions
  - hypothesis: it's known that some parts of CMS move on magnetic field turn on/off, this may create an opening in pixel volume sealing
  - keep track of RH problem, recover during winter 2011/12 stop

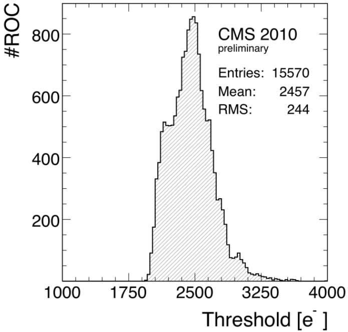
On-line calibrations

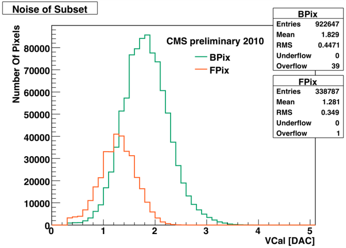
- Proper readout defined by several groups of settings:
  - at module level: ROC and TBM parameters
  - optical readout chain: AOH and DOH parameters
  - FED parameters
- Majority of settings stays unchanged until:
  - detector temperature will be changed
  - significant irradiation will be accumulated
- Some parameters in FEDs regularly re-calibrated:
  - adjust offset in optical receivers to keep signal within ADC range: small corrections made automatically, large - by recalibration
  - ADC levels needed to decode pixel addresses: mostly as a check
  - clock phase: phase of ADC, performed only as a check



On-line calibration: threshold

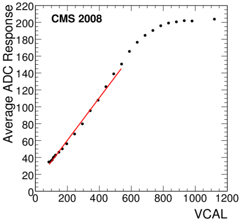
- Motivation:
  - lower threshold - lower pixel charge reconstructable then longer cluster
  - longer cluster size - better spacial hit resolution
- Threshold minimization
  - minimization done with help of internal calibrate signal (VCal)
  - method limitation: x-talk in ROC
- Mean threshold = 2457 electrons
- Mean noise less than 150 electrons
  - Conversion (from X-ray calibration): $Q[e^-] = 65.5 \times VCal[DAC] - 414$

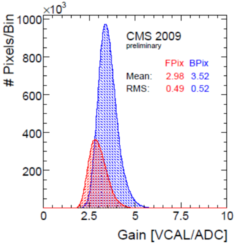


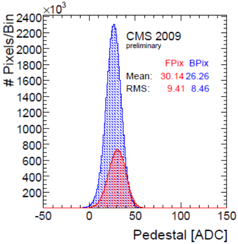


Off-line calibration: ADC to Charge

- Relate PH (ADC) to deposited charge
  - ADC-to-Vcal done once a year (more often for control)
  - VCal-to-Charge calibration done in the lab with X-ray sources
- offline ADC-to-Vcal calibration:
  - fit single pixel response with linear function
  - result of the fit: gain and pedestal
- Granularity of constants used in CMS
  - HLT: averaged over ROC column (payload 800kB)
  - RECO: gain averaged over ROC column, pedestal per pixel (33MB)

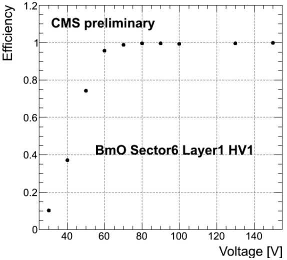


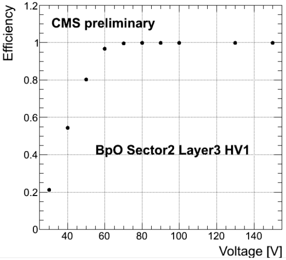


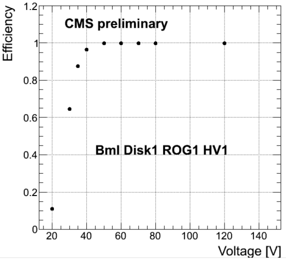


High voltage scan

- HV scan performed on April 2010 and March 2011
- Few modules in BPix and FPix selected to be monitored
- No change observed in the depletion voltage (60-70V)

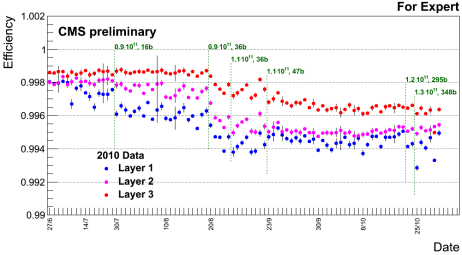


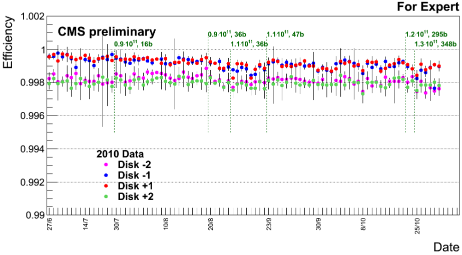




Pixel efficiency

- Barrel Pixel detector in 2010:
  - the initial average protons per bunch and the number of bunches (colliding in CMS) are shown in green
  - expected dynamic efficiency loss due to increased bunch charge and number of bunches (occupancy increase)
  - overall decrease in efficiency in all layers of 0.2%-0.4%
- Forward Pixel detector in 2010
  - Efficiency on the Fpix stays within the systematics uncertainty of 0.002

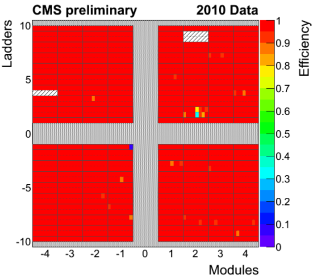




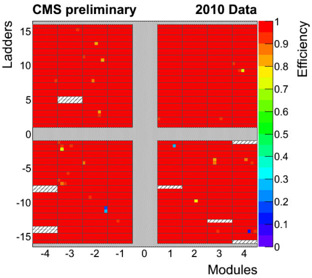
BPix efficiency

- ROC efficiency represented per layer
  - hatched area represents inactive modules
  - ladder index changes along ϕ, module index changes along z
- Systematic uncertainty on ROC efficiency is 2×10^{-3}
- Statistical uncertainty on ROC efficiency is $10^{-4} \div 10^{-3}$
- Inefficiency concentrated in single ROCs

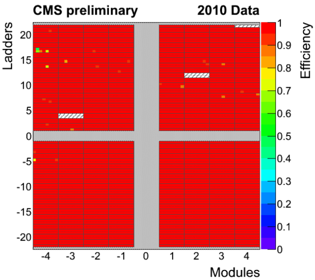
BPix layer 1



BPix layer 2

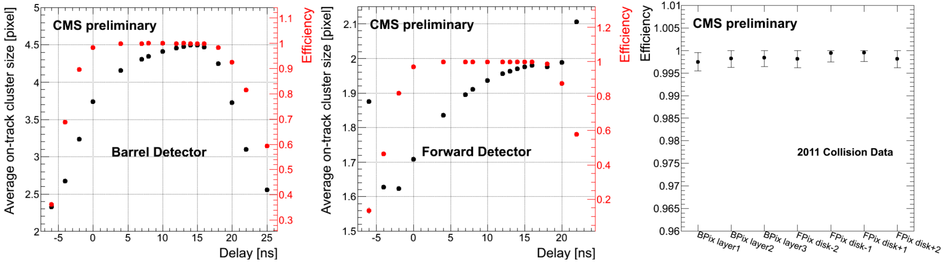


BPix layer 3



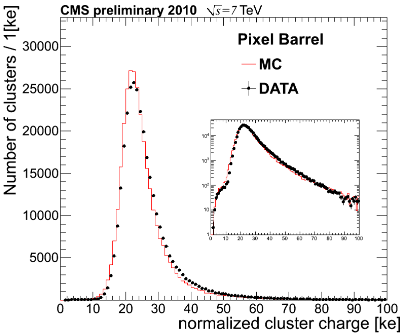
Time delay scan

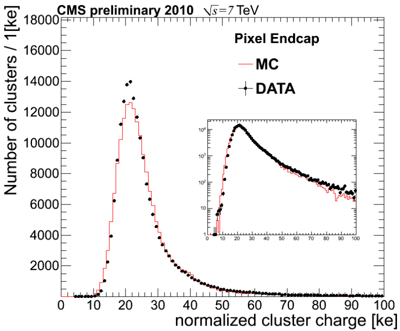
- Timing affects cluster size (charge collection efficiency) due to time walk
  - low pulses exceed threshold later than large pulses
  - adjust timing to latest possible with respect to LHC clock
- Methods used
  - determine maximum cluster size plateau with step 6ns
  - make fine scan with high statistics near the end of plateau (2ns)



Cluster charge distribution

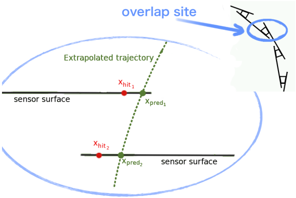
- LHC collision data @ 7 TeV
  - corrected to incident angle hit cluster charge for tracks with $p_\perp$ >2 GeV
- MC simulation provides accurate description of data
  - peak position correct to 2-4%, width 10-15%





Pixel hit resolution

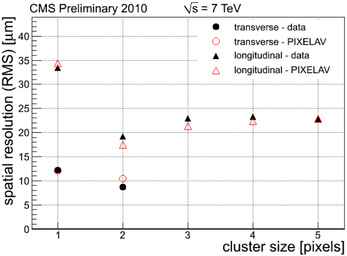
- Intrinsic position resolution with overlap method
  - pairs of consecutive hits of track in the same layer
  - difference of measured hit positions
  - difference of extrapolated hit positions
  - difference of two differences
  - reduced sensitivity to alignment and extrapolation errors



- 1316 overlap regions analyzed (8.3M hit pairs)
- Good agreement data-MC: $\pm 1 \mu m$
- Intrinsic hit position resolution:

$\sigma_{trans} = 11.2 \pm 0.1\ \mu\text{m}$

$\sigma_{long} = 26.8 \pm 0.1\ \mu\text{m}$



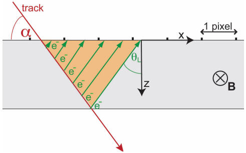
Lorentz angle measurements

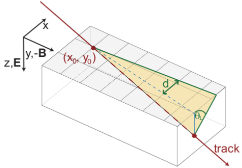
- Lorentz shift makes clusters wider
  - hence, better hit position resolution
  - need to be known for data and in MC

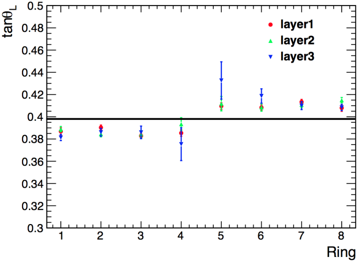
1 Minimum cluster size in cosmics data
  - measure cluster width vs incident angle

2 'Grazing angle' in collision data
  - measure e^- drift length vs production depth

- Detailed MC simulation done with PIXELAV
- Results are consistent in different methods and with MC
  - BPix: cotα=-0.462(452)$\pm$0.003(2)
  - FPix: cotα=-0.074(74)$\pm$0.005(4)
- Main issue forward-backward asymmetry

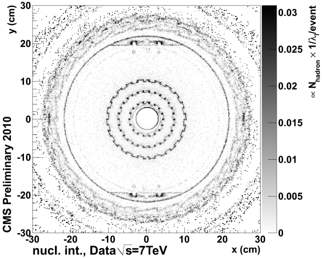


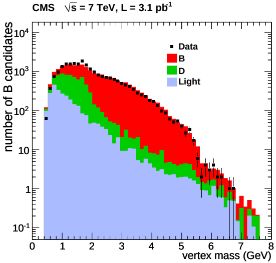


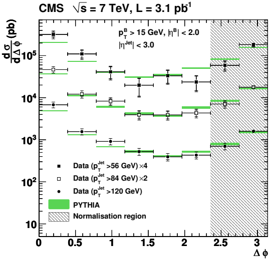


Pixel data applications

- Pixel data has many applications apart of physics:
  - PV allows to monitor beam spot position and width
  - photon conversion or NI points are used for material distribution studies
  - follow Giacomo Sguazzoni talk on CMS Tracker performance
- Physics Example: $b\bar{b}$ angular correlations based on SV:
  - final goal to measure different $b\bar{b}$ production mechanisms: FC, GS and FE, and test pQCD LO and NLO x-sections and their evolution with energy
  - algorithm allows to distinguish 2 b-particles even if 2 b-jets are merged and hence sensitive to small $\Delta\phi_{b\bar{b}}$







Conclusions

- Smooth operation of pixel detector in 2010/11, both in p-p and HI
- Pixel detector provides high quality data used in various physics analysises
- Performance of the detector under control
- Changes in 2010
  - 'unattended' operation of the detector: only central crew and expert on call
  - beam-gas background problem understood and downtime caused reduced
  - functional fraction 96.7% (1.5% lost in 2010), some to be recovered
  - downtime caused by pixel detector improved (already very small), work ongoing to recover remaining losses
- Preparation to cooler operation has started
  - tests of the detector operation and calibration at -10°C
  - RH problem under investigation, working on possible solutions

Back up slides

Organization

- Pixel field manager: one person
- On call experts (former shift leaders)
  - since summer 2010 we do not have permanent pixel shifter at P5 (3 persons a day)
  - only one person (on call expert is responsible for the operation)
  - now we have about 20 people to perform this task
- Pixel DAQ
  - pixel DAQ SW, run control (interface to the central DAQ): 2-3 persons
  - pixel configuration DB: 2-3 persons
- pixel DCS common with strip group: 3 persons from pixel side and 2-3 from strips
- pixel DQM: 2 persons

Detector status: known problems

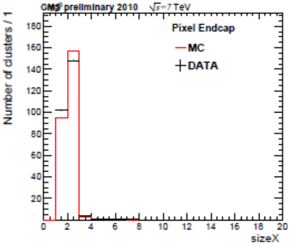
Detector component	# ROCs	Problem
FPix_BmO_D1_BLD9_PNL2	24	low signal amp. (bad TBM)
FPix_BmI_D1_BLD11_PNL2	24	one ROC without analog output, whole panel lost
FPix_BmO_D2_BLD8_PNL2	24	bad Address Levels (slow rise-time)
FPix_BmO_D2_BLD8_PNL1	21	bad Address Levels (slow rise-time)
FPix_BmO_D2_BLD7_PNL1	21	bad Address Levels (slow rise-time)
FPix_BmO_D2_BLD9_PNL1	21	bad Address Levels (slow rise-time)
FPix_BmI_D2_BLD10_PNL1	21	bad Address Levels (slow rise-time)
FPix_BmI_D1_BLD6_PNL1	21	no signal
FPix_BpI_D2_BLD4_PNL1	21	no I2C to AOH, need to open CMS
FPix_BpI_D2_BLD4_PNL2	24	no I2C to AOH, need to open CMS
FPix_BpI_D2_BLD5_PNL1	21	no I2C to AOH, need to open CMS
FPix_BpI_D2_BLD5_PNL2	24	no I2C to AOH, need to open CMS
FPix_BpI_D2_BLD6_PNL1	21	no I2C to AOH, need to open CMS
FPix_BpI_D2_BLD6_PNL2	24	no I2C to AOH, need to open CMS
BPix_BpI_SEC5_LYR3_LDR12F_MOD2	16	no HV
BPix_BpI_SEC8_LYR3_LDR22H_MOD4	8	no HV
BPix_BpO_SEC1_LYR2_LDR1H_MOD4	8	no HV
BPix_BpO_SEC8_LYR2_LDR16H_MOD4	8	no HV
BPix_BpO_SEC7_LYR2_LDR13F_MOD3 TBM-B	8	token lost
BPix_BmI_SEC2_LYR3_LDR4F_MOD3	16	token lost
BPix_BpO_SEC4_LYR2_LDR8F_MOD1 TBM-A	8	bad ROC
BPix_BmI_SEC3_LYR2_LDR5F_MOD3 TBM-A	8	bad ROC header
BPix_BmI_SEC3_LYR2_LDR5F_MOD3 TBM-B	8	ROC cannot be programmed
BPix_BmO_SEC7_LYR2_LDR14F_MOD4	16	dead module
BPix_BpI_SEC8_LYR1_LDR9F_MOD2	16	no trigger
BPix_BmO_SEC4_LYR2_LDR8F_MOD4 TBM-A	8	bad ROC
BPix_BmI_SEC3_LYR1_LDR4F_MOD4 TBM-B	8	no signal (wire bond?)
BPix_BpO_SEC7_LYR3_LDR19F_MOD2	16	tocken lost
BPix_BpI_SEC1_LYR3_LDR3F_MOD2	16	cann't be programmed
BPix_BmI_SEC5_LYR3_LDR13F_MOD2	16	remote sensing wire

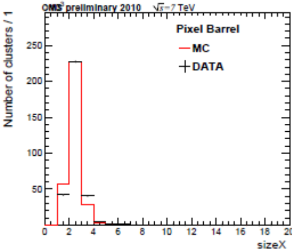
Infrastructure status II

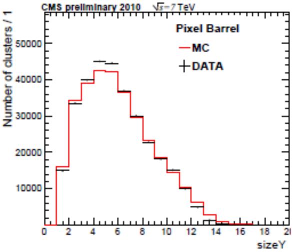
- Detector Control System (DCS)
  - monitor power (LV and HV), T and RH: stable functioning
  - several thing still have been modified (like staged BPix turn on)
  - calibration of humidity and dew-points have been made at the beginning of 2011
- Data Quality Monitor (DQM)
  - with data taking experience permanently improving the monitoring
  - due to unattended pixel operation since summer 2010, central DQM shifters have been provided with clear plots and instructions
- Pixel on-line SW (POS)
  - written very well from the beginning
  - all needed calibrations of the detector work very reliably
  - concerns about man power to support the SW on a long term bases

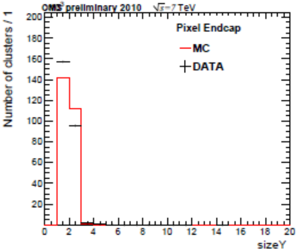
Cluster size

- Cluster size distributions: note different geometry of forward and barrel pixel detectors
  - BPix:
    - local X corresponds to global $r\phi$ (short clusters)
    - local Y corresponds to global z (long clusters)
  - FPix: all tracks almost perpendicular to sensor
    - in both directions clusters are short
- MC simulation describes data quite well



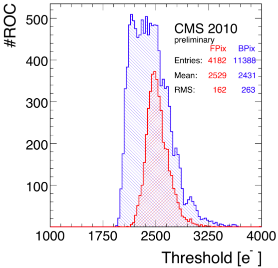


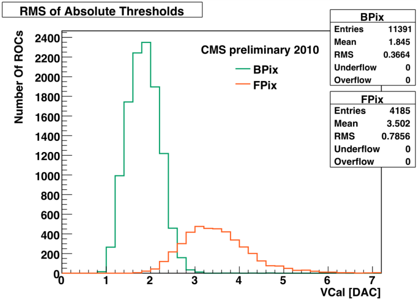




Thresholds

- Procedure :
  - The mean absolute threshold on each ROC is computed from a subset of pixels on the ROC (2%)
  - The absolute threshold of each pixel is obtained from an SCurve calibration covering two bunch crossings
  - An SCurve is the hit efficiency as a function of injected charge (VCal).
  - The threshold is taken as the VCal corresponding to 50% efficiency
- Conversion: #electrons=65.5$\times$VCal - 414 (X-ray calib.)





DACs optimization

- Few operational parameters are T dependent
  - some DACs tuned dynamically, so no need for a special procedure
  - others should be re-adjusted
- BPix
  - 2 sets of DACs for +17°C and -10°C taken at PSI
  - T dependence approximately linear
  - new DACs obtained by linear interpolation from 2 sets
- FPix
  - DACs tuned in P5 using special calibration procedures
- Thresholds are minimized in BPix/FPix: 2740/2480 e^-