Beam backgrounds in the CMS pixel detector

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Contents

* Description of beam background events observed in the CMS pixel detector.

* Rejection algorithm of beam background events using pixel data.
The CMS Pixel Detector

The CMS Pixel Tracking System is designed to provide three high precision three-dimensional determinations of track trajectory points. The system, shown schematically in Fig. 8, consists of three concentric cylindrical barrel layers and four fan-blade disks which close the barrel ends. The barrel layers have an active length of 50 cm and are located at average radii of 4.50 cm, 7.20 cm, and 8.75 cm. The forward disks instrument the regions between radii 4.5- cm and 8.5. cm at mean longitudinal distances of 0.5- cm and .5- cm from the interaction point. The system provides efficient three-hit coverage in the region of pseudorapidity \(|\eta| < 3.95\) and efficient two-hit coverage in the region \(|\eta| < 9.5\). The active elements are 8.7 \(\mu m \times 8.77 \mu m\) hybrid pixels which are oriented with the smaller pitch in the azimuthal direction in the barrel and the radial direction in the forward disks. The 0.5-T magnetic field in CMS causes significant Lorentz drift of the collected electrons in the pixel barrel. The blades of the forward disks are rotated by 97 degrees about their radial axes to produce azimuthal charge sharing and radial Lorentz drift which enhances radial charge sharing.

1.1 Pixel Timing Scan

The pixel detector readout system is based upon an LHC-derived 7 MHz clock. Signals from the CMS trigger system must arrive at the correct time within the 9: ns clock cycle to associate the correct bunch crossing time stamp with any signal above the readout threshold. The trigger timing was adjusted by varying the clock phase until the charge and cluster sizes as measured in minimum bias triggers were maximized. These quantities are plotted versus clock phase in Figs. 9zafi49zcfi55. The clock phase setting of 4. ns was found to optimize all quantities.

1.2 Operating Conditions

In order to make maximal use of experience gained from the operation of the detector with cosmic rays during Summer/Autumn 977, the detector conditions were not changed for the December 977 data taking period. The coolant temperature was kept constant at 55.\(^\circ\)C which implies that the sensor temperatures were approximately 50.\(^\circ\)C. The bias potential applied to the 9.4 \(\mu m\) thick p-spray barrel sensors was a uniform 8.7 V. The bias potential applied to the 9/74 \(\mu m\) thick p-stop forward sensors was a uniform 077 V. Small fractions of the barrel and forward detectors were inactive resulting in a net operational fraction of (-5.w for the entire detector.

The calibration procedures described in Ref [8] were used to determine the ADC gains and pedestals for all channels. The mean and rms of the readout threshold distributions for the zero-suppressed Readout Chips were lowered from the values used during the 977-cosmic ray commissioning [8] to 9/00e \(\pm 8(,e\) in the barrel detector and 9.-0e \(\pm 8,0e\) in the forward detectors. These are set values that apply only to the tuning procedure. Because the bandwidth of the preamplifiers is limited by power considerations, small signals can take more than a

Pixel detector
100x150\(\mu m\) x 285\(\mu m\)
Barrel:
3 layers @ 4.3, 7.2 11 cm
50 cm long, 48 Mpixels
Endcaps
2x2 disks, active region 6<R<14.5 cm,
35 and 50 cm from IP, 18Mpixels
Multiplicities during data taking

- Data taken at the LHC pixel detector is much more busy than expected from pp collisions simulations.
- Two exponential tails, two types of data?
Energy dependency

* The higher the energy of the beam, the more charge we deposit in the pixel detector.
Closer look at a single ‘busy’ event

What we see:

- sprays of particles traversing along the beam pipe
- localized in phi per event, per run no preferred region
- a lot of fake tracks due to the geometry of the event

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Track multiplicity

Also in the track multiplicity we see a large exponential tail due to all the fake tracks.
Closer look at the inner layer

- The barrel works as a bubble chamber, the particles fly parallel to the silicon.

- The background events leave (centimeters!) long charge deposits.

- We see production of secondaries in the silicon volume.
Closer look at a single ‘busy’ event

- particles enter on one side and leave on the other of the pixel detector
- From studies we learned:
  - they come ‘in-time’ with the proton beam
  - they are present in colliding and non-colliding bunches
  - they come from both beams
  - no ‘point source’ was identified
  - an average 7 TeV event has about 50 particles leaving charge in the pixel end-caps
  - beam background events are compatible with beam-gas interactions
Background-event rates

- Rate is calculated by looking at non-colliding bunch crossings and requiring activity in the scintillators (BSC)
- When scaled to the beam intensities the rate is
  - flat over (at least) a period of a run
  - the same for beam 1 and beam 2
  - independent of the beam energy
- The beam-backgrounds rate scale linear with the intensity, the collisions scale quadratically
- We have (so far) not observed dependencies to changing beam parameters (squeezing).

- The rate is estimated around 0.5 Hz/bunch/beam/$10^{10}$ protons
- At a rate of 11kHz of physics events at $10^{11}$ protons per bunch an overlap with a background events is expected at a rate of about 1‰.
Beam-gas simulations

- Simulation of ideal LHC conditions (p.e. vacuum pressure)
- Agrees well with the fluency measurements in the pixel detector.
- The pixel detector is in a very good position to study the background events

CMS uses an iterative tracking algorithm.

Reconstructed pixel hit locations are refined using a template based method.

The template fit searches for the optimal hit reconstruction using the local impact angle of the track hypothesis.

The template fit returns a probability that the track matches the cluster.

If the cluster does not match the impact angle of the track, a low probability is returned.
Fraction of low probability clusters

- Fraction of low-probability clusters versus the total number of clusters (counting only barrel clusters).
- This fraction is sensitive to the number of fake tracks in the event.
- A large number of fake tracks gives a high fraction of low probability clusters.
- The pixel-template filter, removes events with a fraction larger than 0.4.
- Events with no on-track clusters in the barrel cannot be identified and are added to the background category.
Separation of collision and background events

**USING THE PIXEL-TEMPLATE FILTER**

- The pixel-template filter separates the two tails in the multiplicity distributions.
- Collisions and beam background events overlap, a simple cut in the distribution would not have worked.
Conclusions

- The beam-background events are compatible with beam-gas interactions hypothesis
- The rates and fluency are within expectations.
- They leave a lot of charge in the pixel volume.
- They create many fake tracks.

- Beam-background events can be separated from pp collision events using a filter based on the compatibility of the cluster-shape versus the reconstructed track.

- Physics-background overlapping events are expected. The pixel-template filter has prospects to disentangle the two events.

Thanks to all the CMS collaborators
Comparison with other filters

- Other filters are present in CMS based on:
  - a well reconstructed vertex
  - the fraction of high quality tracks
  - the BSC scintillator timing information

- The pixel template filter agrees well with the other available filters.

- The pixel template filter might allow us to separate on a cluster-by-cluster basis the collision from the beam-background contributions in overlapping events.

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On versus off track clusters
Background removal

- Different ways to get beam-background free samples: one possibility is to use triggers from beam scintillation counter (BSC) placed at 11 meters from interaction point

- «Minimum bias»: select events with simultaneous hits on both BSC station

- «Beam halo» veto: suppress events in which particles are producing hits with large delay (>40ns) between both sides signals

- «Beam-gas» veto: suppress events with 2 hits on one side and no hits on the other side