Overview and status of the ATLAS Pixel Detector

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Abstract. The silicon pixel detector for the ATLAS experiment has been completed and installed. The number of dead channels after the assembly is 0.3%. Before the final assembly, a system test, including all services and DAQ system, was performed on one endcap corresponding to 8% of the detector. This system was used for data taking with cosmic rays, showing an efficiency greater than 99% and an almost noiseless operation.

1. The ATLAS Pixel Detector

The Pixel Detector is the vertex tracker of the ATLAS experiment. It consists of three barrel layers, the innermost one located at 5 cm from the interaction region, and six disks, covering with three precise measurements points the region up to $|\eta| < 2.5$.

The basic unit of the Pixel Detector is a module, whose sensitive volume is a silicon tile [2] of dimensions $60.8 \times 16.4 \text{ mm}^2$ and $250 \mu \text{m}$ thickness, segmented in 47232 pixels, mostly of $50 \mu \text{m} \times 400 \mu \text{m}$ size. The sensitive region is connected to 16 front-end electronics chips (FE) by bump bonds, using both In and SnPb technologies [3]. A flex hybrid is glued on the sensor backside. It is used to distribute power to the FEs and to lodge passive components and a Module Controller Chip [4], which manages the communication to and from the FEs and performs the event building. The full Pixel Detector consists of 1744 modules, for a total of more than 80 million channels.

Modules will operate below 0 °C and within a solenoidal magnetic field of 2 T. In the barrel region they are tilted by 20° in order to overcompensate the Lorentz angle [5]. Test beam results have shown that modules are radiation hard up to a NIEL of $10^{15}$ 1 MeV n/cm² and a dose of 500 kGy [6].

The front-end pixel electronics cell [7] consists of a fast charge preamplifier with constant current feedback, followed by a discriminator. The discriminator threshold can be tuned for each pixel in order to provide a uniformity of 40–90 e, much less than the noise level of 140–180 e, when operating at the default threshold of 4000 e. During production a complete module characterization has been performed [8], resulting in an amount of identified bad channels of 0.2%. Timing performance are critical for operation at the LHC. The readout electronics is clocked at 40 MHz, the same as the beam crossing frequency. A signal is assigned to a certain beam crossing according to the clock cycle in which the discriminator fires. Low signals may have a timewalk effect and be assigned to later beam crossings. Pulse height is measured with the time over threshold (ToT) technique. Due to the constant current feedback the ToT is linear with the pulse height in the region of interest for the signal.
2. The system test setup
For commissioning of one end-cap of the detector and the full service and data acquisition chain a system test setup has been built. It is shown in figure 1.

The pixel end-cap consists of three disks, of 48 modules each, corresponding to 8% of the full detector size. It is positioned with the symmetry axis along the vertical direction to maximize acceptance for the cosmic rays data taking described in next section. The detector is connected to a prototype of the Service Quarter Panel (SQP), which is used to perform the conversion of data signal from electrical to optical and to route the services along the beampipe. At the end of the SQP all the optical and electrical paths to the off-detector electronics and power supplies, including a radiation tolerant regulation system, is realized with early production components. Cooling is provided by a \( \text{C}_3\text{F}_8 \) evaporative system and keeping sensor temperature stable about \(-10^\circ\text{C}\) during operation.

This is the first time a big fraction of the detector is operated with a full version of the services and is an essential step in the commissioning of the service, the data acquisition system and in testing the model for detector calibration, implementing calibration runs reproducing the set of module characterization measurements performed during production.

System test operation has been extremely useful in revealing a design problem in the optoelectronic boards [9] on the SQP. Each board provides common services to 7 data links, therefore the components of all 7 links need to have a matching operational point. The dynamic range of these components is found to be reduced at \(-10^\circ\text{C}\) with respect to room temperature, resulting in poor matching of the data links. After this experience the SQP design has been modified, adding heaters to keep the optoelectronic boards at a temperature higher than the rest of the detector and adequate for matching of all channels.

3. Cosmic rays data-taking
In December 2006 the system test setup as been used to take data with cosmic rays. The layout of the trigger system, is shown in figure 2. Trigger is provided by the AND of the top scintillator
3 and the OR of the bottom scintillators 1, 2 and 4. An iron absorber provides a 230 MeV/c momentum cut.

About 1 million triggers on cosmic rays have been collected, 4% of these events have tracks reconstructed through all the three disks. In addition runs with random triggers have been taken for measurement of noise occupancy.

Operating in a regime of threshold over noise of 4000/150, the rate of random noise is expected to be negligible. Figure 3 shows the probability for a pixel to have one hit in one bunch crossing (BCID). In the system test setup, hits in BCIDs 4 to 6 are in time with the trigger, while the others are asynchronous with it and due to noise. An initial noise occupancy of order of $10^{-7}$ is due to a small number of noisy channels. After masking these pixels (about $5\times10^{-5}$ of the total), the noise rate drops to $10^{-10}$, showing a practically noiseless detector. Among the noisy pixels 90% were already identified during module characterization and are included in the amount of defective pixels quoted in section 1.

In the end-cap there is a significant overlapping fraction between adjacent modules, resulting
in 24% of the reconstructed tracks to have hits in the overlap region. Extrapolation uncertainties from one module to the adjacent one are not much affected by multiple scattering, therefore this sample can be used for efficiency measurement and alignment.

There is not enough statistics to provide efficiency numbers for each module, but the average efficiency is found to be better than 99%. Plots of the residuals, i.e. the difference in position between the extrapolated track and the measured point are shown in figure 4 for the precision coordinate before and after alignment. After alignment the residuals distribution corresponds to a detector resolution of 15.7 $\mu$m, which agrees with the 14.1 $\mu$m expectation from the simulation of the setup. This resolution is due to the low momentum of tracks and the wide incidence angle distribution. For high momentum tracks pointing to the interaction region, the expected resolution is about 9 $\mu$m.

4. Conclusions

At the end of the system test the Pixel Detector has been integrated and the full pixel package, including connections for the services and the beam pipe, has been installed in the ATLAS cavern in June 2007. After assembly and installation, the total number of dead components corresponds to an inefficiency of 0.12%, while single defective pixels give an average inefficiency of 0.2%. Due to the sequence of the service connections in ATLAS, it will be able to operate again in spring 2008, when cosmos ray data will be collected for the full detector commissioning.

References

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