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Off-line calibration and data analysis for the silicon beam telescope on the CERN H2 beam

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ABSTRACT

The Silicon Beam Telescope (SiBT07) at the CERN H2 beam is a position-sensitive beam telescope targeted for LHC upgrade tests. The telescope consists of eight consecutive silicon microstrip detectors and slots for two test detectors. This article describes the reconstruction of reference tracks with the CMS data analysis software CMSSW. The related data analysis and calibration procedures, including pedestal corrections, common-mode corrections, and track-based alignment, are also described.

1. Introduction

Silicon pixel and microstrip detectors are widely used in particle physics experiments because of their excellent spatial resolution and well-established manufacturing technology. In modern high-energy physics (HEP) experiments, their operational lifetime is limited by the radiation-induced defects caused by the hostile radiation environment. In future high-luminosity HEP experiments such as those for the planned Super-LHC, the radiation tolerance of silicon detectors will be a critical issue. Various new detector technologies are currently being studied in order to develop more radiation-hard detectors. Extensive tests of these new detectors are needed to demonstrate their feasibility for large-scale tracker systems.

The Silicon Beam Telescope (SiBT07) at the SPS H2 beam at CERN is a compact position-sensitive beam telescope that is intended to measure the operational characteristics of irradiated position-sensitive silicon detectors [1]. In this paper we describe the data analysis, beginning with the signal values for all the strips, as obtained from the data acquisition (DAQ). We also describe the off-line calibration procedures directly linked to the data analysis. Other aspects of the hardware and signal processing are described in detail in Ref. [1].

2. Experimental setup

The experimental setup measures the tracks of high-energy particles at the H2 beamline at CERN. The setup, depicted in Fig. 1, comprises 10 consecutive slots for single-sided silicon strip detectors and supporting electronics, as described in Ref. [1].

2.1. Layout and geometry

The SiBT07 is positioned so that the H2 test beam penetrates all the detector planes and the strip detectors are perpendicular to the beam. The cross-section of the high-intensity area of the collimated muon beam (Fig. 2) has a radius of approximately 1 cm. The energies of the muons were set to 225 GeV and in these conditions the track of each particle can be safely approximated by a straight line. The angular spread of the particle tracks is about 1 mrad.

In the global cartesian X, Y, Z co-ordinate system of the SiBT07, the detector surfaces lie in the X,Z plane and Y-axis points the direction of the beam.[1] In addition, a local cartesian u, v, w co-ordinate system is assigned to each detector so that the origin is in the centre of the detector. The precise measurement direction of each detector is the u-axis, the strip direction is the v-axis, and the

[1] The global co-ordinates are defined by the positions of first and last reference detectors, which are, by definition, perfectly aligned; see Table 1. Direction of the beam was not accurately known prior to installation, and, consequently, an angle of ≈ 3 mrad was measured between the measured most probable direction of tracks and the global Y-axis.

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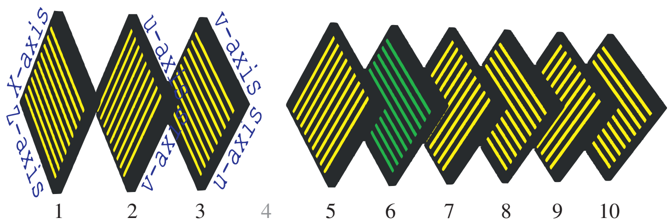

Fig. 1. Detectors are rotated at $+45^{\circ}$ and -45° angles respective to the horizontal plane. Slot 6 houses the test detector, which does not contribute to the reference tracks. The other detectors [8] are called reference detectors, and contribute to the reference tracks unless otherwise stated. In this figure, the beam is traversing from right to left. The global *X*- and *Z*-axes are shown at detector 1. The local *u*- and *v*-axes of detectors 2 and 3 are also shown.

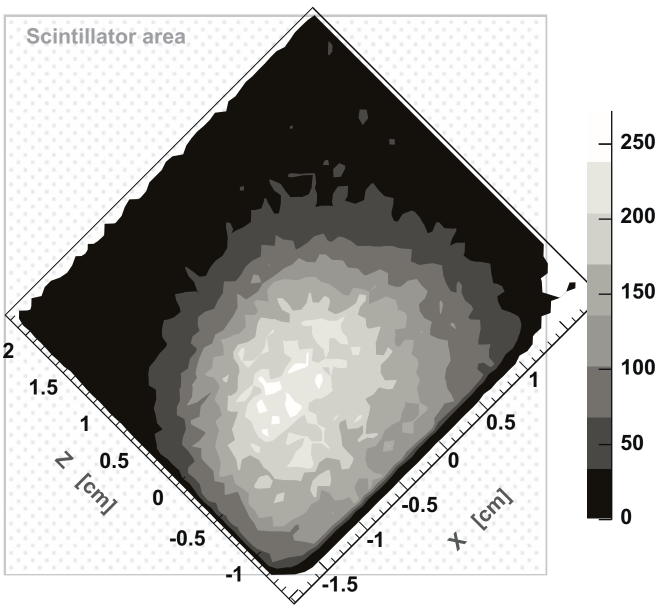

Fig. 2. Beam profile as reconstructed track impact points at the test detector plane 6. The profile contains data from 291 304 events. The unit of the contour colours is tracks/0.8 mm^2.

normal of the detector plane is the *w*-axis. Fig. 1 depicts the different co-ordinate systems and also shows the actual positions and orientations of the detectors in the test runs covered in Ref. [1].

When the actual position of each detector is acquired as the result of an alignment procedure, the u, v, w co-ordinate systems are adjusted with respect to the global *X, Y, Z* co-ordinate system.

2.2. Readout

A particle passing through a silicon strip detector ionises the bulk material creating electric charge, which is collected by the readout strips. The charge is usually divided over a few strips because of diffusion and capacitive coupling [2]. Each readout strip is capacitively coupled into a charge amplifier, and corresponds to one readout channel. In the case of the SiBT07, the amplified signal is periodically sampled into the analogue buffer memory and retrieved from there later on [3]. As the readout charge is distributed over several strips, it is possible to interpolate the hit position between the detector strips [4].

The actual measurements are made in a series of runs. Each run consists of a number of events during which the environmental conditions should not change. Typical test runs taken with the SiBT07 contain 10 000–50 000 events. An event is produced when the trigger system detects the presence of a particle. The data acquisition then reads the measurement data from the readout chips [5], performs on-line data analyses, and finally writes the data to permanent storage [6].[2]

There are three types of runs for the SiBT07: calibration, pedestal, and physics runs. Measurements with the SiBT07 begin with calibration runs, in which the data acquisition software [6] is used to measure the cable delays, data chain analogue parameters, and other hardware-oriented calibration [3] data needed for the physics runs. Pedestal runs are used to measure the pedestal and RMS noise values of each readout channel. The readout is triggered randomly, and thus an event of the pedestal run only rarely coincides with a passing particle. In the physics runs, the only difference is the use of the trigger system [1]. Consequently, most events of a physics run are expected to contain a physical track.

For each event, the amount of charge at the readout chip inputs at a certain moment is saved. Each measurement value is a superposition of the pedestal, common mode, noise, and a possible signal left by a passing particle. The calibration of the measured value is described in detail in Section 3, and the overall procedure goes as follows. A pedestal value is associated with each physical readout channel and is constant over time if the environment, i.e. temperature, humidity, operating voltage, etc. remains stable. The common-mode signal is associated with each event. It is calculated for each APV chip [5] and is assumed to be constant over all 128 strips. It depends on e.g. the mains phase. The noise is the remaining intrinsic fluctuation of the measurement value after the pedestal and common-mode corrections.

3. Off-line data analysis

3.1. Analysis software

The analysis software is built on top of the CMSSW framework [9], which is the simulation, reconstruction, and analysis software of the CMS experiment. Standard CMSSW software components are used with some SiBT07-specific modifications.

3.2. Pedestal calculation

Pedestal levels and noise values for each strip on each detector are calculated from the pedestal run data. Let $R_{i,j}$ be the raw analogue-to-digital converted (ADC) value for strip *i* in the event *j*. $R_{i,j}$ is an integer between 0 and 1022. The pedestal level P_i of a strip *i* is the sample mean of $R_{i,j}$ over *n* recorded events

$$P_i = \frac{1}{n}\sum_{j=1}^{n} R_{i,j} \tag{1}$$

and noise N_i is the standard deviation of the common-mode subtracted data

$$N_i = \sqrt{\langle (R_{i,j} - CM_{i,j})^2 \rangle_j - \langle R_{i,j} - CM_{i,j} \rangle_j^2}. \tag{2}$$

Here $CM_{i,j}$ is the common mode of the APV chip where strip *i* resides, for event *j*, computed as the mean of $R_{i,j} - P_i$. The averages are taken over events, which is shown explicitly in the subscript *j*. The pedestal and noise levels of each strip are saved to be used for physics data analysis.

[2] The data written on the disc by on-line software are formatted in the so-called readout order, which differs from the physical strip order. Hence, the data must be reordered prior to analysis, as described in Ref. [7].