Silicon Sensor Simulation at LHCb

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Abstract
LHCb is an experiment dedicated to searching for New Physics phenomena and performing high precision measurements of CP-violation effects in the heavy quark sector. High-quality simulation is used for studying detector and tracking performance as well as optimisation of selection criteria of various physics analyses. In the case of measuring absolute quantities such as cross-sections carefully prepared simulation samples are also used for efficiency estimation.

Keywords
LHCb; silicon sensor simulation.

1 Introduction

High-quality simulation is of major importance for LHCb experiment. The overall strategy is identical to each sub-detector that exploits silicon-based devices and may differ in some details related mainly to the emulation of the readout electronics. The full processing chain leading to the production of simulated samples is divided into three independent stages:

- generation of proton-proton interaction with a particular final state particles and their propagation through the detector (simulation phase),
- simulation of the detector response (digitisation phase),
- detector output data decoding, track finding and fitting (reconstruction phase)

In the first stage, that is also the most time consuming one, the full truth information (a particle 4-momenta and its identification) is used by the LHCb Gauss application [1] to simulate the effects of the passage of particles through detector material. Gauss is interfaced with Geant4 [3] package that is dedicated to simulating with great precision effects such as energy loss or multiple scattering. The results are then stored in a specialised class called MCHit. The next stage, performed by the LHCb application Boole [2], uses the MCHit objects to perform the detector response simulation (see Section 2). Also, the output of Boole is formatted in an identical way it is sent out to processing in the trigger farm by the respective detectors. Finally, the LHCb Brunel application [4] is used to produce tracks and vertices that are stored in DST files. Brunel is data-type agnostic, i.e., both simulated and collision data are processed in the same way. Also the simulated DST files can be further processed in an identical manner as real data are.

2 Charge deposition and read-out electronics emulation

The MCHit objects that are produced by Gauss application and contain such data as sensitive material entry and exit points and energy loss are subsequently used to simulate detector hits. Using the deposited energy value for each particle, the corresponding number of electron-hole pairs are calculated. This generated charge is then distributed along a particle's path within the silicon. The deposition process progresses in steps (where the number of steps is a tunable parameter) and has three components: the constant core ionisation, random ionisation and high energy δ-ray emission. The relative contribution of these three components is tunable, although, the high energy electron production is simulated in "a posteriori mode". The energy of emitted δ-rays is recovered by comparing the total generated charge and distributed one - if the difference is larger than a given cutoff value the emission process is simulated at a randomly chosen point on the particle's path within active material. Finally, the total distributed charge is normalised to the total generated charge for the consistency.

The distributed charges are then propagated through the sensitive material using a simple projection method that is also the fastest one. At each point, a random lateral diffusion is estimated by sampling a Gaussian distribution and then the charges are placed at the surface of the sensor. At this point, radiation damage effects are taken into account, if necessary, changing appropriately the collected charge distribution. In this pragmatic approach, a simple linear electric field is assumed, and no transient currents are simulated at the sensor collecting electrodes. Using local information on sensor segmentation topology from a detector model description, a list of channels with collected charges is created. The list is next passed to the readout emulation code that adds electronic noise, introduces capacitive couplings between channels, perform digitisation and finally applies activation cuts (zero suppression) and performs clusterisation (hit reconstruction). The last step is the cluster data encoding into the format that is identical with the transport protocol of respective detectors (also called RawBank) that is the input data for the LHCb Brunel application for track reconstruction. In order to reproduce the clusterisation and encoding exactly the emulation and calibration software were partially ported into the simulation platform [6].

3 Simulation results

The results of the simulation process can be broadly divided into two categories: low level including Landau distribution of deposited energy and its dependency on the local position on a sensor, hit rates, occupancies etc., and high-level such track multiplicity, primary and secondary vertices, single hit resolution, vertex resolution, geometrical impact parameter resolution etc.

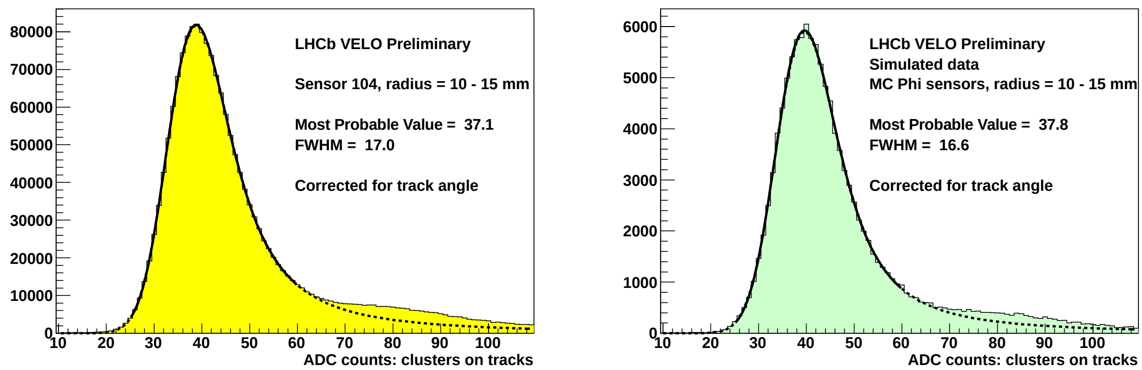

Fig. 1: Energy distribution, measured in arbitrary ADC counts, fitted with a model representing Landau convoluted with a Gaussian for a selected VELO sensor. Left hand-side plot is obtained using collision data whilst the right-side hand one presents simulated data. Plots are not normalised.

The latter set of variables need full track reconstruction to be performed. Some of these observables are of the out-most importance and are very often compared to the corresponding ones obtained for the data. Specifically, the primary vertex resolution (life-time measurements), impact parameter resolution (selection algorithms), spatial resolution (track fitting) and Landau distributions (hit reconstruction and their association to tracks and radiation damage studies) are being carefully monitored. Below we present selected results: the Landau curves and spatial single hit resolution.

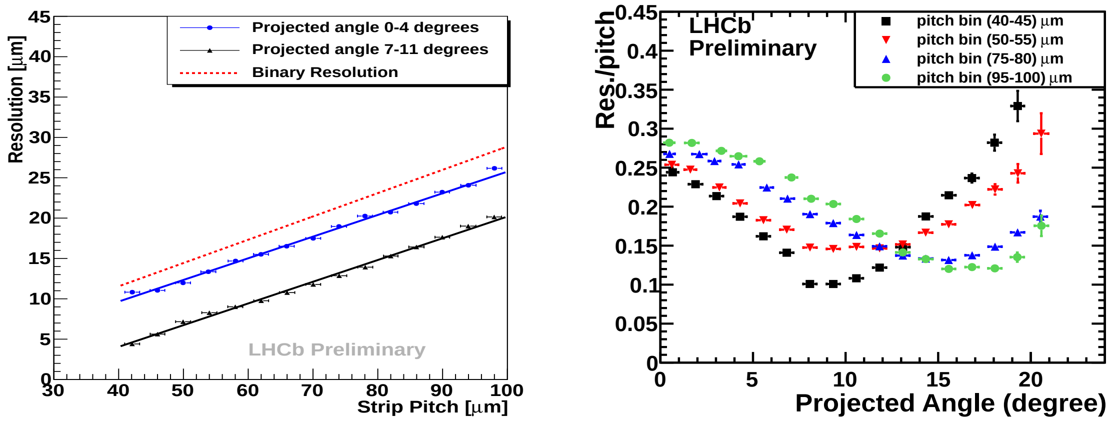

Fig. 2: Single hit spatial resolution measured for the LHCb VELO detector. Right-hand side plot shows the resolution as a function of the sensor pitch for two different track angles and compared to the binary one; the right-hand side plot shows the resolution as a function of track angle for different pitch regions.

4 Summary

The silicon simulation software is an essential part of the detector performance studies (including radiation damage effects) and physics analyses performed by LHCb collaboration. The quality of the simulated samples is continuously improved and cross-checked against the collision data. The constant maintenance and improvements of the simulation code, often using the feedback from measurements, is crucial.

References

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