Nuclear Instruments and Methods in Physics Research A ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Measurement of the two track separation capability of hybrid pixel sensors

F.J. Muñoz [a,*], M. Battaglia [b,c], C. Da Vià [a], A. La Rosa [b,1], N. Dann [a]

[a] University of Manchester, United Kingdom
[b] University of California, Santa Cruz, United States of America
[c] CERN, The European Organization for Nuclear Research, Switzerland

ARTICLE INFO

Article history:
Received 25 March 2016
Received in revised form
22 April 2016
Accepted 22 April 2016

Keywords:
Hybrid pixel detectors
Semiconductor detectors
Track resolution

ABSTRACT

Large Hadron Collider experiments face new challenges in Run-2 conditions due to the increased beam energy, the interest for searches of new physics signals with higher jet pT and the consequent longer decay length of heavy hadrons. In this new scenario, the capability of the innermost pixel sensors to distinguish tracks in very dense environment becomes crucial for efficient tracking and flavour tagging performance. In this work, we discuss the measurement in a test beam of the two track separation capability of hybrid pixel sensors using the interaction particles out of the collision of high energy pions on a thin copper target. With this method we are able to evaluate the effect of merged hits in the sensors under test due to tracks closer than the sensor spatial granularity in terms of collected charge, multiplicity and reconstruction efficiency.

1. Introduction

Vertex detectors in future collider experiments are aiming for stronger requirements in terms of position resolution and track density. In particular, the LHC physics program and larger center-of-mass energies in Run-2 are bringing increased attention on events with boosted jets and highly collimated tracks. In this scenario, the capability of distinguishing tracks in very dense environment on the innermost layers becomes crucial to ensure a correct extrapolation of the tracks to their production vertex and an efficient flavour tagging.

In order to determine the two-track separation capability of hybrid pixel sensors in dense environment, a novel technique for module characterisation has been developed and it is described in next section. Two different devices under test (DUT) were tested, each built in a different technology, a 3D and a planar sensor (PS) from the qualification batch of the ATLAS-IBL [1]. Results presented here belong to measurements done on the 3D silicon pixel sensor using the PS as another telescope downstream plane. Both DUTs are read out by FEI4 chips, the same used at the ATLAS-IBL, with a pixel size is $250 \times 50\ \mu m^2$. In particular, the 3D sensor tested in this work is $250\ \mu m$ thick. The data out of this work have demonstrated that the technique used here is able to emulate real conditions in collider vertex detectors. In a small experiment under realistic conditions, as it is a test beam, we can get better understanding of the vertex detector limitations in extreme conditions giving the possibility to optimise the reconstruction algorithms and validate the simulation tools prior to the final experiment.

2. Experiment and simulation

Experiment: A hybrid 3D silicon pixel detector was tested in a test beam at CERN-SPS beam line using pions of energies up to 180 GeV. A copper target was placed upstream the DUT (Device Under Test) to generate secondary charged particles with a spatial distribution representative of the conditions encountered in dense jets at the LHC. Devices under test and target are in between the two arms of a silicon telescope made out of three FEI4 planar pixel modules per arm. The pixel pitches are 50 and 250 microns in the two coordinates and the central sensor of each arm is 90° rotated to optimise the extrapolation resolution on both coordinates. The pion direction was reconstructed using the three upstream layers of the telescope and the trajectory of the outgoing particles was reconstructed on the three downstream layers of the telescope plus the planar sensor. The layout of the experiment is given in Fig. 1 and shows as well an illustration of one pion interacting with the copper target.

Simulation: Prior to the experiment a GEANT4 [2,3] simulation was carried out in order to study the feasibility of it as well as to

* Corresponding author.
E-mail address: Francisca.MunozSanchez@manchester.ac.uk (F.J. Muñoz).
[1] Now at MPI.

http://dx.doi.org/10.1016/j.nima.2016.04.091
0168-9002/© 2016 Published by Elsevier B.V.

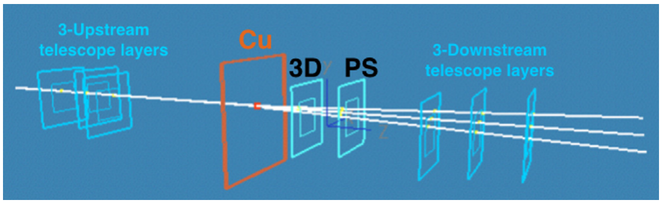

Fig. 1. Schematics of the experiment carried out. From left to right: 3 upstream telescope layers, copper target, 3D pixel sensor, planar sensor and the 3 downstream telescope layers.

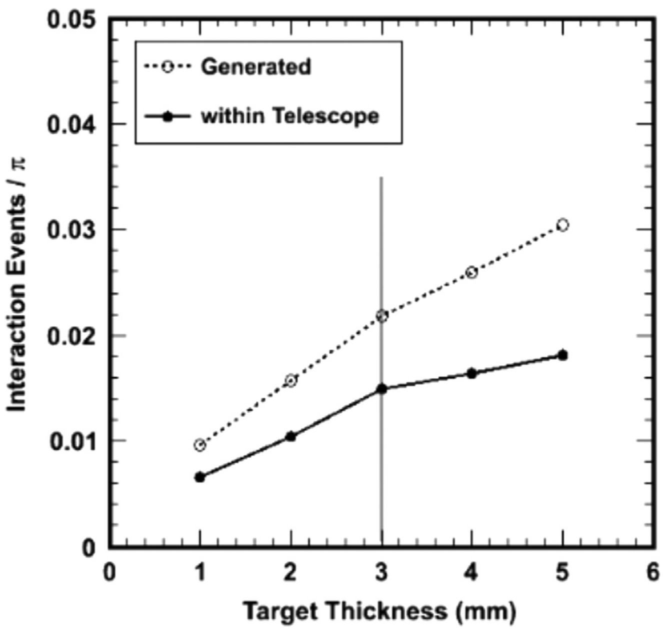

Fig. 2. Simulation results of the ratio of incident pions that interact with the copper target and the total amount of pions in function of the target thickness. The dashed line corresponds with the total amount of interactions and the solid line with those whose trajectory is within the telescope acceptance.

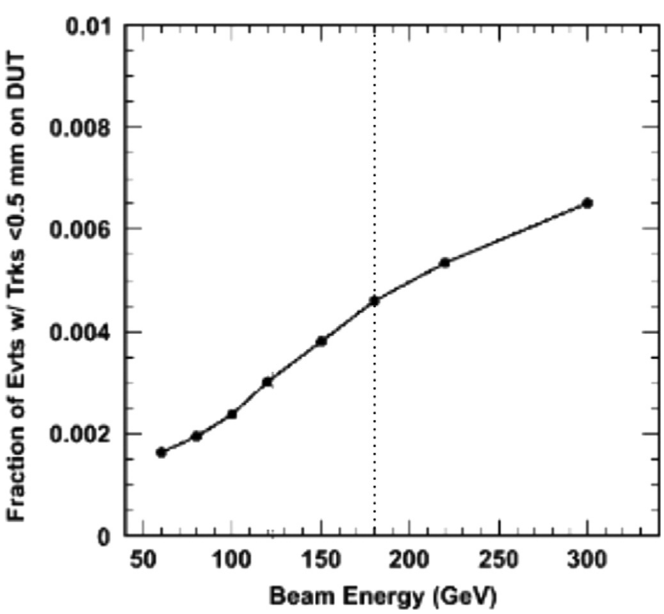

Fig. 3. Simulation showing the fraction of events with tracks distance below 500 μm as a function of the beam energy.

optimise its configuration in terms of the beam energy, copper target thickness and telescope acceptance for different incident beam angles. In Fig. 2 the fraction between incident pions that interact with the copper target and the total amount of impinging pions in function of the target thickness is shown considering as well the telescope geometrical acceptance. A copper thickness of 3 mm was chosen because the expected increment on the number of events for thicker target is not significant and to avoid possible safety problems due to particle scattering. In Fig. 3 the simulation shows the expected fraction of events with distance between tracks below 500 μm in function of the beam energy. We expect to have more events of interest with increasing beam energy, however in this aspect we are limited by the SPS facilities and other users of it.

In addition to the energy and target thickness, we have to take into account the different incident angles. A simulation study about the telescope event acceptance was also carried out to estimate the amount of triggers needed to get enough statistic for our studies.

Analysis: The data analysis was performed offline using custom processors implemented in Marlin framework. The data reconstruction chain includes cluster construction, event selection, alignment, pattern recognition, track and vertex reconstruction and was used for simulated and real data.

Thanks to the simulation studies we knew the best conditions of operation for the experiment and together with the facility constrains we were able to have a successful test beam. A final setup picture is in Fig. 4.

To verify that our customised analysis is performing well only events with one and only one cluster per telescope plane are considered. In this way we avoid scattered particles that can affect our alignment. We analysed first the sensors standalone, not reconstructing tracks or vertices, to confirm that the clustering algorithm is reproducing the expected results. We looked in two different parameters, charge per cluster and cluster size as a function of the beam incidence angle. In case of the FEI4 chip, the charge is measured in Time over Threshold (ToT) units. As you can see in Figs. 5 and 6, the most probable value of the ToT distribution is shifted to higher values for higher incident angle following the tendency of the cluster size as expected.

3. Results

Prior to a more detailed analysis, we need to validate the simulation result with test beam data. To achieve that we compare the distribution of simulated events in the experiment conditions and compare with the distribution obtained out of the experiment. As you can see in Fig. 7, both distributions are consistent with each other, showing us that the simulation is a feasible tool for this and further experiments.

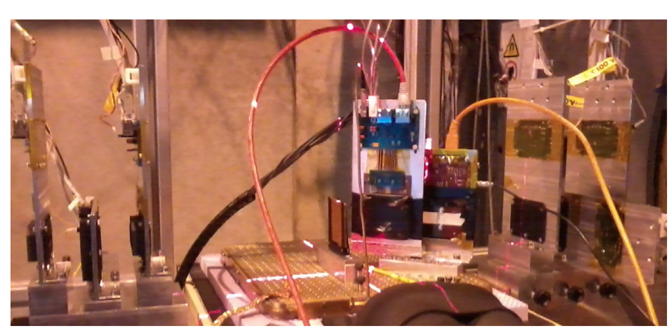

Fig. 4. Picture of the experiment setup along the beam line. The telescope, target and devices under test are visible.