Nuclear Instruments and Methods in Physics Research A 806 (2016) 244–257

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

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

Testbeam studies of pre-prototype silicon strip sensors for the LHCb UT upgrade project

A. Abba [a], M. Artuso [b], S. Blusk [b,f], T. Britton [b], A. Davis [c], A. Dendek [d], B. Dey [e], S. Ely [b], T. Evans [g], J. Fu [a], P. Gandini [b], F. Lionetto [e], P. Manning [b], B. Meadows [c], R. Mountain [b], N. Neri [a], M. Petruzzo [a], M. Pikies [d], T. Skwarnicki [b], T. Szumlak [d], J.C. Wang [b]

[a] Instituto Nazionale di Fisica Nucleare – Sezione di Milano, Italy
[b] Syracuse University, Syracuse, NY, USA
[c] University of Cincinnati, Cincinnati, OH, USA
[d] AGH – University of Science and Technology, Faculty of Physics and Applied Computer Science, Kraków, Poland
[e] Physik-Institut, Universität Zürich, Zürich, Switzerland
[f] European Organization for Nuclear Research (CERN), Geneva, Switzerland
[g] Department of Physics, University of Oxford, Oxford, United Kingdom

ARTICLE INFO

Article history:
Received 7 July 2015
Received in revised form
9 October 2015
Accepted 10 October 2015
Available online 17 October 2015

Keywords:
Silicon strip detector
Testbeam
Sensor irradiation

ABSTRACT

The LHCb experiment is preparing for a major upgrade in 2018–2019. One of the key components in the upgrade is a new silicon tracker situated upstream of the analysis magnet of the experiment. The Upstream Tracker (UT) will consist of four planes of silicon strip detectors, with each plane covering an area of about 2 m^2. An important consideration of these detectors is their performance after they have been exposed to a large radiation dose. In this paper we present test beam results of pre-prototype n-in-p and p-in-n sensors that have been irradiated with fluences up to 4.0×10^{14} n_{eq}/cm^2.

1. Introduction

The Upstream Tracker (UT) detector (see Fig. 1) is a key part of the LHCb Upgrade, replacing the current TT tracking stations [1,2]. The UT improves over the current TT in that it (i) eliminates all gaps within the detector acceptance, (ii) has largely improved granularity to cope with the higher instantaneous luminosity expected in the LHCb upgrade, and (iii) improves the coverage close to the beam pipe by employing a circular cutout to match the beam pipe profile. The UT, like the TT, is situated just in front of LHCb's dipole analysis magnet. In this position, it provides a crucial link between segments reconstructed in the upgraded vertex detector [3] and the tracking chambers downstream [4] of the LHCb magnet. It provides a factor of 3 improvement in speed for the tracking in the fully-software-based trigger [5], reduces the rate of fake tracks being formed by a factor of 2–3, and improves the momentum resolution by about 25% relative to tracks not using UT hits. The factor of 3 in speed is enabled by enabling a very fast estimate of the momentum of charged particles, which can then be used to reduce the size of the hit search windows in the downstream tracking stations. Due to the increased speed of the trigger and the higher purity of tracks considered, larger data sets with better signal-to-background can be acquired.

The UT detector consists of four silicon planes, each about 1.53 m in width and 1.34 m in height. Each plane is composed of 1.5 m long *staves* that are tiled with $\sim$10 cm $\times$ 10 cm silicon wafers. Consecutive wafers are mounted on opposite sides of the stave to ensure no gaps along the height, and adjacent staves are also overlapped to ensure no gaps in the horizontal direction. The majority of the detector area utilizes sensors with an approximate pitch of 190 μm, however the inner region features sensors with half the pitch (95 μm) to cope with higher occupancy. Both n-in-p and p-in-n type sensors are being considered for the outer region, but for the inner region, only n-in-p are being considered due to better radiation hardness. For the innermost region of the UT, the largest fluence expected, with a safety factor of about two, is about 5×10^{14} n_{eq}/cm^2. Outside this region, the fluence is not expected to exceed about 2×10^{13} n_{eq}/cm^2.

The primary goals of this test beam were to quantify the performance of several pre-prototype n-in-p mini-sensors from Micron Semiconductor, Ltd [6], after a high radiation fluence, and compare to corresponding results from similar unirradiated

E-mail address: sblusk@syr.edu (S. Blusk).

http://dx.doi.org/10.1016/j.nima.2015.10.031
0168-9002/

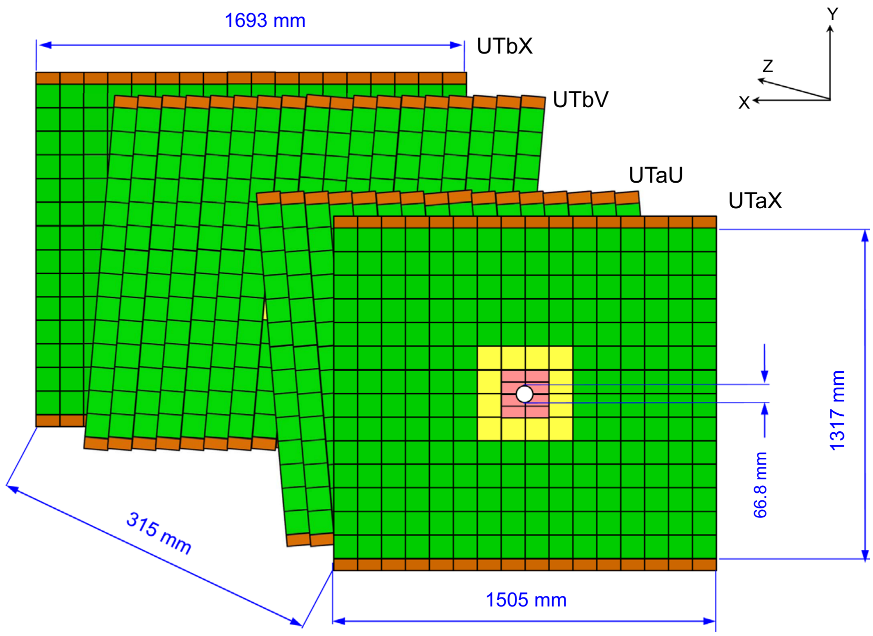

Fig. 1. Cartoon showing the layout and dimensions of the four UT planes.

detectors. The properties investigated include, but are not limited to:

- Landau distributions as a function of bias voltage;
- cluster size vs. bias voltage and angle of incidence;
- charge collected vs. interstrip position;
- resolution vs. angle; and
- characteristics of sensors near the quarter-circle region (these emulate the sensors surrounding the beam pipe).

One p-in-n mini-sensor irradiated to the maximum level expected in the outer region of the UT was also tested, but its study was not a primary focus of the test beam results presented here.

2. Experimental setup

The test beam discussed in this paper was conducted in October 2014 at the SPS at CERN. The beam consisted of positively charged hadrons with momentum of 180 GeV/c. The beam was delivered in spills at rate of about 4 spills/min, with each spill lasting about 4 s. For most of the data taking, the beam size was collimated down to about 0.5 cm in diameter and each spill provided a particle rate of order 1 MHz.

2.1. Telescope description

The pre-prototype UT sensors, or detectors under test (DUT), were studied using the TimePix3 (TP3)-based telescope [7], composed of 8 pixel planes. Each pixel plane is about 1.4 cm $\times$ 1.4 cm and has a pixel size of 55 μm $\times$ 55 μm. The planes are tilted in order to provide more charge sharing, and thus better position resolution. A cartoon of the telescope layout is shown in Fig. 2. With the high momentum beam of 180 GeV/c , the reconstructed tracks provide excellent pointing resolution of about 2 μm at the DUT. The telescope readout does not require an external trigger: hits are recorded continuously once a run is started. For each pixel hit, both position and a time-stamp with 1.56 ns precision is recorded. Tracks are then formed (offline) by combining hits that have compatible time values.

2.2. Detectors under test

The *mini-sensor* pre-prototypes tested in the October 2014 test beam were obtained from Micron Semiconductor, Ltd [6]. One of the sensors tested was a p-in-n, and six were n-in-p. The resistivities of the sensors, as determined from capacitance vs. voltage measurements, were about 0.90 kΩ cm for the p-in-n sensor and about 2.8 kΩ cm for the n-in-p. Each sensor was 1.115 cm $\times$ 1.125 cm in size with a nominal thickness of 250 μm, and had 128 strips with a strip pitch of 80 μm and a strip (implant) width of 30 μm. Prior to irradiation, all of the sensors had a depletion voltage of about 180 V. A schematic of the mini-sensors is shown in Fig. 3. In this schematic, the strips run horizontally.

Of the six n-in-p sensors tested, three had the strips terminated such that they form a quarter-circle inactive region of the sensor. Two different guard-ring structures were implemented, as shown in Fig. 3. More details of the sensors under test are shown in Table 1. The MBP1 and MBP2 sensors are differentiated by the guard ring structures, and are shown on the left and right side of Fig. 3, respectively. The MBP1 (leftmost sensor in figure) differs from the MBP2 sensor (rightmost) in that it implements a stepped structure along the innermost guard ring to maintain an equal separation between the edge of the strip and the innermost guard ring, more like a conventional rectangle-shaped detector.

Six of the seven sensors were irradiated at the Massachusetts General Hospital (MGH) proton irradiation facility [8] in June 2014, using protons of kinetic energy equal to 226 meV and fluences ranging from 0.27×10^{14} n_{eq}/cm^2 to 4.0×10^{14} n_{eq}/cm^2. Between the time of the irradiation in June 2014, and the test beam in October 2014, the sensors were kept in a freezer, at a temperature below -10 °C. The sensors were warmed up to room temperature for no more than 7 days to transport the sensors and for wirebonding.

The DUT readout for this testbeam was based on the Alibava DAQ system [9–12], which uses Beetle chips [13,14] as the front end ASIC. The main components of the Alibava system are a detector board to which sensors are mounted, a *daughterboard* that includes two Beetle chips (128 channels each), and a *motherboard* that manages the data flow to/from the Beetle chips and to/from the data acquisition PC.