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Nuclear Instruments and Methods in Physics Research A 549 (2005) 16–19
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.com/locate/nima

The Belle Silicon Vertex Detector

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Available online 23 May 2005

Abstract

The Belle Silicon Vertex Detector (SVD) was designed to measure B meson decay positions precisely for studies of time-dependent CP violation. Although the first version of SVD (SVD1) worked for 4 years from 1999 with excellent performance, its insufficient radiation hardness drove us to build a second generation SVD (SVD2). The SVD2 was installed in Belle in the summer of 2003 and has been working well. The strip yield is estimated to be more than 95%. The signal-to-noise ratios are obtained to be 18–36, depending on detector ladders. The intrinsic spatial resolutions are obtained to be 12.0 ± 0.4 and $22.3 \pm 0.8\,\mu m$ for ϕ- and z-sides, where z-side measures positions along the beam direction and ϕ side is used for the azimuthal angle measurement. In this letter, an overview and performance results are provided for both generations of the Belle SVD.

PACS: 29.40.Wk

Keywords: Belle; KEKB; Silicon vertex detector

1. Introduction

One of the primary physics goals of the Belle experiment is an accurate measurement of the time-dependent CP violation parameters in the neutral B meson system. Large numbers of B mesons and a precise determination of their decay times are required for that purpose. During the past 4 years the KEKB asymmetric electron–positron collider in Japan, with the world's highest peak luminosity of $1.06 \times 10^{34}\,cm^2\,s^{-1}$, has provided us 152 million $\Upsilon(4S)$ particles. This resonance subsequently decays into two B mesons with a Lorentz boost of $\beta\gamma = 0.425$ in the laboratory frame. A time difference of the two meson decays is obtained from a measured distance of the two decay vertex positions, a distance of $\sim 200\,\mu m$ on average. Since a Silicon Vertex Detector (SVD) [1] enables us to measure the distance with an accuracy of $100\,\mu m$ or better, it is essential for these measurements.

The first version of the SVD (SVD1) had worked for 4 years from 1999 [2]. Its great performance produced many fruitful physics results. For instance, $\sin 2\phi_1$, one of the CP

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doi:10.1016/j.nima.2005.04.018

violation parameters, is measured to be 0.73 ± 0.06 (stat.) ± 0.03 (sys.), the best accuracy ever achieved. Although operation of the SVD1 was successful, it had some shortcomings such as the low radiation tolerance of the front-end electronics. An upgrade version of SVD (SVD2) [3] was designed and built in order to overcome the weak points with substantial modifications and improvements. The SVD2 was installed in Belle in the summer of 2003 and has been operating successfully with expected performance.

In Section 2, an overview of the SVD1 and a description of the SVD1 performance are given. Section 3 presents an overview of the SVD2 including the points of improvement, as well as performance of the SVD2 obtained from cosmic ray muon data.

2. SVD version 1

The SVD1 detector consists of three layers of independent ladders with a polar angle coverage of $23^\circ < \theta < 139^\circ$. Each ladder is made up of two, three and four double-sided silicon strip detectors (DSSDs) reinforced by support ribs and readout front-end electronics (VA1) [4] for the first, second and third layers, respectively. The radii of the three layers are 30, 45.5 and 60.5 mm.

The DSSD fabricated by Hamamatsu Photonics (HPK S6936) has a sensitive area of $57.5 \times 33.5\,\mathrm{mm}^2$ and 300 μm thickness. It comprises 640 readout lines with 50 (84) μm pitch for ϕ (z)-side, where ϕ is the azimuthal angle, and z is the beam direction. In total 102 DSSDs are used, and there are 81,920 readout channels. On each end of both sides of a ladder, five VA1 chips readout signals from a half of the ladder. Versions of the VA1 chips manufactured in a 0.8 μm process could function up to 1 Mrad irradiation. The 640 multiplexed signal outputs from five VA1 chips are fed serially to flash analog-to-digital converters (FADC) with a 5 MHz rate through a 30 m cable. Digital signal processors (DSPs) on the FADCs carry out pedestal and common mode subtraction, sparsification and data formatting.

The radiation dose was monitored using RADFET transistors attached on the beam pipe directly. The total radiation dose on the first layer detector ladders was measured to be 0.9 Mrad.

The signal-to-noise ratio was kept between 20 and 30 during the SVD1 operations despite of a degradation of 30% in the first layer due to the accumulated dose, implying the good separations of signal and noise for all run periods. The hit-finding efficiency was estimated to be about 94% on average. The detector occupancy with the beam collision condition was observed to be about 4%. The impact parameter (IP) resolution is a suitable parameter for a check of detector performances, since it honestly reflects the alignment accuracy and the intrinsic spatial resolution. The IP resolution was obtained using data samples of cosmic ray muons, mu-pair events, and two photon events such as $\gamma\gamma \to \rho^0\rho^0 \to \pi^+\pi^-\pi^+\pi^-$. The momentum and angular dependence of the resolutions for ϕ- and z-sides were estimated to be $\sigma_\phi = 18.6 \oplus 51.3/p_t\beta\sin^{3/2}\theta\,\mu\mathrm{m}$, $\sigma_z = 40.8 \oplus 43.5/p_t\beta\sin^{5/2}\theta\,\mu\mathrm{m}$, where p_t is the transverse momentum in GeV/c, and β is the velocity of the charged particle. The IP resolutions of both ϕ- and z-sides were found to be stable to within 10% throughout all periods, demonstrating that the overall quality of vertex reconstruction with the SVD1 remained uniform.

3. SVD version 2

Although the SVD1 demonstrated satisfactory performance, it left room for improvement. An upgraded SVD, designated SVD2, was designed for the following points of improvement:

- *Radiation hardness*: the VA1TA chip [4] is fabricated in a 0.35 μm CMOS process, permitting operation to at least 20 Mrad irradiation.
- *Vertex resolution and tracking efficiency*: the SVD2 has four layers of ladders for improved tracking efficiency. The innermost layer radius is 20 mm, which is closer to the beam collision point than that of the SVD1, improving the IP resolution by about 20% for low momentum particles less than 250 MeV/c.
- *Enlargement of solid angle*: the SVD2 has a polar angle coverage of $17^\circ < \theta < 150^\circ$, which is