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The BTeV Pixel and Microstrip Detectors

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Abstract

The status of the BTeV pixel vertex detector and the forward silicon microstrip tracker are presented, with some highlights on the recent achievements in our R&D effort.

Key words: BTeV, pixel, silicon microstrip detector

1 Introduction

BTeV is an experiment expected to begin running at the CZero interaction region at Fermilab in the year 2008. Its physics goals are to achieve unprecedented levels of sensitivity in the study of CP violation, mixing, and rare decays in the b and c systems [1]. In order to realize this, the detector will employ a state-of-the-art first level trigger (L1) that will look at every beam crossing to identify detached secondary vertices from charm and beauty hadron decays. The key element to this triggering approach is the pixel vertex detector. This provides high resolution space points near the interactions, which are used both online and offline to reconstruct tracks and associate them with their parent vertices.

Forward tracking is done by a combination of silicon microstrip detectors close to the beam region and straw chambers in the outer region. The major functions of the forward tracking system are to provide high precision momentum measurements for tracks found in the pixel system, to reconstruct and measure all parameters for tracks which do not pass through the vertex detector, and to project tracks into the downstream particle identification systems.

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2 Pixel Detector

The baseline vertex detector consists of 30 stations of silicon pixel detectors distributed along the interaction region (Fig. 1) sitting inside a 1.5T dipole magnet. Each station contains one plane with the narrow pixel dimension vertical, and one with the narrow dimension horizontal. The stations are split, having a left half and a right half. Each half-station contains one $\sim$ 5 cm $\times$ 10 cm precision vertical-position-measuring half-plane, and a smaller, $\sim$ 3.8 cm $\times$ 7.3 cm horizontal-position-measuring half-plane. The left half-stations are positioned at regular intervals along the beam, and the right halves are similarly positioned, but midway between the left-half stations. This allows for possible overlap of half-planes with a variable-sized, small hole left for the beams to pass through.

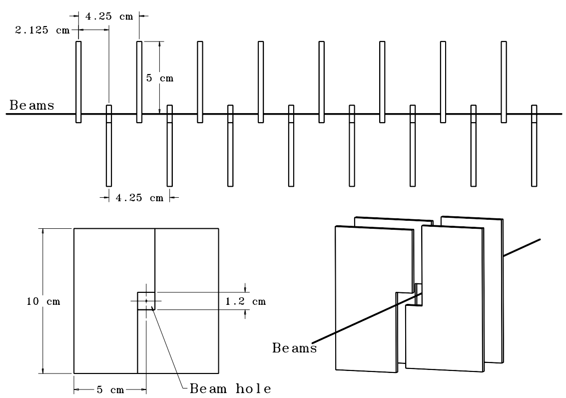

Fig. 1. Schematic drawing of part of the pixel detector.

The vertex detector contains $\sim 23 \times 10^6$ pixels, each 50 μm $\times$ 400 μm, and covers a total active area of $\sim$ 0.5m^2. Each sensor pixel is read out by a dedicated electronics cell. The sensor pixel and the readout cell are connected by a bump bond. The basic building block of the detector is a hybrid assembly consisting of a sensor, a number of readout chips, and a flexible printed circuit which carries I/O signals and power. The sensors are sized to accept variable numbers of readout chips to make the required half-plane shape. Each readout chip has 22 columns by 128 rows, corresponding to 2,816 channels. These hybrid assemblies are supported by a movable carbon substrate that allows the pixel sensors to be positioned a safe distance away from the beam-line until stable beam conditions have been established, at which point they are moved as close to the beam-line as radiation damage considerations will allow. This substrate also provides cooling for the readout electronics. To minimize the material, the pixel half-detectors sit in vacuum, separated from the beams by only a thin rf shield.

BTeV test beam studies, performed with prototype detectors, have demonstrated a spatial resolution between 5 and 9 μm in the narrow dimension, depending on the track angle of incidence[2]. This result shows that excellent resolution can be obtained using charge sharing, even with very coarse digitization. Therefore, we have decided that the final BTeV pixel readout chip will have a 3-bit FADC in each cell.

To minimize the extrapolation error, the pixel detector will be placed as close as 6mm from the beams, and hence will be exposed to a significant level of irradiation. At our maximum projected luminosity of $2 \times 10^{32}\text{cm}^{-2}\text{s}^{-1}$, the innermost pixel detector will receive a fluence of 1×10^{14} minimum ionizing particles/cm^2/year. This significant radiation environment means that all components of the pixel system have to be radiation-hard.

The silicon sensors are based on $n^+/n/p^+$ technology as developed by the LHC experiments. We will also use oxygenated silicon wafers of low resistivity as the starting material for the sensors[3]. The pixel readout chips are manufactured with deep sub-micron (0.25 μm) CMOS technology, an inherently radiation-tolerant process, once enclosed-geometry transistors and appropriate guard ring designs are used [4]. The full-sized readout chip has been submitted for fabrication and will be available for testing soon.

Irradiation tests have been performed up to 0.6×10^{15} 200 MeV protons per cm^2 on the sensors and up to 2×10^{15} 200 MeV protons per cm^2 (equivalent to 87 MRad) on the readout chips. These tests show acceptable operation of the irradiated sensors in terms of leakage current, required depletion voltage, and breakdown voltage[5]. After heavy irradiation, the prototype pixel readout chip shows little change in noise and threshold dispersion[6] (Fig.2). In addition, the measured rates of single event upset are low enough to be handled easily[7]. These irradiation results will be augmented with charge collection and other studies using irradiated detectors in a test beam at Fermilab starting in 2003.

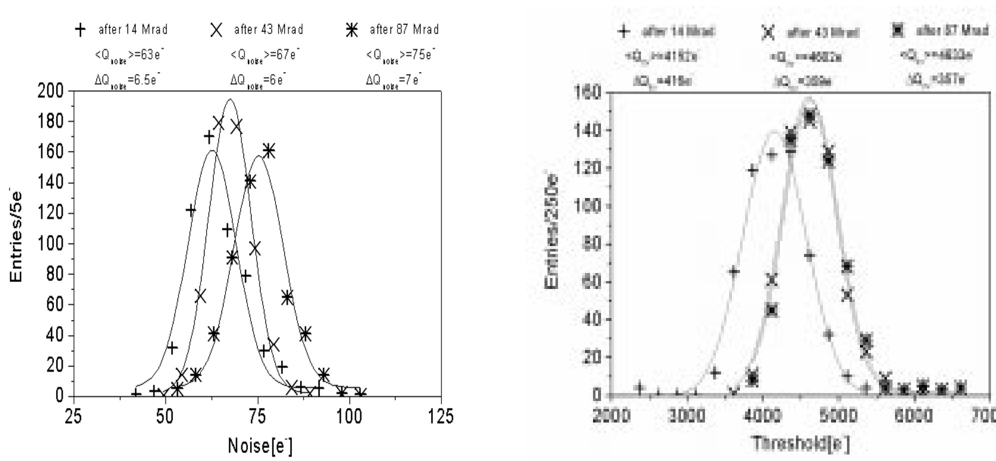

Fig. 2. Noise and threshold distributions of BTeV prototype 0.25μm CMOS pixel readout chip after irradiations to 14, 43, and 87 Mrad.

3 Forward Silicon Tracker

The forward tracking system consists of 7 stations, placed transversely to the beam at various distances from the interaction point. The entire system extends over a distance of $\sim$ 7m. The design of the forward tracking system has been driven by the high density of tracks produced, especially with multiple interactions per crossing. Two different types of detectors are used. Close to the beam region where the track density is high, we will use silicon microstrip detectors (SMD). In the outer region, we will use straw chambers. The maximum occupancy in the SMD is everywhere less than $\sim$4%.

The forward silicon tracker (FST) consists of stations with three planes of 300 μm thick single-sided p-on-n type silicon microstrip detectors with 100 μm pitch. The silicon sensors, which have an area of 7×7 cm^2, are arranged in ladders of 4 sensors daisy-chained in pairs. As illustrated in Fig. 3, a plane is formed by four adjacent ladders. The ladders are mounted on a low mass carbon fiber support which is designed to ensure a relative proper alignment among all the elements of the plane and also among different planes of the same station.

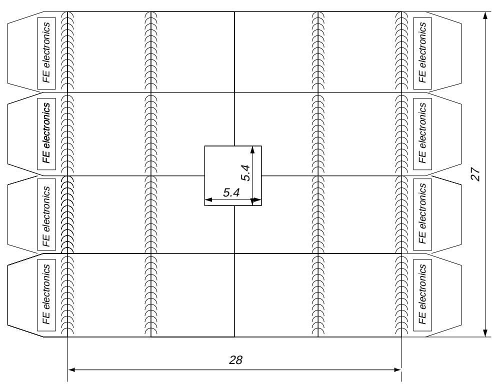

Fig. 3. Sketch of a silicon detector plane. Dimensions are in centimeters.

Three views are provided by rotating the planes by the appropriate angles: X, U and V, where the two stereo views, U and V, are at $\pm$ 11.3^o around the Y bend coordinate. Each plane consists of about 5,600 channels; the entire system of 7 stations has about 128,000 channels in total, covering a total area of 1.5 m^2. The front-end electronics is distributed along the two opposite sides of each plane where it is cooled by a fluid circulating in a duct embedded in the support structure all around the periphery of the plane. Each channel is read out in binary mode providing a resolution of 29μm, adequate for our physics goals.

The radiation level at the FST decreases rapidly with increasing distance from the beam. Radiation damage effects will be confined to a small region around the central hole of the stations. The highest level of radiation occurs at the station closest to the interaction region and is expected to be $\sim 1.6 \times 10^{13}$ particles/cm^2/year. We have started an R&D program on silicon sensors to investigate various possible effects caused by non-uniform irradiation on the sensor.

To read out all hit information in the FST from every crossing, we will develop a new readout chip with a very high output bandwidth. The new preamplifier will feature an ENC $\sim 1000\ e^-$ for semi-Gaussian shaping with 100 ns peaking time and a capacitive load at the input of ~ 20 pF, as expected for our longest strips. The binary readout will be a simplified version of the readout scheme implemented in the pixel readout chip. The SMD readout chip will be designed to interface to the same electronics as used to read out the pixel chips. The new chip will be implemented using 0.25 μm CMOS technology. First prototype submission of this chip is planned for next Spring.

4 Conclusion

The BTeV pixel detector is one of the most crucial elements in the BTeV experiment. While the pixel detector is technically challenging, we have made great progress towards identifying viable solutions for individual components of the system. The forward silicon tracker is based on more mature technology and its design has benefited from the experience of other experiments. Nevertheless, we have started an R&D program on the forward silicon tracker and first results are expected some time next year.

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