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THE SILICON VERTEX TRACKER FOR SuperB*

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We present the latest development of the SuperB Silicon Vertex Tracker (SVT). After a short review on the physics requirements and technical challenges for the SuperB SVT, we discuss different candidate solutions for the inner most layer (layer0) of the SVT, namely strip and pixel detectors. Finally, we present the current preliminary test beam results for Striplets and Hybrid Pixels.

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1. Physics requirements

The SuperB [1] experiment is the next generation B factory, which will be built in the Cabbibo Laboratory in Italy near Rome [2]. It has been funded by the Italian Ministry of Education, University and Research in the framework of the 2011–2013 National Research Plan (Dec. 24, 2010). The design of the detector is based on the reoptimised BaBar detector [3] to match the higher luminosities, reduced boost, beam–beam background and improved detector hermicity in SuperB. The subdetectors in outward order from the interaction point (IP) are: silicon vertex tracker (SVT), drift chamber (DCH), electromagnetic calorimeter (EMC) and instrumented flux-return(IFR).

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The demanding SuperB physics [4] program requires the detector to reach the same level of sensitivity as the BaBar detector, however the conditions under which it is designed to operate are much more technically challenging:

1. Higher luminosity $10^{36}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$;

2. Lower boost: $\beta\gamma = 0.28$ (BaBar's reference $\beta\gamma = 0.55$);

3. Higher beam–beam background coming from:

    (a) $e^+e^- -> e^+e^+e^-e^-$;

    (b) Bhabha scattering;

    (c) Touschek effect;

    (d) Two photon events [5].

Furthermore, the detector has to fulfil the following performance requirements:

1. SVT together with drift chamber (DCH) and magnet provide track and vertex reconstruction;

2. For less energetic particles SVT must be able to give the complete track information;

3. SVT must supply the same precision of time dependent CP violation as the BaBar detector but with boost lowered from $\beta\gamma = 0.55$ to $\beta\gamma = 0.28$, which according to the relation $\Delta z = \beta\gamma c\Delta t$, results in the vertex resolution:

    (a) 50–80 μm for exclusively reconstructed modes, and

    (b) 100–150 μm for inclusively reconstructed modes.

The baseline for SuperB SVT follows the BaBar vertex tracker [3], which consists of five external layers (1–5) situated between 3 cm and 15 cm from the IP with geometry as shown in Fig. 1 (a).

The SuperB SVT will also have these five tracker layers; each layer is made of 50 μm double strip detectors arranged in the same geometry. The front end electronics will be upgraded to enable faster readout.

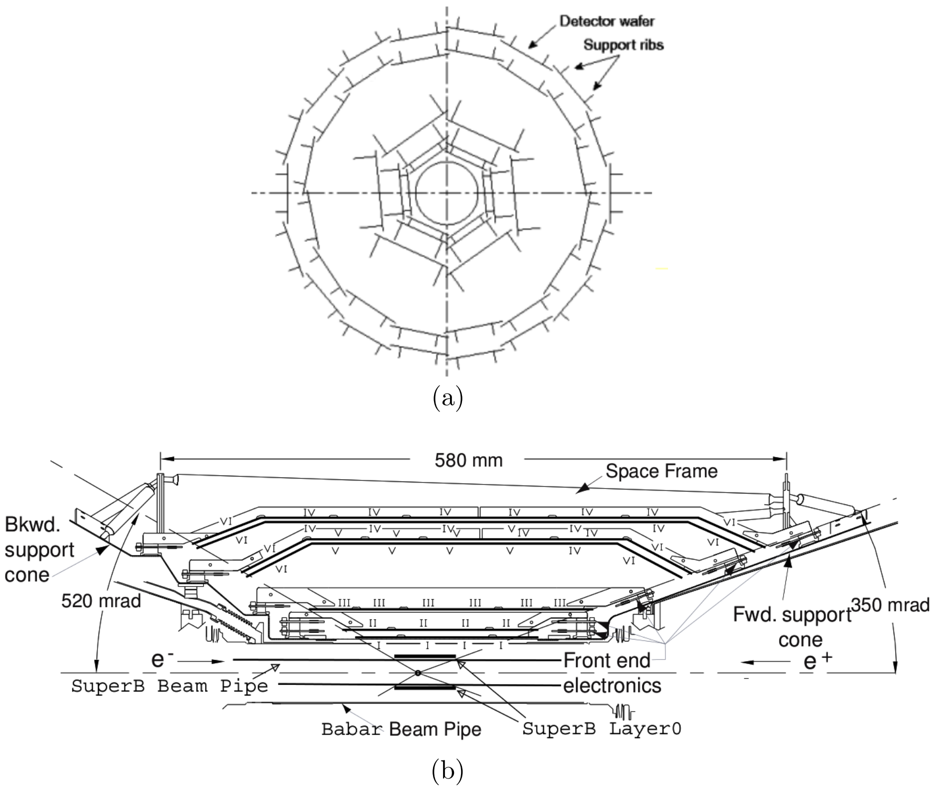


Fig. 1. Technical drawing of BaBar vertex detector. (a) in transverse plane, (b) parallel plane with additional layer0.

2. Layer0

In order to satisfy the performance requirements mentioned above an additional innermost layer, called layer0, is introduced to the SuperB SVT in addition to the 5 layers described in the previous section, which is located at about 1.5 cm radius from the beam line. Layer0 will be constructed using low material budget to minimize multiple scattering. The sensors will be equipped with high-speed readout electronics [6] to minimise the dead-time of acquisition. Current R&D focuses on technologies that can provide a hit resolution at the level of 10 μm, the capability to withstand background hit-rates of the order of 100 MHz/cm^2, a large signal-to-noise ratio and a low power dissipation. Regarding these requirements two competitive technologies have been put forward as potential candidates for layer0: a type of double sided silicon strip detector called striplets, and hybrid pixels.

From MC simulations one can obtain the required sensitivity for Δt resolution for both technologies. The channel $B \to J/\psi K_{\rm s}$ was chosen for the simulation. The result for the errors in $\sin(2\beta_{\rm eff})$ is shown in Fig. 2. For comparison with currently running experiments, the errors for the ATLAS experiment pixels were also simulated.

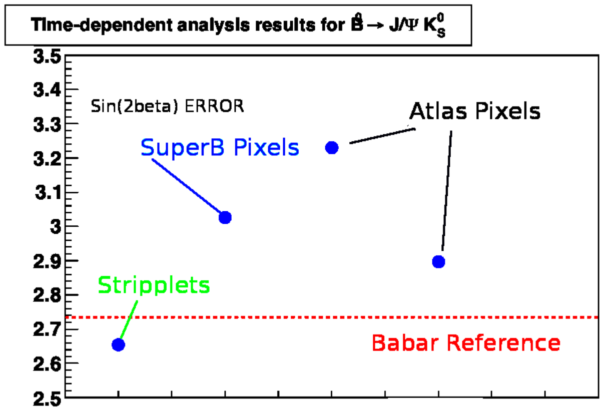


Fig. 2. Error of $\sin(2\beta_{\rm eff})$.

2.1. Striplets

An innermost layer0 made with double-sided silicon strip detectors (DSSD) of 200 μm thick and 50 μm wide is the natural extension of the outer layers. Striplets which consist of short layers (1.83 cm) of DSSD placed at an angle $\pm 45^\circ$ (Fig. 3) has been proposed as a possible design for layer0. Recent studies have shown that striplets offer a reasonably low material budget (about 0.2–0.3% X0 for 200–300 μm silicon thickness) together with the required hit resolution. For the first years of operation striplets have recently been chosen for layer0; however when SuperB will operate at its nominal luminosity the efficiency of striplets will fall below the level required thus an upgrade to hybrid pixels has already been scheduled [3].

The sensors will be connected to the readout board via multiple flexible circuit glued to the sensor [1] using copper traces. The FSSR2 high-bandwidth chip used for the outer layers will also be used for striplets. It has 128 analog channels providing a sparsified digital output with digital output address, pulse height and timestamp for all hits. It was designed in 0.25 μm technology and it works with 132 ns clock. Simulations performed on FSSR2 chip have shown that the efficiency for a striplets layer0 should exceed 90% with a signal-to-noise ratio of around 26.

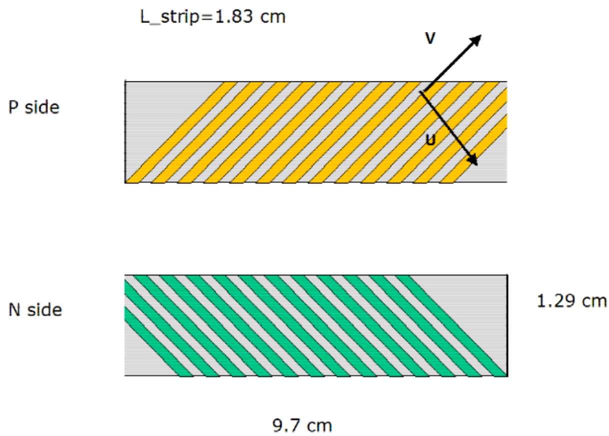


Fig. 3. Design of striplets.

2.2. Hybrid pixel

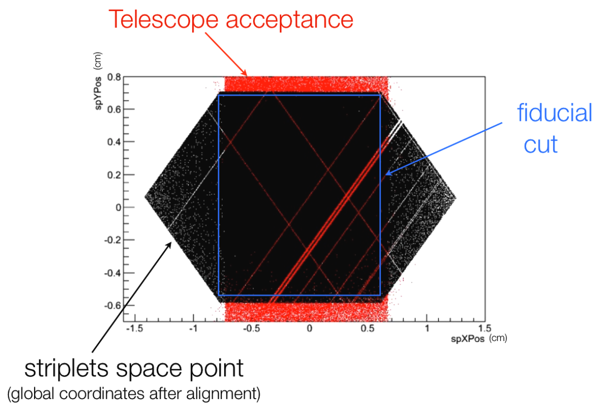
Hybrid pixels have been tested and are currently used in modern detectors. The sensors are produced from 200 μm thick high-resistivity silicon wafers. They are of "n-on-n" type and fabricated at FBK (Trento, Italy) [7]. Hybrid pixels offer the possibility to implement advanced in-pixel electronics such as threshold tuning. The pixel capacitance has been estimated to be around 50 fC from measurements performed on a test structure. They are however made of a relatively large amount of material which is disadvantageous in terms of the probability of particle scattering, but a reduction of material budget may be possible with the latest technology improvements [8]. Integrated readout circuits are built on different substrates and are connected via high density bump-bondings. The pixels are organised in 2-dimensional array of 32×128 elements with a pitch of 50 μm in both x and y directions. Around the array there is a large n^+ guard ring extending up to the cut-line. Electrical isolation between neighbouring n^+ pixels is done using a uniform p-spray implantation. A prototype readout chip with 4096 cells arranged in a 32×128 matrix was submitted for fabrication in standard 130 nm CMOS technology by STMicroelectronics. The sensor was fabricated by FBK-IRST and interconnected with the readout chip by IZM. From electrical tests carried out on the wafers before bump-bonding (and connecting the sensors from the bias side only with a probe on the diode and a probe on the scribe line [9]).

2.3. Beam tests

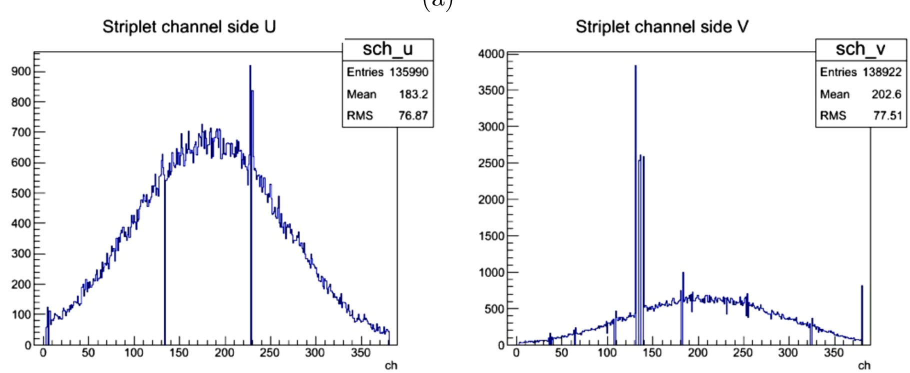
Both candidates (striplets and hybrid pixels) were tested using the test beam in CERN at the SPS H6 beam line delivering 120 GeV pions in spills lasting 9.5 s and separated by about 40 s. The device under test (DUT) was placed in the centre of six telescope planes on a rotating table which could rotate the DUT to the required angle for the test. For this test beam the angles $0°, 15°, 30°, 45°, 60°, 70°$ were chosen.

2.4. Striplets performance

Analysis of data has been carried by L. Fabbri (INFN Bologna) [11]. The first stage of the analysis involved the alignment of the telescope planes by minimising the residual with an additional requirement that at least 4 planes were fired. After alignment of the telescope the same method was used to align the DUT. During the analysis some inactive strips were found (Fig. 4).



(a)



(b)

Fig. 4. (a) Inactive strips in global coordinates. (b) Distribution of hits in x (left) and y (right) directions.

We defined the efficiency in u and v direction as an ratio between tracks that had residual in $u(v)$ smaller than 56 μm and were not in the neighbourhood of inactive strip.

As shown in Fig. 5 striplets performance is high and does not fall below 98.79% at high angles, which fulfils the requirements of layer0. This has been the main reason to choose them for layer0 in the first years of operation of SuperB.

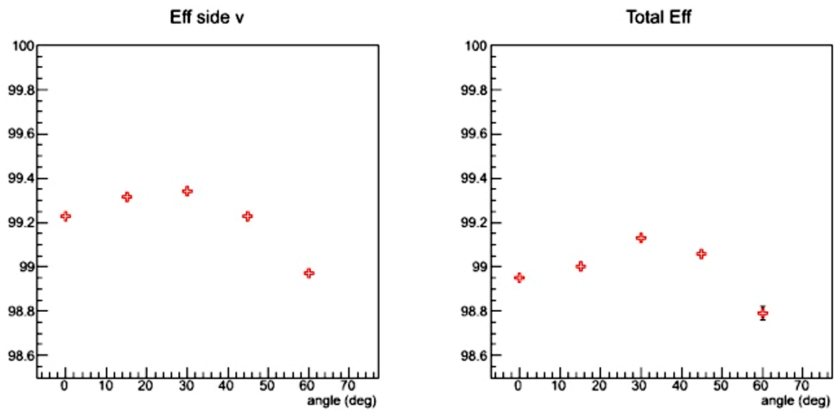


Fig. 5. Efficiency *vs.* rotation angle.

2.5. Hybrid pixels performance

In the test, the pixels were grouped in 32×128 matrices. The alignment procedure was the same as for striplets; in addition, several thresholds were tested. Analysis of the data collected has been done mostly by: Alberto Lusiani, Marcin Chrząszcz, Nicola Neri, Benjamin Oberhof and Antonio Paladino.

For Hybrid pixels several thresholds were tested form about 12.5% to 40.6% of a minimum ionizing particle (m.i.p.). High thresholds were used to overcome data-acquisition limitations of the prototype. To model the threshold for future test beams, a special Monte Carlo simulation has been written. Hits in the DUT plane are associated with clusters of pixels — if the single fired pixels are less than 50 μm from each other in both directions they are said to be in the same cluster.

Alignment for pixels has been made in the same way as for the striplets. The residual distribution with a Gaussian fit is shown in Fig. 6. In the efficiency analysis, we associate a cluster to the track, if the residual is smaller than four times the sigma coming from the Gaussian fit plus 60 μm for the delta rays tails. Some pixels have been found to be inactive due to fabrication errors. In the analysis, we have excluded those pixels along with their neighbours. The efficiency can be defined as a ratio between hits that are associated with tracks to the number of all tracks. The obtained efficiency as a function of angle is shown in Fig. 7. We associate the drop in efficiency and increase of residuals (Fig. 8) to the high threshold: at large angles particle travels through several pixels leaving less charge in them, below the threshold.

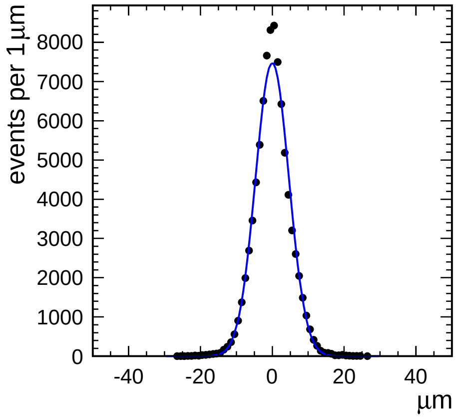


Fig. 6. Residual distribution for Hybrid Pixels in transverse plane.

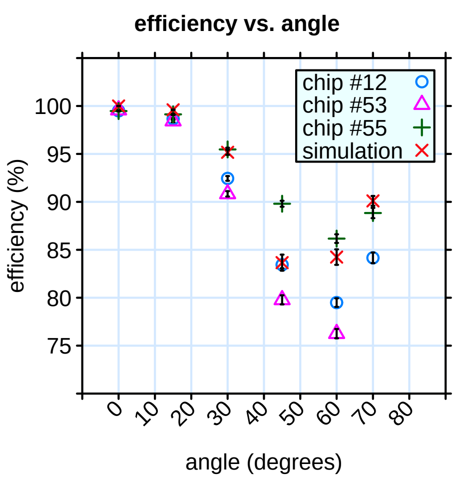


Fig. 7. Efficiency comparison between data for 3 chips and MC.

We use the simulation to estimate the optimal threshold which guarantees a 99% efficient at the highest angles. The result is shown in Fig. 9, from which we have concluded that for the next test beam the threshold should be set to 0.17 m.i.p.

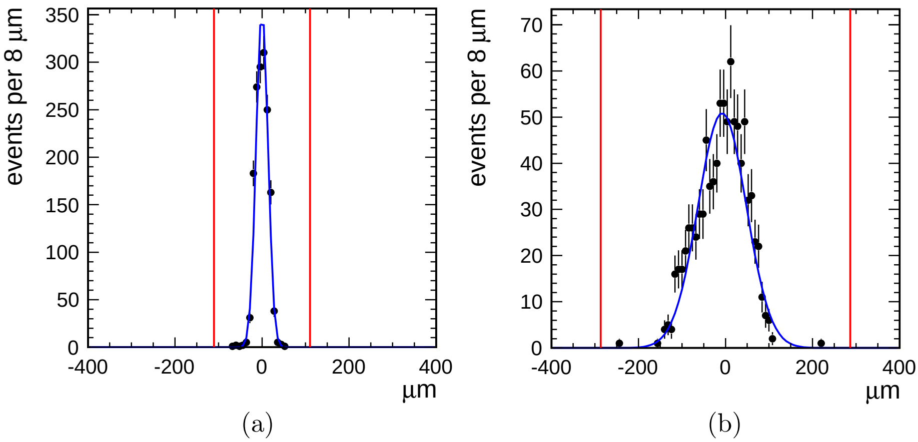


Fig. 8. Residual distributions for rotation angles: (a) 0°, (b) 60°.

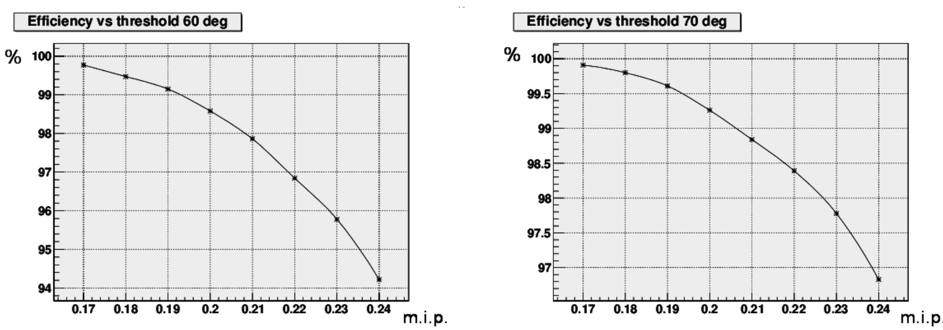


Fig. 9. Efficiency as a function of threshold.

3. Summary

SVT is one of the most important and most complicated subdetectors in the SuperB detector. A substantial amount of research and development work has been done on the SVT and much more is advancing to ensure the highest performance level. A striplet layer0 will be used in the SVT in the first few years of operation as this is the more matured and developed technology; but pixels may be the better choice in the future in order to accommodate higher occupancy followed from the higher luminosity.

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