SIMULATION STUDY FOR A SILICON VERTEX DETECTOR IN EXPERIMENT DØ

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Introduction

Silicon vertex detectors are being proposed in collider experiments to improve the tagging and reconstruction efficiency of heavy quark (b/c) decays. Collider experiments such as MARK II, CDF, and DELPHI are incorporating silicon vertex detectors close to the interaction region. The location of silicon detectors around the beam pipe in collider experiments imposes severe space and accessibility restrictions. It is interesting to note that each of the experiments mentioned above has developed, or is developing, its own readout chip in order to multiplex the many tens of thousands of data lines from the silicon detectors.

We are also investigating the possibility of using silicon detectors to tag heavy quark decays in the DØ experiment. The following is a preliminary report of our simulation studies. The observation of high p_T muons in collider events has been shown to provide a good signature of heavy quark production[1]. Our ability to use the DØ muon detector to trigger muons down to low p_T will be useful in isolating heavy quark decays. In this simulation, we used two geometries to cover the central and forward pseudorapidity ranges.

Simulation

In DØ it is possible to measure the momentum and energy of muons and electrons respectively. A toroidal magnetic field near the muon chambers makes it possible to measure the momentum of charged tracks passing through the muon chambers. It is also possible to measure the energy of isolated electrons in the calorimeter. Since (1) the isolation requirement for muons is not as stringent as those for electrons and (2) the muon trigger can measure tracks at low p_T's, the following study looks at the semi-leptonic decays of hadrons containing b/c quarks decaying into muons.

For this study, a sample of ISAJET[2] two-jet events were generated at a center-of-mass energy of 2 TeV. The two-jet events were required to pass the DØ muon trigger simulator described in another paper in these proceedings[3]. The muon trigger simulator required muons with momentum greater than 4 and 10 GeV in the central and forward regions respectively. A subset of events containing (1) $b\bar{b}/c\bar{c}$ jets with p_T in the range of 20-40 GeV/c and (2) a muon passing the muon trigger simulator were used in the analysis which follows. A sample of 459 events was obtained. The muons passing the muon trigger simulator were from semi-leptonic decays of hadrons containing b/c quarks (e.g. $b \rightarrow c\mu\nu$). The b/c vertices were also displaced from the production vertex according to their respective lifetimes.

These events were then input to the simulation package, DØGEANT. The GEANT[4] program simulates the interactions that particles undergo from the time they are produced to the point where they leave the detector. The physics processes include multiple scattering, dE/dx loss, bremmstrahlung, decays (excluding b/c decays), and pair production. As charged particles interacted with the beam pipe and the silicon detectors, the origin of each tracks was preserved (i.e. whether it came from the primary or b/c vertex).

The simulation programs also included the physical dimensions of the beam and the beam pipe. A beryllium beam pipe with a radius of 2.667 cm was used in the simulation. The dimensions of the beam in the simulation were $\sigma_{trans} = 65\mu$ (x,y plane) and $\sigma_{long} = 30$ cm (z-direction).

The DØ detector does not have a magnetic field near the central detector and vertex detector, thus, allowing low momentum tracks to be included in the reconstructed vertex. The multiple scattering from low momentum tracks results in a vertex resolution larger than the beam spot. Since the beam spot is a well-defined position (i.e. constant in time), the production vertices in GEANT were smeared in the transverse plane consistent with the beam spot ($\sigma \sim 65\mu$), instead of using the reconstructed vertex.

Geometry

Two different silicon detectors were introduced into the GEANT program; one for the central region and another for the forward region. Figure 1 shows the relative orientation of the central and forward geometries. The rapidity coverage of the combined detectors was ±3.5. The measured rapidity coverage is discussed later in the analysis.

In the central region, four concentric silicon layers were positioned around the beam pipe (figures 1,2). Each silicon detector was 300μ thick. The readout strips ran longitudinally (in the beam direction, z) and were equally spaced by 50μ. Nine layers of silicon were positioned on both sides of the central silicon detector to observe tracks in the forward rapidity region. The readout strips on the forward detectors were concentric circles also spaced by 50μ. Figure 1 shows the forward silicon detectors positioned every 10 cm from 35 to 115 cm in z.

The impact parameters measured by the central silicon detector were measured in the x-y plane perpendicular to the beam. In the forward silicon detector, the impact parameters were measured in the r-z plane, the plane containing the track and vertex.

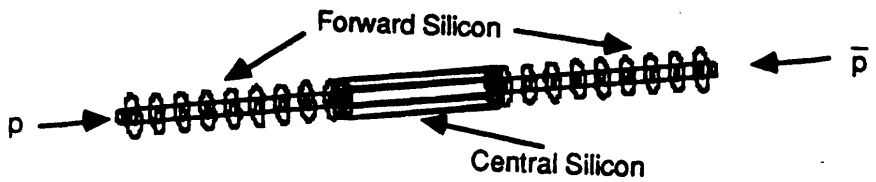

Figure 1. Orientation of the central and forward silicon detectors

Table 1 describes the position of the central and forward silicon detectors.

Dimensions of the silicon detector

Central		
Length	±30 cm	
Radial Position	$r_1 = 3.15$ cm	$r_2 = 3.58$ cm
	$r_3 = 7.07$ cm	$r_4 = 7.53$ cm
Forward		
Inner/Outer Radius	$r_{inner} = 2.7$ cm	$r_{outer} = 7.6$ cm
Longitudinal Position (z)	±35 cm, ±45 cm, ... , ±115 cm	

Table 1

Figure 2 shows the charged tracks of a typical ISAJET event as they pass through the central silicon layers.

Tracking

No track-finding was done in the silicon detector simulation. It should be emphasized that the silicon detector is not meant to be a tracking device in the sense that one expects to do track-finding. Instead, tracks are found in tracking chambers outside the silicon vertex detector to determine roads in which to find hits in the silicon detector. The hits in the silicon detector can be used to improve the extrapolation of the tracks already found[5].

The hits were recorded for each track as they were generated in GEANT. These hits took into account the multiple scattering and secondary interactions. The hits were then smeared by ±10μ in the direction perpendicular to the readout strips. A resolution of 10μ represents a typical resolution using the weighted average of three adjacent hits for an isolated track. Since the simulation program "knows" which hit belongs to a particular track, the question of ambiguous

hits was not addressed, however, approximately 3% of the gaps between adjacent hits in the first central silicon detector were within 100μ.

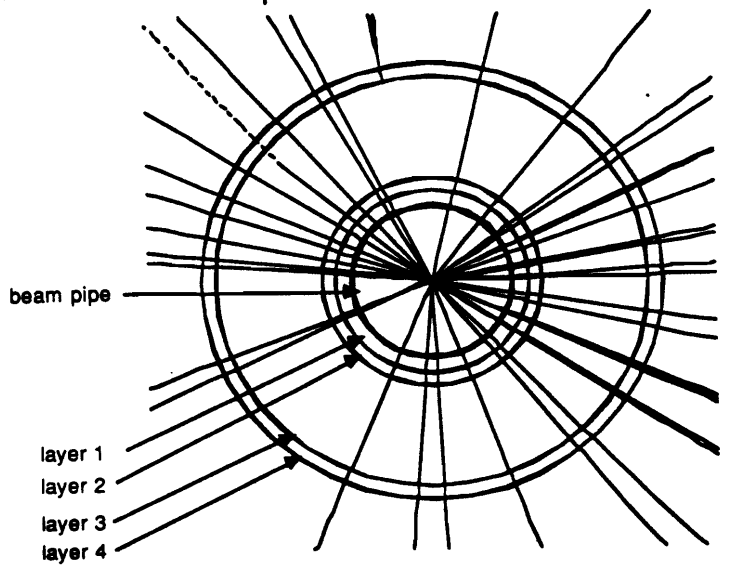

Figure 2. Charged tracks passing through the central silicon layers in DØGEANT

Analysis

To calculate impact parameters, a minimum of 4 points/track were required. Straight-line fits were used for both geometries. Figures 3(a,b) show the impact parameters for all tracks, and all tracks with $p_T > 4$ GeV/c in the central silicon detector.

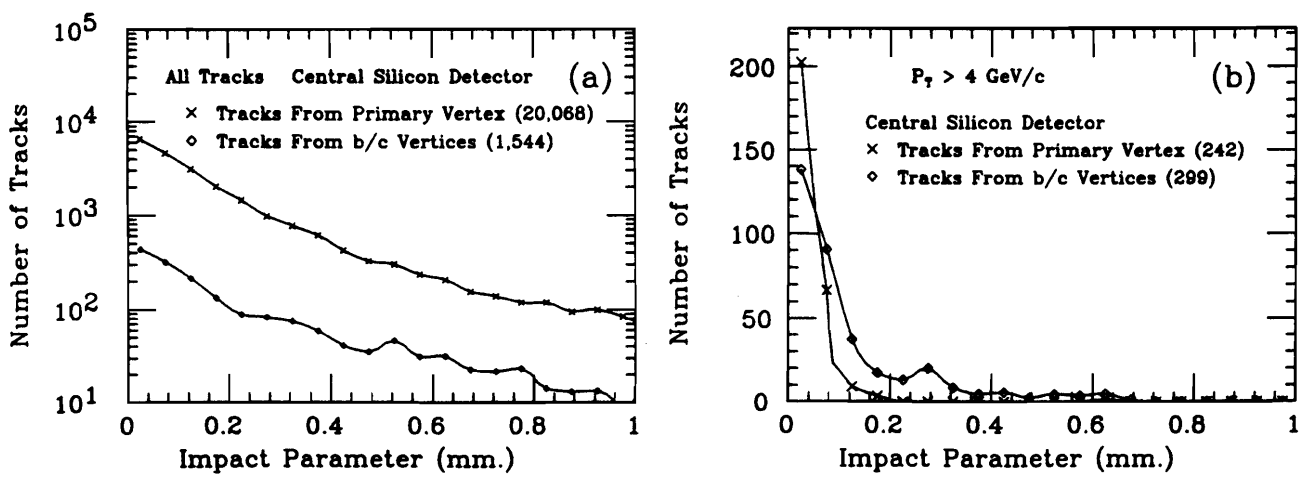

Figure 3. Impact parameters for charged particles traversing the central silicon detector

In figure 3a (no p_T cut), tracks from the primary vertex are observed to have large impact parameters overwhelming any possibility of isolating tracks from b/c decays. Figure 3b shows the impact parameters for charged tracks which pass a p_T cut of 4 GeV/c. This effectively removes most of the tracks with large impact parameter from the primary vertex due to multiple scattering. The most notable effect observed between figures 3a and 3b is that the number of tracks from the b/c vertices dominates at large impact parameters when a p_T cut is imposed. Tracks with impact parameters greater than 150μ are observed to come from b/c vertices 95% of the time. Figure 3b shows the impact parameter resolution one would expect for tracks coming from the primary vertex with $p_T > 4$ GeV/c. This distribution has an rms of 50-60μ. The impact

parameters shown in figures 3(a,b) also include the π/K decays in flight. It was observed that none of the muons from decays in flight of primary tracks would have passed the muon trigger simulator. This is expected since the tracks outside of the b/c jet production have a soft p_T distribution similar to minimum bias tracks.

The impact parameters for tracks in the forward silicon detectors are shown in figures 4(a,b). In these figures, no smearing was introduced in the z direction, however, an uncertainty

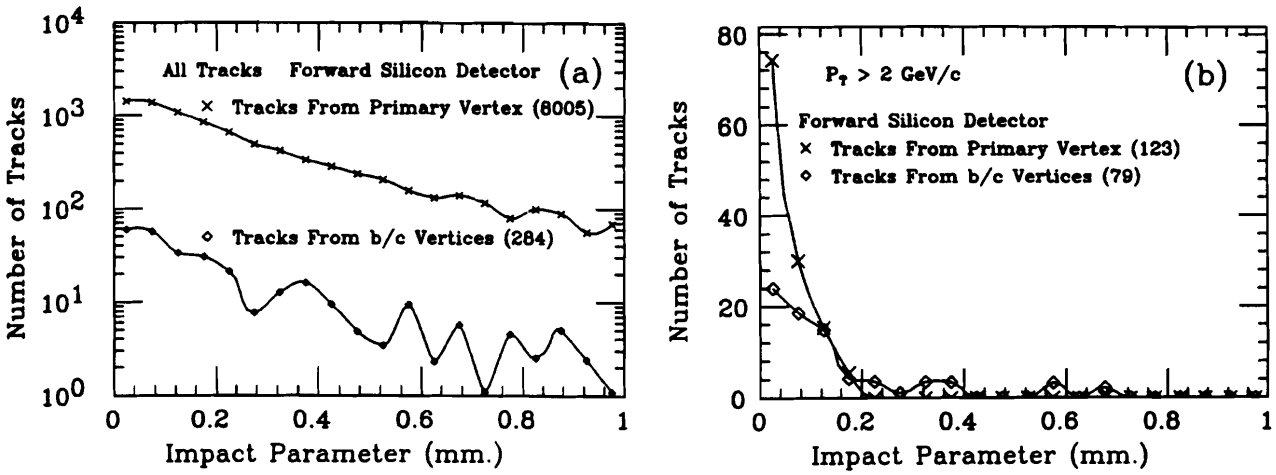

Figure 4. Impact parameters for charged particles traversing the forward silicon detectors

of approximately 1-2 mm is anticipated in the vertex fit in the z-direction. In the forward detectors the rapidity coverage is centered around 3 (fig 5), therefore, the uncertainty in the z direction (1-2 mm) contributes a corresponding error in the impact parameter (δb) of 100-200μ. Figures 4(a,b) shows the impact parameters for (a) all tracks, and (b) all tracks with $p_T > 2$ GeV/c. If an impact parameter cut of 150μ is made, 80% of the tracks are observed to come from b/c decays.

The pseudorapidity range covered by the central and forward detectors is smeared by the longitudinal beam position (±30 cm). Figure 5a shows the pseudorapidity of muons (from 216 events) passing through the central silicon detector. This takes into account the uncertainty in the longitudinal beam position described above. Figure 5a shows that the central silicon detector covers a pseudorapidity range from -2.5 to +2.5. Figure 5b shows that the pseudorapidity coverage in the forward direction is centered at 3 ± 0.4.

A factor which directly influences the error on the impact parameters is the geometry of the beam pipe. The error in impact parameter due to multiple coulomb scatter at fixed p_T is proportional to $\sqrt{t/\sin\theta}$ where t is the beam pipe thickness. This is a substantial error at forward angles (e.g. δb = 3.4 mm at η=3 and p_T = 4 GeV/c). Beam pipe geometries which minimize the amount of material traversed by a track are clearly desirable. Alternatively, one may consider the use of Roman pots as in elastic scattering measurements at the CERN and Fermilab colliders.

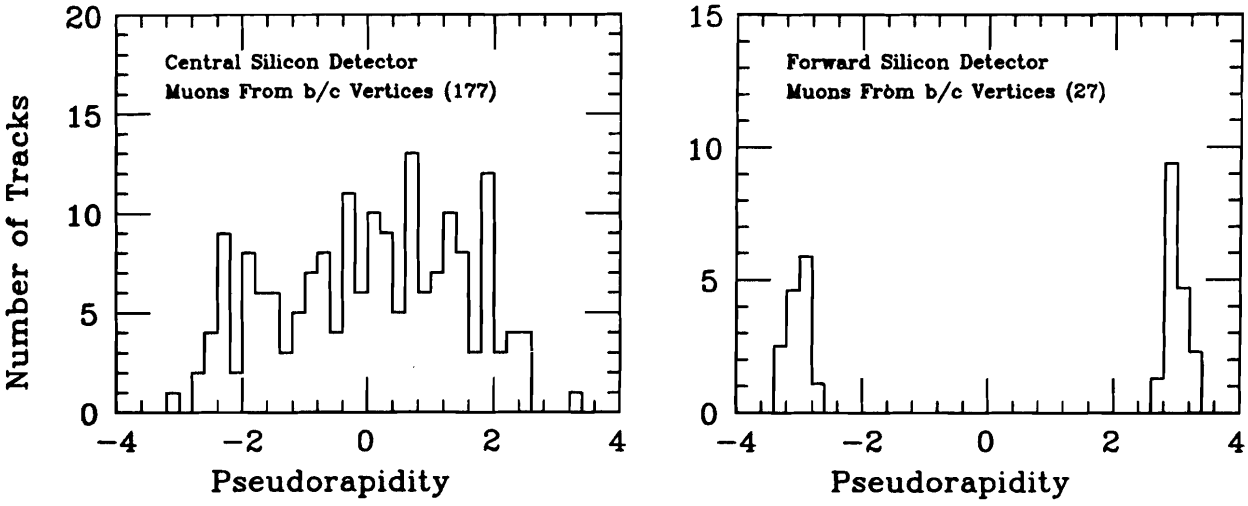

Figure 5. Pseudorapidity distribution of muons "seen" by the central and forward silicon detectors

Conclusion

Even though the results are preliminary, we can see that there is a possibility of identifying muons coming from the semi-leptonic decays of heavy quarks in the DØ experiment. The next step is to use the track information from the central and vertex chambers in DØ to determine the efficiency by which the "correct" hits can be selected in the silicon vertex detector. The large impact parameters due to multiple scattering in the forward direction suggests that we should investigate other beam pipe geometries (i.e. something different than a straight pipe).

Acknowledgements

I want to thank Ed Heflin who wrote the code for the forward silicon detector geometry.

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