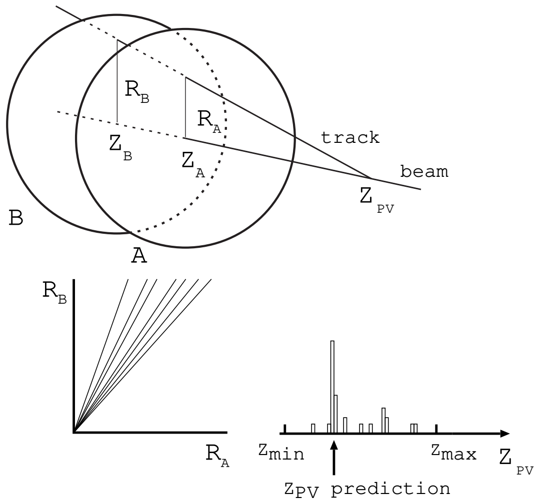

Figure 12.1: Basic principle of detecting the primary vertex PV.

12.3.3 Pile-up Veto as described in TP

Algorithm

At the LHC interaction region, the primary vertex is well defined in the transverse plane; $\sigma_x = \sigma_y = \mathcal{O}(100)$ μm. Along the beam, it has a spread of $\sigma_z = \sim 5$ cm. Therefore, primary vertices created due to multiple pp interactions are spread along the z axis and can be distinguished with a modest vertex resolution.

The z coordinate of a primary vertex ($z_{\rm PV}$) can be obtained using only the radial information of the tracks. By assuming that the primary vertex is at $x = y = 0$, the radial coordinates of a track from a primary vertex ($R_{\rm A}$ and $R_{\rm B}$) measured at two planes (A and B) perpendicular to the beam and placed at $z_{\rm A}$ and $z_{\rm B}$ (Figure 12.1), have the following relation;

$$\frac{R_{\rm B}}{R_{\rm A}} = \frac{z_{\rm B} - z_{\rm PV}}{z_{\rm A} - z_{\rm PV}}. \tag{12.1}$$

Points obtained by combining the two coordinates from the same track lie on a line through the origin in the $R_{\rm A}$-$R_{\rm B}$ plane, if the tracks originate from the same primary vertex. The slope of the line is determined by the z position of the primary vertex; $z_{\rm PV}$. Points made by the two coordinates from different tracks are randomly distributed over the plane.

If points with all the two-coordinate combinations in one event are plotted in the $R_{\rm A}$-$R_{\rm B}$ plane, points from the real tracks line up and the number of lines corresponds to the number of primary vertices. Such lines can be found by scanning the $R_{\rm A}$-$R_{\rm B}$ plane with a line through the origin by varying $z_{\rm VP}$ and counting the number of points on that line for a given $z_{\rm PV}$. By histogramming

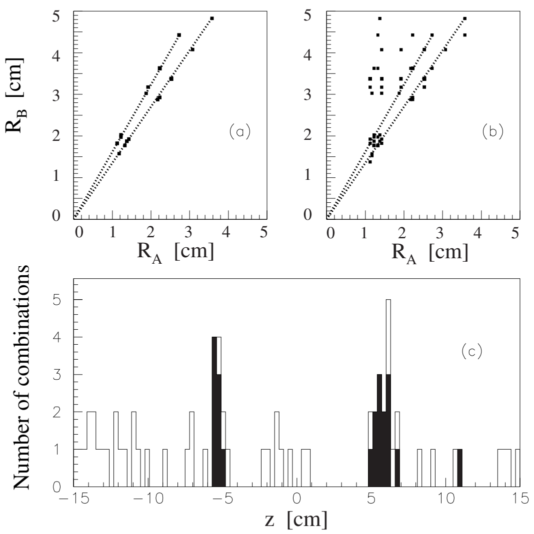

Figure 12.2: Correlation of the measurements in the two planes. A typical event with two vertices is displayed. (a) True combinations, i.e. both hits from the same track, (b) all combinations are shown separately. The slope of a dotted line corresponds to the z-position of a vertex. The z histogram is shown in histogram (c); the shaded bins correspond to true combinations.

the number of points as a function of z_{PV}, a primary vertex appears as a peak in the histogram (Figure 12.1).

To implement the algorithm described above, two planes of silicon detector equipped with circular strips are used. They are placed behind the main vertex detector system at the opposite side of the LHCb interaction region. Each plane is split into six elements covering 60° in azimuth. Each element has 300 circular strips with an effective pitch of 120 to 240 μm depending on the radius. The front-end electronics is placed very close to the detector in the Roman Pot and reads all the 3504 strips within 25 ns. After discrimination, only binary information is sent to off-detector electronics outside the Roman Pot over 3600 10 m long twisted-pair cables.

Simulated R_{A}-R_{B} plots for a double pp interaction are shown in Figure 12.2-a for combinations corresponding to real tracks and Figure 12.2-b for all combinations. The transverse spread of the primary vertex and detector resolution are taken into account in the simulation program. Figure 12.2-c shows the z_{PV} histogram within a defined search window of ± 15 cm. A primary vertex resolution of $\sigma_z \approx 1$ mm is obtained. The two peaks seen in the figure indicate the two pp interactions. The peak height of the second highest peak is sent to the Level-0 decision unit.

Figure 12.3 shows the retention factor for bunch crossings with two pp interactions as a function of that for the single pp interaction bunch crossings. A

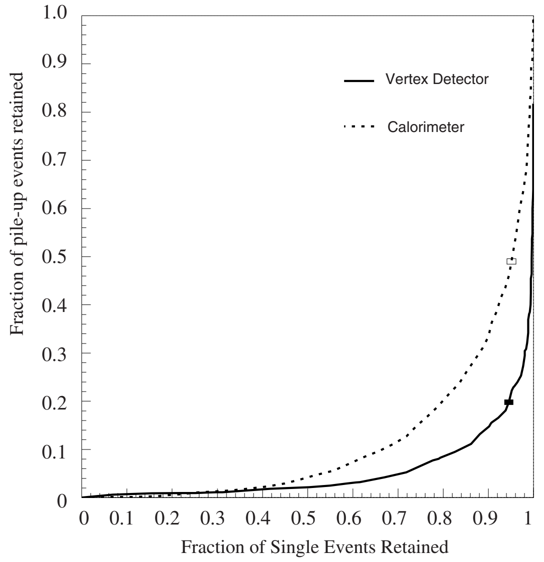

Figure 12.3: Retention of double pp interaction events as a function of retention for single pp interaction events obtained by varying the height of the second peak in the pile-up veto trigger. The performance using the total energy in the calorimeters is also shown.

working point for the LHCb trigger is set to reject 80% of two pp interactions which gives 95% retention for single pp interaction events.

Another parameter that may be used to reject multiple pp interactions is the total energy seen in the calorimeters (E_{tot}) . As seen from Figure 12.3, this method is not effective for rejecting double pp interactions due to the large overlap in E_{tot} distributions for single and double pp interactions . However, it is useful for rejecting bunch crossings with three or more pp interactions. At a luminosity of 5×10^{32} cm^{-2} s^{-1} they become significant.

Implementation

The binary signals of the radial strips are sent out from the Roman Pot to the off-detector electronics (Figure 12.4). The Event Demultiplexer distributes the events to the six vertex finders, each dedicated to one event.

The vertex finder correlates points in the R_{A} and R_{B} plane and counts the number of points on the line. The system can handle 30000 points expected within the search window. The procedure is repeated for all 6 pairs of azimuthal detector elements. The resulting histograms are summed and processed for further analysis. A histogram has about 100 bins, which can be represented by a 6-bit number. The two largest peaks are searched for. The Comparator/Encoder extracts the two vertex candidate positions and the height of the second peak. They are sent to the Level-0 decision unit through the Result Multiplexer.

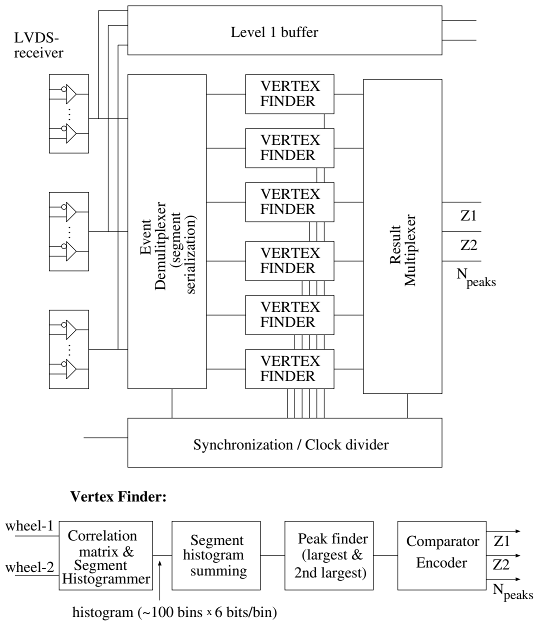

Figure 12.4: Block diagram of the Pile-up Veto.

The amount of logic needed for the Vertex Finder is about 350k gates. If it is built in a single integrated circuit, $2 \times 300 = 600$ inputs and about 50 outputs and control lines are required. In the near future commercial FPGAs will be able to satisfy these requirements. For example, devices such as the Altera FLEX 10K250 with 250k gates and 640 input-outputs (I/O) will be available soon. The size of such devices is expected to grow to 2M gates in the year 2000, e.g. for Altera Raphael architectures.