A Secondary Vertex Trigger for Beauty Search: Results from the BEATRICE/WA92 Experiment

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Abstract

We describe the trigger and the finely segmented silicon microstrip detector used in the WA92 fixed-target experiment at the CERN Omega spectrometer and give preliminary results on their performance during the 1992 and 1993 data-taking periods and on the search for beauty decay topologies.

1 Introduction

Experiment WA92 [1, 2], which took data in 1992 and 1993 at the Ω spectrometer at the CERN SPS, has been designed to study the hadroproduction and the decays of particles containing b quarks. Two factors are important for finding a beauty signal in a fixed-target environment: the selectivity of the trigger and the reconstruction efficiency for decay vertices. A large acceptance for beauty particles and high background rejection have been achieved using the apparatus and the trigger we describe in this paper.

The apparatus consisted of a Si microstrip beam telescope, a 2 mm Cu/W target, the Decay [3] and Vertex [4] detectors, 15 modules of MWPC's in the 1.8 T vertical field of the Ω magnet, 2 drift chamber modules, the Olga electromagnetic calorimeter [5] and the RPC muon detector [6].

The Decay Detector (DD) is made of 17 planes of Si microstrip detectors with $10\,\mu$m pitch covering an area of $5 \times 5\,\text{mm}^2$. The spacing along the beam direction is 1.2 mm for

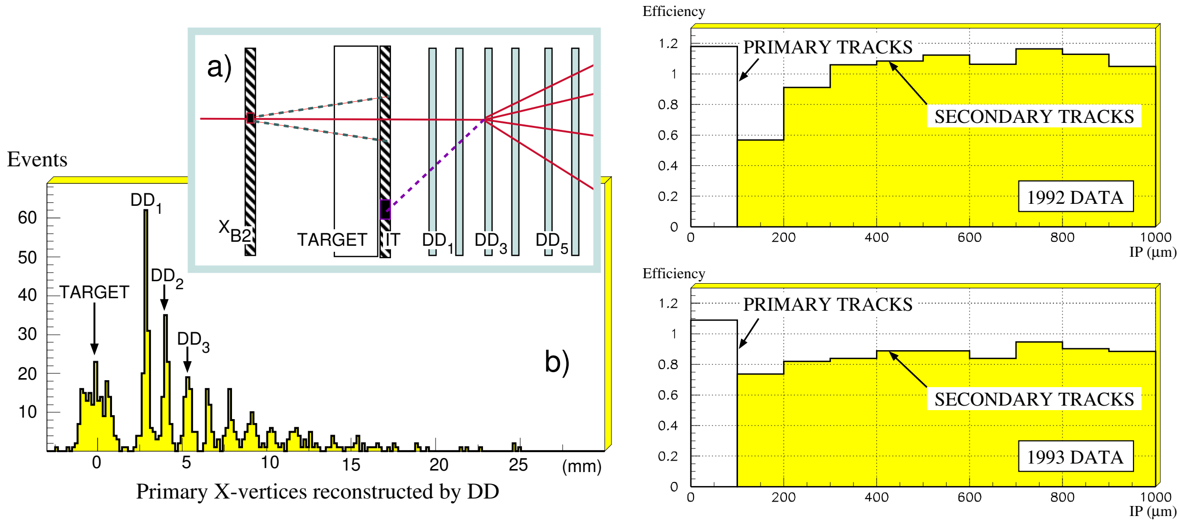

Figure 1: *a) Primary interaction in a DD plane with low-energy back-scattered particle. b) Distribution of reconstructed primary interactions in DD planes which do not satisfy the correlation between hits in X_{B2} and IT. c) BCT track reconstruction efficiency as function of true track impact parameter (from simulation).*

the first 14 planes and 5 mm for the following ones; the first 6 detectors are 150 μm thick and the rest 300 μm thick. Thirteen planes (12 in 1993) measure the Z (vertical) coordinate, 2 (3) the Y (horizontal) coordinate and 2 are inclined for projection matching. All strips are individually read out into 8-bit ADC's; with thresholds set for each strip at 4 times the pedestal RMS we obtain efficiencies of 93% and 97% for the thin and thick planes respectively with a noise level of 10^{-3} per strip. The measured single-point resolution is between 2 and 3 μm and the two-track resolution is of the order of 30 μm. The DD was designed to allow the reconstruction of a decay chain with secondary and tertiary vertices which is an important characteristic of beauty events.

The Vertex Detector consists of 12 planes (6 per projection) of 25 μm pitch Si microstrip detectors spaced by 2.5 cm and 5 inclined planes with 50 μm pitch; all detectors cover an area of $5.12 \times 5.12\,\mathrm{cm}^2$ and have a digital read-out. The 6 Z planes are equipped with a fast read-out and are used in the impact parameter trigger.

2 Trigger

To counter the unfavorable signal-to-noise ratio ($\sigma_{b\bar{b}}/\sigma_{tot} \simeq 10^{-6}$ at $\sqrt{s} = 26\ GeV/c^2$) we used of a combination of several independent trigger components:

- *High transverse momentum Trigger:*
  This trigger selects, in less than 250 ns, events having particles with $P_t \geq 0.6\ GeV/c$ with respect to the beam direction, which can be produced in decays of high-mass particles. The trigger uses two so-called butterfly hodoscopes [7]; as a result of the

deflection in the magnetic field of the Ω spectrometer, a charged particle that originates in or close to the target can cross the butterfly hodoscopes, and thus give a trigger, only if it has P_t larger than the set threshold (0.6 GeV/c).

- *Muon trigger:*
  This trigger takes advantage of the large semi-leptonic branching ratio of B mesons. The μ-trigger [6] is based on two hodoscopes built with resistive-plate chambers, each hodoscope having two chambers to measure the vertical coordinate (Z view) and one chamber to measure the horizontal coordinate (Y view). Using only information for the Z view, a coincidence matrix logic [8] selects in 250 ns muon tracks coming from the target region.

- *Secondary-vertex trigger:*
  The secondary-vertex trigger or beauty contiguity trigger (BCT) exploits the long B lifetime ($c\tau \simeq 450\,\mu$m) which allows decay vertices to be well separated from the primary interaction point. The BCT hardware and the implemented algorithm have been extensively described elsewhere [4, 9, 10] and only their performance will be discussed here, with emphasis on the 1993 upgrades.

2.1 Secondary-Vertex Trigger

The secondary-vertex trigger uses 9 silicon strip detectors, providing views of events in the Z projection, where tracks are not affected by the magnetic field:

- two planes of $20\,\mu$m pitch microstrips that measure the incoming beam trajectory, one plane at $X_{B1} \simeq -71$ cm and one plane at $X_{B2} \simeq -11$ cm upstream of the 2 mm target (half of the 1992 data were recorded with a W target, the rest of the 1992 data and all the 1993 data were recorded with a Cu target). The two coordinates of the primary vertex position (X_V, Z_V) are given respectively by the X_{TG} position of the target centre and by the linear extrapolation to X_{TG} of the track defined by the hits measured in the two beam planes.

- one $200\,\mu$m pitch silicon strip detector, placed $50\,\mu$m after the target, fires if a charge equivalent to at least five minimum-ionizing particles (m.i.p.) is released in one of the strips. This condition is satisfied by $\sim 90\%$ of interactions occurring in the target and by only $\sim 4\%$ of interactions occurring in the DD planes. This detector is referred to as the in-target counter (IT).

- six planes of $25\,\mu$m pitch microstrips with $5.12 \times 5.12\,\mathrm{cm}^2$ active area cover a region extending from $X_{V1} \simeq 6$ cm to $X_{V6} \simeq 42$ cm. Using the hits recorded in these six planes, tracks with at least 5 hits are reconstructed by the BCT and classified according to their impact parameters (IP) with respect to the primary vertex and dip angles.

The trigger algorithm is executed by the BCT in $35\,\mu$s, which is about 3 to 4 orders of magnitude better than is achieved when running a similar algorithm on an off-line computer. The

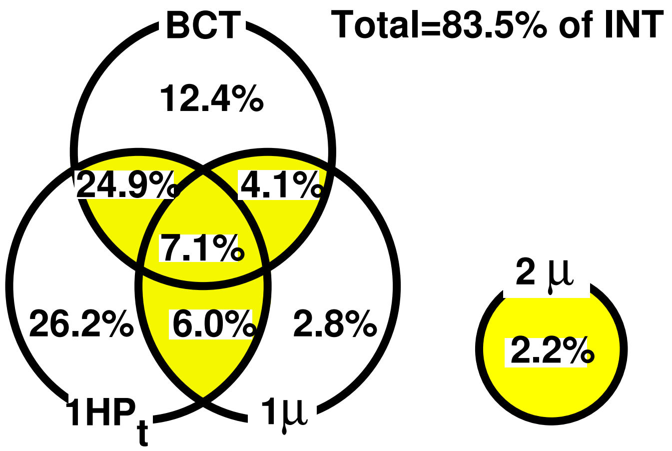

Figure 2: *The shaded region of the diagram represents the 1992 WA92 trigger. The numbers are the beauty acceptance with respect to the INT trigger, which had an efficiency of 75% for beauty events occurring in the target.*

BCT condition used required the presence of at least three primary tracks ($IP \leq 100\,\mu$m), to re-enforce the primary-vertex constraint, and two secondary tracks ($IP \geq 100\,\mu$m), to indicate the existence of a secondary vertex.

We recognized that a weak point of the BCT in the 1992 configuration was the primary vertex definition, where triggering conditions were likely to be satisfied if the primary vertex was not correctly reconstructed. For example, when two or more beam particles arrived during the live time of the front-end electronics (about 200 ns), the wrong (X_V, Z_V) could be found. Also, the existence of a primary vertex in the target could be wrongly flagged because of heavily ionizing nuclear fragments emerging from primary interactions in the DD planes and travelling backwards (see Fig. 1.a). For 1993 we required a spatial correlation between the firing IT strip and the extrapolated (X_V, Z_V). As an example of the improvement achieved, we show in Fig. 1.b the X position of the primary vertex for those events that were rejected by the 1993 BCT configuration but would previously have been accepted.

2.2 Trigger Performance

In triggering on secondary vertices there is a trade-off between beauty acceptance and background reduction, and some attention is needed to avoid (or at least reduce) possible trigger biases. In designing the BCT track-reconstruction algorithm we were careful to minimize the effects of detector inefficiencies and noise and to correctly count and classify tracks according to their IP. In Fig. 1.c the BCT track-finding efficiency is shown as a function of IP class for simulated beauty events. The double counting of tracks falling in two neighbouring IP classes that in 1992 led to an apparent efficiency of greater than one was largely eliminated in 1993 by an improved BCT algorithm. Also, the peak of the primary tracks, associated with a deeper valley in the first IP class, was reduced in 1993. We then obtained a trigger providing an IP selection that is uniformly efficient between $100\,\mu$m and 1 mm.

To understand the trigger behaviour we have fully simulated minimum-bias, $c\bar{c}$ and $b\bar{b}$ events. Minimum-bias events were generated using Fluka [11] as interfaced with Geant 3.21 [12]. This reproduces well the experimentally measured charged particle multiplicities and kinematics, and also the production of heavily ionizing particles, which is important for the simulation of the response of the in-target counter. We generate $c\bar{c}$ and $b\bar{b}$ events using a combination of Pythia 5.4 [13] and Fluka. In the generation process up to 98.5% of the centre-of-mass energy is available for the simulation of hard processes by Pythia; the remaining energy is used to simulate soft processes with Fluka. The passage of generated particles through the experimental apparatus is simulated in detail using Geant 3.21. Non-interacting beam particles, detector inefficiencies and random noise are added in accordance with experimental measurements.

In Table 1 we present the trigger rates obtained for background and signal with the different triggers and in Fig. 2 we represent the beauty acceptance of the 1992 trigger for the Cu target data. The interaction pretrigger (INT) required the presence of an incoming beam particle, incident on the target, and outgoing interaction products, together with a signal of more than 5 m.i.p. in the IT; the 1μ (2μ) trigger required the presence of at least one (two) muon(s); the $1HP_t$ ($2HP_t$) trigger required that there should be at least one (two) particle(s) having a transverse momentum with respect to the beam $\geq 0.6\ GeV/c$; the BCT required at least three primary and two secondary tracks. The 1992 trigger was the logical 'OR' of the 'AND' of any two of the 1μ, HP_t, BCT triggers; all events satisfying the 2μ trigger were accepted. The $1HP_t$ ($2HP_t$) trigger condition was used with the Cu (W) target.

Trigger Type	*Data*	*Min.Bias*	$c\bar{c}$	$b\bar{b}$
INT/σ_{tot}	65 %	67 %	75 %	75 %
$1\mu/INT$	2.8 %	2.5 %	7.8 %	20.0 %
$2\mu/INT$	0.07 %	0.1 %	0.6 %	2.2 %
$1HP_t/INT$	40 %	40.5 %	40.8 %	64.2 %
$2HP_t/INT$	12 %	11.2 %	10.4 %	28.1 %
BCT/INT	5.8 %	5.1 %	15.2 %	48.5 %
1992 Tri/σ_{tot}	2.5 %	2.2 %	8.2 %	31.6 %

Table 1: *Trigger rates for 1992. The first column is for real data, the others are from simulation. For the definition of the trigger components see the text.*

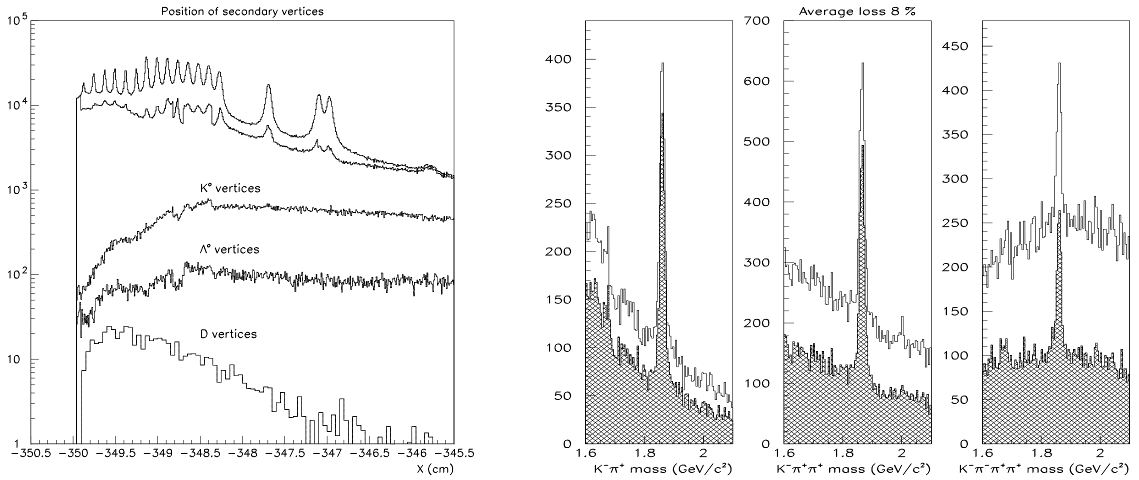

Figure 3: *a) Position of reconstructed secondary vertices in the DD region. The vertices between the two upper curves are rejected as due to secondary interactions in the Si planes. b) D^0 and $D^\pm$ invariant mass distributions showing the effect of the algorithm rejecting secondary interactions.*

3 Rejection of secondary interactions

As shown in Fig. 3.a, most secondary vertices reconstructed in the decay detector region are hadronic interactions in the silicon planes. The DD represents 0.6% of a π interaction length and 4.5% of a radiation length. Given the small beauty production cross-section, the ratio between the number of secondary vertices due to beauty cascade decays and those due to secondary interactions in minimum bias events is of the order of 10^{-5}. A simple cut on the vertex position cannot be used because of the small spacing between the DD planes; we have developed a method based on the large energy release due to nuclear fragments and slow tracks which accompany most of the interactions in the Si planes. Cuts based on the distance between the reconstructed vertex position and the centroid of the large energy deposits reject 91% of the vertices due to secondary interactions while loosing only 3% of K^0_s and Λ^0 and 8% of $D^{0,\pm}$ decays (Fig. 3.b). Some secondary vertices are due to coherent or low-multiplicity hadronic interactions surviving the pulse height cuts and others are fake vertices due to high hit densities (mostly interactions).

4 Search for beauty decays

In the 1992 run we have recorded on tape $80 \cdot 10^6$ events; among these the Trident reconstruction program [14] found $12 \cdot 10^6$ events with a secondary vertex, containing an estimated sample of 750 beauty events (assuming a cross-section of 5 nb/nucleon and a linear dependence on the atomic number). The cut on hadronic interactions has reduced the data sample to $2 \cdot 10^6$ events. The events have then been separated into 3 streams to be

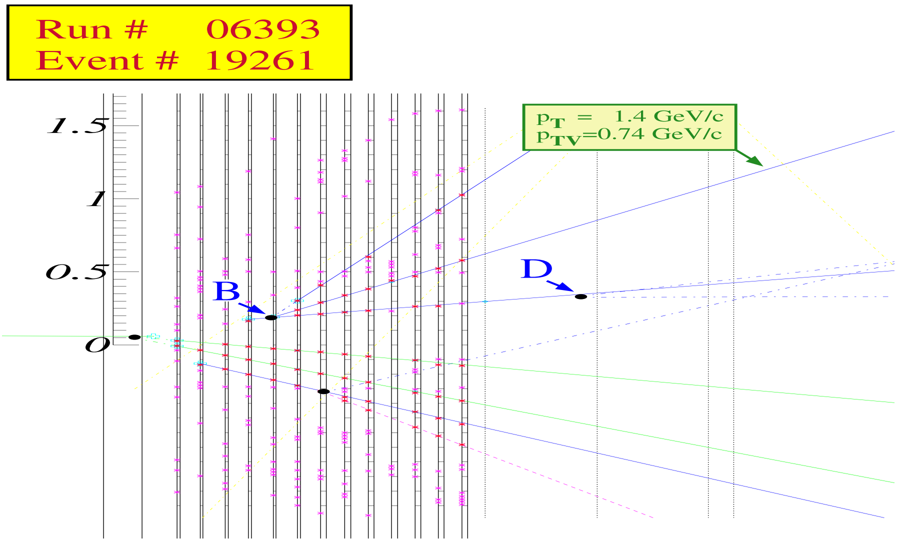

Figure 4: *Display of a beauty multi-vertex candidate event, 1992 data, Cu target. Both $B \rightarrow D$ decay chains are clearly visible.*

analyzed with a graphical display program, in order to exploit the visualizing capabilities of the decay detector:

- events with at least 3 secondary vertices in the decay detector region;
- events with a fully reconstructed charm meson NOT pointing to the primary vertex and accompanied by additional secondary activity;
- events with a high transverse momentum muon NOT associated with the primary vertex and accompanied by additional secondary activity.

These strict selection criteria give, for the Cu target sample, about 5000 events amongst which we expect to observe 20 beauty decays. The use of the DD information in the graphical analysis of these events has significantly enhanced the S/N ratio and has led to the selection of events with cascade decays such as the one shown in Fig. 4. The graphical analysis allows us to check the reconstruction of the tracks and vertices in the DD region, to correctly measure the transverse momenta relative to the line of flight and to search for additional secondary activity and kinks. It is therefore possible to improve on the selection based on the kinematical information alone (transverse momentum of the tracks in the lab frame, invariant mass of tracks attached to a secondary vertex, presence of leptons), and thus obtain a larger background reduction. The background evaluation in the final sample is still in progress, but the observation of events with properties strongly characteristic of beauty decays gives us confidence that we are actually observing beauty decays and that only a small fraction of the final sample may be ascribed to background.

5 Conclusions

A fast trigger looking for secondary vertices has been used for the first time in an experiment to search for beauty particles. The BCT trigger was able, in $35\,\mu$s, to reject 94.2% of the background keeping $\sim$ 50% of the beauty signal (the background rejection and the acceptance for beauty were, respectively, 97.5% and 32% for the global 1992 trigger configuration).

A high precision ($10\,\mu$m pitch) Si telescope has been operated and used to observe directly the cascade decays of beauty particles. Secondary hadronic interactions can be rejected efficiently with cuts correlating the vertex position to the large energy deposits.

The topological trigger, together with the high resolution of the decay detector, enabled us to see beauty events in the data analyzed so far with the help of interactive graphics. More sophisticated code is being developed to improve the event selection and allow us to relax some cuts, thus gaining in acceptance and efficiency.

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