A Vertex Trigger for Fixed Target Beauty

Michael D. Sokoloff
University of Cincinnati

Introduction

The fractional rate for beauty production in fixed target hadron experiments is expected to be approximately 10^{-6} to 10^{-7}. Collecting large samples of beauty events therefore requires selective triggers which are also efficient. Physics signatures which may serve to distinguish events with beauty from background include the presence of high p_T leptons or high p_T hadrons, large global transverse energy (E_T), a change in charge multiplicity downstream of the primary vertex, or the presence of secondary vertices or high impact parameter tracks. I have studied an algorithm for triggering on events with high impact parameter tracks which can be implemented using existing technology and whose approximate efficiency and background reduction power are measured.

The Algorithm

The algorithm assumes that a primary vertex point can be determined from beam track information. Then hits from tracks emanating from the vertex point can be identified and marked out, and the remaining hits examined for evidence of secondary tracks. Given the interaction point, recognizing primary tracks in projection is a well-defined and finite problem. We can consider the specific case where a 1 mm thick target is 2 cm upstream from the first of five silicon microstrip detectors (SMDs), all of which measure the same projection and which are separated by 3 cm each. Let the first two detectors have 25 μm pitch and the last three 50 μm pitch. For the purpose of recognizing tracks, the resolution of such a detector will be about 0.5 mr. Projected onto the first plane, a 0.5 mr road is 10 μm wide. Projected onto the last plane, it is 70 μm wide.

With a point-like target there are a finite number of roads one must consider in looking for primary tracks. Scanning $\pm$100 mr of the beam direction there will be 400 0.5 mr adjacent roads covering a 200 mr angular region. As a real track may leave hits in each of two adjacent roads rather than in one only, we consider also the set of roads offset by 0.25 mr from the original set. This layout is sketched in Figure 1.

Each road is now a list of all of the strips in each plane which could be fired by a track of the specified angle coming from the primary vertex. Recognizing primary tracks simply requires comparing lists of strips fired in an event with

pre-defined lists for each of the roads. Whenever one of the strips within a road is found ON, the corresponding plane is considered ON for that road. When some minimum number of planes is ON for one of the roads, probably three or four, the corresponding track is found. Marking out the hits from the roads where primary tracks have been found leaves the hits from high impact parameter secondary tracks. Recognizing tracks amongst these remaining hits is equivalent to finding the secondary tracks. Not all high impact parameter candidates will be true secondary tracks, and not all secondary tracks will be detected as high impact parameter candidates. It is intended therefore that the trigger will accept events with some minimum number of candidates.

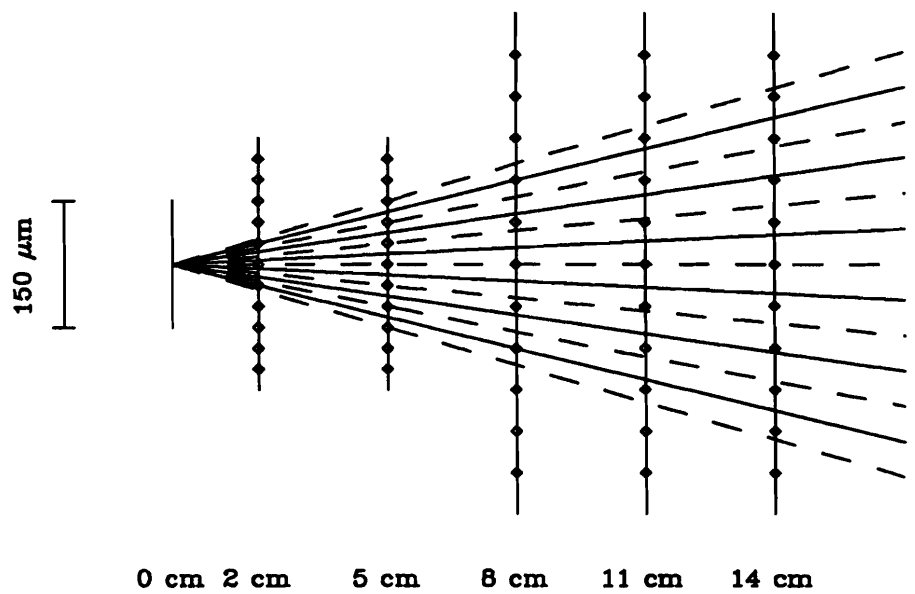

Figure1 : Target region schematic in one projection. The little diamonds represent strip centers. The first two planes have 25 μm pitch, the remaining planes 50 μm pitch. Roads 0.5 mr wide are anchored at the vertex point. The solid lines represent one set of roads and the dashed lines the offset roads.

Trigger Efficiency

How well will such an algorithm work? We can look at hadron data from Fermilab's E691 to estimate background suppression and at Monte Carlo $b\bar{b}$ data to estimate signal acceptance. E691 is a charm photo-production experiment which ran in the Tagged Photon Laboratory at Fermilab using a 5 cm Be target and and an SMD vertex detector followed by a conventional open geometry spectrometer. The SMD system consisted of nine planes of 50 μm pitch detectors subtending approximately 100 mr in three projected views. As a test, E691 also recorded about 8×10^5 250 GeV π^-Be events. The hadron events with primary

vertices in the last 1 mm of the target form the sample for the background studies. Monte Carlo $b\bar{b}$ events generated using the PYTHIA and LUND packages and run through the E691 detector simulation program form the sample for the signal studies.

Starting at the primary vertex position $\pm 20\mu m$ in the transverse coordinate (reconstructed position for the background sample, nominal for the signal sample) all 0.5 mr roads are drawn. In each view any road with hits in at least two planes (out of three) is deemed to have a found track. All the hits falling within such a road are marked out. Each track reconstructed earlier in the offline software is then examined in each projection. (The fast trigger would not have time to correlate these view tracks.) A view track is called a candidate high impact parameter track if at least two of its SMD hits remain after hits from primary tracks have been marked out.

Table I: Trigger Rates

minimum number of high impact parameter track candidates	$b\bar{b}$ Monte Carlo		250 GeV π^-Be Data			
	no E_T cut		$E_T > 2.2$		$E_T > 6$	$E_T > 8$
	events	(%)	events	(%)	events	events
no cut	50	(100)	3296	(100)	578	73
4	38	(76)	133	(4.0)	39	4
5	30	(60)	77	(2.3)	25	2
6	26	(52)	52	(1.6)	16	2
7	20	(40)	24	(0.7)	9	2
8	18	(36)	19	(0.6)	7	2
9	13	(26)	16	(0.5)	6	2
10	11	(22)	10	(0.3)	4	2

The efficiency of the trigger will be the fraction of $b\bar{b}$ events which are accepted by the cut. The background suppression will be one divided by the fraction of background events which are accepted by the cut. Results from the $b\bar{b}$ Monte Carlo and from the E691 hadron data are shown in Table I. The hadron data was taken with a transverse energy trigger which required $E_T > 2.2$ GeV. This accepted about 35% of the inelastic cross-section. Requiring the number of high impact parameter candidates to be at least four (summing over all three projections) accepts 75% of the signal and less than 5% of the $E_T > 2.2$ GeV background, less than 2% of all the background. Requiring larger numbers of high impact parameter tracks drops the background rate dramatically, as does raising the E_T cut.

E691 found that the $E_T > 2.2$ GeV trigger accepted about 80% of photo-produced charm. The $c\bar{c}$ mass threshold is about two and a half times lower than the $b\bar{b}$ threshold, so one might expect a similar acceptance for beauty production with $E_T > 6$ GeV. For $E_T > 6$ GeV and the number of high impact parameter candidates at least 7, the background suppression is of order one thousand. The $b\bar{b}$ acceptance is then 40% times the E_T acceptance factor. For an experiment running at a MHz interaction rate, using this trigger would require a data acqusistion system capable of digitizing and recording 10^3 events per second of beam. The Fermilab charm hadro-production experiment E769 is taking data now with a system almost this powerful. The major question remaining is whether this type of trigger can be built with existing or conceivable technology.

Hardware Implementation

Building the trigger logic for an experiment with a single point-like primary vertex position common to all events would require rather trivial and cheap hardware. Expanding the logic to account for the multitude of possible vertex positions provided by finite size beam and target requires more work. A brute force approach which duplicates the simple logic of a single primary vertex position for each possible primary vertex position would be prohibitively expensive. Assuming the beam is 1 cm across and the transverse resolution is 25 μm we are led to consider 400 primary vertex positions in each view. Two simple techniques can reduce the problem to a tractable size.

For a fixed primary vertex position a road consists of a window in each plane where data hits from the detector are logically OR'ed. If a sufficient number of planes are ON then the track is found. Using a Programmable Logic Array (PLA) chip in conjuncion with a static RAM (SRAM) chip one may build the window for one plane of a track at a fixed angle and many primary vertex positions. Latch bits from a relatively large segment of a detector are fed into a PLA chip along with mask bits from SRAM. The mask bit pattern is selected by the beam track intercept and defines the window appropriate to the angle of the road and the intercept of the primary vertex.

The electronics industry produces PLAs with programmable AND arrays whose product terms feed fixed OR arrays. The road processors described above can be built with these chips. The Altera brand EP1800, one of their family of Erasable Programmable Logic Devices, EPLDs, makes a good example. This device is divided into forty-eight Macrocells with configurable I/O architecture allowing 64 inputs or 48 outputs. Each pin is connected to a buffer which presents both the signal and its complement as inputs to the 480 product terms. The clock frequency is 25 MHz corresponding to a cycle time of 40 ns. The chip measures 0.9 inches square. It is programmed and erased using the device which programs

and erases EPROMs. A logic table incorporating 43 data input bits and 9 mask input bits to define the windows in one plane for a 1 mm primary vertex region (assuming 25 μm resolution) would fit into this chip. Six of the mask bits would be used to define the left-most edge of the track's window in this plane. Three bits would be used to define the width of the window (one to four bits wide).

Defining a single set of roads, as if there were but one primary vertex position, and then shifting all the SMD data according to the offset between the actual primary vertex position and the nominal primary vertex position reduces the the pattern recognition problem at the expense of creating a switching problem. Pattern recognition can still be performed in sets of PLA + SRAM chips, and now the logic for eight roads will fit into a single set. PLAs can also switch the data very quickly. A block of eight input bits can be switched up to 32 bits at a time providing eight output bits. These output bits can be fed back into the same switching system several times to achieve the necessary alignment. For a flat distribution of primary vertex positions in a 1 cm target region, 25 μm resolution generates an average of 3.6 shift cycles per event. A 16K channel SMD system (3 views) would need 2000 sets of PLA + SRAM chips for switching and 1500 for identifying the primary tracks. Another 500 would identify beam tracks. Pattern recognition for secondary tracks could use 15 400 μm windows in the most upstream plane connected by 300 roads to 20 1 mm wide windows in the most downstream plane using 600 chip sets. At $50 a set, the cost of the chips would be about $250K for a total system cost under $500K.

With a fast E_T trigger reducing the rate of events to be processed by the vertex trigger from 10^6 sec^{-1} to 10^5 sec^{-1} the vertex trigger must execute in less than 1 μsec to keep the deadtime below 10%. Once latch bits from the SMD are available, the hardware described above can find beam tracks, recognize and mark out hits from primary tracks, and identify high impact parameter candidates in 500 nsec. Digitizing the SMD signals bucket-by-bucket (18 nsec per bucket at Fermilab) and looking at several beam tracks per bucket are likely to be the most difficult problems. Assuming these technical challenges can be met, a high impact parameter trigger as described in this talk should allow an experiment to record two orders of magnitude more beauty than an open hadronic trigger.

Thanks

The hadron data analyzed for background rates was taken as part of E691 by Fermilab's Tagged Photon Spectrometer Collaboration at the suggestion of D. Green and A. Napier. The trigger rate study used the E691 software. S. Collins, S. Kannapan, and M. Purohit put together the $b\bar{b}$ Monte Carlo. H. Areti and S. Bracker provided valuable discussions of appropriate hardware. This research was supported in part by the U.S. Department of Energy.