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A Dedicated LHC Collider Beauty Experiment for Precision Measurements of CP-Violation

Abstract

The LHC-B Collaboration proposes to build a forward collider detector dedicated to the study of CP violation and other rare phenomena in the decays of Beauty particles. The forward geometry results in an average 80 GeV momentum of reconstructed B-mesons and, with multiple, efficient and redundant triggers, yields large event samples. B-hadron decay products are efficiently identified by Ring-Imaging Cerenkov Counters, rendering a wide range of multi-particle final states accessible and providing precise measurements of all angles, α , β and γ of the unitarity triangle. The LHC-B microvertex detector capabilities facilitate multi-vertex event reconstruction and proper-time measurements with an expected few-percent uncertainty, permitting measurements of B_s -mixing well beyond the largest conceivable values of x_s . LHC-B would be fully operational at the startup of LHC and requires only a modest luminosity to reveal its full performance potential.

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Figure 10.15: Energy [GeV] in the Electro-magnetic and Hadron Calorimeters for single interactions (solid line) and double interactions (dashed line)

crossings. The calorimeter-based triggers are especially sensitive to the presence of a second event in the same bunch crossings. Therefore, our nominal minimum-bias trigger rate of 230 KHz is most effective with the inclusion of a pile-up veto in the Level-1 trigger.

For reasons given above, at least for the main elements of the LHC-B physics programme, the Level-1 trigger will include a pile-up rejection. The trigger efficiencies and the event yields given at the end of this chapter include losses from the pile-up veto discussed above.

10.5 Level-1 hardware implementation

From the descriptions of the various trigger algorithms, it is clear that the corresponding hardware should provide a high level of performance, both in terms of speed and sophistication. The main obstacles to be surmounted are the need to sustain a 40 MHz input rate in a pipelined mode with a rather large amount of inter-communication between detector elements.

In view of the extremely critical role that the trigger plays in LHC-B and of the natural expectation that, at the time of running, unanticipated conditions might have to be met, the chosen trigger hardware should allow a good degree of flexibility and possibil-

Figure 10.16: Full "OR'ed" Level-1 trigger rate as a function of luminosity, including pile-up veto. The dashed curve shows the component of the full Level-1 trigger rate for bunches which contain single-interactions.

ity of expansion. Moreover, given the rapid advances in the performance attainable from digital systems, it is felt that, even for the handling of the calorimeter information, a digital system is preferred to an analogue one. Such requirements point to a choice of a programmable, very high-performance system of parallel processors, capable of very fast data switching.

We wish to point out that a possible solution, meeting all of the demanding requirements, could already be found within the realm of existing developments. As an "existence proof" we note that the system called "3D-Flow", originally designed to provide Level-1 triggering for the high- p_t SSC detectors[5], could satisfy these needs.

The "3D-Flow" consists essentially of a parallel-processing architecture built around an ASIC containing four identical processors. Each processor, highly optimized for fast, parallel communication, contains six communication channels, which can all operate concurrently. In a typical application, an individual processor would be connected as sketched in Fig. 10.17, where in the planar structures each processor is associated directly with individual detector elements or some set of them, and the stack of

planes in the "third dimension" is exploited to achieve pipelined operation.

Figure 10.17: General scheme of the 3D-Flow pipelined parallel-processing architecture

Detailed studies[6] have shown that a suitable architecture of 3D-Flow processors operating at 200 MHz can easily execute the envisaged muon, electron and hadron algorithms within the allowed time limit of $2 \mu\text{sec}$, while providing an environment suitable for expansion or algorithm re-definition.

10.6 Level-1 summary

Here we summarize the combined Level-1 trigger efficiencies and pile-up veto for some of the interesting exclusive decay modes. The individual trigger efficiencies for each component of the Level-1 trigger and their "OR" for accepted events are shown in Table 10.7. The numbers given in the table are obtained from event samples in which the B-mesons are forced to decay to a specific exclusive channel given in the table, while their accompanying $\bar{B}$ -mesons are allowed to decay into all possible final states with their natural branching ratios. The Level-1 trigger efficiency is specified for events which are "accepted". Accepted events have all their B-meson decay products detected and momentum-analyzed in the spectrometer.

The trigger efficiency for the high- p_t triggers is shown in the first three columns where each Level-1 trigger is "tuned" to give a $\sim 1\%$ efficiency for

minimum-bias events. As mentioned earlier, the performance figures for the electron and hadron trigger do not reflect the best possible results that were obtained from such triggers simulations, but, because of the need to generate a large sample of "triggered" events for reconstruction studies, were obtained at an earlier stage of the trigger studies and simulations.

The final column contains the 3-fold OR'ed Level-1 trigger. Both individual and OR'ed trigger efficiencies include the losses due to the pile-up veto on single interaction bunch crossings. The 3-fold OR'ed Level-1 trigger including the pile-up veto has a 2.5% efficiency for minimum-bias events. In each case, the OR of the three triggers contains very few events where more than one trigger is satisfied. In the minimum-bias events, only 4% are selected by more than one trigger.

10.7 Level-2 trigger

The Level-2 trigger envisioned for LHC-B consists of two parts running in parallel and providing the required Level-2 suppression, when the two parts are AND'ed together. The first part consist of improving the Level-1 trigger decisions using information from additional sub-systems. Using the Level-1 trigger track candidates as seeds, track finding in the spectrometer will be carried out, ultimately matching them to the ones found upstream of the magnet and in the silicon. Tracking of the trigger particles to the silicon will decrease the contamination from "ghost" tracks and gamma conversions and, to some extent, from K/π decays. A similar Level-2 algorithm is being developed for the HERA-B experiment[7] using Digital Signal Processors.

The second part of the Level-2 trigger will perform a selection based on the event topology. The topology trigger employed will depend on the trigger satisfied in Level-1. For example for single lepton triggers, this could be the requirement that the trigger muon or electron has a large impact parameter to the primary vertex or the two trigger tracks for di-lepton and di-hadron triggers form a detached vertex and possibly satisfy a mass constraint. Alternatively, we can perform a "Topology" trigger similar to that proposed by the COBEX collaboration, where events consistent with a single vertex hypothesis are rejected.

In principle, the load of the Level-2 trigger should be divided between the two parts, each providing a factor of ≈ 4.5 reduction. With the resulting factor of 20 reduction, the expected Level-2 output rate will be 10kHz. But the performance numbers for the Level-2 trigger, especially the tracking part, require the detailed description of the detector elements and full

Event Sample	Visible B.R.	Decay Acceptance	Efficiency		Events On Tape
			Level-1	Level-2	
$B_d \rightarrow \pi^+ \pi^-$	$2.0 \cdot 10^{-5}$	17.8%	20.6%	33.1%	110k
$B_d \rightarrow J/\psi K_s^0 (\mu\mu)$	$2.1 \cdot 10^{-5}$	14.0%	73.5%	34.5%	340k
$B_d \rightarrow J/\psi K_s^0 (ee)$	$2.1 \cdot 10^{-5}$	12.4%	44.6%	34.5%	183k
$B_d \rightarrow J/\psi K^* (\mu\mu)$	$6.3 \cdot 10^{-5}$	13.7%	75.3%	42.8%	1270k
$B_d \rightarrow J/\psi K^* (ee)$	$6.3 \cdot 10^{-5}$	12.1%	45.5%	42.8%	679k
$B_d \rightarrow \bar{D}^0 K^* (K\pi K\pi)$	$8.0 \cdot 10^{-7}$	12.8%	15.4%	43.3%	3k
$B_s \rightarrow D_s^- \pi^+$	$1.4 \cdot 10^{-4}$	13.0%	14.7%	46.8%	171k
$B_s \rightarrow D_s^- \pi^+ \pi^+ \pi^-$	$3.5 \cdot 10^{-4}$	9.6%	12.0%	50.8%	277k
$B_s \rightarrow D_s^- K^+$	$1.1 \cdot 10^{-5}$	12.6%	14.6%	47.5%	13k
$B_s \rightarrow D_s^+ K^-$	$5.3 \cdot 10^{-6}$	12.6%	14.6%	47.5%	6k
$B_s \rightarrow J/\psi \phi (\mu\mu)$	$4.2 \cdot 10^{-5}$	14.2%	71.8%	42.0%	246k
$B_s \rightarrow J/\psi \phi (ee)$	$4.2 \cdot 10^{-5}$	12.5%	44.0%	42.0%	133k
$B_s \rightarrow \mu^+ \mu^-$	$4.0 \cdot 10^{-9}$	19.2%	84.3%	33.5%	30
$B_d \rightarrow \mu^+ \mu^- K^*$	$2.9 \cdot 10^{-6}$	14.3%	70.0%	42.2%	17k
$B_u \rightarrow \bar{D}^0 K^+ (K\pi)$	$1.5 \cdot 10^{-5}$	14.4%	18.5%	41.9%	76k
$B_u \rightarrow \bar{D}^0 K^+ (K\pi\pi\pi)$	$3.1 \cdot 10^{-5}$	11.9%	14.2%	49.0%	117k

Table 10.12: Events accepted and triggered which are written to tape each year (assuming no loss in Level-3). See text for description. The yields are calculated for a constant luminosity of $\mathcal{L} = 1.5 \cdot 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$.

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