

L1 Drift-Chamber Trigger Upgrade Conceptual Design Requirements ¹

Version 0.3

The DCT Upgrade Team

1 Introduction

The basic requirement for the trigger system as a whole is the selection of events of interest with a *high*, *stable*, and *well-understood* efficiency while rejecting background to a level tolerable for the DAQ, data storage and offline processing. The main physics processes and their production rates for the original PEP-II design luminosity of $3 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$ are listed in Table 1. The two photon interaction processes are also significant physics sources which contribute at comparable rates as the other sources, but the precise rates are unknown and their contributions to the trigger rate are more sensitive to the trigger configuration.

Event type	Cross section (nb)	Production Rate (Hz)
$b\bar{b}$	1.1	3.2
other $q\bar{q}$	3.4	10.2
e^+e^-	~ 53	159
$\mu^+\mu^-$	1.2	3.5
$\tau^+\tau^-$	0.9	2.8

Table 1: Cross sections and production rates for the principal physics processes at 10.58 GeV for a luminosity of $3 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$. The e^+e^- cross section refers to events with either the e^+ , e^- , or both inside the EMC detection volume.

With the essentially continuous PEP-II beam crossing at 4.2 ns spacing, the Front End Electronics (FEE) for all detector subsystems (except SVT) are continuously digitizing the detector data and buffering them with a 12.9 μs long pipeline. The dedicated Level-1 hardware trigger system must deliver the L1 trigger to the Fast Control and Timing System (FCTS) within this latency budget before the data at the FEE pipelines expire. Upon a Level-1 Accept (L1A), all detector subsystem data are read out by the dataflow system, feature extracted (sparsified) and transported to the online processing farm as input to the Level-3 software trigger. All FEE systems follow a four rotating event data buffer scheme to allow another L1 trigger to be accepted while another buffer is being readout. However, there is a minimum command spacing of 2.7 μs between successive L1A which is the only

¹<http://www.slac.stanford.edu/BFROOT/www/Detector/Trigger/upgrade/cdr/requirements.pdf>

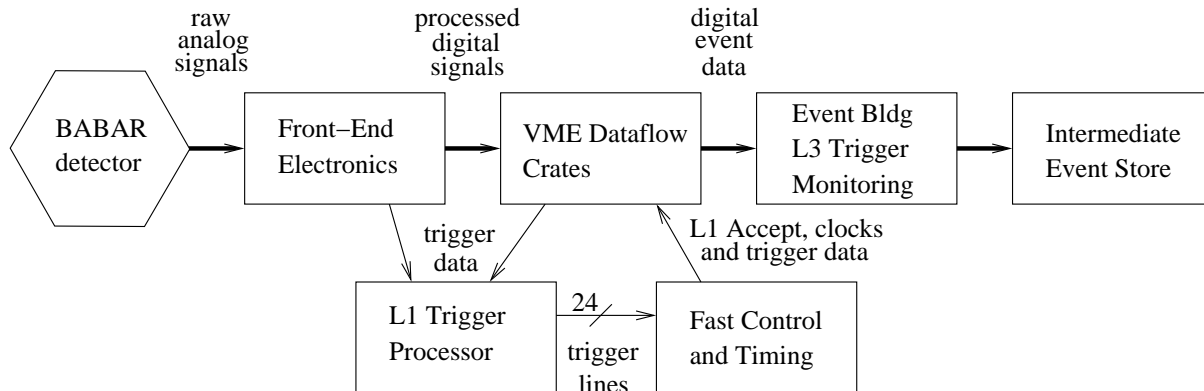


Figure 1: The *BABAR* electronics, trigger, DAQ and online system layout.

significant source of dead time at 0.27%/KHz. The overall layout of the *BABAR* electronics, trigger, DAQ and online system is illustrated in Figure 1.

2 Overview of Current Trigger System

2.1 The original requirements

At design luminosity of $3 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$ beam-induced background rates are typically about 20 kHz each for one or more tracks in the drift chamber with $p_t > 120 \text{ MeV}/c$ or at least one EMC cluster with $E > 100 \text{ MeV}$. Efficiency, diagnostic, and background studies require prescaled samples of special event types, such as those failing the trigger selection criteria, and random beam crossings. The L1 trigger rate was required to be below 2 kHz at the design luminosity, while L3 trigger was required to reduce the output event rate to 120 Hz.

For the existing trigger system, the original requirements demanded the total trigger efficiency of L1+L3 to exceed 99% for all $B\bar{B}$ events and at least 95% for continuum events. Less stringent requirements were applied to other event types, *e.g.*, $\tau^+\tau^-$ events should have a 90-95% trigger efficiency, depending on the specific τ^\pm decay channels. These requirements are indeed met by the current system, with inefficiencies typically shared between L1 and L3 at comparable level. These requirements should still apply to the upgraded system.

The trigger system must be robust and flexible in order to function even under extreme background situations. Performance should only degrade slowly for backgrounds above normal level. Redundancy should be built into the system to measure and monitor trigger efficiencies. It must also be able to operate in an environment with dead or noisy electronics channels. The trigger should contribute no more than 1% to dead time. These requirements are again very much applicable to the upgraded system.

2.2 Current L1 Trigger Implementation

2.2.1 L1 Trigger Overall

The L1 trigger decision is based on charged tracks in the DCH above a preset transverse momentum, showers in the EMC, and tracks detected in the IFR. Trigger data are processed by three specialized hardware processors. The drift chamber trigger (DCT) [2] and electromagnetic calorimeter trigger (EMT) [6] both satisfy all trigger requirements independently with high efficiency, and thereby provide a high degree of redundancy. The instrumented flux return trigger (IFT) is used for triggering $\mu^+\mu^-$ and cosmic rays, mostly for diagnostic purposes. A more complete description of the whole trigger system can be found in [1].

The overall structure of the L1 trigger is illustrated in Figure 2. Each of the three L1 trigger processors generates trigger *primitives*, summary data on the position and energy of particles, that are sent to the global trigger (GLT) every 134 ns. The DCT and EMT primitives sent to the GLT are ϕ -maps. The IFT primitive is a three-bit pattern representing the hit topology in the IFR. The meaning of the various trigger primitive inputs to the GLT are summarized in Table 2.

The GLT processes all trigger primitives to form specific triggers and then delivers them to the FCTS. The FCTS can optionally mask or prescale any of these triggers. If a valid trigger remains, a L1 Accept is issued to initiate event readout. The trigger definition logic, masks, and prescale values are all configurable on a per run basis. For DCT, EMT and GLT, the data used to form the trigger decision are preserved with each event, in the same fashion as the normal subdetector event DAQ data, for efficiency studies.

The L1 hardware is housed in five 9U VME crates. The L1 trigger operates in a continuous sampling mode, generating trigger information at regular, fixed time intervals. The DCH FEEs and the EMC *untriggered personality cards* (UPCs) send raw data to the DCT and EMT at 267 ns intervals which arrive $\sim 1.3 \mu\text{s}$ after the e^+e^- collision. The DCT and EMT event processing times are 4.8–5.8 μs , followed by another $\sim 3.3 \mu\text{s}$ of processing in the GLT to issue a L1 trigger. The L1 trigger takes approximately 1 μs to propagate through the FCTS and the *readout modules* (ROMs) to initiate event readout.

2.2.2 L1 Drift Chamber Trigger

The input data to the DCT consist of one bit for each of the 7104 DCH cells, updated every 269 ns. These bits convey time information derived from the sense wire signal for that cell. The DCT output primitives are candidate tracks encoded in terms of three 16-bit ϕ -maps as listed in Table 2.

The DCT algorithms are executed in three types of modules [2]. First, track segments, their ϕ positions and drift time estimates are found using a set of 24 Track Segment Finder (TSF) modules [3]. These data are then passed to the Binary Link Tracker (BLT) module [4], where segments are linked into complete tracks. In parallel, the ϕ information for segments found in axial superlayers is transmitted to eight transverse momentum discriminator (PTD) modules [5], which search for tracks above a set p_t threshold.

A critical feature of the DCT system is the TSF fine- ϕ data utilizing the time development of the hit patterns to give a hit spatial resolution of ~ 1 mm for a segment. The basic concept

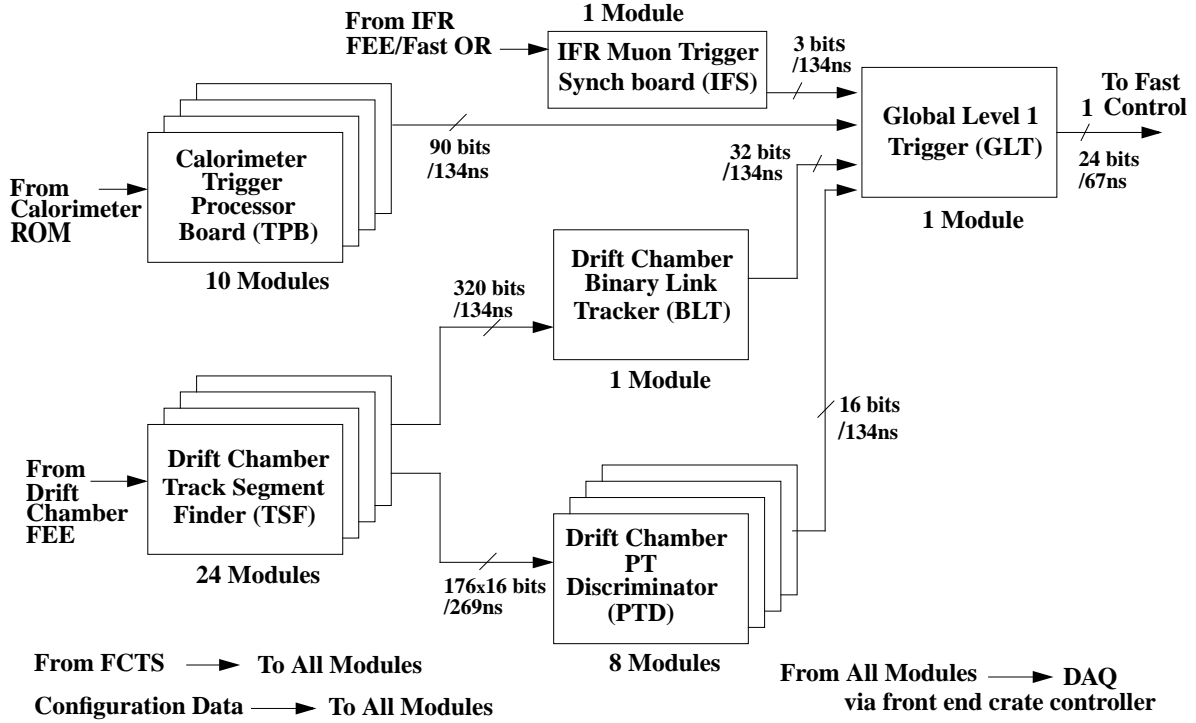


Figure 2: Simplified L1 trigger schematic. Indicated on the figure are the the transmission rates between components in terms of total signal bits.

	Description	Origin	No. of bits	Threshold
B	Short track reaching DCH superlayer 5	BLT	16	120 MeV/c
A	Long track reaching DCH superlayer 10	BLT	16	180 MeV/c
A'	High p_t track	PTD	16	800 MeV/c
M	All- θ MIP energy	TPB	20	100 MeV
G	All- θ intermediate energy	TPB	20	250 MeV
E	All- θ high energy	TPB	20	700 MeV
X	Forward endcap MIP	TPB	20	100 MeV
Y	Backward barrel high energy	TPB	10	1 GeV
U	Muon IFR sextant hit pattern	IFS	3	

Table 2: Trigger primitives from the DCT (BLT,PTD), EMT (TPB) and IFT (IFS). Most energy thresholds are adjustable; those listed are typical values.

is illustrated in Fig.3. The fine- ϕ positions are determined using a Look-Up-Table based on results of calibration for the hit patterns using real data.

2.2.3 L1 Global Trigger

The GLT receives the eight trigger primitives in the form of ϕ -maps as listed in Table 2 along with information from the IFT to form specific triggers that are then passed to the FCTS for the final trigger decision. After time alignment of different types of inputs, the GLT then forms some additional combined ϕ -maps from the DCT and EMT data. These maps include matched objects such as BM for B tracks matched to an M cluster in ϕ , back-to-back objects, B* and M*, which require a pair of ϕ bits separated by a configurable angle of typically $\sim 120^\circ$, and an EM* object for back-to-back EM pairs.

All 16 ϕ -maps are then used to address individual GLT look-up-tables which return three-bit counts of trigger objects contained within those maps, e.g., the number of B tracks or number of M clusters. To count as distinct trigger objects, the map bits are typically required to have a separation of more than one ϕ bin. The resulting 16 counts plus the IFT hit pattern are then tested in logical operations. The permissible operations include: always-pass; or a comparison (\geq , $=$, or $<$) with a configurable selection parameter. A trigger line is then set as the logical AND of these 17 operations. This process is performed for each of the 24 trigger lines.

The GLT derives the L1 trigger time from the timing information of the highest priority trigger. Other trigger signals compatible with this time are retained and cached. The average time is calculated to the nearest 67 ns and the 24-bit GLT output signal is sent to the FCTS every 67 ns. The achieved timing resolution for hadronic events has an rms width of 52 ns.

2.3 L1 Trigger Performance

The L1 trigger configuration consists of DCT-only, EMT-only, mixed and prescaled triggers, aimed not only for maximum efficiency and background suppression, but also for the convenience of trigger efficiency determination.

Although most triggers target a specific physics source, they often also select other processes. For example, two-track triggers are not only efficient for Bhabha, $\mu^+\mu^-$, and $\tau^+\tau^-$ events, but are also useful for selecting jet-like hadronic events and some rare B decays.

The efficiencies and rates of selected L1 triggers for various physics processes are listed in Table 3. Although triggering on generic $B\bar{B}$ events is relatively easy, it is essential to ensure high efficiencies for the important rare low-multiplicity B decays. For this reason, efficiencies for $B^0 \rightarrow \pi^0\pi^0$ and $B^- \rightarrow \tau^-\bar{\nu}$ are also listed.

The efficiencies listed for the hadronic events are absolute and include acceptance losses based on Monte Carlo simulation, and local inefficiency effects. The efficiencies for τ -pair events are for *fiducial* events, *i.e.*, events with two or more tracks with $p_t > 120$ MeV/ c and polar angle θ to reach at least DCH superlayer U5. The Bhabha and μ -pair efficiencies are determined from the data, for events with two high momentum particles, back-to-back in e^+e^- center of mass frame, and within the EMC fiducial volume. The data in Table 3 demonstrate that the DCT and the combined EMT/IFT provide fully efficient, independent

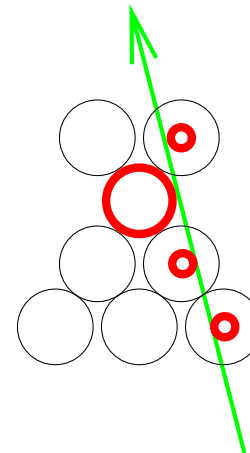
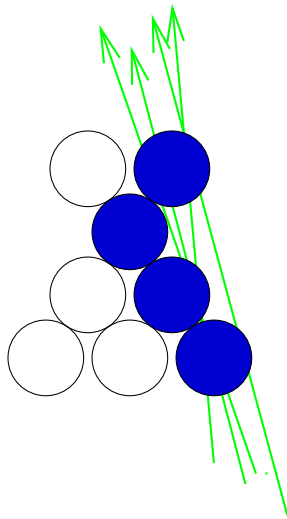
Track Segment Finder Concept

use drift time information to better determine track position and event time

One - shot

versus

Counter - Based



Event time jitter window:

(99% C.L.)

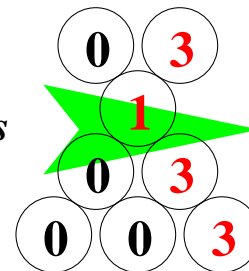
180 ns @ L 1

Position Resolution:

0.05 cell width

→ 1 mm

Look-Up-Table address



position and time

Figure 3: TSF fine- ϕ data concept.

Level 1 Trigger	$\epsilon_{B\bar{B}}$	$\epsilon_{B\rightarrow\pi^0\pi^0}$	$\epsilon_{B\rightarrow\tau\bar{\nu}}$	$\epsilon_{c\bar{c}}$	ϵ_{uds}	ϵ_{ee}	$\epsilon_{\mu\mu}$	$\epsilon_{\tau\tau}$	Rate
A \geq 3 & B* \geq 1	97.1	66.4	81.8	88.9	81.1	—	—	17.7	180
A \geq 1 & B* \geq 1 & A' \geq 1 (D ₂ ⁺)	95.0	63.0	83.2	89.2	85.2	98.6	99.1	79.9	410
Combined DCT (ORed)	99.1	79.7	92.2	95.3	90.6	98.9	99.1	80.6	560
M \geq 3 & M* \geq 1	99.7	98.6	93.7	98.5	94.7	—	—	53.7	160
EM* \geq 1	71.4	94.9	55.5	77.1	79.5	97.8	—	65.8	150
Combined EMT (ORed)	99.8	99.2	95.5	98.8	95.6	99.2	—	77.6	340
B \geq 3 & A \geq 2 & M \geq 2	99.4	81.2	90.3	94.8	87.8	—	—	19.7	170
M* \geq 1 & A \geq 1 & A' \geq 1	95.1	68.8	83.7	90.1	87.0	97.8	95.9	78.2	250
E \geq 1 & B \geq 2 & A \geq 1	72.1	92.4	60.2	77.7	79.2	99.3	—	72.8	140
M* \geq 1 & U \geq 5 (μ -pair)	—	—	—	—	—	—	60.3	—	70
Combined Level 1 triggers	>99.9	99.8	99.7	99.9	98.2	>99.9	99.6	94.5	970

Table 3: L1 Trigger efficiencies (%) and rates (Hz) at a luminosity of $2.2 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$ for selected triggers applied to various physics processes. The symbols refer to the counts for each object.

triggers for most physics processes, although independent triggers for $\mu^+\mu^-$ and $\tau^+\tau^-$ are not individually fully efficient. The efficiencies predicted by the Monte Carlo simulation are generally in good agreement with data when tested using events passing typical analysis selections and based on orthogonal triggers. Prescaled triggers with a very open acceptance of physics events, such as (D2 = B \geq 2 & A \geq 1) or (M \geq 2) are also used to measure the trigger efficiencies.

The trigger rates listed in Table 3 are for a typical run with HER (LER) currents at 650 mA (1350 mA) and a luminosity of $2.2 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$ (current trigger rates for $3.4 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$ is typically 1.2 kHz). These rates are stable to within 20% for the same PEP-II configuration under normal running conditions. However, they are impacted by changes in vacuum conditions, beam currents, and orbits. There are also background spikes from time to time which can double the L1 rate. The joint rate capability of the data acquisition and L3 trigger is currently at $\sim 2.2 \text{ kHz}$ so that most of these fluctuations still do not induce significant dead time.

3 Motivation for the L1 Trigger Upgrade

Although the current L1 system has delivered the required performance for even over the design luminosity of $3 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$, the luminosity for PEP-II is expected to increase by a factor of 10 in the next few years. The ability of smooth datataking at this increased luminosity critically depend on the performance of the trigger and DAQ system.

Dedicated single beam background runs were taken in summer 2000, when PEP-II beam condition was particularly good and stable, to examine the behavior of background as a function of beam current. The L1 trigger rates as a function of the HER beam current is shown in Fig. 4. At the present beam conditions, the HER background dominates the L1 trigger rate. The background trigger rate from HER and LER at the same current was

MD-From-July-6-2000

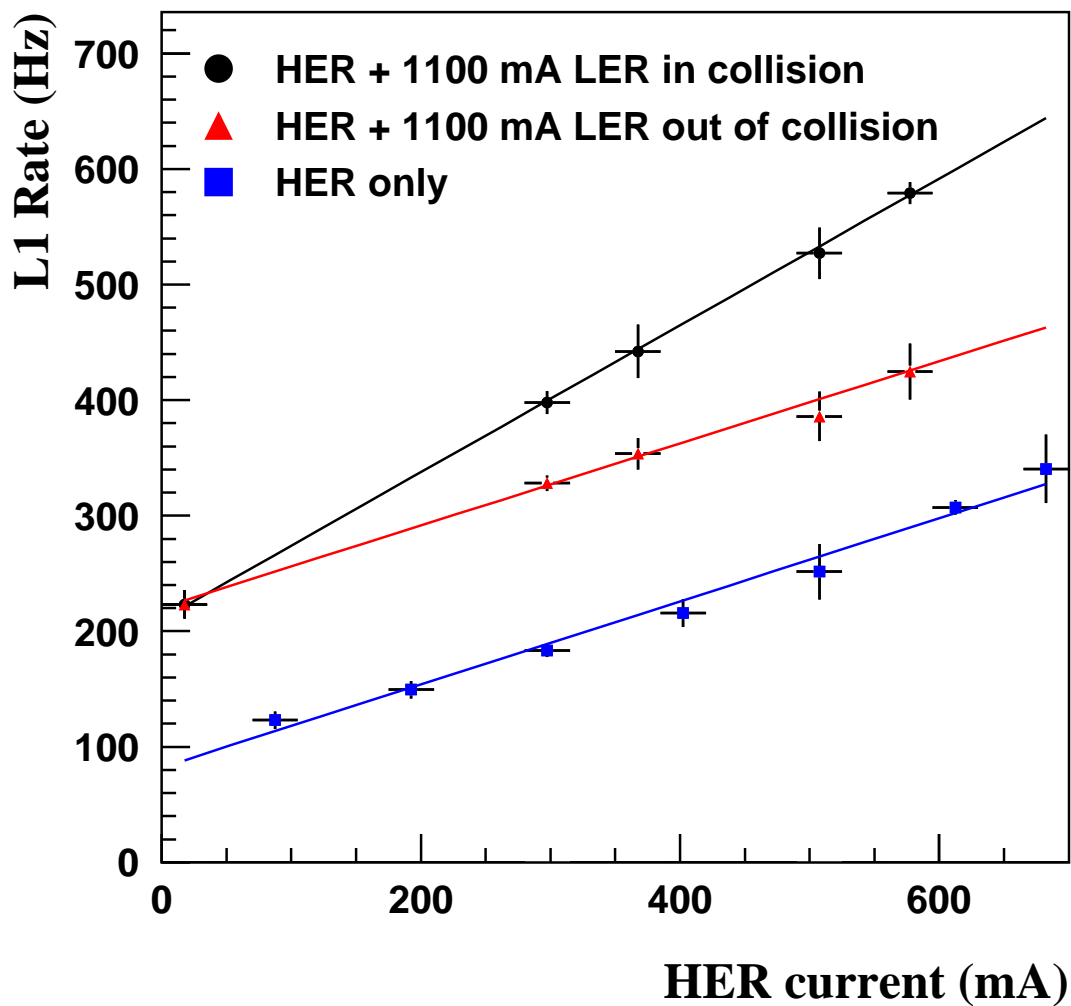


Figure 4: L1 trigger rate as a function of HER current. The luminosity for HER:LER=600mA:1000mA was $1.8 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$. The difference between in and out of collision with both beam present represent the e^+e^- physics collision trigger contribution.

$\sim 3:1$. The extrapolation for L1 trigger rates, based on John Seeman's PEP-II upgrade model and this background study, assuming no trigger upgrade, is listed in Table 4, with separate scaling for the HER and LER background and physics collision terms. For the total expected L1 trigger rate, a best stable condition rate as well as the case of doubling the background trigger rate are listed. The DAQ system should in general never run at the limit of its bandwidth. The doubling background scenario is what the DAQ system must be able to cope with to absorb the background fluctuations without significant dead time loss. This is a necessary standard to match the very high *BABAR* operation efficiency. To ensure stable

Date	Beam	Lumi.	L1 rate (Hz)				
	Current (A) HER/LER	$\times 10^{33}$ ($\text{cm}^{-2}\text{s}^{-1}$)	HER/LER	Lumi.	cosmic & random	Best Total	$2\times$ backgr.
Best 2000	0.8/1.1	2.5	290/140	180	130	740	
Jul/2002	1.1/2.8	8.0	400/360	580	130	1470	2230
Dec/2003	1.3/3.7	11.7	470/470	840	130	1910	2850
Dec/2005	1.5/4.6	33.3	540/590	2400	130	3660	4790

Table 4: Expectations for L1 trigger rate assuming no trigger upgrade for high luminosity scenarios.

running with enough headroom in the DAQ rate, something already need to be done by summer 2002. The online farm upgrade to give Level-3 trigger more CPU capacity will raise the overall rate limitation to 2.8 kHz. Beyond which, some improvements in the dataflow system will be needed.

For expected beam conditions at very high luminosity, there are many elements in the dataflow system can become bottlenecks at L1 rate of 3.5-5 kHz [7]. Some may be solved by possible improvements to feature extraction code, others may involve building more ROMs to share the processing load and improving network bandwidth. An important difficulty in carrying out these improvements is that they all show up at about similar L1 rate, and one must significantly improve *all* of them to move away from the risky operating zone. Any one problem left is sufficient to hold back the whole system. In any case, a more serious bottleneck is the data rate limitation at ~ 4 kHz for the GLINK between DCH FEE and the ROM. To broaden the bandwidth here would require modifications to the DCH FEE to lead out more GLINK fibers in parallel. These concerns all point to the most profitable strategy of improving L1 trigger to reduce the overall L1 rate, which simultaneously avoid all the down stream uncertainties. It also eases the load on the L3 trigger so that L3 can use more CPU time per event to improve its physics selection for logging.

To devise a possible L1 upgrade strategy, we first need to analyze the source of the background L1 triggers. For a typical L1 rate of 1 kHz and luminosity of 2×10^{33} , Bhabha and annihilation physics events amount to ~ 130 Hz. There are also 110 Hz of cosmic ray and 20 Hz of random beam crossing triggers. The remaining triggers are due to lost particles interacting with the beam pipe or other components. The distribution of single track z_0 values as reconstructed by L3 for all L1 triggers is shown in Fig. 5. The most prominent peaks at $z = \pm 20$ cm correspond to a flange of the beam pipe. The peak at $z_0 = -55$ cm

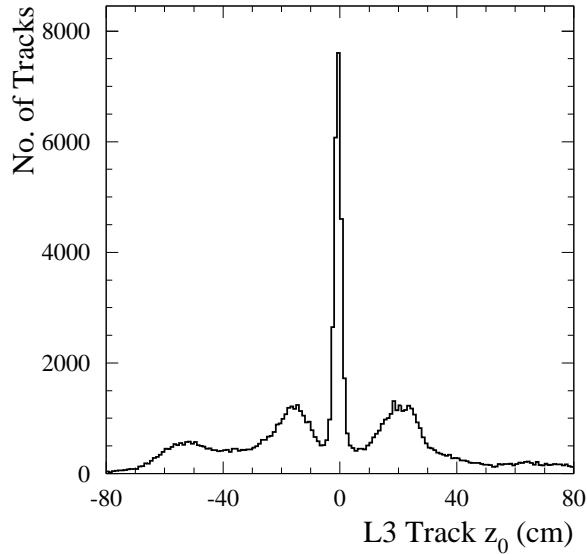


Figure 5: Single track z_0 for tracks in all L1 triggered events, reconstructed by L3.

corresponds to a step in the synchrotron mask. This clearly indicates that an L1 tracking trigger with a resolution of a few centimeters in z would be very effective in suppressing the background tracking triggers. The use of a simple geometrical cut on track z coordinate is more preferable compared to the other main handles of track p_T cut and 2-track back-back angle cuts, which are kinematic based and generally more likely to bias the physics samples. The existing information from the TSF fine- ϕ data for both axial and stereo layers appear to have just the right resolution to allow an upgraded tracking trigger to also selecting tracks in z .

4 DCT Upgrade Design Overview

The various considerations and observations described in the last section has led us to the following proposal for the drift-chamber trigger upgrade:

- A set of 8 new Z - p_T Discriminator (ZPD) boards to replace the existing PTDs. The ZPDs will have 3D tracking capability, utilizing the fine- ϕ data from the TSF for both axial and stereo layers. The ZPDs will still retain the capability of making track p_T discrimination and naturally select only tracks close to the IP in xy also.
- The 24 TSF boards need to be rebuilt to be able to supply the data needed by the new ZPDs. The existing TSFs only output axial layer fine- ϕ data to the PTDs while there are not enough physical traces on board to export the fine- ϕ data from the stereo engines. The new ZPDs also demand more TSF segment data, which can only be effectively selected by merging some of the engines in current TSF.

- There are also 24 new TSF back of crate boards (TSFi) and 8 new interface ZPD boards to transport the factor of 4 more data from TSF to the ZPDs. As each ZPD is meant to be sensitive to tracks with p_T as low as 200 MeV/ c , it also takes data from a wider ϕ region, resulting in an input data volume 6 times that for a PTD. This large input data volume is one of the most challenging aspect of the ZPD design.
- The ZPD can output 2-4 different types of track trigger signals with different p_T and z cuts. They will physically occupy the A' input to the GLT previously used by the PTD and replace the X signal from the EMT, which is not used in any current trigger lines. The replacement of X also require remaking the GLTi interface boards with very simple modification. To utilize the new ZPD signals in the GLT, a very convenient firmware modification is sufficient to supply up to 4 types of trigger objects derived from ZPD signals.

5 DCT Upgrade Design Requirements

The DCT upgrade is primarily to achieve a reduction of background tracking triggers while still preserving good physics efficiency. A reasonable set of goals for the upgrade design are:

- The use of ZPD trigger primitives should allow a $>\sim 50\%$ reduction of the background triggers containing DCT signals in the current trigger configuration, under the current luminosity.
- The above background reduction can be achieved with some loss of efficiency for DCT triggers, but the loss of efficiency for combined pure DCT triggers should not exceed 2% for fiducial 2-prong Bhabha and μ -pairs to be used for luminosity measurements and should not exceed half of the current inefficiencies for $c\bar{c}$ events, fiducial τ events, and for B decay modes already at $<99.5\%$ efficiency.
- The ZPD tracking p_T coverage should extend down to 250 MeV/ c for Superlayer A10 seeds and 200 MeV/ c for Superlayer A7 seeds.
- The combined TSF+ZPD latency must live within the current latency span of TSF+PTD of $5.6 \mu s$ (21 Clock-4 ticks).
- The background rejection performance at the 2005 beam condition (~ 3 times current beam background) should be preserved to be able to reject at least 1/3 of the background triggers containing DCT signals.
- The pure DCT trigger inefficiencies for B decay modes already over 0.5%, should not increase by more than half of its current inefficiency if the DCH operating voltage were to reduce to 1900V compared to the current 1930V setting.

It should be noted that the DCT background trigger reductions should be accompanied by improved control of the EMT background triggers to benefit the overall L1 rate reduction. This may involve going to partially orthogonal triggers for the loose pure EMT triggers

incorporating some DCT information with relatively small kinematical bias. The Z constraint from ZPD should also allow many other alternative p_T and back-back angle cut options to be experimented in conjunction to gain overall efficiency at reduced kinematic bias, yet without significant cost to the L1 rate.

References

- [1] B. Aubert *et al.*, “The *BABAR* Detector”, SLAC-PUB-8569, *Submitted to Nucl. Instr. & Meth.*
- [2] A. Berenyi *et al.*, “Design and Implementation of the Level 1 Charged Particle Trigger for the *BABAR* Detector” submitted to IEEE Transactions on Nuclear Science.
- [3] A. Berenyi *et al.*, “Continuously Live Image Processor for Drift Chamber Track Segment Triggering”, IEEE Trans. Nucl. Sci. 46 (1999) 348.
- [4] A. Berenyi *et al.*, “A Binary Link Tracker for the *BABAR* Level 1 Trigger System”, IEEE Trans. Nucl. Sci. 46 (1999) 928.
- [5] A. Berenyi *et al.*, “A Real-Time Transverse Momentum Discriminator for the *BABAR* Level 1 Trigger System”, submitted to IEEE Transactions on Nuclear Science.
- [6] P. D. Dauncey *et al.*, “Design and Performance of the Level 1 Calorimeter Trigger for the BaBar Detector”, submitted to IEEE Transactions on Nuclear Science.
- [7] C. O’Grady, talk presented at the *BABAR* Detector upgrade Gilchriese review, Oct/2000: <http://www.slac.stanford.edu/BFROOT/www/Organization/Gilchriese/Trg/dataflow.pdf> and an update at the dataflow hypernews: <http://babar-hn.slac.stanford.edu:5090/Hypernews/get/OnlineDataFlow/174.html>