Section V. Subsystem Evaluations

This section of the report contains the detailed evaluations of each major subsystem of the BABAR detector. The general issues relating to increased luminosity are first sketched in the **Motivation and Scope** paragraph(s), and then presented in more detail in terms of a **Risk Assessment**. Where appropriate, the actions that must be taken are described in the subsequent **Remediation** paragraphs. A section on necessary **R&D** may be included. The final section will contain a **Cost and Schedule** estimate. The costs and schedules will be combined and re-presented in **Section VI** of the report, where an assessment of contingency will also be included, for completeness.

A. Trigger

Motivation and Scope

The BaBar trigger system consists of a hardware Level-1 trigger and a software Level-3 trigger with trigger decisions made based on information from the drift chamber and the calorimeter. There was an optional Level-2 trigger in the original design, reserved for future upgrade, with the intention of exploiting the SVT information to improve background rejection. However, the preliminary investigation made in this direction so far indicates that the CPU power required to process the SVT information either at the dataflow ROM level or at the online farm is rather prohibitive. Our consideration for the trigger upgrade is therefore restricted to enhancement in the existing L1 and L3 capabilities.

The existing L1 trigger is designed to deliver decisions within the 12μs common frontend electronics pipeline buffer depth. The design goal was to be able to accept all hadronic and τ physics processes at high efficiency while limiting the L1 trigger rate to <2KHz at the original design luminosity of $3\text{x}10^{33}$. The L1 decisions delivered to the fast control system will result in L1 accepts triggering DAQ readout for the entire detector. The L1 trigger rate limitation is therefore directly coupled to the DAQ readout speed for dead time concerns. The event data delivered to the online farm will then be processed by Level-3 running on the online farm nodes.The original design goal for L3 was to be able to process 2KHz L1 accepts and reject backgrounds to limit the logging rate to <100Hz at $3\text{x}10^{33}$.

The L1 system consists of the drift chamber trigger (DCT), the calorimeter trigger (EMT), the IFR trigger (IFT) which generate their respective trigger primitives and sent to the global trigger (GLT) at 8MHz intervals to allow a global level-1 trigger decision to be made in the GLT. The DCT subsystem contains 24 track segment finder (TSF) modules continuously processing rawdata from the drift chamber at 4MHz intervals. The TSF has a novel feature in exploiting the DCH hit drift time information at hardware level and to give hit resolution at 1mm precision for the fine ϕ data mode. The current system only delivers the fine ϕ data from the 4 axial layers to the 8 Pt discriminator (PTD) modules to form high Pt track triggers. The coarse ϕ data at half cell size resolution from all layers are delivered to the single binary link tracker (BLT) module to identify tracks down to 120 MeV Pt with looser pattern recognition criteria. The DCT output to the GLT are in the forms of 16 bit ϕ maps for the high Pt trigger A' from the PTDs and the long,short track triggers A,B from the BLT. The EMT subsystem contains 8 trigger processing boards (TPB) which processes raw data from the calorimeter ROMs at 4MHz intervals and produce energy sums along 20 ϕ strips and generate 3 types of hit ϕ maps M,G,E for the GLT with different energy thresholds. The forward endcap and the most backward tower ϕ maps X and Y are also sent to the GLT as separate signals. The IFT is used to generate cosmic and μ-pair triggers based on the sextant pairing topology of the IFR hits. The GLT trigger line decisions are typically based on track or calorimeter object counts, or identification of back-back pairs.

The current L1 system logic is essentially all based on rϕ projection information as this is sufficient to satisfy the requirements for a luminosity of $3x10^{33}$.

The L3 system currently operates on 32 online farm Sun Ultra-5 nodes with a processing speed of ~10ms per event, very close to the design goal for handling 2Khz L1 input rate. A small fraction of the online farm CPUs are shared by the online fast monitoring processes. The L3 DCH based filter algorithms use a fast tracking algorithm seeded by the TSF segments to select tracks from the interaction points. The L3 EMC based filters use a fast clustering algorithm over EMC crystals with energy >30MeV. The L3 not only has the main duty of preserving the hadronic and τ physics, it also provides special calibration samples from Bhabhas, $\gamma\gamma$, cosmics, random triggers and L1 passthrough events, as well as serving online luminosity measurement and other important monitoring tasks such as the hadron/Bhabha ratio.

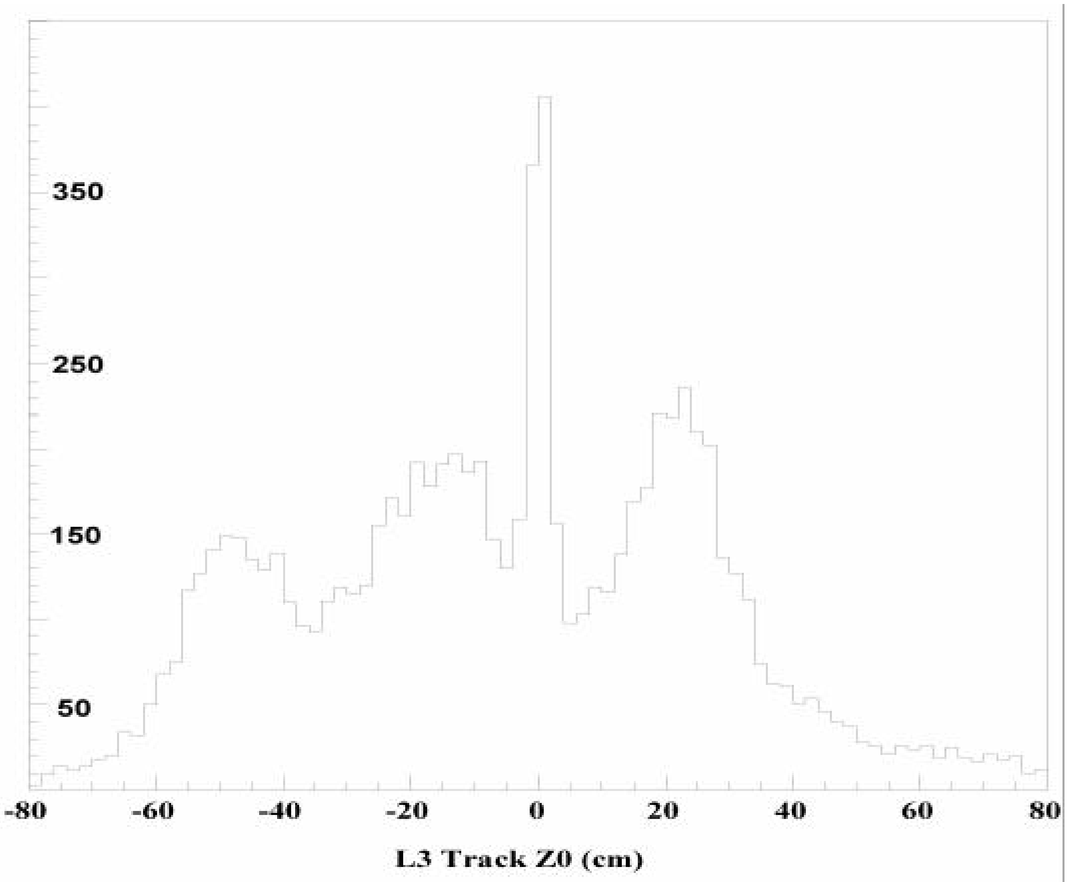
A special task for L3 is the veto and prescaling of Bhabha events. At a luminosity of $3x10^{33}$, the L1 triggered cross section of ~45nb of Bhabha events can amount to 135Hz of logging rate, which is clearly prohibitive. It is therefore essential to identify Bhabha events in an efficient and clean manner, to preserve only a prescaled fraction of Bhabhas while reject the rest.

Both the L1 and L3 triggering algorithms are aimed at high efficiencies for most of the major physics processes using the pure DCH and EMC based triggers separately. This orthogonality allows trigger efficiencies to be measured from data in a simpler manner and also provides maximal stability of the overall trigger efficiency against individual detector performance fluctuations.

Current L1 Rates, Background and Expectations

The L1 trigger rate at $1x10^{33}$ is typically 700Hz , but there is a substantial variation in the rate depending on the PEP-II beam conditions. Sometimes this can change by 50-100%, e.g. during the January 2000 startup. At this luminosity the typical beam currents are 500mA and 1000mA for the HER and the LER respectively. Tests from single beam runs indicate that the dominant source of L1 trigger background comes from the HER. Through the examination of the track origins in L1 passthrough events, it is found that the most significant source of the background triggers are from lost particles interacting with beam line components.

The following plot shows the Level-3 track z_0 for L1 passthrough events in a typical colliding beam run:



The tracks at z_0=0 correspond to colliding beam events. The peaks at Z_0=±20cm and –50cm correspond to lost particles interacted with the beampipe flange and a step in the synchrotron mask respectively. A more detailed analysis of the tracks from these beam wall interactions show that the background vertices are mostly concentrated in two spots at each end of the beampipe in the horizontal plane. Further investigation of the correlation of trigger rates to vacuum conditions around the ring indicate that the trigger rate is mostly only sensitive to the vacuum quality near the IP section. It is clear that these background events are let in primarily because of the lack of track z information in the L1 trigger.

Some recent firmware improvements to the BLT and PTD are expected to bring the typical L1 rate to ~550Hz at $1\text{x}10^{33}$. Further reduction to the L1 rate without upgrade would have to sacrifice the efficiencies or the orthogonality of the triggers through increased particle multiplicity requirement or heavy use of combined DCT and EMT information. This would result in a trigger configuration vulnerable to any deficiencies in either the DCH or the EMC and a much more difficult to measure trigger efficiencies. We therefore only consider the present trigger configuration as the baseline.

The following table summarizes the estimated L1 trigger rate composition expected for the various luminosity upgrade stages without further L1 upgrade. The rates are tabulated for two scenarios S1/S2 which assuming background trigger rates scale linearly and quadratically to the beam currents respectively:

Luminosity (10^{33})	1	3	6	15
Beam currents HER/LER (mA)	500/1000	1100/2000	1100/2900	1300/3800
Cosmics Rate (Hz)	100	100	100	100
Colliding Beam (Hz)	80	240	480	1200
HER background S1/S2 (Hz)	250	550/1210	550/1210	650/1690
LER background S1/S2 (Hz)	120	240/480	350/1010	460/1730
Total L1 rate S1/S2 (Hz)	550	1130/2030	1480/2800	2410/4720

Table 1. L1 Rates Assuming BLT/PTD Firmware Improvements Employed

These two background scaling scenarios probably cover the most optimistic and the most pessimistic cases. The expected L1 rates are already at risk to saturate the current dataflow DAQ rate capability of ~2 KHz for the $6\text{x}10^{33}$ stage, and almost certain to be beyond the current dataflow limit for $1.5\text{x}10^{34}$. In any case, we cannot in fact run exactly at the DAQ limit given the known rate fluctuations. Some head room is always needed in practice.

L1 DCZ Trigger Upgrade

The excessive L1 trigger rates at the beam currents of the high luminosity stages can cause significant stress in the overall online system. It is therefore very much desirable to pursue a viable L1 upgrade which can bring many benefits:

- It eases the demand on the dataflow DAQ upgrade.
- It reduces the input rate to L3.
- A higher physics fraction in L1 triggers also allows L1 trigger efficiencies being measured more easily from L1 passthrough events.

As explained previously, we have very little room to reduce background through kinematic means. Knowing the source of most of our trigger background being beam wall interactions, the only significant distinction remains between the background and physics events are in the track origin information. For this reason, there is very little one can expect to gain from the EMT triggers due to the lack of particle origin information. The current PTD->DOCAD minor upgrade already explores the fine ϕ information in the PTD to reject tracks not coming from the IP in the XY view. Due to the rather small beampipe at a radius of 2.5cm where most of the beamwall interactions originate from, the background reduction from XY view DOCA cuts is rather limited.

The major geometrical information remaining is the track z0. As shown earlier in this section that the major source of background trigger originate from lost particle interactions at $|z|$~20cm. To make a significant step in background reduction, a desirable track z resolution for triggering is 5-10cm. As described in the introduction subsection, the DCT TSFs actually have track fine ϕ data at a resolution of 1mm level. Given a typical stereo angle of 50mrad, the TSF fine ϕ data for the stereo layers translate to ~2cm z resolution. This is in the relevant range for the consideration of a DCZ trigger, but by no means trivial to guarantee the existence of an actual workable design. Given the novelty of using stereo information for L1 trigger, the effectiveness of such a trigger upgrade needs a detailed algorithm study. Fortunately, this design can be done from the existing TSF DAQ data and Monte Carlo simulation to get reliable efficiency and background rejection rate.

If this succeeds to reduce the tracking trigger rate significantly, there is still an issue that the runaway EMT background trigger rates will dominate and undermine the overall L1 rate reduction. We are at present unwilling to place DCT backing to the EMT triggers partly because the DCT information without Z restriction hardly helps the rate reduction if only adding a low track multiplicity backing. Increasing the tracking multiplicity even to 2 or 3 would already start introducing kinematic correlation and bias. With the track Z information from the DCZ, a simple one IP track DCT backing to EMT triggers would be much more useful rate reduction combination with a minimal kinematic bias. We therefore have a coherent overall strategy for L1 rate reduction with the availability of the DCZ.

Assuming that an effective algorithm is obtained, the hardware implementation still has many issues to consider. The new DCZ trigger boards can, for example, become a combined 3D track trigger simultaneously discriminating on track Pt/DOCA/Z. Given the extra complexity, this may take ~16 9u boards to replace the current 1+8 BLT+PTD system. Depending on the actual design of the new DCT, this may or may not involve changes to the GLT to utilize the new DCT inputs.

A major issue of the new DCZ trigger is that they must have the access to TSF fine ϕ data for stereo layers, which are currently not routed to the TSF output. It is very much desirable if it only takes some firmware upgrade to the TSF to bring the relevant signals out. The fine ϕ information are present at the TSF engines for all cells but only the axial layer data are transferred via 12 traces to the PTD data reducer at the TSF output. The stereo layer data are sent to the BLT data reducer in the coarse mode via 2 traces. Even a simple hardware modification such as adding some traces to the existing TSF may be rather difficult as the TSFs will be in operation continuously so that there may not be enough time to make the hardware modifications as well as completing the test all during a shutdown. For the firmware upgrade only option, the possibility of simply sending the data at higher clock rate via the small number of traces between the TSF engine and the data reducer is under investigation. The last resort option is to rebuild all the TSFs, which has all the freedom to make the best modifications to suit the need of the new DCZ, yet these are simple modifications which will effectively only require the M&S cost. However, it will be a major board production and testing effort.

L3 Rate, Composition and Upgrade

For the current L3 version in operation at $1x10^{33}$, the typical output rate can be categorized as follows:

L1 pass-through	5 Hz
Cosmic + random triggers	<0.5 Hz
Bhabha prescale	10 Hz
Other calibration QED processes	4 Hz
DCH+EMC physics filters	40 Hz
Total Rate	60 Hz

Only a small fraction of the L1 passthrough and half of the prescaled Bhabhas are actually fed into OPR for full processing. The `Other calibration QED processes' category contains $\gamma\gamma$, radiative Bhabhas, prescaled online luminosity Bhabha etc. All the categories other than the physics DCH+EMC categories will be maintained at a constant Hz rate at higher luminosities through prescaling. So from a long term point of view, the remaining 40Hz of events passing physics filters will be of more importance as they will *largely scale linearly to luminosity*. Among the 40Hz passing the L3 physics filters, we expect 5.6Hz of hadron+τ+μ (Physics) and 13.5Hz of Bhabhas evaded the current Bhabha veto. The remaining 21Hz is a combination of beam-wall interaction background, as well as other real colliding beam events such as 2-photon interactions. The near future improvements are expected to bring a further 5Hz Bhabha veto and ~10Hz reduction of beam background. This will bring the rate for Physics:Bhabha:Background to 6:6:11 (total ~23nb). With the worst scenario of background scaling linearly with luminosity, this will still be confined to 90Hz at $3x10^{33}$.

However, this 23nb cross section will extrapolate to a rather excessive 370Hz as an upper limit at $1.5x10^{34}$.

The long term task of further reducing the last 6nb of Bhabhas and tackling the last 11nb of background/ other-collision will become more difficult. In the case of the Bhabha veto, even an efficiency of 95% will still miss >2nb of Bhabha events (34Hz at $1.5x10^{34}$) in the physics logging. To carry out these tasks, some improvements to the L3 DCH tracking will be a major help. There are known shortcomings in the L3 tracking constrained by the present L3 CPU budget of 10ms/event:

- Tracking pattern map only covers tracks with Pt>250 MeV/c.
- Tracks must have at least 5 segments in 6 layers. This prevents finding tracks exiting below layer 5.
- Allowed track segment patterns rather simple so that it is rather sensitive to dead cells.
- The L3 track resolution ~ a factor of 2 worse than the full reco tracks.

There can be significant benefits if some of these aspects can be improved. However, these improvements are expected to demand significantly increased CPU budget. For reducing the beam-wall background, we may consider positive identification of beam-wall interaction vertices at known hot spots as a veto process, which can benefit from L3 tracking resolution and efficiency improvements. The Bhabha veto process can profit from some improvements in the low angle tracking where it is known that some Bhabha veto efficiencies are lost due to the missing tracks at low forward polar angles. Background rejection will always improve with tightened d0,z0 cuts which again crucially depends on tracking resolution. Discrimination against other collision processes will rely more on kinematics, for which the reach into low Pt to allow better multiplicity counting would be most helpful. In general, the improvement of tracking will lead to more precise classification of the events.

The L3 upgrade will be an adiabatic process of continuous improvements. There will be a steady increase of L3 load for various types of monitoring and special physics filters. Although most of these additional tasks are unlikely to demand major CPU fractions, the improvement of the basic tools such as the L3 DCH tracking to enhance the performance of all the filters will on the other hand require major increase in the CPU budget. The detailed models for online farm CPU upgrades will be discussed in detail in the computing section.

Cost and Schedule

The cost and schedule for production of the DCZ Level 1 Trigger is detailed in Section VI. Approximately 2 years is expected to be required for design and fabrication. It is assumed to be completed, tested and in place in Summer 2002. However, this implies that the period from late 2001 to early 2002 when PEP-II luminosity can reach 0.6-

$1\text{x}10^{34}$, it is possible that some moderate upgrade of the DAQ system and L3 are already needed by then to cope with possbile L1 rate increase to ~3 KHz.