SDC-91-00098

# SDC
# SOLENOIDAL DETECTOR NOTES

## CONCEPTUAL DESIGN OF THE SDC TRIGGER FROM THE SDC TRIGGER GROUP

September 30, 1991

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# 1 Introduction

In a hadron collider the trigger is the start of the physics event selection process. At SDC the trigger will analyze on the order of $10^8$ events per second. The analysis is done in real time, and there is no going back to recover mistakes. A decision to retain an event for further consideration has to be made every 16 nsec. It is essential for publishing correct and timely physics to know the efficiencies for different physics signatures, to check that everything is working, and to have clear and adequate book-keeping. In this document the SDC trigger group describes the basic trigger design as agreed on in a series of multi-day meetings [1]. There are still some big open questions, but there is broad agreement on many of the fundamental issues and philosophies.

In this note we lay out some of the broadest considerations for the trigger and data pipeline. We need agreement from the rest of the collaboration on the overall philosophy and strategy. Detailed simulation is beginning to firm up the specifics. We are pleased that we have a solution to the overall strategy that is robust against higher luminosities and is relatively immune to large-scale systems problems inherent in connecting many electronics systems spread over a large volume.

In the environment of a hadron collider it is necessary to define individual data sets for different types of analyses early, before taking the data. Thus one will have dilepton and multi-lepton data sets for top and Higgs searches, lepton plus missing $E_T$ for W, W', and top physics, inclusive electron sets for calorimeter calibrations, etc. Background samples for these data sets need to be made at the same time; similarly other samples are necessary for measuring efficiencies in event selection. The trigger has to select these samples in real time along with the main data samples. This requirement has an impact on the structure of the trigger: the trigger has to have the flexibility to have overlapping triggers so that efficiencies can be measured from the data. The overlaps include different thresholds, relaxed individual criteria, prescaled samples with one criterion missing, and overlapping physics signatures. For example, to measure the inclusive jet spectrum one has several triggers of successively higher thresholds, with the lower thresholds prescaled by factors that allow a reasonable rate to tape. One 'layers' such triggers all the way down (in jet threshold) to minimum bias events so that the full spectrum can be reconstructed with statistics. The efficiency and bias of each higher threshold can be measured from the data sets of lower threshold if it is done correctly.

One has only to think of making a single-pass analysis with a rejection factor of $10^5$ or greater without being able to see what one has missed to understand the problem. The measurement of efficiencies and biases as well as the book-keeping have to be designed in from the start.

The design of the trigger is of course a hardware project, but the trigger performs the bulk of the rejection factor in selecting the physics and thus has to be treated as a physics analysis. Philosophy and structure are important to the physics of the whole collaboration. The philosophy we have agreed to is that the trigger is 1) inclusive, 2) local, 3) measurably efficient, and 4) fills the bandwidth with a high purity stream. Inclusive in that it doesn't select on global topologies more than necessary; local in that it uses the local signatures of the basic building blocks- electrons, muons, jets, with (perhaps) neutrinos as the only global entities. Measurably efficient means that we want it to be efficient at a known and relatively large value for the very high $E_T$ processes of interest. The fourth criterion implies that at each point in the pipe-line (Level 1, Level 2, Level 3) one wants as pure a sample as possible in order to be able to see what is happening and to use the bandwidth efficiently. Each of these topics is discussed in turn below.

We have defined several benchmark processes to judge trigger performance. These processes are interesting in their own right, but are typical of final states in more interesting new physics processes. They represent inclusive triggers that should be highly efficient for new physics signatures. The benchmarks are:

1. Electrons from inclusive W's
2. Muons from inclusive W's
3. Jets at high $P_T$
4. High $P_T$ photons
5. Missing $E_T$
6. Low $P_T$ Multileptons (for B physics)

These benchmarks are not the whole story, clearly, but we ask that any trigger design be able to do a decent job on at least these inclusive channels. If it can, it will do well on more distinctive new physics signatures.

We have set the goal, somewhat arbitrarily, that the inclusive lepton triggers be at least 50% efficient for leptons from W's that enter the fiducial volume (the inefficiency is largely due to the kinematic cut on the lepton transverse momentum by the trigger threshold). The spirit of this is that the trigger should be able to recognize moderate-$P_T$ electrons and muons at a high efficiency. The inclusive lepton triggers will also be efficient for $Z \to ee$ and $Z \to \mu\mu$. The 1 Hz of Z's detected will be very useful for calibrating the detector.

By local we mean that the trigger selects electrons, muons, and jets on the basis of the local information that is tied directly to their distinctive signatures, and does not, if possible, select on topologies that depend on the physics of the events. For example, electron showers are small and extremely well defined in the transverse and longitudinal planes. Information from the few calorimeter towers struck, the shower max detector, and the tracking detector in the region of the electron— a small well-defined cone in the detector— is all one needs to define an electron.

By measurably efficient we mean, as discussed above, that the trigger is highly efficient for high $E_T$ processes, and the tools to measure lepton and jet efficiencies are built into the trigger architecture from the start. One such tool is overlapping triggers– the trigger is not hardwired, but is programmable so that multiple triggers of different thresholds and cuts can run in parallel. A second tool is prescaling- triggers of lower threshold or weaker criteria can run in parallel to accumulate data sets for directly measuring the efficiency. We also propose the ability to drop one of the cuts in a trigger on a prescaled basis for the same purpose.

Finally, by efficient use of bandwidth we mean two things. First at each level of the trigger one should aim to do as clean a job as possible at identifying leptons and jets. Carrying events that one does not want in the pipeline muddies the monitoring of the trigger performance and the measurement of trigger efficiencies. The cuts in the trigger should be as consistent as possible with those of the offline (hence the local triggers). Second, bandwidth to permanent media is measured in bytes per second, and not events per second. The number of bytes per event necessary for analysis varies widely- it makes little sense to write the same event size for each event. Calibration events, with only a single electron triggering, could be restricted to just the several towers in the neighborhood of the electron and the track. W or Z events that have no other distinguishing features could be compressed to 1000 words or less. The data sets for monitoring trigger and detector performance can be packed in Level 3 and made much smaller.

The design as we present it below has optical fibers [2] bringing up trigger signals to a mapping of the detector in the control room. However in some systems it makes sense to do the pattern recognition on the detector; this is particularly true of tracking systems with a large number of channels where the fiber count would be enormous. The advantage to downstairs is the decrease in fiber count- the advantages to upstairs are access and the clean interface between front-end and trigger responsibilities. In reality we will end up with a mix, but there are still open questions here for several of the subsystems.

One final introductory comment- the trigger is only as good as the quality of the signals from the detector. The problem of digitizing signals from an extended scintillator source at 60 MHz is not trivial. It will be necessary to have collaborative efforts with front-end groups to certify the quality of the fast-out signals.

We now discuss the level structure of the trigger, and the roles of level 1, level 2 and level 3. A schematic diagram of the dataflow for SDC is shown in Fig. 1.

## 1.1 Level 1

Level 1 is the first level trigger, and operates within the time that every crossing is stored in the data pipeline so that it is nearly deadtimeless. The Level 1 trigger will be determined by 'local' decisions, i.e. one identifies electrons, jets, photons, and muons using information from calorimeters, shower max sampling, preradiators, tracking chambers, and muon systems in a given element of $\eta - \phi$ space. Simple combinations of these items from a digital list form the basis of the Level 1 triggers. This strategy effectively moves a great deal of the event selection down into the very first level of the trigger. The goal would be to have electrons, jets, photons, and muons selected at Level 1 time with a purity of approximately 50%. It will take detailed simulation to see if this is achievable, and what segmentation and information will be necessary. This work has now begun, and the first results on trigger rates are available. The ability to monitor and control trigger rates, hot and dead channels, and pathological conditions will have to be built in to Level 1 from the beginning.

## 1.2 Level 2

Whereas Level 1 has to make a decision within 4 microseconds of every crossing (and of the 4 microseconds less than 2 are available to L1- the rest are in transit times) and is synchronous at 60 MHz, Level 2 can take up to 100 microseconds, and is asynchronously buffered at the Level 1 trigger rate of approximately 10 KHz. These two differences make Level 2 much more flexible than Level 1. Level 2 is the place then that we deal with information that arrives too late or is too complicated to use in Level 1. We feel that it is too risky to count on being able to solve all problems

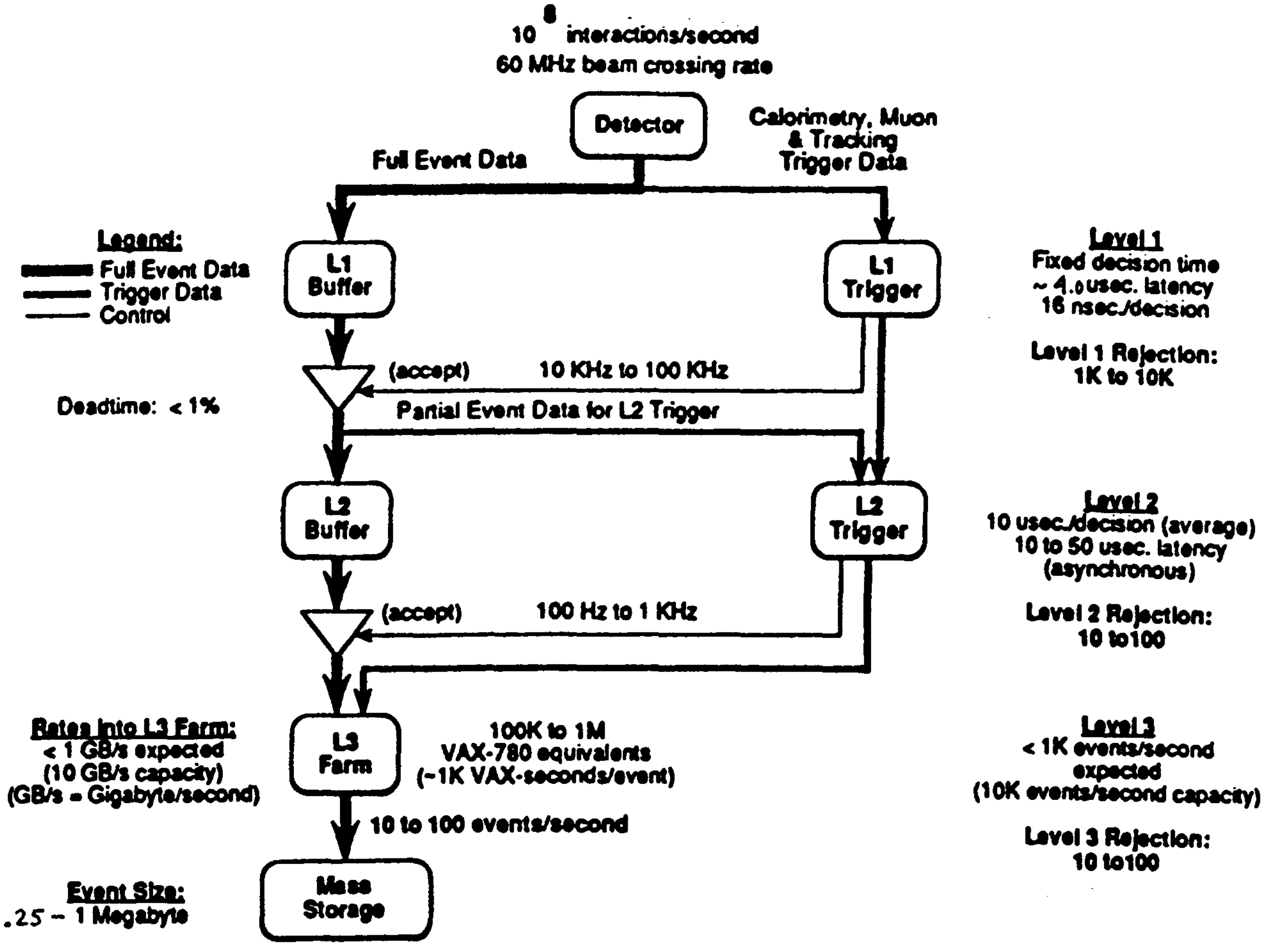


Figure 1: The SDC data flow and trigger structure.

in Level 1 given the tight time constraint, and need the 'hooks' in at Level 2 time for more sophisticated processing.

Level 2 has access to all of the same information that Level 1 does through the trigger crate bus structure. Consequently Level 2 can do further combinatorics and other topological calculations on the digital list of electrons, muons, photons, and jets transmitted from Level 1. In addition Level 2 may access information not available at Level 1 time, such as the information from the silicon vertex detector, which has a separate data path upstairs and could therefore be available to Level 2 to form a displaced vertex trigger. Separate data paths for Level 2 may be added for specific detectors to work at the full granularity of the detector. Because the time available for Level 2 is almost 100 times longer than for Level 1, much less bandwidth is needed for such paths. Finally, there may be specialized processors working downstairs at the full detector granularity that then ship up condensed data. This is easy in one of the two front-end calorimeter schemes, and not in the other, however.

Level 2 thus consists of processors upstairs performing digital operations on the Level 1 list as well as accessing the raw trigger information. In different subsystems, depending on the accessibility of the full granularity information at Level 1 time (a front-end decision), there may be local Level 2 processors downstairs. The processors can be supplemented by hardwired custom digital processing boards for certain calculations, and the process is programmable in a straightforward way. Level 2 also should contain some redundancy and flexibility to deal with unexpected situations in Level 1. As Level 2 has dead-time the book-keeping as well as the control of dead-time, trigger rates, and cross-sections has to be built in from the beginning.

### 1.3 Level 3

Level 3, which consists of an array of commercial computers, does reconstruction and event filtering with the primary goal of making data sets of different signatures on easily accessed media. We envisage that data sets of processes with clear signatures (e.g. multileptons, W's, Z's, high $P_T$ leptons, large missing $E_T$, etc.) would be selected in Level 3 for the final analyses. "Tape" would be used largely for archival purposes and for those analyses not yet mature enough to move the event selection into Level 3.

## 2 General Features of the SDC Hardware Trigger

In general, the SDC trigger identifies physics objects such as electrons, photons, jets, muons, and neutrinos and selects events based on interesting combinations of one or more such objects. The trigger uses detector information from local eta-phi regions to find these physics objects (except for neutrinos). In some cases information from a single detector component is sufficient while in other cases the trigger must match local eta-phi information from several components. The algorithms to identify the various physics objects are discussed below.

Although the basic components of the trigger algorithms come from experience gained at present hadron colliders, trigger simulations are necessary to understand how best to implement these algorithms at the various hardware trigger levels. Trigger simulation studies using fast parameterizations of the SDC detector response [3, 4] are currently in progress, and preliminary results for Level 1 trigger rates as a function of various cuts are available. These rate studies coupled with more detailed studies planned for the near future will help answer many questions concerning how to optimize the trigger algorithms.

Jet triggers require only local calorimeter information. The basic unit of calorimeter trigger information is the trigger tower - in general, 4 physical towers ($2\eta \times 2\phi$, resulting in a trigger tower of size 0.1 X 0.1). At Level 1 the trigger will identify jets by summing the energy over an as-yet undetermined number of EM and HAC trigger towers and comparing this energy with several thresholds. The optimal number of trigger towers, which will be determined from simulation studies, is a function of jet efficiency and hardware considerations for the summing circuits. Figure 2 shows the Level 1 jet trigger rates versus $E_T$ threshold as a function of the number of trigger towers.

Electron and photon triggers require information from the calorimeters, shower max detectors, and tracking chambers in order to keep thresholds low enough without raising the trigger rates above DAQ specifications. The Level 1 algorithm used to identify electrons or photons will contain some or all of the following requirements:

1. Compare EM trigger tower energy with several thresholds (one for inclusive electrons, one for di-leptons, one for photons, one for very high $E_T$ electrons, ...).

2. Require that the ratio of HAC/EM calorimeter energy in the trigger tower be small.

3. Require that a track, with $P_T$ greater than some threshold, point to the cluster.

4. Require that there is a position match in the phi direction between the above track and the shower max detector shower.

5. Require that the calorimeter energy deposited in the region surrounding the electron/photon cluster be small for the isolated electron/photon trigger.

The trigger requirements for EM clusters will vary considerably depending on the trigger type. A relatively low $E_T$ inclusive electron trigger will need very strict cuts to keep the rates low enough for the DAQ system. A photon trigger will obviously require the absence of a track; consequently, the $E_T$ threshold will be higher than the inclusive electron threshold. Since the rate for di-lepton triggers is much lower than the rate for inclusive triggers, the thresholds can be lowered, and/or the requirements can be relaxed. For such a trigger, the electron $E_T$ threshold will be lower and both the isolation and track match cuts may be loosened or eliminated. High $E_T$ leptons are an important signature of new physics; therefore, the trigger efficiency should be

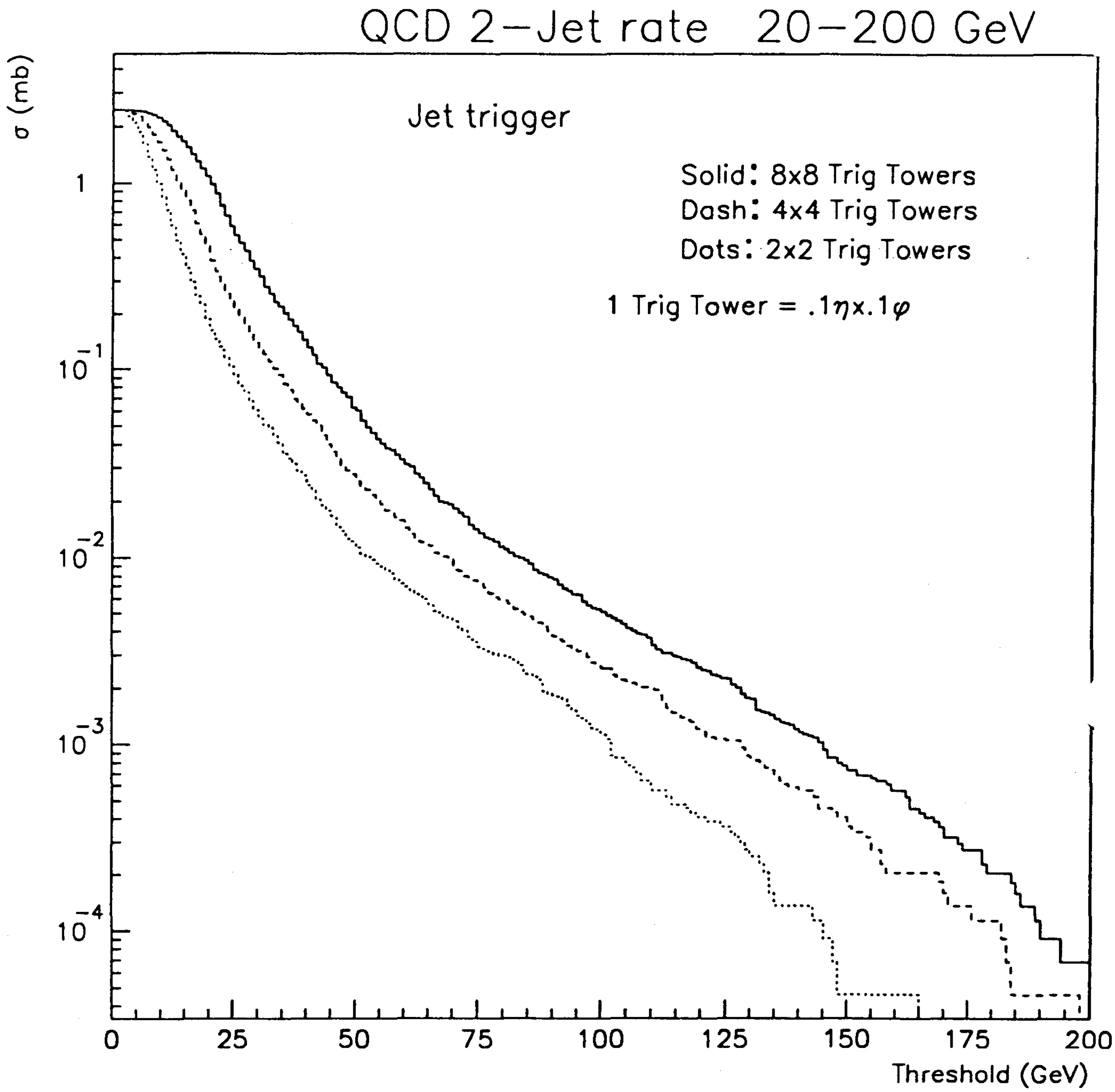


Figure 2: The level 1 inclusive jet trigger rate versus the $E_T$ threshold for various tower sizes.

very high for these objects. There will be an inclusive, high $E_T$ lepton trigger with loose cuts. For electrons this trigger may only require high $E_T$ and small HAC/EM.

Figure 3 shows the inclusive central electron trigger rate versus cluster $E_T$ for various sets of cuts. Table 1 lists the inclusive electron trigger rates versus cluster $E_T$ where the trigger rate is for both central and endplug electrons. In the central region the Level 1 rates using isolation and track cuts are in the range of a few kHz at a 15 GeV threshold. Using these central cuts and requiring only HAC/EM and isolation cuts in the endplug region, the inclusive rate is under 3 kHz for a central threshold of 15 GeV and an endplug threshold of 30 GeV. In parallel with this trigger a central trigger at the higher threshold of 25 GeV with no isolation requirement would add approximately 3 kHz. The 15 GeV threshold would also have some fraction of triggers, say 5%, prescaled with each cut, isolation, track match, etc., relaxed or removed.

| *Rate* (kHz) | | Endplug Threshold (GeV) | | | | |
|---|---|---|---|---|---|---|
| | | 10 | 20 | 30 | 40 | 50 |
| Central Threshold (GeV) | 10 | 20 | 8.5 | 6.0 | 5.5 | 5.5 |
| | 15 | | 5.0 | 2.7 | 2.4 | 2.2 |
| | 20 | | 4.8 | 2.3 | 2.2 | 2.0 |
| | 25 | | | 2.0 | 1.8 | 1.7 |
| | 30 | | | ~2.0 | - | - |

Table 1: Inclusive electron trigger rates for had/em < .05 and isolation < .07. A track with $P_T > 10.0$ GeV was required in the central region.

At Level 2 the trigger may have access to additional information relevant to the electron cluster. The Silicon Tracking detector should produce track segments by Level 2 times. This information could be used in several ways. If the intermediate tracking chambers do not provide tracks for the trigger, than tracks from the Silicon tracker could fill this need at Level 2. Matching central and/or intermediate tracking chambers and silicon tracker segments could provide increased momentum resolution at Level 2. Finally, conversions are expected to be the dominant background to inclusive electrons. Tracks in the silicon tracker could be used in a conversion-finding algorithm to help reduce some of this background (or confirm these as electrons for calibration).

There is still some question about when the shower max information will be used in the trigger (i.e. Level 1 or Level 2). Presently the simulation studies do not include parameterizations for the shower max response. The response based on Geant simulations [5] will soon be included, and better estimates of the background rejection from shower max matching will then be available.

The simulation was developed to understand which background processes contributed significantly to the electron rates. Using detailed information about the particles incident at the calorimeter face of the electron trigger tower, the backgrounds were separated into 4 classes: (overlap between a photon and a charged hadron, con-

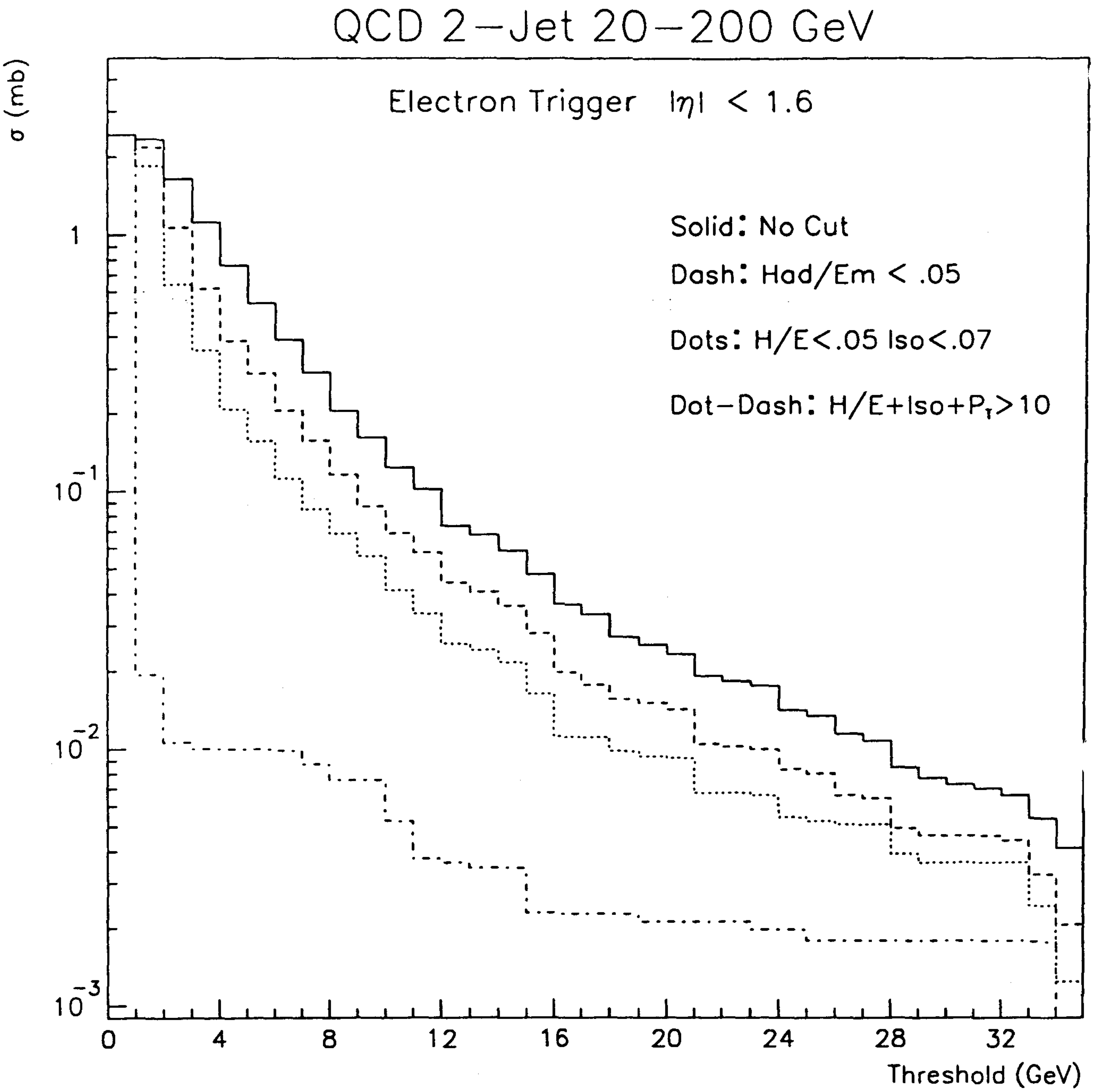


Figure 3: The level 1 inclusive electron trigger rate in the barrel calorimeter versus the $E_T$ threshold for no cut (solid), Had/Em cut (dashed), Had/Em and isolation (dot), and finally adding the requirement of a track match in $\phi$ with the tower (dot-dash).

version, charged hadron showering early in the EM calorimeter, both overlap and conversion). Table 2 shows preliminary results on the percentage of background for loose cuts (HAC/EM < 0.1, isolation < 0.1, track $P_T > 5$ GeV, cluster $E_T > 10$ GeV) and for tight cuts (HAC/EM < 0.05, isolation < 0.07, track $P_T > 5$ GeV, cluster $E_T > 10$ GeV). The statistics were moderate and the percentages in general did not vary greatly as a function of the cluster $E_T$.

| Cuts | Event Type | Number of Events | Percentage |
|---|---|---|---|
| Loose | Overlap | 18 | 25 |
| | Conversion | 30 | 42 |
| | Early shower | 15 | 21 |
| | Overlap/conv | 8 | 11 |
| Tight Cuts | Overlap | 9 | 20 |
| | Conversion | 26 | 57 |
| | Early shower | 6 | 13 |
| | Overlap/conv | 5 | 10 |

Table 2: Various contributions to level 1 inclusive electron trigger rate. The Et threshold was 10 GeV, and the $\eta$ region was $\eta < 1.6$

The level 1 muon trigger will come from signals from the muon scintillator and muon chambers located outside the muon toroid. The scintillators provide a low momentum cutoff and provide the timing tag needed to associate a muon with a specific crossing. The muon chambers give better momentum resolution than the scintillators; the limit is imposed by multiple scattering and the spread in the interaction point along the Z direction.

The dominant source of signals from the muon system is low $P_T$ muons from light quark decay. Because of multiple scattering and the spread of the interaction point the momentum resolution of the outer muon system alone may not be sufficient to reduce the muon rate to an acceptable level. There are three additional handles available for increasing the momentum resolution - using the inner muon layer, using the central tracking system and using phi matching.

The first method is to use to information from the inner theta muon layer. This eliminates much of the uncertainty due to the interaction point variation.

The second method is to use information from the tracking chamber and matching the track with a hit in the muon chamber. There are a couple of problems with this. The momentum resolution from a single layer is not much better than multiple scattering, so linking of track segments between layers will have to be done. Another problem is that the tracking system identifies tracks in phi but not in eta, while the muon system bends in eta and has relatively poor phi resolution from the theta chambers.

The third method would be to use the phi measurement from the tracking system and match to a muon stub found in the phi muon chambers. This could give rather good momentum resolution, but detailed studies have not yet been done. Combining the muon system with tracking at level 1 may be difficult given the arrival time of the muon information, in which case it would be done in level 2.

There is also a possibility of applying a calorimeter-based isolation cut on muons. This would reduce the background from light quark decays. Again, this question needs more study.

Neutrino identification consists of calculating the event missing $E_T$ vector. The missing $E_T$ can be found in one of two ways: first, all calorimeter trigger tower energies can be summed vectorially; second, only physics objects would be used in the sum. In the first case, the sums would begin with adding the EM and HAC energies over some single tower threshold to form trigger tower energies and then proceed through calorimeter crate energies to the global sum with directional information (x and y components) hardwired at the appropriate step in the adder tree. In the second case, the vector $E_T$ of the individual physics objects would be used to construct the missing $E_T$ vector.

In addition to the triggers described above, there will be triggers which do not require the presence of a physics object. One example is a minimum bias trigger. Since there is on average more than one interaction per crossing, we may simply prescale (possibly as a function of luminosity) beam crossings to select the minimum bias sample. A second example is a sum $E_T$ trigger. Essentially the same hardware used to calculate the event missing $E_T$ can be used to find the sum $E_T$ where in the latter case the directional information will be dropped.

# 3 Level 1

This is not an attempt to lay out a detailed trigger design, but rather an attempt to put forth the general features of the trigger which represent, we believe, a consensus from the trigger group. More detailed ideas on how these general features may be implemented in hardware [6, 4, 7] are left out as we have not yet had the time or facts to make these decisions. The consensus ideas put forth here are based on the idea of sending raw calorimeter data to a Level 1 trigger "upstairs". However, there is also a conceptual design placing local pattern logic on the calorimeter [8] allowing the trigger to use the full granularity of the calorimeter at the expense of some inaccessibility and increased interconnects on the detector. There are advantages to both schemes and both are still viable as SDC trigger designs.

## 3.1 Level 1 Pipeline Length

The proposal for the level 1 pipeline is that its length will not be less than 3.0 $\mu$sec and not more than 4.0 $\mu$sec. Representatives from Silicon, Central Tracking, Calorimetry and Muon front end electronics systems were involved in this decision. The conclusion from these systems was that while all could manage 4.0 $\mu$sec, there were significant difficulties for some to go beyond 4.0 $\mu$sec. In addition, there would be significant, but not insurmountable, difficulties for the silicon system to reach a 4.0 micro- second pipeline length for some architectures. The representatives of the Tracking, Calorimeter, Muon and Global trigger systems contributed to the calculations shown below that demonstrate the necessity for a range between 3.0 and 4.0 $\mu$sec. The actual calculation results in a range from 3.1 to 3.9 $\mu$sec. The pipeline length is determined by the muon drift time. The overall uncertainty in cable paths and electronics locations expands the range by 0.1 $\mu$sec on each side. However, it is important to add that the calculation is based on locating the central trigger decision and distribution in the counting house on the surface. If the trigger is located in the gallery, then the reduction in cable length of 40.7 m each way translates into a 0.4 $\mu$sec or 26 crossing savings.

### 3.1.1 Calculation of Level 1 Pipeline Length

The following table sums up the time for the trigger data from an interaction to reach the trigger logic and proceed through this logic to the final decision for the Level 1 Accept. The particular system chosen is the muon system, since it takes the longest and varies between 50 and 100 crossings depending on whether the muon drift time is 800 to 1600 nsec, respectively.

| *Muon through Global:* | |
|---|---|
| Propagation to Chamber | 2 |
| Drift in Chamber | 50–100 |
| Propagation along Wire | 2 |
| Segment Finder | 2 |
| Segment Linker | 6 |
| Transmission to GFLT | 50 |
| GFLT Calculation | 20 |
| **Total crossings** | **132–182** |

The following table sums up the delay incurred in transmitting the Level 1 Accept signal from the Global Level 1 Logic(GFLT) back to the front end electronics storage pipelines.

| Cause of Delay | Time (crossings) |
|---|---|
| GFLTB→pipeline controller (nearby) | 1 |
| Pipeline setup & synchronization | 2 |
| Pipeline Controller→Pipeline Fanout (far) | 50 |
| Local Fanout to Pipeline | 10 |
| Phase between pipeline and sample | ±0.5 |
| Pipeline overhead in sample select | 1 |
| Particle interaction→pipeline front | −5 |
| Presamples | 6 |
| Signal shaping for sample of rise | −1 |
| **Total crossings** | **64** |

The total pipeline length is the sum of the propagation of the trigger signals through the trigger logic to the final Level 1 Accept, which is 132 to 182 crossings for the muon system, and the propagation of the Level 1 Accept back to the front end pipelines, which is calculated to be 64 crossings. The resulting total crossings ranges between 196 and 246, or between 3.1 and 3.9 $\mu$sec. This is the range of possible Level 1 pipeline lengths, where the lower figure corresponds to a muon drift of 800 nsec and the larger a drift of 1.6 $\mu$sec.

## 3.2 Subsystem Segmentation and Information at Level 1.

The systems sending information to be used at level 1 are: calorimetry, tracking (central and intermediate), shower max ($\phi$ only), and muons (scintillator and $\eta$ chambers). A summary of the subsystem segmentation and trigger information from each subsystem is given in tables 3-7.

### 3.2.1 Calorimetry

The barrel calorimeter consists of 64 total wedges (32 $\phi$ wedges/side) with a wedge spanning 1.6 in $\eta$. The $2 \times 2$ physical towers are summed to give $.1\eta \times .1\phi$ trigger towers for a total of $64\phi \times 16\eta \times 2 sides$ trigger towers from the barrel. Within a wedge there are $2\phi \times 16\eta = 32$ trigger towers with each tower having an electromagnetic and a hadronic section. The assumption here is that the energy for each section within a trigger tower is encoded into an 8 bit nonlinear scale and sent to the level 1 trigger. The use of an 8 bit scale has not been finally determined, detailed simulations [3, 4] may prove it necessary to use 8 bits value plus 1 bit range for example. If it is determined necessary to use a greater number of bits the final number of optical fibers may have to modified.

The endcap calorimeter consists of 8 octants/end covering the rapidity range $1.6 < |\eta| < 3.0$. The physical towers are summed to give $64\phi \times 8\eta \times 2$ ends trigger towers total. Within an octant there are $8\phi \times 8\eta$ trigger towers with each having an electromagnetic and a hadronic section. Again, the energy for each section is encoded into an 8 bit nonlinear scale for input to level 1.

In the forward region ($3.0 < |\eta| < 5.0$) the proposed level 1 information is the total $E_T^x$ and $E_T^y$ for each side. However, we need to check that this does not harm missing $E_T$ resolution or compromise jet physics.

### 3.2.2 Shower Maximum Detector

From a level 1 viewpoint the shower max detector is composed of $1024\phi$ bins in four $\eta$ sections over the range $-3.0 < \eta < 3.0$. There are two barrel sections and two endcap sections.

In the barrel there are $32\phi$ bins for each wedge giving $1024\phi$ bins for each side of the barrel. For each bin there is 1 bit indicating whether or not that $\phi$ strip is above a preset "electron" threshold. This yields 32 bits per wedge of shower max information for input to level 1.

For the endcap shower max there are $128\phi$ bins for each octant to give $1024\phi$ bins total per side. As for the barrel there is 1 bit of shower max information for each $\phi$ bin giving 128 bits per octant of shower max data for level 1.

It may prove useful to use the full eta segmentation ($\Delta\eta = .2$) of the shower max detector at level 1. The shower max detector could then be matched to the calorimeter trigger towers covering the corresponding eta range giving matching at $.2\eta$ segmentation. The electron trigger would then require a phi match with a stiff track. This would also alleviate the need for "ORing" the eta bins on the front end cards at the expense of a greater number of optical fibers (e.g. a factor of eight in the barrel region).

Finally, one may want to to perform an algorithm on the shower max information while still at the detector. The shape would be examined for consistency with that of an electron and/or photon and the result sent to the trigger over optical fiber.

### 3.2.3 Tracking

The barrel tracking covers the region $|\eta| < 1.6$ matching the barrel calorimeter coverage. For each calorimeter $\phi$ tower (64 total on each side) the tracker outputs 4 bits $\phi$ and 4 bits $P_T$ for the highest momentum track in that tower. The 4 bits of $\phi$ information gives $16\phi$ bins/tower $\times 64$ towers $= 1024\phi$ bins to match the granularity of the shower max detector. The 4 bits of $P_T$ are composed of 1 sign bit and 3 momentum bits. The total information from the tracker to level 1 is 16 bits per calorimeter wedge.

The intermediate tracker covers the range $1.6 < |\eta| < 2.5$. Again, as in the barrel, the tracker gives 4 bits $\phi$ and 4 bits $P_T$ for the highest momentum track in each of the 64 $\phi$ towers in the endplug calorimeter giving a total of $1024\phi$ bins.

### 3.2.4 Muons

The central muon system covers the range $|\eta| < 1.0$ and has a scintillator segmentation of $32\phi \times 46\eta \times$ 2 ends. This gives $4\phi \times 46\eta \times$ 2 ends per octant. For level 1 the octant is logically divided into regions $4\phi \times 4\eta$ in size allowing the $\eta$ and $\phi$ position to be encoded into 4 bits. For each region 8 bits of information (2 bits $\phi$ + 2 bits $\eta$ + 4 bits $P_T$) are output for each of the two highest momentum muon stubs. This corresponds to 16 bits muon information per region with 12 regions per octant.

The intermediate muon system covers the region $1.0 < |\eta| < 2.5$ with a scintillator segmentation of $32\phi \times 36\eta$ for each end. There are $4\phi \times 36\eta$ per octant. One octant is divided into 9 regions of $4\phi \times 4\eta$ per region. Again, each region outputs 8 bits (2 bits $\phi$ + 2 bits $\eta$ + 4 bits $P_T$) for each of the two highest momentum muons in the region for a total of 16 bits per region.

It may be that after final descoping, trigger rate studies for the muon system indicate the need for additional "knobs" in the muon trigger. For example, studies may indicate that the muon trigger rate using only the outer $\eta$ chambers, as a measure of $P_T$, is not very sensitive to the $P_T$ threshold. Then, given the uncertainties in trigger rates and the fact that a factor of two or three in rate could be fatal, additional information must be available to level 1 as a way to turn down the rate if it is necessary. Additional "knobs" may include something like using the $\phi$ wires to match to the tracker thus sharpening the $P_T$ threshold.

| Calorimeter | | |
|---|---|---|
| **Barrel** | Coverage | $-1.6 < \eta < 1.6$ |
| | $\Delta\eta$ | .1 |
| | $\eta$ bins | 32 |
| | $\Delta\phi$ | $\sim .1$ |
| | $\phi$ bins | 64 |
| **Endplug** | Coverage | $1.6 < \|\eta\| < 3.0$ |
| | $\Delta\eta$ | *varies* |
| | $\eta$ bins | $8/end$ |
| | $\Delta\phi$ | $\sim .1$ |
| | $\phi$ bins | 64 |
| **Forward** | Coverage | $3.0 < \|\eta\| < 5.0$ |
| | $\Delta\eta$ | TBD |
| | $\eta$ bins | TBD |
| | $\Delta\phi$ | TBD |
| | $\phi$ bins | TBD |

Table 3: The calorimeter level 1 segmentation.

| Muons | | |
|---|---|---|
| **Barrel** | Coverage | $-1.0 < \eta < 1.0$ |
| | $\Delta\eta$ | varies |
| | $\eta$ bins | 92 |
| | $\Delta\phi$ | $\sim .2$ |
| | $\phi$ bins | 32 |
| **Intermediate** | Coverage | $1.0 < \|\eta\| < 2.5$ |
| | $\Delta\eta$ | varies |
| | $\eta$ bins | $36/end$ |
| | $\Delta\phi$ | $\sim .2$ |
| | $\phi$ bins | 32 |

Table 4: The muon level 1 segmentation.

| Tracking | | |
|---|---|---|
| **Barrel** | Coverage | $-1.6 < \eta < 1.6$ |
| | $\Delta\eta$ | 1.6 |
| | $\eta$ bins | 2 |
| | $\Delta\phi$ | $\sim .006$ |
| | $\phi$ bins | 1024 |
| **Intermediate** | Coverage | $1.6 < \|\eta\| < 2.5$ |
| | $\Delta\eta$ | .9 |
| | $\eta$ bins | $1/end$ |
| | $\Delta\phi$ | $\sim .006$ |
| | $\phi$ bins | 1024 |

Table 5: The tracking level 1 segmentation.

| Shower Max | | |
|---|---|---|
| **Barrel** | Coverage | $-1.6 < \eta < 1.6$ |
| | $\Delta\eta$ | 1.6 |
| | $\eta$ bins | 2 |
| | $\Delta\phi$ | $\sim .006$ |
| | $\phi$ bins | 1024 |
| **Intermediate** | Coverage | $1.6 < \|\eta\| < 3.0$ |
| | $\Delta\eta$ | 1.4 |
| | $\eta$ bins | $1/end$ |
| | $\Delta\phi$ | $\sim .006$ |
| | $\phi$ bins | 1024 |

Table 6: The shower maximum level 1 segmentation.

| subsystem | Total channels | L1 segmentation | L1 data |
|---|---|---|---|
| Barrel Calor. | $64\phi \times 32\eta$ | $.1\phi \times .1\eta$ | EM & HAC Energy |
| Endplug Calor. | $64\phi \times 8\eta \times 2$ ends | TBD | EM & HAC Energy |
| Forward Cal. | TBD | TBD | $E_T^x$ & $E_T^y$ |
| Barrel Muons | $32\phi \times 92\eta$ | $4\phi \times 4\eta$ regions | $(2\phi + 2\eta + 4P_T)$ bits $\times$ 2 tracks |
| Intermed. Muons | $32\phi \times 36\eta \times$ 2 ends | $4\phi \times 4\eta$ regions | $(2\phi + 2\eta + 4P_T)$ bits $\times$ 2 tracks |
| Tracking | $64\phi \times 4\eta$ | $.1\phi$ | $(4\phi + 4P_T)$ bits/$\phi$ bin |

Table 7: Level 1 subsystem segmentation and trigger information. The TBD means to be determined, and needs to be worked out in collaboration with the calorimetry and front end electronic groups.

## 3.3 Level 1 System Layout (An implementation of the Preliminary Design).

One possible implementation of the Level 1 trigger (see ref [6] for a detailed description of another implementation) is shown in figure 4. The trigger information from the various subsystems on the detector is sent over 1 Gbit/sec optical fibers creating a "map" of the detector at the trigger crates upstairs. Also shown in this implementation is 1 fiber per crate with the beam crossing count for the crate going to the level 1 trigger. Using 1 Gbit/sec fiber at 60MHz leads to a basic unit of 16 data bits per fiber.

The calorimeter sends the raw trigger tower energies to the trigger. Each tower sends 8 bits hadronic plus 8 bits electromagnetic energy for each beam crossing, giving 16 bits/beam crossing $\times$ 60 MHz or approximately 1 Gbit/Sec per trigger tower. This requires 1 fiber per trigger tower. Given the segmentation assumed above, the barrel calorimeter uses a total of $1024 \times 2 = 2048$ fibers to send data to the trigger. The total number of trigger towers in the endplug region is 512 per end or 1024 total fibers for the endplug tower data. The total number of fibers for the entire calorimetry trigger tower data is 3072.

The shower max detector has a total of $1024\phi$ bins which breaks down into 32 bins per wedge. Each bin sends 1 bit of information, so it uses 2 fibers (=32 bits) per wedge. The total number of fibers is then 2 fibers/wedge x 32 wedges x 4 regions = 256 fibers.

The tracker outputs 8 bits($4\phi + 4P_T$) per $\phi$ trigger tower or 1 fiber(=16 bits)/wedge. This gives 1 fiber/wedge x 32 wedges x 4 = 128 total fibers from the tracker.

The muon system sends 8 ($2\phi + 2\eta + 4P_T$)bits/muon x 2 muons/region = 1fiber(16bits)/region. The central muon system ($\eta < 1.0$) has 96 "regions" per side for a total of 192 fibers. The intermediate/forward system has 72 "regions" per side for a total of 144 fibers. The entire muon system then sends data over 236 total fibers.

The calorimetry, shower max, and tracking information for the detector is collected in a group of crates (figure 4) where "lists" of electron, photon, and jet objects are created and forwarded to the global trigger. One possible layout for such a crate is shown in Fig. 5. As seen from the figure, the information is grouped into local regions (a wedge in this implementation) where local pattern logic is performed to identify electrons and photons which are locally defined objects. Each of the crates creates a list of objects for that region which is forwarded to fan-in crates and subsequently sent to the global level 1 trigger (Fig. 6).

In the case of muons, muons are found with local pattern logic on the detector. These locally defined muons, found over the entire detector, are collected in level 1 muon crates (see figure 4). The information collected at these crates is combined and a muon list is forwarded from each of the crates to the global trigger logic (figure 6).

The global trigger is shown schematically in figure 6. The final level 1 trigger decision is based upon the physics "objects", sent to the decision crate as lists of muons, electrons, photons, jets and $E_T$ vectors. This crate also has the function of summarizing the level 1 trigger lists and forwarding the lists of objects to level 2. This allows the level 2 trigger to promptly examine the level 2 information relevant to the level 1 objects and their locations.

# 4 Level 2

Level 2 differs from Level 1 in that it does not have to finish before the data come out of the pipeline. Level 2 consequently has a flexibility that Level 1 cannot have- it can take longer than a few microseconds, for a much smaller number of events. Level 2 can consequently implement triggers for which it is difficult to get the information to Level 1 in time or for which Level 1 would take too long. Two areas that are candidates are the silicon system (particularly displaced vertex triggers), and intermediate tracking. But Level 2 has access to all the Level 1 trigger information and could be used to sharpen any of the Level 1 triggers. It is the strong sentiment of the trigger group that while it may be possible to have enough power within Level 1 that one could feed Level 3 directly at an acceptable rate, the hooks must be in place for Level 2. As the luminosity rises over the life of the detector we will need to exploit greater rejection power in the trigger, and Level 2 is the place where it can be done efficiently and with great cost-effectiveness. The largest cost is in the collection of data from the front-end cards; once it is organized upstairs new Level 2 processors using the latest technology are relatively straight-forward to implement.

Some specific examples of Level 2 triggers that are being considered are [10]:

1. A displaced vertex trigger using the silicon vertex detector.

2. An electron trigger using the silicon vertex detector that rejects electrons from photon conversions (our trigger simulation studies show that half of the Level 1 electron triggers are from conversions; as these are perfectly good electrons nothing more can be done to them at Level 1).

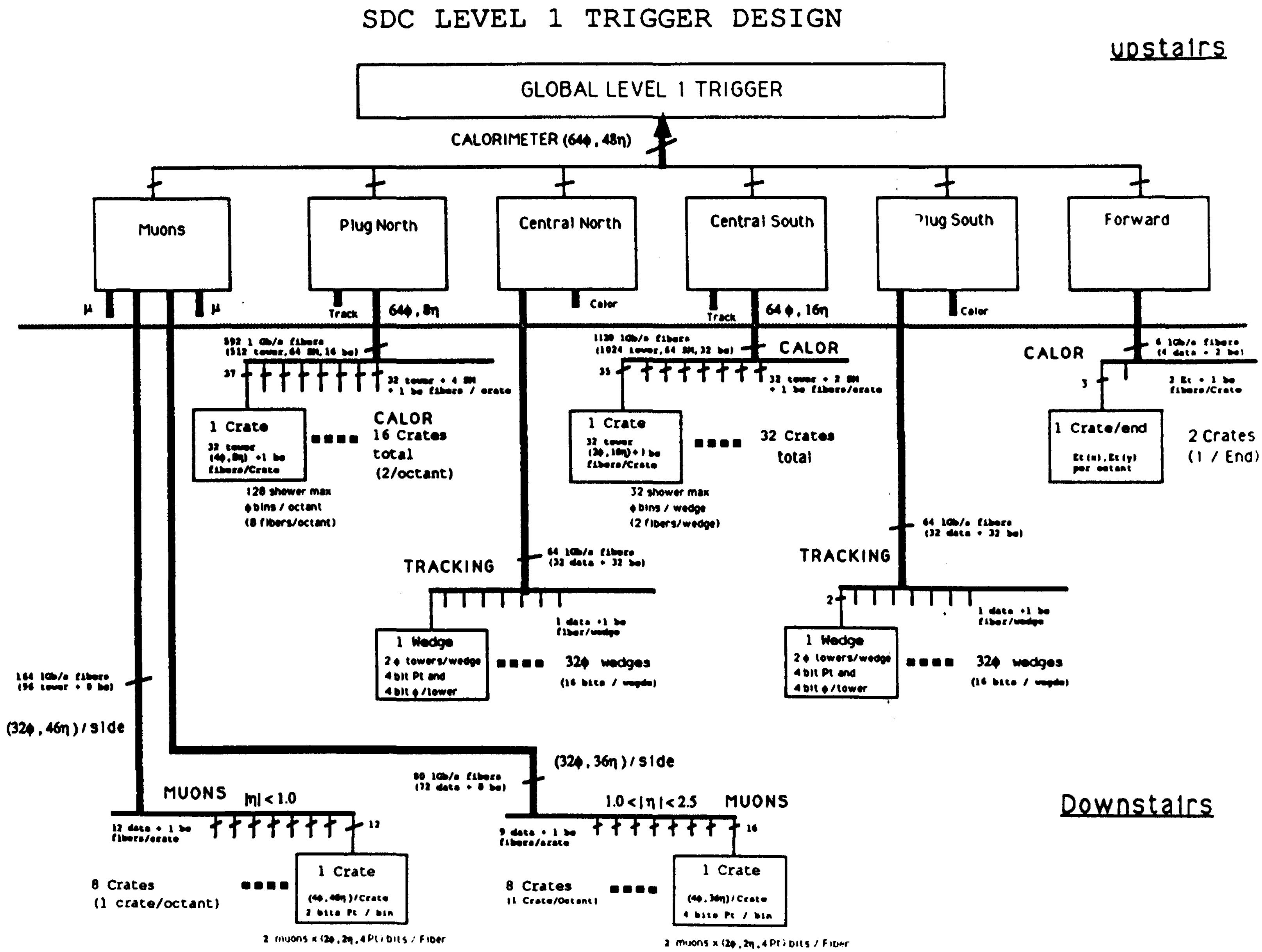


Figure 4: One possible implementation for the SDC level 1 trigger.

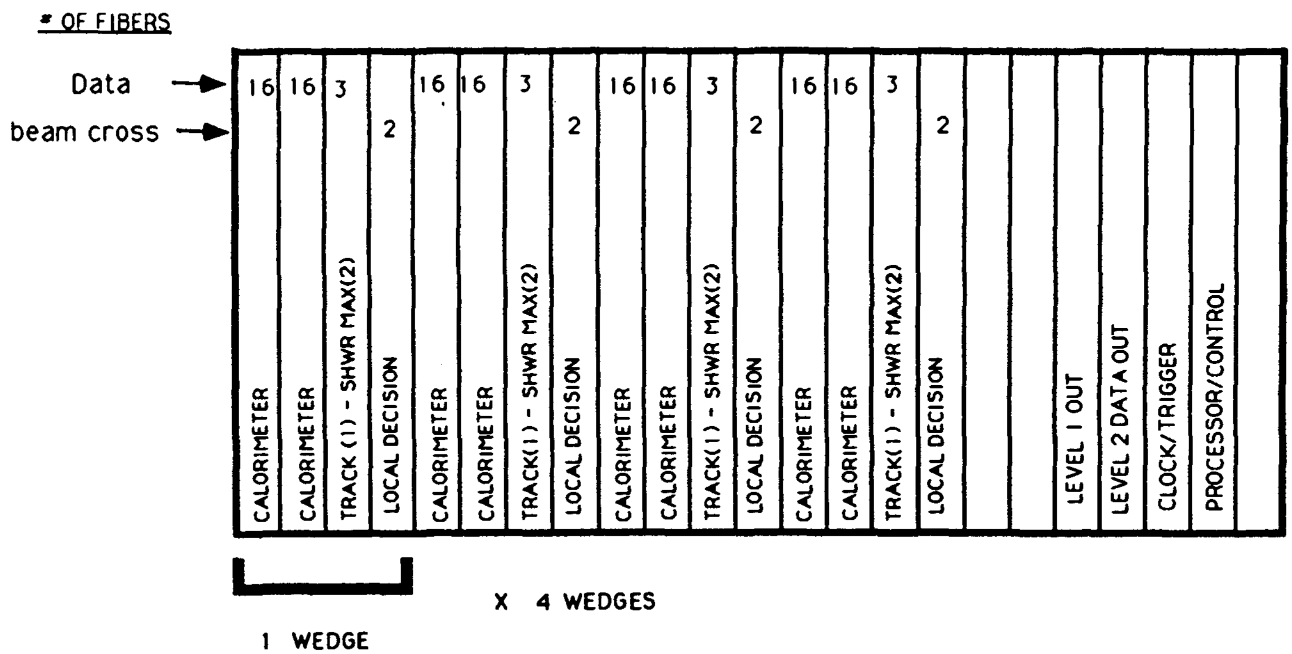


Figure 5: Organization of the level 1 calorimeter trigger crate.

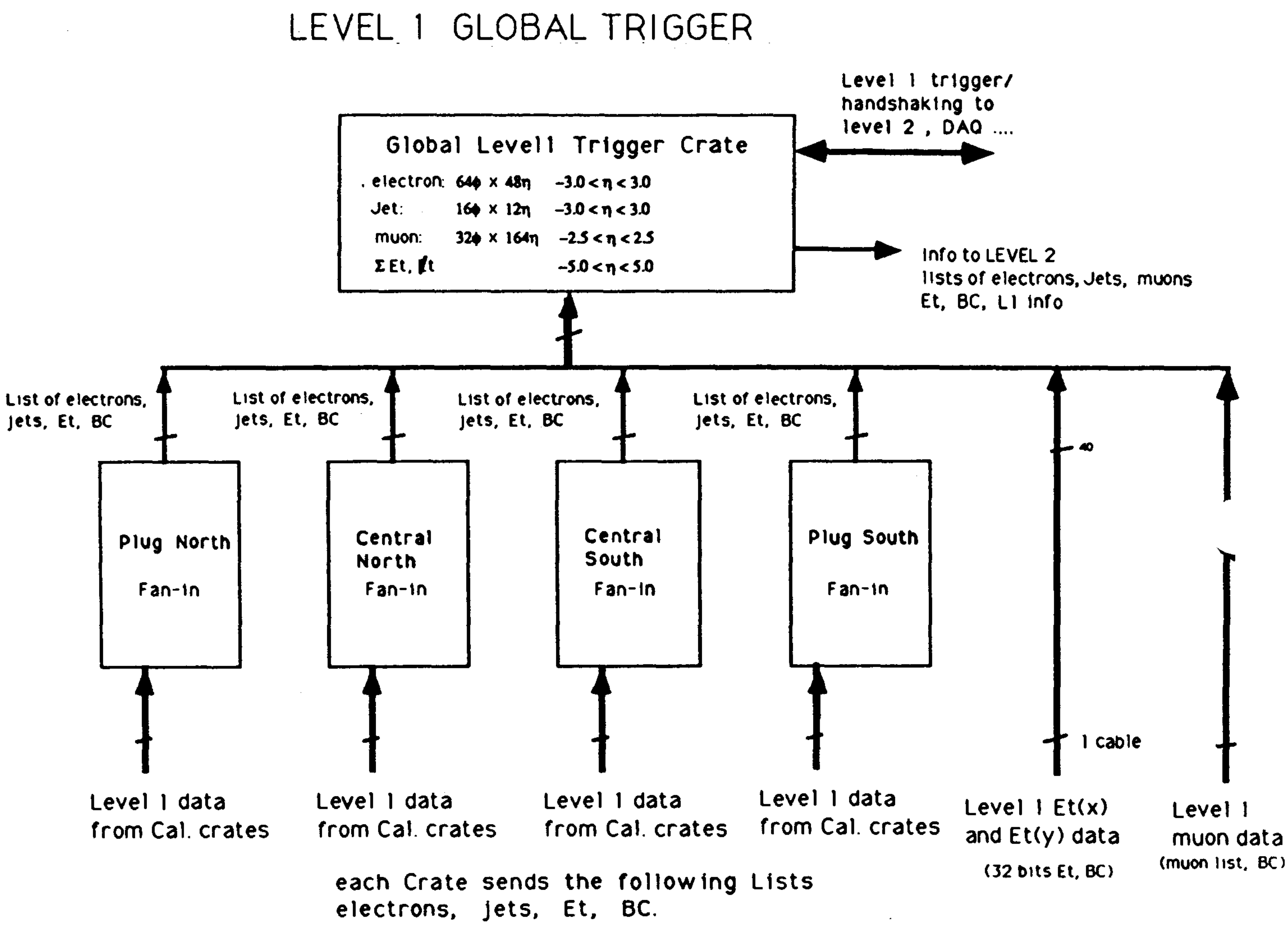


Figure 6: The global trigger at the top of the level 1 trigger.

3. An electron trigger at intermediate angles that associates tracks in the silicon detector with electromagnetic clusters in the calorimeters.

4. A shower max profile shape and precise track match using the full granularity of the shower max detector.

5. A muon trigger with a sharpened Pt thresholds using muon chamber timing and phi information.

6. A muon trigger with a precise match between the tracking and the muon system and good momentum resolution from the tracking.

7. Redundant triggers with level 1 that replay the level 1 trigger with finer granularity and more flexible algorithms to get fast online diagnostic and monitoring.

# 5 Clock and Control

At any given moment there are several events, spaced by 16 feet in distance from the interaction region, moving out radially through the detector. It will be a difficult job to keep the electronics in phase with the signals, each of which has a delay inherent in its own detection apparatus. The system that controls the function, phasing and synchronization of the front ends is the Clock system. We have agreed that the design and construction of the Clock system is part of the responsibility of the trigger group.

The functions of the clock are:

1. communication with the accelerator RF clock.
2. communication with the accelerator beam pickup electronics.
3. providing the phase lock of the 16 nsec clock.
4. distributing the clock to the front-end crates.
5. distributing the bunch-crossing number to the front-end crates and trigger.

Some of the necessary trigger control functions are:

1. distributing the Level 1 and Level 2 Accept/Reject signals and other control signals to the front-end crates.
2. receiving all control signals from the front-end crates.
3. tracking the disposition of each crossing, i.e. whether accepted, rejected, or lost due to downtime of trigger and/or DAQ.
4. monitoring the subsystem deadtimes and status.
5. determining if the detector is able to accept the trigger and, if necessary, to determine the correct crossing to issue the trigger.

A more detailed example of the clock and trigger control structure can be found in [9].

# References

[1] Ann Arbor, April 5; Chicago, May 6-8; Madison July 17-19 (1991)
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[2] R. Jared and M. Levy private communication.

[3] G. Sullivan and M. Miller, *Calorimetry trigger rates at the SDC*, SDC note SDC-91-00099, 1991.

[4] T. Gorski, J. Lackey, W.H. Smith, *Isolated electron pattern logic design and performance at the SSC*, SDC note SDC-91-00087, 1991.

[5] P. BonAmy, private communication

[6] W.H. Smith et al., *SDC Trigger Preliminary Conceptual design*, SDC note SDC-91-00090, 1991.

[7] G. Sullivan et al., *Proposal for the SDC Level 1 Trigger Design*, SDC Note SDC-91-00100, 1991.

[8] G.W. Foster et al., *SDC Trigger design using Local Calorimeter Pattern Logic*, Fermilab.

[9] W.H. Smith et al., *SDC Global level 1 Processor: Clock & Control*, SDC note SDC-91-00092, 1991.

[10] P. LeDu, private communication.