Fermilab Library
0 1160 0039841 6

SDC-93-532

SDC
SOLENOIDAL DETECTOR NOTES

Proposed SDC Level-1 Calorimeter Trigger Performance Requirements

September 7, 1993

Sridhara Dasu and Welsley Smith
University of Wisconsin

Greg Sullivan
University of Chicago

SDC-93-532
September 7, 1993

Proposed SDC Level-1 Calorimeter Trigger Performance Requirements

Sridhara Dasu and Wesley Smith
University of Wisconsin, Madison, WI 53706

Greg Sullivan
University of Chicago, Chicago, IL

Abstract

This document describes the performance requirements for SDC level-1 calorimeter trigger. Physics and rate based requirements on trigger are specified.

1 Overview

The SDC technical design report[1] states that the SDC trigger system should be capable of selecting leptons and jets over the pseudorapidity range $|\eta| < 2.5$, with an efficiency which is very high above some threshold in transverse momentum. For single lepton triggers it is required that the trigger is fully efficient in the pseudorapidity range $|\eta| < 2.5$, with a threshold of $p_t > 40$ GeV/c. For dilepton trigger the threshold required is $p_t > 20$ GeV/c for each lepton in the same rapidity range. In addition single photon and diphoton triggers are required with thresholds similar to those of the leptons. Single and multiple jet triggers are also required with a well defined efficiency in order to reconstruct the jet spectrum with overlap from data attainable at lower energy colliders such as Tevatron. For higher transverse momenta the jet trigger should also be fully efficient. Finally, a missing transverse energy trigger with a threshold of 100 GeV is also needed. To satisfy these physics requirements, simulations indicate that the level-1 trigger E_t thresholds must be smaller by about 10-15 GeV.

Efficiencies of triggering on leptons from W and top decay processes have been considered as benchmarks in the trigger simulation studies. The requirement based on these processes is that 50% or more of W decay leptons in the fiducial volume are triggered. The inefficiency is expected to be due to the E_t cut.

At the nominal SSC design luminosity of $10^{33}\text{cm}^{-2}\ \text{s}^{-1}$, an average of 1.6 interactions occur at the beam crossing frequency of 60 MHz. This input rate of 10^8 interactions per second must be reduced to a rate of about 100 Hz, which can be archived, by the data acquisition system. In order to achieve such high degree of selection the trigger systems is envisioned to comprise of 3 levels. The level-1 trigger, which can be implemented in integrated circuits and PC boards with fixed algorithms operating on local information, is required to reduce the rate from input 10^8 down to about 10-100 kHz. In order to handle the high input rate the level-1 trigger system is pipelined with a fixed decision time of 16 ns. The level-2 trigger, which can be implemented in generic programmable processors with simple algorithms correlating across the complete detector, is required to reduce the rate further down to about 1-10 kHz. The level 3 trigger, which can be implemented in commercial processors with offline-like full detector analysis, is expected to bring the rate down to 10-100 Hz for archival.

The trigger systems are also required to work, or be easily upgradable, for future high luminosity (10^{34}cm^{-2} s^{-1}) running of the SSC. Significant upgrades to the trigger system, in particular to level-1, are not possible without extensive disturbance in the running of the experiment. In order to satisfy this requirement most of the level-1 trigger components need to be designed to tolerate 10 times the nominal luminosity.

This structural design has several implications for level-1 trigger. In particular, all initial decisions are based on local information, rather than on global event topology. The level-1 trigger processors works by selecting events based on single particles or jets. The dilepton, diphoton and other combination triggers are achieved by a global processor which counts the numbers of individual triggers. Some correlation in the positions is possible. In addition, the input data bandwidth and processing time considerations limit the information available from different subdetectors. The cross-correlation of information from different subdetectors is not always possible and is left for the level-2 trigger.

The level-1 trigger for electrons, photons, jets and neutrinos is primarily based on the calorimeter. The charged particle transverse momentum information from the central tracker is expected to be used to attain somewhat lower momentum threshold for electrons as compared to photons. In order to establish the requirements, and specify algorithms, for the level-1 trigger, several Monte Carlo studies using a parametric response of the calorimeter were done. Detailed reports of these studies is available elsewhere[2, 3, 4, 5]. Conceptual level-1 trigger design is also discussed elsewhere[6]. Only the criteria used for triggers and results of simulation are briefly described here.

2 Trigger Performance Simulations

2.1 Electrons and Photons

The primary criterion used for selecting electrons and photons is large transverse energy deposit in the electromagnetic section of a calorimeter tower. The secondary criterion is the requirement of relatively small transverse energy deposit in the corresponding hadronic compartment of the calorimeter tower. An additional requirement that the transverse energy deposit in the neighbouring hadronic towers be small provides more discrimination. Electron trigger rates are further reduced by requiring a high p_t track stub in the outer tracker to match in ϕ with the calorimeter. Trigger rates for these cuts[2], for nominal luminosity cases,

E_t	Single Tower Trigger Rate (kHz)			Two Tower Trigger Rate (kHz)		
GeV	No Cut	$H/E < 0.05$	$Iso. < 1.5$ GeV	No Cut	$H/E < 0.05$	$Iso. < 1.5$ GeV
15	61.3	33.2	21.3	108.	58.2	34.8
20	25.9	12.7	7.27	48.6	24.3	13.0
25	12.8	5.47	2.72	24.4	10.9	5.12
30	7.43	2.95	1.30	13.8	5.65	2.27
35	4.54	1.65	0.75	8.61	3.35	1.24
40	2.96	1.06	0.44	5.54	1.95	0.71

Table 1: QCD 2-jet background trigger rates for single and two tower photon triggers for E_t thresholds in the range 15-40 GeV. Background electron trigger rates after requiring a stiff track stub in the central tracker are expected to be a factor of 3-4 lower.

Eff.	Single Tower Trigger Thresholds (GeV)			Two Tower Trigger Thresholds (GeV)		
%	No Cut	$H/E < 0.05$	$Iso. < 1.5$ GeV	No Cut	$H/E < 0.05$	$Iso. < 1.5$ GeV
0	32.5	24.5	21.0	39.0	29.5	24.0
80	38.0	29.5	24.0	41.0	31.0	24.0
95	53.0	40.5	35.0	43.0	32.5	26.0

Table 2: Photon trigger thresholds for single and two tower triggers as a function efficiency. The 0% efficiency E_t thresholds correspond to QCD 2-jet background rate of 6 kHz. The electron trigger thresholds corresponding to these efficiencies are expected to be about 3-5 GeV lower.

are tabulated in Table 1 for various level-1 type trigger algorithms. Note that in order to achieve full efficiency for electron or photon transverse momentum of 40 GeV, as required by the SDC physics goals, one needs to have a EM transverse energy deposit cut of around 25 GeV at level-1. The thresholds can be sharpened up by using sums of two neighbouring EM towers. The efficiency thresholds are listed in Table 2.

Efficiencies of triggering on electrons from W and top decays were also studied[2] for these criteria. Level-1 trigger efficiencies upwards of 70% can be achieved with the use of transverse isolation, H/E and transverse energy cut.

2.2 Jets and Hadrons

Jet identification and good knowledge of jet p_t dependence of the cross section, are mandatory for studying QCD. The main factor in determining the requirements on jet trigger are the sharpness of the trigger efficiency versus jet p_t curve. Jet trigger transverse energy thresholds were studied[3] in detail, as a function of number of neighbouring towers required to be summed up, the digital energy scale used to transmit information, and the effect of using overlapping versus non-overlapping grid of towers. The sharpest jet p_t versus efficiency curve is obtained by triggering on sums of transverse energies in 1.6×1.6 $\eta - \phi$ regions. The triggers based on sums of 0.8×0.8 $\eta - \phi$ region are quite acceptable. The choice of using non-overlapping sums is also acceptable. The choice of the type of 8-bit digital energy scale, used for transmission of transverse energies from the calorimeter front-end electronics to trigger system, has insignificant effect, as long as the range covers energies upto about 200 GeV.

2.3 Missing E_t and Sum E_t

The missing E_t and sum E_t triggers require that the information from the summation trees used for the jet triggers be continued to span the entire detector.

3 Performance Requirements

3.1 Physics Requirements

3.1.1 Angular coverage

TDR: Electron trigger should exist in the pseudorapidity range $|\eta| < 2.5$ where tracking information is available. Photon trigger should exist in the barrel and endcap calorimeter, i.e. $|\eta| < 3$. Single and multi-jet triggers should span the entire calorimeter acceptance, including the forward calorimeter, i.e. $|\eta| < 5$.

Comment: Smaller pseudorapidity range for the electron trigger is due to the span of the tracking devices.

Justification: Although signals for interesting physics processes occur over the full angular acceptance, the very forward regions are plagued by high background rates. Therefore, tracking information is not available in the region $|\eta| > 2.8$ resulting in the somewhat relaxed angular coverage requirement for lepton triggers.

Status: Stable

3.1.2 Single Electron Efficiency and Threshold Requirement

TDR: Single electron trigger efficiency should be perfect with a p_t threshold of $p_t > 40$ GeV/c.

Revised: Single electron trigger 80% efficiency E_t threshold should be less than 25 GeV. Electron trigger efficiency should be greater than 95% above E_t of 30 GeV.

Justification for TDR: Most physics processes of interest for SDC are best studied using leptons. They provide the cleanest signals with least backgrounds. However, the branching fractions hurt the signal rates dramatically, and, therefore, the threshold transverse momentum for the leptons should be as low as possible while the efficiency is maintained as high as possible. The "true" electron rate is small enough that the threshold transverse momentum can be very small. However, the fake rate dominated by the photons from the π^0 decays places a constraint on how low the transverse momentum threshold can be set. Since many processes of interest, for instance associated production of Higgs and W, involve W-bosons which are tagged by decays to leptons, demanding a high efficiency for triggering on W decay electrons is crucial. To achieve $> 50\%$ efficiency for tagging W events in the fiducial volume a p_t threshold of 40 GeV is required[2]. Example physics processes that require single electron trigger are:

- $W \rightarrow e\nu$; Greater than 50% efficiency
- $Z \rightarrow e^+e^-$; Greater than 50% efficiency
- $t \rightarrow e\nu b$
- $WH \rightarrow e\nu\gamma\gamma$
- $tH \rightarrow e\nu b\gamma\gamma$
- $pp \rightarrow WW \rightarrow e\nu jetjet$
- $pp \rightarrow ZZ \rightarrow e^+e^-l^+l^-$
- $pp \rightarrow ZZ \rightarrow e^+e^-jetjet$
- $H \rightarrow WW \rightarrow e\nu jetjet$
- $H \rightarrow ZZ \rightarrow e^+e^-l^+l^-$
- $H \rightarrow ZZ \rightarrow e^+e^-jetjet$
- $H \rightarrow ZZ \rightarrow e^+e^-\nu\nu$

The tightest constraints come from inclusive W and top trigger requirement.

Justification for Revision: The revised requirement is more quantitative. The 95% efficiency E_t threshold is somewhat lower in the revised requirement because the TDR requirement is for the complete trigger, rather than just the level-1. In addition, this tighter requirement is needed to pass greater than $> 50\%$ of W events in the fiducial region to the next trigger level.

Comment: The goal for the trigger should be to reduce the single electron threshold as low as possible because the physics gains in doing so would be considerable.

Status: Stable

3.1.3 Single Photon Efficiency and Threshold Requirement

TDR: Single photon trigger is required with thresholds similar to that for the lepton trigger.

Revised: Single photon trigger 80% efficiency E_t threshold should be less than 30 GeV. Photon trigger efficiency should be greater than 95% above E_t of 35 GeV.

Justification for TDR: Higgs decays, gauge boson pair production ($Z\gamma$, $W\gamma$) and other processes generate photons. Example physics processes that require single photon trigger are:

- $pp \rightarrow \gamma X$
- $pp \rightarrow \gamma\gamma X$
- $pp \rightarrow \gamma Z X$
- $pp \rightarrow \gamma W X$
- $WH \rightarrow l\nu\gamma\gamma$
- $tH \rightarrow l\nu b\gamma\gamma$

Justification for Revision: TDR requirement is for the complete trigger. The revised statement reflects somewhat tighter requirement for level-1. Electron trigger threshold energies are lower than photon threshold energies because of additional rejection that can be achieved by the use of tracker trigger.

Status: Stable

3.1.4 Dilepton Thresholds

TDR: Dilepton trigger with a threshold of $p_t > 20$ GeV/c for each lepton is required.

Revised: Dilepton trigger 80% efficiency E_t threshold should be less than 13 GeV (for each lepton). Dilepton trigger efficiency should be greater than 95% above E_t of 15 GeV (for each lepton).

Justification for TDR: Many physics processes involve multiple leptons. Since the p_t of the inclusive single lepton triggers is high, it is desirable to reduce the thresholds for the multilepton events. The fake rate for these events should be much smaller than single lepton events with similar thresholds. The threshold value is again set by the fake triggers. Example physics processes that require dilepton trigger are:

- $Z \rightarrow e^+e^-$; Greater than 50% efficiency
- $t \rightarrow e\nu b \rightarrow e\nu\mu\nu X$
- $pp \rightarrow ZZ \rightarrow e^+e^-l^+l^-$
- $pp \rightarrow ZZ \rightarrow e^+e^-jetjet$
- $H \rightarrow ZZ \rightarrow e^+e^-l^+l^-$
- $H \rightarrow ZZ \rightarrow e^+e^-jetjet$
- $H \rightarrow ZZ \rightarrow e^+e^-\nu\nu$

Justification for Revision: The revised requirement specifies efficiencies required at the said thresholds. TDR requirement is for the complete trigger. The revised statement reflects somewhat tighter requirements for level-1.

Comment: Dilepton triggers should include ee. $\mu\mu$ and $e\mu$ triggers. Spatial correlation of the two leptons is not required at level-1.

Status: Stable

3.1.5 Diphoton Thresholds

TDR: Diphoton trigger is required with thresholds similar to that for the dilepton trigger.

Revised: Diphoton trigger 80% efficiency E_t threshold should be less than 15 GeV (for each photon). Diphoton trigger efficiency should be greater than 95% above E_t of 18 GeV (for each photon).

Justification for TDR: Higgs decays and other processes generate photons. Example physics processes that require diphoton trigger are:

- $pp \rightarrow \gamma\gamma X$
- $WH \rightarrow l\nu\gamma\gamma$
- $tH \rightarrow l\nu b\gamma\gamma$

Justification for Revision: The revised requirement specifies efficiencies required at the said thresholds. TDR requirement is for the complete trigger. The revised statement reflects somewhat tighter requirements for level-1. These thresholds are higher than those for dileptons because tracking information cannot be used to reduce QCD background diphoton rate.

Status: Stable

3.1.6 Lepton+Photon Thresholds

TDR: Not specified.

Revised: Lepton+Photon trigger with 80% efficiency E_t threshold of 12 GeV for the lepton and 15 GeV for the photon is required. The efficiency should be 95% above E_t of 15 GeV for the lepton and 18 GeV for the photon.

Justification for Revision: Some physics processes involve leptons and photons. The fake rate for these events should be much smaller than single lepton events with similar thresholds. The threshold value is again set by the fake triggers. Example physics processes that require lepton+photon trigger are:

- $WH \rightarrow e\nu\gamma\gamma$

- $tH \rightarrow e\nu b\gamma\gamma$

Comment: Spatial correlation of the lepton and photon is not required at level-1.

Status: Stable

3.1.7 Jet Trigger Requirement

TDR: Single and multiple jet triggers over the full calorimeter acceptance are required for many generic studies.

Revised: Single and multiple jet triggers with well measured efficiency over the full calorimeter acceptance are required. Ability to span lower E_t ranges using some prescaling is required.

Justification: Since clustering algorithms are not likely to be very sophisticated at level-1 the efficiency turn on will be somewhat slow [3]. The rate limitations on the jet trigger further decrease the efficiency. Therefore, it is important that the trigger efficiencies are well measured. For QCD studies, there should be jet energy overlap with results from current collider experiments. Greater than 95% efficiency where data from current experiments have little statistics, i.e. 200 GeV, is desirable.

Status: Stable

3.1.8 Single Hadron Trigger Requirement

TDR: *Not listed*

Revised: Single hadron trigger with a threshold of about 50-60 GeV is required.

Justification: Provides a trigger to enrich τ sample.

Status: Under study.

3.1.9 Sum E_t Trigger Requirement

TDR: Sum E_t Trigger is required.

Justification: Provides unbiased sample of high p_t events. These events provide a generic trigger, and are usefull for trigger efficiency studies.

Comment: An E_t threshold of about 300 GeV for $|\eta| < 3.0$ is desirable.

Status: Stable

3.1.10 Missing E_t Trigger Requirement

TDR: Missing E_t Trigger with a threshold of 100 GeV is required.

Justification: Enables selection of events with hard neutrinos and other noninteracting particles. These events are especially usefull for SUSY particle searches. such as those for gluinos.

Status: Stable

3.2 Rate Requirements

3.2.1 Decision frequency

TDR: One trigger decision every 16.667ns.

Justification: Required in order to maintain a pipeline trigger with zero deadtime at the clock cycle of SSC.

Status: Stable

3.2.2 Latency

TDR: Less than $4\mu s$ latency

Justification: Amount of memories achievable, in the front end electronics chips/boards, places a constraint on the maximum latency. The minimum latency is dictated by the length of the fibres and processing time of the various electronics in the trigger decision path.

Status: Under revision.

3.2.3 Decision time

TDR: Less than $1.2\mu s$ decision time.

Justification: Most of the latency is in signal propagation time.

Comment: Larger decision time for calorimeter trigger is possible ubecause the latency requirement is dominated by the muon system. More accurate numbers are not going to be available till preliminary designs are available.

Status: Work is in progress to pin this down.

3.2.4 Output rate

TDR: Total rate in to level-2 of less than 100 kHz.

Justification: Based on the threshold and efficiency requirements for local objects identified in the level-1 calorimeter trigger a total rate of about 30 kHz at nominal luminosity is achievable. Upon using a safety factor of 3, to account for uncertainties in the rate estimation, this turns out to be 100 kHz. Techniques being considered for level-2 cannot handle higher rate. In addition, higher level-1 rate requires larger storage buffers in the front-end electronics.

Status: Stable.

3.3 Input Data Requirement

TDR: The data is required in 0.1×0.1 $\eta - \phi$ segments with 8 bits of EM and HAC transverse energy information.

Addendum: The complete dynamic range provided by the calorimeter electronics should be accesible for trigger use. The transfer function which translates 12-bit floating point total energies available in the front-end to 8-bit encoded transverse energies for the trigger purpose needs to be programmable.

Justification for TDR: Cost considerations require the segmentation to be no larger than that proposed above. Coarser segmentation results in higher rates, and is likely to yield higher than tolerable rates with the required thresholds, particularly at high luminosity. 8 bit energy scale is needed to provide resolution needed for the electron/photon trigger and the dynamic range needed for the jet trigger.

Justification for the Addendum: The scale needs to have a resolution of 100 MeV at low end, with a range spanning upto 200 GeV. Since this data is shared with the level-2, the requirements are somewhat tighter than that would be needed just for level-1. A quad linear scale with resolutions of 0.1, 0.5, 1.0 and 1.5 GeV bins satisfies this requirement. i.e. 0.-6.3 GeV in 0.1 GeV steps, 6.4 - 37.9 GeV in 0.5 GeV steps, 38.4 - 101.4 in 1.0 GeV steps, and 102.4 - 195.4 GeV in 1.5 GeV steps. The highest 8-bit value, 255, should indicate energies greater than or equal to 196.9 GeV.

Status Work is in progress to pin this down.

3.4 Miscelaneous Requirements

3.4.1 Prescaling

TDR: Ability to prescale triggers is required.

Addendum: All single particle triggers must allow for a lower set of thresholds with ability to prescale.

Justification: Prescaled triggers are required for efficiency measurement and studying high rate physics.

Status: Stable.

3.4.2 Threshold programmability

TDR: Thresholds should be programmable.

Addendum:

- Single electron and photon trigger EM E_t cutoffs should be tunable within the range $10 < E_t < 35$ GeV in small energy steps (e.g. 0.5 - 1 GeV). The maximum programmable E_t cutoff value should be at least 100 GeV.
- Double electron/photon trigger EM E_t cutoffs should be tunable within the range $10 < E_t < 15$ GeV in small energy steps (e.g. 0.5 - 1 GeV). The maximum programmable E_t cutoff value should be at least 100 GeV.
- H/E ratio cut and any isolation cut should be programmable.
- Single hadron trigger HAC E_t cutoff should be tunable within the range $10 < E_t < 60$ in small energy steps (e.g. 2 - 3 GeV). The maximum programmable E_t cutoff value should be at least 100 GeV.
- Single and multi jet, missing E_t and sum E_t trigger, E_t cutoffs should be tunable within the range $30 < E_t < 400$ GeV in moderate energy steps (≈ 5 GeV). The maximum programmable cutoff value should be at least 1000 GeV.

Justification: The threholds should be programmable to allow for various physics triggers desirable for a data run. The actual choice of thresholds can be determined during the experiment taking into account luminosity, rate, bandwidth, physics interest etc.. It is necessary to allow programmability with reasonably good resolution in the energy scale. The lower limit for the cutoff, particularly for the jet trigger, is specified so that the prescaled triggers can also be set with desired precision. The very large upper limits are specified so that in case of any unforeseen circumstance, which severely limits bandwidth out of level-1, we should still be able to operate the trigger. These very high values need not be fine tunable.

Status: Stable.

3.4.3 Luminosity monitoring

TDR: *Not listed*

Revised: Histograms of energy hits above about six programmable thresholds accumulated each crossing, in 0.8×0.8 regions, but reported at regular intervals.

Justification: Online measurement of luminosity, and backgrounds are needed for monitoring the accelerator performance[7].

Status: Under study

References

[1] SDC Collaboration, *Solenoidal Detector Collaboration - Technical Design Report*, SDC Note SDC-92-201, 1992.

[2] W. Temple, S. Dasu, W. H. Smith, J. Lackey, T. Gorski, *SDC Level-I Electron Trigger Simulation Results*, SDC Note SDC-92-345, 1992 and *Update on SDC Level-1 Photon/Electron Trigger Studies*, 1993.

[3] W. Temple, S. Dasu, T. Gorski, J. Lackey, W.H. Smith, *SDC Jet Trigger Performance Studies*, SDC Note SDC-92-232, 1992.

[4] G. Sullivan and M. Miller, *Calorimetry trigger rates at the SDC*, SDC Note SDC-91-99, 1991.

[5] G. Sullivan et al., *Proposal for the SDC Level-1 Trigger Design*, SDC note SDC-91-001, (1991).

[6] W. H. Smith et al., *SDC Trigger Design Documents*, WISC-EX-91-320, 1991.

[7] K. Riles and B. Roe, *Proposed requirements for a relative luminosity monitor using calorimeter level-1 trigger signals*, SDC-Note-93-510.