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CONCEPTUAL DESIGN OF THE FIRST LEVEL TRIGGER FOR THE SDC EXPERIMENT

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Presented at the 6th Pisa Meeting on Advanced Detectors
La Biodola, Isola d'Elba

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Conceptual Design of the First Level Trigger for the SDC Experiment [1)]

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Abstract

We report on a conceptual design of the First Level Trigger for the SDC Experiment at the SSC. Level 1 algorithms employ barrel and intermediate trackers, and electromagnetic and hadronic calorimeters. Results of simulations of background rates and efficiencies are presented together with a discussion of the simulation method. Tracking and calorimetric triggers are discussed in detail. Some hardware implementation ideas for the trigger algorithms are mentioned.

1. Introduction and Solenoidal Detector Overview

A trigger for the SSC (LHC) has to reduce event rates of 10^8 Hz (10^9 Hz) to $\sim$ 100 Hz (capability of mass storage). Most event analysis has to be done within the trigger and overall trigger biases will be hard to recover. Some processes (*eg.* low-mass Higgs discovery) require very high trigger efficiency. High beam crossing rates and latency limitations imposed by buffer sizes suggest a multilevel trigger architecture.

The SDC experiment adopted a three level trigger architecture [1]. L1 was to be a fixed decision time, fully pipelined trigger producing a decision every beam crossing (16 ns) with 3-4 μs latency. The expected L1 accept rate was of the order of 10 kHz-100 kHz. The role of the L1 trigger was to define "physics objects" (*eg.* electrons, photons, muons, jets) using local detector information. The SDC detector is described in detail elsewhere [3]. The subdetectors to be used in the L1 Trigger are the Barrel Straw Tracker (BT) and Intermediate Microstrip Tracker (IT), Electromagnetic Barrel and Endcap scintillator tile-lead sandwich Calorimeter (EC) with the fine granularity scintillator-strip Shower Maximum Detector (SMD), Barrel and Endcap Hadronic Calorimeter (HC) and the Muon System. The BT and IT cover $|\eta| < 2.8$. Barrel and Endcap calorimeters cover $|\eta| < 3$. The tracking system is placed in a 2 T solenoidal magnetic field. The material in the tracking system and beam pipe affects the electron trigger. The beam pipe and Silicon Vertex Detector (SVX), which extends to $r = 36$ cm and $|z| = 258$ cm, contain $\sim 6\%$ of X_0. There is $\sim 11\%$ of X_0 on average within the magnetic volume. Material in the Superconducting Coil ($1.2\,X_0$ and $0.25\,\lambda$) can be treated as part of the EC.

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2. First Level Trigger Algorithms and MC Simulation

The main background to the trigger comes from QCD 2-jet events. The spectrum of these events falls as $\sim 1/p_T^4$. Jets with $p_T > 20\,\mathrm{GeV}/c$ occur with $\sim 1\,\mathrm{MHz}$ rate at the SSC energy of $40\,\mathrm{TeV}$ and luminosity of $10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$. Hadrons deposit $\sim 50\%$ of their energy in the EC.

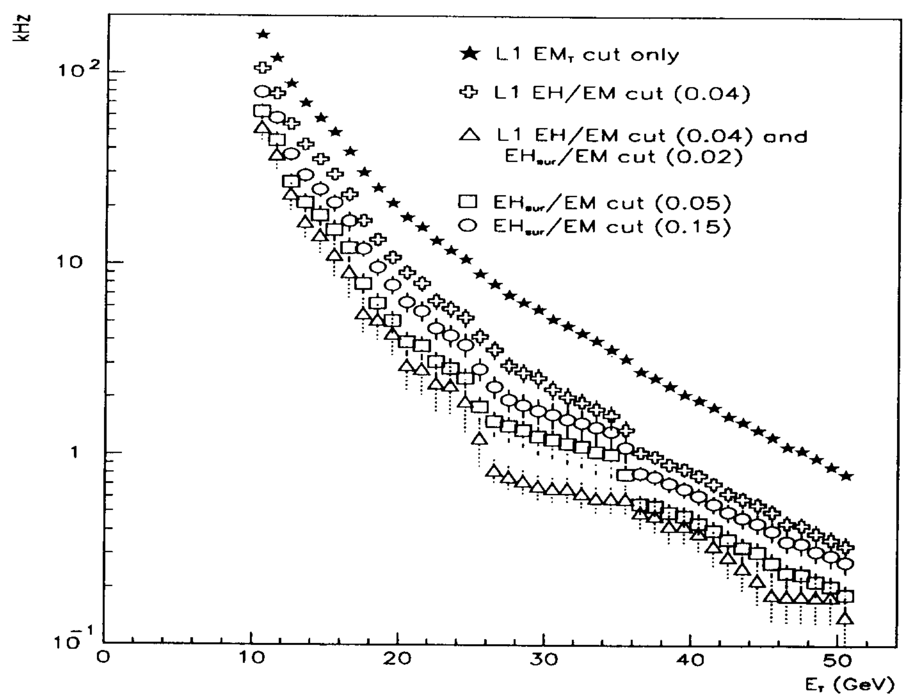

Figure 1: The QCD 2-jet background rate as a function of the EM_T cut for the single electron/γ trigger. The rate reduction due to the EH/EM cut and the transverse isolation cut is illustrated.

The L1 trigger consists of an electron trigger, muon trigger, photon trigger, "double object trigger" ($\gamma\gamma$, ee, eγ, $\mu\mu$, eμ), jet and missing E_T trigger. Jet and missing E_T triggers were discussed in [4],[5]. The muon trigger will not be discussed here. As the γ and electron triggers differ at L1 only in the track requirement, we will concentrate on a discussion of the electron trigger.

ELECTRON TRIGGER ALGORITHMS:

1. Cut on EM_T in 0.1×0.1 EC tower.
2. Cut on EH/EM in 0.1×0.1 tower.
3. Require signal above threshold in at least 1 SMD strip.
4. Require high p_T track stub in BT or IT matching to a trigger tower in ϕ.

Option:

5. Cut on EH_{sur}/EM (EH_{sur} = HC energy in 8 0.1x0.1 towers).
6. Match the track with hit SMD strip.

1) Due to the small tower size used (0.1×0.1) the cut on EM_T suppresses effectively the jet background. A cut on $EM_T > 30\,\mathrm{GeV}$ reduces the background of jets with $p_T > 30\,\mathrm{GeV}/c$ by a factor ~ 30. With (0.1×0.2) towers the same reduction is achieved with a cut of 40 GeV. However, a fixed tower size trigger has slow efficiency turn-on for two reasons:

– Electron bremsstrahlung far from the calorimeter. Electrons are separated from γ in the magnetic field. A 20 GeV electron which loses 30% of its energy due to bremsstrahlung in the $0.02\,X_0$ beam pipe is separated from the photon by $\sim$ 12 cm at the entrance to the calorimeter.

– Finite transverse shower profile. Molière radius of SDC EC calorimeter was $\sim$ 1 cm and the tower dimension $\sim$ 12 cm, so this problem was less important.

2) A cut on EH/EM (longitudinal isolation) eliminates effectively hadrons leaving π^0 dominated jets. 3) We have required a signal of more than $\sim$ (20-10) MeV in at least one (1 cm wide) SMD strip in the tower. This cut removes possible calorimetric noise background, and also some early showering hadrons [6] which may deposit large energies in the EM but spread over a larger transverse area. 4) Track requirement removes π^0 jets, leaving converted γ background and overlap background. 5) To avoid the loss of radiating electrons only energy in the HC was used in the transverse isolation cut (EH_{sur}/EM). The cut could be "switched off" for electrons which pass a sufficiently high E_T threshold. 6) Fine match of the track with a SMD deposit removes the overlap background [6] and also "ghost trigger tracks". The "double object" ($\gamma\gamma$, ee, eγ) trigger should allow for lower thresholds. Unless sufficient spatial separation of "objects" is required the background to this type of trigger is due to converted γ's and radiating electrons.

Monte Carlo Simulations

ISAJET was used to simulate 2-jet QCD background ($4.4 < p_T < 200\,\mathrm{GeV}/c$) and high-$p_T$ physics. To save CPU time generated background 2-jet QCD events were divided into four p_T bins, and events surviving the L1 trigger in each p_T bin were added with the appropriate weights. Minimum bias background (PYTHIA min. bias or ISAJET low-p_T QCD 2-jets) was summed over two previous events and added with appropriate weights.

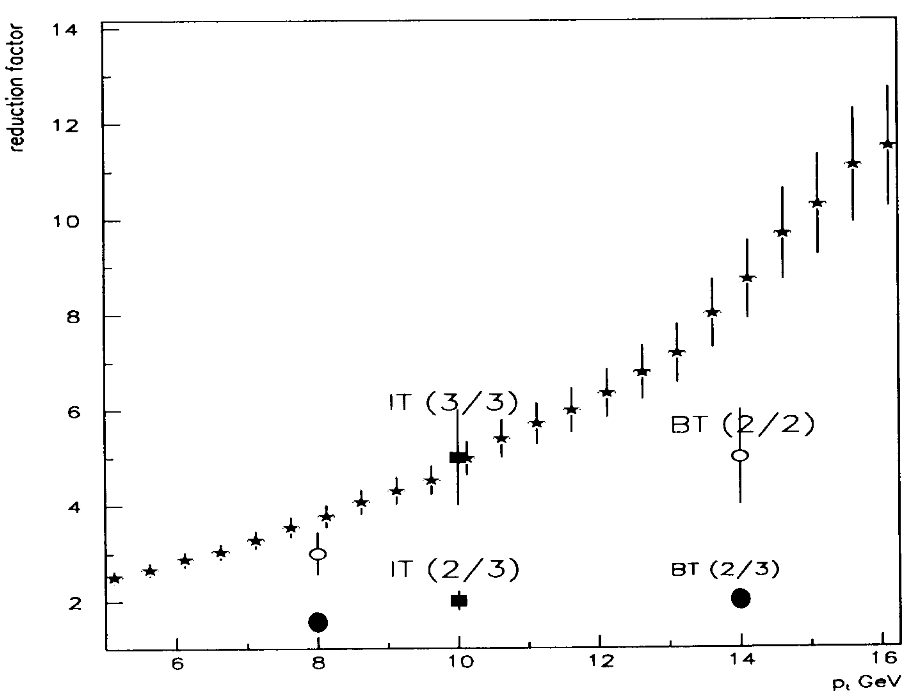

Figure 2: The background rate reduction factor for the BT trigger (circles) and IT trigger (squares) for events that passed calorimetric trigger with $EM_T > 20$ GEV and $EH/EM < 0.05$. The "ideal" tracking trigger background reduction factor as a function of the p_T cut is given for comparison (stars).

We have used two types of detector simulation programs: one based on a parametric description of the detector (FASTSIM) and one based on GEANT with an accurate detector geometry (SDCSIM). SDCSIM and FASTSIM were interfaced with each other. This allowed us to use FASTSIM as a *filter* to SDCSIM and also to *cross-check* FASTSIM against SDCSIM. *Eg.* we cross-checked single pion and electron deposits in the EC and HC, and the rate and spatial distribution of γ conversions. Our approach allowed for a statistically significant simulation of the trigger chain and for a future interface to the DAQ and trigger architecture simulation. For calorimetric trigger studies FASTSIM was used. For tracking trigger studies FASTSIM was used as a filter to SDCSIM.

3. Simulation Results:

Table 1 contains a summary of L1 trigger studies. All presented rates and efficiencies are for $10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ luminosity and in the $-3 < \eta < 3$ range.

Table 1: The summary of the L1 trigger background rates and efficiencies. Quoted efficiencies do not include the geometry factor - all e/γ/jets were contained in the $|\eta| < 3$ region. Luminosity $10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$.

Trigger and cut	background rate (kHz)	efficiency
Single e/γ $EM_T > 20$ GeV $EH/EM < 0.05 - 0.1$	10-15	75 % on $t- > (Wb)- > (e\nu b)$ 97 % on e with $E_T > 40$ GeV 60 % on D-Y W $W- > (e\nu b)$
Single e $EM_T > 20$ GeV $EH/EM < 0.05$ track($p_T > 14 - 10$) GeV	2.5	72 % on $t- > (Wb)- > (e\nu b)$ 95 % on e with $E_T > 40$ GeV 60 % on D-Y W $W- > (e\nu b)$
$EM_T > 20$ GeV $EH/EM < 0.05 - 0.1$ $EH_{sur}/EM < 0.02 - 0.05$	2-5	72 % on $t- > (Wb)- > (e\nu b)$ 95-98% on e with $E_T > 40$ from $t- > (Wb)- > (e\nu b)$
single γ $EM_T > 30$ GeV $EH/EM < 0.05 - 0.1$	2-4	98% γ with $E_T > 50$ GeV 97 % (90-120) GeV $H_0- > \gamma\gamma$
ee or $\gamma\gamma$ $EM_T > 10$ GeV $EH/EM < 0.05 - 0.1$ "double object"	5-8	96 % on uncorr. ee or $\gamma\gamma$ with $E_T > 30$
jet trigger $E_T(0.8X0.8) > 110$ GeV	3	90 % for jets $E_T > 300GeV$

<u>Calorimetric Triggers</u>
Figure 1 shows QCD 2-jet event background rates for the electron–photon trigger as a function of calorimetric cuts.
A 20 GeV cut on transverse energy in the electromagnetic calorimeter 0.1×0.1 tower and a longitudinal isolation cut reduce the jet rate to ~ 10 kHz, thus reducing the rate of jets with

$p_T > 20\,\mathrm{GeV}/c$ by a factor of ~ 100. Surviving background (mainly γ from π^0) can be reduced further by a transverse isolation cut. To achieve $\sim$ (2-3) reduction factor the transverse energy cut must be tight (EH_{sur}/EM < 2%-5%). Inefficiency for electrons from $t \rightarrow (Wb) \rightarrow (e\nu b)$ decays introduced by the transverse isolation cut is small (2% -3%) but this cut biases the topology of the event and effectively removes electrons from b decays.
Background rates and efficiencies for 0.1×0.2 tower size were presented in [4]. We checked that "Atlas style" [2] towers do not improve our electron efficiency versus background rate curve, as we had to raise the threshold to achieve the same background rate as in the 0.1×0.1 option. Radiating electrons we recovered this way are likely to be lost again once a tracking trigger with a certain p_T threshold is applied and/or $p_T - E_T$ match is required (at L2). To recover radiating electrons at the tracking trigger level would require a clustering algorithm which looks for radiated photons. A similar comment applies to the use of smaller towers at L2.
As 30% of calorimetric energy is seen in the next beam crossing, events with large energy deposits may lead to multiple triggers. We estimated that "multiple trigger" background will not increase e/γ trigger rates by more than 20%. A scheme which unfolds calorimetric signals [7] based on their expected time shape was proposed to cure this problem.

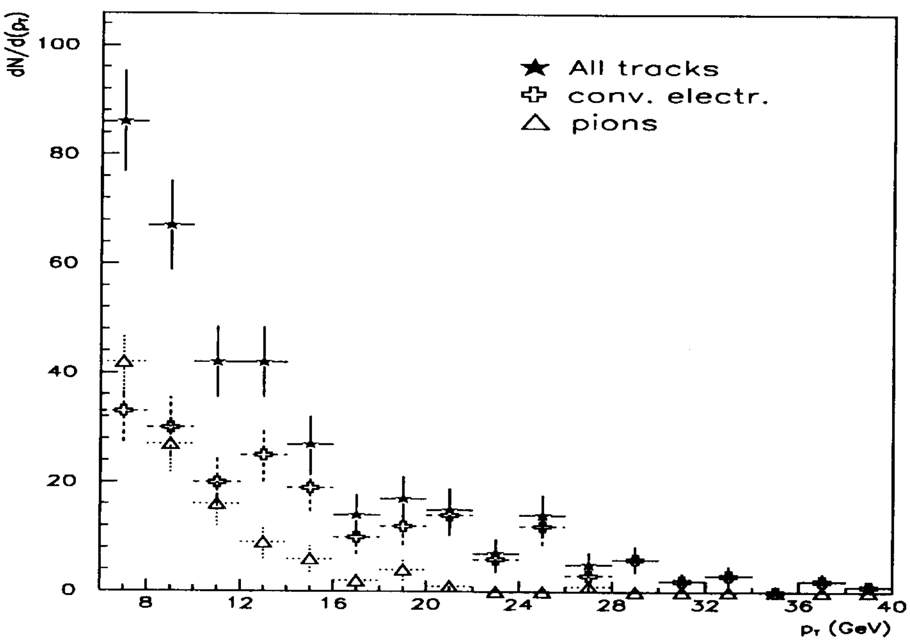

Figure 3: The p_T spectrum of leading particles matching to a trigger tower with $EM_T > 20$ GEV and $EH/EM < 0.05$ for background events.

Tracking Trigger

The L1 track trigger is based on the straw drift tube tracker [3] in the barrel region and on the microstrip tracker in the intermediate region. The straw tracker trigger is described in [8]. In the barrel region three superlayers of straws (each containing 8 layers of 4 mm diameter staggered straw tubes) were to be used in the trigger. Patterns of straws within the same ϕ row within the same superlayer are searched for coinciding drift times by means of mean-timers. Selected patterns of straws from different superlayers are linked along narrow paths expected for high momentum tracks. Track stubs are matched in ϕ with calorimeter trigger towers. Straws at the boundary of the towers can belong to both towers. The intermediate microstrip tracker [3] has projective geometry both in η and ϕ. It consists of three ring-shaped superlayers of strips in planes perpendicular to the z-axis. The microstrips have $200\,\mu$m pitch in ϕ. The trigger looks for patterns of hit strips in 3 superlayers which have similar ϕ. Both intermediate and barrel tracker triggers allow for several p_T thresholds to be applied (*eg.* different for single and double object triggers).

The reduction factor for the IT trigger is close to the ideal trigger reduction (Fig. 2) factor if hits in all 3 superlayers are required. If only 2 superlayers are required the trigger is dominated by random combinations. In the barrel, good background reduction is achieved (Fig. 2 and Table 2) if only 2 outer superlayers (2/2) are used for pattern linking. For 2/2 (2/3) option there is 10% (40%) probability that a track stub will be matched with a trigger tower due to random combinations. The efficiency of the barrel track trigger with $p_T > 14\,\mathrm{GeV}/c$ is greater than 95% for electrons which passed the calorimetric Level 1 trigger with $EM_T > 20\,\mathrm{GeV}$ and $EH/EM < 0.05$.

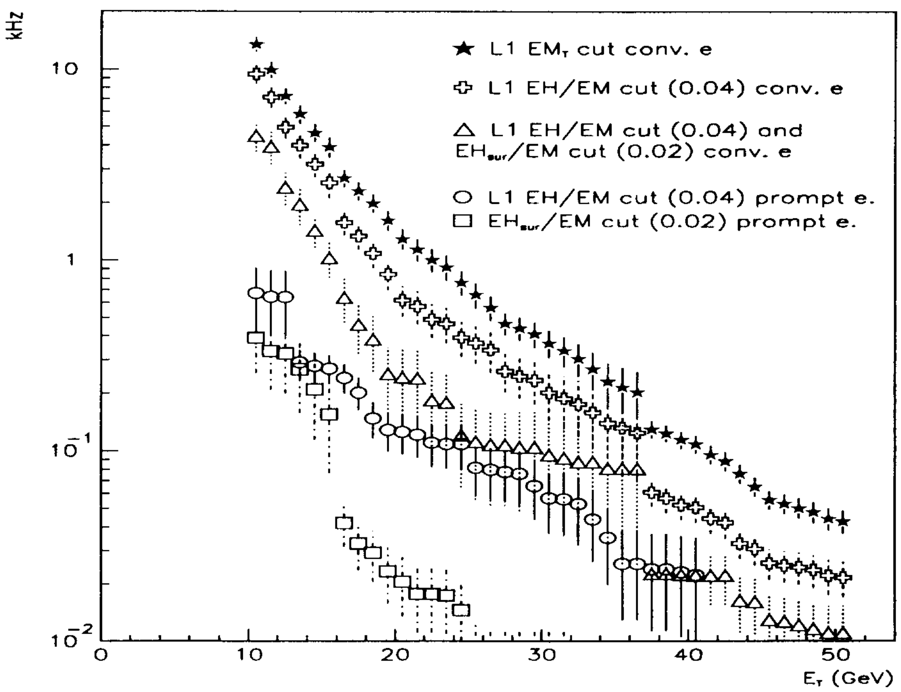

Figure 4: The conversion electron background rate and the prompt electron rate from the QCD 2-jet events as a function of the E_T cut in the L1 tower and of the L1 algorithm.

Table 2: Sample electron trigger rates.

Cut	region	rate (kHz)	rate composition (kHz)
$EM_T > 20$ $EH/EM < 0.05$ track $p_T > 14$ GeV (2/2 option)	BT	2	fakes 0.7 conversions 0.7 overlaps 0.5 prompt e 0.1

More than 50% of real tracks with $p_T > 14\,\mathrm{GeV}/c$ matching a trigger tower come from converted γ's (Fig. 3). We have studied conversion electron and prompt electron backgrounds as a function of calorimetric cuts (Fig. 4). With $EM_T > 20\,\mathrm{GeV}$ and $EH/EM < 0.04$ the conversion electron rate is $\sim 1\,\mathrm{kHz}$ and the prompt electron rate is $\sim 200\,\mathrm{Hz}$ [1]. With $EH_{sur}/EM < 0.02$ the conversion background is reduced to $\sim$ 300 Hz.

4. Summary and Conclusions

We have presented background rates and efficiencies for the Level 1 trigger of the SDC experiment at a luminosity $10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ in the $-3 < \eta < 3$ range. The simple calorimeter based trigger including electron/photon, jet, missing energy and "double-object" triggers can reduce background rates to $\sim 25\,\mathrm{kHz}$. The trigger is reasonably efficient for high-p_T physics.
The calorimetric L1 trigger rate is dominated by the single electron/photon trigger.
We have proposed a L1 tracking trigger which can reduce the electron trigger rate to about $2.5\,\mathrm{kHz}$ while preserving high efficiency for high-p_T physics. The background is dominated by conversion electrons.

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[1] Electrons from W and Z production are not included here