LOWEST LEVEL TRIGGER FOR SSC GENERAL PURPOSE DETECTORS.

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I. INTRODUCTION

At 40 TeV c.m. energy pp collisions [1], the inelastic cross section is estimated to be around 100 mb which for $\mathcal{L}=10^{33}\ s^{-1}\ cm^{-2}$ implies collision rates of $10^8\ s^{-1}$. Events of interest might have yields of 100 $year^{-1}$. The reduction factor of $\simeq \pi\times10^{13}$ will necessarily be achieved in a series of steps, the first of which is most likely to consist of analog processing of signals from a general purpose detector in order to produce a so called *ANALOG TRIGGER*.

It is generally accepted that the most promptly useable information for the generation of an analog trigger, will be provided by the inevitable 4π, crackless and hermetic calorimeter [2]. In the following we present a scheme for producing a first level trigger, based on calorimetry only, which we believe capable of achieving a reduction of a factor of 10^4 in the number of events to be passed on to more sophisticated levels of screening. While many of the assumptions and strategies outlined in the following are by necessity somewhat arbitrary, they are motivated by the desire to define an effective trigger applicable to a *GENERIC, GENERAL PURPOSE* detector, which can produce enormous amounts of irrelevant information.

It is moreover true that we must be reasonably optimistic in believing that continuous progress in electronics will allow new, just emerging, advanced analog and digital data acquisition techniques to become usable in large scale and at acceptable cost per channel. In particular we refer to waveform sampling, at high rates and accuracies, of hundreds of thousands of channels and special purpose digital processing to remove pile-up.

While it might seem unrealistic to discuss trigger schemes for every possible type of 4π calorimeter, we wish to point out that in fact the basic requirements for the detector response which are necessary for generating an efficient trigger for physics at the 1 TeV mass scale, are truly minimal. The

Snowmass 84 report has several times concluded that the best calorimetry at the SSC might be achieved with liquid argon. One drawback of liquid argon is the slow charge drift velocity [3]. For a 2 mm gap the collection time is 400 ns. This problem is of course somewhat alleviated by the fact [4] that 3/4 of the charge is collected in 200 ns, 1/2 in 120 ns etc. The necessary integration of the signal, to remove preamp noise, loses some of this advantage. One-millimeter argon gaps together with thin layers of absorber material is another possibility. However it would make construction of a 10 to 15 absorption lengths calorimeter a real challenge! There is of course the possibility of increasing drift velocity by use of methane (or perhaps amphetamines?). We wish to argue here that a 500 ns response of the calorimeter is in fact quite acceptable; some tradeoffs might be required, but they are probably necessary anyway, because of noise and pileup considerations. (In 500 ns, some 50 inelastic interactions take place.) In fact, however, any tower in a reasonably segmented detector is on average empty at the postulated collision rate. The main question is of course at what level pile-up becomes a problem in the trigger and at what level tails in the distribution of common events will interfere with the rare physics of interest. While the second question is answered by other groups in this workshop, we find no problem with the first. As will be explained later, we assume, for trigger purposes, that the detector is subdivided in 5000 towers, each covering an η-ϕ range of $\Delta\eta\times\Delta\phi\approx 0.1\times 0.1$.

We obtain a first order estimate of signals and their variances from the calorimeter elements by assuming that at $\sqrt{s}$=40 TeV the average neutral plus charge multiplicity for inelastic collisions is 150 and that the average E_T of each particle is 0.5 GeV. Each tower therefore sees an average energy signal of:

$$S=0.5\text{GeV}\times 10^{8}\text{s}^{-1}\times 10^{-6}\times 150/5000=1.5\ \text{GeV}/\mu\text{s}.$$

If each tower signal is first sensed by a charge sensitive preamp with a 100μs decay constant the preamp output is, in average, S=150 GeV. Since in fact the preamp is A.C. coupled to the detector, the output is in average zero, but fluctuates around zero with a variance of ≈5 GeV. The signal, in energy units, is shown in figure 1. The large fluctuations are due to the fact that the signal is "returning" to -150 GeV with a rate $dS/dt=|d/dt[150\exp(-t/100)]|_{t=0} = 1.5$ GeV/μs. Taking the finite time difference $S(t)-S(t-\tau)$ for τ=0.5μs reduces the rms fluctuation to ≈0.8 GeV. Therefore, while every 0.5 μs there are in average 1.5

particles in each tower, a 25 GeV signal, shown at t=150μs in figures 1

Figure 1. Preamp output, for 100 μs time constant.

and 2, is quite visible and is measured to an accuracy of a few percent. It is this basic point, notwithstanding the crudeness of the model used, justified in part by the small η-ϕ range covered by each tower, that makes an analog trigger relatively easy to implement and powerful.

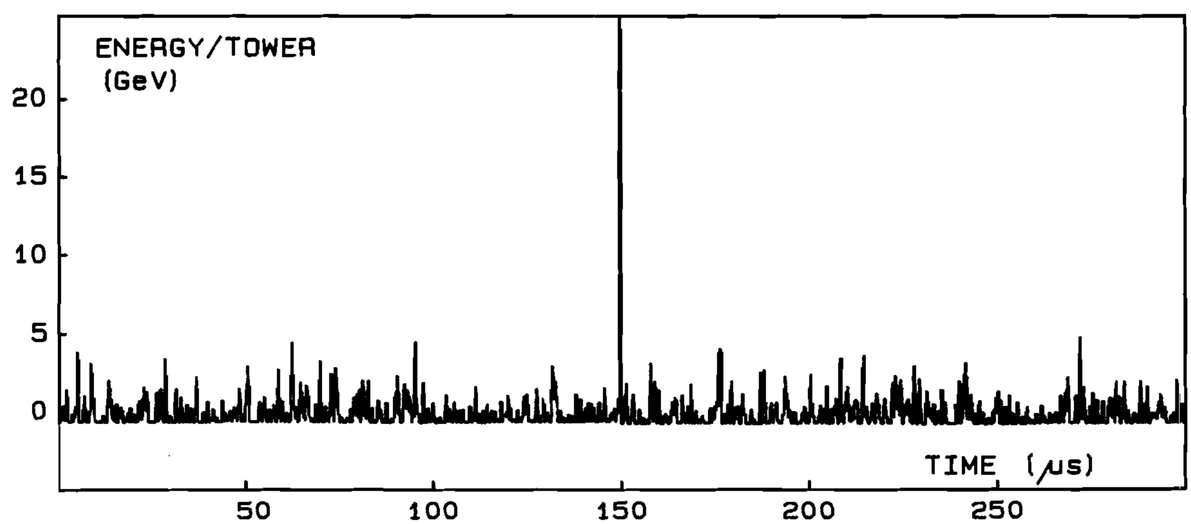

Figure 2. The signal of figure 1, after 0.5 μs clipping.

The signal of figure 2 can of course be made much cleaner by taking finite time difference with $\tau\approx$30-100ns. The feasibility of doing this is determined by the rise time of the detector signals. For $t_{rise}<\tau$, reducing τ just increases the electronic noise as $\surd(1/\tau)$. For $t_{rise}>\tau$, the electronic noise increases as $\approx 1/\tau^2$.

There is no need for the analog trigger to require τ<<500ns. The fact that in 500ns there are 50 inelastic collisions is not a source of confusion.

In order to obtain the best measurements of the energy deposits in the detector element several samplings of the preamp outputs are necessary. A slow rise time poses burdens on the number of samplings necessary. A fast rise time can only be utilized at the cost of larger noise. Probably the best compromise consists of several low accuracy samples and two or three precise samples 1-2μs apart. Auxiliary timing information might be required for optimal results.

II. WHAT ANALOG TRIGGERS?

From the general discussion on physics at the SSC [1,5] it appears that signals of universal interest for standard model physics to wilder speculations consists of large P_T leptons and or jets and missing P_T. In the following we discuss three types of triggers which can be generated in a short time with analog techniques from calorimeter signals.

1) Isolated electrons with E_T>25 GeV.

2) Isolated jets with E_T>40 GeV.

3) Total E_T and missing P_T.

It is in general assumed that this first level [6] analog trigger is complemented by a second level,more sophisticated trigger which further manipulates the information used by the first level trigger,and passed-on in analog form as well as other information allowing further decrease of the crude data rates.

III. DETECTOR SIGNALS FOR THE ANALOG TRIGGER.

We assume, as elsewhere in this workshop, that the hermetic calorimeter consists of 50,000 towers covering a $\Delta\phi\times\Delta\eta$ interval of 0.03×0.03. This segmentation is much too fine for containment of a hadronic shower but roughly of the order of the size of an e.m. shower.

The probability of an e.m. shower being shared between two neighboring towers is,however, rather large and therefore we group calorimeter towers into trigger towers covering an $\Delta\phi\times\Delta\eta$ interval of 0.1×0.01. This corresponds to adding 10 towers, close enough to 3×3=9. Ignoring 10% rounding off we are led to 5000 trigger towers. Each tower is probably further subdivided in depth for good em/hadronic shower separation, full absorption of high energy hadronic showers, etc. For trigger purposes it is sufficient to deal with two signals per tower, one from the front part of each tower for good measurement of the e.m. shower energy and one from a few interaction lengths behind for good measurement of the hadronic energy. In the following we therefore assume that 10,000 signals are extracted from the calorimeter and used in the trigger generation.

These signals are best generated at the place where the calorimeter signals become first available, for instance where the charge sensitive preamps are located; presumably the signal feeds through ports on the cryostat containing the liquid argon. The signals are also supposed to be weighted by cosθ (or probably $|\cos\theta|$) to represent E_T rather than E. See figure 3.

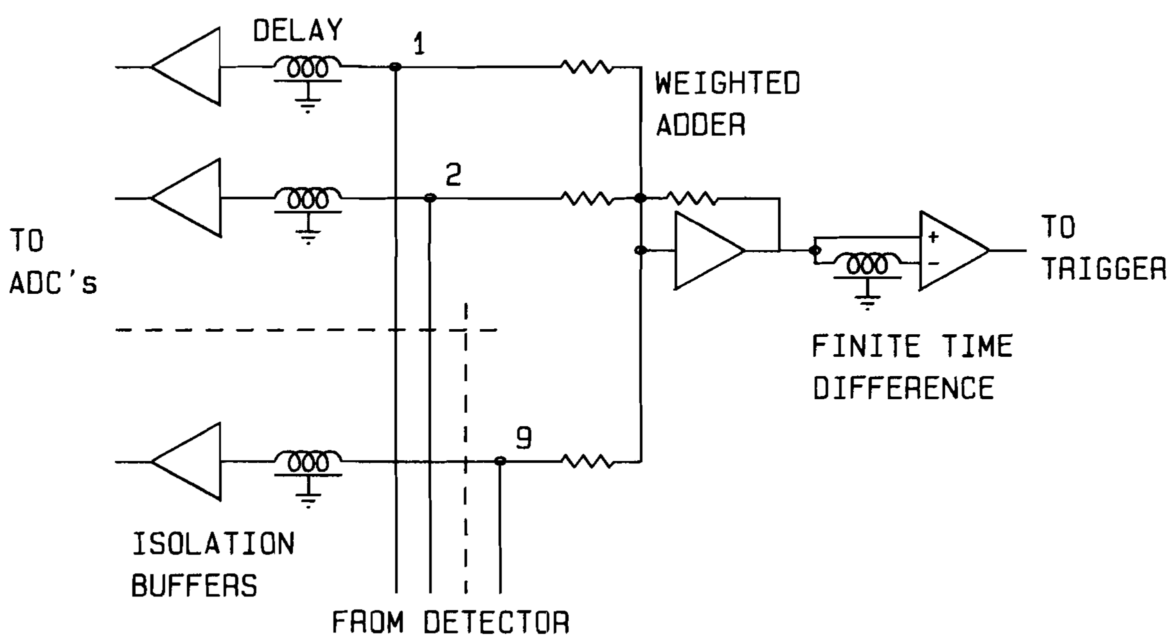

Figure 3. First level sums with clipping.

Finite time differences are also taken of the 9 tower sums as indicated in figure 3. The 10,000 input signals to the trigger must be collected to a single point from a physically large detector. It is estimated that cable runs of ~250ns will conservatively allow bringing all signals together to a point on the detector itself and optimistically to a location well shielded from the interaction area, for instance on top of the detector after muon absorber and radiation shielding. It will certainly be very hard to go below ~200ns.

Since the time required before initiating readout is at least twice the above value, delay lines are necessary between preamps and precision ADC's. Miniature, high quality delay lines in the μs range are easily available today and are likely to remain a more economic alternative to constantly digitizing the output signals.

IV. ELECTRON TRIGGER.

An electron trigger consists of detection of a large energy deposit in the first (e.m.) compartment of a tower with very small energy appearing in the following compartment. This can be performed with two discriminators, the first detecting e.m. signals greater than a fixed threshold, the second insuring the absence of hadronic signals greater than 5 to 10% of the e.m. signals, figure 4.

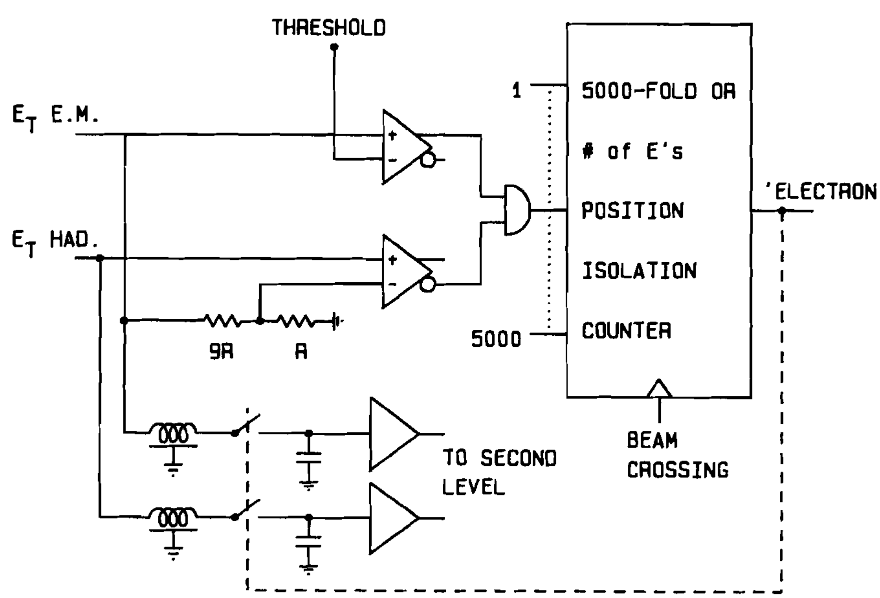

Figure 4. Electron trigger.

Note that the comparator outputs are strobed into registers at the appropriate *time*, defined by the crossing time, the difference interval τ, the detector response time, and ultimately by the acceptable noise level.

Comparators with propagation delays of 3-5 ns, together with use of ECL logic allows the operation sketched in figure 4 to be performed in well less than the time interval between crossings. Noise considerations ultimately determine the *time*. While it is not possible to discuss here noise for an unknown detector we can mention that, as pointed out earlier, for times of 500 ns the limiting noise is due to pile-up from events and is of the order of ~0.45 GeV for e.m. energy and 0.65 GeV from hadronic energy. While this noise decreases as $(time)^{1/2}$ the electronics noise increases as $(time)^{1/2}$ but most important, signal/noise gets worse as $(time)^{1/2}$ for fast detector response and as $(time)^{2}$ for slow detector response.

Assuming a preamp input impedance R and cell capacitance C, such that RC<50 ns, followed by a single RC integration of 100 ns and a finite time difference with τ=150 ns, the electron trigger can be generated in 650-750 ns, including the two-way signal transmission (500ns) and additional manipulation (see later) at noise levels of ≈1 GeV. Thus for E_{th}=25 GeV one has a threshold rms spread of ~4%. If one asks for $E_{had}>0.1 \times E_{em}$, then the probability that a true 25 GeV electron is rejected because of noise in the hadronic channels is < 1%.

There are 5000 "electron" channels. A 5000-fold "or" of their outputs might be enough for the crudest trigger information. Additional logic should however be incorporated to produce a count or a list of all triggered channels, check for isolation and which bunch crossing generated the trigger [5]. This information could further restrict the acceptance of a trigger or be transmitted to the second level analog trigger. It should be noted that the scheme described still has severe inefficiencies for electrons close to the boundaries of the 3×3 trigger towers. The standard solution is to generate an additional set of trigger signals from a grid displaced by one unit in both coordinates. This requires a doubling of the whole electron trigger system but insures full efficiency. The same problem appears, more severely, in the case of jets, where we explicitly confront it.

V. JETS, E_T AND MISSING P_T.

To generate E_T and missing P_T signals it is necessary to impose strong cuts on the input signals [3] to be added since otherwise E_T and P_T will typically have mean values of $\surd(5000)\times\surd[E^2_{noise}(had.)+E^2_{noise}(em)]$ which might well be in excess of 100 GeV. Figure 5 shows an example of the total E_T distribution, observed in a 5 μs time interval, for a detector response time of 330 ns. Only E_T>0.5 TeV would be an acceptable trigger in this case, after a 5 GeV cut on each tower, as indicated.

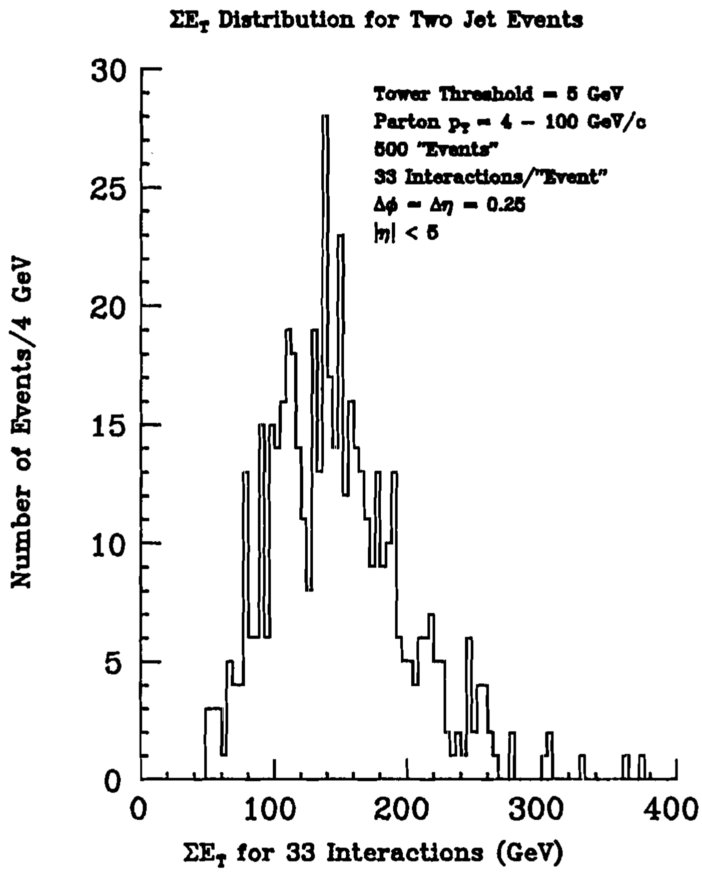

Figure 5.(From R. G. Wagner)

Even searching for jets in $\Delta\phi\times\Delta\eta\approx0.5\times0.5$ regions requires adding 50 signals resulting in an rms noise of 10 GeV.

Before adding energies from e.m. and hadronic tower sectors, the signals must be passed through analog gates which have appropriate thresholds. These gates must be fast and have very low switching noise. An example [7] of such gate, with a DMOS FET, is shown in figure 6. Hybrid or monolithic version of a threshold analog gate would allow close packing of the electronics for the 10 000 channels required. The circuit in figure 6, including first order nulling of charge injection, is similar to those used by many groups.

Towers of jet size must be assembled from the 5000 e.m. plus 5000 hadronic sections in overlapping grids in η,φ space, to both avoid inefficiencies at tower

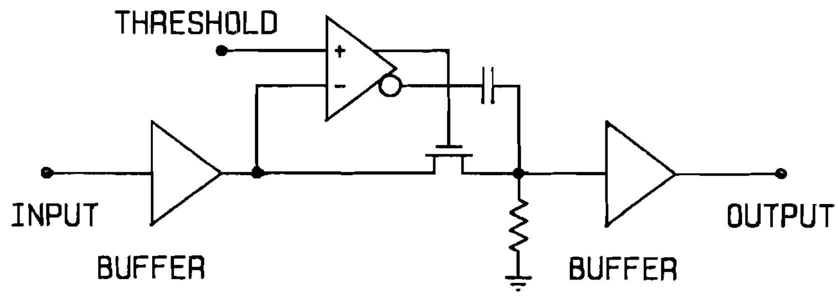

Figure 6. Analog gate with threshold.

boundaries and to check for isolation. In the following we sketch a method (by no means meant to be the best solution but just an example [8]) for finding isolated jets with E_T greater than some threshold, counting the total number of jets present and generating the total E_T for all jets found.

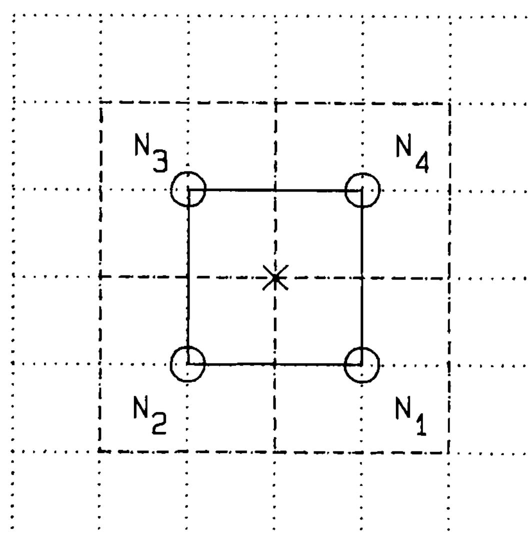

Figure 7. Clusters for jets. N stands for neighbor.

We begin by adding sixteen adjacent towers, i.e. the 16 e.m. signals plus the 16 hadronic signals. The 4×4 tower groups are shown by dotted lines in figure 7, in η,ϕ space. There are ≈300 4×4 groups. Four of these groups are finally combined in clusters of size $\Delta\eta\Delta\phi\approx0.8\times0.8$ ($R\approx0.45$) such as the one centered around the × mark in figure 7. A second set of clusters, displaced by 0.4 in η and ϕ is also generated, such as those centered at the ⊙ mark in figure 7. A total of 2×80 cluster signals are generated.

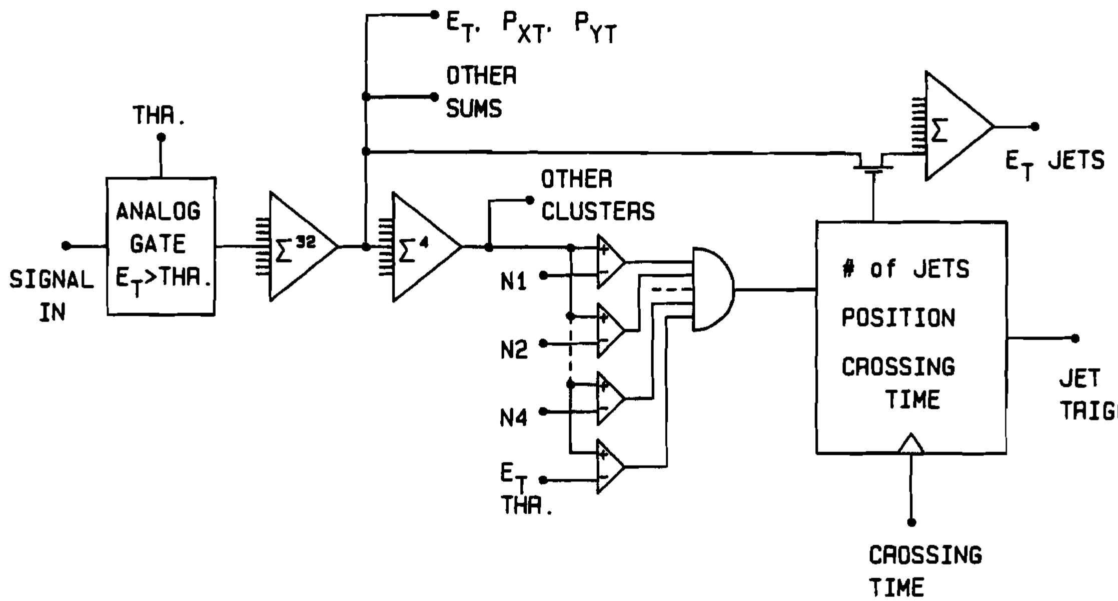

Figure 8. Jet trigger.

The E_T signal from each cluster is required to be above a threshold and is compared with the E_T deposited in the four partly overlapping neighbor clusters (N_1-N_4). In this way the detector is subdivided in ≈80 physically distinct towers, out of which those with a local peak in the E_T signal, above a certain threshold, are identified. Figure 8 gives a schematic picture of the jet trigger. Generation of E_T and missing p_T signals at this point just requires proper sinϕ, cosϕ weighing and appropriate adders.

VI. TRIGGER RATES AND TRIGGER EFFICIENCY.

Most of the estimates for the expected rates from the triggers described above are from simplified calculations [9], without taking into account e.m. shower nor hadronic cascade development in the calorimeter. Except for the simple example given in section I, all the estimates use Isajet of F. Paige as event generator. In addition the calculation presented at this workshop by F. Paige have been extensively used. Finally the estimates for fake electron trigger were obtained by F. Paige during the workshop. It is generally felt that the results listed below are not overly optimistic. More extensive calculations will require very large amounts of computer time, for event generations at the required statistical accuracy and especially for e.m. shower and hadronic cascade developments.

In table 1 we give the expected rates, in hertz for various triggers, from true physical processes. We believe that the additional contributions from electronics noise are always negligible.

TABLE I

Trigger	Rate (Hz)
Isolated electron, E_T>25 GeV	20 000
Missing P_T>50 GeV	20 000
Total E_T>300 GeV	10 000
TOTAL TRIGGER RATE	50 000
2 Jets, each with E_T>40 GeV	100 000

The total trigger rate of 50 000 above is probably still much too high for a first level screening of uninteresting processes and certainly one should not add in the two jet trigger. It is however possible to require both an isolated electron and two 40 GeV jets. This should result in a trigger rate of 10 000 Hz. Likewise one obtains 10 000 Hz for the missing P_T case together with the requirement of two jets. Thus total trigger rates of order of 20 000 to 30 000 Hz appear reasonably feasible. This in turns implies that 30-50 μs are available for performing more sophisticated operations. While the trigger described is essentially free of dead-time, the information passed to the second level, in the way presented here, is available only until receipt of the next trigger. The possible dead time incurred in this way can be entirely removed by substituting the S&H function shown in figure 4 with analog shift register, properly keeping track of the crossing time to which they belong [6].

The most relevant question left is of course what interesting new physics will be lost by the trigger. Since we do not know what the new physics is, we cannot answer such a question! However if something of interest happens at 1 TeV mass scale it will result in signals at that scale which are certainly recognized by the trigger. As a bench mark, it was proposed during the workshop to concentrate on the scattering of two virtual W's, appearing in the final state as two W's on the mass shell. It appears very difficult to ever be able to trigger on $WW \to q\bar{q}q\bar{q} \to 4$ jets. Final states such as $\ell\nu qq$ are much more promising. From F. Paige graphs one reads the following answers:

Efficiency for WW final states
"Electron trigger" ≈60% for $e\nu qq$
"Missing P_T trigger" ≈60% for $e\nu qq$
≈80% for $\mu\nu qq$
Addition of the two jet requirement will however probably reduce these efficiencies by about 30%.

VII. A COST ESTIMATE.

The following items form the major components of the trigger discussed above:

1). 10 000 adder with delay line difference.
2). 5 000 'electron' trigger channels
3). 10 000 analog gates with threshold
4). 160 'jet' trigger channels.

Assuming today's part prices and cost for hybrid manufacture, a conservative estimate of the cost per signal used in the trigger (5000 e.m. sums and 5000 hadron sums) is ≈$ 60. This breaks down as $ 23 for parts, $ 25 for manufacturing and assembly and $ 12 for crates, power supplies etc. In addition, $ 10 per signals of cables are necessary. We ignore at this level all control and counting logic. The total cost of the trigger, from the above numbers, is therefore estimated to be ≈ $ 700 000.

VIII. CONCLUSIONS.

As many other groups have before concluded, we find it very promising to be able to deploy a fast, analog trigger capable of reducing the initial interaction rate at the SSC of more than 10^8 Hz to more manageable levels in the tens of kHz range. While the formidable initial interaction rate and high level of occupancy of a calorimeter might make accurate measurements of the energy deposits difficult, but not impossible, this does not appear to be a problem at the lowest trigger level where unique signatures stand out quite clearly.

ACKNOWLEDGEMENTS

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9. Some calculations,reported here, were performed by R. G. Wagner. See also ref. 3.