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PHYSICS AT 10^{34} cm^{-2} s^{-1}

R. Diebold and R. Wagner
Argonne National Laboratory, Argonne, IL 60439

Introduction

Most of the detector studies at Snowmass-84 have rightfully concentrated on detailed studies of individual interactions - their rates, signatures, and backgrounds. Depending on the physics and the detector components, there seems to be agreement that general-purpose detectors will likely be able to accept luminosities up to 10^{32-33} cm^{-2} s^{-1}.

The purpose of this paper is to show how the "physics reach" of the SSC is extended by going to a luminosity of 10^{34} cm^{-2} s^{-1}, to take a first look at what sort of detector could be used at this luminosity, and to discuss how one might trigger on interesting events in the presence of many overlapping "minimum bias" events. We will assume that the SSC turns on at 10^{31} or 10^{32} cm^{-2} s^{-1}, with an increase of luminosity to 10^{33} over a period of a few years as the machine and detectors become better understood. Thus, the lower mass scale will have been explored and we can set our thresholds high when running 10^{34}.

If the machine (assumed here to be pp at $\sqrt{s}$ = 40 TeV) can be run at this high luminosity, appropriate detectors will be able to collect adequate numbers of events at high $\sqrt{s}$ to allow the discovery of very massive particles, constituents, new types of interactions, etc. Just as going from 10^{32} cm^{-2} s^{-1} to 10^{33} probably means giving up precision silicon-strip vertex tracking chambers, going to 10^{34} probably means giving up nearly all tracking.[1]

While we will thus have less detailed information on our events, and there will be overlap with many (perhaps 30) "minimum bias" events, interactions with high mass particles or high p_T should still stand out clearly. At these energies, we are no longer looking for needles in the low-p_T haystack, we are looking for tractors! Each piece of straw no longer must be individually examined to see if it might be the golden needle - rather, the straw can be thrown away by the scoopful - it's easy to tell when the scoop runs into a tractor!

Obviously, one cannot do all physics at 10^{34} cm^{-2} s^{-1}. Some processes will require both high luminosity and detailed analysis to uncover a subtle signature, and will have to await further improvements in detector technology, or bigger accelerators (higher energy pp or e^+e^-).

Although the exact factor varies from process to process, for physics with a distinctive signature an order of magnitude increase in luminosity is calculated to extend the discovery reach by roughly the same amount as a doubling of the energy at fixed luminosity (see Ref. 2, referred to throughout this paper as EHLQ). Increasing the luminosity should be far cheaper than doubling the energy, however, at least up to some limiting luminosity.

Still, this goes against our intuition - our experience in the past has been that energy is often the dominant factor for new physics. The SSC is in a regime, however, far beyond that in which we have developed our intuition. At these high energies, the cross sections have fallen to very low values ($\sigma \propto 1/\hat{s}$), and we are generally limited by statistics to the region of low x, far below the kinematic limit of the machine. Thus, the observable thresholds for new particles or processes are expected to turn on much more slowly than at lower energies. In the past, fixed target machines always had plenty of luminosity, but were limited by the fact that the particles of interest (such as those with charm) had relatively low mass and gave a signature not so different from ordinary hadronic events. At the SSC, the opposite is expected to be true for many interesting phenomena - the rates are low, but the signatures are distinctive.

Machine Parameters at 10^{34}

An example of how 10^{34} cm^{-2} s^{-1} might be achieved is given in Table 1.[3] It assumes a bunch spacing of 5 m = 17 ns, giving an average number of inelastic interactions $\langle n \rangle$ = 17/crossing at 10^{34} cm^{-2} s^{-1} (for an effective cross section of 100 mb). The beam-beam tune shift is $\Delta\nu$ = 0.003, as achieved at the S$\bar{p}$pS, and β^* = 0.5 m is assumed as reasonable after a few years experience with the machine.

Table 1. Comparison of RDS (6.5 T) parameters with a *possible* mode for eventual operation at high luminosity.

		RDS-A	High Lumin.
Beam Energy	E (GeV)	20	20
Luminosity	$\mathcal{L}$ (cm^{-2} s^{-1})	10^{33}	10^{34}
Bunch spacing	D_B (m)	10	5
Inel. events/crossing	$\langle n \rangle$	3.3	17
Machine param. at IP	β^* (m)	1	0.5
Inv. emittance (rms)	ϵ_n (10^{-6} m)	1	1
Beam-beam tune shift	$\Delta\nu$ (10^{-3}/IR)	1.7	3.0
Protons/bunch	N (10^{10}/bunch)	1.4	2.2
Protons/90-km ring	N_{ring} (10^{14})	1.3	4.0
Stored beam energy	U (MJ/ring)	400	1300
Syn. rad. power	P_{sr} (kW/ring)	8	25
Length. of lum. region	$\sigma_{diamond}$ (cm)	5	5

Although no fixed limit is presently known, the biggest uncertainty in the parameters in Table 1 has to do with the number of stored protons, 3.2 times that of Reference Design Study A (RDS-A). Handling the increased synchrotron radiation is straightforward; it will require additional refrigeration, the total load at 4.5°K going from 58 kW to 96 kW for RDS-A (but a smaller effect at lower fields). For RDS-A the design already includes an installed capacity of 84 kW for cooldown, backup, etc. More problematic are effects associated with the large stored energy in the beam. Although the abort system and its beam dump looks straightforward, the inadvertent loss of only a small fraction of the beam could cause a magnet to quench. A very carefully designed machine, including a sophisticated collimator/scrapper system will be required, together with operational experience.

As outlined below, considerable additional physics can be explored at higher luminosity. **A prime purpose of this note is to alert the machine designers to the fact that > 10^{34} cm^{-2} s^{-1} can be handled by**

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suitable detectors and will be needed if the machine is to be fully exploited. Indeed, the machine design should, from the beginning, facilitate the ultimate achievement of the highest possible luminosity.

A Detector for 10^{34}

For purposes of discussion, we will assume a relatively simple detector consisting of two major subsystems. The first is a calorimeter system covering $|y| \le 5$ (down to $\theta = 13$ mrad) with towers having projective geometry. Taking cells of dimension $\Delta\phi = 5^\circ$ by $\Delta\eta = 0.1$ units of pseudorapidity gives 7200 cells, each with several longitudinal readouts to allow electromagnetic/hadronic separation. (This is relatively modest compared to the 4π detectors developed at this workshop, with typically 40,000 EM shower counter towers.[4]) For the Monte Carlo studies described below, we assumed an energy resolution for jets of $\sigma_E = 0.5\sqrt{E}$ (for E in GeV). Strip chambers at one or more depths might be used to give more precise position information for showers above some threshold.

The second major subsystem is an ~4π muon detection system, with thick iron toroids and associated drift chambers, similar to those of the 4π detectors.[4] Such detectors typically have a momentum resolution at high momentum of about $\sigma_p/p = 0.2$ p for p in TeV/c.

The detector will thus measure energy flow, including missing p_T, as well as muons and isolated electrons. It will not, in general, be able to measure the momenta of charged tracks, or even count the number of particles from an interaction.

Some redundancy might be very desirable, however, and this could be achieved by the measurement of track segments just in front of the calorimetry. For example, this would verify that isolated high-p_T hits in the EM shower counter are indeed electrons as expected, and not π^0's, and would provide a check of muon trajectories. If a solenoidal field were available, both e and μ tracks could be checked for high p_T; for example, 1.5 Tesla over a 2-meter radius, combined with two layers of drift chambers separated by 2 cm, each with resolution of 200 μm, would yield $\sigma_p/p = 0.03\ p_T$, or ±30% for $p_T = 10$ GeV/c. This would reject the vast majority of low-momentum tracks. Using the assumptions of the Tracking Group[1] of 18 charged particles/event within $|y| < 1.5$ and ionization of 10^6 e^-/charged particle, we calculate that a drift chamber of cell size 0.5 cm at 2 m radius would have a current draw of 1.2 μA/sense wire. This is only slightly above the 1 μA limit assigned by the Tracking Group.

Triggering

High luminosity would do us no good if pile-up effects dominate and the trigger thresholds must be set so high that events of interest are thrown away. To examine this question we followed the work of the calorimeter trigger subgroup[6] and considered both the first-level and final trigger requirements.

Although the beam-bunch spacing would likely be reduced to achieve 10^{34} cm^{-2} s^{-1}, we have been conservative and assumed as did the trigger group, that the first-level trigger sensitive time is 33 ns. For an inelastic cross section of 100 mb, this gives an average of 33 events which the trigger must handle at one time, ten times that considered by the trigger group. For convenience we will refer to these 33-ns intervals as "crossings," even though more than one actual beam crossing may be involved.

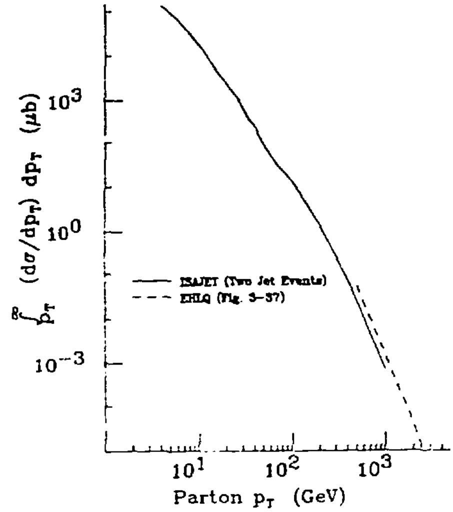

Fig. 1. The integral cross section for two-jet production as a function of p_T. The ISAJET curve is for $|y_{1,2}| < 5$, while that from EHLQ has $|y_{1,2}| < 2.5$.

ISAJET[5] was used to generate 16,500 "jet events" with parton $p_T > 4$ GeV/c; both beam and scattered-parton fragmentation particles were generated. The integrated cross section so obtained is shown in Fig. 1; the program gives 140 mb for $p_T > 4$ GeV/c and we have taken this to be our "minimum bias" sample.

As a ballpark figure, the first-level trigger should have an output rate of about 10^5 Hz, a reduction in the total cross section rate by a factor of about 10^4. From Fig. 1, this implies an effective threshold of $p_T = 100$ GeV.

For each crossing, the energy from 33 interactions was summed for each of 960 supertowers ($\Delta\eta = 0.25$ by $\Delta\phi = 15^\circ$) with pseudorapidity $|\eta| < 5$. After the 33 events were accumulated, a threshold cut (E_{thr}) was imposed and only towers above this cut were used in forming sums giving the total E_T and its projected components (E_{Tx}, E_{Ty}). Whether the threshold cut is best made on supertowers or on single towers (or both) will require additional Monte Carlo study.

Looking at the interactions individually, with $E_{thr} = 0$, an average of 73 (rms = ±24) charged particles were produced with $|\eta| < 5$; including neutrals, this becomes a total of 116 (rms = ±39) particles observed per interaction. The average E_T deposited is 44 GeV per interaction (44/116 = 0.38 GeV average per particle), with an rms spread in E_T of ±16 GeV. The missing p_T is defined for these fast-trigger studies as the maximum of ($|E_{Tx}|$, $|E_{Ty}|$); it has an average of 3 GeV with a ±2 GeV rms spread for a single event. These quantities empirically scale with the number of interactions, n, as expected:

$$E_T = 44\, n\, (1 \pm 0.35/\sqrt{n})\ \text{GeV},$$

$$p_T^{\text{mis}} = 3\sqrt{n}\, (1 \pm 0.6)\ \text{GeV}.$$

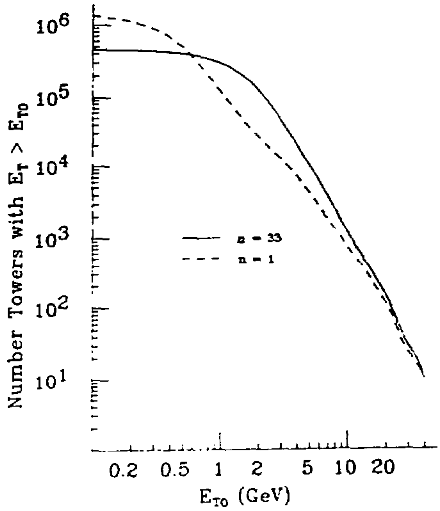

Fig. 2. The integral number of supertowers with transverse energy > E_T. The supertower size is $\Delta\eta = 0.25$ by $\Delta\phi = 15^\circ$. The solid curve is for 1 event per bunch-bunch crossing (16,500 crossings) and the dashed curve for 33 events per crossing (500 crossings).

Thus, for n = 33 we have $E_T = 1430 \pm 90$ GeV and $P_T^{mis} = 19 \pm 11$ GeV.

For n = 33, there are approximately 2400 charged tracks within $|\eta| \leq 5$. Can one even look at track segments (as suggested above for electrons) with all this clutter? If a solenoid is used, some of these tracks will be swept away (for example, tracks with $p_T \leq 450$ MeV/c in a 1.5-T field will be trapped within 2-m of the beam pipe). Ignoring this, the average density of these (mostly) random tracks is $N_{chg}/\Delta\eta\Delta\phi$ = 2400/(10 × 2π) = 38 tracks per unit rapidity per radian, or 1 track per $\Delta\eta\Delta\phi = 0.16^2$. In the central region at a radius of 2 m, this works out to about 1 charged track per square foot; thus, the random pile-up clutter should not be a *fundamental* problem in finding track segments.

The average number of particles (charged plus neutral) per supertower turns out to be 4.0 for n = 33, giving an average "noise level" of $E_T = 1.5$ GeV/supertower. The integral spectra of E_T in the supertowers is shown in Fig. 2 for both n = 1 and n = 33. As expected, the main effect of pile-up is to shift the spectra by a few GeV; the long tails correspond to the real jets of moderate p_T in this "minimum bias" sample. Pile-up effects in individual cells are, of course, much less. For the 7200 cells taken above ($\Delta\eta\Delta\phi = 0.1 \times 5^\circ$), the average occupancy is 0.5 particles/cell at n = 33.

As n increases, E_{thr} must be raised if the trigger is to remain efficient. For $\bar{n} = 3$, the trigger group used a 10 GeV threshold for the supertowers.[6] At n = 33, a 20-GeV threshold works well, but we did not try to fine tune this parameter; at n = 100, the 20-GeV threshold did allow significant pile-up to become apparent, but as shown in Fig. 3, this was suppressed with a 30-GeV cut. Of the 16,500 "minimum bias" interactions generated, only 85 deposited $E_T > 20$ GeV in one or more supertowers when taken one event at a time, mainly from events with significant p_T in the jets. Collecting these events into 500 crossings of 33 interactions each, the resulting pile-up resulted in only a minor increase to 101 crossings with one or more supertowers above 20 GeV, mainly due to an effective shift in threshold due to the few GeV of "noise" in each supertower.

Special ISAJET runs were made to generate 500 jet-jet interactions at each of several parton p_T values ranging from 40 to 160 GeV/c. Each of these events was then added in with 32 "minimum bias" jet-jet events and the *efficiency* for triggering on such crossings was examined as a function of the E_{thr} and ΣE_T cuts. Examples are shown in Fig. 4 for $p_T = 100$ GeV/c jets with and without the additional minimum bias events. As E_{thr} is increased, the n = 1 and n = 33 curves approach one another, as expected. For E_{thr} = 20 GeV, the effect is basically a shift in the curve by 10 or 15 GeV in ΣE_T.

The trigger efficiency as a function of parton p_T is shown in Fig. 5 for E_{thr} = 20 GeV and several values of the ΣE_T cut. The question, of course, is whether the pile-up seriously degrades the rapid turn on of the efficiency curve as p_T is increased. We studied the effective slope of the curves by plotting in Fig. 6 the ratio of the p_T value corresponding to 80% efficiency to that for 20%. While the necessary interpolation prevented precise results, for a given ΣE_T cut there is an optimal value of E_{thr} giving a minimum in the ratio.

The trigger cross sections for E_{thr} = 20, ΣE_T cut = 120 GeV were calculated by hand, folding the efficiencies from Fig. 5 together with the $d\sigma/dp_T \propto p_T^{-4}$ dependence shown by Fig. 1 for this p_T region. The result was 21 μb for n = 1 and 31 μb for n = 33, a factor of about 1.5 in trigger rate from pile-up. (While this is already a pleasantly small effect, it should be noted that a substantial part of this increase comes from an effective lowering of the threshold at high rates, an effect easily remedied by a slight adjustment of the ΣE_T cut to restore the n = 1 effective threshold.)

If we define "useful" data to lie in the region of > 80% efficiency, then the effective threshold is p_T = 108 (101) GeV/c for n = 1 (33), and 53% (45%) of the triggers would contain a useful event. For the low-rate n = 1 case, E_{thr} can be reduced to 5 GeV and this results in a somewhat sharper turn-on, as shown in Fig. 6. Again requiring $\Sigma E_T > 120$ GeV, the effective threshold is then p_T = 84 GeV/c for 80% efficiency, and 68% of the triggers will contain scatters of this p_T or greater. Thus, the loss in trigger cleanliness due to pileup is roughly a factor of 68%/45% = 1.5.

Note that the above cross sections are a bit larger than we were aiming for. To achieve the 10^{-4} suppression at level-1, a simple trigger of this sort would need an effective threshold for jet-jet events of about p_T = 140 GeV, for which pile-up effects are less important.

Other types of triggers might also be available at the first-level. For example, Fig. 7 shows the correlation of P_T^{mis} and ΣE_T for crossings of n = 1,33 minimum-bias jet-jet events and E_{thr} = 20 GeV. At lowish ΣE_T on the plot one can easily see crossings where only one supertower is above threshold, giving $P_T^{mis} = \Sigma E_T$. Nonetheless, by requiring a large P_T^{mis}, one can reduce the ΣE_T cut by roughly a factor of two for the same trigger rate, and thus increase the efficiency for interesting events with missing neutrinos and supersymmetric particles.

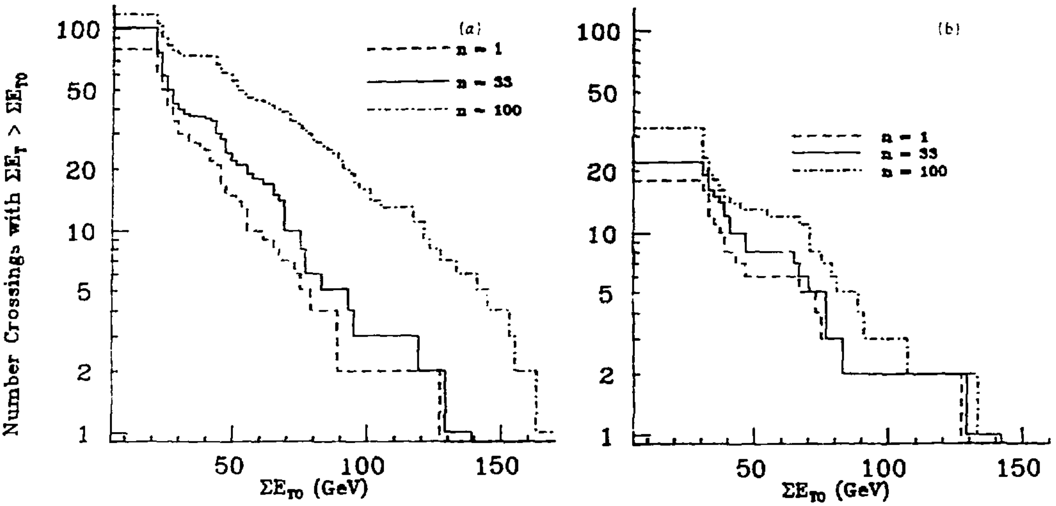

Fig. 3. Numbers of crossings with $\Sigma\ E_T > \Sigma\ E_{T0}$ value for the indicated number of interactions per bunch-bunch crossing. (a) Only supertowers with E_T > 20 GeV threshold included in sum. (b) 30 GeV threshold.

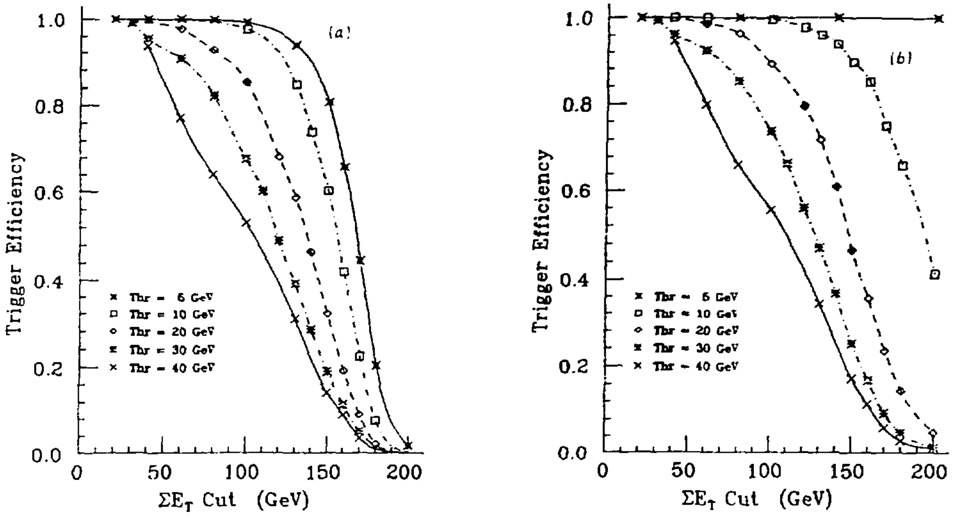

Fig. 4. Trigger efficiency vs. $\Sigma\ E_T$ cut for two-jet events with p_T = 100 GeV/c. Curves correspond to different threshold values for the supertowers to be included in the sum. (a) One 100-GeV/c event per bunch crossing, (b) 32 "minimum bias" two-jet events plus one p_T = 100 GeV/c two-jet event in crossing.

Alternatively, one could improve the sensitivity for electrons of medium p_T by looking at the individual EM towers for hot spots. Or, one could look for events with multiple jets giving > 3 well-separated supertowers above threshold. While we have not studied these latter two schemes in detail, rough calculations indicate that pile-up will cause little degradation of these triggers.

Following the work of the trigger group at 10^{33} cm^{-2} s^{-1}, we have looked at the $\Sigma\ E_T$ cut necessary at the final trigger level to achieve 0.2-Hz rates at 10^{34} cm^{-2} s^{-1} for each of several types of triggers. The biggest factor will come from the rejection of QCD interactions giving two jets with p_T/jet ≤ 2.3 TeV. Since (as discussed below), we expect that running at 10^{33} cm^{-2} s^{-1} will have allowed studies out to p_T = 6 TeV, this is not a serious limitation.

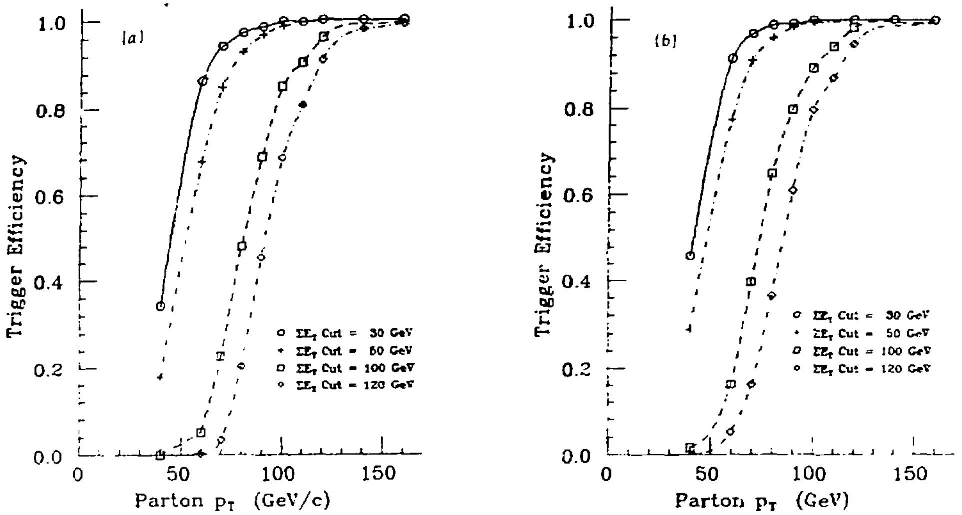

Fig. 5. *Trigger efficiency vs. parton p_T for two-jet events with various Σ E_T cuts.* Only supertowers with E_T > 20 GeV threshold are included in Σ E_T. (a) One event per crossing. (b) 32 "minimum bias" events plus a two-jet event with the indicated p_T in the crossing.

We will also assume that each additional jet reduces the QCD rate by a factor of 30, as did the trigger group, and that a missing p_T cut will give a factor of 1000. The 35-GeV/c cut used for the latter factor at 10^{33} cm^{-2} s^{-1} would presumably have to be raised somewhat at n = 33; a better method may be to look for events with P_T^{mis} greater than some fraction of the observed E_T. The factor of 14 × 10^3 rejection of QCD jets assumed for a cut giving isolated leptons with p_T > 25 GeV at 10^{33} cm^{-2} sec^{-1} will be degraded at 10^{34} and will depend upon the details of e and μ detection. Working with individual towers (instead of the level-1 supertowers) and raising the threshold somewhat, one can conservatively expect at least a factor of 1000.

Using Fig. 1, extended to higher E_T by EHLQ (Fig. 3.37) gives the required E_T cuts listed in Table 2 (to be compared to Table III of Price et al.[6]). This table is clearly an oversimplification; at some level correlations and other physics will come into play.

As indicated by Fig. 1, additional jet pairs are expected from the "minimum bias" events. For n = 33, an event of interest will be accompanied by a random jet-jet event with $p_T \gtrsim 150$ GeV/c about 0.1% of the time, the same rate assumed in Table 2 for two additional QCD jets. Since the multijet events of interest (e.g., from the production and decay of massive $Q\bar{Q}$'s) do not generally have pairs of jets balancing p_T, the random jets could be largely

Table 2. Final E_T trigger cut (TeV) vs. event topology for QCD background rates of 0.2 for each topology. If the final E_T cut is below the first-level trigger cut, this is indicated by an asterisk.

	Topology Factor	Number of Jets 2	3	4
Jets only	30/jet	4.7	2.4	1.1
P_T^{mis}	10^3	1.1	0.5	0.2
Isolated lepton	10^3	1.1	0.5	0.2
Isolated lepton plus P_T^{mis}	10^6	0.2	*	*

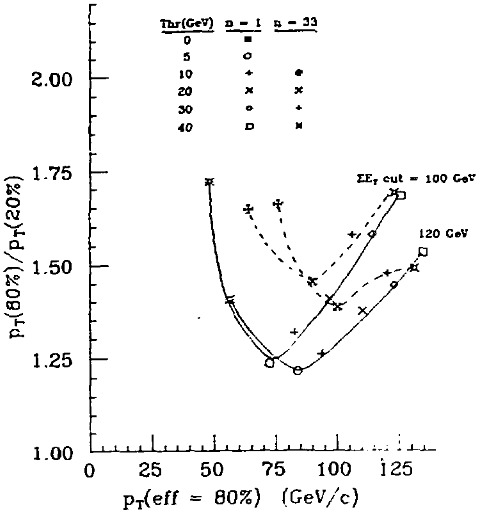

Fig. 6. The ratio of parton p_T at 80% trigger efficiency to that at 20% efficiency for Σ E_T cuts of 100 GeV and 120 GeV. The various points correspond to different threshold E_T's for a supertower to be included in Σ E_T. The hand-drawn curves correspond to n = 1 (solid) and n = 33 (dash) events per crossing.

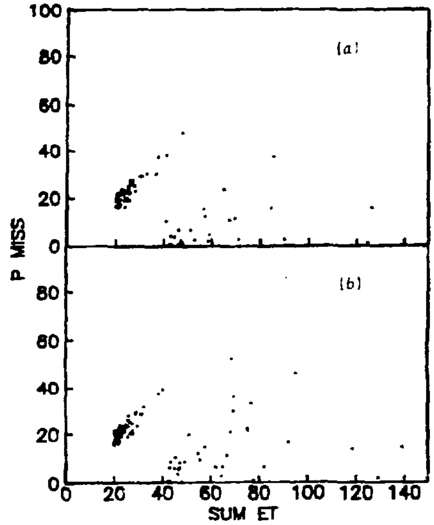

Fig. 7. p_T^{mis} vs. ΣE_T for (a) n = 1 "minimum bias" event per crossing (b) and n = 33 events per crossing. p_T^{mis} is taken as the maximum of $|E_{T_x}|$ and $|E_{T_y}|$.

rejected by eliminating such jet pairs.

If one were looking for heavy resonances decaying into 2 or 3 W's, random W's from other interactions would be a concern. At n = 33, the probability of having a random $W^{\pm}$ along with an event of interest is about 7×10^{-5}. Most of these will have very low p_T, however, and will not provide much background for massive particles decaying into energetic W's.

Physics Examples

Here we use the EHLQ results to give us the p_T or mass "discovery" range opened by 10^{34} cm^{-2} s^{-1} (10^{41} cm^{-2} integrated) at $\sqrt{s}$ = 40 TeV. We will assume that studies have been made for a year or two with general-purpose 4π detectors at 10^{33} cm^{-2} s^{-1} for an integrated luminosity of 10^{40} cm^{-2}. Since we don't have to repeat this exploratory work, we can set the thresholds high and still have good efficiency for the regions of interest for many processes.

For comparison, we have also used the same discovery criteria to compare the range opened by this factor of 10 in luminosity to that which would be opened by keeping a fixed luminosity (10^{33} cm^{-2} s^{-1}), but going to $\sqrt{s}$ = 100 TeV. The results are summarized in Table 3 and discussed below.

QCD Jets. According to EHLQ (Fig. 3-37), an integrated luminosity of 10^{40} cm^{-2} should yield 100 two-jet events with each jet in the central region ($|y|$ < 2.5) and $E_T = 2p_T > 12.2$ TeV. Going to 10^{41} cm^{-2} would boost this to 15.2 TeV ($x = E_T/\sqrt{s}$ = 0.38). These events will be easy to detect since this is the largest known cross section giving large E_T. A *systematic* measurement error of $\pm$1% would give $\sigma(E_T)$ = 150 GeV. Roughly 1% of the time, one of the ~33 events in the time gate will have an unrelated scattering giving a pair of jets with E_T this size or larger. If desired, this can be easily suppressed by rejecting "soft" back-to-back jet pairs; such a cut results in little loss of real jets from the same event due to gluon bremsstrahlung.

It will clearly be a long time before jets of these E_T's are available from e^+e^- colliders. Even at 100 MV/m, 12.2 TeV would take a total of 122 km of linac; the additional range opened by a pp machine at 10^{34} would require yet another 30 km!

Luminosity is not as important as energy for jet pairs since we are already at fairly large x at 10^{33} cm^{-2} s^{-1}. An increase in energy to $\sqrt{s}$ = 100 TeV would greatly improve the E_T range, up to about 23 TeV at 10^{33} cm^{-2} s^{-1}.

Heavy Quarks. Here we use EHLQ Fig. 5-2 to find the quark mass corresponding to the central production of 50 quark pairs, pp $\rightarrow Q\bar{Q}$ + anything, each quark having $|y|$ < 1.5. For 10^{40} cm^{-2} this gives M_Q = 2.7 TeV. About half the time, both quarks will each decay into three jets, with a total E_T of typically $\pi/4 \times 2 \times 2.7$ = 4.2 TeV, an average of 700 GeV per jet. With E_T's of this size, there should be no problem in easily passing the trigger and analysis cuts with high efficiency.

The rate for QCD jets with E_T > 4.2 TeV is about 5000 times larger. Using the rule of thumb of Price et al. that each additional hard jet costs a factor of 0.03, requiring six jets would suppress the QCD jet background by a factor of 10^{-6}; athough this is no doubt optimistic, it does suggest that backgrounds will not be a problem.

A Monte Carlo study[7] done for CDF showed that even for quarks of "only" 150 GeV mass, it is possible to devise algorithms of high efficiency and good resolution to both find the six jets and then to properly combine them into two sets of three jets each (for which there are ten possible combinations). The algorithm found the six jets 75% of the time (the other 25% mainly having jets either too close to one

Table 3. Discovery limits (TeV) for several energy-luminosity combinations, based on EHLQ calculations (Ref. 2) and criteria described in the text.

Quantity	Reaction	Signature	$\sqrt{s}$ (TeV) $\mathcal{L}$ (cm^{-2} s^{-1}) $\int \mathcal{L} dt$ (cm^{-2})	40 10^{33} 10^{40}	40 10^{34} 10^{41}	100 10^{33} 10^{40}
$x_T = E_T/\sqrt{s}$	pp $\rightarrow$ jet jet	2 jets		0.30	0.39	0.23
M_Q	pp $\rightarrow Q\bar{Q}X$	6 jets 4 jets + ℓ + E_T^{mis}		2.7	3.8	4.8
M_L	pp $\rightarrow L^+L^-X$	4 jets (W^+W^-) + E_T^{mis}		0.56	1.1	0.77
$M_{W'}$	pp $\rightarrow W'X$	$\ell + E_T^{mis}$		6.5	9.3	11
$M_{\tilde{g}}$	pp $\rightarrow \tilde{g}\tilde{g}X$	4 jets + E_T^{mis}		1.6	2.3	2.6
$M_{\tilde{\ell}}$	pp $\rightarrow \tilde{\ell}\tilde{\ell}X$	$\ell^+\ell^- + E_T^{mis}$		0.4	0.8	0.5

another or of too low an energy). The combinatoric background was largely eliminated by requiring the effective masses of the two sets of jets to be equal within errors. This type of analysis should be even easier at higher masses.

Alternatively, one can look at events where one quark goes to $eq\nu$ (or $\mu q\nu$) while the other decays to three quarks. The lepton and missing p_T (each typically 700 GeV for a mass of 2.7 TeV) should give a very distinctive signature and a rough mass estimate, while the three jets from the other heavy quark can be used for a precise measurement of the mass. Taking into account the standard branching ratios, we would expect about 25 six-jet events plus 10 4-jet plus lepton events. Even allowing for losses from cuts, we should be well above the six-event level used by UA1 to discover the top quark.

For 10^{41} cm^{-2} the 50-event limit is extended to M_Q = 3.8 TeV, a not-insignificant extension of sensitivity. Going to $\sqrt{s}$ = 100 TeV is even better, the range being extended to 4.8 TeV at 10^{40} cm^{-2}.

Heavy Leptons. Here we consider the process $pp \to L^+L^-$ + anything, with $L^{\pm} \to W^{\pm}N$, where N is an invisible neutrino. For $\sqrt{s}$ = 40 TeV, EHLQ Fig. 5-6 shows 150 events produced per 10^{40} cm^{-2} at lepton mass M_L = 560 GeV. For slowish L's of this mass, we would expect to see two W's, each having an energy of about 300 GeV. For $W \to q\bar{q}$ the opening angle between the two jets would be typically 30°, well suited for reconstruction of the parent W's. The two missing neutrinos would give a p_T imbalance of typically 400 GeV.

In spite of the relatively low mass, the signature should be rather distinctive (four jets with ΣE_T = 600 GeV, pairing to give two W's, and large missing p_T = 400 GeV), and the trigger and analysis cuts should have a reasonable efficiency for accepting the events of interest. For example, using the scheme of Price et al., the E_T cut to achieve the online trigger rate of 0.2 Hz (for four jets and missing p_T) would be 0.2 TeV. One might even hope that a "discovery" could be made with fewer than the 150 produced events assumed.

For 10^{41} cm^{-2} the mass limits of 150 events at $\sqrt{s}$ = 40 TeV would be pushed to about 1.1 TeV. In this case, luminosity is more important than energy, the corresponding 10^{40} cm^{-2} limit at $\sqrt{s}$ = 100 TeV being "only" 0.77 TeV.

Heavy W's. EHLQ use a discovery limit of 1000 events for $pp \to W'^{\pm}$ + anything, with $|y_{W'}| < 1.5$. Assuming that $W'^{\pm} \to e^{\pm}\nu$ is again the best decay for observing charged intermediate bosons, this might give about 80 events of interest. For $\sqrt{s}$ = 40 TeV and 10^{40} cm^2, ELHQ Fig. 5-10 gives a mass of 6.5 for this criteria; for 10^{41} cm^2, the limit extends to 9.3 TeV. We are thus looking for an isolated electromagnetic shower of 2 to 5 TeV, not balanced in p_T. This should be readily detectable with high efficiency and low background even at 10^{34} cm^{-2} s^{-1}. For example, the rate for jets with $p_T > 1.5$ TeV/c at 10^{34} cm^{-2} s^{-1} is expected to be 2/sec; reducing this to a trigger rate of < 0.2 Hz should be easy using weak cuts on missing p_T, and the electron signal. The mass limit of 9.3 TeV could alternatively be reached using the same criteria at 10^{40} cm^2 with a machine having $\sqrt{s}$ = 75 TeV.

Supersymmetric Particles. EHLQ consider the production and detection of several types of supersymmetric particles. They estimate the mass discovery limits at $\sqrt{s}$ = 40 GeV and 10^{33} cm^{-2} s^{-1} to range from 0.4 to 1.6 TeV depending on the particle. The decay modes are generally complicated and not well-specified, but include jets, leptons, and missing E_T. Here we consider two processes as examples: the production of gluino pairs and selectron pairs.

For $M(\tilde{g})$ = 1.6 TeV (the 10^{33} limit), and assuming the dominant decay to be $\tilde{g} \to q\bar{q}\tilde{\gamma} \to$ 2 jets plus missing E_T, a typical event will have E_T = 1.7 TeV and missing E_T = 0.6 TeV. The triggers and analysis cuts should be highly efficient at passing such events.

The 10^{33} limit on $M(\tilde{\ell})$ of 0.4 TeV is the lowest of the limits considered here, and therefore not as easy to trigger on. The decay $\tilde{\ell} \to e^{\pm}\tilde{\gamma}$ would result in a typical E_T = 300 GeV and missing E_T = 200 GeV/c. Further work is needed to determine if the two isolated electrons (each with E_T typically 150 GeV) provide a sufficiently distinctive trigger. It seems quite unlikely, however, that the random pile-up of interactions is likely to mimic such a signature.

Conclusions

By increasing the luminosity of the SSC to 10^{34} cm^{-2} s^{-1} the physics reach of the machine is extended considerably and it is highly desirable to design the accelerator to handle this luminosity. We have shown that 10^{34} allows an extension in x from 0.30 to 0.38 for QCD jets and a factor of 1.4 to 2 in the mass range for new particles, as summarized in Table 3.

The detector for this luminosity depends mostly on calorimetry and would require a hermetic, good resolution, radiation-damage resistant, segmented calorimeter. With sufficient iron, muon detection should still be feasible; some minimal central tracking may even be possible.

Finally we have shown that Monte Carlo studies indicate that we can trigger on interesting events even when they are overlapped with many "low" p_T QCD events. While the trigger thresholds must be increased somewhat to achieve the additional factor of 10 rejection necessary for a given data rate, these thresholds are generally still well below the levels for the events of interest.

Obviously, the real limits for the SSC will only be understood with experience, but the initial indications for high luminosity are certainly encouraging.

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