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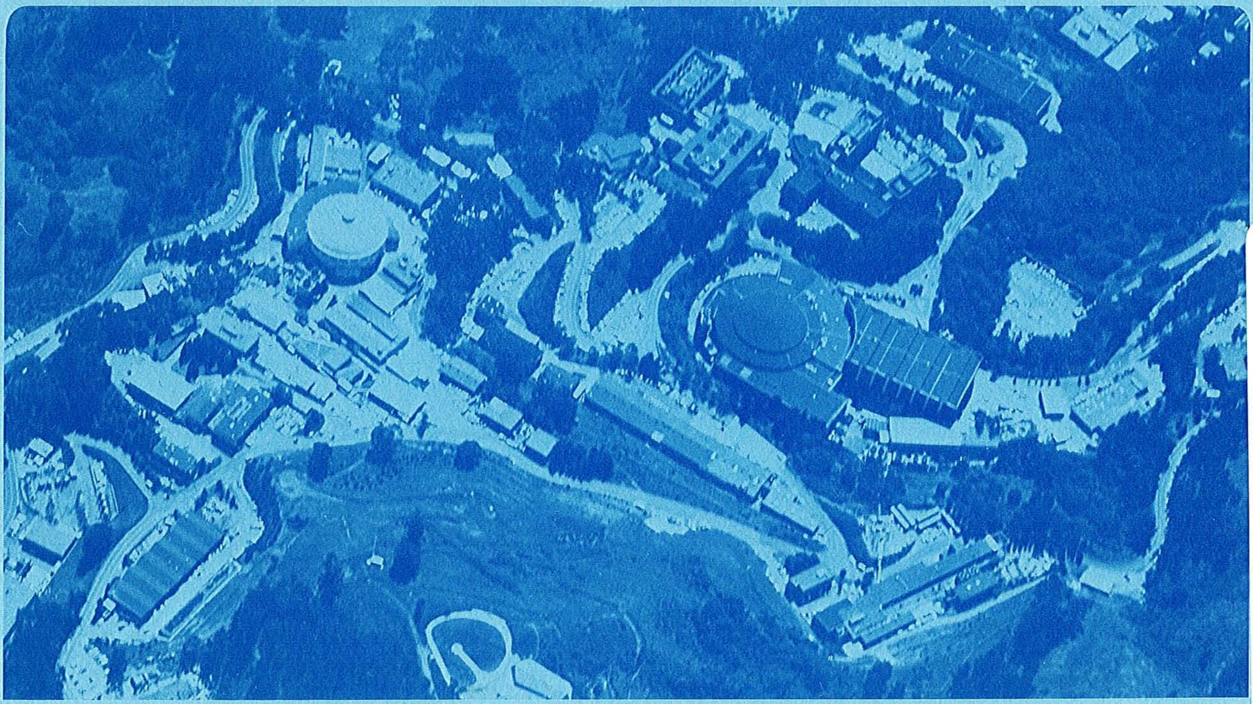

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PHYSICS MOTIVATIONS FOR SSC/LHC DETECTORS * †

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ABSTRACT

In this talk, I review the some of the physics goals and simulation work done in the SSC and LHC experimental proposal. I select the processes that illustrate the strengths and weaknesses the proposed detectors.

1 Overview

An impressive amount of work has been done on simulation of physics at both the SSC and LHC. The gaol of most of this work has been to optimize the design of the detectors. Many documents have been produced by the collaborations and proto-collaborations. For SSC, the SDC[1] and GEM[2] collaborations have produced technical design reports. For LHC there are letters of intent from ATLAS [3] and CMS [4]; more detailed design reports should appear soon [5]. While emphasizing different aspects of SSC physics, all of these detectors aim to cover most of the new physics for which the SSC/LHC is being built. All of the detectors have a central tracker that covers $|\eta| \lesssim 2.5$, a calorimeter system that reaches $|\eta| \sim 5.5$ (slightly less for the LHC detectors), and a muon system covering $|\eta| \lesssim 2.5$

The SDC and GEM detectors have different strengths. SDC is built around a powerful tracking system that has very high momentum resolution of $\delta p_t/p_t = .16(p_t/TeV) \oplus .003$ at $\eta = 0$. The resolution is almost independent of η for $|\eta| \leq 1.5$, it then degrades, becoming about 4 times worse at $|\eta| = 2.5$ where the tracking coverage ends. Outside the superconducting solenoid is a scintillating tile electromagnetic calorimeter that covers $|\eta| \leq 3$ with good resolution $\delta E/E \sim 0.14/\sqrt{E} \oplus .01$, ‡ a hadron calorimeter and muon system. The combined calorimeters result in an energy resolution for jets of order $\delta E/E \sim 0.61\sqrt{E_t} \oplus .04$. The iron toroid muon system in conjunction with the central tracker provides a momentum resolution for muons of 10% at $|\eta| = 0$ and $p_t = 500$ GeV.

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‡Unless otherwise stated, all energies are in GeV.

By contrast, GEM is built entirely within a large solenoid that provides the bending power for a muon system that has a resolution of order 5% at $|\eta| = 0$ and $p_t = 500$ GeV. Two large iron structures shape the magnetic field in the forward region so that the muon resolution is only degrades by a factor of 2.5 at $|\eta| = 2.5$. The muon system is very robust and will provide good resolution even at very high luminosities when the central trackers may have died. Inside the muon system are the hadronic and electromagnetic calorimeters. The former has a jet resolution similar to SDC. The liquid argon or krypton electromagnetic calorimeter has excellent resolution $\delta E/E \sim .06/\sqrt{E} \oplus .004$. The small tracking system has resolution $\delta p_t/p_t \sim 1.2(p_t/TeV) \oplus .03$ at $|\eta| = 0$.

The ATLAS detector is similar in concept to SDC. The tracking volume is smaller and the tracking resolution worse than SDC. The electromagnetic calorimeter resolution is slightly worse than that of GEM and better than SDC. The muon system uses air cored toroids and consequently has resolution of of order 8% at $|\eta| = 0$ and $p_t = 500$ GeV even when the inner tracker is not used. The ability to operate without the inner tracker is more important at LHC than SSC since the machine is expected to operate at higher luminosity.

CMS is the most ambitious of the detectors. It uses a 4 Tesla solenoid to achieve a tracing resolution of of order 2.5% at $|\eta| = 0$ and $p_t = 100$ GeV in a small tracking volume. Its muon resolution is of order 4% at $|\eta| = 0$ and $p_t = 500$ GeV, better than any other detector.

The higher design luminosity of LHC is designed to compensate for the higher energy of the SSC (14 *vs.* 40 TeV), so that the physics capabilities are roughly comparable. Figure 1 shows the rate for some selected particles as a function of the center of mass energy. [§] It can be seen from this figure that the trade-off between energy and luminosity is dependent upon the mass of the produced object. For particles of low mass (an extreme example is the b-quark) the cross section rises only slowly with energy. At very high masses, the rate rises rapidly with energy. For example, at SSC the rate for production of a Higgs of mass 100 (800) GeV is 3 times (5) larger than at LHC. For a new Z of mass 1 (4) TeV the factor is 5 (20). Even when the luminosity compensates for the energy so that the rate is the same, the signal/background ratio is likely to favor the higher energy machine.

2 Top quark properties

It is likely that the top quark will have been discovered before SSC/LHC experiments have data. However, SSC/LHC experiments will garner enormous numbers of top decays enabling detailed studies to be carried out. Two things have been studied in detail; the

[§] The LHC detector studies are mostly done with an energy of 16 TeV. However as reported at this meeting[5] the current LHC design energy is 14 TeV. The LHC rates quoted in this article refer to 16 TeV unless otherwise stated.

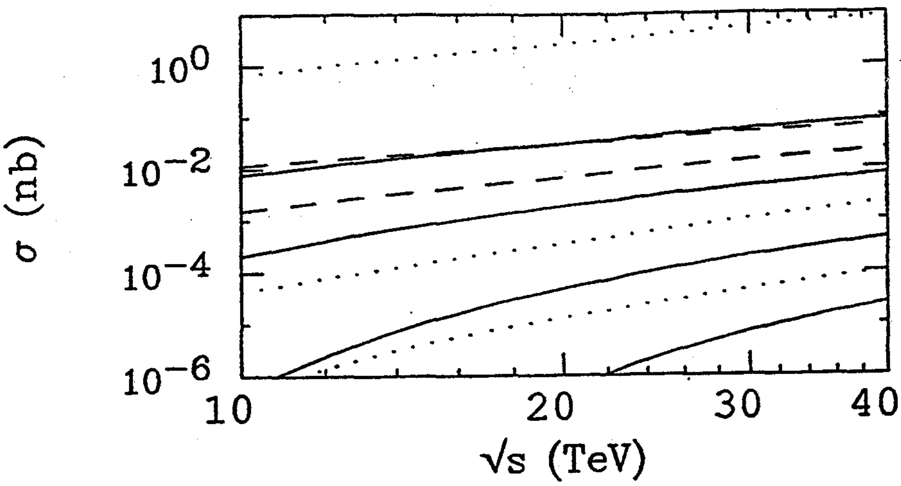

Figure 1: The total cross-section for the production of a set of particles as a function of the center of mass energy in $p\bar{p}$. The solid lines (highest to lowest) correspond to a new Z (standard model couplings) of mass 1, 2, 4 and 7 TeV. The lower (upper) dashed line upper to lower correspond to a Higgs of mass 800 (100) GeV. The dotted lines (highest to lowest) correspond to a heavy quark of mass 150 and 1000 and 2000 GeV.

precise determination of the top quark mass and the search for a top decay to a Higgs boson. The latter is discussed below. There are two main methods for determining the mass. A determination based on the event rate will not be very accurate since it depends on the assumption that the branching ratio of the top quark into the observed channel is known and on the QCD calculation of the $t\bar{t}$ production rate which is uncertain at the 20% level [6].

The first method is based upon the detection of an isolated lepton (ℓ either e or μ) and a non-isolated μ of the opposite charge that is close in rapidity-azimuth space. One is attempting to find the decay $t \to Wb \to \ell\nu\mu\nu c$. There is a correlation between the dilepton invariant mass distribution and the top quark mass. The errors on the inference of the top mass will be dominated by systematic errors which are mainly due to two effects. The fragmentation function of a b quark determines the momentum distribution of the non-isolated muon in the b—quark rest frame. This fragmentation function is measured at LEP [7]; the current errors on it imply an uncertainty on the top mass of order 2% according to ATLAS [3] and 1% according to GEM and SDC. There is an additional error from the transverse momentum distribution of the top quark. This error is due to uncertainties in the QCD calculations of the shape of the distribution (errors in the normalization are not relevant). ATLAS estimates this error at ±2 GeV. Hence it is reasonable to expect a total error of about 4 (5) GeV if the top mass is 200 (250) GeV. The error can be expected to decrease as b−quark fragmentation is better understood.

The second method involves searching for the final state $t\bar{t} \to WbW\bar{b} \to \ell\nu bq\bar{q}\bar{b}$. The lepton from the W decay serves as a trigger; combinations of jet invariant masses are then formed. A two-jet mass distribution is made and events are selected around the W mass. This dijet system is then combined with another jet, and a peak searched for. The background arises dominantly from $W + jets$ events and can be reduced by requiring the presence of b quark jets in the events. This can be done either by looking for the semi-leptonic b-decays that give a muon inside a jet or by looking for jets with vertices that are not at the interaction point and that arise from the decays of b hadrons. A peak in the three jet mass distribution should be visible even without this b-tag [3], but the tag greatly improves the clarity of the signal. The dominant systematic error is the jet energy scale. This is affected by calorimeter response, jet definitions and jet fragmentation effects. The dijet peak at the W mass can be used to correct the energy scale. To the extent that the b quark does not fragment into hadrons in the same way as a u, d, c or s quark, there is a residual systematic error. ATLAS estimates a total systematic error of 6 GeV, SDC is more optimistic quoting 3 GeV.

3 Higgs Bosons

A vast amount of simulation effort has been expanded on methods to search for the Higgs boson. A general purpose detector should be able to find a Higgs if its mass lies anywhere in the allowed range. Since a Higgs bosons of mass below about 80 GeV or so should be detectable at LEPII and one of mass greater than 800 GeV or so is not consistent in the minimal standard model[8], a detector must cover the range between these values. In the mass range above $\sim$ 140 GeV, the final state $H \to ZZ \to 4\ell$, where ℓ is either an electron or muon, provides a clean signal above background. The limitation on detection is provided only by the small cross-section at the upper end of this range. A Higgs of this large mass has a large width which can be measured easily by any of the detectors. This mode does not impose any significant constraints on the muon systems or electromagnetic calorimeters. In view of the small event rate at very large masses, it will be useful to be able to find confirming evidence in at least one more final state. $H \to Z(\to \nu\nu)(Z \to \ell\ell)$ provides such a state. Here the signal shows up as an excess of events in the transverse mass distribution of the reconstructed $Z \to \ell\ell$ and the missing transverse energy, carried off by neutrinos. Background arises from ZZ events and from $Z + jets$ events where the missing transverse energy comes from mismeasurement of the hadronic energy. This is one of the processes that constrains the calorimeter coverage. A detector without a forward calorimeter can generate a fake missing E_t signal from jets lost into the uncovered region.

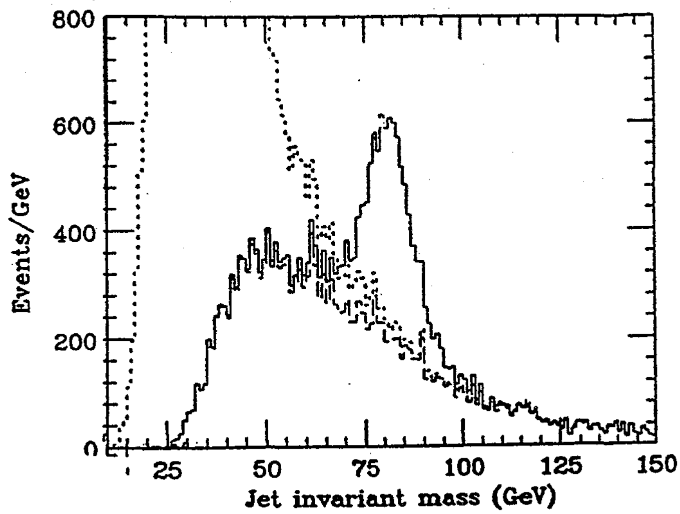

Figure 2: The distribution of dijet invariant masses from $H \to W(\to jets)W(\to \ell\nu)$ solid line and $W \to (\ell\nu)$ dashed line (see text), figure from SDC; the relative normalization of the signal and background is arbitrary.

There is also the possibility that the final states $H \to Z(\to \ell\ell)Z(\to jets)$ or $H \to W(\to \ell\nu)W(\to jets)$ can be reconstructed. In the former case there is background from the final state $Z(\to \ell\ell)+jets$. This background can be reduced by requiring that the jet system has invariant mass near the Z mass. The cuts used by the SDC collaboration are typical. One is looking for two boosted jets arising from the decay of a Z at large p_t. These jets are typically narrower than QCD jets of the same p_t. Jets are first selected using a rather wide cone in rapidity azimuth space of $\Delta R = 0.6$. Within this cone events are selected if there are two jets of $p_t \geq 25$ GeV and of size $\Delta R \leq 0.15$. The mass distribution of the invariant mass in the big cone is now looked at; see Figure 2. The signal now shows a peak at the Z or (W) mass while the background does not. The clarity of the peak is affected by the segmentation and resolution of the calorimeter. As the segmentation and resolution are improved, the peak becomes sharper. There is a limit provided by the spread of hadronic showers and clustering effects due to jet fragmentation and additional energy entering the jet cone from the underlying events. Segmentation of $\delta\eta \times \delta\phi = 0.1 \times 0.1$ is adequate. Events can now be selected if they have a jet system consistent with the Z (or W) mass. By boosting to the rest frame of the two thin jets and looking at the angular distribution of the fastest jet relative to the boost direction (θ^*), additional background rejection is possible [1]. The W decay produces a distribution that is fairly flat in $\cos\theta^*$, whereas the background, reflecting the collinear singularities of perturbative QCD, is peaked near $\cos\theta^* = 1$. An invariant mass plot of the $Z(\to \ell\ell)Z(\to jets)$ mass distribution can be made. For an 800 GeV Higgs, the GEM collaboration finds a signal/background ratio of about 1/3. Unfortunately the signal and the background have the same shape, so the extraction of a signal depends on the ability to carefully estimate the background. The conclusion about the shape of the signal and background is shared by the ATLAS collaboration but not by CMS which shows a peak in the signal but not in the background at the Higgs mass.

In the case of the WW final state, while jet mass cuts are effective in reducing the $W + jets$ background, then cannot be used to reject the background from $t\bar{t}$ events since these events lead to W pair final states. There have been many studies using cuts on the jet activity in candidate events.[9] The basic idea is that the signal process $qq \to qqH$ produces two jets at large rapidity. Since no color is exchanged between the two quarks, there is not expected to be much jet activity in the central region of rapidity. On the other hand there is no reason for the $Z + jets$ or $t\bar{t}$ final states to result in forward going jets. Furthermore there is expected to be more jet activity in the $t\bar{t}$ events which are initiated by gluon-gluon fusion.

These ideas lead to the concepts of forward jet tagging and central jet vetoing. Events are selected that have jets at $|\eta| \geq 3$ and rejected if there is significant jet activity in the central, $|\eta| \leq 3$, region. The ZZ case was studied by SDC and GEM. SDC requires a tagging jet to be in the range $2.5 \leq |\eta| \leq 5$ and to be reconstructed in a cone of size $\Delta R = 0.6$. In the single (double) tag case the jet is required to have $E \geq 3(1.5)TeV$ and $p_t \geq 50GeV$. The events from $qq \to qqH$ have a tagging efficiency of 23% for a single tag and 5% for a double tag. For the $Z + jets$ (or $W + jets$) background the efficiencies are 11% and 0.5%, while for $t\bar{t}$ events they are 3.5% and 0.2%. In the case of the ZZ final state therefore, the single (double) tag can be used to enhance the signal/background ratio by a factor of 2 (10) at the cost of the loss of 75% (95%) of the signal. Event rates are not large, so the double tag is not useful. The GEM collaboration state that "tagging was studied and not found to be effective".

ATLAS have studied the tagging in the case of a 1 TeV Higgs decaying to WW. Their tagging cuts are somewhat looser than SDC but the conclusions are similar. The select tagging jets with $2 \leq |\eta| \leq 5$, $E \geq 600$ GeV, $p_t \geq 25$ GeV and $\Delta R = 0.5$. They get a single (double) tagging efficiency of 61% (14%) for the signal and 18% (0.8%) for the $t\bar{t}$ background. ¶. Central jet vetoing, which appears to be quite effective in partonic studies [10] has not been investigated.

As the Higgs mass falls below 140 GeV or so, its branching ratio into 4 charged leptons becomes too small for this mode to be viable. One must then search in the two photon final state. There is a large background from the production of photon pairs from the $q\bar{q}$ and gg initial states. In a bin of width $\Delta M \sim 1.5$ GeV the signal to background ratio is

¶Recall that this is the dominant background in this channel

Higgs Mass (GeV)	SDC	GEM	ATLAS
80	180	50	250
100	40	12	60
120	15	4	25
140	10	2	12

Table 1: The integrated luminosity in fb^{-1} required to establish a 5σ signal in $H \to \gamma\gamma$ for various Higgs masses and detectors.

of order 1/60 (1/12) for a Higgs of mass 80 (130) GeV. Event rates are large, but good resolution is needed to extract a signal, particularly at very low masses. In order to get the desired mass resolution, the event vertex must be known with great precision. This is only a problem if there is more than one interaction per beam crossing, since all of the other (charged) particles in the event can then be used to find the vertex. At SSC, where the mean number of interactions per beam crossing is 1.8, one can use the vertex with the largest multiplicity as it is unlikely that the additional events will also contain a hard scattering. The GEM detector has the ability to find the direction of the photon using the shower shape and can therefore correctly assign the vertex. The problem at LHC (which has about 10 times as many interactions per beam crossing) is more severe. There, the unresolved vertex ambiguity is equivalent to a resolution in the diphoton mass of 1.5% [11]. The LHC detectors need to have direction resolution on the photons in order to overcome this problem.

In addition to the background from photon pairs, there are backgrounds from the $jet-jet$ and $jet-\gamma$ final states, where the jet fragments in such a way that it looks to the detector to be a photon. Figure 3 shows the γ/jet rejection factor that must be achieved so that the these backgrounds are equal to the irreducible $\gamma\gamma$ rate. In order to contribute to the background a jet must yield an isolated π^0 or photon. The jet background can therefore be reduced by requiring that the "photon" be isolated. The shape of the EM shower can also be used to discriminate against π^0's (in the case of GEM [2] this contributes a factor of 4). The rejection factor obtained is different for quark and gluon jets, owing to the different fragmentation properties. ‖ The rejection factors are somewhat larger at larger Higgs masses, GEM gets factors ranging from 1.2×10^{-4} (4.1×10^{-4}) for gluon (quark) jets at $M_H = 80$ GeV to 0.83×10^{-4} (3.4×10^{-4}) at $M_H = 140$ GeV. The $jet-jet$ background is dominated by gluon jets while the $jet-\gamma$ is dominated by quark jets. If I require a

‖Quark jets have a harder fragmentation distribution and hence isolation results in a smaller rejection factor.

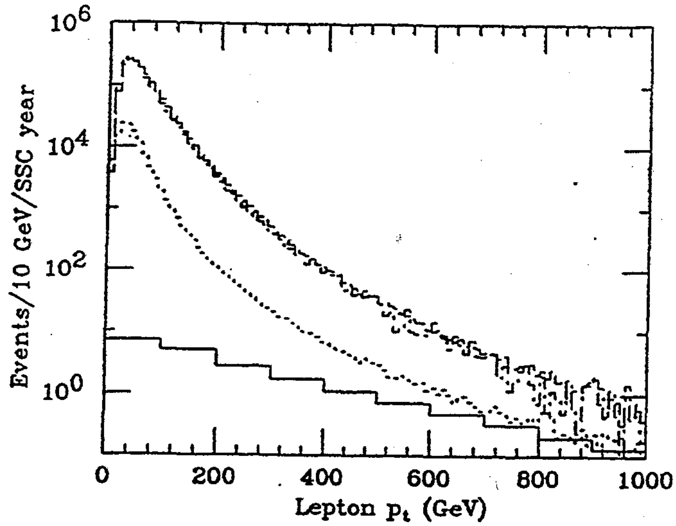

Figure 4: The transverse momentum distribution for leptons (electron or muon) in events with a pair of leptons at SSC (there are 2 entries per event). Events are required to have two leptons of $|\eta| \leq 2.5$. The solid histogram is the signal for a model of a strongly coupled W^+W^+ system. The dashed (dotted) is from $t\bar{t} \to W(\to \ell^+)W(\to \ell^-)b\bar{b}$ ($t\bar{t} \to W(\to \ell^+)WbW\bar{b}(\to \ell^+X)$). The dot dashed is the $q\bar{q} \to W(\to \ell^+)W(\to \ell^-)$ rate

quite so good. Additional rejection of the $t\bar{t}$ background may be needed and will require topological cuts [12]. This process is easier to detect at SSC than LHC for two reasons; the isolation requirements needed to reject the b-quark background are more effective at lower luminosity and the cross-section in approximately a factor of 10 larger at SSC that at 14 TeV. [14]

There have been studies of the detection possibilities for non-standard Higgs bosons. Most of this work has concentrated on the Higgs bosons in the minimal supersymmetric model [15]. There are three neutral and one charged bosons in this model. At least one of these bosons is quite light. There is a problem in that the branching ratio to ZZ is never large, so this relatively straightforward channel is not very useful. The $\gamma-\gamma$ final state can be used. It may also be possible to detect the decay $H^0 \to \tau^+\tau^-$[16]. If supersymmetry is the correct model, the other new particles will be easier to detect than the neutral Higgs bosons.

The charged Higgs bosons will he detectable if they can be produced in the decay of top quarks. If kinematically allowed, the branching rations $t \to Wb$ and $t \to Hb$ will be comparable. The decay of top quarks will then be the dominant source of charge Higgs bosons. The dominant charged Higgs decay modes are expected to be to $\tau\nu$ or $c\bar{s}$. One searches for the former by looking for a violation of $e/\mu/\tau$ universality in $t\bar{t}$ events.[2, 3, 1]. The latter can be detected by looking for the final state $t\bar{t} \rightarrow WbH\bar{b} \rightarrow \ell\nu bc\bar{s}$ which manifests itself as an isolated lepton and some hadronic jets. The $c\bar{s}$ decay can be detected by searching for a peak in the dijet mass distribution [3, 1] If the decay $t \rightarrow Hb$ is not allowed kinematically, then the process $q\bar{q} \rightarrow H^+H^-$ will be dominant. This has a very small rate and the detection of it is difficult.

4 Supersymmetry

The supersymmetric particles that are easiest to detect are the squarks and gluinos since they have the largest production rate. Sleptons and electro-weak gauginos (the mass eigenstates of the partners of the W, Z, γ and Higgs bosons) are produced directly with small rates, although the electro-weak gauginos are produced in the decays of squarks and gluinos and these rates are likely to dominate over direct production. The detection of directly produced weak gauginos has been studied [17]; detailed detector simulations are lacking.

There are several possible final states that are reached by decays or squarks and gluinos *viz.* $\tilde{g} \rightarrow q\bar{q}\chi^+(\rightarrow \chi^0 e\nu)$, $\tilde{g} \rightarrow q\bar{q}\chi^0_1(\rightarrow \chi^0 Z)$, $\tilde{g} \rightarrow q\bar{q}\chi^0_1(\rightarrow \chi^0 q\bar{q})$ $\tilde{g} \rightarrow q\bar{q}\chi^0$, $\tilde{q} \rightarrow q\chi^+(\rightarrow)$. Here χ is used generically to denote a weak gaugino. The strong decays $\tilde{q} \rightarrow \tilde{g}q$ or $\tilde{g} \rightarrow \tilde{q}q$ will dominate if they are kinematically allowed. χ^0 is assumed to be weakly interacting and sufficiently long lived so that it exists the detector giving rise to a missing energy signature. The GEM and ATLAS collaborations choose a set of parameters in the minimal supersymmetric model [18] and then analyse the signals in that case. SDC assumes that the gluino is lighter than the squark, so that the latter production is negligible, and then analyses the signal with certain (reasonable) assumptions concerning the decay modes of the gluino. There are basically three types of signals that have been studied; the final state of jets and missing transverse energy; leptons and jets, usually same sign dileptons; and Z's plus jets.

The first of these cannot be observed if the detector lacks a forward calorimeter. In all of the designs such a device is present and the dominant background arises from final states that contain neutrinos (such as $Z(\rightarrow \nu\nu) + jets$). The signal is not visible in the inclusive missing transverse energy spectrum [2]. Topological cuts are needed to reduce these backgrounds below the signal. The calorimeter resolution is not critical to the ability to extract a signal. Figure 5 shows an example. One cannot easily determine the gluino mass from the event rate since the branching ratios are unknown, but some information can be obtained from the shape of the missing energy spectrum [2].

The second process where each of a pair of gluinos decays to a lepton of the same sign (recall that the gluino is a Majorana fermion) has a background mainly from $t\bar{t}$ events. The background can be eliminated almost entirely by requiring that both leptons be isolated,

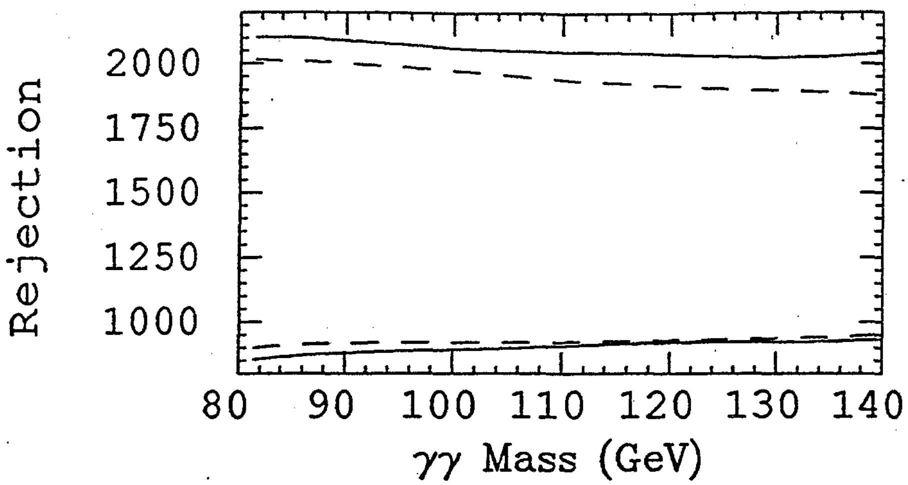

Figure 3: The rejection factor needed to make the $jet - jet$ (solid and dotted lines) and $jet - \gamma$ (dashed and dotdashed lines) rate the same as the $\gamma - \gamma$ rate as a function of the $\gamma\gamma$ invariant mass. All photons and jets are required to have $|\eta| \leq 1.5$. The solid and dashed (dotted and dot-dashed) lines are for SSC (LHC)

5σ statistical significance for discovery, I can use the studies of the various detectors to compare them. Table 1 shows the integrated luminosity needed to establish a 5σ signal. It can be seen that the better EM calorimeter of GEM enables it to be more effective than SDC. Note that at these low masses the extra luminosity of LHC (if it can be exploited) more than compensates for the reduced energy.

In view of the poor signal/background ratio of this channel, the production of a Higgs in association with a W or $t\bar{t}$ pair can be considered. Here an additional isolated lepton from the decay of the W is detected. This has two advantages; its tags the vertex and has a larger signal/background ratio (of order 1). Its disadvantage is its low rate (approximately 1/40 of the direct production rate). Table 2 shows the integrated luminosity needed to establish a 5σ signal in this channel. It can be seen that the increased signal to background in this channel is such that the better EM calorimeter of GEM less of an advantage over SDC. By combining the channels (and possibly the experiments), it should be possible to cover the entire range of interesting masses, although several years of running may be needed for $M_H \leq 100$ GeV.

Very difficult to detect are the signals for a "strongly coupled weak sector".[13] Here there is no conventional Higgs boson, but the dynamics of weak symmetry breaking is manifested in the strong coupling between (longitudinally polarized) W and Z bosons at

Higgs Mass (GeV)	SDC	GEM	ATLAS
80	55	40	125
110	40	30	75

Table 2: The integrated luminosity in fb^{-1} required to establish a 5σ signal in $H \to \gamma\gamma$ for various Higgs masses and detectors. The events are required to have an additional isolated lepton.

large invariant mass. The dynamics responsible for the breaking may produce bound states in the two gauge boson channels (technicolor models). In certain cases, these bound states may be narrow and, although they have small production rates, be easy to detect. An example is the $\omega_T \to Z\gamma$, a particle that can appear in certain models. The resonance is clearly identifiable in the final state $Z(\to \ell\ell) + \gamma$[1][3]; there is little background. If there are no narrow resonances, the signals will manifest themselves as excesses of events over standard model expectations. In this case it will be easier to establish a signal if the channel has very few events in the standard model. W^+W^- and ZZ have substantial contributions from $q\overline{q}$ initial states. Better is W^+W^+ (or W^-W^-). The inability to reconstruct the invariant mass of the WW system in the final state $WW \to \ell\nu\ell\nu$ due to the two missing neutrinos is not a problem since one does not expect to see any narrow peaks.

In order to measure this channel, the detector must be able to determine the sign of the leptons. Backgrounds arise from the final states $t\overline{t} \to WbWb \to \ell^+\nu\ell^-\nu b\overline{b}$ where the lepton charge is mismeasured, and from $t\overline{t} \to W(\to \ell^+)bW\overline{b}(\to \ell^+)$. Figure 4 shows these backgrounds as well as well as the signal to be expected in a model. It can be seen from the figure that the signal/background ratio increases at large transverse momentum. In order to reject the background from oppositely charged leptons, the resolution must be excellent. SDC has considered the tails of the tracking resolution and concluded that it can obtain a wrong charge rejection of better than 10^{-3} for $p_t = 500$ GeV even at a luminosity of 3×10^{33} cm^{-2} sec^{-1}. This is adequate to reject the opposite sign background. The GEM detector has much worse tracking resolution and is therefore probably restricted to the final state $\mu^+\mu^-$ with the concomitant loss of a factor of four in rate. The leptons arising from b decay are not isolated from other hadrons, hence isolation cuts can be used to reduce this background. **. Rejection factors of order 10^{-3} can be obtained for $p_t \geq 100$ GeV by requiring that there be less than 5 GeV of transverse energy in a cone of $\Delta R = 0.3$ around the lepton at SSC [1]. The isolation requirements at LHC (12 GeV in $\Delta R = 0.2$ [3]) are somewhat looser due to the pile up of underlying events and hence the rejection not

**Isolation does not help to reduce the opposite sign background

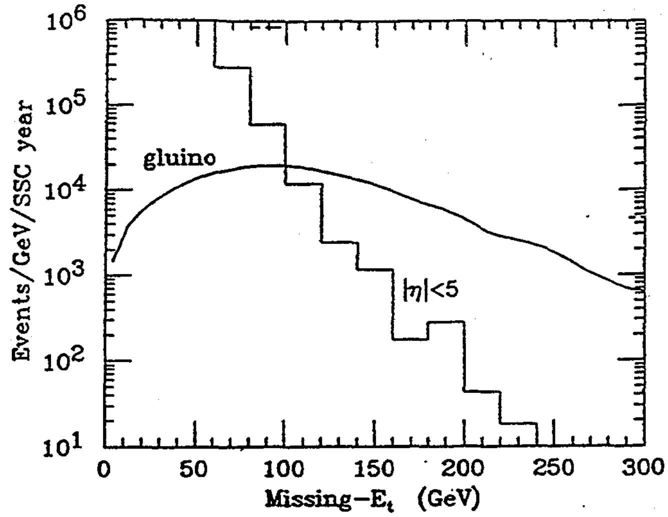

Figure 5: The missing transverse energy distributions from gluinos of mass 300 GeV (solid line) and background (histogram). The gluino decays are assumed to be $\tilde{g} \to q\bar{q}\chi^0$ and $\tilde{g} \to q\bar{q}\chi_1^0(\to \chi^0 q\bar{q})$ with a combined branching ratio of 4%. Events are required to have at least 3 jets with $E_t \geq 70$ GeV separated by $\Delta R \geq 0.7$. Events are rejected if one of the jets is within 40^0 is azimuth of the missing transverse energy vector. Squark production is ignored . Figure from SDC

since, in order to get two leptons of the same sign, at least one of must come from a b or c decay and will not be isolated. Note that because of the cascade decays the transverse momenta of the leptons rarely exceeds 600 GeV, the background from oppositely charged lepton pairs where one charge is mismeasured is not a problem even for GEM. These final state are more useful in determining the masses [1, 19, 20].

5 b–physics

One aspect of SSC/LHC physics that has not received much attention is that of bottom physics. While not associated directly with the understanding of weak symmetry breaking, a detailed understanding of b particle decays, in particular those connected with CP violation, can help lead to an understanding of the flavor problems in the standard model. The cross section for the production of b quarks at SSC/LHC is very large. Rates of order 0.1 to 1 mb can be expected at LHC. The rate at SSC is larger by a factor of 2 or so. There are substantial uncertainties in these estimates arising from structure functions at small values of x (preliminary data from H1[21] and ZEUS[22] indicate that commonly used structure functions may be an underestimate) and from uncertainties in the perturbative QCD estimates of the rates. The perturbative QCD estimates are expected to be much more unreliable at SSC energies than they are at the Tevatron. Indeed it is difficult to speak with any confidence of a perturbative QCD result. The uncertainties are less once the b-quarks have appreciable transverse momentum; this is usually required in order to trigger.

The ATLAS and CMS collaborations have studied the possibility of observing CP violation via the decay $B_d \to \psi(\to \mu^+\mu^-)K_S(\to \pi^+\pi^-)$. Since b quarks are produced in $b\bar{b}$ pairs, the determination of the sign of one of the quarks is sufficient to tag the other one as being a b or a $\bar{b}$. The simplest tag is provided by the semileptonic decay to a muon. The sign of the muon then tags the quark that produced it as a b or $\bar{b}$. Defining N_{μ^+} as the number of events where a $B_d \to \psi(\to \mu^+\mu^-)K_S(\to \pi^+\pi^-)$ is reconstructed in events with such a muon tag, define

$$A = \frac{N_{\mu^+} - N_{\mu^-}}{N_{\mu^+} + N_{\mu^-}}$$

Since the final state ψK_S is a CP eigenstate that can be reached from either B_d or $\overline{B_d}$, A is CP violating and can be related to the angle β in the unitarity triangle of the Cabbibo-Kobayashi-Maskawa matrix [23].

$$a = D \sin 2\beta \frac{x_d}{\Gamma}$$

Here D is a dilution factor that takes account of the fact that, due to $B-\overline{B}$ mixing, the tag is occasionally incorrect. Note that if the tagging B is charged, there is no ambiguity. There is also the possibility of a wrong tag by detecting the lepton from the charm produced in the decay of the b-quark. $x_d = \Delta m/\Gamma$, where Δm is the mass difference between the weak eigenstates of the $B_d\overline{B_d}$ system and Γ is the average width.

ATLAS requires a single muon trigger with $p_t \geq 20$ GeV and $|\eta| \leq 2$; this results in a rate of approximately 100 Hz at a luminosity of 10^{33} cm^{-2}sec^{-1}. The decay products from the ψ and K_S are required to have $p_t \geq 1$ GeV and $|\eta| \leq 2$, the ψ to have $p_t \geq 10$ GeV (so that the muons can be identified in the muon system) and the K_S decay path to be between 1 cm and 30 cm. They obtain a reconstruction efficiency of 0.1 and $D = 0.77$, leading to the conclusion that $\sin 2\beta$ can be measured to ± 0.1 with 10 fb^{-1} of data. If the time dependence could be measured using the vertex system, this error could be reduced. This preliminary study is encouraging, indeed it is competitive with the proposed e^+e^- b factories [24]. The conclusions of the CMS collaboration are similar. The powerful tracking system of SDC should ensure that they are at least competitive.

Other decay modes of the B have not been investigated. The angle α of the unitarity triangle can be measured using the decay $B \to \pi^+\pi^-$. The branching ratios for $\pi\pi$ and $\psi(\to \mu^+\mu^-)K_S$ are comparable, so the final state $\pi\pi$ may be accessible This channel has much more background than ψK_S. However CDF has demonstrated that by requiring that the decay products come from a separated vertex, the background to b events from non-b decays can be substantially reduced [25]. Assuming that such a requirement can eliminate the non-b background, one is left with the background from $B \to K\pi$ which has a comparable branching ratio (the CLEO data are not yet able to separate them [26]). None of the proposed SSC/LHC detectors has any particle identification so that the only way to separate the modes is via mass resolution. Since this mode is very difficult to use at the e^+e^- b factories due to its small rate, it it worthy of further study. At both SSC and LHC there have been expressions of interest in dedicated b physics detectors [27]. The general question of how much b physics can be done by the general purpose detectors is not resolved.

6 Other processes

Many other signals for new physics have been investigated in detail. These include: the search for a new gauge boson via its decay to e^+e^-, $\mu^+\mu^-$ [2, 1, 3, 4] or $\tau^+\tau^-$ [1]; deviations in the jet cross section at large transverse momentum as a signal for quark compositeness [2, 1, 3, 4]; deviations in the Drell-Yan cross-section at large dilepton invariant mass as a signal for quark-lepton compositeness [2].

7 Conclusions

The general purpose detectors have studied many of the physics processes that might be expected to show up at SSC/LHC energies. One must hope that this generic set of processes is sufficient that if a detector is able to observe them, it will be able to observe the process that we have not thought of.

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