PHYSICS AT 10^{34} CM^{-2}SEC^{-1}

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Abstract

Accelerator and detector operation at a luminosity of 10^{34} cm^{-2}sec^{-1} are briefly discussed. While not all physics can (nor need be) studied at such luminosities, interactions with appropriate and distinctive signatures can be observed even in the presence of many other simultaneous events. The highest luminosities will be needed to reach the highest masses and/or to compensate for loss of rates from small branching ratios. As a rule of thumb, an order-of-magnitude increase in luminosity is a relatively cheap way of achieving the equivalent of a doubling of the beam energy for many processes. In spite of the high rates, the data acquisition and analysis for the detector described here are expected to be easier than for the standard 4π detector operating at 10^{33} cm^{-2}sec^{-1}.

Need for High Luminosities

Due to the composite nature of the proton and the momentum distribution of its constituents, the effective mass ranges that can be explored for many processes are limited by the expected rates. Increased luminosity can extend the range of the SSC, but the resulting high rates make experimentation more difficult -- the detector, trigger, and data reduction must all be capable of handling the multiple interactions from each beam bunch crossing.

High luminosity may also be needed to compensate for low branching ratios to final states having manageable backgrounds. For example, J. Gunion at this workshop has discussed observation of processes yielding two intermediate vector bosons. Final states involving decays to hadronic jets may be swamped by backgrounds from QCD processes. Leptonic decays are expected to be relatively background free, but suffer from rate reductions due to the low branching ratios. The most distinctive final state, with $ZZ \rightarrow e^+e^-e^+e^-$, is reduced by a factor of 1000.

However, the signatures for such final states, and more generally for very massive particles, are quite distinctive even in the presence of a large number of simultaneous interactions. The backgrounds from the "minimum bias" multitude of events and from the overlap of two or more "semi-hard" events fall rapidly at the very large p_T's generated by very massive particles.

A Snowmass-84 study[1] showed that even with the "pile-up" expected at 10^{34} $cm^{-2}sec^{-1}$, p_T thresholds in the neighborhood of only about 100 GeV/c would be required in the Level-1 trigger, resulting in relatively small inefficiencies for the TeV and multi-TeV masses of interest at these luminosities. Analytic studies show that the overlap of "semi-hard" processes should not provide significant backgrounds. Indeed, the dominant backgrounds appear to be "physics backgrounds" such as those calculated by Gunion et al.

The SSC at 10^{34} $cm^{-2}sec^{-1}$

Machine intensity and/or luminosity are difficult to predict with certainty. The SSC Central Design Group has understandably taken a relatively conservative goal of 10^{33} $cm^{-2}sec^{-1}$ as the design luminosity. For comparison, though at much lower energy, the one previous pp collider, the CERN ISR, had as its design specification 4 x 10^{30} $cm^{-2}sec^{-1}$, one and half orders of magnitude below its ultimate record of 1.4 x 10^{32} $cm^{-2}sec^{-1}$.

The Snowmass-84 study of high luminosity gave a plausible example of how the SSC luminosity could be raised to 10^{34} $cm^{-2}sec^{-1}$ without violating nominal accelerator design parameters:

a. bunch spacing: 10m → 5m, comparable to that at Fermilab;

b. focusing at IR: β = 1m → 0.5m, as has been shown reasonable by SSC studies;

c. beam-beam tune shift: $\Delta\nu = 0.0017 \rightarrow 0.003$, compared with values of 0.003 to 0.005 often taken as the limit; and

d. protons per bunch: $1.4 \times 10^{10} \rightarrow 2.2 \times 10^{10}$, still less than used at Fermilab.

Other parameters such as beam emittance were left unchanged.

High-Luminosity Detector

Here we will consider only a relatively simple 4π detector; no doubt it could be embellished in many ways. It would be primarily a calorimeter detector with towers of, say, $\Delta\eta \times \Delta\phi = 0.04 \times 0.04$, as suggested by Gilchriese at this workshop. For a pseudorapidity range of ±5 units (more than adequate for the high masses considered here), this works out to about 40,000 towers. A muon detector would be added to the outside of the calorimeter, and a 2-m radius, 1.5-Tesla solenoid with rudimentary tracking placed inside the calorimeter.

For a non-diffractive cross section of 100 mb, each bunch collision would generate an average of 17 inelastic events, spaced by 17-nsec intervals. Following the Snowmass study,[1] we assume that the effective time resolution of the detector is such that it is effectively sensitive to two bunch crossings at any given time, an average of 33 inelastic events. For the model used for minimum bias events (ISAJET jet events with $p_T \geq$ 4 GeV/c per jet), this gave approximately 2400 charged tracks within the resolution time and $|\eta| \leq 5$. While this seems at first glance to be horrendous, on average there is only 2400/40000 = 1 track per 16 calorimeter towers. Thus, the random background of particles with 1 GeV/c or less transverse momentum is easily ignorable when looking for TeV-mass objects with the calorimeters. Indeed, this pileup effect is similar to a low level of dark current or noise in phototubes, easily ignorable in the calorimetry by the use of a relatively low threshold.

In contrast, tracking is made much more difficult by the high multiplicity. Clearly, the computer time to do detailed tracking of 2400 particles would be prohibitive even if the tracking chamber could support such a multiplicity. In the central region near the solenoid coil, however, the track density is still manageable. At a 2-m radius, the track density is on average one per square foot (this calculation neglects the curl-up of low momentum tracks below 450 MeV/c in the solenoidal field, so the average density will be even less). The density of tracks will be much higher within the high-p_T jets of interest, of course, but this would be true even at low luminosities with a single interaction within the time window.

The primary reason for tracking is the identification of electrons and muons. Even a rudimentary tracking system would greatly aid in background reduction through the requirement of a high-p_T track pointing at the hot spot in the shower counter (the CDF shower counter[2] has a position resolution of ±2mm), or linking up to a muon candidate track in the muon detector. For example, a resolution of $\Delta p/p = 0.01\ p_T$ (GeV/c) would be given by two drift chambers just inside the solenoid coil, each with ±200 micron resolution, separated by 6 cm. This would give ±30% at 30 GeV/c, eliminating most backgrounds from the large number of low momentum particles. Clearly, one might hope to do even better with more detector planes and/or better spatial resolution.

To conclude, a 4π detector relying primarily on calorimeter towers should be able to study many physics processes with distinctive signatures in the presence of multiple background interactions at high luminosities. Care should be taken to preserve this option when designing the SSC and associated detectors.

References

1. R. Diebold and R. Wagner, Proc. 1984 Summer Study on the Design and Utilization of the Superconducting Super Collider, p575 (Snowmass, 1984).
2. P. Schoessow et al., Proc. DPF Santa Fe Meeting, p366 (1985).