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A Fast Calorimeter Simulation for SSC Detector Design*

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A FAST CALORIMETER SIMULATION FOR SSC DETECTOR DESIGN

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Abstract

We have developed a fast and easily varied simulation of a "generic" 4π calorimeter. The progam enables one to study the gross features of detector response for various physics processes. The simulation program is described and some examples of its use are presented.

1. INTRODUCTION

Computer simulations of detectors are now one of the most widely used tools for detector design. As detectors have become more complex, the computer simulations have also grown and become much more complicated. We have written a computer simulation which is both fast and flexible. The speed is obtained by using parametrizations for showers and a fairly simple geometry. The flexibility is provided by allowing many characteristics of the simulated detector including thickness, segmentation, resolution, and electron/hadron response to be easily set by the user. We see this program not as a replacement for the more elaborate computer simulations of detectors but rather as a complementary tool. A simple program may be used to determine which detector issues are worthy of study with the more time-consuming and detailed programs.

2. DESCRIPTION OF THE SIMULATION PROGRAM

The simulated detector is shown in Figure 1. It consists of three regions: a decay volume, an electromagnetic calorimeter and a hadronic calorimeter. Both calorimeters are spherical shells with conical holes for the beam pipe. The rapidity cutoff is specified by the user. The decay volume contains a cylindrical region where a solenoidal magnet field may be present. The radius of the spherical decay volume is chosen to just enclose the cylinder. The cylinder's size and the magnetic field strength are specified by the user. The radiation length, absorption length and thickness of each calorimeter are also settable. We mention here two limitations of the detector geometry. The first is that all of the calorimetry is outside of the magnetic field. Most SSC detector designs under consideration place at least some of the calorimetry inside the magnet. Secondly, in this

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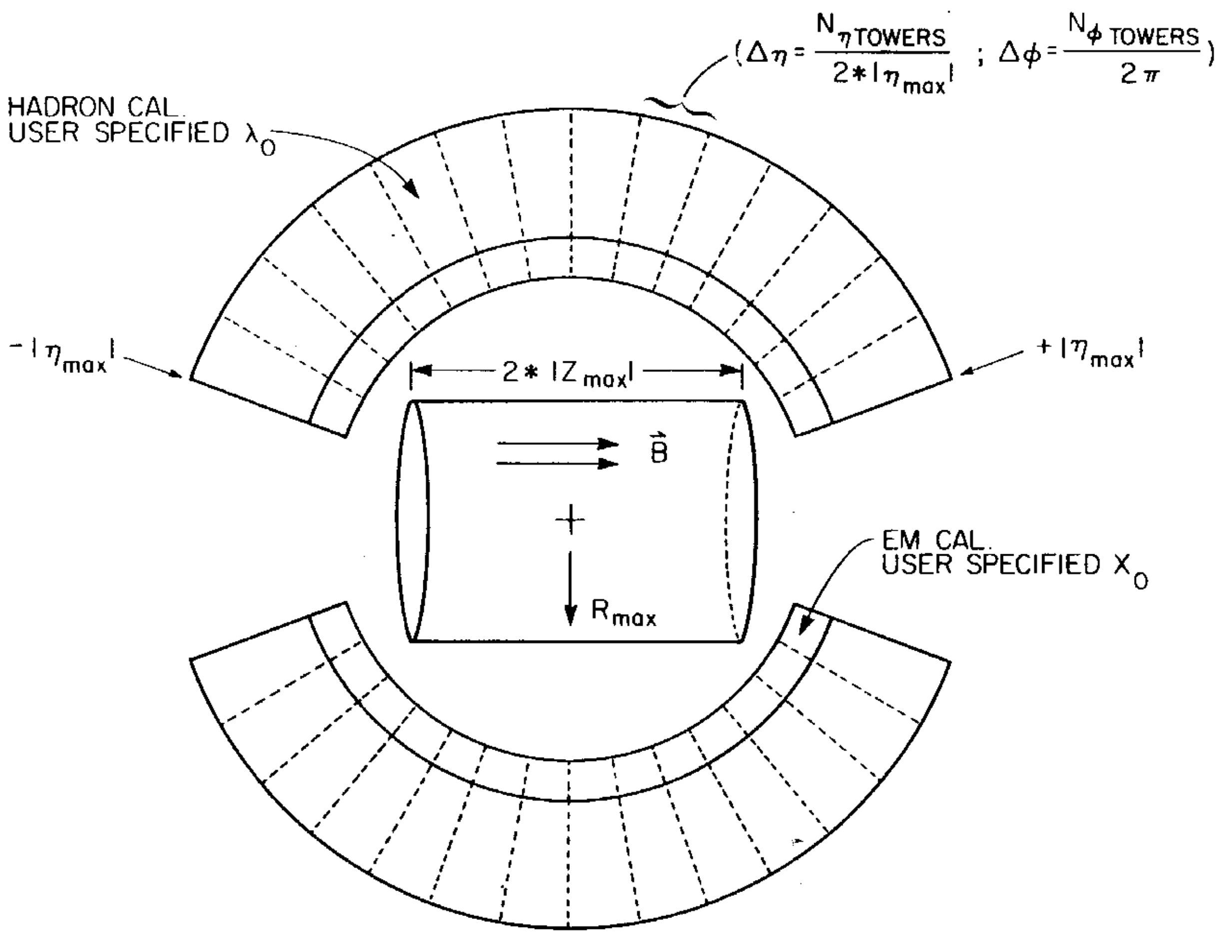

Figure 1. Diagram of the simulated detector.

program, the segmentation of the electromagnetic and hadronic calorimeters is required to be the same whereas detector designs generally make the electromagnetic calorimeter more finely segmented. These restrictions may be relaxed in a subsequent version of the program.

The program is currently interfaced to the event generation program of the Collider Detector at Fermilab (CDF) which allows one to use a variety of generators as input. The program goes through a list of particles made by the generation program. For each particle, a distance to decay point, distance to electromagnetic conversion and distance to hadronic interaction are calculated using probablity distributions appropriate for the particle type. Particles are then tracked through the detector one by one. In the decay volume, a particle will decay if the distance to its decay point is less than the distance it travels through this volume. If a nonzero magnetic field has been specified, charged particles follow helical trajectories.

When a particle reaches its predetermined shower or conversion point, parameters for its shower are generated. The shower parametrization has been described elsewhere [1]; longitudinal and transverse shower profiles as well as fluctuations are modelled. This parametrized shower is then integrated over the distance between the shower point and the calorimeter edge. If a shower starts in the electromagnetic calorimeter, the same shower is continued into the hadronic calorimeter. The electromagnetic/hadronic energy response is settable for each calorimeter. Note that in this model, a particle may not decay once its shower has begun. The total (electromagnetic + hadronic) energy deposited in the calorimeters is available for each particle both before and after smearing with a resolution function. The resolution is assumed to be of the form $\sigma_E/E = const/\sqrt{E} + 1\%$ where the constant is supplied by the user for each calorimeter (electromagnetic and hadronic) and the additional 1% is a systematic error associated with calibration. In addition, the energy is deposited in an η - ϕ array with specifiable segmentation. Energy is shared between the central tower (i.e., the one to which the particle track pointed) and its four nearest neighbors in η - ϕ space. The fraction of energy deposited in the central tower depends on the ratio of the shower size to tower size. The remaining energy is shared equally among the four nearest neighbor towers. Electromagnetic and hadronic calorimeter energies are saved separately in the η - ϕ array; only their sum is saved in the particle-oriented arrays. A simple clustering algorithm is used to find energy clusters in the η - ϕ array.

At a luminosity of 10^{33} cm^{-2}/sec, one expects an average of about 10 interactions in a 100 ns integration time. Our simulation includes an option to overlap minimum bias events with the generated events of interest. The average number of events to overlap may be varied. Then the actual number of overlapped interactions is determined for each

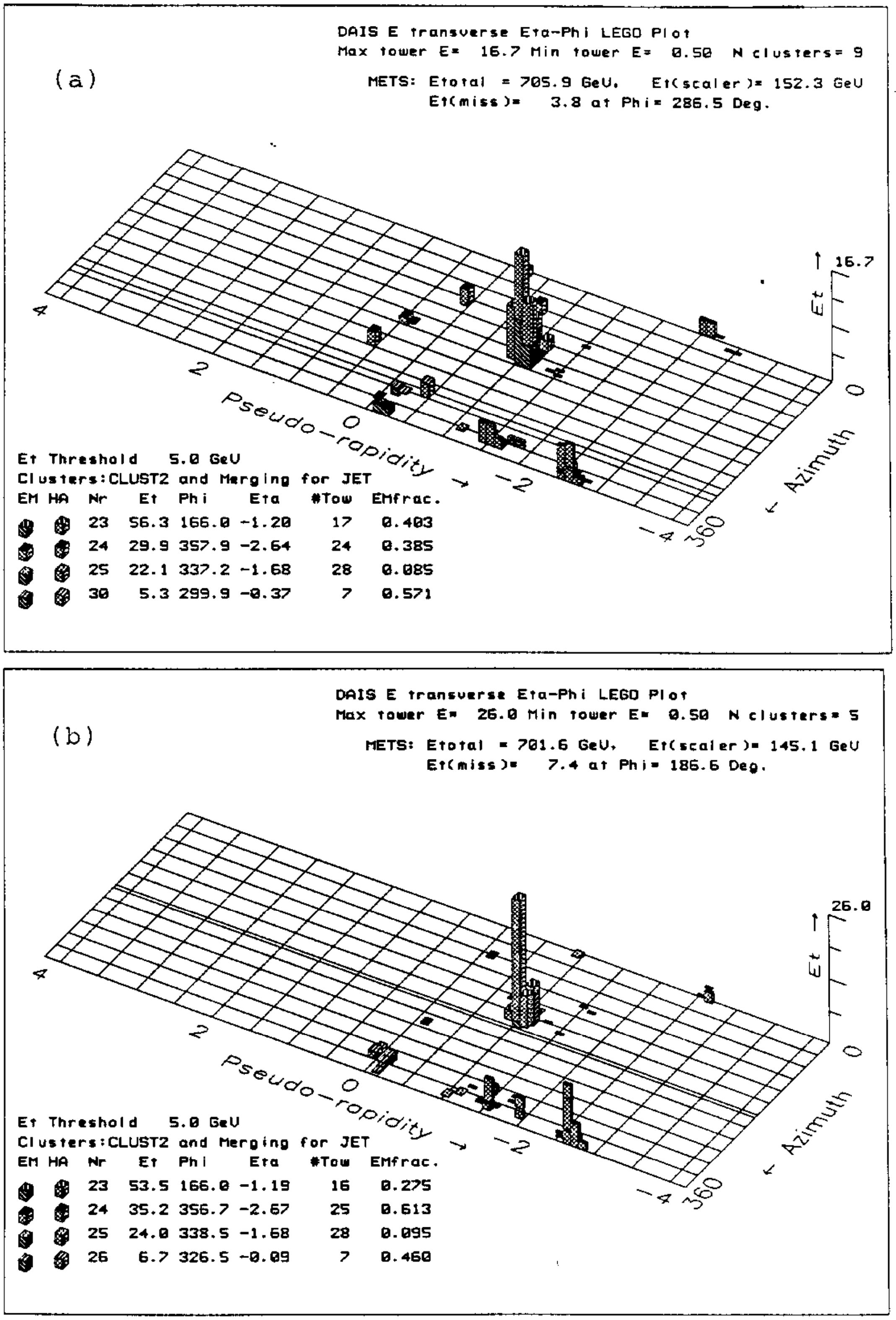

Figure 2. Transverse energy in η-ϕ towers for this program (a) and the full CDF simulation (b).

event by sampling from a Poisson distribution with the specified mean.

Figure 2 shows the energy in the η - ϕ array for an event simulated by this program (Fig. 2a) compared to the same event simulated by the full CDF simulation program (Fig. 2b). The distributions, as well as the list of clusters in the lower left corner of each plot, are in good agreement. On a VAX 8650, the program requires 100 msec for initialization. The time taken per event depends on the topology of the events being studied. For W pair events at $\sqrt{s} = 40$ TeV, with the W's decaying to quarks, the average number of produced particles is about 900 and the time required is about 2.5 sec/event. For comparison, the full CDF detector simulation (which also uses parametrized showers but much more complicated geometry) takes about 100 times longer.

3. AN EXAMPLE OF THE PROGRAM'S USE

We present here some results obtained with the simulation program as examples of its utility. We choose for illustration to study the invariant mass distribution for 500 GeV P_t W's decaying into quarks which then hadronize into jets. This example is discussed in more detail in Reference 2. The parameters used by the simulation program for this example are given in Table I. The first five parameters in Table I were chosen to match the CDF detector.

Table I

EM calorimeter radiation length	1.94 cm
EM calorimeter absorption length	48.36 cm
Hadron calorimeter radiation length	2.94 cm
Hadron calorimeter absorption length	33.25 cm
EM calorimeter thickness in rad lengths	17.82
Hadron calorimeter thickness in abs lengths	10.0
EM calorimeter energy resolution	$15\%/\sqrt{E}$
Hadron calorimeter energy resolution	$50\%/\sqrt{E}$
EM calorimeter e/h response ratio	1.0
Hadron calorimeter e/h response ratio	1.0
Tracking volume radius	140.0 cm
Tracking volume half-length	140.0 cm
Magnetic field	0.0 Tesla
Maximum absolute value of η	2.5
Number of η bins	160
Number of ϕ bins	210

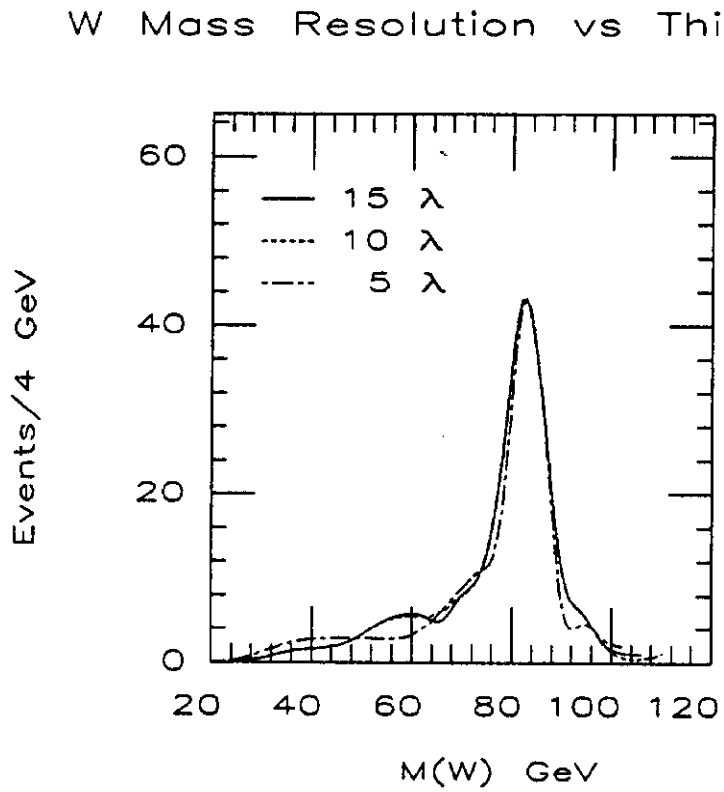

Figure 3. Effect of calorimeter thickness on W mass resolution.

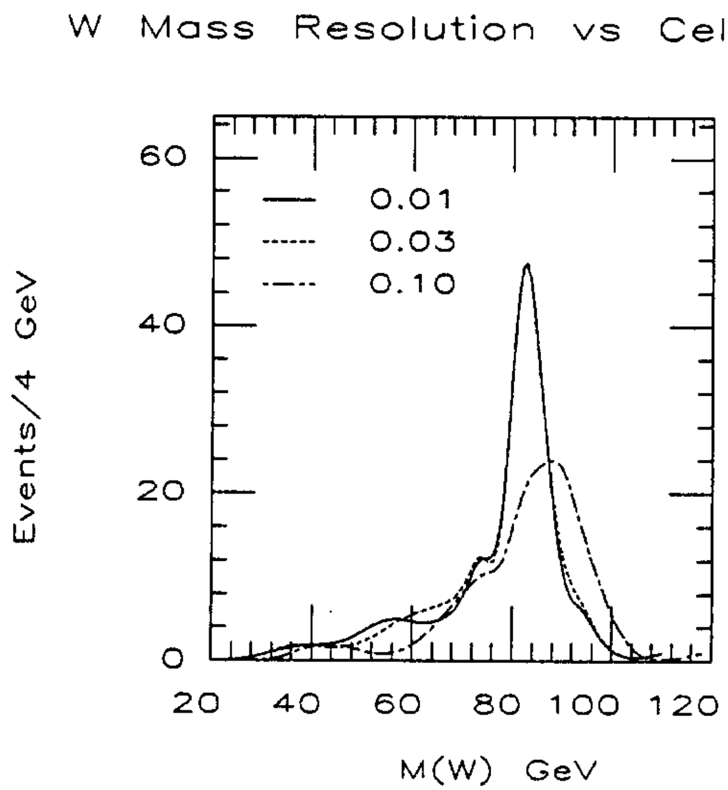

Figure 4. Effect of segmentation on W mass resolution. The three curves are for three different tower sizes where a tower is a rectangle in η-ϕ space.

The events were generated using the ISAJET program [3] (version 5.2). The W's were produced by the WPAIR option, with θ between 80° and 90°, and the P_t range 450 - 550 GeV. After the events were created, the simulation was used to generate calorimetry energy depositions. Clusters were then found in the calorimetry using a simple algorithm. To reconstruct the W invariant mass each tower within $R < 0.7$ of the cluster center was treated as a massless particle with all energy assumed to be deposited in the tower center, and the resultant invariant mass of this set of "particles" was calculated. Here R is defined as:

$$R = \sqrt{((\phi - \phi_i)^2 + (\eta - \eta_i)^2)}$$

where (η,ϕ) is the cluster direction and i is the tower index. We note that these calculations are very insensitive to the clustering algorithm used, since only the cluster direction is required. Some additional cuts were applied to suppress problems in pattern recognition. The jets produced by the decay of 500 Gev W's are coalesced in our choice of calorimeter geometry. To ease pattern recognition, we chose events where no more than 25 GeV E_t of cluster energy was outside of the two leading clusters, and where the ratio of E_t's of the leading to the next to leading cluster was less than 1.25 . These cuts were typically 40% efficient. The remaining events can in principle be used, but the pattern recognition is more difficult.

The curves shown in Figures 3-6 are from a sample of approximately 175 W's per case for the W analysis. Figure 3 shows the effect of calorimeter thickness on the W mass resolution. Clearly thickness is not very important for this process. This is partially caused by the cuts that define the event sample. The requirement of cluster E_t balance suppresses events where there is substantial leakage or punchthrough. In addition, the jets from the W decay are fairly soft, again reducing the effect of leakage.

The results are sensitive to the segmentation chosen as shown in Figure 4. In our invariant mass algorithm, the tower size is very important. All energy deposited in a tower is assumed to come from the tower center, so the larger the tower, the larger the possible error in determining the direction of the energy flow into the tower. Figure 4 shows the W invariant mass distributions for three cases of tower size: $\delta R = 0.01$, 0.03, and 0.1 . The resolution suffers substantailly if the tower size is as large as 0.1.

Figure 5 indicates that calorimeter resolutions mentioned in typical SSC detector designs are reasonable for observing the process under consideration. We note though that low energy particles in the lab frame can make large contributions to the invariant mass calculation. It is important to measure these particles accurately.

Figure 6 indicates that the problem of overlapping events at high luminosities may

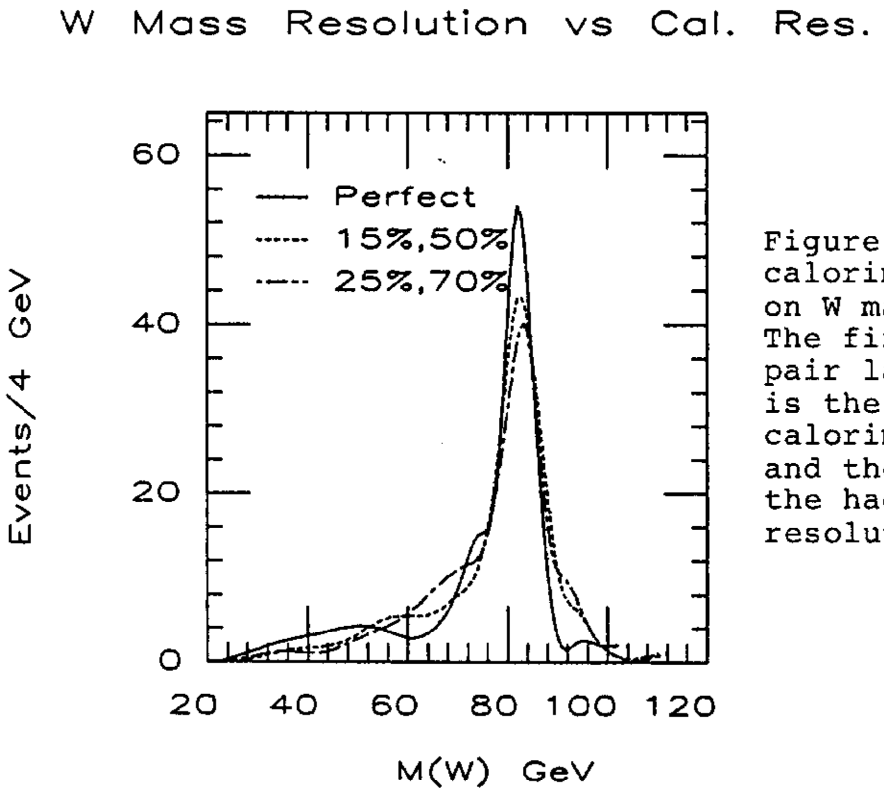

Figure 5. Effect of calorimeter resolution on W mass resolution. The first number of the pair labelling the curve is the electromagnetic calorimeter resolution, and the second number is the hadron calorimeter resolution.

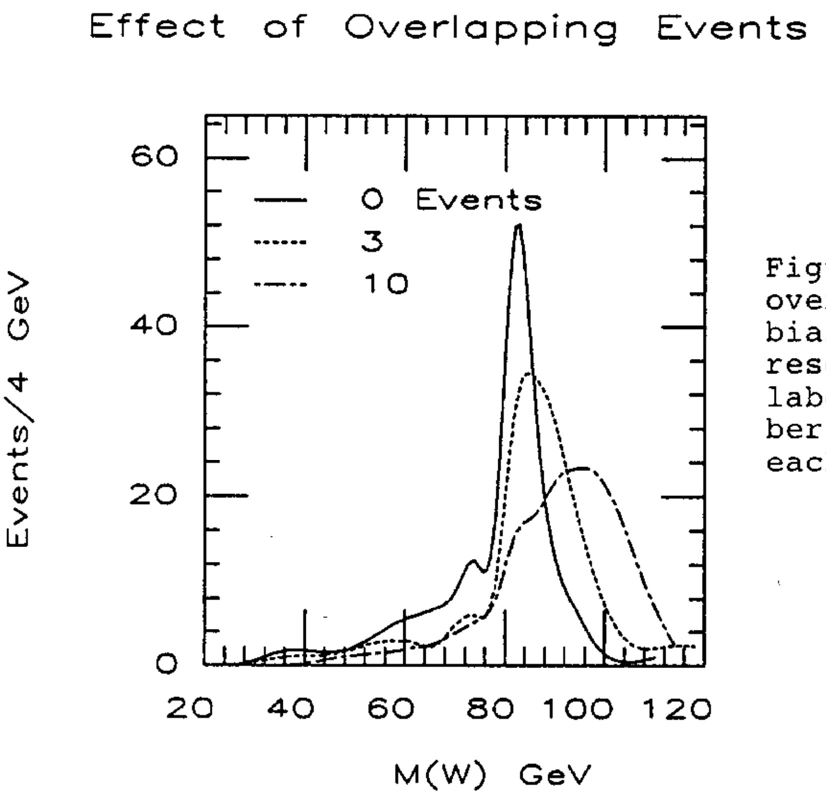

Figure 6. Effect of overlapping minimum bias events on W mass resolution. The curve labels are the mean number of events added to each W event.

significantly worsen a detector's ability to reconstruct W's from two jets. For this study, we considered the effect of additional background events which fall within the detector resolving time of the signal events. For the background events, we used ISAJET TWO-JET events with jet P_t's between 3 and 15 GeV. This corresponds to about 150 millibarns of cross section at 40 TeV, so it should be a reasonable model for the background. The W mass resolution has a striking sensitivity to the number of superimposed background events.

4. CONCLUSION

We have written a simple Monte Carlo simulation program which may be used as a design tool for SSC detectors. Different process may be studied with the program and gross detector features easily changed. This allows one to see which detector characteristics are most important for processes of interest. Detailed design studies with more elaborate simulation programs then become more efficient and manageable.

References

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3. F.E. Paige and S.D. Protopopescu, "ISAJET: A Monte Carlo Event Generator for pp and $\bar{p}$p Interactions", 1982 DPF Summer Study, Snowmass, CO, June 1982, p. 471.