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DETECTION OF HIGGS BOSONS DECAYING TO BOTTOM QUARKS*

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In the 1984 Snowmass meeting the capability of detecting at the SSC a Higgs boson decaying to top quarks was examined in some detail.[1] The decay $H^0 \rightarrow \bar{t}t$ is relevant to the case of the so-called "intermediate mass" Higgs (roughly, 80 to 170 GeV for M_H) if, as some evidence indicated at that time, the t quark has a mass of 30 to 50 GeV. For lower Higgs masses, below about 80 GeV, its discovery is likely to be the province of SLC, LEP I, or LEP II. If the Higgs mass is above 2 M_W, the decay to gauge bosons becomes the primary decay mode and a different analysis is needed to examine the possibilities for its detection.

For the case where $H^0 \rightarrow \bar{t}t$, the overall prognosis for Higgs detection was gloomy, especially after appropriate cuts were made to reduce backgrounds, jet reconstruction ambiguities were taken into account, and detector resolution folded in. These experimental realities, as approximated in that study, expanded the width of the reconstructed Higgs mass peak (with an input mass of 120 GeV/c^2) to about 20 GeV/c^2. Moreover, there were substantial tails outside of that acceptance, particularly on the low mass side because of semileptonic decays involving missing neutrinos. The result was a predicted signal/background ratio in the accepted mass band of about 0.04; this was gloomy indeed.

Since 1984, several things have happened to make a re-examination of this subject of interest. First, our level of certainty about the t quark mass has decreased; at this time it is quite possible that the t quark is even heavier than the W. Second, the Monte Carlo programs to generate both signal and background events have very much improved. Third, additional ideas and corresponding algorithms to enhance and/or separate heavy quark jets from jets due to light quarks or gluons have been developed. Finally, the possibility that $H^0 \rightarrow \bar{b}b$ might be the decay mode of choice for detecting the intermediate mass Higgs seems likely to improve the signal to background ratio. This is so because (a) background processes containing $\bar{b}c$ combinations, where the c is mistaken for a b, are suppressed by KM angles; and (b) the long b lifetime gives the opportunity for identification of b quark jets by means of secondary vertices that would not be available for t jets.

For all these reasons, it is of interest to take another look at how one might detect an intermediate mass' Higgs at the SSC, particularly if a prominent decay mode was $H^0 \rightarrow \bar{b}b$. In the following, we have done just that, using the PYTHIA Monte Carlo program[2] to generate both signal and background events. For the signal, events were generated of the type $pp \rightarrow H^0 + (W^\pm \text{ or } Z^0) + X$, with $H^0 \rightarrow \bar{b}b$. We are using the presence of the W or Z to enhance the likelihood of Higgs production and to reduce the potentially enormous background.

Background events generated were of the type $pp \rightarrow g + (W^\pm \text{ or } Z^0) + X$, with the gluon fragmenting according to the rules of the model. The two highest energy jets in a central rapidity region ($|y| < 5$) were selected as the candidates for Higgs decay. The mass of the Higgs boson was set at 120 GeV/c^2, while that of the t quark was fixed at 150 GeV/c^2, high enough to make it irrelevant in Higgs decay or as a potential background in the mass region of interest. A minimum p_T value of 50 GeV/c was used for the initial hard scattering.

Two strategies were used initially to select preferentially b quark jets: (1) it was required that one of the two jets contain a lepton with transverse momentum (relative to the jet axis) greater than 1 GeV/c; (b) a shape parameter developed by Gottschalk[3] was used to select the more collimated jets, since it was observed that b quark jets tended to be narrower than gluon jets. This shape parameter, R, is defined as the radius in azimuthal angle and rapidity space, centered on the jet axis, which contains 70% of the energy of the jet. For this purpose, the total energy of the jet was defined to be the amount contained in a cone of radius 2.

Figure 1 shows the two-jet mass spectrum for both signal and background samples with only the acceptance cut in rapidity, $|y| < 5$), and without simulation of detector resolution. Neutrinos, however, are undetectable and have been omitted from the mass calculation. (No W or Z branching fractions have been applied to the cross section, since it is still uncertain which decay modes will be recognizable.) A narrow Higgs peak is seen with, however, a significant low tail due to the missing neutrinos. It is tempting to think that one could cut on the narrow peak region to achieve a fairly good signal to background ratio, but detector resolutions will significantly broaden the peak. In Fig. 2, signal and background spectra are plotted for the same conditions as Fig. 1, except that an approximation of experimental reality has been

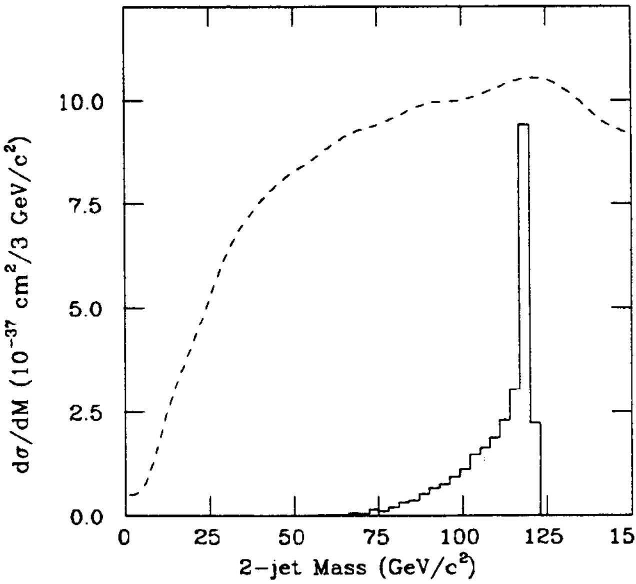

Fig. 1. Two jet mass spectrum for Higgs signal (solid histogram) and for background events divided by 10 (dashed line). No experimental resolutions have been imposed, except that neutrinos have not been included.

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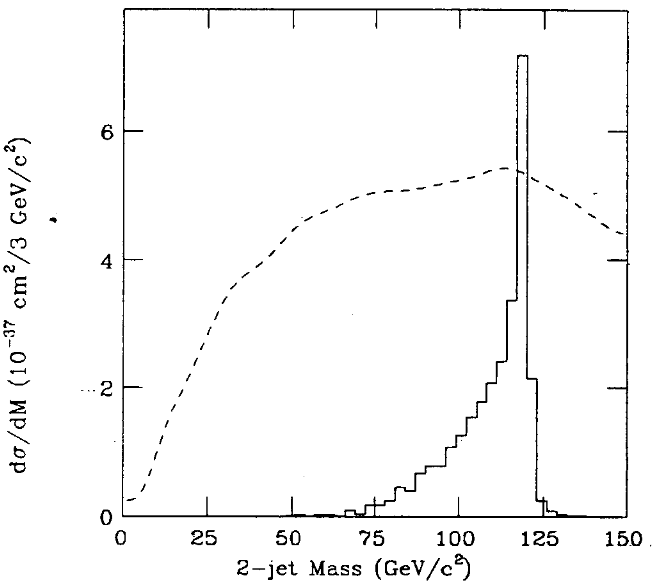

Fig. 2. Two-jet mass spectrum for Higgs signal (solid histogram) and for background events divided by 20 (dashed line). Experimental losses and resolutions have been included as described in the text.

inserted in three ways: a) particles nominally part of a jet, but making an angle of more than 90° to the jet axis are not included; (b) energy resolutions have been imposed of $0.15/\sqrt{(E)}$ for electromagnetic showers and $0.40/\sqrt{(E)}$ for hadronic showers; and (c) particles with less momentum than 0.5 GeV/c have been discarded as undetectable. The result, of course, is a considerably broadened peak. In the region from $100 < m < 120$ GeV/c^2, the signal/background ratio is 0.027 with the signal corresponding to a cross section of 2.1×10^{-36} cm^2.

We now apply the two cuts aimed at enriching the fraction of b quarks in the sample. In Fig. 3, it has been required that one of the jets contain a lepton with a transverse momentum, relative to the jet axis, of greater than 1 GeV/c. In the same 20 GeV/c^2 mass region, the signal to background ratio has increased to 0.06 and the remaining signal corresponds to a cross section times branching ratio of is 3.2×10^{-37} cm^2. Finally, in Fig. 4 the additional requirement for both jets that $R < 0.5$ is made. The result is a signal/background ratio of 0.8 and a signal that corresponds to a cross section times branching ratio of 2.0×10^{-37} cm^2. A warning, however, is in order at this point. In the process of making cuts, the background sample was essentially exhausted; the background level is based on only one remaining event and the shape in Fig. 4 is taken from the background in Fig. 3.

With the above reservations about the level of statistics, the result at this point is that a year's running at the SSC (i.e., an integrated luminosity of 10^{40} cm^{-2}) would produce 2000 Higgs events in a 20 GeV/c^2 slice around the rather broad peak in the reconstructed Higgs mass. This is arguably detectable, but given the deterioration in resolution that must still come from realistic jet pattern recognition, etc., it cannot be considered a guarantee of success.

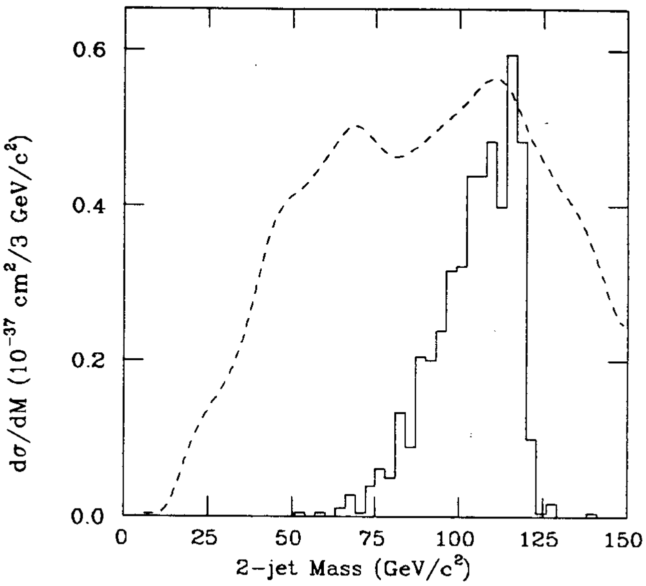

Fig. 3. Two jet mass spectrum for Higgs signal (solid histogram) and for background events divided by 10 (dashed line). Experimental losses and resolutions have been included and one of the jets is required to contain a lepton with $p_T > 1$ GeV/c.

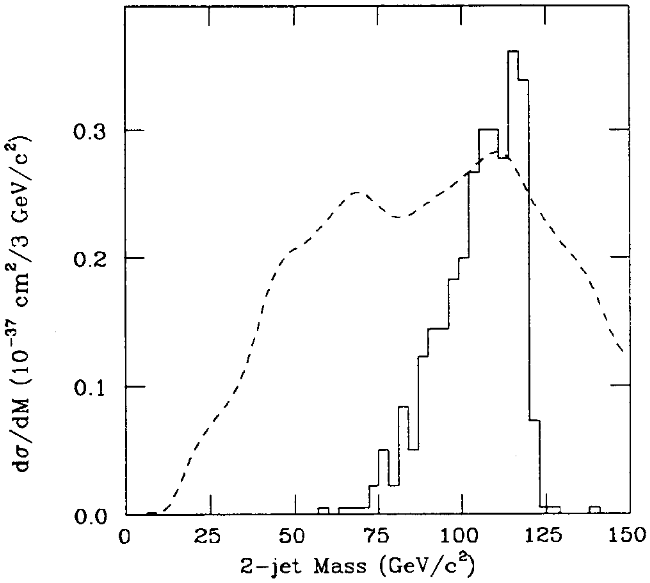

Fig. 4. Two-jet mass spectrum for Higgs signal (solid histogram) and background (dashed line). Background is not scaled for display, but because of poor statistics the shape of the background is taken from Fig. 3. Experimental losses and resolutions have been included and it is required that a) one jet have a lepton with $p_T > 1$ GeV/c and b) both jets have $R < 0.5$.

It is, however, still possible to enhance the signal to background ratio considerably by use of the b decay vertex. This is an area where a realistic simulation is mandatory for calculating both efficiency and background rejection; this has not yet been done. However, it should be noted that most of the background contained in the mass plots above involves events which contain one and only one b quark. One could expect a significant enrichment by imposing a secondary vertexing requirement, but it would have to be imposed on both jets to significantly affect the background. Thus, although a factor of five enrichment may well be attainable, thereby bringing the signal well above the background, the cost is not unlikely to be a loss of efficiency by a factor of 10 or more, leaving us with a dangerously small signal.

While there are still open questions, we can conclude that the $H^0 \rightarrow \bar{b}b$ channel, if important, would be much more favorable for detection of the Higgs than $H^0 \rightarrow \bar{t}t$ was found to be. This is mainly because of the smaller background. Finding the intermediate mass Higgs in this manner of course requires cooperation on the part of the top mass and, even in the best case, will not be a simple matter. This study, though, indicates that it merits continued work.

References

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