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HIGGS BOSONS AT THE SSC: SUPPLEMENT TO EHLQ

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Abstract

Cross section and background estimates are presented for the production of single charged and neutral Higgs bosons which decay into pairs of heavy quarks. In addition, pair production of Higgs scalars in $q\bar{q}$ collisions is estimated.

Single Production of Standard Higgs Bosons

In §IV.D of EHLQ[1] we have given estimates of the cross sections for production and decay of the neutral Higgs boson of the Weinberg-Salam model for assumed values of the top quark mass of 30 and 70 GeV/c^2. The top mass enters both in the estimate of the production rate by gluon fusion via a quark loop and in the computation of the $t\bar{t}$ branching fraction, as well as in the evaluation of the QCD background of $gg \to t\bar{t}$. Suggestions[2] that the top quark mass may lie around 45 GeV/c^2 make it interesting to repeat our analysis for this mass.

Using the expressions for Higgs production given in (4.88) – (4.95) of EHLQ and the decay rates given there in (4.81) – (4.83), we compute the cross section for the reaction

$$pp \to H^0 + \text{anything}, \quad H^0 \to t\bar{t}\,, \tag{1}$$

with $m_t = 45$ GeV/c^2, at c.m. energies of 2, 10, 20, 40, 70, and 100 TeV. The results are shown in Fig. 1, where the rapidities of both t and $\bar{t}$ are restricted to $|y| < 1.5$. For comparison we show in Fig. 2 the corresponding results for $m_t = 30$ GeV/c^2, as given in Fig. 4-51 of EHLQ. With the larger top-quark mass, the $H^0 \to t\bar{t}$ yield is increased by about a factor of two for $M_H \approx 100$ GeV/c^2, and by about an order of magnitude, for $M_H \approx 400$ GeV/c^2

The expected cross sections are substantial, but the anticipated backgrounds are significantly larger. The two-jet background, arising from the reaction

$$pp \to \text{jet}_1 + \text{jet}_2 + \text{anything}\,, \tag{2}$$

is shown in Figs. 3-21 – 3-23 of EHLQ. It exceeds the $H^0 \to t\bar{t}$ signal by many orders of magnitude. If the t-quarks can be identified, the signal-to-background is improved – but still discouraging. We show in Fig. 3 the cross section for $t\bar{t}$ production via the process

$$gg \to t\bar{t}\,, \tag{3}$$

with $m_t = 45$ GeV/c^2. [The corresponding background for 30 GeV/c^2 top quarks is given in Fig. 4-52 of EHLQ.] Even this restricted background is far larger than the signal.

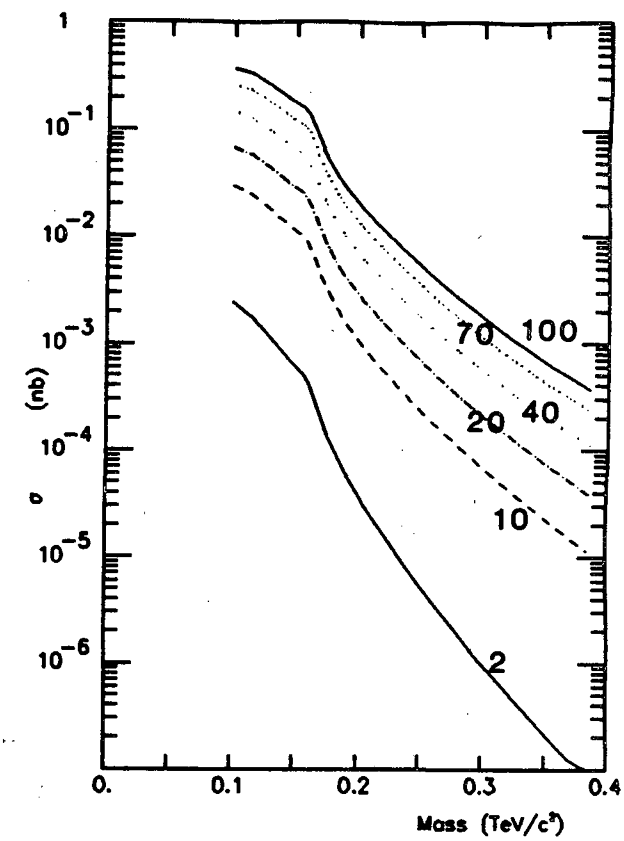

Fig. 1 Cross section for the reaction $pp \to (H \to t\bar{t})$ + anything as a function of M_H with $m_t = 45$ GeV/c^2, according to the parton distributions of Set 2 at $\sqrt{s} = 2$, 10, 20, 40, 70, and 100 TeV. The t and $\bar{t}$ must satisfy $|y_t| < 1.5$.

We conclude that (with three quark generations) the observation of a Higgs boson with $M_H < 2\,M_W$ in the decay

$$H^0 \to t\bar{t}\,, \tag{4}$$

will be problematical in $p^{\pm}p$ collisions, with $m_t = 45$ GeV/c^2, just as with $m_t = 30$ GeV/c^2.

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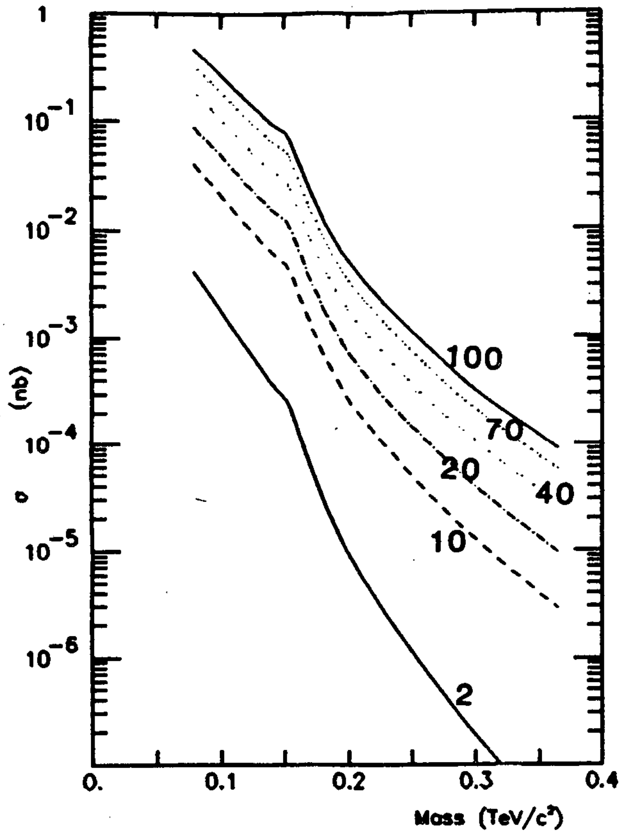

Fig. 2 Cross section for the reaction $pp \rightarrow (H \rightarrow t\bar{t})$ + anything as a function of M_H with m_t = 30 GeV/c^2, according to the parton distributions of Set 2 at $\sqrt{s}$ = 2, 10, 20, 40, 70, and 100 TeV. The t and $\bar{t}$ must satisfy $|y_t| < 1.5$.

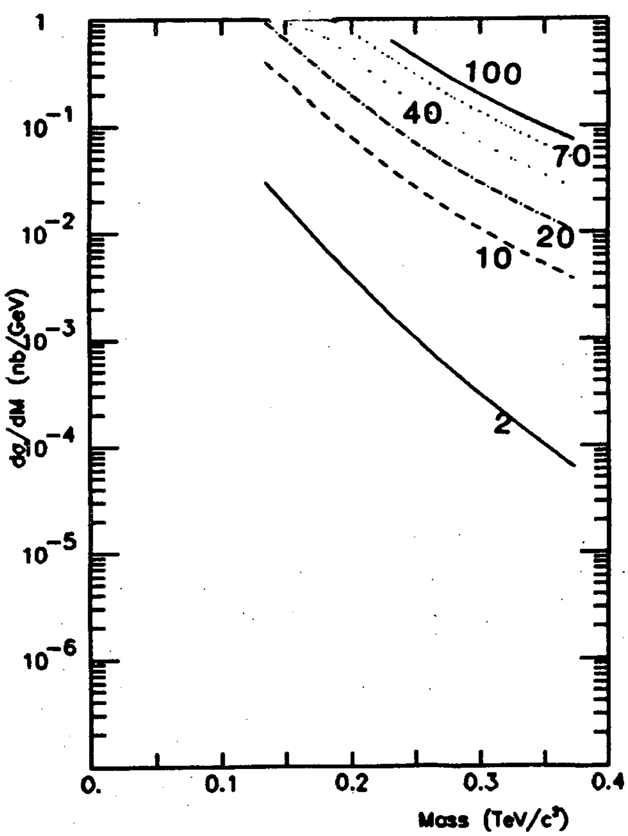

Fig. 3 Mass spectrum of $t\bar{t}$ pairs produced in proton-proton collisions, according to the parton distributions of Set 2, with m_t = 45 GeV/c^2. The rapidity of each produced quark is constrained to satisfy $|y_t| < 1.5$.

Single Production of Charged Higgs Bosons

Models with a richer Higgs structure than the minimal Weinberg-Salam model will contain charged as well as neutral Higgs scalars.[3] Although couplings of Higgs bosons to fermions are model dependent in such cases, it is a reasonable guess that the strength of the $H^+ \rightarrow U\bar{D}$ transition is proportional to the mass of the heavier quark. In this situation, the cross section for the production of a charged Higgs boson in the reaction

$$t\bar{b} \rightarrow H^+ , \qquad (5)$$

may be computed from (4.86) and (4.87) of EHLQ, with $m_i = m_t$.

In the EHLQ structure functions, the t and b quarks arise only from perturbative evolution.[4] As a consequence, the resulting cross sections are sensitive to the assumed quark masses, and to the choice of the scale parameter Q^2. The EHLQ structure functions were evolved using m_t = 30 GeV/c^2. Near the threshold, these will somewhat overestimate the top content of a proton, should the top mass be 45 GeV/c^2. In our estimates, we have chosen the scale Q^2 at which the parton distributions are evaluated to be s. A smaller choice would also tend to reduce the predicted signal. Where the top quark mass appears explicitly, we have taken m_t = 45 GeV/c^2.

We show in Fig. 4 the cross sections estimated for the reactions (summed)

$$pp \rightarrow H^+ + \text{anything}, \quad H^+ \rightarrow t\bar{b} \qquad (6a)$$

$$pp \rightarrow H^- + \text{anything}, \quad H^- \rightarrow \bar{t}b \qquad (6b)$$

at c.m. energies of 2, 10, 20, 40, 70, and 100 TeV. We have included contributions from $c\bar{s}$ and $t\bar{b}$ initial states. In a model with an arbitrary number (>1) of Higgs doublets the charged Higgs will decouple from W_Z. We ignore here the possibility of the decay $H^+ \rightarrow W^+H^0$. The expected cross section at 40 TeV is about 20 pb for a 100 GeV/c^2 charged Higgs boson. If the decay products cannot be identified as heavy quarks, the large QCD background shown in Figs. 3-21 – 3-23 of EHLQ renders hopeless the detection of a charged Higgs signal. If, however, both t and b can be tagged, the prospects are enormously improved, and the situation is far more promising than for $H^0 \rightarrow t\bar{t}$.

In this case the background is represented by the mass spectrum of heavy quark pairs produced in the reaction

$$pp \rightarrow (tb \text{ or } \bar{t}\bar{b} \text{ or } \bar{t}b \text{ or } t\bar{b}) + \text{anything} , \qquad (7)$$

which proceeds by the one-gluon-exchange scattering of heavy quarks from the sea. The background computed with $Q^2 = p_\perp{}^2$ is shown in Fig. 5. With our estimate of the b and t content of the proton, it presents no impediment to the detection of $H^\pm$.

We shall not discuss the discovery reach for charged Higgs bosons because it is so critically dependent on the efficient identification of t- and b-quarks. However, it is important to emphasize the model dependence of our rate estimates, which derives from

(i) a somewhat arbitrary choice of the $Ht\bar{b}$ coupling;

(ii) the uncertain mass of the t-quark, and its effect on the $t\bar{b}$ luminosity at fixed Q^2;

(iii) the choice of a Q^2 scale at which to evaluate the parton distributions.

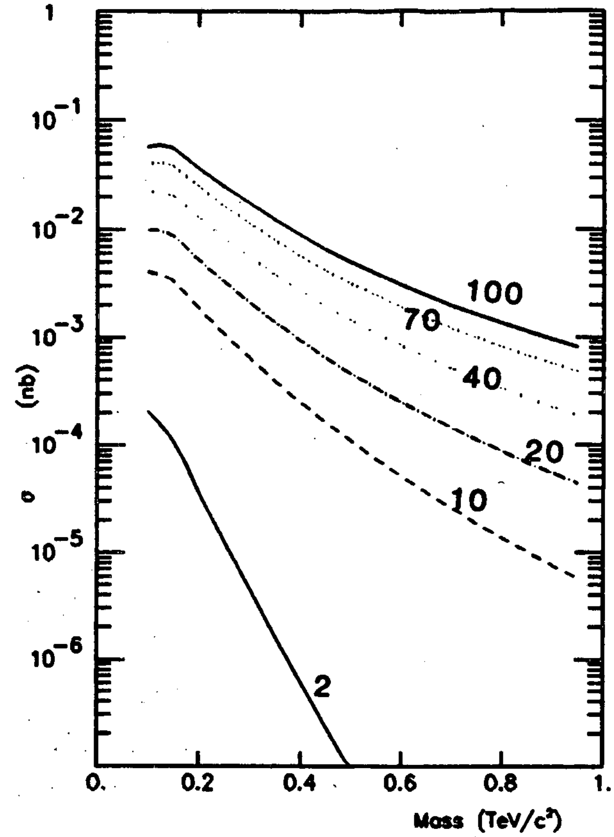

Fig. 4 Cross section for the reaction $pp \to H^{\pm}$ + anything as a function of M_H, according to the parton distributions of Set 2 at $\sqrt{s}$ = 2, 10, 20, 40, 70, and 100 TeV. Both decay products ($t\bar{b}$ or $\bar{t}b$) must satisfy $|y| < 1.5$.

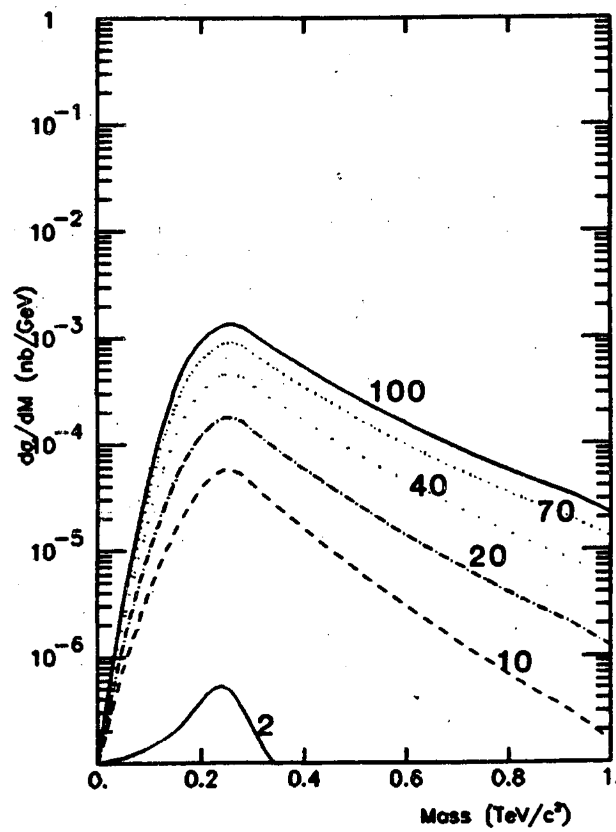

Fig. 5 Mass spectrum of tb plus $\bar{t}\bar{b}$ plus $\bar{t}b$ plus $t\bar{b}$ pairs produced in proton-proton collisions, according to the parton distributions of Set 2. The rapidity of each produced quark is constrained to satisfy $|y| < 1.5$.

The first of these affects only the signal, whereas the second and third should have similar effects on both signal and background. Roughly speaking, we expect the uncertainties due to the parton distributions to be at the factor-of-two level, rather than the order-of-magnitude level. It is probable that our estimates for this case tend toward optimism.

Pair Production of Higgs Bosons

Higgs bosons can also be produced in pairs via $q\bar{q}$ annihilation through an intermediate W, Z or photon. The coupling of a gauge boson to H_iH_j may be written as[3]

$$(V(q) \to H_i(p) + H_j(k)) \equiv ie\, A_{ij}\, \varepsilon(q)\cdot(p-k)\ , \qquad (8)$$

where ε is the polarization vector of the gauge boson. For any model with two or more Higgs doublets

For charged Higgs pairs	$A_{+-}{}^{\gamma} = 1$
	$A_{+-}{}^{Z} = \cot 2\theta_W$.
For neutral Higgs pairs	$A_{ij}{}^{Z} = R_{ij}{}^{Z}/\sin 2\theta_W$
and for charged/neutral pairs	$A_{+i}{}^{W} = R_{+i}/2 \sin\theta_W$

The quantities R are dependent upon mixing angles (ratios of vacuum expectation values) between Higgs multiplets. Notice that $R_{ii}{}^{Z} = 0$ for all i. The cross-sections are trivial modifications of the Drell-Yan formula used in Sec. 5 of EHLQ[1] to predict rates for lepton pairs and will not be given here. For the purposes of the estimates given below we have chosen $R_{ii}{}^{Z} = 0$ and all other R's equal to one. For any model the rates can be obtained trivially from these results. Figs. 6-8 show the rates for $pp \to H^{\pm}H^0$, H^+H^- and $H^0H^{0\prime}$ as functions of the Higgs mass (assumed equal) for set 2 of distribution functions.[1] The rates are quite small. For example the rate of H^+H^- pairs is considerably less than that of single H^+ or H^- (see Fig. 4). Even given the large uncertainties in the latter estimate it appears that single production is more favorable.

An alternative source of Higgs pairs is via two gluon annihilation into H^+H^- via a heavy quark loop. An estimate of the cross sections yields

$$\sigma = \frac{2}{3\pi}\,\frac{\alpha_s^2\alpha_{em}^2}{\sin^4\theta_W}\left(\frac{m_t}{2M_W}\right)^4 \log\,(s/m_H^2) \qquad (9)$$

where the $H^+t\bar{b}$ coupling was taken to be $g_W(m_t/2M_W)$ as before. With m_t = 45 GeV this is smaller than the Drell-Yan cross section by a factor of order 10^4. This factor cannot be compensated by the larger gluon-gluon luminosity (see Sec. 2 of Ref. 1). Consequently the rate from this mechanism is not expected to be important.

The background is more difficult to estimate in the case of pair production. The final state consists of four heavy quarks, and the background from QCD production of two heavy flavor pairs.

Acknowledgments

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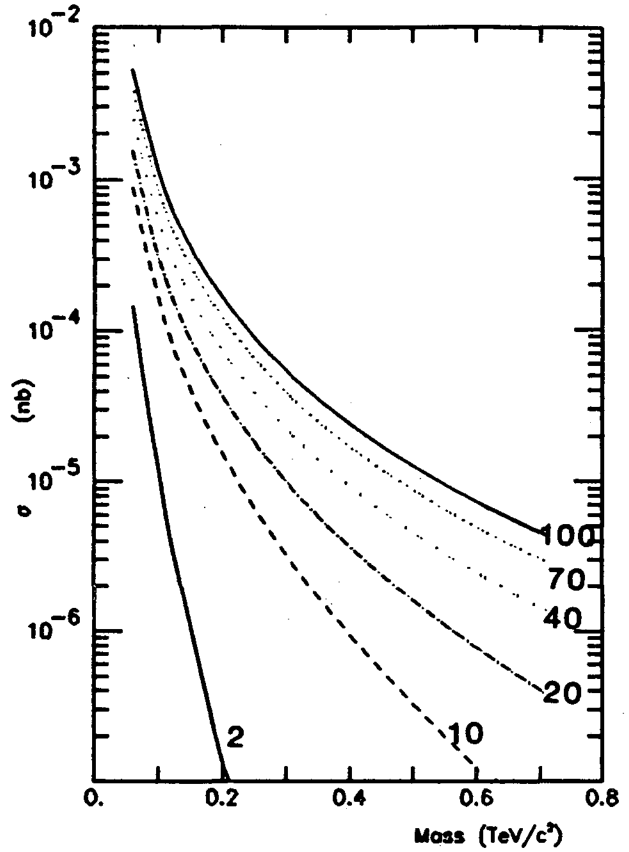

Fig. 6 Cross section for the production of $H^+ H^0$ and $H^- H^0$ (summed) in pp collisions as a function of the mass of the Higgs ($H^\pm$ and H^0 assumed degenerate). Both $H^\pm$, H^0 must satisfy $|y| < 1.5$.

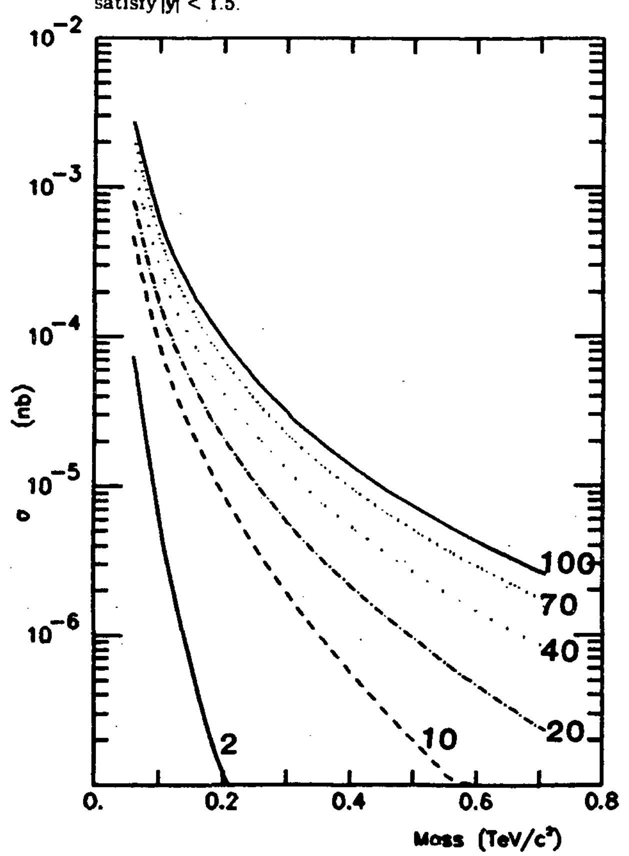

Fig. 7 Cross section for the production of H^+H^- pairs in pp collisions as a function of the mass of H^+. Both H^+ and H^- must satisfy $|y| < 1.5$.

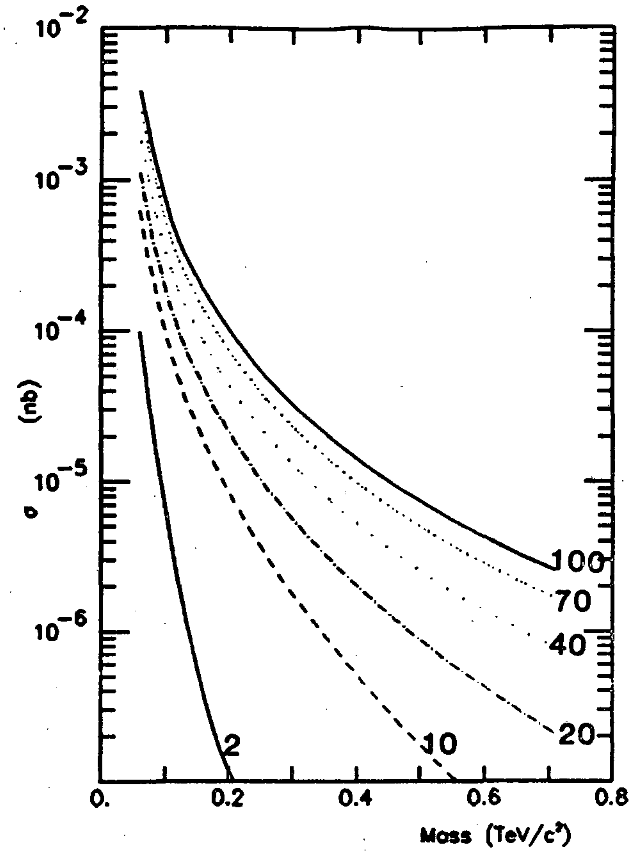

Fig. 8 Cross section for the production of $H^0H^{0\prime}$ pairs in pp collisions as a function of the H^0 mass ($H^{0\prime}$ mass assumed equal). Both H^0 and $H^{0\prime}$ must satisfy $|y| < 1.5$.

References

1. E. Eichten, I. Hinchliffe, K. Lane, and C. Quigg, Fermilab-Pub-84/17-T, to appear in Reviews of Modern Physics.

2. Reports on the UA-1 experiment given at this workshop by A. Savoy-Navarro, J. Rohlf, D. Cline, and C. Rubbia.

3. For a review see K. Lane in Proceedings of 1982 DPF Summer Study of Elementary Particles and Future Facilities, Ed. by R. Donaldson , F. Paige, and D. Gustafson, Fermilab, Batavia, p.222.

4. This is consistent with current understanding of the production of heavy flavors in QCD. See the report by S. Ellis in these proceedings.