Fermi National Accelerator Laboratory

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Associated Production of Higgs and Top Pairs at CMS

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Introduction

The discovery channel for a light Higgs at the LHC has been assumed to be $H \rightarrow \gamma\gamma$ [1]. The region of mass between the LEP II mass reach, ~ 110 GeV, and the onset of a substantial ZZ Higgs branching ratio, mass ~ 150 GeV, has been studied for the two photon decay mode. Note that the branching fraction is only 0.0015, so that the dominant b pair mode is ~ 700 times more copious. However, other modes are needed in order to ascertain the character of the Higgs state. For this reason, associated production of the Higgs with other particles has been explored in the hope that a convincing signal could be extracted for low mass Higgs states.

The production of a Higgs in association with another boson, W or Z, has been studied experimentally. Although it improves the signal to noise for the two photon final state, the bb final state appears, at the Tevatron, to still be badly buried under an irreducible QCD background of b pairs [2]. The purpose of this note is to investigate other associated production modes that might allow the use of the b pair decay mode of the Higgs.

$Ht\bar{t}$

The production of the Higgs boson by different mechanisms is shown in Fig. 1. Note that the largest production cross section is by way of gluons "fusing" into virtual top pairs which then form the Higgs. This mechanism overcomes the weak coupling of the Higgs to ordinary matter which is due to the fact that the Higgs couples to mass. For a 14 TeV center of mass energy, a 200 GeV Higgs is produced from sources in the proton which have momentum fraction ~ $\langle x \rangle \sim M/\sqrt{s} = 0.014$. At that x the dominant parton is the gluon. The virtual top pairs are the necessary intermediary, as the Higgs preferentially couples to mass.

Note that the diagrams for direct gg production and gg production in association with a top pair are very similar. All the vertices are the same, but in the former case the top is virtual, while in the latter the top appears in the final state. Obviously this process is not of much use at the Tevatron, but at the LHC, the penalty incurred from the source functions, $\langle x \rangle \sim (M + 2Mt)/\sqrt{s} = 0.038$ for a 200 GeV Higgs mass, is not too large. Viewing Fig.1, the reduction in cross section is ~ 1/20 to 1/50 for a Higgs mass from 100 to 200 GeV. The ratio at the Tevatron is approximately 200 for a 180 GeV Higgs mass, by comparison.

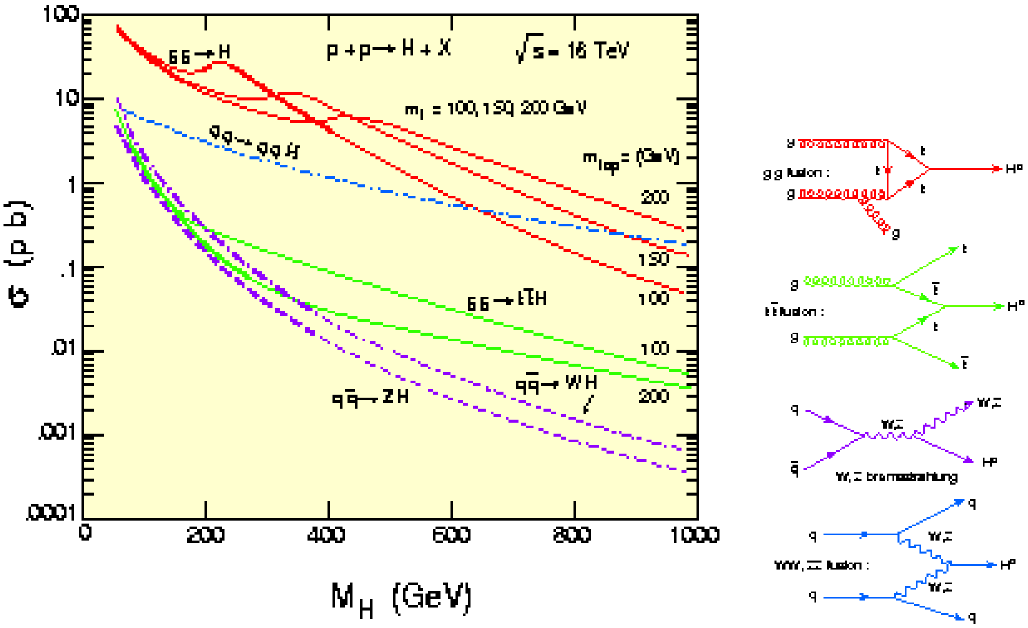

Figure 1: The cross section for Higgs production at the LHC as a function of the Higgs mass. The contributions of various distinct mechanisms making up the full cross section are also shown.

The production cross section was checked using the Monte Carlo program COMPHEP [3]. The Feynman diagrams for the partonic process gg → $t\bar{t}$ are shown in Fig.2.

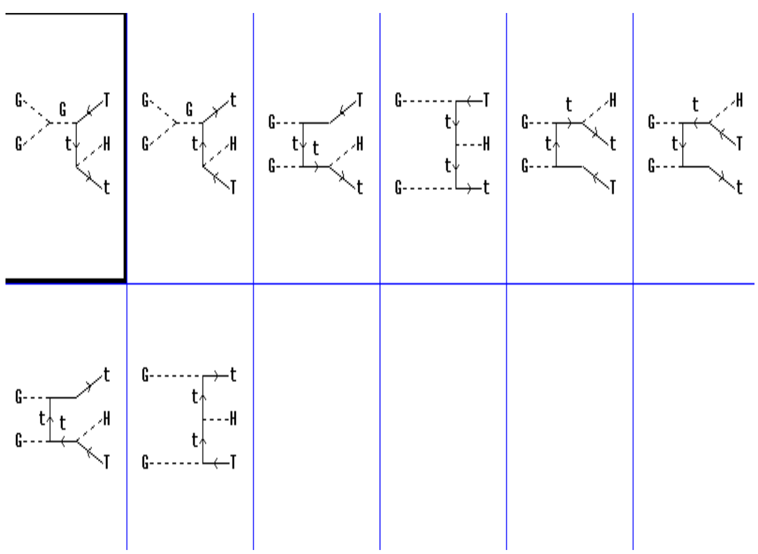

Figure 2: Feynman diagrams for gg → $t\bar{t}$ at lowest order.

Note that, from Fig. 2, the mass of the top pairs may be substantial in this reaction. The distribution of top pair masses is given in Fig. 3. Note the slow falloff; only ~ 7x down from the peak at 1 TeV, 100x down at 2 TeV.

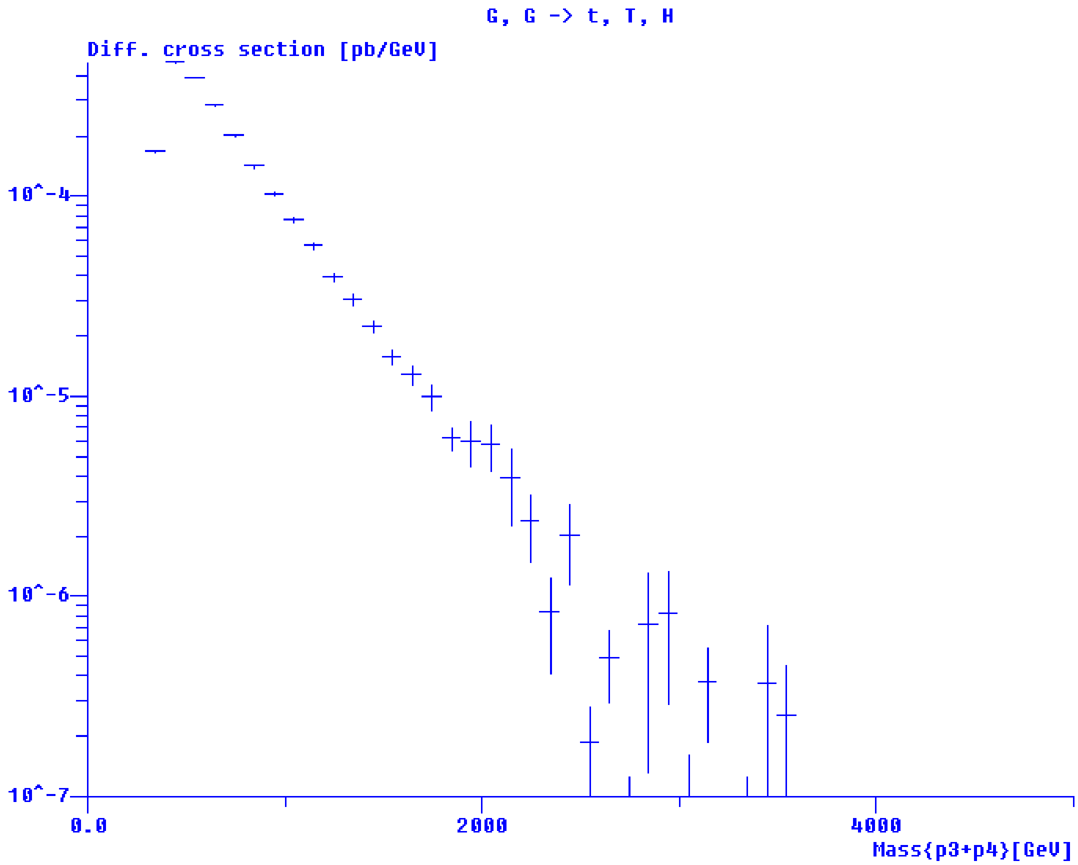

Figure 3: Distribution of top pair effective mass for associated Higgs production.

The cross section for associated production means that for 1/10 the design luminosity, with a 1/3 duty factor, there are 2500 $Ht\bar{t}$ produced in 1 year of startup LHC running. Assuming that the $b\bar{b}$ decay mode is attempted the branching fraction for the Higgs is very large. Assume that the decays t $\rightarrow$ Wb with W $\rightarrow$ $u\bar{d}$ are utilized, leading to branching fractions near one. The 8 jet final state has four jet mass constraints, 2 for W and 2 for t. Since there are 4 b jets in the final state, we assume that backgrounds without top pairs in the final state can be made a negligible background with the appropriate experimental cuts.

$\mathbf{b\bar{b}t\bar{t}}$

We assume that the dominant background is an irreducible QCD background leading to the identical non-resonant final state by means of gg production. A sample of the 35 diagrams which survive when intermediate W, γ, Z, and H are excluded is shown in Fig. 4.

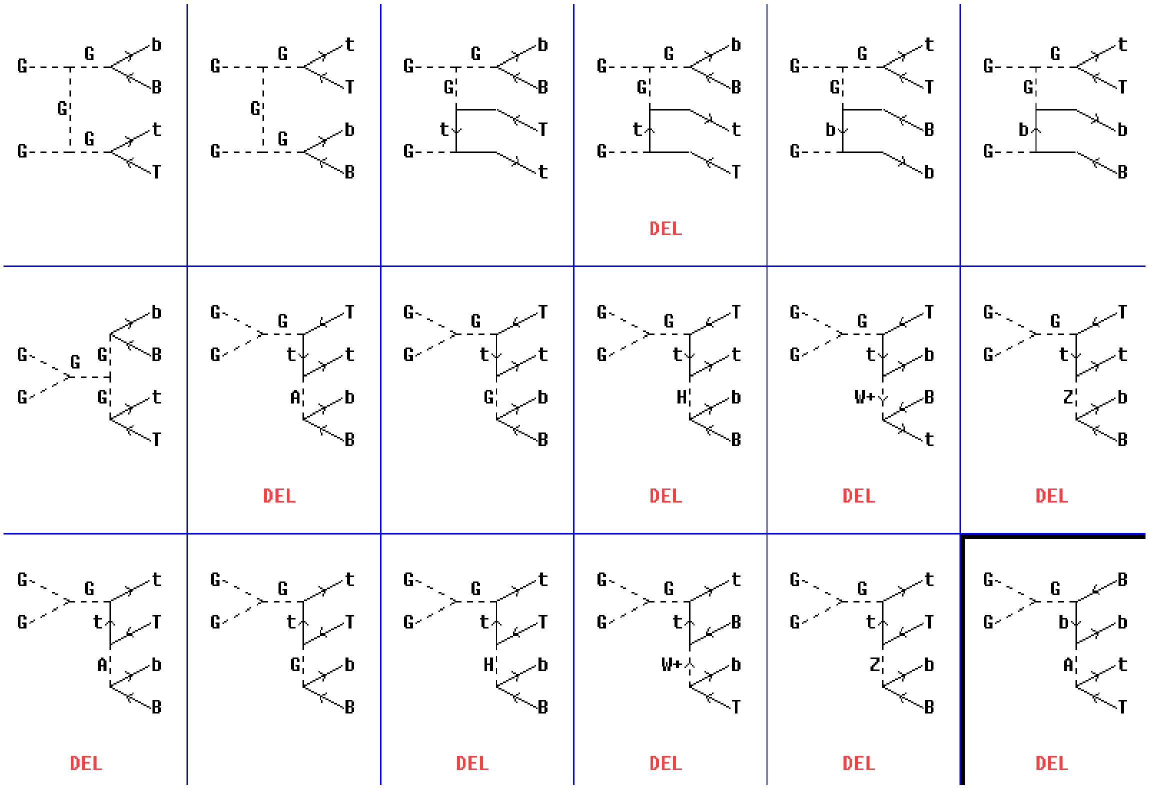

Figure 4: Feynman diagrams for the partonic process gg → $t\bar{t}b\bar{b}$. Note that all diagrams with intermediate bosons have been excluded.

The pp cross section was found to be 35 pb. This is about 100 times the resonant signal. The b pair effective mass distribution is shown in Fig. 5. Note that it is sharply peaked at the lowest pair mass, as might be expected from the diagrams shown in Fig. 4.

Note that the mass distribution has a value 0.008 pb/GeV at a pair mass of 180 GeV. In a 40 GeV mass window the cross section for this background is 0.32 pb. As the Higgs signal is expected to be fully contained in this window, a signal to noise of ~ 1:1 is expected. Note that this is rather more favorable than the signal to noise ratio available in the 2 photon final state.

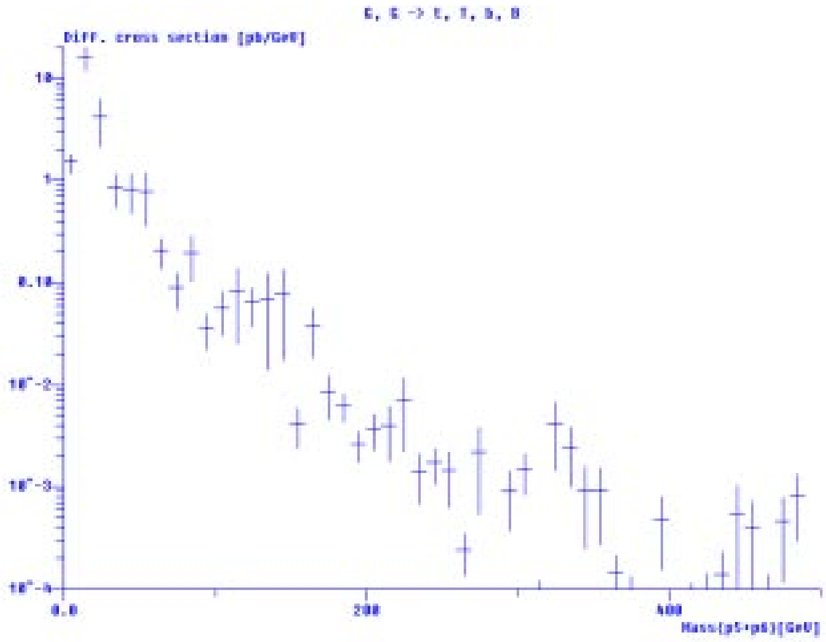

Figure 5: Effective mass of the b pairs in the reaction pp → $b\bar{b}t\bar{t}$ at 14 TeV cm energy.

The top pair mass is shown in Fig. 6. In comparison to the Higgs case, Fig. 3, the falloff with mass is somewhat steeper. At 1 TeV the falloff is a factor 20 from the peak, compared to a factor 7 for the signal case. Therefore, the signal to noise can be improved by placing a cut on the minimum top pair mass allowed.

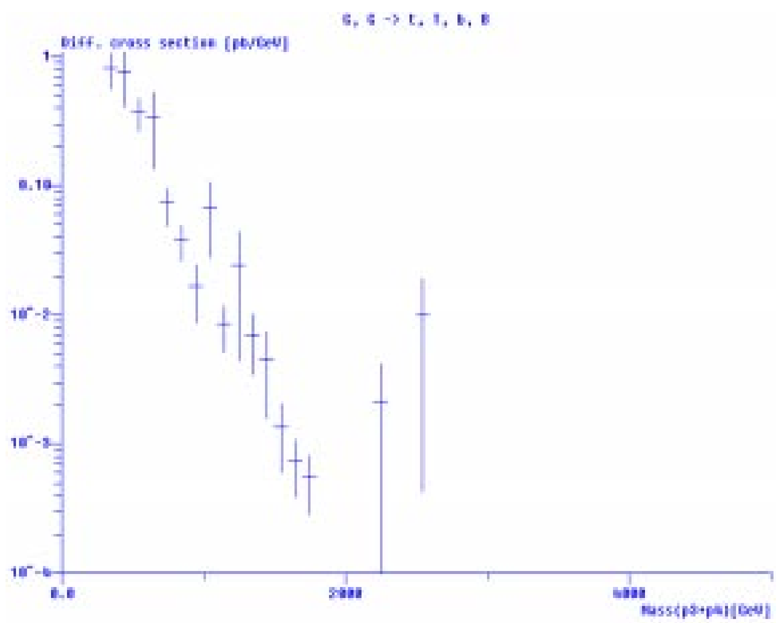

Figure 6: Effective mass of the top pair in the process pp → $b\bar{b}t\bar{t}$.

$ggt\bar{t}$

If the cleanliness of the b tagging is not rather high, then there is an additional background due to false tags. It is assumed that the top pairs will still be real because of the 4 mass cuts and 2 b jets that can be required. The mistag background is assumed to be due to the subprocess gg → $ggt\bar{t}$. There are 60 Feynman diagrams that survive even after excluding diagrams containing H, W, Z and γ. A sample of these diagrams is shown in Fig. 7.

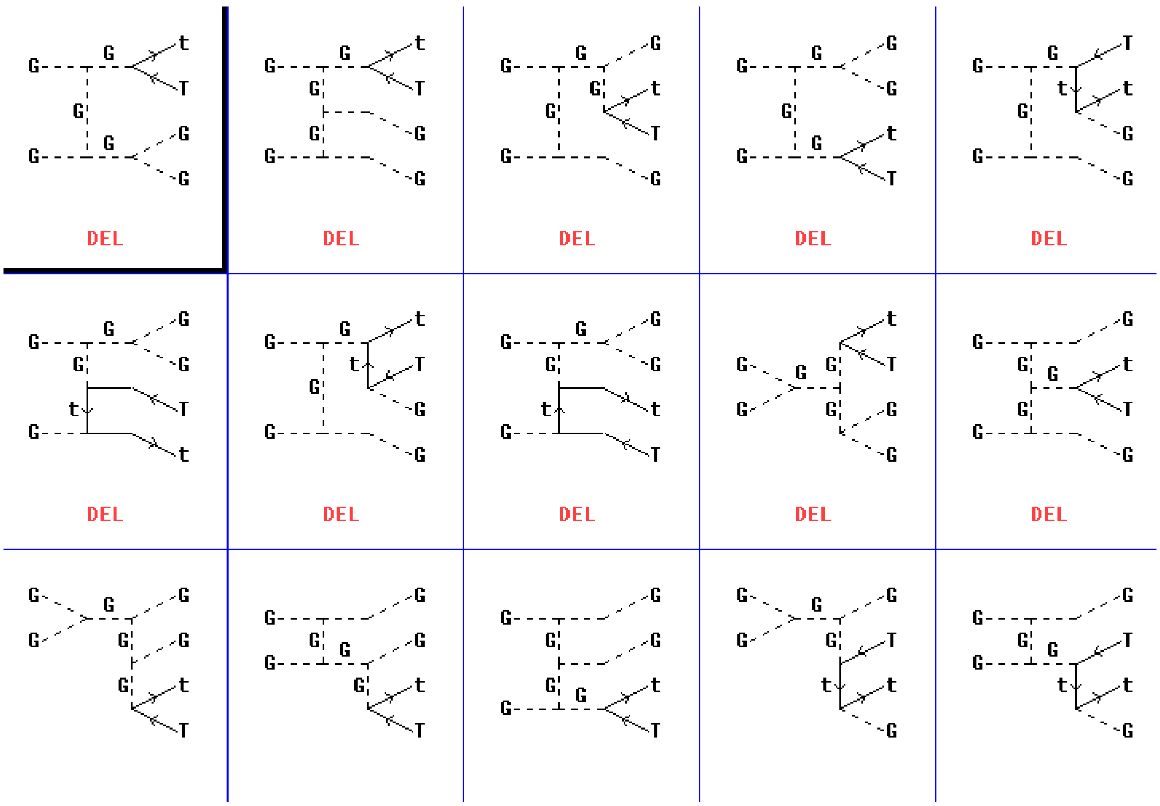

Figure 7: Feynman diagrams for the subprocess gg → $ggt\bar{t}$.

The cross section for the pp process at 14 TeV is about 1000 pb. The mass distribution of the b pairs is less sharply peaked to low pair masses than the $b\bar{b}t\bar{t}$ process. At 180 GeV gluon pair mass, the cross section is ~ 5 pb/GeV as seen in Fig.8.

Compared to the distribution in Fig.5, the gluon pairs have a cross section at 180 GeV pair mass that is 625 times larger than that for b pairs. Therefore, a rejection factor of 25 or larger is needed in order to have the background dominated by irreducible processes. The top mass distribution is shown in Fig. 9. Note that it falls very steeply. The distribution drops 4 orders in magnitude from the threshold to 1 TeV in top pair mass.

This steep dropoff with respect to the signal process can be used to improve the signal to noise as needed if the statistical error permits hard cuts.

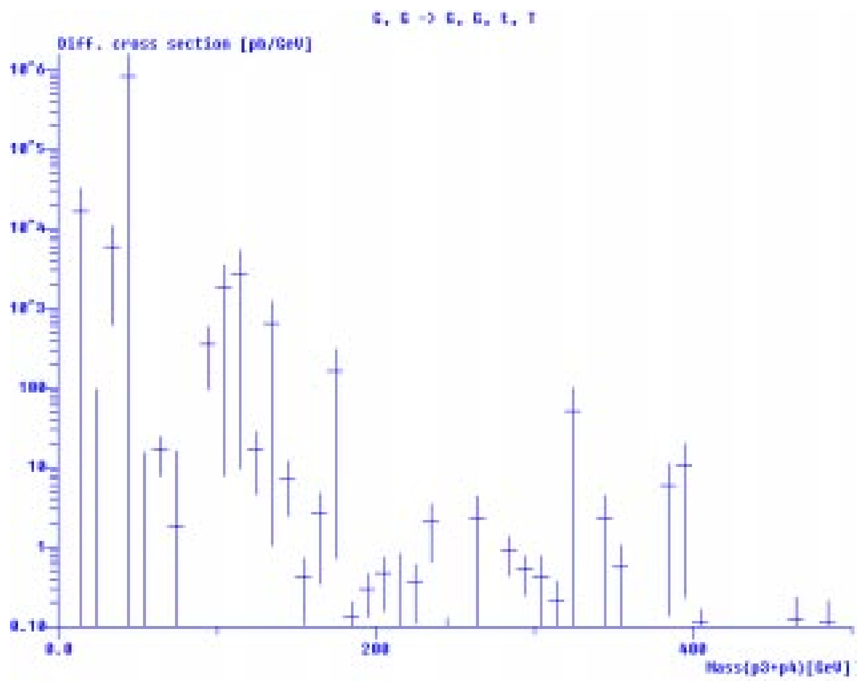

Figure 8: : Effective mass of the gg pair in the process pp → $gg t\bar{t}$.

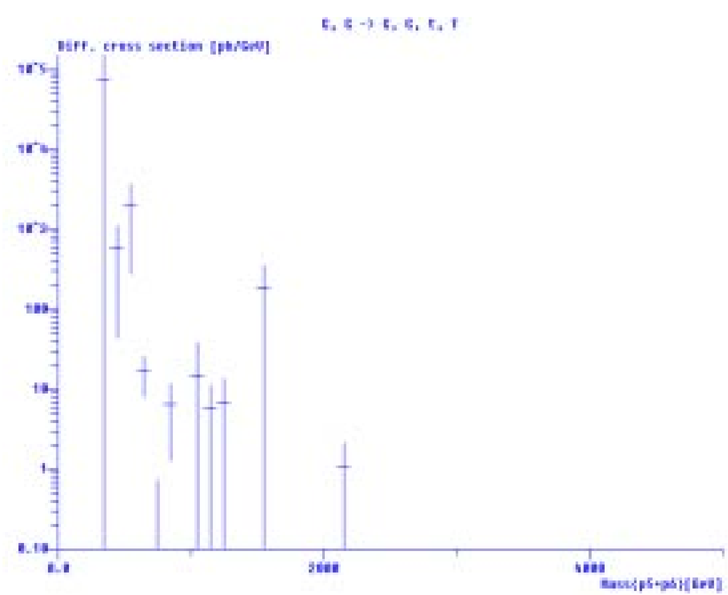

Figure 9: Effective mass of the top pair in the process gg → $gg t\bar{t}$.

The estimated tagging efficiency for b jets and the estimated mistagging rate is shown in Fig.10 for the CMS tracker [4]. For a 180 GeV Higgs, the b jets have a transverse energy

~ 90 GeV, which is well away from the efficiency rise at low Et. For a 60% b tagging efficiency, there is a 2% probability to assign a b tag to a g jet. The ratio of 30 is such that, if 2 b tags are required, the gluon rejection makes this background less than the irreducible $b\bar{b}t\bar{t}$ background.

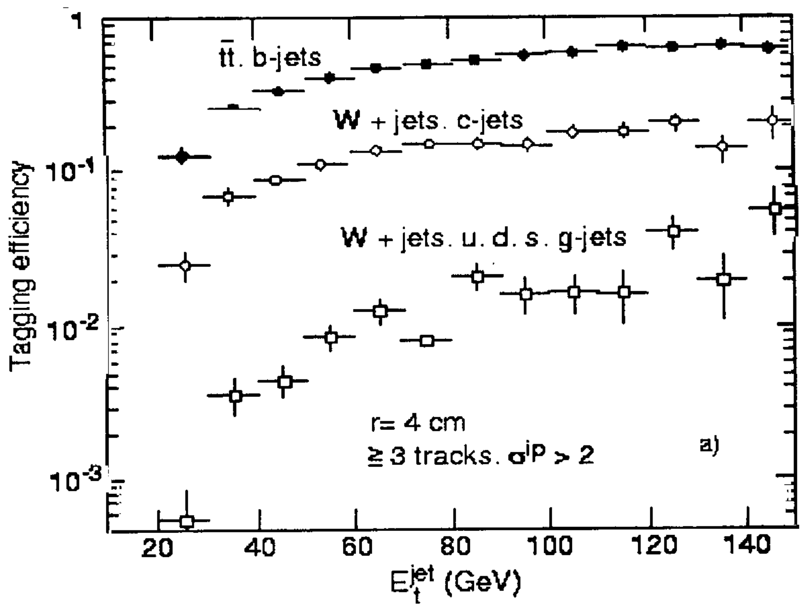

Figure 10: Tagging efficiency in the CMS detector for jets of light and heavy quarks.

Summary

The cross section for the production of a 180 GeV Higgs boson produced in association with top pairs has been evaluated to be 0.25 pb at 14 TeV cm energy. The irreducible background of b pairs + top pairs has a signal:noise ratio of ~ 1:1 at the Higgs mass, of 0.008 pb/GeV x 40 GeV = 0.32 pb. For an initial luminosity of 1/10 of design and a 1/3 duty factor $t\bar{t}H \rightarrow b\bar{b}$ events are produced in a single year. Ignoring the geometric reconstruction efficiencies and putting in only the b tagging efficiency of 0.6, there are 900 Higgs events on a background of ~ 900 +- 30 $b\bar{b}$ events. The background in the Higgs mass window due to $ggt\bar{t}$ events is estimated to be [5 pb/GeV]/[0.008 pb/GeV][0.02/0.6]^2. This leads to the estimate of an additional 625 mistagged events in the Higgs mass window, or 1525 +- 39 events.

Clearly the situation appears favorable enough that a complete simulation should be made. If the indications seen here remain valid, then a good alternative method to look for the b pair decay of a light Higgs using an all jet final state is available at the LHC. [5]

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