B-tagging of light Higgs boson in cascade decays of gluino

by
L. Didenko and B. Lund-Jensen

Royal Institute of Technology
Physics Department Frescati
Frescativägen 24
S-10405 Stockholm

Abstract

The possible signature from the cascade decays of gluino via light Higgs boson production at LHC energy is studied. The dominant decay channel $h^0 \rightarrow b\bar{b}$ is considered. The branching ratio of h^0 production reaches 50 % for some set of the SUSY parameters. It is shown that it is possible to extract signal $h^0 \rightarrow b\bar{b}$ from $t\bar{t}$ background after applying SUSY event cuts.

1 Introduction

The standard way to search for squark and gluino production is to find events with a large missing transverse energy (E_T^{mis}) and 2 or 4 jets. This signature is created when gluinos and squarks decay directly into the lightest neutralino: $\tilde{g} \to q + \bar{q} + \tilde{\chi}_1^0; \tilde{q} \to q + \tilde{\chi}_1^0$. At the LHC energy a mass region up to 1 TeV for squark and gluino is reachable. At the large mass values the branching ratios for direct decays are about 15% [1] and the cascade decays are dominant. In this case the gluino (or squark) decays into a heavier chargino or neutralino:

$$
\begin{array}{lrcl}
1. & \tilde{g} & \to & q + \bar{q} + \tilde{\chi}_i^0 \\
2. & \tilde{g} & \to & q + \bar{q'} + \tilde{\chi}_i^{\pm} \\
3. & \tilde{g} & \to & g + \tilde{\chi}_i^0
\end{array}
$$

The charginos and neutralinos in turn decay into lighter supersymmetrical particles and Z^0, $W^{\pm}$, H^0, $H^{\pm}$:

$$
\begin{array}{lrcl}
1. & \tilde{\chi}_i^0 & \to & \tilde{\chi}_k^0 + Z^0(H^0) \\
2. & \tilde{\chi}_i^0 & \to & \tilde{\chi}_k^{\pm} + W^{\mp}(H^{\mp})
\end{array}
$$

In this case the SUSY events have the following signature: softened E_T^{miss} distribution, large multiplicity of jets and isotropic topology. As a result of the chargino and neutralino decays the final state in general contains $Z^0, W^{\pm}, H^0, H^{\pm}$ particles. Thus another interesting signature could be to look for light Higgs boson (h^0) production in the final state [2].

In the Minimal Supersymmetric Standard Model (MSSM) the branching ratios for the different decay modes and mass values of chargino and neutralino depend on five basic parameters. The observation of the h^0 signal in SUSY events could be helpful in restricting the parameter space that is available.

The dominant decay channel for the light neutral Higgs boson h^0 is $h^0 \to b\bar{b}$ (about 90 %). This signal cannot be extracted in the standard model processes due to a large background of $pp \to t\bar{t} + X$ processes. In the SUSY scenario, however, event cuts give a good possibility to reduce the $t\bar{t}$ background sufficiently and to obtain a visible $h^0 \to b\bar{b}$ signal. This could be another way to discover the light Higgs boson.

In our previous Internal Note [3] we presented some results concerning detection of light Higgs boson in cascade decays of gluino. Now we have used more efficient SUSY event cuts and managed to get significant reduction of $t\bar{t}$ background.

2 The Detector Model and Simulation.

The simulation of SUSY events was done with the ISASUSY Monte Carlo [4], while for the $pp \to t\bar{t}$ background PYTHIA 5.5 was used. A generation of nonzero lifetimes for unstable particles and second vertex definition have been implemented in ISASUSY in order to simulate b-tagging.

For the tracking part of the detector a simplified model made by S.Gadomski and described in detail in [5] has been used. This model is based on a detector consisting of a Silicon Tracker/Vertex (SITV), an outer tracker and a forward tracker. Magnetic field, multiple scattering and detector response were taken into account to get the resolution for the impact parameter. The impact parameter resolution is given as a function of momentum and rapidity of charged particles and is valid for $|\eta| \leq 2$ and a momentum $P \geq 1$ GeV/c.

To simulate the calorimeter particle energies are deposited in a grid with energy smearing according to $\Delta E/E = 10\%/\sqrt{E} \oplus 1\%$ for the electromagnetic calorimeter and $\Delta E/E = 50\%/\sqrt{E} \oplus 2\%$ for the hadronic calorimeter. In both cases the granularity of $\Delta\eta \times \Delta\phi = 0.05 \times 0.05$ was taken. A fairly standard jet algorithm was then used to find the cell with the highest transverse energy, collect all energy in a cone around the cell and to define the jet energy and the jet axis. A cone size of $R = \sqrt{\Delta\eta^2 + \Delta\phi^2} = 0.3$ was chosen.

3 The Parameter Space

For the first approximation of the MSSM particle spectrum five basic parameters are needed : $M_{\tilde{g}}$ - the gluino mass; $M_{\tilde{q}}$ - the squark mass; $\tan\beta = v_2/v_1$, where $v_1 = \langle H_1^0 \rangle$ and $v_2 = \langle H_2^0 \rangle$ are the two vacuum expectation values for two Higgs doublets; μ - the Higgsino mixing mass parameter; M_{CH} - the mass of the charged Higgs boson (or any other Higgs mass).

In this work the following parameter regions have been chosen:

$$\begin{array}{lll} 1.\ M_{\tilde{g}} & = & 300 - 1200 GeV; \\ 2.\ M_{\tilde{q}} & = & 2M_{\tilde{g}}; \\ 3.\ \tan\beta & = & 2, 10; \\ 4.\ \mu & = & -400 - 400 GeV; \\ 5.\ M_{CH} & = & 300 - 700 GeV. \end{array}$$

For this region of the parameters the mass of the h^0 boson is within the interval 74-89 GeV for $\tan\beta = 2$ and 104-116 GeV for $\tan\beta = 10$.

4 The Branching Ratios

The branching ratios (Br.R.), defined as the fraction of gluino pair production events with at least one h^0 boson, are presented in Fig 1 and 2. From these figures one can see that the Br.R. reaches 50% for large gluino mass $M_{\tilde{g}} > 500$ GeV, $\tan\beta = 2$ and some region of the μ parameter. These data are given for $M_{CH} = 300$ GeV, but there is no considerable change up to $M_{CH} = 700$ GeV. For $\tan\beta = 10$ the Br.R. are smaller than for $\tan\beta = 2$ except for the gluino mass $M_{\tilde{g}} = 1200$ GeV. Br.R. ≤ 1 % for all values of μ if $\tan\beta = 10$ and $M_{\tilde{g}} \leq 500$ GeV.

For futher simulations two sets of parameters have been chosen:

$$\begin{array}{llllll} 1. & M_{\tilde{g}} = 750GeV, & M_{\tilde{q}} = 2M_{\tilde{g}}, & \tan\beta = 2, & \mu = 300GeV, & M_{CH} = 300GeV; \\ 2. & M_{\tilde{g}} = 1000GeV, & M_{\tilde{q}} = 2M_{\tilde{g}}, & \tan\beta = 2, & \mu = -400GeV, & M_{CH} = 300GeV; \end{array}$$

In both cases the mass of the top quark is assumed to be 140 GeV. In case 1 the mass of the h^0 boson is equal to 84 GeV, while in the case 2 it is 87 GeV.

5 B-tagging

Several processes contribute to the b-jet production in SUSY events for this set of parameters:
1. h_0 decay;
2. first stage of the gluino decay;
3. first stage of the gluino decay into $t\bar{t}$ jets with the sequent decay $t\bar{t} \to W^+W^-b\bar{b}$;
4. $Z^0 \to b\bar{b}$ decay.

The contributions from these processes and mean values of the transverse momenta of the $b(\bar{b})$ jets for gluino masses $M_{\tilde{g}} = 750$ GeV and $M_{\tilde{g}} = 1000$ GeV are given in Table 1. One can see that the contribution from h^0 decay to b-jet production is about 40% and the background from other processes is not small. However the mean value of the transverse momentum for the b-jets produced in the first stage of the gluino decay is 2-3 times higher than the ones from the h_0 decay. This gives a chance to reduce the combinatorial background from such processes.

The standard b-tagging procedure used is based on the detection of charged particles in a jet with an impact parameter greater than 200 μm and $P_T > 2$ GeV/c. If the jet has more than n_{cut} tracks satisfying these requirements it is tagged as a b-jet.

The efficiency of b-tagging and the mean multiplicity of real b-jets before and after b-tagging for SUSY events are given in Tables 2 and 3. To estimate the possible background from non-b jets the efficiency for c-jets to be tagged as b-jets and the mean multiplicity of c-jets were calculated and are also shown in Tables 2,3. One can see that the efficiency of b-tagging is 65% for real b-jets and 24% for c-jets. The multiplicity of c-jets after b-tagging is 0.36(0.38). This value is not small in comparison with the multiplicity of the b-jets produced from h^0 decay: $< n_b >_h = 0.46 < n_b >_{b-tag}$. In order to reduce non-b jets background we increased the required value of transverse momentum in the b-tagging criteria to $P_T \geq 4$ GeV/c. The efficiency of b-tagging for real b and c-jets in this case is given in the same tables.

For the b-tagging the jets were first reconstructed at particle level. The LUCLUS routine from PYTHIA have been adapted to the ISASUSY Monte Carlo to reconstruct the jets and to define the jet axis. The impact parameter smeared by the resolution function was then calculated for each particle in the jet. If some particle level jet passed the b-tagging criteria the direction of this jet was compared with the direction of jets found by clusterring in the calorimeter. The jet found in the calorimeter was then tagged as b-jet if the difference in direction was within the interval $\Delta\eta, \Delta\phi \leq 0.1$.

6 The SUSY event cuts

To reduce b-jets coming from $t\bar{t}$ events the following SUSY event cuts have been used:

1. $E_T^{mis} \geq 150GeV, \quad N_{jet}(E_T \geq 50GeV) \geq 6, \quad circularity \geq 0.2, \quad \sum E_{Ti} \geq 1000GeV;$
2. $E_T^{mis} \geq 150GeV, \quad N_{jet}(E_T \geq 50GeV) \geq 6, \quad circularity \geq 0.2, \quad \sum E_{Ti} \geq 1200GeV.$

where N_{jet} is the multiplicity of jets fullfilling the E_T cut and *circularity* is the sphericity in the transverse plane. The sum of transverse energy deposited in the cells $\sum E_{T_i}$ is made over all cells within $\mid \eta \mid \leq 3$. Cut 1 was applied to SUSY events with the gluino mass $M_{\tilde{g}} = 750$ GeV and cut 2 for events with $M_{\tilde{g}} = 1000$ GeV.

Since high P_T b-jets are more likely to come from $\tilde{g} \rightarrow b\bar{b} + X$ rather than from h^0 decay (see Table 1) they have been excluded to reduce combinatorial background. This procedure help us to reduce combinatorial background from $t\bar{t}$ events more because the mean multiplicity of jets in $t\bar{t}$ events is smaller than in SUSY events. In each event we excluded three jets with largest P_T found in the calorimeter and then selected b-jets according to the procedure described in section 5.

7 Results

The invariant mass distributions of all combenations of two b-tagged jets for the SUSY events with gluino masses 750 GeV and 1000 GeV and for $t\bar{t}$ background after cuts are shown in Fig.3-6. The total statistic for these plots corresponds to an integrated luminosity of $10^5 pb^{-1}$.

A clear signal from the light Higgs boson is observed in all plots above the $t\bar{t}$ events background as well as above the combinatorial background for SUSY events. For b-jets tagged within interval $\eta \leq 1.0$ combinatorial background becomes less.

The possible contribution from $Z^0 \rightarrow b\bar{b}$ production in the cascade decays of gluino calculated for the SUSY parameter space used (Sec.3) doesn't exceed 10%.

8 Conclusion

The signal from $h^0 \rightarrow b\bar{b}$ production in the cascade decays of gluino can be observed above $t\bar{t}$ background for some set of the SUSY parameters after applying SUSY event cuts. For the gluino mass $M_{\tilde{g}} = 750$ GeV the statistical level is sufficient to detect the signal at an integrated luminosity of $10^4 pb^{-1}$ while for a gluino mass equal to 1000 GeV an integrated luminosity of $10^5 pb^{-1}$ is required.

This means that a new way to discover the signal from the SUSY processes is possible. On the other hand this is also the way to observe the light Higgs boson production in the dominant decay channel $h^0 \rightarrow b\bar{b}$. Some further work using a more realistic detector simulation concerning tracking, magnetic field and pile-up effects should however be done. A detailed study of the parameter space for which it will be possible to observe signal is also required.

References

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[2] C.Fuglesang. EAGLE Internal Note PHYS-No-..., CERN, June, 1992.

[3] L.Didenko, C.Fuglesang and B.Lund-Jenson. ATLAS Internal Note PHYS-No-20, CERN, April, 1993.

[4] ISASUSY 1.0 written by H.Baer, F.E.Paige, S.D.Protopopescu and X.Tata.

[5] S.Gadomski,D.Froidevaux,M.Turala. EAGLE note,PHYSICS-NO-006,CERN, Geneva,1992.

9 Figure captions

Fig.1. Branching ratio for $h^0 \to b\bar{b}$ production in the cascade decays of gluino at $\tan\beta = 2$ and gluino mass $M_{\tilde{g}} = 300, 500, 750, 1000, 1200$ GeV.

Fig.2. Branching ratio for $h^0 \to b\bar{b}$ production in the cascade decays of gluino at $\tan\beta = 10$ and gluino mass $M_{\tilde{g}} = 750, 1000, 1200$ GeV.

Fig.3. The invariant mass distributions of the two b-tagged jets within $\eta \leq 2.0$ in SUSY and $t\bar{t}$ background events after applying the SUSY event cuts.
Non-shaded histogram - SUSY events with the gluino mass $M_{\tilde{g}} = 750$ GeV;
shaded histogram - $t\bar{t}$ background.

Fig.4. The same as Fig.3 but for b-jets tagged within interval $\eta \leq 1.0$.

Fig.5. The invariant mass distributions of two b-tagged jets within $\eta \leq 2.0$ in SUSY and $t\bar{t}$ events after SUSY events cuts.
Non-shaded histogram - SUSY events with the gluino mass $M_{\tilde{g}} = 1000$ GeV;
shaded histogram - $t\bar{t}$ background.

Fig.6. The same as Fig.5 but for b-jets tagged within interval $\eta \leq 1.0$.

Table 1.

$M_{\tilde{g}} = 750$ GeV			$M_{\tilde{g}} = 1000$ GeV	
Proceses	Contribution to b-jets	$\langle P_T \rangle_{b-jet}$, GeV/C	Contribution to b-jets	$\langle P_T \rangle_{b-jet}$ GeV/c
$h^0 \rightarrow b\bar{b}$	46%	69	42%	72
$\tilde{g} \rightarrow b\bar{b} + X$	30%	144	25%	196
$\tilde{g} \rightarrow t\bar{t} + X$	22%	73	30%	84
$Z^0 \rightarrow b\bar{b}$	1%		1.3%	

Table 2

$M_{\tilde{g}} = 750$ GeV		
Multiplicity of jets, efficiency of b-tag.	Imp.par.$\geq 0.2mm$, $P_T \geq 2$ GeV	Imp.par.$\geq 0.2mm$, $P_T \geq 4$ GeV
$\langle n_{b-jet} \rangle$	2.2	2.2
eff. of b-tag. for b-jets	65%	52%
$\langle n_b \rangle_{b-tag}$	1.41	1.1
$\langle n_{c-jet} \rangle$	1.5	1.5
eff. of b-tag. for c-jets	24%	14%
$\langle n_c \rangle_{b-tag}$	0.36	0.22

Table 3

$M_{\tilde{g}} = 1000$ GeV		
Multiplicity of jets, efficiency of b-tag.	Imp.par.$\geq 0.2mm$, $P_T \geq 2$ GeV	Imp.par.$\geq 0.2mm$, $P_T \geq 4$ GeV
$\langle n_{b-jet} \rangle$	2.9	2.9
eff. of b-tag. for b-jets	66 %	52%
$\langle n_b \rangle_{b-tag}$	1.9	1.5
$\langle n_{c-jet} \rangle$	1.75	1.75
eff. of b-tag. for c-jets	22 %	14 %
$\langle n_c \rangle_{b-tag}$	0.38	0.24

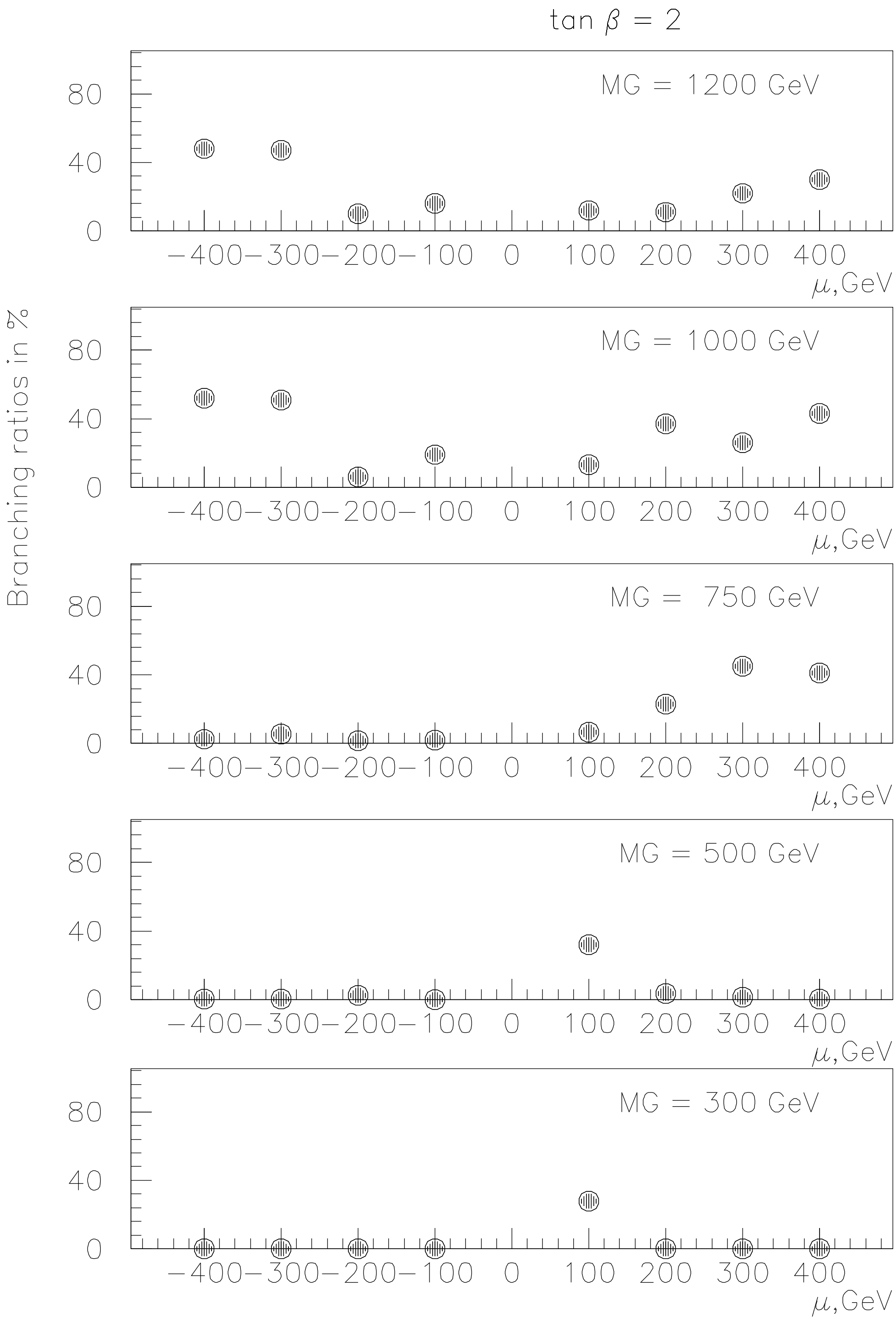

tan β = 2
MG = 1200 GeV
MG = 1000 GeV
MG = 750 GeV
MG = 500 GeV
MG = 300 GeV
Branching ratios in %
0
40
80
−400−300−200−100 0 100 200 300 400
μ,GeV

Figure 1:

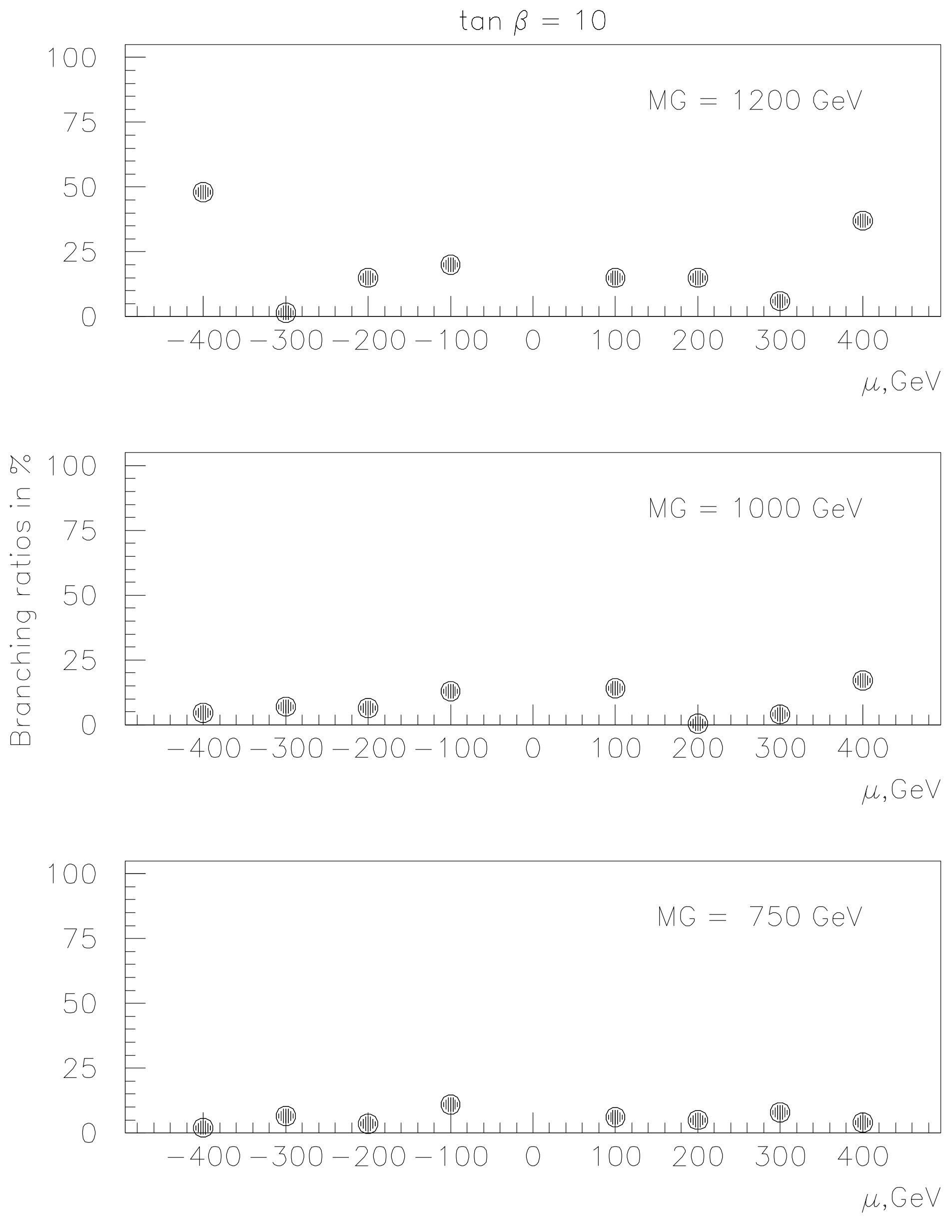

tan β = 10
MG = 1200 GeV
MG = 1000 GeV
MG = 750 GeV
Branching ratios in %
100
75
50
25
0
−400 −300 −200 −100 0 100 200 300 400
μ,GeV

Figure 2:

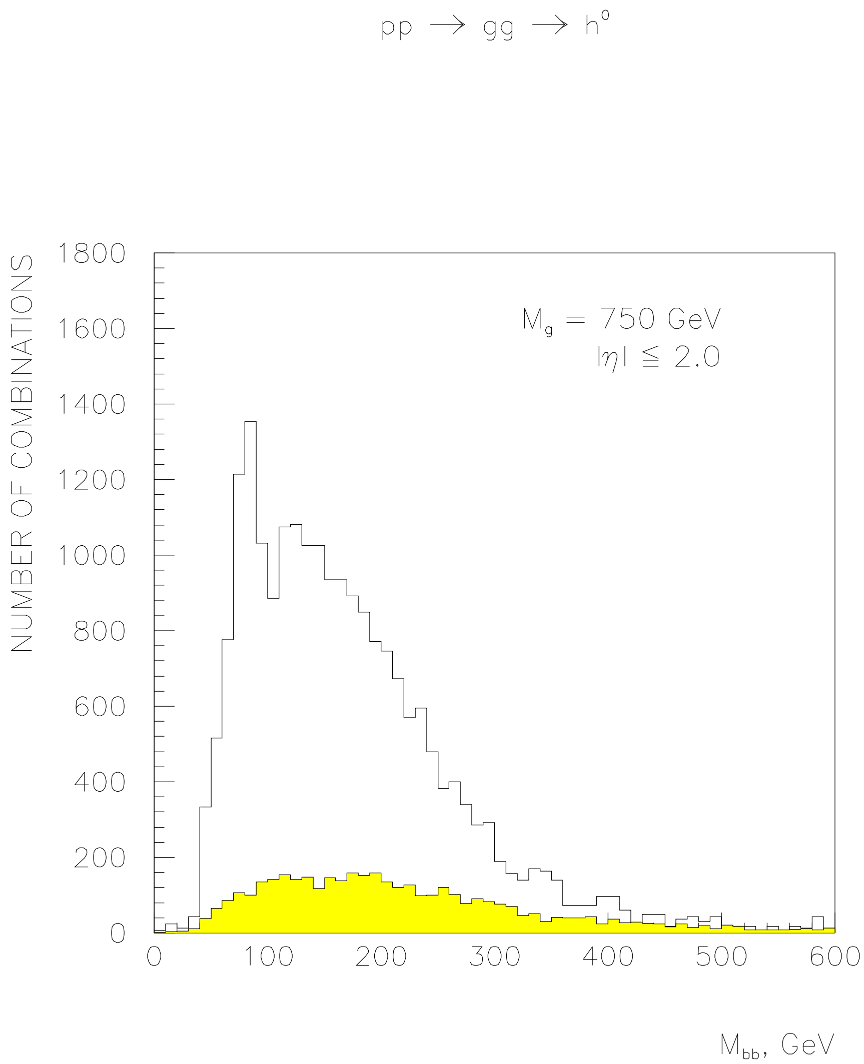
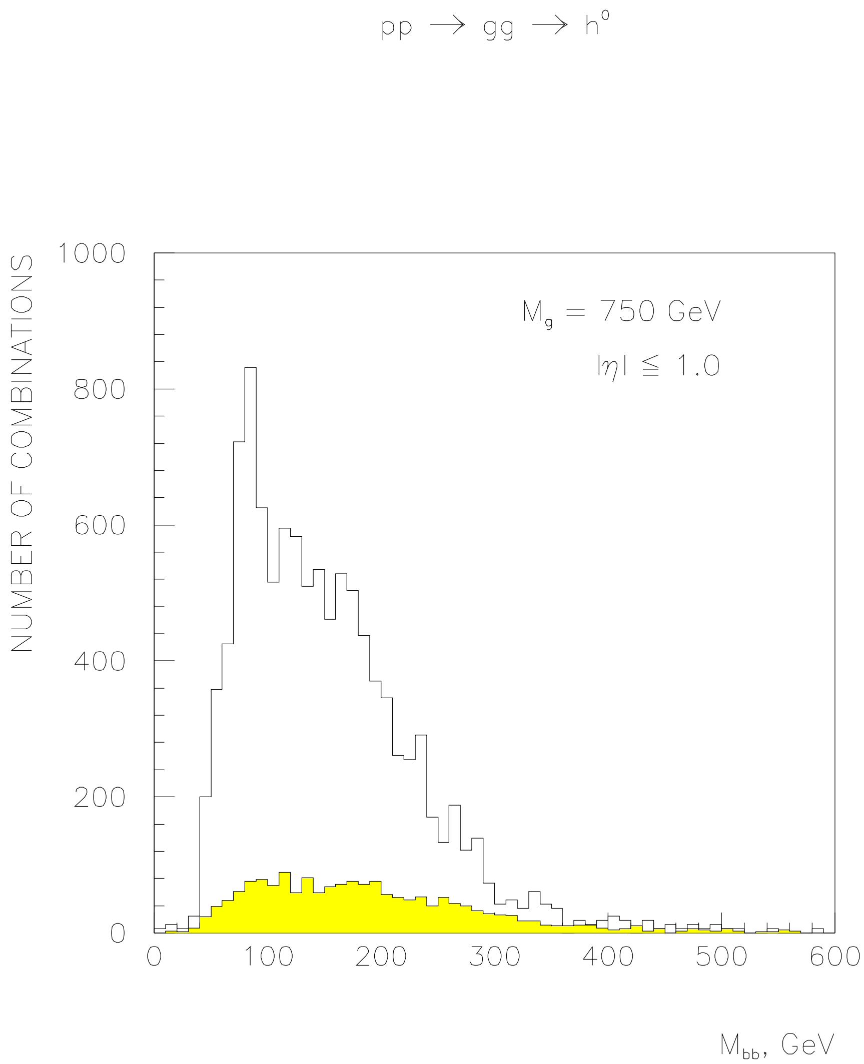

pp → gg → h°
NUMBER OF COMBINATIONS
1800
1600
1400
1200
1000
800
600
400
200
0
0
100
200
300
400
500
600
M_g = 750 GeV
|η| ≦ 2.0
M_bb, GeV

Figure 3:



pp → gg → h^{0}
NUMBER OF COMBINATIONS
M_{g} = 750 GeV
$|\eta| \leqq 1.0$
0
200
400
600
800
1000
0
100
200
300
400
500
600
M_{bb}, GeV

Figure 4:

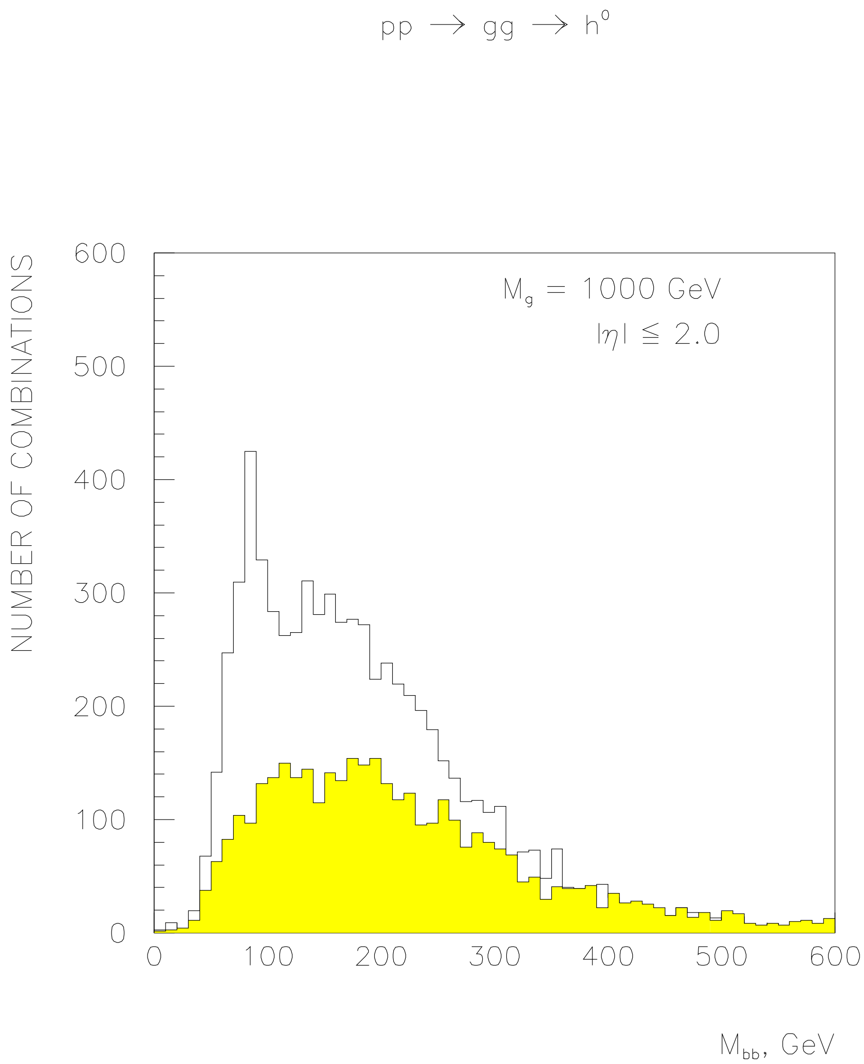

pp → gg → h^0
M_g = 1000 GeV
$|\eta| \leqq 2.0$
NUMBER OF COMBINATIONS
0
100
200
300
400
500
600
M_{bb}, GeV

Figure 5:

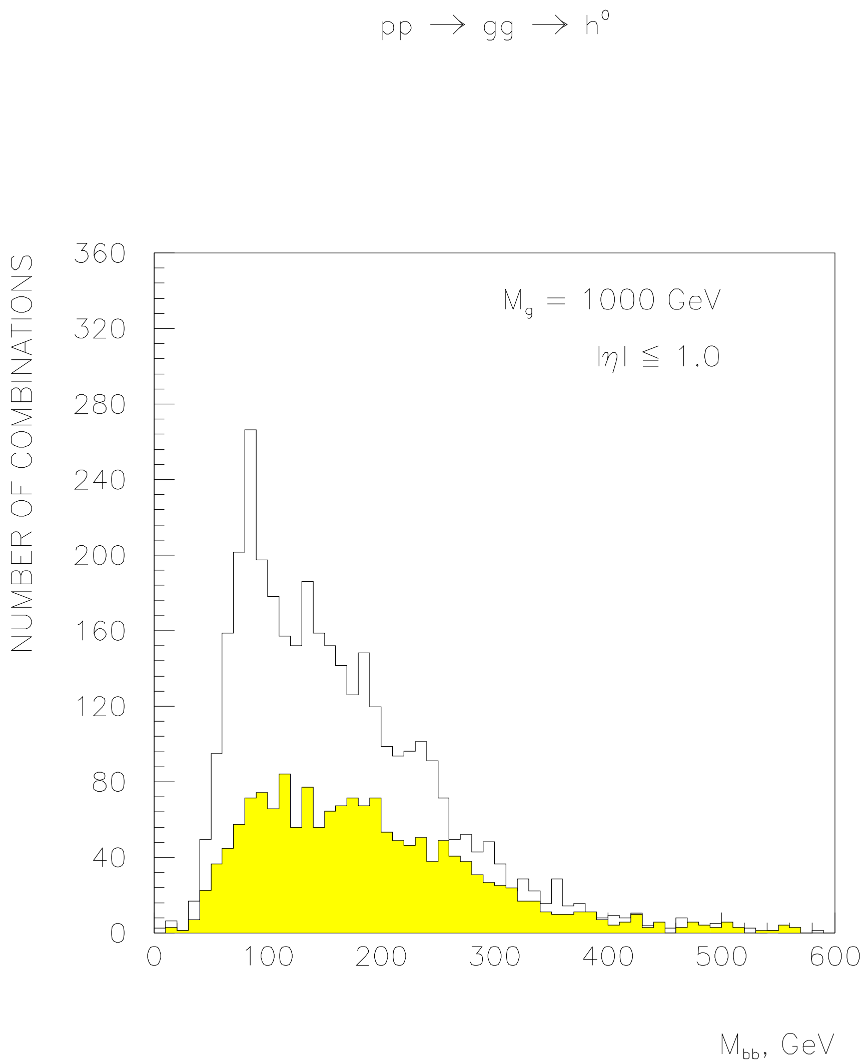

pp → gg → h°
NUMBER OF COMBINATIONS
M_g = 1000 GeV
|η| ≦ 1.0
0
40
80
120
160
200
240
280
320
360
0
100
200
300
400
500
600
M_bb, GeV

Figure 6: