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The Tau of Higgs

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Abstract

Experimental issues in the detection of light Higgs decay to two taus are discussed.

1. H→ ττ Why Bother?

The primary interest in this mode rests with the desire for sensitivity to light Higgs decays at the SSC. Phenomenologists argue that a light Higgs in the Standard Model (SM) does not co-exist with some larger unknown scale of new physics (i.e. GUT scale) without fine tuning of model parameters. Something like supersymmetry (SUSY) fixes this (and other problems which lie beyond the context of the SM).

We address some experimental issues of the Higgs sector in the Minimal Supersymmetric Standard Model (MSSM) at the SSC. The Higgs sector of the MSSM is more complicated than that of the SM[1,7]. Two Higgs doublets are required yielding two vacuum expectation values (v1, v2), three neutral Higgs bosons (A (pseudoscalar), h, and H) and two *charged* Higgs (H^+, H^-). The masses of h, H , H^+ and H^- can be given in terms of (m_A, tan β) where m_A is the pseudoscalar higgs mass and tan β = v2/v1. Figure 1 shows the 5 sigma significance contours typical for LHC experiments [4].

It is noteworthy that in MSSM, the ZZ decay modes are suppressed compared to SM. The pseudoscalar Higgs, A, doesn't even couple to ZZ. Even the 2 gamma decay mode is suppressed by 10 for some regions of (m_A, tan β). It has been pointed out that with the patchwork of the various Higgs decay modes, a hole for MSSM Higgs decays exists for hadron supercolliders[2]. The possibility of closing the hole using the two tau decay mode was raised in the LHC letters of intent[4,5,6]. Initial studies of H→ττ for the LHC indicate that this will be indeed challenging[3]. This will be looked at for the SSC in another study. We now revisit the issue and look at the possibility of associated production, tt + H decay to two taus. We look at the feasibility of background reduction using top jet tagging.

2. Physics Processes

The signal process of interest is given below

$$gg \to tt+H$$
$$\to \tau\tau$$
$$\to e + X\ ,\ \mu + X$$

the backgrounds considered are

$$gg \to t\,t$$
$$\to \tau\tau$$
$$\to e+X,\ \mu + X$$

$gg \rightarrow tt$

$\rightarrow e+X, \mu+X$

Other backgrounds like $Z \rightarrow \tau\tau$ are not included. The magnitude of the problem is given by the table below showing the raw cross sections for signal and the backgrounds:

Table 1 Cross Sections at SSC

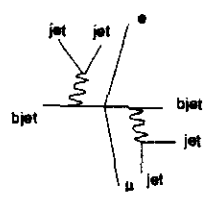
tt+H	$tt \rightarrow e+\mu$	$tt \rightarrow 2\tau \rightarrow e+\mu$
241 ev/yr	3.2e6	1.0e5

We generate signal and backgrounds using Pythia 5.6/Jetset 7.3[8]. The above rates are for SM Higgs m=100 GeV, m_{top} = 140 GeV, and include branching into e + μ final states. This corresponds roughly to a MSSM Higgs with tan $\beta = 1$ (rates are smaller for other tan β).

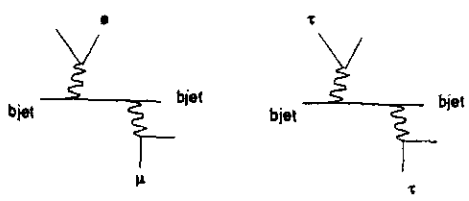
3. Kinematics and Reconstruction

We try to exploit the feature of the signal which has two τ's plus two top quarks which decay to W's and b jets. A background tt event would yield e and μ plus two b jets and nothing else (except for initial state radiation.)

the topology of the signal is given below:



the topology of the top background is:



We examine a number of observables listed below:

a. $\eta_{e,\mu} < 3.$
b. $pt_{e,\mu} > 10$ GeV
c. pt_{jet} for leading, 2nd and 3rd highestEt
d. pt for non b jets
e. $m_{jet\text{-}jet}$ for non b jets
f. $m_{\tau\tau}$ reconstructed

The assumptions are that we have perfect e, μ identification and perfect b jet tagging. A jet is reconstructed using a standard clustering algorithm where 4-vectors are binned in (η,ϕ) , seed towers ordered in Et, and any cluster within a cone of radius = 0.7 in (η,ϕ) is associated with a given jet.

We begin by finding appropriate η and pt cuts for the e and μ . The rapidity distributions of the leptons are shown in Fig.2. We take $\eta < 2.5$ as an appropriate cut. Fig. 3 shows the distribution of pt of the softest lepton. A cut of pt > 10 GeV is taken.

At this point, we wish to discuss the reconstruction of τ momenta even though two neutrinos are undetected. This is made possible if we measure the missing pt well and we know the directions that the two neutrinos are travelling. If we use the electron and muon directions as the tau directions (a good assumption for fast moving taus), then we can project the missing Et onto the electron and muon directions and fully reconstruct the tau momenta:

$$p_{\tau\upsilon 1}\,\hat{\tau}1 + p_{\tau\upsilon 2}\,\hat{\tau}2 = \vec{E}t \text{ missing}$$

A light Higgs is very narrow (<< 1GeV) so a very good measurement of the real missing Et is necessary. Fig. 4 shows the degradation of $m_{\tau\tau}$ due to mismeasurement of missing Et due to

beam hole effects. The energy resolution effects, where the particle momenta are smeared with a resolution or $0.01 + 0.15/\sqrt{E}$ for e and γs and $0.02 + 0.5/\sqrt{E}$ for hadrons, is also shown in Fig. 5. We will use an $\eta = 5$ beam hole for the remaining analysis.

4. Top Jets

As indicated earlier, the signal in principle should have 2 b jets and 4 jets (from 2 W) from the two top quarks in addition to the e, μ from the τ's from the Higgs decay. The tt background should have 2 bjets after the e $+\mu$ are removed. We will make the optimistic assumption that we can tag and remove *all* b jets from the event. We then try to look at the remaining non b jets for additional background rejection. Sources are from initial and final state parton radiation.

The first set of cuts involves looking at the Et of the highest, 2nd highest and 3rd highest Et non b jet with jet $\eta < 3$. Figs. 6-7 show the distributions where the $\eta < 2.5$ and pt> 10 GeV for the leptons have been previously applied. Based on the signal plot, we then impose an Et > 50, 30, 20 GeV cut on the leading 3 jets.

We now look at the various jet mass combinations shown in Figs 8-9. We see that the m_{j2j3} combination shows a clear W peak for the signal. If we cut generously for $60 < m_{j2j3} < 100$ GeV, we gain additional background rejection. Fig. 10 shows the reconstructed 2 τ mass after all cuts.

5. Summary and Other Caveats

The Table below shows the cumulative effects of the cuts discussed thus far.

tt + H

cut	generated	fraction	events/yr
raw	5000	1.00	241
$\eta_{e,\mu}$	3882	0.77	187
$pt_{e,\mu}$	1637	0.33	79
Et_j	1404	0.28	68
m_{j2j3}	689	0.14	33
$m_H$bin	422	0.08	20

$tt \rightarrow e + \mu$

cut	generated	fraction	events/yr
raw	50000	1.00	3.2e6
$\eta_{e,\mu}$	35379	0.71	2.3e6
$pt_{e,\mu}$	33411	0.66	2.1e6
Et_j	9987	0.20	6.4e5
m_{j2j3}	2579	0.05	1.7e5
$m_H$bin	36	7.2e-4	2.3e3

$tt \rightarrow \tau\tau \rightarrow e + \mu$

cut	generated	fraction	events/yr
raw	50001	1.0	1.0e5
$\eta_{e,\mu}$	35379	0.71	7.1e4
$pt_{e,\mu}$	11792	0.24	2.4e4
Et_j	3739	0.07	7.4e3
m_{j2j3}	947	0.02	1.9e3
$m_H$bin	42	8.4e-4	8.4e1

We see that in the $m_H$bin ($80 < m_H < 100$ GeV), the background still overwhelms the signal. Additional requirements, such as a top mass requirement of the W with a b jet, were not examined. The event rate already is low.

We could have used the $\tau \rightarrow 1$ and 3 prong decays and gained a large factor in the signal. but the background problems would still remain. In addition, a hadronic τ decay would present further problems with triggering.

6. Conclusions

Without overstating the point, if a light Higgs with SUSY makes more sense than without it, we face a more complicated Higgs sector than with the SM. The Higgs decay modes previously studied for the SM scenario are insufficient for ruling out all of MSSM Higgs parameter space for hadron colliders. The $\tau\tau$ mode was

thought to close this hole (at least the event rates times branching ratio indicate enough events). We considered a few backgrounds from top (there are more) and find them overwhelming after some obvious jet cuts and perfect b jet tagging. In addition, detector effects such as beam hole and resolution degrade one's ability to find a peak. We conclude that the "hole" in MSSM Higgs acceptance at the SSC is not filled by the two τ decay mode of the Higgs + tt.

References

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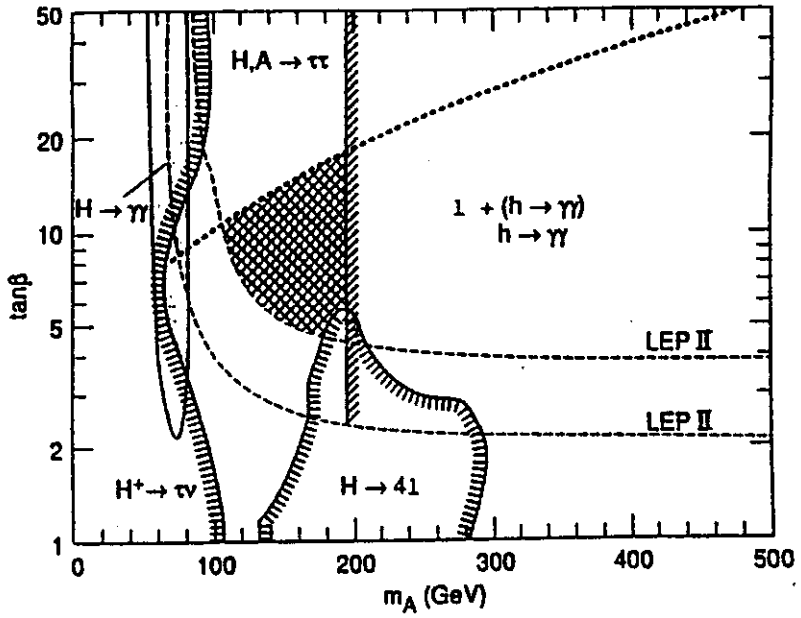


Fig 1 From ref [4]

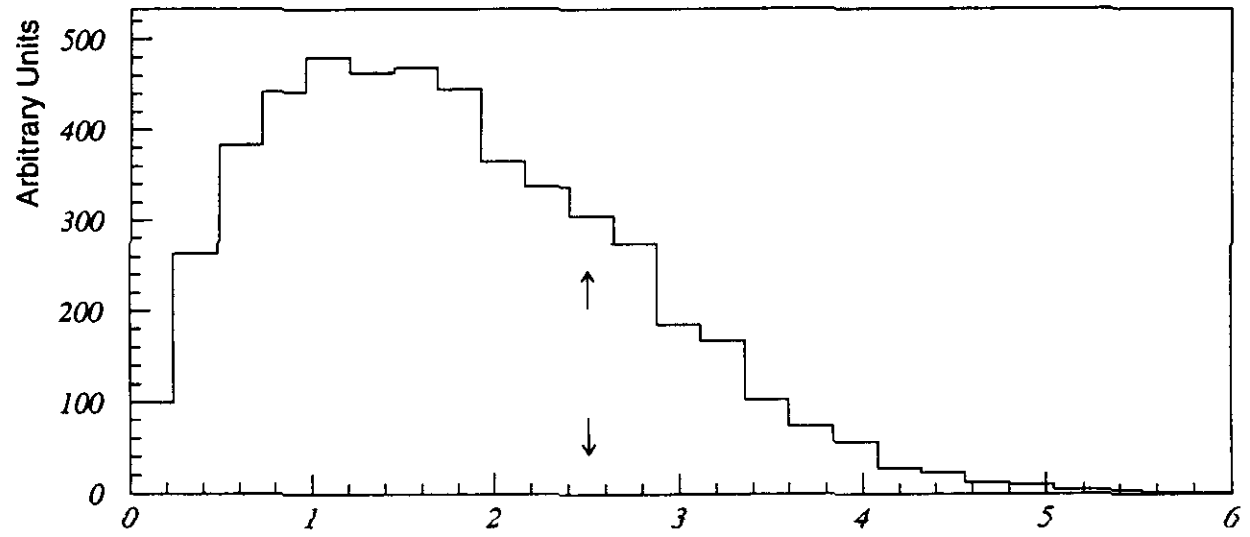
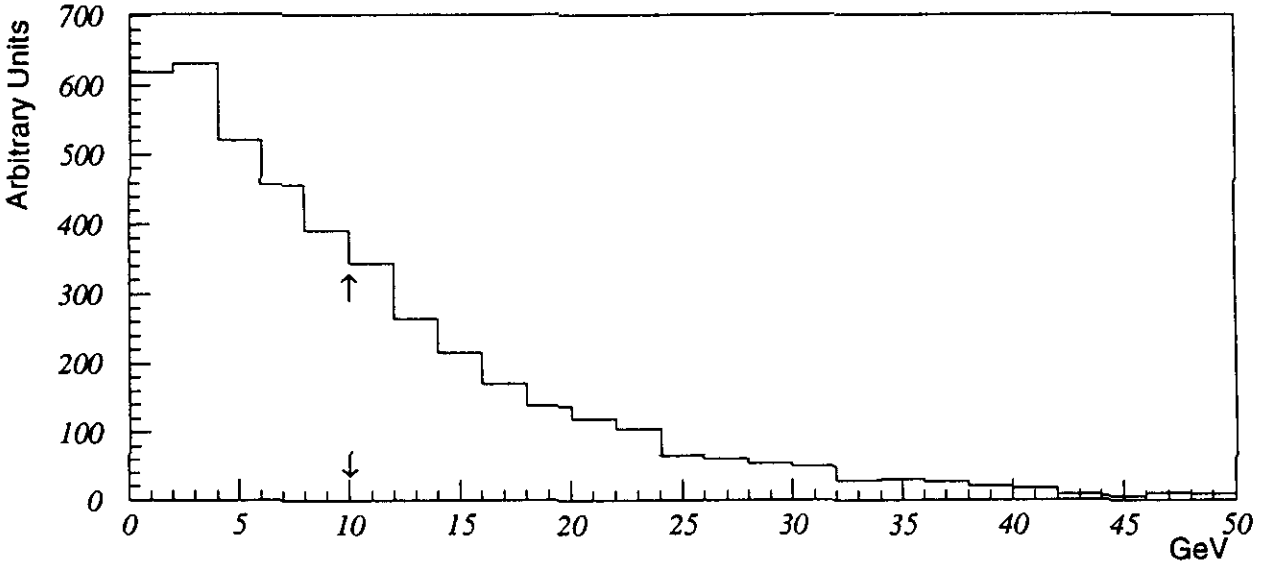


Fig 2

max(etareale,etarealmu)

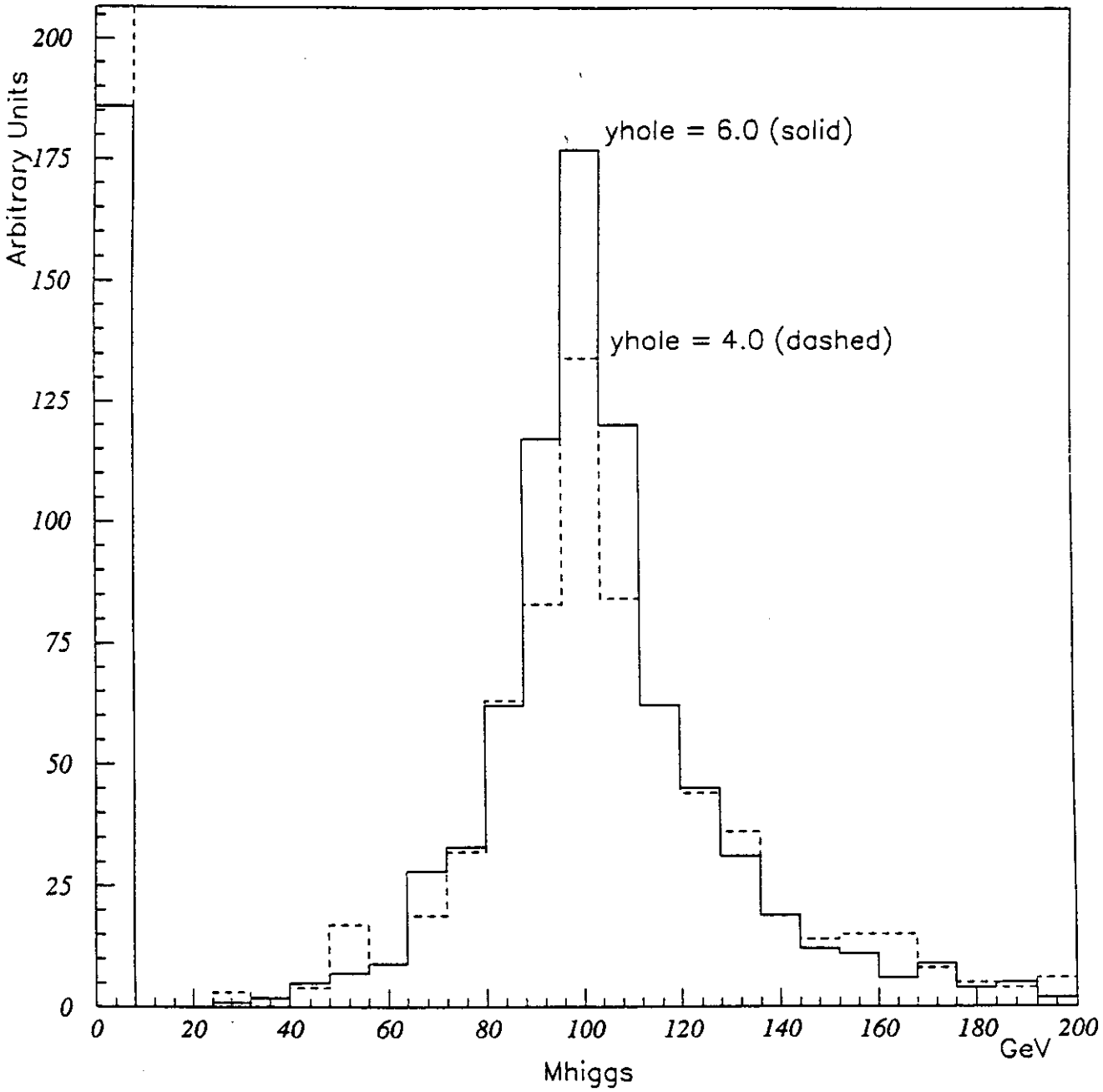


min(ptreale,ptrealmu)

Top: Pseudorapidity(η) distribution of most forward signal (ttH) lepton. The η=2.5 cut is indicated.

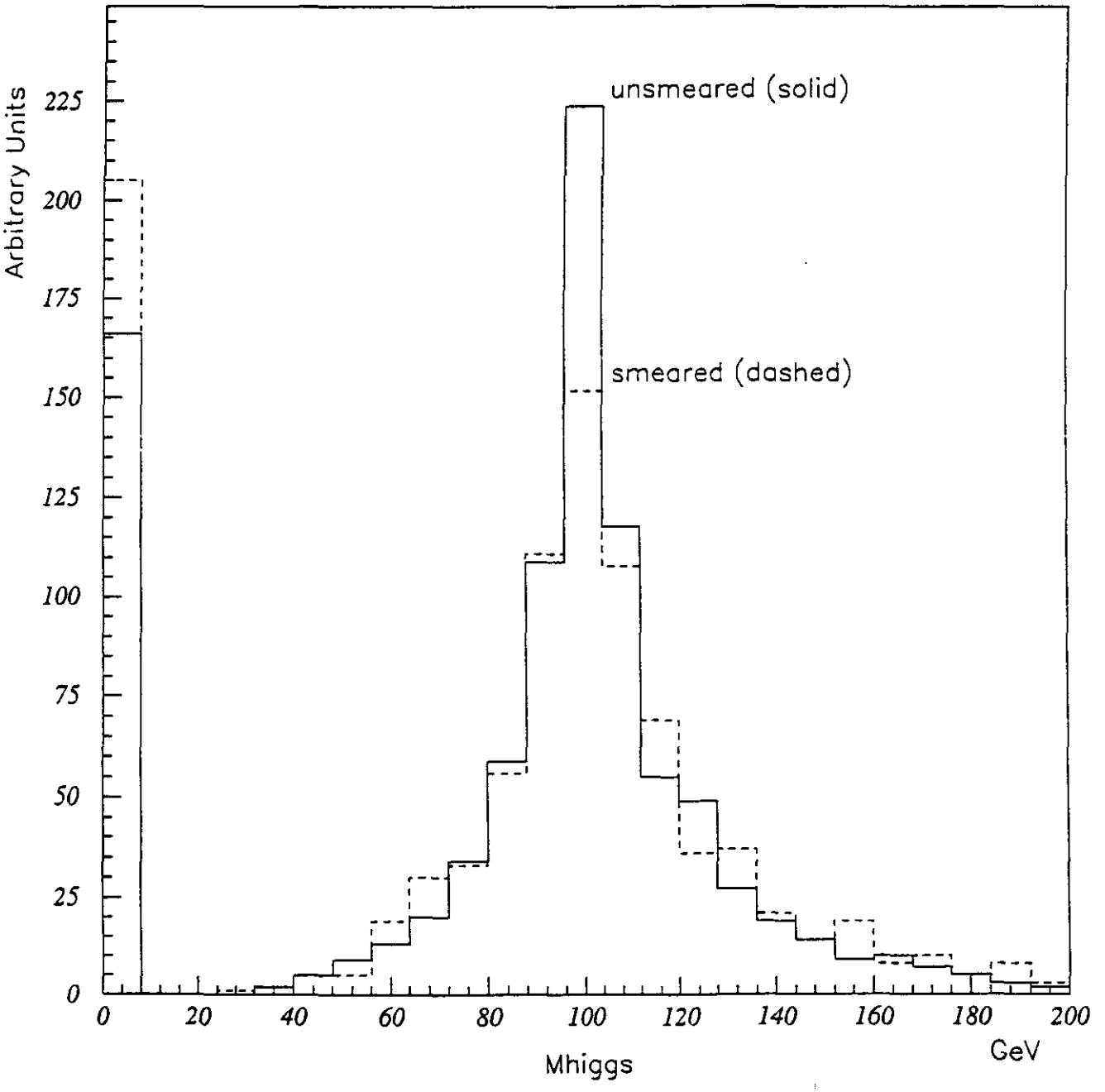
Bottom: Transverse momentum(pt) distribution of softest signal (ttH) lepton after the η<2.5 cut. The pt=10. threshold is indicated.

Fig 3



Beam Hole effects; Changing the beam hole size (yhole) degrades the Higgs mass peak.

Fig 4



Energy resolution effects: Smearing the measured particles' momenta degrades the Higgs mass peak.

Fig 5

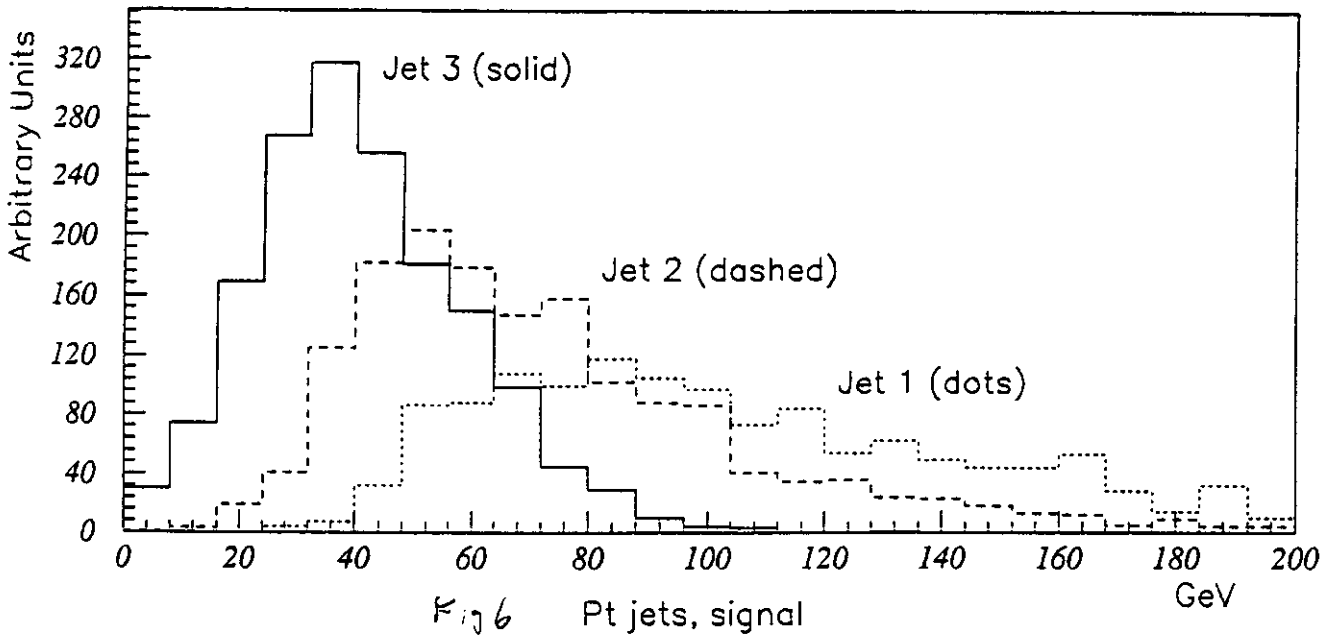


Fig 6 Pt jets, signal

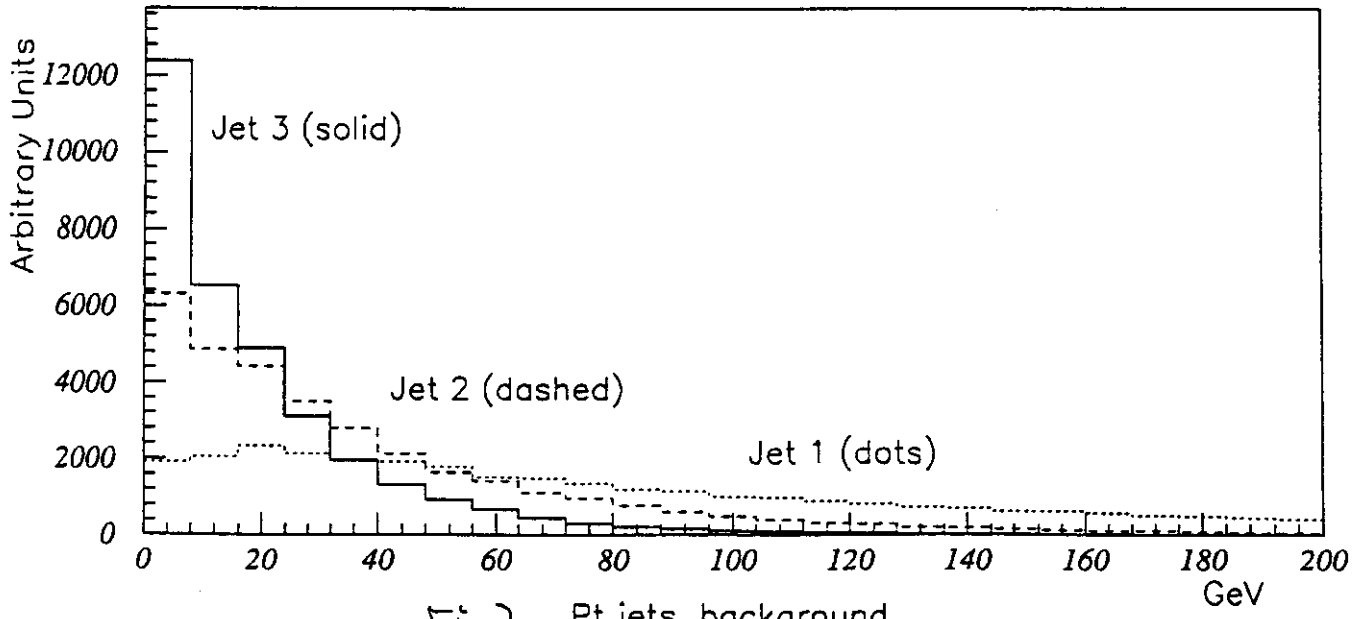


Fig 7 Pt jets, background

Transverse momenta of three highest-pt non-b jets for ttH signal (top) and tt→WWbb→e+μ+X background (bottom). We impose thresholds of 50, 30, and 20 GeV on jets 1,2, and 3, respectively.

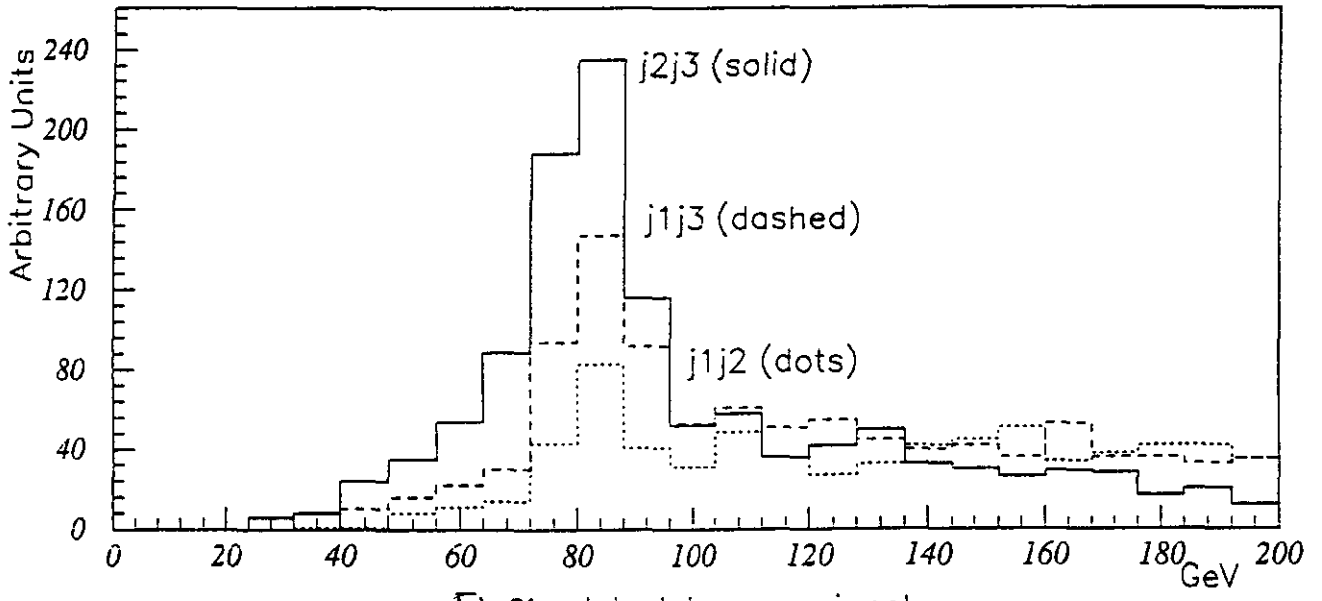


Fig 8 Jet–Jet mass, signal

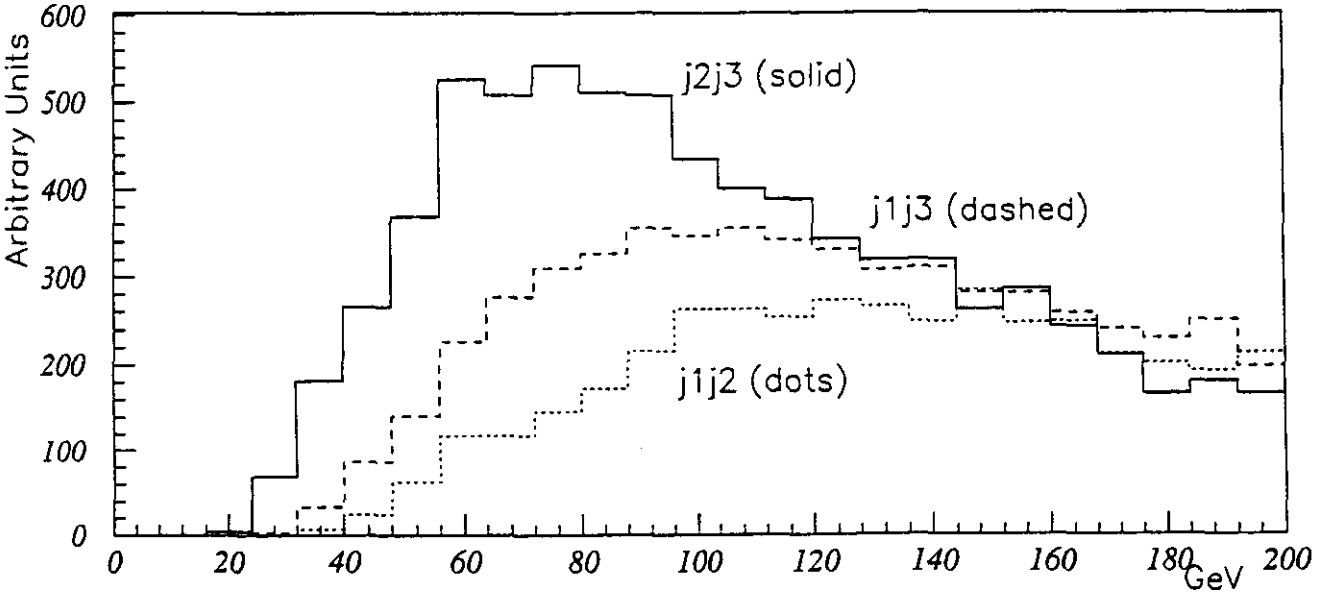


Fig 9 Jet–Jet mass, background

W Tagging: Two-jet reconstructed masses of three highest-pt non-b jets for ttH signal (top) and tt→WWbb→e++X background (bottom); the j2j3 mass shows the clearest peak. We impose a 60-100 GeV mass cut for Mj2j3.

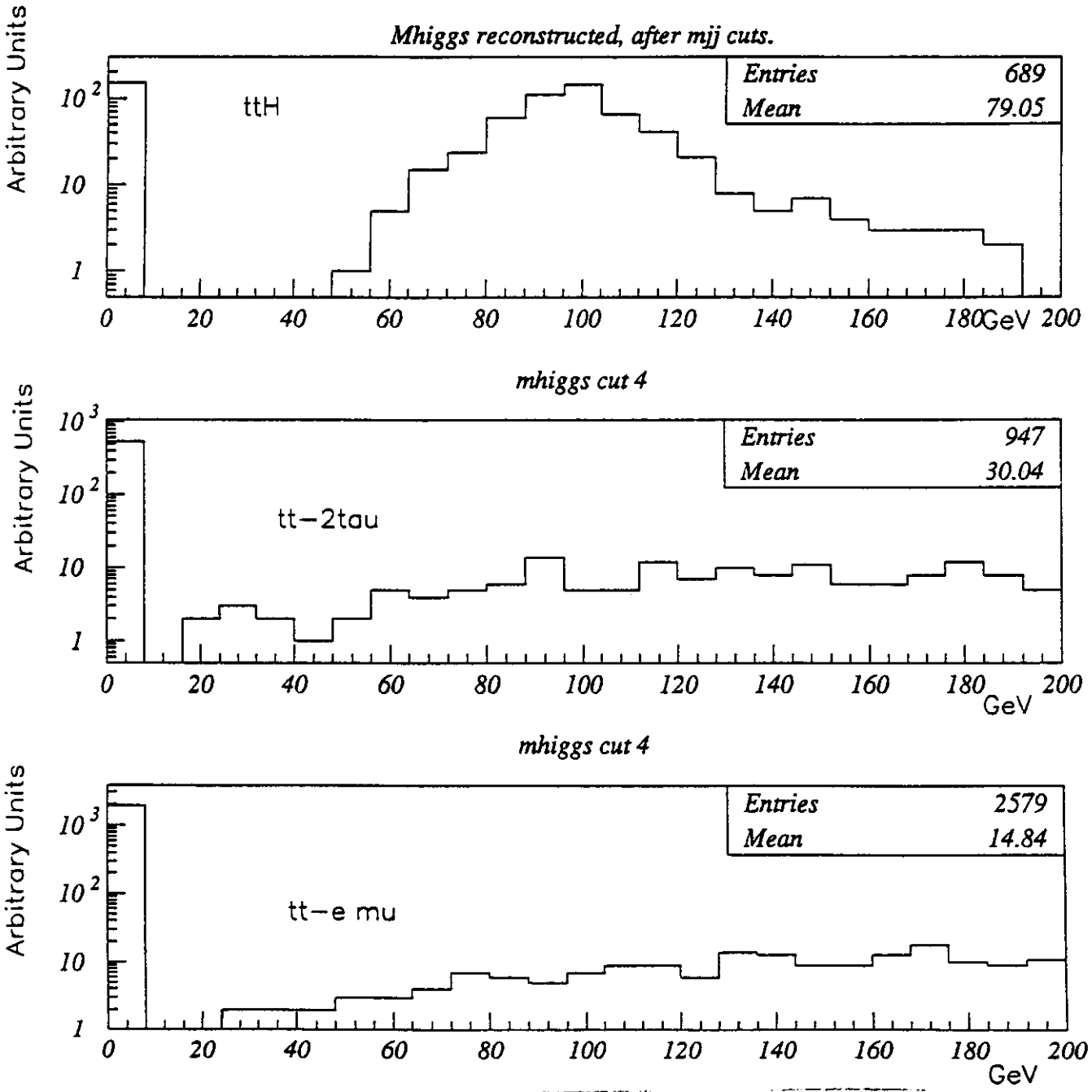


Fig 10

Mhiggs: These are plots of the reconstructed Higgs mass for ttH signal (top), tt-> 2tau(mid), and tt-> e mu (bottom) after implementation of the mjj and all prior cuts. The first bin (zeros) contains all entries for which the missing-pt projection fails, i.e. when it appears that a neutrino does not travel in the direction of a lepton.