Monte Carlo Studies of $p\bar{p} \to t\bar{t}H$ at CDF

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Outline:

- The Higgs Mechanism and EWSB
- Properties of the Higgs Boson
- The Channel $p\bar{p} \to t\bar{t}H$
- A look at $t\bar{t}H$ Simulation
- Summary and Outlook

Electroweak Symmetry Breaking and the Standard Model

The $SU(2)_L \times U(1)_Y$ Electroweak Lagrangian incorporates:

- Massless fermions
- Three massless $SU(2)$ and one massless $U(1)$ gauge bosons

EWSB introduced with 4 self-interacting scalar fields:

$\phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix}$ with vacuum expectation value $\phi_0 = \sqrt{\frac{1}{2}} \begin{pmatrix} 0 \\ v \end{pmatrix}$

Via the Higgs mechanism, 3 degrees of freedom from scalar fields give mass to $W^{\pm}$ and Z^0 bosons

Remaining degree of freedom: The Higgs Boson

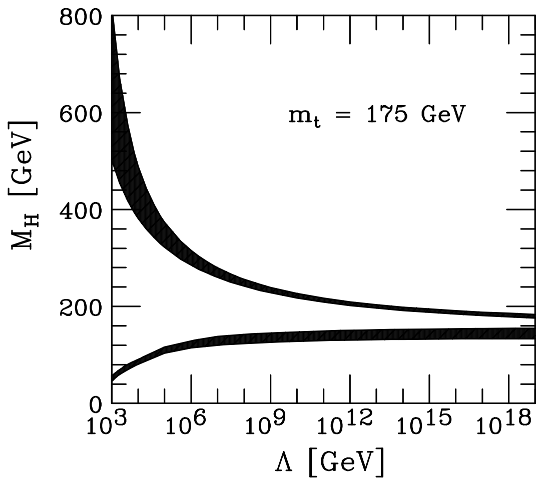
Fermions also gain mass through coupling with Higgs field.

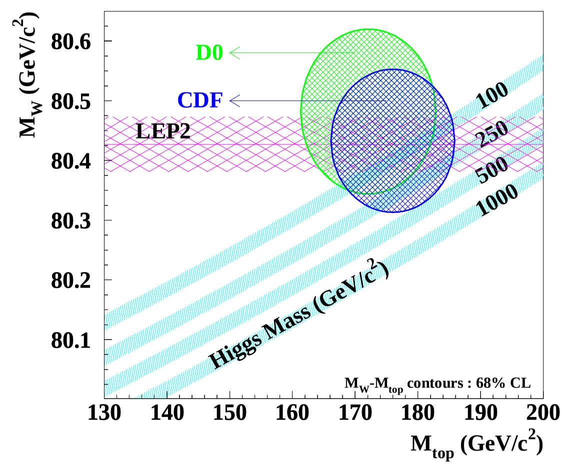
Higgs Mass is Sensitive to m_W, m_t and New Physics

No direct prediction of m_H in the Standard Model

Electroweak fits and sensitivity to new physics constrain m_H

(Direct searches also rule out $m_H < 114$ GeV at 95% C.L.)





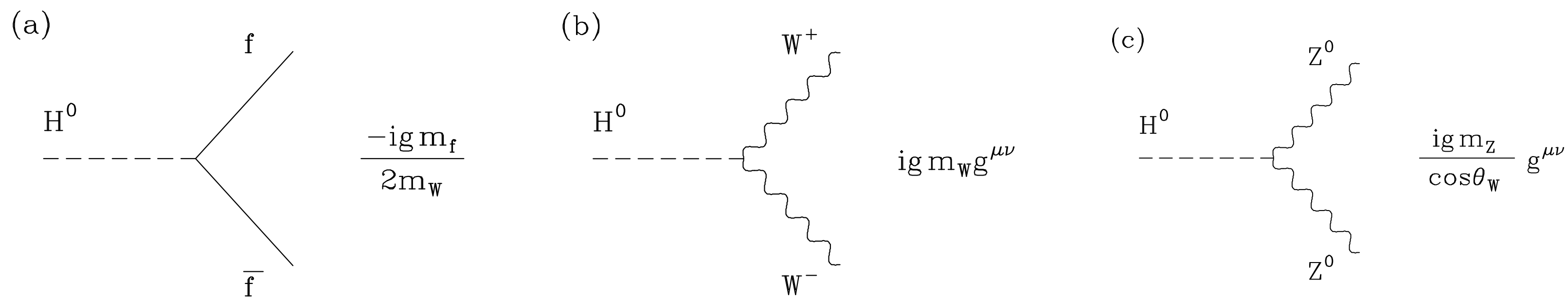
Upper bound on m_H: Higgs self-coupling becomes non-perturbative

Lower bound on m_H: Electroweak Minimum unstable

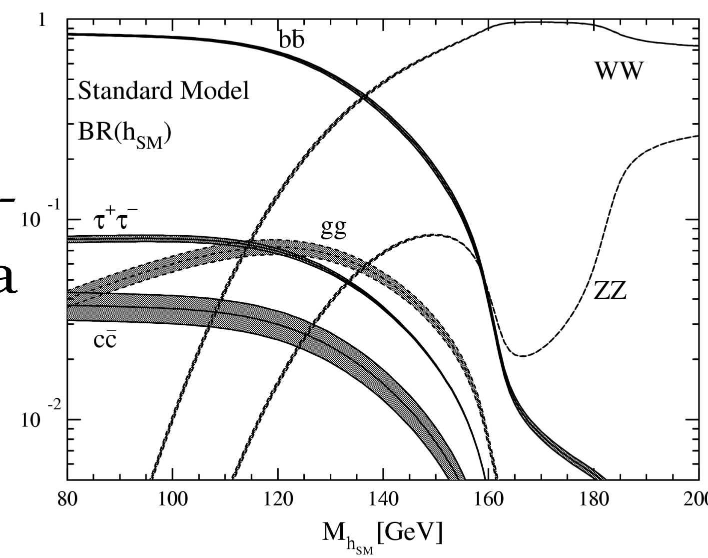
Constraints via m_W, m_t: Corrections to masses dependent logarithmically on m_H

Standard Model Higgs Couplings

Standard Model particles couple to Higgs with strength proportional to their mass

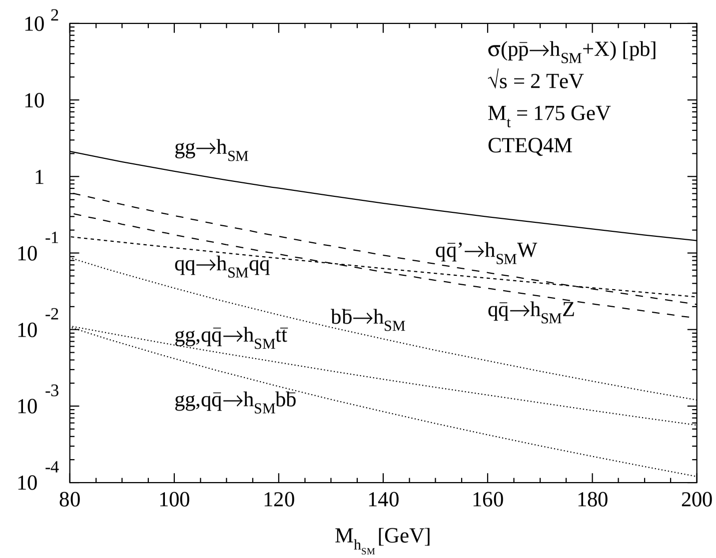


Branching ratios of Higgs decays can be predicted as a function of Higgs mass



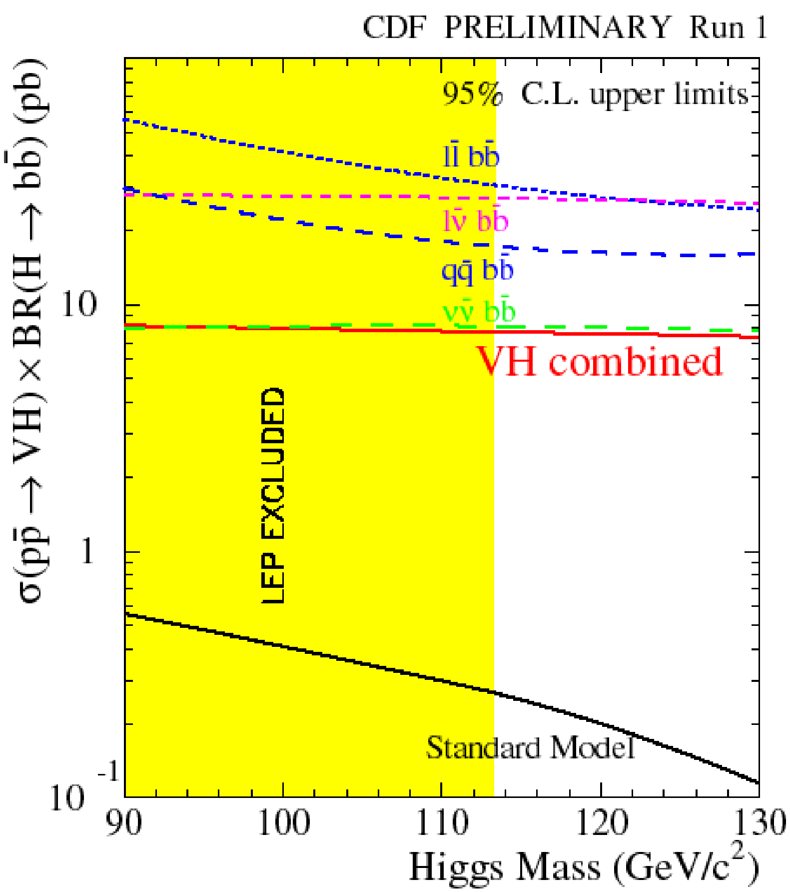
Higgs Production at the Tevatron

Production Cross Sections in $p\bar{p}$ Collisions at $E_{CM} = 2.0$ TeV



- Direct production $gg \to H \to b\bar{b}$ most copious channel, but swamped by QCD dijet background
- Promising channels involve associated production with $W^{\pm}, Z^0$
- The channel $t\bar{t}H$ worth investigating despite low cross section

Run I CDF Limit on Higgs Cross Section

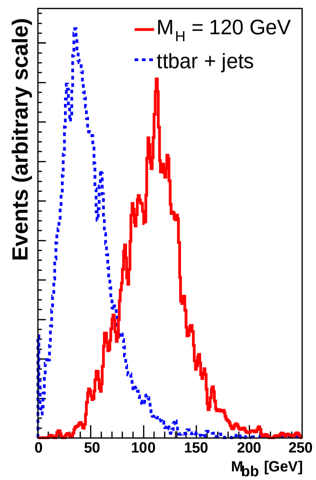


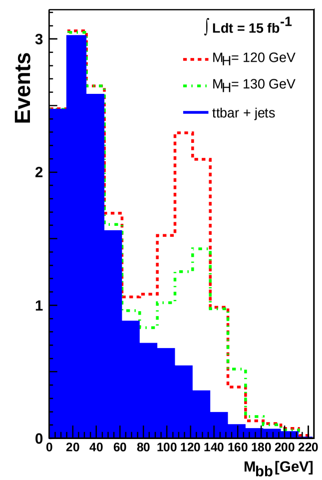
CDF Run I Limit

Contributions from
$p\bar{p} \to W^{\pm}H, Z^0H$

The Channel $p\bar{p} \to t\bar{t}H$

- First look at $t\bar{t}H$ for Tevatron energies in Goldstein *et al.* PRL **86** 1694 (2001).
- For $m_H < 135$ GeV, signature given by $W^+W^-b\bar{b}b\bar{b}$.





- Advantage: Distinctive signature allows for better S/B ratio
- Disadvantage: Cross section $\sigma_{t\bar{t}H} = 4.8$ fb for $m_H = 120$ GeV

Primary Backgrounds $p\bar{p} \to t\bar{t}H$

Process	Cross Section (fb)	Process	Cross Section (fb)
$t\bar{t} + jj$	1030	$t\bar{t} + jj$	1030
$t\bar{t} + b\bar{b}$	27	$t\bar{t} + W$	17
$t\bar{t} + Z$	9.9	$t\bar{t} + Z$	8.9
$WZ + jj$	300		

Monte Carlo Samples

Used CompHep V. 41.10 to generate 4000 events each:

- $t\bar{t}H$ for $m_H = 110, 115, 120, 125$ GeV
- $t\bar{t}$, $t\bar{t}Z$, $t\bar{t}b\bar{b}$, $t\bar{t}c\bar{c}$

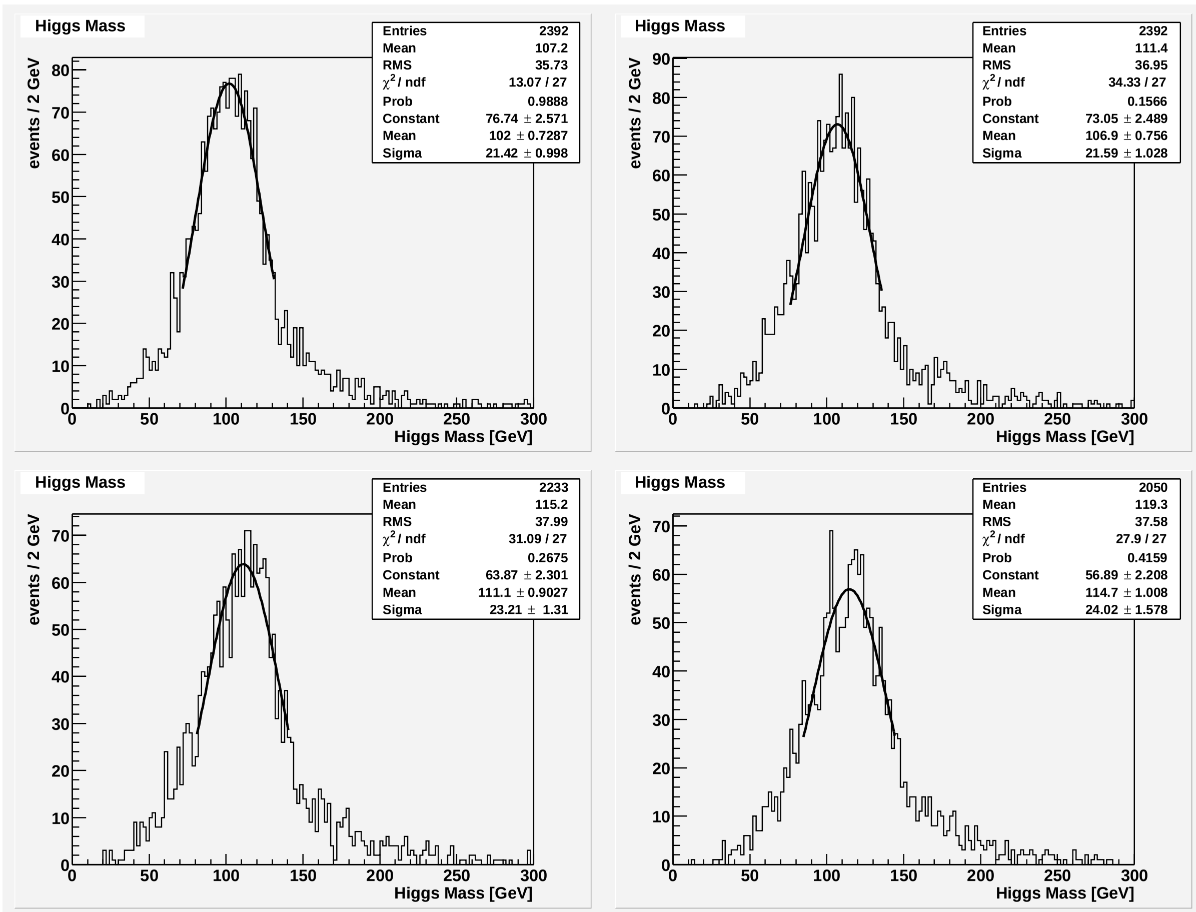
Fragmentation done by Pythia 6.2

CDF Simulation and Reconstruction using RunMC V.11

Ntuple created using TopFind

A Look at $b\bar{b}$ Invariant Mass Resolution

$H \rightarrow b\bar{b}$ Invariant Mass from Jet-Parton Matching



Preliminary Selection Criteria

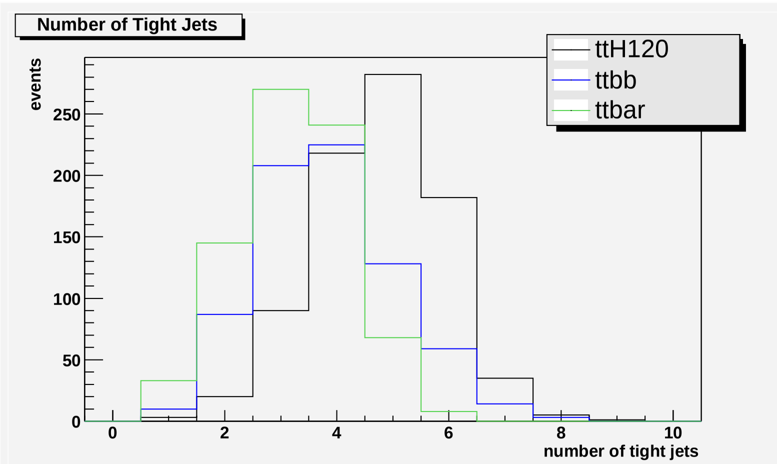
Start with some naïve criteria:

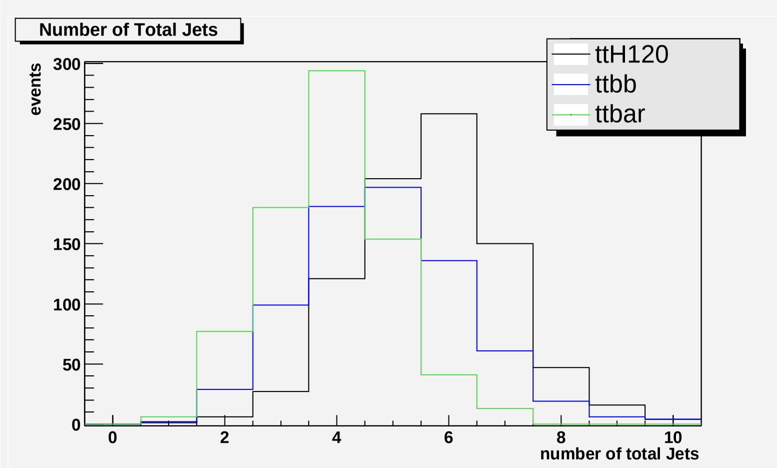
- 1 tight lepton
- $\not{E}_T > 15$ GeV
- # of tight jets between 5 and 8 or # of total jets between 6 and 9

Look at quantities such as:

- jet multiplicity
- total jet transverse energy J_T
- tag multiplicity
- $b\bar{b}$ invariant mass

Jet Multiplicity





Tight Jets and Total Jets in:

$t\bar{t}H, t\bar{t}b\bar{b}, t\bar{t}$

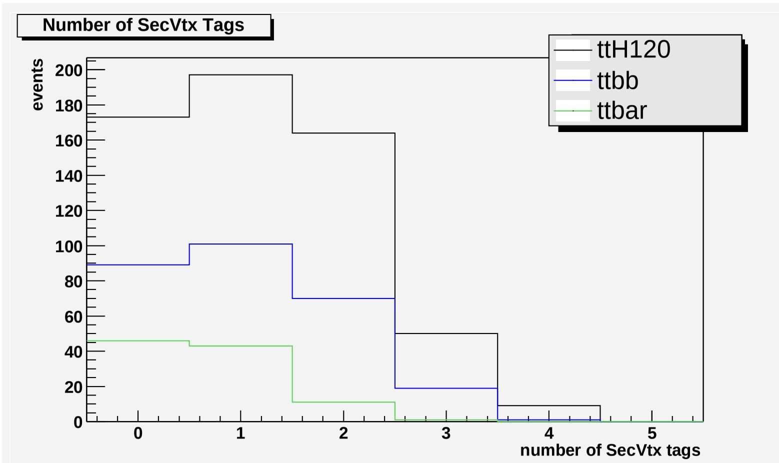
Require:

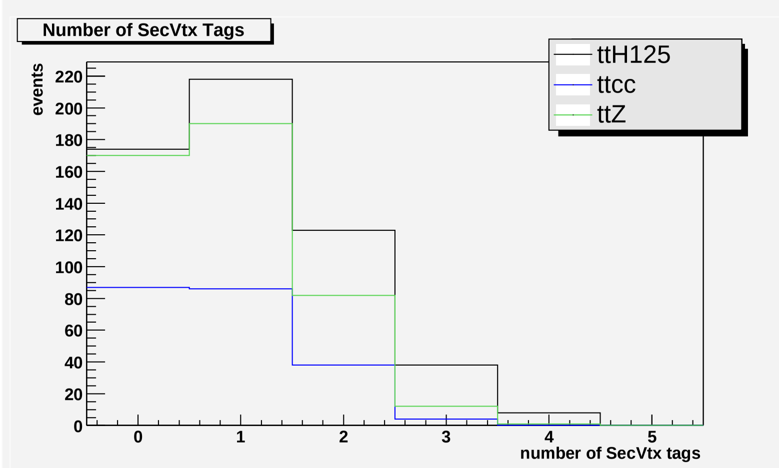
Tight Jets between 5 and 8

OR

Total Jets between 6 and 9

SecVtx Tags

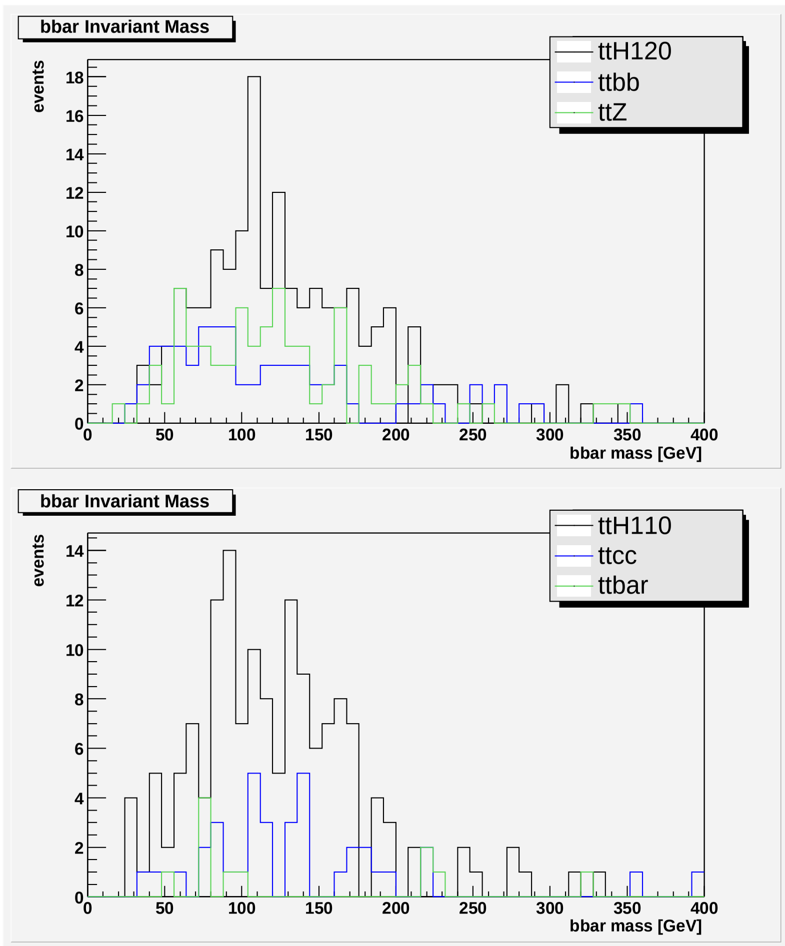




SecVtx Tags for:

$t\bar{t}H, t\bar{t}b\bar{b}, t\bar{t}, t\bar{t}c\bar{c}, t\bar{t}Z$

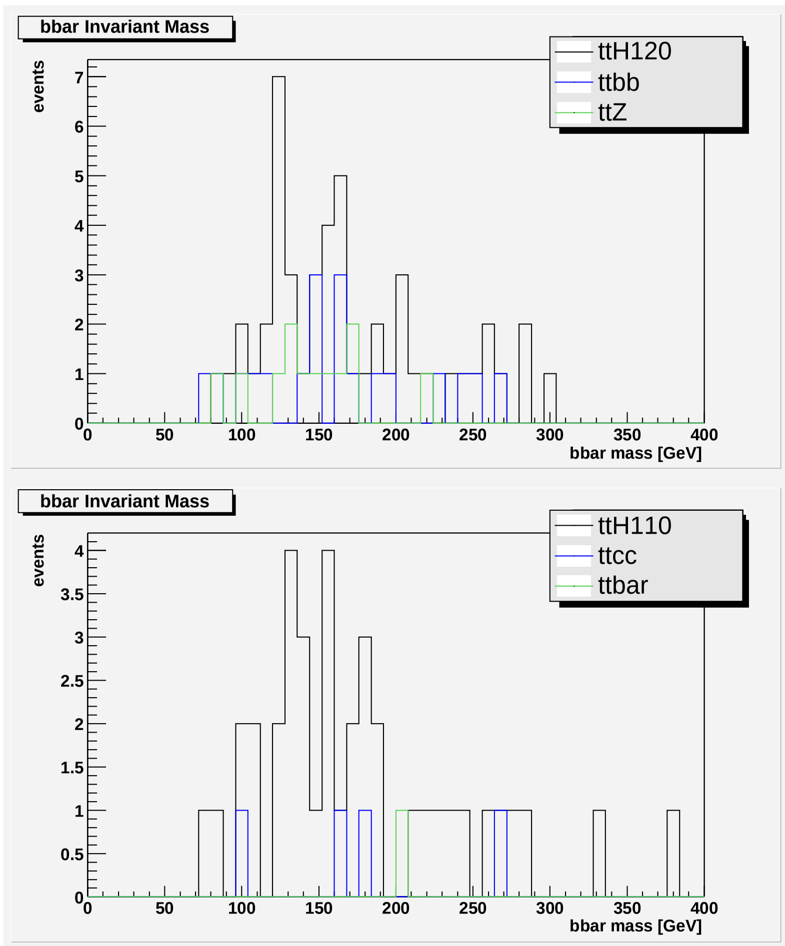
Invariant $b\bar{b}$ Mass for Double Tagged Events



Events with 2 SecVtx Tags

Invariant $b\bar{b}$ mass distribution

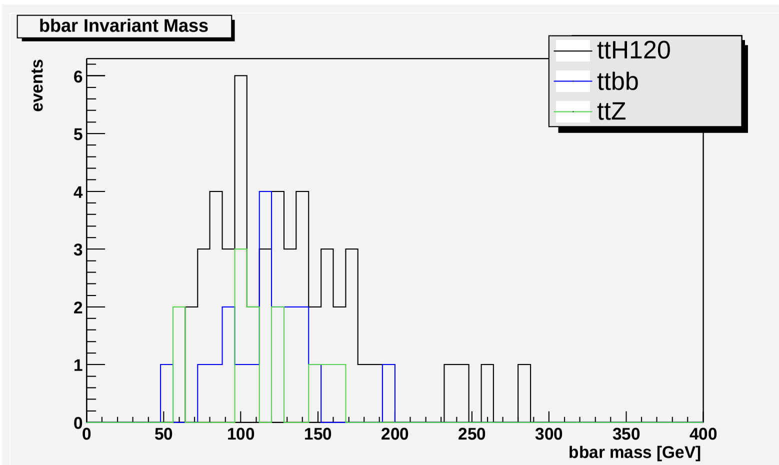
Invariant $b\bar{b}$ Mass for Triple Tagged Events

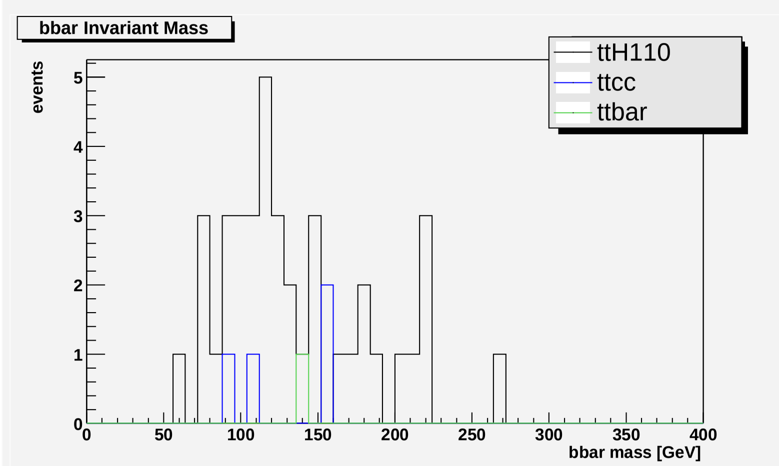


Events with 3 SecVtx Tags

Invariant $b\bar{b}$ mass distribution of highest $M_{b\bar{b}}$

Invariant $b\bar{b}$ Mass for Triple Tagged Events

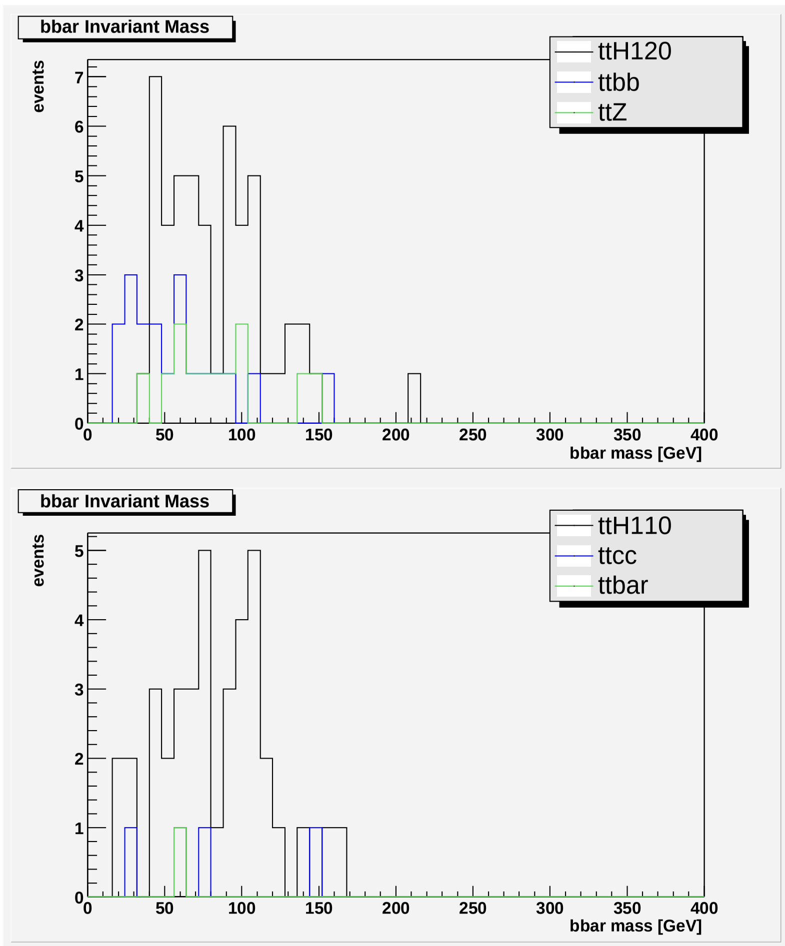




Events with 3 SecVtx Tags

Invariant $b\bar{b}$ mass distribution of second highest $M_{b\bar{b}}$

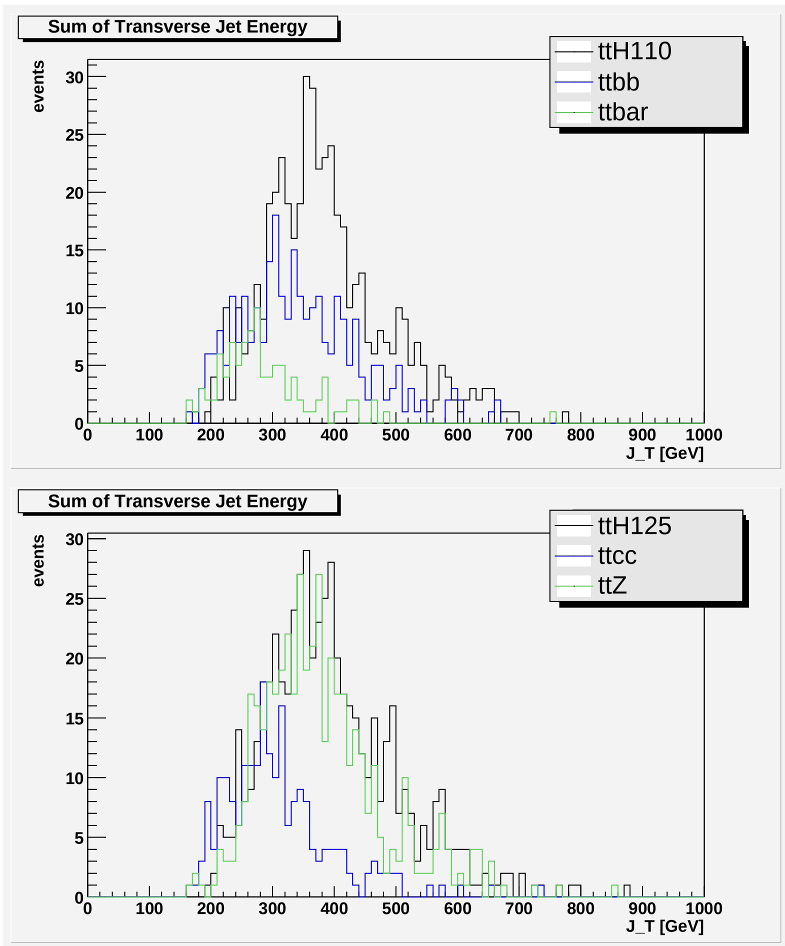
Invariant $b\bar{b}$ Mass for Triple Tagged Events



Events with 3 SecVtx Tags

Invariant $b\bar{b}$ mass distribution of lowest $M_{b\bar{b}}$

Total Jet Transverse Energy



Scalar sum of Jet Transverse Energy for Tight and Loose Jets

Generic Jet Corrections applied

Preliminary Event Yield Estimate

Events expected per fb^{-1}

Requiring 3 or more SecVtx tags:

Topology	110	115	120	125	$t\bar{t}b\bar{b}$	$t\bar{t}c\bar{c}$	$t\bar{t}Z$	$t\bar{t}$
Events	0.08	0.07	0.06	0.06	0.14	0.12	0.03	1.7

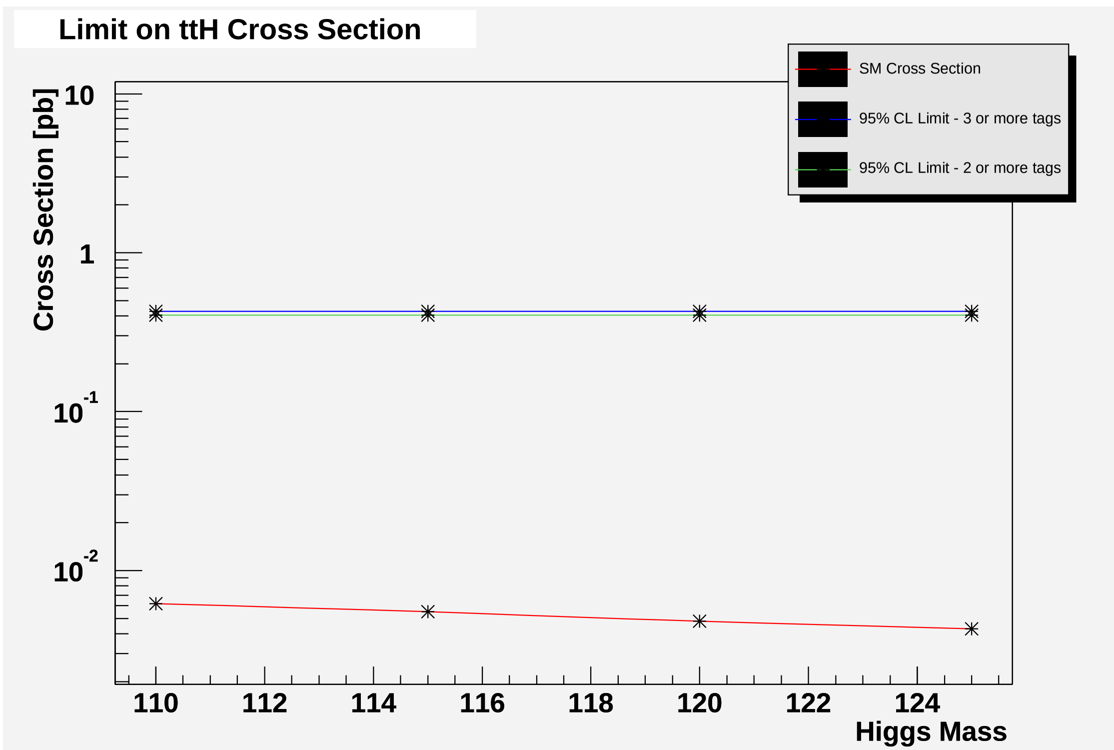
Requiring 2 or more tags, with $M_{b\bar{b}} > 104$ GeV if only 2 tags:

Topology	110	115	120	125	$t\bar{t}b\bar{b}$	$t\bar{t}c\bar{c}$	$t\bar{t}Z$	$t\bar{t}$
Events	0.21	0.19	0.17	0.15	0.37	0.9	0.15	8.4

Preliminary *a priori* Limit for $t\bar{t}H$

Assume that above backgrounds are the only source of signal contamination

Assume that event yields are known without any uncertainty (for 1 fb^{-1})



Summary and Outlook

- Investigated simulated signal and background for $t\bar{t}H$
- Signal yield is very low - improved b-tagging will help (3D ?)
- Naïve *a priori* limit set on $p\bar{p} \rightarrow t\bar{t}H$ cross section
- Need to study the kinematics of signal and background in more detail