Boosting the charged Higgs search using jet substructure at the LHC

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Overview

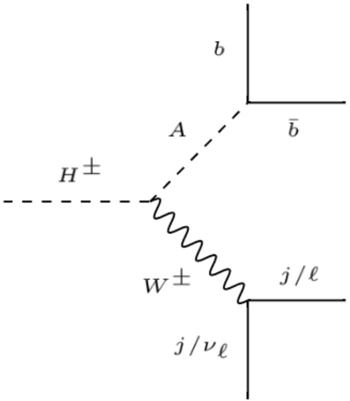
Two Higgs Doublet Model

- Add a second Higgs doublet
- Choose how these doublets couple $\rightarrow$ 2HDM Type II
- Generates 4 more Higgs particles
  1. A second CP even Higgs $\rightarrow H$
  2. A CP-odd pseudo-scalar Higgs $\rightarrow A$
  3. Two oppositely charged Higgs $\rightarrow H^{\pm}$
- Parameter Space
  1. $tan(\beta) = 1$
  2. $sin(\beta - \alpha) = .9$
  3. $500 \leq m_{H^{\pm}} \leq 1000$ GeV
  4. $100 \leq m_A \leq 200$ GeV

$$\begin{aligned} V(\Phi_1, \Phi_2) &= m_{11}^2 \Phi_1^\dagger \Phi_1 + m_{22}^2 \Phi_2^\dagger \Phi_2 - m_{12}^2 (\Phi_1^\dagger \Phi_2 + \Phi_2^\dagger \Phi_1) \\ &+ \frac{1}{2}\lambda_1 (\Phi_1^\dagger \Phi_1)^2 + \frac{1}{2}\lambda_2 (\Phi_2^\dagger \Phi_2)^2 + \lambda_3 (\Phi_1^\dagger \Phi_1)(\Phi_2^\dagger \Phi_2) + \lambda_4 (\Phi_1^\dagger \Phi_2)(\Phi_2^\dagger \Phi_1) \\ &+ \frac{1}{2}\lambda_5 ((\Phi_1^\dagger \Phi_2)^2 + (\Phi_2^\dagger \Phi_1)^2) + \frac{1}{2}\lambda_6 ((\Phi_1^\dagger \Phi_1)(\Phi_1^\dagger \Phi_2) + h.c.) + \frac{1}{2}\lambda_7 ((\Phi_2^\dagger \Phi_2)(\Phi_1^\dagger \Phi_2) + h.c) \end{aligned}$$

The Channel

- Semi-Leptonic Channel
  $\rightarrow$ $tH^{\pm} \rightarrow bb\bar{b}\ell\nu jj$
- Hadronic Channel
  $\rightarrow$ $tH^{\pm} \rightarrow bb\bar{b}jjjj$
- Motivation
  $\rightarrow$ $H^{\pm} \rightarrow t\bar{b}$ well studied
  $\rightarrow$ $H^{\pm} \rightarrow WA$ not well studied
  $\rightarrow$ $b \rightarrow s\gamma \Rightarrow m_{H^{\pm}} \geq 480 GeV$
- How
  $\rightarrow$ Highly boosted particles
  $\rightarrow$ A job for Jet Substructure



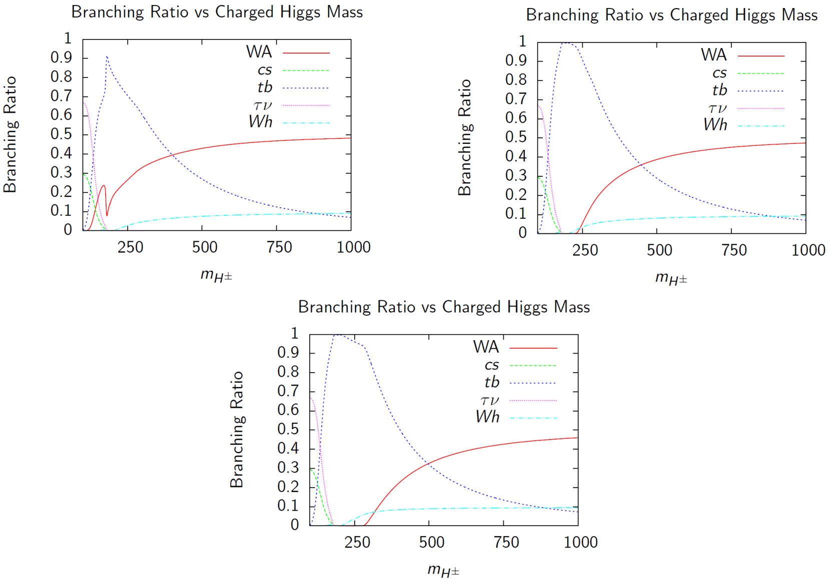


Figure: BR($H^\pm \to WA$) for top left: $m_A = 100 GeV$, top right: $m_A = 150 GeV$ and bottom: $m_A = 200 GeV$.

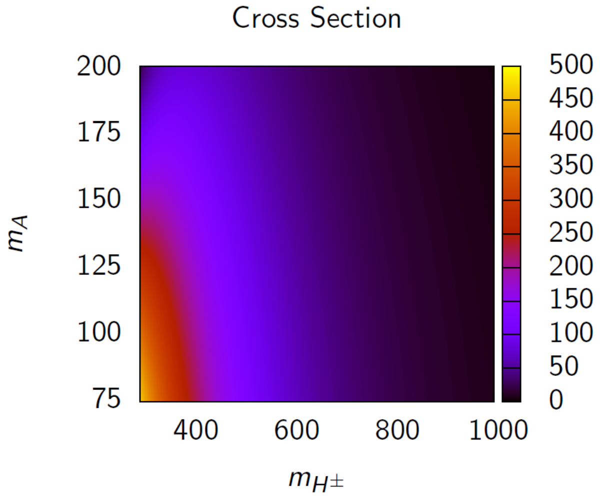
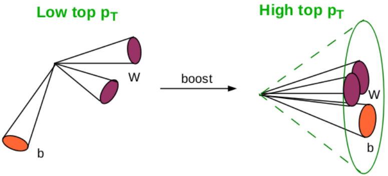


Figure: Cross section as a function of pseudo-scalar and charged Higgs masses with $\tan(\beta) = 1$ and $\sin(\beta - \alpha) = .9$.

Jet Substructure

1. Find/Cluster Jets via conventional means (Delphes with Cambridge-Aachen Algorithm)
2. Undo final step of clustering
3. Use MassDrop Tagger to find substructure
    1. For a jet j, label two subjets j_1 and j_2 such that $m_{j_1} \geq m_{j_2}$.
    2. If:
        1. $m_{j_1} > \mu m_j$ and,
        2. $\min(pT^2_{j_1}, pT^2_{j_2})\Delta R^2_{j_1,j_2} > y_{cut} m^2_j$
    3. Then tag j as a "fat" jet.
    4. If not: Redefine $j = j_1$.
4. Iterate through all jets with MDTagger.
5. Re-cluster unrelated jet components with anti-kt algorithm and call them narrow jets.



Acceptance Cut

1. At least 1 Higgs Jet (The Pseudo-Scalar)
2. Exactly 1 Lepton, with $pT \geq 20GeV$
3. bjets have $pT \geq 20GeV$

Cut 1

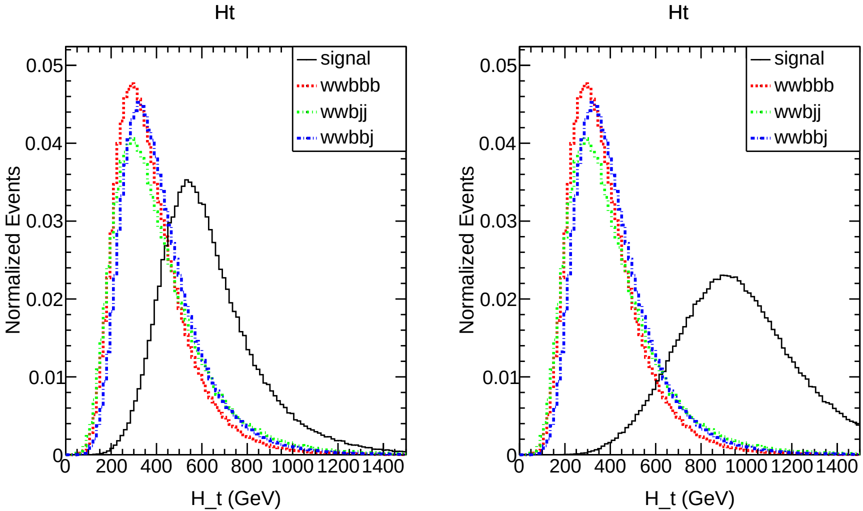


Figure: Cut scalar sum of pT $\geq$ 500 GeV (left) and 600 GeV (right).

Cut 2

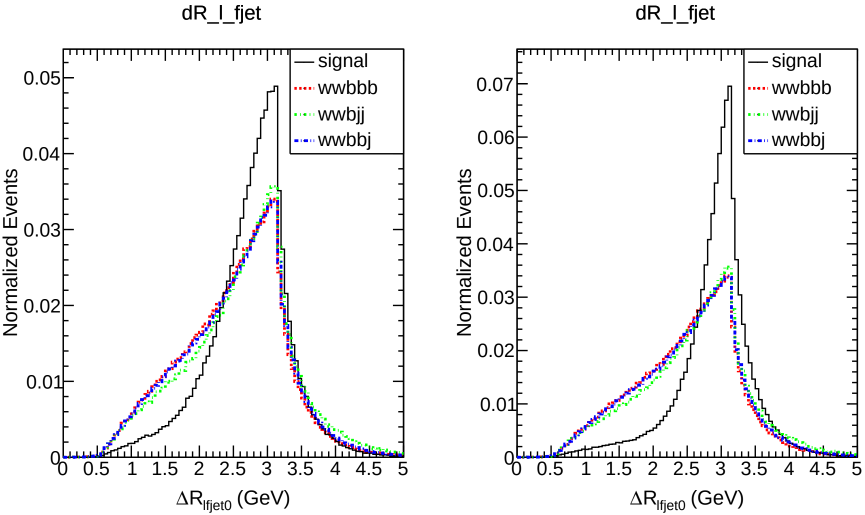


Figure: Cut on ΔR of lepton and hardest fat jet $\geq .25$

Cut 3

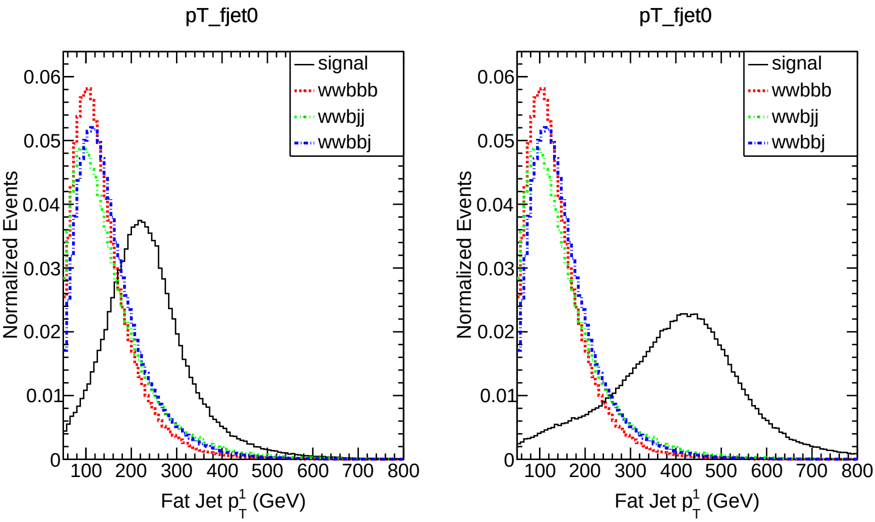


Figure: Cut on pT of hardest fat jet $\geq$ 200 GeV(left) and 250 GeV (right).

Cut 4

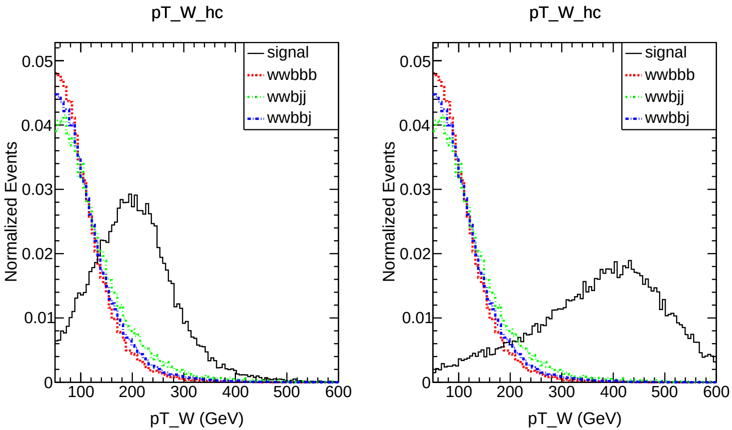


Figure: For $m_A = 100\text{GeV}$ and $m_{H^\pm} = 500\text{GeV}$ cut on pT of W from charged Higgs $\geq 150\text{GeV}$. For $m_A = 200\text{GeV}$ and $m_{H^\pm} = 1000\text{GeV}$ cut on pT of W from charged Higgs $\geq 200\text{GeV}$.

Cut 5

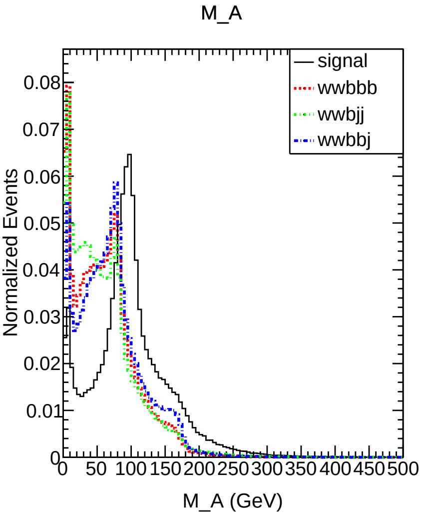


Figure: Cut $|m_A - m_{higgsjet}| \leq 15$ GeV.

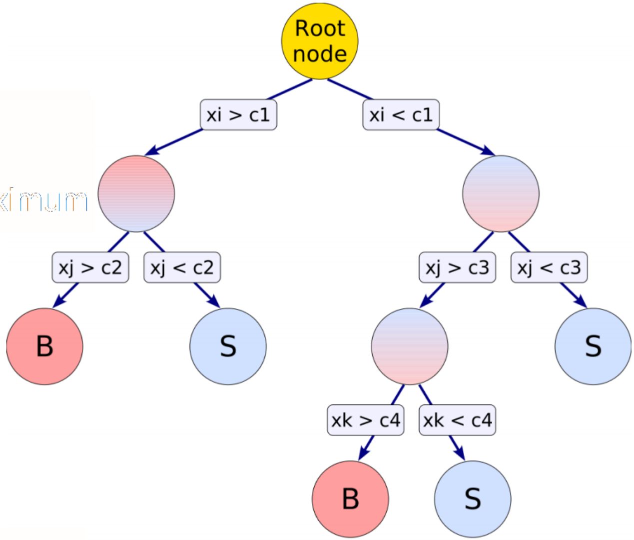
Cut Flow

	Signal		Background			
Cut	1	2	wwbbb	wwbbj	wwbjj	Total
Trigger	232.9	11.2	1.6×10^5	5.2×10^3	3.3×10^4	2.0×10^5
1	166.2	10.4	2.9×10^4	1.3×10^3	8.3×10^3	3.9×10^4
2	115.8	8.7	1.8×10^4	8.2×10^2	5.5×10^3	2.5×10^4
3	89.4	7.8	1.1×10^4	5.6×10^2	3.8×10^3	1.6×10^4
4	76.4	6.5	1.0×10^4	5.1×10^2	3.5×10^3	1.4×10^4
$\frac{S}{\sqrt{B}}$	**6.37**	**1.72**				
5	25.25		1.89×10^3	5.08×10^2	3.51×10^3	5.9×10^3
		1.9	4.6×10^2	2.2×10^1	1.8×10^2	6.6×10^2
$\frac{S}{\sqrt{B}}$	**3.3**	**2.4**				

Table: Cut Flow table for signal benchmark 1: $m_A = 100$ GeV and $m_{H^\pm} = 500$ GeV and $\mathcal{L} = 100 fb^{-1}$ and signal benchmark 2: $m_A = 200$ GeV and $m_{H^\pm} = 1000$ GeV and $\mathcal{L} = 1000 fb^{-1}$

Cut Optimization

1. Multivariate Analysis: Boosted Decision Tree



Conclusion

1. We have a decent signal to background statistic for the leptonic channel.
2. Is semi-leptonic or fully hadronic better?
3. Jet Substructure techniques are incredibly powerful - will become very important in future.
4. Cut optimization through boosted decision tree.

Thank You