Jet Clustering Techniques for New Higgs Boson Searches in Hadronic Final States

Shubhani Jain

S.Jain@soton.ac.uk

Supervisor- Prof. Stefano Moretti

University of Southampton

ABSTRACT

We investigate the performance of different jet-clustering algorithms in resolving fully hadronic final states arising from the chain decay of the discovered Higgs boson into pairs of new identical light Higgs states which further decays into bottom anti-bottom quark pairs. We show that, the ability of selecting the multi-jet final state and to reconstruct invariant masses of the Higgs bosons from it depend strongly on the choice of acceptance cuts, resolution parameters, reconstruction procedures and jet-clustering algorithm as well as its settings. Hence, we point out the optimal choice of the latter as our ultimate goal is to search for new physics Beyond the Standard Model (BSM) [1].

METHODOLOGY

Selection of suitable benchmark

- We first select a suitable set of parameters in the 2HDM Type-II [2] framework for our model.
- We work in a scenario where $m_H = 125 GeV$, $m_h = 40, 60 GeV$ as we require $m_h < m_H/2$ for $H \to hh$.
- We have tested these benchmarks against theoretical and experimental constraints by using 2HDMC [3], HiggsBounds [4], HiggsSignals [5] and flavour constraints with SuperISO [6].

Simulations details and Cutflow

- Description of the procedure used and cutflow applied for this model:

Generate signal events for the process $gg \to H \to hh \to b\bar{b}b\bar{b}$ using MadGraph5 [7].

↓

Shower and hadronise parton level events using Pythia8 [8].

↓

Perform jet reconstruction, apply cuts and carry out analysis using MadAnalysis5 [9, 10]

↓

Remove all final state particles with a $p_T < 0.5 GeV$ and $|\eta| > 2.5$

↓

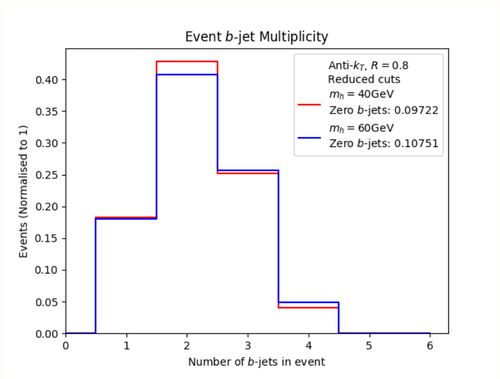
Perform jet reconstruction and b-tagging in Fastjet [11] with Anti-k_T and Variable-R clustering algorithms [12, 13].

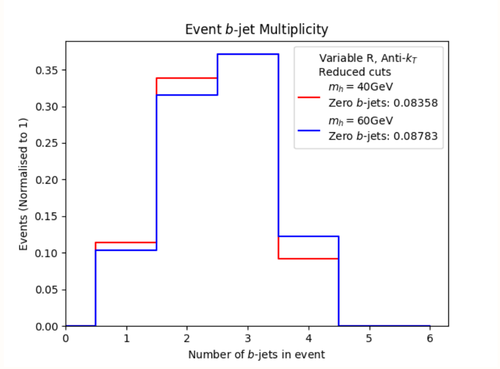
↓

Remove b-jets if p_T of first, second, third, fourth (p_T-ranked) is $< 20, 15, 15, 15 GeV$ respectively.

RESULTS

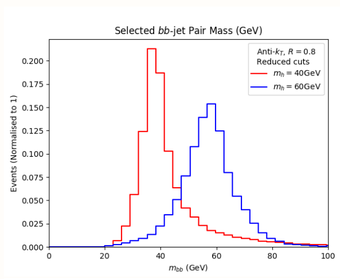
- We start by comparing the b-jet multiplicity plots for Anti-k_t with $R = 0.8$ and Variable-R.

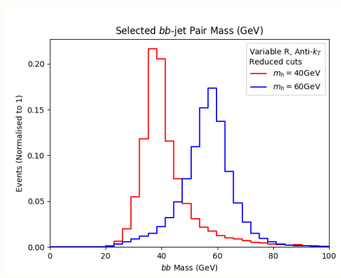


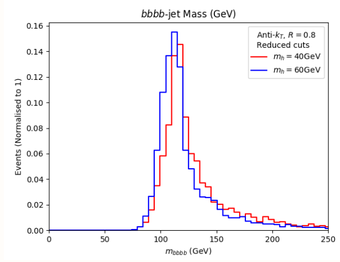


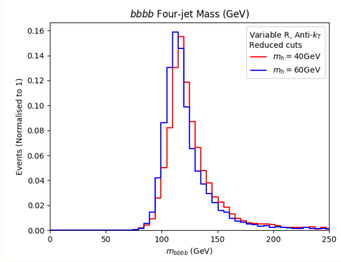
We see double the number of events that contain all four expected b-jets for Variable-R!

- To investigate further we reconstruct the Higgs masses m_h and m_H in the invariant dijet and fourjet masses using Anti-k_t with $R = 0.8$ and Variable-R.









- Clearly for Variable-R sharp visible peaks of signal are present.

Signal to Background Analysis

- To gain more insigth, we calculate the signal-to-background significance rates. In order to do so, we apply a selection procedure to the signal and leading backgrounds $pp \to b\bar{b}b\bar{b}$,$pp \to Zb\bar{b}$ and $pp \to t\bar{t}$:

Select events that contain exactly four b-jets

↓

Remove event if $|m_{bbbb} - m_H| > 20 GeV$

↓

Use di-jet pairings which minimises $|m_{bb} - m_h|$

↓

Remove event if $|m_{bb} - m_h| > 15 GeV$

- The number of events passing are counted and the significance rates is given by:

$$\Sigma = \frac{N(S)}{\sqrt{N(B_{b\bar{b}b\bar{b}}) + N(B_{Zb\bar{b}}) + N(B_{t\bar{t}})}}. \qquad (1)$$

- We calculate the significance for two values of (integrated) luminosity, e.g., $\mathscr{L} = 140$ and $300\ fb^{-1}$.

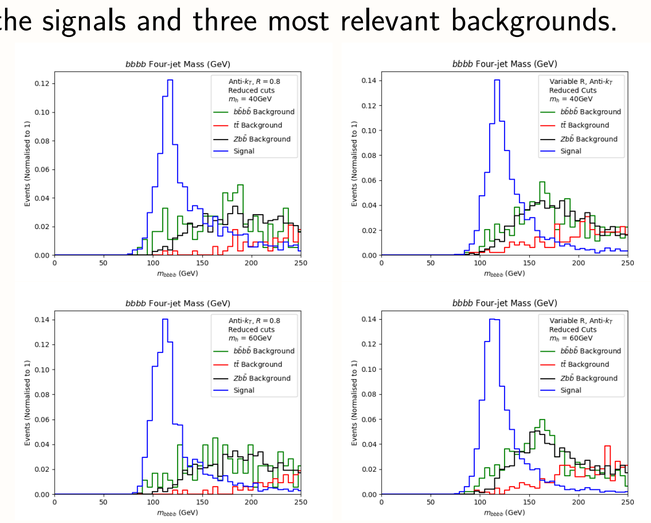
For $\mathscr{L} = 140\ fb^{-1}$, the final Σ values are:

m_h	variable-R, $\rho = 20$ GeV	$R = 0.4$	$R = 0.8$
40 GeV	0.343	0.061	0.160
60 GeV	5.841	2.074	3.138

For $\mathscr{L} = 300\ fb^{-1}$, the final Σ values are:

m_h	variable-R, $\rho = 20$ GeV	$R = 0.4$	$R = 0.8$
40 GeV	0.502	0.089	0.234
60 GeV	8.550	3.036	4.593

- For completeness, we present the m_{bbbb} spectra for the signals and three most relevant backgrounds.



CONCLUSION AND OUTLOOK

- We have demonstrated that the potential scope of the LHC experiments (from a theoretical perspective) in accessing BSM Higgs signals are suppressed with current jet reconstruction parameters.
- Variable-R jet clustering can outperform fixed-R implementations currently in use.
- The results can be applied to any BSM models with four-b final states.
- We plan to define a suitable 4b jet trigger for the model.
- We are currently investigating the use of image recognition to distinguish between signal and backgrounds jets.

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