Search for Resonant Production from $hh \rightarrow b\bar{b}b\bar{b}$ in ATLAS Detector using Superboosted Analysis

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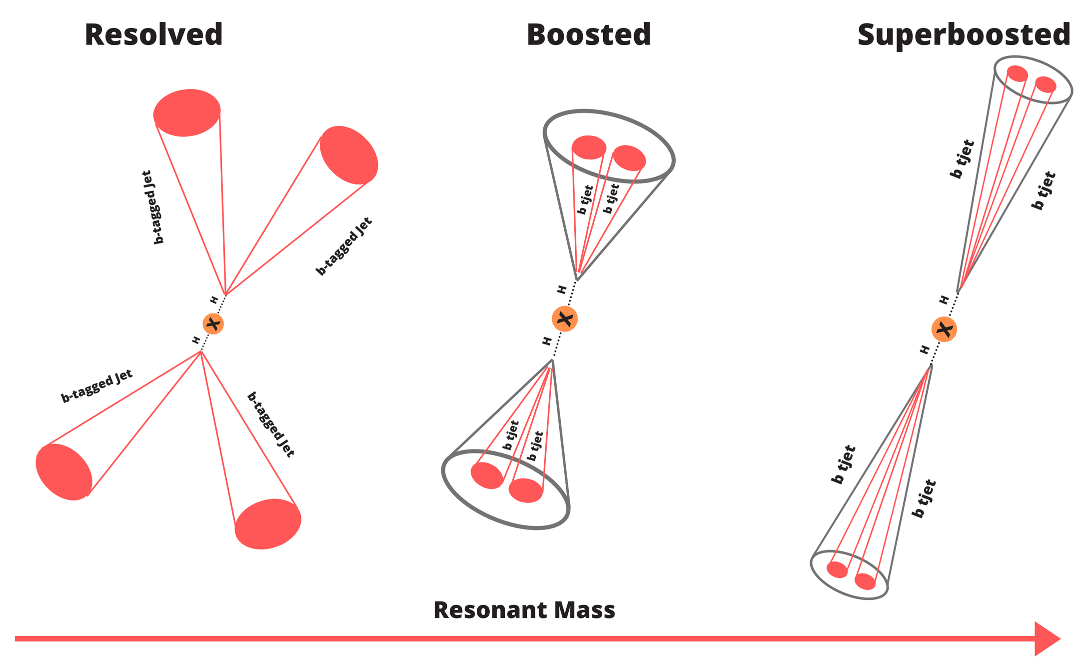
Abstract

This project involves with searching for resonant production from $hh \rightarrow b\bar{b}b\bar{b}$ channel on ATLAS 139 fb^{-1} Run-2 data using Superboosted Analysis. The production cross section of hh in ATLAS is expected to be enhanced in Beyond Standard Model (BSM) compared to Standard Model. In this project, there are 2 different BSM theories involved which are Kaluza-Klein Graviton particle from Randall-Sundrum Model and Heavy Neutral Scalar particle from 2 Higgs Doublet Model (2HDM). Both theories expect the particle decays into hh. The $b\bar{b}b\bar{b}$ channel splits into 3 regime which are Resolved, Boosted and Superboosted. The Superboosted analysis covers the resonant mass range from 1.6 TeV $< m_X <$ 5 TeV for both BSM theories. A Kinematic comparison with current Boosted regime has been performed in which the Superboosted regime has better signal efficiency around m_X >2 TeV for both BSM theories. For expected limit, Superboosted regime has better sensitivity up to 34% around m_X >3 TeV compared to Boosted regime.

Introduction

- In $hh \rightarrow b\bar{b}b\bar{b}$ analysis, two BSM theories that are currently studied in which expected to decay into Higgs pairs [1]:
  - Kaluza Klein Graviton from Randall-Sundrum Model
  - Heavy Neutral Scalar from 2 Higgs Doublet Model
- The $b\bar{b}b\bar{b}$ hannel is one of the main channel of interest due to it's large branching ratio which is around 33%
- Heavier Resonant Mass that decay into Higgs pairs are expected to decay into 4 collimated B-Hadron jets.
- The Superboosted analysis is a new analysis regime in $b\bar{b}b\bar{b}$ channel that focuses searching collimated $b\bar{b}b\bar{b}$ jets that decayed from Higgs pairs that originate from very heavy Resonant particle.



Event Selection

The higgs pair production are divided into leading Higgs (h_1) and subleading Higgs (h_2) candidates. Each of the Higgs candidates are reconstructed based on the kinematic selection below.

- Calorimeter jet:
  $p_T^{lead} >$ 450 GeV , $p_T^{subl} >$ 250 GeV
  $m >$ 50 GeV , $|\eta| <$ 2.0, $\Delta\eta_{jj} <$ 1.3, $m/p_T <$ 0.2
  Algorithm: Anti-k_t $R = 0.4$ Particle-Flow
- Track jet:
  $p_T >$ 5 GeV , $|\eta| <$ 2.0, $\Delta R^{calo,track} <$ 0.4
  Algorithm: Anti-k_t Variable Radius (0.02 $< R <$ 0.4)
- Muon:
  $p_T >$ 5 GeV ,$|\eta| <$ 2.0, $\Delta R^{calo,muon} <$ 0.4

Analysis Region

The region of interest for this analysis are in the elliptical region within $X_{hh} <$ 1.6 in $m_{h1} - m_{h2}$ plane. There are 3 different regions are defined in the analysis:

- Signal Region (SR) : $X_{hh} < 1.6$ (Region of interest)

$$X_{hh} = \sqrt{\left(\frac{m_{h1} - 124\ \text{GeV}}{0.1 m_{h1}}\right)^2 + \left(\frac{m_{h2} - 115\ \text{GeV}}{0.1 m_{h2}}\right)^2} \quad (3)$$

- Validation Region (VR) : $R_{hh}^{VR} <$ 33 GeV

$$R_{hh}^{VR} = \sqrt{(m_{h1} - 124\ \text{GeV})^2 + (m_{h2} - 115\ \text{GeV})^2} \quad (4)$$

- Control Region (CR) : $R_{hh}^{CR} <$ 58 GeV

$$R_{hh}^{CR} = \sqrt{(m_{h1} - 134\ \text{GeV})^2 + (m_{h2} - 125\ \text{GeV})^2} \quad (5)$$

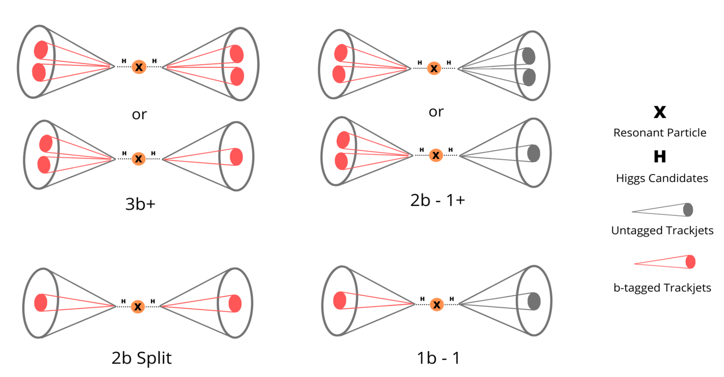
Tag Region Definition

High Tag: Region of interest and background modelling

- **3b+**: 2b tagged trackjets on 1 calo jet 1b/2b tag trackjets on the other
- **2b split** : 1b tagged trackjets on each calo jet

Low Tag: Use for background modelling

- **2b - 1+** : At least pass 2 b-Tagged (on either 2 jets) and have total of at 3/4 trackjets on both jets.
- **1b - 1** : pass only 1 b-Tagged (on either 2 jets) and have only 1 trackjet on each jets.



Superboosted Background Modelling and Analysis Results

Background Modelling:

- Main background contribution:
  - QCD multijet
  - $t\bar{t}$
- Total background on each tag region (N_{tot}^{ν}) are modelled from calculating the normalization factors for QCD (μ_{qcd}) and $t\bar{t}$ ($\alpha_{t\bar{t}}$) contributions
- The normalization factors are derived from data and MC driven in low-tag region (for μ_{qcd}) and high tag region (for $\alpha_{t\bar{t}}$)
- The predicted background on VR and CR are compared with High-tag region data on VR and CR for validation.

$$N_{tot}^{\nu} = \mu_{qcd}(N_{data}^{\nu-1} - N_{t\bar{t}}^{\nu-1}) + \alpha_{t\bar{t}}\, N_{t\bar{t}}^{\nu} \quad (1)$$

Tag Region	μ_{qcd}	$\alpha_{t\bar{t}}$
3b+	0.0930 +/- 0.0057	0.9166 +/- 0.2339
2b Split	0.0465 +/- 0.0018	0.8018 +/- 0.0740

Kinematic Reweighting

To perform better background m_{hh} modelling, a kinematic reweighting applied to several kinematic variables on calorimeter jets and track jets. These reweighting procedure only applied on low-tag region. The kinematic reweighting are performed in several iterations using cublic splines until the ratio of the kinematic distributions between high tag and low tag region converges to 1.

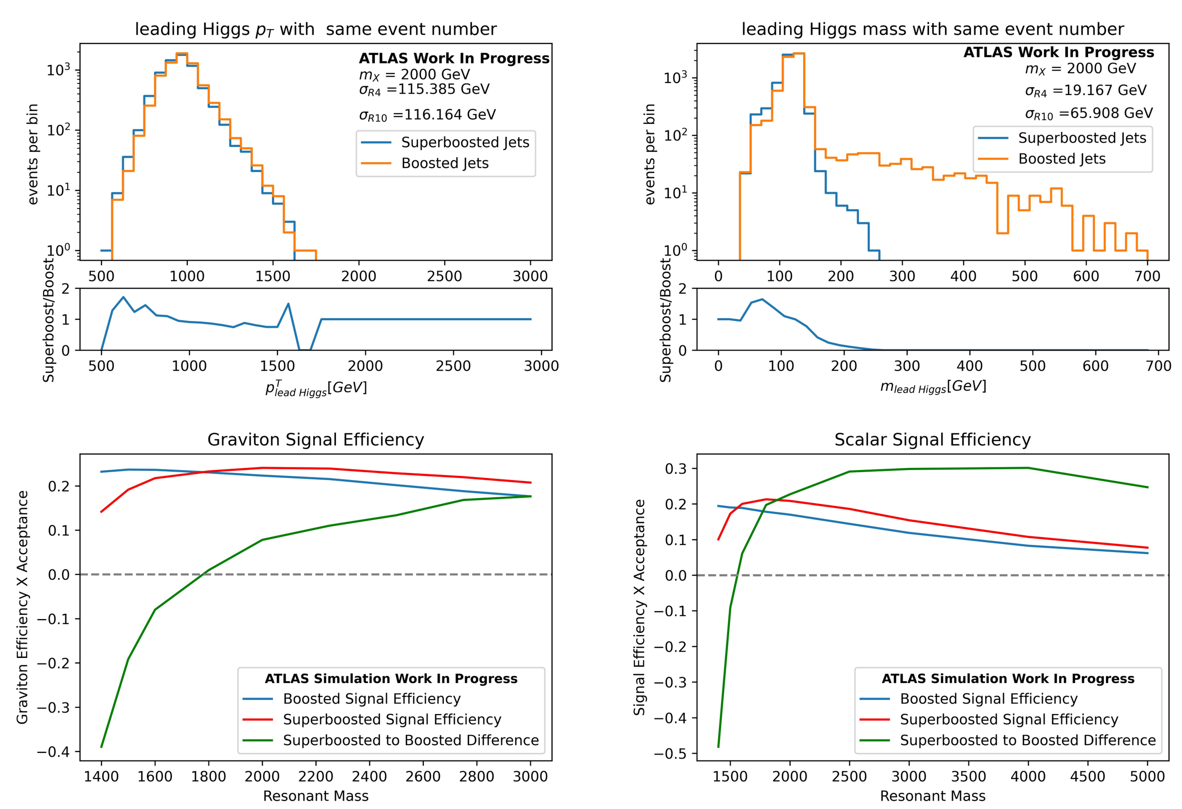
m_{hh} Smoothing

In order to reduce statistical fluctuations and better modelling on high m_{hh} region, a smoothing function is applied on predicted m_{hh} distribution. The nominal function that is used for the smoothing is shown below.

$$f(x) = p_0 \frac{1-x}{p_1 x} e^{-p_2 x}, \quad x \equiv \frac{m_{hh}}{13\ TeV} \quad (2)$$

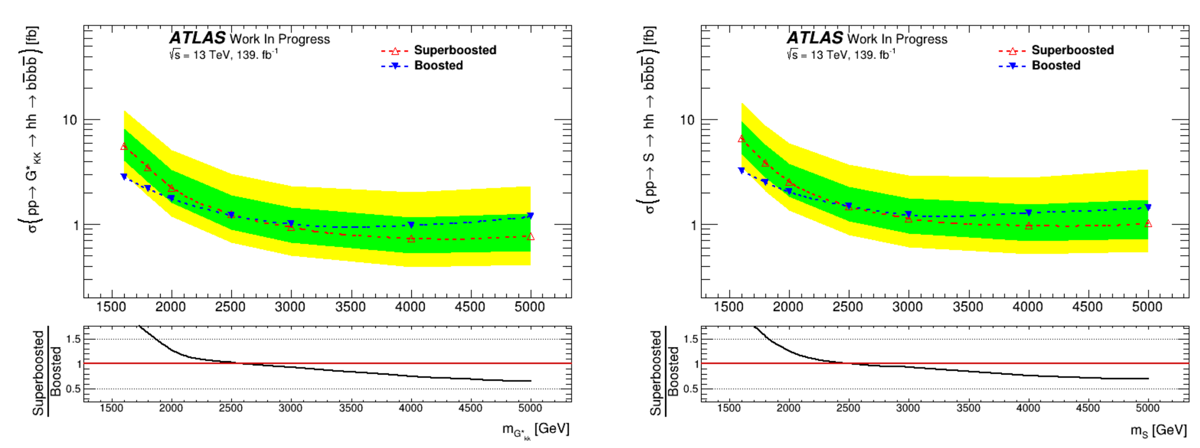
Kinematic Comparison with Boosted Analysis

- Superboosted jets tend to get better diHiggs signal efficiency at high resonant mass. (≈ 2TeV)
- Boosted jets tend to construct larger jet mass as jet p_T increases.
- Superboosted jets keep the jet masses lower at high p_T. Hence, better jet mass resolution around signal region.
- Benefit for very high Lorentz boost particle decays.



Limit Setting

The discriminant that is considered for limits in this analysis is m_{hh}. The upper limits are derived from statistical tests via log-likelihood ratio. The test statistic q_μ value are taken to obtain the ratio of probabilities of Signal and Background to Background ratio based on 95% Confidence Interval $CL(\mu)$. The value of the signal normalization μ are varied in each mass points until the $CL(\mu)$ reaches 0.05. The obtained μ value will be taken into account for limits and convert into cross section for $hh \rightarrow b\bar{b}b\bar{b}$. The expected limits are derived using Asimov data with background only hypothesis.



Conclusion and References

Superboosted analysis obtains more signal than Boosted analysis around resonant mass m_X >2 TeV. For expected limit, Superboosted analysis has better sensitivity than Boosted analysis up to 34%.

References: [1] ATLAS Collaboration, Search for resonant pair production of Higgs bosons in the $b\bar{b}b\bar{b}$ final state using pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector, Submitted to Phys. Rev. D. arXiv:2202.07288v1