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Studying BLSSM Model Through Light and Heavy Higgs Decay to a Pair Of Bottom Quarks at CM 13.6 GeV.

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ABSTRACT

Among the most sensitive investigations of beyond the Standard Model (BSM) physics are searches for Higgs decays into two muons, heavy particle decays into two heavy vector bosons (WW or ZZ), and the predominant decay mode (H to bb), which has been definitively detected. The branching percentage is anticipated to be around 58% for a Higgs boson mass of mH = 125.35 GeV. Despite reduced detection effectiveness, the signal may remain statistically significant because of the substantial branching ratio. Experimental techniques have been developed to enhance sensitivity to (b b-) decays. Jets originating from bottom quarks may be discerned by secondary vertex tagging. .

Recently, the CMS collaboration discovered possible evidence of an extra neutral Higgs boson, center-of-mass (CM) energies of $\sqrt{s} = 8$ and 13 TeV, with a mass between 94 and 98 GeV, in the gluon-fusion initiated channel leading to the di-photon final state ($gg \rightarrow h \rightarrow \gamma$) with integrated luminosities of 19.7 and 35.9 fb^{-1}. A resonant pattern with local and global significance of 2.8 and 1.3 standard deviations was found by the CMS team in the $M\gamma\gamma$ spectrum at these data, Given this study, the BLSSM a particular extension of the MSSM with a complicated Higgs sector has two Higgs singlets and

Higgs doublets, may be able to explain the observed anomaly.

INTRODUCTION

The Brout–Englert–Higgs mechanism elucidates EW symmetry breaking and enables the weak gauge bosons to acquire mass within the standard model of particle physics. The LHC physics program's main aim was to collaborate at the CERN LHC. The process forecasts the existence and quantifies the Higgs scalar field, the Higgs boson, as shown by both ATLAS [1] and CMS [2,3] in 2012. This has heightened the pursuit of Beyond the Standard Model (BSM) and New Physics (NP), since it is established that the Standard Model (SM) is inadequate for elucidating the mass value indicated above the energy scale of the standard model, which demonstrates both theoretical and experimental shortcomings [4,5] Supersymmetry (SUSY) can address several challenges, including the lack of coupling unification, the hierarchy problem, inadequate matter-antimatter asymmetry, dark matter candidate absence, and the oscillations of neutrino mass.

Although the Minimal Supersymmetric Standard Model, in its most basic form, is compatible with both collider and dark matter data (MSSM)[6], it remains a subject of scrutiny. Nevertheless, theoretically plausible and more compatible are non-minimal implementations of supersymmetry,including those have an expanded gauge and Higgs sector such as the B−L Supersymmetric Standard Model (BLSSM), an extension of the MSSM that introduces an additional $U(1)_{B-L}$ gauge symmetry, along with an extended Higgs sector involving two singlets and two doublets. The HL-LHC is capable of measuring the decay modes of the Higgs boson into fermion-antifermion pairs, such as top-antitop (t^-t^+), bottom-antibottom (b^-b^+), tau-antitau leptons ($\tau^-\tau^+$), and muon-antimuon (μ−μ+), with (BR) Branching Ratios contingent upon the squares of the masses of the respective fermions. Besides serving as a mechanism for exploring Physics Beyond the Standard Model (BSM), it facilitates the examination of the Higgs coupling to second-generation fermions. Among the most sensitive investigations of beyond the Standard Model (BSM) physics are searches for Higgs decays into two muons, heavy particle decays into two heavy vector bosons (WW or ZZ), and the predominant decay mode (H to bb), which has been definitively detected. The branching percentage is anticipated to be around 58% [7,8] for a Higgs boson mass of mH = 125.35 GeV.

MATERIALS AND METHODS

In this study we scanned on valid working points (benchmarks), use two of them, which for BM1 mH is around 90.1 GeV and for BM2 mH is around 96.2 GeV. The matrix element generator MadGraph5 was utilized to produce samples for the signals and Standard Model background. The hadronization process was modelled using the LUND string fragmentation model, as implemented in PYTHIA8 [9] because of the requirement for quark confinement [10, 11]. Furthermore, the purported Final and Initial States Radiation Using Pythia8, FSR and ISR from Electroweak and QCD processes were simulated. To reproduce the detector response, the DELPHES fast detector simulator [12] was utilized.

We anticipated that the detector configuration in our simulation will resemble that of the (CMS) which is a Compact Muon Solenoid detector in the High Luminosity Large Hadron Collider (HL-LHC). In this study, "background" denotes various standard model processes, whereas "signal" indicates decaying of Higgs bosons into a pair of fermion-antifermion (bottom quarks). Conversely, the term "background" refers to other prevalent model processes, including top-antitop (tt), diboson (VV) production (WW, WZ, and ZZ), and DY;The CMS [13–15] and ATLAS [16,17] collaborations have conducted searches for H production. Collaborations possess collision data from the LHC proton-proton interactions at integrated L = 138 fb^{-1} and 13 TeV Nevertheless,in this study will pertain to bottom-antibottom. The cross-section is measured in pico-barns (pb) for the backgrounds' and signals' besides branching ratios in the channel.

Table1. Shows the cross-sections and the branching ratios for the signals and Back ground.

	BM1SIGNAL H1	BM1SIGNAL H2	BM2SIGNAL H1	BM2SIGNAL H2	SM-BACKGROUND H1
CROSS SECTION IN PB	2.6793 ± 0.000685	5.072 ± 0.001	3.9049 ± 0.00106	5.627 ± 0.00154	2.97e+06 ± 512
BRANCHING RATIOS	8.008×10^{-01}	5.158×10^{-01}	4.572866×10^{-03}	3.18637×10^{-03}	6.3823×10^{-3}

Every event for the baseline selection must have two isolated b-quarks in the final state. The two quarks must meet the operational point criterion. Furthermore, each b-jet possesses a transverse momentum, pT > 20 GeV, namely $|\eta| < 2.5$,Transverse momentum and pseudorapidity cuts reflect standard CMS detector acceptance criteria, optimized for b-jet reconstruction and background suppression in Run III.

Here, (η) is the pseudorapidity coverage, defined by the equation ($\eta = \ln\tan(\theta/2)$), where (θ) is the polar angle in the yz-plane of the CMS coordinate system. The rarity of the signal requires meticulous event selection and a sufficiently big dataset to ensure adequate statistics for sensitivity to NP. Consequently, events must have at least two oppositely charged quarks. This condition is crucial for eliminating backgrounds from operations involving leptons of the same charge. Events are selected if the pT-leading b-jet has pT > 20 GeV and the pT-subleading b-jet has pT > 15 GeV. Furthermore, each event must possess an invariant mass (M_{bb} > 40 GeV) to mitigate backgrounds consisting of (WW, WZ, and ZZ) vector bosons, and the processes including top-anti top (tt^-).

RESULTS AND DISCUSSION

At the end of the current Run III of the LHC, with a dataset size of 0.3 ab^{-1}, Table.2 displays the expected number of weighted events found before (initial) and after the selection cuts outlined in Section 3.

Table2. shows the signal (H1 to $b^+ b^-$) , (H2 to $b^+ b^-$) and sm-background with $_{Lint}$=0.3 ab^{-1} for BM1 and BM2 significance in the right of the table.

	H1	H2	sm	sm+H2	$\frac{S}{\sqrt{B}}$
No cut (BP1)	7.83350×10^5	1.48186×10^6	8.85667×10^{11}	8.8566148×10^{11}	0.832
After cut (BP1)	17005	25665	119834	145499	0.116
No cut (BP2)	1.14232×10^6	1.64402×10^6	8.85667×10^{11}	$8.85668644 \times 10^{11}$	1.214
After cut (BP2)	18810	25393	119834	145227	0.129

The distributions of PT for the primary and secondary signal b-jets are depicted in **Fig. 1** for BM1 and BM2 at 13.6 TeV and with Lint = 0.3 ab^{-1}. As illustrated in Fig.1, the transverse momentum (PT) of the leading b-quark originating from the light Higgs is approximately 40 GeV, 35 GeV from the standard model sm- Higgs, and 45 GeV from other background particles, with the majority concentrated between 30 and 40 GeV, predominantly below 65 GeV, and below 40 GeV for the signal, which differs from the sm-Higgs.The sub-leading b-jet originating from the light Higgs has a PT around 27 GeV, 33 GeV for the standard model Higgs, and 26 GeV for various background processes.

It is noteworthy in this plot that the majority of the b-jets originating from the light Higgs are concentrated below 55 GeV, as illustrated in **Fig.2** (a) and (b) for the two distinct benchmarks .

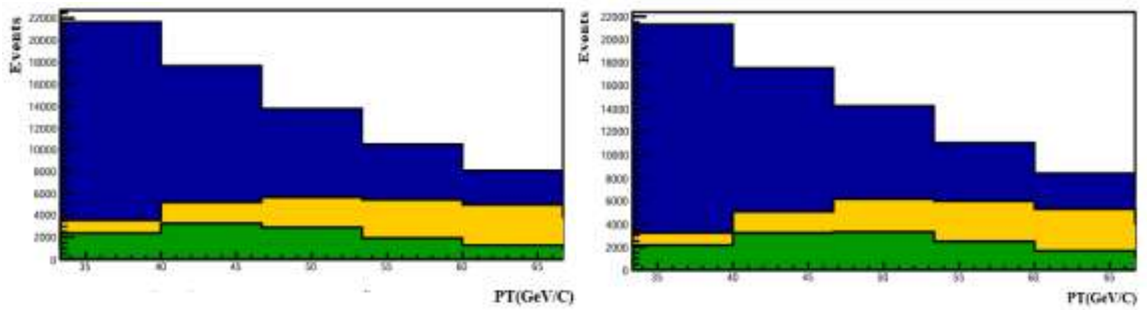
Fig 3. is an important plot, as the b-jet events coming from the light Higgs signal can be selected from other SM background events by the reconstructed Higgs mass (mH = 90.0 GeV).The pT distribution of the reconstructed object from the two b-jets is shown in **Fig. 4**. ; The events from the light Higgs sample at 15 GeV, for the sm-higgs sample at 17 GeV and at 12 GeV for background. The following histograms show events coming from the Higgs boson from that commencing from other new particles predicted by new physics; like Z`-boson and B-meson [18] are accumulated around 10 to 20 GeV which different from light and sm-higgs that takes a wide range.

Fig. 5 depicts the pseudo-rapidity flat distribution for the two b-jets at Lint with the maximum momentum. It is possible to differentiate between the ($H \rightarrow b^{+} b^{-}$) events originating from the decay of a spin-zero particle (such as the Higgs boson) and those originating from the decay of new heavy particles, such as Z`, which is a vector boson with spin = 1 and will produce a different from light and sm-higgs that takes a wide range.

Ultimately, (**Δ**R), The angular separation between two jets is defined as

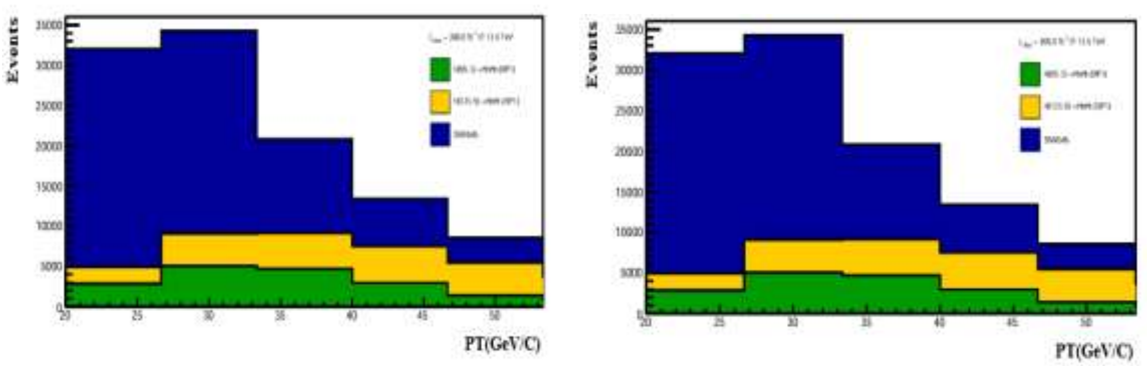
$\Delta R = \sqrt{(\Delta\eta^2 + \Delta\varphi^2)}$, where $\Delta\eta$ is the difference in pseudorapidity and $\Delta\varphi$ is the difference in azimuthal angle , is illustrated in **Fig. 6** (a) and (b) for both benchmark scenarios.

The value in the peak area is around 3.19, corresponding to an angle of 180 degrees, indicating that the two b-quarks are released back-to-back as a result of Higgs boson decay.



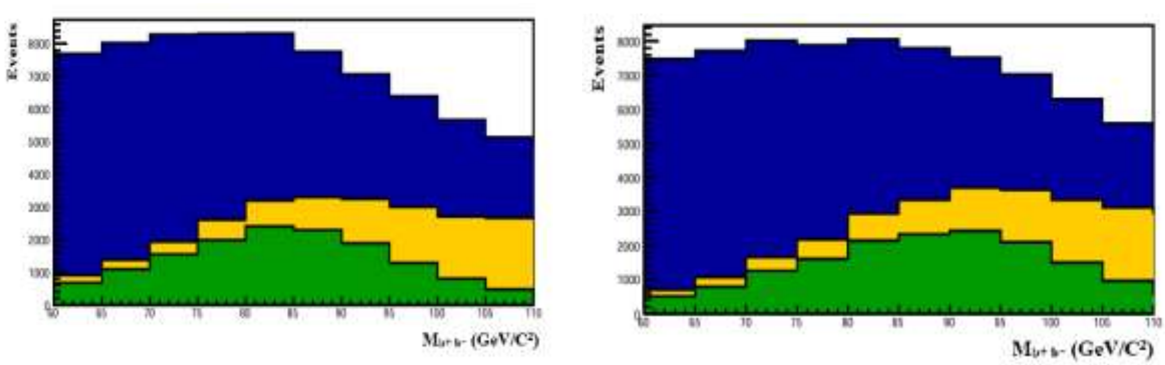
(a) (b)

Fig.1.png. Transverse momentum distributions pT for the leading b-jet of the ($H \rightarrow b^{+} b^{-}$) signal after all selections© at 13.6 TeV and L_{int}= 0.3 ab^{-1}



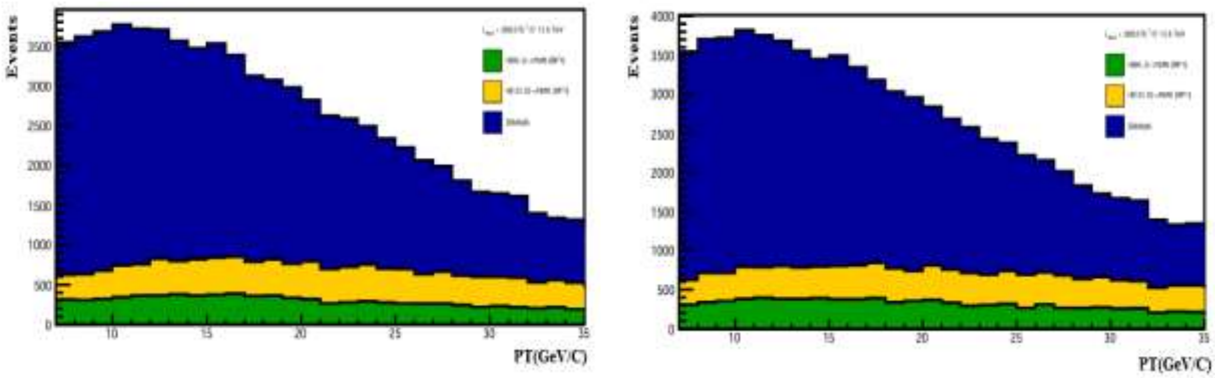
(a) (b)

Fig.2.png.Transverse momentum distributions PT for the subleading b-jet of the ($H \rightarrow b^{+} b^{-}$) signal after all selections© at 13.6 TeV and L_{int}= 0.3 ab^{-1}



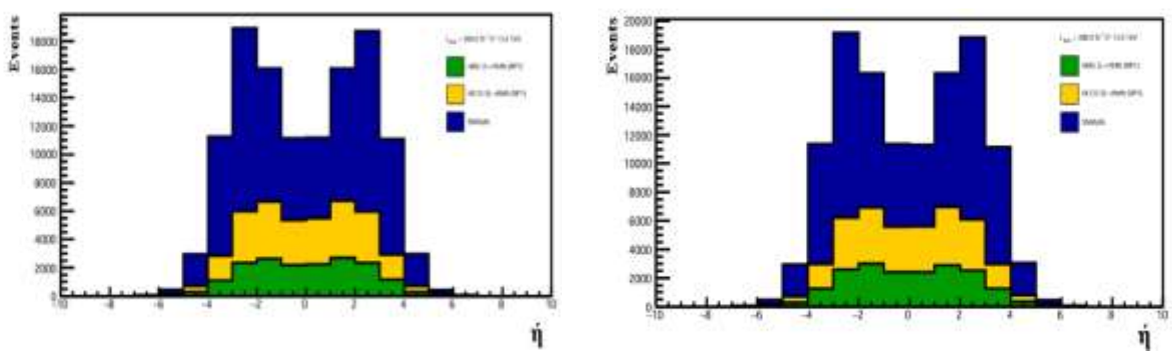
(a) (b)

Fig.3.png. The two b-jet invariant mass spectrum after the full selection at 13.6 TeV, L_{int}= 0.3 ab^{-1}.



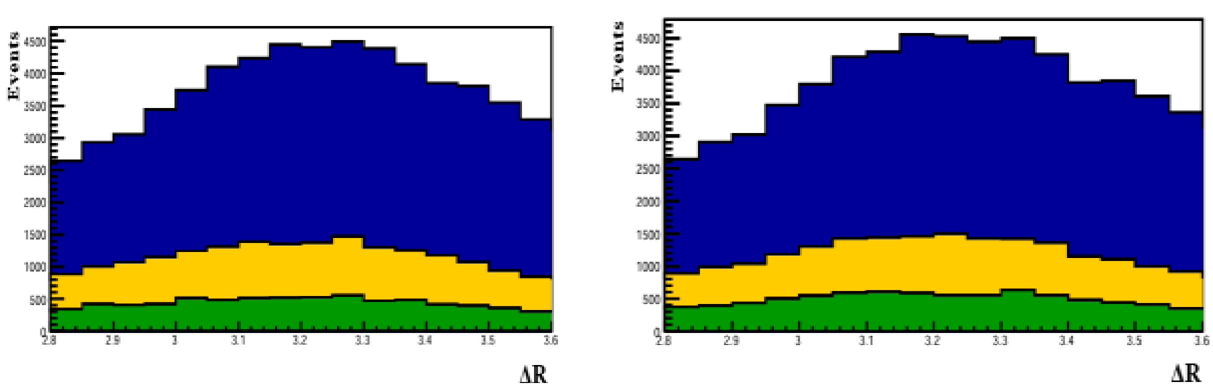
(a) (b)

Fig.4.png. Transverse momentum distributions pT of b-jet ($H \rightarrow b^+ b^-$) at L_{int}= 0.3 ab^{-1} and 13.6 TeV for two different benchmarks at (a) and (b).



(a) (b)

Fig.5.png. η-distribution. of b-jets of the ($H \rightarrow b^+ b^-$) at 13.6 TeV and L_{int}= 0.3 ab^{-1} at (a) and (b) for two different benchmarks.



(a) (b)

Fig.6.png. The angular separation (**Δ**R) between the leading and sub-leading b_jet at 13.6 TeV,L_{int}= 0.3 ab^{-1}.

CONCLUSION

This study investigated the decay of the light and sm-Higgs boson to a pair of bottom quark at s = 13.6 TeV and L_{int}= 0.3 ab^{-1} (accessible in Run III), showing the differences between them in some significant parameters such as, PT, invariant mass, BR and integrated luminosity that Our results are in qualitative agreement with previous CMS searches indicating an excess in the 94–98 GeV mass range, lending indirect support to the BLSSM predictions.

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