Probing HHH production via 4τ2b channel at a 100 TeV hadron collider

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Outline

- Motivation
- Samples
- Analysis strategy
- Event selections
- Results
- Summary

Motivation

Triple Higgs production at future colliders -- a growing interest

- Pioneering works in the early 2000s:
  - → SM prospects very limited rates
  - → BSM rates more appealing
- SM rates: between 100 ab @ 13 TeV to a few fb @ 100 TeV

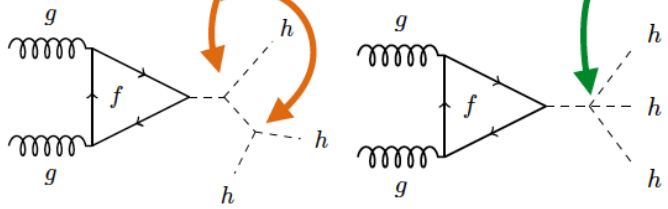
CEPC/FCC working group studies shows:

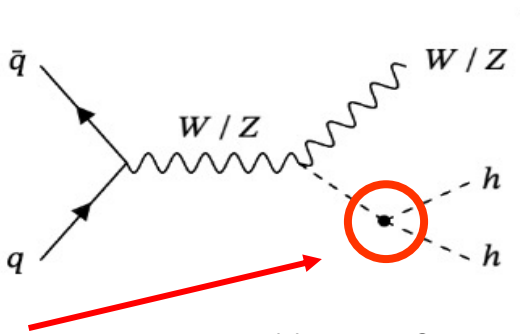
- Large rates can be reached in many BSM models
  - → Extra resonant contributions
  - → Coupling modifiers
- Multiple Higgs production measurements are available at CEPC/FCC given its high luminosity and high energy

Motivation

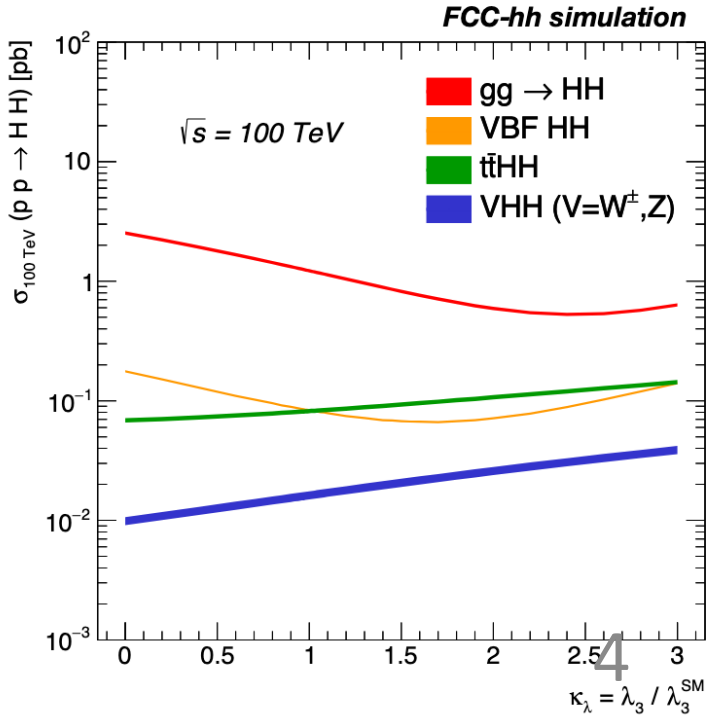
- HHH production: direct probe of quartic Higgs self-coupling λ_{hhhh} and trilinear Higgs self-coupling λ_{hhh}

$$V_h = \frac{1}{2}m_h^2 h^2 + (1+\kappa_3)\lambda_{hhh} v h^3 + \frac{1}{4}(1+\kappa_4)\lambda_{hhhh} h^4$$





- VHH can also contribute to the trilinear coupling λ_{hhh}
  - Hard to distinguish from HHH in our final states
  - Treated as part of signal in our study
  - Provide extra constraints on the positive side of κ_λ



Motivation

$hhh \to$ final state	BR (%)	σ (ab)	$N_{30ab^{-1}}$
$(b\bar{b})(b\bar{b})(b\bar{b})$	19.21	1110.338	33310
$(b\bar{b})(b\bar{b})(WW_{1\ell})$	7.204	416.41	12492
$(b\bar{b})(b\bar{b})(\tau\bar{\tau})$	6.312	364.853	10945
$(b\bar{b})(\tau\bar{\tau})(WW_{1\ell})$	1.578	91.22	2736
$(b\bar{b})(b\bar{b})(WW_{2\ell})$	0.976	56.417	1692
$(b\bar{b})(WW_{1\ell})(WW_{1\ell})$	0.901	52.055	1561
$(b\bar{b})(\tau\bar{\tau})(\tau\bar{\tau})$	0.691	39.963	1198
$(b\bar{b})(b\bar{b})(ZZ_{2\ell})$	0.331	19.131	573
$(b\bar{b})(WW_{2\ell})(WW_{1\ell})$	0.244	14.105	423
$(b\bar{b})(b\bar{b})(\gamma\gamma)$	0.228	13.162	394
$(b\bar{b})(\tau\bar{\tau})(WW_{2\ell})$	0.214	12.359	370
$(\tau\bar{\tau})(WW_{1\ell})(WW_{1\ell})$	0.099	5.702	171
$(\tau\bar{\tau})(\tau\bar{\tau})(WW_{1\ell})$	0.086	4.996	149
$(b\bar{b})(ZZ_{2\ell})(WW_{1\ell})$	0.083	4.783	143
$(b\bar{b})(\tau\bar{\tau})(ZZ_{2\ell})$	0.073	4.191	125

[Papaefstathiou & Sakurai (JHEP`16)]

Our $4\tau 2b$ channel

- Though suffer from lower signal yield
- Clean backgrounds relative to b-riched channel

HHH decay table main channels:

- At least 100 events with 30 ab^{-1} @ 100 TeV
- The golden $4b2\gamma$ mode [Papaefstathiou & Sakurai (JHEP`16)]
  - Clean signature and excellent photon resolution
  - 2σ reachable in the SM case
- The $2b2\ell 4j$ + MET mode [Kilian, Sun, Yan, Zhao & Zhao (JHEP`17)]
  - High-level variables (like MT2)
  - Challenging for the SM, potentially powerful for BSM
- The $6b$ & $4b2\tau$ mode [Papaefstathiou, Robens & Tetlalmatzi-Xolocotzi (JHEP`21)], [BF, Kim & Lee (PLB`17)]
  - Require good b-tagging
  - High-level variables
  - 2σ reachable in SM case

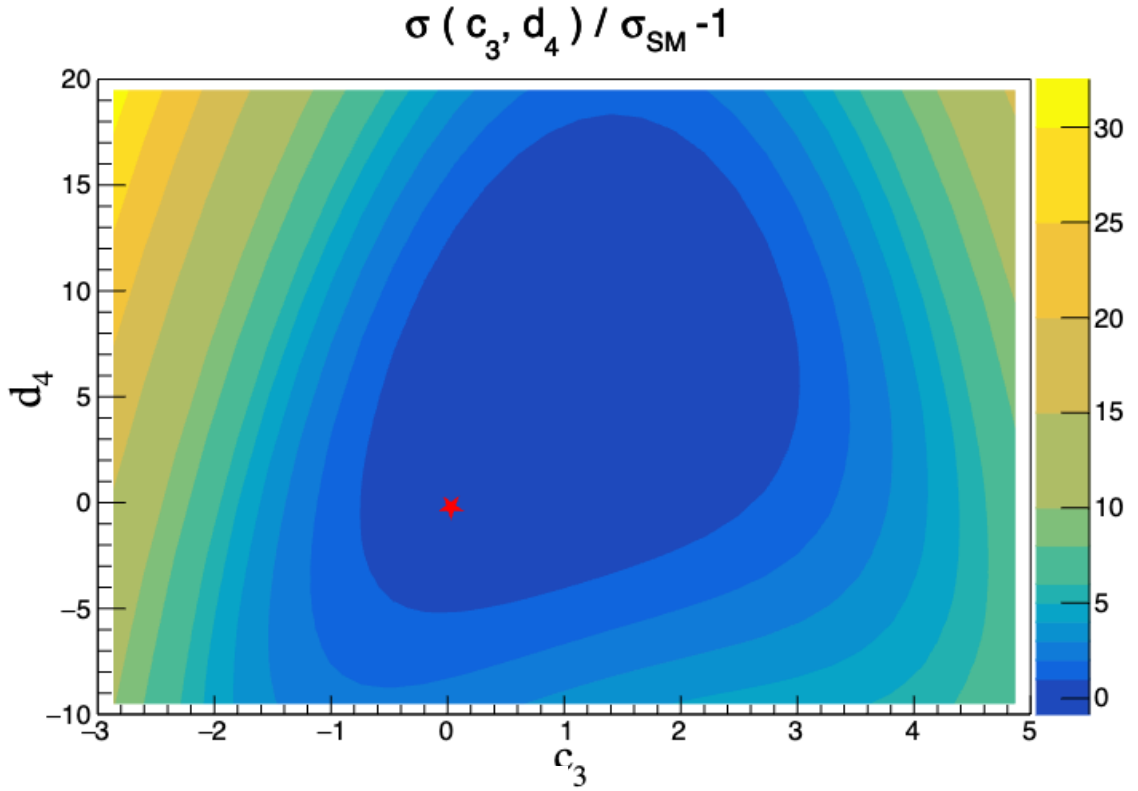
Theoretical framework

Theoretical framework for HHH signal

- Modified Higgs potential

$$V(h) = \frac{1}{2}m_H^2 h^2 + \lambda_{\mathrm{SM}}(1+c_3)v_0 h^3 + \frac{1}{4}\lambda_{\mathrm{SM}}(1+d_4)h^4,$$

- c_3 and d_4 provide a parametric framework to investigate deviations from the SM predictions
- Cross section of HHH production in the (c3, d4) plane
- Fitting result:



$$\frac{\sigma_{\mathrm{HHH}(c_3,d_4)}}{\sigma_{\mathrm{HHH(SM)}}} - 1 = 0.0297 \times c_3^4 - 0.2017 \times c_3^3 + 0.0395 \times c_3^2 d_4 + 0.7236 \times c_3^2 \quad (2.2)$$
$$+0.0154 \times d_4^2 - 0.1409 \times c_3 d_4 - 0.6658 \times c_3 - 0.1119 \times d_4,$$

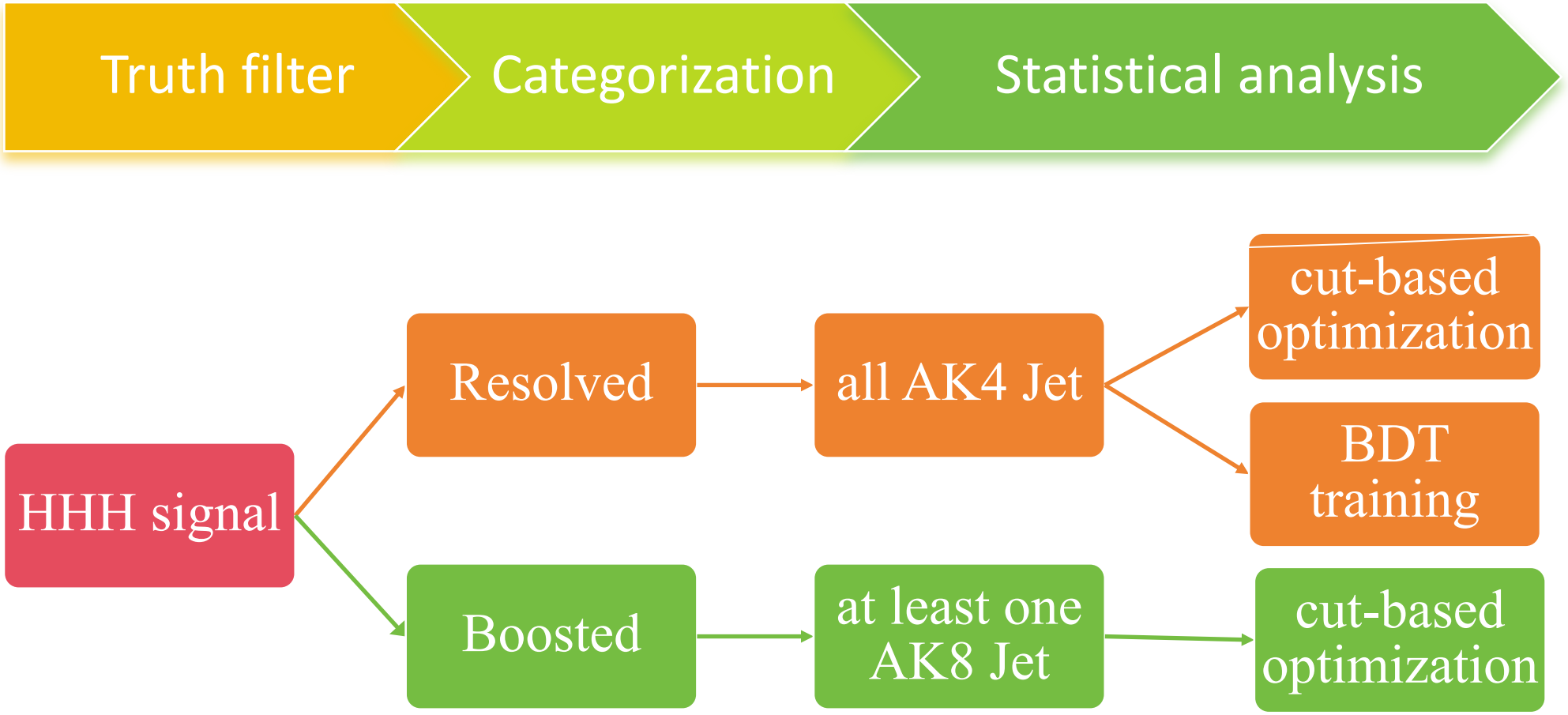
Samples

- Signal
  - HHH: scan (c3, d4) plane
  - Consider VHH as part of signal which is sensitive to c3
- Two groups of background
  - t/W related samples
  - $X_{bb}Y_{\tau\tau}Y_{\tau\tau}$ (including H_{bb}, Z_{bb}, $H_{\tau\tau}$, $Z_{\tau\tau}$, DY …)

Class	Process	$\sigma \times$ BR. (ab)
HHH signal	$HHH \to (b\bar{b})(\tau_h\tau_h)(\tau_h\tau_h)$, $c_3 = 0.0$, $d_4 = 0.0$ (SM)	3.0
	$HHH \to (b\bar{b})(\tau_h\tau_h)(\tau_h\tau_h)$, $c_3 = 1.0$, $d_4 = 0.0$	2.6
	$HHH \to (b\bar{b})(\tau_h\tau_h)(\tau_h\tau_h)$, $c_3 = 1.0$, $d_4 = 9.0$	0.67
	$HHH \to (b\bar{b})(\tau_h\tau_h)(\tau_h\tau_h)$, $c_3 = 2.0$, $d_4 = 19.0$	7.6
	$HHH \to (b\bar{b})(\tau_h\tau_h)(\tau_h\tau_h)$, $c_3 = -1.0$, $d_4 = 0.0$	7.9
	$HHH \to (b\bar{b})(\tau_h\tau_h)(\tau_h\tau_h)$, $c_3 = -1.0$, $d_4 = -6.0$	8.3
	$HHH \to (b\bar{b})(\tau_h\tau_h)(\tau_h\tau_h)$, $c_3 = -2.0$, $d_4 = -11.0$	16.7
VHH signal	$HHZ \to (b\bar{b})(\tau_h\tau_h)(\tau_h\tau_h)$, $c_3 = 0.0$ (SM)	2.7
	$HHZ \to (b\bar{b})(\tau_h\tau_h)(\tau_h\tau_h)$, $c_3 = 1.0$	4.2
	$HHZ \to (b\bar{b})(\tau_h\tau_h)(\tau_h\tau_h)$, $c_3 = 2.0$	6.1
	$HHZ \to (b\bar{b})(\tau_h\tau_h)(\tau_h\tau_h)$, $c_3 = -1.0$	1.8
	$HHZ \to (b\bar{b})(\tau_h\tau_h)(\tau_h\tau_h)$, $c_3 = -2.0$	1.3
t/W samples	$t\bar{t}\tau\tau$ + jets (LO)	7.609×10^4
	$t\bar{t}H$ (LO)	1.598×10^4
	$t\bar{t}\tau\tau\nu\nu$ + jets (LO)	5.381×10^2
	$t\bar{t}t\bar{t}$ (NLO)	3.869×10^2
$X_{b\bar{b}}Y_{\tau\tau}Y_{\tau\tau}$ samples	$Z\tau\tau\tau\tau(Z \to b\bar{b})$ (NLO)	1.140×10^2
	HZZ (NLO)	0.518×10^2

Table 1: Cross sections for gluon fusion triple Higgs production, VHH production (only ZHH is considered in the $4\tau 2b$ final state) and SM background processes in the $4\tau 2b$ final state at a 100 TeV proton-proton collider. Signal processes with different Higgs self-coupling parameters are considered.

Analysis Strategy



Event Selections

Jet selections

Resolved AK4 Jet		Boosted AK8 Jet	
Variables	Selections	Variables	Selections
p_T	> 20 GeV	p_T	> 300 GeV
$\|\eta\|$	< 2.5	$\|\eta\|$	< 2.5

- B tagging efficiency: 70%
- Tau tagging efficiency: 80%

Hadronic Tau selections

- Electron veto:
  - p_T > 12 GeV and |η| < 2.5
- Muon veto:
  - p_T > 8 GeV and |η| < 2.4

Tau pairing selections

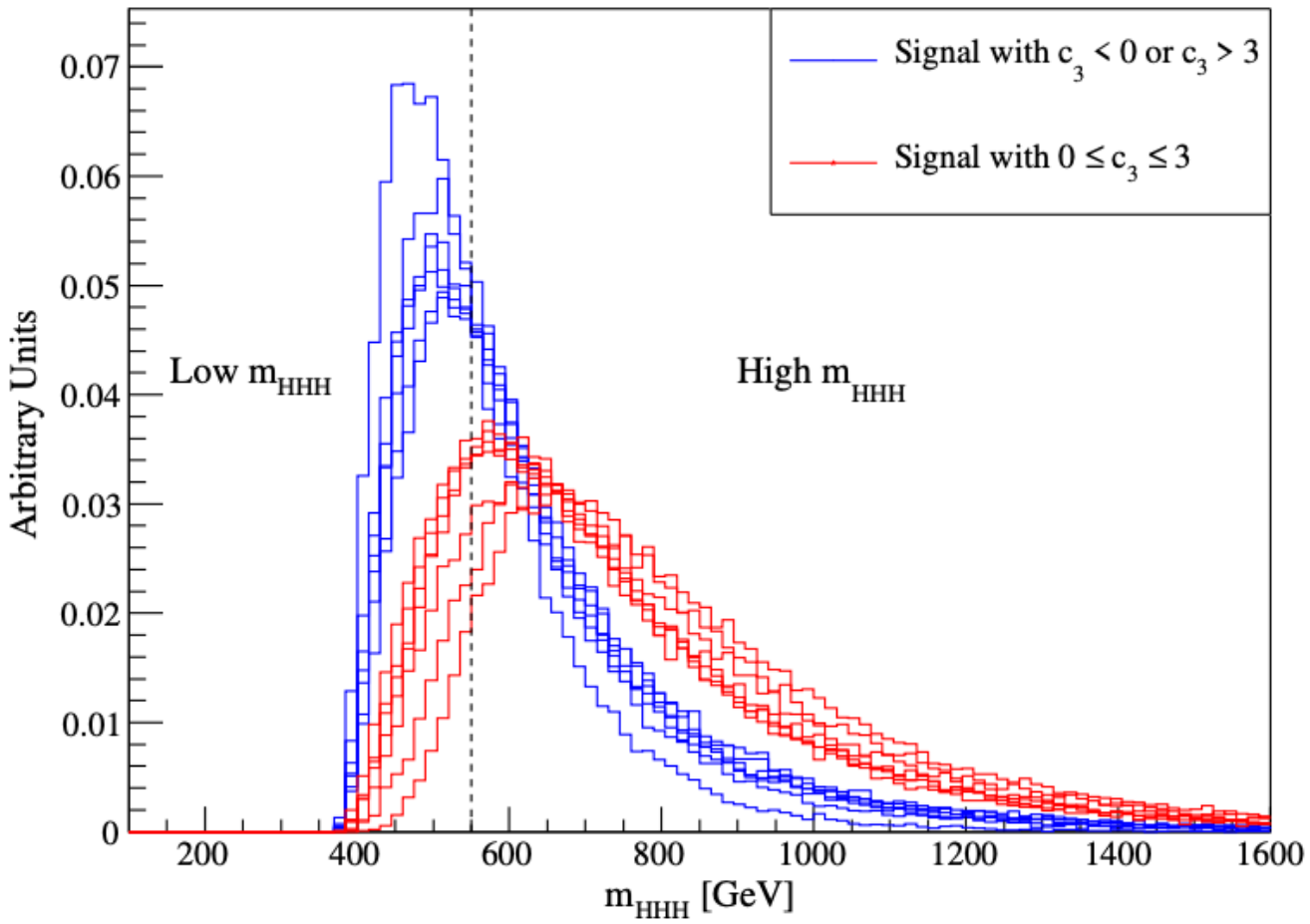
- These 4 tau jets are paired by a minimization of d_{HH}

$$d_{HH} = \frac{|m_{H1} - k m_{H1}|}{\sqrt{1+k^2}}, \mathrm{k} = 1.08$$

Event Selections

Truth level m_{HHH} spectrum

- Varies with trilinear coupling c3
- Signal of $0 \leq c_3 \leq 3$
  - Tend to a higher mass region
- Signal of $c_3 < 0$ or $c_3 > 3$
  - Tend to a lower mass region
- Define two categories according to m_{HHH}



Event Selections

Overall categorization method

- Resolved category:
  - Apply subcategorization by m_{HHH}

Group	Category
Resolved	$m_{\mathrm{HHH}} \leq 550$ GeV
	$m_{\mathrm{HHH}} > 550$ GeV
1 Boosted Higgs	1 boosted H_{bb}
	1 boosted $H_{\tau\tau}$ (leading $\tau\tau$ pair)
2 Boosted Higgs	1 boosted H_{bb} + 1 boosted $H_{\tau\tau}$ (leading $\tau\tau$ pair)
	2 boosted $H_{\tau\tau}$
3 Boosted Higgs	2 boosted $H_{\tau\tau}$ + 1 boosted H_{bb}

- Boosted category:
- Due to the indistinct m_{HHH} distribution in boosted events
- No m_{HHH} based categorization is applied
- Apply subcategorization by number of AK8 Jet

Event Selections

Cut based optimization

- Use a modified $\frac{S}{\sqrt{B}}$: $Z_A = \sqrt{2\left[(s+b)\ln\left(1+\frac{s}{b}\right)-s\right]}$,
- Variables: m_{bb}, $m_{\tau\tau 1}$, $m_{\tau\tau 2}$ and m_{T2}

$$M_{T2}(m_s,\vec{s},m_t,\vec{t},\vec{\not{p}};\chi_1,\chi_2) = \min_{\substack{\vec{p},\vec{q}\ \text{s.t.}\\ \vec{p}+\vec{q}=\vec{\not{p}}}} \left\{\max\left[M_T(m_s,\vec{s},\chi_1,\vec{p}),M_T(m_t,\vec{t},\chi_2,\vec{q})\right]\right\} \qquad (1.1)$$

where the *transverse mass* is given by

$$M_T(m,\vec{v},\chi,\vec{p}) = \sqrt{m^2+\chi^2+2\sqrt{m^2+|\vec{v}|^2}\sqrt{\chi^2+|\vec{p}|^2}-2\vec{v}\cdot\vec{p}},$$

- mT2 can significantly reject the t/W related background

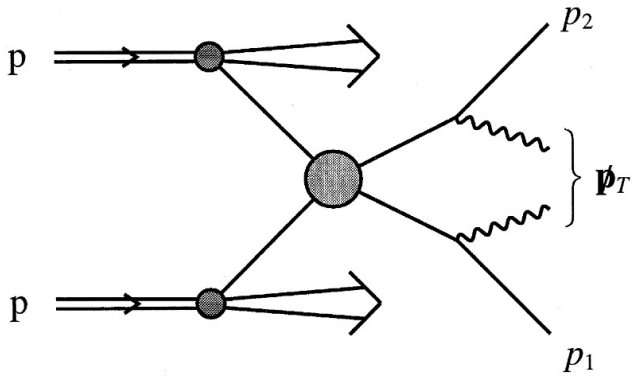
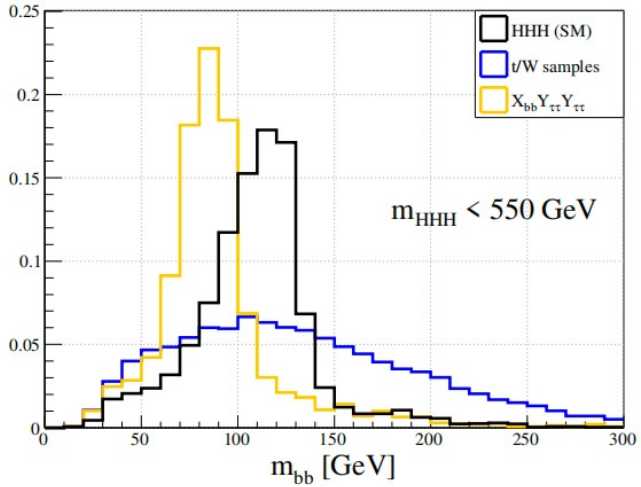
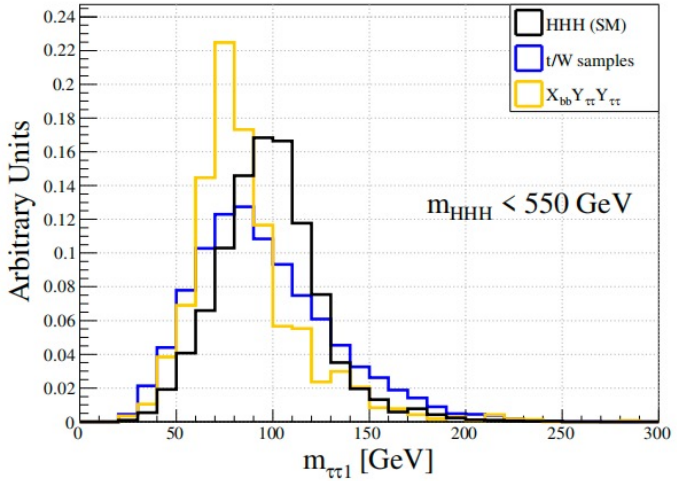


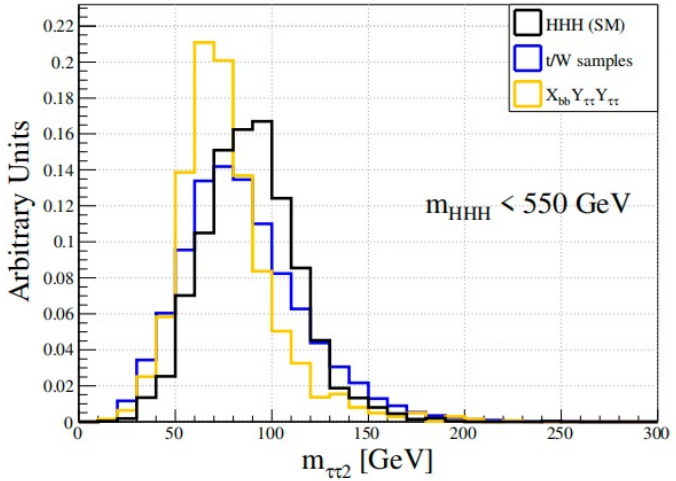
Fig. 1. Diagram of the generic process that we consider. A hadronic collision that leads to a pair of particles being produced, which each decay into one particle that is observed with momenta p_1 and p_2 respectively; and one particle (shown as a wavy lines) that is not directly detected, and whose presence can only be inferred from the missing transverse momentum, $\not{p}_T$.

Event Selections

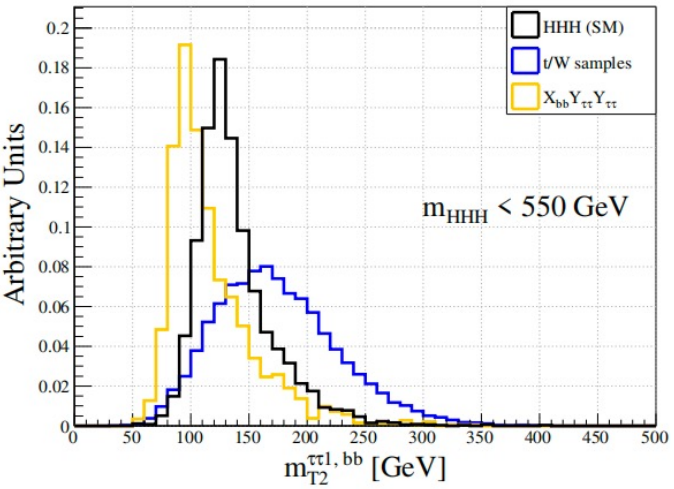
1. Resolved Low m_{HHH} category: mass and mT2

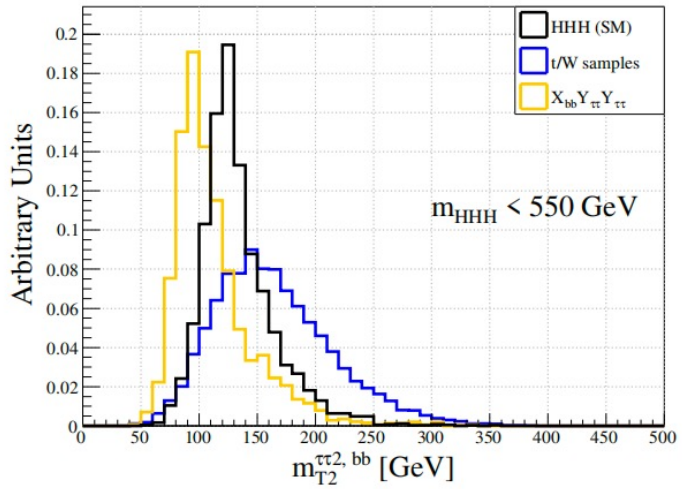


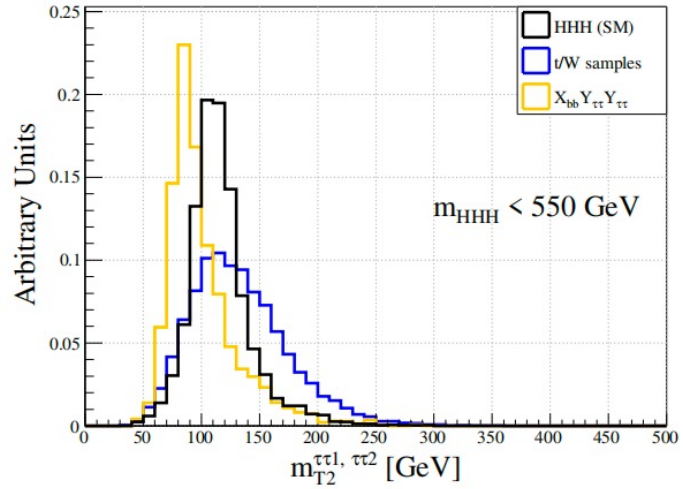




mass



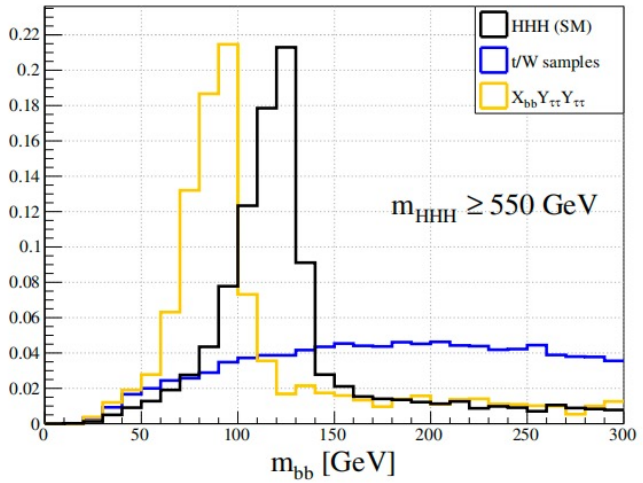


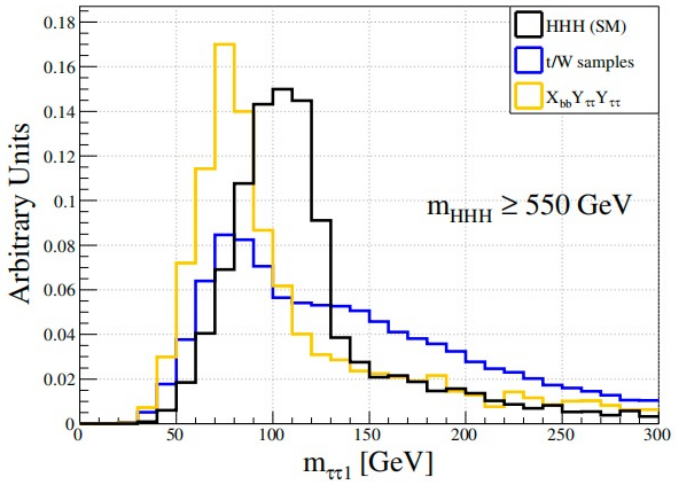


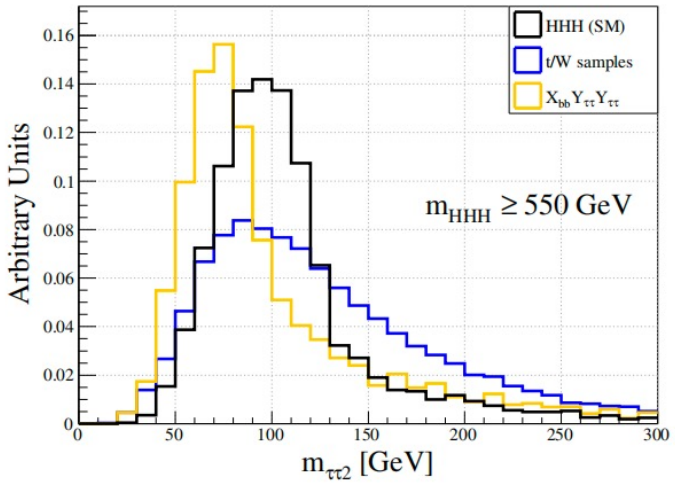
mT2

Event Selections

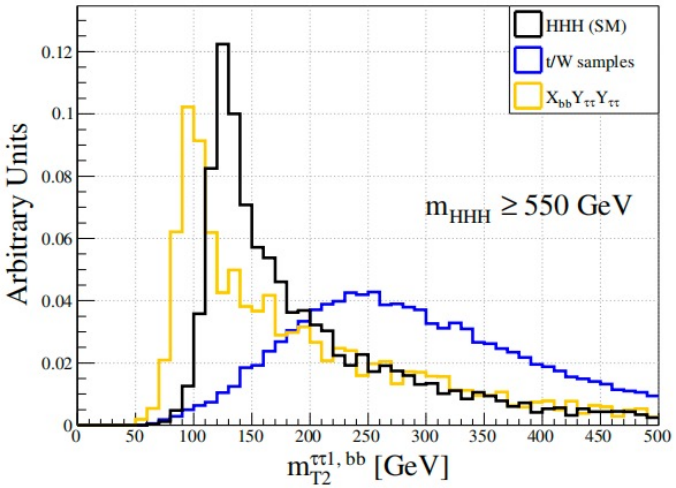
2. Resolved High m_{HHH} category: most powerful category!

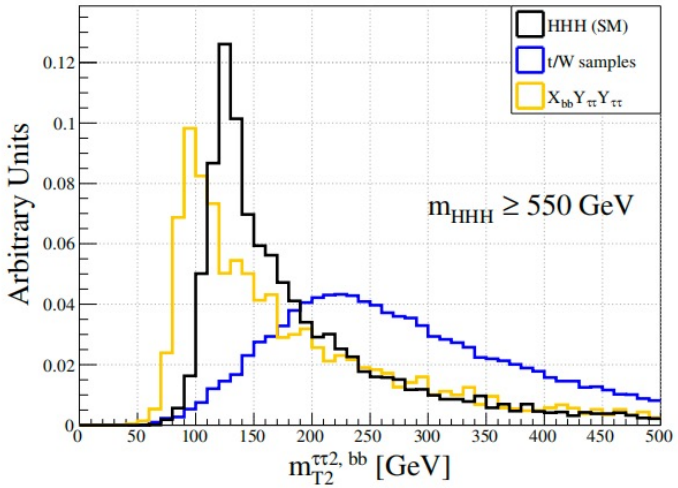


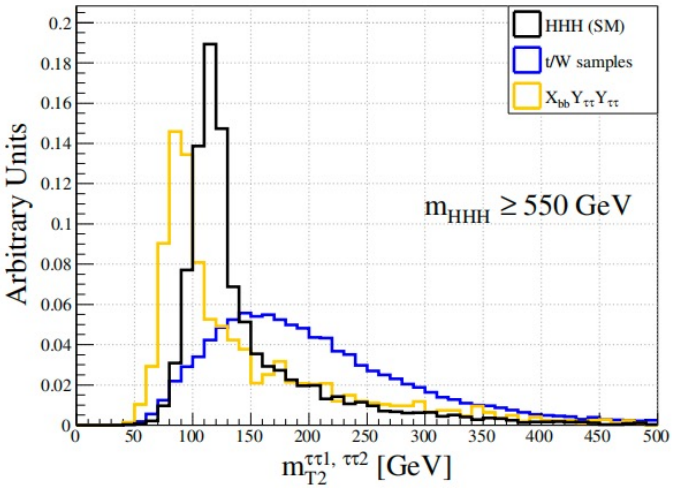




mass



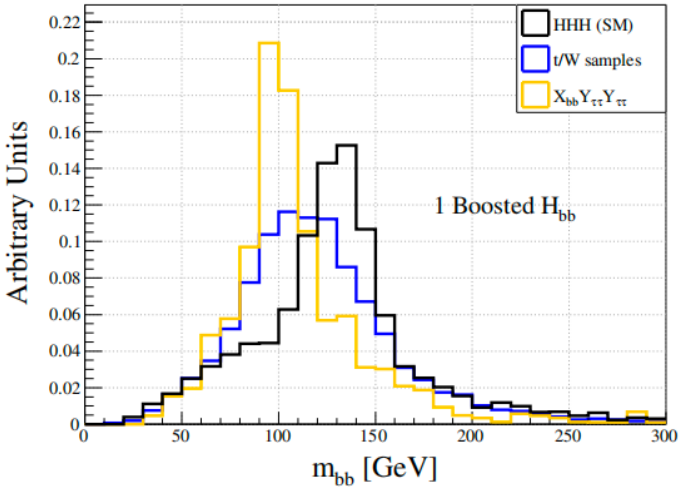


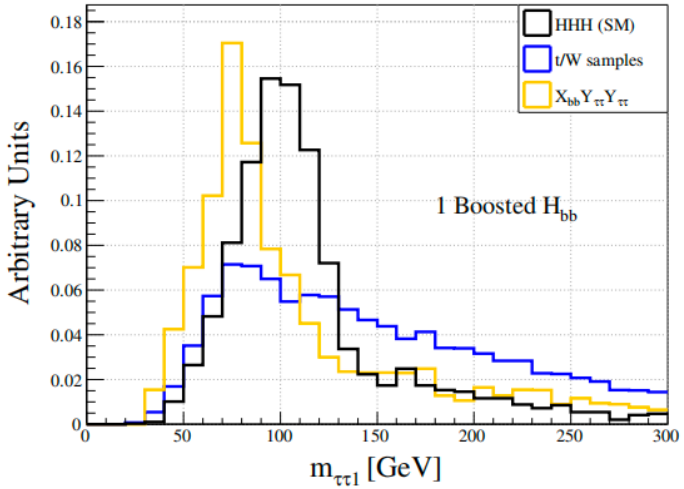


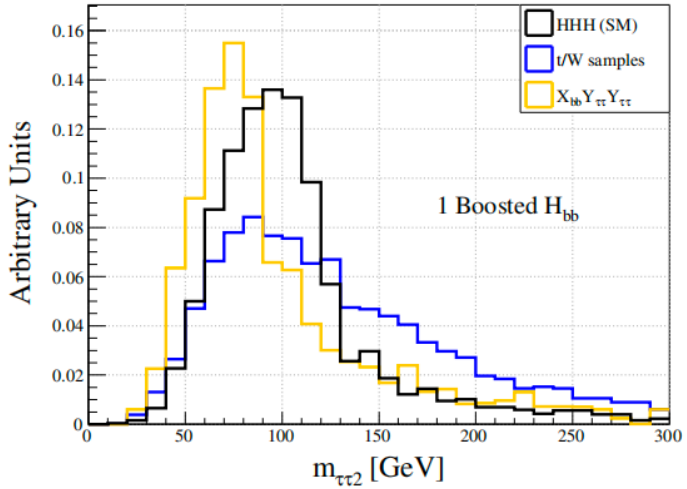
mT2

Event Selections

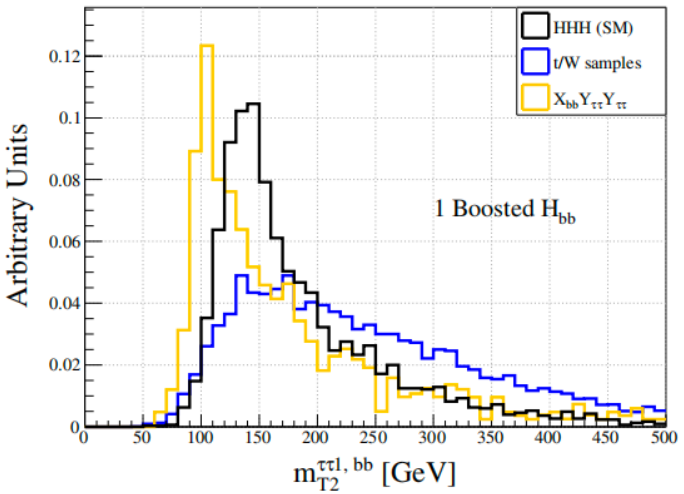
3. One Boosted H_{bb} category: mass and mT2

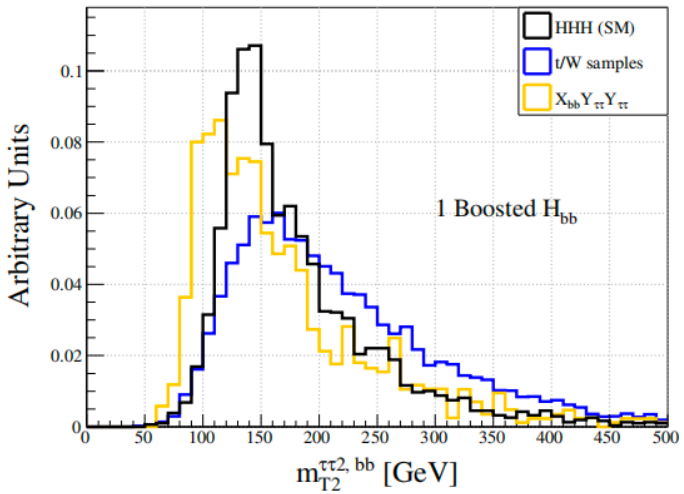


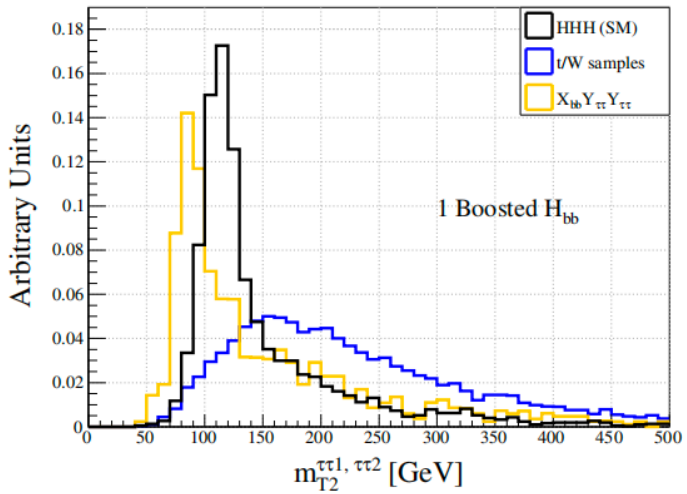




mass



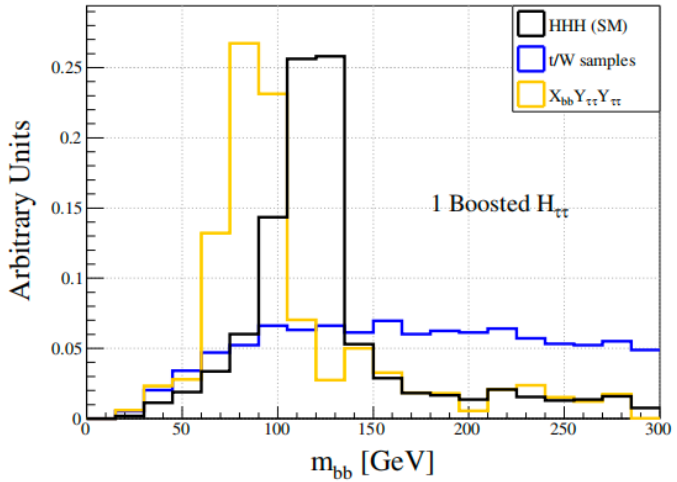


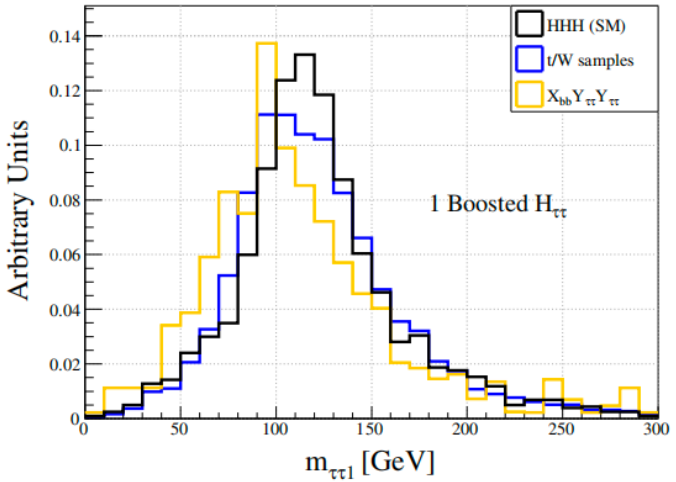


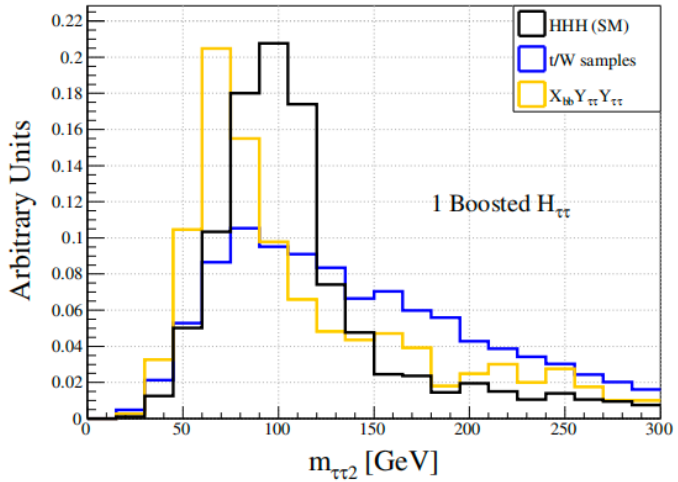
mT2

Event Selections

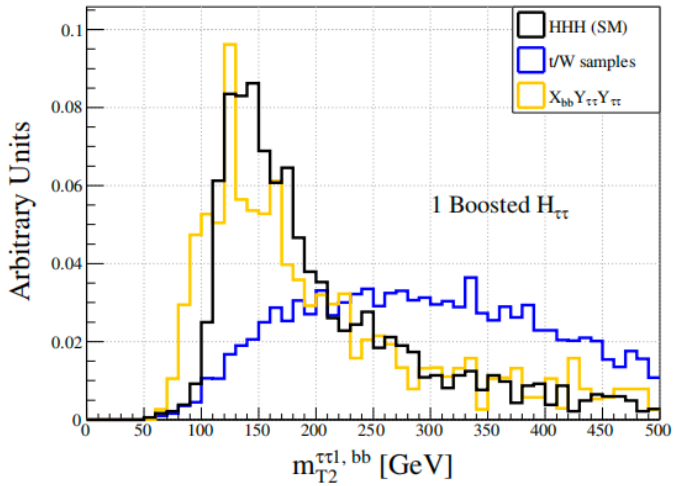
4. One Boosted $H_{\tau\tau}$ category: mass and mT2

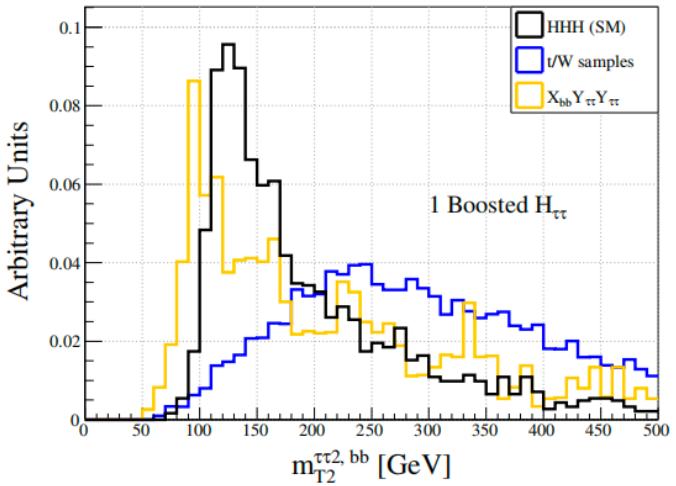


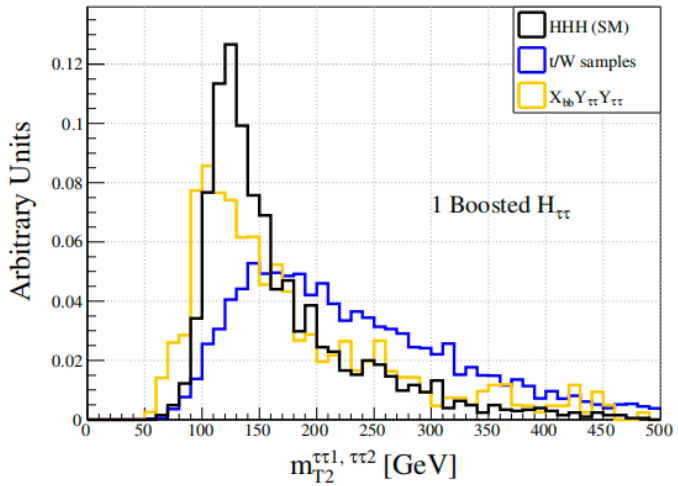




mass



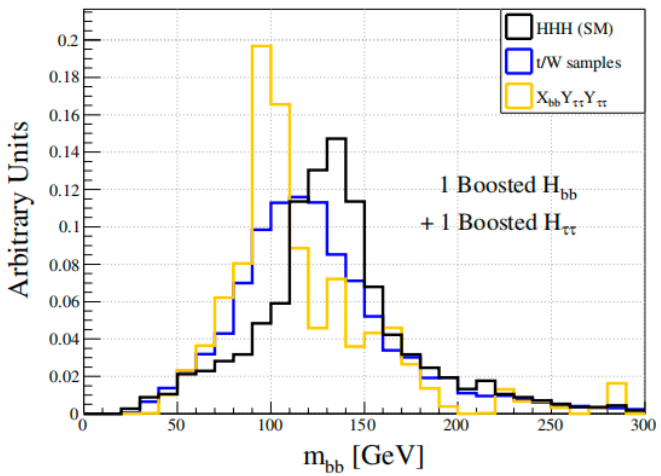


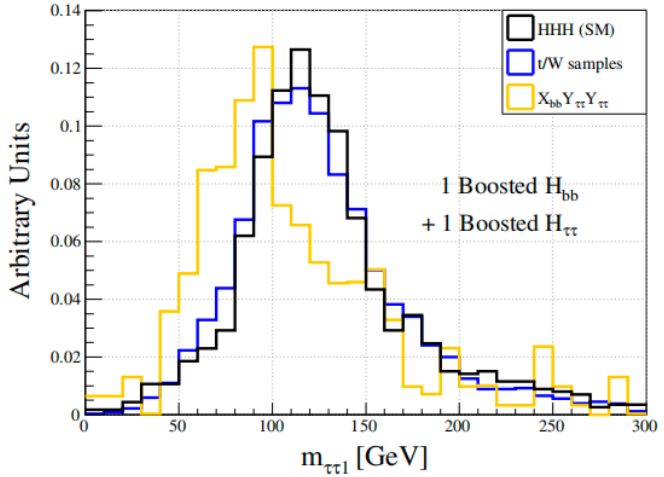


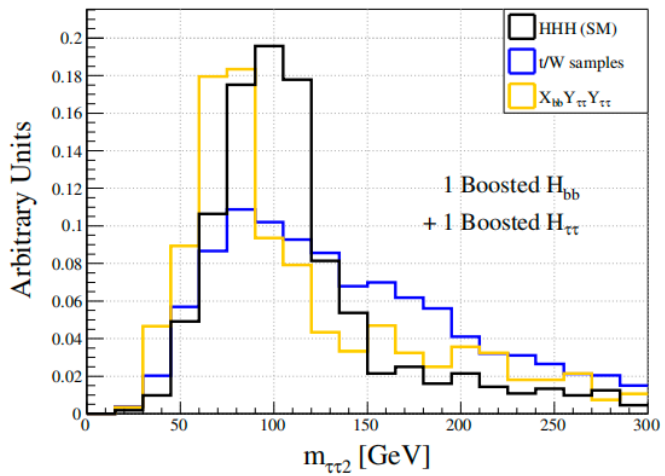
mT2

Event Selections

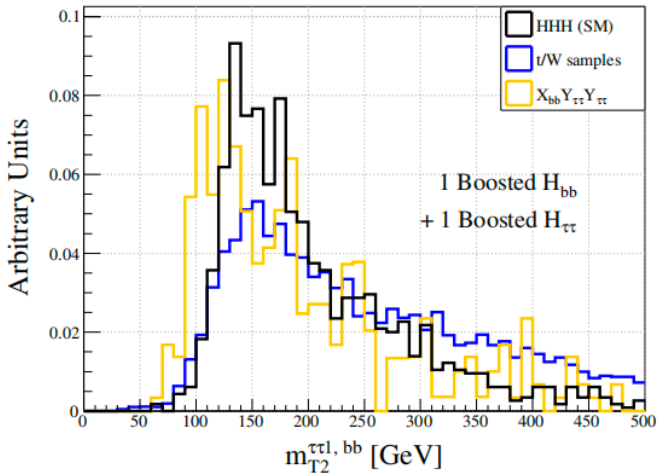
5. Two Boosted $H_{\tau\tau}$ & H_{bb} category: mass and mT2

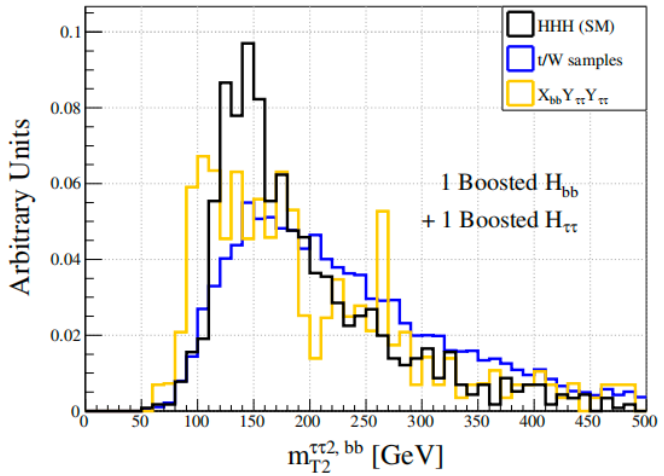


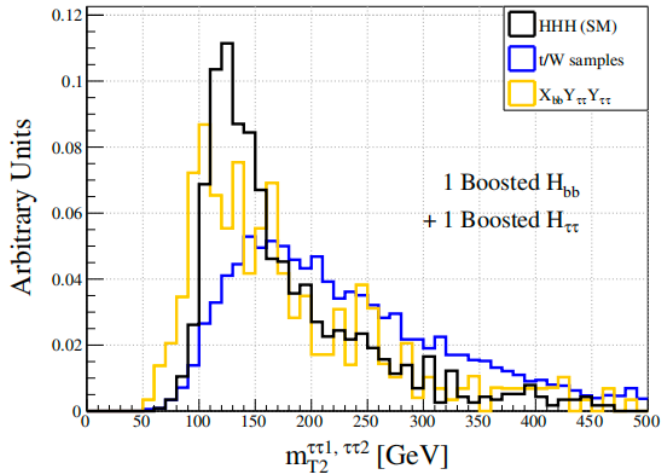




mass



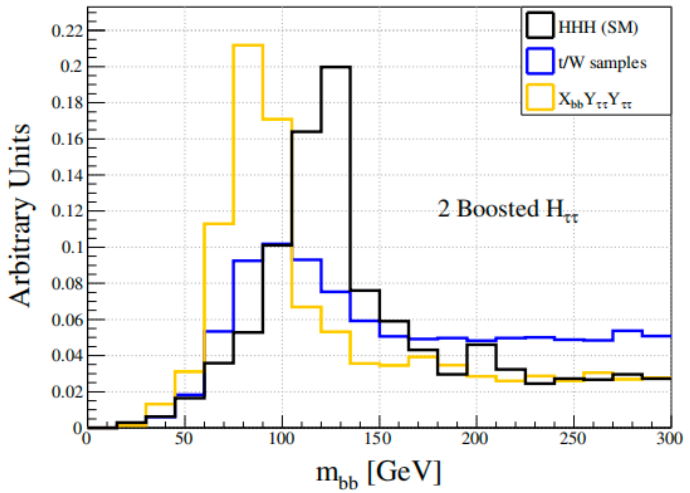


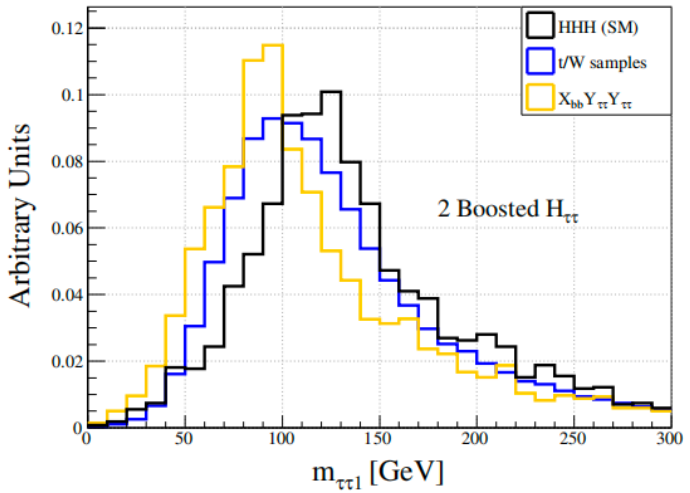


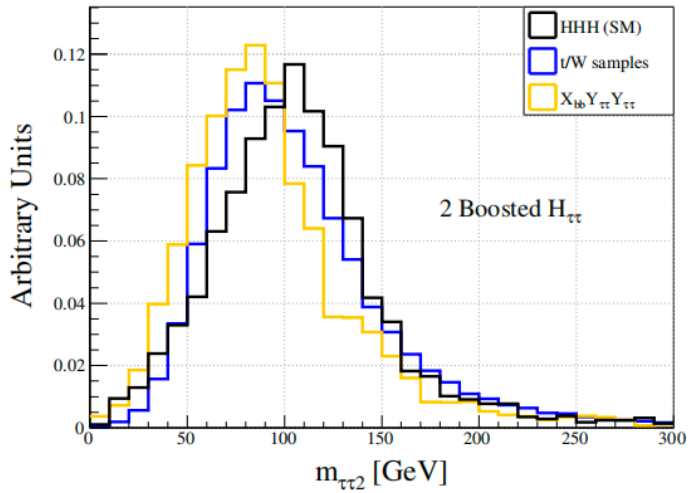
mT2

Event Selections

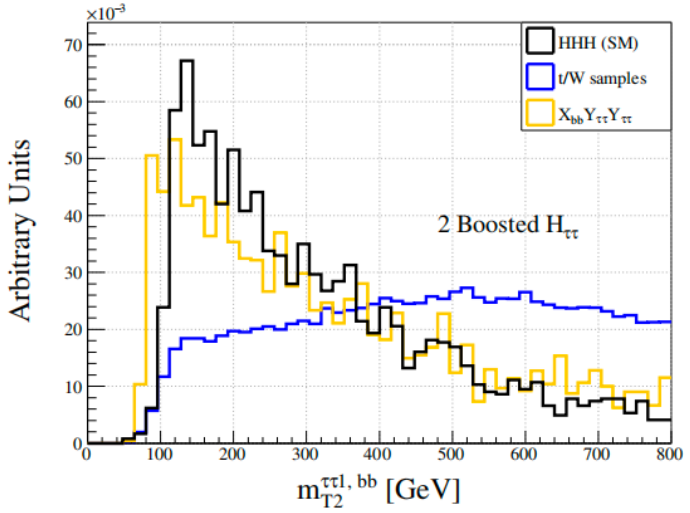
6. Two Boosted $H_{\tau\tau}$ category: mass and mT2

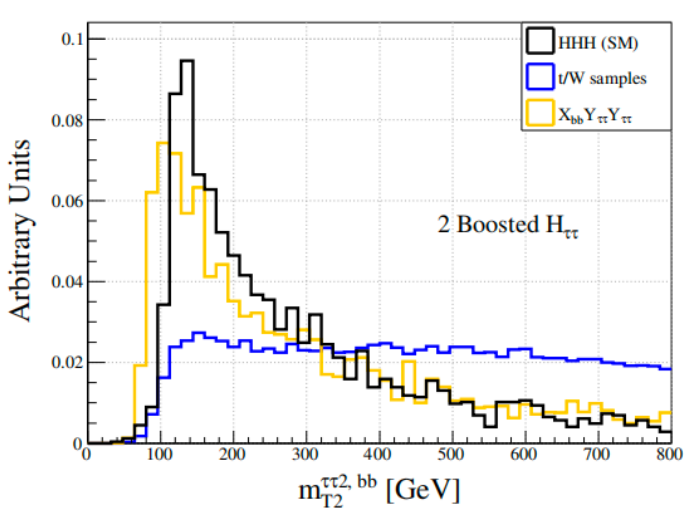


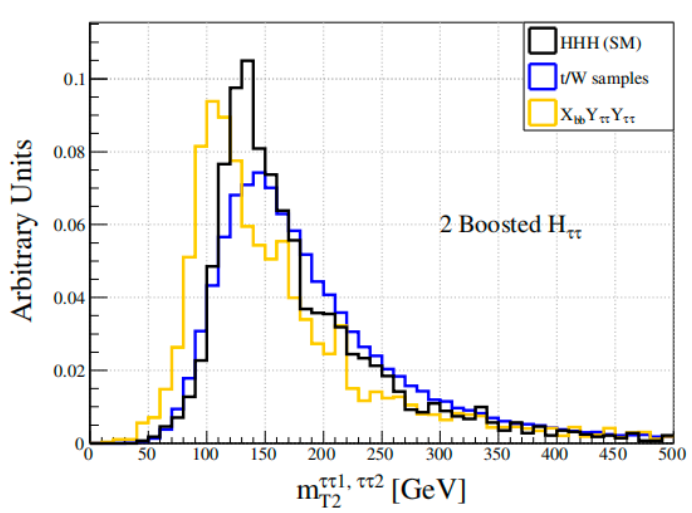




mass



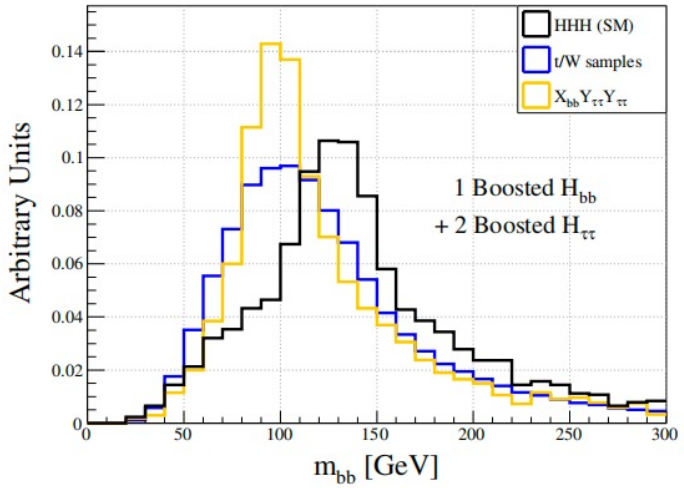


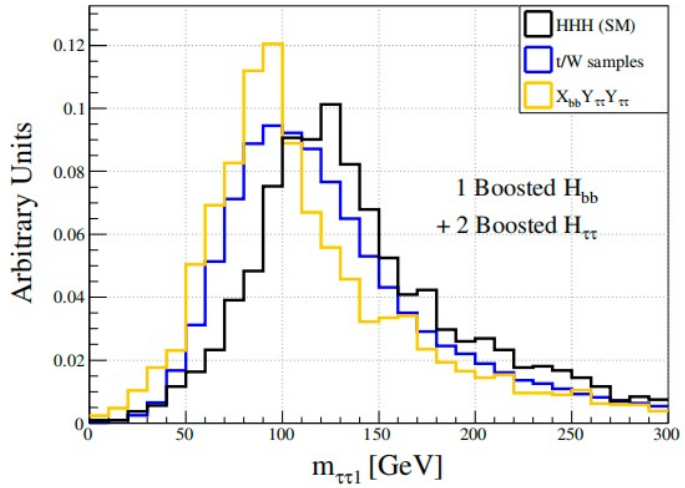


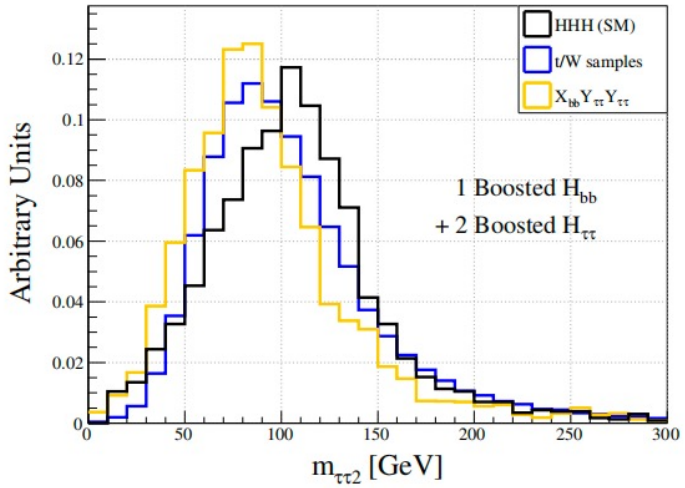
mT2

Event Selections

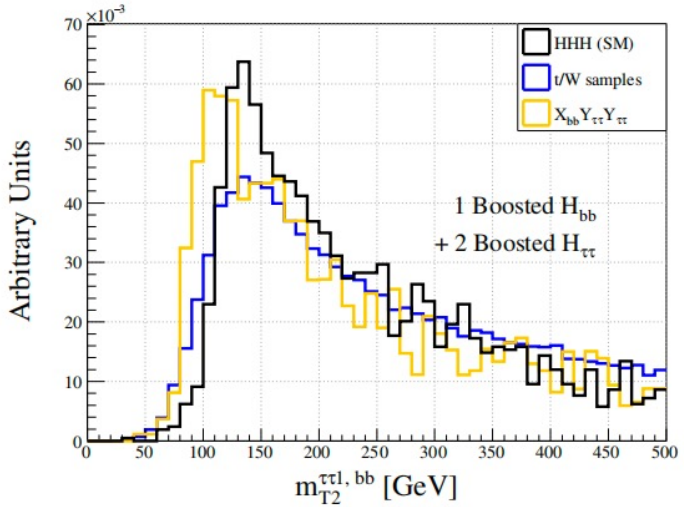
7. Three Boosted category: mass and mT2

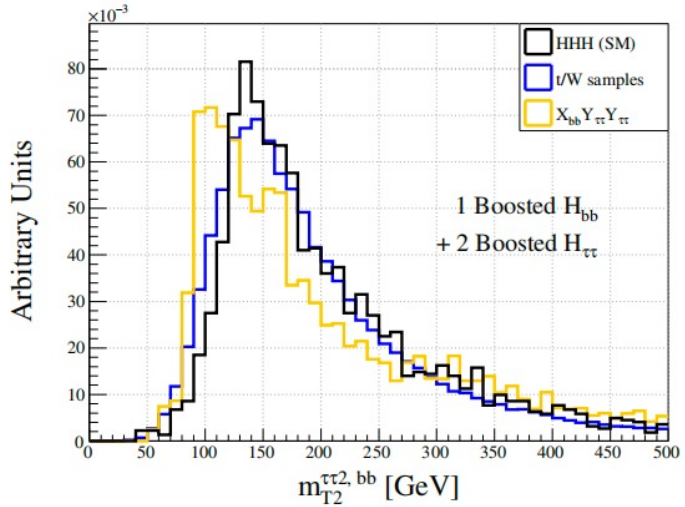


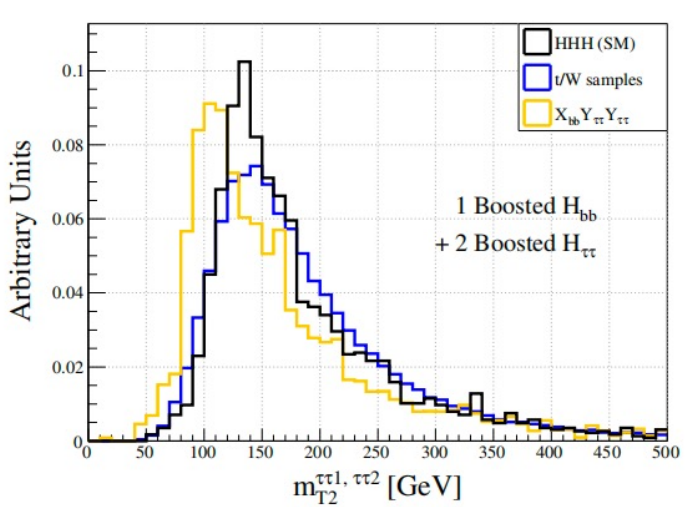




mass







mT2

Event Selections

Final selections applied in the resolved categories

Observable	Low m_{HHH} category	High m_{HHH} category
$p_T^{b,\tau}$	> 20 GeV	> 20 GeV
$\lvert\eta\rvert$	< 2.5	< 2.5
$m_{b\bar{b}}$	$\in [80, 135]$ GeV	$\in [90, 135]$ GeV
$m_{\tau\tau 1}$	$\in [80, 135]$ GeV	$\in [90, 135]$ GeV
$m_{\tau\tau 2}$	$\in [70, 145]$ GeV	$\in [70, 200]$ GeV
$m_{T2}^{\tau\tau 1,\tau\tau 2}$	< 130 GeV	< 130 GeV
$m_{T2}^{\tau\tau 1,b\bar{b}}$	< 150 GeV	< 300 GeV
$m_{T2}^{\tau\tau 2,b\bar{b}}$	< 180 GeV	< 300 GeV

Event Selections

Final selections applied in the boosted categories

Observable	1 Boosted H_{bb}	1 Boosted $H^1_{\tau\tau}$	2 Boosted $H_{\tau\tau}H_{bb}$	2 Boosted $H^{1,2}_{\tau\tau}$	3 Boosted $H^{1,2}_{\tau\tau}H_{bb}$
$p_T^{b,\tau}$			> 20 GeV		
$p_T^{H_i}$			> 300 GeV		
$\lvert\eta\rvert$			< 2.5		
$m_{b\bar{b}}$	$\in [110, 200]$ GeV	$\in [110, 130]$ GeV	$\in [110, 300]$ GeV	$\in [100, 150]$ GeV	$\in [110, 300]$ GeV
$m_{\tau\tau 1}$	$\in [85, 135]$ GeV	$\in [100, 300]$ GeV	$\in [50, 300]$ GeV	$\in [50, 300]$ GeV	$\in [50, 300]$ GeV
$m_{\tau\tau 2}$	$\in [60, 200]$ GeV	$\in [70, 130]$ GeV	$\in [50, 130]$ GeV	$\in [50, 300]$ GeV	$\in [50, 300]$ GeV
$m_{T2}^{\tau\tau 1,\tau\tau 2}$	< 130 GeV	< 180 GeV	< 300 GeV	< 300 GeV	< 300 GeV
$m_{T2}^{\tau\tau 1,b\bar{b}}$	< 300 GeV	< 150 GeV	< 300 GeV	< 300 GeV	< 300 GeV
$m_{T2}^{\tau\tau 2,b\bar{b}}$	< 300 GeV	< 300 GeV	< 300 GeV	< 300 GeV	< 300 GeV

Event Selections

Event yields and significance after sequential cuts

Category	Cut flow	HHH (SM)	HHH+VHH (SM)	t/W samples	$X_{b\bar{b}}Y_{\tau\tau}Y_{\tau\tau}$	$Z_A(S_1)$	$Z_A(S_2)$
Resolved low m_{HHH}	Baseline	1.72	2.86	6437.39	5.86	0.02	0.03
	Mass window	0.72	1.13	741.15	1.01	0.03	0.04
	m_{T2}	0.51	0.82	228.40	0.80	0.04	0.06
Resolved high m_{HHH}	Baseline	3.53	5.14	13560.52	8.37	0.03	0.04
	Mass window	0.99	1.23	222.69	0.40	0.08	0.09
	m_{T2}	0.72	0.90	37.74	0.24	0.22	0.23
1 Boosted $H_{b\bar{b}}$	Baseline	1.48	2.13	3740.43	3.23	0.03	0.03
	Mass window	0.54	0.67	438.26	0.30	0.03	0.03
	m_{T2}	0.37	0.46	70.45	0.17	0.04	0.05
1 Boosted $H_{\tau\tau}$	Baseline	0.95	1.43	2954.61	0.04	0.03	0.03
	Mass window	0.16	0.17	33.23	0.02	0.03	0.03
	m_{T2}	0.06	0.06	2.26	< 0.01	0.04	0.04
2 Boosted $H_{b\bar{b}}H_{\tau\tau}$	Baseline	0.53	0.80	1823.57	0.02	0.02	0.02
	Mass window	0.28	0.37	483.37	0.02	0.02	0.02
	m_{T2}	0.25	0.32	264.86	0.18	0.02	0.02
2 Boosted $H_{\tau\tau}^{1,2}$	Baseline	1.36	3.78	30653.17	10.22	< 0.01	0.02
	Mass window	0.36	0.69	1680.29	1.00	< 0.01	0.02
	m_{T2}	0.27	0.49	1021.44	0.68	< 0.01	0.02
3 Boosted $H_{b\bar{b}}H_{\tau\tau}^{1,2}$	Baseline	1.12	3.38	33788.98	8.22	< 0.01	0.02
	Mass window	0.68	1.85	15968.47	3.02	< 0.01	0.01
	m_{T2}	0.41	0.89	6110.52	0.04	< 0.01	0.01

- The resolved high m_{HHH} category provide the strongest sensitivity
- The mT2 variable shows great performance
- Events with one boosted Higgs provide complementary sensitivity
- Multiple boosted Higgs events shows negligible contribution to the overall sensitivity

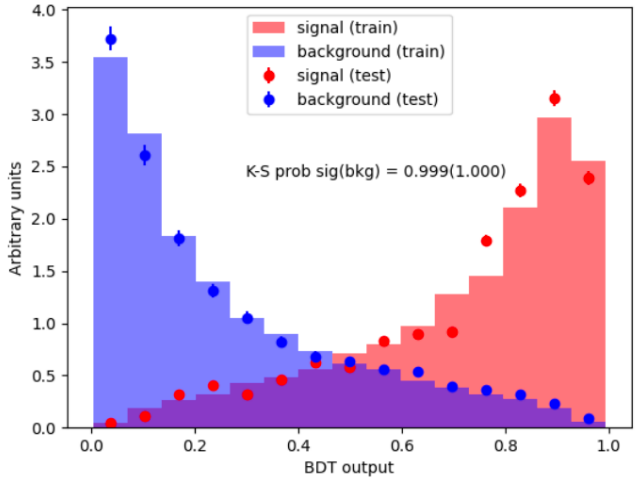
Event Selections

BDT analysis

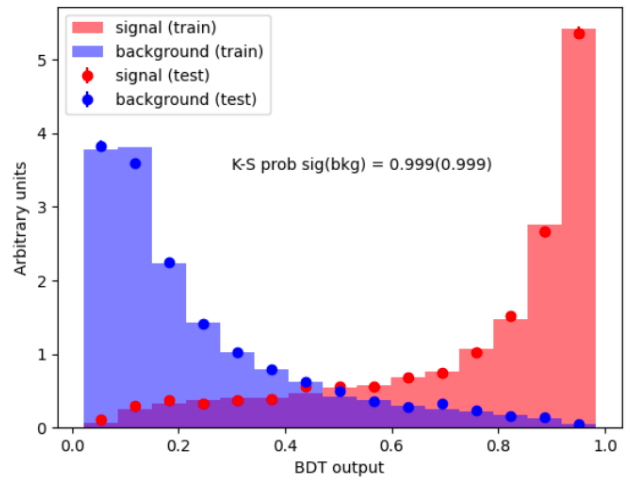
- In the Resolved category, the statistic is sufficient to employ a BDT training
- Summary of input variables for the XGBoost BDT training

Input variables	Description
$p_T^{b_{1,2}}, p_T^{\tau_{1,2,3,4}}, p_T^{bb}, p_T^{\tau\tau 1}, p_T^{\tau\tau 2}, p_T^{4\tau}, p_T^{4\tau 2b}$	Transverse momentum (p_T) of the two b-jets, four τ, di-b-jets, two τ pairs, 4τ and 4τ2b system.
$\eta_{b_{1,2}}, \eta_{\tau_{1,2,3,4}}, \eta_{bb}, \eta_{\tau\tau 1}, \eta_{\tau\tau 2}$	Pseudorapidity (η) of the two b-jets, four τ, di-b-jets, two τ pairs.
$m_{bb}, m_{\tau\tau 1}, m_{\tau\tau 2}, m_{4\tau}, m_{4\tau 2b}$	Invariant mass of the di-b-jets, two τ pairs, 4τ and 4τ2b system.
ΔR_{bb}, $\Delta R_{\tau\tau 1}$, $\Delta R_{\tau\tau 2}$, $\Delta R_{bb,\tau\tau 1}$, $\Delta R_{bb,\tau\tau 2}$, $\Delta R_{\tau\tau 1,\tau\tau 2}$	Angular distance ($\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$) between the constituents of the di-b-jets, two τ pairs. ΔR between the di-b-jets and τ pairs ($\tau\tau 1, \tau\tau 2$), ΔR between the two τ pairs
$\Delta\eta_{bb}$, $\Delta\eta_{\tau\tau 1}$, $\Delta\eta_{\tau\tau 2}$, $\Delta\eta_{bb,\tau\tau 1}$, $\Delta\eta_{bb,\tau\tau 2}$, $\Delta\eta_{\tau\tau 1,\tau\tau 2}$	Difference in pseudorapidity ($\Delta\eta$) for the di-b-jets, two τ pairs. $\Delta\eta$ between the bb-system and each τ pairs , $\Delta\eta$ between two τ pairs
$\Delta\phi_{bb}$, $\Delta\phi_{\tau\tau 1}$, $\Delta\phi_{\tau\tau 2}$, $\Delta\phi_{bb,\tau\tau 1}$, $\Delta\phi_{bb,\tau\tau 2}$, $\Delta\phi_{\tau\tau 1,\tau\tau 2}$	Difference in azimuthal angle ($\Delta\phi$) for the di-b-jets, two τ pairs. $\Delta\phi$ between the bb-system and τ pairs, $\Delta\phi$ between two τ pairs
$\frac{p_T^{\tau_{1,2}}}{m_{\tau\tau 1}}$, $\frac{p_T^{\tau_{3,4}}}{m_{\tau\tau 2}}$, $\frac{p_T^{b_{1,2}}}{m_{bb}}$, $\frac{p_T^{bb}}{m_{bb}}$	Ratios of the p_T of single τ/b-jet/di-b-jets to the invariant mass of τ pairs /di-b-jets
$\frac{p_T^{\tau\tau_{1,2}}}{m_{4\tau}}$, $\frac{p_T^{\tau\tau_{1,2}}}{m_{4\tau 2b}}$, $\frac{p_T^{4\tau}}{m_{4\tau 2b}}$, $\frac{p_T^{2b}}{m_{4\tau 2b}}$	Ratios of the p_T of τ pairs/4τ system/4τ2b system to the invariant mass of 4τ system/$4\tau 2b$ system
$m_T^{\tau_{1,2,3,4}}, m_T^{\tau\tau_{1,2}}, m_T^{bb}, m_T^{total}$	Transverse mass (m_T) of the single τ, τ pairs, di-b-jets and total $4\tau 2b$ system
$m_{T2}^{\tau\tau 1}, m_{T2}^{\tau\tau 2}, m_{T2}^{bb}$, $m_{T2}^{\tau\tau 1,bb}, m_{T2}^{\tau\tau 2,bb}, m_{T2}^{\tau\tau 1,\tau\tau 2}$	Stransverse mass (m_{T2}) of τ pairs, di-b-jets, m_{T2} between the τ pairs and di-b-jets, and between the two τ pairs

- Train two models separately for low and high m_{HHH} categories
- Good performance without overfitting



(a) Low m_{HHH} category



(b) High m_{HHH} category

Results

Significance of cut-based and BDT-based analyses

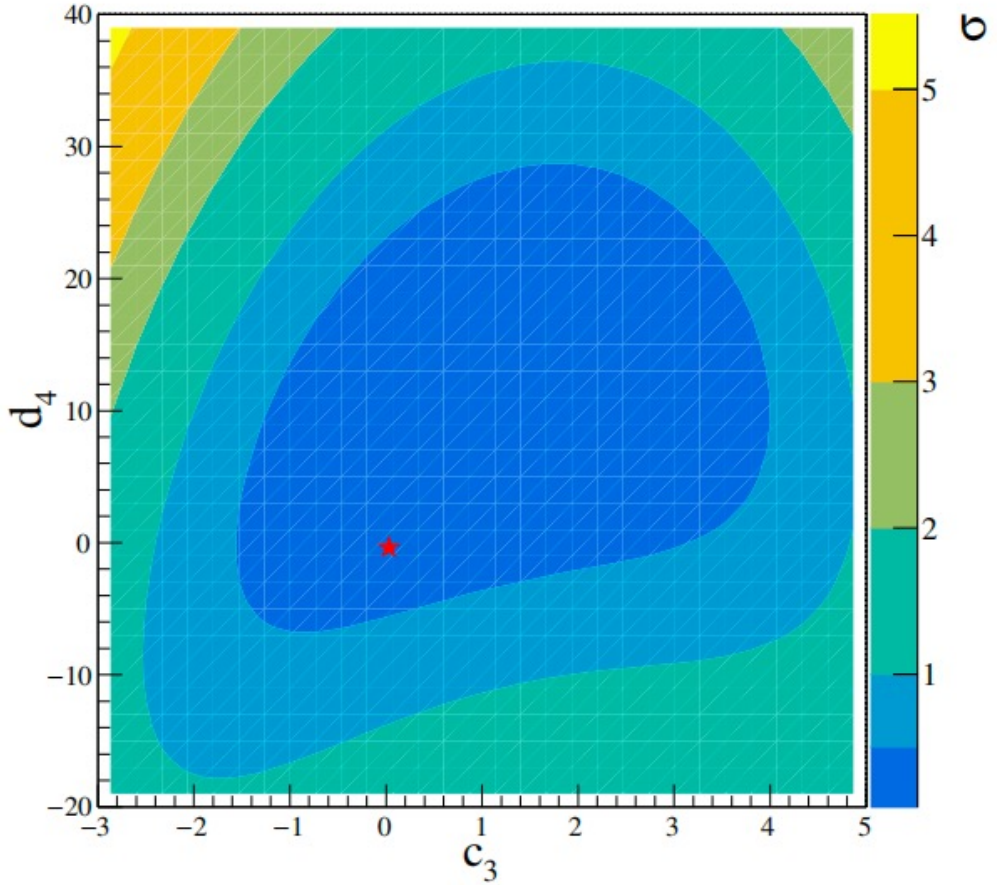
- BDT method consistently outperforms the cut-based approach
  - Improvements ranging from 60% to 150%
- SM case: 0.39 σ
- BSM case: can reach 5σ in c3 $\lesssim -1$ and d4 $\gtrsim 10$ region

HHH signal	σ (cut-based)	σ (BDT)	Improvement
SM $c_3 = 0, d_4 = 0$	0.239	0.385	61.44%
BSM $c_3 = 4, d_4 = 9$	0.478	1.237	158.82%
BSM $c_3 = -2, d_4 = -11$	0.806	1.825	126.42%
BSM $c_3 = 3, d_4 = -21$	2.140	4.095	91.34%
BSM $c_3 = 0, d_4 = -21$	1.714	3.139	83.21%
BSM $c_3 = -2, d_4 = 19$	1.548	3.622	134.1%
BSM $c_3 = -3, d_4 = 9$	2.171	5.504	153.4%
BSM $c_3 = -3, d_4 = 14$	2.578	6.327	145.4%

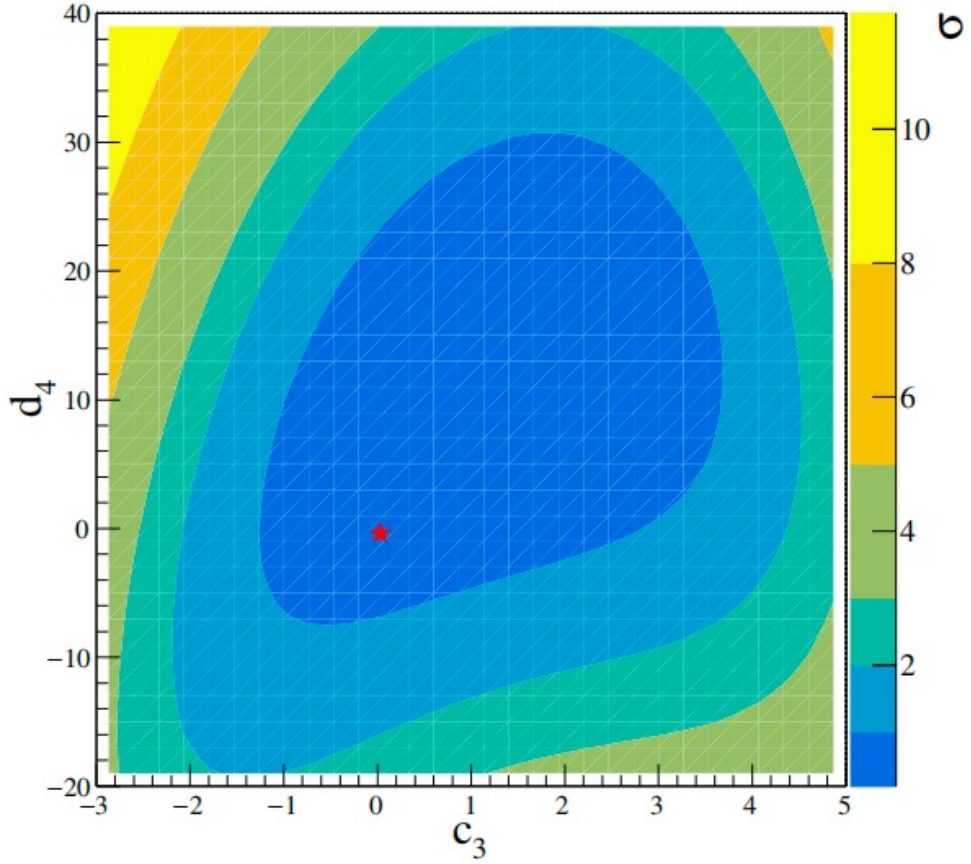
Results

Scenario1 Pure HHH signal: Significance contour on (c3, d4) plane

- VHH is considered as background in this case



Cut-based

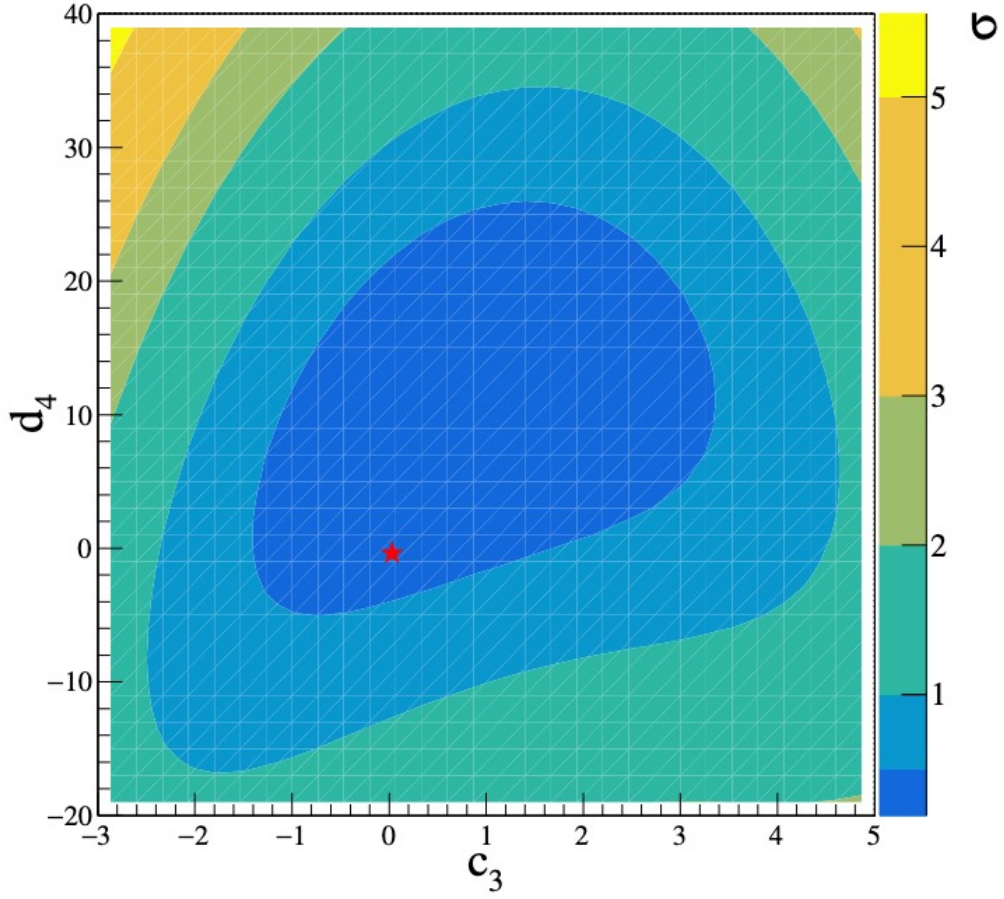


BDT

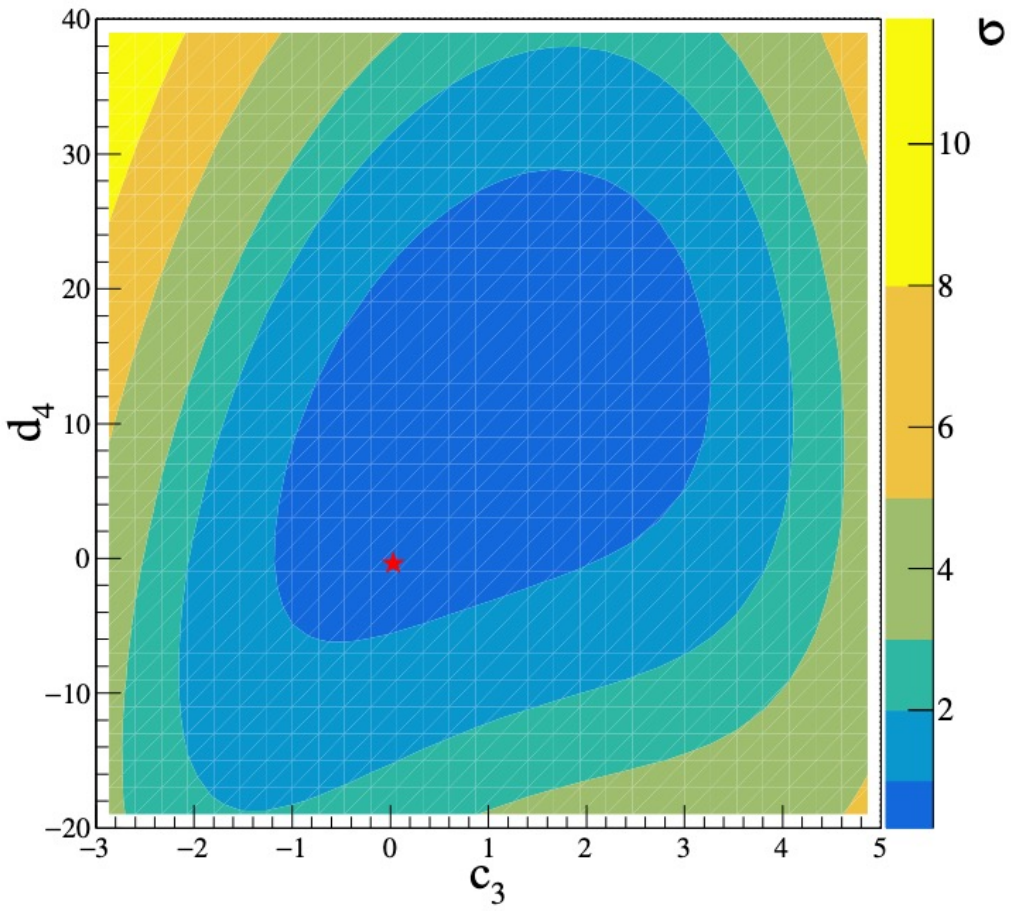
Results

Scenario2 HHH+VHH signal: Significance contour on (c3, d4) plane

- VHH exhibits a non-linear dependence on c3, provide extra constraints on positive $c_3$region



Cut-based



BDT

Summary

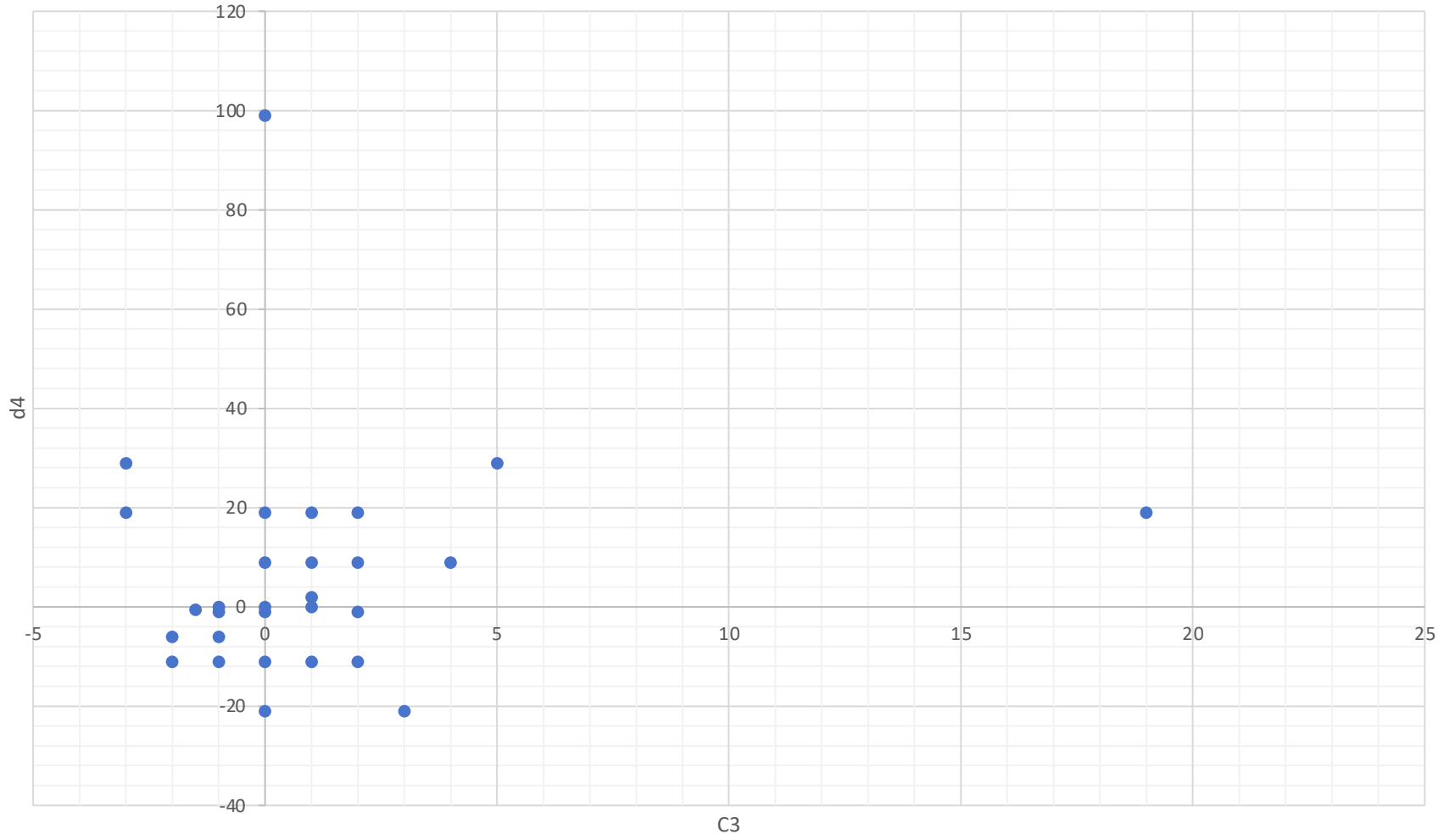
- First study of HHH production in the 4τ2b channel at a 100 TeV collider, with both resolved and boosted reconstruction techniques.
- The 4τ2b channel demonstrate the ability to achieve good sensitivity in this challenging final state, especially in c3 $\lesssim -1$ and d4 $\gtrsim 10$ BSM region where 5 σ in significance could be reached.
- The coupling-dependent categorization of the m_{HHH} phase space proved particularly effective.
- Employed two complementary approaches: a traditional cut-based optimization and an advanced BDT-based analysis. The BDT training shows significant improvements in sensitivity.
- This work has been published in JHEP. For more details, see:
- https://doi.org/10.1007/JHEP08(2025)040

Thanks

Back up

Progress of 4τ2b channel

- Signal scan list



Optimization

Estimate different variables, including:

- mass of bb, taupair, bbtautau, bbtautautautau
- mT, mT2, MET
- Pt_over_mass, deltaR

Use the most powerful: mass and mT2 to optimization

- Full cut scan For each category

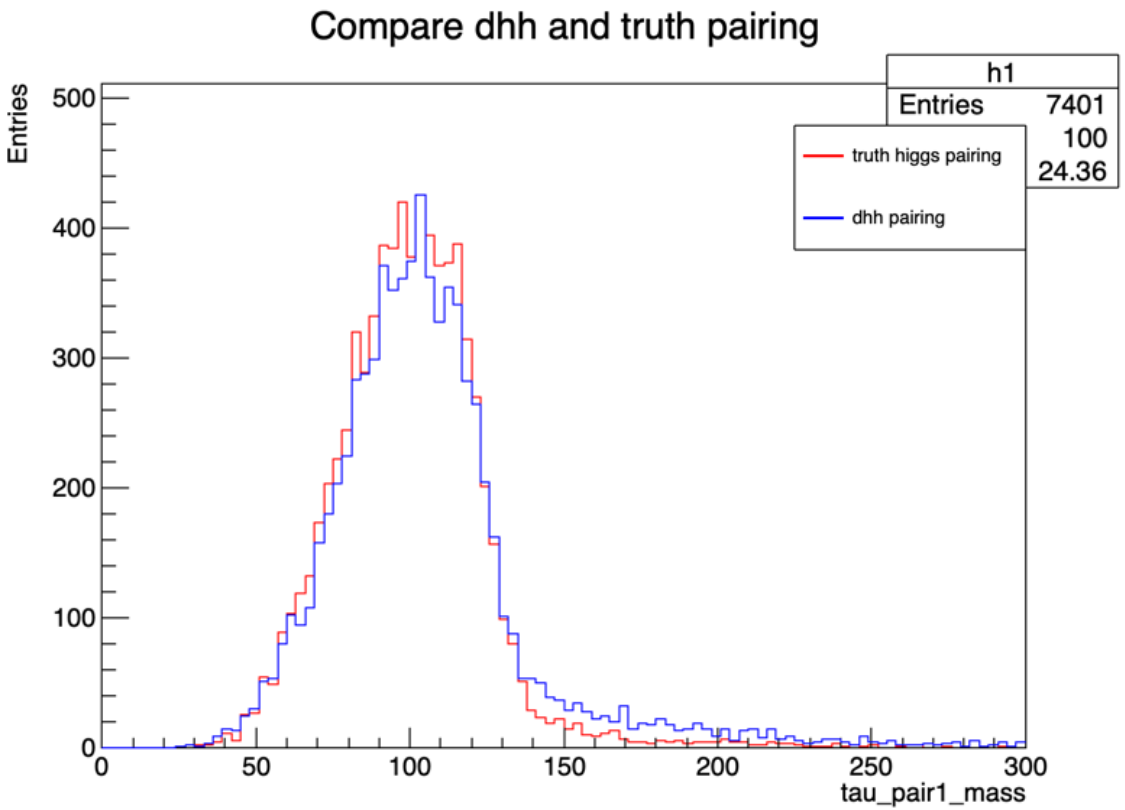
Progress of 4τ2b channel

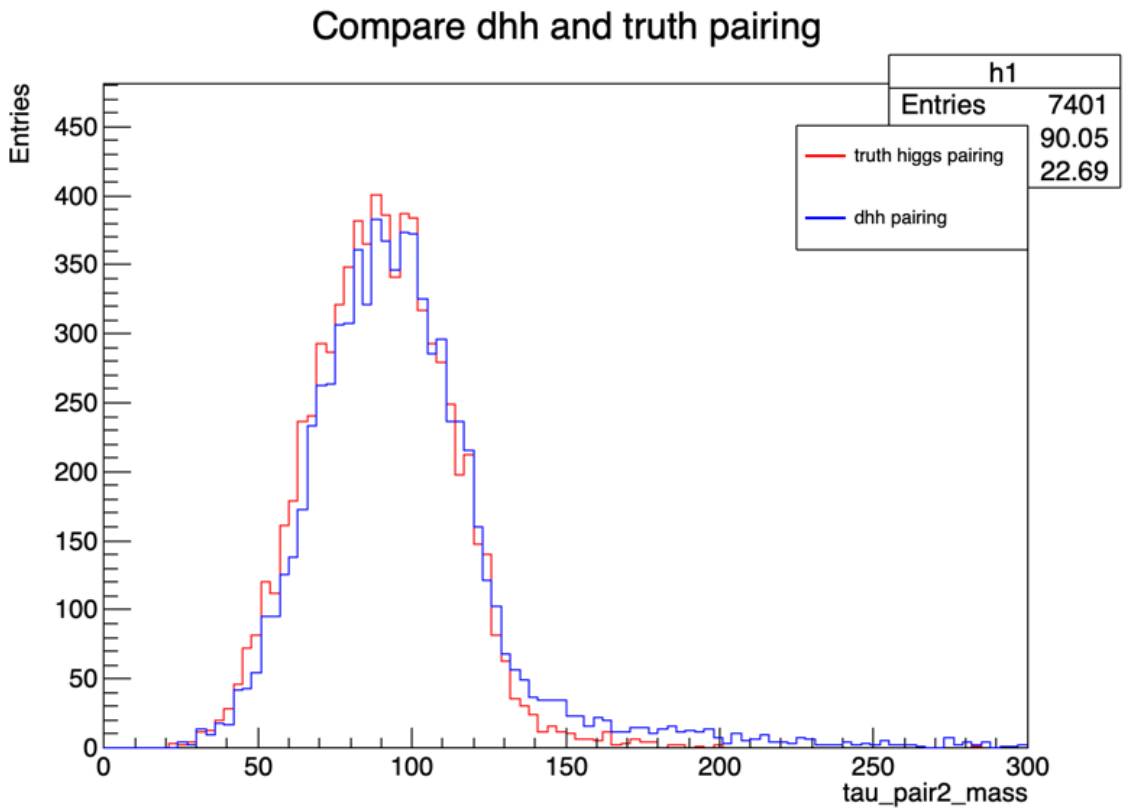
- HHH Truth filter
- 50000 events
- After truth filter (4tau 2b) : 22306 events 44.4%

			test
• 4 Tau hadron decay filter :	$(0.65)^4 = 17.8\%$	3955 events expected	3998
• 3 Tau hadron 1 tau lep :	$C_4^1(0.65)^3(0.35)^1 = 38.4\%$	8533 events expected	8658
• 2 Tau hadron 2 tau lep :	$C_4^2(0.65)^2(0.35)^2 = 31.1\%$	6911 events expected	6851
• 1 Tau hadron 3 tau lep :	$C_4^3(0.65)^1(0.35)^3 = 11.1\%$	2466 events expected	2493
• 4 Tau lep decay filter. :	$(0.35)^4 = 1.5\%$	333 events expected	306

Progress of 4τ2b channel

- tau pairing accuracy of 77.9%

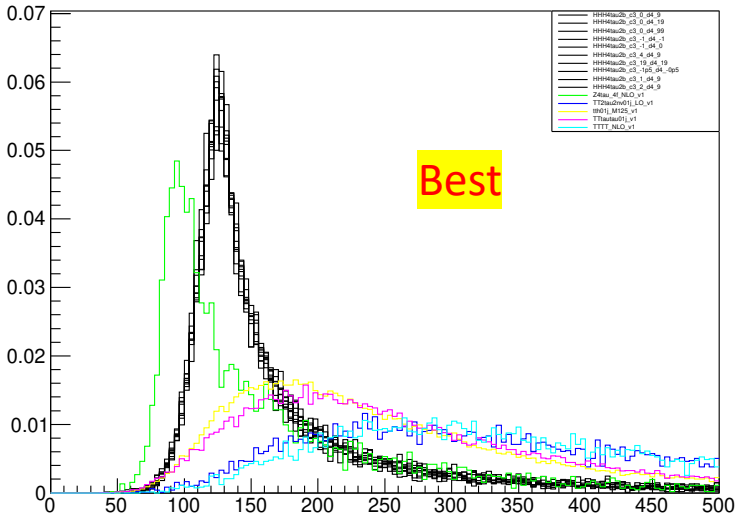




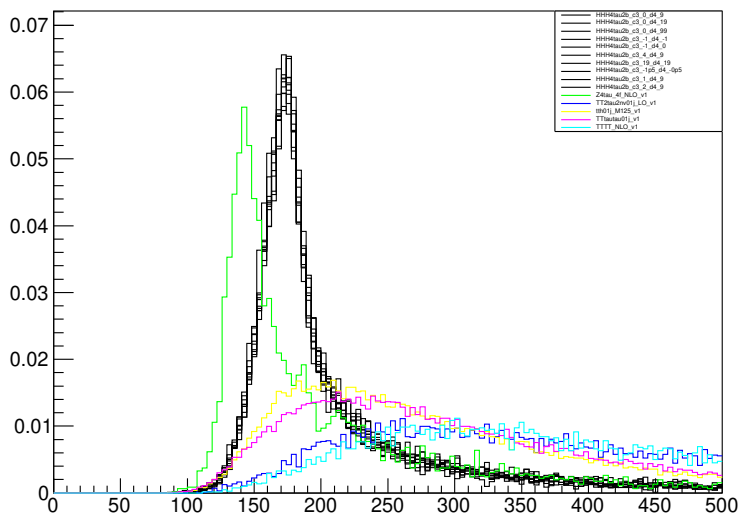
Progress of 4τ2b channel

- Asymmetric MT2:

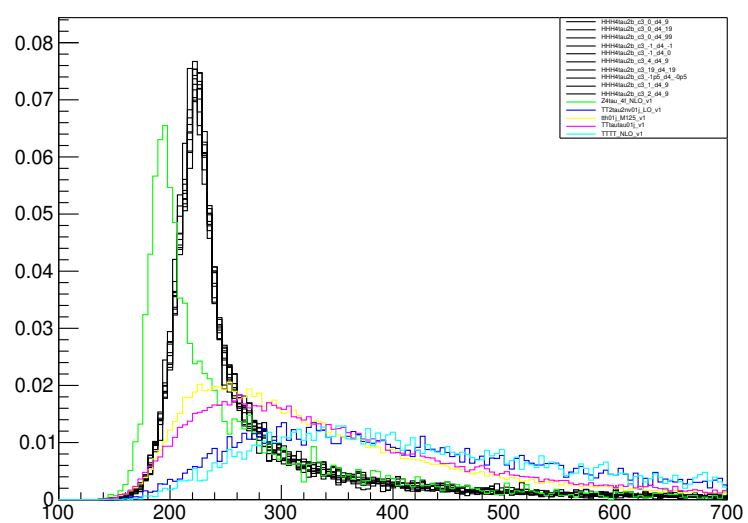
mT2_taupair1_2bj_0



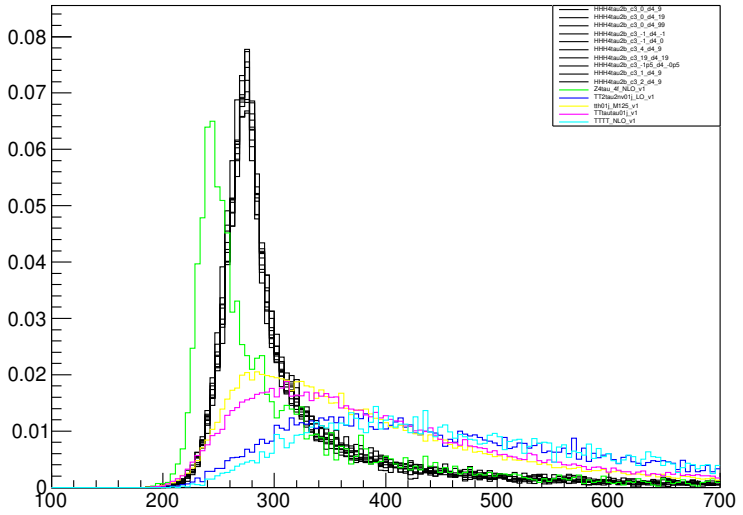
mT2_taupair1_2bj_50



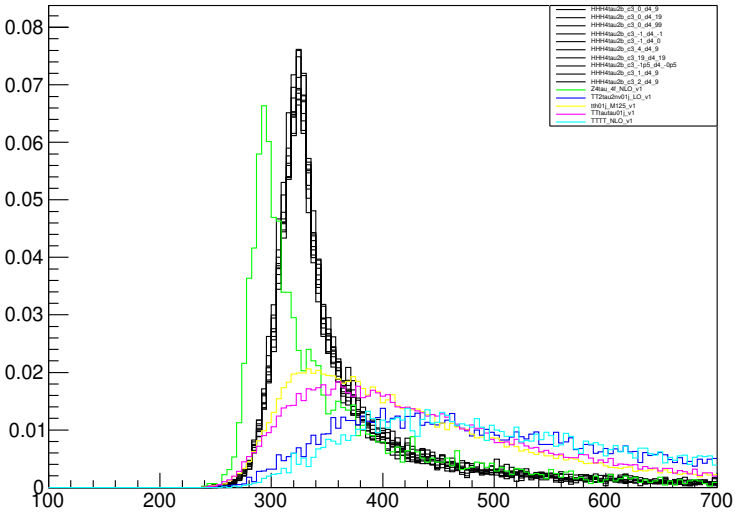
mT2_taupair1_2bj_100



mT2_taupair1_2bj_150

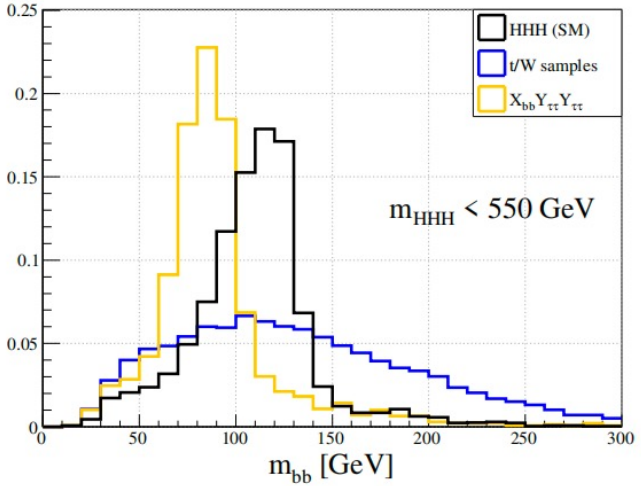


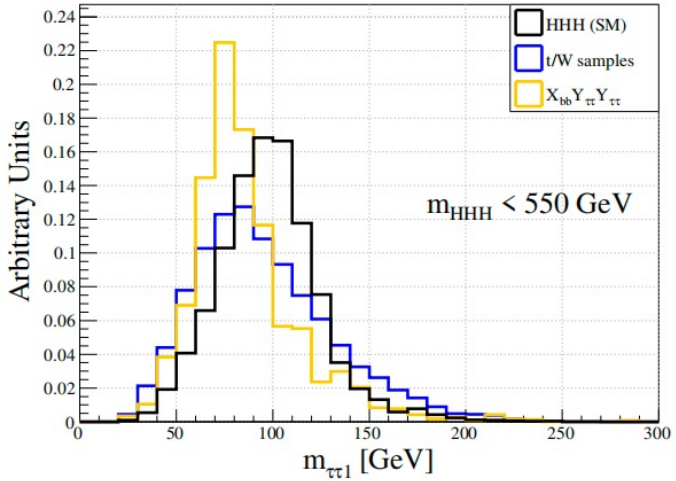
mT2_taupair1_2bj_200

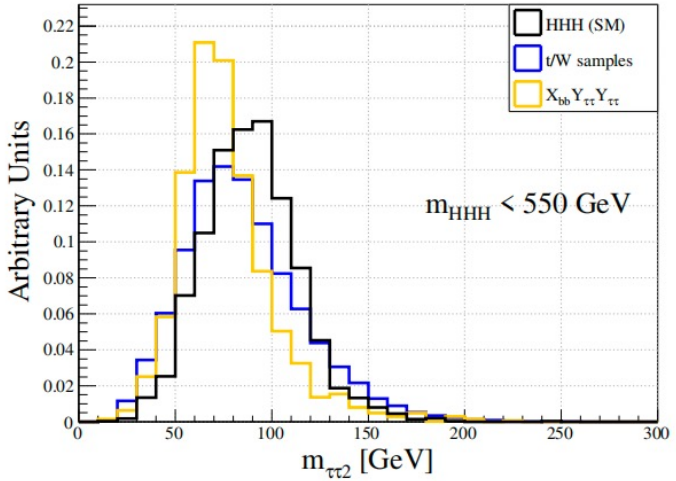


Event Selections

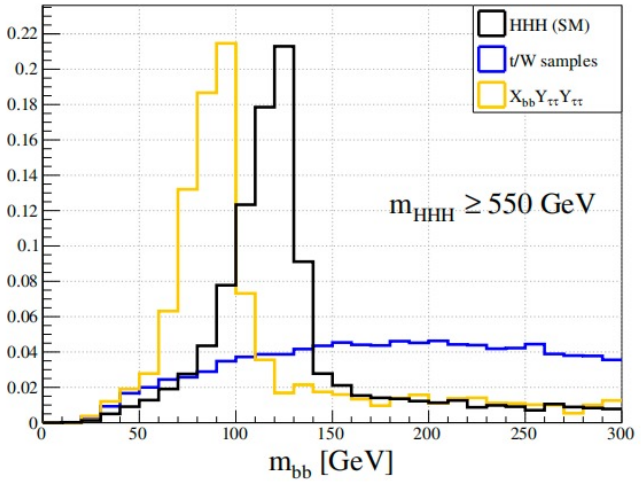
Resolved categories: m_{bb}, $m_{\tau\tau 1}$, $m_{\tau\tau 2}$

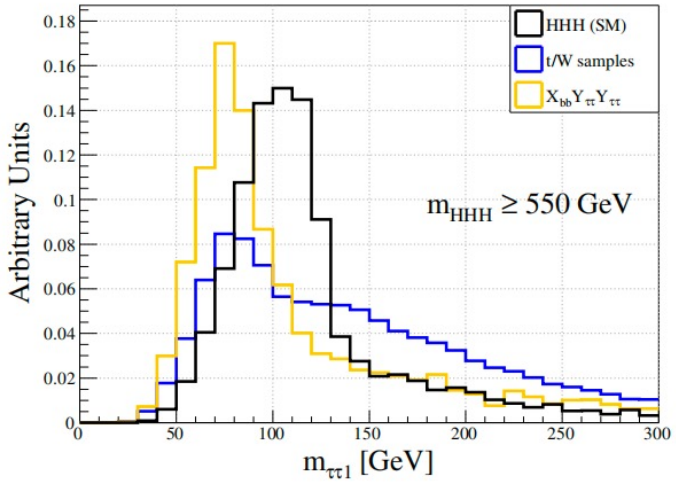


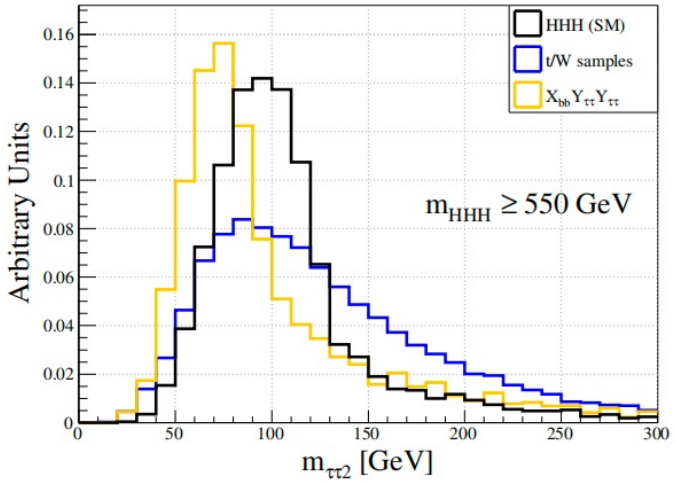




Low m_{HHH}



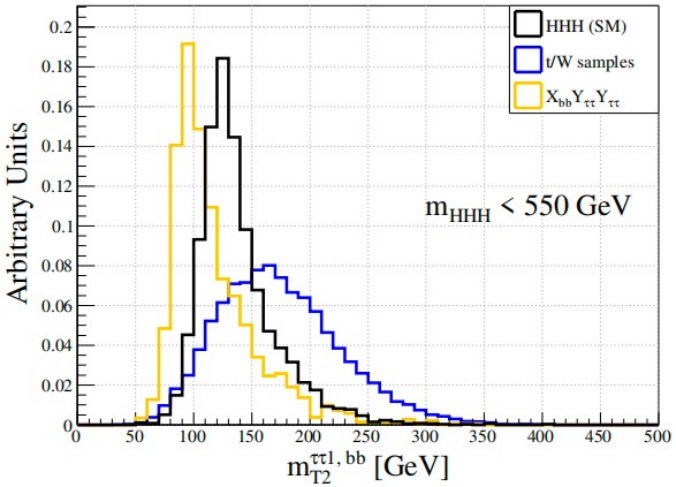


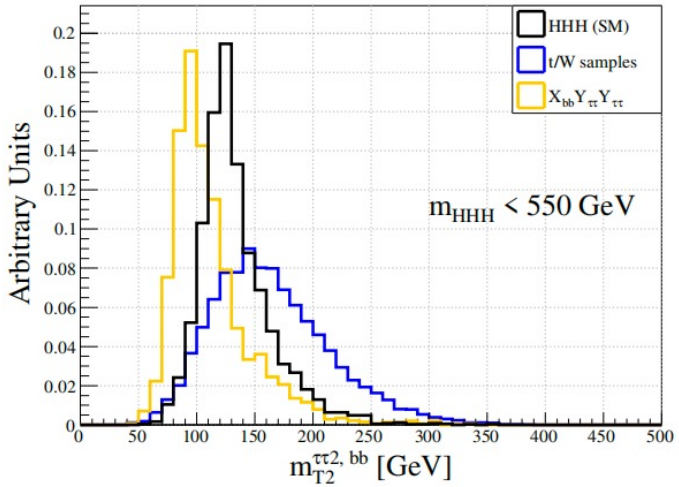


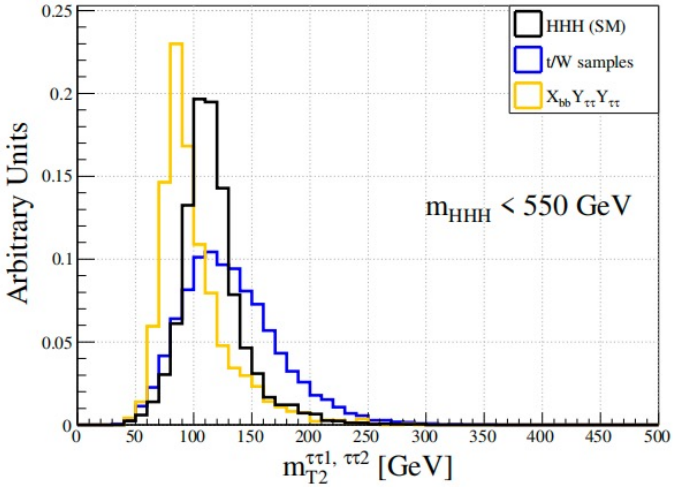
High mHHH

Event Selections

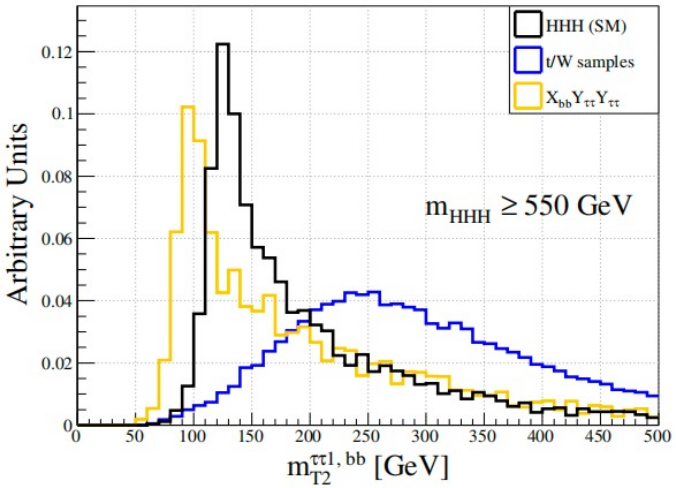
Resolved categories: $m_{T2}^{bb,\tau\tau 1}, m_{T2}^{bb,\tau\tau 2}, m_{T2}^{\tau\tau 1,\tau\tau 2}$

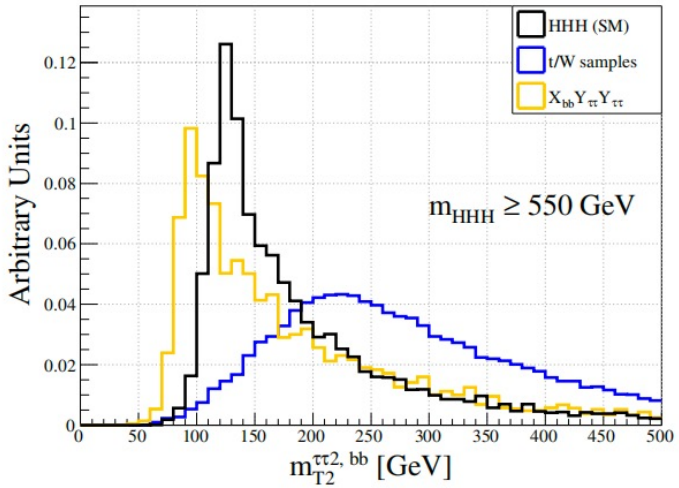


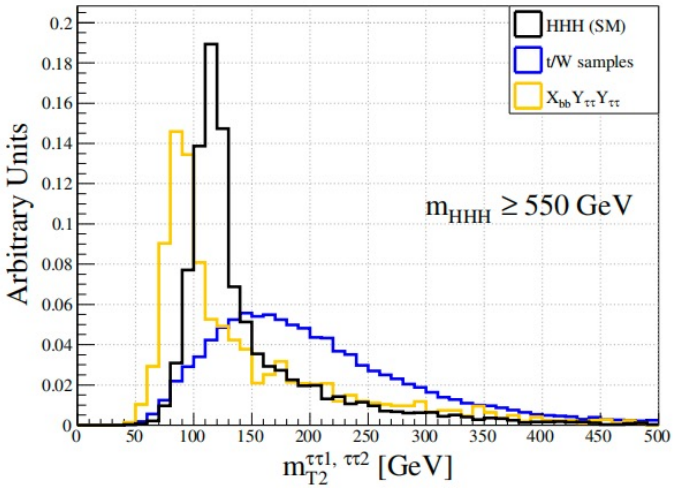




Low m_{HHH}







High mass