

HH non-resonant searches at future pp colliders

Paola Mastrapasqua*, Angela Taliercio, Claudio Caputo, Pietro Vischia, Nicola De Filippis, Pushpa Bhat
(Université catholique de Louvain, Politecnico and INFN Bari, Fermilab)

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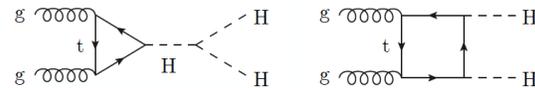
arXiv:2203.08042

Physics Motivation

Access to the Higgs trilinear self coupling and, hence, to the structure of the scalar potential

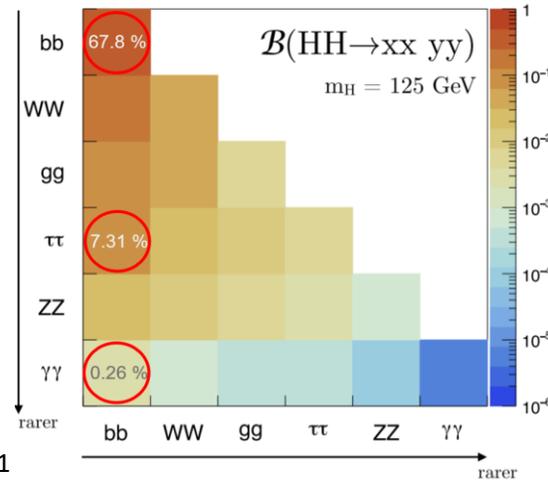
$$V(h) = \frac{m_H^2}{2} h^2 + \lambda_{3H} v h^3 + \lambda_{4H} v h^4$$

Investigated channels



(ggF)HH production in the most sensitive decay channels:

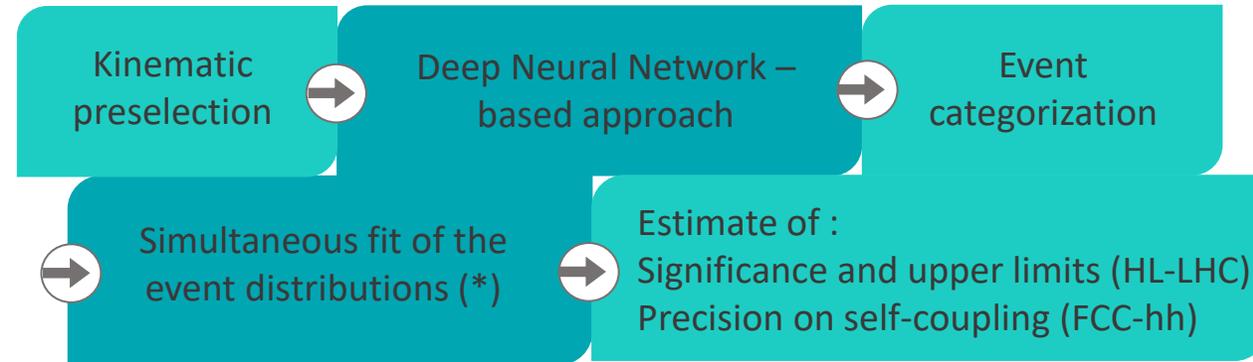
- $b\bar{b}\gamma\gamma$: highest purity, low BR
- $b\bar{b}\tau\tau$: medium purity and BR
- $b\bar{b}b\bar{b}$: highest BR, high bkg



Investigated scenarios

- HL-LHC : $\sqrt{s} = 14$ TeV, $\mathcal{L} = 3$ ab^{-1}
- FCC-hh : $\sqrt{s} = 100$ TeV, $\mathcal{L} = 30$ ab^{-1}
- HE-LHC : $\sqrt{s} = 27$ TeV, $\mathcal{L} = 1$ ab^{-1} (work in progress)

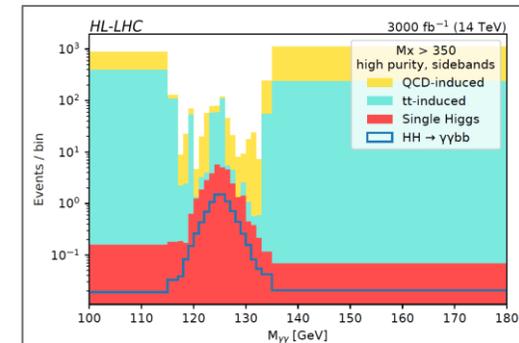
Analysis Strategy



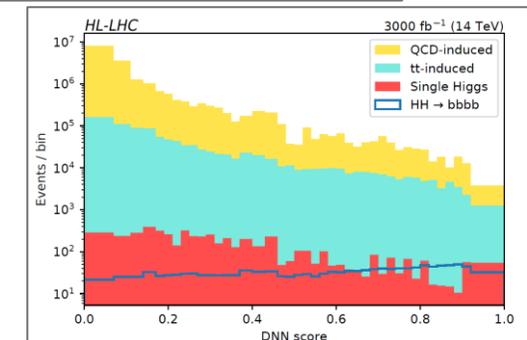
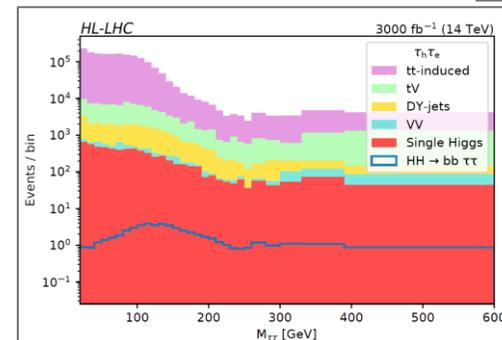
(*)

$b\bar{b}\gamma\gamma$: di-photon mass

$b\bar{b}\tau\tau$: stransverse mass



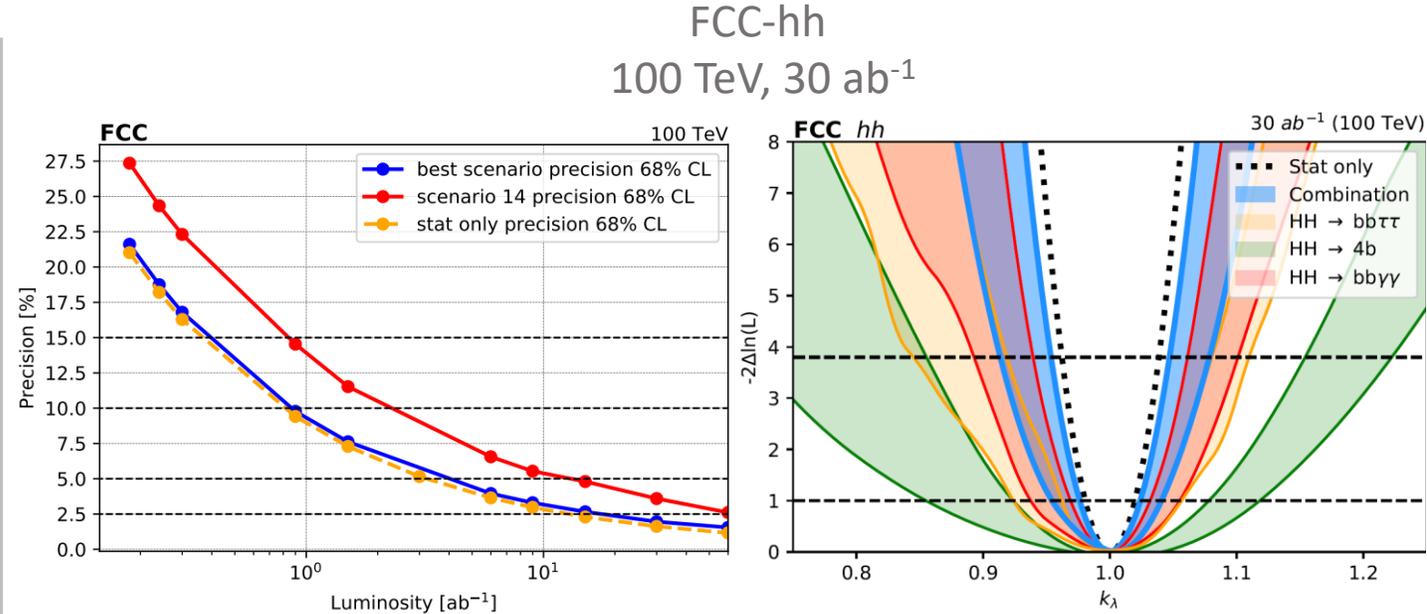
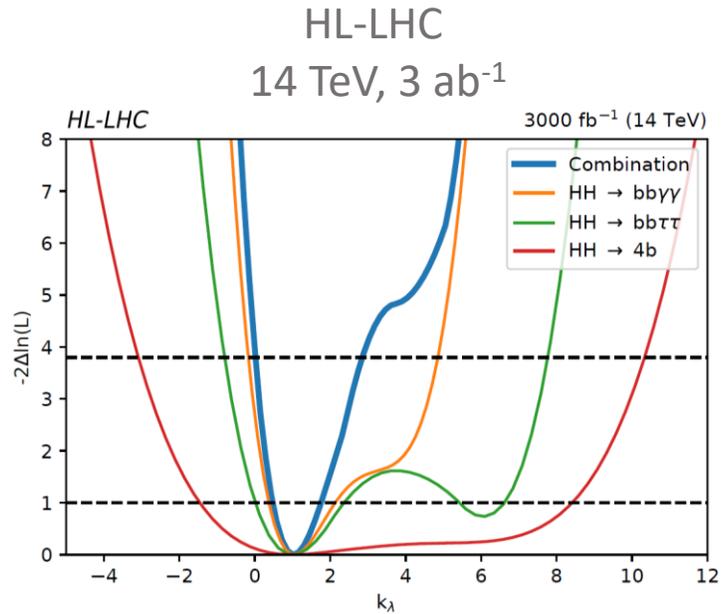
$b\bar{b}b\bar{b}$: dnn score



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	$b\bar{b}\gamma\gamma$	$b\bar{b}\tau\tau$	$b\bar{b}b\bar{b}$	comb
Upper lim. 95% CL	1.09	1.37	2.00	0.76
κ_λ constr. 95% CL	[-0.2,4.9]	[-0.84,7.75]	[-3.16,10.41]	[-0.02,3.05]
Significance	1.94	1.70	1.06	2.80

	$b\bar{b}\gamma\gamma$		$b\bar{b}\tau\tau$		$b\bar{b}b\bar{b}$		comb	
	κ_λ	μ	κ_λ	μ	κ_λ	μ	κ_λ	μ
Precision on (at 68% CL)								
Stat only	2.6	2.4	3.3	2.6	8.0	3.9	2.0	1.6
Best scen *	3.1	3.0	4.0	3.4	9.4	4.0	2.4	2.0
14TeV scen	5.6	5.5	6.6	5.3	13.5	18.2	3.9	3.6

Improvement wrt prev public results

8 %	21 %	12 %	8 %*
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(*) Improvement wrt best scenario of the previous public results ~ 15-30 % *

*preliminary results
Ongoing collab with previous paper authors

*Even without bbVV channel!

Backup

$b\bar{b}\gamma\gamma$

Simulated samples

	Process
Signal	$(gg)HH \rightarrow b\bar{b}\gamma\gamma$ ($\kappa_\lambda = 1$) $(gg)HH \rightarrow b\bar{b}\gamma\gamma$ ($\kappa_\lambda = 2.45$) $(gg)HH \rightarrow b\bar{b}\gamma\gamma$ ($\kappa_\lambda = 5$)
Single Higgs	$(gg)H \rightarrow \gamma\gamma$ $qqH \rightarrow \gamma\gamma$ $VH \rightarrow \gamma\gamma$ $ttH \rightarrow \gamma\gamma$
QCD-induced	$pp \rightarrow \gamma\gamma + jets$ $pp \rightarrow \gamma + jets$ $pp \rightarrow jets$
tt-induced	$pp \rightarrow t\bar{t}\gamma\gamma$ $pp \rightarrow t\bar{t}\gamma had$ $pp \rightarrow t\bar{t}\gamma semi lep$ $pp \rightarrow t\bar{t}\gamma fully lep$ $pp \rightarrow t\bar{t} inclusive$

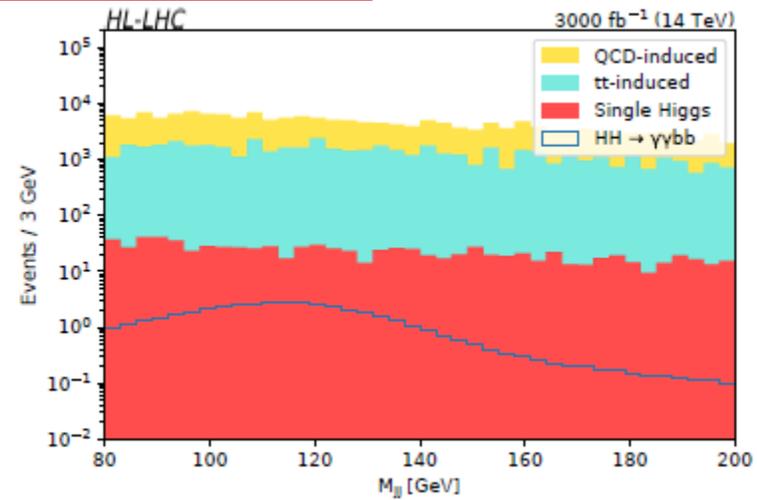
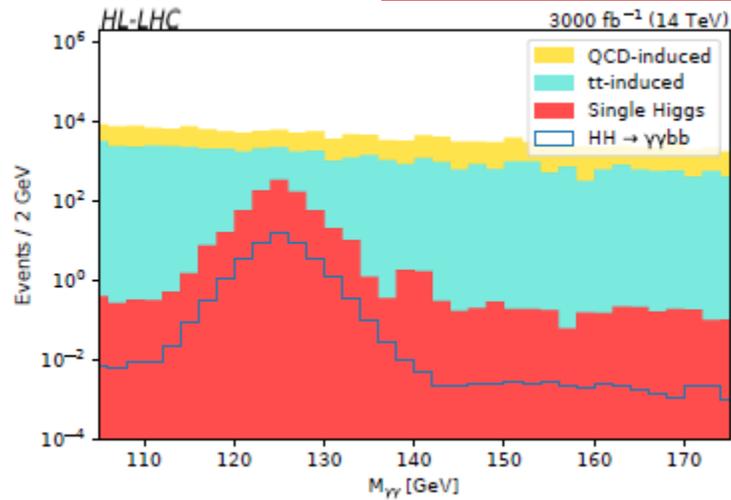
Event selection

	Variable	Requirement
Electrons	ID	tight
	ISO	tight
	$ \eta $	< 1.44 or in $[1.57, 2.5]$
	p_T	> 10 GeV
Muons	ID	tight
	ISO	tight
	$ \eta $	< 2.5
	p_T	> 10 GeV

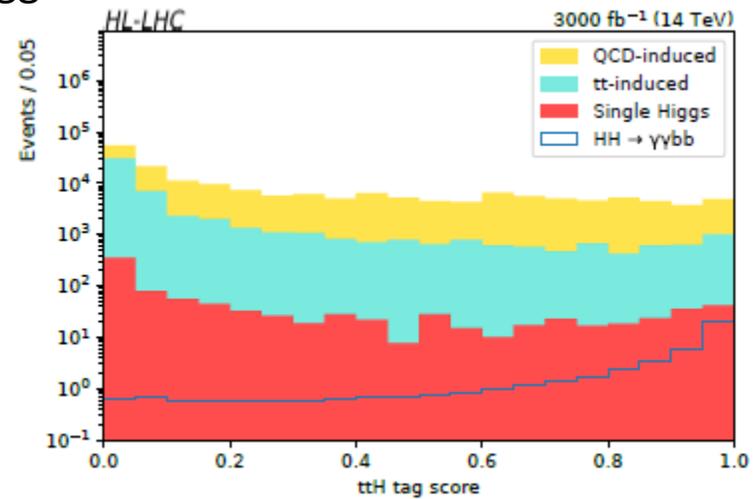
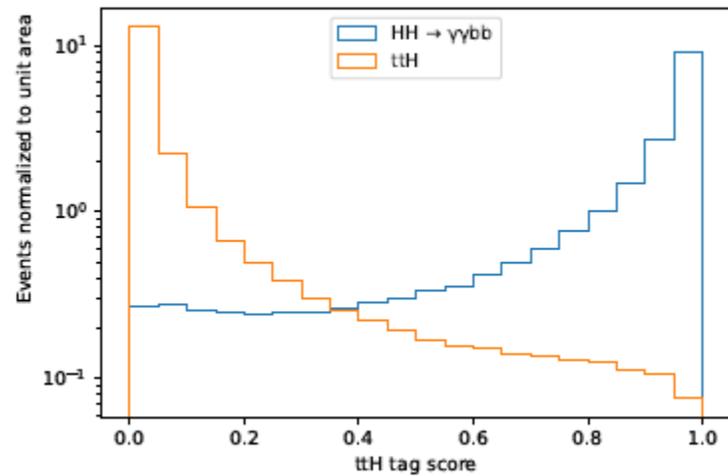
Variable	Requirement	Variable	Requirement
ID	tight	ID	loose
b-tag	loose	ISO	tight
$ \eta $	< 2.5	$ \eta $	< 1.44 or in $[1.57, 2.5]$
p_T	> 30 GeV	p_T (sub)lead	> 30 (20) GeV
m_{jj}	in $[80, 200]$ GeV	$p_T/m_{\gamma\gamma}$ (sub)lead	$> 1/3$ (1/4)
		$m_{\gamma\gamma}$	in $[100, 180]$ GeV

$b\bar{b}\gamma\gamma$

Mass distribution after event selection

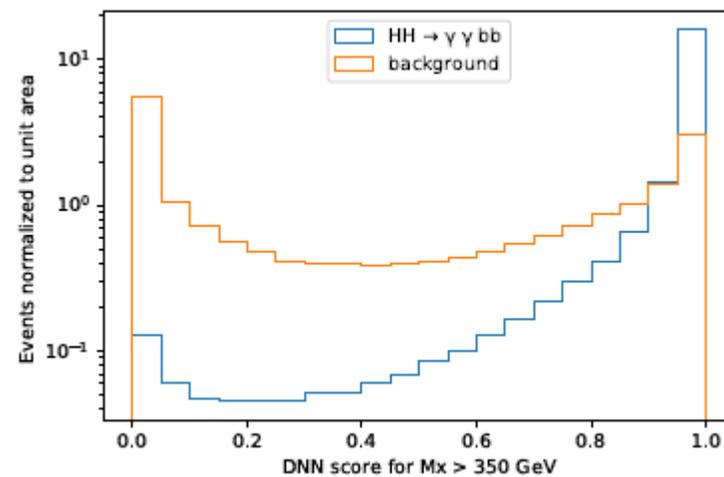
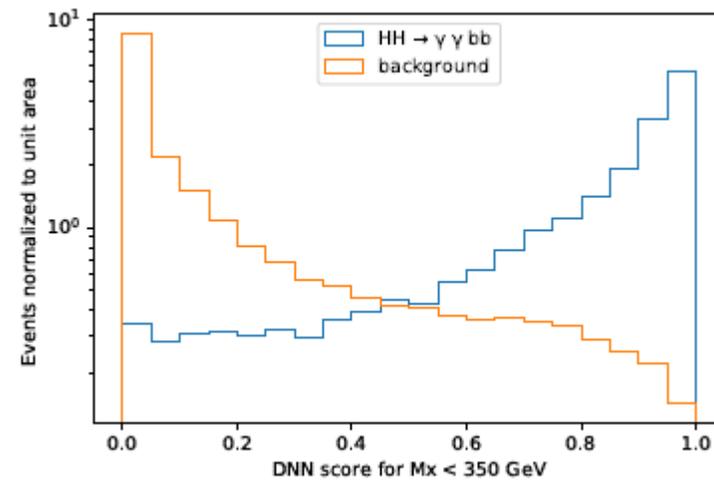
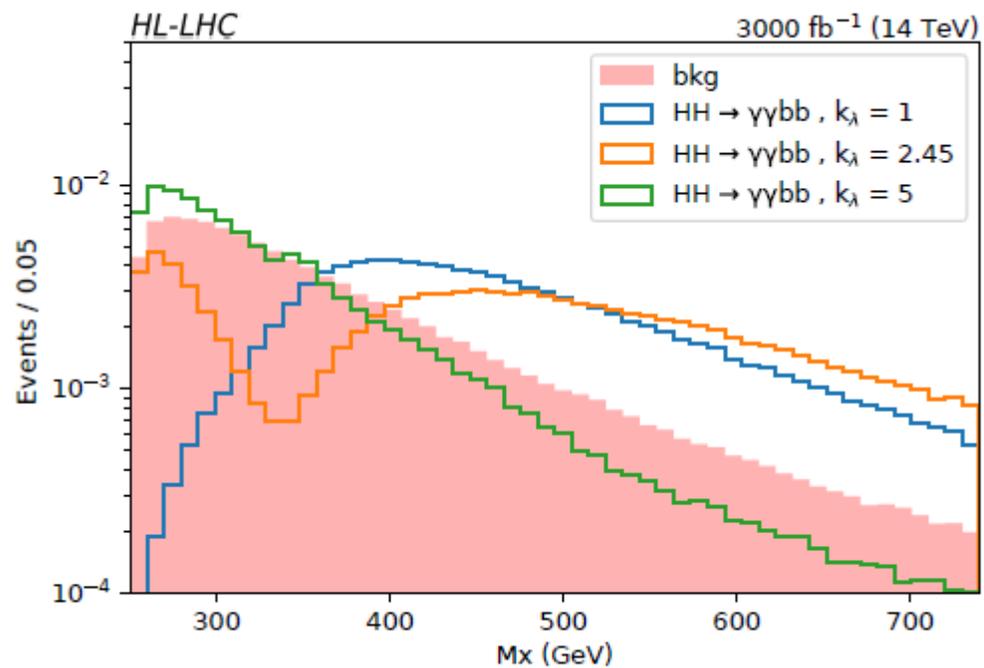


tH tagger



$b\bar{b}\gamma\gamma$

Event categorization



$b\bar{b}\gamma\gamma$

Signal extraction

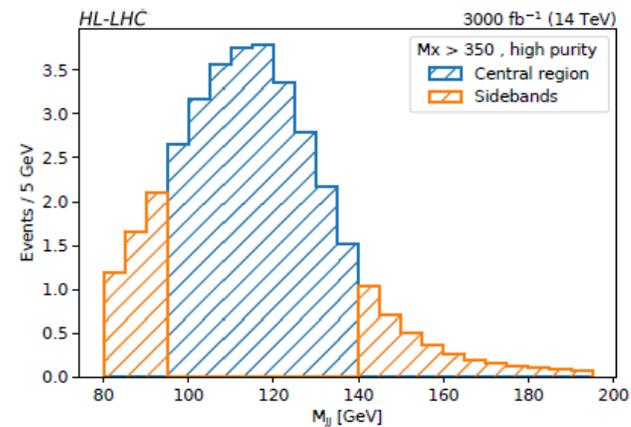


Figure 14: dijet invariant mass distribution for the high mass, high purity category, showing the division in central region and sidebands. The histogram is scaled to cross section and luminosity.

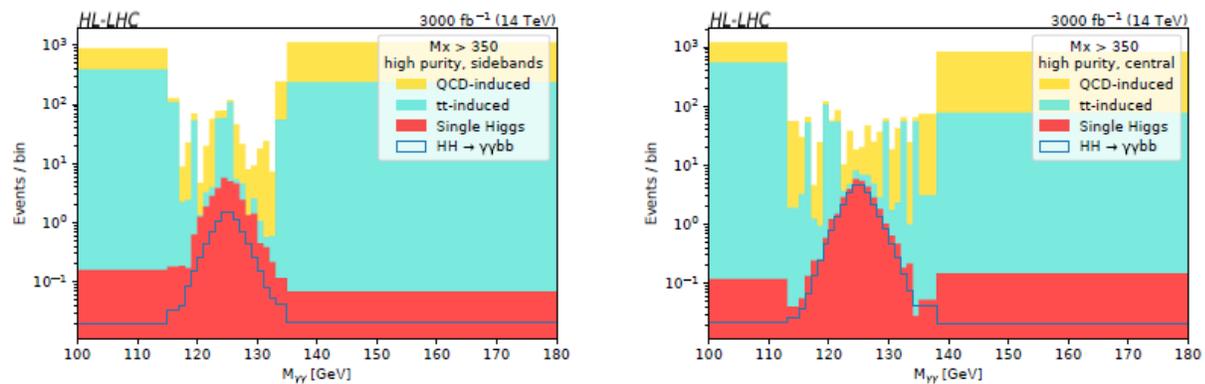


Figure 15: diphoton invariant mass for high mass, high purity, sidebands (Left) central (Right) categories.

$b\bar{b}\tau\tau$

Simulated samples

	Process
Signal	$(gg)HH \rightarrow b\bar{b}\tau\tau$ ($\kappa_\lambda = 1$) $(gg)HH \rightarrow b\bar{b}\tau\tau$ ($\kappa_\lambda = 2.45$) $(gg)HH \rightarrow b\bar{b}\tau\tau$ ($\kappa_\lambda = 5$)
Single Higgs	$(gg)H \rightarrow b\bar{b}$ $(gg)H \rightarrow \tau\tau$ $ttH \rightarrow b\bar{b}$ $ttH \rightarrow b\bar{b}$ $ZH, Z \rightarrow q\bar{q}, H \rightarrow b\bar{b}$ $ZH, Z \rightarrow ll, H \rightarrow b\bar{b}$ $W^+H, W \rightarrow q\bar{q}', H \rightarrow b\bar{b}$ $W^+H, W \rightarrow ll, H \rightarrow b\bar{b}$ $W^-H, W \rightarrow q\bar{q}', H \rightarrow b\bar{b}$ $W^-H, W \rightarrow ll, H \rightarrow b\bar{b}$ $VH, H \rightarrow b\bar{b}$
Single Boson	tW $\bar{t}W$ $tZq, Z \rightarrow ll$ $W \rightarrow lv + jets$
Double Boson	WW $ZZ \rightarrow llq\bar{q}$
Drell-Yan	$DY \rightarrow ll + jets$ HT 100 to 200 $DY \rightarrow ll + jets$ HT 200 to 400 $DY \rightarrow ll + jets$ HT 400 to 600 $DY \rightarrow ll + jets$ HT 600 to 800 $DY \rightarrow ll + jets$ HT 800 to 1200 $DY \rightarrow ll + jets$ HT 1200 to 2500 $DY \rightarrow ll + jets$ HT 2500 to Inf
tt	$t\bar{t}$ inclusive

Considered final states

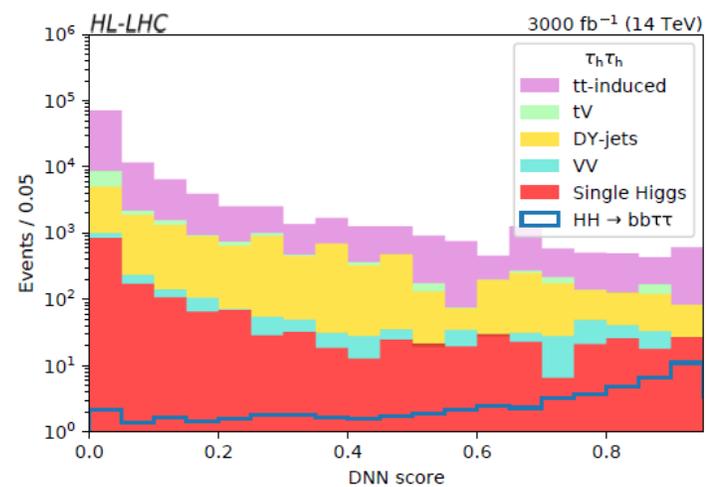
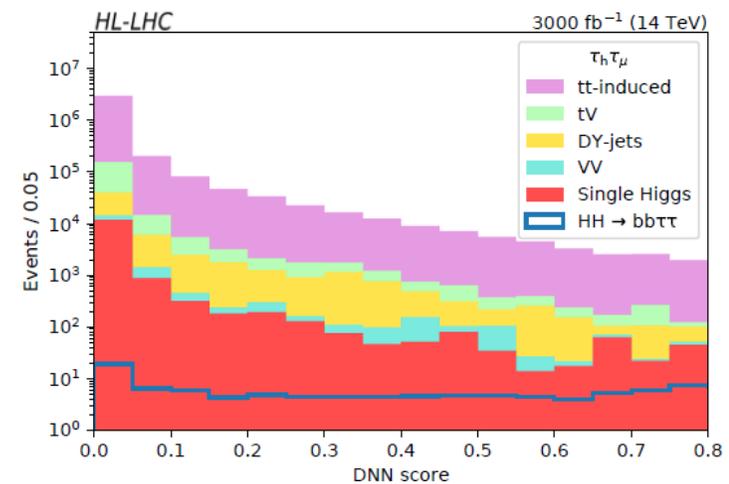
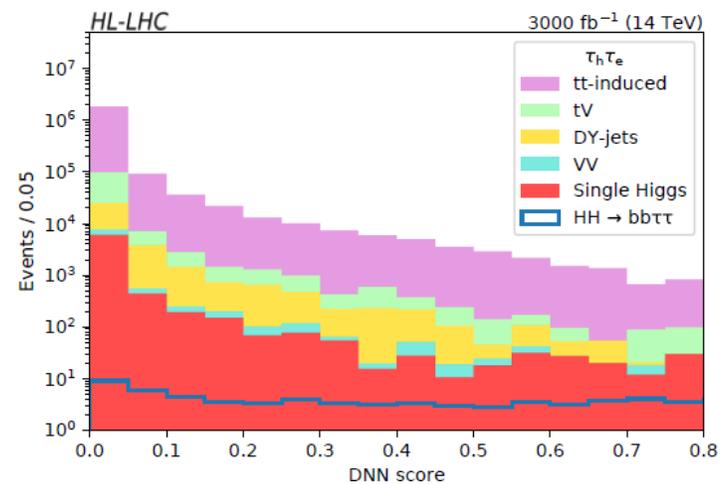
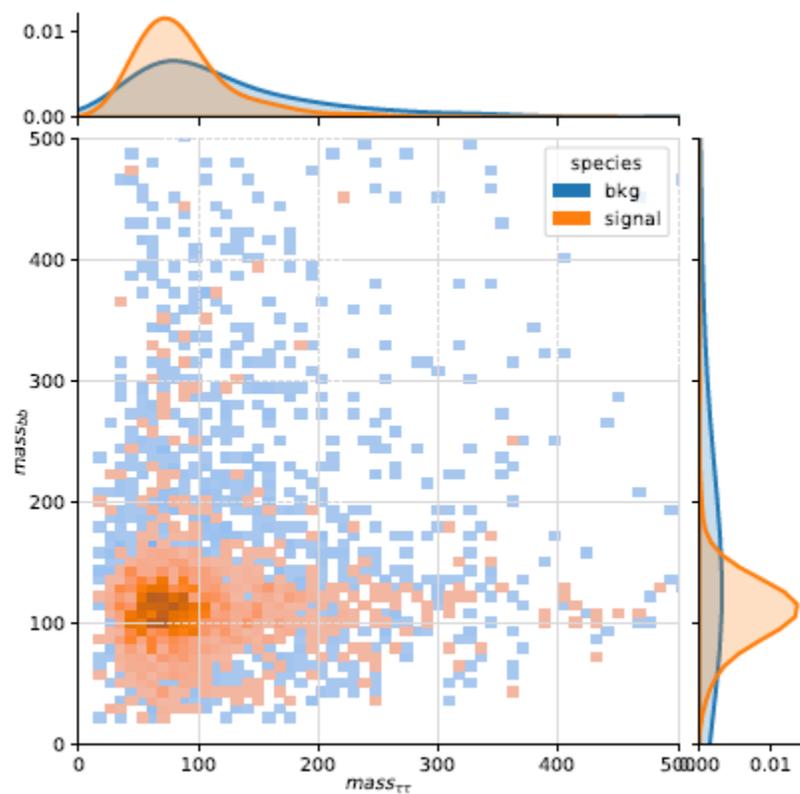
$\tau_h\mu, \tau_h e, \tau_h\tau_h$

Event selection

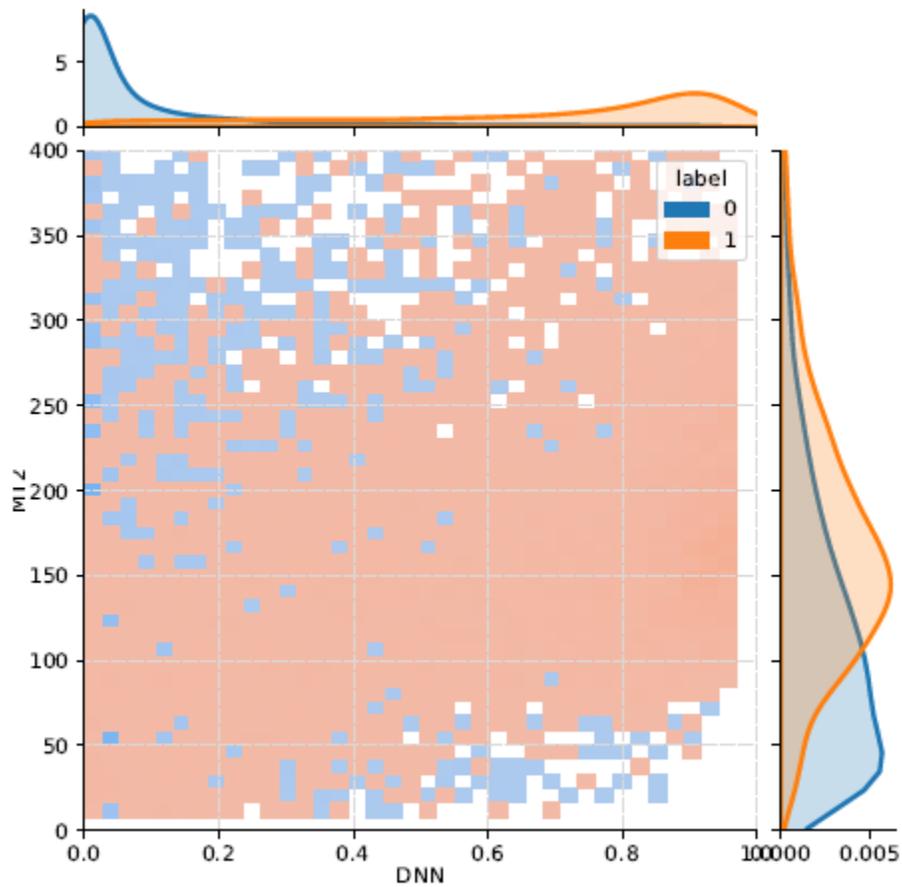
Lepton	Min p_T	Max η	Max iso
Primary muon	23	2.1	0.15
Primary electron	27	2.1	0.1
Veto muon/electron	10	2.4	0.3
Hadronic τ			
$lep \tau_h$	20	2.3	
$\tau_h \tau_h$	45	2.1	

Variable	Requirement
b-tag	medium
$ \eta $	< 2.5
p_T	> 30 GeV
$\Delta R(lept, jet)$	> 0.5

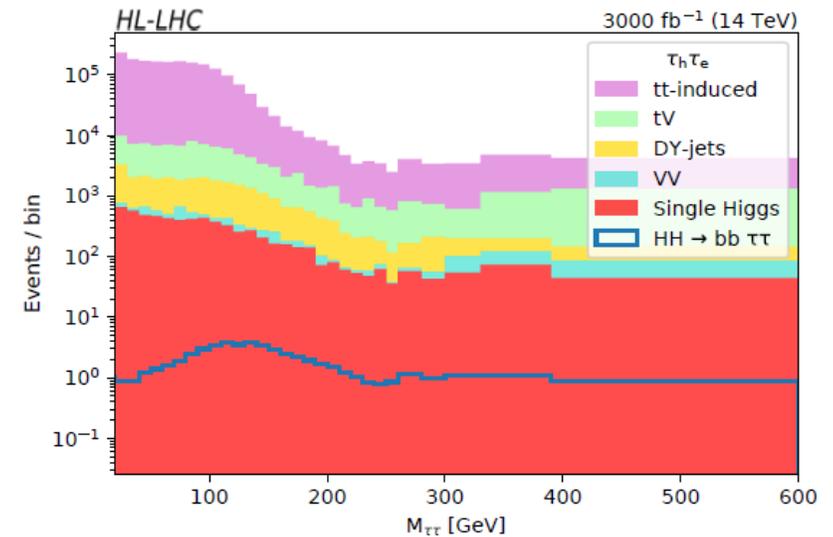
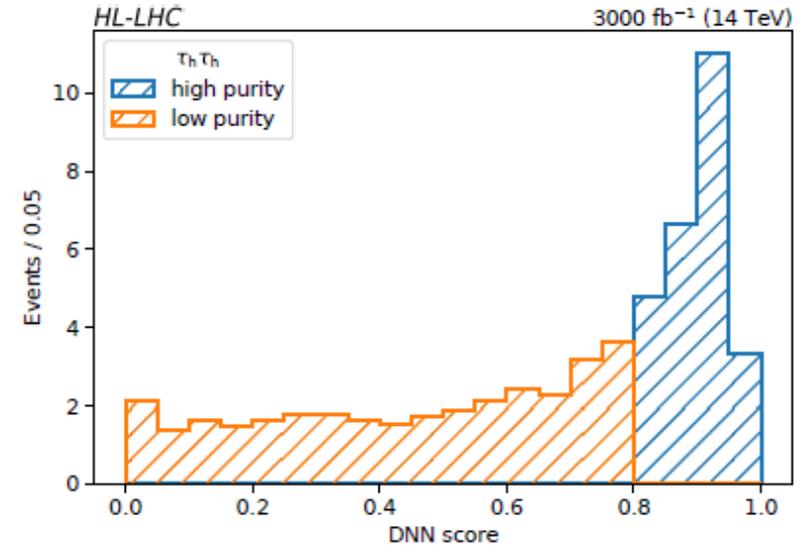
$b\bar{b}\tau\tau$



$b\bar{b}\tau\tau$



- Purity regions defined according to the DNN score
- Transverse mass shape used to extract the significance



$b\bar{b}b\bar{b}$

Simulated samples

	Process
Signal	$(gg)HH \rightarrow b\bar{b}b\bar{b}$ ($\kappa_\lambda = 1$)
	$(gg)HH \rightarrow b\bar{b}b\bar{b}$ ($\kappa_\lambda = 2.45$)
	$(gg)HH \rightarrow b\bar{b}b\bar{b}$ ($\kappa_\lambda = 5$)
Single Higgs	$(gg)H \rightarrow b\bar{b}$
	$(gg)ZH, Z \rightarrow q\bar{q}, H \rightarrow b\bar{b}$
	$ZH, Z \rightarrow q\bar{q}, H \rightarrow b\bar{b}$
	$W^+H, W \rightarrow q\bar{q}', H \rightarrow b\bar{b}$
	$W^-H, W \rightarrow q\bar{q}', H \rightarrow b\bar{b}$
	$VBFH, H \rightarrow b\bar{b}$
QCD	HT 200 to 300
	HT 300 to 500
	HT 500 to 700
	HT 700 to 1000
	HT 1000 to 1500
	HT 1500 to 2000
	HT 2000 to Inf
$t\bar{t}$	$t\bar{t}$ inclusive
	$t\bar{t}$ extended

Event selection

Variable	Requirement
b-tag	medium
$ \eta $	< 3.5
p_T	$> 45 \text{ GeV}$

$$\sqrt{(m_{H_1} - 120 \text{ GeV})^2 + (m_{H_2} - 120 \text{ GeV})^2} < 40 \text{ GeV}$$