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HIGGS BOSON PRODUCTION VIA NEW VECTOR-LIKE TOP QUARK DECAYS AND DETECTION AT THE LHC

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Higgs boson production via new vector-like top quark decays and detection in diphoton or multilepton plus multijets channels at the LHC

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Motivated by the recent stringent constraints from the search for direct Higgs boson production at the LHC, over a wide Higgs mass range, we first build a minimal model of vector-like quarks where the dominant Higgs production process at the LHC, via gluon fusion, can be significantly suppressed. Within this model, compatible with the present experimental constraints, we demonstrate that the Higgs production via a heavy vector-like quark, t_2, decay, $pp \to t_2 \bar{t}_2$, $t_2 \to th$, allows to discover a Higgs boson and measure its mass, through the decay channels $h \to \gamma\gamma$ or $h \to ZZ$. We also comment on the recent hint in LHC data from a possible ~ 125 GeV Higgs, in the presence of heavy vector-like top quarks.
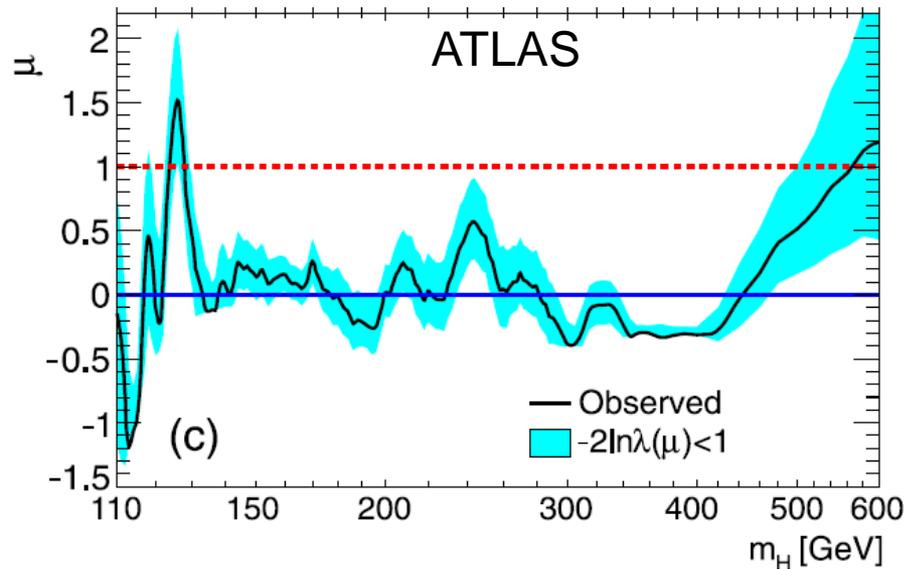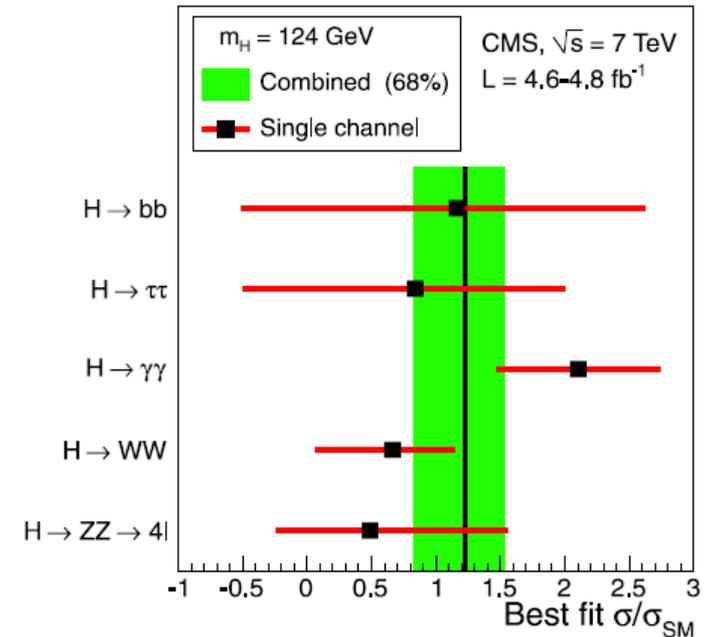
PACS numbers:

I. INTRODUCTION

One of the primary goals of the Large Hadron Collider (LHC) is the direct search for the cornerstone of the Standard Model (SM), namely the Higgs boson, or of any signal from alternative Electro-Weak Symmetry Breaking (EWSB)

arXiv:... 6 [hep-ph] 29 Mar 2012

3/29/2012   Marta Felcini   2

Higgs status: may be… may be not…

Physics Letters B 710 (2012) 49–66

Physics Letters B 710 (2012) 26–48

By end of this year
If a SM like Higgs observed -> ascertain its origin at LHC 14 TeV-> keep looking BSM
If a SM like Higgs excluded -> --> keep looking BSM

BSM search. including the Higgs sector, very important
irrespective of the Higgs outcome of this year
→ keep investigating BSM Higgs signatures
→Higgs produced in the decays of BSM heavy particles
→Discover Higgs and BSM at once   Marta Felcini   3

Higgs production via heavy top decay
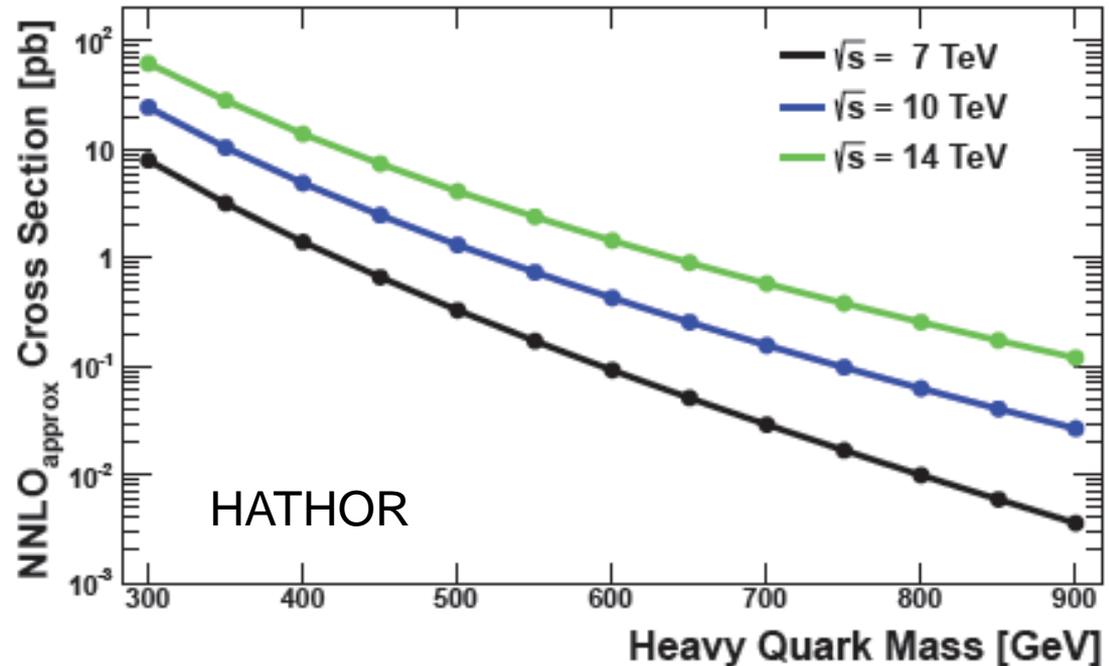
BSM theoretical model with **new heavy top-like states**:

t_3, t_2, t_1
$m_{t3} > m_{t2} > m_{t1}$
t_1 = top quark ; $m_{t1} = m_t$

In this model, consider the **production and decay of the lightest of the two heavy new states t_2**
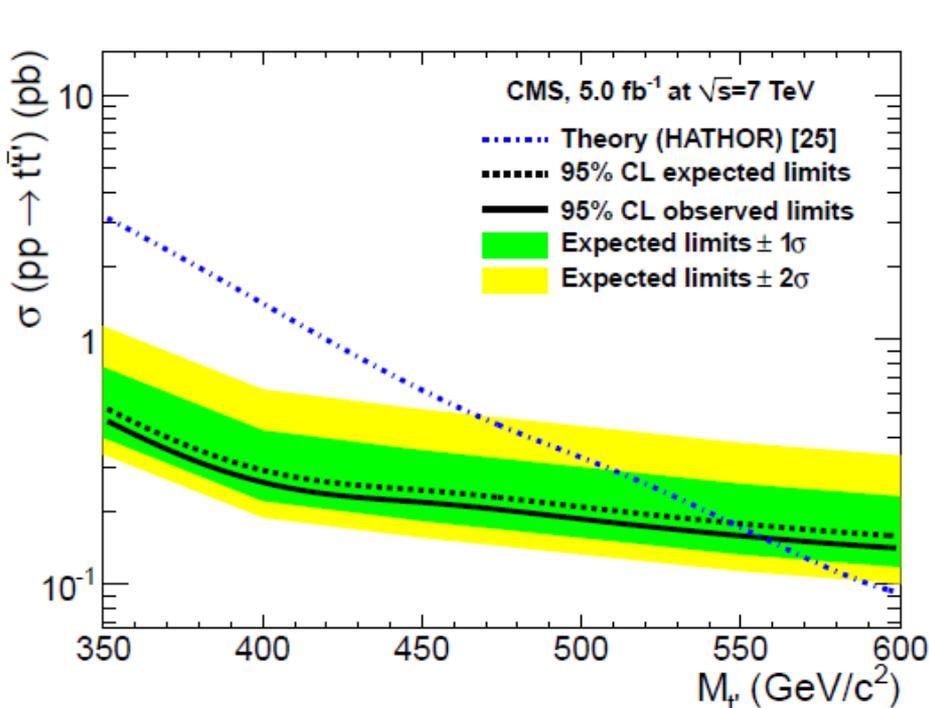
pp-> t_2 t_2 cross-section

Production: pp $\rightarrow$ t_2 $\bar{t_2}$
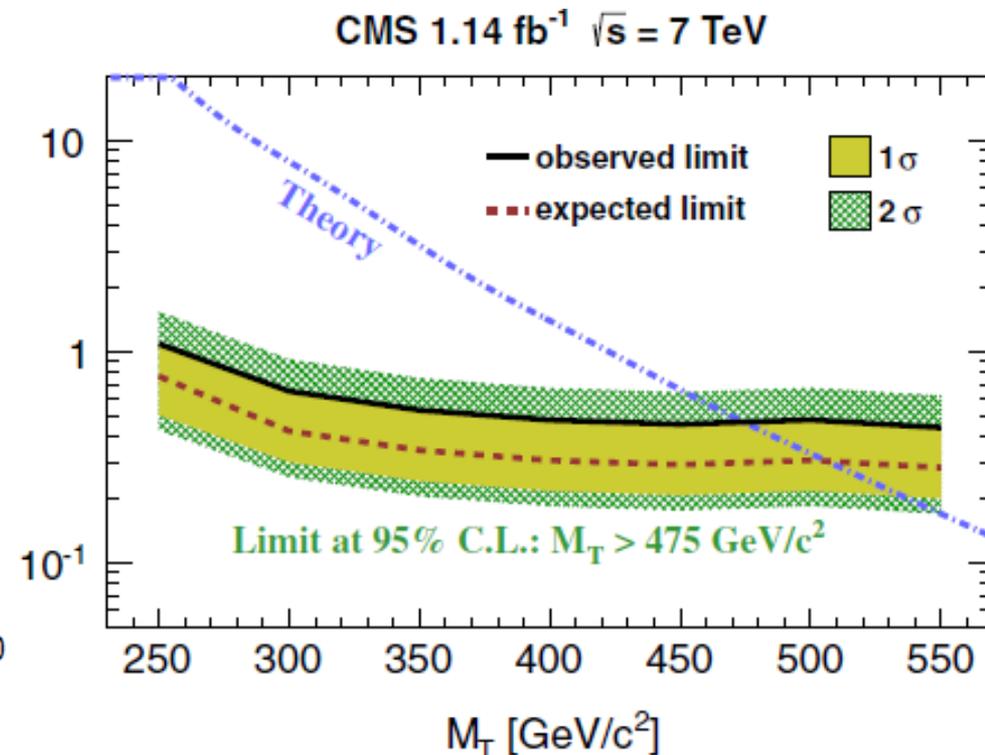**Decays**: $t_2 \rightarrow$ th, $t_2 \rightarrow$ tZ $t_2 \rightarrow$ bW

Heavy top decays – experimental searches

pp-> t_2 t_2 t_2 -> bW   pp-> t_2 t_2 t_2 -> tZ

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PRL 107, 271802 (2011)

Theory framework and benchmarks

see preprint

Parameter Set	A1	A2	B	C	D
$Y / \dot{Y}$	-1.43 / 2	1.02 / -0.1	1.15 / 0.4	1.12 / -0.5	1.05 / -0.3
Y' / Y''	1.85 / -1	1 / 0.55	-1.5 / 1.6	1.1 / 1.65	1.7 / 1.9
m / m' (GeV)	0 / 370	0 / 675	0 / 770	0 / 810	80 / 1100
m'' (GeV)	510	645	980	850	1100
m_{t_3} (GeV)	722	804	1181	1125	1454
m_{t_2} (GeV)	403	599	626	572	788
m_h (GeV)	125	125	255	320	540
$\sigma_{gg\to h}^{SM}$ (pb) @ 7 TeV	15.31	15.31	3.18	2.25	0.58
$\sigma_{gg\to h}^{SM}$ (pb) @ 14 TeV	49.85	49.85	13.50	10.59	3.85
$\sigma_{gg\to h}^{t'}/\sigma_{gg\to h}^{SM}$	1.27	1.31	0.45	0.40	0.65
$\sigma_{t_1 t_1 h}^{t'}$ (pb) @ 7 TeV	0.0194	0.076	0.0037	0.0016	$7\ 10^{-4}$
$\sigma_{t_1 t_1 h}^{t'}$ (pb) @ 14 TeV	0.138	0.0539	0.036	0.021	0.015
$\sigma_{t_2 t_2}$ (pb) @ 7 TeV	1.361	0.0936	0.0709	0.136	0.0115
$\sigma_{t_2 t_2}$ (pb) @ 14 TeV	13.53	1.465	1.164	1.975	0.284
$B_{t_2\to t_1 h}$ (%)	62.6	82.1	60.8	13.5	43.0
$B_{t_2\to t_1 Z}$ (%)	28.6	14.7	25.0	46.1	40.3
$B_{t_2\to bW}$ (%)	8.8	3.2	14.2	40.4	16.6
Γ_{t_2} (GeV)	4.4	3.5	19.8	6.5	8.8
$\sigma_{t_2 t_2} B_{t_2\to bW}^2$ (pb) LHC bound [72]	0.01 < 0.26	$8\ 10^{-5}$ < 0.14	0.001 < 0.14	0.022 < 0.16	0.000(3) ×
$\sigma_{t_2 t_2} B_{t_2\to t_1 Z}^2$ (pb) LHC bound [73]	0.11 < 0.5	0.002 < 0.4	0.004 < 0.4	0.029 < 0.4	0.002 ×
S / T	0.05 / 0.05	0.03 / 0.03	-0.01 / 0.23	-0.01 / 0.30	-0.01 / 0.28

light Higgs allowed

heavier Higgs allowed

Search strategy

pp→ **t_2 t_2** →th bW, thtZ, th th
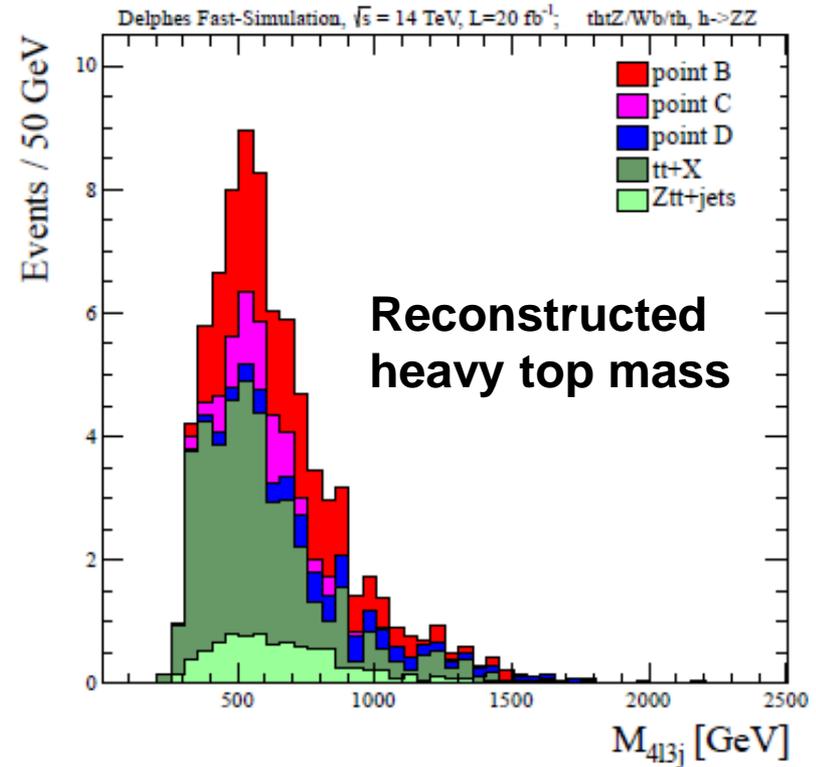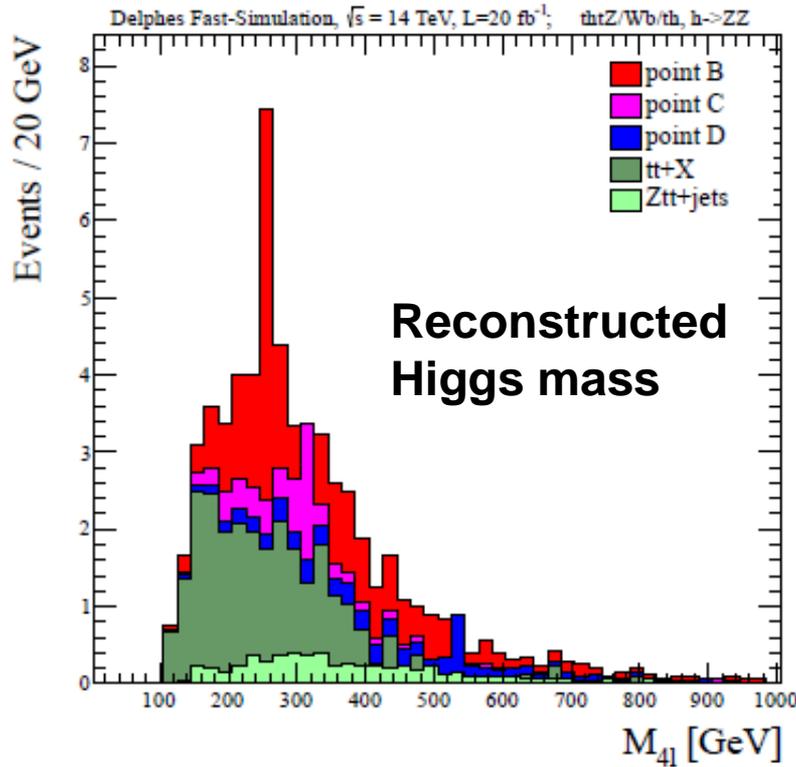consider
h→$\gamma\gamma$ and h→ZZ→4l
decays

14 TeV

Signal event Yield per fb^{-1}

Parameter set	m_{t_2}(GeV)	m_h(GeV)	$\sigma_{\tilde{t}_2 t_2}$(fb)	$B_{t_2 \to th}$	$B_{t_2 \to tZ}$	$B_{t_2 \to bW}$	$B_{h \to VV}^{SM}$	$f_{h \to VV}^{t'/SM}$	$Y_S(h \to VV)$(fb)		
									thbW	thtZ	thth
Point A1	403	125	$1.353\ 10^4$	0.626	0.286	0.088	$2.29\ 10^{-3}$	0.91	3.11	10.1	22.1
Point A2	599	125	$1.465\ 10^3$	0.821	0.147	0.032	$2.29\ 10^{-3}$	0.90	0.159	0.729	4.07
Point B	626	255	$1.164\ 10^3$	0.608	0.25	0.142	0.298	1.00	59.9	105	256
Point C	572	320	$1.975\ 10^3$	0.135	0.461	0.404	0.309	1.00	66.6	76.0	22.2
Point D	788	540	$0.284\ 10^3$	0.43	0.403	0.166	0.265	1.06	11.4	27.6	29.5

see preprint

$t_2 t_2 \rightarrow$th bW, thtZ, th th, h$\rightarrow$ZZ$\rightarrow$4l

Delphes Fast-Simulation, $\sqrt{s}$ = 14 TeV, L=20 fb^{-1}; thtZ/Wb/th, h->ZZ

Reconstructed Higgs mass

Events / 20 GeV — M_{4l} [GeV]

point B, point C, point D, tt+X, Ztt+jets

Delphes Fast-Simulation, $\sqrt{s}$ = 14 TeV, L=20 fb^{-1}; thtZ/Wb/th, h->ZZ

Reconstructed heavy top mass

Events / 50 GeV — M_{4l3j} [GeV]

see preprint

	Signal: $thbW/thtZ/thth$, $h \rightarrow ZZ$				Total signal S, M_{4l}(GeV) cut			
Parameter set	Y_S (fb)	N_{4l}	N_{N_J, H_T}	N_{2b}	no mass cut	> 200	> 300	> 500
Point B	59.9 / 105 / 256	8.1 / 23.7 / 37.8	5.5 / 18.0 / 28.9	3.52 / 11.5 / 18.5	33.4	30.4	17.0	4.9
Point C	66.6 / 76.0 / 22.2	7.7 / 15.8 / 3.1	4.8 / 11.3 / 2.2	3.07 / 7.23 / 1.41	11.7	10.7	7.4	2.0
Point D	11.4 / 27.6 / 29.5	1.5 / 6.6 / 4.7	1.1 / 5.3 / 3.9	0.70 / 3.40 / 2.50	6.6	6.2	5.1	2.7
	Background				Total background B, M_{4l}(GeV) cut			
Process	σ(fb)	N_{4l}	N_{N_J, H_T}	N_{2b}	no mass cut	> 200	> 300	> 500
$t\bar{t}$ + jets	$9.19 \, 10^5$	4680	1480	27.5	35.5	23.5	13.2	6.8
$t\bar{t}b\bar{b}$ + jets	$2.50 \, 10^3$	5.60	3.10	2.0	Statistical ΔB, M_{4l}(GeV) cut			
$t\bar{t}W$ + jets	$1.99 \, 10^2$	1.20	0.40	0.036	no mass cut	> 200	> 300	> 500
$t\bar{t}Z$ + jets	97.3	25.0	9.5	6.0	6.0	4.9	3.6	2.6

$t_2 \, t_2 \rightarrow$ th bW, thtZ, th th, $\quad$ h$\rightarrow\gamma\gamma$

Reconstructed Higgs mass

Reconstructed heavy top mass
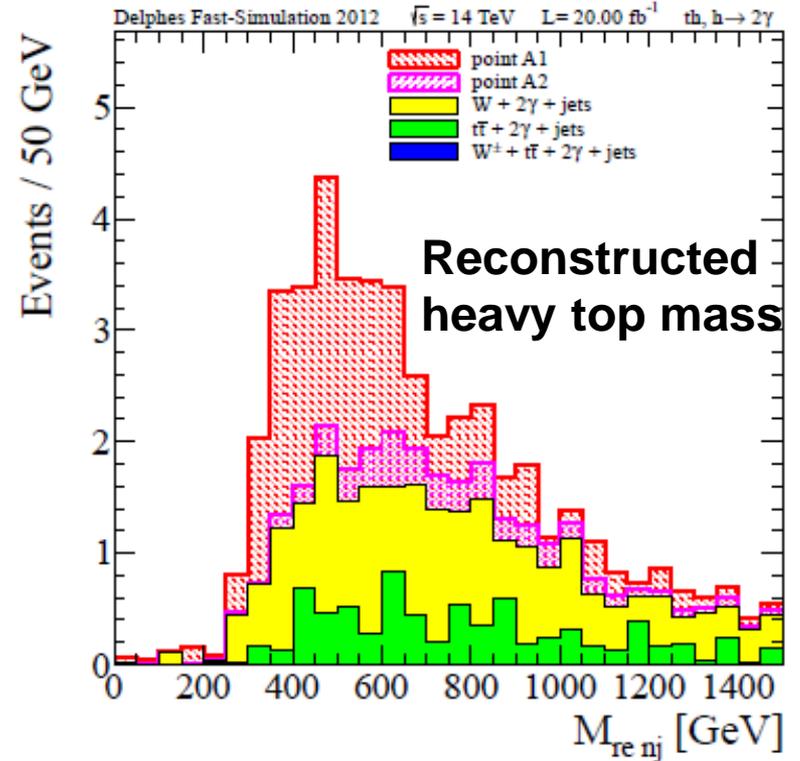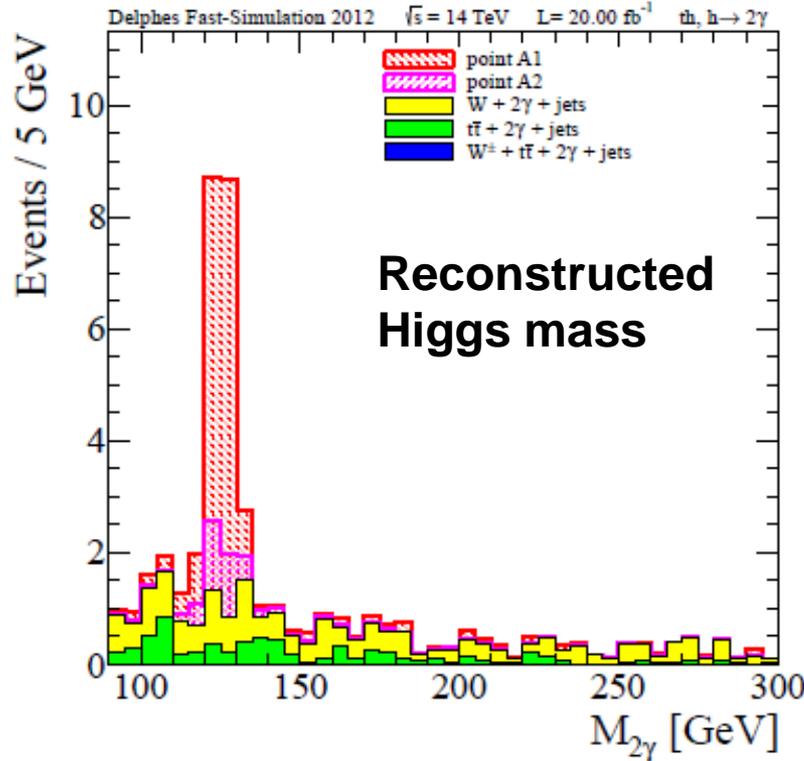
see preprint

	Signal: $thbW/thtZ/thth,\ h \to \gamma\gamma$				Total signal S, $M_{2\gamma}$ (GeV) cut	
Parameter set	Y_S (fb)	$N_{2\gamma}$	$N_{N_J>6}$	$N_{N_J>8}$	> 90	$[115,135]$
Point A1	3.1 / 10.1 / 22.1	5.4 / 15.4 / 30.4	4.1 / 12.7 / 27.1	1.4 / 6.2 / 14.5	22.1	17.7
Point A2	0.16 / 0.73 / 4.1	0.34 / 1.35 / 6.98	0.27 / 1.17 / 6.6	0.10 / 0.62 / 3.8	4.5	3.2
	Background				Tot, background B, $M_{2\gamma}$ (GeV) cut	
Process	σ(fb)	$N_{M_{2\gamma}>90}$	$N_{N_J>6}$	$N_{N_J>8}$	> 90	$[115,135]$
$W\gamma\gamma$ + jets	450	422	110	19.6	27.8	4.38
$t\bar{t}\gamma\gamma$ + jets	15.5	11.8	11.3	8.18	Statistical ΔB, $M_{2\gamma}$ (GeV) cut	
$t\bar{t}W\gamma\gamma$ + jets	0.0678	0.0577	0.0515	0.0272	> 90	$[115,135]$
					5.3	2.1

Conclusions

- **New possibilities** to discover a Higgs boson and/or measure its properties
  $pp \rightarrow t_2 \, t_2 \rightarrow$ **th bW, thtZ, th th**

                       with
                      $h \rightarrow \gamma\gamma$ **and** $h \rightarrow ZZ \rightarrow 4l$ **decays**

- **Investigate Higgs boson production** **over the whole mass range ~120-600 GeV**

- **Discover** (5σ) at the **14 TeV LHC** with luminosities **~20 - 200 fb^{-1}**

- **Measure Higgs and heavy top** masses (+other properties) with 200 fb^{-1} or more

- **For details see**
  Preprint on arXiv March 30th or
  https://indico.cern.ch/getFile.py/access?contribId=41&sessionId=5&resId=0&materialId=slides&confId=162621