

# Search for generic heavy Higgs at ATLAS

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#### Introduction

No hint of CP even heavy higgs from previous search PRL 125, 051801

- **Driven by 2HDMs** •
- Focusing on ggF production in VV, ditau decay •

New Ideas!

- Higher dimensional operator: Dim-6 arXiv:1905.05421 •
- Fermiphobic coupling •

#### First search of this kind at the LHC



### Search with VH production



- With dim-6 operator, VH cross section is factor of 2 higher than VBF.
- Sensitivity dominated by VH.

M=600 GeV, fW=1000, fWW=1000

Opp	osite sian	Signal	Z+QCD Jets	Other
	OS2L	4.0	41.6	3.5
		Signal	WZ+QCD jets	Other
	3L	3.6	7.2	1.3
	same-sign	Signal	WZ+QCD jets	Other
	•			

- In VH process, same-sign dilepton (SS2L) dominates discovery significance. So currently we focus on SS2I final state
- Detailed phenomenology study (<u>PLB 804</u> (2020) 135358)

## Signal and background



 $M_{eff} = \sum P_T^{Lepton} + \sum P_T^{V-jets} + E_T^{miss}$ 

- Two same-sign (SS) leptons
  - $\circ$  High  $M(\ell\ell)$
- One large-R jet (boosted) or two small-R jets (resolved)
  - $\circ \quad \text{Mass around W}$
- High ETmiss
- No b-tagged jets

Backgrounds (rank in relevance):

Control region	0
	ຼັ
Data-driven	0
	_ 0
MC simulation	0
	0

WZ: third lepton is not reconstructed/selected tt~, single-t, W+jets: non-prompt lepton from jets Z+jets: charge of one lepton is mis-reconstructed Vgamma: photon is mis-identified as lepton TopX: ttW, ttZ, tZ

VBS WW, triboson (VVV, WWW), ZZ

## **Object selection**

#### Muon

- pT > 20 GeV
- $|\eta| < 2.5$
- Identification: medium
- Isolation: PLVTight

#### small-R jet

- pT > 20 GeV
- $|\eta| < 2.5$
- JVT: medium

#### Electron

- pT > 20 GeV
- |η| < 2.47 and outside crack region:</li>
  1.37< |η| < 2.47 < 1.52</li>
- Identification: TightLH
- Isolation: PLVTight

#### large-R jet

- pT > 200 GeV
- $|\eta| < 2.0$
- mass: (50 GeV, 200 GeV)

### Analysis strategy and backgrounds

•	• Signal region: $\overline{SS2\ell} \left( l^{\pm} l^{\pm}_{\pm} = e^{\pm} e^{\pm}, e^{\pm} u^{\pm}, u^{\pm} e^{\pm}, u^{\pm} u^{\pm} \right)$		Pass W-tag	SF	R same-sign 2	2L		WZ CR:
0	Boosted	Resolved						
-	Two same-sign leptor 3 <sup>rd</sup> le no b-jet @	ns with $p_T > (27)20$ GeV epton veto 85% MV2c10	Failed W-tag	Va	lidation regio	n		
	$M_{ll} >$	• 100 GeV						
	$E_T^{miss} > 80 \text{ GeV}$	$E_T^{miss} > 60 \text{ GeV}$		$e^{\pm}$	$e^{\pm} e^{\pm} \mu^{\pm} \mu^{\pm}$	$\pm e^{\pm} \mu^{\pm} \mu^{\pm}$		31
	$N_J \ge 1$	$N_j \ge 2$						
	$p_T(J_1) > 200 \text{ GeV}$ $p_T(j_1), p_T(j_2) > 20 \text{ GeV}$					WZ CR		
	$J_1 @ 80\%$ W tagger	$M_{ii} \in (50, 110) \text{ GeV}$	I WZ C	R:	Boosted	Reso	olve	ed
	. 66	JJ	1		3 lepton	s with $p_T > 27, 20$ $4^{th}$ lepton veto	), 2(	)GeV
	Validation re	aion:			at least one pair o	f same-flavour opp	oosi	te sign leptons

 $80 \text{ GeV} < M_{II}^Z < 100 \text{ GeV}$ 

no b-jet @ 85% MV2c10

 $E_T^{miss} > 40 \text{ GeV}$ 

 $\geq$  2 small-R jets

 $p_T(j_1), p_T(j_2) > 20 \text{ GeV}$ 

 $\geq$  1 large-R jet

 $p_T > 200 \, \text{GeV}$ 

- Validation region:
  - Similar with SR  $\bigcirc$
  - Failed the W-tag (Boosted) or Mjj cut Ο (Resolved)

# WZ background

- WZ is the dominant background
  - One of the lepton is mis-identified or mis-reconstructed
- WZ CR is defined to constrain WZ in the final fit:
  - Take the shape from MC simulation
  - Normalization factor is one of the free parameters

#### boosted



resolved

### Non-prompt background



Number of events: N = data - prompt background from MC simulation Fake factor (FF) = N(C)/N(D) No W-tag or Mjj cut to increase statistics in region C and D

#### Fake factor estimation regions,

- Very pure non-prompt in region C
- ~40% non-prompt in region D



Number of events: N = data - prompt background from MC simulation Fake factor (FF) = N(C)/N(D)

	electrom	muon
Fake factor	0.048+-0.007	0.018+-0.001



## Charge-flip background

- Charge mis-identification is mainly comes from Z+jets
- Data-driven method:
  - Zee CR is defined to estimate charge-flip rate
  - Charge flip rate = N(SS)/N(OS)
  - The rate is applied to the OS SR to estimate the SS contribution in SR

 $-0.0 < |\eta| < 0.6$ 

0.6 < |n| < 1.1

► 1.1 < | n | < 1.52</p>

-1.52 < |n| < 1.7

- 2.3 < | n | < 2.5





## Validation region

- Check background estimation: ssWW, WWW, WZ
- Bkg-only fit:
  - Data-driven background is applied
  - $\circ$  Normalization factor for WZ (~0.82) is the only free parameter



	Boosted	Resolved
ТорХ	$6.01\pm0.09$	$7.91 \pm 0.11$
WWW	$9.40 \pm 0.13$	$25.02\pm0.35$
ssWW	$24.87 \pm 0.33$	$24.65\pm0.34$
VVV	$0.08 \pm 0.00$	$0.23\pm0.00$
ZZ	$0.26 \pm 0.00$	$2.44\pm0.04$
WZ	$26.35 \pm 0.74$	$98.84 \pm 2.77$
NonPrompt	$5.56 \pm 0.10$	$33.78 \pm 0.55$
ChargeFlip	$2.34\pm0.03$	$16.38\pm0.22$
$V\gamma$	$2.02 \pm 0.03$	$14.55 \pm 0.21$
Total Sum	$76.89 \pm 1.25$	$223.80 \pm 3.97$
Data	$79.00 \pm 8.89$	$257.00 \pm 16.16$

#### Boosted Events / 200 GeV 240 ATLAS 35 -- Data Events / 400 GeV χ<sup>2</sup> KS --- Data ATLAS χ<sup>2</sup> KS $220 \int Ldt = 139 \text{ fb}^{-1} \text{ (s} = 13 \text{ TeV}$ 0 Stat -0 minin GHH3f0fm3000 GHH3f0fm3000 30 Ldt = 139 fb -1 (s = 13 TeV -0 0 Stat 200 UH→VVV, SS2I SR Syst -0 0 -0 0 GHH6f650f0 Syst GHH6f650f0 VH→VVV, SS2I SR Inclusive Shape -0 0 Shape -0 0 ssWW ssWW 180 Resolved 25 Boosted ATLAS Work in Progress ATLAS Work in Progress 160 F Vgamma Vgamma NonPrompt NonPrompt 140 20 ChargeFlip ChargeFlip 120 ТорХ TopX 15 100 pre-fit pre-fit ZZ ZZ 80 10 vvv VVV 60 www www 40 WZ wz 20 - Signal x 2 - Signal x 2 ---- (Data-Bkg)/Bkg (Data-Bkg)/Bkg ---- (Data-Bkg)/Bkg 0.4 (Data-Bkg)/Bkg 0.4 Stat 0.2 Stat 0 Stat+Shape 0 Stat+Shape -0.2 Stat+Sys -0.2 E Stat+Sys -0.4 -0.4 E 600 800 1000 1200 1400 1600 1800 2000 400 200 300 500 600 800 900 1000 400 700 M<sub>eff</sub>[GeV] M<sub>eff</sub>[GeV]

Signal region

signal	Mass[GeV], fw, fww	Boosted	Resolved
GHH3f0fm3000	300, 0, -3000	3.10	10.00
GHH6f650f0	600, 650, 0	2.28	0.80
GHH9f0fm5000	900, 0, -5000	3.28	0.97

	Boosted	Resolved
GHH6f650f0	$2.28\pm0.06$	$0.80 \pm 0.04$
TopX	$2.17 \pm 0.12$	$6.97 \pm 0.23$
WWW	$5.42 \pm 0.16$	$31.17\pm0.45$
ssWW	$4.30\pm0.08$	$10.64\pm0.13$
VVV	$0.02 \pm 0.00$	$0.19\pm0.02$
ZZ	$0.06 \pm 0.01$	$1.80\pm0.12$
WZ	$6.03 \pm 0.19$	$86.93 \pm 1.53$
NonPrompt	$3.39 \pm 0.32$	$35.94 \pm 1.10$
ChargeFlip	$0.55 \pm 0.07$	$11.62\pm0.34$
$V\gamma$	$0.70 \pm 0.57$	$10.00\pm2.42$
Total Sum	$24.92 \pm 0.72$	$196.07 \pm 3.13$

#### Resolved

# Summary

- The search for fermi-phobic heavy higgs with dim-6 operator in same-sign dilepton and hadronic W final state is performed for the first time.
- Two categories (boosted and resolved) are defined according to boosted level.
- The dominant background is WZ and it's estimated from WZ CR.
- Non-prompt and charge-flip background is estimated from data-driven method.
- Good agreement of data and MC is observed in validation region.

### Backup

### Data and MC simulation

#### • Data:

- full run2 (2015-2018)
- Derivation: HIGG2D4
- P-tag: 3640 (will update soon)
- Signal MC:
  - o pp->WH->WWW->llvvjj
  - MadGraph+MadSpin
  - Free parameters: mass, fw, fww
  - 24 signal samples with different parameters
  - P-tag: 3641
  - 0



## **Object selection**

Signal Muon Selection MUOR	<b>1</b>	
Reconstructed muon		
Kinematic acceptance: $p_{\rm T} > 20 \text{ GeV}$		
Geometrical acceptance: $ \eta  < 2.5$		
Object Quality: medium		
Longitudinal impact parameter requirement: $ z_0 \times \sin \theta  < 0.5 \text{ mm}$		
Transverse impact parameter requirement: $\frac{d_0}{\sigma_{d_0}} < 3$		
Isolation working point: PLVTight		

Signal Electron Selection		
Reconstructed electron candidate		
Kinematic acceptance: $p_{\rm T} > 20 \text{ GeV}$		
Geometrical acceptance: $ \eta  < 2.47$ , outside crack region $1.37 \le  \eta  \le 1.52$		
Object quality: author == 1, addAmbiguity $\leq 0$		
Identification criteria: TightLH		
Transverse impact parameter requirement: $\left \frac{d_0}{\sigma_{d_0}}\right  < 5$		
Longitudinal impact parameter requirement: $ z_0 \times \sin \theta  < 0.5 \text{ mm}$		
Isolation/Prompt lepton veto tagger: PLVTight_noLooseCone		
ECIDS working point: Loose		

	small-R jet	large-R jet
	small-R jet	large-R jet
Jet collection	AntiKt4EMPFlow	AntiKt10LCTopoTrimmedPtFrac5SmallR20Jets
$p_{\mathrm{T}}$	> 20 GeV	> 200 GeV
$ \eta $	< 2.5	< 2.0
mass	-	(50, 200 GeV)
W/Z-tagger	-	80% WP
JVT	Medium	_
b-tagging	MV2c10 @ 85%	-

#### Pre and post fit in WZ CR (boosted)





#### Pre and post fit in WZ CR (resolved)

