Multiscalar Final States in the TRSM

Gilberto Tetlalmatzi-Xolocotzi

Based on:

A. Papaefstathiou, T. Robens, GTX: 2101.00037/ JHEP 05 (2021) 193

CPPS, Theoretische Physik 1, Universität Siegen

Center for Particle Physics Siegen

UNIVERSITÄT SIEGEN

Two Real Singlet Extension of the SM
TRSM

$$V(\Phi,\phi_i)=V_{SM}(\Phi)+V(\Phi,S,X)$$

Reduce the number of parameters by imposing

$$\mathbb{Z}_2^S: S\to -S\,,\ X\to X$$

$$\mathbb{Z}_2^X: S\to S\,,\ X\to -X$$

$$V(\Phi,X,S)=\mu_\Phi^2\Phi^\dagger\Phi+\lambda_\Phi(\Phi^\dagger\Phi)^2+\mu_S^2S^2+\lambda_S S^4+\mu_X^2X^2+\lambda_X X^4+\lambda_{\Phi S}\Phi^\dagger\Phi X^2+\lambda_{SX}S^2X^2$$

$$S=(\phi_S+v_S)/\sqrt{2}$$

$$X=(\phi_X+v_X)/\sqrt{2}$$

Change to the physical basis

$$\begin{pmatrix}h_1\\h_2\\h_3\end{pmatrix}=R(\theta_X,\theta_S)\begin{pmatrix}\phi_h\\\phi_S\\\phi_X\end{pmatrix}$$

$h_1=h$ *is the SM Higgs boson*

$$M_1=125\,GeV$$

Free independent parameters

$$M_2, M_3, \theta_{hS}, \theta_{hX}, \theta_{SX}, v_S, v_X$$

Robens, Stefaniak, Wittbrodt: 1908.08554

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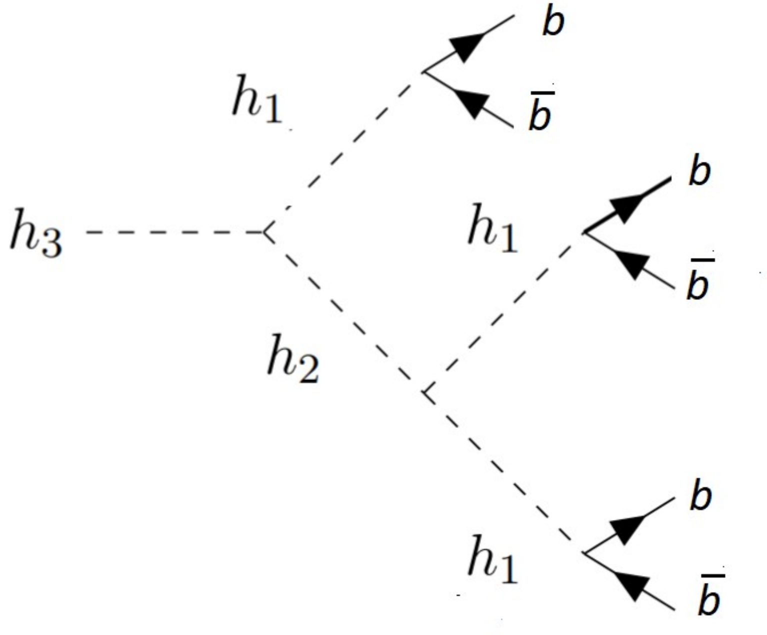
Benchmark Scenario of Study BP3

Here we focus in the BP3 Scenario introduced in 1908.08554 which allows for a large $h_1 h_1 h_1$ production while obeying current theoretical and experimental constraints.

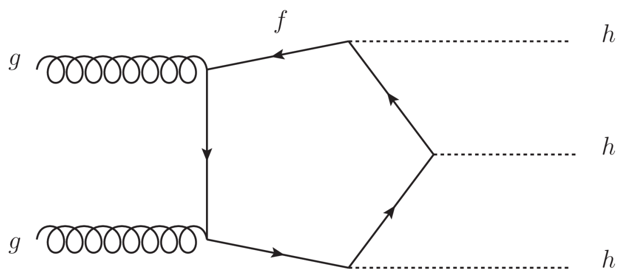
Parameter	Value
M_1	125.09 GeV
M_2	[125, 500] GeV
M_3	[255, 650] GeV
θ_{hS}	−0.129
θ_{hX}	0.226
θ_{SX}	−0.899
v_S	140 GeV
v_X	100 GeV

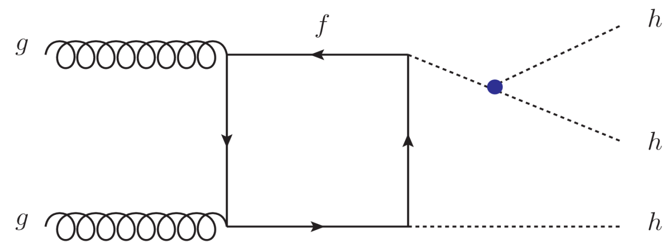


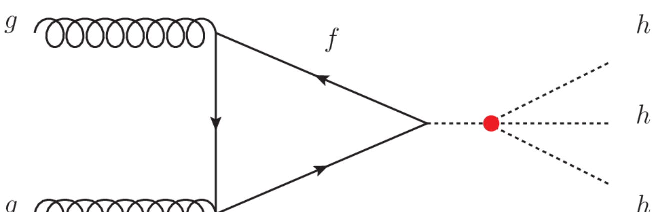
We consider the mass hierarchy $M_1 < M_2 < M_3$

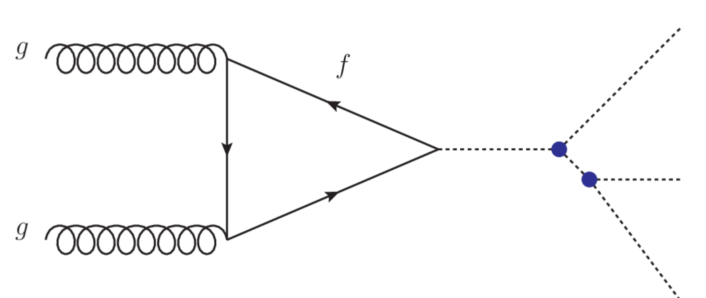
Triple Higgs production

$$g\,g \longrightarrow h\,h\,h$$









In the HL-LHC
as in the SM
(pp @ 14 TeV)

$\sigma = 0.05\ fb$

~*O(100)* events
Hopeless!

de Florian, Fabre, Mazzitelli: 1912.02760

Within the TRSM it is possible to reach up to $\sigma = 50\ fb$

Details on the study of the 6b final state

- Parton level events (signal/background) generated with MadGraph5_aMC@NLO.

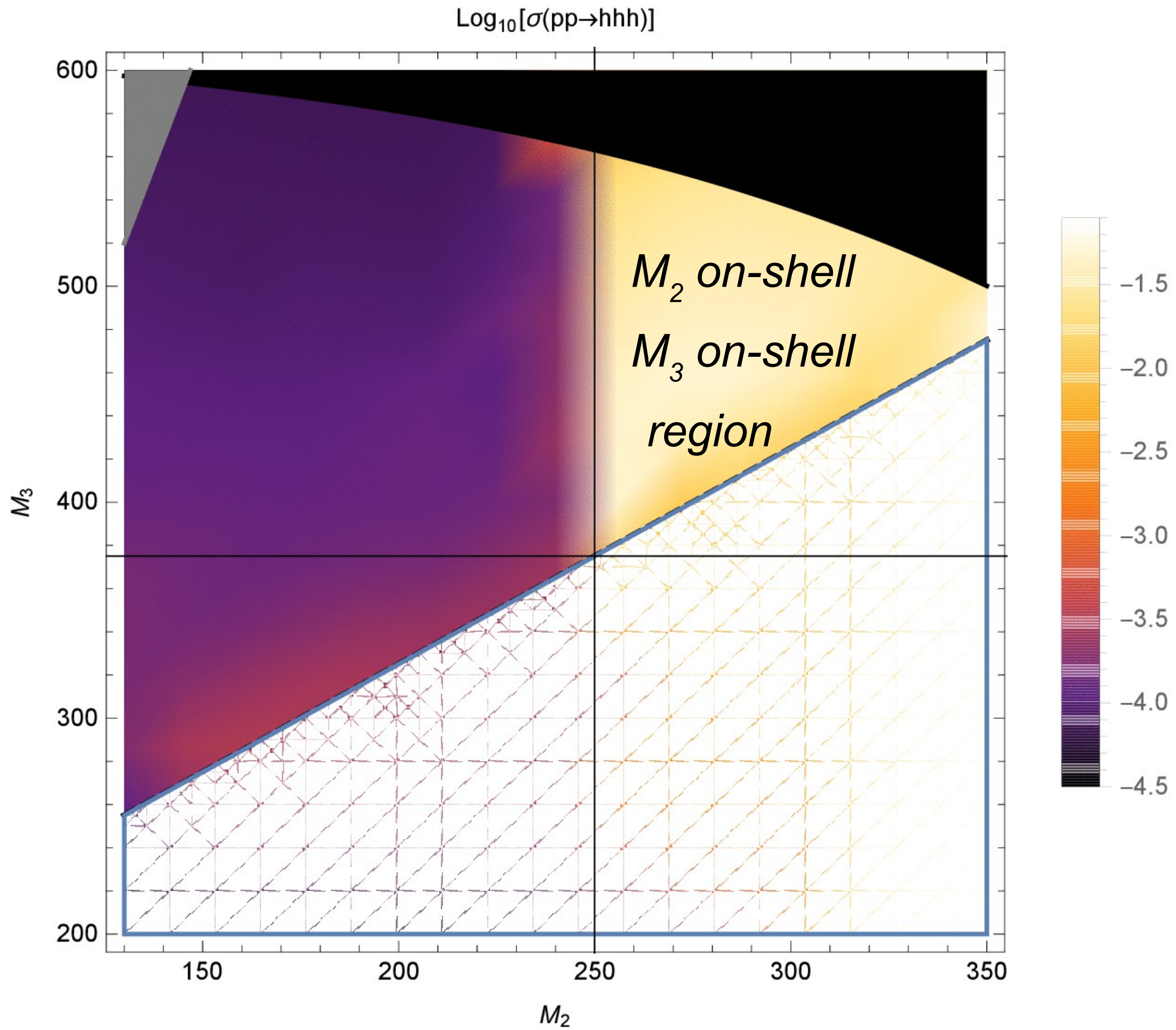
- The main source of background is QCD-6b-Jets.

- The production of the 6b-final state is challenging, it was generated in the Siegen computer cluster using the gridpack option available in MadGraph5_aMC@NLO.

- Parton shower and non-perturbative effects included with Herwig 7.

- The analysis was performed using the Herwig package HwSim. [*Papaefsathiou*, https://bitbucket.org/andreasp/hwsim]

Production cross section



The X-Section can reach up to 50 fb for M_2~(263,280) GeV and M_3~450 GeV

Cross sections per Benchmark point

Label	(M_2, M_3) [GeV]	$\sigma(pp \to h_1 h_1 h_1)$ [fb]	$\sigma(pp \to 3b\bar{b})$ [fb]
A	$(255, 504)$	32.40	6.40
B	$(263, 455)$	50.36	9.95
C	$(287, 502)$	39.61	7.82
D	$(290, 454)$	49.00	9.68
E	$(320, 503)$	35.88	7.09
F	$(264, 504)$	37.67	7.44
G	$(280, 455)$	51.00	10.07
H	$(300, 475)$	43.92	8.68
I	$(310, 500)$	37.90	7.49
J	$(280, 500)$	40.26	7.95

For a QCD 6 b-quarks induced final state the SM background amounts to

$$\sigma = 6.38\ pb$$

Selection Analysis

- *Require 6 b-tagged jets*

- *Construct all the possible combinations of 3-pairs of b-jets:* J
  Do something analogous for all the combinations of 2-pairs: I

- *For each combinations* I *and* J calculate the observables

$$\chi^{2,(4)} = \sum_{qr \in I} \left(M_{qr} - m_h\right)^2 \qquad \chi^{2,(6)} = \sum_{qr \in J} \left(M_{qr} - m_h\right)^2$$

- *Our best candidates to Higgs bosons are defined in terms of the pairings that minimize*

$$S = \chi^{2,(4)}_{min} + \chi^{2,(6)}_{min}$$

Results

Label	(M_2, M_3) [GeV]	$\varepsilon_{\text{Sig.}}$	$S\|_{300\text{fb}^{-1}}$	$\varepsilon_{\text{Bkg.}}$	$B\|_{300\text{fb}^{-1}}$	$\text{sig}\|_{300\text{fb}^{-1}}$	$\text{sig}\|_{3000\text{fb}^{-1}}$
A	$(255, 504)$	0.025	14.12	8.50×10^{-4}	19.16	2.92	9.23
B	$(263, 455)$	0.019	17.03	3.60×10^{-5}	8.11	4.78	15.11
C	$(287, 502)$	0.030	20.71	9.13×10^{-5}	20.60	4.01	12.68
D	$(290, 454)$	0.044	37.32	1.96×10^{-4}	44.19	5.02	15.86
E	$(320, 503)$	0.051	32.54	2.73×10^{-4}	61.55	3.76	11.88
F	$(264, 504)$	0.028	18.18	9.13×10^{-5}	20.60	3.56	11.27
G	$(280, 455)$	0.044	38.70	1.96×10^{-4}	44.19	5.18	16.39
H	$(300, 475)$	0.054	41.27	2.95×10^{-4}	66.46	4.64	14.68
I	$(310, 500)$	0.063	41.42	3.97×10^{-4}	89.59	4.09	12.94
J	$(280, 500)$	0.029	20.67	9.14×10^{-5}	20.60	4.00	12.65

Analyses performed for different points in the
M_2 -M_3 (on-shell, on-shell) region

Closing Remarks

- *The TRSM extends the SM with two scalar singlets and imposes two discrete symmetries to reduce the parameter space.*

- *The TRSM leads to interesting phenomenological predictions which can be tested at the HL-LHC including enhancements in Triple Higgs production.*

- *Triple Higgs production $h_1 h_1 h_1$ as in the SM cannot be probed at the LHC due to its tiny cross section.*

- The *6b jet* final state is a good candidate to look for the *TRSM (BP3) through triple Higgs production in the HL-LHC.*

THANK YOU!