Overview of ATLAS HH/SH Run-2 results and Run-3 plan

David Brunner
on the behalf of Stockholm University ATLAS group

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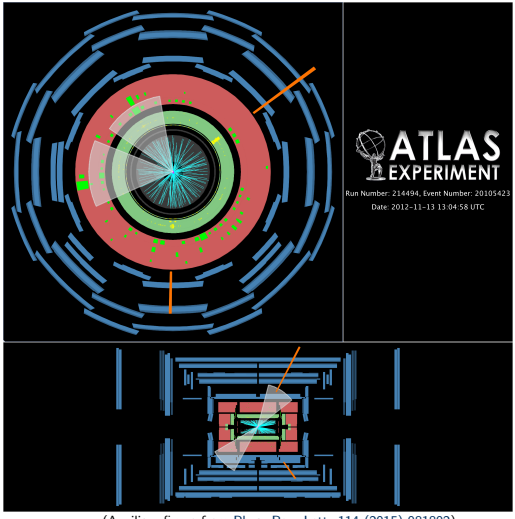
What are we exactly looking for?

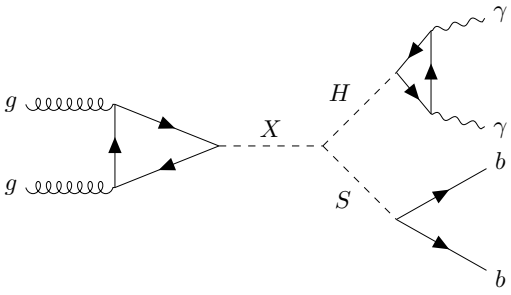


(Auxiliary figure from Phys. Rev. Lett. 114 (2015) 081802)

- A (quite old) event display of a di-jet + di-photon event

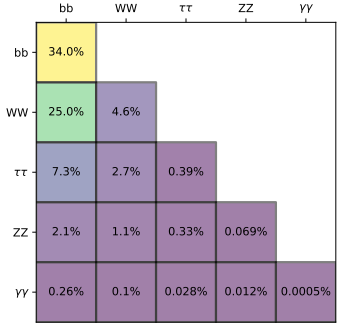
SH signal process

Physical process of interest:



- X and S Higgs-like heavy bosons, with $m_X > m_S$
- H as Standard Model Higgs boson

Choice of final state:



- *bbbb* with large branching ratio, but challenging dominating multi-jet background
- $bb\gamma\gamma$ with small branching ratio, but smaller and easier to handle background

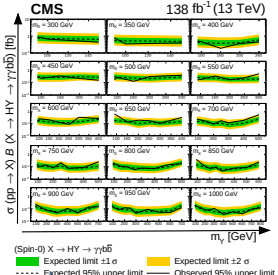
Latest results of the SH searches in the $bb\gamma\gamma$ final state

ATLAS:

Search for a resonance decaying to a scalar particle and a Higgs boson in the final state with two bottom quarks and two photons in proton-proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

Coming soon to your favourite high energy particle physics journal!

CMS: (see arXiv:2310.01643)



- Analysis with $\sqrt{s} = 13$ TeV and integrated luminosity of 138 fb^{-1}
- X are 260-1000 GeV and 300-1000 GeV, with the Y mass range being 90-800 GeV
- Local (global) significance of 3.8 (2.8) standard deviations for X and Y masses of 650 and 90 GeV

Recent analysis with other final states*:

- ATLAS bbbb decay mode arXiv:2202.07288
- ATLAS bb$\tau\tau$ decay mode arXiv:2209.10910
- ATLAS bb$\gamma\gamma$ decay mode arXiv:2112.11876
- CMS bbbb decay mode arXiv:2204.12413
- CMS bbWW decay mode arXiv:2112.03161
- CMS $\tau\tau$WW/$\tau\tau\tau\tau$/WWWW decay mode arXiv:2206.10268

*(most of the time resonant HH analysis, where an additional heavy resonance study is performed)

Current analysis and plans for next iteration

What is currently done:

- Analysis in the $bb\gamma\gamma$ final state with data taken from 2016-2018 (Run 2)
- Mass window cut on di-γ mass and usage of mass-parametrised in X and S mass to increase signal sensitivity
- Simplified signal model used (no underlying physics model is used)

What is planned (so far) for the next analysis iteration:

- Study both decay modes $S(\rightarrow bb)H(\rightarrow \gamma\gamma)$ and $S(\rightarrow \gamma\gamma)H(\rightarrow bb)$
- Analyse the kinematic phase space with highly boosted jets
- Use more sophisticated physics models for signal modeling

TRSM in a nutshell (arXiv:1908.08554)

TRSM potential:

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

Field parametrisation in unitary gauge:

$$\Phi = \begin{pmatrix} 0 \\ \frac{\varphi_h + v_h}{\sqrt{2}} \end{pmatrix}, \quad \phi_S = \frac{\varphi_S + v_S}{\sqrt{2}}, \quad \phi_X = \frac{\varphi_X + v_X}{\sqrt{2}}$$

Mass eigen states parametrisation:

$$\begin{pmatrix} h_1 \\ h_2 \\ h_3 \end{pmatrix} = R(\theta_{XS}, \theta_{SH}, \theta_{XH}) \begin{pmatrix} \varphi_h \\ \varphi_S \\ \varphi_X \end{pmatrix}$$

with $m(h_3) > m(h_2) > m(h_1)$

7 free parameters:

$v_X, v_S, \theta_{XS}, \theta_{SH}, \theta_{XH}, m_a, m_b$

Model scenarios

Two scenarios lead to wished signal configuration:

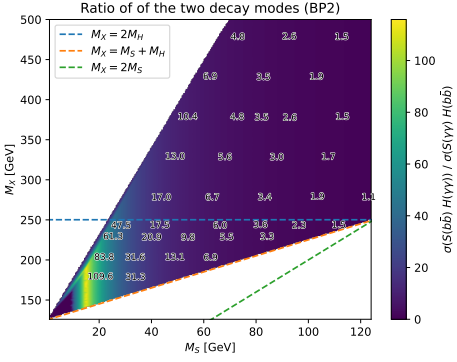
- h3 = X, h2 = S, h1 = H_{SM} (BP3)
- h3 = X, h2 = H_{SM}, h1 = S (BP2)

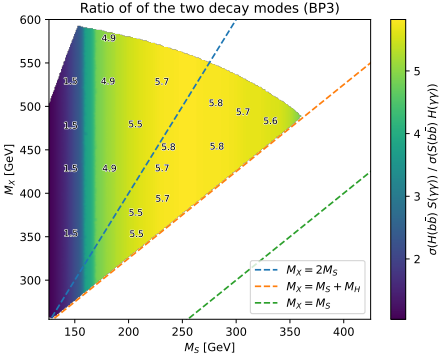
Benchmarks studied in paper and in the analysis:

Parameter	Benchmark scenario					
	BP1	**BP2**	**BP3**	**BP4**	**BP5**	**BP6**
M_1 [GeV]	[1, 62]	[1, 124]	125.09	[1, 62]	[1, 124]	125.09
M_2 [GeV]	[1, 124]	125.09	[126, 500]	[1, 124]	125.09	[126, 500]
M_3 [GeV]	125.09	[126, 500]	[255, 650]	125.09	[126, 500]	[255, 1000]
θ_{hs}	1.435	1.352	−0.129	−1.284	−1.498	0.207
θ_{hx}	−0.908	1.175	0.226	1.309	0.251	0.146
θ_{sx}	−1.456	−0.407	−0.899	−1.519	0.271	0.782
v_s [GeV]	630	120	140	990	50	220
v_x [GeV]	700	890	100	310	720	150

Phenomenological studies (performed by Iram Haque)

Cross section comparison $S(\to bb)H(\to \gamma\gamma)$ **vs** $S(\to \gamma\gamma)H(\to bb)$**:**





- Interesting observation: In BP3 is $S(\to \gamma\gamma)H(\to bb)$ enhanced compared to $S(\to bb)H(\to \gamma\gamma)$

Summary

- A lot of activity in the Higgs sectors
- Mostly SM di-Higgs boson searches, but beyond SM di-Higgs searches getting more attention
- SU was and is involved in heavy Higgs resonance searches at ATLAS

Tack för er uppmärksamhet!

(Thanks for your attention!)

Contact

David Brunner
david.brunner@cern.ch
david.brunner@fysik.su.se