UPPSALA UNIVERSITET

ATLAS EXPERIMENT

CMS

The Higgs boson self-interaction at the LHC (and beyond)

a.k.a: Twice the Higgs, twice the fun!

Arnaud Ferrari (Uppsala University, Sweden)

LPSC Grenoble, 26/01/2023

Once upon a time in the Universe...

Only picoseconds after the Big Bang, the Universe experienced a phase transition into a state of lower energy, in which nearly all fundamental particles became massive by interacting with the *Higgs field*.

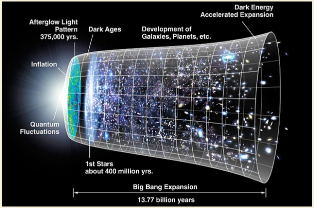


Image: NASA/WMAP Science Team

Once upon a time in the Universe...

Only picoseconds after the Big Bang, the Universe experienced a phase transition into a state of lower energy, in which nearly all fundamental particles became massive by interacting with the *Higgs field*.

About 13.8 billion years later...

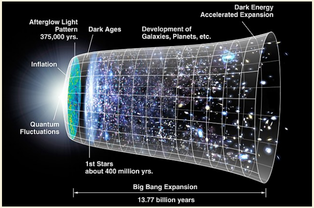
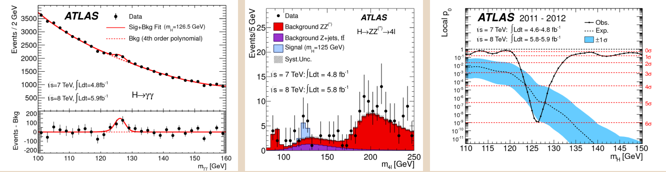


Image: NASA/WMAP Science Team

First came the Higgs-dependence Day...

4 July 2012: the ATLAS and CMS collaborations at CERN's Large Hadron Collider (LHC) announced the discovery of a spin-0 particle with a mass of about 125 GeV.



Images: ATLAS Collaboration, Phys. Lett. B 716 (2012) 1.

Once upon a time in the Universe...

Only picoseconds after the Big Bang, the Universe experienced a phase transition into a state of lower energy, in which nearly all fundamental particles became massive by interacting with the *Higgs field*.

About 13.8 billion years later...

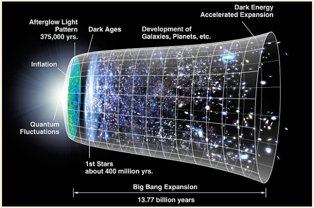


Image: NASA/WMAP Science Team

Then came the Nobel prize.

8 October 2013: the Nobel prize in physics was awarded to Englert and Higgs ”for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN’s LHC”.


The Higgs sector in the Standard Model

The Standard Model (SM) has been vastly explored and confirmed by the LHC experiments. At its core lies a scalar sector, responsible for electroweak symmetry breaking and mass generation.

Since the Higgs boson discovery in 2012, the scalar sector has been greatly studied by ATLAS and CMS.

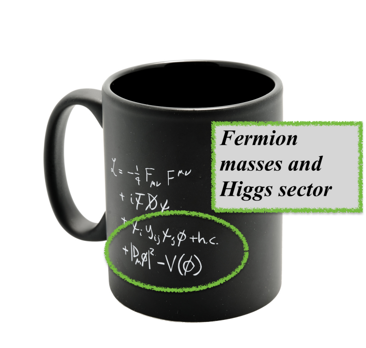
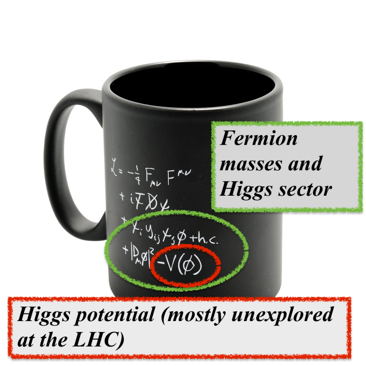


Image: https://visit.cern/shop

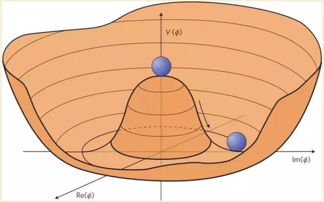
The Higgs sector in the Standard Model

The Standard Model (SM) has been vastly explored and confirmed by the LHC experiments. At its core lies a scalar sector, responsible for electroweak symmetry breaking and mass generation.

Since the Higgs boson discovery in 2012, the scalar sector has been greatly studied by ATLAS and CMS. All of it? No, the indomitable Higgs potential has not yet been conquered by the LHC physicists.



After discovering the Higgs boson, the ultimate probe of the SM is to fully measure the Higgs potential.

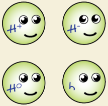


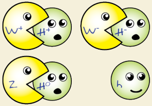
The Higgs sector in the Standard Model

In the mathematical framework of the SM, the Higgs field is a complex Higgs doublet ϕ and the Higgs sector is described by:

$$\mathcal{L} = |D_\mu \phi|^2 - V(\phi).$$

The first term describes the coupling of ϕ to gauge bosons:



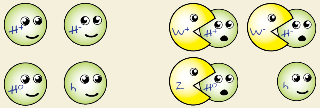


The Higgs sector in the Standard Model

In the mathematical framework of the SM, the Higgs field is a complex Higgs doublet ϕ and the Higgs sector is described by:

$$\mathcal{L} = |D_\mu \phi|^2 - V(\phi).$$

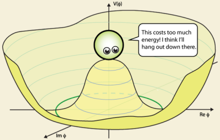
The first term describes the coupling of ϕ to gauge bosons:



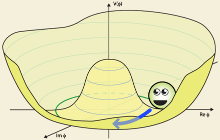
The second term, $V(\phi)$, is the Higgs potential. In its *minimal* form, it is:

$$V(\phi) = -\mu^2 \phi^2 + \lambda \phi^4.$$

If μ^2 and λ are both positive, the minimum of the Higgs potential lies at a vacuum expectation value $v \neq 0$.



Universe = a hot soup of massless stuff

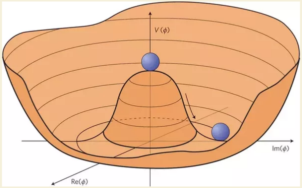


Universe = a cool place to live in

All Sketches from www.quantumdiaries.org

The ultimate probe of the Higgs sector

The shape of the Higgs potential, which is controlled by the parameters μ^2 and λ, completely determines the properties of the Higgs sector.

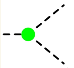


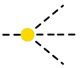
$$<\phi_0> = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ v \end{pmatrix}, \quad v = \sqrt{\mu^2/\lambda}.$$

$$V(\phi) = -\mu^2\phi^2 + \lambda\phi^4 \overset{\phi\to v+H}{\supset} \lambda v^2 H^2 + \lambda v H^3 + \frac{1}{4}\lambda H^4$$

mass term $\frac{1}{2}m_H^2 H^2$

self-interaction terms (never observed)

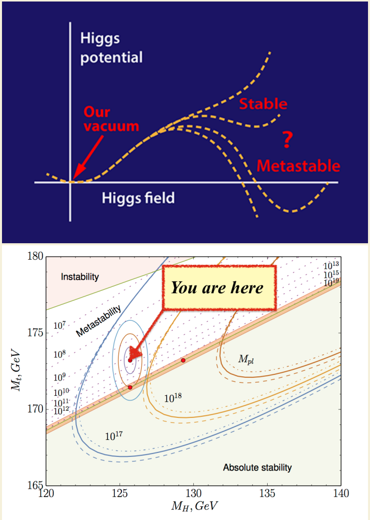




$\Longrightarrow$ To fully test the Higgs sector, one must observe the self-interaction term(s) and measure the Higgs boson self-coupling λ via Higgs boson pair production.

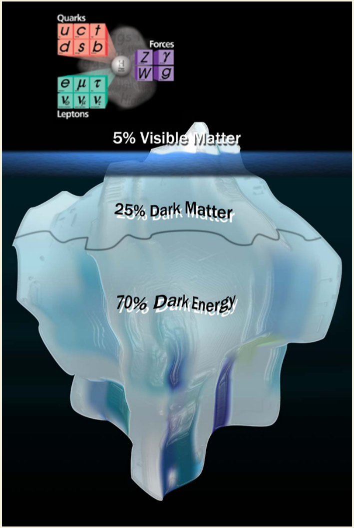
Why does it matter?

- The shape of the Higgs potential has other implications beyond the mass-generation mechanism.
- In particular, the vacuum state of the Universe depends on the Higgs potential.
- Whether the Universe exists in a true or metastable vacuum can be calculated from the Higgs boson and top-quark masses.
- In the absence of new physics that may affect the Higgs sector, there is a (borderline) possibility that our Universe is in a metastable state, i.e. a false vacuum.



Images: APS/Alan Stonebraker (top) and adapted from Phys. Rev. Lett. 115 (2015) 201802 (bottom).

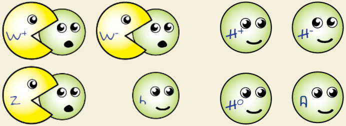
Why does it matter?



Sketches adapted from www.quantumdiaries.com

There are already many (indirect) hints of new physics beyond the SM! And its Higgs sector has serious short-comings:

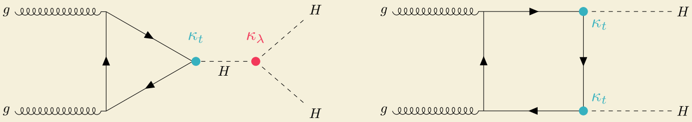
- Why so many orders of magnitude across the fermion couplings to the Higgs field?
- m_H should be driven to a very large scale by quantum loop corrections, why such a remarkably precise cancellation against the bare mass?
- Why should the Higgs potential have a minimal form, and could there be an extended Higgs sector?



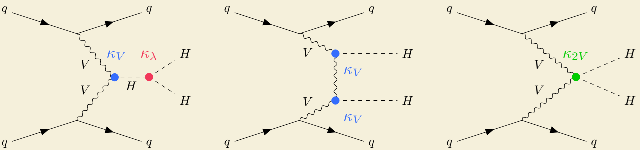
Higgs boson pair production

Non-resonant pairs of Higgs bosons (HH) arise from several diagrams, some of which interfere destructively. Very small cross-sections!

Gluon-gluon fusion: $\sigma^{\mathrm{SM}}_{\mathrm{ggF}} \simeq 31\ \mathrm{fb} \pm 3\%(\mathrm{PDF} + \alpha_s)\,^{+6\%}_{-23\%}(\mathrm{scale} + m_t)$ [13 TeV].



Vector-boson fusion: $\sigma^{\mathrm{SM}}_{\mathrm{VBF}} \simeq 1.7\ \mathrm{fb} \pm 2.1\%(\mathrm{PDF} + \alpha_s)\,^{+0.03\%}_{-0.04\%}(\mathrm{scale})$ [13 TeV].



Other production modes (e.g. VHH, ttHH) have even smaller cross-sections.

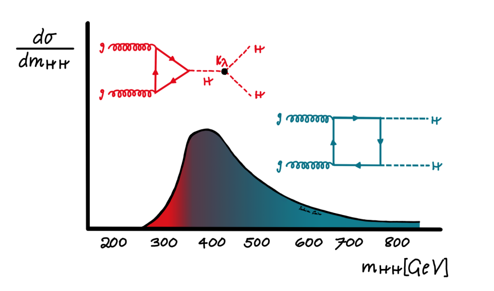
Non-resonant HH mass distribution(s)

- HH events from the self-interaction diagrams are soft.

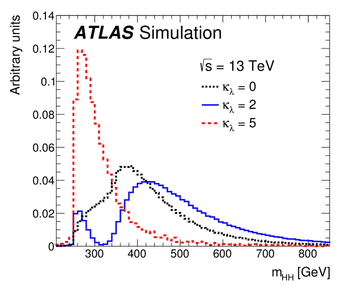
  ⇒ Challenge for triggers and detector object reconstruction/identification!

- $\kappa_\lambda \neq 1$ modifies the cross-section and kinematical properties of HH pairs.

  ⇒ Allows to disentangle κ_λ hypotheses (it also holds for other couplings, e.g. κ_{2V} in VBF).



ATLAS Physics Briefing: Twice the Higgs, twice the challenge



Phys. Lett. B 800 (2020) 135103

HH decays and search channels

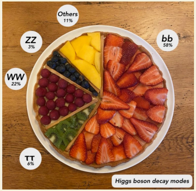


Image: @PhysicsCakes (Twitter)

Multitude of Higgs boson decays ⇒ $\mathcal{O}(\text{multitude}^2)$ of HH search channels, each with specific experimental challenges and sensitivity reach.

- Not a single "golden" channel;

	bb	WW	ττ	ZZ	γγ
bb	34%				
WW	25%	4.6%			
ττ	7.3%	2.7%	0.39%		
ZZ	3.1%	1.1%	0.33%	0.069%	
γγ	0.26%	0.10%	0.028%	0.012%	0.0005%

Image by Katharine Leney

HH decays and search channels

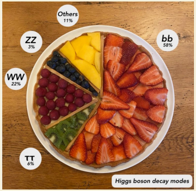
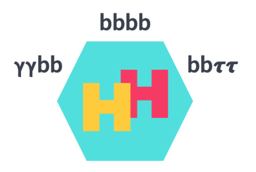


Image: @PhysicsCakes (Twitter)

Multitude of Higgs boson decays ⇒ $\mathcal{O}(\text{multitude}^2)$ of HH search channels, each with specific experimental challenges and sensitivity reach.

- Not a single ”golden” channel;
- But (at least) three silver bullets!

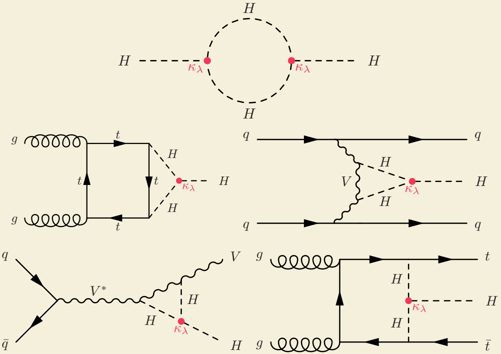


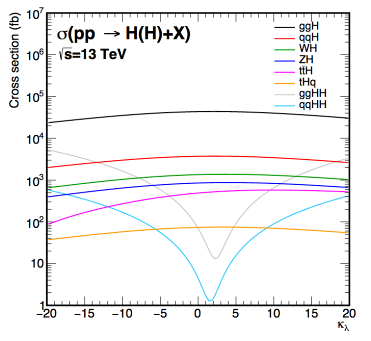
	bb	WW	ττ	ZZ	γγ
bb	34%				
WW	25%	4.6%			
ττ	7.3%	2.7%	0.39%		
ZZ	3.1%	1.1%	0.33%	0.069%	
γγ	0.26%	0.10%	0.028%	0.012%	0.0005%

Image by Katharine Leney

Self-interaction and single Higgs bosons

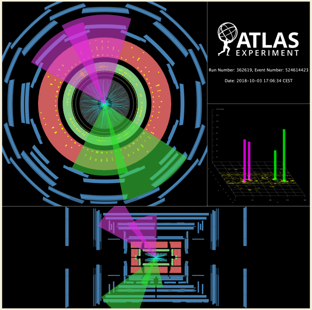
- Single Higgs boson processes do not depend on κ_λ at LO.
- However, NLO electroweak loops allow κ_λ to affect single Higgs boson production and decay modes.

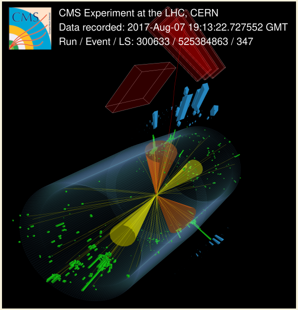




LHCHWG-2022-002

HH $\rightarrow$ bbbb



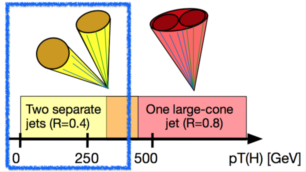


- Highest branching ratio... but large multi-jet background!
- Mostly probes large m_{HH} $\Rightarrow$ sensitivity to HH events with large $p_{\mathrm{T}}^{\mathrm{H}}$.

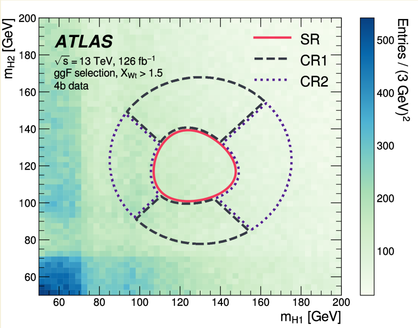
- ATLAS: arXiv: 2301.03212 [hep-ex]
- CMS: Phys. Rev. Lett. 129 (2022) 081802 & arXiv:2205.06667 [hep-ex]

HH → bbbb – resolved topology

- Start from triggered events with ≥2 (ATLAS) or ≥3 (CMS) b-jets.
- SR = two b-jet pairs compatible with a Higgs boson.
- Data-driven background model based on SR event re-weighting:
  - 2b → 4b (ATLAS);
  - 3b → 4b (CMS);
  - Re-weighting function derived with machine-learning techniques in CRs around the SR.

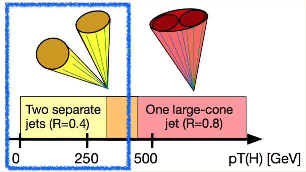


Sketch by Daniel Guerrero

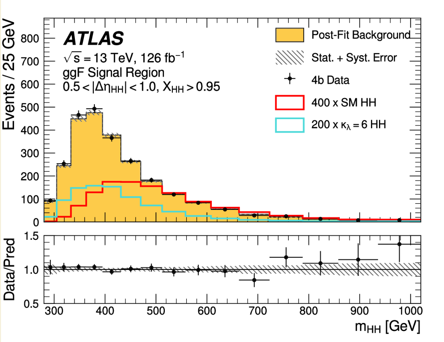


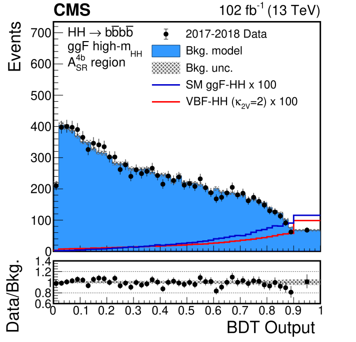
HH → bbbb – resolved topology

- ggF- and VBF-like event categories based on forward jets and kinematic properties of HH.
  - ATLAS: fit m_{HH} in all categories;
  - CMS: fit an MVA classifier output or m_{HH} in different categories.



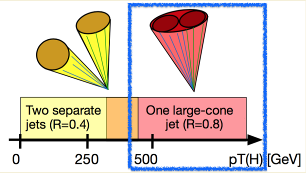
Sketch by Daniel Guerrero



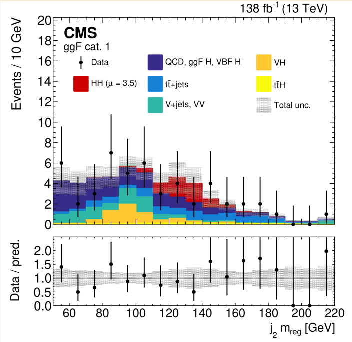


HH → bbbb – boosted topology (CMS)

- Two large-radius jets as H→bb candidates.
- Sophisticated tagger to discriminate against QCD-induced jets.
- Multi-jet background estimated using transfer factors from CRs with looser H→bb tagging requirements.
- ggF-like SRs: jet mass as discriminant.
- VBF-like SRs ↔ 7 bins in H→bb tagger purity and m_{HH}.



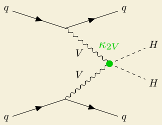
Sketch by Daniel Guerrero

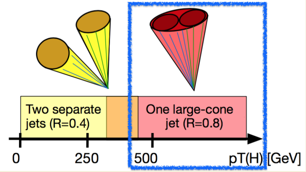


HH → bbbb – boosted topology (CMS)

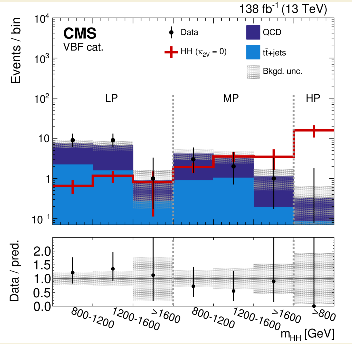
- Two large-radius jets as H→bb candidates.
- Sophisticated tagger to discriminate against QCD-induced jets.
- Multi-jet background estimated using transfer factors from CRs with looser H→bb tagging requirements.
- ggF-like SRs: jet mass as discriminant.
- VBF-like SRs ↔ 7 bins in H→bb tagger purity and m_{HH}.

⇒ Sensitive to κ_{2V}: more on this later!

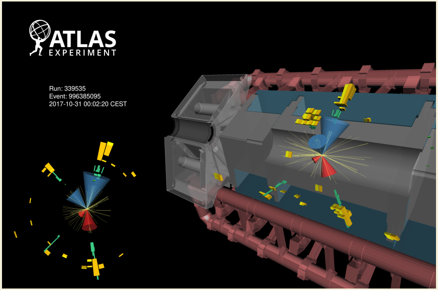


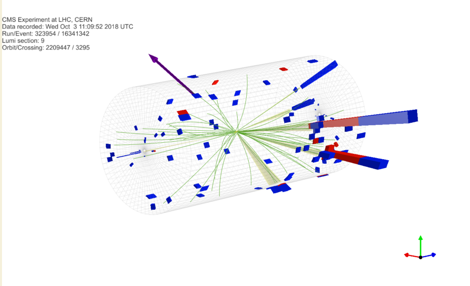


Sketch by Daniel Guerrero



HH → $bb\tau\tau$



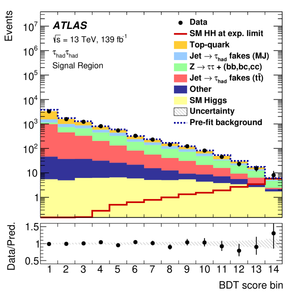


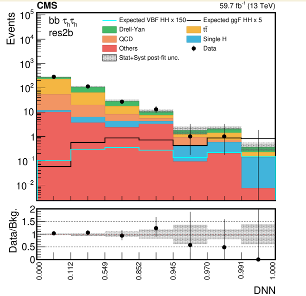
- Intermediate branching ratio... but clean final state with moderate backgrounds!

- ATLAS: arXiv:2209.10910 [hep-ex]
- CMS: arXiv:2206.09401 [hep-ex]

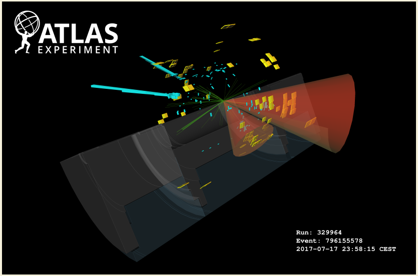
HH → bb$\tau\tau$

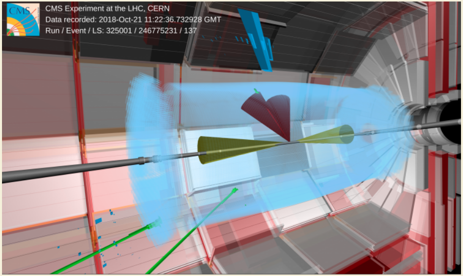
- bb$\tau_h\tau_e$, bb$\tau_h\tau_\mu$ and bb$\tau_h\tau_h$ final states + further event categories:
  - CMS: 5 VBF-like regions + 3 ggF-like regions based on the H→bb topology (resolved 2b, resolved 1b, boosted);
  - ATLAS: 3 inclusive regions based on the trigger strategy.
- Background modelling:
  - $t\bar{t}$ and Z+jets: simulation with data-driven corrections;
  - data-driven method if a gluon- or quark-initiated jet mimics τ_h.
- Signal extraction: MVA classifiers for both ATLAS and CMS.





HH → bbγγ



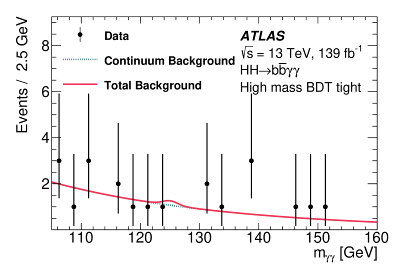


- Tiny branching ratio... but very clean signature: excellent $m_{\gamma\gamma}$ resolution and small backgrounds!
- Enhanced sensitivity at low m_{HH}, hence to the Higgs boson self-interaction.

- ATLAS: Phys. Rev. D 106 (2022) 052001
- CMS: JHEP03 (2021) 257

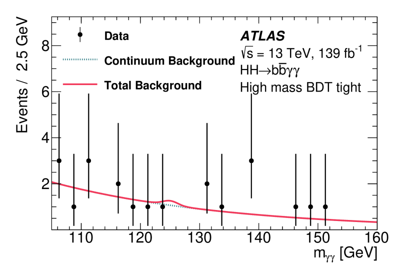
HH → $bb\gamma\gamma$

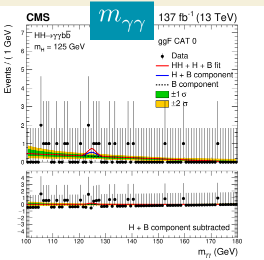
- Di-photon trigger and event selection + 2 b-jets.
- Event categories based on:
  - • $m_{bb\gamma\gamma}$;
  - • various purity regions based on MVA outputs;
  - • ggF- and VBF-like topologies (in CMS).
- Signal and backgrounds:
  - • HH and single-H shapes from simulation;
  - • continuum background shape from data;
- ATLAS: parametric fit of $m_{\gamma\gamma}$ only.
- CMS: parametric fit in the $(m_{\gamma\gamma}; m_{bb})$ plane.

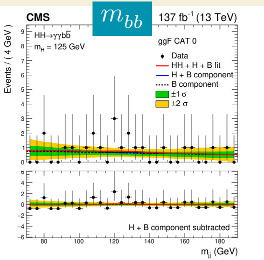


HH $\to b b\gamma\gamma$

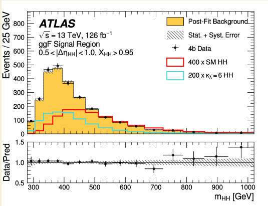
- Di-photon trigger and event selection + 2 b-jets.
- Event categories based on:
  - $m_{bb\gamma\gamma}$;
  - various purity regions based on MVA outputs;
  - ggF- and VBF-like topologies (in CMS).
- Signal and backgrounds:
  - HH and single-H shapes from simulation;
  - continuum background shape from data;
- ATLAS: parametric fit of $m_{\gamma\gamma}$ only.
- CMS: parametric fit in the $(m_{\gamma\gamma}; m_{bb})$ plane.

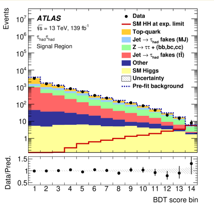


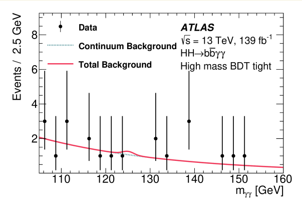




Putting it all together...

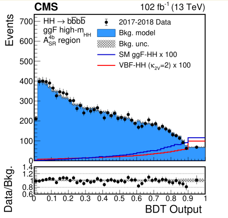


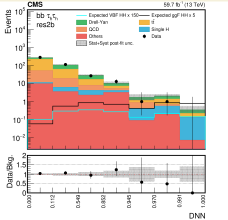


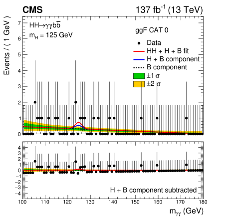


No golden HH search channel: combinations are key.

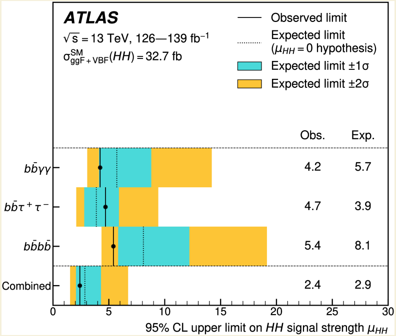
- ATLAS: arXiv:2211.01216 [hep-ex]
- CMS: Nature 607, 60-68 (2022)

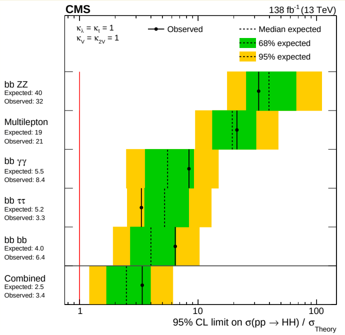






HH combined results: limits on $\sigma^{HH}_{ggF+VBF}$





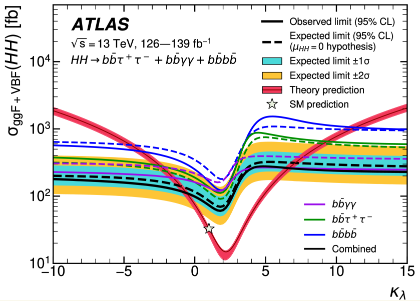
Obs. (exp.) 95% CL combined limit: 2.4 (2.9) × SM prediction.

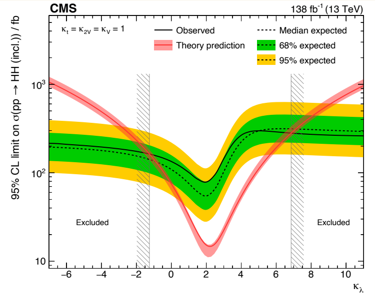
Obs. (exp.) 95% CL combined limit: 3.4 (2.5) × SM prediction.

CMS: the individual *bbbb* limit combines resolved and boosted topologies.

HH combined results: limits on κ_λ

ATLAS and CMS 95% CL limits on $\sigma^{HH}_{ggF+VBF}$ vs κ_λ (all other κ's at 1):

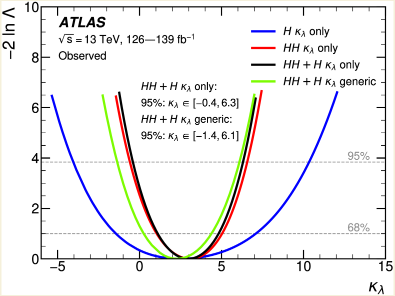


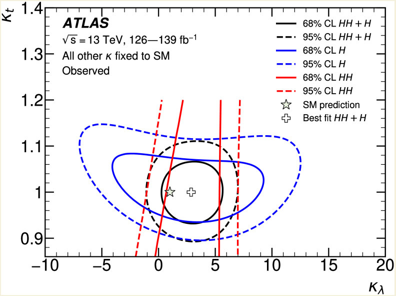


HH+H: constraints on κ_λ [ATLAS]

Constraints on κ_λ via a scan of the negative-logarithm of the profile likelihood, for various fit configurations:

- HH searches only, single-H measurements only, or their combinations.





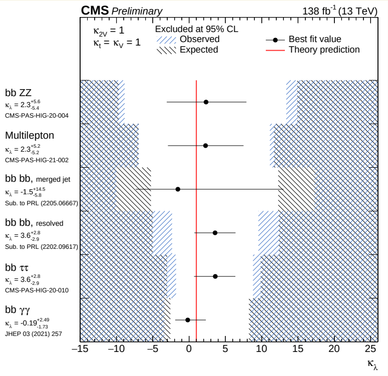
Summary of ATLAS HH+H combined results:

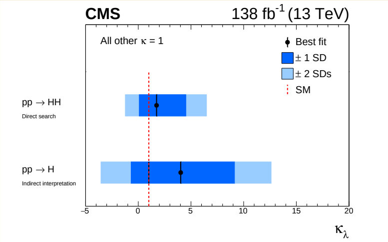
- Profile κ_λ only: $-0.4 < \kappa_\lambda < 6.3$ (95% CL).
- Profile κ_λ, κ_t, κ_V, κ_b, κ_τ: $-1.4 < \kappa_\lambda < 6.1$ (95% CL).

HH+H: constraints on κ_λ [CMS]

Constraints on κ_λ via a scan of the negative-logarithm of the profile likelihood, for various fit configurations:

- HH searches only, single-H measurements only.





Summary of CMS single-H and HH results (profile κ_λ only):

- Single-H: $-3.6 < \kappa_\lambda < 12.6$ (95% CL).
- HH: $-1.2 < \kappa_\lambda < 6.5$ (95% CL).

HH in Effective Field Theories

Effective Field Theories (EFTs) provide a model-independent framework to parametrise deviations from the SM, where higher-dimension operators modify the interactions of the SM particles.

In the Higgs EFT (HEFT) formalism, anomalous couplings are expected to be the dominant source of new physics. Also, the couplings to single Higgs bosons and Higgs boson pairs are separate → most suitable for HH interpretations.

$$\mathscr{L}_{\text{HEFT}} \supset -m_t \left(c_{tth} \frac{h}{v} + c_{tthh} \frac{h^2}{v^2} \right) \bar{t}t - c_{hhh} \frac{m_h^2}{2v} h^3 + \frac{\alpha_s}{8\pi} \left(c_{ggh} \frac{h}{v} + c_{gghh} \frac{h^2}{v^2} \right) G^a_{\mu\nu} G^{a,\mu\nu}$$

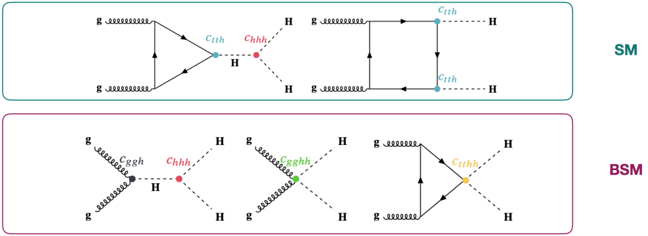


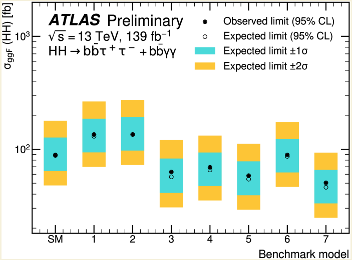
Image by Christina Dimitriadi

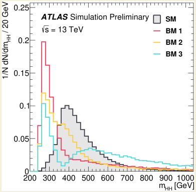
HH in Effective Field Theories

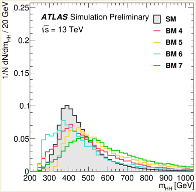
ATLAS has performed HEFT re-interpretations of HH searches in the $bb\gamma\gamma$ and $bb\tau\tau$ decay channels, and their combination.

Benchmark model	c_{hhh}	c_{tth}	c_{ggh}	c_{gghh}	c_{tthh}
SM	1	1	0	0	0
BM 1	3.94	0.94	1/2	1/3	−1/3
BM 2	6.84	0.61	0.0	−1/3	1/3
BM 3	2.21	1.05	1/2	1/2	−1/3
BM 4	2.79	0.61	−1/2	1/6	1/3
BM 5	3.95	1.17	1/6	−1/2	−1/3
BM 6	5.68	0.83	−1/2	1/3	1/3
BM 7	−0.10	0.94	1/6	−1/6	1

Seven HEFT benchmarks are used, with representative m_{HH} shape features.





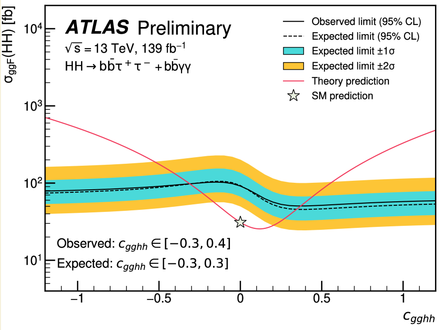


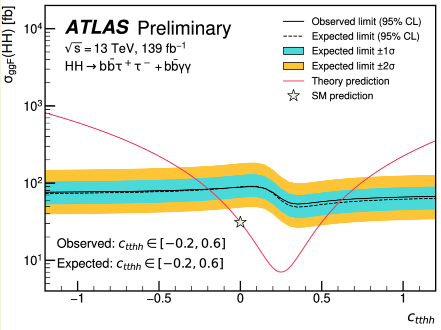
ATL-PHYS-PUB-2022-019

HH in Effective Field Theories

ATLAS has performed HEFT re-interpretations of HH searches in the $bb\gamma\gamma$ and $bb\tau\tau$ decay channels, and their combination.

Constraints on the c_{gghh} and c_{tthh} (other couplings set to their SM value):

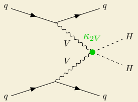




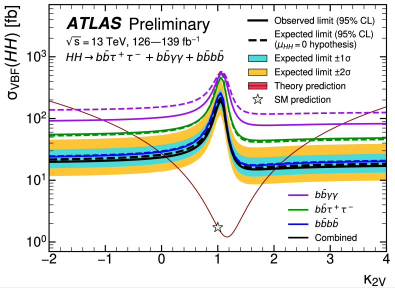
ATL-PHYS-PUB-2022-019

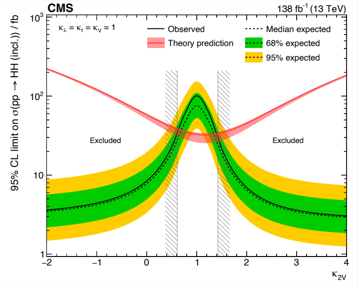
VVHH quartic coupling

Searches for VBF Higgs boson pair production allow to uniquely probe the VVHH quartic coupling.



Summary of the ATLAS and CMS 95% CL limits on $\sigma_{\mathrm{VBF}}^{\mathrm{HH}}$ as a function of κ_{2V} (all other couplings set to their SM values):



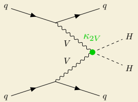


κ_{2V} values outside [0.1; 2.0] are excluded at 95% CL.

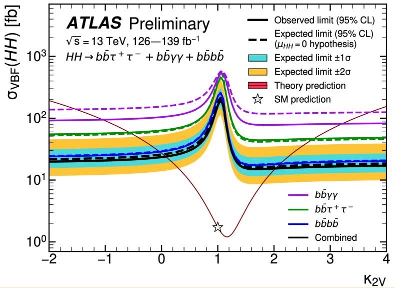
κ_{2V} values outside [0.7; 1.4] are excluded at 95% CL.

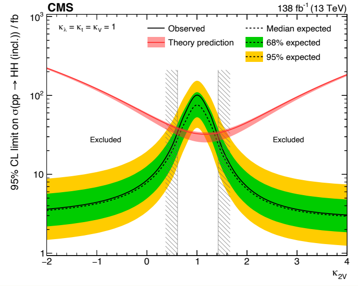
VVHH quartic coupling

Searches for VBF Higgs boson pair production allow to uniquely probe the VVHH quartic coupling.



Summary of the ATLAS and CMS 95% CL limits on $\sigma^{\mathrm{HH}}_{\mathrm{VBF}}$ as a function of κ_{2V} (all other couplings set to their SM values):

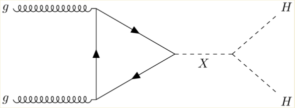




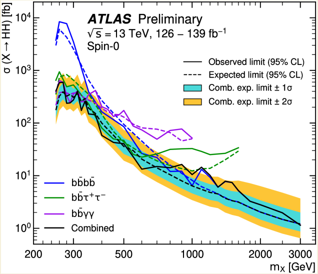
CMS excludes the $\kappa_{2V} = 0$ hypothesis with a significance of 6.6 standard deviations!

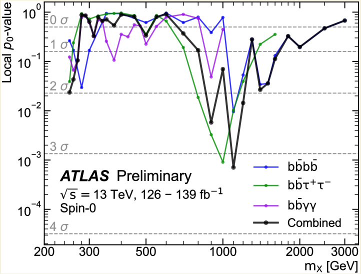
Resonant HH searches [ATLAS]

Pairs of Higgs bosons can also be produced via the decay of a hypothetical heavy resonance, and many BSM theories predict the existence of such heavy particles.



Summary of individual and combined resonant HH limits ($bb\gamma\gamma$, $bb\tau\tau$, $bbbb$): the largest excess in the combined limit is found at 1.1 TeV and corresponds to a local (global) significance of 3.2σ (2.1σ).

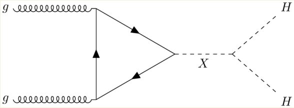




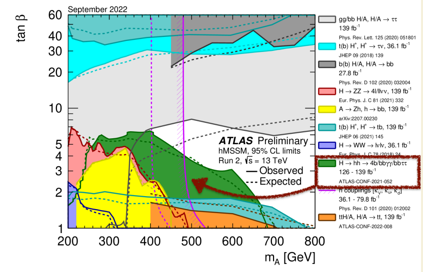
ATLAS-CONF-2021-052

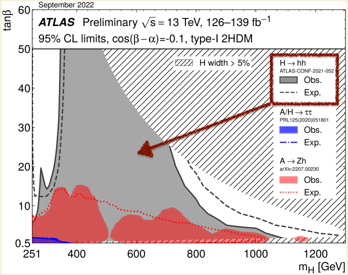
Resonant HH searches [ATLAS]

Pairs of Higgs bosons can also be produced via the decay of a hypothetical heavy resonance, and many BSM theories predict the existence of such heavy particles.



Searches for resonant HH production can then be interpreted in various BSM scenarios with an extended Higgs sector, e.g. in the hMSSM (left) and in the type-I 2HDM for $\cos(\beta - \alpha) = -0.1$ (right).

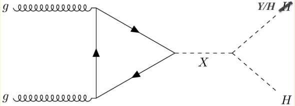




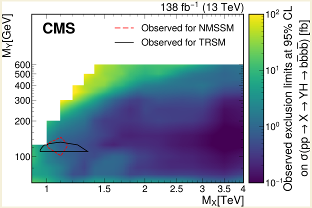
ATL-PHYS-PUB-2022-043

Resonant YH searches [CMS]

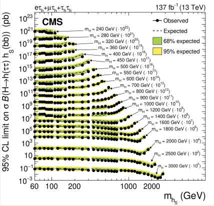
Asymmetric pairs of Higgs bosons can also be resonantly produced in some BSM scenarios, typically beyond the MSSM or CP-conserving 2HDM.



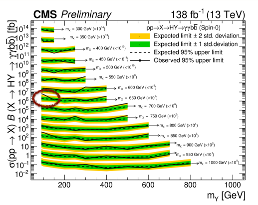
Several YH searches by CMS in $bbbb$, $bb\tau\tau$ and $bb\gamma\gamma$:



arXiv:2204.12413 [hep-ex]



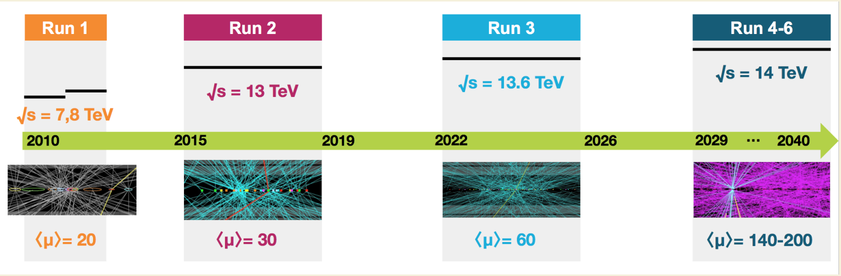
JHEP 11 (2021) 057



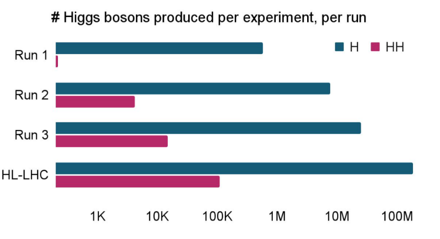
CMS-PAS-HIG-21-011

YH $\rightarrow bb\gamma\gamma$: excess at $m_X = 650$ GeV and $m_Y = 90$ GeV, with a local (global) significance of 3.8 (2.8) standard deviations.

HH prospects at the HL-LHC



A major task of the HL-LHC is to further explore the Higgs sector, in particular establish and measure the Higgs boson self-interaction.



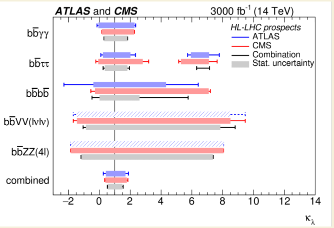
Both images by Elizabeth Brost

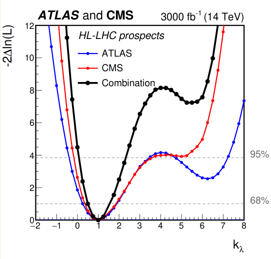
HH prospects at the HL-LHC

HH prospect studies for the European Particle Physics Strategy Update in 2018:

- Combination of five HH channels, many of which were based on the extrapolation of partial ATLAS and CMS Run 2 results.
- The combined significance was $\gtrsim 4$;
- The 68% confidence interval for κ_λ was $[0.52; 1.5]$.

	Statistical-only		Statistical + Systematic	
	ATLAS	CMS	ATLAS	CMS
$HH \to b\bar{b}b\bar{b}$	1.4	1.2	0.61	0.95
$HH \to b\bar{b}\tau\tau$	2.5	1.6	2.1	1.4
$HH \to b\bar{b}\gamma\gamma$	2.1	1.8	2.0	1.8
$HH \to b\bar{b}VV(ll\nu\nu)$	-	0.59	-	0.56
$HH \to b\bar{b}ZZ(4l)$	-	0.37	-	0.37
combined	3.5	2.8	3.0	2.6
	Combined 4.5		Combined 4.0	

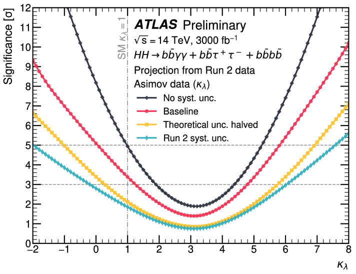


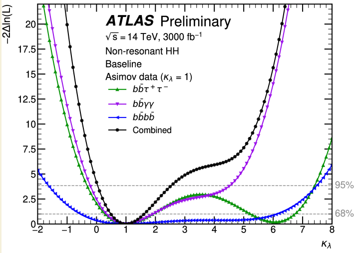


HH prospects at the HL-LHC

Updated HH prospect studies (2022):

- ATLAS updated their projections in the $bb\gamma\gamma + bb\tau\tau + bbbb$ channels, based on the extrapolations of full Run 2 HH search results:
  - 95% CL limit at 0.55 × the SM prediction;
  - Combined significance at 3.4;
  - 68% confidence interval for κ_λ at $[0.5; 1.6]$, comparable to 2018 ATLAS+CMS projections.
  - See ATL-PHYS-PUB-2022-053.

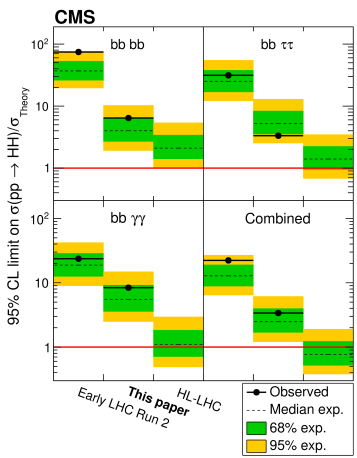




HH prospects at the HL-LHC

Updated HH prospect studies (2022):

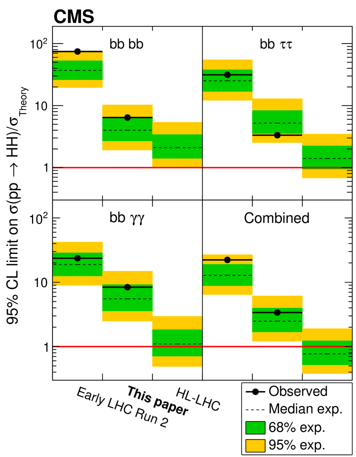
- CMS also recently updated their projections in the three main HH search channels:
  - 95% CL limit below 0.8 × the SM prediction.



HH prospects at the HL-LHC

Updated HH prospect studies (2022):

- CMS also recently updated their projections in the three main HH search channels:
  - 95% CL limit below 0.8 × the SM prediction.



- Despite experimental challenges at the HL-LHC, hard work and creativity in both event reconstruction and analysis techniques have allowed to improve the projected sensitivities since 2018.
- **Imagine what we can do in the next 20 years!!**

- Introduction
- Higgs boson pairs: production and decay modes
- ATLAS and CMS results: individual HH searches
- ATLAS and CMS results: combined HH (and single-H) searches
- Beyond the Higgs boson self-interaction
- Beyond the LHC Run 2
- Conclusion

Summary

- Elusive non-resonant pairs of Higgs bosons are the prime experimental signature of the Higgs boson self-interaction.
- Electroweak corrections in single-H processes provide additional sensitivity to the Higgs boson self-interaction.
- ATLAS+CMS have published impressive results with LHC Run 2 data:
  - σ_{HH} above 2.4–3.4 times the SM predictions is excluded at 95% CL;
  - $\kappa_\lambda \in [-0.4; +6.3]$ at 95% CL (ATLAS).
  - $\kappa_\lambda \in [-1.2; +6.5]$ at 95% CL (CMS).
- VBF HH searches uniquely allow to probe the VVHH quartic coupling: the $\kappa_{2V} = 0$ hypothesis has been excluded with a significance of 6.6σ!
- Resonant production of Higgs boson pairs (HH as well as YH) allows to probe several models with an extended Higgs sector.
- ATLAS and CMS experimentalists are eager to analyse the upcoming LHC datasets to further probe HH events.

Summary

- Elusive non-resonant pairs of Higgs bosons are the prime experimental signature of the Higgs boson self-interaction.
- Electroweak corrections in single-H processes provide additional sensitivity to the Higgs boson self-interaction.
- ATLAS+CMS have published impressive results with LHC Run 2 data:
  - σ_{HH} above 2.4–3.4 times the SM predictions is excluded at 95% CL;
  - $\kappa_{\lambda} \in [-0.4; +6.3]$ at 95% CL (ATLAS).
  - $\kappa_{\lambda} \in [-1.2; +6.5]$ at 95% CL (CMS).
- VBF HH searches uniquely allow to probe the VVHH quartic coupling: the $\kappa_{2V} = 0$ hypothesis has been excluded with a significance of 6.6σ!
- Resonant production of Higgs boson pairs (HH as well as YH) allows to probe several models with an extended Higgs sector.
- ATLAS and CMS experimentalists are eager to analyse the upcoming LHC datasets to further probe HH events.

Many tHHanks for your attention!!