

Multiboson interactions: from HH searches to EFT SM measurements

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Electro-Weak Interactions

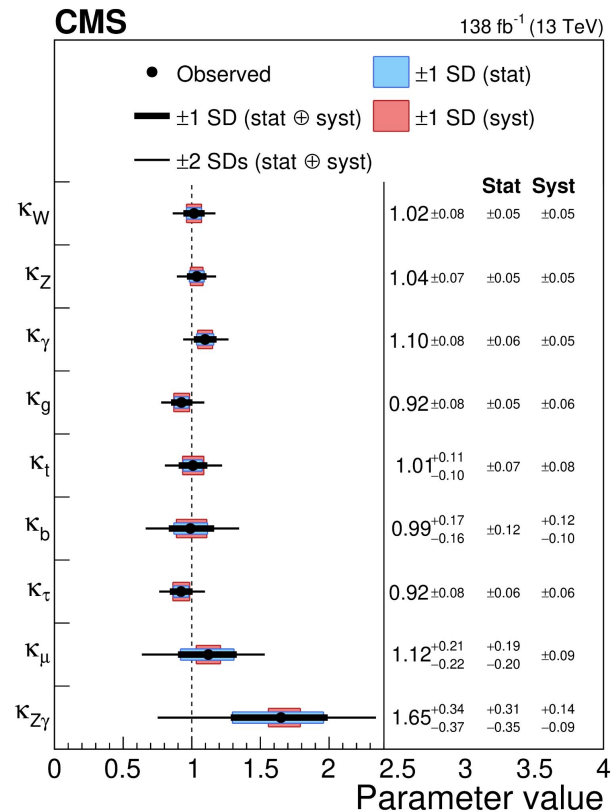
The **EW sector** of the SM is an extremely predictive and successful theory

Unified
 $SU(2)_L \times U(1)_Y$

Perturbative
down to small
energy scale

Few free
parameters

Tested to high precision by last and next-to-last generation of HEP experiments



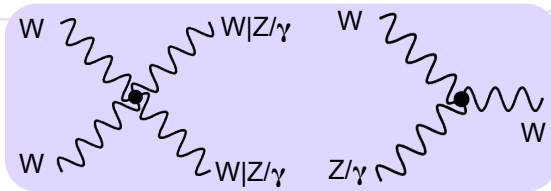
[Nature 607 \(2022\) 60-68](#)

Multiboson Couplings

The SM predicts the existence of **multiboson** couplings

Multi-gauge

- From non-Abelian structure of SU(2)
 - Gauge invariance of vector boson kinetic terms enforces triple and quartic couplings
 - No vertices with only Z/γ , since both stem from the same field W_3 after GWS mixing

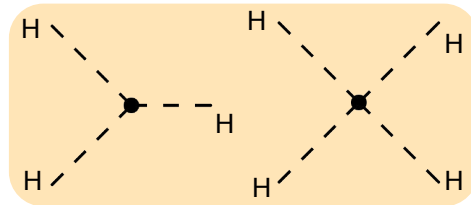


In common:

- All **coupling strengths predicted exactly** in EW theory
- Very **hard to measure experimentally** since relevant processes also occur through competing (dominant) diagrams

Multi-Higgs

- From shape of Higgs potential (quartic)
- From field expansion around the VEV (triple), after symmetry breaking



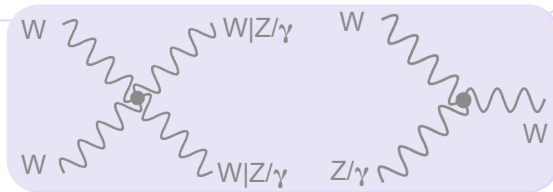
Multiboson Couplings

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In this talk

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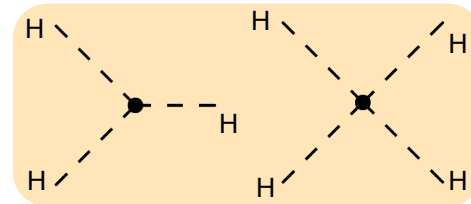


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Multi-Higgs

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Non-SM effects constrained using parameterization based on **Effective Field Theories**

- Do not introduce SM modifications of arbitrary magnitude
- Makes sure that the dimensionality of the respective operators is suppressed by a corresponding power of the new physics scale (Λ)



Standard Model EFT (SMEFT)

Consistent EFT **generalization of the SM** with a series of higher dimensional operators which are invariant under $SU_C(3) \times SU(2)_L \times U(1)_Y$, using **only SM fields**

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_{i=1}^{n_d} \frac{c_i^{(d)}}{\Lambda^{d-4}} \mathcal{O}_i^{(d)}, \quad d > 4$$

Free parameters: Wilson coefficients

Gauge invariant operators

Non-SM effects constrained using parameterization based on **Effective Field Theories**

- Do not introduce SM modifications of arbitrary magnitude
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Standard Model EFT (SMEFT)

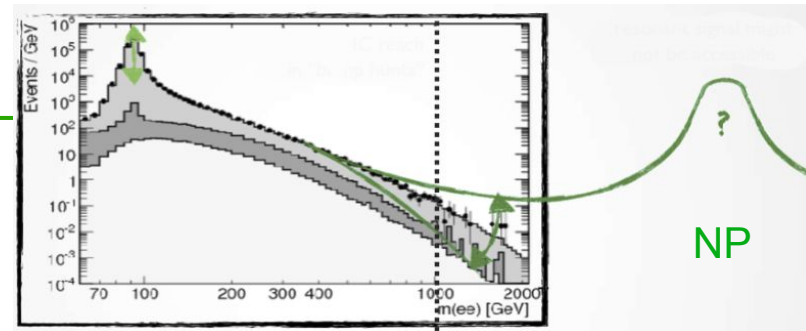
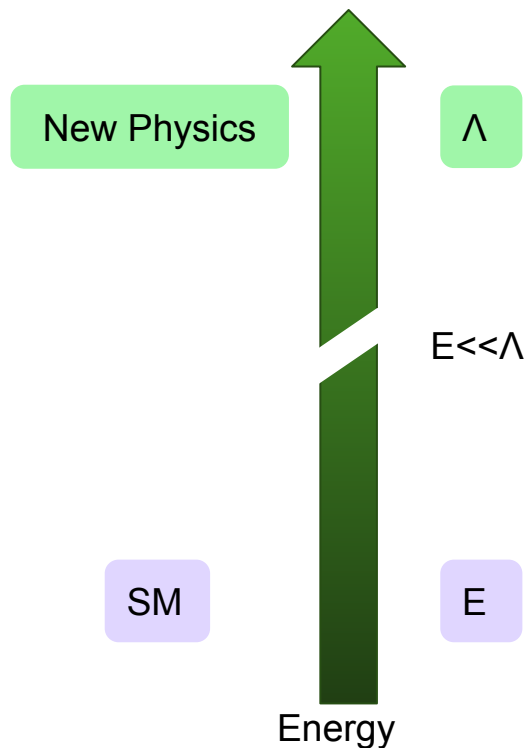
Pros

- **Model independent**
- different **measurements can be combined** leading to more stringent results

Cons

- Invalid at energies too close to Λ or above (**unitarity violation**)
- Power of data diluted by the large **freedom** in **choosing** which **operator** to consider
- no common agreement on **how to estimate uncertainties from missing higher orders**

EFT: bottom-up approach



Knowledge of NP not required

Information on NP can be **inferred** by measuring c_i

SM with fields
and symmetries

E/Λ

$\mathcal{L}_{EFT}^{(n)}$

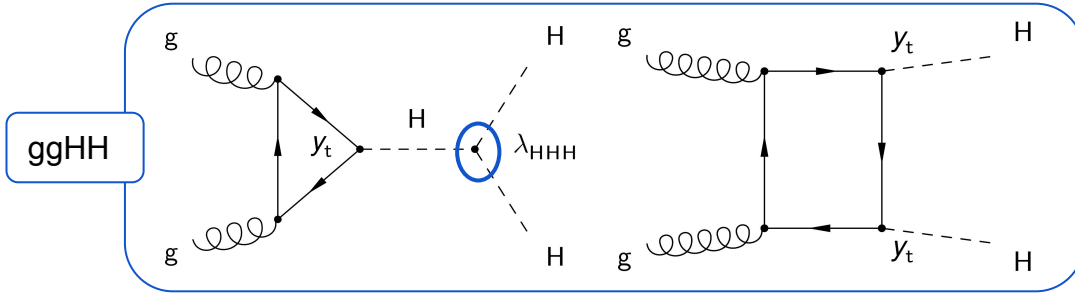
- all allowed operators at $(E/\Lambda)^n$
- free parameters c_i

HH production (non-resonant)

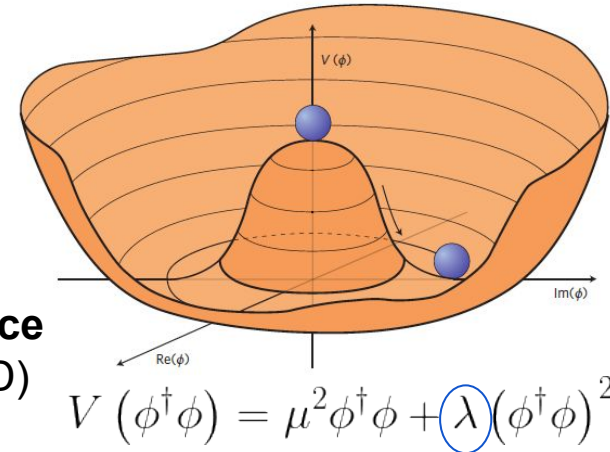
HH production can be used to directly study **Higgs boson self-coupling** and Higgs potential

At LHC mainly produced through **gluon fusion** via fermion loop

[arXiv:1312.5672](https://arxiv.org/abs/1312.5672)

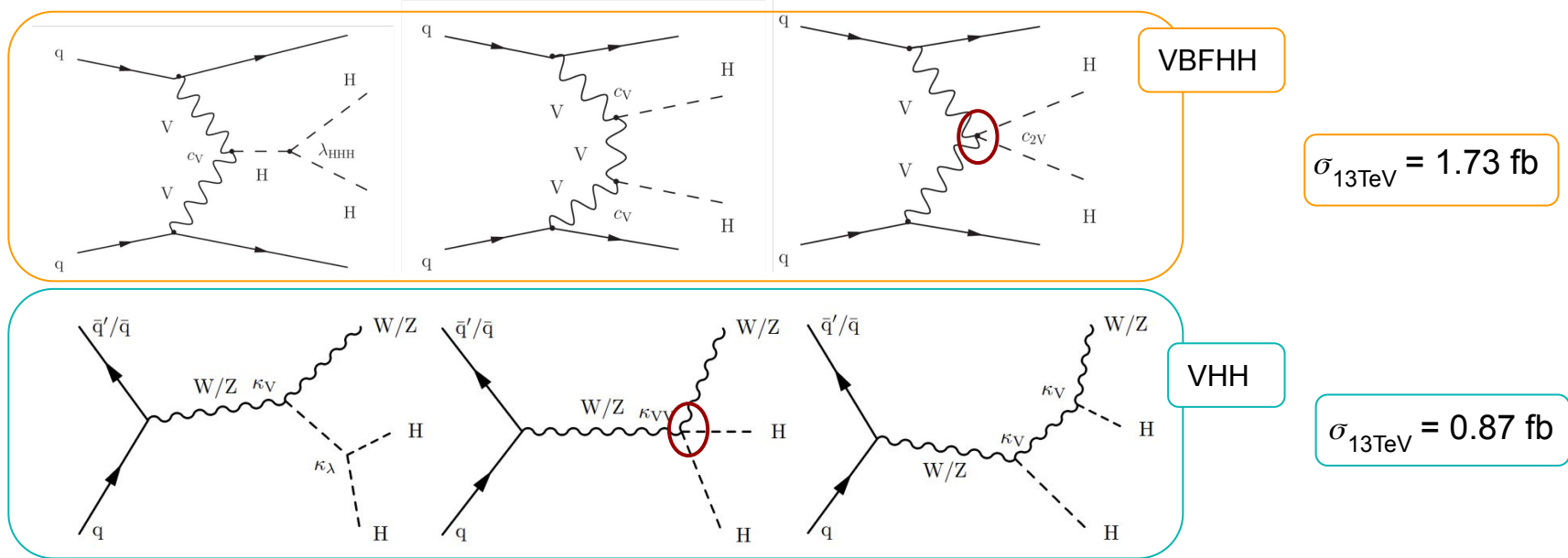


- In SM, amplitude from 2 contributions, **destructive interference**
→ Tiny cross-section, known with **high precision** (NNLO QCD)
 $\sigma_{13\text{TeV}} = 31.05^{+6\%}_{-23\%} \text{ fb (scale + } m_t)$
- Beyond SM, only **triangle diagram** sensitive to new physics in the Higgs potential (λ)
(anomalous Yukawa **Htt** couplings would modify both)



VBFHH and VHH

With full Run 2, possible to target also **subdominant** production modes: **VBFHH**, **VHH**
→ Diagrams also involve a different coupling: **VVHH**



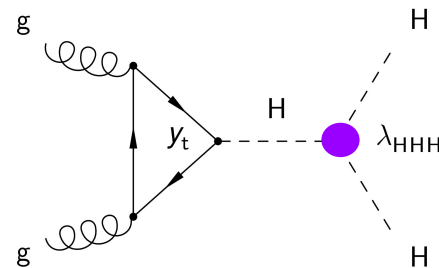
Exp. **observation very hard**, but small **modifications** to **VVHH** would lead to **big changes** in σ

HH beyond the SM: SMEFT

BSM processes can **modify cross-section** and **kinematic properties**

BSM effects parametrized as **multiplicative modifier** of the SM parameter λ : k_λ

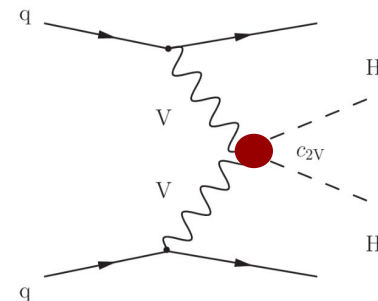
→ For **purely scalar operators**, description in terms of Wilson coefficients or modifiers are **equivalent**



For **VVHH** BSM effects also parametrized as modifier of the SM coupling: k_{2V}

→ Not equivalent to a SMEFT approach (only true for some models)

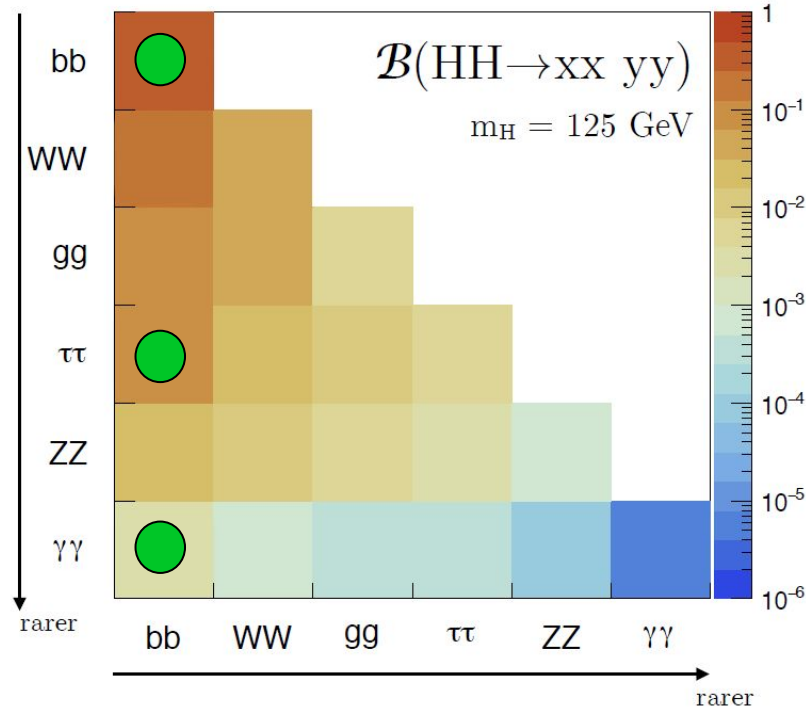
To combine with other anomalous quartic couplings, need proper dim-8 parametrization → [JHEP 09 \(2022\) 038](#)



more on this later

HH Experimental Searches

In Run 1

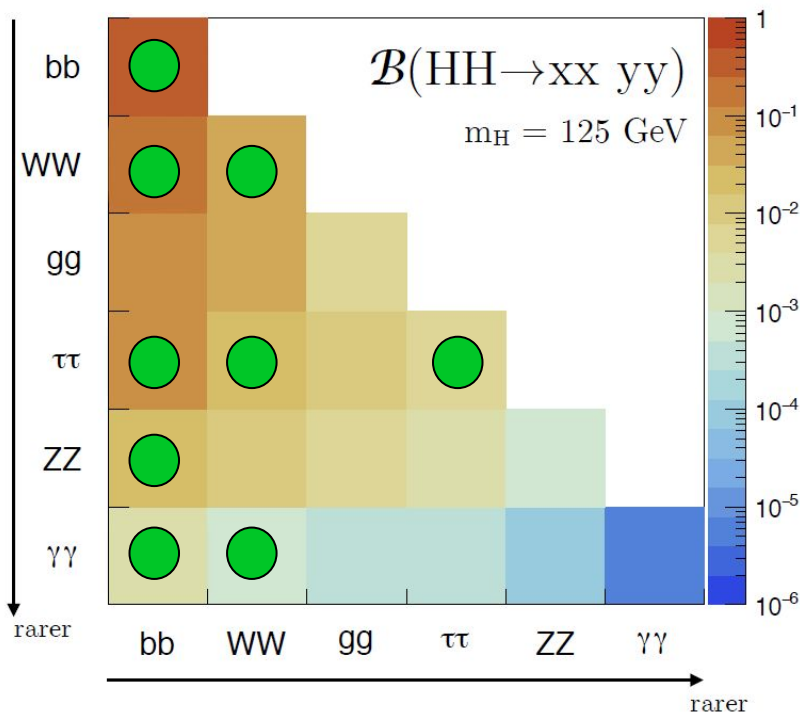


Experimental searches performed in many final states

“Higgs hunter’s rule”: larger BR corresponds to lower purity and vice versa

HH Experimental Searches

In Run 2:
many **new**
final states
explored!



And many **new**
measurements
performed!

- k_λ
- k_{2V}
- VBFHH and VHH production modes

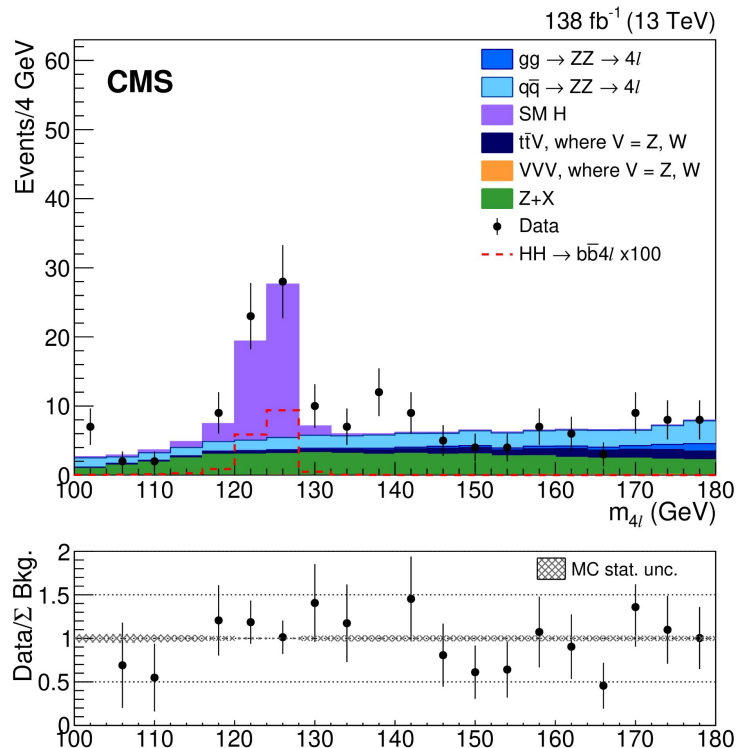
HH Search in Rare Channels: $bb4l$

First result in this channel!

→ **Clear signature** thanks to $4l$ decay,
but **tiny BR = 0.014%** @ $m_H = 125\text{GeV}$

- Triggers: single/double/triple and cross e, μ
- Selection:
2 pairs of OS SF leptons (e, μ) forming ZZ cand +
at least 2 AK4 jets with $p_T > 20\text{GeV}$ and $|\eta| < 2.4$
- If > 2 jets in event, those with higher btag score (deepCSV) selected
- **Signal region:** $115 < m_{4l} < 135$

To veto
VBFH($4l$)
events



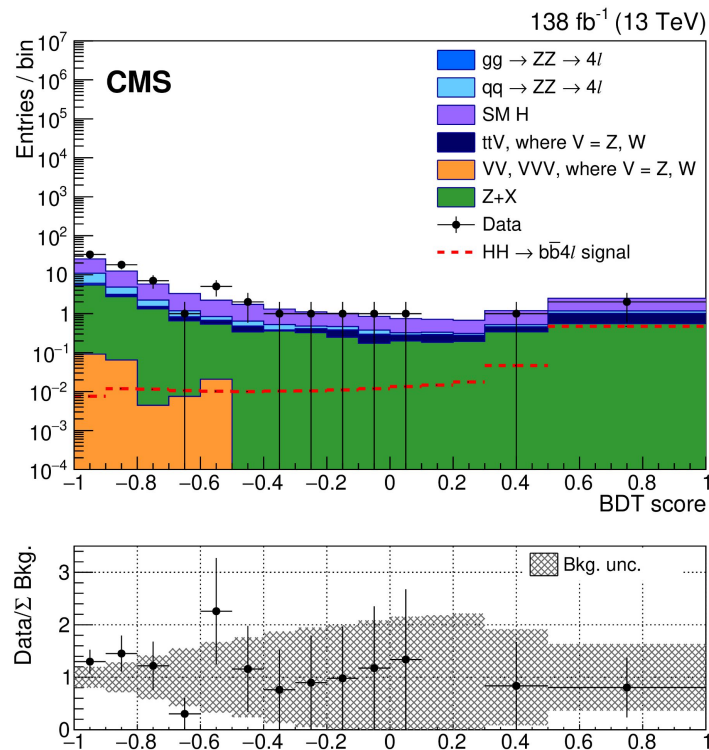
[JHEP 06 \(2023\) 130](#)

HH Search in Rare Channels: $bb4l$

- backgrounds: single H and ZZ production (from MC), reducible background (from data)
- **BDT** to separate signal from background
- Results extracted fitting BDT discriminant

Observed (expected) limits @95% CL:

- $\sigma(\text{HH} \rightarrow bb4l) < \mathbf{32.4}$ (39.6) σ_{SM}
- $\mathbf{-8.8 < k_\lambda < 13.4}$ ($-9.8 < k_\lambda < 15.0$)



[JHEP 06 \(2023\) 130](#)

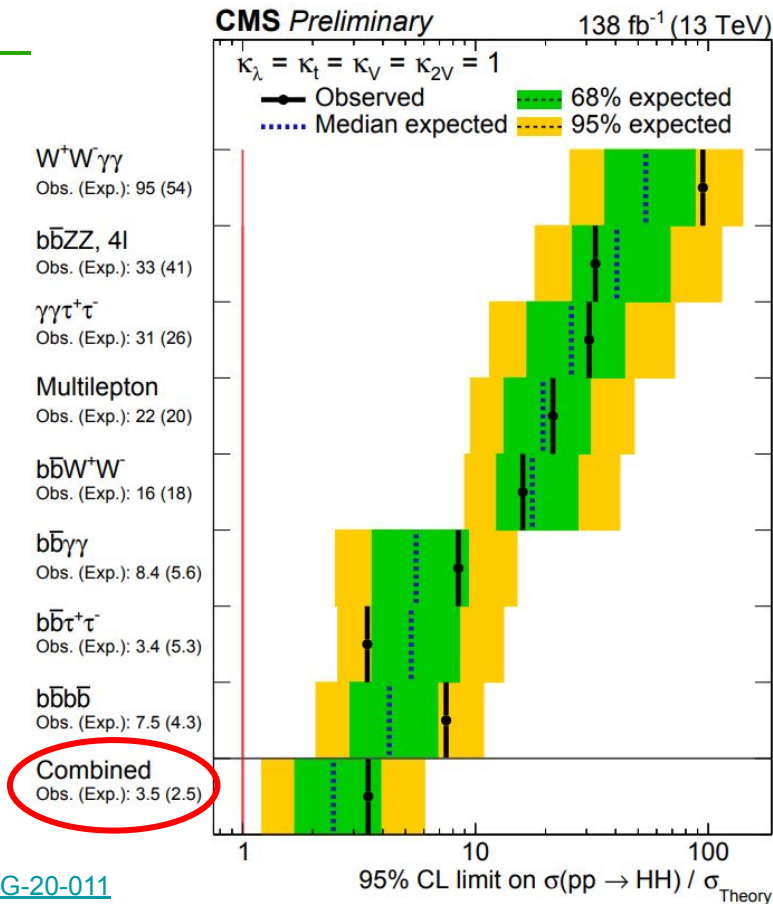
Full Run 2 Combination

Limit on **production cross-section** from full Run 2 combination of many channels

$$\sigma(\text{HH}) < \mathbf{3.5} \text{ (2.5)} \sigma_{\text{SM}}$$

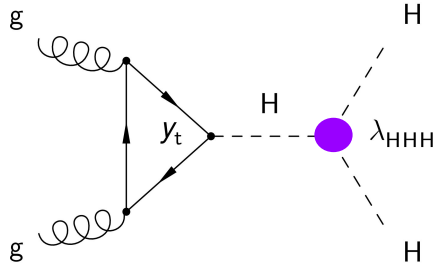
Improvements w.r.t previous combinations (2016 results: $\sigma(\text{HH}) < 22 \text{ (12)} \sigma_{\text{SM}}$) thanks to:

- analyses improvement/optimization
- object tagging improvement and trigger development
- addition of new channels



[CMS-PAS-HIG-20-011](#)

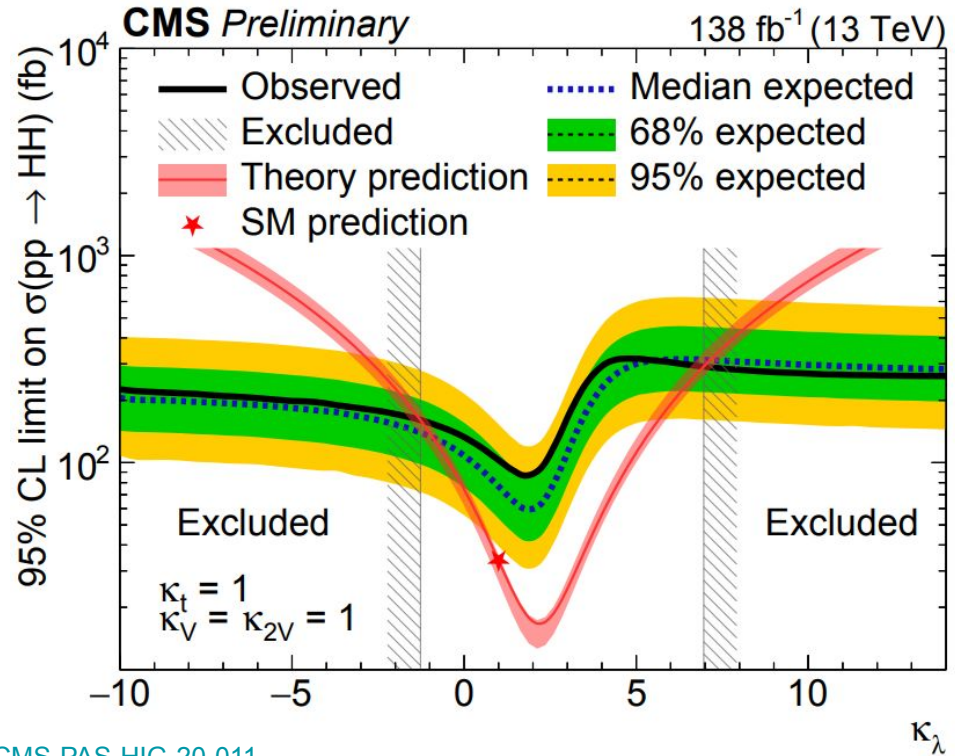
Limits on trilinear coupling



Observed (expected) limits at 95% CL:

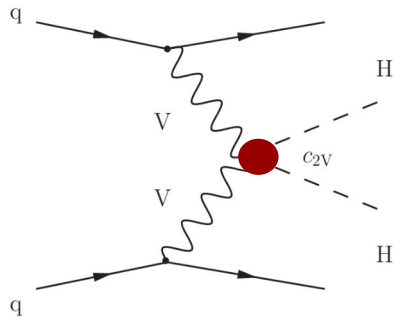
$$\mathbf{-1.39 \text{ } (-1.02) < k_\lambda < \mathbf{7.02 \text{ } (7.19)}$$

Assuming SM values for all other k s



[CMS-PAS-HIG-20-011](#)

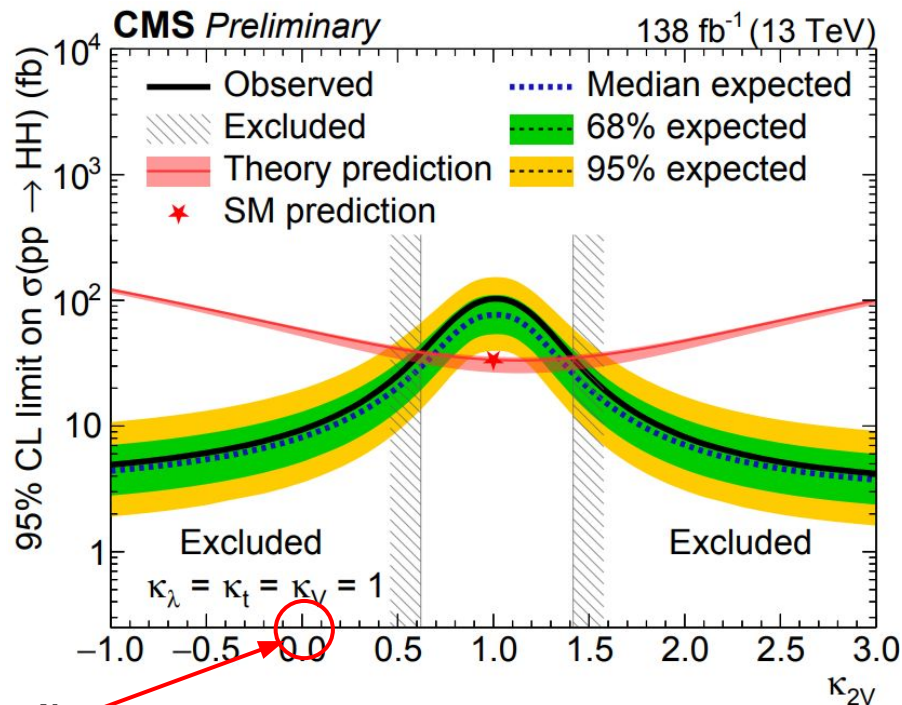
Limits on quartic coupling



Observed (expected) limits at 95% CL:

$$0.62 \text{ (0.69)} < k_{2V} < 1.42 \text{ (1.35)}$$

Assuming SM values for all other k s



$k_{2V} = 0$ excluded!

[CMS-PAS-HIG-20-011](#)

- Thanks to **constructive interference**, **VVH** production is significant in range $3 < k_\lambda < 7$ where **VBFHH** and **ggHH** have reduced cross-section for **destructive interference**
- Possibility to target **ZZHH** and **WWHH** couplings separately

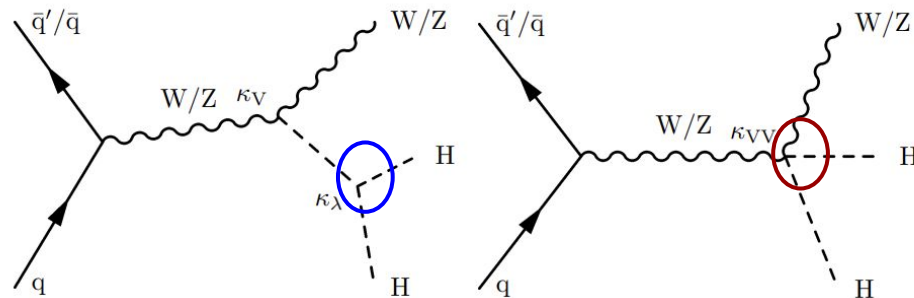
Search for **VHH non-resonant**, in $HH \rightarrow bbbb$

→ compensate small σ with large BR (33%)

→ $V=W, Z$, both leptonic and hadronic decays considered

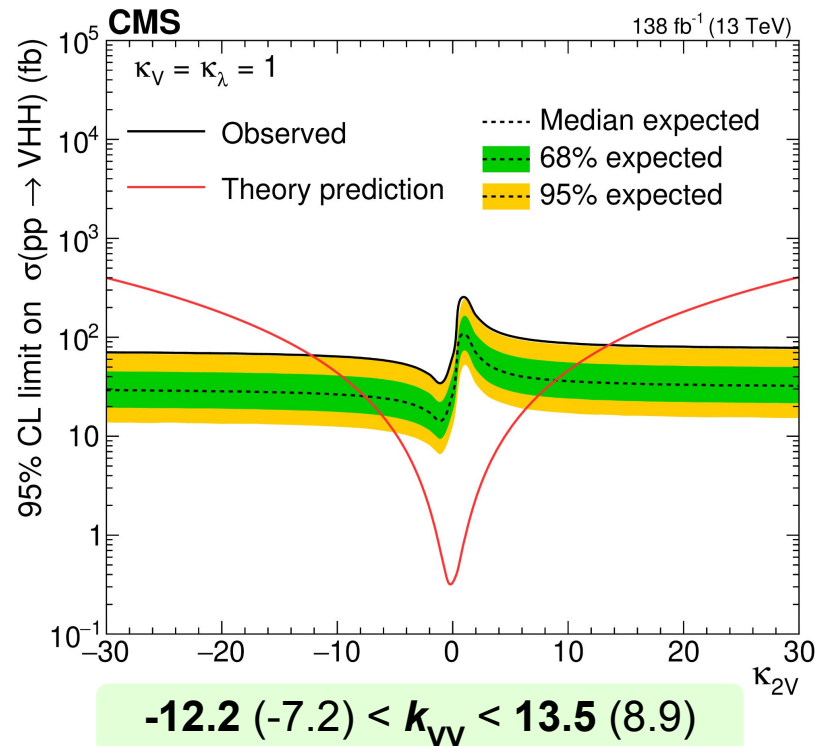
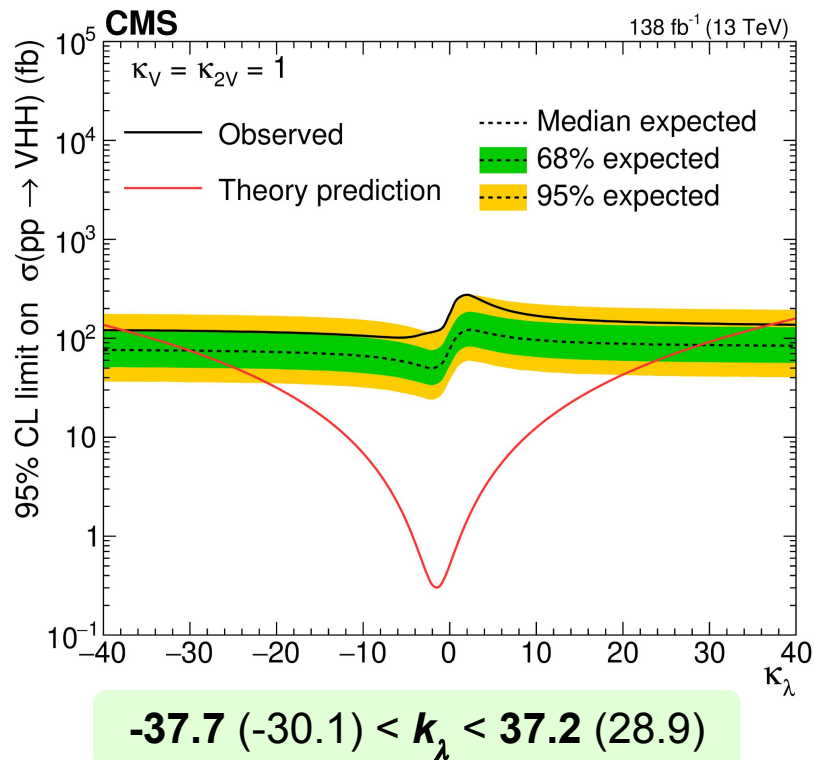
Observed (expected) limits at 95% CL:

$$\sigma(\text{VHH}) < \mathbf{294} \text{ (124)} \sigma_{\text{SM}}$$



Search for VHH

[JHEP 2410 \(2024\) 061](#)



Final states with multiple Gauge and Higgs Bosons

Final states suitable to investigate **VVHH interactions**

In this work:

- Reinterpret HH experimental results in terms of **dim-8 EFT operators**
- Focus on **genuine** SMEFT anomalous quartic operators
- **Unitarity constraints** considered
 - dedicated technique adopted
 - mass-dependent constraints set

Results in [JHEP09\(2022\)038](#)

Processes Considered

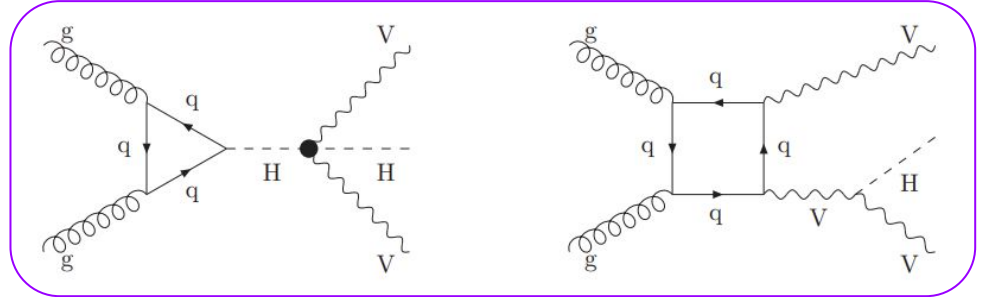
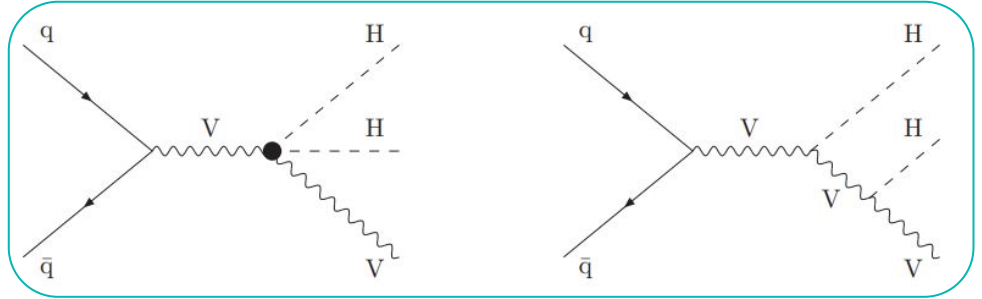
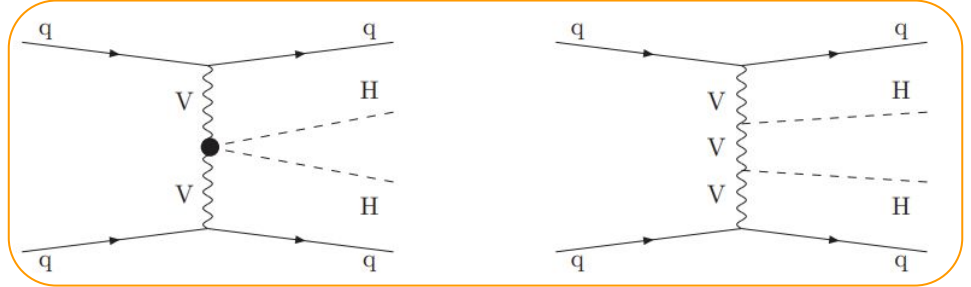
VBF-HH

Typical lowest order diagrams
for the processes considered

- with EFT contribution (left)
- without EFT (right)

ZHH

$gg \rightarrow ZZH$



$$L_{\text{LEFT}} = L_{\text{SM}} + \sum_i \frac{c_i}{\Lambda^2} \mathcal{O}_{i,\text{dim-6}} + \sum_j \frac{c_j}{\Lambda^4} \mathcal{O}_{j,\text{dim-8}}$$

Triple gauge couplings

Quartic gauge couplings

- Complete operator basis considered:

$$\begin{aligned}\mathcal{O}_{S,0} &= [(D_\mu \Phi)^\dagger D_\nu \Phi] \times [(D^\mu \Phi)^\dagger D^\nu \Phi] \\ \mathcal{O}_{S,1} &= [(D_\mu \Phi)^\dagger D^\mu \Phi] \times [(D_\nu \Phi)^\dagger D^\nu \Phi] \\ \mathcal{O}_{S,2} &= [(D_\mu \Phi)^\dagger D_\nu \Phi] \times [(D^\nu \Phi)^\dagger D^\mu \Phi]\end{aligned}$$

SCALAR

$$\begin{aligned}\mathcal{O}_{M,0} &= \text{Tr}[\hat{W}_{\mu\nu} \hat{W}^{\mu\nu}] \times [(D_\beta \Phi)^\dagger D^\beta \Phi] & \mathcal{O}_{M,4} &= [(D_\mu \Phi)^\dagger \hat{W}_{\beta\nu} D^\mu \Phi] \times B^{\beta\nu} \\ \mathcal{O}_{M,1} &= \text{Tr}[\hat{W}_{\mu\nu} \hat{W}^{\nu\beta}] \times [(D_\beta \Phi)^\dagger D^\mu \Phi] & \mathcal{O}_{M,5} &= [(D_\mu \Phi)^\dagger \hat{W}_{\beta\nu} D^\nu \Phi] \times B^{\beta\mu} + \text{H.c.} \\ \mathcal{O}_{M,2} &= [B_{\mu\nu} B^{\mu\nu}] \times [(D_\beta \Phi)^\dagger D^\beta \Phi] & \mathcal{O}_{M,7} &= [(D_\mu \Phi)^\dagger \hat{W}_{\beta\nu} \hat{W}^{\beta\mu} D^\nu \Phi] \\ \mathcal{O}_{M,3} &= [B_{\mu\nu} B^{\nu\beta}] \times [(D_\beta \Phi)^\dagger D^\mu \Phi]\end{aligned}$$

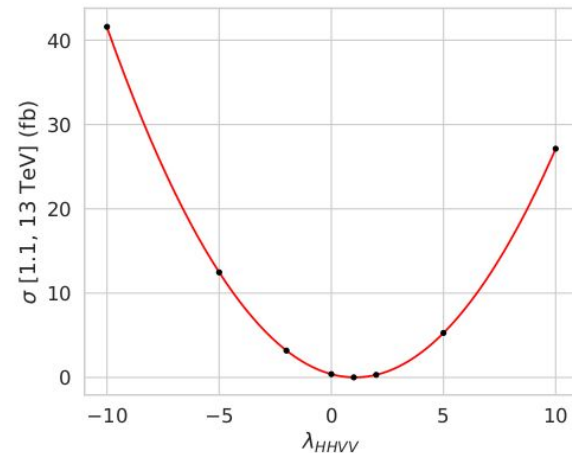
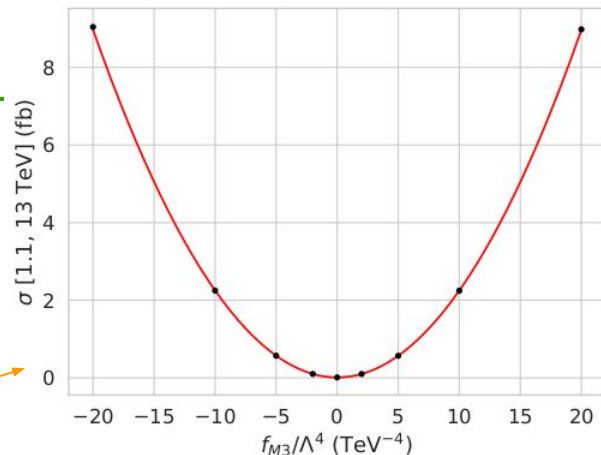
MIXED

Simulation Setup

- Generator: **MadGraph5_aMC@NLO v2.7.3**
- Processes:
 - VBF-HH, ZHH, $gg \rightarrow ZZH$,
 - VBS ($W^\pm W^\pm$, $W^\pm Z$, $W^+ W^-$) (for validation)
 - Zbbbb (main background for ZHH)
- **Wilson coefficients variations** $f_x/\Lambda^4 = \{0, \pm 2, \pm 5, \pm 10, \pm 20\} \text{ TeV}^{-4}$
- for VBF-HH, also **k_{2v} variations** ($k_{2v} = \{0, 1, \pm 2, \pm 5, \pm 10\}$)

Observable used to estimate the EFT sensitivity:

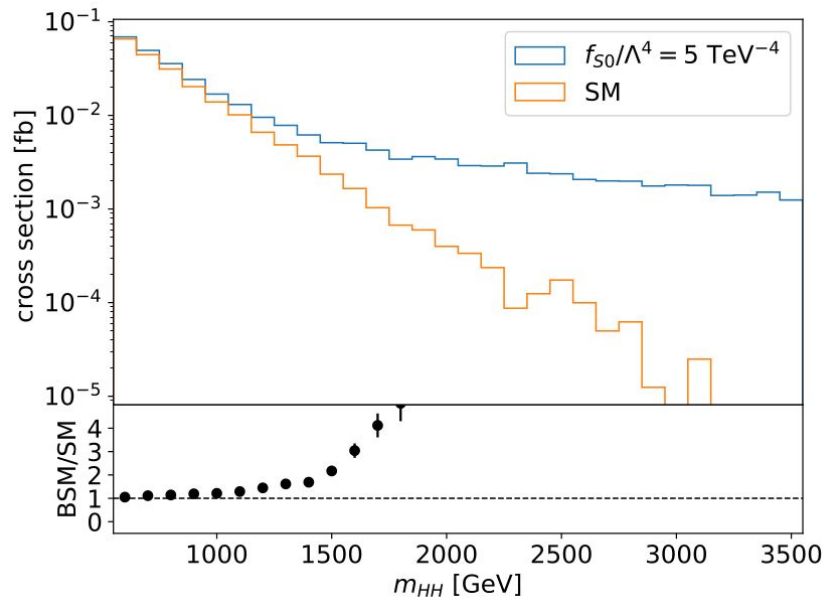
- $\sigma[m_{\min}, m_{\max}]$ (cross-section in mass interval)
 m = invariant mass of the di- or tri- boson states
 $m_{\min} = 1.1 \text{ TeV}$



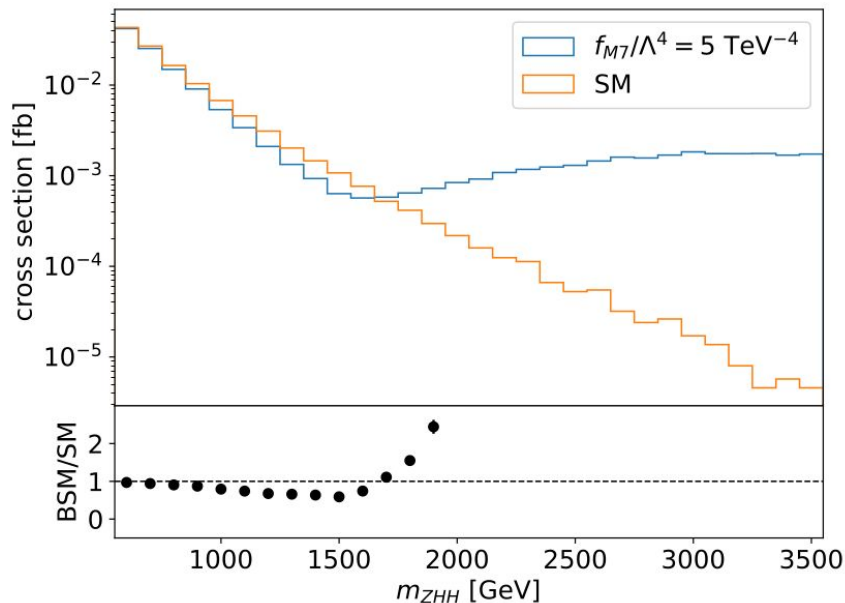
The effect of SMEFT

Quartic couplings modifications **distort the differential spectra**, primarily the invariant mass distribution → **enhanced rates** in the high energy **tails**

VBF-HH



ZHH



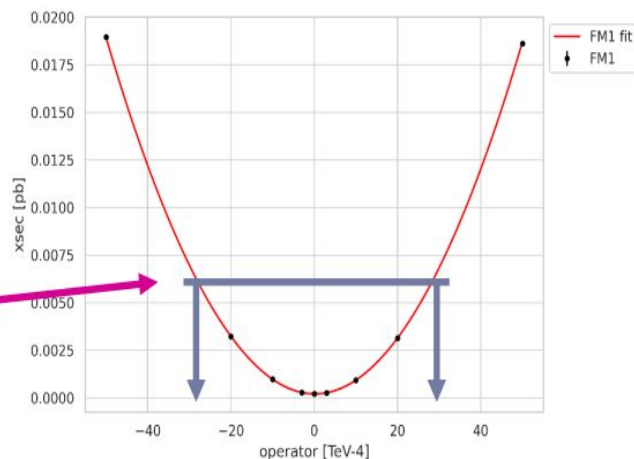
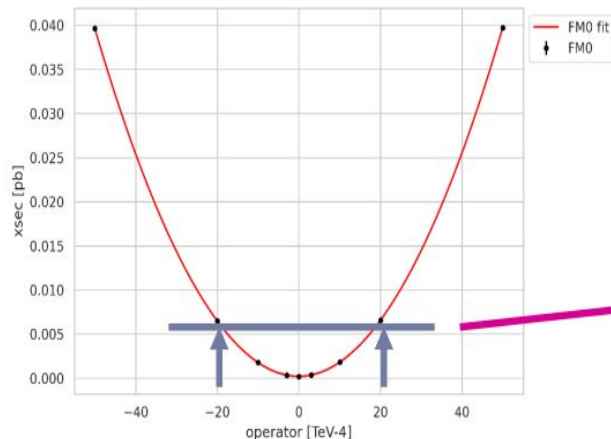
Validation on VBS

- Try to **reproduce CMS results**, for multiple processes
- σ computed as function of $f_x/\Lambda^4 \rightarrow$ quadratic fits performed

in this case, $m_{\max} = \sqrt{s}$ (no upper bound on inv. mass)

1. Take experimental limit on one operator from CMS publication
2. Superimpose on the parabola the limit on the operator to extrapolate 95% CL exclusion limit on σ
3. Derive limits on all other operators
4. Compare obtained limits with the published ones

Steps repeated for different choices of initial input



Validation on VBS

- CMS results found to be incomplete, several operators not examined
- **Validation successful:** manage to reproduce results 

	VBS $W^\pm W^\pm \rightarrow 2\ell 2\nu$		VBS $W^\pm Z \rightarrow 3\ell\nu$		VBS $W^\pm V$ semileptonic	
Coeff.	CMS exp.	estimated	CMS exp.	estimated	CMS exp.	estimated
f_{M0}/Λ^4	[-3.7,3.8]	[-3.9,3.7]	[-7.6,7.6]	input	[-1.0,1.0]	[-1.0,1.0]
f_{M1}/Λ^4	[-5.4,5.8]	input	[-11,11]	[-11,11]	[-3.0,3.0]	[-3.1,3.1]
f_{M2}/Λ^4	/	/	–	[-13,13]	–	[-1.5,1.5]
f_{M3}/Λ^4	/	/	–	[-19,19]	–	[-5.5,5.5]
f_{M4}/Λ^4	/	/	–	[-5.9,5.9]	–	[-3.1,3.1]
f_{M5}/Λ^4	/	/	–	[-8.3,8.3]	–	[-4.5,4.5]
f_{M7}/Λ^4	[-8.3,8.1]	[-8.5,8.0]	[-14,14]	[-14,14]	[-5.1,5.1]	input
f_{S0}/Λ^4	[-6.0,6.2]	[-6.1,6.2]	[-24,24]	[-25,26]	[-4.2,4.2]	[-6.7,6.8]
f_{S1}/Λ^4	[-18,19]	[-18,19]	[-38,39]	[-38,39]	[-5.2,5.2]	[-8.3,8.4]
f_{S2}/Λ^4	–	[-18,19]	–	[-25,26]	–	[-8.4,8.5]

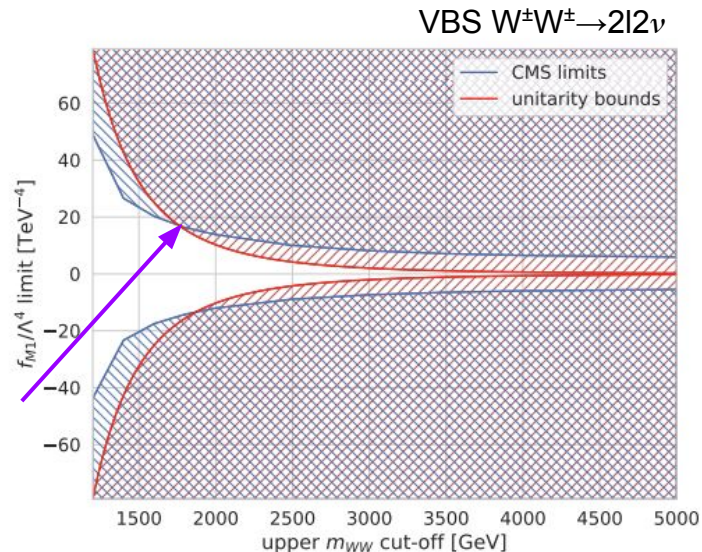
Implementation of unitarity in VBS

1. Evaluate $\sigma[\mathbf{m}_{\min}, \mathbf{m}_{\max}]$ for several $\mathbf{m}_{\max}$
(in exp analysis, would mean not to use data above $\mathbf{m}_{\max}$)
2. For each σ , obtain $\mathbf{m}_{\max}$ -**dependent limits** on operator coefficients with same procedure used for validation
(limits rescaled since only part of exp. data fall in $[\mathbf{m}_{\min}, \mathbf{m}_{\max}]$)

$\mathbf{m}_{\max} \rightarrow$ from $\mathbf{m}_{\min} + 100\text{GeV}$ to max kinematically allowed mass

Coeff.	VBS $W^{\pm}W^{\pm}$	VBS $W^{\pm}Z$	VBS $W^{\pm}V$ semilep.
f_{M0}/Λ^4	/	/	$[-3.3, 3.5]$
f_{M1}/Λ^4	$[-13, 17]$	$[-67, 71]$	$[-7.4, 7.6]$
f_{M2}/Λ^4	/	/	$[-9.1, 9.0]$
f_{M3}/Λ^4	/	/	$[-32, 30]$
f_{M4}/Λ^4	/	$[-36, 36]$	$[-8.6, 8.7]$
f_{M5}/Λ^4	/	$[-29, 29]$	$[-10, 10]$
f_{M7}/Λ^4	$[-21, 18]$	$[-59, 57]$	$[-11, 11]$
f_{S0}/Λ^4	$[-17, 20]$	/	$[-8.5, 9.5]$
f_{S1}/Λ^4	/	/	/
f_{S2}/Λ^4	/	$[-25, 26]$	$[-21, 25]$

intersection: max m to set limits not violating unitarity



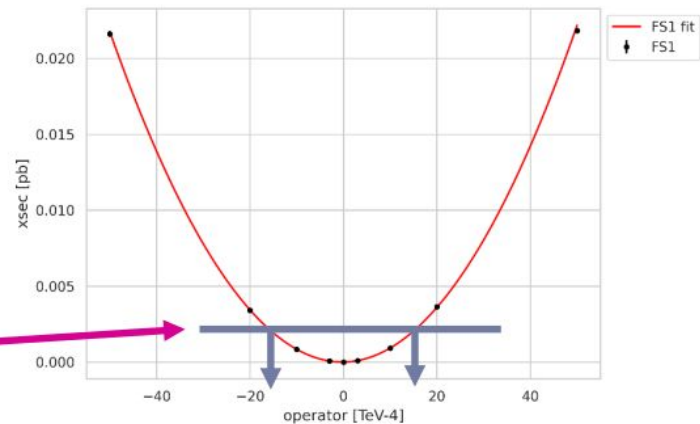
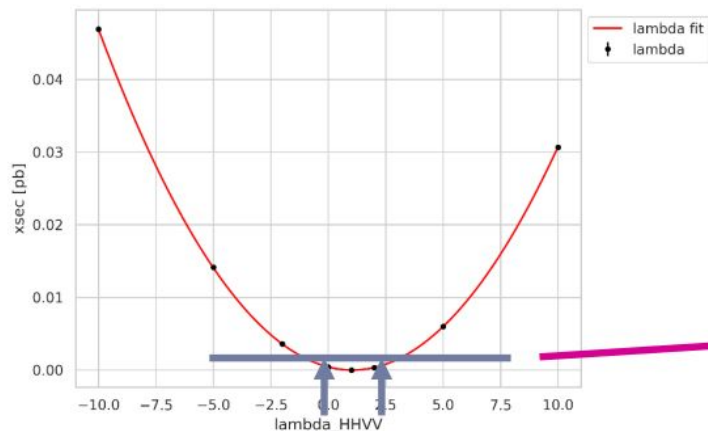
- Limits obtained w/ unitarity less stringent than those w/o (especially at low $\mathbf{m}_{\max}$ bc reduced statistics in $[\mathbf{m}_{\min}, \mathbf{m}_{\max}]$)
- If curves don't cross, available data are not enough to set limits more stringent than those from unitarity alone

VBFHH Process

Similar to VBS, but experimental results in terms of k_{2V}

1. Consider public HH $\rightarrow$ 4b 95% CL limit on k_{2V}
2. Use the VBF-HH simulation as function of k_{2V} to set limit on the parabola and obtain limit on σ
3. From limit on σ , extract limits on corresponding coefficient

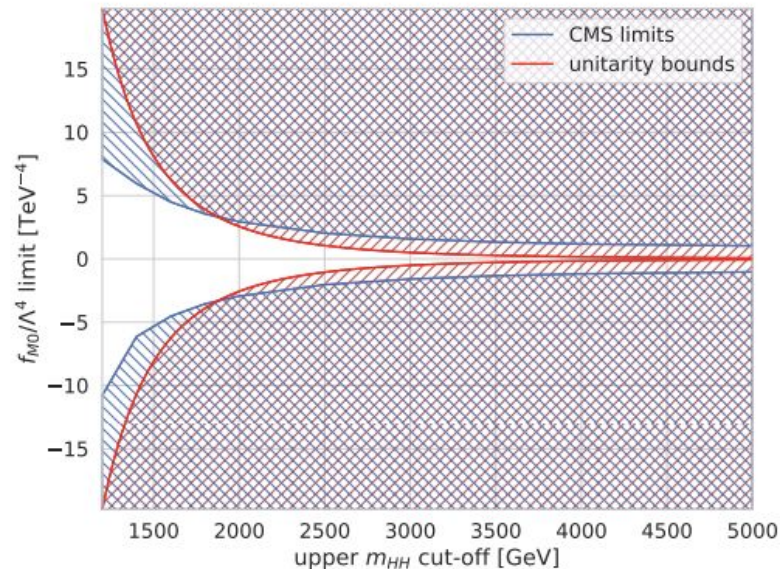
Validation: use limits on f_x as input and reproduce CMS limits on k_{2V}



VBFHH Results

- **VBF-HH** estimated limits **supersede** those obtained with VBS for f_{M0} , f_{M2} , f_{M3}
- Unitarity boundaries added as described for VBS

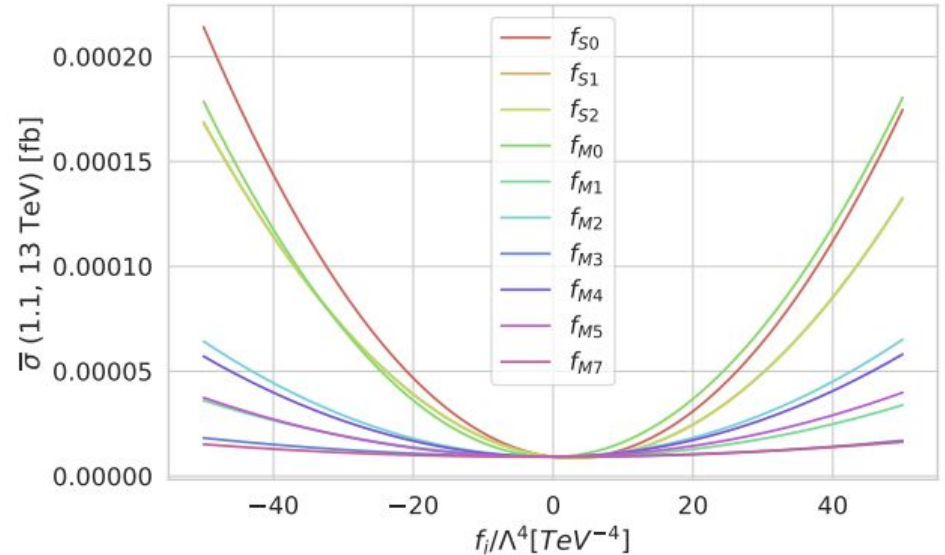
	VBS $W^\pm V$ semileptonic		VBF $HH \rightarrow b\bar{b}b\bar{b}$	
Coeff.	no unitarity	w/ unitarity	no unitarity	w/ unitarity
f_{M0}/Λ^4	[-1.0,1.0]	[-3.3,3.5]	[-0.95,0.95]	[-3.3,3.3]
f_{M1}/Λ^4	[-3.1,3.1]	[-7.4,7.6]	[-3.8,3.8]	[-13,14]
f_{M2}/Λ^4	[-1.5,1.5]	[-9.1,9.0]	[-1.3,1.3]	[-7.6,7.3]
f_{M3}/Λ^4	[-5.5,5.5]	[-32,30]	[-5.2,5.3]	[-29,30]
f_{M4}/Λ^4	[-3.1,3.1]	[-8.6,8.7]	[-4.0,4.0]	[-14,14]
f_{M5}/Λ^4	[-4.5,4.5]	[-10,10]	[-7.1,7.1]	[-26,26]
f_{M7}/Λ^4	[-5.1,5.1]	[-11,11]	[-7.6,7.6]	[-27,27]
f_{S0}/Λ^4	[-4.2,4.2]	[-8.5,9.5]	[-30,29]	/
f_{S1}/Λ^4	[-5.2,5.2]	/	[-11,10]	/
f_{S2}/Λ^4	-	[-21,25]	[-17,16]	/



New experimental final states: $gg \rightarrow ZZH$

Exploratory feasibility study to investigate the potential sensitivity

- Loop Induced process
- Very low σ
- $H \rightarrow bb$ and $Z \rightarrow ll$ ($l=e,\mu$) considered
- Even with large variations of Wilson coefficients σ remains small
→ process **not sensitive enough** to be investigated at LHC
- But, it demonstrates that is **possible to simulate the process with new NLO UFO model** constructed including dim-8 operators



New experimental final states: ZHH

No exp. result for ZHH available yet → Simple analysis performed

- Estimate the **number of detectable events**: $N = \sigma \cdot L \cdot \varepsilon \cdot A$
 - Decays: $H \rightarrow bb$ and $Z \rightarrow ll$ ($l = e, \mu$)
 - Acceptance (A) requirements, typical LHC requirements:
 $p_T(b) > 30 \text{ GeV}$, $p_T(e, \mu) > 20 \text{ GeV}$
 $|\eta(b)| < 2.5$, $|\eta(e, \mu)| < 2.4$
 - Efficiency (ε) for identification and selection taken from experimental papers
- **Background** Zbbbb process (simulated with $115 < m_{bb} < 135 \text{ GeV}$)
- Estimate **upper limits** on σ with Feldman-Cousins
- Similar procedure as before to estimate **limits on Wilson coefficients**

With Run2 luminosity ($L = 140 \text{ fb}^{-1}$) no limits w/ unitarity

	ZHH $\rightarrow \ell^+ \ell^- b\bar{b}b\bar{b}$
Coeff.	no unitarity
f_{M0}/Λ^4	$[-8.4, 8.7]$
f_{M1}/Λ^4	$[-15, 15]$
f_{M2}/Λ^4	$[-12, 12]$
f_{M3}/Λ^4	$[-20, 20]$
f_{M4}/Λ^4	$[-20, 21]$
f_{M5}/Λ^4	$[-18, 18]$
f_{M7}/Λ^4	$[-29, 30]$
f_{S0}/Λ^4	$[-210, 200]$
f_{S1}/Λ^4	$[-350, 380]$
f_{S2}/Λ^4	$[-350, 380]$

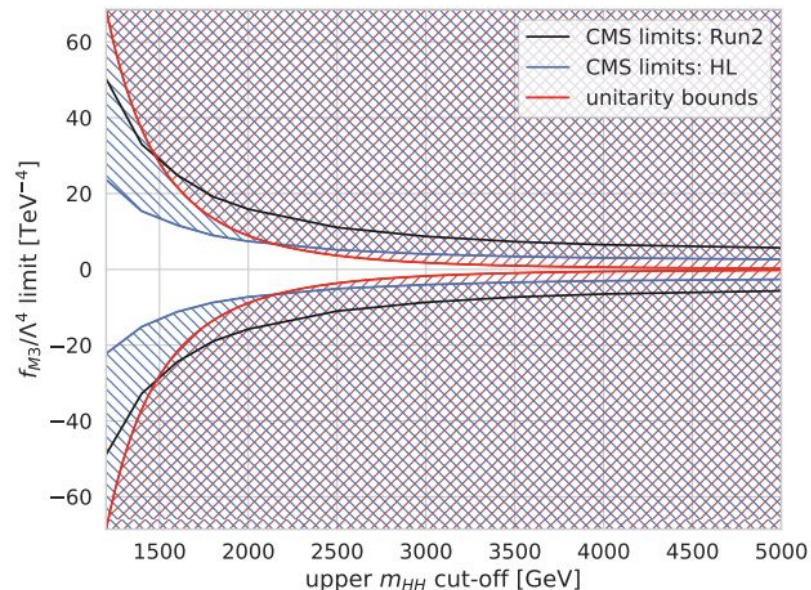
Perspectives for HL-LHC: VBFHH

- Limits w/o unitarity obtained rescaling the excluded σ by $L^{-1/2}$ ($L = 3 \text{ ab}^{-1}, 13 \text{ TeV}$)
- Limits w/ unitarity present significant gain more since m_{max} moves to larger values, allowing inclusion of more data in the sensitivity estimate

→ limits improve by factor 4-5

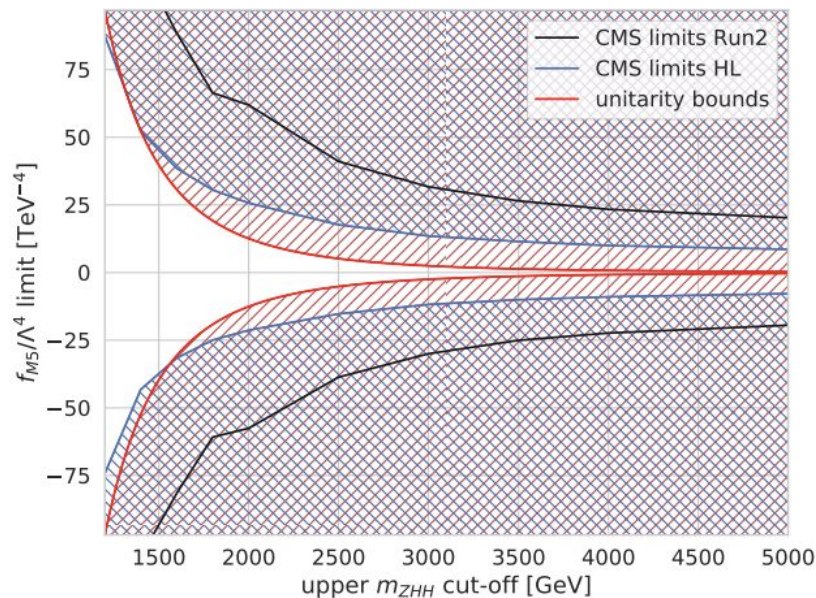
→ first physical limit on f_{s1}

	VBS $W^\pm V$ semileptonic		VBF $HH \rightarrow b\bar{b}b\bar{b}$	
Coeff.	no unitarity	w/ unitarity	no unitarity	w/ unitarity
f_{M0}/Λ^4	[-0.47,0.47]	[-0.96,1.02]	[-0.43,0.43]	[-0.90,0.87]
f_{M1}/Λ^4	[-1.5,1.5]	[-2.3,2.4]	[-1.7,1.7]	[-3.5,3.5]
f_{M2}/Λ^4	[-0.69,0.68]	[-2.1,2.1]	[-0.62,0.61]	[-1.7,1.7]
f_{M3}/Λ^4	[-2.5,2.4]	[-6.8,6.3]	[-2.4,2.4]	[-6.5,6.6]
f_{M4}/Λ^4	[-1.4,1.4]	[-2.4,2.5]	[-1.8,1.8]	[-3.9,4.0]
f_{M5}/Λ^4	[-2.0,2.0]	[-3.0,3.1]	[-3.2,3.2]	[-6.9,7.0]
f_{M7}/Λ^4	[-2.4,2.4]	[-3.5,3.5]	[-3.5,3.5]	[-7.1,7.1]
f_{S0}/Λ^4	[-1.8,2.0]	[-2.6,3.3]	[-14,13]	/
f_{S1}/Λ^4	[-2.4,2.4]	[-5.8,6.1]	[-5.1,4.5]	/
f_{S2}/Λ^4	[-2.3,2.4]	[-4.8,5.2]	[-8.1,7.1]	/



Perspectives for HL-LHC: ZHH

- Exclusion limit on σ recomputed for $L = 3 \text{ ab}^{-1}$, 13 TeV
- Possible to **set limits w/ unitarity requirements on some M-type operators**
- This was just simple analysis: important to develop strategies to enhance signal w.r.t. bkg



	ZHH $\rightarrow \ell^+ \ell^- \bar{b} \bar{b} \bar{b}$	
Coeff.	no unitarity	w/ unitarity
f_{M0}/Λ^4	[-3.4, 3.7]	/
f_{M1}/Λ^4	[-6.4, 5.9]	[-66, 31]
f_{M2}/Λ^4	[-4.7, 4.8]	/
f_{M3}/Λ^4	[-8.4, 8.2]	/
f_{M4}/Λ^4	[-8.2, 8.9]	/
f_{M5}/Λ^4	[-7.1, 7.7]	[-34, 52]
f_{M7}/Λ^4	[-12, 13]	[-91, 160]
f_{S0}/Λ^4	[-90, 83]	/
f_{S1}/Λ^4	[-140, 160]	/
f_{S2}/Λ^4	[-140, 160]	/

Conclusions

Considered multiboson, in particular **multi-Higgs**, interactions

- limits from CMS experiment on HHH and VVHH couplings set on couplings modifiers from ggHH, VBFHH, VHH production
- for VVHH, not possible to directly combine with other anomalous couplings
→ reinterpretation in SMEFT needed

Presented study that reinterprets experimental results on k_{2V} limits in terms of constraints on Wilson Coefficients of **dim-8** SMEFT operators

- VBFHH can set limits comparable or even more stringent than those from VBS
→ this time, combination with results from VBS possible!

COMETA European COST Action

Comprehensive Multiboson Experiment-Theory Action (COMETA)

Aim: improve measurements and interpretation of **multiboson** processes at LHC

Involves experts from **theory** and **experimental** HEP, and **AI experts** within and outside academia

20+ EU countries involved
150+ members
~150k€/year for 4 years

Foster **communication** between diverse research groups to develop advanced technology

Create an inclusive environment for **young** scientists, promote researchers in underfunded European countries

Next events:

- . [COMETA General meeting](#) (April)
- . [Positivity, Amplitudes and Phenomenology](#) (April)
- . PhD school on ML: [ML4Physics@Ljubljana](#) (June)



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