Summary WG4

6 Dec 2024

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1 IFIC Valencia
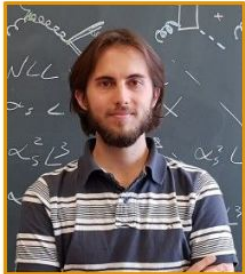
2 CERN

3 Monash University

4 KIT

Group organization

Many thanks to Javier, Maggie, and Stefano for leading the group!

Call for nominations for a new theory WG4 (HH and Multi-Higgs Production) convenor. Please send your nominations by email to **lhc-higgs-steering-committee@cern.ch** before 6th of December. Self-nominations are strongly encouraged.

2

New triple-H subgroup with conveners Benjamin Fuks (theory), Greg Landsberg (CMS) and William Balunas (ATLAS)

2

WG4 activities in 2024

- Update recommendations for 13 TeV

  - VBF HH with NLO EW corrections

  - ggHH with fixed Powheg bug + update PDF set

- Cross section recommendations for 13.6 TeV

- ggHH: work ongoing for recommendations on NLO EW corrections, on top mass scheme uncertainties

  + HH generator accounting for quartic coupling effects

Kickoff effort for CERN report 5

report 5 will be as separated documents submitted by the LHCHWG on SciPost

- **June 2025: deadline for priority projects for SciPost submission**
    - Priority document content (see also Javier's talk on Friday)
    - **-> Call for our community to contribute on these topics**
   - Experimental summary and projections to HL-LHC
        - ggF HH production
            - Higher order corrections (QCD and EW)
            - Theory uncertainties:
                - Mtop shape uncertainties
                - Missing higher order EW uncertainty
            - Dependence from k3 and k4 including NLO EW effects
        - VBF HH
        - ttHH
        - VHH
        - single-Higgs + heavy-flavour jets background modelling

**Further submission deadlines after June 2025:**

- EFT, HHH and Resonant HH

- **open to other proposals (or adjustments) on the selected topics**
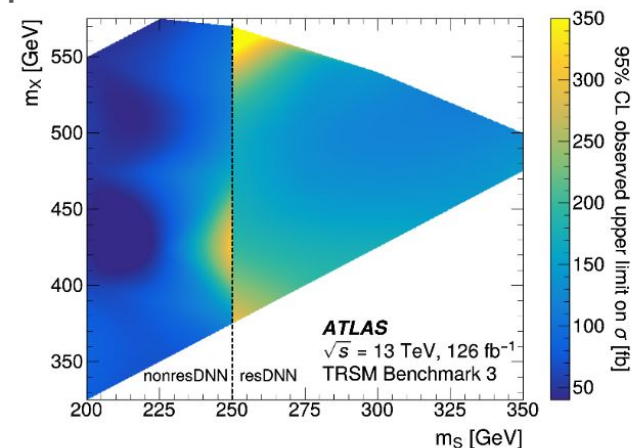
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Ramping up triple-Higgs effort

- HHH connected to Higgs potential, phase transition, universe evolution
  - Theory motivations, benchmarks in T. Robens talk (and HHH white paper)

- EW phase-transition scenarios enhancing HHH in O. Karkout talk

- First search results in W. Balunas talk
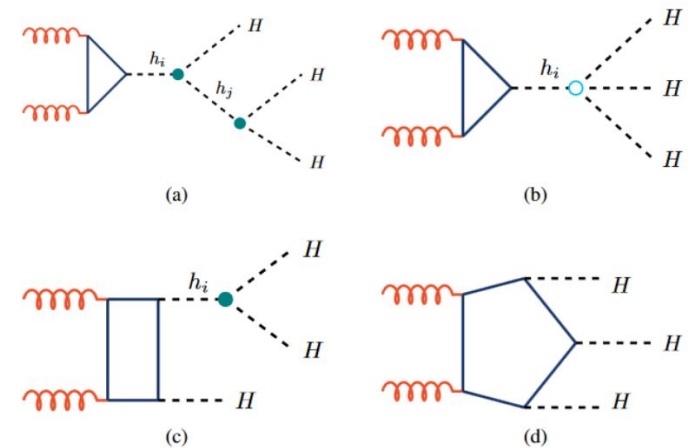
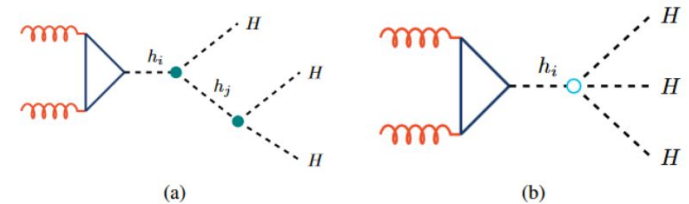Constraints on (k_3, k_4) from search for nonresonant HHH
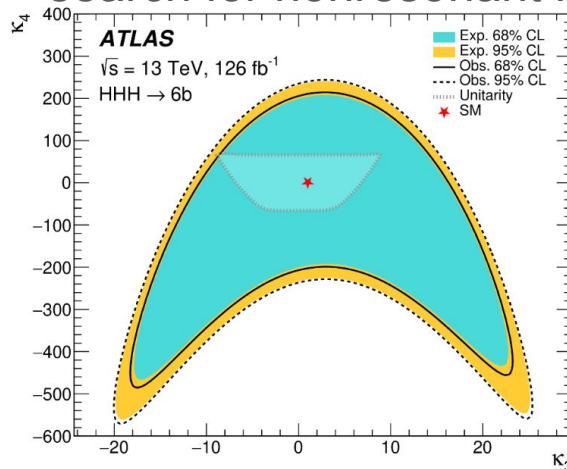
Constraints on resonant HHH production in TRSM benchmark

Ramping up triple-Higgs effort

- HHH connected to Higgs potential, phase transition, universe evolution
  - Theory motivations, benchmarks in T.

Comments/suggestions from theory community
- Theory predictions for nonresonant HHH at 13.6 TeV
- Interpret experimental searches in other TRSM benchmarks

Already homework for HHH subgroup :)
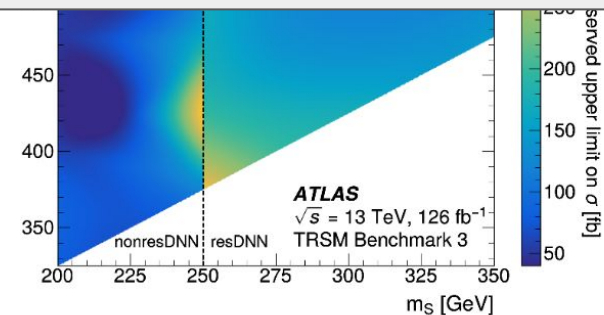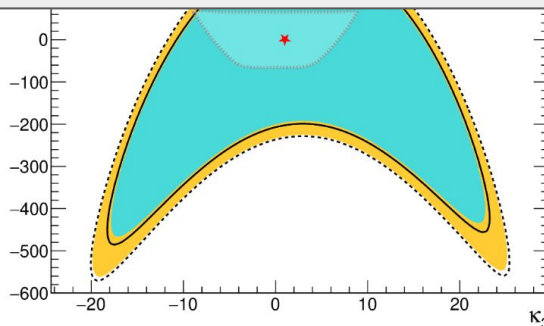
Recent results from CMS and ATLAS

From ATLAS substantial improvements
of searches in Run 2 data

bbττ			
	Old: JHEP 07 (2023) 040	< 4.7 (obs)	< 3.9 (exp)
	New: PRD 110 (2024) 032012	< 5.9 (obs)	< 3.3 (exp)

bbγγ			
	Old: PRD 106 (2022) 052001	< 4.2 (obs)	< 5.7 (exp)
	New: JHEP 01 (2024) 066	< 4.0 (obs)	< 5.0 (exp)

4b res.			
	ggF (36.1 fb⁻¹): JHEP 01 (2019) 030	< 12.9 (obs)	< 20.7 (exp)
	VBF (126 fb⁻¹): JHEP 07 (2020) 108	< 840 (obs)	< 550 (exp)
	New: PRD 108 (2023) 052003	< 5.4 (obs)	< 8.1 (exp)

From CMS Run 2 HH comb

and extend
parameter
space probed
by resonant
HH searches

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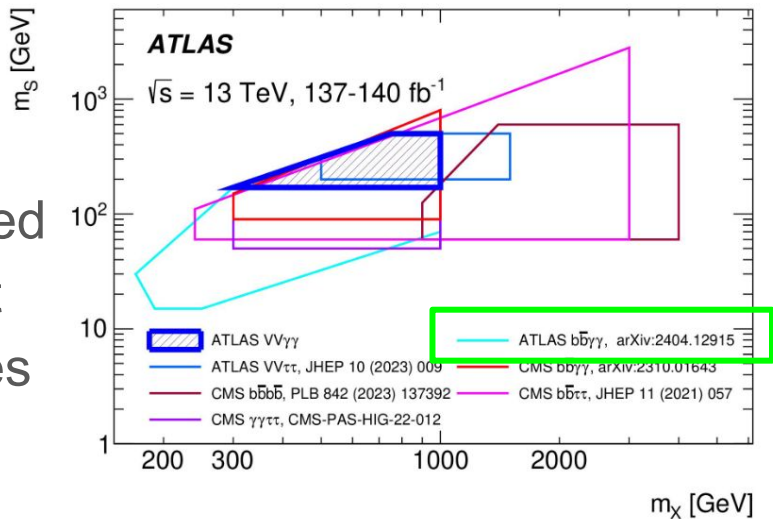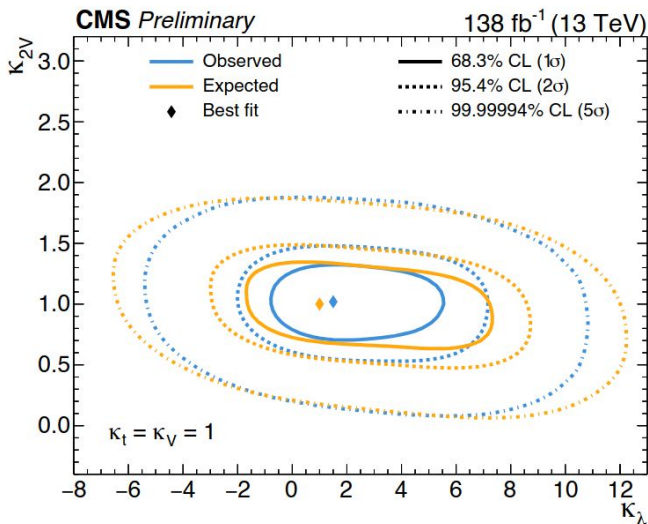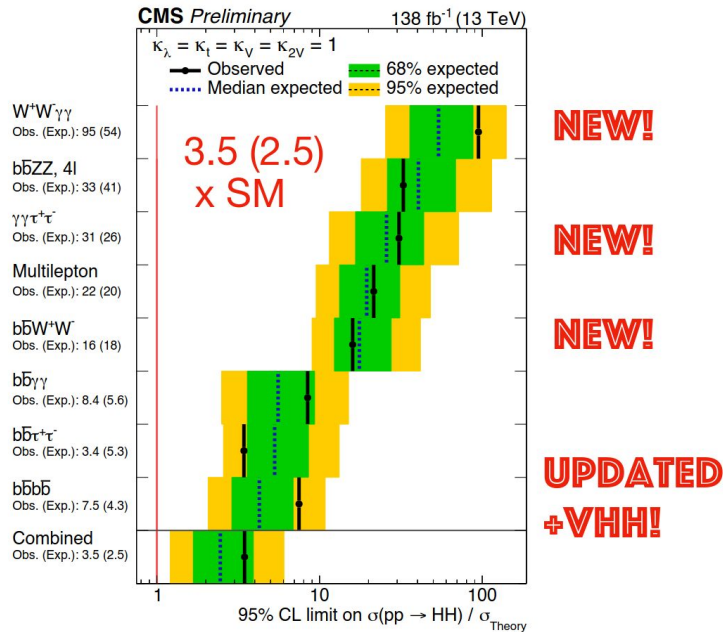
Perspectives for HL-LHC

Discovery significance vs integrated lumi for ATLAS HH(bbττ) channel

Discovery significance vs integrated lumi for CMS HH combination
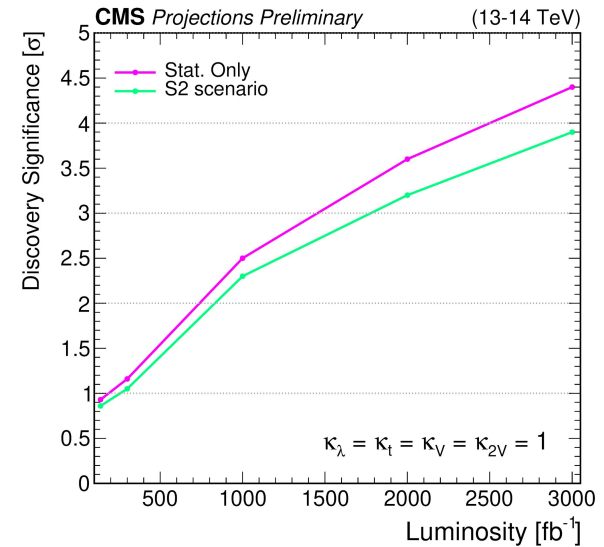
k_λ likelihood scan for the CMS HH combination
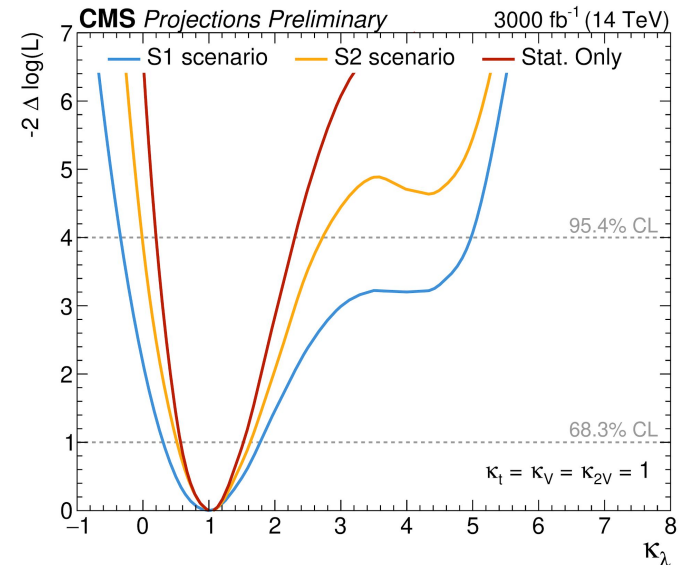

- Evidence around 1.5 ab^{-1}

- Discovery combining CMS and ATLAS searches

- ~50% precision on k_λ from single experiment

Developments in VBF HH simulation

VBF HH predictions at NLO QCD in HEFT framework in <u>Jens Braun talk</u>

Parametrization of VBF HH XS vs (c_λ, c_V, c_{2V})

$$\frac{\sigma}{\sigma_{SM}} = A_0\, c_\lambda^2 c_V^2 + A_1\, c_V^4 + A_2\, c_{2V}^2 + A_3\, c_\lambda c_V^3 + A_4\, c_\lambda c_V c_{2V} + A_5\, c_V^2 c_{2V}$$

Parameter	$\mu_F = \mu_r = \mu_0/2$	$\mu_F = \mu_r = \mu_0$	$\mu_F = \mu_r = 2\mu_0$
A_0	0.7011(46)	0.6889(35)	0.6830(30)
A_1	22.15(12)	21.71(9)	21.55(8)
A_2	11.86(7)	11.59(5)	11.55(4)
A_3	−6.139(42)	−6.025(33)	−5.984(27)
A_4	3.865(29)	3.786(23)	3.773(19)
A_5	−31.44(18)	−30.75(14)	−30.56(11)

NLOQCD/LO k-factor vs c_λ, c_V, or c_{2V}

PRELIMINARY

Ratio to LO

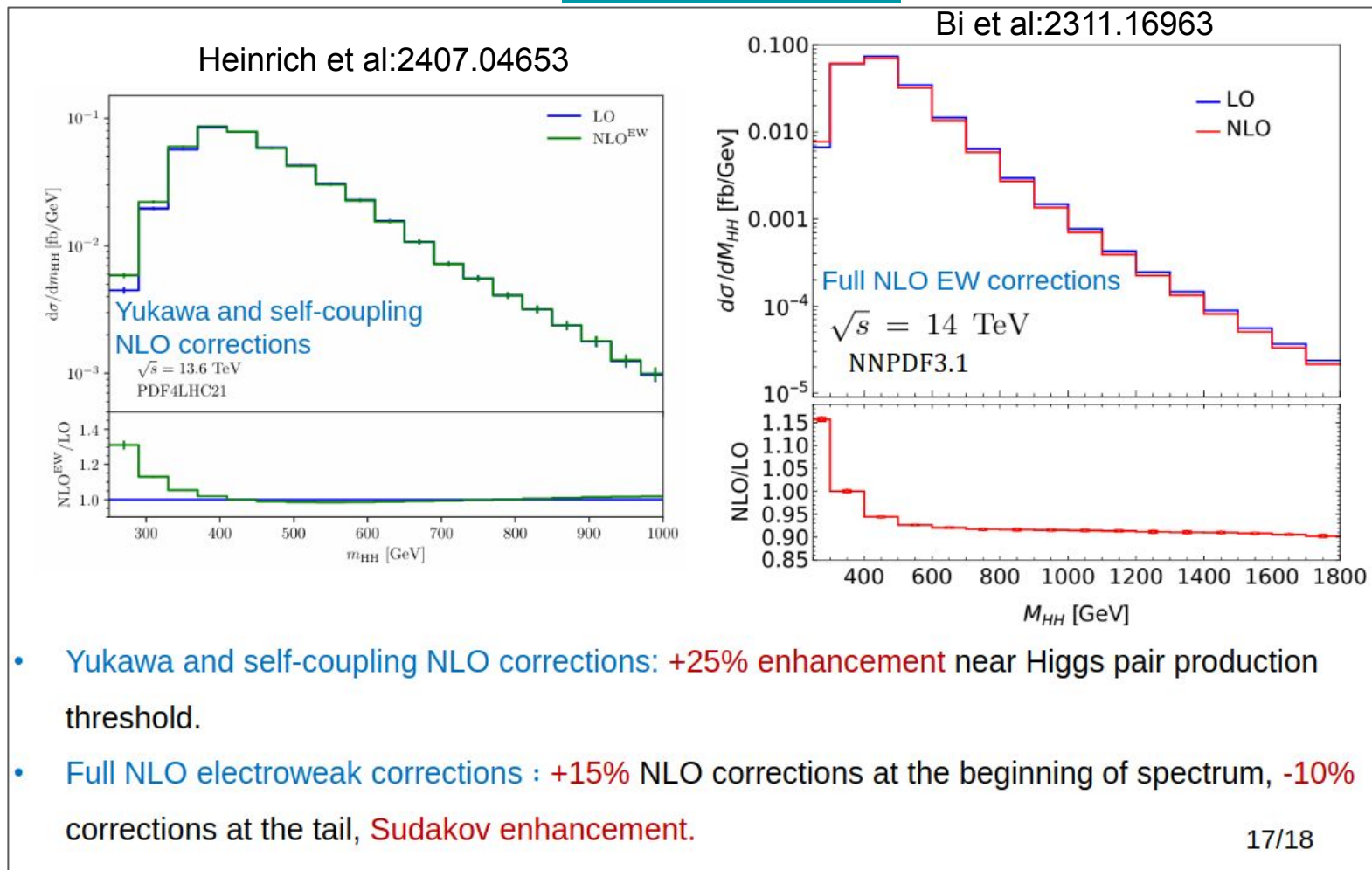$c_\lambda = 1 + 5\xi$
$c_V = 1 + \xi/10$
$c_{2V} = 1 + \xi/2$
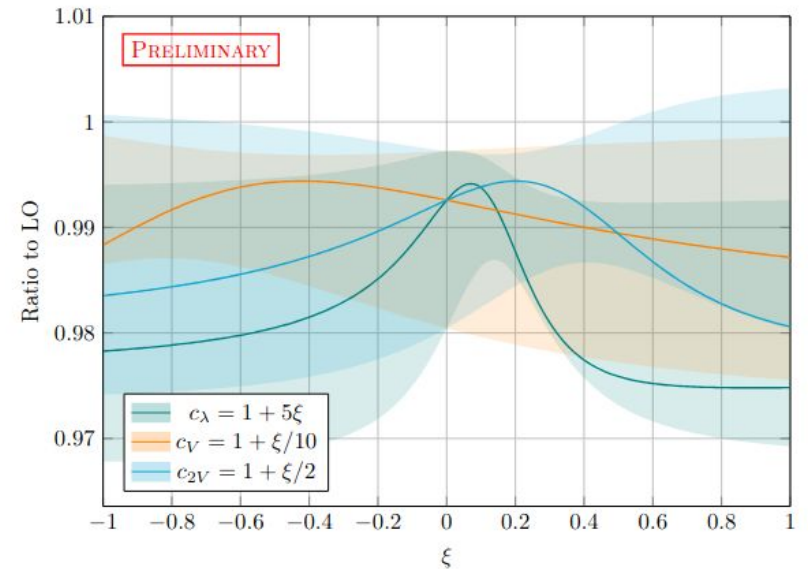
Work in progress for implementation in POWHEG → see <u>S. Reinhardt talk</u>

NLO EW corrections to ggF HH production

● Substantial corrections especially at the threshold

Huai-Min Yu talk
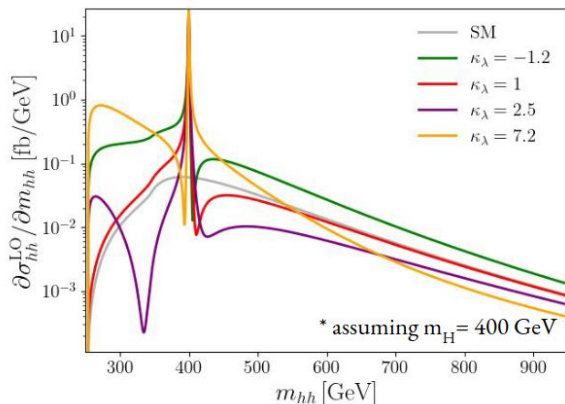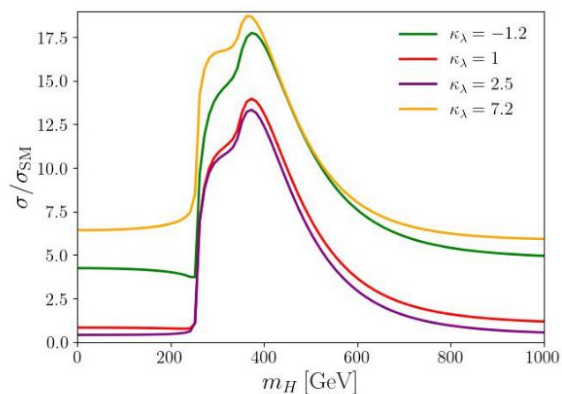
Resonant HH: interference & high-order corrections

- Resonant and nonresonant HH production in general do not factorize

Explicit implementation in singlet model via event-reweighting tool

From [K.Radchenko talk](#)

Full process can be enhanced by both deviations in κ_λ and a resonant scalar

arxiv:2409.06651
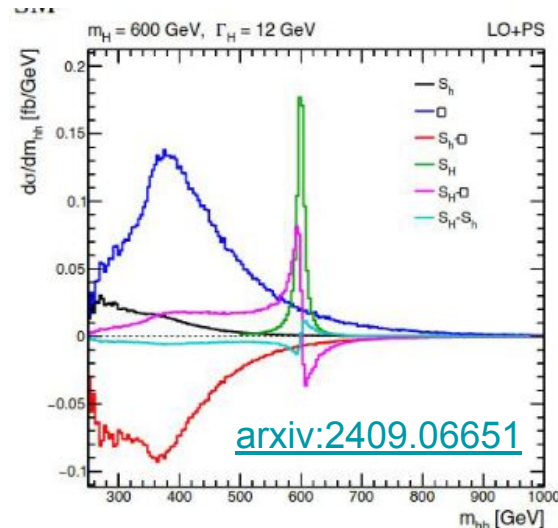
[Taken from Daniel Winterbottom's [talk](#) at Extended Scalars from All Angles]

Save the date for the HH workshop

Link to indico

Higgs Pairs 2025:

Hotel Hermitage, Elba Island, Italy, 11-17 May 2025

Higgs Pairs organizing committee:

Alessandra Betti
Valentina Cairo
Ramona Gröber
Nan Lu
Stefano Manzoni
Javier Mazzitelli
Fabio Monti
Margarete Mühlleitner
Marco Valente

Local organising committee:

Alberto Annovi
Paolo Azzurri
Giuseppe Bagliesi
Edoardo Bossini
Dario Buttazzo
Giorgio Chiarelli
Maria Agnese Ciocci
Silvio Donato
Paolo Francavilla
Sandra Leone
Chiara Roda
Andrea Rizzi
Angelo Scribano
Monica Verducci

We hope to see you in Elba!