Anomaly
Higgs Hunting
September 12-14, 2022 Orsay-Paris, France

Discussion of H(125) General Combination Talks by Fabio Monti (CMS) and Paolo Francavilla (ATLAS)

Bob Cousins
UCLA (CMS)

1) **Analysis techniques (and theory) have advanced in many ways since 2012, yielding an amazing catalog of results from huge Run 2 data sets.**
2) **We have entered era where statistical uncertainties not always dominant $\Rightarrow$ for discoveries, need (bounds on?) *tails* of syst unc. Applies to Machine Learning. Shapes!**
3) **Extracting κ_c and κ_b and from p_T distributions.**
4) **(If time) A word about using results of unfolding.**

N.B. Last year, there was spirited discussion of EFT's in this session. This year, there is dedicated session tomorrow.

The 10th Anniversary was a lot more than just a celebration of 2012

It worked out (lots of hard, focused work!) that most of the full Run 2 results, and their combination, were ready for the Nature papers, or for the 4th July Symposium at CERN.

In looking at many of the results, some clear trends

1) Machine learning is everywhere, with all that implies.
2) We are well into the era of jet and event substructure, with continuing innovation.
3) We are leaving the era of domination of statistical uncertainties in rate measurements, with all that implies:
   - Going forward, *shapes* of distributions (already useful) will be more and more important: normalization syst unc is essentially irrelevant at zeroth order; higher-order syst unc only from evolution of syst effect as function of shape variable.
   - For discovery, understanding *tails* of systematic uncertainties will be crucial. (Biggest challenge?)

Tremendous progress on combinations in the past year

Karsten Köneke, combination discussion HH 2021

Adinda De Wit, CERN 10th Anniversary Symposium, 4th July 2022

Inputs and Global μ

Decay channel	ggF		VBF		VH		ttH+tH	
	ATLAS	CMS	ATLAS	CMS	ATLAS	CMS	ATLAS	CMS
$H \to \gamma\gamma$	139	77 ⟳	139	77 ⟳	139	⟳	139	77 ⟳
$H \to ZZ^* \to 4\ell$	139	137 ⟳	139	137 ⟳	139	137 ⟳	139	137 ⟳
$H \to WW^*$	36[1] ⟳	36	36[1] ⟳	36		36 ⟳		
$H \to bb$	⟳	36 ⟳	<31[1] ⟳		139	77	36[1] ⟳	77
$H \to \tau\tau$	36[1] ⟳	77 ⟳	36[1] ⟳	77 ⟳	⟳	77	⟳	
ttH multilepton							36[1] ⟳	77 ⟳
$H \to \mu\mu$	139[1]	36 ⟳	139[1]	36 ⟳	139[1]	⟳	139[1]	⟳
$H \to$ invisible		⟳	139[1]		⟳	⟳	⟳	

Full Run 2

⟳ Updated result available; not yet in main public combination

[1] Not used in STXS fit

Global signal strength:

- ATLAS: $\mu = 1.06 \pm 0.07 = 1.06 \pm 0.04(\text{stat.}) \pm 0.03(\text{exp.})^{+0.05}_{-0.04}(\text{sig. th.}) \pm 0.02(\text{bkg. th.})$
- CMS: $\mu = 1.02^{+0.07}_{-0.06} = 1.02 \pm 0.04(\text{stat}) \pm 0.04(\text{exp}) \pm 0.04(\text{theo})$

Karsten Köneke 3

Combined measurements: ingredients

- Individual analyses study **specific** Higgs boson characteristics
  ➔ need to **combine** them to get a **full view** of the Higgs boson
- Targeted signatures **included in combined measurements**:

	ggH		qqH		VH		ttH/tH	
H➔γγ	ATLAS	CMS	ATLAS	CMS	ATLAS	CMS	ATLAS	CMS
H➔ZZ	ATLAS	CMS	ATLAS	CMS	ATLAS	CMS	ATLAS	CMS
H➔WW	ATLAS	CMS	ATLAS	CMS	ATLAS	CMS	ATLAS	CMS
H➔ττ	ATLAS	CMS	ATLAS	CMS	ATLAS	CMS	ATLAS	CMS
H➔bb	ATLAS	CMS	ATLAS		ATLAS	CMS	ATLAS	CMS
H➔μμ	ATLAS	CMS	ATLAS	CMS	ATLAS	CMS	ATLAS	CMS
H➔cc					ATLAS			
H➔Zγ	ATLAS	CMS	ATLAS	CMS	ATLAS	CMS	ATLAS	CMS
H➔inv		CMS	ATLAS	CMS	ATLAS	CMS		

Most of the main production x decay channels included

Note: some additional channels not yet included in combined measurements

Rare decay modes starting to feature in combined measurements

Searches for invisible H decays (for coupling strengths)

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https://indico.ijclab.in2p3.fr/event/5923/

https://indico.cern.ch/event/1135177/

Updates for CMS (Fabio) and ATLAS (table courtesy of Paolo)

Analyses	Integrated lumi (fb^{-1})	ggH	qqH	VH	ttH & tH
H(γγ)	138	X	X	X	X
H(ZZ→4l)	138	X	X	X	X
H(WW)	138	X	X	X	X
H(Zγ)	138	X	X		
H(bb)	36(ttH) 77(VH) 138(ggH)	X	X	X	X
H(ττ)	138	X	X	X	X
ttH multilepton(ττ, WW, and ZZ)	138				X
H(μμ)	138	X	X		X
H(invisible)	138	X	X	X	

	ttH	tH	ggF	VBF	WH	ZH
γγ	139	139	139	139	139	139
ZZ* (4l)	139		139	139	139	
WW*			139	139	36.1	36.1
bb	139		incl. boost: 139	126	139	139
ττ	139		139	139	139	
ttH multilept	36.1					
cc					139	
μμ	139			139		
Zγ	(inclusive) 139					
inv				139		Z(ll)H: 139
			Not in Kinematic (NO STXS)			
			Only for Kinematic (ONLY STX			
			Only for floating kc			
			K models with Binv & Bu			

This conference is of course a great place for cross-fertilization of ideas.
I think that we can assume that:

1) The rest of the production and decay processes will be filled in by both collaborations, where any are missing at the moment. Are there any missing capabilities?
2) Recent advances by either collaboration will be propagated to the other collaboration.

So I do not think that we need to use this discussion time to enumerate checklists – see Adinda's 4th July talk, and today's updates. But I can ask:
What are points of contention in combinations, within and/or between collaborations?
Are any useful to discuss here?
Any comments on extracting κ_c and κ_b and from p_T distributions? (arxiv:1606.09253)?

Going forward, let's hope that we have (many) anomalies to pursue! (Zγ ?).
What systematic uncertainties will be most problematic in Higgs combinations as we go forward with increasingly smaller statistical uncertainties?
Remember: for discoveries, we need *tails*, not just an estimate of the syst's std dev.
Issues of how to *combine* theory uncertainties.

If we run out of things to talk about

Beware of issues when fitting *unfolded* distributions (or testing hypotheses).
“Should unfolded histograms be used to test hypotheses?, RC, May, Sun,
https://arxiv.org/abs/1607.07038
Bottom line test: Check that scientific result in unfolded space is not materially different from that in the smeared space: smeared theory tested against not-unfolded data.

BACKUP

PRL **118**, 121801 (2017) PHYSICAL REVIEW LETTERS week ending 24 MARCH 2017

Constraining Light-Quark Yukawa Couplings from Higgs Distributions

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We propose a novel strategy to constrain the bottom and charm Yukawa couplings by exploiting Large Hadron Collider (LHC) measurements of transverse momentum distributions in Higgs production. Our method does not rely on the reconstruction of exclusive final states or heavy-flavor tagging. Compared to other proposals, it leads to an enhanced sensitivity to the Yukawa couplings due to distortions of the differential Higgs spectra from emissions which either probe quark loops or are associated with quark-initiated production. We derive constraints using data from LHC run I, and we explore the prospects of our method at future LHC runs. Finally, we comment on the possibility of bounding the strange Yukawa coupling.

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102 citations in Inspire – whole literature of related ideas. How confident can we be that κ_c could be a genuine Higgs Anomaly discovery path?