Status of Higgs boson precision measurements

Johannes Erdmann on behalf of the ATLAS and CMS Collaboration

QCD@LHC 2024 Freiburg October 8, 2024 **ATLAS** EXPERIMENT





RNTHAAC UNIVERSITY





events



I will report on 12 new analyses that came out after Moriond this year

Higgs Precision







events



Fiducial Cross Sections



CMS-PAS-HIG-23-013 CMS-PAS-HIG-24-013 CMS-PAS-HIG-23-014 arXiv:2407.16320 (ATLAS) ATLAS-CONF-2024-010







CMS Combination @ 13 TeV





+ N_{jets}, p_T^{jetl} , $|y_H|$, $\Delta \eta_{jj}$, m_{jj} , T_c^j from the combination of 2-4 channels



4

CMS Combination @ 13 TeV

Interpretations in K framework ...





$\mathsf{CMS} \mathsf{H} \to 4\ell @ \mathsf{I}3.6 \mathsf{TeV}$

Fiducial, total and first differential measurements with Run-3 data (p_T , |y|) $\sigma_{\text{fid}} = 2.94 + 0.53 + 0.29 + 0.29 + 0.29 + 0.27 \text{ fb}$ with $\sigma_{\text{fid}} = 3.09 + 0.27 + 0.27 \text{ fb}$ predicted













2024)

CSB

CMS-PAS-HIG-23-014

TeV









$CMS H \rightarrow \gamma \gamma @ 13.6 TeV$

Fiducial and first differential measurements with Run-3 data (p_T , |y|, N_{jets})

 $\sigma_{\rm fid} = 78 \pm 11 \,({\rm stat.}) {}^{+6}_{-5} \,({\rm syst.}) \,{\rm fb}$



with $\sigma_{\rm fid} = 67.8 \pm 3.8 \, {\rm fb}$ expected









Updated measurement of JHEP 08 (2022) 175

- 8 STXS bins for VBF
- improved ttH (had.) classification
- p_T^H regression with NN



arXiv:2407.16320

ATLAS $H \rightarrow T^+T^-$ @ 13 TeV

			<u> </u>		
	ATLAS	Η→ττ	ls	= 13 Te	V , 140
	–Tot. ∎Syst. ∖∖Theory	p-value = 6%			
			Tot.	(Stat.	Syst
gg→H, 1-jet, 120 ≤ p _T ^H < 200 GeV		0.35	+0.61 -0.61	(+0.38 -0.37	+0.49 -0.48
gg→H, ≥ 1-jet, 60 ≤ p _T ^H < 120 GeV	 -	0.50	+0.89 -0.89	(+0.52 -0.52	+0.72 -0.72
gg→H, ≥ 2-jet, m _{jj} < 350, 120 ≤ p _T ^H < 200 GeV	H	0.53	+0.75 -0.74	(+0.49 _0.48	+0.57 -0.56
gg→H, ≥ 2-jet, m _{jj} ≥ 350 GeV, p _T ^H < 200 GeV		5.09	+3.09 -2.49	(+1.66 -1.64	+2.61 –1.87
gg→H, 200 ≤ p _T ^H < 300 GeV		0.99	+0.39 -0.36	(+0.28 -0.28	+0.27 -0.22
gg→H, p _T ^H ≥ 300 GeV		1.51	+0.59 -0.50	(^{+0.44} _0.43	+0.39 -0.26
qq'→Hqq', ≥ 2-jet, 60 ≤ m _{jj} < 120 GeV	₽₽₽	0.94	+0.68 -0.65	(^{+0.57} _0.55	+0.38 -0.36
qq'→Hqq', ≥ 2-jet, 350 ≤ m _{ji} < 700 GeV, p _T ^H < 200 GeV	F	-0.96	+1.17 –1.31	(^{+0.83} _0.81	+0.81 –1.03
qq'→Hqq', ≥ 2-jet, 700 ≤ m _{ii} < 1000 GeV, p _T ^H < 200 GeV	H	-0.24	+0.79 -0.89	(+0.63 -0.60	+0.49 -0.65
qq'→Hqq', ≥ 2-jet, 1000 ≤ m _µ < 1500 GeV, p _T ^H < 200 GeV	H e -I	1.68	+0.61 -0.55	(+0.50 -0.47	+0.35 -0.29
, aq'→Hqq', ≥ 2-jet, m _{ii} ≥ 1500 GeV, p _τ ^H < 200 GeV		0.12	+0.34 -0.33	(+0.30 -0.27	+0.16 -0.18
, aq'→Hqq', ≥ 2-jet, 350 ≤ m _{ii} < 700 GeV, p _T ^H ≥ 200 GeV	H	-1.16	+0.87 -0.81	(+0.75 -0.55	+0.44 -0.59
qq'→Hqq', ≥ 2-jet, 700 ≤ m _{ii} < 1000 GeV, p _T ^H ≥ 200 GeV		0.98	+0.73 -0.63	(+0.67 -0.59	+0.28 -0.23
qq'→Hqq', ≥ 2-jet, 1000 ≤ m ⊂ 1500 GeV, p ^H ≥ 200 GeV		1.40	+0.56 -0.50	(+0.52 -0.47	+0.20 -0.18
		1.29	+0.39 -0.34	(+0.35 -0.32	+0.18 -0.13
" ttH, p ₊ ^H < 200 GeV		2.1	+1.8 -1.5	(+1.5 (-1.3	+0.8 -0.8
ttH, 200 ≤ p_ ^H < 300 GeV		-2.2	+1.3 –1.1	(+1.1 _0.8	+0.6 -0.8
ttH, p ^H ≥ 300 GeV		3.6	+2.9 -2.3	(+2.6 2 1	+1.3
ТТ					
	0 5	10		15 (σ×Β) ^r	20 ^{neas} /(o





ATLAS $H \rightarrow T^+T^-$ @ 13 TeV

Best single measurement of VBF production



Also $d\sigma_{fid}/dX$ in VBF phase space,





ATLAS VH with $H \rightarrow bb$ @ 13 TeV

Updated measurement of <u>PLB 816 (2021) 136204</u>, <u>EPJC 81 (2021) 178</u> and <u>EPJC 82 (2022) 717</u>

• Now $H \rightarrow bb$ and $H \rightarrow c\overline{c}$ combined

Improvements to

- Flavour tagging (DLIr), event classification
- Monte Carlo statistics (Sherpa 2.2.11, truth-tagging, CARL)

+ STXS

- ~20% improvement in $\sigma_{VH(bb)}$
- First single observations of
 - WH(bb) with 5.3σ







events



Yukawa Couplings



ATLAS-CONF-2024-010 CMS-PAS-HIG-23-010 arXiv:2407.15550 (ATLAS) arXiv:2407.10904 (ATLAS)





ATLAS VH with $H \rightarrow cc$

Updated measurement of <u>PLB 816 (2021) 136204</u>, <u>EPJC 81 (2021) 178</u> and <u>EPJC 82 (2022) 717</u>

• Now $H \rightarrow$ bb and $H \rightarrow$ cc combined



95% CL upper limit on $\mu_{VH^{cc}}$: II (10) observed (expected) and on K_c of 4.2 (4.1) observed (expected)







CMS H+c with $H \rightarrow \gamma\gamma$

First searches for H+c production by CMS and ATLAS

using $H \rightarrow \gamma \gamma$ (low backgrounds)





- Upward fluctuation
 - of the background
- μ_{cH} < 243 (355)

obs. (exp.)

 $\kappa_{c} < 38.1$ (72.5),

with $\mu_{non-cH,H\rightarrow\gamma\gamma} = I$ PRD 100 (2019) 073013









ATLAS H+c with H \rightarrow yy

First searches for H+c production by CMS and ATLAS

using $H \rightarrow \gamma \gamma$ (low backgrounds)





- Gaussian process regression with $K(m, m') = \exp\left(-\frac{(m m')^2}{2\ell^2}\right)$ to interpolate from sidebands to $m_{YY} \in [120, 130]$ GeV **ATL-PHYS-PUB-2020-028**
- Upper limit on σ_{H+c} of 10.4 pb (8.6 pb expected)
- $\sigma_{H+c} = 5.2 \pm 3.0 \text{ pb}$





ATLAS ttH, H → bb Run-2 Re-Analysis

Updated measurement of JHEP 06 (2022) 097 with expected sensitivity $2.7\sigma \rightarrow 5.4\sigma$ (!)

better b-tagging EPJC 83 (2023) 681



looser preselection:

> $1\ell_{5j}3b \& 2\ell_{3j}3b$ with control regions defined by multiclass classifier

event classification

& p^T^H reconstruction with transformer



• tt+bb simulation setup in 4FS **EPJC 78 (2018) 502** Powheg-Box-Res + OpenLoops with settings from ATL-PHYS-PUB-2022-006









ATLAS ttH, H → bb Run-2 Re-Analysis



arXiv:2407.10904







events



<u>CMS-PAS-HIG-23-011</u> <u>CMS-PAS-HIG-24-001</u> <u>PRL 133 (2024) 101801 (ATLAS)</u> <u>CMS-PAS-HIG-23-012</u>

Rare Processes







CMS H+y and Light Yukawa from $H \rightarrow 4\ell$ CMS-PAS-HIG-23-011



Light-quark Yukawas from $\sigma_{\rm H} \propto BR(4\ell)$

 $\sigma_{H\to 4\ell} \downarrow \text{with } \kappa_q \uparrow, \text{ as}$ $\sigma_{H\to 4\ell} \sim 1/\Gamma_H(\kappa_q)$

A THE REAL PROPERTY AND A SHORE AND A

 $|ar{\kappa}_u|$ < 1.06 $|\bar{\kappa}_d| < 0.97$ $|\bar{\kappa}_s| < 0.89$ $|\bar{\kappa}_c| < 0.88$

CMS W[±]W[±]H VBS with H \rightarrow bb

CMS-PAS-HIG-24-001

$= \sum_{g \in \mathcal{A}} \nabla f L A \otimes \nabla higgs = Combination + CMS Dihiggs \rightarrow bbqqqq$

HH → $b\bar{b}VV$ → $b\bar{b}qqqq$ (boosted) VV-tagging with ParticleTransformer -0.04 < κ_{2V} < 2.05 @ 95% CL Updated combination of PLB 843 (2023) 137745

• improved bbbb, $bb\tau\tau$, $bb\gamma\gamma$ + 2 new

*K*₂*V*

21

22

- Reported on 12 new analyses since Moriond
- Run-2 data is a treasure that keeps being explored with new ideas and methods
- Run-3 data analysis has started and is long not over
- see also talks by M. Golbirsch-Kolb (Thursday), N. Readioff, A. Raspiareza & J. J. Teoh (yesterday)

Summary

Bonus

ATLAS Dihiggs Combination

700

800

ratio

 10^{-1}

JHEP 06 (2019) 066

 K_{λ}

ATLAS Dihiggs Combination

26