Higgs Production at the LHĆ

Matt Klein, Southern Methodist University 2024 May 20

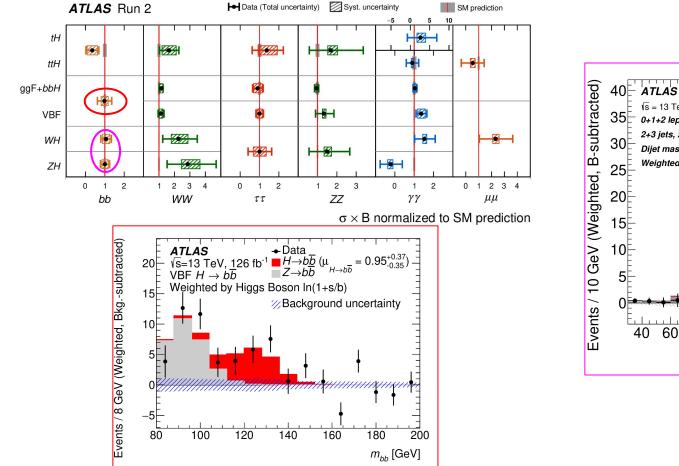


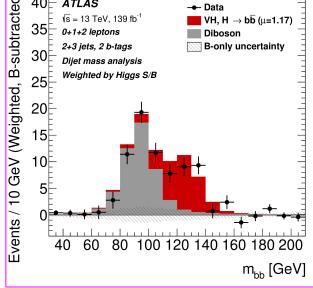


Overview

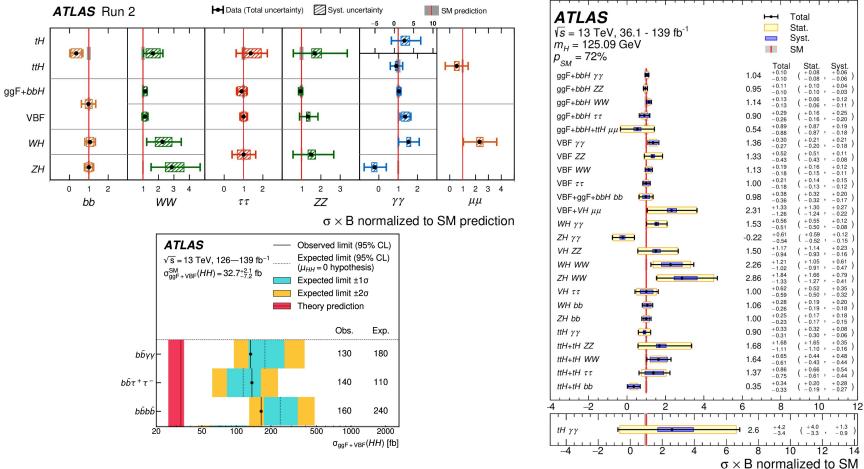
- Individual Measurements
 - Production Mode x Decay
 - Semi-differential: STXS
 - Fully differential
- Interpretations
 - Combined x-sections
 - $\circ \quad \text{Combined STXS} \quad$
 - Kappa-framework
- Properties
 - $\circ \quad \text{Mass}$
 - \circ Width

Measurements: Cross-section (1)





Measurements: Cross-section (2)

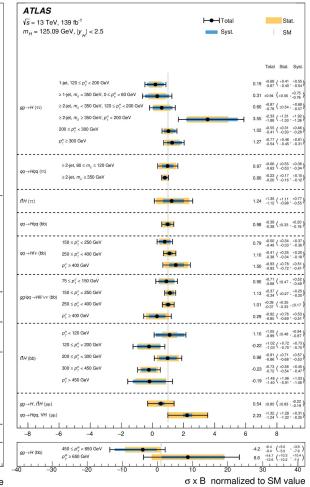


Measurements: STXS

m _H = 125.0	99 GeV, y _H < 2.5	Syst.	SM
			Total Stat. Sys
<i>gg→H</i> (WW*)	0-jet, p_T^H < 200 GeV	1.27	$^{+0.18}_{-0.17}$ ($_{\pm 0.08}$, $^{+0.1}_{-0.1}$
	1-jet, $p_T^H < 60 \text{ GeV}$	0.66	$^{+0.59}_{-0.58}$ ($^{+0.30}_{-0.29}$, $^{+0.5}_{-0.58}$
	1-jet, $60 \le p_T^H < 120 \text{ GeV}$	H 0.68	$^{+0.49}_{-0.46}$ (±0.32 $^{+0.3}_{-0.3}$
	1-jet, $120 \le p_T^{\prime\prime} < 200 \text{ GeV}$	1.43	+0.89 (+0.63 +0.6 -0.62 +0.6
	\geq 2-jet, $p_{\tau}^{\prime\prime}$ < 200 GeV	1.54	$^{+0.95}_{-0.84}$ ($^{+0.43}_{-0.42}$, $^{+0.8}_{-0.7}$
	$p_{\tau}^{\prime\prime} \ge 200 \text{ GeV}$	•• 1.37	+0.91 (+0.63 +0.6 -0.76 (-0.62 ,-0.4
qq→Hqq (WW*)	≥ 2-jet, 350 ≤ m_{ii} < 700 GeV, p_{i}^{ii} < 200 GeV	0.12	+0.60 (+0.45 -0.58 (-0.41 ,±0.4
	≥ 2-jet, 700 ≤ m_{ii} < 1000 GeV, p_{ii}^{H} < 200 GeV	0.57	+0.68 (+0.57 ,+0.3 -0.61 (-0.51 ,-0.3
	≥ 2-jet, 1000 ≤ m _y < 1500 GeV, p _T ^H < 200 GeV	1.32	+0.64 (+0.50 +0.4 -0.51 (-0.45 -0.4
	≥ 2-jet, $m_j \ge 1500 \text{ GeV}, p_\tau^H < 200 \text{ GeV}$	1.19	+0.48 (+0.42 +0.2 -0.42 (-0.38 +-0.1
	\geq 2-jet, $m_{j} \geq$ 350 GeV, $p_{_{T}}^{^{H}} \geq$ 200 GeV	1.54	+0.61 (+0.51 +0.3 -0.51 (-0.46 -0.2
	0-jet, p ^H _T < 10 GeV	0.93	+0.36 (+0.30 ,+0. -0.30 (-0.27 ,-0.
	0-jet, 10 ≤ p_T^H < 200 GeV	1.15	+0.23 (+0.18 +0.1 -0.20 (-0.17 -0.1
gg →H (ZZ*)	1-jet, $p_T^H < 60 \text{ GeV}$	0.31	+0.43 (+0.40 +0.1 -0.38 (-0.36 -0.1
	1-jet, 60 ≤ ρ_T^{μ} < 120 GeV	1.42	+0.52 (+0.42 +0.3
	1-jet, $120 \le p_T^H < 200 \text{ GeV}$	0.41	+0.84 (+0.80 +0.2 -0.59 (-0.58 -0.0
	\geq 2-jet, $p_{\tau}^{\prime\prime}$ < 200 GeV	0.35	+0.60 (+0.55 +0.2
	$p_{\tau}^{H} \ge 200 \text{ GeV}$	2.41	+1.52 (+1.32 +0.7 -1.09 (-1.04 ,-0.3
qq→Hqq (ZZ*)	VBF	1.49	+0.63 (+0.61 +0.1 -0.50 (-0.50 ,-0.0
	≥ 2-jet, 60 < m _j < 120 GeV	1.51	+2.83 (+2.79 +0.4 -2.24 (-2.22 '-0.2
	≥ 2-jet, m_j ≥ 350 GeV, p_{γ}^H ≥ 200 GeV	0.18	+2.09 (+2.08 ,+0.1
VH-lep (ZZ*)	 =	• 1.29	+1.67 (+1.67 +0. -1.05 (-1.05 -0.1
tīH (ZZ*)		1.73	+1.77 (+1.72 +0.3

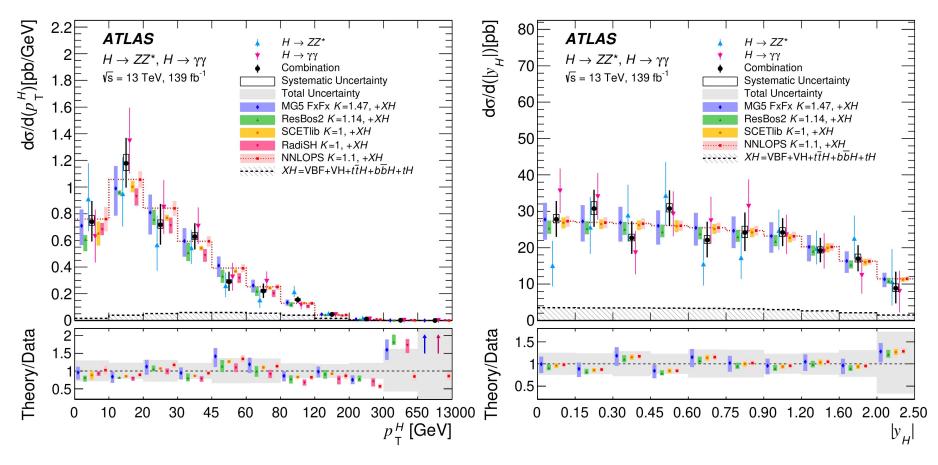
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ATLAS			0
	eV, 139 fb ⁻¹	⊢●⊣Total	Stat.
$m_{H} = 125$.09 GeV, y _H < 2.5	Syst.	SM
			Total Stat. Syst
	0-jet, p [#] < 10 GeV	0.66	+0.27 -0.26 (±0.24 , +0.12
<i>9</i> 3 → <i>H</i> (γγ)	$0 - jet, 10 \le p_{\gamma}^{\mu} < 200 \text{ GeV}$	1.24	
	1-jet, p ^µ _r < 60 GeV	1.24	-0.17 (±0.15 , -0.06 +0.39 (±0.36 , -0.11
	$1 - jet, \beta_r < 0.0 \text{ GeV}$		
	1-jet, 120 ≤ p_{τ}^{H} < 200 GeV	1.14	
		0.93	-0.330.36 -0.1
	≥2-jet, m_{ij} < 350 GeV, $p_{T}^{\prime\prime}$ < 120 GeV	0.58	-0.54 -0.52 ' -0.1
	\geq 2-jet, m_g < 350 GeV, 120 $\leq \rho_{\tau}^{H}$ < 200 GeV	1.31	-0.48 -0.47 '-0.0
	\geq 2-jet, $m_{ij} \geq$ 350 GeV, $p_{T}^{H} <$ 200 GeV	1.09	10.00 (-0.89 -0.3
	$200 \le p_{\gamma}^{\prime\prime} < 300 \text{ GeV}$	1.56	-0.41 (-0.39 '-0.1
	$300 \le p_{\gamma}^{H} < 450 \text{ GeV}$	0.17	+0.56 -0.49 (+0.54 -0.47 , +0.1
	<i>p</i> ^{<i>H</i>} _{<i>T</i>} ≥ 450 GeV	2.11	+1.47 -1.18 (+1.42 +0.4 -1.15 -0.2
			40.96 (40.90 40.3
	≤ 1-jet and VH-veto	1.05	-0.000.04 -0.1
	≥2-jet, VH-had	0.21	-0.03 +-0.020.1
qq→Hqiq (yy)	≥ 2-jet, 350 ≤ m_j < 700 GeV, p_{γ}^{H} < 200 GeV	1.28	-0.60 -0.56 -0.2
	\geq 2-jet, 700 \leq m_{i} < 1000 GeV, p_{γ}^{H} < 200 GeV	1.47	-0.68 -0.64 -0.2
	≥ 2-jet, m_{θ} ≥ 1000 GeV, p_{τ}^{H} < 200 GeV	1.31	+0.46 -0.38 (+0.36 ,+0.2 -0.33 ,-0.2
	\geq 2-jet, 350 \leq m_g $<$ 1000 GeV, $p_T^{\prime\prime} \geq$ 200 GeV	0.31	-0.01 -0.00 -0.1
	\geq 2-jet, $m_{ij} \geq$ 1000 GeV, $p_{\tau}^{H} \geq$ 200 GeV	1.69	+0.67 -0.57 (+0.61 +0.2 -0.52 + -0.2
	p ^v ₂ < 150 GeV	1.75	+0.82 (+0.80 +0.1
$q \rightarrow H v (\gamma \gamma)$	p ^v _r ≥ 150 GeV	1.65	
			-0.90 \-0.89 \-0.1
g/qq→Hll/vv (γγ) ρ ^v _τ < 150 GeV	-0.64	+0.88 (+0.87 , +0.1
	$\rho_T^{\vee} \ge 150 \text{ GeV}$	0.39	+1.10 (+1.08 +0.2 -0.92 (-0.91 +-0.1
đн (үү)	<i>p</i> ^{<i>µ</i>} / _{<i>r</i>} < 60 GeV →	0.83	+0.82 (+0.81 +0.1
	60 ≤ <i>p</i> [#] < 120 GeV	0.81	+0.60 (+0.59 +0.0
	120 ≤ p ^µ ₁ < 200 GeV	0.65	-0.51 C0.50 '-0.0 +0.64 (+0.63 +0.1 -0.54 (-0.53 -0.0
	200 ≤ p ⁴ ₇ < 300 GeV	1.23	
	p ^µ ₇ ≥ 300 GeV		-0.65 (-0.65 '-0.0 +0.96 (+0.95 +0.1 -0.75 (-0.74 '-0.1
	p ₇ 2 300 dev	1.17	-0.75 (-0.74 '-0.1
 + (γγ)	—	2.06	+4.13 (+3.94 , +1.2 -3.27 (-3.14 , -0.9
/(Z γ)		2.05	+0.97 (+0.88 , +0.4
∽ <i>n</i> Cilii			-0.00 -0.07 -0.0
-8	-6 -4 -2 0 2	4 6	8 10

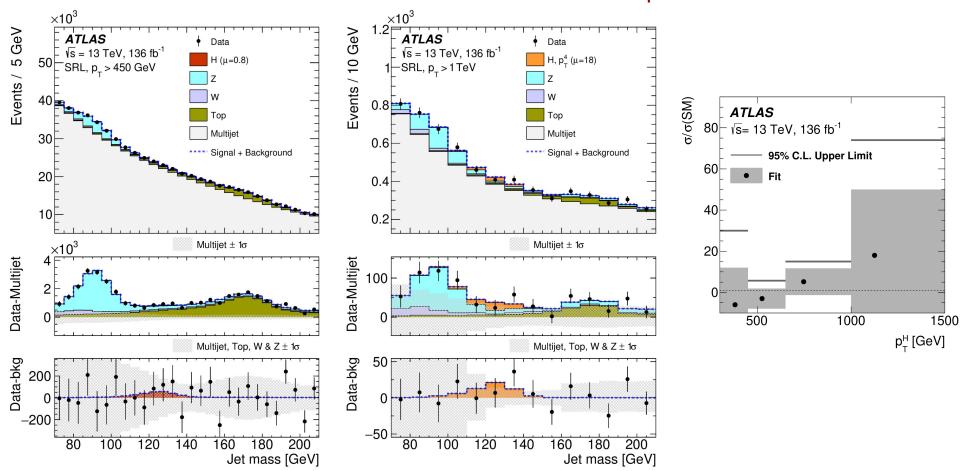


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Measurements: Differential

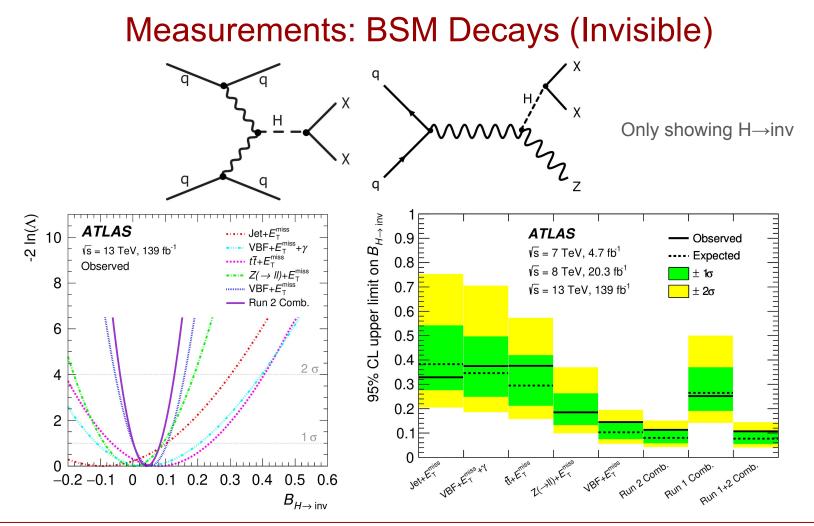


Measurements: High p_{τ}

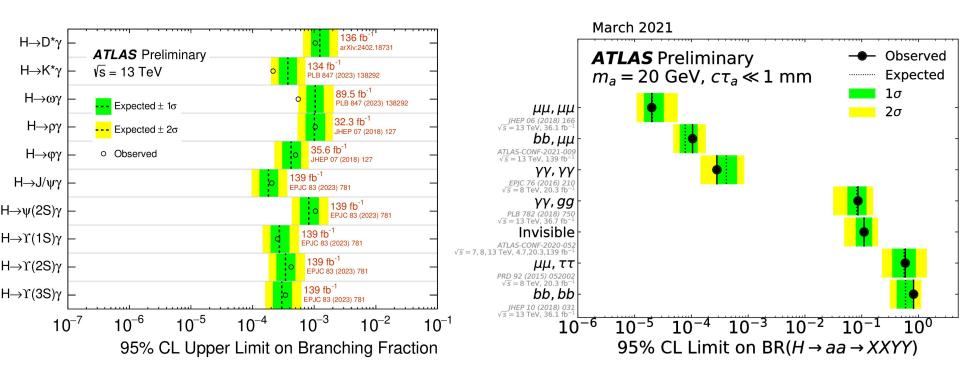


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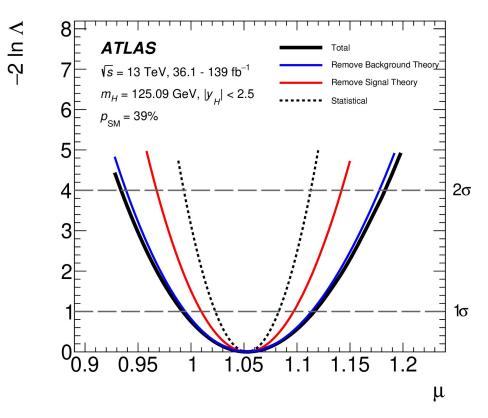


Measurements: BSM Decays (Other)

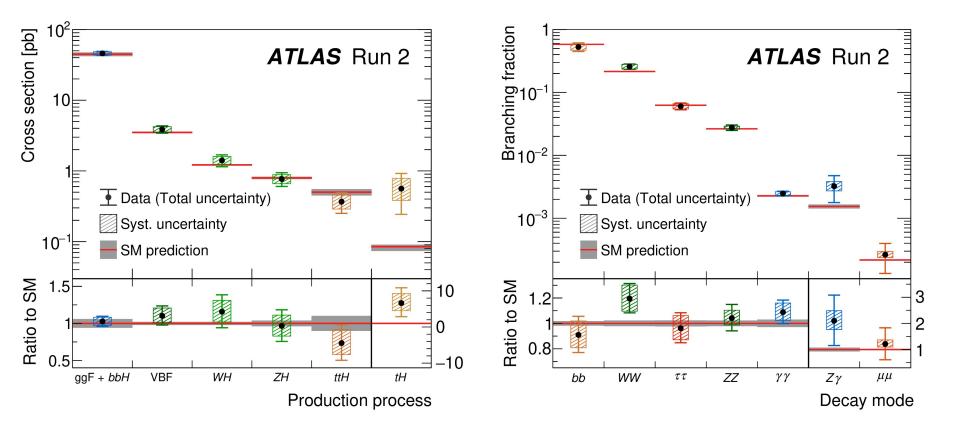


Interpretations: Inclusive Cross-section

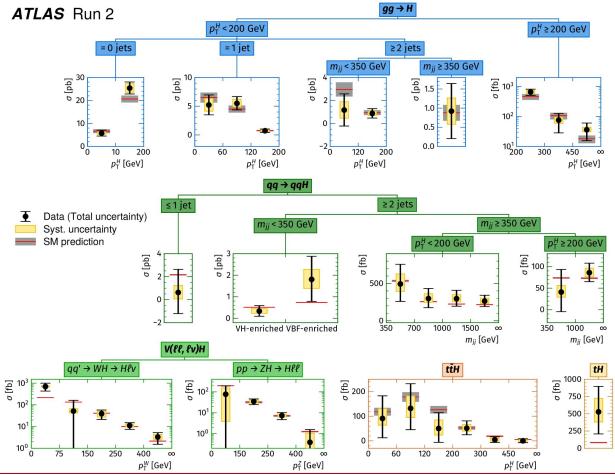
 $\mu = 1.05 \pm 0.06 = 1.05 \pm 0.03$ (stat.) ± 0.03 (exp.) ± 0.04 (sig. th.) ± 0.02 (bkg. th.)



Interpretations: Production and Decays



Interpretations: STXS

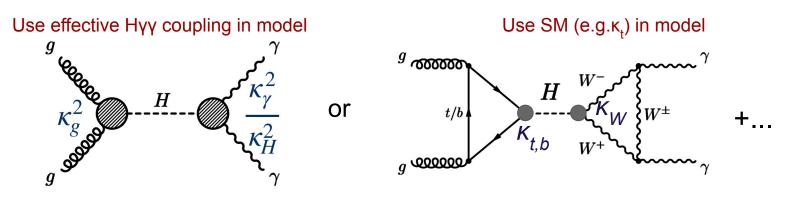


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Interpretations: Kappa-Framework (1)

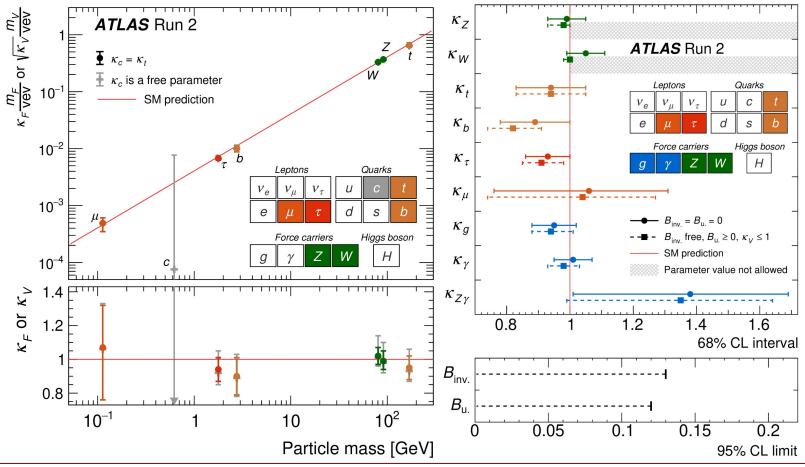
- Assign modifiers (κ_i) to couplings to SM particles
- Two choices for effective couplings (e.g. Hγγ)



• Higgs width also affected by addition of invisible and undetected decays

$$\kappa_H^2(\kappa, B_{\rm inv}, B_{\rm undet}) = \frac{\sum_j B_j^{\rm SM} \kappa_j^2}{(1 - B_{\rm inv} - B_{\rm undet})}$$

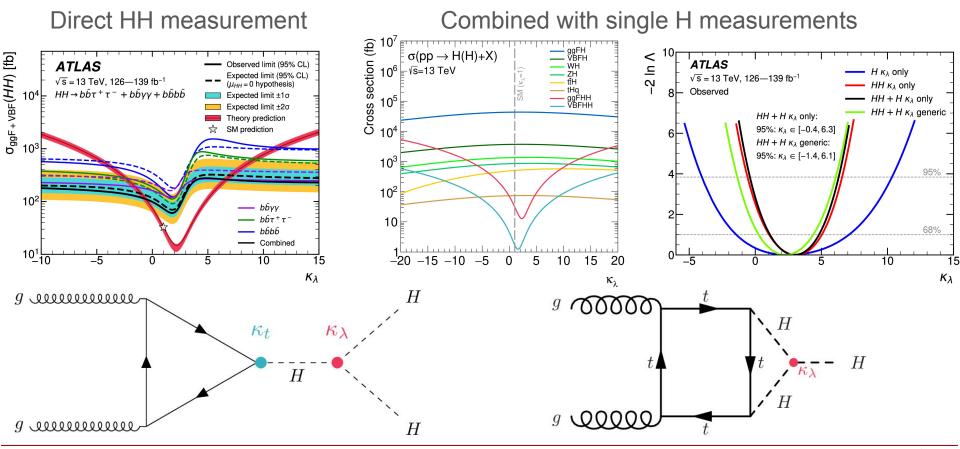
Interpretations: Kappa-Framework (2)



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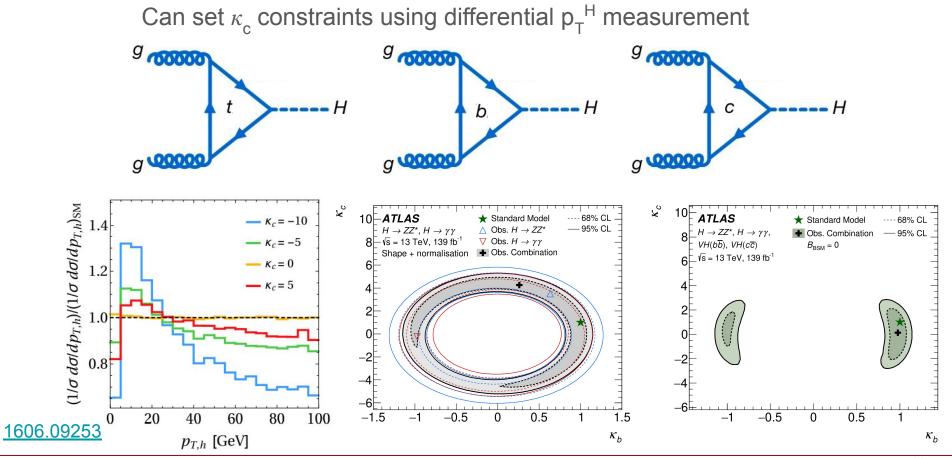
Interpretations: Higgs Self-Coupling



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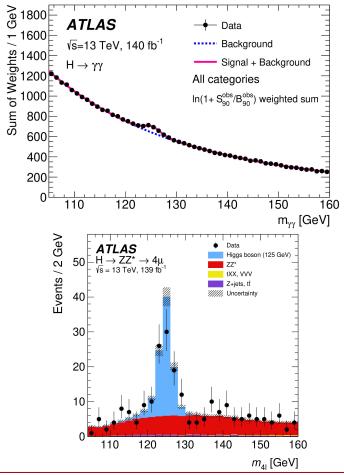
Interpretations: Differential

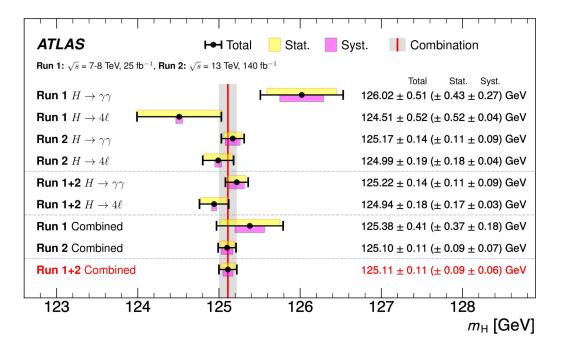


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Properties: Higgs Boson Mass



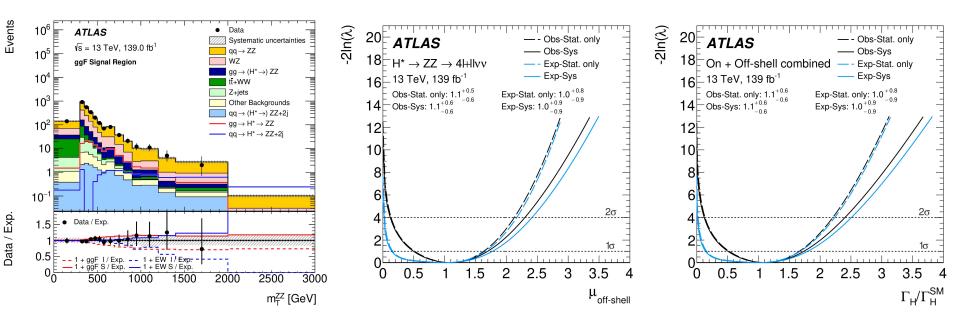


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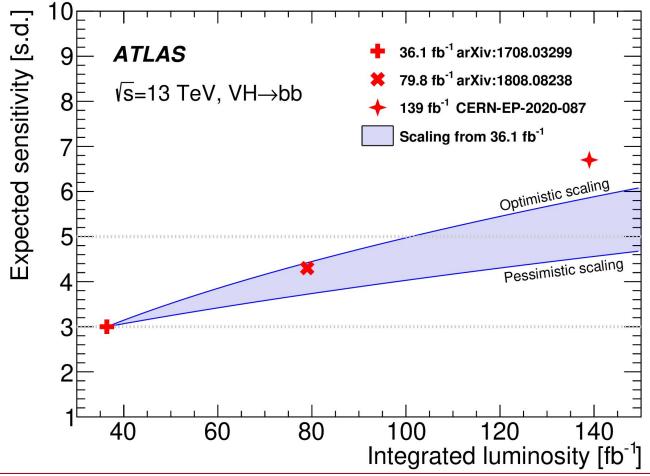
Properties: Higgs Boson Width

Indirect, based on measurement of off-shell production

SM width too narrow to measure directly



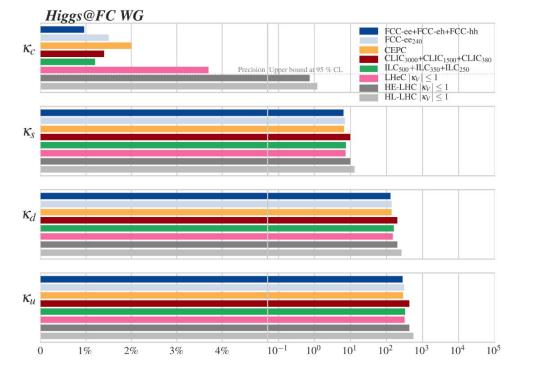
The Future?



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Conclusions

- ATLAS and CMS have many Higgs boson measurements
- Technically what I showed is still just a subset
- Can expect large improvements in the long and very long term



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1905.03764

Backup

References

- <u>Coupling combination</u>
- HH combination
- Differential combination
- Boosted Hbb
- Offshell production
- <u>Mass measurement</u>