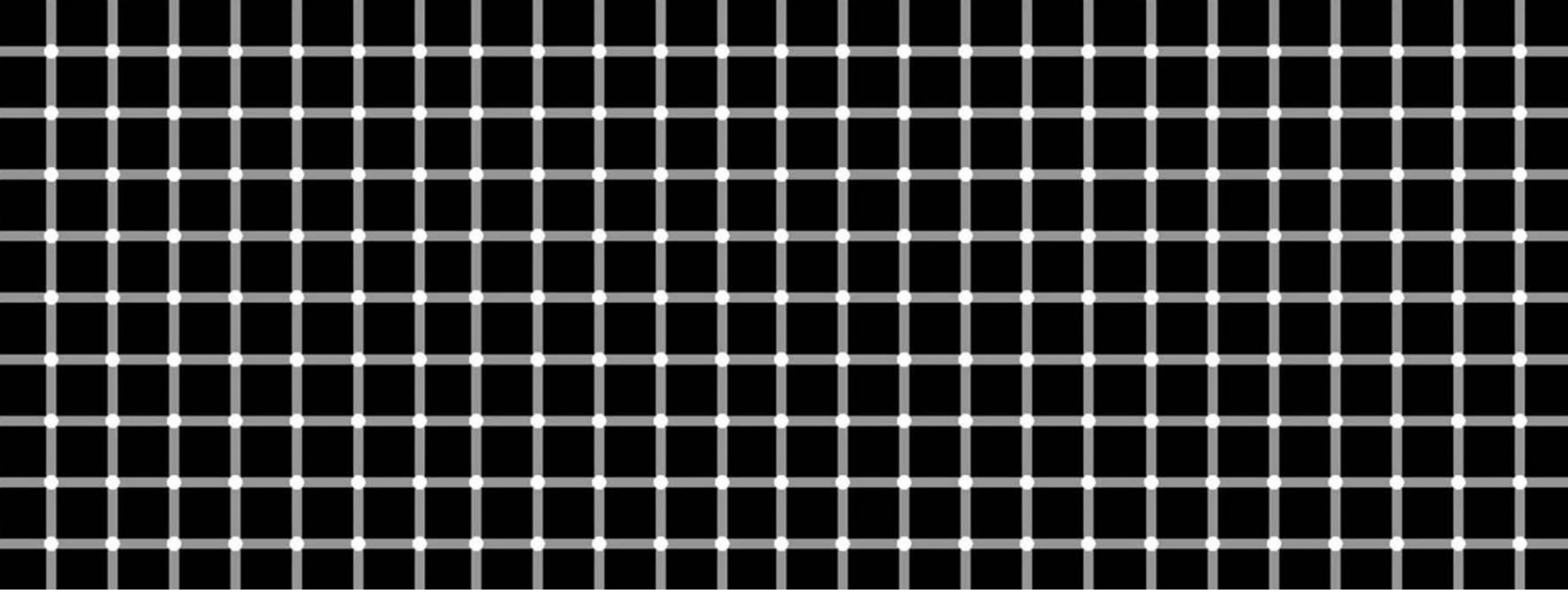
T(T)H AND COMBINED ANALYSES COMPARISON

A. David (CERN)

With thanks to the speakers for early access to contents.

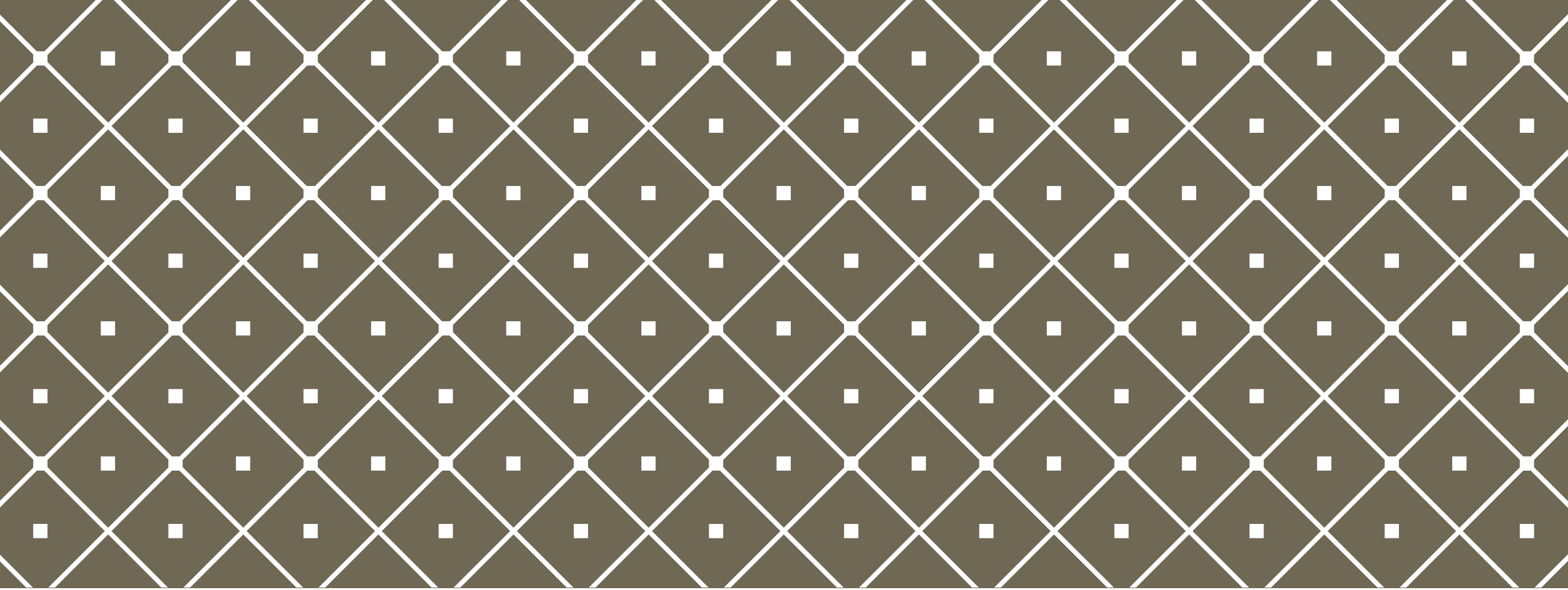


T(T)H AND COMBINED ANALYSES **SELECT** COMPARISON

A. David (CERN)

10TH HIGGS HUNTING

The choice of results and any mistakes are solely my fault.



T(T)H PRODUCTION

Part I

TTH — A LANDSCAPE OF COMPLEMENTARITY

Systematics-limited

$H \longrightarrow b\bar{b}$

- High yield.
- Theory-limited tt+HF backgrounds.

In between

$H \longrightarrow (WW, \tau\tau)$ multileptons

- Moderate yield.
- Reducible background from non-prompt leptons.

Statistics-limited

$H \longrightarrow 4\ell$

$H \longrightarrow \gamma\gamma$

TTH — AFTER THE "OBSERVATION" GOLD RUSH

ttH Run-2	CMS "μ + expected, total-only, uncertainties"		ATLAS "Cross-sections galore"	
Combination	Run-1 + 36 fb^{-1}	μ= 1.26 ±0.29 (±0.16 stat) 4.2σ exp (5.2σ obs)	Run-1 + 36–80 fb^{-1}	μ= 1.32 ±0.27 (±0.18 stat) 5.1σ exp (6.3σ obs)
H→bb	UP! 77 fb^{-1}	μ= 1.15 ±0.15 ±0.27 3.5σ exp (3.9σ obs)	36 fb^{-1}	μ= 0.84 ±0.29 ±0.56 1.6σ exp (1.4σ obs)
H→multi-ℓ	UP! 77 fb^{-1}	μ= 0.96 ±0.32 4.0σ exp (3.2σ obs)	36 fb^{-1}	μ= 1.6 ±0.4 ±0.4 2.8σ exp (4.1σ obs)
H→γγ	UP! 77 fb^{-1}	μ= 1.7 ±0.6 (±0.5 stat) 2.7σ exp (4.1σ obs)	UP! 139 fb^{-1}	μ= 1.38 ±0.39 (±0.33 stat) 4.2σ exp (4.9σ obs)
H→4ℓ	UP! 137 fb^{-1}	μ= 0.13 ± ~1	UP! 139 fb^{-1}	μ*= 1.2 ±1.2 ± 0.2 *STXS 0, |η|<2.5.

TTH — WHAT MAKES SENSE

ttH Run-2	CMS "μ + expected, total-only, uncertainties"		ATLAS "Cross-sections galore"	
Combination	Run-1 + 36 fb^{-1}	μ= 1.26 ±0.29 (±0.16 stat) 4.2σ exp (5.2σ obs)	Run-1 + 36–80 fb^{-1}	μ= 1.32 ±0.27 (±0.18 stat) 5.1σ exp (6.3σ obs)
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H→multi-ℓ	UP! **77 fb^{-1}**	μ= 0.96 ±0.32 **4.0σ exp** (3	**36 fb^{-1}**	μ= 1.6 ±0.4 ±0.4 **2.8σ exp** (4.1σ obs)
H→γγ	UP! **77 fb^{-1}**	μ= 1.7 ±0.6 (±0.5 stat) **2.7σ exp**	UP! **139 fb^{-1}**	μ= 1.38 ±0.39 (±0.33 stat) **4.2σ exp** (4.9σ obs)
H→4ℓ	UP! 137 fb^{-1}	μ= 0.13 ± ~1	UP! 139 fb^{-1}	μ*= 1.2 ±1.2 ± 0.2 *STXS 0, |η|<2.5.

Tough √2 ✅ – much work on systs.

~√2 ✅ on stat.-limited channel

TTH – THEORY UNCERTAINTY MATTERS

ttH Run-2	CMS "μ + expected, total-only, uncertainties"		ATLAS "Cross-sections galore"	
Combination	Run-1 + 36 fb^{-1}	μ= 1.26 ±0.29 (±0.16 stat) 4.2σ exp (5.2σ obs)	Run-1 + 36–80 fb^{-1}	μ= 1.32 ±0.27 (±0.18 stat) 5.1σ exp (6.3σ obs)
H→bb	UP! 77 fb^{-1}	μ= 1.15 ±0.15 **±0.27** **3.5σ exp** (	36 fb^{-1}	μ= 0.84 ±0.29 **±0.56** **1.6σ exp** (1.4σ obs)
H→multi-ℓ	UP! 77 fb^{-1}	μ= 0.96 ±0.32 4.0σ exp (3.2σ obs)	36 fb^{-1}	μ= 1.6 ±0.4 ±0.4 2.8σ exp (4.1σ obs)
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H→4ℓ	UP! 137 fb^{-1}	μ= 0.13 ± ~1	UP! 139 fb^{-1}	μ*= 1.2 ±1.2 ± 0.2 *STXS 0, |η|<2.5.

tt+HF modeling

Discussed in CERN Collider Cross-Talk series.

TTH, H⟶BB – SYSTEMATICS

CMS: 77 fb^{-1}
PAS HIG-18-030

Uncertainty source	$\Delta\hat{\mu}$
Total experimental	+0.15/−0.13
b tagging	+0.08/−0.07
jet energy scale and resolution	+0.05/−0.04
Total theory	+0.23/−0.19
signal	+0.15/−0.06
$t\bar{t}$+hf modelling	+0.14/−0.15
QCD background prediction	+0.10/−0.08
Size of simulated samples	+0.10/−0.10
Total systematic	+0.28/−0.25
Statistical	+0.15/−0.15
Total	+0.32/−0.29

ATLAS: 36 fb^{-1}
arXiv:1712.08895

Uncertainty source	$\Delta\mu$	
$t\bar{t}+\geq 1b$ modeling	+0.46	−0.46
Background-model stat. unc.	+0.29	−0.31
b-tagging efficiency and mis-tag rates	+0.16	−0.16
Jet energy scale and resolution	+0.14	−0.14
$t\bar{t}H$ modeling	+0.22	−0.05
$t\bar{t}+\geq 1c$ modeling	+0.09	−0.11
JVT, pileup modeling	+0.03	−0.05
Other background modeling	+0.08	−0.08
$t\bar{t}+$ light modeling	+0.06	−0.03
Luminosity	+0.03	−0.02
Light lepton (e,μ) id., isolation, trigger	+0.03	−0.04
Total systematic uncertainty	+0.57	−0.54
$t\bar{t}+\geq 1b$ normalization	+0.09	−0.10
$t\bar{t}+\geq 1c$ normalization	+0.02	−0.03
Intrinsic statistical uncertainty	+0.21	−0.20
Total statistical uncertainty	+0.29	−0.29
Total uncertainty	+0.64	−0.61

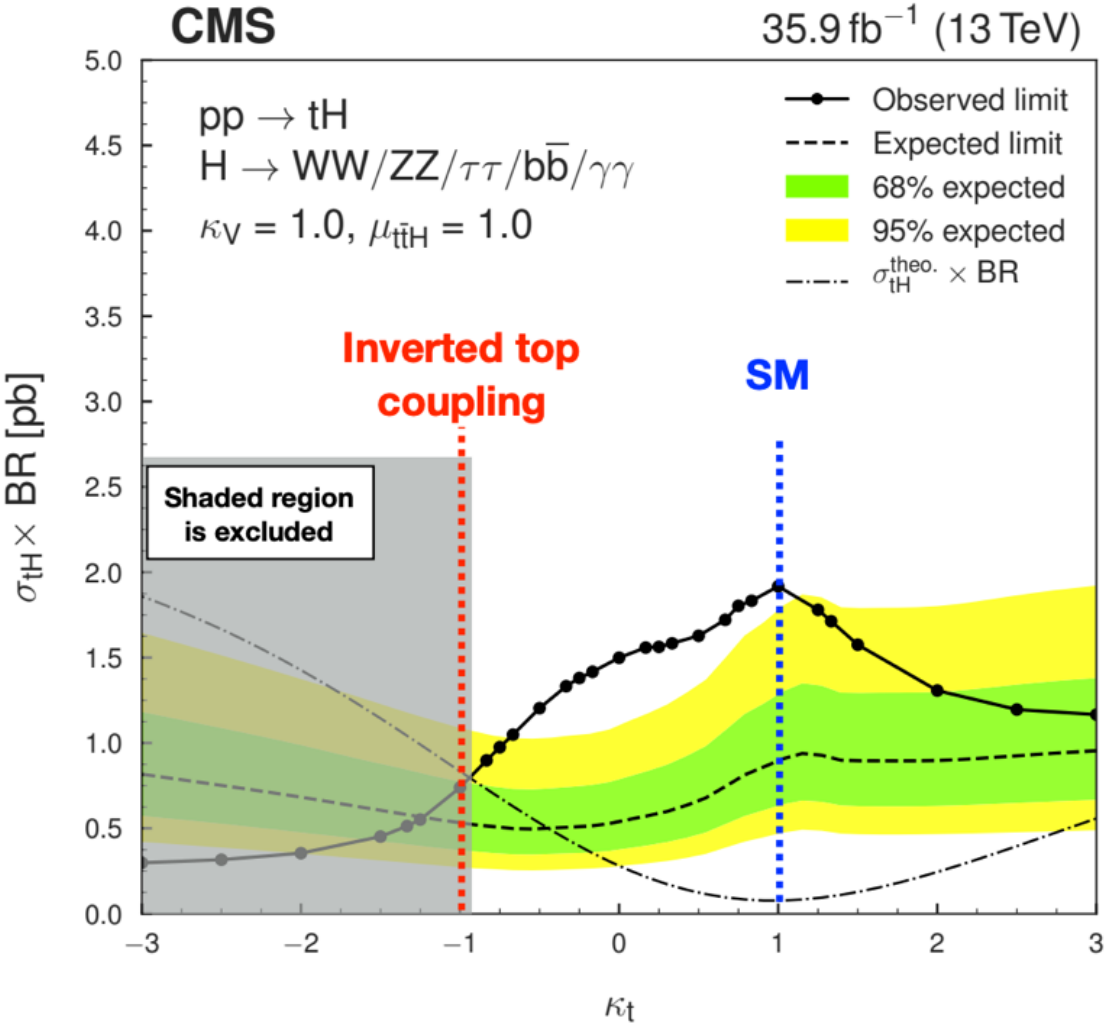
TH+Q/W – A SPECIALTY ITEM

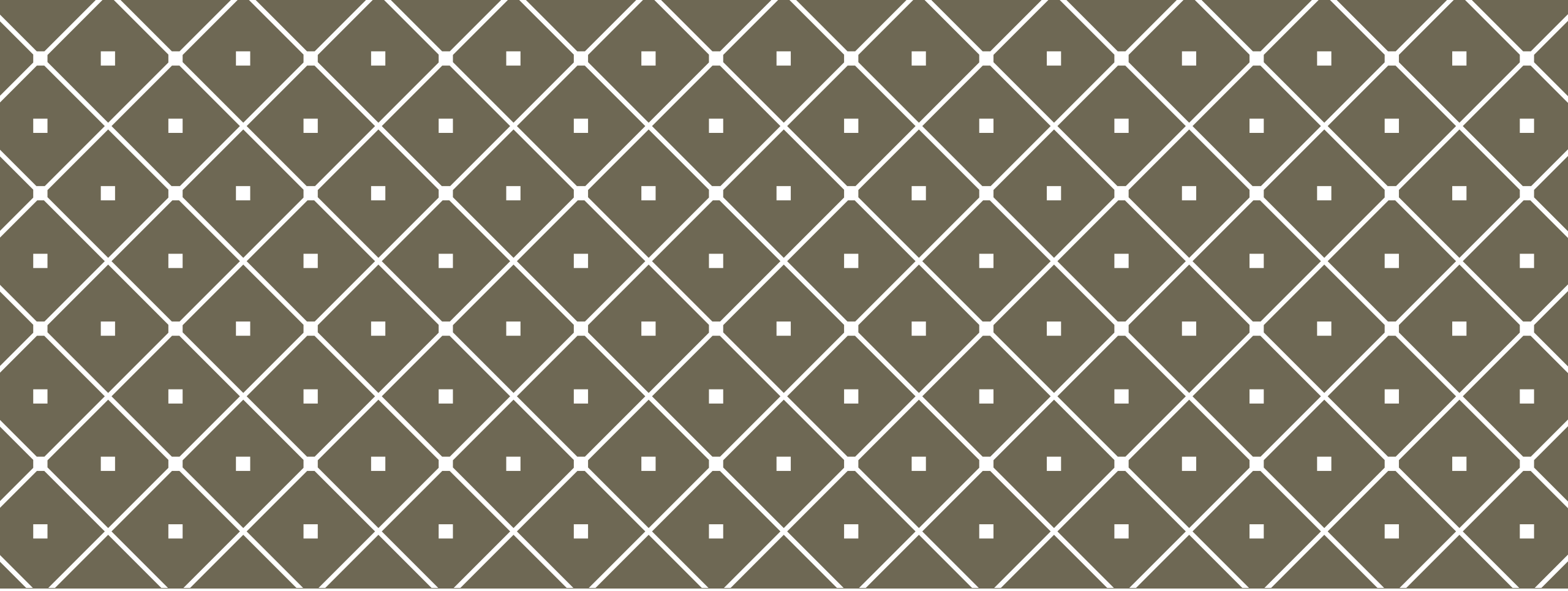
CMS: Run-2 combination. →

ATLAS: No dedicated Run-2 result. Yet?

📝 tH+q/W can exclude $\kappa_{top} = -\kappa_V$.

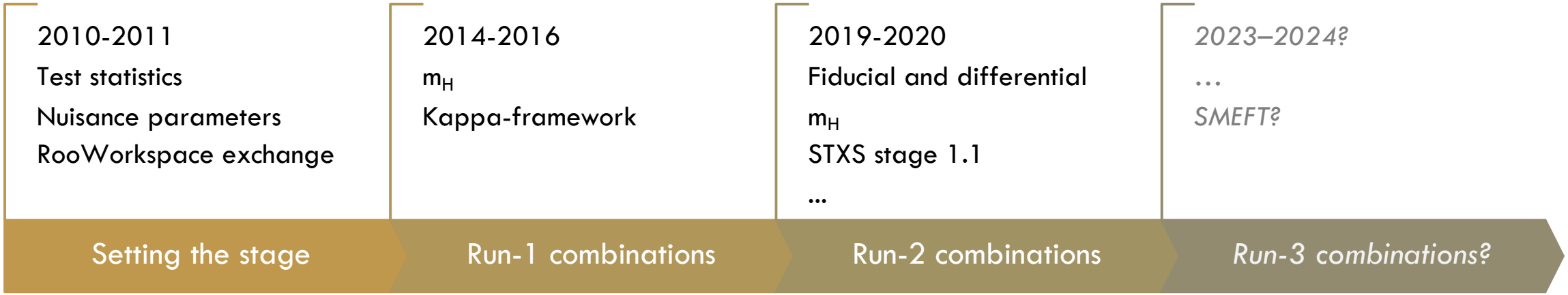
- arxiv:1211.3736





COMBINATIONS

Part II



Post-fit observation: the LHC HGC has strong interactions every 4 to 5 years…

LHC HIGGS COMBINATION GROUP

LATEST OVERALL COMBINATIONS

ATLAS
CONF-2019-005

Analysis	Integrated luminosity (fb^{-1})
$H \to \gamma\gamma$ (including $t\bar{t}H$, $H \to \gamma\gamma$)	79.8
$H \to ZZ^* \to 4\ell$ (including $t\bar{t}H$, $H \to ZZ^* \to 4\ell$)	79.8
$H \to WW^* \to e\nu\mu\nu$	36.1
$H \to \tau\tau$	36.1
VH, $H \to b\bar{b}$	79.8
VBF, $H \to b\bar{b}$	24.5 – 30.6
$H \to \mu\mu$	79.8
$t\bar{t}H$, $H \to b\bar{b}$ and $t\bar{t}H$ multilepton	36.1
$H \to$ invisible	36.1
Off-shell $H \to ZZ^* \to 4\ell$ and $H \to ZZ^* \to 2\ell 2\nu$	36.1

CMS
arXiv:1809.10733

	ggH	VBF	VH	ttH
H→γγ	✓ (36 fb^{-1})	✓ (36 fb^{-1})	✓ (36 fb^{-1})	✓ (36 fb^{-1})
H→4ℓ	✓ (36 fb^{-1})	✓ (36 fb^{-1})	✓ (36 fb^{-1})	✓ (36 fb^{-1})
H→WW	✓ (36 fb^{-1})	✓ (36 fb^{-1})	✓ (36 fb^{-1})	✓ (36 fb^{-1})
H→ττ	✓ (36 fb^{-1})	✓ (36 fb^{-1})		
H→bb	✓ (36 fb^{-1})		✓ (36 fb^{-1})	✓ (36 fb^{-1})
H→μμ	✓ (36 fb^{-1})	✓ (36 fb^{-1})		
H→inv	✓ (36 fb^{-1})	✓ (36 fb^{-1})	✓ (36 fb^{-1})	

OVERALL SIGNAL STRENGTH – 10% PRECISION

ATLAS

$$\mu = 1.11^{+0.09}_{-0.08} = 1.11 \pm 0.05\,(\text{stat.})\,^{+0.05}_{-0.04}\,(\text{exp.})\,^{+0.05}_{-0.04}\,(\text{sig. th.})\,\pm 0.03\,(\text{bkg. th.})$$

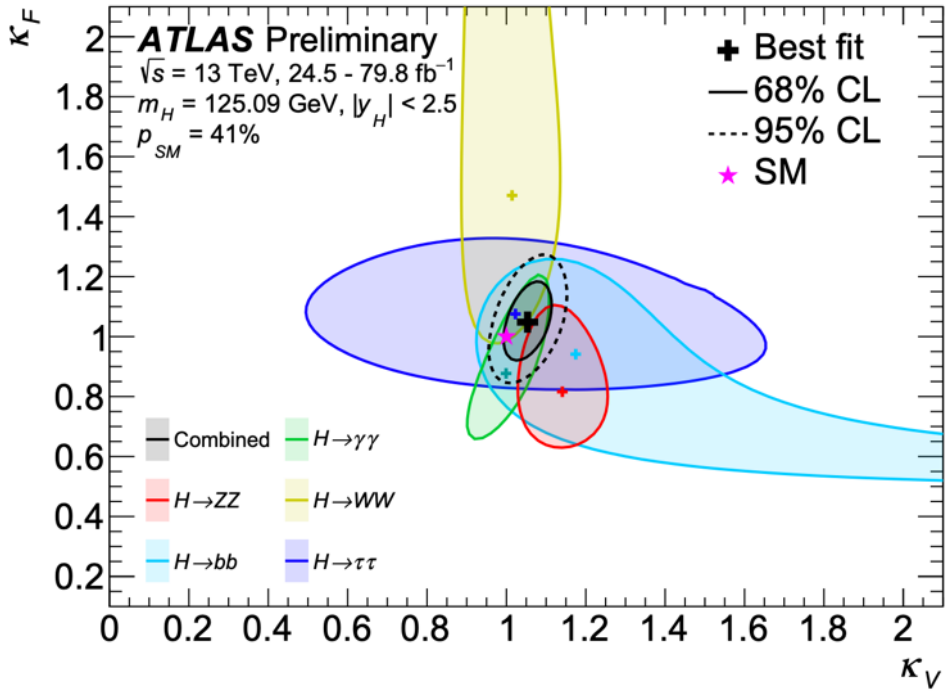
CMS

$$\begin{aligned}\mu &= 1.17 \pm 0.10 \\ &= 1.17 \pm 0.06\,(\text{stat})\,^{+0.06}_{-0.05}\,(\text{sig theo})\,\pm 0.06\,(\text{other syst}),\end{aligned}$$

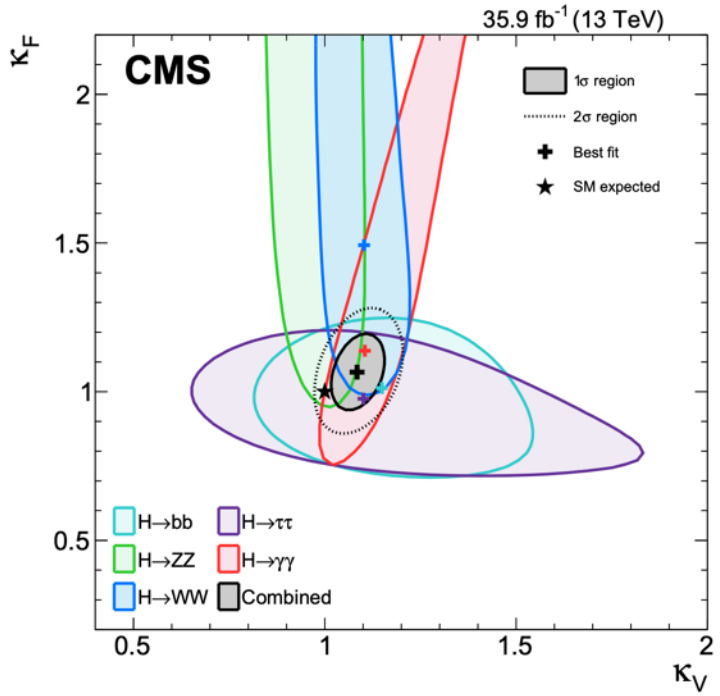
REDUCED KAPPAS – A CLASSIC

ATLAS

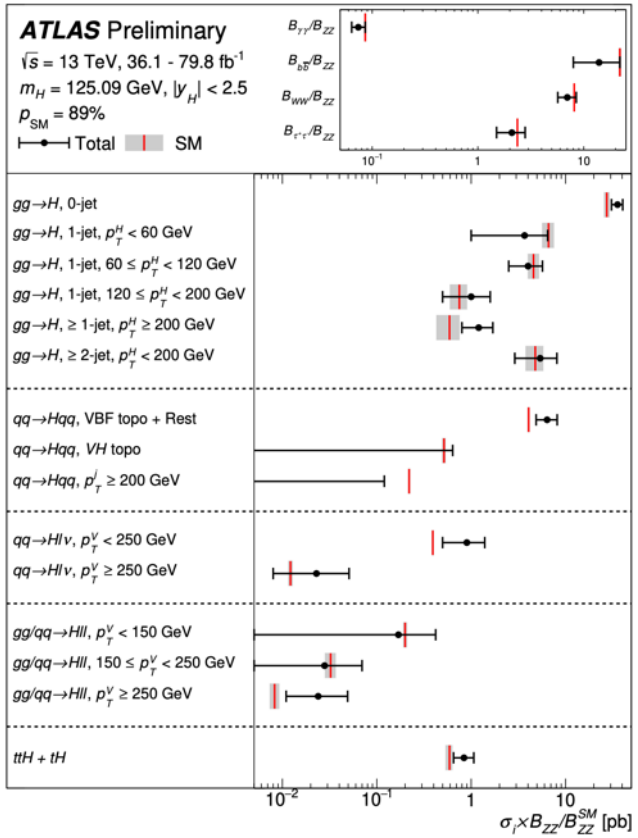
4ℓ and $\gamma\gamma$ close κ_F (2× lumi)

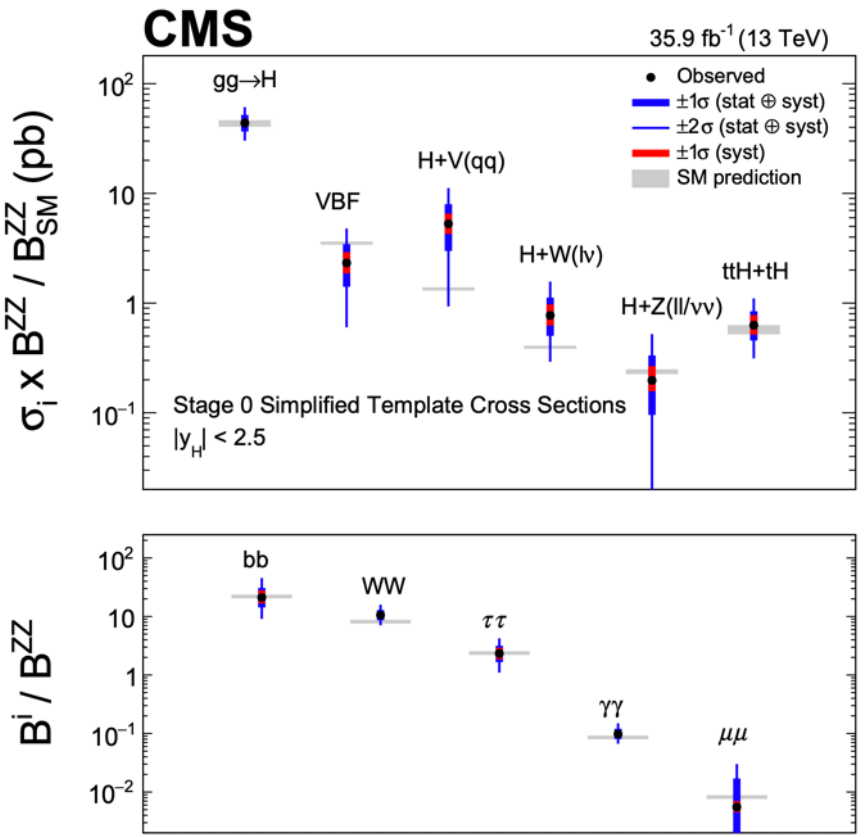


CMS



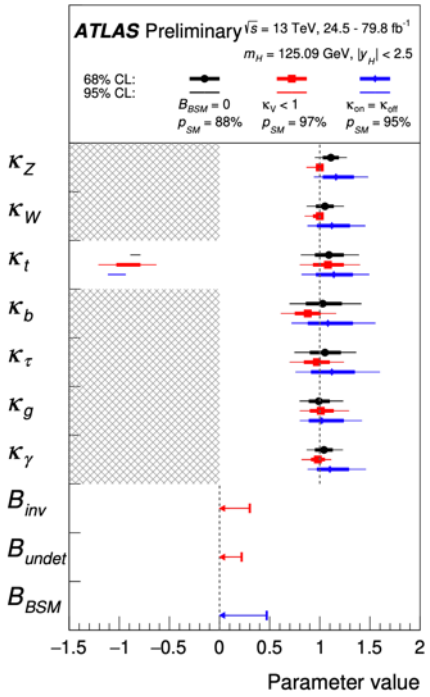
STXS – 🍎 AND 🍊


ATLAS Preliminary
√s = 13 TeV, 36.1 - 79.8 fb-1
mH = 125.09 GeV, |yH| < 2.5
pSM = 89%
Total
SM
gg→H, 0-jet
gg→H, 1-jet, pTH < 60 GeV
gg→H, 1-jet, 60 ≤ pTH < 120 GeV
gg→H, 1-jet, 120 ≤ pTH < 200 GeV
gg→H, ≥ 1-jet, pTH ≥ 200 GeV
gg→H, ≥ 2-jet, pTH < 200 GeV
qq→Hqq, VBF topo + Rest
qq→Hqq, VH topo
qq→Hqq, pTj ≥ 200 GeV
qq→Hlν, pTV < 250 GeV
qq→Hlν, pTV ≥ 250 GeV
gg/qq→Hll, pTV < 150 GeV
gg/qq→Hll, 150 ≤ pTV < 250 GeV
gg/qq→Hll, pTV ≥ 250 GeV
ttH + tH
σi×BZZ/BZZSM [pb]

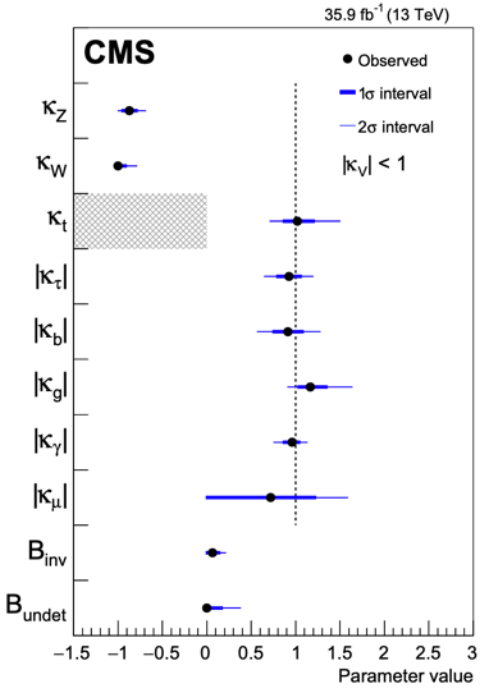

CMS
35.9 fb-1 (13 TeV)
Observed
±1σ (stat ⊕ syst)
±2σ (stat ⊕ syst)
±1σ (syst)
SM prediction
gg→H
VBF
H+V(qq)
H+W(lν)
H+Z(ll/νν)
ttH+tH
Stage 0 Simplified Template Cross Sections
|yH| < 2.5
σi x BZZ / BZZSM (pb)
bb
WW
ττ
γγ
μμ
Bi / BZZ

ALL KAPPAS – FISHBONE

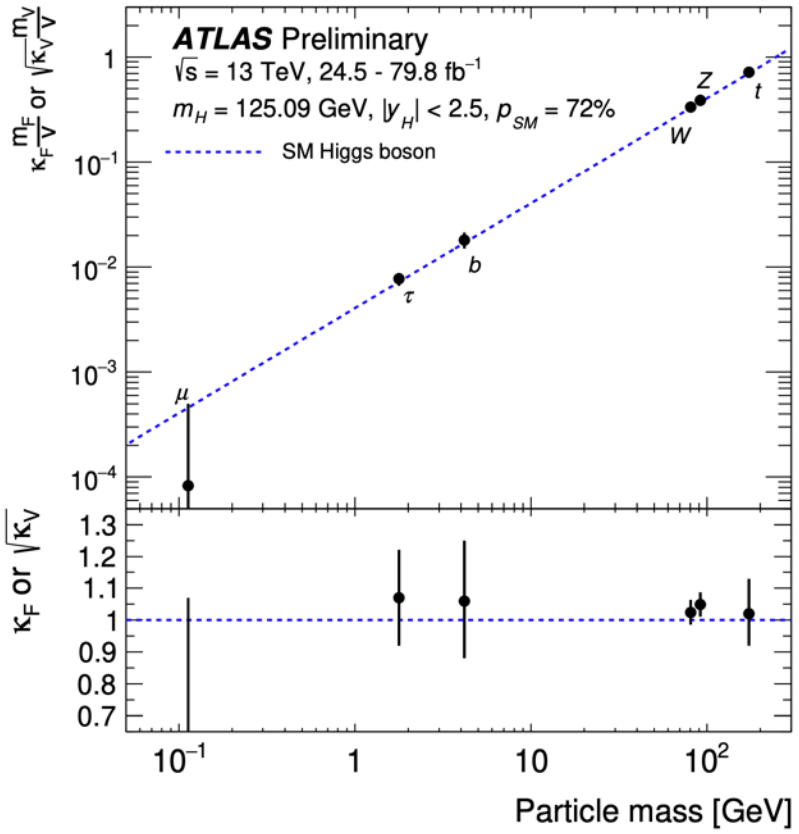
ATLAS
Includes off-shell

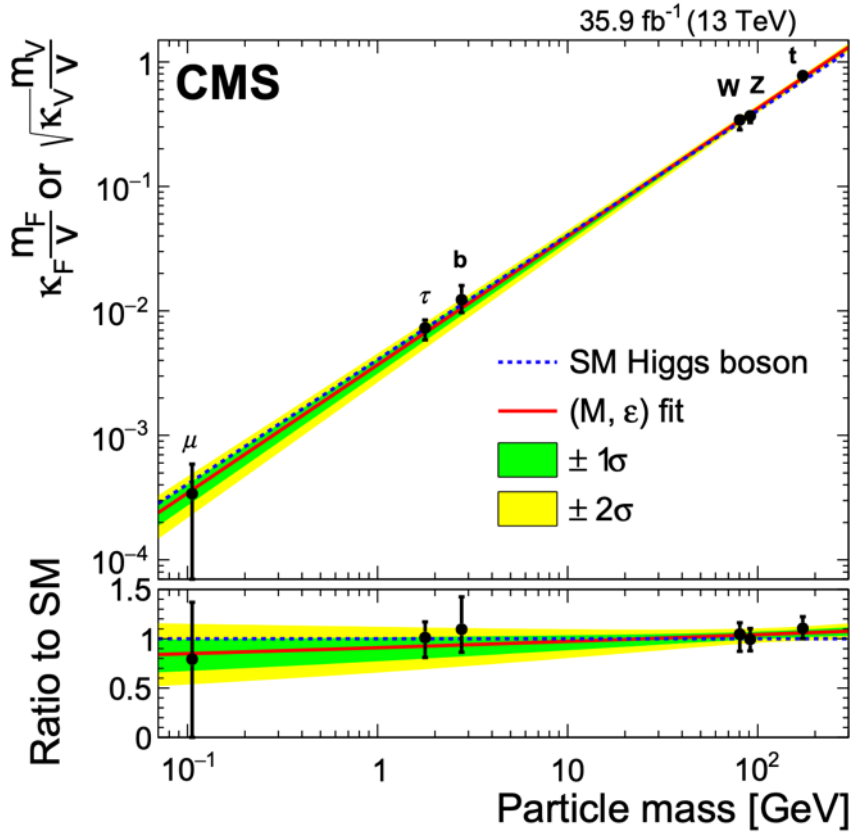


CMS

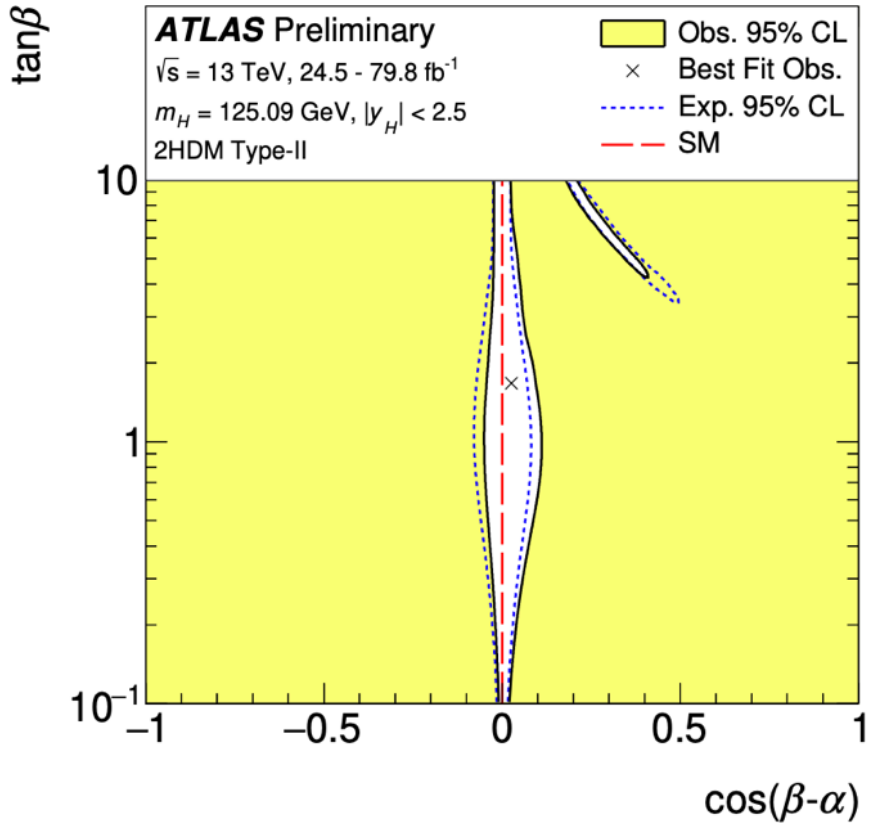


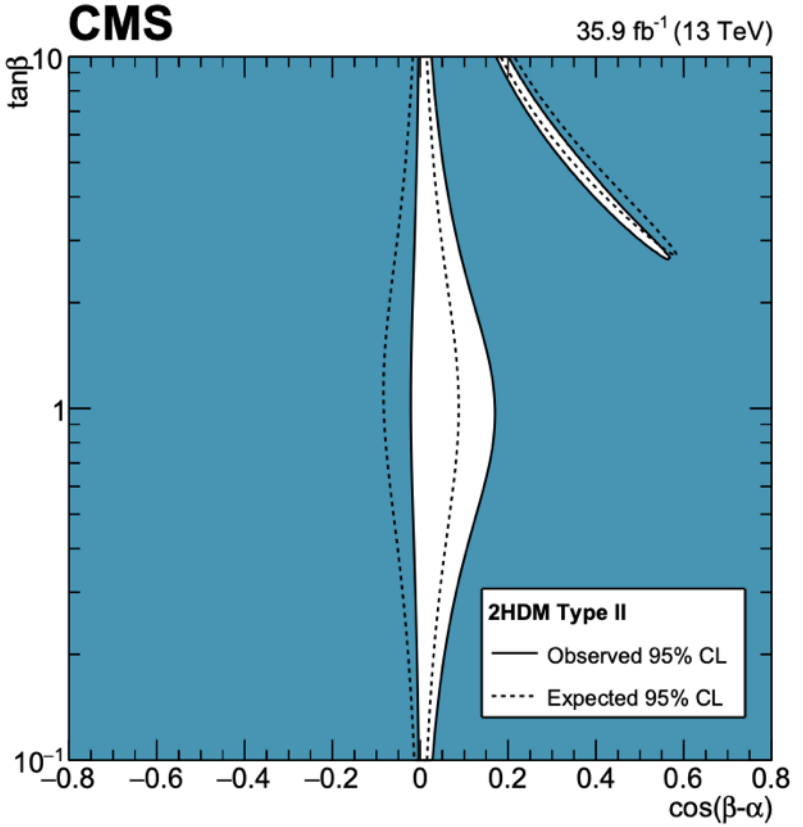
“REGGE PLOT”


ATLAS Preliminary
√s = 13 TeV, 24.5 - 79.8 fb⁻¹
m_H = 125.09 GeV, |y_H| < 2.5, p_SM = 72%
SM Higgs boson
μ
τ
b
W
Z
t
Particle mass [GeV]


35.9 fb⁻¹ (13 TeV)
CMS
SM Higgs boson
(M, ε) fit
± 1σ
± 2σ
μ
τ
b
w z
t
Ratio to SM
Particle mass [GeV]

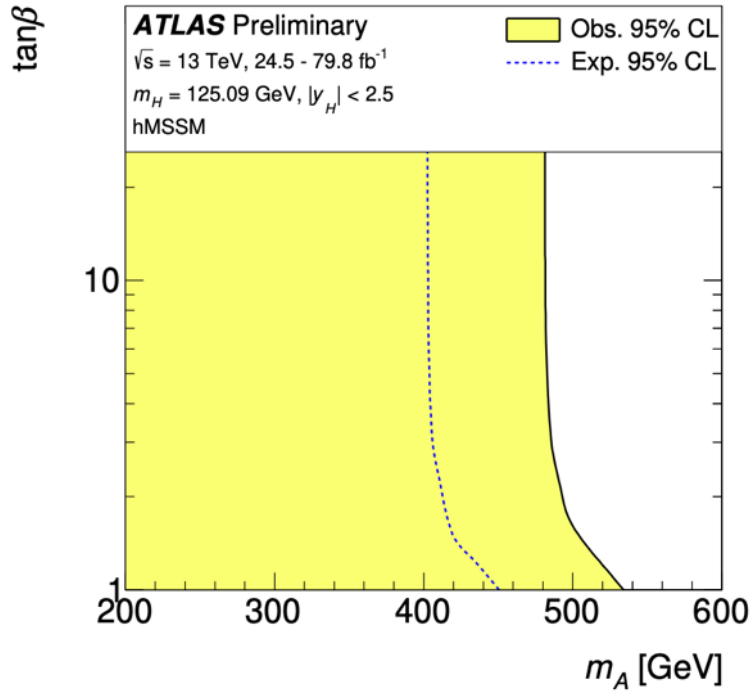
EXTENDED SCALAR SECTORS – 2HDM TYPE-II



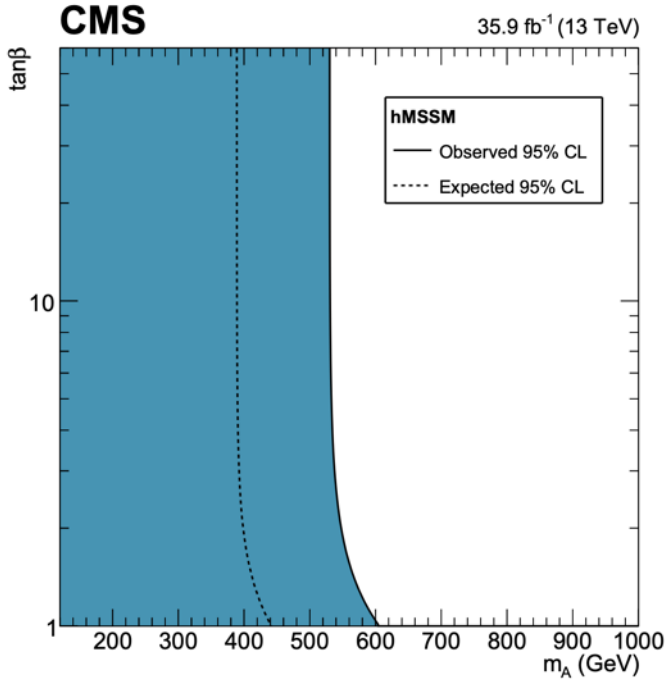


EXTENDED SCALAR SECTORS – HMSSM

ATLAS
(μ>1 ⇒ Obs. > Exp.)



CMS
(*ditto*)



ONE-SLIDE SUMMARY

💥 **t(t)H** – Observed, moving on.

- On the way to full Run-1+Run-2 analyses.
- Theory syst. under scrutiny in ttH, H→bb since some time.
- ATLAS working on 13 TeV tH+q/W analysis?

Combinations – Evolving in scope, complexity.

- Moving beyond kappa-framework.
- The rise of STXS and fiducial differential combinations.
- Run-1 experience set common language.

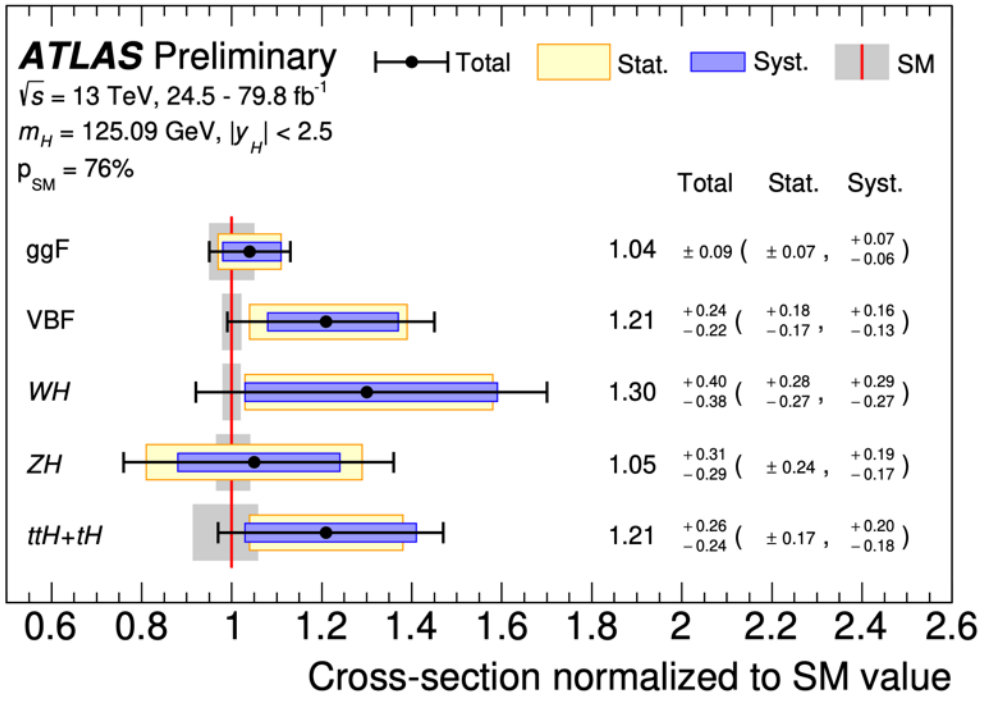
🌅 **At the horizon** – Combined SMEFT constraints?

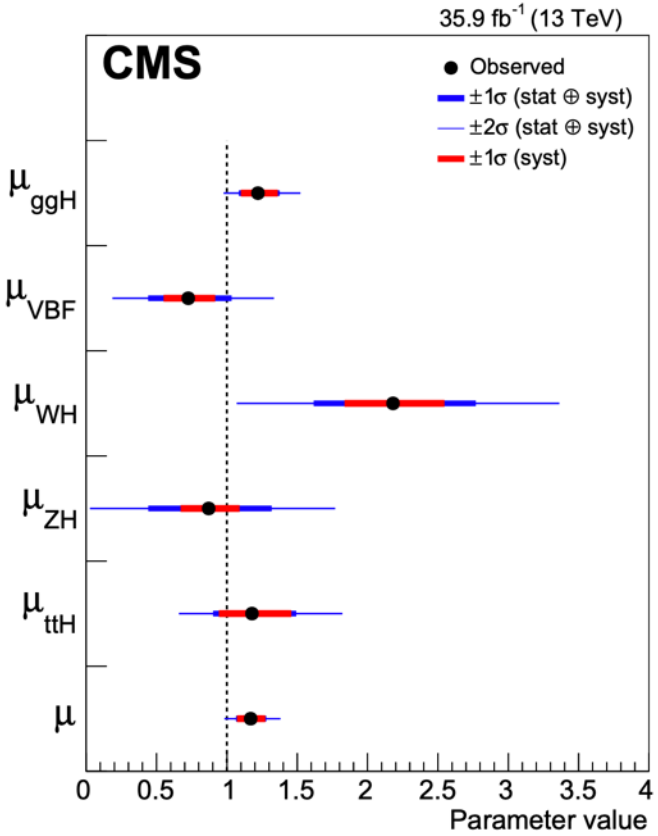
- 🦄 Also with Top and Electroweak measurements?

Inspired by Physics Nobel prize winner.™

FOR DISCUSSION

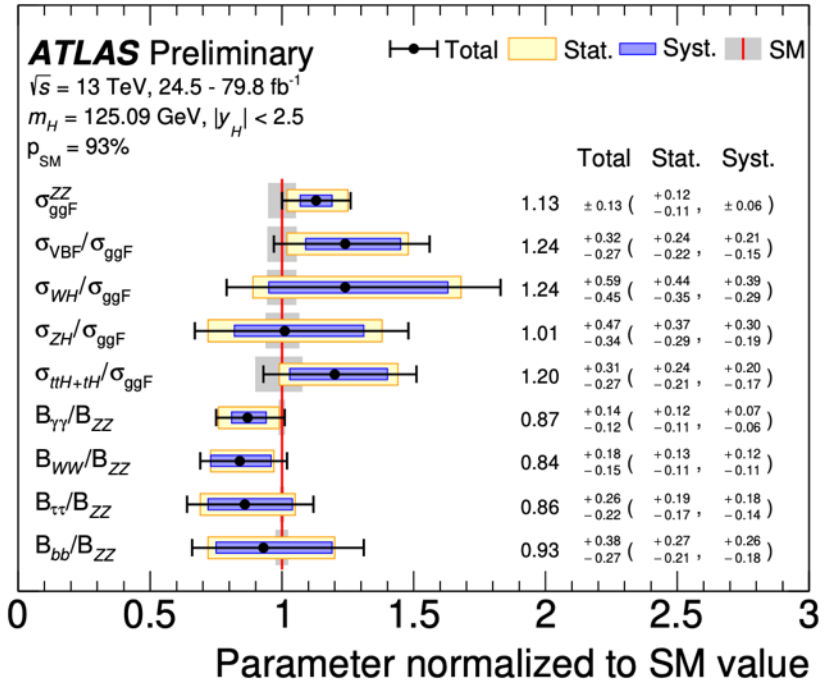
PRODUCTION MODES WITH BR_{SM}



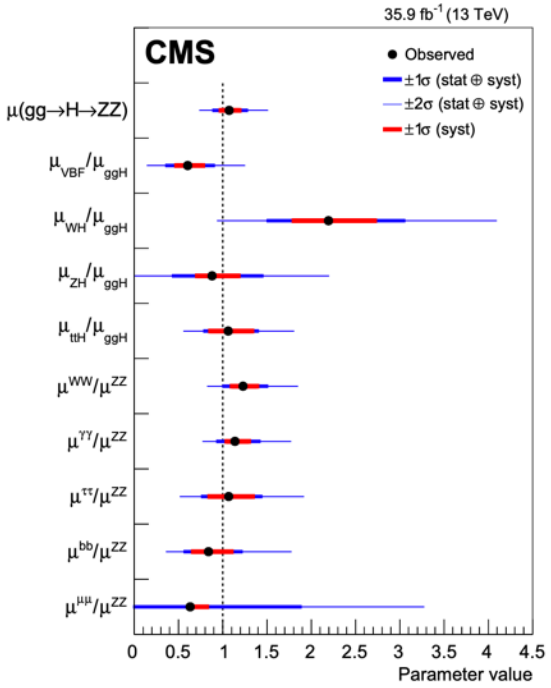


PRODUCTION AND DECAY RATIOS

ATLAS

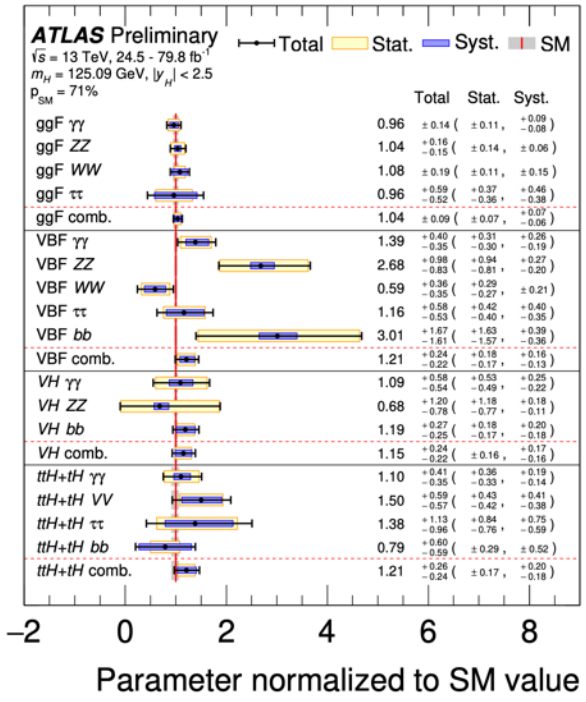


CMS
Includes μμ

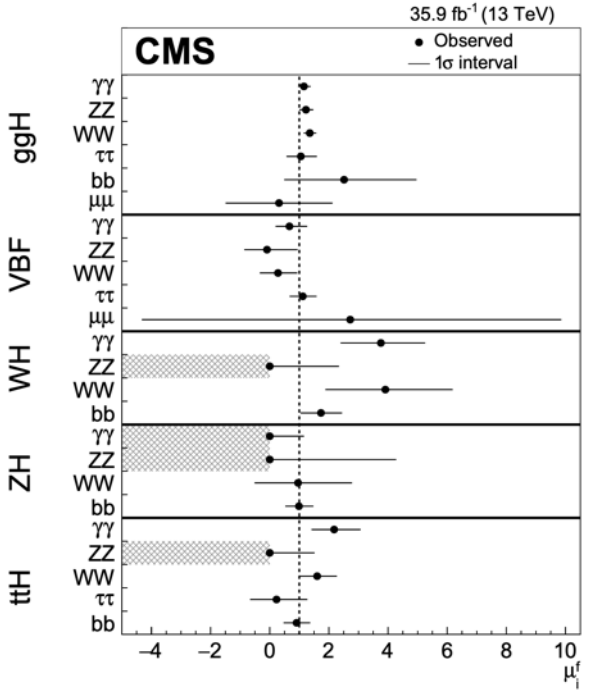


PRODUCTION PROCESSES × DECAY MODES

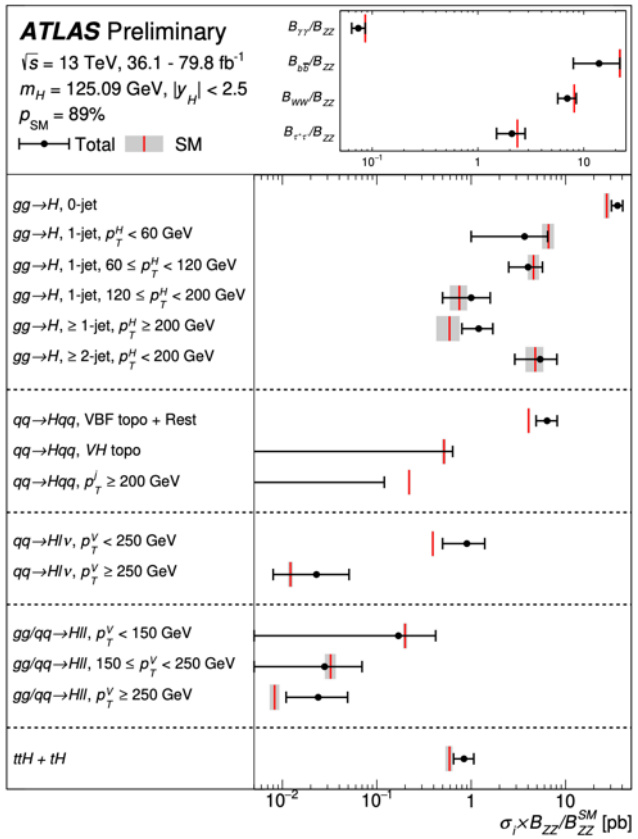
ATLAS

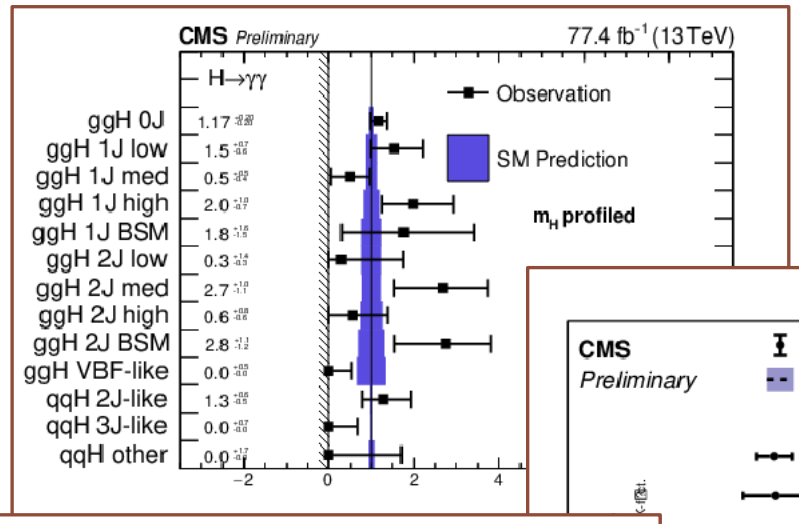


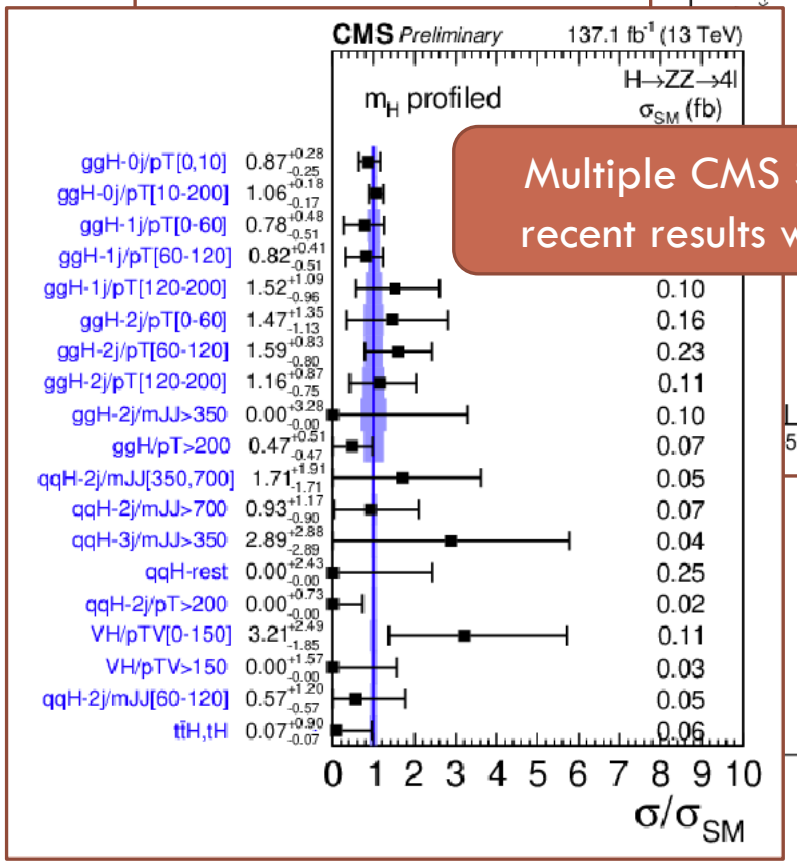
CMS
Includes μμ

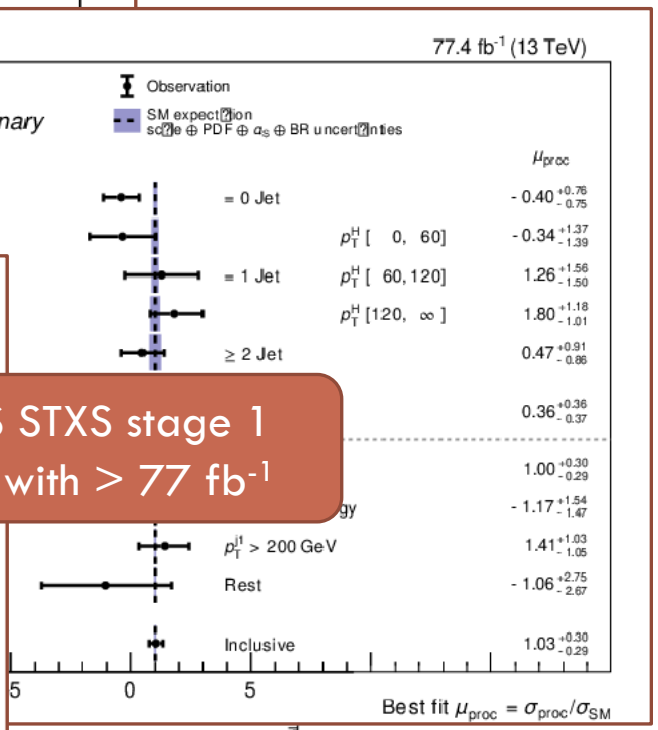


STXS – 🍎 AND 🍏

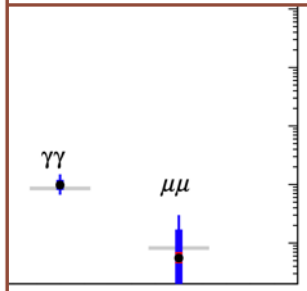








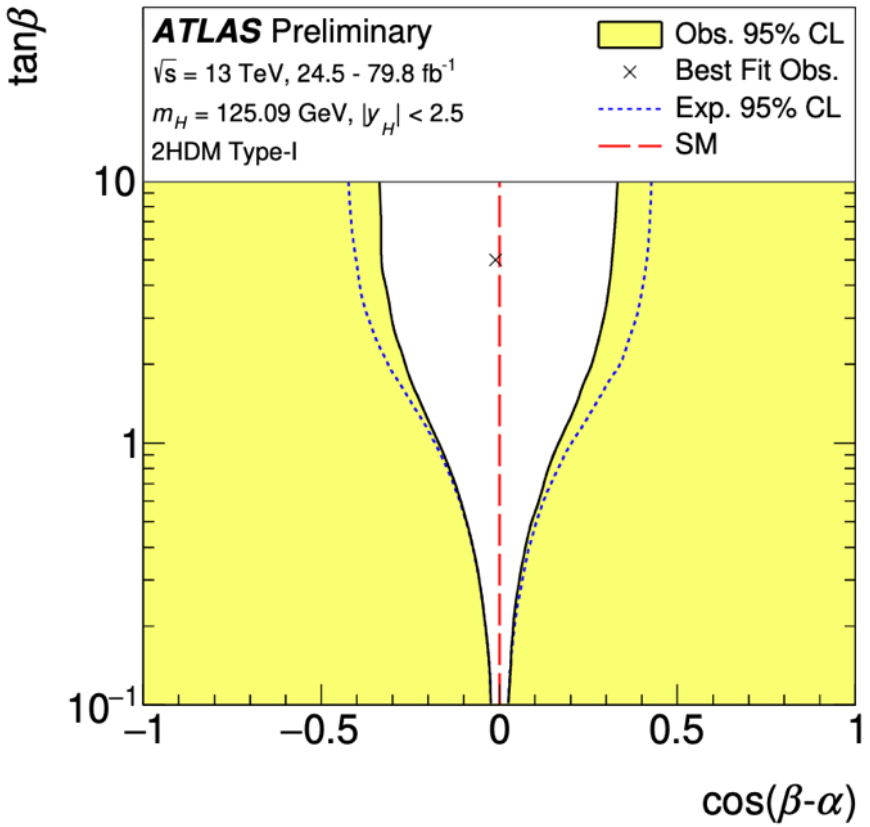
Multiple CMS STXS stage 1 recent results with > 77 fb^{-1}

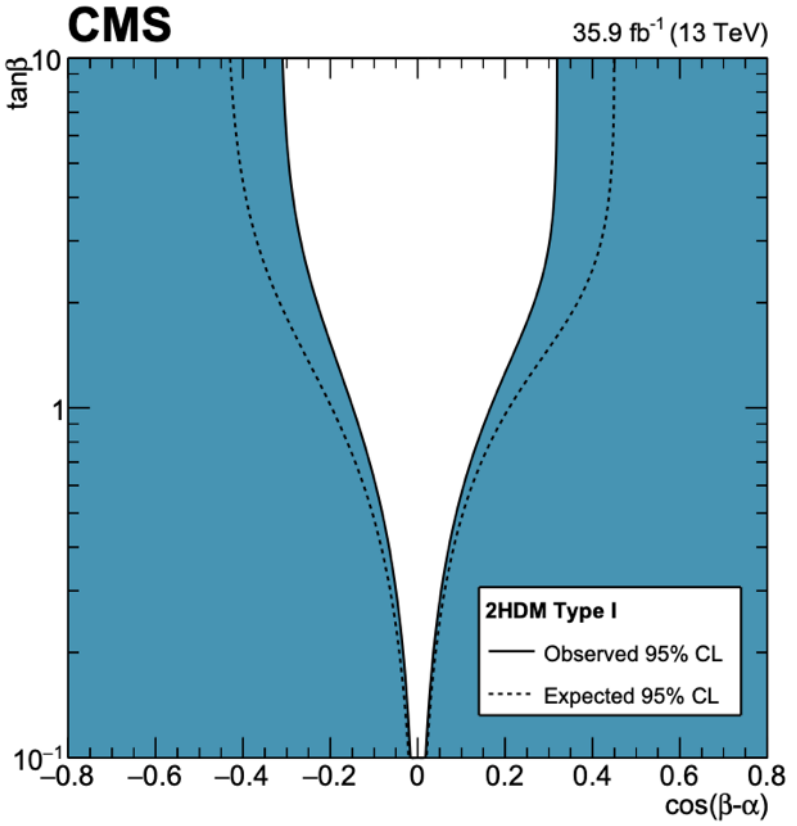


FROM H(125) TO 2HDM MODELS

	2HDM				hMSSM
	Type I	Type II	Type III	Type IV	
κ_V	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$	$\frac{s_d+s_u\tan\beta}{\sqrt{1+\tan^2\beta}}$
κ_u	$\cos(\alpha)/\sin(\beta)$	$\cos(\alpha)/\sin(\beta)$	$\cos(\alpha)/\sin(\beta)$	$\cos(\alpha)/\sin(\beta)$	$s_u\frac{\sqrt{1+\tan^2\beta}}{\tan\beta}$
κ_d	$\cos(\alpha)/\sin(\beta)$	$-\sin(\alpha)/\cos(\beta)$	$\cos(\alpha)/\sin(\beta)$	$-\sin(\alpha)/\cos(\beta)$	$s_d\sqrt{1+\tan^2\beta}$
κ_l	$\cos(\alpha)/\sin(\beta)$	$-\sin(\alpha)/\cos(\beta)$	$-\sin(\alpha)/\cos(\beta)$	$\cos(\alpha)/\sin(\beta)$	$s_d\sqrt{1+\tan^2\beta}$

EXTENDED SCALAR SECTORS – 2HDM TYPE-I

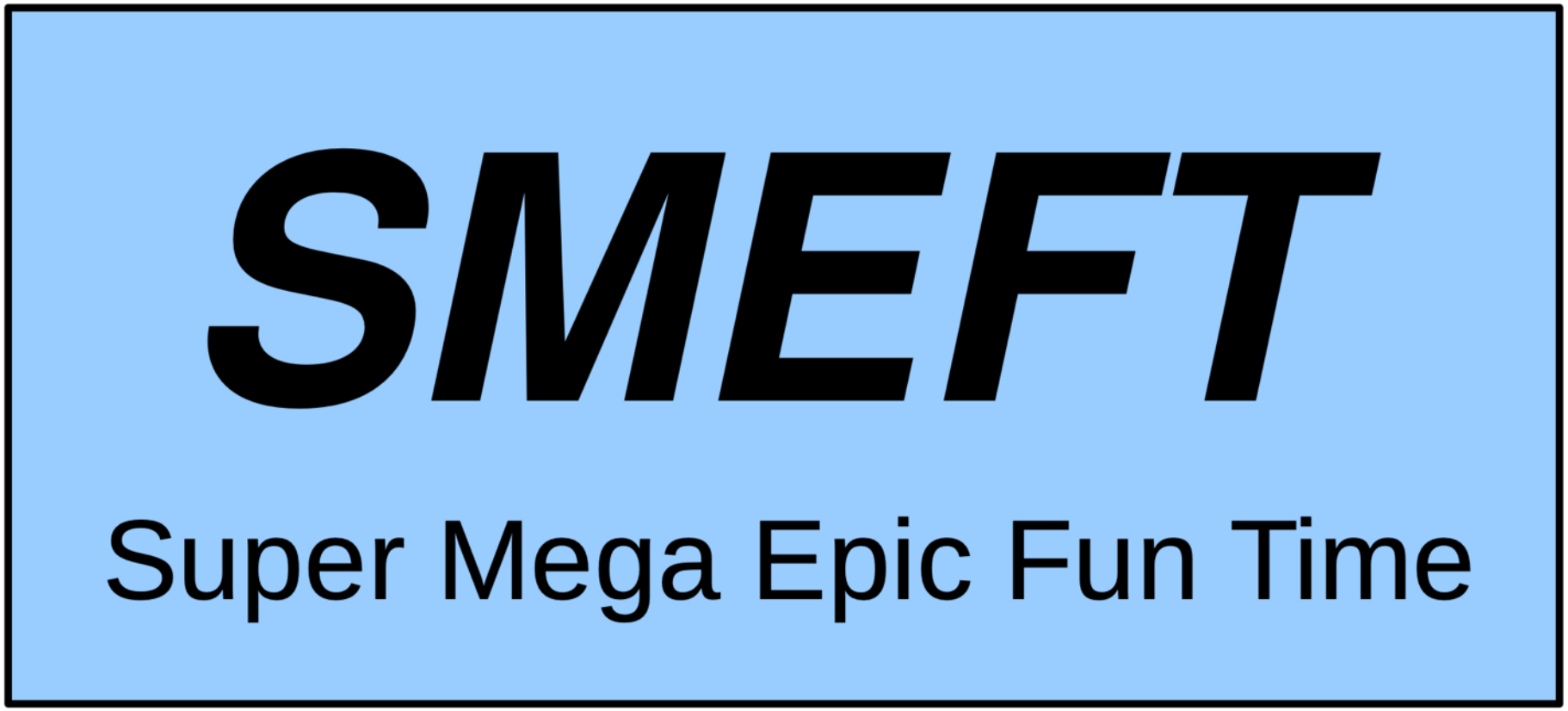




FOR EVEN MORE DISCUSSION

https://indico.cern.ch/event/745783/contributions/3082126/attachments/1690683/2720321/lecture2.pdf

🤦 GETTING THERE?



SMEFT – SM FIELDS, ONE SCALAR DOUBLET

$$\mathcal{L} = \mathcal{L}_{\text{SM}}$$

SMEFT – … AND ADD HIGHER-DIM OPERATORS

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{1}{\Lambda_{\delta L \neq 0}}\mathcal{L}_5 + \frac{1}{\Lambda^2_{\delta B = 0}}\mathcal{L}_6 + \frac{1}{\Lambda^2_{\delta B \neq 0}}\mathcal{L}'_6 + \frac{1}{\Lambda^3_{\delta L \neq 0}}\mathcal{L}_7 + \frac{1}{\Lambda^4}\mathcal{L}_8 + \ldots$$

SMEFT – SM FIELDS AND NEW OPERATORS

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{1}{\Lambda_{\delta L\neq 0}}\mathcal{L}_5 + \frac{1}{\Lambda^2_{\delta B=0}}\mathcal{L}_6 + \frac{1}{\Lambda^2_{\delta B\neq 0}}\mathcal{L}'_6 + \frac{1}{\Lambda^3_{\delta L\neq 0}}\mathcal{L}_7 + \frac{1}{\Lambda^4}\mathcal{L}_8 + \dots$$

4 – The SM, SU(3)×SU(2)×U(1)

- **Glashow 1961; Weinberg 1967; Salam 1967**

5 – Majorana mass

- Weinberg 1979; Zee, Wilczek 1979

6 – The Good

- **Leung, Love, Rao 1984; Buchmuller Wyler 1986; Grzadkowski, Iskrzynski, Misiak, Rosiek 2010**

6' – The Bad

- Weinberg 1979; Abbott Wise 1980

7 – The Ugly

- Lehman 1410.4193; Henning et al. 1512.03433

8 – The next level

- **Lehman, Martin 1510.00372; Henning et al. 1512.03433**

SMEFT – WHAT'S USUALLY DISCUSSED

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{1}{\Lambda^2_{\delta B=0}}\mathcal{L}_6 + \frac{1}{\Lambda^4}\mathcal{L}_8 + \dots$$

6 – The Good

- Leung, Love, Rao 1984; Buchmuller Wyler 1986; Grzadkowski, Iskrzynski, Misiak, Rosiek 2010

8 – The next level

- Lehman, Martin 1510.00372; Henning et al. 1512.03433

http://inspirehep.net/search?ln=en&p=find%20smeft%20or%20%22sm%20eft%22&of=hcs

SMEFT – A CONSISTENT, IMPROVABLE, QFT

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{1}{\Lambda^2_{\delta B=0}} \mathcal{L}_6$$

Heavy lifting in the last 6 years

114 papers found, 106 of them citeable (published or arXiv)

Citation summary results	Citeable papers
Total number of papers analyzed:	106
Total number of citations:	2,636
Average citations per paper:	24.9
Breakdown of papers by citations:	
Renowned papers (500+)	0
Famous papers (250-499)	1
Very well-known papers (100-249)	2
Well-known papers (50-99)	14
Known papers (10-49)	39
Less known papers (1-9)	36
Unknown papers (0)	14
h_{HEP} index [?]	29

1. **Renormalization Group Evolution of the Standard Model Dimension Six Operators II: Yukawa Dependence**
Elizabeth E. Jenkins, Aneesh V. Manohar (UC, San Diego), Michael Trott (CERN). Oct 17, 2013. 16 pp.
Published in **JHEP 1401 (2014) 035**
DOI: 10.1007/JHEP01(2014)035
e-Print: **arXiv:1310.4838 [hep-ph]** | PDF
References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
CERN Document Server; ADS Abstract Service; Link to Article from SCOAP3
Detailed record - Cited by 237 records 100+

• • •

114. **The Higgs width in the SMEFT**
Ilaria Brivio, Tyler Corbett, Michael Trott. Jun 17, 2019. 41 pp.
e-Print: **arXiv:1906.06949 [hep-ph]** | PDF
References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
ADS Abstract Service
Detailed record

https://arxiv.org/abs/1008.4884

59 OPERATORS – 76 PARAMETERS*

$$\frac{1}{\Lambda^2_{\delta B=0}}\mathcal{L}_6$$

* For three flavor generations there are 2499, "but that's just copy-pasting".

X^3		φ^6 and $\varphi^4 D^2$		$\psi^2\varphi^3$	
Q_G	$f^{ABC}G^{A\nu}_{\mu}G^{B\rho}_{\nu}G^{C\mu}_{\rho}$	Q_φ	$(\varphi^\dagger\varphi)^3$	$Q_{e\varphi}$	$(\varphi^\dagger\varphi)(\bar{l}_p e_r \varphi)$
$Q_{\widetilde{G}}$	$f^{ABC}\widetilde{G}^{A\nu}_{\mu}G^{B\rho}_{\nu}G^{C\mu}_{\rho}$	$Q_{\varphi\Box}$	$(\varphi^\dagger\varphi)\Box(\varphi^\dagger\varphi)$	$Q_{u\varphi}$	$(\varphi^\dagger\varphi)(\bar{q}_p u_r \widetilde{\varphi})$
Q_W	$\varepsilon^{IJK}W^{I\nu}_{\mu}W^{J\rho}_{\nu}W^{K\mu}_{\rho}$	$Q_{\varphi D}$	$\left(\varphi^\dagger D^\mu\varphi\right)^\star\left(\varphi^\dagger D_\mu\varphi\right)$	$Q_{d\varphi}$	$(\varphi^\dagger\varphi)(\bar{q}_p d_r \varphi)$
$Q_{\widetilde{W}}$	$\varepsilon^{IJK}\widetilde{W}^{I\nu}_{\mu}W^{J\rho}_{\nu}W^{K\mu}_{\rho}$				

$X^2\varphi^2$		$\psi^2 X\varphi$		$\psi^2\varphi^2 D$	
$Q_{\varphi G}$	$\varphi^\dagger\varphi\, G^A_{\mu\nu}G^{A\mu\nu}$	Q_{eW}	$(\bar{l}_p\sigma^{\mu\nu}e_r)\tau^I\varphi W^I_{\mu\nu}$	$Q^{(1)}_{\varphi l}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{l}_p\gamma^\mu l_r)$
$Q_{\varphi\widetilde{G}}$	$\varphi^\dagger\varphi\,\widetilde{G}^A_{\mu\nu}G^{A\mu\nu}$	Q_{eB}	$(\bar{l}_p\sigma^{\mu\nu}e_r)\varphi B_{\mu\nu}$	$Q^{(3)}_{\varphi l}$	$(\varphi^\dagger i\overleftrightarrow{D}^I_\mu\varphi)(\bar{l}_p\tau^I\gamma^\mu l_r)$
$Q_{\varphi W}$	$\varphi^\dagger\varphi\, W^I_{\mu\nu}W^{I\mu\nu}$	Q_{uG}	$(\bar{q}_p\sigma^{\mu\nu}T^A u_r)\widetilde{\varphi}\,G^A_{\mu\nu}$	$Q_{\varphi e}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{e}_p\gamma^\mu e_r)$
$Q_{\varphi\widetilde{W}}$	$\varphi^\dagger\varphi\,\widetilde{W}^I_{\mu\nu}W^{I\mu\nu}$	Q_{uW}	$(\bar{q}_p\sigma^{\mu\nu}u_r)\tau^I\widetilde{\varphi}\,W^I_{\mu\nu}$	$Q^{(1)}_{\varphi q}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{q}_p\gamma^\mu q_r)$
$Q_{\varphi B}$	$\varphi^\dagger\varphi\, B_{\mu\nu}B^{\mu\nu}$	Q_{uB}	$(\bar{q}_p\sigma^{\mu\nu}u_r)\widetilde{\varphi}\,B_{\mu\nu}$	$Q^{(3)}_{\varphi q}$	$(\varphi^\dagger i\overleftrightarrow{D}^I_\mu\varphi)(\bar{q}_p\tau^I\gamma^\mu q_r)$
$Q_{\varphi\widetilde{B}}$	$\varphi^\dagger\varphi\,\widetilde{B}_{\mu\nu}B^{\mu\nu}$	Q_{dG}	$(\bar{q}_p\sigma^{\mu\nu}T^A d_r)\varphi\, G^A_{\mu\nu}$	$Q_{\varphi u}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{u}_p\gamma^\mu u_r)$
$Q_{\varphi WB}$	$\varphi^\dagger\tau^I\varphi\, W^I_{\mu\nu}B^{\mu\nu}$	Q_{dW}	$(\bar{q}_p\sigma^{\mu\nu}d_r)\tau^I\varphi\, W^I_{\mu\nu}$	$Q_{\varphi d}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{d}_p\gamma^\mu d_r)$
$Q_{\varphi\widetilde{W}B}$	$\varphi^\dagger\tau^I\varphi\,\widetilde{W}^I_{\mu\nu}B^{\mu\nu}$	Q_{dB}	$(\bar{q}_p\sigma^{\mu\nu}d_r)\varphi\, B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\widetilde{\varphi}^\dagger D_\mu\varphi)(\bar{u}_p\gamma^\mu d_r)$

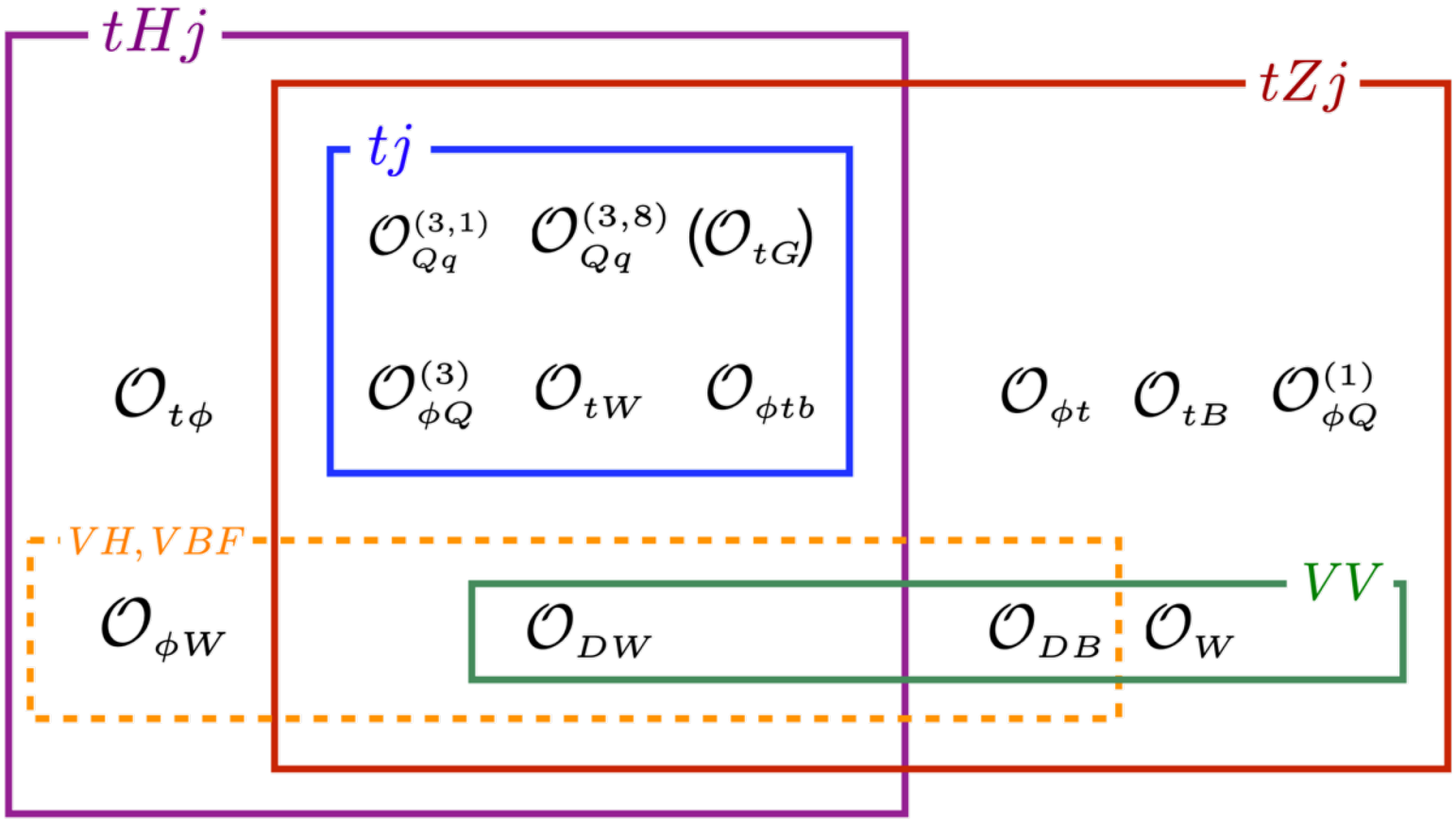
Table 2: Dimension-six operators other than the four-fermion ones.

$(\bar{L}L)(\bar{L}L)$		$(\bar{R}R)(\bar{R}R)$		$(\bar{L}L)(\bar{R}R)$	
Q_{ll}	$(\bar{l}_p\gamma_\mu l_r)(\bar{l}_s\gamma^\mu l_t)$	Q_{ee}	$(\bar{e}_p\gamma_\mu e_r)(\bar{e}_s\gamma^\mu e_t)$	Q_{le}	$(\bar{l}_p\gamma_\mu l_r)(\bar{e}_s\gamma^\mu e_t)$
$Q^{(1)}_{qq}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{q}_s\gamma^\mu q_t)$	Q_{uu}	$(\bar{u}_p\gamma_\mu u_r)(\bar{u}_s\gamma^\mu u_t)$	Q_{lu}	$(\bar{l}_p\gamma_\mu l_r)(\bar{u}_s\gamma^\mu u_t)$
$Q^{(3)}_{qq}$	$(\bar{q}_p\gamma_\mu\tau^I q_r)(\bar{q}_s\gamma^\mu\tau^I q_t)$	Q_{dd}	$(\bar{d}_p\gamma_\mu d_r)(\bar{d}_s\gamma^\mu d_t)$	Q_{ld}	$(\bar{l}_p\gamma_\mu l_r)(\bar{d}_s\gamma^\mu d_t)$
$Q^{(1)}_{lq}$	$(\bar{l}_p\gamma_\mu l_r)(\bar{q}_s\gamma^\mu q_t)$	Q_{eu}	$(\bar{e}_p\gamma_\mu e_r)(\bar{u}_s\gamma^\mu u_t)$	Q_{qe}	$(\bar{q}_p\gamma_\mu q_r)(\bar{e}_s\gamma^\mu e_t)$
$Q^{(3)}_{lq}$	$(\bar{l}_p\gamma_\mu\tau^I l_r)(\bar{q}_s\gamma^\mu\tau^I q_t)$	Q_{ed}	$(\bar{e}_p\gamma_\mu e_r)(\bar{d}_s\gamma^\mu d_t)$	$Q^{(1)}_{qu}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{u}_s\gamma^\mu u_t)$
		$Q^{(1)}_{ud}$	$(\bar{u}_p\gamma_\mu u_r)(\bar{d}_s\gamma^\mu d_t)$	$Q^{(8)}_{qu}$	$(\bar{q}_p\gamma_\mu T^A q_r)(\bar{u}_s\gamma^\mu T^A u_t)$
		$Q^{(8)}_{ud}$	$(\bar{u}_p\gamma_\mu T^A u_r)(\bar{d}_s\gamma^\mu T^A d_t)$	$Q^{(1)}_{qd}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{d}_s\gamma^\mu d_t)$
				$Q^{(8)}_{qd}$	$(\bar{q}_p\gamma_\mu T^A q_r)(\bar{d}_s\gamma^\mu T^A d_t)$

$(\bar{L}R)(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$		B-violating	
Q_{ledq}	$(\bar{l}^j_p e_r)(\bar{d}_s q^j_t)$	Q	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(d^\alpha_p)^T C u^\beta_r\right]\left[(q^{\gamma j}_s)^T C l^k_t\right]$
$Q^{(1)}_{quqd}$	$(\bar{q}^j_p u_r)\varepsilon_{jk}(\bar{q}^k_s d_t)$	Q_{qqu}	$[(q^{\alpha j}_r)^T C q^{\beta k}_s]$
$Q^{(8)}_{quqd}$	$(\bar{q}^j_p T^A u_r)\varepsilon_{jk}(\bar{q}^k_s T^A d_t)$	Q_{qqq}	$\varepsilon^{\alpha\beta\gamma}$ $(q^{\gamma m})^T C l^n_t]$
$Q^{(1)}_{lequ}$	$(\bar{l}^j_p e_r)\varepsilon_{jk}(\bar{q}^k_s u_t)$	Q	$[(d^\alpha_p)^T C u^\beta_r]$
$Q^{(3)}_{lequ}$	$(\bar{l}^j_p\sigma_{\mu\nu}e_r)\varepsilon_{jk}(\bar{q}^k_s\sigma^{\mu\nu}u_t)$		

Table 3: Four-fermion operators.

OPERATE ME THIS – THJ AND TZJ PRODUCTION



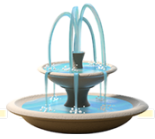
https://indico.cern.ch/event/727560/contributions/3019707/attachments/1672341/2683328/BEHEP_KM_20180621.pdf

OPERATE ME THIS – THJ AND TZJ PRODUCTION

top county

Higgs heights

Jets wilderness



EWK plaza

BUT IT'S NOT JUST POLES – TAILS ARE 💎

For H decays, or inclusive production, $\mu \sim O(v, m_H)$

$$\delta O \sim \left(\frac{v}{\Lambda}\right)^2 \sim 6\% \left(\frac{\mathrm{TeV}}{\Lambda}\right)^2$$

⇒ **precision** probes large Λ

e.g. $\delta O = 1\% \Rightarrow \Lambda \sim 2.5$ TeV

For H production off-shell or with large momentum transfer Q, $\mu \sim O(Q)$

$$\delta O_Q \sim \left(\frac{Q}{\Lambda}\right)^2$$

⇒ **kinematic reach** probes large Λ even if precision is low

e.g. $\delta O_Q = 15\%$ at $Q = 1$ TeV ⇒ $\Lambda \sim 2.5$ TeV

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BUT IT'S NOT JUST POLES – TAILS ARE 💎

decays, or inclusive production, μ~O(v,m_H)

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For H productio

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⇒ kinem

if precision is low

e.g. δO_Q =15% at Q=1 TeV ⇒ Λ~2.5 TeV

Just a Higgs example.

Applicable to **large-Q^2 processes** and **differential distributions.**