EFT example

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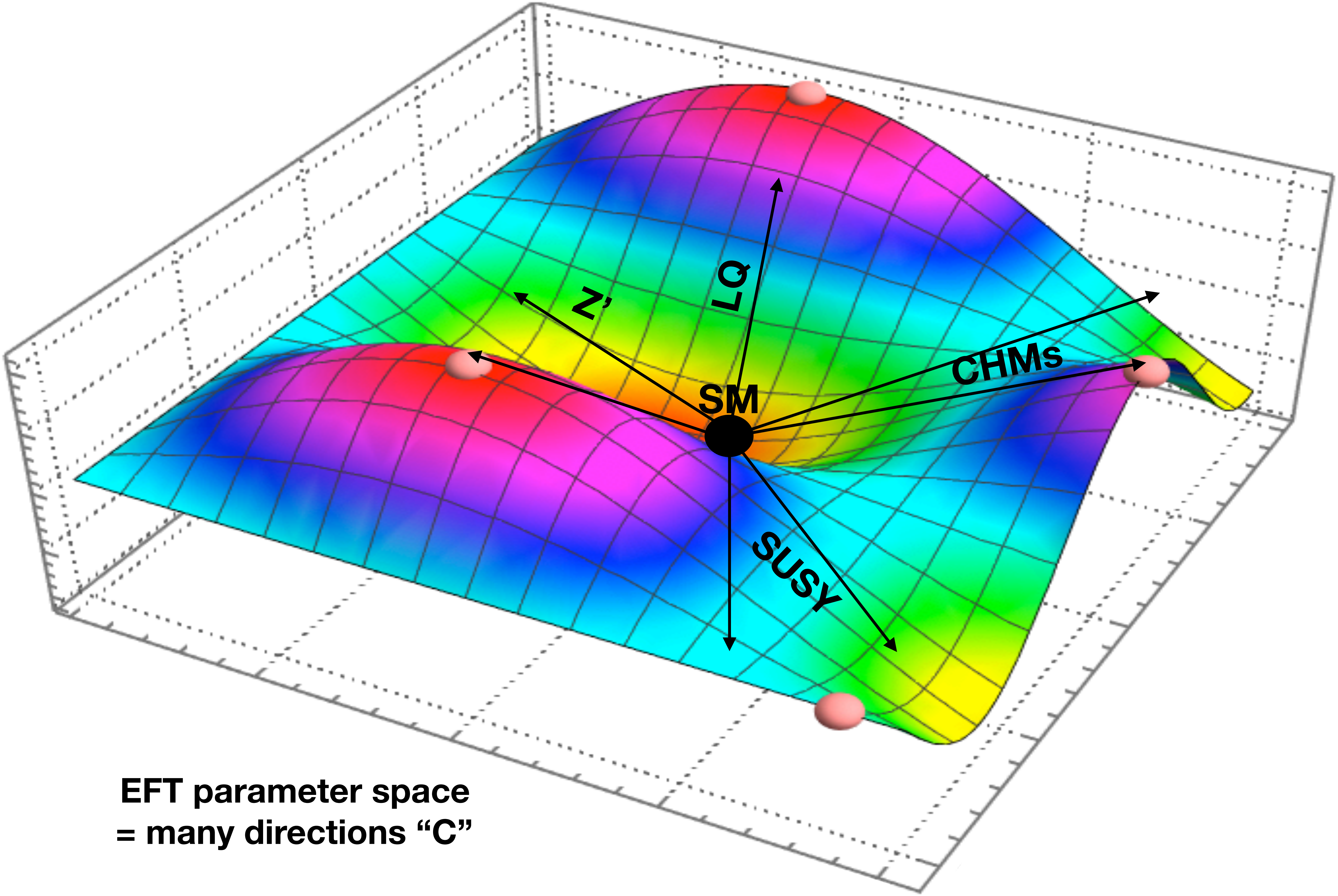
Publication of statistical models: hands-on workshop 2021

Global EFT analyses nowadays use
EWPT, LEP WW,
Higgs, Top, HTop, 2F, 4F from
Tevatron, LHC Run1 and Run2 inclusive and differential
and even flavour in some cases

So it's a game of matching hundreds of observables with a very large parameter space, and give a **consistent view** when all EFT directions are taken into account

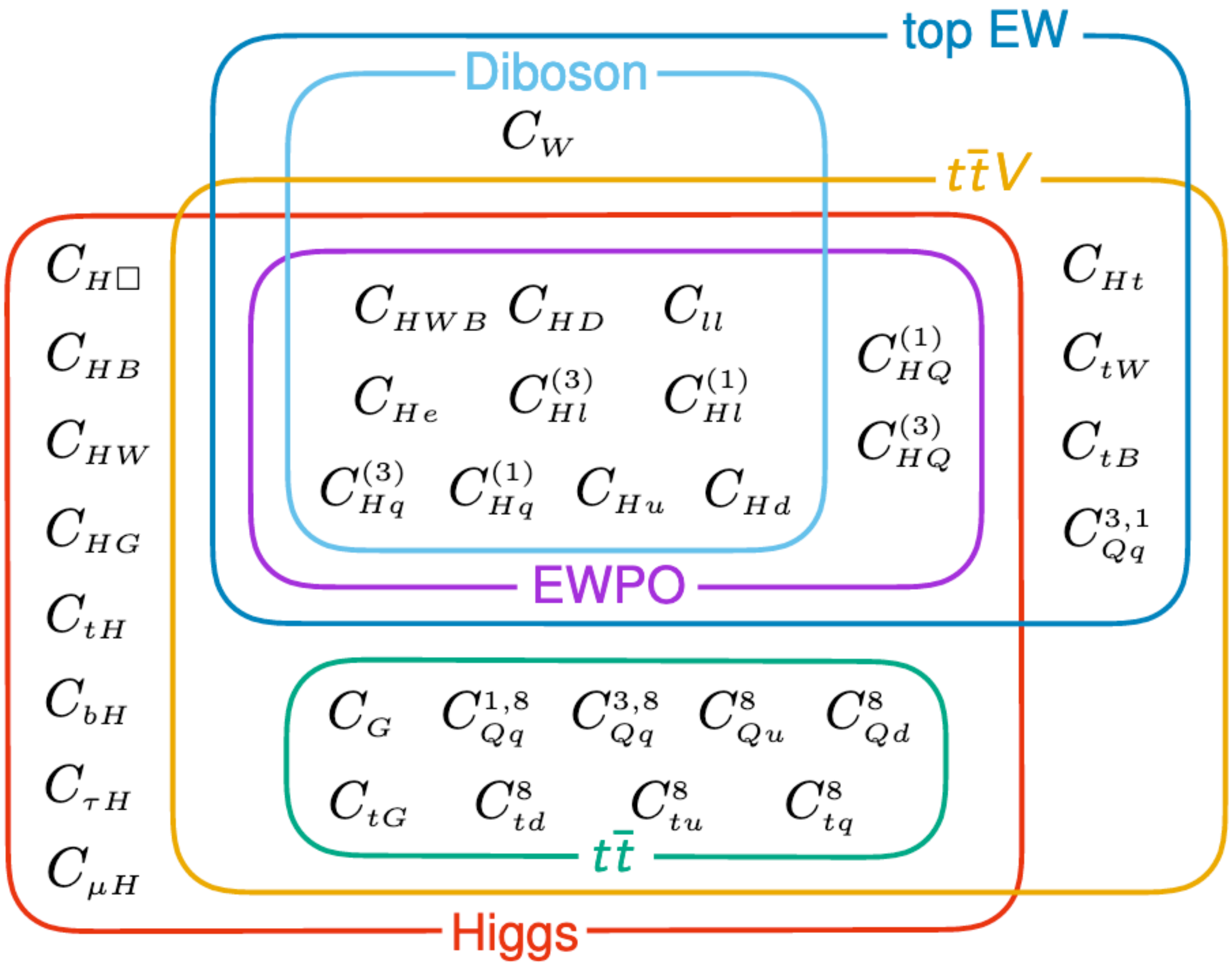
This is very tricky, theoretically and experimentally

EFT approach



EFT parameter space
= many directions "C"

Combination is important: each operator affects many observables beyond the LHC group separation



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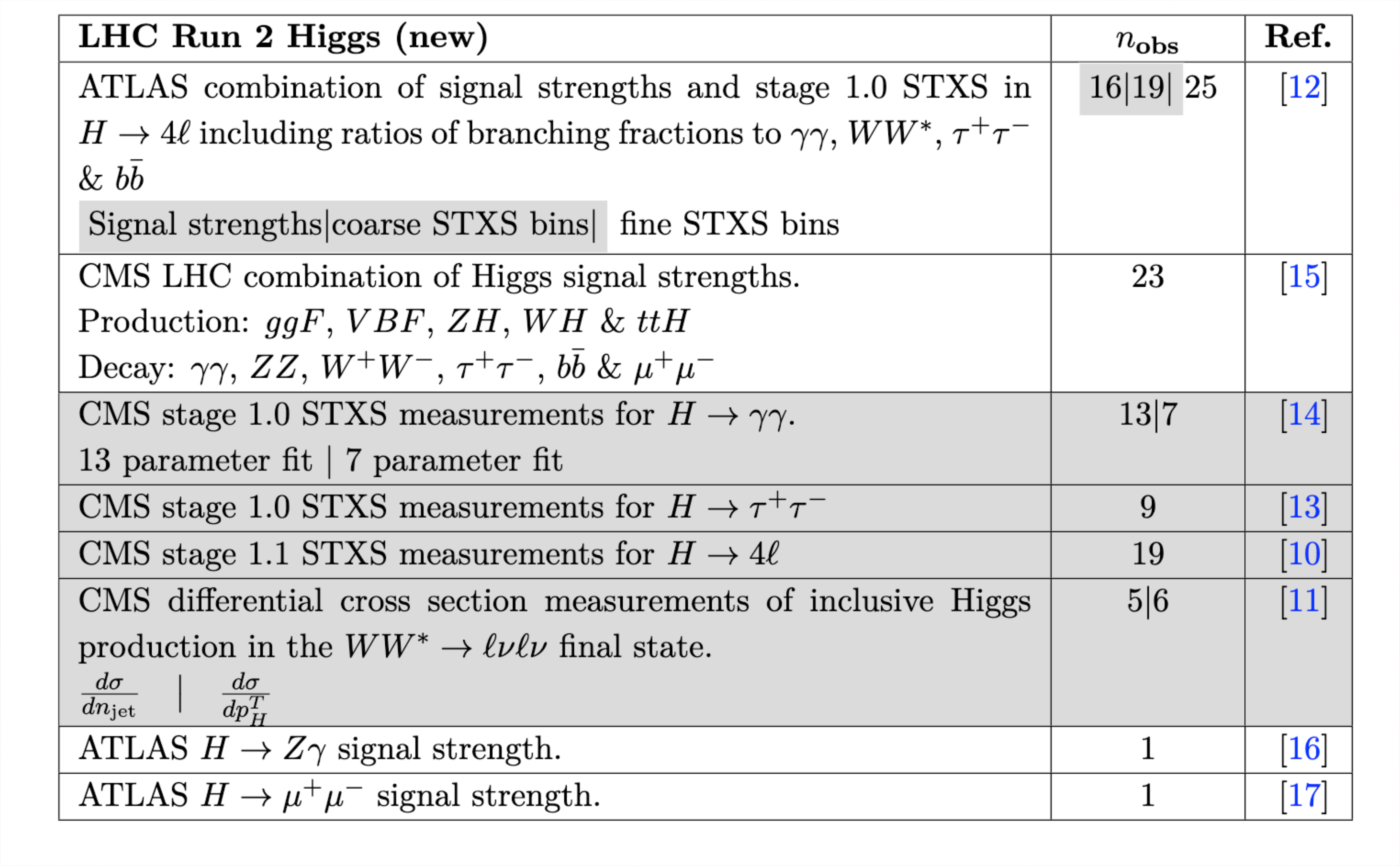
JHEP(21), 2012.02779

We have to choose which observables to use, to avoid **double-counting** Those choices are not straightforward/unique



LHC Run 2 Higgs (new)	n_{obs}	**Ref.**
ATLAS combination of signal strengths and stage 1.0 STXS in $H \to 4\ell$ including ratios of branching fractions to $\gamma\gamma$, WW^*, $\tau^+\tau^-$ & $b\bar{b}$ Signal strengths|coarse STXS bins| fine STXS bins	16|19| 25	[12]
CMS LHC combination of Higgs signal strengths. Production: ggF, VBF, ZH, WH & ttH Decay: $\gamma\gamma$, ZZ, W^+W^-, $\tau^+\tau^-$, $b\bar{b}$ & $\mu^+\mu^-$	23	[15]
CMS stage 1.0 STXS measurements for $H \to \gamma\gamma$. 13 parameter fit | 7 parameter fit	13|7	[14]
CMS stage 1.0 STXS measurements for $H \to \tau^+\tau^-$	9	[13]
CMS stage 1.1 STXS measurements for $H \to 4\ell$	19	[10]
CMS differential cross section measurements of inclusive Higgs production in the $WW^* \to \ell\nu\ell\nu$ final state. $\frac{d\sigma}{dn_{\text{jet}}}$ | $\frac{d\sigma}{dp_H^T}$	5|6	[11]
ATLAS $H \to Z\gamma$ signal strength.	1	[16]
ATLAS $H \to \mu^+\mu^-$ signal strength.	1	[17]

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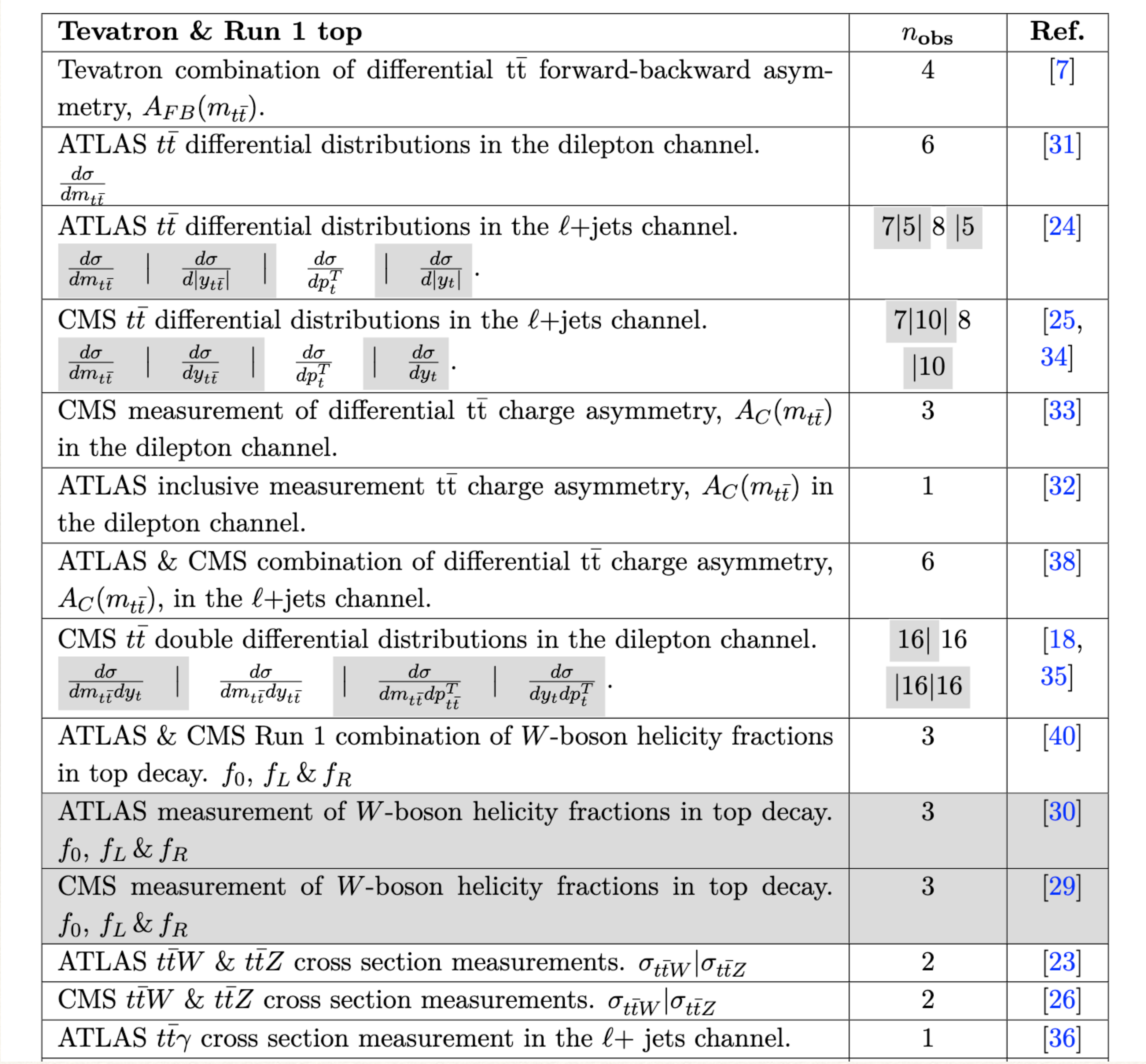
more on this…



Tevatron & Run 1 top	n_{obs}	**Ref.**
Tevatron combination of differential $t\bar{t}$ forward-backward asymmetry, $A_{FB}(m_{t\bar{t}})$.	4	[7]
ATLAS $t\bar{t}$ differential distributions in the dilepton channel. $\frac{d\sigma}{dm_{t\bar{t}}}$	6	[31]
ATLAS $t\bar{t}$ differential distributions in the ℓ+jets channel. $\frac{d\sigma}{dm_{t\bar{t}}} \mid \frac{d\sigma}{d\lvert y_{t\bar{t}}\rvert} \mid \frac{d\sigma}{dp_t^T} \mid \frac{d\sigma}{d\lvert y_t\rvert}$.	7|5| 8 |5	[24]
CMS $t\bar{t}$ differential distributions in the ℓ+jets channel. $\frac{d\sigma}{dm_{t\bar{t}}} \mid \frac{d\sigma}{dy_{t\bar{t}}} \mid \frac{d\sigma}{dp_t^T} \mid \frac{d\sigma}{dy_t}$.	7|10| 8 |10	[25, 34]
CMS measurement of differential $t\bar{t}$ charge asymmetry, $A_C(m_{t\bar{t}})$ in the dilepton channel.	3	[33]
ATLAS inclusive measurement $t\bar{t}$ charge asymmetry, $A_C(m_{t\bar{t}})$ in the dilepton channel.	1	[32]
ATLAS & CMS combination of differential $t\bar{t}$ charge asymmetry, $A_C(m_{t\bar{t}})$, in the ℓ+jets channel.	6	[38]
CMS $t\bar{t}$ double differential distributions in the dilepton channel. $\frac{d\sigma}{dm_{t\bar{t}}dy_t} \mid \frac{d\sigma}{dm_{t\bar{t}}dy_{t\bar{t}}} \mid \frac{d\sigma}{dm_{t\bar{t}}dp^T_{t\bar{t}}} \mid \frac{d\sigma}{dy_t dp^T_t}$.	16| 16 |16|16	[18, 35]
ATLAS & CMS Run 1 combination of W-boson helicity fractions in top decay. f_0, f_L & f_R	3	[40]
ATLAS measurement of W-boson helicity fractions in top decay. f_0, f_L & f_R	3	[30]
CMS measurement of W-boson helicity fractions in top decay. f_0, f_L & f_R	3	[29]
ATLAS $t\bar{t}W$ & $t\bar{t}Z$ cross section measurements. $\sigma_{t\bar{t}W} \mid \sigma_{t\bar{t}Z}$	2	[23]
CMS $t\bar{t}W$ & $t\bar{t}Z$ cross section measurements. $\sigma_{t\bar{t}W} \mid \sigma_{t\bar{t}Z}$	2	[26]
ATLAS $t\bar{t}\gamma$ cross section measurement in the ℓ+ jets channel.	1	[36]

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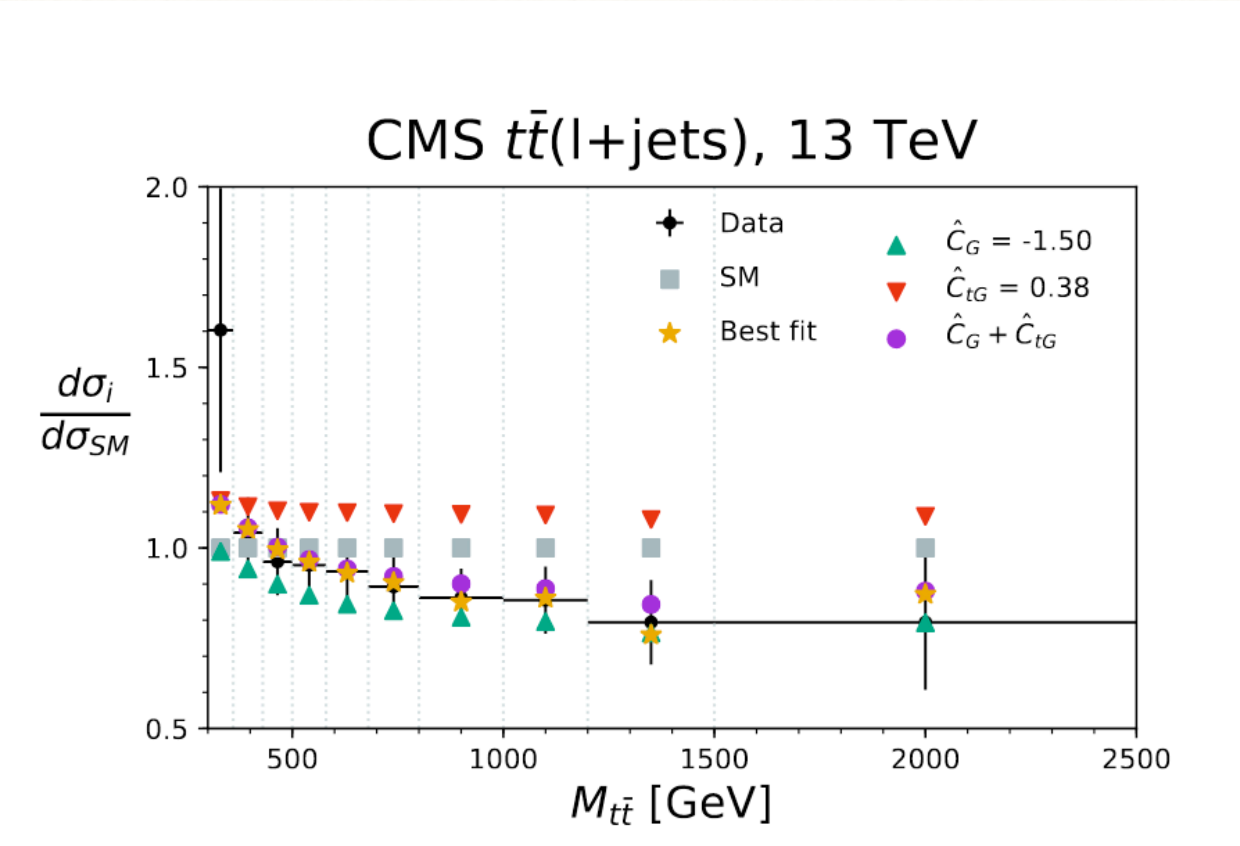


Note that:

We can only use observables whose dependence on the EFT coefficients we can **simulate** and fit eg, mtt(C's) for the experimental bins

When considering many observables at once:

With a fixed set of cuts we can compute how the EFT coefficients correlate among different observables but lack information on how all these measurements correlate, even within each experiment (lumi, pdfs, jet resolution, …)

More comments:

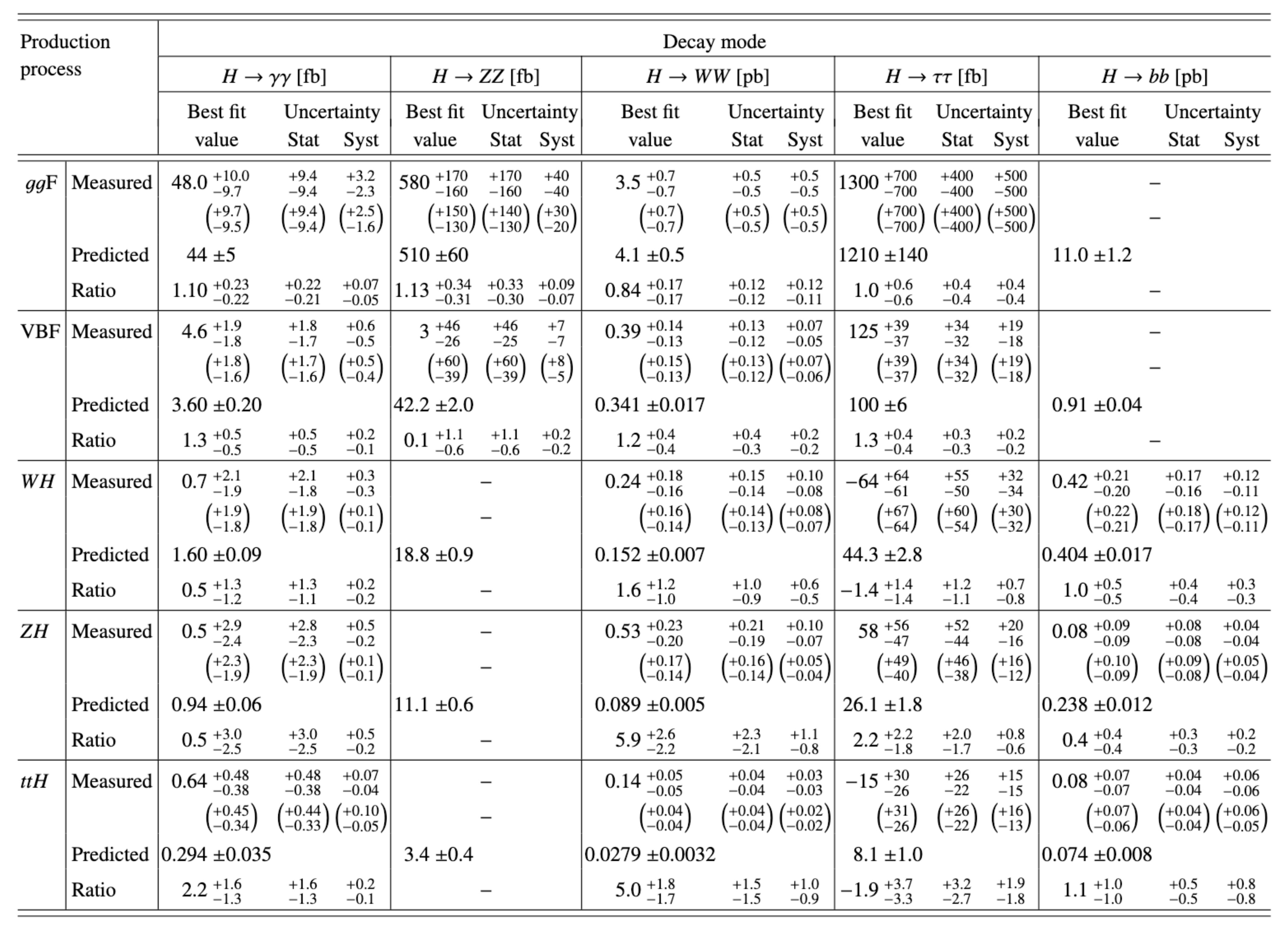
Signal and **backgrounds** can both be affected by EFT effects,
and background composition changes
within the differential distribution
whereas typical analyses assume BSM affects signal only

It is clear that with more information we would be able to
push further these studies
aim is to find a **robust deviation**
which may not have a clear equivalent in one distribution/
individual channel which could explain it
so we need to make sure each element in the fit is at its best

Sample case:

For the white paper, we did a simple exercise just Higgs, compare single vs combined experimental results

COMBINATION



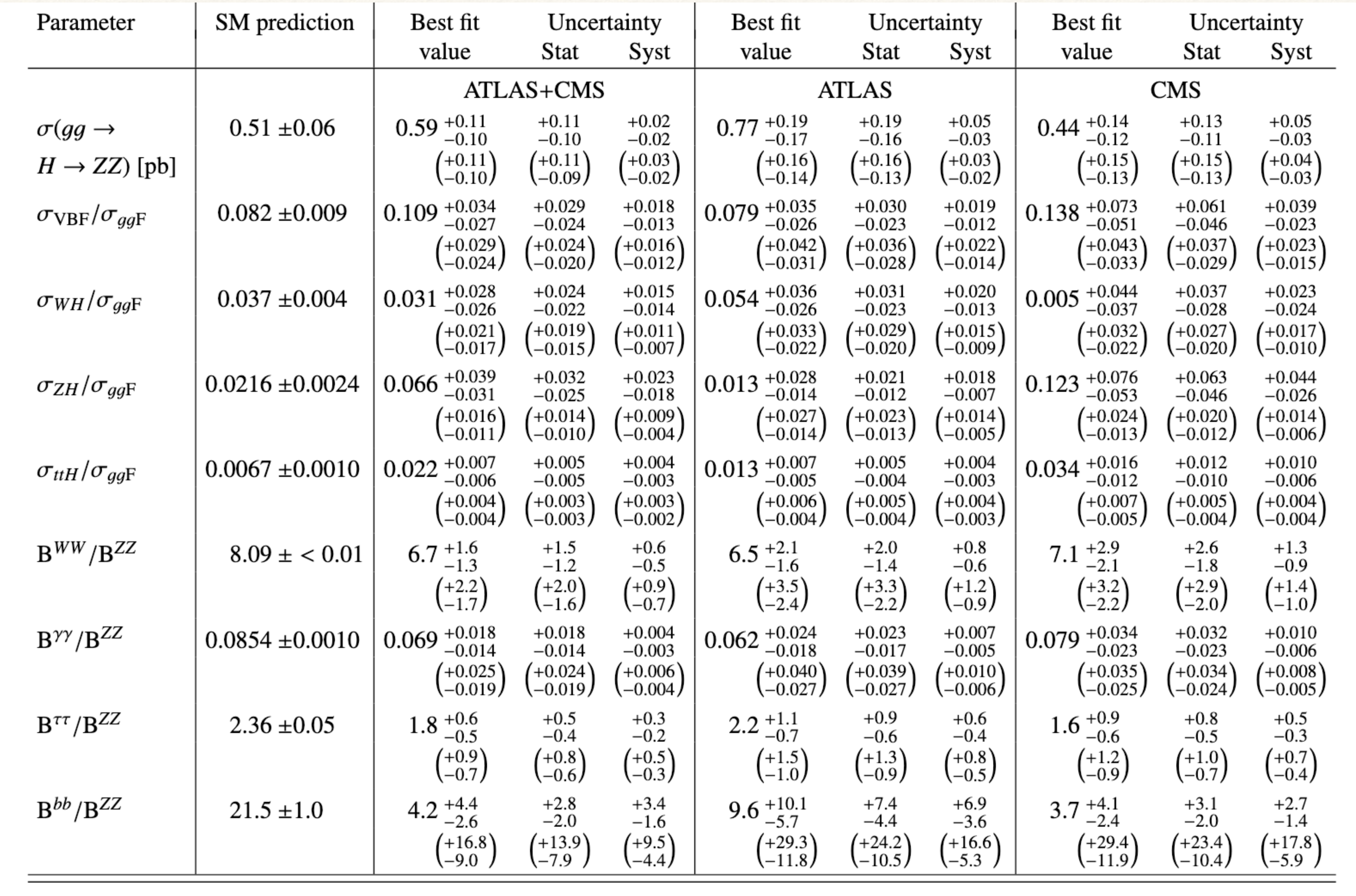
Production process		Decay mode														
		$H \to \gamma\gamma$ [fb]			$H \to ZZ$ [fb]			$H \to WW$ [pb]			$H \to \tau\tau$ [fb]			$H \to bb$ [pb]		
		Best fit value	Uncertainty Stat	Syst	Best fit value	Uncertainty Stat	Syst	Best fit value	Uncertainty Stat	Syst	Best fit value	Uncertainty Stat	Syst	Best fit value	Uncertainty Stat	Syst
ggF	Measured	$48.0^{+10.0}_{-9.7}$	$^{+9.4}_{-9.4}$	$^{+3.2}_{-2.3}$	580^{+170}_{-160}	$^{+170}_{-160}$	$^{+40}_{-40}$	$3.5^{+0.7}_{-0.7}$	$^{+0.5}_{-0.5}$	$^{+0.5}_{-0.5}$	1300^{+700}_{-700}	$^{+400}_{-400}$	$^{+500}_{-500}$	–		
		$\binom{+9.7}{-9.5}$	$\binom{+9.4}{-9.4}$	$\binom{+2.5}{-1.6}$	$\binom{+150}{-130}$	$\binom{+140}{-130}$	$\binom{+30}{-20}$	$\binom{+0.7}{-0.7}$	$\binom{+0.5}{-0.5}$	$\binom{+0.5}{-0.5}$	$\binom{+700}{-700}$	$\binom{+400}{-400}$	$\binom{+500}{-500}$	–		
	Predicted	44 ±5			510 ±60			4.1 ±0.5			1210 ±140			11.0 ±1.2		
	Ratio	$1.10^{+0.23}_{-0.22}$	$^{+0.22}_{-0.21}$	$^{+0.07}_{-0.05}$	$1.13^{+0.34}_{-0.31}$	$^{+0.33}_{-0.30}$	$^{+0.09}_{-0.07}$	$0.84^{+0.17}_{-0.17}$	$^{+0.12}_{-0.12}$	$^{+0.12}_{-0.11}$	$1.0^{+0.6}_{-0.6}$	$^{+0.4}_{-0.4}$	$^{+0.4}_{-0.4}$	–		
VBF	Measured	$4.6^{+1.9}_{-1.8}$	$^{+1.8}_{-1.7}$	$^{+0.6}_{-0.5}$	3^{+46}_{-26}	$^{+46}_{-25}$	$^{+7}_{-7}$	$0.39^{+0.14}_{-0.13}$	$^{+0.13}_{-0.12}$	$^{+0.07}_{-0.05}$	125^{+39}_{-37}	$^{+34}_{-32}$	$^{+19}_{-18}$	–		
		$\binom{+1.8}{-1.6}$	$\binom{+1.7}{-1.6}$	$\binom{+0.5}{-0.4}$	$\binom{+60}{-39}$	$\binom{+60}{-39}$	$\binom{+8}{-5}$	$\binom{+0.15}{-0.13}$	$\binom{+0.13}{-0.12}$	$\binom{+0.07}{-0.06}$	$\binom{+39}{-37}$	$\binom{+34}{-32}$	$\binom{+19}{-18}$	–		
	Predicted	3.60 ±0.20			42.2 ±2.0			0.341 ±0.017			100 ±6			0.91 ±0.04		
	Ratio	$1.3^{+0.5}_{-0.5}$	$^{+0.5}_{-0.5}$	$^{+0.2}_{-0.1}$	$0.1^{+1.1}_{-0.6}$	$^{+1.1}_{-0.6}$	$^{+0.2}_{-0.2}$	$1.2^{+0.4}_{-0.4}$	$^{+0.4}_{-0.3}$	$^{+0.2}_{-0.2}$	$1.3^{+0.4}_{-0.4}$	$^{+0.3}_{-0.3}$	$^{+0.2}_{-0.2}$	–		
WH	Measured	$0.7^{+2.1}_{-1.9}$	$^{+2.1}_{-1.8}$	$^{+0.3}_{-0.3}$	–			$0.24^{+0.18}_{-0.16}$	$^{+0.15}_{-0.14}$	$^{+0.10}_{-0.08}$	-64^{+64}_{-61}	$^{+55}_{-50}$	$^{+32}_{-34}$	$0.42^{+0.21}_{-0.20}$	$^{+0.17}_{-0.16}$	$^{+0.12}_{-0.11}$
		$\binom{+1.9}{-1.8}$	$\binom{+1.9}{-1.8}$	$\binom{+0.1}{-0.1}$	–			$\binom{+0.16}{-0.14}$	$\binom{+0.14}{-0.13}$	$\binom{+0.08}{-0.07}$	$\binom{+67}{-64}$	$\binom{+60}{-54}$	$\binom{+30}{-32}$	$\binom{+0.22}{-0.21}$	$\binom{+0.18}{-0.17}$	$\binom{+0.12}{-0.11}$
	Predicted	1.60 ±0.09			18.8 ±0.9			0.152 ±0.007			44.3 ±2.8			0.404 ±0.017		
	Ratio	$0.5^{+1.3}_{-1.2}$	$^{+1.3}_{-1.1}$	$^{+0.2}_{-0.2}$	–			$1.6^{+1.2}_{-1.0}$	$^{+1.0}_{-0.9}$	$^{+0.6}_{-0.5}$	$-1.4^{+1.4}_{-1.4}$	$^{+1.2}_{-1.1}$	$^{+0.7}_{-0.8}$	$1.0^{+0.5}_{-0.5}$	$^{+0.4}_{-0.4}$	$^{+0.3}_{-0.3}$
ZH	Measured	$0.5^{+2.9}_{-2.4}$	$^{+2.8}_{-2.3}$	$^{+0.5}_{-0.2}$	–			$0.53^{+0.23}_{-0.20}$	$^{+0.21}_{-0.19}$	$^{+0.10}_{-0.07}$	58^{+56}_{-47}	$^{+52}_{-44}$	$^{+20}_{-16}$	$0.08^{+0.09}_{-0.09}$	$^{+0.08}_{-0.08}$	$^{+0.04}_{-0.04}$
		$\binom{+2.3}{-1.9}$	$\binom{+2.3}{-1.9}$	$\binom{+0.1}{-0.1}$	–			$\binom{+0.17}{-0.14}$	$\binom{+0.16}{-0.14}$	$\binom{+0.05}{-0.04}$	$\binom{+49}{-40}$	$\binom{+46}{-38}$	$\binom{+16}{-12}$	$\binom{+0.10}{-0.09}$	$\binom{+0.09}{-0.08}$	$\binom{+0.05}{-0.04}$
	Predicted	0.94 ±0.06			11.1 ±0.6			0.089 ±0.005			26.1 ±1.8			0.238 ±0.012		
	Ratio	$0.5^{+3.0}_{-2.5}$	$^{+3.0}_{-2.5}$	$^{+0.5}_{-0.2}$	–			$5.9^{+2.6}_{-2.2}$	$^{+2.3}_{-2.1}$	$^{+1.1}_{-0.8}$	$2.2^{+2.2}_{-1.8}$	$^{+2.0}_{-1.7}$	$^{+0.8}_{-0.6}$	$0.4^{+0.4}_{-0.4}$	$^{+0.3}_{-0.3}$	$^{+0.2}_{-0.2}$
ttH	Measured	$0.64^{+0.48}_{-0.38}$	$^{+0.48}_{-0.38}$	$^{+0.07}_{-0.04}$	–			$0.14^{+0.05}_{-0.05}$	$^{+0.04}_{-0.04}$	$^{+0.03}_{-0.03}$	-15^{+30}_{-26}	$^{+26}_{-22}$	$^{+15}_{-15}$	$0.08^{+0.07}_{-0.07}$	$^{+0.04}_{-0.04}$	$^{+0.06}_{-0.06}$
		$\binom{+0.45}{-0.34}$	$\binom{+0.44}{-0.33}$	$\binom{+0.10}{-0.05}$	–			$\binom{+0.04}{-0.04}$	$\binom{+0.04}{-0.04}$	$\binom{+0.02}{-0.02}$	$\binom{+31}{-26}$	$\binom{+26}{-22}$	$\binom{+16}{-13}$	$\binom{+0.07}{-0.06}$	$\binom{+0.04}{-0.04}$	$\binom{+0.06}{-0.05}$
	Predicted	0.294 ±0.035			3.4 ±0.4			0.0279 ±0.0032			8.1 ±1.0			0.074 ±0.008		
	Ratio	$2.2^{+1.6}_{-1.3}$	$^{+1.6}_{-1.3}$	$^{+0.2}_{-0.1}$	–			$5.0^{+1.8}_{-1.7}$	$^{+1.5}_{-1.5}$	$^{+1.0}_{-0.9}$	$-1.9^{+3.7}_{-3.3}$	$^{+3.2}_{-2.7}$	$^{+1.9}_{-1.8}$	$1.1^{+1.0}_{-1.0}$	$^{+0.5}_{-0.5}$	$^{+0.8}_{-0.8}$

Table 8 in 1606.02266

Sample case:

For the white paper, we did a simple exercise just Higgs, compare single vs combined experimental results

INDIVIDUAL



Parameter	SM prediction	Best fit value	Uncertainty Stat	Syst	Best fit value	Uncertainty Stat	Syst	Best fit value	Uncertainty Stat	Syst
		ATLAS+CMS			ATLAS			CMS		
$\sigma(gg \to H \to ZZ)$ [pb]	0.51 ±0.06	$0.59^{+0.11}_{-0.10}$ $\binom{+0.11}{-0.10}$	$^{+0.11}_{-0.10}$ $\binom{+0.11}{-0.09}$	$^{+0.02}_{-0.02}$ $\binom{+0.03}{-0.02}$	$0.77^{+0.19}_{-0.17}$ $\binom{+0.16}{-0.14}$	$^{+0.19}_{-0.16}$ $\binom{+0.16}{-0.13}$	$^{+0.05}_{-0.03}$ $\binom{+0.03}{-0.02}$	$0.44^{+0.14}_{-0.12}$ $\binom{+0.15}{-0.13}$	$^{+0.13}_{-0.11}$ $\binom{+0.15}{-0.13}$	$^{+0.05}_{-0.03}$ $\binom{+0.04}{-0.03}$
$\sigma_{\mathrm{VBF}}/\sigma_{ggF}$	0.082 ±0.009	$0.109^{+0.034}_{-0.027}$ $\binom{+0.029}{-0.024}$	$^{+0.029}_{-0.024}$ $\binom{+0.024}{-0.020}$	$^{+0.018}_{-0.013}$ $\binom{+0.016}{-0.012}$	$0.079^{+0.035}_{-0.026}$ $\binom{+0.042}{-0.031}$	$^{+0.030}_{-0.023}$ $\binom{+0.036}{-0.028}$	$^{+0.019}_{-0.012}$ $\binom{+0.022}{-0.014}$	$0.138^{+0.073}_{-0.051}$ $\binom{+0.043}{-0.033}$	$^{+0.061}_{-0.046}$ $\binom{+0.037}{-0.029}$	$^{+0.039}_{-0.023}$ $\binom{+0.023}{-0.015}$
σ_{WH}/σ_{ggF}	0.037 ±0.004	$0.031^{+0.028}_{-0.026}$ $\binom{+0.021}{-0.017}$	$^{+0.024}_{-0.022}$ $\binom{+0.019}{-0.015}$	$^{+0.015}_{-0.014}$ $\binom{+0.011}{-0.007}$	$0.054^{+0.036}_{-0.026}$ $\binom{+0.033}{-0.022}$	$^{+0.031}_{-0.023}$ $\binom{+0.029}{-0.020}$	$^{+0.020}_{-0.013}$ $\binom{+0.015}{-0.009}$	$0.005^{+0.044}_{-0.037}$ $\binom{+0.032}{-0.022}$	$^{+0.037}_{-0.028}$ $\binom{+0.027}{-0.020}$	$^{+0.023}_{-0.024}$ $\binom{+0.017}{-0.010}$
σ_{ZH}/σ_{ggF}	0.0216 ±0.0024	$0.066^{+0.039}_{-0.031}$ $\binom{+0.016}{-0.011}$	$^{+0.032}_{-0.025}$ $\binom{+0.014}{-0.010}$	$^{+0.023}_{-0.018}$ $\binom{+0.009}{-0.004}$	$0.013^{+0.028}_{-0.014}$ $\binom{+0.027}{-0.014}$	$^{+0.021}_{-0.012}$ $\binom{+0.023}{-0.013}$	$^{+0.018}_{-0.007}$ $\binom{+0.014}{-0.005}$	$0.123^{+0.076}_{-0.053}$ $\binom{+0.024}{-0.013}$	$^{+0.063}_{-0.046}$ $\binom{+0.020}{-0.012}$	$^{+0.044}_{-0.026}$ $\binom{+0.014}{-0.006}$
$\sigma_{ttH}/\sigma_{ggF}$	0.0067 ±0.0010	$0.022^{+0.007}_{-0.006}$ $\binom{+0.004}{-0.004}$	$^{+0.005}_{-0.005}$ $\binom{+0.003}{-0.003}$	$^{+0.004}_{-0.003}$ $\binom{+0.003}{-0.002}$	$0.013^{+0.007}_{-0.005}$ $\binom{+0.006}{-0.004}$	$^{+0.005}_{-0.004}$ $\binom{+0.005}{-0.004}$	$^{+0.004}_{-0.003}$ $\binom{+0.004}{-0.003}$	$0.034^{+0.016}_{-0.012}$ $\binom{+0.007}{-0.005}$	$^{+0.012}_{-0.010}$ $\binom{+0.005}{-0.004}$	$^{+0.010}_{-0.006}$ $\binom{+0.004}{-0.004}$
$\mathrm{B}^{WW}/\mathrm{B}^{ZZ}$	8.09 ± < 0.01	$6.7^{+1.6}_{-1.3}$ $\binom{+2.2}{-1.7}$	$^{+1.5}_{-1.2}$ $\binom{+2.0}{-1.6}$	$^{+0.6}_{-0.5}$ $\binom{+0.9}{-0.7}$	$6.5^{+2.1}_{-1.6}$ $\binom{+3.5}{-2.4}$	$^{+2.0}_{-1.4}$ $\binom{+3.3}{-2.2}$	$^{+0.8}_{-0.6}$ $\binom{+1.2}{-0.9}$	$7.1^{+2.9}_{-2.1}$ $\binom{+3.2}{-2.2}$	$^{+2.6}_{-1.8}$ $\binom{+2.9}{-2.0}$	$^{+1.3}_{-0.9}$ $\binom{+1.4}{-1.0}$
$\mathrm{B}^{\gamma\gamma}/\mathrm{B}^{ZZ}$	0.0854 ±0.0010	$0.069^{+0.018}_{-0.014}$ $\binom{+0.025}{-0.019}$	$^{+0.018}_{-0.014}$ $\binom{+0.024}{-0.019}$	$^{+0.004}_{-0.003}$ $\binom{+0.006}{-0.004}$	$0.062^{+0.024}_{-0.018}$ $\binom{+0.040}{-0.027}$	$^{+0.023}_{-0.017}$ $\binom{+0.039}{-0.027}$	$^{+0.007}_{-0.005}$ $\binom{+0.010}{-0.006}$	$0.079^{+0.034}_{-0.023}$ $\binom{+0.035}{-0.025}$	$^{+0.032}_{-0.023}$ $\binom{+0.034}{-0.024}$	$^{+0.010}_{-0.006}$ $\binom{+0.008}{-0.005}$
$\mathrm{B}^{\tau\tau}/\mathrm{B}^{ZZ}$	2.36 ±0.05	$1.8^{+0.6}_{-0.5}$ $\binom{+0.9}{-0.7}$	$^{+0.5}_{-0.4}$ $\binom{+0.8}{-0.6}$	$^{+0.3}_{-0.2}$ $\binom{+0.5}{-0.3}$	$2.2^{+1.1}_{-0.7}$ $\binom{+1.5}{-1.0}$	$^{+0.9}_{-0.6}$ $\binom{+1.3}{-0.9}$	$^{+0.6}_{-0.4}$ $\binom{+0.8}{-0.5}$	$1.6^{+0.9}_{-0.6}$ $\binom{+1.2}{-0.9}$	$^{+0.8}_{-0.5}$ $\binom{+1.0}{-0.7}$	$^{+0.5}_{-0.3}$ $\binom{+0.7}{-0.4}$
$\mathrm{B}^{bb}/\mathrm{B}^{ZZ}$	21.5 ±1.0	$4.2^{+4.4}_{-2.6}$ $\binom{+16.8}{-9.0}$	$^{+2.8}_{-2.0}$ $\binom{+13.9}{-7.9}$	$^{+3.4}_{-1.6}$ $\binom{+9.5}{-4.4}$	$9.6^{+10.1}_{-5.7}$ $\binom{+29.3}{-11.8}$	$^{+7.4}_{-4.4}$ $\binom{+24.2}{-10.5}$	$^{+6.9}_{-3.6}$ $\binom{+16.6}{-5.3}$	$3.7^{+4.1}_{-2.4}$ $\binom{+29.4}{-11.9}$	$^{+3.1}_{-2.0}$ $\binom{+23.4}{-10.4}$	$^{+2.7}_{-1.4}$ $\binom{+17.8}{-5.9}$

Table 9 in 1606.02266

The fit was done using **MultiNest** approach, ph/0809.3437

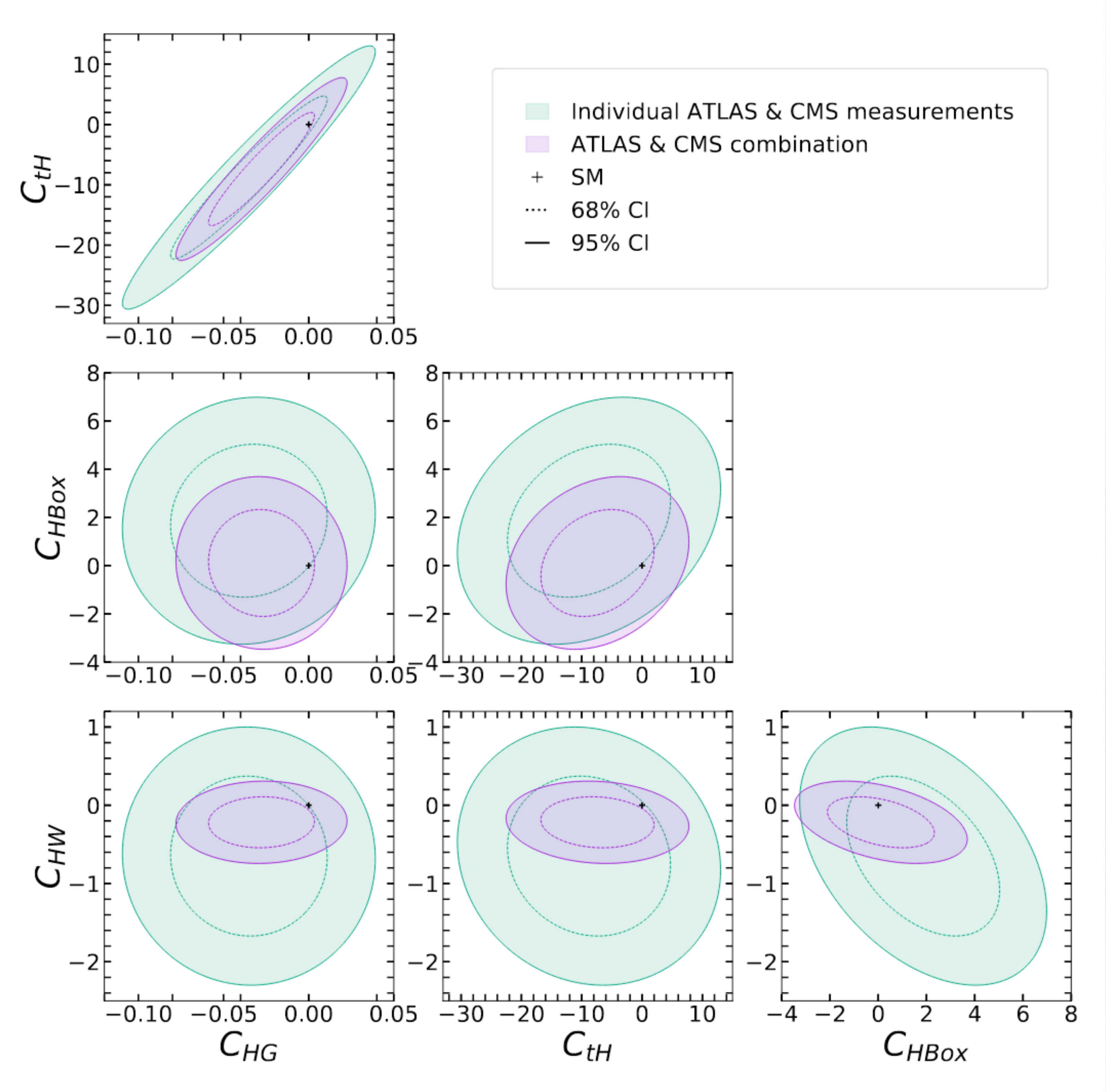
$$lnL(\hat{x};x) = -\frac{1}{2}\left(\frac{\hat{x}-x}{\sigma+\sigma'(x-\hat{x})}\right)^2$$

we did **not** symmetrise the errors, used a likelihood called 'Variable Gaussian' from Barlow's physics/0406120

Main differences in the datasets:

1. The combination by ATLAS and CMS takes into account correlations of systematic uncertainties etc - overall it should be a more *correct* combination as they have access to more statistical information.
2. The individual datasets each consist of 9 datapoints, presented in terms of cross sections and branching ratios. The combination is a table of 23 datapoints, all in the form of signal strengths. This recombination into more datapoints and a new parametrisation provides more constraining power on the EFT coefficients.

With all this in mind, this plot simply illustrates that with more information one can do a better job



nothing mind-blowing…