

EFT vs Top Down Approaches



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→ leads to actual **discoveries**

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Provocative Statement:

“Direct Search” → Top Down Approach

“Indirect Search” → Effective Field Theories (EFT)

Top Down Approach

ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits

Status: May 2019

ATLAS Preliminary

$\int \mathcal{L} dt = (3.2 - 139) \text{ fb}^{-1}$

$\sqrt{s} = 8, 13 \text{ TeV}$

Model	ℓ, γ	Jets [†]	E_T^{miss}	$\int \mathcal{L} dt [\text{fb}^{-1}]$	Limit	Reference	
Extra dimensions	ADD $G_{KK} + g/q$	$0 e, \mu$	$1-4 j$	Yes	36.1	M_D 7.7 TeV	$n = 2$
	ADD non-resonant $\gamma\gamma$	2γ	-	-	36.7	M_S 8.6 TeV	$n = 3$ HLZ NLO
	ADD QBH	-	$2 j$	-	37.0	M_{th} 8.9 TeV	$n = 6$
	ADD BH high $\sum p_T$	$\geq 1 e, \mu$	$\geq 2 j$	-	3.2	M_{th} 8.2 TeV	$n = 6, M_D = 3 \text{ TeV}$, rot BH
	ADD BH multijet	-	$\geq 3 j$	-	3.6	M_{th} 9.55 TeV	$n = 6, M_D = 3 \text{ TeV}$, rot BH
	RS1 $G_{KK} \rightarrow \gamma\gamma$	2γ	-	-	36.7	G_{KK} mass 4.1 TeV	$k/\overline{M}_{Pl} = 0.1$
	Bulk RS $G_{KK} \rightarrow WW/ZZ$	multi-channel	-	-	36.1	G_{KK} mass 2.3 TeV	$k/\overline{M}_{Pl} = 1.0$
	Bulk RS $G_{KK} \rightarrow WW \rightarrow qq\bar{q}\bar{q}$	$0 e, \mu$	$2 J$	-	139	G_{KK} mass 1.6 TeV	$k/\overline{M}_{Pl} = 1.0$
	Bulk RS $G_{KK} \rightarrow tt$	$1 e, \mu$	$\geq 1 b, \geq 1J/2j$	Yes	36.1	G_{KK} mass 3.8 TeV	$\Gamma/m = 15\%$
	2UED / RPP	$1 e, \mu$	$\geq 2 b, \geq 3 j$	Yes	36.1	KK mass 1.8 TeV	Tier (1,1), $\mathcal{B}(A^{(1,1)} \rightarrow tt) = 1$
Gauge bosons	SSM $Z' \rightarrow \ell\ell$	$2 e, \mu$	-	-	139	Z' mass 5.1 TeV	
	SSM $Z' \rightarrow \tau\tau$	2τ	-	-	36.1	Z' mass 2.42 TeV	
	Leptophobic $Z' \rightarrow bb$	-	$2 b$	-	36.1	Z' mass 2.1 TeV	
	Leptophobic $Z' \rightarrow tt$	$1 e, \mu$	$\geq 1 b, \geq 1J/2j$	Yes	36.1	Z' mass 3.0 TeV	$\Gamma/m = 1\%$
	SSM $W' \rightarrow \ell\nu$	$1 e, \mu$	-	Yes	139	W' mass 6.0 TeV	
	SSM $W' \rightarrow \tau\nu$	1τ	-	Yes	36.1	W' mass 3.7 TeV	
	HVT $V' \rightarrow WZ \rightarrow qq\bar{q}\bar{q}$ model B	$0 e, \mu$	$2 J$	-	139	V' mass 3.6 TeV	$g_V = 3$
	HVT $V' \rightarrow WH/ZH$ model B	multi-channel	-	-	36.1	V' mass 2.93 TeV	$g_V = 3$
	LRSM $W_R \rightarrow tb$	multi-channel	-	-	36.1	W_R mass 3.25 TeV	
	LRSM $W_R \rightarrow \mu N_R$	2μ	$1 J$	-	80	W_R mass 5.0 TeV	$m(N_R) = 0.5 \text{ TeV}, g_L = g_R$
CI	CI $qq\bar{q}\bar{q}$	-	$2 j$	-	37.0	Λ 21.8 TeV	η_{LL}^-
	CI $\ell\ell\bar{q}\bar{q}$	$2 e, \mu$	-	-	36.1	Λ 40.0 TeV	η_{LL}^-
	CI $tt\bar{t}\bar{t}$	$\geq 1 e, \mu$	$\geq 1 b, \geq 1 j$	Yes	36.1	Λ 2.57 TeV	$ C_{4t} = 4\pi$
DM	Axial-vector mediator (Dirac DM)	$0 e, \mu$	$1-4 j$	Yes	36.1	m_{med} 1.55 TeV	$g_q = 0.25, g_b = 1.0, m(\chi) = 1 \text{ GeV}$
	Colored scalar mediator (Dirac DM)	$0 e, \mu$	$1-4 j$	Yes	36.1	m_{med} 1.67 TeV	$g = 1.0, m(\chi) = 1 \text{ GeV}$
	VV $\chi\chi$ EFT (Dirac DM)	$0 e, \mu$	$1 J, \leq 1 j$	Yes	3.2	M_χ 700 GeV	$m(\chi) < 150 \text{ GeV}$
	Scalar reson. $\phi \rightarrow t\bar{t}$ (Dirac DM)	$0-1 e, \mu$	$1 b, 0-1 J$	Yes	36.1	m_ϕ 3.4 TeV	$y = 0.4, \lambda = 0.2, m(\chi) = 10 \text{ GeV}$
LQ	Scalar LQ 1 st gen	$1, 2 e$	$\geq 2 j$	Yes	36.1	LQ mass 1.4 TeV	$\beta = 1$
	Scalar LQ 2 nd gen	$1, 2 \mu$	$\geq 2 j$	Yes	36.1	LQ mass 1.56 TeV	$\beta = 1$
	Scalar LQ 3 rd gen	2τ	$2 b$	-	36.1	LQ_3^u mass 1.03 TeV	$\mathcal{B}(LQ_3^u \rightarrow b\tau) = 1$
	Scalar LQ 3 rd gen	$0-1 e, \mu$	$2 b$	Yes	36.1	LQ_3^d mass 970 GeV	$\mathcal{B}(LQ_3^d \rightarrow t\tau) = 0$
Heavy quarks	VLQ $TT \rightarrow Ht/Zt/Wb + X$	multi-channel	-	-	36.1	T mass 1.37 TeV	SU(2) doublet
	VLQ $BB \rightarrow Wt/Zb + X$	multi-channel	-	-	36.1	B mass 1.34 TeV	SU(2) doublet
	VLQ $T_{5/3} T_{5/3} T_{5/3} \rightarrow Wt + X$	$2(SS) \geq 3 e, \mu \geq 1 b, \geq 1 j$	Yes	36.1	$T_{5/3}$ mass 1.64 TeV	$\mathcal{B}(T_{5/3} \rightarrow Wt) = 1, c(T_{5/3} Wt) = 1$	
	VLQ $Y \rightarrow Wb + X$	$1 e, \mu \geq 1 b, \geq 1 j$	Yes	36.1	Y mass 1.85 TeV	$\mathcal{B}(Y \rightarrow Wb) = 1, c_Y(Wb) = 1$	
	VLQ $B \rightarrow Hb + X$	$0 e, \mu, 2 \gamma \geq 1 b, \geq 1 j$	Yes	79.8	B mass 1.21 TeV	$k_B = 0.5$	
	VLQ $QQ \rightarrow WqWq$	$1 e, \mu \geq 4 j$	Yes	20.3	Q mass 690 GeV		
Excited fermions	Excited quark $q^* \rightarrow qg$	-	$2 j$	-	139	q^* mass 6.7 TeV	only u^* and d^* , $\Lambda = m(q^*)$
	Excited quark $q^* \rightarrow q\gamma$	1γ	$1 j$	-	36.7	q^* mass 5.3 TeV	only u^* and d^* , $\Lambda = m(q^*)$
	Excited quark $b^* \rightarrow b\gamma$	-	$1 b, 1 j$	-	36.1	b^* mass 2.6 TeV	
	Excited lepton ℓ^*	$3 e, \mu$	-	-	20.3	ℓ^* mass 3.0 TeV	$\Lambda = 3.0 \text{ TeV}$
	Excited lepton ν^*	$3 e, \mu, \tau$	-	-	20.3	ν^* mass 1.6 TeV	$\Lambda = 1.6 \text{ TeV}$
Other	Type III Seesaw	$1 e, \mu$	$\geq 2 j$	Yes	79.8	N^0 mass 560 GeV	
	LRSM Majorana ν	2μ	$2 j$	-	36.1	N_R mass 3.2 TeV	$m(W_R) = 4.1 \text{ TeV}, g_L = g_R$
	Higgs triplet $H^{\pm\pm} \rightarrow \ell\ell$	$2, 3, 4 e, \mu$ (SS)	-	-	36.1	$H^{\pm\pm}$ mass 870 GeV	DY production
	Higgs triplet $H^{\pm\pm} \rightarrow \ell\tau$	$3 e, \mu, \tau$	-	-	20.3	$H^{\pm\pm}$ mass 400 GeV	DY production, $\mathcal{B}(H_L^{\pm\pm} \rightarrow \ell\tau) = 1$
	Multi-charged particles	-	-	-	36.1	multi-charged particle mass 1.22 TeV	DY production, $ q = 5e$
	Magnetic monopoles	-	-	-	34.4	monopole mass 2.37 TeV	DY production, $ g = 1g_D$, spin 1/2

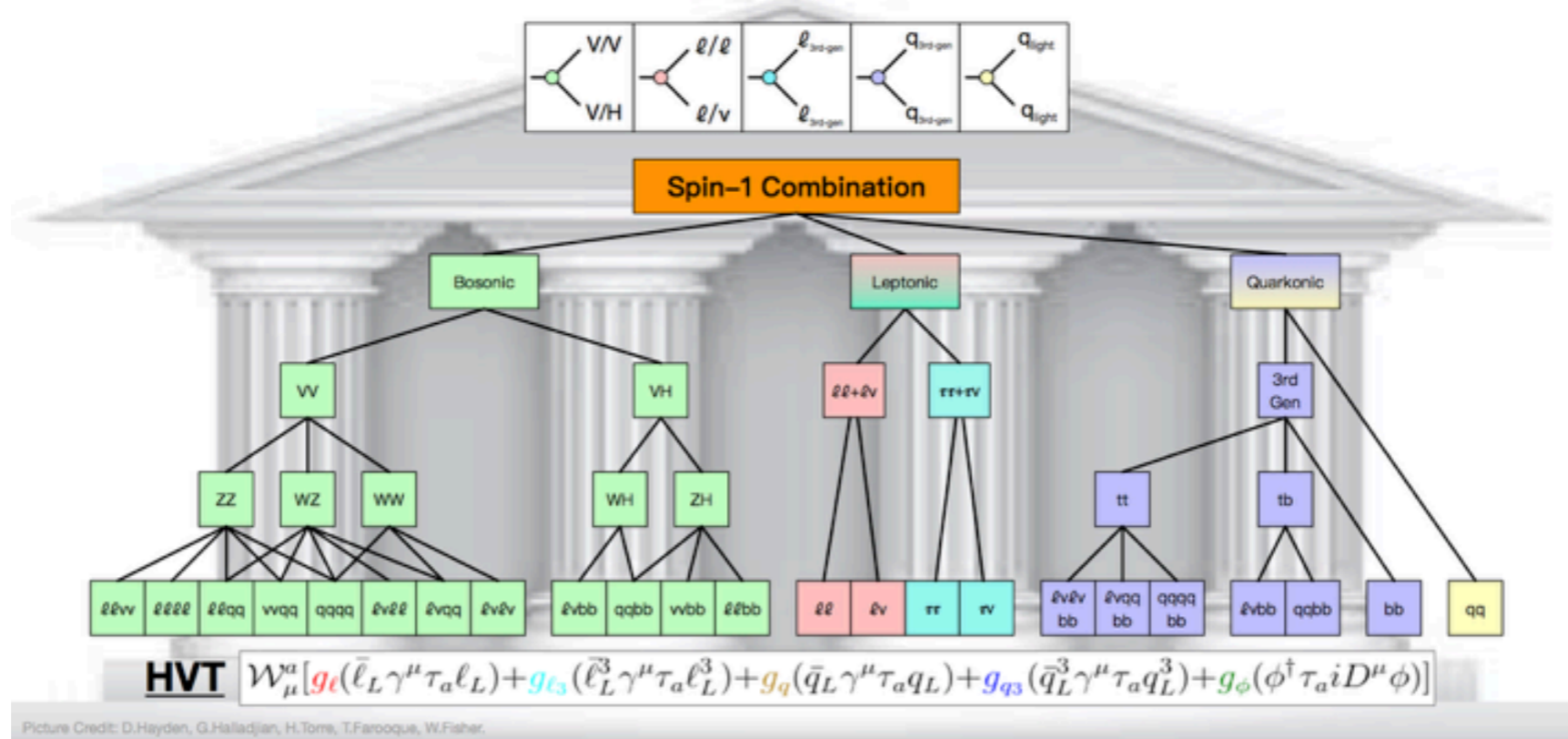
*Only a selection of the available mass limits on new states or phenomena is shown.

† Small-radius (large-radius) jets are denoted by the letter j (J).

- Key Idea: If new physics is directly observable at the LHC, should be seen as a resonance or broad excess/deficit.
- LHC experiments cover many different final states with dedicated searches for specific models.

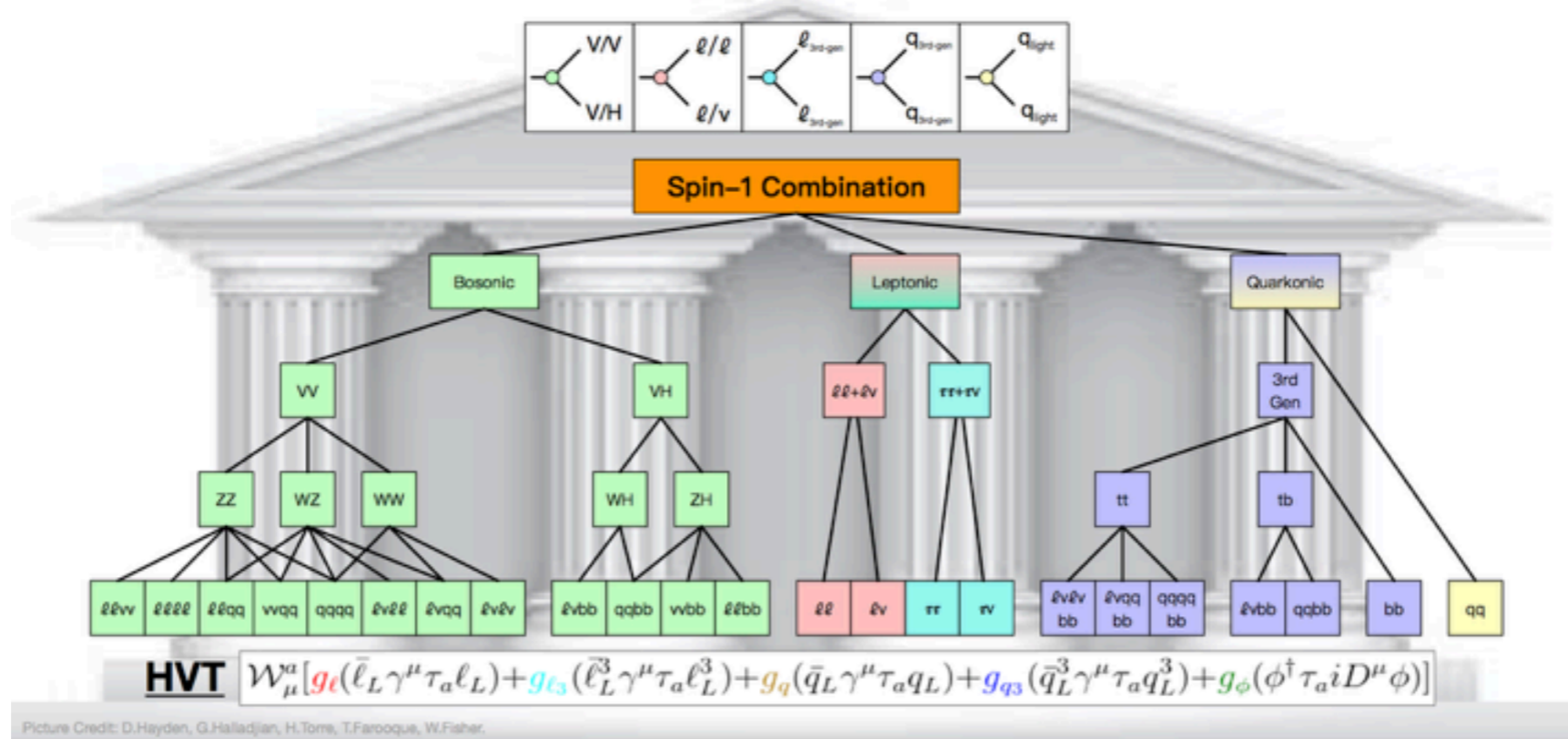
Top Down Approach

- Are efforts in both ATLAS and CMS to bring these separate searches together into a more general framework.



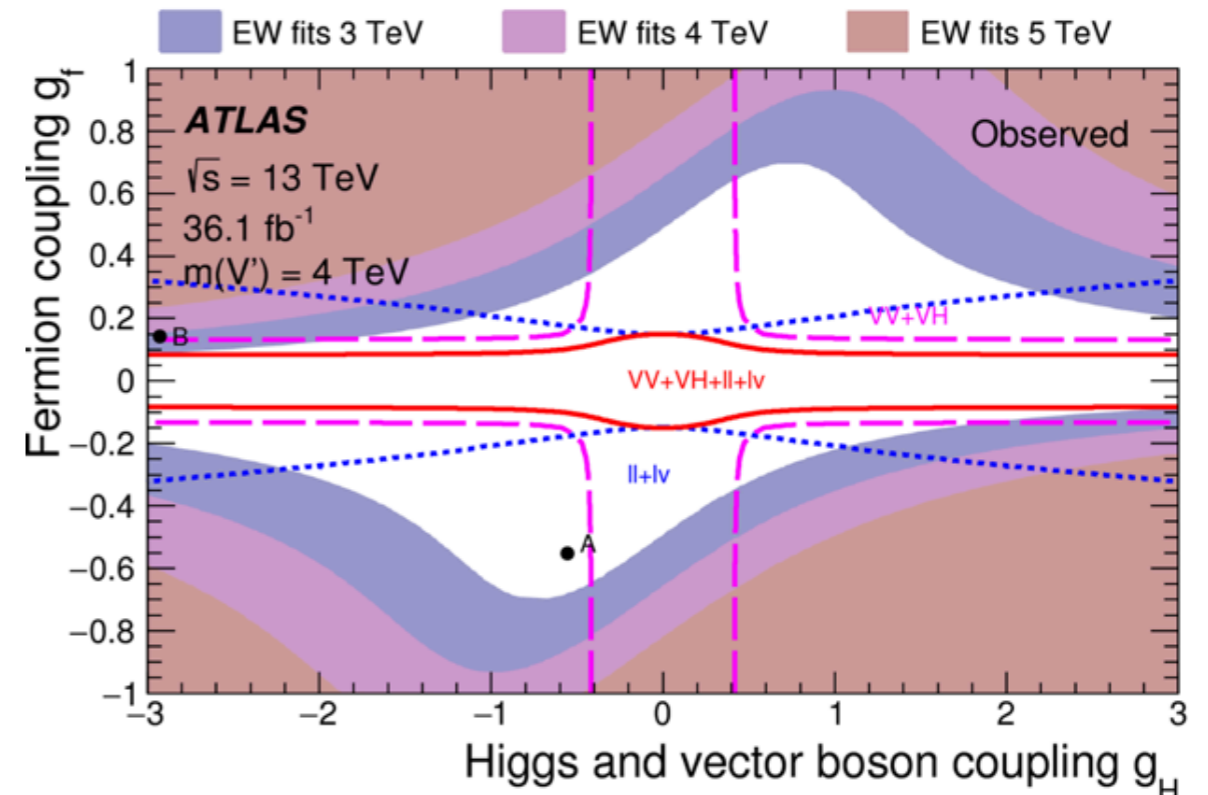
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[Link](#)

- Rather than simply setting limits on xsec and mass, also make statement about SM coupling.
- Still not truly agnostic (Spin-0/2, non-resonant, complex structure)
- Searches != Precision Measurements



Limitations

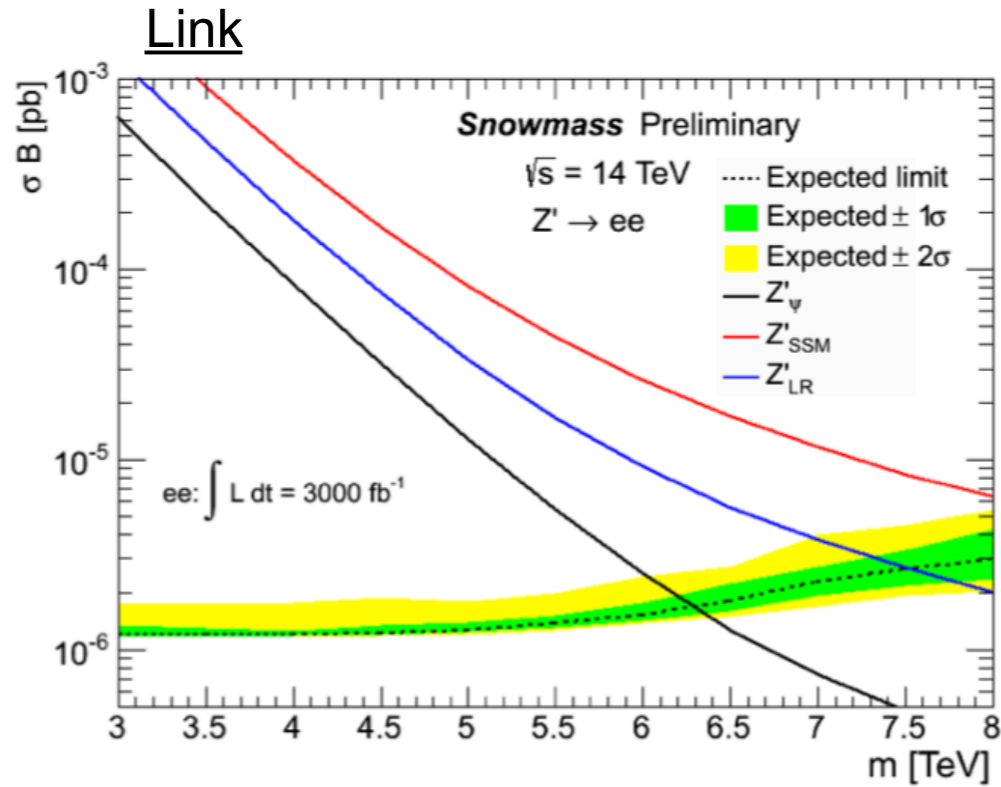


Figure 1-26. Upper cross-section limits for the process $q\bar{q} \rightarrow Z' \rightarrow e^+e^-$, set at 95% CL using a Bayesian statistical interpretation given 3000 fb^{-1} of data collected at $\sqrt{s} = 14 \text{ TeV}$. Various signal scenarios are overlaid, with mass exclusion limits extracted at the intersection of the theory-expected lines.

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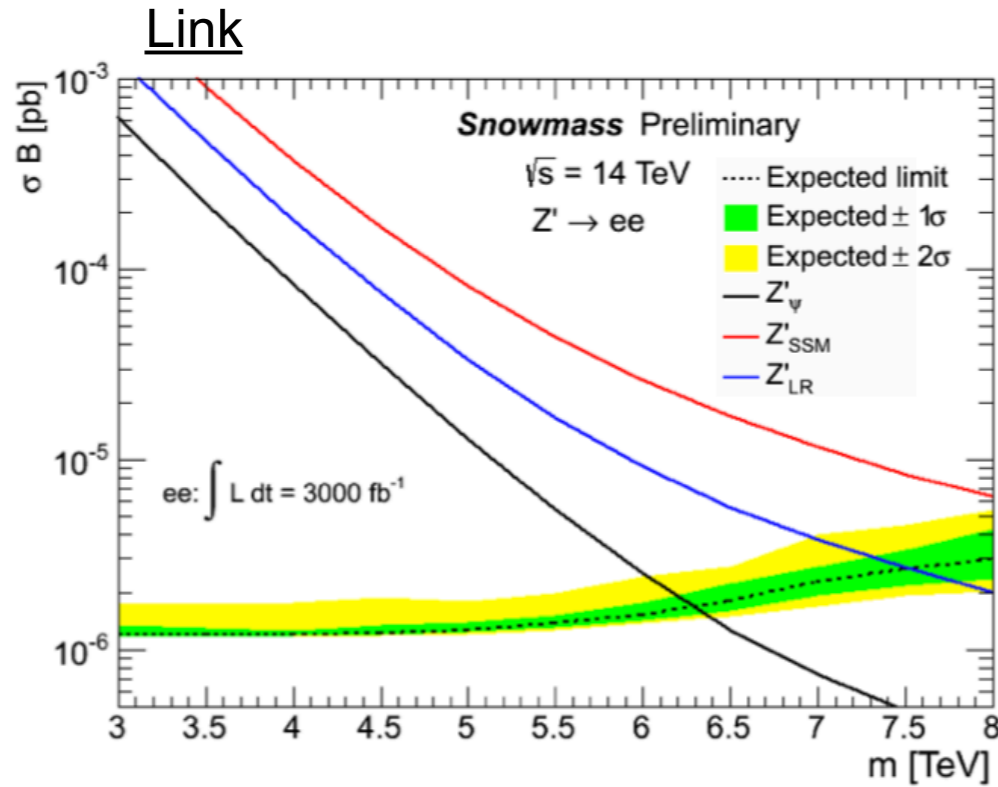
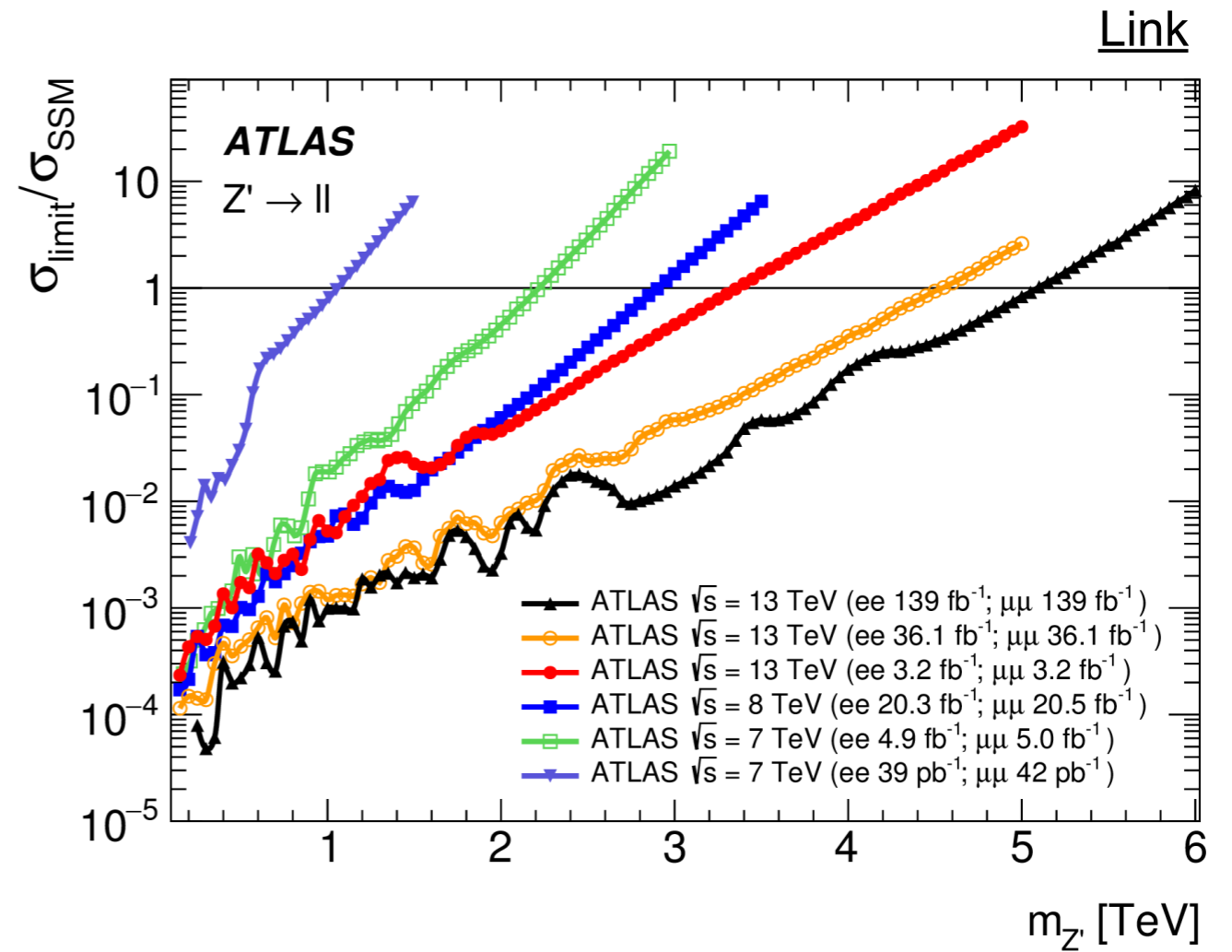


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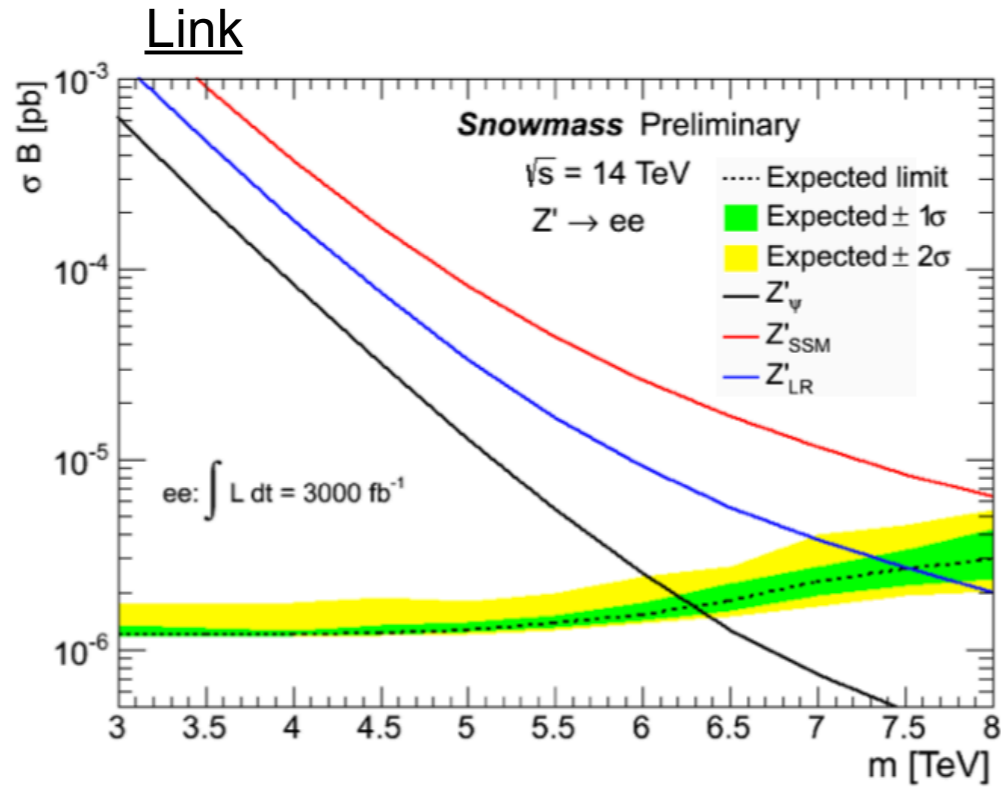
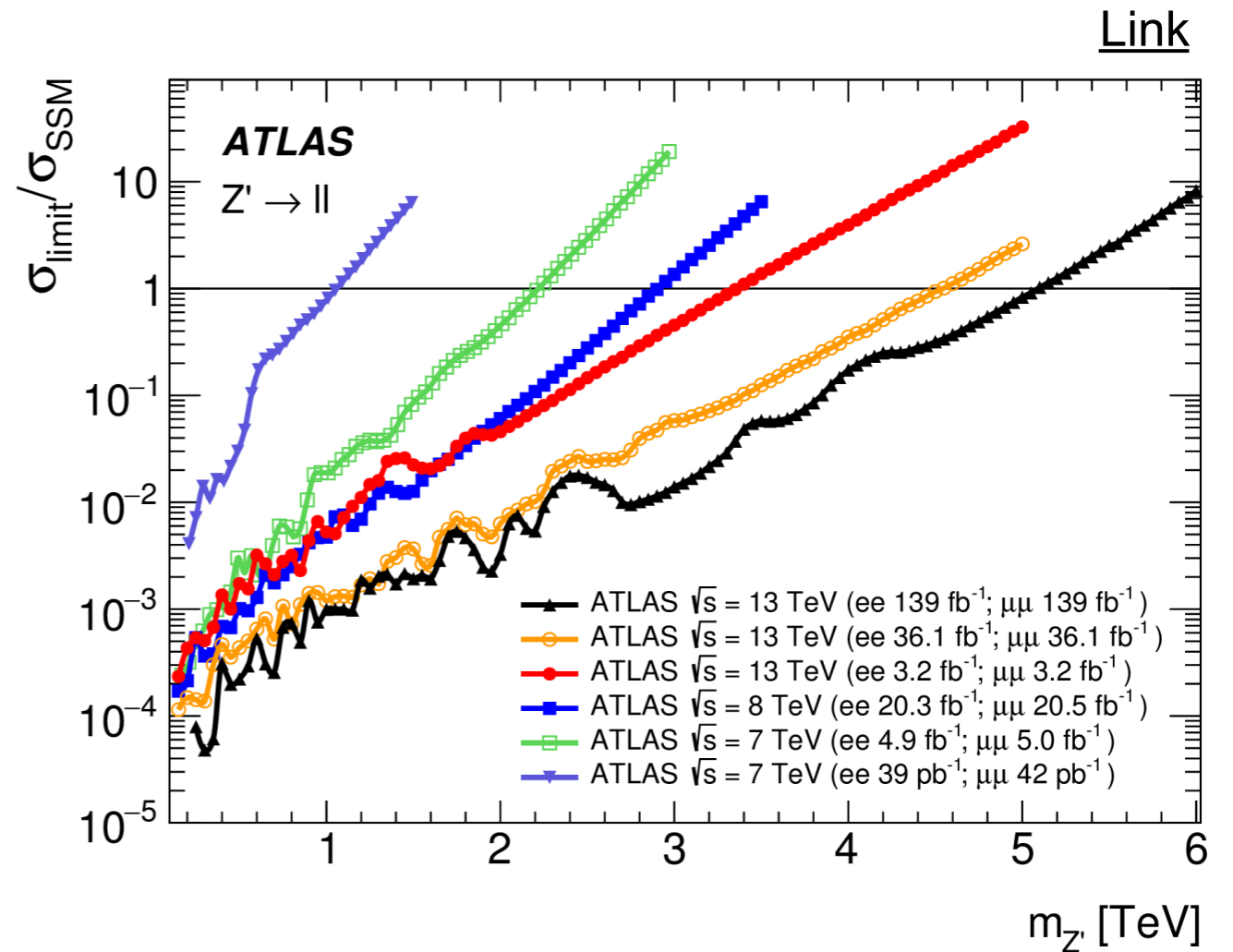
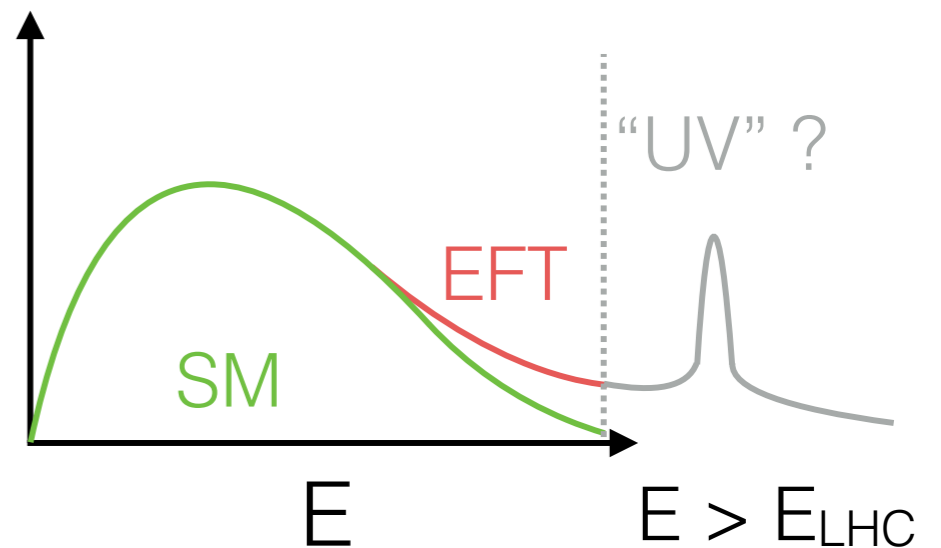
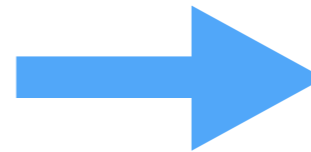
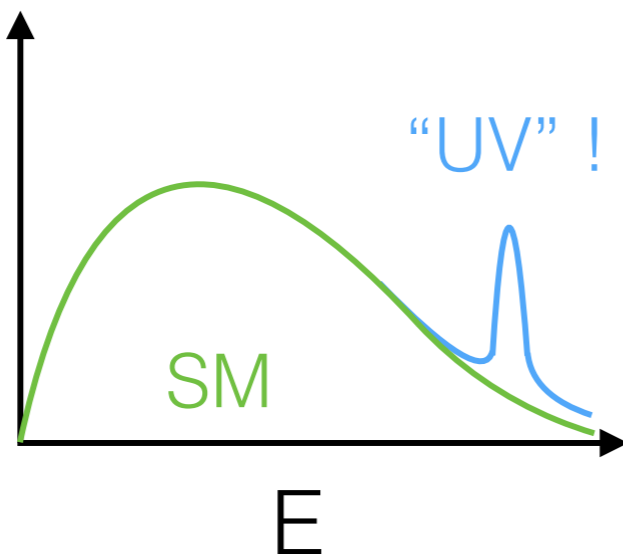


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From K. Mimasu

direct searches



EFT Approach

- Key Idea: If new physics is characterized by a very large energy scale Λ (particle mass / compositeness scale / ...), it's impact at the LHC can be described by an EFT.
- Pros of EFT Approach:
 - Model independent, within assumptions.
 - Do not need knowledge of UV model to make predictions.
 - Better than just anomalous couplings, as it's a full QFT.
 - Gives a systematic classification of all possible BSM effects.
 - Gives access to physics beyond LHC reach.

An EFT for BSM searches: The SMEFT

- fundamental assumptions:
- ▶ new physics nearly decoupled: $\Lambda \gg (v, E)$
 - ▶ at the accessible scale: **SM** fields + symmetries

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Taylor expansion in canonical dimensions ($\delta = v/\Lambda$ or E/Λ):

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \frac{1}{\Lambda} \mathcal{L}_5 + \frac{1}{\Lambda^2} \mathcal{L}_6 + \frac{1}{\Lambda^3} \mathcal{L}_7 + \frac{1}{\Lambda^4} \mathcal{L}_8 + \dots$$

$$\mathcal{L}_n = \sum_i C_i \mathcal{O}_i^{d=n}$$

C_i free parameters (Wilson coefficients)

\mathcal{O}_i invariant operators that form a complete, non redundant basis

What precision is needed?

A back-of-the-envelope estimate:

on poles

$$\text{NP impact} \sim \frac{v^2 g}{M^2} = \frac{v^2}{\Lambda^2}$$

UV coupling to SM
mass of new resonances
EFT cutoff

$g \simeq 1$ $M \gtrsim 2 - 3 \text{ TeV}$ (LHC reach) \rightarrow **1%** **at least!**

on tails

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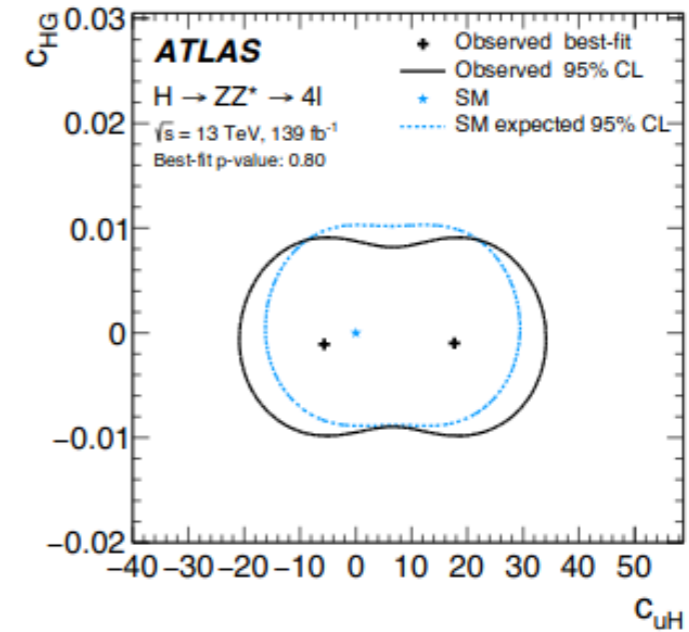
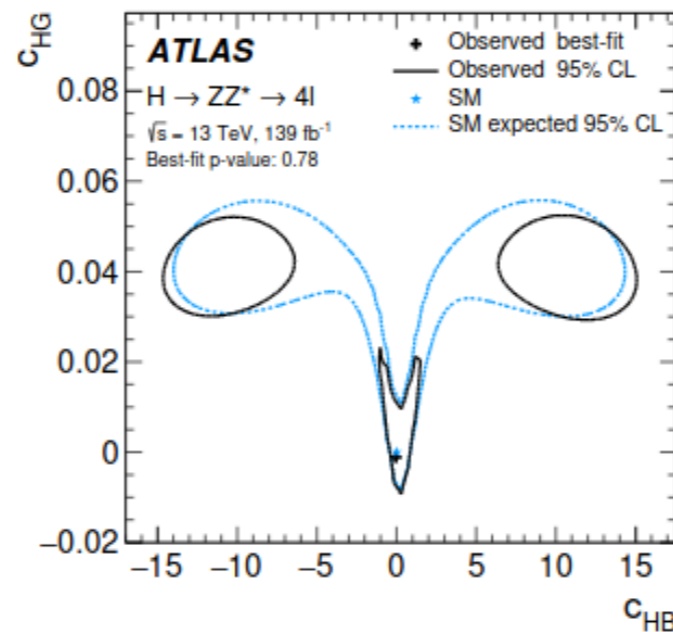
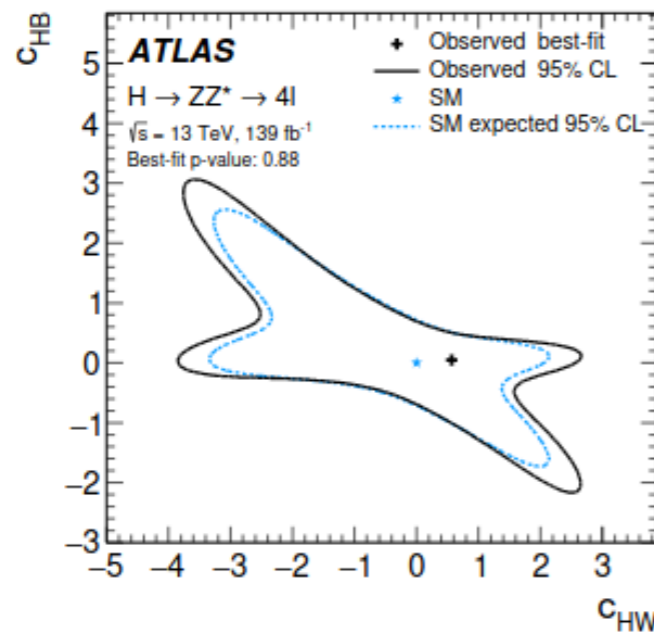
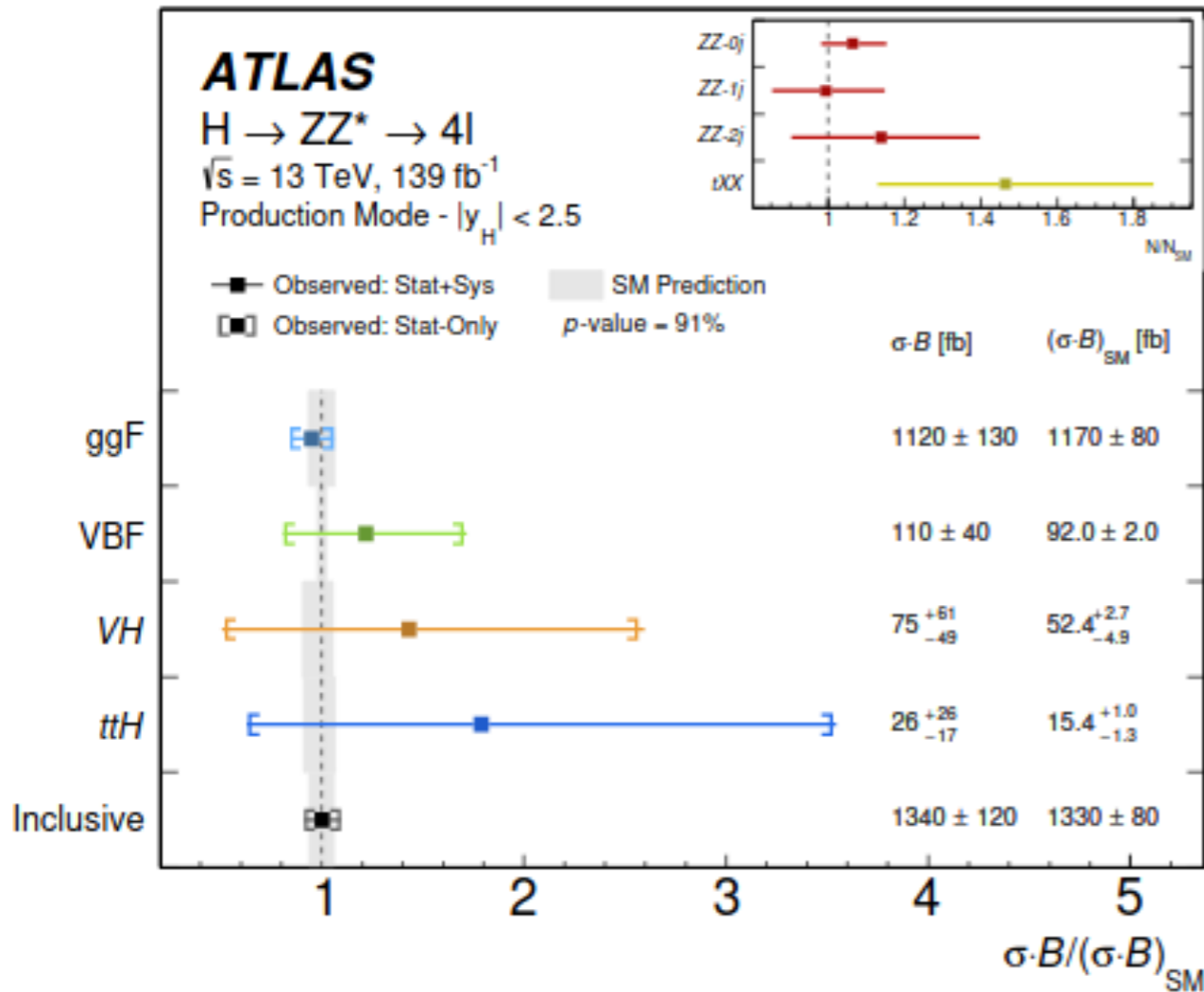
- A parameter space reduction
- B experimental precision required

	pole observables	tails of dist.
A	remarkable	difficult (ψ^4)
B	need 1 %	ok with tens of %

Pole and tails are complementary!

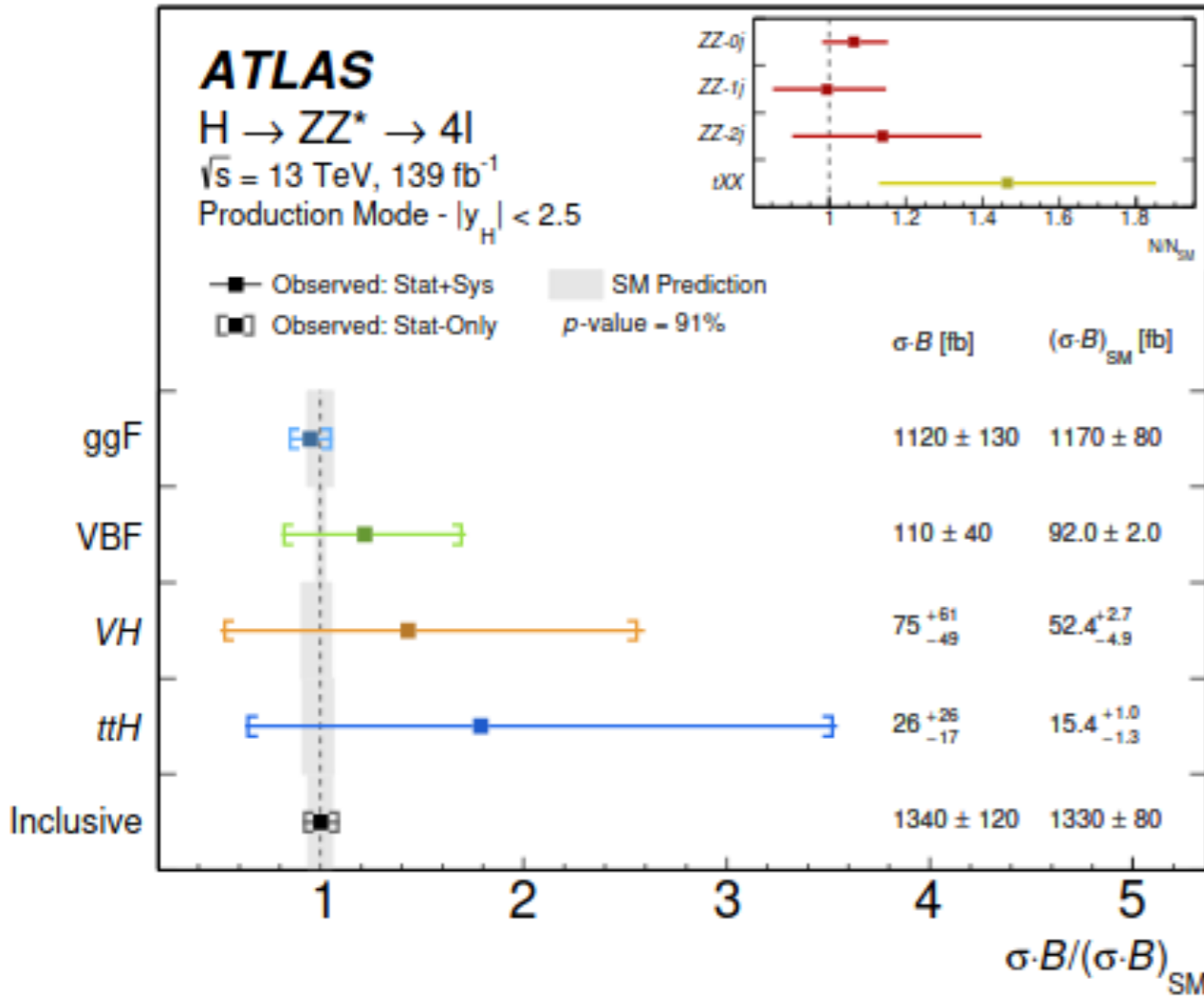
Current Measurements & HL-LHC Projections

[Link](#)



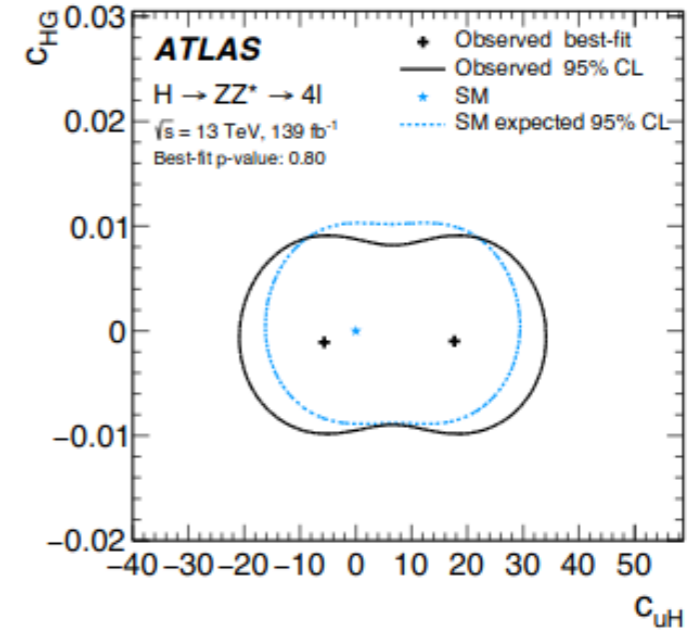
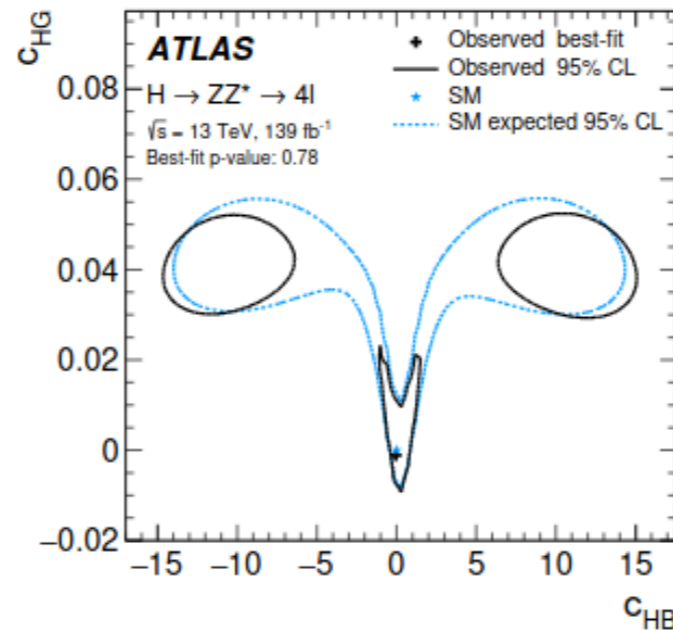
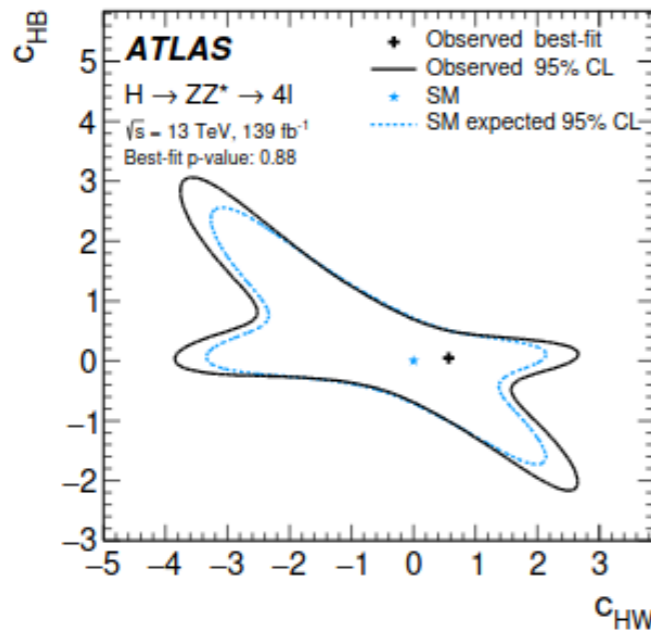
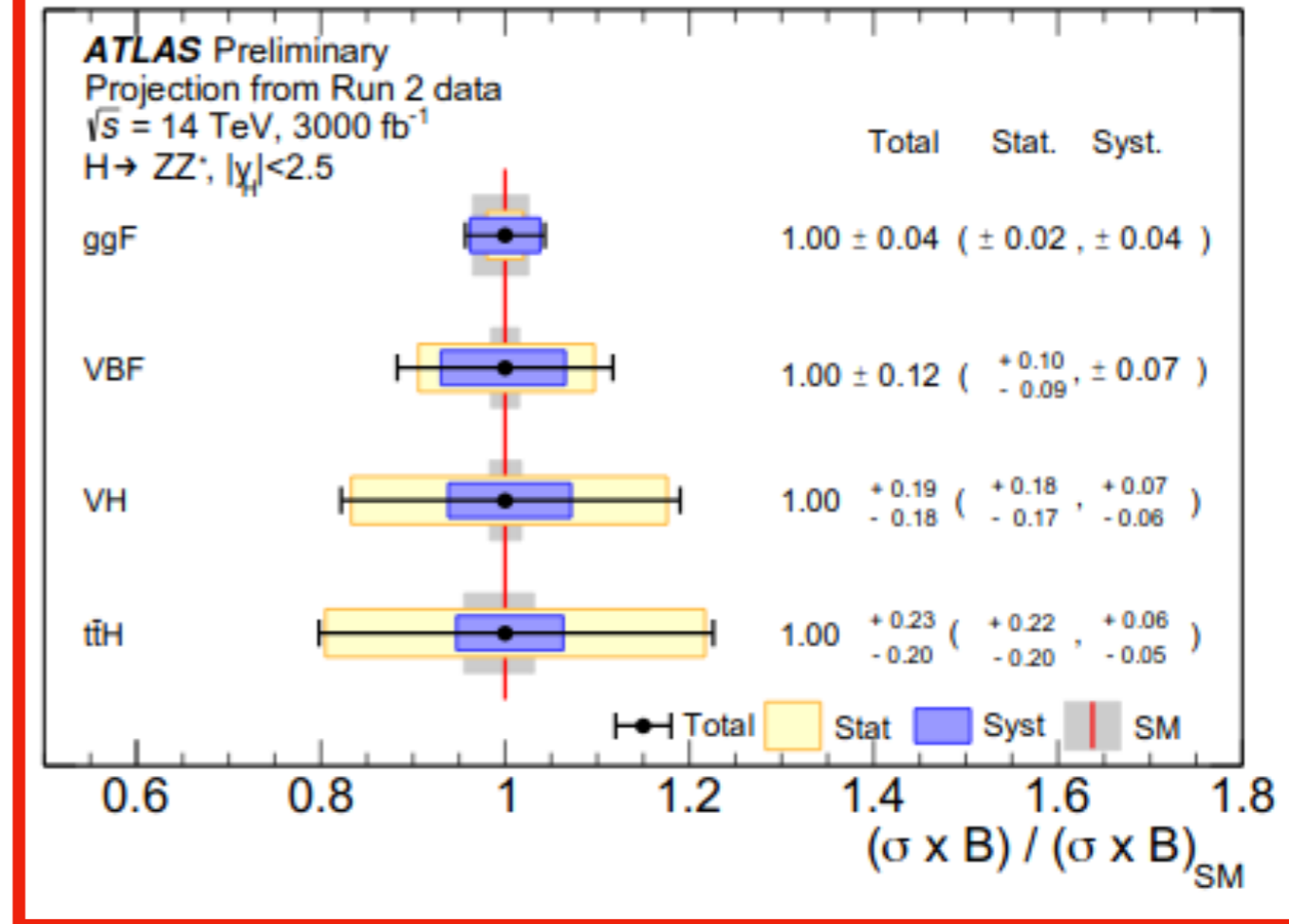
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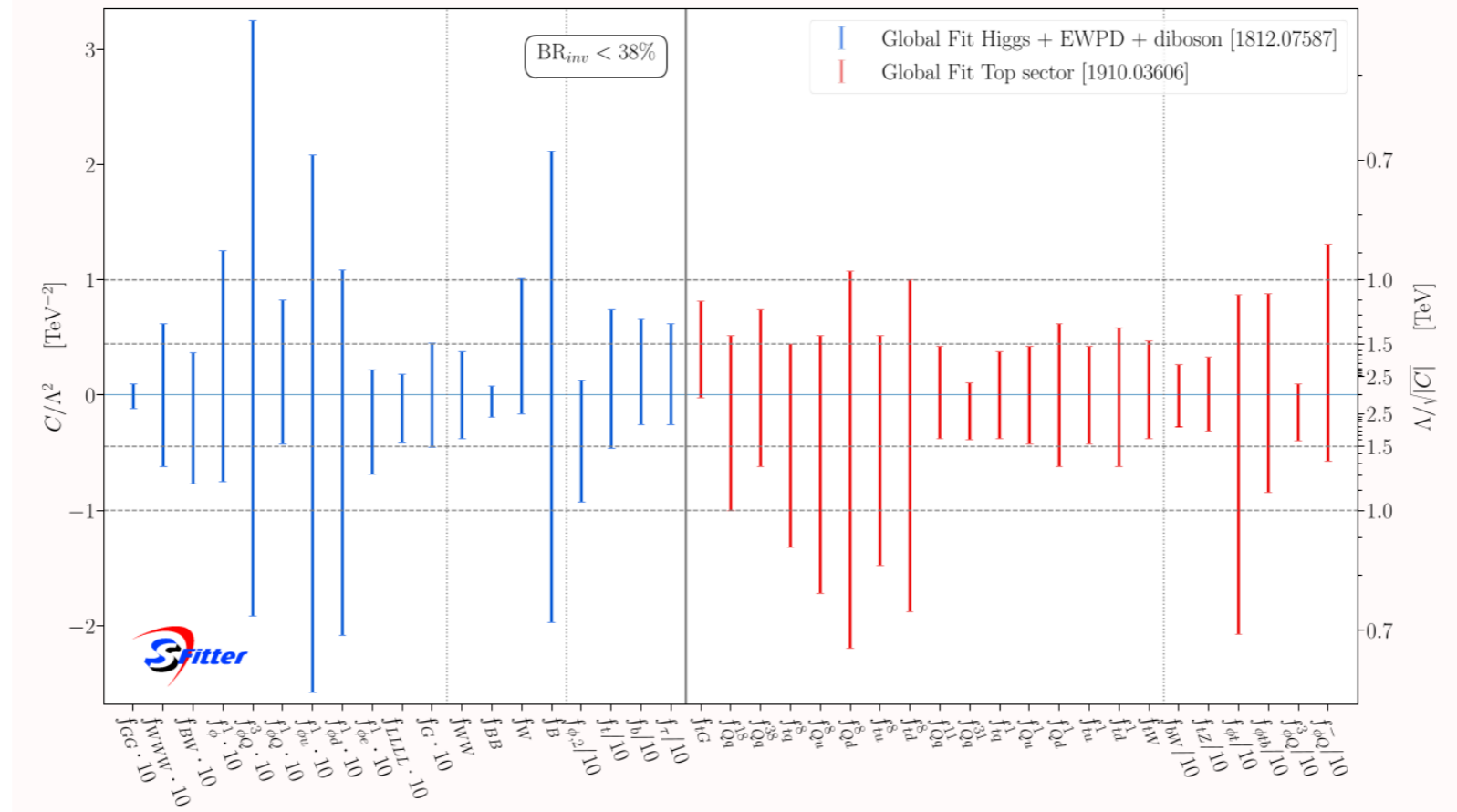
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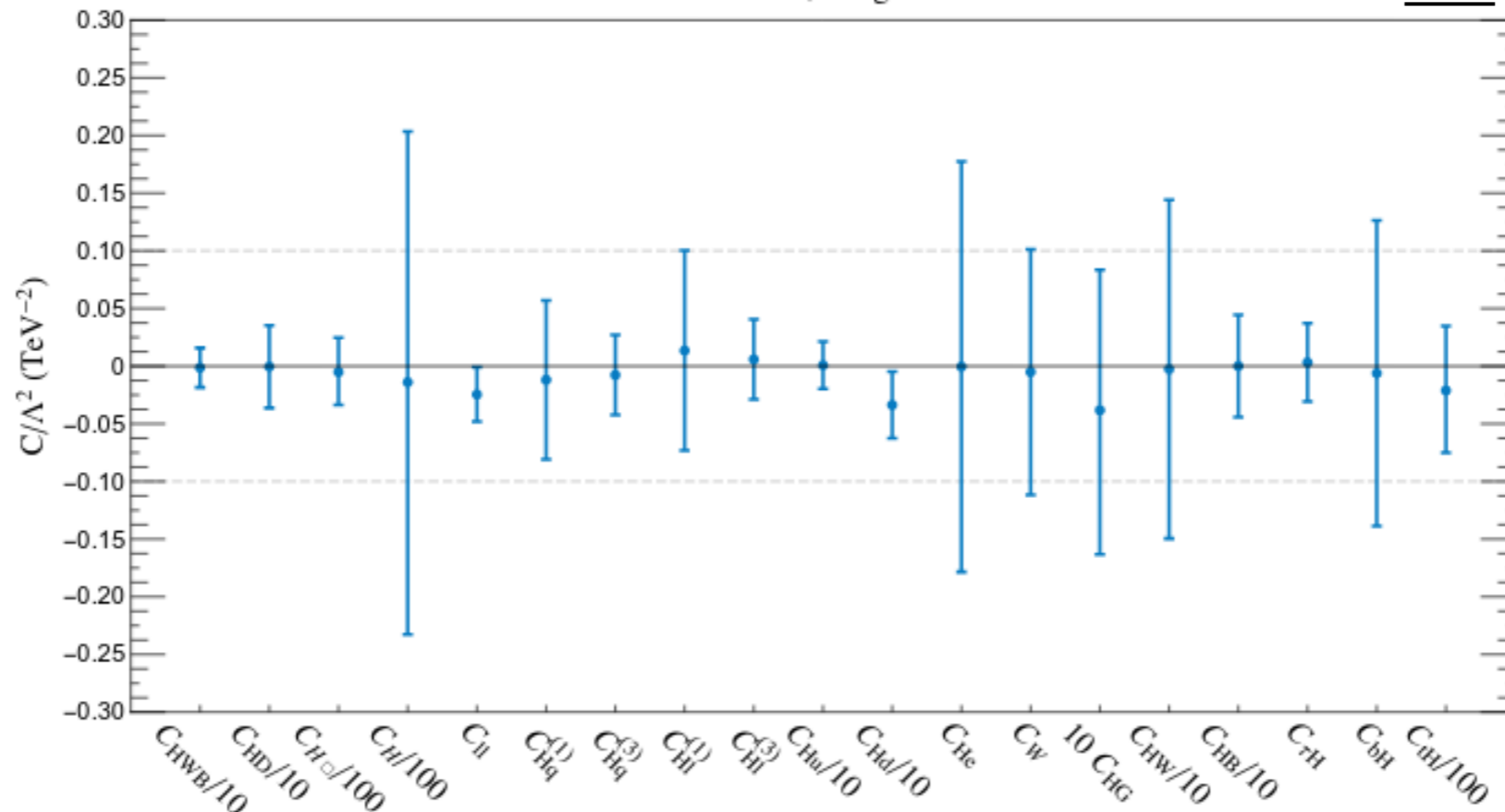
Status in Global Fits

EWPD + LHC Run I + II, 95% C.L.



95% Limits, Marginalized

[Link](#)



Some Starter Questions for Discussion...

1. How does the EFT reach, in terms of new physics scale, compare to that of direct searches?
2. What is the precision needed for EFT to do better than Top Down?
 - Which measurements can realistically expect this?
3. Is there any regime where the two approaches overlap?
 - If so, how can this complementarity be best exploited?
 - Otherwise, is there a blind spot?
4. How can we better control the large theory uncertainties which limit both approaches? Is one approach more resilient?
5. Can searches performed with the Top Down approach in mind be easily cast into EFT?
 - Could be useful for where precision measurements do not exist.