Updated Global SMEFT Fit
to Higgs, Diboson and Electroweak Data

- Global fit to dimension-6 operators using precision electroweak data, W+W- at LEP, Higgs and diboson data from LHC Runs 1 and 2
- Results in Warsaw and SILH bases
- Improvements in the constraints from Run 2
- Constraints on BSM models
  - Some contribute to operators at tree level
  - Stops that contribute at loop level
- With a supplement on dimension-8 operators

John Ellis

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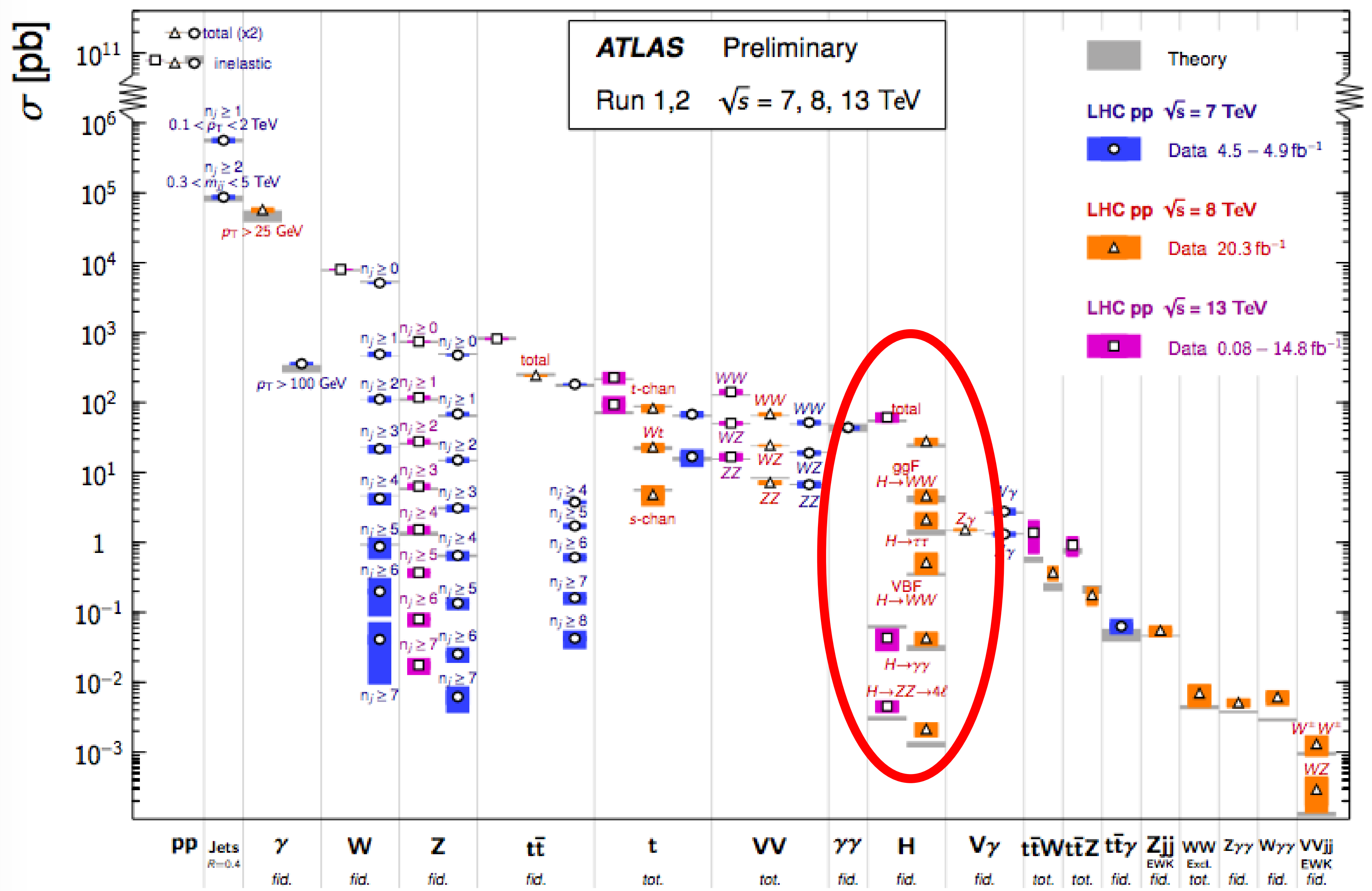
Chris Murphy, JE, Verónica Sanz & Tevong You, arXiv:1803.03252

JE & Shao-Feng Ge, arXiv:1802.02416

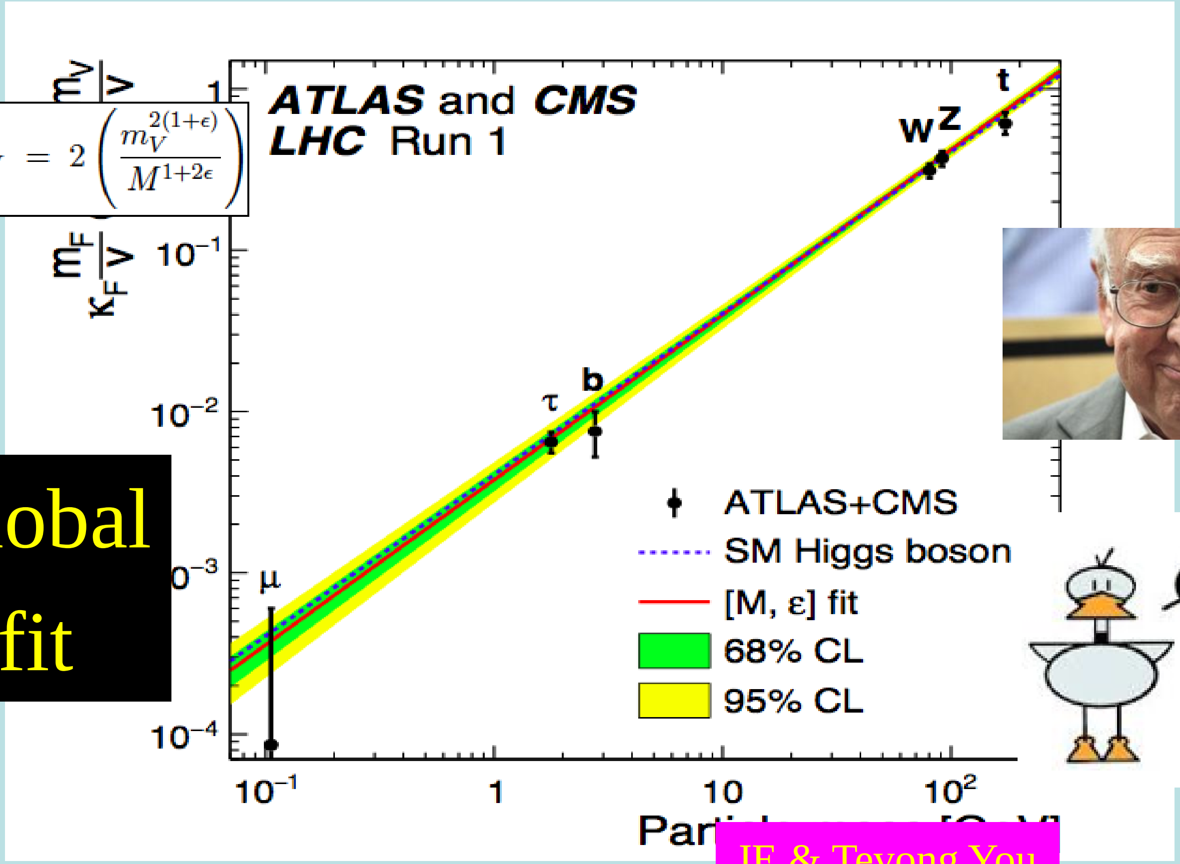
Physics Measurements @ LHC



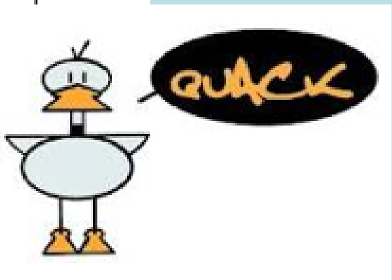
It Walks and Quacks like a Higgs

- Do couplings scale ~ mass? With scale = v?

$$\lambda_f = \sqrt{2}\left(\frac{m_f}{M}\right)^{1+\epsilon}, \; g_V = 2\left(\frac{m_V^{2(1+\epsilon)}}{M^{1+2\epsilon}}\right)$$



Global fit

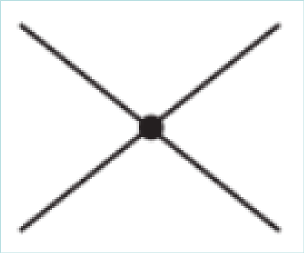


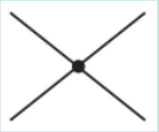
JE & Tevong You

- **Blue** dashed line = Standard Model

Effective Field Theories (EFTs)
a long and glorious History

- 1930's: "Standard Model" of QED had d=4
- Fermi's four-fermion theory of the weak force



- Dimension-6 operators: form = S, P, V, A, T?
- Due to exchanges of massive particles?
- V-A ➔ massive vector bosons ➔ gauge theory
- Yukawa's meson theory of the strong N-N force 
- Due to exchanges of mesons? ➔ pions
- Chiral dynamics of pions (dπdπ)ππ clue ➔ QCD

Assuming H(125) is SM-like: Model-independent search for new physics

Standard Model Effective Field Theory

- Higher-dimensional operators as relics of higher-energy physics, e.g., dimension 6: $\mathcal{L}_{\text{eff}} = \sum_n \frac{f_n}{\Lambda^2} \mathcal{O}_n$
- Operators constrained by SU(2) × U(1) symmetry:

$$\begin{aligned}
\mathcal{L} \supset\ & \frac{\bar{c}_H}{2v^2}\partial^\mu\left[\Phi^\dagger\Phi\right]\partial_\mu\left[\Phi^\dagger\Phi\right] + \frac{g'^2\ \bar{c}_\gamma}{m_W^2}\Phi^\dagger\Phi B_{\mu\nu}B^{\mu\nu} + \frac{g_s^2\ \bar{c}_g}{m_W^2}\Phi^\dagger\Phi G^a_{\mu\nu}G_a^{\mu\nu} \\
+\ & \frac{2ig\ \bar{c}_{HW}}{m_W^2}\left[D^\mu\Phi^\dagger T_{2k}D^\nu\Phi\right]W^k_{\mu\nu} + \frac{ig'\ \bar{c}_{HB}}{m_W^2}\left[D^\mu\Phi^\dagger D^\nu\Phi\right]B_{\mu\nu} \\
+\ & \frac{ig\ \bar{c}_W}{m_W^2}\left[\Phi^\dagger T_{2k}\overleftrightarrow{D}^\mu\Phi\right]D^\nu W^k_{\mu\nu} + \frac{ig'\ \bar{c}_B}{2m_W^2}\left[\Phi^\dagger\overleftrightarrow{D}^\mu\Phi\right]\partial^\nu B_{\mu\nu} \\
+\ & \frac{\bar{c}_t}{v^2}y_t\Phi^\dagger\Phi\ \Phi^\dagger\cdot\bar{Q}_L t_R + \frac{\bar{c}_b}{v^2}y_b\Phi^\dagger\Phi\ \Phi\cdot\bar{Q}_L b_R + \frac{\bar{c}_\tau}{v^2}y_\tau\ \Phi^\dagger\Phi\ \Phi\cdot\bar{L}_L\tau_R
\end{aligned}$$

- Constrain with precision EW, Higgs data, TGCs …

Which Operators Contribute to which Observables?

EWPTs	Higgs Physics	TGCs
$\mathcal{O}_W = \frac{ig}{2}\left(H^\dagger \sigma^a \overleftrightarrow{D}^\mu H\right) D^\nu W^a_{\mu\nu}$		
$\mathcal{O}_B = \frac{ig'}{2}\left(H^\dagger \overleftrightarrow{D}^\mu H\right) \partial^\nu B_{\mu\nu}$		$\mathcal{O}_{3W} = g\frac{\epsilon_{abc}}{3!} W^{a\,\nu}_{\mu} W^{b}_{\nu\rho} W^{c\,\rho\mu}$
$\mathcal{O}_T = \frac{1}{2}\left(H^\dagger \overleftrightarrow{D}_\mu H\right)^2$	$\mathcal{O}_{HW} = ig(D^\mu H)^\dagger \sigma^a (D^\nu H) W^a_{\mu\nu}$	
$\mathcal{O}^{(3)\,l}_{LL} = (\bar{L}_L \sigma^a \gamma^\mu L_L)(\bar{L}_L \sigma^a \gamma_\mu L_L)$	$\mathcal{O}_{HB} = ig'(D^\mu H)^\dagger (D^\nu H) B_{\mu\nu}$	
$\mathcal{O}^e_R = (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{e}_R \gamma^\mu e_R)$	$\mathcal{O}_g = g_s^2 \lvert H\rvert^2 G^A_{\mu\nu} G^{A\mu\nu}$	
$\mathcal{O}^u_R = (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{u}_R \gamma^\mu u_R)$	$\mathcal{O}_\gamma = g'^2 \lvert H\rvert^2 B_{\mu\nu} B^{\mu\nu}$	
$\mathcal{O}^d_R = (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{d}_R \gamma^\mu d_R)$	$\mathcal{O}_H = \frac{1}{2}(\partial^\mu \lvert H\rvert^2)^2$	
$\mathcal{O}^{(3)\,q}_L = (iH^\dagger \sigma^a \overleftrightarrow{D}_\mu H)(\bar{Q}_L \sigma^a \gamma^\mu Q_L)$	$\mathcal{O}_f = y_f \lvert H\rvert^2 \bar{F}_L H^{(c)} f_R + \text{h.c.}$	
$\mathcal{O}^q_L = (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{Q}_L \gamma^\mu Q_L)$	$\mathcal{O}_6 = \lambda \lvert H\rvert^6$	

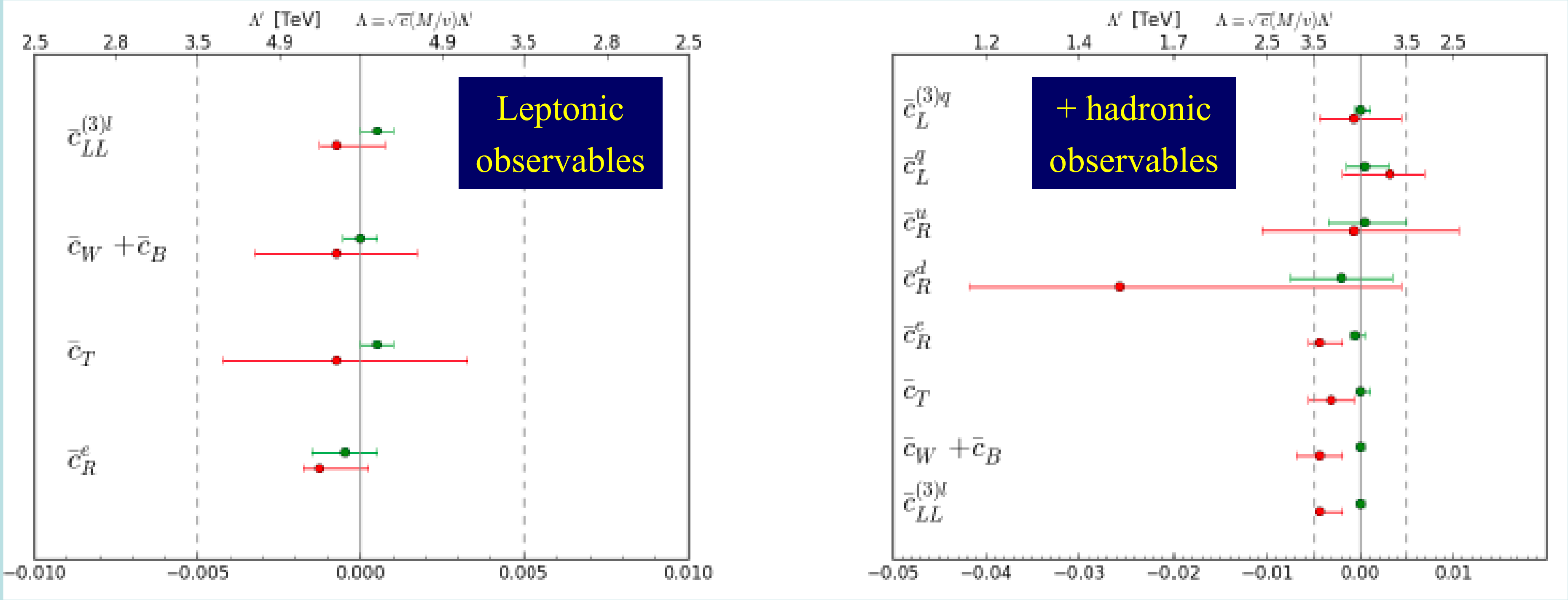
- **Precision electroweak**
- **Higgs**
- **Diboson production**

In SILH basis

JE, Sanz & Tevong You, arXiv:1410.7703

Previous Fit to Electroweak Precision Data

- Constraints from LEP et al. data



- **Fits to individual dimension-6 operators**
- **Global fit to all operators together**

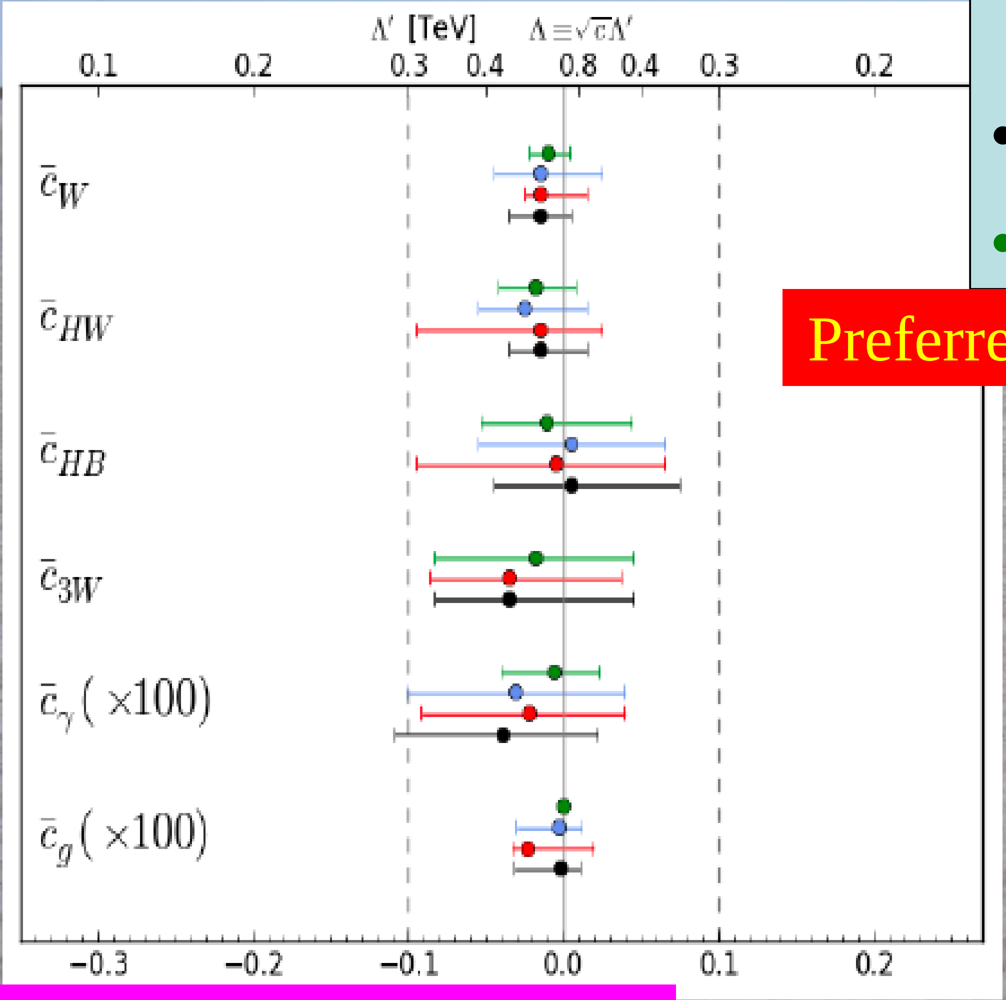
JE, Sanz & Tevong You, arXiv:1410.7703

Fit to Run 1 H, W^+W^- Data

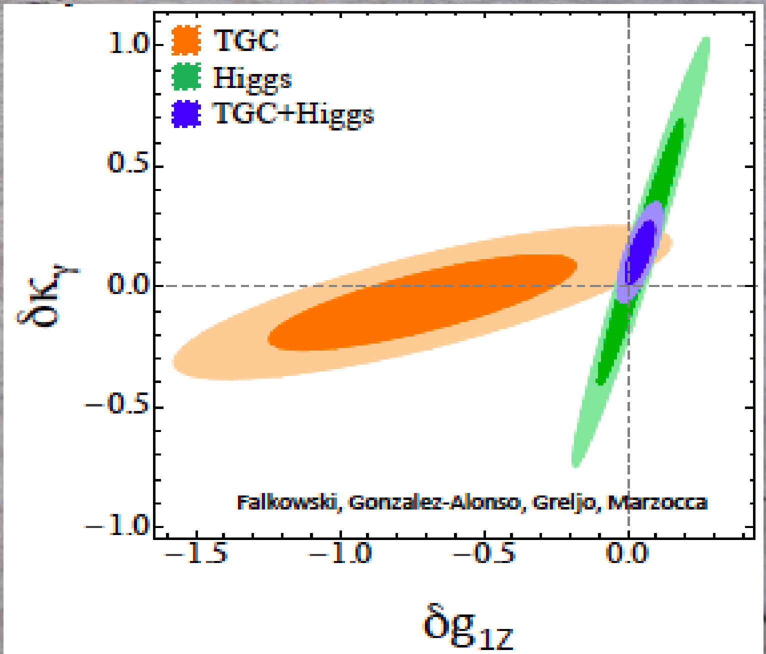
- **Associated H production rates & kinematics**
- **LHC Triple-gauge couplings**
- Global combination
- **Individual operators**

Complementary!

Preferred framework for analyzing Run 2

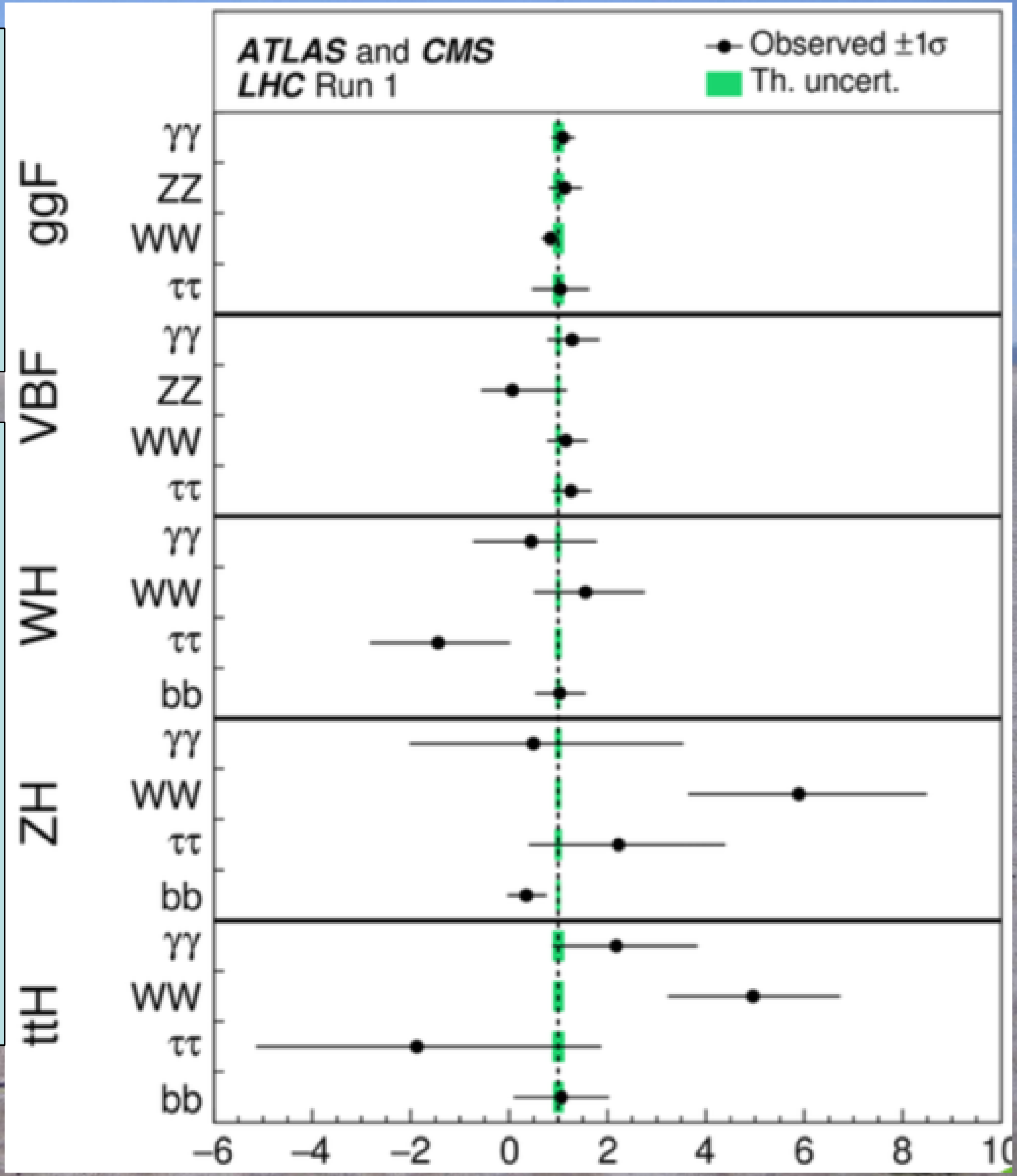


JE, Sanz & Tevong You, arXiv:1410.7703



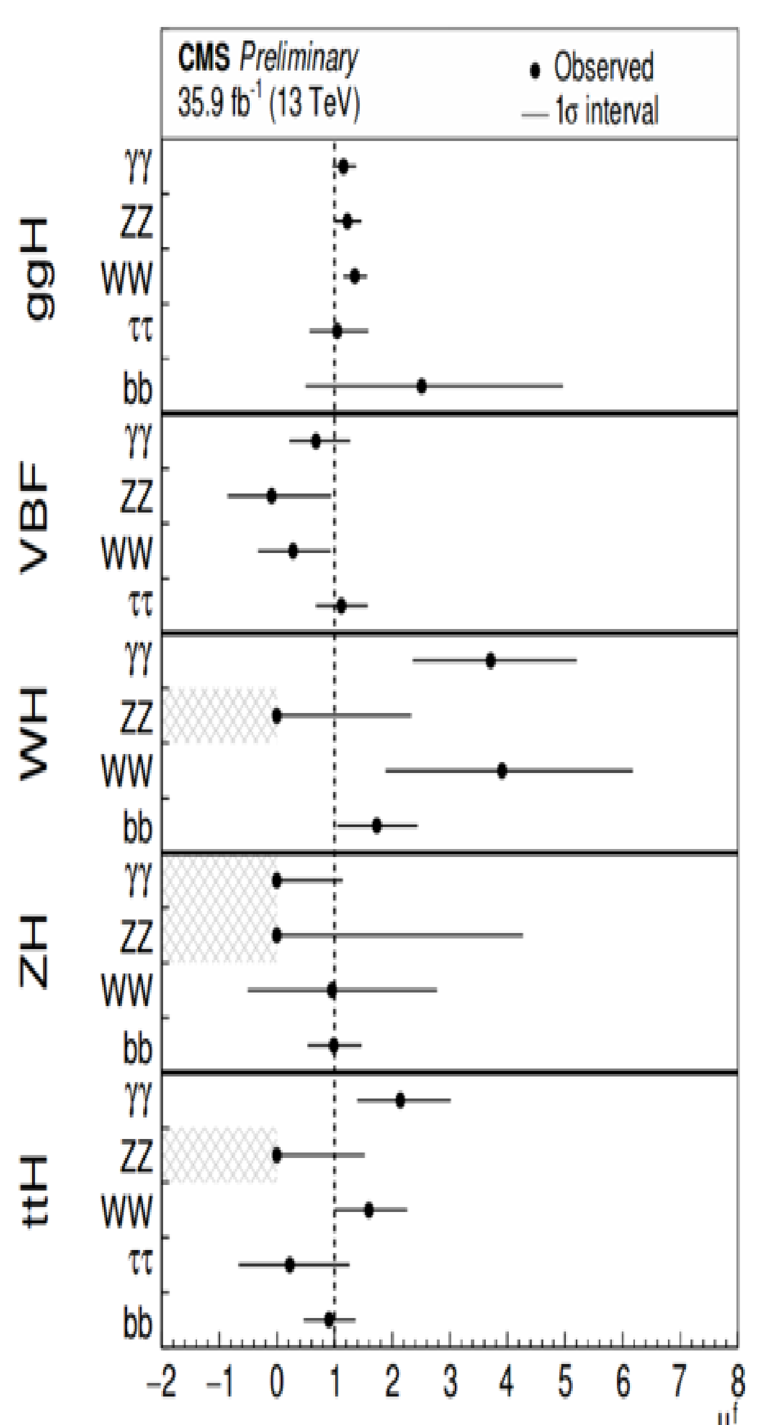
H Production Measurements in Run 1

- Open questions:
  - H➔bb?
    - 2.6σ @ LHC
    - 2.8σ @ FNAL
  - H➔➚μ?
  - ttH production?
  - tH production?



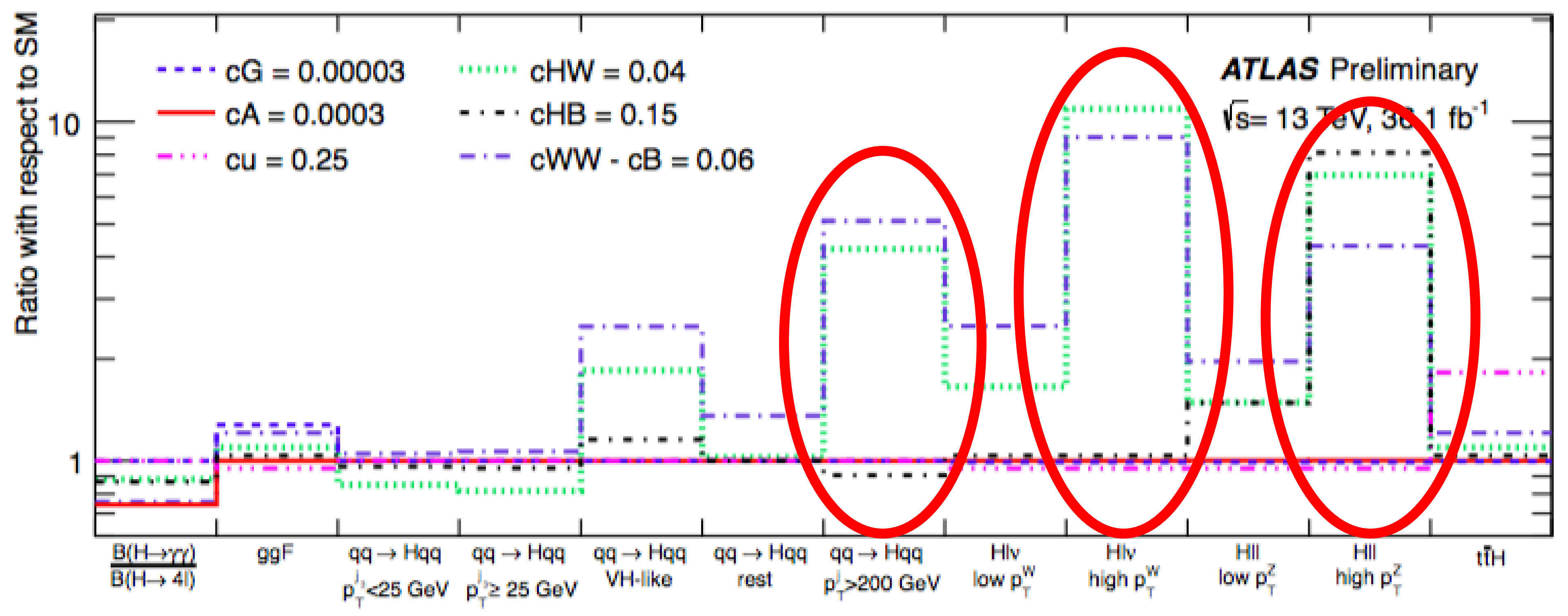
H Production Measurements in Run 2

- Improvements in:
  - H➔bb
  - ttH



Sensitivities to Operators

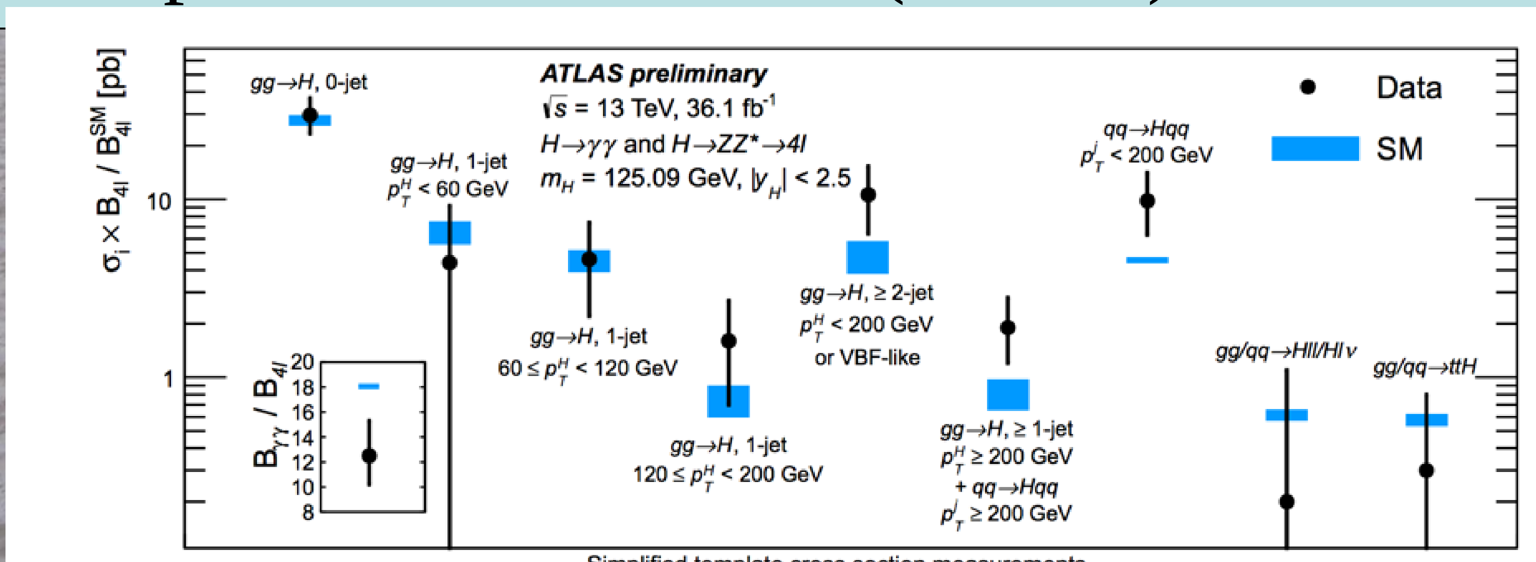
- Rate relative to SM with different operators



- **Higher sensitivity at higher p_T**
- **But lower statistics**

Next-Generation Analysis

- Previously assumed
  - EW precision >> diboson >> Higgs precision
- No longer justified, theoretically unsatisfactory
- Kinematic information encoded in Simpified Template Cross Sections (STXSs)



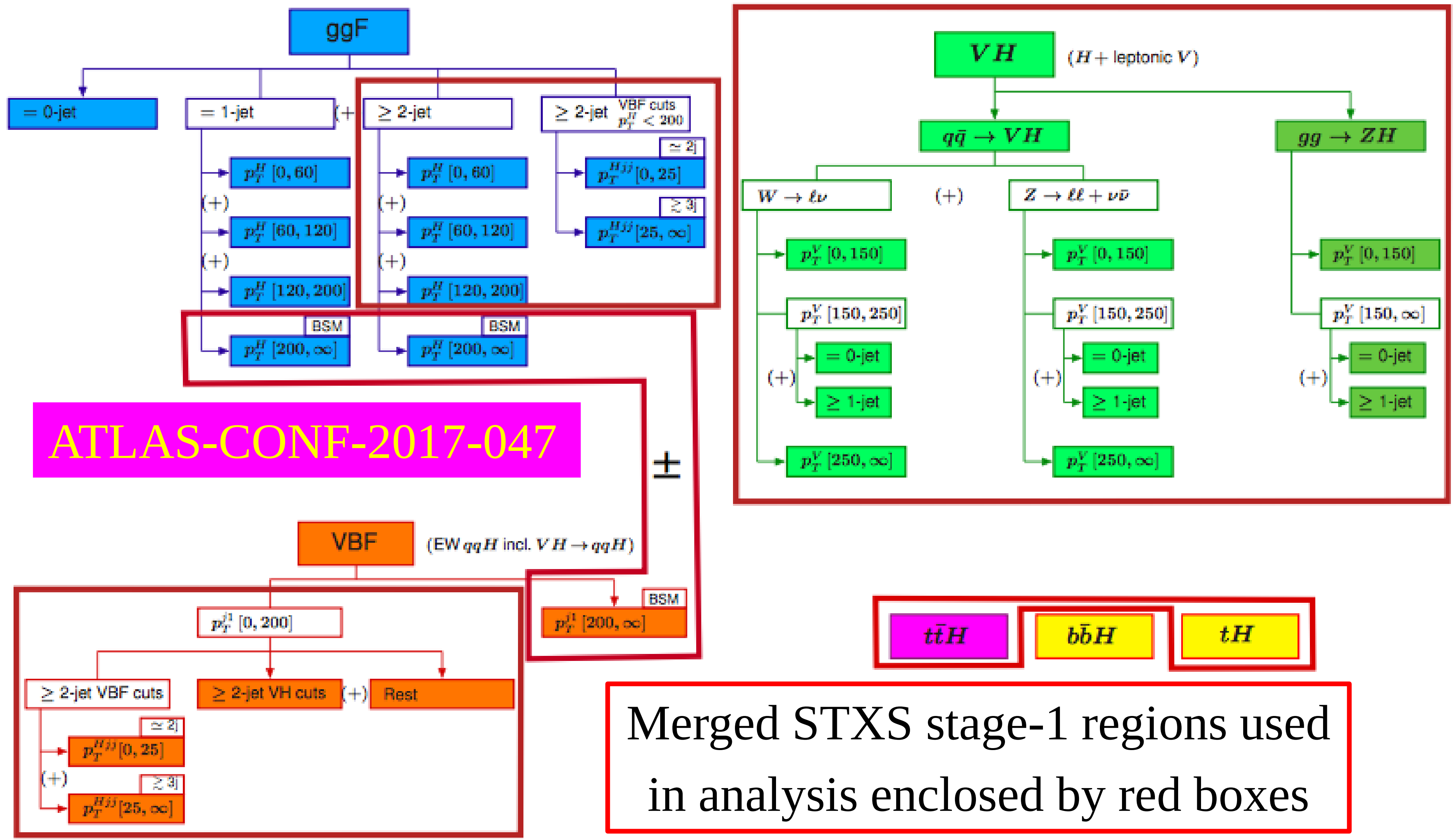
Simplified Template Cross Sections (STXSs)

- Tool to use information on kinematics
- Known dependences on operator coefficients

Cross-section region	$\sum_i A_i c_i$
$gg \to H$ (0-jet)	
$gg \to H$ (1-jet, $p_T^H < 60$ GeV)	$56c'_g$
$gg \to H$ (1-jet, $60 \leq p_T^H < 120$ GeV)	
$gg \to H$ (1-jet, $120 \leq p_T^H < 200$ GeV)	$56c'_g + 18\mathrm{c3G} + 11\mathrm{c2G}$
$gg \to H$ (1-jet, $p_T^H \geq 200$ GeV)	$56c'_g + 52\mathrm{c3G} + 34\mathrm{c2G}$
$gg \to H$ ($\geq$ 2-jet, $p_T^H < 60$ GeV)	$56c'_g$
$gg \to H$ ($\geq$ 2-jet, $60 \leq p_T^H < 120$ GeV)	$56c'_g + 8\mathrm{c3G} + 7\mathrm{c2G}$
$gg \to H$ ($\geq$ 2-jet, $120 \leq p_T^H < 200$ GeV)	$56c'_g + 23\mathrm{c3G} + 18\mathrm{c2G}$
$gg \to H$ ($\geq$ 2-jet, $p_T^H \geq 200$ GeV)	$56c'_g + 90\mathrm{c3G} + 68\mathrm{c2G}$
$gg \to H$ ($\geq$ 2-jet VBF-like, $p_T^{j_3} < 25$ GeV)	$56c'_g$
$gg \to H$ ($\geq$ 2-jet VBF-like, $p_T^{j_3} \geq 25$ GeV)	$56c'_g + 9\mathrm{c3G} + 8\mathrm{c2G}$
$qq \to Hqq$ (VBF-like, $p_T^{j_3} < 25$ GeV)	$-1.0\mathrm{cH} - 1.0\mathrm{cT} + 1.3\mathrm{cWW} - 0.023\mathrm{cB} - 4.3\mathrm{cHW}$ $-0.29\mathrm{cHB} + 0.092\mathrm{cHQ} - 5.3\mathrm{cpHQ} - 0.33\mathrm{cHu} + 0.12\mathrm{cHd}$
$qq \to Hqq$ (VBF-like, $p_T^{j_3} \geq 25$ GeV)	$-1.0\mathrm{cH} - 1.1\mathrm{cT} + 1.2\mathrm{cWW} - 0.027\mathrm{cB} - 5.8\mathrm{cHW}$ $-0.41\mathrm{cHB} + 0.13\mathrm{cHQ} - 6.9\mathrm{cpHQ} - 0.45\mathrm{cHu} + 0.15\mathrm{cHd}$
$qq \to Hqq$ ($p_T^j \geq 200$ GeV)	$-1.0\mathrm{cH} - 0.95\mathrm{cT} + 1.5\mathrm{cWW} - 0.025\mathrm{cB} - 3.6\mathrm{cHW}$ $-0.24\mathrm{cHB} + 0.084\mathrm{cHQ} - 4.5\mathrm{cpHQ} - 0.25\mathrm{cHu} + 0.1\mathrm{cHd}$
$qq \to Hqq$ ($60 \leq m_{jj} < 120$ GeV)	$-0.99\mathrm{cH} - 1.2\mathrm{cT} + 7.8\mathrm{cWW} - 0.19\mathrm{cB} - 31\mathrm{cHW}$ $-2.4\mathrm{cHB} + 0.9\mathrm{cHQ} - 38\mathrm{cpHQ} - 2.8\mathrm{cHu} + 0.9\mathrm{cHd}$
$qq \to Hqq$ (rest)	$-1.0\mathrm{cH} - 1.0\mathrm{cT} + 1.4\mathrm{cWW} - 0.028\mathrm{cB} - 6.2\mathrm{cHW}$ $-0.42\mathrm{cHB} + 0.14\mathrm{cHQ} - 6.9\mathrm{cpHQ} - 0.42\mathrm{cHu} + 0.16\mathrm{cHd}$
$gg/q\bar{q} \to ttH$	$-0.98\mathrm{cH} + 2.9\mathrm{cu} + 0.93\mathrm{cG} + 310\mathrm{cuG}$ $+27\mathrm{c3G} - 13\mathrm{c2G}$

Hays, Sanz & Zemaityte, LHCHXSWG-INT-2017-01

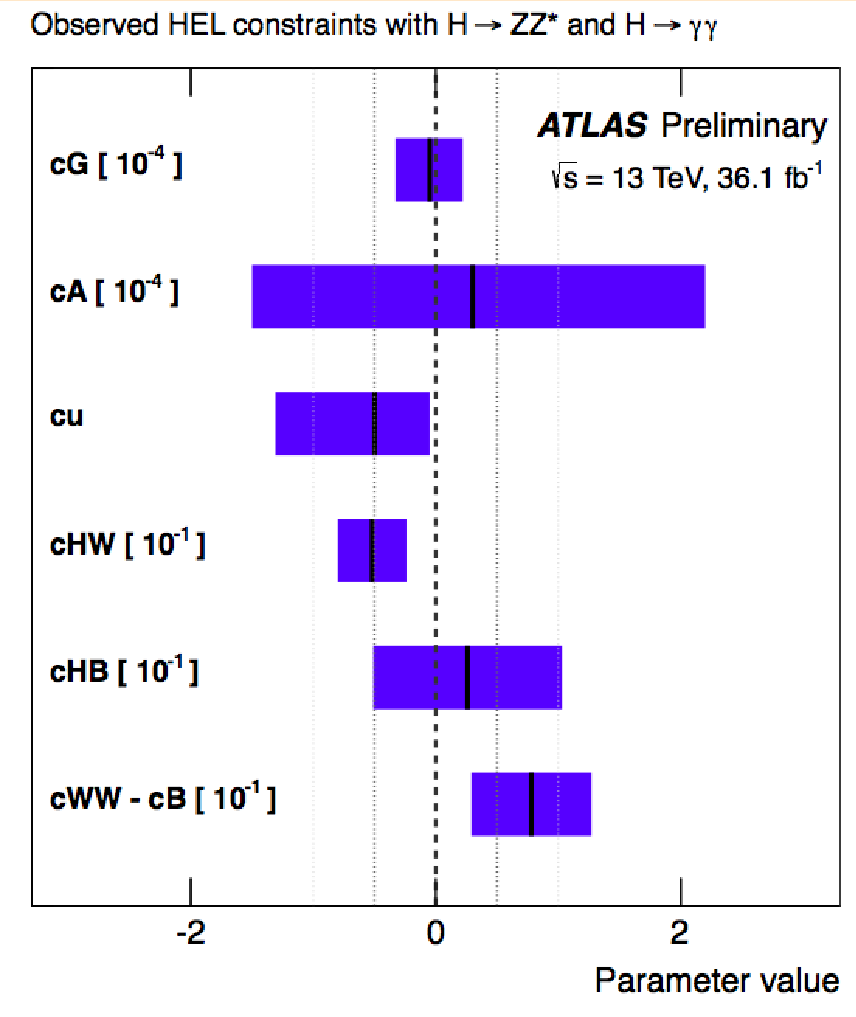
Used in ATLAS Higgs EFT Analysis

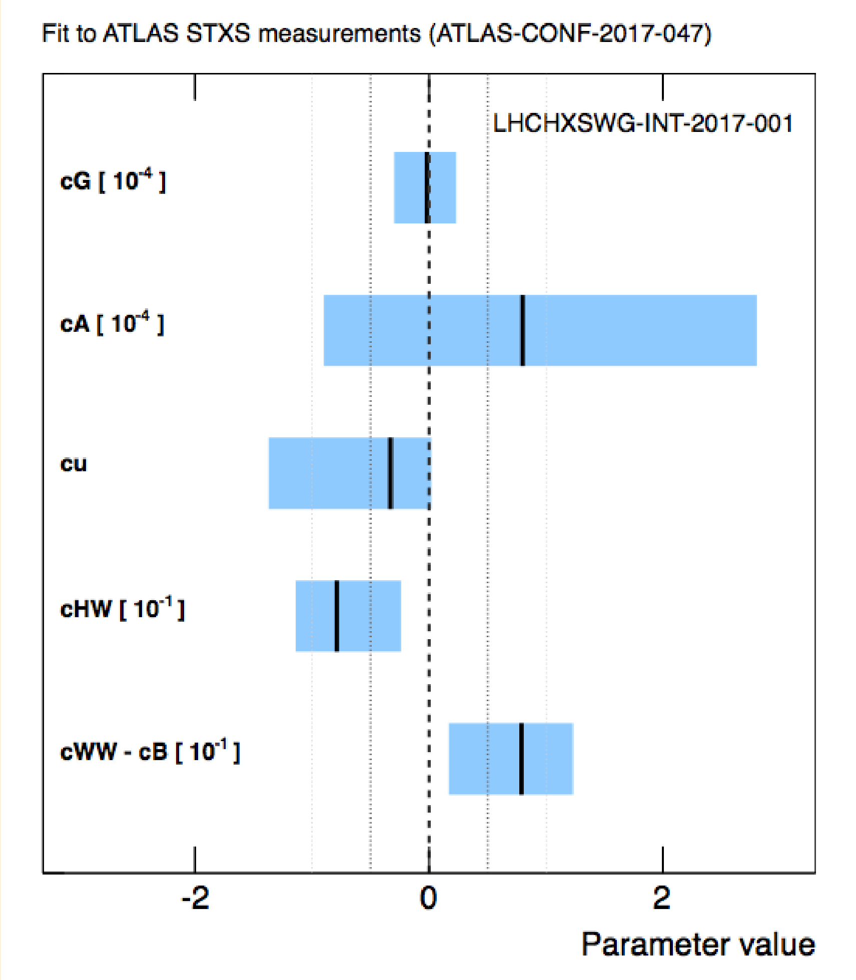


ATLAS-CONF-2017-047

Merged STXS stage-1 regions used in analysis enclosed by red boxes

EFT vs STXS Comparison





Chris Hays

EMSY, arXiv:1803.03252

Analysis Framework

- Leading dimension-6 operators:

$$\mathcal{L}_{\mathrm{SMEFT}} \supset \mathcal{L}_{\mathrm{SM}} + \sum_i \frac{c_i}{\Lambda_i^2} \mathcal{O}_i$$

- Work to linear order in operator coefficients
- Assume $U(3)^5$ symmetry for fermion operators
- Use G_F, M_Z, α as input parameters
- Use STXS Stage-1 as far as possible
- First attempt, so many caveats:
  - STXS framework being extended, Higher-order corrections, Theoretical uncertainties, …

Dimension-6 Operators in Warsaw Basis

- Involved in precision electroweak, diboson data

$$\mathcal{L}_{\rm SMEFT}^{\rm Warsaw} \supset \frac{\bar{C}_{Hl}^{(3)}}{v^2}(H^\dagger i \overleftrightarrow{D}^I_\mu H)(\bar{l}\tau^I\gamma^\mu l) + \frac{\bar{C}_{Hl}^{(1)}}{v^2}(H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{l}\gamma^\mu l) + \frac{\bar{C}_{ll}}{v^2}(\bar{l}\gamma_\mu l)(\bar{l}\gamma^\mu l)$$
$$+ \frac{\bar{C}_{HD}}{v^2}\left|H^\dagger D_\mu H\right|^2 + \frac{\bar{C}_{HWB}}{v^2} H^\dagger \tau^I H\, W^I_{\mu\nu} B^{\mu\nu}$$
$$+ \frac{\bar{C}_{He}}{v^2}(H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{e}\gamma^\mu e) + \frac{\bar{C}_{Hu}}{v^2}(H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{u}\gamma^\mu u) + \frac{\bar{C}_{Hd}}{v^2}(H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{d}\gamma^\mu d)$$
$$+ \frac{\bar{C}_{Hq}^{(3)}}{v^2}(H^\dagger i \overleftrightarrow{D}^I_\mu H)(\bar{q}\tau^I\gamma^\mu q) + \frac{\bar{C}_{Hq}^{(1)}}{v^2}(H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{q}\gamma^\mu q) + \frac{\bar{C}_W}{v^2}\epsilon^{IJK} W^{I\nu}_\mu W^{J\rho}_\nu W^{K\mu}_\rho$$

$$\boxed{\bar{C} \equiv \frac{v^2}{\Lambda^2} C}$$

- Operators affecting Higgs observables

$$\mathcal{L}_{\rm SMEFT}^{\rm Warsaw} \supset \frac{\bar{C}_{eH}}{v^2}(H^\dagger H)(\bar{l}eH) + \frac{\bar{C}_{dH}}{v^2}(H^\dagger H)(\bar{q}dH) + \frac{\bar{C}_{uH}}{v^2}(H^\dagger H)(\bar{q}u\widetilde{H})$$
$$+ \frac{\bar{C}_G}{v^2} f^{ABC} G^{A\nu}_\mu G^{B\rho}_\nu G^{C\mu}_\rho + \frac{\bar{C}_{H\Box}}{v^2}(H^\dagger H)\Box(H^\dagger H) + \frac{\bar{C}_{uG}}{v^2}(\bar{q}\sigma^{\mu\nu}T^A u)\widetilde{H}\, G^A_{\mu\nu}$$
$$+ \frac{\bar{C}_{HW}}{v^2} H^\dagger H\, W^I_{\mu\nu} W^{I\mu\nu} + \frac{\bar{C}_{HB}}{v^2} H^\dagger H\, B_{\mu\nu} B^{\mu\nu} + \frac{\bar{C}_{HG}}{v^2} H^\dagger H\, G^A_{\mu\nu} G^{A\mu\nu}\,.$$

Dimension-6 Operators in SILH Basis

- Involved in precision electroweak, diboson and Higgs data

$$
\begin{aligned}
\mathcal{L}_{\mathrm{SMEFT}}^{\mathrm{SILH}} \supset\ & \frac{\bar{c}_W}{m_W^2}\frac{ig}{2}\left(H^\dagger\sigma^a \overleftrightarrow{D}^\mu H\right) D^\nu W^a_{\mu\nu} + \frac{\bar{c}_B}{m_W^2}\frac{ig'}{2}\left(H^\dagger \overleftrightarrow{D}^\mu H\right)\partial^\nu B_{\mu\nu} + \frac{\bar{c}_T}{v^2}\frac{1}{2}\left(H^\dagger \overleftrightarrow{D}_\mu H\right)^2 \\
& + \frac{\bar{c}_{ll}}{v^2}2(\bar{L}\gamma_\mu L)(\bar{L}\gamma^\mu L) + \frac{\bar{c}_{He}}{v^2}(iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{e}_R\gamma^\mu e_R) + \frac{\bar{c}_{Hu}}{v^2}(iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{u}_R\gamma^\mu u_R) \\
& + \frac{\bar{c}_{Hd}}{v^2}(iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{d}_R\gamma^\mu d_R) + \frac{\bar{c}'_{Hq}}{v^2}(iH^\dagger\sigma^a \overleftrightarrow{D}_\mu H)(\bar{Q}_L\sigma^a\gamma^\mu Q_L) \\
& + \frac{\bar{c}_{Hq}}{v^2}(iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{Q}_L\gamma^\mu Q_L) + \frac{\bar{c}_{HW}}{m_W^2} ig(D^\mu H)^\dagger\sigma^a(D^\nu H)W^a_{\mu\nu} + \frac{\bar{c}_{HB}}{m_W^2} ig'(D^\mu H)^\dagger(D^\nu H)B_{\mu\nu} \\
& + \frac{\bar{c}_{3W}}{m_W^2} g^3\epsilon_{abc}W^{a\,\nu}_{\mu}W^b_{\nu\rho}W^{c\,\rho\mu} + \frac{\bar{c}_g}{m_W^2} g_s^2|H|^2 G^A_{\mu\nu}G^{A\mu\nu} + \frac{\bar{c}_\gamma}{m_W^2} g'^2|H|^2 B_{\mu\nu}B^{\mu\nu} \\
& + \frac{\bar{c}_H}{v^2}\frac{1}{2}(\partial^\mu|H|^2)^2 - \sum_{f=e,u,d}\frac{\bar{c}_f}{v^2} y_f|H|^2\bar{F}_L H^{(c)} f_R \\
& + \frac{\bar{c}_{3G}}{m_W^2} g_s^3 f_{ABC}G^{A\nu}_{\mu}G^{B\rho}_{\nu}G^{C\mu}_{\rho} - \frac{\bar{c}_{uG}}{m_W^2} 4g_s y_u H^\dagger\cdot\bar{Q}_L\gamma^{\mu\nu}T_a u_R G^A_{\mu\nu}\,.
\end{aligned}
\tag{6}
$$

Precision Electroweak Measurements used in SMEFT Fit

EMSY, arXiv:1803.03252

Observable	Measurement	SM Prediction
Γ_Z [GeV]	2.4952 ± 0.0023	2.4943 ± 0.0[illegible]5
$\sigma^0_{\rm had}$ [nb]	41.540 ± 0.037	41.488 [illegible]
R^0_ℓ	20.767 ± 0.025	[illegible]
$A^{0,\ell}_{\rm FB}$	0.0171 ± 0.0010	[illegible]$.00009$
$\mathcal{A}_\ell\,(P_\tau)$	0.1465 ± 0.0[illegible]	[illegible]$ \pm 0.0004$
$\mathcal{A}_\ell$ (SLD)	$0.1513 \pm$ [illegible]	[illegible]$.1470 \pm 0.0004$
R^0_b	0.021[illegible]6	0.2158 ± 0.00015
R^0_c	[illegible]030	0.17223 ± 0.00005
$A^{0,b}_{\rm FB}$	[illegible]$ \pm 0.0016$	0.1031 ± 0.0003
[illegible]	[illegible]0707 ± 0.0035	0.0736 ± 0.0002
[illegible]	0.923 ± 0.020	0.9347
[illegible]	0.670 ± 0.027	0.6678 ± 0.0002
M_W [GeV]	80.387 ± 0.016	80.361 ± 0.006
M_W [GeV]	80.370 ± 0.019	80.361 ± 0.006

Probe 8 SMEFT directions

LEP1 and SLC: 12 Z-pole, (74 W^+W^-) measurements

New M_W measurement by ATLAS

Measurements used in Global SMEFT Fit

- ATLAS + CMS Higgs data from LHC Run 1

Production	Decay	Signal Strength	Production	Decay	Signal Strength
ggF	$\gamma\gamma$	$1.10^{+0.23}_{-0.22}$	Wh	[illegible]	[illegible]
ggF	ZZ	$1.13^{+0.34}_{-0.31}$	Wh	[illegible]	1.0 ± 0.5
ggF	WW	0.84 ± 0.17	[illegible]	[illegible]	$0.5^{+3.0}_{-2.5}$
ggF	$\tau\tau$	1.0 ± 0.6	[illegible]	WW	$5.9^{+2.6}_{-2.2}$
VBF	$\gamma\gamma$	1.3 ± 0.5	[illegible]	$\tau\tau$	$2.2^{+2.2}_{-1.8}$
VBF	ZZ	[illegible]	Zh	bb	0.4 ± 0.4
VBF	WW	[illegible]	tth	$\gamma\gamma$	$2.2^{+1.6}_{-1.3}$
VBF	$\tau\tau$	[illegible]	tth	WW	$5.0^{+1.8}_{-1.7}$
Wh	[illegible]	[illegible]	tth	$\tau\tau$	$-1.9^{+3.7}_{-3.3}$
Wh	[illegible]	$1.6^{+1.2}_{-1.0}$	tth	bb	1.1 ± 1.0
pp	[illegible]	$2.7^{+4.6}_{-4.5}$	pp	$\mu\mu$	0.1 ± 2.5

Probe 10 SMEFT directions

LEP 2 W^+W^- Measurements used

- Data from L3
- Also other Collaborations

σ	$\sqrt{s}$ [GeV]	Experimental value [pb]	Ref.	[illegible]etical value [pb]	Ref.
$\sigma_{\ell\nu\ell\nu}$	188.6	$1.88 \pm 0.16 \pm 0.07$	[illegible]	[illegible]$(1 \pm 0.5\%)$	[43]
	191.6	$1.66 \pm 0.39 \pm 0.07$	[illegible]	[illegible]$\pm 0.5\%)$	[43]
	195.5	$1.78 \pm 0.24 \pm 0.0$[illegible]	[illegible]	[illegible]$0.5\%)$	[43]
	199.6	1.75 ± 0.25[illegible]	[illegible]	[illegible]$5\%)$	[43]
	201.8	$1.51 \pm$[illegible]	[illegible]	[illegible])	[43]
	204.8	1.5[illegible]	[illegible]	[illegible]$5\%)$	[43]
	206.5	[illegible]	[illegible]	[illegible]$\pm 0.5\%)$	[43]
	208.0	[illegible]	[illegible]	[illegible]2 $(1 \pm 0.5\%)$	[43]
$\sigma_{\ell\nu qq}$	18[illegible]	[illegible]	[illegible]	$7.14\,(1 \pm 0.5\%)$	[43]
	[illegible]	[illegible]	[illegible]	$7.26\,(1 \pm 0.5\%)$	[43]
	[illegible]	[illegible]	[43]	$7.38\,(1 \pm 0.5\%)$	[43]
	[illegible]	[illegible]	[43]	$7.44\,(1 \pm 0.5\%)$	[43]
	[illegible]	[illegible].08	[43]	$7.47\,(1 \pm 0.5\%)$	[43]
	[illegible]	[illegible]± 0.13	[43]	$7.50\,(1 \pm 0.5\%)$	[43]
	[illegible]	[illegible]0.30 ± 0.08	[43]	$7.50\,(1 \pm 0.5\%)$	[43]
	[illegible]	[illegible]18 $\pm 1.21 \pm 0.09$	[43]	$7.50\,(1 \pm 0.5\%)$	[43]
[illegible]	[illegible]	$7.17 \pm 0.24 \pm 0.12$	[43]	$7.42\,(1 \pm 0.5\%)$	[43]
	[illegible]	$6.78 \pm 0.56 \pm 0.12$	[43]	$7.56\,(1 \pm 0.5\%)$	[43]
	[illegible]5.5	$6.92 \pm 0.34 \pm 0.11$	[43]	$7.68\,(1 \pm 0.5\%)$	[43]
	199.6	$7.91 \pm 0.36 \pm 0.13$	[43]	$7.76\,(1 \pm 0.5\%)$	[43]
	201.8	$7.09 \pm 0.52 \pm 0.12$	[43]	$7.79\,(1 \pm 0.5\%)$	[43]
	204.8	$7.66 \pm 0.37 \pm 0.13$	[43]	$7.81\,(1 \pm 0.5\%)$	[43]
	206.5	$8.07 \pm 0.29 \pm 0.13$	[43]	$7.82\,(1 \pm 0.5\%)$	[43]
	208.0	$7.29 \pm 1.16 \pm 0.11$	[43]	$7.82\,(1 \pm 0.5\%)$	[43]

Probe 8 SMEFT directions
3 unconstrained by Z, W data

Run 2 Higgs Measurements used in SMEFT Fit

Include all available kinematical information + 1 W^+W^- measurement at high p_T

CMS

Production	Decay	Sig. Stren.
1-jet, $p_T > 450$	$b\bar{b}$	$2.3^{+1.8}_{-1.6}$
Zh	$b\bar{b}$	0.9 ± 0.5
Wh	$b\bar{b}$	1.7 ± 0.7
$t\bar{t}h$	$b\bar{b}$	$-0.19^{+0.80}_{-0.81}$
$t\bar{t}h$	$1\ell + 2\tau_h$	$-1.20^{+1.50}_{-1.47}$
$t\bar{t}h$	$2\ell ss + 1\tau_h$	$0.86^{+0.79}_{-0.66}$
$t\bar{t}h$	$3\ell + 1\tau_h$	$1.22^{+1.34}_{-1.00}$
$t\bar{t}h$	$2\ell ss$	$1.7^{+0.6}_{-0.5}$
$t\bar{t}h$	3ℓ	[illegible]
$t\bar{t}h$	4ℓ	[illegible]
0-jet	WW	[illegible]
1-jet	[illegible]	[illegible]
2-jet	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	$2.1^{+2.3}_{-2.2}$
[illegible]	[illegible]	-1.4 ± 1.5
[illegible]	$\gamma\gamma$	$1.11^{+0.19}_{-0.18}$
[illegible]	$\gamma\gamma$	$0.5^{+0.6}_{-0.5}$
[illegible]	$\gamma\gamma$	2.2 ± 0.9
Vh	$\gamma\gamma$	$2.3^{+1.1}_{-1.0}$
ggF	4ℓ	$1.20^{+0.22}_{-0.21}$
0-jet	$\tau\tau$	0.84 ± 0.89
boosted	$\tau\tau$	$1.17^{+0.47}_{-0.40}$
VBF	$\tau\tau$	$1.11^{+0.34}_{-0.35}$

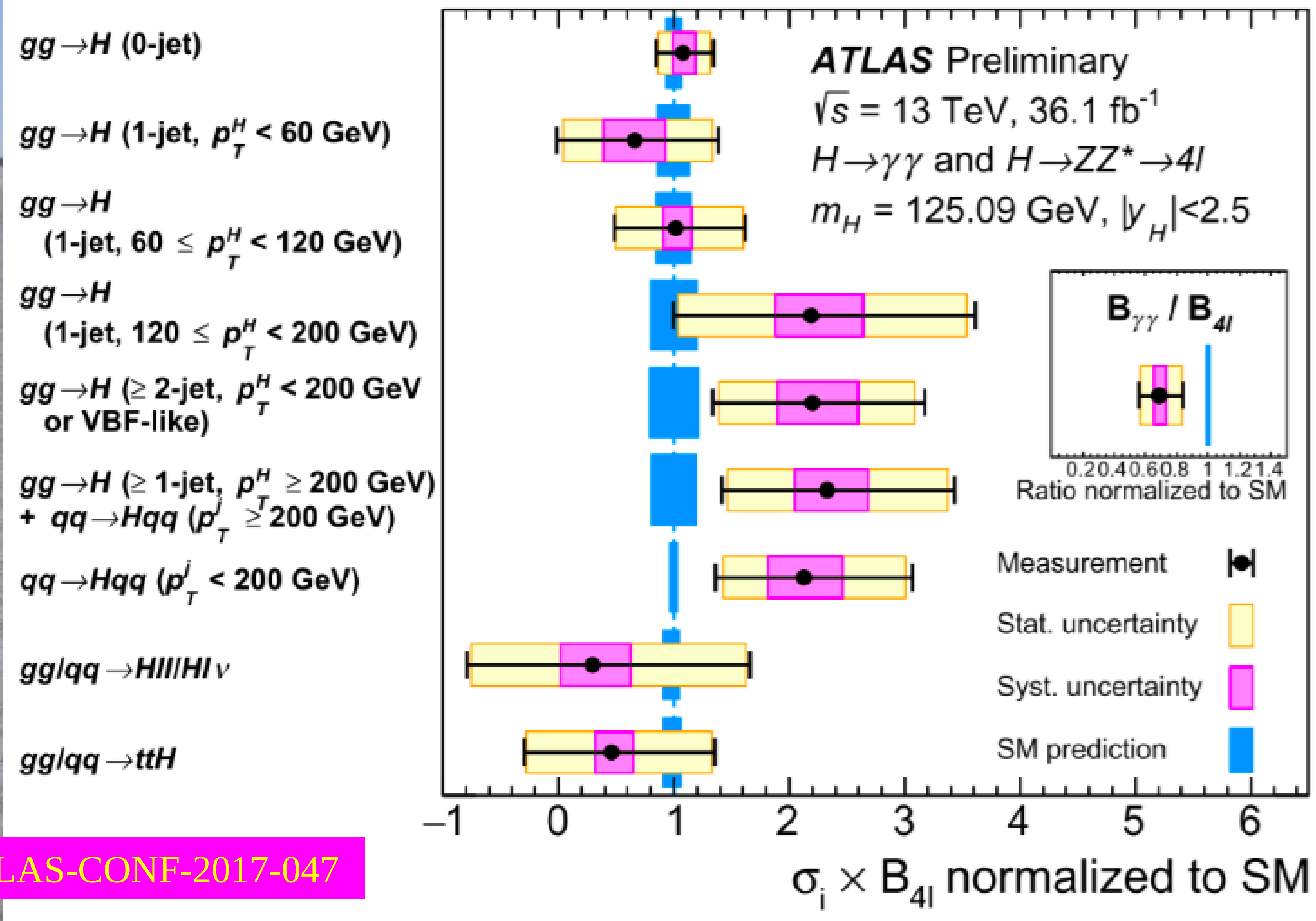
ATLAS

Production	Decay	[illegible]
pp	$\mu\mu$	[illegible]
Zh	[illegible]	[illegible]
Wh	[illegible]	[illegible]
$t\bar{t}h$	[illegible]	[illegible]
$t\bar{t}h$	[illegible]	$1.7^{+2.1}_{-1.9}$
[illegible]	[illegible]	$-0.6^{+1.6}_{-1.5}$
[illegible]	[illegible]	$1.6^{+1.8}_{-1.3}$
[illegible]	$2\ell ss + 1\tau_h$	$3.5^{+1.7}_{-1.3}$
[illegible]	3ℓ	$1.8^{+0.9}_{-0.7}$
[illegible]	$2\ell ss$	$1.5^{+0.7}_{-0.6}$
ggF	WW	$1.21^{+0.22}_{-0.21}$
VBF	WW	$0.62^{+0.37}_{-0.36}$
$B(h \to \gamma\gamma)/\ B(h \to 4\ell)$		$0.69^{+0.15}_{-0.13}$
0-jet	4ℓ	$1.07^{+0.27}_{-0.25}$
1-jet, $p_T < 60$	4ℓ	$0.67^{+0.72}_{-0.68}$
1-jet, $p_T \in (60, 120)$	4ℓ	$1.00^{+0.63}_{-0.55}$
1-jet, $p_T \in (120, 200)$	4ℓ	$2.1^{+1.5}_{-1.3}$
2-jet	4ℓ	$2.2^{+1.1}_{-1.0}$
"BSM-like"	4ℓ	$2.3^{+1.2}_{-1.0}$
VBF, $p_T < 200$	4ℓ	$2.14^{+0.94}_{-0.77}$
Vh lep	4ℓ	$0.3^{+1.3}_{-1.2}$
$t\bar{t}h$	4ℓ	$0.51^{+0.86}_{-0.70}$
Wh	WW	$3.2^{+4.4}_{-4.2}$

Use STXS

Probe 12 SMEFT directions

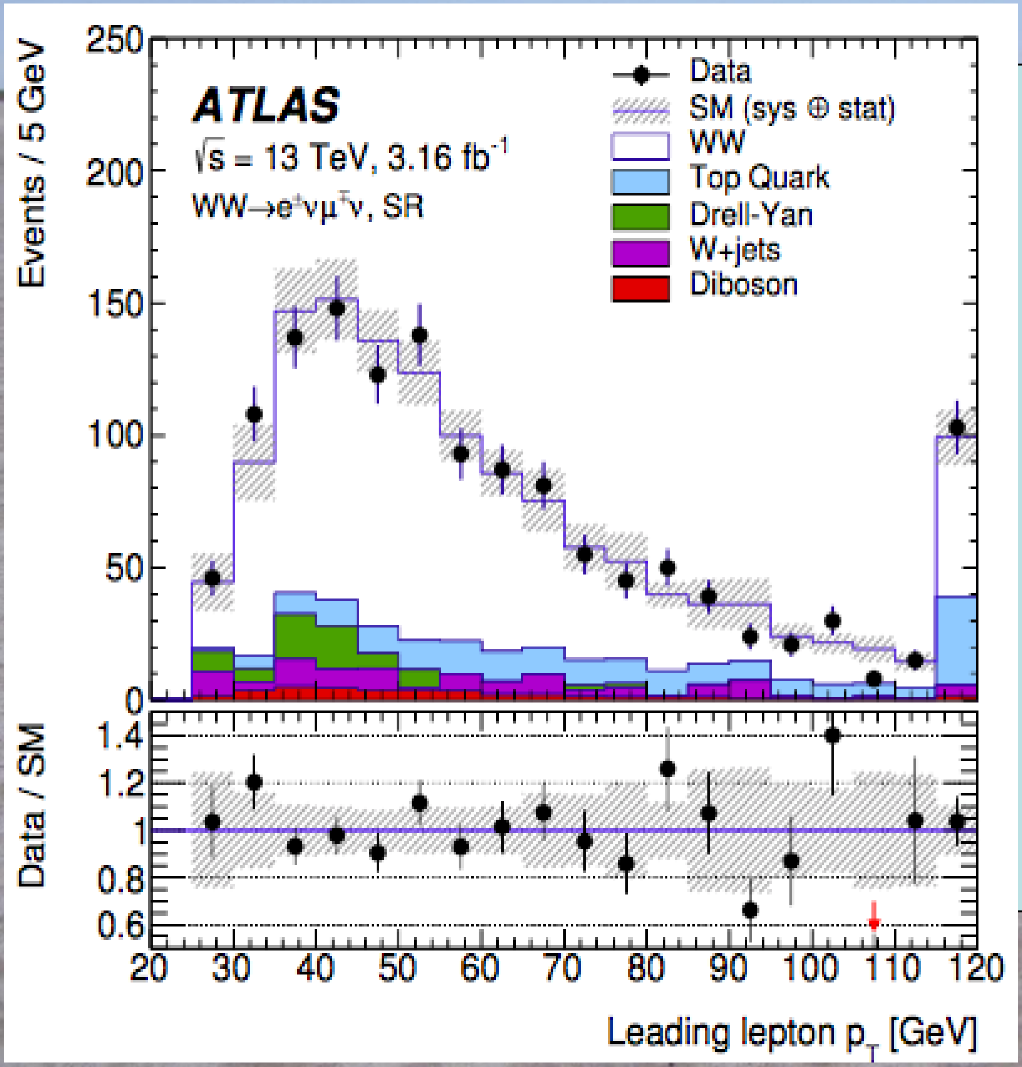
ATLAS STXS Measurements



ATLAS-CONF-2017-047

EMSY, arXiv:1803.03252

LHC W^+W^- at large p_T



- Overflow bin only
- Most sensitive to d=6
- Dependence on SILH operator coefficients:

$1-1.4c_{3W}-4.3c_{HW}-1.5c_W$

- Quadratic terms small

Constraints on Oblique Parameters

Warsaw basis

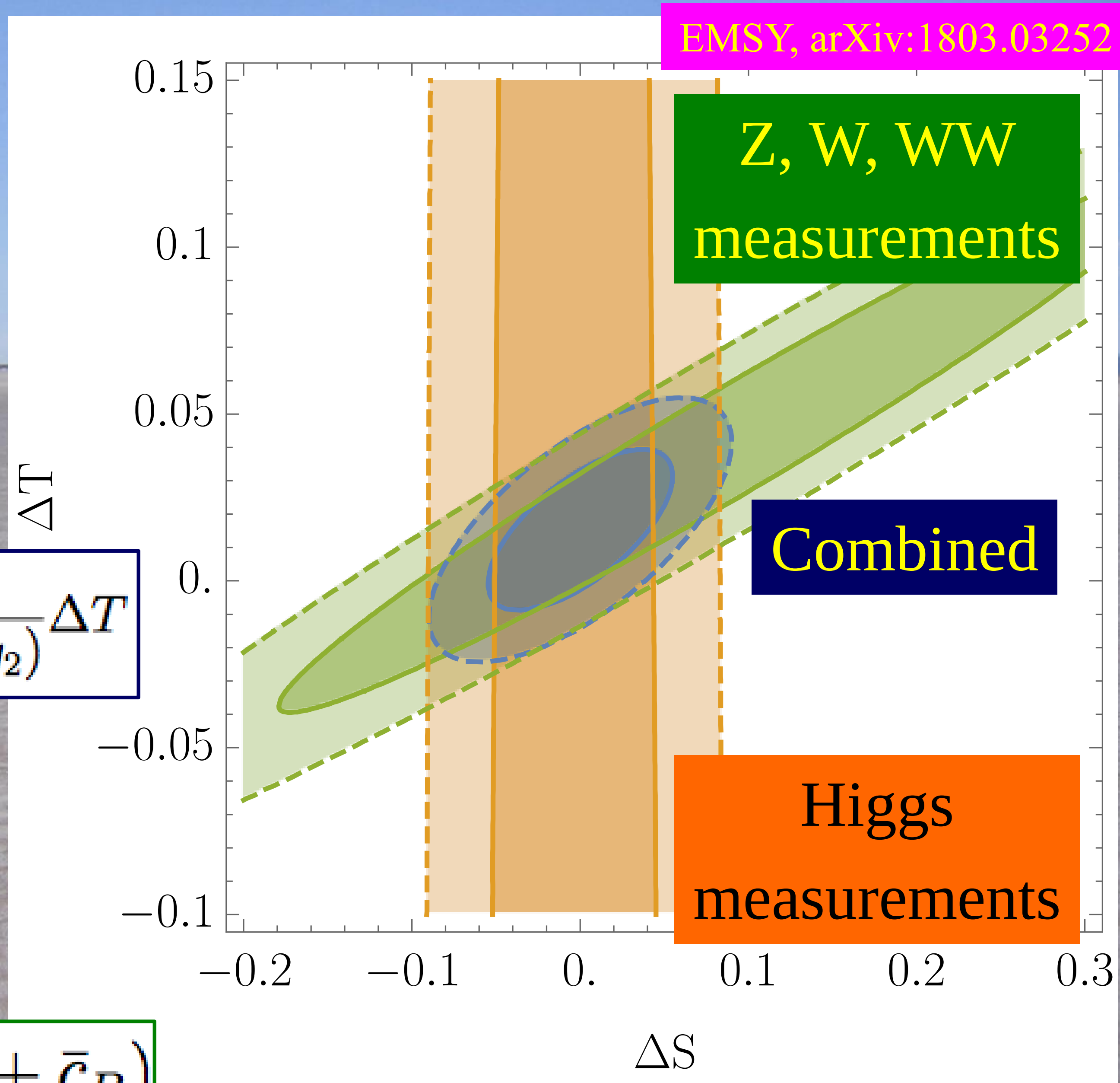
$$\frac{v^2}{\Lambda^2}C_{HD} = -\frac{g_1 g_2}{2\pi\,(g_1+g_2)}\Delta T$$

$$\frac{v^2}{\Lambda^2}C_{HWB} = \frac{g_1 g_2}{16\pi}\Delta S$$

SILH basis

$$\alpha\Delta T \;=\; \bar{c}_T$$

$$\alpha\Delta S = 4s_W^2(\bar{c}_W + \bar{c}_B)$$

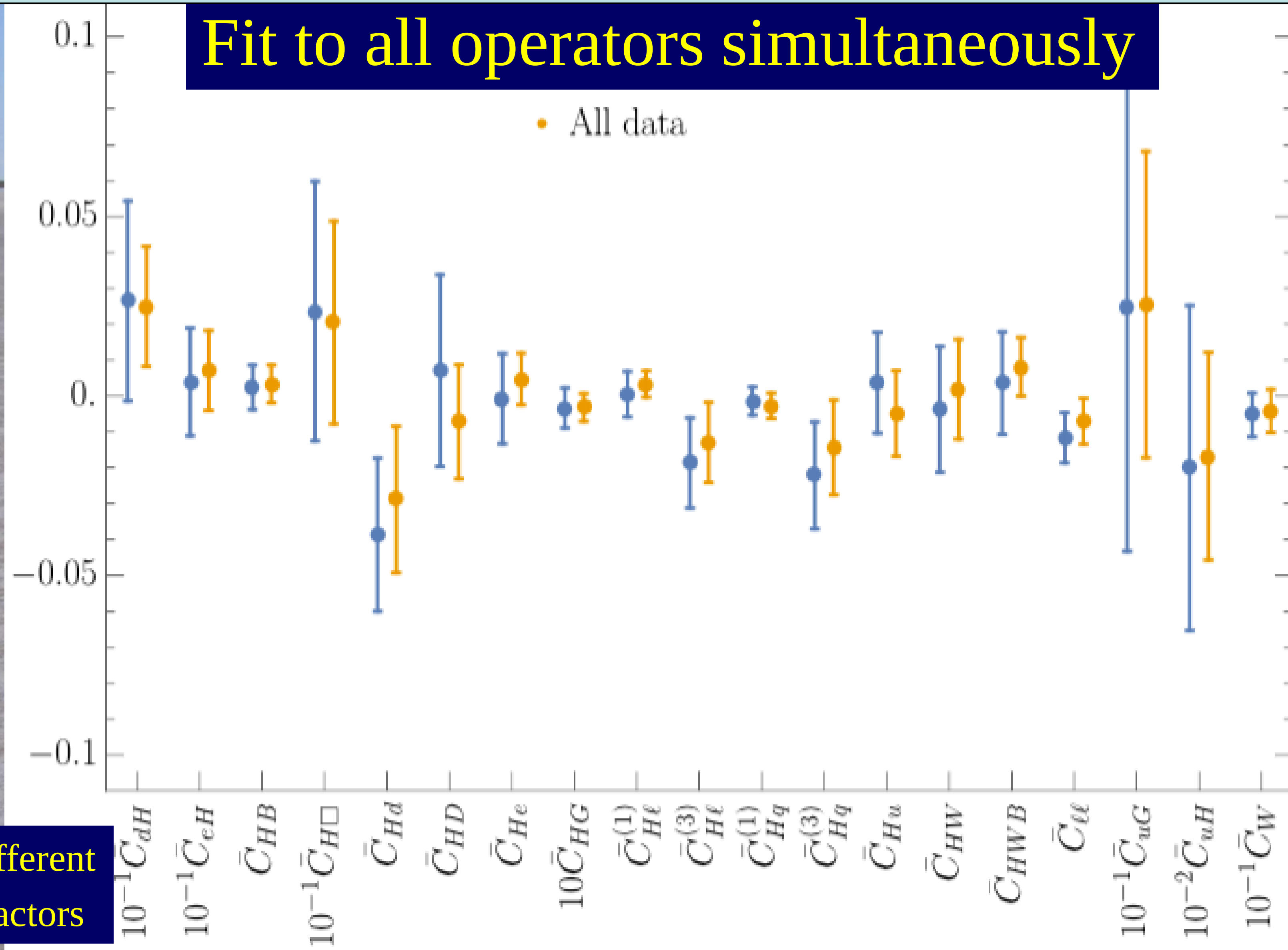


Complementary, comparable importance

EMSY, arXiv:1803.03252

Results of Global Fit in Warsaw Basis

Fit to all operators simultaneously

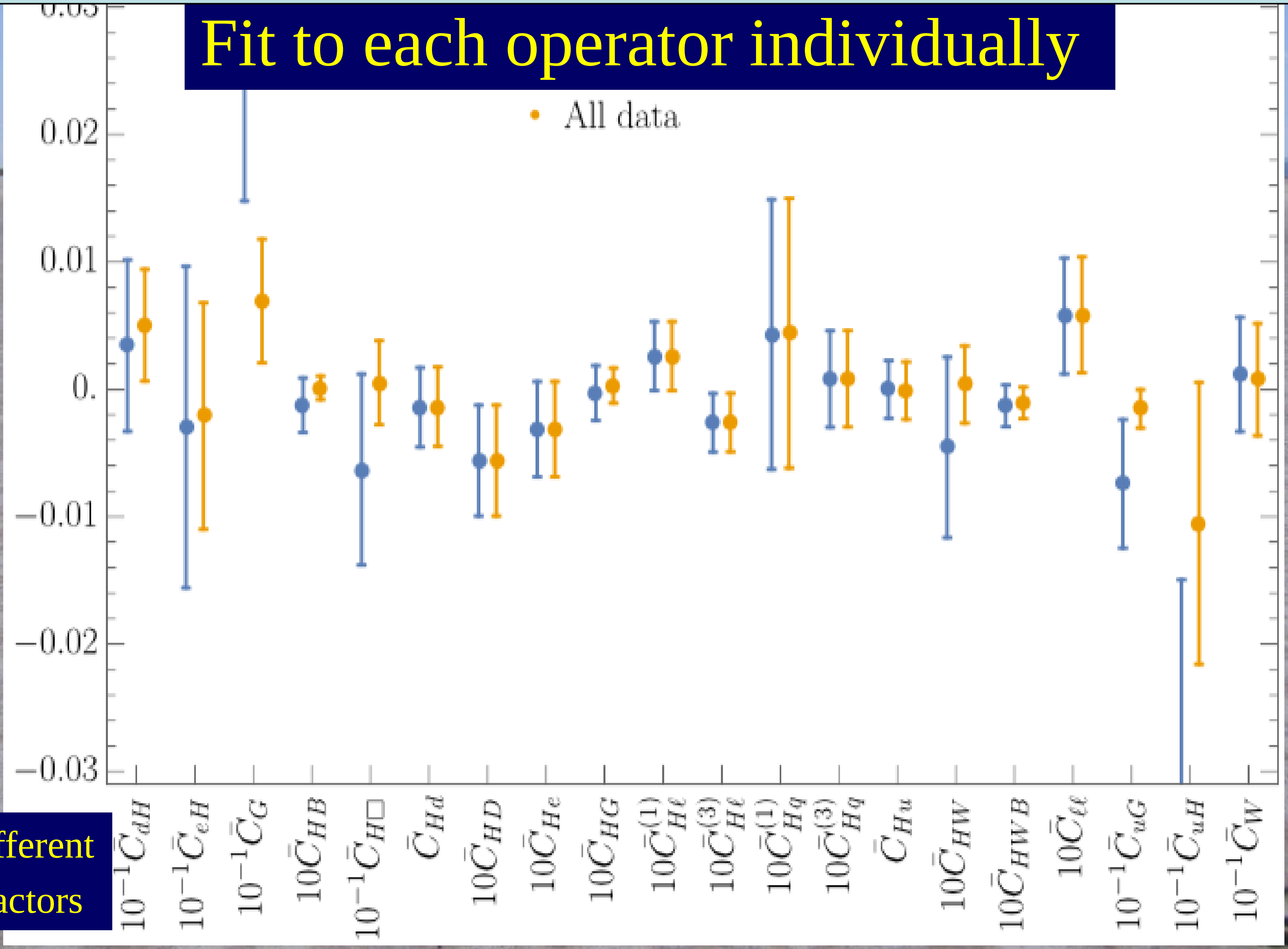


NB: Different scale factors

EMSY, arXiv:1803.03252

Results of Global Fit in Warsaw Basis

Fit to each operator individually

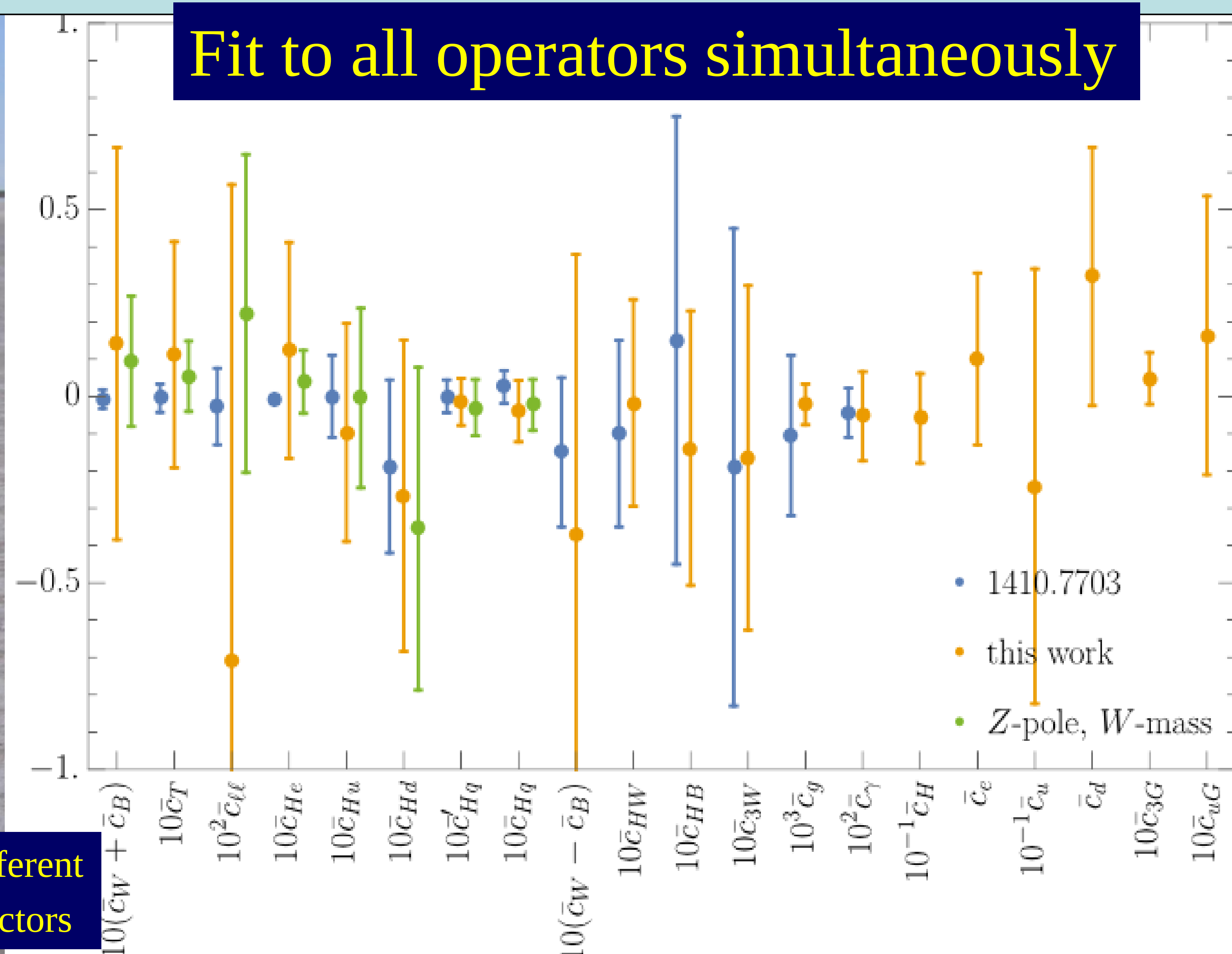


NB: Different scale factors

EMSY, arXiv:1803.03252

Results of Global Fit in SILH Basis

Fit to all operators simultaneously

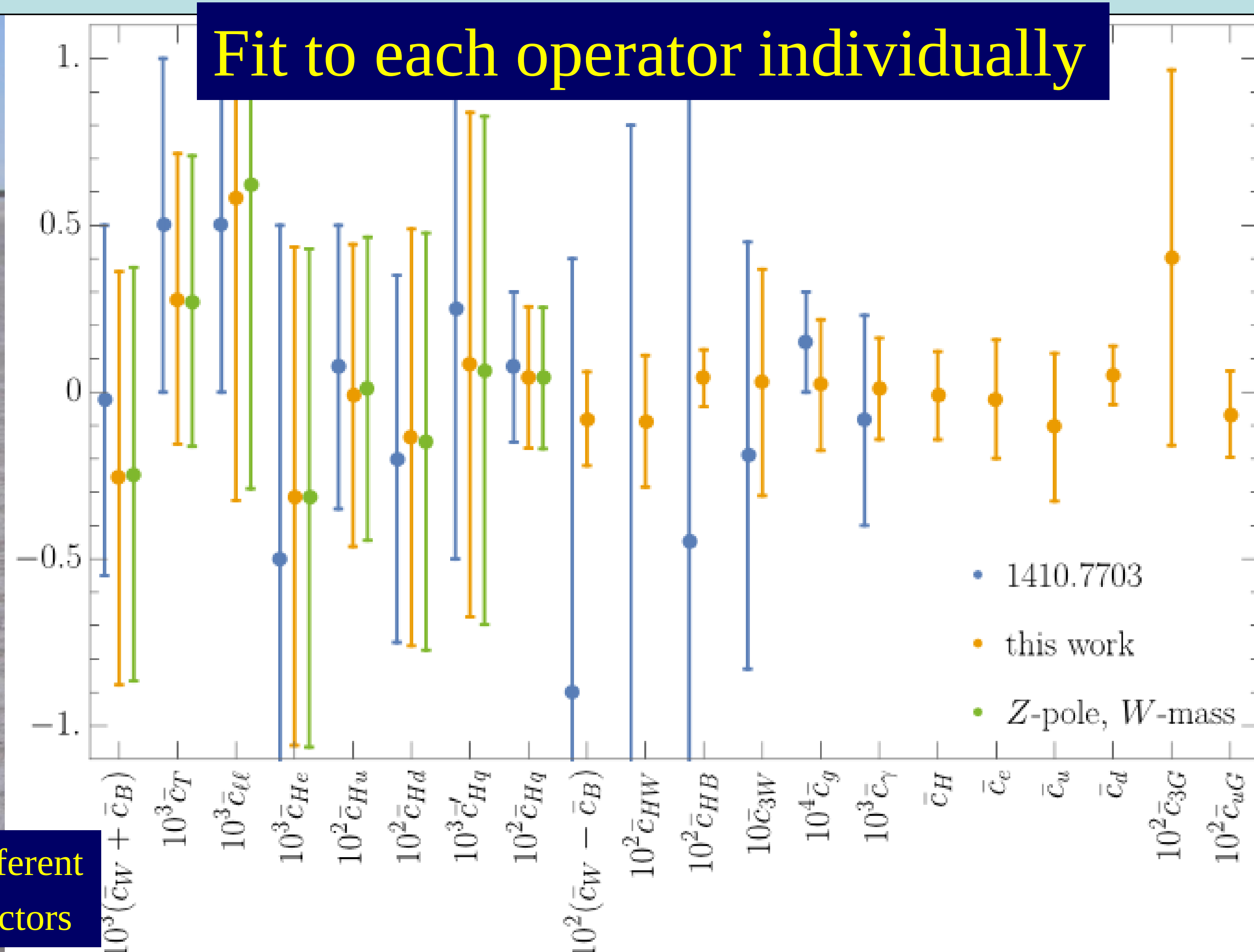


NB: Different scale factors

EMSY, arXiv:1803.03252

Results of Global Fit in SILH Basis

Fit to each operator individually



NB: Different scale factors

EMSY, arXiv:1803.03252

Numerical results from SMEFT Fit

Warsaw basis

Coefficient	Central value	1-σ
$\bar{C}_{dH}$	0.33	0.15
$\bar{C}_{eH}$	0.06	0.10
$\bar{C}_{G}$	0.09	0.06
$\bar{C}_{HB}$	0.003	0.005
$\bar{C}_{H\Box}$	0.50	0.27
$\bar{C}_{Hd}$	-0.036	0.017
$\bar{C}_{HD}$	-0.001	0.014
$\bar{C}_{He}$	0.002	0.007
$\bar{C}_{HG}$	0.0002	0.0003
$\bar{C}^{(1)}_{H\ell}$	0.002	0.003
$\bar{C}^{(3)}_{H\ell}$	-0.015	0.011
$\bar{C}^{(1)}_{Hq}$	-0.002	0.003
$\bar{C}^{(3)}_{Hq}$	-0.017	0.013
$\bar{C}_{Hu}$	0.000	0.011
$\bar{C}_{HW}$	-0.002	0.014
$\bar{C}_{HWB}$	0.006	0.007
$\bar{C}_{\ell\ell}$	-0.009	0.006
$\bar{C}_{uG}$	0.7	0.4
$\bar{C}_{uH}$	-4.8	2.6
$\bar{C}_{W}$	-0.05	0.06

SILH basis

Coefficient	Central value	1-σ
$\bar{c}_{3G}$	0.005	0.003
$\bar{c}_{3W}$	-0.018	0.023
$\bar{c}_{d}$	0.36	0.15
$\bar{c}_{e}$	0.09	0.11
$\bar{c}_{g}$	0.00002	0.00002
$\bar{c}_{H}$	-1.1	0.6
$\bar{c}_{HB}$	-0.013	0.018
$\bar{c}_{Hd}$	-0.035	0.017
$\bar{c}_{He}$	0.007	0.013
$\bar{c}_{Hq}$	-0.003	0.004
$\bar{c}'_{Hq}$	-0.003	0.003
$\bar{c}_{Hu}$	-0.03	0.013
$\bar{c}_{HW}$	0.002	0.014
$\bar{c}_{\ell\ell}$	-0.009	0.006
$\bar{c}_{T}$	0.005	0.013
$\bar{c}_{u}$	-4.7	2.6
$\bar{c}_{uG}$	0.031	0.016
$\bar{c}_{W} - \bar{c}_{B}$	-0.04	0.04
$\bar{c}_{W} + \bar{c}_{B}$	0.003	0.024
$\bar{c}_{\gamma}$	-0.001	0.0006

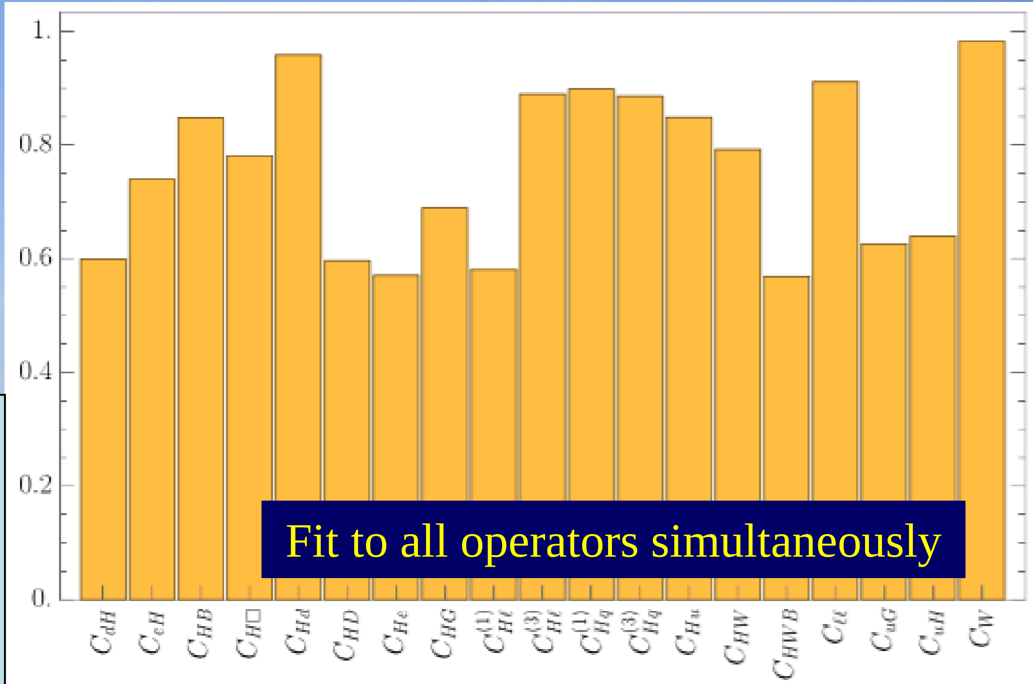
EMSY, arXiv:1803.03252

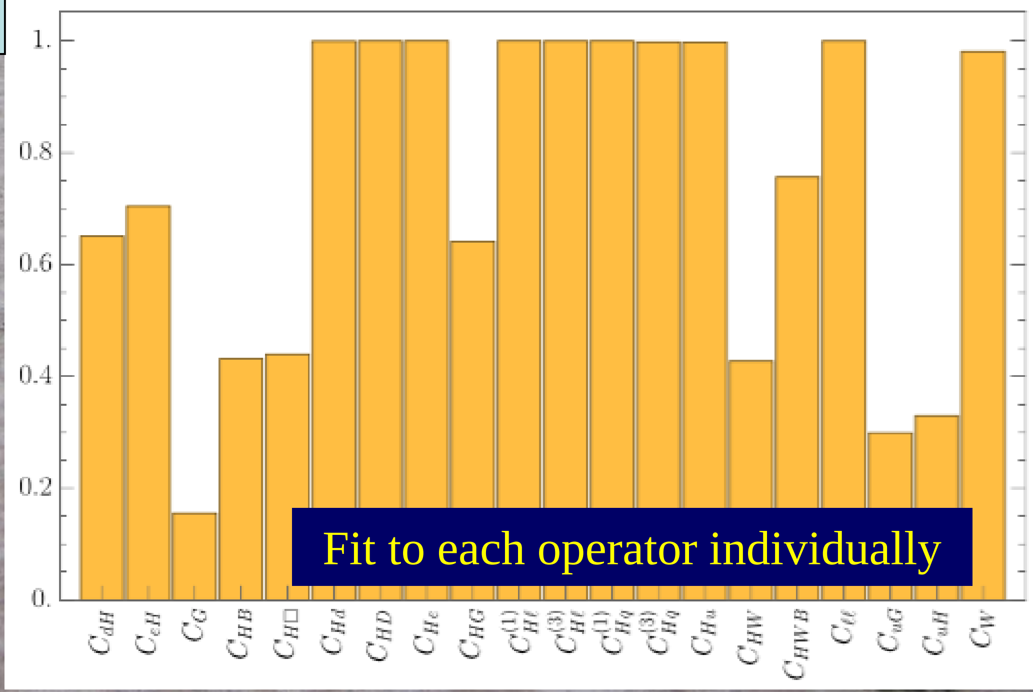
Impacts of Measurements in Warsaw Basis

Coefficient	Z-pole + m_W	WW at LEP2	Higgs Run1	Higgs Run2	LHC WW high-p_T
$\bar{C}_{dH}$	×	×	36	64	×
$\bar{C}_{eH}$	×	×	49.6	50.4	×
$\bar{C}_{G}$	×	×	2.3	97.7	×
$\bar{C}_{HB}$	×	×	19	81	×
$\bar{C}_{H\Box}$	×	×	19.7	80.3	0.01
$\bar{C}_{Hd}$	99.88	×	0.04	0.07	×
$\bar{C}_{HD}$	99.92	0.06	×	×	×
$\bar{C}_{He}$	99.99	0.01	×	×	×
$\bar{C}_{HG}$	×	×	34	66	0.02
$\bar{C}_{H\ell}^{(1)}$	99.97	0.03	×	×	×
$\bar{C}_{H\ell}^{(3)}$	99.56	0.41	×	×	0.01
$\bar{C}_{Hq}^{(1)}$	99.98	×	0.01	0.01	×
$\bar{C}_{Hq}^{(3)}$	98.6	0.96	0.19	0.23	0.07
$\bar{C}_{Hu}$	99.5	×	0.2	0.3	0.04
$\bar{C}_{HW}$	×	×	18	82	×
$\bar{C}_{HWB}$	57.9	0.02	8.2	33.9	×
$\bar{C}_{\ell\ell}$	99.66	0.32	×	0.01	0.01
$\bar{C}_{uG}$	×	×	7.8	92.2	×
$\bar{C}_{uH}$	×	×	9.5	90.5	×
$\bar{C}_{W}$	×	96.2	×	×	3.8

Improvements with Run 2 Data

Warsaw basis



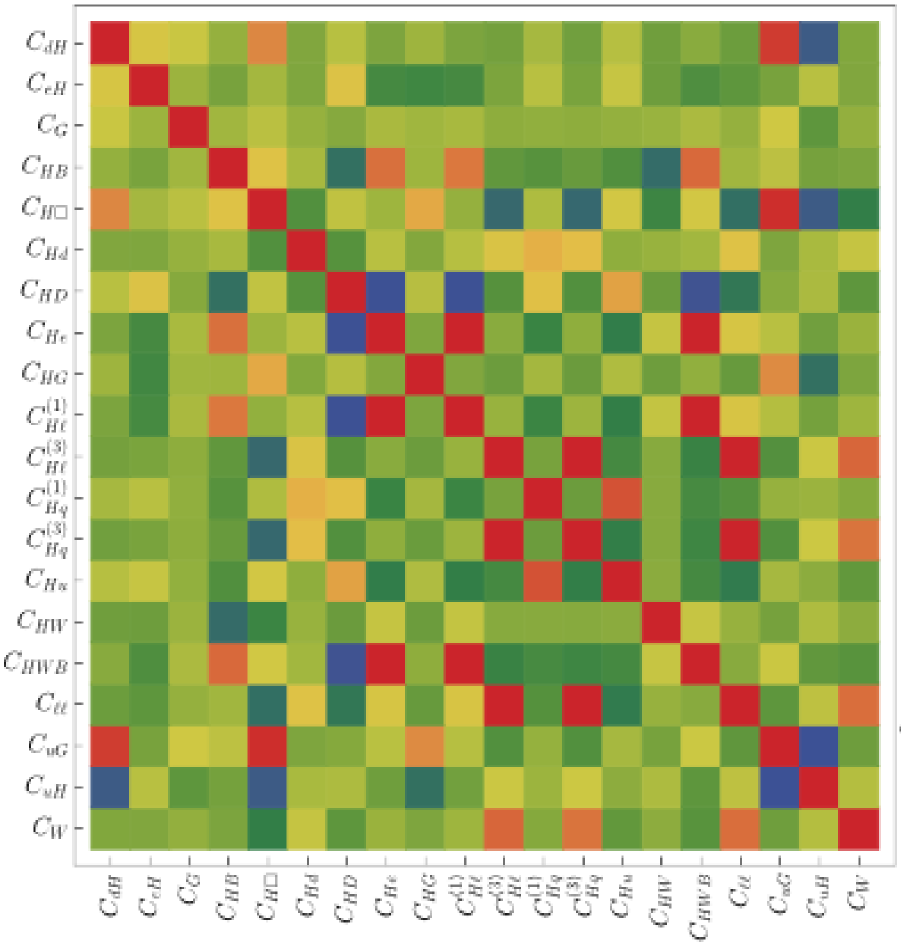


EMSY, arXiv:1803.03252

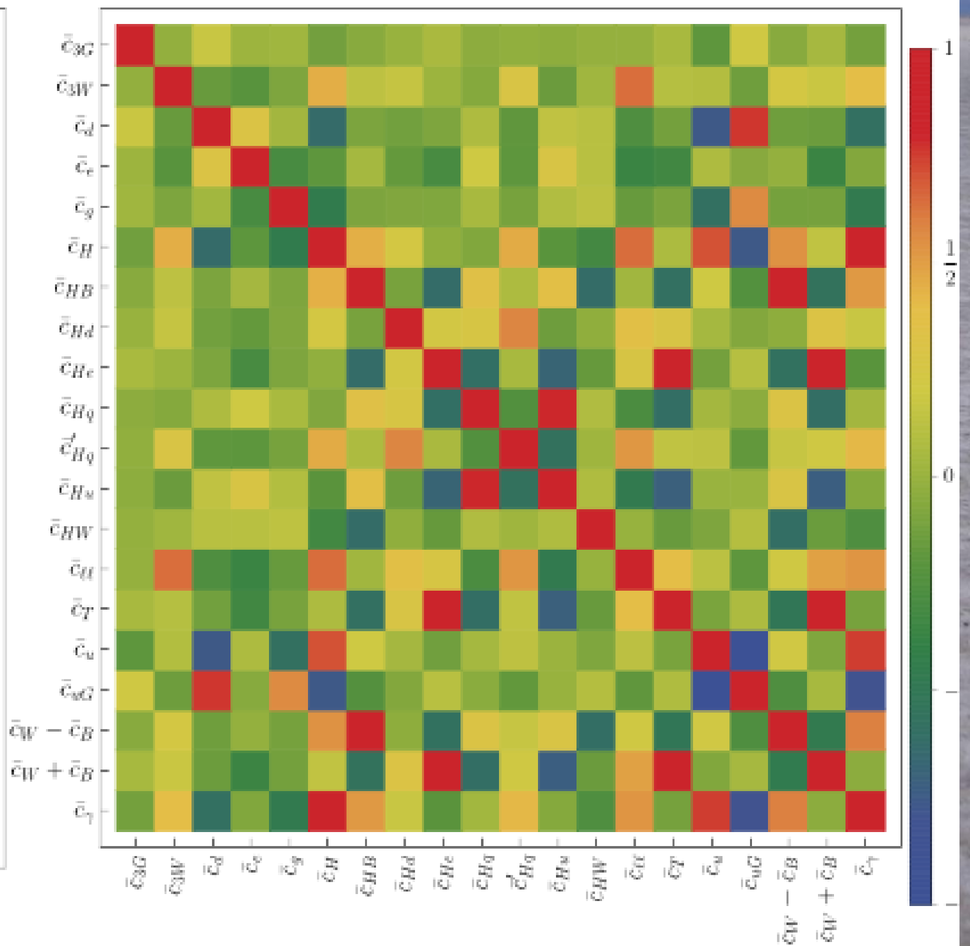
EMSY, arXiv:1803.03252

Correlations in Global SMEFT Fit

Warsaw basis



SILH basis



Simple Extensions of the Standard Model

Name	Spin	$SU(3)$	$SU(2)$	$U(1)$	Name	Spin	$SU(3)$	$SU(2)$	$U(1)$
$\mathcal{S}$	0	1	1	0	Δ_1	$\frac{1}{2}$	1	2	$-\frac{1}{2}$
$\mathcal{S}_1$	0	1	1	1	Δ_3	$\frac{1}{2}$	1	2	$-\frac{1}{2}$
φ	0	1	2	$\frac{1}{2}$	Σ	$\frac{1}{2}$	1	3	0
Ξ	0	1	3	0	Σ_1	$\frac{1}{2}$	1	3	-1
Ξ_1	0	1	3	1	U	$\frac{1}{2}$	3	1	$\frac{2}{3}$
$\mathcal{B}$	1	1	1	0	D	$\frac{1}{2}$	3	1	$-\frac{1}{3}$
$\mathcal{B}_1$	1	1	1	1	Q_1	$\frac{1}{2}$	3	2	$\frac{1}{6}$
$\mathcal{W}$	1	1	3	0	Q_5	$\frac{1}{2}$	3	2	$-\frac{5}{6}$
$\mathcal{W}_1$	1	1	3	1	Q_7	$\frac{1}{2}$	3	2	$\frac{7}{6}$
N	$\frac{1}{2}$	1	1	0	T_1	$\frac{1}{2}$	3	3	$-\frac{1}{3}$
E	$\frac{1}{2}$	1	1	-1	T_2	$\frac{1}{2}$	3	3	$\frac{2}{3}$

de Blas, Criado, Perez-Victoria & Santiago, arXiv:1711.10391

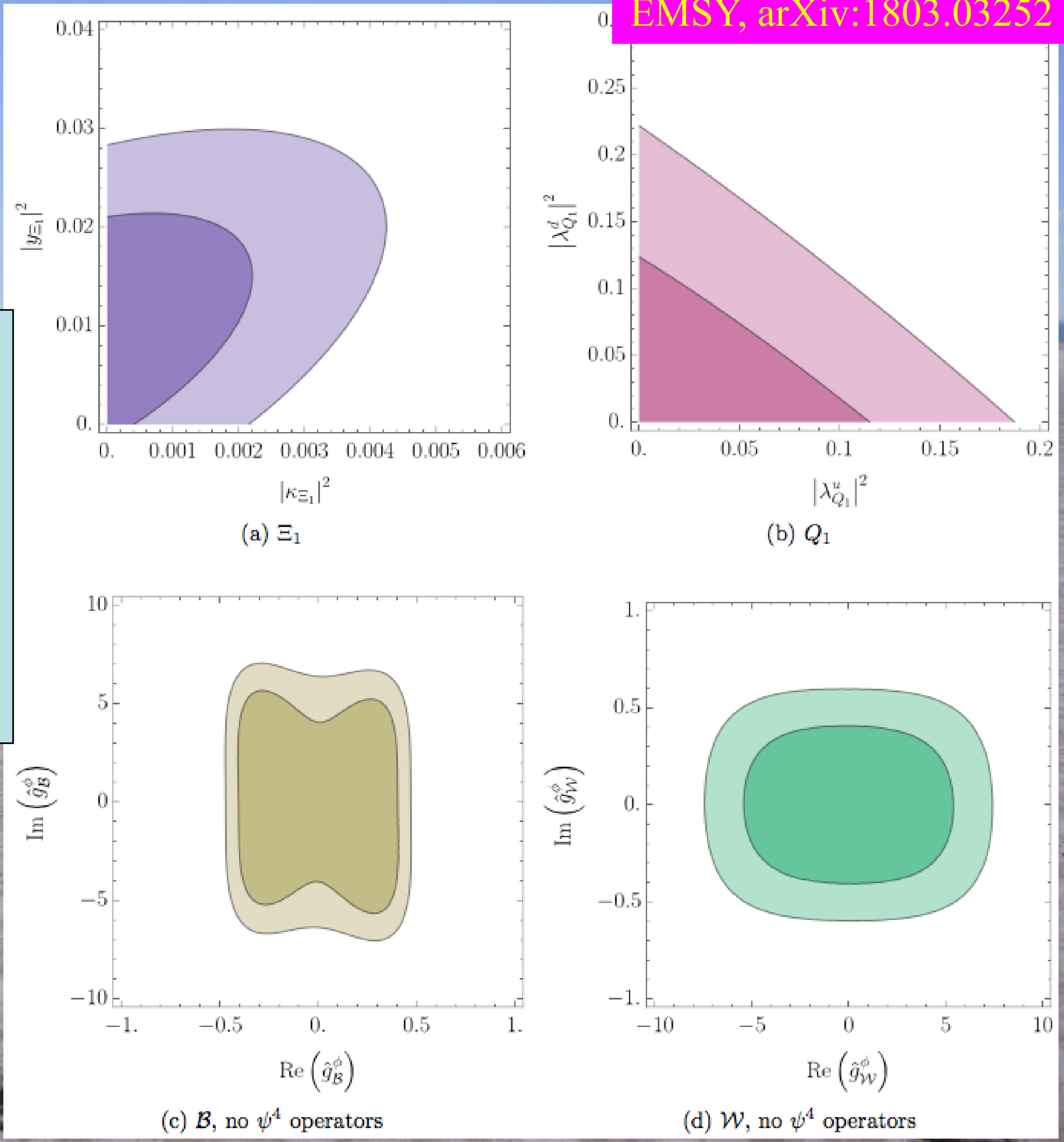
EMSY, arXiv:1803.03252

Numerical Constraints on Extensions

Model	χ^2	χ^2/n_d	Coupling	Mass / TeV
SM	157	0.987	-	-
$\mathcal{S}_1$	156	0.986	$\lvert y_{\mathcal{S}_1}\rvert^2 = (6.3 \pm 5.9) \cdot 10^{-3}$	$M_{\mathcal{S}_1} = (9.0,\ 49)$
φ, Type I	156	0.986	$Z_6 \cdot \cos\beta = -0.64 \pm 0.59$	$M_\varphi = (0.9,\ 4.3)$
Ξ	155	0.984	$\lvert\kappa_\Xi\rvert^2 = (4.2 \pm 3.4) \cdot 10^{-3}$	$M_\Xi = (12,\ 35)$
N	155	0.978	$\lvert\lambda_N\rvert^2 = (1.8 \pm 1.2) \cdot 10^{-2}$	$M_N = (5.8,\ 13)$
$\mathcal{W}_1$	155	0.984	$\left\lvert\hat{g}^\phi_{\mathcal{W}_1}\right\rvert^2 = (3.3 \pm 2.7) \cdot 10^{-3}$	$M_{\mathcal{W}_1} = (4.1,\ 13)$
E	156.9	0.993	$\lvert\lambda_E\rvert^2 = (2.0 \pm 9.7) \cdot 10^{-3}$	$M_E = (9.2,\ \infty)$
Δ_3	156	0.990	$\lvert\lambda_{\Delta_3}\rvert^2 = (0.8 \pm 1.1) \cdot 10^{-2}$	$M_{\Delta_3} = (7.3,\ \infty)$
Σ	156.7	0.992	$\lvert\lambda_\Sigma\rvert^2 = (0.9 \pm 2.0) \cdot 10^{-2}$	$M_\Sigma = (5.9,\ \infty)$
Q_5	156	0.990	$\lvert\lambda_{Q_5}\rvert^2 = 0.08 \pm 0.10$	$M_{Q_5} = (2.4,\ \infty)$
T_2	156.8	0.992	$\lvert\lambda_{T_2}\rvert^2 = (2.0 \pm 5.1) \cdot 10^{-2}$	$M_{T_2} = (3.8,\ \infty)$
$\mathcal{S}$	157	0.993	$\lvert y_\mathcal{S}\rvert^2 < 0.32$	$M_\mathcal{S} > 1.8$
Δ_1	157	0.993	$\lvert\lambda_{\Delta_1}\rvert^2 < 5.7 \cdot 10^{-3}$	$M_{\Delta_1} > 13$
Σ_1	157	0.993	$\lvert\lambda_{\Sigma_1}\rvert^2 < 7.3 \cdot 10^{-3}$	$M_{\Sigma_1} > 12$
U	157	0.993	$\lvert\lambda_U\rvert^2 < 2.8 \cdot 10^{-2}$	$M_U > 6.0$
D	157	0.993	$\lvert\lambda_D\rvert^2 < 1.4 \cdot 10^{-2}$	$M_D > 8.4$
Q_7	157	0.993	$\lvert\lambda_{Q_7}\rvert^2 < 7.7 \cdot 10^{-2}$	$M_{Q_7} > 3.6$
T_1	157	0.993	$\lvert\lambda_{T_1}\rvert^2 < 0.13$	$M_{T_1} > 3.0$
$\mathcal{B}_1$	157	0.993	$\left\lvert\hat{g}^\phi_{\mathcal{B}_1}\right\rvert^2 < 2.4 \cdot 10^{-3}$	$M_{\mathcal{B}_1} > 21$

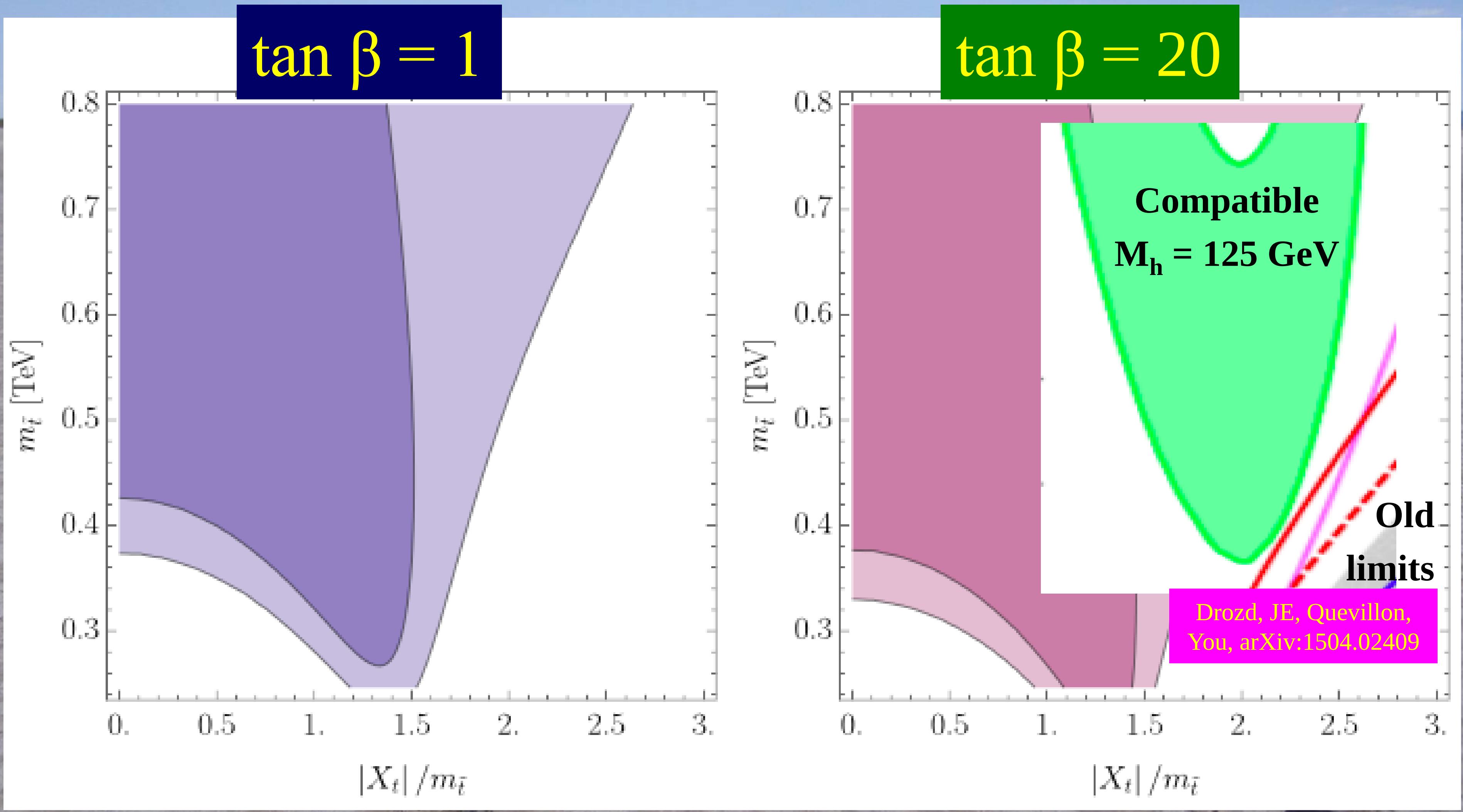
Constraints on SM Extensions

EMSY, arXiv:1803.03252



EMSY, arXiv:1803.03252

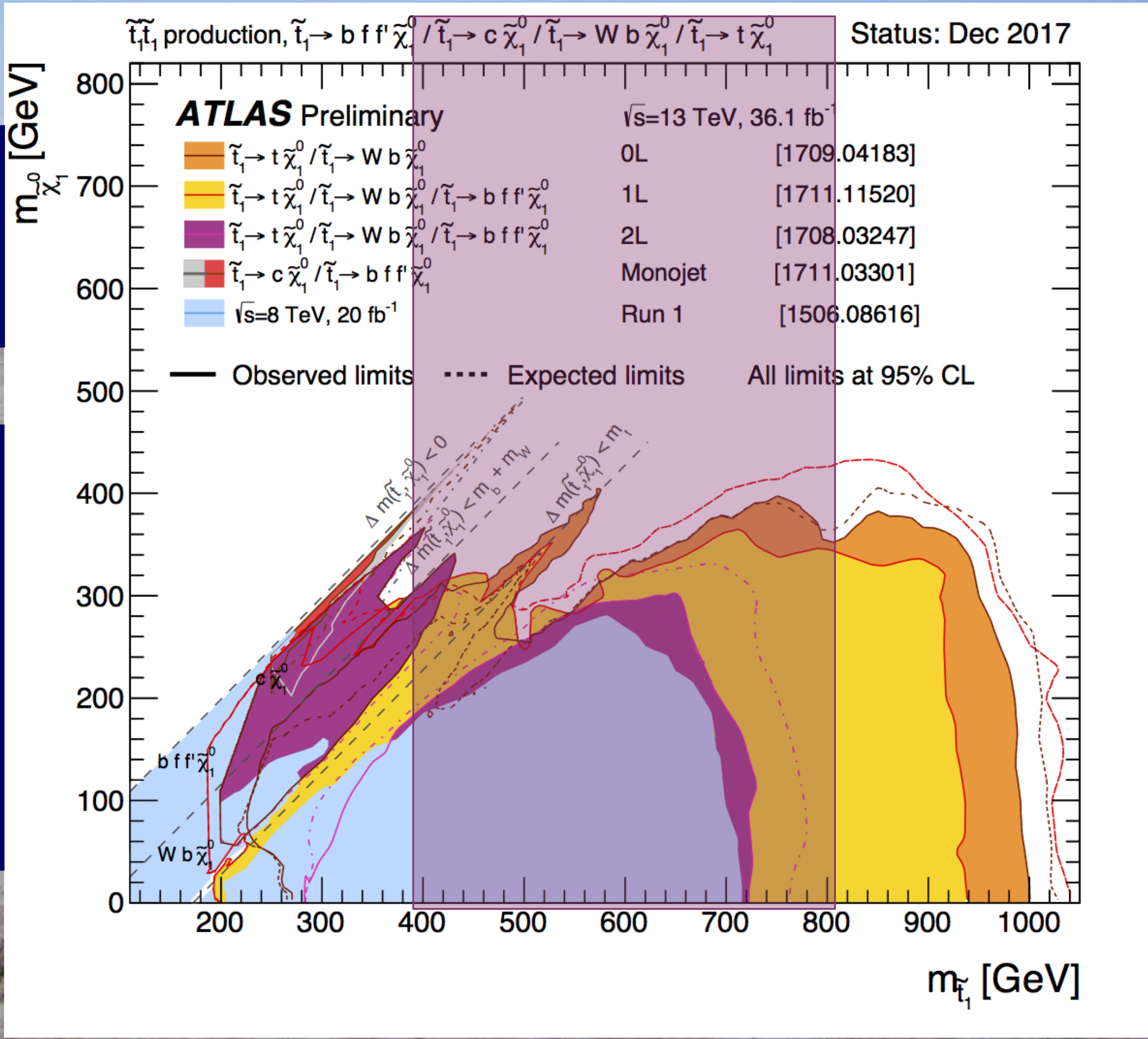
SMEFT Constraints on Light Stops



Direct Constraints on Light Stops

Depend on m_{LSP} not on tan β

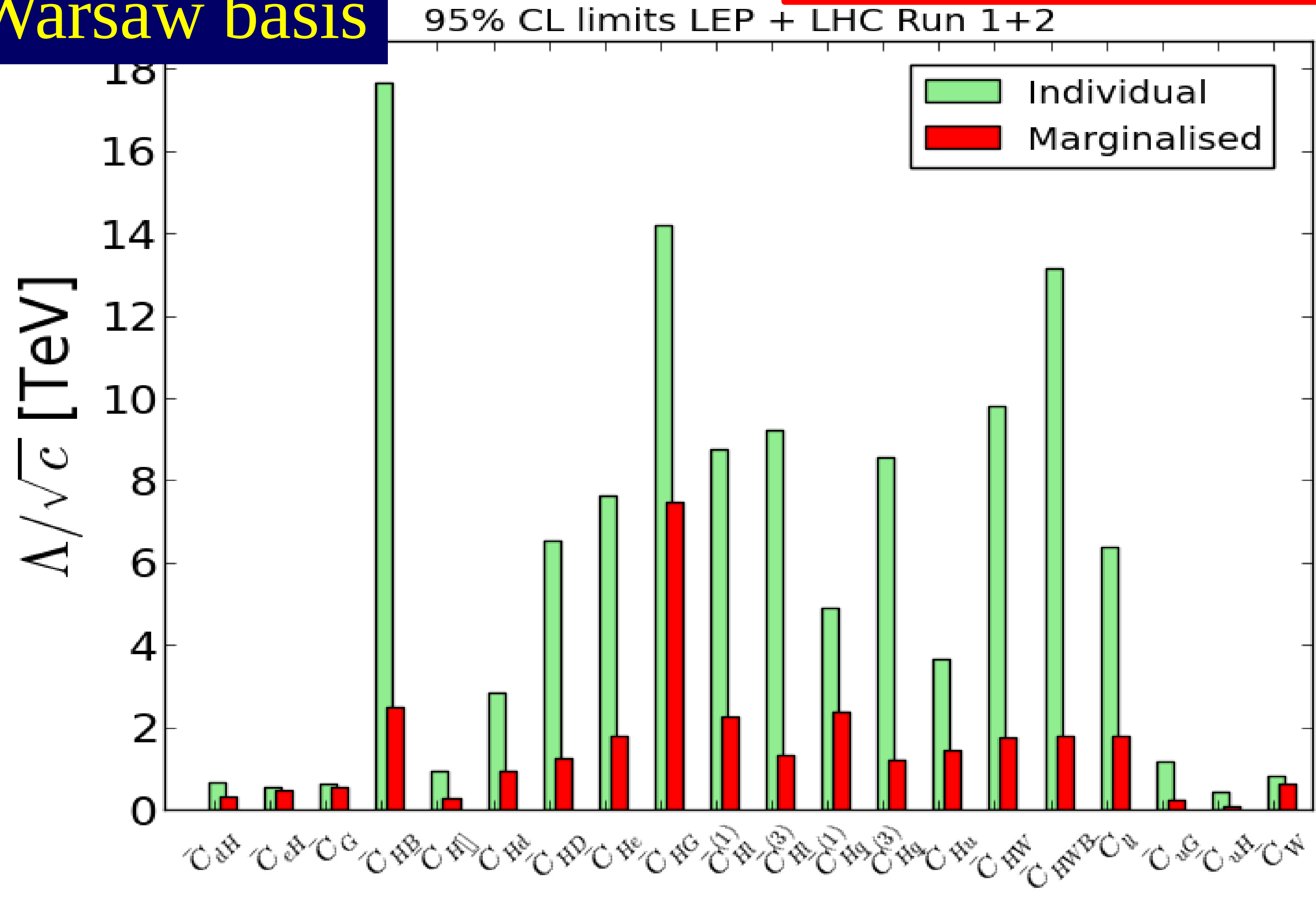
Comparison with SMEFT depends on mixing X_t



Summary

Theory	χ^2	χ^2/n_d	p-value
SM	157	0.987	0.532
SMEFT	137	0.987	0.528
SMEFT*	143	0.977	0.564

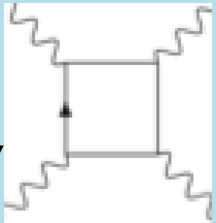
Warsaw basis



Supplement on dimension-8 operators

Light-by-Light Scattering in QED

- Electron (charged particle) loops induce light-by-light scattering: γ



- First calculations:

Bemerkungen zur Diracschen Theorie des Positrons.

Von **W. Heisenberg** in Leipzig.

(Eingegangen am 21. Juni 1934.)

Folgerungen aus der Diracschen Theorie des Positrons.

Von **W. Heisenberg** und **H. Euler** in Leipzig.

Mit 2 Abbildungen. (Eingegangen am 22. Dezember 1935.)

$$\mathfrak{L} = \frac{1}{2}(\mathfrak{E}^2 - \mathfrak{B}^2) + \frac{e^2}{hc}\int_0^\infty e^{-\eta}\frac{d\eta}{\eta^3}\left\{ i\eta^2(\mathfrak{E}\mathfrak{B}) \cdot \frac{\cos\left(\frac{\eta}{|\mathfrak{E}_k|}\sqrt{\mathfrak{E}^2 - \mathfrak{B}^2 + 2i(\mathfrak{E}\mathfrak{B})}\right) + \text{konj}}{\cos\left(\frac{\eta}{|\mathfrak{E}_k|}\sqrt{\mathfrak{E}^2 - \mathfrak{B}^2 + 2i(\mathfrak{E}\mathfrak{B})}\right) - \text{konj}} + |\mathfrak{E}_k|^2 + \frac{\eta^2}{3}(\mathfrak{B}^2 - \mathfrak{E}^2)\right\}$$

Born-Infeld Theory

Foundations of the New Field Theory.

By M. Born and L. Infeld,† Cambridge.

(Communicated by R. H. Fowler, F.R.S.—Received January 26, 1934.)

- Original Born-Infeld modification of QED:

$$\mathsf{L} = b^2\left(\sqrt{1 + \frac{1}{b^2}(\mathbf{H}^2 - \mathbf{E}^2)} - 1\right).$$

- Based on “unitarian” idea of maximum electromagnetic field, cf, velocity of light
- Limit on Coulomb potential

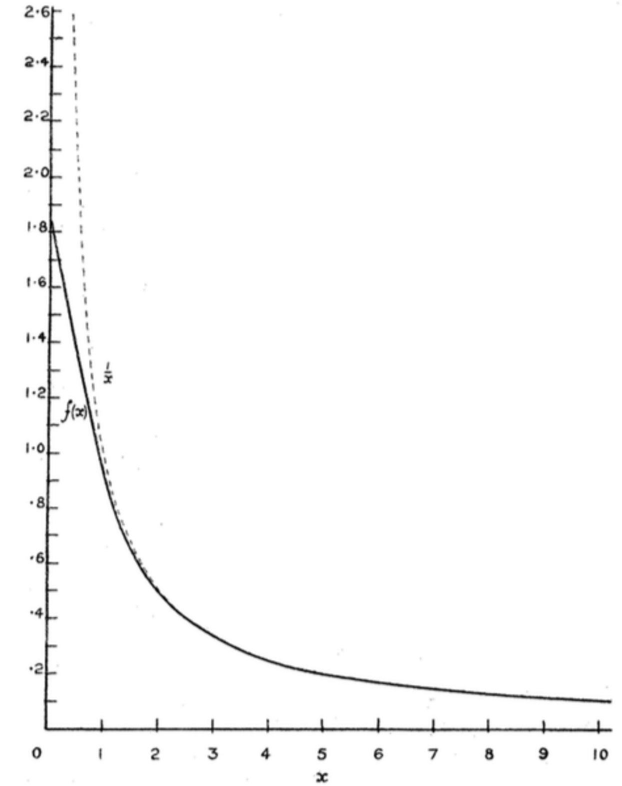


Fig. 1.

Born-Infeld & String Theory

- Original Born-Infeld modification of QED: Born & Infeld 1934

$$\mathcal{L}_{\rm QED} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} \to \mathcal{L}_{\rm BI} = \beta^2\left(1-\sqrt{1+\frac{1}{2\beta^2}F_{\mu\nu}F^{\mu\nu}-\frac{1}{16\beta^4}(F_{\mu\nu}\tilde{F}^{\mu\nu})^2}\right)$$

- Derived from string theory: Fradkin & Tseytlin 1985

in D dimensions: $\int d^D y \left[\det\left(\delta_{\mu\nu}+2\pi\alpha' F_{\mu\nu}\right)\right]^{1/2}$

4 dimensions: $[\det(\delta_{\mu\nu}+\bar{F}_{\mu\nu})]^{1/2} = [1+\frac{1}{2}\bar{F}^2_{\mu\nu}+\frac{1}{16}(\bar{F}_{\mu\nu}\bar{F}^*_{\mu\nu})^2]^{1/2}$

- Limiting gauge field ⟷ brane velocity = light

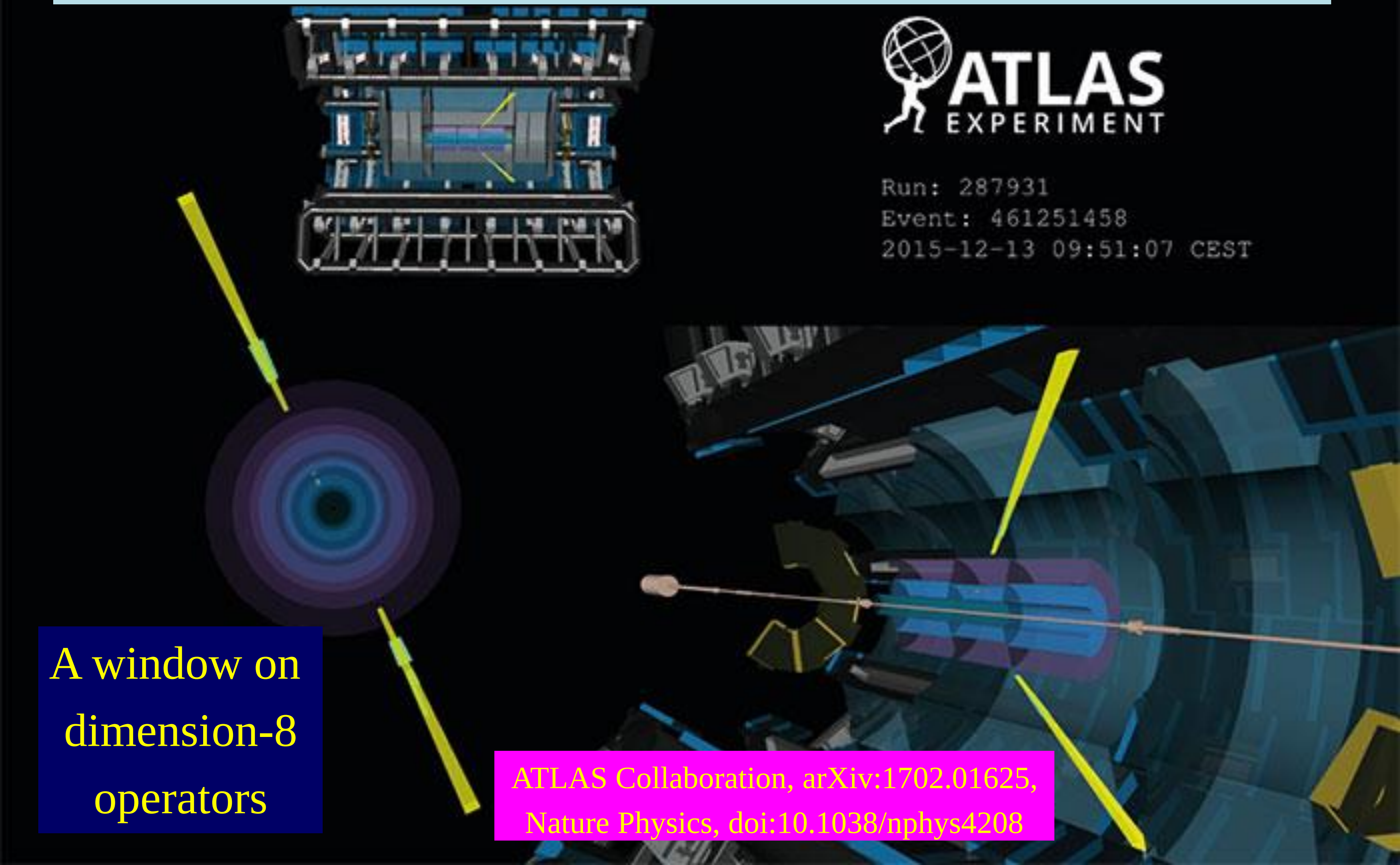
$$\mathcal{L}_{BI} \propto \sqrt{1-(2\pi\alpha' e\mathbf{E})^2} \quad \leftrightarrow \quad \mathcal{L}_{particle} \propto \sqrt{1-v^j v_j}$$

Bachas, hep-th/9511043

- Mass scale M = √β

⟷ 1/distance between branes, ≥ TeV?

Light-by-Light Scattering

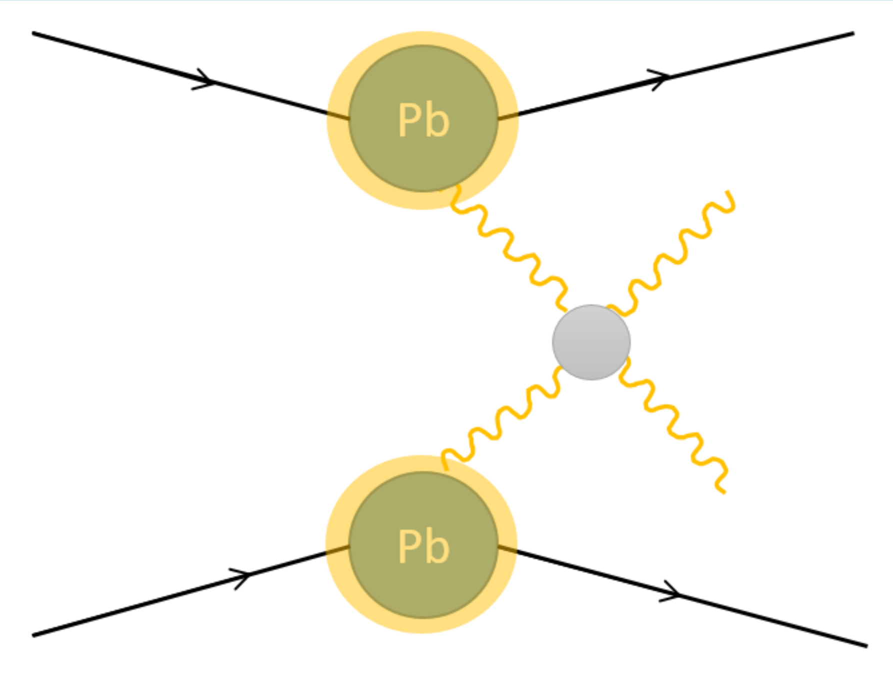


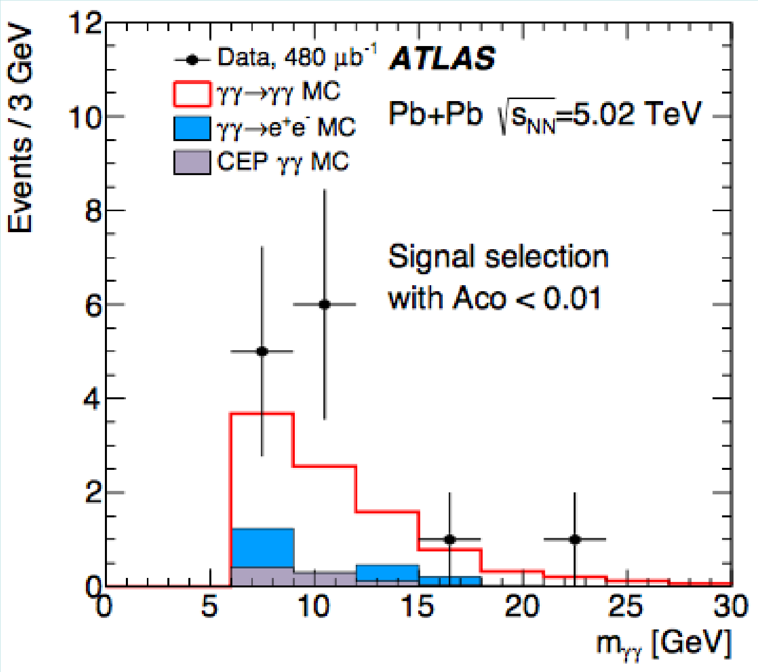
A window on dimension-8 operators

ATLAS Collaboration, arXiv:1702.01625, Nature Physics, doi:10.1038/nphys4208

First Measurement of Light-by-Light Scattering

- Peripheral heavy-ion collisions at the LHC: $\gamma\gamma \rightarrow \gamma\gamma$





- Expected in ordinary QED from fermion loops
- ATLAS measurement agrees with QED

Heisenberg & Euler 1936

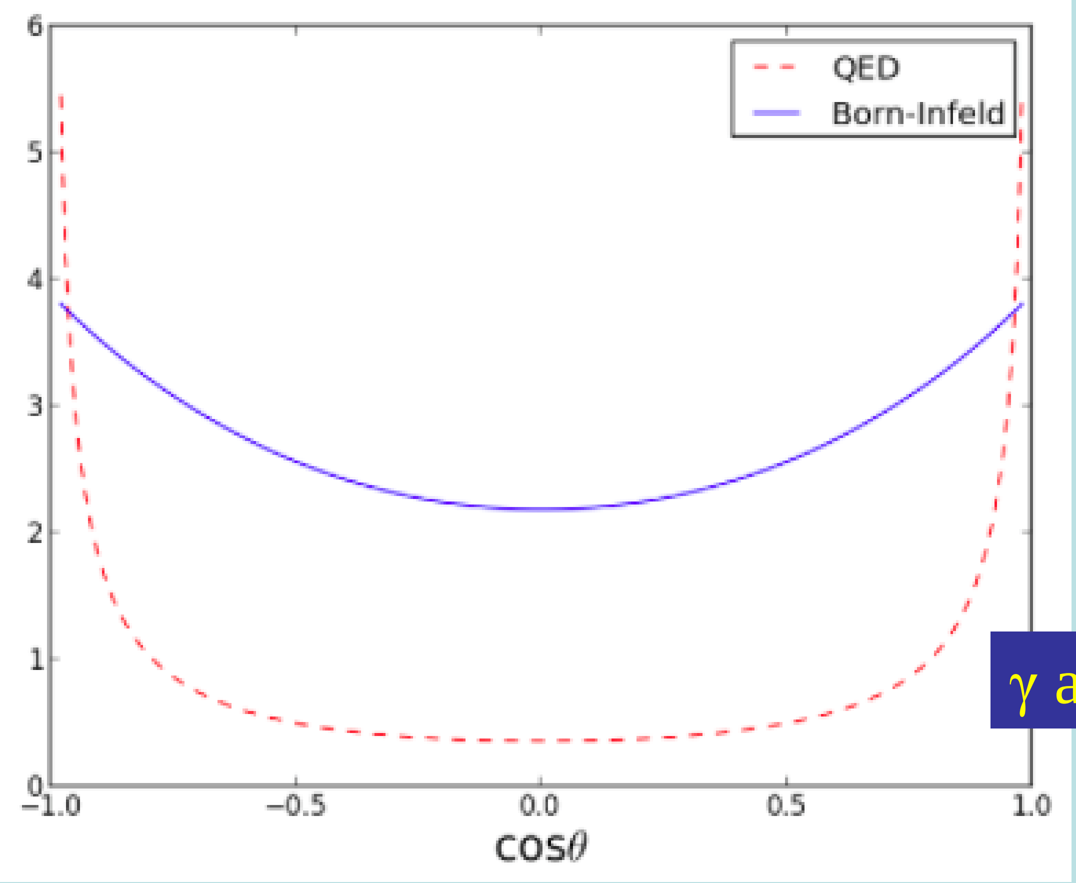
- Can be used to constrain nonlinearities in Born-Infeld

JE, Mavromatos & You: arXiv:1703.08450

Light-by-Light Scattering: QED vs Born-Infeld

JE, Mavromatos & You, arXiv:1703.08450

- Characteristic angular distributions



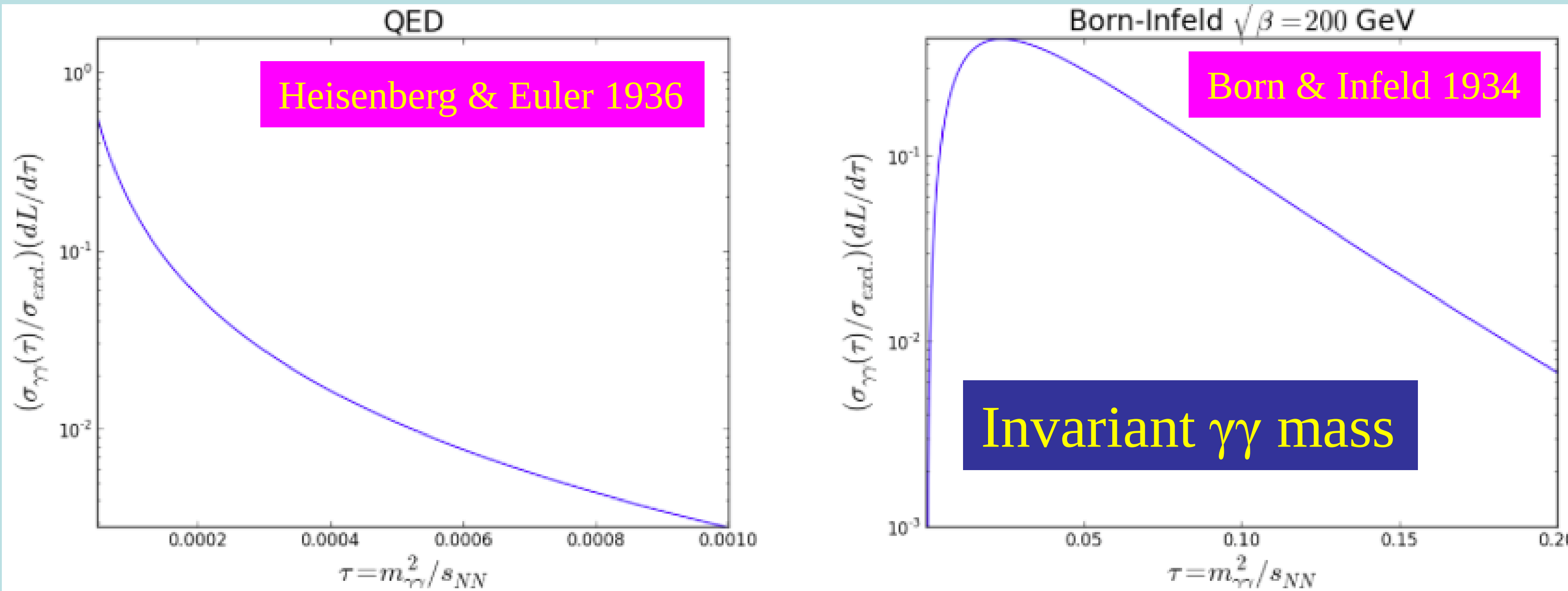
γ angle

- Born-Infeld more isotropic, larger γγ masses

Light-by-Light Scattering: QED vs Born-Infeld

JE, Mavromatos & You, arXiv:1703.08450

- Characteristic mass distributions

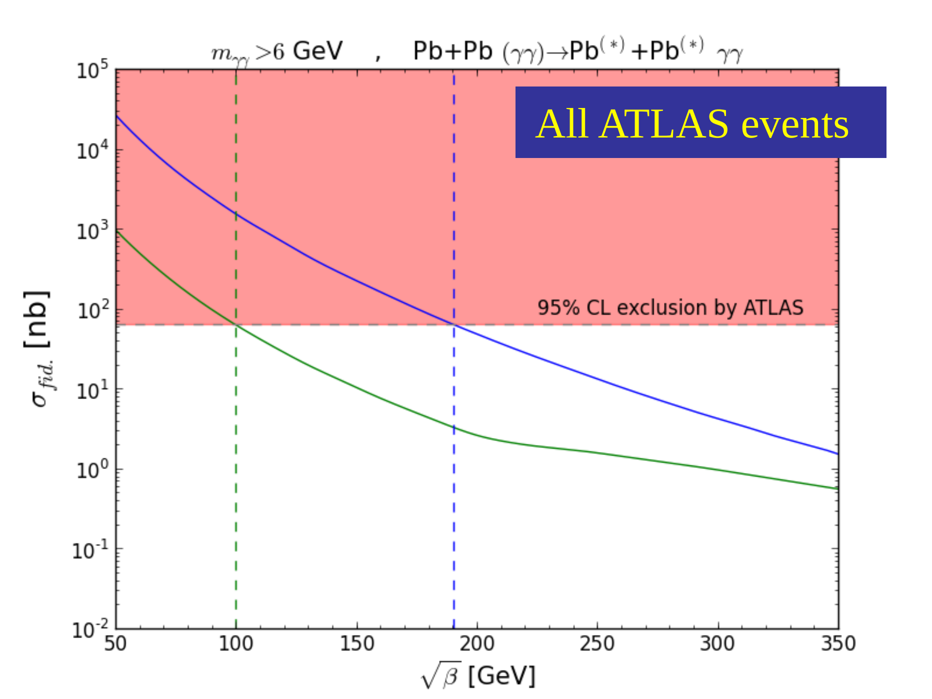


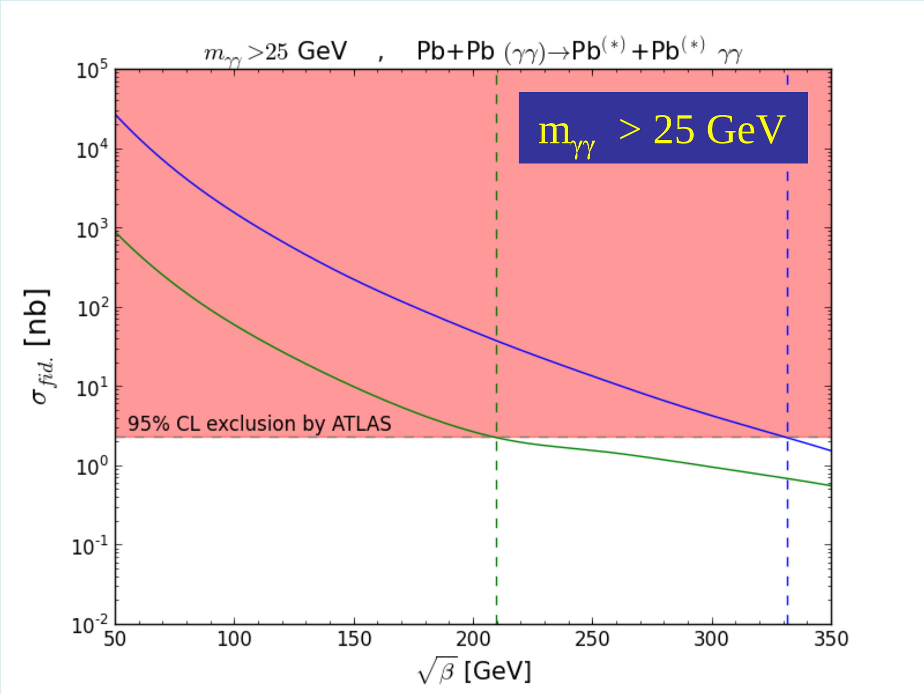
- Born-Infeld ➔larger γγ masses
- Conservative constraint: use total # of ATLAS events
- Plausible approach: cut $m_{\gamma\gamma}$ > 25 GeV (no events)

Constraint on Born-Infeld Scale

JE, Mavromatos & You, arXiv:1703.08450

- ATLAS constraint on σ(γγ➔γγ) constrains M = √β

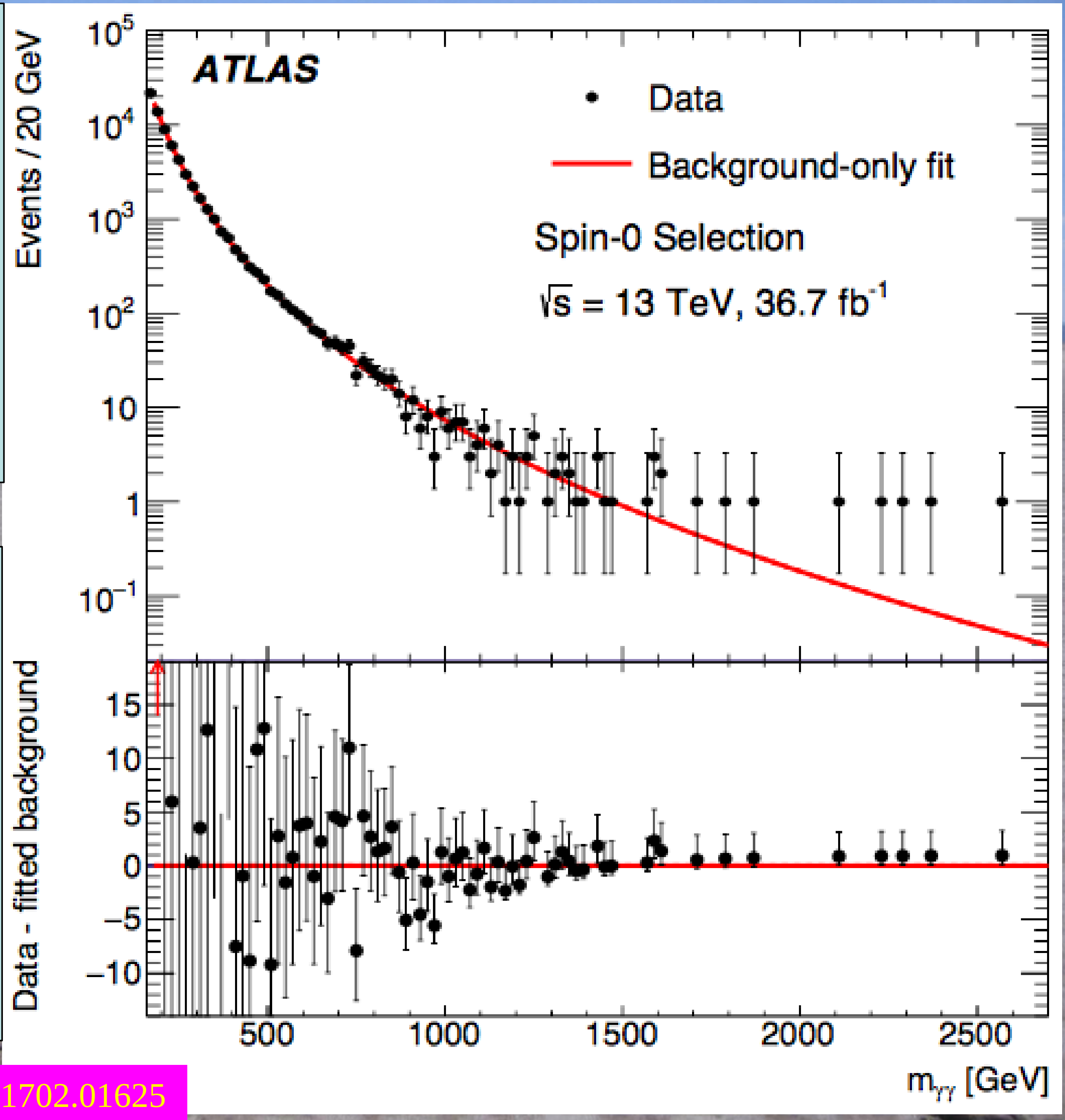




- All events with $m_{\gamma\gamma} \leq M$: limit M ≈ 100, 210 GeV
- Assume $\sigma = 1/m_{\gamma\gamma}^2$ at higher masses: M ≈ 190,330 GeV
- **Entering range of low-scale brane models**

Production of Isolated γγ at LHC

- Data agree with SM
- Can be used to constrain dimension-8 ggγγ operators



ATLAS Collaboration, arXiv:1702.01625

JE & Ge, arXiv:1802.02416

Effects of Dimension-8 ggγγ Operators

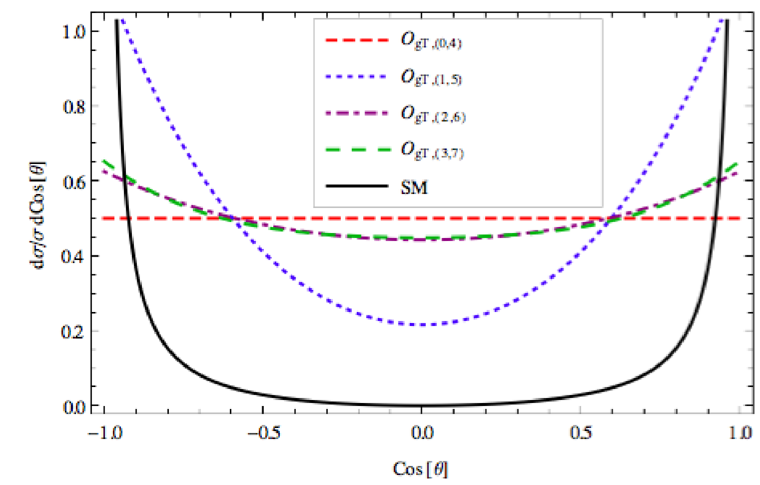
Dimension-8 operators

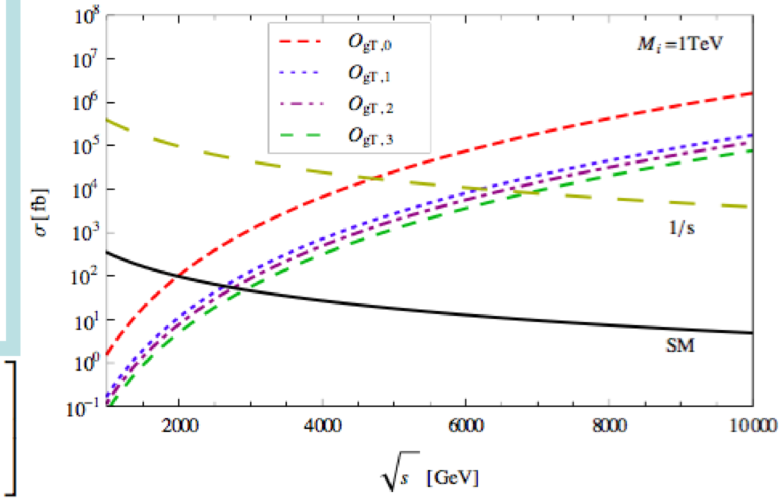
$$
\begin{aligned}
\mathcal{O}_{gT,0} &= \sum_a G^a_{\mu\nu} G^{a,\mu\nu} \times \sum_i W^i_{\alpha\beta} W^{i,\alpha\beta}, \\
\mathcal{O}_{gT,1} &= \sum_a G^a_{\alpha\nu} G^{a,\mu\beta} \times \sum_i W^i_{\mu\beta} W^{i,\alpha\nu}, \\
\mathcal{O}_{gT,2} &= \sum_a G^a_{\alpha\mu} G^{a,\mu\beta} \times \sum_i W^i_{\nu\beta} W^{i,\alpha\nu}, \\
\mathcal{O}_{gT,3} &= \sum_a G^a_{\alpha\mu} G^a_{\beta\nu} \times \sum_i W^{i,\mu\beta} W^{i,\nu\alpha}, \\
\mathcal{O}_{gT,4} &= \sum_a G^a_{\mu\nu} G^{a,\mu\nu} \times B_{\alpha\beta} B^{\alpha\beta}, \\
\mathcal{O}_{gT,5} &= \sum_a G^a_{\alpha\nu} G^{a,\mu\beta} \times B_{\mu\beta} B^{\alpha\nu}, \\
\mathcal{O}_{gT,6} &= \sum_a G^a_{\alpha\mu} G^{a,\mu\beta} \times B_{\nu\beta} B^{\alpha\nu}, \\
\mathcal{O}_{gT,7} &= \sum_a G^a_{\alpha\mu} G^a_{\beta\nu} \times B^{\mu\beta} B^{\nu\alpha},
\end{aligned}
$$

Born-Infeld

$$
\beta^2 \left[1 - \sqrt{1 + \sum_{\lambda=1}^{12} \frac{F^\lambda_{\mu\nu} F^{\lambda,\mu\nu}}{2\beta^2} - \left(\sum_{\lambda=1}^{12} \frac{F^\lambda_{\mu\nu} \widetilde{F}^{\lambda,\mu\nu}}{4\beta^2} \right)^2 } \right]
$$

Cross sections

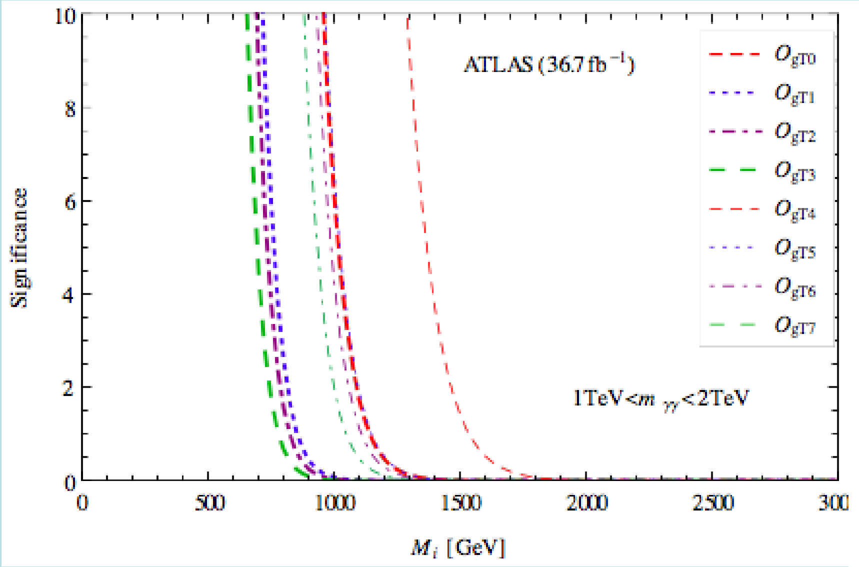


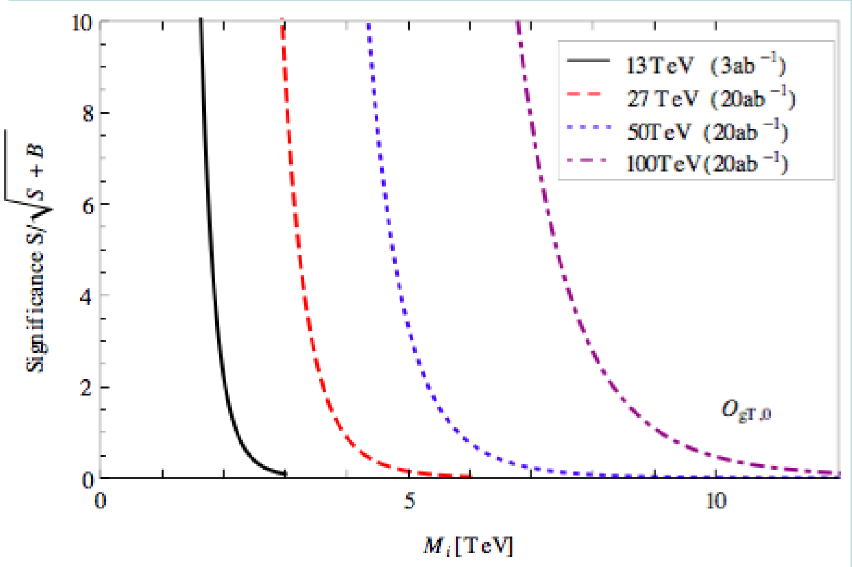


JE & Ge, arXiv:1802.02416

Constraints from Collider Data

- ATLAS: 95% CL lower limits in TeV range





- Prospective sensitivities of future colliders in multi-TeV range
- **Unique window on dimension-8 physics**

Summary

- EFTs are good to look for new physics in a model-independent way ☺
- Proven track record (weak and strong forces)
- SMEFT good way to analyze LHC & other data in a global way (EW + H + diboson)
- LHC Run 2 data significant step forward
- No hint yet of any deviation from SM ☹
- Much more data to come ☺