



THE UNIVERSITY OF
CHICAGO

Probing Non-Universal Theories Through Higgs Processes at the LHC

Wen Han Chiu, Zhen Liu, Liantao Wang

Phenomenology 2019 Symposium
May 7, 2019

Where are we now?

- Standard Model = Success*
- Still need description of NP
- Assume:

$$SU(3) \times SU(2)_L \times U(1)_Y \subset G$$

- IR limit of NP obeys SM gauge symmetries

SM-EFT

- Extend SM with all operators obeying SM-gauge symmetry

$$\mathcal{L} = \mathcal{L}_{\text{SM}} + \sum_{d=5}^{\infty} \sum_i \frac{c_{d,i}}{\Lambda^{d-4}} \mathcal{O}_{d,i}$$

- In the Warsaw basis
 - $d = 5$ has 2 operators
 - $d = 6$ has 59 CP-even operators ← LO correction to SM

Probing EFT parameter space

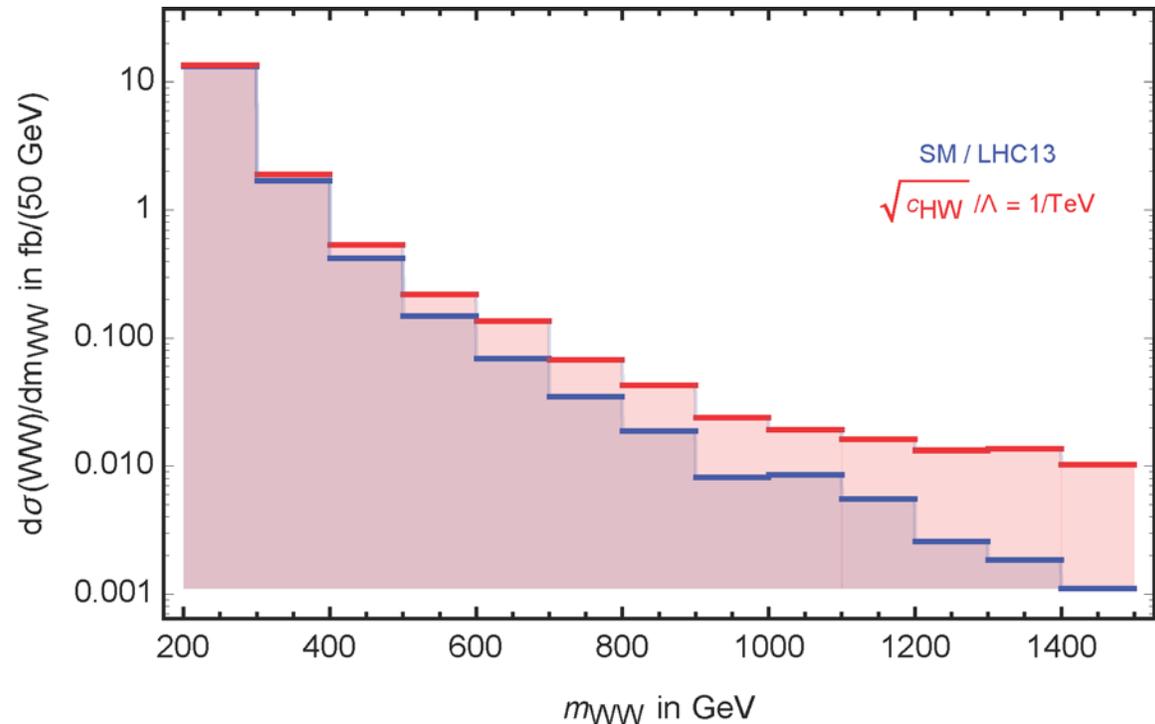
- High Λ suppression \Rightarrow Needs precision measurements
- Typically associated with EWPO
$$\delta \lesssim \mathcal{O}(1\%)$$
- But is this the only way?

Probing EFTs with LHC

- Doable if

$$\frac{S}{B} \propto E^n, \quad n \geq 1$$

- Example: Diboson processes



¹Figure from LT Wang

Diboson at LHC

First generation only

1

Operators	
\mathcal{O}_{Hu}	$(iH^\dagger \overleftrightarrow{D}_\mu H) (\bar{u}_R \gamma^\mu u_R)$
\mathcal{O}_{Hd}	$(iH^\dagger \overleftrightarrow{D}_\mu H) (\bar{d}_R \gamma^\mu d_R)$
\mathcal{O}_L	$(iH^\dagger \overleftrightarrow{D}_\mu H) (\bar{Q}_L \gamma^\mu Q_L)$
$\mathcal{O}_L^{(3)}$	$(iH^\dagger \sigma^a \overleftrightarrow{D}_\mu H) (\bar{Q}_L \gamma^\mu \sigma^a Q_L)$

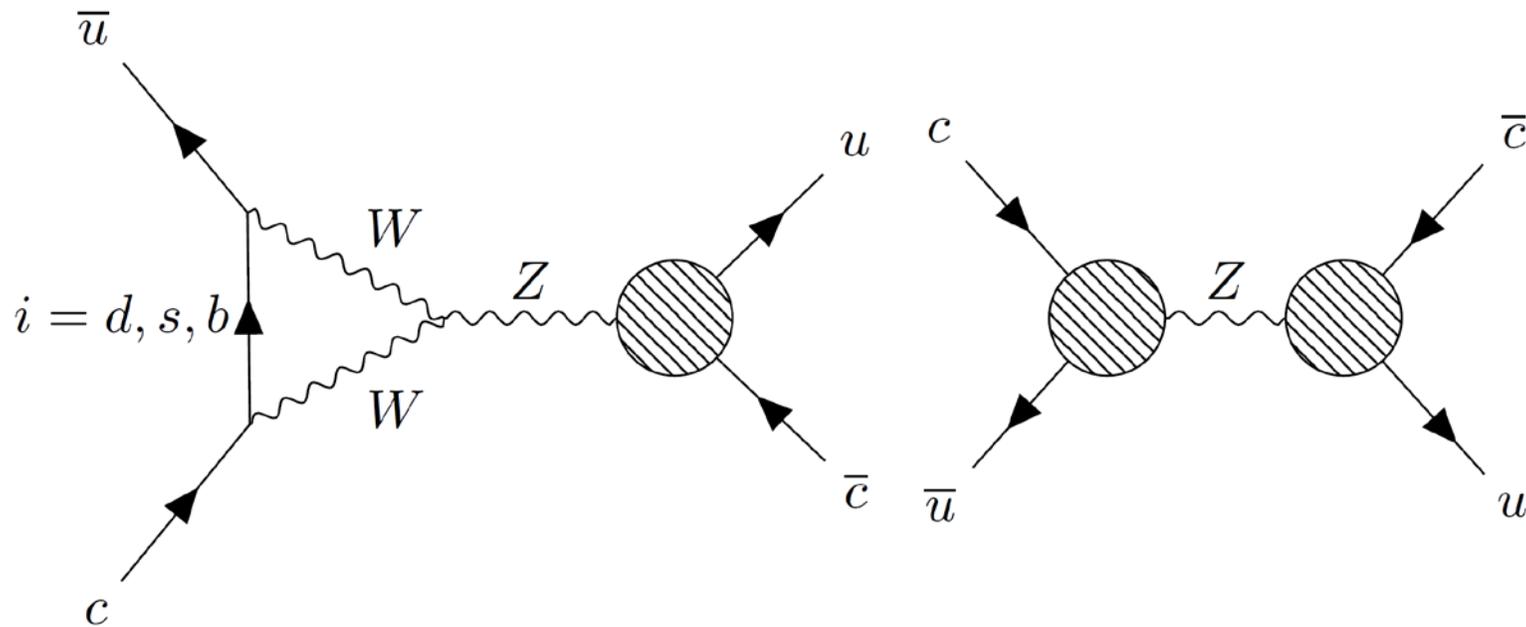
Process	High – energy primaries
$\bar{u}_L d_L \rightarrow W_L Z_L, W_L h$	$\sqrt{2} c_L^{(3)} / \Lambda^2$
$\bar{u}_L u_L \rightarrow W_L W_L$ $\bar{d}_L d_L \rightarrow Z_L h$	$(c_L + c_L^{(3)}) / \Lambda^2$
$\bar{d}_L d_L \rightarrow W_L W_L$ $\bar{u}_L u_L \rightarrow Z_L h$	$(c_L - c_L^{(3)}) / \Lambda^2$
$\bar{f}_R f_R \rightarrow W_L W_L, Z_L h$	c_{Hf} / Λ^2

¹R. Franceschini et al, [1712.01310](#)

See also: C. Grojean et al, [1810.05149](#) & S. Banerjee et al, [1807.01796](#)

Constraints from flavor

- This type of model contributes to FCNCs
- For $\Delta C = 2$, 2 classes of processes:



Constraints from flavor (cont.)

- Contributes to 2 different $\Delta C = 2, d = 6$ operators:

$$\bar{c}_L u_R \bar{c}_R u_L \text{ and } \bar{c}_R \gamma_\mu u_R \bar{c}_R \gamma^\mu u_R$$

- Parametrically, the corresponding Wilson coefficients are given by

$$\frac{1}{16\pi^2} \frac{v^2}{M_Z^2} \frac{M_b^2}{M_W^2} \frac{c_{Hu}}{\Lambda^2} |V_{ub}| |V_{cb}| \left(U_{R,uu}^\dagger U_{R,uc} \right) \lesssim 1.6 \times 10^{-7} \left(\frac{1}{1 \text{ TeV}} \right)^2$$
$$3 \left| \frac{c_{Hu}}{\Lambda^2} v \left(U_{R,uu}^\dagger U_{R,uc} \right) \right|^2 \lesssim 5.7 \times 10^{-7} \left(\frac{1}{1 \text{ TeV}} \right)^2$$

Constraints from flavor (cont.)

- Model dependent: Assume $\left| U_{R,uu}^\dagger U_{R,uc} \right| \sim |V_{ud}| |V_{us}|$

$$\text{SM} - \text{EFT}: \frac{C_{Hu}}{\Lambda_{\text{TeV}}^2} \lesssim 48.0$$

$$\text{EFT} - \text{EFT}: \frac{C_{Hu}}{\Lambda_{\text{TeV}}^2} \lesssim 8.86 \times 10^{-3}$$

- Very strong

Constraints from flavor (cont.)

- Consider 2 generation universal theories

$$U_{R,uu}^\dagger U_{R,uc} \rightarrow U_{R,uu}^\dagger U_{R,uc} + U_{R,uc}^\dagger U_{R,cc} = -U_{R,ut}^\dagger U_{R,tc}$$

- Dominated by

$$\begin{aligned} \frac{\Delta\Gamma(Z \rightarrow c\bar{c})}{\Gamma(Z \rightarrow c\bar{c})} &\approx 1.6\% \quad ^1 \\ &\rightarrow \frac{c_{Hu}}{\Lambda_{\text{TeV}}^2} \lesssim 0.163 \end{aligned}$$

¹ PDG, [Phys.Rev.D98, 030001](#)

Analysis

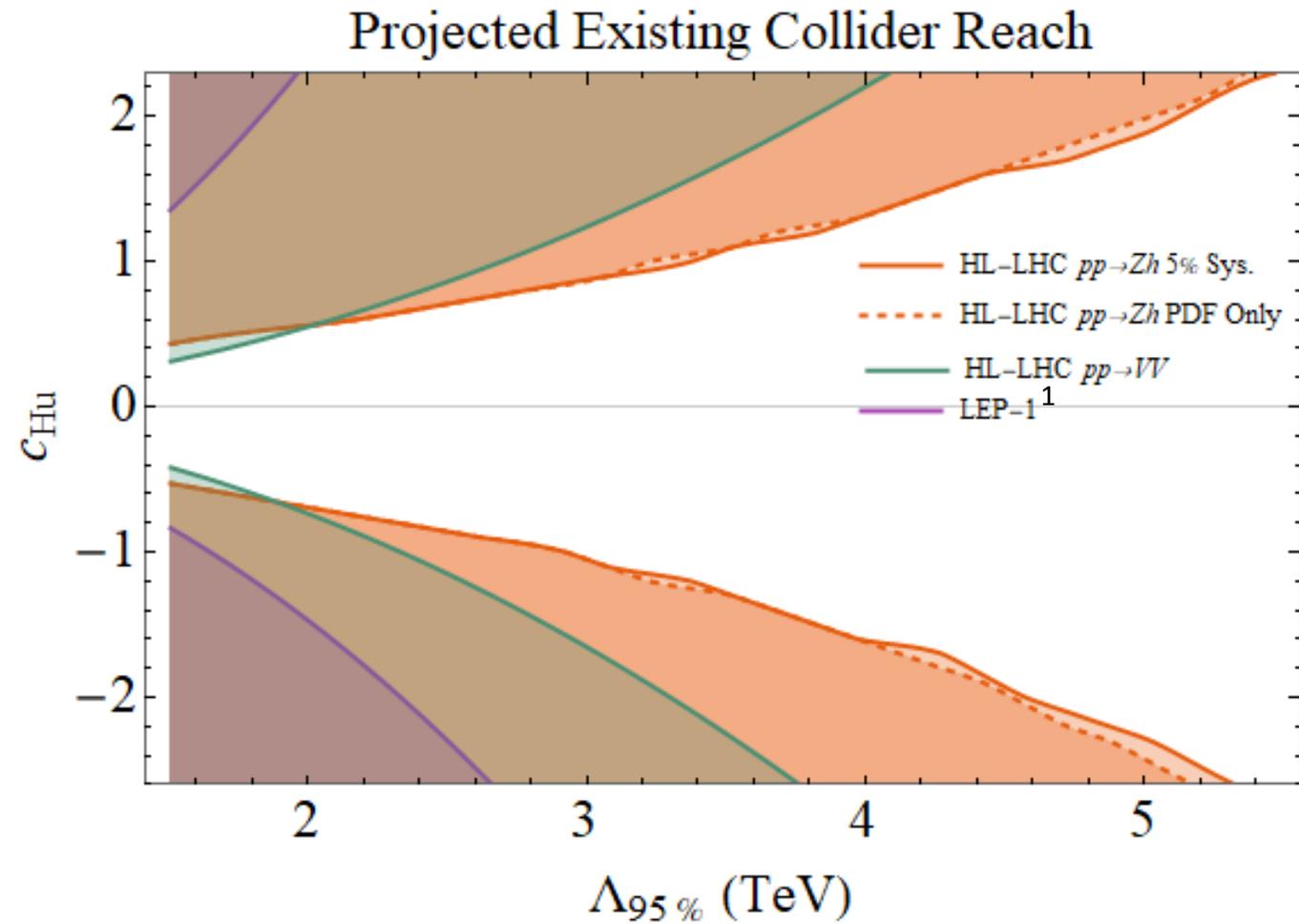
- Implemented operator in MadGraph5 using a UFO file from FeynRules
- Generated Zh events while scanning values of c_{Hu}/Λ^2
- Background estimated from 2017 ATLAS heavy resonance search¹
 - Extended range by fitting tail to exponential
- Cuts imposed to mimic the ATLAS study and scaled to match SM Zh

¹ The ATLAS Collaboration, [1712.06518](#)

Analysis

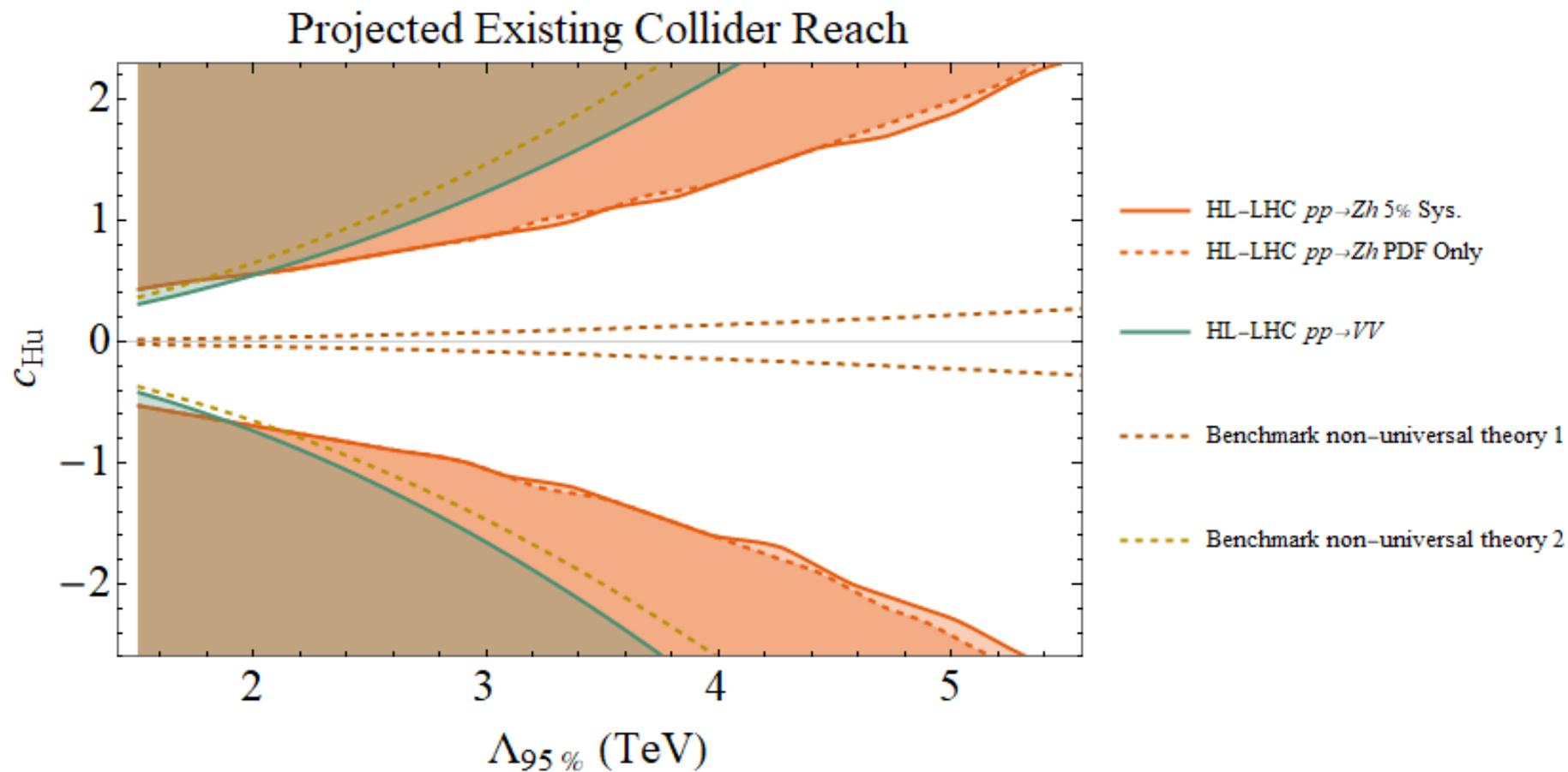
- Data binned by M_{Zh} with bin sizes of 150 GeV
- Exclude regions with total significance of bins with $M_{Zh} < \Lambda$ greater than 2
- Two scenarios for uncertainties:
 - 5% universal systematic uncertainty
 - PDF dominated

Results



¹ A. Efrati et al, [1503.07872](#)

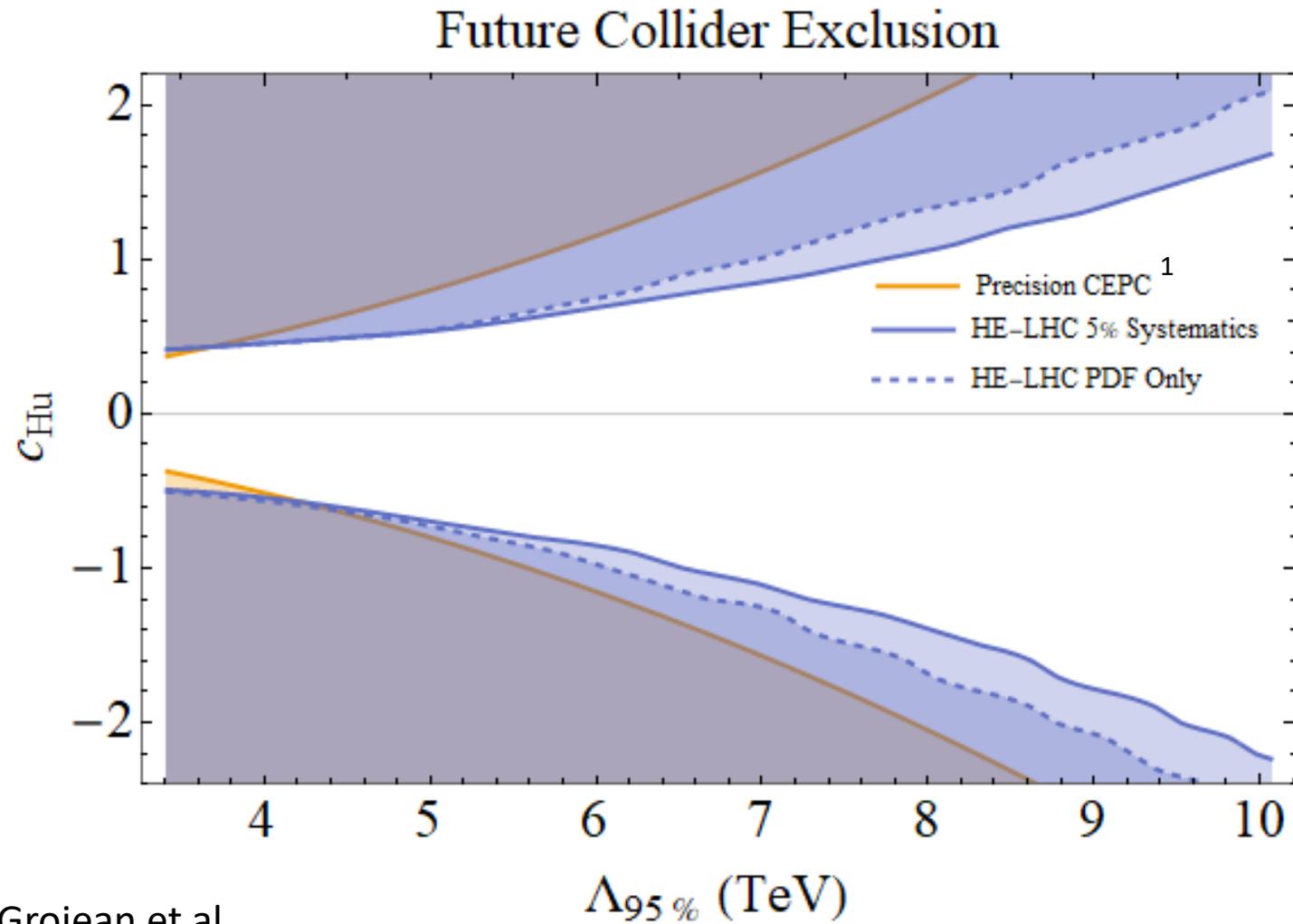
Results (cont.)



Analysis (cont.)

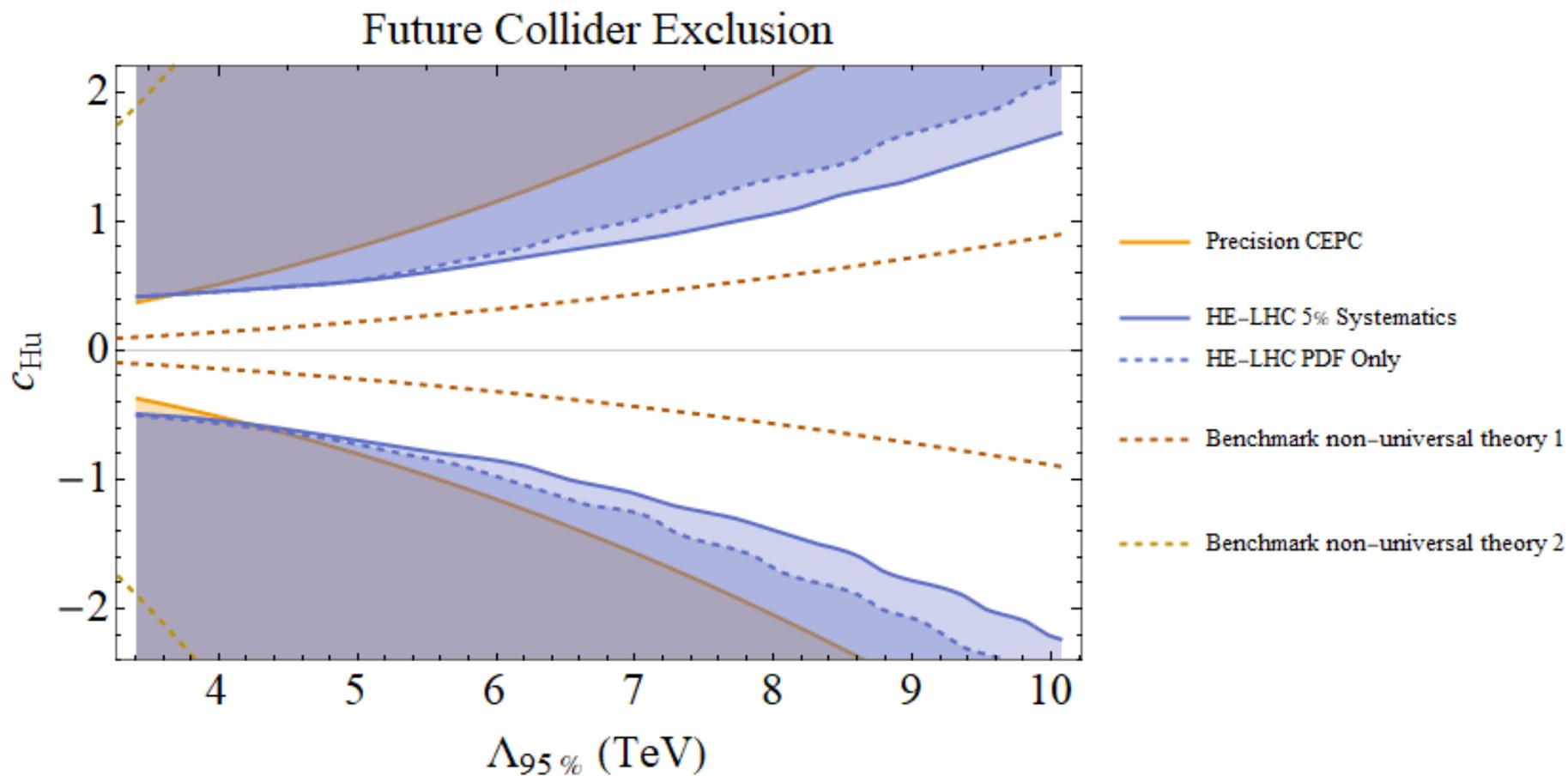
- Repeated analysis for 27 TeV HE-LHC
- Scaled background events by per-bin parton luminosity ratio

Results



¹ Numbers from C Grojean et al

Results (cont.)



Summary

- Explored existing constraints on flavor models
- Projected reach of NP parameter space