Probing Non-Universal Theories Through Higgs Processes at Hadron Colliders

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- IR limit of NP obeys SM gauge symmetries

SM-EFT

- Extend SM with all operators obeying SM-gauge symmetry

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

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

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- But is this the only way?

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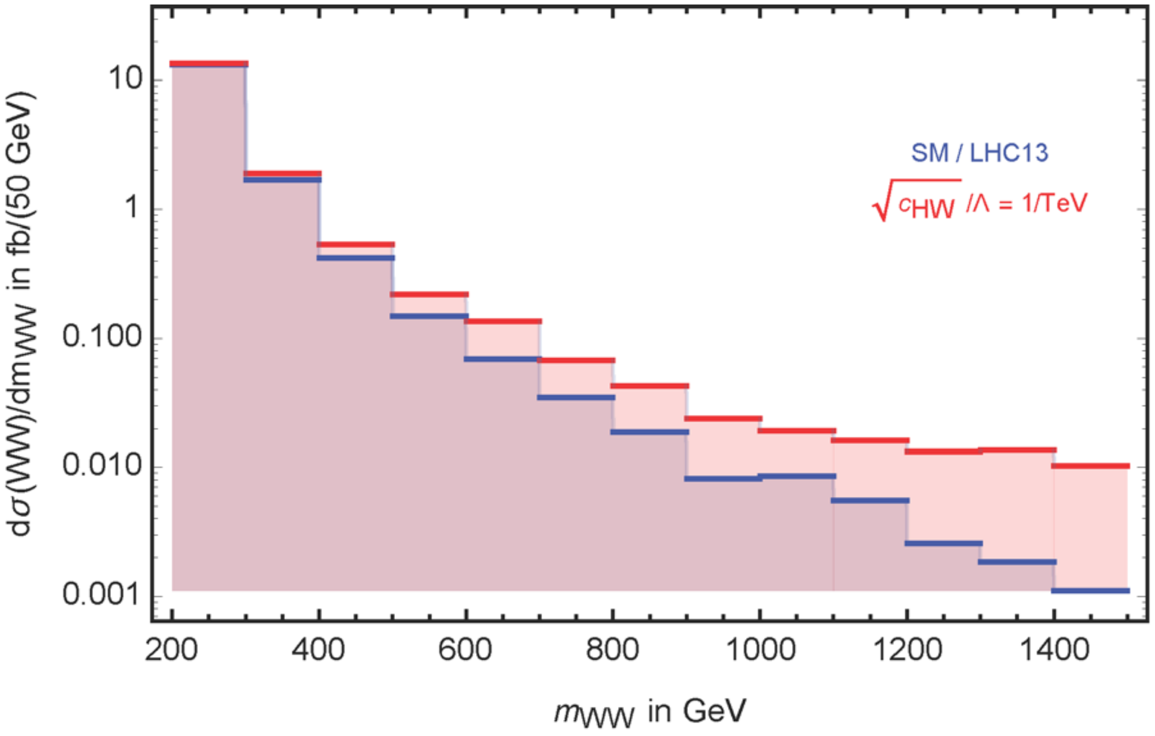
- Example: Diboson processes



[1]Figure from LT Wang

Diboson at LHC

1

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

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

Diboson at LHC

First generation only

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[1]R. Franceschini et at, 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

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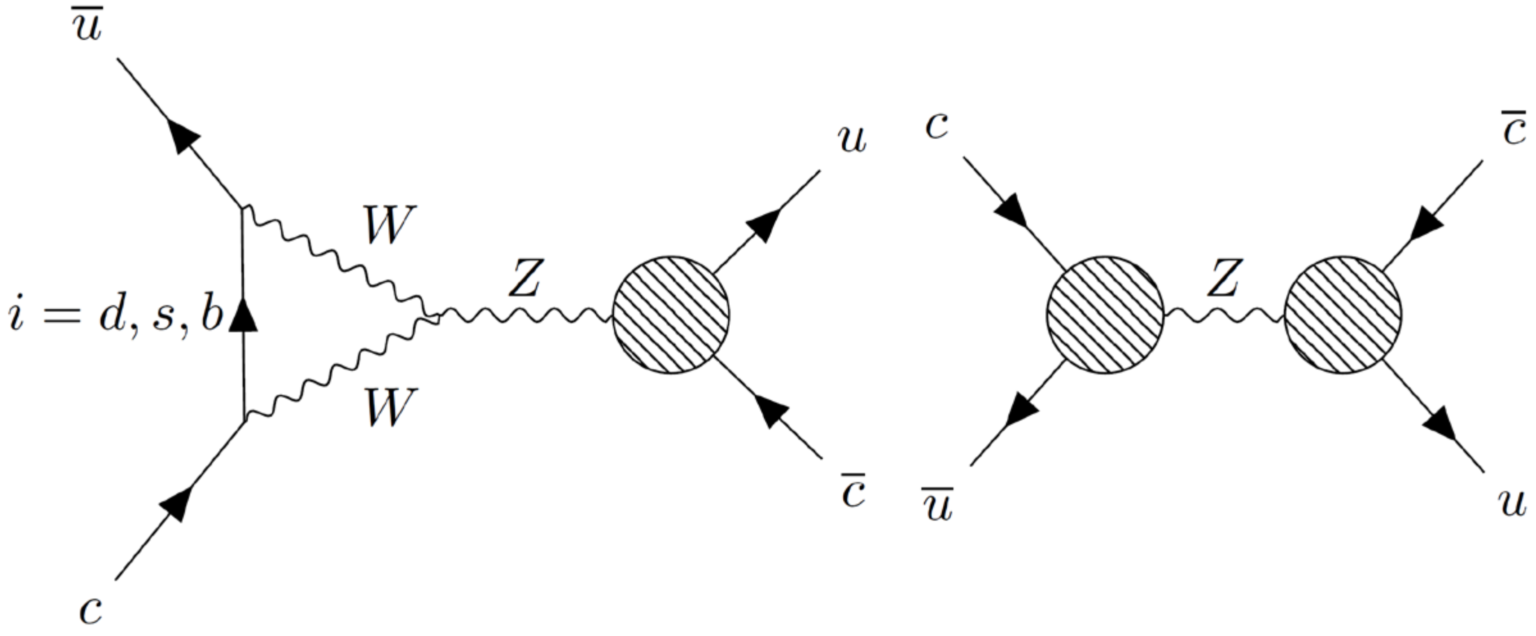
- For $\Delta C = 2$, 2 classes of processes:



Constraints from flavor (cont.)

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

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- Parametrically, the corresponding Wilson coefficients are given by

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

$$3\left|\frac{c_{Hu}}{\Lambda^2} v \left(U_{R,uu}^\dagger U_{R,uc}\right)\right|^2 \lesssim 5.7 \times 10^{-7}\left(\frac{1}{1\ \mathrm{TeV}}\right)^2$$

[1] O. Gedalia et al, 0906.1879

Constraints from flavor (cont.)

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

$$\text{SM} - \text{EFT}: \frac{c_{Hu}}{\Lambda^2_{\text{TeV}}} \lesssim 48.0$$

$$\text{EFT} - \text{EFT}: \frac{c_{Hu}}{\Lambda^2_{\text{TeV}}} \lesssim 8.86 \times 10^{-3}$$

Constraints from flavor (cont.)

- Consider 2 generation universal theories

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

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- Dominated by

$$\frac{\Delta\Gamma(Z \rightarrow c\bar{c})}{\Gamma(Z \rightarrow c\bar{c})} \approx 1.6\%$$ [1]

$$\rightarrow \frac{c_{Hu}}{\Lambda^2_{\mathrm{TeV}}} \lesssim 0.163$$

[1] PDG, Phys.Rev.D**98**, 030001

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  - Extended range by fitting tail to exponential
- Cuts imposed to mimic the ATLAS study and scaled to match SM Zh

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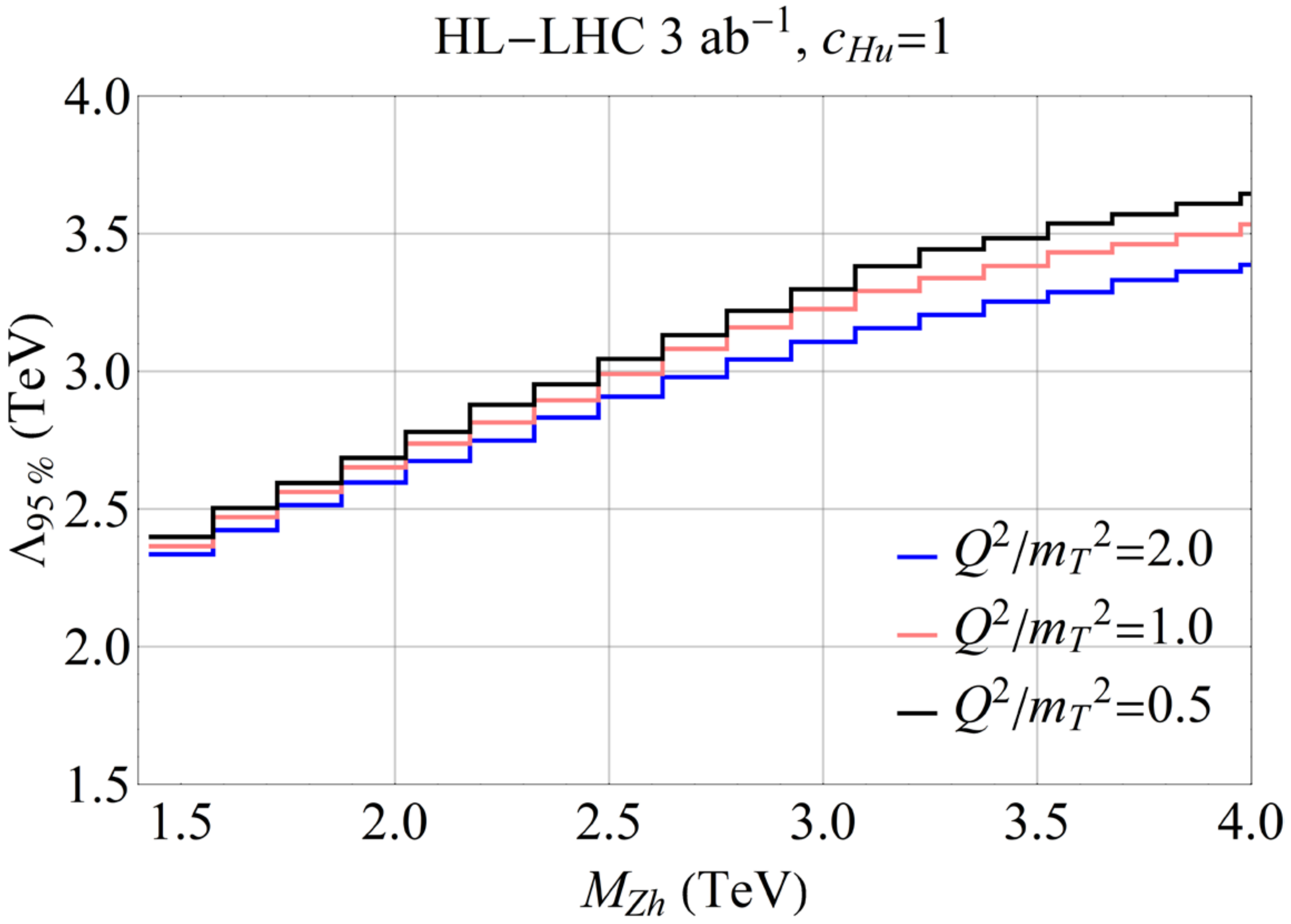
Analysis

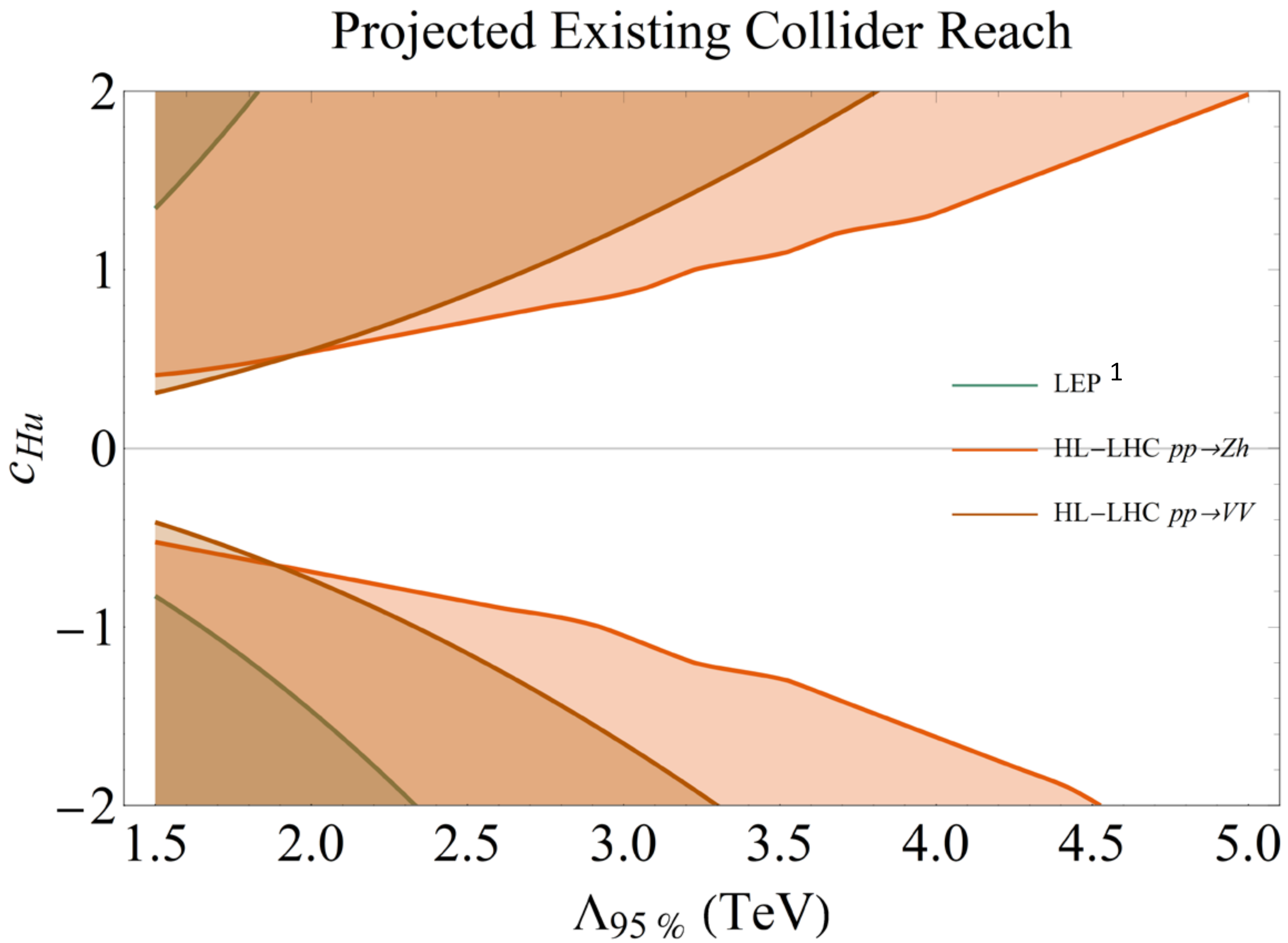
- Data binned by M_{Zh} with bin sizes of $150\ \mathrm{GeV}$
- Exclude regions with total significance of bins with $M_{Zh} < \Lambda$ greater than 2

Uncertainty estimates

- Assume a universal 5% systematic uncertainty
- Theoretical uncertainty from scale uncertainty→Assumed to be gaussian and folded in

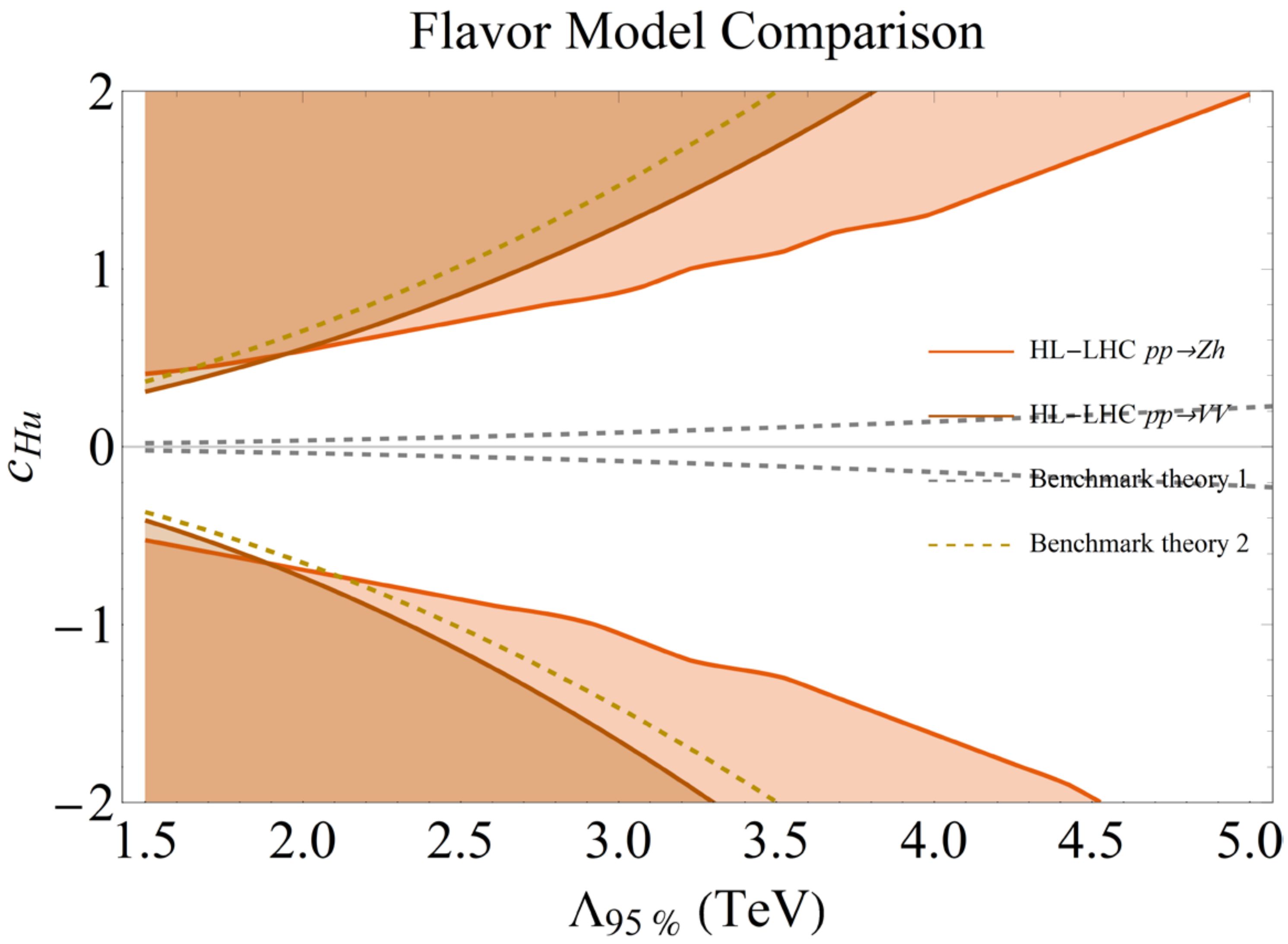


Results



[1] A. Efrati et al, [1503.07872](https://arxiv.org/abs/1503.07872)

Results (cont.)



Analysis (cont.)

- Repeated analysis for several potential future colliders:

Collider	$\sqrt{s}$	$\int \mathcal{L}dt$
HE-LHC	27 TeV	$15\ \mathrm{ab}^{-1}$
FCC-hh	37.5 TeV	$30\ \mathrm{ab}^{-1}$
FCC-hh	100 TeV	$30\ \mathrm{ab}^{-1}$

- Estimated background via differential rescaling from parton luminosity ratios

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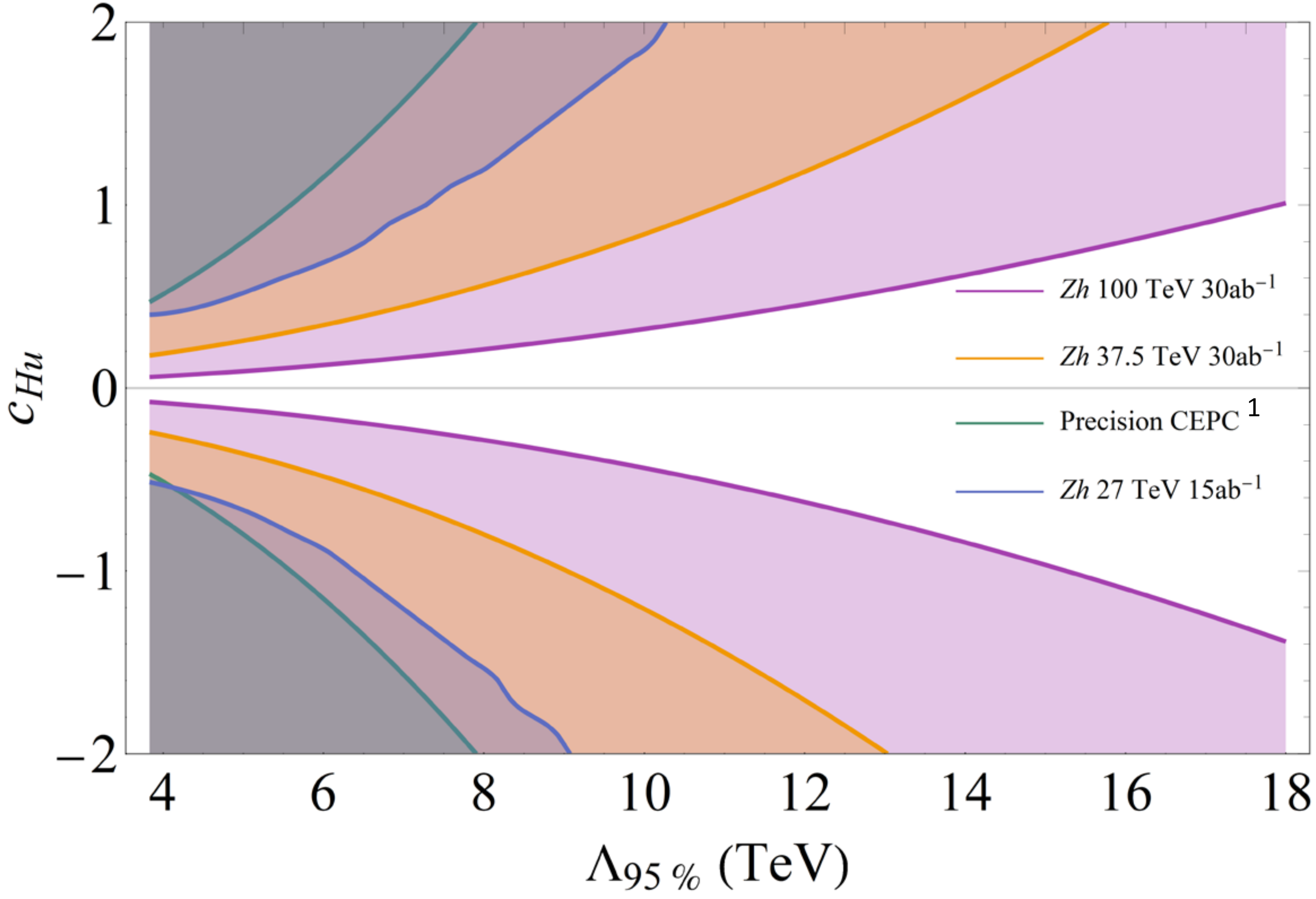

[1] Numbers from C Grojean et al

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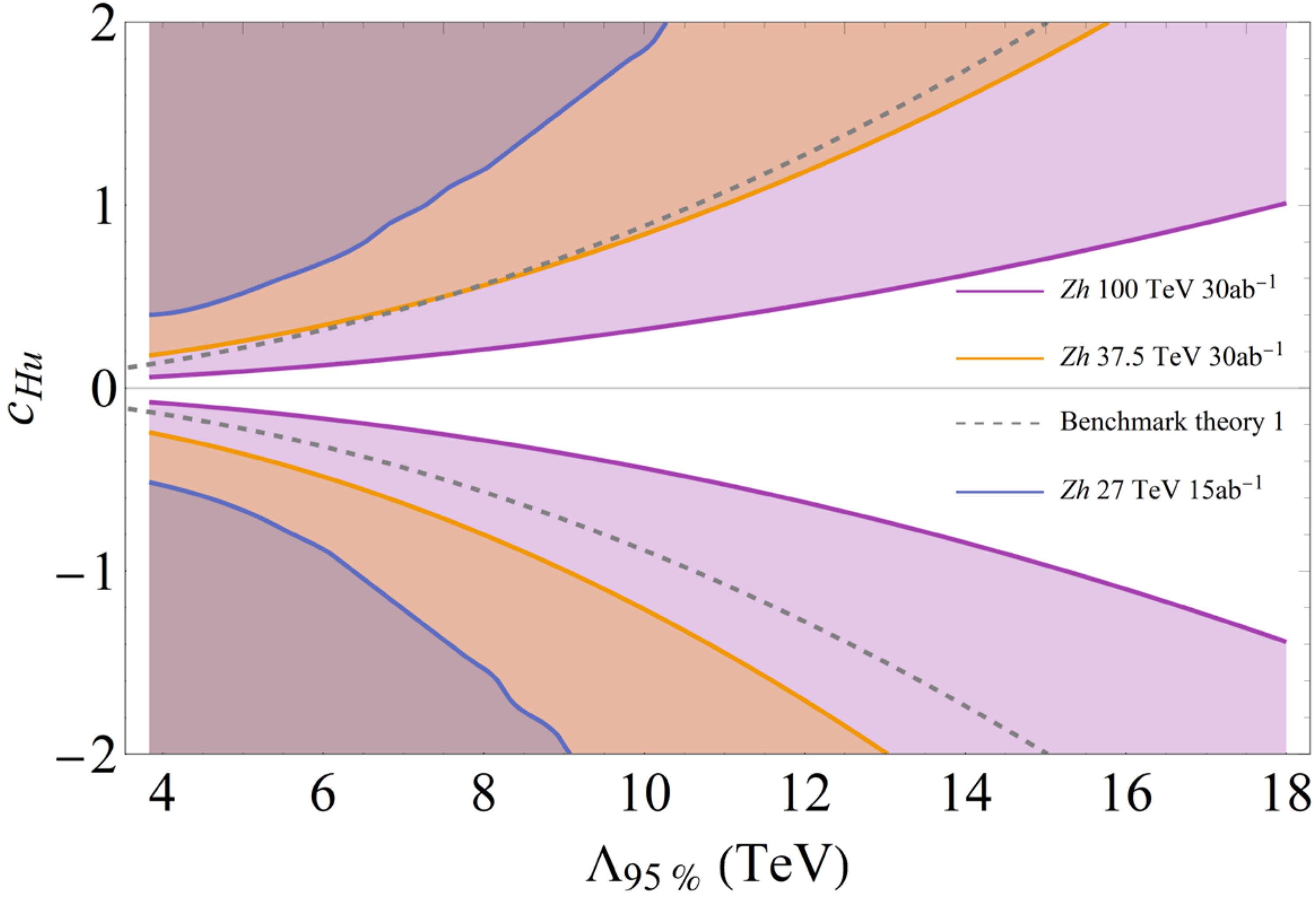
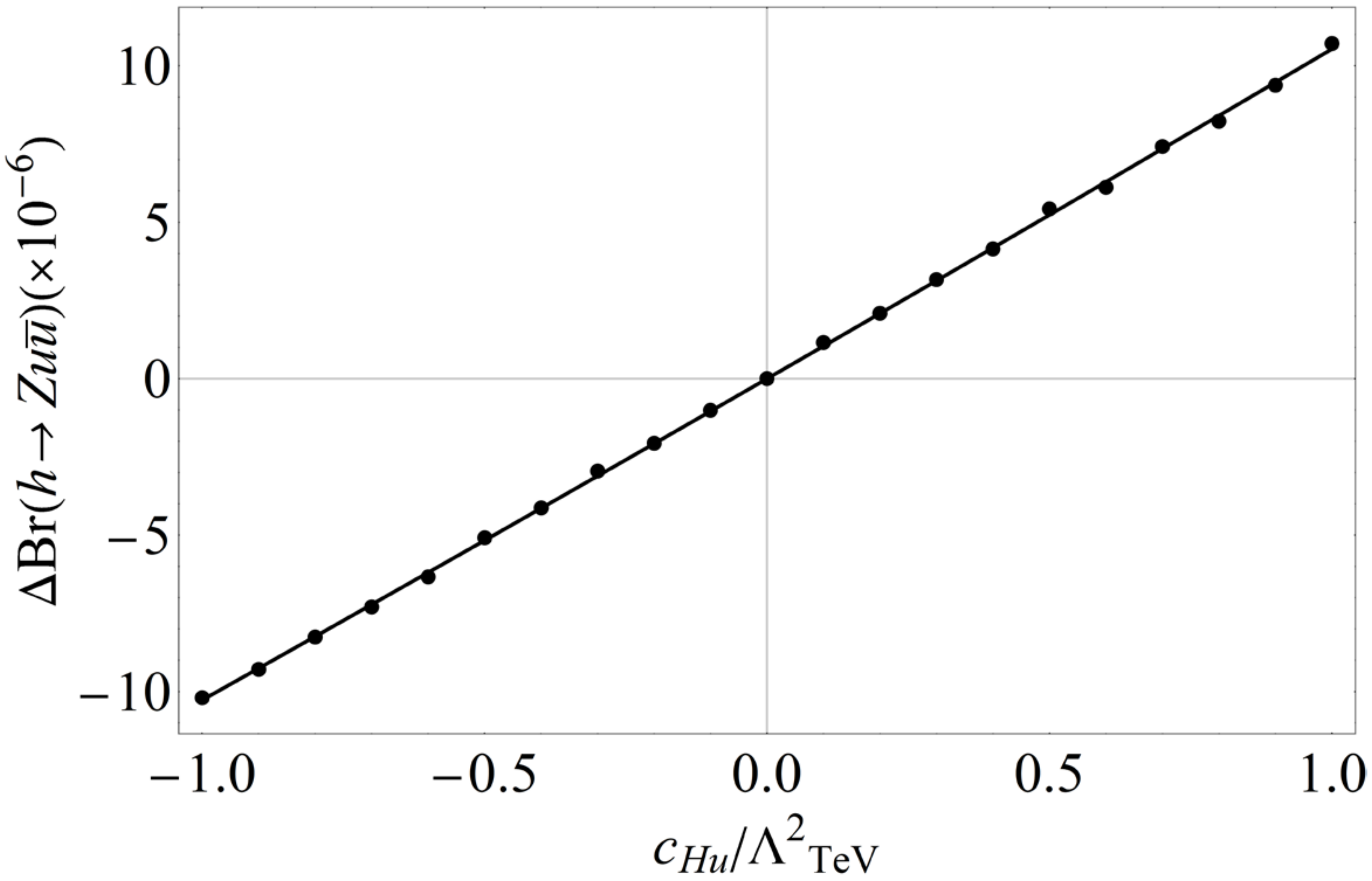


Complementarity with Higgs exotic decays



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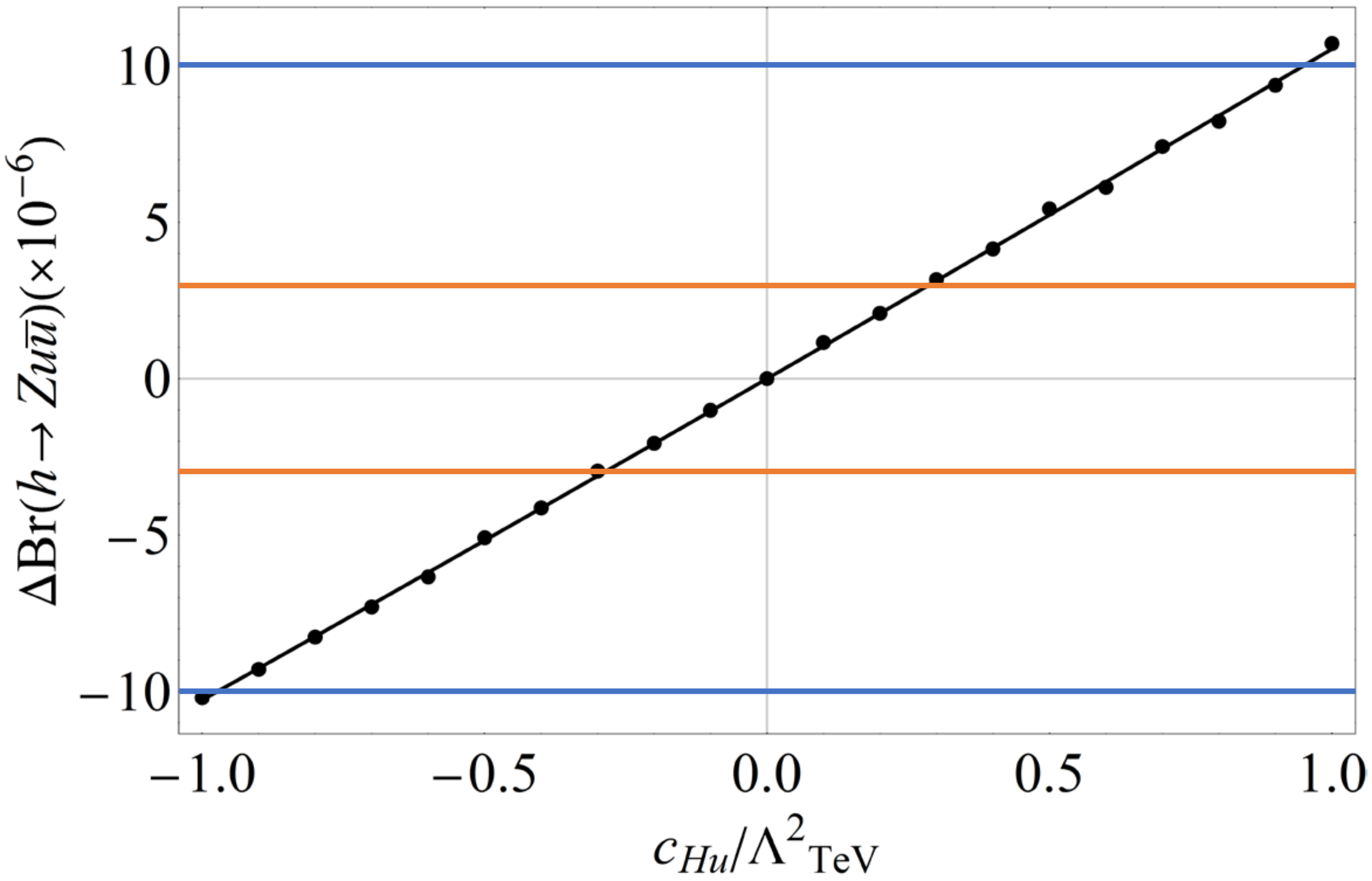

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- Higgs exotic decay searches at lepton colliders provide complementary information