Higgs to ZZ and Zγ in the SMEFT at NLO

Pier Paolo Giardino

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Based manly on S. Dawson, P.P.G. arXiv:1801.01136 [hep-ph]

BROOKHAVEN NATIONAL LABORATORY

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H to ZZ is un-physical, first step to H to Zff

Why the SMEFT?

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$$g_{SM} \to \kappa\, g_{SM}\,,\, (\kappa - 1) \propto \frac{v^2}{\Lambda^2}$$

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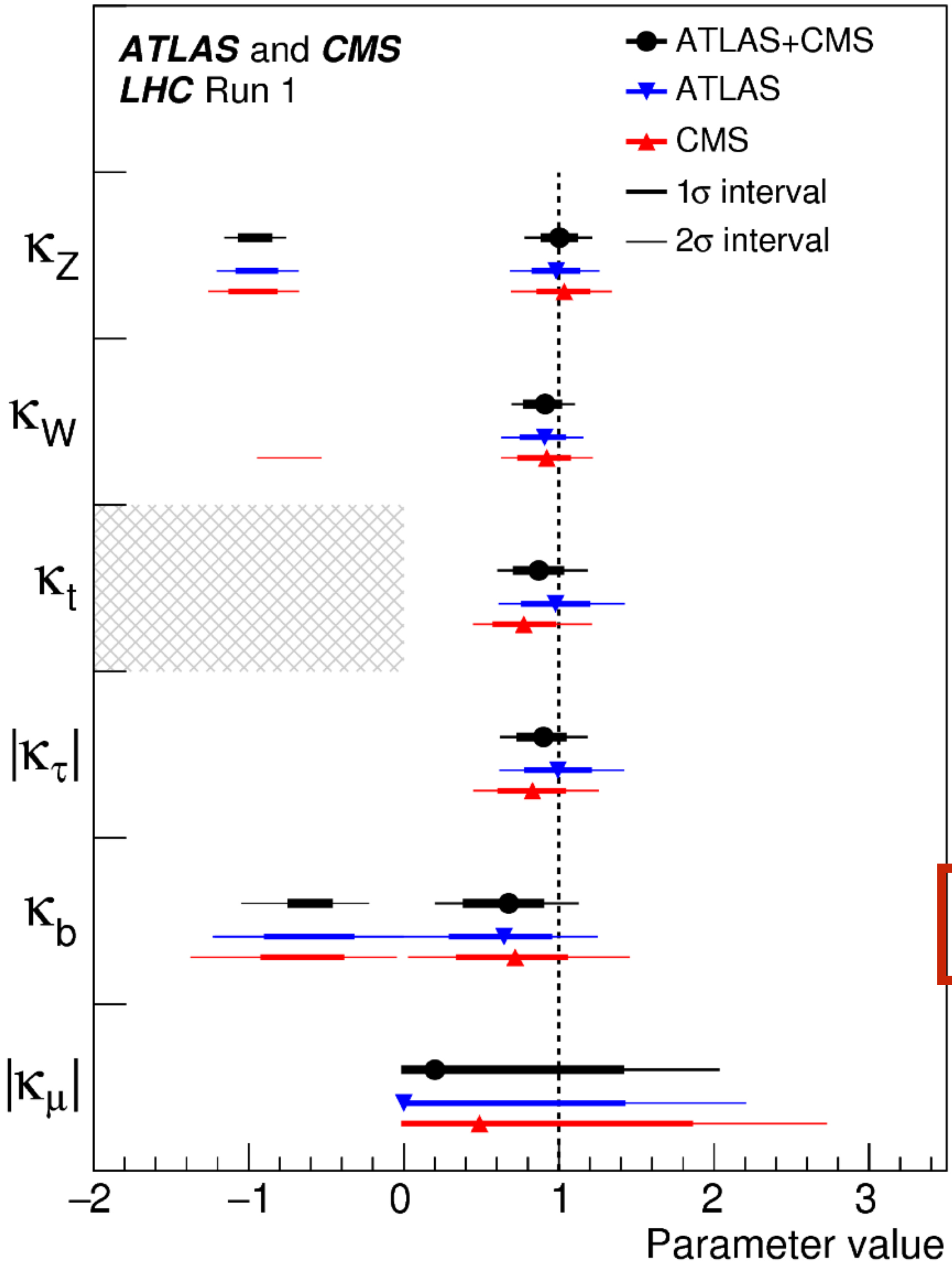

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Small variation from SM=High energy scale!

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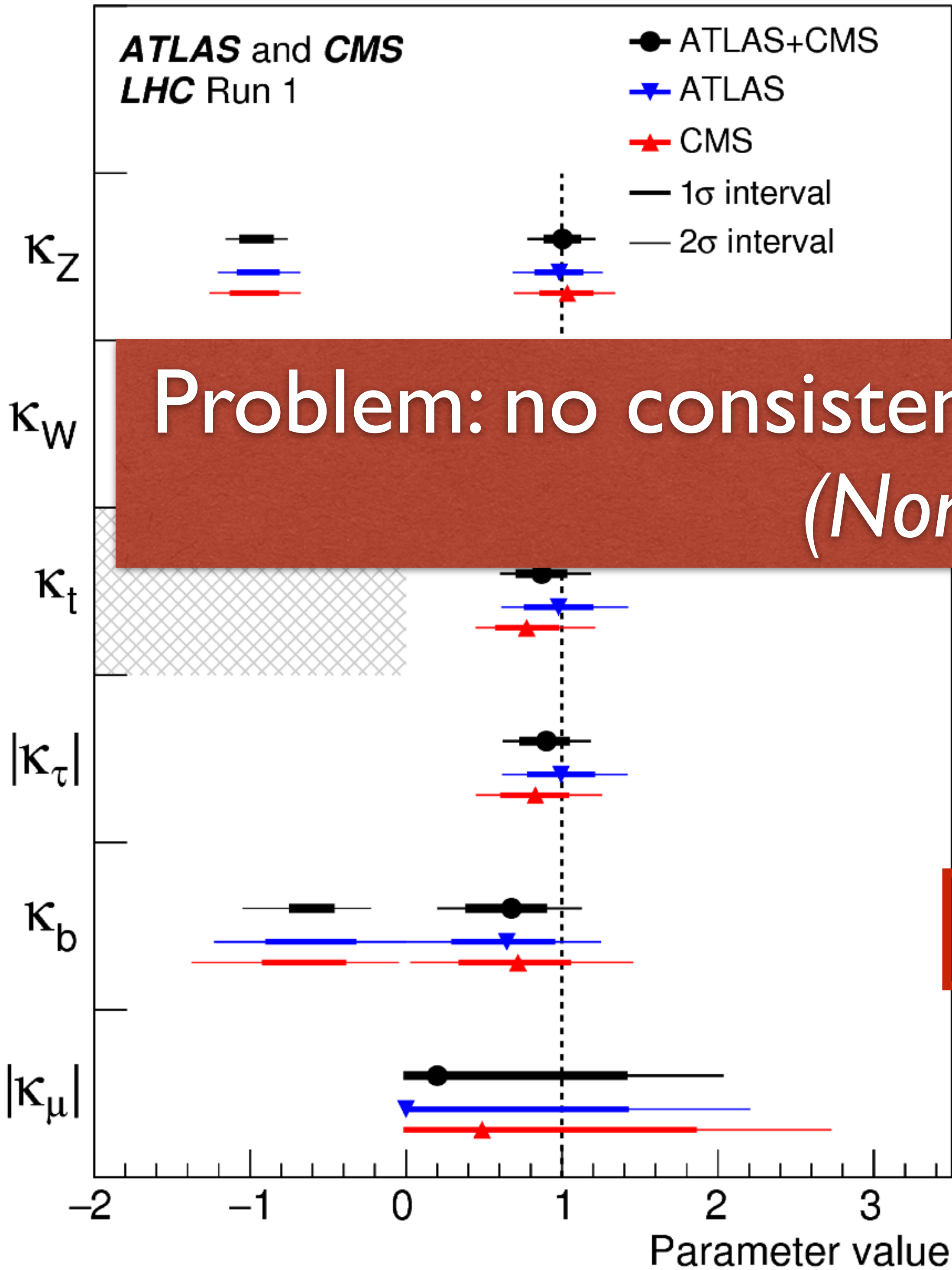

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Small variation from SM=High energy scale!

Problem: no consistent way to calculate perturbations!

(Non renormalizable)

A sounder approach is to introduce a set of gauge invariant operators

$$\mathcal{L} = \mathcal{L}_{SM} + \sum_{k=5}^{\infty} \sum_{i} \frac{\mathcal{C}_i^k \mathcal{O}_i^k}{\Lambda^{k-4}}$$

The resulting theory (SMEFT) allows perturbative calculations

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Some work done:

$H \to \bar{b}b, H \to \bar{\tau}\tau$ Gauld, etc.15, 16.

$H \to \gamma\gamma$ Ghezzi, etc.15, Hartmann, etc. 15. Dedes, etc. 18

$H \to W^+W^-$ Ghezzi, etc. 15

$H \to ZZ, H \to Z\gamma$ Ghezzi, etc. 15;
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Still a lot to do!

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Why Complete?

There are ~2500 Dimension-6 Operators in SMEFT

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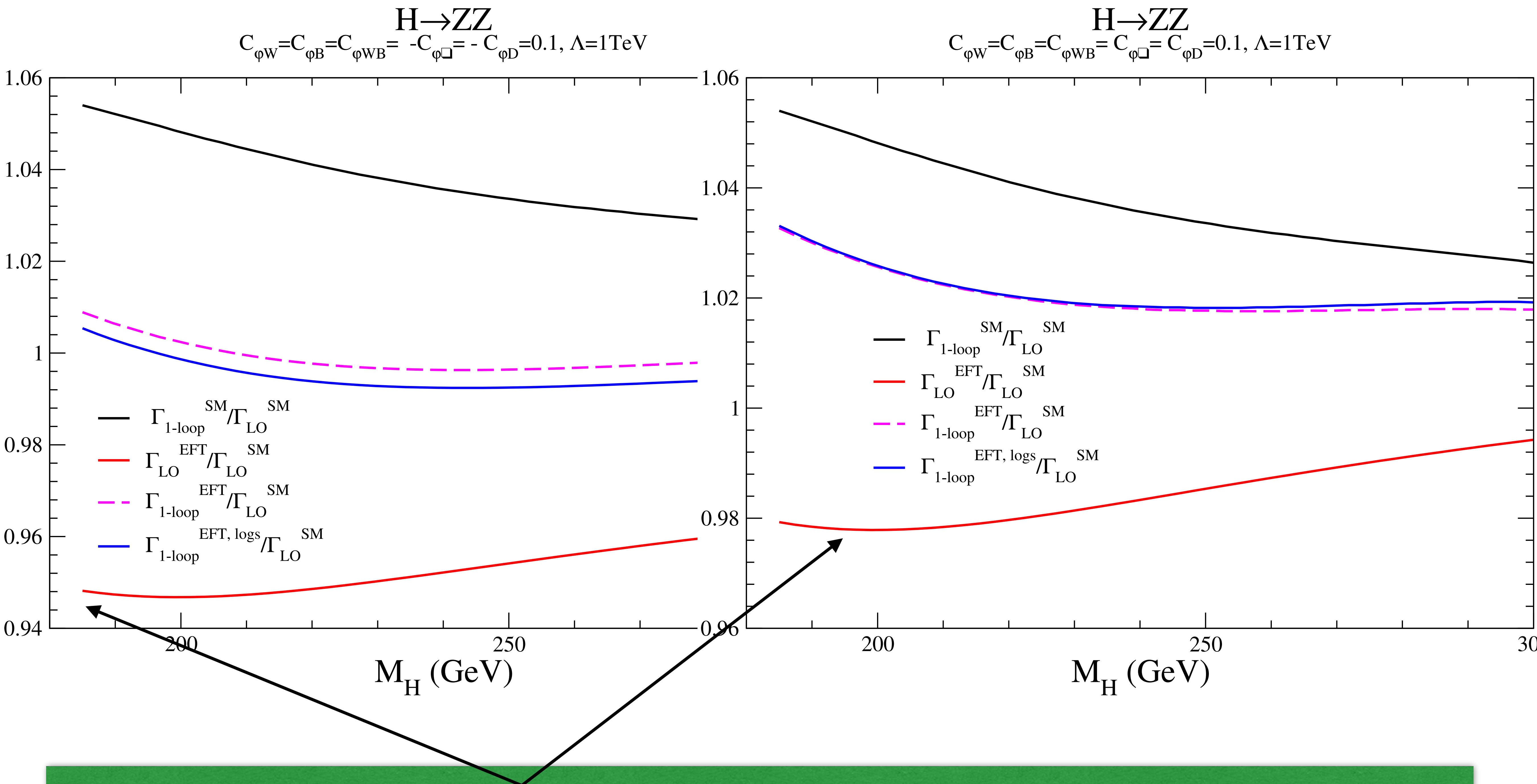
7 operators enter $H \to ZZ$ at LO and 12+7 at NLO

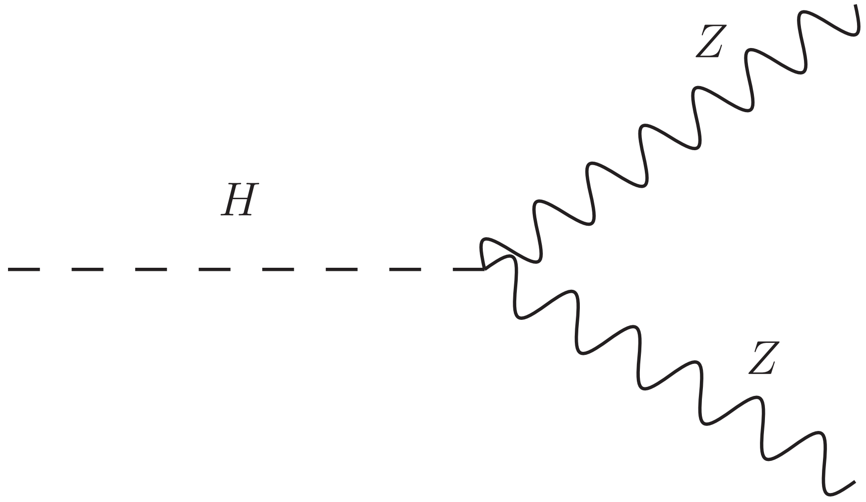
$\mathcal{O}_W$	$\epsilon^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$	$\mathcal{O}_\phi$	$(\phi^\dagger\phi)^3$	$\mathcal{O}_{\phi\Box}$	$(\phi^\dagger\phi)\Box(\phi^\dagger\phi)$
$\mathcal{O}_{\phi D}$	$\left(\phi^\dagger D^\mu\phi\right)^* \left(\phi^\dagger D_\mu\phi\right)$	$\underset{p,r}{\mathcal{O}_{u\phi}}$	$(\phi^\dagger\phi)(\bar{q}'_p u'_r \widetilde{\phi})$	$\mathcal{O}_{\phi W}$	$(\phi^\dagger\phi)\, W_{\mu\nu} W^{\mu\nu}$
$\mathcal{O}_{\phi B}$	$(\phi^\dagger\phi)\, B_{\mu\nu} B^{\mu\nu}$	$\mathcal{O}_{\phi WB}$	$(\phi^\dagger\tau^I\phi)\, W^I_{\mu\nu} B^{\mu\nu}$	$\mathcal{O}_{uW}$	$(\bar{q}'_p\sigma^{\mu\nu}u'_r)\tau^I\widetilde{\phi}\, W^I_{\mu\nu}$
$\underset{p,r}{\mathcal{O}_{uB}}$	$(\bar{q}'_p\sigma^{\mu\nu}u'_r)\widetilde{\phi}\, B_{\mu\nu}$	$\underset{p,r}{\mathcal{O}^{(1)}_{\phi l}}$	$(\phi^\dagger i\overleftrightarrow{D}_\mu\,\phi)(\bar{l}'_p\gamma^\mu l'_r)$	$\underset{p,r}{\mathcal{O}^{(3)}_{\phi l}}$	$(\phi^\dagger i\overleftrightarrow{D}^I_\mu\,\phi)(\bar{l}'_p\tau^I\gamma^\mu l'_r)$
$\underset{p,r}{\mathcal{O}_{\phi e}}$	$(\phi^\dagger i\overleftrightarrow{D}_\mu\,\phi)(\bar{e}'_p\gamma^\mu e'_r)$	$\underset{p,r}{\mathcal{O}^{(1)}_{\phi q}}$	$(\phi^\dagger i\overleftrightarrow{D}_\mu\,\phi)(\bar{q}'_p\gamma^\mu q'_r)$	$\underset{p,r}{\mathcal{O}^{(3)}_{\phi q}}$	$(\phi^\dagger i\overleftrightarrow{D}^I_\mu\,\phi)(\bar{q}'_p\tau^I\gamma^\mu q'_r)$
$\underset{p,r}{\mathcal{O}_{\phi u}}$	$(\phi^\dagger i\overleftrightarrow{D}_\mu\,\phi)(\bar{u}'_p\gamma^\mu u'_r)$	$\underset{p,r}{\mathcal{O}_{\phi d}}$	$(\phi^\dagger i\overleftrightarrow{D}_\mu\,\phi)(\bar{d}'_p\gamma^\mu d'_r)$	$\underset{p,r,s,t}{\mathcal{O}_{ll}}$	$(\bar{l}'_p\gamma_\mu l'_r)(\bar{l}'_s\gamma^\mu l'_t)$
$\underset{p,r,s,t}{\mathcal{O}^{(3)}_{lq}}$	$(\bar{l}'_p\gamma_\mu\tau^I l'_r)(\bar{q}'_s\gamma^\mu\tau^I q'_t)$				

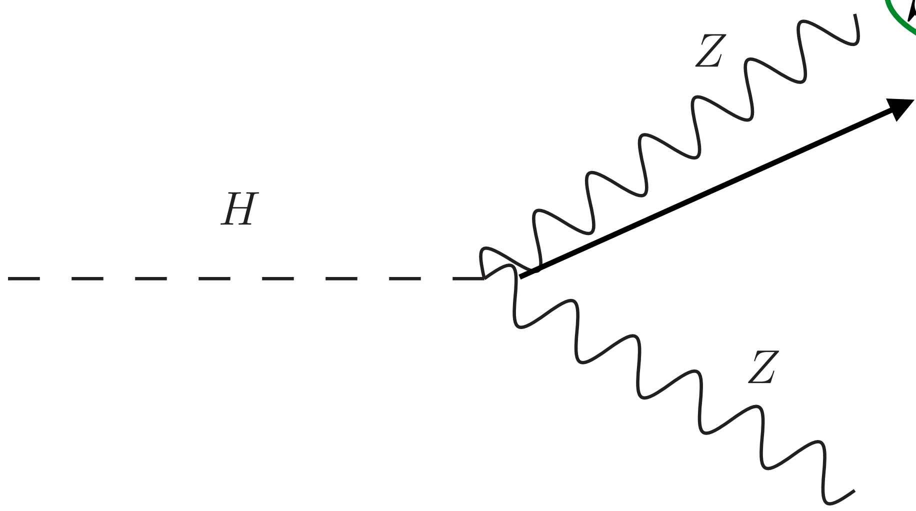
Let’s concentrate on the LO



There could be large cancellations between contributions

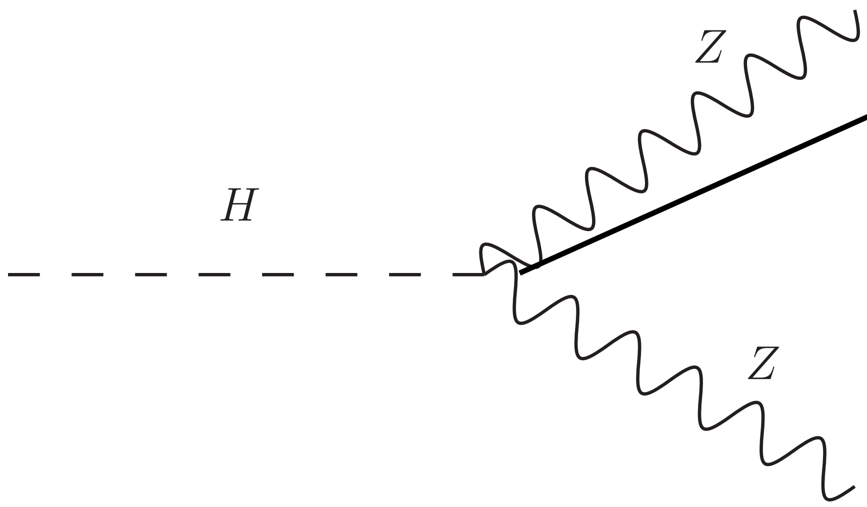
Why NLO?


Z
H
Z



$$SM + \sum a_i C_i^{LO}$$

LO

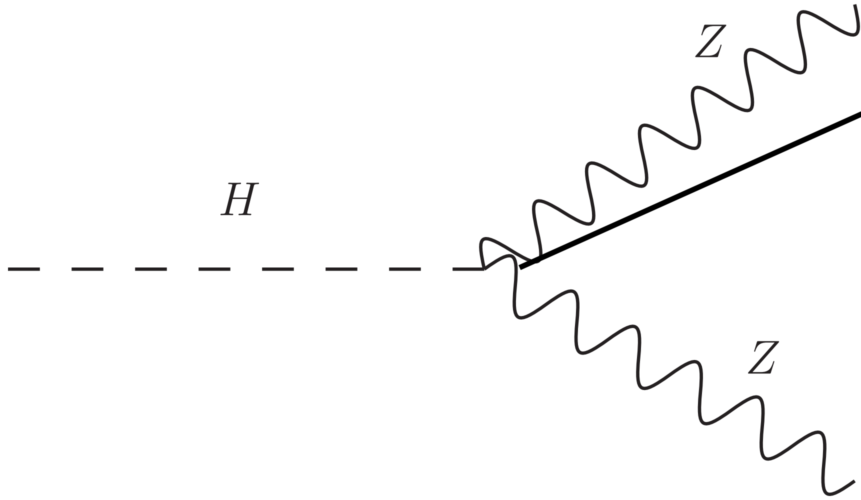


$$SM + \sum a_i C_i^{LO}$$

LO

$$+ \log\left(\frac{\Lambda^2}{M_z^2}\right)\left(\sum b_i C_i^{NLO}\right)$$

Log “enhancement” from anomalous dimensions



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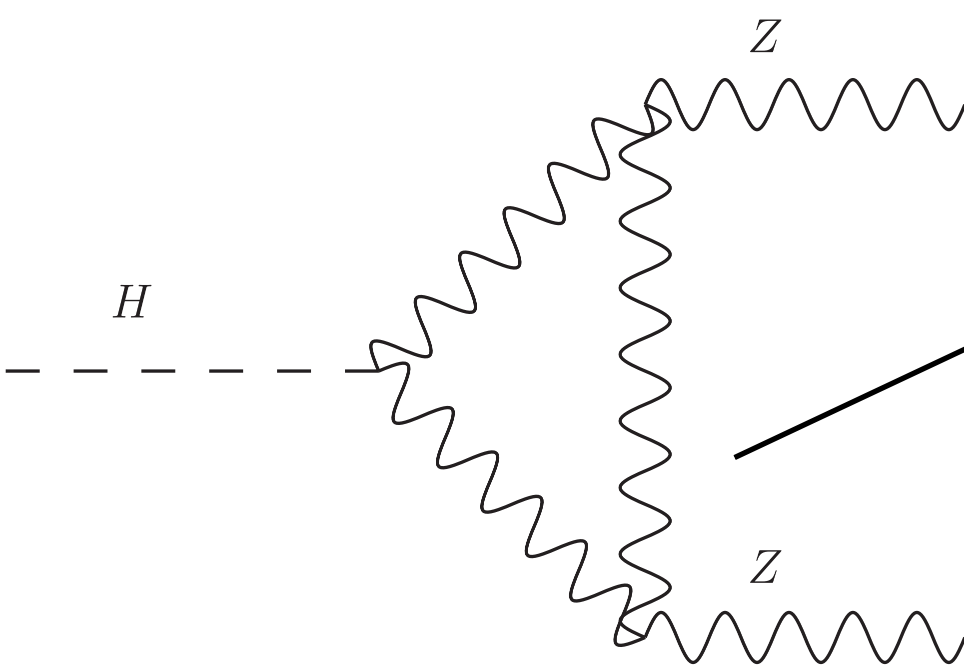
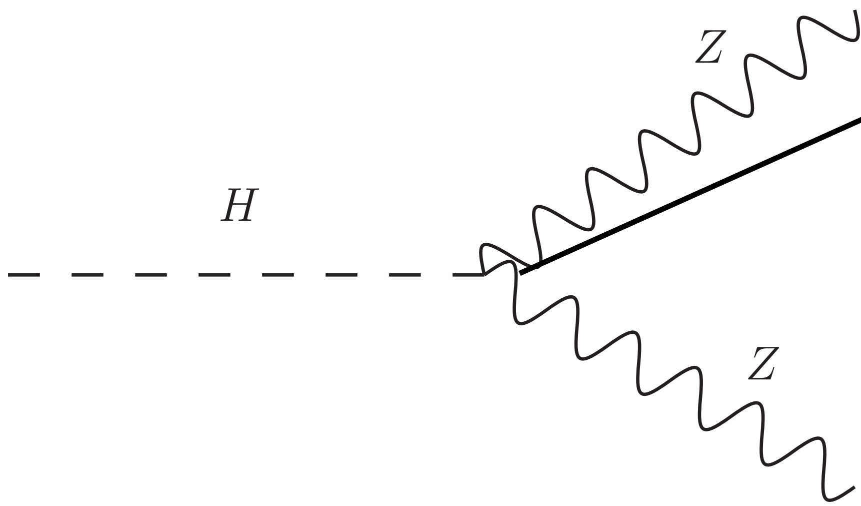


Actual Loop calculation



$$SM + \sum a_i \mathcal{C}_i^{LO}$$

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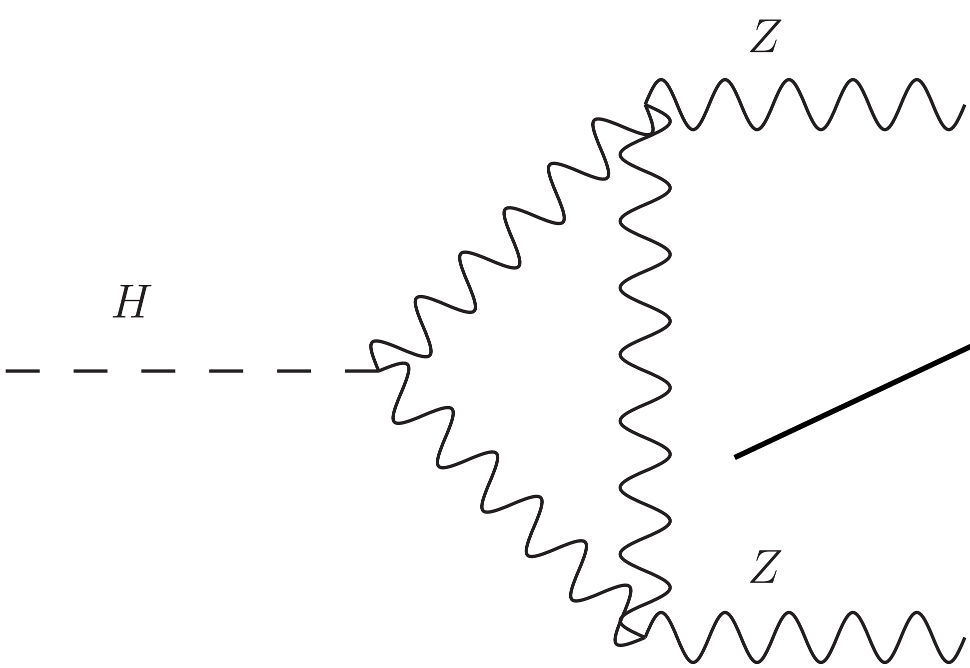
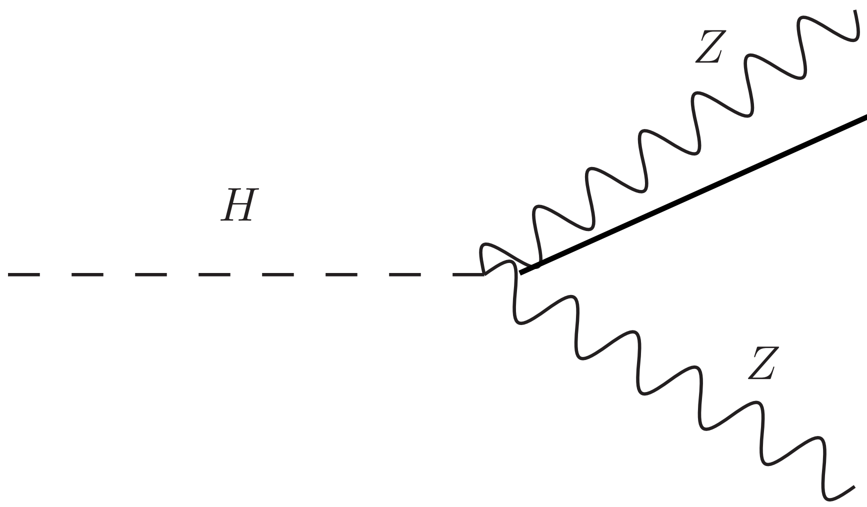


Actual Loop calculation

54 diagrams in the SM



$$SM + \sum a_i C_i^{LO}$$

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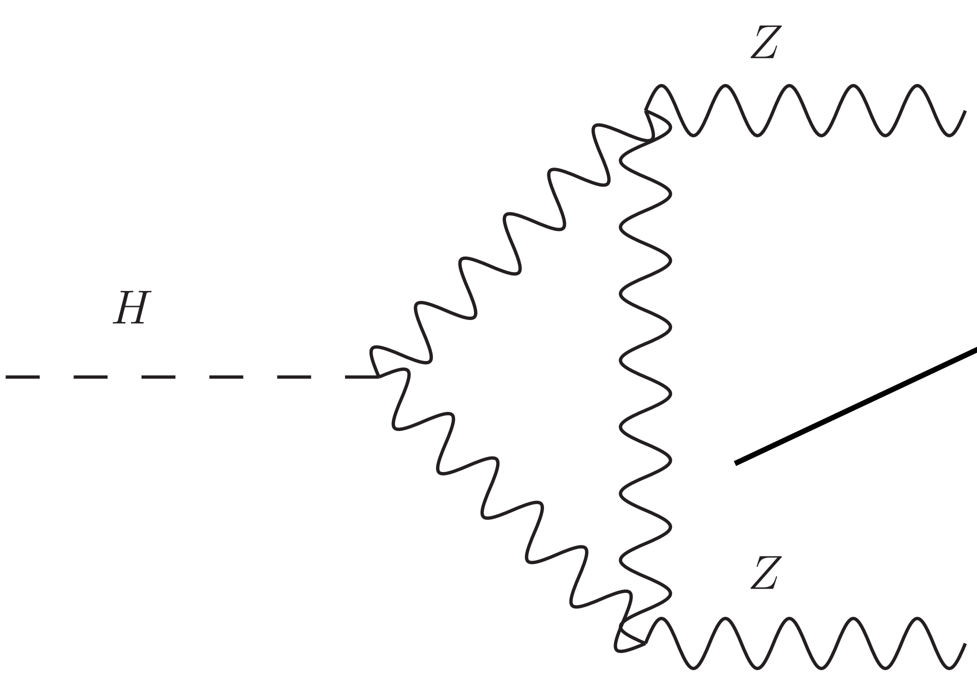
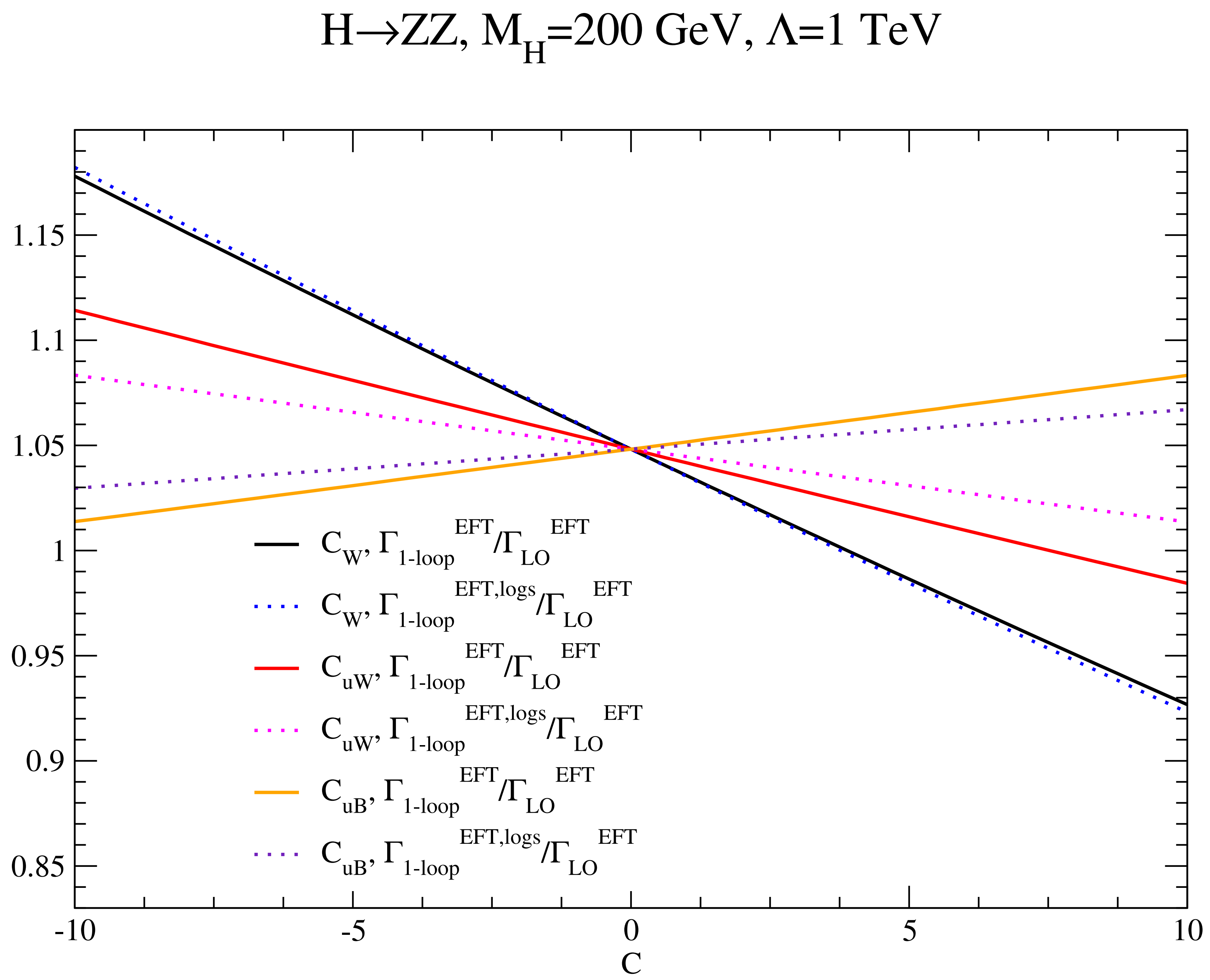


Actual Loop calculation

54 diagrams in the SM

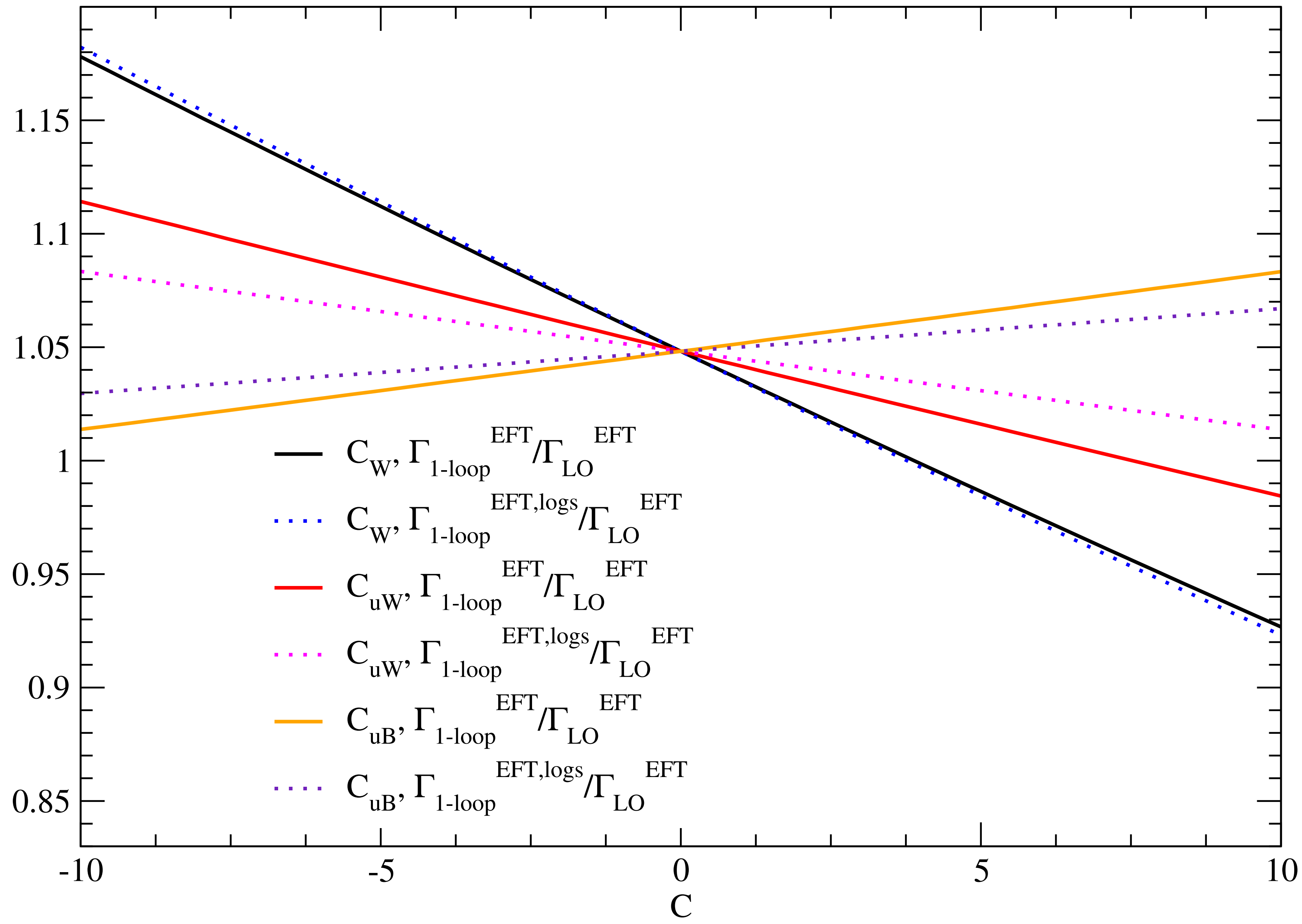
288 diagrams in the SMEFT



Operators that do not appear at LO could be less constrained

Large contributions!

$H \to ZZ$, M_H=200 GeV, Λ=1 TeV



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Large contributions!

Notice that Logs are predominant

Not true in general!

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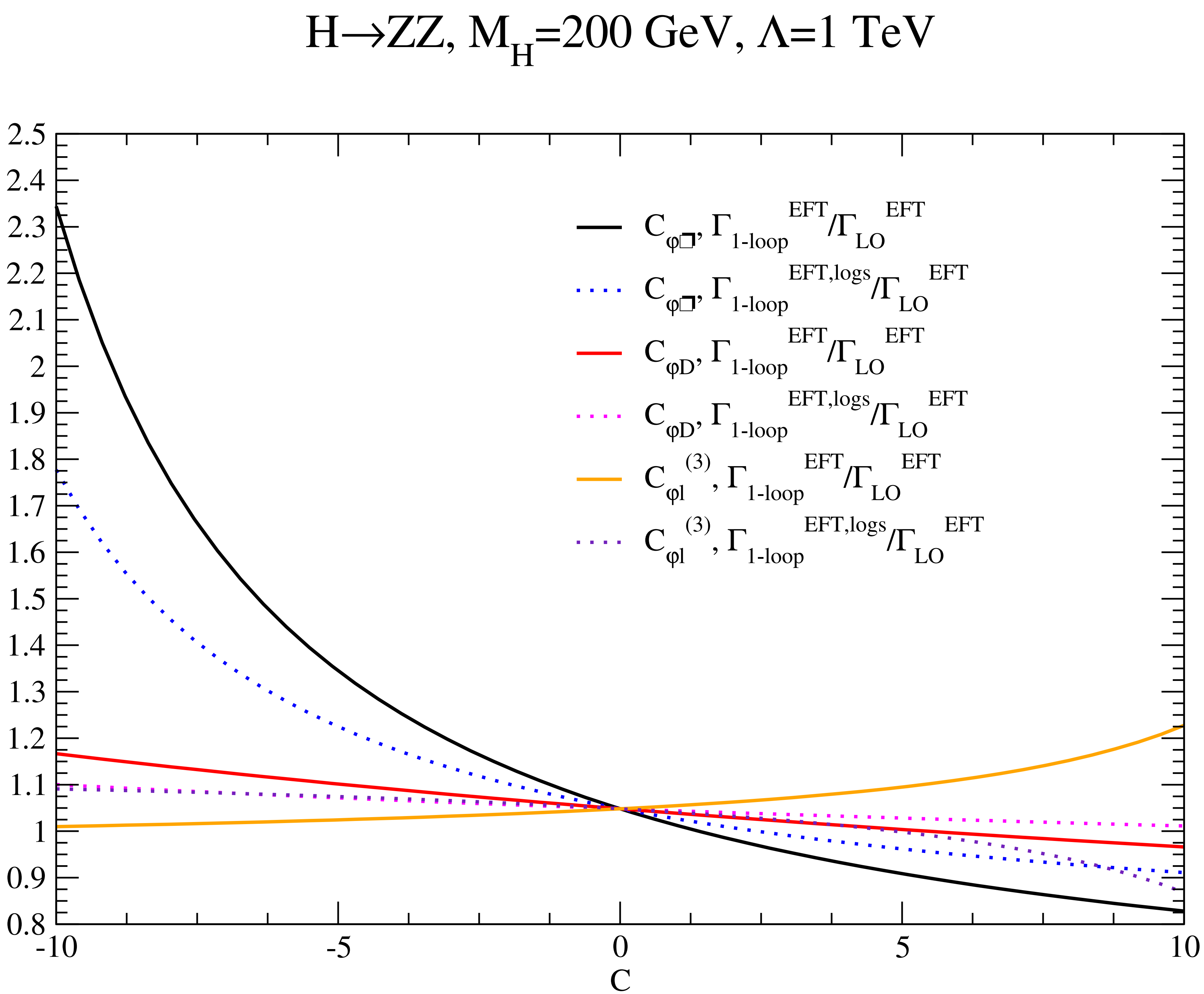

A complete computation of the NLO contribution is necessary

Conclusions

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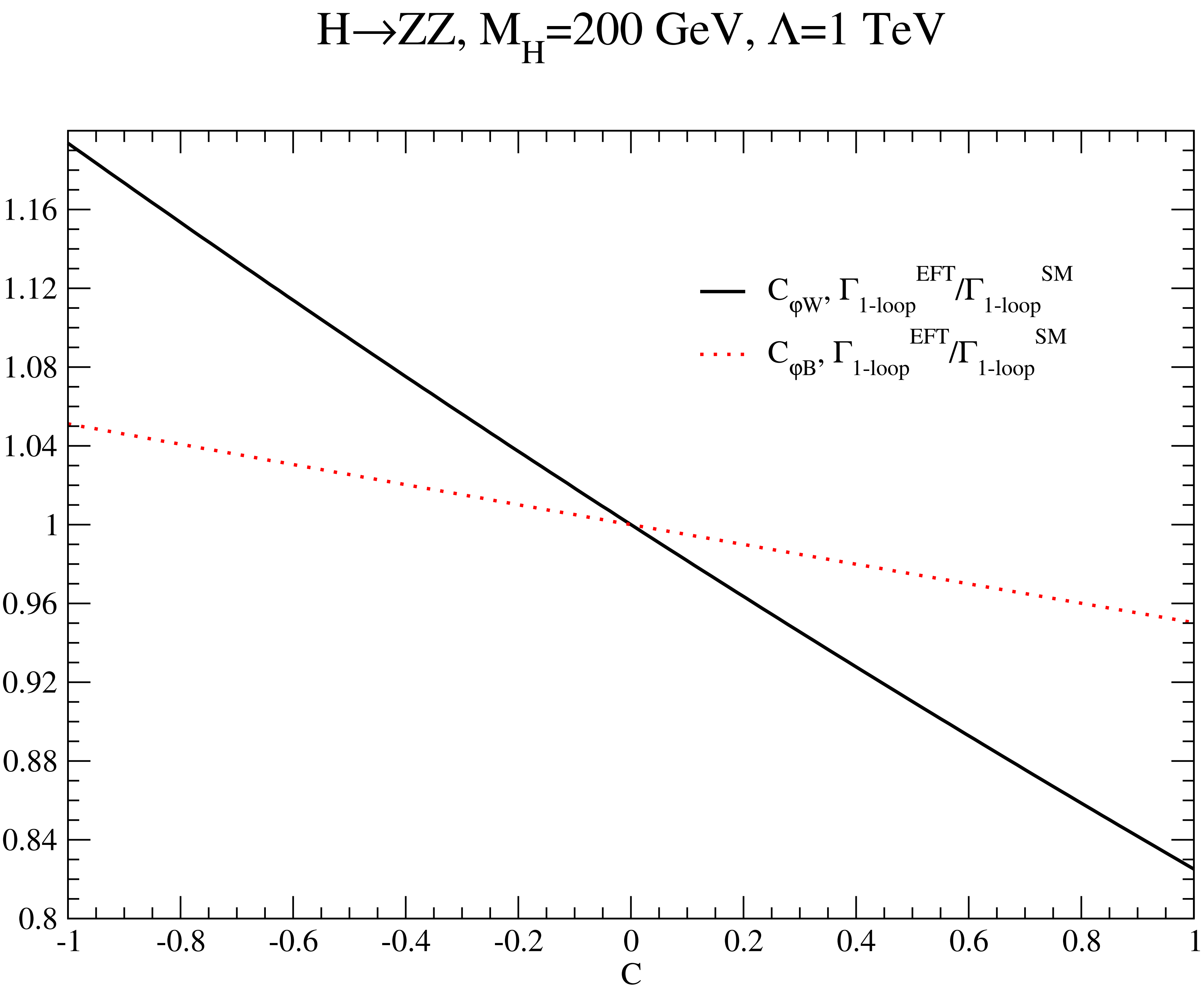
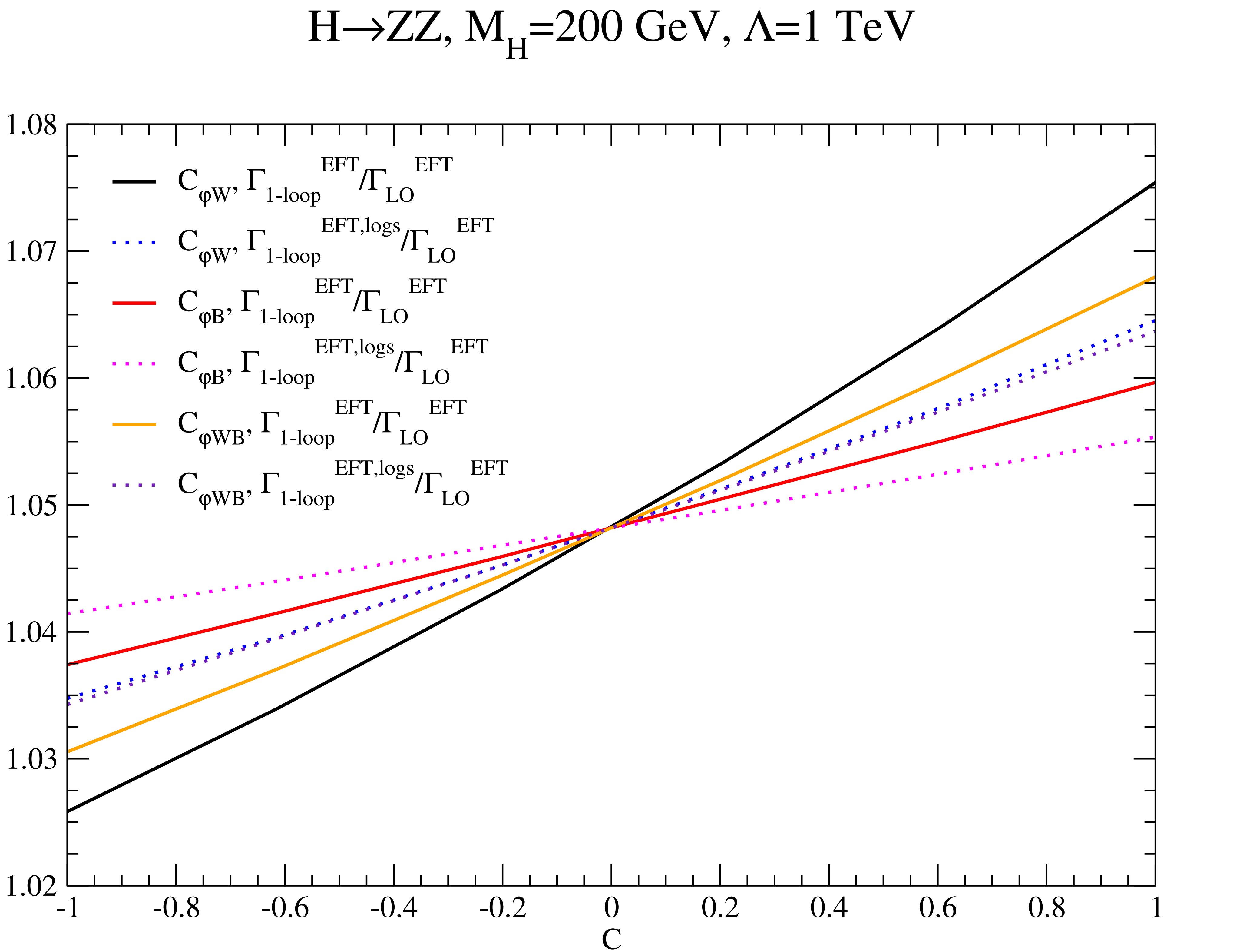
- NLO can have large effects.
- Calculation of Logs is often not sufficient.
- This is the first step towards the physical decay.

Backup Slides

SMEFTNLO vs. SMNLO



For reasonable values of the parameter the difference could be of order 10%


H→ZZ, M_H=200 GeV, Λ=1 TeV
C_φW, Γ_1-loop^EFT/Γ_LO^EFT
C_φW, Γ_1-loop^EFT,logs/Γ_LO^EFT
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C_φB, Γ_1-loop^EFT,logs/Γ_LO^EFT
C_φWB, Γ_1-loop^EFT/Γ_LO^EFT
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1.08
1.07
1.06
1.05
1.04
1.03
1.02
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
C