$H \to \ell^+\ell^- Z$ at NLO in the SMEFT

2411.xxxxx with Sally Dawson and Pier Paolo Giardino

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See also related talk on $e^+e^- \to ZH$ by Konstantin Asteriadis

Standard Model Effective Field Theory

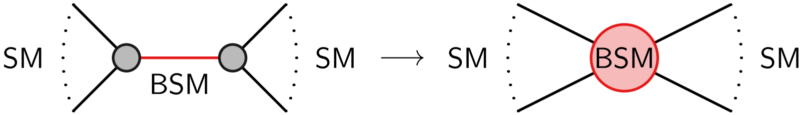
For heavy BSM physics at scale Λ, effects in low energy observables can be computed using effective field theory techniques:

$$\mathcal{L} = \mathcal{L}_{\mathrm{SM}} + \sum_i \frac{C_i}{\Lambda^2} \mathcal{O}_i + \ldots$$

Systematically improvable, both in loops and powers of Λ

Comprehensive framework for constraining heavy BSM models with LHC and low-energy data

For precise constraints, need to go to higher loop orders



$H \to 4\ell$

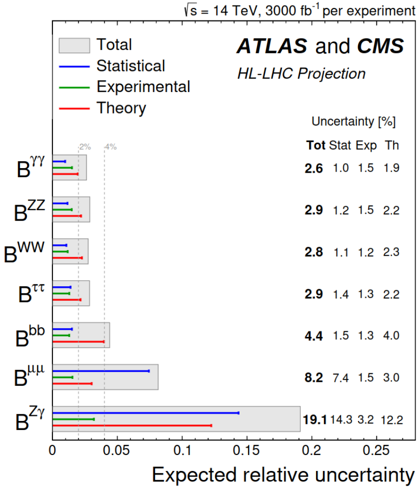
$H \to 4\ell$ is one of the best measured decay modes!

SM known to NLO EW [hep-ph/0604011], [1912.02010]

Most Higgs decays are known at one-loop in the SMEFT, but $H \to 4f$ still missing

As precision improves, Higgs decays become sensitive to loop effects

Necessary ingredient for NLO accurate fits



HL-LHC working group [1902.00134]

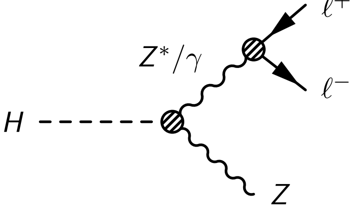
$H \to \ell^+\ell^- Z$ in the SMEFT

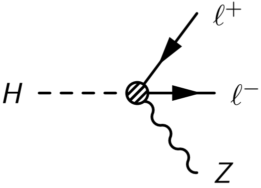
We have the complete one-loop calculation of $H \to \ell^+\ell^- Z$ in the SMEFT at dimension-6 with fully general flavour structure

With the narrow width approximation, dominant contributions to $H \to 4\ell$

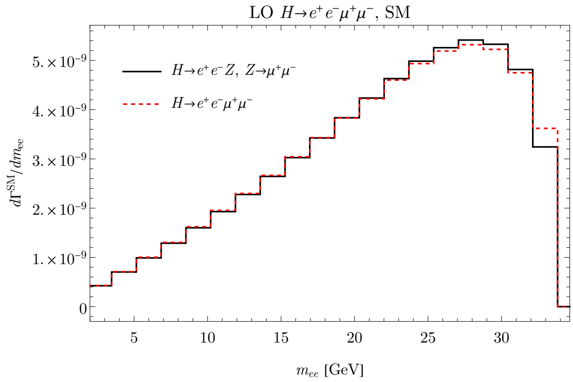
At LO $\sim$ 10 operators contribute, with new kinematic dependence

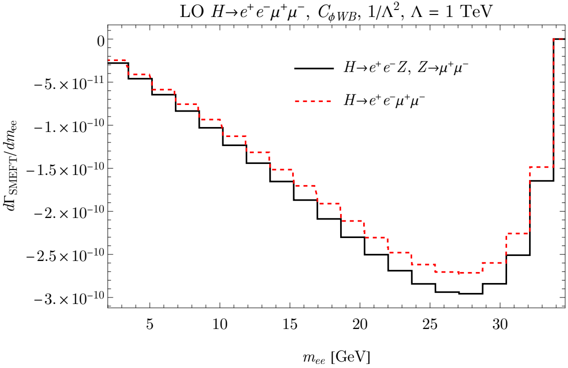
- $\mathcal{O}_{\phi B} = \phi^\dagger \phi B_{\mu\nu} B^{\mu\nu}$
- $\mathcal{O}_{\phi\Box} = (\phi^\dagger \phi)\Box(\phi^\dagger \phi)$
- $\mathcal{O}_{\phi D} = |\phi^\dagger D^\mu \phi|^2$
- $\mathcal{O}_{\phi e} = (\phi^\dagger i \overleftrightarrow{D}_\mu \phi)(\bar{e}_R \gamma^\mu e_R)$
- ...





How good is the narrow width approximation?





Examples for the SM and an example EFT coefficient ($C_{\phi WB}$)

Other operators similar – quite good agreement for $H \to e^+e^-\mu^+\mu^-$

We don't have full NLO $H \to 4\ell$, but we do in the NWA!

Going to NLO: real emission

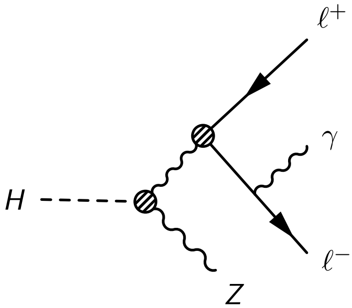
At NLO, virtual photon contributions have soft and collinear divergences that cancel against $H \to \ell^+\ell^- Z\gamma$ contributions

Treat with standard dipole subtraction techniques

Requires 4-body phase space!

For non-inclusive observables, logarithms $\sim \log Q^2/m_\ell^2$ appear

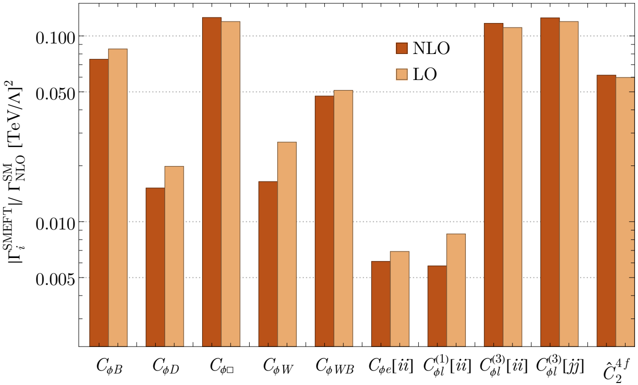
$\to$ e^+e^- and $\mu^+\mu^-$ modes differ at NLO after experimental cuts



NLO corrections are large

Up to a 40% correction for some operators at NLO

(Results shown with $\Lambda = 1$ TeV, $C_i = 1$)



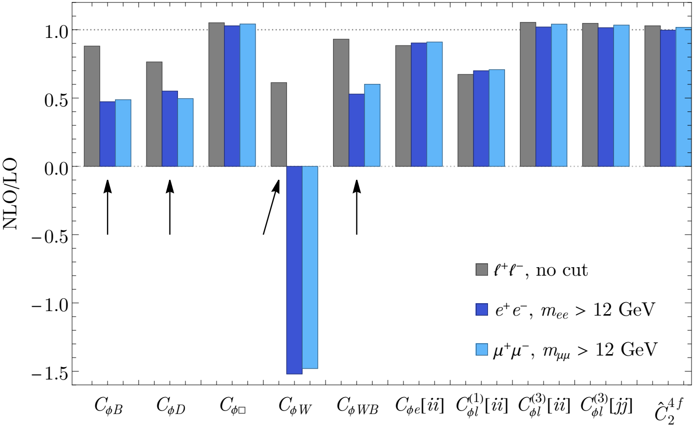
Realistic experimental cuts

Becomes even larger ($> 50\%$) with realistic $m_{\ell\ell} > 12$ GeV cut

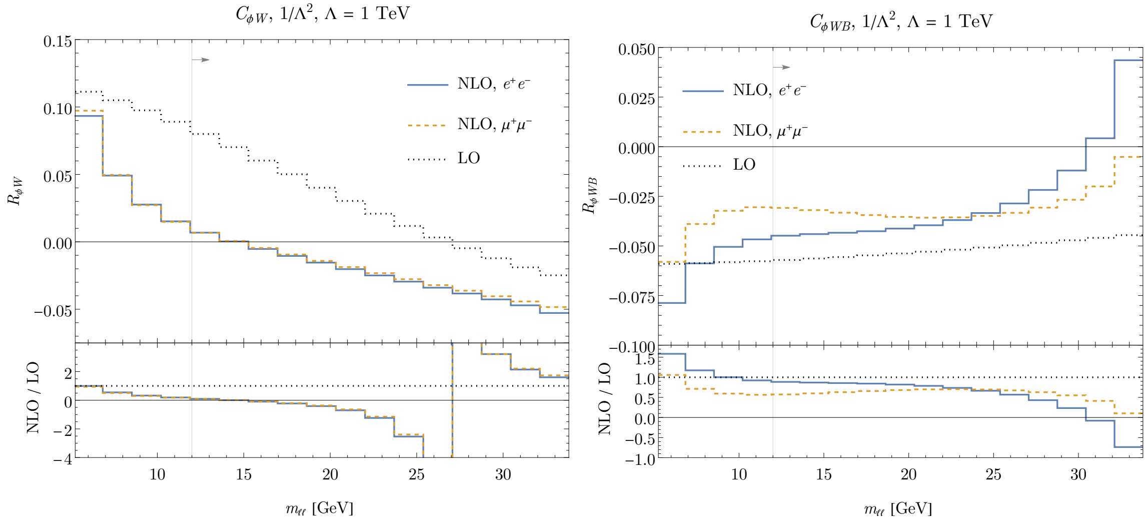
Significant differences for $C_{\phi B}$, $C_{\phi D}$, $C_{\phi W}$, $C_{\phi WB}$

$C_{\phi W}$ switches sign!

Now mildly flavour dependent: up to $\sim$10% differences



Differential distributions



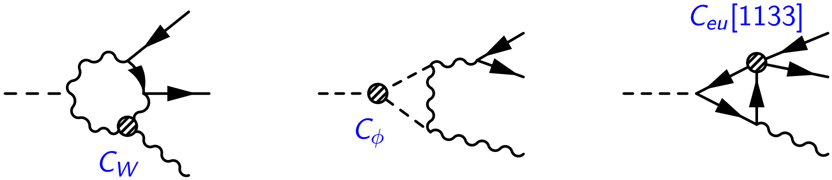
$R_i = \text{SMEFT}/\text{SM}$

New operators at NLO

About ~ 70 new operators first enter at NLO in ~ 25 combinations

Of these, most are quite small. Notable exceptions:

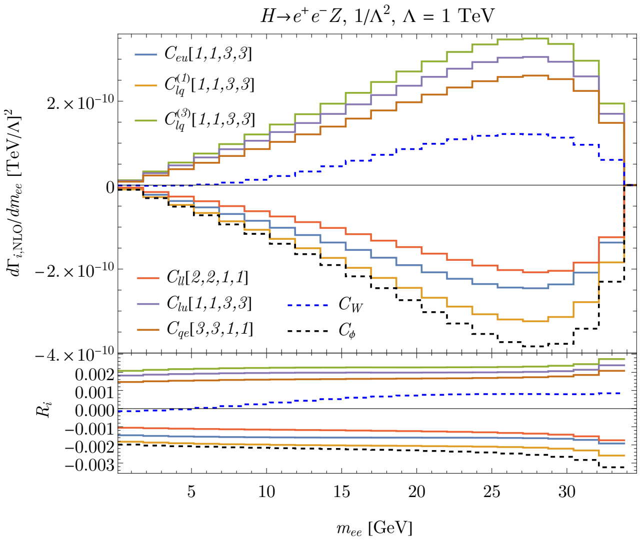
- Top-quark operators: $\mathcal{O}_{lq}^{(1)} = (\bar{L}\gamma_\mu L)(\bar{Q}\gamma^\mu Q)$, $\mathcal{O}_{\phi u} = (\phi^\dagger i \overleftrightarrow{D}_\mu \phi)(\bar{t}_R \gamma^\mu t_R)$, ...
- Higgs self-coupling: $\mathcal{O}_\phi = (\phi^\dagger \phi)^3$
- Anomalous triple gauge coupling: $\mathcal{O}_W = \epsilon_{IJK} W_\mu^{I\nu} W_\nu^{J\alpha} W_\alpha^{K\mu}$



Differential distributions

New operators at NLO have SM-like distributions

Exception: C_W has novel momentum dependence



Estimating the impact on constraints

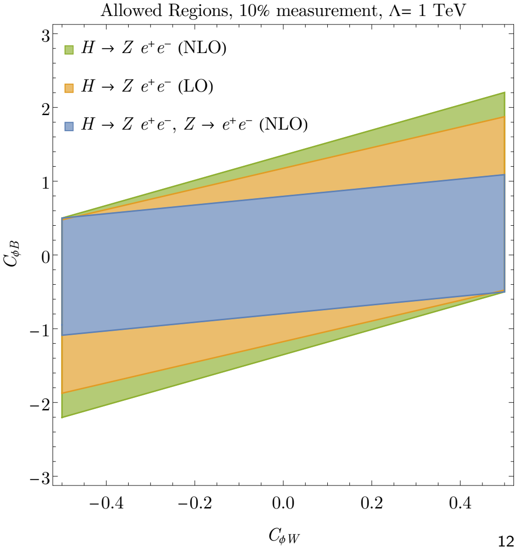
Toy example: consider a 10% measurement of $H \to 4\ell$

Combine with known $Z \to \ell^+\ell^-$ at NLO in the SMEFT [1909.02000]

$\to$ Full $H \to 4\ell$ at NLO in NWA

Correlations change shape at NLO

Proper constraints require NLO accurate production modes as well in a general fit



Bounding C_ϕ

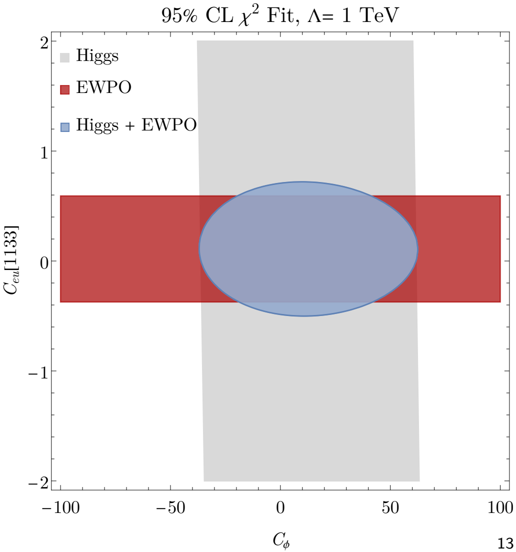
Higgs self-coupling constraints depend on other operators

An example: C_{eu} doesn't appear in the production mode

$\mathcal{O}_{eu}[1133] = (\bar{e}_R\gamma_\mu e_R)(\bar{t}_R\gamma^\mu t_R)$

Production mode C_ϕ dependence included

Would like to do this for all operators, but need to know production mode dependence



Conclusions

We have computed $H \to \ell^+\ell^- Z$ to full NLO in the SMEFT

- One of the last remaining H decays to one-loop accuracy

Several operators appearing at LO experience large corrections at NLO

- In particular, $C_{\phi W}$, $C_{\phi B}$, $C_{\phi WB}$, $C_{\phi D}$, $C_{\phi l}^{(1)}$
- Experimental cut of $m_{\ell\ell} > 12$ GeV changes results significantly

Higgs self-coupling and anomalous top-quark couplings enter at NLO

- Extraction of Higgs trilinear depends on assumptions about other operators

Our calculation is one more step towards fully NLO accurate SMEFT fits

Thank you!