

# Estimation of NLO-in-EFT Errors for Collider SMEFT Searches

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# Why should we care about uncertainties in signals?

- Neglecting or downplaying signal-function theory errors is common in the BSM community
  - Idea being that you can clean up the calculations once we find something, but signatures won't change drastically
- Neglecting errors is never correct in precision measurements or calculations, though, and that's where EFT measurements are going

# The Ideal EFT Interpretation Tool

- With automated matching and fitting tools, it should be quick and painless for any new UV model to be quickly tested against EFT measurements from LHC and lower energies
- Ideal output should say if a model is unconstrained, potentially constrained (and thus potentially needing model-specific searches in the same data) or definitely constrained.



# What are these errors?

## In SMEFT

- Lagrangian expanded as power series in  $\frac{c}{\Lambda}$ 
  - $\mathcal{L} \supset \sum_d \frac{O_d}{\Lambda^{d-4}}$
- Hard process calculated to some order in all relevant couplings (including Wilson Coefficients).

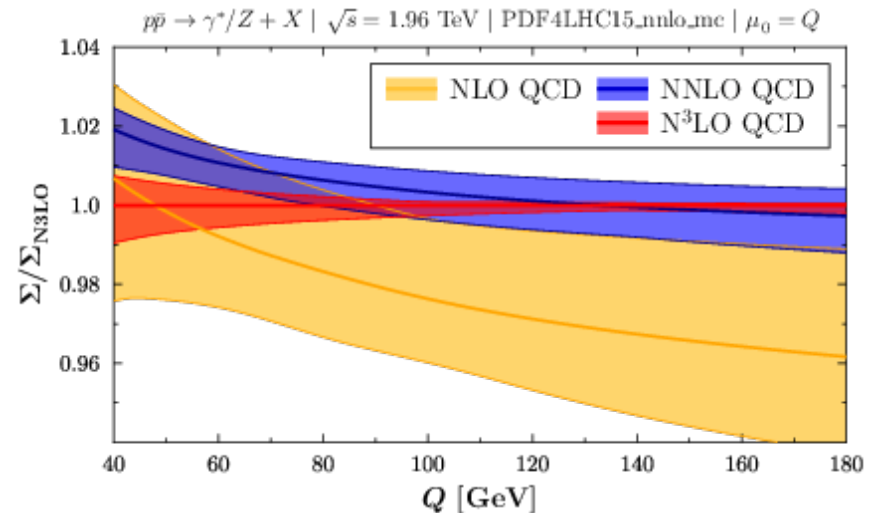
## In QCD

- Lagrangian is fixed
- Hard process calculated to some order in  $\alpha_s$
- Complications arise in parton distribution functions, fragmentation functions

In both cases, the errors are coming from the next order in the perturbative expansion

# How do we estimate them in QCD?

- Perturbation theory in QCD gives us a convenient partial next-order result
  - RG scale dependence predicts divergent part of next-order calculation
- We can use that partial calculation, with a rule of thumb, to estimate how large the full next-order correction will be
  - We even have a good heuristic for when this guess commonly fails: new topologies



# Simulation-powered error estimation

focusing on  $\Lambda^{-4}$  case – technique similar to any order

- We can construct the  $d6^2$  distribution as numerical coefficients times couplings with e.g. SMEFTSim
  - Relatively few events needed, particularly with  $p_T$  weighting options
  - Requires only  $\frac{N(N+1)}{2}$  distinct runs, parton level
- Bin error distribution into histograms of interest for analysis

# Troubles with Simulated Errors

- Using this to fit next-order error would:
  - Neglect the effects of next order in Lagrangian
  - Require considering every dim-6 coefficient as an error parameter in addition to a signal parameter?
  - Lead to underconstrained parameters due to EFT “flat directions”
- We need to come up with a better choice for how to parametrize this error, including accounting for the partial nature of the sim

# Error Parameter Reduction

- We need to somehow add all the components of the flat directions together into one nuisance
- Want to do this for an arbitrary distribution of experimental interest
- Goal is to represent the error distribution with as few parameters as possible
- This lends itself to consideration of the same statistical techniques that are used to explore constraint strengths e.g. PCA approaches

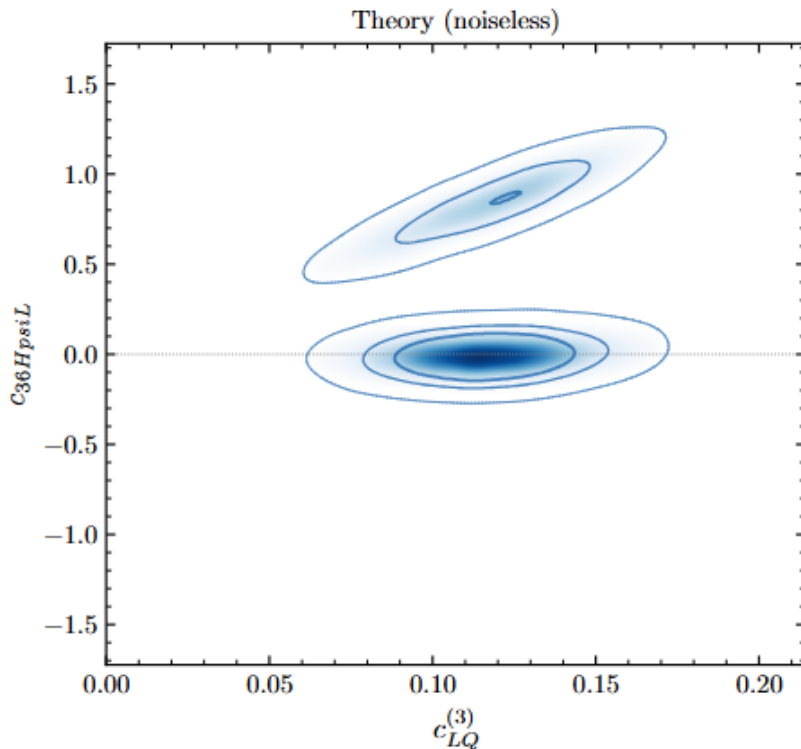
# Error Parameter Reduction

- Bin your error sim into the observable bins you're interested in
- Find the smallest amount of operators you can use to reproduce that with appropriate fidelity
  - Accuracy can be matched statistically to sim
- Directly captures flat directions using a single parameter
- For  $K$  needed operators gives  $K(K+1)/2$  different distributions
- We track the distribution of needed couplings to fit the full sim and resample from it for the distribution of nuisance parameter values

# Decorrelation, Expansion, Heuristics

- Now to account for the fact that this is a partial next-order result, we want additional freedom and increased distribution magnitudes
- To increase freedom of shape, we let each distribution vary independently from every other
  - Breaking e.g. relation between  $c_1^2$ ,  $c_2^2$ , and  $c_1 c_2$  terms
- To boost the error size to account for partiality of simulated vs true EFT at next order, we increase the distribution by a factor of  $\sqrt{2}$ .
  - This comes from the exact same place as the factor of two scaling of renormalization scale in the QCD story

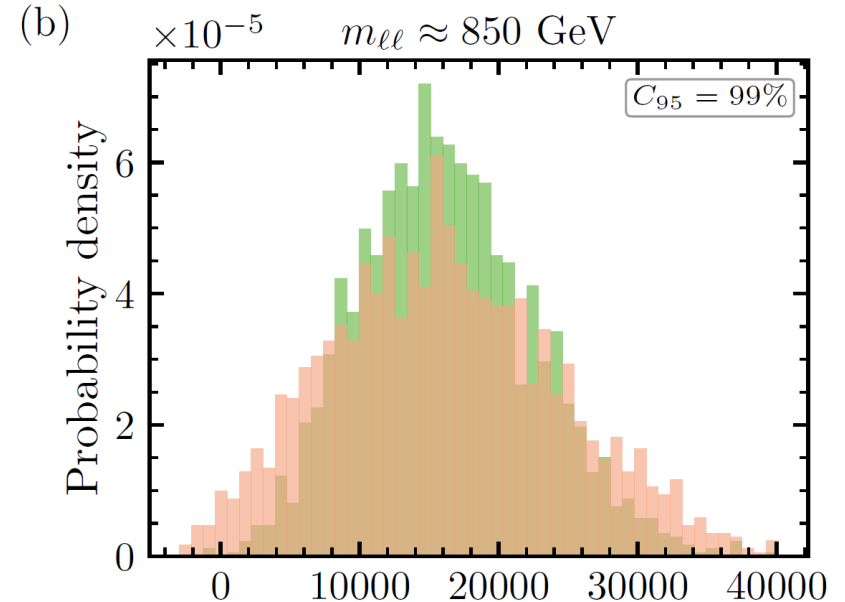
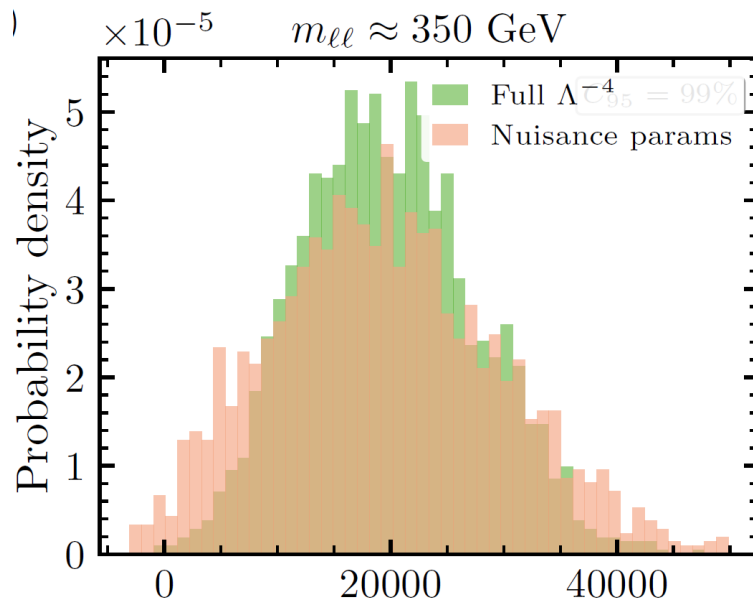
# Example: Drell-Yan



- Fitting Drell-Yan  $d6^2$  distributions requires just 2/19 operators
- Note: Distributions of needed Wilson Coefficients are not simple gaussians
- Resampling straight from this distribution would give the statistical ensemble of  $d6^2$  distributions

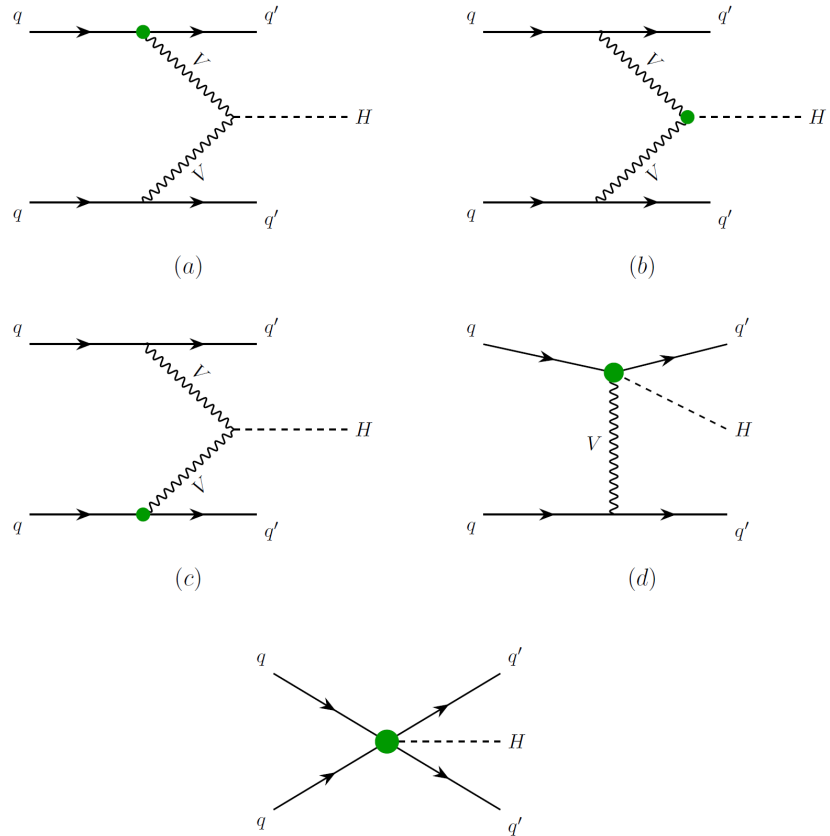
# Example: Drell-Yan

- Adding in 40 randomly-distributed  $d8$  operators (Green in plot)
- Decorrelate 3 distinct distributions, expand coefficients by factor  $\sqrt{2}$ , giving estimated shape (Gold in plot)

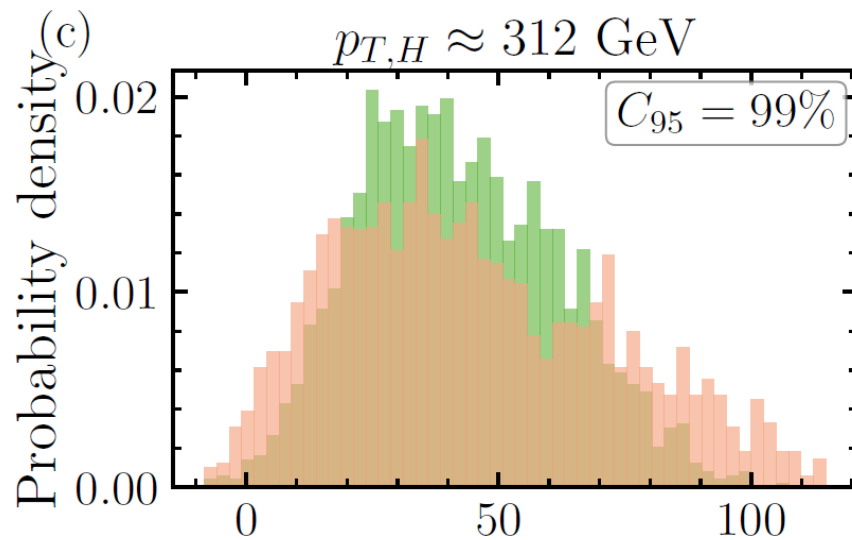
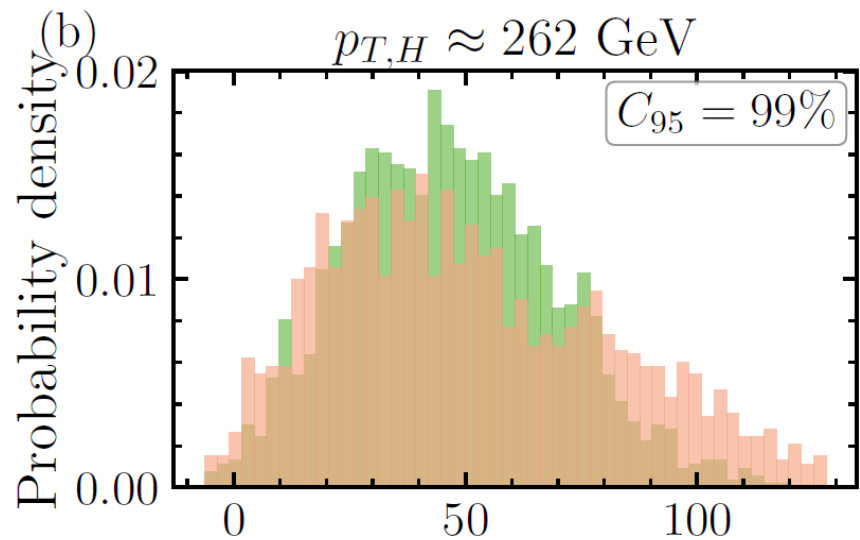
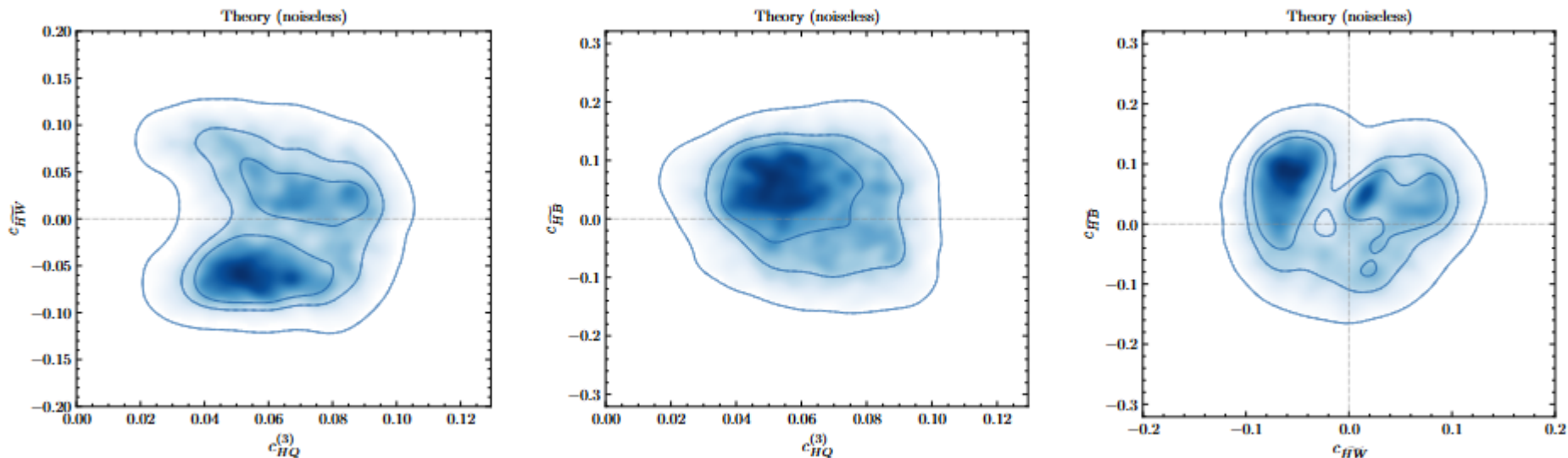


# Example: VBF Higgs

- $2 \rightarrow 4$  process
- New topology at d8!
- Following the same recipe as previous case
  - Bin  $d6^2$
  - Fit with minimal operators
  - Decorrelate, expand, and sample to estimate full  $\Lambda^{-4}$



# Example: VBF Higgs



# Summary

- While many different operator combinations contribute to the next-order EFT error, we can approximate it very well with few parameters
- Error approximation by algorithm
  - Process independent
  - Order-in-EFT agnostic
- Proof of principle in cases with known  $\Lambda^{-4}$  results
  - Without and with new topology effects

**Thank You!**