Truncation Errors and Interpretability in the SMEFT

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Why should we care about uncertainties in signals?

- Neglecting or downplaying signal-function theory errors is very common in the pheno 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 the business we're in

How far beyond linear: What question are we asking?

What might we have seen?

- Asking for potential that something could have showed up
- Optimism in what we can calculate and believe is more appropriate in this case
- Travelling beyond linear gives additional signal, increases potential reach of analysis

What would we have seen?

- Asking for certainty that we've constrained something
- Here we want to only count on what we're confident we know
- Care must be taken to include estimates of higher-order EFT effects as uncertainties in the analysis

A Quote from a Model Builder

- "Whatever bound you get from your EFT, I can always write down a model that passes the test against data and violates the bound you claim to have." – Bhaskar Dutta

How to build a conservative EFT search

- Canonical search design boils down to plugging a new physics model into Monte Carlo tools and constraining what comes out
  - Many nice tools exist for this purpose now, e.g. SMEFTsim
- Greatest challenge to such a search is the concern about EFT consistency; this description breaks down when the new particles are light enough
  - Ensuring EFT internal consistency is the best model-independent way of addressing this concern

An example analysis: Dileptons from SMEFT

- Focusing on the most striking signatures, we consider only operators that give growing-with-energy rates
  - Selects out only 4-fermion operators

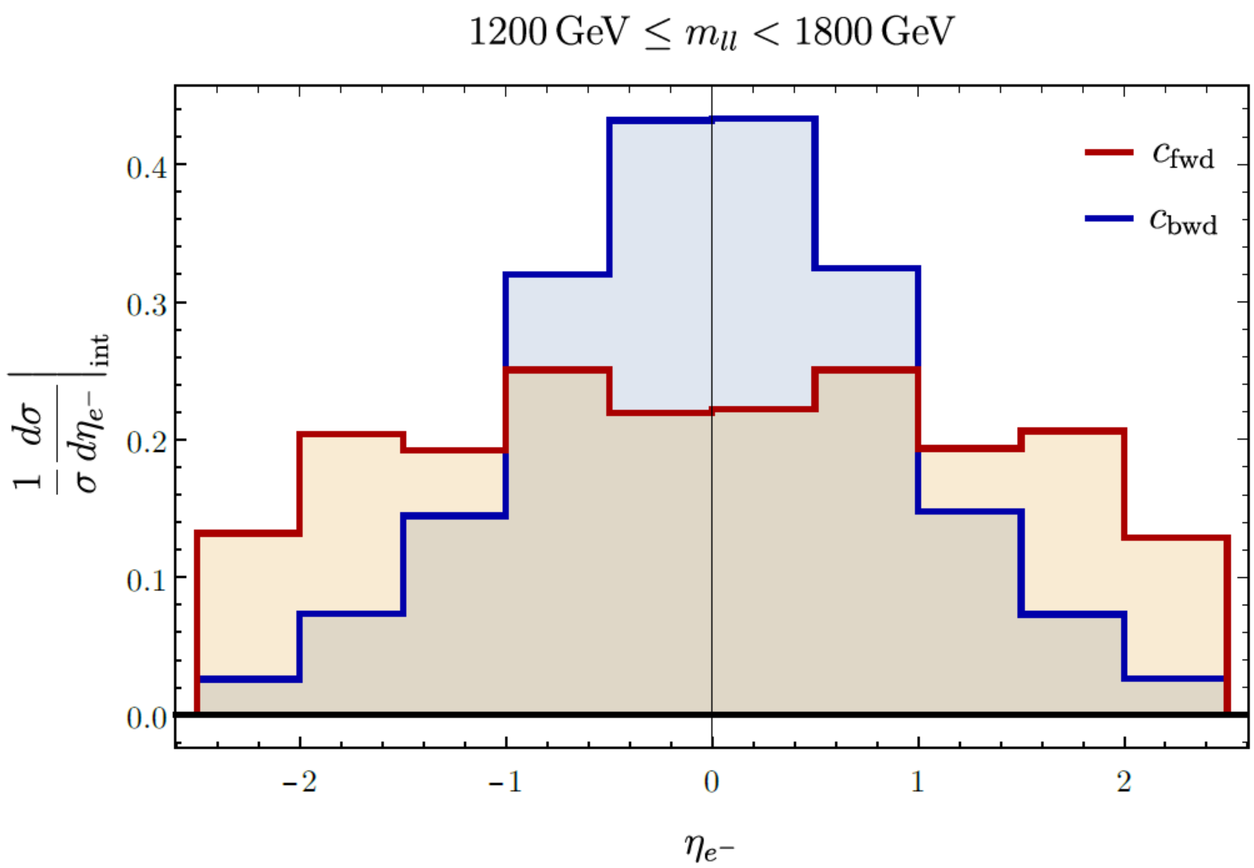
$Q_{lq}^{(1)}$	$(\bar{l}_p \gamma_\mu l_p)(\bar{q}_s \gamma^\mu q_s)$
$Q_{lq}^{(3)}$	$(\bar{l}_p \gamma_\mu \tau^I l_p)(\bar{q}_s \gamma^\mu \tau^I q_s)$
Q_{eu}	$(\bar{e}_p \gamma_\mu e_p)(\bar{u}_s \gamma^\mu u_s)$
Q_{ed}	$(\bar{e}_p \gamma_\mu e_p)(\bar{d}_s \gamma^\mu d_s)$

Q_{lu}	$(\bar{l}_p \gamma_\mu l_p)(\bar{u}_s \gamma^\mu u_s)$
Q_{ld}	$(\bar{l}_p \gamma_\mu l_p)(\bar{d}_s \gamma^\mu d_s)$
Q_{qe}	$(\bar{q}_p \gamma_\mu q_p)(\bar{e}_s \gamma^\mu e_s)$

Forward/Backward production

$c_{\rm fwd} = C_{lq}^{(3)} - 0.48\, C_{eu} - 0.33\, C_{lq}^{(1)} + 0.15\, C_{ed}$

$c_{\rm bwd} = C_{lu} + 0.81\, C_{qe} - 0.33\, C_{ld}$



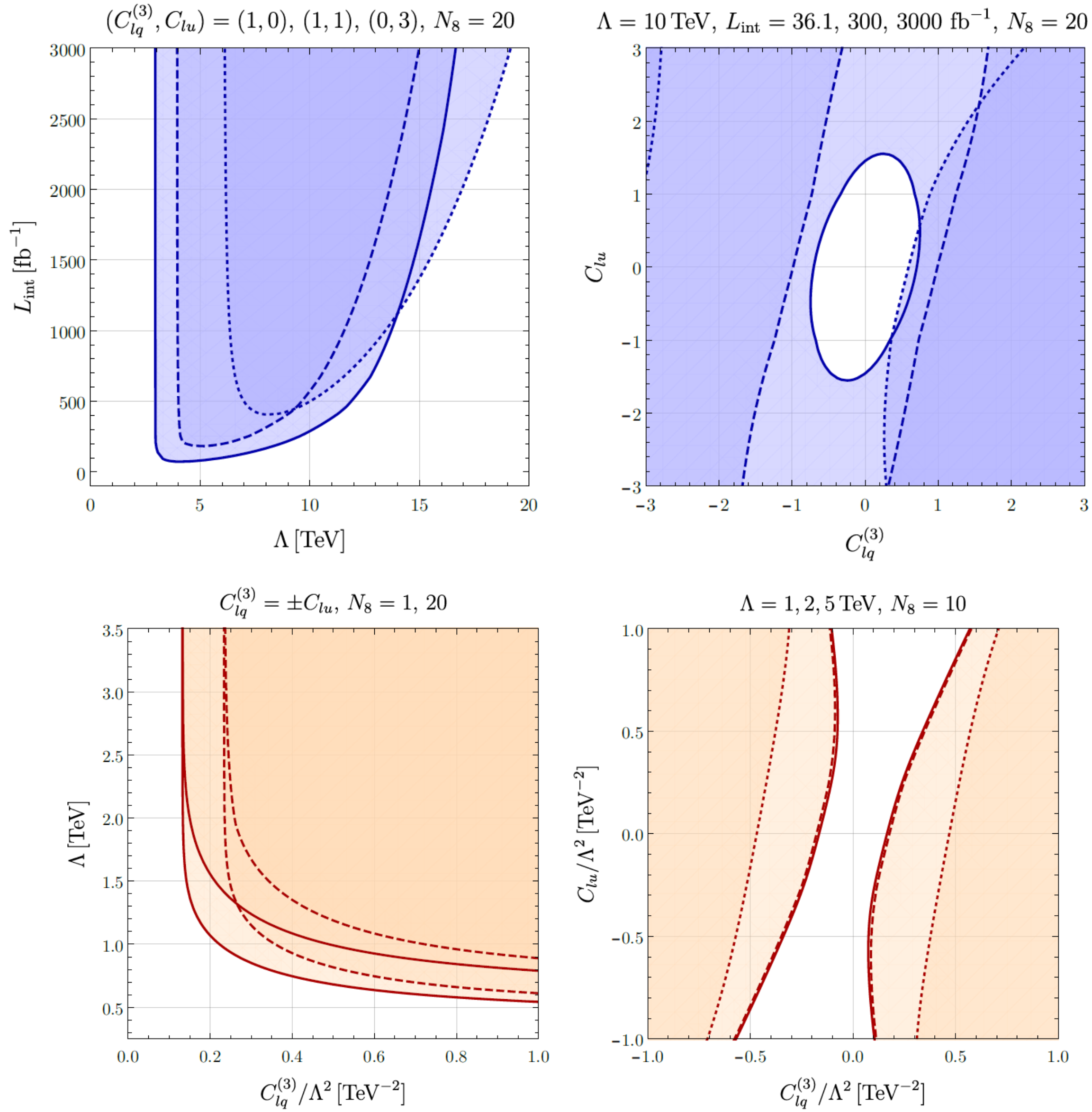
EFT error treatment

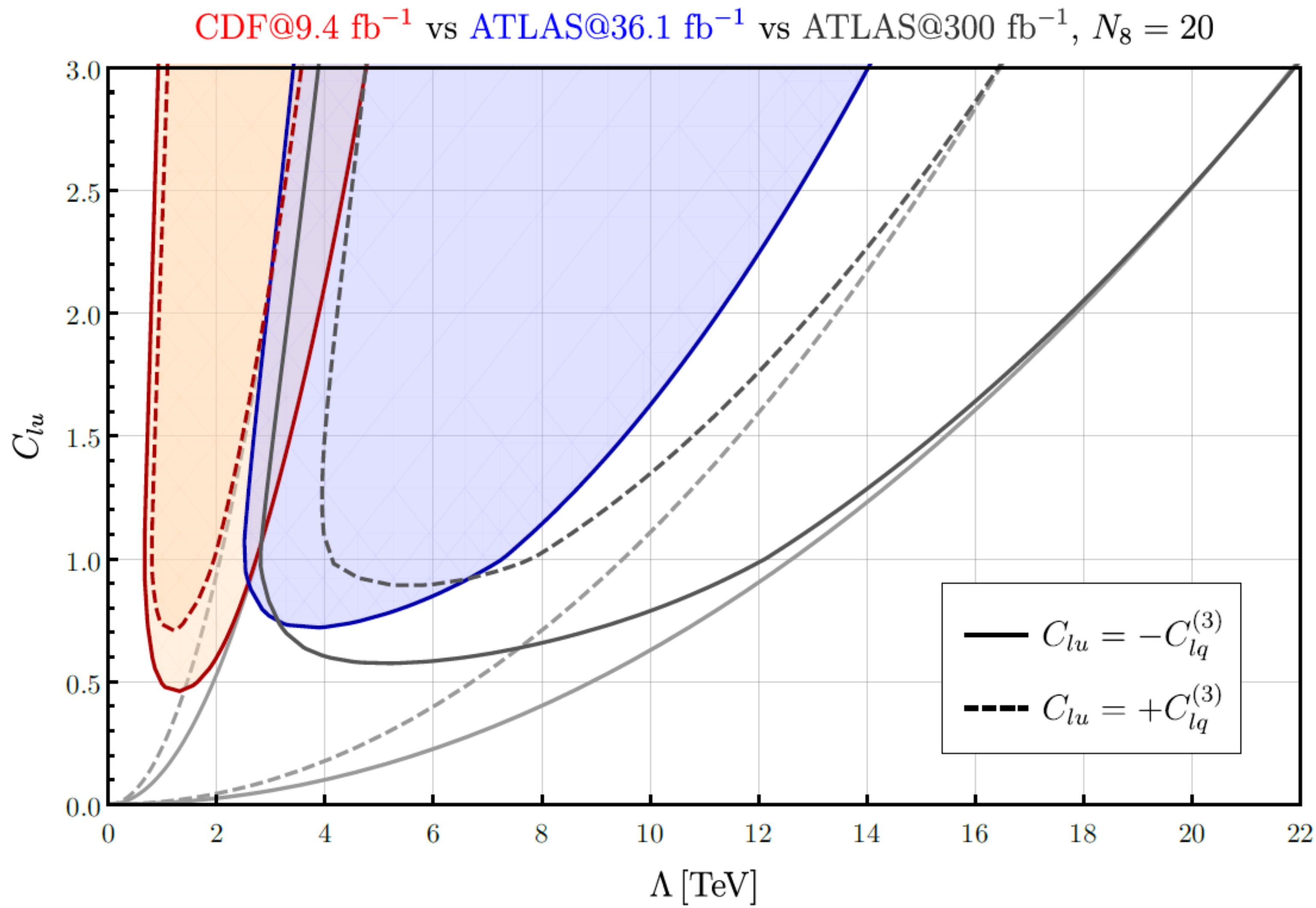
- The consistent EFT treatment is to expand the observable in a power series
  - Cross section, not amplitude
- Must include the full set of contributing operators at dim-6
  - Surprisingly, only two independent angular distributions contribute strongly
  - Remaining small differences arise from PDF evolution
- As we only have the full dim-6 contribution, everything else can be discarded
- The dim-6 squared piece is a proxy for the size of the unknown total dim-8 contribution
  - Note that additional operators needn't give correlated angular distribution

Interpretation of EFT Bounds

- EFT signal size is only sensitive to the combination c_i/Λ^2, cannot distinguish the two
  - Broken weakly by RG effects
- This leaves us two ways to interpret the bounds coming from any EFT search
  - If we fix the new physics scale, searches bound Wilson coefficients
  - Fixed coefficients lead to bounds on mass scale

LHC and Tevatron Sensitivity




CDF@9.4 fb^{-1} vs ATLAS@36.1 fb^{-1} vs ATLAS@300 fb^{-1}, $N_8 = 20$
C_{lu}
0.0
0.5
1.0
1.5
2.0
2.5
3.0
0
2
4
6
8
10
12
14
16
18
20
22
Λ [TeV]
$C_{lu} = -C_{lq}^{(3)}$
$C_{lu} = +C_{lq}^{(3)}$

What does this look like practically?

- Signal function is `generate p p > l+ l- NP^2==1`
- Basic uncertainty distribution is `generate p p > l+ l- NP==1`
- The uncertainty distribution should be scaled to represent how many operators we expect to contribute at higher orders by a factor:

$$1 + \sqrt{N_8}\frac{g_{\rm SM}^2}{\mathfrak{C}_6\Lambda^2}\sqrt{1 + \frac{1}{\mathfrak{C}_6^2\Lambda^4}}$$

- This scaled uncertainty then sums with all other errors in quadrature

The Take-Away

- Neglecting theory errors gets our analyses ignored by model-builders, who should be our biggest customers, so definitely stop doing that!
  - Produce results that they can’t evade by utilizing an honest error estimate
  - ‘New and improved’ sales pitch needed to bring them back
  - Push back against any claim that a model can always be built to evade our EFT results
- Practical approach is available using current tools to apply this approach to any observable of interest

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.

The Ideal EFT Interpretation Tool

- A traffic-light model of EFT search and fit output is the ideal solution
- We need both aggressive and conservative methods for this – two different search strategies and designs

We need to make Bhaskar (half) wrong about this!

- "Whatever bound you get from your EFT, I can always write down a model that passes the test against data and violates the bound you claim to have." – Bhaskar Dutta

Thank You!