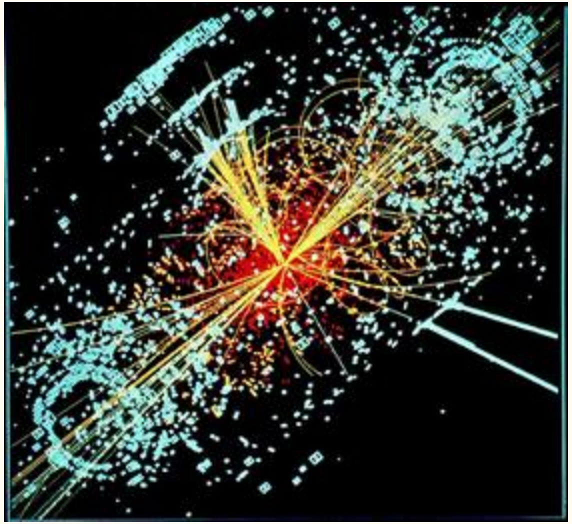
Drell-Yan in the SMEFT Including Coupling Shift Effects

Alyssa Horne, Jordan Pittman, Marcus Snedeker, William Shepherd, Joel W. Walker, arXiv:2006±1.XXXXX

Outline



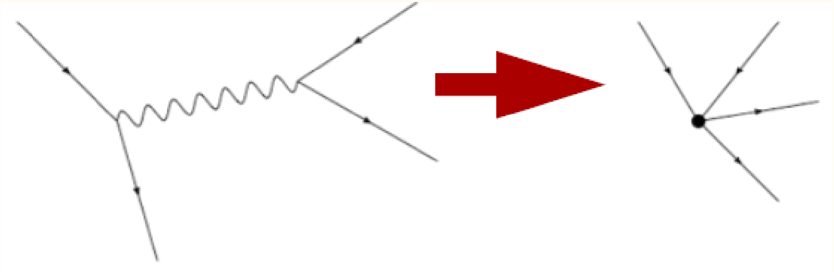
- ➢ Introduction
- ➢ Why SMEFT
- ➢ The operators and tools used
- ➢ Error Calculations and Parameters
- ➢ Results
- ➢ Outlook

Motivation

- In absence of new on-shell phenomena, model independence is becoming more important to precision measurement interpretation at the LHC.
    - LHC has effectively become an intensity-frontier experiment
    - Precise measurements are hard; don’t want a new one for each model nor to analyze just one model
    - Reusability for yet-unknown future models important to data utility preservation

Effective Field Theory

- The canonical example of an EFT is Fermi's theory of weak decay
  - A real limit of the SM
  - We still use this today!



- Captures physics in a particular energy regime
  - Perturbation expansion in powers of E/M_W
- Ability to systematically improve theory predictions is the key virtue of EFTs

S.M.E.F.T.

- The Standard Model Effective Field Theory accepts the absence of light new particles and sets up an expansion in E/Λ_{NP} (here we assume $\Lambda_{NP} = 10$ TeV)
    - Assumes that h(125) is THE Higgs of EWSB; assuming otherwise yields the related Higgs EFT
    - Retains full SM gauge group in higher-dimensional operators
- SMEFT effects organized by operator dimension:

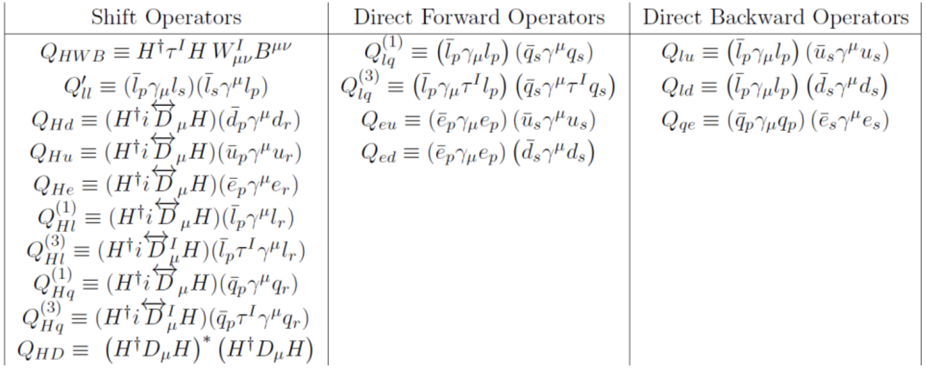
$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \mathcal{L}^{(5)} + \mathcal{L}^{(6)} + \mathcal{L}^{(7)} + \mathcal{L}^{(8)} + \dots$$

$$\mathcal{L}^{(i)} = \sum_{k=1}^{N_i} \frac{c_k^{(i)}}{\Lambda^{i-4}} Q_k^{(i)}$$

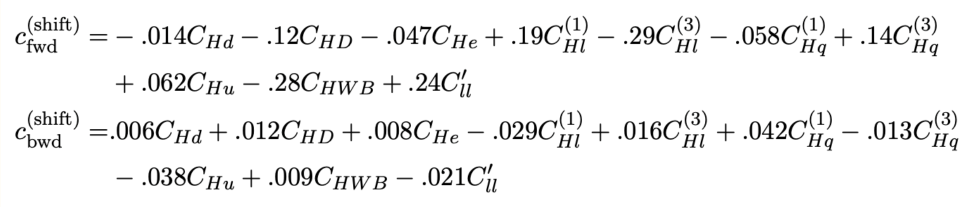
- Operators built entirely out of SM fields

Relevant Operators to Drell-Yan

- Direct 4-fermion operator effects grow with energy, but they aren't the only SMEFT effect in Drell-Yan
- Other class of operators shifts definitions of would-be SM couplings, leading to non-growing contributions
- Four classes of physically-distinct behavior caused by SMEFT operators
    - Two energy times two angular behaviors



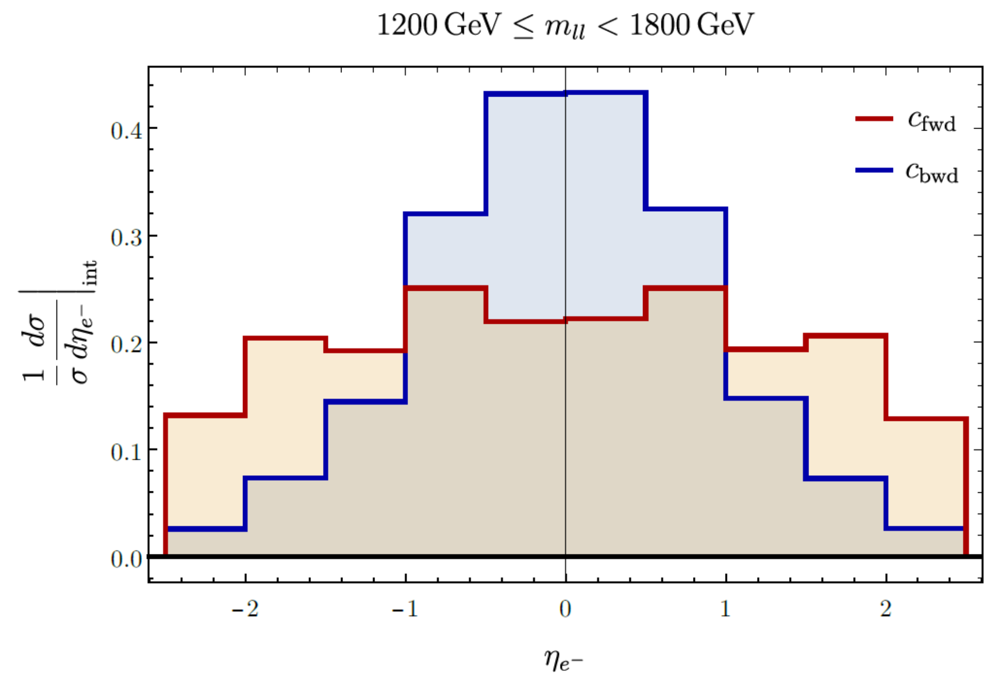
Shift Operators	Direct Forward Operators	Direct Backward Operators
$Q_{HWB} \equiv H^\dagger \tau^I H\, W^I_{\mu\nu} B^{\mu\nu}$	$Q^{(1)}_{lq} \equiv (\bar{l}_p \gamma_\mu l_p)\,(\bar{q}_s \gamma^\mu q_s)$	$Q_{lu} \equiv (\bar{l}_p \gamma_\mu l_p)\,(\bar{u}_s \gamma^\mu u_s)$
$Q'_{ll} \equiv (\bar{l}_p \gamma_\mu l_s)(\bar{l}_s \gamma^\mu l_p)$	$Q^{(3)}_{lq} \equiv (\bar{l}_p \gamma_\mu \tau^I l_p)\,(\bar{q}_s \gamma^\mu \tau^I q_s)$	$Q_{ld} \equiv (\bar{l}_p \gamma_\mu l_p)\,(\bar{d}_s \gamma^\mu d_s)$
$Q_{Hd} \equiv (H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{d}_p \gamma^\mu d_r)$	$Q_{eu} \equiv (\bar{e}_p \gamma_\mu e_p)\,(\bar{u}_s \gamma^\mu u_s)$	$Q_{qe} \equiv (\bar{q}_p \gamma_\mu q_p)\,(\bar{e}_s \gamma^\mu e_s)$
$Q_{Hu} \equiv (H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{u}_p \gamma^\mu u_r)$	$Q_{ed} \equiv (\bar{e}_p \gamma_\mu e_p)\,(\bar{d}_s \gamma^\mu d_s)$	
$Q_{He} \equiv (H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{e}_p \gamma^\mu e_r)$		
$Q^{(1)}_{Hl} \equiv (H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{l}_p \gamma^\mu l_r)$		
$Q^{(3)}_{Hl} \equiv (H^\dagger i \overleftrightarrow{D}^I_\mu H)(\bar{l}_p \tau^I \gamma^\mu l_r)$		
$Q^{(1)}_{Hq} \equiv (H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{q}_p \gamma^\mu q_r)$		
$Q^{(3)}_{Hq} \equiv (H^\dagger i \overleftrightarrow{D}^I_\mu H)(\bar{q}_p \tau^I \gamma^\mu q_r)$		
$Q_{HD} \equiv (H^\dagger D_\mu H)^* (H^\dagger D_\mu H)$		



$$\begin{aligned} c^{(\text{shift})}_{\text{fwd}} =& -.014 C_{Hd} - .12 C_{HD} - .047 C_{He} + .19 C^{(1)}_{Hl} - .29 C^{(3)}_{Hl} - .058 C^{(1)}_{Hq} + .14 C^{(3)}_{Hq} \\ & + .062 C_{Hu} - .28 C_{HWB} + .24 C'_{ll} \\ c^{(\text{shift})}_{\text{bwd}} =& .006 C_{Hd} + .012 C_{HD} + .008 C_{He} - .029 C^{(1)}_{Hl} + .016 C^{(3)}_{Hl} + .042 C^{(1)}_{Hq} - .013 C^{(3)}_{Hq} \\ & - .038 C_{Hu} + .009 C_{HWB} - .021 C'_{ll} \end{aligned}$$

Forward/Backward at the LHC

- Forward and backward at partonic level map to higher and lower $|\eta|$ in the symmetric LHC environment
- We bin 'forward' as events with $|\eta_{e^-}| > |\eta_{e^+}|$, also bin in $m_{\ell\ell}$
- Operators of forward class preferentially, but not exclusively, populate appropriate bin



Statistical Paradigm and Error Calculations

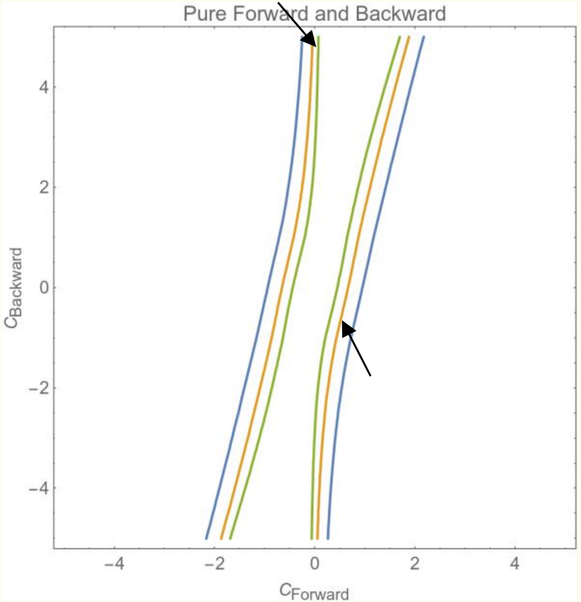
- Statistical inferences were accounted for by a χ^2 test
  - How large could a dimensionless coupling be, or how low could a scale of new physics be, before we could definitively rule it out with a given amount of data?
- Three classes of errors are added in quadrature
  - Statistical errors are pure Poisson
  - Systematic errors create an asymptotic floor for improvement of sensitivity with statistics
    - Modeled as improving proportional to statistics until reaching relative size of 2%
  - Theoretical errors in signal modelling are also nontrivial here

Theoretical Uncertainties in the SMEFT

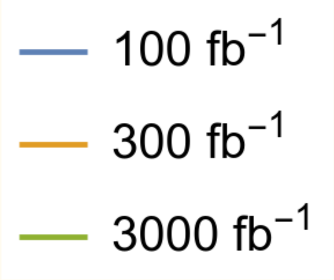
- A consistent EFT expansion is for an OBSERVABLE (e.g. cross-section, not amplitude), and includes ALL contributions at a given order
- Amplitudes for dimension-6 EFT operators go like Λ^{-2} and dim-8 go like Λ^{-4}
- Squaring to get the cross-section, the dim-6 cross-term with the SM gives leading contributions.
- The dim-6 squared term is a suitable proxy for the shape of unknown dim-8 term; we estimate the multiplicity of dim-8 operators contributing to the error, and include the dim-6 squared cross section as an error as well

Results (preliminary)

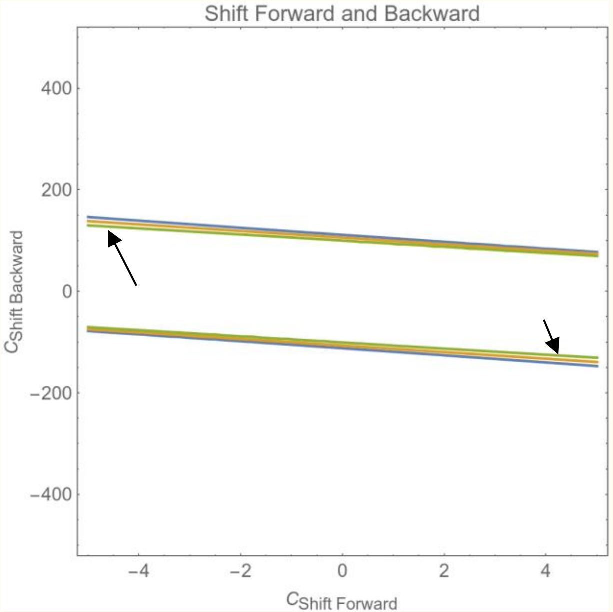
Direct forward and backward



- Strong constraint from σ_{tot}
- Weak constraint from forward-backward asymmetry
- Widening at larger C due to increasing theory errors

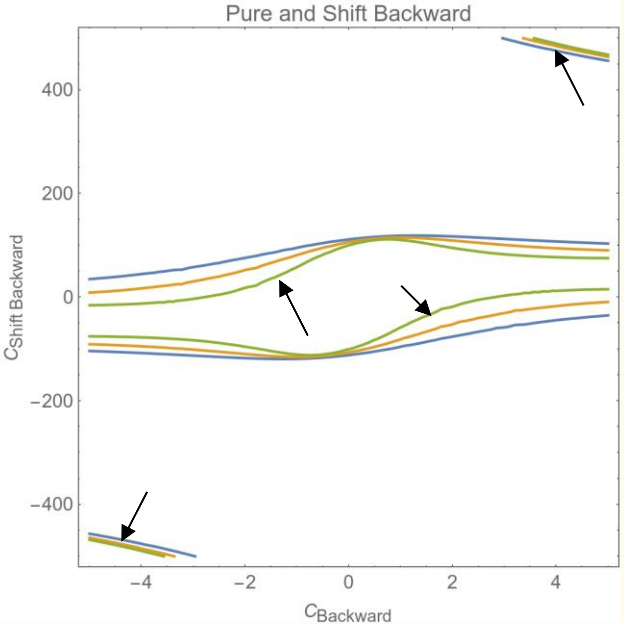


Shift forward and backward



Results (preliminary)

Direct backward and shift backward



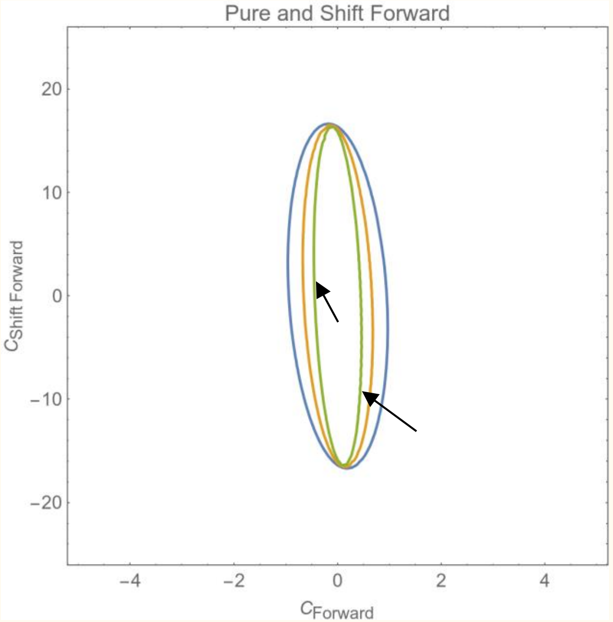
Loss of constraint at large C due to theory error's quadratic growth vs signal's linear

— $100\ \text{fb}^{-1}$

— $300\ \text{fb}^{-1}$

— $3000\ \text{fb}^{-1}$

Direct forward and shift forward



Outlook

- The SMEFT is the technology at the center of the next-generation of the work championed by the LEP EWWG.
- It is important that our model independent searches be both broadly applicable and accurate in their claims; this is only true when theory errors are carefully considered.
- This completes the SMEFT study of hadronically-quiet dilepton production, yielding 4 total constraints, one of which bounds new physics at the 10 TeV scale
- Ultimately, combining these bounds with those from other precision measurements can lead to a global view of what is definitely ruled out in the SMEFT coupling parameter space

Thank You!