Removing Flat Directions in SMEFT Fits: Complementing the LHC with polarized EIC data

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Based on:
Boughezal/Petriello/DW - (arXiv: 2004.00748)
The Why, the What and the How

- **the Why**
  - No smoking gun(s) at LHC
  - Standard Model Effective Theory (SMEFT) is a systematic way to combine and analyze data and look for New Physics in a model-independent way

- **the What**
  - Four-Fermi Operators are a large class of SMEFT operators
  - **Flat directions** are a prevalent problem → resolve before global fit

- **the How**
  - Future **Electron-Ion** Collider (EIC):
    - Lift flat directions by combining polarized observables
  - Combine with LHC data for strongest bounds (here: Drell-Yan)
Standard operating HEP procedure:

1) Pick BSM Model → 2) Make Prediction → 3) Compare to Data (ft Exclusion Plot) → GoTo 1)
**SMEFT - Motivation**

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**More Economic Way:**

Average over heavy modes at SM energies (Effective Action: Wilson et al)

\[ \frac{1}{\Lambda^2} + O\left(\frac{1}{\Lambda^4}\right) \]
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Quantify deviation from SM through comparison with data

- **Model independent constraints** on new physics
- Maximal gain from data
- Part of the **LHC legacy**

Non-SM operators **suppressed by powers of** $\frac{1}{\Lambda}$:

- Higher dimensional operators built from SM fields
- Modification of SM couplings/EWSB/...
Write down all possible operators that new physics could induce

- Stay consistent with SM symmetries!
- Build from SM field content!

Lot’s of tricks to eliminate redundant operators, e.g.

\[ \partial_\mu \phi \partial^\mu (\partial^2 \phi) \leftrightarrow -\phi \partial^4 \phi \]
The Warsaw Basis

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Many equivalent bases – not all created equal

\[
\mathcal{L}_{SMEFT} \supset \mathcal{L}_{SM} + \frac{C_5}{\Lambda} \mathcal{O}^5 + \frac{C_6^i}{\Lambda^2} \mathcal{O}_i^6 + \frac{C_7^i}{\Lambda^3} \mathcal{O}_i^7 + \cdots
\]

Warsaw Basis: 59 Operators ($\delta B = 0, \delta L = 0$)

Grzadkowski/Iskrzynski/Misiak/Rosiek (1008.4884)
The Warsaw Basis

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Integration-by-Parts (IBP) \( (\partial_\mu \phi) \partial^\mu (\partial^2 \phi) \leftrightarrow -\phi \partial^4 \phi \)

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We focus at 1-loop/Dim-6 4-Fermi
(Z-couplings better probed @ Z-Pole)
What’s a flat direction?
- More Wilson coefficients than observables
- Either exact or approximate (in a certain regime)
- Severely limits possible bounds on individual coefficients
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Too many Wilson Coefficients: kinematic variable distributions show flat directions (e.g.: Rapidity, Lepton $m_{ll}$, ...)

Alte/König/Shepherd (1812.07575)
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Approximate flat-direction in Drell-Yan fit (high $m_\ell$ bins)
Technical assumptions of the analysis:

- CoM Energy up to $\sqrt{S} = 140\text{GeV}$
- 70% Polarized electron and proton Beams
- Projected luminosity $\mathcal{L} \sim 10\text{ fb}^{-1}$ ($100\text{ fb}^{-1}$?)
- Assume angular variable $0.1 < y < 0.9$ and momentum fraction $x < 0.2$

Standard Model and SMEFT contributions (here: leading order, NLO under control)

https://www.bnl.gov/eic/

Aschenauer et al (1309.5327, 1705.08831)
EIC - Overview

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Expected size of SMEFT effect in DIS (including PDF error, $\Lambda = 1 \text{ TeV}$)

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General Idea:
- Use different combinations of polarized observables to lift flat directions
- Observables: Polarized/Unpolarized Protons vs 2 Electron Polarizations
- Ultimate Goal: Simultaneous fit of PDFs AND Wilson Coefficients
Probing SMEFT at EIC (I)

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![Graphs showing different Wilson coefficients for different electron polarizations]
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**Different Wilson coefficients contribute for different electron polarizations**

Additional Contribution: Charged Current $u \; e^- \rightarrow d \; \nu_e$  

Signature not as clean but only sensitive to $C_{lq}^{(3)}$

(Off-shell W-analysis for Drell-Yan at LHC not available yet though)
Probing SMEFT at EIC (II)

Impact of Systematic Errors (left) and polarized proton beam data (right)
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Impact of Systematic Errors (left) and polarized proton beam data (right)

Takeaways to keep in mind:

- **Polarized observables** are crucial (even though larger experimental uncertainty)
- Impact of systematic error on bounds is fairly small
- **High $Q^2$/High $x$ bins** are most important (best SMEFT/SM ratio)
Fitting Methodology (68% CL):

For EIC/DIS:
- Integrate over \((x, Q^2)\) bins
  - Determine binning through syst./stat. uncertainties
- Assume uncorrelated errors
- \(\Delta \sigma_{SMFT}\) measures deviation from SM

Define \(\chi^2\) test statistic (DIS case):

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\chi^2 = \sum_{\text{Bins}} \sum_{\text{Pol/\pm}} \left( \frac{\Delta \sigma_{SMFT}}{\Delta \sigma_{Err}} \right)^2
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ATLAS Collab. (1606.01736)
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- Luminosity increase only has moderate impact
- Correlation (= flat direction) is determined by degree of polarization of beam(s)
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**Additional Drell-Yan flat direction can lifted analogously through EIC observables, e.g.:**
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SMEFT suffers from a large number of flat directions

- We presented a strategy to lift 4-Fermi flat directions

The future EIC will complement LHC data

- Combine EIC observables with different polarizations additionally to LHC measurements
- Interplay of different measurements improve bounds significantly
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Possible Future Directions:

- How to probe higher generation coefficients, e.g. $C_{ee}^{2211}$? (COMPASS $(p + \mu^\pm)$ might be starting point, but needs higher COM energy)

- $pp \rightarrow \mu^+\mu^-$ Drell-Yan bounds from LHC (Compare with SEAQUEST?)

Thank you!