Flat Directions in the SMEFT: LHC and PVES

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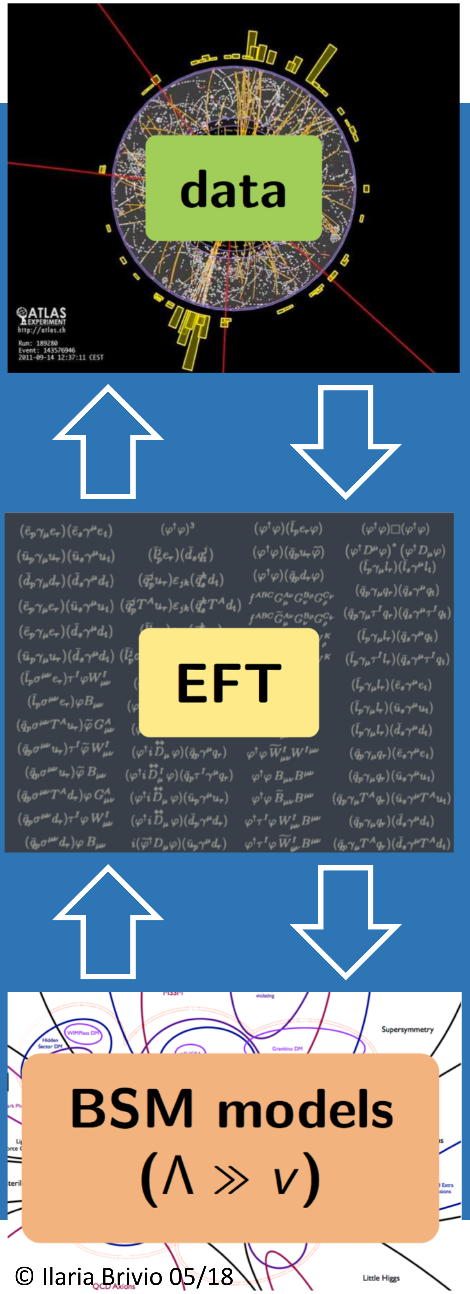
@Pheno21 – 5/25/2021

Based on:

Boughezal/Petriello/DW - (arXiv: 2104.03979)



Overview

- No smoking gun(s) at LHC
  - Indirect searches might tell us where New Physics lies
  - Standard Model Effective Field Theory (**SMEFT**) is a systematic way to combine and analyze data and constrain New Physics in a model-independent way

- Flat directions are a prevalent problem

  ⇨ Important to know which measurements to combine

- Future Measurements & Experiments :

  ⇨ **Extract best bounds from available** data (e.g.: **Drell-Yan**)

  ⇨ Disentangle dim-6/dim-8 **Low-energy SoLID/P2** data

SMEFT @ Dim-8

$$\mathcal{L}_{SMEFT} \supset \mathcal{L}_{SM} + \frac{C_6^i}{\Lambda^2}\mathcal{O}_i^6 + \frac{C_8^i}{\Lambda^4}\mathcal{O}_i^8 + \cdots$$

Dimension 6		Dimension 8	
$\mathcal{O}_{lq}^{(1)}$	$(\bar{l}\gamma^\mu l)\,(\bar{q}\gamma_\mu q)$	$\mathcal{O}^{(1)}_{l^2q^2D^2}$	$D^\nu\,(\bar{l}\gamma^\mu l)\,D_\nu\,(\bar{q}\gamma_\mu q)$
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Semi-leptonic **dimenion-8** derivative operators

Many **dim-8 extensions** of Four-Fermi operators. Focus on **derivatives**:

$$\frac{C_6}{\Lambda^2}(\bar{\psi}\gamma^\mu\psi)(\bar{\psi}\gamma_\mu\psi)$$

$$\frac{C_8^{(1)}}{\Lambda^4}\boldsymbol{D^\nu}(\bar{\psi}\gamma^\mu\psi)\boldsymbol{D_\nu}(\bar{\psi}\gamma_\mu\psi) \qquad \frac{C_8^{(2)}}{\Lambda^4}(\bar{\psi}\gamma^\mu\overleftrightarrow{\boldsymbol{D}}^{\boldsymbol{\nu}}\psi)(\bar{\psi}\gamma_\mu\overleftrightarrow{\boldsymbol{D}}_{\boldsymbol{\nu}}\psi)$$

SMEFT @ Dim-8

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Angular distributions
cannot distinguish

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Distinguish C_6 and C_8^t
with **angular observables**

$$\mathcal{L}_{SMEFT} \supset \mathcal{L}_{SM} + \frac{C_6^i}{\Lambda^2}\mathcal{O}_i^6 + \frac{C_8^i}{\Lambda^4}\mathcal{O}_i^8 + \cdots$$

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Distinguish C_6 and C_8^t with **angular observables**

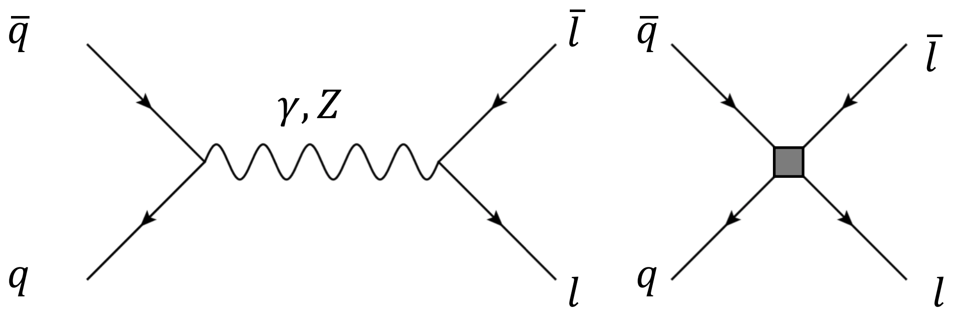
Need different approach to distinguish dim-6 and dim-8 contributions!

Combine Low-Energy precision experiments ($\frac{\hat{s}}{\Lambda^2}$ is suppressed!) with High-Energy data to disentangle dim-6 and dim-8

Flat Directions: Drell-Yan

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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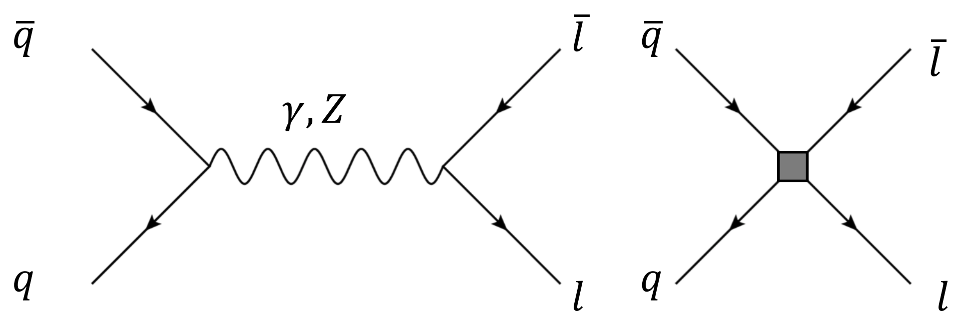
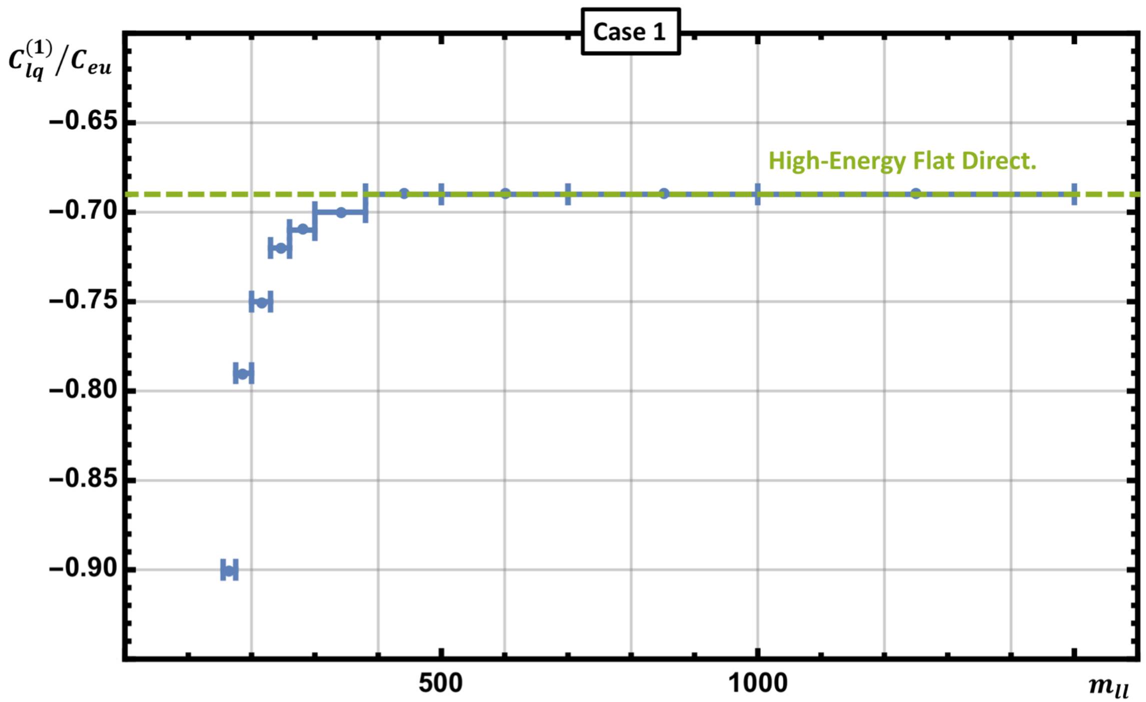
Example: **Drell-Yan** observables are only sensitive to a few combinations of Coefficients

Too many Wilson Coefficients:
kinematic variable distributions show flat directions (e.g.: Rapidity , Lepton m_{ll}, …)

Alte/König/Shepherd (1812.07575)





Approximate flat-direction in Drell-Yan fit (high m_{ll} bins)

Boughezal/Petriello/DW (2004.00748)

SoLID/P2 - Overview

Parity-Violating Deep Inelastic Scattering (**PVDIS**)

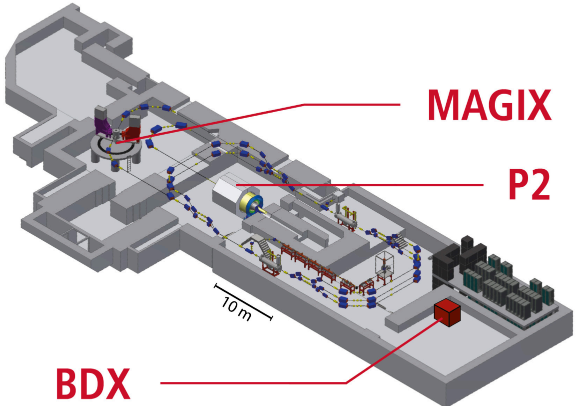
Asymmetry Parameter: $$A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} = -\left(\frac{G_F Q^2}{4\pi\alpha\sqrt{2}}\right)[Q_W - F(E,Q^2)]$$

Technical Details (P2):

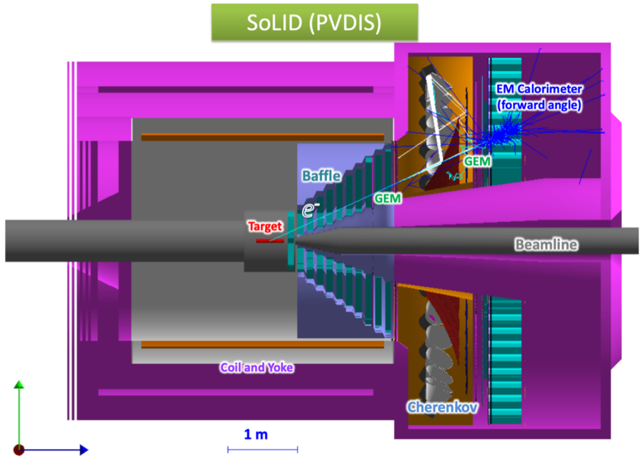
- Fixed H and ^{12}C targets for measuring $Q_W \sim s_W^2$
- Complement QWEAK, atomic PV, DIS, E158(SLAC)

Technical Details (SoLID):

- Fixed p^+ target for measuring ${}^{d(x)}/_{u(x)}$ ratio
- Fixed D^+ target for BSM searches



P2 Collab (1802.04759)



SoLID Collab (1409.7741)

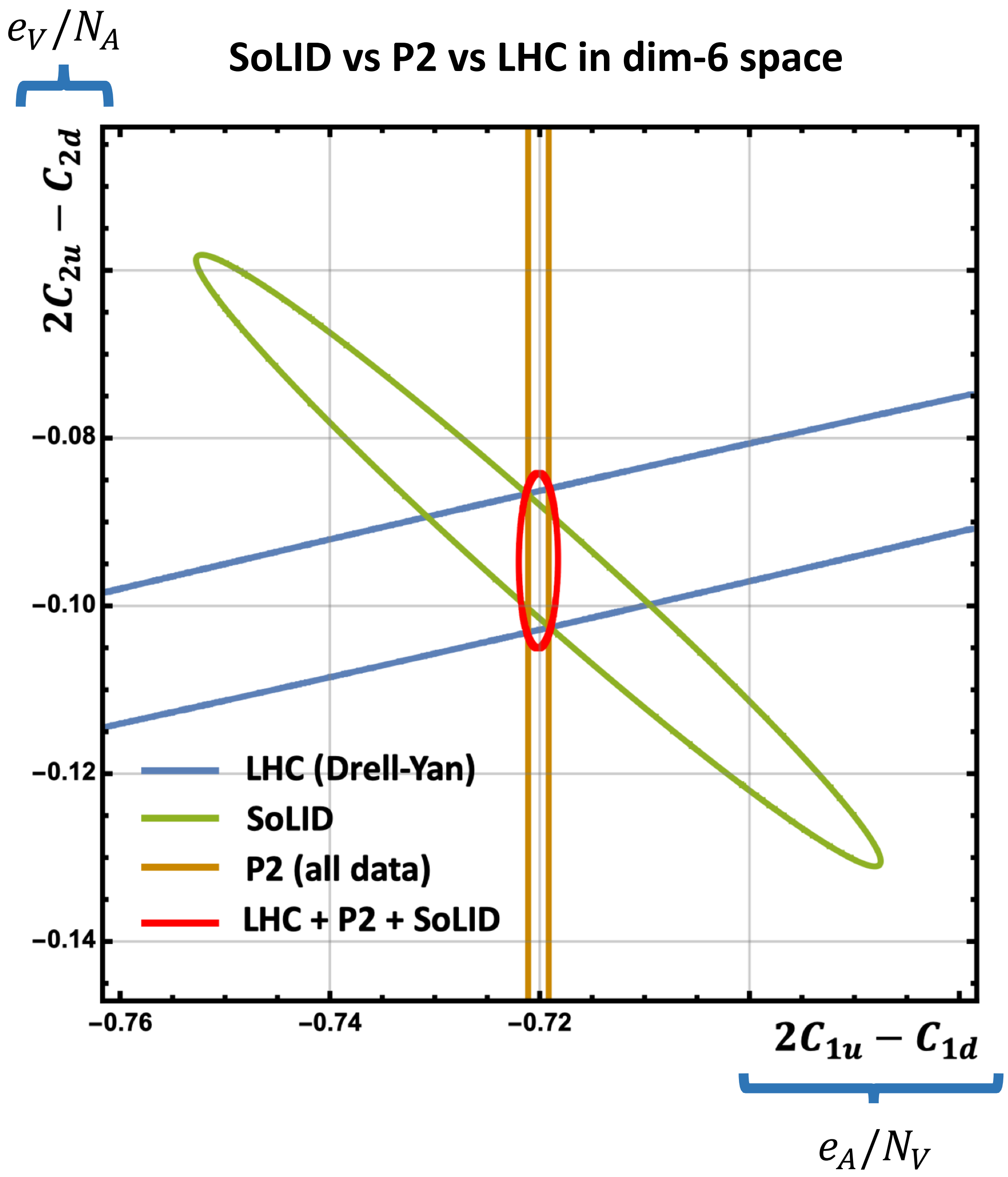
PVES at Low Energies

To illustrate the difference between P2 and SoLID:

Use historic Four-Fermi PV Lagrangian, in terms of **axial/vector** couplings instead of $\boldsymbol{\gamma^\mu P_{L,R}}$
(and fix Λ to Higgs vev)

⇨ Linear transformation to SMEFT basis

PVES at Low Energies



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Elastic Scattering (P2)

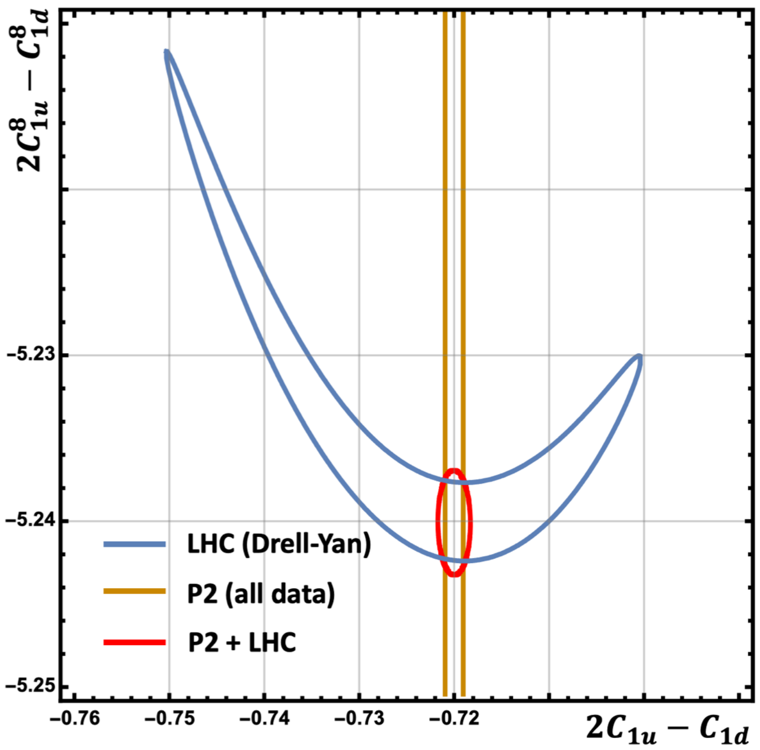
$$\frac{C_{1q}}{v^2}(\bar{e}\gamma^\mu\gamma_5 e)(\bar{q}\gamma_\mu q)$$ contributes via γ-interference

Deep Inelastic Scattering (SoLID)

Mostly $$\frac{C_{2q}}{v^2}(\bar{e}\gamma^\mu e)(\bar{q}\gamma_\mu\gamma_5 q)$$ contributes

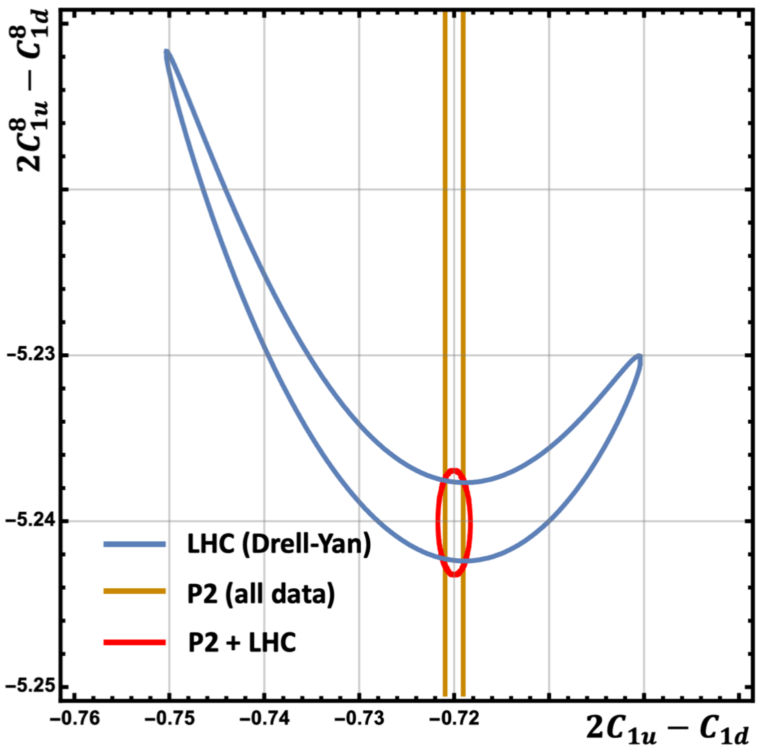
Dimension-8 PV Operators

Dim8 Extension: $\frac{C_{1q}^{8}}{v^4} D^{\nu}(\bar{e}\gamma^{\mu}\gamma_5 e) D_{\nu}(\bar{q}\gamma_{\mu} q)$



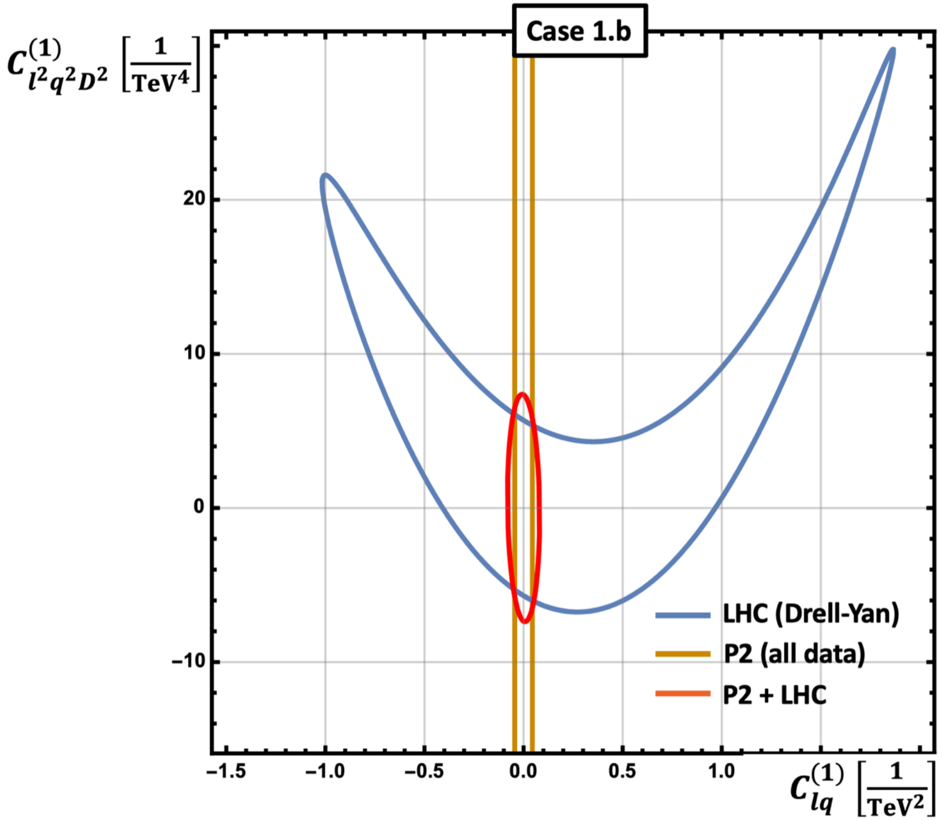
Dimension-8 PV Operators

Dim8 Extension: $\frac{C^8_{1q}}{v^4} D^\nu(\bar{e}\gamma^\mu\gamma_5 e)D_\nu(\bar{q}\gamma_\mu q)$



Translate bounds into SMEFT basis

$$C^6_{1u} \to \frac{v^2}{2\Lambda^2}\left\{-\left(C^{(1)}_{lq} - C^{(3)}_{lq}\right) + \cdots\right\}, \ldots$$



Example SMEFT fit dim-6/dim-8
(Normalized to $\Lambda = 3\text{TeV}$)

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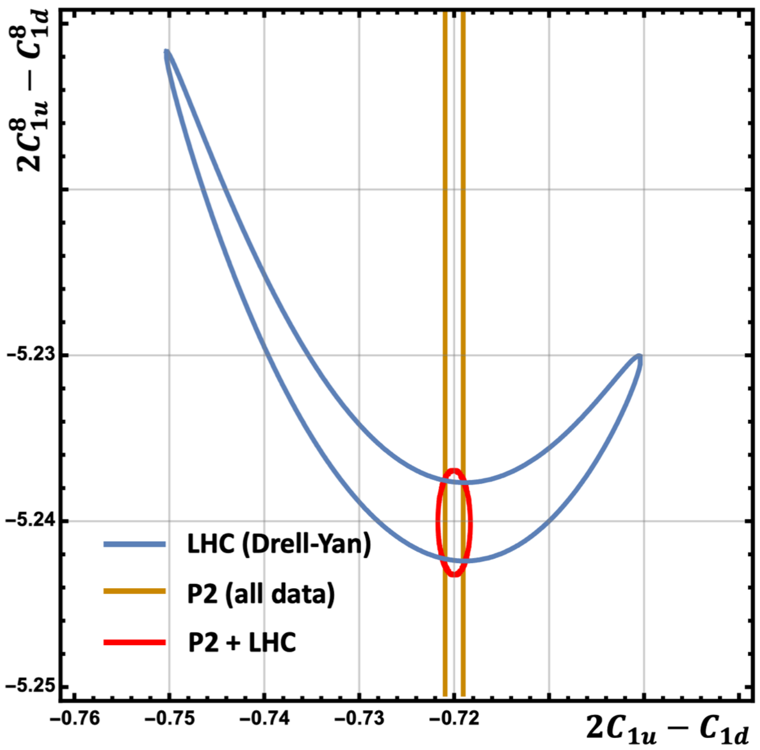

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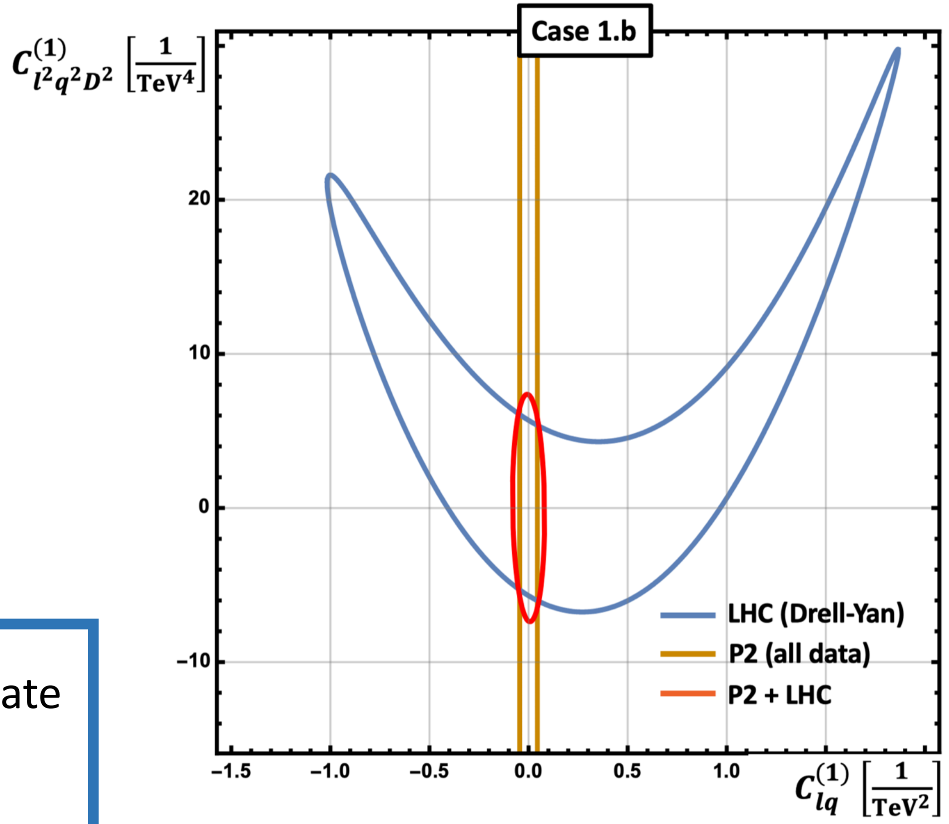

Example SMEFT fit dim-6/dim-8 (Normalized to $\Lambda = 3\mathrm{TeV}$)

- LHC Drell-Yan measurements only poorly differentiate dim-6/dim-8 SMEFT combinations
- **Low-Energy A_{PV} measurements lift the degeneracy and allow for tighter bounds**

Summary and Conclusions

SMEFT is a practical framework to constrain new physics!

SMEFT suffers from a large number of flat directions

↳ Combine different observables to optimize fit

↳ We presented a strategy to lift 4-Fermi **flat directions at dim-6 and dim-8**

The future **Low-Energy experiments** will take data soon

↳ **Energy suppression** can be used to disentangle dim-6 and dim-8

⇒ **Correct interplay of different measurements improve bounds significantly!**

Thanks!