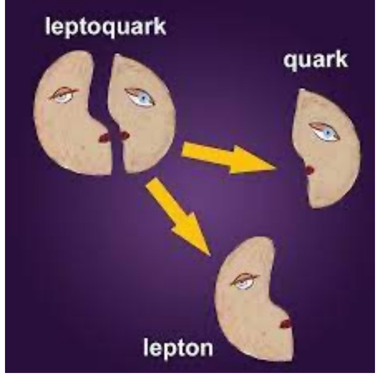
Phenomenology of TeV-scale scalar leptoquarks in the EFT

S. Bar-Shalom, J. Cohen

A. Soni, J. Wudka

(presenter)

Leptoquarks



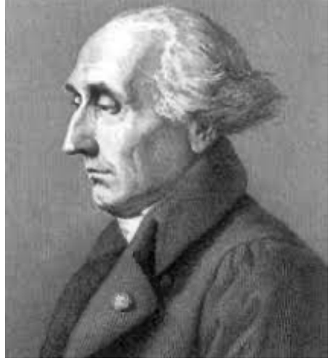
Can address persistent anomalies in B decays

… but if present … do they come all alone?

I will here assume they come with friends

… but without specifying who these friends are
Will use EFT to describe their effects.

Lagrangian



SM + down-type LQ: $\phi(3,\ 1,\ -1/3)$

SU(3) SU(2) U(1)

$$\mathcal{L}_{\phi SM} = \mathcal{L}_{\rm SM} + \mathcal{L}_{Y,\phi} + \mathcal{L}_{H,\phi} + \mathcal{L}_{\tt eff}$$

$$\mathcal{L}_{Y,\phi} = y^L_{q\ell}\bar{q}^c i\tau_2 \ell \phi^* + y^R_{ue}\bar{u}^c e \phi^* + y^L_{qq}\bar{q}^c i\tau_2 q\phi + y^R_{ud}\bar{u}^c d\phi + \text{H.c.}$$

B violating → drop

$$\mathcal{L}_{H,\phi} = |D_\mu\phi|^2 - M^2_\phi|\phi|^2 + \lambda_\phi|\phi|^4 + \lambda_{\phi H}|\phi|^2|H|^2$$

$$\mathcal{L}_{\tt eff} = \sum_{n=5}^{\infty}\frac{1}{\Lambda^{n-4}}\sum_i f_i O_i^{(n)}$$

$\Lambda > M_\phi$

Local, gauge invariant operators with SM fields and ϕ

The ϕ alone

Production:

	$M_\phi = 1\,\mathrm{TeV}$	$M_\phi = 2\,\mathrm{TeV}$
$gg \to \phi\phi$	$5\,\mathrm{fb}$	$0.01\,\mathrm{fb}$
$ug \to \phi\ell$	$100\,\mathrm{fb}$	$2\,\mathrm{fb}$
$dg \to \phi\ell$	$50\,\mathrm{fb}$	$0.5\,\mathrm{fb}$

B decay anomalies:

terms containing $y^L_{q\ell}$ & y^R_{ue}

Searches & limits

$$\phi \to \ell/\nu + j \quad \Rightarrow \quad M_\phi \gtrsim 1.5\,\mathrm{TeV}$$

ϕ and (virtual) friends

Will assume that the NP

- Is not directly produced (seen through virtual effects only)
- It is weakly coupled
- It is decoupling

$$\mathcal{L}_{\tt eff} = \frac{f_W}{\Lambda_W}\bar\ell^c\tilde H^\star \tilde H^\dagger \ell + \frac{f_{\ell d\phi H}}{\Lambda_{\ell d\phi H}}\bar\ell d\tilde H \phi^* + \frac{f_{d^2\phi^2}}{\Lambda_{d^2\phi^2}}\bar d d^c \phi^2 + \text{H.c.} + \cdots$$

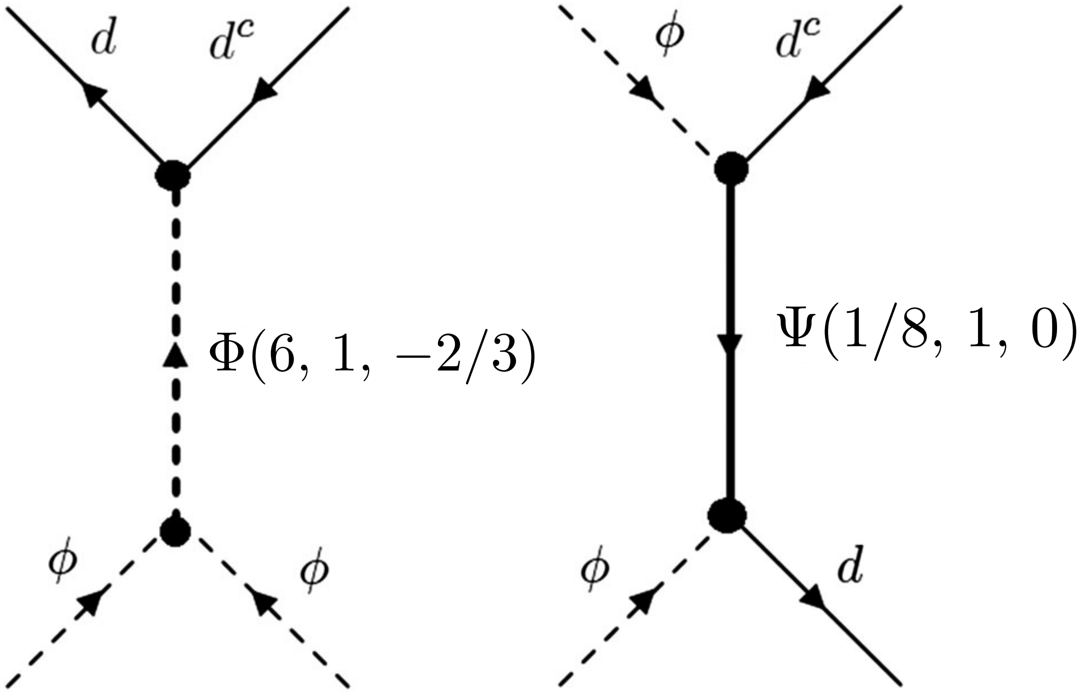
$$O^{(5)}_{d^2\phi^2} = \bar d d^c \phi^2$$

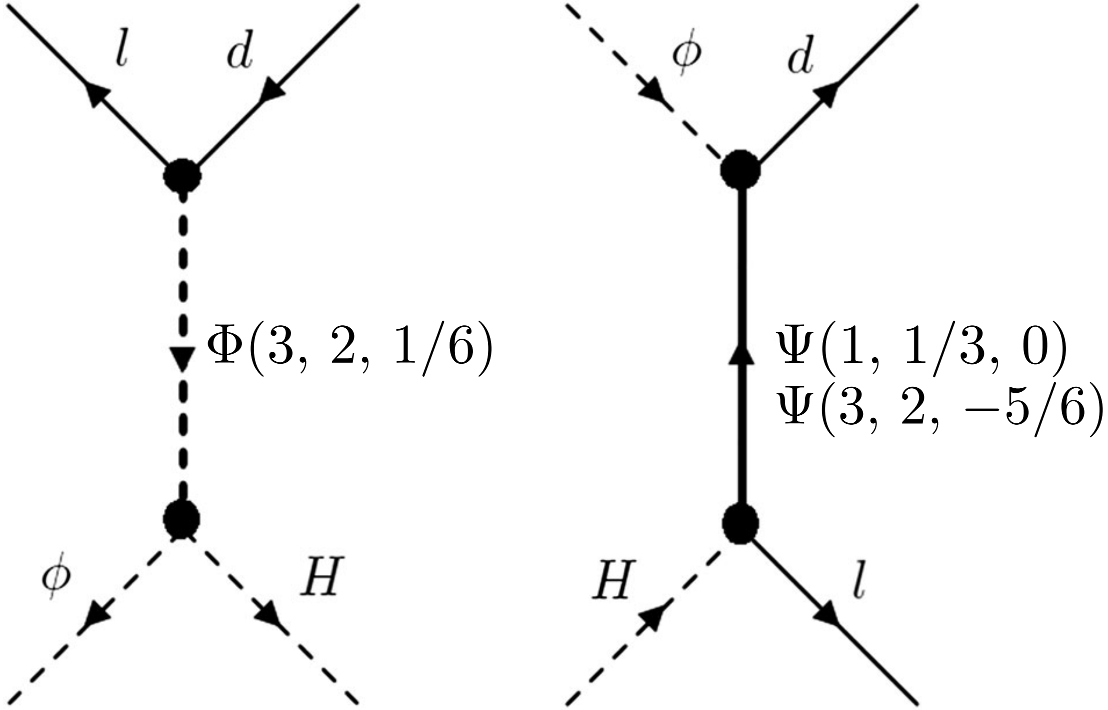
$$O^{(5)}_{\ell d\phi H} = \bar\ell d\tilde H \phi^*$$

$$O^{(5)}_W = \bar\ell^c \tilde H^\star \tilde H^\dagger \ell$$

Generated @ tree-level by **different** heavy fermions and scalars

EFT operators

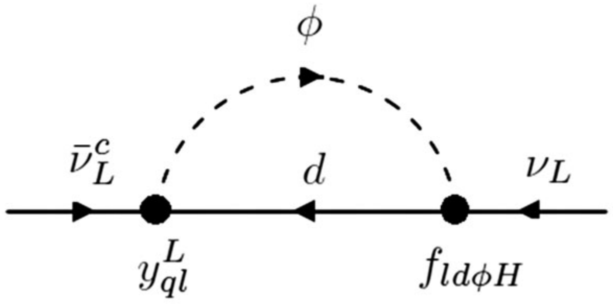




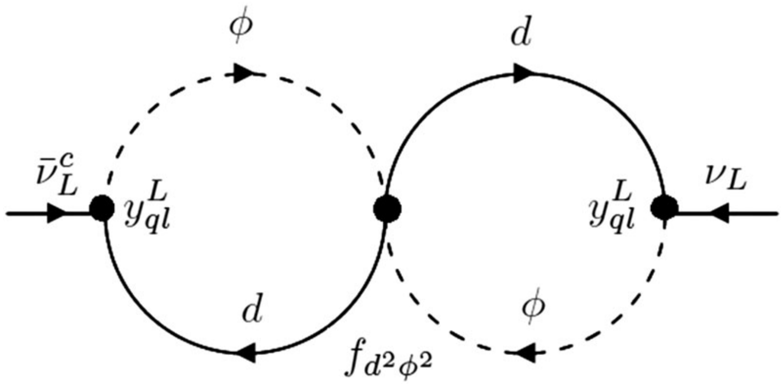
$$O_{d^2\phi^2} = \bar{d}d^c\phi^2$$

$$O_{\ell d\phi H} = \bar{\ell}d\tilde{H}\phi^*$$

Neutrino masses



$$m_\nu(\Lambda) \sim \frac{f \cdot \left(y^L_{q\ell}\right)^2}{(16\pi^2)^2} \frac{3m_d^2}{\Lambda} \cdot \ln^2\left(\frac{\Lambda^2}{M_\phi^2}\right)$$



$$m_\nu(\Lambda) \sim \frac{3m_d}{16\pi^2} \frac{f \cdot y^L_{q\ell}}{\sqrt{2}} \frac{v}{\Lambda} \ln\left(\frac{\Lambda^2}{M_\phi^2}\right)$$

For b: y small or Λ much larger

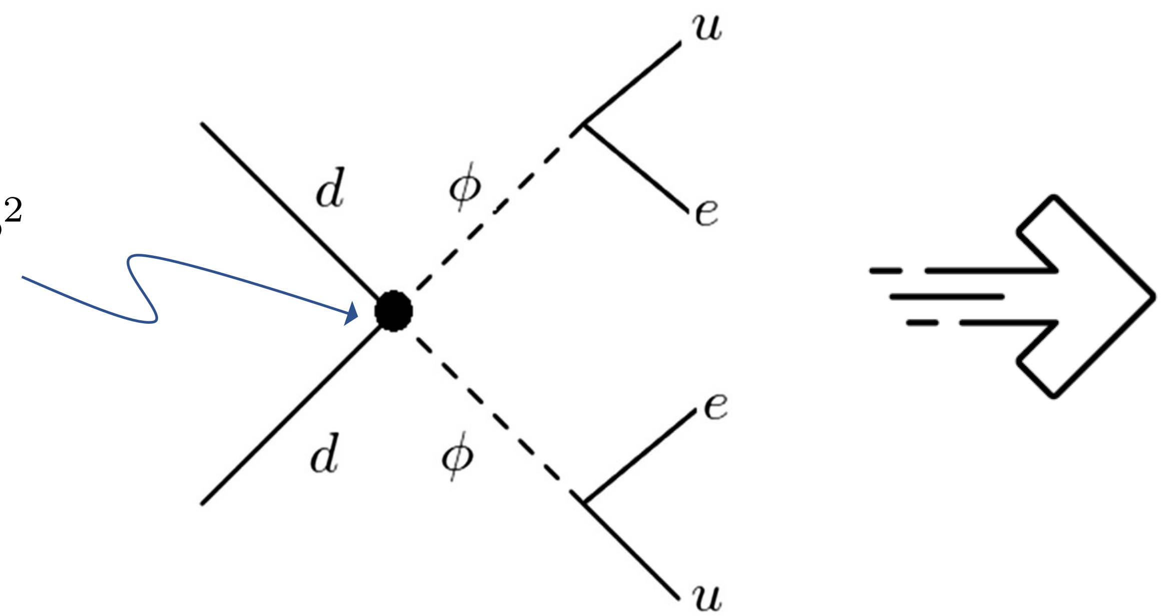
M_ϕ = 1 TeV

$$\frac{m_\nu(\Lambda = 5\ \text{TeV})}{f \cdot y^L_{q\ell}} \sim 10^{-3} \cdot m_d$$

$$\frac{m_\nu(\Lambda = 5\ \text{TeV})}{f \cdot \left(y^L_{q\ell}\right)^2} \sim 10^{-4} \cdot \frac{m_d^2}{\text{TeV}}$$

0νββ decay

$O_{d^2\phi^2} = \bar{d}d^c\phi^2$



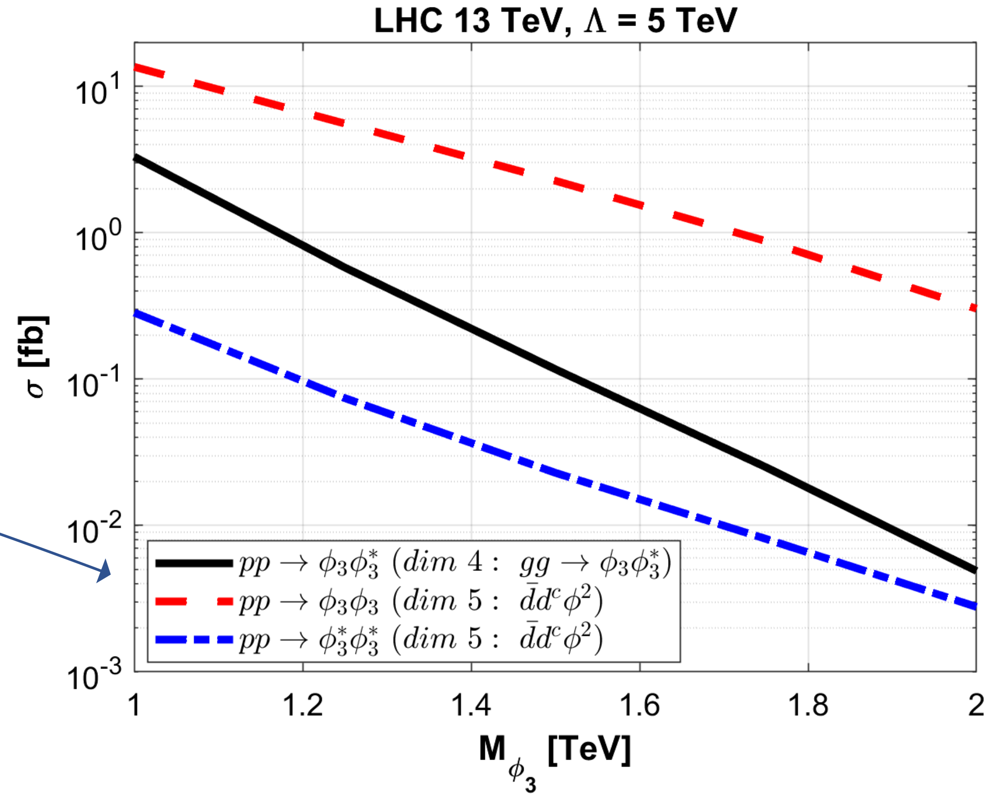
$$\frac{\Lambda}{\text{TeV}} \gtrsim 150 \cdot \frac{f \cdot |y_{ue}^R|^2}{(M_\phi/\text{TeV})^4}$$

ϕ @ the LHC

Assume $\phi = \phi_3$: 3rd generation leptoquark

Limit (CMS): $M_{\phi_3} \gtrsim 900\,\mathrm{GeV}$ $\mathrm{BR}(\phi_3 \to t\,\tau) = 1$

Production:



$O_{\ell d\phi H} = \bar{\ell} d \tilde{H} \phi^*$ excluded by neutrino masses

Assume

$$\mathrm{BR}(\phi_3 \to t\,\tau) \sim 1$$

Final states:

$$pp \to \phi_3\phi_3 \to 2 \cdot j_b + \not{E}_T$$

$$pp \to \phi_3\phi_3 \to tt\tau^-\tau^-$$

$$pp \to \phi_3\phi_3 \to t\tau^- + j_b + \not{E}_T$$

Asymmetry

$$\sigma(pp \to tt\tau^-\tau^-) \gg \sigma(pp \to \bar{t}\bar{t}\tau^+\tau^+) \quad \Rightarrow \quad \frac{\sigma(pp \to \tau^-\tau^- + X_j) - \sigma(pp \to \tau^+\tau^+ + X_j)}{\sigma(pp \to \tau^-\tau^- + X_j) + \sigma(pp \to \tau^+\tau^+ + X_j)} \simeq 1$$

☺ Statistical significance ~ 7 (with an efficiency ~0.01).

☹ LHC (13 TeV) is sensitive only for $M_\phi < 2$ TeV


THANK
YOU